Charged Particle Electric Dipole Moment Measurements at Storage Rings

Jamal Slim

RWTH Aachen University

slim@physik.rwth-aachen.de

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Content

- Physics motivation of EDM searches
- EDM in conventional storage rings and beyond
- Achievements at COSY
- Precursor EDM experiment: limits of the magnetic storage rings
- Prototype EDM ring

Baryon asymmetry in the Universe

- Just after big bang, production and annihilation in thermal equilibrium
- We exist, what caused the matter antimatter asymmetry?

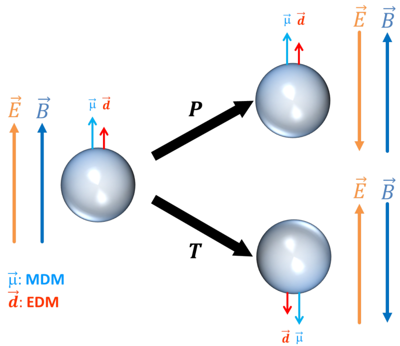
	$\eta = (n_b - n_{\bar{b}})\,/\,n_\gamma$
Observation	10^{-10}
Expectation	10^{-18}

Preconditions needed to explain this imbalance (Sakharov, 1967):

- **C** and **CP** violation

The electric dipole moment (EDM) - CP violation

- $\vec{\mu} = g \cdot \frac{q}{2m}\vec{S}$
- $\vec{d} = \eta \cdot \frac{q}{2mc}\vec{S}$
- $\mathcal{H} = -\vec{\mu} \cdot \vec{B} - \vec{d} \cdot \vec{E}$
- $\mathbf{P} : \mathcal{H} = -\vec{\mu} \cdot \vec{B} + \vec{d} \cdot \vec{E}$
- $\mathbf{T} : \mathcal{H} = -\vec{\mu} \cdot \vec{B} + \vec{d} \cdot \vec{E}$
- EDM provides a tool to probe for CP violation beyond the SM



Roadmap towards the ultimate EMD machine

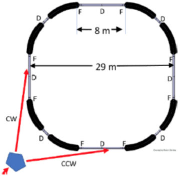
Stage 1

- precursor experiment

- magnetic storage ring
- Now

Stage 2

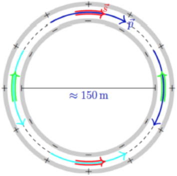
- prototype ring



- electric/magnetic bends
- simultaneous ↺ and ↻ beams
- 5 years

Stage 3

- dedicated storage ring



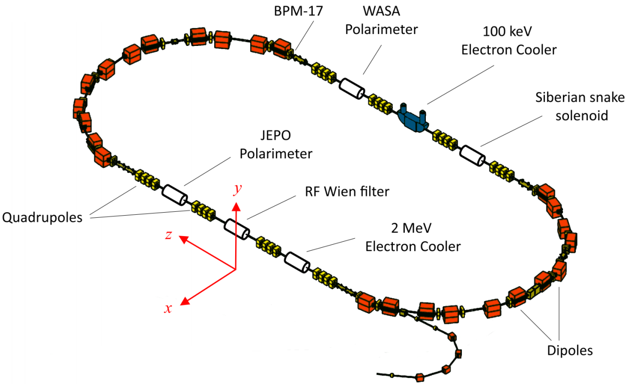
- at magic p momentum
- 10 years

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

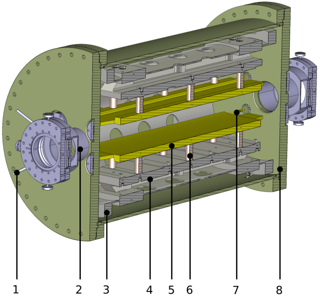
10^{-17} 10^{-18} 10^{-19} 10^{-20} 10^{-21} 10^{-22} 10^{-23} 10^{-24} 10^{-25} 10^{-26} 10^{-27} 10^{-28} 10^{-29}

The Cooler Synchrotron (COSY)

- Medium energy accelerator and storage ring
- Unique facility for spin physics
- Polarized protons and deuterons with p = 0.3 – 3.7 GeV/c



The Cooler Synchrotron (COSY) with the WF



(a) CAD drawing of the design of the RF Wien filter. 1: RF feed, 2: beam pipe, 3: inner mounting cylinder, 4: inner support structure, 5: lower electrode, 6: insulator, 7: RF connector, and 8: vacuum vessel.

T-BMT equation

Spin dynamics in arbitrary electromagnetic field

$$\frac{\mathrm{d}\vec{S}}{\mathrm{d}t} = \underbrace{\left(\vec{\Omega}^{\mathrm{MDM}} + \vec{\Omega}^{\mathrm{EDM}}\right)}_{=\vec{\Omega}^{\mathrm{tot}}} \times \vec{S}\,,$$

where

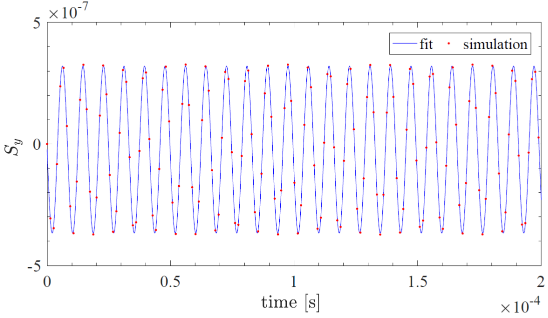
$$\vec{\Omega}^{\mathrm{MDM}} = -\frac{q}{m}\left[\left(G + \frac{1}{\gamma}\right)\vec{B} - \frac{G\gamma}{\gamma+1}\left(\vec{\beta}\cdot\vec{B}\right)\vec{\beta} - \left(G + \frac{1}{\gamma+1}\right)\frac{\vec{\beta}\times\vec{E}}{c}\right],$$

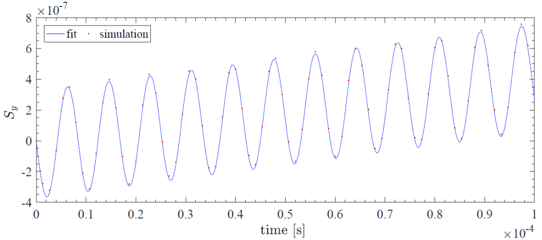
$$\vec{\Omega}^{\mathrm{EDM}} = -\frac{q}{mc}\frac{\eta_{\mathrm{EDM}}}{2}\left[\vec{E} - \frac{\gamma}{\gamma+1}\left(\vec{\beta}\cdot\vec{E}\right)\vec{\beta} + c\vec{\beta}\times\vec{B}\right].$$

The Cooler Synchrotron (COSY)

- In a magnetic ring without an RF Wien filter
- No accumulation of vertical asymmetry
- EDM cannot be measured

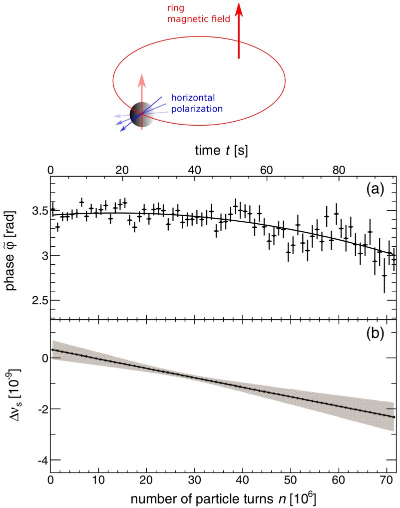
- Given the Wien filter is running on resonance
- Polarization build-up can be observed
- Access to EDM signal





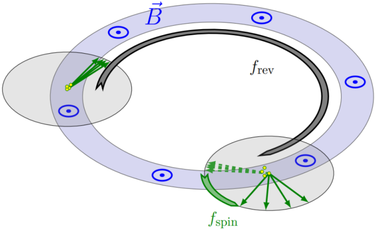
High-precision determination of the spin tune

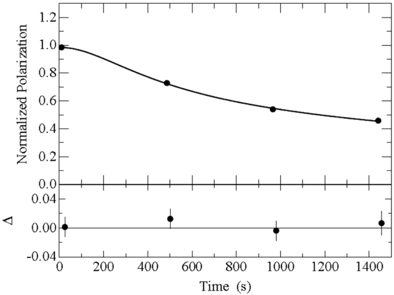
- Spin tune ν_s: spin revolution per turn
- Precision determination of spin tune
- $\Delta\nu_s/\nu_s \approx 10^{-10}$
- Very precise determination of the spin precession frequency $f_s = \nu_s \cdot f_{\mathrm{rev}}$



Long spin coherence time (SCT)

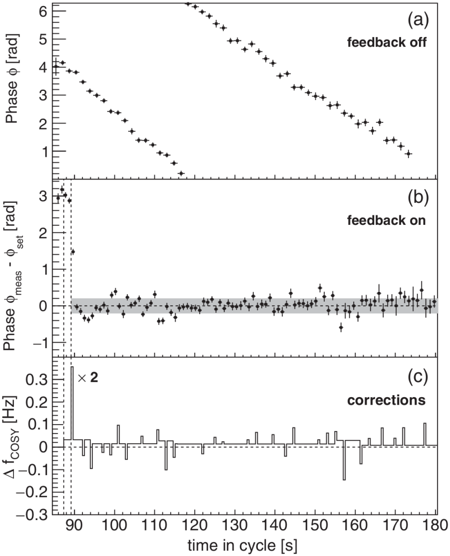
- Bunching
- Beam cooling
- Sextupole scans
- Long spin coherence time (SCT)





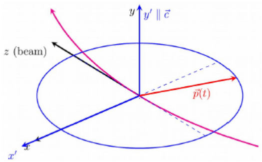
Phase-lock feedback system

- The new RF device must operate in resonance with the spin
- Fixed phase relation between the RF fields and the spin
- Measure polarimeter events, revolution frequency and the RF Wien filter frequency using one time reference
- Measure phase difference between spin and the RF Wien filter
- Set the Wien filter frequency

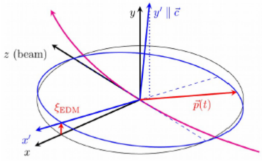


RF Wien filter method

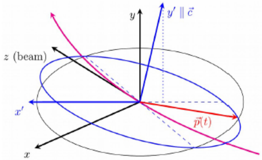
- Ideal ring, no EDM



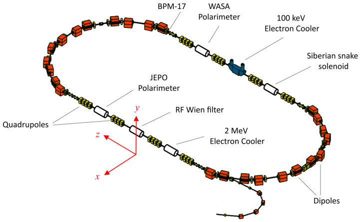
- Ideal ring, with EDM

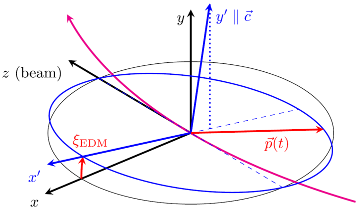


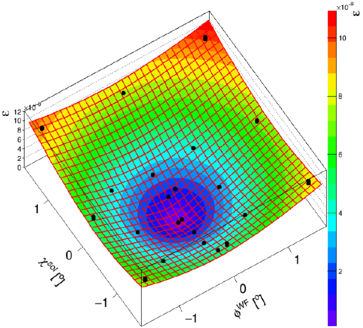
- Real ring, with EDM



Measurements of the EDM resonance strength

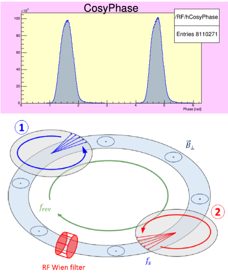


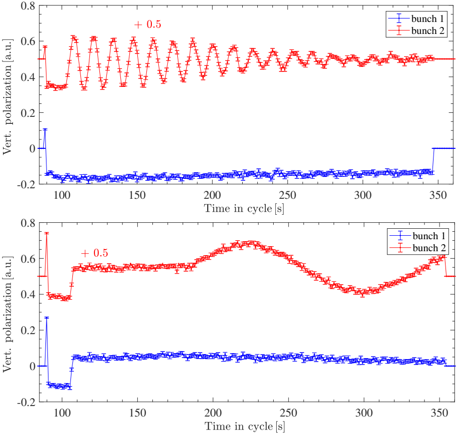




- When the magnetic field axis and the invariant spin axis are parallel, the resonance strength vanishes.
- A tool to measure the direction of the invariant spin axis

Pilot bunch Co-magnetometer

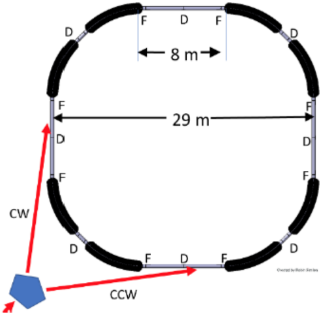




- Very recent experiment
- Offline analysis is in progress

Stage 2: Prototype EDM storage ring (PTR)

- 100 m circumference
- p at 30 MeV all-electric CW-CCW beams operation
- p at 45 MeV frozen spin including additional vertical magnetic fields
- CW-CCW
- Spin-coherence time
- Polarimetry
- Magnetic moment effects
- Stochastic cooling



Primary purpose of PTR

- study open issues.
- first direct proton EDM measurement.

Summary

- EDM can be a good candidate to answer one of the major open questions of physics
- Many milestones for charged particle EDM have been achieved at COSY
- The analysis of the systematic limits of magnetic storage rings are currently analysis
- Next step, design and build a prototype EDM ring.

Questions