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THE STUDY OF THE TRACK PROFILE OF RELATIVISTIC PARTICLES IN A PHOTOGRAPHIC EMUSLION

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In this paper we have studied the distribution of the edges of the grains forming the track of the relativistic particle in the emulsion with respect to the axis of the track in the plane of the track axis (i. e. the track's profile) for protons with kinetic energies 2 and 9 GeV. This study had been performed with the nuclear emulsion of NIKFI-R type, irradiated by an internal beam from the synchrophasotron of the High Energies Laboratory in JINR in Dubna. The results say that the mean square value of the distribution of the edges of the grain formations with respect to the axis of the track for given energies of protons does not depend (or depends only very slightly) on the energy of particle. The density of the „excesses" of the edges of grains formations over certain distance (determined by a convenient multiple of the mean square value of the metioned distribution) from the track axis depends on the energy of particle; for the quantity of measuring, performed in this work the difference of the densities of the mentioned „excesses" for protons with kinetic energy 2 and 9 GeV is statistical'y significant up to the level $\alpha = 0.005$. The density of the „excesses" could be used as a factor for identification of relativistic particles in the nuclear emulsion. The method of the experimental determination of this parameter is analogous to measurint of the density of δ-electrons „by the effective range", but it is not influenced by subjective factors.

INTRODUCTION

The charged relativistic particles in a nuclear emulsion can be identified by measuring the ionisation and the Coulomb multiple scattering along the track of an unknown particle [1]. There are some cases, however, in which the measuring of these two parameters is not sufficient (in the areas near the points of intersection of the curves showing the dependence of the ionization on $p\beta c$ for the particles of various masses). That is why the possibility of determining experimentally another independent parameter characterizing the track of a relativistic particle is important for particle identification.

The possibility of using δ-electrons on the track of an unknown particle as an identifying factor was referred to in papers [2, 3]. Using the method based on the determination of the low-energetic δ-electron density is complicated by the fact that we have to decide whether certain groupings of grains can be considered as a δ-electron or not.

The aim of this paper was to study more fully the structure of a relativistic particle track in an emulsion; to study especially the distribution of the edges of the grains forming the track of the particle in the emulsion with respect to the axis of the track. Pursuing this research we found a possibility to measure the parameter of the track of a relativistic particle depending on the speed of the particle and not influenced by subjective factors.

THE STUDY OF THE STRUCTURE OF THE TRACK

Experimental Results

Since the growth of developed grains forming the particle track in the emulsion is determined by more than one factor (the properties of the emulsion, the influence of the photo-chemical process, the amount of the energy lost by the particle in the given grain of AgBr), the centres of the developed grains will not be situated in places over which the particle has actually passed, i. e., on the axis of the track, but will be distributed in a certain way with respect to the axis. We shall assume the axis symmetry for this distribution. If this assumption is realized, it is sufficient to study this distribution in a plane crossed by the axis of the track, i. e. to study the track's profile.

The experimental study of the profile of the relativistic particle tracks has been performed with an emulsion of the NIKFI-R type irradiated by an internal beam from the synchrophazotron of the High Energies Laboratory in JINR in Dubna, by protons with kinetic energies $E_k = 2$ GeV and $E_k = 9$ GeV in the plane of the emulsion in mutually perpendicular directions. The measurements have been performed with ZEISS KSM 1 microscope.

Owing to the fact that the relativistic particle track in the emulsion could be considered a straight line along a short segment, we had the possibility to measure the track profile in the plane of the emulsion in the following way. The measured track segment was directed as exactly as possible in the direction x of the microscope table. Then we measured the y-coordinates (perpendicular to x) of both edges [1]) of all the formations on the given track, i. e., of single grains forming the track, of grain agglomerates, of the δ-electron tracks and of single grains situated near the track about which it could not be determined with certainty whether they belonged to the track or to the background of the emulsion. The y-coordinates were read on a microscopical micrometer with

[1]) Later we shall speak about the upper edge, or the lower one respectively, in accordance with the microscopic field of view.

a price of scale division of 0.1 μ; the hundredth parts (10^{-2}) of microns were estimated.

The profile of the track has been measured on the total length of the track equal to 2 cm (there were more than 4000 formations on it) for each of the considered proton energies. The measurements have been performed on several tracks (15 tracks for each energy) selected at random in various areas of the emulsion. In order to compare as objectively as possible the profiles of the proton tracks of the two energies we chose for measuring only the primary tracks situated in the middle third of the zone of the emulsion layer. The measurements were made on segments of a 100 μ length.

It was found that the second differences of the y-coordinates of the upper and lower grain edges are most characteristic for the grain distribution with respect to the track axis in the plane of the emulsion. These second differences will be denoted in the following by ${}^2D_h$, ${}^2D_d$. Therefore the second differences from the measured y-coordinates were calculated. In this way the statistical sets of the second differences have been obtained, with the number of cases $n = 4078$ for protons with an $E_k = 2$ GeV and $n = 4183$ for the protons with an $E_k = 9$ GeV; the measurements have been done separately for the upper and lower grain edges. Then the mean values ${}^2\bar{D}$ and the mean square values s have been calculated for these sets. The obtained distributions of the second differences are shown in Fig. 1, 2.

Owing to the fact that apart from single grains forming the particle track

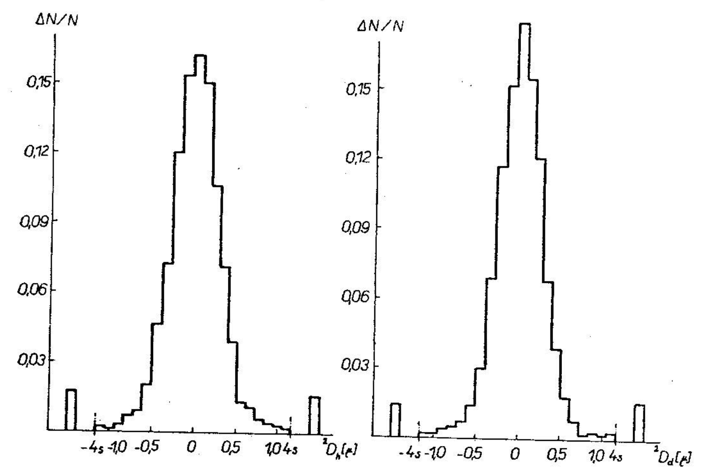

Fig. 1. The distribution of the second differences of the y-coordinates of the upper grain edges ${}^2D_h$ and lower grain edges ${}^2D_d$ on the trakcs of protons with a kinetic energy $E_k = 2$ GeV

(whose distribution with respect to the track axis can be assumed normal considering the mechanism of the particle track formation in the emulsion) other cases were measured as well, caused by δ-electrons and by the emulsion background, there can be found some elements of a high absolute value which evidently do not belong to the basic distribution formed by single grains of the track. Therefore we use the cut off method when calculating the parameters of the second differences distributions. Doing so we excepted the elements not belonging to the interval $\langle -D - 4s,\ ^2D + 4s\rangle$ from the sets of ^2D. The final results of the calculations of distribution parameters are shown in Table 1. As it can be seen in the Table 1, the mean values of all the four

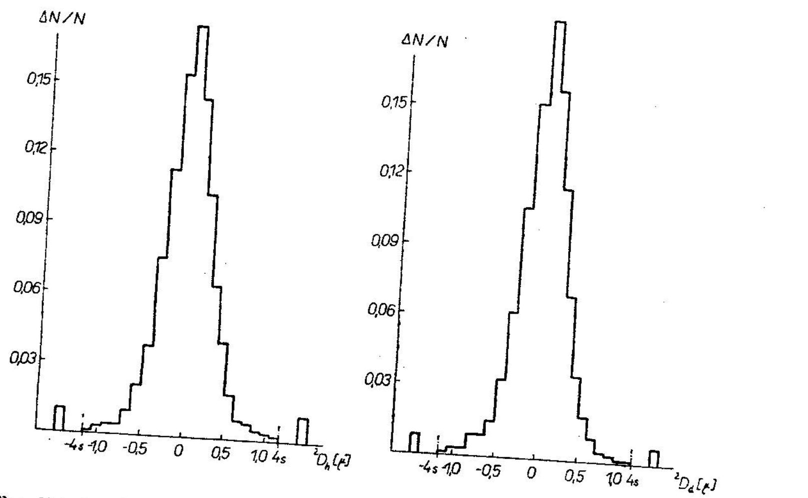

Fig. 2. The distribution of the second differences of the y-coordinates of the upper grain edges ^2D_h and lower grain edges ^2D_d on the tracks of protons with a kinetic energy $E_k = 9$ GeV.

Table 1

E_k	distribution	$\overline{^2D}$ [μ]	s [μ]	s' [μ]
2 GeV	^2D_h	− 0.007 ± 0.005	0.295	0.279
	^2D_d	+ 0.004 ± 0.005	0.283	0.262
9 GeV	^2D_h	− 0.005 ± 0.005	0.298	0.273
	^2D_d	+ 0.002 ± 0.004	0.282	0.255

distributions approach zero and can be taken as zero in the statistical error limits.

The determination of the mean square values of sample was also performed from the integral representation of the second differences distributions with the help of the method described in paper [4]. In this method we mark the integral representation of the set on a plot in which the straight-line distribution is normal (analogy with so called probability paper) and the mean square value is determined from the line slope. These values are marked by the symbol s' in Table 1. Applying this method we have found out that the large majority of all the four experimental distributions of the second differences (in the area near the mean value which contains ~ 80 % of the elements of distribution) agrees well with the normal distribution whose mean square value is s'.

The obtained results show that the mean square values of sample are practically equal for both considered protons energies. It means that the mean square value of the second differences distribution and therefore the mean square value of the distribution of the grain edges with respect to the track axis does not depend (or depends only very slightly) on the energy of the particle for the given exactness of measurements in the case of our protons energies. We can suppose that it will be so in the whole interval of the kinetic proton energies from 2 to 9 GeV.

Then we analyzed the cases causing that $|^2D| > 4s$ (if $\overline{^2D} = 0$). In Fig. 1 and 2 the frequencies of the cases $^2D < -4s$, $^2D > 4s$ are plotted outside the interval $\langle -4s, 4s\rangle$. Most of these cases correspond to the „excess" of the edge of grain agglomeration over a sufficiently great distance from the track axis. The mentioned „excesses" are caused by the emulsion background and, above all, by δ-electrons with a sufficiently high energy. If an upward excess shown on a primary particle track (when looking into the microscope), a high positive value appears in the set of ^2D_h. Analogically, a downward excess causes the appearance of a high negative value in the set of ^2D_d[2]). If we are interested in the total number of „excesses" over the track axis at a distance corresponding to the value $4s$ on some track segment, then we have to sum up the cases $^2D_h > 4s$ and $^2D_d < -4s$.

Let us compare the number of these cases for the protons with kinetic energy 2 and 9 GeV. The fact that the mean square value of the second differences distribution does not depend on the energy of the particle makes it possible to use for this comparison the same value $\bar{s}$ equal to the average mean square values of all the four experimental distributions of the second differences. If

[2]) The sign of the second difference depends on the choice of the coordinate system. The given consideration holds for the coordinate system of the microscope ZEISS KSM 1.

we want to make the density of the considered ,,excesses" a suitable characteristic of the relativistic particle track, we have to eliminate as far as possible all the cases from among the cases $^2D_h > 4\bar{s}$ and $^2D_d < -4\bar{s}$ which do not correspond with the agglomerate of grains belonging to the track but are caused by the emulsion background etc. This was done according to the following criteria:

a) if the second differences of the y-coordinates of the edges of a given grain or grain agglomerate correspond at the same time to the relations $^2D_h > 4\bar{s}$ and $^2D_d > 4\bar{s}$ (or at the same time to the relations $^2D_h < -4\bar{s}$ and $^2D_d < -4\bar{s}$), then such a case is considered as caused by the emulsion background and must be eliminated.

b) if a high value ^2D_i with a certain sign appears in the sequence of the calculated second differences, then in its neighbourhood the values $^2D_{i-1}$, $^2D_{i+1}$ with an opposite sign and approximately half the absolute value appear. All these near values are to be eliminated if their absolute value exceeds $4\bar{s}$.

c) if the second differencies of the y-coordinates of the edges of some grain agglomerate correspond at the same time to the conditions $^2D_h > 4\bar{s}$ and $^2D_d < -4\bar{s}$ (i. e. two ,,excesses" caused by one grain agglomerate only), then there is only one value to be left in the set of the considered cases, the one which is higher in its absolute value.

The density of the cases for which $^2D_h > 4\bar{s}$ and $^2D_d < -4\bar{s}$ hold and which are not eliminated by the criteria a), b), c) will be assumed to be a characteristic of the relativistic particle track in the emulsion.

There are in Table 2 the experimental results obtained by measuring the profile of the track of protons with $E_k = 2$ and 9 GeV on 2 cm of the track for each energy. There are given the results without the application of the criteria a), b), c); then there are given the numbers of cases eliminated by the criteria a), b), c) and the final results after applying these criteria as well. Thus we get the values $N_\delta = 38.5$ for p with $E_k = 2$ GeV and $N_\delta = 22.5$ for p with $E_k = 9$ GeV (in 1 cm of the track) for the density of the considered cases.

In order to determine the character of the distribution of cases given in the last column of Table 2 and to compare these distributions for the protons of

Table 2

E.	number of cases $^2D_h > 4\bar{s}$, $^2D_d < -4\bar{s}$				
	before correction	corrections			after correction
		a	b	c	
2 GeV	118	22	13	6	77
9 GeV	78	17	10	6	45

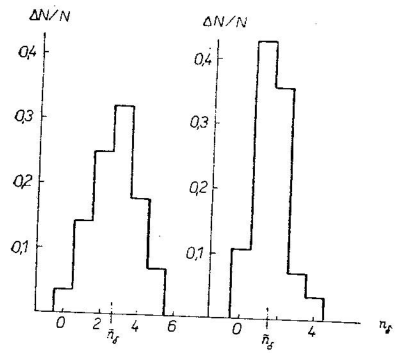

Fig. 3. The distributions of the number n_δ of cases $^2D_h > 4\bar{s}$, $^2D_d < -4\bar{s}$ in a segment of the length $t = 700\,\mu$ for protons with $E_k = 2$ GeV (right) and with $E_k = 9$ GeV (left).

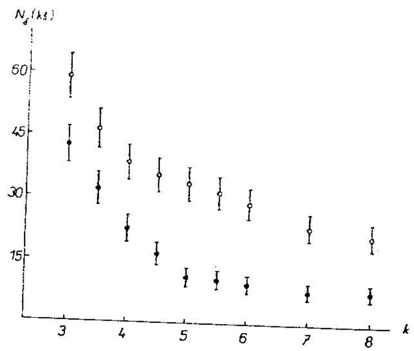

Fig. 4. The dependence of the density N_δ of the cases $^2D_h > k\,.\,\bar{s}$ and $^2D_d < -k\,.\,\bar{s}$ on k for protons. ○ -with $E_k = 2$ GeV, ● -with $E_k = 9$ GeV.

both the energies considered, we divided the measured part of the track into segments of the length $t = 700\,\mu$. The distributions of the number of considered cases n_δ in a segment with the length t for both protons energies are shown in Figure 3. The mean values of these distributions are n_δ (2 GeV) = 2.68 and n_δ (9 GeV) = 1.50. Then we tested the statistical significance of the difference $\Delta n = \bar{n}_\delta$ (2 GeV) $- \bar{n}_\delta$ (9 GeV) supposing the distributions in Fig. 3 to be the Poisson distributions. This assumption can be made on the basis of the independence of single ,,excesses" and on the basis of a low probability of the appearance of an ,,excess". This testing was done by a criterion based on an approximation of a Poisson distribution by a normal one and, besides, by a criterion for testing the significance of the difference of two distributions obtained experimentally [5]. The result of applying the two criteria shows that the value Δn is statistically significant up to the significance level $\alpha = 0.005$. The density N_δ of the cases $^2D_h > k\,.\,s$ and $^2D_d < -k\,.\,s$ depending on k is shown in Fig. 4.

DISCUSSION

The results of studying the profile of relativistic particle tracks in emulsion have shown that the distributions of second differences ^2D_h, ^2D_d for the protons with kinetic energies 2 and 9 GeV agree well with a normal distribution, with the exception of the area of high absolute values of the second differences (containing about 20 % of elements forming the distribution), where deviations from the normal occur. It can be supposed that the distribution of the edges of separate grains forming the track is normal with a mean square value s'. The deviations from the normal in the area of high absolute values of the second differences are caused by formations on the track which are formed by more than one grain (agglomerates of grains, δ-electrons). It was shown that the mean square values of the distributions ${}^2D_h$, ${}^2D_a$ for the protons of kinetic energies 2 and 9 GeV neither depend (or depend only very slightly) on the energy nor on the particle speed for the given exactness of measuring.

The comparison of the number of elements from the sets of ${}^2D_h$ and ${}^2D_a$, for which ${}^2D_h > 4\bar{s}$ and ${}^2D_a < -4\bar{s}$, (the elements eliminated by the criteria a), b), c) are not considered) has shown for the protons with $E_k = 2$ GeV and $E_k = 9$ GeV that it is a value dependent on particle speed. That could be expected for the reason that the overwhelming majority of these cases corresponds to the presence of δ-electron on the primary particle's track. We can see from Fig. 4 that the choice of k in a sufficiently long interval does not influence the character of the results. If k is fixed (being $k \geqslant 4$), the value N_δ is not very sensitive to the exactness of the determination of the mean square value of distribution. It means we should have got results of the same quality even then if we had used value s' from Tab. 1 instead of s, eventually if we had chosen another k.

Hence a possibility is shown to determinate experimentally a new parameter of the track N_δ. This measuring method is analogous to the method of measuring the density of δ-electrons „by effective range" [6]. The advantage of the method described in this paper is in its higher sensibility (caused by the fact that a smaller value of the minimum „effective range" is used, corresponding to the value $4s$). Thus we get a larger statistics by measuring the same segment of the track. The main advantage of the described method is, however, in its objectivity. The disadvantage is in its labour-consuming character, which could be avoided by a proper mechanization of measuring and calculating.

The significance of the difference N_δ (2 GeV) $- N_\delta$ (9 GeV) suggests a possibility of using the parameter N_δ for the identification of particles in a relativistic area in which the speed increases to a sufficient extent besides the increase of energy.

It is shown that in order to distinguish the protons with $E_k = 2$ GeV and $E_k = 9$ GeV by the described method at the risk of 5 % it is necessary to measure ~ 1 cm of the track. As for the protons and π^+-mezons in the area of $1.5\ \text{GeV} \leqslant p\beta c \leqslant 2.5\ \text{GeV}$ (where the identification cannot be performed by measuring the ionization and the mean angle of multiple Coulomb scattering), the identification could be performed in some smaller segment than in the one for the protons with $E_k = 2$ and 9 GeV, with respect to the fact that the difference of speed between p and π^+ is bigger to some extent than the one for

the protons with the considered energies. Identifying in this way, it will be advantageous to use a method of sequence analysis [7].

CONCLUSION

Let us sum up the results of this paper. The study of the track profile of the protons with $E_k = 2$ GeV and 9 GeV has shown that the mean square value of the distribution of the edges of grains forming the particle track in the emulsion does not depend (or depends only very slightly) on the particle's energy -with regard to the axis of the track in the plane of the emulsion, at the given exactness of measuring.

Studying this problem we found a possibility to determine experimentally the parameter of the track N_δ depending on the speed of the particle by using a method which is sufficiently sensitive and objective.

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