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Towards JEDI Polarimetry

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In the upcoming JEDI project (Juelich Electric Dipole moment Investigations), the essential point would be to measure a tiny change of beam polarization over a long period. The particle scarcity in the polarized beams (deuteron or proton) and its slow extraction rate puts very difficult experimental limitations on the polarimetry. At present, the EDDA detector is being used to measure the beam polarizations of protons and deuterons circulating inside the storage ring COSY. For the future EDM experiments, based on the storage ring method, a dedicated high precision polarimeter is required. We have developed a new concept based on the following principles: achieving the maximum identifaction efficiency for the elastic events off carbon target (polarimetry reaction), providing the dead-time less data taking, and avoiding strong magnetic and electric fields. The measurements will last over several years, so the long-term stability and strong radioactive hardness of the detector material is a crucial requirement as well. To fulfill this specifications, a fast, dense, high resolution (energy and time), and radioactive hard novel crystal scintillating material LYSO is supposed to be used for particle detection/identification. The LYSO crystal samples, the PMT/SiPM photo-sensors and its HV dividers are under intensive tests. A new idea of target design is also under investigation, based on using small diamond pellets ($10 \div 100$ μm) to sample the beam and provide a 2-dimensional polarization profile of the beam's cross section. The Monte-Carlo simulation of the detector performance and its configuration are in progress. Laboratory tests of the detector modules, the noise performance of the electronics, and the LED irradiation of the different light sensors (like PMT's and SiPM's) are the ongoing activities.

In this contribution, the new polarimetry concept and all above mentioned activities will be presented.

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1. Introduction

The search for permanent electric dipole moments (EDM) of elementary particles (e.g., electron, neutron and proton) is of fundamental scientific importance, since a finite EDM would indicate a violation of time-reversal (T-) invariance. The equivalent CP-violation is a key ingredient for the conditions required to explain the apparent matter-antimatter asymmetry of our universe. The JEDI collaboration [1] aims to perform series of experiments to search for charged particle (proton, deuteron) EDM's using storage rings. The proposed method (srEDM) will exploit stored polarized beams and observe a miniscule rotation of the polarization axis as a function of time due to a finite EDM. The recent results achieved within this program at COSY can be found in [2, 3, 4].

The *key technology* required for the success of the srEDM is a highly sensitive and efficient way to determine the change in polarization direction during a beam store. In order to observe the expected tiny effect ($< 10^{-5}$), a highly efficient polarimeter with minimum beam dissipation is required. Moreover, the restriction of not using a magnetic field (which affects spin motion via the magnetic dipole moment (MDM)) makes a requirement to measure a particle energy without magnetic tracking information. At present, the EDDA detector [5], built with plastic scintillators, is being used to measure beam polarization change in the COSY ring. To fulfill the specifications for precision srEDM measurements, a fast, dense, high resolution (energy and time), and radiation-hard novel crystal scintillating material LYSO:Ce [6] is planned to be used for particle detection/identification.

The design of the polarimeter favors the observation of the elastic $\vec{d}C \rightarrow dC$ scattering of deuterons from a carbon target at forward angles where the spin-orbit interactions create a large polarization sensitivity (see Fig. 1). The so-called Figure-of-Merit (FoM) which is a product of the differential cross section and the square of the analyzing power, $FoM = \sigma \times A_y^2$, shows large values at 270 MeV deuteron kinetic energy. The $5^\circ < \Theta_{lab} < 20^\circ$ scattering angle range exhibits a reasonably large FoM. This feature makes carbon an ideal material for the polarimeter target near 270 MeV energy. The shape of the FOM shows the relative importance of forward angles over higher angles where the inelastic contribution from the nuclear reaction is more important.

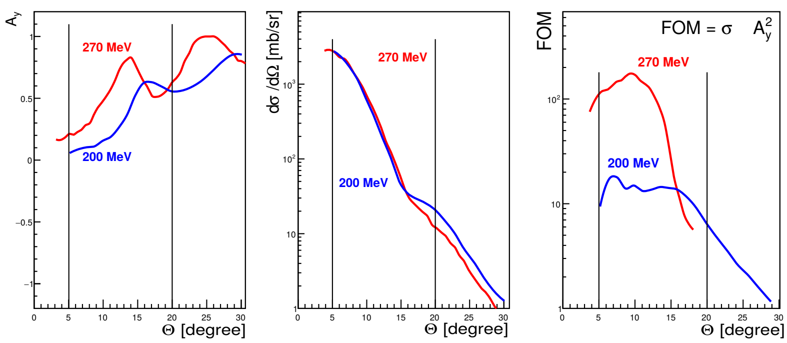

Figure 1: Measurements of the vector analyzing power A_y, the laboratory differential cross section $d\sigma/d\Omega$ (mb/sr), and the Figure-of-Merit (FoM) for deuteron elastic scattering from carbon at 270 MeV [7].

2. JEDI polarimetry concept

The concept of the JEDI polarimeter is shown in Fig. 2. It will monitor the change in the asymmetry using the elastic scattering reaction $\vec{d}C \rightarrow dC$ with very high accuracy. The concept of the polarimeter is based on a simple principle: measuring the full energy deposited in the detector by the deuterons from the elastic dC scattering process. The later includes: (i) the best elastic scattering identification capability; (ii) 100% DAQ efficiency; (iii) full acceptance in a reasonable coverage of the maximum Figure-of-Merit (*FoM*) region; (iv) no magnetic/electric fields, and (v) long term stability (> 10 years). Currently, the idea is to use a heavy element crystal calorimeter to select elastically scattered deuterons (protons) from the carbon target. In addition, for tracking a plastic scintillator (Pl. Sci.) array will be installed in front of the 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 because of its unique properties. It has a very high light output (75% of that of NaI (Tl)), a fast decay time constant of 40 ns, and a very high density of 7.1 g/cm^3.

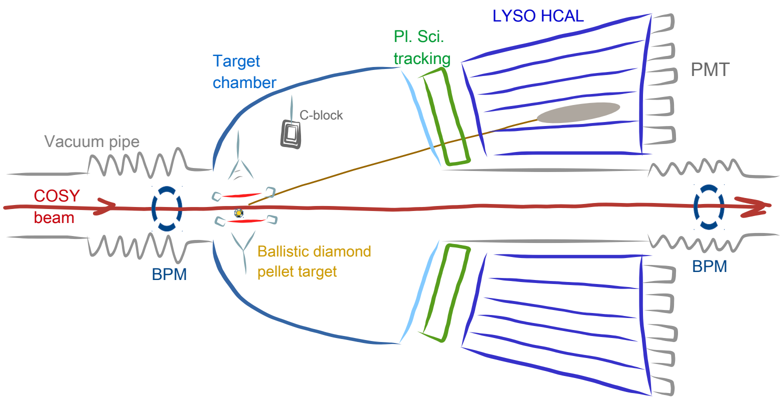

Figure 2: The sketch of the srEDM polarimeter. It will consist of three main parts: 1) The target chamber, 2) The vacuum flight chamber, and 3) The detection system built with thin plastic ϕ-sensitive scintillator counters, located in front of the hadron calorimeter consiting of LYSO crystals.

The very first (and ongoing) step of this development program is to study the choice for the detector material. The information collected after the first measurements in the lab and then at COSY (see next paragraph) will provide essential input for the development of the simulation code using the GEANT4 toolkit. The Monte-Carlo model of the polarimeter is shown in Fig. 3 (left panel). In this version, the modular assembly with a standardized aluminum support structure is shown (right panel of Fig. 3). Such a construction allows us to build the polarimeter with an arbitrary number of crystals and with an optimal configuration. The simple support structure, consisting of standard aluminum elements, gives us an opportunity to build the polarimeter in a very easy way. Also, such a simple construction makes it easy to set up the polarimeter in two or more different places in the storage ring and monitor spin rotation [2].

In Figure 4, the main building blocks of the polarimeter the LYSO crystal module are shown. The goal of this module is to stop the elastically scattered deuterons or protons and measure their total energy and time with high precision. The crystal dimensions are optimized using a Geant4

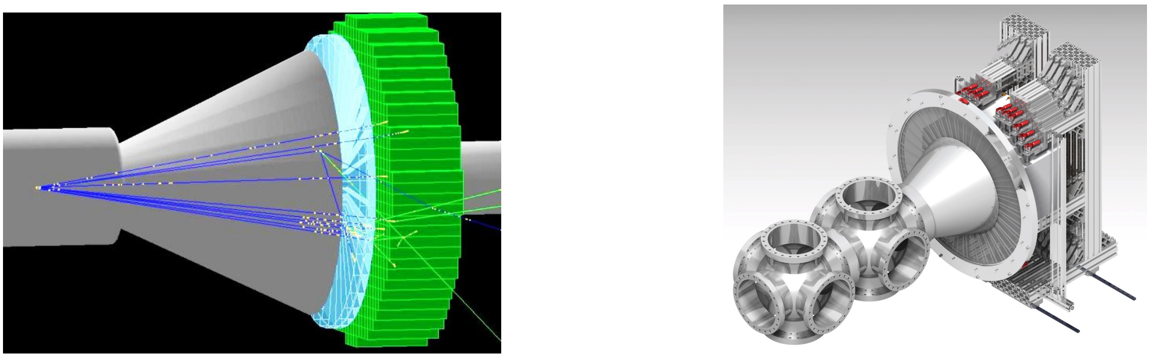

Figure 3: Left: The GEANT simulation model of the polarimeter. The walls of the COSY beam pipe and target chamber are shown with gray color, LYSO crystals with green, and the scintillation hodoscopes with light blue. A few tracks, coming from the point-like target, are also shown. Right: The current engineering drawing (detector and the target chamber) togather with the supporting system is shown. From left to right there are two cross type flanges, one for beam position monitors (BPM's) and the second one for the target. In the middle it is a vacuum chamber. Next, the two layers of ϕ-sensitive plastic scintillator and the LYSO HCAL are placed to absorb the total energy of the scattered particles.

Monte-Carlo simulation. For the majority of the modules the size of the crystals will be $30 \times 30 \times 100$ mm. In the first ring, small Θ angles are covered by scintillators with a front face size of 15×30 mm. These are always are used in pairs in the modules. The readout of the crystal is done using Hamamatsu R1548-07 PMTs [10] which have a rectangular input window with dual channel readout. Big crystals have combined the dual channels. That increases the stability of the system. For the high count rate modules with split crystals, the single channel readout is used, which roughly doubles the count rate capability.

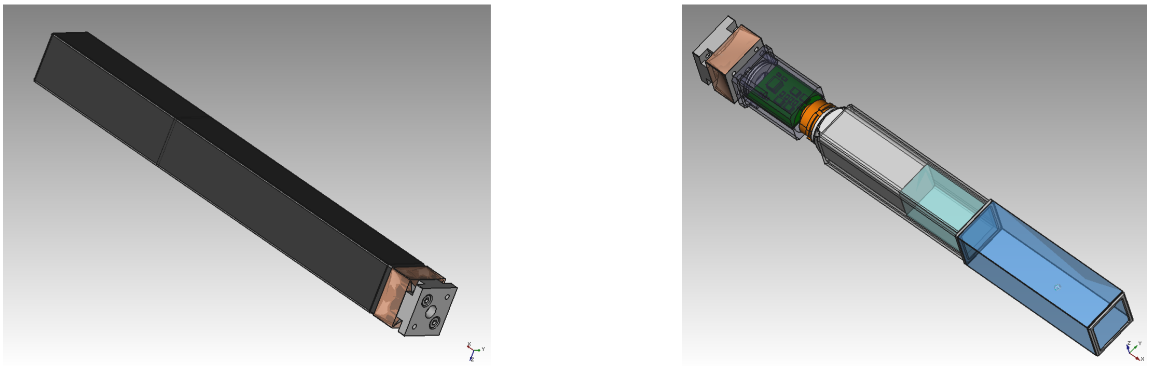

Figure 4: Left: The LYSO calorimeter module in the carbon fiber enclosure. Right: The single module without housing. In this configuration, the 100 *mm* LYSO crystal is attached to the 48 *mm* light guide which is coupled to the dual channel PMT. The HV divider is also seen.

3. Laboratory tests

At present, we already own the five LYSO crystals needed to build four independent calorimeter modules. These are equipped with LYSO crystals from two different companies: Saint-Gobain

(SG) [8] and EPIC Crystals (EP) [9]. Among 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. The design of the LYSO modules is final. The prototype modules will be assembled and tested during the COSY test beam time in March 2016 [11]. The first, very simple test has already been performed in a laboratory environment. The left panel of Figure 5 shows spectra recorded using the $30 \times 30 \times 100$ mm LYSO crystal wrapped in two layers of 50 μm Teflon and covered with one layer of lightly tied 50 μm Tedlar. For this measurement, the optical contact between the crystal and the PMT is made using optical grease. The red data points correspond to measurements with the LYSO crystal along with a ^{60}Co radioactive source. The green data points show the internal radiation of the LYSO crystal, which is mainly caused by ^{176}Lu decay. In the difference spectrum (blue), the two peaks of the cobalt sequential decay lines can be observed. Since the crystal size is big, the probability to measure both photons is quite large. The right panel in Figure 5 shows a model fit of two cobalt photons plus the sum of the two. In this case, the spectrum analyzed represents just one photocathode. The resolution (FWHM/amplitude) for the 2.5 MeV energy deposition shown here is 8%, which is already a very promising result.

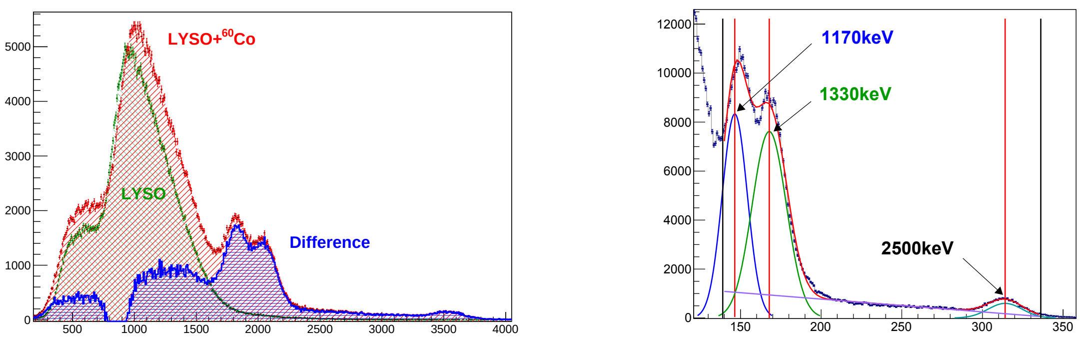

Figure 5: Left: The spectrum of the LYSO crystal internal activity (^{176}Lu) and external ^{60}Co radioactive source. Right: The Gaussian fits of the ^{60}Co gamma lines.

The goal of the planed tests [11] is to provide a set of data taken in a situation that reflects actual operating conditions in the EDM polarimeter, including thick targets, polarized beam, and detectors clustered at small scattering angles. This enables us to see whether there are problems or features that affect the performance of the system for making a polarization measurement. It also provides a set of data that may be compared eventually to Monte Carlo calculations that would be made in the design of the final EDM polarimeter.

4. Summary and outlook

The LYSO crystal samples, the PMT/SiPM photo-sensors and its HV dividers are under intensive testing and development. The FADC-based readout system and the beam test of the first prototype is in preparation as well. In parallel to the detector developments there are plans to advance the new idea of a special target within the framework of a separate project (JuDiT, A Jülich Ballistic Diamond Pellet Target [12]). The idea is based on a single solid diamond pellet (diameter

$10-100$ μm) that will be thrown in vacuum repeatedly through the circulating polarized beam by means of two *shooter/catcher* systems. The demonstration of proof-of-principal is planned in the storage ring COSY-Jülich. Being a precision controlled micro-object movement, it may also find many other applications (*e.g.* in nuclear, particle and accelerator physics, medical treatment or space science).

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[12] Application has been submitted for ERC consolidator grant 2016 (available via JEDI home page).