The PANDA barrel-TOF detector at FAIR

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Abstract

The barrel-Time-of-Flight detector is one of the outer layers of the multi-layer design of the PANDA target spectrometer. PANDA, which is being built at the FAIR facility, will use cooled antiprotons on a fixed Hydrogen or nuclei target, to study broad topics in hadron physics.

The detector is designed to achieve a time resolution below 100 ps and provides the interaction times of events as well as the particle ID. The B-TOF is designed with a minimal material budget in mind mainly consisting of 5 mm thin plastic scintillator tiles read out by a serial connection of 4 SiPMs. The signal transmission is embedded in large 16 layer PCB in micro strip lines.

We will first review the detector concept which is described in the TDR then some more recent developments, with a study of different PCB layouts for signal transmission, the readout with the TOFPET2 ASIC and its performance and presenting the results of a study on the influence of the scintillator thickness on the time resolution.

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1. Introduction

In order to handle the high luminosity of $2 \times 10^{32}\ cm^{-2}s^{-1}$ foreseen for the PANDA experiment and the debunched beam of the High Energy Storage Ring (HESR) the overall detector needs excellent timing capabilities to disentangle overlapping detector hits of different $\bar{p}p$ anihilations reaching an average interaction rate of up to 20 MHz [1]. This timing information will be delivered by a barrel shaped scintillating tile hodoscope covering the azimuthal angle along the beam line from $\theta = 22^\circ$ to 140° around the interaction point forming the Barrel Time-of-Flight detector (B-TOF).

In addition to simple timing the detector will allow us, using information of other subdetectors such as tracking information, to perform particle identification without the need for a dedicated start timer for interactions.

2. Detector Components and Performance

The B-TOF comprises 16 independent $2460 \times 180 \times 20\,\mathrm{mm}^3$ detector modules placed around the interaction point, forming a barrel as seen in Fig. 1, with a diameter of around 1 m [2]. Each such module carries 120 scintillating tiles in two rows, made from the plastic scintillator EJ-232, which are read out by four SiPMs connected in series on each short side of the scintillator.

All scintillating tiles are connected to a large PCB that builds the basis of the module. It acts both as a mechanical support structure for all the elements as well as a signal transmission framework for the analogue pulses created by the SiPMs to the front-end-electronics (FEE) situated on the modules behind the interaction point, spared from the harshest radiation due to the forward boost of particles in a fixed target experiment.

2.1. Signal Transmission

As stated above, the analogue signals of the SiPMs along the detector are transmitted to the FEE via a large PCB. These boards are made up of 16 layers for which three signal shielding

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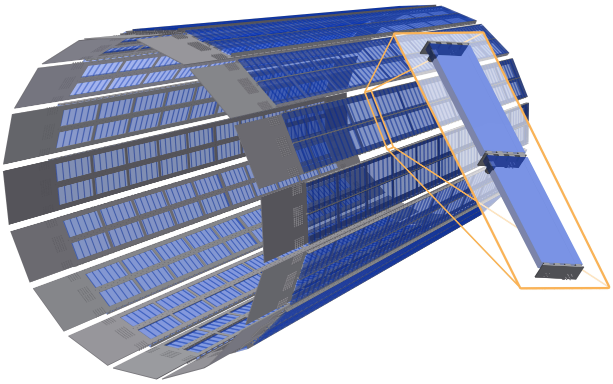

Figure 1: Schematic design of the Barrel Time of Flight detector (2460 mm long, radius of $r \approx 50$ cm) covering an azimuthal angle of $\theta = 22°$ to $140°$ around the interaction point.

designs which are currently being tested. With signal lines in close proximity and connection lengths of up to two meters, signal lines need to be shielded from picking up electro magnetic noise and crosstalk between the lines while not attenuating the high frequency SiPM signals themselves.

Our first approach was to shield every signal line with individual ground layers above and below the respective lines similar to a coaxial cable and shielding lines horizontally by a global ground layer. This approach was tested delivering crosstalk levels of around 4.5% in the relevant frequency region [2] of around 350 MHz. A second approach is to reduce the number of independent ground layers and combine two shielding grounds into one that however is still separate from the global ground shielding the lines horizontally. A third approach is to use a single interconnected ground layer around all signal lines with different via densities. These designs are all being tested to see their influence on the signals, their attenuation and the crosstalk.

2.2. *Performance*

Prototypes of scintillating tiles of various thicknesses from 3 mm up to 6 mm read out by 4 SiPMs in series on each short side were tested at the university of Erlangen. The tests were performed in a decommissioned radiation facility well suited for the measurements due to its low noise environment.

It was hypothesized that a better match of the scintillator thickness to the sensitive area of the SiPMs ($3 \times 3\, mm^2$) would result in an improved photon collection efficiency which potentially then would improve the time resolution of the tiles.

Using a ^{90}St beta source and a motorized arm the $87 \times 29.4 \times l$ mm^3 scintillator tiles are scanned, measuring the timing of the left and right SiPMs as well as the amount of detected photons for different scintillator thicknesses l, varying from 3 to 6 mm. A small scintillating crystal on a single SiPM was used as a trigger for the data acquisition comprised of the CAEN **model #** TDC and CAEN **model #** QDC.

Using this setup a mean time resolution of ~ 51 ps with good homogeneity of $\sigma = \pm 3$ ps along the tile was achieved.

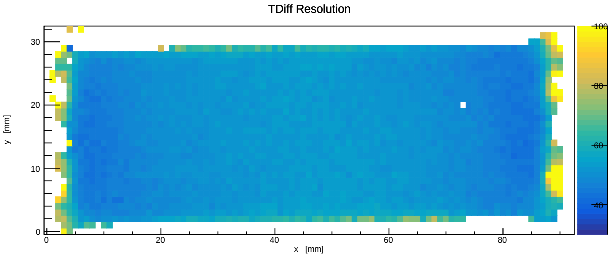

Figure 2: Scan of the timing performance of one 5 mm thick scintillating tile read out by four SiPMs connected in series, delivering a mean time resolution of 51 ps.

Comparing the time resolution delivered by the different scintillator tiles it becomes apparent that the increase in detection efficiency does not outweigh the the loss reduction of produced photons due to the shorter path of the particles in the scintillator, leading to a time resolution increase of ~ 20% compared to 5 and 6 mm. A scintillator of 6 mm thickness however does not show a significant improvement compared to 5 mm. So in order to reduce material in the detector, 5 mm scintillator tiles will be used.

Assuming a time resolution of 75 ps, the achieved time resolution of a single tile plus a safety margin, simulation studies of the particle identification capabilities were performed. Since PANDA has no dedicated start timer for interactions conventional time-of-flight measurements are not possible. The interaction time will however be calculatable by different methods [2]. Using the Monte-Carlo interaction times and tracking information by other detectors a separation power of more than 3 σ and up to 25 σ was achieved for protons, kaons and pions below the Cherenkov threshold.

3. Conclusion

Tests and evaluations of detector components are still ongoing such as the measurements on the signal transmission scheme in a large multi-layered PCB and the detector electronics, but the general detector layout is fixed. Using plastic scintillators (EJ-232) with the optimal thickness of 5 mm, a position dependent average time resolution of about ~ 50 ps was achieved. Using the described geometry and a performance 75 ps, simulations our detector in PANDA showed an excellent particle identification performance delivering a separation power of more than 3 σ and up to 25 σ for protons, kaons and pions below the Cherenkov threshold.

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