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TEST OF A LIQUID-ARGON MULTISTRIP IONIZATION CHAMBER
WITH 8.5 μ m r.m.s. RESOLUTION

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Abstract

The feasibility of a high spatial resolution detector was investigated. For this aim we build up a prototype detector. Here we present the design, construction and test results of a liquid-argon multistrip ionization chamber with 20 μm strip spacing. Applying a 10 kV/cm field we get a spatial resolution of 8.5 μm and a two track resolution of about 50 μm with an efficiency of nearly 100%.

1. Introduction

The growing need in high accuracy detection devices which can be operated in intense beams demands further development in this field. High resolution of a detector should be accompanied by a sufficient time resolution. The most significant advance in this direction in the last ten years was reached by gas filled multiwire proportional and drift chambers. For specific tasks however, the achieved resolution of 100 μm is not sufficient. The main physical restrictions for the space resolution in ionization chambers come from the diffusion of the ionization electrons and from delta electrons /1/. A higher density of the chamber medium would reduce the range of the delta electrons and also the diffusion, and at the same time allows the reduction of the chamber thickness. This is the reason for the increasing interest to use noble liquids in coordinate detectors /2-6/.

A small gap ionization chamber filled with liquid argon could be a promising device for a detailed study of the interaction vertex, especially for those reactions, where short-lived particles are produced. A detection system with a spatial resolution in the order of 10 μm and a good two track resolution would give the possibility to separate the production and decay vertices down to lifetimes in the order of 10^{-13} sec.

We report on measurements with liquid argon filled multistrip ionization chambers, having a 20 μm strip spacing. The aim was to determine the main parameters of such device as measuring accuracy, efficiency and two track resolution. Besides that some construction principles had to be tested in view of a possible real detector for a future experiment. The measurements were performed in an unseparated particle beam with momentum up to 10 GeV/c at the CERN Proton Synchrotron.

2. Experimental apparatus

2.1. Construction of the chambers

The chambers used in the measurements were multistrip ionization chambers with flat parallel electrodes like those used by Derenzo et al. /2/.

The anode consisted of a series of metallic strips (chromium or gold), each strip 3 mm long and 10 μ m wide with a 20 μ m center-to-center distance. At each side, a guard electrode at the same potential flattened the electric field in the active area (see fig.1). The anode pattern was deposited on a glass plate using standard integrated circuit techniques. The cathode at a distance of about 2 mm was a structureless flat metallic surface made from copper coated glass fibre reinforced epoxy. The anode plate was mounted in a holder consisting of three plates. The plate facing the cathode carried the electric connections. Distance plates between anode and cathode defined the chamber gap (fig.2).

2.2. Chamber telescope

For position detectors with a resolution in the order of ten microns the relative positioning of the chambers in a telescope is crucial. The problem is solved in the following way: Two of the edges of the glass plates were polished and formed together a right angle with high precision. The anode pattern was deposited relative to the edges such, that the strips were parallel to one of the edges and the center of the pattern was at a fixed distance (7.5 mm) from both edges. Whereas slight deviations in the relative position can be measured and corrected in a later stage with straight particle tracks, the strips in the different chambers must be parallel within 5 mrad. Thus, the anode plates were inspected after manufacturing mainly for this parameter. Plates were selected with a maximum deviation from parallelness with respect to the polished edge of less

than 2 mrad, which corresponds to a difference of the distance from the edge of less than 5 μm over the length of the strip. The variation of the pattern position was less than 30 μm . The chambers were mounted on a special glass-ceramics support. Two polished flat plates were mounted together at right angle, forming a corner. Into this corner two spring pins pushed the chambers with the two reference edges of the anode glass plate (fig.3).

Special measurements were performed to check the reproducibility of the chamber position and angle while mounting a chamber several times. The maximum angular spread was 5 mrad. The position of the center of the pattern with respect to both support planes was reproduced within 30 μm .

A total of 5 chambers were mounted on the support. The inner 3 chambers had the described anode pattern, while for the two outer chambers the strips were replaced by one single electrode. The signals of the outer chambers were used to tag the particle traversal through the strip-zone of the inner chambers.

2.3. Chamber liquid

As chamber liquid we used argon. It is a cheap noble gas, easy to purify and to liquify. We used commercial argon with less than 50 ppm total impurities and less than 3 ppm oxygen as the most dangerous electro-negative impurity. The gas was further purified by using a single Oxisorb patron /7/.

According to the technical data, the oxygen impurities should be less than 0.1 ppm. A rough test measurement showed a value of 0.3 ± 0.3 ppm. During the experiments, no direct measurements of the gas purity were done. We had however an information about the stability from the signal amplitudes of a special test chamber with a α - source Am^{241} .

The argon was liquified by a liquid nitrogen cooled helix directly inside the metallic cryostat containing the main telescope and the α - chamber. During liquification and measure-

ments the pressure inside the cryostat was kept at 1.4 ± 0.1 bar thus ensuring that the argon stayed in the liquid phase.

2.4. Electronics

The anode strips of the chambers were connected to printed boards which carried the signals outside the cryostat. On the same boards, the charge preamplifiers (taken with slight modifications from /8/ and shown in fig.4) were mounted.

A common test pulse could be fed through small capacitors C_{Test} of known values (~ 5 pF) to the preamplifier inputs in order to check and calibrate the full electronics chain including the ADC.

From the preamplifiers, the signal was sent via 20 m cable to a pulse shaping amplifier (fig.5). Due to his limited bandwidth ($T_{\text{int}} = .2 \mu\text{s}$, $T_{\text{dif}} = 2 \mu\text{s}$) this amplifier reduced noise as well as low and high frequency pick-up. The output of the shaping amplifier was directly connected to the ADC (Le Croy Research Systems, Model 2249A).

3. Measurements

Four scintillation counters $S_1 - S_4$ (see fig.6) provided a trigger on particles traversing the setup. This trigger opened the ADC gates for 800 ns. Only for a small fraction of triggers however, the particle traverses the strip-region of the chambers. In this case also the trigger chambers show signals. Because of their large rise time, these signals are available 500 ns after particle traversal. They therefore have been used in a second level decision: Their absence caused a clear for the ADC's and a suppression of the readout command. Before the runs the telescope has been aligned parallel to the beam by minimizing the number of clears.

For each valid trigger the signal amplitudes from all chamber strips were recorded on magnetic tape.

Before each run series of calibrations with a common test pulse at all preamplifier inputs was performed. The test pulses had the same linear rise as the signals from particles. The known charge $Q = C_{\text{Test}} U_{\text{Test}}$ allows the absolute calibration of the electronics chain.

4. Analysis

As the first step, the measured amplitudes A_i for each strip i are transformed into a charge:

$$Q_i = (A_i - \overline{P_i}) K_i$$

where $\overline{P_i}$ is the mean value of the ADC pedestal and K_i a proportionality factor, derived from the mean values of the amplitudes recorded with the test pulses.

A hit on a strip number i is acknowledged if the measured charge exceeds a given amount $Q_i > C \delta_i$, where δ_i is the rms width of the pedestal peak and C an arbitrary factor. If a hit is present, the coordinate $X_m = X_i - X_0$ is calculated, where X_i is the coordinate of the strip center relative to the center of the anode pattern and X_0 the shift of this center relative to the telescope axis.

If two or more adjacent strips were hit, the cluster coordinate is defined as the arithmetic mean of the individual hit coordinates.

The track finding was done by a 'brute force' method, fitting a straight line $X = AZ + B$ through all possible combinations of clusters found in the chambers. For the selection of good tracks the residual $\text{RES} = \frac{1}{f} \sum (X_{\text{Fit}} - X_{\text{Meas}})$ [f = number of degrees of freedom] was used. The track with the smallest residual was taken as a good track, if its residual was below a certain cut value.

Except from the conversion into charge which corrects the gain differences of the individual channels the data handling

was equivalent to the methods which are (partially by hardware) used for other track detectors like MWPC.

As stated in section 2.2., the positioning of the chambers was not good enough for the expected measuring accuracy. As a consequence, the shift parameters X_0 had to be determined from the experimental data. For this, events were selected with only one cluster in each chamber at a 4 δ charge cut. The X_0 's of the outer two chambers were assumed to be the optically measured value. The shift parameter of the middle chamber was then determined by the condition that the mean deviation of the measured and fitted coordinates for each chamber was less than 2 μ m.

With this method, the coordinate system is fixed by the ad hoc shift parameters of the outer two chambers (distance 24 mm), the positioning of whose may be wrong as well. The possible deviation of the obtained coordinate system from a rectangular one, however, is in the order of 1 mrad and has no influence on the results.

The mean value of the slope parameter A is consistent with zero, indicating that the Z axis is parallel to the beam. The full width of the distributions for both parameters are well matched to the total width of the chambers and the length of the telescope.

For the unbiased investigation of the amount of charge collected at individual strips an iterative procedure was used avoiding any charge cuts. The particle coordinate was defined as the weighted mean of the coordinates of 9 adjacent strips:

$$\bar{X} = \frac{\sum Q_i X_i}{\sum Q_i} \quad (i = -4, \dots, 0, \dots, +4)$$

The central strip of the cluster X_0 is calculated from the mean value of the previous iteration. As a starting value, the coordinate was taken where the sum charge of any five adjacent strips reaches a relative maximum for the given event. For single track events, the coordinate X_0 was stable after two iterations.

5. Results

5.1. Charge collection and signal to noise ratio

The total free charge of one sign produced by ionization by a relativistic particle in liquid argon is well known and is 1.43 fC per mm [9]. Because of diffusion effects this charge generally is collected on several adjacent strips.

In principle, a part of the produced free charge is not seen at the anode because of the presence of free positive ions which practically do not change their position during electron collection. For chambers with large plane parallel electrodes this effect leads to a reduction by a factor 0.5. In our case because of the strip structure, the reduction is negligible. Also, free electrons may be captured during collection by argon ions or by electronegative impurities. These effects strongly depend on the purity of the liquid and on the electric field. In fig.7, the spectra at 9 adjacent strips are shown. The central strip (strip 0) corresponds to the particle coordinate and was determined by the iterative procedure described in the previous section. Single particle events were selected requiring single clusters at high charge cuts in the remaining two chambers.

The mean value of the collected charges decreases symmetrically to both sides of the central strip, reaching the pedestal value at strips +4 and -4. The width of the pedestal gives an estimate of the rms noise charge $\delta = 0.15$ fC. The signal to noise ratio can be defined as the mean detected charge $\overline{Q_i}$ divided by the rms noise charge

$$S / N = \overline{Q_i} / \delta$$

We get $S/N = 9$ for the central strip at $E = 10$ kV/cm and a chamber gap of 2.2 mm.

In fig.8 the total charge as the sum of individual charges from the 9 strips is plotted. The mean value of this sum agrees well with the expected value of 3.2 fC for our chamber gap.

5.2. Coordinate measurement

The rms measuring error for a single chamber was derived from the residual distribution of the straight line fits. Generally we have

$$\chi^2 = \sum_{K=1}^n \frac{(X_F^K - X_M^K)^2}{\sigma_K^2}$$

with X_M^K and X_F^K being the measured and fitted coordinates in chamber K, n the total number of chambers in the fit, and σ_K the a priori unknown measuring error. If one assumes the σ_K to be nearly equal for all chambers one has

$$\chi^2 = \frac{1}{\sigma^2} \sum_{K=1}^n (X_F^K - X_M^K)^2 = \frac{1}{\sigma^2} f \text{ RES}$$

For a 3-point fit ($n = 3$; $f = 1$) the distribution of $R = \ln(\sqrt{\text{RES}} dN(\text{RES}) / d\text{RES})$, which is easily computed from the experimental distribution $N(\text{RES})$ of the residuals should show a linear dependence:

$$R = \text{CONST} - 0.5 \sigma^2 \text{ RES}$$

The inclination of the line is directly related to σ . Fig.9 shows the parameter R as a function of the residual for different charge cuts applied at the stage of cluster selection in the chambers. Up to a residual of about 300 μm the experimental points show a linear behaviour as expected. At higher residuals deviations from linearity occur, which are stronger at low charge cuts. These deviations are caused by spurious clusters found with increasing probability at lower charge cuts, which show a different residual distribution, if the mathematical procedure has fitted them to tracks.

The lines in fig.9 are straight line fits to the experimental points for $\text{RES} \leq 300 \mu\text{m}^2$. This region has been used to determine σ .

The value of σ compiled for data sets at 4 and 10 GeV/c beam momentum and for different charge cuts are given in fig.10. The resolution gets slightly better with increasing cut. This

is due to the decreasing content of spurious tracks. At highest cuts the efficiency of the chamber (see section 5.4.) starts to drop, hence for a realistic operating condition we take the values of the 4δ charge cut, which are

$$\sigma_{10} = (8.5 \pm 0.15) \mu\text{m at } 10 \text{ GeV/c}$$

$$\sigma_4 = (9.3 \pm 0.2) \mu\text{m at } 4 \text{ GeV/c.}$$

The difference is caused by multiple scattering only. A quadratic correction gives

$$\sigma = (8.4 \pm 0.15) \mu\text{m}$$

as the intrinsic rms measuring error of our chambers.

In order to cross check the result we used the distributions of $\Delta = X_F^K - X_M^K$.

The expected rms deviation of this distribution can be calculated from the covariance matrix of the fit, which is determined by the Z coordinates of the chambers only. In fig.11 the distribution of Δ for one of the chambers is given. The Gauss curve is calculated from $\sigma = 8.4 \mu\text{m}$ and the covariance matrix and represents the data very well.

The error stated is only statistical. There are several sources of systematic errors, as for example uncertainties in the Z coordinates in the three chambers and their relative positioning including a possible rotation. An estimation of these errors gives the final result for the rms measuring error in one chamber:

$$\sigma = (8.4 \pm 0.5) \mu\text{m}$$

5.3. Two point resolution

This parameter is important, if more than one particle should be detected in a chamber. In case of our multistrip ionization

chamber it is defined by the width of the charge distribution at the anode.

In fig.12 the mean values of the collected charge (from fig.7) are plotted as a function of the strip number. Taking into account the effective strip width of 20 μm , we calculate a width of the charge distribution at the anode of 22 μm rms. With the simple cluster procedure described in section 4, that imitates a hardware discriminator with yes/no output, the minimum distance for which two tracks can be seen separately will strongly depend on the applied charge cut (discriminator level). In any case, however, tracks which are closer than the FWHM (50 μm) of the charge distribution at the anode (fig.12) are no more resolvable.

5.4. Detection efficiency

To determine the efficiency we selected events with single clusters in two chambers. In the third chamber we looked for clusters with the iterative procedure described in section 4. If these clusters existed and remained within $\pm 4\sigma$ at the same place after a charge cut we called the chamber efficient.

The plot of the efficiency as a function of the charge cut is shown in fig.13. The efficiency stays at values above 99% up to a charge cut of about 4σ . Above that value it starts to decrease

5.5. Diffusion

Information on the diffusion of the electric charges on their path to the anode can be derived from the charge distribution of fig.12.

The real charge distribution is distorted by the measuring process, so it has to be corrected for several effects:

- the true coordinate of the particle is equally distributed over the width of the central strip,
- the charge collected at a certain strip is the integral over a part of the charge distribution,
- the particle in general has a certain inclination with respect to the anode plane, so that the projection in the anode plane is a line instead of a point.

All these effects are small. The last one has been neglected, the other two both lead to a quadratic correction of the order of $6 \mu\text{m}$ at a rms width of the charge distribution of over $20 \mu\text{m}$.

A point charge starting at a distance Z from the anode produces a charge distribution, which can be described by a Gaussian with a standard deviation $\sigma_c = \tilde{D} \sqrt{Z}$, where $\tilde{D}$ is the diffusion factor. The distribution produced by a particle is therefore an integral over the track length. In principle, part of the charge recombines, the probability for this being the bigger the farther the charge originally was from the anode. As we collect the full charge within the calibration uncertainties, no recombination corrections have been applied.

A fit to the charge distribution including all corrections mentioned before leads to a value of

$$\tilde{D} = (18 \pm 2) \mu\text{m}/\sqrt{\text{mm}}$$

for a drift field of 10 kV/cm .

This value is less than measured by Derenzo et al. /2/ of $\tilde{D} = (28 \pm 2) \mu\text{m}/\sqrt{\text{mm}}$, derived at $E = 2.7 \text{ kV/cm}$. The main part of the difference is explained by the low field used in /2/ which gives a lower drift velocity. Using the predictions for the drift velocities given in /10/, we transformed Derenzos value to a value at our field. The result is $\tilde{D} = (23 \pm 2) \mu\text{m}/\sqrt{\text{mm}}$ in reasonable agreement with our value.

6. Conclusions

We conclude that it is possible to construct and to operate a detector, having a rms measuring error below 10 μm and a two point resolution in the order of 50 μm at 100 % efficiency. Sufficiently clean conditions can be held over long periods. The signal-to-noise ratio should be improved by at least a factor of two. This will give more comfortable operating conditions even with some impurities in the liquid and would allow a reduction of the chamber gap resulting in a better two point resolution and possibly accuracy.

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Figure Captions

- Fig.1 The central part of the anode pattern (19 metallic strips, 10 μm width, 20 μm center to center distance)
- Fig.2 The construction of a multistrip-ionization chamber. The fan outs of the anode pattern are bonded to the printed circuit fan outs of the signal electrodes
- Fig.3 Artists view of a chamber with support
- Fig.4 Circuit diagram of the charge sensitive preamplifier
- Fig.5 Circuit diagram of the pulse shaping amplifier
($T_{\text{int}} = 0.2 \mu\text{s}$, $T_{\text{dif}} = 2 \mu\text{s}$)
- Fig.6 Set up used in the measurements. The cryostat with the telescope inside was mounted on a rotating support for the alignment of the telescope in the beam line
- Fig.7 Charge collection at 9 adjacent strips. The central strip (strip '0') corresponds to the coordinate of the particle
- Fig.8 Distribution of the total collected charge
- Fig.9 The transformed residual distribution for different charge cuts ($\delta = 0.15 \text{ fC}$). The straight lines are fitted to the first 5 points
- Fig.10 The rms resolution for 4 and 10 GeV/c as a function of different charge cuts ($\delta = 0.15 \text{ fC}$)

Fig.11 Distribution $\Delta = X(\text{fitted}) - X(\text{measured})$. The line is the expected curve calculated for $\sigma = 8.4 \mu\text{m}$ and a 3 point fit

Fig.12 Mean value of the collected charge as a function of the strip number. The line is a Gaussian fit to the points given a standard deviation of $22 \mu\text{m}$

Fig.13 Efficiency as a function of different charge cuts
($\delta = 0.15 \text{ fC}$)

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FIG. 1

Fig. 2

Fig. 3

Fig. 4

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S.
F.

Fig. 6

Fig. 7

Fig.8 .

Fig.9

Fig. 10

Fig.11

Fig.12

Fig. 13