Beam-based alignment at the Cooler Synchrotron (COSY)

Tim Wagner on behalf of the JEDI Collaboration
Forschungszentrum Jülich & RWTH Aachen University

Physics Motivation

Electric Dipole Moment (EDM):

- Fundamental property of a particle, like mass or magnetic dipole moment
- Requires $\mathcal{P}$ and $\mathcal{T}$ $\overset{\mathcal{CPT}}{=}$ $\mathcal{CP}$ violation
- Close connection to matter antimatter asymmetry
- Axions can create oscillating EDM
- Charged particle EDM can be measured in a storage ring. The signal is a build-up of a vertical polarization.

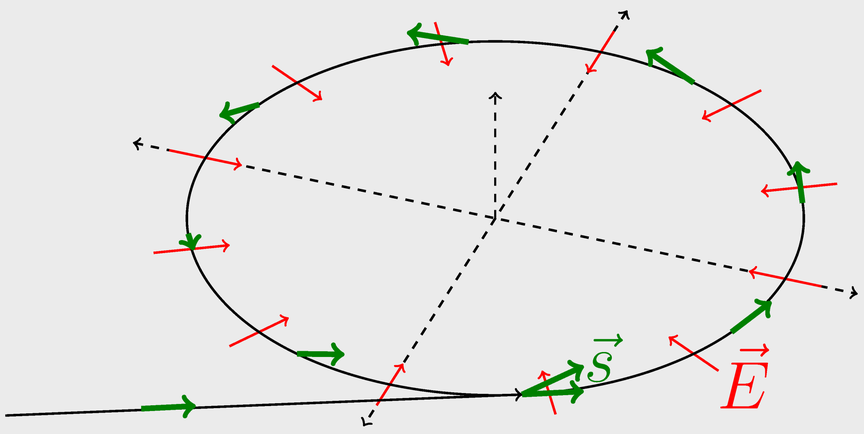

Figure: Basic principle for an EDM measurement. The vertical buildup of the polarization happens due to the interaction of the EDM with the electric field.

- **But:** Orbit distortions lead to a fake signal [1]
  $\rightarrow$ Improve the orbit
  $\rightarrow$ Beam-based alignment

Technique

- Use the beam to optimize the beam position inside quadrupole
- Vary quadrupole strength k by $\pm\Delta k$, then observe and minimize orbit change
- Orbit change [2] described by:

$$\Delta x(s) = \left(\frac{\Delta k x(s_0)\ell}{B\rho}\right)\left(\frac{1}{1 - k\frac{\ell\beta(s_0)}{2B\rho\tan\pi\nu}}\right) \times \frac{\sqrt{\beta(s)}\sqrt{\beta(s_0)}}{2\sin\pi\nu}\cos(\phi(s) - \phi(s_0) - \pi\nu)$$

- Minimized with the following merit function:

$$f = \frac{1}{N_{\mathrm{BPM}}}\sum_{i=1}^{N_{\mathrm{BPM}}}(x_i(+\Delta k) - x_i(-\Delta k))^2$$
$$f \propto (\Delta x(s))^2 \propto (x(s_0))^2$$

- Merit function has the shape of a paraboloid and the minimum is the optimal position in the quadrupole

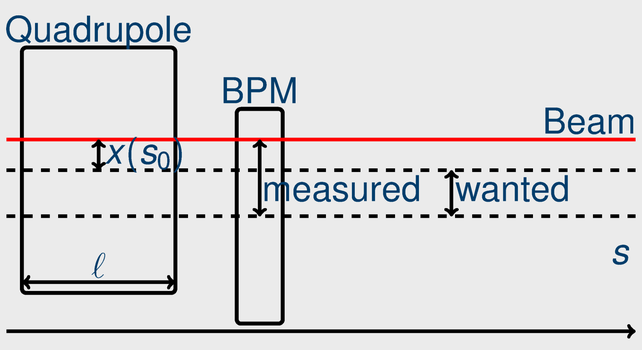

Figure: The optimal beam position is in the center of the quadrupole ($x(s_0) = 0$). When that point is found one can determine the offset between the BPM and the quadrupole.

Results

- Measurement performed for 12 quadrupoles
- Beam moved inside the quadrupoles to different horizontal and vertical positions

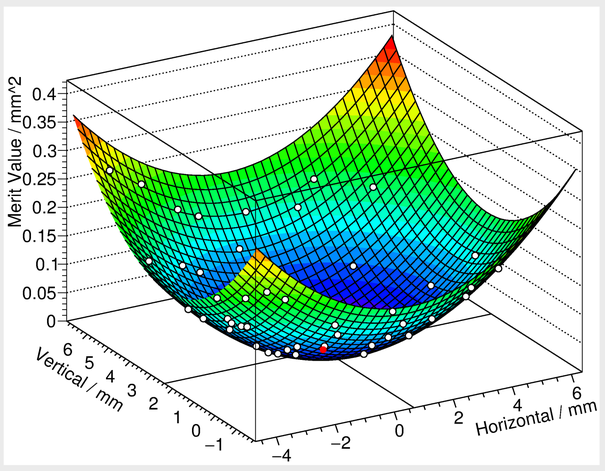

Figure: Example for one measurement of the beam based alignment. The x- and y-axis show the beam position inside the quadrupole and the z-axis shows the evaluated merit function. The white dots are measured points and the red dot is the minimum of the fit, i.e. the optimal position.

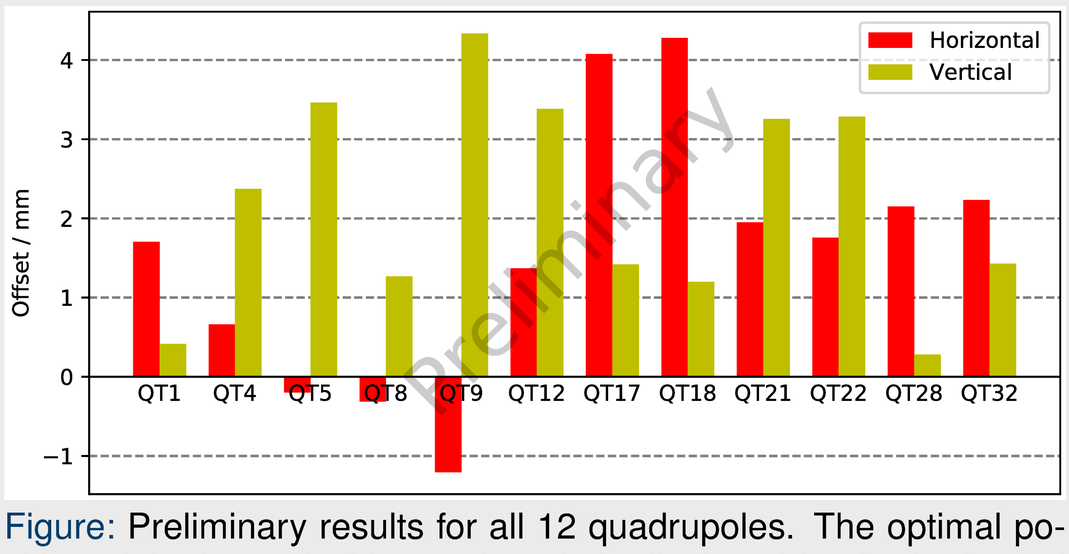

Figure: Preliminary results for all 12 quadrupoles. The optimal position of the beam inside quadrupole is displayed for the horizontal and vertical direction. The optimal position can be used to determine the offset of nearby beam position monitors.

- With these optimal positions inside the quadrupoles the offset for 6 beam position monitors has been calculated
- The new offsets lead to an improvement of the corrected orbit in the accelerator

	Orbit RMS$_y$	Steerer Current RMS
no offsets	1.21 mm (100%)	2.66 A (100%)
with offsets	1.01 mm (83%)	2.10 A (79%)

- Lower orbit RMS leads to a lower systematic error for an EDM measurement
- Measurement of all 56 quadrupoles in COSY planned in the future to calibrate all BPMs and further improve the orbit

References

[1] M. S. Rosenthal. "Experimental Benchmarking of Spin Tracking Algorithms for Electric Dipole Moment Searches at the Cooler Synchrotron COSY". PhD thesis. RWTH Aachen University, 2016.

[2] G. Portmann et al. "Automated beam based alignment of the ALS quadrupoles". In: *Conf. Proc.* C950501 (1996), pp. 2693–2695.

Contact: Tim Wagner - t.wagner@fz-juelich.de