Storage Rings for the Search of Charged Particles Electric Dipole Moments

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Recent achievements in polarization technology in storage rings


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: $p$, $d$, $^3$He

Goal is to bring the limit for $p$ to $10^{-29}$ e·cm
Requirements

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: \( \tau = 1000 \) s
- Large electric fields: \( E \sim 10 \) MV/m
- Efficient polarimetry with:
  - large analyzing power: \( A = 0.6 \)
  - high efficiency detection: \( \text{eff.} = 0.005 \)

Expected statistical sensitivity in 1 year of data taking:

\[
\sigma_{\text{stat}} = \frac{\hbar}{\sqrt{N_f \tau \text{PAE}}} \Rightarrow \sigma_{\text{stat}} = 10^{-29} \text{e} \cdot \text{cm}
\]

Experimentalist’s goal: provide \( \sigma_{\text{syst}} \) 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)

Stage 2
prototype ring

Stage 3
dedicated storage ring

- magnetic storage ring
- electrostatic storage ring
- simultaneous $\odot$ and $\odot$ beams

now
5 years
10 years

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

<table>
<thead>
<tr>
<th>Operations</th>
<th>Rank</th>
<th>Comment</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>spin control feed-back</td>
<td>G</td>
<td>COSY R&amp;D</td>
<td>App. A.1.3</td>
</tr>
<tr>
<td>spin coherence time</td>
<td>G(+)</td>
<td>COSY R&amp;D</td>
<td>App. A.1.2</td>
</tr>
<tr>
<td>polarimetry</td>
<td>Y</td>
<td>polarimetry is destructive</td>
<td>Chap. 11</td>
</tr>
<tr>
<td>beam current limit</td>
<td>R</td>
<td>enough protons for EDM</td>
<td>Sect. 7.2</td>
</tr>
<tr>
<td>CW/CCW operation</td>
<td>R</td>
<td>systematic EDM error reduction</td>
<td>Ref. [1]</td>
</tr>
</tbody>
</table>

**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    | systematic error?                            | Chap. 10           |
| beam sample extraction            | Y    |                                                | 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])