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THE USE OF A PAIR OF TIME PROJECTION CHAMBERS AS A WIDE-ANGLE VERTEX DETECTOR
FOR THE Ω' SPECTROMETER AT CERN

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ABSTRACT

A pair of time projection chambers have been tested in an 85 GeV/c π^- beam. The chambers were placed inside the magnetic field of the Ω' spectrometer at CERN. A description of the device and the associated electronics is given. Results obtained on track and vertex reconstruction accuracy are presented.

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1. INTRODUCTION

The time projection chambers (TPCs) that will be described in this paper are part of a vertex detector for a CERN-SPS hybrid experiment [1] designed to search for beauty particles produced by a 350 GeV/c π^- beam in nuclear emulsion. A sketch of the complete vertex detector is presented in fig. 1, where a simulated interaction of a 350 GeV/c incident π^- in the emulsion target is also shown. The microstrip detector [2] telescope will handle the part of the event contained in the forward cone ($\theta < 90$ mrad) making use of its excellent accuracy (15 μ m r.m.s.) and two-track separation (150 μ m). The role of the TPC system will be to cover a wide angular region ($65 < \theta < 600$ mrad) providing space points and track segments with good accuracy (~ 200 μ m r.m.s.) in order to improve the matching efficiency between the visual information contained in the emulsion target and the information that the Ω' spectrometer [3] gives on the same event.

Wide-angle tracks are expected to be very important in the matching procedure, since their pattern constitutes the "signature" of an event, especially when emulsions are exposed perpendicularly to a high momentum beam.

In section 2 we describe the chambers, in section 3 the electronics, in section 4 the test set-up, and in section 5 the experimental results.

2. THE TIME PROJECTION CHAMBERS

The time projection chamber [4] is a device well suited to the handling of multitrack events. In this type of detector the ionized trails produced in a large gas volume drift to a plane of proportional wires, where recording of position, drift-time and pulse height provides a very detailed description of the event pattern (see fig. 5).

At present several Collaborations are using [5] or plan to use [6] TPCs, especially for experiments at colliding-beam accelerators. The main advantage of such a detector is that it gives true "space points" and thus it considerably simplifies the pattern recognition problem. In the WA71 [1] experiment two major requirements were demanded of the TPC:

- i) It should cover a wide angular range ($\theta < 600$ mrad), where track coordinates should be known within $200 \mu\text{m}$ r.m.s. in order to guarantee a good matching between emulsion and TPC information.
- ii) It should introduce a negligible thickness (in radiation and nuclear length) between the target and the Ω' spectrometer in order to avoid the deterioration of the track pattern measured by these two devices.

The solution we have chosen after some measurements with a test TPC [7] is to split the detector into two (TPC-UP and TPC-DOWN) in such a way as to measure tracks produced in the angular range: $65 \leq \theta \leq 600$ mrad, where the limited two-track resolution (2-3 mm) of the TPC does not introduce sensible inefficiencies. For $\theta < 65$ mrad the vertex detector function is taken over by a telescope of 6 microstrip detectors with $50 \mu\text{m}$ pitch and $2.5 \times 2.5 \text{ cm}^2$ sensitive area. Figure 1 presents the full vertex detector, while fig. 2 shows an exploded view of a TPC. The main characteristics of a TPC are listed in table 1.

The high voltage drift (HVD) plane (see fig. 2) is a mesh of wires of $50 \mu\text{m}$ diameter with $500 \mu\text{m}$ spacing. The uniformity of the electric field that causes the electrons to drift at constant speed is obtained by using wires, 5 mm apart, linked to appropriate potentials and surrounding the drift volume. The equipotential lines obtained with such a method have been calculated [8] and are shown in fig. 3; appreciable field inhomogeneities enter the sensitive region of the TPC for less than 5 mm. The two TPCs are contained in a gas-tight aluminium vessel, with wide ($40 \times 40 \text{ cm}^2$) windows in the front and the back. The windows are made of $50 \mu\text{m}$ mylar and thin copper mesh. The material seen by the particles crossing the TPC amounts to about 0.075 g/cm^2 for $\theta < 600$ mrad. The signal and field wires of the proportional detector (see fig. 4 where the field map in operating conditions is also shown) have been positioned with an accuracy of 0.05 mm to guarantee the uniformity of the gain. The pads on the ground plane have been made using a printed-board technique.

3. THE ELECTRONICS

3.1 Pad electronics

The signal coming from each pad is treated by a linear chain^{*)} made of a charge amplifier placed on the chamber and a differential receiver at the end of a 30 m long twisted-pair cable. The pulse height is then digitized through a CAMAC 8-bit analogue-to-digital converter (ADC) (LRS 2249A^{**}). The gain of the linear chain is 500 mV/pC and the output pulse is 250 ns wide with a flat top of about 100 ns. The long tails of the pulse are cut by summing to the original pulse the same pulse delayed by 200 ns and inverted.

3.2 Wire electronics

The signal coming from each wire is amplified and shaped using a circuit where after an amplifier stage, a constant fraction discrimination [9] is applied to the pulse[†]).

The effect of different track inclinations and drift paths on anode pulse shape have been calculated taking into account the electron diffusion in gas.

It has been demonstrated [10] that a constant fraction discrimination technique applied to anode pulses minimizes the variance of the measurement of the drift coordinate.

The relevant parameter of the amplifier-discriminator chain have been optimized for our TPC (time constant of the amplifier = 15 ns; delay line of the constant fraction stage = 18 ns; fraction = 0.6).

The digital signal on the differential outputs of the amplifier/discriminator reaches a multiple time digitizer (MTD type 290) [11] at the end of a 30 m long twisted-pair cable.

^{*)} Designed at CERN by J.C. Santiard.

^{**}) A more refined read-out system based on 7-bit flash-ADC and automatic zero suppression is at present under test.

[†]) Designed at RAL by D.J. White.

The MTD system has been modified in order to cover 4 μ s total drift-time, with an accuracy of about 2 ns r.m.s. The MTD system works in "delayed stop mode", i.e. it inspects a 4 μ s long memory filled in 16 ns steps with the yes/no answer coming from the discriminator only when a trigger, digitally delayed by 4 μ s, is given to the MTD controller. An MTD 290 has been chosen because it is a completely digital circuit, with no need for calibrations, and because it allows multihit recording.

4. THE TEST SET-UP

The TPCs have been placed in the magnetic field ($|\vec{B}| = 12$ kG) of the Ω' spectrometer at CERN. The first wire of each chamber was 27 cm downstream of the emulsion target. An 85 GeV/c hadron beam with small divergence ($\lesssim 0.5$ mrad) hit the target; the beam position is measured by two proportional chambers (beam chambers) with 1 mm pitch, placed 1 m upstream. The intensity of the beam ranged from 10^5 to 10^6 pps (corresponding to 10^4 - 10^5 pps in each TPC) and the beam spot was 7×3 mm². Interactions in the thin (1.2 mm) emulsion pellicle are selected according to the following requirements:

- i) the energy release in a silicon detector [12] must be bigger than an amount fixed previously (corresponding to the mean energy release of two minimum ionizing particles), and
- ii) the charged multiplicity must be larger than three in some Ω' proportional chambers.

About 5×10^5 interactions in the target (most of the time a 1.2 mm copper sheet) were recorded on magnetic tapes during a 10-day setting-up run in June 1982.

5. EXPERIMENTAL RESULTS

We report here only results on drift coordinate measurements, the pad pulse-height analysis still being preliminary.

The easiest way of starting the discussion on experimental results is to show what an event looks like in the (z,x) plane. This is illustrated in fig. 5, where

numbers indicate hits associated with a track by the program. The association is done by requiring at least 7 hits out of 12 (the extreme wires give slightly less precise results so we left them out of the fitting procedure) being in a path of $\pm 500 \mu\text{m}$ from the straight line defined by two pivot planes. The reconstruction can be done after adjustment of the drift speed (we notice a difference of about 1% from one wire to another) and absolute calibration. This last step was performed through a comparison of the parameters of a sample of tracks measured in the TPC and in the Ω' spectrometer. The mean number of tracks reconstructed per event is 4 (two per TPC) and the distribution of the number of hits per track is shown in fig. 6. From fig. 6a, taking into account the TPC angular acceptance, we calculated the wire efficiency to be 95%; the redundancy is anyhow large enough to overcome these losses. The spatial accuracy s has been defined as the difference between the z -coordinate calculated with the linear fit procedure ($= z_c$) and the z -coordinate measured ($= z$).

Loose requirements are put on the linear fit constraints (path = 5 mm) in order to avoid biases in this measurement. The result for one wire is shown in fig. 7; the accuracy, integrated over 16 cm of drift, is $250 \mu\text{m}$ r.m.s. if one fits data with a Gaussian, neglecting the long-tail contributions. The tail of the accuracy distribution is larger for $z_c > z$ because of the δ -ray effect on the space-time relation.

The dependence of the accuracy on drift distance has been calculated:

$$\sigma(z) = \sqrt{\sigma_0^2 z + \sigma_1^2} \quad (\text{with } z \text{ in cm})$$

where $\sigma_0 = 55 \mu\text{m}/\sqrt{\text{cm}}$ is the diffusion-dependent term and $\sigma_1 = 100 \mu\text{m}$ is the constant contribution due to the accuracy of the time-measuring electronics. A scatter plot of the accuracy versus the drift distance is shown in fig. 8.

Vertices have been reconstructed along z and x with a simple algorithm that finds the centre of gravity of all track-pair intersections. A weighting factor $\text{tg } \alpha$, where α is the angle between the two tracks of a pair, is applied in the search for the vertex along x . The reconstructed vertices are shown in fig. 9, where the target profile along x is also drawn.

The z-coordinate of the vertices is then compared with the z coordinate of the incoming beam measured by the beam chambers. The difference between these two measurements, shown in fig. 10, indicates that the accuracy of the vertex along z is

$$\sigma_v(z) = \sqrt{\sigma_d^2 - \sigma_b^2} = \sqrt{1200^2 - 900^2} = 800 \text{ } \mu\text{m} ,$$

where σ_d is the r.m.s. of the distribution in fig. 10 and σ_b is the r.m.s. of the beam chamber prevision at the target (taking into account the pitch of the chambers, their position along the beam, and the beam divergence). The value of $\sigma_v(z)$ obtained corresponds to that calculated taking into account the multiple scattering in the material between the target and the TPC (1 g/cm²), and the accuracy and position of the TPC.

The agreement between the measured and the calculated value for $\sigma_v(z)$ indicates that there are no significant systematic effects in the TPC measurement.

6. CONCLUSIONS

A pair of TPCs, placed in a 12 kG magnetic field, have been tested reconstructing interactions made by an 85 GeV/c π^- beam hitting a thin emulsion target. The space accuracy (r.m.s.) along the drift direction has been measured as

$$\sigma(z) = \sqrt{\sigma_0^2 z + \sigma_1^2} \quad (\text{with } z \text{ in cm}) ,$$

where $\sigma_0 = 55 \text{ } \mu\text{m}/\sqrt{\text{cm}}$ is the diffusion-dependent term and $\sigma_1 = 100 \text{ } \mu\text{m}$ is the electronic constant dispersion. The use of a properly tuned constant fraction discriminator makes this accuracy independent of the track angle.

Vertices have been reconstructed using only the information from the TPCs. They have been measured to an accuracy (r.m.s.) of 800 μm along z and of 1 cm along x (beam direction). The good agreement between these values and Monte Carlo simulations indicates that the calibration procedure is understood.

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Table 1

Chamber characteristics

Anode wires $\emptyset$	20 μm
Cathode wires $\emptyset$	100 μm
Field wire $\emptyset$	100 μm
Spacing (anode wires)	12 mm
Proportional gap	6 mm
Drift gap	160 mm
Pad area	$6 \times 8 \text{ mm}^2$
Pad spacing	1 mm
Number of anode wires/TPC	16
Number of pad columns/TPC	3
Number of pads per column	32
Gas mixture	$\left\{ \begin{array}{l} 70\% \text{ argon} \\ 29\% \text{ isobutane} \\ 1\% \text{ isopropyl alcohol} \end{array} \right.$

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Figure captions

- Fig. 1 : Sketch of the vertex detector for the WA71 experiment at CERN (see text for details). The coordinate system used in the article is also shown.
- Fig. 2 : Exploded view of a TPC. A = pad plane; B = anode and field wire plane; C = grid plane; D, E = field shaping wires; F = HVD plane.
- Fig. 3 : Equipotential lines calculated in the drift region of the TPC (HVD = -15.5 kV).
- Fig. 4 : Field map in the proportional cell (HV = 2.1 kV, HVD = -17 kV).
- Fig. 5 : Display of an event in the (z,x) plane.
- Fig. 6 : Number of hits per track with two different requirements for reconstruction. a) path = 5 mm; b) path = 0.5 mm.
- Fig. 7 : Spatial accuracy of the TPC along the drift direction, integrated over the full drift space.
- Fig. 8 : Scatter plot of the spatial accuracy versus the drift coordinate.
- Fig. 9 : Vertices reconstructed by the TPC. a) along z; b) along x. The source dimensions (shaded areas) are also shown. The peak at -23 cm in (b) is due to interactions in a beam defining counter.
- Fig. 10 : Distribution of the differences between the z coordinate of the vertex measured with the beam chambers and the same quantity measured with the TPC.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

EVENT NUMBER 17

Fig. 5

Fig. 6

Fig. 7

Fig. 8

a)

b)

Fig. 9

Fig. 10