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ЦЕНТРАЛЬНЫЙ НАУЧНО-ИССЛЕДОВАТЕЛЬСКИЙ ИНСТИТУТ
ИНФОРМАЦИИ И ТЕХНИКО-ЭКОНОМИЧЕСКИХ ИССЛЕДОВАНИЙ
ПО АТОМНОЙ НАУКЕ И ТЕХНИКЕ

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A NEW METHOD OF DATA PROCESSING FROM X-RAY-EMULSION FILMS IN INVESTIGATING NUCLEAR INTERACTIONS

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НОВЫЙ МЕТОД ОБРАБОТКИ ИНФОРМАЦИИ С РЕНТГЕНОЭМУЛЬСИОННЫХ ПЛЕНОК ПРИ ИССЛЕДОВАНИИ ЯДЕРНЫХ ВЗАИМОДЕЙСТВИЙ

В работе впервые предлагается использовать метод максимального правдоподобия для восстановления параметров электронно-фотонного каскада, регистрируемого на рентгеновских пленках.

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A NEW METHOD OF DATA PROCESSING FROM X-RAY-EMULSION FILMS IN INVESTIGATING NUCLEAR INTERACTIONS

It is proposed for the first time to use the maximum likelihood method for the restoration of parameters of the electron-photon cascade registered on X-ray films.

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At present there are two methods of information readout from the X-ray-emulsion chambers (XEC): the integral method based on the darkening point photometering by circular diaphragms of various radii [1] and the differential method based on the automatic scanning of local densities of the darkening point by microdensitometers with high spatial resolution [2]. The γ-quanta energy restoration in [2] is carried out by means of the method of moments over the density matrix obtained with different scan steps. In this letter it is proposed for the first time to apply the maximum likelihood method allowing to obtain consistent, asymptotically normal and efficient estimates of spatial-energy parameters of the γ-family source 3 .

In the system of coordinates of the XEC film plane there is a darkening point caused by a γ-quanta with the energy E_0, zenith and azimuthal angles θ and φ , respectively. The generation point of the cascade shower is located in the layer of absorber at a distanse t from the point center (x_0, y_0). The X-ray-emulsion film is scanned by the automatic microdensito - meter with the scan step Δx, $\Delta y = \Delta x$, and the local densities of darkening ρ_{ij} within the rectangular cells $(\Delta x, \Delta y)$

with the center coordinates x_i, y_j, $(i, j = 1,...N)$ are determined. The scanning raster dimensions in dividing it into N^2 elementary areas are equal to $x_\eta = \Delta x \cdot N$, $y_\eta = \Delta y \cdot N$, respectively. The problem is the restoration of the γ - quanta parameters $(E, \theta, \varphi, x_0, y_0)$ according to the darkening density matrix $\{\rho(x_i, y_j)\}$, if the distribution function of the general set $f(\rho(x,y)|\vec{\eta})d\rho$ is given. The distribution function $\overset{\rho}{f}(\rho|\vec{\eta})$, where $\vec{\eta} = \eta(E_0, \theta, \varphi, x_0, y_0)$ is defined by the a priori information based on the axial approximation of the cascade theory [1,2].

It is known that the cascade shower projection on the X-ray film in the absence of fluctuations and at the given vector of parameters is approximated by ellipses of darkening of equal densities, their semiaxes being determined by the axial approximation of cascade theory:

$$\lg(\bar{\rho}_K) = 2 \cdot \lg(E_0/10) + \sum_{i=1}^{6} a_i(t)\{\lg(R_K E_0/10)\}^{i-1}, \qquad (1)$$

where R_K is the distance from the point center (x_0, y_0) to the k-th cell center. The values $a_i(t)$ are the tabulated constants that depend on the cascade shower generation depth (t). In the expression (1) the γ-quanta energy (E_0) is measured in units of TeV. The average density of darkening $\bar{\rho}$ represents the average number of equivalent electrons that have passed through the X-ray film unit area. The fluctuations of the electron number in cells are considered to be distributed according to Poisson. The variation region $\rho = \frac{n}{S}$, where $S = \Delta x \cdot \Delta y$ is determined by the darkening curve of X-ray films and by analogy with [2].

is equal to $2.10^{-3} = \rho_{min} \leqslant \rho \leqslant \rho_{max} = 5.10^{-1} \mu m^{-2}$, respectively. The density matrix contains also the background fluctuations which are independent of the parameter vector and are distributed according to Poisson with the average value $\bar{\rho}_f = 4.10^{-2}$ μm^{-2}.

On the basis of a priori data on the structure of the darkening point (1) the likelihood function is determined as follows:

$$F(\{\rho_{ij}\}|\vec{\eta}) = \prod_{K_0=1}^{N_0} f_0(n_{K_0} \leqslant n_{min}|\vec{\eta}) \prod_{K_1=1}^{N_1} f_1(n_{K_1}|\vec{\eta}) \prod_{K_2=1}^{N_2} f_2(n_{K_2} \geqslant n_{max}|\vec{\eta}), \quad (2)$$

where $N_0 + N_1 + N_2 = N.N$, f_0 and (f_2) are the probabilities that in the cell k_0 (k_2), corresponding to the coordinates x_i, y_i, the number of equivalent electrons is less (more) than the threshold value n_{min} (n_{max}) at the given $\vec{\eta}$.

N_0 and (N_2) are the number of cells from the density matrix satisfying these conditions.

By the Monte-Carlo simulated density matrix $\{\rho_{ij}\}$, obtained for the fixed $N, \Delta x = \Delta y$, E_0, θ, φ, x_0, y_0, n_f, n_{min}, n_{max} one may easily minimize on a computer the expression

$$\Delta(E_0, \theta, \varphi, x_0, y_0) = -\ln F(\{\rho_{ij}\}|\vec{\eta}) \quad (3)$$

and obtain the point estimates of E_0', θ', φ', x_0', y_0' with corresponding values of standard deviations $\sigma_E, \sigma_\theta, \ldots \sigma_y$ according to the matrix of second derivatives of the likelihood function. We present in table the E'/E values and corresponding errors at $\theta = 30^\circ$ and $\varphi = 60^\circ$ for the three energies of

γ - quanta (2,5,10) TeV, various thicknesses of absorbers (d) in cascade units (c.u.) and the scan step $\Delta x = \Delta y = 10\ \mu m$. The value of the darkening density logarithm (1) was determined by the Lagrange parabolic interpolation with the interpolation nodes $t_\ell = 2 \cdot \ell$, ($\ell = 1,2,\ldots 10$) c.u. The coefficients $a_i(t_\ell)$, $i = 1,2,\ldots 6$ in the expression (1) are taken from [4]. By averaging the energy estimates under various thicknesses with the account of the weights inversely proportional to the squares of calculated errors, we have achieved the high [illegible] accuracy of the parameter estimation by the [illegible] method (the [illegible] line in table). Note that the averaging technique is applicable only if the calculated error is adequate to the real one. This important condition is perfectly fulfilled in the case of the maximum likelihood method.

Table

Accuracies of the definition of the value E'/E

[illegible]	2	5	10
[illegible]	[illegible]±0.42	[illegible]	0.86±[illegible]
[illegible]	0.87±0.22	1.00±[illegible]	1.2±[illegible]
[illegible]	1.05±0.10	0.99±0.07	1.00±[illegible]
10	0.91±0.03	0.93±0.13	1.00±[illegible]
12	-	1.01±0.27	1.03±0.17
weights accounted	1.01	0.972	1.003

It follows from our results, that in the data processing from XEC the maximum likelihood method allows to reach the highest accuracies of the restoration of the darkening point source parameters (the relative accuracy of estimates is of a few per cent). This fact significantly increases the efficiency of the XEC techniques in investigating the nuclear interactions of superhigh energies.

Note also that the suggested method may be applied as well in the case of superimposed (overlapping) darkening points caused by several γ - quanta. For this purpose one should make a substitution $\bar{n} = \sum_{i=1}^{n_\gamma} \bar{n}(E_i, R_i) + \bar{n}_f$ in the likelihood function (2). Respectively, the maximum number of unknown parameters in the minimization procedure (3) including also the n_γ quantity of γ -quanta in the family, will be equal to $5n_\gamma - K + 1$ where K is the number of kinematic relations between parameters.

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