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INTERACTIONS OF PIONS AND PROTONS WITH EMULSION NUCLEI AT 60 GEV AND 200 GEV.

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ODDZIAŁYWANIA PIONÓW I PROTONÓW Z JĄDRAMI EMULSJI PRZY ENERGII 60 GEV I 200 GEV.

ВЗАИМОДЕЙСТВИЯ ПИОНОВ И ПРОТОНОВ С ЭНЕРГИЕЙ 60 ГЭВ И 200 ГЭВ С ЯДРАМИ ФОТОЭМУЛЬСИИ.

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Summary

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

Streszczenie

W pracy badane są parametry opisujące krotności cząstek relatywistycznych i śladów wyparowania oraz korelacje między tymi parametrami. Obserwowane różnice w oddziaływaniach pionów i protonów z jądrami emulsji przy tej samej energii mogą być wytłumaczone różnicą średniej drogi swobodnej pionu i protonu w jądrze.

Резюме

В работе проведён анализ и рассмотрены корреляции параметров касающихся множественности релятивистских частиц и следов испарения. Наблюдаемые разницы во взаимодействиях пионов и протонов данной энергии можно обяснить разницей среднего пробега пионов и протонов в ядре.

Introduction

In the last few years one could observe an increasing interest in high energy hadron-nucleus interactions. Several theoretical and experimental papers have been published, the most recent ones dealing mainly with the emulsion data. However, there are considerably fewer papers concerning pion-nucleus than proton-nucleus interactions. Therefore it seems interesting to compare some typical parameters describing the multiplicity of particles produced and the number of heavy ionizing tracks for pion-nucleus with those of proton-nucleus interactions.

Before presenting our results we would like to define some parameters which will be used in this paper. We are doing it to avoid confusion, as in various papers concerning hadron-nucleus interactions these parameters are differently defined.

n_s - the number of charged relativistic $/\beta > 0.7/$ particles produced in hadron-nucleus interaction,

N_h - the number of heavy ionizing $/\beta < 0.7/$ particles: evaporation tracks, slow recoil protons and slow particles produced,

n - the total number of charged particles produced: n_s-particles, slow recoil protons and slow particles produced.

There is no way of directly determining the total number of charged particles produced /n/ from the experiment. Slow recoils 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 the certain model of hadron-nucleus interaction. This number is close to unity in model in which the incoming particle subsequently interacts inside the nucleus /1,2/. Thus in the following we shall use $n = n_s + 1$.

Experimental material

The pion-emulsion interactions investigated /788 events at 60 GeV and 973 events at 200 GeV/ were found by an along the track scanning in emulsion stacks irradiated at Serpukhov and Batavia. The proton-emulsion data at 67 GeV and 200 GeV were published by us earlier /3/. In our present samples only inelastic interactions occur /elestic and coherent events were rejected/. To enlarge the statistics in proton-emulsion interactions we also used the data from Tashkent at 67 GeV and 200 GeV /4/ and Barcelona and other laboratories at 200 GeV /5/. The total number of proton-emulsion interactions used are 1186 events at 67 GeV and 3960 events at 200 GeV.

Distributions of heavy ionizing particles /N_h/

It is well known /7,9,2/ 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 /3-8/. It contains over 9000 events and its mean value equals $\bar{N}_h = 7.45 \pm 0.08$. For pion-emulsion interactions at 60 GeV and 200 GeV the N_h distributions are identical, whithin the statistical errors, and their mean values are 7.11 ± 0.26 and 6.73 ± 0.22 respectively. The composite N_h distribution /1767 events/ for pion-emulsion interactions at 60 GeV and 200 GeV is shown in Fig.1 /error bars/ and its mean value equals $\bar{N}_h = 6.90 \pm 0.17$. This value is less than that for primary protons.

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 1 /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 that for proton-emulsion interactions, contrary to what is observed in elementary collisions.

<u>Normalized multiplicity</u>

In many papers that deal with hadron-nucleus interactions parameter R describing the 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 offer different approaches calculating parameter R. In the following we shall use $R=[\bar{n}_s-1]/[\bar{n}_H-2]$, where $\bar{n}_H$ is the mean charged multiplicity in hadron-proton collision. We believe that this R is a good approximation to the normalized mean charged multiplicity of created particles, i.e. produced particles minus those involved in the collision.

Table 2 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 67 GeV and 200 GeV. One can see that R_p/R_π values are close to the ratio $\bar{\nu}_p/\bar{\nu}_\pi=1.17$ of the mean number of collisions of protons and pions inside the average emulsion nucleus.* However, from this one cannot draw conclusions about the character of R vs ν dependence.

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* The R_p/R_π ratio is rather insensitive to the different definitions of R.

R vs N_h dependence

In several papers e.g. /3,10/ 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 $R = /1.23 \pm 0.03/ + /0.085 \pm 0.004/N_h$ is the best fit to the pion data at 60 GeV and 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.

Dispersion versus mean multiplicity dependence

It was shown /see e.g./5,11// that in wide energy range the dependence of the dispersion D of the multiplicity distribution of relativistic particles n_s for proton-emulsion interactions is well approximated by linear relation. For the existing proton-emulsion data in the energy range 6 GeV - 300 GeV /3-8,12/ we got $D = /0.597 \pm 0.004/\bar{n}_s$. Bearing in mind that the mean number of charged particles produced is $n = n_s + 1$, we can see that the dispersion D is proportional to /n-1/ similarly to proton-proton collisions /13/.

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 component, it was shown /11/ 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 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.

Conclusions

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

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.

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 valuefor pion induced interactions is smaller than that for primary protons.

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/ is proportional to the mean value of n_s for proton-emulsion interactions. The same dependence seems to be valid for pion induced interactions as well. Calculated values of the ratio of the dispersion to the average multiplicity for target nuclei with different mass numbers A are an energy independent constant, the same for all nuclei and quite close to the values found for hadron-proton collisions.

We would like to stress that our results concerning mean multiplicities of relativistic particles are in agreement with those obtained by W. Busza at al. /14/ by means of counter technique.

The differences observed in pion-emulsion and proton-emulsion interactions can be understood if one assumes that in hadron-nucleus collision the particles are produced in a number of subsequent collisions of the incoming particle and that this number is determined by the cross-section of the primary particle.

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References

1. M. Mięsowicz, Progress in Elementary Particle and Cosmic Ray Physics, Vol.X, 103 /1971/.
2. J. Babecki, Acta Phys. Polonica B6, 443 /1975/,
   Raport No.911/PH, Institute of Nuclear Physics - Kraków /1976/.
3. J. Babecki et al., Phys. Lett. B47, 268 /1973/,
   Acta Phys.Polonica B5, 315 /1974/.
4. Alma-Ata and other Labs. Jadernaja Fizika, 19, 1046 /1974/
   K.G. Gulamov, private communication.
5. J. Herbert et al., Phys. Lett. B48, 467 /1974/,
   XIV Cosmic Ray Conference Vol.7, 2248 München 1975.
   I. Otterlund, private communication.
6. P.G. Bizetti et al., Nuovo Cimento, 27, 6 /1962/.
7. H. Meyer et al., Nuovo Cimento 28, 1399 /1963/.
8. A. Barbaro-Galtieri et al., Nuovo Cimento 21, 469 /1961/.
9. E.M. Friedlander and A. Friedman, Nuovo Cimento 52A, 912 /1967/.
10. E.M. Friedlander and A.A. Marin, Lett. Nuovo Cimento 9, 346 /1974/.
11. A. Białas et al., Nuclear Physics, B100, 103 /1975/.
12. H. Winzeler, Nuclear Physics, 69, 66 /1965/.
13. A. Wróblewski, Acta Phys.Polonica, B4, 857 /1973/.
14. W. Busza at al., paper presented at XVI Krakow School of Theoretical Physics, Zakopane May 1976.

Table 1.

	Elementary interactions		Pion-Emulsion inter.		Proton-Emulsion inter.	
1	2	3	4	5	6	7
E/GeV/	$\bar{n}_{\pi p}$	$\bar{n}_{pp}$	$\bar{n}_s$	D	$\bar{n}_s$	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

Table 2.

E/GeV/	R_π	R_p	R_p/R_π
60/67	1.90±0.05	2.19±0.05	1.15±0.07
200	1.82±0.05	2.23±0.04	1.23±0.06

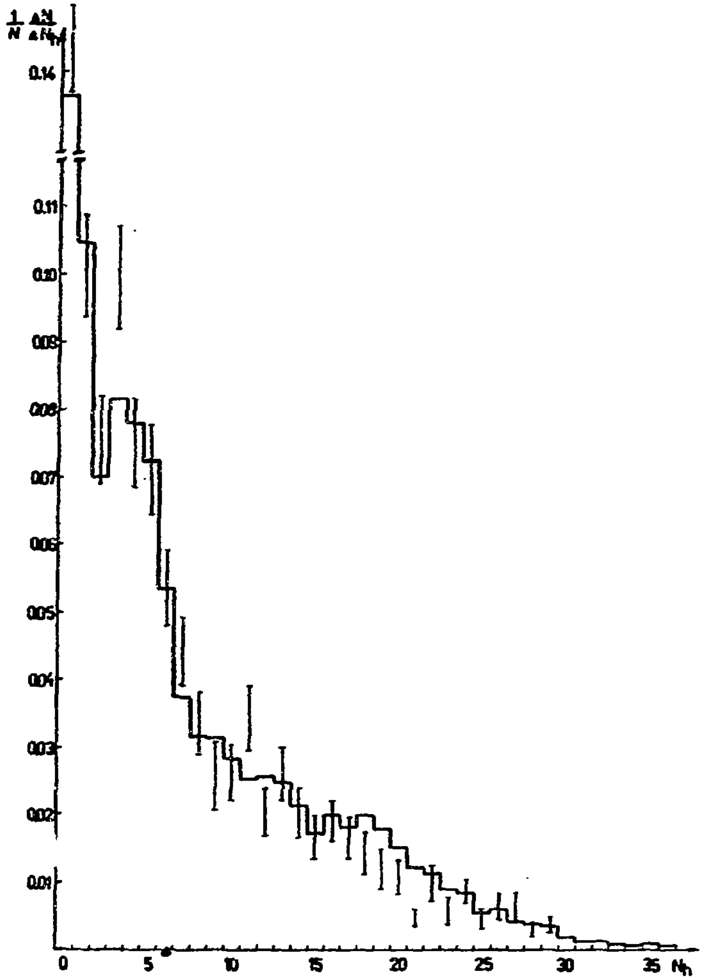

Fig. 1 Distribution of N_h tracks. histogram - primary protons, error bars - primary pions.

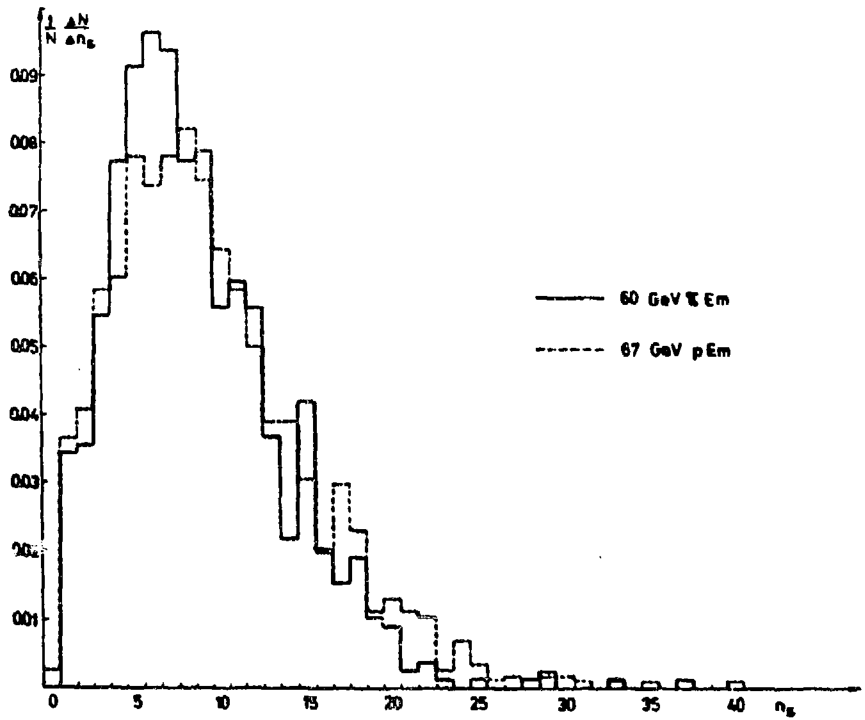

Fig. 2 Multiplicity distributions of n_s tracks.
full line - primary pions at 60 GeV,
dashed line - primary protons at 67 GeV.

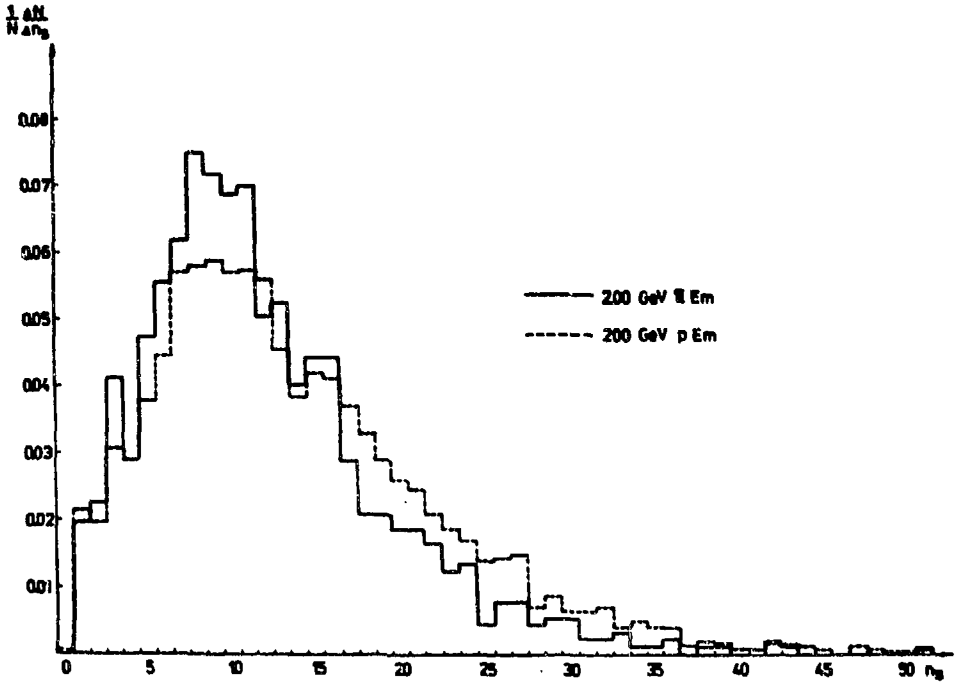

Fig. 3 Multiplicity distributions of n_s tracks.
full line - primary pions at 200 GeV,
dashed line - primary protons at 200 GeV.

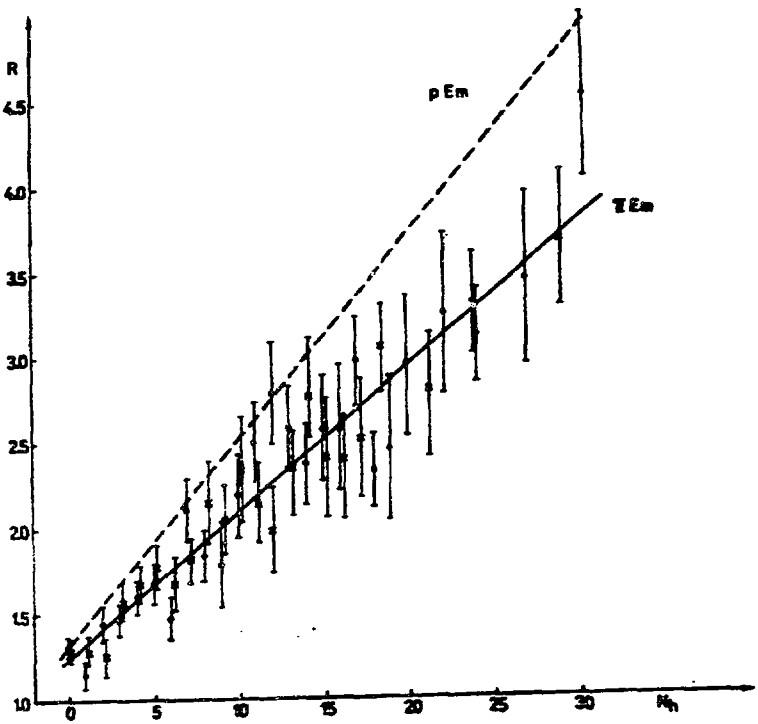

Fig. 4 Normalized multiplicity R vs N_h.
- pion-emulsion data at 60 GeV and 200 GeV respectively,

full line - best fit to the pion-emulsion data,

dashed line - best fit to the proton-emulsion data at 67 GeV and 200 GeV.

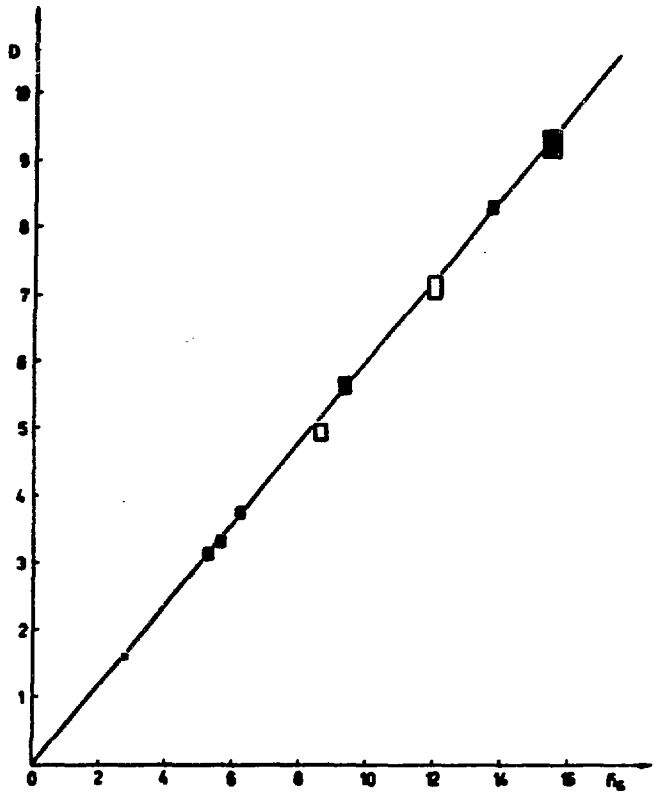

Fig. 5 Dispersion of n_s distribution D vs n_s.
■ - proton-emulsion data at 6.2, 20.5, 22.5, 27, 67, 200 and 300 GeV,
□ - pion-emulsion data at 60 and 200 GeV,
full line - best fit to the proton-emulsion data.