Electric Dipole Moments of Charged Particles
— Activities at COSY/Forschungszentrum Jülich - Plans for a new Storage Ring at CERN

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Electric Dipole Moment (EDM) requires dedicated new storage ring (→ long term project)
this talk:
  - intermediate steps using existing storage ring COSY at Forschungszentrum Jülich, Germany
  - design of a new storage ring (at CERN)
Electric Dipole Moments (EDM)

- permanent separation of positive and negative charge
- fundamental property of particles (like magnetic moment, mass, charge)
- existence of EDM only possible via violation of time reversal $\mathcal{T}$ ($\mathcal{CPT} = \mathcal{CP}$) and parity $\mathcal{P}$ symmetry
- close relation to origin of matter-antimatter asymmetry in the universe
Experimental Method: Generic Idea

For all EDM experiments (neutron, proton, atoms, ...):

Interaction of $\vec{d}$ with electric field $\vec{E}$

For charged particles: apply electric/magnetic field in a storage ring:

$$\frac{d\vec{s}}{dt} \propto \vec{d} \vec{E} \times \vec{s}$$

In general:

$$\frac{d\vec{s}}{dt} = \vec{\Omega} \times \vec{s}$$

build-up of vertical polarization $s_\perp \propto |\vec{d}|$
storage ring for protons and/or deuterons ($p \approx 1\text{GeV/c}$)

polarized hadron beams ($P = 0.8$)

high intensity beams ($N = 4 \cdot 10^{10}$ per fill)

long spin coherence time ($\tau = 1000\text{ s}$),

large electric fields ($E = 10\text{ MV/m}$)

polarimetry (analyzing power $A = 0.6$, acc. $f = 0.005$)

\[
\sigma_{\text{stat}} \approx \frac{\hbar}{\sqrt{Nf\tau \text{PAE}}} \quad \Rightarrow \quad \sigma_{\text{stat}}(\text{1 year}) = 10^{-29}\text{ e}\cdot\text{cm}
\]

**challenge**: get $\sigma_{\text{sys}}$ to the same level
Storage Ring EDM

- Only storage ring measurement: muon (parasitic measurement to muon $g - 2$)
- COSY at Forschungszentrum Jülich, Germany: magnetic storage ring, \textbf{pol. proton} and \textbf{deuteron} beams up to 3 GeV/$c$
  \quad $\rightarrow$ ideal starting point
Cooler Synchrotron COSY

**polarized** protons and deuterons with $p = 0.3 - 3.7 \text{GeV/c}$
Recent achievements and activities

1. **Spin coherence time:** $\tau > 1000 \text{ s}$  
   (PRL 117, 054801 (2016))

2. **Spin tune:** $\nu_s = -0.16097 \cdots \pm 10^{-10}$ in 100 s  
   (PRL 115, 094801 (2015))

- Spin feedback: polarisation vector kept within 12 degrees  
  (PRL 119 014801 (2017))
- Polarimetry
- Deflector development
- Beam instrumentation
- Spin Tracking (benchmarking of codes)

Based on this: first measurement of deuteron EDM in 2018  
(proof of principle)
Spin Precession

Spin precession frequency: $f_{spin} = \gamma G f_{rev} \approx 120$ KHz

with $\Delta \gamma \approx 10^{-6} \rightarrow$ decoherence after $10^6$ turns $\approx 1$ s

gyromagnetic anomaly $G(\text{deuteron}) = -0.142561789$
1.) Spin Coherence Time (SCT)

RF: all particles have same revolution time

sextupoles used to correct path length
1.) Spin Coherence Time (SCT)

\[ Q = 2\pi \cdot 120\text{KHz} \cdot 1000\text{s} \approx 10^9 \]
2.) Spin Tune $\nu_s$

$$f_{\text{spin}} = \gamma G f_{\text{rev}}$$

\[ \vec{P}_1 = \left\langle \sum_{i=1}^{N} \frac{\vec{S}_i}{S_i} \right\rangle \]

$$|\vec{P}_2| < |\vec{P}_1|$$

$$\sigma(\nu_s = \gamma G) \approx 10^{-10} \text{ in } 100 \text{ s}$$

Note: $\gamma G = \frac{f_{\text{MDM}}}{f_{\text{rev}}}$, $\frac{f_{\text{EDM}}}{f_{\text{rev}}} \approx 10^{-10}$ for EDM $d = 10^{-24} \text{ e cm}$
CPEDM (charged particle EDM) collaboration established

- **srEDM**
  - since ≈2000, BNL/Korea
  - design for $E$ ring for proton

- **JEDI**
  - Jülich Electric Dipole moment Investigations
  - since 2011, Jülich/Aachen
  - EDM experiments at COSY, design for $E/B$ ring

- **CPEDM**
  - since 2017, CERN
  - feasibility study for EDM ring at CERN

Kick-off meeting 1-2 March 2017
## Work packages

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**KAIST:** Korea Advanced Institute of Science & Technology  
**FZJ:** Forschungszentrum Jülich

**Goal:** Feasibility study for proton/deuteron storage ring
## Options for an EDM ring

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<th>Combined Ring</th>
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<td>No $\vec{B}$ field needed, CW/CCW beams simultaneously work only for particles with $G &gt; 0$ with (e.g. $p$ with 0.7007 GeV/$c$)</td>
<td>Works for $p$, $d$, $^3$He, ... Both $\vec{E}$ and $\vec{B}$ required; field reversal needed to run CW/CCW</td>
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**Design Sensitivity:** $4 \times 10^{-29}$ e-cm

**Requires:**
- Electrostatic deflector 8MV/m
- Magnetic shielding
- High precision SQUID BPMs to monitor the total radial magnetic field by vertical beam position separation between CW/CCW
Possible Site at CERN

Linac2 and Linac3

Linac4 (points almost in right direction)
EDMs are unique probe to search for new CP-violating interactions

**charged** particle EDM searches require new high precision storage rings

Activities are underway at magnetic storage ring COSY at Forschungszentrum Jülich

Collaboration (CPEDM) established to investigate possibility for the construction of new storage ring

Goal: Feasibility study end of 2018