

BEAM-BASED ALIGNMENT AT COSY Prerequisite for an EDM measurement

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MOTIVATION

Baryon asymmetry

	Standard Model	Observed
$rac{n_B-n_{ar B}}{n_\gamma}$	$pprox 10^{-18}$	$6 imes 10^{-10}$

Criteria for the asymmetry

- Baryon number violation
- C and CP violation
- No thermodynamic equilibrium

Sakharov (1967)



MOTIVATION

CP violation in the Standard Model

- Electroweak sector (CKM Matrix)
 - \rightarrow First observation: 1964 decay of the neutral K meson
- Strong interaction (θ-term)
 - \rightarrow Not observed experimentally (very small)

Predictions are orders of magnitude to small to explain the matter antimatter asymmetry!

New sources for CP violation in the Standard Model are needed.

Possible candidate: **Electric Dipole Moment** of elementary particles



ELECTRIC DIPOLE MOMENT (EDM)

- EDM oriented along the spin axis
- Permanent EDMs of light hadrons are $\mathcal T$ and $\mathcal P$ violating
- \mathcal{CPT} theorem $\rightarrow \mathcal{CP}$ violation
- Measurement of EDMs of charged hadrons in storage rings

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





ELECTRIC DIPOLE MOMENT (EDM)



EDM MEASUREMENT OF CHARGED PARTICLES

Principle: Observe the interaction of the EDM with the electric fields



$$rac{dec{S}}{dt}\sim dec{E} imesec{S}$$

Buildup of vertical polarization $d \propto$ Spin rotation angle





COOLER SYNCHROTRON - COSY

- 184 m circumference
- Polarized protons and deuterons
- Current experiment uses deuterons with p = 970 MeV c⁻¹
- 10⁹ to 10¹⁰ particles
- Electron cooling
- Spin manipulation





WHY IS BEAM-BASED ALIGNMENT NEEDED?

- For an EDM measurement the orbit has to be as good as possible
- Orbit RMS should be lower than 100 μm \rightarrow Orbit Control
- Goal is to go central through all magnets (i.e. quadrupoles)
- Thus BPM to quadrupole offset has to be known
 - \rightarrow Beam-based alignment

Orbit y _{RMS}	"Fake" EDM
1.3 mm	$\sim 10^{-19}$
0.16 mm	$\sim 10^{-20}$



- Use beam to optimize the beam position
- Vary quadrupole strength
- Observe orbit change
- Try to minimize the orbit change





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How does the orbit change when varying the quadrupole strength?

$$\Delta x(s) = \frac{\Delta k \cdot x(s_0)I}{B\rho} \cdot \frac{1}{1 - k \frac{I\beta(s_0)}{2B\rho \tan \pi \nu}} \cdot \frac{\sqrt{\beta(s)}\sqrt{\beta(s_0)}}{2\sin \pi \nu} \cos[\phi(s) - \phi(s_0) - \pi \nu]$$

Not possible to calculate x(s₀) due to lack of precise knowledge of all other parameters

$$f = rac{1}{N_{ ext{BPM}}}\sum_{i=1}^{N_{ ext{BPM}}} \left(x_i(+\Delta k) - x_i(-\Delta k)
ight)^2 \propto \left(rac{oldsymbol{x}(oldsymbol{s}_0)}{oldsymbol{x}(oldsymbol{s}_0)}
ight)^2$$

• By finding the minimum ($f \rightarrow 0$) the optimal beam position can be found



BEAM-BASED ALIGNMENT MEASUREMENT

Constraints and Procedure

- Constraints at COSY
 - Quadrupoles are powered in families of four
 - On the poles of 12 quadrupoles additional back-leg windings are mounted
 - The back-leg windings can be recabled to act as a quadrupole



BEAM-BASED ALIGNMENT MEASUREMENT

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- Constraints at COSY
 - Quadrupoles are powered in families of four
 - On the poles of 12 quadrupoles additional back-leg windings are mounted
 - The back-leg windings can be recabled to act as a quadrupole
- Procedure
 - Effectively the strength of these quadrupoles can be varied
 - Local bumps are applied at the positions of the quadrupoles
 - Observing the effect on the orbit while varying the quadrupole strength



BEAM-BASED ALIGNMENT MEASUREMENT

Locations of the 12 quadrupoles



RESULTS

Examples for the fits



RESULTS

Examples for multiple measurements



Forschungszentrum

RESULTS





SUMMARY

- Beam-based alignment used to determine offset between beam position monitors and quadrupole centers
- Optimal position inside 8 quadrupoles could be determined, 4 still being analysed
- Now known beam position monitor offset can be corrected for to have a better orbit
- Plan to measure all the other quadrupoles without back-leg windings in the ring

