The Barrel DIRC Detector for the PANDA Experiment at FAIR

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Abstract. Charged particle identification in the barrel region of the PANDA target spectrometer will be delivered by a Barrel DIRC detector. The design of the Barrel DIRC has been developed using Monte-Carlo simulation and validated with a full-scaled prototype in particle beams. It features the narrow radiators made of synthetic fused silica, focusing optics with 3-layer spherical lenses, and a compact prism-shaped expansion volume instrumented with MCP-PMTs.

Keywords: particle identification, Cherenkov detector, DIRC

1 Introduction

The PANDA experiment [1] is designed to shed a light on fundamental aspects of QCD by performing hadron spectroscopy. A sophisticated detector system with 4π acceptance, precise tracking, calorimetry, and particle identification (PID) is designed to accomplish that goal [2]. Hadronic PID for the target region of the PANDA detector will be delivered by a DIRC (Detection of Internally Reflected Cherenkov light) counter, see Fig. 1 (left). It is designed to cover the polar angle range from 22° to 140° and provide at least 3 s.d. π/K separation power up to 3.5 GeV/c, matching the expected upper limit of the kaon momentum distribution, shown in Fig. 1 (right).

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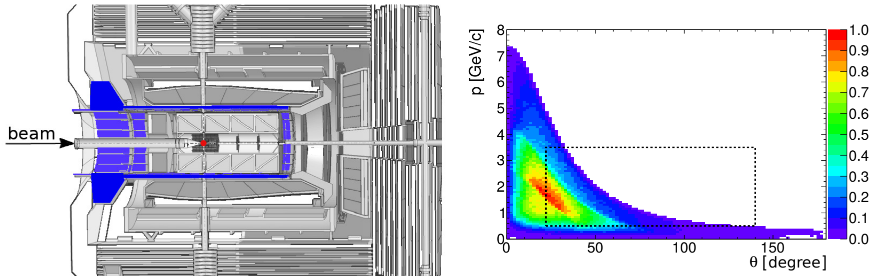

Fig. 1. Left: The PANDA target spectrometer with highlighted Barrel DIRC. Right: Phase space distribution as a function of kaon momentum and polar angle combined for eight benchmark channels at $p_{\bar{p}} = 7$ GeV/c. The Barrel DIRC coverage is marked with the dashed rectangle.

2 Barrel DIRC design and performance

The design of the PANDA Barrel DIRC [3] is shown in Fig. 2 (left). The base concept of it is inspired by the BaBar DIRC counter [4]. It is constructed in a form of barrel using 16 optically isolated sectors each made of radiator box and a compact, prism-shaped expansion volume (EV). The radiator box contains three synthetic fused silica bars of $17 \times 53 \times 2400$ mm^3 size, positioned side-by-side with a small air gap in between them. A flat mirror at the forward end of each bar is used to reflect Cherenkov photons to the read-out end, where a 3-layer spherical lens images them on an array of 11 Microchannel-plate Photomultiplier Tubes (MCP-PMTs) [5]. The MCP-PMT consists of 64 pixels of 6.5×6.5 mm^2 size and is able to detect single photons with a precision of about 100 ps. A modernized version of the HADES readout board [6] and front-end electronics [7] is used for a signal readout.

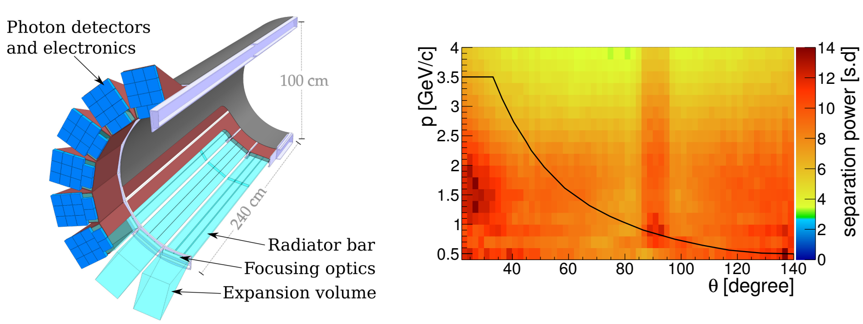

Fig. 2. Left: CAD drawing of the Barrel DIRC. Only half of the sectors are shown. Right: π/K separation power as a function of particle momentum and polar angle in GEANT4 simulation.

Two reconstruction methods have been developed to determine the performance of the detector [8]. The *geometrical* reconstruction performs PID by reconstructing the value of the Cherenkov angle and using it in a track-by-track maximum likelihood fit. This method relies mostly on the position of the detected photons in the reconstruction, while the *time imaging* utilizes both, position and time information, and directly performs the maximum likelihood fit. The results of the time imaging reconstruction of the GEANT4 simulations are shown in Fig. 2 (right), where the π/K separation power is shown for different momenta and polar angle of the particles. With a separation power of 4–16 s.d., the design exceeds the PANDA PID requirement for the entire charged kaon phase space, indicated by the area below the black line.

3 Prototype tests

Multiple aspects of the Barrel DIRC's design were tested in hadronic particle beams during the 2011-2016 period. Several design options, such as a monolithic expansion volume and a traditional spherical lens with an air gap, were excluded due to insufficient performance. The final design configuration with narrow bars was verified at the CERN proton synchrotron in 2015 [9]. Additional tests were carried out in 2016 to evaluate the performance of an alternative design with wide plate radiators instead of narrow bars. Such a design would significantly reduce the cost of the detector.

The full-scale prototype included all relevant parts of the PANDA Barrel DIRC sector. Both radiator geometries, a narrow fused silica bar ($17.1 \times 35.9 \times 1200.0$ mm^3) and a wide fused silica plate ($17.1 \times 174.8 \times 1224.9$ mm^3) were tested. One end of the radiator was coupled to a flat mirror and the other end to a focusing lens and expansion volume. An array of $3{\times}5$ MCP-PMTs was attached to the back side of the EV and used to detect Cherenkov photons.

A wide range of data measurements were taken for the π/p beam at different polar angles and momenta. The external PID for charged particle was provided by a time-of-flight system. Fig. 3 shows the result of the time imaging reconstruction for a 25° polar angle and a 7 GeV/c momentum. The resulting separation

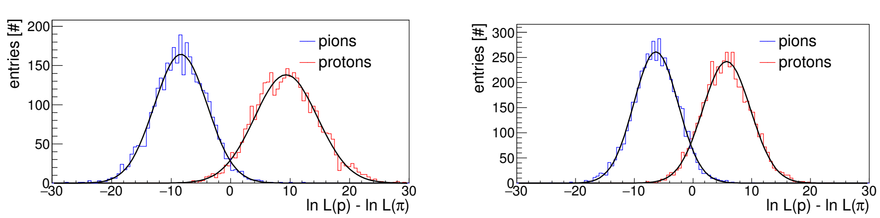

Fig. 3. Proton-pion log-likelihood difference distributions from proton data (red) and pion data (blue) at 7 GeV/c beam momentum and 25° polar angle as a result of the time-based imaging reconstruction. The distributions are for the narrow (left) and wide (right) radiator with the 3-layer spherical and 2-layer cylindrical lens, respectively.

powers of 3.6±0.1 s.d. for the bar (left) and 3.1±0.1 s.d. for the plate (right) at 7 GeV/c π/p momentum correspond to 3.8±0.1 s.d. and 3.3±0.1 s.d. at 3.5 GeV/c π/K momentum. While the result with a narrow bar is clearly superior to the result with the plate, both performances satisfy the PANDA Barrel DIRC requirement and are in a good agreement with simulations.

4 Conclusions

The PANDA Barrel DIRC will deliver hadronic PID, in particular π/K separation better than 3 s.d. up to 3.5 GeV/c. The final design features narrow radiators made of synthetic fused silica, focusing optics with 3-layer spherical lenses and a compact prism-shaped expansion volume instrumented with MCP-PMTs.

The latest prototype tests with particle beams at CERN validated this design. In addition the configuration with wide plate radiator and cylindrical lens also prove to give sufficient PID performance. Nevertheless, the narrow bar design was selected due to the superior PID performance and because the plate requires significantly better timing precision, which may not be available at the beginning of the PANDA physics run.

The production of the optical components, photon sensors and electronics for the PANDA Barrel DIRC is scheduled for the 2019-2022 period. The final assembly and installation should take place in 2023.

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