The Focusing Disc DIRC for the PANDA experiment at FAIR

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Abstract. The Focusing Disc DIRC is a novel detector concept for particle identification based on the detection of internally-reflected Cherenkov light. A thin synthetic silica disc of 1 m radius will be used as radiator and for light transportation. At the rim LiF bars are foreseen to passively correct for dispersion. Focusing elements map the angles of the propagating photons to spatial positions on the focal plane covered with position sensitive photon detection devices. This novel 2D(+1t) detector concept will contribute to the outstanding particle identification performance of the general purpose PANDA detector. The aims of the PANDA experiment are to address fundamental questions of the strong force, to explore the structure of the nucleon and to search for new matter. The technical design, the current status of the development and recent results from prototype test experiments for the Focusing Disc DIRC are presented.

1. Introduction
The PANDA (anti-Proton ANnihilation at DArmstadt) [1] experiment at FAIR (Facility for Anti-proton and Ion Research) [2] will provide a general purpose spectrometer for investigations of fundamental questions in hadronic physics with outstanding performance [3]. Several detectors for tracking and particle identification measurements will perform high precision measurements at high luminosity.

One of the proposed particle identification detectors is the FDD (Focusing Disc DIRC) [4]. This novel design is based on DIRC (Detection of total-Internally-Reflected Cherenkov light) using a thin synthetic silica disc as a radiator and LiF (Lithium Floride) bars for passive dispersion correction. Focusing optical elements are used for compactness and to map photon propagation angles to spatial positions. Photon detectors with small-pitch linear readout pattern capable of detecting single photons are placed on the focal plane of the optical elements. Two measured spatial parameters — the azimuthal coordinate of the photon detector and the strip coordinate on the photon detector surface — allow the precise reconstruction of the emission angle $\theta_C$ of the Cherenkov photons.
2. The PANDA detector

The PANDA detector (see fig. 1) will use an outstanding beam of anti-protons. Previously unobtainable momentum precision of $\delta p/p < 10^{-5}$ and high luminosity up to $2 \times 10^{32}$ cm$^{-2}$s$^{-1}$ within a wide momentum range between 1.5 GeV/c and 15 GeV/c are foreseen. The beam will scatter off hydrogen or various nuclear targets. This allows the investigation of a wide range of fundamental questions in hadronic physics without any limitation in quantum numbers. Using a forward spectrometer and a target spectrometer, complete solid angle coverage will be achieved.

The field strength of the magnetic field for the target spectrometer will be up to 2 T. For the scientific program very good particle identification is mandatory. Detection of total-internally-reflected Cherenkov light can be used to measure particle velocities. This technique allows a compact Endcap Cherenkov detector design (see fig. 1) to contribute to the acceptance for various decay reactions (see fig. 2) [5],[6].

3. The novel Focusing Disc DIRC

The aims of the novel FDD (see fig. 3(a)) [4] are to measure velocities of charged particles precisely and to separate kaons from pions. This new detector concept will combine a disc as radiator, passive dispersion correction with LiF bars and focusing optical elements for compactness. This novel technique provides a compact and fast detector for particle identification. Synthetic silica is chosen as disc material as it is sufficiently radiation hard for the anticipated lifetime of the PANDA experiment [7]. The disc has a radius of approximately 1 m, a thickness of around 15 mm and a central opening matching the acceptance of the forward spectrometer. With this setup particle polar angles from 5 deg to 22 deg will be covered.

Two measured spatial values — the azimuthal coordinate $\phi$ of the photon detector and the strip coordinate $p$ on the photon detector surface — allow the precise reconstruction of the
Figure 2. Acceptance for an Endcap Cherenkov detector. (a) Particle polar angle acceptance from 5 deg to 22 deg for decays like $J/\Psi$. (b) Longitudinal versus perpendicular momentum of the particles for the $D^+D^-$ decay.

Figure 3. (a) Novel disc geometry as radiator for a DIRC based detector. Arrows indicate the corresponding 2D-hit pattern on the right side (b) 2D-hit pattern for different particle impact position.

relevant properties of the Cherenkov photons. The resulting patterns for reconstruction are illustrated in Fig. 3(b). Additional timing information (1t) with a moderate timing resolution of around 300 ps can be used for background suppression and event separation [8].

The produced Cherenkov light has a wide range of wavelengths ($\lambda$). This causes a smearing of the opening Cherenkov light cone angle as indicated by

$$\cos(\theta) = \frac{1}{n(\lambda) \beta},$$

where the opening angle of the Cherenkov light cone $\theta$ depends on the refractive index $n(\lambda)$ and particle velocity $\beta=\nu/c$. Therefore dispersion correction is necessary to minimize the uncertainty in the angular measurement. Active chromatic correction by straight Time-of-Propagation
measurement requires very challenging timing resolution below a few tens of ps. Directing the Cherenkov light through an optical element acting as a prism, made of a different material with an appropriate refractive index mitigates the effects of dispersion in the fused silica radiator (see fig. 4(a)). For the FDD, the crystal tiles are made of LiF and have the dimensions 15 mm × 50 mm × 50 mm. Focusing lightguides are foreseen to map the polar angle of the propagating Cherenkov light onto spatial positions on the surface of photon detection devices (see fig. 4(b)).

The requirements for photon detection are various and several options are available. Potential photon detection devices have to detect single photons in a 1.5 T magnetic field with a large number of channels for position measurements, must have uniform gain of around $10^6$ and must be capable for high hit rates of around 2 MHz/cm$^2$. Currently Microchannel-Plate PMTs and Geiger-mode APDs are under investigation [9], [10].

The PANDA experiment will not feature a hardware first level trigger as signal and background have similar signatures. The readout electronics therefore have to work without a central trigger. Instead a timestamping system with 20 ps timing resolution [11] will be used to generate virtual high level triggers for event preselection in a massive parallel computing network [12]. Various options for the frontend electronics are under investigation [13]. A conventional setup with preamplifier, shaper and Time-to-Digital-Converter would fit the requirements. An extended readout with analog and time measurement by sampling technique allows calibration in situ. In total there are 128 LiF bars and focusing lightguides with around 4000 readout channels.

4. Performance
For the design requirements various simulations were carried out to ensure the desired performance. Figure 5 shows the required $\pi$-K-separation as a function of the particle momentum and for two representative particle polar angles.

Various test beam experiments are carried out to verify the simulations against experimental
data. During a recent test experiment a primary proton beam with 2 GeV kinetic energy was used, impinging on a fused silica bar under various angles and various positions (see fig. 6(a)). One of the aims of this experiment was the validation of simulations for light generation, transportation and detection of Cherenkov photons. In addition as the integral absorption coefficient $\eta$ for the selected wrapping being unknown several simulations within the range $0.5 \leq \eta \leq 1.0$ were carried out.

The result shown in figure 6(b) indicates good agreement of the simulation with experimental data since the points follow same shape. Another result shows that the selected wrapping has an integral absorption coefficient of $\eta \approx 0.6$. These results can be used to improve further simulations and to remove ambiguity.

5. Conclusion
For the wide range of its scientific program the general purpose PANDA detector at FAIR will require an excellent particle identification system. By using several new techniques in this field the FDD is designed to assist in providing the necessary particle identification capabilities. A thin synthetic silica disc is foreseen as radiator to generate Cherenkov photons. LiF crystal bars will be used to correct passively for dispersion. Focusing elements will map propagating photon angles to spatial positions by using total-internally-reflecting parallel-to-point optics.

Despite the integral absorption coefficient $\eta$ of the wrapping was unknown, first tests show good agreement between simulations and experimental data as the points follow the same shape. The integral absorption coefficient $\eta$ for the selected wrapping was determined to be around 0.6.

Further test experiments will be carried out to verify the planned optical imaging system.
Figure 6. Performance (a) Test detector setup (b) Comparison of the simulation for light generation, transportation and detection with experimental data for the polar angle range from 5 deg to 22 deg and for various absorption coefficients $\eta$ of the wrapping, which was unknown.

Additional detector simulations are ongoing to improve the capability of online data reduction, event reconstruction and thus particle identification.

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