



SEARCH FOR ELECTRIC DIPOLE MOMENTS AT COSY IN JÜLICH

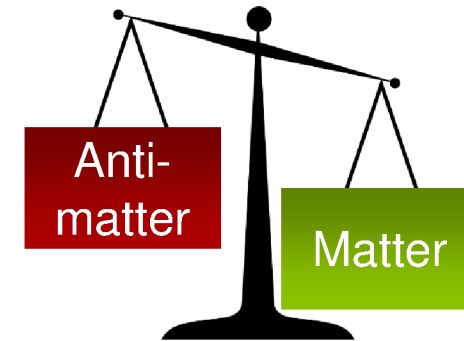
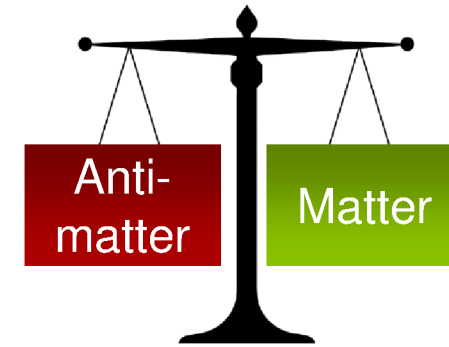
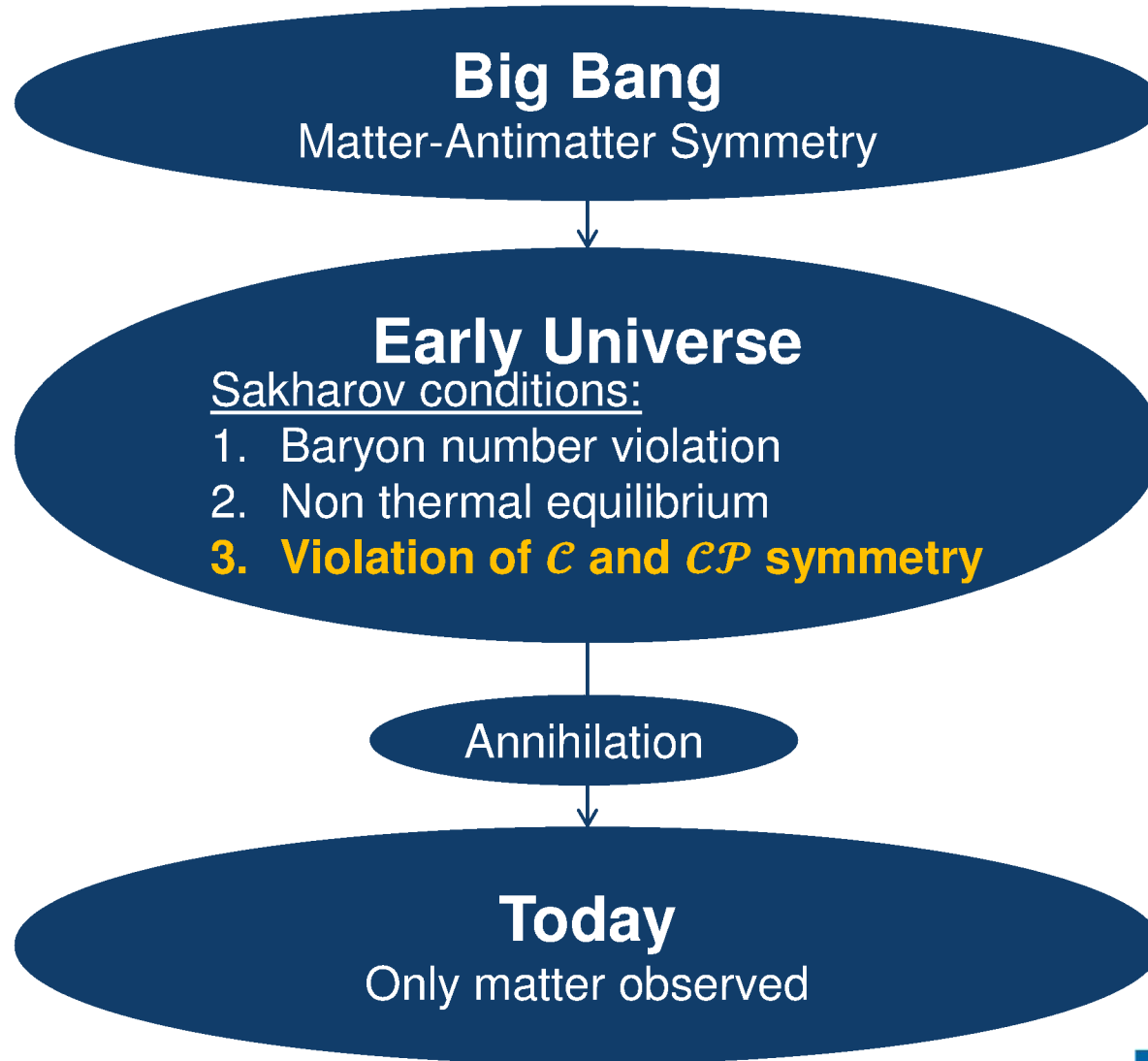
Closed-orbit and spin tracking simulations

19.03.2018 | VERA SCHMIDT on behalf of the JEDI collaboration

CONTENT

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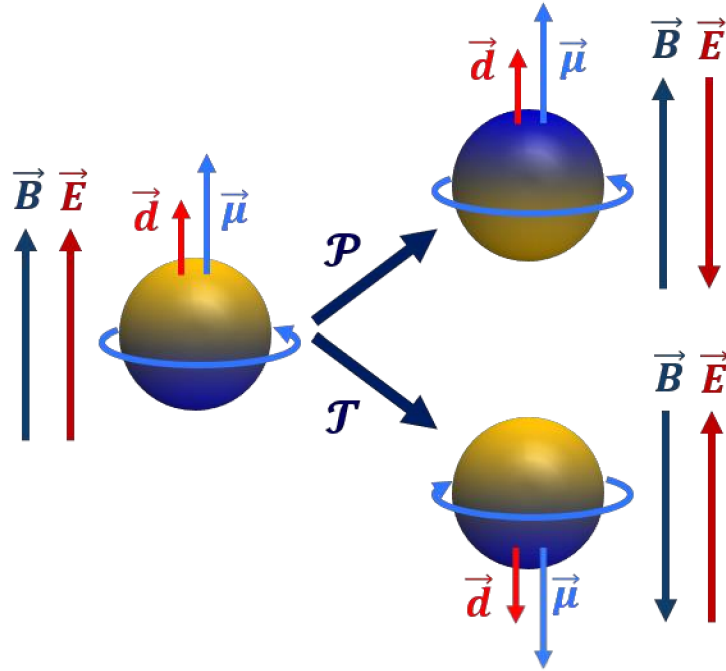
BARYOGENESIS



Baryon-to-photon density ratio	
Measured	$(6.14 \pm 0.25) \cdot 10^{-10}$
Theory	10^{-18}



ELECTRIC DIPOLE MOMENTS (EDMS)



$$\mathcal{H} = -\vec{\mu} \cdot \vec{B} - \vec{d} \cdot \vec{E}$$

$$\mathcal{P}: \mathcal{H} = -\vec{\mu} \cdot \vec{B} + \vec{d} \cdot \vec{E}$$

$$\mathcal{T}: \mathcal{H} = -\vec{\mu} \cdot \vec{B} + \vec{d} \cdot \vec{E}$$

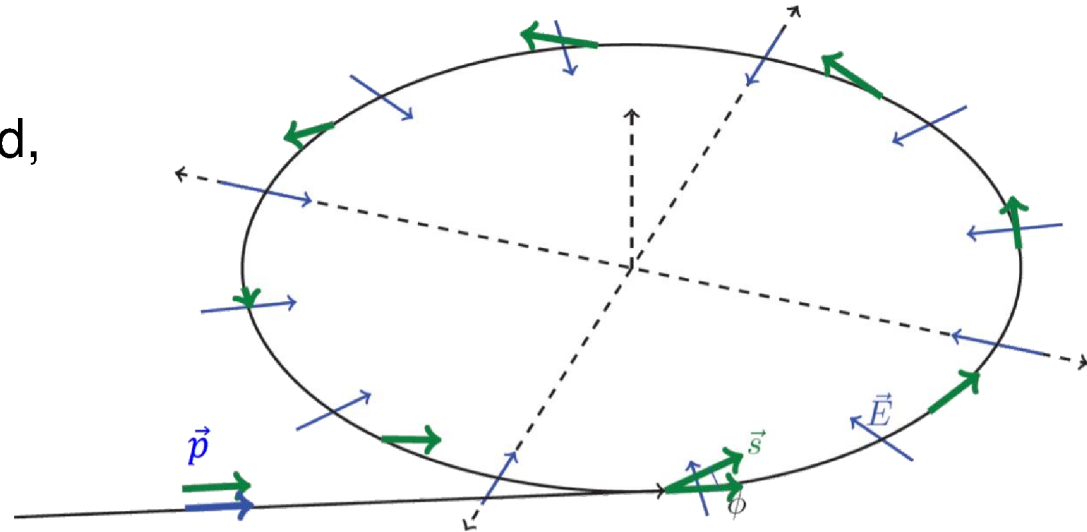
- Permanent EDMs of light hadrons are $\mathcal{T}$ - and $\mathcal{P}$ -violating
 ➔ $\mathcal{CPT}$ theorem $\Rightarrow \mathcal{CP}$ violation
- Measuring EDMs of charged particles in storage rings

EDM		
Classical	$\vec{d} = \sum_i q_i \cdot \vec{r}_i$	Water molecule $d \approx 4 \cdot 10^{-9} e \cdot cm$
QM	$\vec{d} = \eta \cdot \frac{q}{2mc} \vec{S}$	Neutron $d < 3 \cdot 10^{-26} e \cdot cm$

EDM MEASUREMENTS IN STORAGE RINGS

EDM experiments

- Different methods possible: E-field, B-field, combined
- Pictured: pure E-field method
- Interaction of EDM $\vec{d}$ and electric field $\vec{E}$
 $\Rightarrow$ *spin rotation*
- Charged particles: Lorentz force
- Storage ring as particle trap

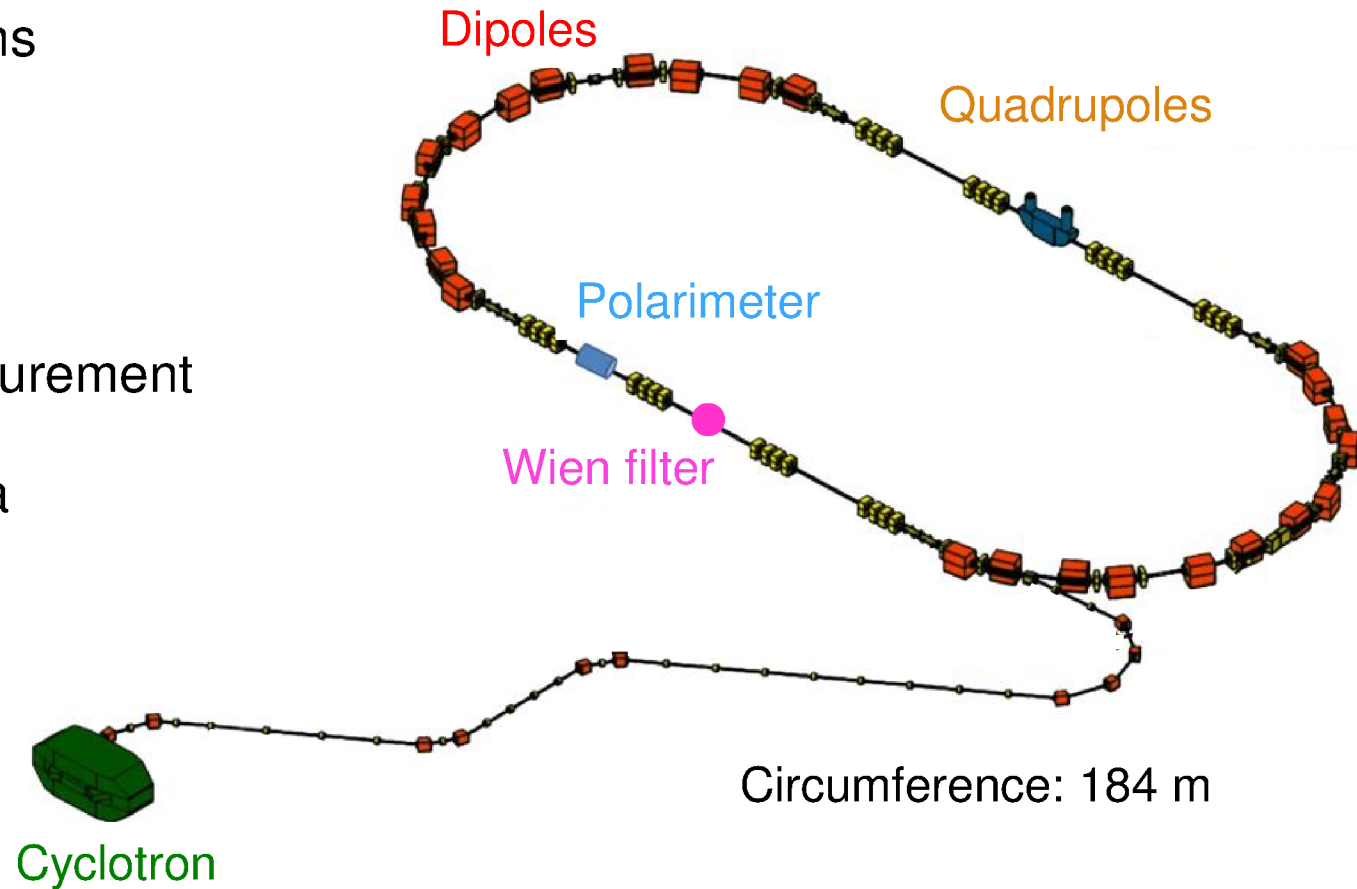


Basic idea:

- Inject particles with $\vec{p} \parallel \vec{s}$
- Apply radial electric field
- For $\vec{d} \neq 0$: spin rotates out of horizontal plane
- Measure: build-up of vertical polarization ($\phi \propto |\vec{d}|$)

COOLER SYNCHROTRON COSY IN JÜLICH

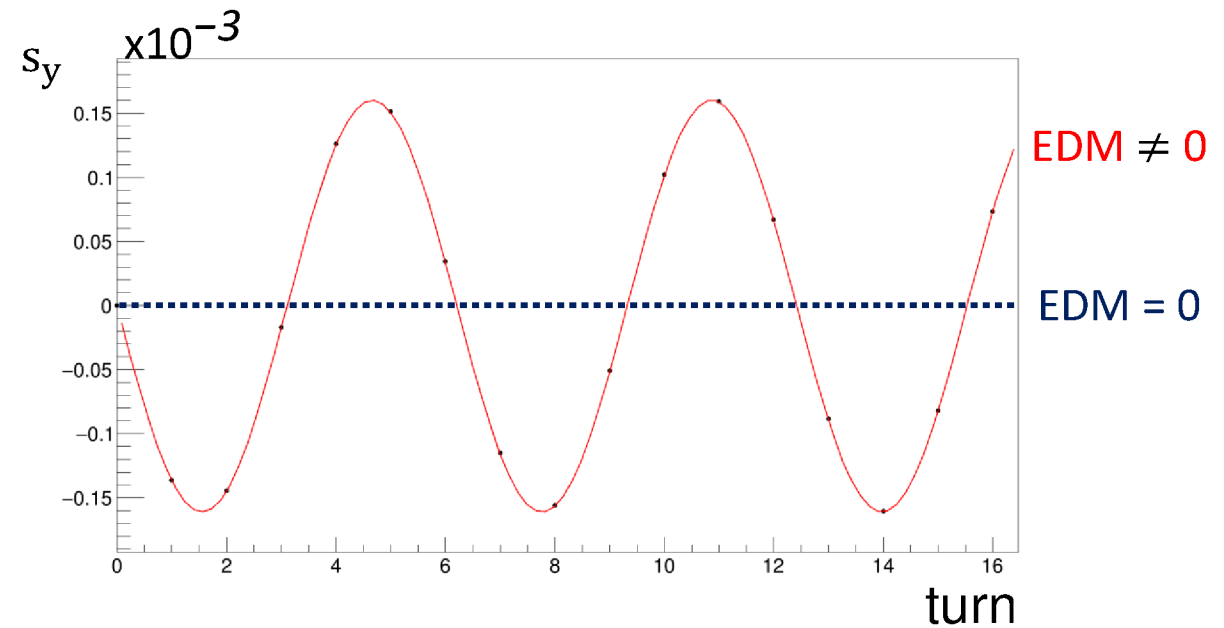
- Polarized protons & deuterons
- Current experiments with deuterons at $p = 970 \text{ MeV}/c$
- RF Wien filter for EDM measurement
- Measuring polarization with a polarimeter



RESONANT WIEN FILTER METHOD

$$\frac{d\vec{S}}{dt} = (\vec{\Omega}_{MDM} + \vec{\Omega}_{EDM}) \times \vec{S} = \left(\frac{q}{m} G \vec{B} + \frac{q\eta}{2m} \vec{\beta} \times \vec{B} \right) \times \vec{S}$$

- Vertical fields
- $\vec{S} \parallel \vec{p}$
- Spin rotates in horizontal plane
- $\vec{d} \neq 0$: vertical spin build-up



→ No net EDM effect

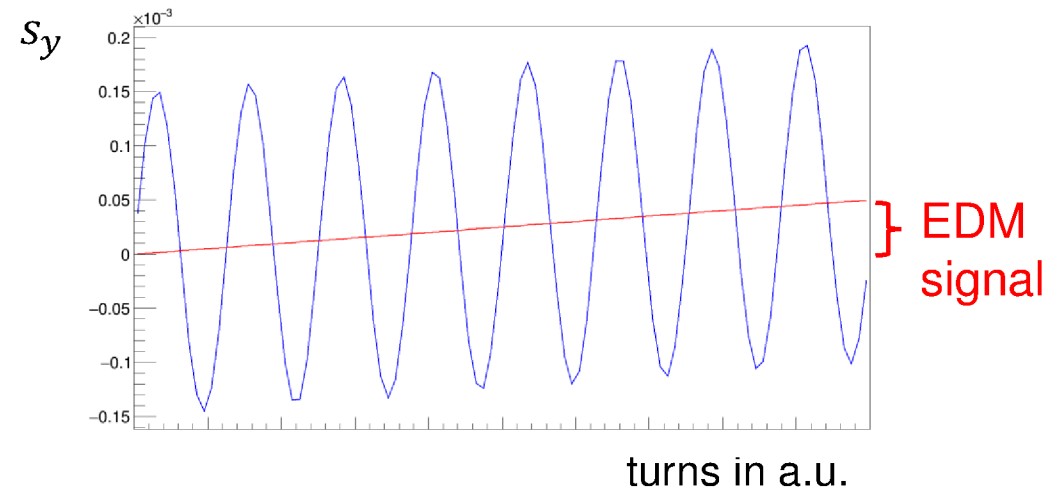
RESONANT WIEN FILTER METHOD

- RF device used to accumulate the EDM signal:

Radial electric field: $E_x \sim \cos(\omega t + \varphi)$

Vertical magnetic field: $B_y \sim \cos(\omega t + \varphi)$

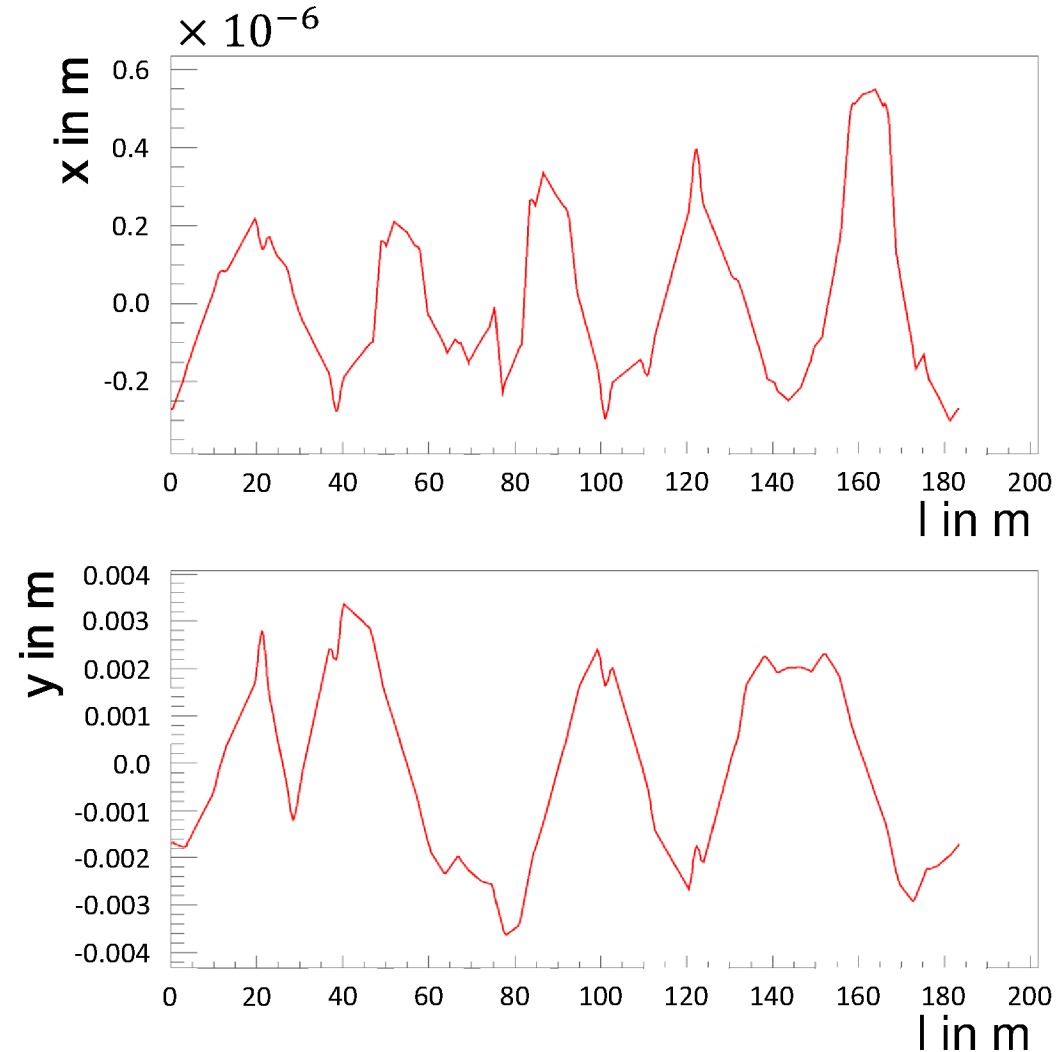
- Wien filter: Lorentz force vanishes $\rightarrow$ no beam perturbation
- RF frequency tuned to horizontal spin precession ($\nu_s \approx -0.161$)



$\rightarrow$ Net EDM effect

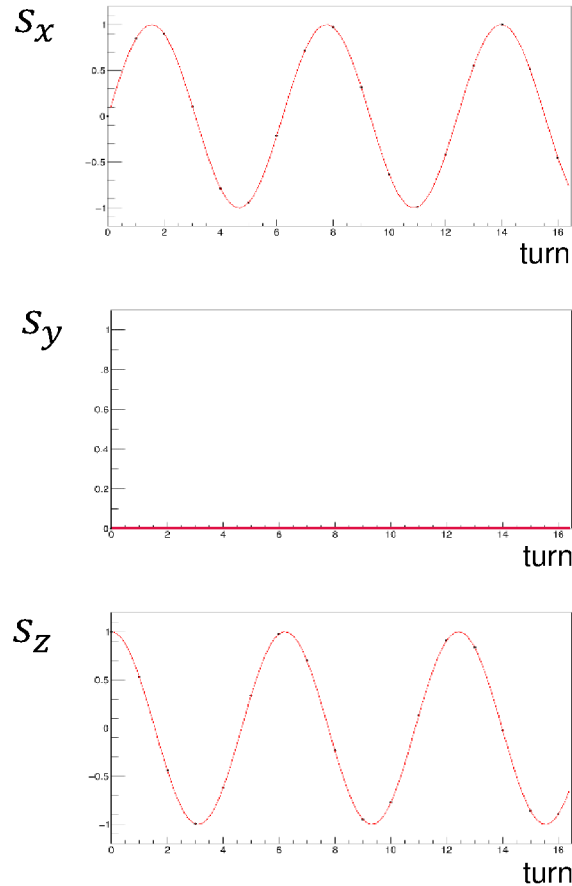
MISALIGNMENT OF QUADRUPOLES

- Disturbed closed-orbit due to QP misalignment
- Spin sees radial magnetic field
- Radial magnetic fields lead to vertical spin build-up

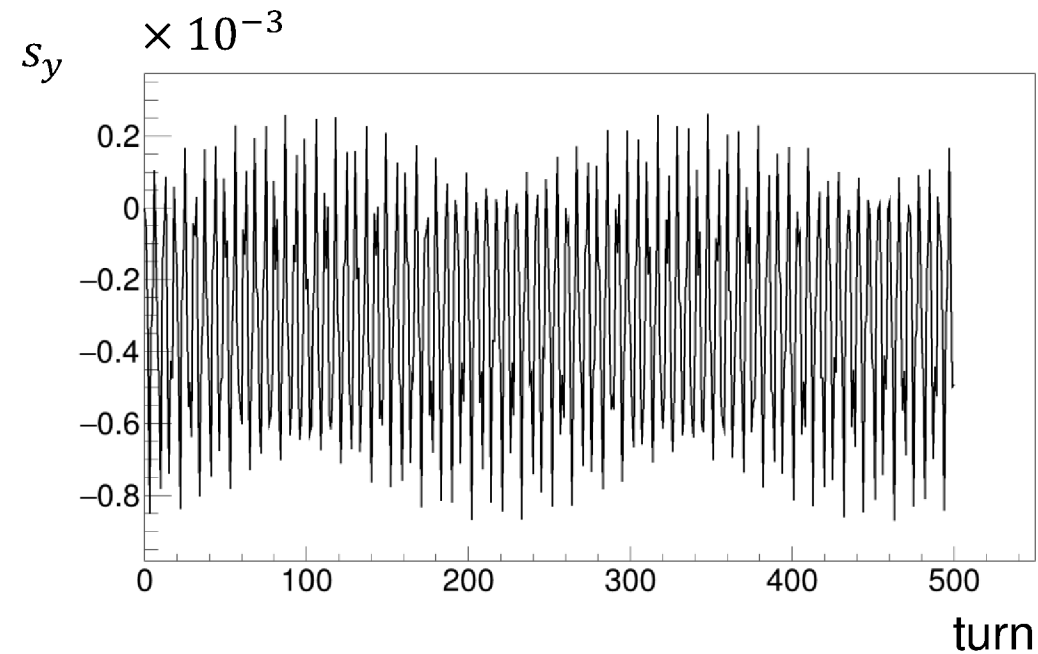


SPIN MOTION AND QP MISALIGNMENTS

$\eta = 0$
(no EDM)

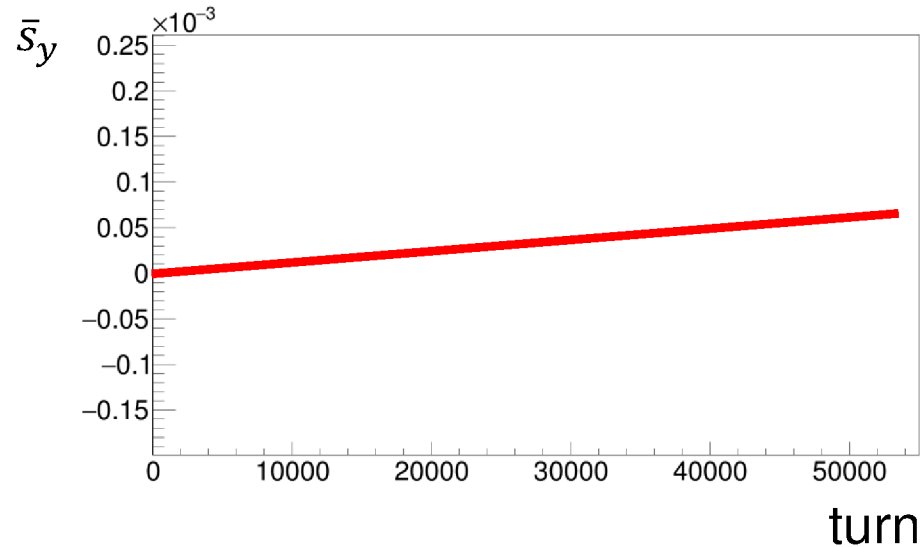


One QP vertically shifted by 1 mm

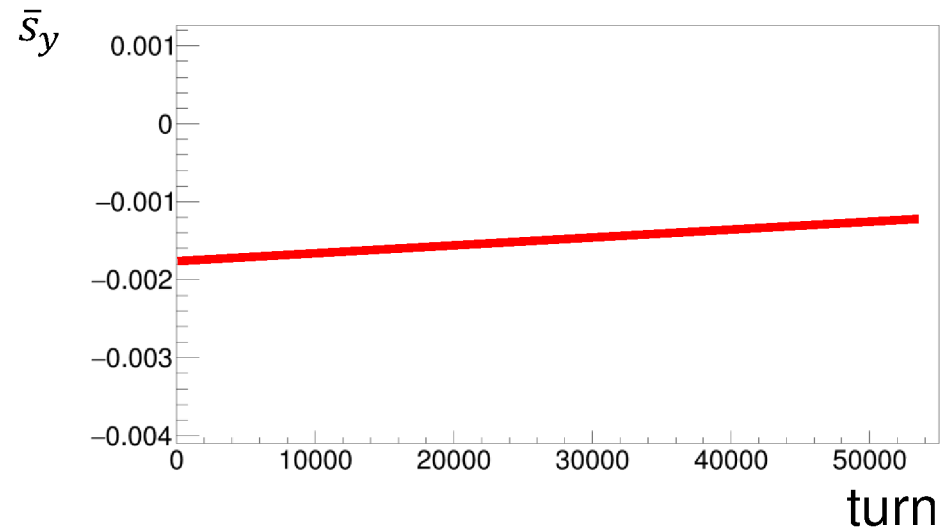


SPIN MOTION AND QP MISALIGNMENTS

$$\eta = 0.0001$$
$$(d \approx 1.5 \cdot 10^{-19} e \cdot cm)$$



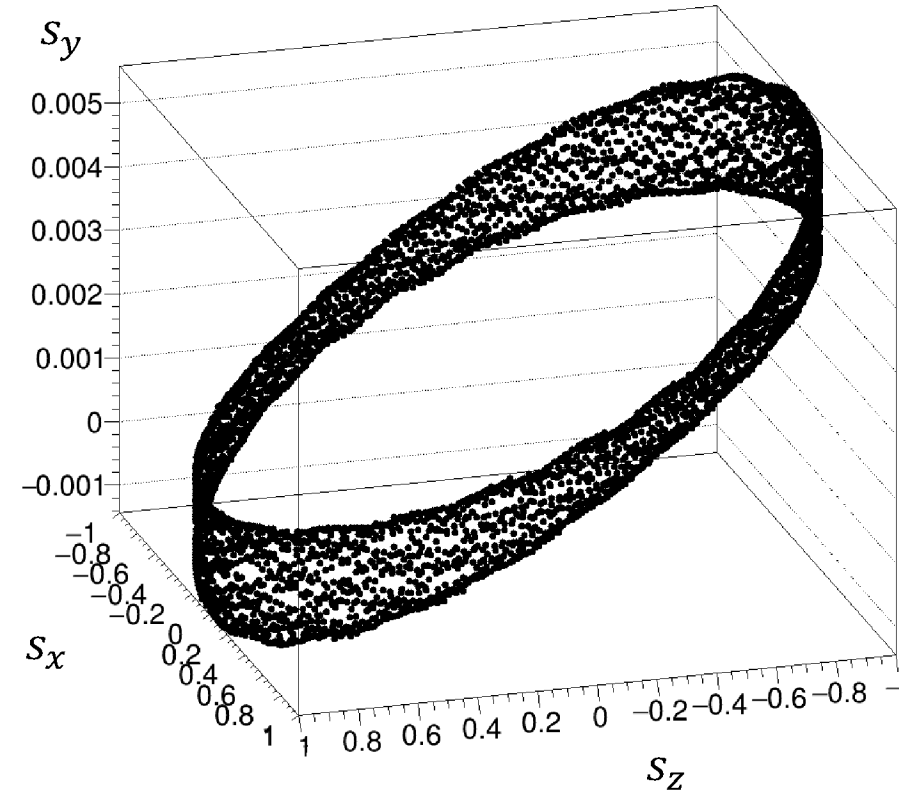
$$\eta = 0 + \text{random QP misalignments}$$
$$(\mu = 0 \text{ mm and } \sigma = 1 \text{ mm } (\sigma = 1 \text{ mrad}))$$



Vertical spin build-up due to EDM and QP misalignments!

INVARIANT SPIN AXIS

- Gaussian distributed QP misalignments with $\mu = 0$ mm ($\mu = 0$ mrad) and $\sigma = 1$ mm ($\sigma = 1$ mrad)
- Reference particle with initial coordinates $x = y = z = 0$

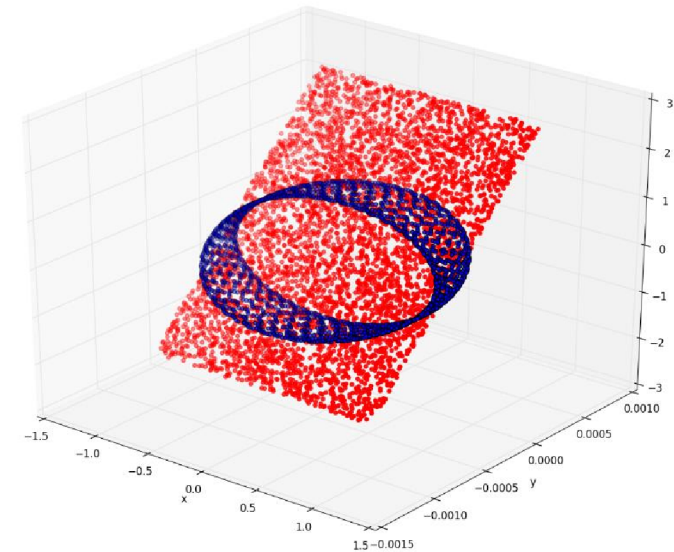
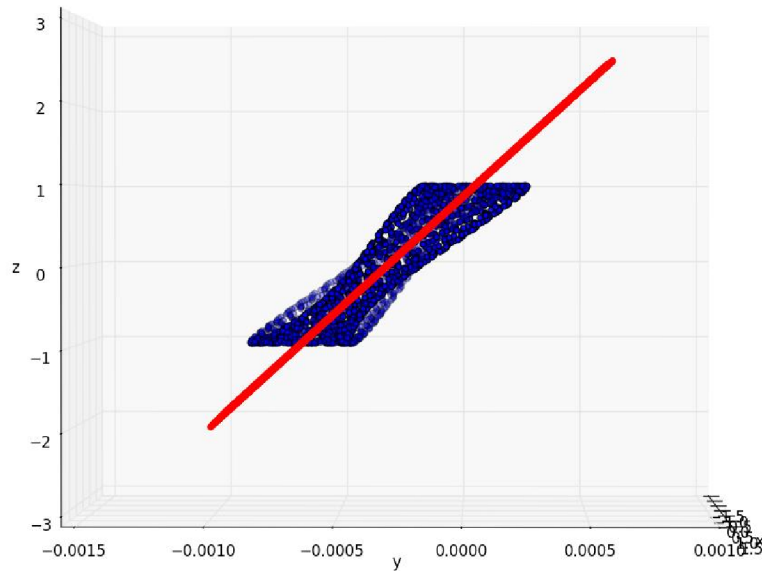


INVARIANT SPIN AXIS

Invariant spin field: $\hat{n}(\vec{z}, \theta + 2\pi) = \hat{n}(\vec{z}, \theta)$

$$R(\vec{z}_i, \theta) \hat{n}(\vec{z}_i, \theta) = \hat{n}(\vec{z}_f, \theta), \quad R: \text{one turn spin map}$$

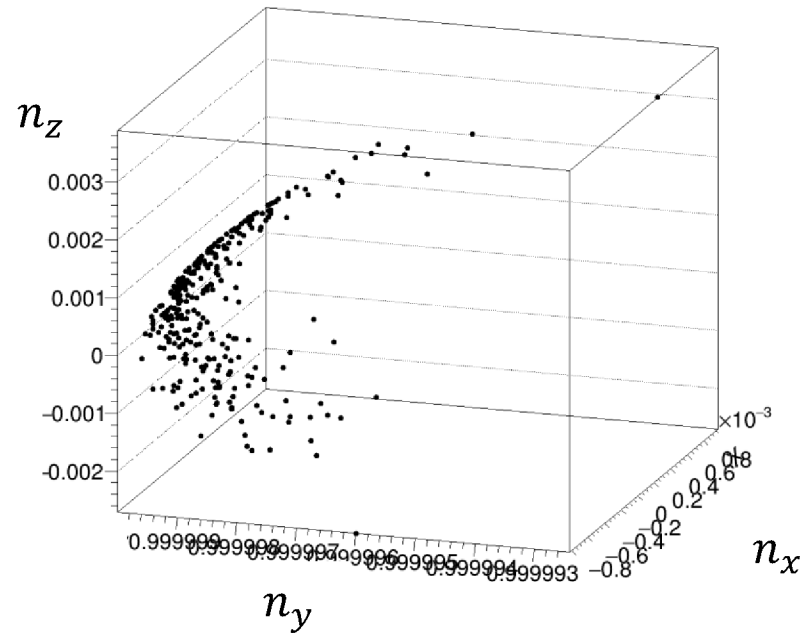
→ Determine **best-fit plane** and find **average spin rotation axis**



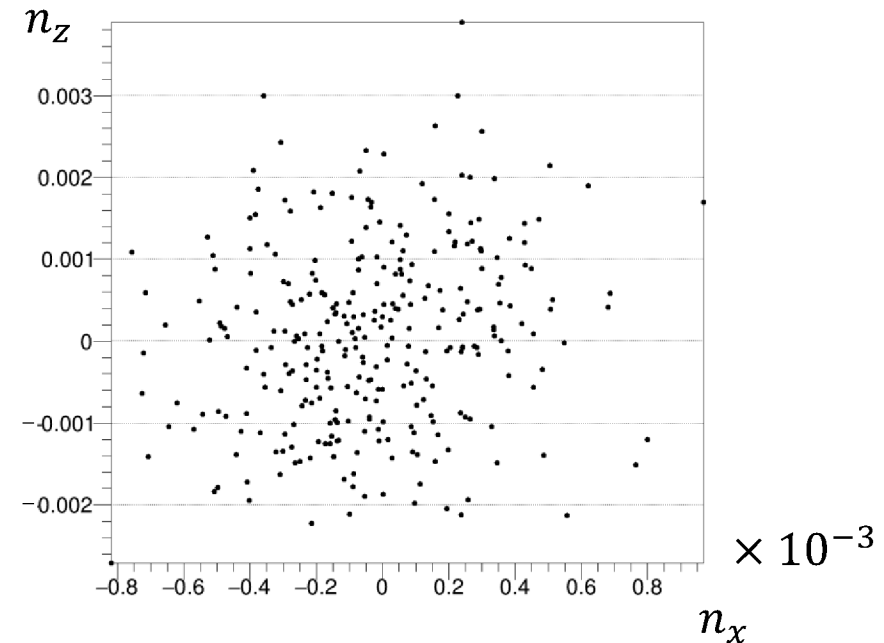
INVARIANT SPIN AXIS

300 sets of random QP misalignments

preliminary



preliminary



$$RMS_{n_z} \approx 0.001 \rightarrow \sigma_{EDM} = 3 \cdot 10^{-18} e \cdot cm$$

SUMMARY & OUTLOOK

- EDMs as candidate for physics beyond the Standard Model
- Measure EDM at COSY with RF Wien filter method
- Quadrupol misalignments lead to disturbed closed-orbit and vertical spin build-up
- Time dependent spin rotation axis $\rightarrow$ averaging over many turns lead to average rotation axis for a fixed set of QP misalignments
- Implementation of measured magnet misalignments at COSY
- Use CW and CCW beams to overcome systematic effects due to misaligned magnets