COSY Beam Time Request

For Lab. use	
Exp. No.:	Session No.
E 005.6	**10**

Collaboration: **JEDI**

An improved pilot bunch-based spin phase-lock feedback system for the measurement of the deuteron electric dipole moment

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Spokespersons for the beam time:

Jamal Slim (Aachen)
Alexander Nass (Jülich)
Frank Rathmann (Jülich)
Giuseppe Tagliente (Bari)

Spokespersons for the collaboration:

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

Address:
Institut für Kernphysik
Forschungszentrum Jülich
52428 Jülich
Germany

Phone: **+49 2461 61 85256** Fax: **+49 2461 61 3930** E-mail:

slim@physik.rwth-aachen.de
a.nass@fz-juelich.de
f.rathmann@fz-juelich.de
giuseppe.tagliente@ba.infn.it

lenisa@fe.infn.it
pretz@physik.rwth-aachen.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	Intensity or internal reaction rate (particles per second) 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, electron cooler, RF solenoid	**none**	**November 1, 2019**	**1 MD + 1 week**

An improved pilot bunch-based spin phase-lock feedback system for the measurement of the deuteron electric dipole moment

The JEDI collaboration

May 24, 2019

Abstract

The JEDI collaboration would like to request a beam time to test an improved spin phase-lock feedback system. This will allow, for the first time, the direct measurement of the deuteron electric dipole moment using the oscillation frequency of the vertical polarization P_y instead of only using the initial slope of P_y. Consequently, upon success, the EDM resonance strength could be mapped out as a function of the Wien filter phase and solenoid field.

For this investigation **we would like to request 1 week of machine development time and 1 week of measurement time**, to be tentatively scheduled at the end of the 4^{th} quarter 2019 (November/December).

1 Commissioning the waveguide RF Wien filter

- The RF Wien filter is fully operational with a total power of up to $P = 1.5\,\mathrm{kW}$, fully sufficient to perform a first direct EDM measurement.
  - Higher RF power levels by about a factor of 2.5 are achievable with the presently used four RF amplifiers.
  - Beyond that, another factor of 2 in RF power becomes available, when eight instead of the presently used four slaves are employed.
- All four feedback loops for the stable operation of the RF Wien filter have been tested and are operational.
  - **Loop 1:** Locks the relative phase of the RF of the Wien filter with respect to the in-plane polarization.
  - **Loop 2:** Minimizes the Lorentz force $\vec{F}_{\mathrm{L}}$, exerted on the beam at the four harmonics of the spin frequencies [2]:

$$\begin{aligned} K &= -1 : 871\,\mathrm{kHz}\,, \qquad & K &= +1 : 630\,\mathrm{kHz}\,, \\ K &= -2 : 1621\,\mathrm{kHz}\,, \qquad & K &= +2 : 1380\,\mathrm{kHz}\,. \end{aligned} \tag{1}$$

  - **Loop 3:** Minimizes the phase between the E and B fields inside the Wien filter.
  - **Loop 4:** Keeps the horizontal and vertical beam position stable at the entrance and exit of the beam in the RF Wien filter.
- The remote rotation of the RF Wien filter around the longitudinal axis from the experiment control at COSY Warte for small angles of $\pm 5°$ has been implemented in the Lab View control system.
  - Electronic levels[1] are used to set the rotation of the RF Wien filter around the beam axis with a precision of at least 170 µrad.

2 An improved spin lock feedback system

2.1 Motivation

It was noticed during the previous precursor run, that the spin phase-lock feedback looses its track of the spin signal once the spin has been rotated into the vertical direction. Figure 1 shows an example of a polarization build-up excited by the waveguide RF Wien filter running at one of the resonant spin precession harmonics (*i.e.*, 871 kHz). The most important parameter is the slope indicated by the red solid line. One can see that the fit starts from nearly 160 s and ends at 200 s that is exactly where the feedback loop (in its current version of implementation) cannot proceed further.

[1]ZEROTRONIC inclination sensor, WYLER AG, Winterthur, Switzerland https://www.wylerag.com.

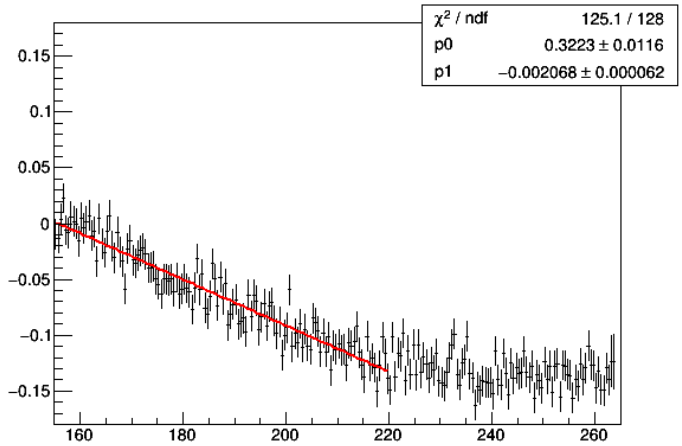


Figure 1: Polarization build-up while running the RF Wien filter on resonance continuously.

In Fig. 2, we measured the spin precession frequency for a short time and then set the frequency of the Wien filter only once (not continuously, as we did before), an irregularly shaped sinusoidal signals appeared. As a conclusion, it seems that the feedback system is producing undesirable effects on the measurements.

To further understand the effects of the feedback, some simulations have been conducted. The simulation scenario included an RF Wien filter running continuously on resonance. Roughly speaking, this requires measuring the spin tune continuously, *i.e.*, turn-by-turn. The results are shown in Panel (a) of Fig. 3. First of all, one can see that the spin tune values of the extremum range between -0.166 and -0.156, are too large and cannot match the spin precession frequency. Panel (b) elaborates more on these results: taking the moving mean of the data shown on Panel (a), (blue line with the left scale) shows a variation between $-0.161\,15$ and -0.1608. Surprisingly, this corresponds to a frequency variation of the order of $\Delta f \approx 150\,\mathrm{Hz}$. Because the calculations used a field amplification factor of $f_a = 10^4$, dividing the ratio $\Delta\hat{f} = \Delta f / f_a$ yields a value of $\Delta\hat{f} = 15\,\mathrm{mHz}$. From the simulations, $\Delta\hat{f}$ does not coincide with the estimated resonance width *i.e.* $\Gamma = 14.1\,\mathrm{mHz}$. (see Sec. 2.2 of

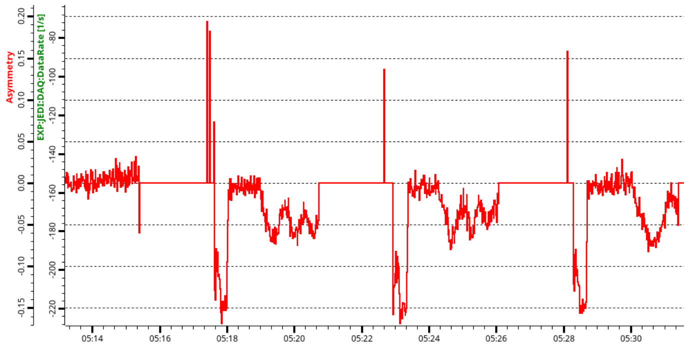
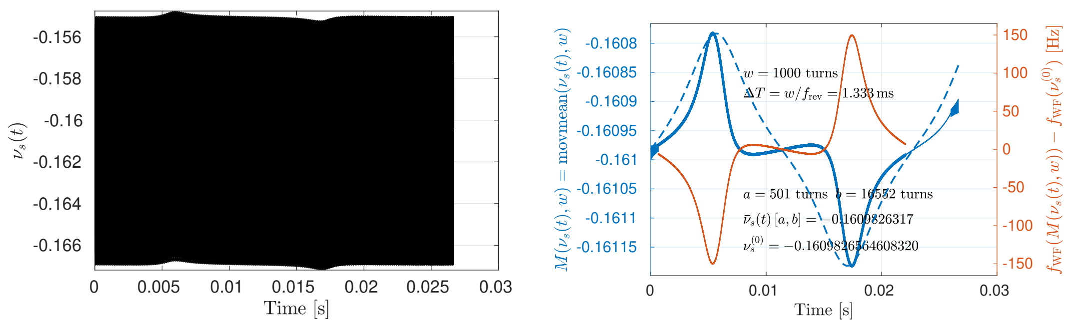


Figure 2: Polarization build-up while the RF Wien filter is running without continuous feedback.

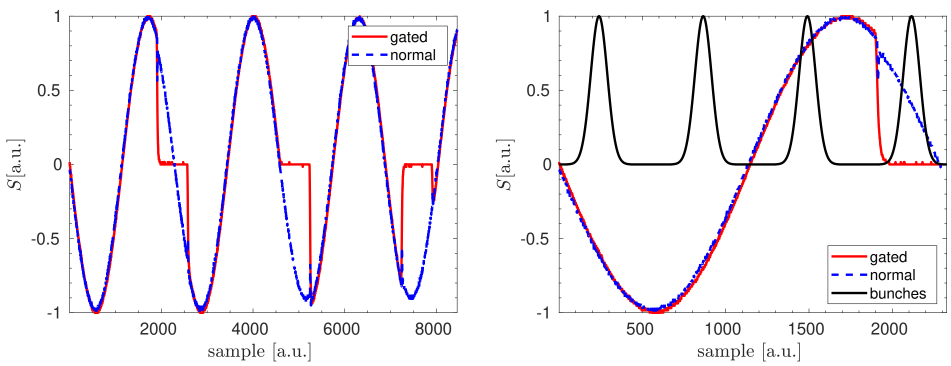
Ref. [1] detailed explanation)



(a) preliminary (b) preliminary

Figure 3: (a): Running spin-tune per turn. (b): Left scale (blue) shows the moving mean of the spin tune while the dashed line is an analytic prediction of the time dependence of the running spin tune scale. The right scale (red) denotes the corresponding running frequency difference [1]. To accelerate the computations, the fields of the RF Wien filter has been amplified by a factor of $f_a = 10^4$.

The conclusion is, **when measuring the spin tune, the RF Wien filter should be switched off**, and this shall be tested in the requested beam time. Measuring the *in-plane* spin precession while the fields of the RF Wien filter are oscillating does **not** strictly correspond to the spin tune, but rather to the *running* spin tune.



(a) (b)

Figure 4: (a) Blue: an example of an un-gated signal; red: an example of a gated signal; (b) Blue: one period of an un-gated signal; red: one period of a gated signal; black: four-bunches beam signal.

2.2 Proposed solution

To solve this problem, we propose to run the precursor experiment with a multi-bunch beam structure. The COSY group has already successfully operated the machine with four bunches for a complete beam time.

In multi-bunched beam, the fields of the RF Wien filter will be visible to only three of the four bunches. This leads to an RF field-free bunch, also known as pilot bunch. The spin tune will be only measured using the pilot bunch. Then, using Loop-1 (see Sec. 1), the feedback system maintains the spin precession frequency and the phase at the RF Wien filter.

To realize the aforementioned idea, the driving circuit of the RF Wien filter is modified to include a gating circuit. The basic idea is to cut off a portion of the wave either that is feeding the amplifiers (small-signal gating) or possibly, the amplified signals (large-signal gating) in a way that at least one bunch does not see the fields of the RF Wien filter. Panel (a) of Fig. 4 shows an example of a gated signal (red graph) and an *unperturbed* one (blue graph). Panel (b) indicates exactly the intended scenario. The requested beam time should achieve that at least one of the four bunches stored in COSY is not affected by the fields of the RF Wien filter.

For the experiment, it is sufficient to run the RF Wien filter in the so-called 90° mode, *i.e.*, vertical electric field and radial magnetic field. In this mode of operation, only vertically polarized beam is required. We would like to obverse driven spin oscillations on all the bunches except the pilot bunch.

The new feedback system shall be used to determine the frequency of the polarization which can be used to determine the EDM resonance strength. Upon success, all four frequencies of the RF Wien filter [Eq. (1)] will be tested as well.

3 Additional hardware

The current setup of the driving circuit, uses a single signal generator that could be synchronized with the rest of COSY RF equipments via a 10 MHz reference signal. A 1:4 splitter is used to distribute the input RF signal into the power amplifiers. The problem is that, these amplifies are not identical, *i.e.*, they possess slightly different gain and phase response. The power fed at the input terminal is not homogeneous as intended. To solve this problem, we decided to use a multi-channel signal generator[2]. With the new instrument, it will be possible to control the amplitude and phase of each branch simultaneously, while keeping the frequencies at each branch synchronized. Additionally, the new signal generator does provide additional outputs that can be used for other purposes such as providing the polarimeter and the corresponding BPM with signals that are synchronized with the main frequency of the Wien filter without altering the power levels. The polarimeter would use this signal to setup the feedback system and the BPM requires this signal to measure the Lorentz force. This new hardware/setup, we would like to test during the requested beam time.

[2]Zurich Instruments AG, Zurich, Switzerland www.zhinst.com.

4 Request

For this investigation **we would like to request 1 week of machine development time and 1 week of measurement time**, to be tentatively scheduled at the end of the 4^{th} quarter 2019 (November/December).

References

[1] F. Rathmann. Systematics considerations for the EDM precursor experiment at COSY, part B. 2018.

[2] J. Slim, R. Gebel, D. Heberling, F. Hinder, D. Hölscher, A. Lehrach, B. Lorentz, S. Mey, A. Nass, F. Rathmann, L. Reifferscheidt, H. Soltner, H. Straatmann, F. Trinkel, and J. Wolters. Electromagnetic Simulation and Design of a Novel Waveguide {RF} Wien Filter for Electric Dipole Moment Measurements of Protons and Deuterons. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 828:116 – 124, 2016.