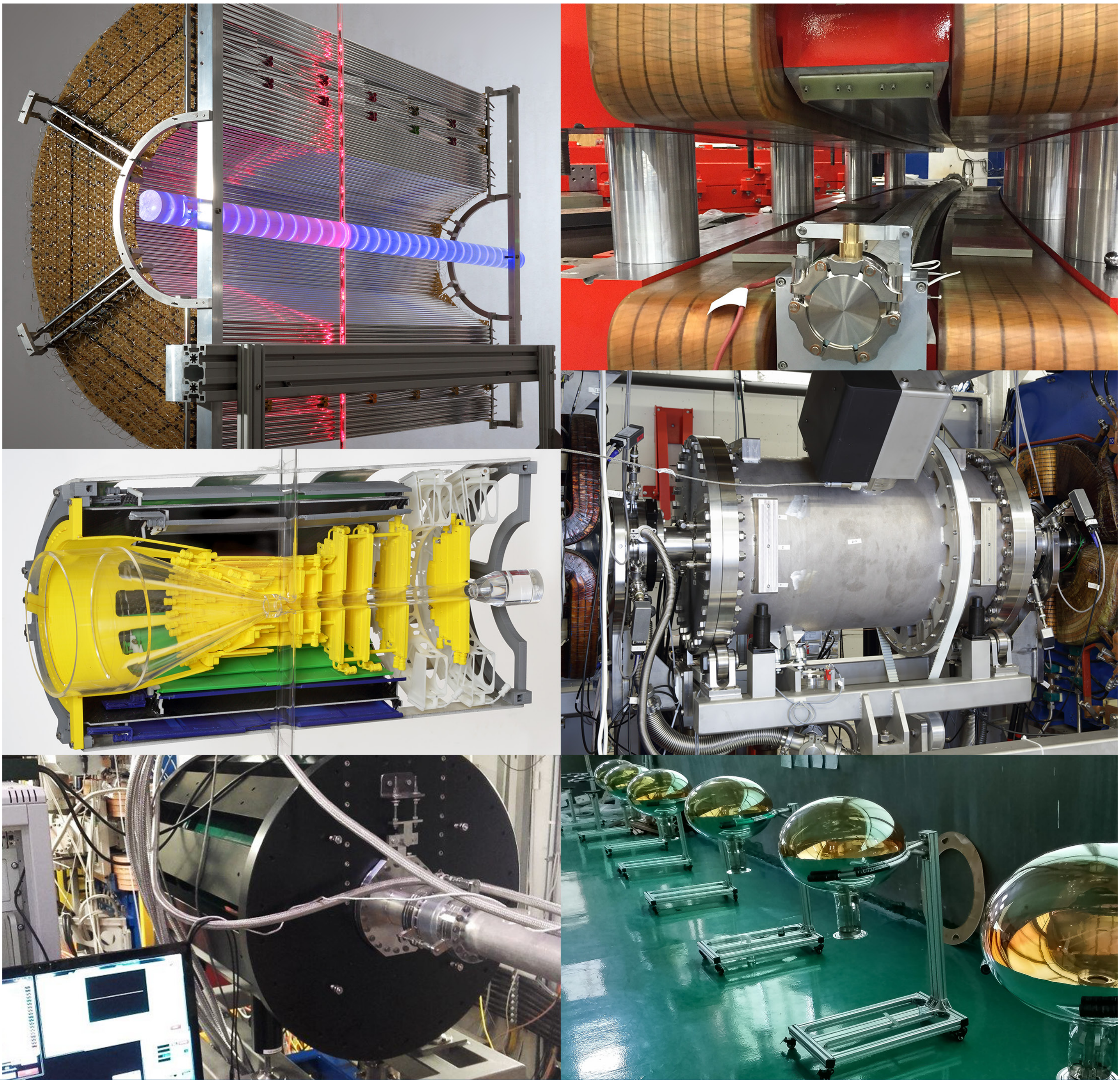

# ANNUAL REPORT 2017

## Institut für Kernphysik • COSY

**Jül-4408**

Mitglied der Helmholtz-Gemeinschaft

JÜLICH
Forschungszentrum

Berichte des Forschungszentrums Jülich 4408

# Annual Report 2017

## Institut für Kernphysik / COSY

**DIRECTORS AT THE IKP:**

| | |
|---|---|
| **Experimental Hadron Structure (IKP-1):** | **Prof. James Ritman (managing director)** |
| **Experimental Hadron Dynamics (IKP-2):** | **Prof. Hans Ströher** |
| **Theory of the Strong Interactions (IKP-3/IAS-4):** | **Prof. Ulf-G. Meißner** |
| **Large-Scale Nuclear Physics Equipment (IKP-4):** | **Dr. R. Gebel** |



**Cover picture:**

The title page shows pictures of components related to some activities at IKP. The upper left photo shows a part of the straw tube detector (STT) for PANDA and below is a model of the PANDA micro vertex detector (MVD) which are the essential components for particle tracking. At the top on the right is a photo of a dipole for HESR, the high energy storage ring at FAIR. The IKP is responsible for the design, production and in future its installation and commissioning. Below is the RF Wien filter of the JEDI experiment for the measurement of an electric dipole moment (EDM) by the rotation of the polarization vector due to an electric field. At the bottom on the left is a picture of the "Sibirian Snake", a solenoid magnet which rotates the spin needed for spin filter measurements with logitudinal spin direction. And the bottom right photo shows the setup used to test photomultpliers for the neutrino detector JUNO which is under construction in China.

# Contents

# Preface

This year‘s annual report deviates from the usual IKP annual report because we want to exploit the effort entered into the preparation of the report for the POF evaluation. The report for the evaluation of the IKP activities within the project oriented funding of the Helmholtz association was one of the most important activities in 2017. The report covers nearly all achievements of 2017 and and thus it is highlighted in this annual report, and has been enhanced by including additional information.
The highlights of 2017 include further achievements towards electric dipole measurements (JEDI), progress in the preparation of the PANDA detector and in the HESR component construction, results from COSY hadron physics experiments, strong increase of IKP contributions to neutrino physics experiments, a strong incresae in the CLAS analysis and preparation of phase-0 FAIR experiments at HADES.
From the finished COSY experiments various scientific results have been produced, such as investigations of the properties of $\eta$ mesons at WASA, and continued analysis of data related to the d*(2380) resonance and the charge symmetry breaking reaction $dd \rightarrow {}^4\mathrm{He}\pi^0$. During the time before PANDA begins to produce data, the participation in the CLAS data taking and analysis at JLAB is ongoing and for the phase-0 experiments at FAIR a straw tube detector system for the HADES detector at GSI is being built.
The preparations for FAIR are ongoing on the accelerator as well as on the experiment side. All dipoles for HESR were now tested and shipped to Darmstadt. The implementation of the HESR project is on time and in budget and also the developments for PANDA are progressing well.
The activities towards electric dipole measurements achieved further steps in the aim of ultimate precision in polarization measurement and manipulation by controlling the spin precession rate and phase with a polarization feedback.
The neutrino physics activities were extended with contributions to running (Borexino) and future (SOX, JUNO) experiments.
Our activities within the different POF programs were very positively evaluated. The committee was impressed by the scientific program and realized that we deliver essential contributions for the various program topics. Our activities were considered as forefront, crucial and outstanding. This very good evaluation result is due to the work of all IKP colleagues during the last years. In spite of the unclear future of IKP the colleagues stayed highly motivated which was impressively demonstrated in the presentations for the POF review committee.
I would like to thank all IKP members for their work resulting in the excellent POF midterm evaluation and the support from the colleagues of the infrastructure departments and our national and international collaboration partners.

Jülich, May 2018

James Ritman

## Report for the POF evaluation, extended and adapted

### 1. Overview

The Nuclear Physics Institute (Institut für Kernphysik (IKP)) is one of the (ten) research institutes of Forschungszentrum Jülich. It consists of four research units and a general service division as shown in the following organizational chart.

| **Nuclear Physics Institute**<br>Managing Director Prof. James Ritman | | | |
|---|---|---|---|
| **IKP-1**<br>Experimental Hadron Structure<br>**Prof. James Ritman**<br>14 scientists,<br>4 PhDs,<br>3 technicians* | **IKP-2**<br>Experimental Hadron Dynamics<br>**Prof. Dr. Hans Ströher**<br>14 scientists,<br>9 PhDs,<br>2 technicians* | **IKP-3/IAS-4**<br>Theory of the Strong Interactions<br>**Prof. Dr. Ulf-G. Meißner**<br>13 scientists,<br>4 PhDs | **IKP-4**<br>Large-Scale Nuclear Physics Equipment<br>**Dr. Ralf Gebel**<br>24 scientists,<br>3 PhDs,<br>22 technicians* |

| **IKP-TA**<br>Technical and Administrative Infrastructure | | |
|---|---|---|
| Electronics Lab / Construction / Mechanical Workshop<br>**Dr. Thomas Sefzick**<br>13 staff members* | Radiation Safety<br>**Dr. Olaf Felden**<br>3 staff members* | Administration<br>**Gisela Roes, Dipl. Kfr. Anke Kelleners**<br>6 staff members* |

** number of FTE as of December 31, 2016*

The research units within IKP contribute to the programs *Matter and the Universe* (MU), *Matter and Technologies* (MT) as well as to FAIR (see also Section 4). An overview is given in Figure 1 depicting the personnel (left) as well as the corresponding participation in terms of the funding recommendation of the Helmholtz Senate for the year 2016.

In addition to the two experimental and the accelerator research units, IKP has a theory research unit, which is at the same time part of the Institute for Advanced Simulation (IAS) and therefore financed in the PoF-program *Supercomputing & Big Data* (SCBD) within the research field Key Technologies. At this point we would like to stress the intense and fruitful collaborations between the experimental and the theoretical groups – whenever appropriate, contributions and results from IKP-3/IAS-4 will be mentioned. Dr. Ralf Gebel is the acting director of IKP-4, after Prof. Mei Bai left IKP to move to the GSI (*Gesellschaft für Schwerionenforschung*) earlier this year.

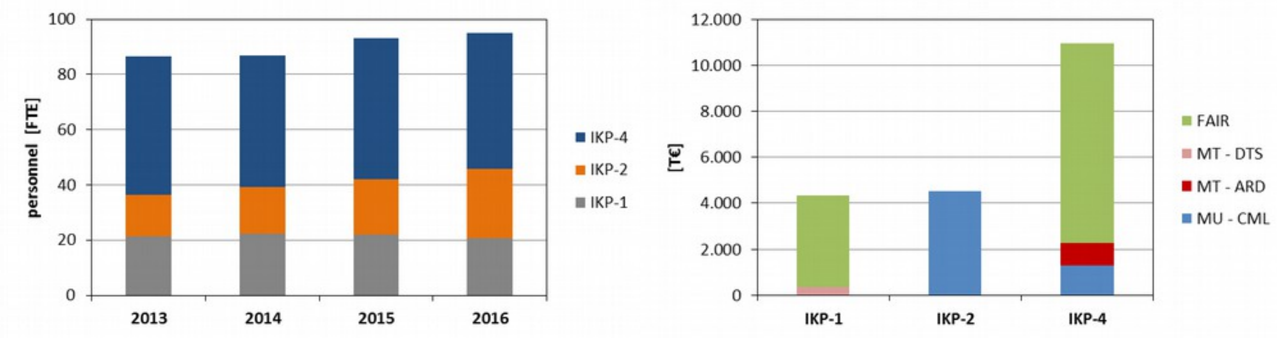


*Fig. 1: Overview of the research units of IKP under review. Left: core funded personnel given in Full Time Equivalents (FTE); Right: funding recommendation 2016 of the Helmholtz Senate for each research unit and per program/topic.*

## 2. Introduction

IKP was formally founded in 1961, but it actually started operating in Jülich in July 1967 after the buildings and early infrastructure – most importantly the isochronous cyclotron JULIC ("JUelich Light Ion Cyclotron") – had been finalized. For many years, JULIC provided proton and deuteron beams for nuclear physics experiments. By the end of 1986, a new project – COSY ("COoler SYnchrotron") – was accepted by the supervisory board (*Aufsichtsrat*) of KFA (*KernForschungsAnlage*) Jülich, as Forschungszentrum Jülich was known at the time. In 1988, the foundations of COSY were laid and its official inauguration was in 1993. The first beam from the injector JULIC was provided in 1992; experiments started in 1995 at six first-generation detector systems (Big Karl, COSY-11, COSY-13, EDDA, MOMO and TOF). In the following years, new equipment was added as second-generation internal (ANKE, PAX, WASA) and external (ENSTAR, GEM, HIRES, JESSICA, NESSI, PISA) detector facilities. Over the past 23 years, COSY – with the guidance of a "Program Advisory Committee" (PAC) and more recently the "COSY Beam Advisory Committee" (CBAC) – has delivered about 100.000 hours of beamtime, mostly for hadron physics experiments, which were executed by up to 450 national and international users. Instrumental for the success of COSY and its physics program was support from the surrounding universities in form of the user-group "CANU" (*COSY-Arbeitsgemeinschaft Nordrhein-Westfälischer Universitäten*), including theoretical work. Equally important was (and still is) the technological collaboration between IKP's experimental research units and the local mechanical and electronics workshops as well as the corresponding central institutes (ZEA).

IKP and JULIC/COSY have always also provided service to other institutes of Forschungszentrum Jülich, most notably fast extracted proton beams for spallation-neutron tests and, still today, cyclotron beams for radionuclide production. Presently, COSY is operational for about 5000 hours per year. It remains the workhorse of the experimental scientific program at IKP with almost two thirds of the beam time being used for FAIR ("Facility for Antiproton and Ion Research") accelerator equipment and detector tests and for JEDI ("Jülich Electric Dipole moment Investigations"). The remaining beam time is used for machine development, set-up for experiments, irradiations and tests, e.g., in connection with future neutron-sources.

## 3. **Research**

IKP conducts fundamental research in the fields of nuclear and elementary particle physics. The physics program addresses two big questions of modern physics, namely the matter-anti-matter asymmetry of our universe ("Fate of antimatter?" – this is also the motif of JARA-FAME – see below) and a basic understanding of the building blocks matter is comprised of ("How does nature make hadrons and nuclei?"). Both issues are tied together by the quest to understand "Why do we exist at all?" The pursuit to investigate and answer these questions is a central element of the strategy/mission of the Helmholtz Association. The program is planned and carried out through long-term commitments within large international collaborations. It is also intimately connected to the theory activities of IKP-3/IAS-4.

The major part of the experimental program is conducted at the cooler synchrotron and storage ring COSY on our campus at Forschungszentrum Jülich. COSY consists of both unpolarized and polarized sources, the injector cyclotron JULIC and the cooler storage ring. COSY is a unique facility on a world-wide scale and has the capability to provide phase-space cooled proton and deuteron beams with momenta up to 3.7 GeV/c to internal as well as external target stations. Cooling, beam-diagnostics, spin-manipulation and extraction techniques have been developed and exploited over the years for hadron physics for not only unpolarized but also single and double polarized experiments. At the end of the second period of the program-oriented funding (PoF II) in 2014, IKP together with the management of Forschungszentrum Jülich has decided to terminate the hadron physics program at COSY. Since then, COSY is no longer an official Helmholtz User Facility (so-called LK II) although we still provide beam for internal and external users.

For PoF III, starting in 2015, IKP has focused its scientific portfolio on two topics:

(i) Developments concerning FAIR, which is currently under construction (the symbolic groundbreaking took place in July 2017) at GSI (Darmstadt), with the two projects HESR ("High Energy Storage Ring") and its internal detector system PANDA ("Proton Antiproton Detector at Darmstadt").

(ii) Research and development for a charged-particle storage ring EDM ("Electric Dipole Moment") search (JEDI).

For both activities, COSY is essential as an R&D and proof-of-principle facility. The transition was very well received in the PoF III review; in particular the panel stated that it "*fully endorses this first phase [of R&D at COSY] to establish the feasibility of an EDM measurement by the end of* PoF III". It should be noted that FAIR (except for the part concerning Helmholtz-Institut Mainz (HIM) and the Helmholtz-Institut Jena (HIJ)) was not part of the PoF III review – thus no recommendations were made concerning our FAIR activities. As a new initiative of the research field, the program *Matter and Technologies* (MT) was started in PoF III to bundle the technological competences of the different Helmholtz Centers in two topics: (i) *Accelerator Research and Development* (ARD) and (ii) *Detector Technology and Systems* (DTS). In both topics, IKP (along with ZEA-2 in DTS) is involved.

In addition to these major projects – based on the know-how and equipment which is available in our institute as well as to complement our research – IKP also pursues the following smaller research topics (also see sections below):

(i) Hadron physics with electromagnetic probes (CLAS at Jefferson Lab, USA),

(ii) exotic atoms (pionic hydrogen and deuterium),

(iii) polarized fusion,

(iv) polarized molecules,

(v) polarized antiprotons (PAX), and

(vi) time-reversal invariance violation (TRIC/TIVOLI).

The accelerator group contributes to various accelerator projects worldwide:

(i) FAIR (in addition to HESR),

(ii) NICA at the "Joint Institute for Nuclear Research" (JINR, Dubna, Russia),

(iii) ELENA (CERN), and

(iv) bERLinPro at the Helmholtz-Zentrum Berlin (HZB).

IKP research is conducted as teamwork involving the IKP research units (including theory IKP-3/IAS-4) and large international collaborations, most notably PANDA and JEDI, and it is embedded in the Jülich-Aachen Research Alliance (JARA), section *Forces and Matter Experiments* (FAME), with RWTH Aachen University. In this latter context a group working in neutrino physics has recently been established to complement the fate-of-antimatter aspect of our work. This group, led by Prof. L. Ludhova, is funded via the Helmholtz Recruiting Initiative and is a member of the Borexino (located in Gran Sasso, Italy) and JUNO (Jiangmen, China) collaborations (see below, Section 4.7).

The Institute for Advanced Simulation – Theory of the Strong Interactions (IAS-4) performs research in one of the most demanding fields of contemporary physics, namely the emergence of structure in Quantum Chromodynamics (QCD), the gauge field theory underlying strong interaction physics. The research comprises topics in particle, hadronic and nuclear physics, and most notably, research on hadron resonances, nuclear lattice and lattice QCD simulations, and hadronic molecules. Further research topics are the extraction of hadron-hadron scattering lengths from final-state interactions and multi-hadron systems, coupled-channel dynamics of meson-baryon scattering and pion photo-production, baryon-baryon interactions in chiral EFT, precision calculations in few-nucleon systems and electric dipole moments of hadrons and light nuclei, and strongly-correlated phenomena in low-dimensional systems.

## 4. Scientific Results

### 4.1. Introduction

As stated above, the two experimental research units (IKP-1, IKP-2), the accelerator research unit (IKP-4) and also the theory research unit (IKP-3/IAS-4) have all been closely collaborating on the major, partially completed, research projects of the institute in the past and they continue to do so for the ongoing ones – thus, it was felt to be appropriate to present the scientific results in terms of projects rather than research units.

The experience acquired during the hadron-physics period at COSY – from the operation of a storage ring with an internal beam and its extraction and the spin manipulation of polarized beams for carrying out internal and external experiments – has been invaluable for our new projects HESR, PANDA and JEDI.

For most of the projects listed above, the cooperation of IKP with the two Central Institutes for Engineering, Electronics and Analytics (ZEA, *Zentralinstitut für Engineering, Elektronik und Analytik*) of Jülich – ZEA-1 ("Engineering and Technology") and ZEA-2 ("Electronic Systems") – is indispensable. Both for PoF II and PoF III, bilateral agreements on the allocation of resources have been established.

### 4.2. FAIR: High Energy Storage Ring (HESR)

**Introduction and Timeline**

The HESR is a central part of the upcoming FAIR accelerator complex at GSI (Darmstadt). Originally, HESR was designed to accelerate and store antiprotons in the momentum range between 1.5 GeV/c and 15 GeV/c, but meanwhile its performance has been extended to also provide heavy ion beams with momenta between 0.6 and 5.8 GeV/c. IKP-4 is leading all activities from the design to the construction of the HESR except for the building and its infrastructure. The total investment for all accelerator components amounts to more than € 64 million. Although the financial responsibility has been split between Forschungszentrum Jülich and FAIR, IKP-4 is responsible for the technical aspects of the complete accelerator. Apart from Jülich, there are contributions from FAIR, GSI, and partner institutions from Romania and Slovenia. Figure 2 shows a schematic overview of the HESR layout, which has a circumference of 575 m. The locations of the PANDA detector as well as the KOALA and the SPARC experiments (see below) are also indicated:

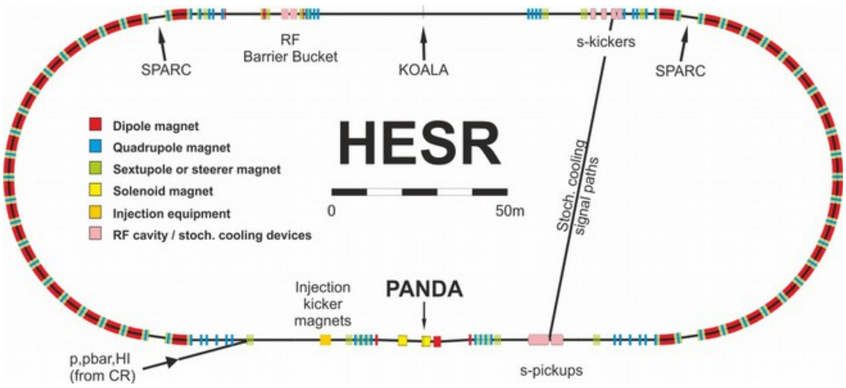


*Fig. 2: Schematic overview of the planned HESR layout including the positions of the PANDA detector and the KOALA and SPARC experiments.*

Starting already during PoF II, the HESR has been the largest German in-kind contribution to the FAIR facility. The activities of IKP comprise design and manufacturing of the components and, in future, installation and commissioning of HESR. All components have been investigated in detail to determine their specifications. Only critical components required in small numbers, such as the stochastic cooling tanks, are manufactured on-site in Jülich. All other components, in particular magnets and power supplies, are produced elsewhere, but closely monitored during fabrication by IKP-4 in close collaboration with ZEA-1. Originally, the installation of the HESR accelerator components at FAIR was scheduled to begin at the end of 2018. A new schedule has shifted the ground breaking for the HESR tunnel to 2020, the release of the buildings to users to the end of 2021, and the start of the commissioning of the facility to the end of 2022. This schedule depends upon the progress of the buildings construction: HESR is one of the last buildings that will be built on the FAIR campus. The IKP-4 contribution to FAIR, however, is expected to be completed on-time (as well as in-budget).

### Beam Dynamics

In order to guarantee the smooth commissioning and operation of the HESR the ion-optical design has been optimized with beam-dynamics simulations. Ongoing measurements of the magnetic fields of the bending dipoles and quadrupoles already produced provide a more precise insight into the magnetic-field Fourier components of these elements. These new results are used to update the existing ion-optical setting including dynamic aperture calculations.

[Proc. IPAC´16, Busan (Korea), MOPOY002; doi; Proc. IPAC'17, Copenhagen (Denmark), WEPIK067; doi]

### Re-design of the RF-system

A redesign of the acceleration system was required after shifting the originally planned "Recuperated Experimental Storage Ring" (RESR) – which was intended as an accumulator for antiprotons before their injection into the HESR – to module 6 of the FAIR "Modularized Start Version" (MSV) and thus to a later stage of the full facility. Using a scheme of longitudinal stacking, the HESR capabilities were extended to cover the accumulation function previously assigned to RESR. Replacing water cooling by air-cooling in combination with high permeability cores allows the multi-harmonic cavities of HESR to be operated by semiconductor amplifiers. In this context the feasibility of the selected air cooling concept has been demonstrated. The cavities are designed to generate waveforms for acceleration and the so-called "barrier-bucket" mode, which is mandatory for the injection scheme. The feasibility of the longitudinal-stacking injection has also been shown in COSY experiments.

[Proc. IPAC´14, Dresden (Germany), WEPRO064; link]

### Phase-space Cooling

One technological highlight of the developments for HESR at Forschungszentrum Jülich is the use of newly invented antennas for the stochastic cooling pick-ups and kickers, which avoid movable electrodes. This cooling method is required for HESR to deliver particle beams with highest phase space density to the experiments. In the framework of the HESR-project for FAIR, these completely new stochastic cooling structures have been developed in close collaboration between IKP-4 and ZEA-1 of Forschungszentrum Jülich and CERN. Note that the corresponding expertise during more than 25 years of work in the field of stochastic cooling has been developed in many collaborations, e.g., with Nihon University (Japan), CERN, the "Joint Institute of Nuclear Research" (JINR) in Dubna (Russia), GSI Darmstadt and the "Institute of Modern Physics" (IMP) in Lanzhou (China).

Stochastic cooling at HESR is not only used to reduce beam size and momentum spread during the experiment, but also to accumulate antiprotons due to the postponed RESR. Thus stochastic cooling is one of the most important key-components of the HESR. The cooling structures were initially operated in a small test tank in a first version comprising 16 rings and tested at COSY as pickup only, later also as pickup and kicker at the "Nuclotron" (JINR, Dubna), where longitudinal cooling was successfully demonstrated. The amplifiers needed in HESR to generate the feedback signal will make use of the latest generation of semiconductor developments using gallium nitride (GaN). Currently, one pick-up tank operating at 20 *K* and one kicker tank are completely assembled. To verify the amplifier performance they are presently installed at COSY. It should be stressed that the small cooling system mentioned above also acts as a test-bench for the NICA ("Nuclotron-based Ion Collider fAcility") project, where the same structures can be used. This success has been acknowledged by JINR by awarding the "Encouraging Prize" for the „Development and Start-up of the Stochastic Cooling System for Nuclotron Ion Beams at the NICA Accelerator Complex" to the scientists involved, among them members of IKP-4. Besides JINR, IMP also has great interest in these new and unique structures.

Simulations of the stochastic cooling process have shown that stochastic cooling alone is not sufficient to reach the beam requirements at HESR due to the energy loss in the thick PANDA target. However, together with a “barrier-bucket” cavity – to compensate the mean energy loss – stochastic cooling was successfully tested at COSY with targets similar to those which will be used in PANDA. New methods for ripple control of the barrier-bucket signal, which allow suppressing the formation of micro-bunches during cooling, have been developed at IKP-4.

In parallel to the experimental investigations, the theoretical description of the stochastic cooling process has been refined, for the first time taking into account the possible complement by electron cooling as well as barrier-bucket operation. The results were used to confirm that operation of the HESR with heavy ions up to uranium is feasible. The developed codes were benchmarked against measurements in COSY.

[Proc. IPAC'17, Copenhagen (Denmark), WEPVA050; doi; Report FZJ-2016-02157, ISBN 978-3-95806-127-9]

Work and progress in (high energy) electron cooling is reported in Section 4.5 below.

**Project Coordination and Status**

The HESR synchrotron with its large diversity of installed components, delivered from many different international partners within the HESR consortium, presents a challenge to both the project coordination and to the goal of staying on-time and in-budget. Regular supervisory meetings monitor progress in order to ensure the success of the project. Together with the ZEA institutes and other partners a rigid ISO (“International Organization for Standardization”) quality-control has been implemented. Key components such as power converters for the quadrupole magnets, for the chicane dipoles, and for the injection dipole, as well as RF semiconductor amplifiers, and RF ferrite cores have already been delivered to Jülich. The power converters for sextupole and orbit correction magnets are awaiting the release of series production. They are part of the Romanian in-kind contribution to FAIR. The injection kicker system (magnets and semiconductor pulsers) has reached the required rise and fall time as well as the amplitude of the magnetic field inside the vacuum tank.

Significant milestones in component design and fabrication have been reached. About 55% of the project investment money is bound by contracts; more than 45 % of it has been spent. All main magnets (dipoles and quadrupoles) have already been delivered to Jülich. After entrance tests and preassembly, the components are currently transported to a storage space close to the GSI campus for later installation in the HESR tunnel. All dipoles have arrived in Jülich and about 65 % of the dipole magnets have already been assembled and transferred to Darmstadt.

Detailed planning of all work packages on various levels is still ongoing, especially 3D space management in the tunnel. Presently, the focus is on the interface with the infrastructure planning at FAIR (air conditioning, cooling water, cabling, sequence of installation etc.). Our current plan aims to have as many as possible of the approximately 200 support structures for the magnets ready for installation by 2019. The power converters for the main dipole magnets will be ordered just in time to allow commissioning with the installed magnets by 2021/22. The vacuum pumps will be mounted after the sub-assemblies have reached their final positions, foreseen in 2022.

The cooperation with PANDA and SPARC (“Stored Particles Atomic Research Collaboration”) is well established to ensure the smooth integration of both experiments into the HESR. For PANDA, this implies in particular a close participation with ZEA-1, e.g., for the mechanical design of the vacuum pipes in the target area.

[Proc. IPAC´15, Richmond (USA), THPF034; doi]

### 4.3. FAIR: Proton Antiproton Detector at Darmstadt (PANDA)

One of the main scientific pillars of FAIR will be research with high-energy antiprotons. In addition to the activities mentioned above for the HESR storage ring, Forschungszentrum Jülich is leading efforts to design, construct and later operate the PANDA experiment, the major internal experiment at HESR. IKP has taken over major responsibilities within the PANDA collaboration on a number of tasks, mostly related to charged particle tracking, computing and physics analysis. Furthermore, IKP-4 is responsible for the beam pipe and interaction region and the central institutes ZEA-1 and ZEA-2 are responsible for numerous mechanical aspects of the detectors, as well as the detector readout systems. We recently published a popular overview of the project for a wide audience.

[Nucl. Phys. News, 27,3, 24-29, (2017); doi]

#### Micro Vertex Detector (MVD)

The MVD directly surrounds the interaction point. Its task is the precise tracking of charged particles with a point resolution better than 100 µm. Based on this tracking information it is possible to identify long living particles with a decay length of the order of 100 µm. This capability is essential for PANDA's open and hidden charm physics program. In addition, the overall momentum resolution is improved by about a factor of 2 compared to stand-alone tracking with only the Straw-Tube-Tracker (STT, see below).

The MVD faces the most severe operation conditions in PANDA due to its proximity to the interaction point. It has to operate with the highest track density, the highest radiation dose and very stringent requirements for the radiation length of the detector. To cope with these requirements two different detector technologies will be used: a silicon pixel detector with about 10 million channels in the inner part, and a silicon strip detector with about 200 thousand strips in the outer part. The detectors are arranged in four barrel layers around the interaction point, accompanied by six disk stations in the forward direction. Three institutions are working together to build the MVD: the INFN Torino, the University of Giessen and Jülich. The tasks of Forschungszentrum Jülich are to develop:

i. The support and cooling structures of the strip part,
ii. The forward strip disk stations and
iii. A flexible high rate readout system to test the different front-end electronics prototypes for the pixel and strip part.

Several prototypes of the strip support structures have been produced together with the ZEA-2 and the IKV (*Institut für Kunststoffverarbeitung*) at RWTH Aachen University. Extensive thermal tests of these structures have been performed which showed the suitability of the used materials and the cooling concept. The wedge-shaped silicon strip sensor for the disk stations has already been designed, produced and tested. Novel free-running front-end electronics for strip detectors called PASTA ("PANDA Strip ASIC") were developed and successfully tested at COSY with proton beams with different beam momenta. The "Jülich Digital Readout System" has been used and continuously upgraded over several years to test both the pixel readout ASIC TOPIX ("Torino Pixel") as well as PASTA.

#### Straw-Tube-Tracker (STT)

The main tracking device for momentum reconstruction in the PANDA target spectrometer is the STT. It consists of about 4200 individual straw tubes, each measuring 140 cm in length and with an inner diameter of 1 cm. The tubes, made of very thin (<30 µm) aluminized Mylar film, are arranged in close-packed multi-layer modules, which are self-supporting at a gas overpressure of 1 bar. This specific IKP technology minimizes the materials budget for the detector by avoiding massive supports. IKP is responsible for the straw production and is developing, together with the central electronics institute (ZEA-2), a new electronic readout system that measures both the drift time and the collected charge within the tubes. Within the relevant time frame for this review the following status has been reached: the technical design report for the STT was approved in 2013 and the series production including quality control for all straw tubes was set up at IKP.

[Eur. Phys. J. A 49,2 (2013) 1; doi]

By the beginning of 2018, production will be completed with a total of 7000 assembled straws for the STT, test systems and spares. Currently, one complete sector with about 700 straws is being assembled with the complete readout electronics for a pre-series test of the full system in 2018. A major task for the STT is to also measure the specific energy loss in order to enable particle identification of protons, kaons and pions below about 1 GeV/c. Two different readout methods have been proposed: (i) time-over-threshold and (ii) pulse-shape sampling and integration. Both were successfully tested using the COSY beam. Currently larger pre-series setups are being built to study proton and deuteron beams in the range from 0.6 to 3.0 GeV/c to provide a correspondingly large range of specific energy loss from 5 to 50 keV/cm in Ar/$CO_2$ at 2 bar. The results of the beam tests in 2018 will determine which of these systems is realized for the STT.

### Phase-0 Experiments at HADES

In order to use some of the PANDA detectors before the full FAIR facility is ready, a sequence of so-called “Phase-0 experiments” is planned. One of these projects is to incorporate parts of the PANDA STT detection systems into the HADES experiment at GSI. They will be used to track particles emitted at low polar angles ($\Theta < 8^o$), thereby massively increasing the acceptance of HADES for baryons from hyperon decay. The goal is to measure the time-like transition form factors of excited hyperons such as $\Lambda(1520) \rightarrow \Lambda e^+e^-$ produced in proton-proton or proton-carbon reactions. The measurements are planned to begin by the end of 2018. IKP will provide one of the two straw stations and the whole electronic readout system for both forward tracking stations with about 1600 straw channels in total. As for science, the theory group provides benchmark predictions for these time-like form factors.

### Luminosity Detector (KOALA)

In order for PANDA to measure absolute cross sections with a relative precision of about 3%, elastic scattering in the Coulomb-nuclear interference (CNI) regime will be measured in parallel. Due to the small acceptance range of the planned luminosity detector, the biggest source of systematic error arises from the poor quality of existing data on the shape of the differential cross section spectrum. To address this, IKP has built and commissioned a recoil detector (KOALA, “Key experiment fOr PANDA Luminosity determinAtion”) at COSY to measure the large angle partner in the elastic scattering. The next step is to install the forward arm in order to lower the threshold into the purely Coulomb region for an essential cross check that eliminates many sources of systematic error.

[Eur. Phys. J. 50, A: 156 (2014); doi]

### Computing

PANDA will run without a first level hardware trigger in contrast to most current particle physics experiments. The reason for this is that the signatures of many interesting physics channels are so similar to their background that no easy separation between the two is possible based on information from a limited number of sub-detectors. Nevertheless, PANDA must reduce its data size before storage by a factor of 1000 otherwise it will exceed its available storage capacity of 1 PByte per year. Therefore, PANDA will use an event filter based on the online processing of the complete data set of all sub-detectors. This requires the processing to be on average as fast as the production of the data. IKP is strongly involved in developing the reconstruction system, especially the online tracking, which is one of the most demanding tasks in the data processing. The simulation framework of PANDA, called "PandaRoot", was extended to simulate continuous data streams from the sub-detectors to mimic the real data taking once PANDA is in operation. In addition, several different track finding and fitting algorithms have been developed and implemented both on CPUs and on GPUs and their performance was evaluated.

[J. Phys. Conf. Ser. 664:8, 082006 (2015); doi; J. Phys. Conf. Ser. 664:7, 072046 (2015); doi]

### Simulations

Ξ and Ω baryon spectroscopy has been identified as one of the key topics of the PANDA physics program during the first years of operation, as it combines high scientific importance with the competitiveness of the experiment even at luminosities significantly below the design value. Consequently, the activities in physics simulation and analysis at IKP have shifted towards feasibility studies addressing the Ξ excitation spectrum. In particular, the reaction $pp \rightarrow \Xi^{+}\Xi^{*-} \rightarrow \Xi^{+}\Lambda K^{-}$ and its charge conjugate channel with the Ξ(1690) and the Ξ (1820) as resonant states have been analyzed. As further topics, charmonium and charmonium-like states, the width of narrow $D_s^*$ states in threshold scans, the form factor of the $D_s$ semileptonic decay, and the ΔΔ component in the deuteron have been addressed in simulation studies using the "PandaRoot" software package. The theory group makes important contributions to the understanding of such exotic states.

[J. Phys. Conf. Ser. 742:1, 012028 (2016); doi]

#### 4.4. Matter and the Universe: Electric Dipole Moment (EDM) – JEDI-Collaboration

According to our present understanding, the early Universe contained the same amount of matter and anti-matter and, if the Universe had behaved symmetrically as it developed, every particle would have been annihilated by one of its antiparticles. One of the great mysteries in the natural sciences is therefore why matter dominates over antimatter in the visible Universe. The breaking of the combined charge conjugation and parity symmetries (CP-violation, CPV) in the Standard Model of elementary particle physics (SM) is insufficient to explain this and further sources of CPV must be sought. These could manifest themselves in electric dipole moments (EDMs) of elementary particles, which occur when the centroids of positive and negative charges are mutually and permanently displaced. An EDM observation would also be an indication for CPV beyond the CKM ("Cabibbo-Kobayashi-Maskawa") mechanism of the SM, frequently termed "physics beyond the SM" (BSM).

Investigations on different systems are required to pin down CPV sources and new proposals such as, e.g., JEDI aim to lay the foundations for the study of new CPV mechanisms by searching for EDMs of charged hadrons in a new class of precision storage rings. The EDM measurement principle, the time development of the polarization vector subject to a perpendicular electric field, is simple, but the smallness of the effect makes this an enormously challenging project. JEDI will develop the key technologies and achieve a first directly measured EDM limit for deuterons (and protons) at COSY. By this it will provide the basis for a possible new European flagship research infrastructure towards the ultimate scientific vision: finding an EDM as a signal for new physics beyond the SM and perhaps explaining the puzzle of our existence.

To advance further in terms of the required technology, steps in the direction of a precision storage ring with two counter-rotating beams are needed: the research environment of IKP, including COSY, again will provide the optimum foundation.

The following major milestones have been achieved during the reporting period:

(1) A new method to determine the spin tune was established and tested. In an ideal planar magnetic storage ring, the spin tune – defined as the number of spin precessions per turn – is given by $\nu_s = \gamma G$ (γ is the Lorentz factor, G the gyromagnetic anomaly). At 970 MeV/c, the deuteron spins coherently precess at a frequency of about 120 kHz in COSY. The spin tune was deduced from the up-down asymmetry of deuteron-carbon scattering. In a time interval of 2.6 s, the spin tune was determined with a precision of the order $10^{-8}$, and to $10^{-10}$ for a continuous 100 s accelerator cycle. This renders the new method a precision tool for accelerator physics; observing and controlling the spin motion of particles to high precision is mandatory, in particular, for the measurement of electric dipole moments of charged particles in a storage ring.

[Phys. Rev. Lett. 115, 094801 (2015); doi]

(2) A deuteron beam polarization lifetime near 1000 seconds in the horizontal plane of the magnetic storage ring COSY has been observed. This long spin coherence time was maintained through a combination of beam bunching, electron cooling, sextupole field corrections, and the suppression of collective effects through beam current limits. This record lifetime is required for a storage ring search for an intrinsic electric dipole moment on the deuteron at a statistical sensitivity level approaching $10^{-29}$ e·cm.

[Phys. Rev. Lett. 117, 054801 (2016); doi]

(3) The successful use of feedback from a spin polarization measurement to the revolution frequency of a 0.97 GeV/c bunched and polarized deuteron beam in the Cooler Synchrotron (COSY) storage ring has been realized in order to control both the precession rate (≈ 120 kHz) and the phase of the horizontal polarization component. Real time synchronization with a radio frequency (RF) solenoid made possible the rotation of the polarization out of the horizontal plane, yielding a demonstration of the feedback method to manipulate the polarization. In particular, the rotation rate shows a sinusoidal function of the horizontal polarization phase (relative to the RF solenoid), controlled to within a one standard deviation range of $\sigma$ = 0.21 rad. The minimum possible adjustment was 3.7 mHz out of a revolution frequency of 753 kHz, which changes the precession rate by 26 mrad/s. Such capability meets the requirement for the use of storage rings to look for an intrinsic electric dipole moment of charged particles.

[Phys. Rev. Lett. 119, 014801 (2017); doi]

(4) An extended paper entitled "Spin tune mapping as a novel tool to probe the spin dynamics in storage rings" has recently been published. It was motivated by the fact that precision experiments, such as the search for electric dipole moments of charged particles using storage rings, demand understanding of the spin dynamics with unprecedented accuracy. A new method based on the spin tune response of a machine to artificially applied longitudinal magnetic fields, called "spin tune mapping", has been developed. The technique was experimentally tested in 2014 at COSY and, for the first time, the angular orientation of the stable spin axis at two different locations in the ring has been determined to an unprecedented accuracy of better than 2.8 μrad.

[Phys. Rev. Accel. Beams 20, 072801 (2017); doi]

The IKP-3/IAS-4 has performed a number of benchmark calculations for the EDM of proton, neutron and light nuclei using lattice QCD simulations and chiral effective nuclear field theory.

### Preparations for a precursor experiment at COSY

For 2018, the JEDI collaboration plans a first measurement of the deuteron EDM at COSY. In a pure magnetic storage ring such as COSY, an EDM will generate an oscillation of the vertical polarization component. For a 970 MeV/c deuteron beam with the spin precession frequency of 120 kHz, a tiny amplitude is expected, e.g., $3 \cdot 10^{-10}$ for an EDM of $d = 10^{-24}$ e·cm. To allow for a build-up of the vertical polarization proportional to the EDM, a radio-frequency (RF) Wien-filter has to be operated. A prototype was successfully installed and operated in COSY in 2014. A new device with a stronger magnetic field (0.05 T·mm) was developed and constructed together with the *Institut für Hochfrequenztechnik* (IHF) at RWTH Aachen University and ZEA-1 in Jülich. This new RF Wien-filter was installed in COSY in May 2017. A first commissioning run was successfully conducted in June 2017.

[Nucl. Instr. Meth. A 859, 52 (2017); doi; Nucl. Instr. Meth. A 828, 116 (2016); doi]

### Physics-Beyond-Colliders (PBC) Initiative

Triggered by the workshop “Physics Beyond Colliders” (PBC) organized by CERN in September 2016, a new collaboration (CPEDM for “Charged Particle EDM”) was formed with the aim of preparing a feasibility study for a dedicated EDM storage ring at CERN as input for the update of the “European Strategy for Particle Physics” (ESPP), which is due end of 2018. A first meeting took place at CERN in March 2017. Members of our institute assumed responsibility in several work packages, such as the layout of the storage ring, beam control, polarimetry and ring components.

### European Research Council (ERC) Advanced Grant (AdG)

In March 2016, the ERC has given a prestigious AdG to IKP (Principal Investigator Hans Ströher, additional beneficiaries are: INFN Ferrara (Italy) and RWTH Aachen University) for the project “Search for Electric Dipole Moments using Storage Rings” (srEDM, Grant agreement No. 694340). The project started in October 2016 and will run until September 2021. The aims of srEDM are to demonstrate key-technologies and to perform a proof-of-principle as well as a first EDM measurement at COSY. Further details can be found at: www.sredm-ercgrant.de

### Outreach

The JEDI-collaboration has published articles in popular journals to advertise the science case and the approach for charged particle EDM searches at storage rings.

[CERN Courier, Sept. p. 27 (2016); link; Nucl. Phys. News, 27,3, 10-13 . (2017); doi]

## 4.5. Matter and Technologies: Accelerator Research & Development (ARD), Detector Technology & Systems (DTS)

### ARD: Spin Tracking and Implications

Full spin tracking simulations of the entire experiment are crucial to explore the feasibility and the systematic limitations of the planned EDM searches (see above, Section 5.1.5.4). Existing spin tracking programs (COSY Infinity, MODE, B-MAD) have been extended to properly simulate spin motion in the presence of an EDM. Concurrently, benchmarking experiments were performed at COSY to check and further improve the simulation tools. In recent years, simulations of beam and spin dynamics have focused on studies of systematic effects for the deuteron “precursor experiment” at COSY as well as the dedicated deuteron EDM storage ring, where the sensitivity for two different methods (“frozen spin” and “quasi-frozen spin”) have been studied in detail. It was found that quadrupole misalignments and the related closed-orbit deviations of the beam play a major role. Consequently, the COSY beam-positioning system has been upgraded and additional so-called "Rogowski position monitors" have been installed. A survey and subsequent adjustment of the main COSY magnets has been performed in order to significantly reduce deviations in the particle´s closed orbit. This will reduce the systematic uncertainty for the COSY precursor experiment by roughly one order of magnitude.

[Proc. IPAC´15, Richmond (USA), THPF032; doi; Proc. IPAC´17, Copenhagen (Denmark), TUPVA082; doi; Proc. IPAC´17, Copenhagen (Denmark), TUPVA083; doi]

### ARD: Deflector Development

The efforts in deflector development are related to the EDM project, IKP is pursuing (see above, Section 4.4). The theoretical investigations are complemented by necessary hardware developments. First, a prototype RF Wien filter was developed and successfully tested with polarized beams at COSY. Subsequently, a waveguide RF Wien filter for the EDM precursor experiment was built and installed in the COSY ring and commissioning started in 2017. The deflector development for a final deuteron EDM ring, which requires combined *ExB* deflectors, is focused on high-field devices of roughly 17 MV/m. High electrostatic field gradients could be achieved on a test bench at RWTH Aachen University. To maximize field gradients, different materials and electrode shapes have been investigated and surface treatments (mechanical polishing and cleaning) have been applied. With two small half-spheres (R = 10 mm) of stainless steel and 17 kV voltage at 1 mm plate distance, a field gradient of 17 MV/m could be reached, respectively for aluminum with 3 kV voltage at 0.1 mm plate distance a field gradient of 30 MV/m. In addition, a first technical design for an electromagnetic deflector was completed and a prototype test device will be produced to further investigate and optimize the field gradient of high electrostatic fields in superimposed magnetic fields. In particular, the sparking behavior in the presence of magnetic fields will be studied in detail, since it is expected that the sparking mechanism and therefore the related threshold for the breakdown voltages will be significantly different.

### ARD: Ion Source Research and Development for Existing and Future Accelerators

One of the important objectives of IKP-4 is the performance improvement of the ion sources at COSY. The existing sources have been optimized based on the existing infrastructure at IKP. The limited acceptance of the cyclotron defines the requirement for beams with high brightness. In addition, complex procedural sequences for vector polarized protons or vector and tensor polarized deuterons are required. The ion source developments greatly benefit from ZEA's expertise in engineering and handling special materials for high temperature or plasma applications. The long term experience with ion sources at the COSY injector also enabled the design, delivery and commissioning of an ion source system with matched high brilliance for an extremely low-energy synchrotron (ELENA) for antiprotons at CERN. The first beam from the source system was stored in ELENA ("Extra Low ENergy Antiproton ring") by the end of 2016, shortly after the ring vacuum had been closed.

[Proc. IPAC´15, Richmond (USA), THPF029; doi]

### ARD: RF Development (Cross Topic and FAIR Contribution)

Within the framework of developing super-conducting acceleration structures, starting with linac preparations for the ESS ("European Spallation neutron Source") in Jülich and HIPPI ("High Intensity Pulsed Proton Injector") during the "6$^{th}$ Framework Program" of the European Commission (FP6), spoke-type cavities have, for example, been designed and optimized as a cross topic contribution to continuous-wave RF acceleration structures. By means of staff exchanges at national and international accelerators facilities over recent years, the accelerator research unit

IKP-4 has contributed to new and upcoming facilities, such as the IFMIF ("International Fusion Materials Irradiation Facility"), the ESS and bERLinPro ("Berlin Energy Recovery Linac Prototype").

The RF-systems for HESR have been continuously improved by simulations and design tests at COSY and at GSI accelerator facilities during the past years. In particular, the low intensity of antiproton beams requires careful injection and accumulation procedures. The final operation with dense targets will profit from preparations at COSY where different cooling methods, the HESR RF-systems and the PANDA target can be tested together, well before installation at Darmstadt. New compact stochastic systems, 2 MeV electron cooling and precise beam control will be available by the end of 2017.

[Proc. COOL'15, Newport News, (USA), MOYAUD02; link; Proc. COOL'15, Newport News, (USA), MOYAUD03; link; Proc. COOL'15, Newport News, (USA) MOXAUD02; link; Proc. COOL'15, Newport News, (USA), FRWAUD01; link; Proc. IPAC'17, Copenhagen (Denmark), TUPVA080; doi]

### ARD: High Energy Electron Cooling

The high-energy electron-cooling (2 MeV) system for COSY was proposed to further boost the luminosity for internal experiments in the presence of strong beam-heating effects due to high density targets. This device will also be very useful as an injection-energy cooler in the start-up phase of HESR at FAIR as well as for testing new features of the planned/proposed high-energy electron-cooler of HESR. The investigations at COSY were performed using bunched and continuous proton beams of energies (momenta) in a range up to 2.3 GeV (3.1 GeV/c). The influence of RF on or off, of barrier-bucket RF, and of internal cluster target on or off has been studied.

[Proc. COOL'15, Newport News, (USA), MOXAUD02; link;
Proc. RuPAC´16, St.Petersburg (Russia), WECAMH04; doi]

### DTS: Free-Running Front-End Electronics for Silicon Strip Detectors

Many future particle physics experiments use the full data set of all sub-detectors to decide which data to store for offline analysis or to ignore. This concept is often called "triggerless readout" in contrast to a triggered readout where only a small sub-set of detectors sends their data continuously and only if something interesting occurs do they trigger the readout of the rest of the detector.

This novel readout concept requires the development of new front-end electronics, which are able to transmit continuously the complete measured data. Forschungszentrum Jülich together with the INFN Torino and the University of Giessen have focused on the development of a front-end ASIC suitable to read-out silicon strip detectors with an excellent time resolution better than 1 ns and an analogue resolution of 12 bit. Since the end of 2015 a prototype of the ASIC is available on readout boards and very detailed tests have been performed to study its features.

[Journal of Instrumentation (JINST) 12 no.03, C03063 (2017); doi]

### DTS: Usage of Graphics Processors for fast Track Finding in Magnetic Fields

The continuous data stream of a trigger-less readout of a detector requires that all data is processed almost at the same rate as it is produced in the experiment. One of the most demanding tasks in this context is the finding and fitting of tracks of charged particles especially in magnetic fields where they fly on helices. This puts huge requirements onto the hardware as well as the algorithms and their implementation. On the hardware side one possible solution would be the usage of "General Purpose Graphics Processor Units" (GPGPUs) which offer thousands of parallel operating cores with somewhat reduced complexity.

Several different track finding algorithms have been developed in Jülich together with the “NVIDIA Application Lab on GPUs” such as the triplet finder, the “Hough track finder” or the cellular automaton track finder to cope with the requirements. The evaluation, optimization and combination of the different algorithms are all still ongoing.

[GPU in HEP 2014 Proceedings; doi]

### DTS: DAQ Prototype for Photon Detection and Common Technology Platform

Originally motivated by the common involvement in JUNO, Jülich’s ZEA-2 is active in the concept and design of a “System-on-a-Chip” (SoC) IC-based PMT read-out solution in 65nm CMOS technology (TSMC) to develop the basic competence. This involves the complete signal chain including digital data reduction for highest sensitivity. The second prototype tape-out was just executed. Forschungszentrum Jülich’s contribution to the “Common DAQ Platform” is based on the experience from previously developed IP-blocks on the extremely powerful “ZYNQ” (FPGA-uC platform) SoC framework, which has led to examples in atmospheric research and neutron detection.

## 4.6. Physics of Hadrons and Nuclei: COSY Experiments (ANKE, COSY-11, PAX, TOF, TRIC and WASA)

The experimental hadron physics program at the cooler synchrotron COSY has been ongoing for more than two decades using a changing set of internal (ANKE, COSY-11, EDDA, WASA) and external (Big Karl with detectors ENSTAR, GEM and MOMO as well as JESSICA, NESSI, PISA, TOF) detectors and target (solid, liquid, gas; unpolarized and polarized) systems. After the termination of the program at the end of 2014, a “legacy paper” summarizing the major scientific and technological achievements was published. It should also be emphasized that the IKP theory research unit has significantly contributed to the success of this program.

[Eur. Phys. J. A 53: 114 (2017); doi]

In the following, we restrict ourselves to the facilities in operation during 2013/14 and the results obtained during the whole reporting period:

**ANKE** (a large acceptance forward magnetic spectrometer inside the COSY ring)
ANKE is a second-generation internal experiment, comprising three dipole magnets (D1, D2 (movable perpendicular to the beam direction) and D3), which used solid, gas cluster-jet and polarized H-/D- atoms from an atomic beam source for experiments. For polarized targets, an openable (during COSY injection) storage cell, which was closed for the measurements to increase luminosity, was used. ANKE had the capability to detect both positively and negatively charged reaction products, and in particular low-energy recoil particles with “Silicon Tracking Telescopes” (STT). In 2017, the D2 magnet was dismounted and removed from the COSY ring. Recent scientific highlights are:

(1) The differential cross section for proton-proton elastic scattering has been measured for beam energies of 1.0 GeV and in 200 MeV steps from 1.6 to 2.8 GeV for small center-of-mass angles with an overall normalization of about 3%. The data have a significant impact upon the results of partial wave analyses.

    [Phys. Lett. B 755,92 (2016); doi]

(2) The proton analyzing power in proton-proton elastic scattering has been measured at small angles for 6 beam energies between 0.8 and 2.4 GeV using a polarized proton beam. The

results agree with the many published data and partial wave predictions for the lowest energy, but they lie well above the corresponding predictions for higher energies. An updated phase shift analysis of all data leads to a much better description.

[Phys. Lett. B 739, 152 (2014); doi]

(3) The charge exchange of vector-polarized deuterons on a polarized hydrogen target has been studied for a deuteron beam energy of 726 MeV. By selecting two fast protons of low relative energy ("diproton"), the measured analyzing powers and spin correlations, which are sensitive to interference terms between specific neutron-proton charge-exchange amplitudes, were found to be reasonably well described by the current neutron-proton partial wave solution.

[Phys. Lett. B 744, 391 (2015); doi]

(4) Diproton production in proton-proton interactions in the region of the Δ-resonance exhibits a peak in the energy dependence of the forward differential cross section with a minimum at zero degree as well as large analyzing powers. This result is interpreted as a manifestation of two two-baryon resonance like states with $J^P = 0^-$ and $2^-$ at an invariant mass of about 2.2 $GeV/c^2$.

[Phys. Rev. C 93, 065206 (2016); doi]

**COSY-11** (an internal magnetic spectrometer for threshold studies)
The COSY-11 measurement program including meson and hyperon production studies close to threshold was already finished before the start of this review period but the data analysis led to the following result during the period:

(1) The excitation function of the ($pp \rightarrow pp\,\eta'$)-reaction close to threshold has been used to deduce the (η'-proton) scattering length.

[Phys. Rev. Lett. 113, 062004 (2014); doi]

**PAX** (a set-up to investigate "spin-filtering" as a method to produce polarized (anti-proton) beams)
The PAX-project aims to provide a method to produce an intense beam of polarized antiprotons; it was supported by an ERC-Advanced Grant ("POLPBAR") between 2010 and 2016. While waiting for a possibility to study spin-filtering with antiprotons, the necessary equipment was built and tests have been performed with proton beams at COSY:

(1) The machine studies and commissioning of the experimental equipment required for the first spin-filtering experiment with protons at a beam energy of 49.3 MeV in COSY have been summarized in an extended paper.

[Phys. Rev. STAB 18, 020101 (2015); doi]

(2) A "Siberian Snake" was delivered to IKP in January 2016. It was commissioned in the laboratory and installed into COSY for planned longitudinal spin-filtering experiments. The CBAC has recommended commissioning beam time, but due to higher priority projects, this has not yet been scheduled.

(3) A new four-quadrant PAX silicon-vertex detector, with each one comprising three layers of double-sided silicon-strip sensors, has been realized in a collaboration of the University of Ferrara (Italy) and IKP and was recently (spring 2017) commissioned with COSY beam.

**TOF** (a non-magnetic spectrometer for the extracted COSY beam)
The TOF ("Time-of-Flight") detector offers large acceptance and high precision, using low mass tracking detectors in a vacuum. Together with geometrical constraints for the kinematically over-determined reconstruction of events, investigations of hyperons, for example, over the full available phase space have been performed. In this period:

(1) High statistics data samples of $\Lambda$-hyperon production were collected. A Dalitz-plot analysis resulted in a clear observation of a cusp structure at the $\Sigma$-N threshold, and a model independent measurement of the spin triplet p-$\Lambda$ scattering length.

[Eur. Phys. J. A, 52: 7 (2016); doi; Phys. Rev. C95, 034001 (2017); doi]

(2) The spin transfer from the polarized proton beam to the produced hyperon ($\Lambda$ and $\Sigma$) has been measured.

[Eur. Phys. J. A, 52: 337 (2016); doi]

**TRIC** (a test of time reversal invariance)
The TRIC project aims to improve the upper limit for T-symmetry violation by at least one order of magnitude. A genuine T-violating "null observable" will be studied by conducting a new precision experiment, using the COSY facility as accelerator, storage ring, ideal zero-degree spectrometer and detector. The total cross section for double-polarized proton-deuteron interactions will be extracted from the measurement of the lifetime of the coasting COSY beam. In preparation for the measurement, a new precision beam current measurement system (FCT, "Fast Current Transformer") has been purchased and extensively tested in the laboratory; meanwhile it has also been installed in the COSY ring. The PAX detector, mentioned above, will be used as polarimeter in the measurements.

[J. of Phys.: Conference Series 447 (2013); doi]

TRIC has been submitted as an ERC Starting Grant with a final panel score "A" (fully meets the ERC´s excellence criterion and is recommended for funding if sufficient funds are available), but, unfortunately, was not inside the ranking range for funding. The project is currently on hold – the proposal has been updated/extended and recently resubmitted to ERC.

**WASA** (an internal 4$\pi$ spectrometer for neutral and charged particles):
WASA has been transferred from the CELSIUS storage ring at TSL ("The Svedberg Laboratory", Uppsala, Sweden) to COSY in 2005 to complement the detection capability for hadron physics experiments by an electromagnetic calorimeter. It was installed inside the COSY ring and used unpolarized hydrogen or deuterium pellets (size about 25 µm) as target. WASA was operated for physics experiments until the end of PoF II. The following major scientific results have been obtained in recent years:

(1) After initial indications for a new resonance d* (mass ~2380 MeV, width ~70 MeV and quantum numbers $I(J^P) = 0(3^+)$) in proton-neutron double pionic fusion had been obtained in earlier WASA experiments, additional evidence for this narrow resonance-like structure, a so-called "dibaryon", was found in polarized neutron-proton scattering.

[Phys. Rev. Lett. 112, 202301 (2014); doi]

(2) A search for a "dark photon" was conducted in ($pp \rightarrow pp\,\pi^0$)-data, where the neutral pion subsequently decayed into a photon and an electron-positron pair. In 5 x $10^5$ such events, no evidence for a so-called "U-boson" was found, which rules out a large region of the parameter space suggested as a possible explanation for the discrepancy between a direct measurement and the prediction of the Standard Model for the anomalous magnetic moment of the muon.

[Phys. Lett. B 726, 187 (2013); doi]

(3) Charge symmetry breaking in the ($dd \rightarrow {}^4He\,\pi^0$)-reaction has been studied at higher excess energies to complement previous high precision data from TRIUMF and IUCF. First data on the differential cross section are consistent with s-wave prion production.

[Phys. Lett. B 739, 44 (2014); doi]

Meanwhile additional data have been collected and analyzed: the new differential cross sections clearly indicate the presence of higher partial waves in the final state. A corresponding publication is under way. Meanwhile additional data have been taken and analyzed: the new differential cross sections clearly indicate the presence of higher partial waves in the final state. A corresponding publication is under way.

[arXiv:1709.01060; link]

(4) Over the years, WASA has collected a sample of 3 x $10^7$ $\eta$ mesons from the 2-body (pd → $^3$He $\eta$)-reaction, and evaluated various decay branching ratios, including an upper limit on the CP-violating asymmetry in the decay into a pion pair and an electron pair. Detailed analyses of selected decay channels are currently under way.

[Phys. Rev. C 94, 065206 (2016); doi]

(5) In a measurement of the Dalitz plot of the $\omega \to \pi^+ \pi^- \pi^0$, produced in the reaction (pp → pp $\omega$), for the first time, a deviation from pure p-wave phase space has been observed.

[Phys. Lett. B770, 418 (2017); doi]

(6) The reactions (dd → $^3$He n $\pi^0$) and (dd → $^3$He p $\pi^-$) have been studied to establish new upper limits for the formation of $\eta$-mesic $^4$He nuclei.

[Nucl. Phys. A 959, 102 (2017); doi]

### 4.7. Theortical Investigations in IKP-3/IAS-4

Research topics within the IAS-4 involve extraction of hadron-hadron scattering lengths from final-state interactions and multi-hadron systems, coupled-channel dynamics of meson-baryon scattering and pion photoproduction, baryon-baryon interactions in chiral EFT, precision calculations for meson transition form factors, few-nucleon systems and electric dipole moments of hadrons and light nuclei and the investigation of exotic hadrons containing heavy quarks. Much of this research is done in the framework of the Sino-German collaborative research center (SFB-Transregio 110) "Symmetries and the Emergence of Structure in QCD" comprising researchers from the IAS-4, Bonn University, Technical University Munich, the Institute of High-Energy Physics, Beijing, and Peking University, Beijing, China[1]. This CRC was recently successfully renewed for an additional 4 years period (07/2016 - 06/2020).

Lattice QCD (LQCD), the numerical implementation of QCD based on lattice stochastic methods, is an active area of research within the IAS-4. Within the past years relevant to this status report, emphasis has been placed on using LQCD to calculate the hadronic components of the nucleon Electric Dipole Moment (EDM) due to charge and parity (CP)-violating interaction terms. Such a quantity, if measured experimentally, would present a `smoking gun' for the presence of beyond the standard model (BSM) physics. To date, the IAS-4 has concentrated on understanding the nature of the nucleon EDM induced by the strong-$\Theta$ term, and has employed two methods, imaginary $\Theta$-term and infinitesimal $\Theta$-term via gradient flow. Additional terms, such as the Weinberg operator and quark chromo electric interaction are currently being investigated, as well as the nature of hyperon-nucleon interactions. The nature of the three-neutron interaction, and in general, the three-nucleon interaction, will be studied in the next few years.

1 http://crc110.hiskp.uni-bonn.de

(1) Nuclear Effective Field Theory on a Lattice

The nuclear Effective Field Theory on a lattice (NLEFT) allows for calculation of the non-perturbative solution of the nuclear A-body problem employing the precisely known 2, 3 and 4 nucleon forces constructed within chiral perturbation theory. This new technology made it possible for the first time to theoretically describe nuclear excitations like the famous Hoyle state, the positive parity spin 0 excited state of Carbon. After this the formalism was applied to understanding alpha-alpha scattering, a key first step in the production of carbon in stars. Currently NLEFT is investigating nuclear matter at finite temperature, and will investigate the limits of stability of nuclei by focusing on nuclei near neutron drip lines.

[Phys. Rev. Lett. 109, 252501 (2012), link; Phys. Lett. B 732, 110 (2014), link; Phys. Rev. Lett. 112, 102501 (2014), link; Nature 528, 111 (2015),link ; Phys. Rev. Lett. 117, 132501 (2016), link; Phys. Rev. Lett. 119, 222505 (2017), doi; Rev. Mod. Phys. (2017), link]

(2) Is life on earth an accident?

Since we are now in command of nuclear amplitudes in a formalism with a chiral structure consistent with QCD it became feasible to study the impact of the variation of fundamental parameters of the Standard Model on the emergence of structure in nature. More concretely, studies of both Big Bang as well as stellar nuclear synthesis allowed us to conclude that the electromagnetic fine structure constant and the light quark masses need to be within a few percent of their true values for life on earth to emerge. It is now a question to the physics beyond the Standard Model to tell us if this is fine tuning or emerges naturally from the dynamics.

[Phys. Rev. D 87, 085018 (2013), link; Phys. Rev. Lett. 110, 112502 (2013), link; Eur. Phys. J. A 49, 82 (2013), link; Sci. Bull. 60,43 (2015), link]

(3) Pion-Nucleon interaction

Employing Roy-Steiner equations which are coupled dispersion relations consistent with analyticity as well as unitarity it became possible to pin down the pion nucleon interactions at low energies to high precision. In particular it became feasible to extract the pion nucleon sigma term with an unseen accuracy. Lattice calculations have yet to produce such consistent and precise values for this term.

[JHEP 1206, 043 (2012), link; Phys. Rev. Lett. 115, 092301 (2015),link ; Phys. Rev. Lett. 115, 192301 (2015),link ; Phys. Rept. 625, 1 (2016), link; Phys. Lett. B 760, 74 (2016), link]

(4) Effective field theory for few nucleon systems

Since many years a lot of effort was put into improving our understanding of the two-nucleon interaction in formalism with a sound connection to QCD namely chiral perturbation theory. In 2017 this effort was pushed to next-to-next-to-next-to-next-to-leading order (N4LO) resulting in a two nucleon potential that describes the existing database perfectly. In addition, also the coupling of few nucleon systems to external currents was investigated for various probes.

[Eur. Phys. J. A 51, 53 (2015), link ; Phys.Rev. C 93, 044002 (2016), link; Phys. Rev. Lett. 115, 122301 (2015), link; Ann. Phys. (NY) 378, 317 (2017), link; Eur. Phys. J. A 52, 146 (2016),link ; Phys. Rev. C 88, 064003 (2013), doi]

(5) Electric dipole moments of nucleons and light nuclei

In order to understand the matter-anti-matter asymmetry of the Universe there must be CP violation beyond what the Standard Model provides via the CKM-phase. Observables expected to be very sensitive to this new type of interaction, if it manifests itself in the strong sector, are the EDMs of proton, neutron as well as light ions. Members of the institute not only recently performed lattice QCD calculations of proton and neutron EDMs emerging from a QCD theta term using different methods but also calculated the EDMs of light nuclei that should emerge from different possible scenarios beyond the Standard Model.

[JHEP 07, 069 (2014), link; JHEP 03, 104 (2015), link ; JHEP 1212,097 (2012), doi; Phys. Rev. Lett. 115, 062001 (2015), link; Phys. Rev. D 92, 094518 (2015), link; Int. J. Mod. Phys. E 25, 1641008 (2016), link]

(6) Baryon-Baryon interaction and dense matter

Based on a recently developed chiral perturbation theory description of the hyperon-nucleon interaction calculations were performed for dense matter in the presence of hyperons. Indications were found that the property of this newly found interaction to become repulsive at higher energies provides a solution to the hyperon puzzle - the observation that the presence of hyperons in neutron stars seems to be at odds with the existence of neutron stars with two solar masses.

[Nucl. Phys. A 915, 24 (2013), link; Nucl. Phys. A 936, 29 (2015), link; Eur. Phys. J. A 52,15 (2016), link; Eur. Phys. J. A 53,121 (2017), link; Eur. Phys. J. A 51, 17 (2015), link]

(7) Exotic states and hadronic molecules

An additional focus of the group are exotic hadrons containing a heavy quark and its antiquark. In particular it was shown that all currently existing data are consistent with Y(4260) being a D1-D and Z(3900) as well as X(3872) being DD* bound states. In particular this assignment allowed us to predict the reaction Y(4260) → X(3872) based on the observation of Y(4260) → π Z(3900). This prediction was confirmed experimentally shortly afterwards. These investigations are of high relevance for the physics program of PANDA at FAIR. In addition we also studied the recently found hidden charm pentaquarks and proposed that at least the narrow one could be a kinematical effect from the opening of the $\chi_{c1}p$ channel. This proposal could be tested in a photo-production experiment - an idea already picked up by the Jefferson Laboratory in the US.

[Phys. Rev. Lett. 111, 132003 (2013), link; Phys. Lett. B 725,127 (2013), link; Phys. Rev. Lett. 115, 202001 (2015), link ; JHEP 1706, 158 (2017), link; Phys. Rev. D 92, 071502 (2015), link; Phys. Rev. D 92, 034022 (2015), link; Commun. Theor. Phys. 65, 593 (2016), link; Rev. Mod. Phys., 90, 015004 (2018), doi]

(8) Hadrons in finite volume

In various systematic studies we on the one hand extended the Lüscher method to higher partial waves and moving frames and on the other hand developed tools to extract resonance information from lattice data. Moreover we succeeded to provide an analytic solution for the energy spectrum of a bound three particle system in the unitarity limit - this calculation is becoming a benchmark result for the lattice community.

[Phys. Rev. D 86,094513 (2012), link; Eur. Phys. J. A 48, 114 (2012), link; Nucl. Phys. B 886, 1199 (2014), link; Nucl. Phys. B 910, 387 (2016),link; Phys. Rev. Lett. 114,091602 (2015), link; J. Phys. G. 42, 023101 (2015), link]

(9) Baryon resonances

We have developed an extensive coupled channel approach that includes photo-induced reactions. This allowed us to analyze a large amount of additional data within this unitary coupled channel model which allowed us to pin down the parameters of a large number of non-strange baryon resonances.

Moreover, using unitarized chiral perturbation theory we were able to establish the two pole structure underlying the $\Lambda(1405)$ - the results are now part of the Review of Particle Physics of the Particle Data Group.

[Eur. Phys. J. A 49, 44 (2013), link; Eur. Phys. J. A 50, 101 (2014), link; Eur. Phys. J. A 51, 70 (2015), link ; Eur. Phys. J. A 51, 30 (2015), link; Chin. Phys. C 40, 100001 (2016), link]

(10) Nuclear Structure

Based on a newly developed method it became possible to calculate dipole giant resonances for stable and unstable neutron rich nuclei. Within this formalism it became possible to solve the long standing puzzle of the mass number dependence of this collective phenomenon. The studies are of high relevance for the nuclear program at FAIR.

[Phys. Rev. Lett. 109, 092502 (2012), link; Phys. Rev. C 94, 034306 (2016), link]

(11) Monte-Carlo Simulations for low-dimensional systems

The methods developed for lattice QCD also be employed to investigate other strongly interacting systems. This was demonstrated recently by us in their application to carbon-nano-tubes. In particular the formalism allows on to study the electron-electron correlations in particular configurations. Currently extensions towards Graphen are being worked on.
[Phys. Rev. B **93, 155106** (2016), link; Europhys.Lett. 119, 60006 (2017), link; EPJ Web Conf. 175 , 03009 (2018), doi]

(12) Outreach

The IAS-4 organizes biannually both highschool student and teacher training programs covering current issues in nuclear and particle physics. The programs are financed by CRC-110.

#### 4.8. New PoF III Activity: Neutrino Physics (Borexino, SOX, JUNO)

**Borexino** (a 300 ton liquid scintillator neutrino detector)
Borexino, located in the "Laboratori Nazionali del Gran Sasso" (LNGS, Italy), has been collecting data since 2007. The unprecedented radiopurity of the scintillator has led to a series of accomplishments in the field of solar neutrinos, geoneutrinos, as well as in setting stringent limits on several rare processes. The results and achievements of the collaboration with contributions from the IKP Neutrino group (founded in November 2015) are:

(1) The first simultaneous precision spectroscopy of pp, 7Be, and pep solar neutrinos in an extended energy range (0.19 - 2.93) MeV. The results are in agreement with and improve the precision of the previous Borexino measurements on the restricted energy scales.

[High Energy Physics – Experiments, July (2017), arXiv:1707.09279; link]

(2) An updated search for the solar neutrino effective magnetic moment has been performed. The limit of $\mu_\nu^{eff} < 2.8 \times 10^{-11}\ \mu_B$ at 90% C.L. has been set using constraints on the sum of the solar neutrino fluxes implied by the radiochemical gallium experiments.

[High Energy Physics – Experiments, July (2017), arXiv:1707.09355; link]

(3) A test of electric charge conservation with Borexino. The analysis is very similar to the one which led to the pp-neutrino result published in Nature in 2014. A new limit on the stability of the electron for decay into a neutrino and a single 256 keV photon was also obtained. The new bound is $\tau > 6.6 \times 10^{28}$ yr at 90% C.L.

[Phys. Rev. Lett. 115, 231802 (2015); doi]

(4) A search for low-energy neutrino and antineutrino signals correlated with “Gamma-ray Bursts” (GRB). No statistically significant excess above background was observed.

[Astropart. Phys. 86, 11 (2017); doi]

(5) The seasonal modulation of the solar $^{7}$Be neutrino rate: this observation is direct proof of the solar origin of the measured neutrino signal.

[Astropart. Phys. 92, 21 (2017); doi]

(6) Successful installation of the new trigger system. The group has coordinated the data quality control in direct collaboration with the hardware team.

**SOX** (Short-distance neutrino Oscillations with BoreXino)
The very low radioactive background of the Borexino detector, its large size, and its well proven capability to detect low-energy neutrinos make it an ideal case for the study of short-distance neutrino oscillations with artificial sources. The SOX project aims at a confirmation or clear disproof of the existence of a light sterile neutrino with $\Delta m^2 \sim 1\,eV^2$. A 4 to 5 *PBq* $^{144}$Ce $^{144}$Pr antineutrino source, producing about $10^{15}$ anti-$\nu_e$ per second, will be placed below the Borexino detector at a distance of 8.3 *m* from the detector's center in early 2018 with data taking for about 1.5 years. The current activities of the IKP group are: (i) co-coordination of the analysis group, (ii) preparation of the 2-3 months long calibration campaign of the Borexino detector with radioactive sources in autumn 2017, and (iii) optimization of the antineutrino selection cuts, background studies, and estimation of the final sensitivity of the project.

**JUNO** (Jiangmen Underground Neutrino Observatory, under construction in China)
JUNO will be the first multi-*kton* liquid scintillator neutrino detector ever constructed and will be placed at a depth of 720 *m*. The expected start of the data acquisition is in 2020. The main aim of the project is to determine the neutrino mass hierarchy by measuring reactor antineutrinos with a baseline of 53 *km*. It also has the potential to increase the precision of already measured neutrino oscillation parameters and can make a major contribution in the field of geo-neutrinos. Astrophysical measurements of solar, supernova, and potentially DSNB (“Diffuse Supernova Neutrino Background”) neutrinos are also part of the physics program.
The IKP-2 group concentrates on analysis and simulations: a meeting was organized at IKP in April 2016 to trigger the coordination among the European JUNO groups. Substantial effort is put into muon-tracking and wave-form reconstruction algorithms. Recently, this effort was extended to clustering algorithm, electronics simulations, pulse-shape discrimination, and the study of different systematic effects on the sensitivity to the mass-hierarchy measurement. The group is also involved in the evaluation of JUNO’s sensitivity to geo-neutrinos and solar neutrinos.

### 4.9. Further Activities (CLAS, Polarized Fusion, Polarized Molecules, Exotic Atoms)

**CLAS Analyses and Experiments** (detector system operated at JLab (USA))
As an extension of the meson decay and the transition form factor program at the WASA-at-COSY experiment, the IKP-1 group is part of a data-mining effort of existing CLAS (“CEBAF Large

Acceptance Spectrometer") data and it is the leading institute for an approved measurement (JLab proposal E12-06-108B) with the new JLAB-Hall B detector CLAS12:

[EPJ Web of Conf. 130 (2016) UNSP 04004; doi]

(1) Light Meson Decays: Photo-production data from CLAS are used to access light mesons up to the phi-($\phi$) meson. IKP is focused on Dalitz-plot analyses (decays into three pions contribute to the Dalitz-plot analysis project at the "Jefferson Physics Analysis Center" (JPAC)) and on the electromagnetic transition form factors of pseudoscalar and vector mesons, studied in the decay into an electron-positron pair and a third particle. A paper of the cross section determined via this decay channel is in preparation and provides insight into the pion production mechanisms for photon beam energies up to 5.45 GeV.

(2) Transition form factor of the $\eta'$ meson with CLAS12: the muon (g-2) anomaly (i.e., the discrepancy between theory and experiment of about $3\sigma$) might indicate physics beyond the Standard Model and has triggered a lot of experimental activity. The largest uncertainty of the SM prediction comes from the hadronic quantum corrections, in particular "hadronic vacuum polarization" (HVP) and "hadronic light-by-light scattering" (HLbL). The HLbL can be accessed by measuring the Dalitz-decay of the light pseudoscalar mesons. The proposed measurement will increase world statistics by a factor 35 for $\eta' \rightarrow \gamma^*\gamma$ and will be able to distinguish between theoretical predictions, thus eliminating one of the mentioned $(g\text{-}2)_\mu$ uncertainties.

**Polarized Molecules** (experiments with an ABS at an IKP laboratory)
The polarized "Atomic Beam Source" (ABS), previously used to feed the polarized target of the ANKE experiment, is now in use to produce nuclear polarized molecules from hydrogen and its isotopes by recombination of the polarized atoms in strong magnetic fields. This unique apparatus allows new insights into various fields of physics and chemistry, ranging from fundamental research to possible applications:

(1) Recombination processes on various surfaces have been investigated by studying the polarization preservation of hydrogenic molecules. It was found that a PFPE ("perfluorpolyether", *Fomblin*) surface completely conserves the atomic polarization in the molecules. Therefore, $H_2$, $D_2$, and HD molecules with a polarization above 0.8 in single spin-isomers can be produced.

[Phys. Rev. Lett. 115,113007 (2015); doi]

(2) The coupling of the rotational magnetic moment of the molecules with the nuclear spins was observed, in particular the effect of the shift of the rotation axis closer to the deuteron in the HD molecule.

In a next step, the polarized molecules should be frozen out to produce polarized ice, in which the spins of the protons and deuterons can be adjusted by the ABS separately, i.e., the spins in the HD molecule can be set either parallel or antiparallel or the deuteron spin perpendicular to the proton spin.

**Polarized Fusion** (cooperation with internal (PGI-6) and external (BINP, INFN, PNPI) groups)
The increase of the energy output or the reduction of the costs of a fusion reactor by use of polarized fuel has been under discussion for many years. To solve the outstanding problems, the techniques developed and experience gained for polarized sources and targets in our institute are invaluable tools, which are now exploited as part of various international collaborations:

(1) The yet unknown cross sections for the double-polarized deuteron-deuteron fusion reactions will be measured with a polarized jet target from an ABS and a polarized deuteron beam at

energies up to 100 keV at the "Petersburg Nuclear Physics Institute" (PNPI) in Gatchina (Russia), together with scientists of the University of Ferrara (Italy) and PNPI.

[Springer Proc. in Phys. 187, 35-44 (2016); doi]

(2) While polarized helium-3 is commercially available and tritium is in principle at hand via optical pumping, sufficient quantities of polarized deuterium is still missing. One option towards larger quantities is the production and storage of polarized $D_2$ (see "Polarized Molecules" section above). Another possibility, spin-filtering of a molecular deuterium beam with a superconducting Stern-Gerlach magnet, is under development at the "Budker Institute of Nuclear Physics" (BINP) in Novosibirsk (Russia), together with the University of Düsseldorf and PGI-6 in Jülich. This project is supported by a grant of the German Research Foundation (*Deutsche Forschungsgemeinschaft*, DFG Grant BU 2227/1-1).

[JETP Lett. 105 (5):289 (2017); doi]

(3) An important question is the polarization preservation in the fusion plasma, either in the magnetic confinement of a tokamak or in inertial fusion, e.g., in laser-induced plasmas. A first test to measure the polarization of out-coming $^3He^{2+}$ ions from this type of laser-induced plasma based on polarized $^3He$ gas is on the way at the PHELIX laser at GSI in a collaboration involving PGI-6, GSI and IKP.

[Proc. PSTP2015, Bochum (Germany), PoS 002; link; Springer Proc. in Phys. 187, 55-68 doi]

**Exotic atoms** (on-going analyses of experiments at PSI, Switzerland)

The study of light pionic atoms using X-ray spectroscopy with ultimate resolution provides insight into low-energy hadron physics as well as the complex dynamics of atomic collisions and de-excitation processes. The corresponding experiments were performed at the Paul Scherrer Institute (PSI, Switzerland) within an international collaboration (8 institutes from 6 countries, led by the IKP group), using a bent crystal spectrometer.

[Spectrochimica Acta Part B 120, 9-18 (2016); doi]

Data taking at PSI was completed a couple of years ago, but the data analyses and supplementary measurements of fluorescence X-rays at IKP are on-going. Recently published results are:

(1) Doppler broadening caused by collisional effects has been studied in detail in muonic hydrogen in order to improve the extraction of the scattering length from pionic hydrogen.

[arXiv:1709.05950; link submitted to Eur. Phys. J. D.]

(2) Measurements on pionic hydrogen and deuterium have yielded information on the pion production strength at threshold and the pion-nucleon scattering lengths with unprecedented precision.

[Eur. Phys. J. A, 50: 190 (2014); doi]

(3) A new value for the charged pion mass with an accuracy of 1.3 ppm has been obtained, an improvement of the precision of the world average value by a factor of two.

[Phys. Lett. B 759, 583 (2016); doi]

(4) New X-ray standards in the low keV range have been established by using highly ionised atoms. Such lines have a natural line width as small as μeV in favorable cases and allow the comparison of experimental results and QED calculations at the 1ppm level.

[Phys. Rev. A 88, 022503 (2013); doi]

The theory research unit (IKP-3/IAS-4) has used these measurements to extract the most precise values ever of the pion-nucleon S-wave scattering lengths, which led to a high-precision determination of the much discussed pion-nucleon sigma term.

## 5. **Future Program Development**

It can be predicted with high probability that both the MU- and the MT-activities of IKP will have a bright future scientifically:

- FAIR had its groundbreaking in July 2017 and construction will go ahead, including the IKP-promoted HESR as one major accelerator facility;

- PANDA is being constructed with major contributions from IKP, presumably in stages, and will start its forefront hadron physics program by the middle of the next decade;

- JEDI, driven by IKP, will deliver a proof-of-principle for charged-particle EDM searches, which will be an enormous milestone in the ongoing activities towards the long-term goal of a dedicated precision EDM storage ring – wherever it may be built;

- PAX, initiated by IKP, will be continued at FAIR, once antiproton beams are available there. As a first step, "spin-filtering" must be demonstrated with antiprotons, to be followed by investigations for (and the design of) a dedicated polarizer ring.

The FAIR is the top recommendation of the new 2017 "Long Range Plan" (LRP) of NuPECC ("Nuclear Physics European Collaboration Committee"), called "Perspectives for Nuclear Physics": "*Complete urgently the construction of the ESFRI flagship FAIR and develop and bring into operation the experimental program of its four scientific pillars APPA, CBM, NUSTAR and PANDA."*

Further LRP recommendations concerning the IKP-projects are: "*Perform R&D programs for possible future facilities: In order to lay the foundations for exciting new science opportunities in the long-term future, the respective communities must vigorously pursue coordinated research and development programs, aiming at: (i) the concept of (a) precision storage ring(s) to search for charged particle electric dipole moments (EDM), based on the ongoing studies at COSY; [and] (ii) the design of a polarizer ring to produce high intensity polarized antiproton beams as one upgrade option for HESR at FAIR.*"

The prospect of our projects continuing within Forschungszentrum Jülich, however, is doubtful due to the conclusions of the strategy discussions. For example, no mention of IKP activities in the PoF IV strategic planning of the research field Matter is made (see Section 5.1.12 Future Perspectives). A recent initiative ("TransFAIR") foresees that the above science, currently pursued at Forschungszentrum Jülich will be transferred to GSI (see Section 4.1).

## 6. **Cross Cutting Section**

IKP-4 together with PGI-6 is participating in the **ATHENA** project ("Accelerator Technology HElmholtz iNfrAstructure"). ATHENA is a multi-center project within the Helmholtz Association that is required for bringing compact and cost-effective laser plasma accelerators to user readiness with applications in science and medicine. IKP-4 will bring in its expertise on the production of polarized hadron beams. One of the scientific goals of ATHENA is to generate such beams worldwide for the first time with laser-plasma technology. These activities include Monte-Carlo simulations on the supercomputers of the Forschungszentrum Jülich which are carried out in close collaboration with the Jülich Supercomputing Centre (JSC). Within ATHENA the **JuSPARC** laser system in Jülich will be upgraded. An important goal of the research at Jülich is the production of polarized hadron beams, as well as the production of neutron bunches. Both institutes are also associated partners of **EUPRAXIA** ("European Plasma Research Accelerator with eXcellence in Applications"), which aims at providing a conventional design report for the first 5 GeV plasma-based accelerator in the world with industrial beam quality and user areas. Forschungszentrum Jülich is in a good position to contribute to EUPRAXIA with its long-term experience in operating cryogenic mass-limited targets at storage rings.

[Proc. IPAC'17, Copenhagen (Denmark), TUOBB3; doi]

## 7. Cooperation

IKP cooperates with numerous national and international universities and research institutes via individual research projects or as a partner in international collaborations. The following list includes the major collaborations during the PoF III period.

**German universities and research institutes**: GSI Helmholzzentrum für Schwerionen-forschung GmbH (including the Helmholtz Institute Mainz (HIM)), Westfälische Wilhelms-Universität Münster, Forschungszentrum Dresden-Rossendorf, Heinrich-Heine Universität Düsseldorf, TU Dortmund, Rheinische Friedrich-Wilhelms-Universität Bonn, Friedrich-Alexander-Universität Erlangen-Nürnberg, Eberhard Karls Universität Tübingen, Justus-Liebig-Universität Giessen, Universität Regensburg, Ruhr-Universität Bochum, RWTH Aachen University (including JARA-FAME), Technische Universität München (TUM).

**International institutions**: Agrarian University (Tbilisi, Georgia), BINP (Novosibirsk, Russia), CERN (Geneva, Switzerland), Georgian Technical University (Tbilisi, Georgia), PNPI (Gatchina, Russia), Tbilisi State University (Tbilisi, Georgia), Polish Academy of Sciences (Poland), Uppsala University (Uppsala, Sweden), Duke University (USA), Jagellonian University (Krakow, Poland), Jefferson Laboratory (Newport News, USA), Indian Institute of Technology (Indore, India), L.D. Landau Institute (Moscow, Russia), University of Groningen and Kernfysisch Versneller Instituut (The Netherlands), ITEP (Moscow, Russia), Università degli Studi di Ferrara and INFN (Ferrara, Italy), IMP Chinese Academy of Sciences (Lanzhou, China), Southwest University, School of Physical Science and Technology (China), JINR Dubna (Moscow Region, Russia)**,** University Beijing (PKU), Chinese Academy of Sciences, Beijing (IHEP@CAS and ITP@CAS).

**International collaborations:** ANKE (COSY), bERLinPro (HZB), Borexino (LNGS, Italy), CLAS (JLab, USA), PANDA (FAIR), JEDI (COSY) and CPEDM (CERN), ELENA (CERN), FCC (CERN), JUNO (Jiangmen, China), PAX (COSY), SOX (LNGS, Italy), TOF (COSY), TRIC (COSY) and WASA (COSY)

## 8. Research Infrastructures

**COSY at IKP of Forschungszentrum Jülich** (operated and developed by IKP-4)

The COoler SYnchrotron (COSY) is a worldwide unique facility for polarized and phase-space cooled hadron beams, which was utilized for hadron physics experiments until the end of 2014, and since then has been used as a test and exploration facility for accelerator and detector development as well as for the preparation and execution of precision experiments (JEDI, TRIC). The COSY facility (see floor plan below) comprises sources for polarized and unpolarized protons and deuterons, the injector cyclotron JULIC, the synchrotron to accelerate, store and cool beams, and internal and external target stations for experimental set-ups.

H⁻ (D⁻)-ions are pre-accelerated up to 0.3 (0.55) GeV/c in JULIC, injected into COSY via stripping injection and subsequently accelerated to the desired momentum below 3.7 GeV/c. Three installations for phase-space cooling are in use: (i) a low-energy electron cooler (between 0.3 and 0.6 GeV/c), installed in one of the straight sections, (ii) stochastic cooling above 1.5 GeV/c, and (iii) a new high-energy electron cooler in the opposite straight section, which can be operated between 0.3 and 3.7 GeV/c.

Well-established methods are used to preserve polarization during acceleration. A fast tune jumping system, consisting of one air-core quadrupole, has been developed to overcome depolarizing resonances. Preservation of polarization across imperfection resonances is achieved by the excitation of the vertical orbit using correcting dipoles to induce total spin flips. The polarization can be continuously monitored by an internal polarimeter (EDDA); an additional polarimeter, making use of the WASA forward detectors, has recently been set up, and a further new polarimeter, based on LYSO-scintillators, is under development. For protons, a beam polarization of 75% up to the highest momentum has been achieved. Vector and tensor polarized deuterons are also routinely accelerated with a degree of polarization of up to 60%. Dedicated tools have been developed to manipulate the stored polarized beam and to precisely determine the beam energy.

Together with the COSY floor-plan (left) the number of beam hours delivered over the years by COSY for machine development and user time as well as the unscheduled down times (right) are shown in Figure 3.

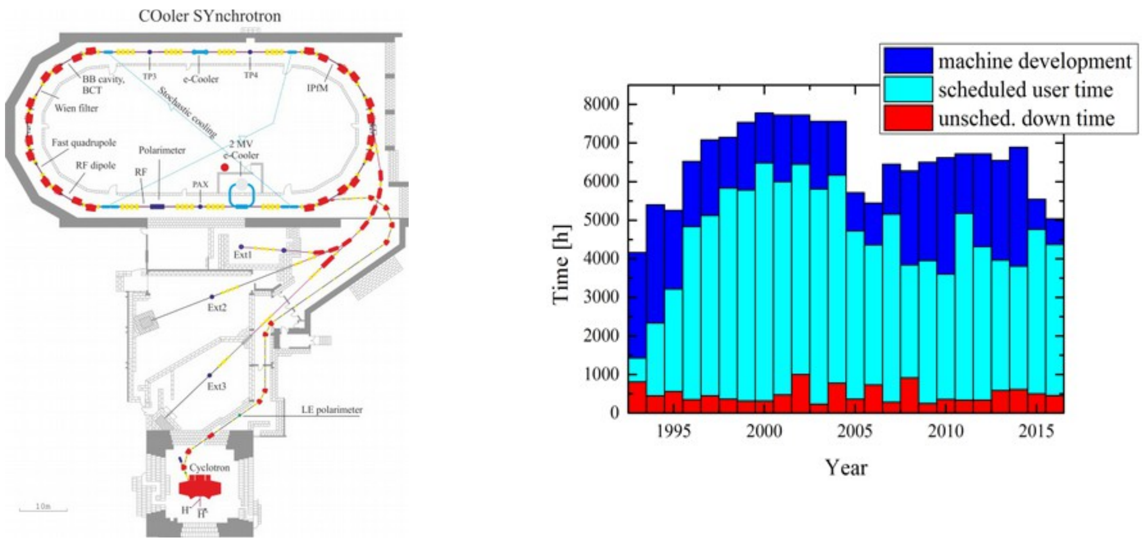


*Fig. 3: COSY at IKP of Forschungszentrum Jülich; COSY floor plan (left) and number of beam hours per year according to type of operation.*

**Borexino at LNGS** (used by the neutrino group of IKP-2)

Borexino is a liquid scintillator detector located in the underground "Laboratory Nazionali del Gran Sasso" (LNGS) in Italy. The radiopurity of this unsegmented detector has reached unprecedented levels. The detector design is based on the principle of graded shielding, with the inner scintillator core at the center of a set of concentric shells of decreasing radio-purity from inside to outside. The active medium, 278 tons of "pseudocumene" (PC) doped with 1.5 g/l of PPO ("2,5-diphenyloxazole", a fluorescent dye), is confined within a thin spherical nylon vessel with a radius of 4.25 m surrounded by 2212 photomultipliers (PMT), defining the so-called "Inner Detector" (ID).

The detector core is shielded from external radiation by 890 tons of buffer liquid, a solution of PC and 3-5 g/l of the light quencher "dimethylphthalate" (DMP). The buffer is divided into two volumes by the second nylon vessel with a radius of 5.75 m, preventing inward radon diffusion. A 6.85 m radius "Stainless Steel Sphere" (SSS) encloses the central part of the detector and serves as a support for PMTs. An external water tank of 9 m radius and 16.9 m height, filled with ultra-high purity water, serves as a passive shield against neutrons and gamma rays as well as an active muon veto. The Cherenkov light radiated by muons passing through the water is measured by 208 external PMTs defining the so-called "Outer Detector" (OD). IKP with its recently established neutrino group is involved in all ongoing and planned developments (e.g. SOX).

## 9. Career Development and Gender Equality

The institute is fully committed to the career development of its scientific and technical staff at all levels: starting with our **MSc and PhD students**, we frequently send them to national and international conferences to present, discuss and defend their results and to start building their own scientific networks. The following examples may be mentioned:

- Dr. Zara Bagdazarian (IKP-2) received a "Cotutelle" PhD degree from the two universities of Cologne (Germany) and Tbilisi (Georgia); she was selected to attend the Lindau Nobel Lectures in 2016. After her PhD she took up a post doctorate position in the IKP neutrino group.
- Dr. Marcel Rosenthal (IKP-4) received a "JARA Excellent Junior Award" for his PhD project "Spin Tracking Studies towards Electric Dipole Moment Measurements in Storage Rings" from RWTH Aachen University. He now has a fellowship at CERN.
- Dr. Andreas Herten (IKP-1) received a prize for the best Ph.D. thesis within the PANDA Collaboration in 2015. He now has a staff position at the JSC at Forschungszentrum Jülich.
- Dr. Maria Żurek (IKP-2) has been offered a post doctorate position within the ERC AdG project "srEDM" after she graduated with "summa cum laude" for her PhD thesis "Investigation of the Charge Symmetry Breaking Reaction $dd \to {}^4He\pi^0$ with the WASA-at-COSY Facility" at the University of Cologne.

At the post doctorate level, we helped to establish a so-called **SMART|EDM_Lab** at the "Ivane Javakhishvili Tbilisi State University" (TSU) in Tbilisi (Georgia) as the new scientific base for Dr. David Mchedlishvili, who performed his PhD-studies and afterwards stayed as a postdoctoral researcher for 2 years at IKP-2. He continues to have strong ties with IKP via the JEDI-project and has recently applied for an ERC StG with FZJ as host institution.

We succeeded in establishing three **W2-professorships with RWTH Aachen University** in our institute: Jörg Pretz (in 2012, staff member of IKP-2 since 2017), Andreas Lehrach (IKP-4, in 2013) and Livia Ludhova (IKP-2), in 2015; in addition Frank Goldenbaum (IKP-1) was appointed Associate Professor at the University of Wuppertal (Germany) in 2016.

We also give support to our younger staff scientists and advanced postdocs to gain **teaching experience** at nearby universities, e.g. Irakli Keshelashvili (IKP-2) at the University of Cologne (Elementary Particle Physics, Tools for Nuclear and Particle Physics), Tobias Stockmanns (IKP-1) (Hadron Physics, Detector Physics, Physics of Massive Neutrinos) and Elisabetta Prencipe (IKP-1) (Nuclear Astrophysics), both at the University of Bochum (Germany).

IKP organizes a biannual ***Hadron Physics Summer School*** (HPSS), and as an example, in 2016 around 65 students from 11 countries participated in the 9$^{th}$ school in this series. Furthermore, a biannual high school student and teacher **training program** in *Hadron and Particle Physics* (HPP) is organized by IKP-3/IAS-4 with separate lectures for teachers and students. The programs took place in 2013 and 2015, each with about 50 participants. Furthermore, we frequently invite students from abroad to visits via the Forschungszentrum **exchange programs:** the GGSB ("Georgian-German Science Bridge") is one example, where 20 students from Georgia will join us in Jülich for the "QUALI Start-up Lectures" in September – and the PGSB ("Palestinian-German Science Bridge") for Palestinian student. We also participate in the ERASMUS student exchange program.

IKP will organize the "7th International Symposium on Symmetries in Subatomic Physics" (SSP2018) in Aachen with Profs. Livia Ludhova and Jörg Pretz as co-chairpersons.

Likewise, the institute has taken a number of measures towards achieving **gender equality**:

- After the retirement of the previous head of IKP-4 (Prof. Rudolf Maier), we proactively searched for a female accelerator scientist to replace him: fortunately, we succeeded in hiring Prof. Mei Bai from Brookhaven National Laboratory (BNL, USA) in December 2014. Unfortunately, she left IKP for GSI/FAIR in Darmstadt in May, 2017.
- We encouraged Dr. Dr. Livia Ludhova to apply for a position at our institute via the Helmholtz Recruiting Initiative. Her application met with success, and she is now a W2-professor at RWTH Aachen University and leading the neutrino group in IKP-2. This group currently has two female postdocs.

In total, our institute currently (July 2017) has 31% female PhD students and 40% female postdocs.

## 10. Future Perspectives

As mentioned before, the strategy process of Forschungszentrum Jülich has resulted in an uncertain future for the whole Nuclear Physics Institute: last May the Jülich Supervisory Board (*Aufsichtsrat)* supported the concept of the Board of Directors ("*Strategie des Forschungszentrums 2025*"), which includes the discontinuation of IKP research at Forschungszentrum Jülich, but suggested to find a solution to secure the IKP expertise for the German scientific community. Due to the ERC AdG "srEDM" the operation of COSY and the JEDI activities are secured until September 2021. Recently, discussions under the description of "TransFAIR" have begun considering to separate IKP from Forschungszentrum Jülich in order to attach it to another Helmholtz research center (GSI). At the time of writing this report (July 2017), negotiations between the involved stakeholders (FZJ, HGF, GSI, Federal Ministry (BMBF), local state ministry (MIWF) and RWTH Aachen University) are ongoing. In principle, all of them agree that with its exciting as well as challenging physics programs, IKP must have a future outside Forschungszentrum Jülich.

# A Beam Time at COSY in 2017

For 2017 in total 3896 hours of operation were scheduled for experiments, 1680 hours for FAIR related avtivities, 1344 hours for JEDI, 200 hours for precision experiments and 672 hours for irradiations. About 15 % (784 hours) were used for COSY studies and 1344 hours were spent on machine development and experimental setup. The shutdown periods summed up to 2736 hours which gives a reliability for COSY operation of more than 90 %. The detailed beam-time distribution is given in table 1.

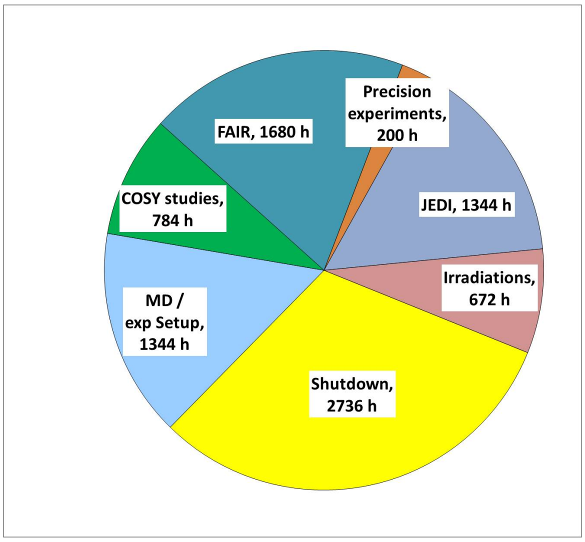


Fig. 4: COSY beam-time statistics in 2017.

Table 1: COSY operation in 2017.

| USER / Experiment | scheduled hours |
|---|---|
| Maintenance | 2736 |
| MD/Exp. Setup | 1344 |
| COSY beam dynamic studies | 784 |
| FAIR preparation | 672 |
| FAIR PANDA MVD | 464 |
| FAIR CBM | 544 |
| JEDI/EDM | 1344 |
| PAX | 200 |
| Irradiations | 672 |

## B Councils

**COSY Beam Time Advisory Committee (CBAC)**

| | |
|---|---|
| Prof. K. Aulenbacher | Universität Mainz, Germany |
| Prof. O. Kester | TRIUMF, Canada |
| Prof. C.J. Schmidt | GSI Darmstadt, Germany |
| Prof. E. Steffens | Universität Erlangen-Nürnberg, Germany (Chairperson until June 2017) |
| Prof. M. Weber | KIT, Karlsruhe, Germany (Chairperson since July 2017) |

# C Publications – Journal Articles in 2017

1. **Cosmic-muon characterization and annual modulation measurement with Double Chooz detectors**
   T. Abrahão *et al.*
   J. Cosmol. Astropart. P. **2017** 017 - 017 (2017)

2. **Connected and disconnected contractions in pion-pion scattering**
   N.R. Acharya *et al.*
   Nucl. Phys. B **922** 480 - 498 (2017)

3. **Measurement of the $\pi^0 \to e^+e^- \gamma$ Dalitz decay at the Mainz Microtron**
   P. Adlarson *et al.*
   Phys. Rev. C **95** 025202 (2017)

4. **Measurement of the $\omega \to \pi^0$ e + e - and $\eta \to e^+e^- \gamma$ Dalitz decays with the A2 setup at the Mainz Microtron**
   P. Adlarson *et al.*
   Phys. Rev. C **95** 035208 (2017)

5. **Search for $\eta$-mesic $^4$He in the $dd \to {}^3\mathrm{He}n\pi^0$ and $dd \to {}^3\mathrm{He}p\pi^-$ reactions with the WASA-at-COSY facility**
   P. Adlarson *et al.*
   Nucl. Phys. A **959** 102 - 115 (2017)

6. **Isoscalar single-pion production in the region of Roper and d * (2380) resonances**
   P. Adlarson *et al.*
   Phys. Lett. B **774** 599 - 607 (2017)

7. **Measurement of the $\omega \to \pi^+\pi^-\pi^0$ Dalitz plot distribution**
   P. Adlarson *et al.*
   Phys. Lett. B **770** 418-425 (2017)

8. **Nucleon in a periodic magnetic field**
   A. Agadjanov, U. Meißner and A. Rusetsky
   Phys. Rev. D **95** 031502 (2017)

9. **Limiting neutrino magnetic moments with Borexino Phase-II solar neutrino data**
   M. Agostini *et al.*
   Phys. Rev. D **96** 091103 (2017)

10. **A Search for Low-energy Neutrinos Correlated with Gravitational Wave Events GW 150914, GW 151226, and GW 170104 with the Borexino Detector**
    M. Agostini *et al.*
    Astrophys. J. **850** 21 - (2017)

11. **Seasonal modulation of the $^7$Be solar neutrino rate in Borexino**
    M. Agostini *et al.*
    Astropart. Phys. **92** 21 - 29 (2017)

12. **Borexino's search for low-energy neutrino and antineutrino signals correlated with gamma-ray bursts**
    M. Agostini *et al.*
    Astropart. Phys. **86** 11 - 17 (2017)

13. **Neutron-proton scattering at next-to-next-to-leading order in Nuclear Lattice Effective Field Theory**
    J.M. Alarcón *et al.*
    Eur. Phys. J. A **53** 83 (2017)

14. **How to employ $\overline{B}^0_d \to J/\psi(\pi\eta, \bar{K}K)$ decays to extract information on $\pi\eta$ scattering-3**
    M. Albaladejo *et al.*
    J. High Energ. Phys. **2017** 10 (2017)

15. **Note on X(3872) production at hadron colliders and its molecular structure**
    M. Albaladejo *et al.*
    Chinese Phys. C **41** 121001-1 (2017)

16. **Drift Chamber Calibration and Track Reconstruction in the P349 Antiproton Polarization Experiment**
D. Alfs *et al.*
Act. Phys. Pol. B **48** 1983 - (2017)

17. **Spin partners of the $Z_b$ (10610) and $Z_b$ (10650) revisited**
V. Baru *et al.*
J. High Energ. Phys. **2017** 1 - 22 (2017)

18. **Can X(3915) be the tensor partner of the X(3872)?**
V. Baru, C. Hanhart and A.V. Nefediev
J. High Energ. Phys. **2017** 1 - 23 (2017)

19. **Möbius domain-wall fermions on gradient-flowed dynamical HISQ ensembles**
E. Berkowitz *et al.*
Phys. Rev. D **96** 054513 (2017)

20. **Parallel Algorithms for Online Track Finding for the $\bar{\text{P}}$ANDA Experiment at FAIR**
L. Bianchi *et al.*
J. Phys.: Conf. Ser. **898** 072040 - (2017)

21. **Effective field theory for triaxially deformed nuclei**
Q.B. Chen *et al.*
Eur. Phys. J. A **53** 204 (2017)

22. **Effects of $Z_b$ states and bottom meson loops on $\Upsilon(4S) \to \Upsilon(1S,2S)\pi^+\pi^-$ transitions**
Y. Chen *et al.*
Phys. Rev. D **95** 034022 (2017)

23. **Antinucleon-nucleon interaction at next-to-next-to-next-to-leading order in chiral effective field theory**
L. Dai, J. Haidenbauer and U. Meißner
J. High Energ. Phys. **2017** 78 (2017)

24. **Re-examining the X ( 4630 ) resonance in the reaction $e^+e^- \to \Lambda_c^+ + \Lambda_c^-$**
L. Dai, J. Haidenbauer and U. Meißner
Phys. Rev. D **96** 116001 (2017)

25. **Pascalutsa-Vanderhaeghen light-by-light sum rule from photon-photon collisions**
L. Dai and M.R. Pennington
Phys. Rev. D **95** 056007 (2017)

26. **First measurement of the polarization observable E and helicity-dependent cross sections in single $\pi^0$ photoproduction from quasi-free nucleons**
M. Dieterle *et al.*
Phys. Lett. B **770** 523 - 531 (2017)

27. **One-loop renormalization of the chiral Lagrangian for spinless matter fields in the SU(N) fundamental representation**
M. Du, F. Guo and U. Meißner
J. Phys. G **44** 014001 - (2017)

28. **Study of open-charm $0^+$ states in unitarized chiral effective theory with one-loop potentials**
M. Du *et al.*
Eur. Phys. J. C **77** 728 (2017)

29. **Ab initio Calculations of the Isotopic Dependence of Nuclear Clustering**
S. Elhatisari *et al.*
Phys. Rev. Lett. **119** 222505 (2017)

30. **Universal dimer-dimer scattering in lattice effective field theory**
S. Elhatisari *et al.*
Phys. Lett. B **768** 337 - 344 (2017)

31. **Renormalization of the three-boson system with short-range interactions revisited**
E. Epelbaum *et al.*
Eur. Phys. J. A **53** 98 (2017)

32. **Wilsonian renormalization group versus subtractive renormalization in effective field theories for nucleon-nucleon scattering**
E. Epelbaum, J. Gegelia and U. Meißner
Nucl. Phys. B **B925** 161-185 (2017)

33. **Non-equilibrium processes in p + Ag collisions at GeV energies**
M. Fidelus *et al.*
Phys. Rev. C **96** 064618 (2017)

34. **SU(4) flavor symmetry breaking in D-meson couplings to light hadrons**
C.E. Fontoura, J. Haidenbauer and G. Krein
Eur. Phys. J. A **53** 92 (2017)

35. **Muon Capture on $^3$H**
J. Golak *et al.*
Few-body systems **58** 16 (2017)

36. **A chiral covariant approach to ρ ρ scattering**
D. Gülmez, U. Meißner and J.A. Oller
Eur. Phys. J. C **77** 460 (2017)

37. **On the constituent counting rule for hard exclusive processes involving multi-quark states**
F. Guo, U. Meißner and W. Wang
Chinese Phys. C **41** 053108 (2017)

38. **Chiral study of the $a_0(980)$ resonance and πη scattering phase shifts in light of a recent lattice simulation**
Z. Guo *et al.*
Phys. Rev. D **95** 054004 (2017)

39. **Production of charmed baryons in pbar p collisions close to their thresholds**
J. Haidenbauer and G. Krein
Phys. Rev. D **95** 014017 (2017)

40. **Lambda-nuclear interactions and hyperon puzzle in neutron stars**
J. Haidenbauer *et al.*
Eur. Phys. J. A **53** 121 (2017)

41. **Scattering of decuplet baryons in chiral effective field theory**
J. Haidenbauer *et al.*
Eur. Phys. J. C **77** 760 (2017)

42. **The branching ratio $\omega \to \pi^+\pi^-$ revisited**
C. Hanhart *et al.*
Eur. Phys. J. C **77** 98 (2017)

43. **Determination of the spin triplet pΛ scattering length from the final state interaction in the $\vec{p}p \to pK^+\Lambda$ reaction**
F. Hauenstein *et al.*
Phys. Rev. C **95** 034001 (2017)

44. **Phase Locking the Spin Precession in a Storage Ring**
N. Hempelmann *et al.*
Phys. Rev. Lett. **119** 014801 (2017)

45. **Li 6 in a three-body model with realistic Forces: Separable versus nonseparable approach**
L. Hlophe *et al.*
Phys. Rev. C **96** 064003 (2017)

46. **Nuclear matter properties with nucleon-nucleon forces up to fifth order in the chiral expansion**
J. Hu *et al.*
Phys. Rev. C **96** 034307 (2017)

47. **Study of η and η′Photoproduction at MAMI**
V.L. Kashevarov *et al.*
Phys. Rev. Lett. **118** 212001 (2017)

48. **Elektrische Dipolmomente gesucht**
K. Kirch, J. Pretz and A. Wirzba
Phys. J. **16** 41-46 (2017)

49. **Sampling general N-body interactions with auxiliary fields**
C. Körber, E. Berkowitz and T. Luu
Europhys. Lett. **119** 60006 - (2017)

50. **First-principle calculations of dark matter scattering off light nuclei**
C. Körber, A. Nogga and J. de Vries
Phys. Rev. C **96** 035805 (2017)

51. **Nuclear axial current operators to fourth order in chiral effective field theory**
H. Krebs, E. Epelbaum and U. Meißner
Ann. Phys. **378** 317 - 395 (2017)

52. **COSY Prepares the First Measurement of the Deuteron Electric Dipole Moment**
P. Lenisa and F. Rathmann
Nucl. Phys. News **27** 10 - 13 (2017)

53. **Generating a resonance-like structure in the reaction $B_c \to B_s\pi\pi$**
X. Liu and U. Meißner
Eur. Phys. J. C **77** 816 (2017)

54. **Fragment Emission in $^{32}$S+$^{197}$Au Collisions at Fermi Energy**
H. Machner *et al.*
Act. Phys. Pol. B **48** 1303 - (2017)

55. **Foundations of strangeness nuclear physics derived from chiral effective field theory**
U. Meißner and J. Haidenbauer
Int. J. Mod. Phys. E **26** 1740019 - (2017)

56. **Deuteron-like states composed of two doubly charmed baryons**
L. Meng, N. Li and S. Zhu
Phys. Rev. D **95** 114019 (2017)

57. **Medium effects in $\Lambda K^+$ pair production by 2.83 GeV protons on nuclei**
E.Y. Paryev, M. Hartmann and Y.T. Kiselev
Chinese Phys. C **41** 124108 - (2017)

58. **Density-dependent effective baryon-baryon interaction from chiral three-baryon forces**
S. Petschauer *et al.*
Nucl. Phys. A **957** 347 - 378 (2017)

59. **Improved method to extract nucleon helicity distributions using event weighting**
J. Pretz
J. Instrum. **12** P02007 - P02007 (2017)

60. **First results of the front-end ASIC for the strip detector of the PANDA MVD**
T. Quagli *et al.*
J. Instrum. **12** C03063 - C03063 (2017)

61. **Feynman-Hellmann theorem for resonances and the quest for QCD exotica**
J. Ruiz de Elvira *et al.*
Eur. Phys. J. C **77** 659 (2017)

62. **Spin tune mapping as a novel tool to probe the spin dynamics in storage rings**
A. Saleev *et al.*
Phys. Rev. Accel. Beams **20** 072801 (2017)

63. **Non-exponential decoherence of radio-frequency resonance rotation of spin in storage rings**
A. Saleev *et al.*
JETP Lett. **106** 213 - 216 (2017)

64. **Ranking and validation of spallation models for isotopic production cross sections of heavy residua**
S.K. Sharma *et al.*
Eur. Phys. J. A **53** 150 (2017)

65. **Elastic and inelastic pion-nucleon scattering to fourth order in chiral perturbation theory**
D. Siemens *et al.*
Phys. Rev. C **96** 055205 (2017)

66. **Reconciling threshold and subthreshold expansions for pion-nucleon scattering**
D. Siemens *et al.*
Phys. Lett. B **770** 27 - 34 (2017)

67. **Feasibility study for the measurement of $\pi N$ transition distribution amplitudes at $\overline{\text{P}}$ANDA in $\overline{p}p \to J/\psi\pi^0$**
B. Singh *et al.*
Phys. Rev. D **95** 032003 (2017)

68. **Modern Chiral Forces Applied to the Nucleon-Deuteron Radiative Capture**
R. Skibiński *et al.*
Few-body systems **58** 28 (2017)

69. **Computational framework for particle and spin simulations based on the stochastic Galerkin method**
J. Slim, F. Rathmann and D. Heberling
Phys. Rev. E **96** 063301 (2017)

70. **Polynomial Chaos Expansion method as a tool to evaluate and quantify field homogeneities of a novel waveguide RF Wien Filter**
J. Slim *et al.*
Nucl. Instr. Meth. Phys. Res. A **859** 52-62 (2017)

71. **Design of the forward straw tube tracker for the PANDA experiment**
J. Smyrski *et al.*
J. Instrum. **12** C06032 - C06032 (2017)

72. **Double-polarization observable G in neutral-pion photoproduction off the proton**
A. Thiel *et al.*
Eur. Phys. J. A **53** 8 (2017)

73. **Commissioning of a Si(Li) Compton polarimeter with improved energy resolution**
M. Vockert *et al.*
Nucl. Instr. Meth. Phys. Res. B **408** 313 - 316 (2017)

74. **Permanent electric dipole moments of single-, two- and three-nucleon systems**
A. Wirzba, J. Bsaisou and A. Nogga
Int. J. Mod. Phys. E **26** 1740031 - (2017)

75. **Helicity-dependent cross sections and double-polarization observable E in $\eta$ photoproduction from quasifree protons and neutrons**
L. Witthauer *et al.*
Phys. Rev. C **95** 055201 (2017)

76. **Photoproduction of $\eta$ mesons from the neutron: Cross sections and double polarization observable E**
L. Witthauer *et al.*
Eur. Phys. J. A **53** 58 (2017)

77. **$J/\psi$ N interactions revisited and $\Lambda_b^0 \to J/\psi K^-(\pi^-)p$ decays**
C. Xiao
Phys. Rev. D **95** 014006 (2017)

78. **Investigations of the D-multi- $\rho$ interactions**
C. Xiao
Eur. Phys. J. A **53** 176 (2017)

79. **Where does the X (5568) structure come from?**
Z. Yang, Q. Wang and U. Meißner
Phys. Lett. B **767** 470 - 473 (2017)

80. **Isospin analysis of $B \to D^*\overline{D}K$ and the absence of the $Z_c(3900)$ in B decays**
Z. Yang, Q. Wang and U. Meißner
Phys. Lett. B **775** 50 - 53 (2017)

# D Talks and Colloquia in 2017

## D.1 Conference and workshop contributions

1. M. Agostini *et al.*
First Simultaneous Precision Spectroscopy of $pp$, $^7$Be, and $pep$ Solar Neutrinos with Borexino Phase-II
15th International Conference on "Topics in Astroparticle and Underground Physics", Sudbury, Canada: 2017-09-24 - 2017-09-28

2. A. Aksentyev *et al.*
The Test of Time Reversal Invariance at Cosy (TRIC)
Jagiellonian Symposium on Fundamental and Applied Subatomic Physics, Crakow, Poland: 2017-06-04 - 2017-06-09
Act. Phys. Pol. B 48 1925 -

3. V. Baru *et al.*
Heavy-Quark Spin Symmetry Partners of the X (3872) Molecule
Proceedings of the 14th International Conference on Meson-Nucleon Physics and the Structure of the Nucleon (MENU2016), Kyoto, Japan: 2016-07-25 - 2016-07-30

4. E. Berkowitz *et al.*
Job Management and Task Bundling
The 35th International Symposium on Lattice Field Theory, Granada, Spain: 2017-06-18 - 2017-06-24

5. E. Berkowitz *et al.*
Extracting the Single-Particle Gap in Carbon Nanotubes with Lattice Quantum Monte Carlo
The 35th International Symposium on Lattice Field Theory, Granada, Spain: 2017-06-18 - 2017-06-24

6. E. Berkowitz *et al.*
Calm Multi-Baryon Operators
The 35th International Symposium on Lattice Field Theory, Granada, Spain: 2017-06-18 - 2017-06-24

7. B. Breitkreutz *et al.*
Stochastic Cooling Hardware for Low Energy Deuterons at COSY
8th International Particle Accelerator Conference, Copenhagen, Denmark: 2017-05-14 - 2017-05-19

8. C.C. Chang *et al.*
Nucleon axial coupling from Lattice QCD
The 35th International Symposium on Lattice Field Theory, Granada, Spain: 2017-06-18 - 2017-06-24

9. R.W. Engels
"‘Polarized D2/HD Molecules: An Option to Produce Polarized Fuel for Fusion Experiments¿‘
Workshop on "Polarized Fusion", Novosibirsk, Russia: 2017-02-02 - 2017-02-02

10. R.W. Engels
"‘Polarized Internal Targets“
Institute for Modern Physics, Lanzhou, China: 2017-09-27 - 2017-09-27

11. R.W. Engels
"‘Production of Polarized HD Molecules in different Spin States“
Workshop on "‘Polarized Fusion“, Ferrara, Italy: 2017-10-03 - 2017-10-03

12. R.W. Engels
"‘Production and Storage of Polarized H2, D2 and HD Molecules“
Workshop on pol. beams, targets and polarimetry, Daejeon, South Korea: 2017-10-17 - 2017-10-17

13. R.W. Engels
"‘Advantages of Polarized Fuel in Nuclear Fusion - Polarized Fusion“
Workshop on pol. beams, targets and polarimetry, Daejeon, South Korea: 2017-10-20 - 2017-10-20

14. R.W. Engels
"‘A Sona Transition for the BOB Experiment“
DFG Priority Program 1491 - Closing Convention, Burghausen, Germany: 2017-11-01 - 2017-11-01

15. R.W. Engels
"‘The Test Stand for Storage Cells in Jülich“
SMOG2 + LHCSpin at CERN, Genf, Schweiz: 2017-11-30 - 2017-11-30

16. J. Haidenbauer
Baryon-Baryon Interaction from Chiral Effective Field Theory
Proceedings of the 12th International Conference on Hypernuclear and Strange Particle Physics (HYP2015), Sendai, Japan: 2015-09-07 - 2015-09-12

17. J. Haidenbauer
Production of charmed baryons and mesons in antiproton-proton annihilation
8th International Workshop on Charm Physics, Bologna, Italy: 2016-09-05 - 2016-09-09

18. J. Haidenbauer
Antinucleon-nucleon interaction in chiral effective field theory
CRC-110 Workshop on Nuclear Dynamics and Threshold Phenomena, Bochum, Germany: 2017-04-05 - 2017-04-07

19. J. Haidenbauer
Musing about the $DN$ and $\Lambda_c N$ interactions
ECT* Workshop on The Charm and Beauty of Strong Interactions, Trento, Italy: 2017-07-17 - 2017-07-28

20. J. Haidenbauer
Antinucleon-nucleon interaction in chiral effective field theory
International Conference on Exotic Atoms and Related Topics, Vienna, Austria: 2017-09-11 - 2017-09-15

21. J. Haidenbauer
Baryon-baryon interaction from chiral perturbation theory
2nd EMMI Workshop: Anti-matter, hyper-matter and exotica production at the LHC, Torino, Italy: 2017-11-06 - 2017-11-10

22. A. Halama
Model Development for the Automated Adjustment of the 2 MeV Electron Cooler Beam Line at COSY
3rd Annual Matter and Technology Meeting, Darmstadt, Germany: 2017-01-31 - 2017-02-02

23. A. Halama
Model Development for the Automated Setup of the 2 MeV Electron Cooler Transport Channel
International Workshop on Beam Cooling and Related Topics, COOL'17, Bonn, Germany: 2017-09-18 - 2017-09-22

24. C. Hanhart
The PDG meson team
The International Workshop on Partial Wave Analyses and Advanced Tools for Hadron Spectroscopy, Bad Honnef, Germany: 2017-03-13 - 2017-03-17

25. C. Hanhart
Theory of hadronic molecules applied to the XYZ states
International workshop on $e^+e^-$ collisions from Phi to Psi, Mainz, Germany: 2017-06-26 - 2017-06-29

26. C. Hanhart
Hadron Spectroscopy and Exotics - Theory
Particles and Nuclei International Conference 2017, Beijing, China: 2017-09-01 - 2017-09-05

27. N. Hempelmann
An Active Spin Tune Feedback System for the Cooler Synchrotron (COSY)
DPG Frühjahrstagung Hadronen und Kerne, Dresden, Germany: 2017-03-19 - 2017-03-24

28. J. Hetzel *et al.*
Beam-Dynamics Simulation Studies for the HESR
8th International Particle Accelerator Conference, Copenhagen, Denmark: 2017-05-14 - 2017-05-19

29. D. Jeschke *et al.*
Recent Results from Borexino
2nd International Conference on Particle Physics and Astrophysics, Moscow, Russia: 2016-10-10 - 2016-10-14
J. Phys.: Conf. Ser. 798 012114 -

30. Y. Kiselev *et al.*
Modification of the strange meson properties in nuclear matter
XXIII International Baldin Seminar on High Energy Physics Problems Relativistic Nuclear Physics and Quantum Chromodynamics, Dubna, Russia: 2016-09-19 - 2016-09-24
Eur. Phys. J. Web of Conferences 138 04002 -

31. C. Körber, E. Berkowitz and T. Luu
Hubbard-Stratonovich-like Transformations for Few-Body Interactions
The 35th International Symposium on Lattice Field Theory, Granada, Spain: 2017-06-18 - 2017-06-24

32. B. Lorentz *et al.*
COSY Extraction Line Characterization and Modeling
8th International Particle Accelerator Conference, Copenhagen, Denmark: 2017-05-14 - 2017-05-19

33. L. Ludhova
Limiting the effective magnetic moment of solar neutrinos with the Borexino detector
15th International Conference on "Topics in Astroparticle and Underground Physics", Sudbury, Canada: 2017-09-24 - 2017-09-28

34. L. Ludhova
Low energy neutrino physics with liquid scintillator detectors
18th Lomonosov Conference on Elementary Particle Physics, Moscow, Russia: 2017-08-24 - 2017-08-28

35. L. Ludhova
Solar neutrinos: recent results and future prospect
5th NuPhys conference NuPhys2017: Prospects in Neutrino Physics, London, United Kingdom: 2017-12-20 - 2017-12-22

36. L. Ludhova
Real-time detection of solar neutrinos with Borexino
15th Incontri di Fisica delle Alte Energie, Genoa, Italy: 2016-03-30 - 2016-04-01

37. K. Miyagawa and J. Haidenbauer
Faddeev Calculation of the $K^{-}d \to \pi\Sigma n$ Reaction in the $Lambda(1405)$ Resonance Region
Proceedings of the 12th International Conference on Hypernuclear and Strange Particle Physics (HYP2015), Sendai, Japan: 2015-09-07 - 2015-09-12

38. B.T. Nauschütt
Automated Measurement of Beam Parameters in the COSY Injection Beam Line
3rd annual MT Meeting, Darmstadt, Germany: 2017-01-31 - 2017-02-02

39. A. Pérez-Obiol, A. Nogga and D.R. Entem
Non-Mesonic Weak Decay of the Hypertriton with Effective Field Theory
Proceedings of the 12th International Conference on Hypernuclear and Strange Particle Physics (HYP2015), Sendai, Japan: 2015-09-07 - 2015-09-12

40. E. Prencipe and PANDA-Collaboration
Open charm physics: from $e^{+}e^{-}$ experiments to ppbar machines
FAIRNESS2017, Barcelona, Spain: 2017-05-28 - 2017-06-03

41. E. Prencipe *et al.*
Interface of the general fitting tool GENFIT2 in PandaRoot
22nd International Conference on Computing in High Energy and Nuclear Physics, CHEP 2016, San Francisco, USA: 2016-10-10 - 2016-10-14
J. Phys.: Conf. Ser. 898 042037 -

42. J. Pretz
Electric Dipole Moments of Charged Particles
Physics Beyond Collider Workshop, CERN, Switzerland: 2017-11-21 - 2017-11-22

43. J. Pretz
Precision Experiments: Search for static electric dipole moments
Future of non-collider physics, Mainz, Germany: 2017-04-27 - 2017-04-28

44. J. Ritman
Time-like Hyperon Formfactor Measurements at HADES and PANDA
ECT* - Space-like and time-like electromagnetic baryonic transitions, Trento, Italy: 2017-05-08 - 2017-05-12

45. J. Ritman
Bericht zum Status von IKP-COSY
KHuK-Jahrestreffen, Bad Honnef, Germany: 2017-11-30 - 2017-12-01

46. A.K. Rumaiz *et al.*
Fabrication and testing of monolithic 384 Germanium strip detector with highly integrated readout
IEEE Nuclear Science Symposium and Medical Imaging Conference, NSS/MIC, Atlanta, USA: 2017-10-21 - 2017-10-28

47. S. Schadmand
Measurements of meson decays and meson transition form factors at CLAS
PhiPsi17 - International workshop on $e^+e^-$ collisions from Phi to Psi, Schloss Waldthausen/Johannes Gutenberg University of Mainz, Germany: 2017-06-26 - 2017-06-29

48. S. Schadmand
Light meson decay
CLAS Collaboration Meeting, Jefferson Lab, Newport News, Virginia, United States of America: 2017-06-03 - 2017-06-16

49. S. Schadmand
Light Meson Decays
Workshop WASA at GSI/FAIR, Darmstadt, Germany: 2017-11-27 - 2017-11-28

50. S. Schadmand
Measurements of meson decays and meson transition form factors at CLAS
PhiPsi17 - International workshop on $e^+e^-$ collisions from Phi to Psi, Schloss Waldthausen/Johannes Gutenberg University of Mainz, Germany: 2017-06-26 - 2017-06-29

51. S. Schadmand
Light meson decays
CLAS Collaboration Meeting, Jefferson Lab, Newport News, Virginia, USA: 2017-06-03 - 2017-06-16

52. V. Schmidt and A. Lehrach
Analysis of Closed-Orbit Deviations for a First Direct Deuteron Electric Dipole Moment Measurement at the Cooler Synchrotron COSY
International Particle Accelerator Conference, Copenhagen, Denmark: 2017-05-14 - 2017-05-19

53. Y. Senichev
Search for the Charged Particle Electric Dipole Moments in Storage Rings
XXV Particle Accelerator Conference, St. Petersburg, Russia: 2016-11-21 - 2016-11-25

54. M. Simon *et al.*
COSY Slow Orbit Feedback System
8th International Particle Accelerator Conference, Copenhagen, Denmark: 2017-05-14 - 2017-05-19

55. A. Skawran and A. Lehrach
Spin Tracking for a Deuteron EDM Storage Ring
International Particle Accelerator Conference, Copenhagen, Denmark: 2017-05-14 - 2017-05-19

56. O.Y. Smirnov *et al.*
Borexino: Recent results and future plans
International Session-Conference of the Section-of-Nuclear-Physics (SNP) of Physical-Sciences-Division (PSD) of the Russian-Academy-of-Sciences (RAS) on Physics of Fundamental Interactions, Dubna, Russia: 2016-04-12 - 2016-04-15
Phys. Part. Nuclei 48 1026 - 1029

57. R. Stassen
Stochastic Cooling Experiment and Hardware at COSY and HESR
workshop on eletctron cooling and stochastic cooling, Tokyo, Japan: 2016-10-04 - 2016-10-10

58. R. Stassen *et al.*
First Experiences with HESR Stochastic Cooling System
8th International Particle Accelerator Conference, Copenhagen, Denmark: 2017-05-14 - 2017-05-19

59. S.R. Stock *et al.*
Tomography with energy dispersive diffraction
Developments in X-Ray Tomography XI, San Diego, United States: 2017-08-06 - 2017-08-10

60. T. Stockmanns
PandaRoot - The computing framework of PANDA
Seminarvortrag University of Science and Technology of China, Hefei, China: 2017-07-20 - 2017-07-20

61. T. Stockmanns and PANDA-Collaboration
FairMQ for Online Reconstruction - An example on PANDA test beam data
22nd International Conference on Computing in High Energy and Nuclear Physics, CHEP 2016, San Francisco, USA: 2016-10-10 - 2016-10-14
J. Phys.: Conf. Ser. 898 032021 -

62. A.I. Studenikin *et al.*
RESULTS FROM BOREXINO AT LNGS
Seventeenth Lomonosov Conference on Elementary Particle Physics, Moskau, Russia: 2015-08-20 - 2015-08-26

63. N. Tartoni *et al.*
High channel density germanium detector demonstrator for high throughput X-ray spectroscopy
IEEE Nuclear Science Symposium and Medical Imaging Conference, NSS/MIC, Atlanta, USA: 2017-10-21 - 2017-10-28

64. A. Vishneva *et al.*
Test of the electron stability with the Borexino detector
27th International Conference on Neutrino Physics and Astrophysics, London, England: 2016-07-04 - 2016-07-09
J. Phys.: Conf. Ser. 888 012193 -

65. M. Vockert *et al.*
Commissioning of a Si(Li) Compton polarimeter with improved energy resolution
IEEE Nuclear Science Symposium and Medical Imaging Conference, NSS/MIC, Atlanta, USA: 2017-10-21 - 2017-10-28

66. P.A. Walker *et al.*
HORIZON 2020 EuPRAXIA Design Study
International Particle Accelerator Conference, Copenhagen, Denmark: 2017-05-14 - 2017-05-19

67. C. Weidemann *et al.*
CALIBRATION OF LINEAR OPTICS OF COSY BASED ON ORM DATA
8th International Particle Accelerator Conference, Copenhagen, Denmark: 2017-05-14 - 2017-05-19

68. P. Wintz
STT & Phase-0 Update
Technical Forum at PANDA Collaboration Meeting, Darmstadt, Germany: 2017-06-06 - 2017-06-09

69. P. Wintz
STT Status
PANDA TEC Meeting, GSI Darmstadt, Germany: 2017-04-27 - 2017-04-27

70. P. Wintz
Readout Decision Process
STT Readout Meeting, GSI Darmstadt, Germany: 2017-05-15 - 2017-05-15

71. P. Wintz
STT Cable Routing
STT Readout Meeting, GSI Darmstadt, Germany: 2017-07-11 - 2017-07-11

72. P. Wintz
STT Status
Tracking and Micro Vertex Detector Session at PANDA Collaboration Meeting 17/3, Budker Institute, Novosibirsk, Russia: 2017-09-04 - 2017-09-08

73. P. Wintz
T0 Determination by STT
STT Readout Meeting, GSI Darmstadt, Germany: 2017-10-25 - 2017-10-25

74. P. Wintz
Status ASIC/TRB System
STT Readout Meeting, GSI Darmstadt, Germany: 2017-10-25 - 2017-10-25

75. P. Wintz
STT Status
PANDA TEC Meeting, GSI Darmstadt, Germany: 2017-11-30 - 2017-11-30

76. A. Wirzba
Electric dipole moments of hadrons and light nuclei in chiral effective field theory
Low-energy probes of new physics, Mainz, Germany: 2017-05-02 - 2017-05-24

77. R. Woods *et al.*
A monolithic 64-channel germanium strip detector system with integrated circuit readout for energy dispersive X-ray diffraction
IEEE Nuclear Science Symposium and Medical Imaging Conference, NSS/MIC, Atlanta, USA: 2017-10-21 - 2017-10-28

78. F. Zahariev *et al.*
Developments for the Injection Kicker Vacuum System of the HESR at FAIR
8th International Particle Accelerator Conference, Copenhagen, Denmark: 2017-05-14 - 2017-05-19

79. M. Zurek
Charge Symmetry Breaking in the Reaction $dd \to {}^4He\pi^0$ with WASA-at-COSY
XVII International Conference on Hadron Spectroscopy and Structure, Salamanca, Spain: 2017-09-25 - 2017-09-29

80. M. Zurek
Charge Symmetry Breaking In The $dd \to \alpha\pi^0$ Reaction With WASA-at-COSY
26th International Nuclear Physics Conference, Adelaide, Australia: 2016-09-11 - 2016-09-16

## D.2 Colloquia

1. R.W. Engels
"'Polarized D2/HD Molecules: An Option to Produce Polarized Fuel for Fusion Experiments"
Hamburg, Germany: 2017-07-13 - 2017-07-13

2. R.W. Engels
"'Advantages of Polarized Fuel in Nuclear Fusion - Polarized Fusion"
Garching, Germany: 2017-09-12 - 2017-09-12

3. J. Haidenbauer
Revisiting the antinucleon-nucleon interaction in the wake of FAIR
Graz, Austria: 2017-04-20

4. A. Halama
Elektronenkühlung und die Modelentwicklung zur automatisierten Einstellung des 2 MeV Elektronenkühlers am COSY
MAMI-Seminar, Mainz, Germany: 2017-11-23 - 2017-11-23

5. L. Ludhova
JUNO
Erlangen, Germany: 2017-06-28 - 2017-06-28

6. A. Nogga
Predictions for light hypernuclei based on chiral and similarity renormalization group-evolved interactions
East Lansing, Michigan State University, USA: 2017-04-18

7. J. Ritman
IN2P3 - HGF Cooperation on HADES and PANDA for the FAIR-Phase0 Experiments (and beyond)
IN2P3-HGF-Coordination Meeting, KIT Karlsruhe, Germany: 2017-10-17

8. C. Weidemann
High precision beam control, COSY orbit control, COSY orbit control
EDM kick-off meeting, Geneva, Switzerland: 2017-03-13 - 2017-03-14

9. P. Wintz
"Scope of the meeting"
PANDA-STT Readout Workshop, Krakow, Poland: 2017-01-30 - 2017-01-31

10. P. Wintz
Aims of Decision Process
PANDA-STT Readout Workshop, Krakow, Poland: 2017-01-30 - 2017-01-31

11. P. Wintz
PAND-STT Readout Requirments and Open Points
PANDA-STT Readout Workshop, Krakow, Poland: 2017-01-30 - 2017-01-31

12. P. Wintz
Readout Status during 2016 Beam Tests
PANDA-STT Readout Workshop, Krakow, Poland: 2017-01-30 - 2017-01-31

13. M. Zurek
Searches for Electric Dipole Moments (EDM) at Storage Rings
Nuclear, Particle and Astrophysics Seminar, University Basel: 2017-11-30

# E Diploma and Ph.D. Theses

## E.1 Dissertation / PhD Thesis

1. S. Chekmenev
   Investigation of Possibilities to Measure the Deuteron Electric Dipole Moment at Storage Rings
   RWTH Aachen University

2. F. Hinder
   Development of Beam Diagnostic Systems for Electric Dipole Moment Measurements at Particle Accelerators
   RWTH Aachen University

3. E. Valetov Field Modeling, Symplectic Tracking, and Spin Decoherence for EDM and Muon g-2 Lattices
   Michigan State University

4. M. Zurek
   Investigation of the Charge Symmetry Breaking Reaction $dd \to {}^4He\pi^0$ with the WASA-at-COSY Facility
   Univeristy of Cologne

## E.2 Master Thesis

1. H. Awwad
   Production of polarized molecules built from polarized hydrogen and deuterium atoms
   Heinrich Heine Universität Düsseldorf

2. V. Schmidt
   Analysis of Closed-Orbit Deviations for a first direct Deuteron Electric Dipole Moment Measurement at the Cooler Synchrotron COSY
   RWTH Aachen University

3. A. A. Skawran
   Comparison of Frozen and Quasi Frozen Spin Concepts for a Deuteron Electrical Dipole Moment Storage Ring
   RWTH Aachen University

## E.3 Bachelor Thesis

1. L. Brandes
   Proper extraction of the pion radius from data
   Bonn

2. F. Brueckerhoff-Plueckelmann
   Spin symmetry partners of Y(4260)
   Bonn

3. Y. Gan
   Design, Construction and Test of a Sona Transition Unit for metastable Hydrogen and Deuterium Atoms
   FH Aachen

4. M. Geiger
   Lineshapes of near threshold states
   Bonn

5. D. Stamen
   Analysis of VMD vs. dispersive techniques for production reactions
   Bonn

# F Third Party Funded Projects

| Project | Responsible | Funded by |
|---|---|---|
| HGF - Fellow Award C.Roberts Preisgeld | U. Meißner | HGF |
| PGSB: Experimental tests of time-reversal | H. Ströher | HGF |
| (CASCADE) Computational Science for Comp | T. Luu / U. Meißner | HGF |
| SFB/TRR 110 Quantenchromodynamik TP A01 | J. Haidenbauer | DFN/SFB, NFSC |
| SFB/TRR 110 Quantenchromodynamik TP B03 | C. Hanhart | DFN/SFB, NFSC |
| SFB/TRR 110 Quantenchromodynamik TP B06 | U. Meißner | DFN/SFB, NFSC |
| SFB/TRR 110 Quantenchromodynamik TP B06 | A. Nogga | DFN/SFB, NFSC |
| SFB/TRR 110 Quantenchromodynamik TP Z01 | U. Meißner | DFN/SFB, NFSC |
| SFB/TRR 110 Quantenchromodynamik TP Z02 | C. Hanhart | DFN/SFB, NFSC |
| SFB/TRR 110 Quantenchromodynamik TP B09 | T. Luu / U. Meißner | DFN/SFB, NFSC |
| PANDA/ Straw Tube Tracker | J. Ritman | Industrieprojekt mit der GSI GmbH |
| PANDA/ Micro Vertex Detector | J. Ritman | Industrieprojekt mit der GSI GmbH |
| HESR - Dipole und Quadrupole | R. Tölle | Industrieprojekt mit der FAIR GmbH |
| HESR - sonstige Magnete | U. Bechstedt | Industrieprojekt mit der FAIR GmbH |
| HESR - Netzgeräte | M. Retzlaff | Industrieprojekt mit der FAIR GmbH |
| HESR - Hochfrequenz | R. Stassen | Industrieprojekt mit der FAIR GmbH |
| HESR - Injektion | R. Tölle | Industrieprojekt mit der FAIR GmbH |
| HESR - Strahldiagnose | V. Kamerdzhiev | Industrieprojekt mit der FAIR GmbH |
| HESR - Vakuum | F. Esser | Industrieprojekt mit der FAIR GmbH |
| HESR - Stochastische Kühlung | R. Stassen | Industrieprojekt mit der FAIR GmbH |
| HESR - Panda-Integration | D. Prasuhn | Industrieprojekt mit der FAIR GmbH |
| AVA MSCA I TN | D. Grzonka | EU |
| srEDM ERC Advanced Grant Management | H. Ströher | EU |
| srEDM ERC Advanced Grant Research | H. Ströher | EU |

# G External Cooperations/Projects

| **Project** | **Institute** | **Responsible** |
|---|---|---|
| PD Dr. A. Khoukaz | Westfälische Wilhelms Universität Münster | Mesonenproduktion in Nukleon-Nukleon- und Nukleon-Kern-Stößen an COSY |
| Prof. Dr. Vorobyev | PNPI Gatchina | The np-reaction studies using the ANKE STTs |
| Prof. Dr. M. Nioradze | Tbilisi State University | Polarimetry development for JEDI project |
| PD Dr. D. Eversheim | HISKP Universität Bonn | Time Reversal Invariance Test at COSY (TRIC) |
| Prof. N. Nikolaev | L.D. Landau Institute Moscow, Russia | Numerical simulations of spin dynamics for JEDI experiments, searching for permanent Electric Dipole Moments of deuterons and protons at COSY |
| Prof. A. Roy | Indian Institute of Technology Indore, India | The $\eta$ meson decay into $\gamma\gamma^*$ in pp reactions with WASA-at-COSY |
| Dr. A. Kulikov | JINR Dubna, Moscow Region, Russia | Spin Experiments at ANKE |
| Prof. P. Lenisa | Università degli Studi di Ferrara, Italy | Spin-filtering studies in storage rings |
| Prof. A. Schmeink | RWTH Aachen, Fakultät für Elektrotechnik und Informationstechnik | A secure real-time remote control and operation of COSY subcomponents |
| Prof. Dr. K. Brinkmann | Justus-Liebig-Universität Gießen | Development and Validation of Detector Components and Preassembly for the PANDA MVD |

# H Conferences (co-)organized by the IKP

## H.1 90 years of RF Accelerators

In 1927 Rolf Wideröe completed his seminal doctoral thesis in Aachen, Germany. 2017 was the 90 year anniversary of the first linear RF accelerator, constructed by Wideröe in Aachen, and of his visionary idea for a circular accelerator. DESY and RWTH Aachen invited to a high level symposium to mark this anniversary and the subsequent achievements in our accelerator community: Symposium "90 Years of RF Accelerators" Commemorating the 1927 PhD of Rolf Wideröe at Aachen, Germany.
The half-day symposium celebrated this event with talks on the history and modern accelerators from the LHC to the XFEL and medical applications. After welcome addresses by Ernst Schmachtenberg (Rector RWTH Aachen), Arnulf Quadt (Board member of the DPG) and Helmut Dosch (Vice President Helmholtz Association, Chairman DESY Directorate), the program compromised the following talks:

- Rolf Wideröe, Life and Work, N. Holtkamp (SLAC)
- From Wideröe to the LHC as a Masterpiece of Science & Technology, O. Brüning (CERN)
- From Wideröe to the EuXFEL for Cutting-Edge Exploration of Matter, H. Weise (DESY)
- Accelerators in Modern Society for Medical Treatment, H. Rohdjess (Siemens Healthcare GmbH)
- Towards a Revolutionary Generation of Compact Accelerators, W. Leemans (LBNL)

The participants also had a lively discussion on RF accelerators and future developments in the morning of the second day.
Organisers: Ralph Assmann (DESY), Andreas Lehrach (RWTH & FZJ), Achim Stahl (RWTH).

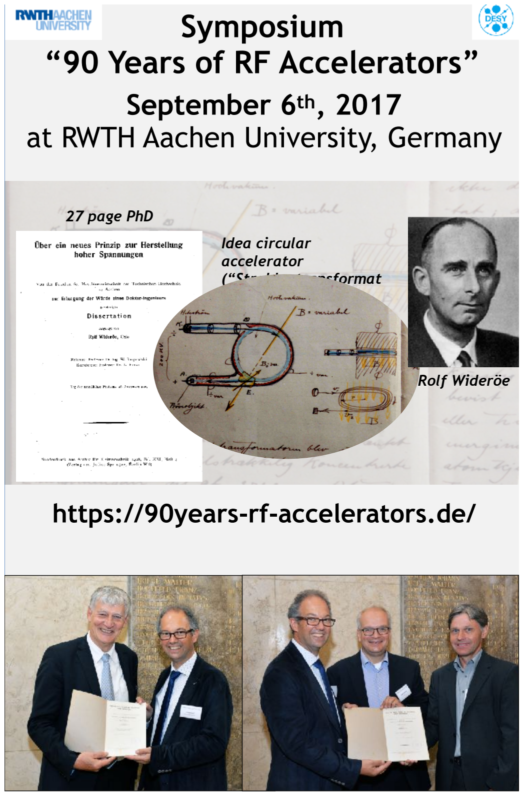


Fig. 5: Symposium poster and photos taken at the event, Prof. Schmachtenberg with Prof. Stahl (left side) and Prof. Stahl with Dr. Assmann and Prof. Lehrach (right side).

## H.2 QUALI-Start-Up Science Lectures in Jülich

Twenty two students from four Georgian universities (AUG, GTU, ISU and TSU) have visited Forschungszentrum Jülich for nine days in September 2017 to attend the autumn-school QUALI-Start-Up Science Lectures. This was the first school of its kind in Jülich and a follow-up of two previous events in Georgia in 2013 and 2015. The participants had been selected earlier in 2017 in personal interviews in Georgia. The lectures were organized by IEK, INM, IKP, JCNS and ZEA of Forschungszentrum and co-funded by the Georgian Ministry of Education and Science (MoE) and institutes of Forschungszentrum Jülich. During the lectures, the students were introduced to the science conducted at the institutes and they had the chance to perform hands-on practices in laboratories. They also visited RWTH Aachen University and had the possibility to do sightseeing in Aachen and Cologne.

Fig. 6: Students from Georgia and Jülich staff attending the "Autumn School" at Forschungszentrum Jülich

## H.3 High–School–Student and Teacher Training Program in Hadron and Particle Physics

Funded by the Collaborative Research Center 110 and organized by members of the IKP/IAS of the Forschungszentrum as well as the Physikalisches Institut of Bonn University both a one–day teacher training program ('Lehrerfortbildung Teilchenphysik' with 25 participants) as well as a one–week program for high–school students ('Schülerakademie Teilchenphysik' with 27 participants) took place in the University of Bonn and the Science College of Haus Overbach in Jülich Barmen, respectively. Fundamentals as well as current issues in nuclear, hadron and particle physics were discussed like the formation of elements, computer simulations, exotic hadrons and basics of string theory. The high–school students had in addition the opportunity to visit COSY as well as the supercomputers in the Forschungszentrum Jülich and to work on an own project in a small group.

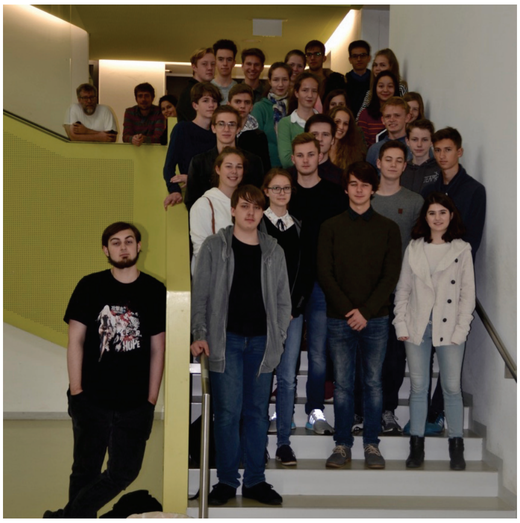

Fig. 7: Participants of the 3$^{rd}$ Schülerakademie Teilchenphysik, October 2017, Jülich Barmen, Germany

# I Teaching Positions

| Institute | Name | University |
|---|---|---|
| IKP-1 | PD Dr. A. Gillitzer | Bonn |
| | Prof. Dr. F. Goldenbaum | Wuppertal |
| | Prof. J. Ritman Ph.D. | Bochum |
| | Dr. T. Stockmanns | Bochum |
| IKP-2 | Prof. Dr. D. Gotta | Köln |
| | PD Dr. F. Rathmann | Aachen |
| | Prof. Dr. L. Ludhova | Aachen |
| | Prof. Dr. Dr. h.c. H. Ströher | Köln |
| | Prof. Dr. J. Pretz | Aachen |
| IKP-3/IAS-4 | Univ. Doz. Dr. J. Haidenbauer | Graz |
| | Prof. Dr. C. Hanhart | Bonn |
| | Prof. Dr. T. Luu | Bonn |
| | Prof. Dr. U.-G. Meißner | Bonn |
| | Dr. A. Nogga | Bonn |
| | PD Dr. A. Wirzba | Bonn |
| IKP-4 | Prof. Dr. M. Bai | Bonn |
| | Prof. Dr. A. Lehrach | Aachen |

# J Personnel

DP D. Alfs (IKP-1) (since 1st September 2017)
F. Abusaif (IKP-2) (since 1st October 2017)
Dr. Z. Bagdasarian (IKP-2)
Prof. M. Bai (IKP-4) (until 31st May 2017)
Dr. U. Bechstedt (IKP-4)
Dr. I. Bekman (IKP-4) (since 1st March 2017)
C. Berchem (IKP-TA)
Dr. E. Berkowitz (IKP-3/IAS-4)
DP L. Bianchi (IKP-1)
Dr. C. Böhme (IKP-4)
M. Böhnke (IKP-4)
Dr. J. Böker (IKP-4)
DI N. Bongers (IKP-4)
Dr. B. Breitkreutz (IKP-4)
P. Brittner (IKP-4)
J. But (IKP-TA)
Dr. L. Cao (IKP-1) (until 17th January 2017)
W. Classen (IKP-4)
M. Comuth-Werner (IKP-TA)
Dr. C. Constantinou (IKP-3/IAS-4) (until 30th April 2017)
DI F.U. Dahmen (IKP-4)
Dr. L. Dai (IKP-3/IAS-4)
DI N. Demary (IKP-TA)
MBA A. Derichs (IKP-1)
C. Deliege (IKP-4)
G. D'Orsaneo (IKP-2)
R. Dosdall (IKP-1)
Dr. Y. Dutheil (IKP-4) (until 15th August 2017)
C. Ehrlich (IKP-4)
Dr. R. Engels (IKP-2)
B. Erkes (IKP-4)
DI F.-J. Etzkorn (IKP-4)
Dr. O. Felden (IKP-TA)
H.-W. Firmenich (IKP-TA)
N. Fröhlich (IKP-4) (since 1st February 2017)
Y. Gan (IKP-2) (until 31th May 2017)
Dr. R. Gebel (IKP-4)
Dr. J. Gegelia (IKP-3/IAS-4)
Msc. C. Genster (IKP-2)
R. Geppert (IKP-TA)
PD Dr. A. Gillitzer (IKP-1)
J. Göbbels (IKP-TA)
K. Göbbels (IKP-TA) (until 11th April 2017)
PD Dr. F. Goldenbaum (IKP-1)
Prof. Dr. D. Gotta (IKP-2)
Dr. D. Grzonka (IKP-1)
Univ. Doz. Dr. J. Haidenbauer (IKP-3/IAS-4)
K. Haladyn (IKP-1) (until 14th November 2017)
BSc. I. Hammer (IKP-3/IAS-4)
Prof. Dr. C. Hanhart (IKP-3/IAS-4)
D. Han (IKP-2) (since 15th September 2017)
T. Hahnraths-von der Gracht (IKP-TA)
BEng. A. Halama (IKP-4)
Dr. M. Hartmann (IKP-2)
DI R. Hecker (IKP-TA)
Dr. V. Hejny (IKP-2)
Dr. N. Hempelmann (IKP-2)
Dr. J.-H. Hetzel (IKP-4)
Dr. F. Hinder (IKP-4) (until 28th February 2017)
M. Holona (IKP-TA)
Dr. J. Hu (IKP-3/IAS-4)
L. Huxold (IKP-2) (until 31th May 2017)
Dr. A. Kacharava (IKP-2)
Dr. V. Kamerdzhiev (IKP-4)
Msc. P. Kampmann (IKP-2)
Dipl.-Kffr. A. Kelleners (IKP-TA)
Dr. I. Keshelashvilli (IKP-2)
A. Kieven (IKP-4)
S. Kistemann (IKP-TA)
A. Krampe (IKP-2) (since 5th Sept. until 4th Dec. 2017)
B. Klimczok (IKP-TA)
MSc. C. Körber (IKP-3/IAS-4)
M. Kremer (IKP-TA)
DI T. Krings (IKP-TA)
M. Küven (IKP-4)
S. Kumaran (IKP-2) (since 15th September 2017)
Dr. M. Kunkel (IKP-1)
Dr. T. Lähde (IKP-3/IAS-4)
DP A. Lai (IKP-1)
K.-G. Langenberg (IKP-4)

Prof. Dr. A. Lehrach (IKP-4)
Dr. D. Lersch (IKP-1)
H. Le Thi (IKP-3/IAS-4)
Dr. N. Li (IKP-3/IAS-4) (until 31st October 2017)
X.-H. Liu (IKP-3/IAS-4)
Dr. B. Lorentz (IKP-4)
Dr. B. Lu (IKP-3/IAS-4) (until 30th September 2017)
Prof. Dr. L. Ludhova (IKP-2)
Prof. Dr. Th. Luu (IKP-3/IAS-4)
Dr. D. Marschall (IKP-4) (since 1st February 2017)
M. Maubach (IKP-TA) (since 26th January 2017)
DI H.-P. May (IKP-4)
Prof. Dr. U.-G. Meißner (IKP-3/IAS-4)
Dr. S. Merzliakov (IKP-4)
C. Müller (IKP-TA) (until 28th August 2017)
DP F. Müller (IKP-2)
S. Müller (IKP-TA)
DP P. Musiol (IKP-1) (until 31st July 2017)
J. Nadenau (IKP-2) (since 1st October 2017)
Dr. A. Naß (IKP-2)
B. Nauschütt (IKP-4) (until 28th April 2017)
Dr. A. Nogga (IKP-3/IAS-4)
V. Payak (IKP 2) (since 18th December 2017)
Msc. Ö. Penek (IKP-2)
BSc J. T. Peters (IKP-4)
Dr. D. Prasuhn (IKP-4)
Dr. E. Prencipe (IKP-1)
D. Prothmann (IKP-TA)
H. Pütz (IKP-4)
DP J. Pütz (IKP-1)
MSc. S. Quilitzsch (IKP-4)
PD Dr. F. Rathmann (IKP-2)
Msc. M. Redchuk (IKP-2)
DI K. Reimers (IKP-4)
DI M. Retzlaff (IKP-4)
Prof. J. Ritman (IKP-1)
Dr. E. Roderburg (IKP-1) (until 31st March 2017)
G. Roes (IKP-TA)
N. Rotert (IKP-4) (until 31st May 2017)
D. Ruhrig (IKP-4)
PD Dr. S. Schadmand (IKP-1)
MSc. M. Schever (IKP-2)
Dr. R. Schleichert (IKP-2)
MSc. V. Schmidt (IKP-4)
F. Scheiba (IKP-4)
H. Schiffer (IKP-TA)
M. Schmühl (IKP-4)
K. Schumacher (IKP-TA) (since 14th August 2017)
Dr. Th. Sefzick (IKP-TA)
Prof. Dr. Y. Senichev (IKP-4)
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R. Shah (IKP-2) (since 15th September 2017)
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DP S. Vejdani (IKP-1)
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H. Zens (IKP-4)

Dr. L. Zhao (IKP-3/IAS-4) (until 31st March 2017)

Dr. Y. Zhou (IKP-1) (since 1st February 2017)

Dr. M. Zurek (IKP-2)

IKP-1 = Experimental Hadron Structure
IKP-2 = Experimental Hadron Dynamics
IKP-3/IAS-4 = Theory of the Strong Interactions
IKP-4 = Large-Scale Nuclear Physics Equipment
IKP-TA = Technical Services and Administration

# K Further Contributions

available on-line under downloads: http://www.fz-juelich.de/ikp/

## Poster prepared for the POF evaluation.

1. PANDA - Parallel Algorithms for Online Track Finding
2. PANDA - Data Acquisition System for prototypes of the Micro Vertex Detector Front-End Electronics
3. PANDA - Study of $\Xi$ Resonances
4. PANDA - KOALA
5. CLAS12 - Machine Learning for Particle Identification
6. Light Meson Decays - The Structure of Hadrons
7. Light Meson Decays - Fundamental Properties of Hadrons
8. Charge Symmetry Breaking - Probing the quark mass difference
9. Neutrino physics with Borexino - Solar neutrino analysis
10. Neutrino Physics with JUNO - Waveform Reconstruction
11. Electric Dipole Moments - LYSO Scintillator Based Polarimetry
12. Electric Dipole Moments - RF Wien Filter Development
13. Electric Dipole Moments - Spin Tune Feedback
14. Electric Dipole Moments - Spin tune mapping at COSY
15. Electric Dipole Moments - Spin Tracking and Closed Orbit Simulations
16. Electric Dipole Moments - Beam Position Monitor based on Rogowski coils
17. 2 MeV Electron Cooler - Experimental Results and Model Development
18. HESR - Beam-Dynamics Simulation Studies
19. Stochastic Cooling - High Brilliance Beams for HESR

## Short reports

1. GUI and utility development for the 2 MeV electron cooler model software suite
2. COSY Beam Loss Monitor System
3. Detection of $\Xi$ Resonances in the Reaction $\bar{p}p \to \Xi^- + \Xi^-\pi^0$ with PANDA
4. Track reconstruction and particle identification in the P-349 Antiproton Polarization Experiment
5. A FPGA-Driven Signal Source for the Barrier Bucket Cavity at COSY
6. New Technologies for the HESR Stochastic Cooling System
7. Stochastic Cooling Results with first HESR Pickup and Kicker at COSY
8. The upgraded beam position measurement system at COSY

Jül-4408 • Mai 2018
ISSN 0944-2952



JÜLICH
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