Performance of a prototype Straw Tube Tracker for the PANDA experiment

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Abstract. The PANDA experiment is one of the pillars of the future Facility for Antiproton and Ion Research (FAIR) in Darmstadt, Germany. The PANDA physics program is focused on answering fundamental questions related to Quantum Chromo Dynamics (QCD), using antiproton collisions on proton and nuclear targets. The central Straw Tube Tracker (STT) will be the main tracking detector which will reconstruct tracks induced by charged particles (with a transversal spatial resolution of $\approx 150 \mu m$) and it will measure the specific energy-losses for particle identification (PID) with an energy resolution better than 10%. The PID information is especially needed to separate protons, kaons and pions in the momentum region below 1 GeV/\textit{c}. Results obtained with a prototype STT using a proton and a deuteron beam in the momentum range from 0.5 to 3.0 GeV/\textit{c} are shown and discussed.

1. Introduction

FAIR is a new international accelerator facility which is under construction in Darmstadt. It will offer an accelerator complex, which will create the opportunity to perform experiments with antiprotons, ions and exotic nuclei thanks to the diversity of beams available. PANDA experiment is one of the pillars of the new FAIR facility. It will cover a diversified and broad hadron physics program. The design of the detector together with the unique high quality antiproton beam will give the opportunity for unprecedented research. The aim is to broaden our knowledge in the field of the strong interaction and hadron structure. PANDA will also contribute to the existing knowledge of the field by supplying very high statistics and improvements to the precision of the measurements. In order to achieve the physics objectives, a sophisticated detector system is needed. This system should have $4\pi$ acceptance, high resolution for tracking, calorimetry and particle identification, together with high rate capabilities of the detectors and their electronic readout systems. The PANDA detector (see figure 1) is about 13 meters long and has a diameter of about 5 meters.
2. Overview of the Straw Tube Tracker

The Straw Tube Tracker (STT) is the main tracking detector of PANDA (see figure 2). It has two main tasks: the spatial reconstruction of the tracks of the charged particles (with a precision of 150 μm) for momenta of a few hundred MeV/c to about 8 GeV/c. The second task is the PID through specific energy-loss measurements (dE/dx). More specifically, the separation of kaons, protons and pions for momenta below 1 GeV/c is of crucial importance. The detector is using gas-filled drift tubes as the basic detection element. The STT has a cylindrical shape with an inner radius of 150 mm, an outer radius of 420 mm, a length of 1650 mm and an angle coverage from 10° to 140°. It consists of 4224 straw tubes with 27 layers in radial direction. The layers are positioned in such a way that 19 of them are in parallel with the beam direction and 8 of them are skewed. This will allow for a 3D reconstruction of the trajectories of the particles. The tubes (see figure 3) have a length of 1400 mm, a diameter of 10 mm and they are made of aluminized Mylar films with a total thickness of 27 μm as cathode. Inside the tubes, a gold-plated tungsten-rhenium anode wire with a diameter of 20 μm is used.
3. Experimental setup

Two beam tests took place in order to study the performance of a prototype STT detector in the COSY-TOF experimental hall at Forschungszentrum Jülich. The first test was performed with a proton beam while the second one with a deuteron beam. The momenta available for the proton beam were: 0.55, 0.75, 1.00, 2.95 GeV/c, while for the deuteron beam was 0.65, 0.75 and 1.5 GeV/c. The reason for using different particle species was to examine the PID performance of the prototype. For both beam tests, the same STT setup was used (see figure 4), which was of rectangular shape and a total of 144 tubes divided into 6 layers. Each layer had 24 tubes along the beam direction.

![Figure 4: The prototype STT.](image)

An Application Specific Integrated Circuit (ASIC) chip is used for the readout of the signals. This chip is using the Time Over Threshold (TOT) technique as an approach for the PID via measurements of the energy losses in the straw tubes. When a particle crosses the tube, the gas inside is ionized and pairs of ions and electrons are created. The electrons are collected to the anode. Two timing values are registered by the readout system, namely, the leading-edge time and the trailing-edge time. There is a common threshold for all the channels of the setup, and an individual baseline threshold for each of the channels. The leading-edge time is the first point of the signal that is above both thresholds. Similarly, the trailing-edge time is the last point of the signal over both thresholds. The TOT value, used for the PID, is simply the difference between the trailing time and the leading time. The leading time itself is used for the tracking reconstruction and for the calculation of the isochrone radius, which is the distance between the reconstructed track and the wire of each tube. The difference between the reconstructed track and the isochrone radius is called residual. This is the value used for the calculation of the spatial resolution.
4. Results

The PASSTRECv1 chip [3] can have several settings concerning gain and peaking time of the signal. The results shown in this section have a gain equal to 1.8 mV/fC and a peaking time equal to 35 ns. The threshold was set to 20 mV and the voltage applied was 1800 mV, which will be the operational value for PANDA. In table 1 the spatial resolution values obtained for all momenta are given. The values are obtained from a Gaussian fit to the distribution of the residuals. During the proton beam, several problems with the setup and the electronics were present and thus, the results are worse than those of the deuteron beam.

### Table 1: Spatial resolution values obtained from both beam tests.

| Momentum (GeV/c) | Proton beam (μm) | Deuteron beam (μm) |
|-----------------|------------------|--------------------|
| 0.55            | 185              | —                  |
| 0.65            | —                | 170                |
| 0.75            | 202              | 172                |
| 1.00            | 217              | —                  |
| 1.50            | —                | 198                |
| 2.95            | 223              | —                  |

To examine the PID performance, the mean TOT/dx value is used, where dx is the total distance the particles travelled through the whole setup. A truncation of 30% is used on the higher values of TOT/dx in order to improve the resolution of our energy loss measurements. In figure 5 the results obtained are shown for all momenta, while in table 2 the resolutions of the mean TOT/dx values are given which are obtained from a Gaussian fit to the distributions.

![Figure 5: Mean TOT/dx values after 30% truncation for all momenta and beam types. Crosses with a black colour show the proton beam results while the red crosses depict the results from the deuteron beam. The errors shown are the sigma values from the Gaussian fit applied.](image-url)
Table 2: Mean TOT/dx resolutions obtained from both beam tests.

| Momentum (GeV/c) | Proton beam (%) | Deuteron beam (%) |
|------------------|-----------------|-------------------|
| 0.55             | 5.1             | —                 |
| 0.65             | —               | 7.1               |
| 0.75             | 4.6             | 5.2               |
| 1.00             | 6.7             | —                 |
| 1.50             | —               | 4.1               |
| 2.95             | 5.3             | —                 |

5. Conclusions

The performance of a prototype STT detector was studied extensively during two beam tests. The first goal of the tests was to calculate the spatial resolution that can be obtained and compare it with the value calculated from simulations. The second goal was to examine the PID capability of the prototype, i.e. how well it can separate particles of different species. The results for the spatial resolution and the PID capability through the TOT/dx method are presented which show that both goals have been achieved to a great extent. It can be easily seen that the results of the deuteron beam are much better than those from the proton beam. The reason for this is the presence of several problems during the first beam test. One can also conclude that the ASIC readout is quite sensitive to the first electrons reaching the anode wire. This is one of the main reasons that the spatial resolution becomes worse towards the minimum ionizing region. Concerning the PID capability of the prototype, the fact that we have two different particle species, helps us to draw safe conclusions about the performance. One can study the separation for different momenta within the same species, i.e. only investigate protons or deuterons for different momenta. However, since there is a common momentum for both, it is more safe to investigate the separation between the different particle species. One can see from figure 5 that there is a clear separation between protons and deuterons at 0.75 GeV/c. The resolution obtained for the PID, is better than the expected value (~ 10%). Improvements on the prototype STT, the readout and the analysis methods, can only further improve the existing results.

References

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