ACCURATE POSITION CALIBRATION OF BEAM POSITION MONITORS IN STORAGE RINGS

Beam-based alignment at COSY

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JEDI

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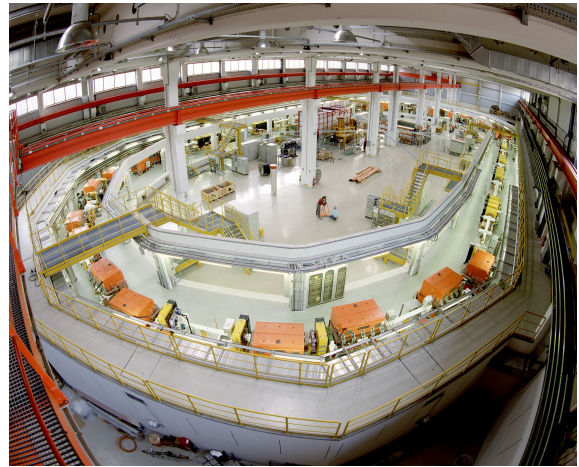
OVERVIEW

- Cooler Synchrotron COSY in Jülich
- Why is a calibration of beam position monitors needed?
- Method of beam-based alignment
- Measurements done up to now
- Measurements in the future

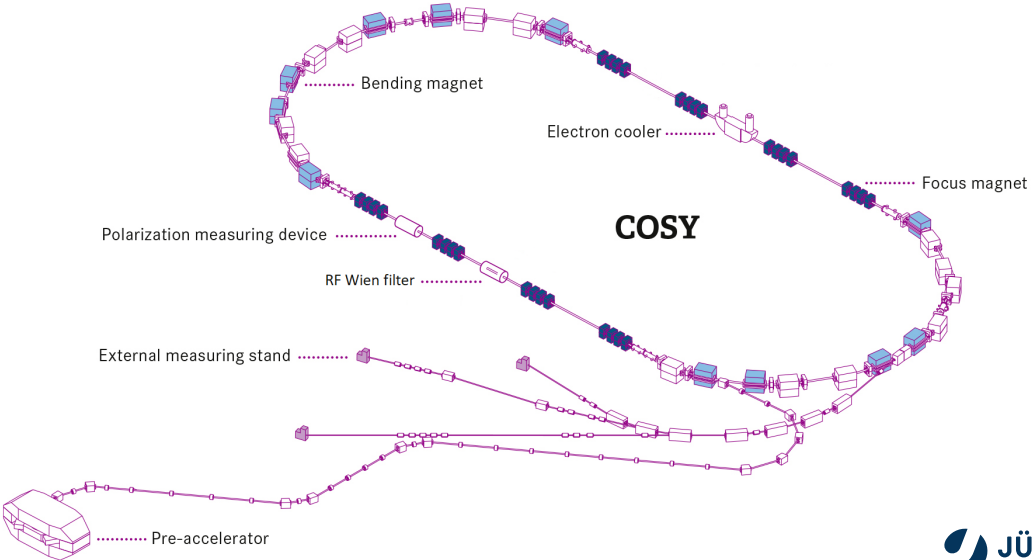

COSY

COOLER SYNCHROTRON - COSY

- 184 m circumference
- Polarized protons and deuterons
- 10^9 to 10^{10} particles
- Electron cooling
- Spin manipulation
- Current JEDI experiment uses deuterons with $p = 970\,\mathrm{MeV\,c^{-1}}$
- JEDI collaboration measures the electric dipole moment of deuterons



COOLER SYNCHROTRON - COSY



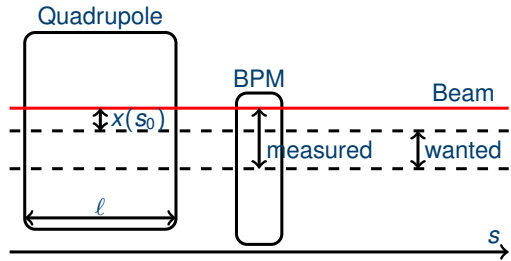
WHY IS A POSITION CALIBRATION NEEDED?

- Regular surveys of the accelerator make sure that the magnets are aligned properly
- Surveys use markers mounted on magnets as reference points
- Beam position monitors (BPMs) do not have those markers, thus exact positioning is not known precisely

- Want to have a good orbit with a small RMS for the electric dipole measurement
- Need method to measure the exact positioning of the BPM to have a well known orbit $\rightarrow$ Beam-based alignment

HOW DOES BEAM-BASED ALIGNMENT WORK?

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



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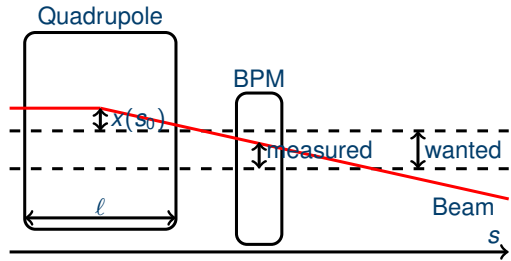

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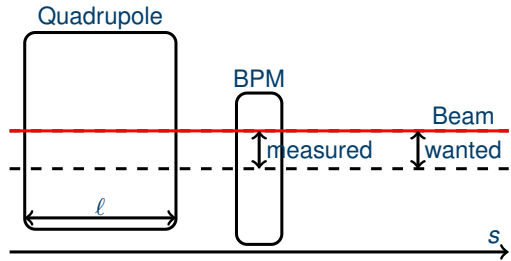

HOW DOES BEAM-BASED ALIGNMENT WORK?

- How does the orbit change when varying the quadrupole strength?

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

- Not possible to calculate $x(s_0)$ due to lack of precise knowledge of all other parameters

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

- By finding the minimum ($f \to 0$) 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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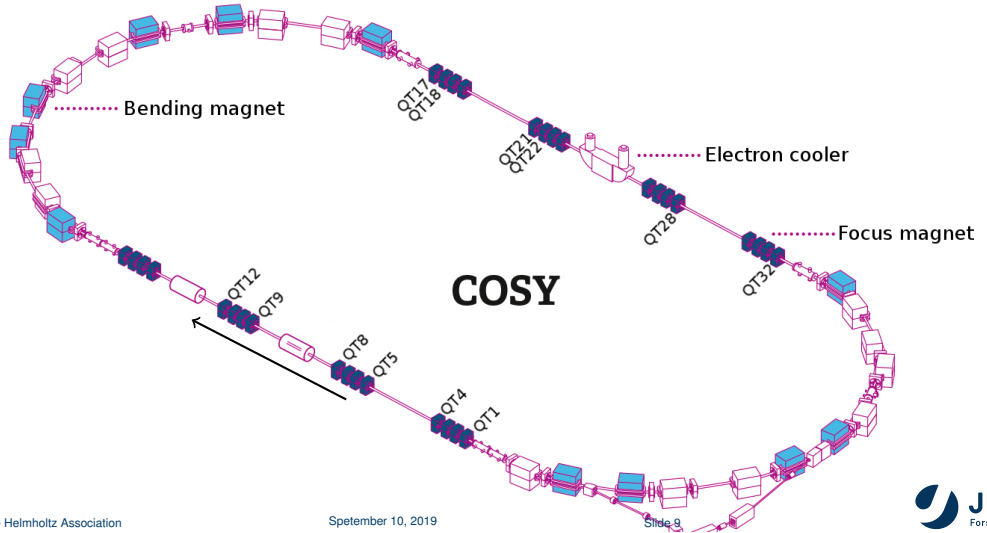
- Procedure
  - Effectively the strength of these quadrupoles can be varied
  - Local bumps are applied at the positions of the quadrupoles
  - Observing the effect on the orbit while varying the quadrupole strength

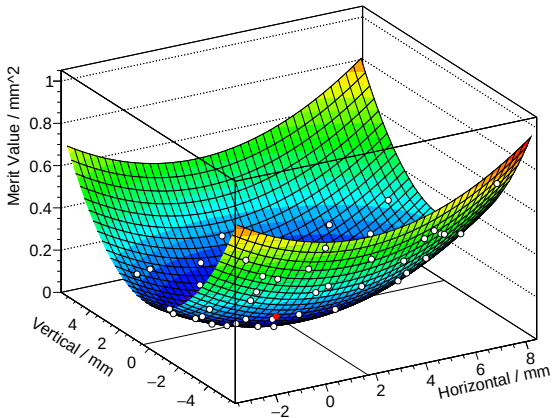
BEAM-BASED ALIGNMENT MEASUREMENT

Locations of the 12 quadrupoles

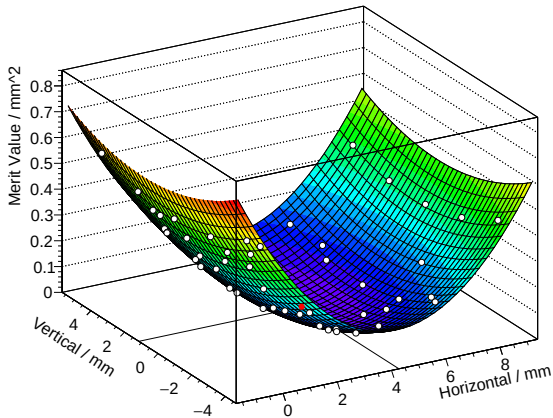


RESULTS

Examples for the fits

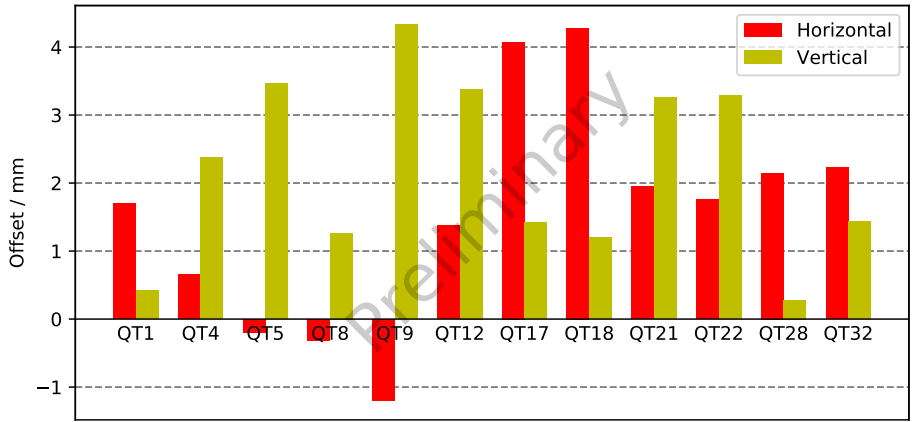


QT1, $\frac{\chi^2}{\text{d.o.f.}} = 0.96$



QT18, $\frac{\chi^2}{\text{d.o.f.}} = 1.77$

RESULTS


Horizontal
Vertical
Offset / mm
4
3
2
1
0
−1
QT1
QT4
QT5
QT8
QT9
QT12
QT17
QT18
QT21
QT22
QT28
QT32
Preliminary

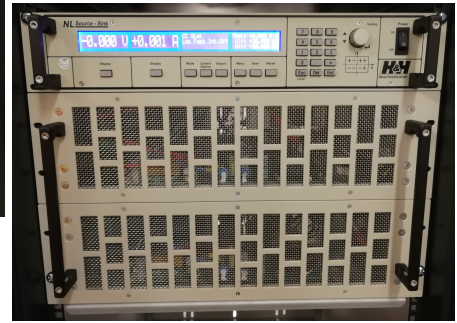
RESULTING BPM CALIBRATION

BPM name	Horizontal correction	Vertical correction
BPM02 (s = 10.4 m)	(1.705 ± 0.008) mm	(0.416 ± 0.005) mm
BPM06 (s = 29.5 m)	(1.371 ± 0.007) mm	(3.382 ± 0.011) mm
BPM18 (s = 100.2 m)	(4.177 ± 0.007) mm	(1.308 ± 0.005) mm
BPM19 (s = 110.1 m)	(1.868 ± 0.005) mm	(3.273 ± 0.010) mm
BPM20 (s = 123.3 m)	(2.149 ± 0.007) mm	(0.281 ± 0.007) mm
BPM21 (s = 133.2 m)	(2.232 ± 0.008) mm	(1.430 ± 0.006) mm

Resulting orbit improvement from $\mathrm{RMS}_y = 1.21$ mm to 1.01 mm
with only 20% of the BPMs calibrated.

MEASUREMENT FOR ALL QUADRUPOLES

- New power supplies bought
- All quadrupoles are equipped with connectors for the power supplies
- “Plug and play” system can be operated by nearly everyone



- Faster change of quadrupole during the measurement and also possible at any time
- Measurement will start end of September

SUMMARY

- Beam-based alignment used to determine offset between beam position monitors and quadrupole centers
- Optimal position inside 12 quadrupoles could be determined at COSY
- Now known beam position monitor offset can be corrected for to have a better orbit

- There are 56 quadrupoles in total in COSY to be measured
- Plan to measure all the quadrupoles in the ring starting end of September