Storage Rings for the Search of Charged Particles Electric Dipole Moments

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Motivation

Addressing the most intriguing puzzles of contemporary physics

Problems

- Preponderance of matter over antimatter
- Nature of Dark Matter

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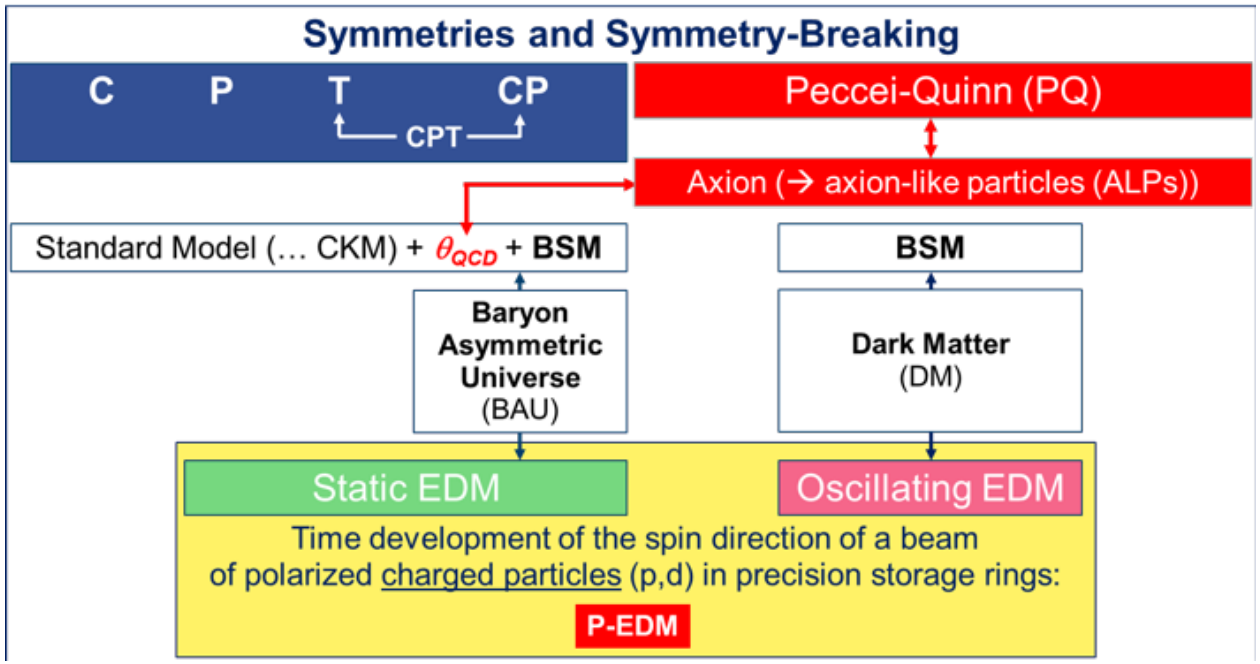
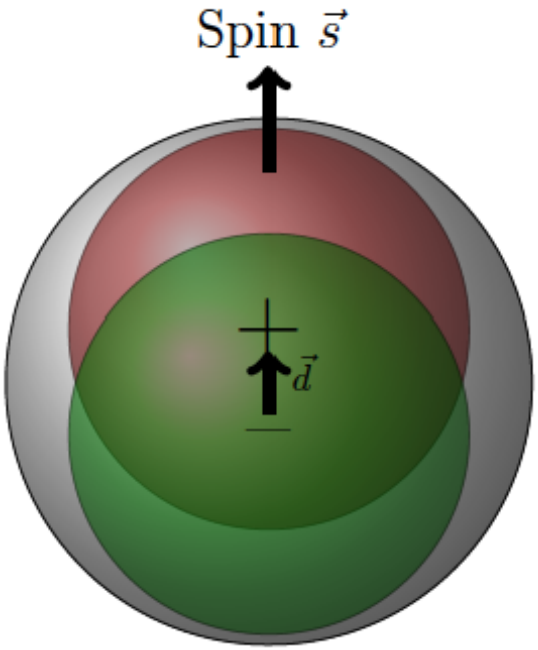
Approach

- Measurements of static Electric Dipole Moments (EDM) of fundamental particles.
- Searches for axions and axion-like particles (ALPs) as Dark Matter candidates through oscillating EDM



Electric Dipole Moments (EDM)



- Permanent separation of + and - charge
- Fundamental property of particles (like magnetic moment, mass, charge)
- Possible only via violation of time-reversal $T \overset{CPT}{=} CP$ and parity P
  - connection to matter-antimatter asymmetry

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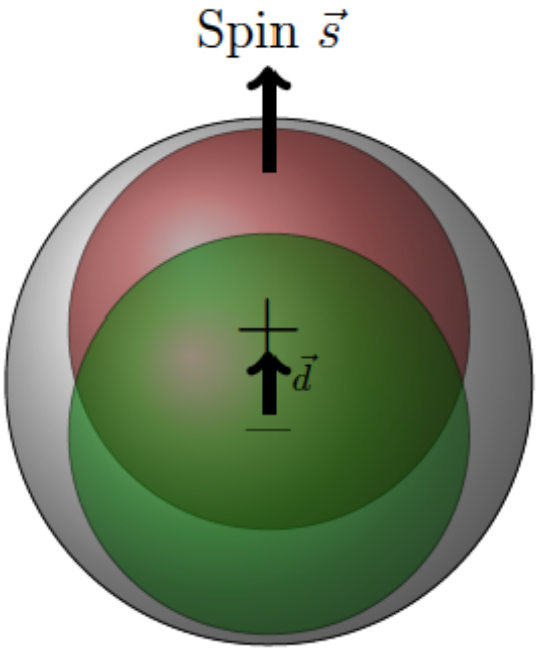

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EDM meas. test violation of P and T symmetries ($\overset{CPT}{=}$CP)

Matter dominance:

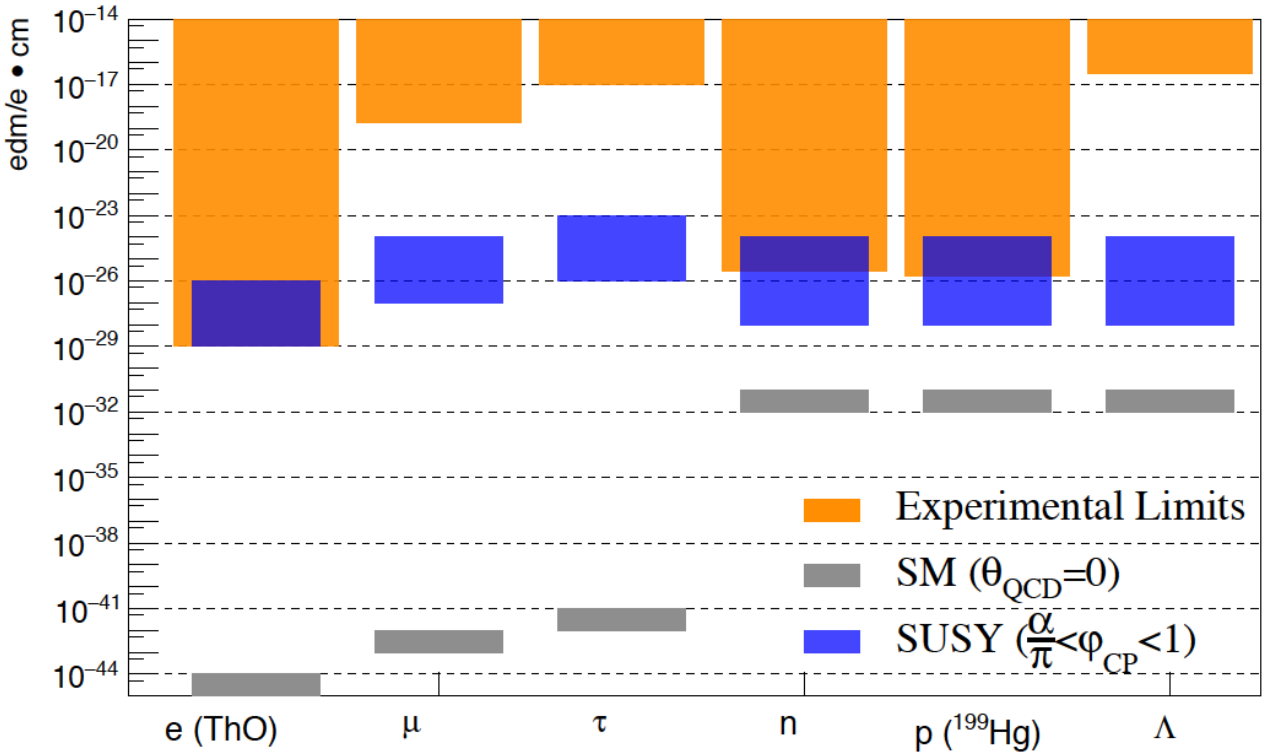
- Excess of Matter in the Universe:

$\eta = \frac{n_B - n_{\overline{B}}}{n_\gamma}$	observed	SM prediction
	6×10^{-10}	10^{-18}

- Sacharov (1967): CP-violation needed for baryogenesis

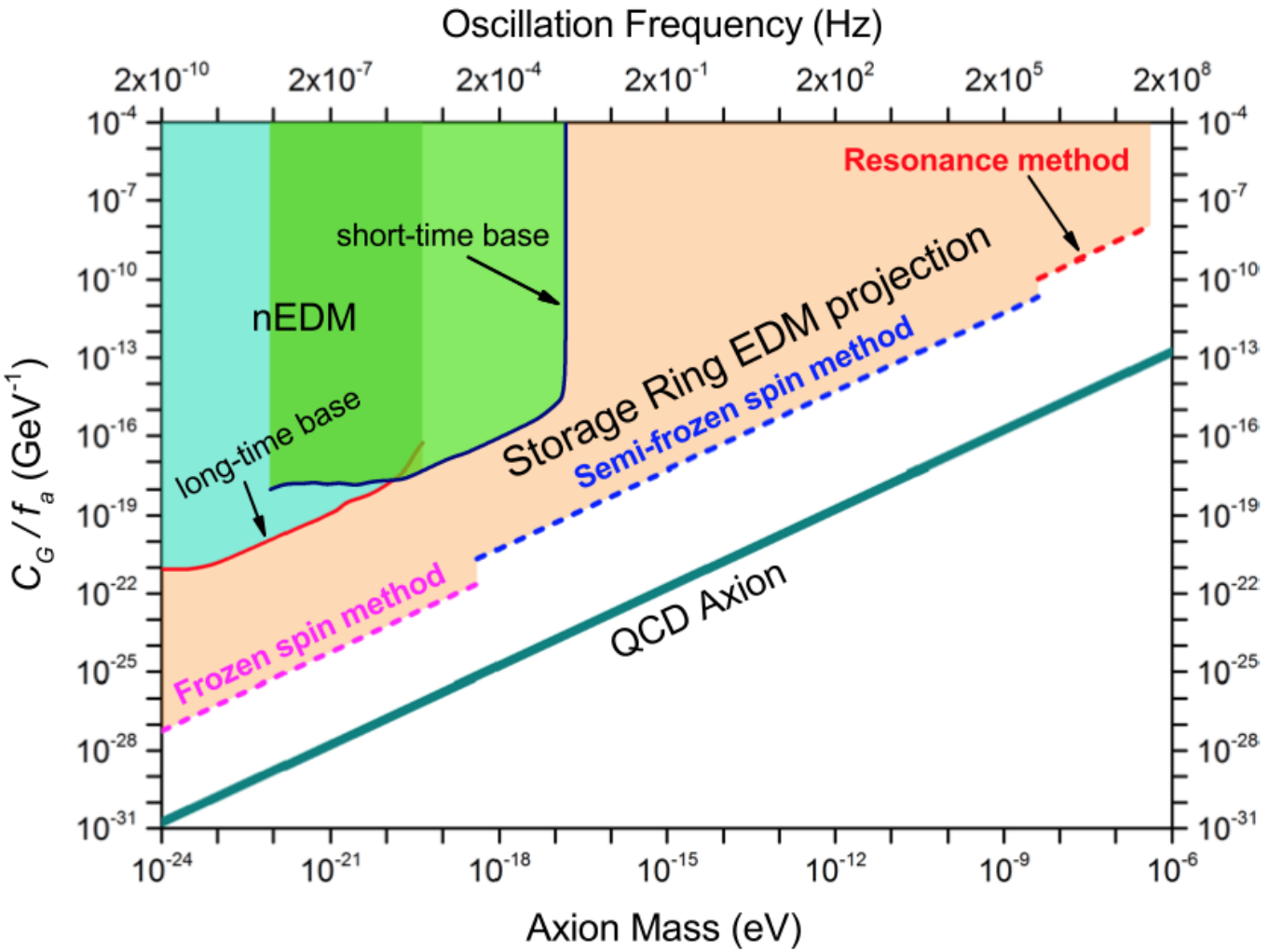
- $\Rightarrow$ New CP-V sources beyond SM needed
- Could show up in EDMs of elementary particles

EDM: Current upper limits



- Presented EoI: EDMs of charged hadrons: *p*, *d*, ^{3}He
- Goal is to bring the limit on p to 10^{-29} e · cm

Axion mass vs gluon coupling



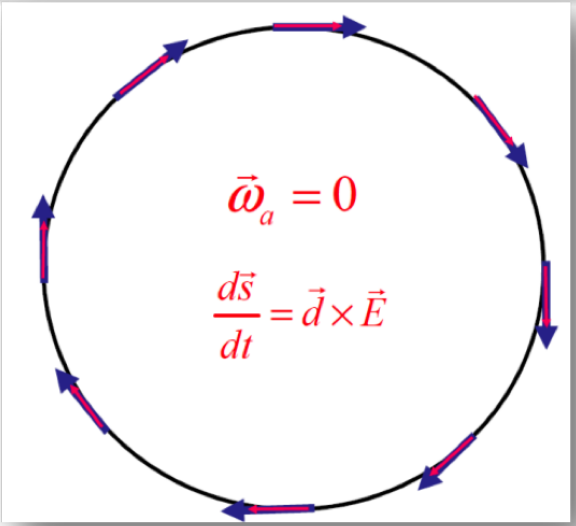
- Experimental limits for the axion-gluon coupled oscillating EDM measurement.
- The nEDM results are included for comparison.

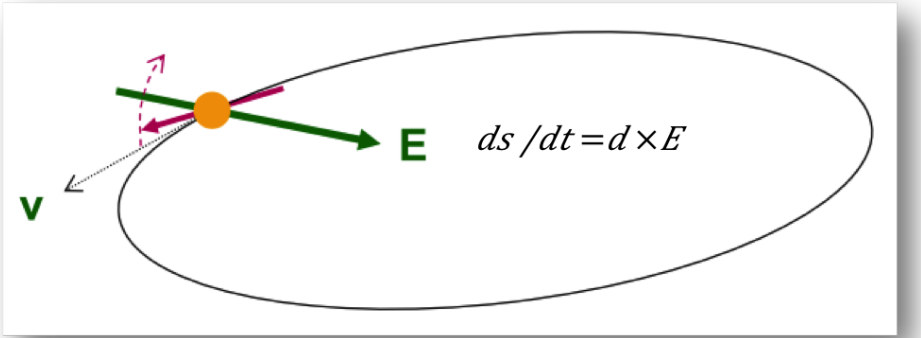
Experimental method

Search for static EDM in storage rings: concept

Pure E ring

1. Inject particles in storage ring
2. Align spin along momentum ($\rightarrow$ freeze horiz. spin-precession)
3. Search for time development of vertical polarization





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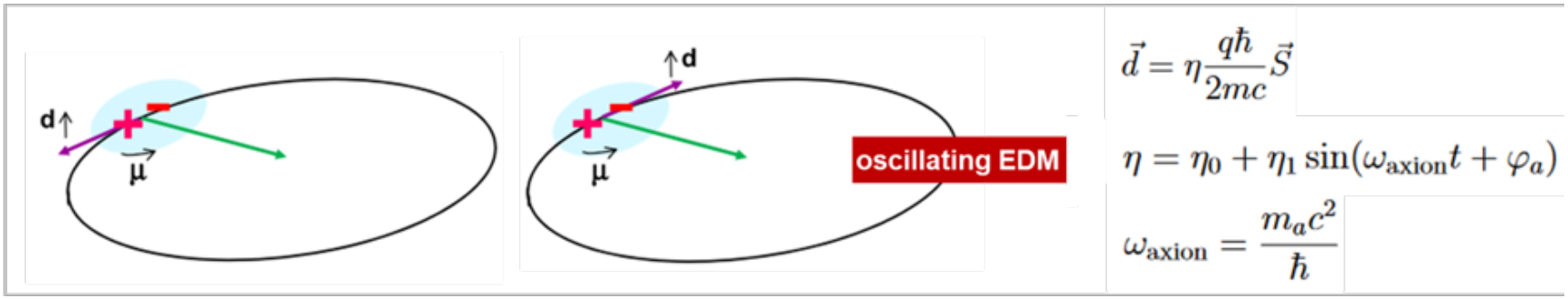


Combined E-B ring

- The particle spin precesses in the horizontal plane due to a magnetic field and its effect on the MDM
- An oscillating EDM (oEDM) at the right frequency, creates a resonant situation in which not only the torque changes sign, but also the EDM vector changes direction, and as a result, one obtains a constructive out-of-plane rotation
- Changing the beam momentum in the storage ring, the precession frequency, the oEDM frequency and thus the Compton frequency, proportional to the axion/ALP mass, can be probed

Towards a storage ring EDM measurement

Staged approach

Stage 1

precursor experiment

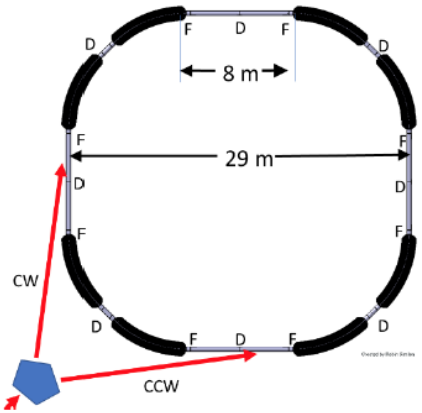
at COSY (FZ Jülich)

- magnetic storage ring

now

Stage 2

prototype ring

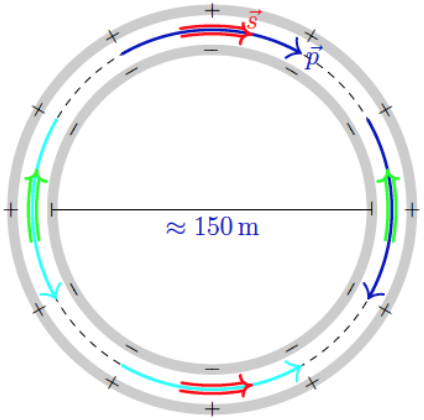


- electrostatic storage ring
- simultaneous ↻ and ↺ beams

5 years

Stage 3

dedicated storage ring



- magic momentum

(701 MeV/c)

10 years

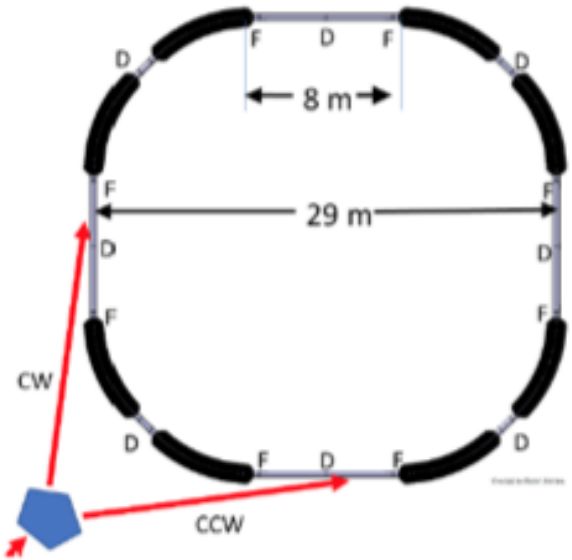
$\sigma_{EDM}/(e \cdot \mathrm{cm})$

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}

Stage 2: prototype EDM storage ring

100 m circumference

- p at 30 MeV all-electric CW-CCW beams operation
- p at 45 MeV frozen spin including additional vertical magnetic fields



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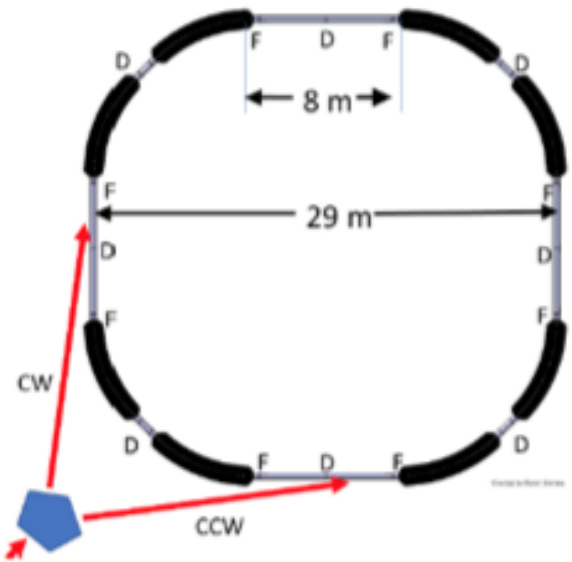


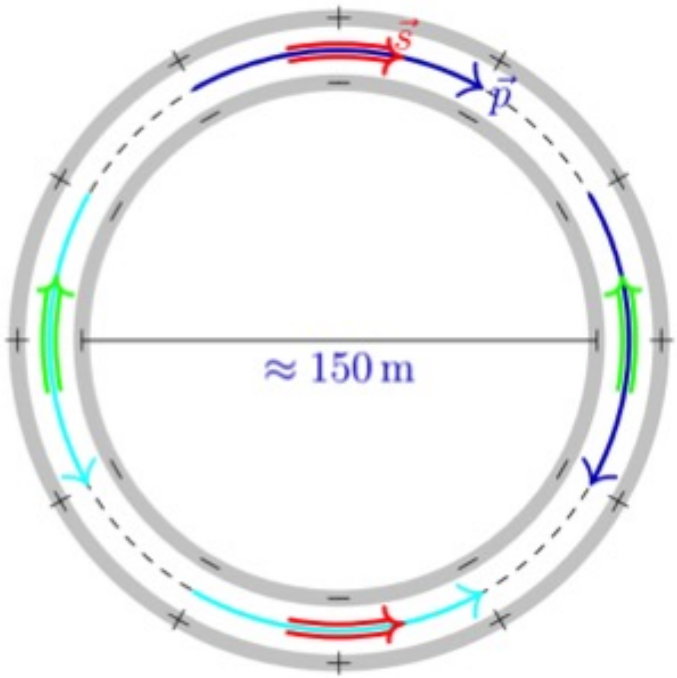
Challenges

- 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

- All-electric deflection
- Magic momentum for protons (p = 701 MeV/c)



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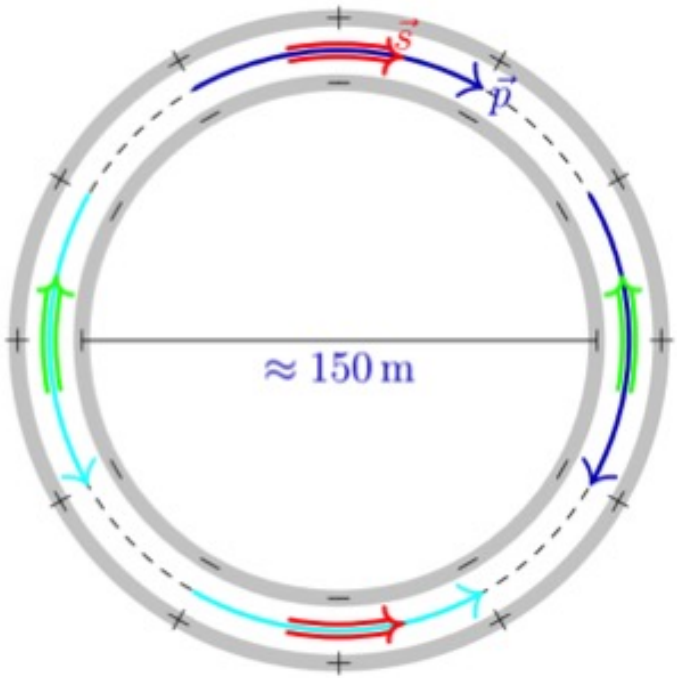

Challenges

- 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)

Conclusions

EDM searches in storage rings offer excellent synergic perspectives between nuclear/hadron, astroparticle physics and accelerator technology

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Search for oscillating EDMs

- Axion gluon coupling
- Dark matter search

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Staged approach to face challenges in accelerator technology

- Precursor measurements at COSY
- Design of a small-scale prototype ring
- Feasibility study of a pure electrostatic EDM proton ring