Feasibility studies for the Forward Spectrometer

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Abstract: The Forward Spectrometer designed for the $\bar{P}$ANDA detector will consist of many different detector systems allowing for precise track reconstruction and particle identification. Feasibility studies for Forward Spectrometer done by means of specific reactions will be presented. In the first part of the paper, results of simulations focussing on rate estimates of the tracking stations based on straw tubes will be presented. Next, the importance of the Forward Tracker will be demonstrated through the reconstruction of the $\psi(4040) \rightarrow D\bar{D}$ decay. Finally, results from the analysis of the experimental data collected with a straw tube prototype designed and constructed at the Research Center in Juelich will be discussed.

1. Introduction

$\bar{P}$ANDA is one of the major experiments that will be installed at the international FAIR facility in the site of the GSI laboratory (Darmstadt, Germany). It will use the high-intensity phase-space cooled antiproton beams provided by the High Energy Storage Ring (HESR). The $\bar{P}$ANDA experiment will use the antiproton beam from the HESR colliding with an internal proton target to carry out a rich and diversified hadron physics program, which includes the charmonium and open charm spectroscopy, the search for exotic hadrons and the study of in-medium modifications of hadron masses [1]. $\bar{P}$ANDA will be a fixed target experiment consisting of a Target Spectrometer (TS), surrounding the interaction point, and a Forward Spectrometer (FS), covering the acceptance of the spectrometer at low angles. A solenoid and a dipole will provide the magnetic field inside the TS and FS, respectively.The combination of the two spectrometers allows for a full angular coverage and high acceptance for a wide range of energies. The detector has a modular structure and can be easily adopted for the needs of different measurements.

2. The Forward Tracking system (FTS)

The role of the Forward Tracking (FT) is the momentum analysis of charged particles deflected in the field of the $\bar{P}$ANDA dipole magnet. The FT will detect particles emitted within an angular range of (-10°, 10°) and (-5°, 5°) in the horizontal and vertical directions, respectively. The system consists of three pairs of tracking stations (see figure 1): one pair (FT1, FT2) is placed in front, the second (FT5, FT6) behind the dipole magnet and the third pair (FT3, FT4) is placed inside the magnet gap to track low momentum particles.

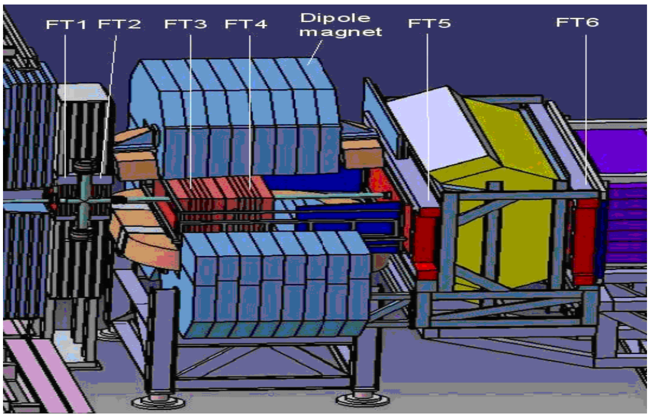

Figure 1. Layout of the three pairs of tracking stations.[2]

Each FT station will consist of four sets of planar double layers of straw tubes oriented at vertical and stereo angles (0°,+5°,-5°,0°) . Each tube will have a 10 mm inner diameter, a 30 μm aluminized Mylar foil as cathode and a 20 μm diameter gold-plated tungsten-rhenium wire as anode. The tubes will be filled with a gas mixture of $ArCO_2$ (90/10) and will be operated at a 2 bar absolute pressure. The tracking stations will be exposed to high local particle fluxes, reaching 10^4 $cm^{-2}s^{-1}$ close to the beam pipe at the maximum interaction rate of $2\cdot10^7$ s^{-1} expected in the high luminosity mode of $\bar{P}$ANDA.

3. Simulation of the PANDA detector

Systematic studies of the FT occupancies were performed by means of the PandaROOT software, described in details in [3]. In order to estimate the counting rates in FT, $\bar{p}$-p and $\bar{p}$-N reactions at 15 GeV/c have been simulated using event generators based on Dual Parton Model [4,5] and UrQMD [6], respectively. The results for the three (FT1, FT3, FT5) tracking stations are presented in figure 2. There is a significant increase of the rate in the downstream counters as a function of the distance to the beam pipe (up to 1.4 MHz for the innermost tubes). It is mainly due to secondary particles produced in the interaction with the beam pipe elements. These high counting rates present a challenge for the detector, as for the readout electronics.

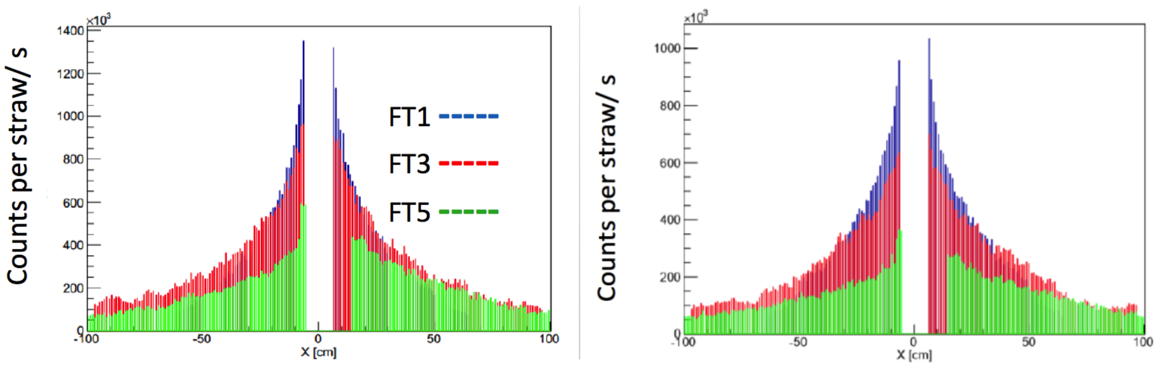

Figure 2. Calculated count rates per straw for $\bar{p}$-p (left), and for $\bar{p}$-A (right) in FT1 (before dipole magnet), FT3 (inside of the dipole magnet) and FT5 (after the dipole magnet)

The impact of the acceptance of the FT for the reconstruction of some physics channels relevant for the $\bar{P}$ANDA physics program has been studied as well. The $\bar{p}$-p $\rightarrow\psi(4040)\rightarrow D^{*+} D^{*-}$ reaction with the anti-proton momentum set to 7.71 GeV/c has been simulated and reconstructed. In particular,

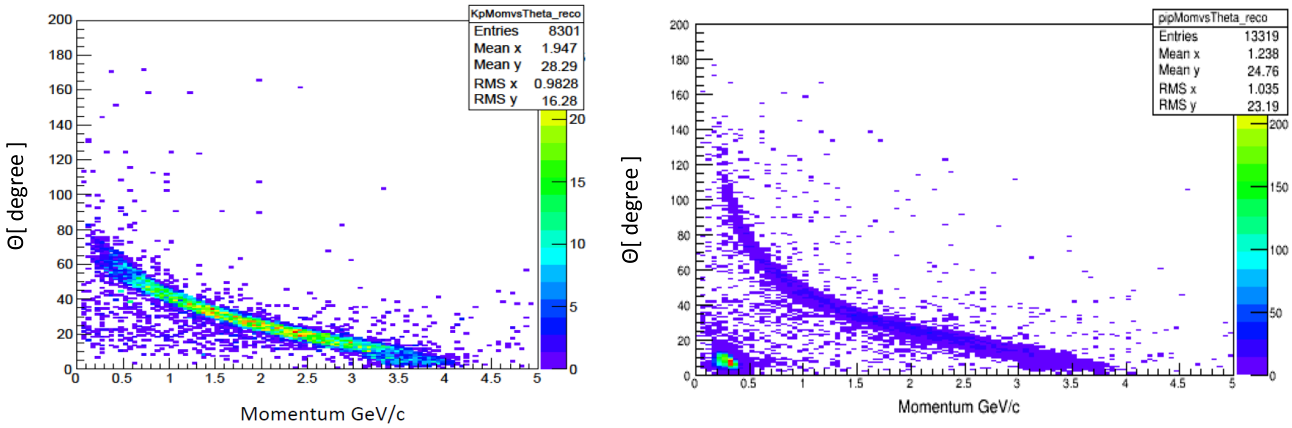

Figure 3. Distribution of theta vs momentum for pions (right) and kaons (left).

the D* mesons decay into a (D^0, π) pair and the subsequent $D^0 \rightarrow K\,\pi$ decay was investigated. A particular feature of this reaction is that, due to the low energy excess above the decay threshold, a significant part of the pions and kaons coming from the D meson decays are emitted below 10 degrees and enter the FTS (see figure 3. left). Thanks to the FTS one can still reconstruct the D^* meson with a good efficiency (see figure 4 -right).

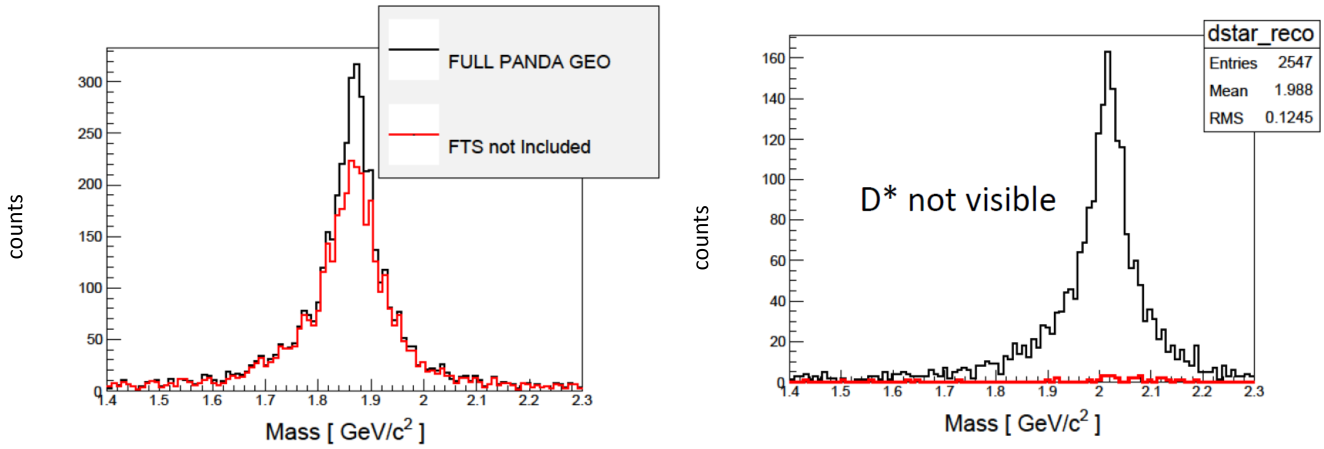

Figure 4. Reconstructed invariant mass of the D^0 (left) and D* meson (right). Black and red lines represent the result of the event reconstruction in spectrometer with and without FTS, respectively.

On the contrary, if the FTS is excluded from the reconstruction there is almost no D* visible in figure 4 right (red line). Although the importance of the FTS has been demonstrated here for this specific reaction, one can in general conclude that such a situation will also occur for other channels with similar kinematics. Figure 5 shows the reconstructed invariant mass of the $\psi(4040)$ meson with a total efficiency of 8.5% .

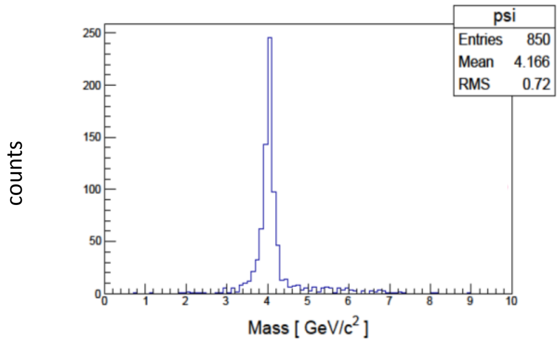

Figure 5. Reconstructed invariant mass of the ψ (4040) meson.

4. Prototype test

A Straw Tube Tracker prototype (referred to as STT) consisting of 32 tubes was tested at the Research Center in Juelich using a collimated proton beam with momentum of 0.9 GeV/c coming from COSY@IKP (Cooler Synchrotron). The beam was crossing the STT prototype, as shown in figure 6, scintillators A and B act as the trigger.

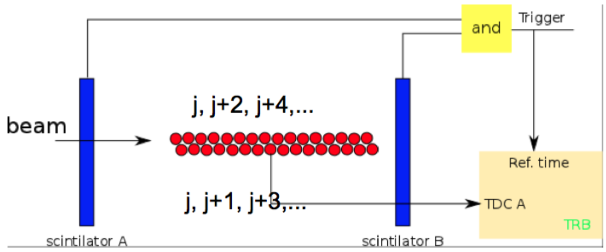

Figure. 6 The experimental setup, consisting of 32 straw chamber prototype detector, two scintillators providing a trigger and the readout chain.

To readout the signals coming from the detector specialized front-end (FE) boards were designed and developed. The main part of the FE was a custom ASIC chip, developed by AGH Cracow (figure 7) [7], featuring preamplifier and shaper with a baseline stabilization and tail cancellation circuits. This is especially important for high rate application. Furthermore, the chip provides also a leading edge discriminator allowing for the time and Time over Threshold (ToT) measurement. ToT is related to the signal amplitude and allows for energy loss measurement. Signals from the ASIC board are being processed by Trigger and Readout Board[8], working as a 256 channel TDC.

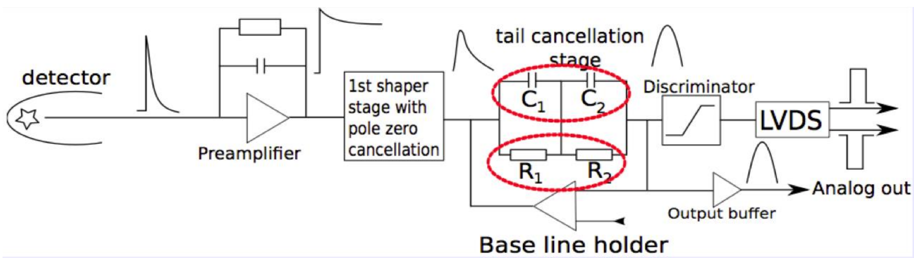

Figure. 7 Schematics of the ASIC chip, three stages of signal processing 1st tail cancellation, 2nd pole- zero cancellation and 3rd discriminator .

For each channel an electron drift time spectrum was obtained. Next, the drift radius vs time correlation was obtained using uniform irradiation method. Finally, track reconstruction has been performed on event-by-event basis as described in [9]. In order to extract spatial and energy resolutions of the detector, events with tracks which passed at least 10 straw tubes were considered in the analysis. The obtained residual distribution (distance between the experimental point and the calculated track of the proton) is presented in figure 8 and shows a resolution of 150 μm.

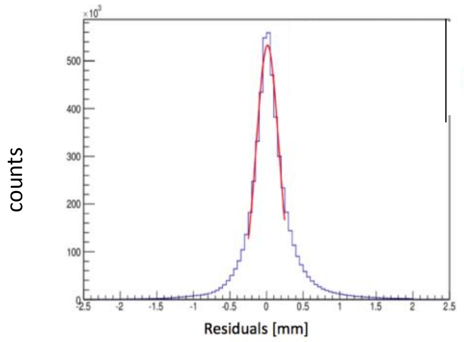

Figure. 8 Residual distribution fitted with a Gaussian function.

This resolution meets the requirements of the future $\bar{P}$ANDA experiment, as specified in the respective Technical Design Report for the PANDA Straw Tube Tracker [7].

The energy loss in straw tubes has been calculated by means of the ToT measurement, shown in figure 10 (left) together with a fit using Gaussian function revealing 5.5% resolution.

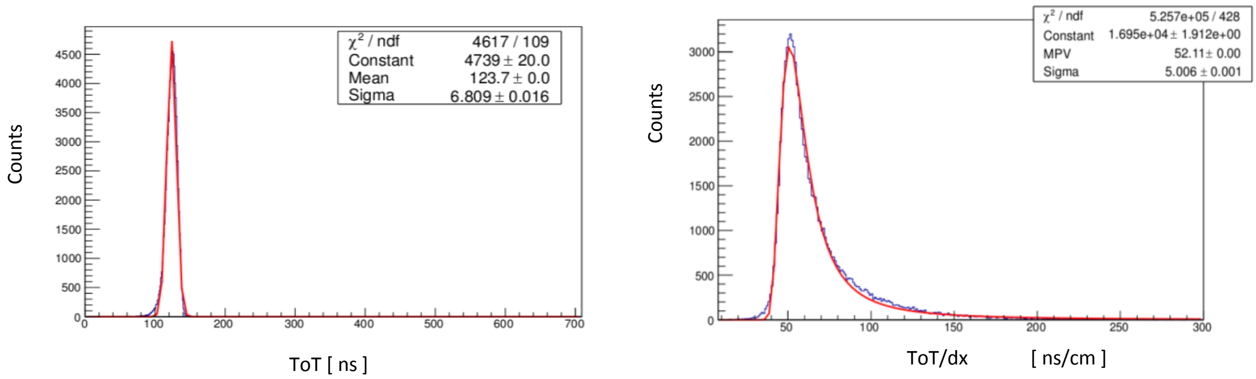

Figure. 9 Left: Mean ToT distributions for selected tracks traversing 10 straws together with a fit using Gaussian distribution, Right: a similar distribution but divided by the length of the track (dx)(cm), fitted with Landau function.

Figure 9 right shows the ToT/dx distribution calculated by means of the total track length obtained from the tracking . The distribution follows the expected distribution represented by the Landau function, shown by red line (result of fit). The measurements demonstrate a potential of the ToT method to measure energy loss.

5. Conclusions

Obtained results from simulation and the prototype test show that:

- The FTS will be exposed to a high particle flux with a maximal rate to 1.4 MHz per straw. Such high rates require a dedicated fast front-end electronics with tail cancelation and base line stabilization. Such

FEE electronics has been designed and tested using proton beams

- Tests show good performance of the detector and the developed FEE, however further tests are needed to evaluate in details resolution of the energy loss measurement based on ToT technique.
- Selected physics channel simulations show the importance of the FTS in reconstruction of the states above the open charm threshold.

References

[1] PANDA Physics Preformance Report, arXiv:0903.3905

[2] http://www-panda.gsi.de/framework/content/detector/det_mdc.html

[3] http://www-panda.gsi.de/framework/computing.php

[4] S. A. Bass et al., Prog. Part. Nucl. Phys. 41, 225 (1998)

[5] M. Bleicher et al., J. Phys G25, 1859 (1999)

[6] A. Capella, U. Sukhatme, C.-I.Tan, and J. Tran Than Var, Phys. Rept. 236, 225 (1994)

[7] Technical Design Report for the PANDA Straw Tube Tracker, arXiv:1205.5441

[8] Kajetanowicz, M. ; Korcyl, K. ; Krzemien, W. ; Palka, M. ; Salabura, P. et al. “A General Purpose Trigger and Readout Board for HADES and FAIR-Experiments”, IEEE Trans. Nucl. Sci 55, 59 (2008)

[9] Costanza S. , Design of the Central Tracker of the PANDA experiment, PhD thesis, Università degli Studi di Pavia, ISBN 978-88-95767-38-3 (2010)