Executive summary for "Beam time request on Beam-based alignment"

For Lab. use

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	10

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)**
		September 01, 2019	3 weeks + 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

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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 calibrate the BPM positions. Beam-based alignment will lead to smaller systematic errors for the EDM measurement, as the beam passes through the center of the magnets.

After the successful beam time in February 2019 (A015), where the optimal beam position inside 12 out of 56 quadrupoles could be determined. We would like to perform an additional beam-based alignment measurement, now for all 56 quadrupoles with protons or deuterons at $970\,\mathrm{MeV\,c^{-1}}$. We ask for three weeks 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 twelve quadrupoles (with back-leg windings) this has already been done, but there are many more quadrupoles where the offsets need to be determined in order to get a better orbit in the machine.

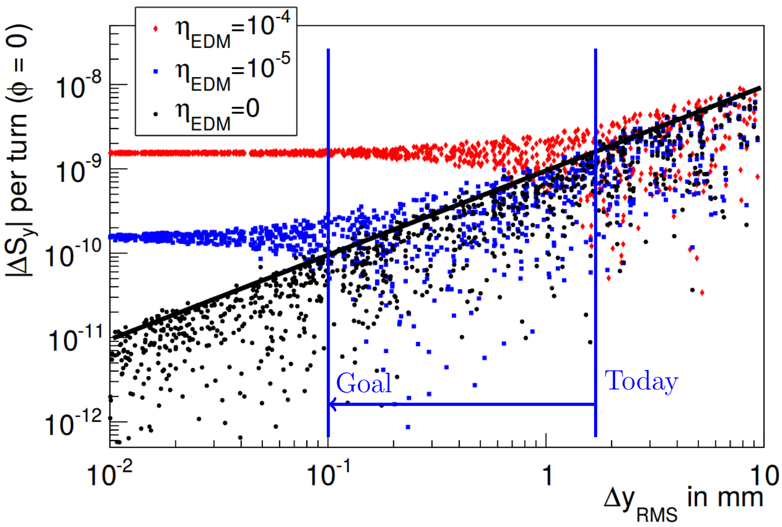

Figure 1: Spin buildup for different EDM values (red and blue) depending on the orbit RMS. The buildup due to the EDM freezes out at some point whereas the contribution due to misalignments (black) keeps decreasing [1].

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.

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.

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 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 measurements at COSY of this kind are discussed in the next chapter.

3 Beam-based alignment measurements

3.1 Measurements up to now

Up to now, the beam-based alignment measurement has been performed for 12 out of 56 quadrupoles. All of those 12 quadrupoles have back-leg windings, which could be used to vary the strength of the quadrupole. Those back-leg windings are usually used as steerers, but it is possible to recable them to act as a quadrupole at the same position and thus modifying the whole quadrupole field. After some first tests with only one quadrupole, a beam time (A015) of one week was granted to perform the beam-based alignment measurement for all 12 quadrupoles which have those back-leg windings.
This beam time (A015) of February 2019 was a success and the optimal position of the beam in all 12 quadrupoles could be determined. The results of the measurement can be seen in Figure 2. There one can see the offset of the optimal position of the beam inside the quadrupole with respect to the beam position monitor coordinate system.
As the position of the quadrupoles have been measured and aligned with a precision

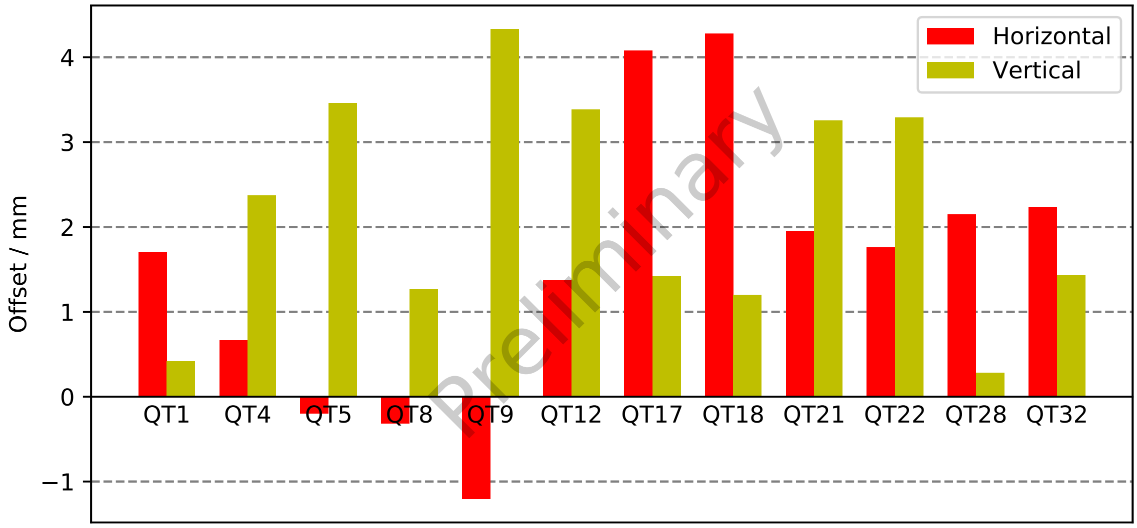

Figure 2: Results of the Beam-based alignment measurement. The offset for all 12 measured quadrupoles with back-leg windings is shown. The optimal beam position inside the quadrupole is given with respect to the nearby beam position monitors.

of 0.2 mm [3] one can use the information from the beam-based alignment to calibrate the beam position monitor offsets, as the beam position monitors have no fiducial markers to measure their position accurately. With the optimal beam position inside the 12 quadrupoles one can determine the offset for 6 beam position monitors. This is because one needs either a quadrupole very close to a beam position monitor or a quadrupole on each side of the beam position monitor to determine the offset.
The now properly calibrated beam position monitors are BPM02, BPM06, BPM18, BPM19, BPM20 and BPM21. The offsets applied to the beam position monitors are given in Table 2. To verify that this leads to a better orbit a short test was performed after applying the offsets in April 2019. The orbit was corrected with the orbit correction software before and after applying the beam position monitor offsets. The orbit RMS_y, which describes how good the orb it is with respect to the optimal orbit, was 1.21 mm before applying the offsets and after applying the offsets it was 1.01 mm. In addition to a better orbit RMS_y also less steerer strength was needed to achieve the correction. Before the RMS Steerer current was 2.66 A and after application of the offsets it was 2.11 A. This way one can clearly see that the beam-based alignment measurement helps with the improvement of the orbit in COSY.

3.2 Future measurements

In order to also measure the optimal beam position in all the other quadrupoles a new way to vary the quadrupole strength has to be chosen. For that additional power supplies are needed and in order to change the current through the main coils of the quadrupoles, which have no back-leg windings. In order to not buy 56 new power supplies the decision was made to get four new power supplies and make it possible to change the connected quadrupole by a simple electric plug. For that, all

BPM name	Horizontal Offset	Vertical Offset
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

Table 2: The offsets that were applied to the BPMs are listed in this table. These offsets have to be subtracted from the BPM reading in order to be in the center of the quadrupole.

quadrupoles will be equipped with an additional plug in order to connect the power supply to the main coils of the quadrupole and either bypass some current or add some current to the coils. This way one can vary the strength of all quadrupoles in COSY by plugging one of the four new power supplies into them when needed for the measurement.

3.3 Time requirement for the measurement

The February 2019 beam time took one week and it was possible to measure the optimal position inside 12 quadrupoles. During that beam time it was only possible to recable the back-leg windings once per day, as the power supply group had to do it. For the next beam time with the new power supplies the change from one to the next quadrupole is simple by just plugging in a plug to the correct quadrupole. Therefore it can be done by anyone who has been instructed before and a faster measurement can be performed.
By extrapolating the time requirement of the February beam time with 12 quadrupoles to 56 quadrupoles one would end up with 4.5 weeks. But as the change from one to the next quadrupole can be easier done the time should be about 3 to 3.5 weeks for the beam-based alignment measurement for all 56 quadrupoles in COSY.

4 Request

The collaboration would like to request three weeks of beam time preceded by one week of machine development with protons or deuterons at $970\,\mathrm{MeV\,c^{-1}}$. During this time we want to measure the optimal beam position inside all quadrupoles in COSY with the beam-based alignment method in oder to have an orbit that is as good as possible for the electric dipole moment measurements at COSY.

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.

[3] Vermessungsbüro Stollenwerk und Burghof. private communication. 2018.