Mainz Institute for Theoretical Physics

Scientific Activities 2014

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

JG|U
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

This report provides a brief overview of the scientific activities at the Mainz Institute of Theoretical Physics (MITP) in 2014.

MITP is part of the PRISMA Cluster of Excellence which was installed in November 2012 as part of the second Excellence Initiative of the German federal government. PRISMA, Precision Physics, Fundamental Interactions and the Structure of Matter, supports fundamental research in the areas of elementary particle physics, precision hadron physics, astro-particle physics, atomic physics with trapped atoms and anti-protons, physics with ultra-cold neutrons, nuclear chemistry, and mathematics. MITP is one of the three structural initiatives of PRISMA founded on the campus of Johannes Gutenberg University.

The Mainz Institute for Theoretical Physics serves as an international center for theoretical research. It is modeled after successful theory institutes around the world, such as the KITP in Santa Barbara or the GGI in Florence. MITP is the first of its kind in Germany. It sets out to create an environment where visiting scholars from Germany and abroad can focus on key questions at the frontiers of their fields that include but are not limited to those areas central to the physics efforts of PRISMA.

MITP provides resources to host a variety of scientific activities like scientific programs of several weeks, one-week topical workshops, and conferences. These activities are always co-organized by a team of external organizers and local scientists. MITP also organizes physics schools as well as outreach events and offers fellowships to theorists for sabbatical stays at MITP.

MITP is a theory center for the international community and run by the international community: The external organizers are responsible for the scientific program, while the MITP provides the infrastructure for it. Proposals for MITP activities can be submitted in January. The international advisory board evaluates all applications. Thus the theory community decides about the program.

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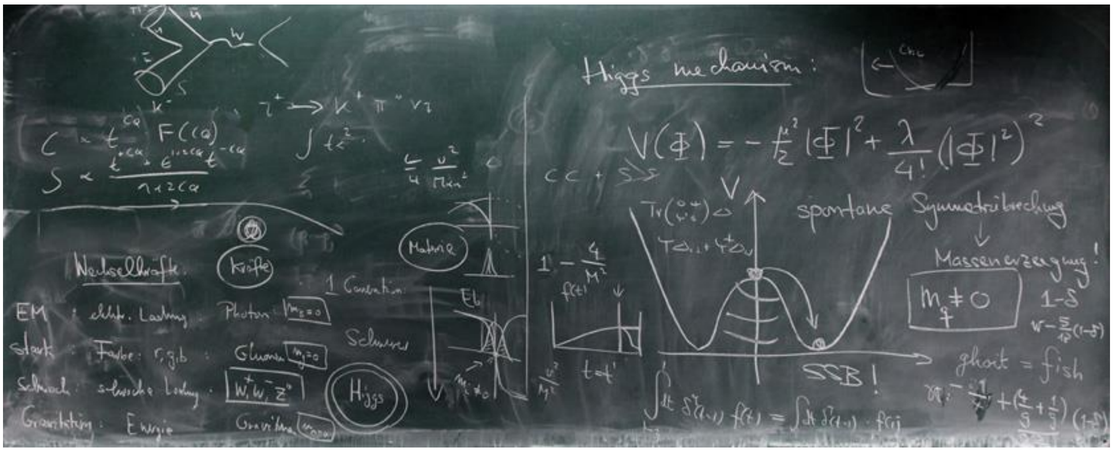
mitp Mainz Institute for Theoretical Physics

Table of Contents



Introduction **3**

1 Topical Workshops **4**

Hadronic contributions to the muon anomalous magnetic moment: strategies for improvements of the accuracy of the theoretical prediction 4
Proton radius puzzle 5

2 Scientific Programs **6**

High precision fundamental constants at the TeV scale 6
Theory facing experiment on Electroweak Symmetry Breaking, Flavor and Dark matter: where do we stand 7
Probing the TeV scale and beyond 9
Jets, particle production and transport properties in collider and cosmological environments 10
String theory and its applications 12

3 Further Activities **13**

MITP Graduate School 13
MITP Guest Program 13
Outreach 13

Introduction

In 2014 the Mainz Institute for Theoretical Physics has expanded significantly. The number of MITP activities is on the increase. In 2013 there were 7 weeks of program, this year (2014) there have been 16, and next year (2015) there will be 20 weeks scheduled.
In total, there have been 244 participants and more than 400 applicants this year. In the following two sections all scientific programs and topical workshops in 2014 are presented.

MITP has also provided resources to host a physics school and several outreach events. Moreover, it has offered fellowships to theorists who wish to use its resources for collaborations and sabbatical stays (see section 3).

MITP activities are intended to stimulate discussions and collaborations among the participants. In 2014 the support of MITP has been acknowledged by participants of MITP activities in 75 publications and preprints.

This year the new MITP guest center has been established on the campus of Johannes Gutenberg University. The guest center includes office space for 33 external scientists, a new MITP seminar room with up to 50 seats, and a meeting and discussion area ("MITP Lounge").

1 Topical Workshops

Hadronic contributions to the muon anomalous magnetic moment: strategies for improvements of the accuracy of the theoretical prediction

Tom Blum Univ. of Connecticut, Simon Eidelman INP Novosibisrk, Fred Jegerlehner HU Berlin, Dominik Stöckinger TU Dresden, Achim Denig, Marc Vanderhaeghen JGU Mainz

April 1–5, 2014, JGU Campus Mainz

The anomalous magnetic moment of the muon provides stringent tests for the electroweak Standard Model (SM) and is an excellent monitor for new physics. Being one of the most precisely measured and at the same time very precisely predictable observable in elementary particle physics, the present persisting deviation between theory and experiment is probably the best established indication of physics beyond the SM. Theoretical predictions are limited by the uncertainties of non-perturbative contributions: the hadronic vacuum polarization (HVP) and the hadronic light-by-light scattering contribution (HLbL). The workshop focused on the question how to reduce theoretical uncertainties to match the precision of forthcoming experiments at Fermilab in the US and possibly also at J-PARC in Japan. One major achievement of the workshop was that one was able to attract many new researchers to actively participate in the field. In fact, a number of new ideas and approaches to tackle the difficult problems have been presented and have been lively debated in the discussion sessions. The topics covered by the working groups were:

• Perspectives for reducing the hadronic vacuum polarization (HVP) error by new cross section measurements (Novosibirsk, Frascati, Beijing, Belle, BaBar). Theory issues are the necessary radiative corrections calculations required for the extraction of the cross sections from the experimental data.

• Exploiting low-energy effective theories in conjunction with experimental data (including hadron production in gamma gamma physics) as required for the calculation of the HLbL contribution or for the inclusion of the tau-decay spectra and pi-pi scattering phase shifts to improve the HVP contribution.

• Perspectives for improvements of lattice QCD calculations of the HVP and HLbL contributions. Participants discussed how to reduce systematic errors in the HVP contribution, which included fitting and related systematics arising in the very low momentum regime. New methods based on taking moments of correlation functions and computing in the time-like region were also discussed.

Among the highlights of the workshop have been the demonstrations that -in contrast to common belief – the HLbL can also be evaluated via dispersion relations in terms of appropriate experimental data.

Moreover, the workshop provided an excellent opportunity for very intense interactions between experimentalists and theorists which are mandatory to substantially improve the control of low-energy hadronic effects.

Proton radius puzzle

Carl Carlson College of William and Mary, USA, Savely Karshenboim MPI for Quantum Optics, Munich, Marc Vanderhaeghen JGU Mainz

June 2–6, 2014, Waldthausen Castle near Mainz

The size of the proton is one of the most fundamental observables in hadron physics. It is measured by an electromagnetic form factor. The latter is directly related to the distribution of charge and magnetization of the baryon and provides the basis for nearly all studies of the hadron structure.

Recently, a precise knowledge of nucleon form factors has become important as input for precision experiments in several fields of physics. Well-known examples are the hydrogen Lamb shift and the hydrogen hyperfine splitting. The atomic physics measurements of energy level splittings reach an impressive accuracy of up to 13 significant digits. Its theoretical understanding, however, has a lower accuracy at the part-per-million level (ppm). The main theoretical uncertainty lies in proton structure corrections, which limit the search for new physics in these kinds of experiments.

In this context, the recent PSI measurement of the proton charge radius via the Lamb shift in muonic hydrogen has given a value that is a startling 4%, or 5 standard deviations, lower than the values obtained from energy level shifts in electronic hydrogen and from electron-proton scattering experiments.

At present, the interpretation of this discrepancy is an open issue. To extract the proton charge radius from the muonic hydrogen Lamb shift result, the form factors, proton structure functions and polarizabilities are required as input for a quantitative understanding of the hadronic corrections. The precise knowledge of such corrections is also crucial before interpreting the muonic Lamb shift discrepancy as a harbinger of new physics, as speculated in recent papers.

The highlights of the conference were the new data, publicly presented for the first time, on the Lamb shift in muonic Helium-4, and the presentation of several experiments that held out the promise of data being publicly delivered before the end of 2014. These included the three precision atomic spacing experiments in ordinary hydrogen and the initial state radiation experiment at MAMI that would allow measuring proton form factors at very low Q^2. In addition, there were a number of theory talks that presented new form factor analyses and new higher order corrections. Furthermore, the surprising result that, in contrast to its Hydrogen equivalent, the Helium muonic Lamb shift shows no discrepancy has already initiated new theoretical work.

2 Scientific Programs

High precision fundamental constants at the TeV scale

Sven-Olaf Moch Univ. Hamburg, Stefan Weinzierl JGU Mainz

March 10–21, 2014, JGU Campus Mainz

Our current knowledge of the fundamental constants in the Standard Model is often the limiting factor in the uncertainty of theoretical predictions, a prominent example being the strong coupling constant and its impact on cross sections at the Large Hadron Collider. The lack of accuracy in the value of these fundamental constants has direct impact on precision tests of the Standard Model and on the interpretation of potential deviations in experimental measurements in terms of new physics phenomena.

The scientific program gathered experts to determine key parameters at the Tera-scale, such as the strong coupling constant, the Higgs mass, the top-quark mass in order to review the situation and to establish a work program. This program aimed at the resolution of current discrepancies between different methods or different sets of data used to determine the same parameter. The program also sets out to identify areas where theory improvement is necessary.

The strong coupling is a fundamental parameter of quantum chromodynamics. Its numerical value affects many cross sections at the Large Hadron Collider. Therefore, our current uncertainty on the numerical value has a direct impact on precision tests of the Standard Model and on the interpretation of potential deviations in experimental measurements in terms of new physics phenomena.

The strong coupling can be extracted from various measurements, like deep inelastic scattering, hadronic Z-decays, event shapes and jets in electron-positron annihilation, jets in hadron-hadron collisions, hadronic tau decays, heavy quarkonia decay, and lattice QCD. Most of these methods were discussed in the scientific program. The numerical value of the strong coupling constant is determined by comparing experimental data from those measurements with the corresponding theoretical predictions including perturbative and non-perturbative corrections. In this way the error on the theory predictions translates into an error on the coupling constraint. In recent years, tremendous progress in higher-order perturbative corrections has been made, resulting in very small theoretical uncertainties.

However different determinations of the strong coupling constant are, at best, marginally compatible within their errors. The potential sources of these discrepancies were intensively discussed. In some cases the origins of the discrepancies were identified.

Moreover, it emerged in the discussions of the scientific program, that coherent action regarding the precision and the interpretation of top-quark mass

measurements is needed. The first issue concerns the definition of the mass parameter in the Monte-Carlo generators used in the Tevatron and the LHC analyses and their interpretation in theory, i.e. the relation of these top mass measurements from kinematically reconstructed top-quark decays to a Lagrangian mass in a given renormalization scheme. The second topic concerns the validation of Monte Carlo tools, in particular a comparison of the MC mass definition with well-defined theoretical calculations for events in differential kinematics.
A comprehensive MITP report about all topics discussed at the scientific program has been written and is available on the archive (arXiv:1405.4781 [hep-ph]).

Theory facing experiment on Electroweak Symmetry Breaking, Flavor and Dark matter: where do we stand

Giulia Ricciardi Univ. Naples, Laura Covi Univ. Göttingen, Csaba Csaki Univ. Cornell, Antonio Masiero Univ. Padua, Tobias Hurth, Matthias Neubert JGU Mainz

May 19–30, 2014, Capri, Italy

Experiments like LHC, new B factories, earth and space based astro-particle experiments give us a unique opportunity to understand long-standing puzzles in electroweak symmetry breaking, flavor and dark matter.
Higher energy is the natural path to follow in the exploration of the gauge structure, with the study of the implications of the Higgs data for the SM and for models containing one or more Higgs-like scalar particles. Signatures of new physics beyond the SM may be identified at the LHC in the near future, and it will

be important to delineate the implications for physics beyond the Standard Model, for the nature of dark matter, and for extended theories of gravity.
Higher intensity is necessary for the exploration of the flavor structure with the study of rare or forbidden decays, both in the quark and in the lepton sector, of tiny deviations from the SM expectations, unification, undiscovered symmetries, the search for other sources of CP violation, the possibility of a weakly coupled hidden sector related to dark matter. Comparison of constraints from different measurements are fundamental to assess the consistency of different theories. This includes astrophysical and cosmological observations, along with numerous dark-matter experiments expected to reach new levels of precision in the next few years.
The goal of the scientific program was to interpret the results coming from a wide range of experiments and to formulate a coherent framework to account for them. At the same time, outdated models and schemes which are no more in line with experiments were identified, and theoretical approaches were based on a more solid basis.
This program brought together key researchers from different disciplines in order to enhance the development of a highly integrated approach to new physics and to develop strategies to face the three experimental frontiers characterizing particle physics, namely the energy, intensity, and cosmic frontiers.
In the center of the scientific program, a 3-day workshop took place which was attended by additional physicists, both experimental and theoreticians. First-hand information on experimental status provided additional input for discussions.

Probing the TeV scale and beyond

Paul Langacker Princeton Univ., Zygmunt Lalak, Stefan Pokorski Univ. Warsaw, James Wells CERN

June 30 – Juli 25, 2014, JGU Campus Mainz

The program was organized after the end of the first phase of the LHC experiments. The discovery of the 125 GeV Higgs boson and the absence of any obvious signals of physics beyond the Standard Model have largely shaped the scientific discussions and the research conducted during the program. The lack of definitive evidence for new physics and the variety of theoretical possibilities require a careful reexamination of questions such as the likely scales of new physics and how to look for them at the LHC and at other present and future facilities. The well-known naturalness problem of the Standard Model, considered for many years as the main guiding principle for searches of physics beyond the Standard Model, is increasingly challenged by experimental data.

Among the most important topics discussed and analyzed by the participants were the theories for dark matter and the status of their experimental searches in colliders as well as in direct and indirect detection experiments. Several talks and a special discussion session were devoted to the dark matter issue. Some of the existing, though not yet confirmed signals of dark matter such as the gamma-ray excess from the galactic center and the anomalous x-ray line from galaxy clusters, reveal specific models of dark matter that may then be probed in colliders. It was also stressed that the new results from the direct detection experiment (LUX) provide very strong constraints on a WIMP as the dark matter candidate, in particular in supersymmetric models. The role of the synergy between different experiments in the search for the dark matter particle was obvious. The new LHC run will provide further significant probes of the supersymmetric dark matter.

Another topic discussed was of course the fate of the naturalness of the Higgs potential that is the fate of the theories proposed as solutions to the naturalness problem. A special discussion session was devoted to the search for the supersymmetric particles in the second phase of the LHC experiments starting in 2015. So-called simplified models are very useful for estimating the discovery potential of the new LHC run, with an unwanted conclusion: the range of the stop mass accessible in the new run will not increase significantly enough for drawing any new strong conclusions on the naturalness of the minimal supersymmetric Standard Model (MSSM). It has been stressed that the colorless supersymmetric particles are equally important and promising targets for the new LHC run. Composite Higgs models and their experimental signatures were also presented by several participants who pointed out that the present error bars on the Higgs boson couplings measured by ATLAS and CMS still leave some room for its compositeness.

Interesting events, spontaneously arranged by volunteers eager to contribute with short presentations, included a small symposium on potential anomalies seen at the LHC. The list of topics contained single plus di-lepton plus jets rate, di-Higgs resonance, W-boson pair production rate, tri-lepton signature and the decay rate for B-meson into a K-meson and a lepton pair. The presentations, followed by critical discussions, showed clearly that these exotic events are far from being convincing hints for new physics.

Jets, particle production and transport properties in collider and cosmological environments

Nora Brambilla TU Munich, Dietrich Bödeker Bielefeld Univ., Guy D. Moore McGill Univ., Frank D. Steffen MPI for Physics Munich, Antonio Vairo TU Munich, Harvey Meyer JGU Mainz

Juli 28 – August 8, 2014, JGU Campus Mainz

Heavy ion collisions taking place at LHC and RHIC are designed to recreate the quark gluon plasma, the state of matter that existed microseconds after the Big Bang. The theory capability to define and to calculate processes taking place inside a hot medium - the jet quenching behavior, the thermal production and interaction properties of particles, the particle transport properties (conductivity, viscosity) - greatly affects our understanding of this new state of matter and the behavior of nuclear matter for nonstandard values of temperature and pressure. This in turn has a large impact on cosmology. Two of the most important open problems in particle physics and cosmology, namely the nature and origin of the dark matter and the origin of the baryon asymmetry are affected by our capability to control the production rate of particles (e.g., of right-handed neutrinos or of SUSY particles) from the thermal plasma.

The main idea of the program was to discuss the computational framework and methods used in thermal field theory, both in the context of heavy-ion collisions and in cosmology. In this way, participants of one field could learn about the important issues in the other field and possibly apply useful methods to their field.
In talks and discussions sessions the outstanding issues in leptogenesis and in electroweak baryogenesis were identified. Another question was, which problems in cosmology do require new techniques. Further topics were thoughts on tools for far-from-equilibrium systems, concrete relations between cosmology and heavy ion physics, energy-loss in a medium beyond leading order.
An effective field theory formulation of the physics of heavy quark and heavy quark bound states in a hot medium was presented. The different regimes where the Debye screening length is larger or lower than the size of the quarkonium quasi-bound state were analyzed, and the effect of the quarkonium moving in the plasma has been quantified.
Moreover, the treatment of jets via effective field theories was addressed. including a possible path to NNLL calculations and another approach of dealing with jets in a medium using an effective kinetic theory.

String theory and its applications

Johanna Erdmenger MPI for Physics Munich, Myrjam Cvetic University of Pennsylvania, Fernando Marchesano UAM/CSIC Madrid, Carlos Nunez Swansea University, Timo Weigand Univ. Heidelberg, Gabriele Honecker JGU Mainz

September 1–26, 2014, JGU Campus Mainz

The program was built on two closely intertwined pillars: string phenomenology and gauge-string duality. Topics in string phenomenology and string cosmology include the status of supersymmetry, the emergence of extra dimensions and the Higgs mechanism in string compactifications as well as implications of the preliminary LHC results on new gauge bosons and light string excitations. Further topics included stringy candidates for the dark sector, inflation, quark and lepton flavor structures in string theory, in the context of gauge/gravity duality, gauge mediation of supersymmetry breaking, the computation of scattering amplitudes using gauge-string dualities and newly developed perturbative methods using heavy forefront mathematics in theories with various amounts of supersymmetry and numerous advances in different aspects of field theories at strong coupling.
Moreover, gauge/gravity duality relates black holes on the one hand with strongly coupled systems on the other. These systems include gauge theories at strong coupling with applications to the QCD phase diagram as well as critical phenomena in condensed matter physics such as superconductivity. Both directions, string phenomenology and gauge/gravity duality, build on the same computational and mathematical methods, so there was a fruitful interchange between the two communities.
The MITP conference on The String Theory Universe with 130 participants was embedded into the scientific program. The conference was dedicated to all aspects of superstring, supergravity and supersymmetric theories.

3 Further Activities

MITP Graduate School

Together with the graduate school "Symmetry Breaking", MITP has organized the International Summer School on "Symmetries, Fundamental Interactions and Cosmology" on the Chiemsee island in the Frauenwörth Abbey (September 1-5, 2014). Outstanding experts in particle physics gave lectures, including Freddy Cachazo, Jos Engelen, Michael Peskin, Antonio Pich, Christopher Sachraijda, Iain Stewart, Guido Tonelli, Uwe-Jens Wiese, and Giulia Zanderighi. In all, 65 students took part in this activity.

MITP Guest Program

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. There have been three short-term visitors (less than one week), Tobias Huber (Univ. Siegen), Leonardo Vernazza (Univ. Genua), and Erich Weihs (Univ. Zurich), while one long-term guest, Jens Erler (Mexico City) visited the MITP from July 16 2013 until August 15 2014. Erler's expertise is mainly in electroweak precision physics. He has played an active role in several MITP events as local organizer. Further guest scientists at MITP have been Stefan Groote (Tartu, Estonia), March 15 - April 5, October 10 – 25, 2014, Michael Ivanov (Dubna), May 1 -31, 2014, and Carlos Vacquera Araujo (Univ. Colima, Mexico), November 1 – December 15, 2014.

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. Matthias Neubert (JGU Mainz) already gave the first lecture of this series in the fall of 2013.
Also in 2014 excellent speakers addressed the audience, namely Christof Wetterich (Univ. Heidelberg) with a talk about "Dark energy, dark matter, and the big bang theory", the Max-Planck Director Dieter Lüst (MPI Munich) with a presentation on string theory, Hartmut Wittig (JGU Mainz) on the fabulous world of quarks, and the General Director of CERN Rolf Heuer on 60 years of research at CERN. The intense discussion sessions after each talk have been very impressive. Because of the overwhelming public response, the lecture series moved from the orchestra hall with 200 seats to the bigger stages in the theater with 500 or even 1000 seats respectively.