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Carbon wire chamber at sub-atmospheric pressure

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ABSTRACT

Present in many experiments, wire and drift chambers have been used in a large variety of shapes and configurations during the last decades. Nevertheless, their readout elements has not evolved much: tungsten, sometimes gold-plated or aluminum, wires. By taking advantage of the developments in the manufacture of conducting carbon fiber, we could obtain interesting improvements for wire detectors. In this article, we present recent tests and simulations using carbon fibers to readout signal in place of traditional tungsten wires. Unlike metallic wires, their low weight guaranties a reduced quantity of material in the active area.

1. Introduction

Since their first operation by Charpak et al. in 1967 [1], multiwire chambers have been widely used to track nuclei and particles in subatomic physics experiments. At the time, they were a huge step forward as they combined a very good time resolution, a good position accuracy and the self-triggering capability. This class of detectors now encompasses a myriad of variants, from drift chambers [2,3] to time projection chambers [4]. They provide spatial resolution of the order of 100 μm; they have a good transparency since particles pass through thin windows (typically a few tens of microns of Mylar) and a limited volume of gas; they are relatively simple to operate; they can be tailored to very large active surfaces; and they have a rather low cost in light of their level of performance.

Among their limitations is the possible interaction of the incoming particle with the wires. This is not really a concern for experiments involving minimum ionization particles, but heavy ions or low momentum particles hitting the wires will be significantly scattered. If the momentum change is small enough, the event may not be discarded but its kinematics will be flawed. The fact that the area covered by the wire plane is usually small (1 or 2%) can mitigate this effect since only a fraction of the events are affected. This inhomogeneity of the detector may yet be considered as a major drawback, for example in the perspective of using multiwire chambers in very high-resolution experiments or in early stages of a recoil spectrometer such as the Fragment Separator [5], the upcoming Super-FRS [6] at GSI and ALERT [7] at JLab. To remove this limitation, the energy loss of the incoming nuclei must be reduced. This can be achieved by using thinner wires or lower-Z materials. Ultra-thin wires are not really an option because of the mechanical and electrical constraints. In this case, the saturation of gas multiplication appears at low voltage, such that the operator has to choose between a high gain to ensure a good uniformity of the drift lines or the energy linearity. Hence, using low-Z material appears as a more promising route. Gold-plated tungsten being the reference choice for wires, aluminum is a first improvement; but carbon would be an even better choice in this frame.

Driven by recent developments concerning carbon fibers, new wires combining excellent mechanical properties and good conductivity are now available. For a given diameter the energy loss in a wire can be significantly reduced in comparison to gold-plated tungsten. Indeed, switching from tungsten to carbon increases the radiation length from 0.35 to 18.8 cm. The difference of stopping power between heavy and light material is mainly due to the density of electrons in each material and is weakly dependent on the energy. Going from tungsten to carbon, for a given material thickness, the energy loss is divided by about 3 for incoming nuclei in the energy range of a few MeV per nucleon. This factor increases with the kinetic energy of the incoming nuclei: in the range of hundreds of MeV per nucleon, it is around 5 [8].

Moreover, the tensile strength required to ensure the geometrical linearity of such wire is smaller than for tungsten. Indeed, when the tension to apply is dominated by the reduction of the sag and not by electrostatic forces, carbon fiber will require less tension (T) as the sag (f) depends on the mass (m) of the wire, as shown by the approximate relationship [9]:

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$$f \simeq \frac{mlg}{8\,T} \tag{1}$$

where, l is the length of the wire and g the gravitational acceleration.

Studies with carbon wires were carried out in the past, see for example [10] and references therein, but the development was limited by the fact that the wires had a very small diameter (7 μm). We present in this article tests carried out to measure signal from a 34 μm diameter carbon wire. We first introduce the setup. After detailling the data analysis, the results are shown. The last part focuses on simulations performed to complete our results.

2. Experimental setup

We tested the ability of carbon fibers to readout signal with a test bench initially designed to measure electron drift speed in low pressure gases. This is not our purpose here, yet the device was adapted to our needs which are simply to be able to readout a wire from a wire chamber. Since the setup uses alpha particles that have to cross several centimeters of gas, it can only be operated at low pressure, 10 mbar to about 200 mbar. We present here the setup, the parameters chosen for this experiment and its principle of operation.

2.1. Setup

It is composed of a large vacuum box in which the gas enters via a flow meter. The gas output is composed of a controlled valve MOVE 1250 OERLIKON [11] connected to the chamber and a vane-type pump for the primary vacuum. The pressure is then regulated by a CERAVAC CTR 100 OERLIKON. The chamber (Fig. 1), placed inside this box, has a 70 mm drift space and a 1.7 mm amplification gap separated by a 80×50 mm^2 grid of gold-plated tungsten wires. The anode of the amplification gap is made of 7 wires spaced by 10 mm; only the central one is readout.

The homogeneity of the electric field in the drift space is obtained by three field rings powered, along with the grid, by a potential divider such that the grid is grounded. The expected voltage map is shown in Fig. 2.

An ^{241}Am source, having an activity for alpha particles of approximately 100 Bq, is placed about 5 mm below the cathode plane of the drift space. On the other side of the drift chamber, a 500 μm thick and 5 mm diameter silicon detector is placed; it is used as trigger. In this configuration, the track of the alpha particle emitted by the source is parallel to the wire under consideration.

The geometrical parameters were selected in order to keep an acceptable error on the drift time. In standard gases, like pure isobutane used here, the typical electron drift velocity is around 50 mm/μs. With our electronics, we expected to obtain an error on the drift time of 10 ns, therefore we fixed the electron drift distance to more than 50 mm in order to guarantee an error lower than 1%.

The signal of the silicon detector and the one from the relevant wire

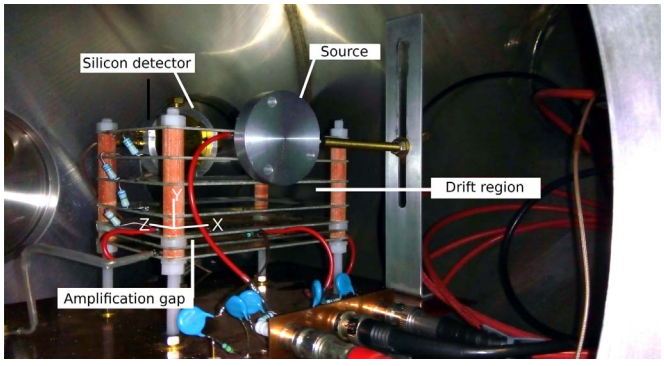

Fig. 1. Picture of the wire chamber.

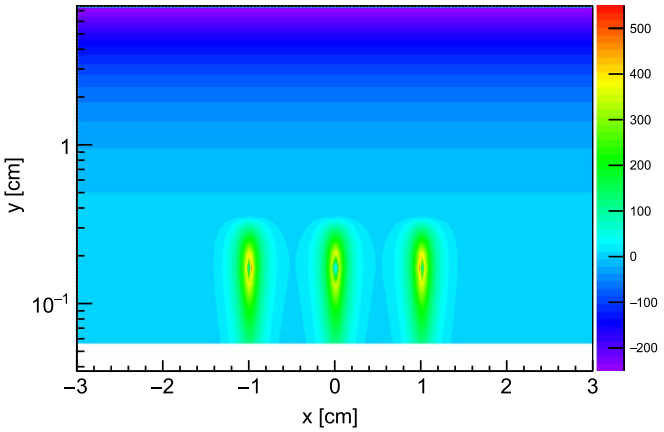

Fig. 2. Simulation of the expected voltages in the chamber obtained with Garfield++ [12,13]. The color scale is in Volts.

are sent after a RC filter to charge preamplifiers CREMAT [14] CR-110 (gain of 1.4 V/pC). The output of each preamplifier is connected to a Lecroy WavePro 715Zi oscilloscope [15]. In the configuration used during the tests (50 Ω, DC), its bandwidth is 1.5 GHz. As shown later, it was sufficient for our needs since it allows to measure properly signals with a rise time as fast as $0.35/1.5\times10^9$=0.23 ns.

The oscilloscope is triggered with the signal of alpha particles in the silicon detector. The rate is 2–3 events per minutes. Electrons created along the path of the particle drift toward the anode plane, and are multiplied in the vicinity of the anode wires. The signal of the wire of interest is then read on the oscilloscope with a delay. In this experiment we focus on the comparison between wires made from different materials and not on the time delay.

2.2. Operating conditions

During the tests the drift field was set to 33 V/cm. It ensures a good transparency and reduced ion back flow. The anode wire voltage was set to 550 V. The gas, pure isobutane, was circulated at a pressure of 20.2 mbar. The oscilloscope acquisition frequency was set to 250 MHz which was adapted to the rise time of the signal as we will see later.

Two types of wires were tested. Their properties are summarized in Table 1. Before stretching the wires, we checked that the electrostatic repulsion would not change the position of the wires. The mechanical tension required to compensate the electrostatic repulsion between wires is given by [16]:

$$T = \frac{1}{4\pi\epsilon_0}\left(\frac{CV_0L}{s}\right)^2 \tag{2}$$

where C is the capacitance per unit length of a wire, V_0 is the applied voltage, L is the length of the wire, and s the distance between two adjacent wires. Using the following expression of the capacitance [16] for wires of radius a and distant of d from a cathode plane:

$$C = \frac{2\pi\epsilon_0}{\pi d/s - \ln(2\pi a/s)} \tag{3}$$

one finally gets an expression of the minimal tension to impose on the

Table 1
Properties of the two wires tested.

	Gold-plated tungsten wire	Carbone wire
Diameter	30 μm	34 ± 2.5 μm
Resistivity	0.67 Ω/cm	1.67 kΩ/cm
Density	19.17 g/cm^3	1.8 g/cm^3
Tensile strength	1.51 GPa	0.86 GPa
Tensile modulus	410 GPa	41.5 GPa