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THE PARALLAX CALCULATION METHOD AND COORDINATE CORRECTIONS FOR *X*-RAY BEAMS IN THE DETECTORS BASED ON STRAW DRIFT TUBES

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1 Introduction

For experimental research of determination of the coordinates of neutral particles in gaseous detectors, appears the well-known problem of parallax. When particles flux passes in the plane nonorthogonal to anode wire, the spatial resolution of such detectors becomes worth in comparison with normal case. In the article [1] have been shown the possibility of discount of a parallax error, for improving the spatial resolution, suggesting that coordinate distribution function of X-ray beam is described by Gaussian distribution.

This work is devoted to the experimental testing and farther improvement of method of parallax correction for one-dimensional linear counter, based on straw tubes with cathode read-out [2, 3].

2 Conditions of experiment

The special collimator (see fig.1) have been made for research with an orthogonal slot a (thickness $d = 40\ \mu m$) and a slanting slot b (thickness $d = 80\ \mu m$).

The detector [2] have been purged by a gas mixture Ar/CH_4 (80/20) or Xe/CH_4 (80/20) under normal pressure. The source of ^{55}Fe irradiated the detector through the slots a and b simultaneously. The collimator could be moved vertically up-downwards on a distance up to 1 mm with an accuracy better than 20 μm.

The orthogonality of X-ray beam is considered enough when the vertical shifting of the collimator does not produce any shifting of coordinate peak from slot a.

The typical coordinate distributions from these two slots, for the mixture of argon and mixture of xenon, are shown on fig.2 (a) and (b). It is obvious, that the gas with larger absorption coefficient is more preferable, as then it is possible to separate two neighboring picks from thin X-ray beams, nonorthogonal to anode wire. For example, that is important for X-ray structure research where xenon gas mixture with high pressure is more suitable.

3 Mathematical data processing

3.1 The model

From the experimental data (see fig.2(a, b)) it is obvious, the in linear coordinate distribution of thin X-ray beam (for large angles of deviation from orthogonal plane) is not shifted and is not expanded Gauss function. For processing of such an experimental data, in contrast to the work [1], we suppose Gauss coordinate distribution in counter from each absorbed X-ray quantum and the σ of this distributions to be the spatial resolution of detector. Moreover, we suppose the independence of σ from drift path of primary electron cloud of ionization for each absorbed X-

ray quantum. Physically it means neglection of diffusion in the drifting primary electron cloud.

In experiment the situation shown in fig.3 was realized. The case, when the vector of a direction of a flow of X-ray, the vector normal to a plane of a flow of X-ray and the vector in a direction of an anode wire do not lie in one plane, was not considered.

According to our supposition, we have the differential probability of detecting an event in a point x:

$$dP_g \sim e^{-(x-x_m)^2/2\sigma^2}, \tag{1}$$

where x_m is the x-coordinate of point of absorption of X-ray quantum. The differential probability of an absorption is given by the formula:

$$dP_a \sim e^{-\mu s}, \tag{2}$$

where μ is the absorption coefficient of a gas mixture in the detector, s is the path of X-ray quantum in the gas. As both processes are independent, the full differential probability to detect an event on the anode is:

$$dP(x) \sim e^{-\mu s} e^{-(x-x_m)^2/2\sigma^2} dV. \tag{3}$$

Integrating the expression (3) in the region of intersection of a stream of X-ray beams with gas mixture of the detector we obtain the full probability of registration of the event in a point x in a form:

$$P(x) \sim \int\limits_{x_0-d/(2\sin\alpha)}^{x_0+d/(2\sin\alpha)} dx_0' \int\limits_{-R}^{R} dz \int\limits_{-\sqrt{R^2-z^2}}^{\sqrt{R^2-z^2}} dy \ \left\{e^{-\mu s} e^{-(x-x_m)^2/2\sigma^2}\right\}, \tag{4}$$

with

$$s = [(R^2 - z^2)^{1/2} - y]/\sin\alpha, \quad x_m = x_0' + y\,\mathrm{ctg}\alpha,$$

where x_0 is the cross point of an anode wire with a medial plane of a flow of X-ray, parallel, by definition to the slot of the collimator, d is the thickness of a flow of X-ray, but the growth of the thickness of this flow connected with a divergence of the beam is neglected.

Thus, the function assigning a model, is $P(x, x_0, \sigma, \alpha)$.

3.2 Fitting

The parameter σ is determined as follows: we put $\alpha = 90°$ in formula (4) and use this expression to fit the experimental data without parallax (see fig.2 (b), the slot a) and RMS of this experimental data is $\approx 56\ \mu m$ (see fig.5). If we fit the experimental data by Gaussian (in the region of good coincidence with experimental data) we obtain $\sigma_G \approx 45\ \mu m$. Now, assuming the parameter $\sigma = 50\ \mu m$ to be known, we fit by our model the experimental data from the slanting slot b (fig.2 (b)) and get

$x_0 = 0.2274 \pm 0.0009\ cm$, $(90^\circ - \alpha) = 13.17^\circ \pm 0.10^\circ$, which is in a good agreement with measured angle of used collimator ($13.25^\circ \pm 0.15^\circ$).

The result of such a fitting of experimental data are shown in fig.6.

4 Conclusion

The mathematical model (4) which describes the distribution of coordinates registered by the detector based on thin-film drift tubes with cathode read-out of information is proposed. This model takes in account the geometry of the detector and the geometry of incoming beam. The model is in agreement with experimental data and can be applied in experiments, which have isolated in the space fluxes of γ - quantum beams, as, for example, is the case of X-structural analysis.

We suggested the method (5)(see appendix), by help of which in situation mentioned above not only the coordinate x_0 is essentially updated, but also, from the shape of coordinate distribution of peak from a thin X-ray beam we can find an angular coordinate α, which is connected with parallax.

The experimental distributions of coordinates in the detector (fig.2) are obtained. From this experimental data the angular coordinate of thin X-ray beam have been found for the first time, the main absorption mechanism of which is the photoeffect.

The proposed method can be applied in future planar detectors of image on the synchrotron radiation [4].

The using of numerical integration (see appendix) increases the time of numerical processing in the case of complicating the model with the purpose of improvement of accuracy in determination coordinates x_0 and α (for example, by taking in account diffusion or more detail geometry of incoming beam). In this situation the obtaining of the result in the limited time depends only on power of used computers. [1]

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Appendix

The main difficulties of evaluation of the integral (4)

$$P(x) \sim \int_{x_0-d/(2\sin\alpha)}^{x_0+d/(2\sin\alpha)} dx'_0 \int_{-R}^{R} dz \int_{-\sqrt{R^2-z^2}}^{\sqrt{R^2-z^2}} dy \ \left\{ e^{-\mu s} e^{-(x-x_m)^2/2\sigma^2} \right\},$$

are connected with the following features:

a) the impossibility of analytical evaluation of this integral;

b) the direct application of numerical integration leads to a long time of numerical processing, which is connected with three-dimension range of integration.

[1] The computer AMD-K-6-II, 333 MHz/32 Mb RAM was applied to mathematical processing in this work/. Time of processing the experimental data (fig. 6) was 25 minutes.

But we can make the analytical integration for variables y and x_0' sequentially. As a result, after simplifications we get the expression:

$$
\begin{aligned}
& I(x, x_0, \sigma, \alpha) \equiv \\
& \int_{-R/2}^{R/2} dz \Bigg(\bigg(-2 + e^{2\sqrt{R^2-z^2}\,\mu\,\csc(a)}\, Erf\Big(\frac{2x - 2x_0 - 2\sqrt{R^2-z^2}\,\cot(a) + d\csc(a)}{4\frac{\sigma}{\sqrt{2}}}\Big) + \\
& e^{2\sqrt{R^2-z^2}\,\mu\,\csc(a)}\, Erf\Big(\frac{-2x + 2x_0 + 2\sqrt{R^2-z^2}\,\cot(a) + d\csc(a)}{4\frac{\sigma}{\sqrt{2}}}\Big) + \\
& e^{\sqrt{R^2-z^2}\,\mu\,\csc(a)} \bigg(e^{\frac{\mu\sec(a)\left(2x - 2x_0 - d\csc(a) + \mu\sigma^2\sec(a)\right)}{2}} \\
& \Big(Erf\Big(\frac{-2x + 2x_0 - 2\sqrt{R^2-z^2}\,\cot(a) + d\csc(a) - 2\mu\sigma^2\sec(a)}{2\sqrt{2}\,\sigma}\Big) - \\
& Erf\Big(\frac{-2x + 2x_0 + 2\sqrt{R^2-z^2}\,\cot(a) + d\csc(a) - 2\mu\sigma^2\sec(a)}{4\frac{\sigma}{\sqrt{2}}}\Big)\Big) + e^{\frac{\mu\sec(a)\left(2x - 2x_0 + d\csc(a) + \mu\sigma^2\sec(a)\right)}{2}} \\
& \Big(-Erf\Big(\frac{2x - 2x_0 - 2\sqrt{R^2-z^2}\,\cot(a) + d\csc(a) + 2\mu\sigma^2\sec(a)}{4\frac{\sigma}{\sqrt{2}}}\Big) + \\
& Erf\Big(\frac{2x - 2x_0 + 2\sqrt{R^2-z^2}\,\cot(a) + d\csc(a) + 2\mu\sigma^2\sec(a)}{4\frac{\sigma}{\sqrt{2}}}\Big)\Big)\bigg) + \\
& Erfc\Big(\frac{-2x + 2x_0 - 2\sqrt{R^2-z^2}\,\cot(a) + d\csc(a)}{4\frac{\sigma}{\sqrt{2}}}\Big) + Erfc\Big(\frac{2x - 2x_0 + 2\sqrt{R^2-z^2}\,\cot(a) + d\csc(a)}{4\frac{\sigma}{\sqrt{2}}}\Big)\bigg) \sin(a)\Bigg) \\
& \frac{1}{e^{2\sqrt{R^2-z^2}\,\mu\,\csc(a)}\,\mu}.
\end{aligned}
\tag{5}
$$

The last integration by z is evaluated numerically. [2] Normalization constant is determined by formula

$$
K = \frac{1}{\int_{-\infty}^{\infty} dx I(x, x_0, \sigma, \alpha)}. \tag{6}
$$

Finally, the model is given by expression

$$
p(x, x_0, \sigma, \alpha) = \frac{I(x, x_0, \sigma, \alpha)}{\int_{-\infty}^{\infty} dx I(x, x_0, \sigma, \alpha)} \equiv KI, \tag{7}
$$

where the integration in the nominator and in the denominator are given with five significant digit precision.

Because of complexity of model (7) for the first time was used the Newton method for minimization of χ^2-functional, which converges in minimal number of iterations. But this numerical method does not give explicit functional dependence of parameters $\{x_{0min}, \alpha_{min}, \sigma_{min}\}$, which minimize the functional, from the experimental data $\{N_i, x_i\}$, which makes difficult the explicit evaluation of errors of obtained parameters. Therefore, the following reception is used: the model (7) is interpolated by cubic polinomial (spline interpolation) on x and on $\{x_0, \alpha, \sigma\}$ in neighborhood $\{x_{0min}, \alpha_{min}, \sigma_{min}\}$. Then the method of polynomial regressions [5] is

[2] area of the integration by z differs from the area in the expression (4) as the detector had the collimator (window) of the width 0.5 см. (R) along the straw.

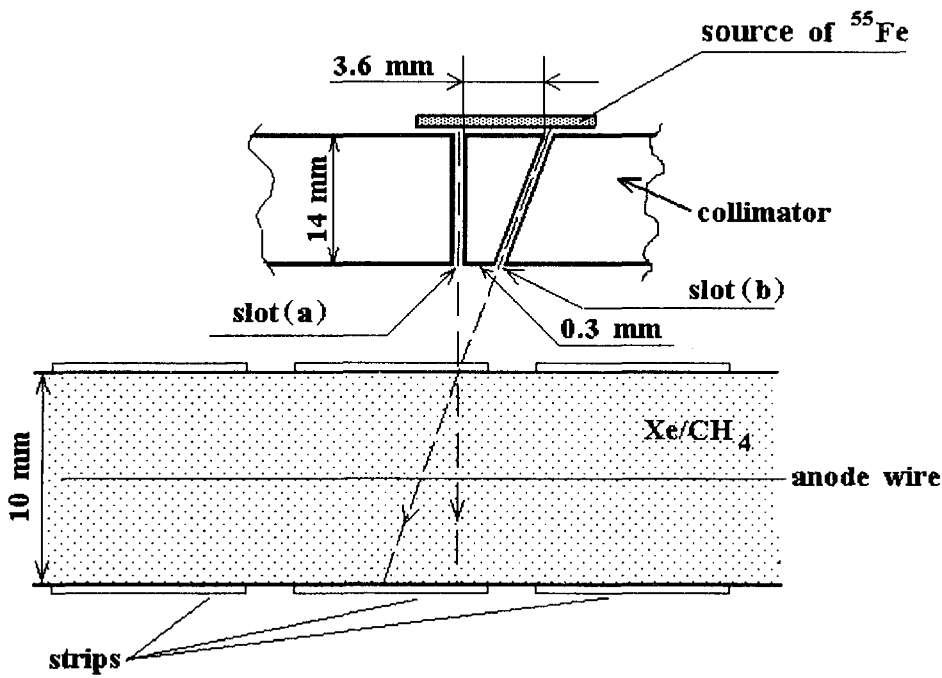

Fig. 1. The scheme of the experiment.

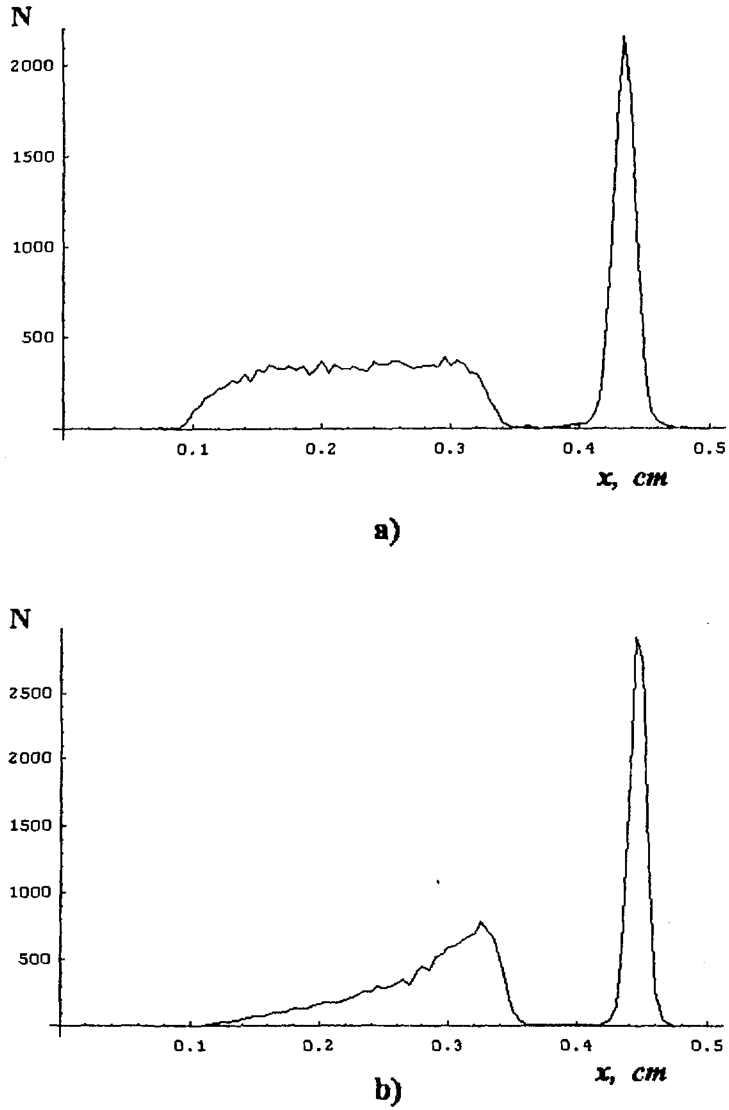

Fig. 2. Typical coordinate distributions from X-ray beams for argon (a) and xenon (b) gas mixture (size of one bin is equal to 50 μm).

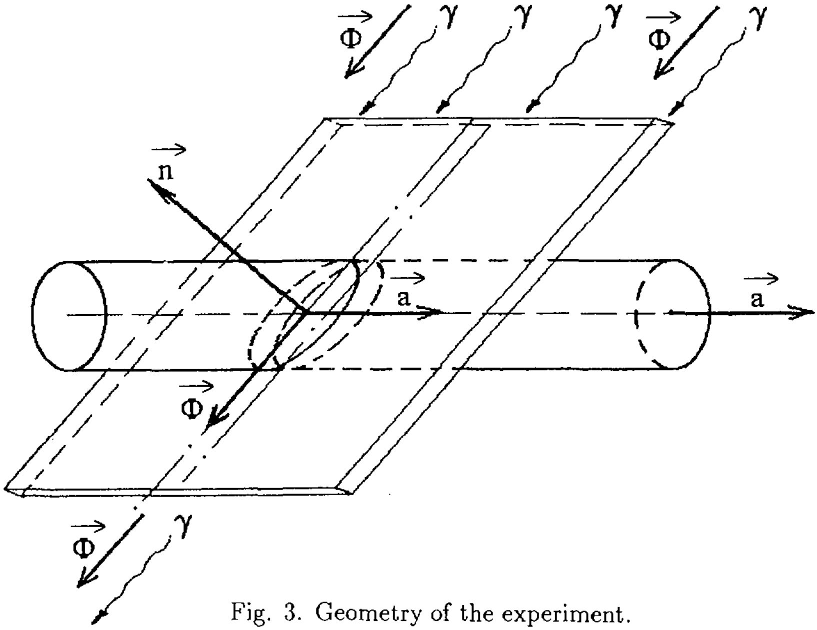

Fig. 3. Geometry of the experiment.

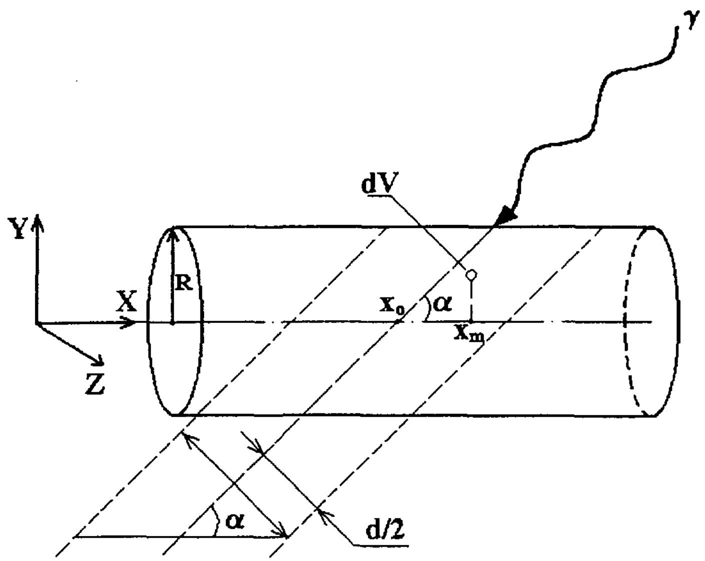

Fig. 4. The schematic picture of the process.

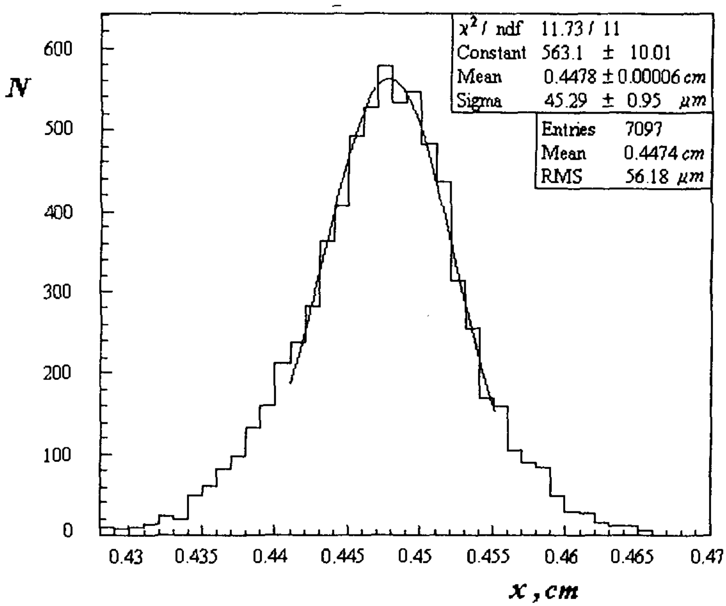

Fig. 5. Gaussian fitting (size of one bin is equal to 10 μm).

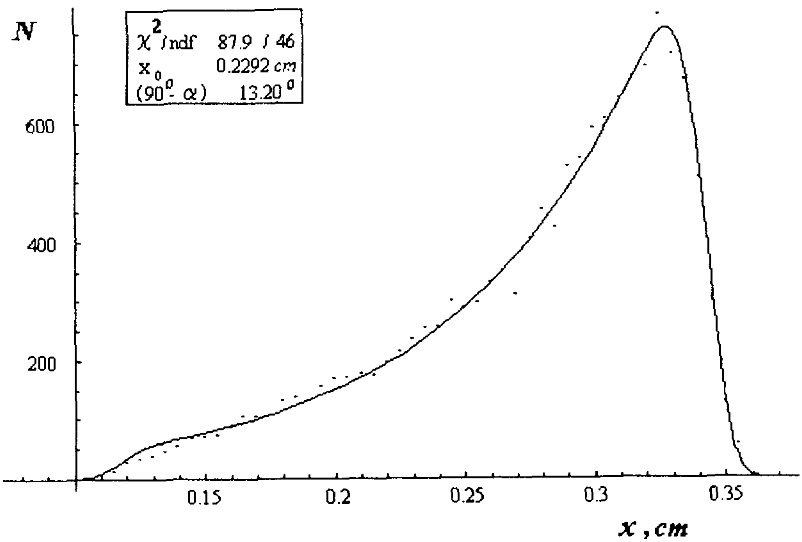

Fig. 6. Fitting by the model (4)(size of one bin is equal to 50 μm).

applied, which gives explicit dependence of the parameters $\{x_{0min}, \alpha_{min}, \sigma_{min}\}$ from $\{N_i, x_i\}$, that allows more precisely to evaluate the errors of this parameters.

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