LYSO crystal testing for an EDM polarimeter

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Abstract. Four detector modules, built from three different LYSO crystals and two different types of light sensors (PMTs and SiPM arrays), have been tested with a deuteron beam from 100 MeV – 270 MeV at the COSY accelerator facility for the srEDM project at the Forschungszentrum Jülich in Germany. The detector modules were arranged in a cluster hand mounted on a positioning table. The deuteron beam was targeted at the center of each individual crystal for data analysis. The signals were digitized using a 14 bit, 250 MS/s flash ADC. Further, the energy spectra were calibrated using the known beam energies from the accelerator. From the calibrated spectra, the energy resolution was calculated. A resolution of 3% for the low energies and down to 1% for the high energy of 270 MeV was achieved. A deuteron reconstruction efficiency of almost 100% for low energies and around 70% for high energies was achieved. The SiPM light sensor showed a very good performance and will be used for the next generation of detector modules.

1. Introduction

As stated in [1, 2] our aim is to build a polarimeter detector consisting of individual LYSO crystal detector modules for deuteron electric dipole moment (EDM) measurements [3]. As a first prototype, four detector modules using different LYSO crystals and different types of light sensing parts have been built and tested. The modules were analyzed in a deuteron beam with four different beam energies of 100, 200, 235 and 270 MeV. All test were done at the COSY accelerator facility at the Research Center Jülich in Germany. The test setup was installed on a external beam line.

2. Experimental Setup

The experimental setup for the LYSO crystal tests mainly consisted of two parts: A cluster of four detector modules consisting of LYSO crystals and light sensing parts, and a positioning table that allowed the simulation of the arrangement of the detector modules in the final polarimeter. Figure 1 shows a schematic overview of the experimental setup. After leaving the beam pipe, the deuterons had to penetrate two 2 mm plastic scintillators before they were stopped in the LYSO crystal. In between these two plastic scintillators (start counters) an additional scintillator with a hole was installed, and acted as a forward veto. The trigger condition of the DAQ system was as follows: A hit in both start counters but no hit in the forward veto. The four detector modules were arranged as a 2x2 cluster. Surrounding this cluster, four 6 mm plastic scintillators were installed and each of it was read out individually by four SiPMs mounted on the chamfered

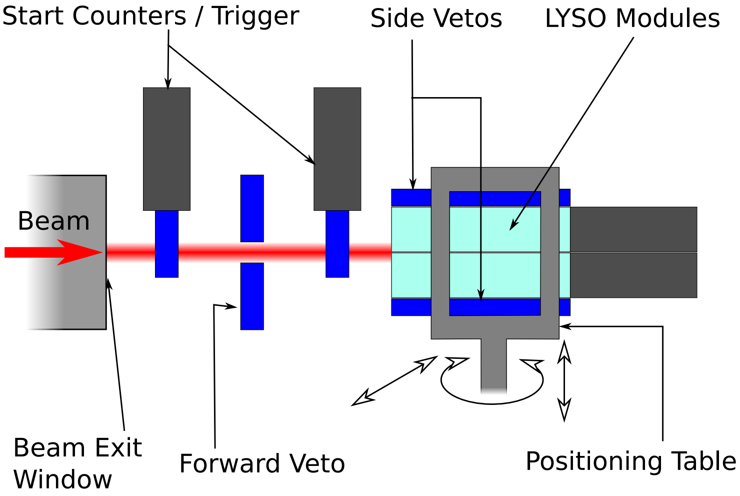

Figure 1. Schematic overview of the experimental setup.

edges. These scintillators were used as side vetos in the offline analysis to exclude events were a particle was escaping the LYSO crystal.

The positioning table was used to move the detector module cluster in the vertical and the horizontal direction as well as rotating it around the vertical axis. This allowed the simulation of different positions of the cluster in the final polarimeter as well as to target the deuteron beam to the center of the individual LYSO crystals. The positioning table was moved using stepper motors and designated drivers that were controlled by a RaspberryPi computer. A web-based user interface was used to set the positions of the cluster remotely as the experiment was not accessible when the beam was on. The position of the cluster was monitored using two webcams. Further, the web-based user interface allowed to set the high-voltage on the PMT based detector modules and switching on and off the side vetos.

The detector modules were built using LYSO crystals from two different manufacturers: Saint-Gobain [4] (Module 2 - 4) and Epic Crystals [5] (Module 1). Two different sizes of LYSO crystals were used: Module 1, 2 and 3 consisted of one LYSO crystal with a dimension of 30x30x100 mm. Module 4 was built of two LYSO crystals, each with a dimension of 15x30x100 mm.

To read out the LYSO crystals, two different types of sensors were utilized. The fist type of light sensing part (Module 1, 2 and 4), was made of a dual channel PMT [7], which was connected with the LYSO crystal by a light guide. This PMT was driven by a specially designed high-voltage divider. All components were enclosed by a steel housing and attached to the LYSO crystal using Kapton strips. These strips were strained by a spring tensioning device attached to the end of the light sensing part housing and were therefore pressing the light guide to the LYSO crystal. Module 4 consisting of two LYSO crystals had two individual light guides from each crystal to a channel of the PMT.

The second type of light sensing part (Module 3) was comprised with four SiPM arrays. Each array was made of 2x2 SiPMs, each with a side length of 6mm [8]. This SiPM array was connected to a passive circuit for the forward voltage supply and enclosed in a 3D printed ABS housing. As the PMT type, the LYSO crystal was connected to the SiPM array by Kapton strips and a spring tensioning device.

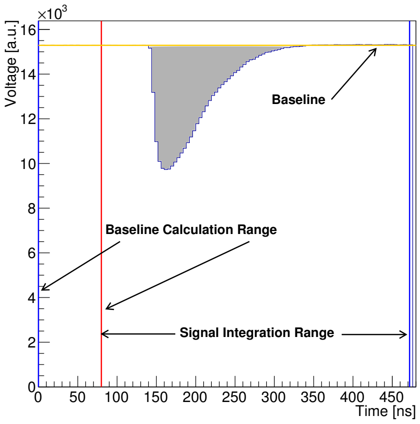

Figure 2. Valid signal shape. The shaded area is proportional to the deposited energy of the deuteron.

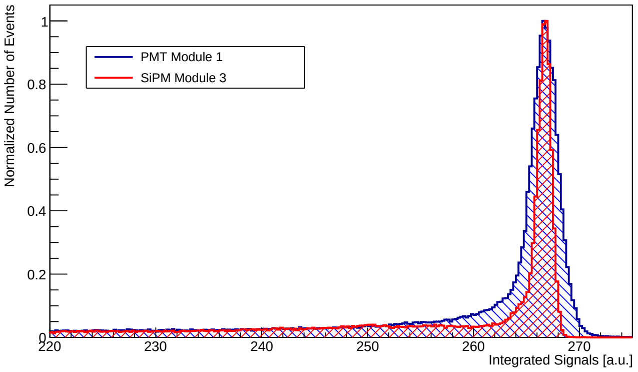

Figure 3. Comparison of the spectra at 270 MeV beam energy from Module 1 (blue) with a PMT and Module 3 (red) with a SiPM as light sensor.

3. Data Analysis

For the data taking, the deuteron beam was directed to the center of each detector module successively. The signals from each module were digitized by a 14 bit, 250 MS/s Flash ADC from Struck [6]. A baseline was calculated from the flat part before the actual signal shape (baseline calculation range, see Figure 2). To exclude misaligned baselines, a χ^2 test was performed on each baseline calculation. The signal shape was integrated (signal integration range, see Figure 2) and the baseline was subtracted from the integrated signal. To avoid events where a pile-up occurred, a peak count algorithm was implemented, and only events with one peak in the signal shape were preserved for the further analysis.

The integrated signals were filled into histograms to create spectra that shows the energy distribution (see Figure 3). A cut on the spectra of the start counters was applied to exclude head-on pile-ups where only one peak was visible in the signal shape. Additionally, a cut on the spectra of the side vetos and the neighboring modules was performed to exclude events in which a break-up reaction took place, or the deuteron was scattered out of the crystal.

To perform an energy calibration for each module, the peak position in the spectrum of the integrated signals was plotted against the beam energy. A GEANT4 simulation was used to correct the beam energy and take into account the energy losses in the start counters and the beam exit widow. This plot was fitted with a second order polynomial.

4. Preliminary Results

Two main results were obtained from the calibrated energy spectra. For each beam energy and module, the peak was fitted using a Gaussian. The energy resolution $R(E)$ was defined as $R(E)$ = FWHM(E) / $< E >$. The resolution for all beam energies and modules is shows in Figure 4 and was fitted using the standard formula for the resolution.

The second result that was obtained is the deuteron reconstruction efficiency. This is a very important quantity as the main task of the final polarimeter will be the identification of scattered deuterons. The deuteron reconstruction efficiency ϵ is defined as follows: $\epsilon = \int$ Signal Range / $\int$ Full Range. The expectation value of the fitted peak $< E >$ was defined as 100%. For the signal, a range from 90% up to +6 σ of the Gaussian was used. The asymmetrical range around the peak was taken due to the fact that the peak cannot be fully described by a Gaussian. The values of ϵ for all modules were plotted *vs.* the beam energy (see Figure 5) and fitted with an exponential decay function.

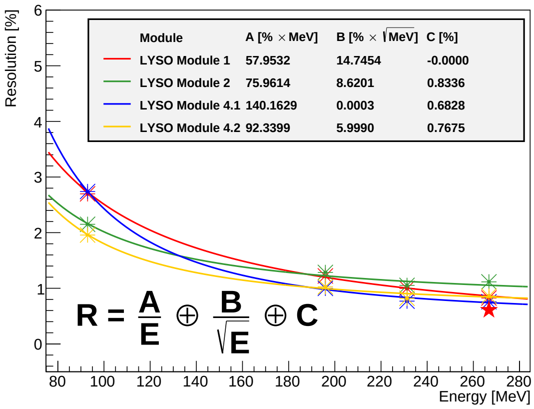

Figure 4. Energy resolution for all LYSO detector modules. The red star at 270 MeV denotes the resolution from the SiPM module 3.

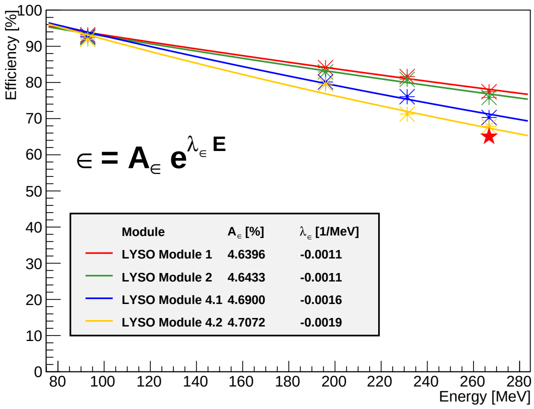

Figure 5. Deuteron reconstruction efficiency for all LYSO detector modules. The red star at 270 MeV denotes the measurement from the SiPM module 3.

5. Conclusion

With the experimental setup described above, we were able to obtain resolutions of 3% for low energies and even around 1% for the energy of interest of 270 MeV. These values are more than satisfactory for the needs of the final polarimeter. The deuteron reconstruction efficiency lies around 100% for low energies and decreases to around 70% (due to break-up reaction in the LYSO crystal) for higher energies, which still is a good value and sufficient for our needs.

Module 3 with a SiPM readout shows very good performance although we were only able to measure at the energy of interest of 270 MeV due to technical difficulties with the accelerator at the end of the beam-time. As the SiPM array was read out without a signal amplifier, a simple circuit consisting of only passive components can be used for it. Besides, a bias voltage of only 30 V was needed for this array. If the final polarimeter would be built of modules using SiPMs as a light sensor, there would be no need for a multichannel high-voltage supply.

In a more sophisticated next experiment, we will further investigate on the SiPM modules and directly measure elastically scattered deuterons from a carbon target [9].

References

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