Design of the forward straw tube tracker for the PANDA experiment


Abstract: The design of the Forward Tracker for the Forward Spectrometer of the PANDA experiment is described. The tracker consists of 6 tracking stations, each comprising 4 planar double layers of straw tube detectors, and has a total material budget of only 2% $X_0$. The straws are made self-supporting by a 1 bar over-pressure of the working gas mixture (Ar/CO$_2$). This allows to use lightweight and compact rectangular support frames for the double layers and to split the frames into pairs of C-shaped half-frames for an easier installation on the beam line.

Keywords: Particle tracking detectors (Gaseous detectors); Overall mechanics design (support structures and materials, vibration analysis etc); Front-end electronics for detector readout

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1 Introduction

The PANDA (antiProton ANnihilation at DArmstadt) detector [1] at the future Facility for Antiproton and Ion Research (FAIR) is designed for measurements of reactions induced by high intensity antiproton beams with a momentum between 1.5 GeV/c and 15 GeV/c interacting with hydrogen as well as nuclear targets. The main physics topics of the experiment, discussed in details in ref. [2], are hadron spectroscopy, in particular the search for exotic states in the charmonium mass region and spectroscopy of multi-strange baryons, investigation of properties of mesons embedded in nuclear medium, spectroscopy of double-hypernuclei and study of the nucleon structure.

The fixed target arrangement of PANDA results in a forward peaking of the reaction products. Therefore, to ensure a geometrical acceptance close to $4\pi$ and a good momentum resolution in a wide range, the chosen setup consists of two spectrometers: the Target Spectrometer (TS) based on a 2 T solenoid magnet surrounding the interaction point and the Forward Spectrometer (FS) equipped with a large gap 2 Tm dipole magnet for momentum analysis of particles emitted at the most forward angles. The FS covers an angular range of $\pm 10^\circ$ in the horizontal plane and $\pm 5^\circ$ in the vertical one.

For measurement of particles momenta based on the deflection of their trajectories in the magnetic field of the FS dipole magnet, the Forward Tracker (FT) is foreseen. The FT has to fulfill several basic requirements: high momentum resolution of 1-2%, momentum acceptance extending down to at least 0.03 $\cdot p_{\text{beam}}$, high rate capability corresponding to particle fluxes reaching up to $2.5 \cdot 10^4 \text{cm}^{-2}\text{s}^{-1}$ close to the beam pipe and a total counting rate of about $5 \cdot 10^7 \text{s}^{-1}$.

Besides the above requirements, tracking detectors in the FT should fulfill also specific boundary conditions. The detectors should contain an opening for the beam pipe in the center of the active area. It should be possible to split the detectors located upstream and downstream the dipole magnet into two halves for the installation on the beam line. Furthermore, frames of detectors located inside the dipole magnet gap should fit in the available space restricted in vertical direction to only 55 mm.
To meet these requirements, the Forward Tracker is based on self-supporting straw tube detectors. The basic details of the straw tube detectors, the layout of the Forward Tracker, the readout electronics and the performed tests of prototype detectors are presented in the next four sections and the paper ends with a summary.

2 Self-supporting straw tube detectors

The design of the FT is based on self-supporting straw tubes, with 10 mm in diameter, similar to those developed for the COSY-TOF experiment [3] and which will also be used in the PANDA Straw Tube Tracker (STT) [4], the main tracking device of the PANDA Target Spectrometer. In these straws, the applied gas overpressure of 1 bar provides their mechanical stiffness and maintains the anode wire tension. The role of the detector frames is limited to position the straws. The straw tubes are made of aluminized Mylar foil, with a thickness of only 27 µm, which results in a very low material budget of only 2% $X_0$ for the entire FT containing 24 double layers of straws. As anode, a gold-plated tungsten-rhenium wire, with 20 µm diameter, is used. For the straw detectors we designed dedicated end-plugs allowing a quick and easy assembly. The details of these end-plugs and the tooling for their assembly will be presented in a separate publication.

For the FT, a gas mixture of Ar-CO$_2$ (90:10) was chosen for its high rate capability and low aging properties. For a working voltage of the anode wires of +1800 V (resulting in a gas gain of $\sim 5 \cdot 10^4$) the maximum drift time is about 130 ns in the straws located outside the magnetic field of the dipole magnet, and extends to about 150 ns in the maximum field of of the magnet equal to 0.9 T. It corresponds to a drift path equal to the straw radius, i.e. 5 mm.

3 Layout of the Forward Tracker

The design of the Forward Tracker has a modular layout. One module contains 32 straw tube detectors placed in two staggered layers glued together. Modules closely arranged next to each other and mounted on the same support frame form a double layer of straw tubes (see figure 1). Each module can be mounted and dismounted from the support frame without the need to remove the neighboring modules. This allows for fast repair and/or replacement of modules suffering from aging effects or broken straws during the detector lifetime.

The FT consists of three pairs of tracking stations: one pair (FT1, FT2) is placed upstream of the FS dipole magnet, the second pair (FT5, FT6) - downstream of the magnet, and the third pair (FT3, FT4) is placed inside the magnet gap in order to track also low momentum particles hitting the magnet yoke (see figure 2). Each tracking station consists of four double layers of straws: the first and the fourth one contain vertical straws and the two intermediate - the second and the third one - are composed of straws inclined at $+5^\circ$ and $-5^\circ$, respectively. The double layers are mounted on rectangular support frames. One frame is used for a pair of double layers, which are attached on both sides. In this way, the four double layers in one tracking station are mounted on two frames.

For easy installation on the beam line, which passes through a central opening in the tracking stations, the rectangular support frames in the stations located before and after the dipole magnet are split into pairs of C-shaped half-frames. The half-frames are mounted on linear bearings so that
**Figure 1.** Double layer formed by seven straw tube modules with 125 cm long straws placed on a test stand equipped with an X-ray scanner for measuring positions of straw tubes and anode wires.

**Figure 2.** The PANDA dipole magnet shown in section and the three pairs of the FT stations.
they can be pulled out of the tracking stations (see figure 3). This solution also allows easy access to the modules and thus enables their quick repair.

**Figure 3.** Two half-frames equipped with straw tube modules placed on a base frame for the FT5 and FT6 tracking stations. One of the half-frames (left one) is drawn aside and the other one is located in the experimental position.

The rectangular support frames of the tracking stations inside the dipole magnet gap are mounted on a base frame which is slid inside the gap during the installation. The space inside the dipole magnet gap available for the support frames and for other passive elements of the tracking stations, is limited to 55 mm in the vertical direction. The choice to use the self-supporting straw tube detectors allows the usage of very compact frames which fit in the available space.

The active area of the tracking stations in the FT ranges from \(x \times y = 134 \times 64 \text{ cm}^2\) in FT1, FT2 to \(392 \times 120 \text{ cm}^2\) in FT5, FT6. The total number of modules in all tracking stations equals 400 and the number of straw tubes equals 12 224.

4 Readout electronics

To readout the straw detectors at the high counting rates expected in the FT, a front-end chip called PASTTREC [5] was developed. The chip is an ASIC designed in the CMOS 0.35 \(\mu\text{m}\) technology. One chip contains eight channels, each one including a preamplifier stage, a shaper, an ion tail cancelation and a baseline stabilization circuit, a leading edge discriminator for time and time-over-threshold (TOT) measurements with LVDS output as well as an analog output. The preamplifier gain, peaking time, tail cancelation parameters, common discrimination threshold and individual baseline levels are programmable, allowing to optimize the chip performance for given working conditions of the straws.

The time of the leading and trailing edges of the PASTTREC discriminator pulses are measured with the Trigger Readout Board version 3 (TRB.v3), which was developed for the HADES experiment [6]. One board contains 192 TDC channels implemented in four FPGA chips (48 converters per chip). The maximum data rate corresponds to a hit rate of 56 kHz/channel of pulses supplied to the entire board [7]. The TRB.v3 is integrable with the PANDA readout synchronization system SODAnet.
5 Tests of prototypes

Prototypes of the straw tube detectors for the FT were extensively tested with proton beams from the COSY-Juelich accelerator. Tests were performed for a few beam momenta in the range from 0.55 to 3.0 GeV/c. Registered detector pulses show no baseline shift even at rates reaching 10 MHz [5]. Spectra of the TOT of the detector pulses show a clear dependence on the beam momentum. This demonstrates the applicability of the TOT measurement for the determination of the specific energy loss and thus allowing particle identification [7]. Proton tracks, registered at rates of a few hundred kHz per straw, the same expected in the PANDA experiment, could be reconstructed with a good spatial resolution of 150 $\mu$m ($\sigma$).

6 Summary

In the PANDA experiment, for momentum analysis of forward emitted charged particles, a large gap dipole magnet and the Forward Tracker (FT) will be used. According to the presented design, the FT contains 24 double layers of pressure stabilized straw tube detectors grouped in 6 tracking stations with a total material budget of only 2% $X_0$. The double layers are built of separate modules consisting of 32 straws arranged in two staggered layers, which allows for fast repair and/or replacement of broken modules. For easy installation on the beam line, the rectangular support frames for the double layers of the tracking stations located outside the magnet yoke are split into pairs of movable C-shaped half-frames. The readout of the FT is based on the newly developed PASTTREC ASIC and the TRB.v3 TDC converters, which are used for measurement of the drift time and the time-over-threshold of the detector signals.

Acknowledgments

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References

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