Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research

Dubna International Advanced School of Theoretical Physics
Helmholtz International Summer School

Dubna, Russia, **August 25-September 6 , 2014**

Lattice QCD, Hadron Structure and Hadronic Matter

SCIENTIFIC PROGRAM:

Introduction to lattice gauge theory
Hadron structure and spectroscopy
Non-zero temperature and baryon number density
Chiral perturbation theory
External field effects
Lattice gauge theory and nuclear theory
Non-QCD applications of lattice gauge theory
Simulation algorithms

ORGANIZERS:

Owe Philipsen (Inst. for Theoretical Physics, Goethe Univ. Frankfurt)
Ernst-Michael Ilgenfritz (VBLHEP and BLTP, JINR Dubna)
Oleg Teryaev (JINR, Dubna)

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Topics:

Introduction to Lattice Gauge Theory
Chiral perturbation theory
Hadron structure and spectroscopy
Non-zero temperature and baryon number density
Heavy quark physics
External field effects
Lattice Gauge Theory and nuclear theory
Non-QCD applications of Lattice Gauge Theory
Simulation algortihms

International Programme Committee:

Vitaly Bornyakov (IHEP, Serpukhov and ITEP, Moscow)
Victor Braguta (IHEP, Serpukhov and ITEP, Moscow)
Ernst-Michael Ilgenfritz (VBLHEP and BLTP, JINR Dubna)
Valentin Mitrjushkin (BLTP, JINR Dubna)
Michael Mueller-Preussker (Humboldt Univ. Berlin)
Owe Philipsen (Institute for Theoretical Physics, Goethe Univ. Frankfurt)
Stefan Schaefer (NIC, DESY Zeuthen)
Oleg Teryaev (BLTP, JINR Dubna)

Local Oranizing Committee:

David Blaschke	(Wroclaw Univ. and BLTP, JINR Dubna)
Evgenij Davydov	(BLTP, JINR Dubna)
Alexander Filippov	(BLTP, JINR Dubna)
Elena Kolganova	(BLTP, JINR Dubna)
Valentina Novikova	(JINR Dubna)
Irina Pirozhenko	(BLTP, JINR Dubna)
Oleg Teryaev	(BLTP, JINR Dubna)
Petr Tretyakov	(BLTP, JINR Dubna)
Vyachevslav Zhuravlev	(BLTP, JINR Dubna)

From 25 August to 5 September 2014, 49 students from 14 countries came to the BLTP of JINR Dubna to participate in the Helmholtz International Summer School (HISS) ``Lattice QCD, Hadron Structure and Hadronic Matter''. The strongest groups of students came from Russia and Germany (both 14), followed by students from Belarus and Japan (both 3), Ukraine, Sweden, Austria, Poland and India (all 2), and finally Armenia, USA, Ireland, Italy, and Portugal (1).

The School was part of the permanent series of pedagogical events going on in BLTP, under the roof of the Dubna International Advanced School for Theoretical Physics (DIAS-TH), devoted primarily to the qualification of young scientists (ranging from master student to young post docs).

The Organization Committee consisted of Prof. Owe Philipsen (Frankfurt University), Prof. Ernst-Michael Ilgenfritz (VBLHEP and BLTP, JINR Dubna) and Prof. Oleg Teryaev (BLTP, JINR Dubna).

This was the 21-st HISS, after this series has been launched in 2004 with the financial support provided by the President of the Helmholtz Association. Other traditional sponsors besides of JINR itself, are the ``Russian Foundation for Fundamental Research'' and the ``Dynastia'' foundation from the Russian side.

The Helmholtz Association is one of Germany's research organizations, including 18 non-university research centers and 6 on-site institutes at universities, being responsible for the scientific policy in 10 thematic complexes, oriented to solving problems of basic research character in natural sciences and medical research.

Recently, the participation of the Helmholtz Association in the Dubna Schools has been reorganized and broadened. Nowadays, 10 Helmholtz Centers and Institutes working in the focus program ``Structure of Matter'' (instead of the two traditional partners of JINR, DESY and GSI) are directly involved by sponsoring the activities of the HISS. Some of these Helmholtz Institutes only recently became part of the Helmholtz Association. It is hoped that this step will lead to an extension and diversification of the relations between the Helmholtz Association and JINR.

The Director of the Helmholtz Institute Mainz, Prof. F. Maas, was one of the lecturers at the school, lecturing about the objectives of the future FAIR (Darmstadt) in the field of precision experiments in particle physics at low energies. This experimental program, for example, raises the quest for high-precision spectral calculations in lattice QCD.

It is widely recognized that Lattice Gauge Theory, in particular Lattice QCD, represents a framework for theoretical investigations which is not restricted to the possibilities of perturbation theory. Roughly speaking, describing (1) processes at low energy and impulse transfer, (2) composite systems in their ground state or at low excitation (like hadrons themselves) and (3) extended hadronic systems at high temperature and density, would not be possible within perturbation theory or would hit the borders of its applicability.

Its exclusive role of lattice field theory as a general, model-independent method, amenable to systematical improvement, ``the lattice'' owes to the fact, that it is mainly based on the use of numerical simulations, and on (to some extent very) sophisticated methods of analyzing the simulation data, guided by field theoretic principles. In the result, the lattice approach can be called an approach ``from first principles'', and the precision is only limited by the availability of resources in computing power (limiting the statistics) and data storage (limiting the lattice sizes).

By large, due to the fundamental character of the subject, the School was mainly a school of methods, and the main topics of the School have been the same as of the previous, first HISS Lattice School Dubna 2011. Deviations can be justified by having the whole stream of Helmholtz International Lattice Schools in view (see below).

Two lecture series given by M. Mueller-Preussker [Berlin] and K. Jansen [DESY Zeuthen] were of introductory character, independent of each other and of increasing difficulty, thus giving both lecturers room also to emphasize their individual points of view, for example the role of topological effects in QCD (Mueller-Preussker). Quarks and gluons, the basic degrees of freedom of Quantum Chromo Dynamics, have never be observed in isolation. Instead, they are permanently confined within particles (namely hadrons). This was the first puzzle which has given rise to the emergence of lattice field theory thanks to the groundbreaking idea of K. G. Wilson.

Two other lecture series given by C. Hoelbling [Wuppertal] and M. Goeckeler [Regensburg] were dealing with the potential of Lattice QCD to explain the hadron mass spectrum and to explore the internal structure of hadrons. Amplitudes, hadronic matrix elements and parton distribution functions are the link to exclusive and inclusive scattering processes studied in High Energy Physics (where only hadrons and leptons are finally observed). The masses and decays of the new so called ``XYZ states'', discovered in the past decade by the Belle, BaBar, CLEO-c, CDF, D0, CMS, LHCb and BES-III collaborations in the range of few GeV, are a particular challenge for lattice spectroscopy.

There is a another series of HISS in Dubna on QCD at high energy and matter density. Therefore, this particular aspect of Lattice QCD, which is exceedingly important for JINR because of the institute's activity in Heavy Ion Physics, was this time restricted to be part of the broader lectures given by O. Philipsen [Frankfurt], who concentrated on the question of ``how'' aspects of hot and dense matter can be explored. The corresponding field of application (ranging from cold matter in Neutron Stars to hot matter created in Heavy Ion Reactions) has been presented and will be presented in future at the ``Dense Matter in Heavy Ion Collisions and Astrophysics'' series of HISS, on average taking place every other year.

A similar remark applies to the ``Physics of Heavy Quarks and Hadrons'' series, organized every three or four years in Dubna. The states of charmonia and bottomonia (hidden heavy flavor) and open charm or beauty states (heavy-light hadrons) are addressed by lattice spectroscopy, while the lectures of C. Hoebling were restricted to hadrons built exclusively out of light quarks (and anti quarks).

Another aspect missing this year was ``Supersymmetry on the Lattice'', which meets particular difficulties already on the level of mathematical formulation. For example, there is no obvious Leibniz rule on the lattice. It is recommendable to invite one or two such lectures to the regular summer schools on SUSY field theory, which have a good tradition in Dubna, in order to complement the traditional approaches.

The specifics of the ``Lattice QCD, Hadron Structure and Hadronic Matter'' Schools should also in future be the possibility to obtain insight more into ``how to do lattice gauge theory'' as a universal framework with many applications to hadron physics (as indicated above) than ``what are the most recent results'', since these results are sufficiently often presented to the broader auditorium as ``ultimate truth''.

In this year, lectures in Chiral Perturbation Theory given by M. Golterman [San Francisco] have been for the first time on the agenda at HISS, because ChPT is an indispensable tool to provide justified extrapolations towards realistic quark masses (including the theoretically challenging chiral limit of vanishing quark masses) from simulation results obtained at numerically accessible, normally somewhat heavier quark masses (and to infinite lattice volumes from lattices which are finite by necessity). For example, Lattice QCD is able to provide the so-called Low Energy Coefficients which are parametrizing the interactions within the chiral effective hadron theory. They are open for fitting to experiment, as long as they are/were unknown from a first principles' calculation on the lattice.

As a relatively new field of applications, lattice theorists have discovered for them Nuclear Theory during recent years. A. Walker-Loud [Jefferson Lab.] has been distinguished by the ``Wilson award'' (the little ``Lattice Nobel Price'') of the year 2013 at the annual Lattice Conference for his contributions to this field. He has given an exciting overview over many fundamental questions (raised by dark matter, the baryon asymmetry of the universe and the nuclear synthesis). Many of known facts are the results of unbelievable fine-tunings, including the conditions of life in our universe. These puzzles might find a solution through a ``renaissance of Nuclear Physics'' achieved through the connection with QCD, which will finally lead to a proper understanding of Nuclear Physics from first principles (i. e. from the Standard Model plus input from ``Beyond Standard Model Physics''). This might come into reach soon with increasing computing power. Still, the lecturer's promise of ability to describe fewnucleon systems (say, up to carbon) by lattice simulations were not as optimistic as other lattice physicists claim. Unfortunately, a second lecturer to this field had to cancel his participation.

Three lectures had been devoted to ``Forthcoming Experiments''. Besides the FAIR lectures of F. Maas (mentioned in the beginning), the forthcoming experiments at the two Dubna facilities ``Baryon Matter at Nuclotron'' (BM@N) and the technical challenges of the NICA heavy ion collider complex have been the topics of lectures given by O. Rogachevsky (JINR Dubna) and G. Trubnikov (JINR Dubna).

A special part of the program had been devoted to ``Theoretical Topical Lectures'', each with a smaller, limited scope.

In the high temperature, deconfined phase of QCD, the many-hadron structure of a specimen of hadronic matter becomes transformed into a kind of fluid, inside of which, however, localized excitations other than hadron-like, namely topological ones of the gauge field (monopoles and vortexes) are seen to exist. They are condensing at lower temperature, thereby probably causing the difficult-to-understand confinement. Their appearance in the high-temperature phase might explain the unusually small viscosity of the hadronic fluid, contradicting the plain weakly interacting quark-gluon gas picture. V. Bornyakov [ITEP Moscow] gave two lectures about this nice facet of high-temperature QCD.

Another pair of special lectures was given by G. Endrodi [Regensburg], the second ``Lattice Nobel Laureate'' (of 2014) among the lecturers, on the effect of external magnetic fields on the phase structure and the properties of hot hadronic matter. Magnetic fields of a strength even stronger than existent in astrophysics are created in the process of non-central heavy-ion collisions, having influence on the subsequent phase transition back to hadron matter.

O. Teryaev [JINR Dubna] gave two lectures about ``Rotating QCD matter'', pointing out important consequences of the chiral anomaly, including the possibility of transferring mesoscopic rotation (vorticity) to the polarization of emerging spinning particles.

P. Buividovich [Regensburg] gave two lectures on ``Anomalous Transport from a Lattice Point of View'', demonstrating the possibility of non-dissipative quantum-fluid phenomena (similar to well-known superconductivity and super fluidity) by a careful consideration of the lattice regularization.

While these examples are addressing directly the properties of the quark-gluon plasma generated in heavy-ion collisions, another pair of special lectures delivered by D. Smith [Darmstadt] was devoted to ``Graphene as Lattice Field Theory''. Lattice gauge theory has many non-QCD applications, but in addition to this the carbon-polymer material graphene is a fantastic solid-state system providing a showcase of an emerging quasi-relativistic, two-dimensional field theory embedded in the usual three-dimensional world, which may inherit interesting, technologically useful properties from a suitable substrate. Besides this physics side, the lecturer described the specifics of the simulation algorithms applied to the system of itinerant carbon valence electrons.

A. Sternbeck [Jena], during three lectures, has taught the Hybrid Monte Carlo method for simulating gauge field gluons receiving feedback (loop effects) from ``dynamical quarks''. He started from the ``quenched approximation'', where this back reaction was usually neglected for simplicity, a common practice applied during the first decades of lattice QCD. While many features of spectroscopy are relatively independent of this approximation, once few hadron masses are put to their physical values, the world of phase transitions is impossible to understand without the step from ``quenched'' to ``dynamical QCD''. In a tutorial, the lecturer provided to all interested students a working program, which allows to understand all principles of HMC being at work for the case of a non-gauge field theory.

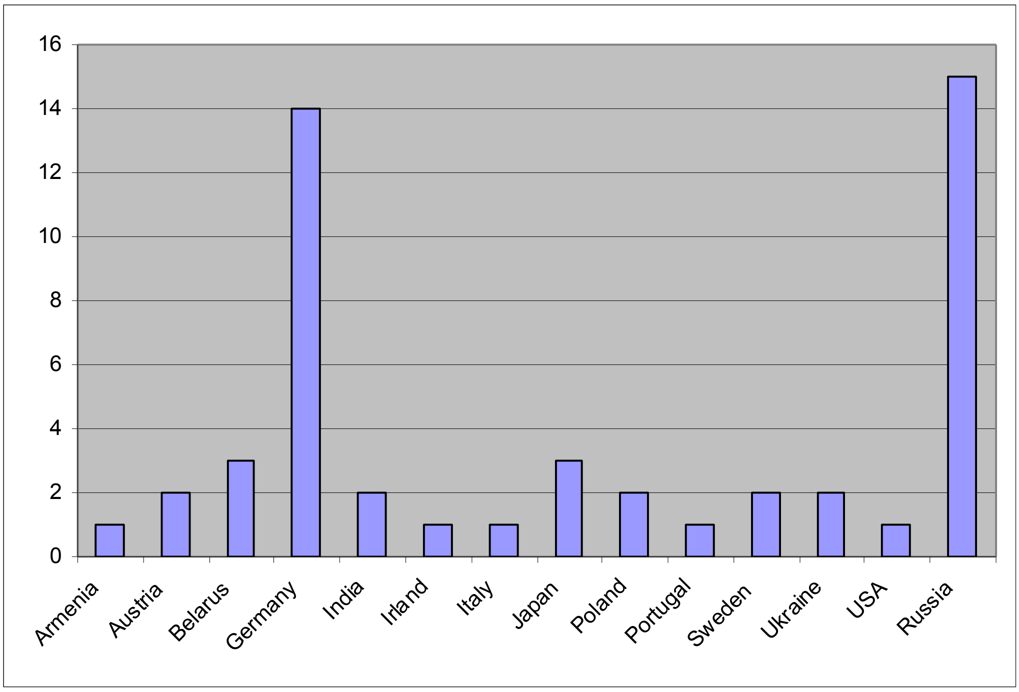
Programming for Lattice QCD, according to the homogeneous distribution of field degrees of freedom, is very suitable for parallel programming on multiprocessor (CPU) complexes guided by the domain decomposition idea. Still, a large part of the computing time is used for operations of very easy arithmetic (linear algebra), such that part of the computing load can better be exported to specialized processors (for example GPU, graphical processing units). Therefore, heterogeneous computer architectures are becoming more and more interesting for purposes of lattice simulations. The hybrid computing group of LIT (D. Podgainy, O. Streltsova, E. Alexandrov, E. Zemlyanaya, T. Shapozhnikova, M. Zuev, A. Ayriayan) has given an introduction into the programming philosophy and the possibilities being under development at LIT (the cluster ``HybriLIT'') in five lectures/tutorials under the title ``Parallel programming technologies of hybrid architectures''.

23 students had prepared posters documenting how far they had already penetrated into lattice field theory and simulations. They have presented their, partly already impressive, successes in applying

lattice and other path integral techniques to various problems of theoretical physics. Four of them have been specially awarded.

List of Students

1.AGADJANOV Andria	Bonn University, Germany
2.AGADJANOV Dimitri	Bonn University, Germany
3.ALVAREZ-CASTILLO David	BLTP JINR, Dubna, Russia
4.ANIKIN Evgeny	MIPT, Dolgoprudny, Russia
5.ANTROPOV Sergii	Dnipropetrovsk National University, Ukraine
6.BEGUN Alexander	Far Eastern Federal Univ., Vladivostok, Russia
7.BIRYUKOV Alexander	Samara University, Russia
8.BORLA Umberto	Uppsala University, Sweden
9.BOYDA Denis	Far Eastern Federal Univ., Vladivostok, Russia
10.BOZ Tamer	National University of Ireland, Ireland
11.CALLE JIMENEZ Sergio	Tokyo Institute of Technology, Japan
12.CAN Kadir Utku	Tokyo Institute of Technolog, Japan
13.COLASANTE Damaso	University Tor Vergata, Roma, Italy
14.DENISSENYA Mikhail	University of Graz, Austria
15.DOI Takahiro	Kyoto University, Japan
16.DUBININ Alexandr	University of Wroclaw, Poland
17.ERBEN Felix	Mainz University, Germany
18.FERREIRA Marcio	University of Coimbra, Portugal
19.FRIZEN Alexandra	BLTP JINR, Dubna, Russia
20.GARCIA VERA Miguel	DESY/Humboldt University Berlin, Germany
21.GLESAAEN JONAS Rylund	Frankfurt University, Germany
22.GOY Vladimir	Far Eastern Federal Univ., Vladivostok, Russia
23.GUENTHER Jana	Wuppertal University, Germany
24.HELMES Christopher	Bonn University, Germany
25.HOLICKI Lukas	Technical University, Darmstadt, Germany
26.HUA Jiayu	Mainz University, Germany
27.IVANOV Alexander	Moscow State University, Russia
28.KALTENBORN Mark Alexander	Knoxville University, USA
29.KHANDRAMAI Viachaslau	Gomel State Technical University, Belarus
30.KOCHETKOV Oleg	Regensburg University, Germany
31.KOLOMOYETS Natalia	Dnepropetrovsk National University, Ukraine
32.KUMAR Narinder	Nat. Inst. of Technology, Jalandhar, India
33.LUKASHEVICH Svetlana	Gomel State Technical University, Belarus
34.MARCZENKO Michal	University of Wroclaw, Poland
35.MEYER Florian	Bielefeld University , Germany
36.MOHANTA Protick	NISER, Bhubaneswar, India
37.NIKOLAEV Alexander	Far Eastern Federal Univ., Vladivostok, Russia
38. PADMANATH Madanagopalan	University of Graz, Austria
39. PEROTTI Elisabetta	Uppsala University, Sweden
40. PILOYAN Arpine	Yerevan Physics Institute, Armenia
41. PUHR Matthias	Regensburg University, Germany
42. SHLEENKOV Mark	Samara University, Russia
43. SOLOVJEVA Olga	MEFI, Moscow, Russia
44. TALKACHOU Dzianis	Gomel State University, Belarus
45. TRUNIN Anton	BLTP JINR, Dubna, Russia
46. USUBOV Rahim	BLTP JINR, Dubna, Russia
47. VALGUSHEV Semen	ITEP, Moscow, Russia
48. VARNHORST Lukas	Wuppertal University, Germany
49. WITTEMEIER Christian	Muenster University, Germany
50. YAHIBBAEV Ravil	Saratov University, Russia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Armenia
Austria
Belarus
Germany
India
Irland
Italy
Japan
Poland
Portugal
Sweden
Ukraine
USA
Russia

List of Lecturers

1. M. Mueller-Preussker, Humboldt-Universitaet Berlin (Germany)
2. K. Jansen, NIC, DESY-Zeuthen (Germany)
3. A. Sternbeck, Friedrich-Schiller Universitaet Jena (Germany)
4. O. Philipsen, J. W. Goethe Universitaet Frankfurt (Germany)
5. C. Hoelbling, Bergische Universtitaet Wuppertal (Germany)
6. M. Goeckeler, Universitaet Regensburg (Germany)
7. M. Golterman, San Francisco State University (USA)
8. A. Walker-Loud, College of William & Mary and Jefferson Lab. (USA)
9. F. Maas, Helmholtz Institut Mainz (Germany)
10. O. Rogachevsky, VBLHEP, JINR Dubna (Russia)
11. G. Trubnikov, JINR Dubna (Russia)
12. V. Bornyakov, IHEP Serpukhov and ITEP Moscow (Russia)
13. G. Endrodi, Universitaet Regensburg (Germany)
14. P. Buividovich, Universitaet Regensburg (Germany)
15. O. Teryaev, BLTP, JINR Dubna (Russia)
16. D. Smith, Technische Universitaet Darmstadt (Germany)
17. D. Podgainy, LIT, JINR Dubna (Russia)
18. O. Streltsova, LIT, JINR Dubna (Russia)
19. E. Alexandrov, LIT, JINR Dubna (Russia)
20. E. Zemlyanaya, LIT, JINR Dubna (Russia)
21. T. Sapozhnikova, LIT, JINR Dubna (Russia)
22. M. Zuev, LIT, JINR Dubna (Russia)
23. A. Ayriyan, LIT, JINR Dubna (Russia)

Germany – 10

Russia – 11

USA – 2

Scientific Programme

1. Fundamental courses

M. Mueller-Preussker, Humboldt-Universitaet Berlin (Germany)
"Introduction to lattice gauge theory I"
K. Jansen, NIC, DESY-Zeuthen (Germany)
"Introduction to lattice gauge theory II"
A. Sternbeck, Friedrich-Schiller Universitaet Jena (Germany)
"Simulations with (hybrid) Monte Carlo algorithms"
O. Philipsen, J. W. Goethe Universitaet Frankfurt (Germany)
"QCD at high temperature and baryonic density"
C. Hoelbling, Bergische Universtitaet Wuppertal (Germany)
"Lattice hadron spectroscopy"
M. Goeckeler, Universitaet Regensburg (Germany)
"Hadron structure from lattice QCD"
M. Golterman, San Francisco State University (USA)
"Chiral perturbation theory"
A. Walker-Loud, College of William & Mary and Jefferson Lab. (USA)
"Connecting QCD to nuclear physics with the lattice"

2. Future experiments

F. Maas, Helmholtz Institut Mainz (Germany)
"Low energy precision physics"
O. Rogachevsky, VBLHEP, JINR Dubna (Russia)
"Perspectives for relativistic nuclear physics at the NICA accelerating complex"
G. Trubnikov, JINR Dubna (Russia)
"Accelerator complex NICA: a low energy heavy ion collider"

3. Theoretical topical lectures

V. Bornyakov, IHEP Serpukhov and ITEP Moscow (Russia)
"Color-magnetic monopoles in finite teperature QCD"
G. Endrodi, Universitaet Regensburg (Germany)
"External magnetic fields in lattice QCD"
P. Buividovich, Universitaet Regensburg (Germany)
"Anomalous transport phenomena: lattice perspective"
O. Teryaev, BLTP, JINR Dubna (Russia)
"Rotating QCD media"
D. Smith, Technische Universitaet Darmstadt (Germany)
"Graphene as lattice field theory"

4. Programming techniques on hybrid architectures*

D. Podgainy, "Excursion to the Central Information and Computing Complex of LIT"
O. Streltsova, "Introductory talk"
E. Alexandrov, "Introduction to work on the cluster"
E. Zemlyanaya, "OpenMP parallel programming technology"
T. Sapozhnikova, "MPI parallel programming technology"
O. Streltsova/M. Zuev, "Parallel programming with CUDA"
A. Ayriyan, "OpenCL parallel programming technology"
LIT group, "Practical training: comparison of GPU, multi-core CPU and IntelXeonPhi coprocessor approaches"

**) Lectures and tutorials by the heterogeneous computations group of the JINR Labotatory of Information Technologies (LIT)*

Schedule: first week 25-29/08/2014

	Monday August 25	Tuesday August 26	Wednesday August 27	Thursday August 28	Friday August 29	Saturday August 30	Sunday August 31
8:30-9:15 **9:15-9:30**	Registration **Opening**					Picnic and Excursion (TBA)	
9:30-10:30	Mueller-Preussker I	Mueller-Preussker III	Jansen III	Hoelbling III	Golterman I		
10:30-11:00	Coffee-break						
11:00-12:00	Mueller-Preussker II	Mueller-Preussker IV	Jansen IV	Hoelbling IV	Golterman II		
12:10-13:10	Teryaev I	Jansen I	Hoelbling I	Bornyakov I	Philipsen		
13:10-15:00	Lunch						
15:00-16:00	Teryaev II	Jansen II	Hoelbling II	Bornyakov II	Poster Session		
16:00-16:30	Coffee-break						
16:30-17:30	Maas I	Rogachevsky	Philipsen I	Philipsen II	Poster Session		
17:40-18:40	Maas II	Trubnikov	Mueller-Preussker TUT	Jansen TUT			

Schedule: second week 1-6/09/2014

	Monday September 1	Tuesday September 2	Wednesday September 3	Thursday September 4	Friday September 5	Saturday September 6
9:30-10:30	Golterman III	Golterman IV	Smith I	Smith II	Buividovich I	Departure
10:30-11:00	Coffee-break					
11:00-12:00	Goeckeler I	Goeckeler II	Goeckeler III	Goeckeler IV	Buividovich II	
12:10-13:10	Walker-Loud I	Walker-Loud II	Walker-Loud III	Walker-Loud IV	Streltsova /Zuev	
13:10-15:00	Lunch					
15:00-16:00	Philipsen IV	Philipsen TUT	Sternbeck	Sternbeck	Ayriyan	
16:00-16:30	Coffee-break					
16:30-17:30	Podgainy Streltsova	Sternbeck	Excursion NICA	Endrodi I	LIT group training	
17:40-18:40	Zemlyanaya Sapozhnikova	Sternbeck		Endrodi II	**Farewell**	

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Dubna International Advanced School of Theoretical Physics / Helmholtz International Summer School

Lattice QCD, Hadron Structure and Hadronic Matter

Dubna, Russia, **August 25-September 6 , 2014**

CERTIFICATE OF ATTENDANCE

This is to confirm that Christian WITTEMEIER (Muenster University, Germany) participated in the Helmholtz International Summer School **"Lattice QCD, Hadron Structure, and Hadronic Matter"**, which took place at the Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research, Dubna, Russia, from August 25 to September 6, 2014.

C. Wittemeier presented a poster "Non-perturbative renormalization of axial current in N_f=3 lattice QCD with Wilson fermions and tree-level improved gauge".

For the Organizers

Prof. Ernst-Michael Ilgenfritz
(VBLHEP & BLTP JINR, Dubna)

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