Mainz Institute for Theoretical Physics

Scientific Activities 2017-2018

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Cluster of Excellence Precision Physics, Fundamental Interactions and Structure of Matter
PRISMA

mitp Mainz Institute for Theoretical Physics

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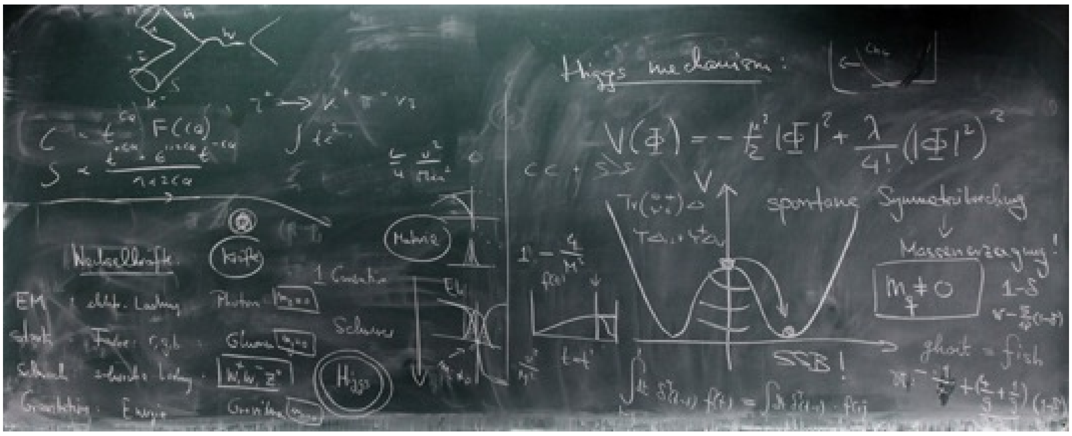

Mainz Institute for Theoretical Physics
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Mainz, March 2019

1 Mission of MITP

The Mainz Institute for Theoretical Physics (MITP) offers a platform for visiting scholars from all around the world to discuss cutting-edge developments in theoretical physics. Modeled after successful theory institutes such as the Kavli Institute for Theoretical Physics at UC Santa Barbara or the Galileo Galilei Institute in Florence, MITP is the first institute of its kind in Germany.

Its main objective is to create an environment in which scientists can work on key questions at the frontiers of their fields, supporting an atmosphere that allows for spontaneous interactions and creative cooperation. Since its first days in 2013, MITP has rapidly been developing into an internationally recognized and highly regarded center for scientific exchange and collaboration, covering a broad range of topics in theoretical particle physics, nuclear physics, astrophysics, mathematical physics, and related areas.

The core mission of MITP is to provide the infrastructure and financial support to the international scientific community for organizing short topical workshops and longer scientific programs. Topical workshops typically last about a week and feature a dense program of talks and discussion sessions. The duration of scientific programs is up to four weeks, and the schedule is more flexible, with typically only one or two talks per day. In fact, the main focus of these programs is to stimulate collaborations and informal scientific exchanges among participants. This can be achieved by requiring participants to stay for at least two weeks, and by providing architectural measures that facilitate and encourage discussions.

MITP also contributes to the education of graduate students and postdoctoral researchers. Every year MITP organizes a three-week topical summer school in theoretical physics. The lectures are video-recorded and made available to the public on YouTube.

The science at MITP is community-organized. External scientists are responsible for the MITP activities while MITP provides the infrastructure for them. Moreover, proposals for scientific programs and workshops can be submitted by scientists from around the world and at all career levels in response to an annual call for proposals. These proposals are evaluated and ranked by the International Advisory Board consisting of internationally renowned scientific leaders.

2 Development of MITP in 2017 and 2018

Recent performance The number of scientific activities and of participants has been increasing steadily since 2013 (see Figure 1). Compared to 16 weeks in 2014, MITP has scheduled 26 weeks of scientific programs, workshops and a summer school in 2018. While we had 244 scientists participating in the MITP activities in 2014, the MITP's events in 2017 and 2018 were attended by 1106 participants from 44 different countries.

Both in 2017 and in 2018, about 70% of the participants who worked at MITP came from outside of Germany (see figure 2 and 3). Despite the fact that several competing theory institutes are located in the US (such as the KITP in Santa Barbara, INT in Seattle, the RIKEN-BNL Center in Brookhaven and the Aspen Center for Physics), more than 20% of MITP participants came from the North American continent. The remaining foreign participants represent a long list of countries in Europe (including many in Eastern Europe), the Middle East, Asia, Central and South America, and Australia.

The 13 scientific programs and 14 topical workshops were organized in 2017 and in 2018 at MITP. These events covered an expressive range of topics. The complete program of MITP scientific activities will be presented in this report. The scientific summaries of these events are listed in the next two sections which were offered by the external organizers and which were edited for this report.

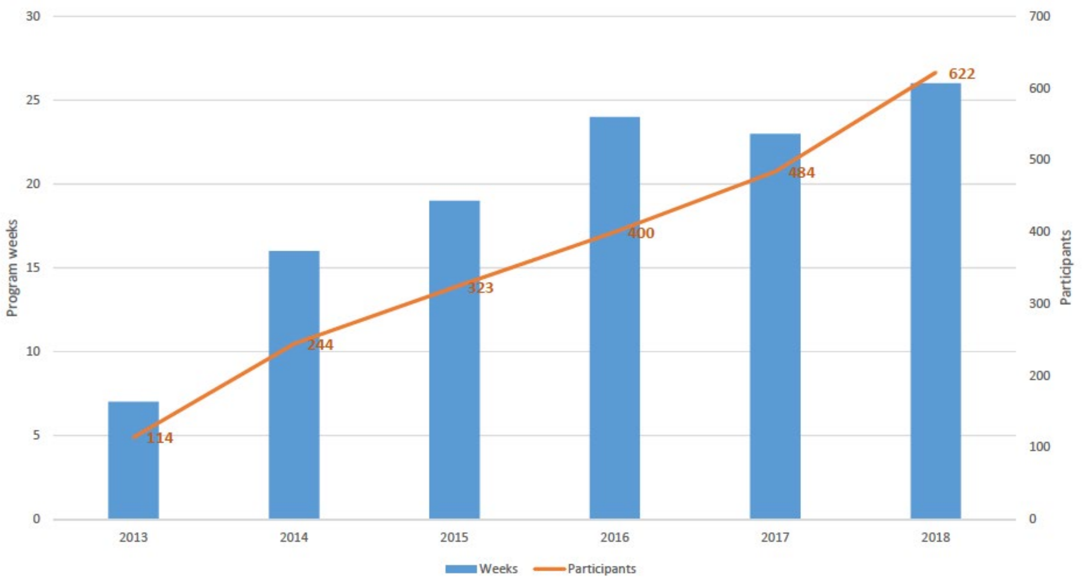


Figure 1: Number of MITP program weeks and number of participants in 2013-2018.

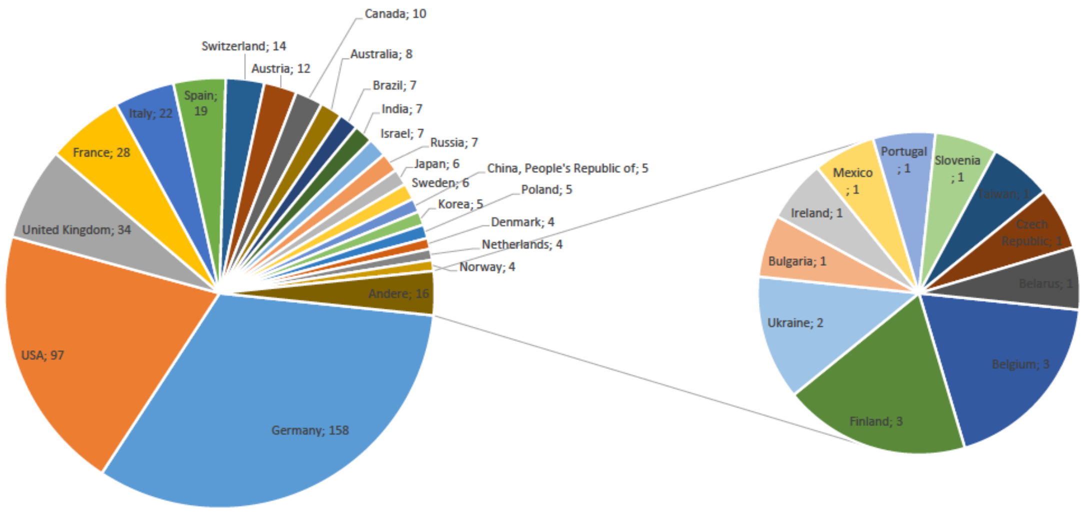


Figure 2: Countries of residence of the 484 MITP participants in 2017 (33 countries in total).

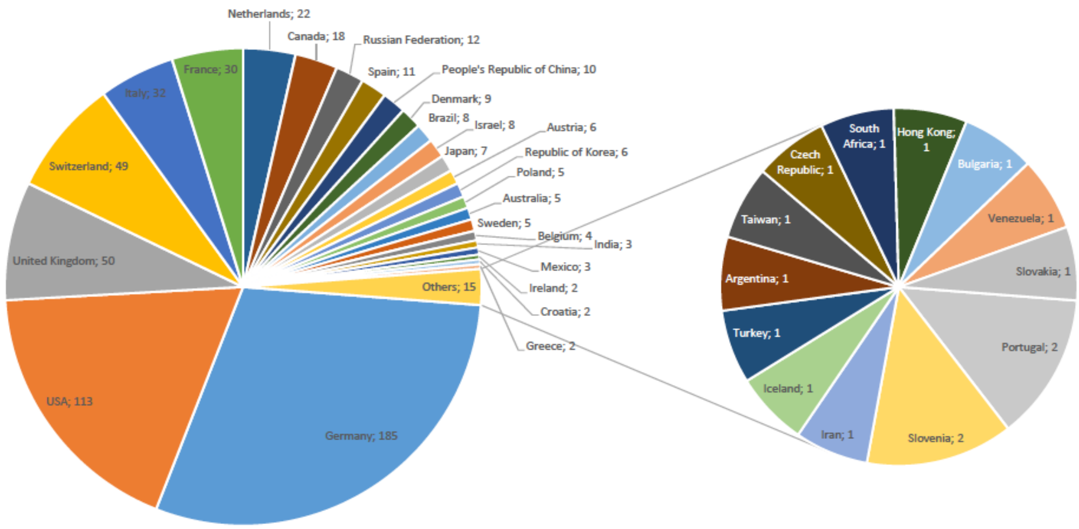


Figure 3: Countries of residence of the 622 MITP participants in 2018 (39 countries in total).

Selection process, equal opportunity and diversity During the past four years we have annually received about 20 proposals for scientific programs and workshops from external scientists, which would have amounted to approximately 40 weeks of scientific activities. In line with the available financial resources of MITP and following the ranking provided by the International Advisory Board, up to 24 -26 weeks of activities can be supported each year.

The number of applicants has also increased significantly. We had 428 applicants in 2015, 554 in 2016, 665 in 2017, and now 925 in 2018. About 70% of the applicants have admitted as participants. The targeted number of participants per week is 25 for a scientific program and 30 for a topical workshop.
The impressive response to the MITP call of proposals and the strong increase of applicants for MITP activities demonstrate the high acceptance of MITP as a theory center by the international community and the need for such an institution in the center of Germany.

While the program organizers are responsible for selecting the participants of the scientific programs and workshops, MITP guidelines emphasize that gender and age balance should be considered in the selection. Young applicants (postdocs and junior faculty) and scientists from developing countries should have a good chance of being admitted. One of the organizers of each program serves as an Equal Opportunity & Diversity Officer. We ask organizers to pay particular attention to gender balance and aim for 30% of female participants in any MITP activity, which is far above the average in the field. This has resulted in an increase of female participation rates, from 14.2% in 2015 and 2016 to 17.2% in 2017 and 2018. Occasionally, MITP has organized workshops specifically targeted at female scientists, such as the workshop *Women at the Intersection of Mathematics and High Energy Physics* in March 2017.

MITP is also especially committed to supporting young scientists (postdocs and young faculty) and scientists from countries where scientific infrastructure and funding are not yet at an internationally competitive level. Therefore, cooperation agreements with institutes in South America and in India have been signed by MITP (see below).

New International Advisory Board All proposals are evaluated and ranked by the MITP Advisory Board consisting of internationally renowned scientific leaders The first board served for 6 years. Former members were Nima Arkani-Hamed (IAS Princeton), Marcela Carena (Fermilab and U. Chicago), Michael Creutz (Brookhaven National Lab.), Stefan Dittmaier (U. Freiburg), Gian Francesco Giudice (CERN), Dirk Kreimer (Humboldt U. Berlin), Manfred Lindner (MPI fur Nuclear Physics, Heidelberg), Jan Louis (U. Hamburg), William Marciano

(Brookhaven National Lab.), Martin Savage (INT Seattle), Neal Weiner (New York U.), Christof Wetterich (U. Heidelberg) and Dieter Zeppenfeld (U. Karlsruhe).

A new board was appointed the last year. The current board members are Veronique Bernard (IPN Orsay). Chiara Caprini (Laboratoire Astroparticule et Cosmologie, Paris), Mirjam Cvetic (University of Pennsylvania, Philadelphia), Csaba Csaki (Cornell University), Claude Duhr (CERN), Christof Gattringer (Karl-Franzens-University, Graz), Arthur Hebecker (University of Heidelberg), Gino Isidori (University of Zurich), John March-Russell (University of Oxford), Maxim Pospelov (Perimeter Institute for Theoretical Physics), Achim Schwenk (TU Darmstadt), Geraldine Servant (DESY), Thomas Schwetz-Mangold (KIT), Tim Tait (University of California, Irvine), Giulia Zanderighi (CERN, Oxford)

Infrastructure and personnel of MITP The close proximity to Frankfurt International Airport (one of the main airline hubs in Europe) makes travelling to Mainz efficient and affordable. Since 2014, the operation of MITP has been profiting from a highly optimized infrastructure and logistics. The institute is located next to the Institute of Physics and is thus close to the local theory groups. We are able to offer access to computing facilities and attractive office space to 33 external scientists. The MITP seminar room with up to 50 seats contains state-of-the-art video equipment and blackboards and can be used any time by the participants of MITP activities. Furthermore, the casual MITP Lounge in the center of the institute provides an attractive discussion area and meeting space.

The staff of MITP strives to make each MITP activity a success. Apart from the Director, a Scientific Coordinator and the Head of Administration serve as contact persons for external scientists. An IT Officer and three Administrative Assistants are part of the current team and ensure, that all MITP guests are attended according to their individual needs. This also includes adequate housing for the participants.

Funding of MITP In the last two years, the State of Rhineland-Palatinate and Johannes Gutenberg University Mainz (JGU) have established MITP as a permanent institution, supplying the salaries of the core personnel as the operating budget, which until now has been provided by the Cluster of Excellence PRISMA - a funding line by the German Government for institutions with an internationally outstanding reputation in their respective fields. The budget includes accommodation costs for over 600 participants and organizers of scientific programs and topical workshops as well as support for the annual MITP summer school. Significant investments by JGU have been made to create high-quality office space, the large seminar room and the discussion lounge.

MITP preprints One of the main goals of a theory center like MITP is to stimulate discussions and induce new scientific ideas and collaborative work. In the last two years the participants of the MITP activities have explicitly acknowledged MITP's support in 158 publications, since the inception of MITP in more than 450 publications. All these publications are listed on the MITP homepage, https://www.mitp.uni-mainz.de/600.php .

International co-operations of MITP In November 2016, MITP signed a cooperation agreement with the South American Center for Fundamental Research ICTP/SAIFR at Sao Paulo (Brazil) with the goal to facilitate the exchange of scientific personnel between Germany and the South American continent. Similarly, in December 2017 MITP signed a cooperation agreement with the Tata Institute for Fundamental Research (TIFR) in Mumbai (India), strengthening the ties to another rapidly developing country and facilitating contacts of Indian researchers with the European community. Further cooperation agreements with international institutions have been made by MITP during the last years in order to facilitate the exchange of scientific personnel, namely with the Fermi National Accelerator Laboratory in Batavia, Illinois, and the Kavli IPMU in Tokyo. Illinois, and the Kavli IPMU in Tokyo.

3 Scientific Programs

Amplitudes: practical and theoretical developments

Organized by Fabrizio Caola (CERN), Herbert Gangl (Durham Univ.), JaroslavTrnka (UC Davis), Johannes Henn (JGU Mainz), Stefan Müller-Stach (JGU Mainz) and Stefan Weinzierl (JGU Mainz).

6-17 February 2017

Scattering amplitudes are a fascinating and rapidly developing subject of current research, in supersymmetric quantum field theories and for applications to collider physics. At the same time, there are many connections to mathematics. This interplay between the different research communities is very productive. The two-week MITP scientific program ``Amplitudes: practical and theoretical developments'' brought together about thirty-five physicists and mathematicians in the intersection from the fields of high energy physics, mathematics and string theory. The main emphasis of the program was on scattering amplitudes, a fascinating topic relevant to precision calculations in particle physics and enjoying remarkable mathematical properties. The scientific program was carried out in a stimulating and productive atmosphere, with one talk usually scheduled in the morning and another talk scheduled in the afternoon. But the most important parts of the scientific program were the discussions among the participants during and after the talks.

Scattering amplitudes in particle physics are related to the probability with which a certain scattering process occurs. Perturbative quantum field theory offers – in theory at least – a systematic way to calculate the scattering amplitudes through Feynman diagrams. However, any practitioner in the field soon realizes that an approach based on Feynman diagrams is feasible only for the simplest processes. The complexity of the calculation increases with the number of external particles and with the number of internal loops. Often the final answer is much shorter than any intermediate expression. This indicates that not all structures and symmetries of the problem have been identified. Furthermore, scattering amplitudes in Yang-Mills theory show a close connection to scattering amplitudes in perturbative gravity. Recent years have shown great progress in this area and have given rise to an active interaction between high energy physics, mathematics and string theory.

The scientific program started in medias res with a talk by David Broadhurst, who reported on impressive results for specific 18 loops diagrams, which he related to particular values of Dirichlet L-functions. This was followed in the afternoon by a talk of Lorenzo Tancredi who related maximal cuts of Feynman diagrams to solutions of the corresponding homogeneous differential equations. Jacob Bourjaily challenged the audience with an "integration polemics" on unitarity methods. Leonardo Vernazza reported on progress on two-parton scattering in the high-energy limit. Dmitrii Chicherin talked on the duality of Wilson form factors, Harald Ita on numerical unitarity at two-loop.

There was an afternoon session on elliptic generalizations of polylogarithms with expositions by Pierre Vanhove, Matt Kerr and Christian Bogner, followed by a general discussion on this topic on the next day. Dario Consoli reported on simplifying one-loop amplitudes in superstring theory. At the end of the first week Claude Duhr taught the audience about defining a co-action on one-loop graphs. The second week started with an overview on perturbative calculations by Kirill Melnikov. Simon Badger spoke on mass renormalization and unitarity cuts. Henrik Johansson presented new and simple formulas for Einstein-Yang-Mills amplitudes, Carlos Cardona reported on S-matrix singularities and CFT correlation functions.

These talks often triggered discussions which were continued in the coffee room. In this way the MITP scientific program "Amplitudes - practical and theoretical developments" was very successful and it is not unlikely that several new collaborations and research projects grow out of this scientific program.

Quantum Vacuum and Gravitation: Testing General Relativity in Cosmology

Organized by Manuel Asorey (Univ. Zaragoza), Emil Mottola (LANL), Ilya Shapiro (Univ. Juiz de Fora) and Andreas Wipf (Univ. Jena).

13-24 March 2017

The scientific program was intended to provide a discussion of the latest advances of both observational and theoretical aspects of cosmology and astrophysics, with direct participation of the active workers in the related fields such as astrophysics, black holes, quantum gravity and quantum field theory in curved space-time. The organization of the 2017 scientific program was based on the successful topical workshop at MITP in June 2015. This time there was a less intensive, two-week scientific program at the MITP bringing together theorists from particle physics and general relativity with observational cosmologists to develop new approaches to outstanding problems. From the theoretical side, the scientific program was especially focused on the field-theoretical methods such as renormalization group and conformal anomalies, effective action method and the implications in astrophysics and cosmology. From the cosmological side, there were a few review talks that included the latest experimental and observational data and their understanding in the framework of existing theoretical constructions. Moreover, there were quite remarkable high-quality short presentations on the observational side, including the ones given by younger researchers.

The scientific program boosted new collaborations among the participants in both theory and observational parts, confronting theoretical ideas with the new data that are becoming available. All talks were at very high scientific level and captured the attention of participants and in some cases also that of the local group of theoretical physics, who is well-known by research work in the areas of the scientific program. A few review talks of 75 minutes were presented, while most of other presentations were limited to 40-50 minutes. At the end of each daily session there was a special discussion which reviewed the talks of the day and related subjects. These discussions were very interesting and very useful for a better understanding of the points of view of different researchers and problems which focus on cosmology, high-energy and gravitational physics

The main review talks were the following: Ivan Agullo from Louisiana State University reported on recent developments of loop quantum cosmology, which has become a robust framework to describe the highest curvature regime of the early universe. In this theory, inflation is preceded by a bounce replacing the big bang singularity. After summarizing the theoretical framework, the corrections to the inflationary predictions were discussed, including the primordial spectrum of cosmological perturbations in the pre-inflationary quantum gravity phase of the early universe evolution. The impact of the bounce on non-Gaussianity and the exciting relation to the observed large scale anomalies in the cosmic microwave background (CMB**)** was also discussed.

Matthias Bartelmann from the University Heidelberg gave an overview on the cosmological standard model and the standard approach to the formation and evolution of cosmic structures. Furthermore, he discussed a new approach to cosmic structure formation based on a non-equilibrium, statistical field theory for correlated, classical particle ensembles. This approach allows to calculate statistical properties of cosmic structures at low orders in perturbation theory even at small scales and deeply in the non-linear regime. The theory is based on first principles and does not include adjustable parameters. The evolution of cosmic structures, in particular in its late non-linear phases, provides important clues on the evolution of the universe as a whole. In view of possible subtle deviations from general relativity and the cosmological standard model, non-linear cosmic structures, as for example traced by the population of galaxy clusters, may act as magnifiers to enhance small dynamical effects above observational thresholds. For such conclusions, one needs to understand cosmic structure formation in detail in particular on small scales and at late times.

Glenn Starkman from Case Western Reserve University reviewed the status of CMB anomalies 25 years after COBE. Several unexpected features have been observed in the temperature of the microwave sky at large angular scales, from COBE to WMAP and Planck. These include lack of both variance and correlation on the largest angular scales, alignment of the lowest multipole moments with the motion and geometry of the Solar System, lack of variance in the northern hemisphere, a hemispherical power asymmetry or dipolar power modulation, a preference for odd parity modes, and an unexpectedly large cold spot in the Southern hemisphere. The individual p-values of the significance of several of these features are in the per mille to per cent level, compared to the expectations of the best-fit inflationary ΛCDM model. There are no good physical models for these anomalies, but it was explained that one can make progress by considering how the existence of measured anomaly alters the predictions of ΛCDM for other observables and/or making predictions from reasonable phenomenological expectations for the physics contents of measured anomalies.

Alexei Starobinsky from the Landau Institute for Theoretical Physics discussed the recent theoretical and observational progress in the study of inflationary phase of the universe. It is possible to make a reconstruction of inflationary models in classical general relativity and f(R) gravity by using information on the power spectrum of scalar perturbations only. He also discussed the ambiguity of this procedure and how it can be fixed by aesthetic assumptions on the absence of new physical scales during and after inflation. The problem of the onset of inflation can be seen from the perspective of generic classical curvature singularity preceding it.

Emil Mottola from Los Alamos reviewed and explained his well-known works on the quantum effects on black holes. Classical general relativity (GR) together with conventional equations of state suggest that in a complete gravitational collapse a singular state of matter with infinite density could finally be reached, a so-called "black hole." In addition to its interior singularities, the characteristic feature of a black hole is its apparent horizon, the surface of finite area at which outwardly directed light rays are first trapped. The loss of information to the outside world this implies gives rise to additional difficulties with well-established principles of quantum mechanics and statistical physics. An interesting alternative to the black hole formation is the gravitational vacuum condensate star proposal which was made by Mottola et al in 2001. In this case there is no event horizon, and the Schwarzschild time of such a non-singular gravitational condensate star is a global time fully consistent with unitary time evolution in quantum theory. Another observational test of gravitational condensate stars vs. black holes is the discrete surface modes of oscillation and echoes which should be detectable by their gravitational wave signatures.

Ruth Durrer from the University of Geneva reviewed the recent progress in the study of the cosmic microwave background (CMB). Most numbers in cosmology have been measured by using the anisotropies and polarization of the CMB. So far other data has mainly been used for consistency checks; very few inconsistent measurements exist. The reason for this is twofold. First of all, the theory of the CMB is nearly linear and therefore quite simple. Secondly, the CMB spectrum peaks around frequencies which allow relatively precise observations from the ground and especially from space. Durrer explained the relatively simple physics behind CMB anisotropies and polarization and gave some examples of how it can be used to measure cosmological parameters. Furthermore, she outlined ideas of how to go beyond present measurements which mainly constrain cosmological parameters. After all, one can use the CMB to test general relativity on cosmological scales. The interesting new developments in the theory of large scale structure (LSS) observations give rise for the hope that future LSS surveys can compete with and complement CMB observations.

Cliff P. Burgess from McMaster and Perimeter talked about "Effective field theories and modifying gravity: the view from below". From the effective field theory perspective there are nowadays contradictory messages about how successfully we understand gravity. General relativity seems to work very well in the earth's immediate neighborhood, but a lot of arguments suggest that it needs modification at very small and/or very large distances. The situation can be better understood in the broader context of similar situations in other areas of physics such as QCD. The main lesson is that effective theories provide the natural and in many cases precise language for framing proposals. Special attention has been given to the treatment of higher derivatives, which was also the subject of discussions in several other talks.

Martin Crocce from the Space Science Institute of Barcelona gave an overview of the next decade program for Observational Cosmology focused on the analysis of the large scale structure (LSS). The goal is to undertake large astronomical surveys that, by scanning millions of galaxies across cosmic time, will study the origin and evolution of the large scale structure of the universe. In his talk Crocce analyzed which are the probes that these surveys use to test GR, such as galaxy clustering and weak lensing. Crocce also discussed current constrains and their implications. Moreover, he also analyzed the main goals of LSS from the perspective of ongoing and future surveys such as the dark energy survey (DES) or the ESA/Euclid satellite.

Andrei Barvinsky from the Lebedev Institute presented the last results concerning the application of effective action method to the very early quantum universe. The recent advances in using the effective action method in cosmology were explained with a special emphasis on its application in the theory of quantum initial conditions for the very early universe and the models of Higgs and curvature-squared inflation. Barvinsky discussed the role of local gradient expansion and conformal anomaly for the effective action and applied it to the micro-canonical state of the universe. Furthermore, Barvinsky introduced his model of a new type of “hill-top” inflation.

Alessandra Buonanno from the Max Planck Institute for Gravitational Physics presented a review on the next theoretical challenges for gravitational-wave observations. One hundred years passed after Einstein predicted the existence of gravitational waves on the basis of his theory of general relativity. Quite recently LIGO announced the first observation of gravitational waves passing through the earth emitted by the collision of two black holes one billion four hundred million light years away. The review included the theoretical groundwork that allowed the identification and interpretation of gravitational-wave signals, tests of general relativity in the strong-field, highly dynamical regime, and also the next theoretical challenges in solving the two-body problem in general relativity. Such a solution is very important if one wants to take full advantage of the discovery potential of upcoming gravitational-wave observations.

Low-energy probes of new physics

Organized by Martin Jung (TU Munich), Peter Fierlinger (TU Munich) and Susan Gardner (Univ. of Kentucky).

2-24 May 2017

Astrometric observations reveal that most of the energy content of the universe is of unknown form and thus provides a compelling case for the existence of physics beyond the standard model of particle physics (SM). The discovery of the Higgs Boson at the Large Hadron Collider (LHC) completed the particle spectrum of the SM. However, there is much that remains unexplained. The biggest questions include what forces prevalent at the Big Bang produced a matter-dominated universe. Further questions deal with dark matter and dark energy. The answers lie in “new physics”, that is, new particles and forces that have measurable effects, which can be investigated in laboratory experiments, either at high-energy colliders or through sensitive or precise measurements in low-energy systems. Advances in technology for low-energy experiments together with further data at 13 TeV from the LHC have provided a new environment, requiring a reassessment of the focus of the field. The scientific program covered the theory and experiment of a wide range of low-energy searches for new physics that provide unique and complementary information to accelerator-based searches, independent of potential discoveries at the LHC and future colliders.

This scientific program brought together the proponents of major low-energy experimental efforts to discuss the techniques, challenges, and progress. The major topics were slow-neutron physics, searches for time-reversal symmetry breaking electric dipole moments (EDMs), exotic effects such as light "axion-like" particles, parity violation, fundamental muon physics, and precision tests of SM radiative corrections. Theoretical participants included phenomenologists with expertise in calculations of particle-physics and QCD effects in specific systems such as nuclei, atoms, and molecules. The aim was to compare and combine techniques, address specific crucial questions for the experiments and to analyze the impact of existing and proposed experiments on the theoretical picture.

While the SM is extremely successful in describing phenomena at vastly different energy scales, it is known to be incomplete. In particular, the observational evidence for dark matter and energy and the amount of the matter-antimatter asymmetry in the universe cannot be addressed within the SM. Possible extensions to the SM predict new phenomena at all energy scales. Low-energy precision experiments are complementary to searches at the LHC. For example, very weakly coupled light particles such as axions would not be observed at a high-energy collider. Signals of new physics at short range may be revealed by precision measurements in systems such as slow neutrons, atoms, and muons, where the sensitivity is due to a combination of the coupling strength and energy scale of the new phenomena. Interpreting low-energy measurements provides insights into the nature of new phenomena. Strong upper limits or determinations for specific combinations of model parameters could be combined with direct measurements of new particles to set the structure of the new sector. Since each measurement is subject to physics from different energy scales, the MITP event strengthened the links between the communities involved. Techniques were discussed which so far have been only marginally treated to maximize the potential of greatly increased experimental sensitivities.

The main motivation of this scientific program was to strengthen the links between the communities and groups involved in different low- energy tests and to add new expertise and techniques from usually disparate fields in order to realize and interpret measurements of greatly increased precision, also to intensify the understanding of the interplay between all experiments on a theoretical basis. The scientific program covered the theoretical and experimental developments and status in a variety of fields, including the following high topics. In neutron decay and advances in neutron methods for fundamental measurements, new experiments with 10-100 times improved sensitivity are on track, probing the 10-100 TeV scale. One of the major experiments is the Munich-based PER experiment by strong international activities. There are a variety of new EDM searches either underway or already producing results: 100-times more sensitive measurements using neutrons and protons are currently developed, with new synergetic effort that lead for larger-than-customary collaborations. Atomic EDM experiments have advanced enormously in their technology in the very recent past and have an important potential for discovery in the coming years, also motivating the development of new approaches for theory. Quantum phenomena in slow neutrons, i.e. gravitationally bound states of neutrons, are a new concept which is evolving into a precision technique, notably to search for light “axion-like” or “chameleon” particles, but also other exotics. Parity violation in atomic systems (APV) provides the most precise measurement of the Weinberg angle near zero momentum transfer, which becomes a window to new physics when compared to higher-energy measurements. Efforts to measure with even higher precision require new experimental techniques, for example cold atoms as well as new efforts in theory. New experiments to measure rare decay modes of the muon, like the $\mu \to 3e$ and $\mu \to e$ conversion, are currently being realized with sensitivities reaching into the PeV scale. The discrepancy between the precision measurement of the anomalous magnetic moment of the muon and its SM prediction including QED, weak and QCD contributions is an intriguing laboratory signal for new physics. A new measurement will improve the experimental precision and provide a better assessment of systematic errors. At the same time advances in theory, in particular regarding strong-interaction contributions, are crucial to interpreting the results.

Each experiment can establish new physics, but it cannot determine its precise form so that the interpretation of results is complex. Therefore, the following problems in theory were analyzed in this scientific program: (i) the calculation of parameters on different scales, e.g. QCD, nuclear and atomic levels, which are often separated due to the different communities. (ii) placing phenomenological constraints on the parameter space for preferred new-physics scenarios by combining new experimental results, given the new boundaries of two years of high-energy data from LHC.

Due to the increasing scale of size and costs of the next generation of experiments, the identification of synergies is a key for advancing our measurements. In this scientific program this issue was also addressed. For example, laser techniques and the control and generation of small magnetic fields have advanced tremendously in the last years. Searches for the proton EDM using particle beams, measuring neutron and atom EDMs, and using trapped particles for precision QED tests employing table-top techniques started. In the discussions, the exchange of knowledge and ideas between the previously rather disjunctive communities achieved a significant potential for synergies.

The TeV scale: a threshold to new physics?

Organized by Csaba Csaki (Cornell Univ.), Christophe Grojean (DESY), Pedro Schwaller (DESY) and Andreas Weiler (TU Munich).

12 June – 7 July 2017

After the discovery of the Higgs boson, the SM of particle physics is theoretically complete but phenomenologically limited and it also leaves many questions unanswered. The most important open questions are the naturalness of the electroweak scale, the nature of dark matter, the origin of matter in the universe and the structure of flavor. Eagerly awaited to comply with the naturalness arguments, the LHC has revealed no unambiguous signs of new physics so far. This situation raises the question whether the TeV scale is indeed a threshold to new physics. This question was debated and scrutinized in many different ways during the scientific program. If no definitive conclusion can be reached, there is certainly no evidence yet that Hinchlife's rule applies. The diversity of the models presented and discussed by the participants is a motivation to continue the exploration of the TeV threshold.

The format of the workshop has been chosen to enhance interactions among participants, to foster discussions by raising topics during in-depth technical presentations followed by public and private debates. We deliberately limited the numbers of talks to one per day. For these talks, we also gave priority to young scientists without permanent jobs and we encouraged black-board presentations. The format and the spirit of the workshop were overwhelmingly appreciated by the participants. It resulted in in-depth discussions on a variety of active topics. Discussions during lunch and dinner time took place in smaller groups. The atmosphere was very informal with a schedule organized at a late time, taking into account the participants' suggestions. This played a great role in making the younger researchers immediately comfortable and triggered many informal discussions. The scientific program has run over 4 weeks with a total of 20 talks. The workshop was heavily oversubscribed with more than 130 applications of a very high level. Participants were chosen based on their proven expertise on the field, keeping an eye on assuring balance among various aspects. A total number of 57physicists joined (including 6 locals and 2 Ph.D. students), of which 23/34 European/out-of-European origin, 49/8 men/women.

A few models of TeV scale new physics were discussed. In addition, several new developments were presented and elaborated. One main concern was the hierarchy problem. Variations of the well-established minimal models (supersymmetry and compositeness) were discussed. In particular some explicit UV realizations of composite Higgs models were presented which rely on six dimensional constructions and establish a connection to little Higgs and twin Higgs models. Fermion compositeness scenarios utilizing non-linearly realized supersymmetry were introduced and it was shown that they can soften the usual constraints on contact interactions and predict specific patterns of interactions exhibiting a stiff growth with energy. It was also shown that non-minimal SUSY models can still be realized at or even below the TeV scale. That reveals that the strong constraints on super-partners which are often quoted do not always apply. Furthermore, it was pointed out that the LHC, while generally thought of as discovery machine, could also indirectly reveal new physics via precision measurements of standard model processes such as Drell-Yan. In the meantime, the exploration of the Higgs sector will remain a high priority on the experimental side and require a strong involvement of the theory community. Recent alternative solutions to the hierarchy problem are the so called relaxion and clockwork models. As of today there are no phenomenologically fully realistic models. Ongoing activities on the model building side were presented by the world experts on these topics.

Two of the strongest data-driven motivations for new physics are dark matter and baryogenesis. Here some models were introduced that go beyond the usual paradigms,. New ways of probing dark matter and dark sectors experimentally were highlighted. While solid quantum field theory arguments strongly motivate the TeV scale as new physics threshold, experimental data do not point to any definite scale as of today. Therefore, the search for new physics has to continue on all frontiers, including very weakly coupled states at lower scales like axions or dark photons. New methods for probing such light states were elaborated. In particular, the new method of using isotope shift spectroscopy to constrain new interactions benefitted from the presence of local experts in atomic physics who added a refreshing and stimulating interdisciplinary aspect to the workshop.

After the consolidated results of the LHC at 13 TeV with more than 30/fb, the timing of the scientific program was very appropriate. The flavor anomalies reported by LHCb were extensively discussed. But the absence so far of clear evidence of new physics at the TeV raised many questions. Thus, a scientific program like this one with ample time for informal discussions is the perfect avenue to ponder on the current situation and foster new unconventional and creative ideas. The program was extremely successful in motivating people with very different strengths and expertise to discuss and collaborate on the challenges posed by the LHC results. Many of the most pressing and sometimes controversial questions were addressed – without the usual (negative) constrains (time, closed experimental collaborations, presence of non-specialized audience). A very positive and constructive atmosphere has characterized all the meetings.

Cluster of Excellence Precision Physics, Fundamental Interactions and Structure of Matter
PRISMA

Mainz Institute for Theoretical Physics

Progress in Diagrammatic Monte Carlo Methods for Quantum Field Theories in Particle-, Nuclear-, and Condensed Matter Physics

Organized by Christof Gattringer (Graz Univ.), Shailesh Chandrasekharan (Duke Univ.) and Dean Lee (North Carolina State Univ.).

18 -29 September 2017

Monte Carlo simulations are among the most powerful tools for obtaining non-perturbative results in quantum field theories. They are used for a wide range of applications in particle-, nuclear-, and condensed matter physics. In these different fields of physics applications, Monte Carlo techniques developed significantly in recent years. With new ideas like rewriting the systems in terms of new degrees of freedom, serious challenges were overcome such as problems related to the sign problem. Exchanging ideas and discussing the new Monte Carlo approaches used in the various communities will certainly speed up the development of the new techniques. More specifically, the central goal of the scientific program was to explore recent advances in Monte Carlo methods, especially those that use the Monte Carlo sampling of diagrams. The specific topics covered were organized in the following fields: (i) techniques for fermions, (ii) weak coupling diagrammatic Monte Carlo, (iii) dual variables in lattice field theories, (iv) tensor networks, (v) special topics.

Different formats for structuring the scientific program were used: conventional lectures, tutorial lectures, moderated discussions as well as a poster session. In addition, there was ample time for discussions and work in smaller groups. To make sure that all areas of interest were met in our scientific program, an opening discussion at the beginning of each of the two weeks took place in which the participants chose the relevant scientific topics.

In the context of techniques for fermions, Uwe-Jens Wiese led a moderated discussion on the significance of the sign problem. It also dealt with the question whether it is really a problem for general fermionic systems. He tried to clarify his work in which they had claimed that the problem was considered to be NP hard.

Based on diagrammatic Monte Carlo methods, Nikolay Prokofiev argued that general fermionic systems can be solved in polynomial time, although success seemed to depend on the convergence of the diagrammatic series. The conclusion was that the sign problem in Monte Carlo methods sampling the partition function may be qualitatively different from those in diagrammatic Monte Carlo methods sampling the effective action.

Shailesh Chandrasekharan gave two tutorial type lectures on the fermion bag approach. He discussed how the idea is based on rewriting the fermionic path integral in the lattice Lagrangian approach, namely as a sum over fermion world lines and then regrouping the sum differently than it is traditionally done. He discussed how this approach could be combined with the world line approach for bosons to solve new sign problems. He then showed how these ideas could also be extended to lattice Hamiltonian formulations. He argued that this extension leads to fermion algorithms which are faster than conventional methods.

Timo Lähde gave an overview of recent advances in Monte Carlo methods for graphene and carbon nanotubes. This led to some lively discussions, as there were several others in the workshop also working on auxiliary field simulations of graphene. He discussed the advantages of the hexagonal lattice simulations, the incorporation of physical lattice effects, and the difference between Hubbard-like interactions and Coulomb interactions. Calculations are now underway to determine the energy gap in carbon nanotubes with radii up to 1 nanometer.

Fakher Assaad led a discussion on fermion algorithms. He presented some of his recent results and thoughts on the comparison between hybrid Monte Carlo (HMC) and the auxiliary field Monte Carlo (AFMC) methods. He concluded that while the HMC method scales well for a class of problems, the AFMC continues to perform better for another class of problems - at least for lattice sizes that are currently studied. While electron-phonon models fall in the former class, Hubbard models seem to fall in the latter class. Assaad later also led a discussion on the recent excitement related to phase diagrams in 2+1 dimensional Dirac systems. Using a specific example, he explained that there are new predictions of non-Landau type second order phase transitions between phases with two different mass order parameters. These transitions are related to the presence of topological terms in the action. Later, Toshihiro Sato presented specific results in a conventional talk entitled Dirac fermions with competing mass terms and emergent symmetry.

In the framework of weak coupling diagrammatic Monte Carlo, Boris Svistunov discussed the Bose-Hubbard system tuned to the Wilson-Fisher fixed point with a single-site impurity potential. Since the impurity potential is varied, the number of particles localized by the impurity relative to the uniform background is typically an integer number. However, worm algorithm simulations show that there is a special point at which the number of localized particles is a half integer. This feature is called a halon, a polaron with half-integer charge.

Pavel Buividovich gave a talk entitled diagrammatic Monte-Carlo for non-abelian lattice field theory at weak coupling. He outlined the strategies and techniques for setting up the diagrammatic Monte Carlo approach in the weak-coupling regime. The talk discussed simple examples in detail so that not only Pavel's work, but also the method itself became clear to a broader audience. This turned out to be very helpful for appreciating the talks by Nikolay Prokofiev and Felix Werner. They gave two back-to-back blackboard talks on dealing with the sign problems through diagrammatic Monte Carlo evaluations of the perturbative series in the thermodynamic limit.

One of the significant new developments was an algorithm to sum all connected diagrams for fixed positions of the vertices by Riccardo Rossi. Prokofiev gave some computational time estimates for reaching set error tolerances under some general assumptions about diagrammatic convergence, and Werner discussed the resummation of divergent series and the large-order behavior of diagram amplitudes. Markus Wallerberger gave a tutorial talk in which he explained how one can convert many interesting quantum many-body problems into a quantum impurity problem and solve the quantum impurity problem using diagrammatic Monte Carlo methods. Approximations such as the dynamical mean field theory (DMFT) are based on this connection. Wallerberger also discussed some limitations of the method.

Falk Bruckmann, Christof Gattringer and Tin Sulejmanpasic organized a moderated discussion entitled sign problems from topological terms. The first part of this session was used to outline the strategy for mapping lattice field theories to a dual representation in terms of world lines and world sheets. The role of topological terms in relativistic quantum field theories was discussed by comparing this role to the one in quantum field theories in condensed matter theory. In the second part examples were discussed in which the complex action problem from the topological term is overcome by a dualization. Bruckmann gave a talk entitled dual variables in O(N) / CP(N-1) and in QCD with scalar quarks. For the two spin models, dualizations in terms of worldlines were presented which allow for a Monte Carlo simulation at arbitrary values of the chemical potential. The representation is correct at all orders of the strong coupling expansion. For QCD with scalar quarks only the leading terms of the strong coupling expansion are accessible but hopefully these terms already reveal some of the structure expected for non-abelian gauge theories coupled to matter fields.

Maria-Carmen Banuls and Roman Orus gave two pedagogical reviews on tensor network theory. Banuls focused on basics and introduced the concepts that go into the construction of tensor network states. Ideas of matrix product states and connections to density matrix renormalization group (DMRG) were introduced. Banuls also discussed an application of the method to the Schwinger Model, the simplest model example of lattice gauge theory. Orus then discussed extensions to higher dimensions, especially focusing on projected entangled pairs (PEP) and on multiscale entanglement renormalization ansatz (MERA). In the afternoon Maria-Carmen Banuls and Roman Orus led another discussion session where attempts were made to synthesize the lectures and make connections with other approaches like quantum Monte Carlo methods. An interesting question that came up was whether there was a way to combine the two ideas. It was pointed out that the loop cluster algorithm for quantum spin systems precisely accomplishes this connection. In terms of physics, questions about the lattice Schwinger model and the need to explore two different mass terms were discussed.

Anders Sandvik analyzed some recent developments in computing time correlations and spectral functions, going beyond the usual maximum entropy approach. He discussed the stochastic analytic continuation method which includes a sampling temperature, but encounters problems when configurational entropy becomes dominant. He then presented an improved stochastic analytic continuation method that can incorporate sharp edge features in the spectrum by using a distribution of delta functions with equal weight. Dean Lee gave a tutorial on lattice effective field theory simulations relevant for few-body systems. The topics discussed were the implementation of chiral effective field theory at leading order on the lattice, the adiabatic projection method for scattering and reactions, and the pinhole method for calculations of density distributions.

Ribhu Kaul presented a tutorial lecture on deconfined critical points. He argued that such points were more ubiquitous than earlier thought and were related to topological excitations that arise naturally in quantum systems. He later gave a more conventional talk on the physics of critical points in quantum spin systems, especially spin-one systems, relating them to CP(N-1)models. Tin Sulejmanpasic gave a talk in which he explained how some of the physics of quantum spin systems were related to anomalies in gauge theories through ‘t Hooft’s anomaly matching conditions. Thomas Lang presented an overview of the recent applications of machine learning to quantum many body physics. He explained that while the method was promising, there were also many hurdles to overcome before it could be used as a viable alternative to quantum Monte Carlo methods.

The poster session was held on Wednesday of the second week and the following posters were presented: Stefan Beyl, revisiting the hybrid quantum Monte Carlo method for Hubbard and electron-phonon models; Mario Giuliani, condensation thresholds and scattering data; Daniel Göschl, worldline simulation of the Schwinger model; Emilie Huffman, fermion bag approach to Hamiltonian lattice field theories in continuous time; Carla Marchis, a test for dynamical stabilization in complex Langevin simulations: the XY-model; Francesco Parisen Tolden, Entanglement properties of the Hubbard chain model; Zhenjiu Wang, spin and valence bond dynamics across a DQCP in a fermionic SU(3) Model; Manuel Weber, directed-loop quantum Monte Carlo method for retarded interactions; Savvas Zafeiropoulus, Complex Langevin simulations of a finite density matrix model for QCD.

The scientific program successfully fostered of fostering the exchange of methods and techniques in the area of diagrammatic Monte Carlo among the three communities represented at the scientific program, high energy physics, nuclear physics and condensed matter.

Probing Physics Beyond the Standard Model with Precision

Organized by Ansgar Denner (University Würzburg), Stefan Dittmaier (University Freiburg) and Tilman Plehn (Heidelberg University).

25 February – 9 March 2018

The LHC and other particle-physics experiments continue to confirm the Standard Model in an impressive manner. No conclusive evidence for New Physics in the TeV range has been found so far. In this situation, precision measurements are an adequate measure to search for physics beyond the Standard Model. To fully support the experimental program of the LHC and in particular its high-luminosity extension, precise theoretical predictions are crucial. The rapid progress in techniques for the evaluation of perturbative corrections and the accompanying automation open the possibility to routinely calculate higher-order corrections also in extended models. The goal of the scientific program was to bring together experts in the field of higher-order calculations with researchers in the phenomenology of theories Beyond the Standard Model (BSM) and effective field theories (EFTs) to discuss the need and the preparation of appropriate automated tools for precise predictions in extended models.

In the first week of the scientific program, the focus of the meeting was on EFTs for the description of deviations from the Standard Model. In the second week, the discussion dealt with specific extensions of the Standard Model. Each week started with talks by experimentalists to update the participants concerning the latest experimental findings of the LHC collaborations. In the following days there was a theoretical overview talk of about one hour each day in the late morning, followed by discussions. Several of these talks were presented by junior participants without a permanent position. For the presentations we asked the audience not to bring their laptops. This worked out very well and had a positive effect on fostering discussions during and after the talks. The topics of the talks were: Electroweak precision observables and EFTs (Matthias Schott, ATLAS), Multi-boson interactions (Matthias Mozer, CMS), Introduction to EFT (Ian Lewis), The Standard Model EFT-tools and strategies (Ilaria Brivio), EFT and perturbation theory (Michael Trott), EFT summary (Christoph Englert), Experimental results and open theory-related aspects (Luca Perozzi, CMS), Introduction and overview of BSM theories (Werner Porod), Renormalization of BSM theories (Heidi Rzehak), Automation of NLO calculations for BSM theories (Jean-Nicolas Lang), BSM summary (Michael Krämer).

The discussions during the workshop focused on important questions for the development of the field. Some examples are: Can the EFT of the Standard Model become a standard to describe deviations? How should large effects from squares or products of dimension-6 operators be interpreted? When and how should dimension-8 operators be incorporated in prediction? Are precision calculations within the Standard Model EFT a worthwhile exercise? Are precision calculations within BSM theories needed? Are gauge-dependent renormalization schemes useful?

While the discussion of some of these questions was quite controversial, there was a clear request from the experimentalists to continue precision calculations for the Standard Model and to come up with recommendations for analyses in BSM theories. Moreover, there was a consensus that automation of precision calculations for BSM theories should be continued. The workshop was used by many participants to start new and to reinforce existing collaborations. We here list some examples of such projects: renormalization of mixing angles, precise predictions for vector-boson pair production within EFTs, supersymmetric Higgs mass calculations in the EFT framework, theory preparation for upcoming high-precision measurements at the LHC (W-boson mass, effective weak mixing angle), interpretation of electroweak precision data as part of LHC analyses, interplay of anomalous fermion-gauge couplings on EFT analyses in the Higgs sector, impact of parton distributions on current limits on four-fermion Wilson coefficients. The scientific program will certainly influence the further development of the field.

Bridging the Standard Model to New Physics with the Parity Violation Program at MESA

Organized by Jens Erler (UNAM), Mikhail Gorshteyn (JGU Mainz) and Hubert Spiesberger (JGU Mainz).

23 April -- 4 May 2018

The main objective of the two-week program was to review the physics opportunities which ultra-high precision polarization experiments at MESA may present within the Standard Model (SM) and beyond. It involved 28 longer (45 to 60 minutes) talks and three shorter ones (about 15 minutes) on topics ranging from searches for physics beyond the SM and their necessary radiative corrections to recent developments in neutrino scattering to neutron skins and hadronic parity violation (HPV). There were ample and lively discussions following the presentations which were continued in four dedicated discussion sessions. In the following, a summary of the issues is given. It refers to new ideas and to the progress made in their understanding.

In his opening talk, Bill Marciano introduced the idea of adding the option of a polarized positron beam to MESA operations. The radiative corrections to e^+p scattering result in a smaller asymmetry compared to the e^-p case increasing the new physics sensitivity and providing complementarity. The challenges involved in the production of a high intensity e^+ beam with sufficient polarization would be enormous, but may deserve a closer look.

There are searches for physics beyond the SM in parity violating electron scattering (PVES) in Mainz and at Jefferson Lab. No conclusive evidence for new physics has been reported so far. Drell-Yan cross section and forward-backward asymmetry measurements in dilepton final states contribute to precision determinations of the weak mixing angle (talk by Siqi Yang) and cut into the available new physics parameter space. In the absence of new light and very weakly coupled particles, the new physics may be described model-independently by an effective field theory.

Vincenzo Cirigliano and Adam Falkowski reviewed the charged and neutral current sectors, and Paul Souder raised the question to what extent the highest energy bins at the LHC with sensitivity to the (non-interfering) square of dimension-6 amplitudes provide strong constraints on sums of positive terms without cancellations. This would be of greater concern for the new physics motivation for PVDIS at SoLID than for elastic scattering at MOLLER (talk by Krishna Kumar), Qweak (David Armstrong) or P2 (Frank Maas). The loopholes to his argument include new gauge bosons that are leptophobic or have large invisible widths, very light degrees of freedom, and possibly four-quark or diquark-diboson operators. It is important to quantify them and to revisit the complementarity between the approaches at the high-energy and high-intensity frontiers (Michael Ramsey-Musolf). Moreover, novel approaches like the CONUS coherent neutrino scattering experiment, presented by Manfred Lindner, may contribute with complementary results in the long run.

Low-energy SM tests have reached a precision where previously ignored radiative corrections (RC) become important. Ayres Freitas, Aleks Aleksejevs, Rodolfo Ferro reported on recent progress regarding higher order corrections; Konstantin Ottnad and Jonas Wilhelm presented results from lattice QCD on non-perturbative corrections.

A vivid discussion concerned the ways to present the running of $\sin^2\theta_W$. A more radical suggestion was made by Hiren Patel in the context of a two-loop RC to Møller scattering, namely to use SM EFT with heavy bosons and quarks integrated out. It would operate with only four-fermion operators and the respective Wilson coefficients (say, C_1's and C_2's) and all RC would be purely QED and QCD. While it would allow to treat all large logarithms on the same footing (which is a valid point for 2-loop RC), it would lead to giving up the renormalizability of the SM and various other problems which the follow-up discussion could not solve.

As for super-allowed $0^+ \to 0^+ \beta$-decays, the γ-W box contributions (Chien Yeah Seng) need to be re-evaluated already at the level of free neutron decay. But the effects due to the nuclear environment must also be scrutinized. The issue is analogous to γ-Z box diagrams (Peter Blunden) in the neutral current sector. Data from β-decays and neutron lifetime measurements provide the information required for a determination of V_{ud}. The status of experiments in this area was reviewed by Werner Heil and John Hardy. Bill Marciano pointed out that using g_A as obtained via post-2002 asymmetry measurements, plus V_{ud} from superallowed decays, would lead to the conclusion that the neutron lifetime obtained from bottle experiments is preferred over that from beam experiments. Alejandro Garcia reported on the progress in assessing new tensor inter-actions with a high-precision measurement of the a and b correlation coefficients in ^{6}He decay.

Barry Holstein and Jordy de Vries reported on a new paradigm according to which HPV may be organized with respect to NC enhancements and $\sin^2\theta_W$ suppressions. To test it, more experimental data are needed. Beyond the recently completed NPDγ experiment at ORNL, Mike Snow reported on the status of spin rotation in polarized n-^{4}He scattering. Discussions pointed out a possible input from the future MESA program. Along the nucleon anapole moment, which is an important part of the P2 program, an energy-upgrade to 200 MeV MESA+ will allow to probe the PV π^+ production at threshold which would mainly be sensitive to the PV coupling h_1^π. A feasibility study for the latter measurement was proposed.

Dionysis Antypas reviewed recent progress on PNC effects in Dy and Yb atoms, subject to an active experimental program in the local group of Dima Budker. Yevgeny Stadnik presented an overview of atomic theory required to extract information from these and future atomic PNC experiments, discussed sensitivity of atomic experiments to Dark Matter effects (e.g. axions), and proposed new neutrino-mediated long-range PV forces which may become testable on the experiment in the near future.

PVES experiments such as PREX and CREX (Krishna Kumar) or the ancillary aluminum measurement at Qweak (Wouter Deconinck) may be used to understand neutron skins in nuclei (Concettina Sfienti) and neutron stars (Chuck Horowitz). An important question is which nuclei precision measurement at MESA would optimize the physics output. Xavier Roca Maza proposed to use charge radii of mirror nuclei as an additional observable beyond the symmetry energy and electric dipole polarizability to constrain nuclear models that are then used to obtain information on the equation of state of neutron-rich matter via neutron skin measurements. In beta decay, mirror nuclei are important systems for the V_{ud} extraction. Thus a joint analysis of the two reactions should be advantageous.

The beam normal spin asymmetries on nuclei may help testing our understanding of the Coulomb distortion corrections which are an important ingredient for extracting the neutron skin from PV asymmetry measurements. Coherent pi-0 production on nuclei at low momentum transfer, previously proposed as an alternative method to access the neutron skin, requires further theoretical work to remove a systematic uncertainty due to strong interaction effects connecting the measured cross sections to the neutron skin.

From Kinematic Space to Bootstrap: Modern Techniques for CFT and AdS

Organized by Bartlomiej Czech (Institute for Advanced Study), Michal P. Heller (Max Planck Institute for Gravitational Physics) and Alessandro Vichi (Ecole polytechnique fédérale de Lausanne).

22-30 May 2018

Conformal field theories (CFTs) are a cornerstone of modern physics;. They are a basic tool for all condensed matter theorists and many particle physicists. The last two decades have revealed that certain CFTs have a fascinating bonus application. Under the holographic duality (the AdS/CFT correspondence), they encode the quantum dynamics of gravitational systems, enabling the study of quantum gravity and the unitary of black holes in controlled settings. At the same time, the structure of CFTs is so tightly constrained that it is possible to derive many facts about them from self-consistency and unitarity alone. The attendant effort to characterize and classify all CFTs is known as the bootstrap program. Until recently, the bootstrap program and the AdS/CFT correspondence have mostly developed as two independent and complementary fields. Luckily, this has changed in the last few years – in part because these research enterprises made sufficient progress to establish contact and in part because there were several breakthrough insights. The goal of scientific program was to nurture the current convergence of the bootstrap program and the AdS/CFT correspondence, to use insights from one to foster progress in the other, and develop new joint tools for exploiting conformal symmetry. An example for such a tool is the kinematic space, a formalism invented by two of the organizers which clarifies the manipulations carried out in bootstrap calculations, but which also provides an efficient description of the gravitational dynamics of the dual anti-de Sitter (AdS) spacetime.

The scientific program "Modern Techniques for CFT and From Kinematic Space to Bootstrap" was a productive meeting with engaged participants, productive discussions, and excellent talks. Participants appreciated the relaxed schedule that included plenty of time for discussions (two talks per day), the young age of the participants (many postdocs) and the lively and creative atmosphere.

There were four major topics or classes of questions: (i) kinematic space, (ii) black holes from bootstrap, (iii) the question of the general character of holography, and (iv) locality in AdS. A majority of the talks spanned several if not all of these topics. This includes Jan de Boer's "The Interior Geometry of a Typical Microstate," Alejandra Castro's "Wilson Lines in AdS3," Henry Maxfield's "A view of the bulk from the worldline," Lampros Lamprou's "Entanglement Holonomies," Gilad Lifschytz's "A new perspective on bulk reconstruction," and Felix Haehl's "Gravity and Entanglement from Entanglement." Several other talks were more focused: Nele Callebeaut's "The Gravitational Dynamics of Kinematic Space," Charles Melby-Thompson's "Double Trace Interfaces," Charles Rabideau's "Higher-dimensional DifferenJal Entropy: Toward the Reconstruction of Surface Areas" and Claire Zukowski's "What is the structure of phase space in holography?", Micha Berkooz's "Chord Diagrams, Exact Correlators in Spin Glasses and Black Hole Bulk ReconstrucJon" and Moshe Rozali's "Fine Grained Chaos in AdS2 Gravity" and Hengyu Chen's "Aspects of Spinning Wiien Diagrams, from Geodesic to Mellin". Alessandro Vichi did an excellent job delivering a talk "Informal Introduction to Modern Conformal Bootstrap" which set the subjects covered elsewhere in the scientific program against the background of the bootstrap program, with emphasis on its modern elements. The participants could be seen at white boards, busily discussing and planning future projects, way into the evenings and past the official closing hours of MITP.

The Sound of Spacetime: The Dawn of Gravitational Wave Science

Organized by Luis Lehner (Perimeter Institute), Rafael Porto (ICTP SAIFR)], Riccardo Sturani (IIP Natal) and Salvatore Vitale (MIT).

4 - 15 June 2018

The recent historical detection of gravitational waves (GWs) by the LIGO scientific and Virgo collaborations heralded an unprecedented new era for fundamental physics investigations. After the remarkable landmark of detection, GW science will soon turn into the study of the properties of the sources and address fundamental questions in astrophysics, fundamental gravity and cosmology. In particular, binary coalescences – of comparable masses or extreme-mass ratios – are posed to become the leading probe to test gravitational dynamics and the physics of compact objects under unique conditions. The number of events detected up to now has demonstrated the feasibility of direct detection of GWs emitted by coalescing compact objects and that black holes in binary systems are relatively common in nature. We expect many events per year once LIGO is running at designed sensitivity. The correct interpretation of results and their physical consequences will thus become the ultimate goal of the field. Typical searches for GWs thus require very precise signal templates, which in turn demands state-of-the-art numerical and analytical models to make the most accurate parameter estimation possible. Moreover, extracting the most information from the waveforms requires very efficient search algorithms for data analysis.

The new era of GW science will become a truly interdisciplinary subject. The nascent field of gravitational wave astronomy encompasses source modeling, data analysis, fundamental gravity, cosmology and astrophysics to realize the full potential of this new era.

The scientific program brought together researchers focusing in different areas of this emerging field that is under the umbrella of GW physics and ranging from field-theoretical methods, numerical gravity, astrophysics to signal analysis. Our main motivation is to create an environment that fosters exchange between scientists with different backgrounds. The format of the meeting consisted of 2-3 long talks (1h each) in the mornings and 1 in the afternoons, followed by open discussions.

Maria Haney presented the most recent LIGO/Virgo gravitational wave (GW) detection results with emphasis on the fundamental physics tests made possible by these observations. Badri Krishna talked about testing general relativity consistency in the signals from compact binary coalescence by comparing the inspiral phase in which the two initial compact objects are approaching each other to the ring-down phase in which the two initial objects have merged into a final black hole. The discussion session was about the question how much more accurate theoretical modelling one needs to interpret observational results.

Talks by John Carrasco, Stefano Foffa, Natalia Maia and Rafael Porto all focused on the use of effective field theory to model the two-body dynamics in gravity theory. Carrasco introduced new ideas for amplitude computations, Foffa gave an introductory talk about reducing the gravitational dynamics to computable scattering amplitudes. Maia showed her latest results on next-to-next-leading order in radiation reaction force of compact object with spin. Porto concluded with an overview of the effective field theory approach to general relativistic 2-body dynamics. The discussion was about the impact of theoretical computation on wave form modelling.

Matalia Korsakova gave an overview on the sources and data analysis issues foreseen for LISA. The space GW detector is due to start its mission in the mid 30ies. Salvatore Vitale presented a comprehensive study of the astrophysical implications obtained so far. He also considered possible implications in the near future of GW detections on stellar mass black astrophysical parameter distributions. Following on this line, Matias Zaldarriaga presented the binary formation mechanism favored by present data and asked what can be expected from further LIGO/Virgo detections. The discussion was centered on how GW detections can constrain the binary formation channels, with the conclusion that at present the common envelope model (object already in pairs before they become compact) is favored.

The next topic was the use of the luminosity distance measured by GWs to test gravity in the weak curvature, long distance regime. Stefano Foffa showed how the current standard cosmological model can be challenged by other models with the same number of parameters and comparable evidence. He also showed how future GW observations by third generation detectors can enable choosing between one model and the other. Jose Exquiaga reiterated the topic by demonstrating how dark energy - or whatever is at the basis of the present cosmological acceleration - can be probed by future GW detections in a model-independent way. The discussion was about all possible ways - beyond standard sirens – how cosmological information can be inferred from GW data.

The talks by David Nichols, Horn Sheng Chia, Badri Krishnan and Xavier Calmet were dedicated to exotic aspects of gravitational waves. Nichols talked about memory effects, which are effects in standard general relativity. Chia explained the concept of super-radiance (amplification of GWs by a spinning black hole) and how it can be detected if it is further enhanced. Krishnan gave a data analysis perspective of the non-standard source of GWs and the way to detect them.

Calmet presented the results of his approach which consists of adding higher curvature corrections inspired from quantum gravity to Einstein equations. He also looked for detectable effects in both the conservative and dissipative sector of gravity. The discussion after the talks focused on possible exotic effects in GWs. Krishnan presented ongoing efforts to connect the GWs measured at infinity to assess the behavior of horizons. This mapping would provide crucial insights on the nature of strong field gravity and trapped surfaces. Frans Pretorius discussed opportunities and challenges in the context of eccentric mergers, reviewing the rich phenomenology such systems could display and the physics one can conclude from this. Georgios Gerakopoulos, in turn, surveyed what is known on the possible existence of chaos in binary system of large mass ratio and its consequences, stressing, however, that further research is needed on this topic. These talks were followed by a discussion on gravitational wave building blocks, specifically considering the extent to which departures from general relativity are taken into account currently. Moreover, possible limitations in light of the limited theoretical knowledge were also discussed.

Luis Lehner summarized possible surprises with respect to current templates that compact binaries in General Relativity might display. He also offered an overview of what is known regarding extensions of GR and alternative compact objects. Hinderer surveyed the know-how on semi-analytical ways to encode the full waveform for both vacuum and non-vacuum binaries. Aaron Zimmerman presented a detailed description of the analysis and physics drawn from GW170817 (binary neutron star coalescence). He also gave an overview of results and opportunities to extract information of gravitational physics from pulsars. The discussion focused on the question if and how currently used waveform models can catch appropriately non-dominant feature in the data.

Donal O'Connel showed how to recover gravitational dynamical quantities like scattering amplitudes in gravity by appropriately squaring analogue computations in vector-gauge mediated processes. Nicola Franchini showed the result of his investigations on how strong field gravity like in neutron star interior can hide new physics to be probed by GWs. The discussion focused on the possibility that modern field theory techniques like double copy can open for classical gravity phenomenological computations.

There was also an intense journal club discussion led by Jose Exquiaga about papers that recently appeared on the archive, namely arXiv:1801.00386 on dark matter (small) effects on GW2 propagation and on arXiv:1806.04920 which showed how to derive the classical, non-relativistic limit of general relativity from relativistic scattering amplitude of massive particle with graviton-mediated interactions.

Aaron Zimmerman focused on The Bayesian inference and model comparison, displaying the caveats that one has to keep in mind when looking for deviations from general relativity in GW data - deviations which cannot only be model dependent, but are also dependent on the astrophysical system, loosening the strength of the tests published by several groups, including the LIGO/Virgo collaboration.

Salvatore Vitale concluded the program with an overlook of future generation GW detectors and their foresee-able impact in astrophysical parameter estimations to constrain stellar mass black hole population and galactic evolution history. Throughout the scientific program, a flexible schedule allowed and encouraged ample discussions which provided a forum where ideas and expertise were exchanged in a lively and constructive environment.

The Future of BSM Physics

Organized by Gian Giudice (CERN), Giulia Ricciardi (Univ. Naples), Tobias Hurth (JGU Mainz), Joachim Kopp (JGU Mainz) and Matthias Neubert (JGU Mainz).

4 – 15 June 2018

The early LHC data have stimulated theorists to look for entirely new directions in physics beyond the SM, while abandoning some of the old scenarios. This scientific program was dedicated to reflecting the theoretical motivation of new physics and exploring radically new theoretical concepts for the current data-driven era of particle and astroparticle physics. New scenarios of NP have been proposed or revised, for instance some aspects of dynamical SUSY breaking. Particular emphasis was placed on extensions of the Standard Model, featuring light or very weakly coupled new particles. All talks were blackboard presentations with intense discussion sessions afterwards.

In the first week, axions were discussed in particular detail (talk by Filipo Sala) as well as axion-like particles (ALPS) in phenomenological connections with LHC and kaon factories data (Tien Tien Yu). The infrared structure of Nambu-Goldstone bosons was reanalyzed in the framework of effective actions for Nambu-Goldstone bosons (talk by Ian Low). Other probes of NP, which were object of discussions, were exotic sterile neutrinos (Bibhishan Shakya) and atomic physics (Claudia Frugiuele). Dark matter (DM) has been thoroughly investigated, in particular the concept of co-decaying dark matter (Eric Kuflik). Finally, the idea of femto-lensing of gamma ray bursts was revisited as an exciting possibility to probe exotic astrophysical objects such as small primordial black holes or ultra-compact dark matter minihalos (Andrey Katz).

The second week of the workshop started out with a discussion of effective field theories led by Dave Sutherland (focusing on particle physics aspects) and Javi Serra (focusing on massive gravity theories). The primary emphasis of the second week, however, was on new physics at low mass scales. This included a lively discussion of the MiniBooNE anomaly (which has recently reached a statistical significance of 4.8 sigma) led by Joachim Kopp, the prospects of ALP detection at kaon factories (Kohsaku Tobioka), connections between axion physics and gravitational waves (Ben Stefanek), and the appearance of light pseudo-scalars in composite Higgs models (Thomas Flacke). The topic of composite Higgs models was also taken up by Ramona Groeber, who discussed dark matter candidates in such models. The program was completed by talks on the search for new physics with particularly small coupling constants (Greg Landsberg) and on deriving the Affleck-Dine superpotential from monopoles (Yuri Shirman). Beyond the official program of the workshop, discussions centered around gravitational waves, various aspects of dark matter, early universe cosmology, and effective field theories.

Probing Baryogenesis via LHC and Gravitational Wave Signatures

Organized by Germano Nardini (University of Bern), Carlos E.M. Wagner (University of Chicago / Argonne Nat.Lab.) and Pedro Schwaller (JGU Mainz).

18-29 June 2018

The origin of the baryon asymmetry of the universe is one of the main open questions in fundamental science. The solution to this puzzle requires physics beyond the SM (BSM) to which the LHC is supposed to be sensitive. TeV scale baryogenesis mechanisms typically require a strong first order phase transition, which might be responsible for setting the dark matter abundance in asymmetric DM scenarios.

The scientific program brought together experts from the fields of collider physics, model building, baryogenesis and phase transitions, dark matter and gravitational wave physics to tackle the puzzle of the baryon asymmetry of the universe. Several SM extensions that aim at generating a baryon asymmetry with signatures that should be testable in the forthcoming decades, were analyzed. Such signatures include EDMs, LHC searches and GW measurements. All of them were reviewed and critically reinterpreted in view of the models that have been discussed.

Particular emphasis was dedicated to the GW observables, since this field is quite new for the particle physics community. The participants showed great interest in this topic. Their better comprehension of the GW phenomena is expected to impact their future publications, allowing them to provide estimates according to the state of the art in the field. In particular one expects general improvements about the reliability of the predictions, where the uncertainties on the GW signals are not overlooked.

The scientific program also highlighted that even for the experts on the GW production from phase transitions there remain several open questions. These are possibly due to the fact that our comprehension of this GW phenomenon is strongly based on the outcome of the numerical simulations, because the analytic understanding is still not sophisticated enough. In view of this, the few researchers working on analytic results will hopefully not be discouraged by the complexity of the subject and keep scrutinizing the outcome of the simulations by means of analytic methods.

As regards the general discussions on the possible baryogenesis realizations it has been observed that it is somewhat difficult to achieve simple UV completions of the SM that produce the observed BAU and at the same time naturally overcome the present EDM and LHC constraints. The explanation of the BAU thus seems to require some tuning in the minimal extensions, or a radical departure from minimality. In some cases, the (non-minimal) SM extensions manage to modify the scale of the EW symmetry breaking by order of magnitudes. Due to this feature, it seems reasonable that, for instance, the typical frequency of the SGWB spectrum possibly generated by the EW phase transition is not necessarily within the LISA band. Of course, insights on the complete model of particle physics can be deduced by breakthroughs in complementary fields. As stressed in several discussions, the problem of the BAU can be connected to the puzzle of DM (via e.g. phase transitions in the hidden sector or asymmetric dark matter), the origin of the primordial magnetic fields, or the breaking of high-scale symmetries (e.g. leading to cosmic strings). In the scientific program there was only time to briefly mention these aspects. In order to analyze these topics in some detail, workshops dedicated to each of these subjects would be necessary.

The main goal of the scientific program was to support collaborations. The multiple discussions carried out in large groups were aimed at summarizing the state of the art of the BAU problem and, moreover, draw the participants' attention to the most relevant open issues. It looks that the participants spontaneously formed small groups to start new projects. The publications of these groups will be an objective measure of the success of the program.

High Time for Higher Orders: From Amplitudes to Phenomenology

Organized by Fabrizio Caola (Durham University), Bernhard Mistlberger (CERN) and Giulia Zanderighi (CERN).

13-24 August 2018

A substantial part of the current research on QCD in collider physics focuses on the following closely interconnected topics: the formal calculation of amplitudes and integrals, their use in higher-order calculations and the merging of these fixed-order calculations to all order results, either analytic resummations or parton-shower simulations.

This scientific program brought together the world leading experts on these topics and addressed several key issues paramount to the future development of high-precision collider phenomenology such as
(i) the bridge between the formal computation of amplitudes or formal next-to-next-to leading (NNLO) subtraction schemes to practical realizations and actual phenomenology. In particular issues like advantages, performances, differences, shortcomings of the different subtraction and slicing methods for double real radiation were addressed.
(ii) Furthermore recent advances in the computation of virtual corrections: analytic versus numerical computation and their respective advantages, performance and shortcomings were analyzed.
(iii) Also the merging fixed order calculations to parton showers, building NNLO parton showers (NNLOPS) and a comparison between different current NNLOPS approaches were discussed.
(iv) Finally, improvements on shower algorithms were considered.

The Large Hadron Collider (LHC) in Geneva currently provides a flurry of measurements that allow the scientific community to explore fundamental forces in previously entirely inaccessible ways. Furthermore, the obtained results support the existing understanding of fundamental interactions at unprecedented levels of precision. It is crucial to the success of the physics exploration spearheaded by the rapid experimental advancement to develop our theoretical understanding of the processes observed in experiment. These theoretical developments were at the core of the scientific program. In particular, it focused on the most recent developments in our understanding of quantum field theory that allows us to derive the highest possible accuracy for the prediction of the outcome of scattering processes in the collision of particles. This area of research is coined by rapid mathematical and technological advancement and yet has to face a great variety of challenges in order to fully exploit the experimental results obtained at the LHC. The desire to predict and understand the outcome of highly energetic interaction as observed in experiment often goes hand in hand with a deepening of our fundamental understanding of quantum field theory.

A diverse group of world leading scientists exploring the above-mentioned topics participated in the scientific program. Recent developments in different areas of the field were discussed in one or two presentations each day. These talks managed to bring the participants up to date on recent scientific progress and led to ample discussions about future directions of research.

During the scientific program two leaders of the experimental community, Matthias Schott and Greg Landsberg, from the ATLAS and CMS collaboration respectively, presented their insights on the current interplay of theoretical and experimental challenges. They shed light on various aspects, in particular on the question where the boundaries between these fields need to be overcome. They also outlined key aspects of future experimental progress that will strongly demand further theoretical insight. The presentation of these two speakers served as a solid reference point revealing where the future research has to go. They pointed out opportunities for scientific exploration that are currently not entirely developed.

The past couple years have seen rapid progress of extending perturbative quantum field theory computations for a vast class of observables to second order in perturbation theory and beyond. The key to this success was the development of methods to handle infrared singularities in the computation of such observables. Methods to regulate and subtract singularities efficiently and with a high degree of automation are in progress and subject to ongoing research. Franz Herzog, Alexander Huss, Tom Melia, Raoul Roentsch and Paulo Torielli reported on their fascinating advances in this particular direction. To accomplish computations for higher order scattering cross sections it is crucial to have complicated scattering amplitudes readily available. The more complex the scattering process the more difficult the calculation becomes. Costas Papadopoulos reported on recent advances in his research of five particle scattering amplitudes at second perturbative order. The intricacies of this highly demanded functions extend the boundaries of our mathematical understanding of Feynman integrals. The exploration thereof has ties deep into the realms of pure mathematics. Claude Duhr and Lorenzo Tancredi shared some recent insights into so-called Elliptic Multiple-Polylogarithms with the participants. Furthermore, Huaxing Zhu showed how novel analytic techniques can be exploited to better understand otherwise familiar event-shape observables.

Describing real scattering processes requires us to think beyond purely strong interactions and to consider all difficulties of computation within the full Standard

Model of particle physics. The presence of masses of particles and of electro-weak interactions makes such calculations very challenging. This is why Paulo Nason, Simon Plaetzer, Sebastian Sapeta and Christopher Wever illuminated several recent developments in the treatment of massive fermions in perturbative computation at high order. Valentin Hirschi also reported furthermore on recent developments to incorporate the full complexity of the standard model into automated computer codes at first perturbative order in a consistent manner. Some observables measured by the LHC are inaccessible to predictions by fixed-order perturbative quantum field theory. Therefore it is crucial to the advancement of our understanding of quantum field theory in general and for LHC phenomenology in particular to understand how one may resum part of the perturbative series and explore such regimes. Dingyu Shao shared his rsearch in the treatment of so-called non-global logarithms in resummation techniques.

Ian Moult and Jian Wang gave talks on how resummation frameworks can be extended even beyond the leading power of a kinematic limit. Finally, Keith Ellis sparked a discussion about the future of our field. He presented an out-look and insights about a new experimental machine yet to be built that will shatter the boundaries of what currently can be explored. The collaborative atmosphere and the interesting variety of cutting edge research topics discussed at our scientific program made it a great success. The stimulating discussions and ample exchange of new ideas certainly triggered a range of new research projects.

String Theory, Geometry and String Model Building

Organized by Philip Candelas (University of Oxford), Andre Lukas (University of Oxford), Xenia de la Ossa (University of Oxford), Daniel Waldram (Imperial College London), Gabriele Honecker (JGU Mainz) and Duco van Straten (JGU Mainz).

10 –21 September 2018

This scientific program brought together mathematicians and theoretical physicists working at the interface of geometry and string theory. The focus was on new developments in Calabi-Yau varieties and related supersymmetric backgrounds such as flux geometries and so-called non-geometries, as well as their applications to compactifications of string theory as models for particle physics and cosmology. There was a flexible schedule of focused talks, reflecting both mathematical and physical problems. It allowed ample time for discussion and more informal presentations. A number of new results and collaborations emerged from the meeting, several due to interactions that would not have been possible without the instigation of the scientific program. The scientific program focused on several broad topics following the framework of the original proposal while at the same time responding to ideas that emerged during the meeting:

(i) Hull–Strominger system and related non-Calabi–Yau flux compactifications: These are the most generic geometries describing compactifications of the heterotic string relevant to building models of particle physics. The presence of flux implies the background gives a natural non-Kähler generalization of CY geometry. A central point of discussion was the characterization of the moduli spaces of such backgrounds.

(ii) Generalized geometry and "non-geometric" CY manifolds: Generic supersymmetric string flux backgrounds have a natural description using generalized geometry, that is structures on an extended tangent space. More radically one can consider "non-geometric" analogues of CY manifolds which are consistent as string conformal field theories but have no global geometric descriptions. Understanding both topics, and in particular the moduli spaces of such backgrounds, was a topic that dominated the meeting.

(iii) Generalized CICYs: The classic constructions of CY spaces as complete intersections (CICYs) have recently been generalized by allowing line bundles which are not positive relative to the projective ambient spaces. This gives rise to a new classification problem and also requires non-trivial generalizations of standard methods, for example for the computation of bundle cohomology on these spaces. Aspects of these issues were discussed throughout the meeting.

(iv) String theory and machine learning: This is an emerging topic within the string community which generated significant interest and discussion. The basic idea is to tackle the problem of analyzing a large number of string vacua using advanced computational methods that include tools from data science and machine learning.

(v) F-theory and duality to heterotic backgrounds: F-theory characterizes non-perturbative string backgrounds in terms of elliptically fibered CY geometries and is a key approach to model building. Study of explicit constructions using CICYs, possible singularity structures, and the nature of the dualities to equivalent heterotic models were central points of discussion.

(vi) G_2-holonomy manifolds: M-theory compactified on a G_2 -manifold is a third source of effective theories relevant to model building. Several topics were covered, including instanton corrections and the construction of non-perturbative superpotentials and the role of limits of K3 metrics in the construction of G_2 geometries.

(vii) Arithmetic of Calabi–Yau manifolds and the attractor mechanism: An relation between the arithmetic properties of Calabi-Yau spaces defined over finite fields and the attractor properties of back-hole solutions in the four-dimensional theories associated to string compactifications on these Calabi-Yau spaces was presented. This relationship between number theory and properties of string vacua led stimulating discussions about its possible physical interpretation. Beyond these broad themes, important applications to understanding the space of string models within all possible theories (the so-called “swampland”), explicit supersymmetric models of particle physics and consistent truncations of supergravity models came up in several presentations.

A measure of the success of the scientific program was the number of new results and collaborations, in many cases as a direct result of the interdisciplinary nature of the meeting. A few of the key new results are the following. There was a lively discussion about the question of the moduli spaces of Hull–Strominger systems. This led to several new conjectures and synergies between a number of complimentary approaches. Talks by Antonella Grassi and Gil Calvalcanti both addressed singularities in Calabi–Yau manifolds. They were able to outline the equivalence of their two approaches (via complex and symplectic geometry). Tristan Hubsch, Andre Lukas and Andrei Constantin started a number of calculations on generalized CICYs, specifically aimed at understanding the new methods required to calculate bundle cohomology on those spaces. Philip Candelas and Sven Krippendorf discussed the possibility of applying machine learning to the Kreuzer-Skarke list of reflexive polytopes to acquire a better understanding of large classes of Calabi-Yau manifolds.

There was a number of new collaborations. Callum Brodie, Magdalena Lafors, Andre Lukas and Fabian Ruehle started a project on building SU(3)-structure geometries on Calabi-Yau hyper-surfaces in toric four-folds. Emanuel Malek, Michela Petrini and Daniel Waldram started a new project on generic constructions of N=2 consistent truncations via generalised geometry. After discussion with Tristan Hubsch, Andrei Constantin and Andre Lukas started a new project to find analytic formulae for line bundle cohomology on surfaces, including del Pezzo surfaces. This project will likely lead to applications of machine learning, a direct result of the discussions on this topic at the meeting.

Overall, the scientific program was remarkably successful. The opportunity to bring together a wide range of experts from mathematics and physics, over a sustained period and with plenty of scope for informal discussion, led to an significant of new results and collaborations engendered by the meeting. The framework of an MITP scientific program was ideal, both in length and the number of participants. It led to a significant progress at the interface between string theory and geometry, and opened up a number of fascinating new directions. This suggests that there is significant potential for a follow-up meeting at MITP.

4 Topical Workshops

Quantum methods for lattice gauge theories calculations

Organized by Ignacio Cirac (MPI for Quantum Optics), Simone Montangero (Ulm Univ.) and Peter Zoller (Univ. Innsbruck).

6-10 February 2017

This topical workshop brought together the expertise of scientists on high-energy-physics, lattice calculations and scientists exploring the route toward quantum lattice calculations. The bridge between these two communities was surely beneficial to the current research program indicating possible critical aspects, and revealing new ideas and approaches based on decades of experience in lattice calculations. Two different dimensions were explored:

(i) The development of theoretical and numerical quantum information tools to study lattice gauge theories (LGTs): sophisticated numerical simulations performed on classical computers mainly based on - but not limited to – matrix product states and tensor networks, which were originally developed in the context of quantum information science and represent promising alternative numerical tools to address challenging questions in strongly correlated condensed matter and in LGTs.

(ii) The development of the theoretical tools to design, develop and verify quantum simulations of LGTs and the implementation of experimental proof of principle quantum simulations of LGTs: While it is currently unclear which combination of theoretical approaches (Wilson's LGT or quantum link models), numerical method (hybrid Monte Carlo, cluster algorithms), and experimental quantum technology (ultracold atoms, trapped ions, or superconducting circuits) is best suited to solve these challenging problems, current research aims at shedding light on these fundamental questions.

The topical workshop was enthusiastically appreciated by the whole community as witnessed by the high number of registrations. There were representatives of different communities and approaches. Within the workshop program, various presentations gave a complete overview of the different platforms and experimental protocols which were proposed to perform quantum simulations of lattice gauge theories. Moreover, the currently unique experiment in this direction carried out on a trapped ions quantum simulator has extensively been reported, both in its experimental and theoretical aspects. In a pioneering experiment the group of Rainer Blatt in Innsbruck managed to show the building blocks of a quantum simulator for the Schwinger model. On the opposite side of the spectrum of the subjects belonging to this interdisciplinary field, colleagues coming from the high-energy and lattice communities presented their view on the subject. They introduced stimulating open problems and possible points of contacts, resulting in an enhanced communication capabilities among the different communities and suggesting the possible next steps of the development of the quantum methods for lattice gauge theories. Finally, experts in tensor network methods working in the field presented their latest results and the open problems that they are facing together with the future challenges they plan to tackle. In particular, different presentations openly pointed out the challenges they are encountering to extend the present methods to higher dimensional systems, and the strategies that they are exploring to overcome them.

The objectives of the topical workshop were fully achieved. Different actors coming from the different communities had an in-depth and productive discussion, which emphasized the major challenges for the future. Novel collaborations are in sight, and a growing community of scientists has been attracted to this new fascinating interdisciplinary field. It has become clear that there are two major challenges: on the one hand the extension of tensor network method to higher dimensional systems and on the other hand, the scaling in the number of components of the quantum simulator for lattice gauge theories. These goals, although being very challenging and definitely not reachable in the near future, are pursued with clear strategies, effective tools and methods. There are no fundamental limitations which could completely stop the research program pursued. In conclusion, the workshop participants shared the expectation that a consistent effort and investment of resources will result in the successful development of efficient novel methods to study lattice gauge theories which can perfectly complement the powerful methods developed in the last decades.

Women at the Intersection of Mathematics and High Energy Physics

Organized by Gabriele Honecker (JGU Mainz), Sylvie Paycha (Univ. Potsdam), Kasia Rejzner (Univ. of York) and Katrin Wendland (Univ. Freiburg).

6 -10 March 2017

This workshop brought together mathematicians and theoretical physicists working at the forefront of research in areas of mathematical physics which share analytic, algebraic geometric and number theoretic methods as underlying common features. The workshop focused on applications of these methods in the context of quantum field theory, quantum gravity and string theory.

The program was centered broadly around the concepts of (i) locality and observables, (ii) symmetry and duality, (iii) string compactifications, (iv) numbers and singularities. The program consisted of 90 minute introductory talks on Monday to Thursday mornings and 45 minute research talks in the afternoons and on Friday morning. This schedule allowed for ample time for free discussions. The character of the workshop was interdisciplinary. This is not only reflected by the diverse list of external participants but also by the fact that local mathematicians and theoretical physicists attended the event.

A public outreach event was organized on the International Women's Day, Wednesday 8 March 2017, where Anda Degeratu (Freiburg and Stuttgart) gave a public evening lecture about gravitational waves.

Beyond its ambitious scientific goals, the concept of the topical workshop aimed to support women, who are currently only represented by a very small fraction of researchers in the field. To achieve this goal, world-leading women in their respective fields where chosen as speakers.

Anne Taormina (Durham) opened the MITP topical workshop with a pedagogical review on string theory as a unified theory of all fundamental interactions and the challenges posed on the compactification of six extra space-like dimensions to match four-dimensional gauge and gravity theories. Xenia de la Ossa (Oxford) reviewed the mathematics of particular compactifications of heterotic string theories and discussed open issues in the description of vector bundles and moduli spaces. The shorter research talks by Mariana Grana (Saclay) and Michela Petrini (LPTHE Paris) addressed open questions that arise when generic closed string background fluxes are included. Thus, the six compact dimensions do not constitute a Calabi-Yau variety but have to be described by the mathematical framework of generalized geometry or - for sufficiently simple backgrounds - by means of double field theory. The research talk by Magdalena Larfors (Uppsala) further discussed the mathematical issues that arise when the compact space is enhanced by one dimension to form a G_2 manifold. This can be used to describe the flow between different geometries with SU(3) structure. The application of geometric descriptions of Calabi-Yau varieties of complex dimension four was discussed in the research talks by Antonella Grassi (U. Penn) and Mirjam Cvetic (U. Penn) in the context of the so-called F-theory which interpolates between Type-IIB string theory at strong string coupling and the heterotic $E_8 \times E_8$ string theory. While Antonella Grassi focused on ongoing research in algebraic geometry and on topology features, in particular the structure of singularities which determine the four-dimensional gauge theory, Mirjam Cvetic focused on the relation of the geometry to discrete gauge symmetries.

The review talk by Johanna Knapp (TU Vienna) focused on newly emerging complementary techniques to describe string compactifications by means of gauged linear sigma models on the string worldsheet, which allow to compute quantum corrections to the four-dimensional effective field theory. The discussion of supersymmetric field theories was picked up by Marialuisa Frau (Turin), who presented new techniques of resummation for all the instanton contributions that are not treatable with other techniques in four dimensions

Valentina Forini (HU Berlin) extended the discussion of sigma model techniques and dualities to extract finite coupling information, which is of great interest in the context of the AdS/CFT correspondence, and she confronted analytical extrapolations with numerical results from lattice field theory. Also related to the study of dualities was Mara Ungureanu's (HU Berlin) research talk, in which she described a classical enumerative problem, the Jonquiere count of certain prescribed hyperplane tangency conditions to a smooth curve embedded in projective space, and related it to certain ergodic dynamical systems, thereby making the connection between enumerative geometry and cohomological field theory.

A series of talks dealt with singularities in quantum field theory. A way to circumvent infrared singularities is to work on a discrete space-time where the path integral becomes finite-dimensional. In her introductory talk, Catherine Meusburger (Erlangen-Nürnberg) explained how the concept of a lattice gauge theory with values in a group can be generalized to a gauge theory with values in a Hopf algebra on a graph embedded into a surface. She set up a relation between Kitaevs lattice model – a special case of the older and more general combinatorial models – for a finite-dimensional semi-simple Hopf algebra and the combinatorial quantization of Chern-Simons theory for its Drinfeld double. Singularities can simplify computations, as exemplified in an introductory talk by Ruth Britto (Dublin &CEA Saclay) on scattering amplitudes. Britto presented the physical context in which amplitude calculations are required, with a focus on singularities and discontinuities as key tools for exploration and computation.

Singularities are inherent to Feynman integrals, one of the most important tools of perturbation theory for high precision calculations in particle physics. Feynman graphs are the point where singularities and numbers meet, since intriguing numbers arise from Feynman graphs. Luise Adams (JGU Mainz) addressed the question as to what type of functions appears in the Laurent expansion of regularized Feynman integrals and showed that the constant term of one-loop integrals involves the logarithm and the dilogarithm. Similarly, many multi-loop integrals can be expressed in terms of generalizations of the logarithm and the dilogarithm - the so-called multiple polylogarithms. However, Adams also showed how the multiple polylogarithms can be generalized to express the constant term in the Laurent expansion of some Feynman integrals such as the sunrise integral. Number patterns in Feynman graphs were the topic of Karen Yeats' (Simon Fraser University, Burnaby) talk. He presented an introduction to periods of Feynman graphs, showing their relevance for both mathematics and physics. Motives and graphs were the subject of Susama Agarwala's (U. S. Naval Academy, Annapolis) talk in which she gave a different graphical representation (unrelated to Feynman diagrams) for the numbers that arise as amplitude calculations in quantum field theories (QFTs), i.e. mixed Tate motives. Daniela Cadamuro (Göttingen) talked about locality of observables. She presented a pedagogical introduction into mathematically rigorous treatments of QFT. She started with Wightman axioms and then moved on to Haag-Kastler axioms and to the presentation of new developments in algebraic quantum field theory. Kristina Giesel (Erlangen-Nürnberg) gave an overview talk on loop quantum gravity and pointed out conceptual difficulties with the notion of observables in quantum gravity.

The topical workshop was a great success, as can be seen from the impressive scientific quality of the talks, covering a broad choice of topics. The talks were followed by lively discussions where scientific ideas were exchanged and further developed. The speakers and participants represented a cross section of scientists including experienced and established researchers, postdoctoral fellows and advanced graduate students. This created a friendly and stimulating atmosphere, which was appreciated by the participants.

Geometry, Gravity and Supersymmetry

Organized by Vicente Cortés (Univ. Hamburg), José Figueroa-O'Farrill (Univ. Edinburgh) and George Papadopoulos (King's College London).

24 -28 April 2017

The main goal of the topical workshop was to bring together geometers and mathematical physicists working on problems related to two related areas: the classification of supergravity backgrounds and the study of moduli spaces and special geometric structures in order to first gauge the progress that has been made so far in these research areas, and then to identify directions in which these areas can develop further.

The core of the scientific tradition is to describe physical phenomena in terms of mathematics. A very early example of this is the description of our physical space as a 3-dimensional Euclidean space. This was continued with the introduction of Einstein's general relativity and the description of spacetime as a (pseudo)

Riemannian manifold. The realization that the universe at large scales is geometric has deep scientific and philosophical significance. It also has the potential to answer key questions which include the origin and the final fate of the universe. The main idea of the topical workshop was to make a contribution to this outstanding tradition.

The emergence of new theories of gravity like strings and M-theory requires new types of geometry for their description. During the topical workshop, experts of the geometry community and theoretical physicists working on strings and M-theory gathered together to discuss the new developments on these two fields in order to find common ground and identify new areas for development. The workshop was attended by about 30 participants. The workshop set out to maximize interaction between the two groups of participants but at the same time it offered a platform for researchers to present their results. A typical day of the workshop included three 45-minute talks by leading experts as well as three 30-minute talks by younger researchers. There were two breaks, a 40-minute coffee break after the first two talks of the day and a longer 4-hour break including lunch time. This arrangement worked out very well. Discussions continued during the breaks.

Several areas have been identified which suggest that further collaboration between geometers and theoretical physicists may be of useful for both fields. For example many discussions took place between those that investigating the classification of supersymmetric solutions of supergravity theories and their geometrical properties and those using these solutions to explore physical applications. The first group was represented by the speakers Ulf Gran, Stefan Ivanov, Thomas Mohaupt, Andrea Santi, Peter Sloane, Eiril Eik Svanes and the other group by the speakers Ulf Chow, Stefan Lozano, Thomas Ortin, Andrea Tomasiello and Achilleas Passias.

Another useful collaboration was identified, namely the one between the geometers working on the classification and properties of homogeneous spaces (and/or the theory of G-structures) and those applying these results in the context of strings and M-theory. The first group was represented by the speakers Dmitri Alekseevsky, Wolfgang Globke, Boris Kruglikov, the other group by the researchers Alexander Haupt and Andrea Santi.

The investigation by theoretical physicists into the structure of supergravity theories continues to have applications in geometry and more specifically into special geometric structures. Such developments from the physics perspective were presented in the talk by Antoine Van. The geometric perspective was presented by Peter-Simon Dieterich, Anton Galaev, and Antoine Suhr. There were related talks to the above topics by other researchers which include Alessio

Marrani, Nano Romao, Carlos Shahbazi and Mohab Abou Zeid. Several papers already acknowledged the excellent scientific environment at the meeting. These papers reach out into various scientific communities, including high energy physics theory, differential geometry and representation theory.

Foundational and structural aspects of gauge theories

Organized by Claudio Dappiaggi (Univ. Pavia), Klaus Fredenhagen (Univ. Hamburg) and Marco Benini (Univ. Potsdam).

25 May -2 June 2017

In modern theoretical physics gauge symmetry represents one of the main pillars in several successful frameworks. The standard model of elementary particles is probably the most famous example and especially in the realm of quantum physics, many models implementing the gauge principle have been formulated and thoroughly studied.

Yet, it is widely accepted that our present understanding of the structural aspects of these theories and their role in a foundational and axiomatic framework for quantum field theory is not as developed as our current knowledge of their phenomenological consequences. A topical example is the quest for the construction of a good class of observables in a quantum theory of gravity in view of diffeomorphism invariance. In general, we would like to better understand in which sense the rich structure of gauge theories with its fruitful relations to mathematics, also well-known at the classical level, has a counterpart in the quantized theory.

In the past, mainly the path integral approach to quantization was used for establishing such connections. Arguments based on this approach are suggestive but typically not conclusive in view of the poorly understood mathematics behind path integrals. At the same time, approaches in axiomatic field theory are often very far from the models of interest for physics. Moreover, they are restricted by the lack of a physical principle that determines the mathematical structures of the so-called unphysical degrees of freedom. For these reasons this topical workshop was a timely event which represents an important occasion to review recent achievements and to start a productive discussion on open issues and on the directions of future research. The format of the topical workshop was the standard one: Renowned scientists gave seminal lectures, summarizing the state of the art while a substantial share of the slots was reserved for contributed talks. Younger scientists were encouraged to participate actively to the event by presenting novel results and ideas. With this format the short term impact of the meeting improved the visibility of this research field in the international scientific landscape. In the long term, one foresees the establishment of new collaborations between research groups who often only tend to have marginal contact.

The algebraic approach to quantum field theory (AQFT) is a well-established branch of theoretical physics which emphasizes the role of observables and their interplay with the notions of locality and causality. From a physical point of view, this approach has the net advantage of also being naturally applicable when the underlying background is curved. Particularly in the past few years, the formulation of all free field theories on arbitrary globally hyperbolic spacetimes has been thoroughly analyzed and understood. The construction of the full algebra of observables has come together with the precise characterization of the quantum states which are physically admissible and with their explicit construction in a large class of interesting scenarios. More importantly, this analysis has been crucial to the definition of a Wick product of fields and to the construction of an extended algebra of observables. Starting from these tools, perturbative interactions have been rigorously formulated and the renormalization group has been extensively investigated bringing quantum field theory on arbitrary curved backgrounds almost on par with its counterpart on Minkowski spacetime.

Despite all these successes, several questions remain open and represented the main issues of the topical workshop. A notable example is that of gauge symmetry. While global gauge groups were already thoroughly studied decades ago, local gauge invariance has been neglected, being considered an insurmountable obstacle. Yet, within the past few years, several papers, reverting this attitude, have been published. At first glance they are based on different approaches: One focused on a novel functional analytic approach towards interacting and gauge theories, which emphasizes the role of functional analysis. Another one advocated the necessity of a constructive procedure, mostly based on the underlying algebra of operators, while yet another one also analyzed gauge theories from a more geometrical perspective, mainly using techniques from algebraic topology.

First of all, it emerged clearly that, combining the principle of local gauge invariance together with the algebraic framework, leads to several open issues concerning both the choice of a good algebra of gauge invariant observables and the implementation of all structural properties desired. Most notably, it appears that the principle of general local covariance, a cornerstone of the modern axiomatic approach towards the quantization of field theories on a generic curved background, cannot be implemented to its fullest extent. The reasons for such problem are manifold, but the main one can be ascribed to our current lack of a full understanding of the interplay between the topology of the underlying structures and the quantization scheme employed.

Despite these obstacles, it has been realized how the algebraic approach is well-suited to combine the infinite dimensional geometric and analytic structures proper of quantum field theories with well-established approaches towards gauge invariance such as the BRST-BV formalism.

On the one hand, one of the main goals of such an investigation was to achieve a better understanding at a quantum level of the rich structure of gauge theories with its useful relations to mathematics which are best known at the classical level. Usually the translation in a quantum framework of classical structures and properties of gauge theories is established via the path integral approach to quantization. Arguments based on this approach are suggestive but typically not conclusive in view of the poorly understood mathematics of path integrals, especially in a e setting. The advantages of the algebraic approach in offering a mathematically rigorous description are often blunted by the difficulties in building a direct connection to models of physical interest. In this respect, one of the key goals of the topical workshop was to create a close contact with other research groups.

On the other hand, the BRST- BV formalism, combined with the tools of infinite dimensional analysis, has been applied to the quantization of general relativity. It turns out that the construction of a good class of observables for a quantum theory of gravity is problematic, especially in view of the underlying invariance under the action of the diffeomorphism group. Despite a better understanding of the problem, a complete solution is still not within our grasp and a comparison with different approaches from other areas of theoretical physics is desirable, if not essential.

These are a few examples of different communities, who do not have close contacts on a regular basis but share a common aim, namely the investigation of structural and foundational aspects of gauge theories. The topical workshop offered the ideal environment for our endeavor to build a bridge between these different communities. It also strengthened the exchange between the leading experts and younger scientists.

Supernova Neutrino Observations: What can we learn? What should we do?

Organized by Hans-Thomas Janka (MPI for Astrophysics), Irene Tamborra (NBI, University of Copenhagen), Michael Wurm (JGU Mainz) and Lutz Köpke (JGU Mainz).

9 -13 October 2017

The experimental landscape for low-energy neutrino astronomy (few to few tens of MeV) is evolving rapidly. Several existing or planned large detectors world-wide will produce high-statistics signals of the next Galactic stellar collapse event (supernova or black-hole formation). The diffuse supernova neutrino background (DSNB) is coming into reach with the gadolinium enhancement of Super-Kamiokande and the JUNO scintillator detector. This topical workshop was meant to interface the communities of supernova and neutrino theorists and protagonists of the evolving experimental side. The goals were to enhance the information flow and mutual understanding between these communities and to develop a better definition of the observational targets (What can we learn?) and of the deliverables that should be provided by neutrino and SN theory as possible benchmarks for detector optimization and observation strategies (What should we do?). This topical workshop continued the discussions of previous workshop at the INT in Seattle in August 2016.

The topical workshop was focused on the following important topics:
(i) What are the perspectives to measure MeV and ultra-high-energy neutrinos from stellar explosions?, Which sources are the most promising ones, in particular for multi-messenger supernova (SN) physics?

(ii) What are the current model predictions for individual SNe, and the diffuse supernova neutrino background (DSNB).

(iii) What are the current frontiers in describing the microphysics needed for the source modeling? What are major uncertainties?

(iv) What can we learn about the core-collapse physics from a future galactic SN event?

(v) What do we know about neutrino-flavor oscillations in SNe?

(vi) What is the impact of non-standard physics scenarios on the expected neutrino signal from SNe?

(vii) What “hard” signatures of oscillations and core-collapse physics are predicted for the SN neutrino signal (i.e. features fairly independent of underlying model assumptions)?

(viii) Given the present diversity of small, medium and grandly sized SN neutrino experiments using different detection techniques: What benefit can be gained by a combined analysis of their various neutrino signals?

(ix) Which is the potential of upcoming large scale neutrino detectors such as the Hyper-Kamiokande Cherenkov detector, the JUNO scintilla-tor detector and the DUNE liquid argon detector? To what extent can the enrichment of the existing Super-Kamiokande detector with gadolinium and other novel techniques improve the SN neutrino detection?

(x) What are the most promising experimental techniques for the DSNB detection?

These major topics were covered by one to two overview talks per day and a number of shorter contributions in the afternoon sessions, preparing the ground for subsequent moderated discussion sessions. Among the main results were the formulation of a list of 13 questions that can be addressed by a possible future detection of a SN neutrino burst as well as of 10 questions associated with the interpretation of an upcoming DSNB detection. Both topics will require steadily improved theoretical studies to build reliable foundations for extracting information from the measured data.

The SNOBS participants decided to set up a Supernova Neutrino Advance Readiness Exercise (SNARE) in which the practical handling of neutrino detections shall be exercised by channeling fake signals through a detection data-processing pipeline for subsequent interpretation of the signal with respect to their physics contents. The goal is to convince as many existing and planned experiments as possible to participate and test their analysis chains on the data simulated. The exercise is seen as a first step towards a multi-experiment and multi-messenger exploration of galactic supernova signals.

Among the most relevant open problems, the following points are of very high priority: an improved conceptual understanding and a more rigorous solution of neutrino-flavor oscillations in the neutrino-dense SN environment; the exploration of consequences of non-standard neutrino physics on the source dynamics and associated neutrino-signal predictions; a better theoretical and experimental consolidation of neutrino interactions with heavy nuclei in the upcoming new detector facilities; the possible benefit of combining the findings of present (and future) neutrino observatories in deciphering the signatures of core-collapse and oscillation physics embedded in the SN neutrino signal.

4th LISA Cosmology Working Group Workshop

Organized by Chiara Caprini (Laboratoire AstroParticules et Cosmologie (APC) Paris), Valerie Domcke (Laboratoire AstroParticules et Cosmologie (APC) Paris), Germano Nardini (Bern University), Pedro Schwaller (JGU)

16 -20 October 2017

The topical workshop at MITP was the 4th LISA Cosmology Working Group Workshop. After the selection of the LISA mission by ESA following the call for mission in autumn 2016, and the end of ESA design study in summer 2017, the configuration of the LISA interferometer is substantially fixed. It was therefore necessary to precisely assess the capability of the new LISA configuration to test different aspects of cosmology and fundamental physics. Moreover, the community has to start to focus on new issues connected with data analysis techniques and with the needs of the LISA Consortium to address ESA requests. The goal of the topical workshop was to obtain concrete results in this respect, therefore, it was mostly dedicated to collaborative work in teams, accompanied by a few seminars on new results.

The workshop covered the following main topics: first order phase transitions, detection of stochastic backgrounds, topological defects, standard sirens, testing general relativity, inflation and beyond, primordial black holes and dark matter, structure formation.

The following topics were discussed at the 4th LISA CosWG:

(i) SGWB from phase transitions: The spectral shapes used in the previous LISA paper need to be updated in view of the new knowledge on the runaway condition, the turbulence, and the collisions/sound sources. It is strategical to further diffuse and clarify plots and results resuming all information and forecasts on signals coming from phase transitions. It is strategical to explore the potential of LISA for particle physics.

(ii) Beyond the Standard Paradigms (BSM here): Light degrees of freedom coupled to the mass must be included. It was briefly reviewed how this situation emerges within some BSM models. There was a discussion on how this idea can be connected to light (pseudo)scalars and possibly to dark matter. There are different approaches that can be explored for this topic: modification of emission (different orbits, extra radiation), different properties of propagation and detection. The recent paper published by LIGO/Virgo on constraining additional GW propagation modes and recent theoretical papers connected to this measurement was reviewed.

(iii) Standard Sirens: There were reviews and discussion about MBHB formation models, their rates in LISA, their spins, and counterpart generation. A presentation was given of the last LISA constraints on cosmological parameters together with forecasts on combining several sources at different redshifts. Old results on the statistical method to identify the redshift of the GW emitting binary were presented. There was also a discussion of H0 constraints by LIGO/Virgo using the NS binary coalescence and em counterparts.

(iv) Inflation and primordial BHs: The latest inflation paper could be updated with the latest power-law sensitivity curve [TBD]. It turned out to be essential to get a very good characterization of the SGWB also beyond the power spectrum. A discussion took place about PBHs and the question how this hypothesis can be confirmed and distinguished from the stellar origin.

(v) Topological defects: The state of the art concerning topological defects versus LISA was reviewed. The ability of LISA to detect cosmic strings and how it depends on the cosmic string model was discussed. There are issues in the subject that need long-term investigations.

The Evaluation of the Leading Hadronic Contribution to the Muon Anomalous Magnetic Moment

Organized by Carlo Carloni Calame (INFN Pavia), Massimo Passera (INFN Padua), Luca Trentadue (University of Parma) and Graziano Venanzoni (INFN Pisa).

19 – 23 February 2018

The topical workshop focused on the hadronic contribution to the anomalous magnetic moment of the muon, both analyzing the most recent experimental results for its determination in time-like processes and taking into consideration the most recent dedicated lattice calculations.

In this context, a series of seminars and discussions were devoted to consider a recently proposed possibility of extracting the muon anomalous magnetic moment by using an alternative method which exploits experiments where space-like processes are involved such as the μ-e scattering or Bhabha processes. The aim was to discuss and to explore in detail the state of the art of precision radiative corrections to μ-e scattering and Bhabha processes in order to master the theoretical tools necessary to develop dedicated Monte Carlo simulation codes. Finally, part of the discussion was devoted to survey the experimental challenges for the extraction of the hadronic contribution to the running of the electromagnetic coupling constant in space-like processes. The foreseeable impact is represented by the possibility of testing the consistency of the standard model at the level of quantum corrections with an unprecedented precision and the possibility of ascertaining the presence of new physics virtual effects in a robust (and unambiguous) way.

The state of the art of the determination of the muon anomalous magnetic moment has been the main physics issue beyond the topical workshop. The latter was meant to directly focus on an alternative and independent determination of the hadronic contribution to the anomalous magnetic moment, i.e. the recently proposed possibility of extracting the muon anomalous magnetic moment by exploiting experiments that consist in space-like processes as the Bhabha scattering or t-channel in muon-electron scattering. The long standing discrepancy between the experimental value and the standard model prediction of the muon anomalous magnetic moment is dominated, on the theoretical side, by the leading order hadronic contribution. Traditionally, this is computed via a dispersion integral by using the hadronic production cross section in electron-positron annihilation at low energies. In the near future, the theoretical determination of the hadronic contribution will be further improved by the continuous efforts in the measurement of the low energy hadronic cross section.

The topical workshop explored the theoretical and experimental feasibility of an independent and competitive determination of the hadronic contribution w.r.t. the dispersive approach to g-2 by means of a high precision determination of the electromagnetic running coupling constant in the space-like region. The experimental challenges posed by the measurement of the effective electromagnetic coupling in the space-like region at low-momentum transfer with high precision was addressed. Together with the possibility of performing the measurement by means of the elastic scattering of 150 GeV muons (currently available at CERN North area) on atomic electrons of a low-Z target as well as by the Bhabha process at flavor factories.

As an introduction, the most recent experimental results for its determination in time-like processes as well as the most recent dedicated lattice calculations were reviewed. In the following discussions were devoted to exploit both the theoretical and the experimental issues involved in the new approach proposed.

In the first part of the topical workshop, the implications for a calculation of the electron muon impact section with NNLO accuracy were discussed. The calculation with these accuracy represents the necessary preliminary theoretical basis. The multi-loop calculation techniques by means of this evaluation will be possible were explored. A further important point was the development of a Monte Carlo code for the simulation of the events with comparable NNLO accuracy. The possibility of implementing NNLO precision calculations into a simulation code was analyzed. A preliminary version of a code accurate at the NLO was presented. World experts described the state of the art of Monte Carlo simulation codes for the processes under consideration. Contributions from the teams that developed codes such as BABAYAGA, PHOKHARA were presented.

In the subsequent sessions a series of important experimental aspects was discussed such as particle identification and hypotheses of possible detector structure especially in view of a test beam program scheduled for the year 2018. The detector is going to be optimized in order to be able to keep the systematic effects at the required level of 10 ppm.

The tracking system and the set up of the silicon detectors were discussed. The state of the art as well as the possible options for MUonE were considered. An extensive discussion was devoted to the issue of multiple scattering effects within the detector and to modelling the multiple scattering of the targets and simulations of the same effects. A several results in reproducing multiple scattering were obtained. Further work on this is underway.

The discussions during the sessions were alive. During all the presentations the discussions and comments were extremely useful. Some hypotheses of future collaborations concerning the theoretical accounts at NNLO were discussed, also the development of alternative MonteCarlo codes for the simulation of particle identification and robust particle identification. The latter issue was part of an open and thorough discussion.

To sum up, the topical workshop made it possible to come up with the bases of the most relevant theoretical and experimental questions. The competences of the participants helped to define and consolidate many of the working hypotheses. With regrad for all aspects discussed, further investigations will be necessary and work is in progress. Progress on the physics issues discussed was possible thanks to the active and continuous participation of our colleagues.

Applied Newton-Cartan Geometry

Organized by Eric Bergshoeff (University of Groningen), Niels Obers (NBI Copenhagen and Dam Thanh Son (University of Chicago).

12 -16 March 2018

The field of applied Newton-Cartan geometry is currently a rapidly developing field which attracts researchers from different directions. Recent studies of non-AdS holography involving Lifshitz spacetimes have led to field theories with non-relativistic scaling coupled to an extension of Newton-Cartan geometry that includes so-called twistless torsion. Parallel to this development, effective field theories in a Newton-Cartan background have been studied in condensed matter physics and are used to describe a variety of non-relativistic systems such as the fractional quantum Hall effect, chiral superfluids, and simple fluids. Besides the holographic and effective field theory applications, there have been many other recent applications of Newton-Cartan geometry in different fields ranging from hydrodynamics to modified gravity, and even connections to string theory. For instance, it has been shown that Horava-Lifshitz gravity and novel extensions can be described using dynamical Newton-Cartan geometry. Furthermore, Newton-Cartan geometry obeys a duality with its ultra-relativistic cousin, Carroll geometry. Carroll symmetries have been shown to occur as symmetries of strongly coupled gravity and, more recently, of plane gravitational waves while a conformal extension of it is related to the so-called BMS symmetry of flat-space holography. Finally, studying supersymmetric non-relativistic field theories on curved Newton–Cartan backgrounds makes it possible to apply powerful localization techniques to extract exact non-perturbative results for these field theories such as the partition function and the vacuum expectation value of Wilson lines.

The aim of this interdisciplinary topical workshop was to advance the recent exciting applications of Newton-Cartan geometry in different directions and to enable participants from different backgrounds (condensed matter physics, mathematics, statistical physics, gravity and string theory) to interact and exchange new ideas. The first topical workshop of this kind was organized at the Simons Center for Geometry and Physics in Stony Brook (USA) in March 2017. The Simons workshop was a huge success and led to many contacts across different disciplines which otherwise would never have been established. The aim of the Mainz workshop was to repeat the success of the Simons workshop and keep the momentum in this growing research field by organizing a similar topical workshop in Europe.

The schedule of the workshop consisted of a number of 60 minute overview talks, which were given at the beginning of each day, plus a number of 45 minute and

30 minute presentations. Between and after the talks there was ample time for informal discussions. The week started with an overview of Newton-Cartan Geometry by Matthew Roberts (Imperial College). On the same day there were interesting talks from the mathematical point of view about a twistor formulation of Newton-Cartan spacetimes (Maciej Dunasjski, Cambridge) and from the physics point of view about higher-spin extensions (Daniel Gruemiller, Vienna). The day was closed with an informal welcome reception. Tuesday started with an overview talk by Peter Horava (Berkeley) about non-relativistic naturalness thereby putting the issue of non-relativistic physics in a somewhat wider perspective. Other interesting talks that day were presented by Dieter van den Bleeken (Istanbul) who pointed out that the conventional post-Newtonian approximation allows a natural extension to include so-called twistless torsion and by Marios Petropoulos (Paris) about Carrollian hydrodynamics. On Wednesday Jelle Hartong (Edinburgh) gave an interesting overview talk on non-relativistic holographic dualities and the role of non-relativistic strings. Other particularly stimulating talks were the one by Kevin Grosvenor (Copenhagen) about recent coset constructions of non-relativistic geometries and the one by Sergej Moroz (Munich) on a specific application of Newton-Cartan geometry to effective field theory in a condensed matter setting. Thursday opened with an inspiring overview talk by Marika Taylor (Southampton) about BMS symmetries for AdS spacetimes which led to many interesting discussions. Noteworthy talks of the same day were the one by Francisco Pena-Benitez on non-relativistic scaling in semimetals and the one by Giagreco Puletti on Entanglement entropy in generalized Quantum Lifshitz theories. The day was closed with a social conference dinner at a local restaurant in town. The last day of the workshop started with an overview talk by Jan Rosseel on non-relativistic supergravity which gave rise to the hope that non-relativistic supersymmetry may play a crucial role in calculating the exact partition function of a non-relativistic supersymmetric field theory. That same day both Jose Figueroa-O'Farrill (Edingburgh) as well as Stefan Prohazka (Bruxelles) gave talks about specific features of (non-relativistic) kinematical Lie algebras.

Overall, the topical workshop featured a highly communicative atmosphere along with an active participation of all participants. It strengthened already existing networks of collaboration and widened the field of interested researchers. Moreover, the topical workshop led to new collaborations and exchanges. It is also deserves to be mentioned that there was a healthy age distribution, ranging from senior professors to junior faculty and postdocs all the way to younger PhDs, which shows that this field also attracts and stimulates the next generation of researchers. Finally, a proactive effort was undertaken to make sure that there was not only diversity in age, but also in gender, which lead to a (relatively) high fraction of female participants and speakers. The MITP topical workshop revealed that the field of applied Newton-Cartan geometry is currently a rapidly developing field which attracts researchers from different directions, that are inspired to uncover the many possible interconnections and applications. New directions where set in motion at the topical workshop like novel applications of massive gravity in the fractional quantum Hall effect, the role of hydrodynamics without boost invariance and new applications of torsion in holography and condensed matter physics. Moreover, in the directions that were already under investigation (such as non-relativistic gravity theories, including supersymmetry, relations to non-AdS holography and string theory, connections to novel algebras and symmetry structures, effective field theories) further progress was made thanks to the lively interaction at the topical workshop. There is no doubt that the Mainz workshop has given a significant boost to this emerging field and its cross-disciplinary opportunities.

Challenges in Semileptonic B Decays

Organized by Paolo Gambino (University of Turin), Andreas Kronfeld (Fermilab), Marcello Rotondo (INFN - LNF) and Christoph Schwanda (Österreichische Akademie der Wissenschaften).

9 - 13 April 2017

The magnitudes of two of the elements of the CKM quark mixing matrix, V_{ub} and V_{cb}, are extracted from semi-leptonic B-meson decays. The results of the B factories, analyzed in the light of the most recent theoretical calculations, remain puzzling, because – for both $|V_{ub}|$ and $|V_{cb}|$– the exclusive and exclusive determinations are in tension by about 3σ. Recent experimental and theoretical results reduce the tension but the situation remains unclear. Meanwhile, measurements in the tau channels at Belle, Babar, and LHCb show discrepancies with the Standard Model predictions, pointing to a possible violation of lepton flavor universality. LHCb and the upcoming experiment Belle II have the potential to resolve these issues in the next few years.

Thirty-five participants met in Mainz to develop a medium-term strategy of analyses and calculations aimed at the resolution of these issues. Lattice and continuum theorists discussed with experimentalists how to reshape the semi-leptonic analyses in view of the much larger luminosity expected at Belle II and how to best exploit the new possibilities at LHCb, searching for ways to systematically validate the theoretical predictions, to confirm new physics indications in semi-tauonic decays, and to identify the kind of new physics responsible for the deviations.

The topical workshop took place during a period of five days, allowing for ample discussion time among the participants. Each of the five workshop days was devoted to specific topics: the inclusive and exclusive determinations of $|V_{cb}|$ and

$|V_{ub}|$, semi-tauonic B decays and how they can be affected by new physics as well as related subjects such as purely leptonic B decays and heavy quark masses. In the mornings, there were overview talks from the experimental and theoretical sides, reviewing the main aspects and summarizing the state of the art. In the late afternoon, a discussion sessions led by experts of the various topics, addressing questions that were brought up before or during the morning talks.

Exclusive heavy-to-heavy decays: The $B \to D^{(*)} l \nu$ decays have received significant attention in the last few years. New Belle results for the q^2 and angular distributions have allowed studies of the role played by the parametrization of the form factors in the extraction of $|V_{cb}|$. It turns out that the extrapolation to zero-recoil is very sensitive to the parametrization employed, a problem that can only be solved by precise calculations of the form factors at non-zero recoil. Until these are completed, the situation remains unclear - with repercussions on the calculation of $R(D^*)$ and with diverging views on the theoretical uncertainty of present estimates based on HQET expressions.

In addition to a critical reexamination of these recent developments, several incremental and qualitative improvements in lattice QCD were discussed - also in baryonic decays. Though unlikely to contribute to the V_{cb} determination, the latter decays offer great opportunities to test lepton-flavor universality violation (LFUV) and lattice QCD. The discussions also addressed the fact that the QCD errors are now almost as small as the effects from QED. Thus, further improvement must be theoretically made by properly studying the effect of QED radiation, especially the treatment of soft photons and photons that are neither soft nor hard. Their sensitivity to the meson wave functions has to be considered, too. Concerning studies of LFUV, we discussed the role played by higher excited charmed states in establishing new physics and the challenges which the present $R(D^{(*)})$ measurements pose for model building.

Exclusive heavy-to-light decays: This determination relies on non-perturbative calculations of the form factor of $B \to \pi l \nu$ which, up to now, is the most precise channel. We discussed the status of the LCSR calculations and several recent improvements in lattice QCD. In particular the most recent lattice calculations by the Fermilab/MILC and the RBC/UKQCD collaborations and the future prospects. The Fermilab/MILC calculation alone leads to a remarkably small total error on$|V_{ub}|$, of about 4%. While at present the most precise extraction of $|V_{ub}|$ comes from $B \to \pi l \nu$, it has been stated that in the future the golden channel could be $B_s \to K l \nu$ because here the lattice-QCD calculations are affected by smaller uncertainties. $B_s \to K l \nu$ can be accessible at Belle II in the run at the $\Upsilon(5S)$ and a precision of about 5-10% could be achieved with $1 fb^{-1}$.

The great opportunities for charmless semi-leptonic decays at LHCb have been demonstrated by the precise measurement of the ratio $B(\Lambda_b\to p\mu\nu)/(\Lambda_b\to\Lambda_c\mu\nu)$ in the high q^2 region. This measurement, combined with a precise lattice calculation of the form factors ratio, allowed the extraction of ratio $|V_{ub}/V_{cb}|$ with an uncertainty of 7%. The ongoing analysis of the $B(B_s\to K l\nu)/B(B_s\to D_s l\nu)$ ratio, is going to give a new determination of $|V_{ub}/V_{cb}|$ ratio. We also discussed other channels, in particular how to study $B\to\pi\pi l\nu$ including the resonant structures. Careful studies of other heavy to light channels will also be crucial to improve the signal model for the inclusive $|V_{ub}|$ measurements.

Inclusive heavy-to-heavy decays: The theoretical predictions in this case are based on an operator product expansion. We learned that better control of all higher-order corrections is needed to reduce theoretical uncertainties which are already dominant. In this respect, it would be important to have the QCD perturbative corrections to the coefficient of the Darwin operator and to check the treatment of QED radiation in the experimental analyses. A full $O(\alpha_s^3)$calculation of the total width may be within reach with recently developed techniques. From the experimental point of view, new and more accurate measurements will be most welcome, in particular to understand the correlations. An improved determination of the higher hadronic mass moments and a first measurement of the forward-backward asymmetry would be advantageous for the global fit, as would a better understanding of higher power corrections. The importance of having global fits to the moments in different schemes and by different groups has also been stressed. This calls for an update of the 1S scheme fit and could lead to a cross-check of the present theoretical uncertainties. Lattice QCD already provides inputs to the fit with the calculation of the heavy quark masses which were reviewed. New developments discussed at the workshop may soon be able to provide additional information that can be fed into the fits such as constraints on the heavy-quark parameters μ_π^2 and μ_G^2. The two main approaches are (i) computing inclusive rates directly on the lattice and (ii)using the heavy quark expansion for meson masses, precisely computed at different quark mass values. The state of theoretical calculations for inclusive semi-tauonic decays was also discussed, as they represent an important cross-check of the LFUV signals.

Inclusive heavy-to-light decays: This determination is based on various well-founded theoretical methods which generally agree nicely. The 2017 endpoint analysis by BaBar seems to challenge this consolidated picture suggesting discrepancies between some of the methods and a lower $|V_{ub}|$. For future scientific projects, the complete NNLO corrections in the full phase space should be implemented and the various methods should be upgraded in order to make the best use of the Belle II differential data based on much higher statistics. These data will make it possible to test the various methods and to calibrate them, as they will contain information on the shape functions. The SIMBA and NNV_{ub} methods seem to have the potential to fully exploit the $B \rightarrow X_u l \nu$ (and possibly radiative) measurements through combined fits to the shape function(s) and $|V_{ub}|$. The separation of $B^\pm$ and B^0 in the experimental analyses will certainly help to constrain weak annihilation, but the real added value of Belle II could be precise measurements of kinematic distributions in M_X, q^2, E_l, etc.. A detailed measurement of the high-q^2 tail might be very useful, also in view of attempts to check quark-hadron duality. Experimentally, better hybrid (incl.+excl.) Monte Carlos are urgently needed. S-bar s popping should be investigated to develop a deeper understanding of kaon vetos. The $b \rightarrow c$ background will be measured more precisely which will be advantageous for these analyses.

Leptonic decays: The measurement of $B \rightarrow \tau\nu$ is not yet competitive with semi-leptonic decays for measuring $|V_{ub}|$, because of a 20% error on the rate. Belle II will improve this. The corresponding lattice-QCD calculation is very precise, with an error below 1%, according to the forthcoming report from FLAG and mainly based on a result from Fermilab/MILC presented at the topical workshop. That said, the mode is useful today to model builders trying to understand new physics explanations of the tension between inclusive and exclusive determinations of $|V_{ub}|$. Belle-II will also access $B \rightarrow \mu\nu(\gamma)$ with the possibility to reach an uncertainty on the branching fraction of about 5% with 50ab−1, allowing for a new determination of $|V_{ub}|$ in the long run. The LHCb contribution to leptonic decays with the process $B \rightarrow \mu\mu\mu\nu_\mu$ was also discussed, where a couple of muons comes from virtual γ or light vector boson decays. The study of this channel has recently been shown at CKM2018. The very stringent upper limit obtained, which is inconsistent with the existing branching fraction predictions, calls for new reliable theoretical calculations.

Conclusion: The topical workshop was very successful and was appreciated by all participants. It brought together scientists from different disciplines working on the same subject. Various new ideas have been put forward in order to scrutinize the current understanding of the current discrepancies and anomalies and eventually to resolve or confirm them. New calculations are still necessary and new analyses will be possible at Belle II and LHCb. The discussion sessions turned out to be very useful to develop these ideas.

Tensions in the LCDM paradigm

Organized by Cora Dvorkin (Harvard), Silvia Galli (Institut d'Astrophysique de Paris), Fabio Iocco (ICTP-SAIFR) and Federico Marinacci (MIT).

14 – 18 May 2018

The establishment of the Lambda cold dark matter paradigm in cosmology has brought together physics on very diverse scales, with a mesmerizing variety of observational techniques and a unique theoretical effort. Today the consistency of this paradigm is hindered by some tensions, either of internal consistency between datasets of different nature or of seeming friction between theoretical predictions and observations. Observational and theoretical efforts are currently under way in order to both understand the possible sources of systematics affecting the data and to explain these frictions on theoretical grounds.

This topical workshop aimed at bringing together the communities involved in this effort, building a bridge between observers and data analysists, theorists, and simulators, in order to address the following fundamental questions about the tensions in the CDM paradigm: Is the current tension in the determination of Hubble constant by different probes due to new physics or to systematics? What are the real sources of the inconsistencies between theoretical predictions and observations at the smallest galactic scales? Is it a problem that we see no new physics at LHC?

The ideal two-fold goal of the topical workshop was that of understanding whether tensions appearing on several scales are only episodical and disconnected from each other – and to which extent they are due to experimental systematics – or if they represent real cracks in the building of the ΛCDM. In the latter case, it remains to be assessed whether they are structural, thus hinting toward a major revision of our vision of the cosmological universe, or whether they can be cured separately with minor modifications at different scales.

Thus, the main aim of the topical workshop was to identify the leading sources of debate on the internal consistency of the ΛCDM paradigm, often referred to as "tensions in cosmology", in order to critically assess their current status, the actual occurrence of real frictions either between different data-sets or techniques for the same observable, or between the predictions of the model and the observables. The question to be considered was also if they present the serious threat to the internal consistency of the currently leading cosmological paradigm. "Tensions" in the cosmological paradigm, as commonly addressed during this topical workshop, are of different nature. Yet they can be grouped into two broad categories: those affecting the "large scales", i.e. the determination of cosmological parameters as a global property, with different observables, and those on galactic and sub-galactic scales. Most notably, the first group comprises the discrepancy between the determination of the Hubble parameter H_0 with different observables as well as some seeming inconsistencies in the determination of cosmological parameters when different data sets are adopted. To the second group belong some of the longest standing problems in the astro–cosmological communities such as the so–called “missing satellite” problem. Before summarizing the debate on each (and more), as discussed in the topical workshop, it is worth mentioning here that while on the scale of galaxies the potential frictions arise from a mismatch (or an alleged one) between the predictions of the framework/model and the observational data, in the case of the “cosmological scales” the nature of the frictions is the mismatch of results between different data-sets or techniques.

The “large-scale” tensions: The Planck best fit model presents interesting mild differences with a few astrophysical datasets, while being in very good agreement with others. The Planck measurements (talk by Karim Benabed) are in fact in remarkable agreement with the latest baryon acoustic Oscillations (BAO) measurements from the SDSS-BOSS galaxy survey (talk by Andreu Font-Ribera, Hector Gil-Marin), the high redshift supernovae data from the JLA and Pantheon catalogues (talk by Dan Scolnic) or measurements of primordial element abundances and Big Bang Nucleosynthesis measurements. Moreover, tests of agreement between the Planck data and other CMB experiments such as WMAP (talk by Chuck Bennett) and SPT (talk by Wai Ling Kimmy Wu) indicate that in the overlapping range of multipoles and sky fraction observed by these experiments there is a good consistency, suggesting that the CMB data yield a coherent picture (although some $\sim 2\sigma$ discrepancy between Planck and SPT best-fit cosmologies arise if one includes the very small scales probed by SPT alone).

On the other hand, Planck presents differences with supernovae data in the determination of the Hubble constant H_0 (talk by Adam Riess). The latest Planck measurements in fact yield $H_0 = 67.36 \pm 0.54$ km s^{-1} Mpc^{-1}, while direct, local measurements using supernovae data calibrated on Cepheid variable stars favor a value of $H_0 = 73.48 \pm 1.66$ km s^{-1} Mpc^{-1} , a difference of 3.6σ. It is interesting to note that also the inverse distance ladder method, which combines BAO and primordial deuterium measurements, yields low values of H_0, e.g. 66.98 ± 1.18 km s^{-1} Mpc^{-1} (talk by Graeme Addison, Eduardo Rozo).

Similarly, the Planck measurements yield a value of the parameter σ_8, which is a measure of the root mean square of matter perturbations today at 8 Mpc h^{-1} and is about 1.5σ higher than the one measured with galaxy cluster counts (talk by Laura Salvati) or by weak lensing experiments (talk by Hendrik Hildebrandt, Elisabeth Krause).

There are three possible explanations for these tensions. The first is that they are due to systematic effects, either in the Planck and/or in the other astrophysical datasets. The second, possibly more interesting explanation, is that these tensions are pointing towards a modification of the ΛCDM model. In fact, most of the statistical power of the Planck measurements come from observing the primary CMB anisotropies at high redshifts, z=1100. Therefore, parameters such as H_0 or σ_8 which provide information about the status of the universe today, are inferred from the Planck measurements under the assumption of the ΛCDM model. Therefore, changing this assumption, for example by allowing extensions of the ΛCDM model that predicts a different late time evolution of the universe, could reduce these tensions (talk by Vivian Miranda). The third possibility, still applicable to the σ_8 case (but hardly to the H_0 tension) is that these differences are just due to statistical fluctuations. Upcoming and future CMB (talk by Thibault Louis) and large-scale structure (talk by Tim Eifler) experiments will therefore be able to discriminate between these possibilities. Confirming that the source of these tensions is due to a failure of the ΛCDM model would have important consequences from a fundamental physics point of view, potentially leading to a deeper understanding of the nature of our universe.

An important outcome of the topical workshop was the insight that the resolution of the H_0 tension as an extension of the Standard Model of cosmology cannot easily be found as a non-standard late-time evolution of dark energy. Rather it would require a change in the early time physics of the universe, most probably from a change in the expansion rate of the universe before the time of recombination, leading to a change in the physical dimension of the sound horizon (allowing the change in the H_0 measured by CMB and the inverse distance ladder method.).

The “small scale” tensions: The importance of cosmological simulations as a tool to investigate the assembly and evolution of structures populating the universe has seen a steadily increased in recent years. Indeed, this type of simulations is becoming the standard theoretical approach for studying the small-scale tensions between ΛCDM paradigm and the observations. The actual status of historical, “classical” small-scale problems was discussed in detail during the workshop. These include: (i) the “missing satellite” problem. Too many satellites galaxies are produced in pure dark matter simulations compared to observations; (ii) the too big to fail problem: Most massive satellites produced in cosmological simulations seem to have a circular velocity profile (i.e., with a too large peak velocity) that is inconsistent with observational constraints; (iii) the core/cusp problem: Observations of the circular velocity profiles of dwarf galaxies seem to prefer a cored dark matter distribution at the center, rather than a cuspy one as predicted by cosmological simulations.

It emerged as a generally agreed lore, that the use of the outcome of simulations addressing only the gravitational clustering of collision-less dark matter particles, in the comparison with observations (more on this later), is not fair. Neglecting small-scale (i.e. sub-galactic scale) physical effects either arising from dark matter and baryons coupling (talks by Azadeh Fattahi, Cecilia Scannapieco, and Christine Simpson) or because self-interaction of dark matter particles (talk by Mark Vogelsberger), highly biases the results of simulations, thus preventing a reliable representation of “reality” (wrong “modelling”). Moreover, progress has been made from the observational side as well. For instance, more and more satellites have been discovered (the DES survey being a prominent example), thus reducing some of the observational tensions such as the missing satellite problem. Furthermore, mock observations of simulation data are rapidly becoming an essential technique for interpreting observational effects (talk by Kyle Oman). However, uncertainties still remain in the interpretation of data relative to the dark matter distribution in the halo centers, with studies arguing for cored profiles and others sustaining that the evidence for cores is still inconclusive.

Finally, additional problems have emerged from the analysis of the available observational evidence. Among these are: (iv) the “plane of satellites”. Satellite galaxies tend to be on kinematically coherent planes (talk by Marius Cautun and Oliver Müller); (v) the “radial acceleration relation” (RAR): An empirical and extremely tight relationship between the observed total radial acceleration with the one due to the baryons only, which is present in galaxies of all types (talk by Federico Lelli), (vi) the “diversity problem”: Contrary to ΛCDM expectations, there seems to exist a spread in the value of the inner (at 2 kpc) rotation velocity at fixed maximum circular velocity in dwarf galaxies (talk by Peter Creasey and Kyle Oman). They present additional challenges to the ΛCDM paradigm at galactic scales. It is important to address these challenges in order to understand whether non-standard DM models and the complications they might add to the galaxy formation physics processes (talk by Pier Stefano Corasaniti) are really needed.

During the topical workshop, a vast array of models that alleviate the classical ΛCDM small-scale tensions were presented. These can be loosely divided into two categories: baryonic models and self-interacting dark matter models. The first type of solutions is the most studied one and the field in which much of the progress has been achieved in the past. At its core ls the argument that the small scale-tensions can be alleviated if one considers the mutual interplay between the baryonic sector with the dark matter sector. Particularly important is the role played by (stellar) feedback in transferring energy from the baryons to the dark matter sector. It is generally agreed by the vast majority of groups working with cosmological simulations that efficient stellar feedback is needed to form a realistic galaxy population and, at the same time, solve the classic small-scale tensions.

However, there are several ways of achieving these goals. This is especially true for tensions related to the inner structures of dark matter haloes, i.e. the the too-big-to-fail and the cusp-core problems. Indeed, while some baryonic models find that a solution to these issues lies in the formation of dark matter cores at the centers of haloes, other models predict a reduction of the dark matter density at the centers of haloes (necessary to alleviate these tensions) which is a natural consequence of efficient feedback that does not necessarily require the formation of a core. This duality of results appears to be linked to the locations where stars are formed in the simulations and the way feedback energy is distributed to the gas, both of which are model dependent. Further work is needed to reach a full understanding of these aspects and come up with a coherent physical scenario. Self-interacting dark matter models also have progressed in terms of accuracy and sophistication. However, despite the promising results in reproducing the properties of satellites of the Milky Way, the exploration of the combination between self-interacting dark matter and baryons, which are necessary to model in order to investigate whether the simulated dwarf galaxies are realistic in terms of the available observational evidence, has just recently started. Other problems, such as the formation of the planes of satellites, which should be unlikely in the context of ΛCDM, were also discussed at the topical workshop. No clear solution was proposed, but it is unclear whether a more accurate statistical analysis can refute the claim that prominent planes of satellites are not a routinely occurrence in ΛCDM.

To sum up, in order to arrive at a definitive answer to the key question of the workshop "What are the real problems on the smallest galactic scales?", further theoretical investigations, in synergy with observational work, are needed. Indeed, although the solutions to small-scale ΛCDM tensions seems within reach, the lack of a coherent physical framework and the multiplicity of solutions proposed are still an unsatisfactory aspect of the theoretical research in the field that urgently needs to be addressed.

Precision Measurements and Fundamental Physics: The Proton Radius Puzzle and Beyond

Organized by Richard Hill (University of Kentucky / Fermilab), Gil Paz (Wayne State University) and Randolf Pohl (JGU Mainz).

23 - 27 July 2018

The 2010 measurement of the Lamb shift (2S-2P energy difference) in the muonic hydrogen atom has created the “proton radius puzzle”: The proton charge radius R_p determined by the muonic hydrogen Lamb shift differs by 4% or 6 standard deviations from the 2014 CODATA value of R_p which has been obtained from elastic electron-proton scattering and spectroscopy of electronic hydrogen and deuterium. The puzzle is both difficult and fascinating because it impacts and requires expertise from diverse areas of particle, nuclear and atomic physics. Several new experiments have been motivated by the puzzle and are starting to produce results. Correspondingly, there is a great deal of theory effort aimed at all aspects of the puzzle.

The topical workshop summarized new experimental results in atomic spectroscopy and lepton scattering, discussed new theoretical tools and ideas impacting structure effects in scattering and bound state problems; and explored new physics discovery potential with precision tests in muonic and electronic systems.

This is the fourth workshop in a series of workshops dedicated to the proton radius puzzle. The previous editions were in 2012 at ECT* (European Centre for Theoretical Studies in Nuclear Physics and Related Areas), in 2014 at MITP (Mainz Institute for Theoretical Physics), and in 2016 at ECT*. Each day of the topical workshop had a general theme. The talks were clustered in three daily sessions supplemented by a two-hour afternoon discussion.

Several new unpublished experimental results were presented at the workshop: (i) New measurement of the proton charge radius from Lamb shift in hydrogen from York University in Canada. (ii) New measurement of the proton charge radius from 1S−3Sin hydrogen from Max-Planck-Institute for Quantum Optics (MPQ) in Germany. (iii) New measurement of the proton electric form factor at the lowest Q^2 ever $\sim 10^{-4}$ GeV^2 by the PRad experiment at the Jefferson Lab in the USA.

The new 2S−2P measurement from York U. is of particular significance, as it allows for a direct comparison with the 2S−2P transitions in muonic hydrogen, which created the proton radius puzzle. Moreover, in contrast to all other transition frequencies in atomic hydrogen used to determine the proton charge radius, the interpretation of the 2S−2P transition does not depend on the exact value of the Rydberg constant because the measurement takes place between two atomic states with the same principal quantum number n. The York measurement uses a novel technique called "frequency offset separated oscillatory fields"(FOSOF) which is a major improvement compared with the well-known Ramsey method of separated oscillatory fields. The FOSOF technique yields much reduced sensitivity to systematics related to line-shape distortions because the excitation frequency does not have to be scanned. The new measurement presented a preliminary value in agreement with the muonic hydrogen result. Since then, the uncertainty has been further improved and the paper is soon to be published in the journal "Science".

The new 1S−3S measurement from MPQ has similar precision to the published 1S−3S measurement from Paris, but it leads to a smaller radius consistent with the muonic hydrogen extraction. We now have two measurements of the same transition in hydrogen with similar error bars that leads to different values of the proton charge radius. Further insight is expected from ongoing measurements of the hydrogen 1S-4S transition in Paris and Garching, and from 2S-nP ($n \geq 6$) in Garching. The 1S-3S transition in atomic deuterium has been measured in Garching and yields the smaller deuteron radius that has been reported from the 2S-2P measurements in muonic deuterium. The PRad experiment at Jefferson Lab in the USA reported a measurement of elastic electron-proton scattering at the lowest Q^2 ever $\sim 10^{-4}$. It used a very forward detector at scattering angles between $0.7^\circ$and 7.0°. Moreover, a windowless hydrogen target and the simultaneous measurement of Moller scattering (which is a calculable QED process) allow for a very good normalization of the elastic scattering cross section. At the low Q^2 of the PRad experiment, the fit of the form factor data can be performed with significantly reduced model dependence.

As in previous workshops, various methods for extrapolation of the proton form factors to $Q^2=0$ were discussed. There was no agreement on how it should be done. With the publication of the PRad results this issue will become even more prominent. Further low-Q^2 electron-proton scattering measurements are planned at Tohoku University, by ProRad in Orsay, and at MAMI and the future MESA facility in Mainz. New targets such as windowless gas-jet solid hydrogen jets or active-target TPC promise reduced systematic uncertainties from backgrounds and access to very low Q^2.

Substantial progress has been made in calculations of muonic hydrogen energy levels. In general, an agreement between ab initio calculations and dispersion fits of scattering data yields trustworthy nuclear structure contributions to the Lamb shift. The notable exception is muonic helium-4, where a preliminary result from dispersion fits seems to disagree significantly with the ab initio calculations using

NN and 3N forces. This disagreement must be solved to obtain trustworthy charge radii from the muonic Lamb shift measurements. Similarly, the two-photon exchange contributions to the hyperfine splitting in muonic H, D and ^{3}He have recently been significantly improved. Three-photon results are now known for muonic deuterium. Further improvements are required in light of three on-going experiments at J-Parc, RAL and PSI which aim at a measurement of the ground state (1S) hyperfine splitting in muonic hydrogen (and muonic ^{3}He at PSI). The current spread of results would lead to a prohibitively long measurement time of at least half a year for the PSI experiment. An accuracy of 25 ppm for the line position predicted is required for these experiments to become feasible.

Muon-proton scattering is pursued by the MUSE Collaboration at PSI, and first production data will be acquired in 2 beam times in 2019 and 2020. Recently, the COMPASS collaboration at CERN has performed a pathfinder experiment for a high-energy, low-Q^2 measurement of muon-proton scattering. Preliminary results were shown. Both experiments are very important, also in view of obtaining more accurate TPE results which would be required for a possible improved muonic hydrogen Lamb shift measurement at PSI.

On the atomic physics side there are also many new projects with relation to the proton radius puzzle. The advanced laser system is currently developed by the CREMA Collaboration. Their muonic hyperfine measurements could lead to a much more accurate new measurement of the Lamb shift in muonic hydrogen and deuterium. Better charge radii would, however, require similarly improved calculations of the nuclear polarizabilities.

Spectroscopy of He and He^+, underway in Amsterdam, Garching, and elsewhere may soon be compared with results from muonic helium. Similar to the hydrogen case, combining the muonic and electronic measurements yields a very accurate value of the Rydberg constant. Laser spectroscopy of muonic Li and Be ions would allow a hundredfold improved measurement of the corresponding charge radii of Li and Be. In reality, such measurements would be limited to a tenfold improvement by the current calculations of the respective nuclear polarizabilities, but progress seems possible. These light nuclei will become of great interest when spectroscopy of e.g. He-like Li^+ becomes available. Such an experiment is under consideration at MPQ.

Laser spectroscopy of other exotic atoms, such as muonium ($e^-\mu^+$) and positronium (e^+e^-) are underway and may eventually yield values of the Rydberg constant that are free from finite size effects. Ultimately, comparison of Rydberg values from several experiments may be used as a probe for physics beyond the SM, such as Z-dependent deviations or differences between muonic and electronic probes.

Scattering Amplitudes and Resonance Properties from Lattice QCD

Organized by Maxwell T. Hansen (CERN), Sasa Prelovsek (University of Ljubljana / University of Regensburg), Steve Sharpe (University of Washington), Georg von Hippel (JGU Mainz) and Hartmut Wittig (JGU Mainz).

27 – 31 August 2018

Most of hadrons are strongly decaying resonances. This also includes candidates for exotic hadrons that have been discovered in experiments. Properties of the hadronic resonances have to be inferred from underlying scattering amplitudes for the decay products. These properties include resonance masses, decay widths, and electro-weak matrix elements. Lattice QCD allows extraction of two-hadron scattering amplitudes from first-principles QCD. The purpose of the workshop was to discuss formalisms to extract scattering amplitudes and actual lattice results and their implications for relevant hadronic systems.

The formalisms that will allow extraction of three-hadron scattering amplitudes are almost complete, but they still have to be applied in practice to results from lattice QCD simulations. With regard to this topic, the aim was to discuss several approaches to this challenging problem and to find the most practical ways to initiate applications. To this end, the workshop brought together formal experts as well as lattice practitioners in order to review the status of these calculations and discuss future prospects

The topological workshop was attended by 24 participants. Four participants were from the phenomenology community with strong links to lattice studies, one participant was actively involved in theory as well as in experiments, while the remaining participants were part of the lattice community. The daily schedule typically consisted of four 45 minute talks, including significant time for discussions. The environment at the MITP fostered vigorous discussions also outside of dedicated sessions, both in the coffee room and in smaller group meetings in individual offices, including those set aside for the purpose. Participants actively used the time for the discussion during the coffee breaks, lunch time and remaining time in the afternoons.

A major focus was on two-hadron scattering amplitudes, determined from the energies of eigen-states using Lüscher's formalism. An application to the shallow bound states in the meson sector considered scalar and axial D_s mesons (Sara Collins). The first extraction of baryon-baryon interactions using the powerful distillation technique considered the H dibaryon bound state (Andrew Hanlon). The energy determination has improved greatly in precision and reliability, yielding great promise for future studies. High-precision extraction of $\pi\pi$ scattering amplitudes showed the feasibility of using this formalism on larger volumes. The extracted time-like pion form-factor is an important input in the hadronic-vacuum-polarization contribution to the $(g-2)_\mu$ (John Bulava). The successful application to extract the dynamically-coupled partial-wave amplitudes for the scattering of hadrons with spin was demonstrated (Christopher Thomas). Several partial waves are dynamically coupled to a given channel J^P in this case, even in the continuum. The scattering matrix for three coupled two-hadron channels was extracted for the challenging scalar isoscalar sector which features the σ and f_0 scalar resonances (David Wilson). The charmonium resonances that appear in the one- and two-channel scattering were addressed (M. Padmanath). The lattice scattering amplitudes suggest a new paradigm for heavy-light meson spectroscopy in which some of the lightest states do not belong to a $\bar{q}q$ nonet (Christoph Hanhart). Further scattering studies on the lattice were motivated by a review of interesting experimental observables (Alessandro Pilloni).

Resonances also appear in strongly-coupled scenarios of beyond-the-Standard-Model physics, and the first application of the Lüscher formalism to study a vector resonance in a composite Higgs model was discussed (Tadeusz Janowski). The energies of two- as well as three-particle systems also were determined from the sudden jumps in the particle number as a function of the chemical potential within the finite-density systems. The resulting scattering amplitudes agree with the conventional approach for the considered φ^4 theory, where the finite-density sign problem was solved by means of the world-line techniques (Christof Gattringer).

An alternative approach to determine scattering amplitudes using the Nambu-Bethe-Salpeter wave functions has been developed by the HAL QCD collaboration. A detailed description of the formalism, including its advantages and disadvantages relative to the Lüscher approach, was presented as well as an application to exotic Z_c and baryon-baryon interactions (Sinya Aoki). The interesting $bb\bar{q}_1\bar{q}_2$ systems were considered for a pair of static b-quarks, where Born-Oppenheimer potentials were extracted as a function of distance between them. The resulting potential between a pair of B mesons leads to exotic tetraquark bound states as well as resonances (Marc Wagner and Pedro Bicudo).

The strong decay $B_0^* \rightarrow B\pi$ near threshold was addressed using the three-point function as proposed by C. Michael (Benoit Blossier). An overview of the theoretical issues arising in the development of a three-particle quantization condition and a status report on the different approaches being followed were presented. A major emphasis is now on making the formalism practical by appropriate truncations (Steve Sharpe). The latter point was further emphasized in the context of the “finite-volume unitarity” approach by the presentation of the predicted energy levels of the 3π+system using experimental results for phase shifts and chiral perturbation theory (Michael Döring). The large-volume expansion of the shifts of free three-particle energy levels has been extended from the ground state to excited states, opening a new window for determining two- and three-particle scattering parameters (Akaki Rusetsky). The non-relativistic effective field theory approach was presented explained with regard to its strengths and limitations (Hans-Werner Hammer). Recent work within simple models studying three- and four-body resonances was also discussed (Hans-Werner Hammer). A few talks considered general improvements that will be valuable for scattering studies in the future. Identification of underlying spin and parity for mesons in flight within the single-hadron approach will be valuable for resonance studies beyond this simplifying approximation (M. Padmanath). Reduction of the statistical noise based on the factorization of the fermion determinant seems promising for a wide variety of applications (Marco Ce).

The lattice QCD community is making an impressive progress in ab-initio studies of hadronic resonances and scattering amplitudes. Many of the most exciting problems, however, still have to be addressed. These include, for example, extraction of the coupled-channel scattering matrices related to exotic hadrons by means of Lüscher's approach and a lattice determination of three-body scattering amplitudes in QCD. The MITP workshop reflected both the past successes as well as the future challenges.

Quantum Fields – from Fundamental Concepts to Phenomenological Questions

Organized by Astrid Eichhorn (University of Heidelberg), Roberto Percacci (SISSA) and Frank Saueressig (Radboud University Nijmegen).

26 – 28 September 2018

Understanding the structure of quantum field theories and their observational consequences beyond the realm of perturbation theory constitutes one of the central challenges in theoretical physics. Progress along this research frontier may be the key for answering fundamental questions related to the structure of space, time, and matter. In this spirit, the workshop surveyed both fundamental aspects of quantum spacetime and potential quantum gravity signatures observable in particle physics, black holes, and cosmology. The goal was to develop new roadmaps for obtaining a description of our world valid on all scales and identify new connections between the fundamental descriptions and phenomenological consequences within the various approaches.

The topical workshop was held to the honor Professor Martin Reuter's 60th birthday. The broad scope of the scientific program, comprising 17 short scientific presentations, 3 highlight lectures and many discussion sessions, reflected the wide scientific interest of the laureate. All presentations were on an extremely high level, focusing on recent breakthrough results in the field. The discussion of many recent research highlights revealed how the research field started by Martin Reuter two decades ago has matured into a very active and dynamic area of research. In particular, the broad and diverse research interests of the laureate were reflected in a topical workshop which led to many discussions of potential new connections to neighboring fields. The attitudes of the speakers are well-captured by the following quote by one of the participants "I always wanted to give this talk with Martin in the audience. I always wanted to discuss these developments with him."

The highlight lectures, all given by renowned physicists from the United States, constituted a particularly successful element of the workshop, serving as springboards for ensuing discussions. Two of them focused on "Dynamical dimensional reduction as a universal feature in quantum gravity" (Steve Carlip) and "Prospectives for learning about quantum gravity from cosmological observations" (Abhay Ashtekar) surveying some of the current trends in the field. On the technical side, the very pedagogical lecture presented by Prof. Gerald Dunne outlined the method of "resurgence" as a novel and extremely powerful technique for carrying out non-perturbative computations in quantum mechanics and quantum field theory.

While each of the shorter talks definitely warrant a detailed summary, we just mention three key results presented at the topical workshop. On the fundamental side, the talk by Benjamin Knorr highlighted that contrary to widespread belief, the theory space of Lorentz-invariant quantum field theories in general does not act as a low-energy attractor for renormalization group flows. Clearly, this insight will have a significant impact on any quantum gravity program including Lorentz-violating effects at the Planck scale. Moreover, the coordinated talks by Gian Paolo Vacca and Alessandro Codello gave a detailed summary of the status and application perspective for determining conformal field theory data from functional approaches. Prospectives for obtaining a predictive quantum field theory comprising gravity and the matter content of the Standard Model have been summarized by Astrid Eichhorn.

A major outcome of the workshop was the suggestion to honor Martin Reuter's outstanding contributions to the development of asymptotic safety by referring to the non-trivial renormalization group fixed points that appear on the theory spaces of pure gravity and gravity-matter systems as "Reuter fixed points".

Concerning future developments, the construction of the quantum effective action for gravity and gravity matter-systems was flagged as one of the main targets. First steps in this direction were outlined in the presentations by Omar Zanusso, Basim El-Menoufi and Frank Saueressig. Perspectives of using this object to connect various approaches to quantum gravity and quantum gravity phenomenology were discussed. Finding the vacuum state associated with asymptotic safety and the transition from Euclidean to Lorentzian signature, computations were identified as important conceptual questions which should be addressed in the near future. Throughout the presentations and discussion it became apparent that many approaches to quantum gravity and, in particular the asymptotic safety program, have reached a maturity where key physics related to cosmology, blackholes, and the Standard Model of particle physics can be addressed from a fundamental perspective.

The organizers are also very happy that they were able to award two "Universe Presentation Prices" for young scientists (400 SFR each) to Alessia Platania and Basem El-Menoufi for their outstanding presentations on "Cosmological bounds on the field content of asymptotically safe gravity-matter models" and "Infrared quantum gravity: status report". Moreover, proceedings of the topical workshop will be published in a special issue "Quantum Fields – from fundamental concepts to phenomenological questions" within "Universe".

Searching for New Physics with Cold and Controlled Molecules

Organized by Timur Isaev (PNPI NRCKI, St. Petersburg), Mikhail Kozlov (PNPI NRCKI, St. Petersburg), Anna Viatkina (JGU Mainz) and Dmitry Budker (JGU Mainz).

6 – 30 November 2018

Recently a remarkable progress has been achieved in control over both internal (electronic, vibrational, spin and rotational) and external (translational) degrees of freedom for a wide range of molecules. In particular, direct laser and opto-electric cooling of polyatomic molecules has been successfully demonstrated. This opens a way for much higher precision in measuring tiny effects in molecular spectra connected with possible new physical forces, that include exotic spin-dependent interactions, parity (P) and time-reversal invariance (T) violating interactions among others. In this connection, considerable interest should be devoted to, for example, the identification of closed-shell and also chiral laser-coolable molecules/ions. On the other hand, consideration of P- and P,T-odd effects for classes of molecules that were already successfully cooled and trapped is of great interest.

Nearly 30 scientists took part in the topical workshop including several "local" researchers from MITP and Helmholtz Institute Mainz (HIM). About half of the participants were students and young scientists.

The idea of this topical workshop was to bring together people who actively work in the application of AMO (atomic, molecular, and optical) methods to study fundamental physics. It was planned to focus on the remarkable progress that has been recently achieved regrading internal (electronic, vibrational, spin and rotational) and external (translational) degrees of freedom for a wide range of molecules. In particular, the direct laser and opto-electric cooling of polyatomic molecules has been successfully demonstrated. This opens a way for much higher precision of molecular spectroscopic experiments previously only achievable in atomic spectroscopy.

In many cases the molecules appear to be much more sensitive to new physics than atoms. In particular, molecules have higher sensitivity to (i) parity non-conserving interactions (P-odd); (ii) parity and time-reversal invariance non-conserving interactions (P,T-odd); (iii) possible variation of the fundamental constants; and (iv) exotic spin-dependent inter-actions. All this make it possible to search for new physics in a previously unreachable domain. An inspiring example is the recent result of the ACME collaboration on the ThO molecule which placed a new limit on electric dipole moment of the electron d_e (eEDM) at the level of $|d\ |<1.1\times10^{-29}$ e cm. This limit is more than a hundred times more stringent than the limit following from the best atomic experiment on thallium atoms.

At the topical workshop, there were several talks describing new calculations of the P, T-odd effects in di-atomic molecules, molecular ions, and solids. The size of the eEDM signal depends on the effective electric field E_{eff} on the unpaired electrons. Theoretical predictions for the E_{eff} were reported for many molecules including all the molecules that are currently used for the eEDM search.

Anatoly Titov presented some approaches used by him and his colleagues for calculations of various molecular properties, inluding P- and P, T-odd ones. Alexander Petrov reported on a comprehensive theoretical study of the possible systematic effects in the EDM experimentswith ThO and HfF^{+}. Steven Hoekstra reported recent results of the NL-eEDM collaboration from the ongoing eEDM experiment with a slow BaF beam. Timo Fleig discussed the prospects of breaching the gap between the present limit on the eEDM and the value predicted by the Standard model, $|d_e| \approx 10^{-32}$ e cm.

During the workshop, several talks were devoted to the problem of identification of laser-coolable polyatomic molecules, in particular chiral ones. The latter provide a unique opportunity to measure P-odd interaction in purely spectroscopic experiments. Robert Berger gave an extensive overview of the possible studies of new physics with chiral molecules. Martin Zeppenfeld and Hendrick Bethlem reported progress on cooling polyatomic molecules. An impressive talk by Ronald Fernando Garcia Ruiz from CERN showed a fascinating picture of experiments with exotic species, including heavy ions and molecules, which include short-lived isotopes with very interesting properties. All in all, there were 25 talks (including one Skype presentation by Bhanu Das) which were followed by sometimes rather extensive discussions. As part of the week's program, a joint seminar with JGU QUANTUM was held featuring an inspiring talk presented by Hendrick Bethlem.

An important part of the workshop were presentations from young researchers - MS and PhD students. Konstantin Gaul from the Marburg University presented his research on parity and time-reversal violation in laser-coolable triatomic molecules, Sergey Prosnyak and Daniel Maison from Saint-Petersburg University reported on quantum-electrodynamic effects in heavy-atom systems.

The schedule of the topical workshop was not too dense and allowed for discussions between and after the talks and most of the participants used this opportunity to exchange ideas, establish new collaborations and reinforce existing ones.

5 MITP Summer School

Besides its core activities, MITP has organized highly successful summer schools in theoretical physics in 2016, 2017 and also 2018. They build a European counterpart to the *Theoretical Advanced Study Institute* (TASI) in Boulder, Colorado, the leading theoretical particle-physics summer school in the US. MITP has closed an important gap here, as most existing summer schools in Europe are either relatively narrow in their topics or are geared towards both experimentalists and theorists, making them suitable mostly for beginning PhD students, but less so for advanced students in theoretical physics.

The new MITP summer schools took place in a very attractive location in downtown Mainz. They last 3 weeks and provided in-depth courses (consisting of four 90-minute blackboard lectures each) on a variety of cutting-edge subjects in theoretical physics:

Lecturers at the MITP Summer School 2017 - Joint Challenges for Cosmology and Colliders were Evgeny Akhmedov (MPI Heidelberg) - *Neutrino Phenomenology*, Nima Arkani-Hamed (IAS) – *Collider Physics from the Bottom Up*, Matthias Bartelmann (Univ. of Heidelberg) - *Lambda CDM and Early Universe Cosmology*, Brian Batell (Univ. of Pittsburgh) - *Laboratory Probes of Dark Matter and Neutrinos*, David Morrissey (TRIUMF/Univ. of Victoria) - *CP Violation and the Baryogenesis Puzzle*, Stefania Gori (Univ. of Cincinnati) - *Beyond the Standard Model Phenomenology*, Christophe Grojean (DESY/Humboldt Univ. Berlin) - *Standard Model, Electroweak Symmetry Breaking, and the Higgs Boson*, Andreas Ringwald (DESY) - *Axions and Axion-Like Particles*, Tracy Slatyer (MIT) - *CMB and Astrophysical Probes of Dark Matter*, LianTao Wang (U. of Chicago) - *Dark Matter at the Collider*, Neal Weiner (NYU) - *Dark Matter Model Building, and* Thomas Konstandin (DESY) - *Gravitational Waves.*

The lectures at the MITP Summer School 2018: Towards the Next Quantum Field Theory of Nature were given by Thomas Becher (Univ Bern) - Effective Field Theories, Monika Blanke (Karlsruhe Institute for Technology) – Flavor Physics, Radja Boughezal (Argonne/Northwestern U.) - Precision QCD, Nathaniel Craig (UC Santa Barbara) - Naturalness and Top-Down BSM, Valerie Domcke (DESY) - Gravitational Waves, Gia Dvali (MPI Munich/LMU Munich/ NYU) - New Developments in QFTs, Rouven Essig (Stony Brook U.) - Physics of Dark Sectors, Tao Han (Pittsburgh) - Collider Physics, Michael Peskin (SLAC) - The Standard • Model and Higgs Physics, Yael Shadmi (Technion) Supersymmetric Field Theories and Henrik Johansson (Uppsala) - Color-Kinematics Duality and the Double Copy. The lectures were video-recorded and are available to the public on YouTube. The summer schools will be continued annually, with a varying topical focus each year, see The lectures were video-recorded and are available to the public on YouTube: Video Recordings Summer School 2017 (YouTube), Video Recordings Summer School 2018 (YouTube). The summer schools will be continued annually, with a varying topical focus.

6 Outreach

Starting in 2013, MITP has been organizing the public lecture series *Physics in the Theater*. With the State Theater in the center of Mainz an ideal prestigious location was found outside the campus with halls of different sizes. Held about five times per year, this lecture series regularly attracts crowds of 400–950 members of the public (depending on the venue), consistently filling the available auditoriums to capacity. Speakers in the past included Rolf Heuer (Director General of CERN, 2009-2015), Wolfgang Ketterle (Nobel Prize in Physics 2001), Paolo Ferri (Director of ESA's satellite missions).

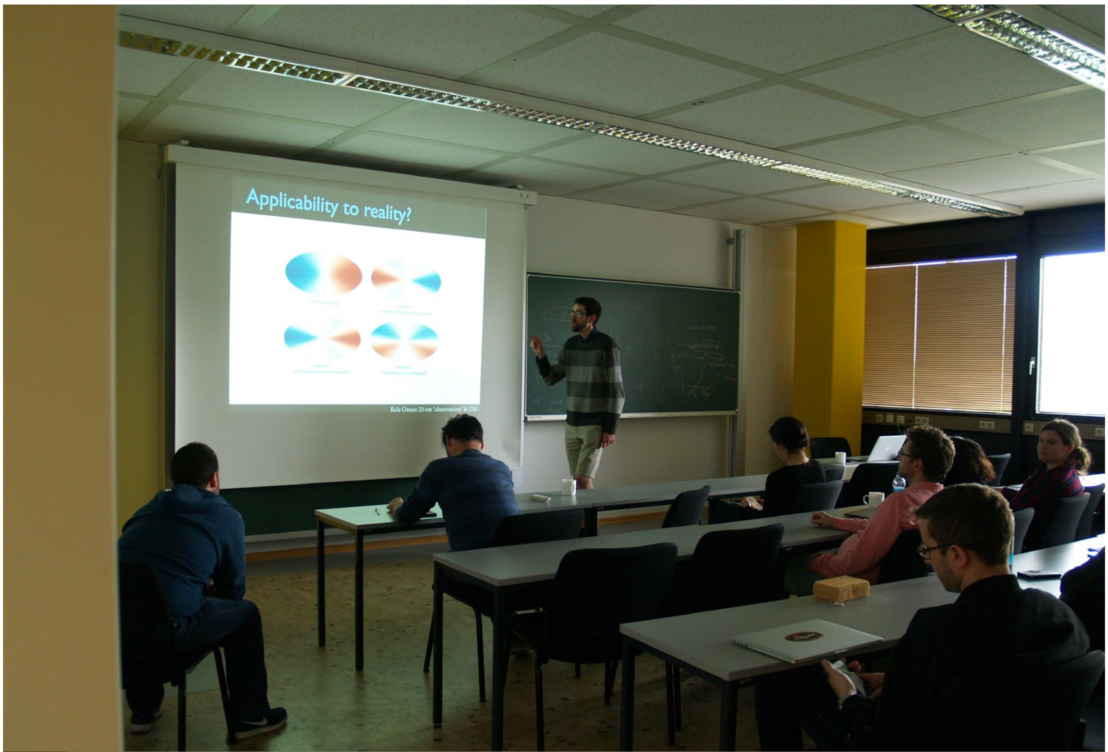
The lectures series in 2017 started out with a talk by Lisa Kaltenegger (Cornell University) on the question, if there is life on other planets in the universe. The second talk was given by Harald Lech (LMU Munich) with the title ”Physics, Triumph and Tragedy, from Being to Becoming”. Karsten Danzmann (Hannover University) talked about the discovery of gravitational waves., while Laura Baudis (University of Zurich) addressed the problem of dark matter in the universe. Finally, Concettina Sfienti explained the physics of star wars.

In 2018, Herbert Dreiner and his students (University of Bonn) presented their particle physics “What’s the matter”. The lecture series was continued by Peter Fierlinger (TU Munich) on the matter antimatter asymmetry and by Randolf Pohl (JGU Mainz) on the proton radius puzzle. Jörg Wrachtrup (Univ. Stuttgart) spoke about the future relevance of quantum physics.

All these hour-long lectures are followed by an open question & answer session, which typically lasts about 45 minutes and is often continued informally afterwards on the plaza outside the theater. The events are recorded and are publicly available on our YouTube channel: YouTube-Playlist Physik im Theater.

7 Pictures of MITP in 2017 and 2018

Impressions from MITP Institute and Scientific Events at MITP:


Applicability to reality?


02 .527

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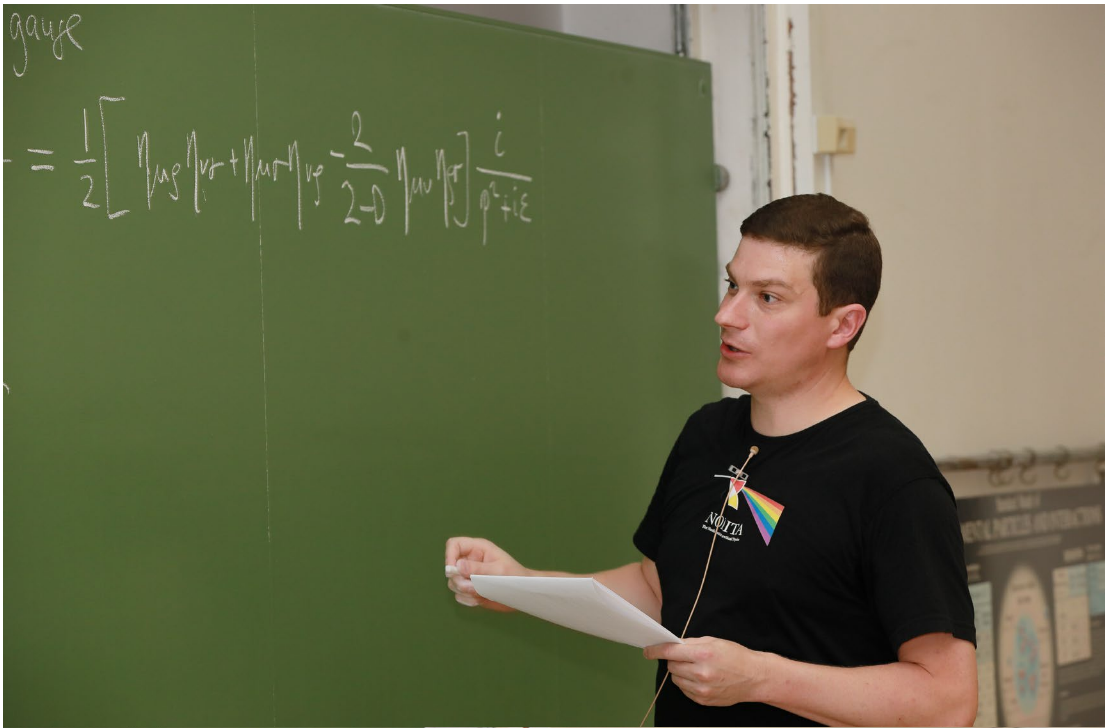
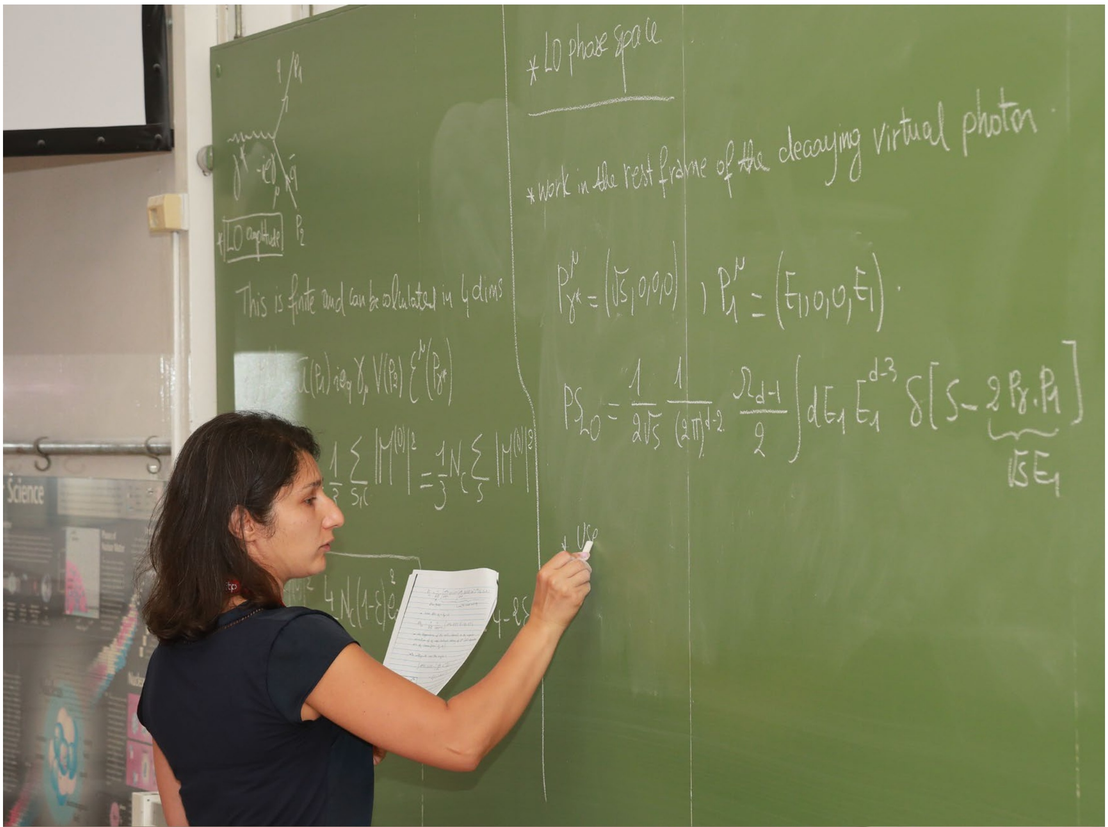
MITP summer schools 2017 and 2018:




* LO phase space
* work in the rest frame of the decaying virtual photon
This is finite and can be calculated in 4 dims

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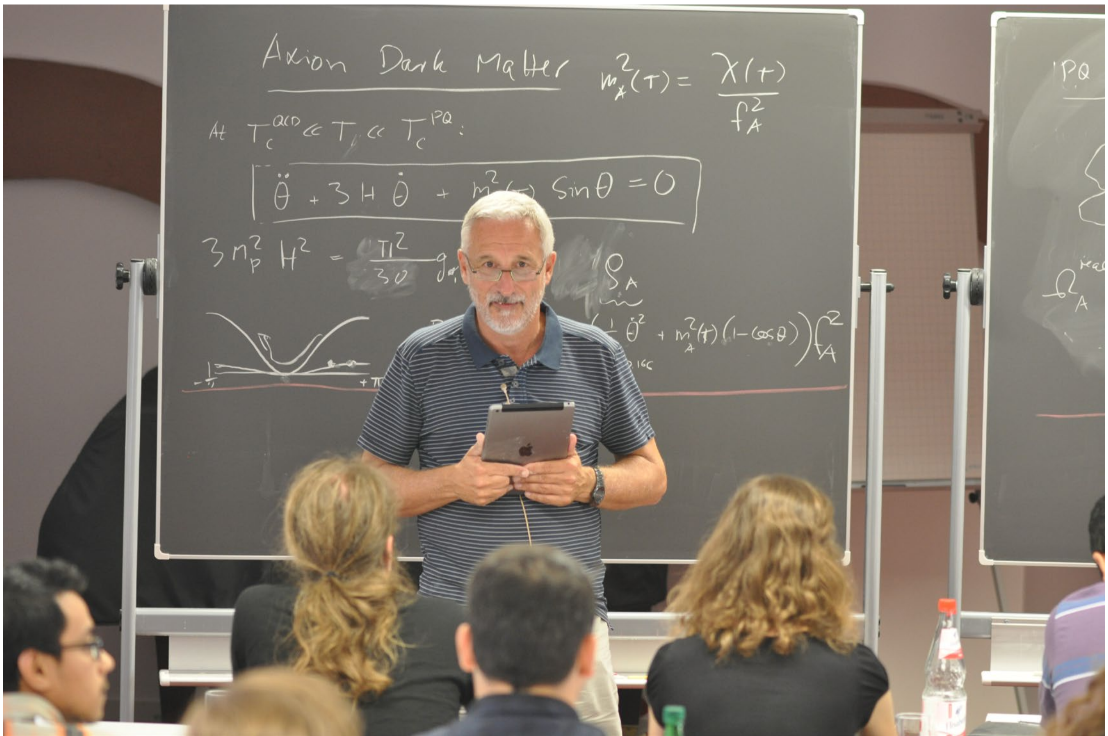

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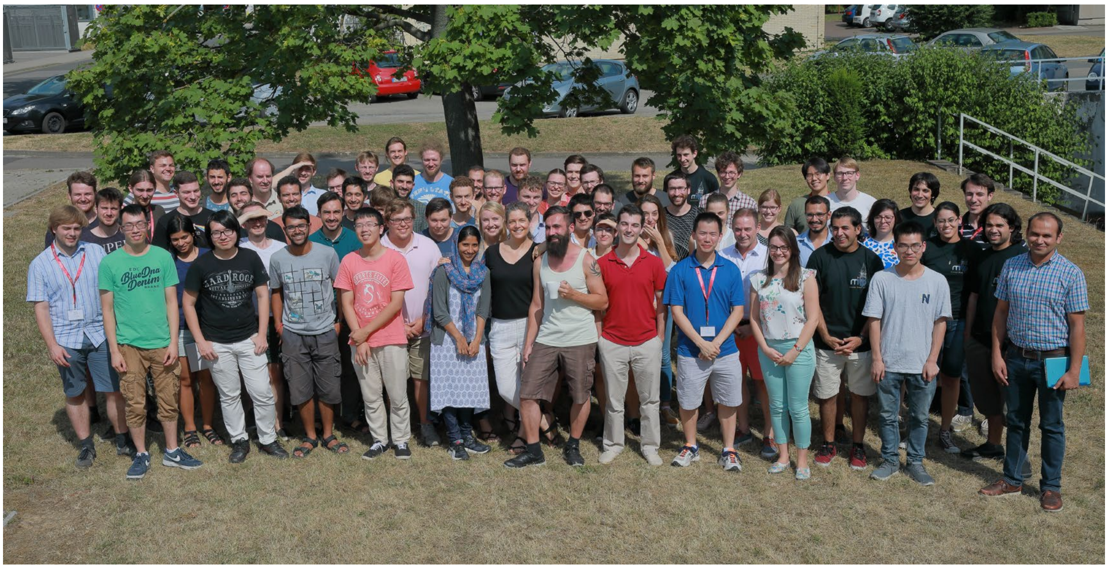
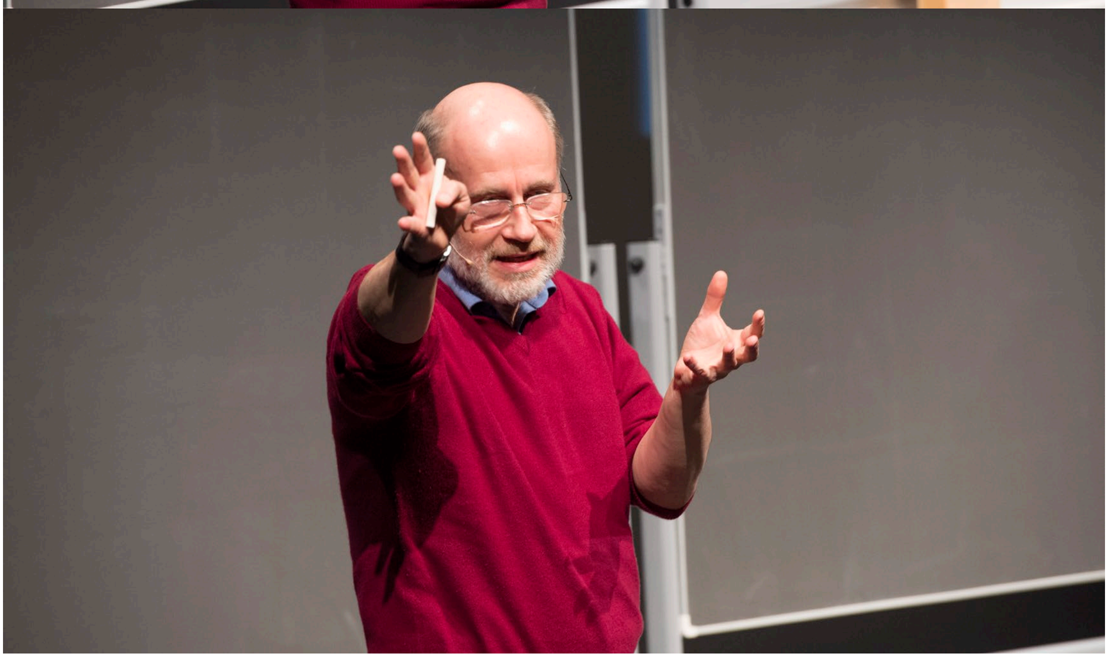


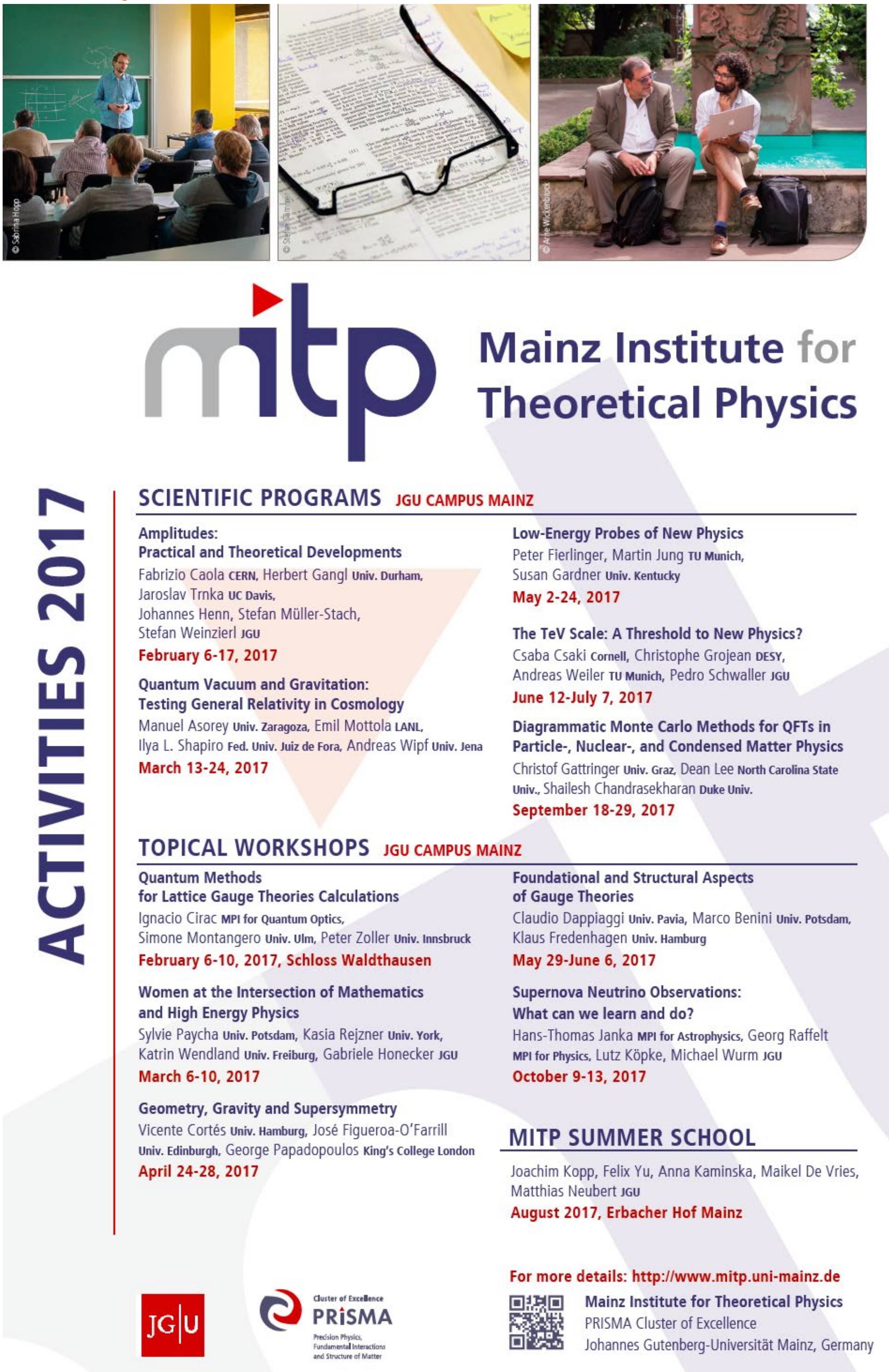
Lecture series "Physics in the Theater":
"The physics of star wars", Concettina Sfienti (JGU Mainz), 11/2017:

”Physics, Triumph and Tragedy”, Harald Lech (LMU Munich), 2/2017:



”What’s (the) Matter”, Herbert Dreiner and students (Univ. Bonn), 3/2018:

8 MITP posters of 2017 and 2018



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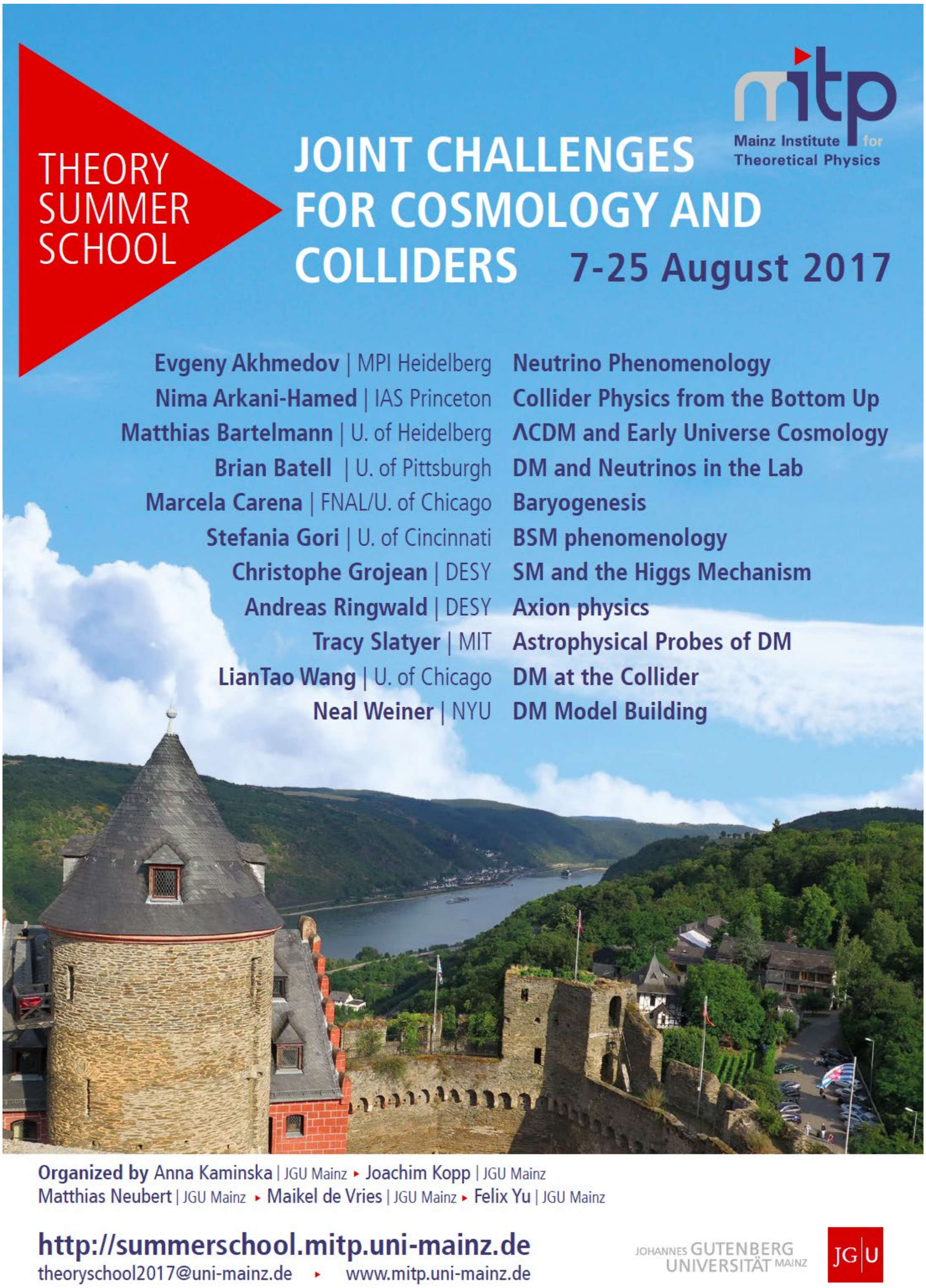

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Mainzer Institut für Theoretische Physik

Physik im Theater

Öffentliche Vortragsreihe im **Staatstheater Mainz | Kleines Haus**

15. Januar 2017, 19:00 Uhr
Sind wir allein im Universum? Auf Spurensuche im All
Prof. Dr. Lisa Kaltenegger | Carl Sagan Institute, Cornell University

8. Februar 2017, 19:00 Uhr | Großes Haus
Physik: Triumph und Tragödie – vom Sein zum Werden
Prof. Dr. Harald Lesch | Ludwig-Maximilians-Universität München

22. Mai 2017, 19:00 Uhr
Gravitationswellenastronomie: Wir können das dunkle Universum hören!
Prof. Dr. Karsten Danzmann | Max-Planck-Institut für Gravitationsphysik, Hannover

10. September 2017, 18:00 Uhr
Die dunkle Seite des Universums
Prof. Dr. Laura Baudis | Universität Zürich

November 2017
Die Physik von Star Wars
Prof. Dr. Concettina Sfienti | JGU

Einlasskarten sind für 5 EUR/Karte online erhältlich: http://ticket.staatstheater-mainz.de

JGU

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Mainzer Institut für Theoretische Physik
Exzellenzcluster PRISMA, JGU
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ACTIVITIES 2018

www.mitp.uni-mainz.de

SCIENTIFIC PROGRAMS

Probing Physics Beyond the SM with Precision
Ansgar Denner U Würzburg, Stefan Dittmaier U Freiburg, Tilman Plehn Heidelberg U
February 26 - March 9, 2018

Bridging the Standard Model to New Physics with the Parity Violation Program at MESA
Jens Erler UNAM, Mikhail Gorshteyn, Hubert Spiesberger JGU
April 23 - May 4, 2018

Modern Techniques for CFT and AdS
Bartlomiej Czech IAS Princeton, Michal P. Heller MPI for Gravitational Physics, Alessandro Vichi EPFL
May 22 - 30, 2018

The Dawn of Gravitational Wave Science
Luis Lehner Perimeter Inst., Rafael A. Porto ICTP-SAIFR, Riccardo Sturani IIP Natal, Salvatore Vitale MIT
June 4 - 15, 2018

The Future of BSM Physics
Gian Giudice CERN, Giulia Ricciardi U Naples Federico II, Tobias Hurth, Joachim Kopp, Matthias Neubert JGU
June 4 - 15, 2018, Capri, Italy

Probing Baryogenesis via LHC and Gravitational Wave Signatures
Germano Nardini U Bern, Carlos E.M. Wagner U Chicago / Argonne Nat. Lab., Pedro Schwaller JGU
June 18 - 29, 2018

From Amplitudes to Phenomenology
Fabrizio Caola IPPP Durham, Bernhard Mistlberger, Giulia Zanderighi CERN
August 13 - 24, 2018

String Theory, Geometry and String Model Building
Philip Candelas, Xenia de la Ossa, Andre Lukas U Oxford, Daniel Waldram Imperial College London, Gabriele Honecker, Duco van Straten JGU
September 10 - 21, 2018

TOPICAL WORKSHOPS

The Evaluation of the Leading Hadronic Contribution to the Muon Anomalous Magnetic Moment
Carlo Carloni Calame INFN Pavia, Massimo Passera INFN Padua, Luca Trentadue U Parma, Graziano Venanzoni INFN Pisa
February 19 - 23, 2018

Applied Newton-Cartan Geometry
Eric Bergshoeff U Groningen, Niels Obers NBI Copenhagen, Dam Thanh Son U Chicago
March 12 - 16, 2018

Challenges in Semileptonic B Decays
Paolo Gambino U Turin, Andreas Kronfeld Fermilab, Marcello Rotondo INFN-LNF Frascati, Christoph Schwanda ÖAW Vienna
April 9 - 13, 2018

Tensions in the LCDM Paradigm
Cora Dvorkin Harvard, Silvia Galli IAP Paris, Fabio Iocco ICTP-SAIFR, Federico Marinacci MIT
May 14 - 18, 2018

The Proton Radius Puzzle and Beyond
Richard Hill U Kentucky / Fermilab, Gil Paz Wayne State U, Randolf Pohl JGU
July 23 - 27, 2018

Scattering Amplitudes and Resonance Properties from Lattice QCD
Maxwell T. Hansen CERN, Sasa Prelovsek U Ljubljana / U Regensburg, Steve Sharpe U Washington, Georg von Hippel, Hartmut Wittig JGU
August 27 - 31, 2018

Quantum Fields – From Fundamental Concepts to Phenomenological Questions
Astrid Eichhorn Heidelberg U, Roberto Percacci SISSA Trieste, Frank Saueressig U Nijmegen
September 26 - 28, 2018

MITP SUMMER SCHOOL 2018

Johannes Henn, Matthias Neubert, Stefan Weinzierl, Felix Yu JGU
July 2018

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Mainz Institute for Theoretical Physics
PRISMA Cluster of Excellence
Johannes Gutenberg-Universität Mainz, Germany

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Physik im Theater

Öffentliche Vortragsreihe im
Staatstheater Mainz | Kleines Haus

19. März 2018, 19:00 Uhr
What's (the) Matter?
Die Teilchenphysikshow
Prof. Dr. Herbert Dreiner und Studierende | Universität Bonn

27. April 2018, 19:00 Uhr
Das Rätsel unserer Existenz:
Die Materie-Antimaterie-Asymmetrie im Universum
Prof. Dr. Peter Fierlinger | TU München

8. September 2018, 19:00 Uhr
Wie groß ist ein Proton?
Prof. Dr. Randolf Pohl | Institut für Physik, JGU

17. November 2018, 19:00 Uhr
Quantensprung in die Zukunft
Prof. Dr. Jörg Wrachtrup | Universität Stuttgart

Einlasskarten sind für 5 EUR/Karte online erhältlich:
http://ticket.staatstheater-mainz.de

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Mainz March 2019

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