Executive summary for "COSY Test Beam Time"

For Lab. use

Exp. No.:	Session No.

Collaboration______JEDI____

Spokesperson for test beam time: Name:___Edward J. Stephenson________________________

Address:
Indiana University CEEM__________
Center for Spacetime Symmetries____
2401 Milo B. Sampson Lane________
Bloomington, IN 47401 USA_______

Phone: _+1-812-855-5469__ Fax: __________________ E-mail: _stephene@indiana.edu_________

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
vector polarized deuterons	970 MeV/c	3×10^8 /fill	$> 10^{10}$ /fill
Experimental area	**Safety aspects (if any)**	**Earliest date of installation**	**Total beam time (No.of shifts)**
WASA	N/A	April, 2018	42 shifts + MD

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

Polarized deuteron ion source, WASA Forward Detector (polarimeter), special targets

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

Proposal

Further Exploration of Spin Dynamics Issues for EDM Search

E.J. Stephenson
Indiana University Center for Spacetime Symmetries, Bloomington, IN 47405 USA

V. Hejny, B. Lorentz
Institut für Kernphysik, Forschungszentrum Jülich, 52425 Jülich, Germany

JEDI Collaboration

ABSTRACT:

For the past ten years, a series of polarized deuteron experiments in COSY have demonstrated the feasibility of various spin manipulation and measurement techniques for the storage ring electric dipole moment (EDM) search. These include real time corrections to polarimeter errors, sextupole field adjustments to COSY to prolong the in-plane polarization (IPP) lifetime, and feedback to control in real time the direction of the IPP. This proposal seeks to address three smaller issues that remain at the end of these investigations. The first asks whether electron cooling is needed for attaining a long IPP lifetime. The second explores the feasibility of high efficiency polarimeter operation based on a fiber rather than a block carbon target. The third seeks to understand what features of the COSY beam setup seem to limit simple operation and long IPP lifetime to less than 10^9 deuterons/fill. This proposal asks for two weeks of dedicated polarized deuteron beam time at p = 0.97 GeV/c to address these issues. We plan to use the newly re-commissioned WASA Forward Detector as the beam polarimeter.

A. Is electron cooling needed?

The EDM storage ring is best represented by the simple picture of a polarized beam in which the polarization direction initially follows the in-plane rotation of the beam velocity and the radial electric field (always present in the particle frame) slowly causes the polarization to precess into the vertical direction. Holding this condition for perhaps half an hour is needed in order that the rising vertical polarization component becomes large enough to measure given repeated stores that continue for many months.

A coasting beam quickly depolarizes since the spread of momenta among the beam particles leads to a spread in the rotational speed of the polarized particles. The speed is governed by the spin tune ν_S = Gγ that depends on the relativistic parameter γ (G is the anomalous magnetic moment). Bunching the beam removes this first-order effect by forcing all the beam particles to be, on average, isochronous. But transverse oscillations of the particles in the ring's focusing fields still gives rise to path length variations and a distribution of speeds. Electron cooling reduces this problem by collecting the beam more tightly around the reference orbit and, in addition, reducing its spread longitudinally around the ring. These efforts bring the lifetime of the in-plane polarization (IPP) up from tens of milliseconds to perhaps tens of seconds. To go the rest of the way to half an hour requires a field correction to the COSY ring. By adding sextupole fields to the existing quadrupole fields, it becomes possible to shift the equilibrium orbit away from the reference orbit by an amount related to the size of the transverse oscillations. When these changes are made in the arcs, then a condition may be created where the length of the orbit circumference becomes independent of the size of such transverse oscillations, and it becomes possible to lengthen the IPP lifetime to values on the order of a thousand seconds [1].

Both electron cooling and sextupole field corrections act on the depolarizing effects of transverse oscillations of particles within the beam. Since electron cooling by itself is not sufficient for a long IPP lifetime, is it possible that sextupole corrections alone could do the job? This depends on such corrections being sufficiently accurate over a longer range, or, put differently, that higher order depolarization effects are small enough not to matter. For a brief time during a run in 2015, this notion was tested by starting with a beam where the IPP lifetime was large and slowly reducing the time that electron cooling was allowed to run during the beam preparation. Somewhat surprisingly, long IPP lifetimes remained even for cooling times as short as 5 seconds. But it was clear that reducing the cooling time changed other characteristics of the beam, so that it was necessary to re-optimize the sextupole field settings as the cooling time got shorter. Then, for no cooling at all, no horizontal polarization was recorded in the COSY ring. This polarization, which starts in the vertical direction following beam injection, is rotated from vertical to horizontal by a series of spin kicks delivered by an rf solenoid. The solenoid currently in use operated on the (1 – Gγ)f_{REV} harmonic of the beam revolution frequency (871 kHz rather than 126 kHz). For particles that are significantly ahead or behind the main beam bunch, the phase of the rf solenoid is no longer correct and the proper rotation of the polarization into the ring plane fails.

This result may be inferred from data taken in 2011 [2]. If things are working well for preserving the polarization, then measurements of the vertical component will show a continuous oscillations when the rf solenoid is run for a long time. However, for the uncooled beam, these oscillations damp quickly, as shown in Fig. 1. The shape with time of the polarization may be unfolded to produce the longitudinal distribution of particles in the beam. This is shown in Fig. 2 where the length is stretched to about 70% of the ring circumference of 183.5 m. For this reason, no studies of the uncooled IPP lifetime are available.

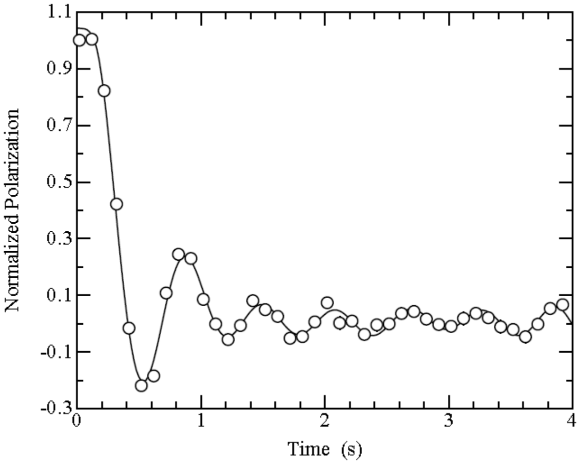

FIG. 1: Normalized measurements of the vertical polarization as a function if time with the rf solenoid operating continuously. The curve is a model fit to the data assuming the distribution of synchrotron amplitudes shown in Fig. 2.

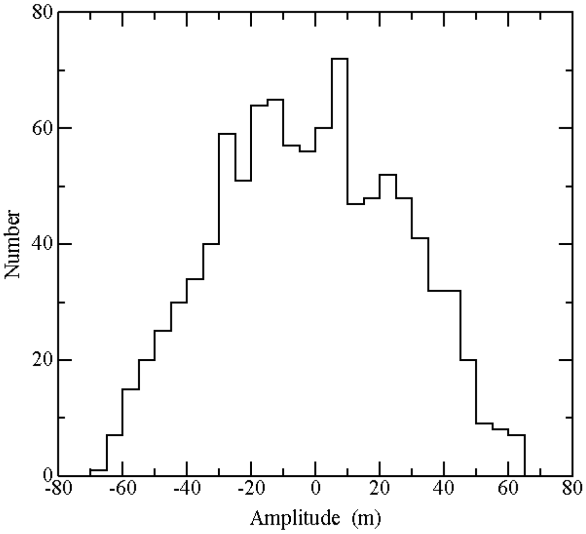

FIG. 2: Distribution of longitudinal positions of particles in the beam unfolded from the measurements of Fig. 1 so as to create a fit to the polarization data.

The longitudinal boundaries of the beam are usually set by the sinusoidal potential (h = 1) created by the rf cavity in COSY. In order to restore the IPP polarization for an uncooled beam, we plan to switch to the cavity used previously for barrier bucket operation. This was originally intended to make even longer bunched beams so as to spread the beam's interaction with nuclear physics targets in time. Instead we plan to reconfigure the harmonic content of the signal driving the cavity so that the bucket is narrow. This should enable us to preserve the polarization as it is rotated into the ring plane.

The setup for this part of the experiment requires the following: (1) preparation of the beam so as to minimize orbit variations away from the median orbit, (2) measurement of the ring chromaticities as a function of sextupole setting in order to locate the values needed to make the X and Y chromaticities vanish, (3) with electron cooling on, make a preliminary scan to locate the settings for maximal IPP lifetime (which should come near values that make the chromaticities vanish), and (4) preparation of the barrier bucket cavity for narrow bucket operation. Once completed, then we plan a scan of IPP lifetime as a function of electron cooling time. This is expected to take about a week.

B. Can the block target be replaced by a fiber target?

For the storage ring EDM polarimeter, it is important to make maximal use of the particles of the beam when measuring the beam polarization. To enhance the efficiency, we have used a carbon block target 17-mm thick located about 3 mm from the center of the beam. The EDDA scintillators, used initially as the beam polarimeter, show an efficiency of about 0.07 % into a detection range of about 9° to 12°. If more forward angles had been accessible, a much larger efficiency would have been recorded. Nevertheless, this efficiency is consistent with measurements of deuteron elastic scattering from carbon [3]. In 2015, tests were made with a fiber target inserted into the center of the beam. In this case, the measure efficiency was a bit above 0.01 %, not even a factor of 10 below the carbon block value.

This result suggests that individual deuterons in the beam pass through the fiber target multiple times before being scattered into the polarimeter detectors, since this is the only way to build up the efficiency. Thus deuterons that pass through the target are being recaptured into the ring acceptance and restored to full beam energy by the rf cavity. This would be desirable as it would permit examination of scattering from parts of the beam and the measurement of a polarization profile, either vertical or horizontal. If there is a change in the vertical polarization across the beam, for example, the block target would tend to intercept different parts of this profile as a function of time, leading to a changing vertical polarization measurement that could be misinterpreted as a signal of an EDM.

This result raises the possibility that the fiber dimensions could be optimized for best efficiency, and even higher values obtained. With the new WASA Forward Detector as a polarimeter, there is now a new target arrangement that allows for multiple targets (including a block target) and target changing without contaminating the ring vacuum. Thus a variety of target shapes could be tried and their efficiency measured. (It might be advantageous to perform this study with aluminum since it would be possible to manufacture fiber targets with varying dimensions more easily.) Changes to both the width and the thickness (along the beam) should be examined.

A good measurement of the efficiency requires that the beam be bunched so that the rf pickup of the beam longitudinal profile has a well-established zero. This may be calibrated to read the circulating current. A polarized beam is not needed for these tests. A complete set of tests, including several targets (with the block target) and beam positions, will take about half a week.

C. What limits increased beam current operation?

The measurements of the IPP lifetime reported in Guidoboni [1] were made with a beam whose particle count was less than 10^9 deuterons/fill. With this restriction in place, the time dependence of the polarization showed simple curves, as seen in Fig. 3 for two different sextupole settings. This situation led to the reported lifetime of 1000 s and a simple correspondence between maximal IPP lifetime and zero chromaticity.

At larger currents (> 10^9 deuterons/fill), things are not as simple. A sample of various polarization time curves is given in Fig. 4. The template of Fig. 3 no longer applies, and the analysis was based instead on polynomial fits to the early time behavior of the polarization. A common characteristic is a break between an early time and a later time slopes. As sextupole fields are changed, there is usually no pattern in the time dependence variations. Measurements at higher currents (> 10^{10} deuterons/fill) present even more complicated shapes.

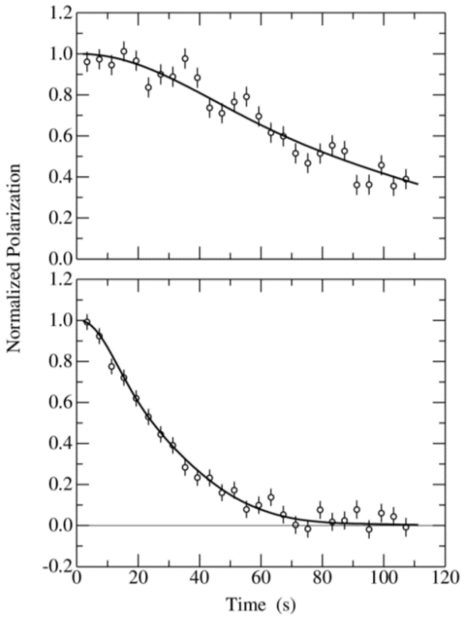

FIG. 3. Normalized measurements of the IPP as a function of time for two different settings of the COSY ring sextupoles. The curves represent an adjusted template taken from COSY beam profiles that is scaled to mimic the time dependence of the polarization.

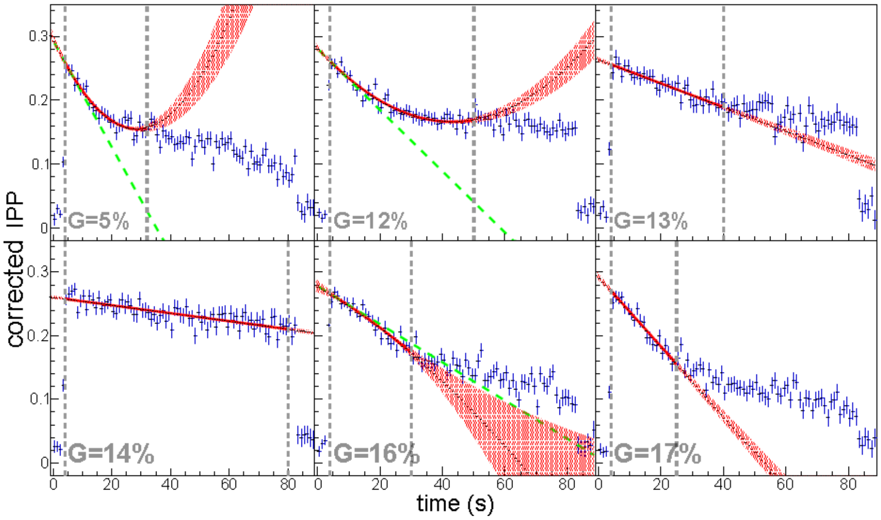

FIG. 4: Measurements of the polarimeter asymmetry as a function of time for a variety of sextupole field settings (denoted by G). The curves show polynomial fits to the early time measurements.

A study of these effects may prove helpful in planning for the EDM ring if we can associate features in the polarization time dependence with specific changes in the properties of the circulating beam. There have been times when head-tail oscillations have been present that show clearly on the longitudinal beam profiles. These features may also be associated with the heating that is applied in order to extract the beam onto the polarimeter target. Some effects may come from the construction of the target.

The setup requirement for this study is similar to that needed for the electron cooling, namely a long IPP lifetime under good conditions. This study is more open-ended, but should not last more than a few days. The stated goal for the EDM storage ring is 10^{11} particles/fill.

Beam Time Summary

In addition to machine development, this proposal requests two weeks of 0.97 GeV/c polarized deuteron operation during the second and third quarters of 2018. The beam should have three polarization states available: vector plus, vector minus, and unpolarized. The beam will be varied between 3×10^8 and $> 10^{10}$ deuterons/fill. The setup will involve a corrected orbit, electron cooling, and vertical white noise extraction of the beam onto a polarimeter target at the WASA target station. Adjustments will be made to the sextupole fields of the ring.

References

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[3] N.P.M. Brantjes *et al.*, Nucl. Instrum. Methods Phys. Res. A **664**, 49 (2012).