Nuclear Instruments and Methods in Physics Research A ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Development of an Endcap DIRC for PANDA

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ARTICLE INFO

Keywords:
Cherenkov radiation
DIRC
Particle identification

ABSTRACT

The aim of this research is to develop a planar DIRC detector showing advantages and performance similar to a classical, barrel shaped DIRC, but at smaller polar angles which cannot be accessed using a cylindrical geometry. The device will complement the PANDA Barrel DIRC by covering polar angles from 5° to 22°. The envisaged π/K-separation is $\geq 3\sigma$ up to 4 GeV/c.

A major challenge is the adaption of the device to the PANDA environment including a magnetic field of $\sim$1–2 T, high rates and radiation, limited space for optics and sensors as well as the lack of a common first-level trigger. This paper discusses a detector design which forms a compromise between these constraints and available hardware, a specific analytic reconstruction method, a performance estimation based on Geant4 simulations and finally the successful particle identification using a recent R&D prototype.

1. Introduction

PANDA [1] will be a general purpose detector for antiproton physics at the upcoming FAIR facility in Darmstadt, Germany. It has been designed as a fixed target, in-ring experiment at the High Energy Storage Ring, which will provide a cooled, quasi-continuous antiproton beam at momenta from 1.5 to 15 GeV/c. A cluster-jet as well as a pellet system are foreseen as internal hydrogen targets. The envisaged cycle-averaged interaction rate is 10 MHz. On a short timescale however, the average rate can increase by a factor of ≥ 2 due to fluctuations in target density. Therefore, all components must be able to handle interaction rates exceeding 20 MHz.

An important technical aspect is the lack of a common first-level trigger. A data-driven approach will be applied instead. All sub-detectors have to sample the signals continuously and stream this information to the data acquisition system (DAQ) for online processing, reconstruction and event selection. Algorithms for pattern analysis have to be available online.

The experiment requires good particle identification (PID) with a pion–kaon separation better than 3σ for polar angles between 5° and 140° and momenta up to 4 GeV/c at the endcap. For this purpose a system of two DIRC[1] detectors is being developed. The Barrel DIRC [2], a detector similar to the BaBar DIRC, will cover the larger polar angles down to 22°. A novel Endcap DIRC is foreseen to provide PID in the region from 5° to 22°, as shown in Fig. 1. While the principle idea of such a device has already been proposed by

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[1] Detection of Internally Reflected Cherenkov light.

http://dx.doi.org/10.1016/j.nima.2014.04.016

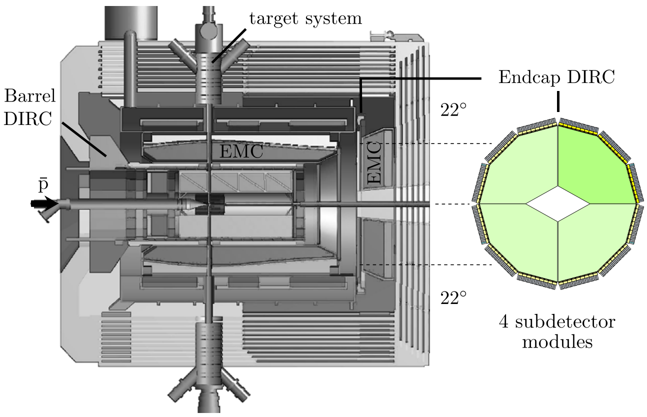

Fig. 1. The planned DIRC system inside the PANDA target spectrometer.

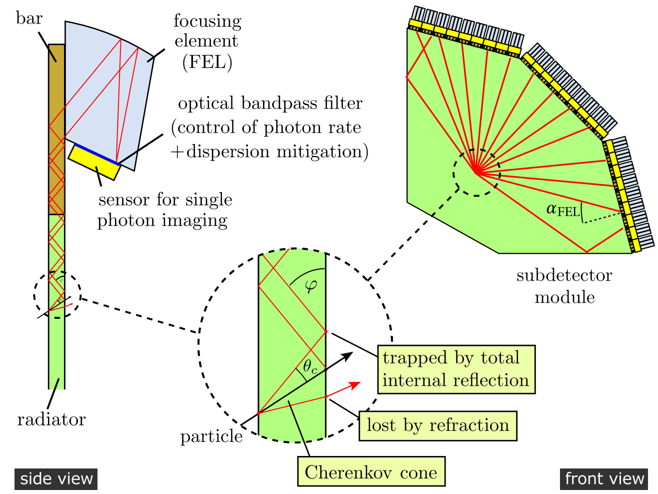

Fig. 2. Working principle of the Endcap DIRC. Red lines are photon tracks. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

Kamae et al. [3] in 1996, a detector of this type has never been realized so far.

One of the bigger challenges concerning the PANDA environment is the selection of a suitable photodetector. A magnetic field of about 1 Tesla at the sensor position restricts the choice to photomultiplier tubes with microchannel plates (MCP–PMTs) and silicon photomultipliers (SiPM). Both options show distinct limitations regarding our application.

SiPMs are susceptible to radiation damage and cooling is usually required to reduce the intrinsically high dark count rate. In contrast to SiPMs, MCP–PMTs have to be aligned with the magnetic field, which adds additional constraints to the focusing optics design, and suffer from aging processes which cause considerable degradation of the photocathode [4].

The degradation of MCP–PMT performance becomes noticeable after a certain extracted charge Q_{max}. At the endcap we expect an average of 3 Cherenkov-emitting tracks per event, resulting in a track rate of 30 MHz. The planned device will use 4×27 MCP–PMTs (2 in.-square), which is already close to the maximum defined by geometrical constraints. Assuming a gain of 10^6, a continuous PANDA runtime of 5 years and an average photon yield per track N_{track}, one gets an integrated anode charge per tube of $Q = N_{track} \cdot 0.28\ \mathrm{C/cm^2}$. At the time of writing, the charge-limit of lifetime-enhanced MCP–PMTs is about 5.9 C/cm^2 [4] what is compatible with $N_{track} \le 21$.

Such long lifetimes became only recently available with the deposition of thin films on MCPs via atomic layer deposition. A few years ago, the maximum extracted charge limit was about 0.2 C/cm^2, corresponding to $N_{track} \approx 1$, which excluded the option of using such MCP–PMTs in our application. Therefore, we investigated a detector option using digital SiPMs from Philips [5]. However, recent irradiation tests showed that these devices are not sufficiently tolerant to the radiation conditions in PANDA [6].

The experience gained by designing the SiPM version has been used to develop an alternative based on MCP–PMTs. To match the lifetime requirement, the design is optimized for a low number of detected photons per track by means of optical filters which also reduce the chromatic error. In the case of significant further improvements in lifetime, filter specifications can be adopted without interfering with other parts of the detector.

2. Detector design

2.1. Subdetector layout and radiator

The Endcap DIRC is positioned 2 m downstream from the interaction point, directly in front of the endcap electromagnetic calorimeter (EMC, Fig. 1). The area from 5° to 22° is covered by 2 cm thick radiator plates made from synthetic fused silica, the only glass with sufficient VIS/UV-transmission and radiation hardness. Charged tracks with $\beta > 0.68$ emit Cherenkov light in this material. Photons with an angle $> 43°$ against the surface normal are trapped inside due to total internal reflection. As indicated in Fig. 2, trapped photons are transported to the perimeter of the radiator by consecutive reflections at the down- and upstream surfaces which have to be exactly parallel to conserve the angular information of the photon. The perimeter is instrumented with readout modules consisting of imaging optics and a position sensitive photodetector. Both the hit time and hit position on the sensor carry information about the Cherenkov angle. Dispersion errors are mitigated by using optical bandpass filters which limit the wavelength acceptance.

An area of about 2 m diameter has to be covered with a precision polished radiator. Discussions with several manufacturers established that the maximum diameter of polished fused silica plates is ~1.5 m (60 in.). To avoid complications induced by combining several tiles into one radiator, a symmetric subdetector layout has been chosen (Fig. 1, right). This setup uses the same, smaller radiator shape in all four devices. Uninstrumented radiator edges do not need a mirror coating as the majority of trapped photons will be internally reflected. The radiator shape is a compromise between the PANDA geometry, the alignment of the sensors to the magnetic field and the number of edges to polish. The latter is correlated with manufacturing cost.

2.2. Readout modules

A readout module (ROM, Fig. 3b) consists of three 16 mm wide focusing elements attached to quartz bars, a 2 in. MCP–PMT with custom anode structure, an ASIC board for the fast digitization of PMT signals and finally a control board providing a connection to the DAQ system via the fiber link.

Photons entering the bars are transported by successive total internal reflection to the curved surface of the focusing element (FEL). This aluminum coated, plano-convex, cylindrical mirror converts angular information into a position information by imaging parallel light onto a single line on the photocathode of the sensor. The position sensitive MCP–PMT measures the position z and arrival time t_a of the photon.

The position is a function of the internal reflection angle φ and the angle α_{FEL} between the photon propagation plane and the

Please cite this article as: O. Merle, et al., Nuclear Instruments & Methods in Physics Research A (2014), http://dx.doi.org/10.1016/j.nima.2014.04.016