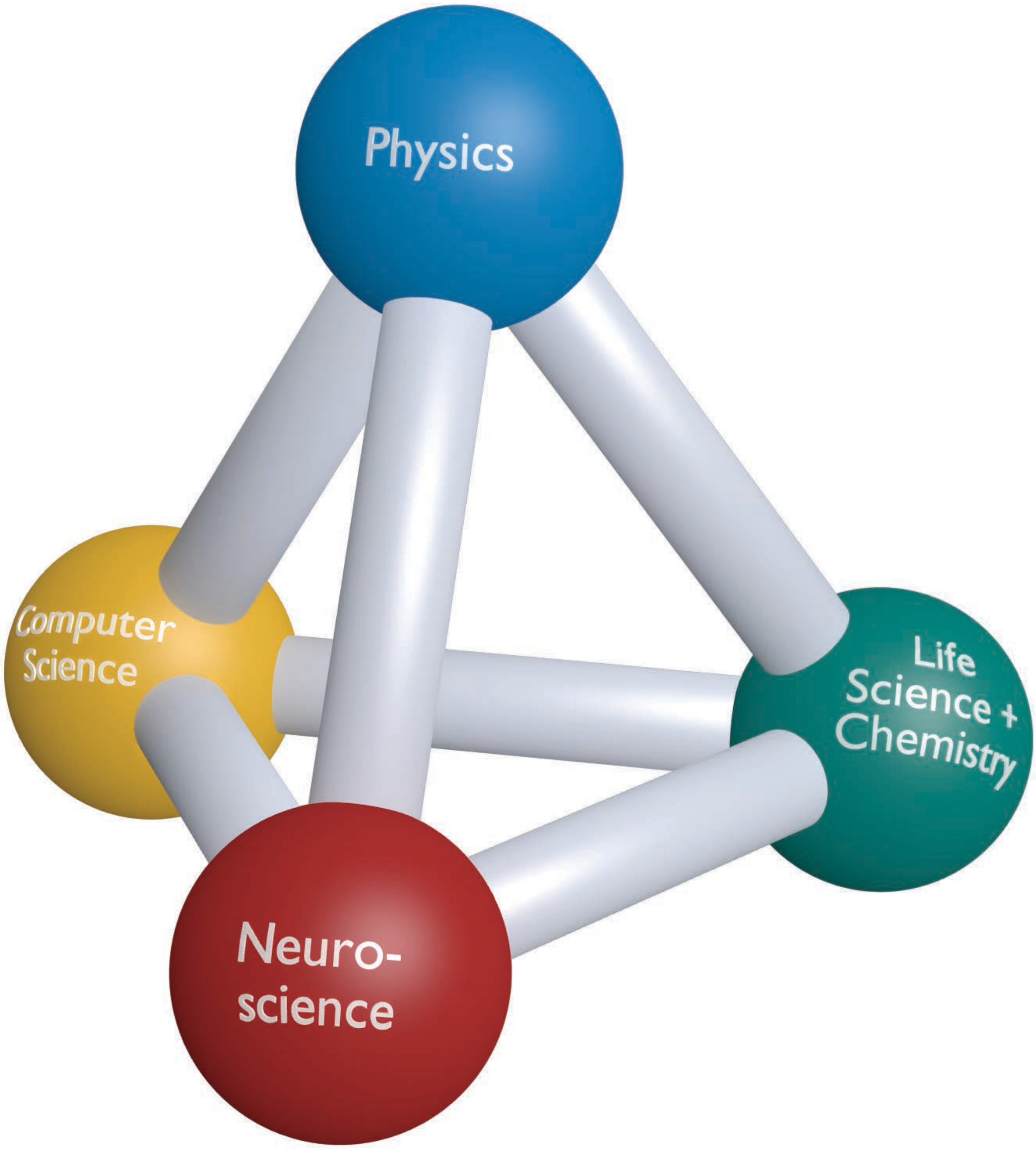
FIAS Frankfurt Institute for Advanced Studies



FIAS Scientific Report 2014

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Table of Contents

Preface

2014 was a special year for FIAS: On December 8, 2014 the institute celebrated its decennial anniversary. By chance, the anniversary of FIAS coincided with the centenary of the foundation of the Goethe University. Ten years ago, in December 2004, the documents constituting the "Frankfurt Institute for Advanced Studies" as a foundation under public law were signed by the then president of Goethe University, Prof. Rudolf Steinberg. Established by its founding directors, Profs. Walter Greiner, Wolf Singer, and Horst Stöcker, FIAS over the last decade has developed into a thriving research institution, dedicated to basic theoretical research in the natural sciences. Today FIAS encompasses about 140 scientists and PhD students. In total, up to now FIAS has attracted more than 60 million Euros of third-party funding from a variety of private sponsors, industrial partners, and funding agencies.

FIAS in the past year has continued on its path, performing cutting-edge research in the natural and computer sciences. The present Annual Report summarizes the scientific achievements of the year, mainly in the form of brief one-page group reports on specific research projects. We also report on recent developments in cooperating institutions, document the teaching activities at the attached Frankfurt International Graduate School for Science (FIGSS) and report on the conferences, scientific seminars and public lectures organized by FIAS in 2014. The Report ends with a comprehensive listing of the talks presented by FIAS members and of the publications written in the year 2014.

There were some new appointments in 2014. FIAS Senior Fellow Prof. Marcus Bleicher joined the Board of Directors of the Institute. Dr. Hermann Cuntz, recipient of the 2013 Bernstein prize for Computational Neuroscience, has been appointed as Research Fellow.

As usual, a number of FIAS alumni obtained new positions over the year. After a stay at Columbia University, New York, former FIAS postdoc Giorgio Torrieri has been appointed to a professorship at the Institute of Physics of the State University of Campinas in Brazil. Similarly, Celine Teulière, former postdoc in the group of Prof. Triesch, was named "Maître de conférence" (corresponding to a junior professorship) at Blaise Pascal University in Clermont-Ferrand, France. Adjunct Fellow Robert Berger, who had been one of the first scientists to join FIAS, moved from his professorship at the University of Darmstadt to accept the chair of Theoretical Chemistry at Marburg University.

Apart from the centenary anniversary, the year 2014 has witnessed another important event: In May a newly erected research building was inaugurated, directly adjacent to FIAS. It is a (nearly) identical twin of the existing FIAS building and will host the researchers of HIC for FAIR, the "Helmholtz International Center for FAIR" which closely collaborates with FIAS in the field of high-energy and nuclear physics. Both buildings have been erected by the Giersch Foundation and together they now are called the Giersch Science Center (GSC).

Scientific accomplishments are usually appreciated mainly by the members of the respective research communities. However, in 2014 FIAS made it into the headlines through an achievement in the area of computing. The group of Senior Fellow Volker Lindenstruth constructed the high-performance computer L-CSC which achieved a record-breaking speed of 5.27 GFlops per Watt consumed, thus winning the top position in the Green500 list of the most energy-efficient supercomputers worldwide.

The tenth anniversary is an occasion for FIAS to take stock of what has been achieved and to look ahead. A strategy committee will be set up, with the task to plan an interdisciplinary and diversified research portfolio for the years to come. One step to establish a new research field at FIAS has already been taken: With funds provided by Dr. Helmut Maucher a new professorship on systemic risk in economic and financial systems is being set up. Prof. Nils Bertschinger, formerly at the Max Planck Institute for Mathematics in the Sciences in Leipzig, has been appointed to this position.

FIAS gratefully acknowledges two new significant donations amounting to one million euro each, from the Giersch Foundation and from the Johanna Quandt University Foundation. These funds will be instrumental to carry FIAS successfully into its second decade and to ensure that the success story continues.

Research highlights 2014

New research sheds light on neural circuit development

Researchers at FIAS and at the Max Planck Florida Institute for Neuroscience report substantial postnatal changes in the functional properties of brain circuits that enhance their ability to encode information. Previous work has shown that individual brain cells refine their responses to stimuli with experience so they can better discriminate between similar features in their environments. However, the signals of individual brain cells can be noisy and imprecise – which means our brains cannot rely solely on the activity of single neurons to make accurate decisions about our world. Instead, we combine the activity of thousands to millions of neurons to ensure a more accurate message, which makes effective communication amongst large populations of neurons a central feature of the brain. This study demonstrates that, over development, neural circuits reorganize themselves to decrease noise and improve the fidelity of communication amongst each other. The critical role these changes play in brain development highlights the importance and urgency in understanding neural circuits in more detail and suggests new avenues for investigating the underlying causes of developmental disorders such as autism.
G.B. Smith, A. Sederberg, Y.M. Elyada, S.D. Van Hooser, M. Kaschube, D. Fitzpatrick: *The development of cortical circuits for motion discrimination*, Nature Neuroscience (2015), doi:10.1038/nn.3921

Noise in the brain

Neural recordings seem very noisy. If the exact same stimulus is shown to an animal multiple times, the neural response will vary substantially. In fact, the activity of a single neuron shows many features of a stochastic process. Furthermore, the spontaneous activity occurring in the absence of any sensory stimulus, which is often treated as a kind of background noise, has a magnitude comparable to the activity evoked by stimulus presentation. These findings have led to a widespread belief that neural activity is indeed very noisy. FIAS scientists from the group of Jochen Triesch have now shown that the key features of neural variability and spontaneous activity can all be accounted for by a simple and completely deterministic neural network learning a model of its sensory inputs. The network's deterministic dynamics give rise to structured but variable responses matching key experimental findings obtained in different species with different recording techniques. These results show that the notorious variability of neural recordings can not be taken as evidence for a noisy brain. Instead it may reflect the dynamics of an essentially deterministic but highly adaptive network learning a model of its sensory environment.
Ch. Hartmann, A. Lazar, J. Triesch: *Where's the noise? Key features of neuronal variability and inference emerge from self-organized learning*, doi:10.1101/011296

Properties of the Quark Gluon Plasma

The behaviour of nuclear matter under the condition of extreme temperatures and densities is a major reseach focus at FIAS. The group of Elena Bratkovskaya has studied the transport properties of the quark gluon plasma (QGP) in a QCD medium at finite temperature T and quark chemical potential μ_q. They have calculated the shear viscosity $\eta(T,\mu_q)$ and the electric conductivity $\sigma_e(T,\mu_q)$ for a system of interacting massive and broad quasi-particles as described by the dynamical quasi-particle model "QPM" at finite temperature and quark chemical potential within the relaxation time approximation. The results are in a good agreement with lattice QCD at finite temperature and show clearly the increase of the transport coefficients with increasing T and μ_q. These results provide the basic ingredients for the study of the hot and dense matter in the Beam Energy Scan (BES) at RHIC and CBM at the future FAIR accelerator facility
H. Berrehrah, P. B. Gossiaux, J. Aichelin, W. Cassing, J. M. Torres-Rincon, E. Bratkovskaya: *Transport coefficients of heavy quarks around T_c at finite quark chemical potential*, Phys. Rev. C90 (2014) 051901R

Inproved predictions for heavy-ion tumor irradiation on the nanoscale

The Monte Carlo model for Heavy-Ion Therapy (MCHIT) developed in FIAS has been extended recently to

nano-scales (Burigo, Pshenichnov, Mishustin, Bleicher). First investigations of ion track structure have been performed using detailed history Monte Carlo simulations using the Geant4-DNA package. Now MCHIT is able to reproduce measured dose distributions within a broad range of radial distances around the ion track, from nanometer to micrometer scales. Ionization electron cluster-size distributions in nanometric volumes (measured in low-pressure gas chambers traversed by individual ions) are also successfully described by the extended MCHIT. This information can be used to evaluate the probabilities of different types of DNA damage induced by various ions.
L. Burigo, I. Pshenichnov, I. Mishustin, M. Bleicher: *Microdosimetry spectra and RBE of* ^{1}*H,* ^{4}*He,* ^{7}*Li and* ^{12}*C nuclei in water studied with Geant4*, Nucl. Instrum. Meth. B 320, 89 (2014)

Renewable energy and the electricity grid

Researchers at FIAS in collaboration with scientists at Aarhus University, Denmark, are studying in detail the transition of the electricity supply towards renewable energy sources ("Energiewende"). The electrical power distribution in Europe up to the year 2050 has been modeled. As these sources (predominantly solar and wind energy) tend to fluctuate strongly, increased electricity transmission is needed for securing the energy supply. Using accurate historical weather data the requirements for the future electricity grid have been determined. As one of the findings of the calculation it could be shown that for an efficient use of renewable energies a five-fold extension of the transmission grid capacities by 2050 is required.
S. Becker, R.A. Rodriguez, G.B. Andresen, S. Schramm, M. Greiner: *Transmission grid extensions during the build-up of a fully renewable pan-European electricity supply*, Energy 64 (2014) 404

World wide most efficient super computer designed at FIAS

For scientific computations on the FAIR-related research field the new supercomputer L-CSC was developed by FIAS researchers, which is installed at GSI. It is implemented as a hybrid cluster, combining two generic processors with 4 of the latest high-performance graphics cards. The system has a peak computational power of 1 PF (10^{15} double precision floating point operations per second). The total cost of the system was 1.7 MEuro. A particular highlight of this system is its measured power efficiency of 5.2 GF/W. It is the first time ever that a system achieves more than 5 GF/W and with its 5.2 GF/W the L-CSC is world wide the most efficient computer and the only one above 5 GF/W.
The Green500 list: `www.green500.org`.

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Dr. Laura Tolos, Institute of Space Sciences, IEEC, Barcelona

1. Partner Research Centers

HIC for FAIR Annual Report 2014

by Marcus Bleicher, Gabriela Meyer, Peter Kreutz

Since it was founded in 2008, HIC for FAIR has been committed to excellence in FAIR-related scientific research and cutting-edge technical development of concepts and methods for the construction and operation of FAIR. After a successful evaluation in April 2014, HIC for FAIR has been granted prolongation by the Hessen State Ministry of Higher Education, Research and the Arts until the end of 2015. Thus, the ambitious activities continue to collimate and strengthen the expertise of the participating Hessian institutions towards one of the largest fundamental research projects in physics. In November, the Program Advisory Committee congratulated HIC for FAIR on its continuous success and excellence in science.

HIC for FAIR expert groups made significant advances in a broad range of research fields this year, ranging from the development and refinement of fundamental theories to optimization of the relative biological effectiveness (RBE) in tumor therapy with ion beams. A few accounts of research accomplishments by scientists affiliated to both FIAS and HIC for FAIR are featured below.

- The L-CSC supercomputer emerged as the most energy-efficient supercomputer in the world, according to the 16th edition of the Green500 list. Due to savings on the electricity bill L-CSC runs with significant lower operating costs than less energy-efficient supercomputers of equivalent speed. The supercomputer is enabling Lattice-QCD computational research using one of the fastest OpenCL implementations for research applications in the world. Obtaining the world champion title for the L-CSC is already the third success within four years: In 2010, the LOEWE-CSC reached eighth place as Europe's most environmental-friendly supercomputer. Two years later SANAM, reached second place on the list. In 2014 the world record crowned the series.
- The excitation function for the direct and elliptical flow was calculated for a wide range of FAIR beam energies using transport simulations of heavy ion collisions.
- Microdosimetry-data were used to extend the Monte Carlo model for Heavy Ion Therapy (MCHIT) in order to calculate the relative biological effectiveness (RBE) of different ion-beams. It was found that nuclear fragmentation can reduce the RBE of heavy nuclei by 10 to 15 percent. The results suggest that helium and lithium beams should be considered as favourable options for cancer therapy. They have reduced fragmentation cross sections compared to the carbon beam and have a reduced lateral scattering in comparison to the proton beam. At the same time the biological effectiveness of these beams is only slightly lower than that of the carbon beam.

In 2014 HIC for FAIR scientists have published more than 100 papers in refereed journals, and more than 40 contributions to conference proceedings. FIAS members were (co-)authors of 34 of these publications.

HIC for FAIR organized or supported 21 conferences or workshops and several seminars and popular science lectures to foster internal and external communication. In May 2014 FIAS hosted the HIC for FAIR Workshop "Heavy flavor physics with CBM" where the case of charm and open charm physics at CBM was discussed. The HIC for FAIR Physics Day on High Performance Computing (HPC) November also took place at FIAS. The contributions informed about the status of the hard- and software for the FAIR experiments and illustrated the importance of HPC for simulations and calculations in basic physics research.

ExtreMe Matter Institute EMMI

by Carlo Ewerz

The Extreme Matter Institute EMMI is dedicated to research in the area of matter at the extremes of density and temperature, ranging from the coldest to the hottest and densest forms of matter in the Universe. This comprises in particular the four key areas a) quark-gluon plasma and the phase structure of strongly interacting matter, b) neutron matter, c) electromagnetic plasmas of high energy density, d) cold quantum gases and extreme states in atomic physics. This research is performed with a special emphasis on interdisciplinary aspects and common underlying concepts connecting the different research areas.

EMMI had been founded in the framework of the Helmholtz Alliance 'Cosmic Matter in the Laboratory' and is managed by the GSI Helmholtz Center for Heavy Ion Research in Darmstadt. So far funded by the Helmholtz Association, EMMI will be continued in a sustained way as part of GSI from 2015 onwards with a foreseen budget of 500 kEuro per year.

EMMI activities are carried out in close collaboration with its 13 national and international partner institutions; the German partners are the universities of Darmstadt, Frankfurt, Heidelberg and Münster, the Forschungszentrum Jülich, the Max-Planck-Institut for Nuclear Physics in Heidelberg, and FIAS. To the latter EMMI has particularly close ties.

In 2014, more than 400 scientists contributed to the activities of EMMI, among them more than 150 doctoral students and more than 100 postdocs. The structured graduate education of doctoral students within EMMI is organized in close collaboration with the surrounding graduate schools, among them the Helmholtz Graduate School for Hadron and Ion Research (HGS-HIRe), the Heidelberg Graduate School of Fundamental Physics (HGSFP), and the Helmholtz Research School Quark Matter Studies (H-QM).

EMMI members have published more than 350 papers in refereed journals, and more than 100 contributions to conference proceedings during 2014. EMMI runs an active workshop program. 5 EMMI workshops and a four-week program with strong international participation were organized in 2014. In addition, EMMI has a very active seminar program with talks by international experts and guest scientists. 5 renowned experts visited EMMI partner institutions for extended periods in 2014 as EMMI Visiting Professors, and have made progress in their collaborations with EMMI members. These and further EMMI activities (outreach etc) are listed at www.gsi.de/emmi.

In 2014, EMMI organized 3 EMMI Rapid Reaction Task Force (RRTF) meetings. These meetings are a new instrument which allows EMMI to bring together a group of about 15 to 20 world-leading experts in order to address a focussed scientific problem in intense discussions. RRTFs can be organized on a very short timescale. This allows EMMI to react flexibly and quickly to new and emerging developments in the EMMI research areas. Usually, the results of EMMI Rapid Reaction Task Forces are published in a summary paper.

The future focus of EMMI will be in particular on the sustained continuation of its by now well established most successful programs: EMMI workshops, EMMI Rapid Reaction Task Forces, and EMMI Visiting Professorships.

Bernstein Focus Neurotechnology Frankfurt

by Visvanathan Ramesh and the BFNT PI team

The Bernstein Focus Neurotechnology (BFNT) Frankfurt project is aimed at bringing together an interdisciplinary team to design and implement a cognitive vision framework that demonstrates autonomous learning and multiple cue fusion in the context of specific applications such as security, surveillance and robotics. The essence of our platform builds upon the systems engineering viewpoint on computer vision system design; i.e. visual cognition involves context-dependent hypotheses generation followed by detailed estimation via deliberation or iteration. At the Goethe University, where the systems engineering effort is undertaken, core advances have been made in: an engineering and rapid prototyping platform for cognitive systems design and optimization, a simulation platform for generative modeling of contexts, performance evaluation and learning for cognition. At FIAS, the focus has been more on the scientific aspects on autonomous learning, invariant object recognition, spontaneous formation of feature representations, and cue integration. Some of the highlights of this year's scientific efforts at FIAS include the following:

a) **Basic research in object recognition, spontaneous formation of feature detector hierarchy and memory and top-down mediated cue integration:** In the context of *Spontaneous formation of hierarchy of feature detectors in strongly recurrent neuronal circuits* we conducted a study that analyses a spiking network to show that recurrent inhibition renders cortical direction selectivity robust against noise, even on a single trial basis [2]. The second study shows that when motion sensitive cells emerge during early cortical development, not only become these cells more motion direction selective, but at the same time the variability and co-variability (noise-correlation) of their responses decreases, resulting in enhanced motion sensitivity on the population level [3]. This work was carried out in collaboration with an experimental group at the Max-Planck Florida Institute, Jupiter FL, USA. We also made considerable progress in our research on memory and top-down mediated cue integration by analyzing spontaneous categorization in random recurrent networks both in computational circuit models and in experimental data in awake, behaving mice. Preliminary results were presented at the Bernstein Conference 2014 [4]. The role of spontaneous activity in building neural activity patterns that can represent visual input was explored in depth and preliminary results were presented at the annual meeting of the society for neuroscience in 2014 [5]. We expect that the insights gained about these processes will have impact on next-generation artificial vision systems.

b) **Invariant object recognition:** As part of the effort to describe and implement mechanisms for invariant object recognition we completed work on the self-organization of control structures for dynamic mappings between the image domain and the model domain. The underlying task is the transfer of visual structure from variable camera (or retina) coordinates to invariant, object-intrinsic coordinates, all while preserving spatial relations of features, so that images of objects can be compared directly with stored models. The task is achieved with the help of control units that govern the switching of fiber projections. These control units need highly specific connectivity patterns, and the work described lets these connectivity patterns grow and adapt from simple initial states (see [6], [7]).

c) Self-calibrating stereo and motion vision: We have investigated how sensorimotor loops for stereo vision and motion vision can autonomously self-calibrate. Our solution to this problem is based on our recent active efficient coding (AEC) idea. It is an extension of the classic efficient coding hypothesis for sensory systems to the case of active perception that involves movements of the sensors. We have demonstrated the autonomous learning and self-calibration of object tracking behavior in the iCub humanoid robot based on AEC [8]. In addition, we have proposed an integrated approach for the self-calibration of stereo and motion vision based on AEC [9]. This approach treats stereo and motion processing and the associated tracking and vergence eye movements from a unified perspective rooted in information theory.

d) **Activity analysis prototype:** In collaboration with Goethe University we have extended the scheme for recognizing human activities. By porting computationally demanding parts of the code to graphics processing units (GPUs), we have developed a version of the software that runs in real time (e.g., 42 frames per second using 4 GPUs). We integrated and tested this software with the iCub robot achieving a performance of around 80% correct recognition on a set of 8 different activities performed by different people.

We published a review article on '*The role of spatial interactions in object recognition'*. In this review we suggested two possible ways of how the different types of cortical architectures observed in primates vs. rodents might impact visual processing [1]. In addition, our past work in autonomous learning has been published in Journal of Machine Learning Research in 2014 ([10], [11]). We have also published several peer-reviewed papers at international conferences and journals and we had several posters in Bernstein conference 2014.

In summary, we have a strong and balanced progress in both science and engineering of vision systems. The science and engineering threads are executed in parallel with the rapid engineering platform supporting seamless transition of scientific results.

[1] M. Kaschube, *Neural maps versus salt-and-pepper organization in visual cortex,* Current Opinion in Neurobiology 2014, 24:95-102

[2] A. Sederberg, M. Kaschube, *Inhibition facilitates direction selectivity in a noisy cortical environment*, J. Comput. Neurosci. 2014

[3] G.B. Smith, A. Sederberg, Y.M. Elyada, S.D. Van Hooser, M. Kaschube, D. Fitzpatrick, *The development of cortical circuits for motion discrimination,* Nature Neuroscience, in press

[4] B. Eppler, D.F. Aschauer, S. Rumpel, M. Kaschube, *Discrete representations in mouse auditory cortex and their stability in the presence of synaptic turnover,* Bernstein Conference 2014

[5] M. Kaschube, B. Hein, K. Neuschwander, G.B. Smith, D.E. Whitney, D. Fitzpatrick, *Chronic imaging of GCaMP6 population activity in ferret visual cortex reveals spontaneous modular patterns of activity prior to eye opening***.** Program No. 155.11. Neuroscience 2014 Abstracts. Washington, DC: Society for Neuroscience, 2014 Online

[6] T. Fernandes and C. von der Malsburg, *Self-Organization of Control Circuits for Invariant Fiber Projections*. Neural Computation, in print

[7] T. Fernandes, *Self-Organization of Control Circuits for Invariant Fiber Projections*, PhD Thesis, submitted to FB 12, Goethe-Univ. Frankfurt, Dec. 2014

[8] C. Teulière, S. Forestier, I. Lonini, C. Zhang,Y. Zhao, B. Shi, J. Triesch, *Self-calibrating smooth pursuit through active efficient coding*, Robotics and Autonomous Systems, 2014

[9] T.N. Vikram, C. Teulière, C. Zhang, B. Shi, J. Triesch, *Autonomous learning of smooth pursuit and vergence through active efficient coding*. ICDL-EpiRob, Genoa, Italy, 2014

[8] A. S. Sheik, J. A. Shelton, J. Lücke, *A Truncated EM Approach for Spike-and-Slab Sparse Coding*, JMLR 15 (2014) 2653-2687

[9] M. Henniges, R. Turner, M. Sahani, J. Eggert, J. Lücke, *Efficient Occlusive Components Analysis*, JMLR 15 (2014), 2689-2722

2. Graduate Schools

Helmholtz Graduate School for Hadron and Ion Research

and

Helmholtz Research School for Quark Matter Studies

by Henner Büsching and Gerhard Burau

Supported by the Initiative and Networking Fund of the Helmholtz Association, the Helmholtz Graduate School for Hadron and Ion Research (HGS-HIRe for FAIR) was established in October 2008 as a joint endeavor of the GSI Helmholtzzentrum für Schwerionenforschung together with the Frankfurt Institute for Advanced Studies (FIAS) and the universities at Darmstadt, Frankfurt, Giessen, Heidelberg and Mainz to promote and support structured doctoral education for research associated with GSI and the Facility for Antiproton and Ion Research (FAIR). An integral part of HGS-HIRe is the Helmholtz Research School for Quark Matter Studies (H-QM) to specially support a selected group of highly talented doctoral students performing research in the field of heavy-ion physics, which is the largest field of research within the graduate school.

More than 370 doctoral students in 10 fields of research relevant for GSI and FAIR are participating in the program of HGS-HIRe by the end of 2014. Likewise impressive is the number of 207 participants who finished their doctoral thesis so far and became alumni of the graduate school. More than 50 of them graduated in 2014. Altogether more than 190 participants and alumni (33%) are of international origin.

The great popularity of HGS-HIRe and H-QM allowed for a consequent continuation of the structured doctoral program in 2014.

An essential pillar of this structure is the doctoral education program. Numerous HGS-HIRe and H-QM events on various topics, which addressed both, scientific and transferable skills training, have been organized in 2014: eight lecture weeks, three power weeks, and a total of ten courses on transferable skills. Special events, as the HGS-HIRe Perspectives events to facilitate the career planning of the students after finishing the doctoral thesis, the Quark Matter 2014 Student Center organized by HGS-HIRe, and the HGS-HIRe Summer Student Program at GSI with 41 participating students from 19 GSI/FAIR partner countries complemented the educational program of HGS-HIRe and H-QM in 2014.

The central event of the year was the annual HGS-HIRe Graduate Days, held at Gut Hühnerhof in Gründau on October 23 and 24. We celebrated the sixth anniversary of the graduate school by plenary talks on current physics highlights, scientific talks and poster sessions organized and chaired by the doctoral students. This year's HGS-HIRe Excellence

Awards went to Katharina Kupka (GSI & TU Darmstadt) and Ralf-Arno Tripolt (TU Darmstadt) for their outstanding achievements during their doctoral studies. The annual Participant Council and the "HIRe Feier" with the Excellence Award ceremony and reception complemented the program of this event.

An important pillar of HGS-HIRe is the scientific travel program for the participants consisting of the individual travel budgets for the doctoral students to attend conferences, workshops etc., and the HGS-HIRe Abroad program which offers participants a limited number of grants, awarded in a competitive process several times per year, for a one to three months research stay abroad to facilitate their thesis project and to intensify research collaborations. Moreover, the graduate school serves, strongly supported by FIAS, as central contact and care center for the doctoral students, their supervisors and the administration of our partner institutions. Administrative and social aspects are handled here as, for example, the administration of more than 370 individual PhD committees, help with student status issues and visa/residence permits. Within the activities of this contact and care center, HGS-HIRe provides and centrally organizes the successful doctoral scholarship programs of GSI and HIC for FAIR.

Last but not least HGS-HIRe continued its public outreach activities with strong involvement of the doctoral students, namely participation in the Primary School Program in collaboration with the Polytechnische Gesellschaft Frankfurt, in the national and international Masterclass Program within the BMBF-initative "Netzwerk Teilchenphysik", and participation in the campaign “Hessen schafft Wissen” by, e.g., experimental stations at “Hessentag 2014” in Bensheim and “Night of Science” at Goethe University Frankfurt.

FIGSS

The Frankfurt International Graduate School for Science

by Jochen Triesch

The Frankfurt International Graduate School for Science (FIGSS) is the graduate school of FIAS. It provides a framework for doctoral education at FIAS, while PhD degrees are officially granted by Goethe University. The students are expected to obtain their PhDs within three years. Typically, they are funded by research grants to their advisors, since FIGSS does not receive any direct funding.

In 2014, 9 FIGSS students obtained their PhDs. This number falls in the normal range with, e.g., only 5 graduations in 2012, but 19 in 2013. The total number of students enrolled in FIGSS at the end of 2014 was slightly lower than that of last year: 41 in December 2014 compared to 44 in December 2013. The fraction of female students has continued to drop and was at 10% at the end of 2014 (down from 18% and 15% in the previous two years). The student population remains quite international with 37% of our students being foreign nationals. However, this number has also been declining from 54% and 45% in the previous two years. The composition of FIGSS with respect to the different research disciplines was as follows (numbers in parentheses are from the previous year; reference month is always December): Physics: 49% (52%), Neuroscience: 27% (18%), Computer Science: 20% (20%), Life Sciences: 5% (9%).

A core activity of FIGSS continues to be its weekly lunch seminar held in the FIAS Faculty Club on Mondays. Each week a FIGSS student or FIAS post-doc reports on the status of their research, while the audience enjoys pizza. Care is taken that the talks are understandable to a broad interdisciplinary audience and of high quality. To this end, we use feedback forms that attendees fill in after every presentation. In addition, the talks are videotaped to give speakers feedback about their presentation style. The best talk of each semester is awarded a bottle of Champagne. In the winter semester 2013/2014 two students shared the first prize. These were Sarah Becker with her presentation „What can transmission do for a fully renewable Europe?“ and Yuri Malyshkin with his talk: „Elimination of nuclear waste and production of transuranic elements in spallation targets". In the summer semester 2014 the prize went to Pramod Chandrashekhariah for his work „Curious vision system for autonomous object learning.“

In 2014 the students also started to revive the tradition of organizing a 5-day retreat for fostering interdisciplinary exchange. This retreat is taking place in Goethe University's Haus Bergkranz in the Kleinwalsertal in Austria in January 2015.

Courses offered at FIGSS

Summer Semester 2014

J. Triesch	Methods for the study of complex systems, 2+1h
I. Mishustin E. Bratkovskaya	Dynamical models for relativistic heavy-ion collisions, 2h
T. Burwick	Visual system - Neural structure, dynamics, and function, 2h
S. Schramm	Quantum theory on the lattice, 2+1h
H. van Hees	From Quantum Field Theory to (semi)classical transport equations II, 2h
P. Nicolini	Classical and quantum physics of black holes II, 2+1h
C. Gros	Self-Organization: Theory and Simulations, 4+2h
D. Schuch	Nonlinearities and dissipation in classical and quantum physics, 2h
H.J. Lüdde	Nonlinear dynamics and complex systems 2+2h
M. Wibral	Information theory and coding - with applications to neural systems, 2h

Winter Semester 2014/15

M. Kaschube J. Triesch	Theoretical neuroscience, 2+2h
T. Burwick	Brain dynamics: From neuron to cortex, 2h
I. Mishustin E. Bratkovskaya	Physics of strongly interacting matter, 2h
V. Lindenstruth	High-performance computing architectures, 4h
C. Sasaki	Introduction to chiral effective field theories, 2h
S. Schramm	Nuclear and neutrino astrophysics, 2+1h
S. Schramm, M. Greiner	Complex renewable energy networks
P. Nicolini	Classical and quantum physics of black holes I, 2+1h
L. Rezzolla	Hydrodynamics and Magnetohydrodynamics, 2+1h
F. Giacosa	Decays in Quantum Field Theory
D. Schuch	Is Quantum Theory intrinsically nonlinear?, 2h

Regularly held seminars

FIGSS Seminar	FIAS Fellows
Interdisciplinary FIAS Colloquium	FIAS Fellows
Current topics in theoretical neuroscience	Triesch
NeuroBio Theory seminar series	Kaschube, Triesch, Gros
Transport phenomena in heavy ion collisions	Bleicher, Petersen, C. Greiner, Rischke
Nuclear/Heavy ion group meeting	Mishustin
Astro coffee meeting	Mishustin, Schramm, Rezzolla, Schaffner-Bielich, Sedrakian
Journal club in high-energy physics	Nicolini
Journal club on relativistic heavy ion physics	Petersen

Ph.D. degrees received by FIAS/FIGSS students in the year 2014

1	P	Yaser Martínez Palenzuela	14.02.2014	Ground State Properties of Superheavy Nuclei within the Statistical Learning Framework
2	P	Torsten Schürhoff	06.05.2014	Applications of a chiral model in nuclear and astrophysics
3	I	David Rohr	23.06.2014	On development, feasibility, and limits of highly efficient CPU and GPU programs in several fields
4	L	Maren Herrlitz	07.2014	Elucidation of DNA methylation changes in response to ionizing radiation induced double strand breaks
5	P	Yury Malyshkin	11.07.2014	Monte Carlo modeling of neutron production and transport in fissile spallation targets
6	L	Lucas Burigo	16.07.2014	Modelling radiation fields of ion beams in tissue-like materials
7	N	Daniela Pamplona	04.08.2014	Ecological Perspectives on Local Image Statistics
8	I	Sarah Becker	15.10.2014	Transmission grid extensions in renewable electricity systems
9	P	Isaac Rodríguez Gonzáles	16.12.2014	Neutron Stars within Pseudo-complex General Relativity

Fields

I	Information/Computer Science	2
L	Life Science	2
N	Neuroscience	1
P	Physics	4

3. FIAS Scientific Life

Seminars and Colloquia at FIAS in the year 2014

The organization of common colloquia and seminars has played an inportant role for fostering an interdisciplinary spirit at FIAS. From the beginning, in the weekly "Interdisciplinary FIAS Colloquium" distinguished speakers were invited to give overview talks covering all scientific areas represented at FIAS. In addition, the "FIGSS Seminar" is organized, mainly as a platform for Ph.D. students to present their work. These events are addressing the 'general public' at FIAS and bring together the researchers and students from all scientific branches. In addition, various group seminars are held with a more focussed specialization. Their schedules are not listed in the following.

FIAS Colloquium

23.01.2014 **Dr. Kathi Zarnack,** European Molecular Biology Laboratory, European Bioinformatics Institute (EMBL-EBI), Hinxton, Cambridge UK
Genomic views of protein-RNA interactions

13.02.2014 **Prof. Dr. Klaus Pawelzik,** Institute for Theoretical Physics/Center for Cognitive Sciences, University of Bremen
Criticality of control in man and markets

20.03.2014 **Prof. Dr. Hermann Requardt,** Siemens AG, Munich
Outcome and Evidence: The future role of technology in healthcare systems

15.05.2014 **Dr. Andreas Redelbach,** Faculty for Physics and Astronomy, University of Würzburg
Searching for Supersymmetry at the ATLAS Detector

15.06.2014 **Dr. Paolo Palazzi,** CERN, Geneva, Switzerland
Mass rules, shell models, and the structure of hadrons

10.07.2014 **Prof. Dr. Laurenz Wiskott,** Institut für Neuroinformatik, Ruhr University Bochum
Slow feature analysis and beyond

07.08.2014 **Prof. Dr. Heino Falcke,** Dept. of Astrophysics, Radboud University Nijmegen
Towards imaging the event horizon of the supermassive black hole in our Milky Way

25.09.2014 **Prof. Dr. Sibaji Raha,** Bose Institute, Kolkata, India
Baryogenesis confronts QGP: Dark Matter and Dark Energy within the standard model

04.12.2014 **Prof. Dr. Gabriel Martínez Pinedo,** Institute for Nuclear Physics, Technical University, Darmstadt, Germany
Explosive nucleosynthesis of heavy elements

18.12.2014 **Prof. Dr. Raoul-Martin Memmesheimer,** Department for Neuroinformatics, Radboud University Nijmegen, Netherlands
Nonlinear dendritic amplification, sleep and memory

FIGSS Seminar

13.01.2014 **David Rohr**
Fast vectorized and GPU-accelerated algorithms for multiple applications

20.01.2014 **Yuri Malyshkin**

Elimination of nuclear waste and production of transuranic elements in spallation targets

27.01.2014 **Taesoo Song**
Mean-field effects on matter and antimatter flows in quark-gluon plasma

10.02.2014 **Hanna Kamyshanska**
Force fields, potential energies and neural networks: how to use physics in image processing

14.04.2014 **Jussi Auvinen**
A Monte Carlo simulation study of the collisional energy loss of high-energy quarks and gluons in a strongly interacting medium

05.05.2014 **Daniel Miner**
Self-Organization in cortical wiring

19.05.2014 **Matthias Kretz**
Vc: Portable and easy SIMD programming with C++

26.05.2014 **Bettina Hein**
Emergence of orientation preference organisation in visual cortex using a neuronal network model

16.06.2014 **Pramod Chandrashekhariah**
Curious vision system for autonomous object learning

30.06.2014 **Ritam Mallick**
Magnetars: New frontier of neutron stars

07.07.2014 **Jon Willits**
What can children learn from six million words?

14.07.2014 **Daniela Pamplona**
Ecological perspectives on local image statistics

13.10.2014 **Dmytro Oliinychenko**
The tallest sandcastle with a given base

03.11.2014 **Vikram Narayan**
Autonomous learning of smooth pursuit and vergence through active efficient coding

01.12.2014 **Oliver Richters,** University of Oldenburg
A stock-flow consistent input-output model with applications to energy price shocks, interest rates, and heat emissions

Conferences and meetings (co)organized by FIAS in the year 2014

▹ **Ernst Strüngmann Forum, *"Heavy Metals and Infectious Diseases",***
FIAS, Frankfurt, January 19 – 24, 2014
`www.esforum.de/forums/esf16_heavy_metals.html`

▹ **Mind Group, *"Moral Agency & Cognitive Science"***, 20. Meeting of the Junior Research Group "Philosophy of Mind", Frankfurt, March 13 – 14, 2014
`fias.uni-frankfurt.de/mindgroup/index.php/meeting-20.html`

▹ **Ernst Strüngmann Forum, *"Diseases of the Nervous System: What Is to Be Done?",***
FIAS, Frankfurt, March 16 – 21, 2014
`www.esforum.de/forums/esf17_diseases_of_the_nervous_system.html`

▹ **FCTTC2014, *"Fifth International Workshop for Future Challenges in Tracking and Trigger Concepts",*** FIAS, Frankfurt, May12 – 14, 2014
`fias.uni-frankfurt.de/de/cs/conferences/fcttc-2014/`

▹ **Star Collaboration Meeting,**
FIAS, Frankfurt, May13 – 16, 2014
`fias.uni-frankfurt.de/en/physics/conferences/star2014/`

▹ **ICIS 2014 Pre-Conference *"Computational Models of Infant Development",***
Berlin, July 2, 2014
`www.er.ams.eng.osaka-u.ac.jp/icis2014-preconference/`

▹ **ACCN 2014, *"Advanced Course in Computational Neuroscience 2014",***
FIAS, Frankfurt, August 3 – 30, 2014
`fias.uni-frankfurt.de/de/accn/`

▹ **Ernst Strüngmann Forum, *"Where's the Action? The Pragmatic Turn in Cognitive Science",***
FIAS, Frankfurt, October 26 – 31, 2014
`www.esforum.de/forums/esf18_where_is_the_action.html`

▹ **NEOS 2014, *"Nuclear Equation of State for Compact Stars and Supernovae",***
FIAS, Frankfurt, December 3 – 5, 2014
`fias.uni-frankfurt.de/~neos2014/`

▹ **Workshop on *"Neural Information Dynamics, Causality and Computation near Criticality",***
FIAS, Frankfurt, December 12 – 13, 2014
`fias.uni-frankfurt.de/de/neuro/conferences/neural-information-dynamics-2014/`

Public lectures at FIAS in the year 2014

The public-outreach activities of FIAS strive to strengthen the understanding of scientific issues in the general public and at the same time to raise the awareness level of the Institute in Frankfurt and the Rhein-Main area. This traditionally is done within the framework of the *FIAS Forum*, which organizes public evening lectures on a wide variety of scientific topics addressed to a broader audience of interested citizens. In the year 2014 the FIAS Forum has been suspended. Instead, in the winter semester 2013/14 to large public acclaim a lecture series dedicated to the topic "Vom Urknall ins Labor – Materie unter extremen Bedingungen" was held, with external financing by Deutsche Bank AG and the Helmholtz Center HIC for FAIR. In addition, accompanying the summer school "Advanced Course in Computational Neuroscience 2014" four public evening talks were organized.

Deutsche Bank Lecture Series

16.01.2014 **Prof. Dr. Wolfgang Bauer,** Michigan State University, East Lansing, USA
Genesis - Der Ursprung der Elemente

30.01.2014 **Prof. Dr. Hans-Thomas Janka,** Max-Planck-Institut für Astrophysik, Garching
Rätselhafte Supernova – Den Geheimnissen der größten kosmischen Explosionen auf der Spur

30.01.2014 **Prof. Dr. Harald Lesch,** Ludwig-Maximilians-Universität, München
"Wir irren uns empor" – Schlagzeilen vom Rand der Wirklichkeit

Special Public Lectures

05.06.2014 **Prof. Dr. Thomas Stieglitz,** Albert-Ludwigs-Universität Freiburg, Germany
Technik die unter die Haut geht –
Neurotechnische Implantate im peripheren und zentralen Nervensystem

06.06.2014 **Prof. Dr. Paolo Palazzi,** CERN, Geneva, Switzerland
The early days of the WWW at CERN – a personal recollection

Evening Lectures – Advanced Course in Computational Neuroscience 2014

06.08.2014 **Prof. Dr. Erik De Schutter,** Okinawa Institute of Science and Technology, Japan
Data publication to improve data sharing

13.08.2014 **Prof. Dr. Hans-Joachim Pflüger,** Freie Universität Berlin, Germany
Ethics in science and good scientific practice

20.08.2014 **Prof. Dr. Erin Schuman,** Max Planck Institute for Brain Research, Frankfurt, Germany
The neural basis of memory

27.08.2014 **Prof. Dr. J. Kevin O'Regan,** Laboratoire Psychologie de la Perception, CNRS, Paris, France
A sensorimotor account of consciousness

4. Research Reports

4.1 Nuclear Physics, Particle Physics, Astrophysics

Strange meson-baryon interaction in hot and dense nuclear matter: from hadronic models to transport simulations

Collaborators: Daniel Cabrera[1,2], Andrej Ilner[1,2], Laura Tolos[1,3], Jörg Aichelin[4], Elena Bratkovskaya[1,2], Wolfgang Cassing[5].

[1] Frankfurt Institute for Advanced Studies, [2] Institut für Theoretische Physik, Goethe-Universität Frankfurt, [3] Institut de Ciències de l'Espai (IEEC/CSIC), Bellaterra, Spain, [4] Subatech, Université de Nantes, France, [5] Institut für Theoretische Physik, Universität Gießen

We study the dynamics of strange pseudoscalar and vector mesons in hot and dense nuclear matter within a selfconsistent coupled-channel approach based on the meson-baryon chiral Lagrangian. Our results set up the starting point for implementations in microscopic transport approaches of heavy-ion collisions, particularly at the conditions to be met in the future experiments at GSI/FAIR and NICA@Dubna. Such developments are in progress, exploiting the successful collaboration between the transport groups of Nantes and FIAS-Frankfurt.

In the $\bar{K}N$ sector we focus on the calculation of in-medium (off-shell) transition rates for the most relevant binary reactions involved in strangeness production close to threshold energies, with special attention to the role of sub-threshold hyperon resonances and isospin effects (e.g. $\bar{K}p$ vs $\bar{K}n$, cf. Fig. 1). Together with the spectral function and the nuclear optical potential of strange mesons and hyperons, our results permit a systematic accounting of medium effects in the $S=-1$ sector regarding the production, propagation and rescattering of light strange hadrons.

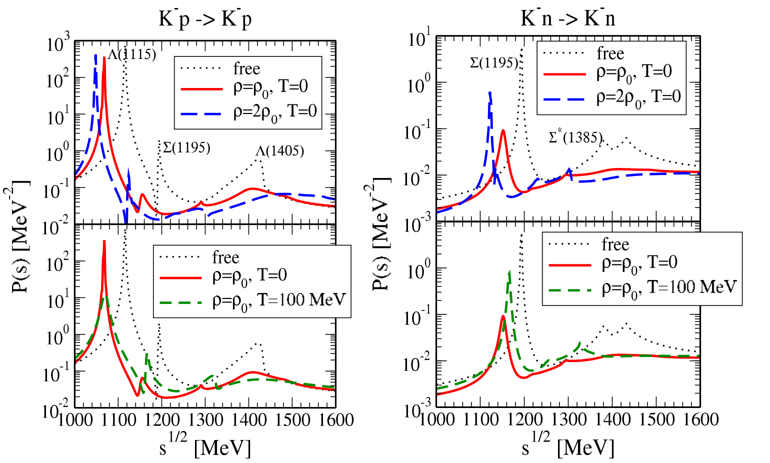


Figure 1: In-medium transition probability $\mathscr{P}$ for the elastic K^-p (left) K^-n (right) reactions. The peaks associated to the $\Lambda(1115)$, $\Sigma(1195)$ and $\Lambda(1405)$ resonances are clearly visible in the vacuum case.

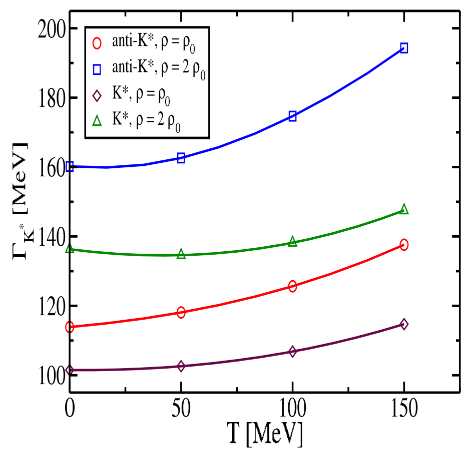


Figure 2: Temperature evolution of the $\bar{K}^*(K^*)$ width – or selfenergy – due to $\bar{K}(K)\pi$ in-medium decays at $\rho=\rho_0, 2\rho_0$.

We have also pursued recent theoretical developments regarding the dynamics of strange vector mesons (K^*, $\bar{K}^*$ and ϕ) in the nuclear medium, in connection with on-going experimental activity from heavy-ion collisions and nuclear production reactions. Our work focuses on the extension to finite temperatures of previous chiral hadronic models for the vector meson selfenergy in dense matter (cf. Fig. 2), where the key mechanisms for medium modification are: (i) the excitation of strange baryon resonances in quasielastic scattering (e.g. $\bar{K}^*N \to \bar{K}^*N$ plus related absorption channels) and (ii) the decay into predominant hadronic modes (e.g. $\bar{K}^* \to \bar{K}\pi$).

Related publications in 2014:

1) D. Cabrera, L. Tolos, J. Aichelin and E. Bratkovskaya, Phys. Rev. C 90, 055207 (2014)
2) A. Ilner, D. Cabrera, P. Srisawad and E. Bratkovskaya, Nucl. Phys. A 927, 249 (2014)
3) L. Tolos, D. Cabrera, C. Garcia-Recio, R. Molina, J. Nieves et al., J. Phys. Conf. Ser. 562, 012010 (2014)
4) D. Cabrera, L. M. Abreu, E. Bratkovskaya, A. Ilner et al., J. Phys. Conf. Ser. 503, 012017 (2014)

Heavy-quark dynamics in a hot and dense medium

Collaborators: H. Berrehrah[1], E. Bratkovskaya[1], W. Cassing[2], P.B. Gossiaux[3], J. Aichelin[3]

[1] Frankfurt Institute for Advanced Studies, [2] Institut für Theoretische Physik, Univ. Gießen, [3] Subatech, Nantes, France

We study the dynamics of on- and off-shell heavy quarks Q in the quark-gluon plasma (QGP) as produced in relativistic nucleus-nucleus collisions. The interactions of heavy quarks with the partonic environment at finite temperature T and finite quark chemical potential μ_q are investigated in terms of transport coefficients within the dynamical quasiparticle model (DQPM) designed to reproduce the lattice-QCD (lQCD) results (including the partonic equation of state) in thermodynamic equilibrium. The collisional scattering cross sections σ^{Q}_{elas} are evaluated for perturbative partons (massless on-shell particles) and for dynamical quasi-particles (massive on or off-shell particles) using the leading order Born diagrams [2,3].

Based on σ^{Q}_{elas} in a finite T and μ_q medium [1– 4], the on- and off-shell heavy quark dynamical collisional energy loss and transport coefficients are computed [1,3,4]. As an example, the charm spatial diffusion coefficient D_s is shown in Fig. 1 at finite T (left) and finite T and μ_q (right) where our non-perturbative DpQCD model (Dressed pQCD using DQPM pole masses for the partons) is confronted with nuclear many-body calculations below and close to the critical temperature T_c from Ref. [5].

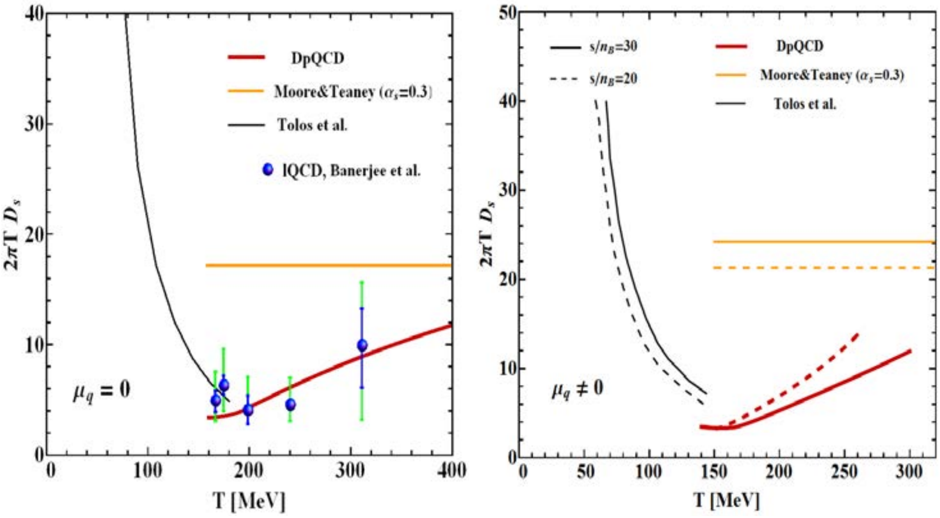


Figure 1: Spatial diffusion coefficient for heavy quarks, D_s, as a function of T for $\mu_q = 0$ (left) and $\mu_q \neq 0$ (right). The hadronic diffusion coefficient is taken from [5]. For partonic environment the result from the DpQCD model is compared to pQCD [6] and lattice calculations from Ref. [7].

The hadronic and partonic D_s join smoothly and show a pronounced minimum close to T_c at $\mu_q = 0$ as well as at finite μ_q . Close to and above T_c its absolute value matches the lQCD calculations for $\mu_q = 0$. The smooth transition of the heavy-quark transport coefficients from the hadronic to the partonic medium corresponds to a crossover transition in line with lattice calculations, and differs substantially from perturbative-QCD calculations (Moore & Teaney) which show a large discontinuity at T_c. This indicates that in the vicinity of T_c dynamically dressed massive partons should be the effective degrees of freedom in the quark-gluon plasma.

The heavy quark scattering cross sections and transport properties [1– 4] form the basis of a consistent study of the heavy quark dynamics in heavy-ion collisions at FAIR, SPS, RHIC and LHC energies where the partonic processes are implemented into the Parton-Hadron-String-Dynamics (PHSD) transport approach.

Related publications

[1] H. Berrehrah et al., Phys. Rev. C 90, 051901 (2014)
[2] H. Berrehrah et al., Phys. Rev. C 89, 054901 (2014)
[3] H. Berrehrah, P.-B. Gossiaux, J. Aichelin, W. Cassing, and E. Bratkovskaya, Phys.Rev. C90, 064906 (2014)
[4] H. Berrehrah, E. Bratkovskaya, W. Cassing, and R. Marty, arXiv:1412.1017 [hep-ph]
[5] L. Tolos and J.M. Torres-Rincon, Phys. Rev. D 88, 074019 (2013)
[6] G.D. Moore and D. Teaney, Phys. Rev. C 71, 064904 (2005)
[7] D. Banerjee et al., Phys. Rev. D 85, 014510 (2012)

Creation and annihilation of antimatter at FAIR energies

Collaborators: P. Moreau[1], J. Aichelin[2], E. Bratkovskaya[1]

[1] Frankfurt Institute for Advanced Studies, [2] Subatech, Université de Nantes, Ecole des Mines de Nantes, France

The 'Big Bang' scenario implies that in the first micro-seconds of the universe the entire state has emerged from a partonic system of quarks, antiquarks and gluons – a quark-gluon plasma (QGP) – to color neutral hadronic matter consisting of interacting hadronic states (and resonances) in which the partonic degrees of freedom are confined. Nowadays this early phase can be reproduced in relativistic heavy ion collisions. They show indeed that such a QGP can exists and that it interacts more strongly than hadronic matter. Consequently the concept of a weakly interacting system described by perturbative QCD (pQCD) has to be questioned.

The dynamics of partons, hadrons and strings in relativistic nucleus-nucleus collisions can be analyzed within the Parton-Hadron-String Dynamics approach [1,2]. In this transport approach the partonic dynamics is based on Kadanoff-Baym equations for Green functions with self-energies from the Dynamical QuasiParticle Model (DQPM) which describes QCD properties in terms of "resummed" single-particle Green functions [3]. The lattice QCD results, of which the parameters of DQPM are fitted on, lead to a critical temperature $T_c \approx 160$ MeV which corresponds to a critical energy density of $\varepsilon_c \approx 0.5$ GeV/fm^3.

The aim of this project is with the help of the PHSD to study the creation and annihilation of anti-matter at the FAIR facility in the future CBM and PANDA experiments. Since anti-matter (or antiparticles) doesn't exist in our world it has to be created first by strong interactions before its dynamics can be studied in different hadronic or partonic environments. These experiments aim at the exploration of the QCD phase diagram, especially to find out the order of the phase transition between hadrons and partons at high baryonic densities. In addition we will study the optical potential of different hadrons and the in-medium properties of hadrons in the strange and the charm sector. To verify that our approach is adequate for this study we start out with the calculation of the measured spectra of particles and anti-particles at RHIC energies. We have found a good agreement with the PHENIX data for single particle spectra in Au+Au (Figure 1) and p+p (Figure 2) collisions at mid-rapidity. One can see that the production of particles and anti-particles in pp collisions is very similar while in Au+Au collisions we observe the effects of anti-baryon absorption at low p_T as well as rescattering on the partonic and hadronic levels.

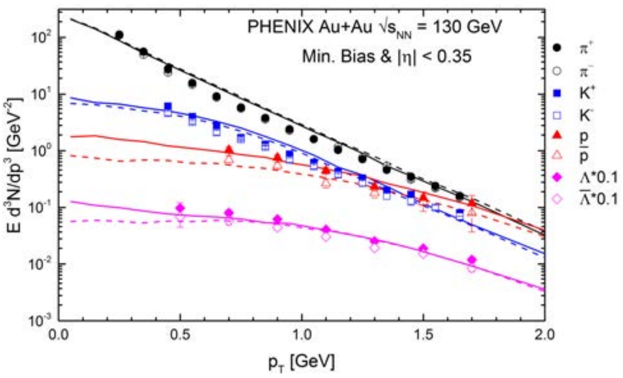


Figure 1: Invariant p_T spectra in Au+Au collisions at $\sqrt{s_{NN}} = 130$ GeV for π^+, π^-, K^+, K^-, p, $\bar{p}$, Λ and $\bar{\Lambda}$ obtained with PHSD, in comparison with the experimental data from the PHENIX collaboration [4,5].

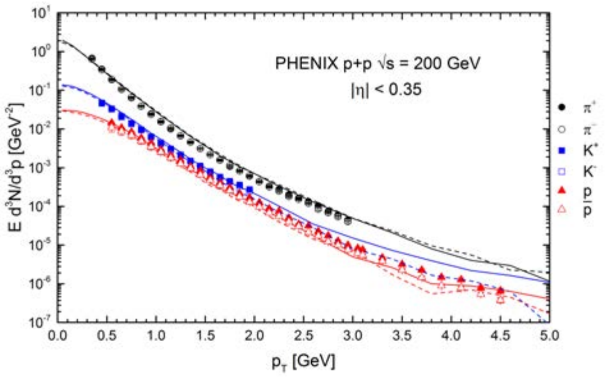


Figure 2: Invariant p_T spectra in p+p collisions at $\sqrt{s} = 200$ GeV for π^+, π^-, K^+, K^-, p and $\bar{p}$ obtained with PHSD in comparison with the experimental data from the PHENIX collaboration [6].

References

[1] W. Cassing and E. L. Bratkovskaya, Nucl. Phys. A 831, 215 (2009)

[2] E. L. Bratkovskaya, W. Cassing, V. P. Konchakovski, O. Linnyk, Nucl. Phys. A 856, 162 (2011)

[3] W. Cassing, Eur. Phys. J. ST 168, 3 (2009)

[4] K. Adcox et al. (PHENIX Collaboration), Phys. Rev. C 69, 024904 (2004)

[5] K. Adcox et al. (PHENIX Collaboration), Phys. Rev. Lett. 89, 092302 (2002)

[6] A. Adare et al. (PHENIX Collaboration), Phys. Rev. C 83, 064903 (2011)

A model comparison for different transport approaches with comparable initial conditions in heavy-ion collisions

Collaborators: R. Marty[1], E. Bratkovskaya[1], W. Cassing[2], J. Aichelin[3]

[1] Frankfurt Institute for Advanced Studies and Institut für Theoretische Physik, Goethe University, Frankfurt, [2] Institut für Theoretische Physik, Univ. Gießen, [3] Subatech, Nantes, France

The state of the matter created in high energy heavy-ion collisions – the Quark-Gluon Plasma (QGP) – can be described by different theoretical models, such as the Nambu-Jona-Lasinio model (NJL) or the Dynamical QuasiParticle Model (DQPM).

In our study we compare the Parton-Hadron-String Dynamics (PHSD)– based on the DQPM for the QGP phase – with the transport approach RSP (Relativistic quantum molecular dynamics for Strongly interacting matter with Phase transition or crossover) – based on the NJL model – using the same initial conditions from PHSD, which have a 'lumpy' energy density profile (see Fig. 1 (a) for the Au+Au collisions at $\sqrt{s} = 200$ GeV).

Although we have the same initial energy density profile, the transport properties of the bulk partonic matter in RSP and in PHSD are not the same [1]. The main difference between both approaches is that RSP uses light quarks which convert into hadrons using NJL cross sections, and that PHSD uses heavy partons (quarks and gluons) which combine into heavy hadrons with broad spectral functions which then decay into light hadrons.

The comparison of final hadronic observables (Fig. 1 (b) and (c)) shows that the initial parton distribution must be out of equilibrium (method 2 and 3) in both approaches (PHSD/RSP) in order to reproduce the multiplicity spectra dN/dp_T and $dN/d\eta$ for Au+Au at RHIC energies. The equilibrium conversion (method 1) fails to reproduce the correct spectra as well as the number of charged particles [2]. The elliptic flow v_2 is not well described without hadronic rescattering which plays an important role as seen for the results of PHSD with rescattering in comparison to the STAR data.

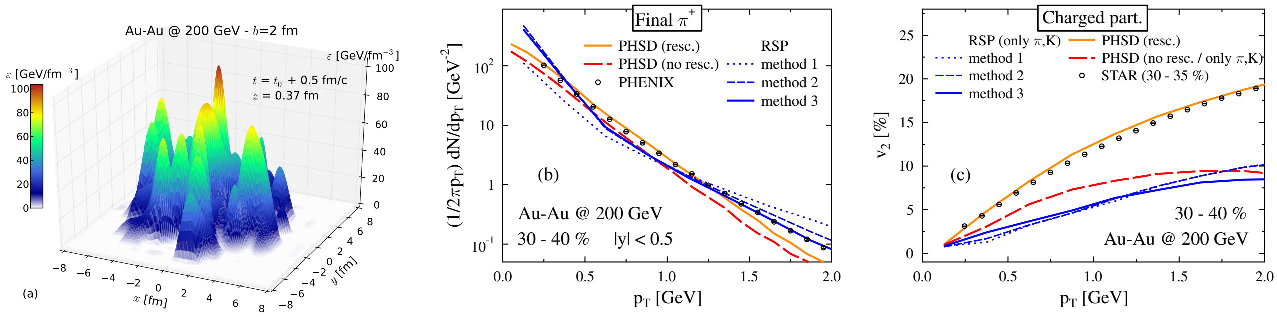


Figure 1: The initial energy density transverse $(x-y)$ profile in the local rest frame (a), and the final transverse momentum distribution dN/dp_T (b) and $v_2(EP)$ (c) of final charged pions in RSP (blue lines) and PHSD for the Au+Au collisions at $\sqrt{s} = 200$ GeV.

The surprising result is that for the two very different transport theories one obtains – for the same initial local energy-density distributions – a similar transverse momentum distributions of mesons as well as elliptic flow v_2 if the non-equilibrium character of the PHSD initial condition is taken into account (method 2 and 3).

The computational resources were provided by the LOEWE-CSC.

Related publications

[1] R. Marty, E. Bratkovskaya, W. Cassing, J. Aichelin, H. Berrehrah, Phys. Rev. C 88, 045204 (2013)
[2] R. Marty, E. Bratkovskaya, W. Cassing, J. Aichelin, arXiv:1412.5375 [hep-ph], submitted to Phys. Rev. C

Charm production in the Parton-Hadron-String-Dynamics (PHSD) model

Collaborators: Taesoo Song[1], Elena Bratkovskaya[1], Hamza Berrehrah[1], Wolfgang Cassing[2]

[1] Frankfurt Institute for Advanced Studies and Institute for Theoretical Physics, Johann Wolfgang Goethe Universität, Frankfurt am Main, [2] Institut für Theoretische Physik, Universität Gießen

Heavy flavor is one of the important probes to investigate the properties of the hot dense nuclear matter created in relativistic heavy-ion collisions. Since charm quark production requires high energy-momentum transfer, the number of produced charm quark pairs in relativistic heavy-ion collisions is proportional to the number of binary nucleon-nucleon collisions. Whether two nucleons collide or not in heavy-ion collisions is decided by the nucleon-nucleon inelastic cross section in geometrical method. From the binary collisions, we choose events which produce a charm quark pair by using Monte Carlo, based on the cross section for charm quark-pair production. Furthermore, we employ Pythia event generator to generate the energy-momentum of charm quark pairs as shown in the left panel of Fig. 1.

The produced charm quarks interact with partons in the quark-gluon plasma. We use the cross sections for the scattering of a heavy quark on the off-shell quarks and gluons (of the QGP) whose masses and widths are given by the Dynamical Quasi-Particle Model (DQPM) which reproduces the lattice QCD equation-of-state [1]. Once the local energy density is lower than a critical value (≈ 0.5 GeV/fm^3), the ccharm quark is hadronzied into a D meson either through fragmentation or through coalescence. The former process is favored by high-p_T charm quarks and the latter one by low-p_T charm quarks. We assume that the probability for coalescence is suppressed in Gaussian form, if the p_T of charm quark is larger than charm quark mass. Hadronized D mesons interact with other hadrons by using the scattering cross sections calculated in a chiral effective lagrangian model where the parameters are fitted to D meson and charmed baryon resonances.

Finally the nuclear modification factor, R_{AA}, is calculated as the number of D mesons produced in heavy-ion collisions divided by that in p+p collisions times the number of binary collisions in heavy-ion collisions as shown in the right panel of Fig. 1 for different centralities.

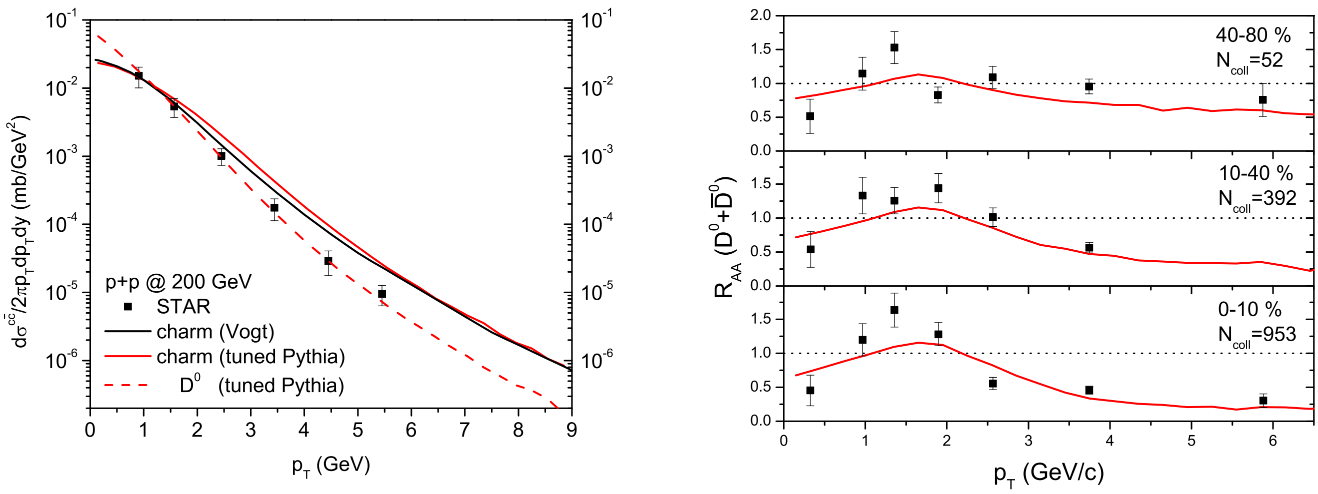


Figure 1: Left: p_T spectra of charm quarks and D mesons from the tuned Pythia simulations compared with FNOLL results by Vogt and that of D mesons from the STAR Collaboration. Right: R_{AA} of D mesons from the PHSD simulations in comparison with the experimental data from the STAR Collaboration for Au+Au collisions at $\sqrt{s_{NN}}$ =200 GeV.

Related publications:

[1] H. Berrehrah E. Bratkovskaya, W. Casing, P.B. Gossiaux, J. Aichelin, M. Bleicher, Phys. Rev. C 89 (2014) 054901

[2] T. Song, E. Bratkovskaya, H. Berrehrah, W. Cassing, *Charm production in the Parton-Hadron-String-Dynamics (PHSD) model*, in preparation

Formation of hypermatter and hypernuclei within transport models in relativistic ion collisions

Collaborators: A.S. Botvina[1,2], J. Steinheimer[1], E. Bratkovskaya[1], M. Bleicher[1], J. Pochodzalla[3,4]

[1] Frankfurt Institute for Advanced Studies, [2] Institute for Nuclear Research RAS, Moscow, Russia, [3] Helmholtz-Institut Mainz, [4] Institut für Kernphysik and PRISMA Cluster of Excellence, Mainz

The investigation of hypernuclei is one rapidly progressing field of nuclear physics, since they provide complementary methods to improve traditional nuclear studies and open new horizons for studying particle physics and nuclear astrophysics. The relativistic ion collisions is very promising: They allow for producing exotic light hypernuclei, heavy hypernuclei (including beyond the drip-lines), hyper-nuclear matter at subnuclear densities, and new experimental methods can be implemented beyond the traditional hypernuclear experiments with hadrons. The goal of this project is to develop effective models to make realistic predictions of yields of hypernuclei for planing future experiments. We use the Ultra-relativistic Quantum Molecular Dynamics (UrQMD) and Hadron-String Dynamics (HSD) models for description of the strangeness production. In order to describe the formation of hypernuclei and hyper-matter we have developed the Coalescence of Baryons (CB) model.

In Figure 1 we show the yields of all hyper-fragments, and also the yields of residues of projectiles and targets with captured hyperons, in relativistic carbon on carbon collisions. These residues are pieces of low-excited hyper-matter, which afterwards disintegrates with producing hypernuclei, including large exotic ones. We demonstrate the results obtained for the region of the most realistic coalescence parameters. We emphasize that the production of hypernuclei in such collisions is universal above the threshold ($\sim$1.6 A GeV). The saturation of the yields of hypernuclei means that this kind of reactions can be studied at the accelerators of moderate relativistic energies, e.g., at GSI/FAIR.

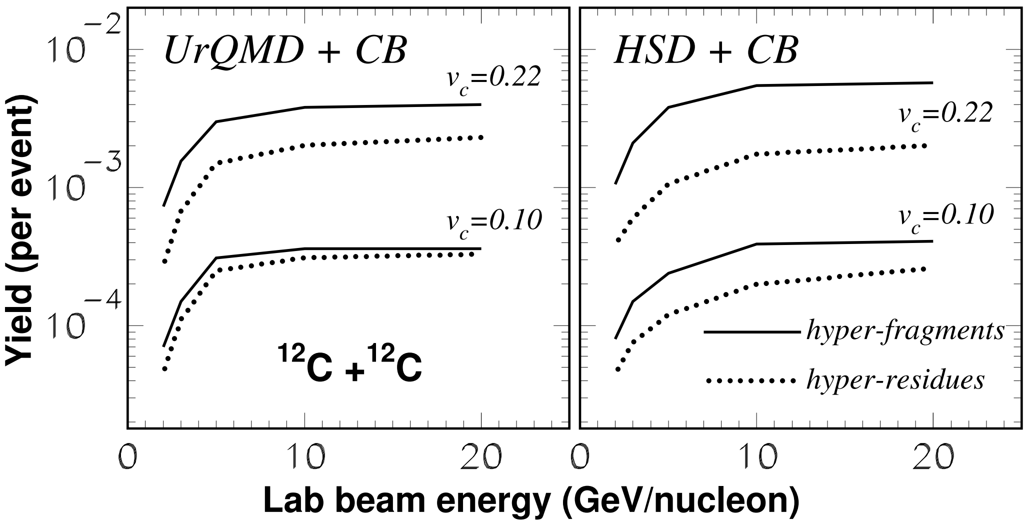


Figure 1: Yields of all produced hyper-fragments (solid lines) and hyper-residues (dotted lines) versus the beam energy in the carbon on carbon collisions for all impact parameters, as calculated within the UrQMD and CB model (left panel) and HSD and CB model (right panel). The coalescent parameters v_c are given in the panels.

Related publications in 2014:

1) A.S. Botvina, J. Steinheimer, E. Bratkovskaya, M. Bleicher, J. Pochodzalla, *Formation of hypermatter and hypernuclei within transport models in relativistic ion collisions*, Phys. Lett. B742, 7 (2015), arXiv:1412.6665 [nucl-th]

K^* dynamics in a nuclear medium

Collaborators: Andrej Ilner[1,2], Daniel Cabrera[1,2], Elena Bratkovskaya[1,2]

[1] Frankfurt Institute for Advanced Studies, [2] Institut für Theoretische Physik, Goethe Universität, Frankfurt

The K^* and the $\bar{K}^*$ are vector mesons that are composed of a light and a strange quark, i.e. the K^* is composed of a u and a $\bar{s}$ quark and the $\bar{K}^*$ is composed of a u and a s quark. We study the in-medium properties of these mesons in a dense and hot nuclear medium. The in-medium properties are based on chirally motivated models and these in-medium effects are parametrised as density or temperature dependent effective masses and widths. For broad in-medium particles we adopt the relativistic Breit-Wigner prescription, i.e. the spectral function

$$A_i(M,\rho_N) = C_1 \, \frac{2}{\pi} \frac{M^2 \Gamma_i^*(M,\rho_N)}{\left(M^2 - M_i^{*2}(\rho_N)\right)^2 + \left(M\Gamma_i^*(M,\rho_N)\right)^2} \,, \tag{1}$$

whereas C_1 stands for a normalisation constant, which is determined as the spectral function must fulfil the sum rule $\int_0^\infty A_i(M,\rho_N)dM = 1$, and $i = K/\bar{K}, K^*/\bar{K}^*$.

The in-medium effects are based on the complex self-energy, i.e. the width of the spectral function is related to the imaginary part of the self-energy as $\Gamma_i^*(M,\rho_N) = -\mathrm{Im}\,\Pi_i(M,\rho_N)/M$ and the mass shift is related to the real part of the self-energy as $(M_i^*)^2 - M_i^2 - \mathrm{Re}\,\Pi_i(M_i^*,\rho_N) = 0$ (with M_i being the nominal mass in vacuum, i.e. $M_{K^*} = 0.892$ GeV).

We distinguish two cases for energies where the medium is dense and is filled with baryonic particles (FAIR) or when the medium is hot and filled with pionic particles (RHIC, LHC). The behaviour of strange vector mesons is different for these two media. Additionally the behaviour of a strange particle is different from the behaviour of a strange anti-particle in a dense nuclear medium, whereas it is the same in a hot nuclear medium (we are dealing with an isotopically symmetric pionic medium).

In figure 1 one can see spectral function for the K^* (and consequently the $\bar{K}^*$) in a hot, pionic medium. The effects of the medium are negligible, there is only a small mass shift and a very small broadening. However, when looking at the logarithmic plot one can see that the K^* gains some enhancement in the low mass region at temperatures $T > 0$.

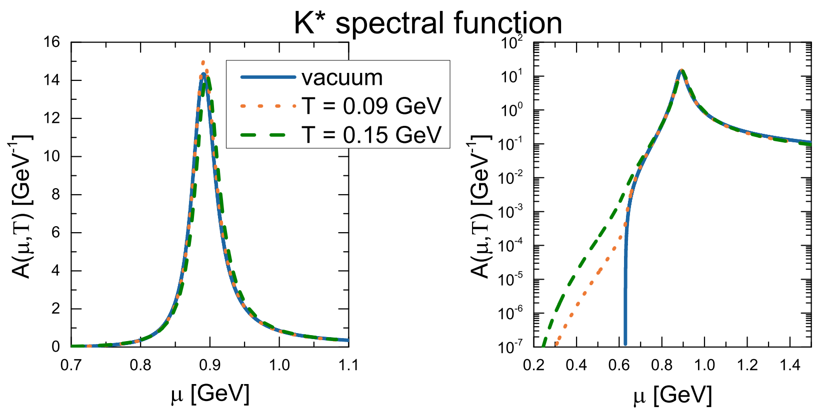


Figure 1: The K^* spectral function as a function of the temperature and the invariant mass is plotted against the invariant mass for different temperatures in linear (left plot) and logarithmic (right plot) scale for a K^* in vacuum (blue solide line), for a temperature of $T = 0.09$ GeV (orange dotted line) and for a temperature of $T = 0.15$ GeV (dashed green line).

Related publications in 2014

1) Andrej Ilner, Daniel Cabrera, Pornrad Srisawad, Elena Bratkovskaya, *Properties of strange vector mesons in dense and hot matter*, Nucl. Phys. A 927 (2014) 249-265

Polarization effects in $\chi_{c2}(1P)$ production in antiproton-nucleus interactions

Collaborators: Alexei Larionov[1,2], Mark Strikman[3], Marcus Bleicher[1,4]

[1] Frankfurt Institute for Advanced Studies, [2] National Research Centre "Kurchatov Institute", Moscow, Russia, [3] Pennsylvania State University, University Park, USA, [4] Institut für Theoretische Physik, J.W. Goethe-Universität, Frankfurt

It is well established, that the total interaction cross section of a small-size quark-antiquark ($q\bar{q}$) configuration with a nucleon is proportional to the average square of the transverse distance between q and $\bar{q}$. If the $q\bar{q}$ wave function has different shapes for different polarizations (P,D,... states) then the cross section will depend on the $q\bar{q}$ polarization. It has been predicted, that $q\bar{q}$ states with different polarizations are absorbed differently in nuclear medium. This is known as a *color filtering*. For example, for $c\bar{c}$(1P) states with $L_z = \pm 1$ the cross section is a factor of two larger than for the states with $L_z = 0$, i.e $\sigma_1 \simeq 2\sigma_0$.

In the case of $\bar{p}p \to \chi_{cJ}$ process, there are restrictions on the helicity ν of χ_{cJ}: The state $\chi_{c1}(\nu = 0)$ is forbidden by charge conjugation invariance, and the states $\chi_{c2}(\pm 2)$ are forbidden by helicity conservation. The helicity ratio $R = \chi_{c2}(0)/[\chi_{c2}(0) + \chi_{c2}(\pm 1)] \equiv |B_0|^2 = 0.13 \pm 0.08$ has been measured at Fermilab. Its smallness can be explained by the dominating three-gluon annihilation mechanism and hadronic helicity conservation in exclusive processes with massless quarks.

In the case of $\bar{p}A$ collisions, two new important effects appear: (i) color filtering leads to the enhanced absorption of the $\chi_{c2}(\pm 1)$ states (dotted line in left Fig. 1), and (ii) the interference term of the direct $\bar{p}p \to \chi_{c2}(0)$ and the two-step $\bar{p}p \to \chi_{c0}(0)$, $\chi_{c0}(0)N \to \chi_{c2}(0)N$ amplitudes significantly influences the ratio R due to the strong coupling of χ_{c0} to the $\bar{p}p$ channel (solid line in left Fig. 1). The interference term is sensitive to the unknown phase of B_0 helicity amplitude for χ_{c2} defined relative to $B_0 \equiv 1$ for χ_{c0} (right Fig. 1). However, since the amplitudes of the nondiagonal transitions are proportional to the difference $\sigma_1 - \sigma_0$, the deviations of $R/|B_0|^2$ from unity at small transverse momenta are sensitive to the P-wave structure of $c\bar{c}$ wave function. This makes promising to study the helicity ratio R for $\bar{p}A$ collisions in the near-future PANDA experiment at FAIR.

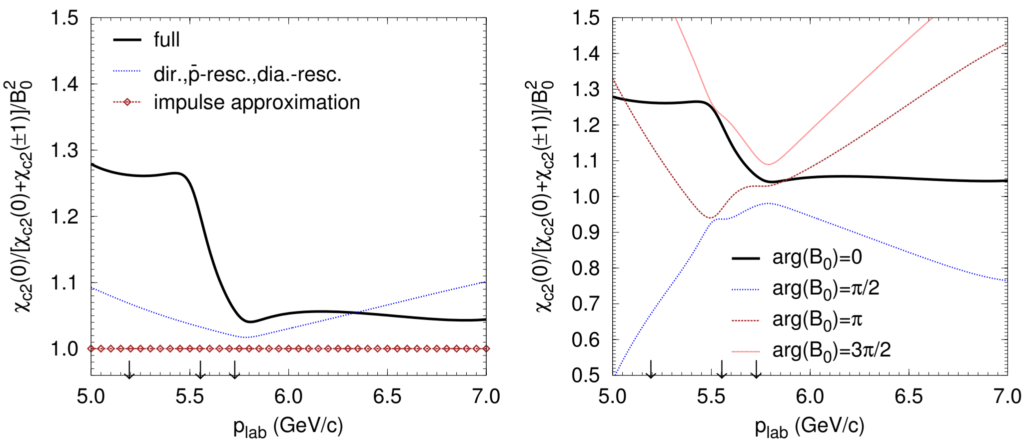


Figure 1: Left – the normalized helicity ratio $R/|B_0|^2$ at $k_t = 0.01$ GeV/c for $\bar{p}^{208}$Pb collisions as a function of beam momentum. Diamonds show the calculation in the impulse approximation. Dotted line shows the results with absorption and elastic rescattering of $\bar{p}$ and charmonium. Full line is obtained by taking into account, in addition, the nondiagonal transitions with $\arg(B_0) = 0$. Right – same, but for the different values of $\arg(B_0)$. Arrows show the beam momenta for the on-shell charmonium production on the proton target: 5.194, 5.553 and 5.727 GeV/c for χ_{c0}, χ_{c1} and χ_{c2}, respectively.

Related publications in 2014:

1) Alexei Larionov, Mark Strikman, Marcus Bleicher, *Polarized χ_{c2}-charmonium production in antiproton-nucleus interactions*, Phys. Rev. C 89, 014621 (2014)

2) Alexei Larionov, Marcus Bleicher, Albrecht Gillitzer, Mark Strikman, *Charmonium production in $\bar{p}$-induced reactions on nuclei*, EPJ Web of Conferences 81, 04007 (2014)

Directed flow as a phase transition signal in relativistic heavy ion collisions

Collaborators: Jan Steinheimer[1,2], Jussi Auvinen[1], Hannah Petersen[1,2], Marcus Bleicher[1,2] and Horst Stöcker[1,2,3]

[1] Frankfurt Institute for Advanced Studies, [2] Institut für Theoretische Physik, Goethe Universität Frankfurt, [3] GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt

Recent STAR data from the RHIC beam energy scan show that the slope of the net-proton directed flow v_1 near midrapidity $y = 0$ changes sign twice within the collision energy range $\sqrt{s_{NN}} = 7.7$ - 39 GeV, which has been predicted by the earlier fluid calculations to be a signal of a first-order phase transition between hadronic matter and quark-gluon plasma. We study this phenomenon utilizing a hybrid model where the non-equilibrium phases at the beginning and in the end of a heavy-ion collision are described by the UrQMD transport model, while the intermediate hot and dense stage is modeled with (3+1)-D ideal hydrodynamics. We examine the sensitivity of the directed flow v_1 to the order of the phase transition by comparing simulations with a first-order phase transition "Bag model" equation of state (EoS) to calculations with a chiral model EoS, which has a cross-over phase transition.

First, to emulate the earlier fluid calculations, we initialize the cold matter of two colliding nuclei as two distributions of energy and baryon density. The UrQMD model is still utilized for the final hadron gas phase. Figures 1a and 1b show the difference in dv_1/dy between the two equations of state for Au+Au collisions at impact parameter b = 8 fm. While the predicted minimum in dv_1/dy with a first-order phase transition is observed when using isochronous hypersurface for the transition from hydrodynamics to transport (Fig. 1a), the difference between the two equations of state is considerably smaller when using iso-energy density condition for fluid to particle transition (Fig. 1b).

Figure 1c shows the energy dependence of the proton and antiproton v_1 slope at midrapidity, obtained from the full hybrid simulation with the initial non-equilibrium transport phase. The directed flow was calculated using events with impact parameter $b = 4.6 - 9.4$ fm, which approximates the $(10-40)\%$ centrality range of the STAR data. The two EoS are completely indistinguishable in the hybrid simulations, questioning the usability of v_1 as a signal of the first-order phase transition. However, the hybrid model results also deviate notably from experimental data, which makes further studies on the topic necessary.

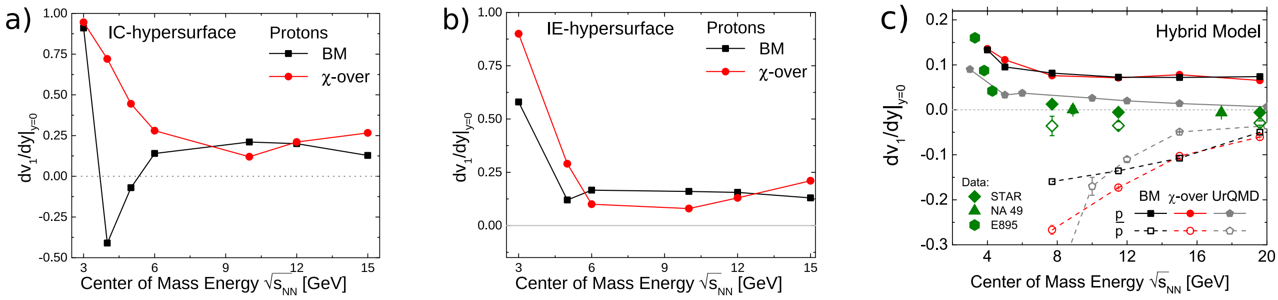


Figure 1: a) and b) Slope of proton v_1 at midrapidity $|y| < 0.5$, calculated for an equation of state with first-order phase transition (black) and cross-over phase transition (red) for isochronous fluid-to-particles transition hypersurface (a) and iso-energy density hypersurface (b) for Au+Au collisions at impact parameter b = 8 fm. c) v_1 slope at midrapidity for protons (solid symbols) and anti-protons (open symbols) for impact parameter range $b = 4.6 - 9.4$ fm, extracted from the hybrid model calculations with a first order (black) and crossover EoS (red). Results are compared with the UrQMD model calculations (grey) and experimental data from STAR, NA49 and E895 collaborations (green).

Related publications in 2014:

1) Jan Steinheimer, Jussi Auvinen, Hannah Petersen, Marcus Bleicher, Horst Stöcker, *Examination of directed flow as a signal for a phase transition in relativistic nuclear collisions*, Phys. Rev. C 89, 054913 (2014)
2) Jussi Auvinen, Jan Steinheimer, Hannah Petersen, *What the collective flow excitation function can tell about the quark-gluon plasma*, arXiv:1408.0098. To appear in Nucl. Phys. A.

Experimental constraints for the temperature dependence of the shear viscosity coefficient to entropy density ratio $(\eta/s)(T)$ of partonic matter

Collaborators: Hannu Holopainen[1], Pasi Huovinen[1,2], Etele Molnár[1,3], Harri Niemi[4]

[1] Frankfurt Institute for Advanced Studies, [2] Institut für Theoretische Physik, Goethe Universität Frankfurt, [3] MTA-DE Particle Physics Research Group, Debrecen, Hungary, [4] Department of Physics, University of Jyväskylä, Finland

One of the goals of the present heavy-ion physics is to experimentally determine the shear viscosity coefficient over entropy density ratio, η/s, of the strongly interacting deconfined matter formed in ultrarelativistic heavy-ion collisions. The effect of shear viscosity is manifested in the azimuthal anisotropy of the observed particles. The anisotropy is measured in terms of the Fourier coefficients, v_n, of the azimuthal distribution. From the theoretical predictions, and from comparisons with well-known substances, we expect that the ratio η/s depends on temperature.

Unfortunately extracting the temperature dependence of η/s of partonic matter from the experimental data is tedious since the final anisotropy is affected by the viscosity during the entire evolution, and especially so during the late hadronic stage of it. However, we have found that if one relaxes the usual assumptions of boost invariance in the modelling of the collision, and studies the collisions at various centralities, signs of the temperature dependence of η/s can be extracted from the data. We used four different parametrizations of η/s with very different temperature dependencies. These parametrizations had been tuned to reproduce the observed v_2 in central collisions at low pseudorapidity, but when we simulated collisions at different centralities, and evaluated v_2 at large pseudorapidity, these parametrizations led to different results (see Fig. 1). This resolving power increases even further when one does the calculations at several collision energies and evaluates not only v_2, but also the higher order coefficients of the anisotropy, v_3 and v_4.

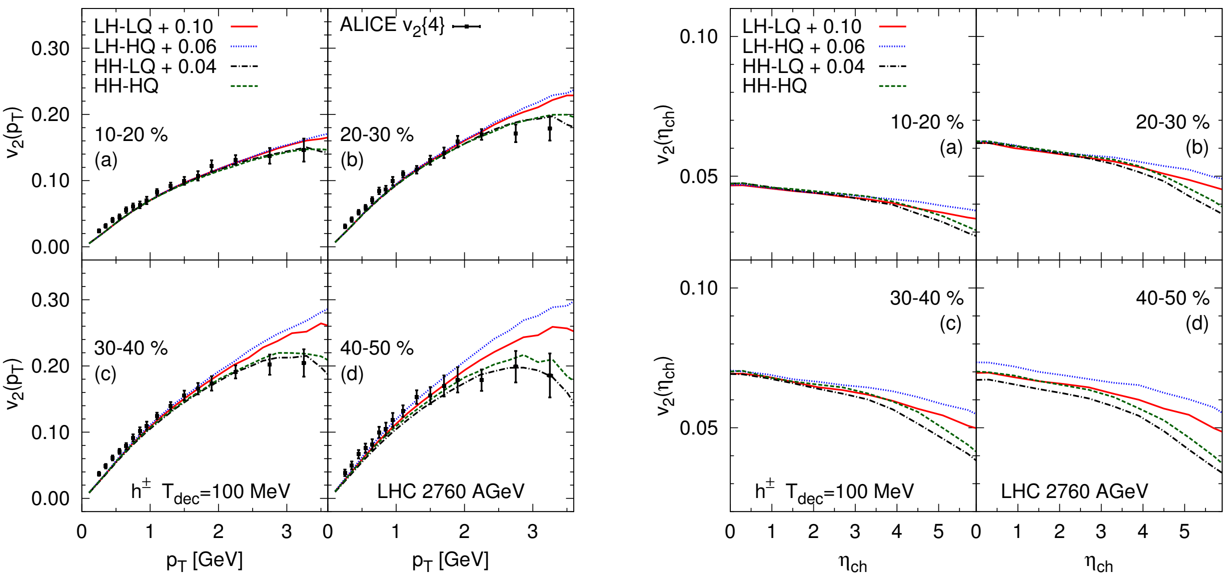


Figure 1: The elliptic anisotropy parameter $v_2(p_T)$ as a function of transverse momentum p_T (left) and the p_T averaged elliptic anisotropy parameter $v_2(\eta)$ as function of pseudorapidity at various centralities. The calculation is done using different parametrizations of $(\eta/s)(T)$, which lead to indistinguishable $v_2(p_T)$ in the 10–20% centrality class. It is seen that in more peripheral collisions and at large pseudorapidity, these parametrisations lead to different results and can be distinguished.

Related publications in 2014:

1) Etele Molnár, Hannu Holopainen, Pasi Huovinen and Harri Niemi, *Influence of temperature-dependent shear viscosity on elliptic flow at backward and forward rapidities in ultrarelativistic heavy-ion collisions*, Phys. Rev. C 90, 044904 (2014), arXiv:1407.8152 [nucl-th]

Systematic investigation of Cooper-Frye negative contributions

Collaborators: Dmytro Oliinychenko[1,3], Pasi Huovinen[2], Hannah Petersen[1,2]

[1] Frankfurt Institute for Advanced Studies, [2] Institut für Theoretische Physik, Goethe Universität Frankfurt, [3] Bogolyubov Institute for Theoretical Physics, Kiev, Ukraine

Many models of heavy ion collisions employ relativistic hydrodynamics to describe the system evolution at high densities. The Cooper-Frye formula [1] is applied in most of these models to turn the hydrodynamical fields into particles. However, the number of particles obtained from the Cooper-Frye formula is not always positive-definite. Physically negative contributions of the Cooper-Frye formula are particles that stream backwards into the hydrodynamical region.

We have investigated negative Cooper-Frye contributions and backscattering using a coarse-grained molecular dynamics approach. Au+Au collisions at $E_{\rm lab} = 5$–160 A GeV energies have been simulated using UrQMD [2], and a hypersurface Σ of constant Landau rest frame energy density has been constructed. On this surface we have calculated two quantities: The ratio of Cooper-Frye negative to positive contributions (r_{eq}), which assumes local thermal equilibrium, and the ratio of UrQMD particles crossing Σ inward to crossing Σ outward (r_{neq}), which does not assume equilibrium.

We found that at all collision energies $r_{eq} \gg r_{neq}$ We explain this by a deviation of pions in UrQMD simulation from equilibrium. A non-monotonous dependency of r_{eq} and r_{neq} on collision energy was found with a maximum at 10-20 A GeV, maximal r_{eq} being around 13% (Fig. 1 a). The size of the negative contributions is a result of an interplay of several factors: the temperature on the hypersurface, the relative velocities between flow and surface, and the relative amounts of volume and surface emission.

Both r_{eq} and r_{neq} are smaller for hadron sorts with higher mass (Fig. 1 b) and decrease for peripheral events (Fig. 1 c).

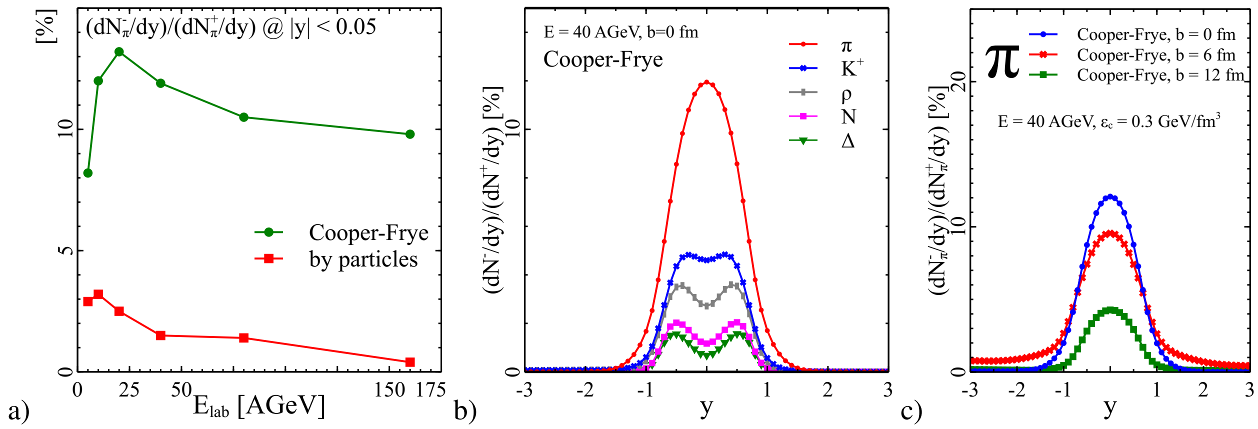


Figure 1: a) r_{eq} and r_{neq} for pions at midrapidity versus collision energy; b) r_{eq} rapidity distribution for different hadron species; c) r_{eq} for pions versus collision centrality

Related publication in 2014:

1) D. Oliinychenko, P. Huovinen and H. Petersen, *Systematic Investigation of Negative Cooper-Frye Contributions in Heavy Ion Collisions Using Coarse-grained Molecular Dynamics*, arXiv:1411.3912 [nucl-th]

References:

[1] F. Cooper, G. Frye, Phys. Rev. D 10, 186, 1974

[2] S. A. Bass, M. Belkacem et al., Prog. Part. Nucl. Phys. **41**, 225 (1998); M. Bleicher, E. Zabrodin, et al., J. Phys. G: Nucl. Part. Phys. **25**, 1859 (1999).

Dilepton Production in Transport-based Approaches

Collaborators: Janus Weil[1], Stephan Endres[1], Hendrik van Hees[1], Marcus Bleicher[1], Ulrich Mosel[2]

[1]Frankfurt Institute for Advanced Studies, [2]Institut für Theoretische Physik, JLU Giessen

Lepton pairs are an ideal probe for studying phenomena at high densities and temperatures. They are created at all stages of a heavy-ion collision, but unlike hadrons they can escape the hot and dense zone almost undisturbed and thus can carry genuine in-medium information out to the detector. One of the groundbreaking experiments in this field was NA60, which revealed that the ρ spectral function is strongly broadened in the medium and that this collisional broadening is mostly driven by baryonic effects. In the low-energy regime, the data taken by the DLS detector have puzzled theorists for years and have recently been confirmed and extended by new measurements by the HADES collaboration. Our investigations based on the GiBUU transport model have shown that the baryonic N^* and Δ^* resonances give important Dalitz-like contributions to dilepton spectra at SIS energies. This finding is based on the assumption that these resonances decay into a lepton pair exclusively via an intermediate ρ meson (i.e., strict vector-meson dominance). The left panel of fig. 1 shows the simulated dilepton spectrum from Ar+KCl collisions at 1.76 AGeV compared to data. One can see that there are strong contributions from the baryonic resonances. We observe an underestimation at intermediate masses and a slight excess in the vector-meson pole region. Reasons for these deviations could be uncertainties in the used resonance parameters or a missing dynamical treatment of density-dependent spectral functions. Such a treatment may be provided by the so-called “coarse-graining“ approach, which is subject of ongoing investigations. In order to get tighter constraints on resonance parameters, pion-induced reactions offer a much cleaner testing ground than AA reactions, since the energy can be tuned to a fixed resonance mass. This makes it much easier to disentangle contributions from different resonances. The right panel of fig. 1 shows the prediction of our model for $\pi^- p$ collision at $\sqrt{s} = 1.49$ GeV, which have recently been measured at GSI. The considered energy is close to the pole mass of the $D_{13}(1520)$. This resonance is believed to have a strong coupling to the ρ meson and thus should have a large influence on dilepton spectra, which can soon be checked directly via the recently measured data.

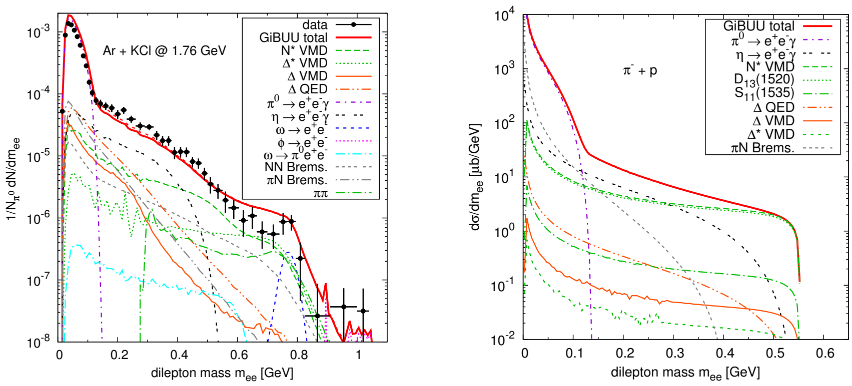


Figure 1: Dilepton spectra from Ar+KCl (left) and πN collisions (right).

Related publications in 2014:

1) Janus Weil, Stephan Endres, Hendrik van Hees, Marcus Bleicher, Ulrich Mosel, *Dilepton Production in Transport-based Approaches*, arXiv:1412.3733, Proceedings of Hot Quarks 2014

2) Stephan Endres, Hendrik van Hees, Janus Weil, Marcus Bleicher, *In-medium Spectral Functions in a Coarse-Graining Approach*, arXiv:1412.2554, Proceedings of FAIRNESS 2014

3) Stephan Endres, Hendrik van Hees, Janus Weil, Marcus Bleicher, *A Coarse-Graining Approach for Dilepton Production at SPS Energies*, arXiv:1412.1965, Submitted to Phys. Rev. C.

4) Janus Weil, Stephan Endres, Hendrik van Hees, Marcus Bleicher, Ulrich Mosel, *Dilepton Production in Transport-based Approaches*, arXiv:1410.4206, Proceedings of PANIC 2014

Equation of state of hadronic gas with hard-core interaction

Collaborators: L. M. Satarov[1,2], K. A. Bugaev[1,3], I. N. Mishustin[1,2]

[1] Frankfurt Institute for Advanced Studies, [2] Kurchatov Institute, Russian Research Center, Moscow, [3] Bogolyubov Institute for Theoretical Physics of NAS of Ukraine, Kiev

Realistic studies of the equation of state (EoS) of hot and dense strongly hadronic matter should take into account finite sizes of hadrons. We investigate thermodynamic properties of hadronic gas with a hard-sphere interaction (HSI) of particles [1]. In the Boltzmann approximation pressure of a one-component matter can be written as $P = nTZ(n)$ where T and n are, respectively, temperature and density of hadrons. The compressibility factor Z is a function of the packing fraction $\eta = nv$ where v is a hard-core volume of a single hadron. Comparison with the virial expansion shows [1] that the Van-der-Waals parametrization used in the excluded volume models (EVM), $Z_{\text{EVM}} = (1-4\eta)^{-1}$, strongly overestimates pressure at $\eta \gtrsim 0.2$. On the other hand, the Carnahan-Starling approximation (CSA), $Z_{\text{CSA}} = (1+\eta+\eta^2-\eta^3)(1-\eta)^{-3}$, agrees well with numerical calculations of Z in a wider domain $\eta \lesssim 0.5$. The main emphasis is given to calculating sound velocity c_s. It is shown that $c_s^{(\text{CSA})} < c_s^{(\text{EVM})}$ at given T and n.

One can apply the same approach to study a multi-component system if all particles have equal sizes. In this case pressure is given by the above expression with replacing n by the total density of all species. We have made the detailed calculations for a chemically equilibrated $\pi+N+\Delta$ mixture assuming that hard-core radii are equal: $R_N = R_\Delta = R_\pi$. For comparison, we have also studied the EoS of $\pi+N+\Delta$ matter in the case $R_N = R_\Delta,\ R_\pi = 0$. Then one can write the relation $P = T\left[n_\pi^{(\text{id})}(T) + n_B Z(n_B)\right]$ where $n_\pi^{(\text{id})}(T)$ is the equilibrium density of point-like pions and $n_B = n_N + n_\Delta$. Figure 1 shows sound velocities of $\pi+N+\Delta$ mixture for these two limiting cases. As compared to the EVM, the CSA predicts a softer EOS. Acausal states $(c_s > 1)$ in the second model are shifted to much larger baryon densities. Presumably, they appear in the deconfined region. As expected, the sensitivity to the pion size becomes stronger at larger temperatures.

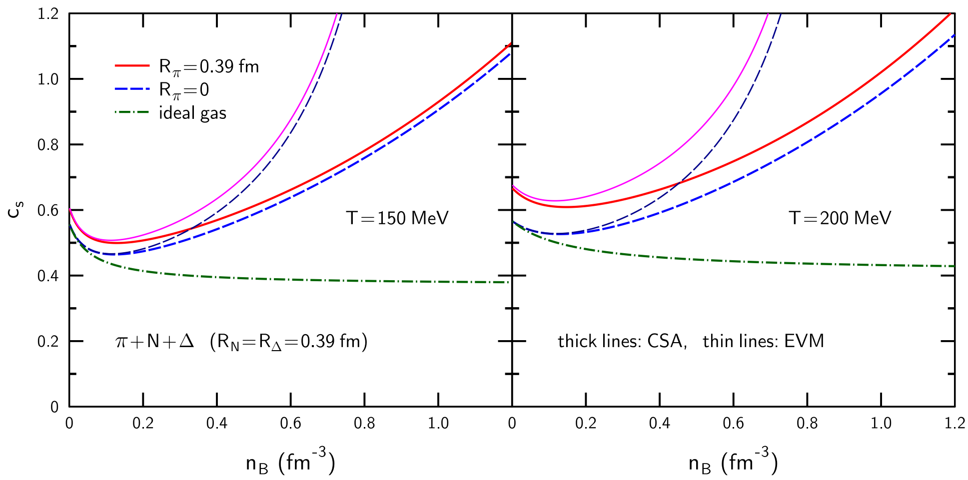


Figure 1: Sound velocity of $\pi+N+\Delta$ matter as a function of baryon density for $T = 150$ and 200 MeV. The solid lines correspond to the case of equal sizes of baryons and pions. The dashed lines show the results in the limit of point–like pions. The dashed-dotted curves correspond to the ideal gas.

Related publication in 2014:
1) L.M. Satarov, K.A. Bugaev, and I.N. Mishustin, *Equation of state and sound velocity of hadronic gas with hard-core interaction*, arXiv: 1412.0718 (2104)

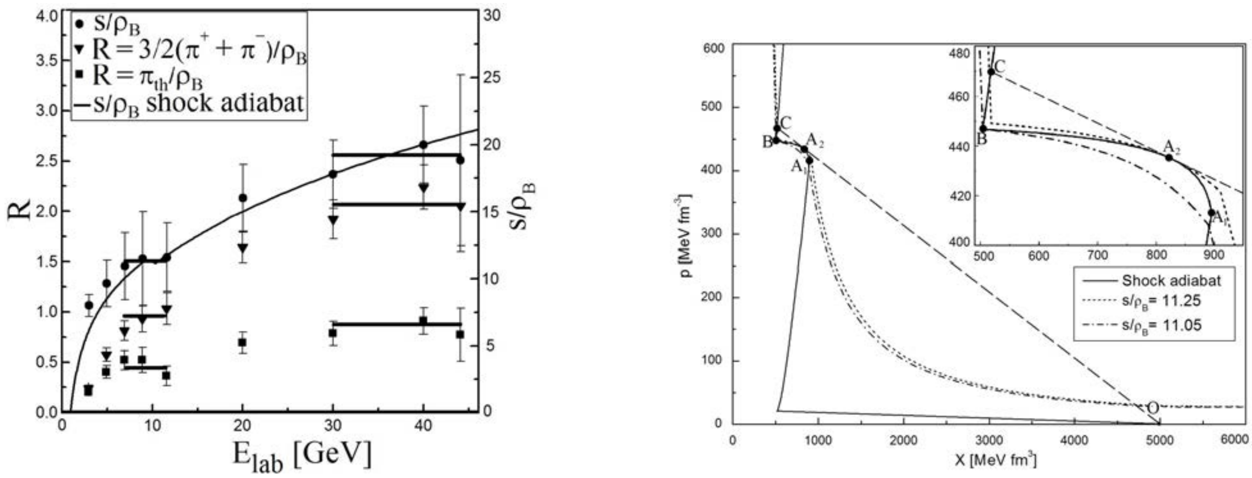
Thermodynamically Anomalous Properties of Mixed Phase and New Signal of Its Formation in A+A Collisions

Collaborators: K.A. Bugaev[1], A.I. Ivanytskyi[1], D.R. Oliinychenko[1,2], V.V. Sagun[1], I.N. Mishustin[2,3], D.H. Rischke[4], L.M. Satarov[2,3] and G.M. Zinovjev[1]

[1] Bogolyubov Institute for Theoretical Physics of NAS of Ukraine, Kiev, Ukraine, [2] Frankfurt Institute for Advanced Studies, [3] Kurchatov Institute, Russian Research Center, Moscow, Russia, [4] Institute for Theoretical Physics, Goethe University, Frankfurt, Germany

Using the most advanced version of the hadron resonance gas model (HRGM) for chemical freeze-out, we have found in [1] such interesting irregularities as the plateaus in the collision-energy dependence of several quantities (see left panel of Fig. 1): a) the entropy per baryon, b) total pion number per baryon, and c) thermal pion number per baryon at laboratory energies 6.9–11.6 AGeV. The low-energy plateaus as in Fig. 1 were predicted a long time ago in [2] as the consequence of the instability of shock transitions from the cold nuclear matter (point O) to the segment A_2BC of mixed quark-gluon-hadron phase of the deconfinement transition (see the right panel of Fig. 1).

On the basis of the shock adiabat model of central nuclear collisions [2] we have calculated the Rankine-Hugoniot-Taub (RHT) adiabat for the equation of state (EOS) with the first order deconfinement phase transition (the right panel of Fig. 1). The hadronic phase EOS was chosen to be a simplified version of the HRGM [1], while for the quark gluon plasma we employed the MIT bag model, but with the coefficients which were fitted to reproduce the entropy per baryon along the RHT adiabat. Our calculations confirmed the presence of thermodynamic anomalous properties inside the quark-gluon-hadron mixed phase. Hence, we conclude that the found low-energy plateaus form a signal of the mixed phase formation.



Left panel: Energy dependence of the entropy per baryon (circles), of the thermal pion multiplicity per baryon (squares), and of the total pion multiplicity per baryon (triangles) found at the chemical freeze-out within the HRGM of [1]. The horizontal bars are found by minimizing χ^2/dof. The solid curve is the RHT adiabat shown in the right panel. **Right panel:** The compression RHT adiabat OA_2BC (solid curve) in the $X - p$ plane. The segments OA_1, A_1B, and BC of the adiabat correspond to the hadronic, mixed, and QGP phases, respectively. Shock transitions into the region of states A_2BC are forbidden. The dotted and dashed-dotted curves show the Poisson adiabats with values of entropy per baryon given in the legend.

Related publications:

1) K.A. Bugaev A. I. Ivanytskyi, D.R. Oliinychenko, V.V. Sagun, I.N. Mishustin, D.H. Rischke, L.M. Satarov and G. M. Zinovjev, *Thermodynamically anomalous regions as a mixed phase signal*, arXiv:1405.3575 [hep-ph] (accepted for publication in Phys. Part. Nucl. Lett.)
2) K.A. Bugaev, M.I. Gorenstein and D.H. Rischke, Phys. Lett. B. 255, 18 (1991)

An effective model for the QCD phase transitions at finite baryon density

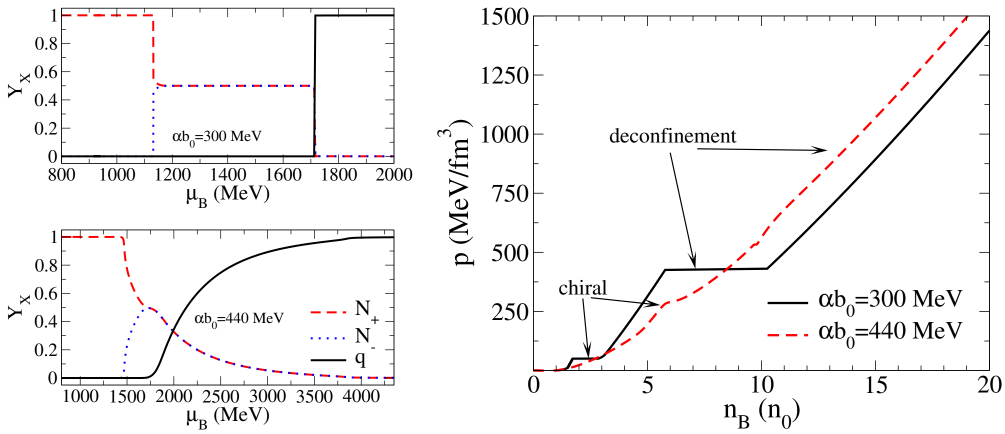
Collaborators: S. Benić[1,2], I. Mishustin[3,4], C. Sasaki[3,5]

[1] University of Zagreb, Croatia, [2] The University of Tokyo, Japan, [3] Frankfurt Institute for Advanced Studies, Germany, [4] National Research Center "Kurchatov Institute", Russia, [5] Institute of Theoretical Physics, University of Wrocław, Poland

We have developed an effective model for the QCD phase transitions at finite baryon densities, which contains both nuclear and quark degrees of freedom in a unified framework. The nucleon sector is described by the parity-dublet model coupled to the dilaton field. The quark sector is described by the linear sigma model scaled with the dilaton field. The effective lagrangian respects both chiral symmetry and scale invariance, thereby encoding the basic QCD symmetries. The in-medium response of the bosonic mean-fields induces the liquid-gas, the chiral and the deconfinement phase transitions.

The new element in our model is an auxiliary bosonic field, we name it the bag field, which plays a decisive role in confining the quarks at low density and suppressing the nucleons at high density. Its coupling to quarks and nucleons is provided through the modification of their distribution functions. We consider a simple model, where the bag field restricts the propagation of nucleons above some momenta, and quarks below some momenta. In terms of the quark degrees of freedom such modification can be understood as a type of infrared confinement, and the inverse value of the bag field characterizes the typical size of a hadron. By introducing a phenomenological vacuum potential for the new bag field and solving its gap equation we are able to induce the deconfinement transition in our model.

At zero temperature the model predicts the chiral and deconfinement phase transitions which are separated in baryon density, with the chiral transition occurring first. This means that the chiral transition is driven by nucleonic degrees of freedom. Depending on the parameters of the model, the density for the chiral transition is between $n_B^{\rm ch} \simeq 2.9 - 8.8 n_0$ while for the deconfinement transition it is above $n_B^{\rm d} \simeq 5.8 n_0$. Both the chiral and the deconfinement transitions can be either first order or crossovers, depending on the model parameters.



Left panel: Particle fractions as function of the baryon chemical potential. **Right panel**: equation of state as a function of total baryon density in terms of the saturation density $n_0 = 0.16\ \mathrm{fm}^{-3}$. The nucleon and its parity partner are denoted as N_+ and N_-, respectively.

References

1) C. Sasaki and I. Mishustin, *Thermodynamics of dense hadronic matter in a parity doublet model*, Phys. Rev. C 82, 035204 (2010)

2) C. Sasaki and I. Mishustin, *The phase structure of a chiral model with dilatons in hot and dense matter*, Phys. Rev. C 85, 025202 (2012)

Related publication in 2014:

1) S. Benić, I. Mishustin, C. Sasaki, *An effective model for the QCD phase transitions at finite baryon density*, submitted for publication in Phys. Rev. D

Fate of charmed mesons near chiral symmetry restoration in hot matter

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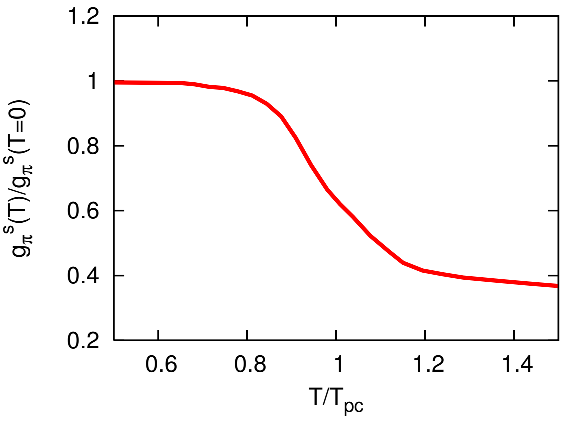
Chiral thermodynamics of charmed mesons is formulated at finite temperature within a $2+1+1$-flavored effective Lagrangian incorporating heavy quark symmetry. The major interactions between the light and heavy-light mesons, which carry a non-trivial thermal dependence are fixed by using the lattice observables (see Fig. 1-left).

The chiral mass splittings are shown to be essentially insensitive to the light-quark flavors, in spite of a non-negligible explicit breaking of the chiral $SU(3)$ symmetry (Fig. 1-right). This "blindness" of the charm quark to the light degrees of freedom is dictated by the heavy quark symmetry. In contrast, the kaon and its chiral partner masses become degenerate at a higher temperature than $T_{\rm pc}$, indicating a delay of the $SU(3)$ symmetry restoration. In the heavy-light sector, on the other hand, the strange charmed meson captures the onset of chiral symmetry restoration more strongly than the strange light meson does.

The quenched $g_\pi^s(T)$ leads also to a strong suppression of the scalar D_s decay toward $T_{\rm pc}$, on top of the suppression due to the small isospin violation. The same should be carried over to the B and B_s mesons with which the heavy quark symmetry is more reliable.



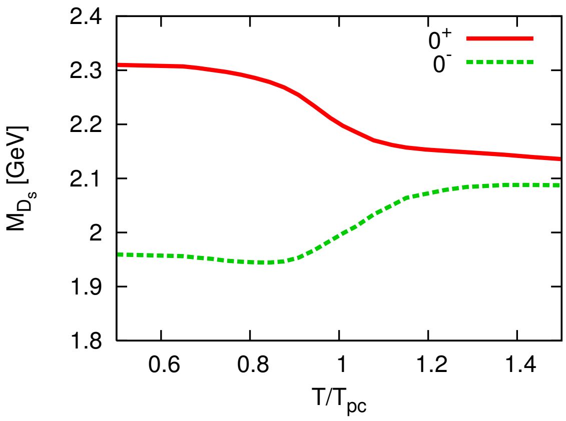


Figure 1: (Left) Effective interaction among light and heavy-light mesons. (Right) In-medium masses of the strange charmed-mesons with positive and negative parity.

C. S. acknowledges partial support by the Hessian LOEWE initiative through the Helmholtz International Center for FAIR (HIC for FAIR), and by the Polish Science Foundation (NCN) under Maestro grant DEC-2013/10/A/ST2/00106.

Related publications in 2014:

1) C. Sasaki, *Fate of charmed mesons near chiral symmetry restoration in hot matter*, Phys. Rev. D 90, 114007 (2014), arXiv:1409.3420 [hep-ph]

Correlations between light and heavy flavors near the chiral crossover

Collaborators: Chihiro Sasaki[1,2], Krzysztof Redlich[2]

[1] Frankfurt Institute for Advanced Studies, [2] Institute of Theoretical Physics, University of Wroclaw, Poland

Various flavor correlations at finite temperature are studied within a chiral effective theory implementing heavy quark symmetry. A particular attention is attributed to properties of these correlations near the chiral crossover temperature, $T_{\rm pc}$.

In the qq and qs sector the qualitative change of correlations coincides with the chiral crossover. This is, however, not the case in the ss sector where the modification of the fluctuations is shifted to a slightly higher temperature above the chiral crossover, due to the large explicit chiral symmetry breaking for the strange quark.

A striking contrast is found in the correlations involving the heavy-light meson mean fields. Those fluctuations exhibit certain qualitative changes around $T_{\rm pc}$, and this feature is independent of the light flavors. Theoretically, it is anchored to the heavy quark symmetry which guarantees that the charm quark does not distinguish the non-strange from the strange flavor in the limit of $m_c \to \infty$.

In the heavy-light system, the heavy quark dynamics is tied to the light flavor physics, and the thermodynamics is strongly dragged by the chiral crossover dominated by the non-strange flavors. Consequently, the fluctuations carried by the strange states can also be used to measure the onset of the chiral symmetry restoration. The situation is essentially different from the pure light-flavored system where the observables with strangeness, e.g. effective masses of the kaon and its chiral partner, are rather insensitive to the onset of the chiral crossover.

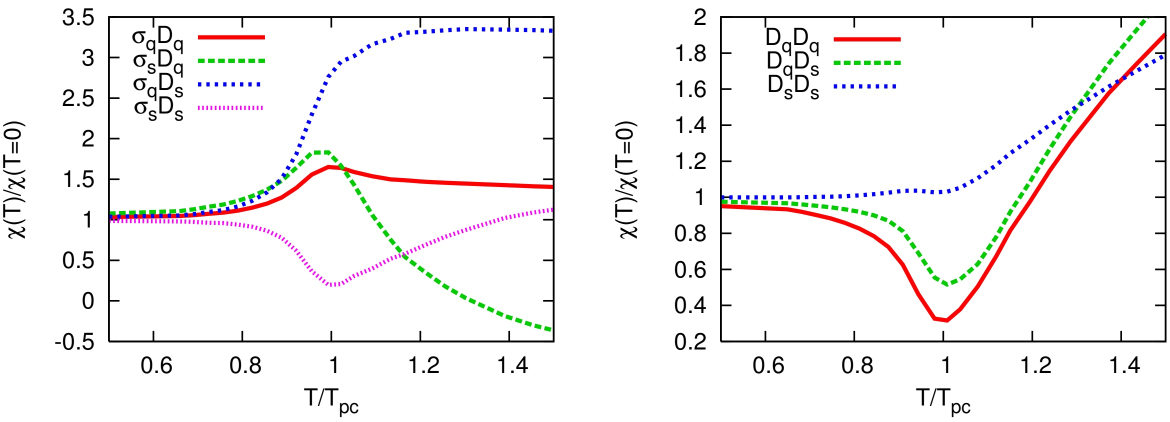


Figure 1: (Left) Flavor correlations between the light and heavy-light mesons. (Right) Flavor correlations between the heavy-light mesons.

C. S. acknowledges partial support by the Hessian LOEWE initiative through the Helmholtz International Center for FAIR (HIC for FAIR), and by the Polish Science Foundation (NCN) under Maestro grant DEC-2013/10/A/ST2/00106.

Related publications in 2014:

1) C. Sasaki and K. Redlich, *Correlations between light and heavy flavors near the chiral crossover*, arXiv:1412.7365 [hep-ph], submitted to Phys. Rev. D

Improved analytical superasymmetric fission model

Collaborators: D. N. Poenaru[1,2], R. A. Gherghescu[1], W. Greiner[2]

[1] National Institute for Physics and Nuclear Engineering, Bucharest, Romania, [2] Frankfurt Institute for Advanced Studies

In the region of heavy nuclei with atomic number $Z = 87 - 96$, the measured ^{14}C, ^{20}O, ^{23}F, $^{22,24-26}$Ne, ^{28,30}Mg, and ^{32,34}Si cluster radioactivities (CD) confirmed our predictions of 1980 and shows up as a rare phenomenon in a huge background of α particles. For α decay (αD) and cluster decay (CD) we are using our ASAF (analytical superasymmetric fission) model employing Myers-Swiatecki's liquid drop model adjusted with a phenomenological correction, E_{cor}, and the UNIV (universal curve). For αD we also have the semFIS (semiempirical model) based on fission theory. For a large number (578) of α emitters the standard deviations within semFIS, UNIV and ASAF are given in Table 1. As can be seen in this table, for αD the improvement of ASAF after optimization is not very important because practically the four points at $A_e = 4$ in Figure 1 are lying on the four smooth curves. The semFIS values are better. The optimization of ASAF model consists in choosing the best values of the parameters (see Figure 1).

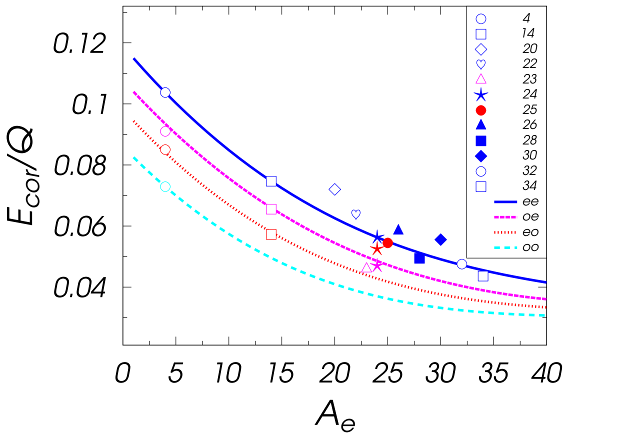


Figure 1: The ratio of correction energy to the Q value versus mass number of the emitted cluster in four groups of parent nuclei: even-even, odd-even, even-odd, and odd-odd. The points correspond to the experimental values.

Group	n	σ_{ASAF}	σ_{ASAF}^{opt}	σ_{UNIV}	σ_{semFIS}
e-e	188	0.420	0.420	0.358	0.225
e-o	147	0.720	0.714	0.641	0.527
o-e	130	0.651	0.643	0.564	0.436
o-o	113	0.869	0.869	0.805	0.603

Table 1: The standard rms deviations of calculated half-lives ($\log_{10} T_\alpha$) compared to experimental ones for α emitters, before and after optimization of ASAF. UNIV and semFIS model values are included.

After optimization we can reproduce better the experimental data on αD, ^{14}C radioactivity of all kind of parent nuclei, as well as ^{24}Ne, ^{28}Mg, and ^{32,34}Si radioactivities of even-even parent nuclei which are either on the smooth line or very close to it. Our ASAF and UNIV models may reproduce both α and cluster decays with deviations not larger than two orders of magnitude, except for αD of ^{228}Ac and ^{24,25}Ne radioactivities of ^{235}U. Within ASAF, UNIV, and semFIS models the deviations for 513 (88%), 524 (90%), and 554 (95%) α emitters out of the total of 578, are under one order of magnitude. Similarly, ASAF and UNIV may reproduce 23 (85%), and 24 (89%) experimental data from the total of 27 cluster emissions with deviations under one order of magnitude.

Related publications in 2014:

1) D. N. Poenaru, R. A. Gherghescu, W. Greiner, *Cluster decay of the heaviest superheavy nuclei*. Invited talk, in Fission and Properties of Neutron-Rich Nuclei (Proc. of the 5th Internat. Conf., Sanibel Island, 2012), (World Scientific, Singapore, 2014), Eds. J.H. Hamilton, A.V. Ramaya, pp. 152-159.

2) D. N. Poenaru, R. A. Gherghescu, W. Greiner, N. S. Shakib, *How Rare Is Cluster Decay of Superheavy Nuclei?*, Invited talk, in Internat. Conf. on Nucl. Phys.: Present and Future, Boppard, Germany, 2013, vol. 2 of FIAS Interdisciplinary Science Series, pp. 131-140. Springer Internat. Publishing, 2014.

Multinucleon transfer reactions as a method for producing light exotic nuclei

Collaborators: Valery Zagrebaev[1,2†] and Walter Greiner[1]

[1] Frankfurt Institute for Advanced Studies, [2] Flerov Laboratory of Nuclear Reactions, JINR, Dubna

Multinucleon transfer reactions occurring in low-energy collisions of heavy ions are currently considered as the most promising method for the production of new heavy and superheavy neutron-rich nuclei, unobtainable by other reaction mechanisms. These reactions can be used both for the production of new neutron-rich isotopes of transfermium elements and new neutron-rich nuclei located along the closed neutron shell $N = 126$ [V.I. Zagrebaev and W. Greiner, Phys. Rev. Lett. (2008)] (area of the nuclear map having the largest impact on the r process of astrophysical nucleosynthesis). Cross sections of these reactions are predicted to be rather large to be studied at available accelerators. The only problem here is the separation of heavy transfer reaction fragments, although proper separators are being designed and manufactured now in several laboratories.

At the same time, fission reactions and high energy fragmentation processes are successfully used for the production of neutron-rich medium mass and light exotic nuclei, correspondingly. Great progress here allowed to discover dozens of new nuclei mainly at the laboratories of NSCL MSU, RIKEN and GSI. The disadvantage in producing light exotic nuclei in fragmentation reactions relies mainly on the fact that the corresponding cross sections drops down very fast when moving away from the stability line. In view of that, one might expect that low-energy multinucleon transfer reactions may also serve as a tool for the production and investigation of very light exotic nuclei, a method that has not been applied so far. The idea would be to use a light and neutron-rich beam on a heavy target. The combination of a large acceptance magnetic spectrometer with a high efficiency and high-resolution multidetector array for γ spectroscopy would be a key instrument in such study.

Within the model developed earlier for the description of damped collisions of heavy ions [V. Zagrebaev and W. Greiner, J. Phys. G (2008)], we studied the multinucleon transfer reactions in low-energy collisions of light heavy ions with heavy targets. Comparison of theoretical calculations with available experimental data demonstrated rather good agreement. Being inspired by this agreement, we calculated the cross sections for the formation of light exotic nuclei in low-energy collisions of ^{18}O, ^{26}Mg and ^{36}S with ^{238}U target. The results of these calculations (see, e.g., Fig. 1) demonstrate that the yields of quite exotic light neutron-rich nuclei produced in the low-energy multinucleon transfer reactions are higher by about 2 orders of magnitude as compared with high energy fragmentation reactions. Thus, the low-energy damped collisions look very promising and quite competitive to the fragmentation reactions for the production of light exotic nuclei.

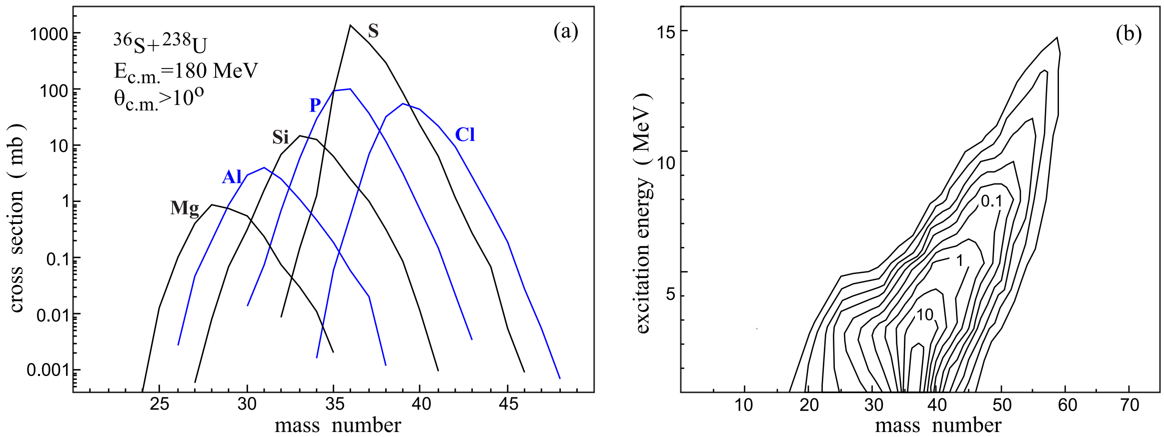


Figure 1: isotopic (a), and excitation energy (b) distributions of projectile-like fragments in collisions of ^{36}S with ^{238}U at $E_{c.m.} = 180$ MeV for the scattering angles $\theta_{c.m.} > 10°$.

Related publications in 2014:

1) V.I. Zagrebaev, B. Fornal, S. Leoni, and Walter Greiner, *Formation of light exotic nuclei in low-energy multinucleon transfer reactions*, Phys. Rev. C 89, 054608 (2014)

†Deceased

Modern Three-Body Forces Lead to the Collapse of Neutron Matter

Collaborators: D. K. Gridnev[1], S. Schramm[1], K. A. Gridnev[1,2], and W. Greiner[1]

[1] Frankfurt Institute for Advanced Studies, [2] Saint Petersburg State University, Russia

Nuclear systems ranging from light nuclei to massive neutron stars can be well described by nucleons interacting through two-body and three-body forces. From electrostatics we know that two identical uniformly charged spheres repel at any distance but the repulsion disappears when the spheres completely overlap. Similarly, in some modern expressions of nuclear three-body force it is assumed that the nuclear repulsion between the three nucleons is zero when they occupy the same position in space. The authors provide a mathematical proof that such form of the three-body force leads to the collapse of large neutron systems: N neutrons form a bound system with the energy growing as N^3 (the effect becomes visible for $N > 10000$). The density of such system is illustrated in Fig. 1. Thus, in order to be compatible with our knowledge of neutron stars – where the constituents form dense nuclear matter with a finite energy per particle – modern expressions for three-body nuclear forces have to be carefully assessed regarding their strong repulsive core which should not vanish even when nucleon triples overlap.

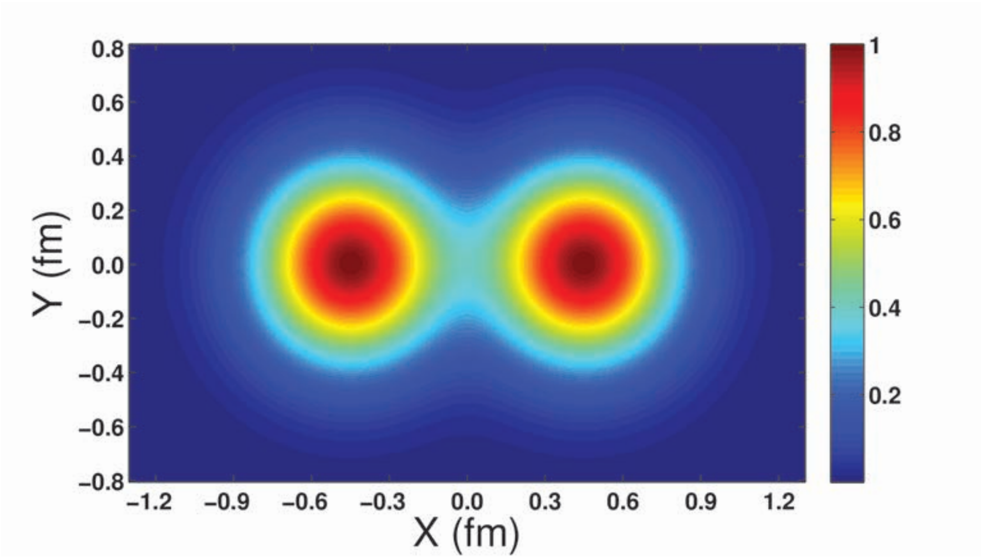


Figure 1: Density profile of the collapsed state of 10000 neutrons in the X-Y-plane along the symmetry axis Z=0 (schematic illustration). Polarized neutrons, which interact through incorrect three-body forces, concentrate in small spheres separated by 0.9 fermi.

Related publications in 2014:

1) D.K. Gridnev, S. Schramm, K.A. Gridnev and W. Greiner, *Nuclear Interactions with Modern Three-Body Forces Lead to the Instability of Neutron Matter and Neutron Stars*, Eur. Phys. J. A 50, (2014) 118 (Highlight in EPJA, Highlight in Europhysics News)

Study of low density nuclear matter by Quantum Molecular Dynamics Simulation: Role of symmetry energy

Collaborators: Rana Nandi[1], Stefan Schramm[1]

[1] Frankfurt Institute for Advanced Studies

One of the main reasons to study heavy-ion physics and astrophysics is to understand the properties of nuclear matter under extreme conditions. At sub-nuclear densities nuclei in nuclear matter form crystalline structure. At higher densities, when nuclei are about to dissolve into uniform matter, various interesting spatial structures such as cylindrical and slab shaped nuclei and cylindrical and spherical bubbles etc., collectively called nuclear "pasta", may appear. Properties of this pasta phase depend on nuclear symmetry energy and its density dependence. For better understanding of these structures a microscopic and dynamic approach is needed.

We have developed a quantum molecular dynamics simulation code to study the pasta phase. To describe interaction between nucleons we use Skyrme type with the Coulomb and the Symmetry terms. Fermionic nature of nucleons are described by a phenomenological potential which has a Gaussian form and prohibits nucleons having same spin and isospin from coming close to each other in phase space. To calculate the long-range Coulomb interaction we employ the Ewald method. With this set up we could successfully form phases with rodlike and slablike nuclei etc. We also observed some intermediate phases with complicated nuclear shapes. For quantitative understanding of the nuclear shape changes and the intermediate phases we calculate Minkowski functionals. Currently I am studying the properties of the pasta phase on the density dependence of symmetry energy and obtained some preliminary results.

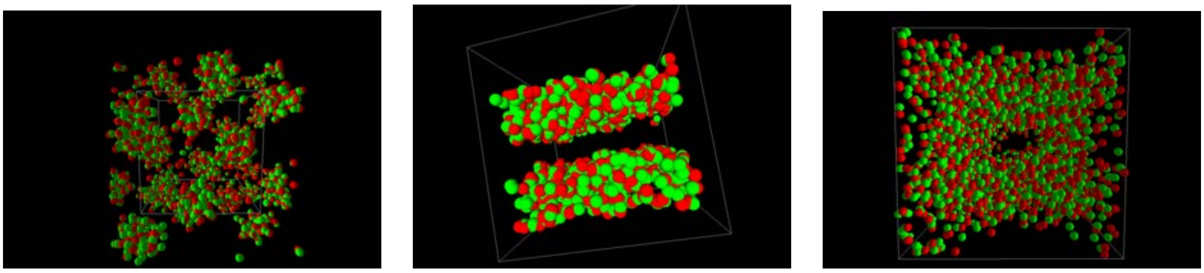


Figure 1: The nucleon distribution of various phases; Left panel: sphere phase, Middle panel: slab phase, Right panel: spherical hole phase

In order to resolve the various large-scale geometric structures involved at such densities, big systems and large time scales are needed, which require extensive computing resources. For speeding up the simulation to practical wall-times we have ported the molecular dynamics code to a GPU version, modifying an existing GPU implementation for molecular dynamics that was developed in FIAS. Our next step is to integrate the molecular dynamics engine in the UrQMD simulation for a better, and much faster, implementation of hadronic potentials in this simulation package. This version might also be used for medical simulations studying tumour therapy with heavy ions.

Many-body forces in the equation of state of nuclear matter

Collaborators: Rosana de Oliveira Gomes[1,2], Veronica Dexheimer[3], Stefan Schramm[2], Cesar A. Zen Vasconcellos[1]

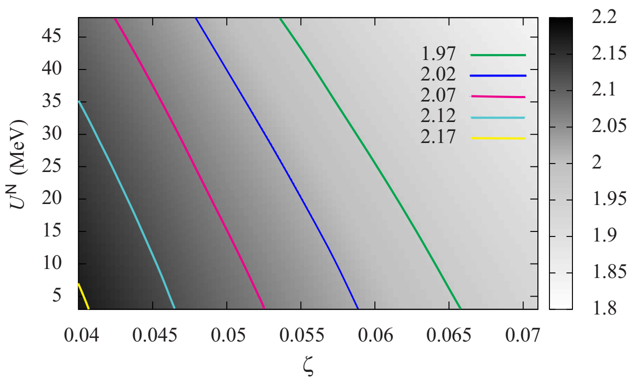
[1] Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil, [2] Frankfurt Institute for Advanced Studies, Frankfurt am Main, Germany, [3] Kent State University, Kent, USA

Substantial efforts have been made to determine the behavior of nuclear matter at high densities. Given the observation of massive neutron stars, it has been suggested that hyperonic matter might not exist in compact stars, due to a possible excessive softnening of the equation of state (EoS) caused by these new degrees of freedom.

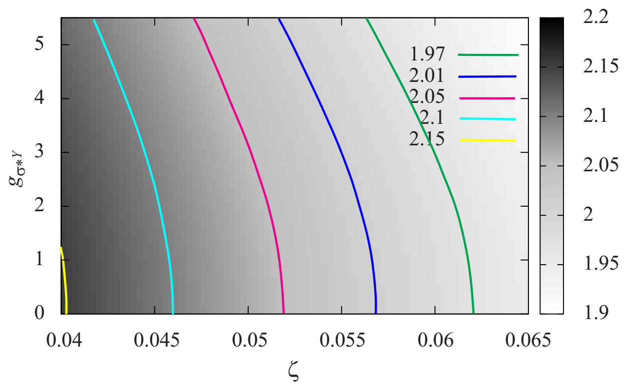
We developed a new class of models for nuclear matter that simulate many-body forces and apply the formalism to describe hyperon stars. We extended the original version of the model proposed by Taurines et al., ir order to consider the complete set of mesons. The many-body contributions were introduced as nonlinear terms contributions to the *effective coupling constants* of the model, whose effect is to turn them indirectly density dependent and also to lower the effective masses of the baryons.

First, we made an extensive anaylisis of the relation between the parameter of the model and the symmetric nuclear matter properties at saturation, from which we selected the parametrizations of the model in good agreement with the experimental data from the literature. Then, choosing the parameters according to nuclear matter saturation properties and the available hypernuclear data, we verified that different parametrizations also yield maximum masses that match recently observed masses of objects PSR J038+0432 ($M = 2.01 \pm 0.04 M_\odot$, Antoniadis et al. 2013) and PSR J1614-2230 ($M = 1.97 \pm 0.04 M_\odot$, Demorest et al. 2010).

We have calculated the dependence of hyperon stars observational properties (mass and radius) on the hyperon potentials and hyperonic couplings. Such anaylisis relate nuclear, hypernuclear and astrophysics data. We have found that our results support previous results found in the literature and are presented in Figure 1.



Parameter space that relates hyperon potentials (U_Ξ^N), many-body forces parameter (ζ) and maximum mass of the stars (M_{max} - in color sequence).



Parameter space that relates hyperon-hyperon coupling ($g_{\sigma^* Y}$), many-body forces parameter (ζ) and maximum mass of the stars (M_{max} - in color sequence).

Related publications in 2014:

1) R.O. Gomes, V. Dexheimer, C.A.Z. Vasconcellos, *Effects of strong magnetic fields on the population of hyperon stars*, Astron. Nachr. / AN 335, No. 6/7, 666–671 (2014)
2) R.O. Gomes, V. Dexheimer, S. Schramm, C.A.Z. Vasconcellos, *Many-body forces in the equation of state of nuclear matter*, submitted, arXiv:1411.4875 [astro.ph]

Nonlinear oscillations of compact stars in the vicinity of the maximum mass configuration

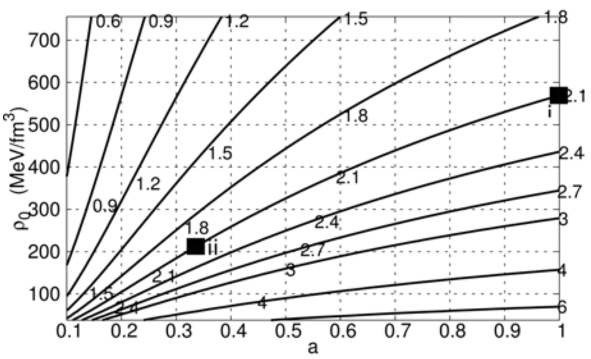
Collaborators: Alessandro Brillante[1,2], Igor N. Mishustin[1,3]

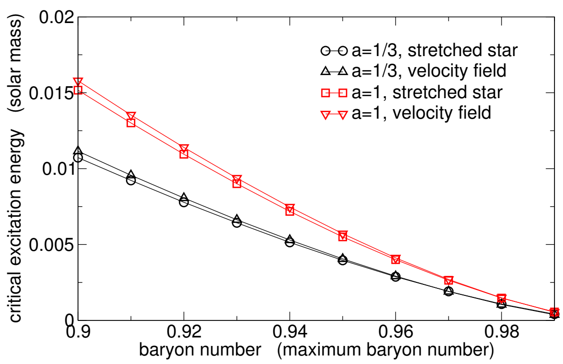
[1] Frankfurt Institute for Advanced Studies, Frankfurt am Main, [2] Institut für Theoretische Physik, Goethe-Universität, Frankfurt am Main, [3] Kurchatov Institute, Russian Research Center, Moscow

Compact stars are stellar remnants and allow to study superdense matter at low temperatures. The equilibrium properties of spherical compact stars are governed by the famous TOV equations of relativistic stellar structure. On the other hand, the numerical solution of compact star oscillations requires the non-stationary solution of the hydrodynamic equations in curved spacetime. It is well known, that spherical compact stars exhibit a change in the stability at the maximum mass configuration. Compact stars with a central baryon density larger than the maximum mass configuration are *dynamically unstable*, i.e. evolve to a black hole, if initially perturbed. In contrast, compact stars with a central density below the maximum mass configuration will perform stable oscillations around the equilibrium configuration.

We have numerically investigated the stability properties of compact stars with the *generalised Zeldovich EoS* $P = a(\rho - \rho_0)$, where a controls the stiffness and ρ_0 the non-vanishing surface density. To this end we have introduced large amplitude perturbations in the vicinity of the maximum mass configuration, preserving the total stellar baryon number. The stellar evolution was obtained with a 1D code for ideal hydrodynamics in curved spacetime with imposed spherical symmetry. Two different choices for the EoS-parameter a were considered, namely $a = 1$ (i), corresponding to the causal limit EoS and $a = 1/3$ (ii), motivated by the MIT bag model (see Figure left). The parameter ρ_0 was chosen in such a way, that the maximum mass equals $2.1M_\odot$. The initial perturbations are made by adding an artificial velocity field or by uniform stretching the star.

The excitation energy is defined as the gravitational mass of the perturbed star minus the gravitational mass of the equilibrium star of the same rest mass. This excitation energy determines, whether the star evolves to a black hole or performs stable oscillations. For every considered value of the rest mass, the critical excitation energy is determined with the help of a bisection strategy. On the stable branch of the mass-radius diagramm the critical excitation energy decreases with increasing rest mass. Compact stars with harder EoS are more resilient to black-hole formation than their softer counterparts. While the critical excitation energy depends also on the specific nature of the perturbation, this dependence turns out to be rather weak (see Figure right).





Left figure: Maximum gravitational mass in the (ρ_0,a)-parameter space for the generalised Zeldovich EoS. The contours denote configurations of constant $M/M_\odot$. The parameter choices used in the simulations are indicated by solid squares. **Right figure**: Critical excitation energy as function of the baryon number for the generalised Zeldovich EoS.

Related publications in 2014:

1. Alessandro Brillante and Igor N. Mishustin, *Radial oscillations of neutral and charged hybrid stars*, Europhys. Lett. 105, 39 (2014)
2. Alessandro Brillante and Igor N. Mishustin, manuscript in preparation

Modeling mixed phase transitions in a dynamical cosmic environment

Collaborators: D. Yueker[1], I. N. Mishustin[1,2], M. Bleicher[1,3]

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The investigation of phase transitions in the early universe is an important testing ground for the standard model of particle physics. Particularly interesting in this context are the electroweak and the QCD phase transitions. Our calculations were done for the deconfinement transition where the high-temperature phase of quarks and gluons transforms to the hadronic matter. The critical temperature for this phase transition is about 170 MeV, reached at a time $t = 10^{-5}$s after the big bang. We have designed a simple field-theoretical model to investigate the significance of background dynamics in this phase transition. Although the deconfinement phase transition at small baryon densities is expected to be of a crossover type, we have also considered a hypothetical possibility of a first order phase transition. In this case one should expect a supercooling effect due to the trapping of the order-parameter field in a metastable state. Such a situation should lead to a mini-inflation scenario, which has been discussed by some authors.

We elaborated cosmological and thermodynamical conditions in the early universe at a QCD phase transition. Then we applied a dilaton-type field-theoretical model for a cosmic phase transition and discussed the characteristic time scales associated with possible supercooling and reheating. The dynamics of a delayed phase transition and its impact on the cosmological evolution were described self-consistently. In the course of this project we have found an exact analytic solution of Friedman's equations for a universe composed of radiation and vacuum energy density, as well as for the evolution of the universe through a mixed phase. Thus we adapted a macroscopic view on the QCD phase transition, assuming that after initial supercooling the system returns back into an equilibrium mixed phase. Its graphical representation is shown in the intermediate stage in the figures below.

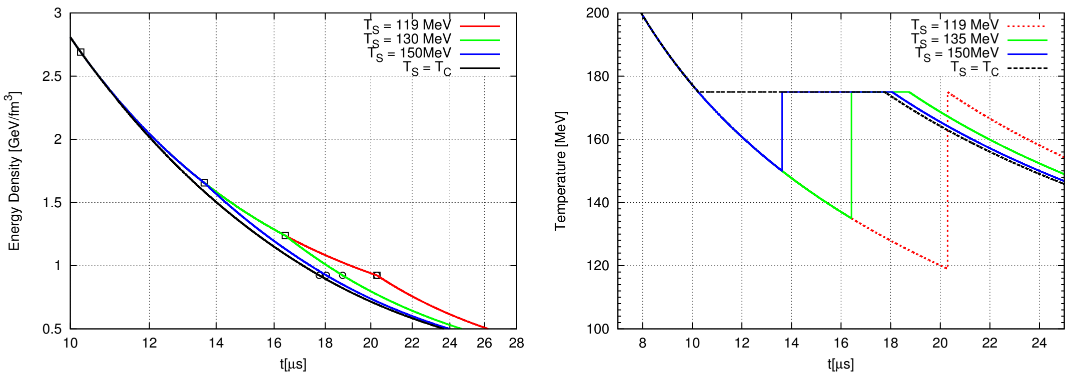

Figure: Plots of total energy density (left plot) and temperature (right plot) for different supercooling scenarios. The black line shows the evolution in an equilibrated scenario, the red line displays the case for the lowest possible supercooling temperature. Intermediate scenarios are colored green and blue.

From our analysis we conclude that trapping of the order-parameter field in the metastable state might cause a mini-inflation behaviour like in a very early universe. However, for this to happen the delay time must be comparable with the time scale of the universe expansion at this epoch, which is very unlikely for QCD-type phase transitions. On the other hand, the supercooling itself leads to important consequences, like additional entropy production. This may cause significant effects in the later evolution. The electroweak phase transition, associated with the Higgs mechanism, will be a good candidate for further investigations in that direction.

Related publication in 2014

D. Yueker, I. Mishustin, M. Bleicher, *Modeling a delayed phase transition in the early universe*, J. Phys. G: Nucl. Part. Phys. 41, 125005 (2014)

Rho-condensate and violent shocks in neutron stars

Collaborators: Ritam Mallick[1], Stefan Schramm[1], Igor Mishustin[1], Rana Nandi[1], Leonid Satarov[1], Veronica Dexheimer[2], Abhijit Bhattacharyya[3]

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Neutron stars (NS) have two extreme condition which can help in the formation of a condensate, namely the strong magnetic field and extreme density at their cores. For a spin-1 particle the magnetic field helps in reducing the energy level or the effective mass of the particle. The baryon mass reduces in dense medium due to in-medium mass effect and assuming a linear dependence of the rho mass on the scalar field we get rho-meson condensate when this two effect are taken simultaneously. For neutron stars, the mass of the ρ^- only has to fall below the electron chemical potential, so that electrons can be replaced by negative rho-mesons for generating a charge-neutral system.

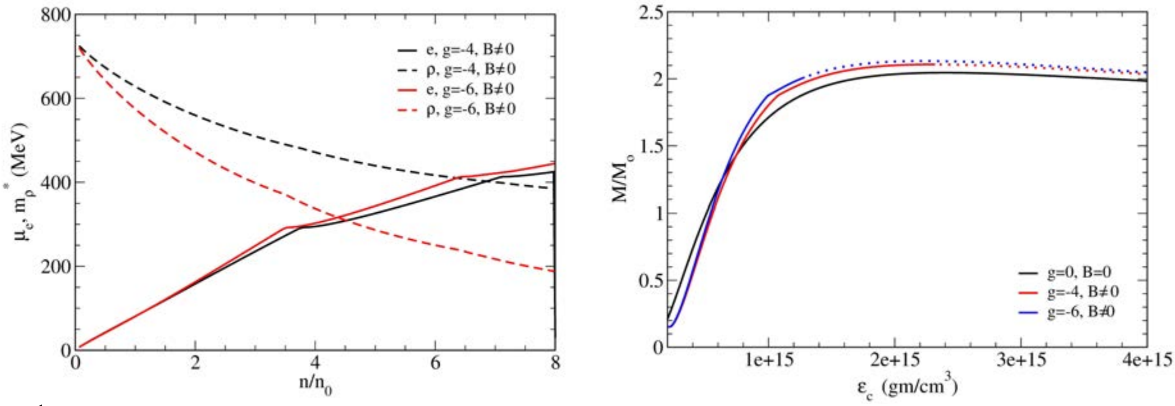

Figure 1: Intersection point (Fig. 1a) showing the apperance of rho-condensation. Fig 1b showing front velocity v_f across the PT front as a function of incoming NM velocity $\tilde{v}_n$ for two initial baryon densities.

We plot curves for the case in which both (in-medium and magnetic) effects are taken into account. With some reasonable value of magnetic field and rho mass modification due to in-medium effects, the condensate appears around 4.4 times nuclear saturation density. For a neutron star with a central density of 6 times nuclear density, a rho-meson condensate appears in the core of the star and extends up to the radius where the nuclear density is 4.4 times nuclear density. We find that as magnetic field or the in-medium effect increases, the condensate appears much earlier, i.e., more and more stars of the sequence have a condensate region in their cores.

The PT from NS to QS is presumably a violent process. The PT should start after the central density exceeds some critical value and the new phase will propagate to the periphery. Since there is no way to stop the propagation of the shock at the equilibrium position in the star, it will overshoot the point and gradually slow down until it finally stops. Then the reverse process may start when the front moves in the opposite direction converting the quark matter (QM) again to hadronic matter. Apparantely, this process will later stop after some again, and the PT front will oscillate around its equilibrium position.

Using the conservation laws at the shock front, we calculate thermodynamic characteristics in the quark core, and have estimated the front velocity as a function of the incoming velocity of nuclear matter. This velocity is expected to be large when the PT is initiated near the star center. This should lead to large initial values of the density and pressure jumps. It is seen that the shock wave will first accelerate but then it becomes slower when moving outwards to less dense regions of the star.

Related publications in 2014:

1) Ritam Mallick, Stefan Schramm, Veronica Dexheimer, Abhijit Bhattacharyya, *On the possibility of rho-meson condensation in neutron stars*, 2014, arXiv:1408.0139 [astro-ph.HE]
2) Igor Mishustin, Ritam Mallick, Rana Nandi, Leonid Satarov, *Phase transition in compact stars due to a violent shock*, 2014, arXiv:1410.8322 [astro-ph.HE]
3) Ritam Mallick, Stefan Schramm, *Deformation of a magnetized neutron star*, Phys.Rev. C89, 045805 (2014)
4) Ritam Mallick, Stefan Schramm, *Oblique magnetohydrodynamic shocks: Space-like and time-like characteristics*, Phys. Rev. C89, 025801 (2014)

Phase transition in compact stars due to a violent shock

Collaborators: Igor Mishustin[1,2], Ritam Mallick[1], Rana Nandi[1], Leonid Satarov[1,2]

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The most interesting property of dense baryonic matter is its possible phase transition (PT) to the deconfined phase at supranuclear densities, a few times the nuclear equilibrium density $n_0 = 0.15$ fm^{-3}. The PT from neutron star (NS) to quark star (QS) is presumably a violent process and can be triggered by several mechanisms. It is most likely that the PT happens due to the nucleation process near the star centre. Such a PT should be accompanied by significant energy release in the form of latent heat, which leads to a neutrino burst thereby cooling the star. This energy release should have several observable signatures like the gamma ray bursts and change in the cooling rate.

In this work we have investigated the dynamics of a first order PT from nuclear matter (NM) to quark matter (QM) in neutron stars. Some part of the energy released during the PT heats up the matter. The actual temperature of the matter will depend on the equations of state (EoS) of two phases. For the NM we adopt the widely used relativistic mean field approach whereas for QM we apply the MIT bag model including quark interactions. We first analyse the equilibrium PT between the hadronic and quark phases at various temperatures. In a dynamical environment the PT from NM to QM may be delayed due to the barrier separating the two phases and therefore it occurs at higher density. Moreover, since the PT from NM to QM leads to jumps in thermodynamical quantities, one may expect the formation of a step-like spatial profiles like in a shock wave. We assume that a shock-like discontinuity is generated somewhere near the centre of a spherically-symmetric star and later on it propagates outwards, leaving behind a compressed quark core. The thermodynamical conditions in the quark core are found from the conservations laws across the transition region.

We find that the dynamics of the star transformation depends strongly on the velocity of the shock front and the density of incoming NM . The pressure and density of the final state increase with the incoming flow velocity. Also, at a given onset density the pressure jump across the front increases with the flow velocity of incoming matter. The shock is found to be violent in the beginning of the conversion process when the velocity of the infalling matter is high. As the shock propagates further from the center the front velocity first increases and reaches a maximum value when the incoming velocity is 0.2. Finally, the front velocity quickly goes to zero as incoming matter velocity approaches zero. We also find that the density ratio ($\lambda = n_q/n_n$) at the phase boundary depends only weakly on the onset density and pressure jump across the front as long as the incoming matter velocity is high.

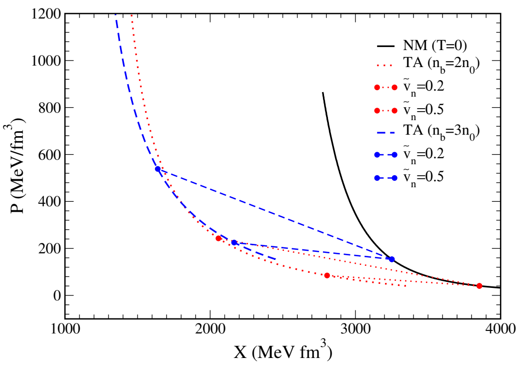

Figure 1: Taub adiabats for shock transitions from NM to QM at different initial baryon densities $n_n = 2n_0$ (dotted line) and $n_n = 3n_0$ (dashed line). Lines with markers indicate shocks with different values of $\tilde{v}_n$, velocity of incoming NM.

Related publications in 2014:

1) Igor Mishustin, Ritam Mallick, Rana Nandi, Leonid Satarov *Phase transition in compact stars due to a violent shock*, arXiv:1410:8322 [astro-ph]

Black holes thermodynamics and phase transitions

Collaborators: P. Nicolini[1,2], M. Bleicher[1,2], R. Casadio[3], A. M. Frassino[1,2], D. Kubiznak[4,5], M. Isi[6], R. B. Mann[4,5], O. Micu[7], J.R. Mureika[6], F. Simovic[5], D. Singleton[8], E. Spallucci[9]

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Black holes are among the most fascinating objects in Physics. One of the most striking features of black holes is that, contrary to the classical viewpoint, they can emit radiation like a black body at a temperature proportional to their surface gravity. This property, found by Hawking in 1975, opened a research line that intersects quantum mechanics, general relativity, thermodynamics and theory of information. One of the long standing problems for a complete understanding of black hole thermodynamics is the absence of a statistical description of their entropy, a quantity that is proportional to the area of their event horizon. As a possible answer to this question we proposed a holographic projection mechanism of some quantum mechanical degrees of freedom, we expect to lie at the center of the black hole. We showed that such a projection is compatible with the values of black entropy, calculated by the number of Planckian pixels covering the black hole horizon. We also extended our analyses to non-Einstein gravity scenarios (*e.g.* Lovelock gravity) and we discovered that black holes can undergo to a rich variety of phases transitions (*e.g.* multi-re-entrant phase transition) with tri-critical points.

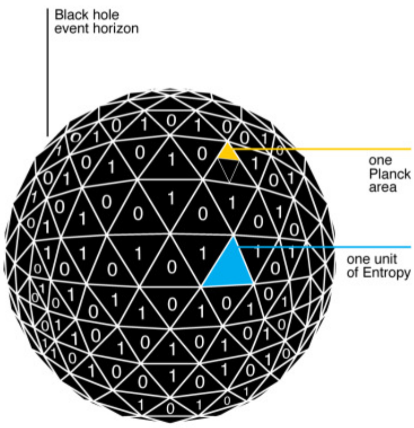

Figure 1: Black hole entropy in terms of pixel (bit of information), *i.e.*, Planck area surface elements. covering the event horizon. A minimum number of bits is require to have a byte the unit of information.

Related publications in 2014:

1) R. Casadio, O. Micu and P. Nicolini, *Minimum length effects in black hole physics*, arXiv:1405.1692 [hep-th]
2) M. Bleicher and P. Nicolini, *Mini-review on mini-black holes from the mini-Big Bang*, Astronomische Nachrichten 335, 605 (2014), arXiv:1403.0944 [hep-th]
3) M. Isi, J. Mureika and P. Nicolini, *Self-Completeness in Alternative Theories of Gravity*, arXiv:1402.3342 [hep-th]
4) P. Nicolini and D. Singleton, *Connecting horizon pixels and interior voxels of a black hole*, Physics Letters B 738, 213 (2014), arXiv:1409.5069 [gr-qc]
5) A. M. Frassino, D. Kubiznak, R. B. Mann and F. Simovic, *Multiple Reentrant Phase Transitions and Triple Points in Lovelock Thermodynamics*, Journal of High Energy Physics 1409, 080 (2014), arXiv:1406.7015 [hep-th]
6) P. Nicolini and E. Spallucci, *Holographic screens in ultraviolet self-complete quantum gravity*, Advanced of High Energy Physics 2014, 805684 (2014), arXiv:1210.0015 [hep-th]

Non-local inflatonless bouncing cosmology in bosonic closed string-field theory

Collaborators: P. Nicolini[1,2], G. Calcagni[3], L. Modesto[4]

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Nonlocal theories belong to the larger family of theoretical proposals aiming to improve Einstein gravity both in the ultraviolet and the infrared limit. Technically nonlocal gravity is formulated by replacing the usual Einstein-Hilbert action with a gravitational action containing an infinite series of derivative terms of the Ricci scalar. We considered one such model of nonlocal gravity which, at the linear perturbative level, reproduces the effective non-local action for the light modes of bosonic closed string-field theory. The action we proposed is

$$S = \frac{1}{2\kappa_D^2} \int \mathrm{d^D x} \sqrt{|g|} \left[\mathrm{R} - \mathrm{G}_{\mu\nu}\, \gamma(\nabla^2)\, \mathrm{R}^{\mu\nu} \right] + \mathrm{S_{matter}}\,, \tag{1}$$

$$S_{\mathrm{matter}} = \int \mathrm{d^D x} \sqrt{|g|} \left[\frac{1}{2} \nabla_\mu \phi\, \mathrm{V}^{-1}(\nabla^2)\, \nabla^\mu \phi + \frac{1}{2\mathrm{n}!} \mathrm{e}^{\mathrm{c}\phi}\, \mathrm{F_{[n]}}\, \mathrm{V}^{-1}(\nabla^2)\, \mathrm{F_{[n]}} \right], \tag{2}$$

where $G_{\mu\nu}$ and $R_{\mu\nu}$ are, respectively, the Einstein tensor and the Ricci tensor associated with the D-dimen-sional target spacetime metric $g_{\mu\nu}$, and, adopting the terminology used in string theory, ϕ is the dilaton field coming from the trace of the field $A_{\mu\nu}$, $n = p+2$, and $F_{[n]}$ are the p-field strengths corresponding to the gauge potentials. The action contains also two nonlocal operators, *i.e.*, $V(\nabla^2)$ and $\gamma(\nabla^2)$ subject to some regularity conditions. Along this line of reasoning, and by exploiting the largely predicted asymptotically safe character of gravity, we derived a model of universe which provides a big bang scenario in terms of a super-accelerating bouncing phase. As a special result, nonlocal effects drive the inflation without the introduction of an artificial inflaton scalar field as in conventional cosmological models.

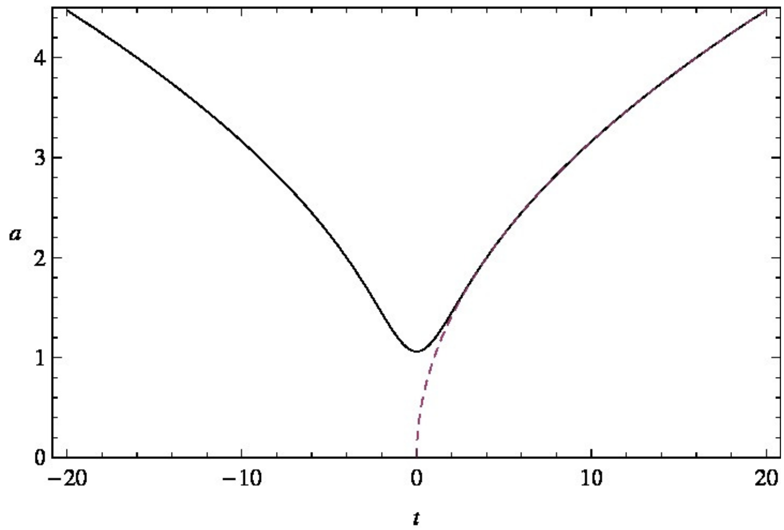
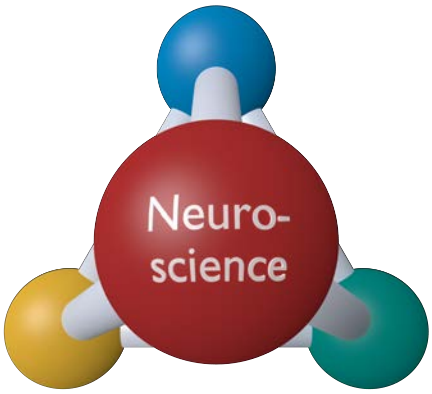


Figure 1: Bouncing super accelerating profile of the nonlocal inflationary universe.

Related publication in 2014:

1) G. Calcagni, L. Modesto and P. Nicolini, *Super-accelerating bouncing cosmology in asymptotically-free non-local gravity*, Eur. Phys. J. C 74, 2999 (2014)

4.2 Neuroscience



Autonomous learning of active visual perception in a humanoid robot

Collaborators: P. Chandrashekhariah[1], S. Forestier[1], L. Lonini[1], A. Priamikov[1], T.N. Vikram[1], C.A. Rothkopf[1], B.E. Shi[2], C. Teulière[3], J. Triesch[1]

[1] Frankfurt Institute for Advanced Studies, [2] Hong Kong University of Science and Technology, Hong Kong, China, [3] Pascal Institute, Université Blaise Pascal, Clermont-Ferrand, France

Biological vision systems learn to perceive the world autonomously, while robots still have to be programmed or taught. We try to better understand the principles of autonomous learning in biological perceptual systems and to exploit these principles for the construction of autonomously learning vision systems for robots. With our collaborator Bert Shi at the Hong Kong University of Science and Technology we have formulated a new princple for such autonomous learning, which we have called *active efficient coding*. It is a generalization of the classic efficient coding hypothesis in sensory Neuroscience to active perception. The central idea is that biological perceptual systems not only learn internal representations to encode sensory signals very efficiently (conventional efficient coding), but they also learn to utilize their movement abilities to further improve the coding efficiency of their sensory systems (active efficient coding). We have explored this idea in the context of systems for binocular vision and motion perception. The former system learns a representation of binocular disparity and vergence eye movements. The latter learns a representation of optic flow and pursuit eye movements. In both cases, our approach leads to completely self-calibrating sensorimotor loops that learn autonomously and are very robust to perturbations. We have also shown how the two systems can be integrated into a single system. It shows how vergence and pursuit eye movements, which have been viewed as very different kinds of eye movements in the past, can develop from the same underlying learning principle: active efficient coding. Next to testing these models on the iCub robot, we have also started to develop a simulation platform for biomechanically accurate simulation of human eye movement control called *OpenEyeSim*.

The iCub robot autonomously learns to track moving objects with its eyes based on the *active efficient coding* principle. The robot tries to encode sensory information as efficiently as possible and learns to exploit its movement abilities to help with this. Learning takes place in simulation and is then validated on the physical robot (not shown).

Related publications in 2014:

1) C. Teulière, S. Forestier, L. Lonini, C. Zhang, Y. Zhao, B. Shi, J. Triesch, *Self-calibrating smooth pursuit through active efficient coding*, Robotics and Autonomous Systems, doi:10.1016/j.robot.2014.11.006 (2014)
2) T.N. Vikram, C. Teulière, C. Zhang, B.E. Shi, J. Triesch, *Autonomous learning of smooth pursuit and vergence through active efficient coding*, Development and Learning and Epigenetic Robotics (ICDL-Epirob), 2014 Joint IEEE International Conferences on, doi: 10.1109/DEVLRN.2014.6983022, pages 448–453 (2014)
3) C. Zhang, Y. Zhao, J. Triesch, B.E. Shi, *Intrinsically motivated learning of visual motion perception and smooth pursuit*, Robotics and Automation (ICRA), 2014 IEEE International Conference on, doi: 10.1109/ICRA.2014.6907110, pages 1902–1908 (2014)
4) A. Priamikov, J. Triesch, *OpenEyeSim — A platform for biomechanical modeling of oculomotor control*, Development and Learning and Epigenetic Robotics (ICDL-Epirob), 2014 Joint IEEE International Conferences on, doi: 10.1109/DEVLRN.2014.6983013, pages 394–395 (2014)
5) P. Chandrashekhariah, J. Triesch, *Hide and Seek: an active binocular tracking system*, 9th Int. Conf. on Computer Vision Theory and Applications (VISAPP) (2014)

Studying cognitive influences on ambiguous perception

Collaborators: K. R. Gegenfurtner[1], L. Scocchia[2], J. Triesch[3], M. Valsecchi[1]

[1] University of Gießen, Gießen, Germany, [2] University of Milano-Bicocca, Milano, Italy, [3] Frankfurt Institute for Advanced Studies

Visual information is often highly ambiguous and our perceptual systems have to resolve the ambiguitiy to arrive at a coherent percept. A classic example is the Necker cube, a line drawing of a cube, which can be interpreted in different three-dimensional configurations. Another classic example is binocular rivalry, where completely different images are shown to both eyes (cf. figure). In this situation subjective perception typically switches from an interpretation corresponding to one eye's image to the other and back in a stochastic fashion. Although such phenomena have been systematically studied for over 100 years, it is still unclear what factors can influence the switching dynamics.

In a previous study we had investigated how holding an object in visual working memory influences the perception of ambiguous stimuli. In that experiment subjects had perceived an ambiguously rotating sphere, which can be perceived as rotating clockwise or anticlockwise. Subjects reported their percept (rotating clockwise or anticlockwise) on a moment to moment basis, while they held in memory a sphere rotating unambiguously with a certain velocity. We had found that the memory content systematically influenced their interpretation of the ambiguous sphere. Subjects were more likely to interpret the ambiguous sphere as rotating in the same direction as the sphere held in memory.

Here we tried to extend our findings to binocular rivalry. Subjects reported perceptual dominance while viewing rivalry stimuli composed of faces and houses or gratings of differing color and orientation (cf. figure). We studied the effects of different cognitive influences such as working memory contents (holding the image of a face or house in one's working memory), prior attention (studying a face or house image prior to the onset of the rivalry stimulus), or a concurrent change detection task (monitoring one part of the rivalry stimulus, e.g., face or house for a subtle appearance change). Our findings show that different cognitive processes can influence binocular rivalry perception, but the effects are not identical to those we found for the ambiguously rotating sphere in our previous study. In particular, while effects of a concurrent change detection task could be demonstrated, we failed to observe an effect of a working memory load. We have summarized these and other findings on top-down influences on ambiguous perception in a comprehensive review article.

Typical binocular rivalry stimulus. The left eye is presented the house image (red), while the right eye sees the face image (green). In this situation, perception spontaneously switches from one interpretation to the other. We have investigated to what extent the switching dynamics are influenced by cognitive factors such as the deployment of attention and working memory.

Related publications in 2014:

1) L. Scocchia, M. Valsecchi, K. Gegenfurtner, J. Triesch, *Differential effects of visual attention and working memory on binocular rivalry*. Journal of Vision 14(5), doi: 10.1167/14.5.13 (2014)

2) L. Scocchia, M. Valsecchi, J.Triesch, *Top-down influences on ambiguous perception: the role of stable and transient states of the observer*. Frontiers in Human Neuroscience. 8:979, doi: 10.3389/fnhum.2014.00979 (2014)

Studying infant cognitive development using gaze-contingency and microbehavioral analysis

Collaborators: G. Deák[1], M. Knopf[2], T. Kolling[2], A. Romberg[3], J. Triesch[4], C. Yu[3]

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Studying infant cognitive development is notoriously difficult due to infants' poorly developed motor abilities. Eye movements are an exception, which is why many paradigms for studying infant cognition rely on their eye movements. With recent advances in remote eye tracking technology, the eye movements of infants can now be measured accurately and non-invasively.

In a first line of research, we have developed gaze-contingent paradigms where infants can control some aspect of their environment through their eye movements. Specifically, we have previously shown that infants as young as 6–8 months can learn that their eye movements produce the appearance of novel images on a computer screen. These findings had been extended in two directions. With our collaborator Prof. Knopf and her group from Frankfurt, we applied the paradigm (and small variations of it) to adult and elderly subjects. These experiments have shown that the paradigm can be used from 6-month-old infants to senior citizens, making it suitable for studying this cognitive development across the life span with one and the same paradigm. With new funding from the DFG we are about to start a new series of experiments to more carefully characterize what factors influence infants' learning in this paradigm. With Prof. Chen Yu at Indiana University we have been exploring the potential use of gaze-contingent paradigms for studying early word learning abilities and the exploration of visual scenes in infants.

In a second line of research, we have continued to investigate the development of gaze following in infants, i.e., their ability to look where someone else is looking. With former colleague Prof. Deák in San Diego, we have published an extensive study involving home observations of mother-infant interactions during naturalistic play situations. Through micro-behavioral analysis of the video records we collected data on gaze shifts, body movements, object manipulations, and utterances. Analysis of these data revealed that infants pay close attention to their caregiver's hands as they manipulate objects. At the same time, analysis of sequential mother-infant behaviors revealed that the caregivers' looking behavior could allow an infant to learn gaze following by establishing associations between where the caregiver is looking and where there is something the infant likes to watch, lending support to a theory we had proposed previously.

Home observation of mother infant interactions during naturalistic play. Shown are two still images from synchronized video cameras focusing on infant and mother, respectively.

Publication in 2014:

1) G.O. Deák, A. Krasno, J. Triesch, J. Lewis, L. Sepeta, *Watch the hands: infants can learn to follow gaze by seeing adults manipulate objects*, Developmental Science 17, 270–281 (2014), doi: 10.1111/desc.12122

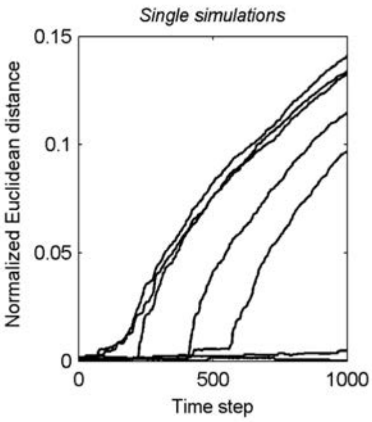
Learning and self-organization in neural network models of brain function

Collaborators: B. Del Papa[1], J. Eser[1], C. Hartmann[1], D. Krieg[1], A. Lazar[2], D. Miner[1], B. Nessler[1], C. Savin[3], J. Triesch[1], P. Zheng[4]

[1] Frankfurt Institute for Advanced Studies, [2] Max-Planck-Institute for Brain Research, Frankfurt, [3] Institute of Science and Technology, Austria, [4] Max-Planck-Institute for Biological Cybernetics, Tübingen

A major line of research of the Triesch lab is to study principles of learning and self-organization with recurrent neural network models. We have been investigating a class of self-organizing recurrent neural network (SORN) models, which exhibit powerful sequence learning abilities and reproduce a range of findings about the structure and dynamics of cortical circuits. These networks combine a number of different plasticity mechanisms including so-called spike-timing-dependent plasticity (STDP) and homeostatic plasticity mechanisms. A key challenge is to understand the network self-organiztion in these models, where current network structure determines network dynamics and where network dynamics induces changes in network structure.

In terms of studying the self-organization of the SORN model, we have characterized how the network dynamics become less chaotic as the network self-organizes. This has lead to the discovery of a dynamical phenomenon that we have termed *deferred chaos* (see figure). It results from the interplay of discrete and quasi-continuous state variables in the SORN model. We could also show how the SORN model robustly develops dynamic activity patterns called *synfire chains*, which have been hypothesized as fundamental dynamic building blocks of brain activity. Further topics have been the role of reward-modulated learning in the development of working memory circuits, an analysis of the effects of sampling on measurements of local circuit structure, as well as a new normative theory for synaptic long-term plasticity. The latter theory unifies classic findings on long-term potentiation and depression, STDP, and so-called meta-plasticity by interpreting all these phenomena as subserving the goal of maintaining a sparse distribution of synaptic efficacies, which may increase the brain's energy efficiency.



Deferred chaos in a self-organizing recurrent neural network (SORN) model. The mixing of discrete and (quasi-)continuous state variables in the SORN model leads to an interesting phenomenon we have called *deferred chaos*. Shown is the growth of different perturbations to the synaptic weight matrix. The Euclidean distance between the perturbed and unperturbed weight matrices is plotted as a function of time since the perturbation. Since changes to the synaptic weights are mediated by the activities of the model neurons which are discrete, a perturbation of the weight matrix will tend to affect the neuron activities only after a delay. Once the neuron activities have been affected by the perturbation, the perturbation can grow and spread across the network.

Related publications in 2014:

1) D. Krieg, J. Triesch, *A unifying theory of synaptic long-term plasticity based on a sparse distribution of synaptic strength*, Frontiers in Synaptic Neuroscience 6, article 3, doi: 10.3389/fnsyn.2014.00003 (2014)
2) J. Eser, P. Zheng, J. Triesch, *Nonlinear Dynamics Analysis of a Self-Organizing Recurrent Neural Network: Chaos Waning*, PLoS One 9(1): e86962. doi:10.1371/journal.pone.0086962 (2014)
3) C. Savin, J.Triesch, *Emergence of task-dependent representations in working memory circuits*, Frontiers in Computational Neuroscience 8, article 57, doi: 10.3389/fncom.2014.00057 (2014)
4) P. Zheng, J. Triesch, *Robust development of synfire chains from multiple plasticity mechanisms*, Frontiers in Computational Neuroscience 8, article 66, doi: 10.3389/fncom.2014.00066 (2014)
5) D. Miner, J.Triesch, *Slicing, sampling, and distance-dependent effects affect network measures in simulated cortical circuit structures*, Frontiers in Neuroanatomy 8, article 125, doi: 10.3389/fnana.2014.00125 (2014)

Modeling the effect of transcranial magnetic stimulation on cortical circuits

Collaborators: M. Murakami[1], C. Rusu[1,2], J. Triesch[1], U. Ziemann[3]

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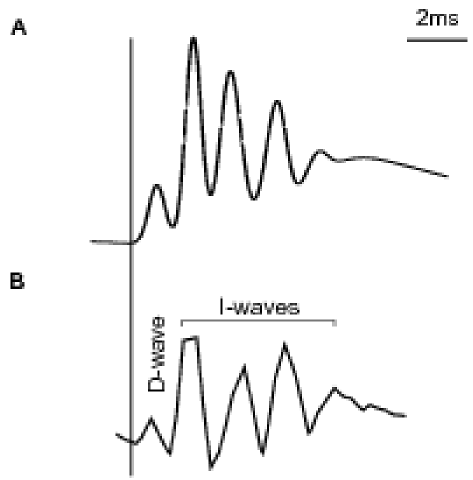
The application of strong transient magnetic fields on the outside of the skull can induce electric currents in the brain that are sufficiently strong to induce neuronal firing. This has been exploited in the development of transcranial magnetic stimulation (TMS) devices, which allow to manipulate neural activity non-invasively. Much research is currently trying to exploit this ability in clinical and basic research settings. However, the details of how TMS induces neural activity patterns in cortical circuits remain poorly understood, which hampers targeted clinical application. In a standard TMS paradigm, single-pulse stimulation over motor cortex produces high-frequency repetitive responses of around 600 Hz in descending motor pathways called D-waves and I-waves. We have used computational modeling to shed light on the mechanisms underlying D-wave and I-wave generation. Our model consists of a detailed layer 5 (L5) pyramidal cell and a population of layer 2 and 3 (L2/3) neurons projecting onto it with synapses exhibiting short-term depression. Specifically, excitatory and inhibitory L2/3 cells project synapses on to various parts of the L5 cell's complex dendritic tree (modeled with the NEURON software). Our model successfully explains all basic characteristics of I-waves observed in epidural responses during *in vivo* recordings of conscious humans. It postulates that the superposition of synaptic inputs on the dendritic tree of L5 cells together with their spike generation mechanism is responsible for I-wave generation. In addition, it shows how the complex anatomical structure of L5 neurons plays an important role in the generation of I-waves. We find that later I-waves are formed due to inputs to distal synapses, while earlier ones are driven by synapses closer to the soma. Finally, the model explains inhibition and facilitation effects in paired-pulse stimulation protocols. In sum, our model explains findings from a range of experiments, is more parsimonious than previous models, and brings us one step closer to designing optimized stimulation protocols for specific clinical purposes.



D-wave and I-waves produced by our model (A) vs. measured through epidural recordings from the spinal cord in conscious humans (B). According to our model, D-waves are produced by direct activation of axons of neurons in layer five of motor cortex projecting to the spinal cord. I-waves result from simultaneous excitatory and inhibitory inputs from cortical layers two and three interacting on the complex dendritic trees of the layer five neurons and producing additional rhythmic spikes in the layer five cells. The D-wave and I-waves measured at the spinal cord result from the superposition of spike trains from many layer 5 pyramidal neurons projecting down the spinal cord.

Related publications in 2014:

1) C. Rusu, M. Murakami, U. Ziemann, J. Triesch, *A Model of TMS-induced I-waves in Motor Cortex*, Brain Stimulation 7(3):404–414, http://dx.doi.org/10.1016/j.brs.2014.02.009 (2014)

The development of cortical circuits for motion discrimination

Collaborators: Gordon B. Smith[1,*], Audrey Sederberg[2,*], Yishai M. Elyada[1], Stephen D. Van Hooser[3], Matthias Kaschube[4,†], David Fitzpatrick[1,†]

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[†] These authors jointly directed this work

Accurate visual discrimination depends critically on the selective responses of neurons in visual cortex for features of the visual scene such as the orientation of edges and their direction of motion. Other aspects of cortical responses, especially those that influence the spatial and temporal patterns of neuronal activity, are also important in visual discrimination. These include response variability, the number of responsive neurons and the degree of correlation in neuronal response, all of which affect the performance of population coding in the mature visual cortex. How these four features of the population response emerge and reach their mature state during the development of the visual cortex remained unclear.

Here we show in ferrets that at eye opening, the cortical response to visual stimulation exhibits several immaturities, including a high density of active neurons that display prominent wave-like activity, a high degree of variability and strong noise correlations. Over the next three weeks, the population response becomes increasingly sparse, wave-like activity disappears, and variability and noise correlations are markedly reduced. Similar changes were observed in identified neuronal populations imaged repeatedly over days (Fig. 1a). Furthermore, experience with a moving stimulus was capable of driving a reduction in noise correlations over a matter of hours (Fig. 1, b and c). We show, that these changes in variability and correlation contribute significantly to a marked improvement in direction discriminability over development (Fig. 1d).

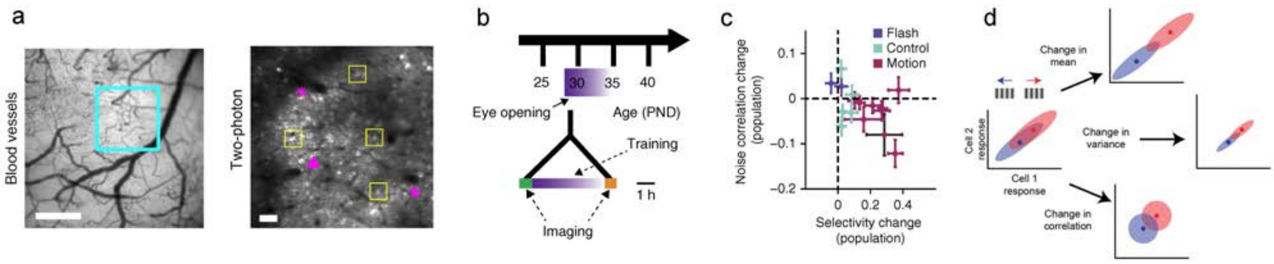

Figure 1: **a** Neural activity in ferret visual cortex. Left, cortical blood vessel pattern. Blue box indicates area for functional imaging. Right, imaging field. Yellow boxes and purple symbols indicate examples of neurons. Scale bars: left, 500 μm; right, 50 μm. **b**, **c** Motion training (paradigm shown in **b**) induces decrease in noise correlations and increase in direction selectivity (**c**). In contrast, no visual stimulation ('Control') or visual stimulation without any motion component ('Flash') shows little effect. **d** Maturation of multi-cell motion discriminability observed in this study (schematic illustration for a population of two neurons). Motion discriminability is large if the fraction of overlap between the response distributions for the two stimulus directions is small. Over development, the overlap decreases as i) cells become more selective (right, upper), ii) the overall magnitude of fluctuations decreases (right, middle) and iii) noise correlations become smaller (right, lower).

Related publication:

G.B. Smith, A. Sederberg, Y.M. Elyada, S.D. Van Hooser, M. Kaschube, D. Fitzpatrick, *The development of cortical circuits for motion discrimination*, Nature Neuroscience 2015 Feb;18(2):252-61

Inhibition facilitates direction selectivity in a noisy cortical environment

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In a broad class of models, direction selectivity in primary visual cortical neurons arises from the linear summation of spatially offset and temporally lagged inputs combined with a spike threshold. Here, we characterize the robustness of this class of models to input noise and background activity that is uncorrelated with the visual stimulus. When only excitatory inputs were considered, moderate levels of noise substantially degraded direction selectivity. By contrast, the inclusion of inhibition produced a direction-selective neuron even at high noise levels. Moreover, if inhibitory inputs were tuned, mirroring excitatory inputs but lagging by a fixed delay, they promoted a highly direction-selective response by suppressing all excitatory inputs in the null direction while minimally affecting excitatory inputs in the preferred direction. Additionally, tuned inhibition strongly reduced trial-by-trial variability, such that the neuron produced a consistent direction-selective response to multiple presentation of the same stimulus. This work illustrates how inhibition could be used by cor- tical circuits to reliably extract information on a single-trial basis from feed-forward inputs in a noisy, high-background context.

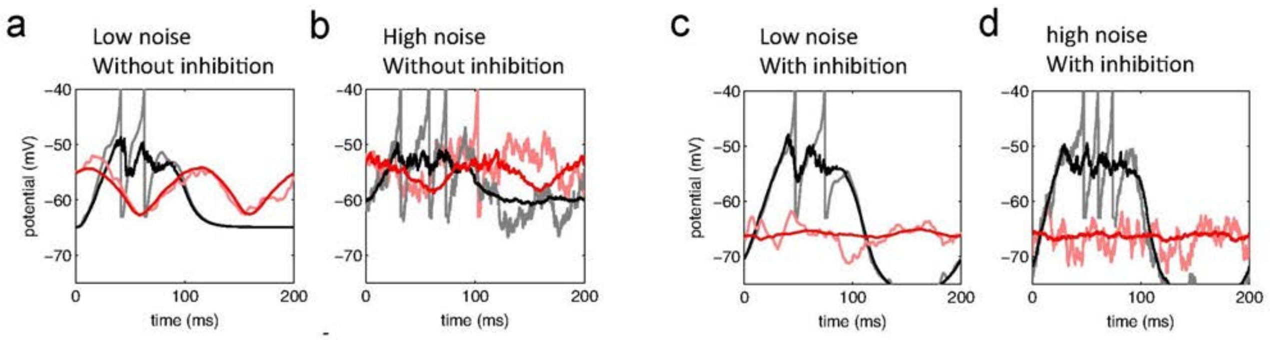

Figure 1: The contribution of direction selective, temporally lagged inhibition to robust direction selectivity. Simulations were performed with an EIF neuron. Single realizations are plotted for responses to preferred motion (gray) and null motion (light red), as well as the average over 50 trials (black, red). When only excitatory inputs are present (**a** and **b**), the model produces a direction-selective response in the low-noise regime (**a**), but not in the high-noise regime (**b**). In contrast, with co-tuned inhibition (**c** and **d**), the model produces a direction-selective response not only in the low-noise (**c**), but also in the high-noise regime (**d**). Mechanism: Co-tuned inhibition is added by introducing a delayed inhibitory input for each excitatory input. For the preferred direction both excitatory and inhibitory inputs each arrive near simultaneously at the neuron. Because of the delay, however, inhibition does not counteract excitation and thus does not reduce significantly the neuron's response to the preferred direction. For the null direction, in contrast, inhibitory input currents arrive dispersed in time and cancel nearly all excitatory currents (which now also arrive dispersed in time), thus reducing the response to null-directed motion. Therefore, with lagged co-tuned inhibition, neurons can maintain high levels of direction selectivity, even in the presence of noisy background activity.

Related publication:

A. Sederberg, M. Kaschube, *Inhibition facilitates direction selectivity in a noisy cortical environment*, J. Comput. Neurosci. 2014 Nov 18 [Epub ahead of print]

A Three-Dimensional Model of the Rat Dentate Gyrus

Collaborators: Calvin J. Schneider[1], Hermann Cuntz[2-4], Ivan Soltesz[1]

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We have previously constructed large-scale network models of the dentate gyrus to isolate variables known to change in epilepsy and to provide a tool for independent investigators to test their own hypotheses. The recent conversion of the model to make it compatible with *parallel NEURON* increased the speed and accessibility of the model, but also removed the limitations on model size and complexity due to the utilization of increased computational resources. While we are now able to simulate the full-scale dentate gyrus containing over a million neurons, the model is limited in its anatomical realism since it is composed of a one-dimensional strip that is populated with simplified, dendritic morphologies consisting of two compartments only. Also, the model does not incorporate variability in morphology and electrophysiology for neurons of the same class. Using experimental three-dimensional reconstructions of both the dentate gyrus structure (Ropireddy et al, 2012, Neuroscience 205, 91-111) and individual neurons, in combination with the TREES toolbox software package that enables the generation of dendritic structures that are embedded spatially (Cuntz et al, 2010, PLoS Comput Biol 6(8):e1000877), we have developed a method by which to grow three-dimensional dendritic trees within a realistic structural context. Two-dimensional sheets representing the flattened granule cell layer and different depths in the molecular layer were transformed to match the three-dimensional extent of their real counterparts (Fig. 1a), and intermediate depths were interpolated. The approximately 9 mm by 4 mm sheets used for the granule cell layer created a volume that closely matched the experimentally reconstructed volume (approximately 3.8 mm^3) and fit over a million granule cell somata, which matches experimental estimations. By distributing target points in the molecular layer in a cone shape derived from single cell reconstructions (Fig. 1b) and then connecting these according to optimal wiring criteria used by the TREES toolbox algorithm, we are able to generate a realistic population of variable granule cell dendritic trees. This improves the accuracy of single cell models, introduces realistic variability into a previously uniform population of neurons, and enables the testing of hypotheses involving a spatial component, such as cutting a virtual hippocampal slice (Fig. 1cd). Through these and other improvements, we aim to construct a more complete full-scale model of the rat dentate gyrus, to provide a better tool to delineate the functional role of cell types within the dentate gyrus and their pathological changes observed in epilepsy.

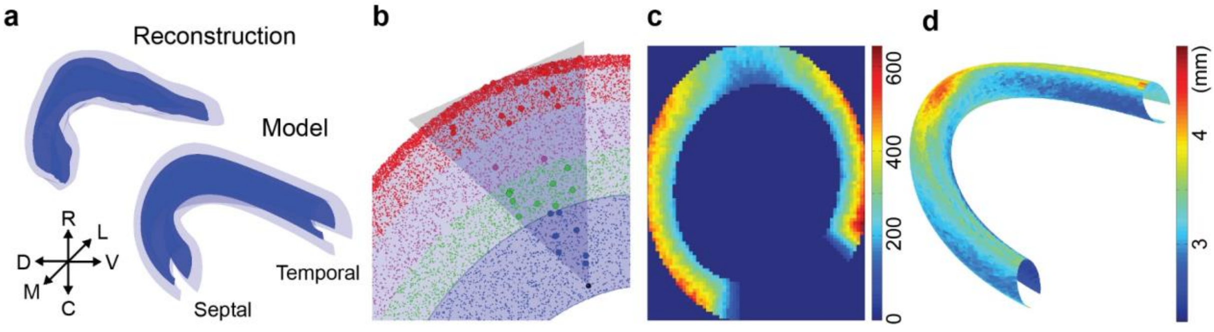

Figure 1: a): Model and reconstructed dentate gyrus volume. b): Outline of elliptical cone of which targets are selected to generate synthetic granule cells, blue – granule cell layer, green/magenta/red – inner/middle/outer molecular layer. c): Number of unique GCs in 25 µm bins. d): Total dendrite length as a function of spatial location.

This work was funded by NASA NNX10AD59G and NIH grant NS35915 to IS as well as by BMBF grant 01GQ1406 to HC.

Related publication in 2014:

Calvin J. Schneider, Hermann Cuntz, Ivan Soltesz, *Linking Macroscopic with Microscopic Neuroanatomy Using Synthetic Neuronal Populations*, PLoS Comput Biol 10(10), e1003921 (2014)

Semantic mechanisms in the development of synesthesia

Collaborators: A. Mroczko-Wąsowicz[1], D. Nikolić[2], P. Spagnoletti[3], C. Keller[3], A. Gendler[4]

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Currently, little is known about how synesthesia develops and which aspects of synesthesia can be acquired through a learning process. We review the increasing evidence for the role of semantic representations in the induction of synesthesia, and argue for the thesis that synesthetic abilities are developed and modified by semantic mechanisms. That is, in certain people semantic mechanisms associate concepts with perception-like experiences-and this association occurs in an extraordinary way. This phenomenon can be referred to as "higher" synesthesia or ideasthesia. The present analysis suggests that synesthesia develops during childhood and is being enriched further throughout the synesthetes' lifetime; for example, the already existing concurrents may be adopted by novel inducers or new concurrents may be formed. For a deeper understanding of the origin and nature of synesthesia we propose to focus future research on two aspects: (i) the similarities between synesthesia and ordinary phenomenal experiences based on concepts; and (ii) the tight entanglement of perception, cognition and the conceptualization of the world. Importantly, an explanation of how biological systems get to generate experiences, synesthetic or not, may have to involve an explanation of how semantic networks are formed in general and what their role is in the ability to be aware of the surrounding world.

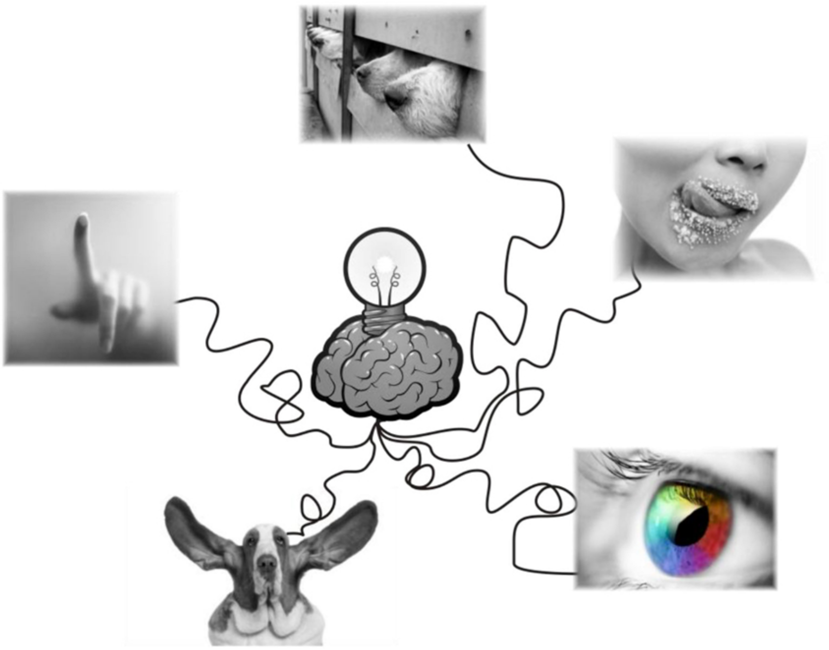

Figure: Illustration of ideasthesia: The light bulb in the middle indicates concepts, whose activation then is responsible for phenomenal sensory experiences (smell, touch, hearing, etc.). The same semantic-sensory relation is proposed to underlie synesthesia.

Related publications in 2014:

1) A. Mroczko-Wąsowicz, D. Nikolić, *Semantic mechanisms may be responsible for developing synesthesia*, Frontiers in Human Neuroscience 8:509 (2014), doi: 10.3389/fnhum.2014.00509

2) D. Nikolić, *Ideasthesia: How do ideas feel?*, TED Ed Lessons Worth Sharing. Animators: P. Spagnoletti. and C. Keller, Script Editor: A. Gendler (2014)

A general theory of adaptive systems

Collaborators: D. Nikolić[1]

[1] Frankfurt Institute for Advanced Studies, Frankfurt

The mind is a biological phenomenon. Thus, biological principles of organization should also be the principles underlying mental operations. Practopoiesis states that the key for achieving intelligence through adaptation is an arrangement in which mechanisms laying a lower level of organization, by their operations and interaction with the environment, enable creation of mechanisms lying at a higher level of organization. When such an organizational advance of a system occurs, it is called a traverse. A case of traverse is when plasticity mechanisms (at a lower level of organization), by their operations, create a neural network anatomy (at a higher level of organization). Another case is the actual production of behavior by that network, whereby the mechanisms of neuronal activity operate to create motor actions. Practopoietic theory explains why the adaptability of a system increases with each increase in the number of traverses. With a larger number of traverses, a system can be relatively small and yet, produce a higher degree of adaptive/intelligent behavior than a system with a lower number of traverses. The present analyses indicate that the two well-known traverses – neural plasticity and neural activity – are not sufficient to explain human mental capabilities. At least one additional traverse is needed, which is named anapoiesis for its contribution in reconstructing knowledge, e.g., from long-term memory into working memory. The conclusions bear implications for brain theory, the mind-body explanatory gap, and developments of artificial intelligence technologies.

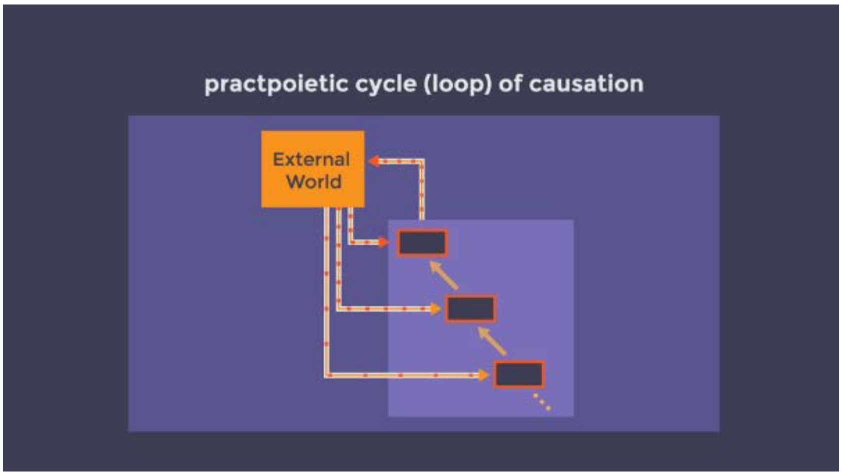

Figure: Illustration of the interactions among different levels of organization in adapative systems. The key to the interactions is the feedback from the environment.

Related publications in 2014:

1) D. Nikolić, *Practopoiesis: Or how life fosters a mind*, arXiv:1402.5332 [q-bio.NC] (2014)
2) D. Nikolić, *Practopoiesis: How cybernetics of biology can help AI*, Singularity Weblog (2014)

Pattern recognition with attentional bias based on oscillatory coherence between excitatory activity and inhibitory minima

Collaborators: Thomas Burwick[1] and Sebastian Blaes[1]

[1] Frankfurt Institute for Advanced Studies

Attention to an object requires, firstly, that the brain selects incoming stimuli that are grouped into a representation of the attended object and, secondly, distracting stimuli have to be suppressed. So far, the mechanisms that realize attention are not known. Recently, however, increasing evidence was found that these mechanisms are related to oscillations of cortical activity in the gamma range (30-90 Hz); see the review in (Womelsdorf and Fries, 2011). With the present research project, we consider theoretical models that may elucidate how the observed oscillations are related to the described attentional selection and suppression processes.

There are two main motivations to study such models. On one hand, we want to use neurophysiological insight to improve on computational intelligence models by allowing the latter to use the brain-like mechanisms. On the other hand, implementing information processing capabilities with neurophysiologically inspired oscillatory dynamics may also shed light on the functionality of the observed brain processes.

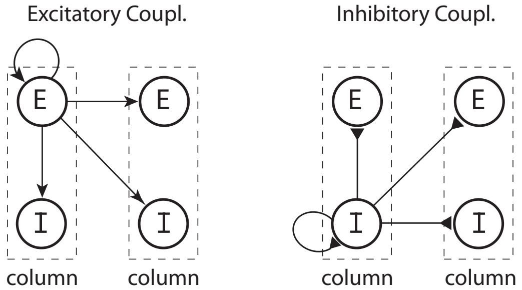

Figure 1: The considered model is an oscillatory neural network model that uses a columnar-like architecture for the couplings between excitatory (E) and inhibitory (I) units. The figure illustrates the excitatory (left panel) and inhibitory (right panel) couplings that are involved with respect to effects of one column on another. The couplings between excitatory units are assumed to be Hebbian, thereby implementing memory of stored patterns.

Given the gamma oscillation phenomena that were observed in neurophysiological experiments (Fries et al., 2001), it is natural to choose an appropriate oscillatory network model to implement the attentional processes. Attending to an object is a process that is also interwoven with recognizing this object. Correspondingly, we built our considerations of the attentional mechanisms on an oscillatory network model that implements perceptual, that is, pattern recognizing dynamics (Burwick, 2011). Going beyond the earlier work, we include a concept of attentional focus that defines the attended object. Thereby, the model is also an extension of an earlier model that introduced a competition for coherence among stored patterns (Burwick, 2007, 2008) as an essential ingredient of pattern recognizing dynamics. Such a dynamics implements the binding process based on temporal coding and may overcome the fundamental so-called superposition catastrophe (Burwick, 2014). When implementing the attentional focus, we consider both spatial attention and feature-based attention.

We succeeded in demonstrating that oscillatory mechanisms may implement an attentional bias. Neurophysiological observations found spike-field coherence as a neural substrate of attention (Fries et al., 2001, Bichot et al., 2005, Womelsdorf et al., 2006). Correspondingly, we implemented this attentional bias as coherence between excitatory activity and inhibitory minima. This reflects the observed coherence between spikes and local field potential (LFP). Recently, additional analysis of the neurophysiological data separated different spiking behaviors with respect to excitatory and inhibitory neurons (Vinck et al., 2013). Our modeling results indicate that the observed correlation between high firing rates and strong synchronization in case of attention (Vinck et al., 2013) point to an essential mechanism to realize the brain's ability to select and bind stimuli into the perception of the attended objects, while suppressing influences from distracting stimuli.

Related publication:

1) T. Burwick, *The Binding Problem*, WIREs Cognitive Science, 2014. 5(3), 305-315 (doi: 10.1002/wcs.1279)
2) S. Blaes and T. Burwick, *Attentional Bias through Oscillatory Coherence between Excitatory Activity and Inhibitory Minima*, Neural Computation, 2015, accepted for publication

Selective synchronization through frequency spread and cross-frequency couplings

Collaborators: Thomas Burwick[1] and Alexandros Bouras[1]

[1] Frankfurt Institute for Advanced Studies

The communication-through-coherence (CTC) hypothesis (Fries, 2005) states that interareal communication is controlled by mutual coherence between different sites: sending and receiving groups of neurons may communicate effectively in case of coherent and phase-locked oscillations at these sites. Experimental evidence for this hypothesis has been found in neurophysiological experiments by Womelsdorf et al. (2007) and Bosman et al. (2012). The former experiment concentrated on linking phase-differences to attentionaly controlled gating of information flow, while the latter extended the results to reporting the obervation of a shift towards higher gamma frequency for the activation resulting from the attended stimulus. Our research project studies the functional relevance of the observed phenomena from a modeling perspective.

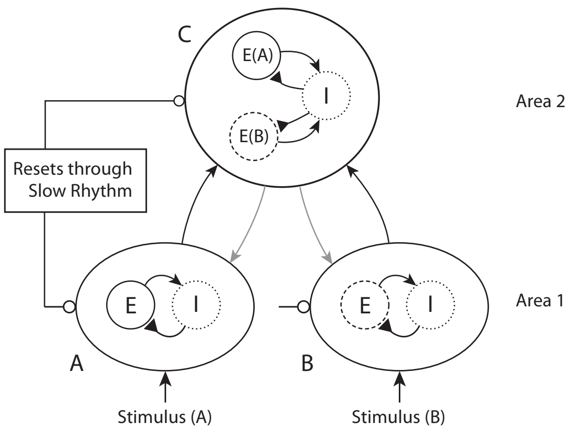

Figure 1: In accordance with the experimental situation, we consider two stimuli that imply separate activations (sites A and B) in an early area (for example, area V1) and activation at a site C in a receiving later area (for example, area V4). We model the observed dynamics through networks of excitatory (E) and inhibitory (I) spiking neurons.

The present research project concentrates on considering a mechanism proposed by Bosman et al. (2012). This mechanism relies on different frequencies of the sending sites. In that respect, consider the situation illustrated with figure 1, where two sending sites (A and B) in one area connect to a receiving site (C) in another area. Here, we assume that there are two stimuli, where A and B each receive only input from one of the stimuli, while site C receives input from both. It was reported already in 1985 (Moran and Desimone) that attention to one of the stimuli gates its information towards the receiving site as if the non-attended stimulus would not be present. The recent proposals related this phenomena to coherence between sites A and C (if attention is on the corresponding stimulus) and lack of coherence for the non-attended stimulus B.

With respect to the attended stimulus, Bosman et al. (2012) observed a shift towards gamma frequency at the attended site (for example, A in V1). Motivated by these observations, they proposed that this shift and the resulting frequency spread in comparison to the activation through the non-attended stimulus have functional relevance for mechanistically gating the information flow. Another ingredient for understanding the relevance of the frequency shifts is the low-frequency (theta rhythmic) resetting process that was observed before (Bosman et al., 2009). Following this reset, the higher frequency of the attended stimulus' activity implies that attended stimulus excites the receiving neurons earlier than the non-attended stimulus. In consequence, also the inhibitory activity at the receiving site C is excited and the signal from the non-attended site B arrives only when inhibition at C is already present, leading to a suppression of the activity that would encode the non-attended stimulus.

Earlier models concentrated on the presence of phase-shift as these were observed by Womelsdorf et al. (2007). Concentrating on the more recent observations by Bosman et al. (2012), we have been able to model essential aspects of the proposed mechanistic role of the frequency shifts in combination with the low-frequency resetting process. The model was implemented with networks of spiking neurons.

Related publication:

1) T. Burwick, *The Binding Problem*, WIREs Cognitive Science, 2014. 5(3), 305-315 (doi: 10.1002/wcs.1279)
2) T. Burwick and A. Bouras, *Selective Interareal Synchronization Through Different Gamma-Frequencies and Theta-Rhythmic Gamma-Phase Reset*, in preparation

4.3 Biology, Chemistry, Molecules, Nanosystems

Passive mechanical forces control cell-shape change during *Drosophila* ventral furrow formation

Oleg Polyakov[1], Bing He[2], Michael Swan[2], Joshua W. Shaevitz[1], Matthias Kaschube[4], and Eric Wieschaus[2,3]

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During epithelial morphogenesis, internally generated forces drive an initial monolayer of epithelial cells to fold, transforming it into complex shapes with remarkable spatial and temporal precision. This process often involves a combination of localized, active force generation in the epithelial sheet and the passive mechanical responses to these forces.

During Drosophila gastrulation, the ventral mesodermal cells constrict their apices, undergo a series of coordinated cell-shape changes to form a ventral furrow (VF) and are subsequently internalized (see Fig.). Although it has been well documented that apical constriction is necessary for VF formation, the mechanism by which apical constriction transmits forces throughout the bulk tissue of the cell remains poorly understood. In this work, we develop a computational vertex model to investigate the role of the passive mechanical properties of the cellular blastoderm during gastrulation. We introduce to our knowledge novel data that confirm that the volume of apically constricting cells is conserved throughout the entire course of invagination. We show that maintenance of this constant volume is sufficient to generate invagination as a passive response to apical constriction when it is combined with region-specific elasticities in the membranes surrounding individual cells. We find that the specific sequence of cell-shape changes during VF formation is critically controlled by the stiffness of the lateral and basal membrane surfaces. In particular, our model demonstrates that a transition in basal rigidity is sufficient to drive VF formation along the same sequence of cell-shape change that we observed in the actual embryo, with no active force generation required other than apical constriction.

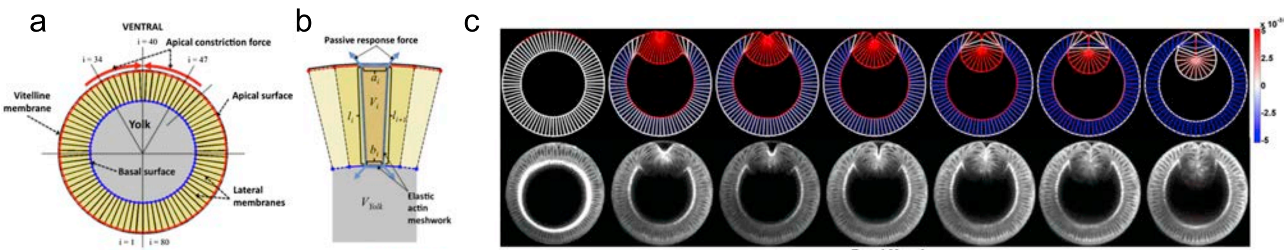

Figure: **a** Vertex model of the cross section of the Drosophila embryo at the end of cellularization. The model is composed of 80 cells connected in a ring that surrounds the yolk. The cells in the ventral region are subjected to apical contractile stress. **b** Each cell is defined to be a unit of cytoplasmic volume V_i surrounded by the apical, lateral, and basal membrane surfaces. The rigidity of the membranes and the constant volume maintenance of V_i respond passively to the apical contractile stress to drive the cell-shape change. **c** Model simulation of furrow invagination (top) and experimental data (bottom). The first frame is the starting configuration. Subsequent frames are energy-minimum states, obtained by adiabatically reducing the basal stiffness. The color bar shows normalized passive forces. Red corresponds to stretching forces and blue to compression forces.

Related publication:

O. Polyakov, B. He, M. Swan, J.W. Shaevitz, M. Kaschube, E. Wieschaus, *Passive mechanical forces control cell-shape change during Drosophila ventral furrow formation*, Biophys J. 107, 998-1010 (2014)

Automated detection of circulating tumor cells with naive bayesian classifiers

Collaborators: Carl-Magnus Svensson[1,2], Solveigh Krusekopf[3], Jörg Lücke[2,4,5], Marc Thilo Figge[1,2,6]

[1] Applied Systems Biology, Leibniz Institute for Natural Product Research and Infection Biology, Hans Knöll Institute (HKI), Jena, [2] Frankfurt Institute for Advanced Studies, [3] GILUPI GmbH, Potsdam, [4] Cluster of Excellence Hearing4all and Department of Medical Physics and Acoustics, School of Medicine and Health Sciences, University of Oldenburg, [5] Faculty for Electrical Engineering and Computer Science, Technical University Berlin, [6] Friedrich Schiller University, Jena

Personalized medicine is a modern healthcare approach where information on each person's unique clinical constitution is exploited to realize early disease intervention based on more informed medical decisions. The application of diagnostic tools in combination with measurement evaluation that can be performed in a reliable and automated fashion plays a key role in this context. As the progression of various cancer diseases and the effectiveness of their treatments are related to a varying number of tumor cells that circulate in blood, the determination of their extremely low numbers by liquid biopsy is a decisive prognostic marker. To detect and enumerate circulating tumor cells (CTCs) in a reliable and automated fashion, we apply methods from machine learning using a naive Bayesian classifier (NBC) based on a probabilistic generative mixture model. Cells are collected with a functionalized medical wire and are stained for fluorescence microscopy so that their color signature can be used for classification through the construction of Red-Green-Blue (RGB) color histograms (Figure 1). Exploiting the information on the fluorescence signature of CTCs by the NBC does not only allow going beyond previous approaches but also provides a method of unsupervised learning that is required for unlabeled training data. A quantitative comparison with a state-of-the-art support vector machine, which requires labeled data, demonstrates the competitiveness of the NBC method.

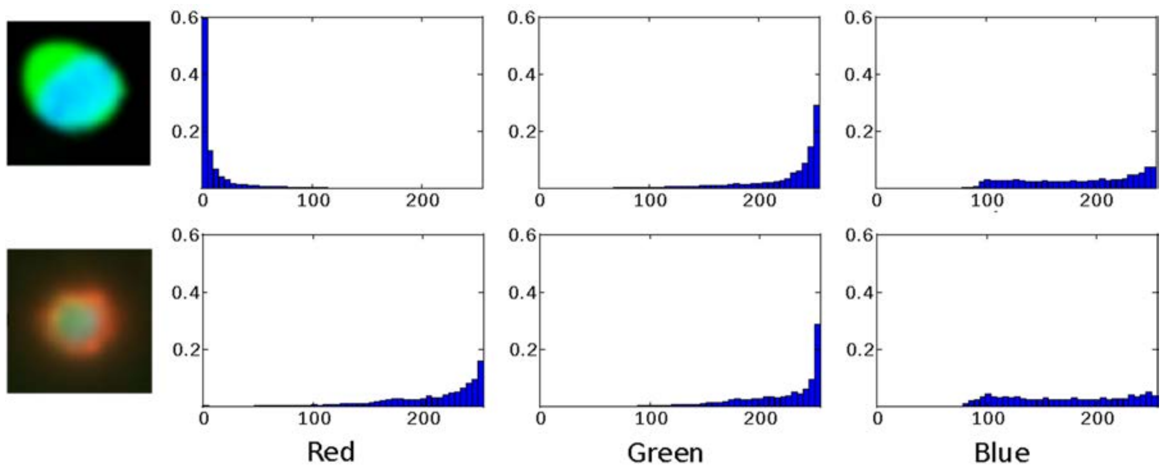

Figure 1: Examples of two cells that are captured by the functionalized medical wire and their respective RGB histograms. CTCs are those cells that exhibit co-localized nuclear (blue) and anti-EpCAM (green) staining (top row). Cells are also counter stained for normal blood cell specific CD45 (red) to distinguish them from CTCs. RGB histograms for a normal blood cell can occur in very different variations and a typical example is shown in the bottom row. The histograms are the basis for classification using both the naive Bayesian classifier (NBC) and the support vector machine (SVM).

Related publication in 2014:

1) Carl-Magnus Svensson, Solveigh Krusekopf, Jörg Lücke, Marc Thilo Figge, *Automated detection of circulating tumor cells with naive Bayesian classifiers*, Cytometry A 85(6), 501-511 (2014)

Monte Carlo modeling of therapeutic ion-beams

Collaborators: Lucas N. Burigo[1,2], Igor A. Pshenichnov[1,3], Igor N. Mishustin[1,4], Marcus Bleicher[1,2]

[1] Frankfurt Institute for Advanced Studies, [2] Institut für Theoretische Physik, Goethe University, Frankfurt am Main, Germany, [3] Institute for Nuclear Research, Russian Academy of Sciences, Moscow, Russia, [4] Kurchatov Institute, Russian Research Center, Moscow, Russia

Patients with localized tumours have been successfully treated in ion-beam cancer therapy applying beams of accelerated protons and carbon ions. Such beams allow to deliver a high dose to the target volume while minimizing the dose to healthy tissues. However, it has still to be answered which specific cases benefit more from a given projectile. Besides, other light nuclei can be also considered as possible therapy options.

The Monte Carlo method is a powerful tool to describe the interactions of ion beams with matter and investigate the irradiation conditions for different treatment scenarios. The Monte Carlo model for Heavy-Ion Therapy (MCHIT) based on the Geant4 toolkit was created in FIAS for simulation of complex radiation fields in ion-beam cancer therapy. MCHIT takes into account fragmentation of beam nuclei leading to secondary particles with their radiobiological properties different from primary nuclei. MCHIT has been coupled with the modified Microdosimetric Kinetic (MK) model (Kase et al. 2006) to investigate the radiobiological properties of different ion beams.

RBE, biological dose distributions and cell survival fraction for beams of protons, helium, lithium, carbon and oxygen ions have been calculated using MCHIT+MK model [1,2]. Figure 1 shows the response of human salivary gland (HSG) cells irradiated by proton, helium, carbon, and oxygen beams optimized to yield 10% cell survival at a 6 cm-wide spread-out Bragg peak (SOB) located at depth of 100–160 mm. Distributions of cell survival in the case of a deeper tumor and 50% cell survival at SOBP is shown in Fig. 2. Results indicate that helium beam reduces the damage to healthy tissues located in front of the tumor compared to other ions. It provides better dose conformation and higher RBE in the tumour compared to protons, while it leads to a reduced fragmentation tail compared to carbon ions. Results indicate that helium beam is a promising option for ion-beam therapy in the future.

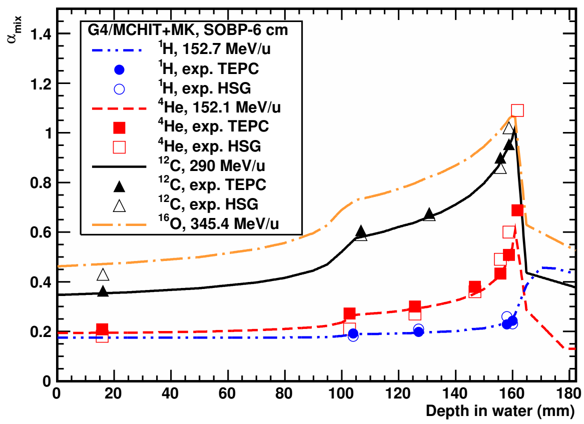

Figure 1: Estimation of LQ-model parameter α for HSG cells irradiated by proton, helium, carbon, and oxygen ions estimated by MCHIT+MK model [2]. Experimental data from Kase et al. 2006.

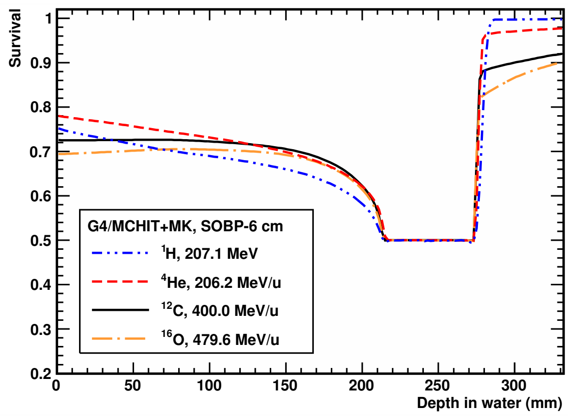

Figure 2: Survival fraction of HSG cells irradiated by proton, helium, carbon, and oxygen ions estimated by MCHIT+MK model [2].

Related publications in 2014:

1. L. Burigo, I. Pshenichnov, I. Mishustin, and M. Bleicher, *Microdosimetry spectra and RBE of ^{1}H, ^{4}He, ^{7}Li and ^{12}C nuclei in water studied with Geant4*, Nucl. Instrum. Meth. B 320, 89–99 (2014)

2. L. Burigo, I. Pshenichnov, I. Mishustin, and M. Bleicher, *Comparative study of dose distributions and cell survival fractions for ^{1}H, ^{4}He, ^{12}C, and ^{16}O beams using Geant4 and Microdosimetric Kinetic model* arXiv:1403.7929 [physics.med-ph]. Manuscript submitted for publication (2014)

Diffusion processes in nanostructured materials

Collaborators: G.B. Sushko[1], A.V. Verkhovtsev[1], S. Schramm[1], A.V. Solov'yov[2]

[1] Frankfurt Institute for Advanced Studies, [2] MBN Research Center, Frankfurt

Short description: We investigated the diffusion process occurring at various interfaces of nanostructured titanium. Investigation of diffusion in the nanocrystalline titanium is of a significant importance because of its numerous technological applications.

Main results: By means of classical molecular dynamics (MD) simulations, we investigated the process of self-diffusion in a nanostructured sample of crystalline titanium [1]. The analysis was carried out for a nanoscale cylindrical sample consisting of three adjacent sectors and various junctions between nanocrystals. Because of the chosen geometry of the sample, we specified five characteristic regions, namely, the sample's crystalline interior, double and triple junctions, surface of the sample, and its edge (see Fig. 1).

On the basis of the performed simulations, we evaluated the temperature dependence of the self-diffusion coefficient of titanium atoms with respect to their location in the sample in a broad temperature range (see Fig. 2). The calculated diffusion coefficient varies by several orders of magnitude for different regions of the sample. The calculated values of the bulk diffusion coefficient correspond reasonably well to the experimental data obtained for solid and molten states of titanium.

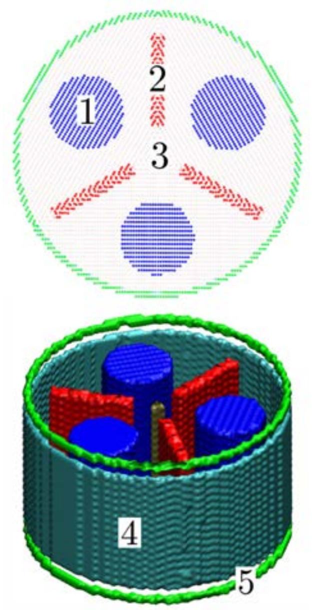

Fig. 1: Five regions of the titanium sample where different types of diffusion were studied [1]. We considered diffusion in bulk material (blue area/1), on double and triple junctions (red/2 and dark-yellow/3 regions, respectively) as well as diffusion on the surface (dark-green area/4) and border (light-green area/5) regions of the sample.

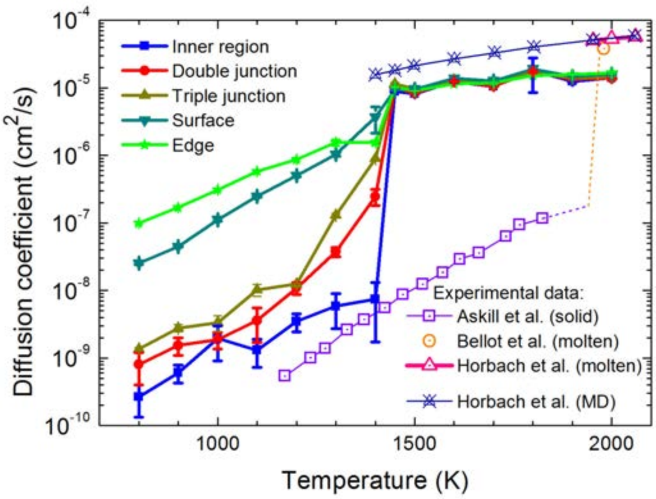

Fig. 2: Temperature dependence of the self-diffusion coefficient of titanium atoms calculated for different regions of the nanostructured sample [1]. Blue squares correspond to the bulk diffusion studied in the inner region of each sector, and red squares and dark-yellow triangles illustrate the results obtained for the case of double and triple junctions, respectively. The diffusion coefficients calculated for atoms located on the surface and the edge of the sample are shown by dark-green triangles and light-green stars, respectively. The results of present MD simulations were compared with experimental data of Askill *et al.* [Phys. Stat. Sol. B 11, 557 (1965)] (solid state), Bellot *et al.* [Metall. Mater. Trans. B 28, 1001 (1997)] (molten state), and Horbach *et al.* [Phys. Rev. B 80, 212203 (2009)] (molten state) as well as with the results of MD simulations by Horbach et al.

Related publications in 2014:

1) G.B. Sushko, A.V. Verkhovtsev, A.V. Yakubovich, S. Schramm, and A.V. Solov'yov: *Molecular dynamics simulation of self-diffusion processes in titanium in bulk material, on grain junctions and on surface*, J. Phys. Chem. A 118, 6685–6691 (2014)

Stability and growth of carbon nanotubes

Collaborators: A.V. Verkhovtsev[1], G.B. Sushko[1], S. Schramm[1], A.V. Solov'yov[2]

[1] Frankfurt Institute for Advanced Studies, [2] MBN Research Center, Frankfurt

Short description: In spite of intensive research and a huge amount of experimental information, the physical mechanisms leading to the catalytically-assisted carbon nanotube growth remain a highly debated issue. The aim of this study was to investigate the process of the carbon nanotube stabilization on a catalytic nickel nanoparticle by means of classical molecular dynamics (MD) simulations.

Main results: The stability of a single-walled carbon nanotube placed on top of a catalytic nickel nanoparticle was investigated by means of MD simulations. As a case study, we considered the $(12,0)$ nanotube consisting of 720 carbon atoms and the icosahedral Ni_{309} cluster [1]. An explicit set of constant-temperature simulations was performed in order to cover a broad temperature range from 400 to 1200 K, at which a successful growth of carbon nanotubes has been achieved experimentally by means of chemical vapor deposition.

We also analyzed the stability of the system depending on parameters of the involved interatomic interactions. It was demonstrated that different scenarios of the nanotube dynamics atop the nanoparticle are possible depending on the parameters of the Ni-C potential. When the interaction is weak the nanotube is stable and resembles its highly symmetric structure, while an increase of the interaction energy leads to the abrupt collapse of the nanotube in the initial stage of simulation (see Fig. 1). In order to validate the parameters of the Ni-C interaction utilized in the simulations, density-functional theory (DFT) calculations of the potential energy surface for carbon-nickel compounds were performed (see Fig. 2). The calculated dissociation $D_e^{\mathrm{Ni-C}}$ energy of the Ni-C bond is in good agreement with the values, which correspond to the case of a stable and not deformed nanotube simulated within the MD approach.

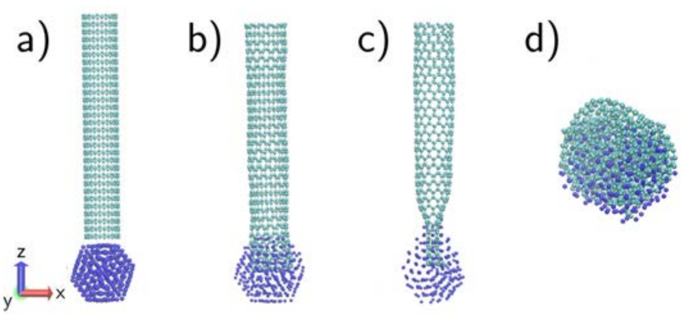

Fig. 1: Evolution of the nanotube structure on top of the Ni_{309} nanoparticle at T = 400 K [1]. Panel (a) shows the initial structure of the system. Panels (b), (c) and (d) illustrate snapshots of the system after 5 ns of simulation at different values of the binding energy between Ni and C atoms: (b) $D_e^{\mathrm{Ni-C}} = 0.2$ eV: the nanotube placed atop the nanoparticle is stable and resembles its original structure; (c) $D_e^{\mathrm{Ni-C}} = 0.8$ eV: the nanotube is stable but the structure of both the nanotube and the nanoparticle is strongly deformed; (d) $D_e^{\mathrm{Ni-C}} = 2.4$ eV: the nanotube is unstable and collapses just after the simulation starts.

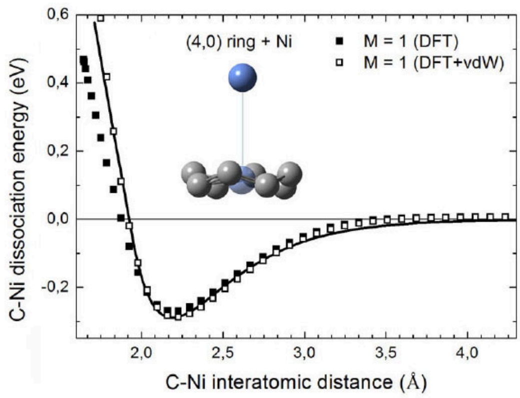

Fig. 2: Dependence of the Ni–C bond dissociation energy on the interatomic distance for the case of the "Ni-carbon ring" system. Open symbols illustrate the results of DFT calculations performed at B3PW91/AUG-cc-pVTZ level of theory, corrected by the van der Waals potential. Solid curves represent fitting of the obtained dependencies with the pairwise Morse potential. The potential energy curve obtained from the DFT calculations without the van der Waals-type correction is shown by filled squares. *M* stands for multiplicity of the system.

Related publications in 2014:

1) A.V. Verkhovtsev, S. Schramm, and A.V. Solov'yov: *Molecular dynamics study of the stability of a carbon nanotube atop a catalytic nanoparticle*, Eur. Phys. J. D 68, 246-(1-11) (2014)

4.4 Scientific Computing, Information Technology

The L-CSC cluster at GSI for Lattice QCD - The most power efficient supercomputer in the world in 2014

Collaborators: David Rohr[1,3], Gvozden Neskovic[1,2], Volker Lindenstruth[1,2,3]

[1] Frankfurt Institute for Advanced Studies, [2] GSI Helmholtz Centre for Heavy Ion Research, [3] Goethe University Frankfurt

The L-CSC (Lattice Computer for Scientific Computing) is a new compute cluster installed at GSI dedicated to Lattice-QCD calculations in the field of Quantum Chromo Dynamics (QCD). QCD is the physical theory describing the strong force, one of the four fundamental interactions in physics. Lattice-QCD (LQCD) is a numerical approach to compute QCD problems, and it is the only general a priori approach available today. LQCD has extreme demands for memory bandwidth in order to produce results in a reasonable timeframe.

The L-CSC supercomputer was developed at FIAS, which also carried out the assembly and the installation. Due to the demands of LQCD, the development laid particular focus on memory bandwidth and on power efficiency. Modern GPUs, which can work as a coprocessor in todays compute clusters, offer both: high memory bandwidth and great power efficiency. Accordingly, FIAS selected an architecture with four GPUs per compute node for L-CSC. This puts high emphasis on GPU computations, while the CPU is merely used for data movement. The L-QCD application for L-CSC uses OpenCL and is hence vendor-independent. It was developed at FIAS in the last years and is also used on the LOEWE-CSC and SANAM clusters.

In order to demonstrate the power efficiency of L-CSC, the HPL-GPU implementation of the Linpack benchmark, was tuned for the particular hardware. This tuned version attempts to distribute the workload between CPU and GPU such, that it is executed most efficiently - and not necessarily as fast as possible. The cluster thus operates slightly slower, but significantly more efficient [1]. In addition to the software, the processor parameters such as voltage and frequency have been tuned to operate at the optimal working point with respect to efficiency. HPL-GPU was already employed on the LOEWE-CSC and SANAM clusters and achieved the 8th and the 2nd place in the Green500 lists of the most power efficient supercomputers in the world in 2010 and 2012. With the new power efficient quad-GPU architecture, and with the new HPL-GPU features aimed at improving power efficiency, L-CSC achieved the top spot of the Green500 list in November 2014 with 5293 GFLOPS/W.

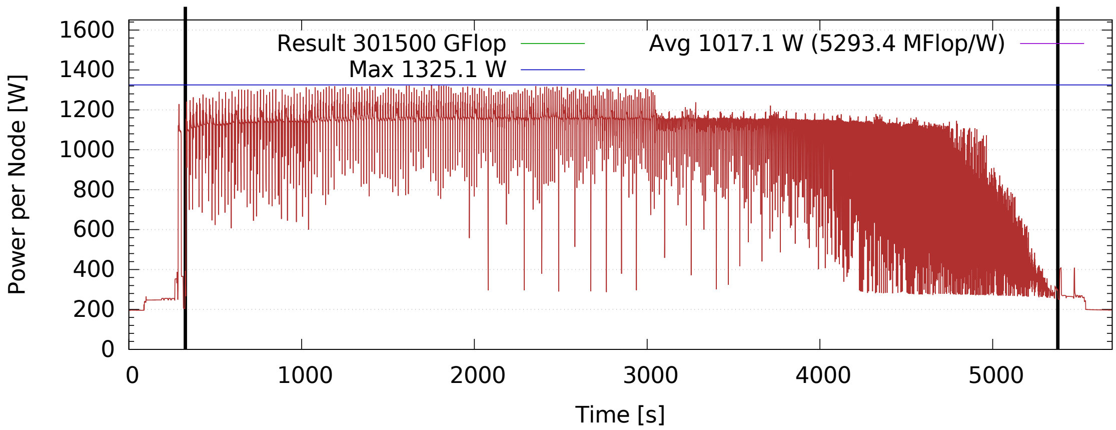

Figure 1: Power measurement of L-CSC during the Linpack run submitted to the Green500 list. The run utilized 56 nodes, the curve shows the average power per node. The final result submitted to the list is 302 TFLOPS with an efficiency of 5293.4 GFLOPS/W. This placed L-CSC 1st in the Green500 list of November 2014.

Related publications in 2014:

1) D. Rohr, S. Kalcher, M. Bach, A. Alaqeeli, H. Alzaid, D. Eschweiler, V. Lindenstruth, A. Sakhar, A. Alharthi, A. Almubarak, I. Alqwaiz, and R. Bin Suliman, *An Energy-Efficient Multi-GPU Supercomputer*, Proceedings of the 16th IEEE International Conference on High Performance Computing and Communications, HPCC 2014, Paris, France. IEEE, 2014

Efficient and fault-tolerant device drivers for supercomputers

Collaborators: Dominic Eschweiler[1,2], Volker Lindenstruth[1,2,3]

[1] Frankfurt Institute for Advanced Studies, [2] Goethe University, Frankfurt, [3] GSI, Darmstadt

Microkernel operating systems run most subsystems as a user-space application. The related term microdriver refers to a driver which run entirely inside the user space. Microdrivers can already drive low speed (USB) and high latency (file systems) applications. Besides a range of advantages, such as fault tolerance and programmability, microdrivers are commonly considered to be slow. The focus of our work is the construction of microdrivers which can drive high-speed and low-latency PCI-devices in high performance computing environments. In [1] we show how most parts of such a driver can work in the user space, leaving a small adapter in the kernel space of Linux. The result is a software library called PDA (**P**ortable **D**river **A**rchitecture) for programming microdrivers of PCI devices. Additionally, we evaluate our concept by using real world hardware [2] - the CRORC (**C**ommon **R**ead **O**ut **R**eceiver **C**ard), which is productively used at a CERN in a high throughput real time application.

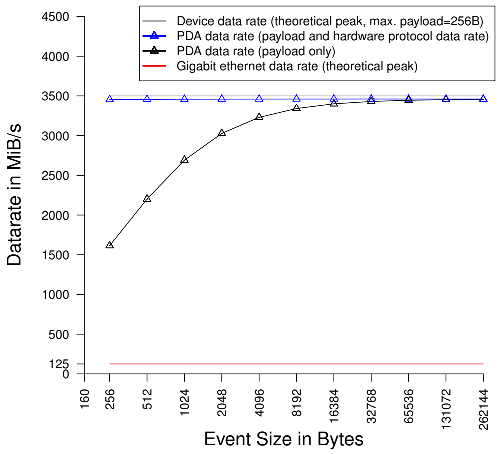

Figure 1: DMA data rate of a CRORC driven by a PDA-based device driver.

Figure 1 shows the results of measurements for which we used a CRORC driven by a PDA-based microdriver. The x-axis shows marks for each measurement for a specific event size and the y-axis outlines the achieved data rate. The gray plot outlines the theoretical peak performance the CRORC can achieve (3.5 GiB/s). A blue line shows the data rate including hardware protocol overhead, which is the real data rate achieved between host and device. The main reason why the payload data rate drops for smaller package sizes is that the device sends an event descriptor for each event into the memory. Transmitting such descriptors also consumes PCIe bandwidth which decreases the payload data rate for smaller event sizes (because more event descriptors are sent). It needs to be mentioned that this is a physical hardware limitation which software cannot compensate. Furthermore, we included the theoretical peak data rate (125 MiB/s, red line) of a gigabit ethernet adapter for a comparison. Such network adapters were used in most cases to evaluate other microdriver concepts.

The results show that the PDA is able to drive fast interconnect boards as they are used in supercomputers without any performance degradation. In Eschweiler et al. [1] we also present a deeper overhead analysis which shows that the overhead of our library is negligible.

Related publications in 2014:

1) Dominic Eschweiler, Volker Lindenstruth, *The Portable Driver Architecture*, 16th RTLWS, 2014

2) Andrea Borga, Filippo Costa, Gordon Crone, Heiko Engel, Dominic Eschweiler, David Francis, Barry Green, Markus Joos, Udo Kebschull, Tamas Kiss, Andreas Kugel, William Panduro Vazquez, Csaba Soos, Pedro Teixeira-Dias, Louis Tremblet, Pierre Vande Vyvre, Wainer Vandelli, Jos Vermeulen, Per Werner, Fred Wickens, *The C-RORC PCIe Card and its Application in the ALICE and ATLAS Experiments*, TWEPP 2014

Microdriver Support for Large DMA-Buffers

Collaborators: Dominic Eschweiler[1,2], Volker Lindenstruth[1,2,3]

[1] Frankfurt Institute for Advanced Studies, [2] Goethe University, Frankfurt, [3] GSI, Darmstadt

DMA (**D**irect **M**emory **A**ccess) devices can read and write into the computer's memory without the help of the main processor. By being decoupled from the virtual memory of the operating system, such a device must manage memory accesses by itself. Therefore, the most DMA-devices can only handle consecutive physical memory buffer. A device must provide a hardware-based scatter/gather-DMA engine if larger buffers are required. Such hardware implementations are redundant and error prone and we therefore integrated a virtual memory scheme for devices [1] into the PDA [1] which makes use of virtualization extensions of modern CPUs (IOMMU - I/O Memory Management Unit). Figure 2 shows a comparison of the buffer fragmentation with IOMMU (red) and without IOMMU (blue, black). A scatter/gather list (SGL) stores a pointer to each fragment of the related buffer. The higher the fragmentation of the DMA-buffer is, the more entries has the corresponding SGL. The results show that the IOMMU-enabled PDA maps the buffers consecutively in all cases.

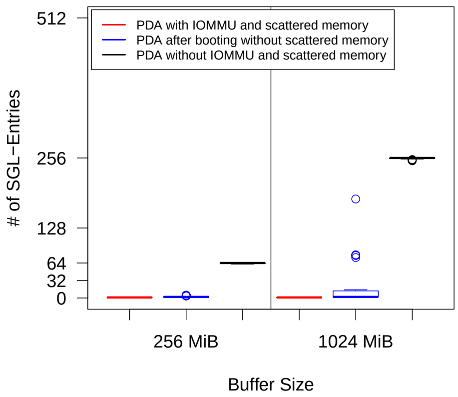

Figure 2: Number of scatter/gather list entries needed for referencing a DMA buffer, with and without an IOMMU.

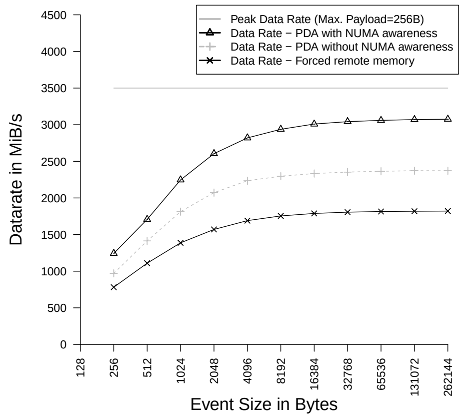

Figure 3: DMA data rate of a CRORC driven by a PDA-based device driver with and without NUMA awareness.

We also show in [1] how the memory management of the PDA can support large DMA buffers in **C**ache **C**oherent - **N**on **U**niform **M**emory **A**ccess (**CC-NUMA**) machines. A NUMA machine has different memory locations, which means that a non-optimal placing can degrade the throughput between device and memory, or between memory and driver process. In general the best way for placing DMA memory buffer and driver process is to locate both to the device connecting CPU-socket. Therefore, we adapted the PDA for finding the best location and for automatically pinning memory and process to that CPU socket. Figure 3 shows the results of the related throughput tests taken on a NUMA machine with two sockets. The black line with crossed dots shows the performance of a CRORC if the DMA memory is entirely allocated on the remote socket. In this case the CRORC achieves worst performance. In contrast the NUMA-aware PDA always pins driver processes and DMA memory automatically to the socket which connects the related device. The black line with the triangle points represents the measurement with a NUMA-aware PDA. This test shows that the PDA automatically allocates the needed DMA buffers to the right socket. The NUMA-aware PDA achieves up to ≈ 1 GiB/s more throughput than before.

Related publications in 2014:

1) Dominic Eschweiler, Volker Lindenstruth, *Efficient Management of Large DMA Memory Buffers in Microdrivers*, ICPADS 2014 (IEEE), 2014.

[1] Please refer to the report "Efficient and Fault-Tolerant Device Drivers for Supercomputers" for further information

Real time track reconstruction on GPU for the ALICE High Level Trigger in OpenCL

Collaborators: David Rohr[1,2], Sergey Gorbunov[1,2], Volker Lindenstruth[1,2]

[1] Frankfurt Institute for Advanced Studies, [2] Goethe University Frankfurt

The Large Hadron Collider (LHC) at the European Center for Particle Physics (CERN) is the most powerful particle accelerator today. Its main purpose is the search for rare particles such as the Higgs boson and the study of hadronic matter under extreme temperature and density. The ALICE Detector (A Large Ion Collider Experiment) is designed specifically for the second case.

The High Level Trigger (HLT) is an online compute farm installed at ALICE. It is capable of performing a full reconstruction of the detected events in real time, it can trigger for physically interesting events such that only relevant events are stored, and it performs on the fly data compression of the incoming raw data. For this purpose, it had to process an incoming data rate of about 25 GB/s.

In 2014 the LHC was switched off during the long shutdown 1 (LS1). During this phase, the experiment is maintained and prepared to operate at full design energy of up to 14 TeV per proton starting from 2015. In addition also the luminosity will increase. This will result in significantly higher data rates for the HLT.

The old cluster was operational for several years and had reached its end of life. Consequently, it was replaced by a new system of around 190 compute nodes.

The reconstruction of particle trajectories (tracking), the most compute intense step of event reconstruction, is performed on GPUs (Graphics Processing Units), which are much more powerful than traditional processors for such parallel tasks. When the tracking algorithm was implemented in 2010, the only feasible GPU framework was NVIDIA CUDA, being the only framework supporting the C++ language. C++ is mandatory as the ALICE analysis framework AliRoot depends on it, and this severely limited the choice of GPU hardware for the HLT.

In the meantime, the OpenCL framework for GPU programming has matured and has evolved to a viable alternative to CUDA. OpenCL is supported by a variety of hardware and not limited to a single vendor like CUDA. Unfortunately, OpenCL does not support C++, but it allows vendors the specification of custom extensions. Advanced Micro Devices (AMD) provides such an extension for C++ support in OpenCL.

The ALICE HLT tracker was thus adapted in order to utilize OpenCL instead of CUDA. It is written in a generic way that encapsulates all the algorithm in a language independent header. There are only framework dependent wrappers which include these headers and contain all the API dependent parts. These headers only represent around 5 % of the source code and most changes to the algorithm affect only the generic header. As a result, all improvement and changes have to be done only once, greatly improving the maintainability. The tracker is thus now operational on CUDA and on OpenCL with C++ extensions, making it vendor independent.

One problem that occurred during OpenCL adaption is that OpenCL distinguishes between different types of pointers, depending on whether the pointer points to global or shared GPU memory. A solution in C++ to this is to use template parameters for the memory type. Unfortunately, this works only for function parameters but not for function return values, because functions differing only by return value cannot overload each other. The solution is a complicated template structure that assigns a memory type qualifier to all objects. When a member function returns a pointer to an object's internal memory, it can automatically return a pointer with the correct qualifier. This template structure is mostly limited to the function declarations, such that modifications to the actual algorithm code are small.

This development enabled a broader hardware choice for the new cluster assembled in 2014. The employed GPU model is the AMD S9000 which has the best cost-performance ratio. The code was tuned for this card and the performance is roughly 10 % better than that of other cards available in the market in the same time frame. In commissioning tests in 2014 the new tracker implementation and the new hardware has proven its stability. The achieved maximum throughput in these tests confirms that the HLT will be able to perform full real time tracking for the highest event rate and event size specified by the ALICE tracking detectors for run 2 starting in 2015.

CBM First-level Event Selector Data Management Developments

Collaborators: Helvi Hartmann, Jan de Cuveland, Volker Lindenstruth

Frankfurt Institute for Advanced Studies, GSI, CBM

The First-level Event Selector (FLES) is a high performance computing cluster functioning as the central event selection system in the CBM experiment. It combines data from a large number of input links to time intervals and distributes them to the compute nodes, via a high-performance network. Simultaneously, the FLES carries out online analyses and complete event reconstruction on the data. Data rates at this point are expected to exceed 1 TByte/s.

The FLES system will consist on one hand of a scalable supercomputer with custom FPGA-based input interface cards and a fast event-building network and will be constructed largely from standard components. On the other hand special developed software allowing to process the incoming data in real-time builds up the FLES. A small scale, highly customizable platform, the Micro-FLES cluster was installed at GSI. Eight identical compute nodes provide a total of 192 logic cores and 512 GB memory plus one head node for infrastructural services. This test system enables studies on the development of the FLES such as elaborating performant software for timeslice building. A *timeslice* is the fundamental data structure managing access to all detector raw data of a given time interval. In addition to existing timeslice building prototype software based on InfiniBand Verbs investigations of a more high-level interface to the network hardware have been performed using MPI. For this purpose a specialized micro benchmark test suite was developed simulating the FLES timeslice building use case. Benchmark results for simultaneous data transfer on the Micro-FLES are displayed in Fig 1. When communication is established only between three nodes, MPI's performance compares to the maximum data rate of point to point communication for Infiniband Verbs (green curve) on the Infiniband-FDR network. However, the data rate decreases by 15% when all eight nodes of the Micro-Fles are participating in an any-to-any communication. Further tests on bigger compute cluster are neccessary to evaluate the achievable data rates for MPI on a big scale and are currently under investigation.

In 2014 the FLES demonstrator system was upgraded signifciantly to the Micro-FLES2. First, the Micro-FLES2 was equipped with the latest Mellanox dual ConnectX-IB HCAs (mlx5), in addition to the existing Mellanox dual ConnectX-3 cards (mlx4). Overall the new cards are faster than the old as shown in Fig. 2. A data rate of 6 GB/s can be achieved using only one of the four ports, already. Furthermore, the new cards feature a 16x PCIe 3.0 interface and therefore allow to saturize the full bandwith of both ports. An accumulated data rate of 18 GB/s can be achieved utilizing all Infiniband ports. With this first upgrade the Micro-FLES2 can send data from node to node three times as fast as before (e.g., 18 GB/s instead of 6GB/s). The improved performance is essential for the development of timesslice building software.

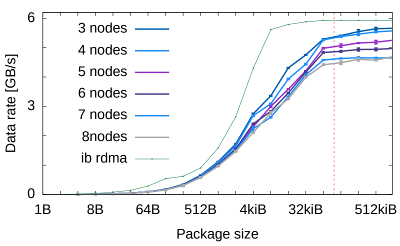

Figure 1: MPI benchmark on the Micro-FLES

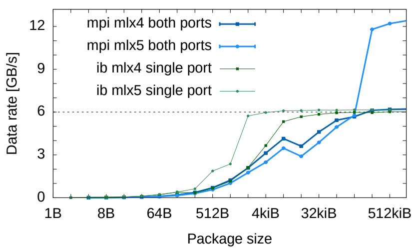

Figure 2: Perfomance tests for the Micro-FLES2..

Secondly, two further Mellanox SX6036 36-port 56Gb/s switches were installed in order to realize different network setups such as a fat tree. This helps investigating routing issues in the development of software when distributing the incoming data. The previous existing switch was connected with full bidirectional bandwidth to both of the new switches making them leaves of a fat tree. All first ports of mlx4 and mlx5 for each node were connected to leaf-switch1 and all second ports to leaf-switch2. Using this setup the network structure and blocking ratio in case of a fat tree can be configured dynamically via the provided internet interface of the switches. The upgraded Micro-FLES2 provides better performance and a greater flexibilty in testing different scenarios allowing to evaluate a greater varity of possibilites for the final system – the FLES.

CBM FLES Input Interface Developments

Collaborators: Dirk Hutter[1], Jan de Cuveland[1], Volker Lindenstruth[1]

[1] Frankfurt Institute for Advanced Studies

The First-level Event Selector (FLES) is the central event selection system in the CBM experiment. Its task is to select data for storage based on online analyses including a complete event reconstruction. To do so, the FLES timeslice building has to combine data from all input links to time intervals and distribute them to the compute nodes. To allow for efficient timeslice building, detector data streams are partitioned into microslices prior to combining them. Microslices are specialized containers covering a constant timeframe of real time, which is the same for all subsystems. This allows data agnostic, subsystem independent timeslice building. This partitioning will be done by the Data Processing Boards (DPB) as they are the last stage of the read-out tree which has to contain subsystem specific components.

The FLES input interface is realized by a custom FPGA PCIe card, the FLES Interface Board (FLIB). Its purpose is to provides the optical interface to the DPBs as well as the interface to the FLES input nodes. The current development is based on the commercial HTG-K7-PCIE board form Hitech Global. It features a Xilinx Kintex-7 FPGA, a 8x PCIe 2.0 interface, up to eight 10 GBit/s links and optionally 8 GB of DDR3 memory. The FPGA design includes the protocol for receiving microslices, a pre-processing engine preparing microslices for timeslice building and a custom full off-load DMA engine. Once configured the DMA engine is capable of constantly transferring microslices and meta data to the PCs memory without involving the host CPU. The only task the CPU needs to perform is to acknowledge processed data segments occasionally to allow reusing buffer space. A measurement of the DMA performance for one to four 10 Gbit/s microslice streams is given in Figure 2. For up to three steams, data is transmitted at full input speed. For four streams, the input data rate exceeds the available PCIe bandwidth. The achieved maximum data rate is 3345 MB/s, which matches the absolute maximum PCIe data rate for the given configuration.

For demonstration and testing the input interface concept in real live applications, the FLIB and flesnet software have been used for read-out in the CERN-PS 2014 testbeam at T9 beamline. In contrast to the final system, current setups lack the DPB layer and do not support the creation of microslices. A specialized FLIB prototype firmware therefore includes a mockup of the DPB design and is capable of directly receiving CBMNet messages as delivered by the CBM front-end electronics. Simplified microslices are generated inside the FLIB and subsequently handled in the same way as foreseen for the final setup. Thus the setup is capable of delivering fully build timeslices to any given consumer. In case of the testbeam, timeslices were written to disk and simultaneously published via a ZMQ socket to CBMroot clients for front-end calibration and online monitoring. In addition the firmware and software includes support for front-end configuration and synchronization over CBMnet which is accessible via a ZMQ interface or from within CBMroot. During the testbeam a single FLIB in conjunction with the flesnet software was successfully used to read-out up to six detector setups in different configurations. Three different flavors of data sources have been employed, Syscore 2, Syscore 3 and TRB boards. Figure 1 shows an overview over five days of data taking. In total 888 GB of data in 84 runs was written to disk without any major read-out related problems. Online performed data consistency checks and first offline analysis did not reveal any issues with the data. To support future setups including DPBs the FLES interface module is currently under development. It will provide a 10 GBit/s link transferring microslices to the FLIB enabling full featured microslice creation on the DPBs.

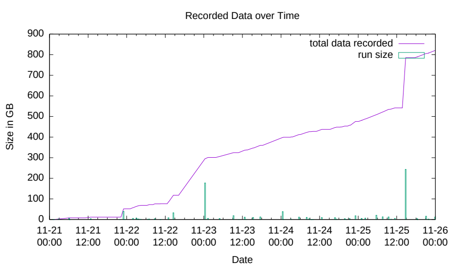

Figure 1: Recorded testbeam data over time

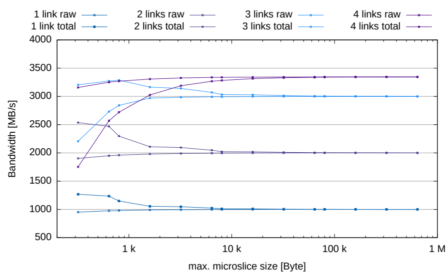

Figure 2: FLIB read-out bandwidth

Readout Upgrade for the ALICE Transition Radiation Detector

Collaborators: Stefan Kirsch[1], Volker Lindenstruth[1]

[1] Frankfurt Institute for Advanced Studies

After a successful Run1 period with Pb-Pb collisions at 2.76 TeV and instant luminosities in the order of $10^{26}/(\mathrm{cm}^2\,\mathrm{s})$, the ALICE experiment at CERN LHC is preparing for the start of Run2, which is going see collisons at 5.5 TeV and peak luminosites of $4 \times 10^{27}/(\mathrm{cm}^2\,\mathrm{s})$.

The ALICE Transition Radiation Detector (TRD) delivers several Level-1 trigger contributions based on the fast online reconstruction of charged particle tracks within few µs after the collision. Global track reconstruction, trigger calculation as well as event buffering and local event fragment building are implemented on the TRD Global Tracking Unit (GTU), a processing system comprised of 109 FPGA-based nodes organized in a three-layer (90-18-1) hierarchy which is connected to the detector front-end at an aggregate bandwidth of 2.6 Tbit/s.

In Run1, a dedicated daughter board, the Source Interface Unit (SIU), constituted the detector-side end point of a link to the data acquisition (DDL) on the each of the 18 GTU's Supermodule Units (SMUs). The SIU operated at 2.125 Gbit/s line rate and limited the available bandwidth for supermodule readout to approx. 190 BiB/s. Simulations (Figure 1) revealed that this is not sufficient to cope with the Run2 target readout rates of up to 500 Hz for a trigger mix of central, semi-central and min. bias collisions, especially when considering increased average event sizes due to the higher multiplicity. In order to benefit from the increase in luminosity and allow for higher readout rates an upgrade of the readout bandwidth is required.

Among several upgrade options considered, a solution where the SIU functionality is integrated into the SMU FPGAs and connected via optical fiber to the recently developed DAQ C-RORC receiver cards is most suitable. It allows to achieve the target readout rate and preserves the current readout format, requiring no changes to the offline processing. Figure 2 sketches the implemented system. One of the previously unused optical transceivers on the SMUs has been employed at a line rate of 4 Gbit/s, which is the limit of the installed hardware. Embedded test infrastructure allows to tune the links in-situ to ensure a high link transmission quality with BERs $< 10^{-14}$. Several optimizations of the GTU data path, buffer stages and a significantly increased SIU core frequency enable a full saturation of the link. As first detector in ALICE using the C-RORC and DDL2 in production, the upgraded system was successfully commissioned in late 2014. 390 MiB/s per DDL2 have been achieved, totalling to an aggregate readout bandwith of 7 GiB/s for the full TRD in Run2.

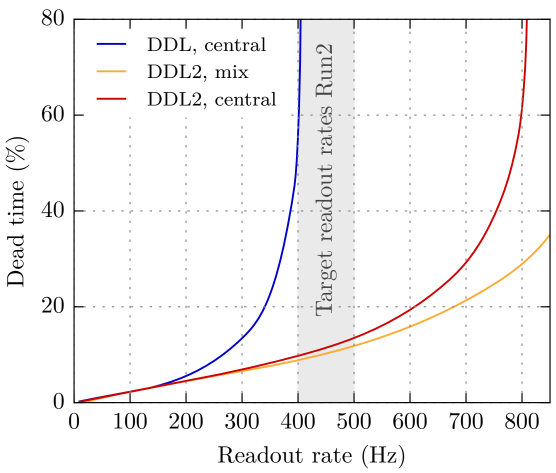

Figure 1: Comparision of the TRD dead time as function of the readout rate (Simulation, 5 % L1/L0 accept ratio) in Run1 (blue) and Run2 (red: central Pb-Pb events, orange: mix central/semi-central).

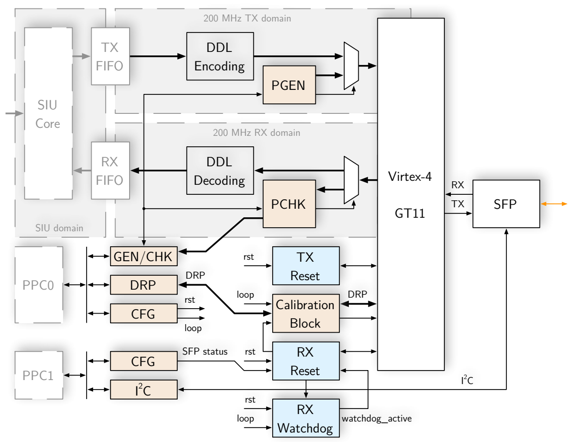

Figure 2: New DDL2 interface and embedded test infrastructure on the SMUs. Integrating SIU functionality more than doubles the effective readout bandwidth compared to Run1 at no additional cost.

Event-by-event extraction of kinetic and chemical freeze-out properties in the CBM experiment

Collaborators: Volodymyr Vovchenko[1,2,3,4], Ivan Kisel[1,2,3], Dmitry Anchishkin[4,5]

[1] GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, [2] Frankfurt Institute for Advanced Studies, [3] Goethe University, Frankfurt, [4] Taras Shevchenko University, Kiev, [5] Bogolyubov Institute for Theoretical Physics, Kiev

The future CBM experiment at FAIR is designed to study properties of strongly interacting matter produced in heavy-ion collisions at high baryon densities. It will employ high intensity beams and large acceptance detectors. One important task is to extract the thermal parameters of matter at stages of kinetic and chemical freeze-out from the observed data. The extraction of thermal parameters is implemented as a package within the CBMROOT framework.

The kinetic freeze-out temperature of charged pions is extracted from their measured momentum spectrum. In the simplest scenario the particles are assumed to have a Boltzmann momentum distribution with no collective radial flow. To test the method, a 1000 Monte Carlo (MC) events with thermally distributed pions ($T = 128$ MeV) were generated and then processed in CBMROOT. Reconstructed STS Tracks, as well as the initial MC Tracks, were used to calculate the average transverse mass of pions $\langle m_T \rangle$, which was then used to estimate the temperature. Due to limited detector acceptance, and due to imperfect reconstruction efficiency, the mean transverse mass of STS tracks differs from the MC one. Therefore, an appropriate correction was performed using the known momentum dependence of acceptance function and reconstruction efficiency. Figure 1 depicts the extracted Boltzmann temperature on the event-by-event level. It is seen that the extracted temperature has a Gaussian-like distribution around the theoretical value of 128 MeV when one uses MC Tracks (blue line) or STS Tracks with proper correction on acceptance (red line). If one neglects this correction on acceptance then one gets essentially different (incorrect) value of temperature (green line).

The parameters of the chemical freeze-out are extracted by fitting the measured particle ratios in the framework of the Hadron Resonance Gas model and using the thermodynamic mean-field approach. All strange and non-strange hadrons which are listed in the Particle Data Tables are included and the model is implemented in CBMROOT. The fit can be performed on event-by-event level and also on the inclusive spectra level. Figure 2 shows the extracted temperature and baryonic chemical potential from MC events generated in the thermal model with $T = 100$ MeV and $\mu_B = 550$ MeV. For each extraction a set of 10 events was used, and the fit error estimates were calculated and depicted as well. The extracted values are consistent with the theoretical input.

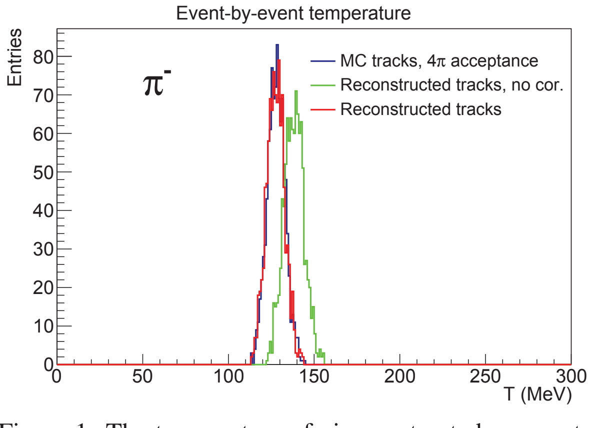

Figure 1: The temperature of pions extracted on event-by-event level using the MC tracks (blue line), STS tracks without acceptance correction (green line), and STS tracks with correction on acceptance (red line).

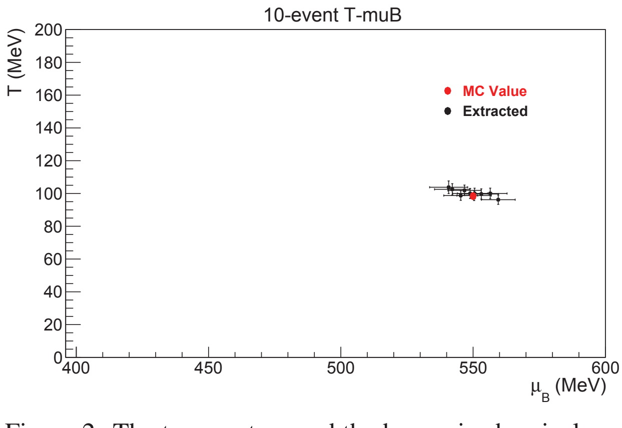

Figure 2: The temperature and the baryonic chemical potential extracted from the 10-event sets in the framework of the Hadron Resonance Gas model. The theoretical MC values is shown by the red dot.

Related publications in 2014:

1) D. Anchishkin, V. Vovchenko, *Mean-field approach applied to relativistic heavy-ion collisions*, arXiv:1411.1444 [nucl-th]

π^0 reconstruction through a γ-conversion method with KF Particle Finder in the CBM experiment

Collaborators: Maksym Zyzak[1,2,3], Ivan Kisel[1,2,3], Iouri Vassiliev[1]

[1] GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, [2] Goethe-Universitaet Frankfurt, [3] Frankfurt Institute for Advanced Studies

The CBM experiment is being designed to study heavy-ion collisions at extremely high interaction rates and track densities. One of the main observables for CBM are light vector mesons decaying through dilepton channels, that are of the particular importance for the physics program of the experiment. Because of the low branching ratio the key issue for reconstruction of light vector mesons is background suppression. Being a major source of this background, π^0 and γ-conversion have to be carefully studied.

The main decay channel of π^0 is a $\gamma\gamma$ channel with a branching ratio of 98.8%. To study this decay π^0 reconstruction through a γ-conversion method was implemented in the KF Particle Finder package for short-lived particle reconstruction. At the first stage tracks from electrons and positrons registered in the Silicon Tracking System (STS) are selected using particle identification (PID) information from the Ring Image Cherenkov Detector (RICH), Transition Radiation Detector (TRD) and Time of Flight (ToF) detector. Selected tracks are combined into γ-candidates. Based on the Kalman filter mathematics, the KF Particle Finder package allows to achieve high reconstruction quality of the particles. For example, distribution of the reconstructed z-position nicely represents the structure of the detector (see Fig. 1). Then the γ-candidates within 3σ region around the peak position ($0\ MeV/c^2$) are selected and combined with each other. High quality of the γ-candidates allows reconstruction of π^0 with a width of $1.7\ MeV/c^2$ and signal to background ratio of 0.77 already for 5 million central AuAu events at 25 AGeV (see Fig. 2).

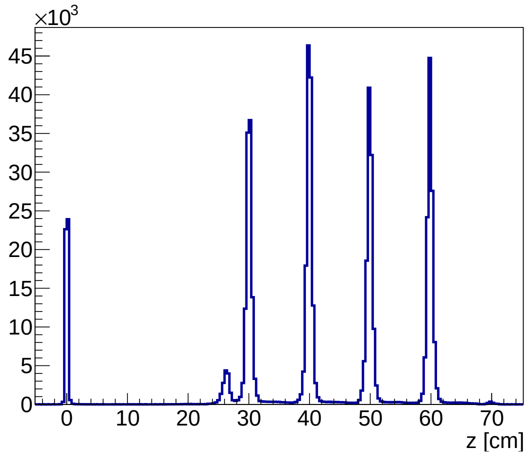

Figure 1: Distribution of γ-particles reconstructed z-position. The obtained histogram represents position of the target, a beam pipe window and four stations of the STS detector.

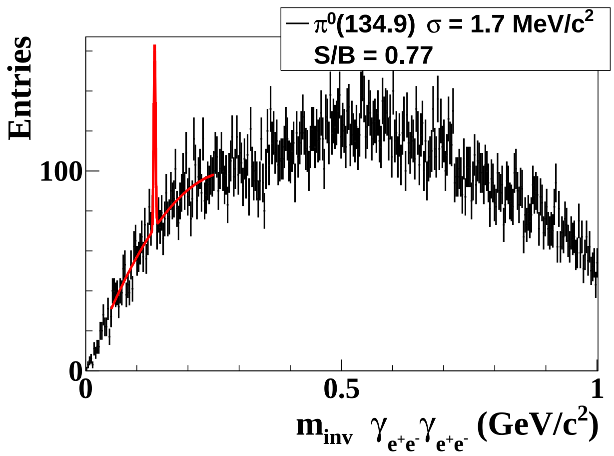

Figure 2: Mass distribution of $\gamma\gamma$ pairs for 5 million central AuAu events at 25 AGeV using PID information form RICH, TRD and ToF detectors. The peak from π^0 is nicely seen with a width of $1.7\ MeV/c^2$ and a signal to background ratio of 0.77.

Average gamma conversion factor within the STS detector is about 6.5%. This gives a probability of $4 \cdot 10^{-3}$ for both γ-daughters to produce tracks. Tacking into account efficiency of the track finding, PID detector and particle construction the overall π^0 reconstruction efficiency is about 10^{-6}. However, the big advantage of the method is high resolution and signal to background ratio.

Summarizing, π^0 reconstruction was implemented in the KF Particle Finder package. High quality of the obtained π^0 particles makes it possible to study the background for dielectron decays of the rare probes.

4-Dimensional Cellular Automaton Track Finder for the CBM Experiment

Collaborators: Valentina Akishina[1,2,3], Ivan Kisel[1,2,4]

[1] Goethe-Universität Frankfurt am Main, [2] GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, [3] Joint Institute for Nuclear Research, Dubna, Russia, [4] Frankfurt Institute for Advanced Studies

The CBM experiment at FAIR will focus on the measurement of rare probes at interaction rates up to 10 MHz. The beam will provide free stream of particles, so that some events may overlap in time. It requires the full online event reconstruction not only in space, but also in time, so-called 4D (4-dimensional) event building. This is a task of the First-Level Event Selection (FLES) package.

The FLES reconstruction package consists of several modules: track finding, track fitting, short-lived particles finding, event building and event selection. The Cellular Automaton (CA) track finder is fast and robust and thereby will be used for the online track reconstruction. The reconstruction efficiency for the primary tracks with momentum higher than 1 GeV/c in case of event-based analysis (see 3D column of Table 1) is 96.1%.

As a special study of the CA track finder stability the algorithm behavior was investigated with respect to the track multiplicity. For the study a super-event, which includes a number of minimum bias events, was reconstructed with no time information taken into account. In a super-event we combine space coordinates of hits from a number of Au+Au minimum bias events at 25*A* GeV and give it to the CA track finder as an input to reconstruct with a regular procedure. The reconstruction efficiency dependence is stable: the efficiency for all tracks changes by 4% only for the extreme case of 100 minimum bias events in the super-event (see (3+1)D column of table 1), comparing to the case of event-based analysis.

Efficiency, %	3D	(3+1)D	4D
All tracks	83.8	80.4	83
Primary high-*p*	96.1	94.3	92.8
Primary low-*p*	79.8	76.2	83.1
Secondary high-*p*	76.6	65.1	73.2
Secondary low-*p*	40.9	34.9	36.8
Clone level	0.4	2.5	1.7
Ghost level	0.1	8.2	0.3
Time/event/core	8.2 ms	31.5 ms	8.5 ms

Table 1: Track reconstruction performance for 3D event-by-event analysis, super-event (3+1)D and time-based 4D reconstruction for 100 mbias Au+Au collisions at 25*A* GeV.

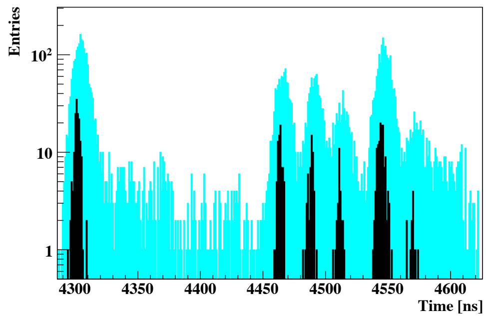

Figure 1: Distribution of time measurement in a part of a time-slice at the interaction rate of 10^7 Hz: hit time measurement (light blue), track time (black).

The time information was included to the algorithm. It has resulted in a higher reconstruction efficiency (see 4D column in table 1). In particular the time information drastically decreased ghost and made the reconstruction 3.7 times faster than without the time information ((3+1)D column of Table 1). The speed now is 8.5 ms and comparable with the event-based analysis. The CA track finder was fully parallelised inside the time-slice. The parallel version shows the same efficiency as a sequential one and achieves a speed-up factor of 10.6 while parallelising between 10 Intel Xeon physical cores with a hyper-threading.

The first version of event building based on 4D track finder was implemented. The hits time measurements distribution illustrating the complexity of defining event borders in a time-slice is shown Figure 1 with blue color, the resulting distribution of reconstructed track time – with black. Reconstructed tracks clearly represent event-corresponding groups. The FLES package is ready for the 4D reconstruction of time-slices in CBM.

Related publications in 2014:

1) V. Akishina, I. Kisel, *Online 4-Dimensional Reconstruction of Time-Slices in the CBM Experiment*, submitted

The network extension problem

Collaborators: Sarah Becker[1], Bethany A. Frew[2], Stefan Schramm[1], and Martin Greiner[3]

[1]Frankfurt Institute for Advanced Studies [2]Department of Civil and Environmental Engineering, Stanford University, Stanford, CA, USA [3]Department of Mathematics, Department of Physics and Aarhus School of Engineering, Aarhus University, Denmark

We investigate an US electricity system in which wind and solar PV produce as much energy as is consumed. The wind/solar mix is picked such that the need for backup energy, which arises when the renewable production occurs at the wrong time, is reduced to its minimum in each Federal Electricity Regulatory Council (FERC) region. This leads to wind shares of 70%-80%.

It is now assumed that a certain amount of additional transmission capacity is available, which we seek to distribute across the individual links to achieve a maximal further reduction in backup energy. This problem could be proven to be convex, which greatly simplifies its solution.

Shown below are three example networks, each constructible by adding about twice the capacity that is already present, calculated with three different methods. The first is a heuristic based on quantiles of unimpeded power flow (consistent with equal line costs), the second is an optimization assuming equal line costs, and the third is an optimization assuming more realistic line costs. Comparing the left to the middle panel, it can be observed that the optimization shifts capacity from east-west to north-south links. Going from the middle to the right panel, it becomes apparent that taking heterogeneous costs into account undoes some of this redistribution, because especially the link between the North-West (NW) and the Midcontinent (MISO) is very long and thus more expensive to extend.

Overall, the reduction in backup energy by using the optimization instead of heuristic methods is small, of the order of some thousandths. The cost reductions by using the optimization are, however, quite substatial and amount to about 10%.

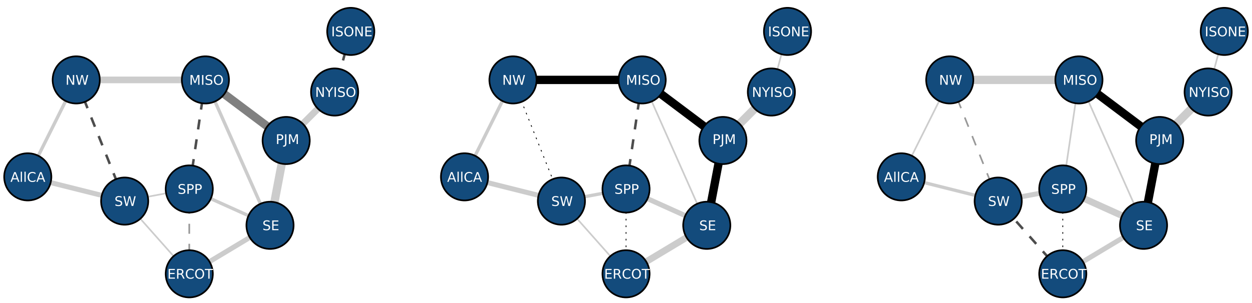

Figure 1: Reinforced US transmission grid, calculated with different methods, for a given investment of approximately twice the value of today's grid. The nodes are the Federal Electricity Regulatory Council (FERC) regions. Link strength is indicated by line style. Left: Transmission capacities are calculated from a (hypothetical) setting in which line capacities are infinite. For each link, the resulting unconstrained flow is binned into a histogram and the transmission capacity is chosen as a high quantile of the unimpeded flow. The two flow directions are treated separately, and the larger directional capacity is picked as link capacity. Middle: Line capacity distribution is optimized in order to yield the least amount of backup energy possible, under the assumption that one unit of capacity costs the same on each link. Right: Same as middle, but with link-specific line costs, dependent on line length and regional building costs.

Related publications in 2014:

Becker, S., Frew, B.A., Andresen, G.B., Zeyer, T., Schramm, S., Greiner, M., and Jacobson, M.Z.: *Features of a fully renewable US electricity system: Optimal mixes of wind and solar PV and transmission grid extensions*, Energy **72**, p. 443–458 (2014). Online at http://dx.doi.org/10.1016/j.energy.2014.05.067; preprint available at http://arxiv.org/abs/1402.2833.

Backup flexibility classes in renewable energy networks

Collaborators: David Schlachtberger[1], Sarah Becker[1], Martin Greiner[2], Stefan Schramm[1]

[1] Frankfurt Institute for Advanced Studies, [2] Aarhus University, Aarhus, Denmark

We study electricity systems with high shares of variable renewables in Europe, consisting only of wind, solar, and backup power systems. We use eight years of historic high resolution weather-based wind and solar power generation data as well as electricity demand data from the same period (2000-2007) to analyze the flexibility requirements of a dispatchable backup system that has to cover the residual load. Motivated by the typical timescales observed for changes in both power consumption and variable renewable energy production, we split the backup system into three flexibility classes for daily, weekly, and seasonal variations. The classes are distinguished by the maximum rates of change m_i of their power output, where $i = ($ daily, weekly, seasonal$)$. The ramp rates m_i are determined by (Gaussian) smoothing the load over 1, 24 hours, and 168 hours, respectively, and setting m_i to the maximum slope of the resulting time series. This reflects the flexibility of the current system without contribution from renewables. The power capacities and the dispatch of the three classes are then optimized for minimal over- and underproduction while using the slower systems first and ensuring a high level of security of supply by covering the load for a quantile $q = 99.9\%$ of all hours. This is done by first minimizing the capacity of the most flexible system within the constraints, and thereby maximizing the possible contributions from the slower systems. This capacity is then fixed to its optimum value, and the procedure is repeated for the next slower class until all three capacities are optimal.

The results of this optimization for different shares of renewable energy generation γ of the mean electricity production are shown in Figure 1. On the left is the case of Germany without international transmission. We find that the current system $(\gamma = 0)$ is dominated by slowly flexible backup generation, but with increasing γ the capacity requirements rapidly shift towards more flexible systems. A large fraction of seasonally and weekly flexible backup systems can no longer be reasonably integrated above a penetration of renewables of around 50% and 90% of the mean load, respectively. This is even more significant if the security of supply requirement is only slightly relaxed, as e.g. the weekly capacity can be further reduced by a large fraction in this case. We also find that the required daily capacity increases to the size of the mean load as γ goes to 1, and not even a significant average overproduction of renewables of $\gamma = 2$ can reduce the need for this large capacity. These results are similar for all other isolated European countries. However, if the countries share their excess generation and backup power through an unconstrained electricity network, the optimal capacity especially of the most flexible class is generally smaller and also decreases for $\gamma > 1$, as shown in the right part of Figure 1.

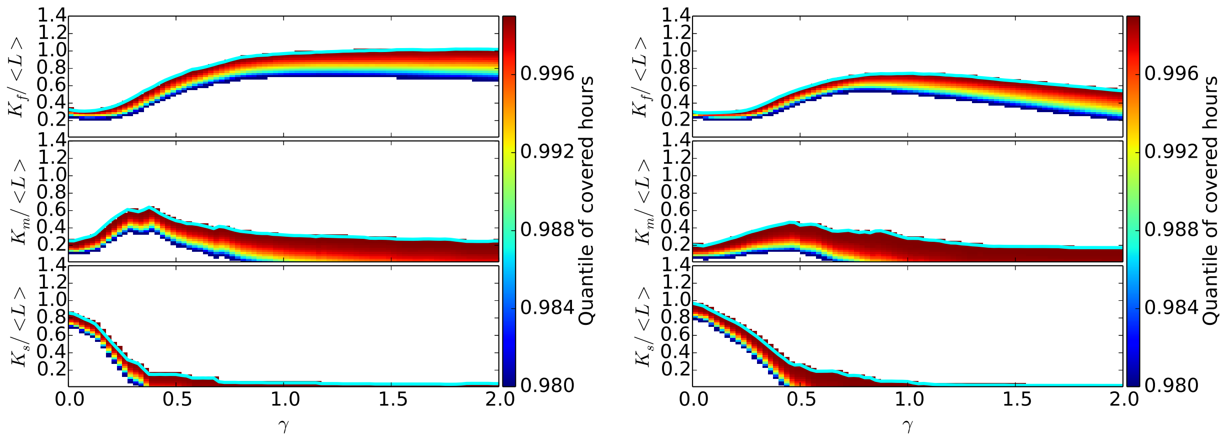

Figure 1: **left:** solid cyan lines are optimal capacities in units of the mean load for the three flexibility classes daily, weekly, seasonal (top to bottom panels), respectively, for $q = 99.9\%$ versus the share of renewables γ for Germany. Also shown, in color code, is the quantile q of fully covered hours if one of the capacities is decreased until $q = 98\%$ while the other two are fixed at their optimum values. **right:** same as left but for the case of an aggregated Europe.

5. Talks and Publications

Conference and Seminar Talks by FIAS Members 2014

Jussi Auvinen

- DPG Spring Meeting, Section "Hadronic and Nuclear Physics", Frankfurt, 17-21 March 2014, *Studying the collision energy dependence of elliptic and triangular flow with a hybrid model*
- XXIV Quark Matter 2014, Darmstadt, Germany, 19-24 May 2014, *What the collective flow excitation function can tell about the quark-gluon plasma*
- 2014 RHIC & AGS Annual Users' Meeting, BNL, USA, 18 June 2014, *Beam energy scan of v_1, v_2 and v_3 using a transport+hydrodynamics hybrid model*
- Workshop on Beam Energy Scan II at RHIC, Berkeley, USA, 27-29 Sept. 2014, *Interpreting Beam Energy Scan Results for v_1, v_2 and v_3 Using a Hybrid Approach*

Sarah Becker

- Workshop "Complexity meets Energy", Münster, Germany, March 2014, *Transmission grid extensions*
- DPG spring meeting, Section "Condensed Matter", Dresden, Germany, April 2014, *Power transmission in a renewable European future*
- Workshop "Sustainability: RE and alternative visions for society", Oldenburg, Germany, April 2014, *Renewable resources and their challenges*
- CONSENSYS workshop, Aarhus, Denmark, June 2014, *Flexibility classes revisited*
- 13th Wind Integration Workshop, Berlin, Germany, Nov. 2014, *Large-scale integration of fluctuating renewables in Europe and the US*
- Workshop and Symposium on Future Energy Systems – Collective Dynamics, Göttingen, Germany, Dec. 2014, *Weather-based generation data*

Hamza Berrehrah

- DPG Spring Meeting, Section "Hadronic and Nuclear Physics", Frankfurt, 17-21 March 2014, *On- and off-shell heavy quark transport properties in the quark gluon plasma (QGP)*
- HIC for FAIR Workshop: "Heavy-flavor physics with CBM", FIAS, Frankfurt, 26-28 May 2014, *Heavy quark scattering and quenching in a finite temperature and chemical potential QCD medium*
- Non-equilibrium Dynamics & Theory of UltraRelativistic heavy Ion Collisions (NeDTURIC) 2014, Hersonissos, Creta, 8-13 June 2014, *Heavy quark transport properties from LHC to CBM energies*
- "Hot Quarks - 2014", Las Negras, Almeria, Spain, 21-28 Sept. 2014, *Transport properties of hot and dense sQGP*

Alexandre Botvina

- International Workshop "Probing the Strong Interaction at A Fixed Target ExpeRiment with the LHC beams", Les Houches School, Les Houches, France, 12-17 Jan. 2014, *Production of hypernuclei from excited nuclear residues in relativistic ion collisions: New opportunities for AFTER@LHC*
- ATHENA Brussels workshop on Astrophysics, Universite Libre de Bruxelles, Belgium, 27-28 Jan. 2014, *Statistical approach for supernova matter and nuclear multifragmentation*
- Annual Spring Meeting, Section "Hadrons and Nuclei", Deutsche Physikalische Gesellschaft, Frankfurt, Germany, 17-21 March 2014, *Production of hypernuclei from excited nuclear residues in relativistic ion collisions*

– Seminar talk at Bogoliubov Laboratory of Theoretical Physics, JINR, Dubna, Russia, 7 July 2014, *Production of hypernuclei from excited nuclear residues in relativistic ion collisions: New opportunities for BM@N and MPD@NICA*
– International SPHERE workshop, Prague, Czech Republic, 9-11 Sept. 2014, *Hypernuclei and hypermatter in relativistic heavy-ion reactions*, invited talk
– Super-FRS Collaboration Meeting, Mörfelden-Walldorf, Germany. 12-14 Nov. 2014, *Universal processes of formation of hypermatter and hypernuclei in heavy-ion collisions: from producing light clusters to evaporation and fission of heavy ones*, invited talk

Elena Bratkovskaya

– EMMI rapid reaction task force on the direct-photon flow puzzle, GSI, Darmstadt, Germany, 24-28 Feb. 2014, *Meson-meson and meson-baryon bremsstrahlung*
– The 30th Winter Workshop on Nuclear Dynamics, Galveston, Texas, USA, 6-12 April 2014, *Electromagnetic probes of the QGP*, invited talk
– XXIV Quark Matter 2014, Darmstadt, Germany, 19-24 May 2014, *Phenomenology of photon and di-lepton production in relativistic nuclear collisions*, invited plenary talk
– Workshop “Opportunities from FAIR to other low energy facilities” & 3rd International Conference on New Frontiers in Physics, Kolumbari, Crete, Greece, 28 July - 6 Aug. 2014, *Electromagnetic probes of the QGP*, invited talk
– INT Program INT-14-3, “Heavy Flavor and Electromagnetic Probes in Heavy Ion Collisions?”, Seattle, USA, 15 Sept. - 10 Oct. 2014, *Electromagnetic probes of the QGP*.
– Workshop “QCD Hadronization and Statistical Model”, ECT, Trento, Italy, 6-10 Oct. 2014, *Heavy-ion dynamics in the PHSD model*, invited talk
– Resonance Workshop in Catania, Catania, Italy, 3-7 Nov. 2014, *Resonance dynamics in the PHSD approach*, invited talk
– HIC for FAIR Physics Day: HPC Computing, FIAS, Frankfurt, 11 Nov. 2014, *Theory and HPC*, invited talk
– The International Workshop on Discovery Physics at the LHC (Kruger-2014), Kruger Gate, South Africa, 1-5 Dec. 2014, *The QGP dynamics in relativistic heavy-ion collisions*, invited plenary talk
– EMMI Workshop “Ab initio approaches in many-body QCD confront heavy-ion experiments”, Heidelberg, Germany, 15-17 Dec. 2014, *Photon production in heavy-ion collisions*, invited talk

Daniel Cabrera

– DPG Spring Meeting, Section “Hadronic and Nuclear Physics”, Frankfurt, 17-21 March, 2014, *Strange meson cross sections and spectral functions at GSI-FAIR conditions*
– HIC for FAIR Workshop: “Heavy-flavor physics with CBM”, FIAS, Frankfurt, 26-28 May 2014, *Heavy meson scattering off hadrons in hot and dense matter: benefits from unitarity, chiral and heavy-quark symmetries*
– The 2nd Strangeness Workshop for SIS18 energies, Heidelberg, 21-22 July 2014, *Strangeness in HSD*, invited talk
– Resonance Workshop at Catania, Catania, Italy, 3-7 Nov. 2014, $S = -1$ *meson baryon interaction in hot and dense matter: chiral symmetry, many-body and unitarization for a road to GSI/FAIR*, invited talk

Lucas Burigo

– International Conference on Translational Research in Radiation Oncology/Physics for Health in Europe (ICTR-PHE), Geneva, Switzerland, 10-14 Feb. 2014, *Properties of therapeutic He, Li and O beams studied with Geant4*

- Lander-Tag, Institute for Applied Physics, Frankfurt, Germany, 24 October 2014, *Modelling radiation effects of ion beams in cancer therapy*

Hermann Cuntz

- 3rd Biennial Meeting Rhine Main Neuroscience Network, Oberwesel, Germany, 25-27 June 2014, *A developmental stretch-and-fill process that optimises dendritic space filling*
- IGSN-Symposium, International Graduate School of Neuroscience, Bochum, Germany, 3 Nov. 2014, *Modelling the formation of neural circuits*

Dominic Eschweiler

- LinuxCon – Real Time Linux Workshop (RTLWS), Düsseldorf, Germany, 10 Oct. 2014, *The Portable Driver Architecture*
- 20th IEEE International Conference on Parallel and Distributed Systems (ICPADS), Hsinchu, Taiwan, 19 Dec. 2014, *Efficient Management of Large DMA Memory Buffers in Microdrivers*

Walter Greiner

- Frontiers of Fundamental Physics 14, Marseille, France, 15-18 July 2014, *There are no black holes: Pseudo-Complex General Relativity*
- VIIth International Symposium on Exotic Nuclei (EXON-2014), Kaliningrad, Russia, 8-13 Sept. 2014, *Outstanding Problems of Nuclear Physics*
- International Workshop on Collectivity in Relativistic Heavy Ion Collisions (IWoC2014), Kolymbari, Crete, 15-19 Sept. 2014, *There are no black holes: Pseudo-Complex General Relativity*

Christoph Hartmann

- Bernstein Conference 2014, Göttingen, Germany, 2-5 Sept. 2014, *Self-organized learning and inference explain key properties of neural variability*

Hendrik van Hees

- EMMI rapid reaction task force on the direct-photon flow puzzle, GSI, Darmstadt, Germany, 24-28 Feb. 2014, *Thermal Photons at RHIC and LHC*
- 19th HQM Lecture Week, Ebernburg, Germany, 31 March - 4 April 2014, Four lectures on *Electromagnetic Probes in Heavy-Ion Collisions*
- CBM Symposium, GSI, Darmstadt, Germany, 9 April 2014, *Heavy flavor at RHIC, LHC, and CBM*
- Lecture at the Quark Matter 2014 Student Day at GSI, Darmstadt, 18 May 2014, *Electromagnetic probes in heavy-ion collisions*
- Thermal Photons and Dileptons in Heavy-Ion Collions, Brookhaven National Laboratory, USA, 20 August 2014, *Photons and dileptons in heavy-ion collisions - Theory*, invited talk
- HADES Collaboration Meeting XXVIII, Bratislava, Slovakia, 29 Oct. 2014, *Dileptons in heavy-ion collisions with transport models*, invited talk
- Resonance Workshop at Catania, Catania, Italy, 3-7 Nov. 2014, *Dileptons in heavy-ion collisions: Messengers from the hot and dense fireball*, invited talk

Pasi Huovinen

- DPG Spring Meeting, Section “Hadronic and Nuclear Physics”, Frankfurt, 17-21 March 2014, *Improving thermal models with sequential freeze-out*
- Seminar talk, University of Jyväskylä, Jyväskylä, Finland, 28 March 2014, *My adventures with thermal model*

- Workshop “Hydrodynamics for strongly coupled fluids”, ECT*, Trento, Italy, 12 May 2014, *Lattice QCD based equation of state at finite baryon density* (invited talk)
- XXIV International Conference on Ultrarelativistic Nucleus-Nucleus Collisions (Quark Matter 2014), Darmstadt, Germany, 19-24 May 2014, *Lattice QCD based equation of state at finite baryon density*
- Seminar talk, University of Sao Paulo, Brazil, 6 June 2014, *Dynamical freeze-out in event-by-event hydrodynamics*
- Colloquium, Instituto de Física Teórica, UNESP, Sao Paulo, Brazil, 9 June 2014, *The hunt for (almost) perfect fluid*
- Colloquium, Escola de Engenharia de Lorena, USP, Lorena, Brazil, 11 June, 2014, *A layman’s introduction to the hunt of (almost) perfect fluid at LHC*

Andrej Ilner

- Conference “Non-equilibrium Dynamics & Theory of UltraRelativistic heavy Ion Collisions” (NeDTURIC 2014), Hersonissos, Crete, 8-13 June 2014, *Properties of K^* in a medium*
- Resonance Workshop at Catania, Catania, Italy, 3-7 Nov. 2014, *K^* dynamics in heavy-ion collisions*, invited talk

Matthias Kaschube

- Seminar talk, Institute of Molecular Pathology (IMP), Vienna, Austria, 28 February 2014, *The role of lateral connections in shaping neural response properties in cortex*
- BioQuant colloquium series at University of Heidelberg, Heidelberg, Germany, 16 April 2014, *Towards a quantitative understanding of morphogenesis*
- ENS-IBRO Training Course: Advanced Course in Computational Neuroscience, FIAS, Frankfurt, 3-30 August 2014, *Self-organization in visual cortex*
- Retreat of Max-Planck Institute for Dynamics and Self-Organization, Mandarfen, Austria, *The development of cortical circuits for motion discrimination*, invited talk

Alexei Larionov

- HIC for FAIR Workshop: “Heavy-flavor physics with CBM”, FIAS, Frankfurt, 26-28 May 2014, *Charmonium production in antiproton-induced reactions close to threshold*
- 13th International Workshop on Meson Production. Properties and Interaction (MESON2014), Krakow, Poland, 29 May - 3 June 2014, *Charmonium production in $\bar{p}$-induced reactions on nuclei*
- 4th International Workshop on Nuclear Dynamics in heavy-ion reactions (IWND2014), Lanzhou, China, 15-15 August 2014, *Antiproton-nucleus reactions at intermediate energies*

Volker Lindenstruth

- Forschungskolleg Humanwissenschaften, Bad Homburg, Germany, 19 Feb. 2014, *Big Data und die damit verbundenen Möglichkeiten*
- CAE Konferenz “Berechnung im Produktprozess”, Volkswagen, Braunschweig, Germany, 20 March 2014, *High performance computing – zukünftige Entwicklungen und deren Auswirkung auf die Software- und Prozesslandschaft*
- Gutenberg Foschungskolleg, Mainz, Germany, 3 Nov. 2014, *Information Coding – Decoding Bach’s Music*
- SIMVEC – Simulation und Erprobung in der Fahrzeugentwicklung, Baden-Baden, Germany, 18 Nov. 2014, *Hochleistungsrechnen – Status und Zukunftsperspektiven*

Rudy Marty

- DPG Spring Meeting, Section “Hadronic and Nuclear Physics”, Frankfurt, 17-21 March, 2014, *Initial state properties in heavy ion collisions at RHIC and LHC energies*
- Conference “Non-equilibrium Dynamics & Theory of UltraRelativistic heavy Ion Collisions” (NeDTURIC 2014), Hersonissos, Creta, 8-13 June 2014, *The influence of initial conditions on the final observables for heavy-ion collisions at RHIC energies*

Igor Mishustin

- 3d International Symposium on Non-equilibrium Dynamics (NeD-2014) and 4th Network Workshop on Theory of UltraRelativistic heavy Ion Collisions (TURIC-2014), Hersonissos, Crete, Greece, 9-14 June 2014, *Non-equilibrium Dynamics of the Chiral Fluid*, invited talk
- Extreme Matter Seminar, Joint Institute for Nuclear Research, Dubna, Russia, 27 August 2014, *Non-equilibrium Dynamics of the Chiral/Deconfinement Phase Transition*
- International Workshop on Nuclear Equation of State for Compact Stars and Supernovae (NEOS2014), FIAS, 5 Dec. 2014, *Concluding remarks*

Max Murakami

- Seminar talk, Technische Universität Dresden, Germany, 17 December 2014, *Hören und Babbeln: Vokalerwerb durch Imitation*

Piero Nicolini

- DPG Spring Meeting, Section “Gravitation and Relativity”, Berlin, Germany, 17-21 March 2014, *Un-Casimir effect*
- 99 years of Black Holes – from Astronomy to Quantum Gravity, Potsdam, Germany, 20-22 May 2014, *Black holes and the generalized uncertainty principle*, plenary talk
- First INFN FLAG meeting “The quantum and gravity”, Bologna, Italy, 28-30 May 2014, *Journey to the un-world*, plenary talk
- London Relativity and Cosmology Seminars, Queen Mary University, London, UK, May 2014, *Black holes and the generalized uncertainty principle*

Danko Nikolić

- Multisense-Synesthesia Symposium, University Clinic, Hamburg, 1 March 2014, *Ideasthesia: the window to cross-modal associations*
- Transylvanian Experimental Neuroscience Summer School (TENSS), Pike Lake, Romania, 1-17 June 2014, *Practopoiesis (or cybernetics in the brain)*
- Seminar talk, University of Huddersfield, UK, 4 June 2014, *Ideasthesia: When meaning and sensations come together*
- Ringberg retreat of ESI, Schloss Ringberg, Germany1 July 2014, *A brief introduction into practopoiesis*
- A retreat of Christian Kell Lab, Schlüchtern, Germany, 23 August 2014, *Practopoiesis (or cybernetics in the brain)*
- Seminar talk, Machine Learning and Robotics Lab., University of Stuttgart, Germany, 13 Sept. 2014, *Practopoiesis: Why we need three traverses for general AI?*
- Seminar talk, University College London, UK, 26 Sept. 2014, *Neuronal dynamics in the primary visual areas*
- Seminar talk, University of Glasgow, Department of Psychology, Glasgow, UK, 3 October 2014, *Neuronal dynamics in the primary visual areas*

- Conference of the National Neuroscience Society of Romania 2014 (SNN2014), Bucharest, Romania, 23-25 October 2014, *Practopoiesis*
- Seminar talk, Justus-Liebig-University Gießen, Germany, 27 Oct. 2014, *Synesthesia/Ideasthesia – An introduction*
- Thinking Film, University of Frankfurt, Germany, 7 Nov. 2014, *Autopoiesis in film and the visual brain*
- Seminar talk, Max Planck Institute for Empirical Aesthetics, Frankfurt, Germany, 17 Dec. 2014, *From synesthesia to ideasthesia and beyond*

Dmytro Oliinychenko

- DPG Spring Meeting, Section "Hadronic and Nuclear Physics", Frankfurt, 17-21 March 2014, *Investigating the transition between hydrodynamics and transport in heavy ion collision simulations*
- FAIRNESS 2014: Workshop for young scientists with research interests focused on physics at FAIR, Vietri sul Mare, Italy, 22-27 Sept. 2014, *Cooper-Frye negative contributions and thermalization at FAIR energies*

Hannah Petersen

- CBM Symposium, GSI, Darmstadt, Germany, 9 April 2014, Collective flow as a signal of the phase transition
- Antrittsvorlesung, Physics Colloquium Goethe Universität, Frankfurt, Germany, 23 April 2014, *Die Eigenschaften von QCD-Materie bei hohen Temperaturen und Dichten*
- Student Day Lecture at Quark Matter 2014, GSI, Darmstadt, Germany, 18 May 2014, *Bulk Properties and Hydrodynamics: Recent Developments*
- Night of Science 2014, Campus Riedberg, Frankfurt, Germany, 27 June 2014, *Visualizing the little bangs – Bilder vom Urknall im Labor*
- HICforFAIR Colloquium, Gießen, Germany, 10 July 2014, *Probing quark gluon plasma properties with collective flow*
- QCD Town meeting, Philadelphia, USA, 13 Sept. 2014, *Dynamical Modeling at Low Collision Energy and High* μ_B
- Critical Point and Onset of Deconfinement (CPOD 2014), Bielefeld, Germany, 17-21 Nov. 2014, *The beam energy dependence of collective flow in heavy ion collisions*

Dorin Poenaru

- International Conference "75-years of Nuclear Fission: Present status and future perspectives", Mumbai, India, 8-10 May 2014, *Fission approach to cluster radioactivity*
- International Workshop on "Collectivity in Relativistic Heavy Ion Collisions", Kolymbari, Crete, 14-20 Sept. 2014, *Newest developments in Cluster Radioactivity*

Igor Pshenichnov

- Workshop on photon-induced collisions at the LHC, CERN, Geneve, 2-4 June 2014, *Electromagnetic fragmentation of nuclei: recent news and future plans*

Chihiro Sasaki

- XXIV International Conference on Ultrarelativistic Nucleus-Nucleus Collisions (Quark Matter 2014), Darmstadt, Germany, 19-24 May 2014, *New Developments in Thermal Field Theory* (invited plenary talk)
- Colloquium talk, University of Wroclaw, Poland, 6 June 2014, *QCD Thermodynamics from Effective Field Theories*
- International Workshop on Collectivity in Relativistic Heavy Ion Collisions, Kolymbari, Greece, 14-20 Sept. 2014, *Chiral Thermodynamics with Charm*

- Critical Point and Onset of Deconfinement (CPOD 2014), Bielefeld, Germany, 17-21 Nov. 2014, *Chiral Thermodynamics with Charm*
- Zimanyi winter school on heavy-ion physics 2014, Budapest, Hungary , 1-5 Dec. 2014, *Thermodynamics with Charm*

Stefan Schramm

- The Structure and Signals of Neutron Stars, from Birth to Death, Florence, Italy, 24-28 March 2014, *Compact stars and general constraints on exotic phases*
- VIIth International Symposium on Exotic Nuclei (EXON-2014), Kaliningrad, Russia, 8-13 Sept. 2014, *Exotic nuclei and matter in a chirally effective approach*
- XIth Quark Confinement and the Hadron Spectrum, Saint Petersburg, Russia, 8-12 Sept. 2014, *Models of Quark-Hadron Matter and Compact Stars*
- Compact Stars in the QCD Phase Diagram IV, Working Group Meeting of COST Action MP1304, Prerow, Germany, 26-30 Sept. 2014, *Hybrid Stars and Exotic Condensates*

Wolf Singer

- Hungarian Academy of Sciences, Budapest, Hungary, 14 Jan. 2014, *Philosophical Implications of Brain Research: Discrepancies between First and Third Person Perspective*
- vhs Stuttgart, Germany, 22 Jan. 2014, *Widersprüche zwischen Intuition und neurobiologischen Erkenntnissen*
- Workshop “Predictive coding and cortical oscillation”, University of Geneva, Switzerland, 6 Feb. 2014, *Pattern specific formation of priors by unsupervised learning and replay during resting activity in primary visual cortex*
- 30th International Congress on Clinical Neurophysiology (ICCN), Berlin, 19-23 March 2014, *Distributed processing and temporal codes in the cerebral cortex*
- UIB-CSIC Seminar, Institute for Cross-Disciplinary Physics and Complex Systems (IFISC), Campo Universitat de les Illes Balears, Palma de Mallorca, Spain, 17-23 April 2014, *Cortical dynamics revisited*
- OCCAM workshop “The brain as a Probabilistic Inference Engine”, Osnabrück, Germany, 7-9 May 2014, *Cortical dynamcis: As challenging as ever*
- 34th Blankenese Conference “Brain Complexity: From Synaptic Dynamics to Connectomics”, Hamburg, Germany, 10-14 May 2014, *The dynamic brain: The role of temporal coordination in normal and disturbed brain functions*
- HBP Brainstorming Workshop on Principles of Brain Computation, Wolfgangsee, Germany, 13-16 May 2014, *The ongoing search for codes utilized by the cerebral cortex*
- 15th International Multisensory Research Forum IMRF2014, Amsterdam, Netherlands, 13 June 2014, *Perceptual coherence and distributed coding: Convergence in time rather than space?*, Keynote Lecture
- Transylvanian Experimental Neuroscience Summer School (TENSS), Pike Lake, Romania, 1-17 June 2014, *Time as coding space in cortical processing*
- Frankfurt Medical School, Kloster Höchst, Germany, 23 July 2014, *Wie es dazu kam – Leben als sich selbst organisierender Prozess*
- Alpbach Technology Symposium, Alpbach, Austria, 21-23 Aug. 2014, *Neuronal Dynamics: Cognition and Consciousness*
- 52nd Annual Meeting of the Society for Laboratory Animal Science GV-SOLAS, Frankfurt, Germany, 11 Sept. 2014, *Warum Tiermodelle in der Hirnforschung immer noch unverzichtbar sind*, Keynote Lecture

- Lecture Series "Hirnforschung, was kannst du? – Potenziale und Grenzen", Gemeinnützige Hertie-Stiftung, Frankfurt, Germany, 11 Sept. 2014, *Kunst und Hirnforschung. Wege auf der Suche nach Stimmigkeit*
- EMBO Members' Meeting, Heidelberg, Germany, 30 Oct. 2014, *The challenge of complexity*
- Katholische Akademie Schwabing, Munich, Germany, 8 Nov. 2014, *Wo steckt das Ich im Hirn?*
- Eugen Biser Lecture, LMU Munich, Germany, 21 Nov. 2014, *Freiheit als soziale Realität. Ein Konflikt zwischen Selbsterfahrung und neurobiologischer Fremdbeschreibung*
- Deutsche Bundesbank, Frankfurt, 9 Dec. 2014, *Das Gehirn, ein sich selbst organisierendes System ohne zentrale Koordinationsinstanz*

Taesoo Song

- HIC for FAIR Workshop: "Heavy-flavor physics with CBM", FIAS , Frankfurt, 26-28 May 2014, *Charm quarks in heavy-ion collisions.*
- Conference "Non-equilibrium Dynamics & Theory of UltraRelativistic heavy Ion Collisions" (NeDTURIC 2014), Hersonissos, Crete, 8-13 June 2014, *Charm dynamics in heavy-ion collisions*
- High energy strong interactions: a school for young asian scientists, Central China Normal Univerisy, Wuhan, China, 22-26 Sept. 2014, *Quarkonium formation time in relativistic heavy-ion collisions*

Jan Steinheimer

- DPG Spring Meeting, Section "Hadronic and Nuclear Physics", Frankfurt, 17-21 March 2014, *Phase Transitions in Fluid Dynamical Simulations of Nuclear Collisions*
- XI International Conference on Hyperons, Charm and Beauty Hadrons (BEACH 2014), Birmingham, UK, 21-26 July 2014, *Particle Production in Nuclear Collisions, Hadronization and QCD*
- FAIRNESS 2014: Workshop for young scientists with research interests focused on physics at FAIR, Vietri sul Mare, Italy, 22-27 Sept. 2014, *Theory Challenges for CBM*
- Workshop on Beam Energy Scan II at RHIC, Berkeley, USA, 27-29 Sept. 2014, *On the QCD equation of state: What we know and need to know*
- Workshop "QCD Hadronization and Statistical Model", ECT, Trento, Italy, 6-10 Oct. 2014, *Final state hadronic interactions with UrQMD*
- Resonance Workshop in Catania, Catania, Italy, 3-7 Nov. 2014, *Final state hadronic interactions with UrQMD*

Jochen Triesch

- Seminar talk, Weizmann Institute, Rehovot, Israel, 11 March 2014, *Efficient Coding in Active Perception*
- Seminar talk, Hebrew University, Jerusalem, Israel, 13 March 2014, *Efficient Coding in Active Perception*
- Seminar talk, Technion, Haifa, Israel, 17 March 2014, *Self-Organization and Unsupervised Learning in Recurrent Networks*
- Human Brain Project Workshop, Fürberg, Austria, 13-16 May 2014, *Self-Organization and Unsupervised Learning in Recurrent Networks*
- Rhein-Main Neuroscience Network (RMN2) Retreat, Oberwesel, 25-27 June 2014, *Self-Organized Learning and Inference Explain Key Properties of Neural Variability*
- Night of Science, Goethe University, Frankfurt, 27 June 2014, *Wie Roboter unseren Alltag erobern*
- International Conference on Infancy Studies, Berlin, 2-5 July 2014, *Learning where to Look: Infants, Models, Robots*
- Advanced Course in Computational Neuroscience, FIAS, Frankfurt, 3-31 August 2014, *Reservoir Computing*

- Advanced Course in Computational Neuroscience, FIAS, Frankfurt, 3-31 August 2014, *Self-Organization and Unsupervised Learning in Recurrent Networks*
- Seminar talk, Institut für Neuroinformatik, Bochum, Germany, 2 October 2014, *Active Efficient Coding*
- Sino-German Symposium on Biomimetics, Chengdu, China, 10-15 October 2014, *Active Efficient Coding: from Neuroscience to Robotics*
- Neurocuriosity Workshop, Bordeaux, France, 5-9 November 2014, *Active Efficient Coding: from Neuroscience to Robotics*
- Seminar talk, Cognitive Science Dept., Univ. of Osnabrück, Germany, 12 November 2014, *Active Efficient Coding*
- Informatik Kolloquium, Computer Science Dept., Univ. of Jena, Germany, 2 December 2014, *Active Efficient Coding*
- Seminar talk, Philosophy Dept., Univ. of Magdeburg, Germany, 9 December 2014, *Plasticity, Learning, and Information Coding in Neural Circuits*
- Seventh International Workshop on Guided Self-Organization, Freiburg, Germany, 16-18 December 2014, *Active Efficient Coding*

Janus Weil

- The 2nd Strangeness Workshop for SIS18 energies, Heidelberg, 21-22 July 2014, *Strangeness in GiBUU*
- 20th Particles and Nuclei International Conference (PANIC2014), Hamburg, Germany, 25-29 Aug. 2014, *Dilepton Production in Transport-Based Approaches*
- "Hot Quarks - 2014", Las Negras, Spain, 21-28 Sept. 2014, *Dilepton Production in Transport-Based Approaches*

FIAS conference abstracts and posters 2014

Computational and Systems Neuroscience (COSYNE2014)

27 Feb. - 2 March 2014, Salt Lake City, UT, USA

- Daniel Miner, Jochen Triesch, *Relating synaptic efficacies and neuronal separation in a simulated layer 2/3 cortical network*, Poster I-88
- Felix Bauer, Matthias Kaschube, *Role of long-range horizontal connections in visual texture classification*, Poster I-99

Annual Spring Meeting, Section "Gravitation and Relativity", Deutsche Physikalische Gesellschaft,

17-21 March 2014, Berlin, Germany

- Alain Dirkes, Michael Maziashvili, Zurab Silagadze, *Black hole remnants due to Planck-length deformed QFT*, Abstract GR16.4
- Aantonia Micol Frassino, Piero Nicolini, Orlando Panella, *Un-Casimir effect*, Abstract MP8.1

Annual Spring Meeting, Section "Hadrons and Nuclei", Deutsche Physikalische Gesellschaft,

17-21 March 2014, Frankfurt, Germany

- Valentina Akishina, Ivan Kisel, *The Parallel Cellular Automaton track finder for the CBM experiment*, Abstract HK5.2
- Maximilian Attems, *Longitudinal thermalization via the Chromo-Weibel instability*, Abstract HK 26.7
- Jussi Auvinen, Hannah Petersen, *Studying the collision energy dependence of elliptic and triangular flow with a hybrid model*, Abstract HK19.4
- Martin Baldenhofer, Vera Derya, Janis Endres, Andreas Hennig, Bastian Löher, Deniz Savran, Werner Tornow, Andreas Zilges, *Two-phonon E1 excitations in ^{40}Ca and ^{140}Ce*, Abstract HK 46.16
- Tobias Beck, J. Beller, V. Derya, J. Isaak, B. Löher, N. Pietralla, C. Romig, M. Scheck, W. Tornow, H.R. Weller, M. Zweidinger, *Präzise Untersuchung der Zerfallseigenschaften $J^\pi = 1^+$ Zustände der Scherenmode in ^{156}Gd*, Abstract HK 24.6
- Hamza Berrehrah, Elena Bratkovskaya, Wolfgang Cassing, Pol-Bernard Gossiaux, Jörg Aichelin, *On- and off-shell heavy quark transport properties in the quark gluon plasma (QGP)*, Abstract HK 26.3
- Alexander Botvina, Marcus Bleicher, Josef Pochodzalla, *Production of hypernuclei from excited nuclear residues in relativistic ion collisions*, Abstract HK 63.1
- Daniel Cabrera, Laura Tolos, Jörg Aichelin, Elena Bratkovskaya, *Strange meson spectral functions and cross sections at GSI-FAIR conditions*, Abstract HK 42.2
- Vera Derya, Janis Endres, Muhsin N. Harakeh, Deniz Savran, Mark Spieker, Heinrich J. Wörtche, Andreas Zilges, *Isospin properties of low-lying electric dipole excitations*, Abstract HK 31.2
- Udo Gayer, Jacob Beller, Vera Derya, Matthew Gooden, Johann Isaak, Bastian Löher, Norbert Pietralla, Christopher Romig, Marcus Scheck, Werner Tornow, Markus Zweidinger, *Bestimmung von Paritätsquantenzahlen dipolangeregter Zustände des mittelschweren Kerns ^{40}Ar*, Abstract HK 11.3
- Andreas Hennig, Vera Derya, Michael Elvers, Janis Endres, Andreas Heinz, Simon G. Pickstone, Desiree Radeck, Deniz Savran, Mark Spieker, Volker Werner, Andreas Zilges, *Study of mixed-symmetric excitations via inelastic proton scattering*, Abstract HK 24.1
- Olena Linnyk, Elena Bratkovskaya, Wolfgang Cassing, *Photon and dilepton production across collision energies and centralities*, Abstract HK 33.1
- Andrej Ilner, Daniel Cabrera, Pornrad Srisawad, Elena Bratkovskaya, *In-medium properties of strange vector mesons in dense and hot nuclear matter*, Abstract HK 42.3

- J. Isaak, M.W. Ahmed, J. Beller, J. Glorius, J.H. Kelley, M. Krticka, B. Lööher, N. Pietralla, C. Romig, G. Rusev, D. Savran, M. Scheck, J. Silva, K. Sonnabend, A.P. Tonchev, W. Tornow, H.R. Weller, M. Zweidinger, *Constraining the electric dipole photon strength function in* ^{130}*Te*, Abstract HK 31.4
- Ivan Kisel, Igor Kulakov, *Stability of the CBM CA based track finder with respect to number of stations* Abstract HK5.3
- Ivan Kisel, Iouri Vassiliev, Maksym Zyzak, *Short-lived particles reconstruction with KF Particle Finder for the CBM experiment*, Abstract HK 63.5
- B. Lööher, T. Aumann, J. Beller, C. Bernards, N. Cooper, V. Derya, M. Duchéne, J. Endres, A. Hennig, J. Isaak, J. Kelley, M. Knörzer, N. Pietralla, C. Romig, D. Savran, M. Scheck, H. Scheit, J. Silva, W. Tornow, H. Weller, V. Werner, A. Zilges, *Photoneninduzierte* γ-γ *Koinzidenzmessungen mit dem* γ^3*-Setup an HI*γ*S*, Abstract HK 32.1
- Alex Meistrenko, Christian Wesp, Hendrik van Hees, Carsten Greiner, *Nonequilibrium dynamics and transport in a quark-meson model*, Abstract HK 26.9
- Dmytro Oliinychenko, Hannah Petersen, *Investigating the transition between hydrodynamics and transport in heavy ion collision simulations*, Abstract HK19.3
- Rudy Marty, Elena Bratkovskaya,Wolfgang Cassing, Jörg Aichelin, *Initial state properties in heavy ion collisions at RHIC and LHC energies*, Abstract HK 19.2
- Felix Rettig, Jochen Klein, Uwe Westerhoff, *ALICE TRD on-line tracking and trigger performance*, Abstract HK 21.1
- Christopher Romig, Jacob Beller, Jan Glorius, Johann Isaak, Norbert Pietralla, Anne Sauerwein, Deniz Savran, Marcus Scheck, Kerstin Sonnabend, Markus Zweidinger, *Relative Selbstabsorptionsmessung an* ^{140}*Ce zur modellunabhängigen Bestimmung von Übergangsbreiten in den Grundzustand*, Abstract HK 10.8
- Diego Semmler, T. Aumann, C. Bauer, M. Baumann, M. Beckstein, J. Beller, A. Blecher, N. Cvejin, M. Duchéne, F. Hug, J. Kahlbow, M. Knörzer, K. Kreis, C. Kremer, R. Lefol, B. Löher, P. Ries, C. Romig, H. Scheit, L. Schnorrenberger, D. Symochko, C. Walz, *The low energy photon tagger NEPTUN: Toward a detailed study of the pygmy dipole resonance with real photons*, Abstract HK 30.6
- Joel Silva, Johann Isaak, Bastian Löher, Deniz Savran, Matjaz Vencelj, Felix Wamers, *Temperature-dependent gain compensation of CsI(Tl) detectors using pulse shape analysis*, Abstract HK 22.6
- Jan Steinheimer, Jorgen Randrup, Volker Koch, *Spinodal amplification of density fluctuations in fluiddynamical simulations of relativistic nuclear collisions*, Abstract HK 26.8
- Iouri Vassiliev, Ivan Kisel, Maxim Zyzak, *Fast reconstruction of multi-strange hyperons in the CBM experiment*, Abstract HK 63.6
- Felix Wamers, Justyna Marganiec, Thomas Aumann, Carlos Bertulani, Leonid Chulkov, Michael Heil, Ralf Plag, Deniz Savran, Haik Simon, *The two-proton halo nucleus* ^{17}*Ne studied in high-energy nuclear breakup reactions*, Abstract HK 48.3
- Dennis Weber, Hans Feldmeier, Thomas Neff, *Phase-space representation for nuclear potentials*, Abstract HK 39.2
- Christian Wesp, Alex Meistrenko, Hendrik van Hees, Carsten Greiner, *Dynamical simulation of a linear sigma model near the critical point*, Abstract HK 20.3

Annual Spring Meeting, Section "Condensed Matter", Deutsche Physikalische Gesellschaft,

20 March - 4 May 2014, Dresden, Germany

- Sarah Becker, Rolando Rodriguez, Martin Greiner, Stefan Schramm, *Power transmission in a renewable European future*, Abstract SOE14.6

5th International Workshop for Future Challenges in Tracking and Trigger Concepts

12-14 May 2014, FIAS, Frankfurt

- V. Akashina, I. Kisel, I. Kulakov, *CA Track Finder*
- D. Anchishkin, I. Kisel, V. Vovchenko, *On-line extraction of model parameters*
- D.V. Belyakov, V.V. Ivanov, P.I. Kisel, M.V. Zyzak, *SIMD Kalman Filteron CPU/Phi/GPU Benchmark Servers at LIT JINR*
- Yuri Fisyak, Ivan Kisel, Iourii Vassiliev, Maksym Zyzak, *KF Particle Finder*
- Matthias Kretz, *On Vectorization and Recent Developments*
- David Rohr *ALICE HLT TPC Tracking for Run1 and plans for Run2*

XXIV International Conference on Ultrarelativistic Nucleus-Nucleus Collisions (Quark Matter 2014)

19-24 May 2014, Darmstadt, Germany

- Stephan Endres, Marcus Bleicher, Hendrik van Hees, *Studying Dilepton Production from SIS to RHIC Energies: Transport Calculations vs. Coarse-grained Dynamics*, Poster G-11
- H. van Hees, T. Lang, J. Steinheimer, M. Bleicher *Open heavy-flvor diffusion at LHC, RHIC, and FAIR*, Poster F-57
- Christoph Herold, Marlene Nahrgang, Igor Mishustin, Marcus Bleicher, Yupeng Yan, *Experimental signals of the QCD first-order phase transition from a stochastic fluid dynamical model*, Poster A-08
- A.I. Ivanytskyi, K.A. Bugaev, D.R. Oliinychenko, V.V. Sagun, I.N. Mishustin, D.H. Rischke, L.M. Satarov, G.M. Zinovjev, *Chemical Freeze-out Irregularities and Quark Gluon Plasma Formation*, Poster J-03
- Iurii Karpenko, Pasi Huovinen, Hannah Petersen, Marcus Bleicher, *Beam energy scan using a 3+1D viscous hydro+cascade model*, Poster H-15
- Olena Linnyk, Elena Bratkovskaya, Wolfgang Cassing, *Photon production and elliptic flow in heavy-ion collisions within the PHSD approach*, Poster G-19
- Rudy Marty, Elena Bratkovskaya, Wolfgang Cassing, Jörg Aichelin, Hamza Berrehrah, *Transport coefficients of QGP*, Poster A-04
- Kenji Morita, Bengt Friman, Krzysztof Redlich, *The Chiral Criticality in the Probability Distribution of Conserved Charges*, Poster I-23
- Dmytro Oliinychenko, Pasi Huovinen, Hannah Petersen, Iurii Karpenko, *Local equilibration and negative contributions: Investigating the transition interfaces in hybrid approaches*, Poster H-24
- V. V. Sagun, K. A. Bugaev, D. R. Oliinychenko, J. Cleymans, A. I. Ivanytskyi, I. N. Mishustin, E. G. Nikonov, *On Chemical Freeze-outs of Strange and Nonstrange Hadrons*, Poster J-04
- Jan Steinheimer, Volker Koch, Jorgen Randrup *The deconfinement phase transition in simulations of relativistic nuclear collisions*, Poster I-39
- J. Steinheimer, S. Schramm, *Do lattice data constrain the vector interaction strength of QCD?*, Poster B-21
- Janus Weil, *Strange and electromagnetic probes of dense nuclear matter at SIS*, Poster G-26

23rd International Conference on the Application of Accelerators in Research and Industry (CAARI 2014)

25-30 May 2014, San Antonio, Texas, USA

- Alexandre Gumberidze, *Electron- and proton-impact excitation of the heaviest Helium-like ions*, abstract #241

Workshop "RT-2014 - 19th Real-Time Conference"

26-30 May 2014, Nara, Japan

- V. Akishina and I. Kisel, *Online 4-Dimensional Event Building in the CBM Experiment*, Poster PS 1-23
- T. Kollegger, *The ALICE High Level Trigger System for LHC Run 2*, Poster PS 1-24

ICNFP 2014 – 3rd International Conference on New Frontiers in Physics

28 June - 6 August 2014, Kolymbari, Crete, Greece

- Ivan Kisel, *Scientific and High-Performance Computing at FAIR*, Poster

2nd International Workshop Neuro-Cognitive Mechanisms of Conscious and Unconscious Visual Perception

30 June - 2 July 2014, Delmenhorst, Germany

- Axel Kohler, Erhan Genc, Johanna Bergmann, and Wolf Singer, *Surface Area of Early Visual Cortex Predicts Individual Speed of Traveling Waves During Binocular Rivalry*, Book of Abstracts p. 39

XIX Biennial International Conference on Infant Studies (ICIS2014)

2-6 July 2014, Berlin, Germany

- J. Triesch, *Learning where to look: infants, models, robots*, Abstract 2-019
- M. Murakami, B. Kröger, P. Birkholz, J. Triesch, *Listen and Babble: A Model of Vowel Acquisition based on Imitation Learning*, Poster

Association for the Scientific Study of Consciousness ASSC18

16 -19 July 2014, Brisbane, Australia

- Thomas Metzinger and Jennifer Windt, *Dreaming, consciousness and the self: Spatiotemporal self-location and minimal phenomenal selfhood*, abstract

Twenty-third annual Computational Neuroscience Meeting CNS2014

26-31 July 2014, Québec City, Canada

- Dmitry Tsigankov, Matthias Kaschube, *The emergence of cohorts of co-active neurons in random recurrent networks provides a mechanism for orientation and direction selectivity*, Poster, BMC Neuroscience 2014, 15 (Suppl 1): P129

20th Particles and Nuclei International Conference (PANIC2014)

25-29 Aug. 2014, Hamburg, Germany

- Janus Weil, Stephan Endres, Hendrik von Hees, Marcus Bleicher, Ulrich Mosel, *Dilepton production in transport-based approaches* Abstract ID: 173

Bernstein Conference 2014

2-5 Sept. 2014, Göttingen, Germany

- Christoph Hartmann, Andreea Lazar, Jochen Triesch, *Self-organized learning and inference explain key properties of neural variability*, Book of Abstracts p. 20
- Bastian Eppler, Dominik F. Aschauer, Simon Rumpel, Matthias Kaschube, *Discrete representations in mouse auditory cortex and their stability in the presence of synaptic turnover*, Poster W40
- Christoph Hartmann, Ipek Oezdemir, Michael Wibral, Ralf Galuske, Jochen Triesch, Matthias Kaschube, *Local Information Dynamics in a Model of A18-PMLS Interaction in Cat Visual Cortex*, Poster W41
- Bettina Hein, Matthias Kaschube, *Low-level coherence in neuronal interactions suffice to generate highly coherent orientation preference maps*, Poster W42
- Rudra Narayan Hota, Patrick Harding, Venkata Subbarao Veeravasarapu, Christoph von der Malsburg, Visvanathan Ramesh, *Top-down Contextual Modeling for Vision*, Poster W62
- Daniel Born, Bernhard Nessler, Jochen Triesch *Interplay of Multiple Learning Rules for Non-Negative Sparse Auto-Encoders*, Poster W74
- Alexander Schmid, Visvanathan Ramesh, Christoph von der Malsburg, *A Simple Dynamic Model for Image Interpretation*, Poster W78
- Viola Priesemann, Michael Wibral, Mario Valderrama, Robert Proepper, Michel Le Van Quyen, Theo Geisel, Jochen Triesch, Danko Nikolić, Matthias H.J. Munk, *Do Highly Parallel Spike Recordings from Rats, Cats, and Monkeys Indicate a Self-Organized Critical State?*, Poster T70

- Venkata Subbarao Veeravasarapu, Rudra Narayanan Hota, Constantin Rothkopf, Visvanathan Ramesh, *Simulation Platform for Cognitive Vision*, Poster T92
- Constantin A. Rothkopf, *Intrinsic costs in human navigation inferred with inverse reinforcement learning*, Poster T73
- Daniel Miner, Jochen Triesch, *Self-Organization in Cortical Wiring: Long Tails and Common Neighbors*, Poster T127
- Alexander Priamikov, Jochen Triesch, *OpenEyeSim – a biomechanical model for studying the development of oculomotor control*, Poster T128

Quark Confinement and the Hadron Spectrum XI

7-12 Sept. 2014, St. Petersburg, Russia

- Stefan Schramm, *Models of Quark-Hadron Matter and Compact Stars*, Book of Abstracts p. 12
- Reinhard Stock, Francesco Becattini, Marcus Bleicher, Jan Steinheimer, *The QCD parton-hadron phase boundary line located from Statistical Model analysis of the hadronic multiplicities in Pb+Pb collisions at SPS and LHC*, Book of Abstracts p. 66
- Laura Tolos, Cristina Manuel, Jaume Tarrus, Sreemoyee Sarkar, *Transport coefficients in superfluid neutron matter*, Book of Abstracts p. 10

Workshop "GPU Computing in High Energy Physics"

10-12 Sept. 2014, Pisa, Italy

- V. Akishina, I. Kisel, I. Kulakov, M. Zyzak, *FLES, First Level Event Selection package for the CBM experiment*, Poster

DPG Physics School on General Relativity @ 99

14-19 September, 2014, Bad Honnef, Germany

- Alain Dirkes, Marco Knipfer, Sven Köppel, Piero Nicolini, *Quantum Gravity improved Black Holes*, Poster

Workshop "Perspectives of GPU Computing in Physics and Astrophysics"

15-17 Sept. 2014, Rome, Italy

- I. Kisel, I. Kulakov, M. Zyzak, *Fast reconstruction of charged particle trajectories on Nvidia GPU*, Poster

Hot Quarks 2014,

21-28 Sept. 2014, Las Negras, Andalucia, Spain,

- I. Karpenko, M. Bleicher, P. Huovinen, H. Petersen, *Beam energy scan using a viscous hydro+cascade model*
- J. Weil, H. van Hees, U. Mosel, S. Endres, M. Bleicher, *Dilepton Production in transport-based approaches*

TRIBCT 2014 Workshop on Translational Research in Ion Beam Cancer Therapy

30 Sept. - 2 Oct. 2014, Aarhus University Hospital, Skejby, Denmark

- M. Krämer, R. Grün, E. Scifoni, F. Schmitz, M. Durante, *Biological effects in ion beam radiotherapy*, Book of Abstracts p. 20

Charged & Neutral Particles Channeling Phenomena – Channeling 2014,

5-10 Oct. 2014, Capri-Naples, Italy

- Gennady Sushko *Electron and Positron Channeling in Straight and Periodically Bent Axial Si Channels*, Poster PS1-16

4th Joint Meeting of the APS Division of Nuclear Physics and the Physical Society of Japan

7-11 October 2014, Waikoloa, Hawaii

- Sungtae Cho, Koichi Hattori, Houng Lee, Kenji Morita *Charmonium spectroscopy in strong magnetic fields by QCD sum rules* Bull. American Physical Society 59 (10) MJ.00006
- Chhanda Samanta, Torsten Schuerhoff, Stefan Schramm, *Neutron Dripline for Magnesium nuclei and hypernuclei*, Bull. American Physical Society 59 (10) EL.00007

International Conference on Science and Technology for FAIR

13-17 October 2014, Worms, Germany
- J. de Cuveland, D. Hutter, V. Lindenstruth, *CBM First-level Event Selector (FLES)*, Poster

Joint IEEE International Conferences on Development and Learning and Epigenetic Robotics (ICDL-Epirob 2014)

13-16 Oct. 2014, Genoa, Italy
- J. Triesch, A. Priamikov, *OpenEyeSim – A platform for biomechanical modeling of oculomotor control* Abstract p. 394

Annual Meeting of the Society for Neuroscience

15-19 November 2014, Washington, DC, USA
- F. Roux, M. Wibral, W. Singer, P.J. Uhlhaas, *Age related changes of MEG alpha and gamma-band activity reflect the late maturation of distractor-inhibition during adolesscence*, Poster A50
- Dmitry Tsigankov, Matthias Kaschube, *The emergence of cohorts of active neurons in random recurrent networks provides the mechanism for acquiring orientation and direction selectivity*, Poster II20
- David E Whitney, Gordon B. Smith, Matthias Kaschube, David Fitzpatrick *ON - OFF maps in supragranular layers of ferret visual cortex*, Poster DD6
- Bettina Hein, Matthias Kaschube, *Weakly coherent neuronal interactions are sufficient to explain highly coherent orientation preference maps*, Poster CC34
- Gordon B. Smith, David E. Whitney, Matthias Kaschube, David Fitzpatrick, *Emergence of ON - OFF maps precedes orientation maps in ferret visual cortex*, Poster DD5
- Matthias Kaschube, Bettina Hein, Klaus Neuschwander, Gordon B. Smith, David E. Whitney, David Fitzpatrick, *Chronic imaging of GCaMP6 population activity in ferret visual cortex reveals spontaneous modular patterns of activity prior to eye opening*, Poster DD7
- V. Priesemann, M. Wibral, M. Valderrama, R. Pröpper, M. Le Van Quyen, J. Triesch, T. Geisel, D. Nikolić, M. Munk, *Spiking activity in vivo suggests a slightly sub-critical brain state in rats, cats and monkeys*, Poster EE14

The International Conference for High Performance Computing, Networking, Storage and Analysis (SC14)

16-21 Nov. 2014, New Orleans, LA
- David Rohr, *The L-CSC cluster: An AMD-GPU-based cost- and power-efficient multi-GPU system for Lattice-QCD calculations at GSI*

HBP Workshop on Stochastic Neural Computation

27 Nov. 2014, EITN, Paris, France
- Andreea Lazar, Wolf Singer, Danko Nikolić, *Signal-to-noise ratio in V1 population activity*, poster
- Christoph Hartmann, Andreea Lazar, Jochen Triesch, *Self-organized learning and inference explain key properties of neural variability*, poster
- Bernhard Nessler, *Stochastic Sampling without Noise*, poster

7th International Symposium on Attention in Cognitive Systems (ISACS2014)

1 December 2014, Bielefeld, Germany
- Constantin A. Rothkopf, *Vision through tasks: from the Bongard problems to sandwich making*, abstract
- Alex Priamikov, *OpenEyeSim: a biomechanical simulator for studying the development of oculomotor control*, abstract

FIAS Publications 2014

In the following all publications from the year 2014 with at least one author quoting the FIAS affiliation are presented. The first listing collects the papers published in regular journals. In the second listing contributions to conference proceedings are displayed, as well as papers which have not (yet) been published in print, but are publicly available on a preprint server. Conference abstracts or posters are not included. A further section lists published books and edited proceedings.

A. Journal publications

[1] B. Abelev and others (ALICE collaboration), "Azimuthal anisotropy of D meson production in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV," *Phys. Rev. C* **90** (2014) 034904, `arXiv:1405.2001 [nucl-ex]`.

[2] B. Abelev and others (ALICE collaboration), "Beauty production in pp collisions at $\sqrt{s} = 2.76$ TeV measured via semi-electronic decays," *Phys. Lett. B* **738** (2014) 97–108, `arXiv:1405.4144 [nucl-ex]`.

[3] B. Abelev and others (ALICE collaboration), "Centrality, rapidity and transverse momentum dependence of J/Ψ suppression in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV," *Phys. Lett. B* **743** (2014) 314–327, `arXiv:1311.0214 [nucl-ex]`.

[4] B. Abelev and others (ALICE collaboration), "Event-by-event mean p_T fluctuations in pp and Pb-Pb collisions at the LHC," *Eur. Phys. J. C* **74** (2014) 3077, `arXiv:1407.5530 [nucl-ex]`.

[5] B. Abelev and others (ALICE collaboration), "Exclusive J/ψ photoproduction off protons in ultra-peripheral p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV," *Phys. Rev. Lett.* **113** (2014) 232504, `arXiv:1406.7819 [nucl-ex]`.

[6] B. Abelev and others (ALICE collaboration), "J/Ψ production and nuclear effects in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$TeV," *JHEP* **1402** (2014) 073, `arXiv:1308.6726 [nucl-ex]`.

[7] B. Abelev and others (ALICE collaboration), "Measurement of charged jet suppression in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV," *JHEP* **1430** (2014) 013, `arXiv:1311.0633 [nucl-ex]`.

[8] B. Abelev and others (ALICE collaboration), "Measurement of prompt D-meson production in p-Pb collisions at $\sqrt{s_{NN}}$ =5.02 TeV," *Phys. Rev. Lett.* **113** (2014) 232301, `arXiv:1405.3452 [nucl-ex]`.

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[12] B. Abelev and others (ALICE collaboration), "Multiplicity dependence of pion, kaon, proton and lambda production in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV," *Phys. Lett. B* **728** (2014) 25–38, `arXiv:1307.6796 [nucl-ex]`.

[13] B. Abelev and others (ALICE collaboration), "Multi-strange baryon production at mid-rapidity in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV," *Phys. Lett. B* **728** (2014) 216–227, `arXiv:1307.5543 [nucl-ex]`.

[14] B. Abelev and others (ALICE collaboration), “Neutral pion production at midrapidity in pp and Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV,” *Eur. Phys. J. C* **74** (2014) 3108, arXiv:1405.3794 [nucl-ex].

[15] B. Abelev and others (ALICE collaboration), “Performance of the ALICE Experiment at the CERN LHC,” *Int. J. Mod. Phys. A* **29** (2014) 1430044, arXiv:1402.4476 [nucl-ex].

[16] B. Abelev and others (ALICE collaboration), “Production of charged pions, kaons and protons at large transverse momenta in pp and Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV,” *Phys. Lett. B* **736** (2014) 196–207, arXiv:1401.1250 [nucl-ex].

[17] B. Abelev and others (ALICE collaboration), “Suppression of $\psi(2S)$ production in p-Pb collisions at $\sqrt{s_{NN}}$ =5.02 TeV,” *JHEP* **1412** (2014) 73, arXiv:1405.3796 [nucl-ex].

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[21] B. Abelev and others (ALICE collaboration), “Two- and three-pion quantum statistics correlations in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV at the CERN Large Hadron Collider,” *Phys. Rev. C* **89** (2014) 024911, arXiv:1310.7808 [nucl-ex].

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[27] L. Adamczyk and others (STAR collaboration), “Beam energy dependence of moments of the net-charge multiplicity distributions in Au+Au collisions at RHIC,” *Phys. Rev. Lett.* **113** (2014) 092301, arXiv:1402.1558 [nucl-ex].

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[32] L. Adamczyk and others (STAR collaboration), “J/ψ production at low p_T in Au+Au and Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV with the STAR detector,” *Phys. Rev. C* **90** (2014) 024906, arXiv:1310.3563 [nucl-ex].

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[34] L. Adamczyk and others (STAR collaboration), “Neutral pion cross section and spin asymmetries at intermediate pseudorapidity in polarized proton collisions at $\sqrt{s}$ =200 GeV,” *Phys. Rev. D* **89** (2014) 012001, arXiv:1309.1800 [nucl-ex].

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C. Books and edited proceedings

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FIAS Journal Publications 2014

Sorted according to frequency

Journal	Impact	2014
		204
Phys. Rev. C	3.72	44
Phys. Lett. B	4.57	20
Phys. Rev. Lett.	7.94	15
J. Phys. G: Nucl. Part. Phys.	5.33	10
Phys. Rev. D	4.69	9
Eur. Phys. J. C	5.25	6
Nucl. Phys. A	1.53	6
JHEP	5.62	4
Cerebral Cortex	6.83	3
Energy	3.65	3
Eur. Phys. J. D	1.51	3
Nucl. Inst. Meth. B	1.27	3
Phys. Rev. A	3.04	3
PLOS ONE	3.73	3
Applied Radiation and Isotopes	1.18	2
Astrophys. J.	6.73	2
Computer Physics Communications	3.08	2
Front. Comput. Neurosci.	2.48	2
Frontiers in Human Neuroscience	2.91	2
IEEE Trans. on Pattern Analysis and Machine	4.80	2
J. of Machine Learning Research	3.42	2
J. Phys. Chem. A	2.77	2
Journal of Magnetic Resonance	2.30	2
Neural Computation	1.76	2
Nucl. Inst. Meth. A	1.14	2
Nuclear Data Sheets	2.67	2
physica status solidi (b)	1.49	2
Ukrainian Journal of Physics		2
Advances in High Energy Physics	3.50	1
Angew. Chem. Int. Ed.	13.73	1
Astrophys. J. Lett.	6.35	1
Biological Psychiatry	9.25	1
Biophys. Journ.	3.67	1
BMC Bioinformatics	3.02	1
Brain Stimulation	4.54	1
Chinese Physics Letters	0.81	1
Current Opinion in Neurobiology	7.34	1
Cytometry Part A	3.71	1
Development	6.21	1
Developmental Science	4.28	1
Eur. J. Phys.	0.64	1
Eur. Phys. J. A	2.04	1
Europhys. Lett.	2.27	1

Sorted according to impact factor

Journal	Impact	2014
		204
Materials Science and Engineering Reports	13.90	1
Angew. Chem. Int. Ed.	13.73	1
Nature Structural and Molecular Biology	11.90	1
Biological Psychiatry	9.25	1
Nucleic Acids Research	8.28	1
Phys. Rev. Lett.	7.94	15
Current Opinion in Neurobiology	7.34	1
Journal of Neuroscience	6.91	1
Cerebral Cortex	6.83	3
Astrophys. J.	6.73	2
Astrophys. J. Lett.	6.35	1
Development	6.21	1
Frontiers in Synaptic Neuroscience	5.78	1
JHEP	5.62	4
Mon. Not. R. Astron. Soc.	5.52	1
J. Phys. G: Nucl. Part. Phys.	5.33	10
Eur. Phys. J. C	5.25	6
PLOS Computational Biology	4.87	1
IEEE Trans. on Pattern Analysis and Machine	4.80	2
Phys. Rev. D	4.69	9
Phys. Lett. B	4.57	20
Brain Stimulation	4.54	1
Developmental Science	4.28	1
Frontiers in Neuroanatomy	4.06	1
IEEE Transactions on Neural Networks and Le	3.77	1
PLOS ONE	3.73	3
Phys. Rev. C	3.72	44
Cytometry Part A	3.71	1
Biophys. Journ.	3.67	1
Energy	3.65	3
Advances in High Energy Physics	3.50	1
J. of Machine Learning Research	3.42	2
Frontiers in Systems Neuroscience	3.37	1
J. Chem. Phys.	3.16	1
Computer Physics Communications	3.08	2
Phys. Rev. A	3.04	3
BMC Bioinformatics	3.02	1
Renewable Energy	2.99	1
Proteins: Structure, Function, and Bioinforma	2.92	1
Frontiers in Human Neuroscience	2.91	2
J. Phys. Chem. A	2.77	2
Physics in Medicine and Biology	2.70	1
Nuclear Data Sheets	2.67	2

Frontiers in Neuroanatomy	4.06	1
Frontiers in Synaptic Neuroscience	5.78	1
Frontiers in Systems Neuroscience	3.37	1
IEEE Transactions on Neural Networks and Le	3.77	1
Int. J. Mod. Phys. A	1.13	1
Int. J. Mod. Phys. E	0.63	1
Int. J. of Geometric Methods in Mod. Physics	0.95	1
J. Chem. Phys.	3.16	1
J. Comput. Neurosci.	2.44	1
J. Phys. A: Math. Theor.	1.77	1
Journal of Instrumentation	1.53	1
Journal of Neuroscience	6.91	1
Journal of Vision	2.48	1
Laser and Particle Beams	2.02	1
Materials Science and Engineering Reports	13.90	1
Mod. Phys. Lett. A	1.11	1
Mod. Phys. Lett. B	0.48	1
Mon. Not. R. Astron. Soc.	5.52	1
Nature Structural and Molecular Biology	11.90	1
Nucleic Acids Research	8.28	1
Physics in Medicine and Biology	2.70	1
Physics of Atomic Nuclei	0.54	1
PLOS Computational Biology	4.87	1
Proteins: Structure, Function, and Bioinforma	2.92	1
Radiation Physics and Chemistry	1.38	1
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Review of Scientific Instruments	1.60	1
Robotics and Autonomous Systems	1.16	1
Wiley Interdiscipl. Reviews: Cognitive Science	1.41	1

Front. Comput. Neurosci.	2.48	2
Journal of Vision	2.48	1
J. Comput. Neurosci.	2.44	1
Journal of Magnetic Resonance	2.30	2
Europhys. Lett.	2.27	1
Eur. Phys. J. A	2.04	1
Laser and Particle Beams	2.02	1
J. Phys. A: Math. Theor.	1.77	1
Neural Computation	1.76	2
Review of Scientific Instruments	1.60	1
Journal of Instrumentation	1.53	1
Nucl. Phys. A	1.53	6
Eur. Phys. J. D	1.51	3
physica status solidi (b)	1.49	2
Wiley Interdiscipl. Reviews: Cognitive Science	1.41	1
Radiation Physics and Chemistry	1.38	1
Nucl. Inst. Meth. B	1.27	3
Applied Radiation and Isotopes	1.18	2
Robotics and Autonomous Systems	1.16	1
Nucl. Inst. Meth. A	1.14	2
Int. J. Mod. Phys. A	1.13	1
Mod. Phys. Lett. A	1.11	1
Int. J. of Geometric Methods in Mod. Physics	0.95	1
Chinese Physics Letters	0.81	1
Eur. J. Phys.	0.64	1
Int. J. Mod. Phys. E	0.63	1
Physics of Atomic Nuclei	0.54	1
Mod. Phys. Lett. B	0.48	1
Ukrainian Journal of Physics		2

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Dr. Andreas Strüngmann
Dr. Thomas Strüngmann