PUBLISHED BY IOP PUBLISHING FOR SISSA

RECEIVED: *August 14, 2009*
ACCEPTED: *August 18, 2009*
PUBLISHED: *September 9, 2009*

WORKSHOP ON FAST CHERENKOV DETECTORS - PHOTON DETECTION,
DIRC DESIGN AND DAQ
MAY 11-13, 2009, GIESSEN, GERMANY

The $\overline{\text{P}}$ANDA Focussing-Lightguide Disc DIRC

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ABSTRACT: $\overline{\text{P}}$ANDA will be a fixed target experiment internal to the HESR antiproton storage ring at the future FAIR complex. The $\overline{\text{P}}$ANDA detector requires excellent particle-identification capabilities in order to achieve its scientific potential. Cherenkov counters employing the DIRC principle were chosen as PID detectors for the Target Spectrometer. The proposed Focussing-Lightguide Disc DIRC will cover the forward part of the Target Spectrometer acceptance in the angular range between 5° and 22°. Its design includes a novel approach to mitigate dispersion effects in the solid radiator of a DIRC counter using optical elements. The dispersion correction will enable the Focussing-Lightguide Disc DIRC to provide pion-kaon identification for momenta well above 3.5 GeV/c.

KEYWORDS: Particle identification methods; Cherenkov detectors

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doi:10.1088/1748-0221/4/09/P09006

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1 Introduction

$\overline{\text{P}}$ANDA [1] is one of the main experimental projects of the planned FAIR complex at the existing Heavy Ion Research Lab (GSI) and is expected to begin operation in 2014. $\overline{\text{P}}$ANDA is a fixed target experiment internal to the High Energy Storage Ring (HESR) and will be using hydrogen and nuclear targets. The HESR is used to accumulate and accelerate antiprotons in the momentum range from 1.5 GeV/c to 15 GeV/c with unprecedented beam intensity and momentum resolution.

$\overline{\text{P}}$ANDA's scientific program [2] addresses fundamental questions of QCD, the theory of the strong interaction, by precise hadron spectroscopy, studying properties of hadrons inside nuclear matter, investigating hypernuclei and detailed studies of the nucleon structure. Such a broad spectrum of measurements requires the detection of the complete final state necessitating a full solid angle coverage and an outstanding detector system with high-precision tracking and calorimetry and very efficient Particle Identification (PID) capabilities.

2 The $\overline{\text{P}}$ANDA detector

The $\overline{\text{P}}$ANDA detector (shown in figure 1) is designed to provide a 4π angular acceptance and achieve high resolution for tracking, particle identification and calorimetry at high interaction rates. The detector is divided into a Target Spectrometer, which surrounds the interaction point, and a Forward Spectrometer, which covers the very forward angles.

The Target Spectrometer is arranged in a barrel part for angles larger than 22° and an end-cap part for the forward range down to 5° (10°) in the vertical (horizontal) plane. The Target Spectrometer consists of Micro-Vertex Detectors (MVD), tracking and PID detectors and an Electromagnetic Calorimeter (EMC) [3] surrounded by a 2 T superconducting solenoidal magnet [4]. The return yoke of the magnet is instrumented with muon detectors. Cherenkov detectors using the DIRC principle [5] were chosen as main PID detectors for the Target Spectrometer due to their compact design yet exceptional performance [6–8]. A barrel DIRC [9] similar to the BaBar DIRC [10] will cover the barrel part of the Target Spectrometer while a novel design is required for the end-cap part. The barrel DIRC counter will be complemented by Time-Of-Flight (TOF) systems to cover momenta below the Cherenkov threshold.

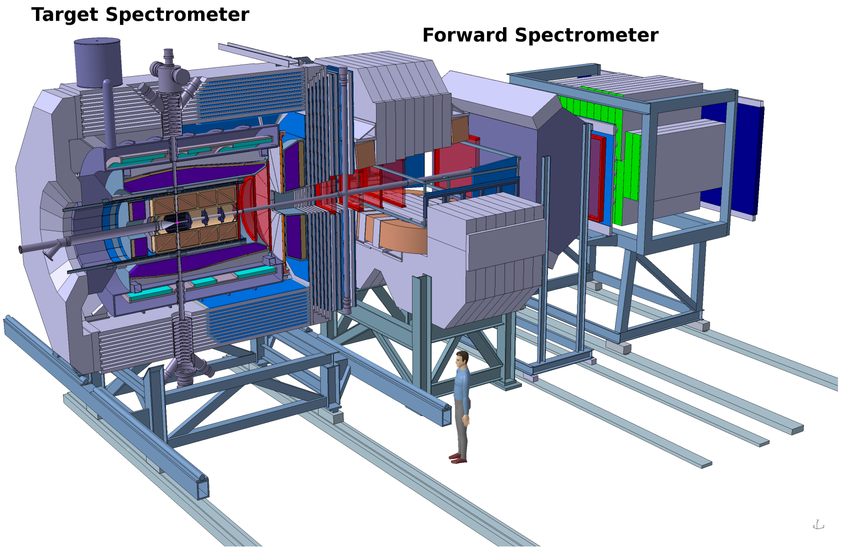


Figure 1. CAD view of the $\overline{\mathrm{P}}$ANDA detector system. The antiproton beam enters from the left into the Target Spectrometer. The Forward Spectrometer is to the right of the Target Spectrometer.

The Forward Spectrometer covers angles below 5°(10°) in the vertical (horizontal) plane. It employs a normal-conducting dipole magnet for the momentum analysis of charged particles. A set of wire chambers will provide tracking of the charged particles. A Ring-Imaging Cherenkov Counter (RICH) and a TOF Wall provide PID. A Shashlyk-type electromagnetic calorimeter and muon detectors complete the Forward Spectrometer.

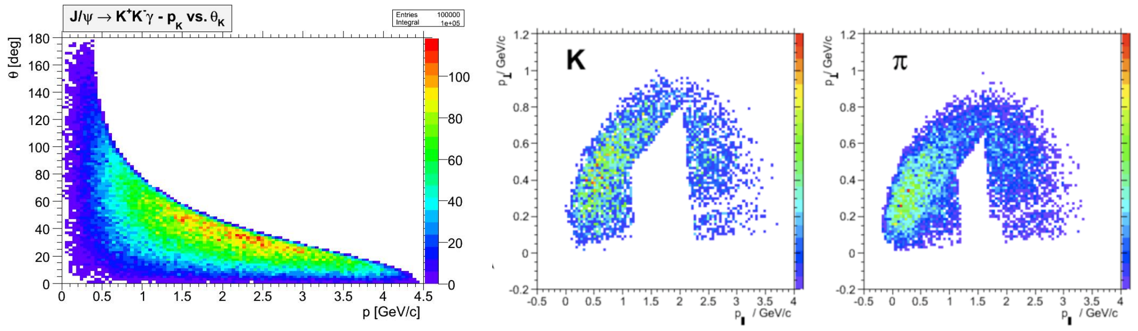
3 $\overline{\mathrm{P}}$ANDA physics requirements

The $\overline{\mathrm{P}}$ANDA collaboration pursues a broad physics programme [2] ranging from hadron spectroscopy, through the study of nucleon structure, to hypernuclei. A full coverage of the final state is mandatory and excellent PID capabilities are required to achieve these goals. Two decay channels from the $\overline{\mathrm{P}}$ANDA physics programme were selected to highlight the requirements for the end-cap DIRC counter: charged kaon distributions from J/ψ decay (see figure 2 a) and charged pion and kaon distributions from D$^+$D$^-$ decay (see figure 2 b).

The J/ψ decay illustrates that the end-cap DIRC has to provide positive kaon identification over a wide range of particle momenta ranging from 1.0 GeV/c to higher momenta well above 3.5 GeV/c. D$^+$D$^-$ decay distributions of charged kaons and pions show that without an end-cap DIRC there would be a significant gap in the acceptance. Advanced analysis approaches like partial wave analysis that will be adopted by $\overline{\mathrm{P}}$ANDA [2] require full coverage of the final-state phase space to yield their full potential.

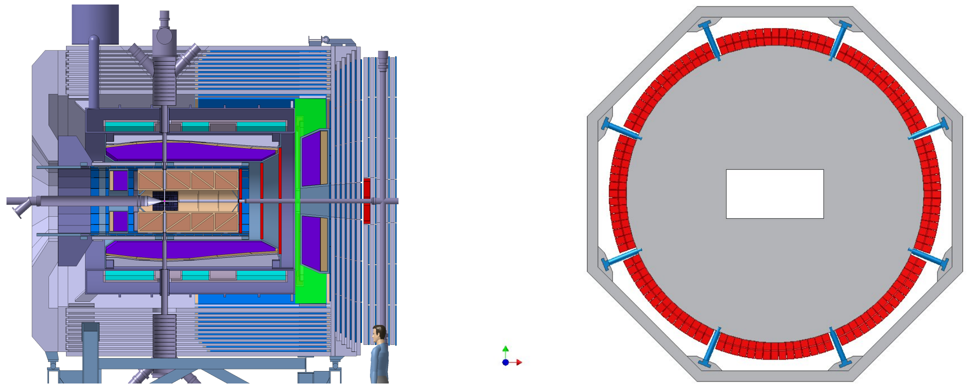
4 Focussing-Lightguide Disc DIRC design

Covering the forward end-cap part of the Target Spectrometer acceptance requires a new DIRC counter design. It has to provide PID at momenta well above 3.5 GeV/c and fit into the available physical space (see figure 3 a). The end-cap DIRC must be installed in the gap between the forward



(a) (b)

Figure 2. (a) Simulated momentum and polar angle distribution of charged kaons from J/ψ decay. The end-cap DIRC has to cover polar angles between 5° and 22°. (b) Simulated longitudinal ($p_{\parallel}$) vs transverse ($p_{\perp}$) momentum distributions of charged kaons (left) and pions (right) from D^+D^- decay without end-cap DIRC.



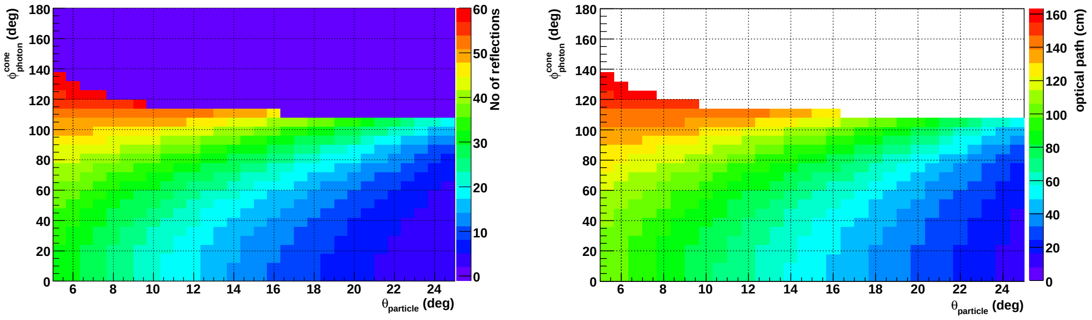
(a) (b)

Figure 3. (a) CAD view of the Target Spectrometer. The antiproton beam enters from the left. The physical space available for the end-cap DIRC is indicated by the green area. (b) CAD view of the Focussing-Lightguide Disc DIRC with support frame. The support frame is matching the octagonal shape of the magnet yoke. The imaging units are shown in red. The central, rectangular opening in the radiator disc corresponds to the acceptance of the Forward Spectrometer.

tracking detectors and the end-cap EMC. In the central part where the radiator will be located, only 60 mm in depth are available. Furthermore, the impact on the EMC performance has to be minimal and places severe limits on the end-cap DIRC design.

The design employs a disc-shaped radiator, which was first proposed in [11], with imaging units which include dispersion-correction elements attached to its rim. A stainless steel frame, matching the octagonal shape of the magnet yoke, provides support to the disc and the imaging units. The entire detector is estimated to weigh approx. 1000 kg. The radiator with attached imaging units and its support frame is shown in figure 3 b. The central opening corresponds to the acceptance of the Forward Spectrometer.

The radiator disc has a polygonal shape with 128 corners. 120 imaging units will be attached to the disc with the remaining corners required for the support structure. The number of imaging units



(a) (b)

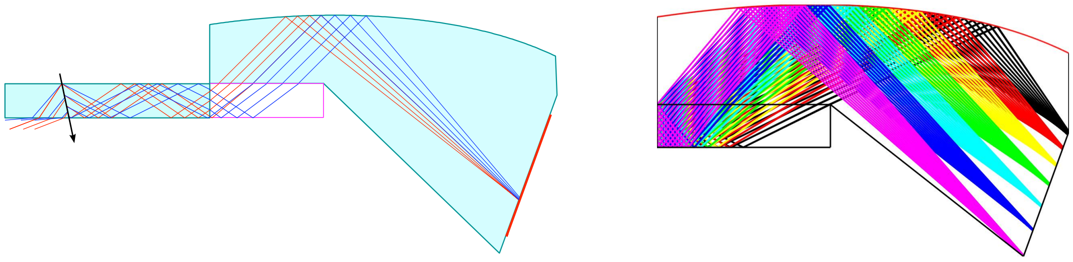
Figure 4. (a) Number of reflections on the radiator surface as a function of the charged particle polar angle θ and the Cherenkov photon azimuthal angle ϕ with respect to the particle track (dispersion effects were neglected). (b) Path length of Cherenkov photons transported inside the radiator disc as a function of the charged particle polar angle θ and the Cherenkov photon azimuthal angle ϕ with respect to the particle track (dispersion effects were neglected).

has been optimised with respect to performance and cost. The radiator will have a radius of approx. 1100 mm and a thickness of 20 mm. The material of choice for the radiator, similar to the BaBar DIRC [12], is synthetic fused silica, which is highly transparent in the optical and UV regime in order to maximise the Cherenkov photon yield. Furthermore, the material is radiation hard [13] and will withstand the estimated accumulated dose of 100 krad over the $\overline{\text{P}}$ANDA lifetime. The radiator disc will be assembled from several pieces as no manufacturer can provide a high-grade fused silica piece large enough for a monolithic disc. The individual pieces will be joined using EPO-TEK 301-2, a slow-curing two-component epoxy resin. This introduces a lower wavelength cut-off of 300 nm for the Cherenkov spectrum. The required optical quality of the radiator depends on the photon yield. The most important loss mechanism is reflection losses on the surfaces due to the inherent surface roughness. Compared to the BaBar Barrel DIRC [12] the Focussing-Lightguide Disc DIRC has significantly fewer reflections (see figure 4 a) which allows the relaxation of the requirements on the surface smoothness to 10 Å (opposed to BaBar specifications of 5 Å [10]). Bulk absorption within the radiator can be neglected as the photon path length (cf. figure 4 b) is significantly smaller than the absorption length Λ of fused silica of $\Lambda = 500$ m at a photon wavelength of 442 nm [12].

The optical imaging system, which is crucial for optimum detector performance, comprises a Lithium Fluoride (LiF) plate for dispersion correction, a focussing lightguide and a position sensitive photon detection device. A sketch of the optical imaging system is shown in figure 5 a.

The LiF plate acts as a dispersing prism in the optical path of the Cherenkov photons thus mitigating the dispersion effects of the fused-silica radiator (see figure 6) and reducing the blur of the Cherenkov ring image. An advantage of this direct method of dispersion correction is that it does not require high-precision Time-Of-Propagation measurements of the Cherenkov photons to determine the wavelength [14, 15].

The focussing lightguide is necessary to remove the photon emission uncertainty due to the finite radiator thickness. The curved surface, which bends only in the central plane of the light-guide similar to a cylindrical lens, needs to be non-spherical to achieve the best performance of the imaging system. Its shape is optimised using ray-tracing methods (see figure 5 b). Only one coor-



(a) (b)

Figure 5. (a) Sketch of the Focussing-Lightguide Disc DIRC imaging system. The arrow indicates a charged particle emitting Cherenkov light. The Cherenkov light enters the Lithium-Fluoride (LiF) plate (shown in magenta) from the left. The photons then enter the focussing lightguide through the top of the LiF plate and are focused onto the focal plane with the photon detector (shown in red). (b) Ray trace of an optimised focussing lightguide. The different colours represent different photon angles. The separation of the different angles on the focal plane is clearly visible.

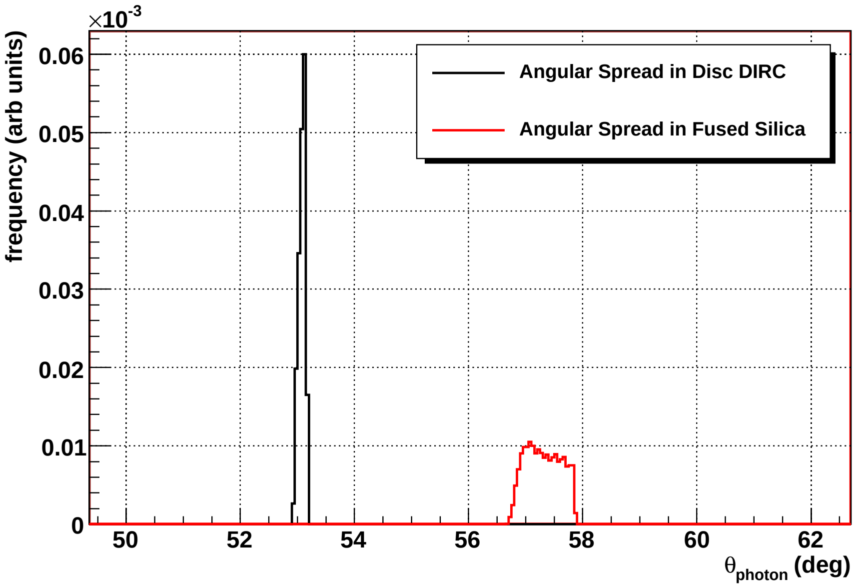


Figure 6. Performance estimate of the optical dispersion correction element (LiF plate) in the Focussing-Lightguide Disc DIRC imaging unit. The initial angular distribution takes the Cherenkov spectrum as well as the quantum efficiency of the PLANACON MCP-PMT and the transmission of EPO-TEK 301-2 into account. The angular spread of the Cherenkov photons is significantly reduced after passing throught the LiF plate.

dinate along the focal plane is then required to reconstruct the projected photon angle on the central plane of the lightguide. The image size has been adjusted to the size of the photon detector. The focal plane tilt angle is adjusted such that the cathode plane of the photon detector is orthogonal to the magnetic field lines to optimise the detector's performance. The lightguide shape is further constrained by the available physical space inside the detector housing.

The imaging units will be equipped with position-sensitive photon detectors. These detectors must operate in magnetic fields up to 1.5 T [4], as the readout is located within the magnet

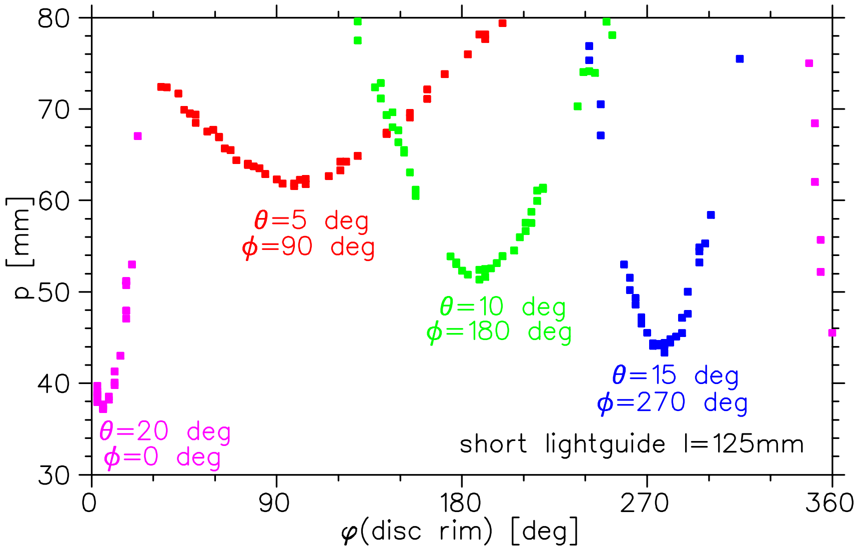


Figure 7. Focussing-Lightguide Disc DIRC photon hit patterns for various polar angles. The position of the lightguide is given on the abscissa as an angle and the ordinate shows the position on the focal plane of each lightguide.

yoke (see figure 3 a), and must provide single photon sensitivity under these conditions. Photonis PLANACON Multi-Channel Plate-PMTs (MCP-PMTs), amongst other devices, have been investigated. These MCP-PMTs currently offer the best performance with an active area of approx. $53 \times 53\,\mathrm{mm}^2$, fast response and the ability to operate in high magnetic fields [16, 17]. A custom anode pattern of 32 strips with a pitch of 1.5 mm will be used to determine the photon hit coordinate. A photon hit rate of 1 MHz per channel is expected.

The $\overline{\mathrm{P}}$ANDA physics programme requires a flexible trigger and data acquisition system to achieve sufficient background suppression, hence $\overline{\mathrm{P}}$ANDA's sub-detectors need to be self-triggering [1, 2]. Therefore, the Focussing-Lightguide Disc DIRC readout needs to provide hit patterns and precise time stamps for each hit. An integrated front-end card including pre-amplifiers, hit detection, time-stamp facilities and data transfer via optical fibres is necessary to cope with the expected data rates. The current design status of the readout electronics for the Focussing-Lightguide Disc DIRC is summarised in reference [18].

The Cherenkov ring image is reconstructed from two coordinates: one is given by the position of the lightguide around the rim and the second by the position on the focal plane of the lightguide. The expected hit patterns for the above described design are shown in figure 7 for different polar angles. In addition, timing information can be used to disentangle overlapping hit patterns. A time resolution better than 300 ps is estimated to be sufficient.

The patterns show a hyperbolic shape with the apex being most important for pattern recognition. The patterns spread across several imaging units as intended with large polar angles producing the narrowest pattern. This proves the necessity of a *stand-off* distance in radial direction for the imaging units in order for the Cherenkov cone to spread across enough imaging units [19]. The current radius of 1100 mm of the radiator disc takes this into account. An overview of the different reconstruction algorithms available for the Focussing-Lightguide Disc DIRC is given in reference [20].

5 Summary

The Focussing-Lightguide Disc DIRC is a novel DIRC-type imaging Cherenkov counter which features an optical dispersion correction element to enhance its performance. First simulations look very promising and it seems feasible to reach the performance required by $\overline{\mathrm{P}}$ANDA. The optimisation of the design is ongoing, especially for the focussing lightguides which are at the heart of the imaging system. A small-scale prototype is currently being built which will be used to investigate the imaging system and test the dispersion correction. Furthermore, it will be used to study the influence of the glue joints on the photon propagation.

Acknowledgments

The authors would like to acknowledge financial support by the UK Science and Technology Facilities Council (STFC) and the EU FP6 grant, contract number 515873, DIRAC-secondary-Beams.

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