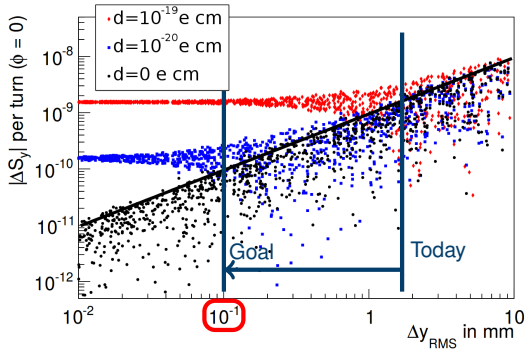
BEAM-BASED ALIGNMENT

Determining BPM offsets and quadrupole alignment

March 17, 2020 | Tim Wagner | IKP-2, Forschungszentrum Jülich

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
  → Orbit Control
- Goal is to go central through all magnets (i.e. quadrupoles)
- Thus BPM to quadrupole offset has to be known
  → Beam-based alignment



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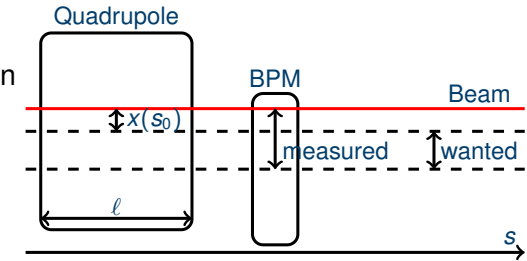
HOW DOES BEAM-BASED ALIGNMENT WORK?

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



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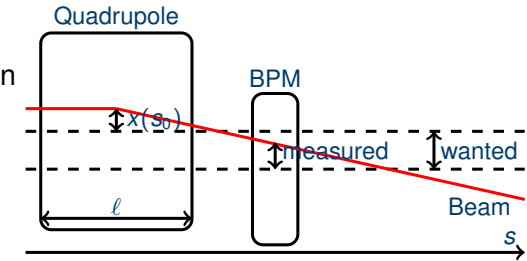

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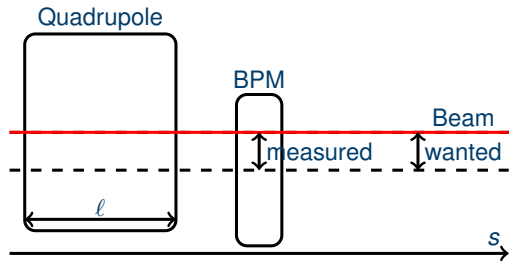


HOW DOES BEAM-BASED ALIGNMENT WORK?

- 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

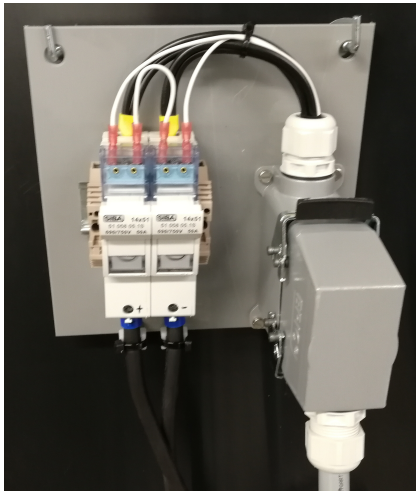
Procedure

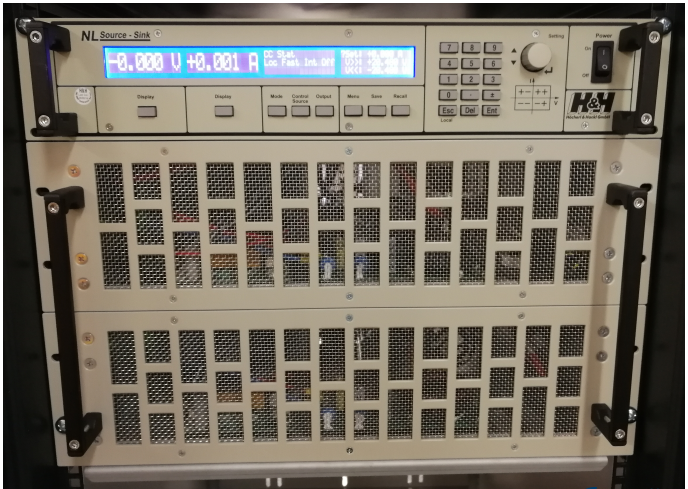
- Four additional mobile power supplies for the quadrupoles
- Apply bumps of different sizes at the position of the quadrupole
- Vary the current through the quadrupole
- Measure the effect on the orbit

- When done connect the power supplies to the next quadrupoles during a short access to the COSY tunnel

BEAM-BASED ALIGNMENT MEASUREMENT

Instrumentation





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BEAM-BASED ALIGNMENT MEASUREMENT

Instrumentation

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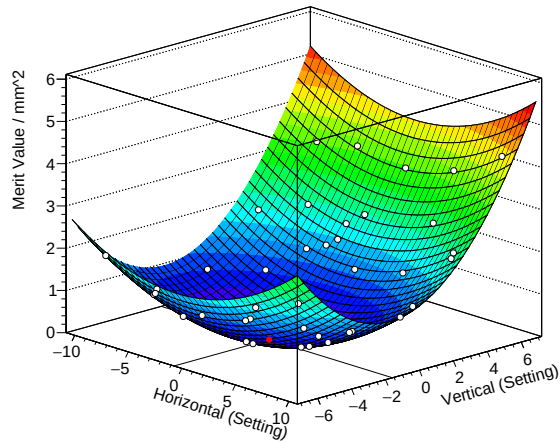
HOW DOES THE ANALYSIS WORK?

Example Run 282 - QT04

- Minimum is located at -0.736 ± 0.010 horizontally and -1.5853 ± 0.0033 vertically in script setting
- Expected merit value at that point is -0.0016 ± 0.0013, which is compatible with zero
- $\chi^2/\text{d.o.f.} = 30.69/35 = 0.88$



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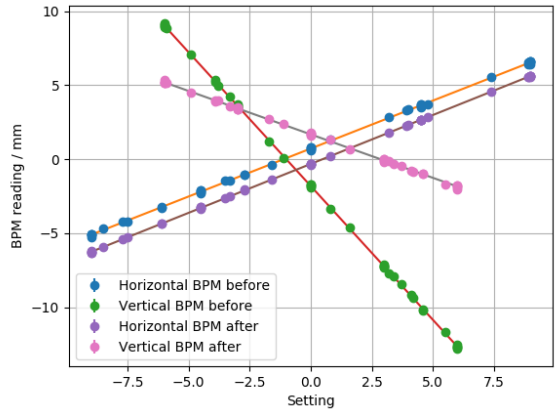
HOW DOES THE ANALYSIS WORK?

Example Run 282 - QT04

- Minimum is located at -0.736 ± 0.010 horizontally and -1.5853 ± 0.0033 vertically in script setting
- Conversion into the position in mm inside the Quadrupole with nearby BPMs while taking steerers into account
- SV02 @ 10bit = -0.018 mrad Kick
- Final optimal position (-0.275 ± 0.013) mm horizontally and (1.791 ± 0.017) mm vertically



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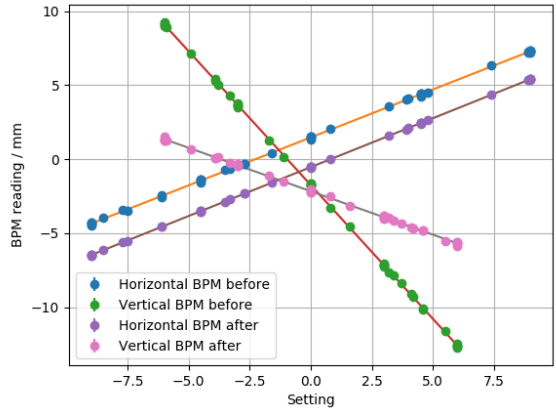
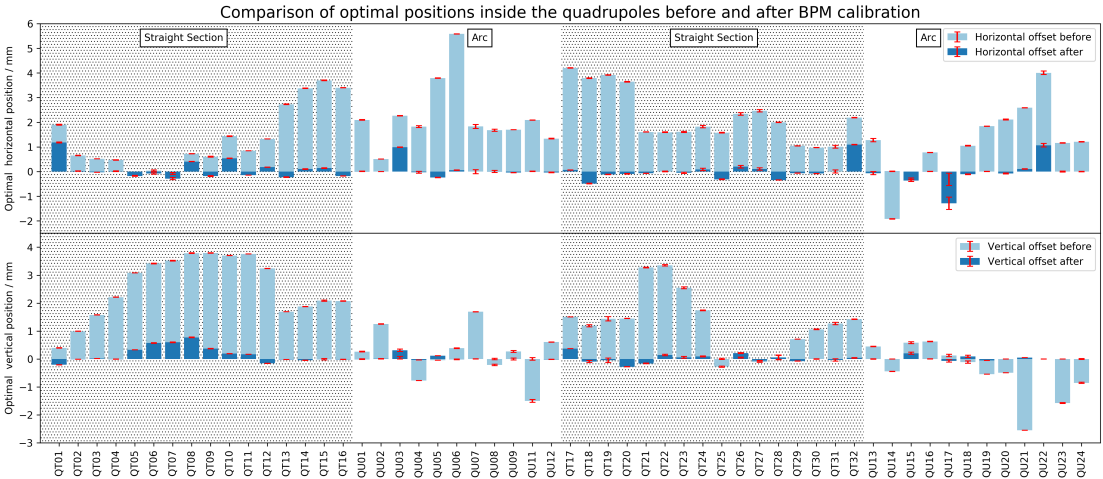
HOW DOES THE ANALYSIS WORK?

Example Run 282 - QT04

- With that value and all the other quadrupoles one can recalibrate the BPMs
- New analysis done with new offsets applied artificially via software
- New optimal position (0.001 ± 0.013) mm horizontally and (-0.005 ± 0.017) mm vertically



RESULTS



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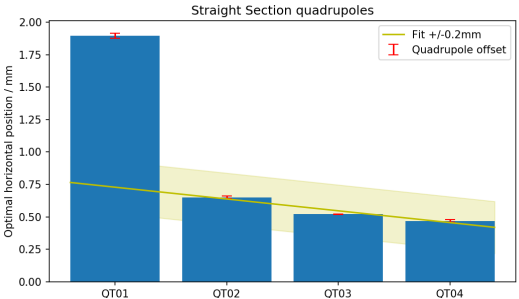
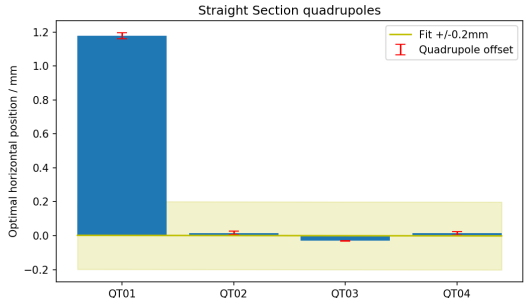
RESULTS

Not everything is nicely aligned...



Before calibration



After calibration

- It was assumed that all quadrupoles are aligned with a precision of 0.2 mm
- BBA measurement shows that this is not true
- Is there a disagreement with the alignment campaign by Stollenwerk?

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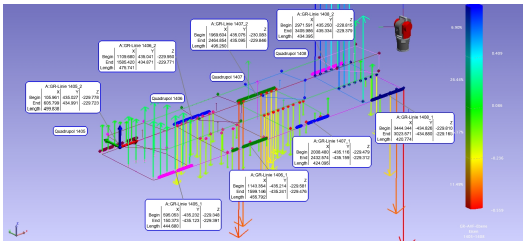
RESULTS

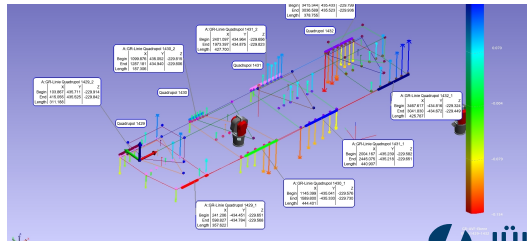
Quadrupoles that are not on axis with their family

- QT01 horizontally by about 1.2 mm
- QT08 horizontally by about 0.7 mm
- QT10 horizontally by about 0.6 mm
- QT18 horizontally by about -0.5 mm
- QT32 horizontally by about 1.1 mm

COMPARISON WITH STOLLENWERK MEASUREMENTS

- Measurements from Stollenwerk state that all quadrupoles are aligned to below 0.2 mm
- BBA measurement seems to disagree (some are off by up to 1.2 mm)
- Local more detailed measurement of the magnets in question performed
- In the end rotations, which are not visible with the BBA measurement, explain the discrepancy and both are in agreement





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RESULTS

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RESULTS

Orbit correction test

- Orbit corrected twice, once with offsets before BBA and once with offsets after BBA
- Unfortunately four steerers for both directions were kept fixed due to the electron cooler and thus the performance is not as good as it could be

	Orbit RMS		Steerer RMS	
	Horizontal	Vertical	Horizontal	Vertical
Before BBA	2.27 mm*	1.09 mm	5.03%	4.39%
After BBA	3.26 mm*	0.52 mm	3.90%	0.79%

Vertical orbit is better by a factor 2 while also needing less steerers by a factor 5.

*For the orbit correction four steerers (both directions) around the electron cooler were excluded from the orbit correction. Thus that part could not be corrected well and the horizontal orbit was 10 mm off in that straight section. This leads to these high RMS values and is not representative of the actual performance.

SUMMARY

- Optimal position inside quadrupoles could be determined
- It was seen that some quadrupoles within their families are off by up to 1.2 mm
- New BPM offsets could be determined
- Overall quite good improvement of the beam position inside the quadrupoles when new offsets are applied
- Orbit RMS decreased by a factor of 2 (to 0.52 mm) while the needed steerer strength decreased by a factor of 5