Executive summary for “Beam time request on Beam-based alignment”

For Lab. use

Exp. No.	Session No. 8

Collaboration: JEDI

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Total number of particles and type of beam (p,d,polarization)	Momentum range (MeV/c)	Intensity or internal reaction rate (particles per second)	
		minimum needed	maximum useful
protons or deuterons	970 MeV/c	stored ~10^9	stored ~10^{10}
Experimental area	Safety aspects (if any)	Earliest date of installation	Total beam time (No.of shifts)
		June 01, 2018	1 week + 1 week MD

What equipment, floor space etc. is expected from Forschungszentrum Jülich/IKP?

Description of request (motivation, milestone(s), goals; maximum 5 pages)

Beam time request
on
Beam-based alignment

Tim Wagner for the JEDI Collaboration

May 18, 2018

Abstract

Beam-based alignment is needed for a precise measurement of the Electric Dipole Moment (EDM) at COSY. This is due to the effect of systematic errors that can be reduced if one knows the offset between the magnets and the beam position monitors (BPMs). With these offsets one can improve the orbit correction in order to obtain more precise beam positions inside the magnets and not only inside the BPMs. Beam-based alignment will lead to smaller systematic errors for the EDM measurement, as the beam passes through the center of the magnets.
We would like to perform a dedicated beam time for the Beam-based alignment measurements with protons or deuterons at $970\,\mathrm{MeV\,c^{-1}}$. We ask for one week of beam time preceded by one machine development (MD) week.

1 Introduction

Beam-based alignment measurements play an important role for the improvement of the beam positions in the accelerator and thus also further reduction of systematic uncertainties. Right now, the orbit root mean square (RMS) at COSY is in the order of some mm, but for the measurement of an EDM it needs to be in the order of about 100 µm or less (see figure 1). This is the case because magnet misalignments can mimic the spin buildup effect of an EDM, thus resulting in a fake signal. In order to prevent that, the orbit control software corrects the beam to a predefined orbit with the data of the beam position monitors. But in order to correct to the centers of the magnets, which is what is wanted, one needs to know the magnet to beam position monitor offset. This offset can be determined with the beam-based alignment technique. For one quadrupole (QT12) this has already been done, but there are many more offsets that need to be determined.

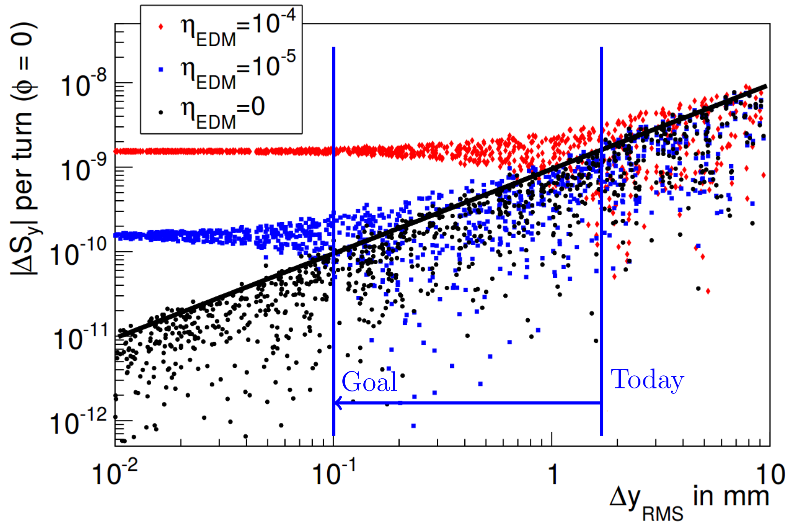


Figure 1: Spin buildup for different EDM values (red and blue) depending on the orbit RMS. The buildup due to the EDM freezes out at some point whereas the contribution due to misalignments (black) keeps decreasing[1].

2 Working principle

For the beam-based alignment measurement, one varies the strength of one quadrupole and analyzes the response of the beam. In case the beam is not in the center of the quadrupole, it will be deflected due to the change in strength. The magnitude of the deflection[2] can be described by

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

where all the parameters are explained in table 1.
If all parameters would be perfectly known, one could just compute the optimal beam position inside the quadrupole with a single measurement, but this is not

Parameter	Meaning
Δx	orbit change
s	measurement position
s_0	position of quadrupole
Δk	change in quadrupole strength
$x(s_0)$	position of the beam with respect to the magnetic center of the quadrupole
l	length of quadrupole
$B\rho$	magnetic rigidity of the beam
k	quadrupole strength
β	beta function
ν	betatron tune
ϕ	betatron phase

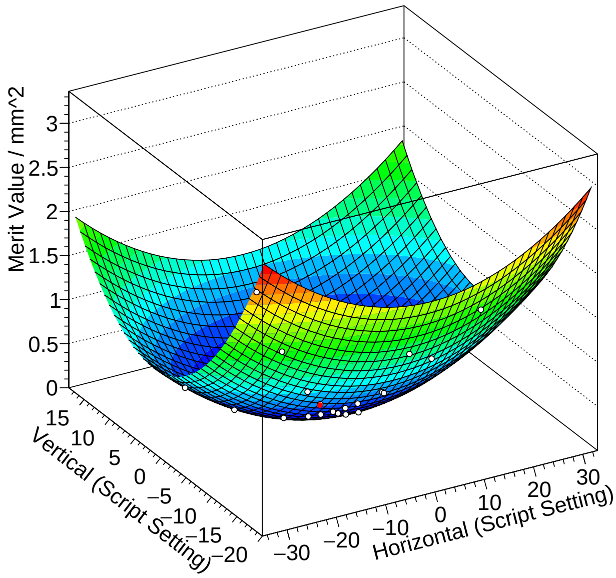
Table 1: Explanation of the parameters of equation 1.

possible. In order to determine the optimal position inside the quadrupole, one has to do several measurements at different beam positions and measure the response of all beam position monitors when changing the quadrupole strength. With the use of a suitable merit function, one can then determine the optimal beam position inside the quadrupole. The first measurement at COSY of this kind is discussed in the next chapter.

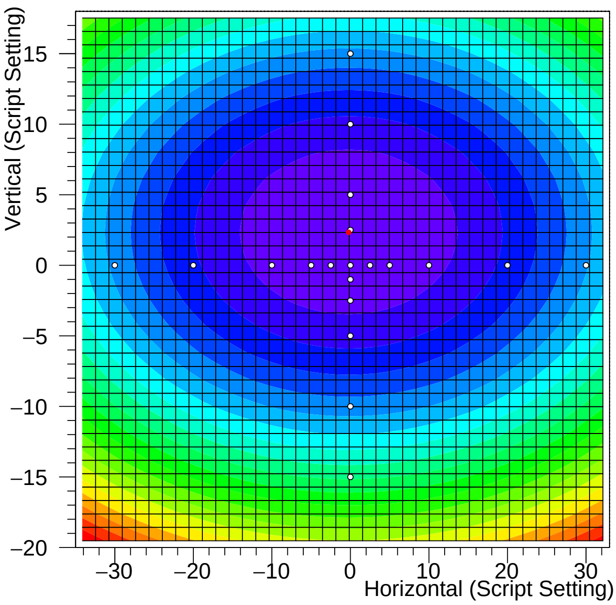
3 Beam-based alignment measurements

3.1 Measurements up to now

Up to now, one quadrupole to beam position monitor offset was determined with the beam-based alignment method. The measurement was carried out during the November/December 2017 JEDI beam time. The back-leg windings of quadrupole QT12, which were previously used as a steerer, were re-cabled to act as an additional quadrupole at the same position as quadrupole QT12. This leads to the possibility to individually change the effective strength of QT12. First, it was verified that the combination of the main quadrupole and the back-leg windings behave as one quadrupole. Then a measurement for the beam-based alignment was performed for that quadrupole. The first measurement was quite slow and took several hours to perform, but for future measurements a faster measurement procedure has been developed. The result of this measurement is that the offset of the quadrupole QT12 to the nearest beam position monitor BPM6 is (-1.98 ± 0.01) mm in horizontal direction and (1.15 ± 0.01) mm in vertical direction (see figure 2). This information can now be used by the orbit correction software to correct the orbit to the center of the quadrupole.



(a) Side view



(b) Top view

Figure 2: First measurement of beam-based alignment at COSY. During the measurement the beam movement was controlled by a script. Thus on the x- and y-axis, one can see the corresponding setting used to move the beam. The positions read by the beam position monitors were put into a merit function. The expected shape of the merit function is a paraboloid, which is also observed. The white dots indicate the position where the merit function was evaluated and the red dot denotes the minimum, *i.e.* optimal beam position, found by the fit. The optimal position was then converted to the reading of the closest beam position monitor BPM6. The BPM6 should read (-1.98 ± 0.01) mm horizontally and (1.15 ± 0.01) mm vertically in order to have the beam centered in quadrupole QT12.

3.2 Future measurements

There are multiple options that can be used for future beam-based alignment measurements. The technique that is easily usable at COSY uses the same measurement principle like the first measurement as explained in section 3.1.

The measurements that are planned for the requested beam time are beam-based alignment measurements with additional quadrupoles along the ring. For quadrupoles with back-leg windings the same measurement principle like for QT12 can be applied, though with a faster procedure. The quadrupoles with back leg windings are QT1, QT4, QT5, QT8, QT9, QT12, QT17, QT18, QT21, QT22, QT28 and QT32. The position of these quadrupoles in the ring can be seen in figure 3. An additional requirement for the beam-based alignment measurement is, that there is a beam position monitor relatively close-by. This is the case for eight of the twelve mentioned quadrupoles (quadrupole to beam position monitor distance of less than 1 m). For the remaining four quadrupoles one has to take additional care when performing the measurement.

When re-cabling the back-leg windings of the quadrupoles, one has to take into account that these were previously used as steerers. Thus one looses some steerers in the ring when performing the measurement, and it is therefore not possible to correct the orbit as good as before. To circumvent the loss of many steerers one can do the measurements one by one and when finished with the measurement for the specific quadrupole, re-cable the back leg windings back to a steerer. In this way one only looses the steerer at the quadrupole where the measurement is performed.

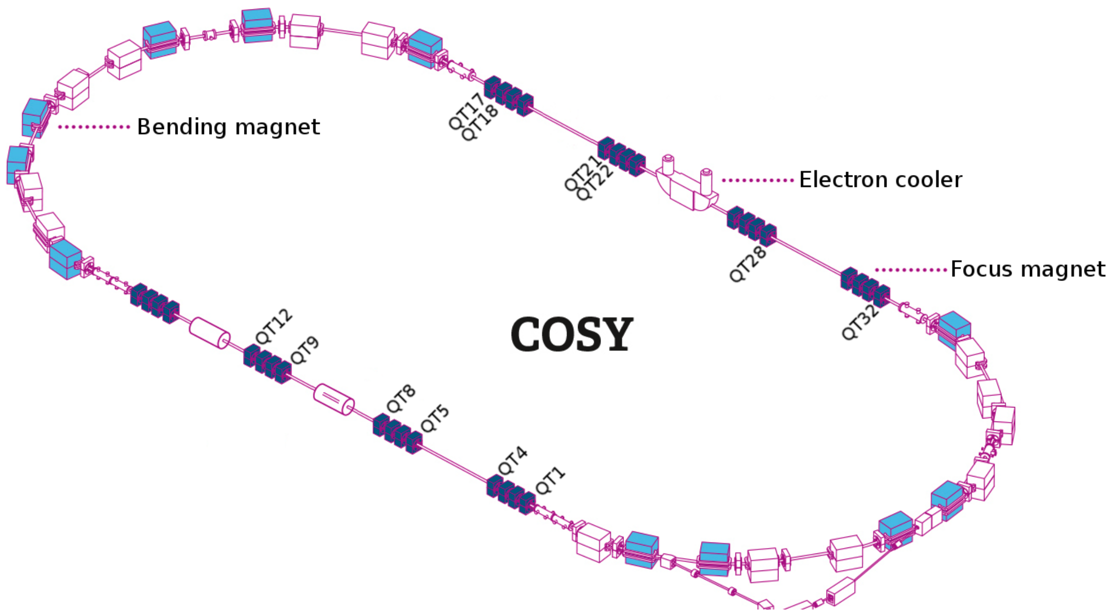


Figure 3: Sketch of the COSY ring with the positions of quadrupoles, which have back-leg windings, indicated. The quadrupoles with back-leg windings are QT1, QT4, QT5, QT8, QT9, QT12, QT17, QT18, QT21, QT22, QT28 and QT32, as mentioned in section 3.2.

Measurement technique	Time
First static Measurement	6h
Improved static measurement	1.5h

Table 2: Time estimation for the measurement of one quadrupole to beam position monitor offset. This time is the measurement time only not including time for setting everything up.

3.3 Time requirement for the measurement

The first measurement at quadrupole QT12 took about one shift. This was due to the relatively slow measurement procedure. For one data point one needed 18 minutes of measurement. This were six cycles of three minutes each. For the 20 measured data points this sums up to six hours. Then in addition some extra time for setting everything up had to be included, which increased this to about one shift. With the new and improved procedure one could do the same measurement in about 1 hour and 30 minutes. This is due to the fact that the new technique takes one data point in one cycle, meaning it is about six times faster.
The time needed for the measurement of all twelve quadrupole to beam position monitor offsets sums up to about one week, as one needs to take into account the time needed for the re-cabling of all those back-leg windings. For re-cabling one back-leg winding from a steerer to a quadrupole or vice versa one takes about one hour. In addition one needs to test that it behaves as expected and set up the bump at the position of the quadrupole. The total time needed for one quadrupole results to about 5 hours. This includes 2 hours fore re-cabling, about 1 hour for testing and setting up the bump and 1.5 hours for the measurement. As the re-cabling is not a trivial task anyone can perform, it can only be done during the day. This means that one can measure the beam position monitor offset for 2 to 3 quadrupoles per day. During the night one could take additional data points for the currently re-cabled quadrupole.
With 2 to 3 quadrupoles per day one needs 4 to 6 days of measurement time for all 12 quadrupoles.

4 Magnet choices

The magnets that can be used for the measurement are listed in table 3. This list contains all quadrupoles that have back-leg windings and also the nearest beam position monitor. If one requires the quadrupole to beam position monitor distance to be less than 1 m, there would be eight out of twelve quadrupoles with back-leg windings left.
For those eight quadrupoles the measurement is basically the same like for quadrupole QT12. For the four quadrupoles where the beam position monitors are further away one has to take extra care and can not directly take the position in the nearest beam position monitor as a reference.

Quadrupoles	Steerer	Position	Closest BPM Pos.
QT01	MSH01	9.9 m	10.3 m
QT04	MSV02	12.7 m	10.3 m / 15.2 m
QT05	MBLW1	19.8 m	17.3 m / 24.3 m
QT08	MBLW2	22.7 m	17.3 m / 24.3 m
QT09	MBLW3	27.1 m	25.5 m / 29.3 m
QT12	MBLW4	30.0 m	29.3 m
QT17	MSH21	99.6 m	100.1 m
QT18	MSV22	100.6 m	100.1 m
QT21	MSV24	109.5 m	110.1 m
QT22	MSH23	110.5 m	110.1 m
QT28	MSV26	123.7 m	123.2 m
QT32	MSV28	133.6 m	133.2 m

Table 3: List of all quadrupoles with back-leg windings. The table shows the names of the quadrupoles and the corresponding name of the steerer that is the back-leg winding. In addition the position of the quadrupole is given and the closest beam position monitor (BPM) position(s) are given. In some cases there are two positions for beam position monitors given, which is because both of them are not very close nearby, but the closest ones to that quadrupole.

5 Request

The collaboration would like to request one week of beam time preceded by one week of machine development with protons or deuterons at 970 MeV c^{-1}. We would also like to have the possibility to create bumps at all quadrupole that have back-leg windings, thus enabling the possibility of this measurement.

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, D. Robin, and L. Schachinger. "Automated beam based alignment of the ALS quadrupoles". In: *Conf. Proc.* C950501 (1996), pp. 2693–2695.