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Study of nuclear interactions of 200 GeV protons in emulsion

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Abstract

We present the results of an international collaboration on protc -nucleus interactions using nuclear emulsions exposed to a 200 Ge proton beam at the National Accelerator Laboratory, Batavia. A large number of interactions have been analysed including events with heavily-ionizing tracks and therefore distributions are give with all final nuclear states included in the data.

The mean-free path measured does not deviate from the values obtained at lower energies. The average-charge multiplicity was found to be $\langle n_s \rangle = 12.9 \pm 0.4$ and the average number of heavy prongs $\langle N_h \rangle = 7.4 \pm 0.2$. These results are impossible to interpret with any simple intranuclear cascade model. The shape of the angular distribution of particles produced and its variation with the number of heavy prongs N_h has been analysed.

1. Introduction and experimental details

Three stacks of Ilford K5 emulsions were exposed to the NAL 200 GeV proton beam in September 1972. Two stacks (40 pellicles each, 20x5x0.06 cm^3) were exposed horizontally (beam parallel to the emulsion surface) and the third stack (20 pellicles, 5x5x0.05 cm^3) was exposed vertically (beam perpendicular to the emulsion surface).

The horizontal stacks were scanned by two different methods, along-the-track scanning and area scanning. Only area scanning was used in the case of the vertical stack.

2. The inelastic mean-free path

Table 1 summarizes the results using along-the-track scanning anc area scanning. Within the statistical errors, the mean free paths measured c not deviate from the value obtained at lower energies

Table 1

Scanning method	Direction of the beam	Number of stars	length of track (m)	λ_{inel} (cm)
track-scanning	parallel	1741	612.76	35.1±0.8
area-scanning	parallel	3841		36.8±1.1
area-scanning	vertical	509		33.1±1.5

3. General characteristics of proton-nucleus interactions at 200 GeV

The mean charged multiplicity of shower particles $\langle n_s \rangle$ is 12.9±0. Dar and Vary (1) have shown that particle-nucleus collisions at high energies could be a sensitive test

of the mechanism of multiparticle production in particle-nucleon collisions at high energy. They have calculated the expected values of the multiplicities assuming two different models, the intranucleus cascading model and the diffractive excitation model

In Table II we compare the experimental multiplicities with those predicted by Dar and Vary. It is evident that the intranucleus cascade model gives values quite different from the experimental result at 200 GeV and that the model does not explain the observed multiplicities.

Table II

Energy	$\frac{\langle n_s \rangle_{p-N}}{\langle n_{ch} \rangle_{p-p}}$		
	Experiment	theory (1)	
		intranucleus cascading model	diffractive excitation model
27 GeV	1.4 ± 0.1	1.14	1.88
200 GeV	1.7 ± 0.1	2.80	1.88

In Fig. 1, $\langle n_s \rangle$ is compared with multiplicities at lower energies and with intranuclear cascade calculations assuming many particle interactions (2). Even if these calculations give the correct value of the multiplicities they fail in predicting the N_h-values at 200 GeV. The predicted value is larger than 12.6. The mean value of N_h is 7.4 ± 0.2 which is the same as the value $\langle N_h \rangle$ = 7.2 ± 0.2 obtained at 27 GeV (3). The dependence on the size of the target is also shown. The most striking property is the comparatively low multiplicities observed in p-N interactions.

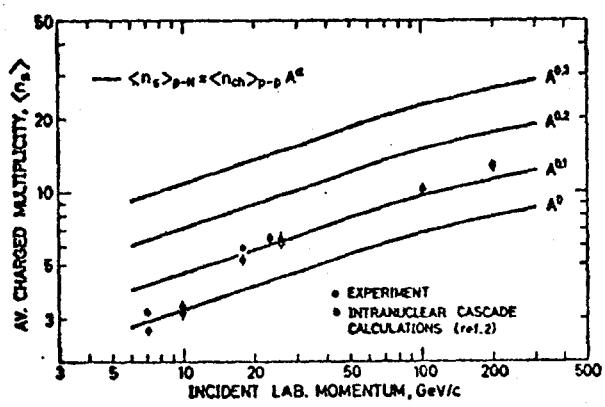

Fig. 1
Mean number of shower particles $\langle n_s \rangle$ observed in proton-nucleus interactions versus lab. momentum of the incident proton.

Figure 2 shows the dependenc between $\langle n_s \rangle$ and N_h. The results obtained from area-scanned interactions are in excellent agreement with those obtained from interactions scanned along the track. We observe an almost linear relationship between $\langle n_s \rangle$ and N_h. The mean multiplicity in interactions with N_h = 0 is 7.72 ± 0.54, which is in good agreement with the value 7.65 ± 0.17 obtained with a hydrogen bubble

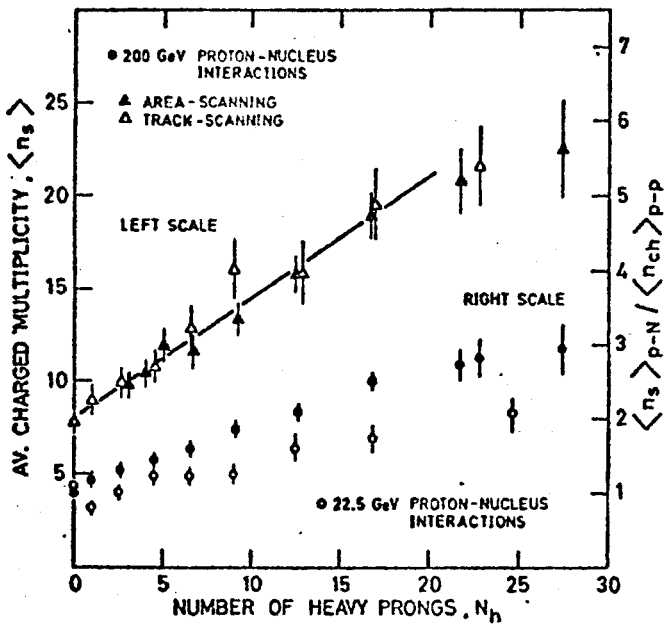

Fig. 2
Mean number of shower particles $\langle n_s \rangle$ versus the number of heavy prongs N_h. The figure also shows the ratio between the multiplicities in proton-nucleus and proton-proton interactions versus the number of heavy prongs.

chamber (4). The largest multiplicity obtained in an event is $n_s = 53 (N_h = 22)$. We also compare with multiplicities at CERN--energies (5). There is a comparatively small increase in the ratio between the multiplicities in proton-nucleus and proton-proton interactions with the energy of the incident proton and with N_h. Table III shows the percentage of stars in various N_h groups at NAL and CERN energies. The interactions were all identified by scanning along-the-track and are therefore directly comparable It is interesting to note the large percentage of stars with $N_h = 0$ and 1 in interactions at 200 GeV. At least 30 % of these a: interactions with a peripheral nucleon in Ag or Br. The increas in the multiplicity is not reflected in any increase in the cascade or in the energy transferred to the targets. This last state ment is supported by the results shown in Fig. 3, where we compare the integral frequency distribution of N_h with the results obtaine at 6-28 GeV (6). The experimental values are obtained by area--scanning and the comparison is made in the region $N_h > 7$, in which area-scanning is known to be unbiased.

Table III

Percentage of stars in various N_h groups

Energy	$N_h \leq 1$	$2 \leq N_h \leq 5$	$5 < N_h$
200 GeV	27.3 ± 1.6	27.6 ± 1.6	45.1 ± 2.2
22.5 GeV	21.5 ± 1.7	29.3 ± 2.1	49.4 ± 2.9
6.2 GeV	16.1 ± 1.0	28.3 ± 1.4	55.7 ± 2.2

4. Some gross features of single particle inclusive angular distributions

We measured the polar angle Θ with respect to the incident particle. In the analysis we chose the variable $U_L = \log_{10} tg\ \Theta$, $\Theta < 90^c$ which is a good approximation to the rapidity y (7). In a high-energy event for which the distribution of charged secondaries is symmetric in the centre-of-mass system $-\langle U_L \rangle = \log_{10}\gamma_c$ (the Castagnoli formula). γ_c is the Lorentz factor for lab. to c.m. transformations.

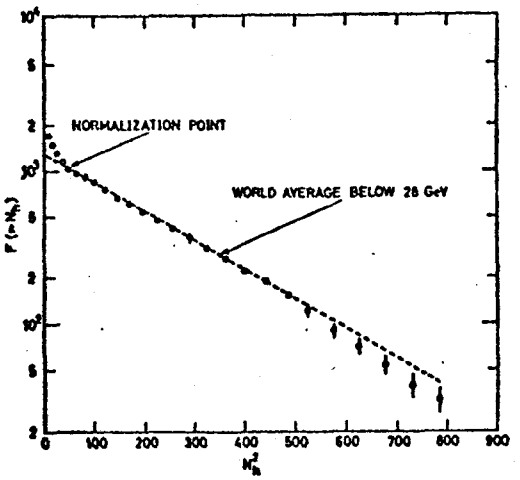

Fig. 3
Integral frequency distribution of N_h. Open circles represent measurements at 200 GeV. Dotted curve shows proton accelerator data.

Figure 4 shows the angular distributions for stars of different size and Figure 5 shows $-\langle U_L \rangle$ and σ =

$$\sqrt{\sum_i \frac{(U_L^i - \langle U_L \rangle)^2}{n_s - 1}}$$

as a function of N_h. In small stars, N_h = 0,1, the majority or particles are emitted in the forward direction. Coherent production of pions as well as the surviving incident protons in p-n interactions contribute to this asymmetry. Stars of medium size have roughly symmetric shower particle distributions in the centre of mass system. In these interactions only a small number of nucleon-nucleon interactions occur. Large stars have an excess of particles emitted backwards. A smooth transition between the two extreme cases can be seen and has been represented by a curve drawn by hand. The changes in the asymmetry with increasing values of N_h indicate that secondary processes are involved.

The anisotropy parameter σ seems to increase slightly with N_h. In interactions with N_h = 0,1, the value of σ is 0.61 ± 0.01. In interactions with N_h > 10 σ is 0.70 ± 0.02.

The small multiplicity and the relatively large number of stars with N_h = 0,1 support an assumption that the leading particle is

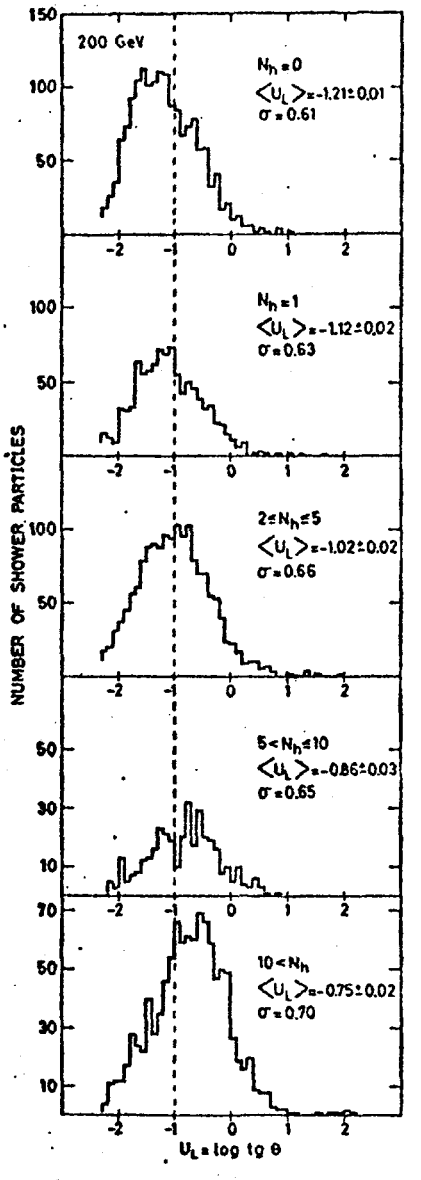

Fig. 4
Differential angular distributions in groups characterized by N_h. 90^0 in the nucleon-nucleon CMS is marked by a dotted line.

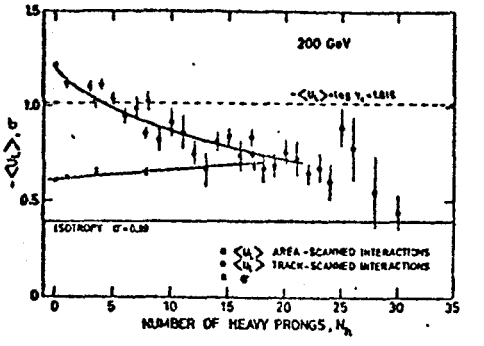

Fig. 5
Variation of the mean angle $\langle U_L \rangle$ and σ with the number of heavy prongs.

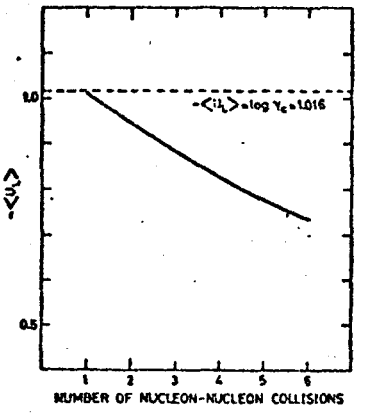

Fig. 6
Variation of the mean angle $\langle U_L \rangle$ with the number of nucleon--nucleon collisions in the target.

most responsible for the production of secondaries and that secondary particles have only a small probability of producing new particles and even small possibility to deliver energy to the target. It is easy to calculate $\langle U_L \rangle$ as a function of the number of collisions between the incident (leading) particle and target nucleons.

Figure 6 shows the results from calculations performed for proton--nucleus interactions at 200 GeV. Multiplicities from free pro-

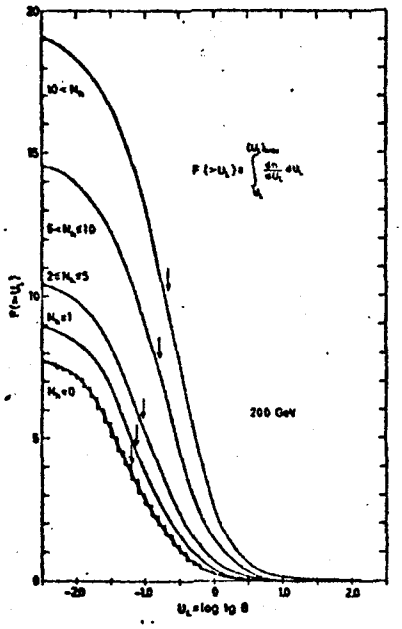

Fig. 7
Multiplicity of shower particles with angles greater than U_L plotted as a function of U_L.

ton-proton interactions and a value of the inelasticity K equal to 0.5 was used. The calculations seem to explain the gross feature of $\langle U_L \rangle$ shown in Figure 5.

Figure 7 shows the integral angular distribution. Most of the particles are found at small U_L, so that $F(>U_L)$ is a rapidly falling function. The arrows in the figure show the value of U_L for which equal numbers of particles are found to the right and to the left. This value is not necessarily the U_L value associated with the centre of mass of either the p-nucleon or the p-nucleus systems.

Acknowledgements

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