INTERACTIONS OF PIONS AND PROTONS WITH EMULSION NUCLEI AT 60 GeV AND 200 GeV*

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Parametrizations of multiplicity distributions of shower particles and evaporation tracks as well as correlations between them are analysed. The observed differences for pion and proton interactions at the same energy are consistent with the hypothesis that the relevant parameter which determines production process is the mean free-path of the incident particle inside the nucleus.

1. Introduction

In the last few years marked by increased interest in high energy hadron-nucleus interactions considerably fewer papers were published on pion-nucleus than proton-nucleus interactions. Therefore it seems interesting to compare some parameters which determine multiplicities of produced particles and the number of heavy ionizing tracks for pion-nucleus interactions with their analogs for proton-nucleus interactions.

First, to avoid confusion, we define some parameters which are used in this paper.

n_s — the number of charged relativistic ($\beta > 0.7$) particles includes: fast particles created, leading particles and fast recoil protons,

N_h — the number of heavy ionizing ($\beta \leqslant 0.7$) particles includes: evaporation particles, slow recoil protons and slow particles produced,

n — the total charged multiplicity (without evaporation particles) includes: n_s-particles, slow recoil protons and slow particles produced.

There is no way of directly determining the total charged multiplicity (n) from the experiment. Slow recoil and slow particles produced cannot be extracted from the total number of N_h particles. However, one can estimate the mean number of recoil protons and slow particles produced using the proton-proton data and assuming a model of

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hadron-nucleus interaction. For interactions of hadrons with emulsion this number is close to unity for models in which the incoming particle multiply interacts inside the nucleus [1, 10]. Thus in the following we shall use $n = n_s + 1$.

2. *Experimental material*

The pion-emulsion interactions investigated (788 events at 60 GeV and 973 events at 200 GeV) were found by scanning "along the track" in emulsion stacks irradiated at Serpukhov and Batavia. The proton-emulsion data at 67 GeV and 200 GeV were published by us earlier [2]. In our present samples only inelastic interactions were taken into account (elastic and coherent events were rejected). To enlarge the statistics in proton-emulsion interactions we also used the data at 67 GeV and 200 GeV from Ref. [3] and at 200 GeV from Ref. [4]. The total number of proton-emulsion interactions used are 1186 events at 67 GeV and 3960 events at 200 GeV.

3. *Distributions of heavy ionizing particles* (N_h)

It is well known [6, 8, 1] that in proton-emulsion interactions the distribution of N_h and its mean value does not depend on primary proton energy for $E > 25$ GeV. This enables us to present the composite N_h distribution (histogram in Fig. 1) for proton-emulsion interactions at primary proton energies 25 GeV — 300 GeV [2–7]. It contains over 9000 events and its mean value equals $\overline{N_h} = 7.45 \pm 0.08$. For pion-emulsion interactions at 60 GeV and 200 GeV the N_h distributions are identical, within the statistical errors,

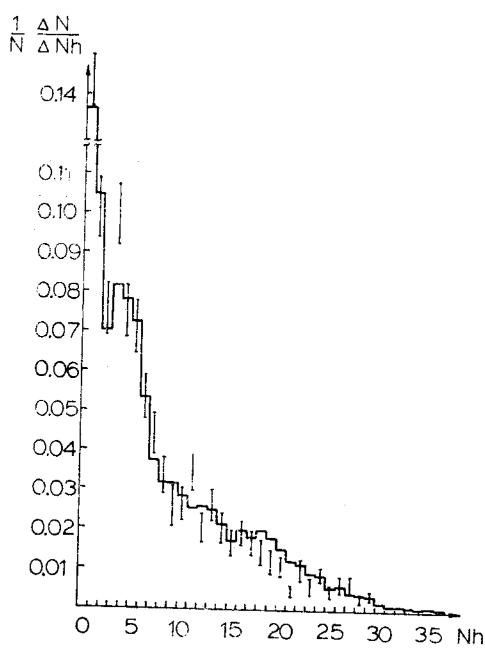

Fig. 1. Distribution of N_h tracks. Histogram — primary protons, error bars — primary pions

and their mean values are 7.11 ± 0.26 and 6.73 ± 0.22 respectively. The composite N_h distribution (1761 events) for pion-emulsion interactions at 60 GeV and 200 GeV is shown in Fig. 1 (error bars) and its mean value equals $\overline{N_h} = 6.90 \pm 0.17$. This value is less than that for primary protons.

4. *Multiplicity distributions*

In Figs 2 and 3 the multiplicity distributions of relativistic particles (n_s) for pion-emulsion and proton-emulsion interactions at 60 and 67 GeV and 200 GeV are presented. The mean values and dispersions of these multiplicity distributions are given in Table I

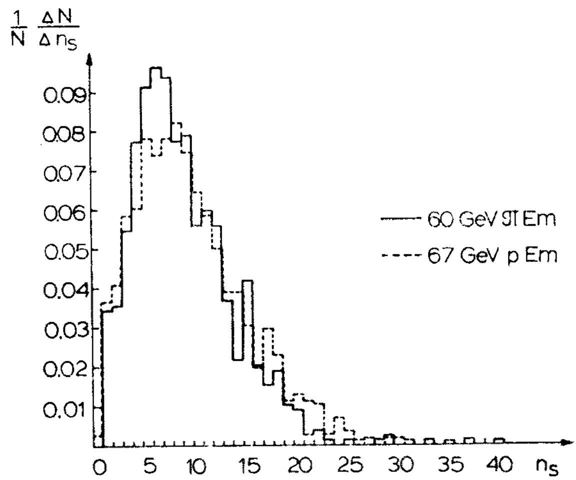

Fig. 2. Multiplicity distributions of n_s tracks. Full line — primary pions at 60 GeV, dashed line – primary protons at 67 GeV

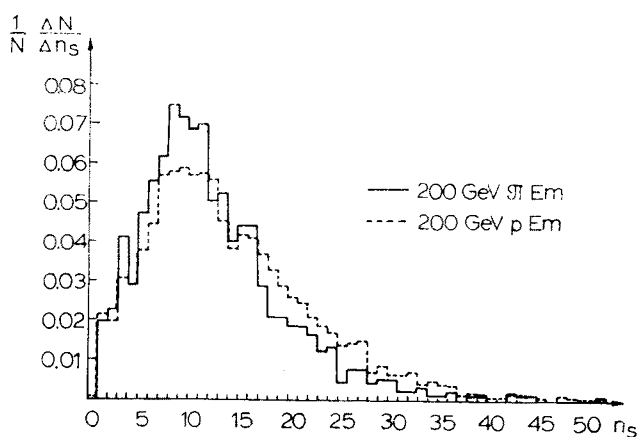

Fig. 3. Multiplicity distributions of n_s tracks. Full line — primary pions at 200 GeV, dashed line — primary protons at 200 GeV

TABLE I

Hydrogen interactions			Pion-Emulsion interactions		Proton-Emulsion interactions	
1	2	3	4	5	6	7
E (GeV)	$\overline{n}_{\pi p}$	$\overline{n}_{pp}$	$\overline{n}_s$	D	$\overline{n}_s$	D
60/67	6.10 ± 0.16	5.89 ± 0.07	8.59 ± 0.18	4.93 ± 0.12	9.33 ± 0.16	5.63 ± 0.12
200	8.02 ± 0.12	7.68 ± 0.07	11.94 ± 0.23	7.09 ± 0.16	13.67 ± 0.13	8.24 ± 0.09

(columns 4–7). The table also presents the mean multiplicities of charged particles produced in pion-proton (column 2) and proton-proton (column 3) interactions.

One can see that at the same primary energy the mean number of charged particles produced in pion-emulsion interactions is smaller than for proton-emulsion interactions, contrary to what is observed in collisions with hydrogen. The same was observed in experiment reported in Ref. [14].

5. *Normalized multiplicity*

In many papers dealing with hadron-nucleus interactions a parameter R which gives multiplication of particles produced in hadron-nucleus relative to hadron-hydrogen collisions (normalized mean multiplicity) is widely used. It is equal to the ratio of the mean charged multiplicities in hadron-nucleus and hadron-proton interactions at the same energies. Due to difficulties in obtaining the total charged multiplicity in hadron-nucleus interactions, various papers give different definitions of parameter R. In the following we shall use $R' = (\overline{n}_s - 1)/(\overline{n}_H - 2)$, where $\overline{n}_H$ is the mean charged multiplicity in hadron--proton collision. We believe that R' is a good approximation to the normalized mean charged multiplicity of created particles, i.e. total charged multiplicity minus particles involved in the collision.

Table II presents the calculated values of R' for proton-emulsion (R'_p) and pion--emulsion (R'_π) interactions together with the R'_p/R'_π ratios at primary energies 60 and

TABLE II

E (GeV)	R'_π	R'_p	R'_p/R'_π
60/67	1.90 ± 0.05	2.19 ± 0.05	1.15 ± 0.05
200	1.82 ± 0.05	2.23 ± 0.04	1.23 ± 0.06

67 GeV and 200 GeV. One can see that R'_p/R'_π values are close to the ratio $\overline{\nu}_p/\overline{\nu}_\pi = 1.17$ of the mean number of collisions of protons and pions inside the average emulsion nucleus[1]. This is in agreement with prediction of Ref. [15].

[1] The R'_p/R'_π ratio is rather insensitive to the different definitions of R — see [14].

6. R' vs N_h dependence

In several papers, e.g. [2, 9], the dependence of R on N_h for proton-emulsion interactions was investigated. It was found that there exists a linear relation between R and N_h which does not depend on primary proton energy for energies greater than about 60 GeV. It appears that the linear relation between R and N_h as well as its independence on primary energy are also valid for pion-emulsion interactions at 60 GeV and 200 GeV.

In Fig. 4 R' is presented versus N_h for pion-emulsion interactions. Full line $R'_\pi = (1.23 \pm 0.03) + (0.085 \pm 0.004)\ N_h$ is the best fit to the pion data at 60 GeV and

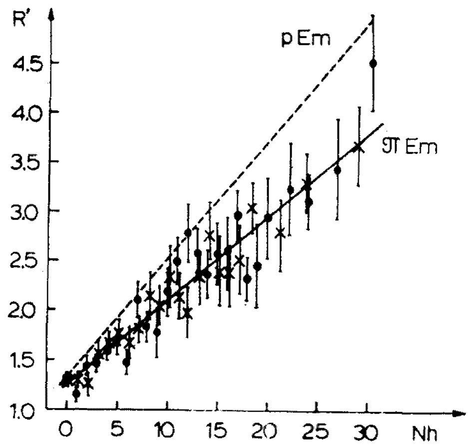

Fig. 4. Normalized multiplicity R vs N_h. ● × — pion-emulsion data at 60 GeV and 200 GeV respectively, full line — best fit to the pion-emulsion data, dashed line — best fit to the proton-emulsion data at 67 GeV and 200 GeV

200 GeV. The dashed line $R'_p = (1.32 \pm 0.02) + (0.120 \pm 0.002) N_h$ is the best fit to the proton data at 67 GeV and 200 GeV. It is seen that the coefficients of linear dependence of R' on N_h are smaller for pion-emulsion interactions than for proton-emulsion interactions.

7. Dispersion versus mean multiplicity dependence

It was shown (see e.g. [4, 10]) that in wide energy range the dependence of the dispersion D of the multiplicity distribution of relativistic particles n_s on the mean multiplicity for proton-emulsion interactions is well approximated by a linear relation. For the existing proton-emulsion data in the energy range 6 GeV — 300 GeV [2–7, 11] we got $D = (0.597 \pm 0.004)\bar{n}_s$. Bearing in mind that the mean total charged multiplicity is $n = n_s + 1$, we can see that the dispersion D is proportional to $(n-1)$ as in proton-proton collisions [12].

The dependence of D on $\bar{n}_s$ for proton-emulsion interactions and for pion-emulsion interactions at 60 GeV and 200 GeV, together with the best linear fit found for proton interactions are presented in Fig. 5. Within the statistical errors there seems to be no difference between the D vs $\bar{n}_s$ dependences for pion and proton interactions with the emulsion nuclei.

Assuming that interactions in emulsion form an incoherent superposition of contributions from different emulsion components it was shown [10] that $D/\bar{n}_s$ ratio measured in emulsion is consistent with the hypothesis that the $D_A/(n_A-1)$ (ratio of the dispersion

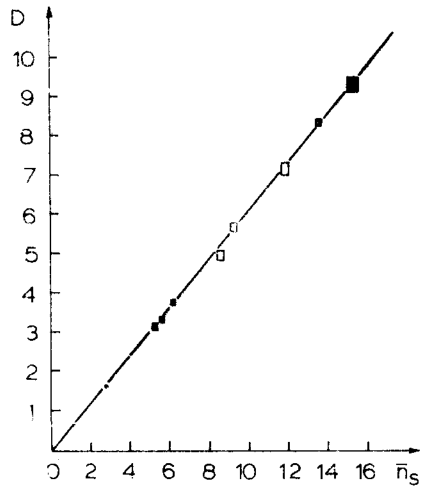

Fig. 5. Dispersion of n_s distribution D vs $\bar{n}_s$. ■ — proton-emulsion data at 6.2, 20.5, 22.5, 27, 67, 200 and 300 GeV, □ — pion-emulsion data at 60 and 200 GeV, full line — best fit to the proton-emulsion data

to the average multiplicity for different target nuclei with the mass numbers A) is an energy independent constant, the same for all nuclei, and close to the value found in proton-proton collisions. Pion-emulsion interactions are also consistent with the above hypothesis. For 60 GeV and 200 GeV pion-emulsion interactions the calculated $D_A/(n_A-1)$ ratio is found to be 0.543 ± 0.020 and 0.564 ± 0.019 respectively. These values are close to the $D/(n-1)$ ratio for pion-proton collisions which was found to be 0.556 ± 0.004.

8. *Conclusions*

The main results of the paper can be summarized as follows:

At 60 GeV and 200 GeV the mean value of the N_h distribution for pion-emulsion interactions is the same within the statistical errors. This suggests that, as in the case of primary protons, the mean value of N_h distribution for primary pions does not depend on primary energy. However, the mean value for pion induced interactions is smaller than that for primary protons.

At the same primary energy the mean value of the multiplicity distribution of relativistic charged particles (n_s) for pion-emulsion interactions is smaller than for proton-emulsion interactions.

The ratio of the normalized mean multiplicity of created particles for proton and pion induced interactions R'_p/R'_π is close to the $\bar{\nu}_p/\bar{\nu}_\pi$ ratio of the mean number of collisions of protons and pions inside the average emulsion nucleus. The slope of the linear fit to the R' vs N_h dependence is smaller for pion-emulsion interactions than for primary protons.

The dispersion of the multiplicity distribution of relativistic particles (n_s) in pion--emulsion interactions is proportional (within the limits of error) to the mean value of n_s, similarly as in proton induced interactions [10].

We would like to stress that our results concerning mean multiplicities of relativistic particles are in agreement with those obtained by W. Busza et al. [13] by means of counter technique.

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