THE SEARCH FOR ELECTRIC DIPOLE MOMENTS OF CHARGED PARTICLES USING STORAGE RINGS

MESON’21 19.05.2021  I  VERA SHMAKOVA FOR THE JEDI COLLABORATION
Why are we going to measure EDMs of charged particles

Time development of spin in storage rings

EDMs are very small and hard to measure, so we use the step approach:

1st step – use an existing storage ring (COSY) to start with

Next steps

Summary & Outlook
• Why current universe is matter dominated?
• Big Bang produced the same amount of matter – antimatter

Comparing the experiment:

\[
\frac{n_b - n_\bar{b}}{n_\gamma} \sim 10^{-10}
\]


expectation from SCM:

\[
\frac{n_b - n_\bar{b}}{n_\gamma} \sim 10^{-18}
\]


• Preference of matter (A. Sakharov criteria)

\[ C, \ CP \text{ violation} \]

There is \( CP \) violation in SM, but not sufficient magnitude

The search for EDMs of charged particles using storage rings

Vera Shmakova

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EDM violates both T, P symmetries

EDM violates CP symmetry (if CPT conserved)

EDM is a probe for CP violation beyond the SM
EXISTING LIMITS ON EDM

The search for EDMs of charged particles using storage rings

Vera Shmakova
• No direct measurement for charged hadron EDMs
• Potentially higher sensitivity for charged hadrons (compared to neutrons):
  • longer lifetime
  • more stored polarized protons/deuterons
  • can apply larger electric fields in storage rings
• EDM of single particle type not sufficient to identify CPV source
At storage rings: vertical $B$ field, radial $E$ field

Frozen spin case is if MDM has no impact on spin motion. Momentum and spin in the absence of EDM would stay aligned.
**THOMAS - BMT EQUATION:**

\[
\frac{d \vec{S}}{dt} = \left[ \vec{\Omega}_{MDM} - \vec{\Omega}_{cycl} + \vec{\Omega}_{EDM} \right] \times \vec{S}
\]

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

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

At storage rings: vertical \( \mathbf{B} \) field, radial \( \mathbf{E} \) field

Frozen spin case is if MDM has no impact on spin motion. Momentum and spin in the absence of EDM would stay aligned.

In case of purely electric ring:
- magnetic field is absent
- momentum is chosen that term \((G - \frac{1}{y^2 - 1}) = 0\)

radial electric field causes the spin to precess out of the plane linearly
EDM FOR CHARGED PARTICLE IN 3 STAGES

**Stage 1**
- precursor experiment
- pure magnetic ring

**Stage 2**
- prototype ring
- combined E/B ring
- simultaneous CW-CCW beams

**Stage 3**
- dedicated storage ring
- all electric proton ring

\[ \sigma_{\text{EDM}}/(e \cdot \text{cm}) \]
COSY (Jülich, Germany)

- magnetic storage ring
- polarized protons and deuterons
- Momenta $p = 0.3 - 3.7 \text{ GeV/c}$

The search for EDMs of charged particles using storage rings
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\vec{\Omega}_{EDM} = -\frac{\eta q}{2mc} \left\{ \vec{E} + c\vec{\beta} \times \vec{B} \right\}
\]

At storage rings: vertical \( B \) field, radial \( E \) field

MDM causes fast spin precession in horizontal plane

In pure magnetic ring motional electric field term \( (c \vec{\beta} \times \vec{B}) \)

access to EDM
In the magnetic ring
momentum ↑↑ spin  →  spin kicked up
momentum ↑↓ spin  →  spin kicked down
no accumulation of vertical asymmetry
In the magnetic ring
momentum ↑↑ spin  ➞  spin kicked up
momentum ↑↓ spin  ➞  spin kicked down

no accumulation of vertical asymmetry

RF Wien filter
Heberling, Hölscher and J. Slim


- Lorentz force \( \vec{F}_L = q(\vec{E} + \vec{v} \times \vec{B}) = 0 \)
- \( \vec{B} = (0, B_y, 0) \) and \( \vec{E} = (E_x, 0, 0) \)
EDM absence case

EDM effect

Magnetic misalignment effect
Coherent ensembles in ring plane - time of the horizontal polarization decoherence - “spin coherence time” - has to be longer than a measurement

- Spin precesses with 120 kHz.
- Wien filter operates on resonance $f = 871.430 \text{ kHz}$.
- Phase lock between spin precession and Wien filter.
The basic workflow

- Feedback monitors spin precession phase and adjust WF frequency to maintain the relative phase between spin precession and Wien filter
- an error of 0.2 rad
During the first precursor (November’18)

31 points measured

2 weeks of pure measurement

Parametric resonance strength based on initial slope

\[ E^{EDM} = \frac{\Omega^P_y}{\Omega^{rev}} \]

Orientation of precession axis at location of RF Wien filter determined from the minimum of the surface:

\[ \varphi^0_{\text{wf}} = -3.80 \pm 0.05 \text{ mrad} \]

\[ \chi^0_{\text{sol}} = -5.51 \pm 0.05 \text{ mrad} \]

Spin tracking calculations should provide the orientation of precession axis without EDM
LIST OF IMPROVEMENTS

- Alignment campaigns of COSY magnet system

- Beam-based alignment  
  *PhD thesis T. Wagner*

- New tool for fast tune and chromaticity measurement  
  *P. Niedermayer and B. Breitkeutz*

- Slow control system  
  *I. Bekman and IKP4*

- COSY signals and distribution was improved  
  *K. Laihem and V. Hejny*

- Rogowski coils at the Wien filter place  
  *PhD thesis F. Abusaif*

- New JEDI polarimeter  
  *I. Keshelashvili and the polarimeter group*

- 8 high-speed RF switchers to gate the WF power for one of the bunches pilot bunch technique  
  *J. Slim, A. Nass, F. Rathmann, G. Tagliente*
Precursor run II March-April 2021

- 3.5 weeks of data taking
- 9 Maps
- Two methods were successfully used:
  - Initial polarization build up
  - Pilot bunch

Pilot bunch method:
- 8 high-speed RF switchers to gate the WF power for one of two bunches
- Capable of short switch time ~ few ns
- Bunch 2 feels the power and oscillate
- Bunch 1 is used as pilot bunch for phase locking
• All electric E & combined E/B deflectors
• 100 m circumference
• protons of 30 MeV – all-electric beam operation
• protons of 45 MeV – frozen spin with additional vertical magnetic fields

**Challenges:**
• Only E & combined E+B deflection
• Storage time
• CW-CCW operation: orbit difference to pm
• Spin coherence time
• Polarimetry

**Why we need the PTR prior to the dedicated ring:**
• To study open issues
• First direct proton EDM measurement

• Current status is summarized in CERN Yellow report

• Next step: CPEDM collaboration prepares Technical Design Report
• All electric E & combined E/B deflectors
• 100 m circumference
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**Cost efficient option to use COSY**
• If placed in the COSY Hall, the arcs-only COSY rebuild as the bunch accumulator

*R. Talman talk, WE-Heraeus-Seminar Towards Storage Ring Electric Dipole Moment Measurements, 2021*
SUMMARY

• Why search for charged hadron EDMs? Possibility to find sources of CP violation and to explain matter-antimatter asymmetry in the universe.

• Precursor experiments performed is a proof of principle of EDM measurement at storage rings. Analysis of the data is ongoing.

• COSY remains a unique facility for such studies.

• Proposal for prototype EDM storage ring prepared by CPEDM.

• The work on Technical Design Report for PTR is ongoing.