HIM HELMHOLTZ
Helmholtz-Institut Mainz

Activity Report 2017 & 2018

HIM Activities 2017 & 2018

1. HIM Facts & Figures

2. HIM Highlight Publications

3. Activities of the HIM Research Sections

- EMP - Hadron Structure with ElectroMagnetic Probes

- SPECF – Spectroscopy & Flavor

- MAM – Matter-AntiMatter Asymmetry

- SHE – Superheavy Elements

- ACID – Accelerator & Integrated Detector

- THFL – Theory Floor

HIM Facts & Figures

HIM in numbers

Staff Research & Development 2017

PIs	21
HYIG	01
Postdoc	20 (thereof 13 international)
Graduate Students (PHD)	30
Staff for Management	8
Staff for basic infrastructure	12
Nations represented	*16*

Staff Research & Development 2018

PIs	21
Postdoc	17 (thereof 8 international)
Graduate Students (PHD)	37
Staff for Management	8
Staff for basic infrastructure	12
Nations represented	*19*

PhDs completed

PhD-theses at HIM in 2017

Measurement of proton electromagnetic form factors using the initial-state-radiation process e+e- ppgamma at BESIII
Dexu Lin

Precise Determination of the Luminosity with the PA N D A - L U M I N O S I T Y D E T E C T O R
Stefan Pflüger

Charge state distributions of low-energy heavy ions passing through dilute gases
Paul Scharrer

Measurement of the Cross Section of the reactions e+e- to pi+pi-2pi0 and e+e- to pi+pi-3pi0
Martin Ripka

PhD-theses at HIM in 2018

A Lattice QCD study of the ρ resonance and the timelike pion form factor
Felix Erben

Feasibility studies for the measurement of the time-like electromagnetic proton form factors at the PANDA experiment
Iris Zimmermann

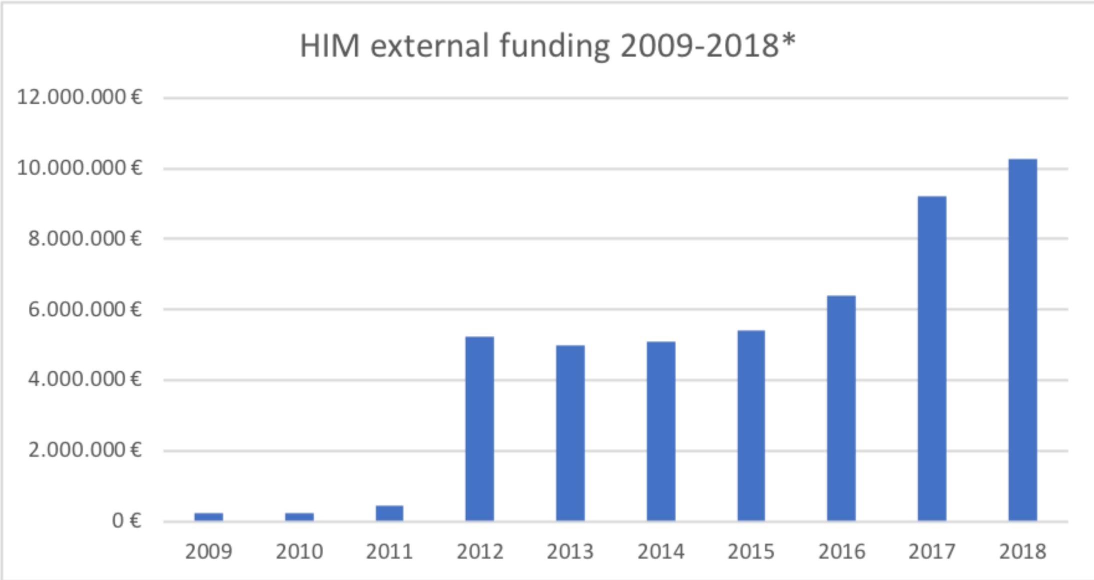
Investigation on intense magnetic flux shielding with a high temperature superconducting tube for a transverse polarized target at the PANDA experiment
Bertold Fröhlich

An investigation of the proton structure in the space-like domain and feasibility studies of the proton electromagnetic form factor measurement in the time-like region
Dmitry Khaneft

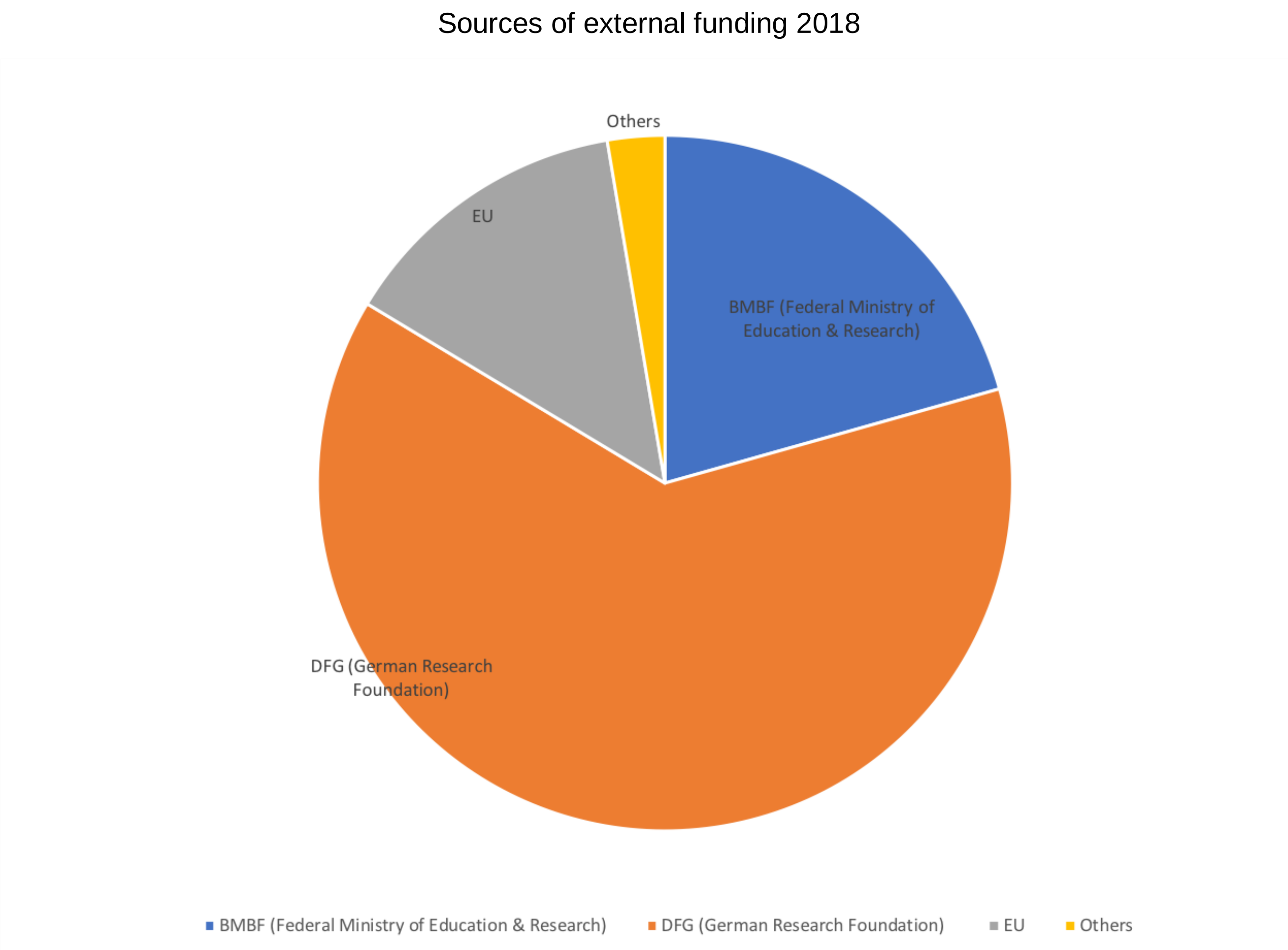
Online coupling of TRIGA-TRAP to the research reactor TRIGA Mainz
Jessica Grund

Laser spectroscopy of nobelium isotopes
Premaditya Chhetri

Third party funding



*including HIM-part of the Cluster of Excellence PRISMA & SFB 1044



Supported Meetings & Conferences

2017

56th Int. Winter Meeting on Nuclear Physics, January 2017, Bormio Italy

Workshop “Future of Non-Collider Physics”, April 2017, Helmholtz Institute Mainz

HIgh MAgnetic Fields for FUNdamental Physics (HIMAFUN), May 2017, LNCMI, Toulouse

Conference “Electromagnetic Interactions with Nucleons and Nuclei (EINN)”, October 2017, Paphos, Cyprus

„International workshop on e+e- collisions from Phi to Psi" (PhiPsi17)

2018

Symposium „50 Jahre Experimente mit Beschleunigern in Mainz“, February 2018, Mainz

“23rd International Conference on High Magnetic Fields in Semiconductor Physics”, July 2018, Toulouse

670th Wilhelm and Else Heraeus-Seminar "Fundamental Constants: Basic Physics and Units", May 2018, Bonn

ECT-Europe “Discrete Symmetries in Particle, Nuclear and Atomic Physics and implications for our Universe”, October 2018, Trento, Italy

Second Plenary Workshop of the Muon g-2 Theory Initiative, June 2018, Helmholtz-Institute, Mainz

Workshop on Future opportunities in Hadron Physics for the European Particle Physics Strategy Process, November 2018, Helmholtz-Institute Mainz

Mainz Institute for Theoretical Physics, Johannes Gutenberg University,
“Searching for new Physics with cold and controlled molecules”, November 2018, Mainz

57th Int. Winter Meeting on Nuclear Physics, 21.-25. January, Bormio Italy

HIM - Visiting Scientists 2017 & 2018

Dr. Yannick Dumeige
Universite de Rennes, France

Friedrich Wilhelm Bessel-Research Award,
Alexander von Humboldt Foundation
02/2018 – 08/2018

Prof. Victor Flambaum
Professor at the Department of Theoretical Physics,
University of New South Wales, Australia

Gutenberg Research Fellowship
4/2018 – 08/2018

Prof. Sayantan Sharma
Professor at The Institute of Mathematical Sciences, Chennai, India

HIM-Guest Scientist Program
06/2018-08/2018

Prof. Dr. Henryk Czyż
Professor at the Institute of Physics, University of Silesia, Poland

HIM-Guest Scientist Program
10/2017 – 10/2018

Dr. Miroslav Ilias
Mate Bel University, Slowenia

HIM-Guest Scientist Program
Summer 2017, Summer 2018

Prof. Dr. Keith Griffeon
College William and Mary, Virginia, USA

HIM-Guest Scientist Program
09/18 – 08/19

Prof. Daniel Rodriguez
Granada University, Spain

HIM-Guest Scientist Program
07/18-08/18

Dr. Tetsuya K. Sato
JAEA Tokai, Japan
05/17-12/17

Dr. Ivica Friščić
MIT, USA
06/2018 & 08/2018 and from 6/8/2018 to 14/8/2018

Dr. Egle Tomasi
CEA, France
11/2018

Dr. Zheng Bo
Japan research Center, Japan
01/2016-12/2017

Dr. V. Reva
BINP Novosibirsk, Russia
09/2018

Awards for HIM-researchers

Prof. Harvey Meyer,
ERC Consolidator Grant by European Research Council, 2018

Dr. Yevgeny Stadnik,
Bragg Gold Medal, 2018

Prof. Victor Flambaum,
Gutenberg Fellowship by JGU Mainz, 2018

Highlight-Publications of the HIM-research sections

EMP- ElectroMagnetic Processes

Dominik Becker (U. Mainz, PRISMA & Mainz U., Inst. Kernphys.) et al.. 2018.
The P2 experiment
Published in Eur.Phys.J. A54 (2018) no.11, 208

A. Esser (Mainz U., Inst. Kernphys.) et al.. 2018.
First Measurement of the Q^2 Dependence of the Beam-Normal Single Spin Asymmetry for Elastic Scattering off Carbon
Phys.Rev.Lett. 121 (2018) no.**2,** 022503

D. Balaguer Ríos (Mainz U., Inst. Kernphys.) et al.. 2017.
New Measurements of the Beam Normal Spin Asymmetries at Large Backward Angles with Hydrogen and Deuterium Targets
Phys.Rev.Lett. 119 (2017) no.1, 012501

F.E. Maas (Helmholtz Inst., Mainz & Mainz U., Inst. Kernphys. & U. Mainz, PRISMA), *K.D. Paschke* (Virginia U.). 2017.
Strange nucleon form-factors
Prog.Part.Nucl.Phys. 95 (2017) 209-244

OLYMPUS Collaboration (B.S. Henderson (MIT) et al.). Nov 14, 2016.
Hard Two-Photon Contribution to Elastic Lepton-Proton Scattering: Determined by the OLYMPUS Experiment
Phys.Rev.Lett. 118 (2017) no.9, 092501

ACID 1 – Accelerator and Integrated Detector

Stepan Yaramyshev et al: 2018
Advanced Approach for Beam Matching along the Multi-Cavity SC CW Linac at GSI
J. Phys.: Conf. Ser. 1067 052005

Malte Schwarz et al: 2018
Beam Dynamics Simulations for the New Superconducting CW Heavy Ion LINAC at GSI
J. Phys.: Conf. Ser. 1067

Barth W et al: 2018
First heavy ion beam test with a superconducting multi gap CH-cavity,
Phys. Rev. ST Accel. Beams 21 020102

K Taletskiy et al: 2018 J.
Comparative Study of Low Beta Multi-Gap Superconducting Bunchers
Phys.: Conf. Ser. 1067 082006

M Gusarova et al: *2018*
Multipactor discharge in superconducting accelerating CH cavities
J. Phys.: Conf. Ser. *1067 082007*

ACID 2 - Accelerator and Integrated Detector

D. Becker et al:
The P2 experiment,
Eur. Phys. J., A54,p.208 (2018)

R. Kempf, K. Aulenbacher et al.
High precision beam parameter stabilization for MESA.
Proceedings IPAC 2018

T. Stengler , K. Aulenbacher et al. :
Cryomodule Fabrication and Modification for High Current Operation at the Mainz Energy Recovering Superconducting Accelerator MESA
Proceedings SRF 2017

K. Aulenbacher et al.:
Status of the turbine concept for relativistic electron coolers
Proceedings COOL2017

M.W. Bruker, S. Friederich and K. Aulenbacher
A test set-up for electron collector efficiency measurements
Nuclear Inst. and Methods in Physics Research, A 872 (2017) 169–173

THFL – Theory Floor

H.B. Meyer and H. Wittig,
Lattice QCD and the anomalous magnetic moment of the muon,
Prog. Part. Nucl. Phys. 104 (2019) 46

H.B. Meyer,
Euclidean correlators at imaginary spatial momentum and their relation to the thermal photon emission rate,
Eur. Phys. J. A54 (2018) no.11, 192

C. Ji, S. Bacca, N. Barnea, O.J. Hernandez and N. Nevo-Dinur,
Ab initio calculation of nuclear structure corrections in muonic atoms,
J. Phys. G45 (2018) no.9, 093002

N. Kivel and M. Vanderhaeghen,
Production of a tensor glueball in the reaction $\gamma\gamma \to G_2\pi^0$
at large momentum transfer,
Phys. Lett. B781 (2018) 169

H.W. Lin, E.R. Nocera, F. Olness,..., H. Wittig and J. Zanotti,
Parton distributions and lattice QCD calculations: a community white paper,
Prog. Part. Nucl. Phys. 100 (2018) 107

SHE – Superheavy Elements

Block, M., Briselet, Düllmann, Ch.E., Heßberger, F.P., Hinde, D.J., et al.
Towards saturation of the electron-capture delayed fission probability: the new isotopes ^{240}Es and ^{236}Bk.
Phys. Lett. B 764 (2017) 265-270.

Thielking, J., Okhapkin, M.V., Głowacki, P., Meier, D.M., von der Wense, L., Seiferle, B., Düllmann, Ch.E., Thirolf, P.G., Peik, E.
Laser spectroscopic characterization of the nuclear clock isomer ^{229m}Th.
Nature 556 (2018) 321-325.

Block, M., C., Düllmann, Ch.E, Götz, S., Heßberger, et. al
Precision measurement of the first ionization potential of nobelium.
Phys. Rev. Lett. **120** (2018) 263003.

Block, M., Borschevsky, Düllmann, Ch.E., Dzuba, V.A., Flambaum, V.V, Götz, S., Heßberger, F.P., et al.
Probing sizes and shapes of nobelium isotopes by laser spectroscopy.
Phys. Rev. Lett. **120** (2018) 232503.

Block, M., Düllmann, Ch.E., et al.
Study of non-fusion products in the ^{50}Ti + ^{249}Cf reaction.
Phys. Lett. B 784 (2018) 199-205.

MAM – Matter-AntiMatter Asymmetry

Sixfold improved single particle measurement of the magnetic moment of the antiproton,
BASE collaboration,
Nature Communications volume8, Article number: 14084 (2017)

D. Antypas, A. Fabricant, V. V. Flambaum, J.E. Stalnaker, K. Tsigutkin, and D. Budker,
Isotopic variation of parity violation in atomic ytterbium,
Nature Physics (2018)

Filip Ficek, Pavel Fadeev, Victor V. Flambaum, Derek F. Jackson Kimball, Mikhail G. Kozlov, Yevgeny V. Stadnik, and Dmitry Budker,
Constraints on exotic spin-dependent interactions between matter and antimatter from antiprotonic helium spectroscopy,
Phys. Rev. Lett. 120, 183002 (2018)

Teng Wu, John W. Blanchard, Derek F. Jackson Kimball, Min Jiang, and Dmitry Budker,
Nuclear-spin comagnetometer based on a liquid of identical molecules,
Phys. Rev. Lett. 121, 023202 (2018)

Antoine Garcon, John W. Blanchard, Gary Centers, Nataniel L. Figueroa, Marina G. Sendra, Arne Wickenbrock, Teng Wu, Dmitry Budker et al
The Cosmic Axion Spin Precession Experiment (CASPEr): a dark-matter search with nuclear magnetic resonance,
Quantum Science and Technology 3(1), 014008 (2017)

SPECF – Spectroscopy and Flavor

M. Ablikim et al. [BESIII Collaboration]
Precise measurement of the e+e- to pi+pi- J/psi cross section at center-of-mass energies from 3.77 to 4.60 GeV
Phys. Rev. Lett. 118 (2017) 092001.

M. Ablikim et al. [BESIII Collaboration],
Evidence of Two Resonant Structures in e+ e- to pi+ pi- hc
Phys. Rev. Lett. 118 (2017) 092002.

A. S. Botvina, K. K. Gudima, J. Steinheimer, M. Bleicher, and J. Pochodzalla
Formation of hypernuclei in heavy-ion collisions around the threshold energies
Phys. Rev. C 95, 014902 (2017).

X. Qui et al. (HKS (JLab E02-017) Collaboration)
Direct measurements of the lifetime of medium-heavy hypernuclei
Nucl. Phys. A 973, 116 (2018).

M. Düren et al.,
The Endcap Disc DIRC of PANDA
Nucl. Instr. Meth. A876 (2017).

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Activity Reports of the Research Sections

Research Section EMP:
Hadron Structure with ElectroMagnetic Probes

F. Maas

The research section EMP has made substantial progress in the following work packages:

- WP1: PANDA Backward endcap calorimeter
  - A) New 16 crystal prototype: A new prototype calorimeter, at -25°C, has been designed, constructed, assembled and tested with beam at MAMI. It incorporates all improvements on the mechanical level, new electronics boards, new way to produce the carbon fiber alveoles and represents an important improvement towards production of the backward endcap calorimeter.
  - B) PANDA Uppsala SADC development: The SADC from Uppsala has been extensively tested. The on-board FPGA firmware has been reprogrammed in order to get a better signal processing and extraction from the raw data. Data transfer of the signal traces is obsolete. The firmware had been extensively tested using a FPGA test board environment before it has been tested with MAMI beam and the new prototype.
  - C) FAIR Phase 0 beam tests: A new electron/photon discrimination detector, made of scintillators and operated in coincidence with the PWO crystal calorimeter had been designed, constructed and tested with direct MAMI beam. It has been used at further beam tests in the A1 spectrometer hall at MAMI with scattered particles from various targets (plastic, carbon, and tantalum) in coincidence with a magnetic spectrometer. The tests have been very successful and will allow the design of the FAIR phase 0 measurement of the pion electroproduction cross section in the Primakoff kinematics at MAMI with the backward endcap calorimeter.
- WP2: Exploration of electromagnetic processes in PANDA
  - A) The Analysis with final state muon pair finished. The feasibility studies for PANDA using a muon pair in the final state for a measurement of the time-like form factors of the proton have been finished. The analysis memo is approved by the collaboration, a paper draft is written. In addition, the analyses of both muon and electron final states, taking into account the reduced luminosity available at the startup phase of the PANDA experiment (PANDA-Phase1) are performed. A paper draft is written (including other Phase1 PANDA physics). It could be shown that during phase 1 of PANDA with reduced luminosity, a precise measurement of the FF can be done with PANDA.
  - B) Analysis for extraction of time-like FF from the unphysical region. A first simulation using PANDAROOT could show, that the process can well be extracted and analysed.
  - C) The cross section, including next to leading order radiative corrections, has been calculated including both virtual and real photon corrections. Based on these calculations, a Monte Carlo event generator has been developed for the future analysis and measurements at PANDA. The

numerical accuracy of the obtained results is currently under investigation. A paper draft is written.

- WP3: GEM-tracker for PANDA tracking: Progress concerning R&D towards a demonstrator has been made. Quality assurance has yielded very much improved quality of new foils from a polish produced TECTRA.

- WP4: Time like form factors of proton and neutron from BES-III
  - A) Proton FF from ISR: Two independent analyses (tagged and untagged ISR analyses) have been finished. The two release notes summarizing these analyses were reviewed and approved by the collaboration. Two paper drafts for reviewed journal publications are under internal review within the BES-III collaboration.
  - B) Proton FF from energy scan: The analysis is finished. The release note describing this work has been approved and a paper draft is under internal review within the BES-III collaboration.
  - C) Neutron FF from energy scan: Major progress has been made in the analysis by combining three independent event selection methods, including time-of-flight measurement, the use of multivariate analysis, and selection criteria based on the electromagnetic calorimeter. This has led to a major improvement of the efficiency for detecting the neutron-antineutron pair in the final state. For two energies of the energy scan, the large statistics has allowed for an angular distribution analysis for the first extraction of the individual electric and magnetic form factors. A release note was written and currently under internal review within the BES-III collaboration.
  - D) Cylindrical GEM as new inner tracker: EMP has contributed to a new inner tracking detector, a cylindrical GEM (work packages: CGEM electronics and data simulation and analysis). The project is headed by INFN and supported by EU in the framework of the HORIZON2020 RISE program, together with Uppsala and IHEP.

- New Helmholtz Excellence Network in connection with PRISMA: The Helmholtz Impuls and Networking fund has made available funds in connection with the successful second step of the excellence initiative in Germany. The PRISMA+ proposal had been selected for presentation of a full proposal.

Footnote: * has left HIM in the meantime.

Research Section SPECF: Hadron Spectroscopy and Flavour

Achim Denig

A quantitative understanding of the force of strong interactions in the non-perturbative regime of the fundamental theory of quantum chromo dynamics, QCD, is the prime focus of contemporary research in hadron and in nuclear physics. The research section SPECF (spectroscopy and flavour) is aiming for world class spectroscopy data both of hadrons and of nuclei by a full exploration of the opportunities given by the future PANDA experiment at FAIR. These results will make significant contributions to the world-wide effort to understand the binding of hadrons and of nuclei based on QCD.
At PANDA, the spectrum of mesons can be investigated up to the mass region of the charm quark. A search for exotic states like glueballs, hybrids and multiquark states in the light quark domain and in hidden and open charm systems will be carried out. Exciting results in the charm sector, indicating the existence of multiquark states – so-called XYZ particles – have been obtained in the past years at electron-positron colliders and at the LHC (Large Hadron Collider). The production of hadrons in a fixed target environment like at PANDA using an antiproton beam offers unique opportunities, which are presently not possible at existing accelerators, for instance regarding the large production cross section for even high spin states, or regarding the direct access of quantum numbers beyond $J^{PC} = 1^{--}$.
Presently, during the construction phase of the PANDA, the main focus of section SPECF is on the preparation of hardware components for the experiment, but the section is also involved in physics analyses and software tools, and furthermore has initiated a project within the Helmholtz Excellence Initiative in cooperation with the PRISMA+ Cluster of Excellence.

I) Hardware activities

For the **luminosity detector**, which will consist of a setup of four layers of pixel detectors based on the HV-MAPS technology and which will measure the elastically scattered antiprotons at small angles, a new vacuum box has recently been constructed. In view of a precise positioning of the sensors under vacuum conditions, the distortions of the box can be kept below 200 µm. The full support and cooling structure for the sensors are ready and a test of a half detector is in preparation. Furthermore, new aluminium flex cables have been developed and already produced for the connection of the sensors. The prototype setup will be used for the FAIR Phase-0 experiment KOALA at FZ Jülich with the aim to measure the elastic proton-proton scattering cross section at low momentum transfer.

The study of strange nuclear systems is an important pillar for our understanding of the hadronic equation of state of dense stellar systems like neutron stars. Within SPECF, the focus lies on the high resolution spectroscopy of **double Lambda-Lambda hypernuclei.** As realized more recently, also a spectroscopy of heavy **hyperatoms** can be carried out with the setup currently prepared for PANDA. For the first time, this will allow to explore the isospin dependence of the nucleus interaction. The main components of these experiments are a dedicated target station, which will be mounted in the backward part of the PANDA detector and the germanium detector DEGAS, which is built in cooperation the NUSTAR collaboration.

Researchers of section SPECF are furthermore involved in the readout of the fused silica radiator bars of the **barrel DIRC detector of PANDA**. For this project, fast and pulsed laser light sources of different wavelengths were qualified for the measure-ment of timing resolutions of photo sensors for RICH detectors.

II) Software and Analysis activities

Due to the high background rate in pbar-p annihilation and due to the numerous benchmark channels at PANDA, a trigger decision is made on the basis of a pure online trigger, for which researchers of section SPECF have successfully developed a selection scheme. As part of the studies for the **PANDA online trigger** several benchmark scenarios have been simulated for the preparation of the technical design report of the PANDA DAQ system.

Recently, researchers of section SPECF have proposed an energy scan around the charmonium resonance ($J^{PC}=1^{++}$) at the electron-positron experiment BES III. The **production of a non-vector ($J^{PC}=1^{--}$) resonance in e+e- annihilation** is only possible via a two-photon process, but such a production mechanism has never been verified before. The analysis of the data obtained in a three-week data taking period is currently analysed. In case the $_{c1}$ resonance is found, a new production mechanism in e+e- physics has been established. At PANDA, the high resolution of the antiproton beam together with the unprecedented statistics will allow for resonance scans of charmonium and charmonium-like particles (e.g. the X(3872) resonance).

III) HIM - PRISMA+ excellence network

Within the excellence network of the Helmholtz association, SPECF researchers - in collaboration with the PRISMA+ Cluster of Excellence - have carried out a feasibility study for light dark matter searches at the future MESA accelerator. Such a search in a dedicated **Beam Dump Experiment BDX@MESA** appears to be highly competitive making use of the extraordinary high number of electrons ($3x10^{23}$ electrons on target), which will be accelerated at MESA. The experiment can run in parallel to the P2 experiment at MESA and a dedicated room is foreseen behind the P2 beam dump.
In a dedicated test beam time at the MAMI (Mainz Microtron) accelerator of the Institute of Nuclear Physics, it could be verified that lead glass crystals as well as PbF_2 crystals are suitable as a detector material for the BDX experiment. For the detection of the Cherenkov light in the crystals an energy threshold of 10 MeV has been verified.

Research Section MAM: Symmetry of Matter and Antimatter

Dmitry Budker

The MAM section is addressing fundamental questions in science related to the observed asymmetry of matter and antimatter in the universe. The asymmetry could indicate differences in the observable properties of antimatter with respect to matter but also unknown symmetry-breaking phenomena in the production mechanism of matter and antimatter in the universe that are not described in the standard model. Even though the section focusses mostly on experimental searches, it is also home to a theory division led by Gutenberg Research Fellow Prof. Dr. Victor Flambaum. He is supported by Humboldt fellow and 2018-Bragg-medal winner Dr. Yevgeny Stadnik as well as two JGU PhD students. HIM MAM theorists devise novel approaches to tests of the standard model with atoms and molecules and to exotic-physics searches. A recent important result used measurements of antiprotonic helium from CERN to derive constraints on hypothetical spin-dependent forces between matter and antimatter.

Experiments performed in the section involve high-precision measurements to compare the fundamental properties of matter and antimatter, precision measurements of symmetry-breaking phenomena within the standard model, and searches for new symmetry-breaking mechanisms not described in the standard model.

The main results to be highlighted in this context since October 2017 are:
The comparison of the magnetic moment of the proton and the antiproton. The proton's magnetic-moment measurements, currently led by Prof. Dr. Jochen Walz, have a long history in Mainz. In 2017 the magnetic moment of the antiproton was measured within the BASE collaboration at CERN with an accuracy of 1.5 ppb and compared to the 2014 proton result from Mainz with a relative uncertainty of 3.3 ppb. This comparison provides the most stringent test of fundamental properties of matter and antimatter and shows no deviation. Additionally, this allows for novel constraint on certain standard model extension and on CPT violation. This result was followed by another improvement of the proton magnetic moment measurement in Mainz by a factor of 11, bringing the uncertainty down to 0.3 ppb, which will enable an even more precise comparison in the near future.
Parity violation in atomic Ytterbium. In 2014 we started to construct an improved experiment to study parity violating effects in atomic Ytterbium. After 2.5 month of data acquisition in 2018 this effort resulted in a ~20 fold improvement on experimental uncertainty in the measurement of the weak charge of the ytterbium nuclei. Additionally, comparison of different ytterbium isotopes allowed for the first time to confirm the predicted dependence of the parity violating effect on the number of neutrons. This results probe physics beyond the standard model and will be used to improve the experiment even further making it sensitive enough to measure the long-coveted neutron-skin and nuclear-anapole-moment effects.
Trapped and cooled thorium ions via calcium (TACTICa). The optical transition of isomeric ^{229}Th is the only nuclear transition that potentially can be interrogated using lasers. Controlling this transition opens an interesting window into high-precision tests of the standard model and on possible variation of fundamental constants. Funded since the end of 2017 within the Helmholtz Excellence Inititative, TACTICa aims to deploy ion trapping techniques like quantum logic spectroscopy to gain access to the nuclear structure of thorium. As an important first demonstration, in 2018, single ^{232}Th^{+} ions were trapped together with a Ca^{+} ions forming a so-called "Wigner cryscal", sympathetically cooled and characterized. The project brings together expertise from the JGU Mainz Institut of Physics, excellence cluster PRISMA and the HIM sections MAM and SHE and is an important example of synergy possible in Mainz.

Cosmic Axion Spin precession Experiment (CASPEr). CASPEr is a multipronged approach to shed light on novel particles extending the standard model and potentially to understand the composition of dark matter. We are constructing experiments in Mainz that are sensitive to the presence of dark-matter axion, axion-like-particles, dark photons and other proposed particles. The experiments look for resonant effects using hyperpolarized nuclear spins as probes for the feebly interacting particles. For the first time in 2018, we were able to start searching in experimentally unconstrained parameter space in the ultra-light particle regime ($<10^{-13}$ eV). The principle components apparatus to search for new particles in a mass range from 10^{-14} eV to 10^{-8} eV have been delivered in 2018. Data taking will commence in early 2019.

Within the last year the section contributed to more than 40 peer-reviewed articles and received 3rd party funding as a pilot project of the national quantum sensing inititative (QUTEGA, BrainsQSens), within the Helmholtz Excellence inititative (TACTICa) and within the most recent EU FET Open call (ASTERIQS) for quantum sensing applications using nitrogen vacancies in diamond.

Research Section SHE: Stability and Properties of Superheavy Elements

Ch. E. Düllmann and M. Block

Since the last HIM-SC meeting in 2017, activities of our section were first focused on the implementation of facility upgrades during the extended period without UNILAC operation, and then on the 2018 UNILAC beamtime block. Selected experiments of the Superheavy Element Chemistry section were performed abroad, e.g., at the Cyclotron Institute at Texas A&M University, College Station, USA, at JAEA Tokai, Japan, and at the University of Jyvaskyla, Finland.

Synthesis/nuclear reactions: data obtained in several experiments at Australian National University's (ANU) Heavy Ion Accelerator Facility give information on the role of quasifission vs. fast fission for different entrance channels. In particular, Mass-Angle-Distributions of binary events have been measured for a large range of SHE-formation reactions using the CUBE spectrometer. Fission fragments from the Ti-48+Pb-204,208 and Ti-50+Pb-206,208 reactions were measured in 2015-2016 with the aim to investigate how the competition between quasi-fission and fusion-fission evolves with small changes in entrance-channel properties associated mainly with the nuclear structure, and these data were now published. Further data collected during these campaigns shed new light on the QF process involving projectiles heavier than Ca-48, which are required to push SHE synthesis beyond oganesson (Z=118). These data, together with data on fusion-evaporation reaction measured, e.g., at TASCA and SHIP, provide a comprehensive dataset to shed light on the strong influence of nuclear structure on the fusion process. In addition, ANU data collected using beams of ^{48}Ca - ^{64}Ni on actinide targets have yielded a clear systematic picture of a strong dynamical evolution when moving from ^{48}Ca to heavier beams. The data will provide a conclusive basis for the choice of the most preferable reaction for the synthesis of new elements beyond Z=118, from the entrance-channel point of view.
Data obtained earlier at TASCA were also evaluated to get a better understanding of non-fusion reactions. A possible quasi-fission contribution to such non-fusion products of the Ti-50+Cf-249 reaction was studied, and the results were also published in 2018. The survival probability of the highly excited nuclei against fission via neutron evaporation after fusion was studied at TASCA in the Ca-48+Yb-176 reaction forming Th-224*. At high excitation energy of about 86 MeV, which is about 30 MeV higher than the previously known highest used energy of 62 MeV, the evaporation of 7-9 neutrons leading to Th-215-217 was observed. The results of this work formed the basis for a bachelor’s thesis.
In June 2018, the recommissioning of the upgraded TASCA separator with a new detector chamber, a new control system, and upgraded electronics was performed with Ca-48 and Ti-50 beams from the UNILAC and proved the full functionality. Some interesting physics results in the heavy element region were obtained, which are currently under final analysis.

High-precision mass measurements: The on-line coupling of the TRIGA-TRAP Penning trap mass spectrometer to the research reactor TRIGA Mainz was achieved in August 2017. The short-lived isotopes ^{90,91,93}Rb$^+$ produced by neutron-induced fission of ^{235}U were extracted by an aerosol-based gas-jet and ionized in a new surface ion source. Their masses were determined in the purification trap with a precision of 10^{-6} and found to agree with AME2016. This work formed the core of a PhD thesis. To further advance the TRIGA-TRAP setup, the Phase-Imaging Ion-Cyclotron-Resonance (PI-ICR) method is currently being implemented.

At SHIPTRAP at GSI the masses of several nobelium and lawrencium isotopes were measured with statistical uncertainties on a 10^{-9} level using PI-ICR, which has originally been developed at that facility. Thanks to a novel cryogenic gas stopping cell, which was installed during the extended shutdown in 2017/18, measurements were performed more efficiently and exploited the high mass resolving power to pin down low-lying isomers with only tens of keV excitation energies unambiguously. Also, the measurement of ^{257}Rf (Z=104) represents the first such measurement beyond the end of the actinide series. The data analysis is ongoing.

Laser spectroscopy: The analysis of the laser spectroscopy campaigns of nobelium at GSI was completed and the result were published in two papers in PRL. From more than 30 identified atomic states in nobelium, its first ionization potential was determined with high accuracy. Hyperfine spectroscopy of ^{253}No confirmed a ground state spin parity of $9/2^+$ and provided nuclear model-independent values for the quadrupole moment and the magnetic moment. In addition, differential charge radii for $^{252-254}$No were obtained. The results were in excellent agreement with theoretical work, which accompanied the experimental efforts.
A new setup for high-resolution laser spectroscopy using the in-gas jet approach developed by KU Leuven is presently constructed in Mainz. Following first offline commission, the first online experiments are planned for spring 2019 trying to determine the spectral resolution that can be obtained in the jet. An experiment on nobelium has been approved at GSI and will in the near future be performed. One of the goals is to determine the structure of the isomer in No-254.

SHE Chemical Properties: In past beamtimes, experiments on the chemical behavior of Fl and Nh in comparison with Hg, Tl, Pb, and Rn were performed at TASCA. The volatility and reactivity of these elements towards surfaces like SiO_2 and Au were measured. The comprehensive analysis of these results was continued and the data on the homologs were published. For Nh, experimental results indicate a reduced volatility and enhanced reactivity compared to Cn and Fl. To render assistance to these gas-phase experiments, calculations of the adsorption energies of these elements and their lighter homologs on Au surfaces have been performed and published using a periodic ADF BAND code. Such periodic calculations of adsorption energies have been performed for the first time for superheavy element systems adsorbing on gold. The results have shown that Cn should be indeed the most volatile element among those under consideration. In addition, molecular properties of group-13 hydroxyls (of Tl and Nh) needed for predictions of their reactivity with quartz and Au have been calculated with the use of most advanced relativistic methods. In difference to the conclusion from earlier predictions, NhOH is expected to be less volatile than TlOH. To study Nh under improved conditions, advanced setups for optimized transport of the element under study to the detection setup, also for less volatile species, have been developed and commissioned. These include approaches to couple COMPACT to a recoil separator by employing the room-temperature SHIPTRAP buffer-gas stopping cell instead of a classical RTC, as well as an optimized RTC-COMPACT combination without any transfer-line. Off-line measurements were performed with Ra-223 and Ac-225 recoil ion sources installed in the buffer gas stopping cell. In separate experiments, the gas-catcher-COMPACT-setup as well as the new RTC-miniCOMPACT setup were flushed with helium gas and allowed performing gas phase chromatography studies the recoil ions Rn-219 ($T_{1/2}$ = 3.96 s) or At-217 ($T_{1/2}$ = 32.3 ms). The efficiency for transporting these isotopes from the source to the COMPACT detector as well as the transport time were studied. High-statistics online parameter studies to complement the offline data set as well as the first online data from Texas A&M University will be obtained in the 2019 UNILAC beamtime block.

The studies of volatile transition metal carbonyl complexes with short-lived isotopes has been continued, using the two-chamber technique which was developed last year. Successful experiments with fission products at TRIGA Mainz focused on studying and optimizing the partial efficiency of the flushing-out of the first into the second chamber confirm that such an approach allows obtaining higher efficiencies than with preseparation, thus paving the way towards experimental studies beyond Sg, for which carbonyl complex formation was shown in 2014.

With the aim to support gas-phase experiments on study of stability and volatility of carbonyls of the heaviest elements, calculations of the electronic structures and properties of group-7 carbonyls, including those of Bh, were published. The most advanced relativistic quantum-chemical methods (ADF BAND, X2c-DFT, DIRAC) were utilized, and properties of the $M(CO)_5H$ species (M= Tc, Re and Bh) have been determined, including radicals $M(CO)_5$. Volatility of these species and first bond dissociation energies were predicted.
To lend assistance to the current suite of gas-phase chromatography experiments at TASCA on the volatility and reactivity of Nh, ADF calculations of adsorption energies of group-13 hydroxyls (of Tl and Nh) on gold were performed and published. The results have shown that the trend in adsorption of MOH, TlOH < NhOH, is opposite to the one of the atoms, where Tl > Nh. The adsorption enthalpies of Nh and NhOH were found to be very similar, so that the identification of the chemical composition by measuring adsorption temperature will be difficult. Investigations of adsorption of Lr on a Ta surface were carried out in part (for specific Ta surfaces) using a periodic ADF BAND code. The work is done in collaboration with JAEA Tokai, Japan, to help interpret their experimental results.

Tailor-made (actinide) samples: A main activity in Mainz is the production of tailor-made samples of (radio)isotopes for applications in basic chemical and physics research. Besides Molecular Plating (MP) a novel target production technique, based on a commercially available “Drop-on-Demand” inkjet printing system has been developed. Several targets for external collaborators were produced with this technique, including the following:
1) Cm-248 targets for the muX collaboration, Paul Scherrer Institute, Villigen, Switzerland. The muX collaboration aims at producing muonic atoms. A first attempt with Cm was performed in 2018.
2) Th-232 targets for IGISOL, University of Jyväskylä, Finland. Multiple targets with different thicknesses on different metal foils including Au and Ti were produced by the DoD method to test the performance of such targets under proton beam irradiation. Data from this beamtime, which took place in November 2018, are under analysis.
3) Th-229 laser targets are under development for collaborative work led by UCLA Los Angeles and LMU Munich, with the goal to pin down the excitation energy of the first excited state in ^{229}Th, theorized to serve as the heart of a nuclear clock.

Nuclear Spectroscopy: Construction of the novel ALpha-BEta-GAmma (ALBEGA) multi-coincidence spectroscopy setup for chemically separated samples continued with testing advanced prototypes of the two ALBEGA core detectors. The tests with several radioactive sources confirmed performance according to specifications. In a next step, the final version of the ALBEGA core detector is currently being characterized.

TACTICa: Together with expertise and infrastructure available in the MAM section, the TACTICa project on “Trapping And Cooling of Thorium Ions with Calcium ions” has started and a first paper has been submitted for publication. Th-232 ions were successfully produced and trapped in a linear Paul trap, sympathetically cooled with Ca ions, and their mass identified via TOF measurement as well as from the voids in the laser-induced Ca fluorescence pattern emitted by the crystal. This paves the way to future high-precision studies of various Th isotopes including Th-229m in the context of fundamental physics or quantum optics.

Guest Program: The program of the SHE section was supported by extended visits of Professor M. Iliaš from Matej Bel University, Banská Bystrica, Slovakia and Prof. D. Rodriguez from the University of Granada, Spain via the HIM Fellow Program, as well as by Dr. T.K. Sato from JAEA Tokai, Japan

Research Section ACID: Accelerator Physics and Integrated Detectors

ACID I

W. Barth

After commissioning of the demonstrator cryomodule equipped with a 217 MHz multi gap Crossbar H-mode structure (CH) and first testing with beam from the GSI High Charge State Injector (2017), two additional Demonstrator machine runs has been accomplished in 2018. The set up reached acceleration of heavy ions up to the design beam energy and beyond. The required acceleration gain of 0.5 MeV/u was achieved with heavy ion beams even above the design mass to charge ratio at maximum available beam intensity and full beam transmission. Systematic beam measurements with varying RF-amplitudes and -phases of the CH-cavity, as well as versatile phase space measurements for heavy ion beams with different mass to charge ratio has been performed. The worldwide first and successful beam test with a superconducting multi gap CH-cavity was a milestone of the R&D work in preparation of the sc cw heavy ion Linac project and other cw-ion beam application. Meanwhile many experiences have been gained in design, fabrication and operation of sc CH-cavities and the associated components. Newly developed beam instrumentation, as a cold beam position monitor, an advanced beam transformator for cw-application (DCCT) and a bunch structure monitor (Feshenko monitor) have been developed, built and tested with heavy ion beam.

A revision of the Linac layout was envisaged. Optimized cavity layouts resulted in modified voltage distributions. Furthermore, the layout - now with three CH-cavities and a rebuncher per cryo module - has been specified with more details. It features high acceleration efficiency with longitudinal and transversal stability, as well as a straightforward energy variation. It can easily be achieved by varying the applied RF-voltage or the RF-phase of the amplifier. Highly charged ions will be accelerated from 1.4 MeV/u up to 3.5- 7.3 MeV/u. The newly developed design is sufficient to accelerate light up to heavy ions ($1 \leq A/q \leq 8.5$). It is already confirmed experimentally that CH-cavities with equidistant rf-structure potentially could accelerate ions up to beam energies even beyond the design limit.

An advanced cryomodule, comprising demonstrator cavity and two new short CH-cavities, a sc-rebuncher cavity and two superconducting solenoids is already in preparation: The first short cavity with a revised design, has been succesfully tested at a vertical test cryostat confirming impressively the high gradient capabilities of sc CH-cavities. A second cavity will be delivered for rf-testing before end of this year and the rebuncher is going to be ordered. A new 5 m long cryostat is now ready for ordering, specifications for solenoids, rf-couplers, vacuum systems and rf-amplifiers are fixed, ordering is foreseen for early next year. A newly developed bunch structure monitor is still in the manufacturing process.

At GSI the test demonstrator area will be extended for housing the advanced cryomodule. The design is already fixed, as well as a new area for set up the rf-amplifiers, control racks, an rf-test lab and for storage capabilities. Two 4.5 t (22.5 degree) dipole magnets (recently transfered from CERN to GSI) will be renewed for insertion at the cw-linac transport line. The Link to the GSI cryo infrastructure will be installed in January 2019, supplying the test area as well as the cw-Linac, the accompanying LHe-transfer line will be ordered soon. The new infrastructure for SRF R&D has been set up at the HIM. Beside a radiation shielded test area, the main feature is a 155 m^2 cleanroom facility with its key components: An Ultrasonic bath and a conductance rinse, a High Pressure Rinsing device and a 120°C vacuum oven. The equipment is now set up and potentially suitable for CH- and other SRF-cavitiy preparation and testing.

ACID-II

Kurt Aulenbacher

ACID-II is mainly performing R&D work concerning electron cooling for the PANDA experiment at the upcoming HESR storage ring. The antiprotons in this ring will circulate with a beam energy of almost 15GeV thus requiring an electron beam energy of nearly 8MeV. Such an energy has so far not been achieved with an electron cooler and the challenge is even increased by the fact that currents of the order of Amperes are required. In addition, the beam has to be immersed in a continuous longitudinal magnetic field. So far the device which operates at the highest energy is the COSY-cooler that was installed by Budker institute Novosibirsk (BINP) and is designed for voltages of 2MV. In cooperation with BINP, ACID-II is aiming to remove a major obstacle for higher energies, namely the potential free powering of the solenoid channel in the several meters long acceleration and decelleration stage.

We have made cooperation agreements with BINP to develop a potentially game changing device for electrostatic accelerators, namely the generation of potential free electrical power via gas turbines. Besides the production of much more electrical power than available with conventional devices, the strongly cooled exhaust gas of the turbines offers improved conditions for thermal management. Turbines were tested successfully at HIM in the past and BINP has developed a prototype stage for 600kV which incoorporates a solenoid as load.

In winter 2018 a successful acceptance test took place at BINP during which the operation of stage was demonstrated. The absence of a pressure vessel limited the operating voltage to 200kV. Meanwhile HIM Mainz has designed a suitable pressure vessel and we have started the procurement. A compressor unit which is able to power three turbines of 5kW power each is in place and has been succesfully set into operation. The prototype stage was transported to HIM in Mai 2018.

In September 2018, a team of BINP specialists re-assembled the stage in the HIM experimental hall. After a very rapid installation process the device was swiftly set into operation and has been succesfully and reliably operated with the turbine drive.
End of 2019 we plan the installation of the stage in the pressure vessel, which should allow to obtain 600kV operation. Medium term plans will go in the direction to cascade two stages and to equip them with three turbines, the additional turine will serve for the electron source and collector. This will represent a full “1:6” scale HESR cooler prototype operating with ample electrical power to focus the beam and to generate auxiliary power for the electron source and the collector. In parallel we continue the work on minimal invasive beam diagnostics with respect to ion trapping and the Thomson laser scanning method.
Further activites of the ACID-II section concern the minimal invasive diagnostics of the high power beam and dynamical effects such as the ion-trapping process by space charge.

Research Section THFL - Theory Floor

Hartmut Wittig

Section THFL addresses a wide range of subjects in hadron and nuclear physics, using state-of-the-art theoretical tool such as QCD factorisation, Lattice QCD and nuclear effective field theory. Activities are focussed on hadron structure, hadron spectroscopy, nuclear effects in muonic atoms, and studies of the QCD phase diagram.

In **Hadron Phenomenology**, highlights of recent research include the analysis of radiative decays of P-wave charmonia, χ_{c1}, using the QCD factorisation approach. In particular, the colour-singlet contributions to the helicity amplitudes with polarised vector mesons in the final state have been determined. The role of the colour-octet contributions may be elucidated using future data for radiative decays of the χ_{c2}. The production of a tensor glueball G_2 was studied in the reaction $\gamma\gamma \to G_2\pi^0$. Within the collinear factorisation approach it was shown that the cross section is dominated by the production of a glueball in the tensor polarisation. The corresponding cross section may be observed in the upcoming Belle II experiment. Forward light-by-light scattering sum rules applied to charmonium states imply a cancellation between contributions from charmonium bound state and those from the continuum above the $D\bar{D}$ threshold, for which we provide a duality estimate. A combined analysis of these sum rules provides a prediction for the unmeasured $\gamma^*\gamma$ coupling of the $\chi_{c1}(1P)$ state.

Research highlights in **Lattice QCD** include the first study of the conjectured *H* dibaryon based on the Lüscher quantisation condition: a combination of high-quality data computed using the “distillation” technique and different kinematical situations allowed – for the first time in the case of a multi-baryon – for the determination of the binding energy from the pole of the scattering amplitude. It was found that the binding energy is smaller compared to previous naïve estimates. In a next step, the calculation will be extended to other dibaryons, such as the deuteron and the dineutron. The Lüscher formalism was also extensively used to study the pion form factor in the timelike regime, which plays an important role in current efforts to determine the hadronic vacuum polarisation contribution to the muon $(g-2)$. Another major activity in lattice QCD is the calculation of nucleon form factors and charges with controlled systematic errors. Accurate results for the axial, scalar and tensor charges, as well as for moments of parton distribution functions have been obtained. In the case of the axial charge and the average momentum fraction, our new results are in good agreement with experiment, as all sources of systematic error are well controlled.

Following the appointment of Sonia Bacca as professor in theoretical physics, a new research focus in **Nuclear Theory** was added to the activities of THFL. The goal is to provide first-principles calculations of nuclear structure and reactions, with fully quantified uncertainties, using state-of-the-art few- and many-body methods. Highlights of the past year include the calculation of nuclear structure corrections in muonic atoms, in particular the inclusion of both systematic and statistical uncertainties in muonic deuterium, and the improved coupled-cluster calculation of the electric dipole polarizability in ^{48}Ca.