RICH for P̄ANDA

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Abstract

The powerful particle identification detection system of the P̄ANDA experiment contains three Cherenkov detectors. In the forward direction a conventional RICH detector is planned. In the high solenoid field of the target spectrometer thin Cherenkov detectors using the DIRC principle are mandatory and are envisaged in the form of a barrel and a vertical disc. The combination of the time of arrival of the photons with their spatial image determines not only the particle velocity, but also the wavelength of the photons. Therefore dispersion corrections on the lower and upper detection threshold is possible. Investigations concerning the development of a 3D-Barrel-DIRC are discussed as well as two different studies realizing a new Disc-DIRC for the forward angles. One is based on the Time of Propagation (ToP) method the other on the readout with focusing light guides.

Key words: Particle identification, Cherenkov counter, ring imaging
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1. Introduction

Cooled antiproton beams of unprecedented intensities in the energy range of 1-15 GeV will be used at P̄ANDA (antiProton ANihilations at DArmstadt) [1] at the FAIR (Facility for Antiproton and Ion Research) project at Darmstadt to perform high precision experiments in the field of Quantum Chromodynamics. The internal fixed target experiment situated in the High Energy Storage Ring (HESR) will use a pellet or a cluster jet target to gain 2×10^7 interactions per second over a wide range of beam energies. This opens the way to an extended and rich physics program and demands a very sophisticated setup for the detection of charged and uncharged particles. Inside the return yoke of the superconducting 2 Tesla solenoid a very compact

electromagnetic calorimeter covers almost 4π. In the limited space around this target spectrometer the very crucial separation of kaons and pions can only be achieved with solid and thin Cherenkov detectors using the DIRC (Detection of Internally Reflected Cherenkov light) method. The velocity deduced from the measured (half) angle of the Cherenkov cone together with the information from the tracking detectors in the magnetic field provides the particle mass and thus a positive particle identification. A subsequent forward spectrometer with an Aerogel Gas RICH detector and a hadronic calorimeter following a dipole field separates and analyzes the high energy ejectiles.

2. RICH detectors

The three RICH detectors at P̄ANDA should cover the full kaon acceptance (see Figure 1 and an example for the distribution of the kaons in the search for glueballs at high-

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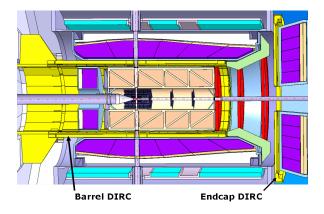
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Fig. 1. *The P̄ANDA detector with the zoom on the target region Cherenkov counters*

est HESR energies, Figure 2). Whereas the barrel DIRC surrounds the target region to measure particles with high transverse momentum the Endcap Disc DIRC detects one part of the forwards ejected particles and the forward RICH the high energy ejectiles. Since the main R&D is invested in the enhancements of the DIRCs this paper concentrates on the DIRC detectors.
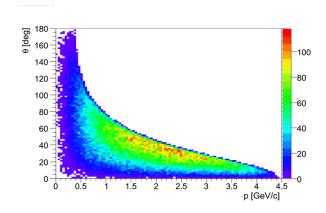

Fig. 2. *Angular distribution of kaons over momentum in the search for glue balls in the reaction $J/\psi \rightarrow K^+K^-\gamma$ at highest HESR energies.*

3. DIRC detectors

Particles passing a dispersive medium faster than the light inside this medium induce the radiation of photons under the specific angle Θ_{Ch} (Cherenkov angle) depending on the particle velocity described by the relation $\cos\Theta_{Ch} = 1/\beta n$. In a DIRC detector the photons are transported via total internal reflections to the radiator end conserving the emission angle.

The Cherenkov angle can be determined by the measurement of the two space coordinates of the photons on a detection plane with known distance to the point of light emittance. One coordinate can also be deduced by taking the time of propagation of photons between their generation by the particle passage and their arrival on the photon detector.

Both, the spatial and the time information are smeared by dispersion. Measuring two of the three coordinates (two spatial and one time coordinate) a dispersion correction with hardware optical elements is necessary. Thus different optical elements for dispersion correction are proposed: dichroic mirrors (section 3.2.1), Lithium Fluoride (section 3.2.2). When all three coordinates are measured with a sufficient accuracy the dispersion even can give information about the wavelength of the Cherenkov photons.

3.1. Barrel DIRC

Around the target region a Cherenkov detector is planed to cover the angular acceptance from $\theta = 22°$ to about $140°$. In the compact target spectrometer having a high magnetic field only a thin radiator with a refractive index n=1.5 and a photon readout outside the acceptance can be used. At P̄ANDA quartz (amorphous fused silica) bars of about 200 cm length, 3.5 cm width and 1.7 cm height serve as radiators as well as light guides to transport the photons under conservation of the Cherenkov angle to the photon detectors upstream - the opposite bar ends are equipped with mirrors. About 100 bars form a barrel with a radius of 50 cm.

This design is initially based on the BaBar DIRC [2] but at P̄ANDA further improvements of the performance are under development. The combination of the spacial image of the photons with their time of arrival gives access not only to their velocity but also to the wavelength of the photons. Thus dispersion correction at the lower and upper detection threshold becomes possible. Further on the reduction of the photon readout in size and number of photon detectors is envisaged. A lens or a set of lenses at the exit of the quartz bar focus the photons to a focal plane behind a readout volume of about 40 cm length. When this volume is filled with a medium with the same refractive index as the radiator material (n_{medium}=$n_{radiator}$=1.5) additional dispersion effects are avoided.
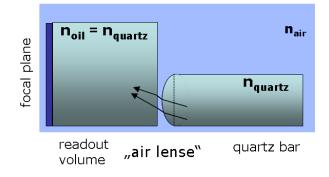

Fig. 3. *Sketch of a photon readout with an air lens.*

Furthermore, the idea of an "air lens" (Figure 3) is under investigation, for air is a non dispersive medium: A focusing lens from quartz connected to the quartz radiator forms an air gap with the rectangular readout volume that has the form of a divergent lens. However, since the refractive

index of air is smaller than the quartz it serves again as a focusing lens. Simulations and first tests using an fish tank as readout volume show promising results: image distortions are reduced and large angle deteriorations are sorted out. In addition the air gap opens the possibility to easily remove and reconnect the photon readout in case of maintenance activities and helps for a simplified integration of the barrel DIRC into the complete P̄ANDA detector.

3.2. Endcap DIRC

In the forward direction 180 cm downstream from the interaction vertex a Cherenkov detector in the form of a quartz disc of 1 to 2 cm thickness should be applied. It has to cover the solid angles from $\theta = 22°$ down to $10°$ (horizontal) and even to $\theta = 5°$ (vertical). The charged particle multiplicity per event emitted from the target vertex into this acceptance was determined with the DPM Generator [3]. Ranging only from 1.0 ± 0.8 (at 2 GeV/c) up to 2.3 ± 1.8 (at 15 GeV/c) the reconstruction efficiency of the detector will not be affected.

For the readout of the internally reflected photons two different design options exist, whereas both are readout at the outer rim outside the acceptance.

3.2.1. Time of Propagation DIRC

In the design of the Time of Propagation (ToP) DIRC an octagonal shaped disc matching the yoke of the target solenoid is foreseen. Each side will be equipped with 120 photo-sensors, overall 960 channels, resulting in an angular resolution of $0.375°$.
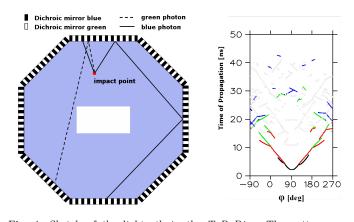

Fig. 4. *Sketch of the lightpath in the ToP Disc. The pattern on the right side is spreaded by the numbers of reflections the photons underwent.*

To gain a high resolution in the second coordinate deduced from the time measurement the resolution of the photons (measured from 400 to 700 nm) has to be in the order of σ=30 ps. Several Micro-channel plate PMTs where tested and with a 6 μm pore size single anode device from Budker Institute of Nuclear Physics (BINP) in Novosibirsk, Russia [4] the demanded resolution was achieved even in high magnetic field [5].

The photo detectors will be located behind wavelength separating dichroic mirrors. They split the wide range of the Cherenkov light into two narrower wavelength bands. This allows to diminish dispersion effects and increases the travel path of the photons inside the radiator. A large ToP supports the discrimination of different particle species at larger momenta. As one can see in Figure 4 one, two and even more rim reflections are possible. The right side of Figure 4 shows the self timing capability of the ToP DIRC design where the time0 can be deduced from a parabola like shape fitted to the first incoming photons.

Furthermore the dichroic mirrors provide the possibility to use this narrow wavelength bands to optimize the material of the photo cathode and adapt its quantum efficiency curve to the incoming light.

3.2.2. Focusing Light guide DIRC

In the Focusing Disc DIRC design the two spatial coordinates are measured. While the φ coordinate is given by the number of one of about hundred optical elements which guide the light to the subsequent photon detector (see Figure 5) the ϑ coordinate is determined by the position of the sensor strip the light is focused on.

The focusing light guides lift the two-fold ambiguity (up-down), corrects the chromatic dispersion and focuses the photon onto the readout plane. The optical elements as well as the radiator plate are made from quartz glass. They are connected with each other over a lithium fluoride (LiF) prism element for dispersion correction. LiF is UV transparent and has particularly low dispersion. By the two boundary surfaces with the radiator disc and the following light guide the chromatic dispersion correction is made to first order angle-independent. The light impinging on the inside of the optical element's curved surface undergoes total internal reflection. Thus the focusing is independent of the wavelength too. Most of the incoming light phase space from the disc is focused on the one-dimensional readout with the photo sensor strips on the focal plane. The cylindrical shape of varying curvature of the focusing element has been optimized resulting in a focus spot size of the different angles of about 1mm on a flat focal plane.
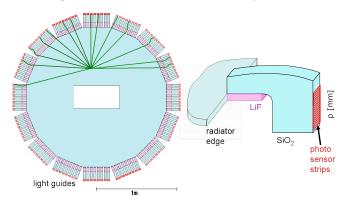

Fig. 5. *Sketch of the focusing disc DIRC. On the right the light guide is zoomed out which is connected to the radiator via a lithium fluoride plate.*

Figure 6 shows the hit distribution simulated for four particles emitted from the target vertex with different θ angles. Shown is on the horizontal axis the φ-coordinate of the optical elements and on the vertical axis the hit coordinate on the readout plane in the optical elements measured in mm. The ϕ-angle of the particles having the same β was changed to avoid overlapping patterns. The variation of the θ angle has two effects on the hit pattern. With θ increasing the apex of the hit pattern moves to smaller p values. With the punch-through point moving closer to the disc rim, the hit patterns become narrower. The latter is due to the fact that less and less photon detectors are included in the detection of the photons.

Typically all of the 40 photons detected per particle arrive within a 4ns time window. This gives a handle for an effective background separation even at higher occupancies.
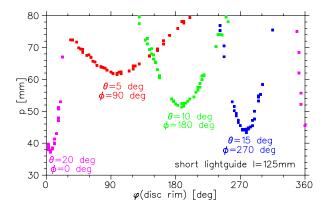

Fig. 6. *Simulated photo hit patterns for four particles with different θ and φ emission angles from the target vertex. φ is the light guide angle on the disc rim, p the position on the photo sensor strips at the back of the focusing light guide.*

4. Discussion

For all the three DIRC designs, for the Barrel DIRC as well as for the ToP and focusing light guide endcap DIRCs, extensive simulations where done. Since the material is the same and the depth (about 1.5 cm) is similar in all detectors about 400 to 500 photons are produced by one particle passing. The individual shape and readout reduces the photons to about 60 detected photons. Apart from photon detector efficiencies the vertical discs loose statistics because a part of the Cherenkov cone is not totally reflected. The loss of photons in the Barrel DIRC due to the large number of internal reflections has to be kept small by high quality surfaces. All DIRC detectors have to work with pattern recognition which have to be developed individually. But first simulations show that a kaon-pion separation can be done with 4σ up to 4 GeV/c with the sigma separation value defined as

$$\sigma_{sep} = \frac{|m_A - m_B|}{\sigma_\beta} = \frac{|m_A - m_B|}{(\sigma_A/2 + \sigma_B/2)}$$

where A and B are two different particle types of the same momentum. The masses m_A, respectively, m_B are Gauss distributed with the σ being the standard deviation.

Studies for radiation hardness of the detector materials were performed on a proton beam [7]. They showed that the radiator material as well as the lithium fluoride serving for dispersion correction 3.2.2 fullfil the requirements of standing the estimated total radiation dose over their lifetime in the $\bar{\text{P}}$ANDA experiment which is in the order of about 100 krad. Further effort has also to be put into the evaluation of the surface quality of the radiators. As mentioned the loss of photons because of a comparably bad surface is not negligible. Scalar scattering theory calculations [6] show that for a photon of 350nm and a surface quality of 2nm the reflection probability is about 99.8%. After typically 100 reflections inside a 200 cm long quartz bar of the Barrel DIRC, however, the probability is reduced to about 82%.

5. Conclusions

The DIRC method used in the a new generation of RICH detectors opened the possibility to apply the Cherenkov principle also in a very compact setup. For the future $\bar{\text{P}}$ANDA experiment three innovative DIRC detectors are under investigation. A reduction of the size of the readout volume is possible using lenses instead of pinhole focusing. Completely new designs as the proposed ToP and the Focusing Light guide DISC show promising results. For all DIRC designs prototypes will be build in near future.

6. Acknowledgments

References

[1] $\bar{\text{P}}$ANDA Collaboration, Technical Progress Report, FAIR-ESAC/Pbar 2005
[2] R. Alexsan et al., Nucl. Instr. Meth. **A 397** 261 (1997)
[3] A. Galoyan, V. V. Uzhinsky, AIP Conf. Proc. 796, pp. 79-82, 2005
[4] A. Yu. Barnyakov et al., Nucl. Instr. Meth. **A 567** (2006) 17
[5] A. Lehmann et al., Performance Studies of Micro-channel Plate PMTs in High Magnetic Fields, Proceedings RICH07, Triest, Italy, 2007, to be published in NIMA
[6] J. Cohen-Tanugi et al. / Nuclear Instruments and Methods in Physics Research **A 515** (2003) 680700
[7] M. Hoek et al., Radiation Hardness Study on Fused Silica, Proceedings RICH07, Triest, Italy, 2007, to be published in NIMA