Mainz Institute for Theoretical Physics

Scientific Activities 2015-2016

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

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

Mainz Institute for Theoretical Physics

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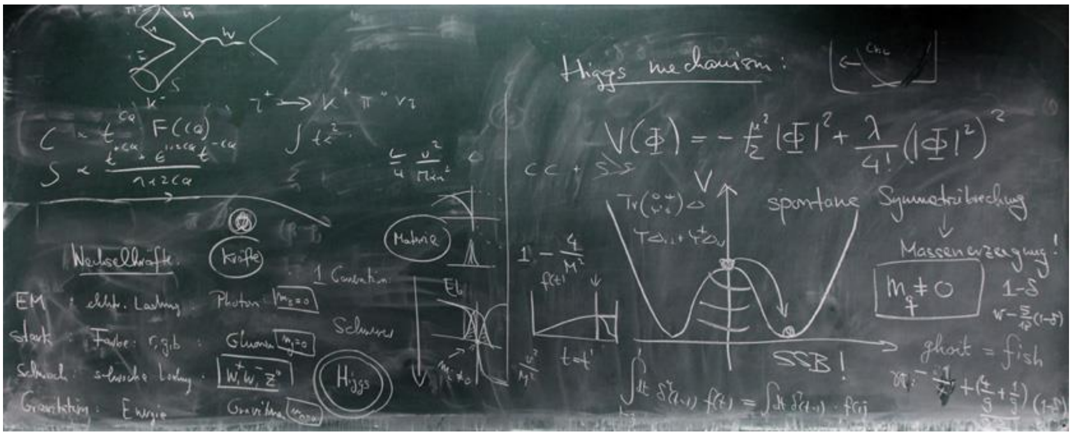

1 Introduction

This report provides an overview of the scientific activities at the Mainz Institute of Theoretical Physics (MITP) in 2015 and 2016.

MITP serves as an international center for theoretical research. 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 visiting scholars from Germany and abroad can work on key questions at the frontiers of their research fields.

The Mainz Institute for Theoretical Physics (MITP) belongs to the PRISMA Cluster of Excellence. Since its inception in 2013, MITP has rapidly evolved 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 key mission of MITP is to provide resources to host a variety of scientific activities like scientific programs of several weeks, one-week topical workshops, and conferences. A team of external organizers and local scientists is responsible for these activities. In order to initiate new projects and new collaborations, the participants are requested to stay at MITP for at least two weeks.

The science at MITP is community organized. 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 an International Advisory Board consisting of internationally renowned scientific leaders. The current board members are 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).

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Mainz, February 2017

2 Development of MITP in 2015 and 2016

In 2015 and 2016, the Mainz Institute for Theoretical Physics has further established itself as an international center for theoretical research in particle, hadron, atomic, and mathematical physics in Germany.

Both the number of scientific activities and of participants have increased steadily since 2013. Compared to 16 weeks in 2014 and 19 weeks in 2015 we have scheduled 24 weeks of scientific programs and topical workshops in 2016. While we had 244 scientists participating in the MITP activities of 2014, there have been 353 participants in 2015, and 400 participants in 2016 (see Figure 1).

The 14 scientific programs and 6 topical workshops in 2015 and in 2016 have covered a vast range of topics. The scientific summaries are listed in the next two sections which were offered by the external organizers and which were edited for this report.

The participants in 2016 came from 37 different countries Three quarters of participants came to MITP from outside of Germany. 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), approximately 25% of MITP participants come 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 (see Figure 2).

During the past two years, we annually received close to 20 proposals for scientific programs and topical workshops from external scientists, which amounted to approximately 40 weeks of scientific activities. In line with the available financial resources of MITP and the ranking provided by the International Advisory Board, up to 24 weeks of activities can be supported each year. The number of applicants has also increased constantly. We had 400 applicants in 2014, 428 in 2015, and 554 in 2016. Between 70% and 75% of applicants have been 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 increasing number 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 it is the responsibility of the program organizers to select the participants for the scientific programs and workshops, MITP guidelines ask that gender and age balance be considered in the selection. Young applicants (postdocs and junior faculty) and scientists from developing countries should have a good chance of being admitted. Since last year, 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 rate of female participants in any MITP activity which is far above the average on the field.

Since 2014, the operation of MITP profits 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 35 external scientists attractive office space and access to computing facilities. The MITP seminar room with up to 50 seats is fully equipped (including video equipment) and can be used any time by the participants of MITP activities. Moreover, the casual MITP Lounge in the center of the institute provides an attractive discussion area and meeting space. The staff of MITP is fully determined to make any 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.

MITP also hosts guest scientists and research collaborations for extended stays independent of running workshops and programs. Small groups of researchers may use the MITP facilities for concentrated (collaborative) work on a particular research project in theoretical physics. During the last two years there have been 16 visitors joining the MITP for 2-4 weeks and collaborating with local scientists.

One of the main goals of a theory center like MITP is to stimulate discussions and induce new scientific ideas and collaborative work. The support of MITP was acknowledged by participants of MITP activities in more than 74 publications and preprints in 2014, 89 in 2015, and 123 in 2016 which are all listed on the MITP homepage (https://www.mitp.uni-mainz.de/600.php).

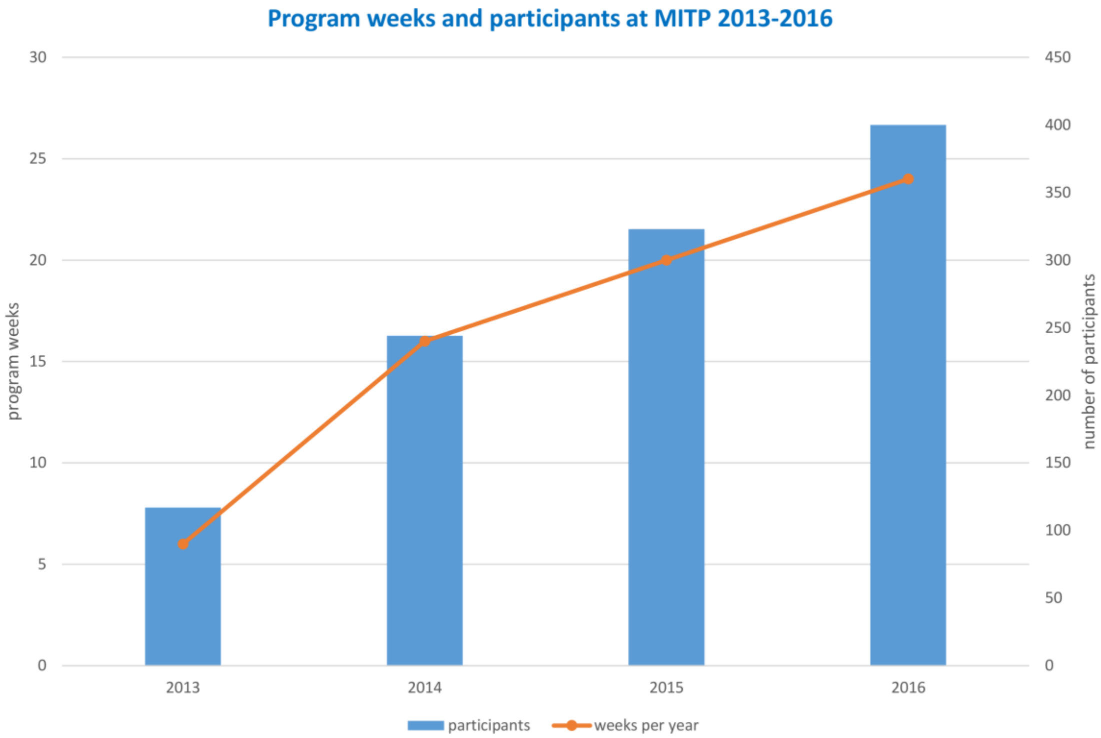


Figure 1: Increase in the number of MITP activity weeks (orange) and number of participants (blue) per year in the period from 2013-2016.

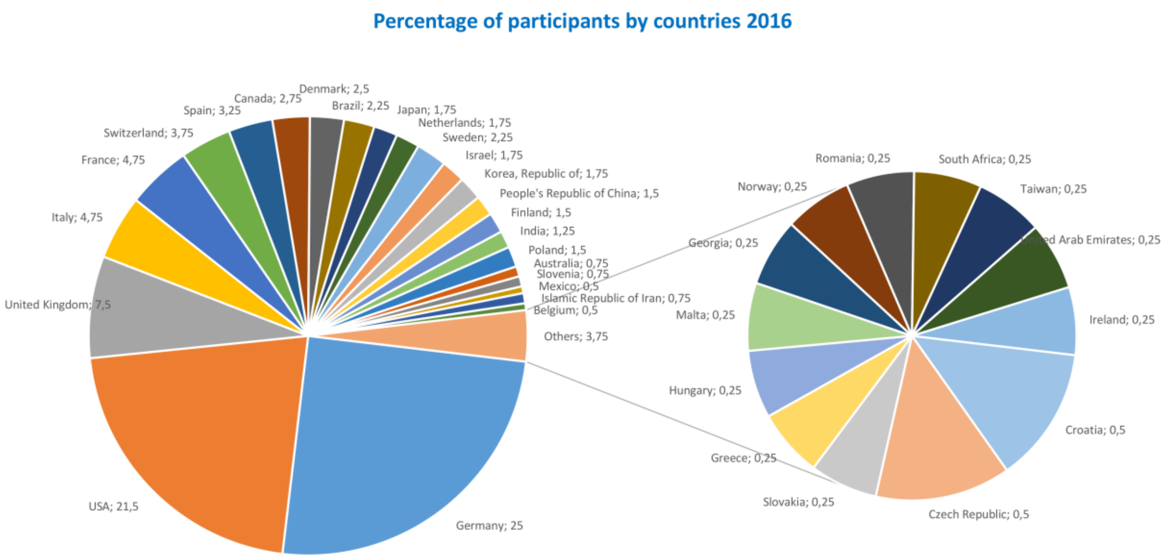


Figure 2: Countries of residence of the 2016 MITP activities (in %).

3 Scientific Programs

Effective Theories and Dark Matter

Organized by Vincenzo Cirigliano (Los Alamos), Richard J. Hill (Univ. Chicago), Achim Schwenk (TU Darmstadt), Tim M.P. Tait (UC Irvine)

March 16-17, 2015, JGU Campus Mainz

The MITP Scientific Program "Effective Theories and Dark Matter" brought together physicists working on a broad range of subjects ranging from theoretical nuclear physics and QCD to model-building, plus a few experimentalists, all with interest in applying the technology of these fields toward understanding the particle nature of the mysterious dark matter which comprises most of the mass of the Universe. Given the broad array of subjects, there was great need for this kind of multi-disciplinary conference to bring together the diverse interests and help integrate cutting edge results between them. From this point of view, the workshop was a great success, with talks scheduled in the morning and more free form discussions in the afternoon. The questions ranged from the very basic to the technically advanced, illustrating the fact that the speakers and discussion leaders did an excellent job of keeping the discussion basic enough for those outside of the primary topic to follow, while still allowing the experts to have useful discussions to advance the state of the art. Several new results, both experimental and theoretical, were presented for the first time at the workshop. These included new Super-CDMS constraints on effective WIMP-nucleon interactions; a new analysis of nucleon sigma terms in two flavor chiral perturbation theory; new results for two-body currents in chiral effective theory; and new results on composite dark matter from the lattice LSD collaboration. Some of the major topics of discussion included:

- What are the cutting edge tools to describe nuclei and their response to being scattered by dark matter particles? How can we make progress in improving and vetting them?
- How does one relate a given theoretical model at the electroweak scale to predictions for observables, including the low energy effective theory at the scale of the strong interactions?
- Given constraints from the wide array of experiments, what are currently the best theories of dark matter? Are there corners of theory space left unexplored?

Direct detection searches use heavy nuclei as targets. The workshop discussed current status of nuclear models, along with prospects and needs for future improvement. The status of spin-dependent cross sections computations, and the impact of two-body and other nuclear effects was reviewed. Particle attention was paid to the discussing the impact of two-body currents deriving from scalar versus tensor quark-level operators.
The participants engaged in a vigorous discussion on the merits of using quark-level versus nucleon-level parameterizations for presenting the observations/ constraints of direct detection searches. The former is required in order to connect to UV models and collider bounds, while the latter provides a more immediate connection to direct detection experiments. It is likely that both approaches will play an important role in understanding future data, and the workshop featured several discussions on the work needed in connecting the different descriptions.

The calculation of WIMP-nucleus scattering cross sections from WIMP-quark and WIMP-gluon effective operators requires interfacing particle and nuclear physics. The workshop brought together dark matter practitioners with theorists in the perturbative QCD community, and featured talks presenting recent work using heavy particle and soft-collinear effective theories, and applications to direct detection, indirect detection, and collider searches. The scalar matrix elements of the strange (and charm) quarks in the nucleon are particularly important for a large class of WIMP candidates. The status and some new results for these and other nucleon-level matrix elements from lattice QCD and chiral perturbation theory were presented.

At the workshop, specific discussion assessed the viability of novel ideas for the nature of dark matter, such as the possibility that it is a bound state composed of charged constituents held together by a dark analogue of the strong force, or that the dark matter possesses a notion of flavor analogous to that present in the quarks and leptons of the Standard Model. In both cases, viable parameter space results with implications for how searches for dark matter should be interpreted if these ideas prove to be realized.

Theoretical models aimed at predicting the mass of the dark matter were explored, and it was demonstrated that there are principles which can suggest a value around the electroweak scale, either based on the observed abundance of dark matter or by tying the scale of the dark matter mass to the breaking of scale invariance.

A major area of discussion was the use of effective field theories to characterize dark matter interactions with quarks and gluons, and their use to interpret LHC searches for dark matter. These effective theories are powerful because they capture the low energy behavior of a large class of models, but care is needed when the masses of the mediators are comparable to the energies present in typical LHC reactions. Progress was made as to how to characterize this feature, but how to optimally present the analysis remains an open question.

Collider constraints on more concrete models of dark matter, such as having a minimally electroweak-charged particle, or in the context of the pMSSM were discussed, and the state of the art bounds were derived from existing data. These point the way to the most likely regions of parameter space. An open question is whether or not these bounds could be improved by additional analyses.

Finally, there was much discussion of an excess of gamma rays from the direction of the galactic center observed by the Fermi LAT. This excess is consistent with simple models for dark matter annihilation, but is difficult to interpret because of largely unknown astrophysical backgrounds. The discussion resulted in the most precise characterizations of this signal to date and explored the class of models capable of explaining it while remaining free from constraint by collider and direct searches. An open question is how one may make progress on better modeling of the astrophysical backgrounds.

Ultimately, the nature of dark matter is a question that must be settled experimentally. The synthesis of these diverse theoretical areas ensures that we make the most of existing experimental searches and understand where in "theory space" dark matter could hide from them.

Amplitudes, Motives and Beyond

Organized by Francis Brown (IHES Paris), Marcus Spradlin (Brown Univ.), Don Zagier (MPIM Bonn), Stefan Weinzierl (JGU Mainz), Stefan Müller-Stach (JGU Mainz)

October 10-14, 2016, JGU Campus Mainz

The three week MITP scientific program "Amplitudes, Motives and Beyond" brought together about thirty mathematicians and physicists in the intersection from the fields of high energy physics, mathematics and string theory. The main emphasis of the program was on the interplay and similarities between physics and mathematics found in the study of scattering amplitudes on the physics side and in the theory of motives on mathematics side. The program evolved in a stimulating and productive atmosphere, with one talk usually scheduled in the morning and another talk scheduled in the afternoon. Very often the talks turned into discussions, which were continued in the coffee room. Albeit participants came from different scientific backgrounds, the common language spoken by all participants was a remarkable fact. 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 realizes soon 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. However, it is very often the case that the final answer is much shorter than any intermediate expression. This is an indication that not all structures and symmetries of the problem have been identified.
The 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. Simplicity with respect to the number of internal loops is obtained by making use of the algebra of transcendental functions, like the algebra of multiple poly-logarithms. Multiple poly-logarithms are an important class of functions. In physics they are closely tied to Feynman integrals with massless propagators.

Talks by D. Broadhurst, F. Dulat, J. Henn, A. von Manteuffel, O. Schnetz and M. Sogaard addressed the problem of expressing amplitudes in terms of multiple polylogarithms. In mathematics multiple poly-logarithms are related to periods of mixed Hodge structures (or motives) of Tate type. The connection between the physics side and the mathematics side is based on representing the parametric Feynman integral as a (possibly divergent) period integral on an algebraic variety given by the complement of a graph hypersurface. Motives and varieties were discussed in the talks of J. Stienstra, A. Mellit and S. Galkin. The relation between periods, multiple poly-logarithms and string amplitudes were addressed in the talks of S. Stieberger and D. Zagier. Of particular interest are motives, which are not of mixed Tate type. This would correspond to Feynman integrals, which cannot be expressed in terms of multiple poly-logarithms. The physics motivation comes from scattering amplitudes with massive particles as well as from amplitudes with sufficient many external massless particles. In going beyond the mixed Tate type one encounters elliptic integrals and elliptic multiple poly-logarithms. Elliptic generalizations have been discussed in the talks by J. Brödel, N. Matthes, O. Schlotterer and Y. Zhang. Simplicity with respect to the number of external legs is obtained by using methods associated to twistor variables, Grassmanians, cluster coordinates or Yangian symmetries. Here, ideas and concepts of string theory propagated into methods for quantum field theory. To give an example: One line of investigation originated from a new method of computing Feynman integrals in QCD based on the twistor formalism and on the positive Grassmannian. Amplitudes are computed as volumes of certain polytopes in twistor space. In the case of N = 4 super Yang–Mills theory this method has been further developed in terms of the amplituhedron generalizing the role of the positive Grassmannian. Polylogarithms appear naturally in this approach. Yangian symmetry, the amplituhedron and N = 4 super Yang–Mills amplitudes were discussed in the talks of B. Eden, L. Ferro, D. Nandan, G. Papathanasiou and M.Staudacher. Closely related is research in the

direction of cluster algebras and quivers. Here on tries to identify natural variables which appear as arguments of poly-logarithms. These ideas were exposed in the talks of J. Drummond and A. Volovich.

Quite recently it was discovered that Yang-Mills amplitudes and gravity amplitudes can be calculated from a (discrete) set of solutions to certain equations, named “scattering equations”. L. Mason explained how these formulae arise from a holomorphic string theory in ambitwistor space. A highlight of the scientific program was certainly the talk by Y. Manin on the motivic structure of quantum cohomology.

The MITP scientific program “Amplitudes, Motives and Beyond” was very successful in bringing together scientist from mathematics and physics. The discussions were very stimulating and fruitful and triggered certainly various scientific research projects.

Higher Orders and Jets for LHC

Organized by Matteo Cacciari (LPTHE Paris), Paolo Nason (INFN Milan), Giulia Zanderighi (Univ. Oxford, CERN)

June 29 - July 17, 2015, JGU Campus Mainz

During the scientific program there was on average one presentation per day on the topics of the program, i.e. on shower algorithms, fixed-order calculations at NLO and NNLO, resummations and jets. Thus, ample space was left for discussions and collaborative work.

In the framework of interfacing shower Monte Carlos with next-to-leading order (NLO) calculations, a presentation has been given on the problem of processes involving strong interaction corrections to the decays of resonances. Several problems arise in this case in the computation of NLO corrections and in the construction of the interface to the parton shower (PS). A novel approach was presented based upon the classification and separation of all possible resonance histories allowed by the process. Preliminary results were presented for single top production and further work was carried out during the workshop in order to address the more complex (and interesting) top-pair production case. With this method, it is clear that double logarithms of the resonance widths are treated correctly, while the fate of single logarithms was questioned during the workshop and discussed in several occasions.

In the framework of NLO calculations, results for WW+1jet production were presented, that are based on pure analytic results for the virtual correction, meaning that the virtual result is given in terms of linear combinations of master integrals where analytic expressions are given both for the integrals and the coefficients. This is in contrast to the widely-used methods, where a numerical procedure is given to compute the coefficients. This problem has a certain relevance because numerical methods often encounter unstable phase space points, thus requiring to resort to quadruple precision, which slows down the calculation considerably. The problem becomes even more important when the NLO result is used in the context of a NNLO calculation and is required in regions where the Born momenta become soft or collinear. The example presented in the workshop suggests that this problem is certainly an important one, and it is far from having a satisfactory answer.

In the context of NNLO calculations, recent results for Higgs plus one jet were presented. The seminar triggered discussions with regard to the subtraction/slicing methods used in these calculations. Although traditionally subtraction methods are now dominant as far as the NLO calculations are concerned, it appears that, because of its intrinsic simplicity, slicing methods should be also considered for NNLO calculations. In particular, slicing methods is Based on the N-jettiness seem to be now a promising venue for these applications. There were several discussions on how to best fix the value of the slicing parameter, since too low a choice leads to large numerical instabilities, while a cut that is too loose leads to too rough an approximation for the NNLO result.

A good part of the scientific program was also dedicated to resummation problems. We had two presentations on $q_T$resummation, one based upon the traditional method, and the other based upon Soft Collinear Effective Theory (SCET). Furthermore, the treatment of jets in SCET, the automation of resummation in SCET and the prospect of treating non-global logarithms in this framework were discussed. Still on resummation, we had one more presentation on the impact of logarithms related to the presence of a small jet-radius. The results presented suggest that the ”small R” logarithms are not as phenomenologically relevant as thought in the past. A longstanding open question is the estimate of theoretical errors due to unknown missing higher-order corrections. There was a presentation of a recent method based upon a

bayesian approach to the problem, where one formulates priors on the behavior of the series beyond what is known given what is known, and extracts a posterior distribution that gives a credibility density profile for the value of the uncalculated remainder of the series. The difficulty of the exercise resides in finding priors that are at the same time general enough, so as not to ‘guess’ the uncalculated higher orders, but also sufficiently appropriate for the process that is being considered. Discussions took place on what a correct approach may be, but the issue is still far from settled and the Bayesian approach will certainly require more work before it can become a commonly used tool.

Besides the technical discussions, there were a number of review seminars, e.g. on the status of vector boson fusion studies at the LHC, on the prospects for Higgs physics, in both gluon-gluon fusion and vector boson fusion, on Dark Matter searches at the LHC, and on the general status of particle physics and its connection to cosmology.

Given that there was about one seminar per day, participants had a lot of time to work on the topics above. Furthermore, several discussions took place about Standard Model physics at a 100 TeV Future Circular Collider. As a result of this, many participants of this MITP event started to work on this topic and will be involved in the write-up of a comprehensive report on this.

Crossroads of Neutrino Physics

Organized by Steen Hannestad (Univ. Aarhus), Patrick Huber (Virginia Tech), Alexei Smirnov (MPIK Heidelberg), Joachim Kopp (JGU Mainz)

July 20 - August 14, 2015, JGU Campus Mainz

One of the focus topics of the scientific program "Crossroads of Neutrino Physics" was the impact of neutrinos in astrophysics. This included an update on solar neutrinos (Alexei Smirnov) and a talk and a lively discussion session on collective effects in supernova neutrino oscillations (Georg Raffelt, Baha Balantekin, Evgeny Akhmedov, Cristina Volpe). It was recently found that this problem is even more challenging than previously thought. Numerous instabilities in the 3-flavor system imply that simplified 1d or 2d treatments cannot be trusted, and only a full 3-dimensional simulation could hope to capture all relevant effects. The effort for such a simulation would be comparable to the effort that goes into hydro-dynamical simulations of supernovae. Moreover, a simulation of neutrino evolution should ideally be coupled with a hydro-dynamical simulation since the two systems influence each other. Moreover, there were several talks (Eli Waxman, Zurab Berezhiani, Mauricio Bustamante, Toshihiko Ota) and a discussion session (Arman Esmaili, Danny Marfatia) on high energy astrophysical neutrinos. In spite of the discovery of high energy astrophysical neutrinos in IceCube, their origin remains a mystery. It was shown that star forming galaxies, which can stop charged cosmic rays up to energies of 100 PeV, are a promising source candidate. The flavor ratios of astrophysical neutrinos remain an intriguing observable, even though measurements are not yet accurate enough to allow for discrimination between models. Finally, some extensions of the Standard Model can leave an imprint on the high-energy neutrino flux, making IceCube well-suited to search for such new physics scenarios. Most of this discussion took place in week 1, and part of it also in week 3. A discussion on results from the ICRC conference, led by Pasquale Serpico, provided a forum for the very latest results on this topic. Week 1 ended with a colloquium on neutrinos in cosmology by Steen Hannestad.

The second major topic of the workshop was neutrino oscillations, including in particular the possibility of new physics in the neutrino sector such as the possible existence of sterile neutrinos. The diverse discussions in this field of research centered around the following issues: How large can non-standard neutrino interactions be in realistic models (Pedro Machado and Yasaman Farzan)? How likely is it that light sterile neutrinos exist, and how could their existence be reconciled with strong bounds from oscillation experiments and from cosmology? This question was addressed in a long and fruitful discussion session led by Baha Balantekin, Andre de Gouvea and Joachim Kopp, and in a talk by Yong Tang. How would the existence of sterile neutrinos influence the search for CP violation in long baseline experiments (Boris Kayser)? How well can one probe neutrino oscillations in a large future iron calorimeter detector (Sanjib Agarwalla)? New analytic results on neutrino oscillation probabilities (Hisakazu Minakata) Can wave packet decoherence influence future oscillation experiments (Steven Wong)? How robust is the reactor neutrino anomaly (Patrick Huber)?

On the more theoretical side, there were several very interesting presentations embedding neutrinos in extensions of the Standard Model. Borut Bajc explained the role that neutrinos play in Grand Unified Theories (GUTs) and how some of their masses and mixing parameters can be predicted in GUTs. Claudia Hagedorn illustrated how sterile neutrinos at the eV scale (for the oscillation anomalies) or at the keV scale (as a dark matter candidate) can be embedded in models of flavor, in particular models with discrete flavor symmetries. Andre de Gouvea discussed various aspects of seesaw models, focusing in particular on what one knows and what one can learn experimentally about the heavy right-handed neutrinos in such models. Motivated by the IceCube events, possibly pointing towards new physics at the PeV scale, Urjit Yajnik discussed a model in which an $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ symmetry is broken at a high scale, and leptogenesis takes place during the breaking of that symmetry. A discussion session on neutrino models was led by Zurab Berezhiani.

In the final week of the workshop, several interesting ways of probing neutrino physics in experiments traditionally not associated with that field of research were presented. Bhupal Dev discussed searches for electroweak scale seesaw models at the LHC, and Pilar Coloma illustrated how neutrino experiments can be exploited to search for dark matter particles directly produced in the neutrino production targets.

Fundamental Parameters from Lattice QCD

Organized by Gilberto Colangelo (Univ. Bern), Heiko Lacker (HU Berlin), Georg von Hippel (JGU Mainz), Hartmut Wittig (JGU Mainz)

August 31 – September 11, 2015, JGU Campus Mainz

Recent years have seen a significant increase in the overall accuracy of lattice QCD calculations of various hadronic observables. Results for quark and hadron masses, decay constants, form factors, the strong coupling constant and many other quantities are becoming increasingly important for testing the validity of the Standard Model. Prominent examples include calculations of Standard Model parameters, such as quark masses and the strong coupling constant, as well as the determination of CKM matrix elements, which is based on a variety of input quantities from experiment and theory. In order to make lattice QCD calculations more accessible to the entire particle physics community, two different initiatives (which have now merged) have sprung up, which collect the available lattice results and produce global averages. Also on the phenomenological side there are groups which produce global averages of flavor physics quantities, for which lattice input is crucial. This scientific program aimed to bring together lattice practitioners with members of the phenomenological and experimental communities who are using lattice estimates as input for phenomenological studies. In addition to sharing the expertise among several communities, the aim of the program was to identify key quantities which allow for tests of the CKM paradigm with greater accuracy and to discuss the procedures in order to arrive at more reliable global estimates.

The program was attended by 19 members of the lattice community and seven phenomenologists, as well as one experimental physicist. The daily program consisted of two one-hour talks each morning, and ample time for discussion in the afternoons. This common program was complemented by separate collaboration meetings of the CKMfitter collaboration (which performs fits to the CKM paradigm of the Standard Model and to New Physics models using precision flavor observables, relying on lattice inputs for many hadronic quantities) and of the Flavor Lattice Averaging Group (FLAG), which publishes averages of lattice determinations of numerous hadronic and fundamental quantities of relevance to flavor physics. Framed by keynote talks from FLAG (presented by A. Vladikas) and the CKMfitter collaboration (presented by S. Descotes-Genon) on the first, and a summary talk (presented by G. von Hippel) on the last day, the program of talks included reviews of the decay and mixing properties of heavy-light mesons (presented by P. Dimopoulos, P. Fritzsch, and S. Collins) and light mesons (presented by C. Kelly, and A. Jüttner), discussions of issues connected with the determination of quark masses (presented by G.Bali, M. Della Morte, and M. Creutz), and the interplay of electroweak and strong interactions (presented by T. Izubuchi, G. Herdoíza, and V. Lubicz). A special presentation of the PDG World Average of the strong coupling α_s (presented by S. Bethke) was complemented by a moderated community discussion, and by talks on determinations of α_s from heavy-quark potentials (presented by X. García i Tormo) and the role of perturbation theory (presented by M. Lüscher). The core issue of data analysis in the presence of systematic errors, which was the topic of two discussion sessions, was addressed with new proposals in a special presentation (presented by J. Charles). The program was rounded off with a talk on the topic of nucleon strange electromagnetic form factors (presented by J. Green). The environment at the MITP fostered vigorous discussions also outside of dedicated sessions, both in the coffee room and in smaller groups meeting in individual offices, including those set aside for the purpose.

A topic that ran through most of the reviews and was addressed in a special presentation and separate discussions was the issue of how to average lattice results in the presence of the theoretical uncertainties which dominate over the statistical ones. This is of crucial importance in order to obtain reliable estimates of the overall systematic errors of lattice averages, which will be needed to constrain fits to the CKM paradigm and to probe the limits of the Standard

Model. While no general consensus on a single unified way to estimate these uncertainties has been achieved so far, the discussions at the scientific program have been helpful in identifying some of the ways in which the lattice community can better provide the information required by the CKM fitting communities, and in elucidating what are the pertinent theoretical and mathematical issues, such as the question of the nature (stochastic or otherwise) of systematic errors, which also influence the question of how these are to be treated in a maximum-likelihood framework.

Another important topic was the issue of including isospin breaking in lattice results, which will be required if sub-percent accuracy is to be achieved. The two major ways in which this problem can be tackled are direct simulations of QCD+QED with unequal-mass light quarks, and the incorporation of a systematic expansion around the isospin symmetric point into lattice calculations via a set of methods developed by the Rome-based RM123 collaboration. Either method will need to address the problem of infrared divergences associated with the lack of a mass gap in QED, and methods to deal with this in the spirit of the Bloch-Nordsieck treatment of IR divergences were discussed at the program. Other sources of systematic error that may become significant at the sub-percent level, including the observables used for scale setting on the lattice, and these of perturbative renormalization, were also the topic of some discussion.

Finally, the coordination of efforts and the improvement of communication channels between the lattice and phenomenological communities have been addressed, and it may be said that this program represented a significant step in this direction. This scientific program connected the communities of the "producers" and "consumers" of lattice results for a discussion of the issues surrounding the use of lattice results in determining the fundamental parameters of the Standard Model, resulting in improved mutual understanding of relevant issues and methods.

Stringy Geometry

Organized by Eric Bergshoeff (Univ. Groningen), Gianfranco Pradisi (Univ. of Rome "Tor Vergata"), Fabio Riccioni (INFN Rome "La Sapienza"), Gabriele Honecker (JGU Mainz)

September 14-25, 2015, JGU Campus Mainz

The field of research aimed at understanding the geometric structure that under lies perturbative and non-perturbative string theory has seen enormous and fast developments in recent years. There has been progress in the area both at a purely theoretical level, where various mathematical tools and different approaches have been worked out and used to give insights into the very nature of string theory and M-theory, and at a more phenomenological level, where these ideas have found applications in providing a better understanding of four-dimensional models that might result relevant for new physics, from a higher-dimensional (and more fundamental) perspective. The Program brought together leading experts in the various approaches that have been proposed, in order to stimulate exchanges of ideas and collaborations. Different lines of research in perturbative string theory go under the names of ‘doubled geometry’, ‘generalized geometry’ and ‘double field theory’, while the inclusion of non-perturbative effects yields additional modifications of the geometric structure, leading to the so-called 'exceptional field theory'. This variety of subjects was taken into account in inviting the scientists and in selecting the speakers.

In the first week, there were four talks on double field theory (namely the talks by Park, Pezzella, Jeon and Aldazabal) and two on exceptional field theory (by Kleinschmidt and Cederwall), while the talks by Varela, Stelle, Massai and Tomasiello were more generally on supergravity theories and their solutions, including non-geometric ones. In the second week, there were three talks on double field theory (Andriot, Grana and Hull), two on generalized geometry (Shabazi and Waldram) and one on exceptional field theory (de Wit). In the second week, there also were the talks by Lozano on non-abelian T-duality, by Cardoso and Zaffaroni on black holes in string theory and M- theory and finally by Minasian on F-theory. Three talks (those of Cederwall, Massai and Shabhazi) were given at the blackboard and further contributed to create an informal atmosphere which stimulated discussions during and after the talks. The slides of most other talks have been collected and made publicly available on the indico page of the scientific program. As it emerges from the analysis of the scientific activity, the program triggered new insights and ideas, documented in many publications by the participants which appeared after the MITP activity. The vast field of activities that goes under the name of 'stringy geometry' is still very prolific. Many questions are still open and many directions are still in their germinal state.

NA62 Kaon Physics Handbook

Organized by Augusto Ceccucci (CERN), Giancarlo D'Ambrosio (Univ. Naples, CERN), Ulrich Haisch (Univ. Oxford), Rainer Wanke (JGU Mainz)

January 11-22, 2016, JGU Campus Mainz

The scientific program started with an introduction to the NA62 experiment. The fortunate combination of having a machine like the CERN SPS available to perform fixed target experiments while serving as an injector for the LHC was recalled. The current schedule of CERN foresees to run the LHC until at least 2035, with regular stops (Long Shutdowns) of about 18 - 24 months every three years of data taking. It is assumed that if a compelling physics case can be made, this line of research could continue into the future with suitable detector improvements and possible changes to the beam configurations, for instance: charged kaons (positive and/or negative); neutral kaons; beam dump.
It should be stressed that while Kaons are emphasized, the science program could also include charged and neutral pion decays, and searches for hypothetical low mass, weakly coupled dark sector and axion-like particles. What makes NA62 superior with respect to previous experiments is the large

acceptance, its high rate capability, its full particle identification (including pion muon separation up to large momenta) and a very light tracking to minimize the interactions of particles with matter. Innovative detector technologies have been developed to cope with the high rate. In particular, NA62 has developed the capability to track beam particles up to a rate of one GHz (Gigatracker) over a surface of a few cm. NA62 was built to minimize the resolution effects induced by multiple scattering thanks to the Straw spectrometer where each tube is an independent leak-tight detector operated in the vacuum decay tank. With respect to the predecessor experiment, this avoids: the presence of He in between the chambers, of a heavy beam-pipe crossing the spectrometer, and of a window separating the decay volume from the tracking volume.
The above, coupled to a system of almost hermetic photon calorimeters form the essential ingredients for addressing the main goal of NA62 which is the measurement of the $K^+ \to \pi^+ \nu \bar{\nu}$ decay. The sensitivity of the experiment was thoroughly assessed a using Monte Carlo simulation and a sample of data from the NA48 experiment. One expects a signal/background ratio of about five with the accumulation of around 45 Standard Model events in a year of data-taking at full proton intensity on target and an overall acceptance × reconstruction × trigger efficiency of 10%. The status of the experiment was recalled: after a commissioning run in 2014, a first sample of about 2×10^{10} kaons was accumulated in 2015, mostly at low beam intensity. Full proton intensity on target was achieved during the last days of the run. Data collected in 2015 should allow to verify the sensitivity of the experiment but are still insufficient to provide a significant physics result. The experiment expects to collect of the order of 10^{13} kaon decays before the end of 2018 when the CERN accelerators will stop for the Long Shutdown 2 (LS2) that will last until the end of 2020.

The keynote talk kaon physics strikes back was given by Andrzej Buras. Renewed interested in the calculation of CP-Violation in $K_L^0 \to \pi\pi$ and correlation between golden quantities in kaon physics were reviewed, in the spirit of recent appraisal of hadronic matrix elements ($B6$ and $B8$) in large N formulations. Effects of final state interactions on the amplitudes was one of the themes of the discussion which continued into the second week with the presentation by Toni Pich. Correlations between $B \to \mu\mu$ and $K^+ \to \pi^+ \nu \bar{\nu}$ were emphasized.

A full day was devoted to the status of kaon physics on the lattice. Chris Sachrajda summarized the progress made through the past few years concerning the lattice computation $of\ K \to \pi\pi$ amplitudes, culminating in the calculation of the B6 operator and the suppression of the δI = $3/2$ transition. Progress on rare decays has also appeared on the lattice. Chris emphasized the importance for the experiments to state precisely the analysis cuts for the electromagnetic radiation. Kaons are a lucky combination where both long distance and short distance aspects can be precisely treated so experiments should be careful in order to profit from the theoretical precision. The talk of Guido Martinelli focused on em and isospin corrections on the lattice. Ab initio calculations of long distance effects are possible on the lattice for kaons because there are no nearby resonances (e.g. hyperfine splitting like in B mesons). A lot of attention on the inclusion of re-scattering on the lattice is to be addressed.

Martin Gorbahn detailed the steps of the Standard Model calculations for the $K^+ \to \pi^+ \nu \bar{\nu}$ rare decays, ϵ_K and ϵ'/ϵ. Questions related to how well can perturbation theory work down to the charm mass were discussed. Soon a NNLO calculation for ϵ_K will become available. Gilberto Colangelo explained the success of dispersion relation techniques to extract the $\pi\pi$ scattering length. It was pointed out that lattice prediction gives a significantly lower result. The application of dispersion relations to K_{e4} decays was described by Peter Stoffer. He showed implications for NA62 and interesting analogies between between K_{e4} and $\pi\pi\pi$ decays were pointed out.

Three presentations were devoted to radiative corrections and radiative decays. Mark Knecht reviewed radiative corrections for $\pi\pi$ and K_{e4} decays. He also expressed interest in possibly improving the pion beta decay measurement. The determination from the super-allowed $0^+ – 0^+$ nuclear transitions is very precise but it is difficult to understand how the radiative corrections are applied. The determination from the neutron beta decay is not a pure vector transition and requires the knowledge of the decay asymmetry. Pion beta decay is ideal from a theoretical point of view, and one is limited by the experimental statistics (PIBETA) because of the extremely small phase space available. Could NA62, with suitably adjusted beam parameters, be competitive? The systematics would certainly be different from the PIBETA measurement which is done at rest. Ramon Stucki reviewed radiative decays of the kaons in the framework of dispersion relations. In particular, he underlined the interest to study better the $K \to l^+ l^-$ transitions, while the phenomenology of $K \to \pi\, l^+ l^-$ decays was described by David Greynat the day after.

Of course, we could not avoid discussing the implication of the $\gamma\gamma$ hints presented in December by the ATLAS and CMS collaborations, a presentation on the topic was given by Sebastian Jäger. Puzzles in B rare decays have re-ignited the interest in looking for lepton flavour violation in rare decays as witnessed by the talks by Diego Guadagnoli and Lewis Tunstall. To place kaon physics in the broader context, Antonio Masiero addressed the question "Where are we going in Particle Physics?" emphasizing the relation between the standard models of cosmology and particle physics. He invited the audience to look through the crystal ball into the relations between particle accelerators, dark matter searches, neutrino mysteries, gravitational waves and multi-messenger astronomy. Going beyond the SM, Sebastian Jäger reviewed supersymmetric models and kaon physics, while non-supersymmetric extensions of the SM were covered by Monika Blanke on the last day of the program.

The ϵ'/ϵ discussion continued with the presentation by Toni Pich which stressed the importance of re-scattering effects and final state interactions. A photo was taken to put on record Andrzej's and Toni's SM predictions for ϵ'/ϵ : 5 versus 19 $\times 10^{-4}$. It was stressed that the cancellations of the $B6$ and $B8$ operators that appear in the SM and make the prediction difficult do not appear beyond the SM.

The impact of kaon observables on the CKM unitarity triangle fits was reviewed by Sebastien Descotes-Genon. A detailed update on the semi-leptonic decays was given by Johan Bijnens, and the phenomenological implications for experiments were carefully addressed by Emily Passemar. Kaon and hyperon semileptonic decays in an effective theory framework were addressed by Jorge Camelich. Giancarlo D'Ambrosio reviewed the structure of weak counterterms and the vector meson dominance hypothesis in several experimentally accessible decays. One session was devoted to the physics of π^0: Karol Kampf thoroughly reviewed the status and Pere Masjuan spoke about searches for new physics in π^0 rare decays. Model-independent, effective theory approaches were discussed by Ulrich Haisch and considerations about flavor as portal to Dark Matter were given by Andreas Crivellin.

Plenty of time was reserved for spontaneous discussion, a lot of coffee, pretzels and cakes fueled the discussions. The write-ups of the participants will be the core part of the NA62 Physics Handbook.

Composite Dynamics: from Lattice to the LHC Run II

Organized by Giacomo Cacciapaglia (IPN Lyon, France), Francesco Sannino (CP3 Origins, Denmark), Thomas Flacke (Korea U., South Korea)

April 4-15, 2016, JGU Campus Mainz

The main goal of this MITP program is to bring together experts from various communities under the flag of understanding the role of strongly interacting theories in particle physics and cosmology, with special focus on theories beyond the Standard Model (BSM). The expertise from the participants to the program ranged from Lattice calculations to collider phenomenology, from Dark Matter to field theory in the strong coupling regime, from model building of Composite Higgs to Cosmology. The great array of interests combined with the flexible schedule created a fertile environment for discussions and exchange of ideas. We organized one informal topical talk per day, in the morning, often co-chaired by two speakers presenting the subject in a critical and provocative way. In the afternoon, time was dedicated to collaborative work and discussion sessions, often organized by the participants themselves. A few afternoon talks were proposed by the participants. All in all, the program was a great success thanks to the many discussions during the two weeks. Many topics were touched upon, a comprehensive description of which goes beyond a summary. The main physics questions that were raised during the workshop are listed below.

• What can Lattice results add to our understanding of strongly interacting BSM models? What theories should be studied on the Lattice?
• What are the key ingredients for natural composite Higgs models? How can solid predictions be made for the LHC Run-II?
• Are there any hints for composite dynamics in the data? What did one learn from the (now gone) excesses in di-boson at 2 TeV and di-photon at 750 GeV?
• Are there new fundamental theories that have not been studied yet? Is asymptotic freedom a must?

Enormous progress has been achieved in lattice calculations aiming at BSM theories. However, many open questions still remain unanswered, as one does not know which underlying theory is most promising in describing a viable model. New Lattice results were presented during two topical talks by J. Kuty and C. Pica during the first week, and E. Pallante and L. del Debbio during the second. In particular, there were heated discussions on how a conformal behavior can be detected on the Lattice. This is a challenging issue as the Lattice itself, due to the discretization of space-time, is not conformal invariant. Yet, conformality, i.e. the existence of a fixed point in the InfraRed, may play an important role in BSM composite dynamics, especially in relation to the flavor problem. The generalization of QCD to many flavors already poses a challenge, as it is not clear if the conformal window starts at 8 or 12 Dirac flavors. Detecting signs of conformal behavior relies on a precise understanding of Lattice effects and on the scaling properties of various quantities. For phenomenology, another important issue is the existence of a light composite scalar resonance that may be identified with the spontaneous breaking of scale invariance - growing evidence is appearing on the Lattice, however how to identify such an object remains unclear.

Composite Higgs models have been mainly studied at the level of effective Lagrangians. The issue on how to define underlying theories based on strongly interacting gauge-fermion models was presented by G. Ferretti and L. Vecchi. During the discussion, it became clear that the key ingredient is the origin of the top mass. Defining an underlying theory of gauge-fermion interactions is a very handy tool to study this issue. One mechanism which became popular recently is the so-called partial compositeness, where fermions become massive by mixing with heavy fermionic bound states. This mechanism is an alternative to the more traditional bilinear four-fermion interactions, where a bilinear of fermions couples to a bilinear of the condensing fermions. The former mechanism, thus, relies on the fact that the fermionic bound states have a larger anomalous dimension that the scalar bilinear, so that the former becomes a relevant operator at low energies before the scalar one does. During the workshop, the issue of anomalous dimensions has been explored in some detail. The concept of anomalous dimensions only makes sense at a fixed point where the theory is conformal, while theories of composite Higgs are, by necessity, not conformal. Also, preliminary calculations were presented by participants showing that it seems unlikely that the anomalous dimension of the fermionic operator is larger than the one of the scalar operator. This result has been achieved in the perturbative regime by means of higher loop computations. Results on the Lattice are ongoing for some of the models discussed during the workshop. This proves the usefulness of having workshops where these communities can meet and exchange ideas. Another key point that has been raised regards the prediction of the Higgs mass, which originates form the spurions related to the top mass. Lattice calculations can help predict some of the form factors that appear in the low-energy Lagrangian.

The issue of the presence of a Dark Sector in composite models has been touched upon in the presentation by M.T. Frandsen and O. Antipin. Many candidates exist in generic composite scenarios, from fermionic bound states which may be protected by an analogue of the baryon number to additional pions. Some issues related to model building have been touched upon, pointing towards the fact that a systematic study of the presence of Dark Matter candidates is still lacking. K. Tuominen also presented results on the role of (elementary) scalars in Cosmology. The 750 di-photon excess In 2015, excitement has been spreading in the community following the announcement of significant excesses in bi-boson (WW, ZZ and WZ in the fully hadronic channel) at a mass of 2 TeV and di-photon at 750 GeV. The newest results announced at Moriond Conference, shortly before the MITP meeting, had confirmed the di-photon one, while disfavoring the 2 TeV di-boson. This situation has been discussed during the meeting, where N. Vignaroli presented general results on the role topological terms can play for the phenomenology of composite models. In fact, via topological anomalies, some of the pions naturally couple to pairs of gauge bosons, with coefficients that are sensitive to the details of the underlying theory, namely the dimension of the representation of the underlying fermion under the confining gauge interactions. Thus, composite pions offer a natural candidate for any resonance in a channel with two gauge bosons. Some explicit examples where discussed during the meeting. Due to the interest of the community, shorter presentations where organized by M. Bauer, A. Carmona and P. Ko who discussed how other models may fit the data. Models in extra dimensions as well as weakly interacting models were discussed. The general consensus has been that composite models seem to fit the excess more di-photon excess was not confirmed by further data in 2016, the exercise proved very useful in characterizing and understanding the physics that may lie behind future signals in these channels. A more general overview of collider searches related to compositeness has also been given by A. Belyaev.

The program has been a great success, thanks to the participation of leading scientists from all over the world and belonging to various communities. The scientific program has been left light, with only one informal presentation per day. Often, the morning presentation merged with the discussion time, thus leading to interesting exchange of ideas. The program initiated new collaborations between the participants.

Dark Matter in the Milky

Organized by Fabio Iocco (ICTP-SAIFR, Sao Paolo), Arianna Di Cintio (Univ. Copenhagen), Miguel Pato (Stockholm Univ.), Christoph Weniger (Univ. Amsterdam)

May 2-13, 2016, JGU Campus Mainz

The science case around which this workshop was built in the first place was to bring together the three communities involved in the effort of unveiling the distribution of Dark Matter (DM) in the Milky Way (MW), a timely endeavour today in light of the dramatic developments that DM searches have undergone in the last decade. Astronomers, simulators and astro-particle physicists have interacted fruitfully during the scientific program and have tackled successfully the original science questions that the workshop aimed at addressing:

• How do hydro-dynamical simulations contribute to our understanding of the Milky Way? And reversely, how to design future simulations in view of the available astronomical data?
• How to use the astronomical data soon to be available in constraining the DM distribution in the Milky Way?
• What are the consequences of both simulations and astronomical observations for the phenomenology of dark matter searches?

Some elements of the format of the workshop were identified as functional to the productive yet amiable atmosphere. The relatively small size (no more than 25 per week) of the participant's pool has been very useful to avoid fragmentation in subgroups. The choice of keeping the program of official meetings very light –with no more than two scheduled sessions per day– has been extremely successful to both concentrate the energies and obtain maximal attention and participation during the events (laptops were left out of the meeting room). This feature also permitted to leave enough time for collaborations and exchange of ideas to take place. Besides the usual talks (both review and topical), few other elements were introduced (Q&A session, 1-slider highlighter of a "hot" problem, general discussion, and project brainstorming) which have required active energy from all participants. All participants have reacted enthusiastically, and these "unusual" sessions have been successful. The location of the institute and the comfortable setting of offices and common spaces are functional to the creation of the right atmosphere.

The three communities have interacted virtuously over the two weeks of the workshop, generating discussions and clarifications. Here the subjects addressed during the workshop are grouped by main topic, but it has not been uncommon that a discussion on cogent issues related to one community's work has been first prompted by members of another community. The practical projects stemmed from discussions and brainstorming are listed on the webpage together with the rest of material: slides, Q&A summary, 1–sliders, journal club overview.

Simulations of Milky Way Galaxy analogues: The simulation community was the most represented at the workshop, with members of several different groups (i.e. MaGICC, NIHAO, EAGLE, ILLUSTRIS) offering diverse points of view, thus playing a pivotal role in addressing the main questions of the workshop. Firstly, it emerged that the identification of a MW like galaxy in simulations currently does not follow a unique criterion: while most of the groups use the stellar mass or the halo mass to select a MW candidate in simulations, others rely upon its rotation curve as a better estimator. Ideally, with the refinement of feedback implementations and more resolution, one should converge into reproducing several MW observables at once. It has been suggested to develop a compact, unique nomenclature for the different criteria adopted.

• One of the key issues that has been discussed is whether or not simulations can univocally predict the distribution of DM within our Galaxy, being this a quantity of vital importance for both direct and indirect DM searches. Members of all simulations groups agree on the fact that the inclusion of baryonic physics effects is crucial in any simulation which wants to properly capture the DM distribution. Yet, the innermost region (< 1 kpc) of a MW-like simulated galaxy poses some questions due to the lack of resolution of current simulations below such scale. At scales just above 1 kpc it is clear, instead, that most simulations codes give a similar answer predicting a contracted distribution of DM with respect to the pure DM only case.
• One of the most cogent topics discussed is the impact of feedback mechanisms, such as stellar feedback or Active Galactic Nuclei (AGN) ones, on the MW's DM distribution. It has been shown that while stellar feedback does not have a considerable impact in such a massive spiral like the MW, the feedback from AGN could, in principle, modify the central region of our Galaxy. The impact of AGN feedback on MW-like galaxies is at the moment unclear, as the simulations

that include such type of feedback are only a few and currently at a very early stage.

Aside from the DM distribution within our Galaxy, a few other topics directly connected to the satellite population of the MW have been discussed, such as the missing satellite problem, the too-big- to-fail one, the cusp-core discrepancy: the discussions lead to the clear conclusion that the baryonic physics has a strong impact on the solution of the mentioned problems, to the point that the implementation of different “recipes” can give very different conclusions. While most of the workshop has been devoted at exploring the formation scenario of MW galaxies within the standard Cold Dark Matter (CDM) universe, other possibilities for DM candidates have been brought up. Particularly, the topic of simulations performed within a Warm Dark Matter (WDM) or a Self-Interacting Dark Matter (SIDM) context has been discussed. The effect of baryonic feedback is often degenerate with that of WDM at the scale of interest for MW studies, making the discrimination between the two mechanisms hard, while in the case of SIDM some recent work highlighted how self- interactions could modify the DM profile already at scales of 20 kpc. As of future perspectives, during the workshop it has been highlighted that the increase in computer power will permit to increase the simulation’s resolution, allowing to look not only at the DM distribution within the inner kpc of MW galaxies, but also at detailed physical processes, that have been neglected so far, important for galaxy formation: magnetic fields, thermal conduction, cosmic rays and radiative transfer are a few examples of these processes.

Astrophysics of indirect and direct dark matter searches: Throughout the workshop the genuine interest of simulators and astronomers on the phenomenological aspects of dark matter (theory, indirect and direct searches) triggered many fruitful exchanges toward knowledge often not entirely clear outside the phenomenology community. In that respect, it is worth highlighting two of the most important punchlines of those phenomenological discussions:

• Dark matter is beyond the WIMP paradigm. Feasible candidates include (non-exhaustively) non- thermal particles, primordial black holes, sterile neutrinos, gravitinos or axions, all addressed during the workshop. In particular, warm dark matter was subject of a dedicated session with emphasis on simulations, observations and phenomenology. Also, the possibility of having multiple dark matter components is usually overlooked but it is entirely feasible, just much more difficult to detect and simulate.
• General particle physics frameworks such as supersymmetry are currently not excluded, and will not be even if LHC finds nothing. However, specific models or classes of models within general frameworks are being and will continue to be severely constrained by collider and other searches.

The input of simulations and observations is crucial to direct and indirect searches and thus the expertise shared by the community of simulators and astronomers has been beneficial to the phenomenology community. One of the points most stressed throughout the workshop was that virtually all present hot topics in both indirect and direct dark matter searches need the crucial input of simulations of Milky Way-sized galaxies and/or astronomical observations of our own Galaxy. For indirect searches, two topics were lively debated:

• Galactic center. The gamma-ray emission from the Galactic center region – detected with the Fermi-LAT instrument– cannot be explained by known astrophysical sources. This excess is significant, very solid against systematics and its morphology and spectrum are well characterized. Our ultimate understanding of the excess relies on the dark matter profile in the very center of the Galaxy (within hundreds of pc), which is currently unknown. Any input on that regard from either simulations or observations is of paramount importance.
• Dwarf galaxies. These constitute a robust target for indirect searches, where the exact dark matter profile is not critical at the current angular resolution of gamma-ray instruments. Instead, the current limits will be considerably improved with more observed dwarfs and more precise spectroscopy, a feat at the reach of the upcoming generation of astronomical observatories. For direct searches, the key topics addressed include:
• Velocity distribution. The velocity distribution of dark matter is a crucial input for direct searches that cannot be extracted from current astronomical data (at least not directly). Simulations play here an important role by providing their three-dimensional velocity distribution of dark matter. More than qualitative aspects, for direct searches it is especially important to quantify the differences between different hydro-dynamical simulation sets, and the comparison between the dark matter only and the hydro-dynamical cases.
• Low-mass WIMPs. The status of claims and limits in the region of the parameter space corresponding to low-mass WIMPs is currently unclear. The potential effect of our lack of knowledge of the local dark matter phase-space distribution is small at these masses. The situation can only be resolved with additional direct detection data.
• Neutrino floor. The coherent scattering of low-energy solar neutrinos off nuclei constitutes an important obstacle for the upcoming generation of direct detection experiments. This is not an ultimate limitation since there is a number

of strategies to tackle it (including directionality, modulation, energy spectrum, non-standard scattering interactions), but they all require relatively large amounts of data to put in practice.

Astronomical observations: Astronomical observations were at the center of the debate during the second week of the workshop. Both simulators and phenomenologists depend greatly on more accurate astronomical data, especially in what refers to our own Galaxy. Fortunately, a batch of new precise data is expected by the end of the decade. The discussion sessions painted a relatively broad overview of this topic and addressed some misconceptions about the extent of usability of some astronomical datasets. Here the most salient points are addressed:

• The future of astronomical data is not only Gaia. Upcoming observatories include PanSTARRS, WEAVE, HERMES, 4MOST, MSE, MOONS, WFIRST. Depending on sky footprint, wave- length, magnitude sensitivity, type of data collected and timeline, the most important observatory for a given application might be one of these or a combination thereof. While Gaia will provide a comprehensive collection of six-dimensional information for local stars, it is useful to keep in mind that Gaia alone will not eventually settle all astrophysical uncertainties relevant to the community of simulators and phenomenologists.
• The measurement of the local dark matter density will be tough but possible in near future with an extended collection of kinematics of local stars. The measurement of the local dark matter velocity distribution, instead, is much more difficult given that we cannot see dark matter and thus its velocity distribution can only be constrained indirectly through self-consistent methods. Refinements and generalizations of these methods will be crucial in the coming years to both understand better the structure of our Galaxy and help interpret the results of direct searches.
• The possibility to detect dark matter haloes using stellar stream gaps is exciting and it has potential consequences to disentangle the nature of dark matter (cold vs hot). The capability of current astronomical observatories starts now to be at the level needed to identify such structures accurately. This is certainly a topic to follow closely in the coming years.
• The dark matter profile close to the Galactic center (inner 2-3 kpc) is currently not possible to measure. This is due to a combination of non-existent or unreliable tracers and the small amount of dark matter compared to baryons. The situation might change with upcoming infrared surveys such as MOONS (2019) and WFIRST (2025-2030?).

On a side note, the role of general relativity on galactic rotation curves was lively discussed during the last week of the workshop. Following recent claims and counter-claims in the literature, it is still unclear whether general relativity actually departs from Newtonian dynamics at galactic scales and, if it really does, whether it is able to reproduce the observed rotation curve using the observed luminous distribution only (i.e., without dark matter).

Neutron Skins of Nuclei

Organized by Charles Horowitz (Indiana Univ.), Jorge Piekarewicz (Florida State Univ.), Concettina Sfienti (JGU Mainz), Marc Vanderhaeghen (JGU Mainz)

May 17- 27, 2016, JGU Campus Mainz

The main goal of the two-week program on Neutron Skins of Nuclei was to gather all stakeholders interested in the determination of the neutron skins of nuclei, their impact on the density dependence of the symmetry energy, and ultimately on the physics of neutron-rich matter. The program attracted nearly 40 scientists — both theorists and experimentalists — working on a variety of areas connected to the main theme of the program, such as electron scattering, atomic parity violation, hadronic reactions, and gravitational wave astronomy. The primary goal of the program was to establish quantitatively the strengths and limitations of the various experimental techniques through a detailed analysis of systematic errors. Moreover, given that in most instances theory must be used to connect the measured experimental observable to the neutron skin, it was also essential to quantify the statistical and systematic errors associated with the given theory. It was enormously gratifying to see most of the participants adhere to these guidelines and to engage in open and frank discussions on the weaknesses of their approach. As a consequence of these sincere discussions, a path forward was carved for the design of a suite of experiments that will provide meaningful constraints on the density dependence of the symmetry energy. In an effort to discuss and compare the variety of experimental techniques, there has been a commitment to publish a topical review in the Journal of Physics G. The aim of the review is to document the relative merits of each experiment and to provide a realistic estimate of systematic errors that include the connection between the measured observable and the extraction of the neutron skin, which often relies on theoretical models. Ultimately, we trust that the topical review will become a long-lasting document that will both animate and illuminate the nature of neutron rich matter.

Exploring the Energy Ladder of the Universe

Organized by Rouzbeh Allahverdi (chair), Pasquale Di Bari, Steve King

May 30 – June 10, 2016, JGU Campus Mainz

The workshop gathered 30 scientists from all over the world aiming at discussing topics in Physics of the early Universe related to the possibility to set new energy scales beyond the established traditional ones, basically the recombination and the BBN scales. A special attention was devoted to proposals and ideas able to provide unified solutions to the cosmological puzzles, a realization of Inflation, a consistent picture of Dark Matter and a model of Baryogenesis, and possibly also to address (phenomenological or purely theoretical) problems in the SM such as neutrino masses and mixing, LHC anomalies (e.g. the 750 GeV di-photon excess), naturalness and hierarchy problems, grand unification, extensions of General Relativity.

The quite broad variety of topics could have been in principle too dispersive with the risk of a lack of interactions among the participants. However, due to the quality of the participants and to the natural links among the topics, it became soon clear, that this actually represents a natural and well blended mix of intrinsically inter-connected topics. In fact, a unified discussion, rather than a too focused and narrow one on a specific topic, presented many different advantages giving the opportunity to all participants to enrich their spectrum, triggering discussions and new collaborations.

The topics have been discussed within a top-down approach, from higher to lower scales, though with some deviations dictated by speakers' constraints.

Here is a chronological list of the discussed topics:

• First Week
* Grand-unified models and their cosmological applications (speakers: George Leontaris, Borut Bajc, Sofiane Boucenna)
* Inflation I (Mar Bastero-Gil, Carlos Tamarit, Stefan Antusch)
* Baryogenesis (Laura Covi, Hooman Davoudiasl)
* Leptogenesis (Bhupal Dev, Zurab Tavartkiladze)

• Second Week
* Inflation II (Anupam Mazumdar, Koushik Dutta, Guillermo Ballesteros, Apostolos Pilaftsis),
* Vacuum Instability (Fedor Bezrukov)
* Dark Matter (Rouzbeh Allahverdi, Seng Pei Liew, Alex Merle, Kevork Abazajian, Nobuchika Okada, Debasish Borah, Ayuki Kamada)
* Neutrino Physics (Danny Marfatia, Zhi-zhong Xing, Shun Zhou)

Every afternoon at the end of the talks, the chairmen led discussions on the topics of the talks. Discussions have lasted up to two hours, on average about one hour, involving at least at the beginning all participants while specialists on the topic were usually remaining until the end. These discussions have triggered then in the next days various interactions among participants. On Wednesday 8th of June, the afternoon discussion has been replaced by a mini-workshop on 'Dark Matter: beyond the WIMP paradigm' chaired by Rouzbeh Allahverdi who initially proposed the mini-workshop (from this point of view participant have been also encouraged to be involved in the organization to some level). Four external speakers covered quite a broad and timely variety of DM scenarios that have been intensively investigated during the last years: keV sterile neutrino DM (Marco Drewes), a gravitational origin of DM (Angnis Schmidt-May), decaying DM detectable at IceCube (Stefano Morisi) and composite DM (Masaki Asano).

It is impossible in this summary to report on all topics and issues that have been discussed. However, the main ones are highlighted:

On Inflation it has been clearly stated in many talks and in the discussions that current constraints set by the Planck collaborations in the plane $r - n\_S$ and that seem to exclude simple and important models, such as those with convex potential $\lambda\varphi$^n with $n \geq 1$, should be regarded as quite simplistic, since many different effects can strongly relax these constraints (for example radiative corrections, or for example as stressed in the talk by Mar Baster- Gil by quite reasonable dissipative effects). Other talks have interesting highlighted the important role of the interplay of more fields for realistic models (e.g. talk by S.

Antusch) and the potential role played by the Higgs itself (e.g. talk by C. Tamarit on Higgs portal coupling).

On Baryogenesis most of the talks have focused on low energy scale models testable in different ways with colliders, including low scale leptogenesis. In this case, it is clear that we have entered with the LHC a particularly exciting era where we can test many of these models and for instance the 750 GeV anomalous di-photon excess might play some role (a nice example model presented by Hooman Davoudiasl in his talk). At the end of this stage one might either single out a particular model or otherwise in the absence of any new physics at the TeV scale then high energy models, first of all traditional thermal leptogenesis, will likely be favored.

In DM a rich variety of models has been discussed. Many talks discussed the opportunities of having a Warm DM such as a sterile neutrino and how this could help understanding some apparent glitches in the standard Cold DM scenario for Large Scale Structure (e.g. the 'too big to fail problem' as nicely discussed by Kev Abazajian) or the detected 3.5 KeV line in the X-ray spectrum. In the talk by L. Covi it was also discussed a possible testable WIMP SUSY model also able to explain the Baryon asymmetry (an asymmetric DM model). Other models that might emerge beyond the WIMP paradigm are for example a decaying DM testable with high energy neutrinos at IceCube (talk by S. Morisi in the mini-workshop). Extensions of GR also might lead to alternative models of DM (see talk by Angnis Schmidt-May).

Many talks also discussed the importance of the new opportunity offered by the discovery of Gravitational Waves to test different models of Inflation or Phase Transitions (talks by Urjit Yajnik, Kousish Dutta, Guillermo Ballesteros).

Flavour and Electroweak Symmetry Breaking

Organized by Giulia Ricciardi (Univ. Naples), Tobias Hurth, Matthias Neubert (JGU Mainz)

June 13-24, 2016, Anacapri (Island of Capri), Italy

The hierarchy problem and the origin of flavor are two major unsolved mysteries of fundamental physics connected to deep questions such as the origin of mass, the stability of the electroweak scale, the matter-antimatter asymmetry, the origin of fermion generations, and the reason for the hierarchies observed in the fermion sector. One cannot say to really understand the SM until we understand these puzzles (both rooted in Higgs Yukawa interactions). Higgs and flavor physics provide unique opportunities to probe the structure of electroweak interactions at the quantum level, thereby offering sensitive probes of physics beyond the SM. Flavor and Higgs physics are foremost in the assessment of results within the Standard Model and search for physics beyond. Analyzing their interplay is fundamental in order to formulate a coherent framework in our ambitious quest for the ultimate laws of physics. The goal of the Institute has been to interpret the results coming from a wide range of experiments, in particular LHC and new B factories, and to formulate a coherent framework to account for them.

One of the main topics was the tentative hint of a 750 GeV di-photon resonance seen by both ATLAS and CMS in the first 13 TeV LHC data. Martin Bauer gave an introduction, discussing the physics implications of the excess in the di-photon channel and the absence of events for any other final state at this mass scale in both the 8 TeV and 13 TeV data set, in an effective field theory (EFT) framework. Based on this EFT analysis, gluon fusion was identified as the preferred production channel, with a b bar b initial state emerging as more tuned option. Other production mechanisms, in particular photon fusion was found to be in strong tension with the zero results from 8 TeV data. The talk then focused on weaknesses and strengths of the most obvious UV completions, and it was established, that both the decay loop and the production loop (in the case of gluon fusion) require new, heavy physics in order to be in agreement with data. In particular, large couplings to the top quark can explain the gluon fusion production cross section, but tree-level decays into top pairs would rule out the observed (loop-suppressed) signal in the di-photon channel. This fact calls for a more complex New Physics sector, including new particles mediating production and decay of the new resonance. It was further pointed out, that the large excess disfavors supersymmetric models, due to the relatively small scalar loop function expected from quark superpartners, compared to new fermionic quark partners, which lead to an eight times larger contribution to the gluon-fusion loop for the same couplings and masses. Bhaskar Dutta discussed possible ways to distinguish the production process of a possible resonance from associated production with jets in the final state. In particular, the different N_j distributions and shapes of the leading jet p_T for $gg, \gamma\gamma$ and WW induced production was stressed. Jonathan Rosner presented a specific embedding in a well-motivated UV theory based on a grand unified group E_6. In this model, the tentative resonance would be part of the 27-plet, that also includes the SM Higgs boson and vector-like fermions appear naturally from the mullets including the SM quarks and leptons.

Another focus of the scientific program has been the various tensions with the SM predictions in the present flavor physics data on $b \rightarrow s$ transitions, the so-called flavor anomalies. Nazila Mahmoudi discussed the tensions in the angular observables of the exclusive decay of B meson into a kaon and a lepton pair. She presented the details of a global fits to the present data and showed that the significance of the deviation from the SM prediction does heavily depend on the assumptions on power corrections in the various analyses. She presented strategies and a number of observables to clear up the source of these anomalies. Roman Zwicky presented details of the calculation of the form factors within the light-cone sum rule approach which enter the analysis of the LHCb anomalies. In particular, he derived correlations in this framework which correspond to the well-known form factor relations in the large energy limit. Finally, Svjetlana Fajfer discussed signs in the data for lepton non-universality and in several ratios of $B \to K$ or $B \to D$ meson decays and reviewed the theoretical SM predictions.

Dark matter has been approached by Felix Yu, Michael Baker and Oleg Lebedev. Felix Yu presented a general classification of simplified models that lead to dark matter co-annihilation processes of the form DM + X → SM1 + SM2, where X is a co-annihilation partner for the DM particle and SM1, SM2 are Standard Model fields. Michael Baker proposed a new alternative to the Weakly Interacting Massive Particle (WIMP) paradigm for dark matter. Rather than being determined by thermal freeze-out, the dark matter abundance in this scenario is set by dark matter decay, which is allowed for a limited amount of time just before the electroweak phase transition. Oleg Lebedev considered the possibility that the dark SU(N) sector couples to the visible sector through the Higgs portal.

Finally, Mikhail Shifman discussed dynamically emergent flavor in a confining theory with unbroken chiral symmetry and Ayan Paul presented the new HEPfit code for the combination of indirect and direct constraints on High Energy Physics Models.

Understanding the First Results from the LHC Run II

Organized by Tilman Plehn (Heidelberg Univ.), Graham Kribs (Univ. Oregon), Shufang Su (Univ. Arizona), Tim Tait (UC Irvine)

June 27 – July 22, 2016, JGU Campus Mainz

After the discovery of a Standard-Model-like Higgs boson the MITP workshop focused on three major aspects of new physics searches at the LHC and other experiments: (i) searches for new physics in the Higgs sector, (ii) new strategies to search for dark matter candidates, and (iii) ideas and tools to improve generic new physics searches at the LHC.

Due to the phenomenological nature of the workshop, the theme in all of these search directions was to confront new ideas on the model side, new analysis ideas, and new experimental ideas beyond the LHC with the most recent analysis tools and measurements. This bridge between pure theoretical physics and experimental results defined not only all talks, but also the typical discussions.

Experimentally, the most prominent anomaly observed by ATLAS and CMS was the di-photon mass peak around 750 GeV. While this was discussed in one of our weekly "Discussion Sessions", the persistent rumors suggested the anomaly would not survive after new data was presented at ICHEP (August 3-10). For the scientific program this meant that this anomaly played a role, but did not dominate the talks and discussions.

The workshop schedule followed the general aim to invite excellent young scientists at the postdoc stage from all over the world (North and South America, Asia, and all of Europe). There were two 30 minute talks with plenty of time for discussion every Monday, Tuesday, Thursday, and Friday; all talks were given by junior participants without a permanent position. Most Wednesdays one or two more experienced participants were invited to trigger and lead a discussion on a current topic of their choice. For the presentations the audience was asked not to bring their laptops. This worked very well and had a hugely positive effect on fostering discussions during and after the talks.

Given the mix of participants varying week to week, a physics focus for each workshop week was not defined, but instead responded to the interest of the participants. The topics featured by our talks include the 750 GeV anomaly and possible interpretations, links to dark matter or other anomalies; Higgs portal models and links between dark matter, baryogenesis, and LHC physics; simplified dark matter models, to expand our interpretation towards lighter new particles; effective Lagrangians of the Higgs-gauge and top sectors, to interface theory and experiment; effective Lagrangians of dark matter, for example to link direct detection and LHC searches; subjet-based searches and multi-jet searches at the LHC; new ideas to identify kinematic features of new physics; higher-order QCD effects on new physics signatures; new experiments to detect axion-like dark matter; new ways to detect light new particles or dark photons; physics at a future Higgs factory; physics at a future 100 TeV hadron collider.

A few general questions structured this wide range of topics and accompanied the participants through the four workshop weeks. First, in the presence of experimental anomalies as well as dealing with experimental constraints it is crucial that one keeps in mind what physics questions one expects the LHC and other experiments to answer. Such fundamental questions are one way to organize the vast landscape for example of LHC searches.
Second, from the current LHC results it is clear that direct searches for highly visible signatures of new physics are not a promising approach to new physics effects at the LHC. Instead, one needs to develop a framework to perform and interpret precision studies searching for direct and indirect effects of new physics, and to put the result into a theoretical context. During the scientific program it became clear that effective Lagrangians describing the Higgs-gauge sector, the top sector, as well as dark matter require a unified approach. Moreover, these effective Lagrangians benefit from a well-defined link to established new physics models.
Third, in particular related to QCD effects, precision predictions, and improved understanding of backgrounds one has to develop powerful new tools for LHC searches in particular including multi-jet signatures.
Finally, there exists a large number of proposed new experiments covering a wide range of particle masses, energies, and cost. Especially searches for dark matter suffer from the fact that one knows very little about the underlying mass scales and interaction structures. A successful global search program has to coherently combine many experimental ideas as well as theoretical frameworks. The usual link between direct, indirect, and collider searches for WIMPs is only one of many such aspects.

Because of the great set-up of the center, the organized discussions very often continued as informal discussions over coffee. Aside from general and targeted discussions, a wide range of papers on many of these topics got started, worked on, and published as part of the scientific program. Many of the international young and high-profile visitors expressed an interest to come back to the area, so one has good reasons to expect long-term collaborations and projects triggered by the MITP program.

Effective Field Theories as Discovery Tools

Organized by Wolfgang Altmannshofer (U. of Cincinnati), Yang Bai (Univ. Wisconsin Madison), Monika Blanke (CERN, KIT), Felix Yu (JGU Mainz), Jose Zurita (KIT)

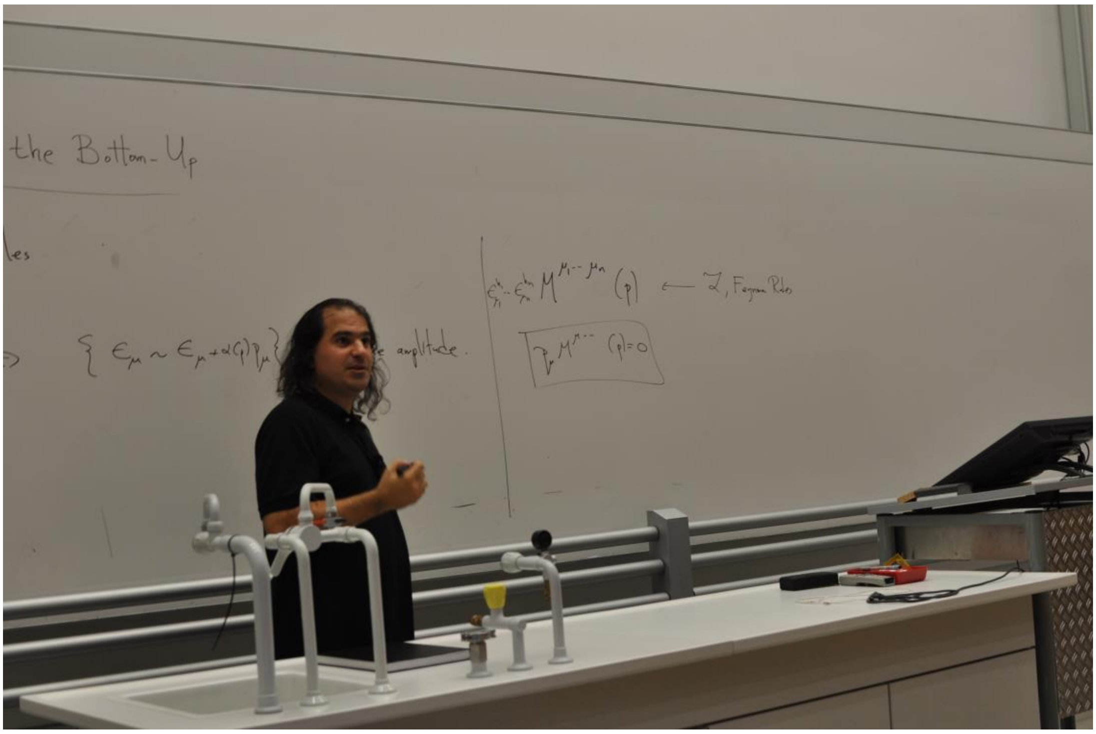
August 22 – September 9, 2016, JGU Campus Mainz

The goal of the three-week program was to lay out and discuss the new physics discovery potential of Run II of the LHC from the effective field theory (EFT) approach. The participants had a strong background on the use of EFTs in the context of flavor, Higgs and/or dark matter physics. The exchange between these various fields was one of the fundamental scopes of the program.

During the three-week program, there was a total of 26 presentations, which were scheduled to be 45 min each. They usually took place in the mornings, leaving the afternoons free for discussions and collaborations among participants. On Thursdays, instead of presentations, discussion sessions were scheduled on the topics of flavor physics, Higgs physics and dark matter physics, respectively.

Most of the current theoretical efforts in flavor physics are driven by the various anomalies observed recently in the flavor sector. These are on the one hand the deviations from standard model predictions observed by the LHCb experiment and the B factories in the semi-leptonic B meson decays $B \to K^{(*)} l\, l$ and $B \to D^{(*)} \tau \overline{\tau}$, but on the other hand also the indications by recent lattice QCD results for tensions in the CP-violating observable ϵ'/ϵin neutral $B_{s,d}$meson mixing. The discussion session during the first week of the workshop provided an overview over the current experimental and theoretical status. The description of all these observables is conveniently done in the EFT picture, collecting both the SM electroweak effects and possible beyond the SM (BSM) contributions in higher-operators. We also had a number of presentations related to flavor physics. Siavash Neshatpour presented the status of $b \to s$ anomalies, and David Straub discussed possible new physics in radiative B decays and gave a brief introduction to the software package “Flavio”. Danny van Dyk in his presentation revisited the known $B \to D^{(*)}$ form factor calculations with the aim to re-assess the underlying uncertainties. Admir Greljo presented recent work, in which he connected the various BSM explanations of the $R(D*)$ anomalies to observable deviations in high-p_T $\tau^+\tau^-$data at the LHC. Concerning BSM flavor model building, Sho Iwamoto presented a supersymmetric model, in which gauge mediation is introduced in a flavor violating manner.

EFTs are also ubiquitous in dark matter phenomenology. For searches at colliders, one has to be aware of the EFT limitations when considering particles recoiling with transverse momenta of the order of the dark matter mass (which led to the use of simplified models). Several presentations scattered throughout the three weeks tackled on many of these aspects. Anibal Medina discussed the validity of using EFT for co-annihilating dark matter in collider searches. Matthew Dolan presented a new algorithm to maximize the sensitivity of jets plus missing 1 energy searches at the LHC. Swasti Belwal discussed the interplay between simplified models and EFT at colliders for WIMP dark matter, while Oleg Antipin and Mikael Chala analyzed the dark matter phenomenology of models with new strong interactions (Composite Higgs and hypercolor). Christian Gross discussed the collider phenomenology of multi-component dark matter, which arises naturally when considering additional (non-SM) gauge interactions. For direct detection experiments, where the dark matter particle recoils with keV energies the application of the EFT is well understood, but yet the traditional approach is to consider only vector and axial currents. In the discussion session led by James Dent and Will Shepherd, it was indeed discussed that those two operators might be insufficient and additional operators are needed. They also discussed the status of indirect searches, and gave an overview of the experimental prospects for the next generation of experiments, and reviewed the current hints for dark matter.



The use of EFTs in Higgs Physics has become of utmost importance in order to parameterize deviations from the SM Higgs case, where all couplings are known. Oscar Cata discussed in detail the case of linearly versus non-linearly realized EFTs in the Higgs sector, while Shao-Feng Ge showed the expected accuracy to extract these couplings at lepton colliders. Due to the large value of the top-Yukawa, considering effective operators in the top sector is also important. The status of top EFTs was reviewed by Durieux Gauthier in his presentation. The current efforts to automatize the inclusion of NLO QCD corrections in MC generators were presented by Cen Zhang for the case of top-anti-top resonances (including interference effects) and by Hai Tao Li on SCET resummation of top pair production. Christian Schwinn presented a generic framework to properly include these NLO QCD effects in the whole SM+EFT Lagrangian, while Minho Son reviewed a recent result that states the "non-interference" between QCD and dimension-6 operators corrections, which he applied to anomalous gauge couplings at the LHC. The discussion on Higgs Physics was led by Benjamin Fuks and Markus Schulze, who summarized the latest results in Higgs physics presented at ICHEP and the content of the new Higgs Yellow Report 4, paying special attention to the prospects of measuring multi-Higgs interactions at the LHC and at the FCC, which are crucial for the stability of the vacuum of our Universe.

In addition to the presentations reviewed above, additional topics related to physics beyond the Standard Model were also discussed in a number of talks, displaying the enthusiasm for the prospect that the LHC will discover new physics. Last but not least, the *leit-motiv* of the program, namely the question of the role of EFTs in a pre-discovery vs. post-discovery era, was revisited many times during coffee breaks and in presentations. One particularly interesting discussion revolved around the validity of truncation methods for generating Monte Carlo and the sensitivity to new physics from tails of kinematic distributions in an EFT context.

The three week programme provided the basis for the exchange of knowledge and very fruitful discussions among the participants. The timing of the workshop, at the early stages of Run II at the LHC, has been extremely appropriate. The format of the workshop has been chosen to maximally encourage and facilitate interactions among participants, to foster discussion by raising topics during in-depth technical presentations followed by ample time for public and private debates. Discussions over lunch and coffee on site and dinner in town followed in smaller groups. The atmosphere has been very informal throughout the workshop, something that has played a role in making the younger researchers immediately comfortable and triggered discussions right away. The scientific program was successful, inspiring, and timely, and one expects that future scientific collaborations and results initiated at the scientific program are forthcoming.

4 Topical Workshops

Challenges in Semileptonic B decays

Organized by Paolo Gambino (Univ. Turin), Andreas Kronfeld (Fermilab), Marcello Rotondo (INFN Padua), Christoph Schwanda (ÖAW Vienna), Sascha Turczyk (JGU Mainz)

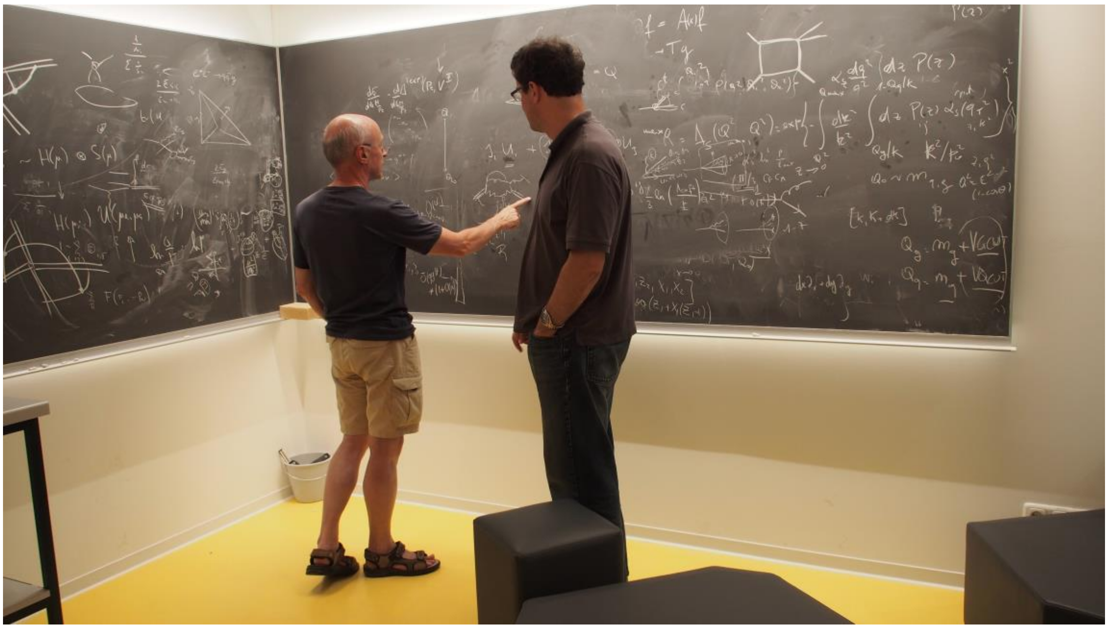
April 20-24, 2015, JGU Campus Mainz

Two of the elements of the Cabibbo-Kobayasha-Maskawa (CKM) quark mixing matrix, Vub and Vcb, are extracted from semi-leptonic B decays. The results of the B factories, analysed in the light of the most recent theoretical calculations, are puzzling. For both $|Vcb|$ and $|Vub|$ the exclusive determination is about 3σ below the inclusive one. This discrepancy has survived several independent checks and could be an indication for New Physics.

Thirty-three participants met in Mainz to develop a medium-term strategy of analyses and calculations aimed at the resolution of the puzzle. 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 in both exclusive and inclusive B decays.

The program took place during a period of five days, allowing for ample discussion time among the participants. Each of the five workshop days has been devoted to a specific topic: the inclusive and exclusive determinations of the two CKM matrix elements, and on the last day the semi-leptonic B decays with heavy leptons in the final state. In the mornings we had overview talks from experimental and theoretical sides, reviewing the main aspects and summarizing the state of the art. In the late afternoon we organized discussion sessions led by experts of the various topics, addressing questions that have been brought up before or during the morning talks.

The inclusive determination of $|Vcb|$ is based on an operator product expansion, and better control on 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 calculation of the total width to the third power of the strong coupling constant may be within reach with recently developed techniques.



From experimental point of view, new and accurate measurements of the third hadronic moment would have an impact on the fit, which may also benefit from the measurement of the forward-backward asymmetry as proposed by Turzcyk. 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 c-quark mass. Further progress on the b-quark mass and the ratio mc/mb is expected, LHCb can in principle provide additional measurements with vanishing cut on the charged lepton energy.

For the exclusive determination of $|Vcb|$ several incremental and qualitative improvements in lattice QCD were discussed. Of the latter, the most notable is to carry out a combined fit of the recoil dependence calculated in lattice QCD together with the measurements. This approach sidesteps an extrapolation of the experimental data to zero recoil, using a parametrization that may have outlived its utility. Two results for $B \rightarrow Dlv$, from the the Fermilab Lattice and MILC collaborations just before the workshop, and from the HPQCD collaboration since, show less tension with inclusive $|Vcb|$. A tantalizing pre-preliminary analysis of unblessed Belle data suggests even less tension. This approach is also possible with $B \rightarrow D^{*}lv$, and the discussions in Mainz emphasized the urgency to perform this analysis. one addressed the fact that the QCD errors are now almost as small as 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 and their sensitivity to the meson wave functions.

The inclusive determination of $|Vub|$ is based on various well-founded theoretical methods which agree nicely. Still, the 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 NNVub methods seem to have the potential to fully exploit the $B \to X_u l\nu$ (and possibly radiative) measurements through combined fits to the shape function(s) and $|Vub|$. The separation of $B_{\pm}$ and B_0 in the experimental analyses will certainly help constraining weak annihilation, but the real added value of Belle-II could be the ability to accurately measure spectra (M_X,q^2, E_l, ...). 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 (inclusive + exclusive) Monte Carlos are badly needed; $s - \bar{s}$ popping should be investigated (how can K-veto be lifted?) The $b \to c$ background will be measured better, which will benefit these analyses.

The exclusive determination of $|Vub|$ relies on non-perturbative calculations of the form factor of $B \to \pi l\nu$ which, up to now, is the most precise channel. There were discussions about the status of the LCSR calculations and several recent improvements in lattice QCD. In particular, two recent lattice calculations by the Fermilab/MILC and the RBC/UKQCD collaborations, released just before the workshop, increase the central value by more than 1σ, when they are combined with the existing measurements of the $B \to \pi l\nu$ differential rate as a function of q^2. The Fermilab/MILC calculation alone leads to a remarkably small total error on $|Vub|$, of about 4%. While at present the most precise extraction of $|Vub|$ comes From $B \to \pi l\nu$, it has been clearly stated that in the future the golden channel will be $B_s \to Kl\nu$ because here the lattice calculations are affected by smaller uncertainties. $B_s \to Kl\nu$ will be accessibile at Belle-II in the run at the $\Upsilon(5S)$ and at the LHCb exploiting the huge amount of B_s already collected in the Run1. The great potential of LHCb has been demonstrated by the unexpected measurement of the partial rate 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 recent lattice determination of the relative form factors, has led to the first measurement of $|Vub/Vcb|$ from baryonic b-decays with a relative uncertainty of only 7%. The result is compatible with the exclusive determination and only marginally compatible with the inclusive one. The baryonic charmless decay is also very interesting because the decay rate is also sensitive to possibile right-handed currents in the $b \to u$ transition. The LHCb result, combined with the constraints from $B \to \pi l\nu$ and the inclusive $B \to X_u l\nu$ does not favor contributions from RH currents. Also other channels sensitive to right-handed currents, in particular $B \to \rho l\nu$ and the analogous B_s decay, $B_s \to K^*$ lν were discussed.

Tension with the Standard Model remains in semi-tauonic decays. BaBar's measurements of the branching ratios for $B \to Dl\nu$ and $B \to D^{*}l\nu$ exceed the SM prediction by 2.0σ and 2.7σ, respectively, or 3.4σ combined. Belle and LHCb analyses are underway and eagerly awaited. The nonzero-recoil form factors from lattice QCD, mentioned above, are useful here too. The measurement of $B \to \tau\, \nu$ is not yet competitive with semi-leptonic decays for measuring $|Vub|$, because of a 20% error. Belle-II will improve this. The corresponding lattice-QCD calculation is more precise, with an error of only 5%. 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 $|Vub|$ (e.g., the right-handed currents mentioned above).

Higgs Pair Production at Colliders

Organized by Daniel de Florian (Univ. Buenos Aires), Christophe Grojean (IFAE Barcelona), Fabio Maltoni (Univ. Louvain), Aleandro Nisati (INFN Rome), José Zurita (JGU Mainz)

April 27–30, 2015, JGU Campus Mainz

An extremely successful campaign of measurements at LHC-Run I has allowed to confirm that the couplings of the Higgs particle with the heaviest quarks, leptons and bosons do agree (within ~10%) with the SM predictions and are consistent with previous indirect precision measurements. Only one of such (large) couplings remains totally unconstrained from all currently available data (from the LHC and LEP), i.e. the strength of the Higgs self-interactions. This also means that the form of the Higgs potential is presently experimentally undetermined. A key, yet very challenging process to gather direct information on this coupling is double Higgs production. The goal of the workshop was to gather theorists (from the QCD, BSM and Monte Carlo communities) and LHC experimentalists together to discuss the status and the prospects of observing, studying and then extracting information from HH production. The workshop has been planned in collaboration with the LHC Higgs Cross Section Working Group (LHCHXSWG) and in the context of the corresponding HH activities of the corresponding subgroup. Even though the main focus was towards Run II, also mid- as well as long-term options (HL-LHC and future colliders) were to be addressed.

The format of the workshop has been chosen to maximally enhance interactions among participants, to foster discussion by raising topics during in-depth technical presentations followed by ample time public and private debates.

Discussions over lunch at the Campus and dinner in town followed in smaller groups. The atmosphere has been very informal from the start (also thanks to the keynote speakers of the first morning), something that has played a role in making the younger researchers immediately comfortable and triggered discussions right away.

The program has run over 7 half-day sessions, each featuring one or two review presentations (14 in total) and a session lead by previously appointed chairpersons (5 in total). Instructions to speakers included our motto "Rather than stressing previous work we should discuss the ideas that would lead to everyone's next paper". The charge of the discussion leaders was to identify the most important points to be addressed in the list of "HH questions" (see below) and to provide a synthesis at the end.

Participants have been chosen only based on their proven expertise on the field, keeping an eye on assuring balance among various aspects. A total number of 32 physicists joined, of which 22/10 theorists/experimentalists, 27/5 Europe/Out-of-Europe origin, 24/8 men/women, 18/14 young/senior physicists.

Before the start of the workshop a list of key questions was sent to all participants. While certainly not attempting here to provide a detailed summary of the discussions and results, one can state that all of them were addressed and some of them indeed generated a lot of discussions among the participants. In the following the questions, followed by a few comments are listed:

1) How large can the $h(125)$ self-coupling and the HH cross section be in concrete models? Can other $HHXX$ couplings be accessed (i.e.: $ttHH, VVHH$)? This has been somewhat considered the mother of all TH questions, being intimately related to importance of having experimental analyses running even when their sensitiveness is only to way cross sections way larger than those predicted by the SM. Florian Goertz and Christophe Grojean stimulated an enlightening discussion on this topic on Tue afternoon.

2) How do HH searches complement with H couplings measurements from boosted H + jet and off-shell H? How does HH production help to constrain the sign of the top Yukawa coupling? These questions were raised and discussed on Tuesday morning and afternoons.

3) How fast do New Physics contributions to HH production (i.e.: top partners) decouple? Ramona Groeber and Christoph Englert discussed these aspects in their talks.

4) What is the foreseeable future of radiative corrections and MC generators for $gg \to HH$? This question lead to a very lively set of presentations and discussions on Wed. The most important mid-term target is the computation of the double-box virtual contributions for $gg \to HH$, with the exact mass dependence. Efforts in estimating such effects have been presented by Eleni Vryonidou, Jonathan Grigo and the first step toward an exact computation by Gudrun Heinrich. The status of the current recommendations and future prospects has been addressed in the ensuing discussion lead by Sally Dawson.

5) Which is the major bottleneck for EXP analysis with $t\,\bar{t}$ as a background ($bbWW$, $bb\tau\tau$)?

6) Are SM + resonant searches comprehensive enough? These aspects have been discussed on Monday afternoon and Wednesday morning triggered by the talks by Nick Styles, Souvik Das and Maxime Gouzevitch, in conjunction with the forthcoming results by ATLAS and CMS on Run I data. In this context, it has been extremely useful to be able to discuss the analyses in detail, allowing a direct exchange of information/requests from experiment to theory and viceversa.

7) What is the status of other productions modes ($VBF, VHH, ttHH$) HL-LHC and the corresponding accuracy in MC generators and EW/QCD corrections? The status of the MC's was reviewed by Marco Zaro, who showed that NLO

(QCD)+PS accuracy has been reached in all production channels (with the exception of the above mentioned limitation in $gg \rightarrow HH$).

8) Are there any new channels available at HL-LHC?

9) Do HH searches benefit from larger energy or from larger luminosity?

10) Which are the prospects for the next generation of colliders (ILC, FCC- hh,...)? The above questions have been addressed in several sessions and especially in on Thu morning in the talks by Roberto Contino and Andreas Papaefstathiou and in the following discussion lead by Aleandro Nisati. In this discussion, the participation of both experimentalists and theorists was essential to clearly identify the desiderata from each community.

The timing of the workshop, between Run I and Run II at the LHC, has been extremely appropriate. The short, yet very focused, program has allowed to bring together a large fraction of the HH experts in the world, both theorists and experimentalists, young and senior scientists, from Europe and abroad. The program was extremely successful in trigger people with very different strengths and expertise to discuss and collaborate on the challenges connected to the determination of the origin and form of the scalar sector. Many of the most pressing and sometimes controversial questions were addressed, giving the possibility of debating freely from the usual (negative) constrains (time, closed experimental collaborations, presence of non-specialized audience). A very positive and constructive atmosphere has characterized all the meetings.

One of the main outcomes of the workshop has been to provide further motivation to all physicists interested in this challenging endeavor. Concrete actions/projects for improving QCD predictions, extending HH searches in various channels, further extend EFT and BSM predictions, and widen/deepen the experimental strategies and analyses in the current and future colliders have been clearly indicated. One will collect the fruits of the work in the coming months/years.

The Ultra-Light Frontier

Organized by Surjeet Rajendran (Stanford), Dmitry Budker (JGU Mainz)

June 15-19, 2015, JGU Campus Mainz

The Workshop started on Monday with an overview talk on axions and ALPs by Georg Raffelt (Munich), who described how these particles arise in the context of the early universe, and what we can learn about them from astrophysics.

Following the general trend of the Workshop of mixing theoretical and experimental talks, this was followed by an overview of the cosmic axion spin precession experiment (CASPEr) currently being setup at Mainz (to search for the "axion-wind" effects) and Boston University (to search for the axion coupling to gluons via induced electric dipole moment EDM, of the nucleus). CASPEr is searching for axions, axion-like particles (ALPs), and other ultralight bosons whose fields are predicted to oscillate at a frequency corresponding to their mass. The workshop was designed to leave ample space for interactions among the (about 35) participants, and so there were only two additional talks on the first day: and overview by Yannis Semertzidis of the experimental activities on EDM and axion searches in Korea, and an overview of the progress of the ADMX-HF (the high-frequency version of the axion-dark-matter-search experiment) given by Maria Simanovskaia.

On Tuesday morning, there were two theory talks with two experimental talks sandwiched between them. In the first talk, Surjeet Rajendran (Berkeley) explained the remarkable and "brand-new" ideas of how axions, rather unexpectedly, may provide a solution to the hierarchy problem of particle physics (in addition to possibly solving most if not all other outstanding problems of cosmology and the standard model). The talk of Joseph Pradler (Vienna) tackled the theoretical aspects axions of lowest masses. The experimental talk by Michael Romalis described testing Lorentz Invariance, CPT, and the equivalence principle with an atomic-physics experiment conducted at the South Pole, while the talk by John Blanchard (Mainz) dealt with the nuclear magnetic-resonance aspects of the CASPEr experiment. Tuesday afternoon was marked by the public event of the Workshop, a Physics colloquium given by Victor Flambaum (Sydney).

The third day of the Workshop (Wednesday) began with an overview of dark matter possibilities by Maxim Pospelov (UBC and Perimeter) over 80 orders of magnitude (!) of energy scales. This was followed by experimental talks by Szymon Pustelny (Krakow) who described the global network of optical magnetometers (GNOME) searching for the correlated transients that would signify the Earth's crossing the "walls" of cosmic, non-oscillating ALP domains and a talk by Lutz Trahms (PTB, Berlin) who described low-frequency co-magnetometry experiments that are prototypical for the CASPEr-Now experiments seeking to reanalyze existing experimental data and to "re-tool" currently running experiments to search for oscillating axion and ALP fields of lowest frequencies. The afternoon and evening of Wednesday were devoted to the conference excursion to a famous Kupferberg wine cellars in Mainz (a.k.a. the "underground" physics session) and the conference dinner.

Thursday morning began with a theoretical overview by Andreas Ringwald (DESI) in possible hints for axions and ALPs, followed by an experimental talk by Nathan Leefer (Mainz) on the results of a search for dark-matter dilatons with atomic dysprosium, which is the first “atomic-clock” search for ultralight dark matter, with a promise of significant additional developments in the future. The morning session concluded with a talk by Harald Merkel (Mainz) describing the searches for dark photons and the Mainz accelerators, MAMI and MESA. In the afternoon, Ben Roberts (Sydney) described theoretical ideas for looking for various cosmic fields with atoms and molecules, followed by experimental talks by Samer Afach (Mainz) describing the recent experiment at the Paul Scherer Institute (PSI) to search for axion-mediated interactions with ultracold neutrons (UCN) and a talk by Grey Rybka (Seattle) on the status of the ADMX experiment.

The last day of the meeting started with the talk of Javier Redondo (Zaragoza) who reviewed various approaches to searching for meV and lighter axions and motivating the proposed International axion observatory (IAXO), followed by talks by Oleg Sushkov (Sydney) who gave a tutorial on EDM searches with ferroelectric solids, and a talk by Andrey Derevianko (Reno) describing using the GPS timing network to search for topological dark matter. Clock networks use a similar approach to that of the magnetometer network (GNOME) but is sensitive to different “portals” for the dark-matter interactions. The final afternoon sessions were devoted to topics at the interface between the main focus of the Workshop and the broader areas of physics. In a joint event with the Mainz Magnetic Resonance Seminar, Alexander Sushkov (Harvard) described the recent spectacular experiments on detecting single nuclear spins using nitrogen-vacancy (NV) centers in diamond. Victor Flambaum (Sydney) gave an inspiring and thought-provoking discussion of possible manifestations of dark matter in atomic and astrophysical phenomena such as, for instance, pulsar “glitches.” The Workshop concluded with a talk by Dmitry Budker (Mainz and Berkeley) introducing an idea of a novel kind of literally a quantum-mechanical (processing ferromagnetic needle) magnetometer that may open the way to explore the electron-spin couplings of ultralight dark-matter candidates.

The Workshop was highly appraised by the participants, and has resulted in new ideas and currently ongoing collaboration.

Quantum Vacuum and Gravitation

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

June 22-26, 2015, JGU Campus Mainz

The workshop was especially focused on the field-theoretical methods like the functional renormalization group and conformal anomalies. The issues related to the implications in Astrophysics and Cosmology were also included, with special focus on Cosmology, Black Hole physics and the study of Analogue Models in Condensed Matter and Quantum Optics. In the cosmological part there were some review talks which included the latest experimental and observational data and their understanding in the framework of existing theoretical constructions. Due to the difficulties in experimental verification of the quantum phenomena such as Hawking radiation, one was interested and included an account of the analog models, which are supposed to mimic the same physical behavior and might serve as testing grounds for the interplay between quantum field theory and gravity.

The talks were always given at the very high scientific level and attracted a lot of attention of the participants and also from the side of local group of theoretical physics, which is well-known by research works in the areas of the workshop. All the talks had some students attending them. The program of the event was very dense, since organizers did not deny to any participants the right to present his/her work in the oral form. A few review talks had 60 minutes for presentation and most of them had 40 minutes. By the end of each day of the event there was a special discussion section, devoted to the talks of the day and related subjects. These discussions were very intensive and fruitful for better understanding of the problems which are in the focus of attention of the nowadays high-energy and gravitation al physics. The brief contents of the review talks were as follows: Christof Wetterich from Heidelberg University spoke about the general status and role of the quantum vacuum in cosmology. In particular, he addressed the following questions: What is the vacuum in cosmology? Does inflation allow us to observe vacuum properties? Can one compute the vacuum for Gravity? How well justified are "natural guesses " for the value of the cosmological constant? What is the role of scale symmetry and its spontaneous breaking? The quantum part of the talk was based on the functional renormalization group (Wetterich equation) which enables one, in principle, to evaluate the non-perturbative quantum effects for vacuum. This first talk attracted a lot of attention and there was a long and interesting discussion about its contents. William Unruh from University of British Columbia gave a review talk about the analog models for black holes in hydrodynamics and explained how the thermal spectrum can be observed in the acoustic waves, such that it can be interpreted as a version of the Hawking evaporation of black holes. Other examples and views of analog models were discussed in the talks by Ralf Schuetzhold from University Duisburg - Essen and by Alessandro Fabbri (Centro Studi e Ricerche Enrico Fermi).

Alexei Starobinsky gave a detailed review talk about present status of inflation, and perspectives of future discoveries. Present knowledge about physical properties of an inflationary stage in the early Universe, including curvature and its rate of change, inflaton mass, etc, which follows from the latest observational data. Different possibilities to make new fundamental discoveries were discussed. There are strong arguments to show that the measured value of the slope of the primordial spectrum of scalar (density) perturbations, under some natural additional assumptions, implies small, but not too small amount of quantum primordial gravitational waves generated during inflation, $r>0.001$, similar to that in the original $R+R^2$ inflationary model (1980). Thus, perspectives of their discovery seem promising. Features in the CMB temperature anisotropy power spectrum in the multipole range $l = 20 - 40$ are of interest in this respect, too, and may point to some new physics during inflation including the existence of new elementary particles more massive than the inflaton.

Ruth Durrer from Geneva University presented an interesting review on the Cosmic Microwave Background (CMB) and its relation for Quantum Physics. The development of CMB measurements, from the era of COBE to Planck, marks an impressive progress in the knowledge of the Universe. Hence it was very important for our theoretical meeting, to learn how the results of these enormous amount of data can be seen from the theoretical and especially quantum perspective.

Valeri Frolov from University of Alberta spoke about recent works about the singularity problem in the black holes with non-local and local form factors in the higher derivative terms. The singularities are traditionally considered to be the most important indications to the modifies gravity, which is supposed to erase singularity and hopefully provide some detectable consequences at the larger-distance scale. In the case of Newtonian singularities we know that, in general, higher derivatives and quantum corrections remove the singularity. However, in the non-linear case of black hole, the situation is much more subtle and interesting. Very interesting and promising theoretical results were obtained recently and were reviewed in this talk.

Martin Reuter from University of Mainz gave a general review of Functional Renormalization Group approach and, in particular, on the application to the asymptotic safety program in Quantum Gravity. Functional Renormalization Group enables one to go beyond the conventional perturbative approach and this is especially relevant for the quantization of gravity which meets well - known difficulties at the perturbative level. The works on the asymptotic safety in Quantum Gravity attracted a great deal of attention in the last decades and it was instructive for the participants to have a review on this issue from the main developer of this idea. Other talks on the same subject were delivered by Julien Serreau from University Paris Diderot and by Daniel Litim from Sussex University. The slides of all presentations are available at the MITP indico page of this event.

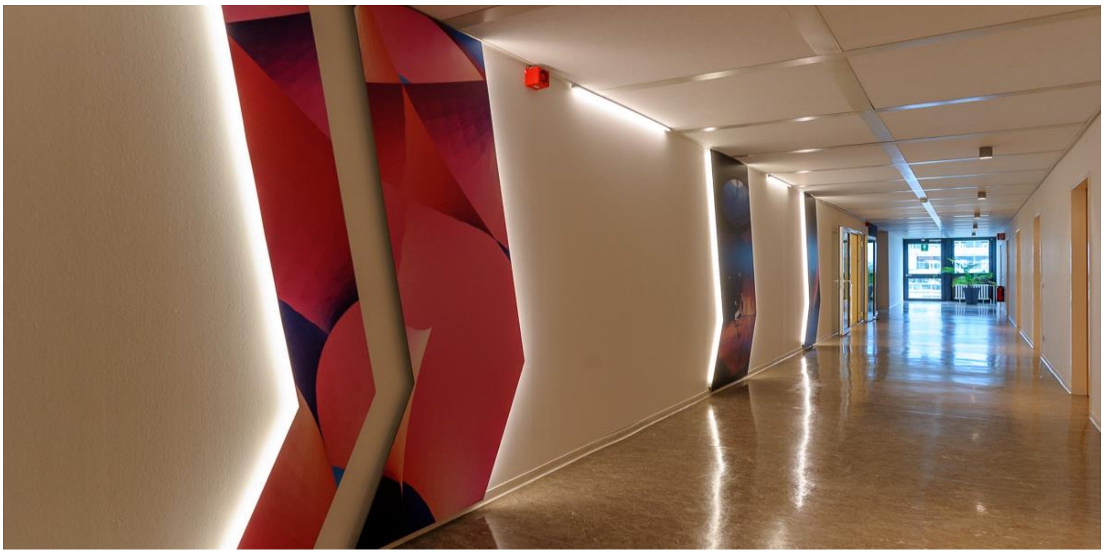
Determination of the Fundamental Parameters in QCD

Organized by Irinel Caprini (IFIN-HH, Bucharest), Konstantyn Chetyrkin (INR, Moscow), Cesareo Dominguez (Univ. Cape Town), Antonio Pich (Univ. Valencia), Hubert Spiesberger (JGU Mainz)

March 7-12, 2016, JGU Campus Mainz

This workshop was a follow-up to a previous workshop on the same topics that took place in Singapore in 2013, and had a similar attendance. The format was that of a true workshop, as opposed to a conference, in that afternoons were devoted entirely to discussions. The general atmosphere of the workshop was collegial, and the afternoon discussions proved to be extremely useful. The topics covered at the workshop were: determinations of the QCD strong coupling, determinations of QCD quark masses and vacuum condensates, non-perturbative QCD, and the muon $(g-2)$ anomaly . To describe it in more detail:

Determinations of the strong coupling covered the low energy region around the tau-lepton, where updated data from the ALEPH Collaboration sparked a fair number of re-analyses using QCD sum rules (QCDSR) and their moments. In this



approach the issue of quark-hadron duality violations (DV) plays a role, and various attempts at quantifying their impact in the uncertainty on the coupling were discussed. More about DV will be dealt separately below. Above the tau-lepton region, there was a talk on the determination of the strong coupling using deep-inelastic electron-proton scattering. This approach is rather involved, and cannot be easily followed by non-experts. Finally, the strong coupling determinations in the heavy-quark region were reviewed, and all related issues covered, e.g. attempts at improving perturbative convergence by using mathematical methods, e.g. Pade approximants. The current status of the experimental data also received considerable attention. One could conclude that while there is still some room for improvement, nothing major should be expected before the next order in the perturbative QCD expansion is calculated. This will not take place before the next five-ten years.

The next topic concerned the determination of the quark masses, with emphasis on the charm- and bottom-quarks. Lattice QCD (LQCD) results were presented, showing unprecedented accuracy, comparable to that now achieved analytically in the framework of QCD sum rules.

The issue of potential renormalon ambiguities affecting the gluon condensate, the dimension d=4 term in the Operator Product Expansion (OPE), was dealt with in one talk. This is a contentious issue, as it is not possible to make quantitative estimates in a model independent way. The summation of very high order bubble-diagrams is model-dependent. On the other hand, the gluon condensate entering the OPE, as used e.g. in QCDSR practical applications, should only be viewed as a parameter of the method, to be determined from the QCDSR themselves together with experimental data. Attempts at going beyond this approach fall outside this phenomenological approach.

The current status of the muon magnetic moment anomaly was reviewed, with emphasis on a new method allowing for a determination of $(g-2)$ without recourse to highly problematic electron-positron annihilation data. This method substitutes the contribution of these data by information on the first derivative of the electromagnetic correlator at the origin ($q^2 = 0$), in each of the three regions (up- , down- , strange-quark), (charm-quark), and (bottom-quark). In the case of the charm- and bottom-quark regions these derivatives can be computed fully from QCD, using the heavy quark expansion at $q^2 = 0$. The results obtained analytically in this method were recently fully confirmed by lattice QCD determinations. What remained was the derivative of the light quark electromagnetic correlator. Triggered by a LQCD talk by Hartmut Wittig, showing results for this correlator as a function of q^2, the importance of this information was highlighted. Two months later, Wittig provided this valuable information, thus, allowing for an entirely QCD determination of $(g - 2)$ of the muon, independent of the problematic electron-positron annihilation data. The result fully agrees with experiment, thus closing the window for "new physics" beyond the Standard Model, at least from this source.

The issue of potential quark-hadron duality violations lead to heated discussions between the proponents of such a scenario, and the sceptics. As pointed out long ago by Pich et al. , violations of quark-hadron duality are difficult to estimate because those effects are unknown by definition. The Barcelona-York-San Francisco group made their case showing strong DV in the region of the tau-lepton, while the Mainz-Cape Town group presented categorical evidence for these DV to be either absent, or blurred by experimental errors. In addition, the Valencia group showed rather clearly that the DV models of the Barcelona-York - San Francisco group were mere fits to the tau-data, thus, not valid beyond the kinematical end point of tau-decay (as maintained by that group). The jury is out on this issue.

Relativistic Hydrodynamics: Theory and Modern Applications

Organized by Francesco Becattini (Florence Univ.), Dmitri Kharzeev (Stony Brook Univ. & BNL), Dirk H. Rischke (Goethe Univ. Frankfurt) Dam Thanh Son (Univ. Chicago), Mikhail Stephanov (Univ. Illinois, Chicago)

October 10-14, 2016, JGU Campus Mainz

Interest in Relativistic Hydrodynamics (RH) has experienced explosive growth recently, motivated by new applications to relativistic heavy-ion collisions as well as by surprising and deep connections to advanced topics in theoretical physics such as anomalies and gauge-gravity duality. A lot of new theoretical work with novel experimental applications has been done recently, beyond one of the traditional applications of RH-relativistic astrophysics. In view of the recent rapid development of RH, the topical workshop reviewed and summarized achievements, addressed open issues, and showed promising directions for future research. The topical workshop brought together physicists working with RH in different contexts (from high-energy nuclear physics and astrophysics to mathematical physics), giving them time to share expertise and ideas, establishing a common language and kindling new collaborations.

The workshop gathered about 30 theoretical physicists from different communities with a common interest in relativistic hydrodynamics, both as a theoretical topic and for its applications to relativistic heavy-ion collisions and astrophysics. It was the main goal of the workshop to get together experts with a different background to discuss about recent advances in the field, share knowledge, and find new directions of common interest. The participants contributed very actively to the workshop, enjoyed the discussions, and all were very happy to have taken part in it.

A series of talks was devoted to new theoretical developments related to the derivation of hydrodynamics as an effective theory for the long-wavelength, low-frequency dynamics of a given system. These addressed formal classification of hydro-dynamical theories (Rangamani), model-independent derivation of magneto-hydrodynamics with polarization (Kovtun), as well as derivation of hydrodynamics from kinetic theory (Denicol, Jaiswal, Noronha), from a path-integral formulation (Hongo, Pinzani), and from a variational principle (Floerchinger). Aspects of hydrodynamics as an asymptotic series and its convergence were presented by Heller. Holographical theories and their hydrodynamical limit were discussed by Starinets. The choice of frame and its impact on the definition of temperature were topic of a talk by Becattini. The thermodynamic coefficients needed to describe relativistically rotating fluids were presented by Grossi. How to implement hydrodynamic noise in the hydrodynamic equations was demonstrated by Kapusta.

Hydrodynamics in systems with large anisotropies, so-called anisotropic hydrodynamics, is nowadays a hot candidate for describing the early-time dynamics of heavy-ion collisions. Theoretical aspects of deriving anisotropic hydrodynamics were presented by Florkowski, Rischke, Ryblewski, Strickland, and Tinti.

Widespread interest has been generated in the heavy-ion community by the observation that the anomalies of Quantum Chromodynamics, the fundamental theory of strongly interacting matter, can give rise to interesting collective effects (the chiral magnetic effect, chiral magnetic waves, etc.). The theory of so-called anomalous hydrodynamics and possible observable consequences in heavy-ion collisions were addressed by Hirono, Kharzeev, Mace, and Wang.

The most recent developments in applying hydrodynamics to the description of the collective dynamics of matter created in heavy-ion collisions were presented in talks by Heinz, Csernai, Niemi, and Schenke. Romatschke presented a critical appraisal of the conclusion that the system created in the relativistic nuclear collisions is a fluid, based on the success of hydrodynamics.

There was a very appreciated session about the application of relativistic hydrodynamics in astrophysics, with talks by Del Zanna and Rezzolla. An interesting new venue, adapting magneto-hydrodynamics as applied in astrophysical scenarios to heavy-ion collisions, was shown in the talk by Inghiram.

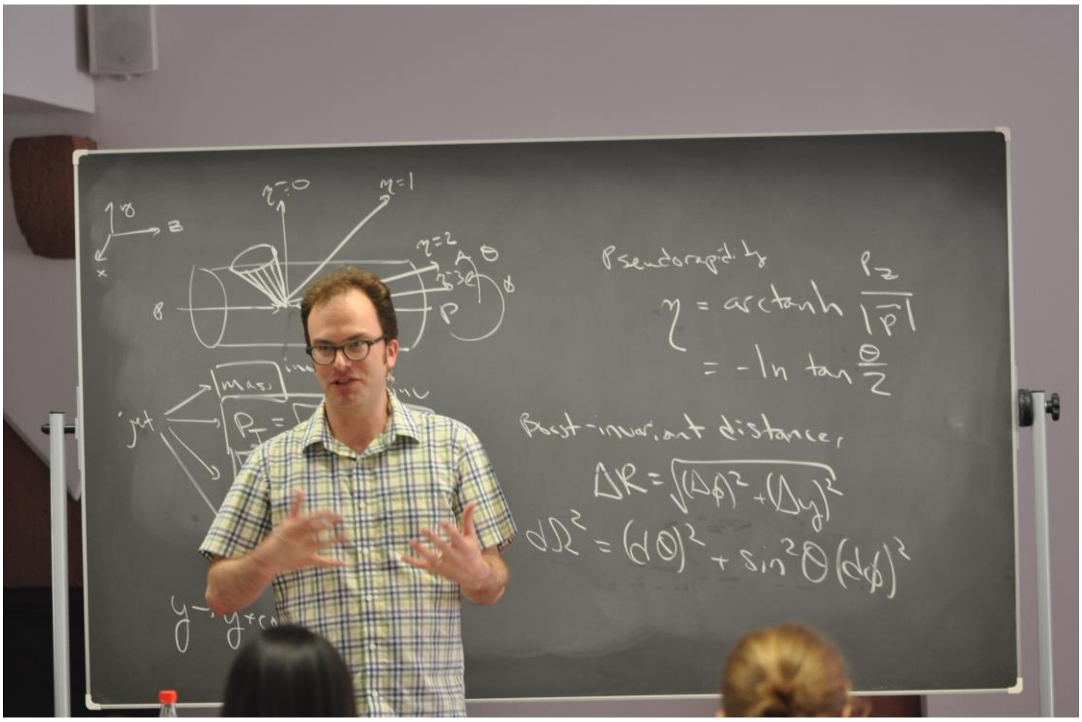
5 MITP Graduate School

MITP sets out to support young scientists. In particular, MITP contributes to the education of graduate students and postdoctoral researchers via topical summer schools. We have already the tradition of one-week summer schools for young physicists to be held every two years in Bavaria. In 2014 MITP organized an International Summer School on the Frauenchiemsee island together with the graduate school “Symmetry Breaking”. Another edition of this series of graduate schools took place in 2016.

Initiated by a group of postdocs from the theoretical high energy physics group here in Mainz, MITP has organized a highly successful summer school in theoretical physics in 2016, as a European counterpart to the Theoretical Advanced Study Institute (TASI) in Boulder, Colorado, the leading theoretical particle-physics summer school in the US. MITP 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 school took place in a very attractive location in downtown Mainz in August 2016. It lasted 2 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 2016 school included Sally Dawson (Brookhaven), Jesse Thaler (MIT), Nima Arkani-Hamed (IAS Princeton), Tilman Plehn (Heidelberg), Yuval Grossman (Cornell), Maxim Perelstein (Cornell), Jessie Shelton (Urbana-Champaign), and Tobias Golling (Yale). The field of participants was also international with students from more than 16 different countries.

The lectures were video-recorded available to the public on YouTube. As the 2016 MITP summer school was considered a great success by students and lecturers alike, the summer school will be held annually, with a varying topical focus each year.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6 Outreach

From the beginning of MITP, it has been the aim to establish a public lecture series. With the State Theater in the center of Mainz an ideal prestigious location was found outside the campus with halls of different sizes.

During the last years, the public lecture series "Physics at the Theater" ("Physik im Theater") has become a true success story. The talks consistently attracted crowds of 450−1000 members of the public, consistently filling the available auditoriums to capacity.

In 2015, Matthias Bartelmann from Heidelberg opened with a talk on "Unsolved mysteries in the dark universe" followed by Paolo Ferri from ESOC in Darmstadt who gave a lecture on "How to fly to a comet and land on it". Georg Raffelt, MPI Munich filled the big stage of the state theater with "The universe seen in the light of neutrinos" whereas local physicist Joachim Kopp explained "How to hunt ghost particles".

Also in 2016, brilliant speakers excited the audience, namely Christoph Wetterich (Univ. Heidelberg) who talked about "Space, time, universe – the puzzle of the beginning", Reinhard Genzel (MPI for extraterrestrial physics, Garching) with a talk about the "Development of galaxies", and Julia Thom-Levy (Cornell) with a presentation on "Particle detectors". Nobel prize laureate Wolfgang Ketterle (MIT) spoke about "New matter near the absolute zero" and Manfred Lehn (JGU Mainz) about the "Leibniz and Newton – the beginning of infinitesimal calculus". For the two latter talks we moved to the big stage again.

These hour-long lectures were given in German. They were always followed by an open question & answer session, which typically lasts about 45 minutes and were often continued informally afterwards on the plaza outside the theater. All lectures have been recorded and are publicly available on YouTube.

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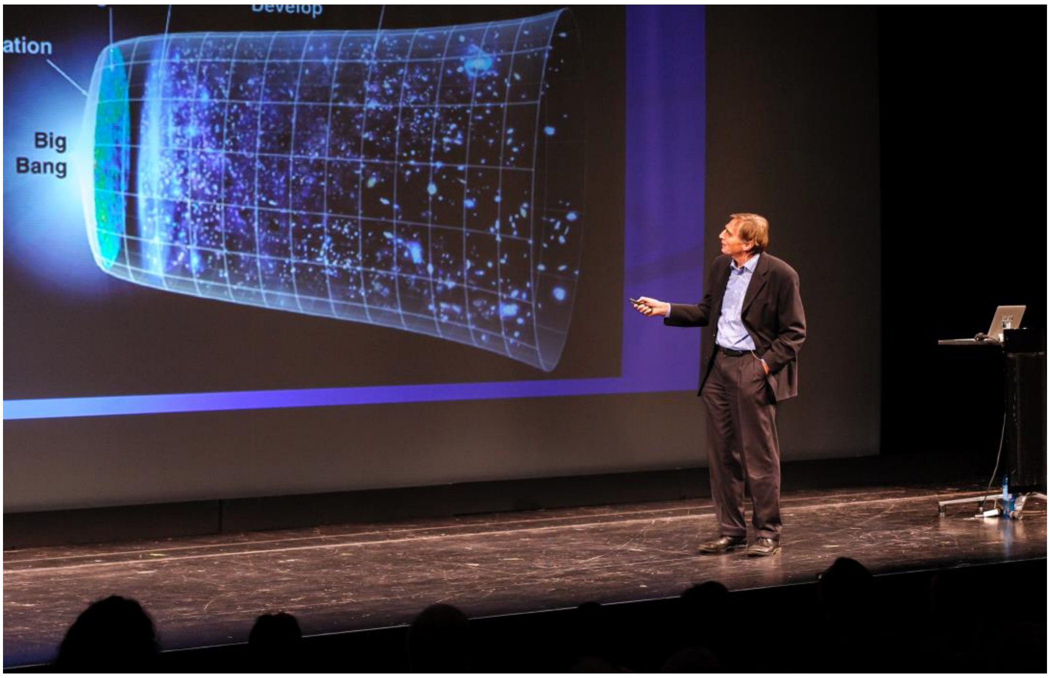

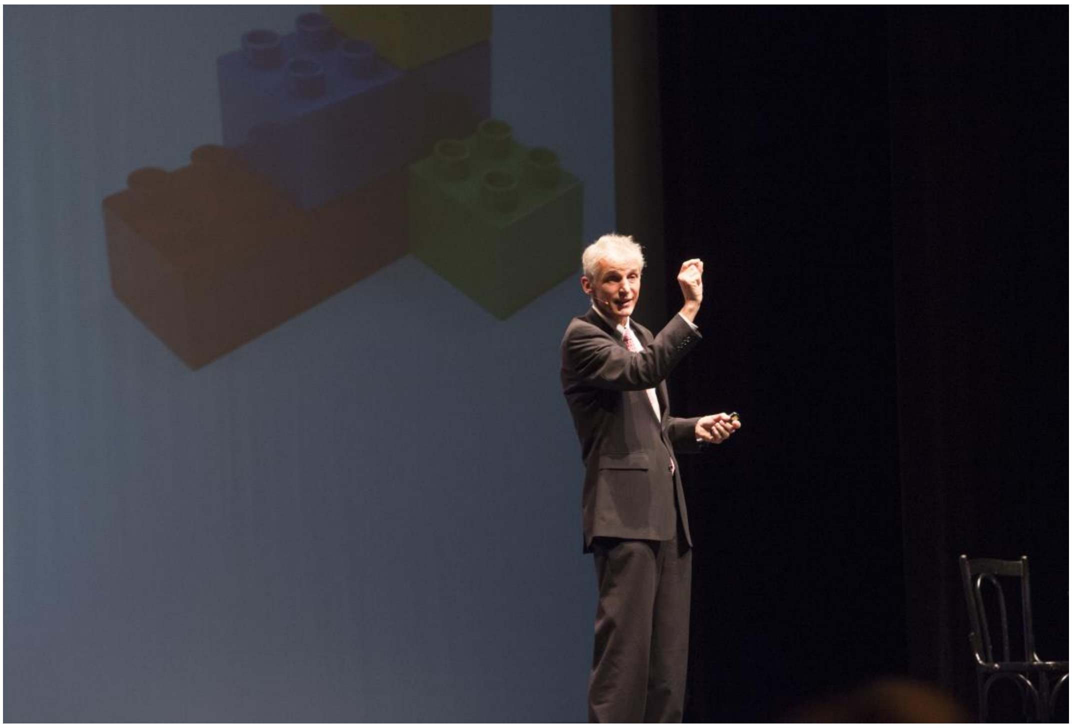

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Mainz February 2017

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