Performance of prototypes for the PANDA barrel EMC

2015 J. Phys.: Conf. Ser. 587 012052

(http://iopscience.iop.org/1742-6596/587/1/012052)

16th International Conference on Calorimetry in High Energy Physics (CALOR 2014) IOP Publishing
Journal of Physics: Conference Series **587** (2015) 012052 doi:10.1088/1742-6596/587/1/012052

Performance of prototypes for the PANDA barrel EMC

D A Bremer[1], T Eissner[1], P Drexler[1], M Moritz[1], R W Novotny[1] for the PANDA collaboration

[1] II. Physikalisches Institut, JLU Gießen , Heinrich-Buff-Ring 16, D-35392 Gießen, Germany

E-mail: `daniel.a.bremer@exp2.physik.uni-giessen.de`

Abstract. The PANDA experiment will be part of the future Facility for Antiproton and Ion Research (FAIR) and aims for the study of strong interaction within the charm sector via antiproton proton collisions up to antiproton momenta of 15 GeV/c. Reflecting the variety of the physics program the PANDA detector is designed as a multi-purpose detector able to perform tracking, calorimetry and particle identification with nearly complete coverage of the solid angle. The Electromagnetic Calorimeter (EMC) contained inside its Target Spectrometer is based on cooled $PbWO_4$ scintillator crystals. In order to ensure an excellent performance throughout the large dynamic range of photon/electron energies ranging from a few MeV up to 15 GeV an extensive prototyping phase is mandatory. This contribution describes the measured response of the EMC barrel part prototype PROTO60 at the largest design energy to secondary beams provided by the SPS at CERN. In addition to PROTO60 a tracking station was deployed, providing precise position information of the 15 GeV/c positrons. For calibration purposes a 150 GeV/c muon beam and cosmic radiation, in combination with estimations from GEANT4 simulations were used. The obtained performance concerning energy, position and time information is presented.

1. Introduction

The PANDA experiment will be located at the future Facility for Antiproton and Ion Research (FAIR), which is an extension of the existing GSI Helmholtzzentrum für Schwerionenforschung GmbH (GSI) at Darmstadt, Germany. The High Energy Storage Ring (HESR) will provide antiproton beams with momenta ranging from 1.5 GeV/c - 15 GeV/c at a precision of $\frac{\Delta p}{p} \approx 10^{-4} - 10^{-5}$. This regime enables access to QCD bound states containing open and hidden charm as well as exotic states like gluonic excitations. Furthermore the fields of hypernuclei physics or nuclear structure experiments are accessible.

1.1. The PANDA detector

The PANDA detector is designed as a multi-purpose detector and is, adhering to fixed target kinematics, divided into two parts: Target- and Forward Spectrometer, as indicated in the schematic overview shown in Fig. 1. Each spectrometer contains several tracking and Cherenkov detectors for particle identification. The detection of electromagnetic probes in the Forward Spectrometer is performed by a Shashlyk type lead / plastic scintillator sampling calorimeter, while the Target Spectrometer contains an electromagnetic calorimeter based on second generation lead tungstate scintillator crystals (PWO-II) of improved quality, compared

Journal of Physics: Conference Series **587** (2015) 012052 doi:10.1088/1742-6596/587/1/012052

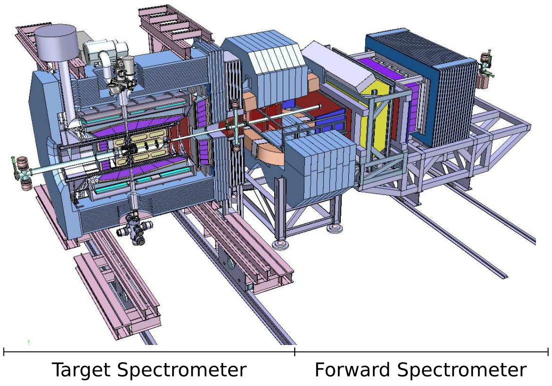

Figure 1. Schematic overview of the PANDA detector.

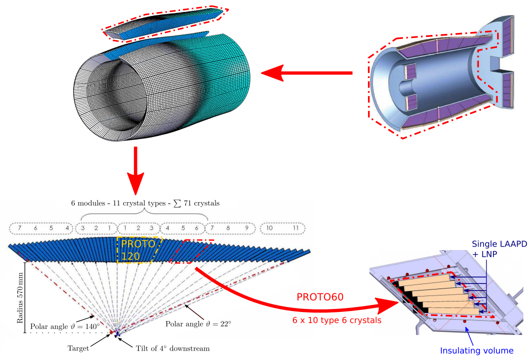

Figure 2. Schematic view of the Barrel EMC subsection represented by PROTO60.

to the crystals employed at the CMS experiment at LHC. Cooled operation at $-25\,^{\circ}$C enhances the light yield by approximately a factor of 4 compared to room temperature, which entails an improved energy resolution and enables measurements over the large dynamic range from 10 MeV to 15 GeV [1], respectively. The Target Spectrometer electromagnetic calorimeter (EMC) in turn is divided into three parts, named according to their position with respect to the beam direction. The Forward Endcap covers polar angles from $5\,^{\circ}$ to $22\,^{\circ}$, the Barrel EMC angles from $22\,^{\circ}$ to $140\,^{\circ}$ and the Backward Endcap angles larger than $140\,^{\circ}$. With this design a virtually complete coverage of the solid angle can be achieved, which is mandatory for the intended physics cases. Due to the fact that the EMC is contained inside the magnetic field of the solenoid and necessarily has to be compact, readout is based on two rectangular Large Area Avalanche Photo Diodes (LAAPDs) per crystal. Merely in the low polar angle regions of the Forward Endcap, the use of one Vacuum Photo Tetrode per crystal is foreseen, which ensures a higher rate capability.

1.2. The Barrel EMC Prototype - PROTO60

The first prototype for the PANDA EMC, the so called PROTO60 consists of a matrix of 6×10 PWO-II crystals. As indicated in Fig. 2, geometrically it resembles a subsection of one of the 16 geometrically identical Barrel EMC slices. All 60 crystals possess the same shape and represent frusta of pyramids with a trapezoidal base with an intermediate degree of tapering (geometry type 6). Each crystal is read out by a single quadratic LAAPD with $1\,\mathrm{cm}^2$ sensitive area (type Hamamatsu S8664-79 1010SPL). The signals of groups of four crystals are amplified by the Low-Noise-low-Power charge preamplifier (LNP, Version Quad)[2] and routed outside the insulated containment by backplane-printed-circuit-boards (PCBs), which are also used for the high voltage distribution. During operation, the complete insulated volume is cooled to $-25\,^{\circ}$C and flooded with slightly over-pressured dry nitrogen to reduce humidity and avoid ice formation. An detailed description of PROTO60's mechanical layout and front end electronics is given in [3].

2. Test Beam at CERN-SPS

2.1. Setup and Readout

Previously several successful beam tests with energy marked photons in the range from 50 MeV to 1.5 GeV were performed and are described in detail in [3]. The test experiment described in this work was performed with a positron beam of 50 $\frac{\mathrm{GeV}}{c}$ momentum, representing the highest design energy of the PANDA EMC. This secondary beam was provided by the H4 beamline at CERN, using a primary protons delivered by the Super-Proton-Synchrotron (SPS). In addition

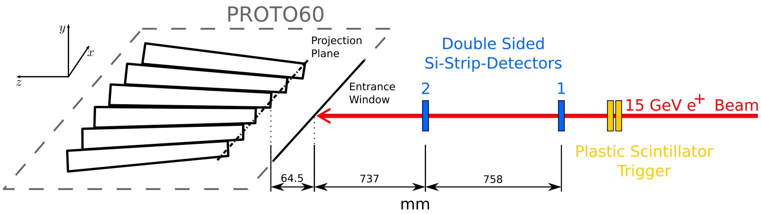

Figure 3. Schematical drawing of the test beam setup at CERN SPS. The depiction is not true to scale.

to PROTO60, the so called Bonn Tracking Station [4] was used for charged particle tracking. In the used configuration it consists of two double sided silicon microstrip detectors (50 μm strip pitch) triggered by a plastic scintillator cross with photomultiplier tube (PMT) readout. A schematic drawing of the setup is displayed in Fig. 3. Each Si-strip detector delivers information on the x- and y- position of the traversing positron, which is linearly extrapolated to the front face of the PROTO60 crystal matrix to obtain the point of impact of the individual positrons. The raw signals provided by the PROTO60 crystals are digitized by Sampling ADCs (Type SIS 3302) with 50 MHz sampling rate. These raw traces were stored to hard disc without further treatment. However, energy and time information are extracted offline via feature extraction algorithms, which are elaborately described in [5]. The energy is extracted from the pulse height after a moving window deconvolution and moving average filter, while for time extraction, the moving average is replaced by a constant fraction timing algorithm.

2.2. Analysis

Due to the expected high energy depositions for crystals located at the centre of the electromagnetic shower, the expected signal output exceeded the limited input charge of the LNP. Therefore, for the 5 innermost crystals of the matrix, the LAAPD gain was reduced to avoid saturation effects, while the outer crystals used gain settings consistent with earlier beam times at lower incident energies. The scheme of the crystal matrix depicted in Fig. 4 shows an overview of the settings applied to the individual crystal as well as the method employed for calibration. The energy calibration via cosmic minimum ionizing particles (MIPs) established in previous PROTO60 beam times is due to the significantly higher energy deposition only applicable for the outermost crystals of the matrix. Crystals exposed to the core of the electromagnetic shower, calibration was performed according to the energy deposited by a muon beam of 150 GeV/c momentum. This method provides a reliable relative calibration even at high energies. However, for an exact absolute energy calibration one has to rely on GEANT4 simulations for determining the absolute amount of energy deposited. Nevertheless, because of the high kinetic energy of the muon beam, which is close to the critical energy of muons inside lead tungstate as measured by [6], these absolute values are prone to uncertainties.

3. Results

3.1. Energy Resolution

The line shape obtained for the energy sum with a single crystal threshold of 1 MeV is depicted in Fig. 5. To extract the energy resolution in an appropriate manner, taking into account the tailing to lower energies, a fit of the Novosibirsk-function [7] was used. In case of the 15 $\frac{\mathrm{GeV}}{c}$ positron beam of approximately 1 cm diameter impinging at the crystal center, a relative energy resolution of $\frac{\sigma}{E} = 1.7\,\%$ was measured. However, to investigate the position dependence of the energy response, the tracker information was used to restrict the beam size to 4 mm diameter, which represents a reasonable compromise between position precision and the number of collected

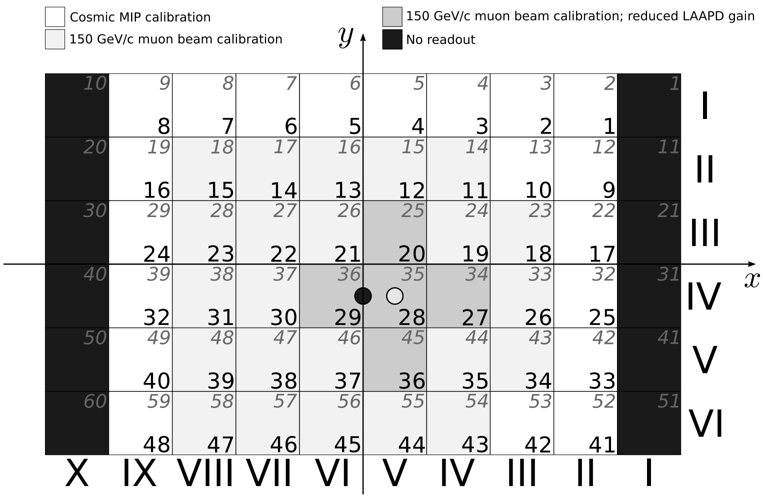

Figure 4. Schematic view of the PROTO60 crystal matrix in beam direction. Grey italic numbers indicate the physical number of the crystal matrix, while black numbers represent the crystal indices used in readout and analysis. The positron beam was impinging either at the center of crystal 28 (run 1) or in between crystal 28 and 29 (run 2), as marked by an open and filled circle, respectively. The schematics are not true to scale.

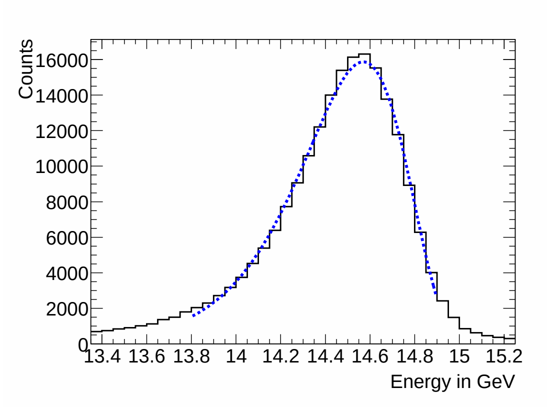

Figure 5. Energy sum line shape obtained at central position and fitted with a Novosibirsk function.

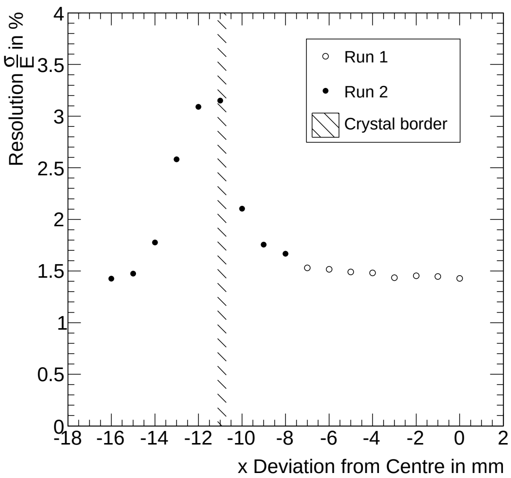

Figure 6. Energy resolution as a function of the deviation of the beam position form the crystal center. The beam size was restricted to 4 mm diameter by software conditions.

events. Fig. 6 shows the obtained relative resolution in dependence on the deviation of the beam position from the crystal center. Apparently, the resolution is significantly deteriorated in the crystal junction region, while shower containment and therefore resolution is achieved at the crystal center. Nevertheless, correction algorithms to reduce these effects were studied and are elaborately described in [8].

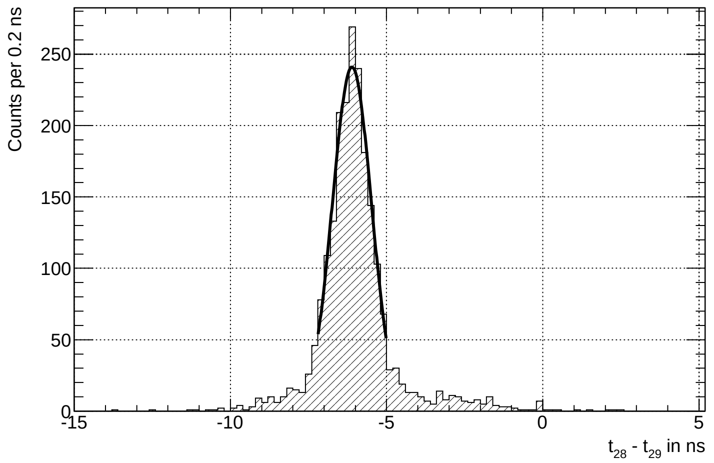

Figure 7. Time difference of the response of crystal 28 and 29 in case of an energy deposition equal within 10 %.

3.2. Time Resolution

Time resolution is extracted from the fluctuations in the time response of two detectors with comparable signal rise times. Therefore, events were selected, where the energy deposition inside the two neighboring crystals 28 and 29 was amounting to the same value within a margin of 10 %. The obtained distribution of their time difference Δt is presented in Fig. 7 and shows a Gaussian shape with a width of $\sigma_{\Delta t} = (631 \pm 14)$ ps. Under the assumption that both crystals contribute equally, the single crystal time resolution at on average 5.5 GeV deposited energy is obtained to be

$$\sigma_t = \frac{\sigma_{\Delta t}}{\sqrt{2}} = (441 \pm 15)\,\mathrm{ps}. \tag{1}$$

3.3. Position Resolution

For position reconstruction a center of gravity algorithm with logarithmic weighting, as given in Eq. 2, was employed, which takes into account the exponential transversal profile of the electromagnetic shower.

$$x_{log} = \frac{\sum_i w_i x_i}{\sum_i w_i}, \qquad\qquad w_i = \max\left\{0, W_0 + \ln\left(\frac{E_i}{\sum_i E_i}\right)\right\}. \tag{2}$$

If selecting the appropriate weighting parameter W_0 a linear position response is achieved, as displayed in Fig. 8. The position resolution is obtained by measuring the width σ_x of the distribution of the difference between reference position x_{Si} provided by the tracker and reconstructed position x_{log}. For slices of 0.5 mm in x_{Si} the extracted position resolution is plotted within Fig. 9. Best resolution of 0.5 mm is observed at the crystal junctions, while in the crystal center the position resolution is limited by the unequal sharing of the electromagnetic showers energy and amounts to 1.3 mm. In y- direction, a comparable behavior of the energy response is obtained. Consequently, the overall position resolution including all events regardless of x_{Si} amounts to $\sigma_x \approx \sigma_y \approx 1.1$ mm, for both x- and y-direction.

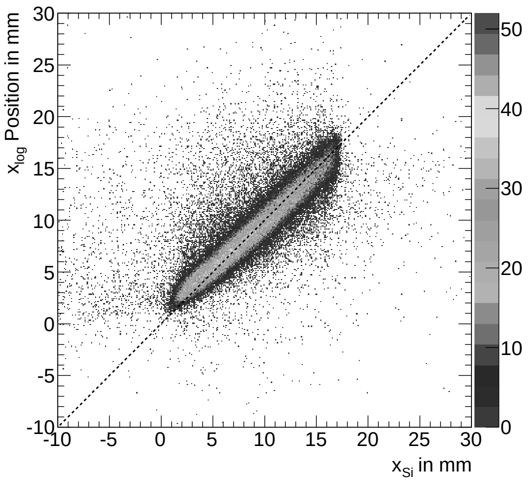

Figure 8. Correlation of reconstructed position x_{log} and reference position x_{Si}. The dashed line corresponds to a linear correlation.

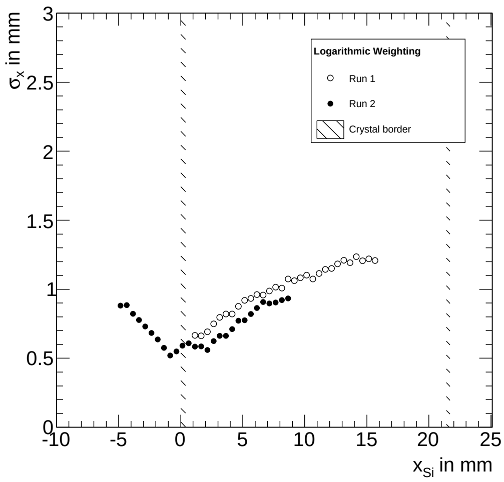

Figure 9. Position resolution in dependence of the reference position x_{Si}.

4. Conclusion

The performance of the first prototype for the PANDA Barrel EMC was measured at its highest design energy with a positron beam of 15 GeV/c momentum. Readout was based on sampling ADCs and offline feature extraction of the sampled detector signal, as described in detail in [3]. A 150 GeV/c muon beam and MIPs from cosmic rays were used for calibration of the detector matrix. Obtained energy, position and time resolution are compliant to the specification given in the EMC's technical design report. An energy resolution at 15 GeV of 1.5 % at the crystal center could be achieved. For all positron impact positions a position resolution better than 1.3 mm was measured. In addition, the obtained time resolution of $\sigma_t = (441 \pm 15)$ ps is in agreement with previous measurements [3] and satisfies the demands of the triggerless readout system for precise timing information. Towards the final design, the LNP will be replaced by an ASIC dual gain output. Therefore, the preamplifier will set no limitations on the LAAPD gain and results in an increased dynamic range. The mandatory tests of the modified readout chain and close to final mechanical integration will be performed with a new prototype consisting of a matrix of 120 strongly tapered PWO-II, which is currently under commissioning.

5. References

[1] PANDA Collaboration 2008 Technical Design Report for: PANDA Electromagnetic Calorimeter (EMC) (*Preprint* `0810.1216v1 [physics.ins-det]`)
[2] Erni W 2012 Basel LNP, a discrete Preamplifier for VPT/T (and APD) readout, model SP883d, Preliminary Version
[3] Kavatsyuk M *et al.* 2011 *Nucl. Instr. and Meth. A* **648** 77 – 91 ISSN 0168-9002
[4] Bianco S, Becker M, Brinkmann K T, Kliemt R, Koop K, Schnell R, Würschig T and Zaunick H G 2011 *PoS(RD11)025*
[5] Kavatsyuk M, Guliyev E, Lemmens P J J, Lohner H, Poelman T P and Tambave G 2009 *Nucl. Science Symp. Conf. Record (NSS/MIC), 2009 IEEE* pp 210–213 ISSN 1095-7863
[6] CMS Collaboration and others 2010 *JINST* **5** P03007 (*Preprint* `0911.5397 [physics.ins-det]`)
[7] Strother P D 1998 *Design and Appplication of the Reconstruction Software for the BaBar Calorimeter* Ph.D. thesis University of London
[8] Eißner T 2013 *The new PWO Crystal Generation and Concepts for the Performance Optimisation of the PANDA EMC* Ph.D. thesis Justus-Liebig-Universität Gießen