ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Genova

INFN/AE-81/2
22 Gennaio 1981

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(Submittet to Nuclear Instr. and Meth.)

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Istituto Nazionale di Fisica Nucleare
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A TIME PROJECTION CHAMBER FOR PRECISE VERTEX DETERMINATION

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SUMMARY.

A Time Projection Chamber, to be used for improving the vertex reconstruction accuracy of the Omega spectrometer at CERN, has been tested on a 7 GeV/c hadron beam. Results on efficiency, space accuracy, multitrack handling and vertex reconstruction precision are presented together with a description of the read-out electronics and details of construction.

1. - INTRODUCTION.

The study of charm and the search for beauty particles in a fixed target experiment with a hybrid spectrometer need the best vertex reconstruction accuracy possible with present techniques mainly for two reasons :

a) to decrease the fiducial volume to be scanned in the nuclear emulsion target for finding the primary vertex ;

b) to distinguish, at least in a fraction of events, a secondary vertex very close (~1 mm) to the primary one.

While the first point is true for all experiments with an emulsion target and downstream spectrometer, the second is specific to an experiment(1) where the decay of a long lived charm is used to trigger the apparatus ; this information is afterwards used to look for the charmed partner or, when the incident particle energy is sufficient, for the beauty parent.

Evidently the separation between the primary and the secondary vertex will greatly help in distinguishing a charm particle decay from the possible sources of background(1), thus im proving the signal to noise ratio. For this reason a vertex reconstruction accuracy of the order of 1 mm in the beam direction is required.

A device with good spacial resolution, simultaneous xy measurements, multiparticle handling and negligible thickness (in radiation and nuclear length) should then be placed very close to the emulsion target to improve the performance of a spectrometer.

The chosen solution was a time projection chamber (TPC)$^{(2)}$ specially suited to handling high multiplicity events and to couple with the Omega prime$^{(3)}$ spectrometer. In the following we give a description of this device, of the electronics we used and of the test set up.

Finally we give experimental results on the relevant parameters.

2. - THE TIME PROJECTION CHAMBER.

The Time Projection Chamber idea was proposed in 1975 by D. Nygren$^{(2)}$ and recently developed by several experimental groups$^{(4)}$ all working at colliding beam machines. This device is an improvement of the drift chamber detector$^{(5)}$ and it is specially suited for the measurement of complex events in a magnetic field.

The aims of the TPC are:

a) to provide, with high precision, three-dimensional space coordinates along trajectories of charged particles;

b) to measure, with a sampling technique, the ionization released by each track in such a way to identify particles over a wide range of momenta.

The specific application described in the introduction requires primarily a precise measurement of track coordinates. We concentrate on point a), since we can rely on the spectrometer for particle identification. This allow us to fill the chamber with an atmospheric pressure gas mixture, avoiding the various mechanical problems rising from the use of the highly pressurized vessel needed for the dE/dx measurement. A sketch of the chamber is shown in Fig. 1.

The TPC behaves as follows:
The electron cloud, surrounding each track passing in the drift volume, moves towards the HV mesh under the action of the electric field: most of the electrons passes through this mesh at

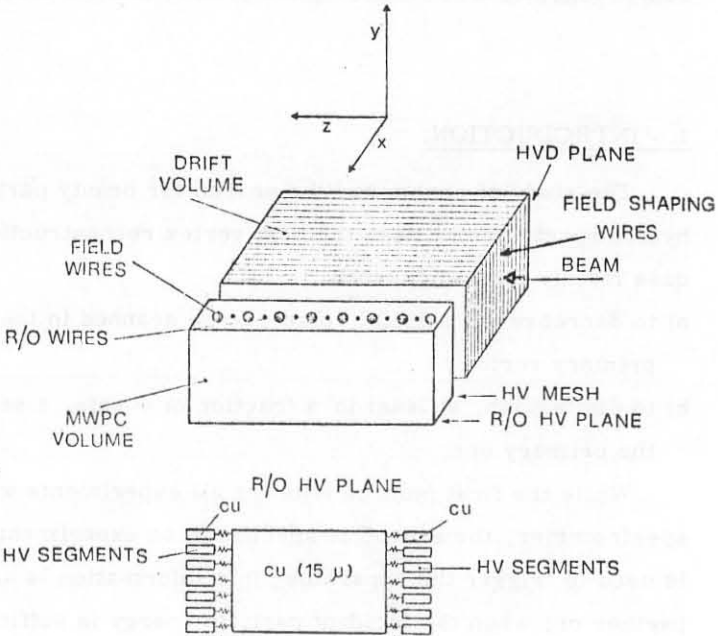

FIG. 1 - Sketch of the chamber.

tracted by the anode wires of the proportional volume and give negative signals there. Opposite sign pulses are induced on the cathode segments (pads).

The time difference between a reference signal and each anodic pulse will give, like in a drift chamber, the x coordinates (see Fig. 1) while the y coordinates are obtained by looking for the center of gravity of the signals induced, at the same time, on the pads(6).

The (x, y) information therefore comes from the same physical effect. This fact avoids wrong combinations (i. e. ghost points) whose number quadratically increases with the event multiplicity. The chamber characteristics are presented in Table I.

The choice of the listed parameters has been dictated by the following considerations:

a) a highly symmetric configuration of the proportional cell is desirable in order to work at relatively low voltage and with a wide efficiency plateau ;

b) a sufficient ($\gtrsim$ 1 cm) gas thickness should correspond to each proportional cell to avoid excessive fluctuations in the number of ion-electron pairs produced ;

c) a good transparency of the grid which separates the drift from the proportional region is required to reach the full efficiency of the TPC ;

d) an optimum size of pads(7) (obtained by making a compromise between the need for a good signal to noise ratio and the requirement of a satisfactory interpolation precision).

TABLE I

Anodes wires ∅	20 μm
Cathode wires ∅	100 μm
Field wire ∅	100 μm
Spacing (all wires)	12 mm
Proportional gap	6 mm
Drift gap	80 mm
Pad area	6 x 8 mm^2
Pad spacing	1 mm
No. of anode wires	21
No. of pad columns	2
No. of pads per column	12

In the chamber described, the vertex measurement is mainly done on the xz projection (see Fig. 1), while the two points on the yz projection add auxiliary conditions and help to solve ambiguities.

Particular care has been taken to minimize the amount of material particles can encounter.

The chamber is contained in a 30 x 30 x 50 cm plexiglass box, with wide 100 μm thick mylar windows ; each thick metallic component, like HV connectors, is then placed at a wide ($> 60^{\circ}$) angle to the incident beam direction.

Field shaping electrodes, separated by 4 mm, surround the drift volume and make the electric field uniform over the TPC sensitive region.

3. - READ-OUT ELECTRONICS.

The amount of information we require from this chamber is greatly reduced compared to the pressurized TPC. For this reason we substitute for the standard approach(8), based on reading out the anode and the cathode pulse heights in small (~ 50 nsec) time slices, a different scheme where we memorize the pad pulse height information only when a pulse is detected on the facing anode. The anodes, on the contrary, are read out via a quasi-standard TDC method. The electronics principle is illustrated in Fig. 2.

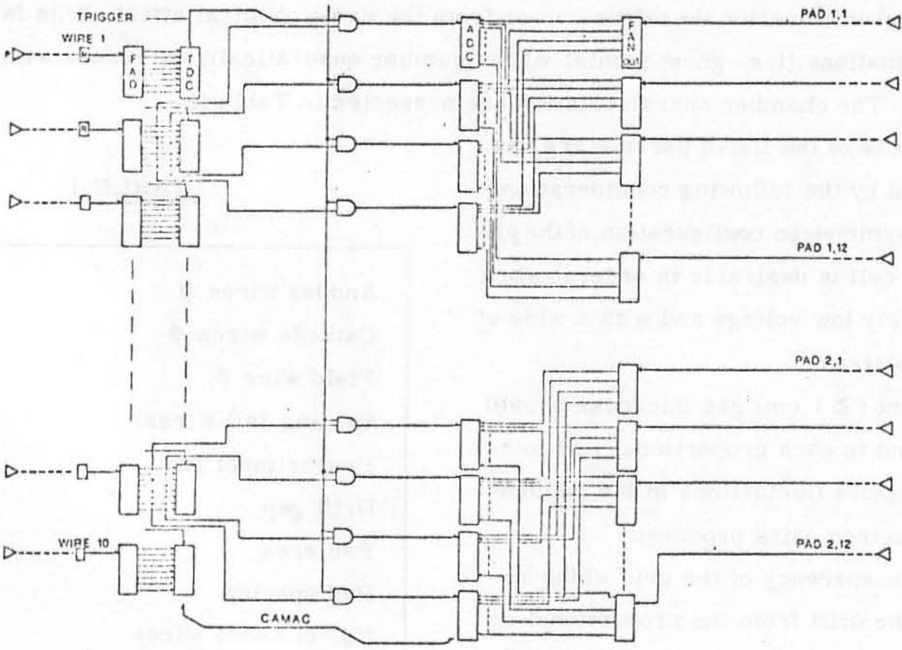

FIG. 2 - Read out electronics layout.

We pick up, out of each anode wire, a maximum of N short (~ 10 nsec) NIM$^{(9)}$ pulses to stop N TDC channels previously started by an external reference signal (N = 12 is the maximum allowed multiplicity).

So we use a standard low impedence amplifier (P) followed, after a long (80 m) twisted pair delay cable, by a shaping receiver (R)$^{(10)}$ and by an ECL fast demultiplexer system (FAD) capable of switching in $\lesssim 4$ nsec from one channel to the next. Standard TDC CAMAC$^{(11)}$ modules (LRS 2228 A type with expanded time scale) are then used to compute the hit spacial position.

The wires$^{(2,9)}$ facing pad rows should also provide longer (~ 70 nsec) pulses to gate the ADC where the cathode information is sent. Each pad read out chain (see Fig. 2) is composed of a charge preamplifier (CP)$^{(12)}$, a coaxial delay line, a linear fan-out (LRS 428 type) and an ADC CAMAC module (LRS 2249 A type).

The approach described is largely based on existing electronics modules ; a more dedicated system is now under study.

4. - THE TEST SET-UP.

A sketch of the test set-up is shown in Fig. 3. S1, S2, S3, S4 are $1 \times 1 \times 10$ cm^3 scintillation counters, SC$_o$ is a $40 \times 40 \times 1$ cm^3 scintillator with a 2.5 cm hole in the middle, T1 and T2 are silicon telescopes(*). T1 is a set of five 100 μm thick and 1.0 cm diameter silicon sheets separated by 100 μm, while T2 is a set of ten 200 μm thick and 2.5 cm diameter silicon sheets separated by 300 μm each.

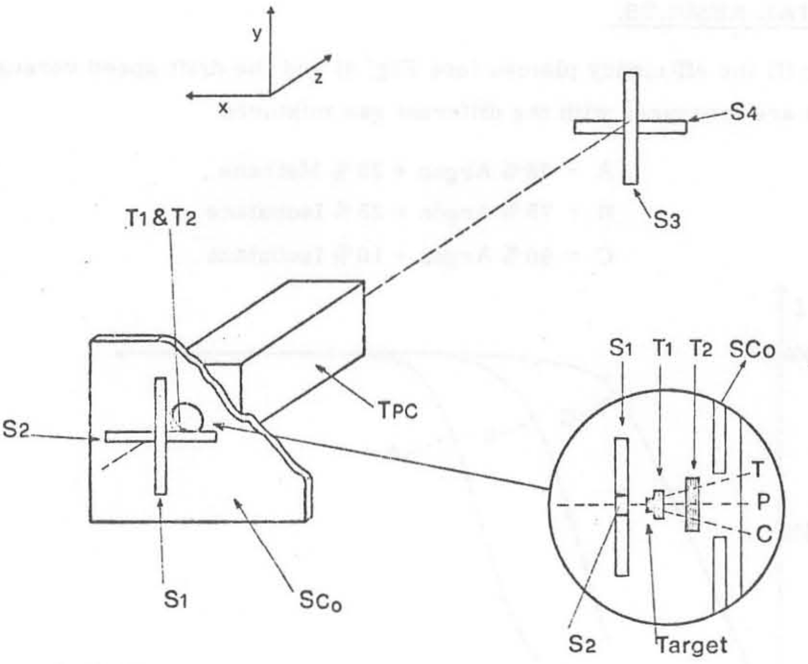

FIG. 3 - Experimental set up.

A 7 GeV/c hadron beam (D31 beam at CERN Protosynchrotron) hits a lead target ($1 \times 1 \times 0.3$ cm) placed just in front of T1. The beam trigger is:

$$S1 \times S2 \times S3 \times S4 \times \overline{SC_o} \ , \tag{I}$$

the interaction triggers are:

$$S1 \times S2 \times SC_o \times (\overline{S3 \times S4}) \tag{II}$$

$$S1 \times S2 \times (\sum_i T1_i \gtrsim \text{thr.}) \times (\overline{S3 \times S4}) \ . \tag{III}$$

The condition $\sum_i T1_i \gtrsim$ thr. corresponds to the requirement that at least 2 minimum ionizing particles should have been seen by the silicon Telescope T1.

(*) - The telescopes, produced by ENERTEC Schlumberger, Strasbourg, France, have been specially studied to trigger on charm particles(1) and were tested together with the TPC(13).

The chamber is filled with 90 % Argon, 10 % Isobutane gas mixture.

The TPC, placed at 10 cm from the target region, is equipped with 10 anodic read out channels ; they are all read out together with the information coming from one pad row. A negative voltage is applied to the drift electrode (HVD in Fig. 1). The sense (anode) wires are connected to a positive voltage and are linked to the preamplifier via high voltage 47 pF capacitors.

5. - EXPERIMENTAL RESULTS.

Using trigger (I) the efficiency plateau (see Fig. 4) and the drift speed versus high voltage curve (see Fig. 5) are measured with the different gas mixtures

A = 75 % Argon + 25 % Methane ,
B = 75 % Argon + 25 % Isobutane ,
C = 90 % Argon + 10 % Isobutane .

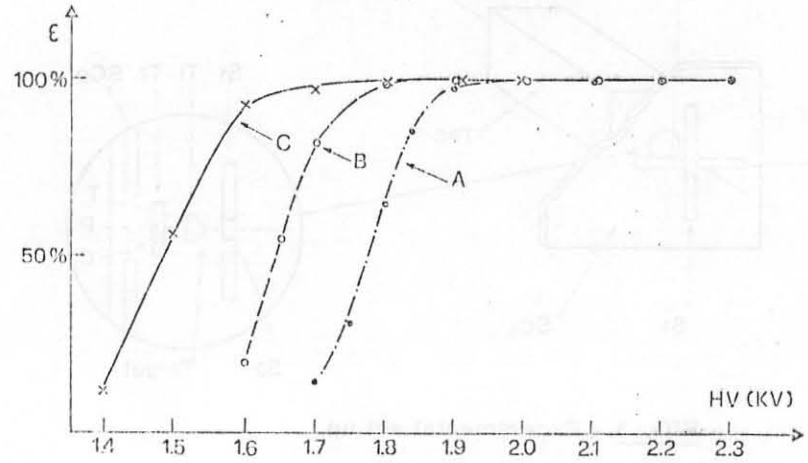

FIG. 4 - Efficiency plateau of the chamber versus voltage applied to the proportional gap for different (see text) gas mixtures.

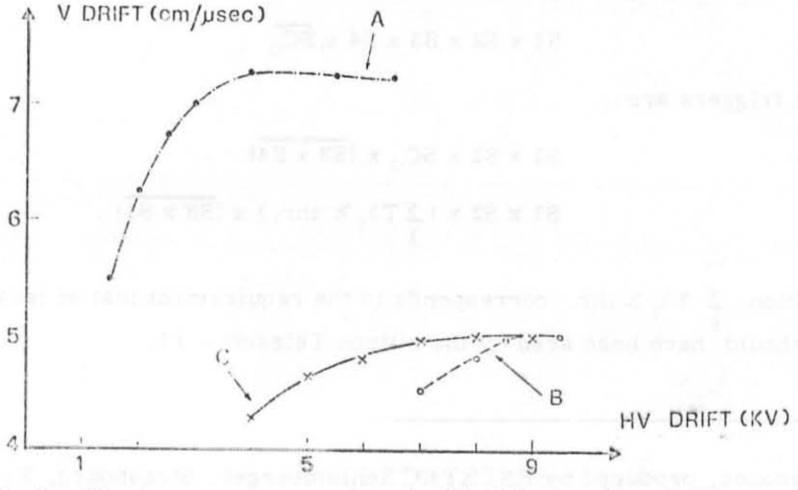

FIG. 5 - Electron speed, measured with different (see text) gas mixtures, versus drift voltage.

We then choose the gas mixture C to pursue the tests because it is possible to work at a modest proportional voltage and because a lower drift speed allows a better two-particle separation when this quantity is dominated by the electronics dead time.

The precision along the drift coordinate is measured by looking at the time difference between wire n and wire n+1 (see Fig. 6) ; neglecting the beam divergence we can write :

$$\sigma_{x(n+1)} = \sigma_{x(n)} = \frac{\sigma}{\sqrt{2}}\, x((n+1)-n)$$

and, from Fig. 6, $\sigma_{x(n)} \simeq 200\ \mu m$ (this value contains the electronics chain jitter).

Up to 10 hits per track can be measured by the TPC with present electronic equipment and can be used for pattern recognition. The track reconstruction precision is measured as follows: first we find the best linear fit among the hits and then we compute the fraction of reconstructed tracks as a function of the maximum allowed distance R between the fitted track and the avalanche position (see Fig. 7).

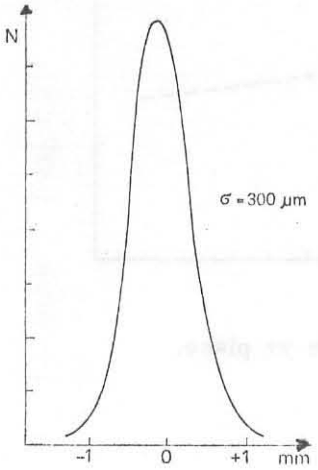

FIG. 6 - Time difference between pulses coming from adjacent wires.

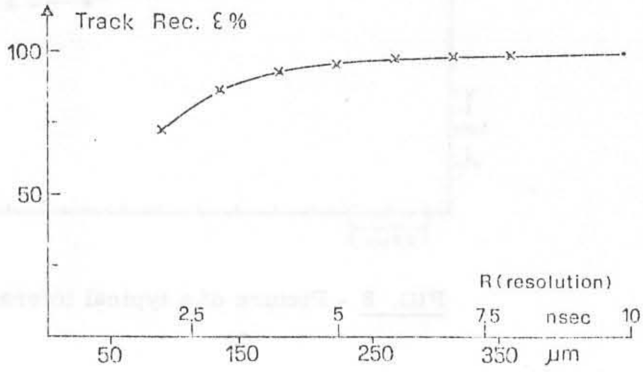

FIG. 7 - Track reconstruction efficiency versus maximum allowed distance R between the fitted track and the avalanche position. **Ten wires of the TPC** are read-out.

A set of points was defined as a track if at least 5 of them were less than a distance R from the fitted track.

Out of this figure we conclude that it is possible to achieve about 90 % track reconstruction efficiency with 150 μm space resolution. Inclining the chamber at 20^{o} in the yz or the xy plane no change is detectable on track reconstruction accuracy.

We then switch to trigger (II) or (III) to look for interactions (the picture of a typical interaction - in the xz plane - is shown in Fig. 8) and we reconstruct vertices in the target region requiring 90 % reconstruction efficiency for single tracks.

The comparison between the vertex accuracy and the target physical dimensions is shown in Fig. 9. We then fit the experimental histograms with a square distribution (the target physical dimension) plus a gaussian (the measurement error). The matching of the data happens with :

$$\sigma_x = 0.7 \pm 0.2 \text{ mm} \; ; \qquad \sigma_z = 2 \pm 1 \text{ mm} .$$

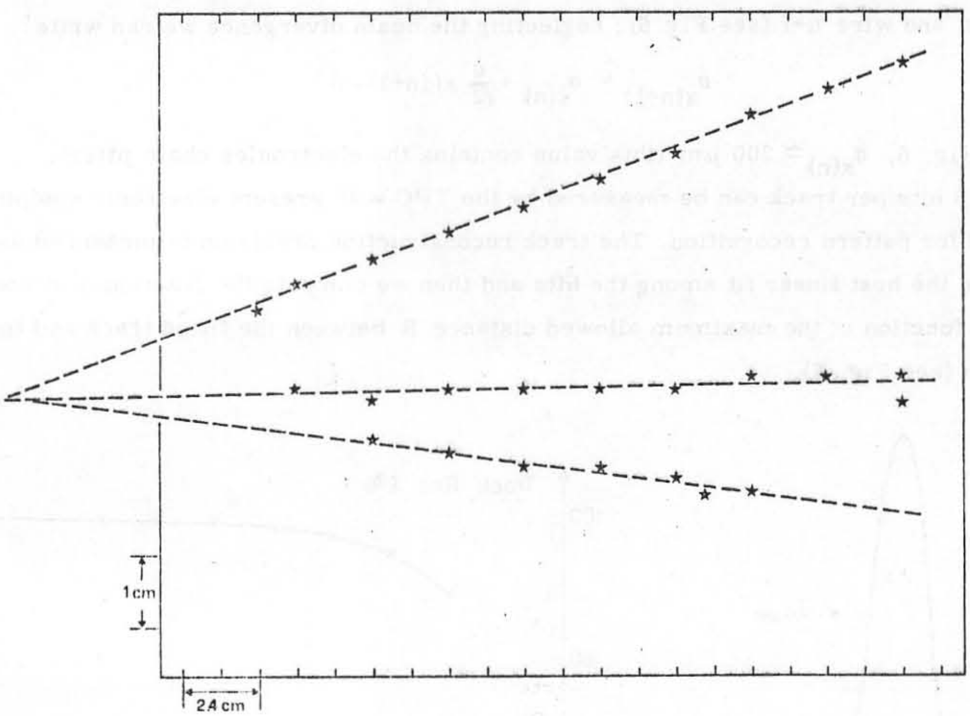

FIG. 8 - Picture of a typical interaction in the yz plane.

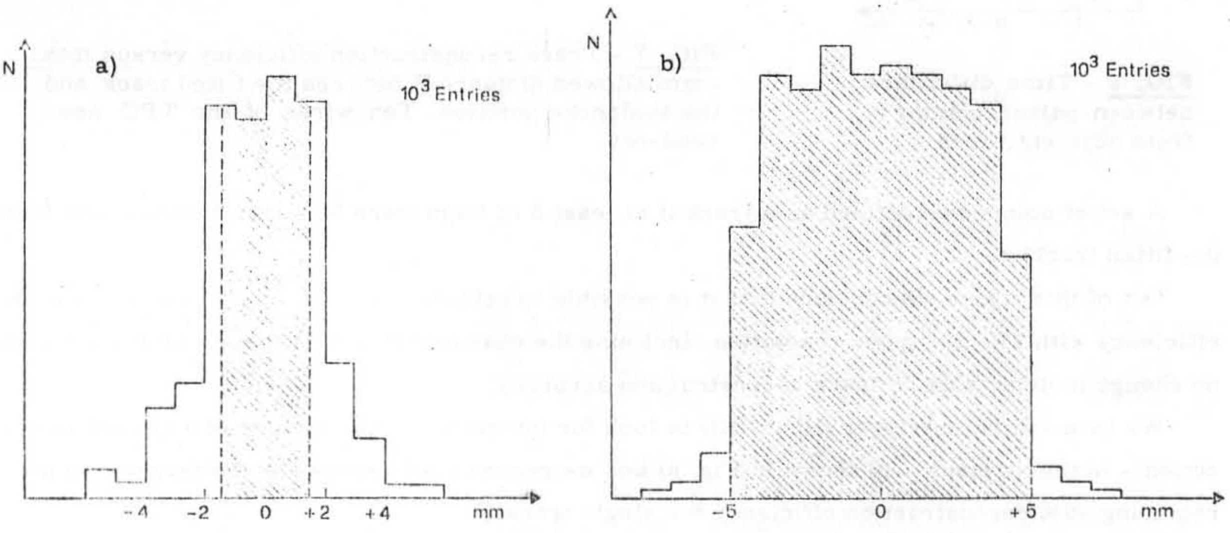

FIG. 9 - Comparison between the target physical dimension (shadowed areas) and the reconstructed vertex position in: a) z direction; b) x direction.

A Monte Carlo program using the experimentally measured accuracy of our TPC and the particle distribution expected from a 70 GeV/c photon beam has been used to compute the number of read out channels necessary for the vertex accuracy optimization in the Ω' experiment (see Fig. 10)(1).

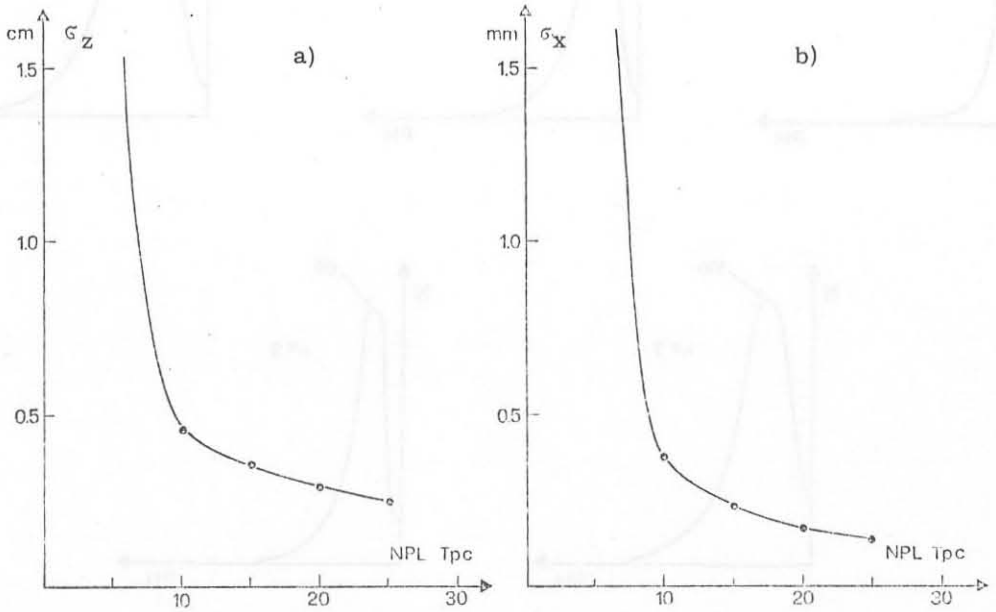

FIG. 10 - Standard deviation of the vertex reconstruction accuracy in: a) z direction; b) x direction; versus number of planes of our TPC. Simulated events induced by 20-70 GeV photons are reconstructed only through a TPC placed at 10 cm from the source.

To study cathode performances we used trigger (I) thus limiting ourselves to tracks parallel to the plane of pads. The Landau pulse height distribution for several contiguous pads facing the beam is shown in Fig. 11. From this figure (and from the scanning of some pulse height distributions) we see that 2 or 3 pads per event are safely (> 3 standard deviations) above the noise level.

The root mean square σ of the gaussian curve fitting(7) the pulse height on a pad versus the distance of the track from the center of the pad itself using the formula:

$$\sigma^2 = \frac{(y_{m-1} - y_{m+1})/2}{\frac{\ln(p_{m-1}/p_m)}{y_m - y_{m-1}} - \frac{\ln(p_m/p_{m+1})}{y_{m+1} - y_m}}$$

where:

y_i is the center of the i-th pad,

p_i is the pulse height of the i-th pad,

m is the value of i for which we have the highest pulse.

Applying this formula to events where three pads are well above the noise level, we get:

$$\sigma = 4.85 \pm 0.15 \text{ mm}.$$

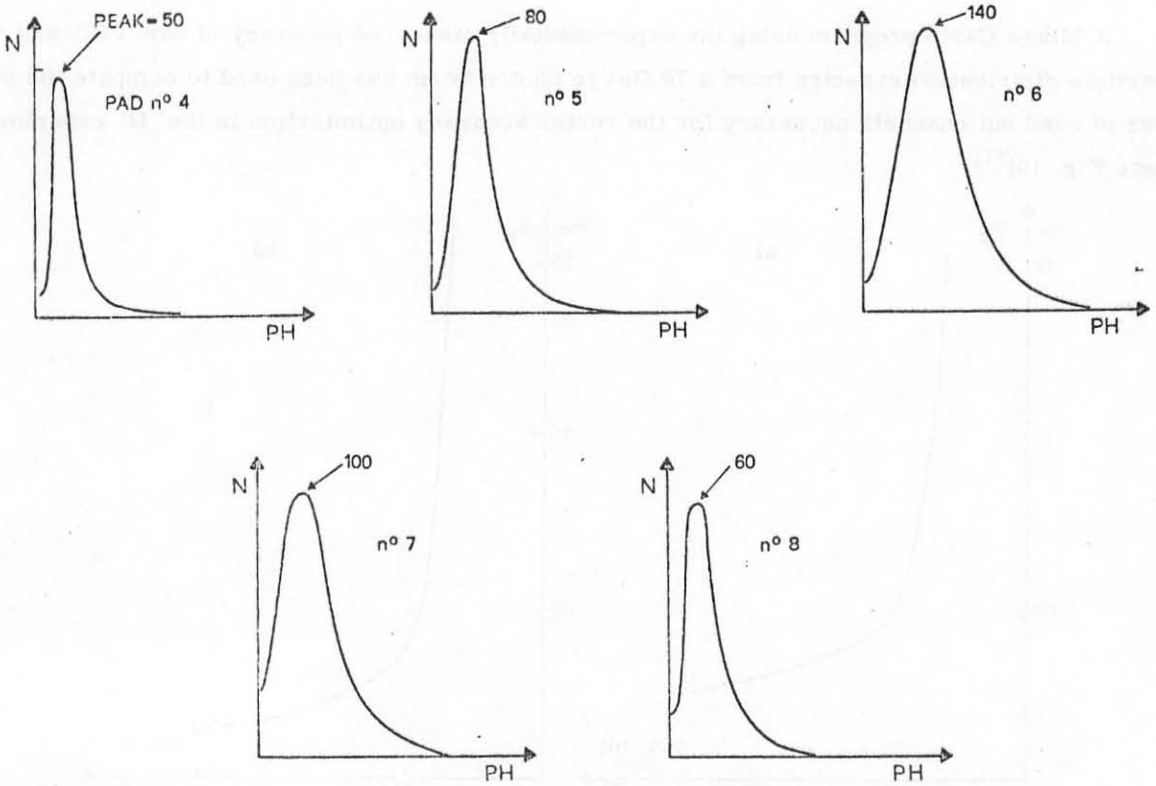

FIG. 11 - Landau pulse height distribution for five contiguous pads facing the beam (arbitrary units).

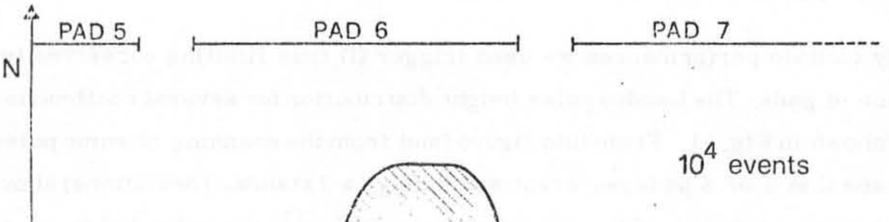

FIG. 12 - Comparison between the beam size (shadowed area) and the same quantity measured with the center of gravity of the signal induced on the pads.

The distribution we obtained tells us the weight we have to apply to cathode pulses to calculate the center of gravity $\bar{y}$ of the induced signals, i. e. the coordinate along the y direction.

The following formulae are applied:

$$\bar{y} = \frac{\sum_{i=1}^{3} y_i \, p_i^{1.5}}{\sum_{i=1}^{3} p_i^{1.5}} \qquad \text{for "3 pad events"} ,$$

$$\bar{y} = \frac{1}{2}(y_2 - y_1) - \sigma^2 \frac{\ln(p_1/p_2)}{y_2 - y_1} \qquad \text{for "2 pad events"} .$$

In Fig. 12 is shown the beam profile over the y direction, the shadowed area is the known size of the triggered beam. Fitting the experimental data with a square distribution plus a gaussian we evaluate the standard deviation σ^1 of the accuracy in y:

$$\sigma^1 = 0.5 \pm 0.1 \text{ mm} .$$

The described behaviour of the TPC is valid up to an incident beam intensity of $\sim 5 \times 10^4$ particles per anode centimeter; exceeding this limit space charge effects reduce efficiency and progressively spoil the chamber characteristics.

Higher intensities are allowed adding a control grid between the drift and the proportional zone and triggering such a grid only when an interesting event is recognized by the counter logic This solution is presently under test.

6. - CONCLUSIONS.

A Time Projection Chamber designed to obtain a good vertex reconstruction accuracy has been tested on a 7 GeV/c hadron beam.

The efficiency and the space accuracy obtained are completely satisfactory and well fit the expectations of the project.

The vertex reconstruction precision experimentally measured at 7 GeV/c incident beam momentum and the extrapolated behaviour at higher energies suggest the use of such a device when an intense incident beam is not required.

ACKNOWLEDGMENTS.

We are grateful to M. Sannino for the support given during the preparation of the TPC electronics. We want also to thank our colleagues of Milan University (P. F. Manfredi, D. Marioli, C. Meroni and G. Vegni) for preparing, setting-up and taking care of running the silicon telescopes read-out and our colleagues of Omega-Photon Collaboration (C. Raine and M. K. Storr) for providing most of the NIM and CAMAC electronics.

We finally want to thank G. C. Barisone and P. Poggi for the ingenuity and competence they demonstrated in the construction of the chamber.

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