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Horizon 2020
Excellent Science

Call: ERC-2020-ADG
(Call for proposal for ERC Advanced Grant)

Topic: ERC-2020-ADG
Type of action: ERC-ADG
(Advanced Grant)
Proposal number: 101019381
Proposal acronym: P-EDM

Deadline Id: ERC-2020-ADG

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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 steps in the submission wizard.

1 - General information

Topic	ERC-2020-ADG	Type of Action	ERC-ADG
Call Identifier	ERC-2020-ADG	Deadline Id	ERC-2020-ADG

Acronym	P-EDM
Proposal title	Pathfinder for a Charged-Particle EDM Storage Ring

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*	PE2_01 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	*PE2_02 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 proposal.The choice of keywords should take into account any multi-disciplinary aspects of the proposal.*

*Abstract**

Electric Dipole Moments (EDM) of fundamental particles are one of most promising candidates for studying physics beyond the Standard Model of Particle Physics (SM), because they break both parity (P) and time-reversal (T) invariance, which indicates charge-parity (CP) violation. This type of violation beyond the electroweak contributions is one of the prerequisites for understanding the apparent matter-antimatter asymmetry in our Universe, one of the great puzzles of contemporary physics. While the experimental sensitivity has been improved over the past decades, no permanent EDM has been found up to now. A new experimental approach is to search for EDMs of charged particles, i.p. protons, in precision electrostatic storage rings, which enable one to push the EDM limits by at least two orders of magnitude. Experimental challenges require a stepwise approach, going from research, development and exploratory measurements at a magnetic storage ring (COSY, Jülich) to design and procurement of an electrostatic prototype ring (E_k= 40 MeV) and the final ring, running at the magic energy (230 MeV) with clockwise and counter-clockwise beams. The inevitable intermediate step is the pathfinder project P-EDM, in which we will: i) develop the key components (deflectors and polarimeter), ii) design the lattice of the prototype ring, and iii) perform a proof-of-principle proton EDM measurement at COSY. P-EDM will be executed under my leadership with an experienced team at IKP (Jülich) and with valuable contributions from CERN, Ferrara University, MPI for Nuclear Physics in Heidelberg, and RWTH Aachen, building on the ground breaking work of srEDM for deuterons at COSY. The ultimate P-EDM goal is to pave the way for a precision storage-ring to search for a static proton EDM with unprecedented sensitivity and to exploit the full potential of oscillating EDMs induced by axions or axion-like particles (ALPs), thus exploring yet unknown parameter space in the search for Dark Matter.

Remaining characters 1

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

Declarations

In case of a Synergy grant application 'Principal Investigator' means 'corresponding Principal Investigator on behalf of all Principal Investigators', and 'Host Institution' means 'corresponding Host Institution'.

1) The Principal Investigator declares to have the written consent of all participants on their involvement and on the content of this proposal, as well as of any researcher mentioned in the proposal as participating in the project (either as other PI, team member or collaborator). The ERCEA may request the applicants to provide the written consent of all participants at any time during the evaluation process.*	☒
2) The Principal Investigator declares that the information contained in this proposal is correct and complete.	☒
3) The Principal Investigator declares that all parts of this proposal comply 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 Host Institution has carried out the self-check of the financial capacity of the organisation on http://ec.europa.eu/research/participants/docs/h2020-funding-guide/grants/applying-for-funding/register-an-organisation/financial-capacity-check_en.htm 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 Host Institution 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 Host Institution 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 Host Institution and each beneficiary applicant will be required to present a formal declaration in this respect.

Note:

For **multi-beneficiary applications**, the coordinator vouches for its own organization and that all other participants confirmed their participation and compliance with conditions set out in the call. If the proposal is retained for funding, each participant will be required to submit a formal declaration of honour confirming this.

False statements or incorrect information may lead to administrative sanctions under the Financial Regulation 2018/1046.

Personal data will be collected, used and processed in accordance with Regulation 2018/1725 and the **Funding & Tenders Portal privacy statement**.

Please be however aware that, to protect EU financial interests, your data may be transferred to other EU institutions and bodies and be registered in the EDES database. Data in the EDES database is also subject to Regulation 2018/1725 and the EDES privacy statement.

2 - Participants & contacts

#	Participant Legal Name	Country	Action
1	GSI HELMHOLTZZENTRUM FUER SCHWERIONENFORSCHUNG GMBH	Germany	
2	University of Ferrara, Dipartimento di Fisica e Scienze della Terra	Italy	
3	EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH	Switzerland	

2 - Administrative data of participating organisations

Host Institution

PIC	***Legal name***
999995214	*GSI HELMHOLTZZENTRUM FUER SCHWERIONENFORSCHUNG GMBH*

Short name: GSI

Address

Street PLANCKSTRASSE 1

Town DARMSTADT

Postcode 64291

Country Germany

Webpage http://www.gsi.de

Specific Legal Statuses

Legal person ....yes

Public body ....no

Industry (private for profit)..................no

Non-profit ....yes

International organisation ....no

International organisation of European interest ....no

Secondary or Higher education establishment ....no

Research organisation ....yes

Enterprise Data

Based on the below details from the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

SME self-declared status...10/12/2008 - no

SME self-assessment .... unknown

SME validation sme...10/12/2008 - no

Department(s) carrying out the proposed work

Department 1

Department name	GSI/IKP -Forschungszentrum Juelich
not applicable	☐
Same as proposing organisation's address	☒
Street	PLANCKSTRASSE 1
Town	DARMSTADT
Postcode	64291
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-2020-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.

ORCID: 0000-0003-3509-1240

Researcher ID:

The maximum length of the identifier is 11 characters (ZZZ-9999-2010) and the minimum length is 9 characters (A-1001-2010).

Other ID: *Please enter the type of ID here* *Please enter the identifier number here*

Last Name*	LENISA	Last Name at Birth	-
First Name(s)*	Paolo	Gender*	(•) Male ( ) Female
Title	Prof.	Country of residence*	Italy
Nationality*	Italy	Country of Birth*	Italy
Date of Birth* (DD/MM/YYYY)	17/06/1965	Place of Birth*	Udine

Contact address

Current organisation name	University of Ferrara
Current Department/Faculty/Institute/ Laboratory name	Dipartimento di Fisica e Scienze della Terra

☐ Same as organisation address

Street	Via Saragat, 1		
Postcode/Cedex	44122	Town*	Ferrara
Phone	+390532974309	Country*	Italy
Phone2 / Mobile	+393493642527		
E-mail*	lenisa@fe.infn.it		

Qualifications

Earliest award (PhD, Doctorate)

Date of award (DD/MM/YYYY) 24/04/1997

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 **GSI HELMHOLTZZENTRUM FUER SCHWERIONENFORSCHUNG GMBH**

First name* **Arjan** Last name* **Vink**

E-Mail* **a.vink@gsi.de**

Position in org. *Head of Grant Office*

Department *GSI HELMHOLTZZENTRUM FUER SCHWERIONENFORSCHUNG* ☒ Same as organisation

☒ Same as organisation address

Street PLANCKSTRASSE 1

Town DARMSTADT Postcode 64291

Country Germany

Phone +49 6159 71 2848 Phone2/Mobile +xxx xxxxxxxxx

Other contact persons

First Name	***Last Name***	***E-mail***	***Phone***
Irene	Reinhard	eu-buero@gsi.de	*+49 6159 71 2633*
Hans	Stroeher	h.stroeher@fz-juelich.de	*+xxx xxxxxxxxx*
Frank	Rathmann	f.rathmann@fz-juelich.de	*+xxx xxxxxxxxx*
Andro	Kacharava	a.kacharava@fz-juelich.de	*+xxx xxxxxxxxx*

Partner organisation

PIC	***Legal name***
917315421	*University of Ferrara, Dipartimento di Fisica e Scienze della Terra*

Short name: UNIFE

Address

Street Via Saragat 1,

Town Ferrara

Postcode 44122

Country Italy

Webpage http://fst.unife.it/

Specific Legal Statuses

Legal person ....yes

Public body ....unknown

Industry (private for profit)..................unknown

Non-profit ....unknown

International organisation ....unknown

International organisation of European interest ....unknown

Secondary or Higher education establishment ....unknown

Research organisation ....unknown

Enterprise Data

Based on the below details from the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

SME self-declared status... unknown

SME self-assessment .... unknown

SME validation sme.. unknown

Department(s) carrying out the proposed work

Department 1

Department name: Dipartimento di Fisica e Scienze della Terra

☐ not applicable

☐ Same as proposing organisation's 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 **University of Ferrara, Dipartimento di Fisica e Scienze della Terra**

First name* **Giuseppe** Last name* **Ciullo**

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

Position in org. *Associate Professor*

Department *Dipartimento di Fisica e Scienze della Terra* ☐ Same as organisation

☐ Same as organisation address

Street Via Saragat, 1

Town Ferrara Postcode 44122

Country Italy

Phone +390532974297 Phone2/Mobile +xxx xxxxxxxxx

Other contact persons

First Name	***Last Name***	***E-mail***	***Phone***
Adele	Del Bello	ricinternaz@unife.it	*+39 0532 293277*

Partner organisation

PIC	***Legal name***
999988133	*EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH*

Short name: CERN

Address

Street ESPLANADE DES PARTICULES 1 PARCELLE

Town GENEVA 23

Postcode 1211

Country Switzerland

Webpage www.cern.ch

Specific Legal Statuses

Legal person ....yes

Public body ....yes

Non-profit ....yes

International organisation ....yes

International organisation of European interest ....yes

Secondary or Higher education establishment ....no

Research organisation ....yes

Industry (private for profit)..................no

Enterprise Data

Based on the below details from the Beneficiary Registry the organisation is not an SME (small- and medium-sized enterprise) for the call.

SME self-declared status..07/07/2008 - no

SME self-assessment .... unknown

SME validation sme..07/07/2008 - no

Department(s) carrying out the proposed work

Department 1

Department name	Beam Department
☐ not applicable	
☒ Same as proposing organisation's address	
Street	ESPLANADE DES PARTICULES 1 PARCELLE 1148
Town	GENEVA 23
Postcode	1211
Country	Switzerland

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 **EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH**

First name* **Christian** Last name* **Carli**

E-Mail* **christian.carli@cern.ch**

Position in org. *Staff member*

Department *Beam Department* ☐ Same as organisation

☒ Same as organisation address

Street ESPLANADE DES PARTICULES 1 PARCELLE 11482 DE MEYRIN

Town GENEVA 23 Postcode 1211

Country Switzerland

Phone +41 22 76 72638 Phone2/Mobile +xxx xxxxxxxxx

Other contact persons

First Name	***Last Name***	***E-mail***	***Phone***
European	Projects	eu.projects@cern.ch	*+xxx xxxxxxxxx*
Mike	Lamont	mike.lamont@cern.ch	*+xxx xxxxxxxxx*

This proposal version was submitted by **Paolo LENISA** on **25/08/2020 06:35:27** Brussels Local Time. Issued by the Funding & Tenders Portal Submission System.

3 - Budget

Beneficiary Short Name	Direct costs														A. Total Direct Costs	B. Indirect Costs	C1. Subcontracting Costs	C2. Costs of in kind contributions not used on the beneficiary's premises	Total Estimated Eligible Costs	Requested EU contribution
	Personnel						Other direct costs							A.3 Internally invoiced goods and services						
	PI	Senior Staff	Postdocs	Students	Other Personnel costs	A.1. Total direct costs for personnel	Travel	Equipment - including major equipment	Other goods and services				A.2. Total Other Direct Costs							
									Consum-ables incl. fieldwork and animal costs	Publications (incl. Open Access fees) and dissemination	Other additional direct costs	Total other goods and services								
Gsi	267750	0	897600	0	0	1165350.00	15000	0	0	20000	8000	28000.00	43000.00	0	1208350.00	302087.50	0	0	1510437.50	1510437.50
Unife	0	0	288000	0	0	288000.00	20000	0	0	0	4000	4000.00	24000.00	0	312000.00	78000.00	0	0	390000.00	390000.00
Cern	0	108000	342000	0	0	450000.00	20000	0	0	0	4000	4000.00	24000.00	0	474000.00	118500.00	0	0	592500.00	592500.00
Total	267750	108000	1527600	0	0	1903350.00	55000	0	0	20000	16000	36000.00	91000.00	0	1994350.00	498587.50	0	0	2492937.50	2492937.50

Section C. Resources (Maximum 8000 characters allowed)

PI position and Host Institution

I have acquired profound experience in conceiving, realizing and managing experiments, exploiting polarization technologies in high-energy, nuclear and fundamental physics for more than 25 years. Should the P-EDM project be successful, I will modify my current professorship status at the University of Ferrara from a full-position to a part-time position for the entire duration of the project. This will allow me to spend 50% of my working time at IKP-GSI in order to successfully lead the P-EDM team and all the project related activities.

The host institution, IKP-GSI of Forschungszentrum Jülich (FZJ), is the ideal place for the realization of the P-EDM project due to the excellent research environment and long standing expertise in the operation of the polarized beams and targets. IKP, currently an institute of FZJ, will be part of the GSI Helmholtz Center starting January 1, 2021, while the Cooler-Synchrotron COSY will remain a property of FZJ. COSY provides high quality polarized proton beams in the required energy range. Since the beginning of 2015, the research focus of IKP-GSI has changed from hadron physics towards precision experiment. The staff of IKP-GSI has 20 years of experience in the operation of polarized beams and polarimeters. According to the present planning, the ring will be operational until 2024, allowing to complete the measurements planned for the P-EDM project.

Team

The P-EDM project requires an experienced and highly committed team, due to the extremely ambitious objectives, both from the point of view of the physics concepts and their technical complexity. The realization of the project is possible due to the commitment and combined effort of scientists of the P-EDM partner institutions (beneficiaries), members of the COSY accelerator crew and experts of the JEDI and CPEDM collaborations and further participating institutions (MPI Heidelberg, RWTH Aachen). Among the identified partners, CERN represents the world leading laboratory in accelerator design and related technological development while UNIFE has more than 20 years of experience in experiments exploiting polarization technology.

As most of the experimental setup is already available, the requested resources focus on installing the team required for the realization of the experiments, measurements and subsequent data analysis, including the development of the proper theoretical framework. In addition, a substantial fraction of resources is needed for the R&D projects. The foreseen activities both on the experimental and theoretical sectors are an ideal field for the education and development of students and young researchers, e.g. at the PostDoc level – no other facility worldwide offers the requested experimental setup and a crew with comparable experience.

Besides for the PI, personnel costs are for PostDoc positions, while additional PhD positions for P-EDM will be provided by the involved institutions. In detail, we request resources for seven PostDoc researchers (see Table 2 above). For the tasks demanding a significant degree of continuity for the various developments to be conceived, implemented and documented, a minimal of 3-year contracts (including a possible extension) is foreseen with the aim of attracting the best candidates. The requested experience for the positions are clarified in the corresponding WP descriptions. For evaluating the budget, the following nominal salaries for the different institutions have been adopted:
- GSI/IKP - PI: 30 months @ 8.9 k€/month - Postdocs: 132 months @ 6.8 k€/month
- UNIFE - Postdocs: 72 months @ 4.0 k€/month
- CERN - Staff (for postdoc supervision): 6 months @ 16 k€/month - 36 months Postdoc @ 9.5 k€/month

In addition to the singled-out scientists and engineers of the JEDI/CPEDM collaboration (V. Carassiti, R. Gebel, I. Keshelashvili, A. Lehrach, A. Nass, J. Pretz, H. Soltner, E. Stephenson, G. Tagliente, R. Talman and A. Wirzba), a number of experts has been identified, which are crucial for the successful implementation of P-EDM:
- M. Grieser (MPI Heidelberg): responsible for the design and construction of the pure electrostatic and cryogenic storage ring CSR at MPI Heidelberg
- J. Borburgh (CERN): huge experience in the construction of accelerator optics elements; already involved the design of the electrostatic bends, quadrupoles, as well as injection elements of the storage ring
- M. Bendig (RWTH Aachen): Chief engineer of the chair of High Voltage Equipment and Technology of the RWTH Aachen with high expertise in the field of high voltage engineering and vacuum insulation technology.

Publications & Dissemination

The P-EDM dissemination and communication strategy consist of different lines:

- Publication of original results in peer-reviewed journals of the highest quality. In our field, these are: Phys. Rev. Lett., Phys. Rev. Accelerators and Beams, Phys. Rev. C and D, Journal of High Energy Physics, Nuclear Physics A and B, Physics Letters B, European Physical Journal A and C, Journal of Physics G, and Nuclear Instruments and Methods A. Publications in more general journals like Nature or Science will be considered for results of very high impact. In order to publish all papers in Open Access, 10k€ is requested for the corresponding fees. In addition, all articles will also be submitted to the arXiv.org repository, where they will be openly available – an option allowed by all journals in the field.
- Presentations (talks, contributions) at the most relevant conferences: SPIN (for the period 2021-24, I will be Chairman of the International Spin-Physics Committee), DISCRETE, PSTP, MENU, MESON, SSP, and STORI. In the past, the PI and other members of the team have been invited frequently as plenary speakers in most of the mentioned conferences and many others.
- A final workshop (10 k€) is foreseen in the framework of the project. The workshop, devoted to both the physics perspectives of EDMs and their technological implications, will be the place where to wrap-up all the results achieved during the five years of the project.
- Presentations for general public and for secondary school students explaining how the present understanding of physics allows the researchers to find a connection among the different scales of the Universe aiming at solving the macroscopic mystery of the matter-antimatter asymmetry by investigating the microscopic scale of the particle dynamics in the proton. All members of the team have experience on talks in schools and in public places, on interviews and invited articles in newspapers. Besides being chair for the orientation and outreach committee for the University of Ferrara I am also involved in the outreach program of INFN at national level.
- A web-site will be set up for the P-EDM project.

Travel

p-EDM team members will have to travel to the three beneficiary sites, in particular to COSY at IKP of FZJ for experiments. In spite of the nowadays very useful video meetings, frequent face-to-face coordination meetings will also be needed. Support of trips to relevant conferences and workshop will be required, especially for the young researchers of the project.

Other

The total audit costs amount to 16k€.

Remaining characters 737

4 - Ethics

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		**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		**Page**
Does your research involve animals?	○Yes ◉No	
6. THIRD COUNTRIES		**Page**
In case non-EU countries are involved, do the research related activities undertaken in these countries raise potential ethics issues?	○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.)?	○Yes ◉No	
Do you plan to import any material - including personal data - from non-EU countries into the EU?	○Yes ◉No	
Do you plan to export any material - including personal data - from the EU to non-EU countries?	○Yes ◉No	
In case your research involves low and/or lower middle income countries, are any benefits-sharing actions planned?	○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		Page
Does your research involve the use of elements that may cause harm to the environment, to animals or plants?	○ 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?	○ Yes ◉ No	
8. DUAL USE		**Page**
Does your research involve dual-use items in the sense of Regulation 428/2009, or other items for which an authorisation is required?	○ Yes ◉ No	
9. EXCLUSIVE FOCUS ON CIVIL APPLICATIONS		**Page**
Could your research raise concerns regarding the exclusive focus on civil applications?	○ Yes ◉ No	
10. MISUSE		**Page**
Does your research have the potential for misuse of research results?	○ Yes ◉ No	
11. 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

Please indicate your percentage of working time in an EU Member State or Associated Country over the period of the grant: Please note that you are expected to spend a minimum of 50% of your total working time in an EU Member State or Associated Country.	100
Please indicate the % of working time the PI dedicates to the project over the period of the grant. Please note that the PI is expected to dedicate a minimum of working time to the project (30% for AdG, 40% for CoG and 50% for StG). The personnel cost for the PI provided in section “3-Budget” cannot be higher than the percentage indicated here. This information will be provided to the experts at Step 2 together with the section “3-Budget”.	50
I acknowledge that I am aware of the eligibility requirements for applying for this ERC call as specified in the ERC Annual Work Programme, 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, in whatever form and medium, 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? This consent is entirely voluntary and refusal to give it will in no way affect the evaluation of your proposal.	◉ 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? This consent is entirely voluntary and refusal to give it will in no way affect the evaluation of your proposal.	◉ Yes ○ No
The European Research Council Executive Agency (ERCEA) occasionally contacts Principal Investigators of funded proposals for various purposes such as communication campaigns, pitching events, presentation of their project's evolution or outcomes to the public, invitations to represent the ERC in national and international forums, studies etc. Should your proposal be funded, do you consent to the ERCEA staff contacting you for such purposes?	◉ Yes ○ No
For purposes related to monitoring, study and evaluating implementation of ERC actions, the ERC may need that submitted proposals and their respective evaluation data be processed by external parties. Any processing will be conducted in compliance with the requirements of Regulation (EU) 2018/1725.	
Have you previously submitted a proposal to the ERC? If known, please specify your most recent ERC application details.	◉ Yes ○ No
Proposal number 786997	

Other details	ERC-AdG "Time Invariance Violating Interactions"

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.

First Name	Yannis
Last Name	Semertzidis
Institution	Institute for Basic Science
Town	Daejeon
Country	Korea (Republic of)
Webpage	https://www.ibs.re.kr/eng.do

First Name	Mei
Last Name	Bai
Institution	GSI - Helmoltzzentrum für Schwerionenforschung GmbH
Town	Darmstadt
Country	Germany
Webpage	https://www.gsi.de/en/start/news.htm

Extended Open Research Data Pilot in Horizon 2020

If selected, all applicants will by default participate in the Pilot on Open Research Data in Horizon 2020[1] , which aims to improve and maximise access to and re-use of research data generated by actions.

However, participation in the Pilot is flexible in the sense that it does not mean that all research data needs to be open. After the action has started, participants will formulate a Data Management Plan (DMP), which should address the relevant aspects of making data FAIR - findable, accessible, interoperable and re-usable, including what data the project will generate, whether and how it will be made accessible for verification and re-use, and how it will be curated and preserved. Through this DMP projects can define certain datasets to remain closed according to the principle "as open as possible, as closed as necessary". A Data Management Plan does **not** have to be submitted at the proposal stage.

Furthermore, applicants also have the possibility to opt out of this Pilot completely at any stage (before or after the grant signature), thereby freeing themselves retroactively from the associated obligations.

Please note that participation in this Pilot does not constitute part of the evaluation process. Proposals will not be penalised for opting out.

We wish to opt out of the Pilot on Open Research Data in Horizon 2020.	○ Yes	◉ No

[1] According to article 43.2 of Regulation (EU) No 1290/2013 of the European Parliament and of the Council, of 11 December 2013, laying down the rules for participation and dissemination in "Horizon 2020 - the Framework Programme for Research and Innovation (2014-2020)" and repealing Regulation (EC) No 1906/2006.

ERC Advanced Grant 2020
Research proposal [Part B1]

Pathfinder for a Charged-Particle EDM Storage Ring

(P-EDM)

Cover Page:

- Name of the Principal Investigator (PI): Prof. Dr. Paolo Lenisa
- Name of the PI's host institution for the project: GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt (IKP, currently Forschungszentrum Jülich, will be part of GSI Darmstadt from January 1, 2021 on (IKP-GSI))
- Proposal duration in months: 60

Electric Dipole Moments (EDM) of fundamental particles are one of most promising candidates for studying physics beyond the Standard Model of Particle Physics (SM), because they break both parity (P) and time-reversal (T) invariance, which indicates charge-parity (CP) violation. This type of violation beyond the electroweak contributions is one of the prerequisites for understanding the apparent matter-antimatter asymmetry in our Universe, one of the great puzzles of contemporary physics. While the experimental sensitivity has been improved over the past decades, no permanent EDM has been found up to now.
A new experimental approach is to search for EDMs of charged particles, i.p. **protons**, in precision electrostatic storage rings, which enable one to push the EDM limits by at least two orders of magnitude. Experimental challenges require a stepwise approach, going from research, development and exploratory measurements at a magnetic storage ring (COSY, Jülich) to design and procurement of an electrostatic prototype ring (E_k= 40 MeV) and the final ring, running at the magic energy (230 MeV) with clockwise and counter-clockwise beams. The inevitable intermediate step is the pathfinder project ***P-EDM***, in which we will: i) develop the key components (deflectors and polarimeter), ii) design the lattice of the prototype ring, and iii) perform a proof-of-principle proton EDM measurement at COSY. ***P-EDM*** will be executed under my leadership with an experienced team at IKP (Jülich) and with valuable contributions from CERN, Ferrara University, MPI for Nuclear Physics in Heidelberg, and RWTH Aachen, building on the ground breaking work of *srEDM* for deuterons at COSY.
The ultimate ***P-EDM*** goal is to pave the way for a precision storage-ring to search for a static proton EDM with unprecedented sensitivity and to exploit the full potential of oscillating EDMs induced by axions or axion-like particles (ALPs), thus exploring yet unknown parameter space in the search for Dark Matter.

Section a: Extended Synopsis of the scientific proposal

1. Introduction: Motivation and Objectives

The Standard Model (SM) of Elementary Particle Physics (EPP), comprising the strong and electroweak interactions, has proven to provide an accurate description of the vast majority of experimental findings in subatomic physics. Nevertheless, the SM fails to explain important observations, including the non-zero but very small neutrino mass, the baryon asymmetry of our Universe (BAU), and cosmological Dark Matter (DM). Unfortunately, the Standard Model fails to explain the smallness or even the non-existence of charge-parity (CP-) violation in the strong interaction, parameterized by the tiny experimental upper limit for the corresponding parameter of the QCD (Quantum-Chromodynamics) Lagrangian. This observation supports the need for new physics beyond the SM (BSM) to answer these big unsolved questions.

My ERC project *Pathfinder for a Charged-Particle EDM Storage Ring* (***P-EDM***) intends to approach two of these problems:

- Why did matter win over antimatter during the evolution of the Universe?
- Which (probably non-SM) particles is Dark Matter made of?

In the long-term, the experiments will search for permanent and oscillating electric dipole moments (EDM) of charged polarized particles, including the proton, in a new class of precision storage rings with unprecedented sensitivity. Finding a finite permanent proton EDM would be a major discovery, since the accurate expectations of the SM are not measurable with current state-of-the-art techniques [1]. Oscillating EDMs, induced by an axion- or axion-like particle (ALP), are well-motivated candidates for DM [2,3,4]. These types of measurements are already possible at magnetic storage rings like COSY and will extend and complement the ongoing searches towards very small axion/ALP masses.

Due to the expected smallness of static and oscillating EDM effects – the experimental limit for the neutron EDM is currently at about 10^{-26} e.cm – the planned precision measurements with storage rings constitute remarkable technological and metrological challenges, which can only be tackled in a stepwise approach and with the correspondingly developed expertise. ***P-EDM*** is a pathfinder project to:

- Develop key components and design the storage ring lattice of a prototype ring.
- Perform proof-of-principle experiments for proton EDM measurements and axion/ALP DM searches at COSY.

Achieving these objectives will pave the way for the final precision storage ring that reaches out towards a sensitivity limit of 10^{-29} e.cm [5].

This science case and the related strategy has been explicitly mentioned in the recent update of European Strategy for Particle Physics (ESPP) (see *c)* of the *Additional Supportive Information* below).

2. Science Case

Discrete symmetries – parity (P), charge conjugation (C) and time reversal (T) – play an outstanding role in particle physics due to the connection of symmetries and conservation laws that originate from the Noether theorem. Notwithstanding the importance of conserved symmetries, EPP scientists are eager to discover and understand the violation of symmetries ("breaking") in order to gain deeper insight into the functioning of Nature. They were successful in connection with P- and C-symmetry violation as well as its combination CP in electroweak interactions (implying also T-violation with the asserted CPT theorem/conservation).

CP-violation (CPV) provides a reason for the difference between matter and antimatter and is one of the required prerequisites formulated by Andrei Sakharov [6] to explain our BAU. The size of CP violation experimentally found up to now falls short of explaining the asymmetry, and thus there is a quest to search for and find new sources of CPV. Electric dipole moments of fundamental particles, including leptons (electron, muon, tau) and hadrons (proton, neutron), violate T- and CP-symmetry and are a generally accepted and widely studied search area for additional CPV. No such EDMs have yet been observed despite the experimental limits for electron (via indirect measurements using molecules) and neutron being pushed to exceedingly small numbers [7]. For the proton, only indirect limits exist, similar to those for the neutron. The ultimate aim is to perform direct proton EDM measurements and push the sensitivity limit by up to three orders of magnitude. As indicated in **Fig. 1**, this limit will be competitive with the indirect electron EDM limit. However, the gap to the SM prediction is only about three (for the proton) instead of almost 10 orders of magnitude (for the electron).

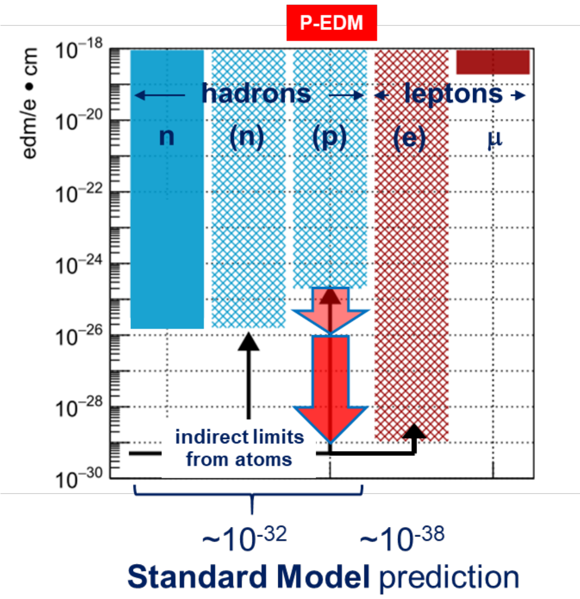


Fig. 1: Summary of experimental upper limits for particle EDMs (full boxes: direct measurements (n, μ), hatched boxes: indirect determinations (n, p, e) using atoms). The approximate predictions of the Standard Model are given below in the same units (e.cm). The charged-particle storage-ring method will achieve 10^{-26} e.cm with the prototype ring and 10^{-29} e.cm with the final ring (see big arrows). ***P-EDM*** *is the essential preparatory step.*

Recently, an additional scientific issue has become apparent that can be studied with the charged-particle storage-ring method: the search for axions or axion-like particles (ALPs) via oscillating EDMs, which are very well motivated candidates for Dark Matter (DM) [2,3,4].
The attractive features of this approach are:

- Search for the (largely unconstrained) ALP mass by changing the stored particle momentum.
- Resonant method, which already can be performed in a magnetic storage ring like COSY.
- Storage of multiple particle bunches with different polarization orientations to reduce systematic errors.

In addition to its primary goals, ***P-EDM*** will develop and exploit this method with measurements at COSY in order to provide a precision DM-search technique for the prototype and the final ring, extending and complementing the multitude of ongoing researches into untried parameter regions.

3. Technological Realization

The experimental method to search for electric dipole moments in storage rings (srEDM) is conceptually very simple. The EDM vector ($\vec{d}$), which is oriented along the spin vector of the particle, is detected via its interaction with an electric field E. Since charged particles are accelerated in electric fields, they need to be confined in traps – for the energies involved (from a few tens to hundreds of MeV) the trap needs to be a macroscopic storage ring, in which a beam of particles circulates (see **Fig. 2**). If the polarized stored beam with its spin directions originally oriented in the ring plane is exposed to a radial electric field, there will be a torque $\vec{d} \times \vec{E}$, which slowly rotates the spins out of the plane, resulting in a build-up of a vertical polarization component. The polarization build-up due to a non-zero EDM is observed in a detector monitoring the beam polarization (polarimeter).
In spite of its principle simplicity, the practical implementation of the storage-ring EDM method faces highly significant challenges due to:

- the fact that angular rotation rate is only on the order of nrad/sec, making the effect very small and therefore hard to measure,
- the existence of much larger of physics background (e.g. due to the magnetic dipole moment of the particle), and
- systematic effects, caused, e.g., by electric/magnetic field inhomogeneities and insufficient shielding of external fields.

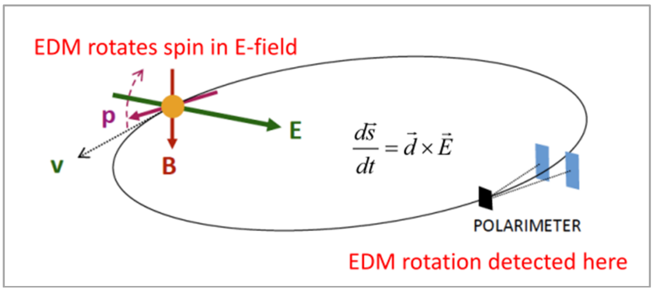


Fig .2: Principle of the charged-particle srEDM method. A beam of particles (polarized in the plane of the ring) is confined in a storage ring by electromagnetic fields. A radial E-field induces a torque $\vec{d} \times \vec{E}$ *on the spin (always oriented along the electric dipole vector) of the individual particles, resulting in a very slow build-up of a vertical polarization component, which is detected in a polarimeter.*

In order to mitigate systematic effects and to push the sensitivity limit of the srEDM method as far as possible, the following measures will be taken:

- Build a storage ring with purely electric deflectors (all-electric ring; only possible for protons).
- Operate the storage ring with clockwise and counter clockwise beams simultaneously.
- Operate the final storage ring at the magic momentum (700.7 MeV/c for protons), for which the spin always points along the momentum direction.

Building on the experience gained from measurements at COSY (magnetic bending) and the prototype ring (non-magic momentum), the goal is to reach a sensitivity of 10^{-29} e.cm for the proton EDM.

The overall strategy towards the charged-particle EDM storage-ring facility is outlined schematically in **Table 1**:

*Table 1: Overview of the stepwise approach for the charged-particle EDM search at storage-rings: from the ongoing proof-of-capability to the **P-EDM** project, which will provide a proof of principle, and the outlook towards the envisioned precision measurements at a newly built storage ring.*

1 Existing Storage Ring	2 Pathfinder Project	3 Prototype/Final Storage Ring
Proof-of-Capability (dEDM)	**Proof-of-Principle (pEDM)**	Precision Measurement (pEDM)

- Magnetic Storage Ring (COSY)
- Technology Development
- Use of RF Wien Filter
- First direct Deuteron EDM Experiment at COSY
	- Key Component Development
	- Lattice Design Prototype Ring
	- First direct Proton EDM Experiment at COSY (RF-WF)
	- Dark Matter Axion Studies
		- All-electric Storage Ring
		  - Prototype (E_k ~ 40 MeV)
		  - Final Ring (E_k ~ 230 MeV)
		- CW-CCW Beams
		- pEDM Measurements

JEDI Collaboration *„srEDM“* ERC Grant 2016 → 2021	CPEDM Collaboration pEDM at COSY until 2023/24 ***P-EDM* (this application)**	Construction/operation of Prototype Design/procurement of Final Ring > 2027

It comprises three major steps:

- A proof-of-capability, using the existing COSY storage ring. This is the ongoing activity of the international JEDI (Jülich Electric Dipole moment Investigations) collaboration, which has achieved major progress (see [8,9,10,11]), in particular it performed a first direct measurement of the deuteron EDM, exploiting a dedicated so called RF (radio-frequency) Wien filter [12,13,14,15]. The data are currently being analyzed.
- A proof-of-principle, including a first direct proton EDM measurement at COSY, which is part of the *pathfinder project*, which constitutes the ***P-EDM*** application. In order to do this, several preliminary studies have to be performed at COSY, most importantly the optimization of the so-called Spin Coherence Time (SCT) – the individual EDM observation interval – for protons. The design of the prototype storage ring (all-electric with the possibility of simultaneous clockwise and counter clockwise beams, but operating at a non-magic momentum) is seen as an inevitable intermediate step and will be undertaken. It is also

essential that key components (electrostatic deflectors, sampling polarimeter) for both the prototype and the final ring will be developed, built, and tested.

- After procurement of the prototype ring, the era of precision EDM experiments of charged particles (protons, after modifications also deuteron and ^{3}He) will start – and culminate in striving for EDM sensitivity limits of 10^{-29} e.cm.

Step 1 will be finalized in 2021 with the end of the ERC AdG project "srEDM". The ***P-EDM*** project, starting in the second half of 2021, will exploit COSY up to the end of 2023/24 – its currently foreseen termination of operations is end of 2024 – and will continue until 2026. After successful completion of ***P-EDM*** with its three pillars (lattice design, key-components and measurements), the construction of precision storage rings can start.

The scientific and technological work packages of ***P-EDM*** are given in **Table 2**:

*Table 2: Overview of the work packages of **P-EDM** with responsible institutions (beneficiaries) and cooperation partners. The intended amount of man-months for each WP and its distribution to the beneficiaries as well as the collaborations involved in the work packages are also given.*

Work-Packages	WP1: Prototype Design / Reports	WP2: Key Components	WP3: Measurements
Deliverables	- Lattice Design Storage Ring - EDM Sensitivity Reach - New Physics Possibilities	- Electrostatic Deflectors - Polarimeter	- First direct pEDM with RF Wien Filter and - Axion/ALP Search at COSY
Request for ***P-EDM*** (Man-months)	CERN (36), IKP-GSI (24), UNIFE (12)	IKP-GSI (60), UNIFE (24)	UNIFE (36), IKP-GSI (48)
Responsibility	**CERN**	**IKP Jülich (IKP-GSI)**	**UNIFE**
Cooperation Partners	IKP-GSI, RWTH, UNIFE	CERN, MPI, RWTH, UNIFE	IKP-GSI
Collaborations	JEDI, CPEDM	JEDI, CPEDM	JEDI

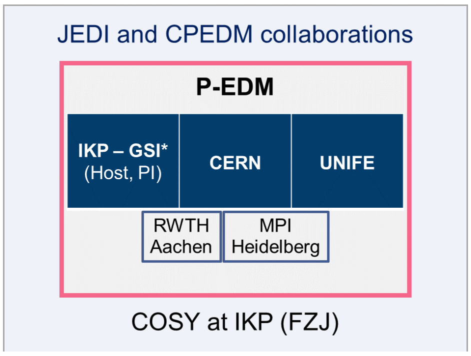
They follow from (i) the experience obtained over the past years by the international JEDI collaboration, working at COSY, in particular within the "srEDM" project, and (ii) the requirements as currently known or projected for the charged-particle EDM storage rings. As emphasized before, the inevitable step towards a final precision storage ring for highest sensitivity (10^{-29} e.cm) – a prototype ring – must be conceived, built and operated. In order to achieve this milestone, its lattice needs to be developed (WP1). A further crucial cornerstone is to plan and fabricate key components such as (i) electrostatic deflectors – the challenge is to obtain highest E-fields and stable operation – and (ii) an innovative beam-scanning polarimeter for determining the EDM observable (WP2). In order to also gain additional experience in the measurement techniques, a proton EDM experiment with an RF Wien filter (as in the deuteron case within "srEDM") and a study of an axion/ALP-search at COSY will be conducted (WP3).
It is also essential to establish the sensitivity limits for both rings with robust simulations. In addition to permanent and oscillating EDMs, new physics opportunities like, e.g., the establishment of the general relativity contribution to the spin rotation as a "standard candle" will be pursued.
Supplementary to the work packages mentioned in **Table 2**, the following activities for the ***P-EDM*** project are foreseen, whose execution and attainment of the objectives is the task of the PI:

- Management of all three WPs.
- Supervision of the postdocs.
- Outreach and dissemination (including provision of a data repository).

4. Boundary Conditions

The cooler synchrotron COSY at Forschungszentrum Jülich (FZJ, Germany) stores polarized proton and deuteron beams of the required energy – it is the only storage ring worldwide, where EDM preparatory tests and measurements currently can be performed. COSY has been used over the past 10 years for R&D towards a storage ring EDM measurement by the *Jülich Electric Dipole moment Investigations* (JEDI) collaboration: during this time, decisive technological and metrological progress, and a much deeper understanding of the challenges of the method have been achieved [5,8-12,14]. An ERC AdG (*srEDM*, #694340) with focus on the (simpler) deuteron EDM studies and a first measurement has been critical. The work packages of ***P-EDM*** will be distributed among the beneficiaries CERN (ring design), Ferrara University (UNIFE) (measurements) and the Institute for Nuclear Physics (IKP) (key components), further fostered by additional partners (MPI Heidelberg (electrostatic storage rings), RWTH Aachen University (physics and engineering departments)) and the cooperation within the two existing collaborations JEDI and CPEDM (Charged Particle EDM). **Table 3** indicates how – under my coordination and leadership – this all fits together:

Table 3: Overview of the P-EDM project beneficiaries, partners and collaborations (indicates that IKP will be affiliated with the GSI Helmholtz Center für Schwerionenforschung (GSI) from 2021).*



With the start of the diversity project at CERN (PBC, Physics Beyond Colliders), the EDM project has been included in the agenda as one of the potential future directions. Subsequently, the CPEDM collaboration between JEDI and CERN has been formed to study the science case, feasibility and strategy. As the major outcome of the common work a feasibility study, which summarizes the current knowledge of storage-ring EDM searches, has been produced [5].

As indicated before, there will be an organizational transition of the Institute for Nuclear Physics (IKP), that runs COSY, from one Helmholtz Center (FZJ) to another (GSI, Darmstadt). The operation of COSY is secured until the end of 2024. The work packages of ***P-EDM*** requiring a storage ring – including a first pEDM measurement and axion/ALP studies – will be worked off during this period-of-time. This is outlined in the general time line for ***P-EDM*** in **Table 4**:

Table 4: Simplified Gantt-chart for P-EDM – a more detailed version is provided in part B2. For WP-3 the time in 2024 is considered a contingency to mitigate the risk in case of delays in measurements.

P-EDM WP-s	2021	2022	2023	2024	2025	2026
	Start of P-EDM			End of 2024: COSY stops		End of P-EDM
WP-1: Prototype Design / Reports		Lattice of the Prototype Ring – Sensitivity for pEDM – Additional Science				
WP-2: Key Components		Prototype Electrostatic Deflector – Sampling Polarimeter				
WP-3: Measurements		pEDM-, Axion/ALP Expts. at COSY		Data Analysis, Publication		

5. Summary

A unique time window is opening for the search for (static and oscillating) Electric Dipole Moments of charged particles in precision storage rings. It is based on the huge experience gained by researchers working in this field for the past 10 years, the availability of the Cooler Storage ring (COSY) at Forschungszentrum Jülich (Germany), and the support by the community at large for this exciting science. The pathfinder project ***P-EDM*** with its beneficiaries and partners will exploit this opportunity to prepare and conduct decisive steps towards a precision measurement aiming at an unprecedented sensitivity of 10^{-29} e.cm with the possibility of a major discovery.

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Additional Supportive Information

CERN Physics Beyond Colliders (PBC):
https://arxiv.org/pdf/1901.09966.pdf
See also: https://www.nature.com/articles/s41567-020-0838-4?proof=trueNov
European Strategy for Particle Physics Update 2020 – Briefing Book:
https://cds.cern.ch/record/2691414/files/Briefing_Book_Final.pdf
European Strategy for Particle Physics Update 2020 – Deliberation Document:
https://home.cern/sites/home.web.cern.ch/files/2020 06/2020%20Deliberation%20Document%20European%20Strategy.pdf

PERSONAL INFORMATIONS

Family name, First name: Prof. Dr. Lenisa, Paolo
Researcher unique identifier(s): orcid.org/0000-0003-3509-1240
Date of birth: June 17, 1965
Nationality: Italian

EDUCATION

2014 Italian National Scientific Habilitation as *Associated Professor* and *Full Professor* in:
- Experimental Physics of Fundamental Interactions
- Nuclear and Sub-nuclear Physics

1997 PhD in Physics (excellent). Title of the thesis *"Development of a novel laser system for laser cooling of ions in a storage ring"* University of Ferrara, Ferrara, Italy

1992 Master Degree in Nuclear Engineering (summa cum laude) Politecnico di Milano, MI(IT)

CURRENT POSITION

Since 2017 Full professor in Nuclear and Subnuclear Physics
Dipartimento di Fisica e Scienze della Terra, Università di Ferrara, Ferrara (IT)

PREVIOUS POSITIONS

2014 – 2017 Associate professor in Experimental Physics of Fundamental Interactions
Dipartimento di Fisica e Scienze della Terra, Università di Ferrara, Ferrara (IT)

1998 – 2014 Researcher Staff- Physics Department, University of Ferrara, Ferrara (IT)

1997 – 1998 Guest Scientist - Max-Planck Institut für Kernphysik, Heidelberg (D)

SUPERVISION OF GRADUATE STUDENTS AND POSTDOCTORAL FELLOWS

Since 2000 15 Postdocs, 11 PhDs, 20 Diploma and Master Students
Department of Physics and Earth Science, University of Ferrara, Ferrara (IT)

TEACHING ACTIVITIES

Since 2017 Course: *Subatomic Physics*, Univ. of Ferrara (IT)

Since 2014 Course: *General Physics (Mechanics),* Univ. of Ferrara (IT)

2015 Lecture: *The history of motion and its impact on the evolution of the scientific thought –* XV Edizione Incontri di Fisica, LNF Frascati, Italy

2014 Lecture: *Silicon Detectors in Particle Physics,* 6th Georgian-German School in Basic Science, Tbilisi, Georgia

2012 – 2015 Course: *Epistemology and History of Physics*, University of Ferrara, Ferrara, Italy

2000 – 2014 Course: *General Physics I (Mechanics)*, University of Ferrara, Ferrara, (IT)

2005 Lectures: *Polarization in Storage Rings,* PhD School on Detectors, Villa Gualino (TO), (IT)

1999 – 2000 Course: *General Physics II (Electromagnetism)*, University of Ferrara, Ferrara (IT)

INSTITUTIONAL RESPONSIBILITIES

2019 Director of the Interdisciplinary Training Course for High-School Teachers *"Science for Environment and Sustainable Development",* University of Ferrara (IT)

Since 2017 Coordinator of the Physics Course (Dean of the Physics Faculty) Univ. Ferrara (IT)

Since 2017 Coordinator of the educational programme for the High-School teachers in Physics University of Ferrara, (IT)

2015 Co-chair of the International PhD School in Physics Niccolò Cabeo: "*Infinities"*, University of Ferrara (IT)

2014 Co-chair of the International PhD School in Physics Niccolò Cabeo: "*Vacuum and Broken Symmetries: from the Quantum to the Cosmos"*, University of Ferrara (IT)

2013 Co-chair of the International PhD School in Physics Niccolò Cabeo: *"Physics beyond the Standard Model: the Precision Frontier"*, University of Ferrara (IT)

Since 2013 Coordinator for the student orientation program in Physics, University of Ferrara (IT)

Since 2005 Member of the PhD Teachers College in Physics, University of Ferrara (IT)

ORGANIZATION OF SCIENTIFIC MEETINGS (Selection)

2018 Chair: *"SPIN2018"* - 23rd International Spin-Physics Symposium, 250 participants, Ferrara (IT)

2015 Co-chair: *"Search for the Electron EDM in an Electrostatic Storage Ring "* - International Workshop - 50 participants, Mainz (D)

2013 Chair: "*Nuclear Fusion with Polarised Nucleons"* – Intern. Workshop, 20 participants, ECT* TN(IT)
2009 Chair: "*PST2009"* - XIII International Workshop on Pol. Sources and Targets, 100 participants, Ferrara (IT)
2008 Chair: *"Transversity 2008"* - 2nd International Workshop on Transverse Polarisation Phenomena in Hard Processes, 90 participants, Ferrara (IT)
2008 Co-chair: *"Polarised Antiprotons"* - International Workshop, 30 participants, Bad Honnef (D)

REVIEWING ACTIVITIES

From 2021 Elected Chair of the International Spin Physics Committee (ISPC)
Since 2017 Chair of the Graduation Commissions for Master and Bachelor Degrees in Physics, University of Ferrara (IT)
Since 2017 Member of the Physics and Earth Science Department Board -Univ. Ferrara (IT)
Since 2017 Chair of Steering Committee of the Course in Physics – Univ. Ferrara (IT)
Since 2017 Chair of the Review Team of the Course in Physics – Univ. Ferrara (IT)
2017 Evaluator, Italian Ministry of Research and Education (MIUR) project FARE (IT)
Since 2017 National responsible for the INFN-financed project JEDI
2016 Evaluator, Italian Ministry of Research and Education (MIUR) VQR-2011-14 (IT)
Since 2015 Member of the Editorial Board of "*ScienzaPerTutti"*, INFN-website for Physics Dissemination (IT) (http://scienzapertutti.lnf.infn.it)
Since 2012 Member of the International Spin Physics Committee (ISPC)
2012 - 2019 Member of the National Scientific Commission 3 (CSN3 - Nuclear Physics), INFN (IT)
2012 - 2019 Referent for Hadron Physics sector of INFN – National Scientific Commission 3
2005 - 2017 National responsible for the INFN-financed project PAX
Since 2005 Reviewer for Nuclear Instruments and Methods, European Physical Journal, Progress in Particle and Nuclear Physics, European Physics Letters

MEMBERSHIPS OF SCIENTIFIC SOCIETIES

Since 2015 Member "*Società Italiana di Storici della Fisica e dell'Astronomia (SISFA)"*, Italy
Since 2007 Member *"Società Italiana di Fisica (SIF)"*, Italy
Since 1998 Member "*Istituto Nazionale di Fisica Nucleare (INFN)*", Italy

PUBLICATIONS, PROPOSALS, PRESENTATIONS

- Co-author of more than 240 publications in refereed journals (h-index: 40, no. of citations: 6204)
- Presenter of 48 talks at international conferences and workshops (23 on invitation)
- Proponent of 13 Experiment proposals and Letters of Intent (9 as Spokesperson).

PARTICIPATION AND LEADERSHIP IN INTERNATIONAL COLLABORATIONS

HERMES at DESY Hamburg. Coordinator of the Internal Polarized Target for the period 2000-2005 (81 joint publications).
Collaborators: Prof. Dr. K. Rith and Prof. Dr. E. Steffens - Univ. Erlangen-Nürnberg (Germany), Prof. Dr. D. Ryckbosh - Univ. Gent (Belgium), Dr. E. Aschenauer - BNL (USA)

PAX at COSY Jülich, (& CERN/AD). Proponent and Co-spokesperson of the Collaboration since 2005 9 joint publications).
Collaborators: Prof. Dr. H. Ströher and Dr. F. Rathmann - FZ-Jülich (Germany), Prof. Dr. H.O. Meyer - Indiana University, Bloomington (USA), Prof. A. Kulikov - JINR, Dubna, (Russia), Prof. Dr. M. Anselmino - Univ. Torino, Torino (Italy)

OLYMPUS at DORIS Hamburg. Proponent and member of the executive board 2011-2015 (3 joint publications).
Collaborators: Prof. Dr. R. Milner – MIT (USA), Prof. Dr. F. Maas - Univ. Mainz, (Germany), Prof. Dr. R. Beck - Univ. Bonn (Germany)

JEDI at COSY Jülich. Proponent and Co-spokesperson of the Collaboration since 2017, Member of the executive board since 2012 (10 joint publications)
Collaborators: Prof. Dr. J. Pretz - RWTH Aachen University, Aachen (Germany), Prof. E. Stephenson – Indiana University (USA), Prof. Dr. Y. Semertzidis - Center for Axion and Precision Physics Research, Institute for Basic Science, Daejeon (Republic of Korea)

CLAS at JLAB Newport News, member of the Collaboration since 2014 (57 joint publications).

Appendix: All ongoing and submitted grants and funding of the PI (Funding ID)

On-going Grants

Project Title	*Funding source*	*Amount (Euros)*	*Period*	*Role of the PI*	*Relation to current ERC proposal*
"srEDM" Electric Dipole Moment Search using Storage Rings	ERC (Grant Number 694340)	628.000 out of 2.400.000	2016-2021	(Host Institute: FZJ PI: Hans Ströher) Lead Investigator Univ. Ferrara for: Polarimetry, Measurements	srEDM´s focus is on deuteron; ***P-EDM*** is the evolution of this grant to protons (and axion studies).
JEDI	INFN	500.000	2017-2021	Principal Investigator	The grant supports the EDM searches at COSY.
WP30-JRA20 "SPINFORFAIR" in STRONG2020	EU	300.000	2019-2023	Principal Investigator	None
WP20-JRA2 "FTE@LHC - Fixed Target Experiments at the LHC" in STRONG2020	EU	150.000	2019-2023	Lead Investigator Univ. Ferrara for: Polarized Target	None

Applications Pending

Project Title	*Funding source*	*Amount (Euros)*	*Period*	*Role of the PI*	*Relation to current ERC proposal*
____________					

B1. c: Ten years track-record

Most important scientific achievements:

1. Group leader of the installation and running of the longitudinally polarized deuterium and transversely polarized hydrogen targets in the HERMES experiment at HERA (DESY, Hamburg). The major results are: the first evidence of transverse effects in Deep Inelastic Scattering related to the "transversity" distribution function; the first evidence of "Sivers effect" related to the angular momentum of quarks; the first measurement of the s-quark helicity; the first measurement of the b_1 structure function.
2. Initiating as Co-spokesperson the PAX program for polarized antiprotons as possible upgrade option for the antiproton project at FAIR/HESR (Darmstadt). Main results are the development of the physics case and associated experimental setup to exploit double polarized proton-antiproton interactions in the hadron physics sector.
3. Leading as Co-spokesperson the spin-flip and spin-filtering experiments with protons at COSY. As 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. For this project, the ERC-AdG "POLPBAR" was awarded in 2010. The PI was Lead-investigator for the Univ. of Ferrara of the formed consortium. Aim of the project was the development of a viable mechanism for the production an intense polarized antiproton beam.
4. Proponent of the OLYMPUS experiment at DORIS (DESY, Hamburg). Leader of the design and construction of the internal storage cell. The main result is the measurement of the contribution of the two-photon exchange to the elastic electron-proton cross section at a beam energy of 2.10 GeV.
5. Initiating the JEDI project at COSY. Aim of the experiment is the search for Electric Dipole Moments (EDM) of charged particles in storage rings. The PI is presently Co-spokesperson of the collaboration. Major results so far are: the achievement of a 1000 s spin-coherence time for a stored deuteron beam; the most precise measurement of the spin-tune for a stored beam; the realization of a spin-feedback system to control the spin-direction of a polarized deuteron beam. For this project, the ERC-AdG "EDM" was awarded in 2016. The PI is Lead-investigator for the University of Ferrara of the formed consortium. The aim of project is the demonstration that storage rings and polarization technology are a viable tool for precision measurements and the first-ever measurement of the electric dipole moment of the deuteron.
6. Proponent and Lead-investigator for the University of Ferrara of the proposal SMOG2. The proposal, approved by CERN, foresees the implementation of a fixed target, exploiting the storage cell technology, upstream the LHCb detector in the LHC. Fixed-target pp and pA collisions at the TeV scale provide unique laboratories for the study of the nucleon's internal dynamics and investigation of the complex phenomena of the non-perturbative regime of QCD. The entire design and realization of the storage cell has been accomplished in Ferrara, under the supervision of the PI. The installation in the LHC was completed in August 2020.

10 representative publications:

1. P. Lenisa et al. (PAX), "*Low-energy spin physics experiments with polarized beams and targets at the COSY storage ring",* EPJ Tech. and Instrum. 6 (2019) 2; 0 citations. Role of PI: Co-spokesp. PAX Coll. – Corr. Author.
2. N. Hempelmann et al. (JEDI), "*Phase Locking the Spin precession in a Storage Ring",* Phys. Rev. Lett. **119** (2017) 014801; 25 citations. Role of PI: Co-spokesperson of the JEDI Collaboration.
4. A. Saleev et al. (JEDI), *"Spin tune mapping as a novel tool to probe the beam dynamics in a storage ring",* Phys. Rev. Acc. and Beams **20** (2017) 72801; 16 citations. Role of PI: Co-spokesperson of the JEDI Coll.
4. B.S. Henderson et al. (OLYMPUS), *"Hard two-photon contribution to elastic electron-proton scattering determined by the OLYMPYS Collaboration"*, Phys. Rev. Lett. **118** (2017) 092501; 37 citations.
5. G. Guidoboni et al. (JEDI), *"How to reach a thousand-second in-plane polarization lifetime with 0.97 GeV/c deuterons in a storage ring",* Phys. Rev. Lett. **107** (2016) 054801; 41 citations. Role of PI: Co-spokesperson of the proposal.
6. V. Anastassopoulos et al., "*A storage ring experiment to detect a proton electric dipole moment",* Rev. Sci. Inst. **87** (2016) 115116; 46 citations.
7. C. Weidemann et al. (PAX), *"Towards polarized antiprotons: machine developments for spin-filtering experiments",* Phys. Rev. ST-AB **18** (2015) 020101; 12 citations. Role of PI: Co-spokesperson of the PAX Collaboration
8. D. Eversmann et al. (JEDI), "*New method for a continuous determination of spin-tune in a storage ring and implications for precision experiments*", Phys. Rev. Lett. **115** (2015) 094801, 62 citations.
9. Z. Bagdazarian et al. (JEDI), "*Measuring the precession of a rapidly precessing deuteron beam*", Phys. Rev. ST-AB **17** (2014) 052803, 24 citations.

10. W. Augustiniak et al. (PAX), *"Polarisation of a stored beam by spin-filtering",* Phys. Lett. B **718** (2012) 64; 21 citations. Role of PI: Co-spokesperson of the PAX Collaboration, corresponding author.

Invited presentations at International Conferences/Schools (selection):

1. 15th Intern. Conference on Meson-Nucleon Physics and the Structure of the Nucleon (MENU2019), *"Search for electric dipole moments of charged particles in storage rings",* June 2-7, 2019, Pittsburg (USA)
2. 18th International Workshop on Polarized Sources, Targets and Polarimetry (PSTP2019), "*LHC-spin a polarized internal target for the LHC",* September 23-27, 2019, Knoxville TN (USA)
3. 18th International Workshop on Polarized Sources, Targets and Polarimetry (PSTP2019), "*Search for EDMs with polarized beams in Storage Rings",* September 23-27, 2019, Knoxville TN (USA)
4. 14th International Conference on Meson Production, Properties and Interactions (MESON 2016), *"Search for EDMs of Charged Particles in Storage Rings",* Krakow, Poland, June 02-07, 2016
5. 7th Caucasian German School and Workshop in Basics Science, *"Perspectives for a HERMES (PAX)-like Internal Gas Target in the LHC",* Tbilisi, Georgia, August-September 29-02, 2016
6. Workshop on Polarization Issues in High-Energy Linear Colliders, *"Performance of a HERMES-like Internal Gas Target in the LHC (and FCC)",* Rome, Italy, 16.04.2016
7. 13th Intern. Conf. on Meson-Nucleon Physics and the Structure of the Nucleon (MENU2013), *"Perspectives for Polarised Antiprotons",* Rome, Italy, September-October 30-04, 2013
8. 15th International Workshop on Polarized Sources, Targets and Polarimetry (PSTP 2011), *"The road to Polarized Antiprotons",* Saint Petersburg, Russia, September, 12-16, 2011
9. 10th International Conference on Low Energy Antiproton Physics (LEAP 2011), *"Perspectives for Polarized Antiprotons",* Vancouver, Canada, April-May, 27-01. 2011
10. 39th International Workshop on Gross Properties of Nuclei and Nuclear Excitations, *"Possible future experiments on Hadron Structure at FAIR",* Hirschegg Austria, January,16-22, 2011

Scientific guidance and management of competitive financed projects:

2016 - 2021	Lead-investigator for the University of Ferrara of the ERC-AdG "*srEDM"*
2019 - 2023	Principal Investigator of WP30-JRA12 "SPINforFAIR" of the project "STRONG2020" financed by EU
2019 - 2023	Lead-investigator for the University of Ferrara of WP20-JRA2 "FTE@LHC" "Fixed Target Experiments at the LHC for the project "STRONG2020" financed by EU
2012 - 2014	WP Lead-investigator Leader INFN of the JRA "*Polarised Antiprotons (PolAntiP)"* of the project Hadron Physics 3 (I3HP3) financed by the EU
2010 - 2016	Lead-investigator for the University of Ferrara of the ERC-AdG *"POLPBAR"*

Editor of research monographs:

2019	Co-editor, Proceedings of *"SPIN2018"*, University of Ferrara, Italy
2011	Co-editor, Proceedings of "*STORI2011"*, Laboratori Nazionali di Frascati, Italy

Contribution to the careers of excellent young researchers (selection):

- **Dr. Susanna Bertelli** (PhD and Postdoc under the supervision of the PI at UNIFE from 2010 to 2019) since 2019 is staff member and responsible for outreach and student orientation at INFN-LNF.
  - Award for the best communication at Section "Nuclear and Sub-nuclear Physics" at the XCVI Congress of the Italian Physical Society (SIF 2010) with the presentation of her PhD activity: *"Deuteron break-up reaction studies at the COSY ring"*, Bologna, Italy, 2010.
- **Dr. Greta Guidoboni** (PhD and Postdoc under the supervision of the PI at UNIFE from 2010 to 2016) is accelerator physicist at EBG MedAustron GmbH, Wien, Austria.
  - Award for the best communication at Section "Nuclear and Sub-nuclear Physics" at the XCVIII Congress of the Italian Physical Society (SIF 2012) with the presentation of her PhD activity: *"Measurement of spin-coherence time of a stored beam of polarized deuterons",* Naples, Italy, 2012
  - Award for the best PhD of the University of Ferrara 2013 for the thesis: *"Spin-coherence time studies for the storage ring EDM search"*
- **Dr. Christian Weidemann** (Postdoc under the supervision of the PI at UNIFE from 2012 to 2015): is staff member at FZ-Jülich, Germany.
- **Dr. Michelle Stancari** (Postdoc under the supervision of the PI at UNIFE, from 2003 to 2009) is a staff member and Group Leader/Scientist for the DUNE experiment at FNAL, Chicago (IL), USA.
- **Dr. D. Reggiani** (PhD and PostDoc under the supervision of the PI at UNIFE, from 2000 to 2005) is a staff member in the accelerator operation and development group, PSI, Zurich, Switzerland.

ERC Advanced Grant 2020
Part B2

Pathfinder for a Charged-Particle EDM Storage Ring (P-EDM)

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

1. Introduction

Fundamental science – through experimental research based on remarkable technological accomplishments on the one hand and by profound theoretical modelling otherwise – has achieved an amazing level of insight into Nature, as exemplified by the Standard Model (SM) of elementary particle physics. Essentially completed with the discovery of the Higgs-boson at CERN in 2012 and highly successful in describing a wealth of subatomic phenomena, the SM is nevertheless not the "final word" (i.e., the ultimate theory), since many mysteries about the Universe are still to be explored, such as, e.g.:

- The preponderance of matter over antimatter.
- The nature of Dark Matter.

A strategy to search for physics beyond the Standard Model (BSM) and then to explore it in detail has been outlined recently by the 2020 update of the European Strategy for Particle Physics (ESPP) [1]. It is suggested, firstly, that the next accelerator step of the so-called energy frontier be a Higgs-factory. Secondly, the precision frontier is emphasized, including in particular:

- Measurements of Electric Dipole Moments (EDM) of fundamental particles.
- Searches for axions and axion-like particles (ALPs) as Dark Matter candidates.

As illuminated below, these two aspects are intimately connected and can be investigated by measuring static and oscillating electric dipole moments of particles. For charged particles – in particular protons and deuterons and ^{3}He ions – such experiments require a new class of precision storage rings. The way towards construction of the necessary facilities and the subsequent exceedingly challenging measurements will be paved with the **P-EDM** project.

2. Science Case for Electric Dipole Moments (EDM) and Dark Matter (DM)

Symmetries, both continuous and discrete, are a cornerstone of modern physics: the discovery and elucidation of the breaking patterns of parity (P), charge-conjugation (C) and time-reversal (T) symmetries and combinations thereof such as CP have been crucial for the development of the Standard Model of particle physics. Ongoing and future experimental symmetry-violating tests will play an essential role in identifying new physics beyond the SM (BSM) and developing the corresponding theoretical model.

Of the discrete symmetries, time-reversal plays a special role: notwithstanding the "arrow of time" that everyone experiences incessantly, T-symmetry has been a feature of the most basic laws of physics throughout most of its history: Newtonian celestial mechanics, Maxwell's electrodynamics and its quantum descendants, and Einstein's general relativity, for example, all respect it. However, in 1964, CP-violation was discovered in K-decays, which implies T-violation if the combined CPT-symmetry is conserved (there are good theoretical reasons to assume that this is the case (CPT theorem)). In the SM, as it is understood today, approximate microscopic T-symmetry is a profound, yet "accidental" consequence of other, more primary principles including quantum mechanics, special relativity, and gauge symmetry, together with the specific particle content of the SM. In fact, as Kobayashi and Maskawa noticed, T-symmetry would be exact (in the absence of the θ_{QCD} term) if there were only two families of fermions. The third family, anticipated by Kobayashi and Maskawa, was discovered experimentally a few years later. The theory of T- (in practice, mainly CP-) violation they proposed has been very fruitful, and it has been checked and confirmed in a wide variety of experiments [2].

CP-(T-) violation (CPV) is required to understand the apparent matter-antimatter asymmetry in our Universe: this has been pointed out by Andrei Sakharov as one of his three conditions for generating a baryon asymmetry [3]: (i) baryon number violation, (ii) C- and CP-violation and (iii) departure from thermal equilibrium (or violation of CPT symmetry). However, the amount of CPV found in the electroweak sector of the SM is too small by many orders of magnitude to account for the experimental asymmetry [4] – new sources have to be identified. One of the best places to search for additional CPV are permanent Electric Dipole Moments (EDMs) of fundamental particles (like electron, proton, neutron, etc.), since EDMs violate both P- and T- symmetry. No such EDM has been found yet, in spite of ongoing searches in different systems over many years and achieving awesome sensitivity. The experimental state-of-the-art is given in **Chapter 3** below.

There is another possible source of T-violation in the Standard Model that lies outside of the Kobayashi-Maskawa framework. It is associated with the so-called θ_{QCD} parameter, which governs the magnitude of an interaction among colored gluons that is allowed by the general principles, but violates T-symmetry. Experimentally, the parameter is found to be exceedingly small with its best determination ($\theta_{QCD} < 10^{-10}$) actually coming from the neutron static EDM upper limit (assuming that the difference between experiment and SM is all due to θ_{QCD}; cf. Ch.3 below). This constitutes the so-called "strong CP-problem", the fact that no violation of the CP-symmetry has ever been seen in any experiment involving only the strong interaction. There are several proposed solutions for this unresolved problem, including (i) unconventional dynamics, (ii) spontaneously broken CP-symmetry and (iii) an additional chiral symmetry [5]. The latter idea was introduced in 1977 by Roberto Peccei and Helen Quinn [6] by effectively promoting θ to a field, which they accomplished by adding a new global symmetry ("Peccei–Quinn (PQ) symmetry"). The PQ-symmetry is spontaneously broken and, as shown by Frank Wilczek and Steven Weinberg, involves a new pseudoscalar particle (called "axion"). Despite not having been found yet, axion models have been studied for over 40 years, giving insight into axion effects that might be detected. Several experimental searches for axions are presently underway; most of them exploit the expected slight interaction with photons in strong magnetic fields. Axions are also one of the few remaining candidates for Dark Matter (DM) particles and might be discovered in some Dark Matter experiments.

A schematic overview of the science case is given in **Fig. 1**. Both static and oscillating EDM measurements for charged particles are based on the observation of the time development of the polarization direction of beams of polarized particles in storage rings. The P-EDM project will extend the EDM searches to protons (and other charged particles, like deuterons, or ^{3}He-ions) by initiating and preparing the required new class of precision storage rings to achieve an unprecedented sensitivity for static EDMs and by accessing a wide range of possible axion/ALP masses for oscillating EDMs.

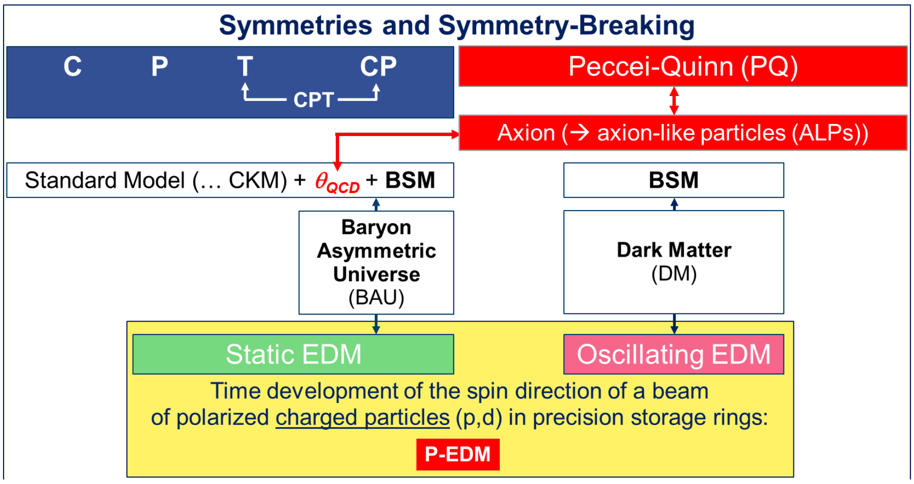


*Fig. 1: Overview of the science case for **P-EDM**. The established discrete symmetries (C, P, T and CP) are shown in the blue box on the left side with T and CP related by the CPT theorem. On the right side in the red box, the presumed PQ-symmetry is given, introduced by Roberto Peccei and Helen Quinn in order to account for the "strong CP-problem" that is parametrized by the smallness of the θ_{QCD} parameter (see text). PQ-symmetry is spontaneously broken, giving rise to a pseudoscalar particle dubbed the axion. The physics motivation behind the quest for additional CP-violation is the observed matter-antimatter asymmetry of the Universe (BAU), while axions (or more generally ALPs) are well-motivated candidates*

*for Dark Matter (DM). Within **P-EDM** the former is investigated with static EDMs, while the latter is searched for with oscillating EDMs.*

3. EDM and DM Landscape

Searches of static Electric Dipole Moments (EDM) of fundamental particles have a long history, dating back to Edward Purcell and Norman Ramsey, who published a first neutron EDM measurement in 1957 [7]. Since then, EDMs have been investigated in many different systems, including free particles (neutron, proton, muon), diamagnetic (^{129}Xe, ^{199}Hg, ^{225}Ra) and paramagnetic (^{205}Tl, Cs, Rb, ^{210}Fr) atoms, molecules (YbF, ThO, BaF, PbF, RaF, PbO, WC, HfF^+, ThF^+), and condensed states (YbOH, $YbOCH_3$, $Gd_3Ga_5O_{12}$, $Gd_3Fe_2Fe_3O_{12}$, $Eu_{0.5}Ba_{0.5}TiO_3$, solid He, liquid Xe) – for an extensive recent review see [8]. No finite EDM has been found yet. An overview of best upper limits for a number of these systems is given in **Fig. 2**:

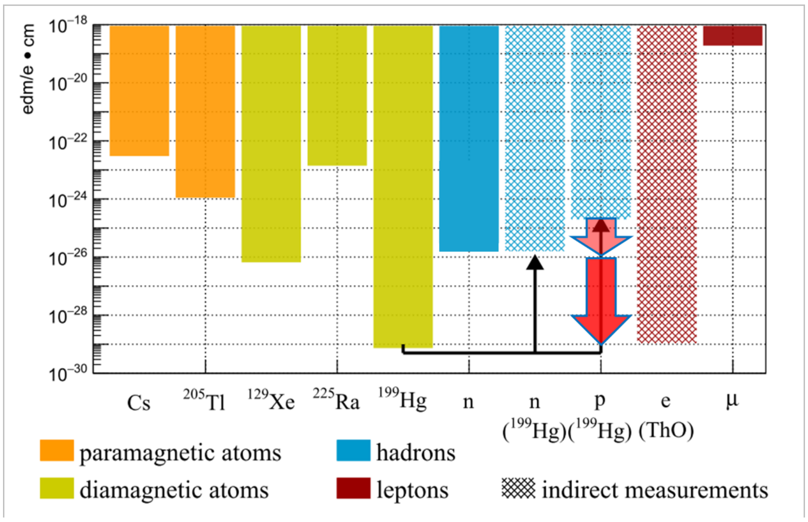


Fig. 2: Experimental limits for Electric Dipole Moments: the full colored boxes indicate results from direct measurements, while the hatched boxes are deduced limits from indirect measurements. The two wide red arrows show the sensitivity limits, aimed for with the prototype ring and the final ring, respectively.

It should be noted that the proton limit has been deduced from an EDM measurement of ^{199}Hg – apparently a direct proton EDM search would be highly preferable, because it will provide a clear-cut experimental result. This is the ultimate goal of the storage-ring project, which has the potential (in sensitivity) to improve the current (indirect) limit on the proton by at least a factor of 1000. As frequently stated before, ***P-EDM*** is the essential pathfinder project toward this goal.

From the theoretical point-of-view, the fundamental issue next to establishing a finite EDM in any system is to identify the EDM sources. In order to do so, different systems need to be investigated as schematically indicated in **Fig. 3**. For further details, see **Chapter 2** of our recent publication [9]:

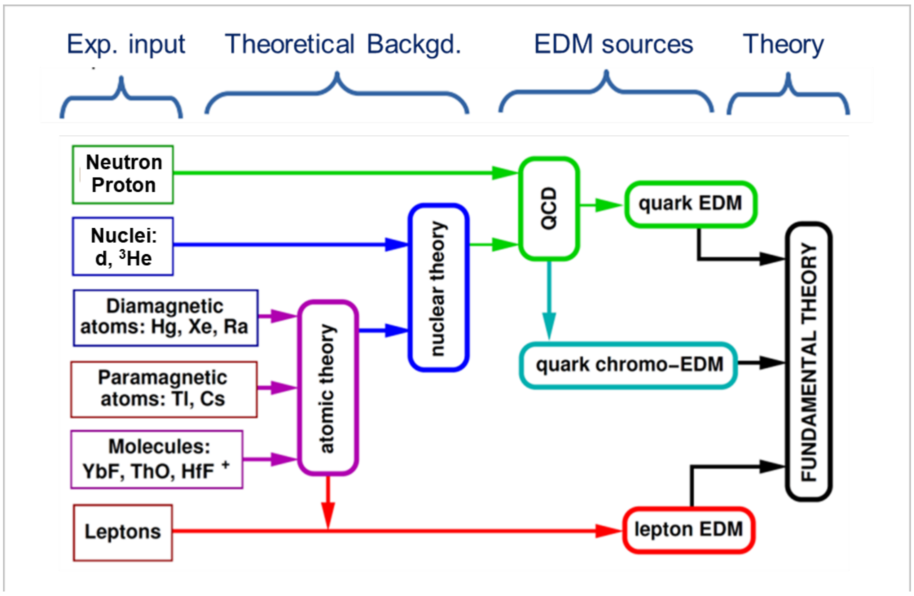


Fig. 3: Schematic linking of experimental EDM results to a fundamental theory. Baryon EDMs appear to be more complex, but also scientifically richer than the leptonic counterparts.

The nature of Dark Matter (DM) is one of the outstanding scientific questions of contemporary astronomy and cosmology, which also has a huge impact on elementary particle physics, because DM may be a yet unknown particle species outside of the SM.

Dark Matter doesn´t emit, absorb or reflect light – up to now its existence has only been inferred from gravitational effects (Note: There are recent so far inconclusive indications for DM effects in laboratory measurements, e.g., XENON1T [10]). DM may interact weakly with normal matter, leading to the following strategies for its identification (in addition to astrophysical observations, involving no SM particles):

- Direct searches, e.g., DM-nucleon scattering.
- Indirect searches: DM annihilation into SM particles.
- DM production in high-energy collisions.

The properties of DM, in particular its mass, are highly unconstrained: it could range over more than 40 orders of magnitude from ultralight DM (10^{-24} eV – if responsible for cosmological structure formation) to massive DM (10^{15} eV – limit if thermally produced in the early Universe). To illuminate parts of this vast mass range, a multitude of experiments has already been conducted, with no positive result yet.

Restricting the search realm to axions and axion-like particles (ALPs), their effects (and thus their potential observation) can be grouped into:

- Coupling to photons (decay into 2 photons).
- Primakoff-like axion conversion.
- Interaction with atomic electrons.
- Interaction with nucleons in nuclei.

If these particles are very light with a high density, they can be regarded as an oscillating classical field with a frequency proportional to its mass "in the local frame of our galaxy. Assuming that all local DM is axions/ALPs in our galaxy, one strategy is to try to measure their coupling to nucleons, resulting in oscillating EDMs. A first (null-) result has been obtained recently by the nEDM (neutron Electric Dipole Moment) collaboration, using data from both ILL and PSI [11], shown in **Fig. 4**:

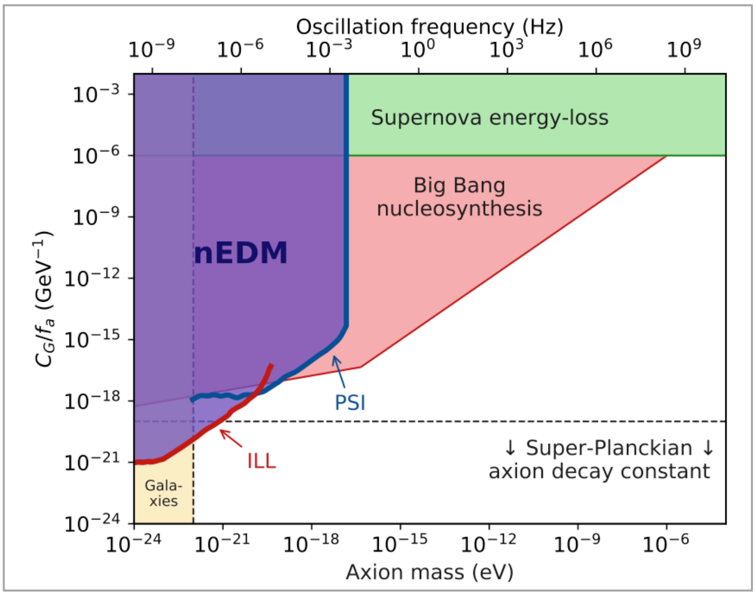


Fig. 4: Exclusion regions plot of axion mass versus gluon coupling. In addition to the oscillating neutron-EDM (nEDM) results from ILL (Institut Laue-Langevin, France) and PSI (Paul Scherrer Institute, Switzerland), astrophysical constraints are indicated [11].

4. Ongoing Activities and New Ideas

In both research fields – EDM and DM – new and/or improved set-ups are being built in order to push the limits further down and to explore as much of the parameter space as possible:

- For the neutron EDM investigations, a cryogenic version of the experiment has been developed. This approach could yield sensitivities hundreds of times higher than is possible now, provided that systematic errors can be controlled to an even higher level.

- For the electron EDM, a next generation of the experiment (Advanced ACME, using the heavy polar molecule ThO) is currently under development, which promises to boost the statistical sensitivity by an order of magnitude and to further reduce systematic errors. There are also new ideas like exploiting laser-cooled YbOH molecules. An excellent recent overview about the use of atoms and molecules for EDM searches and its future potential is given in [12].
- The axion/ALPs dark-matter search is pursued by a plethora of experiments and this will continue in the near future, including new groups and different approaches.

A logical next step in the search for EDMs is to exploit charged particles like the proton, deuteron or ^{3}He nucleus, which had long been ignored because of their non-zero electric charge. Since any EDM measurement requires electric fields, which accelerate charged objects, an observation of an EDM effect of a charged hadron was deemed more complicated. However, if a storage ring is used, in which the charged particles are confined as a beam, such measurements become feasible, e.g., for the proton and other light ions. The principle of these experiments is sketched in **Fig. 5**:

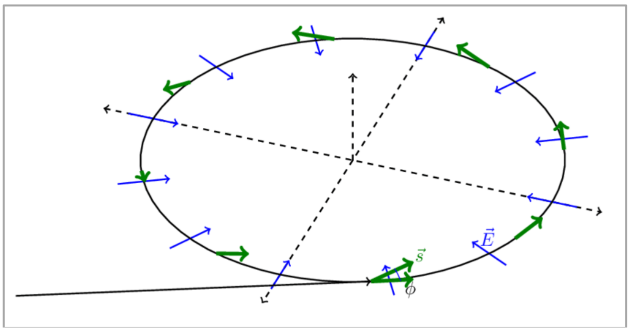


Fig. 5: Principle of a charged-particle EDM measurement. Longitudinally polarized particles enter a storage ring. A radial electric field $\vec{E}$ serves as a guiding field. An EDM will tilt the EDM-vector (parallel to the spin) in the vertical direction. This vertical polarization can be measured with the help of a polarimeter (not shown in the Figure).

The basic assumption of EDM measurements is that the spin and the direction of the EDM vector *d* are always oriented parallel to each other (there is no other preferred direction in the particle's rest frame). Thus, the spin and its possible directional change due to a torque $\vec{d} \times \vec{E}$ will indicate the presence of an EDM. In order to make use of this, one has to start from the behaviour of the spin vector $\vec{S}$ (in the particle rest frame) in electric ($\vec{E}$) and magnetic ($\vec{B}$) fields in the laboratory frame as given by the Thomas-BMT equation [13,14]. Below, the BMT equation is given after subtracting the cyclotron frequency $\vec{\Omega}_{\text{cycl}}$ (see Eqs. (4.4) – (4.6) of [9]):

$$\frac{\mathrm{d}\vec{S}}{\mathrm{d}t} = \left(\vec{\Omega}_{\text{MDM}} + \vec{\Omega}_{\text{EDM}} - \vec{\Omega}_{\text{cycl}}\right) \times \vec{S},$$

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

$$\vec{\Omega}_{\text{EDM}} = -\frac{\eta q}{2mc}\left[\vec{E}_r + c\vec{\beta} \times \vec{B}_y\right]$$

Here, the electric field is radial ($\vec{E} = \vec{E}_r$) and the magnetic field is vertical ($\vec{B} = \vec{B}_y$) with respect to the reference orbit in the machine. G represents the anomalous magnetic moment, m is the mass and q the charge of the particle, $\vec{\beta}$ and γ are the relativistic kinematic variables with c the speed of light. Furthermore, η gives the size of the EDM $d = \eta \frac{q \cdot \hbar}{2mc} S$, where $\vec{d} = d \cdot \frac{\vec{S}}{S}$.

Since the Magnetic Dipole Moment (MDM) is so much larger than the EDM, it is of paramount importance to have the MDM contribution under control – the best possible way to do so is to avoid any magnetic field (i.e., set $B = 0$) and to choose

$$\gamma = \sqrt{1 + \frac{1}{G}},$$

so that the second term in the MDM equation also vanishes; for positive G (i.e., for electron and proton) this happens at the "magic momentum", which is $p = 700.7\ MeV/c$ for the proton. Thus, in order to measure the proton EDM, one should use an all-electric storage ring operating at the magic momentum. (Note: for particles with negative G, such as the deuteron, the vanishing of the MDM part can be achieved by combining an electric and a magnetic field.) The observable of an EDM is the increasing tilt as a function of time of the particle spin from the originally horizontal (ring-) plane into the vertical direction. For a beam of particles, this can be measured in a polarimeter.

If the particle spin (and thus the EDM vector $\vec{d}$) precesses in the horizontal plane due to a magnetic field and its effect on the MDM, a static EDM effect (rotation out of the plane) will be nullified, because the torque $\vec{d} \times \vec{E}$ changes sign if the $\vec{d}$ vector points parallel or antiparallel to the direction of motion. This implies that an EDM cannot be observed in a conventional (magnetic) storage ring without further measures (see below). However, for an oscillating EDM (oEDM) at the right frequency, one obtains a resonant situation in which not only the torque changes sign, but also the EDM vector changes direction, and as a result, one obtains a constructive out-of-plane rotation. This is sketched in **Fig. 6**:

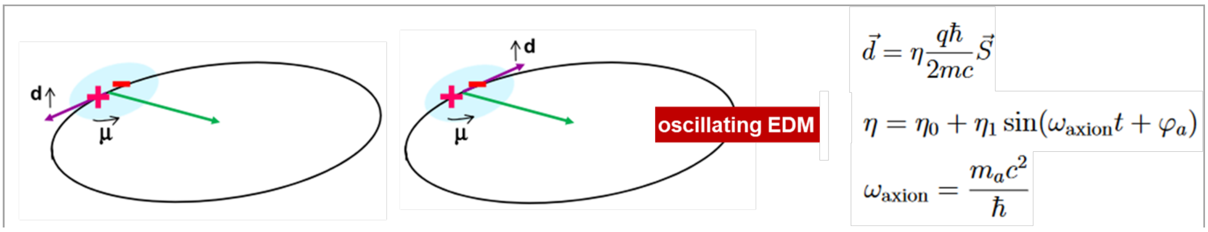


Fig. 6: Oscillating EDMs (indicated by the two charges) are driving the spin in the same out-of-plane direction (in the figure upwards), if the EDM oscillation frequency and the MDM precession frequency are the same (the green arrow indicates the direction of the electric field) . By changing the beam momentum in the storage ring, the precession frequency, the oEDM frequency and thus the Compton frequency, proportional to the axion/ALP mass m_a, can be probed.

5. Objectives of the Pathfinder Project *P-EDM*

Although the principle of both measurements is unsophisticated – one needs to observe the time development of the polarization of a longitudinally polarized beam of charged particles in a storage ring – its realization faces enormous challenges, mainly due to the smallness of the EDM (as experimentally known from previous experiments) and the magnitude of potential background and/or fake effects:

- For static EDMs, the tiniest radial magnetic fields (~ 10^{-17} T) mimic an EDM of 10^{-29} e cm.
- Oscillating EDMs seem less susceptible to systematic effects. In fact, they can be investigated in already existing magnetic storage rings, but a scan over larger frequency/mass range is highly sophisticated.

Working in this field for almost a decade, the JEDI (Jülich Electric Dipole moment Investigations; see web-site under References) collaboration has achieved remarkable progress (A summary can be found in Chap. 6 and Appendix A of [9].), in particular in experiments with polarized deuteron beams at COSY – notably with support of the ERC AdG "srEDM" (2016-2021). It also has become obvious, however, that further extensive effort is required before a final high-precision storage ring for protons can be conceived and procured. Necessary R&D projects comprise:

- All-electric ring design: large electric fields (*E* > 8 MV), capability to simultaneously store two "identical" counter-rotating beams.
- Ring operation: large beam lifetime (~10000 s) and spin-coherence time (~1000 s) in spite of depolarizing resonances.
- EDM observable: in-situ polarimetry of complete beam profile with high sensitivity and efficiency.
- Avoidance and/or shielding magnetic fields.
- Investigation of sensitivity limits by "complete" simulations.
- Long-term symplectic spin tracking, in order to model relevant aspects of EDM experiments, in particular the achievable experimental sensitivity.

P-EDM as the pathfinder project will bridge the gap between the ongoing R&D efforts by the JEDI collaboration at COSY and the final "holy grail" ring envisioned by CPEDM (Charged Particle EDM collaboration) by:

- Lattice design of an intermediate all-electric "prototype" ring for protons (kin. energy ~ 40 MeV).
- Development of key components, including in particular electric deflectors and the polarimeter.

In addition, ***P-EDM*** will provide:

- A direct static proton EDM measurement, exploiting the COSY ring and an RF Wien filter.
- A first axion/ALP DM search study in the mass range accessible at COSY (around $m_a \sim 10^{-8}$ eV).

Based on the previous work and achievements on a proof-of-capability, ***P-EDM*** will thus pioneer the storage-ring method as a tool to investigate static and oscillating EDMs.

6. Scientific Impact and Technological Breakthroughs of *P-EDM*

The expected sensitivity limits of the measurements at COSY will not be comparable to those achieved, e.g., for the neutron after more than 50 years of continuous development. These investigations will, however, demonstrate the potential of storage rings to provide a new method, which will allow us to push the limits into never-explored-before regions in the quest to search for BSM physics.

A large-scale precision facility at the border of state-of-the-art technology is finally required for the static and oscillating proton-EDM search with unprecedented sensitivity [15].

The development for experimental equipment comprises:

- High-field electrostatic deflectors for clockwise and counter-clockwise beams in the storage ring.
- Spin-manipulation and measurement as well as feedback devices in the ring.
- High-precision beam position and beam intensity monitors.
- A fast and effective on-line in-situ sampling polarimeter that reliably determines the individual beam polarization with minimal interference to the beams.

These developments will be applicable in many further accelerators and sub-atomic experiments.

Section b. Methodology

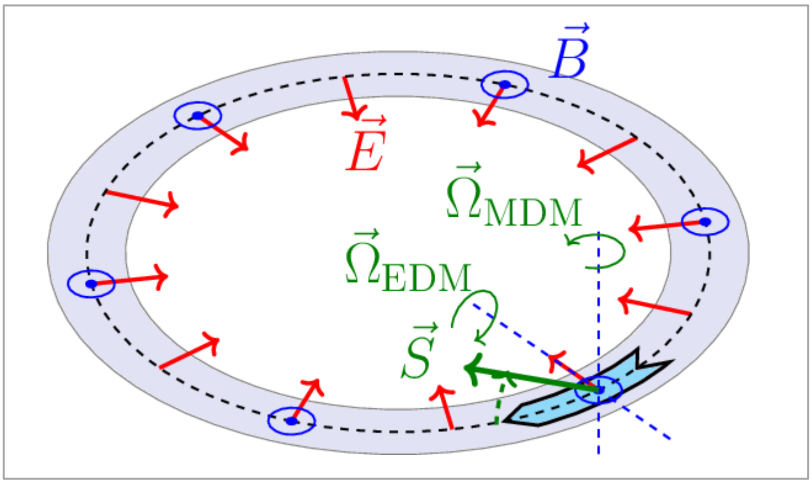
1. Experimental Method to Search for Static and Oscillating EDMs of Charged Particles

The technique to search for an EDM of charged particles is based on the spin evolution in electric and magnetic fields: the EDM $\vec{d}$ couples to the electric fields $\vec{E}$, while the Magnetic Dipole Moment (MDM, $\vec{\mu}$) couples to the magnetic fields $\vec{B}$, leading to:

$$\frac{\mathrm{d}\vec{S}}{\mathrm{d}t} = \vec{d} \times \vec{E} + \vec{\mu} \times \vec{B}$$

(in a simplified expression; the detailed behavior is described by the T-BMT equation given in **Chapter 4** of **Section a.** above). Note that both $\vec{d}$ and $\vec{\mu}$ are collinear to the p article spin $\vec{S}$ at all times.

The experimental situation of a particle (beam), confined in a storage ring by $\vec{E}$ and $\vec{B}$ fields, is indicated in **Fig. 7**:



<u>Fig. 7</u>: Angular velocities $\vec{\Omega}_{\text{EDM}}$ and $\vec{\Omega}_{\text{MDM}}$ of a particle circulating in a (circular) storage ring due to a radial electric field $\vec{E}$ and a magnetic field $\vec{B}$ perpendicular to the ring plane.

If the spin is originally oriented in the plane of the ring, the EDM signal will be the out-of-plane rotation of the spin as a function of time. The experimental observable is the development of a vertical polarization component of a huge number of particles in a beam. This polarization is measured by a polarimeter in a suitable nuclear analyzing reaction, e.g., polarized elastic proton-Carbon scattering.

This leads to the following principal procedures for studying static and oscillating EDMs of charged particles in storage rings:

(i) Static EDM (for protons: use of an all-electric storage ring to avoid spin rotations due to the MDM)
- Inject a longitudinally polarized beam into the ring at the frozen spin momentum.
- Confine the beam in the ring by a radial electric field for as long as possible to maximize the EDM signal; the observation time will be determined by the so-called spin-coherence time (SCT), during which the spins are aligned.
- Finally, determine the vertical polarization component of the beam with a polarimeter.

A detailed description of the experimental method and the related challenges can be found in Ref. [9].

(ii) Oscillating EDM (for protons or deuterons: use of a combined $\acute{E}$and $\acute{B}$ field storage ring)
- Inject a longitudinally polarized beam into the ring.
- Confine the beam in the ring by a magnetic field – due to the MDM, the spins will precess.
- Apply a radial electric field to interact with the EDM; any effect of a static EDM will nullify because the EDM rotation is in opposite directions for one full MDM precession.
- Vary the beam momentum (MDM precession frequency) and look for a non-cancellation, i.e., a resonance condition due to an oscillating EDM (see **Fig. 6** above).

More detailed descriptions including the achievable statistical sensitivities are given in Ref. [16, 17]. It is expected that the experimental boundaries, indicated in **Fig. 4** above, can be pushed by a few orders of magnitude [15].

2. Implementation and Strategy of ***P-EDM***

In order to make progress in this long-term project, it is crucial to be able to perform tests and measurements, which on the one-hand side reveal difficulties and challenges, on the other-hand side provide expert knowledge and guide the way through the demonstration of progress. Fortunately, a unique facility, the magnetic storage ring COSY at Forschungszentrum Jülich, is available for the implementation of all of this. As convincingly demonstrated for deuterons, COSY can be used to study spin-coherence time optimization, the development of the required polarimetry, and indeed for a first direct deuteron-EDM measurement, making use of an RF Wien-filter, which has been developed for this purpose [18].

One of the major insights of the past research is that it will NOT be possible to proceed in one giant leap from COSY R&D and measurements to the “holy grail” precision all-electric proton-EDM storage ring with simultaneously circulating clock-wise and counter clock-wise beams at the magic momentum. Thus, the CPEDM collaboration has developed a 3-stage strategy [9], which is briefly summarized ~~as~~ below (see also **Table 1** in **Part B1)**:

- Stage 1: Proof-of-capability at COSY
- Stage 2: Proof-of-principle in pathfinder project (***P-EDM***)
- Stage 3: Precision measurements with prototype and final ring.

The pathfinder project ***P-EDM*** constitutes an inevitable intermediate step for the following issues:

- Development of key components, in particular electrostatic deflectors for high electric fields and an adequate sampling polarimeter
- Design of the all-electric lattice of the prototype ring, including detailed studies of the achievable EDM sensitivities
- First direct proton-EDM measurement at COSY, requiring long beam lifetime and sufficient spin-coherence time.

These items are further specified in the corresponding work packages in **Chapter 3** below.

Only after the prototype ring has been realized and its capabilities have been demonstrated, the design and construction of the final ring can be embarked on.

Since very recently, it has been proposed to exploit such storage rings for the search for axions/ALPs over a wide range of uncharted parameter space [16], ***P-EDM*** also aims to demonstrate this capability by further detailed studies of oscillating EDMs at COSY.

3. Work Packages of *P-EDM*

The work to be addressed with this application is split into three major work packages, schematically sketched in **Fig. 8**:

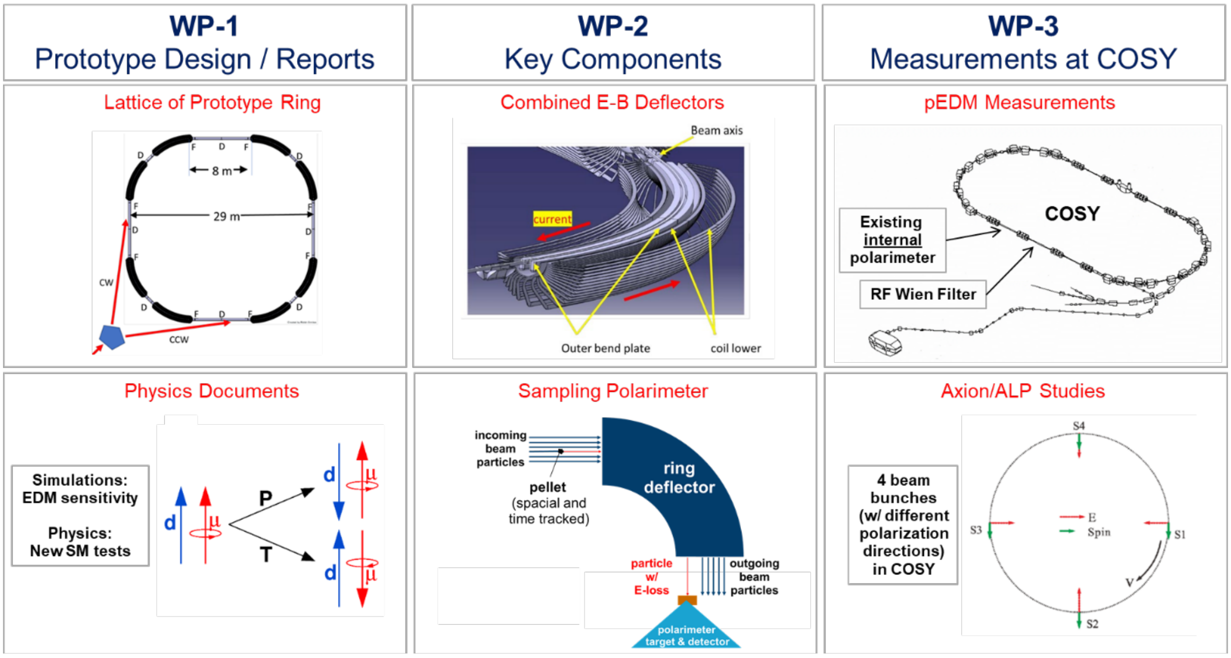


*Fig. 8: Summary of the work packages of **P-EDM**. Further details are given in the following sub-sections.*

3.1 Work Package 1 (WP-1): Prototype Ring Design and Physics Reports

As stated above, the next crucial step toward a final "holy grail" EDM ring is the design of a prototype ring (PTR). A concept for the PTR design has already been developed and is reported in Ref. [9]. According to the preliminary layout, the PTR consists of 8 superimposed electric and magnetic bends; 2 families of quadrupoles – focusing (F) and de-focusing (D); with an optional skew quadrupole family at mid-points of the four 8 m long straight sections (see upper left sketch of **Fig. 8**). The total circumference is about 100 m. The PTR must support storage of clock-wise (CW) and counter clock-wise (CCW) beams. Since the PRT will be host-site independent, a major issue to be investigated is the preparation and injection of the polarized beams.

Objectives

The primary objective of WP-1 is the finalization of the **Prototype Ring Design**. Since the primary purpose of the PTR is studies of issues, which cannot be investigated by other means, it will be kept as small as possible in order to save cost.

It will be operated at two low proton beam kinetic energies: (i) 30 MeV in an all-electric stage and (ii) 45 MeV in a combined E-B field mode.

The 30 MeV will be used to stage demonstrate:

- The ability to store 10^9 polarized protons in a predominantly electric storage ring.
- The capability to produce and manipulate two polarized beams, simultaneously counter-circulating in same ring.
- The capacity to determine the average magnetic field from the difference of the vertical position of two counter-rotating beams.

The goals of the 45 MeV stage are to demonstrate:

- The ability of frozen spin operation.
- The further development and refinement of the experimental methods for measuring the proton EDM in a ring with superimposed electric and magnetic bending.

As a further goal of WP-1, the **EDM Sensitivity Reach** of the srEDM method will be explored theoretically and by quantitative beam and spin simulation tools that are capable to accurately predict all relevant systematic effects (see e.g., Ref. [19]). On this basis, subsequently a trustworthy systematic error evaluation will be given for the operation and physics reach of the PTR, for instance using the polynomial chaos approach to error quantification, described in Ref. [20]. This issue is considered an indispensable step toward the control of all relevant systematic errors for the full-scale EDM facility.

An additional effort of WP-1 will be devoted to explore **New Physics Possibilities**, a novel device such as the PTR may provide. We mention here briefly that through the control of the in-plane spin precession of polarized particles in a storage ring, there are new pathways to experimental test of the SM in dedicated experiments. A first example is a study of parity-conserving (PC) and parity-violating (PV) time-reversal violation (TV), possible in an essentially background-free measurement, as discussed in Ref. [21].

Deliverables

There are three deliverables to be provided for WP-1. The first one is a report about the **Prototype Ring Design**, to be delivered in month 48. A second report on the **EDM Sensitivity Reach** shall be available after month 48, and as a third deliverable, a report on **New Physics Possibilities** will be ready by the end of the project (month 60).

Coordination and Request

WP-1 shall be coordinated by **Christian Carli (CERN)** with major contributions from CERN (design) and IKP-GSI (simulations). Further experts (c.f. **Table 2** below) will add their knowhow to achieve the goals. Three PostDoc positions (equivalent to 72 man-months) are requested within ***P-EDM*** (**Table 1** below).

3.2 Work Package 2 (WP-2): Key Components

At present, it is not known how large the maximum deflection electric field can be made in order to ensure a reliable and long-term operation of an EDM ring. Another aspect is the fact that although great progress has been made in the development of polarimetry and optimization of spin-coherence times (see e.g., App. A of Ref. [9]), the determination of the polarization profile of a beam during an EDM measurement is not yet available. Therefore, in WP-2, the development of a sampling polarimeter, capable to determine the polarization distribution of a beam will be pursued.

Objectives

The first objective of WP-2 is the development of an **Electrostatic Deflector Prototype** combined with a B-field for the PTR. A test setup using a vacuum vessel and a large-aperture dipole magnet is already available at IKP, and shall be used as a test bench to firstly investigate the realistically reachable electric fields. Different coatings and surface treatment procedures shall be studied in this context as well. On the basis of these investigations, a first prototype element for 15^{o} or 22.5^{o} deflection angle shall be developed together with our collaborators from the *Max-Planck-Institute for Nuclear Physics* (MPIK Heidelberg) and the *Institute for High Voltage Equipment and Grids, Digitalization and Energy Economics* **(**IAEW of RWTH Aachen University). A design sketch of a deflector element is shown in the upper middle sketch of **Fig. 8**.

The second goal is the development of a **Sampling Polarimeter** to overcome the major shortcoming of all existing EDM beam polarimeter setups, which is their inability to provide a measurement of the polarization distribution of the beam. The basic new idea is to shoot a carbon pellet (or some other suitable target material) through the beam (see bottom middle of **Fig. 8**). The pellet is tracked optically, while passing through the beam. The stored beam protons that undergo an interaction with the pellet (energy loss and angle deflection) leave the beam and impinge on a thick second carbon polarimeter target (for further details, see App. K of Ref. [9]). Tracking the pellet optically and timing the detector events, allows one to determine the polarization distribution in the beam. The proton polarization asymmetry is measured in a suitable detector system: one possibility will be a polarimeter based on silicon detectors, for which the PI, the UNIFE, and the IKP-GSI group have a huge experience (see CV of PI in part B1, and Ref. [22]). We consider this approach to obtain polarization distributions of the beam a very promising one. Retaining at the same time the already established highly efficient proton- and deuteron-carbon beam polarimetry [23] appears also extremely challenging.

Deliverables

The first deliverables of WP-2 is a real-size **prototype deflector element**, capable to provide simultaneously radial electric and vertical magnetic fields in a bend. As second deliverable, a prototype of a sampling polarimeter shall be developed. Both deliverables shall be physically available at the end of ***P-EDM*** (month 60).

Coordination and Request

WP-2 shall be coordinated by **Frank Rathmann (GSI/IKP)**. Experts from FZJ, MPIK, RWTH Aachen and UNIFE, in addition to members of the JEDI and CPEDM collaborations, will contribute (**Table 2**). The man-power request for ***P-EDM*** is 2 PostDoc positions, corresponding to 84 man-months (**Table 1**).

3.3 Work package 3 (WP-3): Measurements

In WP-3, we will extend the experimental investigations of JEDI at COSY, which up to now focused on deuteron beams (as outlined in the "srEDM" ERC project), to proton beams – which is the particle species for the final all-electric ring. It is planned to exploit the RF Wien filter for a precursor experiment using COSY to determine a first direct proton EDM limit. The second item in WP-3 is to perform axion/ALP search studies using a proton beam in COSY.

Objectives

In WP-3, a **first direct proton EDM measurement** with an RF Wien filter will be performed at COSY. First deuteron EDM measurements are presently being pursued by the JEDI collaboration [24, 25]. The primary reason to begin storage ring EDM studies with deuterons is the absence of depolarizing resonances that might adversely affect the spin-coherence time. Naturally, the first item that must be addressed is the achievement of a sufficiently long **proton spin-coherence time** (≈ 1000 s), in conjunction with a thorough understanding of the connection between spin-coherence, chromaticity and beam emittance growth. Once this is achieved, the next step will be to apply the **RF Wien filter technique** to the stored longitudinally polarized protons to accumulate the EDM signal, as described, e.g., in Ref. [26]. Although the anticipated spin-precession frequencies for protons are substantially larger than for deuterons, no principal difficulties are anticipated. The phase-lock technique, pioneered by JEDI, will be applied as well [27].

The ongoing experimental effort at COSY aims for a search for axion/ALPs using stored deuteron beams. It is essential to apply the experimental technique of measuring oscillating EDMs at COSY also to stored proton beams, since in the prototype and the final ring, protons will be used to study both EDMs. Refined studies are required, since compared with deuterons, in the proton case the spin precession frequencies involved are substantially larger. **Multi-bunch operation** with more than four bunches stored in COSY will be exploited to establish the measuring technique.

Deliverables

As the major milestone of WP-3, data taking for the proton static EDM measurement will be accomplished by month 30, since all relevant experimental equipment is already available. The primary deliverable of WP-3 is a report and a publication of the result of the proton EDM measurement at COSY by the end of the ***P-EDM*** project. In addition, a report on the proton oscillating EDM studies will be finalized in month 36.

Coordination and Request

WP-3 shall be coordinated by **Giuseppe Ciullo (UNIFE)**. In order to successfully finish this WP, huge contributions from the COSY operations team, further IKP-GSI experts and many members of the JEDI-collaboration and is required (**Table 2**). Two PostDoc positions (84 man-months) are requested (**Table 1**).

3.4 Distribution of Resources for *P-EDM*

*Table 1: Distribution of requested **P-EDM** resources (man-months) to the 3 beneficiaries and the 3 work packages.*

Participant		WP-1	WP-2	WP-3	
		Prototype Design / Reports	Key Components	Measurements	total
1	CERN	36	0	0	**36**
2	IKP-GSI	24	60	48	**132**
3	UNIFE	12	24	36	**72**
	total	**72**	**84**	**84**	**240**

Based on the description of workpackages above, the **P-EDM** project is only requesting additional manpower for young researchers to join the experienced team. The proposal of the project is summarized in **Table 1** at the beginning of the section.

4. Team Structure of *P-EDM*

It is obvious that to be successful, the ***P-EDM*** project requires a group of experts, comprising scientists and engineers, which work together coherently and focused on the different tasks. To do so, the team structure indicated in **Table 2** is foreseen:

*<u>Table 2</u>: Identified members of the **P-EDM** team, grouped into the PI, beneficiaries coordinating the work packages from CERN (green), IKP-GSI (orange) and UNIFE (blue) and additional experts from various labs ([E] stands for engineer). In addition, the COSY operations team and the two supporting collaborations (CPEDM, JEDI) will be important contributors. The bottom row indicates the required additional manpower of **P-EDM** for the different WPs.*

PI	**P. Lenisa** (UNIFE, IKP-GSI) Coordination, Management		
Beneficiaries	**C. Carli (CERN)** WP-1	**F. Rathmann (IKP-GSI)** WP-2	**G. Ciullo (UNIFE)** WP-3
Experts	J. Borburgh (CERN) [E]	I. Keshelashvili (IKP-GSI)	J. Pretz (IKP-GSI and RWTH)
	A. Lehrach (IKP-GSI and RWTH)	A. Nass (IKP-GSI)	R. Gebel (IKP-GSI)
		V. Carassiti (UNIFE) [E]	**COSY operations team**
	A. Wirzba (FZJ)	M. Grieser (MPI)	
	R. Talman (Cornell)	H. Soltner (FZJ)	G. Tagliente (INFN)
	A. Stahl (RWTH)	M. Bendig (RWTH) [E]	E. Stephenson (Indiana)
***P-EDM* Request**	NN (PostDoc → Lattice Design)		
	NN (PostDoc → New Physics)	NN (PostDoc → Deflector)	NN (PostDoc → Axion/ALP Studies)
	NN (PostDoc → Sensitivity)	NN (PostDoc → Polarimeter)	NN (PostDoc → pEDM at COSY)
Collaboration	**CPEDM**		**JEDI**

In addition to hiring male and female junior scientists as PostDocs, ***P-EDM*** will allow us to support some of the experts listed above, e.g., for travel and short-term stays at CERN and IKP. For the time span of the project, the PI plans to share his place of residence between UNIFE (50%) and IKP-GSI (50%).

5. Timeline and Milestones of *P-EDM*

*<u>Table 3:</u> Overview of the timeline for the work packages of **P-EDM** including the requested resources (number of months). Also indicated are the major milestones of the project. COSY will be exploited for WP-3 until the end of 2023 with a possible extension until the end of 2024. The time until the end of the project (orange box) will be used for data analysis and publishing of the results.*

Years	2021	2022	2023	2024	2025	2026
Month of *P-EDM* Project	1-12	13-24	25-36	37-48	49-60	
WP-1: Design Report (72) ➢ Lattice Design (48) ➢ pEDM Sensitivity (12) ➢ New Physics (12)	CERN: CERN (PostDoc plus Staff Member); IKP (PostDoc); UNIFE (PostDoc)					
WP-2: Key Components (84) ➢ E-Deflectors (54) ➢ Polarimeter (30)	IKP-GSI: UNIFE (PostDoc); IKP (PostDocs)					
WP-3: Measurements (84) ➢ pEDM Experiment (60) ➢ Axion Studies (24)	UNIFE: UNIFE (PostDocs); IKP (PostDoc)					
Milestones of *P-EDM*	Start of *P-EDM*; Start Hiring; Start COSY Expts	Start of Axion/ALP Studies at COSY	Finalyzing Axion/APL and EDM Expts.; Finalizing Studies for Polarimeter	Contingency for COSY Expts; Analysis of EDM and Axion/APL.	Analysis of EDM and Axion/APL; Finalizing Lattice Design; Completing Study for Adiitional New Physics Cases	Finalizing PEDM Sensitivity Study; Finalyzing E-Deflector Studies; End of *P-EDM*

Table 3 above gives a concise overview of the timeline for ***P-EDM***: while WP-1 and WP-2 are unconstrained, the experimental work for WP-3 will take place at the beginning of the project, since it is currently foreseen that COSY will only be available until the end of 2024.

6. Management Plan of *P-EDM*

The PI has significant experience in shaping, coordinating and conducting challenging projects (see CV) – as co-spokesperson of the JEDI collaboration and member of the CPEDM collaboration, he is well-positioned to lead ***P-EDM***. In order to coordinate the project, the following measures are foreseen:

- Weekly video conferences with beneficiaries (see **Table 1**).
- Quarterly electronic reports about progress and problems for the 7 sub-topics (see **Table 2**).
- Yearly face-to-face meetings (in conjunction with JEDI/CPEDM collaboration meetings).
- A concluding workshop at the end of the project.

A web-site will be set up to collect all information around ***P-EDM***.

7. Risk Assessment and Mitigation of *P-EDM*

The following potential risks have been identified and will be mitigated or eliminated:

- It has been mentioned before that the Institute for Nuclear Physics (IKP) of Forschungszentrum Jülich will be attached scientifically and administratively to GSI Helmholtzzentrum für Schwer-ionenforschung (GSI) from 2021 on, while COSY will remain a property of FZJ. Consequently, the host institute of ***P-EDM*** will be GSI. There will be a cooperation contract between FZJ and GSI on the use of COSY until (at least) end of 2024.
- COSY beam time is recommended by the COSY Beam Advisory Committee (CBAC) after review of corresponding beam time requests. Given the high scientific merit, there is no doubt that beam time for the WP-3 measurements will be granted. In case of a shortage of beam time, a request for an extension of COSY operations will be put forward to FZJ and GSI authorities; if there will be a significant lack of beam time, priority will be given to the pEDM measurements.
- The experiments with polarized protons in COSY will be an essential step for ***P-EDM*** connected with significant challenges like sufficiently long spin-coherence time of the beam. Based on the long-standing experience with polarized beams and the well-established methods to avoid polarization losses, we are confident to master this task – however, it may take time, which we have to invest.
- The axion/ALP studies with polarized protons are a new field as well. We have, however, already shown that such measurements can be performed with polarized deuterons and thus we don´t foresee principle difficulties for protons. We are well aware that achievement of a long spin-coherence time (SCT) for protons will need a lot of effort.
- For WP-1 and WP-2, we do not expect any fundamental problems.

8. Summary

The pathfinder project *P-EDM* is deemed the next inevitable and decisive step in the quest to find physics beyond the Standard Model of elementary particle by a new approach – the search for static and oscillating Electric Dipole Moments (EDM) of charged particles in storage rings. Conceptually simple, the challenges for providing a precision EDM facility are substantial. They will be resolved once the work packages of *P-EDM* have been completed successfully.

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Collaborations:

JEDI (Jülich Electric Dipole moment Investigations): http://collaborations.fz-juelich.de/ikp/jedi/

CPEDM (Charged Particle Electric Dipole Moment): http://pbc.web.cern.ch/edm/edm-org.htm

GSI Helmholtzzentrum für Schwerionenforschung GmbH
Planckstraße 1
64291 Darmstadt
www.gsi.de

GSI · Planckstraße 1 · 64291 Darmstadt · Deutschland

Commitment of the host institution for ERC Calls 2020[1, 2, 3]

The **GSI Helmholtzzentrum für Schwerionenforschung GmbH** which is the applicant legal entity,

confirms its intention to sign a supplementary agreement with

Prof. Paolo Lenisa

in which the obligations listed below will be addressed should the proposal entitled

P-EDM: Pathfinder for a Charged-Particle EDM Storage Rings

be retained.

Performance obligations of the *applicant legal entity* that will become the beneficiary of the H2020 ERC Grant Agreement (hereafter referred to as the Agreement), should the proposal be retained and the preparation of the Agreement be successfully concluded:

The *applicant legal entity* commits itself to hosting *[and engaging]* 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 (action) and spend at least 50% of her/his total working time in an EU Member State or Associated Country;

Geschäftsführung:
Professor Dr. Paolo Giubellino
Dr. Ulrich Breuer
Jörg Blaurock

Vorsitzender des Aufsichtsrates:
Ministerialdirigent Dr. Volkmar Dietz

Sitz: Darmstadt
Amtsgericht Darmstadt HRB 1528

USt-IdNr.: DE 111 671 917
Landesbank Hessen/Thüringen

IBAN DE56 5005 0000 5001 8650 04
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[1] A scanned copy of the signed statement should be uploaded electronically via the Funding and Tenders 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 H2020 ERC Model Grant Agreement (MGA). The H2020 ERC MGA is available on the Funding & Tenders Portal. The reference to the time commitment of the Principal Investigator is stated in the ERC Work Programme 2020.
[3] This statement (on letterhead paper) shall be signed by the institution's legal representative indicating their name, function, and email address along with the stamp of the institution.

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in the case of a Consolidator Grant at least 40% of her/his total working time to the ERC-funded project (action) 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 (action) 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 Agreement, taking into consideration the specific role of the *principal investigator*;

c) enter — before signature of the Agreement — into a '*supplementary agreement*' with the *principal investigator*, that specifies the obligation of the *applicant legal entity* to meet its obligations under the Agreement;

d) provide *the principal investigator* with a copy of the signed Agreement;

e) guarantee the *principal investigator's* scientific independence, in particular for the:

i) use of the budget to achieve the scientific objectives;

ii) authority to publish as senior author and invite as co-authors those who have contributed substantially to the work;

iii) preparation of scientific reports for the project (action);

iv) selection and supervision of the other *team members* (hosted *[and engaged]* by the *applicant legal entity* or other legal entities), in line with the profiles needed to conduct the research and in accordance with the *applicant legal entity's* usual management practices;

v) possibility to apply independently for funding;

vi) access to appropriate space and facilities for conducting the research;

f) provide — during the implementation of the project (action) — research support to the *principal investigator* and the team members (regarding infrastructure, equipment, access rights, products and other services necessary for conducting the research);

g) support the *principal investigator* and provide administrative assistance, in particular for the:

i) general management of the work and his/her team

GSI Helmholtzzentrum für
Schwerionenforschung GmbH
Planckstraße 1
64291 Darmstadt
www.gsi.de

ii) scientific reporting, especially ensuring that the team members send their scientific results to the principal investigator;

iii) financial reporting, especially providing timely and clear financial information;

iv) application of the applicant legal entity's usual management practices;

v) general logistics of the project (action);

vi) access to the electronic exchange system (see Article 52 of the Agreement);

h) inform the *principal investigator* immediately (in writing) of any events or circumstances likely to affect the Agreement (see Article 17 of the Agreement);

i) ensure that the *principal investigator* enjoys adequate:

i) conditions for annual, sickness and parental leave;

ii) occupational health and safety standards;

iii) insurance under the general social security scheme, such as pension rights;

j) allow the transfer of the Agreement to a new beneficiary ('portability'; see Article 56a of the Agreement).

k) take all measures to implement the principles set out in the Commission Recommendation on the European Charter for Researchers and the Code of Conduct for the Recruitment of Researchers[4] - in particular regarding working conditions, transparent recruitment processes based on merit and career development – and ensure that the *principal investigator*, researchers and third parties involved in the project (action) are aware of them.

l) respect the fundamental principle of research integrity and ensure that persons carrying out research tasks follow the good research practices and refrain from the research integrity violations described in the European Code of Conduct for Research Integrity[5]. If any such violations or allegations occur, verify and pursue them and bring them to the attention of the Agency.

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[4] Commission Recommendation 2005/251/EC of 11 March 2005 on the European Charter for Researchers and on a Code of Conduct for the Recruitment of Researchers (OJ L 75, 22.3.2005, p. 67).

[5] The European Code of Conduct for Research Integrity of ALLEA (All European Academies) and ESF (European Science Foundation) of March 2011.

GSI Helmholtzzentrum für Schwerionenforschung GmbH
Planckstraße 1
64291 Darmstadt
www.gsi.de

For the host institution (applicant legal entity):

Date August 19, 2020

Name and Function
Prof. Dr. Paolo Giubellino Scientific Managing Director GSI

Email and Signature of legal representative

p.giubellino@gsi.de ....

Name and Function
Markus Jaeger authorized signatory and Head of the Controlling Department GSI

Email and Signature of legal representative

ma.jaeger@gsi.de ppa. ....

Stamp of the host institution (applicant legal entity)

GSI Helmholtzzentrum
für Schwerionenforschung GmbH
Planckstraße 1
64291 Darmstadt
Deutschland