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Study of the space charge effect in straw tube detectors for the PANDA experiment

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Abstract. The straw tube detectors in the PANDA experiment will work in high particle fluxes reaching up to 25 kHz/cm^2. We performed measurement of the gas gain drop in the PANDA straws due to the space charge effect expected at the high particle fluxes. The applied experimental method and obtained results are presented and are compared with calculations of the gas gain drop based on known mobility of positive ions.

PANDA straw tube trackers

The PANDA detector [1] will be built at the FAIR facility to perform high precision studies of the strong interaction through annihilation of antiproton beam in hydrogen as well as nuclear targets, in the beam momentum range from 1.5 to 15 GeV/c. PANDA consists of two spectrometers: the Target Spectrometer based of on a solenoid magnet and the Forward Spectrometer based a dipole magnet. For momentum analysis of charged reaction products in magnetic field in these two spectrometers, the central Straw Tube Tracker [2] and the Forward Tracker (FT) [3] are used, respectively. The trackers are based on 10 mm in diameter straw tube detectors made of 27 μm thick aluminised-Mylar film and containing a 20 μm diameter gold-plated tungsten anode wire [4]. The straws are filled with Ar:CO_2 (90:10) gas mixture at an overpressure of 1 bar. The FT straw tubes will be operated in very high particle fluxes reaching up to 25 kHz/cm^2 in the central region of the FT.

The space charge effect

In order to check the gas gain drop due to the space charge of positive ions accumulated in the straw volume at expected high particle fluxes, we performed measurements of the gas gain as a function of the particle flux. For this, the straw was illuminated with a strong (1GBq), collimated ^{55}Fe source (see Fig. 1.a). The flux of X-rays was varied by changing the distance between the source and the straw. The number of ionization electrons produced by absorption of the 5.9 keV X-rays from ^{55}Fe is about 210 and is very close to 200 electrons produced by minimum ionizing particle crossing the straw close to the anode [5]. The straw tube pulses were fed to Front-End Electronics (FEE) card containing two PASTTREC chips [6]. The rate of pulses at the digital output of the FEE was registered with a TRBv3 board [7]. The analog pulses from the FEE were recorded using the CAEN DT5742 digitizer.

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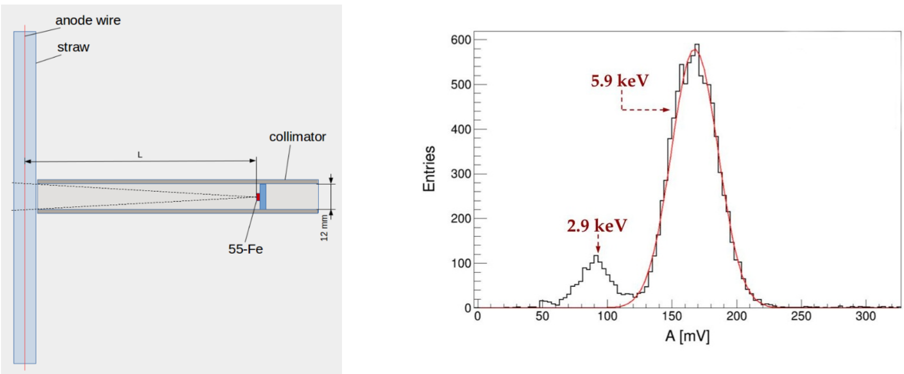
Position of the 5.9 keV peak in the amplitude spectrum, determined from a gaussian fit (see Fig. 1.b), was measured as a function of the rate per unit length of the straw. Results of this measurement, performed for three different voltages of the anode: 1700, 1750 and 1800 V, are shown in Fig. 2. At the highest measured rate of 135 kHz/cm and the voltage of 1800 V, the pulse amplitude drops by 27% compared to the measurement at the lowest rate of 4 kHz/cm. The amplitude drop at a rate of 25 kHz/cm - the highest expected in the FT - is about 10%.



(a) (b)

Figure 1: (a) Experimental setup. (b) Amplitude spectrum for ^{55}Fe source (black line) and a gaussian fitted to the 5.9 keV peak (red line).

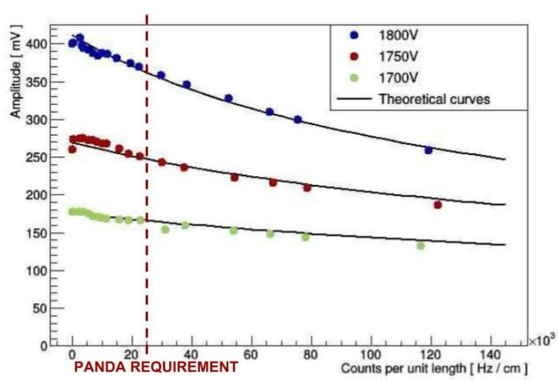


Figure 2: Amplitude of straw tube pulses as a function of counts per unit length of straw tube, measured for three voltages of the anode wire. The highest rate per unit length expected in the PANDA FT is indicated by the red dashed line. Solid black lines represent calculation explained in the text.

For a theoretical description of the obtained results, we used the formula for the effective voltage drop of the anode wire due to the space charge [8]:

$$\Delta V = \frac{b^3 q \phi \ln \frac{b}{a}}{4\pi\epsilon_0 \mu V_0}, \tag{1}$$

where b is the straw tube radius (5 mm), a is the anode wire radius (10 μm), ϕ is the incident particle flux, V_0 is the applied voltage on anode wire, ϵ_0 is the electric permittivity of free space, μ is a mobility of positive ions and q is the total charge produced in avalanche. Due to the charge exchange process, $CO_2{}^+$ ions dominate in the gas mixture and, therefore, for the mobility of positive ions we took the mobility of $CO_2{}^+$ ions which is equal to $1\,\mathrm{m^2V^{-1}s^{-1}}$ [9]. The total charge q produced in avalanche depends on the applied voltage V and was calculated as:

$$q(V) = g(V) \cdot n \cdot e\,, \tag{2}$$

where n is the number ionization electrons (210), e is the elementary charge and $g(V)$ is the gas gain for a given voltage. The gain was determined based on performed measurement of the pulse amplitude as a function of voltage $A(V)$, and the gain measured at $V_0 = 1800$ V, equal to 5×10^4 [5]:

$$g(V) = \frac{A(V)}{A(V_0)} \times g(V_0)\,. \tag{3}$$

The voltage drop ΔV given by Eq.1 was calculated iteratively. First, the calculation was done with the gas gain determined for $V = V_0$. Next, the calculation was repeated taking into account the voltage drop in the gain determination. A stable value of ΔV was reached after a few iterations. The results of the calculation performed for the voltages 1700, 1750 and 1800 V agree well with the experimental points, as shown in Fig. 2.

Conclusions

We performed measurements of the gas gain drop as a function of the rate per unit length in the straw detectors for the PANDA experiment. Obtained results are well described by theoretical calculations based on the known mobility of the positive ions. The gain drop at a rate of 25 kHz/cm - the highest expected in the PANDA FT - is about 10%. This change of the gain is acceptable from the point of view of the required precision of the drift time measurement ($\approx$ 1ns) since the corresponding time walk is about 0.1 ns for pulses corresponding to minimum ionizing particles.

Acknowledgement

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