RICH for $\bar{\mathrm{P}}$ANDA

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Abstract

The powerful particle identification detection system of the $\bar{\mathrm{P}}$ANDA 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 $\bar{\mathrm{P}}$ANDA (antiProton ANnihilations 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 kaon 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 $\bar{\mathrm{P}}$ANDA 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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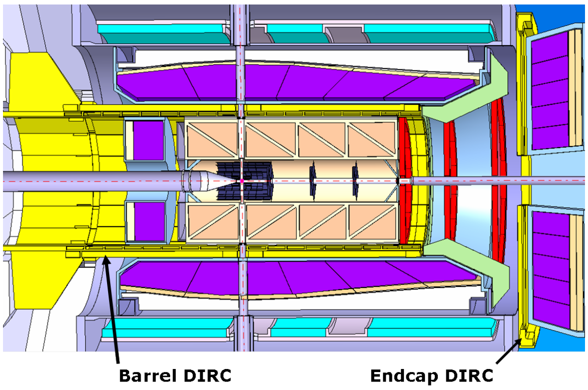

Fig. 1. *The* $\bar{\text{P}}$ANDA *detector with the zoom on the target region Cherenkov counters*

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.

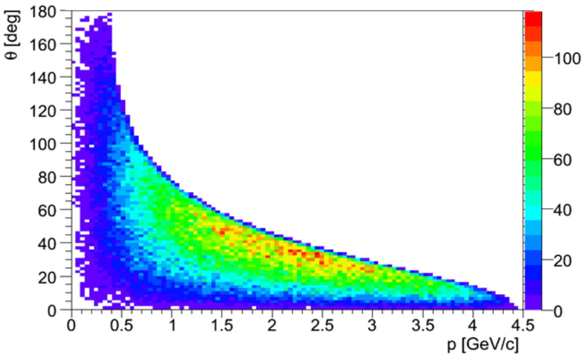

Fig. 2. *Angular distribution of kaons over momentum in the search for glue balls in the reaction* $J/\psi \rightarrow K^+K^-\gamma$ *at highest HESR energies.*

3. DIRC detectors

Particles passing a dispersive medium (refractive index n>1) 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 is nessesary, measuring all three 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 of about 1.5 and a photon readout outside the acceptance can be used. At $\bar{\text{P}}$ANDA quartz (amorphous fused silica) bars of about 200cm length, 3.5cm width and 1.7cm 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 50cm.

This design is initially based on the BaBar DIRC [2] but at $\bar{\text{P}}$ANDA further improvments of the performace 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. Furtheron the reduction of the photon readout in size and number of photo detectors is envisaged. When the photons which sort the quartz bar will be focused with a lens or a set of lenses only a small focal plane with a distance in order of about 40cm from the radiator is needed. Utilizing a medium with the same refractive index as the radiator material (n_{medium}=$n_{radiator}$=1.5, for example paraffin oil) additional dispersion effects are avoided.

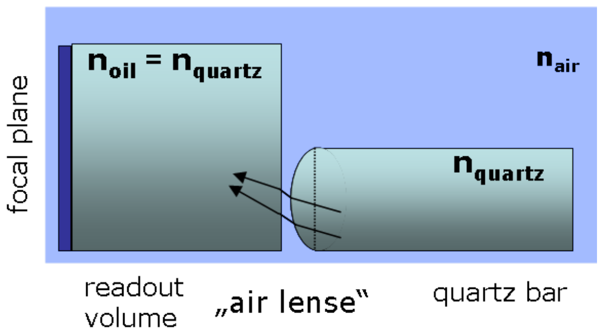

Fig. 3. *Sketch of a photon readout with an air lens.*

In consequence, the idea of an "air lens" (figure 3) is under investigation, for air is a non dispersive medium: Connected to the quartz radiator is a focusing lens from the same material followed by an air gap and a readout volume filled with oil (n_{oil}=n_{quartz}). The air gap has the form of a divergent lens. However, since the refractive index of air is smaller than the quartz is 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 maintanance activities and helps for a simplified integration of the barrel DIRC into the complete $\bar{\text{P}}$ANDA detector.

3.2. *Endcap DIRC*

In forward direction 180cm downstream from the interaction vertex a Cherenkov detector in form of a 1 to 2cm thin quartz disc should cover the solid angles from $\theta = 22°$ down to 10° (horizontal) and even to $\theta = 5°$ (vertical). The charged particle multiplicity per event emmitted from the target vertex into this acceptance was determined with the DPM Generator [3] to be from 1.0±0.8 (at 2GeV/c) upto 2.3±1.8 (at 15GeV/c).

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 octogonal shaped disc matching the yoke of the target solenoid is forseen. Each side will be equipped with 120 photo-sensors, overall 960 channels, resulting in an angular resolution of 0.375°.

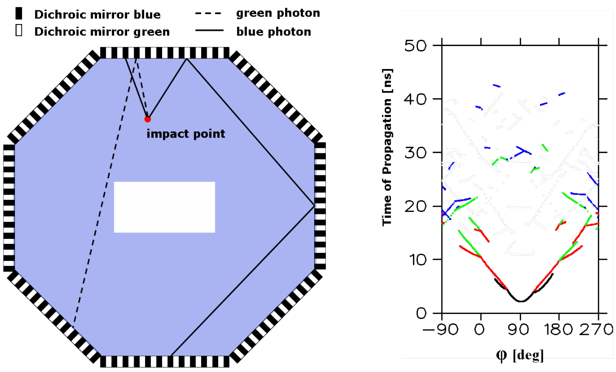

Fig. 4. *Sketch of the lightpath in the ToP Disc. The pattern on the right side is spreaded by the numbers of reflections the photons underwent.*

To gain a high resolution in the second coordinate deduced from the time measurement the resolution of the photons (measured from 400 to 700nm) has to be in the order of σ=30ps. Several Multichannelplate 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 magetic 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 deminish 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 capabilityof 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 photocathode and addapt its quantum efficiency curve to the incoming light.

3.2.2. *Focusing Lightguide 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 lightguides 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 lightguide 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 focussing is independent of the wavelength too. Most of the incomming 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 focussing element has been optimized resulting in a focus spot size of the different angles of about 1mm on an flat focal plane.

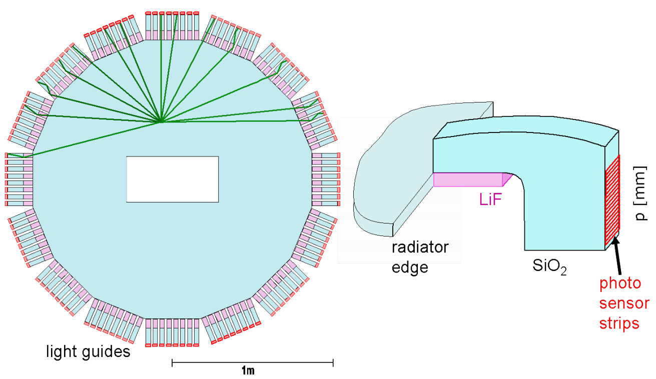

Fig. 5. *Sketch of the focusing disc DIRC. On the right the lightguide is zoomed out which is connected to the radiator via a lithium fluoride plate.*

Figure 6 shows the hit disribution simulated for four particles emitted from the target vertex with different θ and ϕ angles. With growing θ angle corresponding to the position on the focal plane measured in mm the parabola like patterns get more and more narrow.

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.

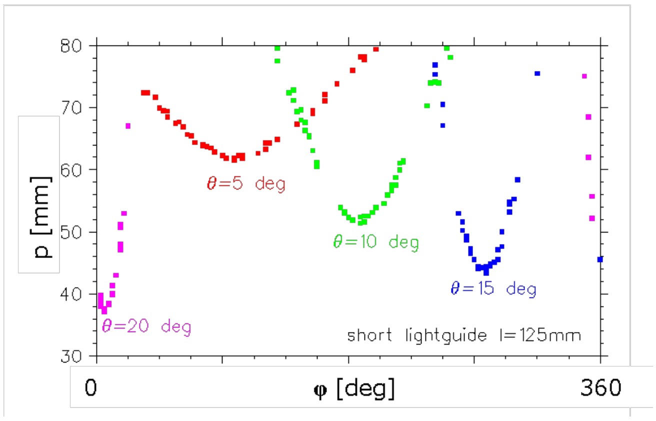

Fig. 6. *Simulated photon hit pattern for four particles depending on the θ and ϕ emission angle from the target vertex. θ is to deduced from the position on the focal plane measured in mm.*

4. Discussion

For all the three DIRC designs, for the Barrel DIRC as well as for the ToP and focusing lightguide endcap DIRCs, extensive simulations where done. Since the material is the same and the depth (about 1.5cm) 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. Where the vertical discs loose on non totally reflected parts of the Cherencov cone the barrel DIRC loose partly on essentially more internal reflections. 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 4GeV/c with the sigma separation value defined as

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

Studies for radiation hardness [7] were performed on a proton beam showing that the radiator material as well as the lithium fluoride serving for dispersion correction 3.2.2 fullfil the requirments of standing the estimated total radiation dose over their lifetime in the $\bar{\text{P}}$ANDA experiment of about 100 krad. Further effort has also to be put into the evaluation of the surface quality of the radiators. As mentioned in section 4 the loss of photons because of a comparably bad surface is not negligable. 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 200cm long quartz bar of the Barrel DIRC, however, the probability is reduced to about 82%.

5. Conclusions

The DIRC detector as a new generation RICH detector opened the possibility to use a Cherenkov detector also in a very compact detector as in the future $\bar{\text{P}}$ANDA experiment. 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 Lightguide DISC show promising results. For all DIRC designs prototypes will be build in near future.

6. Acknowledgements

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