COSY Beam Time Request

For Lab. use	
Exp. No.: **E2.4**	Session No. **6**

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	Intensity or internal reaction rate (particles per second) maximum useful
Extracted beam of polarized deuterons	**200, 270, 300 MeV**	**10^3**	**10^7**
Experimental area	Safety aspects (if any)	Earliest date of installation	Total beam time (No.of shifts)
Set-up with LYSO crystals at BIG KARL area	**none**	**1st November 2017**	**1 week (+ MD)**

JEDI Beam Time Request for the next period

Towards the EDM Polarimetry (Progress report)

for the JEDI collaboration

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

May 19, 2017

Abstract

In this document, we overview the progress made since the last CBAC meeting #5 (December 2016) towards the EDM polarimeter development and request the detector test beam time earliest November 2017. In the proposed measurements, the extracted polarized deuteron beam will be used at the BIG KARL experimental area. The goal of the new request is:
1. Test of the newly build 24 SiPM based LYSO modules.
2. Test of new position sensitive dE triangular plastic scintillator bars.
3. Further development and optimization of the DAQ performance.
4. Assembly of new setup comprising 48 LYSO modules divided into four arms (up, down, left, right) mounted on final aluminum support disk.
5. Exploring possibilities of measuring the total cross section, via tagging incoming and outgoing particles through the target material.
We would be willing to incorporate high granularity tracking chambers from Greece or South Korea to evaluate their compatibility and performance in conjunction with the LYSO calorimeter.

For the planned measurements using the polarized deuteron beam, we request **one week** of COSY beam time preceded by one week of machine development (MD) week at various beam energies between 100 and 300 MeV at the BIG KARL experimental area.

1 Introduction

The next important step towards storage ring EDM polarimeter is to build setup for the use at the internal beam. Beginning of the year, the JEDI collaboration internally decided to use former ANKE target place as a permanent place for the coming polarimeter. This section is one of the four low beta section and is the optimal place for the detector system. Currently, part of its straight section is filled with super conducting solenoid and with the beam position monitors (BPM). The available space is roughly 130 cm, which is enough for the new setup. If needed, the BPMs can be removed, since our setup will incorporate two Rogowski coils at input and output position of the beam. The design work is already in progress. We assume to have this kind of setup starting of the year 2018. The detector part will be tested at the external beam (this request) and will be described in the next section. The target part (ballistic pellet target [1]) is under construction for the laboratory tests and will be a separate Ph.D. topic for a new student; who's is expected to be in Juelich at the end of the year. The figure shows

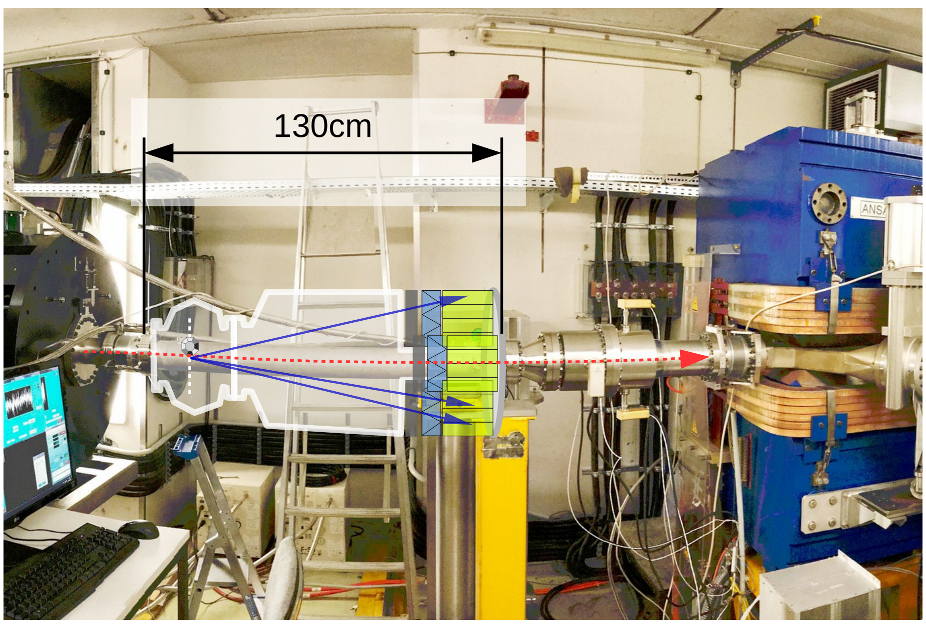

Figure 1: Possible polarimeter setup at former ANKE target place.

the three most important components of the polarimeter concept. Left is the target vacuum chamber with the target system (block or strip type) and the Rogowski coil for the beam position monitor. In the middle, the big vacuum tank as a flight chamber is seen. It will incorporate: (i) a very tiny (to minimize energy loss of the scattered particles) aluminum pipe to avoid impedance distortion due to instant diameter change of the accelerator pipe, and the detector part itself; (ii) the optional absorber layer made by light isotopic material like carbon or aluminum; (iii) a two-dimensional thick plastic scintillator dE triangular bars as an tracking system too; (iv) at the end, the most important LYSO-SiPM calorimeter for the scattered particle absorption.

2 Short overview of the last beam time

The time period between last two beam time was very short. The success of this tests has been symbolized in granting us with an additional week of beam time at the beginning of March 2017. Having such a short time for the next experiment motivated us to make fewer changes in the hardware and concentrate on acquiring more statistics, as well on further software and hardware improvements.

The essential achievements are:

- The main hardware improvement of the 20 mm thick plastic scintillator dE counters, read out by the eight 6×6 mm SiPM with the custom made amplifier. The typical spectra of this measurement is shown on figure 2 and explained into more details on figure 7. This change safely give us a chance to increase energy.

- Exploring additional energy $T_d = 300$ MeV, which was also used during the WASA deuteron database experiment too. The results at this energy can be used as independent cross check of the analyzing power and the differential cross section. In general, the main emphasis was made to concentrate on just three deuteron kinetic energies of $200, 270, 300$ MeV. At all these three energies the analyzing power and differential cross section measurements for all four targets (Carbon, Magnesium, Aluminum, and Silicium) have been made.

- The cross ratio measurements made by triggering on LYSO modules, where the count rate was very high. The results are compared to published data and are in a very good agreement. In addition, during the

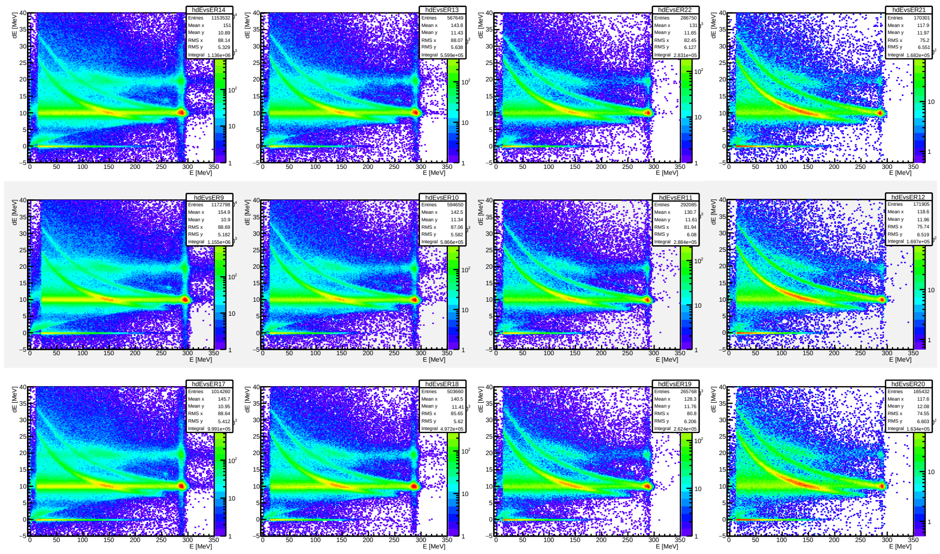

Figure 2: The dE vs E online spectra for the right arm taken on 5 mm carbon target with 300 MeV deuteron kinetic energy.

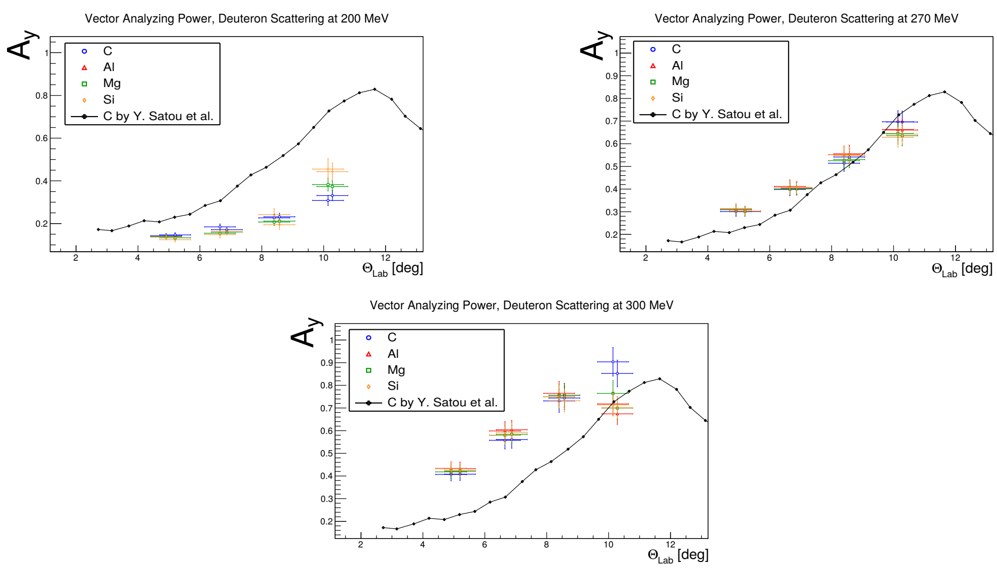

Figure 3: Vector analyzing powers for the different targets at different energies. Note, Aluminum target is missing at 200 MeV beam energy due to technical problems. All results are compared to Satou at al. [3] $\vec{d}C \to dC$ at $T_d = 270$ MeV.

measurement time, online analysis of the cross-ratios has been developed in order to monitor COSY beam polarization (see Fig. 4).

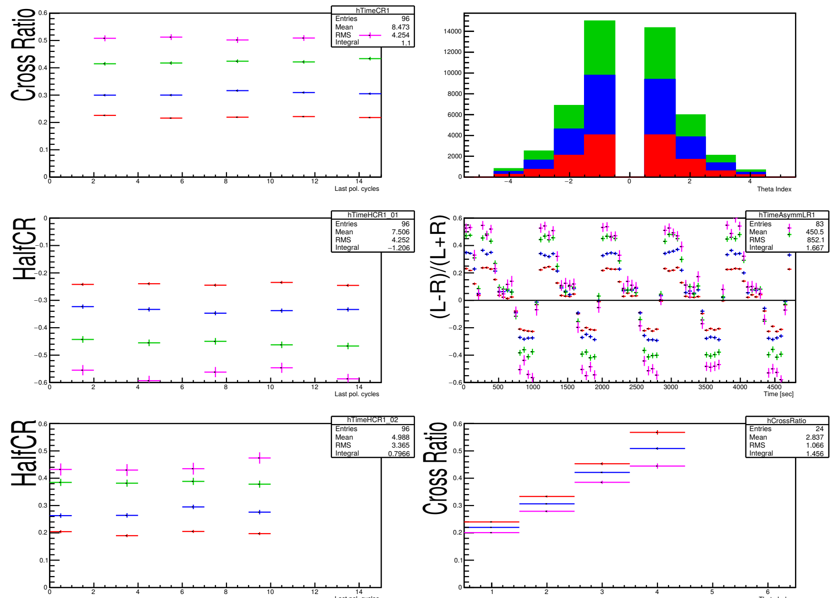

Figure 4: Online asymmetry monitor for the same run as in previews Fig. 2. Left: upper full cross-ratio, middle and bottom half cross-ratios for different cycles. Right: upper stacked histogramm (green upper, blue middle and red lower columns) and the bins represent the different raws left and right sides. Middle left-right asymmetry and bottom cross retion as an function of columns.

- During the differential cross section measurement (see Fig. 5), the trigger is generated using 2 mm thick plastic scintillator start counter installed in the beam line to tag each incoming deuteron. That made cross section measurement too slow since COSY was not able to extract single deuteron beam with single particle at a time. Nevertheless, we were able to collect enough statistics for all targets and energies.

- During last beam time, all spectra were calibrated using statistics of last two beam times. The comparison was made, and good agreement has been found. After the proper calibration, the overall energy cuts

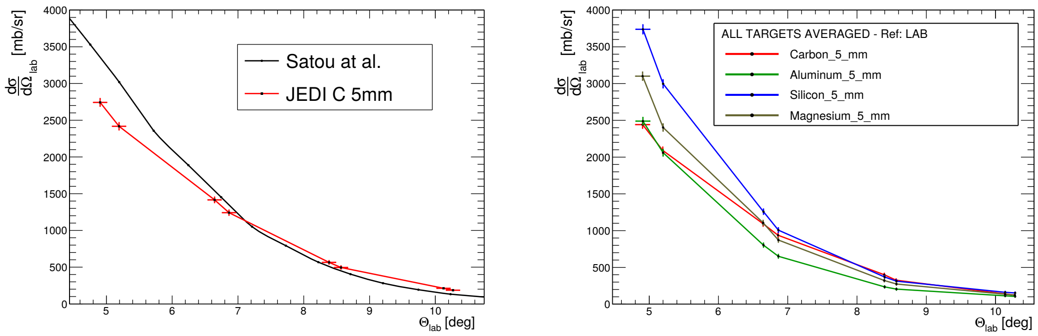

Figure 5: Left: Comparison of the differential cross section for the Carbon at $T_d = 270\ MeV$ Satou at al.[3] and this work. Right: For all targets (C, Mg, Al, Si) at $T_d = 300\ MeV$.

were used on dE and E (see Fig. 2) to produce online asymmetries (see Fig.4).

- The additional improvements on data acquisition system (DAQ) and the high-speed connection between flash ADC modules and the server, made possible to read out two modules in parallel with 10 $GBit/s$ network switch. Each event has been analyzed online, and improved online spectra have been made. We have been successful in analyzing more than 22 $kevents/s$. Further improvements are planned for the next beam time.

- In addition to all these activities, numerous small tests has been made. Such as arms at nominal Θ angle but crystals parallel to beam instead of pointing to the target. The results are consistent to Geant4 MS simulation and are very similar to normal measurements because of low Θ angle. The SiPM array supply voltage scans (up to break down voltage) has also been tested. The beam intensity tests were investigated an different files has been recorded for various count-rates.

The preliminary results will be presented at the international conference of "Technology and Instrumentation in Particle Physics 2017" (TIPP2017)[4] in Beijing end of May.

3 Beam Time Request

The main goal of this beam time will be to test the detector components. In total we ask one week of the beam time with one week machine development.

3.1 Test of the new LYSO modules

Beginning of 2017 we purchased additional 24 LYSO (see Fig. 6) crystals from the same vendor Saint-Gobain [5]. The crystals are expected to be delivered in the middle of July. For the module production, all SensL 8×8 array (see Fig. 6), each SiPM 3×3 mm^2 with 20 μm pixel size [6] are already delivered and will be carefully tested during next weeks. In fact, we must disassemble 18 of our existing modules to send crystals back to Saint-Gobain for the further modification. So this brings us to the situation where we need to assemble 42 LYSO modules and test all of them. Test procedures are already quite good established. The first test is mechanical stability and eye test if everything is in place. Then we check on light tightness and repair if necessary (very rear case). Next, we save three different spectra: One just internal radiation, Lu 176 isotopes. For next quality control checks, we use Cobalt 60 and Sodium 22 sources. So all in all, we expect about two to three weeks of work for all 42 LYSO-SiPM modules.

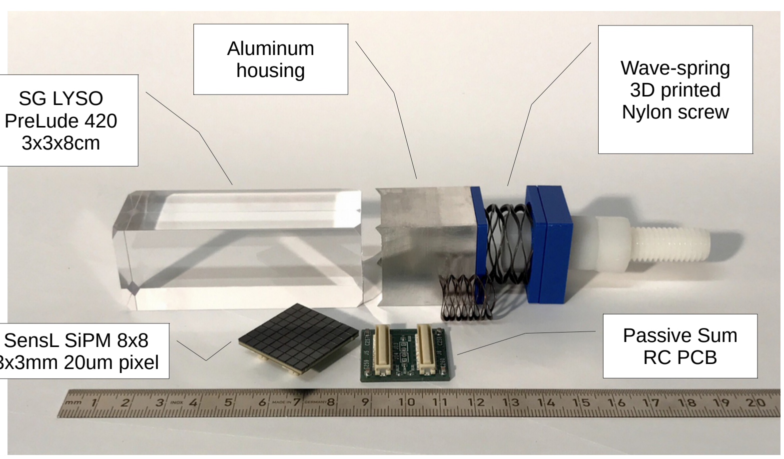

Figure 6: The second version of LYSO polarimeter module with SiPM readout.

3.2 Test of new position sensitive dE counters

In this beamtime, we plan to use position sensitive plastic dE scintillator bars. Each scintillator will be read out by 2 (both side) SiPM, $6 \times 6mm^2$, 50 μm from the Ketek ([8]). The total track length through the 2 cm plastic

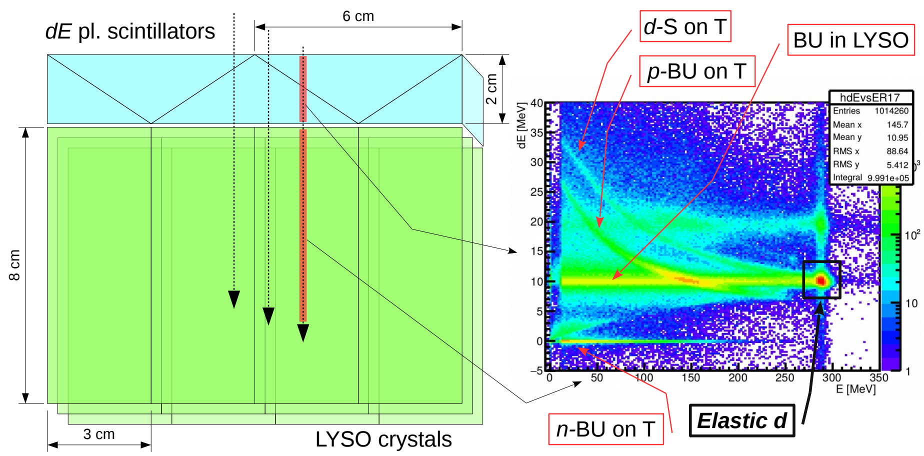

Figure 7: Left: Side view of the 4x3 LYSO cluster with dE plastic scintillator bars which will represent each arm of the detector. Right: dE vs E histogram showing: (d-S on T)-scattered events off target; (p or n-BU on T)-break up events on target; (BU in LYSO)-break-up deuterons inside the LYSO crystals and (***Elastic d***)-deuteron cut.

scintillator will be constant. During previous beam times, we tested 5, 10 and 20 mm plastic dE counters with two different SiPM producers, SensL and Ketek. As expected, the best results we achieved was using 20 mm thick scintillators and large area 6×6 mm^2 Ketek SiPM readout. The figure 7 show experimental results from the last measurement where the clear separation between deuterons, protons, neutrons are seen. Moreover, one can clearly distinguish between elastic and break-up events. With a new system, the position measurement along one axis will also be implemented by weight with energy losses between different bars. In this beam time, we will study and model the position dependence and resolution for such a system. For the future the orthogonal layers can be used for the two-dimensional position reconstruction with ~ 1 mm expected resolution.

3.3 The new test setup

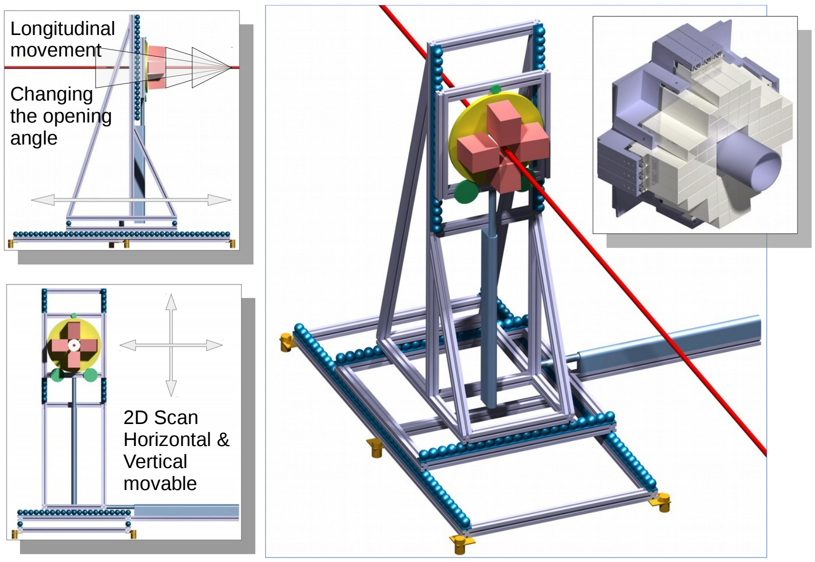

Figure 8: New Setup...

In the new test setup at extracted beam line, the 48 LYSO-SiPM modules divided into four arms (up, down, left, right) mounted on aluminum support disk will be assembled as it is drawn on figure 8. The support structure will give us a possibility to move in all directions. Vertical and horizontal directions will be used to calibrate each crystal, directly putting into the low-intensity beam. By moving whole construction down and upstream will change the solid angle coverage. The same setup will be extended by the next step to adopt detector for the internal beam line.

3.4 Further optimization of the DAQ performance

During this beamtime, we will be using first time four FADC ([7]) modules ($4 \times 16 = 64$ channels) in experimental conditions. Until now we mostly used two modules in total 32 channels and shortly we have tested three modules too. But, in all our data taking we have transferred in total 1 $Gbit/s$ data rate all because of network and software limitations. This time, we will be using parallel readout of all four modules with 4×1 $Gbit/s$ data transfer rate to the 10 $Gbit/s$ network switch connected to dedicated high-performance

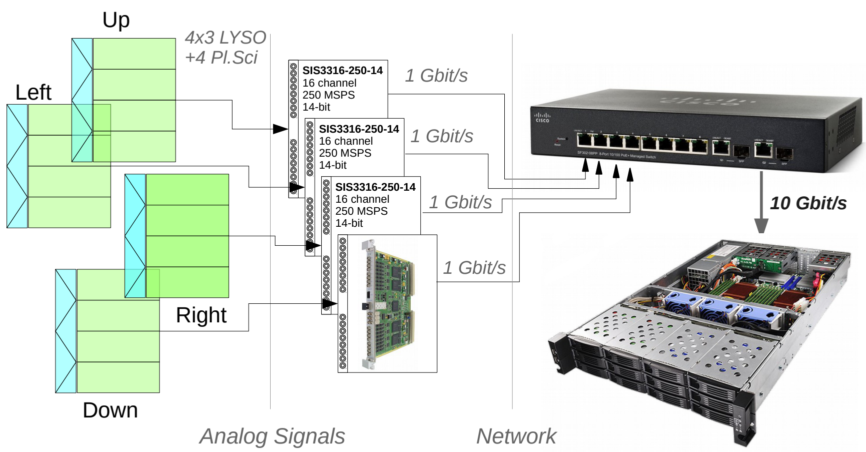

Figure 9: Data acquisition system diagram from LYSO modules up to data analysis server.

server computer. All components are already ordered and will be delivered next month.

3.5 Investigation of total to elastic cross section ratio

To estimate the effectiveness of using the particular material for the target, not only the FOM (figure of merit) defined as equation 1 is important, but also the ratio between extracted beam particles to elastically scattered events needs to be optimized.

$$FOM = \sigma_{ela}(\Theta) \times A_y^2(\Theta) \tag{1}$$

To find the total number of scattered particles we need to measure total cross section. The full process we can parametrize in the following formula:

$$N_{lost} = N_{scattered} + N_{Eloss} + N_{acc} \tag{2}$$

where N_{lost} is a number of lost beam particles during one turn due to different effects. $N_{scattered}$ is a number of scattered particles on target which in fact is proportional of the total cross section. E_{Eloss}, E_{acc} are the particles which are lost due to energy loss and multiple scattering in target and in rest gas of accelerator. Last two can be optimized in the means of reducing target thickness and making an ultra low vacuum inside the accelerator. But the

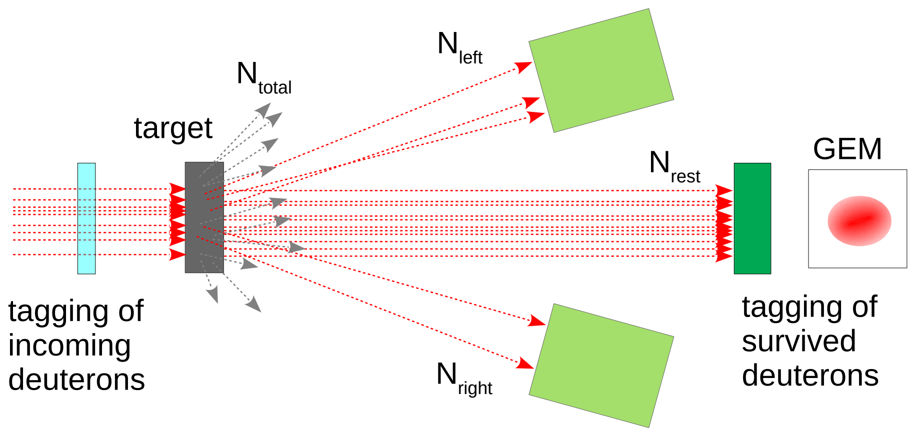

Figure 10: Scattering diagram during the experiment.

number of scattered particles can be expressed in the following ways:

$$N_{scattered} = L \times \sigma_{tot} = N_{el} + N_{inel} = N_{incoming} - N_{rest} \tag{3}$$

From the equation 3 we can estimate several quantities. Figure 10 shows the measurement principle of total cross section by tagging of incoming (which we already use for cross section measurement) and tagging of outgoing (survived) particles. There we can use 2D GEM detector provided by our Korean collaborators ([9]) which simultaneously will be the detector test of the GEM system. A group at the Center for Axion and Precision Physics (CAPP), located at the Korea Advanced Institute of Science and Technology (KAIST) in Daejeon, is currently preparing a prototype of a multilayer GEM detector system that would be suitable as a thin position-sensitive detector. The advantage of having two dimensional histogram gives us possibility to select cutting radius for better estimation of the total cross section. Figure 11 shows the laboratory tests of the GEM detector setup. This example uses 10×10 mm^2 readout pads, but higher granularity readouts are available. The chamber is filled with a 70%/30% Ar/CO2 gas mixture. The test readout consists of a CERN SRS system. Scientists and technicians from KAIST would be available to assist with the installation, commissioning, and operation of this system in advance of the run. The readout based on CERN standardized DAQ system makes whole system more easily configurable.

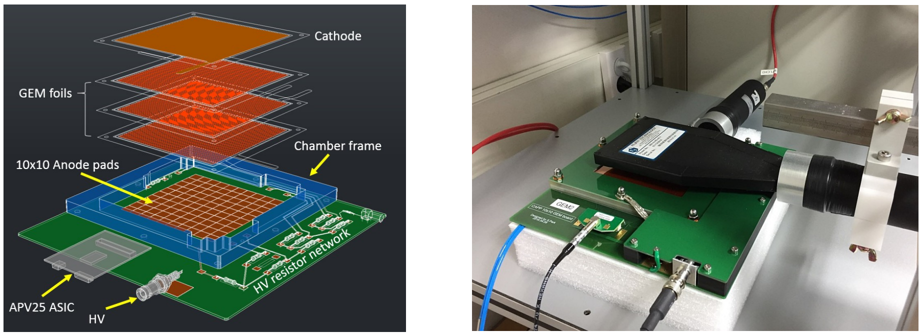

Figure 11: GEM detector at the cosmic tests, constructed by our colaborators from KAIST ([9]).

3.6 Summary

In this document, we shortly presented our preliminary results which are going to be published in the coming months. The results are very similar to the last measurement campaign and are in agreement with previous measurements. The detector performance was excellent and the data quality is only restricted by the extracted beam quality.

In order to continue this very successful development, we ask CBAC committee to grant us one week of polarized deuteron beam time (at the end of the year 2017) with several beam energies up to 300 MeV.

References

[1] Jülich Ballistic Diamond Pellet Target for Storage Ring EDM Measurements Horison 2020 proposal, ERC Consolidator Grant. Call: ERC-2016-COG. Proposal number: 725006

[2] JEDI proposals E1, E2: “Towards the EDM polarimetry”, (May 2015/June 2016).
(http://collaborations.fz-juelich.de/ikp/jedi/documents/proposals.shtml)

[3] Y. Satou et al., Phys. Lett. B **549**, 307 (2002).

[4] Technology and Instrumentation in Particle Physics - TIPP
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[5] Cerium doped Lutetium PreLude420 crystal.
($http://www.crystals.saint-gobain.com/PreLude\_420\_Scintillator.aspx$)

[6] SensL High Fill-Factor Arrays for Fast Timing Applications.
($http://sensl.com/products/sipmarrays/arrayj/$)

[7] SIS3316-250-14 16 channel 250 MSPS 14-bit.
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[8] SensL High Fill-Factor Arrays for Fast Timing Applications.
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[9] Center for Axion and Precision Physics, KAIST, South Korea
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