Polarimetry concept based on heavy crystal hadron calorimeter

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Abstract. In the ongoing JEDI (**J**ülich **E**lectric **D**ipole moment **I**nvestigations) project, the essential point will be to measure a tiny beam polarization change over an extended period of time. The particle scarcity in the polarized deuteron or proton beams and the required slow extraction rate puts tough experimental constrains on the polarimetry. For the EDM measurements, a dedicated high precision polarimeter is required. To fulfill specifications, a fast, dense, high resolution (energy and time), and radioactive hard novel crystal scintillating material is required. LYSO crystals are supposed to be used as an ideal scintillating material for this kind of detector. The LYSO crystal PMT and SiPM readout, with a FADC based system is under the development. The first proton and deuteron beam test of the prototypes are presented here. In this paper, the new polarimetry concept and preliminary results from first proton and deuteron beam time are presented.

1. Introduction

In the search for an electric dipole moment with a storage ring (srEDM), the polarimeter must be sensitive to very small changes in the vertical component of the polarization during a beam store. Such changes require vast statistics and excellent sensitivity; thus, the polarimeter must operate extremely efficient. Due to smallness of the expected EDM signal the precision or calibration of the measurement is not the most important feature. Thus, the design of the polarimeter favors efficient targets and the observation of an elastic scattering, along with low q-value reactions, at forward angles where the spin-orbit interactions create a large polarization sensitivity. This requirement leads to the use of calorimetric detectors that can easily select such events with the use of a lower threshold for the total energy measurement. To maintain sufficient sensitivity to vertical component changes, the detectors, and their thresholds must be very stable over time and across changes in rate or beam properties (direction and angle). It is not as necessary to restrict the acceptance to a single or a few reaction channels as would be needed for a nuclear physics study. This leads to the emphasis on forward-angle elastic scattering and the use of single component detectors. In ref.[1], the vector analyzing power, the differential cross section, and the figure-of-merit (FOM) of deuteron carbon elastic scattering at 200 MeV and 270 MeV deuteron kinetic energies are published. At both energies, the vector analyzing power is positive and quite large over the forward polar angular range covered by the new concept of the JEDI polarimeter [2], show in fig. 1. The FOM is calculated as a product of the differential cross section and the squared analyzing power. But in the real experiment, the detection efficiency (defined as a ratio between the identified number of elastically scattered deuterons and the incoming deuterons) must be taken into account. In such a case, FOM can be defined as:

$$FOM(E) = \{\sigma(E) \times \varepsilon(E)\} \times A_y^2(E) \quad (1)$$

where the additional parameter $\varepsilon(E)$ is introduced as a detection or in our case elastic reaction selection efficiency. This efficiency is determined by placing a threshold at the lower edge of the observed elastic scattering peak (in the deposited energy spectrum), and it depends on the energy resolution of the crystals and the features of the reaction and background tail below the peak. The detection efficiency itself hase been measured as a first experiment [3, 4], where the LYSO modules were directly exposed to the low intensity ($< 10kHz$) tagged deuteron and proton beam.

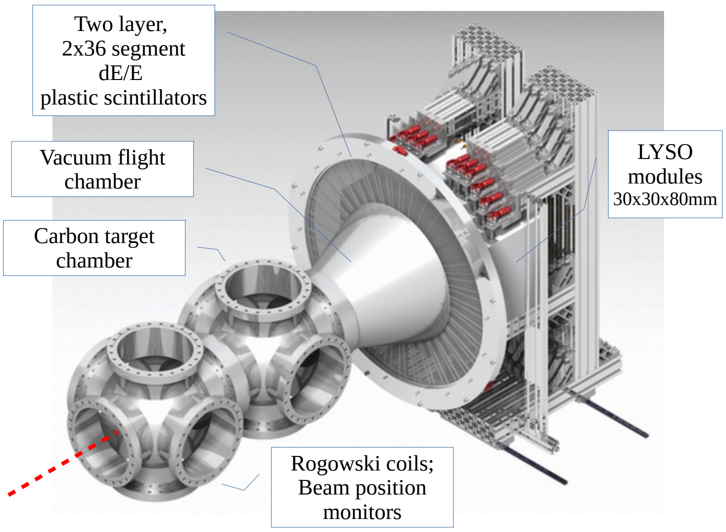

Figure 1. The new JEDI Polarimeter concept is shown. From left to right there are two cross type flanges, one for beam position monitors (BPM) and the second for the carbon targets. In the middle, a vacuum flight chamber. Next, two layers of ϕ sensitive "pizza" shaped, 2x36 plastic scintillators. The last is the LYSO HCAL to totally absorb the energy of the scattered particles.

2. Experiment

The goal of the first step experiment was to investigate characteristics of scintillating material LYSO with deuteron beam. In these tests, five LYSO crystals have been tested (four Saint-Gobain (SG) [5] 2x 30x30x100mm and 2x 15x30x100mm and one EPIC Crystals (EP) [6] 30x30x100mm), forming the four independent calorimeter modules (see fig.: 2). The readout was done using dual channel PMT [8] and SensL 6x6mm SiPMs 4x4 arrays. The optical contact has been made by optical grease and air contact. The air contact was preferred due to unwanted capillary effects in case of the optical grease flowing between crystal and Teflon wrapping. All events are written using Struck FADC [7] and signal forms were analyzed offline. The modules were exposed to direct proton $(100, 150MeV)$ and deuteron $(100, 150, 200, 235, 270MeV)$ beams mounted to the movable test table fig.:3. Using these crystals, two different module configurations can be assembled: three for low (large θ angles) and one for high count rate (small θ angles) use.

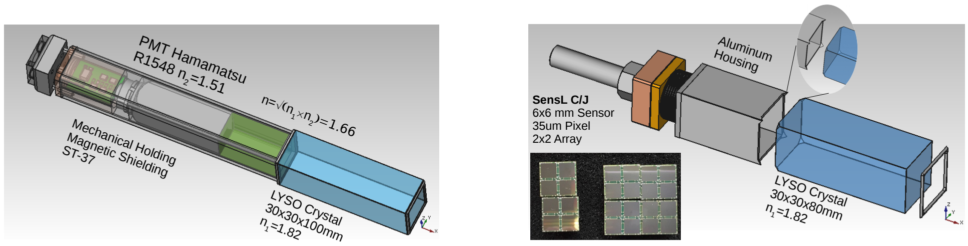

Figure 2. Left: the drawing of a single LYSO module with mechanical holding structure, high voltage passive divider, squared Hamamatsu PMT [8], a light guide, and the LYSO crystal. Right: example of the new prototype module combining a $30 \times 30 \times 80$ mm LYSO crystal with a SiPM [9] readout.

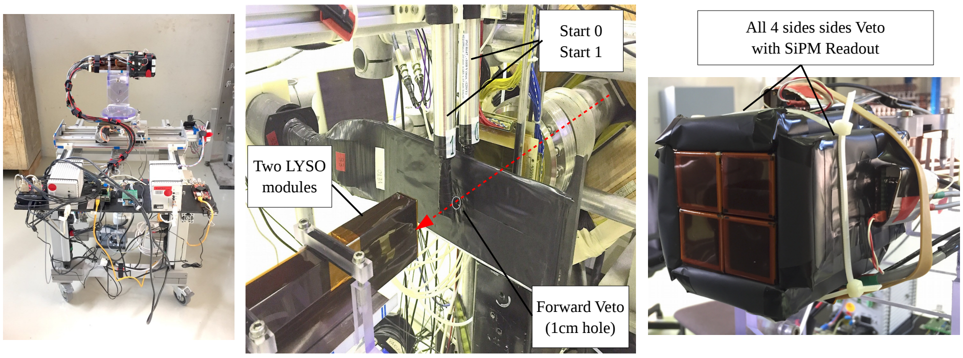

Figure 3. Left: X, Y, Θ test support table; Middle: two LYSO modules in beam with two start, and forward veto counter. Right: the cluster of 4 LYSO modules surrounded with plastic side veto scintillators.

3. Preliminary results and outlook

The main goals of the beam time: LYSO energy resolution, deuteron, proton identification efficiencies and all technical issues have been tested successfully. The energy resolution has been measured as a function of deuteron beam using QDC and FADC. The measurement using QDC is shown in the right plot of the fig.:4. The FADC results can be seen in more details in F. Müller's contribution [4]. The measured deuteron identification efficiency at 270 MeV is estimated as $\sim 70\%$ mainly due to deuteron breakup reaction inside the crystal [2]. Also, the crystal homogeneity scans, the front face scan, and beam incoming with different angles have been explored. All in all, the achieved resolution for the 270 MeV deuteron kinetic energy is 0.5%. The achieved time resolution is well below 300 ps and is good enough for an efficient operation of the polarimeter. The above-mentioned identification efficiency and the dead-time less FADC based data acquisition system are a perfect demonstration of our inorganic scintillator based polarimeter.

The next step is to measure scattered polarized deuterons from different target sizes and materials at the external beamline fig.:3. The main emphasis is to measure elastic and total cross-section ratio dependence on the polar angle at different energies. Also, the possibility to measure asymmetries, during one beam extraction with various targets gives us the opportunity to learn more about target materials. The table construction is made to be very versatile. One can change the polar angles of each arm independently with remote control. The distance between target and crystals can also be modified. The module orientation will also be adjustable. Also, the third static arm with plastic scintillator counter just below the beam line will be used

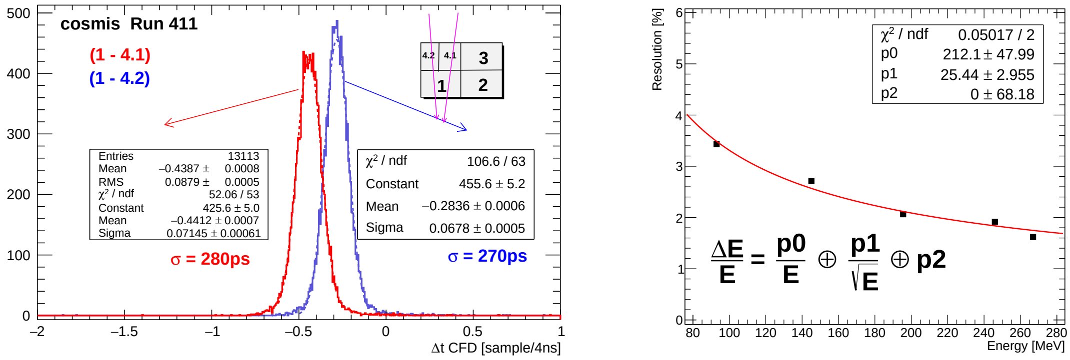

Figure 4. Left: measured time difference for cosmic events between neighbor PMT modules with sampling rate of 250 MS/s. For the time extraction the CFD method have been used. Right: measured LYSO energy resolution using PMT and QDC *vs* incoming beam energies.

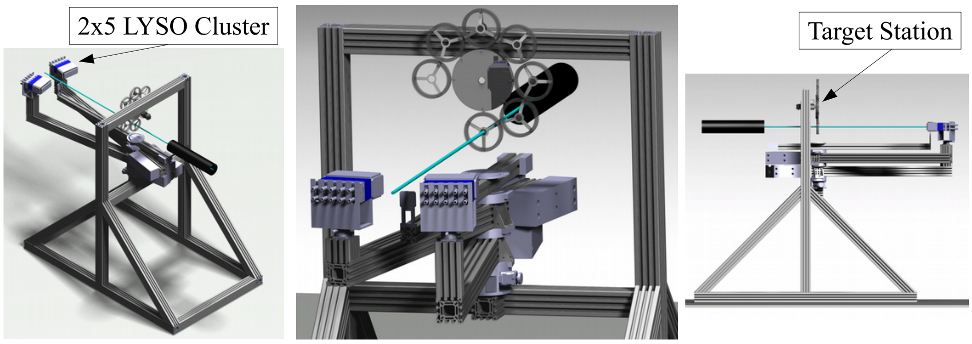

Figure 5. Experimental setup to be constructed for the second step experiment aiming to measure elastic to total cross section ratio and asymmetries with different target materials.

for the normalization purposes.

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[4] F. Müller, Proceeding of CALOR ’16, Korea (2016).
[5] Saint-Gobain, Cerium doped Lutetium PreLude420 crystal.
[6] Epic-Crystal, LYSO Ce scintillator.
[7] Struck, FADC, SIS3316-250-14 16 channel 250 MSPS 14-bit
[8] PMT, Hamamatsu R1548-07.
[9] SiPM, SensL, MicroFC-60035-SMT