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A direct time measurement technique for the two-dimensional precision coordinate detectors based on thin-walled drift tubes

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ABSTRACT

This article presents the results of a study of the longitudinal spatial resolution by means of the direct timing method (DTM) using 2 m long and 9.53 mm diameter straw tubes. The feasibility of achieving the spatial resolution (r.m.s.) better than 2 cm over full length of the straw is demonstrated. The spatial resolution changes little when measured by detecting gammas from a Fe-55 gamma ray source or minimum ionizing electrons from a Ru-106 source. The use of the same type of front end electronics (FEE) both for measuring the drift time of ionization electrons and propagation time of a signal along the anode wire allows one to construct a detector capable for measuring the two dimensional coordinates of charged particles.

1. Introduction

The measurement of the momentum of charged particles moving in a magnetic field requires precise measurements of the spatial coordinates in the direction of deflection, whereas the coordinate along the direction of the magnetic field can be measured with less precision. A high precision coordinate is determined in gaseous drift chambers in the direction orthogonal to the anode wires by measuring the drift time of the ionization electrons produced by charged particles passing through the chamber. A few different methods can be employed for the measurements of the coordinate along the anode wire. They include a cathode readout, and coordinate drift chambers with a pad or strip readout are under construction [1–3]. Both these techniques can be applied for coordinate chambers based on thin-walled drift tubes (straw tubes) but in this case the cathodes should have a resistance higher than 100 kΩ/γ. Moreover, the charge collection time should be increased as well. The longitudinal coordinate in the straw can be also determined by employing the charge-division method when signals are read out from both ends of the resistive anode wire. The highest longitudinal resolution achieved by this method has been obtained with the auxiliary measurements involving a time-charge asymmetry [4,5]. The anode resistivity was 400 Ω/m. The best spatial resolution, σ, proved to be 0.95 cm at the straw center and about 2.5 cm near the ends of the 1.52 m straw if 5.9 keV gammas were registered. However, the resolution deteriorated to ~2.5 and ~6.0 cm, respectively, if minimum ionizing particles were registered.

Earlier, a possibility of registering a longitudinal coordinate in a drift-tube detector by employing the technique of using the time difference between signals arriving to amplifiers connected to the ends of the anode wire has been demonstrated [6]. The technique has been called a direct timing method (DTM). In this case, the anode wire is considered as a transmission line.

In the present article we consider possibilities of using the DTM for registering signals from a prototype constructed of 2 m long straw tubes. The particular features of the prototype include a possibility of operation at the gas-mixture pressure up to 4 bar and the special design of the gas distribution manifolds which allows one to assemble the readout front-end electronics close to the ends of anode wires.

2. The setup

The detector prototype includes a layer of straw tubes with an inner and outer diameter of 9.53 and 9.65 mm, respectively, joined by glue. The 2 m long straw tubes are produced by winding two Kapton strips. The inner strip is a carbon loaded Kapton conductive film of 160XC 370 type, whereas the outer strip is Kapton aluminized film of HN50 type [7,8]. The anode is made of 30 μm gold-plated tungsten wire which has a resistance of 70 Ω/m

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stretched to a tension of 70 g with one polycarbonate spacer at the middle of the straw tube. The transmission line impedance is 360 Ω. The straw tubes were flashed with the gas mixture Ar/CO_2 (80/20) at the pressure of 1 or 3 bar. The layout of the experimental setup is shown in Fig. 1. A straw under study has been irradiated either with 5.9 keV gammas from a Fe-55 radioactive source or with beta rays from Ru-106 source through a slit collimator. In the latter case, the electrons passing through the straw were detected by a scintillation counter viewed by two photomultipliers. Low-energy electrons have been stopped in the 0.5 mm fiberglass absorber located between the straw and the counter.

Low-noise signal amplifiers based on 4-channel microcircuits of the MSD2 type with a gain of 35 mV/μA and a rise time of about 4 ns, an input impedance of 120 Ω [9], are installed close to the ends of the anode wire to minimize the parasitic capacitance and inductance. Such amplifiers are used in detectors when a radial coordinate is determined by measuring the drift time of the ionization electrons [10].

The pulses from the outputs of the amplifiers are fed into two channels (1 and 3) of a DRS4 evaluation board. This board is based on the DRS4 Switched Capacitor Array chip (SCA), which can sample an input signal with a sampling speed of up to 5 GS/s and store an analog waveform in the time window determined by the capacitor array of the DRS4 chip (1024 bins correspond to 200 ns) [11,12]. The maximal amplitude of the input pulses is ± 0.5 V. The data arriving at DRS4 is processed according to the following algorithm (Fig. 2):

(1) select the correlated pulses by introducing a threshold for the incoming anode pulses. In case of data taking with Ru-106 source, request a signal arriving from the scintillation counter at the second DRS4 channel.
(2) determine the pulse amplitudes in the software time window defined as t_s and normalize the delayed pulse to the amplitude of the first pulse.

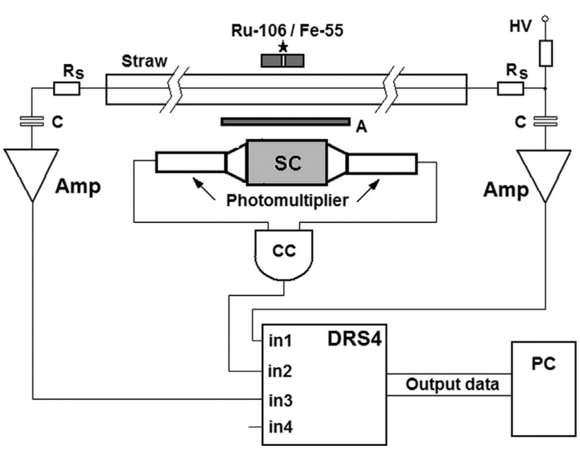

Fig. 1. A schematic diagram of the setup: A—absorber, SC—scintillation counter, Amp—amplifier, CC—coincidence circuit, DRS4—Domino Ring Sampler (DRS).

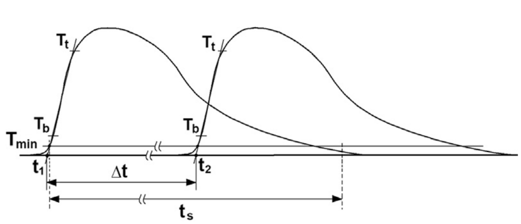

Fig. 2. A diagram of time delay between the first and second pulses.

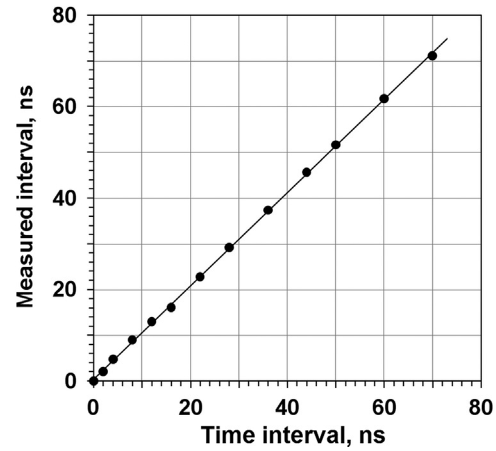

Fig. 3. The measured delay time interval as a function of the calibrated delay interval varied in the range from 2 to 70 ns (DRS4 linearity).

(3) approximate the leading edge by a straight line in the time interval between T_t and T_b determined by the software from the given fraction of the amplitude of the larger pulse.
(4) determine the arrival time for each pulse (t_1 and t_2) as the intersection point of the approximate line and the time axis.
(5) fill a histogram of the time difference between pulses $\Delta t=(t_1-t_2)$ and evaluate the mean and standard deviation to determine the resolution of the method for longitudinal avalanche coordinates along the anode.

If the point of the avalanche origin is displaced along the anode wire by the distance, δL, from the center of a straw, the two signals arriving at amplifiers pass the distance $L/2 \pm \delta L$, where L is the anode length. Therefore, the absolute difference δt is determined as $\delta t = 2\delta L/v$ where v is an electromagnetic wave propagation velocity along the anode wire whereas the sign determines the direction of the coordinate displacement with respect to the center of the wire.

The DRS4 linearity proved to be satisfactory (Fig. 3). It has been verified by feeding a pair of pulses with a calibrated delay time between two pulses, which was in the range from 2 to 70 ns. A comparison of the measured delay time and the input delay time has demonstrated that the apparatus resolution σ is within the range of 60–85 ps. This uncertainty arises from the design principle of the DRS4 chip. The sampling clock is generated by a pulse propagating through an inverter chain. Imperfections in the chip production cause a variation of the individual delays of the inverters, producing a timing non-linearity. Since these imperfections are stable over time, they can be measured and removed by calibration.

3. Parameters of the detected signals

A Fe-55 gamma ray source was used both in the studies of the DTM technique and in the preliminary measurements. The pulses from the amplifiers connected to the ends of the anode wire were quite similar (Fig. 4a) if the source position was at the center of the straw. The measurements of the attenuation of the signal and the pulse propagation velocity along the anode wire have been performed with a scan by using the gamma ray source. Typical pulses registered by an amplifier are shown in Fig. 4b for the gamma ray source located at the end of the straw tube. The attenuation of the signal as a function of the distance, δL, between the source and the straw end is shown in Fig. 4c. The signal