Barrel Time-of-Flight (TOF) Detector for the $\bar{\text{P}}$ANDA Experiment at FAIR

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Abstract. The $\bar{\text{P}}$ANDA experiment at FAIR in Darmstadt will perform a fixed target experiment by using a cooled beam of antiprotons in the momentum range between 1.5 to 15 GeV/c to study open questions in hadron physics. The core program comprises charmonium spectroscopy with precision measurement of mass, width and decay branches, investigation of possible exotic states, search for modifications of charmed hadrons in nuclear matter and γ-ray spectroscopy of hypernuclei.
The barrel TOF counter is located at 50 cm radial distance from the beam axis covering an azimuthal angle from 22.5° to 150°. The detector is designed to achieve a time resolution below 100 ps (sigma) which allows good event separation as well as particle identification below the Chrenkov threshold. With the current prototype a single detector time resolution < 60 ps was achieved.

Keywords: Scintillation counter, semiconductor detector, time-of-flight, particle identification, photomultiplier
list of possible keywords: http://www-library.desy.de/schlagw2.html

1 Introduction

The $\bar{\text{P}}$ANDA experiment at the new international accelerator complex, Facility for Antiproton and Ion Research (FAIR), will perform high precision experiments in the strange and charm quark sector[1]. Therefore a cooled beam of antiprotons with momentum range from 1.5 GeV/c to 15 GeV/c is collided with a fixed proton or nuclear target to allow hadron production and formation experiments with a luminosity of up to $2 \cdot 10^{32}\text{cm}^{-2}s^{-1}$. The scientific program includes: charmonium spectroscopy; investigation of exotic configurations like multiquark states, charmed hybrids, glueballs; search for medium modifications of charmed hadrons in nuclear matter as well as γ-ray spectroscopy of hypernuclei states [2].

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2 Barrel TOF Detector

The Barrel TOF Detector is a cylindrical detector at a radial distance of around 50 cm from the beam axis and serves as precise timing (<100 ps) detector. The detector is placed in a high magnetic field (up to 2 T), therefore the use of non-magnetic material was mandatory. The material has to withstand radiation during 10 years of operation time, which is $\phi_{eq} \approx 9 \cdot 10^{10}$ n_{eq} / cm^2 in total. The installation into $\bar{\mathrm{P}}$ANDA will be done in 2021 and the $\bar{\mathrm{P}}$ANDA experiment will start the experiments with antiprotons in 2025.

$\bar{\mathrm{P}}$ANDA adapts a continuous readout without hardware trigger. The selection is done by a online software framework where the Barrel TOF delivers event sorting, online event time calculation (t_0) and particle identification for low momentum charged particles [3] [4] [5] [6]. Since there is no start-stop detection for a time of flight measurement, time stamps of multiple tracks from the same event are used to determine the event time. With the momentum information of the tracking system the event time is calculated for all possible particle species. The conformity of the event time for each time stamp gives the most probable value for t_0, as its concept is schematically shown in Fig. 1 (left) [7]. For particles with low momentum an excellent separation can be achieved, while the identification for high momentum particles will be done mainly by the Barrel DIRC detector [8] [9].

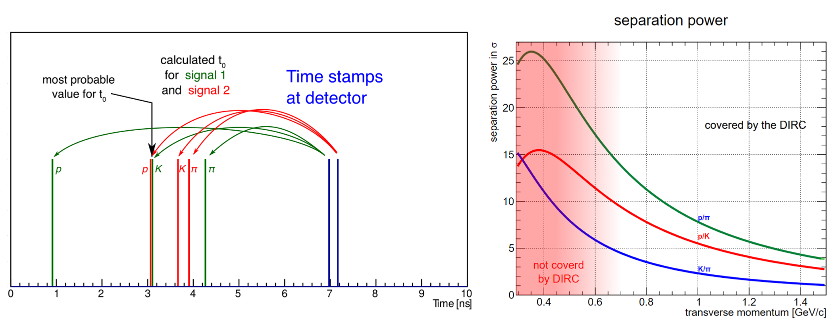

Fig. 1. (left) For each detected signal the track creation times according to mass assumption are calculated. The best conformity is equivalent to the most probable mass configuration [7]. Calculated separation powers of the $\bar{\mathrm{P}}$ANDA Barrel TOF counter as a function of transverse momentum of the particle.

3 Design

The Barrel TOF consists of 16 independent segments (super module) located around the beam axis as sketched in Fig. 2 covering an azimuthal angle of 22.5° to 140°. The sensitive volume consists of scintillator tiles each of which are read out with four Silicon Photomultiplier (SiPM) at each end. A super module comprises of 120 scintillator tiles and 960 SiPM as well as signal transmission lines embedded in a multilayer PCB. The front-end readout electronics (FEE) amplifies and digitises the signal from the SiPM and transfers the data to the $\bar{\text{P}}$ANDA computing node. It is located at the back end of the segment where the hit rate is low.

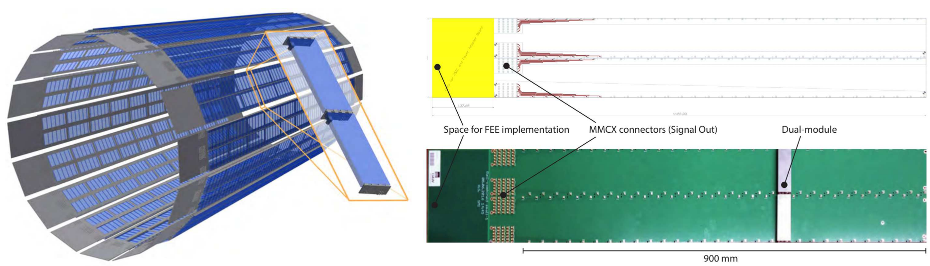

Fig. 2. (left) Drawing of the whole Barrel TOF with sub-structure of a pair of scintillator tiles. (right) Sketch of circuit design of the super module (top), A photo of half length prototype with one pair of scintillator (bottom).

The single tile has a dimension of 87 $\times$ 29.4 $\times$ 5 mm^3 with 4 SiPMs on both ends for readout. For the material a fast timing plastic scintillator is used. Photons are detected using 4 SiPMs with 3 $\times$ 3 mm^2 sensitive area each. They are combined into a single channel to increase the sensitive area without increasing the number of readout channels [10]. There are different ways to connect the SiPMs: serial, parallel or hybrid connection, as illustrated in Fig. 3. While for the parallel connection the bias is common by all SiPM, the signal respond is slower. On the other hand for the serial connection the bias increases linearly with the number of SiPM but the signal respond is faster and gives more precise timing [11] [12] [13].

4 Performance Evaluation of Single Tile

To achieve best time resolution careful optimisation studies have been done in terms of material and geometry resulting in the current design. Wrapping with aluminised Mylar foil gives the best time resolution. For this design for the EJ-232 plastic scintillator a position dependency measurement has been carried out with mean time resolution of σ_t=53,9 ps resulting in position resolution in x-direction of $5, 5$ mm (sigma) [14].

In order to verify the laboratory test results several beam time campaigns were carried out. The best result with the current design was achieved in November 2016 with a beam of 7 GeV/c momentum containing protons, pions, electrons and kaons giving a time resolution of σ_t= 58 ps.

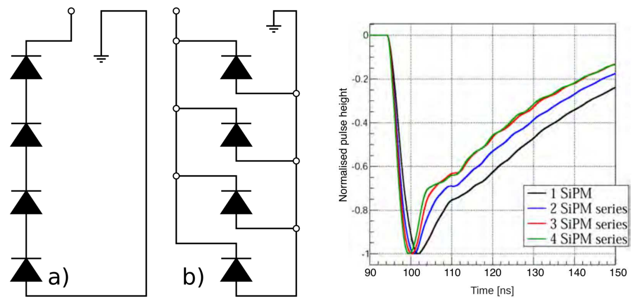

Fig. 3. (left) Schematic of different possibilities of connecting SiPMs for single read out channel: a) serial, b) parallel (right) Signal improvement with serial connection for higher number of SiPMs.

5 Conclusion

The barrel TOF detector provides a robust tool for particle identification at low momentum. With the current design including wrapping and four SiPM on each end an intrinsic time resolution of σ_t= 54 ps in the laboratory was achieved.

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