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FAST TRACKING DETECTOR USING THE MULTIDRIFT TUBES

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ABSTRACT

We describe a tracking detector designed as an assembly of multidrift tube modules; because of its fast time-resolution and good position accuracy, coupled with high reliability, the device seems suitable for operation as vertex detector at a collider, and for other high-rate applications. Recent measurements of localization accuracy obtained when operating the modules with a dimethyl ether gas filling are presented.

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1. INTRODUCTION

The conception of the so-called central tracking or vertex detector around a collider—the most inaccessible part of the experimental apparatus—has to satisfy two major constraints: reliability, and endurance under irradiation. Moreover, the detector has to have the best possible localization accuracy and rate capability. Although solid-state detectors (silicon strips or charge-coupled devices) that suit the above-mentioned requirements are becoming available, their use in large quantities is still restrained by cost and the lack of suitable radiation-resistant large-scale integrated electronics. Most of the present and planned detectors for high-rate colliders include indeed several layers of silicon detectors close to the vacuum pipe, followed by cylindrical multiwire drift chambers of a design optimized for high localization accuracy and multitrack resolution.

Some time ago we proposed [1] to improve the performance and the reliability of a central tracking detector based on multiwire gas chambers, replacing the conventional monolithic construction by a modular assembly of independent elements. For this purpose we have developed a basic detection element, the multidrift module (MDM), capable of making a fast and accurate radial localization of multiple tracks by measuring the drift time on a closely packed array of drift cells. The longitudinal coordinate can be deduced, although with less precision, from a measurement of the ratio of charges detected at the two ends of the resistive anode wires. We have chosen a hexagonal geometry for the drift cell and for the external gas-tight envelope. Figure 1 shows the basic configuration of a module: in each cell the anode wire is surrounded by six cathode wires, and this arrangement is repeated throughout the module. In the present design, we have adopted a cell radius of 1.45 mm (1.27 mm between wire planes) using as the mechanical support and gas-tight envelope a thin, hexagonal, carbon-fibre tube 30 mm in diameter, which allows us to mount 70 drift cells in each module. The tube (present thickness 500 μm) is composed of almost equal proportions of carbon and epoxy. So far the length of the modules has had to be limited to 80 cm owing to the unavailability of longer carbon-fibre envelopes. However, detailed studies of the mechanical deformations and electrostatic deflections of the wires have shown that it is feasible to have modules that are several metres long with only a few simple internal supports (see Section 4).

Modules can be assembled around an intersection as shown, for example, in Fig. 2; in this case, 48 tubes have been used, with a total of about 4000 signal wires. The inner and outer radii of the complete detector are 3 and 12 cm, respectively, but of course these parameters can easily be modified thanks to the modular construction. Each track is sampled an average of 30 times. With the expected (but not yet achieved) radial localization of each wire of around 40 μm r.m.s., a sagitta measurement should therefore be obtained with an accuracy of about 6 μm over 80 mm length (neglecting multiple scattering and systematic errors). Using a resistive anode wire, a longitudinal coordinate localization of 1% or better can easily be achieved [2]. The total amount of material along the radial direction is about 1.5% of a radiation length, but it is much larger (30% of a radiation length) in the end-plates, including the signal cables.

The present paper describes the recent development work and measurements realized with the multidrift tubes.

2. CONSTRUCTION AND OPERATION OF THE MULTIDRIFT MODULES

The method of construction of the MDM has been described in detail elsewhere [3–5] and will be recalled only briefly here. Wires are stretched between two precision-drilled fibre-glass plates and soldered onto miniature brass pins which have V-shaped grooves cut along their axes. The overall radial wire-positioning accuracy thus obtained is better than 20 μm . All cathode pins, and therefore the corresponding wires, are in electrical contact through a layer of copper glued to the external side of the plates, whilst the anode pins, insulated from each other and from the cathodes, allow readout of individual signals from both sides of the module. The geometry of the fibre-glass end-plate is

shown schematically in Fig. 3: small circles correspond to the holes receiving the cathode pins, and the double concentric circles represent the position of the anode pins. In order to ensure good insulation, the copper layer covering the external surface of the plate has a larger diameter bore cut around the holes for the anode pins.

The supporting carbon-fibre envelope is glued on the two plates and is electrically insulated from the electrodes; this enables it to be raised to a suitable potential so as to reduce electrostatic deflections of the wires, as will be discussed in Section 4.

A close-up of one end of a finished MDM is shown in Fig. 4, together with one of the special connectors developed by us for readout. During manufacturing, each end of the module was filled with epoxy, which is used to fasten the carbon-fibre envelope to the end-plates and also to cover all cathode pins completely (leaving just a contact for the high-voltage supply). After the curing process, surfacing on a milling machine exposed the tops of the anode pins, visible in the picture. For the particular model shown here, the electrical contact to the anodes was realized by inserting an anisotropic conducting membrane between the module and the flat printed circuit holding the miniature coaxial cables for the output signals; the contact is established by tightening the two parts together with the help of three threaded pins. This system of connection is cheap and simple to realize; however, because of the rather large variations in the contact serial resistance (a few ohms to several tens of ohms), it is only appropriate for time measurements on the anode wires and not for charge division. For this latter case, we have soldered the miniature cables directly to the anode pins during manufacture. This also helps to reduce the material in the end-plates. Figure 5 shows several finished modules with various connection systems.

All measurements described here have been realized using $20\text{ }\mu\text{m}$ diameter gold-plated tungsten wires for the anodes, and $70\text{ }\mu\text{m}$ copper-beryllium cathode wires. We have since satisfactorily tested modules with thicker anodes (up to $50\text{ }\mu\text{m}$) with the aim of increasing their ruggedness and improving the operating characteristics. The signal cables, about 80 cm long and with a characteristic impedance of $50\text{ }\Omega$, fan the high density of anode wire outputs to a system of fast hybrid amplifier-discriminator circuits [6] connected to CAMAC-based time-to-digital and charge-to-digital converters. For the beam runs, the data were written on tape using a small on-line computer and analysed off-line.

3. EXPERIMENTAL RESULTS

The MDM can be operated efficiently for the detection of radiation using virtually any gas mixture. However, because of the small cell size, the localization accuracy for the detection of fast particles is largely dominated by the primary ionization statistics, i.e. the average distance between primary clusters [$\approx 300\text{ }\mu\text{m}$ in an argon (80%) + methane (20%) mixture at atmospheric pressure]. We have therefore tried using pure dimethyl ether [DME: $(\text{CH}_3)_2\text{O}$] as the gas filling. This is an organic compound with high density at atmospheric pressure ($2.4 \times 10^{-3}\text{ g/cm}^3$ at 20°C), and which, like heavy hydrocarbons, is expected to have a primary ionization density higher than that of argon (maybe by a factor of 2). Our experimental results, although so far not allowing us to deduce the value of the primary ionization, confirm the substantial improvement in accuracy obtained using DME instead of conventional mixtures [3].

Although originally proposed for use in gaseous detectors because of its low electron diffusion and velocity at high fields [7], DME has also proved to be impervious to radiation damage due to polymerization. Indeed, proportional chambers operated with this gas have survived prolonged irradiation up to total detected charges above several coulomb per centimetre of wire [8].

The operating characteristics of the MDM filled with DME at atmospheric pressure are illustrated in Fig. 6, which shows the detection efficiency for minimum-ionizing particles, and the single wire noise (without radiation) as a function of high voltage. Both measurements have been realized with discriminators set at an equivalent input threshold of about $5 \times 10^{-2}\text{ pC}$. The gas

appears to have remarkable quenching properties, and allows us to reach large gains, in excess of 10^6 . A detailed analysis of the detected signal shows that even at the higher operating voltage we could not reach the limited streamer regime observed by other authors who used the same gas but single-wire cylindrical counters [9]. Figure 7 shows the average pulse height for minimum-ionizing particles recorded as a function of their distance from the anode wire (integrated in $200\text{ }\mu\text{m}$ intervals), for a beam crossing the drift cell perpendicular to one side, and at 2.5 kV. Because of the hexagonal geometry of the cell, the total ionization loss should decrease linearly to zero from a distance corresponding to half the cell radius; the detected charge follows the same trend, meaning that even at the higher gains the operational regime is still close to being proportional.

In order to convert from the recorded drift-time to the real coordinate, we had to use a suitable space-time correlation. In view of the lack of data concerning drift velocities at very high fields in DME, we preferred to measure the correlation directly with a pulsed ultraviolet laser in a special MDM having a small quartz window. The result is shown in Fig. 8, measured with a beam traversing the cell parallel to one side. Although these measurements did not enable us to reach the region furthest from the anode (hitting a cathode wire with the laser results in a large swarm of electrons), the curve can be extrapolated sufficiently well for our analysis, making use of existing data at lower fields [10].

Using the space-time correlation, together with a table of reference or zero times (deduced from the data) for each wire, it is possible to compute the drift distance for all wires hit by a track. The reconstruction program then finds the best alignment between the recorded coordinates for each event, employing a standard fitting procedure described in Refs. [4] and [5]. Figure 9 shows a typical reconstructed event in the MDM, and Fig. 10 is the distribution of the difference between fitted and measured coordinates on a wire for a typical run; it has a r.m.s. of $70\text{ }\mu\text{m}$.

4. DISCUSSION OF THE RESULTS AND FUTURE IMPROVEMENTS

Various factors contribute to determining the localization accuracy: the already mentioned primary ionization statistics, the electron diffusion, the electronic noise and slewing, the systematic effects such as wire-positioning accuracy and the exact shape of the space-time correlation. A preliminary simulation of the physical processes, which was done with a Monte Carlo program, and some recent results obtained in the same gas with single-wire proportional counters [9], tend to suggest that our main source of dispersion is at present the electronic slewing, i.e. the dependence of the recorded time on the amplitude and shape of the input signal. This is particularly important for tracks close to the wires because of the time structure of the detected signal (with individual clusters reaching the anode over a larger time span) and because of the higher drift velocity in that region. In order to reduce the dispersion, we are currently experimenting with larger anode-wire diameters in the hope of reaching the limited streamer operation that would partly obliterate the slewing effects, and we are developing better and faster electronics.

Another way of improving the localization accuracy of the module is to increase the operating gas pressure. With the present method of construction, the MDM can withstand a pressure above 10 bars without failure, although with a rather substantial deformation of the tube. We had, however, to improve substantially the insulation between electrodes in order to be able to increase the operating voltage, the most critical problem being due to microdischarges between anode and cathode pins on the surface of the epoxy-covered end-plates, probably owing to small cracks or to pockets of air trapped during the curing process. One prototype has been successfully operated at 1.75 bars in DME; this required a high-voltage value of around 3.5 kV. This development will be further pursued by installing the chamber and carrying out measurements in a minimum-ionizing particle beam.

In order to be able to build longer modules and to operate them at high voltages, we used a computer program to analyse the electrostatic deflections of the wires in the module as a function of high voltage and length. Because of the cylindrical symmetry of the hexagonal cells in our modules, an infinite structure of such cells would be stable at any length and voltage, apart from positioning errors and gravitational sagging effects. In a finite module, however, the symmetry is broken at the boundaries, and this causes a displacement of the outer layers of wires. In normal operating conditions (grounded anodes and envelope, cathodes at -2.2 kV), the cathode wires in the outer layer have an outward maximum displacement of $350\text{ }\mu\text{m}$ in the centre of an 80 cm long tube; the outer layer of anode wires move inward by $150\text{ }\mu\text{m}$ under the same conditions. Although the operation of the module seems unaffected by these displacements (in particular, there is no detectable change in the gain of the modified cells), the tracking algorithm would become rather involved. When the outer envelope is kept at an intermediate potential, around -0.5 kV, the maximum displacements are reduced to $200\text{ }\mu\text{m}$ and $30\text{ }\mu\text{m}$ for the outer cathode and anode wires. This is quite acceptable in the present design (see Fig. 11). The experimental results described in the previous sections were in fact obtained under these conditions.

The electrostatic displacements can be further reduced by designing the module differently. Inspection of the field map in the module (Fig. 12) shows that there is, indeed, an equipotential line waving through the cells close to the cathode wires. Replacement of this line by a physical boundary at the proper potential would leave the symmetry of the infinite structure unperturbed, and no wire would be displaced by electrostatic forces. This geometry can be approximated with a flat surface, such as that of the envelope; this corresponds to a module in which the carbon-fibre tube has been rotated by 30° as compared to the original design. In this case we have computed a maximum displacement of the anode wires of less than $20\text{ }\mu\text{m}$, always for an 80 cm long module operated at -2.2 kV and with the envelope at -1.8 kV.

For longer modules, or at higher operating voltages, it will be necessary to resort to some kind of regular internal wire support, much as is done in large-size multiwire proportional chambers. Various ways of realizing such supports without spoiling the performance are being investigated.

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Figure captions

- Fig. 1 : Schematics of the multidrift module. The basic detection cell consists of an anode wire surrounded by six cathode wires in a hexagonal geometry; the pattern is repeated to fill all the volume contained in a carbon-fibre envelope. In the present design, 70 drift cells are packed within a 30 mm diameter tube.
- Fig. 2 : An example of 48 MDMs assembled around an intersection to constitute a tracking detector. The inner and outer radii of the device are 3 cm and 12 cm, respectively. Tracks are detected and localized both radially (through a drift-time measurement) and longitudinally (through charge division) an average of 30 times.
- Fig. 3 : Schematics of the drilling geometry of the end-plates. Small circles represent the holes for inserting the wire-holding cathode pins; around the anodes, a larger-diameter shallow bore ensures insulation against the copper-covered surface of the plate.
- Fig. 4 : One end of a finished module. The contacts to the anode pins are visible, as well as the tube for the gas and the pin for the high-voltage supply. The three threaded pins are used for assembly and to hold the signal connector in place, the contact being ensured by an anisotropic conducting membrane, also seen in the picture.
- Fig. 5 : Several finished modules with different connectors; the modules are 80 cm long.
- Fig. 6 : Efficiency plateau for minimum-ionizing electrons and singles counting rate on one wire without radiation, measured in a fully instrumented module with DME gas filling.
- Fig. 7 : Average pulse height for minimum-ionizing particles measured as a function of their distance from an anode wire. Tracks cross the hexagonal cell in a direction perpendicular to one side. The decrease of detected charge (full points) corresponds to the geometrical thickness of the sensitive volume (represented by the dashed line), showing the proportionality of the counter (DME at 1 bar, 2.5 kV).
- Fig. 8 : Space-time correlation in DME at 1 bar, measured in a special drift tube with a pulsed laser beam.
- Fig. 9 : Example of a single-track reconstructed event. The circles represent the measured drift time on the hit wires.
- Fig. 10 : Distribution of the difference between the fitted and the measured coordinates on a wire for a typical run with minimum-ionizing particles; it has a r.m.s. of 70 μm .
- Fig. 11 : Computed maximum wire displacements in the centre of a standard MDM, 80 cm long; the scale of the displacement is increased by a factor of 5 in the drawing. Operating conditions: cathodes at -2.2 kV, grounded anodes, outer envelope at -0.5 kV.
- Fig. 12 : Computed electric field and equipotentials in the MDM.

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