COSY Beam Time Request

For Lab. use

Exp. No.:	Session No.
E2	**2**

Collaboration: JEDI

Towards the EDM Polarimetry

Spokespersons for the beam time: **Irakli Keshelashvili (Jülich)**
Bernd Lorentz (Jülich)

Spokespersons for the collaboration: **Andreas Lehrach (Jülich)**
Jörg Pretz (Aachen)
Frank Rathmann (Jülich)

Address:
Institut für Kernphysik
Forschungszentrum Jülich
52428 Jülich
Germany

Phone: **+49 2461 615603** Fax: **+49 2461 613930** E-mail: **a.lehrach@fz-juelich.de**
pretz@physik.rwth-aachen.de
f.rathmann@fz-juelich.de

i.keshelashvili@fz-juelich.de
b.lorentz@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
Extracted beam of unpolarized deuterons	**100, 150, 200, 250, 270 MeV**	**10^3**	**10^7**
Experimental area	Safety aspects (if any)	Earliest date of installation	Total beam time (No.of shifts)
LYSO crystals at external BIG KARL area	**none**	**1st November 2015**	**1 week (+ MD)**

JEDI Beam Time Request for the second half of 2015

Towards EDM Polarimetry

The JEDI collaboration

http://collaborations.fz-juelich.de/ikp/jedi

May 19, 2015

Abstract

The goal of this proposal is to investigate step by step the needs of the JEDI polarimetry development. In a first test beam time, the basic properties of the LYSO crystal as a detector material and its readout chain (PMT+sampling ADC) will be explored. The following items will be examined:

- A dependence (linearity) of the incoming deuteron energy *vs* measured energy deposition;
- The energy resolution $\Delta E/E$ as a function of incident deuteron energy;
- The deuteron detection (reconstruction) efficiency dependence on the incident beam energy;
- Two different types of Hamamatsu PMTs comparison with their dedicated HV dividers;
- A fast, "dead time less" Flash ADC testing.

The **one week** COSY beam time is requested for tests using extracted deuteron beam at various energies ($100, 150, 200, 250, 270\ MeV$) at the BIG KARL experimental area.

1 Introduction

The long term plans and activities of the JEDI collaboration are described in Refs. [1, 2]. In the permanent electric dipole moment (EDM) measurement in storage rings, using a polarized charged particle (deuteron or proton) beams, a slight change of polarization over time is expected. To observe this tiny effect a high precision polarimeter with minimum beam dissipation is required. Moreover, the restriction of not using a magnetic field (which affects spin motion via magnetic dipole moment (MDM)) makes a requirement to measure a particle energy without tracking information. A measurement of the elastically scattered particle kinetic energy via its ionization losses in the calorimeter is crucial for the elastic $dC \to dC$ reaction identification. For the moment, we assume that we will use carbon as a target material for its unique properties in the polarization experiments [3, 4]. A carbon target seems to be a good choice because of its high elastic cross section compared to other light nuclei. At the same time it has quite a large and smooth analyzing powers in the forward direction. Lighter or heavier nuclei have either smaller or diffractive analyzing powers, which makes them less useful. In addition, the so-called figure of merit (FOM), which is a product of differential cross section and analyzing power squared $FOM = \sigma \times A_y^2$, shows the large value at 270 MeV deuteron kinetic energy [5] (see fig.: 1). The indicated scattering angular range ($5^o < \Theta_{lab} < 20^o$) shows reasonably large FOM. Nevertheless, in

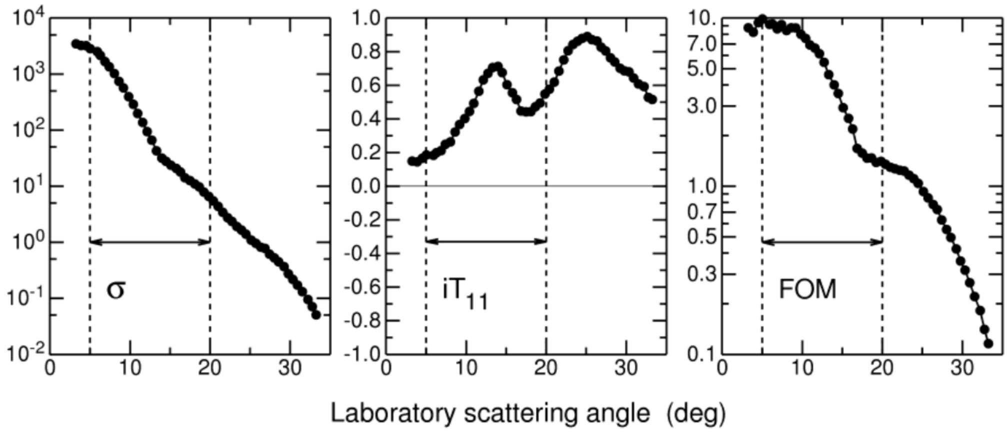


Figure 1: Measurements of the laboratory differential cross section (mb/sr), the vector analyzing power A_y, and the figure of merit (FOM) for deuteron elastic scattering from carbon at 270 MeV [5].

the framework of the polarimetry program, we will explore and compare other materials (neighbour stable isotopes) to carbon as an alternative target material for the precision polarimetry.

At present, the EDDA detector is being used to measure beam polarization in the COSY ring. The study of higher-order (sextupole) fields in the storage ring to lengthen the decoherence time of the stored, horizontal beam polarization. This study has already achieved polarization lifetimes of hundreds of seconds for deuterons [7]. With these milestones in place, the next task is to embark on the design and construction of a polarimeter that is indeed suitable for use on a storage ring dedicated to the search for an EDM. The main requirements are high efficiency, stability, and reproducibility. The polarimeter must operate continuously with high efficiency. A very high polarization (analyzing power) sensitivity is required to detect a polarization rotation of the beam as small as a μrad. There also needs to be control of the systematic errors in detecting this change to a similar level of precision.

The goal of this long-term program would be the design, construction and testing of a prototype polarimeter for use in the first EDM storage ring experiment. This includes the following major steps:

- Development of a broadband database of the cross section and analyzing power for pC and dC scattering.
- Development of conceptual design of the detector and the (carbon) target.
- Polarimeter modeling and Monte Carlo simulations.
- Realization (engineering/design/construction/build) and testing of a prototype.

2 JEDI Polarimetry Concept

The general, the conceptual idea of the polarimeter is shown in figure 2. It will monitor the change of asymmetry using the elastic scattering reaction with very high accuracy. The concept of polarimeter is based on the simple principle: measuring the full deposited energy in the detector by the deuterons from the elastic $dC \to dC$ scattering process. The principle includes: (i) the best elastic reaction identification capability; (ii) 100% DAQ efficiency; (iii) full ϕ acceptance in reasonable coverage of maximum FOM region; (iv) no magmetic/electric field, (v) long term stability (>10 years). Currently, the idea is to use

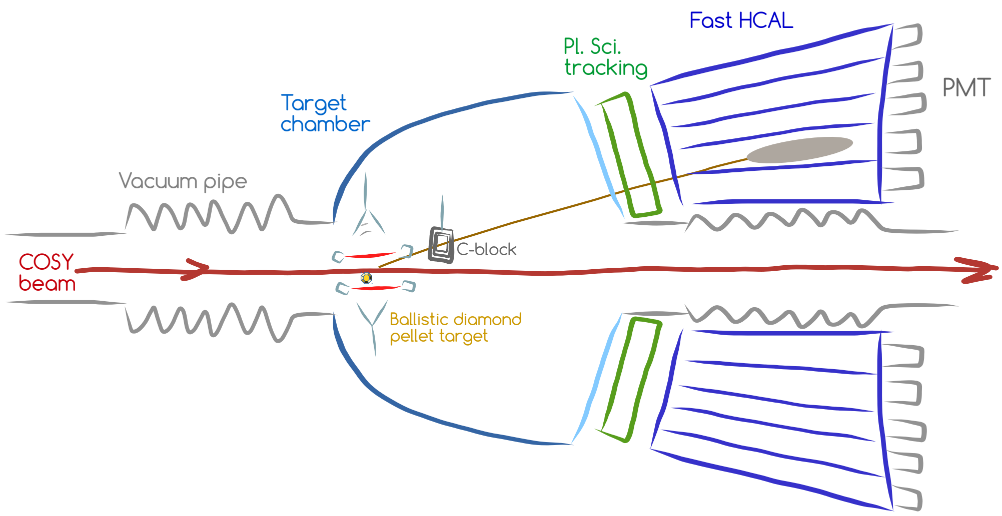
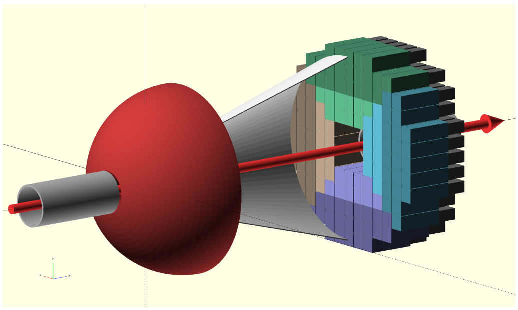


Figure 2: The sketch of the JEDI polarimeter.

heavy crystal calorimeter (see figure 2) to select elastically scattered deuterons (protons) from the fixed carbon target. In addition, for tracking the plastic scintillator (Pl. Sci.) array will be installed in front of hadron calorimeter (HCAL) to increase the position resolution. The material of choice for the fast calorimeter is the novel LYSO (Lutetium-yttrium oxy orthosilicate) crystal for its unique properties [6]. It has very high light output (75% of $NaI(Tl)$), a fast decay time constant of 40 ns, and a very high density of 7.1 g/cm^3. The only drawback is its internal radioactivity. With a spectral endpoint below 1 MeV, there are no difficulties for the considered energy ($T_d = 270\ MeV$). In figure 3 the GEANT model of the polarimeter is shown. The inner rings of the detector indicated with lighter colors are LYSO crystals. For the outer part (marked using darker colors), where much lower count rate is expected (due to rapid fall in the elastic differential cross section), BGO (Bismuth germinate) crystals with equal density, similar light output and rather slower decay time constant can be employed. Currently, the market price of the same size BGO is about 40% less than of the LYSO crystal.

2.1 Step One: Study of LYSO crystal performance as a deuteron detector

The current beam request concerns the very first step of this development program, namely the study of the choice for the detector material. The information collected after these tests will be essential input for developing of the simulation code using GEANT4 toolkit



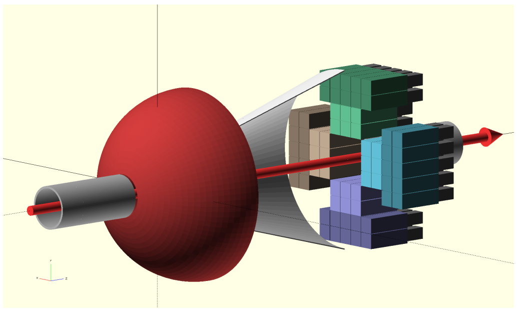


Figure 3: Left: The model of the final, full ϕ and Θ ($5^o \div 20^o$) polarimeter; Right: its first simplified (with fewer elements) version and the outline of its vacuum chamber.

[8]. Currently, our simulation is based on scarce data for this kind of material. The test setup of the proposed measurement is shown in figure 4. The setup is planned to be installed at the BIG KARL, COSY external beam line. The crystal will be mounted on a 2D stepp motor control table that is capable of moving in the vertical direction and rotating around the vertical axis. During these tests, the deuteron beam (with five different energies: $100, 150, 200, 250, 270$ MeV) will be directed to the center of the crystal. In

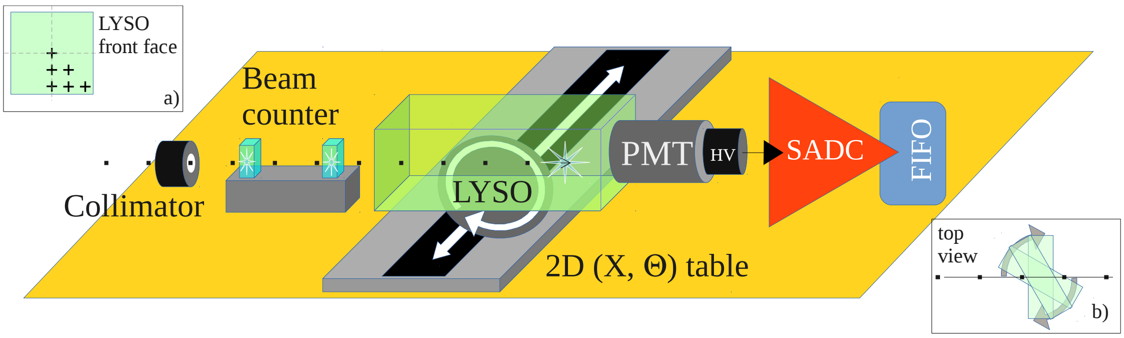


Figure 4: Test setup of the proposed first step measurement. Panel (a) shows the front face of the LYSO crystal and the six target points where the beam will be directed. Panel (b) demonstrates the rotation of the crystal in order to study the different energy losses by the deuteron to explore the Bragg peak distribution.

addition, the position sensitivity of the measured amplitude will be explored by directing the beam to six symmetric points of the one-quarter of the crystal (shown in figure 4 panel (a)). The panel (b) of the same figure, shows how the rotation of the crystal will be used to simulate different path lengths through the crystal. This information can be analyzed, and the Bragg peak function can be reconstructed. In the figure 5, the first sample of LYSO crystal with a Hamamatsu R1548-07 photomultiplier tube (PMT) and its newly developed high voltage divider is shown. This type of PMT has a rectangular input window (24×24 mm) with two independent photocathodes each of 18×8 mm and independent multiplication system. This gives the possibility to use even smaller crystals (15×30 mm) for the first ring of the detector to double the acceptance of each module. A maximum sensitivity of the PMT is exactly at the maximum of the scintillation spectrum (420 nm) of the LYSO crystal. Some parameters of the LYSO crystal will be studied in Lab before the measurements with COSY beam. The values of its response to cosmic rays, the absorption length measurements using ^{22}Na source, and count rate linearity

Figure 5: First sample of the LYSO crystal PreLude 420 produced by Saint Gobain [9]. The size of the crystal is $30 \times 30 \times 100$ mm^3. The Photomultiplier tube (PMT) is a Hamamatsu R1548-07 [10].

using LED pulses will be examined. Understanding the signal shape using two different types of the Hamamatsu PMT (R1548 and R1924) with two newly developed passive high-voltage dividers is planned. The very first laboratory test with cosmic rays shows a very solid signal (-900 mV) for the horizontally aligned crystal (3 cm path) with about 80% of PMT Maximum HV. The front edge of the average signal was measured using one meter 50 Ω coaxial cable to be about 800 ps, which shows the excellent timing characteristic of the LYSO crystal.

In figure 6 are shown: (Left) The deuteron kinetic energy *vs* deposited energy is simulated and a similar experimental plot will be one of the main points of the tests. (Middle) The energy resolution dE/E as a function of the incident and reconstructed deuteron energy will be measured for the planned five energy points $(100, 150, 200, 250, 270\ MeV)$. (Right) One of the crucial points of the tests is to compare the incident and reconstructed number of the deuterons. According to a GEANT4 simulation [8], the detection efficiency should vary somewhere around 90% to 60%. The efficiency is strongly depends on incident and threshold energy, and varies for different physics lists in the GEANT4 simulation. However, the empiric test of the deuteron detection efficiency needs to be exactly measured as a function of the incident deuteron energy. Also, the detection efficiency for the protons is an issue for the next tests. The expected proton reaction loss (indentity), before it is stopped inside the crystal due to the ionization losses, is much less than that for the deuteron. The important issue for the irradiation test is to find out how sensitive the LYSO crystal is to the high-energy (< 270 MeV) charged particles (like protons and deuterons). The chemical content of the LYSO (Lutetium-yttrium oxy orthosilicate) crystal has a high atomic and mass number. One can expect quite a fast degradation not only due to crystal lattice structure damage, but also because of nuclear reactions inside the crystal. At the same time, the LYSO is one of the most radiation hard inorganic scintillator material increasingly used in particle detectors. Nevertheless, low intensity of polarized beams and slow extraction rates onto the target gives a confidence to use LYSO material for the upcoming long-term experimental program for EDM search at COSY (as it is) and beyond.

This beamtime will serve as a first extensive test for the triggerless readout system too. For the data acquisition system (DAQ) we plane to employ the Struck SIS3316-250-

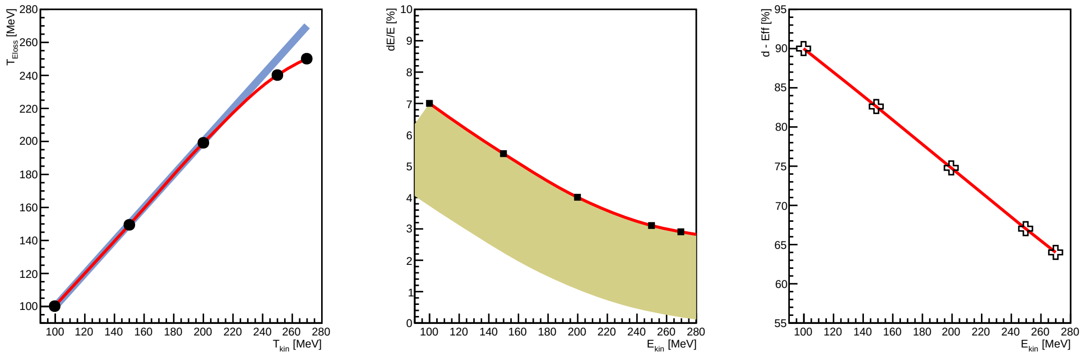


Figure 6: Simulated spectra: (Left) reconstructed energy; (Middle) measured energy resolution; (Right) elastic deuteron detection efficiency *vs* incoming deuteron beam energy $(100, 150, 200, 250, 270\ MeV)$.

14 (16 channel 250 $MSPS$ $14-bit$ high-speed) sampling ADC [11], capable to sample and store continuously for 250 ms. This will be very important for the future plan to use the so-called ballistic diamond target which will only generate events during passage trough the beam (roughly expected as $\sim 1\ ms$ with $\sim 10\ m/s$ pellet speed).

2.2 Outlook

The main objective of the step two is a precise and careful scan of the target materials near to the C. In understanding and making this step effective, an intensive Monte Carlo simulation will be needed. All the acquired information after step one will be an input of the GEANT4 simulation code. The figure 7 describes the test setup for the planned measurement. Like step one, the step two will also utilize the COSY external beam, which gives us the advantage to tag every incoming deuteron. Step three will be as an internal storage ring test of the final JEDI polarimeter concept. The main idea of step two is using extracted polarized deuteron beam for the assymetry measurement. The extraction of the polarized deuteron beam was never widely examined at the COSY accelerator facility. At the same time, the external experiments have used high-energy polarized external proton beams. Close to our energy region of interest (270 MeV) the deuteron depolarization resonances are not expected. Moreover, the main idea of the measurement requires only the **constant polarization** over one cycle extraction, which can be easily obtained. During the slow extraction, the target material **can be continuously switched from carbon to aluminum and back** ($\sim 5\ sec$). This will allow us to measure simultaneously with polarized and unpolarized deuteron beam two main physical quantities: the differential cross section and the vector analyzing power that are the main ingredients of the FOM that is important for the material comparison. As a cross check, one can also use already measured and published vector analyzing powers at 270 MeV [5] to confirm COSY beam polarization. All these measurements must then be repeated for the proton beam as well. This will be the subject of a separate beamtime request.

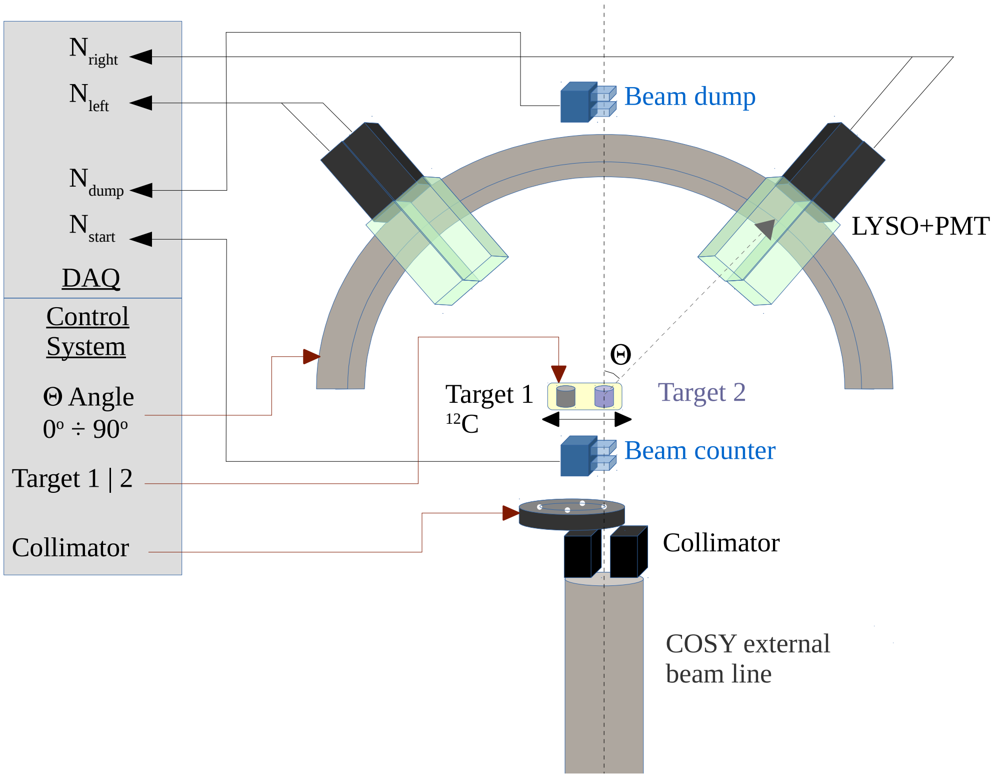


Figure 7: Supposed test setup of the second step measurement.

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[10] Hamamatsu R1548-07

[11] Struck SIS3316-250-14; 16 channel 250 MSPS 14-bit