BEAM BASED ALIGNMENT

Beam time request on Beam-based alignment

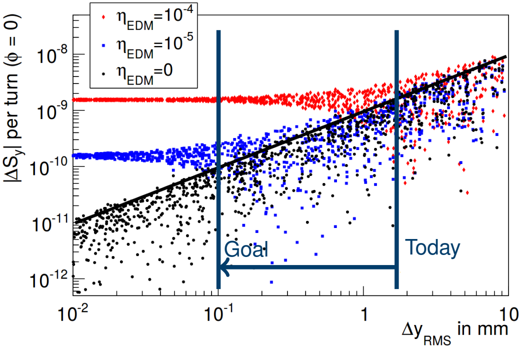
July 2, 2018 | Tim Wagner, on behalf of the JEDI Collaboration | Institut für Kernphysik, Forschungszentrum Jülich

OUTLINE

- Introduction
  - Why is beam-based alignment needed?
  - How does it work?
- Progress so far
  - What has been measured until now?
  - What are the results?
- Plan for the requested beam time
  - How to perform the measurement?
  - Why is one week needed?

WHY IS BEAM-BASED ALIGNMENT NEEDED?

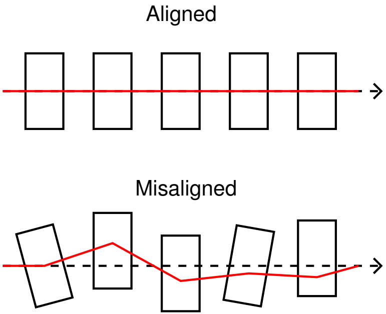
- For an EDM measurement the orbit has to be as good as possible
- Orbit RMS should be lower than 100 μm
  → Orbit Control
- Orbit Control corrects the beam to the BPM zero position
- Goal is to go central through all magnets (i.e. quadrupoles)
- Thus BPM to quadrupole offset has to be known
  → Beam Based Alignment



M.Rosenthal, PhD Thesis (modified)

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



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

HOW DOES BEAM-BASED ALIGNMENT WORK?

- Use the following merit function

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

$$f \propto (\Delta x)^2 \propto (x(s_0))^2$$

- By finding the minimum the optimal beam position can be found

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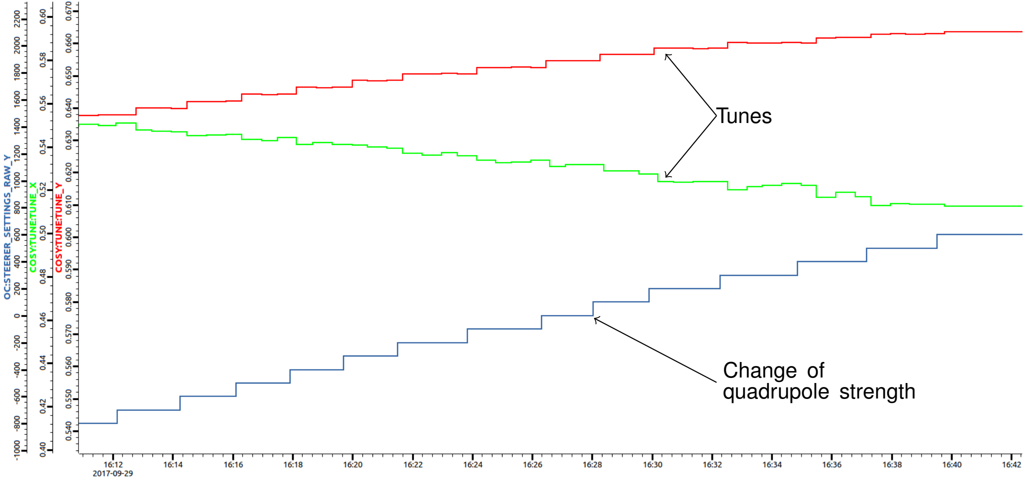
BEAM-BASED ALIGNMENT MEASUREMENT

- Quadrupoles are powered in families of four
- On the poles of quadrupole QT12 the additional back-leg windings of the steerer BLW04 were recabled to work as a quadrupole

BEAM-BASED ALIGNMENT MEASUREMENT

Quadrupole behavior



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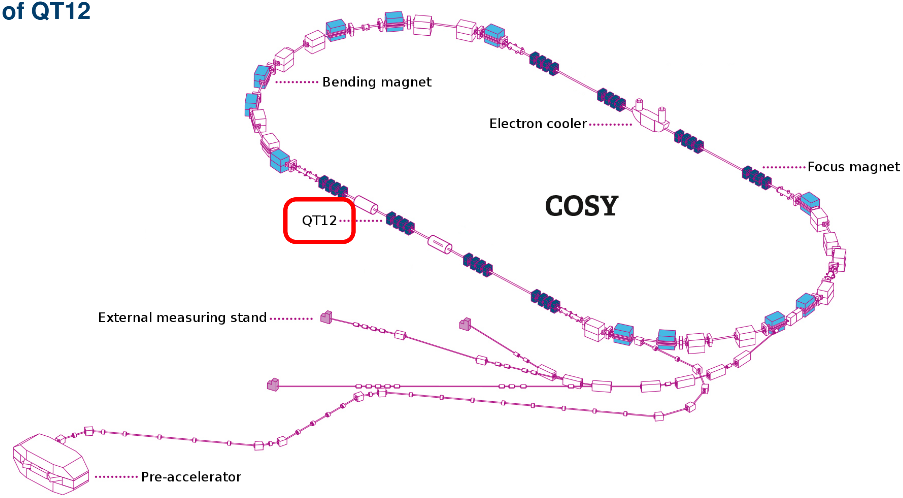
BEAM-BASED ALIGNMENT MEASUREMENT

Location of QT12



J. Slim (modified)

COSY sketch with position of quadrupole QT12 indicated

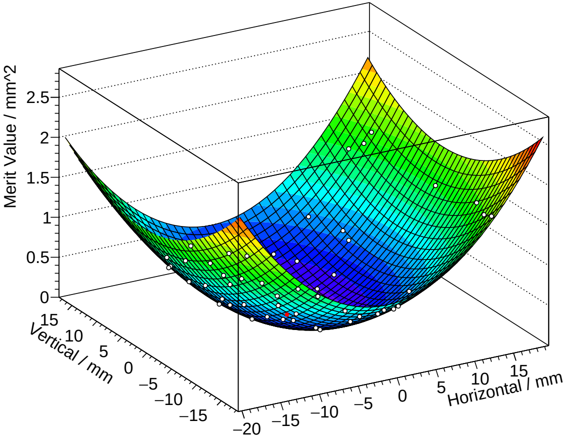
BEAM-BASED ALIGNMENT MEASUREMENT

- Quadrupoles are powered in families of four
- On the poles of quadrupole QT12 the additional coils of the steerer BLW04 were recabled to work as a quadrupole
- Effectively the strength of quadrupole QT12 can be varied
- Local bumps applied at the position of the quadrupole
- Measured effect on orbit upon varying the quadrupole strength

RESULTS

- Two measurements done with quadrupole QT12 (Nov 2017 & May 2018)
- First proof of principle measurement in Nov 2017
- Repetition of measurement in May 2018 for verification of result and test of faster measurement procedure
- Increase in measurement speed by a factor of 6 (20 points in 7 h vs. 50 points in 3 h)

RESULTS


Merit Value / mm^2
2.5
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Vertical / mm
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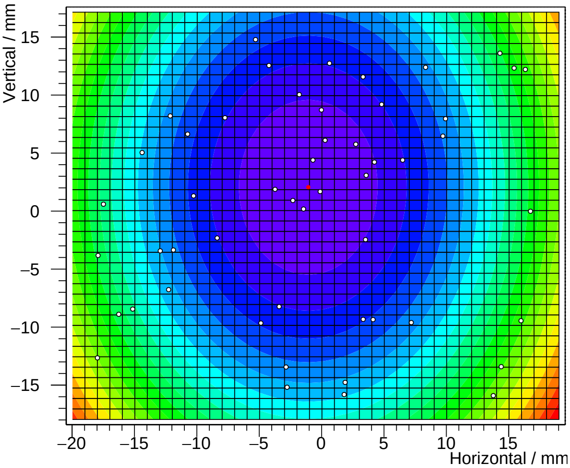
Horizontal / mm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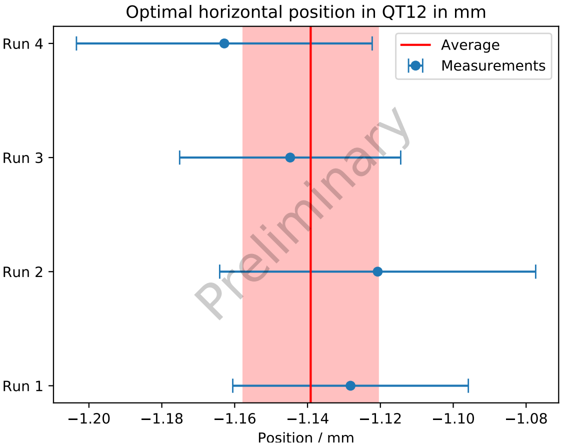
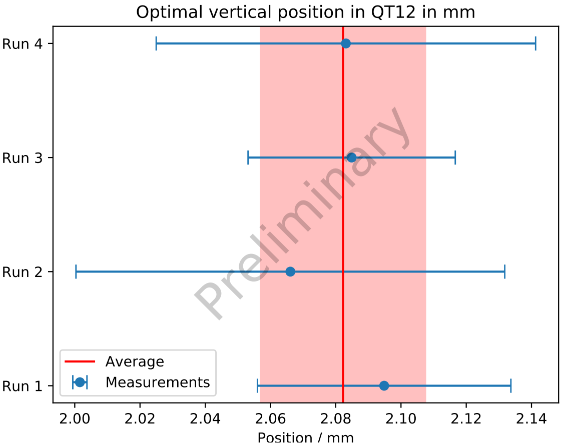
RESULTS

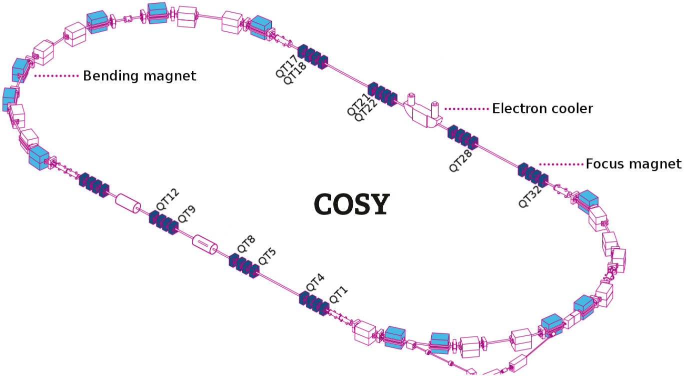




- Optimal horizontal position of $-1.14(2)$ mm and vertical position of $2.08(3)$ mm

PLAN FOR THE REQUESTED BEAM TIME

- Measure Quadrupole to BPM offset for all 12 quadrupoles with back-leg windings
- To prevent loss of steerers it is necessary to do it one by one



MEASUREMENT STRATEGY

- Total quadrupoles to be measured: 12
- Recabling can only be done during the day by dedicated personal
- The recabling (red) takes approx. 2 hours
- The setup (yellow) after recabling was done is estimated with 1 hour
- The measurement (green) takes approx. 3 hours for 50 points
- Sunday as a backup timeslot (blue)

Time	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
07:00							
07:30							
08:00	Setup Bumps	Recable	Recable	Recable	Recable	Recable	Backup Time
08:30							
09:00							
09:30							
10:00	Setup	Setup	Setup	Setup	Setup	Setup	
10:30							
11:00	Measure QT12	Measure QT04	Measure QT08	Measure QT17	Measure QT21	Measure QT28	
11:30							
12:00							
12:30							
13:00							
13:30							
14:00	Recable	Recable	Recable	Recable	Recable	Recable	
14:30							
15:00							
15:30							
16:00	Setup	Setup Orbit 1	Setup Orbit 1	Setup Orbit 1	Setup Orbit 1	Setup Orbit 1	
16:30							
17:00	Measure QT01	Measure QT05	Measure QT09	Measure QT18	Measure QT22	Measure QT32	
17:30							
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20:00	Measure QT01	Measure QT05	Measure QT09	Measure QT18	Measure QT22	Measure QT32	
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23:30							
00:00	Measure QT01	Measure QT05	Measure QT09	Measure QT18	Measure QT22	Measure QT32	
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03:00	Measure QT01	Measure QT05	Measure QT09	Measure QT18	Measure QT22	Measure QT32	
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04:00							
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05:30							
06:00							
06:30							

REQUEST

We request one week of beam time (plus one week MD) with protons or deuterons at $970\,\mathrm{MeV\,c^{-1}}$.

Thank You!

Other Slides

OTHER TIME DISTRIBUTION

<table>
<tr><th>Time</th><th>Monday</th><th>Tuesday</th><th>Wednesday</th><th>Thursday</th><th>Friday</th><th>Saturday</th><th>Sunday</th></tr>
<tr><td>07:00</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>07:30</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>08:00</td><td rowspan="4">Setup Bumps</td><td rowspan="4">Recable</td><td rowspan="4">Recable</td><td rowspan="4">Recable</td><td rowspan="4">Recable</td><td rowspan="4">Recable</td><td rowspan="46">Backup Time</td></tr>
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<tr><td>10:00</td><td rowspan="2">Setup Orbit 1</td><td rowspan="2">Setup Orbit 1</td><td rowspan="2">Setup Orbit 1</td><td rowspan="2">Setup Orbit 1</td><td rowspan="2">Setup Orbit 1</td><td rowspan="2">Setup Orbit 1</td></tr>
<tr><td>10:30</td></tr>
<tr><td>11:00</td><td rowspan="6">Measure QT12</td><td rowspan="6">Measure QT04</td><td rowspan="6">Measure QT08</td><td rowspan="6">Measure QT17</td><td rowspan="6">Measure QT21</td><td rowspan="6">Measure QT28</td></tr>
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<tr><td>00:00</td><td rowspan="2">Setup Orbit 2</td><td rowspan="2">Setup Orbit 2</td><td rowspan="2">Setup Orbit 2</td><td rowspan="2">Setup Orbit 2</td><td rowspan="2">Setup Orbit 2</td><td rowspan="2">Setup Orbit 2</td></tr>
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FORMULA FOR ORBIT CHANGE

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

- Δx = orbit change
- s = measurement position
- s_0 = position of quadrupole
- Δk = change of quadrupole strength
- $x(s_0)$ = position of beam inside the quadrupole
- β = beta function
- ν = tune
- ϕ = betatron phase
- k = quadrupole strength
- l = length of quadrupole
- $B\rho$ = magnetic rigidity of the beam

DERIVATION OF FORMULA FOR ORBIT CHANGE

- Start with effect of a dipole kick θ on the orbit.

$$\Delta x(s) = \theta \times \frac{\sqrt{\beta(s)}\sqrt{\beta(s_0)}}{2\sin\pi\nu}\cos[\phi(s) - \phi(s_0) - \pi\nu]$$

$$\theta = \frac{\Delta Bl}{B\rho}$$

- To first order a beam offset inside a quadrupole sees a change in quadrupole strength as a dipole kick.
- The change of the tune, beta function and betaton phase are effects of second order and can be neglected.

DERIVATION OF FORMULA FOR ORBIT CHANGE

- Quadrupole magnetic field is $B = kx$, thus

$$\Delta B = (k + \Delta k)(x + \Delta x) - kx = \Delta kx + \Delta xk + \mathcal{O}(\Delta k \Delta x)$$

- Combine the equations with $s_0 = s$ to get

$$\Delta x = \frac{(\Delta kx + \Delta xk)l}{B\rho} \frac{\beta}{2 \sin \pi\nu} \cos \pi\nu$$

- and solve for Δx.

$$\Delta x = \Delta kx \frac{\frac{\beta l}{2B\rho \tan \pi\nu}}{1 - \frac{\beta l}{2B\rho \tan \pi\nu}}$$

DERIVATION OF FORMULA FOR ORBIT CHANGE

- With that calculate ΔB

$$\Delta B = \Delta kx \frac{1}{1 - k\frac{\beta l}{2B\rho \tan \pi\nu}}$$

- and insert that into the equation for θ and $\Delta x(s)$.

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