COSY Beam Time Request

For Lab. use

Exp. No.:	Session No.
E 005.4	**7**

Collaboration: **JEDI**

Status of the commissioning of the waveguide RF Wien Filter

Spokespersons for the beam time:

Ralf Gebel (Jülich)
Alexander Nass (Jülich)
Frank Rathmann (Jülich)

Spokespersons for the collaboration:

Paolo Lenisa (Ferrara)
Jörg Pretz (Aachen/Jülich)

Address:
Institut für Kernphysik
Forschungszentrum Jülich
52428 Jülich
Germany

Phone: **+49 2461 615889** Fax: **+49 2461 619450** E-mail: **lenisa@fe.infn.it**
pretz@physik.rwth-aachen.de_

r.gebel@fz-juelich.de
a.nass@fz-juelich.de
f.rathmann@fz-juelich.de

Total number of particles and type of beam (p, d, polarization)	Kinetic energy (MeV)	Intensity or internal reaction rate (particles per second)	
		minimum needed	maximum useful
Polarized 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)
WASA detector, RF Wien filter in PAX section, and electron cooler	**none**	**June 01, 2018**	**1 MD + 3 weeks**

Status of the commissioning of the waveguide RF Wien Filter

The JEDI collaboration

December 10, 2017

Abstract

The 2^{nd} commissioning run for the RF Wien filter was carried out in the last quarter of 2017 (11.11. to 04.12.2017). We lost about two weeks of the foreseen three weeks of beam time, because the polarized source became available only late during the run due to problems with the Cs oven, and in addition, the extraction septum of the cyclotron had to be replaced. This document gives a short account of the achievements from the commissioning effort and describes the most important commissioning items that still need to be carried out.

The collaboration would like to continue the commissioning work of the RF Wien filter during the already allocated beam time in the 1^{st} quarter of 2018 (22.01. to 19.02.2018). The allocated beam time was originally foreseen for *First exploratory deuteron EDM experiments with the waveguide RF Wien Filter* (proposal E005.3), where the Wien filter is in a configuration without installed ferrites. **For these measurements we now request additional beam time that could be carried out at the end of the 2^{nd} quarter 2018 (tentatively, between 04.06. to 02.07.2018).** A 2^{nd} EDM measurement (with ferrites) is then anticipated to take place either late in 2018 or early in 2019.

1 Strategy for the RF Wien filter measurements

The 2^{nd} commissioning run for the RF Wien filter was carried out in the last quarter of 2017 (11.11. to 04.12.2017). Two weeks of the foreseen three weeks of beam time were lost, because the polarized source became available only late during the run due to problems with the Cs oven, and in addition, the extraction septum of the cyclotron had to be replaced.

The JEDI collaboration would like to continue the commissioning work of the RF Wien filter during the beam time that has been already allocated for the 1^{st} quarter of 2018 (22.01. to 19.02.2018). This beam time was originally foreseen for Proposal E005.3, *First exploratory deuteron EDM experiments with the waveguide RF Wien Filter*, with the Wien filter in a configuration without installed ferrites. Thus, for the 1^{st} EDM measurements, the collaboration would now like to request additional beam time, which we would tentatively like to carry out in June 2018.

Subsequently, we anticipate a 2^{nd} EDM measurement with ferrites installed to take place either late in 2018 or early in 2019. Once installed, the ferrites will provide increased field homogeneities and about 20% larger fields [1]. The ferrites for the RF Wien filter[1] have meanwhile arrived in Jülich.

2 RF Wien filter commissioning

2.1 Vertical oscillations

During the November 2017 commissioning run, we could show that the Wien filter is capable to induce vertical oscillations in the beam, when the initial polarization is vertical and the B field of the RF Wien filter points along the radial (x) direction. Figure 1 shows the induced vertical oscillations of the beam polarization for the two used deuteron vector polarization states.

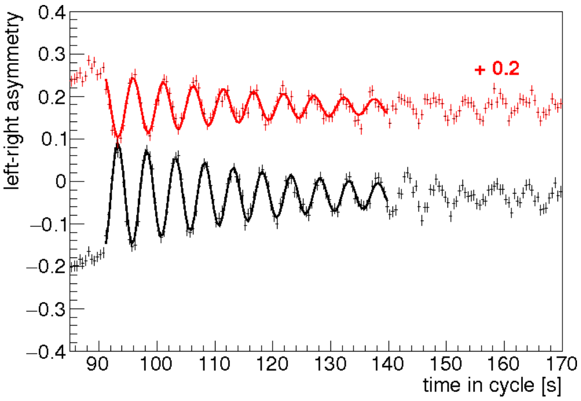


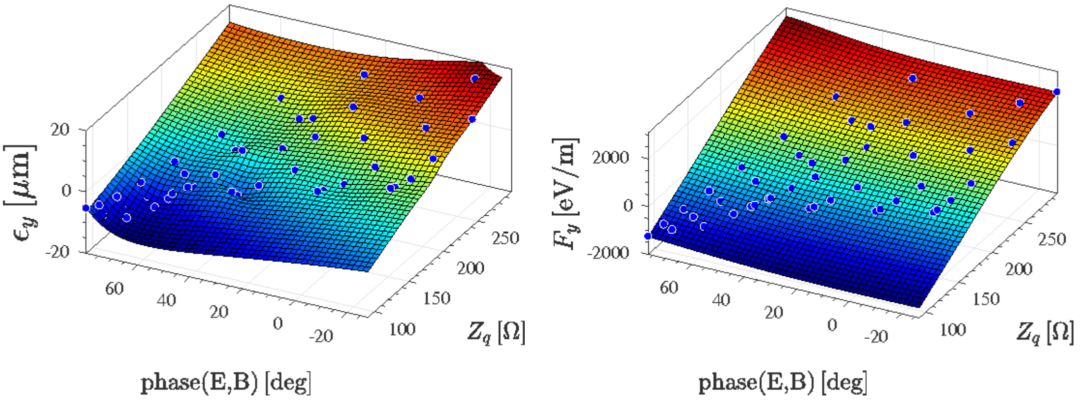
Figure 1: Vertical oscillations induced by the RF Wien filter with sideways B-field for the two spin states. The graph shows the left-right asymmetries, and the oscillation amplitudes differ, because the injected vector polarizations for the two states from the source are different.

---

[1] manufactured by National Magnetics Group, Inc. `http://www.magneticsgroup.com/`.

2.2 Measurement of the Lorentz force

We successfully measured the Lorentz force exerted on the beam by a detuned RF Wien filter via the detection of coherent beam oscillations using two beam position monitors (#16 (horizontal) and #17 (vertical)), located before and behind the last ring dipole in front of the WASA detector. During these measurements, the magnetic field of the RF Wien filter pointed sideways (along x), thus the induced Lorentz force points along the vertical (y) direction. The present limit for the magnitude of the vertical amplitude ϵ_y of the coherent beam oscillation corresponds to about 1 µm. Figure 2 shows preliminary results obtained during the first commissioning with unpolarized protons taken in June 2017.



(a) Measurement of ϵ in μm.

(b) Simulation of F_L in eV/m.

Figure 2: Preliminary results of the amplitude of the coherent beam oscillations ϵ (a) and the Lorentz force F_y (b) as a function of the field quotient (magnitude and phase).

2.3 Initial slope of the vertical polarization build-up

Starting with the deuteron polarization in the ring plane, a number of polarization buildup measurements were carried out with the magnetic field of the Wien filter oriented sideways (x) and vertical (y) with respect to the ring plane. Figure 3 shows for RF Wien filter oriented in EDM mode ($\vec{B} \parallel \vec{e}_y$) three sets of curves showing the initial slope of the vertical polarization $\mathrm{d}S_y/\mathrm{d}t$ as function of the relative phase between deuteron spin and Wien filter RF for different azimuthal rotation angles of the RF Wien filter.

The basics of the operation of the RF Wien filter has been worked out in the JEDI publication on the spin tune mapping technique [2]. The quantitative interpretation of the initial slope of the vertical polarization $\mathrm{d}S_y/\mathrm{d}t$ depends on the relative orientation of the Wien Filter axis and the stable spin axis (SSA) in the COSY ring [see Eqs. (A9), (A7), (A10) of Appendix A of [2]]. The azimuthal orientation of the RF Wien filter can be controlled mechanically by a rotation of the device around the beam direction (see also item 1 of Sec. 2.4.2), and the orientation of the SSA can be manipulated by switching on static solenoids in the ring. For the latter, as explained in [2], the compensation solenoids of the 70 keV electron cooler were employed. Variations of both axes do affect the axis around which the deuteron spins rotate which leads to different patterns of phase motions, as shown in Fig. 3, and a corresponding extension of the formalism developed in [2] is in progress. The data that could be taken during the November commissioning run are sparse. The dependencies of the vertical polarization buildup on the orientation of the SSA and the RF Wien filter need to be investigated in much more detail. The quantification of the ring imperfections is of crucial importance for all storage ring EDM measurements, and we will continue to study them during the next commissioning run.

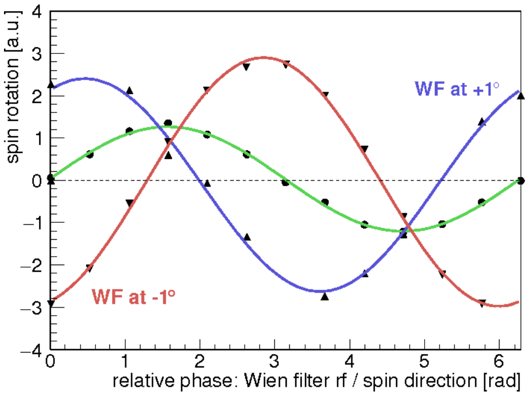


Figure 3: Initial slope of the vertical polarization $\mathrm{d}S_y/\mathrm{d}t$ as function of the relative phase between deuteron spin and Wien filter RF, where the B field of the Wien filter is perpendicular to the ring plane (y), and for three different rotation angles of the Wien filter around the azimuthal (z) axis, $\phi_{\mathrm{WF}} = 0^\circ$ (**green**), $+1^\circ$ (**purple**), and -1° (**red**).

2.4 Work that needs to be carried out before a first EDM production run can take place

Although, as explained in the previous sections, various aspects of the experiment could be tested during the commissioning beam time, some studies that we had planned could not be carried out due to the restricted time available, and some new items appeared that should be addressed before we go after a first direct measurement of the deuteron EDM.

2.4.1 Machine setup

1. For polarimetry the beam is extracted onto a carbon block target by vertical beam heating. The amplitude is controlled by the so-called Schneider box feedback, which maintains a constant detector rate. With polarized beam and low beam current sudden changes in the extraction mechanism have been observed, which need to be studied further.

2. The automatic COSY orbit control with the Schneider box feedback to stabilize the detector rate should run reliably in both the horizontal and vertical ring planes. The purpose is that at the location of the RF Wien filter and at the electron cooler, the beam positions shall not change on flattop. The automatic horizontal orbit control worked fine, the vertical one made problems with polarized beam and Schneider box feedback ON, and there was simply not enough time available to fix the problem.

3. There was no time available to operate the PAX low-β section. During the next run, we would like to carry out tests with smaller β function at the location of the Wien filter and study its effect on the measured Lorentz force.

2.4.2 RF Wien filter

1. We successfully tested the rotation of the RF Wien filter around the longitudinal axis, but the remote control of this function has not yet been implemented into the control system, so that rotations by ±5° from the COSY control room using the new electronic levels become possible. An additional Loop 5 should make sure that the orientation of the Wien filter does not change during operation.
2. The reliability of each of the four feedback loops should be further improved and tested during the next commissioning run:
    - Loop 1: Spin phase-lock,
    - Loop 2: Minimize F_{L},
    - Loop 3: Minimize E/B phase,
    - Loop 4: Keep beam position stable at the entrance and exit of the beam in the RF Wien filter.

In addition, while the above listed four feedback loops have been tested individually, there was no time available to test their mutual interaction and their reliability in a combined fashion. These investigations shall also be carried out during the next commissioning run.

2.4.3 WASA Polarimeter

One week of the recent run was planned to be used for the commissioning of WASA as online polarimeter for polarization monitoring, spin tune measurement and phase-locking the Wien filter RF to the spin precession. In order to use the remaining time with polarized beam for the commissioning of the Wien filter, this activity has been kept at the necessary minimum.

1. The carbon block target has been operated for the first time at WASA. There was no time to optimize the (vertical) target position and the extraction process in view of the detector response using full tracking.
2. The feedback system for phase-locking has to rely on event selection on the trigger level. No high-level information from the detector is available. During this beam time the trigger conditions have not been optimized to maximize the measured asymmetries. This needs to be done in the upcoming run.
3. During the November commissioning time, only a very basic algorithm of the phase-lock feedback has been implemented. Any further optimization can only be tested and improved on-line with polarized beam.

2.4.4 Additional items

Below we list several additional items that appeared during the commissioning period, and some of these we would like to address also in the upcoming commissioning run.

1. The read-back of dipole, steerer, quadrupole, sextupole, and solenoid currents should be implemented, and the data shall be stored in the EPICS database. Also, the settings of the Schneider box should be stored in EPICS, and in addition the active spin bits from the polarized ion source.

2. Two more Zurich lock-in amplifiers[2] shall be implemented in the setup for the Lorentz force measurement. We would like to read each of the four BPM signals individually. At present, we measure the horizontal and vertical amplitude of the beam oscillation induced by an unmatched RF Wien filter using two different BMPs #16 and #17. For the next commissioning run, the measurement of the Lorentz force for both planes should only use BPM #17.

3. A 10 MHz signal from a GPS clock should be distributed to the COSY-RF, the solenoid-RF, and the Wien filter-RF, in order to make sure that all frequency generators agree frequency-wise.

4. For the next run, the Wien filter should be aligned along the COSY ring plane which was determined during the recent COSY magnet survey.

5. Up to now, we operated the RF Wien filter only on the $K = -1$ harmonic near 871 kHz. The company that build the driving circuit[3] will deliver the remaining components to operate of the RF Wien filter also at the 630 kHz ($K = +1$), 1380 kHz ($K = +2$), and 1621 kHz ($K = -2$) [1] in time for the next commissioning run.

6. Due to delays in the manufacturing process, the Rogowski coils up- and downstream of the RF Wien filter could not be calibrated before installation prior to the November commissioning run. The calibration of the new pair of coils is presently being carried out using the laboratory test setup, and for the upcoming commissioning run these calibrated coils will be installed in January 2018, which is possible without removal of the RF Wien filter.

3 Request

The collaboration would like to continue the commissioning work of the RF Wien filter in the 1st quarter of 2018 during the already allocated beam time (22.01. to 19.02.2018), which was originally foreseen for proposal E005.3, *First exploratory deuteron EDM experiments with the waveguide RF Wien Filter*. **For the first exploratory measurements, we would now like to request additional beam time for the end of the 2nd quarter 2018** (tentatively to be scheduled in June 2018, between 04.06. to 02.07.2018). A 2nd EDM measurement with ferrites is then anticipated to take place either late in 2018 or early in 2019.

References

[1] J. Slim et al., Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment **828**, 116 (2016).

[2] A. Saleev et al., Phys. Rev. Accel. Beams **20**, 072801 (2017).

---

[2] Zurich Instruments, Zurich, Switzerland, model HF2LI, `https://www.zhinst.com/products/hf2li`.

[3] barthel HF-Technik GmbH, Aachen, Germany, `http://www.barthel-hf.de/`.