

**ERC Advanced Grant 2015**  
**Research proposal [Part B1]**  
*(Part B1 is evaluated both in Step 1 and Step 2*  
*Part B2 is evaluated in Step 2 only)*

## Electric Dipole Moment Search using Storage Rings

### srEDM

**Cover Page:**

- |   |                                       |
|---|---------------------------------------|
| - Name of the Principal Investigator (PI)           | Prof. Dr. Dr. h.c. mult. Hans Ströher |
| - Name of the PI's host institution for the project | Forschungszentrum Jülich, Germany     |
| - Proposal duration in months                       | 60                                    |

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 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 physics beyond the SM.

Investigations on different systems are required to pin down CPV sources and this proposal aims 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. It will develop the key technologies and achieve a first directly measured EDM limit for protons and deuterons and thus provide the basis for a new European flagship research infrastructure.

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. A stepwise approach, from R&D for key-technologies towards the holy grail of a double-beam precision storage ring with counter-rotating beams, is needed. The research environment of the Forschungszentrum Jülich (Germany), including COSY, provides the optimum basis for one of the most spectacular possibilities in modern science: finding an EDM as a signal for new physics beyond the SM and perhaps explaining the puzzle of our existence.

## Section a: Extended Synopsis of the scientific proposal (max. 5 pages)

### Introduction: Motivation and Objectives

A new class of precision storage rings is required to search for electric dipole moments (EDMs) of charged particles with unprecedented sensitivity. It is the aim of this proposal to take a decisive step towards the design and construction of such a facility by establishing the required key technologies and to deliver the first directly measured EDMs for both the proton and the deuteron using the existing cooler storage ring COSY at the Forschungszentrum Jülich (FZJ) in Jülich (Germany).

Permanent EDMs of particles violate both time reversal (T) and parity (P) invariance and, on the basis of the CPT theorem, they also violate the combined symmetry CP (CPV). Such a symmetry breaking is thought to be responsible for the different behaviour of particles and antiparticles, leading, e.g., to the apparent matter-antimatter asymmetry in the Universe. CPV is found in the electroweak part of the Standard Model of particle physics (SM) but, since SM-CPV is much too weak to explain the matter-antimatter asymmetry, other sources must be sought. An obvious observable to investigate is an EDM since no EDM of a fundamental particle has yet been observed. Finding a finite EDM would very probably also indicate new physics, i.e., that not contained in the SM. Even after a possible positive EDM observation, different systems would have to be investigated in order to identify the CPV-source.

EDMs are very small – the best current limit for the neutron is  $10^{-26}$  e-cm – and the aim for charged particles is at least  $10^{-29}$  e-cm. Although the measurement principle – the time development of the polarization vector subject to a perpendicular electric field – is simple, this represents an enormously challenging project due to the smallness of the expected effect. It will only be mastered through the common effort of an experienced international team of accelerator and spin-physics scientists, supplemented by mechanical and electrical engineers.

It should be noted that, whereas charged particles potentially offer the highest sensitivity with discovery potential, up to now no EDM measurements for protons and deuterons in a storage ring have been performed. However, an upper limit of  $10^{-19}$  e-cm was obtained for muons as a side activity of the measurement of the anomalous magnetic moment ( $(g-2)_\mu$ ) in a storage ring experiment.

Given the history of neutron EDM searches over the past 50 years or so, it is evident that a corresponding level of sensitivity cannot be obtained in one giant leap – a stepwise approach, in which the next generation measurement is based on the expertise and technological know-how gained in the preceding one, is compulsory. The steps towards the holy grail of a charged particle EDM search, using a double-beam precision storage ring with counter-rotating beams, comprise:

1. Research and development of all the key techniques at an existing conventional single-beam storage ring. COSY, the cooler synchrotron and storage ring at the Forschungszentrum Jülich, is the ideal place for these investigations, which involve spin-coherence time optimization, precision polarimetry development, beam tracking measurements, etc.;
2. Precision spin-tracking simulations: an essential requirement for an assessment of the capabilities of the final precision ring is to provide realistic simulations, e.g., for benchmarking EDM test installations in COSY;
3. A proof-of-principle experiment: this measurement will use COSY-Jülich without major transformations except for improvements of the beam position monitor (BPM) system and the assembly of a radiofrequency (rf) Wien-filter which (in an ideal storage ring) would induce spin rotation if an EDM exists;
4. A first direct EDM measurement (for the proton and the deuteron), again exploiting COSY-Jülich, but here upgraded with a short electrostatic deflector inside the ring. The beam chicane could be inserted in one of the straight sections of COSY. This would test one of the key techniques of the final ring and should lead to an EDM upper limit in the order  $10^{-24}$  e-cm. It would also provide a reality check on further key items, e.g., the spin coherence time and polarimetry;
5. Conceptual design report (CDR) and technical design report (TDR) for the final dedicated storage ring, including cost estimates for building and operating the facility;
6. Construction and commissioning of the new facility for EDM searches, once funding has been secured.

The current proposal addresses items 1) – 4). The accelerator scientists and experimental physicists (hadron and spin physics) at the Institut für Kernphysik (IKP) at FZJ [JUELICH], the research environment at center (e.g., mechanical and electronics workshops) – including the cooler storage ring COSY for polarized proton and deuteron beams as a unique asset – as well as the close connections with RWTH

Aachen University [RWTH] (high energy physics, engineers) via the Jülich-Aachen Research Alliance (JARA, section FAME (Forces and Matter Experiments)) and the long-term successful cooperation with University of Ferrara and INFN Ferrara (Italy) [UNIFE] provide the optimal basis for one of the most spectacular possibilities in modern science: finding an EDM as a signal for new physics beyond the SM and perhaps explaining the puzzle of our existence.

## Science Case

Symmetries and symmetry violation (“breaking”) play a very important role in physics. Permanent EDMs of particles violate both time reversal (T) and parity (P) invariance. Via the CPT theorem (which is based on very general assumptions and is therefore generally believed to be an exact symmetry), EDMs also violate CP (the combination of charge (C) conjugation and parity exchange), which compensates for the breaking of T.

The underlying scientific case, i.e., the quest to fundamentally understand the difference between matter and antimatter that has led to our matter-dominated universe, is one of the grand challenges in contemporary physical sciences. This has been widely acknowledged, e.g., in the recently published strategy reports of the European and the US high-energy physics communities.

Up to now measurements of electric dipole moments have concentrated on *neutral* systems (neutron, atoms, and molecules) and, no direct measurements exist for *charged* hadrons. This is due to the fact that charged particles are accelerated in electric fields and so cannot be kept in small volumes like traps. Storage rings have to be used to perform these kinds of experiments. It must be emphasized that charged systems (specifically proton, deuteron and possibly  $^3\text{He}$ ) are not only complementary and potentially more sensitive, but they are also required to disentangle the possible (different) EDM source(s).

If an EDM is measured, e.g., for the neutron, an important question remains: is it caused by *strong* CP violation within the Strong Interaction sector of the Standard Model of elementary particle physics (the so-called  $\theta$ -term) or from physics beyond the Standard Model (BSM)? It is conceivable that a single EDM measurement may be interpreted (fitted) by any of the sources considered, so that at least two measurements are needed to say something about the origin of the CP violation. Experimental data on the EDMs of light nuclei might resolve these ambiguities.

In order to determine which systems are the most promising, several calculations have been performed in recent years for EDMs of the nucleon (neutron, proton) and several light nuclei, using modern effective-field-theory techniques. These show that the  $\theta$ -term could be identified with good accuracy once EDM measurements of the neutron, proton and deuteron have been performed. If this is indeed the source, the EDMs of these systems are all expected to be of the same order of magnitude, but the precise quantitative relations between the individual EDMs are a clear prediction of the  $\theta$ -term. In this way, the existence of strong CP violation could be convincingly determined, potentially solving a puzzle that has been around for almost fifty years.

On the other hand, the size of the deuteron EDM, with respect to the EDM of proton and neutron, is an excellent probe for physics beyond the Standard Model (BSM). As mentioned above, the  $\theta$ -term leads to EDMs of a similar size for the nucleon and the deuteron, while certain BSM sources predict the deuteron EDM to be significantly larger, by up to an order of magnitude. Such a signal, obtained in the envisioned storage ring experiment, would be a “smoking gun” for BSM physics.

In summary, it is necessary to determine electric dipole moments of different systems in order to disentangle the different CPV source(s) by comparing the various model predictions. The deuteron EDM has an especially important discriminating power due to its spin-1 – isospin-0 properties. While lepton- (electron, muon) EDMs are directly related to the underlying fundamental theory, the hadronic results are more complex, but also much more interesting.

## Concept for Charged-Hadron EDM Searches

EDMs are very small – the best current upper limit for the *neutron* is  $10^{-26}$  e·cm – and the goal for *charged particles* in the ultimate project is  $10^{-29}$  e·cm or even better. In spite of the simplicity of the measurement principle – following the time development of the polarization vector of particles subject to a perpendicular electric field – the smallness of the effect provides exceptional challenges, e.g., to identify and/or avoid any fake signal.

The spin precession (i.e., the motion of the polarization vector of a particle beam) in a storage ring is governed by the so-called Thomas-Bargmann-Michel-Telegdi (Thomas BMT) equation. The main challenge is that in general the spin precession due to the *magnetic dipole moment* (MDM) is many orders of magnitude larger than the spin precession expected from an EDM. The aim is thus to find electromagnetic field configurations where the contribution due to the MDM vanishes, i.e., where the spin vector does not precess and always points along the momentum vector in the absence of an EDM. This technique is called “frozen spin”.

For protons, with their positive anomalous magnetic moment, this can be achieved with *purely electric fields* for a “magic” beam momentum of  $p = 700.74 \text{ MeV}/c$ . For particles with a negative anomalous magnetic moment (like deuterons and  $^3\text{He}$ ), a *combination of electric and magnetic fields* has to be used. In either case, a non-vanishing EDM results in a build-up of a vertical polarization component for a beam that was initially polarized in the horizontal plane. A purely electric ring for proton EDM measurements is proposed [<http://www.bnl.gov/edm/Proposal.asp>] by a collaboration at Brookhaven National Laboratory (BNL, USA). A radial electric field of about 17 MV/m between field plates approximately 2 cm apart results in a ring with a bending radius of about 50 m.

An alternative is to use a combined machine, with both radial electric and vertical magnetic fields. By suitable combinations of the E- and B-fields, a ring with a bending radius between 10 and 30 m could be used for protons, deuterons and  $^3\text{He}$  nuclei (“all-in-one” ring). Such a ring is suggested by the JEDI-collaboration [<http://collaborations.fz-juelich.de/ikp/jedi/>] at COSY.

For both options, the use of clockwise (CW) and counter clockwise (CCW) beams is mandatory. This is because the main systematic error will come from an unwanted spin precession due to the MDM in radial magnetic fields which will be indistinguishable from the EDM signal. However, a radial magnetic field causes forces in different directions for the beams in opposite directions and thus it can be controlled to a very high accuracy.

## Implementation

As already stressed, the principle of such measurements is quite simple: if an electric dipole moment exists, the spin vector, which is oriented parallel to the EDM direction, will experience a torque in an external electric field, resulting in a change in the original spin direction. This minuscule spin rotation (about  $1 \mu\text{rad}/\text{s}$  for an EDM of  $10^{-26} \text{ e}\cdot\text{cm}$ ) can be determined with the help of a polarimeter (a detector to determine the spin direction). Alternatively, it might be possible to measure the tiny change of the spin precession frequency due to an EDM by comparing results with different electric field strengths. As emphasized before, the smallness of the expected effect, as well as possible background and fake contributions, will require paramount precision and utmost care. Even with a dedicated new  $\mu\text{EDM}$  storage ring, it will be difficult to improve the current limit  $\sim 10^{-19} \text{ e}\cdot\text{cm}$  for the muon to better than about  $10^{-24} \text{ e}\cdot\text{cm}$ , due to the short muon lifetime. This restriction is not relevant for the hadrons considered here.

In view of the necessary requirements, the existing cooler storage ring COSY at the Forschungszentrum Jülich, with its capability to provide polarized protons and deuterons with momenta up to  $3.7 \text{ GeV}/c$ , is an ideal starting point for a research and development programme and a first direct charged-particle EDM measurement. For an ultimate precision measurement, however, a new class of dedicated storage rings is required, and these do not yet exist. At this point, COSY might be used as an injector to prepare the beams for the EDM ring. Searches for proton and deuteron EDMs have the potential to reach a sensitivity of  $10^{-29} \text{ e}\cdot\text{cm}$  per year of running, which is at least one order of magnitude better than that which is aimed for in future neutron EDM searches.

One of the aims of the current proposal is to establish the required key technologies for precision EDM storage rings for protons and deuterons. Before approaching the concept and design of the final ring, the toolbox of major hardware components needs to be developed and scrutinized in test measurements. In addition, a proof-of-principle test measurement and a first direct EDM measurement will be conducted. To be successful, the project needs expertise in many different fields, ranging from accelerator and elementary particle (spin-) physics to mechanical and electrical engineering. To ensure this, the project is embedded in the recently founded JEDI collaboration at COSY, comprising more than 100 collaborators from France, Georgia, Germany, Italy, Poland, Russia, USA, and other countries, and the US-based storage ring EDM collaboration.

## Expected Impact

Arguably the most important impact of this project will be the first-ever direct measurement of an EDM for charged hadrons in a storage ring, since it will determine the directions of R&D and pave the way for the (new class of) precision storage ring(s) of the future.

Accelerators are the tools for discovery and innovation, not only in the fields of elementary particle, hadron and nuclear physics, but also, e.g., in medical and industrial applications. This is why all developed countries, and in particular Europe, put a lot of emphasis into the further development of accelerators, from high-energy colliders and synchrotron radiation facilities to spallation neutron sources.

The physics case of the EDM project ultimately requires the design of a completely new and innovative storage ring. In order to reduce systematic errors and to identify/control fake effects, counter-rotating beams must be used. In the case of an “all-electric” ring (for protons at the magic momentum), the two beams can be stored in one common vacuum chamber, while for an “all-in-one” machine, with combined electric and magnetic fields (which can be used for protons, deuterons and  $^3\text{He}$  and for different energies), two separate beam tubes are needed. Together with the requirement of ultimate precision, these represent significant challenges. By overcoming these challenges, many innovations are to be expected, from surface treatment of electrostatic deflectors (to provide highest electric fields), shielding techniques (of external electric and magnetic fields), beam position and polarization measurement, to simulation techniques on supercomputers.

Already in the course of the initial steps – R&D, implementation of hardware into COSY, test and first EDM measurements with single beam – the complexity of the project will be a constant driver of innovation in accelerator, detection, and simulation techniques:

- Optimization of the spin coherence time (SCT) of the longitudinally polarized stored COSY beam by accelerator (sextupole) settings;
- Design, construction, and implementation and operation in COSY of a new beam polarimeter, capable of continuous spin tracking with the required sensitivity and stability;
- Design, construction and implementation in COSY, as well as their use, of new high-precision beam-position monitors;
- Design, construction and implementation in COSY of an rf Wien-filter to be used for the proof-of-principle demonstration measurement;
- Design, construction and implementation in COSY of an electrostatic deflector for the first direct EDM measurement;
- Spin-tracking simulations to benchmark experimental investigations and make predictions for new hardware.

While physicists and engineers (from research centres and universities) have to collaborate during the design phase, the later construction of such a precision storage ring will inevitably also involve technologically oriented institutes such as, e.g., the Central Institute for Engineering, Electronics and Analytics (ZEA) of Forschungszentrum Jülich, and high-tech companies, e.g., for building combined E-B deflectors.

An important extra impact will be the training and education of students and young researchers in a wide range of activities, simulations, hardware development, and data analysis. In addition, the existing collaborations at different levels between the core-team partners will be further developed and intensified. The project will also foster interactions within the worldwide community.

## Feasibility

The Cooler Synchrotron COSY at the Institut für Kernphysik (IKP) of Forschungszentrum Jülich has been mentioned repeatedly as the test and development machine for the current proposal. COSY is the state-of-the-art storage ring for polarized proton and deuteron beams. After more than twenty years of operation for hadron physics, it has essentially all of the equipment and techniques needed for spin-manipulations with stored polarized beams, including a so-called “Siberian Snake”, necessary for longitudinally polarized beams that will be delivered during 2015. Therefore, COSY is the only machine in the world where most of the necessary tests for the storage ring EDM project can be performed, including a first direct measurement of proton and/or deuteron EDMs, once the planned COSY upgrades are completed.

The accelerator scientists at IKP have a long-standing experience with the acceleration and storage of polarized beams in COSY. The new head of the Large-Scale Nuclear Physics Equipment Institute (IKP-4)

Professor Mei Bai, who arrived from Brookhaven National Lab in 2014, has committed herself, together with a significant part of IKP-4, to the srEDM project.

The PI's group at IKP performed hadron physics experiments with polarized beams at COSY for about 15 years, using internal detector systems (ANKE, PAX and WASA). With the phasing out of the COSY hadron-physics programme at the end of 2014, most of IKP-2 scientists are now fully focused on srEDM. The central engineering institutes of FZJ (ZEA-1 (mechanics), ZEA-2 (electronics)) are IKP-2 partners in the new project.

Within the institutional cooperation between the Forschungszentrum Jülich and RWTH Aachen University called JARA (Jülich-Aachen Research Alliance), the recently founded section FAME (Forces and Matter Experiments) is concerned with "The Fate of Antimatter", which provides the scientific basis of the project. JARA-FAME brings together hadron (spin-) physics of IKP with the high energy physics as well as the engineering institutes of RWTH. Within JARA, two common W2-professorships have been established and filled by Andreas Lehrach (accelerator physics) and Jörg Pretz (experimental physics). The PI is a founding member of JARA-FAME.

The long-term and extremely successful cooperation between the University and INFN Ferrara (Italy), and IKP-2, e.g., for the PAX polarized-antiproton project, has led to a substantial involvement of the group of Professor Paolo Lenisa (Ferrara) in the srEDM project, in particular in the spin coherence time investigations and polarimetry.

In conclusion it can be stated that all the requirements for a successful planning, implementation, and execution of the proposed studies, including, e.g., the necessary hardware (COSY) and experienced highly motivated personnel, are fulfilled. With a successful application, we will provide the basis for a major avenue to probe new physics beyond the Standard Model of elementary particle physics through a search for charged-particle EDMs with unprecedented sensitivity.

#### **Additional supportive information; references**

1. F.J.M. Farley et al.  
*A new method of measuring electric dipole moments in storage rings*  
Physical Review Letters 93, 052001 (2004)  
This paper introduces the storage ring method for an EDM search of charged particles; the new ideas are to "freeze" the spin at a magic momentum for protons, and the use of clockwise and counter-clockwise beams.
2. Yuri F. Orlov et al.  
*Resonance Method for Electric-Dipole-Moment Measurements in Storage Rings*  
Physical Review Letters 96, 214802 (2006)  
This paper proposes a different storage ring EDM method, which is based on using forced oscillations of the particles' velocities in resonance with the spin precession.
3. Jonathan Engel, Michael J. Ramsey-Musolf, and U. van Kolck  
*Electric Dipole Moments of Nucleons, Nuclei and Atoms: The Standard Model and Beyond*  
Progress in Particle and Nuclear Physics 71, 21 (2013)  
This recent review discusses the theoretical background and challenges to obtain the most robust framework for interpreting the results of EDM searches and delineating their implications. The importance of EDM searches of charged hadrons in storage rings is emphasized.
4. J. de Vries, E. Mereghetti, R. G. E. Timmermans, and U. van Kolck  
*P and T Violating Form Factors of the Deuteron*  
Physical Review Letters 107, 091804 (2011)  
This paper shows in the framework of two-flavor chiral perturbation theory that in combination with the nucleon electric dipole moment the deuteron moments would allow an identification of the dominant EDM source(s).
5. D. Eversmann et al. (JEDI-Collaboration)  
*New method for a continuous determination of the spin tune in storage rings and implications for precision experiments*  
arXiv:1504.00635 [physics.acc-ph]  
This paper by the JEDI-Collaboration summarizes part of the R&D activities at COSY with a newly developed time-stamping method, which represent an important recent accomplishment towards srEDM.

**Section b: Curriculum vitae** (max. 2 pages)**PERSONAL INFORMATION**

Family name, First name: Ströher, Hans  
 Nationality: German  
 Date of birth: August 21, 1952

- **EDUCATION**

1990 Habilitation in Experimental Physics  
 Fakultät für Physik, Justus Liebig Universität Giessen, Giessen, Germany  
 1983 PhD in Physics (summa cum laude)  
 II. Physikalisches Institut, Justus Liebig Universität Giessen, Giessen, Germany  
 1980 Diploma in Physics  
 Institut für Kernphysik, Justus Liebig Universität Giessen, Giessen, Germany

- **CURRENT POSITION(S)**

1998 – today Director of Institut für Kernphysik (Experimental Hadron Dynamics)  
 IKP-2, Forschungszentrum Jülich GmbH, Jülich, Germany  
 1998 – today Full Professor (Experimental Physics)  
 Institut für Kernphysik, Universität zu Köln, Cologne, Germany

- **PREVIOUS POSITIONS**

1995 – 1998 Professor (C3) (Experimental Physics)  
 Institut für Kernphysik, Johannes Gutenberg Universität Mainz, Mainz, Germany  
 1990 – 1995 Scientific Staff  
 II. Physikalisches Institut, Justus Liebig Universität Giessen, Giessen, Germany  
 1987 – 1990 Scientific Assistant to the Director General of GSI  
 Gesellschaft für Schwerionenforschung, Darmstadt, Germany  
 1983 – 1987 Post-Doc at II. Physikalisches Institut Justus Liebig Universität Giessen  
 Short-term stays in JINR (Russia), LBL (USA) and BNL (USA)

- **FELLOWSHIPS AND AWARDS**

1983 PhD Award, Justus Liebig Universität Giessen, Giessen, Germany  
 2010 ERC Advanced Grant POLPBAR  
 2010 Honorary Doctor from Ivane Javakishvili Tbilisi State University, Tbilisi, Georgia  
 2014 Honorary Doctor from Georgian Technical University, Tbilisi, Georgia

- **SUPERVISION OF GRADUATE STUDENTS AND POSTDOCTORAL FELLOW**

2001 – 2015 2 Habilitations, 14 Postdocs, 17 PhD, numerous Diploma- and Master-students  
 IKP-2, Forschungszentrum Jülich GmbH, Jülich, Germany, and  
 Institut für Kernphysik, Universität zu Köln, Cologne, Germany

- **TEACHING ACTIVITIES**

1998 – 2015 Full Professor at Universität zu Köln, Cologne, Germany  
 Introductory Course in Experimental Physics  
 Special Courses: “Elementary Particle Physics”, “Tools for Particle Physics”  
 1995 – 1998 C3-Professor Johannes Gutenberg Universität Mainz, Mainz, Germany  
 Introductory Course in Experimental Physics

- **ORGANISATION OF SCIENTIFIC MEETINGS**

|      |   |
|------|---|
| 2005 | Chairman “STORI’05”, GSI, Bonn, Germany                               |
| 2010 | Chairman “SPIN2010”, Forschungszentrum Jülich, Jülich, Germany        |
| 2011 | Co-Chairman “ECT* Workshop on Electric Dipole Moments”, Trento, Italy |
| 2012 | Co-Chairman “MESON2012”, Jagiellonean University, Cracow, Poland      |
| 2014 | Co-Chairman “MESON2014”, Jagiellonean University, Cracow, Poland      |

- **INSTITUTIONAL RESPONSIBILITIES**

|              |   |
|--------------|---|
| 1998 – today | Faculty member, Universität zu Köln, Cologne, Germany   |
| 2002 – 2004  | Chairman “Komitee für Hadronen- und Kernphysik” (KHuK), Germany   |
| 2004 – 2007  | Member “Komitee für Hadronen- und Kernphysik” (KHuK), Germany   |
| 2003 – today | Member of “Nuclear Physics European Collaboration Committee” (NuPECC)   |
| 2004 – today | Managing Director (twice) at Institut für Kernphysik, Forschungszentrum Jülich, Germany   |
| 2012 – today | Deputy chairman/Chairman of the Scientific Technical Committee (WTR) of Forschungszentrum Jülich, Jülich, Germany   |
| 2013 – today | Founding member of the “Jülich-Aachen Research Alliance” (JARA) section “FAME” (Forces and Matter Experiments) between RWTH Aachen University and FZ Jülich |
| 2014 – today | Deputy chairman of the Scientific Technical Committee Assembly (WTR-V) of the Helmholtz Association of German Research Centres (HGF), Germany               |

- **COMMISSIONS OF TRUST**

|              |  |
|--------------|--|
| 2000 – 2006  | Member Program Advisory Committee (PAC), KVI Groningen, The Netherlands          |
| 2000 – 2006  | BMBF Gutachterausschuss “Hadronen- und Kernphysik”, Germany                      |
| 2004 – 2011  | Co-Editor “Nuclear Physics News International”                                   |
| 2007 – 2010  | Member Program Advisory Committee (PAC), JLab, Newport News, USA                 |
| 2008 – 2014  | Member/Chair of the PhD Committee in Physics at the University of Ferrara, Italy |
| 2009 – 2012  | Member International Advisory Committee (IAC) of CSR and HIRFL, Lanzhou, China   |
| 2013 – today | Co-Editor “European Physical Journal A”  |

- **MEMBERSHIPS OF SCIENTIFIC SOCIETIES**

|              |   |
|--------------|---|
| 1980 – today | Member “Deutsche Physikalische Gesellschaft”, Germany                   |
| 2010 – today | Member “International Spin Physics Committee” (ISPC)                    |
| 2012 – today | Member of “European Mediterranean Academy of Arts and Sciences” (EMAAS) |
| 2014 – today | Member of “Academia Europaea” (AE)                                      |

- **MAJOR COLLABORATIONS**

|      |  |
|------|--|
| ANKE | at COSY Jülich; general responsibility for the scientific program; spokesperson Andro Kacharava, Forschungszentrum Jülich; data taking with ANKE stopped in 2014   |
| JEDI | at COSY Jülich; chairman executive board (EB); spokespersons Andreas Lehrach, Frank Rathmann, Forschungszentrum Jülich, and Jörg Pretz, RWTH Aachen University<br>JEDI is embedded in JARA Fame, the cooperation between Forschungszentrum Jülich and RWTH Aachen University (Germany), which is concerned with “The Fate of Antimatter” |
| LEGS | “Laser Electron Gamma Source” at the National Synchrotron Light Source (NSLS);<br>Spokesperson Andrew Sandorfi, BNL, USA<br>Data taking with LEGS stopped many years ago, but the cooperation around the polarized hydrogen/deuterium ice target continues at JLab   |
| PAX  | at COSY Jülich (and CERN/AD); spokespersons Paolo Lenisa, INFN, Ferrara, Italy and Frank Rathmann, Forschungszentrum Jülich, Germany<br>The collaboration is strongly tied to the ERC AdG POLPBAR  |
| WASA | at COSY Jülich; spokesperson Magnus Wolke, Uppsala University (Sweden)<br>Data taking with WASA stopped in 2014  |



***Appendix: All ongoing and submitted grants and funding of the PI (Funding ID)***  
***Mandatory information (does not count towards page limits)***

**On-going Grants**

| <i>Project Title</i> | <i>Funding source</i> | <i>Amount (Euros)</i> | <i>Period</i> | <i>Role of the PI</i> | <i>Relation to current ERC proposal</i> |
|----------------------|-----------------------|-----------------------|---------------|-----------------------|---|
| POLPBAR              | ERC AdG               | 2.500.000             | Since 2010    | PI of the grant       | None                                    |

**Most important scientific achievements:**

- Leading the scientific exploitation of the ANKE magnetic spectrometer at COSY (Jülich): this experiment has taken data for 15 years until 2014 and was a most successful detector system for unpolarized and polarized internal experiments: among its major achievements were precision data for proton-proton and proton-neutron elastic scattering at forward and backward angles and the mass of the  $\eta$ -meson as well as pion production data to test Chiral Perturbation Theory.
- Initiating the transfer of WASA from CELSIUS (Uppsala) to COSY to install it into COSY: this was a decisive step in order to add photon detection capability to the detector systems operated at COSY: it was operated until 2014; the main research goals were studies of symmetries and symmetry breaking in hadronic reactions and in meson decays; one additional achievement was the observation of a new resonance in double-pionic fusion reactions, which is interpreted as a di-baryon state.
- Initiating the PAX program for polarized antiprotons as a possible upgrade option for the antiproton project at FAIR/HESR (Darmstadt).
- Leading the spin-flip and spin-filtering experiments with protons at COSY – for this project, an ERC-AdG “POLPBAR” was awarded in 2010: as a major result it was shown that only spin-filtering is a viable method to produce an intense beam of polarized antiprotons for use in hadron physics experiments.
- Initiating the JEDI project with the final aim to search for Electric Dipole Moments (EDM) of charged particles in storage rings: this most ambitious project must be divided into a series of steps, ranging from R&D at COSY to the concept, the design and the construction and exploitation of a new high precision storage ring.

**Most important publications:**

1. C. Weidemann et al. (PAX)  
*Toward polarized antiprotons: Machine development for spin-filtering experiments*  
Phys. Rev. ST-AB 18, 020101 (2015)  
0 citations
2. W. Augustyniak et al. (PAX)  
*Polarization of a stored beam by spin filtering*  
Physics Letters B 718 (2012) 64-69  
20 citations
3. P. Adlarson et al. (WASA)  
*Abashian-Booth-Crowe Effect in Basic Double-Pionic Fusion: A New Resonance?*  
Phys. Rev Lett 106, 242302 (2011)  
34 citations
4. P. Goslawski et al. (ANKE)  
*High precision beam momentum determination in a synchrotron using a spin-resonance method*  
Phys. Rev. ST-AB 13, 022803 (2010)  
9 citations
5. D. Oellers et al. (PAX)  
*Polarizing a stored proton beam by spin-flip?*  
Phys. Lett. B 674 (2009) 269-275  
20 citations
6. I. Zychor et al. (ANKE)  
*Lineshape of the Lambda (1405) hyperon measured through its Sigma0-pi0 decay*  
Phys. Lett. B 660 (2008) 167  
67 citations
7. T. Mersmann et al. (ANKE)  
*Precision Study of the eta-3He System Using the dp → 3He eta Reaction*  
Phys. Rev. Lett. 98, 242301 (2007)  
90 citations
8. F. Rathmann et al. (PAX precursor)  
*A Method to Polarize Stored Antiprotons to a High Degree*  
Phys. Rev. Lett. 94, 014801 (2005)  
57 citations

**Invited presentations at international conferences/schools:**

1. International Conference on New Frontiers in Physics (ICNPF 2013)  
*JEDI – the Jülich Electric Dipole Moment Investigations*  
Kolymbari, Crete, Greece, 30.08. 05.09.2013
2. International Workshop on non-perturbative Phenomena in Hadron and Particle Physics (Many manifestations of non-perturbative QCD)  
*The next step – polarized antiprotons for FAIR/HESR*  
Caratuatutuba, Sao Paulo, Brazil, 30.04.- 05.05.2012
3. The 8th International Workshop on the Physics of Excited Nucleons (NSTAR 2011)  
*N\*ews from COSY*  
Newport News, Virginia, USA, 17. – 20.5.2011
4. 8<sup>th</sup> International Conference on Nuclear Physics at Storage Rings (STORI'11)  
*The Road towards Polarized Antiprotons*  
Frascati, Italy, October 9-14, 2011
5. Lepton Moments 2010 Symposium  
*Prospects for a storage ring EDM-facility at COSY*  
Cape Cod, Centerville, USA, 19.-22.06.2010
6. International Conference on the Structure of Baryons (BARYONS 2010)  
*Physics at COSY-Jülich*  
Osaka, Japan, 07.-11.12.2010
7. The 7th International Workshop on the Physics of Excited Nucleons (NSTAR 2009)  
*The N\* Program at COSY-Jülich*  
Beijing, China, 19.-22.4.2009

**Organisation of international conferences:**

1. Chairman “6<sup>th</sup> International Conference on Nuclear Physics at Storage Rings” (STORI'05) in Bonn
2. Chairman “19<sup>th</sup> International Spin Physics Symposium” (SPIN2010) in Jülich, Germany
3. Co-Chairman “ECT\* Workshop on EDM Searches at Storage Rings”, 2012, Trento, Italy
4. Co-Chairman “12<sup>th</sup> and 13<sup>th</sup> International Workshop on Meson Production, Properties and Interaction” (MESON2012, MESON2014) in Cracow, Poland

**Memberships of steering/organisation committees of international conferences:**

1. Local Organising Committee (LOC), e.g.: MESON2006, MESON2008, MESON2010
2. Local Organizing Committee of bi-annual “Georgian German School and Workshop in Hadron Physics/Basic Science” (GGSWHP) since 2004
3. International Spin Physics Committee (ISPC), e.g. for D-SPIN2015, SPIN2014,
4. International Advisory Committee (IAC), e.g.: SSP2015, NSTAR2015, STORI'14, BARYONS2013

**Academy memberships:**

1. Euro Mediterranean Academy of Arts and Sciences (since 2012)
2. Academia Europaea (since 2014)

**Contributions to early careers of excellent researchers:**

1. IKP-2 staff member Magnus Wolke received a Lecturer/Professorship at Uppsala University in 2008
2. PhD Student Alexandra Wronska received an Assistant Professorship at the Jagiellonian University Cracow in 2010
3. Co-worker Izabella Zychor finished her habilitation at the National Center for Nuclear Research (NCNR), Swierk, Poland, in 2013, based on the COSY-ANKE experiments
4. IKP-2 staff member Markus Büscher received a W2-Professorship at University Düsseldorf in 2013
5. Livia Ludhova (INFN Milano, Italy) will receive an IKP-2 staff position combined with a W2-Professorship at RWTH Aachen University within the “recruiting initiative” of the Helmholtz-Association (HGF)