

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

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MATTER-ANTIMATTER ASYMMETRY

Why is our universe is matter dominated?

Big Bang produced same amount of matter – antimatter

Experiment:
V. Barger, et al, Phys.Lett.B566, 8 (2003) $\frac{n_b - n_{\overline{b}}}{n_{\gamma}} \sim 10^{-10}$ Expectation from SCM:
W. Bernreuther, Lect. Notes Phys.591, 237 (2002) $\frac{n_b - n_{\overline{b}}}{n_{\gamma}} \sim 10^{-18}$

Preference of matter (A. Sakharov criteria, 1967)

There is CP violation in SM, but not sufficiently large

ELECTRIC DIPOLE MOMENT





EDM is a probe for CP violation beyond the SM

CHARGED PARTICLE EDM



- 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
- Complementary to neutron EDM
 - EDM of single particle type not sufficient to identify CPV source

EDM AT STORAGE RINGS



THOMAS - BMT EQUATION:

$$\frac{d\vec{S}}{dt} = [\vec{\Omega}_{MDM} - \vec{\Omega}_{cycl} + \vec{\Omega}_{EDM}] \times \vec{S}$$
$$\vec{\Omega}_{MDM} - \vec{\Omega}_{cycl} = -\frac{q}{m} \{ G\vec{B} - (G - \frac{1}{\gamma^2 - 1}) \frac{\vec{\beta} \times \vec{E}}{c} \} \swarrow \vec{\Omega}_{EDM} = -\frac{\eta q}{2mc} \{ \vec{E} + c \vec{\beta} \times \vec{B} \}$$

EDM AT STORAGE RINGS





"Frozen spin": in the absence of EDM spin stay aligned to momentum

In case of purely electric ring:

- magnetic field is absent
- momentum is chosen that term $(G \frac{1}{v^2 1}) = 0$

radial electric field causes the spin to precess out of the plane linearly



EDM FOR CHARGED PARTICLE IN 3 STAGES



* F. Abusaif et al., "Storage Ring to Search for Electric Dipole Moments of Charged Particles - Feasibility Study," 2019.https://arxiv.org/abs/1912.07881

This talk: precursor experiment, with a magnetic ring COSY

PRECURSOR EXPERIMENT AT COSY



COSY (Jülich, Germany)

- magnetic storage ring
- polarized protons and deuterons
- Momenta p = 0.3 3.7 GeV/c





Starting point for EDM measurement

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EDM AT MAGNETIC RING





MDM causes fast spin precession in horizontal plane



RF WIEN FILTER





RF WIEN FILTER





RF Wien filter

Heberling, Hölscher and J. Slim

J. Slim et al. Nucl. Instrum. Methods Phys. Res. A 828, 116 (2016)

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





EFFECT ON INVARIANT SPIN AXIS



EDM absent

Pure EDM effect



EDM + magnetic misalignments



PRINCIPLE OF MEASUREMENTS

- Coherent ensembles in ring plane spin coherence time has to be longer then a measurement
- Spin precesses with 120 kHz.
- Wien filter operates on resonance f = 871.430 kHz
- Phase lock between spin precession and Wien filter

Feedback: the basic workflow





PRINCIPLE OF MEASUREMENTS

- 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



Feedback: the basic workflow



The search for EDMs of charged particles using storage rings



FIRST RESULTS



Precursor experiment I November 2018:

2 weeks of data taking

Wien filter is physically rotated about the beam axis

Additional spin kick from a solenoid elsewhere in the ring

Study dependence of $\alpha(t)$ slope on the phase ϕ between WF and the spin precession

$$\alpha(t) = \arctan\left(\frac{P_y}{P_{xz}}\right)$$

Amplitude depends on the WF rotation and the solenoid kick



Vera Shmakova

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FIRST RESULTS

Precursor experiment I November 2018:

31 points measured

Parametric resonance strength based on initial slope

$$\varepsilon^{EDM} = \frac{\Omega^{P_{Y}}}{\Omega^{rev}}$$

Minimum of the surface shows orientation of precession axis:

 ϕ_0^{wf} = -3.42 +- 0.06 mrad

 $X_0^{sol} = -5.26 + -0.04 \text{ mrad}$

Orientation of precession axis without EDM will come out of spin tracking calculations





LIST OF IMPROVEMENTS



- Alignment campaigns of COSY magnet system
- Beam-based alignment
 PhD thesis T. Wagner **talk of Tim Wagner on ..**
- 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*
- 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 GATING OF THE BUNCH



Precursor experiment 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 switches to gate the WF power for one of two bunches
- Capable of short switch time ~ few ns
- Bunch (1) and (2) orbit at $f_{rev} \approx 750$ kHz
 - coherent ensembles in ring plane
 - precessing at $f_s \approx 120 \text{ kHz}$
- Bunch (2) feels the power and oscillate
- Bunch (1) is used as pilot bunch for phase locking

SUMMARY



- Charged hadron EDMs: Possibility to find sources of CP violation and to explain matter-antimatter asymmetry in the universe.
- Precursor experiments performed as a proof of principle of EDM measurement at storage rings. Analysis of data ongoing.
- COSY remains a unique facility for such studies.
- New method of managing the polarization for one of two bunches in the ring was developed and performed



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