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TRACK RECONSTRUCTION IN LIQUID ARGON IONIZATION CHAMBER

Serpukhov 1979

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Abstract

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It is shown, that particle track parameters can be reconstructed by the currents in the anode cells of the ionization chamber. The calculations are carried out for the chamber with 10 cm anode-cathode gap width. The anode is made of cells with width of 2 cm. The coordinates x, y and track angle θ are reconstructed by currents with errors of up to millimetre and milliradian. The reconstruction errors are proportional to noise levels of electronics and also depend on the track geometry and argon purification.

Аннотация

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Показано, что по токам в секционированном аноде ионизационной камеры можно реконструировать параметры трека частицы. Расчеты были проведены для камеры с зазором анод-катод 10 см. Анод разбит на полосы шириной 2 см. Координаты x, y и угол наклона трека θ восстанавливаются по индуцированным токам с ошибками до долей миллиметра и миллирадиана. Ошибки восстановления пропорциональны уровню шума электроники, а также зависят от геометрии трека и чистоты аргона.

1. INTRODUCTION

In the modern liquid argon detectors/1-3/ the spacial position of a single particle track can either be roughly measured or cannot be measured at all. The measurement precision is determined by the width of the anode cells or strips. An anode consisting of the cells with the width of about 1 mm would have required an undesirably large number of electronics channels.

The present work treats possibilities of construct a detector, in which particle tracks can be reconstructed by the currents induced in the anode cells. It is quite clear that linear dimensions of the area where the induced currents are higher than the noise levels of electronics, are approximately equal to the gap width. The distribution of the currents in this area and their dependence on time are determined by the charge distribution in the gap.

Thus if the anode is made of cells with linear dimension several times smaller than the gap width, by measuring the currents in these cells as the function of time,one can reconstruct the charge density in the gap at the initial moment of time t=0,i.e. reconstruct particle tracks with the precision by an order of magnitude better than the linear dimensions of the cell. A recent progress in argon purification technique [4,5] gives us a possibility to create detectors with the gap larger than 10 cm, i.e. the cell width may be chosen to be about 1 cm. Then the number of the electronics channels do not seem to be enormously large even for the detectors with the volume of about tens of cubic meters.

II. COMPUTATIONAL MODEL

To check the qualitative conclusions made in the introduction we calculated the induced currents. After that a reverse problem was solved, i.e. electronics noises were superimposed onto the calculated currents and then the parameters of the initial event were reconstructed. We assume that the currents are being continuously strobed and the current integrated during a strobe-pulse (1 μs) is then recorded in the CCD [6]. The ENC noice charge is taken to be equal to 2.000 electrons.

For simplicity we dealt with a two-dimensional chamber model, whose geometry is shown in fig. 1.

To make our calculations simpler we considered the charge density along the track to be constant and equal to $\rho_o = 10^4$ electrons/mm.

The drift velocity of electrons was assumed to be $V=5\cdot10^6$ cm/s.

The influence of the electronegative impurities in argon was taken into account in the changes of the charge density of the drifting track according to the law

$$\rho(t) = \rho_o \exp(-\alpha t)$$

where $1/\alpha = \lambda/V$ is the average drift time of electrons before attachment; λ is the average drift path.

The events in the chamber were defined with the following parameters: X and Z coordinates of the event vertex, polar angles θ_i of each track, and track length ℓ_i.

The current $i_k(t)$ in the k-th strip was calculated using the following formula (see Appendix).

$$i_k(t) = \int_0^{h-Vt} dz_o \int_{-\infty}^{\infty} dx_o \Lambda(k, t \mid x_o, z_o) f(x_o, z_o),$$

$$\Lambda(k, t \mid x_o, z_o) = (V/2h)e^{-\alpha t} \sec^2 \frac{\pi(z_o+Vt)}{2h} \times$$

$$\times \left\{ \frac{\operatorname{th}\frac{\pi(x_k-\delta-x_o)}{2h}}{1+\operatorname{tg}^2\frac{\pi(z_o+Vt)}{2h}\operatorname{th}^2\frac{\pi(x_k-\delta-x_o)}{2h}} - \frac{\operatorname{th}\frac{\pi(x_k+\delta-x_o)}{2h}}{1+\operatorname{tg}^2\frac{\pi(z_o+Vt)}{2h}\operatorname{th}^2\frac{\pi(x_k+\delta-x_o)}{2h}} \right\},$$

where x_k and h are the coordinates of the strip centre; δ is its halfwidth.

III. RESULTS

Fig. 2 illustrates the currents induced in the strips by charge point with initial coordinates z=0.5 at x=0.From the comparison of the summed currents at λ =300 mm and $\lambda = \infty$ one may draw a conclusion that attachment effect is quite small at λ = 300.

Fig. 3 shows the currents induced by the drifting track that crosses the chamber at 30°. The origin of the track has the coordinates z = 0.5 and x = 0. The following regularities become evident from fig.3:

1)the currents in the strips, on which the track is projected, have evident peaks of both polarities;

2) sharp rise of the negative current corresponds to the instant of time, when a drifting track is falling on the strip and when current passes across the zero point to the track removes from the strip;

3) the currents in strips 7 and 8, where no track occurs, are smoother and smaller in magnitude.

Fig. 4. shows the current induced by the drift of the vertex with coordinates z = 0.5 and x = 0 and the track angles θ = 30° and θ = 15°. The tracks are crossing the chamber. Similarly with a single track the changes of the current polarity and sharp change of the derivates are induced by the arrival (or leaving) of a drifting track to strip.

In Tables 1 and 2 we enlist the errors in reconstruction of the parameters for the events with simple topology over induced currents in the strips. The parameters and their errors were obtained as a result on minimizing the functional

$$\Phi = \sum_{k,n} \frac{1}{\sigma^2} [i_k(t_n, a) - i_k(t_n, a_o)]^2 \qquad (1)$$

where in $i_k(t_n, a)$ are the currents in the k-th strip at time t_n, generated by the event with the parameters $a = x, z, \theta_1, \ldots, \theta_m$, a_o are the true parameters of the event, σ^2 noise dispersion of the electronics.

Parameter reconstruction errors depend on σ in the range $\sigma = 1000 \div 40000$ linearely. For example for track with $\theta = 30°$ and $\sigma = 4000$ the errors of reconstruction are $\sigma_x = 0.51$, $\sigma_z = 0.94$, $\sigma_\theta = 0.71$.

IV. SOME REMARKS OF ENERGY RESOLUTION

The precision of energy measurements in the ionization chambers with parallel plates is limited by the dependence of the charge value removed from the anode, from the ionization point. It is obvious that any increase of the gap whould result in worsening of the energy resolution (the energy is defined over the total charge).

The energy resolution was calculated for high energy electrons. The computor program for electromagnetic shower generation using a Monte-Carlo method is described in ref.[7]. Fig. 5 presents the dependence of energy resolution for liquid argon calorimeter on the gap sizes for the energy of incident electron of 1 GeV. The thickness of the electrodes in these calculations was taken to be negligibly small, the electronics noise was not taken into account. From fig. 5 it is clear that energy resolution depends on the gap width h as $\sqrt{h}$.

V. CONCLUSION

Recent success in argon purifying technique and manufacturing of the CCD allow us to talk about a problem of constructing a new particle detector i.e. an induction chamber, in which the track coordinates are reconstructed over the currents induced in the anode cells.

From the above calculations it becomes evident that the coordinates and angles of a track may be reconstructed with an accuracy up to fractions of mm and mrad. Moreover the induction chamber provides possibilities to measure ionization.

As we see now there are two ways to solve the track reconstruction problem.

1. A direct solution of an integral equation (A.12), i.e. the initial charge density is reconstructed by measuring the charges induced in anode strips at some disrete moments of time.

2. The shape of current pulses in the strip differ greatly for various events (tracks, two and three prong events). Thus the pulse shape allows us to classify the events and to describe them with several parameters (angles, coordinates, ionization density along the track). The evaluation of the parameters is then made by traditional minimization technique. Indeed this method is not so general as the solution of an inverse problem and is applicable only for a not very large number of hypothesis, but it is less time consuming.

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Appendix

The density of the induced charge $\sigma(x,t)$ is obtained from the Poisson equation

$$\Delta\phi(\vec{R}, t) = -4\pi\rho(\vec{R}, t) \tag{A.1}$$

under the boundary conditions

$$\phi|_{x=-\infty} = \phi|_{x=\infty} = \phi|_{z=0} = \phi|_{z=h} = 0. \tag{A.2}$$

The solution of equation (A.1) at boundary conditions (A.2) may be presented in the following form

$$\phi(\vec{R}, t) = \int d\vec{R}_o G(\vec{R}/\vec{R}_o)\rho(\vec{R}_o, t) \tag{A.3}$$

where the Green function $G(\vec{R}/\vec{R}_o)$ is equal to

$$G(\vec{R}/\vec{R}_o) = \frac{1}{2\pi}\int dk G(kz|z_o) e^{ik(x-x_o)},$$

$$G(kz|z_o) = 2\begin{cases} \dfrac{sh(kz)\, shk(h-z_o)}{k\, sh(kh)} & z < z_o \\[2ex] \dfrac{sh(kz_o)\, shk(h-z)}{k\, sh(kh)} & z > z_o . \end{cases} \tag{A.4}$$

Using the equations

$$\sigma(x,t) = \frac{1}{4\pi}\frac{\partial\phi}{\partial z}\Big|_{z=h}$$

and (A.3) and (A.4) we will obtain

$$\sigma(x,t) = \int_0^h dz_o \int_{-\infty}^{\infty} dx_o \tilde{g}(x,t|x_o, z_o)\rho(\vec{R}, t),$$

$$\tilde{g}(x,t|x_o, z_o) = -\frac{1}{2\pi}\frac{\sin(\pi z_o/h)}{\cos(\pi z_o/h) + ch(\pi(x-x_o)/h)} . \tag{A.5}$$

The charge density in the gap $\rho(\vec{R}, t)$ is determined by the following processes:

1) drift of electrons; 2) electron decrease from the drift track due to attachment; 3) negative ion production.

Assuming that the charge density at t = 0 is given by f(x,z) the first two processes are described by the expression

$$\rho_e(\vec{R}, t) = f(x, z - Vt)e^{-at}, \quad a = V/\lambda, \tag{A.6}$$

and the third one-by a differential equation

$$\frac{\partial \rho_i(\vec{R}, t)}{\partial t} = a\rho_e(\vec{R}, t). \tag{A.7}$$

The solution for this equation will be

$$\rho_i(\vec{R}, t) = \frac{1}{\lambda} \int_{z-Vt}^{z} f(z', x)e^{-(z-z')/\lambda} dz'. \tag{A.8}$$

Then the charge density in the gap will be

$$\rho(\vec{R}, t) = \rho_e(\vec{R}, t) + \rho_i(\vec{R}, t). \tag{A.9}$$

The current density on chamber anode will be

$$i(x, t) = \frac{\partial \sigma(x, t)}{\partial t} + i_e(x, t) \tag{A.10}$$

where

$$i_e(x, t) = i_e(\vec{R}, t)|_{z=h} = V\rho_e(\vec{R}, t)|_{z=h}.$$

Equations (A.1),(A.9), (A.10) give us a possibility to obtain the following expression for the current density

$$i(x, t) = \int_0^{h-Vt} dz_o \int_{-\infty}^{\infty} dx_o\, g(x, t \mid x_o, z_o) f(x_o, z_o),$$
$$g(x, t \mid x_o, z_o) = e^{-at}\, \partial \tilde{g}(x \mid x_o, z_o + Vt)/\partial t. \tag{A.11}$$

Expression (A.11) may be considered as an integral equation to define the space density of the charge $f(x,z)$ at $t=0$ over the current density on the straight line $z = h$.

Integration of (A.11) over the strip width gives an expression for currents from strip at the instant of time t

$$i_k(t) = \int_0^{h-Vt} dz_o \int_{-\infty}^{\infty} dx_o \, \Lambda(k, t \mid x_o z_o) f(x_o, z_o), \tag{A.12}$$

$$\Lambda(k, t \mid x_o, z_o) = e^{-at} \frac{1}{\pi} \frac{\partial}{\partial t} \{ \operatorname{arc\,tg}[\operatorname{tg} \frac{\pi(z_o + Vt)}{2h} \operatorname{th} \frac{\pi(x_k - \delta - x_o)}{2h} - $$
$$- \operatorname{arctg}[\operatorname{tg} \frac{\pi(z_o + Vt)}{2h} \operatorname{th} \frac{\pi(x_k + \delta - x_o)}{2h}]\},$$

which was used in our calculations.

Table 1

Errors in reconstructing of single track parameters σ_x, σ_z in mm, σ_θ - in mrad, σ = 2000 electrons

θ_i	λ = 300 mm						λ = 30 mm		
	ℓ_i=200 mm/cos θ_i			ℓ_i = 50 mm/cos θ_i			ℓ_i = 200 mm/cos θ_i		
	σ_x	σ_z	σ_θ	σ_x	σ_z	σ_θ	σ_x	σ_z	σ_{θ_i}
3°	0.82	0.76	4.3						
7.5°	0.30	0.48	3.9	0.97	0.50	22.0	1.42	4.4.	14.0
15°	0.12	0.44	0.38						
30°	0.25	0.44	0.36	0.30	0.45	6.4	0.37	3.9	1.7
35°	0.38	0.37	0.23						
60°	0.44	0.25	0.11	0.45	0.25	1.5			

Table 2

Errors in reconstructing two and three prong events λ = 300, ℓ_i = 200 mm/cos θ_i, σ = 2000 electrons.

	σ_x	σ_z	σ_{θ_1}	σ_{θ_2}	σ_{θ_3}
Two prong events	0.044	0.103	θ_1 = 30° 0.35	θ_2 = -15° 0.44	
Three prong events	0.036	0.051	θ_1 =45° 0.19	θ_2 = -30° 0.29	θ_3 = - 30° 0.29

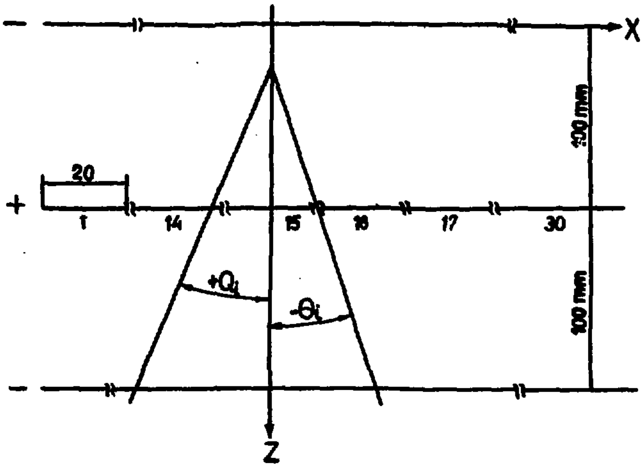

Fig. 1. Chamber geometry.

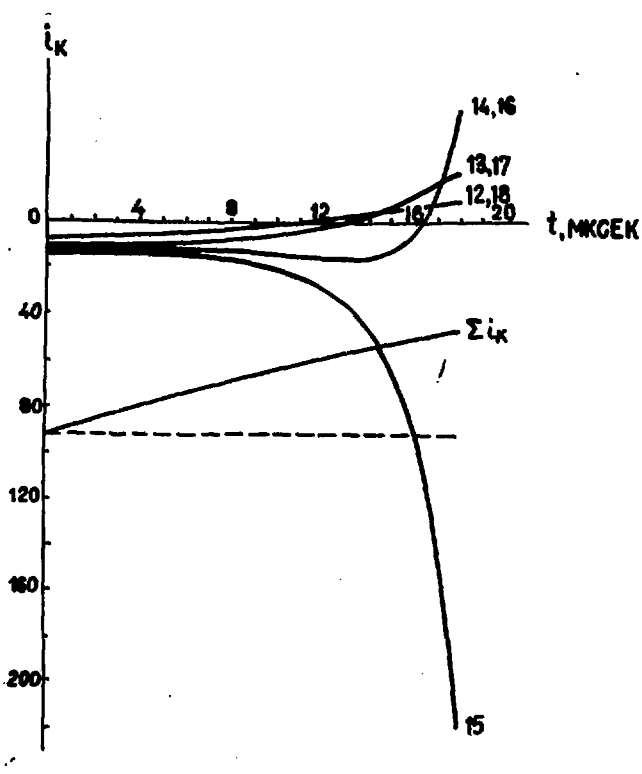

Fig. 2. Currents induced in various strips as a time function at point ionization. The average drift path of electrons $\lambda = 300$ mm. Broken line: the sum of currents in the strips for $\lambda = \infty$. Numbers near the curves indicate the number of a strip. The coordinates of the ionization point are $x = 0$, $z = 0.5$ mm.

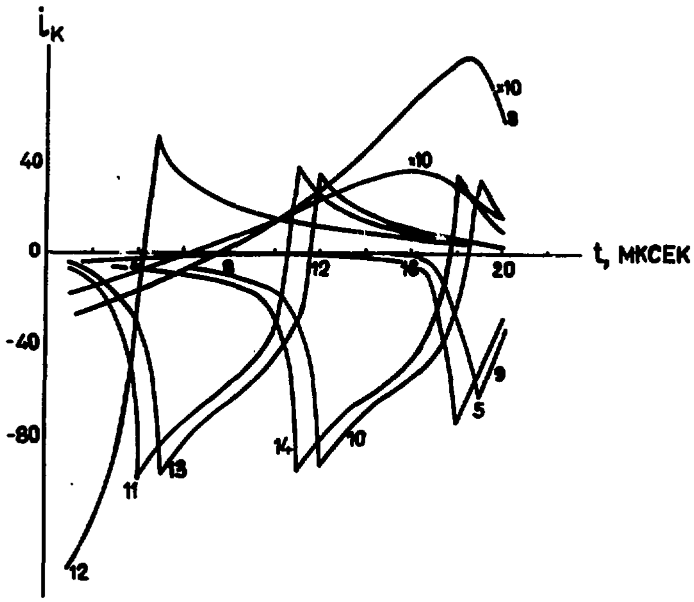

Fig. 3. The same as in fig. 2 but for a track that crosses the chamber at the angle $\theta = 30°$.

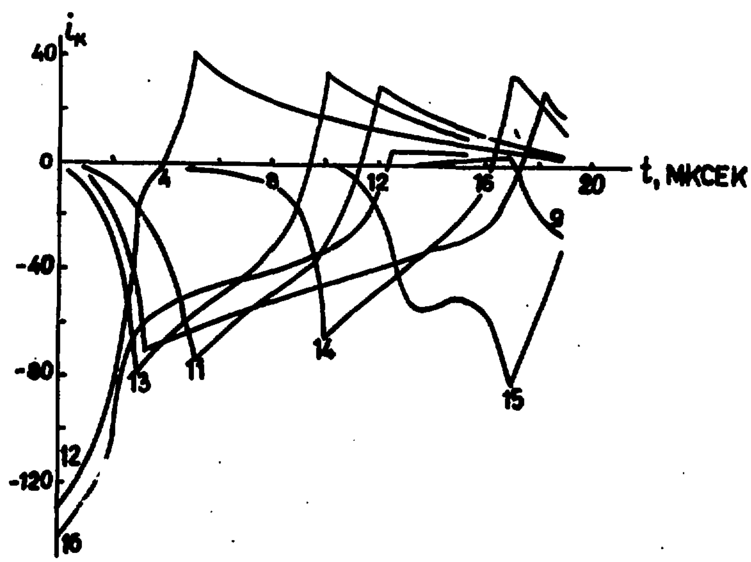

Fig. 4 The same as in figs. 2,3 but the two prong event with $\theta_1 = 30°$, $\theta_2 = -18°$

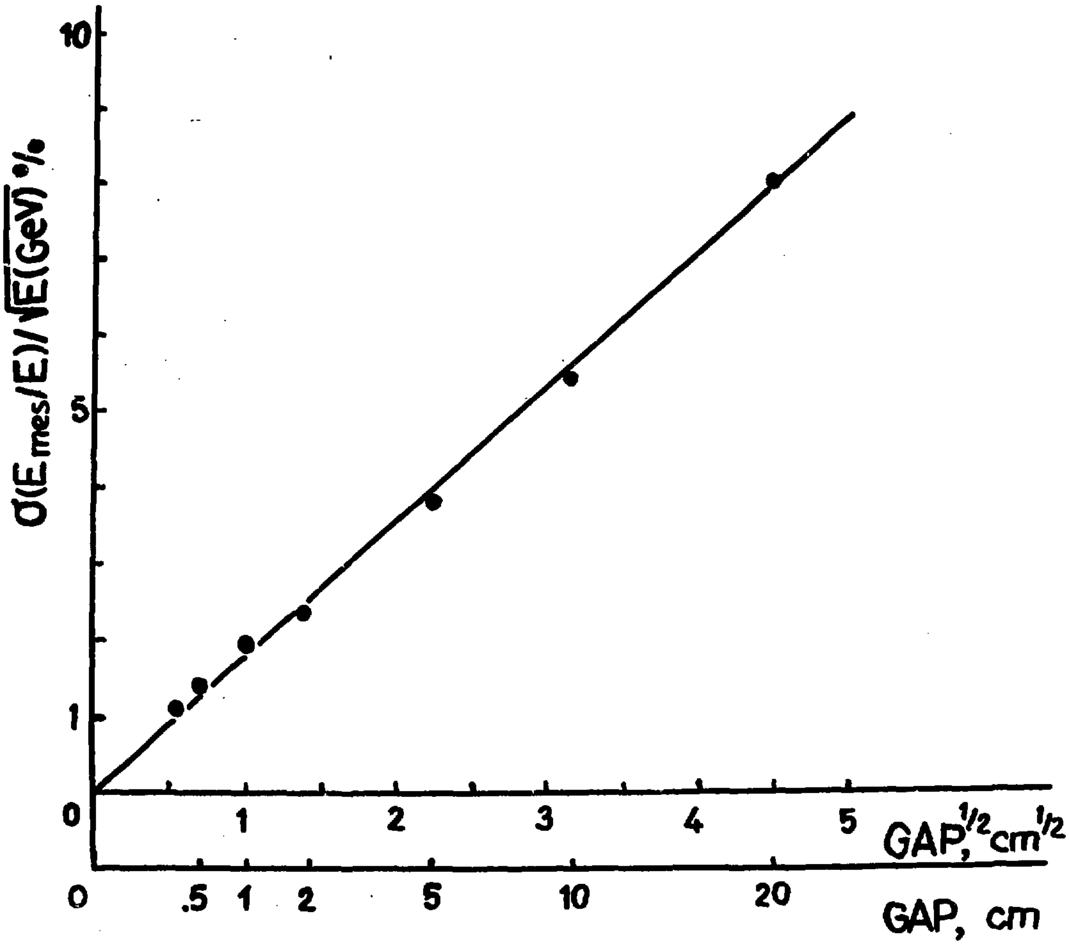

Fig. 5. The dependence of energy resolution for the total absorption detector with liquid argon on the sizes of the gap. Electron energy is 1 GeV. Electronics noises are not taken into account.

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