Prototyping the PANDA Barrel DIRC

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Abstract

The design of the Barrel DIRC detector for the future PANDA experiment at FAIR contains several important improvements compared to the successful BABAR DIRC, such as focusing and fast timing. To test those improvements as well as other design options a prototype was build and successfully tested in 2012 with particle beams at CERN. The prototype comprises a radiator bar, focusing lens, mirror, and a prism shaped expansion volume made of synthetic fused silica. An array of micro-channel plate photomultiplier tubes measures the location and arrival time of the Cherenkov photons with sub-nanosecond resolution. The development of a fast reconstruction algorithm allowed to tune construction details of the detector setup with test beam data and Monte-Carlo simulations.

Keywords: Cherenkov radiation, micro-channel plate photomultipliers, DIRC, particle identification

1. Introduction

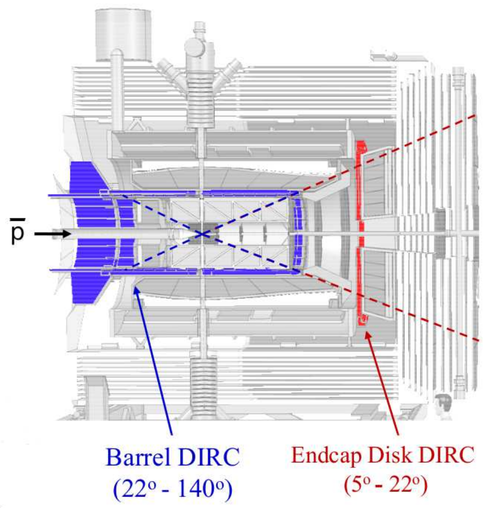

Figure 1: The PANDA target spectrometer with the barrel DIRC (left) and the endcap DIRC (right).

The PANDA Experiment [1] will be one of the key experiments at the Facility for Antiproton and Ion Research (FAIR) which is under construction and currently being built at the premises of the GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt, Germany. A cooled antiproton beam in the momentum range of 1.5 to 15 GeV/c interacting with a fixed hydrogen target will yield luminosities up to $2 \cdot 10^{32}$ cm^{-2}s^{-1} with a precision in momentum of up to $\delta p/p \approx 10^{-5}$. The hermetic PANDA detector consists of two parts, a forward spectrometer and a target spectrometer. The latter comprises tracking detectors, hadronic Particle Identification (PID), an electromagnetic PWO-calorimeter (EMC), and a muon range system within a solenoid with a magnetic field of $B = 2$ T. The hadronic PID will be performed by two Cherenkov-detectors using the DIRC principle (Detection of Internally Reflected Cherenkov light) with radiators made of synthetic fused silica. The barrel DIRC [2] covers an angular range of 22° to 140° (Fig. 1) and the endcap DIRC [3] from 22° down to 5° − 10°. Important improvements compared to the successful BABAR DIRC [4] are focusing optics and readout electronics with fast timing. With a small expansion volume (EV) one can afford the usage of fast timing Micro Channel Plate-PMTs (MCP-PMT). This, however, requires focusing optics like mirrors (FDIRC [5]) or lenses which are envisaged for the barrel DIRC.

2. The barrel DIRC design

The PANDA barrel DIRC uses long, rectangular bars made from synthetic fused silica as radiator and light guide. The

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choice of the material is due to its long transmission length, polishability, moderate dispersion, and radiation hardness [6]. Each bar is 2400 mm long with a cross section of 17×32 mm^2. There are 16 bar boxes holding five bars, placed side-by-side with a small air gap between bars. The radius of the DIRC barrel is $\approx$ 48 cm. Mirrors at the forward end of the bars reflect the photons towards the backward end. Here, a lens focuses the photons through an expansion volume on the photon detection plane. Approximately 15000 channels of readout electronics are foreseen. The depth of the expansion volume is 30 cm (Fig. 2). Candidates for the photon

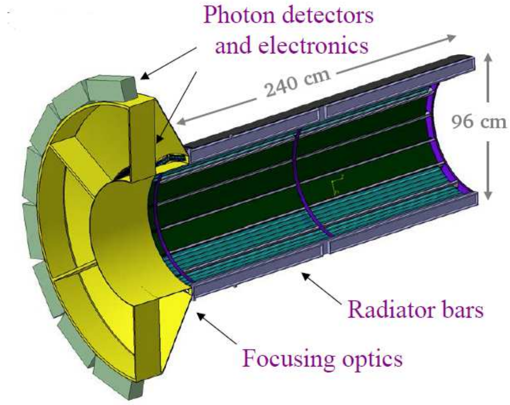

Figure 2: The barrel Dirc with expansion volume (left) and radiators/light guides (right).

detector are MCP-PMTs with a pixel size of 5.9×5.9 mm^2. The expected single photon Cherenkov angle resolution is $\sigma_{C,\gamma} = 8 - 9$ mrad, dominated by the contribution from the photon detector pixel size, $\sigma_{C,Det.} = 6.3$ mrad, and the chromatic resolution, $\sigma_{C,Chrom.} = 5$ mrad [7].

The following design options are under study: instead of using a single expansion volume filled with oil (e.g. Marcol82 [8]) to match the refractive index of the radiator, single prisms made from synthetic fused silica are considered. Their absorption length for photons extends far in the UV region resulting in a better photon yield. However, the reconstruction of the photon path is more complex due to side reflections. The cost of the radiator fabrication is dominated by the polishing of the side surfaces with a surface roughness of $\sigma = 5$ Å. Using a single wide radiator plate per bar box, as proposed for the Belle II TOP [9], reduces the number of surfaces to polish and, therefore, the fabrication cost. The total number of photons reaching the photon detector depends on the choice of the focusing lenses. Traditional singlet or doublet lenses require an air gap between the lens and the EV. However, a large fraction of the Cherenkov photons is reflected at the curved lens/air interface, leading to a loss of photons and a deterioration of the Cherenkov angle measurement. Optimization of the optics in software using ZEMAX [10], standalone ray tracing and PANDARoot/Geant simulation [11, 12] shows that a multi-component lens (Fig. 3), using a material with a higher refractive index than fused silica, may offer a solution to the photon loss issue.

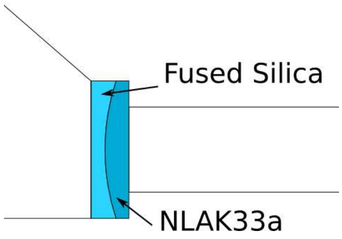

Figure 3: Lens configuration without air gap between lens attached to the expansion volume (left) and the radiator (right).

3. Prototyping

Several key aspects of the current design were implemented in a system prototype and tested in summer 2012 in a secondary hadron/lepton beam at the T9 beam line area of the CERN proton synchrotron, The beam momentum was adjusted between 1.5 and 10 GeV/c. The trigger was provided by two scintillator counters. Two tracking stations using scintillating fibers measured the beam direction. A time-of-flight system provided pion/proton tagging up to 6 GeV/c momentum. Radiator bars and plates were coupled to a prism (Fig. 4) with 300 mm base length. The back side of the prism was covered with nine Planacon MCP-PMTs X85112 from PHOTONIS [13]. The readout was performed with Trigger Readout Boards (TRB) [14]. A total of about 220M triggers were recorded in several configurations. Spherical and cylindrical focusing lenses with and without anti-reflective coating were tested in combination with synthetic fused silica bars produced from different manufacturers, including a 17 cm-wide radiator plate made from the same material. The polar angle between the particle beam and the bar was varied between 20° and 155° and the intersection point between beam and bar was adjusted by some 80 cm along the long bar axis. The detected number of photons is shown in Fig.

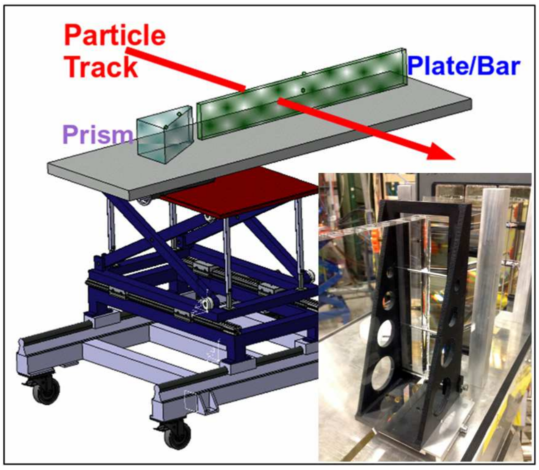

Figure 4: The schematic setup of the prism and the radiator plate and the picture of it as insert (the plate is on the left side).

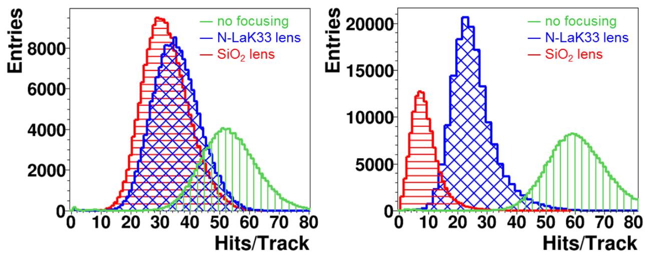

Figure 5: Photon yields for charged particles with 10 GeV/c momentum hitting the radiator at an angle of 126° and 92° in the left and right figure, respectively. The distributions are for different coupling of the radiator to the expansion volume.

5. The distributions show how the radiator (17×32 mm^2) was coupled to the prism: The horizontal hatched distribution is for the coupling by a focusing lens made from fused silica attached to the radiator and an air gap between lens and expansion volume. The cross hatched distribution is for a lens made from N-LaK33 glass (Fig. 3) coupled with fused silica to the prism. The vertical hatched distribution is for the direct coupling of the radiator to the prism. About 40% of photons are lost due to the usage of the lenses compared to the direct coupling without focusing at a track polar angle of 126° (Fig. 5, left). When the beam hits the radiator perpendicularly, the photons hit the end of the bar at an angle close to internal reflection. Here, the curved surface of the lenses reflect back many of the photons by internal reflection (Fig. 5, right). This behavior agrees

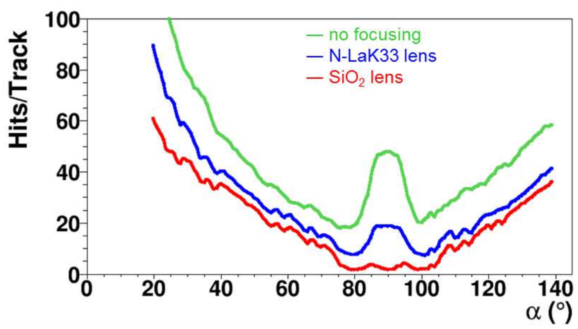

Figure 6: Simulation of the photon yield for charged particles hitting the radiator at an angle α. The curves are for the options without focusing (top), the N-Lak33 lens (middle), and the SiO_2 lens (bottom).

well with the results from a ray tracing simulation shown in Fig. 6. The reconstruction of the Cherenkov angle is accomplished by calculating all possible reflections within the radiator and the prism. The distribution (Fig. 7, left) shows large bin-to-bin fluctuations that are the result of the ring image being mostly parallel to MCP-PMT columns. This pixelization effect can be avoided by combining the data from runs at several different polar angles. The result of a combination of eight runs with polar angles between 122°-124° can be seen in Fig. 7, right. The fit in Fig. 7, right, is centered at 826.3 mrad with a width of $\sigma = 13.0$ mrad as single photon Cherenkov angle resolution. The simulated position and width of the peak is at an angle of 824.9 mrad and 8.9 mrad, respectively. The simulation does not

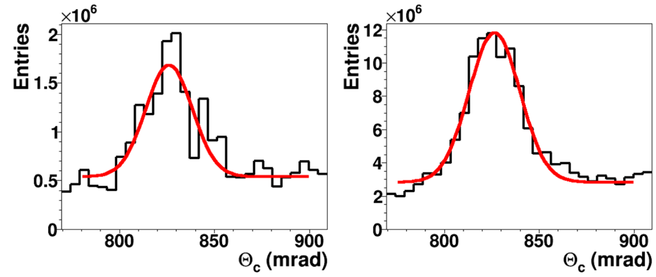

Figure 7: The distribution of reconstructed Cherenkov angles for polar angles of the beam at 124° and between 122° and 124° at the left and right figure, respectively.

include the beam divergence of estimated $6 - 7$ mrad.

4. Conclusion

A test experiment was performed with a versatile prototype of the PANDA DIRC detector. Bars and plates were coupled to a prism and the imaging plane covered with an array of MCP-PMTs. The presented results are for the $17 \times 32\,\text{mm}^2$ radiator bars. The analysis for the plates is still ongoing. Several focusing options were evaluated in terms of photon yield and Cherenkov angle resolution. A design with a high-refractive index lens reached a performance close to the PANDA DIRC PID requirements. More detailed studies with focusing optics, and direct measurements of the Cherenkov angle resolution per track, are scheduled for the summer of 2014 during two test beam campaigns at GSI.

5. Acknowledgements

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