INTERACTIONS OF THE 800 GeV PROTONS FROM FERMILAB WITH THE EMULSION NUCLEI

Baton Rouge[1] — Cracow[2] — Moscow[3] — Tashkent[4,5] Collaboration

BY Y. A. ABDURAZAKOVA[5], A. ABDUZHAMILOV[4], SH. ABDUZHAMILOV[4], S. A. AZIMOV[4], L. BARBIER[1], R. A. BONDARENKO[5], G. M. CHERNOV[5], L. P. CHERNOVA[4], M. M. CHERNYAVSKY[3], S. I. GADZHIEVA[4], K. G. GULAMOV[4], U. G. GULYAMOV[5], R. HOŁYŃSKI[2], W. V. JONES[1], N. LITVINENKO[4], N. S. LUKICHEVA[4], D. MIRKHODZHAEVA[4], V. SH. NAVOTNY[4], G. I. ORLOVA[3], E. A. RAVVINA[4], N. SH. SAIDKHANOV[4], N. A. SALMANOVA[3], L. N. SVECHNIKOVA[4], M. I. TRETYAKOVA[3], W. WOLTER[2], B. WOSIEK[1]* AND K. WOŹNIAK[2]

1. Louisiana State University, Baton Rouge, LA, 70803, USA
2. Institute of Nuclear Physics, Kawiory 26 A, 30-055 Kraków, Poland
3. P. N. Lebedev Physical Institute of the Academy of Sciences of USSR, Moscow, USSR
4. S. V. Starodubtsev Physical Technical Institute, Tashkent, USSR
5. Institute of Nuclear Physics, Uzbek Academy of Sciences, Tashkent, USSR

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We present first results of the analysis carried in our laboratories on the 800 GeV proton-emulsion data obtained from the Fermi National Accelerator Laboratory experiment No. 508. The multiplicity distributions of secondary particles and the pseudorapidity distribution of shower particles are analyzed and compared with those obtained at lower energies.

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1. *Introduction*

In the last decade a continuous interest in high energy hadron-nucleus interactions has been observed (see e.g. [1]). In many experiments nuclear emulsion was used as a nuclear target and particle detector. The excellent space resolution and the ability of registration of low energy particles make the nuclear emulsion a suitable tool for simultaneous investigation of both the multiparticle production and the target nucleus excitation processes.

In 1985 at the Fermi National Accelerator Laboratory in Batavia, when protons were accelerated to the highest energy so far obtained, we performed the experiment (FNAL E508)

* Permanent address: Institute of Nuclear Physics, Kraków, Poland.

in which nuclear emulsions were exposed to the 800 GeV proton beam. Using preliminary data only, we present in this paper the results concerning particle multiplicities and angular distribution of produced particles. For comparison with lower energies we used our previous 200 GeV [2–5] and 400 GeV [6] data of proton-emulsion interactions. We believe that our samples of proton emulsion interactions at different energies have the same (if any) biases because they were obtained in the same laboratories using the same experimental procedure. This strengthens our conclusions derived from the comparison of proton interactions at different energies.

After collecting more experimental material of proton-emulsion interactions at 800 GeV we will be able to discuss in more detail the mechanism of particle production, the correlation between the number of produced particles and the number of independent collisions inside the target nucleus as well as the problem of intranuclear cascade.

2. *Experimental material*

Several emulsion stack composed of GOSNIIHIMFOTOPROEKT BR2 emulsion pellicles of the dimensions 10 cm × 20 cm, 600 microns thick were exposed to the 800 GeV proton beam at FNAL. By along-the-track scanning 1057 inelastic interactions have been found. Out of them 52 were classified as coherent events. When not explicitly specified, the coherent events are not included in the analysed sample of inelastic interactions.

In each event tracks were classified according to the generally accepted emulsion terminology:

s — shower tracks ($\beta > 0.7$),
g — grey tracks ($\beta \leqslant 0.7$ and the range in emulsion greater than 3 mm),
b — black tracks ($\beta \leqslant 0.7$ and the range in emulsion smaller than 3 mm).

The s-tracks are due to the produced singly-charged relativistic particles, whereas g and b-tracks are formed by particles emitted from the target nucleus. The g and b-tracks are mainly recoil protons and evaporation products of the target nucleus, respectively. The g and b-tracks together are usually called h-tracks ($N_h = N_g + N_b$), where "h" stands for the heavy ionizing particle.

Angular distributions of shower, grey and black tracks were carefully measured in each event. Special attention was payed to the angular measurements of shower particles. The emission angles of most energetic particles are so small that only relative measurements with respect to the appropriately chosen neighbouring primary proton tracks can assure reliable angular measurements.

3. *Multiplicity of charged particles*

3.1. Heavy ionizing particles

In Figs 1, 2 and 3 we present the multiplicity distributions of g, b and h-tracks for proton-emulsion interactions at 200, 400 and 800 GeV. The mean values of this distributions are given in Table I. Our data at 800 GeV are consistent with the well established

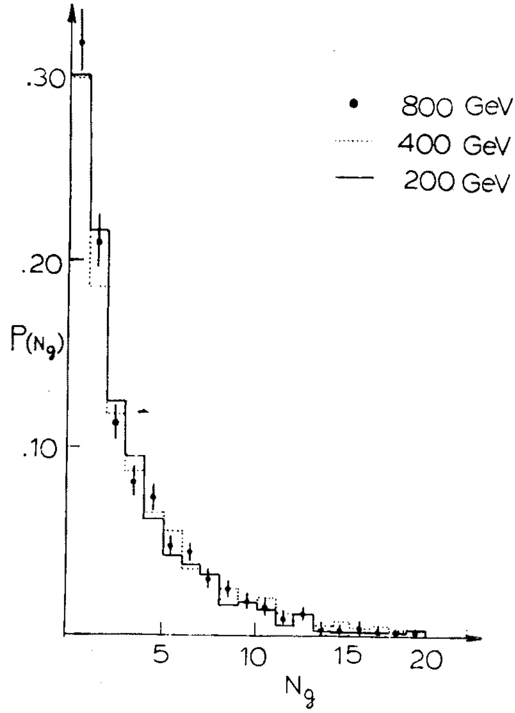

Fig. 1. The distributions of the number of grey tracks in proton-emulsion interactions at 200, 400 and 800 GeV

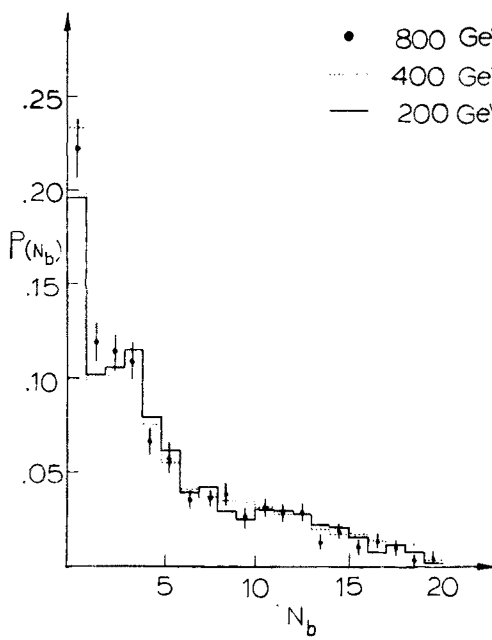

Fig. 2. The distributions of the number of black tracks in proton-emulsion interactions at 200, 400 and 800 GeV

E_0 (GeV)	Number of events	$\langle N_g \rangle$	$\langle N_b \rangle$
200	2592	2.60 ± 0.06	5.02 ± 0.10
400	3482	2.79 ± 0.06	4.62 ± 0.08
800	1005	2.64 ± 0.10	4.56 ± 0.15
800[a]	1057	2.51 ± 0.10	4.33 ± 0.14

[a] with coherent events.

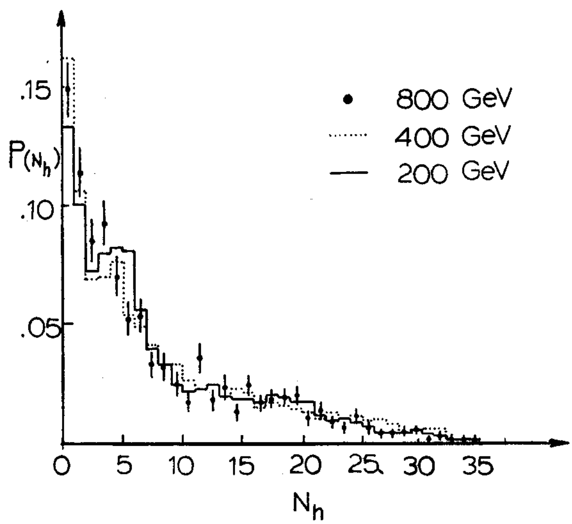

Fig. 3. The distributions of the number of heavy ionizing particles in proton-emulsion interactions at 200, 400 and 600 GeV

fact that the distributions of heavy ionizing particles do not depend on the energy of the incoming particle. This scaling behaviour plays an important role in the analysis of hadron--nucleus interactions from the point of view of the model of multiple collisions of the projectile with the target nucleons. As it was shown in [7, 8] the mean number of intranuclear collisions can be estimated from the observed number of heavy ionizing particles emitted from the interaction. In the next paper we shall continue the above method of analysis of hadron-nucleus interactions which we have already presented in [9, 10], where pion-emulsion interactions were analysed.

3.2. Shower particles

The multiplicity distribution of shower particles emitted from proton-emulsion interactions at 800 GeV is depicted in Fig. 4. In Table I we present the mean values of the multiplicity distributions in proton-emulsion interactions at 200, 400 and 800 GeV. The dispersion D of the multiplicity distribution of shower particles, the ratio $D/\langle n_s \rangle$ and the normalized multiplicity $R = \langle n_s \rangle / \langle n_{ch} \rangle$ are also given. The mean values of charged particles

TABLE I

$\langle N_h \rangle$	$\langle n_s \rangle$	$D(n_s)$	$D/\langle n_s \rangle$	R
7.61 ± 0.15	13.84 ± 0.16	8.15 ± 0.15	0.59 ± 0.02	1.64 ± 0.02
7.41 ± 0.13	$16.42 \pm 0{,}17$	10.03 ± 0.11	0.61 ± 0.01	1.66 ± 0.02
7.20 ± 0.24	19.37 ± 0.37	11.71 ± 0.31	0.60 ± 0.03	1.69 ± 0.03
6.84 ± 0.23	18.63 ± 0.37	11.87 ± 0.31	0.64 ± 0.03	1.63 ± 0.03

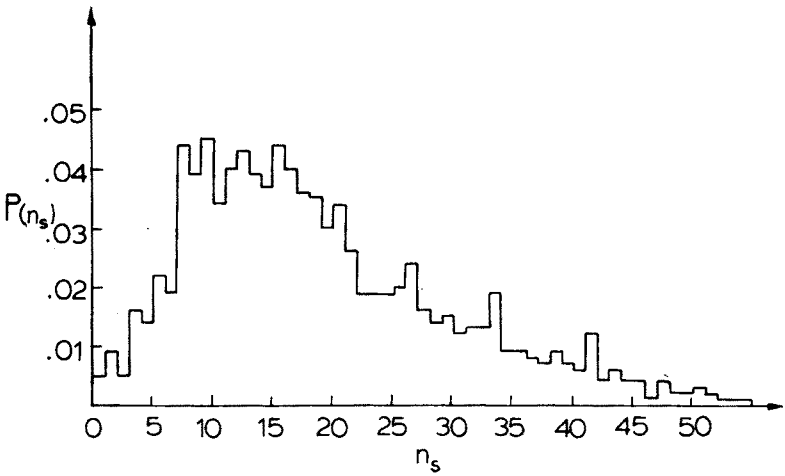

Fig. 4. Multiplicity distribution of shower particles for proton-emulsion interactions at 800 GeV

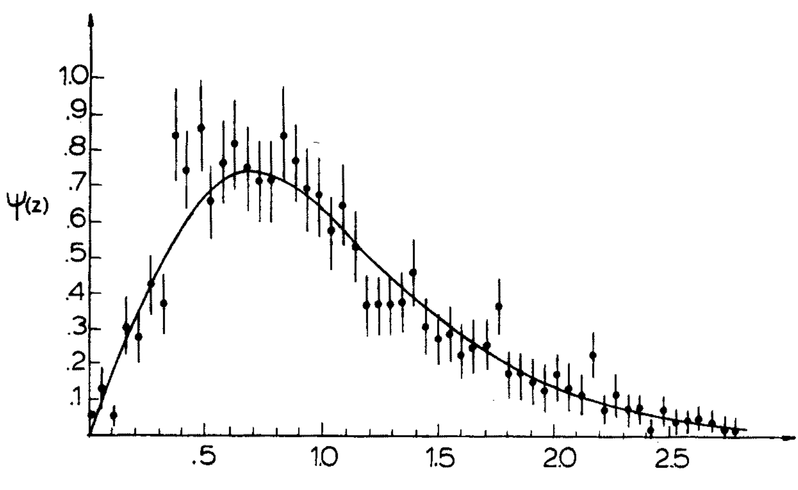

Fig. 5. The KNO scaling for proton-emulsion interactions at 800 GeV. The curve is the best fit to the experimental proton-emulsion data at 200 and 400 GeV

$\langle n_{ch} \rangle$ produced in proton-proton interaction were calculated from the best fit to the experimental data [11]. The $D/\langle n_s \rangle$ and R values do not depend on the primary proton energy within the energy interval considered.

In Fig. 5 we present the multiplicity distribution function $\psi(z) = \langle n_s \rangle P_n$ of shower particles at 800 GeV using the KNO scaling variable $Z = n_s/\langle n_s \rangle$. P_n is the probability that n charged particles are produced in the final state. The solid line in Fig. 5 is the best fit to our proton-emulsion data at 200 and 400 GeV:

$$\psi(z) = (2.52z + 30.9z^3 + 3.29z^5 + 1.04z^7) \exp(-4.08z). \tag{1}$$

Within the statistical error the KNO scalling is valid for 800 GeV proton-emulsion data.

Fig. 6 shows the dependence of the $\langle n_s \rangle$ on the energy of the incident proton. Within the energy interval 67 to 800 GeV the proton-emulsion data are well described by the following relation:

$$\langle n_s \rangle = (-10.31 \pm 0.39) + (4.06 \pm 0.06) \ln s, \tag{2}$$

where $\sqrt{s}$ is the proton-proton CM — energy.

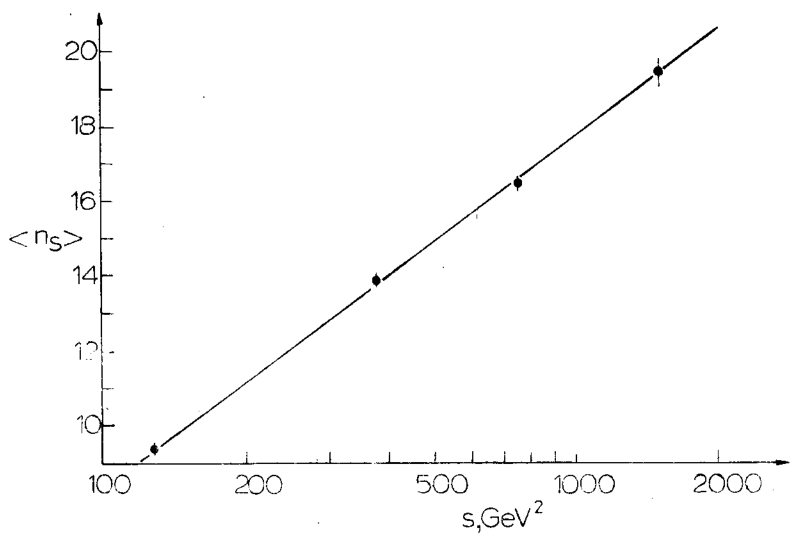

Fig. 6. The mean multiplicity of shower particles $\langle n_s \rangle$ as the function of proton-proton CM-energy squared

4. *Angular distribution of shower particles*

In Figs 7 and 8 we show the inclusive angular distributions of shower particles in the laboratory and projectile rest frames, respectively. We use the pseudorapidity variable $\eta = -\frac{1}{2} \ln \tan \frac{\vartheta}{2}$, where ϑ is the emission angle of the secondary particle. The pseudorapidity in the projectile rest frame was defined as $\eta' = \eta - y_p$ where y_p stands for the

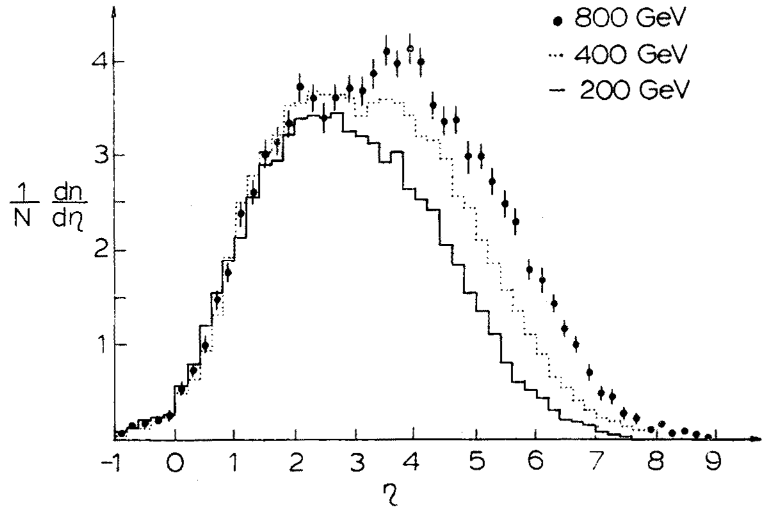

Fig. 7. The inclusive pseudorapidity distributions of shower particles in the laboratory frame for proton-emulsion interactions at 200, 400 and 800 GeV

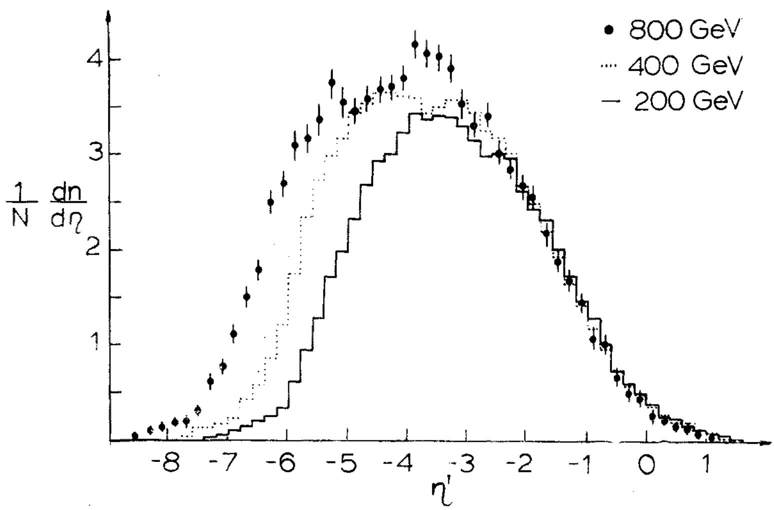

Fig. 8. The inclusive pseudorapidity distributions of shower particles transformed to the projectile rest frames for proton-emulsion interactions at 200, 400 and 800 GeV

rapidity of the incoming proton. The positive values of η' (see Fig. 8) are mainly due to the leading protons for which η is a poor approximation of rapidity.

One can see from Figs 7 and 8 that the inclusive distributions scale for both the target and projectile fragmentation region and the height of the central region of the pseudorapidity distribution increases with increasing primary proton energy.

5. Conclusions

On the basis of the preliminary data consisting of about one thousand inelastic interactions of 800 GeV protons with photographic emulsion nuclei the following conclusions can be drawn:

— The multiplicity distributions of grey and black tracks (heavy ionizing particles) are the same as the corresponding distributions at lower energies.

— The multiplicity distribution of shower particles is well described by the KNO scaling function derived from proton-emulsion interactions at lower energies.

— The ratio $D/\langle n_s \rangle$ and the normalized multiplicity $R = \langle n_s \rangle / \langle n_{ch} \rangle$ are the same within the statistical error for proton-emulsion interactions at 200, 400 and 800 GeV.

— With the increase of energy of primary proton the mean value of multiplicity of shower particles increases as the logarithm of proton-proton CM — energy squared.

— The pseudorapidity distributions of shower particles scale at 200, 400 and 800 GeV in both the target and projectile fragmentation regions, whereas the maximum (plateau) of the distribution increases with increasing primary proton energy.

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