Storage Rings for the Search of Charged Particles Electric Dipole Moments

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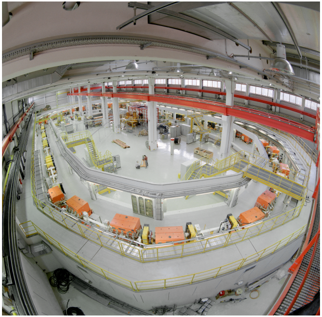
Preface



COSY-SR at FZ-Jülich (Germany)

Recent achievements in polarization technology in storage rings

- Long spin-coherence time *[Phys. Rev. Lett. 117 (2016) 054801]*
- Precise spin-tune measurement *[Phys. Rev. Lett. 115 (2015) 094801]*
- Spin-feedback system *[Phys. Rev. Lett. 119 (2017) 014801]*

Pave the way to the design of a new class of storage rings for precision measurements

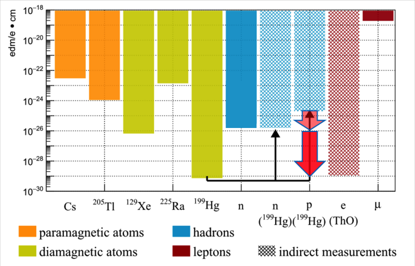
Motivation

Addressing the most intriguing puzzles of contemporary physics

- Preponderance of matter over antimatter
- Nature of Dark Matter

Approach

- Measur. of static Electric Dipole Moments (EDM) of fundamental particles.
- Search for axion-like particles (ALPs) as DM candidates through oscillating EDM



- Presented LoI: EDMs of charged hadrons: p, d, $^3\mathrm{He}$
- Goal is to bring the limit for p to 10^{-29} e · cm

High precision, primarily electric storage ring

- Crucial role of alignment, stability, field homogeneity and shielding from *unwanted* magnetic fields.
- High beam intensity: N=4 $\cdot$ 10^{10} per fill
- Polarized hadron beams: P=0.8
- Long spin coherence time: τ = 1000 s
- Large electric fields: E $\sim$ 10 MV/m
- Efficient polarimetry with:
  - large analyzing power: A = 0.6
  - high efficiency detection: eff. = 0.005

Expected statistical sensitivity in 1 year of data taking:

- $\sigma_{stat} = \frac{\hbar}{\sqrt{Nf\tau PAE}} \Rightarrow \sigma_{stat} = 10^{-29} e \cdot cm$
- Experimentalist's goal: provide σ_{syst} to the same level.

Staged approach

On the basis of the preparedness of the required technological development

Stage 1

precursor experiment

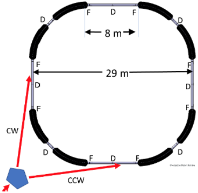
at COSY (FZ Jülich)

- magnetic storage ring

now

Stage 2

prototype ring

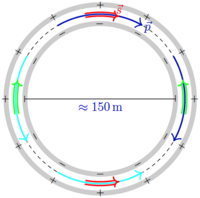


- electrostatic storage ring
- simultaneous ↻ and ↺ beams

5 years

Stage 3

dedicated storage ring



- magic momentum

(701 MeV/c)

10 years

$\sigma_{EDM}/(e \cdot \mathrm{cm})$

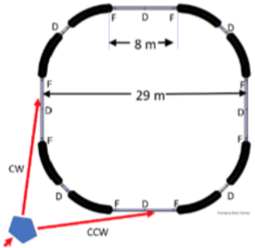
10^{-17} 10^{-18} 10^{-19} 10^{-20} 10^{-21} 10^{-22} 10^{-23} 10^{-24} 10^{-25} 10^{-26} 10^{-27} 10^{-28} 10^{-29}

Stage 2: prototype EDM storage ring

- Build demonstrator for charged particle EDM
- Project prepared by CPEDM working group (CERN+JEDI)
  - Physics Beyond Collider process (CERN)
  - European Strategy for Particle Physics Update
- S.R. to Search for EDMs of Charg. Part. - Feas. Study (arXiv:1912.07881)

100 m circumference

- p at 30 MeV all-electric CW-CCW beams operation
- Frozen spin operation including additional vertical magnetic fields



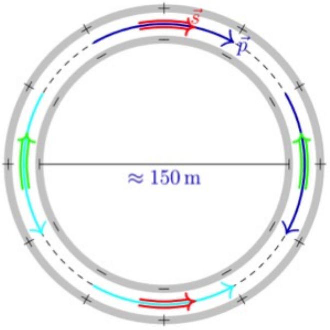
Challenges

- All electric & E-B combined deflection
- Storage time
- CW-CCW operation
- Spin-coherence time
- Polarimetry
- Magnetic moment effects
- Stochastic cooling

Stage 3: precision EDM ring

500 m circumference (with E = 8 MV/m)

- All-electric deflection
- Magic momentum for protons (p = 701 MeV/c)



Challenges

- All-electric deflection
- Simultaneous CW/CCW beams
- Phase-space cooled beams
- Long spin coherence time ($>$ 1000 s)
- Non-destructive precision polarimetry
- Optimum orbit control
- Optimum shielding of external fields
- Control of residual (intentional) B_r field

"Holy Grail" of storage rings (largest electrostatic ever conceived)

Expectations

- Endorsement of scientific case and experimental approach
- Support in unification of international effort

Status preparedness levels for the full-scale all-electric ring.

Operations	Rank	Comment	Reference
spin control feed-back	G	COSY R&D	App. A.1.3
spin coherence time	G(-)	COSY R&D	App. A.1.2
polarimetry	Y	polarimetry is destructive	Chap. 11
beam current limit	R	enough protons for EDM	Sect. 7.2
CW/CCW operation	R	systematic EDM error reduction	Ref. [1]
Theory			
GR gravity effect	G(+)	this paper, standard candle bonus	App. D
frozen spin fixed point stable?	G	stable, this paper	App. G.5.5
intrabeam scattering	Y	may limit run duration	Ref. [3]
geometric/Berry phase theory	Y	needs further study	Ref. [4]
Components			
quads	G	e.g. CSR design	Chap. 9
polarimeter	G	COSY R&D	Chap. 11
waveguide Wien filter	G	COSY R&D precursor	App. A.1.5
electric bends	R(+)	sparking/cost compromise	App. A.1.10
Physics & Engineering			
cryogenic vacuum	Y	required?—cost issue only	Ref. [5]
stochastic cooling	Y	ultraweak focusing issue	Ref. [6]
power supply stability	Y(-)	may prevent phase lock	Chap. 7
regenerative breakdown	R(+)	specific to mainly-electric, not seen in E-separators	
EDM systematics			
polarimetry	G(-)	COSY R&D	Chap. 11
CW/CCW beam shape matching	Y		Chap. 10
beam sample extraction	Y	systematic error?	Chap. 11, App. K
control current resettability	Y		Ref. [7]
BPM precision	Y(-)	Rogowski? Squids?	Chap. 7, Chap. 10
element positioning & rigidity	Y(-)	must match light source stability	Ref. [8]
theoretical analysis			Chap. 10 and refs.
Radial B-field B_r	R	assumed to be dominant	Ref. [1]

Storage Ring to Search for Electric Dipole Moments of Charged Particles - Feasibility Study (arXiv:1912.07881 [hep-ex])