DOI: https://doi.org/10.37547/mesmj-V5-I3-26 Pages: 178-186

MENTAL ENLIGHTENMENT SCIENTIFIC –
METHODOLOGICAL JOURNAL

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APPLICATION OF LEAST SQUARES METHOD FOR PARTICLE IDENTIFICATION AND SAMPLING EVENTS IN PHOTOEMULSION

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ABOUT ARTICLE

Key words: photoemulsion, nucleus, proton, diffractive dissociation, π-season, identification, ionization, impulse, energy, mass, event, collision, coherence, smallest squares.

Received: 09.04.24
Accepted: 11.04.24
Published: 13.04.24

Abstract: To date, much work has been done on the study of coherent diffractive dissociation of π -mesons by protons. In these works, the angles and pulses of secondary particles were mainly measured. There is very little work on the identification of secondary particles. This may be due to difficulties in identifying secondary storm particles in track instruments. In this work, angular, pulse and ionization measurements were carried out on tracks of secondary particles. Strict methods of mathematical statistics for identification of particles and selection of events in photomulsions are described and applied. The results obtained show the reliability and correctness of the method used.

INTRODUCTION

One of the methods of studying the interactions of particles and nuclei with nuclei is the method of nuclear photoemulsions. The emulsion is a detector with continuous sensitivity, capable of storing information for a long period. In addition, photoemulsion makes it possible to study processes occurring with a small cross section. For the selection of such rare events, the use of rigorous methods of mathematical statistics gives good results.

This paper describes the application of the least squares method for particle identification and selection of coherent diffraction interaction events with a certain topology.

EXPERIMENTAL MATERIAL AND MEASUREMENT METHODS

In this work, a photoemulsion stack irradiated with protons with a pulse of 20.8 GeV/c was used. When irradiated, the stack of Ilford K5 emulsions was in a strong magnetic field with a strength of H = 18 T. This made it possible to identify secondary particles and select events using pulse and ionization measurements.

The emulsion was viewed using the accelerated trace scanning method [1], its speed completely excluded any discrimination of events by the number of highly ionizing particles. The viewing efficiency was controlled by repeatedly tracing part of the tracks of primary particles at different speeds and turned out to be very high (~100% for the studied interactions).

The table shows the characteristics of the interactions used in the work.

Table

Characteristics of interactions

P_0, GeV/c	Accelerated solvent	Emulsion type	Viewing m	Number of. measing	Number of hA-collision	Number of hN-collision	Lit.
20,8	CERN	Ilford K 5	3550	9570	722	694	Present work

When viewed as inelastic interactions, all events were recorded except:

– cases of deviation of the traceable track by an angle $\theta < \theta_{el}$ (θ_{el} is the angle corresponding to the conditional upper boundary of elastic proton scattering on nucleons and nuclei); elastic stars were also distinguished from two-ray events using the angle-angle criterion and coplanarity;

– the case of the emission of a δ-electron;

– the case of electromagnetic formation of e^+e^--pairs by a particle of the primary beam.

In each event, the following were determined:

1) the number of all charged particles with their division into s-, g- and b-particles in accordance with the usual emulsion classification:

– relativistic or s-particles were considered particles with relative ionization in the emulsion $I < 1.41\ I_0$ (I_0 ionization of beam particles) and a velocity $\beta = v/c > 0.7$; they they consist mainly of particles born in the collision process (π- mesons);

– "gray", or g-particles, were considered particles with $I > 1{,}41 I_0$, which corresponds to protons with a momentum of $0.2 < p < 1.0$ GeV/c and with an emulsion mileage of 1 > 3 mm; they consist mainly of protons knocked out of the target core during collision; impurity "gray" pions (pulse $60 < p < 170$ MeV/c) are very insignificant [2];

– "black" or b-particles were considered particles with a range of $l < 3$ mm – in most cases protons with a pulse of $p < 0.2$ GeV/c and heavier fragments of the target nucleus; the main part of these slowest secondary particles is emitted by the nucleus in the process of removing nuclear excitation after a long (on a nuclear scale) time after the interaction. Gray and black particles are collectively called highly ionizing or h-particles and their multiplicity is $n_h = n_g + n_b$;

2) spatial (θ) and azimuthal (φ) angles of departure of all charged particles.

Angular measurements. Angular measurements in a stack irradiated in a magnetic field have some difficulties associated with the curvature of the trajectories of charged particles.

To verify the applicability of the angular measurement technique developed for a stack without a magnetic field, control measurements were carried out [3,4]. Basic and repeated measurements were performed on 150 traces of positively charged particles; in the second case, with a distance from the top of the star along the primary and secondary traces ~ 3 times less than in the main measurements. A comparison of the results showed that with selected deletions in the main measurements, the effect of curvature on the measured angles can be neglected.

To assess the errors of angular measurements, control measurements were carried out in this stack, which gave the following results

$$\langle \Delta\varphi \rangle = 2{,}75; \quad (1)$$

$$\langle \Delta\Theta/\Theta \rangle = 0{,}056, \quad (2)$$

showing good accuracy of angular measurements.

Pulse measurements. The pulse of a particle in a photoemulsion irradiated in a strong magnetic field was determined by measuring the second differences D on the trace of this particle [5,6], at a cell length t:

$$D = y_1 - 2y_2 + y_3 . \quad (3)$$

Here yi is the ordinate of the i-th point of the measured trace. The average dependence of noise on the cell length was taken into account.

To estimate the pulses of secondary particles, a linear function of k second differences was used, measured during the continuation of the trace from plate to plate, associated with the result of the p' measurement of the pulse p by the equality

$$p' = eH/|k|c. \quad (4)$$

$$H = 17{,}3 \text{ Тл}. \quad (5)$$

In the approximation of pure Coulomb scattering, following the rules for calculating the weighted average and neglecting the dependence of the scattering constant on the cell length, it is advisable to choose the function k in the form [7,8],

$$k = \cos\alpha \left(\sum_i t_i\right)^{-1} \Sigma\, (D_i/t_i); \quad (6)$$

here α is the angle of immersion of the trace. The error of this value Δk is equal to

$$\Delta^2 k = cos^2\alpha \left(\sum_i t_i\right) \sum_i t_i^{-2} [\pi a^2 t^3/2\, p'^2\, \beta'^2 \cos^3\alpha + (0{,}10 + 0{,}058 t_i/\text{ мм})\, \mu^2], \quad (7)$$

Ionization measurements. The ionization losses -dE/dx of a single-charged particle depend only on the velocity v, therefore, simultaneous measurement of -dE/dx and momentum p makes it possible to determine the mass of the particle.

For a particle heavier than an electron, ionization losses are known to be described by the Bethe-Bloch formula [9],

$$-(dE/dx) = (2\pi nz^2e^4/mv^2)\,[\ln(2\,mv^2W_{max})/(I^2(1-\beta^2)) - 2\,\beta^2 - \delta], \quad (8)$$

where n is the number of electrons in 1 cm^3 of a substance, m is the mass of an electron; $I=I_{oz}$ is the average ionization potential, w_{max} is the maximum energy transferred by an incoming particle to an atomic electron:

$$W_{max} = 2(W + Mc^2 + mc^2)^2mc^2/M^2c^4\,; \quad (9)$$

W is the kinetic energy of a particle with mass M; σ is a correction for the density effect associated with the polarization of the medium.

Ionization losses with the maximum transmitted energy W0 are described by the formula [10]

$$-\{dE/dx\}_{W0} = (2\pi nz^2e^4/mv^2)\,[\ln(2\,mv^2W_0)/(I^2(1-\beta^2)) - \beta^2 - \delta]. \quad (10)$$

During ionization measurements, the secondary trace was divided into sections with an immersion depth of 50 μ with an emulsion thickness of about 600 μ. The trace of the primary proton was selected near each site so that the ratio of the length of the primary trace to the length of the site was the same for all sites and equal to 2-3.

For each particle, the relative ionization density g* and its error Δg* were calculated. The count was conducted up to a set of 5000 blobs on the secondary trail. In total, during the ionization measurements, we counted more than 25 million blobs on the traces of primary and secondary particles.

To verify the correctness of ionization measurements and count errors, each trace was divided into two large sections and the values g* and Δg* were calculated separately for these two sections.

Figure 1 shows the distribution of 1268 traces by magnitude

$$x = (g^*_1 - g^*_2)/(\Delta^2g^* + \Delta^2g^*)^{1/2}. \quad (11)$$

The curve in Fig. Gauss distribution. An approximate agreement with the Gauss curve suggests that fluctuations in a large number of blobs in the Ilford K5 emulsion are well described by Poisson's law, and also indicate the correctness of the ionization measurement technique. Large statistics make it possible to detect even a slight deviation from normality $\chi^2 = 55.7$ with a number of intervals of 22.

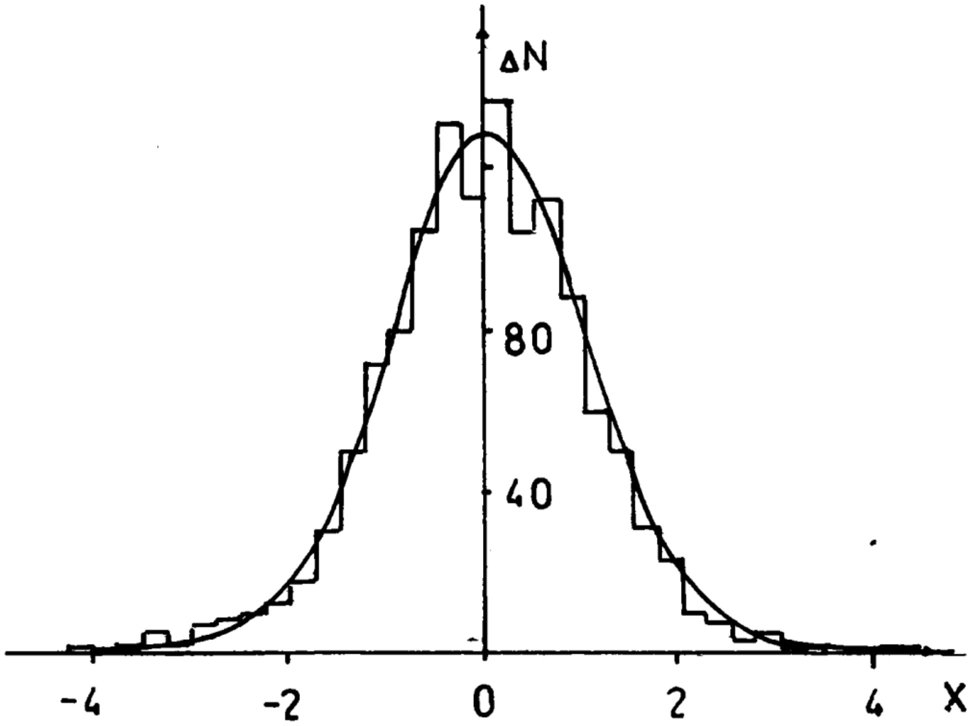

Fig. 1. Experimental distribution of traces by x value. The curve is a Gaussian distribution.

RESULT AND DISCUSSION

Identification of relativistic particles. The identification of secondary relativistic particles in the Ilford K5 emulsion irradiated with protons with a pulse of 20.8 GeV/c in a strong magnetic field was carried out. The identification of secondary relativistic particles was carried out [6] in three groups of stars. Group (a) consists of pure (without strongly ionizing particles, electrons and blobs) stars [7] with the number of secondary relativistic particles equal to $n_g = 3$ and a small average value of the sine of the angle of departure of the secondary particle in h_p.

$$\overline{sin}\Theta i = \frac{1}{n}\Sigma \sin \Theta i < 0{,}2\ . \qquad (12)$$

Most of these stars are made up of three-ray reaction events

$$p + A \rightarrow A(A') + N + n\pi, \qquad (13)$$

in which the nucleus with atomic number A does not change charge and is not excited or weakly excited, and then passes into the ground state by emitting gamma quanta.

Group (b) consists of [7] 116 background stars with $n_s = 3$, mean $\sin\theta < 0.2$. We call background stars having 1 or 2 black traces in the absence of gray ones and stars without strongly ionizing particles, but with slow electrons and blobs. These interactions are usually interpreted as collisions with quasi-free neutrons, in which the target neutron escapes from the nucleus.

Finally, group (b) consists of events with a large number of strongly ionizing particles ($n_h \geq 8$) having at least two relativistic particles with $\theta < 17°06'$. After measuring the curvature of the relativistic traces with $\theta < 17°06'$, ionization was measured for the two particles with the highest momentum. A total of 500 such events were measured at a viewing length of 646 m. In these stars, relativistic particles are formed when primary protons collide with heavy emulsion nuclei.

Methods of mathematical statistics were used to identify the particles. The independence and normal distribution of the values k and g* allow us to make up the value [11]

$$\chi^2 = [|k| - eH/pc]^2/\Delta^2 k + [g^* - I(W_0, p/mc)]^2/\Delta^2 g^*, \qquad (14)$$

here k is a linear function of the second differences, g* is the relative density of the blobs, Δk and Δg* are measurement errors of the corresponding quantities; m and p, respectively, are the mass and momentum of the secondary particle in l.s, e is the elementary charge, I is the theoretical relative ionization.

The minimum value of χ^2min of this value was found for each particle. The relative ionization I was determined by the Sternheimer formula (10) for energy losses in silver bromide due to collisions with transmitted energy less than W_0.

When calculating the minimum value of χ^2, the momentum p and the mass m of the particle were considered as free parameters.

How was the minimum value of χ^2_{min} found for this measured particle? First, the mass of the particle is set. For positive particles, the mass value of one of the π^+, K^+, p, Σ^+ particles was taken. For negative particles, the value of one of the π^-, K^-, Σ^-, Ξ^- particles was taken. At a fixed mass . the value of the particle 's momentum p varies until the minimum value of χ^2 is reached . In this case, the first term in expression (14) reaches a minimum value when the value eH/pc is close to the experimental value of the curvature |k|. The minimum value of the second term in expression (14) is achieved when the expression $I(W_0, p/mc)$ approaches the measured ionization density g*. Then the procedure was repeated by changing the mass - discrete free parameter. Four values of χ^2_{min} were obtained for each of the 1642 traces, for different m, and the smallest of these four values was taken.

With an increase in W_0, the sum of $\Sigma\chi^2$ min for N = 1642 traces decreases from 1300 at W_0 = 2 keV to 1100 at W_O = 30 keV, which indicates the agreement of Sternheimer's theory with the experiment, since the condition is fulfilled

$$\Sigma\chi^2_{min} = 1100 < (N-1) + 2[2(N-1)]^{1/2} = 1755, \qquad (15)$$
$$\text{for } N = 1642.$$

To assess the contribution of strange particles, we repeated the described work, giving the parameter m the values of the masses of the π^+ meson and proton or π-meson. Figure 2 shows an experimental histogram and a χ^2 distribution with one degree of freedom. Good agreement in the region of χ^2min < 1 suggests that the strange particles have $\chi^2_{min} > 1$. Under this assumption, the number of strange particles in each group was determined.

The proportions of the strange particles turned out to be equal (-0,2 ± 4,0)%, (0,7 ± 3,7)% and (15.8 ± 2.3)%, respectively, for groups of events (a), (b) and (c). Thus, strange particles in the cases under consideration are formed in central interactions with heavy emulsion nuclei; in in peripheral collisions of protons with nuclei, they practically do not form.

A more detailed identification of secondary charged particles was carried out using the method described above. For stars with $n_h \geq 8$ and $n_s \geq 2$, in which only two relativistic particles with maximum impulses were identified, the average numbers of protons, π±mesons, positively and negatively charged strange particles turned out to be equal

$$\langle n_p \rangle = 0{,}71 \pm 0{,}03, \quad \langle n_{s+} \rangle = 0{,}19 \pm 0{,}04,$$
$$\langle n_{\pi+} \rangle = 0{,}57 \pm 0{,}03, \quad \langle n_{s-} \rangle = 0{,}13 \pm 0{,}03, \qquad (16)$$
$$\langle n_{\pi-} \rangle = 0{,}40 \pm 0{,}03.$$

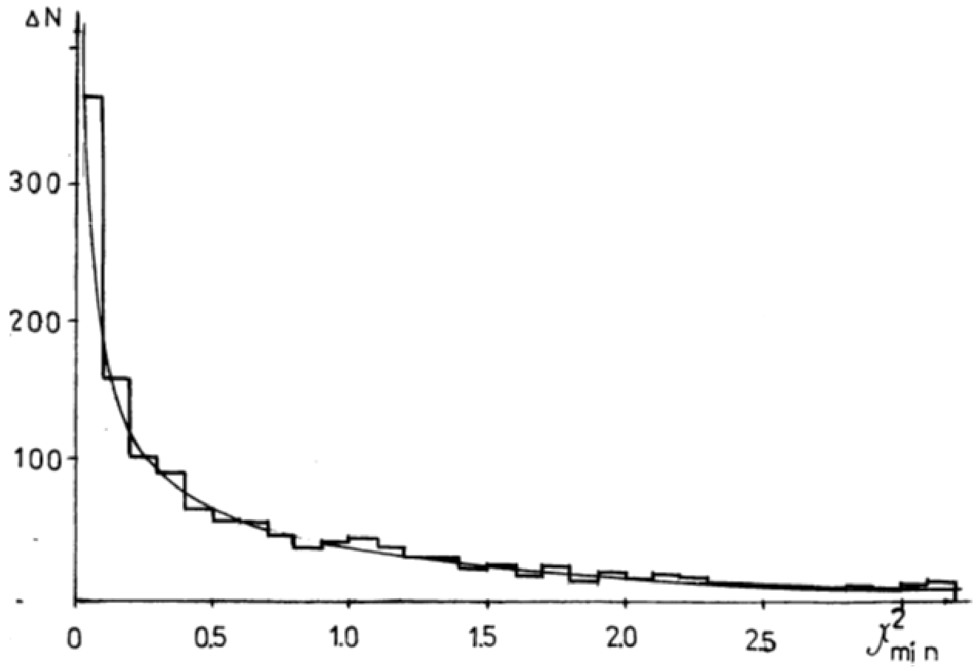

Fig.2. Distribution of traces by the value of χ^2_{min}.

Investigation of the coherent diffraction transformation of protons into the $p\pi^+\pi^-$ system.

Many papers have been devoted to the study of coherent processes in photoemulsion [12,13]. However, most of them are devoted to the study of diffraction processes on specific nuclei [14,15]. To study the coherent diffraction transformation of protons [16]

$$p+A \rightarrow A + p\pi^+\pi^- \qquad (17)$$

with a pulse of 20.8 GeV/s, pure (group a) and dirty (group b) stars with the number of secondary shower particles equal to $n_s = 3$ were used in the $p\pi^+\pi^-$ system.

For the selection of reaction events (17), as well as for the identification of particles, the least squares method is used. The positive particles (there are two of them in this reaction) will alternately be considered a proton, then a π^+ -meson, and a negatively charged particle a π^- -meson.

$$\chi^2 = \Sigma[|k| - eH/pc]^2/\,\Delta^2 k + \Sigma\,[g^* - I(W_0,\, p/mc)]^2/\Delta^2 g^*. \qquad (18)$$

The pulses p_1 and p_2 of positively charged particles will be considered as free parameters, and the momentum of the third particle will be determined from the energy balance in lab.sistem.

$$E_0 = \Sigma E_i \qquad (19)$$

where E_0 is the energy of the primary proton.

We find the minimum value of the value χ^2.

Figure 3 shows the distribution of 98 stars of group a, in magnitude χ^2_{min}. The curve in Fig. 3 is a χ^2 distribution with four degrees of freedom. Normalization by area in the area of $\chi^2_{min} < 11$.

67 stars fall into this area. This corresponds to the reaction cross section (17)

averaged over all nuclei $< \sigma > = 3.5 \pm 0.5$ mbn.

CONCLUSION

The results obtained on the identification of particles and on the selection of rare reaction events (17) show that the application of the least squares method gives good results for studying these processes.

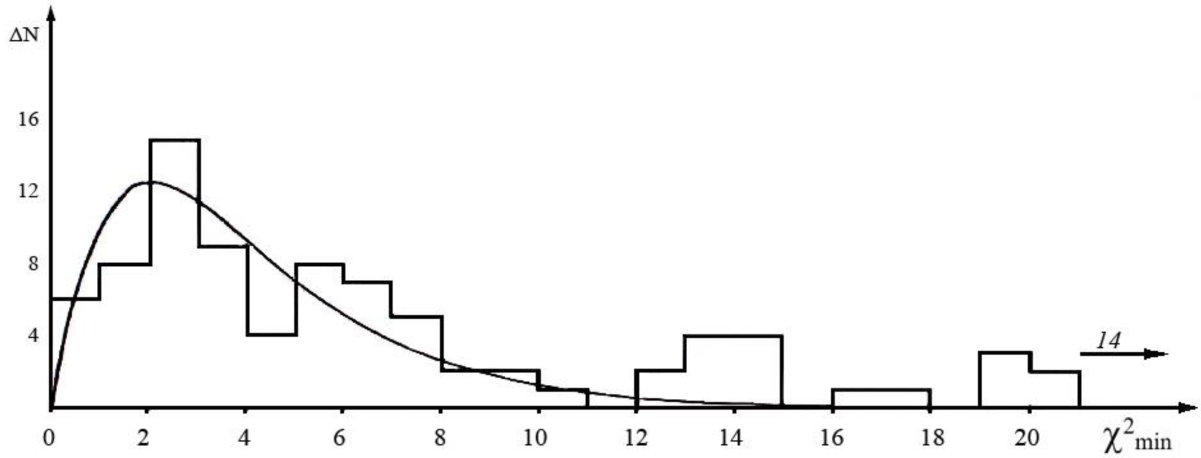

Fig. 3. Distribution of 98 stars of group a, in magnitude χ^2_{min}. The curve in Fig. is a χ^2 distribution with four degrees of freedom. Normalization by area in the area of $\chi^2_{min} < 11$.

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