PoS PROCEEDINGS OF SCIENCE

Experimental results of the dE/dx resolution measurement in PANDA-type Straw Tube Tracker

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Straw tubes are known as excellent tools for particle tracking. A multilayer, densely packed ensemble of about 5000 straw tubes - so called Straw Tube Trackers (STT) is considered as an option for the central tracker of the future PANDA@FAIR experiment. Simulations indicate that the energy loss of particles traversing several layers of straw tubes can in addition result in a decisive contribution to particle discrimination in the momentum range up to 1.5 GeV/c. Experimental investigation of the energy resolution in prototype of the PANDA-type STT have been undertaken in Research Center Jülich (Germany). The experimental setup, readout electronics, method of data treatment and the encouraging results are presented.

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1.Introduction

The experimental program of the future PANDA@FAIR experiment covers the fields of research spreading from the examination of the structure of nucleon through the studies of the properties of nuclear matter including the strangeness and the hadronic in-medium effects up to the various kinds of hadronic spectroscopy [1]. The experiment will utilize the antiproton-proton annihilation taking place after collision of the accelerated, intense antiproton beam (1.5 – 15 GeV/c momentum range) on the stationary proton or nuclear target.

In order to fulfill the scientific challenges of the PANDA program the appropriate multi-component, 4π detector system has been designed and is under preparation. The detection system, in general, consists of the Target Spectrometer (TS) surrounding the interaction point, and the Forward Spectrometer (FS) intended for registration of the higher momentum reaction products. Both the TS as well as a FS will be equipped with the magnets (solenoid and dipole, respectively) allowing for particle momentum reconstruction by measuring their magnetic rigidity.

The crucial task of the track reconstruction will be performed by the ensemble of the tracking devices comprising the Micro-Vertex Detector (MVD), Central Tracker (both situated in the TS) and the set of planar, position sensitive gaseous chambers installed in the FS.

With respect to the central tracker the two alternatives are considered: a Time Projection Chamber (TPC) with the readout realized by means of the stack of Gas Electron Multipliers (GEMs) and the multi-pad readout layer [2] or, as a second option, a set of axially oriented, densely packed, light straw tubes (Straw Tube Tracker – STT) [3,4].

The requirements for a central tracker of PANDA are as follows:

- efficient reconstruction of charged particle trajectories in angular range of 20º to 140º ;
- high precision determination of the particle momenta (dp/p ~ 1.5%);
- reconstruction of multiple tracks and secondary vertexes;
- energy-loss resolution allowing for PID in low momentum range;
- minimal material budget in order to minimize multiple Coulomb scattering and secondary emission;
- high rate capability ($1 \cdot 10^4$ events cm^{-2} s^{-1});
- radiation hardness (0.1 - 1 C cm^{-1} $year^{-1}$).

Among these features the tracking related abilities of the straw trackers are commonly know and proved in variety of experiments (see e.g. [5-7]). They have small effective thickens - only $4.4 \cdot 10^{-4}$ (X/X_0) per straw tube in case of PANDA STT. Sufficient endurance for the ageing effects in STT has been checked [4]. Geometrical properties and the short drift range allow the stable operation of straws detectors up to high counting load.

But could the discrete and thin gaseous chamber work as a precise energy-loss gauge ? In earlier attempt [8] the straw layers was used as a part of Transition Radiation Detector for registration of the X-rays emitted by the high energy particles passing through the transition foils. In this energy range the energy losses are dominated by the emission of transition photons. In low momentum range, in vicinity of the minimum ionizing mode, the abilities of straw detector as an energy detector were not checked up to now. For these reason an experimental studies of energy resolution in multilayer straw tracker have been undertaken in Research Center Jülich (Germany).

Energy resolution allowing for PID in low momentum range means that the energy-loss measured for each particle in the STT will be known precisely enough to separate the curves of specific ionizations, dE/dx vs. particle momentum, and in this manner identify the charged reaction product in their momentum range below 1.5 GeV/c. Simulation performed by Pavia Group (A. Rotondi et al.) shown in fig. 1 suggest that in order to achieve this aim the required energy resolution of the PANDA-STT has to be in the order of 8 % (sigma/mean) in mentioned momentum range.

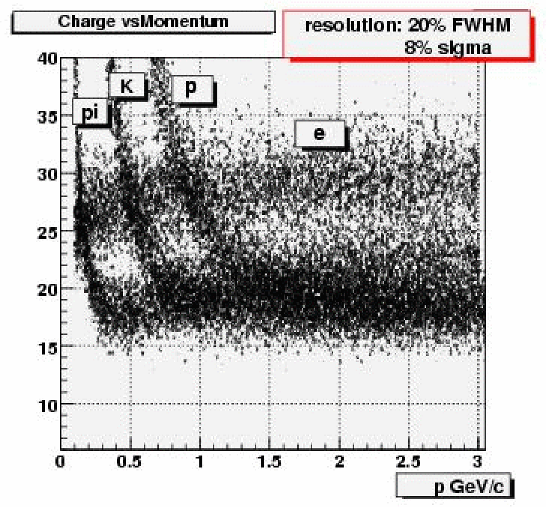

Figure 1. Separation of specific ionization cuves for π, *K*, *p* and *e* in the low momentum range simulated for PANDA STT (Pavia Group - A. Rotondi et al.).

2.Setup

In order to perform the test of the energy resolution is STT the prototype of the detector consisting of 128 straws of the identical parameters like these foreseen for the final PANDA application has been constructed. Detector has 8 layers, each of 16 tubes. Straw tubes are 1.5 m long and have outer diameters of 10 mm. Aluminized and grounded inner surfaces of the mylar tubes form the cathodes whereas the anode wires are made of gold-plated W/Re alloy and have diameters of 20 μm. The construction of the detector uses the novel technology (cf. P. Wintz - COSY-TOF experiment [6,7]) of forming of the self-supporting double layer modules of the densely packed straws. Overpressure of the medium gas stretches the tubes and elongates the sense wires and the ultra-light, rigid, and perfectly positioned multi-tube detector, avoiding any of supporting structures is obtainable.

In order to check the various methods of the signal analysis the read-out electronics were chosen permitting the recording of the analog signal wave-forms. The front-end transresistance amplifier of the 8 ns rise-time and gain factor 10 has been followed by booster amplifier (gain factor 2) translating the differential outputs of transresistance amplifier into single-ended (LEMO) signals. These signals are fed into 16-ch 240 MHz flashADC. The sampling time of the flashADC is 4.17 ns. The examples of the recorded straw-signals are shown in fig.2. The limited bandwidth of the electronic chain does not allow to observe the exact structure of the ionization clusters of the straw detectors signals, however the envelopes of the groups of clusters are still visible. Since the detector works in proportional mode and the response of the electronics is linear, the area of the signal is directly proportional to the primary ionization in the straw tube, i.e. to the energy-loss of the passing through particle.

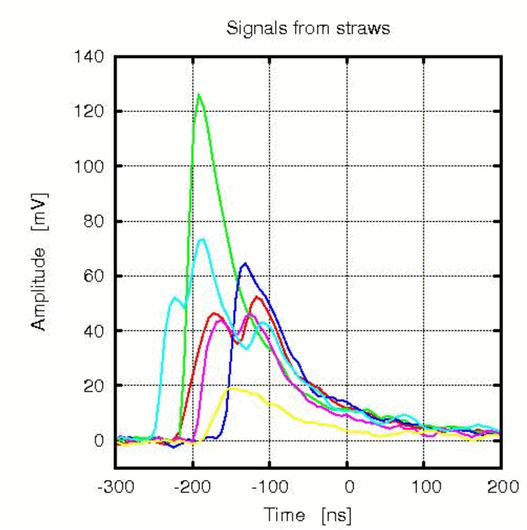

Figure 2. Analog signals from the straw tubes as recorded by a 240 MHz flashADC.

3.Measurements

The test were performed with the use of ß-particles from the $^{90}Y/^{90}Sr$ source and with the monoenergetic proton beam extracted from the COSY (COller SYnchrotron) in Research Center Jülich (Germany). In case of ß-particles the geometry and the trigger conditions were optimized in order to select the highest fraction of the ß-decay spectrum containing only the minimum ionizing electrons. The overall layout of a setup used for measurements with the use of proton beams is presented in fig. 3.

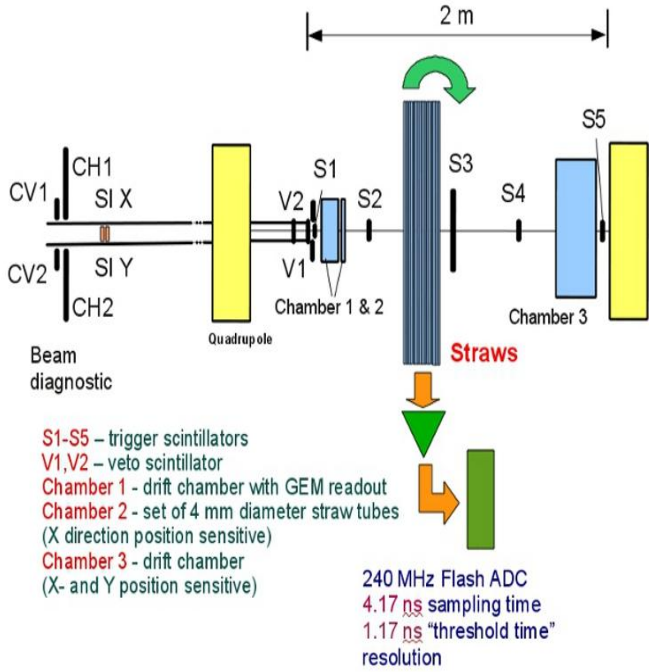

Figure 3. Experimental setup for test of the STT energy resoluton with the use of monoenegetic poton beam from COSY.

The proton beam extracted from the accumulation ring COSY was guided to the external experimental station where the STT prototype together with the auxiliary equipment was installed. The low intensity beam (up to $1 \cdot 10^4$ /s) protons after passing the thin 150 μm stainless-steel window was shut directly onto the STT-prototype. The external trigger was constructed by requirement of coincidence of few small dimension (~ 10 x 10 cm), thin (5 - 10 mm) scintillation detectors situated upstream and downstream of the STT-prototype. The beam was defocused in vertical direction in order to cover broad range of the detector. By narrow sizes of the triggering scintillators the insignificant horizontal angular spread of the beam particles was assured. The 90º and 45º of the proton impinging angle onto the straw detector were selected in order to study the differences of the detector response for the perpendicular and tilted tracks.

The detector was filled with the Ar/CO2 (9/1) mixture at 1 bar overpressure. The HV was set to keep the gas gain factor at the moderate level about $5 \cdot 10^4$.

4.Analysis

The recorded sampled signals allow for an estimation of the drift times with a precision of 4.17 ns. Under this limitation the drift time spectra were built, and the usual isochrone calibration was performed. The three step tracking procedure permitted for the selection of the fired straws belonging to an event and for reasonable calculation of the particles path lengths.

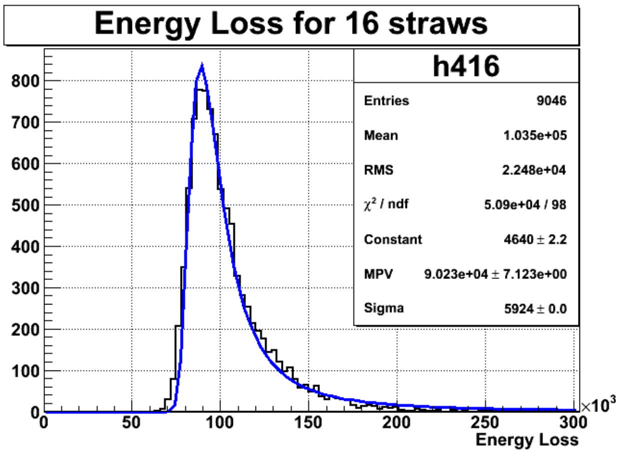

Figure 4. Energy-loss distribution for 2.95 GeV/c protons for reconstructed tracks of 16 straw tubes. Energy in arbitray units.

Signals from selected straws are used to build the energy-loss distributions. The example is shown in fig. 4. As expected the energy-loss spectra have a shape of the Landau distribution. In order to avoid the tail of the Landau distribution, which, in the real experiments would overlap the neighboring specific ionization curves and deteriorate the separation power, the so called "truncated mean" is applied in order to convert the Landau distributions into the symmetric Gaussian-like shapes. By truncation of the fixed fraction of highest energy components in the event (i.e. straws signals belonging to the reconstructed track) the automatic transformation of the tailed distribution into the symmetric one is achieved - c.f. fig.5. For the symmetric distributions the Gaussian fit is applied and the energy resolution as a ratio of a width- (sigma) to mean value of the distribution (mean) can be specified. It was checked that the best resolution is obtainable when the 30 % of the highest energy-loss straw signals is avoided from the energy-loss distribution.

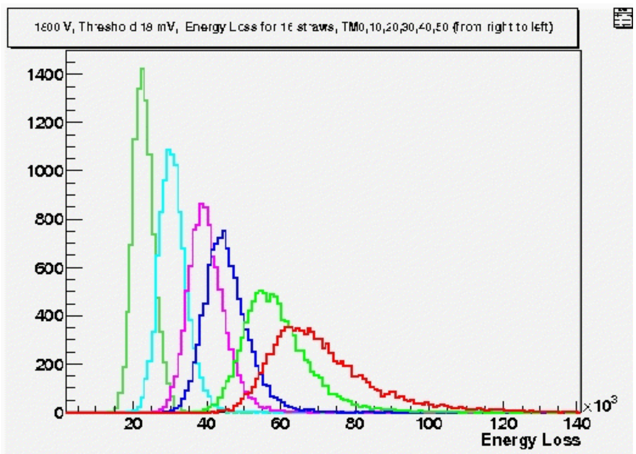

Figure 5. Modification of the experimenal Landau disibution by the so called truncated mean method. From right to left: original distribution, truncatd by 10 %, 20 %, 30 %, 40% and 50%. Energy loss in arbitrary units.

In order to obtain the dE/dx distribution each event of the truncated energy-loss distribution is corrected for the reconstructed ionization path length of the particle.

5.Results

As mentioned above, with the use of minimum ionizing ß-particles and simplified setup some initial checks of the detector response were done. Within them the dependence of the energy loss on the number of straws in which the traversing particle induced the signal was measured (fig. 6) Also the relation of the energy resolution to the number of straws has been tested and result is shown in fig. 7. In this case no truncation of the energy spectra had place. The resolution here is taken as a ratio of sigma to mean derived from the fit of the Landau curve. As expected, the energy dependence is perfectly linear and the resolution follows the reverse square-root relation to the number of firing straws.

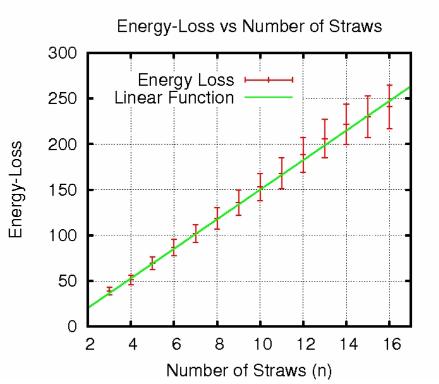

Figure 6. Dependence of energy-loss for minimum ionizing ß-paticles on number of traversed straws. Energy loss in arbitray units.

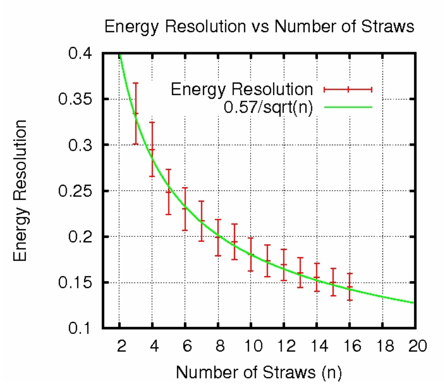

Figure 7. Dependence of energy-resolution for mnimum ionizing ß-paticles on number of traversed straws.

The tests with the protons were performed at the beam momenta of 0.64- and 2.95 GeV/c. The geometry of the experiment allowed for collection of the reasonable data of satisfactory statistics for up to 16 straws in one reconstructed track. Thus, presented here results are for a class of events, in which the tracking procedure identified 16 good signals belonging to the track of a traversing particle.

The example of truncated by 30 % and path length corrected energy-loss distributions for protons at two various momenta are shown in fig. 8. Both distributions have shape well resembling the normal distribution and the fit of the Gaussian curve permits to derive the parameters of the distribution biased only with minimal uncertainties.

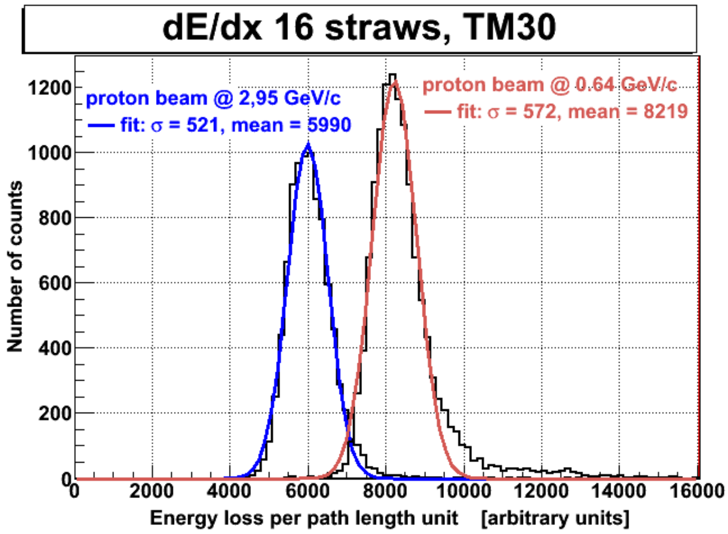

Figure 6. dE/dx distributions for monoenegetic protons at 2.95 GeV/c (left one) and 0.64 GeV/c (right one) with Gaussian fit. Only events of reconstucted tracks with 16 straw tubes are included. Truncation mean of 30 % is applied.

For higher beam momentum the resolution (Gaussian sigma/mean) is equal to 8.7 % whereas for the protons at 0.64 GeV/c (which is in the range of interest of application of STT for PID in PANDA) the best obtained energy resolution is 7.0 %.

Presented results were obtained when the protons passed the detector perpendicularly to the straw axis (impact angle of 90º). For a case when particles traverse the straws at 45º in regard to their axis, the deterioration of the energy resolution by about 1 % is observed. This is caused by the lack of a 3D tracking in the described method and overall small precision of the tracking caused by the uncertainty of the drift time measurement (see section "Setup"). For this reason the systematic error of 1 % has to be introduced.

6.Conclusion

The energy resolution of the prototype of PANDA-type STT has been measured with the use of the monoenergetic proton beam at 0.64- and 2.96 GeV/c. Fort the most favorite case when the 16 straws responded for the traversing particles the average energy resolution is equal to 8 ± 1 % (sigma/mean). This result was achieved when the initial energy-loss distributions were truncated by 30 % of the highest energy component of the events.

The tests were performed with the use of readout-electronics optimized for testing of the energy resolution of the straw detector. Very promising results obtained with this respect triggered the development of the devoted STT read-out electronic fulfilling both the requirements of the precise time measurement (at high detector load) and assuring the satisfactory energy resolution.

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