Horizon 2020

Excellent Science

Call: ERC-2015-AdG

Topic: ERC-ADG-2015

Type of action: ERC-ADG

Proposal number: 694340

Proposal acronym: srEDM

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How to fill in the forms

The administrative forms must be filled in for each proposal using the templates available in the submission system. Some data fields in the administrative forms are pre-filled based on the previous steps in the submission wizard.

This proposal version was submitted by **Hans STROEHER** on **30/05/2015 07:49:43 CET**. Issued by the Participant Portal Submission Service.

1 - General information

Topic	ERC-ADG-2015	Type of action	ERC-ADG
Call identifier	ERC-2015-AdG	Acronym*	srEDM

Proposal title*: Search for electric dipole moments using storage rings

Note that for technical reasons, the following characters are not accepted in the Proposal Title and will be removed: < > " &

Duration in months*: *60*

Primary ERC Review Panel*: PE2 - Fundamental Constituents of Matter

Secondary ERC Review Panel: (if applicable)

ERC Keyword 1*: *Fundamental interactions and fields*

Please select, if applicable, the ERC keyword(s) that best characterise the subject of your proposal in order of priority.

ERC Keyword 2: *Particle physics*

ERC Keyword 3: *Not applicable*

ERC Keyword 4: *Not applicable*

Free keywords: *In addition, please enter free text keywords that you consider best characterise the scope of your research proposal. The choice of keywords should take into account any multi-disciplinary aspects of the proposal.*

Proposal ID **694340** *Acronym* **srEDM**

Abstract

One of the great mysteries in the natural sciences is the dominance of matter over antimatter in the universe. According to our present understanding, the early universe contained the same amount of matter and antimatter. If the universe had behaved symmetrically as it developed, every particle would have been annihilated by one of its antiparticles. We therefore owe our very existence to mechanisms that have led to a world where something that we call matter remains. We propose to study such mechanisms by searching for electric dipole moments (EDMs) of charged hadrons in a new class of precision storage rings. Our project will lay the foundations for a new European flagship research infrastructure. The breaking of the combined charge conjugation and parity symmetries (CP-violation) in the Standard Model is not strong enough to explain the observed excess of matter and further sources of CP-violation must be sought. These sources could manifest themselves in Electric Dipole Moments of elementary particles, which occur when the centroids of positive and negative charges are mutually and permanently displaced. The observation of an electric dipole moment will elucidate the mechanisms which led to the matter that dominates the universe. Although the measurement principle, the time development of the polarization vector subject to a perpendicular electric field, is simple, the smallness of the effect makes this an enormously challenging project. This can only be mastered through the common effort of an international team of accelerator and particle physicists, working closely with engineers. The proponents of this design study and the research environment at the Forschungszentrum Jülich (Germany), including the conventional storage ring COSY, 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 Standard Model and perhaps explaining the puzzle of our existence.

Remaining characters 20

In order to best review your application, do you agree that the above non-confidential proposal title and abstract can be used, without disclosing your identity, when contacting potential reviewers? ◉ Yes ○ No

Has this proposal (or a very similar one) been submitted in the past 2 years in response to a call for proposals under the 7th Framework Programme, Horizon 2020 or any other EU programme(s)? ◉ Yes ○ No

Please give the proposal reference or contract number.
653939

Declarations

1) The Principal Investigator declares to have the explicit consent of all applicants on their participation and on the content of this proposal.*	☒
2) The information contained in this proposal is correct and complete.	☒
3) This proposal complies with ethical principles (including the highest standards of research integrity — as set out, for instance, in the European Code of Conduct for Research Integrity — and including, in particular, avoiding fabrication, falsification, plagiarism or other research misconduct).	☒

4) The Principal Investigator hereby declares that *(please select one of the three options below)*:

- in case of multiple participants in the proposal, the coordinator has carried out the self-check of the financial capacity of the organisation on http://ec.europa.eu/research/participants/portal/desktop/en/organisations/lfv.html or to be covered by a financial viability check in an EU project for the last closed financial year.Where the result was “weak” or “insufficient”, the Principal Investigator confirms being aware of the measures that may be imposed in accordance with the H2020 Grants Manual (Chapter on Financial capacity check).	○
- in case of multiple participants in the proposal, the Principal Investigator is exempt from the financial capacity check being a public body including international organisations, higher or secondary education establishment or a legal entity, whose viability is guaranteed by a Member State or associated country, as defined in the H2020 Grants Manual (Chapter on Financial capacity check).	◉
- in case of a sole participant in the proposal, the applicant is exempt from the financial capacity check.	○
5) The Principal Investigator hereby declares that each applicant has confirmed to have the financial and operational capacity to carry out the proposed action. Where the proposal is to be retained for EU funding, each beneficiary applicant will be required to present a formal declaration in this respect.	☒

The Principal Investigator is only responsible for the correctness of the information relating to his/her own organisation. Each applicant remains responsible for the correctness of the information related to him and declared above. Where the proposal to be retained for EU funding, the coordinator and each beneficiary applicant will be required to present a formal declaration in this respect.

According to Article 131 of the Financial Regulation of 25 October 2012 on the financial rules applicable to the general budget of the Union (Official Journal L 298 of 26.10.2012, p. 1) and Article 145 of its Rules of Application (Official Journal L 362, 31.12.2012, p.1) applicants found guilty of misrepresentation may be subject to administrative and financial penalties under certain conditions.

Personal data protection
Your reply to the grant application will involve the recording and processing of personal data (such as your name, address and CV), which will be processed pursuant to Regulation (EC) No 45/2001 on the protection of individuals with regard to the processing of personal data by the Community institutions and bodies and on the free movement of such data. Unless indicated otherwise, your replies to the questions in this form and any personal data requested are required to assess your grant application in accordance with the specifications of the call for proposals and will be processed solely for that purpose. Details concerning the processing of your personal data are available on the privacy statement. Applicants may lodge a complaint about the processing of their personal data with the European Data Protection Supervisor at any time.

Your personal data may be registered in the Early Warning System (EWS) only or both in the EWS and Central Exclusion Database (CED) by the Accounting Officer of the Commission, should you be in one of the situations mentioned in:

- the Commission Decision 2008/969 of 16.12.2008 on the Early Warning System (for more information see the Privacy Statement), or
- the Commission Regulation 2008/1302 of 17.12.2008 on the Central Exclusion Database (for more information see the Privacy Statement).

List of participants

#	Participant Legal Name	Country
1	FORSCHUNGSZENTRUM JULICH GMBH	Germany
2	RHEINISCH-WESTFAELISCHE TECHNISCHE HOCHSCHULE AACHEN	Germany
3	UNIVERSITA DEGLI STUDI DI FERRARA	Italy

2 - Administrative data of participating organisations

Host Institution

PIC	***Legal name***
999980470	*FORSCHUNGSZENTRUM JULICH GMBH*

Short name: Jülich

Address of the organisation

Street WILHELM JOHNEN STRASSE

Town JULICH

Postcode 52428

Country Germany

Webpage www.fz-juelich.de

Legal Status of your organisation

Research and Innovation legal statuses

Public body .... no
Non-profit .... yes
International organisation .... no
International organisation of European interest ...... no
Secondary or Higher education establishment .... no
Research organisation .... yes
Small and Medium-sized Enterprises (SMEs) .... no

Legal person .... yes

Nace code 721 -

Department(s) carrying out the proposed work

Department 1

Department name	Institut für Kernphysik
	☒ Same as organisation address
Street	WILHELM JOHNEN STRASSE
Town	JULICH
Postcode	52428
Country	Germany

Principal Investigator

The following information of the Principal Investigator is used to personalise the communications to applicants and the evaluation reports. Please make sure that your personal information is accurate and please inform the ERC in case your e-mail address changes by using the call specific e-mail address:

For Advanced Grant Applicants: ERC-2015-AdG-applicants@ec.europa.eu

The name and e-mail of contact persons including the Principal Investigator, Host Institution contact are read-only in the administrative form, only additional details can be edited here. To give access rights and contact details of contact persons, please save and close this form, then go back to Step 4 of the submission wizard and save the changes.

Researcher ID: *If you have a researcher identifier number (e.g. ResearcherID, ORCID) please enter it here.*

Last Name*	STROEHER	Last Name at Birth	Stroeher
First Name(s)*	Hans	Gender*	(•) Male ( ) Female
Title	Prof.	Country of residence*	Germany
Nationality*	Germany	Country of Birth*	Germany
Date of Birth* (DD/MM/YYYY)	21/08/1952	Place of Birth*	Niederweidbach (Hesse, Germany)

Contact address

☒ Same as organisation address

Current organisation name	FORSCHUNGSZENTRUM JUELICH GMBH		
Current Department/Faculty/Institute/ Laboratory name	Institut für Kernphysik		
Street	WILHELM JOHNEN STRASSE		
Postcode/Cedex	52428	Town*	JULICH
Phone*	+492461614408	Country*	Germany
Phone2 / Mobile	*+xxxx xxxxxxxxxxxx*		
E-mail*	h.stroeher@fz-juelich.de		

Qualifications

Earliest award (PhD, Doctorate)	Date of award (DD/MM/YYYY): 30/06/1983

Proposal ID **694340** *Acronym* **srEDM** *Short name* **Jülich**

Contact address of the Host Institution and contact person

The name and e-mail of Host Institution contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and contact details of Host Institution, please save and close this form, then go back to Step 4 of the submission wizard and save the changes. Please note that the submission is blocked without a contact person and e-mail address for the Host Institution.

Organisation Legal Name **FORSCHUNGSZENTRUM JULICH GMBH**

First name* **Anne** Last name* **Bosch**

E-Mail* **a.bosch@fz-juelich.de**

Position in org. *Administrative Officer*

Department *Technologie Transfer*

☒ Same as organisation address

Street WILHELM JOHNEN STRASSE

Town JULICH Postcode 52428

Country Germany

Phone +492461614236 Phone2/Mobile *+xxxx xxxxxxxxxxxx*

Other contact persons

First Name	***Last Name***	***E-mail***	***Phone***
Frank	Rathmann	f.rathmann@fz-juelich.de	

Partner organisation

PIC	***Legal name***
999983962	*RHEINISCH-WESTFAELISCHE TECHNISCHE HOCHSCHULE AACHEN*

Short name: RWTH AACHEN

Address of the organisation

Street TEMPLERGRABEN 55

Town AACHEN

Postcode 52062

Country Germany

Webpage www.rwth-aachen.de

Legal Status of your organisation

Research and Innovation legal statuses

Public body ....yes

Non-profit ....yes

International organisation ....no

International organisation of European interest ......no

Secondary or Higher education establishment ....yes

Research organisation ....yes

Small and Medium-sized Enterprises (SMEs) ....no

Legal person .... yes

Nace code 853 -

Department(s) carrying out the proposed work

Department 1

Department name	III. Physikalisches Institut B
	☐ Same as organisation address
Street	Otto-Blumenthal Straße
Town	Aachen
Postcode	52074
Country	Germany

Contact address of the partner organisation and contact person

The name and e-mail of Partner Organisation contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and contact details of Partner Organisation, please save and close this form, then go back to Step 4 of the submission wizard and save the changes. The contact person needs to be added as 'Main Contact' for the Partner Organisation.

Organisation Legal Name **RHEINISCH-WESTFAELISCHE TECHNISCHE HOCHSCHULE AACHEN**

First name* **Jörg** Last name* **Pretz**

E-Mail* **pretz@physik.rwth-aachen.de**

Position in org. *Professor*

Department *III. Physikalisches Institut B*

☒ Same as organisation address

Street TEMPLERGRABEN 55

Town AACHEN Postcode 52062

Country Germany

Phone +492418027306 Phone2/Mobile +xxxx xxxxxxxxxxx

Partner organisation

PIC	***Legal name***
999839626	*UNIVERSITA DEGLI STUDI DI FERRARA*

Short name: UNIFE

Address of the organisation

Street SAVONAROLA 9

Town FERRARA

Postcode 44100

Country Italy

Webpage www.unife.it

Legal Status of your organisation

Research and Innovation legal statuses

Public body ...... yes

Non-profit ...... yes

International organisation ...... no

International organisation of European interest ...... no

Secondary or Higher education establishment ...... yes

Research organisation ...... yes

Small and Medium-sized Enterprises (SMEs) ...... no

Legal person ...... yes

Nace code 853 -

Department(s) carrying out the proposed work

Department 1

Department name	Dipartimento di Fisica e Scienze della Terra
	☐ Same as organisation address
Street	Via Saragat, 1
Town	Ferrara
Postcode	44122
Country	Italy

Contact address of the partner organisation and contact person

The name and e-mail of Partner Organisation contact persons are read-only in the administrative form, only additional details can be edited here. To give access rights and contact details of Partner Organisation, please save and close this form, then go back to Step 4 of the submission wizard and save the changes. The contact person needs to be added as 'Main Contact' for the Partner Organisation.

Organisation Legal Name **UNIVERSITA DEGLI STUDI DI FERRARA**

First name* **Paolo** Last name* **Lenisa**

E-Mail* **lenisa@fe.infn.it**

Position in org. *Professor*

Department *Dipartimento di Fisica e Scienze della Terra*

☐ Same as organisation address

Street: Via Saragat, 1

Town: Ferrara Postcode: 44122

Country: Italy

Phone: +390532974309 Phone2/Mobile: +393473642527

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3 - Budget

Participant Number in this proposal	Organisation Short Name	Organisation Country	Total eligible costs/€ (including 25% indirect costs) ?	Requested grant/€
1	Jülich	DE	1 160 644	1 160 644
2	RWTH AACHEN	DE	678 909	678 909
3	UNIFE	IT	628 160	628 160
Total			2 467 713	2 467 713

This proposal version was submitted by **Hans STROEHER** on **30/05/2015 07:49:43 CET**. Issued by the Participant Portal Submission Service.

4 - Ethics issues table

1. HUMAN EMBRYOS/FOETUSES		Page
Does your research involve Human Embryonic Stem Cells (hESCs)?	○ Yes ◉ No	
Does your research involve the use of human embryos?	○ Yes ◉ No	
Does your research involve the use of human foetal tissues / cells?	○ Yes ◉ No	
2. HUMANS		Page
Does your research involve human participants?	○ Yes ◉ No	
Does your research involve physical interventions on the study participants?	○ Yes ◉ No	
3. HUMAN CELLS / TISSUES		Page
Does your research involve human cells or tissues (other than from Human Embryos/ Foetuses, i.e. section 1)?	○ Yes ◉ No	
4. PERSONAL DATA (ii)		Page
Does your research involve personal data collection and/or processing?	○ Yes ◉ No	
Does your research involve further processing of previously collected personal data (secondary use)?	○ Yes ◉ No	
5. ANIMALS (iii)		Page
Does your research involve animals?	○ Yes ◉ No	

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6. THIRD COUNTRIES		Page
Does your research involve non-EU countries?	◯ Yes ◉ No	
Do you plan to use local resources (e.g. animal and/or human tissue samples, genetic material, live animals, human remains, materials of historical value, endangered fauna or flora samples, etc.)? (v)	◯ Yes ◉ No	
Do you plan to import any material from non-EU countries into the EU? *For data imports, please fill in also section 4.* *For imports concerning human cells or tissues, fill in also section 3.*	◯ Yes ◉ No	
Do you plan to export any material from the EU to non-EU countries? *For data exports, please fill in also section 4.* *For exports concerning human cells or tissues, fill in also section 3.*	◯ Yes ◉ No	
If your research involves low and/or lower middle income countries, are benefits-sharing measures foreseen? (vii)	◯ Yes ◉ No	
Could the situation in the country put the individuals taking part in the research at risk?	◯ Yes ◉ No	
7. ENVIRONMENT & HEALTH and SAFETY See legal references at the end of the section. (vi)		**Page**
Does your research involve the use of elements that may cause harm to the environment, to animals or plants? *For research involving animal experiments, please fill in also section 5.*	◯ Yes ◉ No	
Does your research deal with endangered fauna and/or flora and/or protected areas?	◯ Yes ◉ No	
Does your research involve the use of elements that may cause harm to humans, including research staff? *For research involving human participants, please fill in also section 2.*	◯ Yes ◉ No	
8. DUAL USE (vii)		**Page**
Does your research have the potential for military applications?	◯ Yes ◉ No	
9. MISUSE		**Page**
Does your research have the potential for malevolent/criminal/terrorist abuse?	◯ Yes ◉ No	
10. OTHER ETHICS ISSUES		**Page**
Are there any other ethics issues that should be taken into consideration? Please specify	◯ Yes ◉ No	

I confirm that I have taken into account all ethics issues described above and that, if any ethics issues apply, I will complete the ethics self-assessment and attach the required documents. ☒

How to Complete your Ethics Self-Assessment

5 - Call specific questions

Eligibility	
I acknowledge that I am aware of the eligibility requirements for applying for this ERC call as specified in the ERC Work Programme 2015, and certify that, to the best of my knowledge my application is in compliance with all these requirements. I understand that my proposal may be declared ineligible at any point during the evaluation or granting process if it is found not to be compliant with these eligibility criteria.*	☒
Data-Related Questions and Data Protection (Consent to any question below is entirely voluntary. A positive or negative answer will not affect the evaluation of your project proposal in any form and will not be communicated to the evaluators of your project.)	
For communication purposes only, the ERC asks for your permission to publish your name, the proposal title, the proposal acronym, the panel, and host institution, should your proposal be retained for funding.	◉ Yes ◯ No
Some national and regional public research funding authorities run schemes to fund ERC applicants that score highly in the ERC's evaluation but which can not be funded by the ERC due to its limited budget. In case your proposal could not be selected for funding by the ERC do you consent to allow the ERC to disclose the results of your evaluation (score and ranking range) together with your name, non-confidential proposal title and abstract, proposal acronym, host institution and your contact details to such authorities?	◉ Yes ◯ No
The ERC is sometimes contacted for lists of ERC funded researchers by institutions that are awarding prizes to excellent researchers. Do you consent to allow the ERC to disclose your name, non-confidential proposal title and abstract, proposal acronym, host institution and your contact details to such institutions?	◉ Yes ◯ No
The Scientific Council of the ERC has developed a monitoring and evaluation strategy in order to help it fulfil its obligations to establish the ERC's overall strategy and to monitor and quality control the programme's implementation from the scientific perspective. As provided by section 3.10 of the ERC Rules for Submission, a range of projects and studies may be initiated for purposes related to monitoring, study and evaluating the implementation of ERC actions. Do you consent to allow the third parties carrying out these projects and studies to process the content of your proposal including your personal data and the respective evaluation data? The privacy statement on grants (http://erc.europa.eu/document-library) explains further how your personal data is secured.	◉ Yes ◯ No

Excluded Reviewers

You can provide up to three names of persons that should not act as an evaluator in the evaluation of the proposal for potential competitive reasons.

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}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 θ-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 θ-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 θ-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 θ-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 MeV/c. For particles with a negative anomalous magnetic moment (like deuterons and ^{3}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}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 μrad/s for an EDM of 10^{-26} e·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 μEDM storage ring, it will be difficult to improve the current limit ~10^{-19} e·cm for the muon to better than about 10^{-24} e·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 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} e·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}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 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); Spokesperson Andrew Sandorfi, BNL, USA 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 The collaboration is strongly tied to the ERC AdG POLPBAR
WASA	at COSY Jülich; spokesperson Magnus Wolke, Uppsala University (Sweden) 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

Project Title	*Funding source*	*Amount (Euros)*	*Period*	*Role of the PI*	*Relation to current ERC proposal*
POLPBAR	ERC AdG	2.500.000	Since 2010	PI of the grant	None

Section c: Ten years track-record (max. 2 pages)

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 η-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-perturbaive QCD)
   The next step – polarized antiprotons for FAIR/HESR
   Caratuatatuba, Sao Paolo, 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. 8th 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 "6th International Conference on Nuclear Physics at Storage Rings" (STORI´05) in Bonn
2. Chairman "19th 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 "12th and 13th 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)

ERC Advanced Grant 2015
Research proposal [Part B2]
(__not__ evaluated in Step 1)

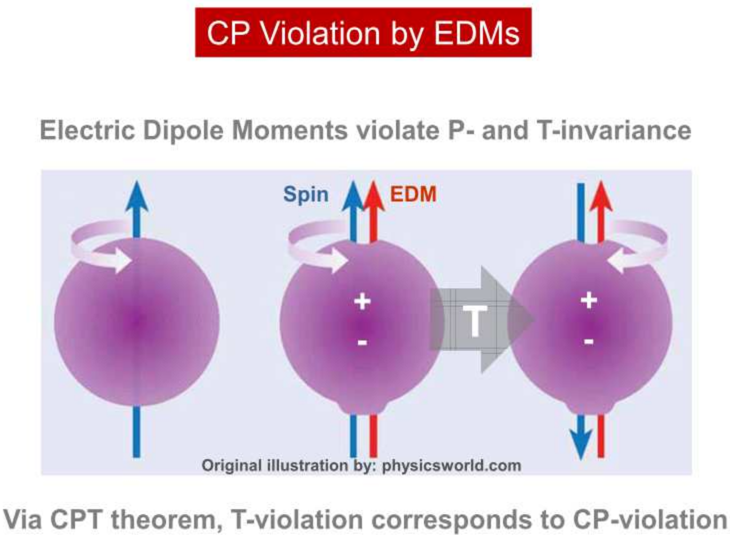
Part B2: *The scientific proposal* (max. 15 pages)

Section a. State-of-the-art and objectives

Science case: WHY? – Explore the reason for the baryon-asymmetry of the Universe; uncover the reason for our existence!

The search for permanent Electric Dipole Moments (EDM) in non-degenerate systems was initiated by Edward Purcell and Norman Ramsey more than 50 years ago for the neutron. Since then a long series of searches with ever increasing sensitivity on neutrons, atoms and molecules has been conducted, but no finite EDM has yet been found. Nevertheless, the experimental upper limits have already had a significant influence on theories of elementary particle physics like, e.g., for supersymmetric models. New generations of experiments are under way or are being planned, which may have the potential to find an EDM – in any case with additional far-reaching theoretical implications.

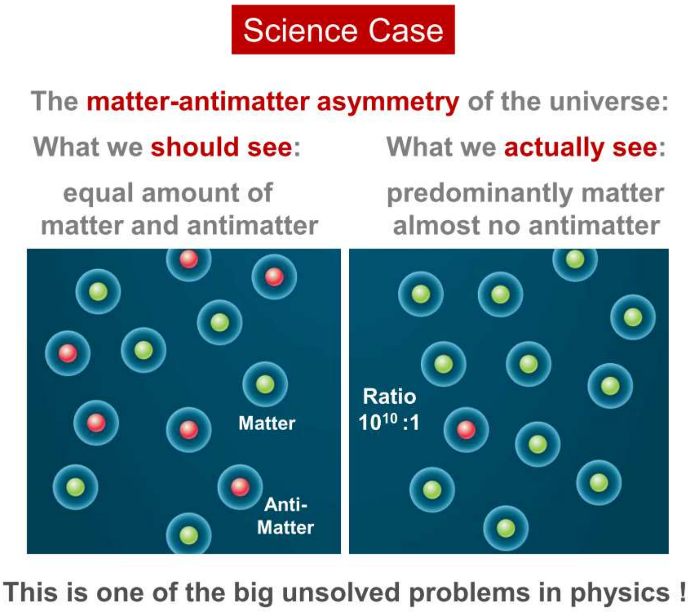
The interest in EDMs originates from the fact that they violate parity (P-) and time-reversal (T-) invariance – for the latter this is schematically shown in the figure below, where application of the T-operation results in a different state. By means of the CPT-theorem, T-violation corresponds to the violation of the combined charge (C-)-parity symmetry CP. Although the discovery of CP-violation (CPV) by James Cronin and Val Fitch (and others) in 1964 came as a complete surprise, it is nowadays a well-studied effect in the quark sector of the weak interaction and included in the Standard Model (SM) of elementary particle physics via the so called CKM mechanism. Given the knowledge of SM-CPV, the predicted size for EDMs of elementary particles is unmeasurably small – at least with current experimental techniques.



There may be, however, additional sources of SM-CPV, e.g., in the leptonic sector. It is intended to search for these in neutrino oscillations – but the corresponding projects are still in its infancy. It could as well be possible that new CPV sources are lurking in electric dipole moments. The existing experimental EDM limits for the neutron (dircctly measured to be ~10^{-26} e·cm) and the proton (~10^{-24} e·cm – deduced from atomic EDM limits) indicate two things: (i) EDMs are very small compared to magnetic dipole moments (MDMs) and (ii) their smallness is not at all understood theoretically – via the so called Quantum Chromodynamics (QCD) θ–term it establishes the *strong CP puzzle*, which is waiting to be be solved.

The strongest motivation for new CPV is obtained from the fact that apparently our Universe contains essentially only matter and almost no antimatter (see figure below) – one might call this the *puzzle of our existence*! There are strong arguments for this assertion based on the Big Bang Nucleosynthesis (abundance of the lightest nuclei), the Cosmic Microwave Background Radiation and on Supernovae, although relic antimatter is also searched for, e.g., with the "Alpha Magnetic Spectrometer" (AMS) on the "International Space Station" (ISS) – as of today without success.

Briefly after the Big Bang, matter was created from energy in the form of particle-antiparticle pairs. Why didn´t these pairs annihilate again into pure energy, leaving no matter behind? For yet unknown reasons, at some point in time, the part which we call matter has had a slight plus over antimatter – after the annihilation phase ended this surplus of matter established the Universe we live in (notwithstanding "Dark Matter" and "Dark Energy"). This process is called *baryogenesis*. Note that the electroweak CPV of the Standard Model would have left over much less matter, leading to a Universe largley devoid of galaxies.



In 1967, Andrei Sakharov determined which properties of Nature are required for baryogenesis, regardless of the exact mechanism. His three key assumptions – now known as *Sakharov conditions* – are:

- At least one baryon-number (B-) violating process, transforming the original B = 0 universe into the universe with a very high B-number ;
- Processes, which violate charge (C-) and charge-parity (CP-) invariance;
- Interactions outside of thermal equilibrium.

These conditions are necessary but not sufficient – one still needs to determine the specific mechanism through which baryogenesis happens. Here, however, we are only concerned with the CPV prerequisite: it exists (see above), but it is too small by many orders of magnitude – additional new sources are required, which most probably will also imply New Physics (NP)!

Permanent Electric Dipole Moments (EDM) of elementary particles can be a door towards NP: in fact, some theories like supersymmetry (SUSY), left-right symmetry and multi-Higgs scenarios, suggest that EDMs may be much larger than the SM predictions and can be within experimental reach.

EDMs are searched for worldwide in the neutron, in atoms, molecules, and solids, steadily pushing the upper limits further for the neutron (nEDM), the proton (pEDM) and the electron (eEDM). Future upgrades will continue to improve these limits, but some general limitations seem to be inevitable:

- Free neutrons are unstable, and thus the measurement time will be principally limited; ultracold neutrons (UCN) cannot be produced and stored in very large quantities – the future goal for nEDM is $\sim 10^{-28}$ e·cm);
- In complex systems like atoms, molecules or even solids, the EDMs of constituents need to be deduced indirectly with the help of sophisticated models.

A new idea to extend the direct measurements to new systems and with the potential to push limits even further is to search for *charged particle* EDMs in dedicated storage rings (srEDM). This is the background and motivation for the present proposal.

Science case: WHAT? – Search for *charged-particle* Electric Dipole Moments in storage rings (srEDM)!

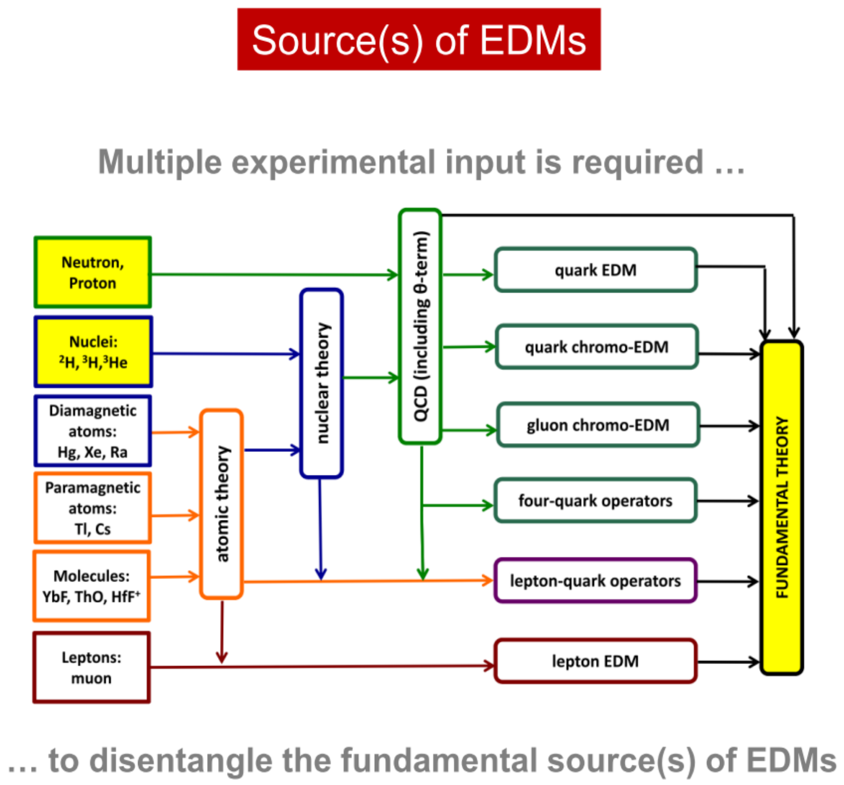
Searching for a non-zero proton and/or deuteron EDM in a dedicated storage ring represents an experimental opportunity to improve the current sensitivity towards 10^{-29} e·cm, which corresponds to:

- nearly 5 orders of magnitude compared to the indirectly obtained pEDM limit;
- roughly 3 orders of magnitude compared to the current nEDM limit, and
- at least an order of magnitude in comparison to the projected future nEDM figure.

For the deuteron, it will establish a first-ever measurement.

If achieved, these limits will provide a significant advancement towards the discovery of a finite permanent EDM in a non-degenerate system.

In addition to the sensitivity potential, it has also become evident in recent years that – after the observation of a finite EDM – it will be required to investigate different systems to elucidate the fundamental source(s): thus, besides the neutron, at least the proton but preferably also the deuteron must be investigated. A more complete picture, including atoms, molecules and leptons, is shown in the following figure: it is seen that for leptons, there is a direct link between experiment and the fundamental theory, while for hadrons (and more complex systems – nuclei, atoms, molecules) the connection becomes more sophisticated by intermediate theoretical steps, e.g., QCD. On the other hand, the possible fundamental insight into the underlying physics is much richer.



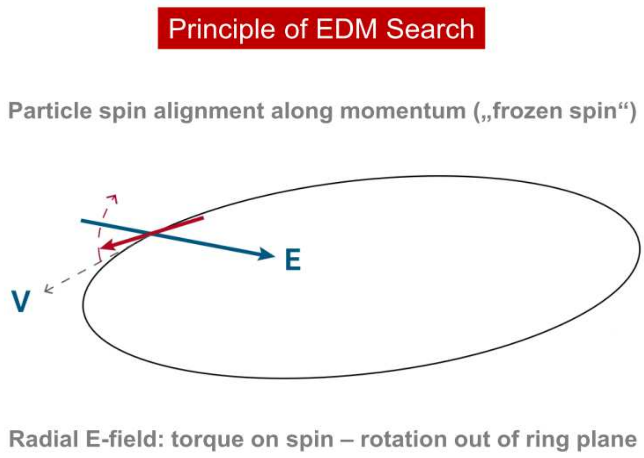
After the discovery of an EDM, e.g., for the neutron, one of the most important questions to be answered will be, whether it is caused by strong CP violation or whether it originates from physics beyond the Standard Model (BSM). The SM-Lagrangian contains a second source of CPV, the QCD vacuum angle (θ-term), whose value is already strongly constrained by experimental neutron EDM limits. The extreme smallness of $|\theta|$ is a long-standing puzzle of the Standard Model. Experimental data on the EDMs of light ions (proton, deuteron) can provide an answer to it. While a single EDM measurement can be interpreted (fitted) by any source, two measurements, e.g., neutron and proton, will allow conclusions about the origin of the CP violation. As a check of the theory, the result for the bound neutron-proton system (deuteron) should as well be available. In recent years several calculations have been performed for EDMs of the nucleon and several light nuclei, using modern effective-field theory techniques, in order to determine how theory can be best constrained: it has been shown that the θ-term could be identified with good accuracy, once results for EDMs of the neutron, proton and deuteron have been obtained. For this 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 θ-term. In this way, the existence/smallness of strong CP violation – a puzzle which has been around for almost fifty years – can potentially be solved.

The size of the deuteron EDM, with respect to the EDM of proton and neutron, is an excellent probe for BSM physics: as mentioned, for the θ-term one expects similar size EDMs for the nucleon and the deuteron, while certain BSM sources predict the dEDM to be significantly larger, up to an order of magnitude. Thus, it can be expected that dEDM has a particularly large discriminating power due to its unique spin-isospin properties.

The calculations are complicated because the models are formulated at very high energy and then need to be evolved down to the scales where experiments take place. Using a cascade of effective field theories such calculations become possible and the EDMs can be expressed in terms of the parameters appearing in the high-energy models. Preliminary results confirm that different classes of models predict different hierarchies of EDMs and thus can be disentangled once experimental results will be available.

Technique: HOW? – Observation of EDM effect on spin motion

The principle of storage-ring EDM measurements of charged particles is 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 of the original spin direction (see figure below). This minuscule spin rotation can be determined with the help of a so called polarimeter (a detector to determine the spin direction). Alternatively, one can search for a tiny change of the spin precession frequency due to an EDM.



The spin motion (precession) of a particle, which possesses both a magnetic dipole moment (MDM) and an electric dipole moment (EDM), in electric (E) and magnetic (B) fields of a storage ring is governed by the Thomas-Bargmann-Michel-Telegdi (Thomas BMT-) equation:

$$\frac{d\vec{s}}{dt} = \vec{S} \times (\vec{\Omega}_{MDM} + \vec{\Omega}_{EDM}),$$

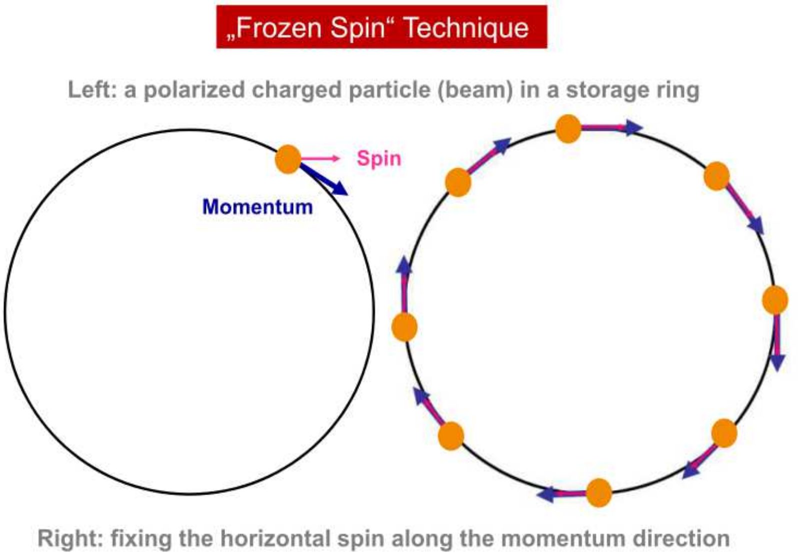
$$\vec{\Omega}_{MDM} = \frac{q}{m} \left[G\vec{B} - \frac{\gamma G}{\gamma+1}\vec{\beta}\left(\vec{\beta}\cdot\vec{B}\right) - \left(G - \frac{1}{\gamma^2-1}\right)\frac{\vec{\beta}\times\vec{E}}{c}\right],$$

$$\vec{\Omega}_{EDM} = \frac{\eta q}{2mc}\left[\vec{E} - \frac{\gamma}{\gamma+1}\vec{\beta}\left(\vec{\beta}\cdot\vec{E}\right) + c\vec{\beta}\times\vec{B}\right].$$

(β, γ are the Lorentz factors, G is the magnetic anomaly, and η parametrizes the size of the EDM; m, q represent mass and charge, and c is the velocity of light). Here the angular velocities (Ω) are defined with respect to the momentum vector of the particle.

The main challenge is that in general the spin precession due to the MDM is many orders of magnitude larger than the spin precession expected from an EDM. The aim is thus to find electro-magnetic 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" (see figure below).

For protons with their positive anomalous magnetic moment, this condition can be achieved with *purely electric fields* for a “magic” beam momentum of p = 700.74 MeV/c. For particles with negative anomalous magnetic moment (like deuterons) 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.

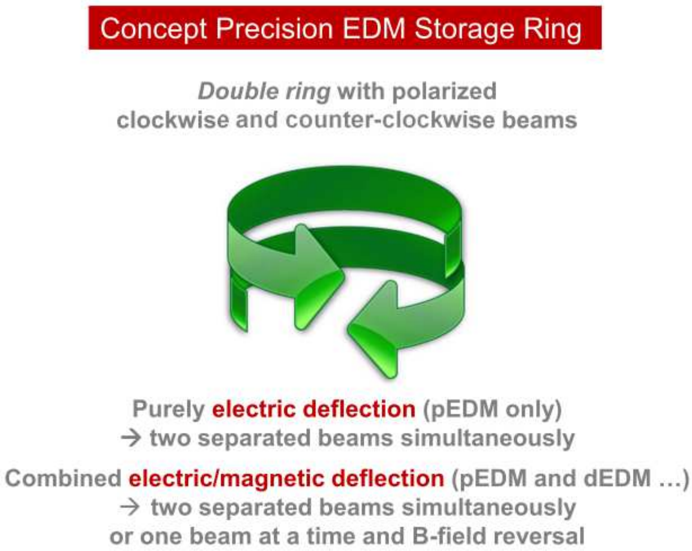


Scholarly aspects: **HOW? – Employ a new class of storage rings for charged-particle EDM searches!**

For the final high-precision ring with a EDM sensitivity goal of 10^{-29} e·cm or even better, both options require the use of clockwise (CW) and counter-clockwise (CCW) beams to remedy, e.g., the following systematic errors:

- Radial magnetic fields;
- Non-radial electric fields;
- Vertical quadrupole misalignments;
- rf cavity misalignments and unwanted field components.

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. A radial magnetic field, however, causes forces in different directions for the beams in opposite directions and thus it can be controlled to a very high accuracy. In addition there will be significant further experimental and technological challenges, for example shielding of external magnetic fields (below 1 nT everywhere), beam position monitoring (in the order of nm) and polarimetry (μrad/1000 s for 10^{-29} e·cm).



Such a dual-ring does not yet exist. The challenges briefly sketched above are basically due to the transition from the ideal physics case to its realization in a piece of equipment – two conclusions must be inferred:

- It will not be possible to reach the projected sensitivity goal in one step, essentially starting from scratch to design build and operate the dual-beam precision storage ring. Since such a facility also represents a significant investment it must only be made after a very careful assessment of all the risk factors has been performed and once all key-technologies are provided.
- An approach, in which these key-technologies are developed and demonstrated, combined with a series of experiments in which the EDM-sensitivity is increased step-by-step, based on the experience gained on the way, is compulsory.

The current proposal ("Electric Dipole Moment Search using Storage Rings") suggests such a step-wise approach: starting with existing equipment, in particular the cooler storage ring COSY at Forschungszentrum Jülich (COSY-Jülich, see below), two objectives will be pursued (WP-x refers to the work packages, described in more detail below):

- Develop the tool-box, comprising:
  - Beam position monitors (BPM), beam current transformers (BCT) [cf. WP-1and WP-4]
  - Electrostatic deflector and combined E-B "bender" [cf. WP-1 and WP-4]
  - Accelerator feedback system [cf. WP-1 and WP-4]
  - Beam polarimeter [cf. WP-2 and WP-4]
  - Spin tracking simulation codes [cf. WP-3]
- Perform EDM measurements with COSY:
  - Proof-of-principle for deuterons, using rf-elements ("Wien filter") [WP-5]
  - First direct measurements for protons and deuterons, using static E/B elements [WP-5]

The acquired know-how will be integrated in a design study (outside of the current srEDM project proposal) with the aim to provide a Conceptual Design Report (CDR) or even a Technical Design Report (TDR) for the final facility, which is a longer-term (>10 years) project.

Section b. Methodology

The srEDM project is a complex high-risk high-impact venture, which needs careful planning and execution. The following sections outline the structure of the necessary experienced team, the required (mostly available) hardware and the work packages (including the deliverables/intermediate milestones) on the way.

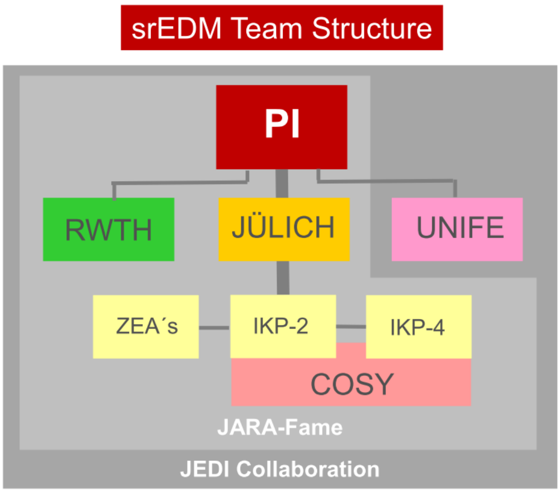
In order to keep track of progress (and possible problems which might lead to re-adjustments), it is planned to document and report all of the results in a timely fashion, e.g., on the srEDM-website, in conferences and in refereed scientific journals; best care and attention will be taken that results as well as the project itself will be presented to the broader scientific community and to the public. The dissemination of the results will be the responsibility of the PI and comprises:

- Implementation and maintenance of a website;
- Scientific internal and external reporting;
- Data and patent management (e.g., storage and access of experimental and technical data);
- Organization of topical internal and external review meetings.

Strategy: HOW? – Structure of the team; partners

Although the Institut für Kernphysik of Forschungszentrum Jülich [JUELICH] – comprising the PI´s institute (IKP-2) and the accelerator department (IKP-4) as well as the central engineering institutes (ZEA-1 (mechanics) and ZEA-2 (electronics)) – provides a very solid basis for the proposed srEDM project, the diversity and complexity requires additional complementary expertise, which can be implemented with the following two partner institutions:

- The Physics Institute (III B) of RWTH Aachen University [RWTH] has internationally acknowledged expertise in design and construction of, e.g., LHC detector components as well as complex data analyses, which will be extremely helpful for the new polarimeter. In cooperation with engineering departments, they have recently started to build and test mock-up models for the electrostatic deflectors. Prof. J. Pretz has been a member of the BNL $(g-2)_\mu$ collaboration, the only previous precision storage ring experiment. Finally, the university provides access to well-prepared PhD students for the project.
- The group at the University of Ferrara and INFN (Ferrara, Italy) [UNIFE], led by Prof. P. Lenisa, is a long-term collaborator, e.g., in PAX (polarized antiprotons) and has acquired unique expertise in polarized sources, targets and polarimetry, which will be invaluable for the success of the beam polarimetry work package and for all of the experimental investigations at COSY. Also Ferrara will be a source of well-trained PhD students.

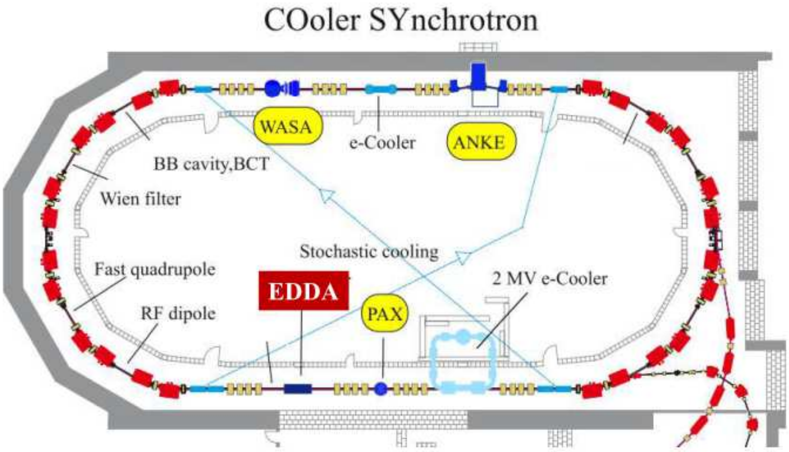


Forschungszentrum Jülich and RWTH Aachen University founded an institutional cooperation called JARA (Jülich Aachen Research Alliance) with one section FAME (Forces and Matter Experiments), which aims to answer the question about the fate of antimatter: all involved Jülich and Aachen institutions are members of JARA-Fame. The JEDI-collaboration (Jülich Electric Dipole Moment Investigations) encompasses all partners (see figure).

Strategy: HOW? – Exploit COSY-Jülich as R&D and EDM-demonstrator facility

The COoler SYnchrotron (COSY) is a conventional single beam storage ring with a circumference of 184 m at the Institut für Kernphysik (IKP) of Forschungszentrum Jülich (FZJ) (see figure); it is the hadron storage ring worldwide which has most of the characteristics required for the charged particle EDM project and it can be employed for the first EDM measurements of this proposal, although it was never conceived as a precision storage ring for this purpose.

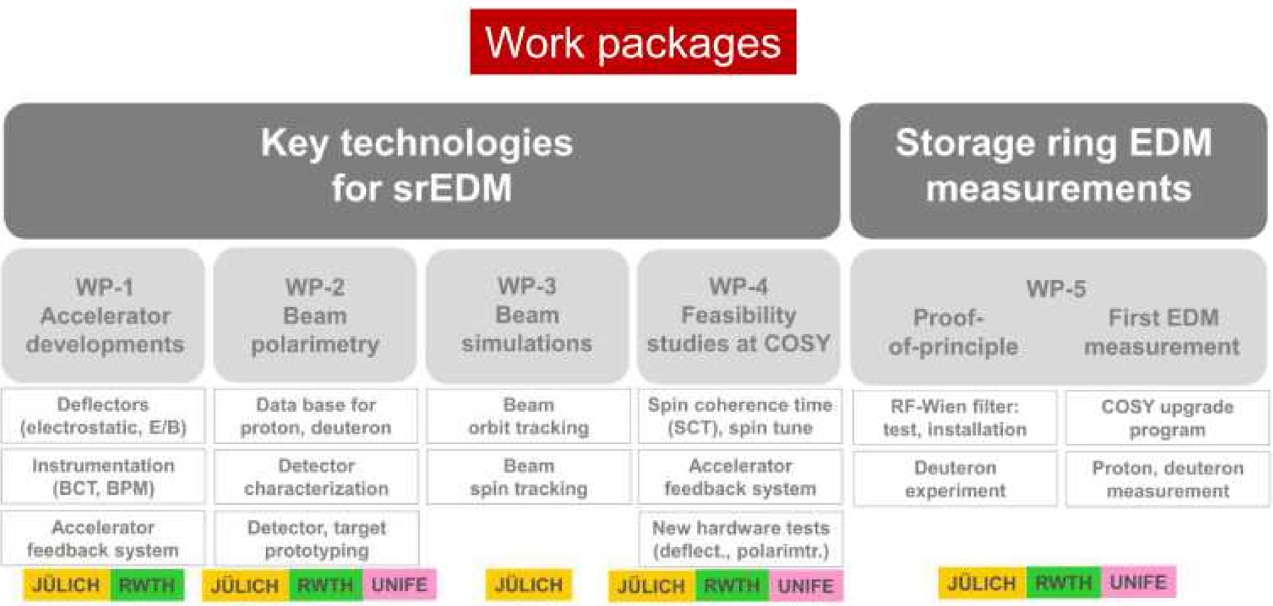
COSY stores and accelerates polarized proton and deuteron beams from the injector cyclotron JULIC to momenta between 0.3 GeV/c (value at injection) and 3.7 GeV/c. To preserve polarization during acceleration for polarized protons, well-established methods are employed: a fast tune-jumping system, consisting of two pulse air core quadrupoles, has been developed to overcome intrinsic resonances; polarization across imperfection resonances is preserved by the excitation of a vertical orbit bump using correcting dipoles to induce total spin flips. The polarization of the circulating beam in COSY can be monitored during acceleration with the internal EDDA detector. This unique tool simplifies the procedure of adjusting the accelerator for polarized beams. The achieved polarization for protons is higher than 75% up to the final momentum. Vector and tensor polarized deuterons are also routinely accelerated in COSY with polarizations up to 60%. COSY also provides phase space cooled beams over the whole momentum range by means of two electron coolers (low energy: up to 100 keV, high energy: up to 2.5 MeV) and a stochastic cooling system.



COSY has been operated for hadron physics experiments for more than 15 years. At the end of 2014 the hadron physics experiments have been stopped and the internal detector facilities (ANKE, WASA and PAX) will be decommissioned in future. For about 1/3 of the time (i.e. about 2000 hrs per year) COSY is now exploited for R&D in conjunction with the EDM project by the JEDI-collaboration. This fraction of beam time will increase once COSY is used as EDM-demonstrator facility (proof-of-principle, first measurements).

Strategy: HOW? – Work packages

The following figure presents the overview of the work packages foreseen for the srEDM-project with the two major deliverables – key technologies and EDM measurements – details are described below:



WP-1: Accelerator developments:
Electrostatic and combined E-B bending elements, instrumentation of the storage ring

To carry out this kind of precision experiments, high-field electrostatic and combined E-B bending elements have to be developed and optimized. For the ultimate sensitivity goal of 10^{-29} $e\cdot$cm of a proton EDM experiment the development of high-field purely electrostatic bending elements are essential. Combined electrostatic - magnetic bending elements have to be developed for an "all-in-one" lattice design to perform a deuteron experiment – such a ring can also be used for protons as well as other light ions, e.g., ^{3}He. For an EDM storage ring of radius r = 30 m transverse electric fields of 17 MV/m with a magnetic field up to 1.6 kG are required.

The EDM measurement also requires a precise monitoring of the beam properties to understand systematic effects. The main systematic error of an EDM measurement is supposed to come from radial magnetic fields which will, via the interaction with the magnetic moment of the particle, mimic an EDM effect.

Objectives

An electrostatic deflector from Fermi National Accelerator Laboratory (FNAL) has been transferred to Jülich to gain experience with ultra-high electrostatic fields. In cooperation with RWTH a clean room and test bench was set-up to test downscaled electrostatic deflector models. To handle systematic contributions by the two apertures of an "all-in-one" machine, the field polarity of the magnetic field has to be changed with very high precision while keeping the electric field completely constant. This will allow for consecutive runs of CW and CCW beams in the different apertures of the combined electrostatic - magnetic bending elements.

Major development steps for the final bending element are the optimization of the shape of electrostatic field plates with suitable magnet field configurations utilizing electromagnetic field simulation programs, electrical and mechanical layout of bending elements and R&D work on surface treatments that can yield ultra-high electric field gradients. Thus, the following steps are required:

1. Test and optimization of bending elements on the test bench:
   - Test and optimization of downscaled electrostatic bending elements;
   - Preparation of test bench and clean room at Jülich to test full-scale bending elements;
   - Refurbishing and performance optimization of FNAL deflector;
   - Development and of surface treatment utilizing the FNAL deflector to increase its performance;
   - Adding magnetic field coils and study field polarity change with very high precision.
2. Development of the final bending elements:
   - Optimization of the shape of electrostatic field plates with suitable magnet field configurations, using electromagnetic field simulation programs;
   - Electrical and mechanical layout of bending elements;
   - Construction of bending element, optimization of field configuration and strength;
   - Performance test and optimization on test bench.

One way of controlling systematic effects is the use of high precision BPMs. The idea is based on the exploitation of magnetic pick-ups in a *Rogowski coil* configuration (an electrical device for measuring alternating currents, which consists of a helical coil of wire). The main advantage of this coil design is the response to the particle bunch frequency and the compactness of the coil itself. In a first step the BPMs will be benchmarked in a laboratory test system. In the next step the calibrated BPMs will be installed and tested at the conventional storage ring COSY. In a further step an extension of the BPMs to measure the relative position of two counter-rotating particle beams must be foreseen.

3. *Rogowski* coil development:
   - Benchmarking in a laboratory test system;
   - Installation and performance testing at COSY.

A radial magnetic field will lead to a vertical separation of the two beams which leads to a non-vanishing magnetic field which could be measured with SQUIDs (superconducting quantum interference device, consists of two superconductors separated by thin insulating layers to form two parallel Josephson junctions; they may be configured as a magnetometer to detect very small magnetic fields). A first estimate shows that one needs sensitivity of the order of 1fT/√Hz. SQUIDs with this sensitivity are available but were never tested in an accelerator environment. SQUIDs were used as a beam current monitor but never as a beam position monitor where a new 4-fold coil setup to measure up-down and left-right positions will be used. This will be addressed in this work package. Note that only the relative positions of the two beams have to be measured. This method only works if the beam currents and phase space of the two beams are the same or are determined very precisely.

4. SQUID BPM development:
   - Design and layout of a SQUID BPM;
   - Installation and performance tested at COSY.

For stabilization of COSY (and any future precision EMD storage ring), signals of as many ring and beam parameters as possible (magnets, rf-systems, spin and betatron tune, closed orbit, chromaticity etc.) need to be monitored and put into a feedback system. Such systems will be developed and then tested in COSY (WP-4).

Deliverables

The list of items given in the subsections 1.- 4. above comprises the tasks that need to be worked off in this work package. As the final goal of this WP, a technical report will be delivered after month 48. Intermediate steps will be topical and review meetings.

Contributions by the partners

The institute where most of the accelerator know-how for storage rings resides, IKP-4 of Forschungszentrum Jülich, will take over the largest fraction of the workload of the work package. The IKP-4 director Prof. M. Bai is committed to lead this WP. IKP-2 with its experience in polarized beams will also contribute under leadership of Dr. F. Rathmann (one of the JEDI-spokespersons). ZEA-1 of FZJ will be strongly involved in all technological developments. RWTH will be responsible for the downscaled electrostatic bending elements. For these tasks, one PostDoc position at FZJ and one at RWTH will be foreseen from this project (see figure below).

For the SQUID-BPM development, cooperation with one of the world experts of SQUIDs (Dr. H.J. Krause, PGI-8 of FZJ) has been started.

WP-2: Polarimetry

The polarimeter for the EDM Storage Ring must operate continuously with high efficiency and high polarization sensitivity (analyzing power) so that polarization rotations of the beam as small as a μrad may be detected if they happen within a time of about 1000 s. There also needs to be control of the systematic errors in detecting this change to a similar level of precision. The conditions of high efficiency (1%) and analyzing power (~0.6) are fulfilled for medium energy protons and deuterons when using a thick (few cm) carbon block onto which the beam particles are directed continuously during the experiment. Elastic scattering of the beam particles from the atomic nuclei in the carbon target will be observed in a series of detectors installed behind the target.

Feasibility studies conducted at COSY have already demonstrated this level of performance and error suppression for a carbon block mounted at the edge of the circulating beam. In an experiment in which the polarization direction is periodically reversed, first-order errors arising from beam position or angle errors, or rate-induced acceptance changes in the detector system, may be cancelled using combinations of the elastic scattering rates for different azimuthal angles. Higher-order systematic effects related to the shape of the beam profile may be corrected based on the information from a reconstruction of individual scattering events if the carbon target is supplemented with a hydrogen gas jet (or frozen pellet beam) that crosses the beam. So part of the polarimeter detector will be a tracking system that allows tracing each particle back to its point or origin, and another outside the first that identifies particles that have scattered elastically. The hydrogen target will also give rise to Coulomb scattered (with spin independence) particles that oscillate about the beam center line and strike the thick carbon blocks on subsequent trips around the storage ring.

Objectives

The goal of the WP will be the design, construction and testing of a prototype polarimeter for use in the first EDM storage ring experiment. This will comprise the following steps:

- Development of a broad-band database for p-C and d-C scattering;
- Detector characterization;
- Polarimeter modelling and Monte Carlo simulations;
- Realization and test of a prototype.

One exciting novel project which has recently been started, is to shoot small diamond pellets (size 1-100 µm) through the beam as target instead of using a bulk carbon block – this has many attractive features, like, e.g., instantly switching the target on/off and obtaining a beam profile, but it requires a new development.

A dedicated target-station in COSY for the data base measurements will be provided at the WASA place (see figure of COSY above); test experiments for detectors can also use the extracted COSY beam.

Deliverables

The data base on polarized proton-carbon and deuteron-carbon scattering will be provided in month 30 (after the start of the project); a polarimeter prototype will be constructed and tested after 36 months, and the feasibility study for the new target system will also be finalized after 3 years.

Contributions by the partners

Forschungszentrum Jülich (the group of the PI in IKP) will develop the polarimeter prototype and work on the new diamond pellet target system; for this purpose a new IKP-2 staff member (Irakli Keshelashvili) has been hired recently, and a cooperation with ZEA-1 (mechanical engineering of FZJ) has been started.

RWTH Aachen will perform detector modelling and MC simulations: under the supervision of Prof. J. Pretz, students will work off this task.

Ferrara will be responsible for the data base. A PostDoc with experience in polarized hadronic reactions will be hired for the group of Prof. P. Lenisa in order to provide the required precision polarization data (analysing power, cross section) from literature and from new measurements at COSY.

WP-3: Beam simulations

Spin tracking simulations of the complete experiment are crucial to explore the feasibility of the planned storage ring EDM searches and to investigate the systematic limitations. For a detailed study during particle storage and build-up of an EDM signal, a large sample of particles must be tracked for billions of turns. The "COSY INFINITY" and "MODE" simulation programs are utilized for this purpose, both based on map generation using differential algebra and the subsequent calculation of the spin-orbital motion for an arbitrary particle. An MPI version is running on the Jülich supercomputer cluster. Given the complexity of the tasks, particle and spin dynamics simulation programs must also be benchmarked by comparing simulation results and experimental data from measurements at the Cooler Synchrotron COSY.

Objectives

Spin tracking simulations to support the first direct measurements and quantify systematic errors have to be performed. In order to identify the best approach using numerical simulation codes, meetings of the world-leading experts will be organized – recently a kick-off meeting was held during the International Particle Accelerator Conference (IPAC15) in Richmond, Virginia (USA). In addition to "COSY INFINITY" and "MODE", integrating programs also have to be used for benchmarking. These simulation programs are suitable to study effects that occur on short time scales.

Deliverables

The goal of the WP will be to deduce the systematic limitations of the resonant method (RF Wien filter; see WP-5 below) with the simulation programs and perform lattice design and spin tracking for the design work of a dedicated EDM storage ring. In a first step the development and implementation of time-dependent transfer maps as well as the EDM extension to spin motion need to be tested and used to investigate the resonant method and its systematic limitations with COSY INFINITY and MODE. Main sources of systematic errors for the resonance method are the alignment of the RF Wien filter, the opening angle of spin ensemble, field quality (fringe fields), the relative frequency slip of the RF Wien filter and the closed orbit deviation of the beam due to misalignments and field errors of ring magnets. In order to improve the systematic EDM limit for this method the closed orbit correction system of COSY has to be improved significantly. For this task detailed beam and spin tracking simulation are essential. The results will be the bases to specify the required COSY upgrade (orbit correction system, beam-position monitors (BPMs), power supply stability, magnet alignment and ring impedances).

For the design study of a dedicated EDM storage ring, lattice design and spin tracking will be the major task in the upcoming years to identify the systematic EDM limit of the experimental methods in conjunction with the design of all accelerator elements.

The WP needs to be dealt with over the full period of the srEDM project, but some parts have to be finalized after about 2 years, since results are needed for the measurements of WP-5.

Contributions by the partners

The simulations within this project will be performed in the IKP accelerator division (Prof. M. Bai) of FZJ with PhD students under the leadership of Prof. A. Lehrach (FZ Jülich / RWTH Aachen). The upgrade of COSY INFINITY will be supervised by Prof. M. Berz (MSU, USA), who is the principal developer of the presently available version and who is a member of the JEDI collaboration.

WP-4: Feasibility studies at COSY

COSY with its polarized proton and deuteron beams offers unique possibilities for test measurements, benchmarking orbit and spin tracking codes (cf. WP-3) and testing new equipment: deflectors, beam position monitors and feedback systems (cf. WP-1) and, e.g., the polarimeter (cf. WP-2). In addition to these tasks, preparatory measurements for EDM experiments will be performed – in the following they are described in more detail.

One of the prerequisites for an EDM measurement in storage rings is the provision of long spin coherence times (SCT – the equivalent of the T_2 relaxation time in NMR). Recently, SCT of several hundred seconds were obtained for a p = 1 GeV/c deuteron beam. Such a large SCT made it possible to measure the spin tune of the beam with an unprecedented precision of 10^{-10} in a measurement time of 100 s (the corresponding paper has been submitted to PRL; see Ref. 5 in part B1 of this project). In a pure magnetic ring the spin tune, defined as the number of spin revolutions per particle turn, is given by the product of relativistic gamma-factor and the anomalous magnetic moment: $\nu_s = \gamma G$. With this measurement the spin tune has been established as a tool to investigate systematic effects. One observation of the measurement was that the spin tune varies within one cycle as well as from cycle to cycle by about 10^{-8}. In a perfectly stable machine there should be no such variations. It is planned to investigate where these changes come from (temperature effects, magnetic field instabilities, etc.). Understanding these systematic effects is one objective of this work package. A second one is to provide long SCTs also for protons.

Objectives

The goal of the WP will be to exploit COSY for feasibility investigations in connection with EDM storage ring experiments. These comprise the following items:

- Investigations to understand systematic effects for spin tune measurements;
- Benchmarking of simulation tools for orbit and spin tracking;
- Provision of large spin coherence times for protons:
- Implementation and test of the feedback systems.

Deliverables

A comprehensive report on systematic errors for EDM measurement will be provided after 42 months. It is planned to publish the SCT results for protons in a refereed journal subsequently.

Contributions by the partners

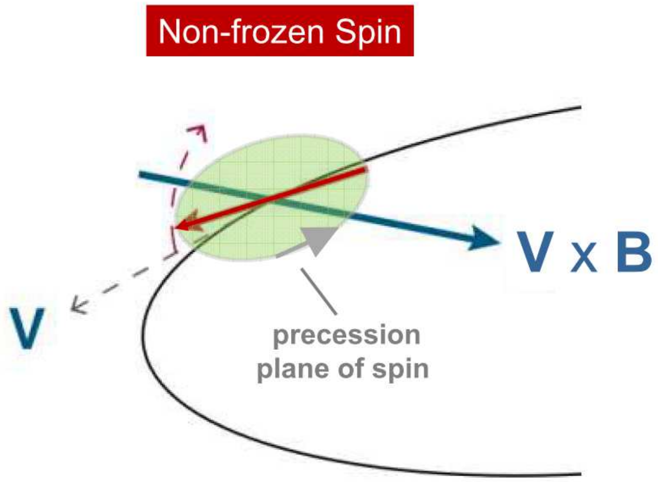
The studies of WP-4 are a task where all three partners contribute (see figure below); a PostDoc for RWTH (4 years) and another one for UNIFE (2 years) are foreseen.

WP-5: Proof-of-principle and First EDM measurements using COSY

A storage ring charged hadron EDM-search has never been conducted (except for the muon (see above) which represents a very special case due to its weak decay), and, given the potential impact of such measurements, a demonstration of the method, i.e., the storage of a polarized beam with large spin coherence time and the application of an E×B field such that no Lorentz-force acts on the particles ("Magic rf Wien filter"), must be conducted as a first step.

During last year (2014), a prototype rf E×B dipole has been successfully commissioned and tested at COSY. The force due to a radial magnetic field is cancelled by a vertical electric one. In this configuration, the dipole fields form a Wien filter that directly rotates the particles' polarization vector. It was verified that the device can be used to continuously flip the vertical polarization of a 970 MeV/c deuteron beam without exciting any coherent beam oscillations. For a first EDM-experiment the rf E×B dipole in Wien-filter mode will be rotated by 90° around the beam axis. This configuration will be used for systematic investigations of sources for false EDM signals.

The magic rf Wien filter will allow us to perform a polarization build-up experiment (see figure below). Since we are using a magnetic machine, the direction of the spin of the particles is not frozen. In order for this technique to work, the frequency of the rf Wien filter must be locked to the spin motion. This will be accomplished by dedicated feedback systems (see WP-1 and WP-4).



The reach in EDM sensitivity using an rf Wien filter is, however, limited by the fact that any magnetic imperfection present in the machine will be amplified by the rf device. Therefore, the machine performance must be controlled to high accuracy, and this will required moderate upgrades. Using the rf E×B Wien filter, we are aiming at a first measurement of the deuteron EDM, which will serve as proof-of-principle measurement for the storage ring EDM technique.

After the experimental demonstration that storage ring EDM measurements can be performed, experiments will be conducted to obtain a first directly measured EDM for the proton and to deduce a first-ever measurement for the deuteron. As mentioned before, it must be understood that in a magnetic storage ring like COSY, there is no frozen spin. Therefore, later on in WP5, we will use a dedicated insertion composed of static electric and magnetic fields that decouples from the magnetic imperfection of the machine. In such an arrangement, the EDM signal will be solely produced by the insertion itself. Such a system will act as a miniature electrostatic storage ring, located inside a magnetic machine. As such, it will pave the way towards the new class of electrostatic storage rings for EDM searches.

Objectives

The goal of the WP is to provide a proof-of-principle measurement of the deuteron EDM using an rf E×B Wien filter. Once the dedicated insertion using a combination of electric and magnetic fields is available, a first-ever measurement of protons and deuterons using a magnetic storage ring will be carried out. Such an insertion is mandatory, as it will use the very same techniques that are required for a dedicated electrostatic machine.

Deliverables

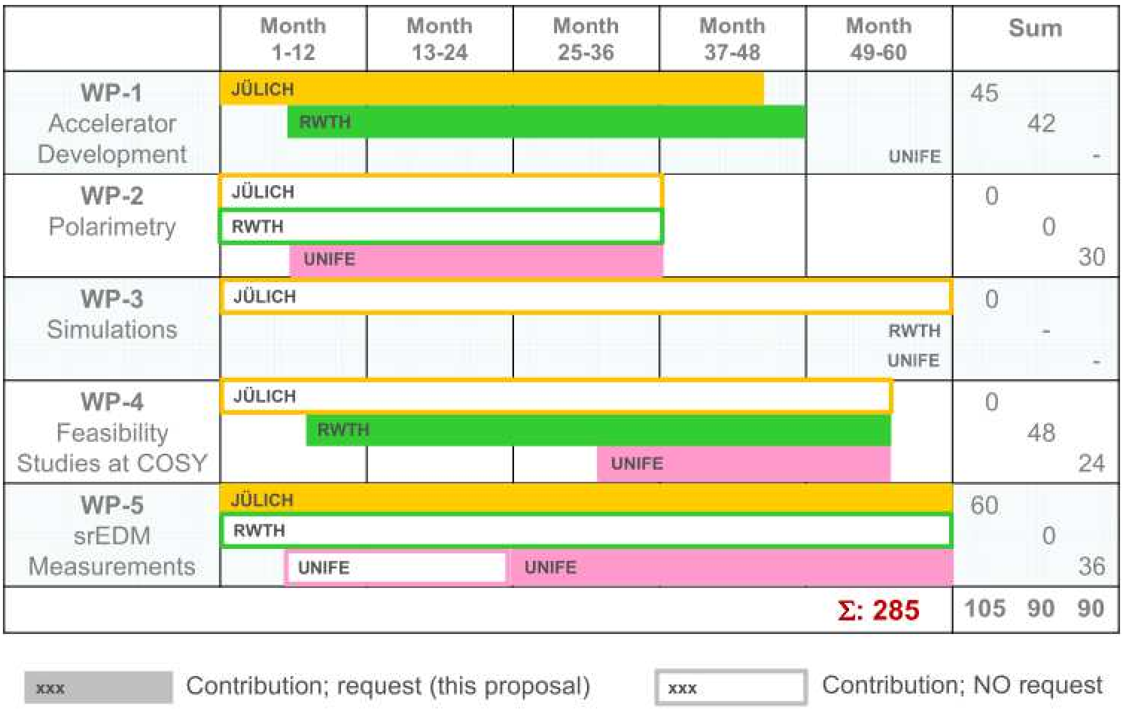
- Proof-of-principle experiment with deuterons using rf E×B Wien filter
- Design study of static insertion, including simulation studies and error estimates
- Technical realization
- Proton and deuteron EDM measurements

All of the above-mentioned items will be scheduled in the second half of the 5 year duration of the srEDM project.

Contributions by the partners

The tasks of WP-5 will constitute a common effort of all three partners. More than one third of the requested personnel resources (one PostDoc for JUELICH for 5 years, necessary for the preparations, and another one for UNIFE for 3 years) will be attributed to this task.

As a summary the following figure shows the distribution of resources of the srEDM project with respect to the five work packages. A distinction is made between resources requested from ERC and additional resources which will be brought in from the PI´s institute and the partner institutions. It should finally be mentioned that the investments will be supplied by IKP of FZJ.



Strategy: WHY NOW? – The right time and the right place

The Institut für Kernphysik of Forschungszentrum Jülich has recently changed the focus of the scientific use of COSY: hadron physics experiments have been completed and – during the next funding period (2015 – 2020) and beyond – COSY will be primarily used to exploit the possibilities of charged particle EDM searches. There is thus a unique time window to demonstrate the principle and to develop all the tools for srEDM – inevitable preconditions for a new dedicated precision (double-beam) storage ring, which undoubtedly would be a European flagship facility.

The current srEDM proposal – if successful – will provide a major boost to this project!

Section c. Resources (including project costs)

In the following table the cost for the srEDM project are specified according to the PI´s institute and the two partner institutions:

Cost Category			Total in Euro			
			JÜLICH	**RWTH**	**UNIFE**	**Total**
Direct Costs[1]	**Personnel**	PI	193456			193456
		Senior Staff				
		Postdocs	619060	447127	376528	1442715
		Students				
		Other				
	i. Total Direct costs for Personnel (in Euro)		812516	447127	376528	1636171
	Travel		30000	30000	60000	120000
	Equipment					
	Other goods and services	Consumables	60000	60000	60000	180000
		Publications (including Open Access fees), etc.				
		Other: Audits	6000	6000	6000	18000
		Other: Workshops	20000			20000
	ii. Total Other Direct Costs (in Euro)		116000	96000	126000	338000
A – Total Direct Costs (i + ii) (in Euro)			928516	543127	502528	1974171
B – Indirect Costs (overheads) 25% of Direct Costs (in Euro)			232128	135782	125632	493542
C1 – Subcontracting Costs (no overheads) (in Euro)			0	0	0	
C2 – Other Direct Costs with no overheads (in Euro)			0	0	0	
Total Estimated Eligible Costs (A + B + C) (in Euro)			1160644	678909	628160	2467713
Total Requested Grant (in Euro)			1160644	678909	628160	**2467713**

For the above cost table, please indicate the % of working time the PI dedicates to the project over the period of the grant:	**41,67 %**

Remarks:

1) UNIFE has higher travel cost than JÜLICH and RWTH, since they frequently have to travel to Forschungszentrum Jülich for tests and COSY beam times.
2) The workshop costs comprise travel support for invited speakers as well as for students.
3) As mentioned previously no equipment cost is included, since the investments are covered by IKP funds. The consumables comprise repair of equipment, spare parts and, e.g., detector gases.

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Forschungszentrum Jülich GmbH · T-DA · 52425 Jülich

To whom it may concern

Ihr Zeichen:
Ihre Nachricht vom:
Unser Zeichen: E2216.01.15
Unsere Nachricht vom:

Ansprechpartner: Anne Bosch
Organisationseinheit: T-DA

Telefon: 02461 61-4236
Telefax: 02461 61-2118

E-Mail: a.bosch@fz-juelich.de

Jülich, 12.05.2015

Commitment of the host institution for ERC Calls 2015[1, 2, 3]

The Forschungszentrum Jülich GmbH, which is the applicant legal entity, confirms its intention to sign a supplementary agreement with Prof. Dr. Hans Ströher in which the obligations listed below will be addressed should the proposal entitled

srEDM: Electric Dipole Moment Search using Storage Rings

be retained.

Performance obligations of the applicant legal entity that will become the beneficiary of the grant agreement, should the proposal be retained and the preparation of the grant agreement be successfully concluded:

The *applicant legal entity* commits itself to engage the *principal investigator* for the duration of the grant to:

a) **ensure that the work will be performed under the scientific guidance of the *principal investigator* who is expected to devote:**

***- in the case of a Starting Grant at least 50% of her/his total working time* to the ERC-funded project and spend at least**

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Telefax 02461 61-8100

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www.fz-juelich.de

[1] A scanned copy of the signed statement should be uploaded electronically via the Participant Portal Submission Service in PDF format.
[2] The statement of commitment of the host institution refers to most obligations of the host institution, which are stated in the ERC grant agreement. The ERC model grant agreement is available on the ERC website at http://erc.europa.eu and via http://ec.europa.eu/research/participants/portal/desktop/en/funding/reference_docs.html.
[3] This statement (on letterhead paper) shall be signed by the institution's legal representative and stating his/her name, function, email address and stamp of the institution.

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50% of her/his total working time in an EU Member State or associated country;

- *in the case of a Consolidator Grant at least 40% of her/his total working time* to the ERC-funded project and spend at least 50% of her/his total working time in an EU Member State or associated country;

- *in the case of an Advanced Grant at least 30% of her/his total working time* to the ERC-funded project and spend at least 50% of her/his total working time in an EU Member State or associated country.

b) carry out the work to be performed, as it will be identified in Annex 1 of the ERC Grant Agreement, taking into consideration the specific role of the *principal investigator*;

c) establish a *supplementary agreement* with the *principal investigator* which specifies that the *applicant legal entity* shall:

   i) support the *principal investigator* in the management of the *team* and provide reasonable administrative assistance to the *principal investigator,* in particular as regards:

      a. the timeliness and clarity of financial information,
      b. the general management and reporting of finances,
      c. the advice on internal *applicant legal entity* management practices,
      d. the organisation of *project* meetings as well as the general logistics of the *project*.

   ii) provide research support to the *principal investigator* and his/her *team members* throughout the duration of the *project* in accordance with Annex 1 ERC Grant Agreement, in particular as regards infrastructure, equipment, products, access rights and other services as necessary for the conduct of the research;

   iii) ensure that the *principal investigator* and his/her *team members* enjoy, on a royalty-free basis, access rights to

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the *background* and the *results* needed for their activities under the *project* as specified in Annex 1 ERC Grant Agreement;

iv) ensure that the principal investigator enjoy adequate contractual conditions, in particular as regards:
   a. the provisions for annual, sickness and parental leave,
   b. occupational health and safety standards,
   c. the general social security scheme, such as pension rights.

v) guarantee the necessary scientific independence of the *principal investigator*, in particular as regards:
   a. the selection and supervision of other *team members,* hosted and engaged by the *applicant legal entity* or other legal entities, in line with profiles needed to conduct the research, including the appropriate advertisement, and in accordance with the beneficiary's usual management practices;
   b. the use of the budget to achieve the scientific objectives;
   c. the preparation of scientific reports to the *ERC Executive Agency*;
   d. the authority to publish as senior author and invite as co-authors only those who have contributed substantially to the reported work.

vi) inform the *principal investigator* of any circumstances affecting the implementation of the *project* or leading potentially to a suspension or termination of the ERC Grant Agreement;

vii) subject to the observance of applicable national law and to the agreement of the *ERC Executive Agency*, the transfer of the grant agreement as well as any pre-financing of the grant not covered by an accepted cost claim to a new legal entity, should the *principal investigator* request to transfer the entire *project or part*

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of it to this new legal entity. The *applicant legal entity* shall submit a substantiated request for amendment or notify the *ERC Executive Agency* in case of its objection to the transfer.

For the host institution (applicant legal entity):

Forschungszentrum Jülich GmbH

Date: 18. Mai 2015

Name and Function:
Prof. Dr. W. Marquardt, Chairman of the Board

Email and Signature of legal representative

w.marquardt@fz-juelich.de; ______________

Name and Function:
Prof. Dr. S. Schmidt, Member of the Board

Email and Signature of legal representative

s.schmidt@fz-juelich.de; ______________

Stamp of the host institution (applicant legal entity:)

Forschungszentrum Jülich GmbH

IMPORTANT NOTE: In order to be complete all the above mentioned items are mandatory and shall be included in the commitment of the host institution.

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