COSY Beam Time Request

For Lab. use	
Exp. No.: **E2.2**	Session No. **4**

Collaboration: JEDI

Towards the EDM Polarimetry

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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 polarized 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 2016**	**1 week (+ MD)**

JEDI Beam Time Request for the second half of 2016

Towards the EDM Polarimetry (Progress report)

for the JEDI collaboration

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

May 24, 2016

Abstract

In this document, we overview the progress done since the last CBAC meeting (December, 2015) towards the JEDI polarimetry development and request the beam time for data-taking in fall 2016.

In the proposed measurements, we will utilize a slowly extracted polarized deuteron beam at the BIG KARL experimental area to get closer to the final setup with increased number of crystals (about 20). We will measure the differential cross sections and vector analyzing power of the deuteron-carbon elastic scattering, between polar angles of 5° to 20°. These data will be compared with the results from the WASA database experiment (also scheduled in fall 2016) including the corrections due to deuteron detection efficiencies obtained in the recent test experiment (March, 2016).

The goal of this request is a combined test of the read-out electronics with the 20 LYSO detector modules to verify the performance of the whole prototype system. The setup comprises with two arms, each consisting of 10 calorimeter modules, and several solid (carbon) target.

For the planed measurements using the polarized deuteron beam, we request **one week** (and at a later stage 2 weeks) of COSY beam time at 5 energies between $100 \div 300$ MeV at the BIG KARL experimental area (as it was prepared in March, 2016).

1 Introduction

This report describes the results of the test beam time performed in March 2016, granted by CBAC #2 from June 2015. We have presented up-dated proposal (E2.1) at CBAC session #3, where the beam request received the following recommendation: *Move decission to CBAC#4 when the results of the March'16 run will be available.*

2 Description of the Test Setup

During March'16 run the BIG KARL experimental area has been prepared for the test measurements using the extracted beam of unpolarized deuterons at 5 different energies ($T_d = 100 \div 300$ MeV). In this tests, five LYSO crystals, forming the four independent calorimeter modules have been used. The photo of the test setup is shown on Figure 1. These crystals came from two different

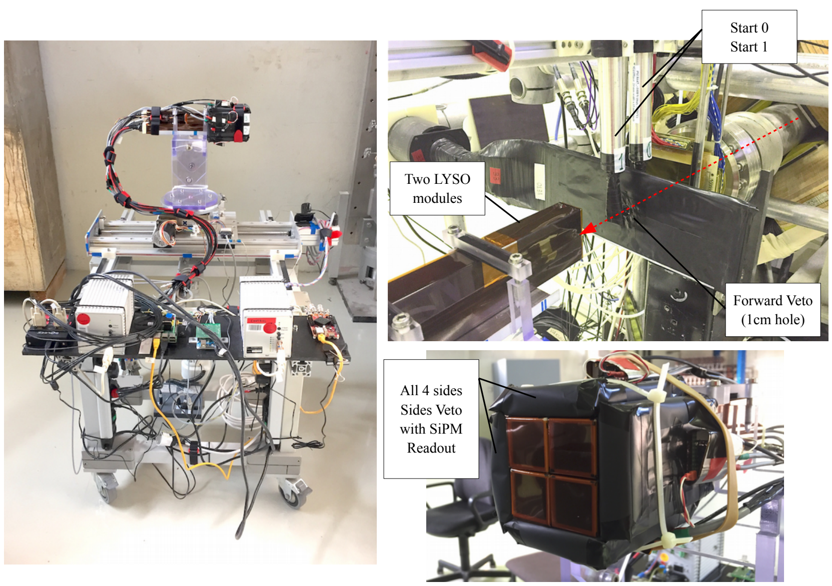

Figure 1: Left: test table setup; Right-up: test table in beam position with two LYSO modules, two start and one forward veto counters. Right-down: the cluster of 4 LYSO modules surrounded with plastic veto scintillators.

companies: Saint-Gobain (SG) [1] and EPIC Crystals (EP) [2]. 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. The big crystals ($30 \times 30 \times 100$ mm) with a rectangular shape, built for low count-rate locations, are shown in Figures 2 and 3. Two modules are from SG and one is from EP. Two additional crystals, which are of $15 \times 30 \times 100$ mm rectangular shape and are also from SG, can be used to build one high count-rate module.

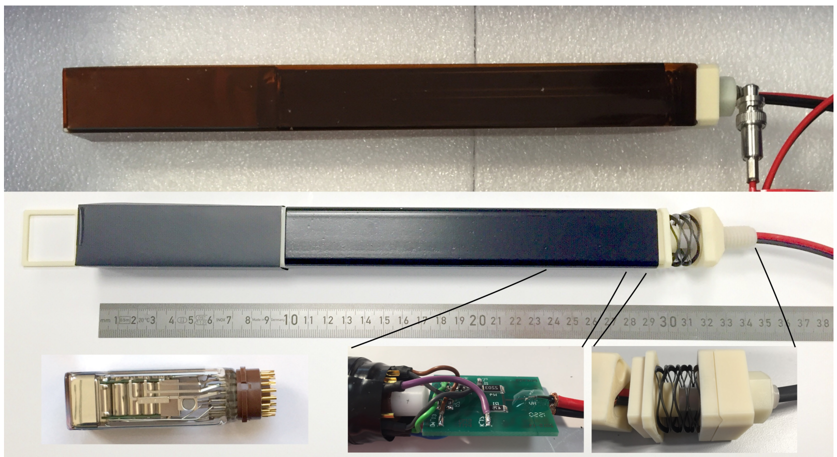

Figure 2: Photo of LYSO module pulled with Kapton foil, the ST-37 stainless steel housing, PMT and its HV divider with 3D printed mechanical holders are shown.

All photosensors were covering a rectangular 24×24 mm area of the backward end of the LYSO crystals. Each crystal was wrapped into two layers of 50 μm Teflon for light reflection/diffusion and one 50 μm Tedlar for the light tightness. In case of a vacuum tubes, dual channel Hamamatsu PMT [3], supplied by a single HV source, were used in combination with plastic light guide. The silicon photo-multiplier arrays (SiPM), comprised of the 4×4 $(4 \times (2 \times 2))$ matrix with units of 6×6 mm sensors of 35 μm pixel size from SensL C [4] series, has been used (see Fig. 3). A holding table for the prototype, with three degrees of freedom (vertical, horizontal, and rotational) is shown in Fig. 1. The table was remotely controlled by the web interface and continuously monitored with two web cameras installed in the BIG KARL experimental area. All the controlling systems were based on open hardware project modules like: *arduino*, *raspberry pi* and *red pitaya*.

More details about the assembly will be given during the oral presentation at the CBAC meeting.

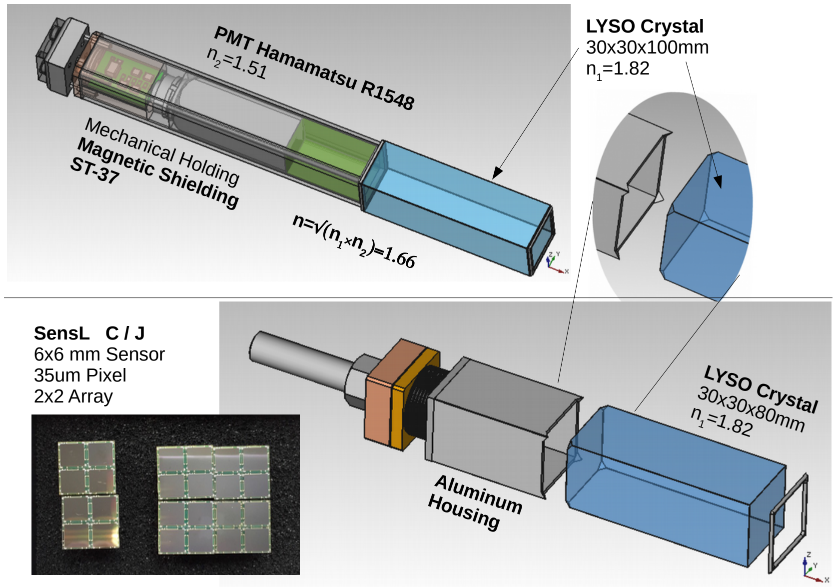

Figure 3: Upper: the drawing of a single LYSO module with: mechanical holding structure, high voltage passive divider, squared Hamamatsu PMT [3], light guide and LYSO crystal. Bottom: example of the new prototype module combining a $30 \times 30 \times 80$ mm LYSO crystal with a SiPM readout.

3 Short Overview of the First Results

In short, the beam time was very successful! All the measurement plans, which were described in the original proposal (E2.1) were accomplished. We have started the measurement with two energies of proton beam at T_p = 100 and 150 MeV, but the data on tape is very scarce. Next step was to prepare the deuteron beam with five different (T_d = 100, 150, 200, 235 and 270 MeV) energies, scanned several times and recorded with two different readout systems, namely a CAMAC based 12 bit QCD and a VME based 14 bit, 250 MS/s FADC. As expected, the first use of renovated experimental hall, the first use of this kind of flash ADC's and quite complicated assembly parts of the LYSO modules, created quite a stressful beginning of the beam time.

One of the most important result is the comparison of SiPM and PMT readouts of the crystals shown on the left panel of Fig. 4. The best resolution (FWHM divided by amplitude) was achieved using the SiPM sensors at the highest energy and was estimated to be **0.5%** whereas for the PMT it was around **1%**. Right panel of Fig. 4 shows the energy resolution dependence on the deuteron beam energy, recorded using the FADC readout. Unfortunately,

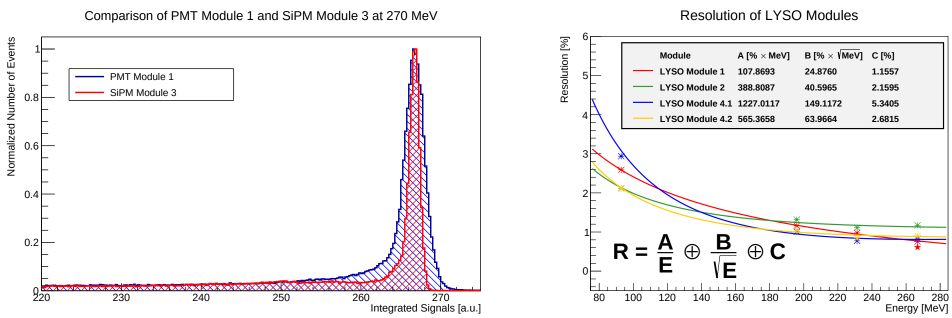

Figure 4: Left: comparison of the SiPM and PMT readouts with T_d = 270 MeV deuterons. Right: measured energy resolution for all modules *vs* incoming deuteron beam energies, recorded using the FADC.

for the 150 MeV beam energy the data point is missing due to some technical problems of the accelerator. But at Fig. 5 all data points for the LYSO module using QDC readout are shown and two different fit functions are compared. On the left panel the simple fit, considering only the photon numbers (stochastic term) and the constant term, is used. On the right

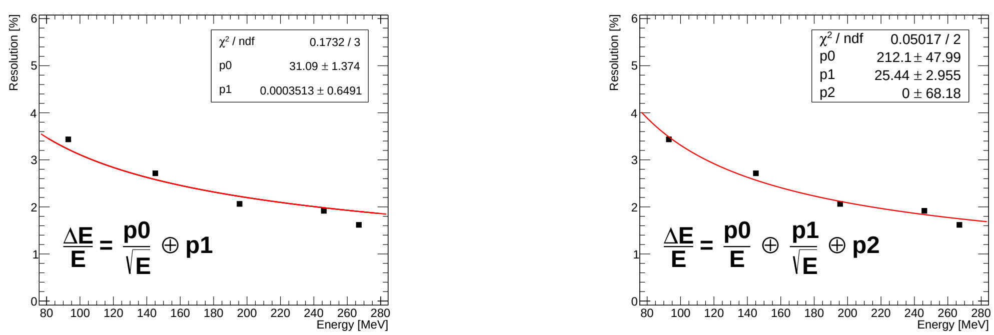

Figure 5: Energy dependence of the energy resolution of the LYSO module 1. NOTE: All energies are scaled down by the GEANT4 simulated energy loss in the material between the exit window and the LYSO crystal itself.

panel, the signal amplitude dependent linear term is also presented. Both fit results are consistent and show an excellent performance of the LYSO crystals.

Other very important results are shown on Fig. 6. The left panel shows the deposited energy distribution in the LYSO crystal for the 270 MeV deuteron beam. The reconstruction/identification efficiency is defined by the ratio between the signal area above 90% and full integral. The right panel shows the energy dependencies of the deuteron identification efficiencies for two crystals, compared with the GEANT4 simulation (blue line). The estimated number of deuteron break-up events inside the LYSO crystal

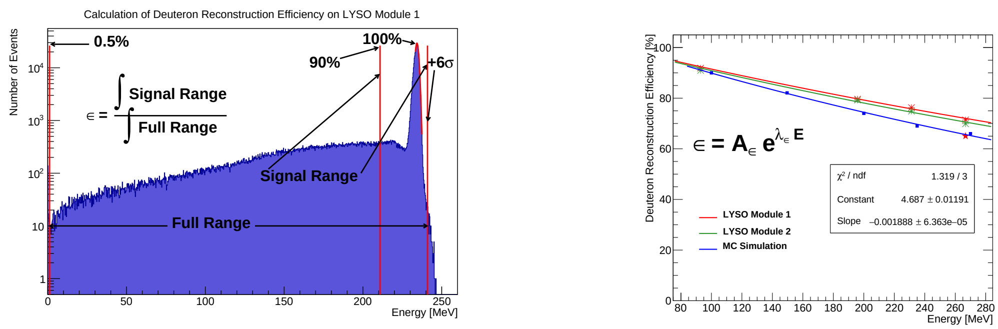

Figure 6: Measured deuteron identification efficiency for module 1 and 2 *vs* incoming deuteron beam energies.

at 270 MeV (highest energy) amounts to about **30%** as a result of the high average atomic number Z of the LYSO crystal.

The time resolution estimated using cosmic muons is the safest estimation of the time response of the modules. The Fig. 7 shows the relative time resolution of two neighbor modules 1 and 4 (splitted crystal) which is also shown in the inserted panel of the figure. The estimated time resolution with digital constant fraction discrimination of the FADC signal shape shows around **300 ps** time resolution. But, time resolution measured with the deuteron beam where the time between trigger (plastic start counter coincidence) and the modules were estimated to be around **500 ps**. In general, such a high time resolution is fairly enough for this kind of polarimeter. Since the maximum count rate per crystal is roughly estimated to be below 1 MHz and the time resolution is also needed for the cluster building algorithm of the energy loss. The time resolution of the LYSO modules shows the excellent performance of the system.

The preliminary results of this beam time has been presented at *the 17th International Conference on Calorimetry in Particle Physics CALOR 2016 held from May 15 to 20, 2016 in Daegu, Korea.*

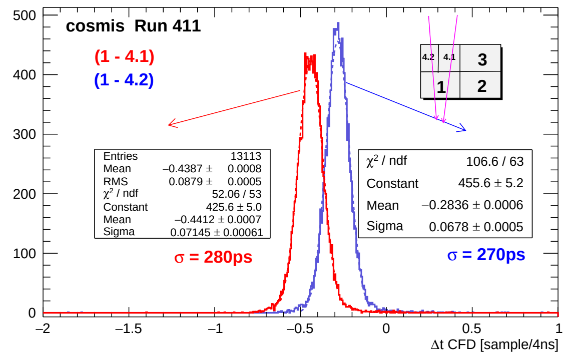

Figure 7: Time resolution measured using cosmic muons passing two neighbor LYSO modules .

4 Next Beam Time Request

Figure 8 shows the engineering drawing of the next experimental setup comprised of **20** LYSO modules. In this concept, a three arm assembly of crystal holders is foreseen: two remotely controlled arms (moving between angles of $-180°$ to $180°$) for the LYSO modules (10 on each arm) and one for a plastic scintillator counter which will be manually adjustable and used for the normalization purpose. Each cluster of crystals will have the capability of being rotated around the vertical axis to simulate different detector segments and will be also movable towards the target to change the solid angle coverage. This will also be the first test of two simultaneously read FADC modules with a total number of 32 channels (2x16 channel) with synchronized clock distribution, which is crucial for the coming srEDM measurement. The target station of this setup includes eight targets which can be changed remotely. Two target inserts will be reserved for a blank and an empty target for calibration and the rest six inserts can be used for different targets. We can use targets of different thicknesses as well as different materials (carbon, aluminum, etc.).

For the planed measurements using the polarized deuteron beam, we request **one week** of COSY beam time at 5 energies between 100, 150, 200, 235 and 270 MeV at the BIG KARL experimental area.

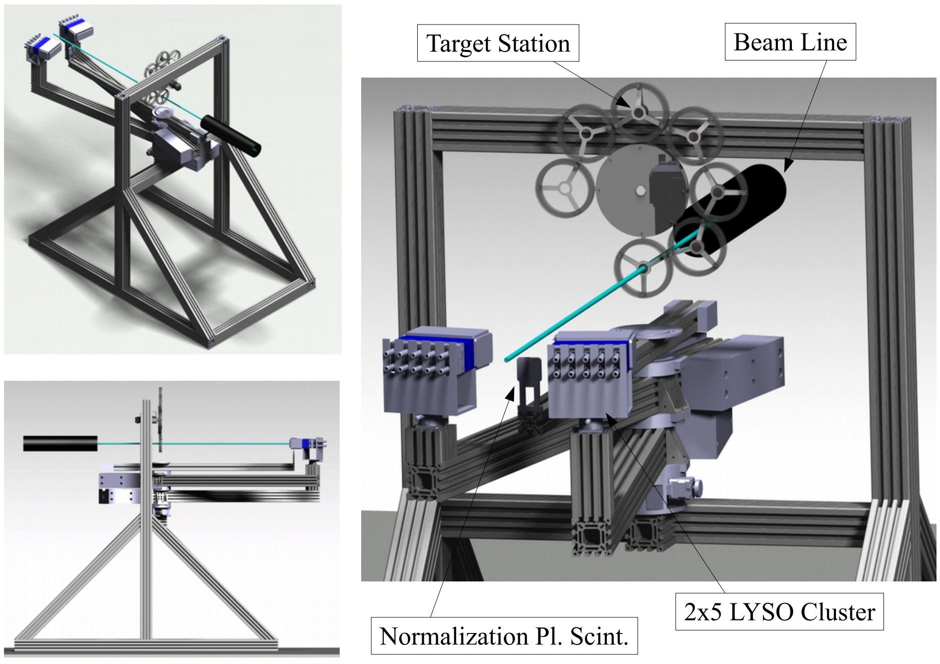

Figure 8: Test setup of the proposed measurement.

References

[1] Cerium doped Lutetium PreLude420 crystal.
$(http://www.crystals.saint{-}gobain.com/PreLude_4 20_S scintillator.aspx)$

[2] LYSO Ce scintillator.
$(http://www.epic-crystal.com/product/lyso-ce-scintillator-crystal)$

[3] Hamamatsu R1548-07.
$(http://www.hamamatsu.com/us/en/R1548-07.html)$

[4] SensL SiPM MicroFC-60035-SMT.
$(http://sensl.com/estore/microfc-60035-smt/)$