Hyperfine Interactions manuscript No.
(will be inserted by the editor)

A Focussing Disc DIRC design for Particle Identification in PANDA

Klaus Föhl

Received: date / Accepted: date

Abstract A Focussing Disc DIRC with dispersion correction is a novel Cherenkov detector design which is proposed for the PANDA experiment at FAIR. Cherenkov photons travel inside a circular disc towards the edge and then enter into one of circa hundred optical elements around the rim that correct the chromatic dispersion of the Cherenkov light and focus the photon onto the element readout plane. This design can achieve positive kaon identification in the momentum range of up to 4÷6 GeV/c in the confined space and high magnetic field of the PANDA target spectrometer endcap.

Keywords Particle identification · Cherenkov counter · ring imaging

PACS 29.40.Ka

1 Introduction

For the PANDA [1] antiproton experiment at the future FAIR laboratory, investigating the charmed quark sector with high luminosity and high precision, the detectors that provide particle identification (PID) are a crucial element.

The PANDA target spectrometer is almost hermetically sealed to avoid solid angle gaps, and to keep material volume low, there is little spare space inside. The prospect of using thin radiator sheets, and placing the readout elements outside of the acceptance (and potentially outside the magnet return yoke) favours the use of DIRC [2,3] designs as Cherenkov imaging detectors for PID.

In a DIRC type Cherenkov detector, photons confined by total internal reflection between parallel surfaces are transported to the edge of the radiator volume with their Cherenkov angle information intact. With typically 50÷100 reflections the light scattering loss per surface reflection has to be minimised, requiring a local (for any millimetre-sized area) surface roughness not exceeding several nanometres RMS.

K. Föhl
School of Physics and Astronomy, University of Edinburgh, James Clerk Maxwell Building, The King's Buildings, Mayfield Road, Edinburgh EH9 2LW, Scotland, United Kingdom
Tel.: +44 131 650 5256
Fax: +44 131 650 7003
E-mail: kf@ph.ed.ac.uk

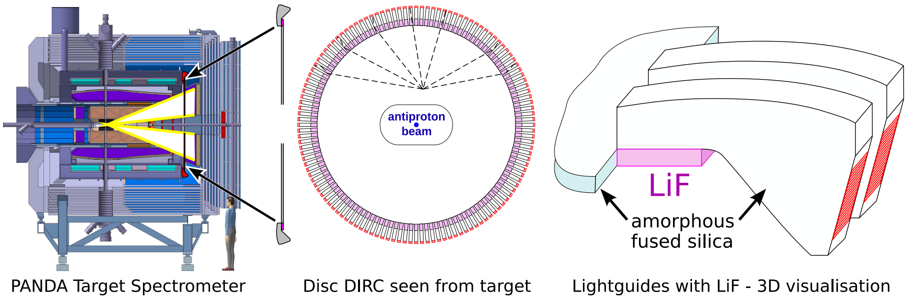

Fig. 1 Left: Endcap angular range highlighted in the PANDA TS, with arrows showing the Disc DIRC location. Middle: Schematic front view with the optical readout elements circling the Cherenkov radiator plate. Right: Edge detail. Each element starts with a lithium fluoride plate for dispersion correction, followed by an amorphous fused silica lightguide with curved top surface to focus the light onto a readout plane at the right.

Given the momentum range that PID needs to cover in the PANDA Target Spectrometer (TS, Fig. 1) endcap, the design has to improve over current DIRC detectors (i.e. BaBar [2]). Hence it is suggested to include an optical focussing property and correct for the wavelength-dependent Cherenkov angle.

2 Focussing Lightguide Dispersion Correcting Disc DIRC

For the Focussing Lightguide Dispersion Correcting Disc DIRC in PANDA (Fig. 1 middle and right), amorphous fused silica is used for radiator disc and the lightguides, and lithium fluoride for the dispersion correction plate. Both materials remain sufficiently transparent in the expected radiation field for PANDA [4]. The light crosses LiF-silica boundaries twice, making the chromatic correction angle-independent to first order. For the expected angle range, photons undergo total internal reflection on the lightguides' focussing surface, and as the light remains within the dense optical medium, the phase space for the light propagation is not reduced. The photon detector pixels are long rectangles as only the position information in the dispersive direction is used.

The optimisation of the detector has to obey several boundary conditions. The space available for the optical components is limited, and external mechanical and physical conditions are imposed on the radiator thickness. Investigation of suitable photon detectors is ongoing [5]. Placing a Multi Channel Plate (the candidate detector type) into the strong magnetic field of $\mathrm{B} = 1 \div 2\,\mathrm{T}$ inside the TS magnet return yoke requires to orient the lightguide focal plane perpendicular to the field lines.

For the lightguide focussing surface (Fig. 2) the cylindrical curvature has been parametrised with a fifth order polynomial. Quantities like lightguide length, orientation of the focal plane, and radiator disc thickness are fixed before the optimisation, which determines an overall minimum for the focus spot sizes of the different angles on the focal plane. For a disc thickness of 15mm the individual standard deviations are well below 1 mm for the instrumented area.

For non-PANDA applications the chromatic correction may not be required. See Figure 2 bottom right for a possible lightguide shape not using any LiF plate.

Charged particles emitting Cherenkov radiation and photon propagation have been simulated for the Focussing Lightguide design, and the detector resolving power derived in analysing the photon hit patterns.

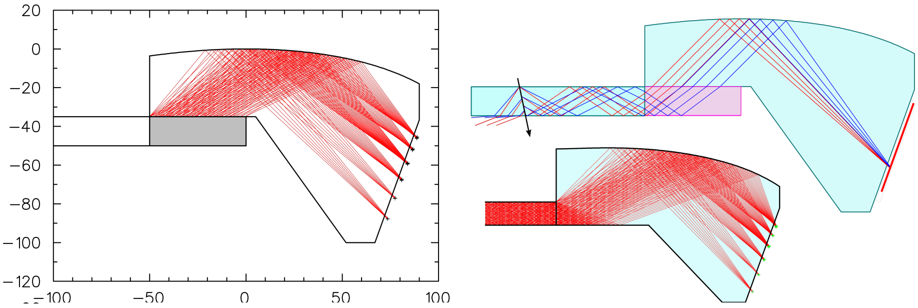

Fig. 2 Side views of Focussing Lightguides (lengths in mm where given) imaging onto a 48 mm focal plane length. The focal plane inclination is set to 70 degrees to be perpendicular to the magnetic field lines. Top right: visualising the effect of the LiF plate, the dispersion effect on the angles is exaggerated. Bottom right: lightguide without dispersion correction plate.

Table 1 Error contibutions for the Focussing Lightguide design shown in Figure 2 left.

Error value [σ]	Error source
3.1÷6.2 mrad	detector granularity of 1.5 mm pixel size (ϑ component only)
0.9÷4.3 mrad	finite spot size of curved lightguide focussing, 15 mm radiator thickness
1.4 mrad	angular straggling of saturated particle p = 2 GeV/c
0.4 mrad	tracking precision upstream of DIRC radiator disc for p = 2 GeV/c
0.1 mrad	track curvature in B field, 2GeV/c and $\vartheta = 18$ degrees at target vertex
5 mrad	chromatic error uncorrected (constant PDE for λ=300nm÷600nm)
<1.5 mrad	maximum chromatic error with LiF correction plate

The charged particle trajectory includes angular straggling, and the wavelength dependence of the refractive indices is parametrised with Sellmeier coefficients. Idealisations in the optical simulations include the assumption of perfectly parallel disc surfaces, no bulk light absorption, and 100% reflectivity for total internal reflection. These effects can be investigated separately and largely factored in into the results.

The photon pattern analysis is seeded with particle vertex information, smeared to the resolution of the upstream tracking detectors. Differential response vectors are computed, one tracking parameter (or β) offset at a time, with artificially high photon number, using the simulation code. The photon emission parameters are varied in a deterministic way to ensure that the difference vectors are not governed by noise. Particle vertex parameters and β are then fitted simultaneously.

Event sets are recorded for two different particle types of same momentum. The detector resolving power $\sigma_{RES} = \frac{|m_A - m_B|}{\sigma_\beta} = \frac{|m_A - m_B|}{(\sigma_A/2 + \sigma_B/2)}$ is then derived from the mean m_i and standard deviation σ_i values of the β=v/c distributions of the two particle types. Figure 3 shows the results for the separation of pions and kaons, the charged particles pair of most interest for PID in PANDA.

In multiple particle events, vertex information provided by the upstream PANDA tracking detectors allows to narrow down the area where Cherenkov photons can be expected, even before the PID step, and thus allows to select the photons belonging to one specific particle only. Shower particles, however, have no tracking, and so their photons cannot be identified and removed from within the kaon photons area. Figure 4 shows the effect of shower photons on the reconstructed kaon mass.

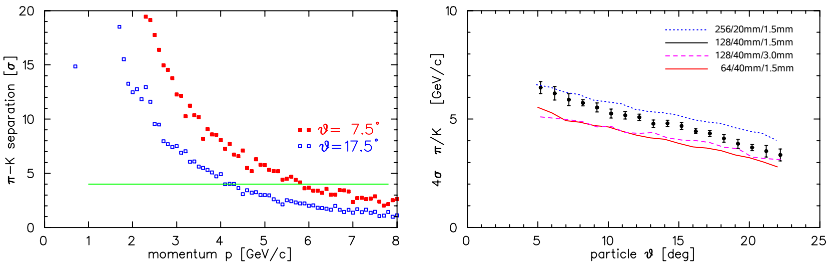

Fig. 3 Left: Detector resolving power as a function of momentum, shown for two particle at target vertex angles, for a DIRC detector with 128 lightguides and 4096 detector pixels, $1.5{\times}40\,\mathrm{mm}^2$ in size with 32 pixels per lightguide. Right: Angle-dependent upper momentum limit for $\sigma_{RES} > 4$ pion-kaon resolving power for $\vartheta = 5{\div}22$ degrees target vertex angles. The black dots show the result for the reference design of 128 lightguides, each 40mm thick, and 1.5 mm pixel size. Calculations with half and double the pixel number are shown as lines.

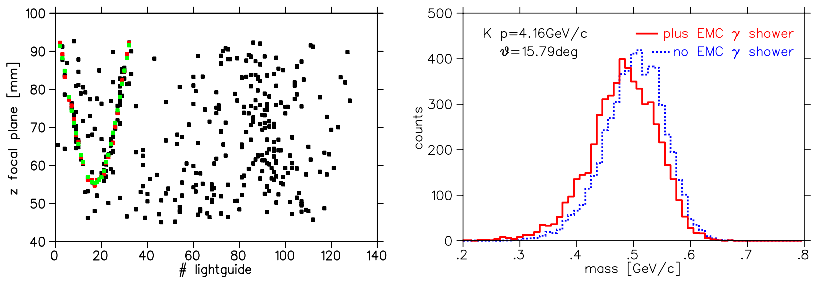

Fig. 4 Background study with Cherenkov light from Barrel Calorimeter shower leakage [6] into the disc superimposing a seeded kaon pattern. For the reconstructed kaon mass the distribution width increases by 10-15%. No timing info has been used here for background photon filtering. The coma effect in the lightguide imaging biasing the acceptance area position for kaon photons causes the kaon mass shift.

3 Conclusion

A disc DIRC fitting inside the PANDA endcap can achieve positive kaon identification up to $\mathrm{p} = 4{\div}6\,\mathrm{GeV/c}$ and is only moderately sensitive to background photons.

Acknowledgements This work is supported by EU FP6 grant, contract number 515873, DIRACsecondary-Beams.

References

1. $\bar{\mathrm{P}}$ANDA Collaboration, Technical Progress Report, FAIR–ESAC/Pbar 2005
2. R. Aleksan et al., Test of a large scale prototype of the DIRC, a Cherenkov imaging detector based on total internal reflection for BaBar at PEP-II, Nuclear Instruments and Methods in Physics Research A **397**, 261 (1997)
3. K. Föhl et al., The DIRC detectors of the PANDA experiment at FAIR, Nuclear Instruments and Methods in Physics Research A **595**, 88 (2008)
4. M. Hoek et al., Radiation hardness study on fused silica, Nuclear Instruments and Methods in Physics Research A **595**, 190 (2008)
5. A. Lehmann et al., Performance studies of microchannel plate PMTs in high magnetic fields, Nuclear Instruments and Methods in Physics Research A **595**, 173 (2008)
6. Bertram Kopf, private communication (2008)