Particle identification using the time-over-threshold measurements in straw tube detectors

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A B S T R A C T

The identification of charged particles based on energy losses in straw tube detectors has been simulated. The response of a new front-end chip developed for the PANDA straw tube tracker was implemented in the simulations and corrections for track distance to sense wire were included. Separation power for $p$, $K^-$ and $\pi^-$ for pairs obtained using the time-over-threshold technique was compared with the one based on the measurement of collected charge.

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1. The PANDA straw tube tracker

Measurement of ionization $dE/dx$ in gaseous tracking detectors has been successfully used in many experiments for particle identification. In the PANDA experiment, the straw tube tracker (STT) designed for momentum analysis of charged particles in a 2 T magnetic field produced by a super-conducting solenoid will be used for separation of protons and charged pions and kaons in the momentum range below 1 GeV/c [1]. The STT consists of 150 cm long straw tube detectors arranged in 27 layers in a cylindrical volume around the beam axis. The straw tubes are made of a 27 μm thick aluminized Mylar foil and have a diameter of 10 mm. A gold-plated tungsten wire with 20 μm diameter is used as a sense wire. The gas overpressure of 1 bar makes the straws self-supporting [2].

For registration of energy losses in the STT, we consider two options: (i) measurement of the time-over-threshold (TOT) of straw tube pulses amplified and shaped in the front-end electronics and (ii) digitization of the pulses in sampling ADC—further on we refer to it as a measurement of charge ($Q$).

For the straw tubes, the TOT technique has been already used by the ATLAS experiment [3]. An advantage of this solution is that the readout electronics can be restricted to time measurements. However, at the high counting rates expected in the PANDA experiment, reaching 800 kHz for the straw tubes in the innermost STT layers, the TOT measurement might be disturbed by pile-up and fluctuation of the baseline in the front-end electronics, resulting from a non-perfect ion tail cancellation. Digitization of pulses in ADC allows in principle to correct for these effects, however, it requires application of advanced real time algorithms, a large data bandwidth and more power consumption.

2. The front-end chip

For reading out the straw tube’s signals in the PANDA experiment, a new front-end chip is being developed [4]. The first prototype containing four channels was designed and fabricated in the AMS 0.35 μm technology. One channel comprises a charge preamplifier stage, a second-order pseudo-Gaussian shaper with 25 ns peaking time, a tail cancellation network and a baseline holder. Besides, a leading edge discriminator circuit with a fast LVDS output and an analog output buffer provide both the timing and the amplitude information. Several parameters of the front-end chip including the preamplifier gain, the shaping time and the tail cancellation are programmable.

In order to optimize the ion tail cancellation, we adjusted the tail cancellation parameters in the chip using signals from the straw tube irradiated with a $^{55}$Fe X-ray source. Test performed with a 2.7 GeV/c proton beam, with a rate exceeding 1 MHz in the single straw, has demonstrated that there was no baseline distortion for the chosen parameters.

3. Simulations of straw tube response

The particle identification based on energy losses in the straw tubes was studied using simulation of the straw tube pulses with...
the Garfield-9 program [5]. The properties of the 90% Ar + 10% CO₂ gas mixture, which was chosen for the STT, were calculated using the Magboltz code, version 8.9.5 [6]. The gas gain in this mixture was measured as a function of the sense wire potential and was very well reproduced by the simulations including 34% of the Penning transfer rate. The straw tube’s pulses were convoluted with a transfer function of the front-end electronics, which was determined as a response to a “delta-like” pulse injected into the front-end channel.

Results of the simulations have been examined by a comparison with tests performed with ⁵⁵Fe and ⁹⁰Sr radioactive sources as well as cosmic rays. In the tests, a prototype detector containing 32 straw tubes was read out by the new front-end electronics. The drift time and the time-over-threshold were registered with the TRBv2 time-to-digital converter developed for the HADES experiment [7]. As an example of a good agreement between simulations and tests, a comparison of TOT spectra simulated and measured with ⁵⁵Fe source is shown in Fig. 1.

![Fig. 1. Time-over-threshold spectrum measured (red open squares) and simulated (blue full squares) for ⁵⁵Fe source. A peak corresponding to the full absorption of the 5.9 keV X-rays from ⁵⁵Fe is clearly separated from the 2.9 keV argon escape peak. In the simulations, electronic noise with a level observed in the measurement was added to the signals. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)](image1)

4. π–K–p separation

Simulations of the particle identification in the straw tubes were performed using pseudo-tracks created by randomly combining 24 hits generated with Garfield, assuming a uniform distribution of the track distance to the sense wire. The simulations were done for the sense wire potential of +1800 V corresponding to a gas gain of 4.4 × 10⁶ and a discrimination threshold for the TOT measurement equivalent to 20 primary electrons. This threshold corresponds to about 10% of the primary ionization produced by minimum ionizing particles crossing the straw tube close to the sense wire. The time-over-threshold and the integrated charge were corrected for the track distance to sense wire using the procedure described in Ref. [3]. Subsequently, a truncated mean was calculated for each track by discarding 30% of the largest values. The values of the truncated average were then used for calculating the separation power of particles A and B defined as $\frac{\langle M_A \rangle - \langle M_B \rangle}{\sigma_A + \sigma_B}$, where $\langle M_A \rangle$, $\langle M_B \rangle$ are the means of TOT (or Q) over the simulated tracks and $\sigma_A$, $\sigma_B$ are the corresponding standard deviations. The separation power determined for $p-K$, $p-\pi$ and $K-\pi$ pairs is shown in Fig. 2 as a function of the particle momentum in the range 0.3–1.0 GeV/c.

Visible differences between the separation power based on the TOT and Q measurements can be explained by saturation of TOT as a function of Q for large values of Q. In the studied momentum range, the TOT for kaons and protons saturates due to relatively large energy deposits in the straw detectors compared to pions being close to the minimum of ionization. On one hand, the saturation of TOT leads to smaller relative smearing of TOT than the one of Q and increases the separation power for TOT. This is the case for the $K-\pi$ pairs, with the TOT from kaons being close to saturation. On the other hand, for two particles with TOT in the saturation region, the differences between TOT values become small which leads to deterioration of the separation power based on TOT. This effect dominates in the case of the $p-K$ pairs.

The discussed differences between the separation power based on the TOT and Q measurements are not large and, therefore, we conclude that for the chosen working point of the straw tubes and the front-end electronics, both methods show comparable performance.

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References