FERMILAB-PUB-75-132-E

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Backward Emission of Relativistic Particles in the Laboratory System in 200 GeV Proton-Nucleus Collisions

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In proton-nucleus collisions at 200 GeV studied in nuclear emulsion, relativistic particles are found to be emitted in the laboratory backward hemisphere frequently. These backward particles consist of pions and protons of relatively high energy. Emission of backward particles increases rapidly with the mass number of the target nucleus. Backward emission of such high energy particles is difficult to explain by the simple superposition of proton-nucleon elementary interactions.

Submitted to the Journal of the Physical Society of Japan

Interesting results have been reported from the Lawrence Berkeley Laboratory[1]. Ions (d and α) accerelated to kinetic energy of 2.1 GeV/nucleon were injected to carbon target. Observing at 2.5 degrees in the laboratory system, they found high energy pions which could not come out from nucleon-nucleon collisions of this energy. Such high energy pions are considered to be produced because of incident particles being ions and not because of target nuclear species. Then such phenomena should be observed even when the target is a nucleon, and in this case it is better to observe particles in backward hemisphere in nucleus rest frame in collisions of accerelated protons with nuclear target at rest.

From this point of view, relativistic particles emitted backward in the laboratory system are investigated, in the course of analysis of multiple production events in nuclear emulsion (36 Ilford K-5 pellicles, $75\times105\times0.6$ mm^3 in size) exposed to 205 GeV/c protons at the Fermi National Accerelator Laboratory. Unbiased events obtained by along-the-track scanning are classified by the number of heavily ionizing tracks (N_h) into three groups, namely,

(A) $N_h=0$ (quasi-proton-nucleon collisions),

(B) $1\leq N_h\leq 8$ (collisions with C, N, O, Ag, and Br),

(C) $N_h\geq 9$ (collisions with Ag and Br).

In this study heavily ionizing tracks are those with grain density larger than 1.4 times of plateau ionization tracks. This grain density corresponds to the velocity of 0.7c.

For group (A), emitted angles of all particles are measured.

For groups (B) and (C), emitted angles of thin and gray ($1.4 \cdot I_{pl} \leq I \leq 3.0 \cdot I_{pl}$) are measured. Hereafter, thin tracks emitted backward in the laboratory system are called as B-tracks, and events with one or more B-tracks as B-events. Numbers of events, measured so far, of B-events and B-tracks are given in Table I. The fraction of B-events increases rapidly with N_h, and this increase is more remarkable than that of average multiplicity of thin particles $\langle n_s \rangle$. This is seen in the last line of Table I. From Table I it is also clear that for all groups the probability of occurence of B-events with two or more B-tracks is nearly the square of that of B-events. This shows that the emission of more than one B-tracks is a phenomenon without correlation.

From the frequency only, the emission of B-events seems to be of different nature from the elementary multiple production process. This becomes more evident from angular distribution of thin particles shown in Fig. 1. This figure is drawn on normal probability paper and the straight line means that the distribution is Gaussian. The abscissa is pseudo-rapidity η ($\eta = -\ln(\tan\frac{\theta}{2})$). For group (A) the η-distribution is close to Gaussian, but for groups (B) and (C) tails at $\eta \lesssim 0$ clearly deviate from the linear shape beyond statistical errors. This tendency is clearer for larger N_h. Thus in proton-nucleus collisions, particles are emitted in the laboratory backward hemisphere more abundantly than expected from the simple superposition of elementary processes, and this is more remarkable when the mass number of the target nucleus increases.

Multiple scattering measurements are carried out for backward thin and gray tracks with projected length longer than one mm and results are shown in Fig. 2 with ionization values. Typical values of errors are 25% and 4% for scattering angle and ionization, respectively. Fig. 2 shows that the appreciable part of B-tracks consists of pions with momenta larger than 140 MeV/c. (There remains a possibility that there are a few electrons and kaons.) From Fig. 2 it is also evident that in backward laboratory hemisphere considerable amount of protons with energy higher than that of protons from evaporation processes are emitted. Pions with energy exceeding kinematic limit of elementary nucleon-nucleon processes have not been found in our limited statistics, but pions lying near this limit are more than to be interpreted as the superposition of elementary processes. This situation is clearer in the case of protons. The kinetic energy of protons extends to 150 MeV or more, and such high energy protons can not be emitted backward in the laboratory system from the ordinary processes in our present knowledge. As according to usual processes backward protons can not have the energy far higher than the Fermi energy inside the nucleus, this fact excludes the possibility that the backward emission of relativistic particles in the laboratory system can be explained by the internal motion of nucleons in the target nucleus.

Thus we can conclude as follows. Relativistic particles emitted backward in the laboratory system at prpton-nucleus collisions can not be interpreted to come out entirely from the superposition of elementary multiple production and scattering processes. Some unknown processes seem responsible for this phenomenon. This backward emission may come from very highly excited states of residual nuclei or shock waves in the nuclear matter may play a role. But at this stage we should refrain from more conjectures and accumulation of more experimental data from different points of view is necessary to clarify phenomena peculiar to high energy hadron-nucleus collisions.

Reference.

1) J. Papp et al.: Phys. Rev. Letters 34 (1975) 601.

Figure captions.

Figure 1. Integral distribution of pseudo-rapidity (η) on normal probability paper.

Figure 2. Ionization vs. $P\beta$.

N_h	0	1∼8	≥9
Events	436	483	348
$\langle n_s \rangle$	8.1	10.8	18.0
B-events	17 (3.9%)	57 (11.8%)	112 (32.2%)
MB-events	0	8 (1.7%)	32 (9.6%)
$\frac{\text{B-tracks}}{\text{All thin tracks}}$	0.50%	1.24%	2.45%

Table I

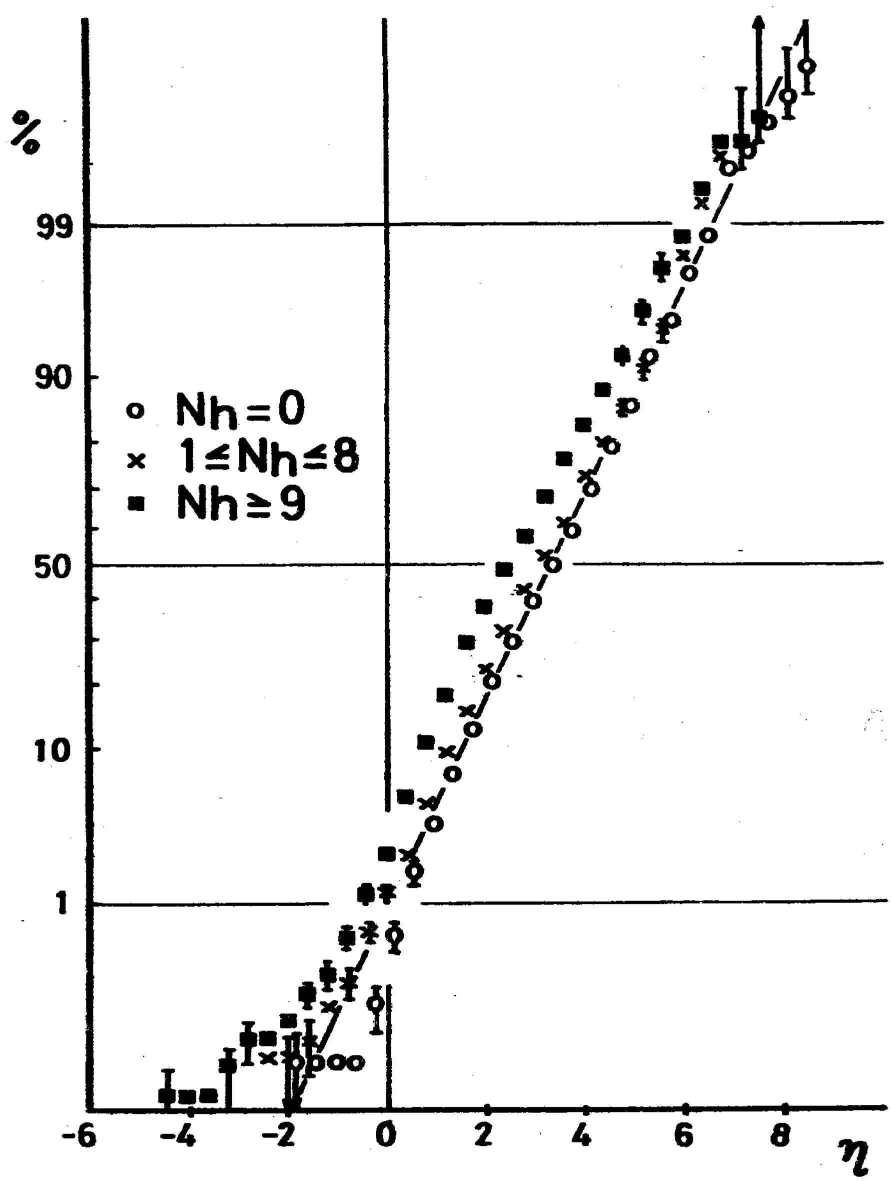

Fig. 1

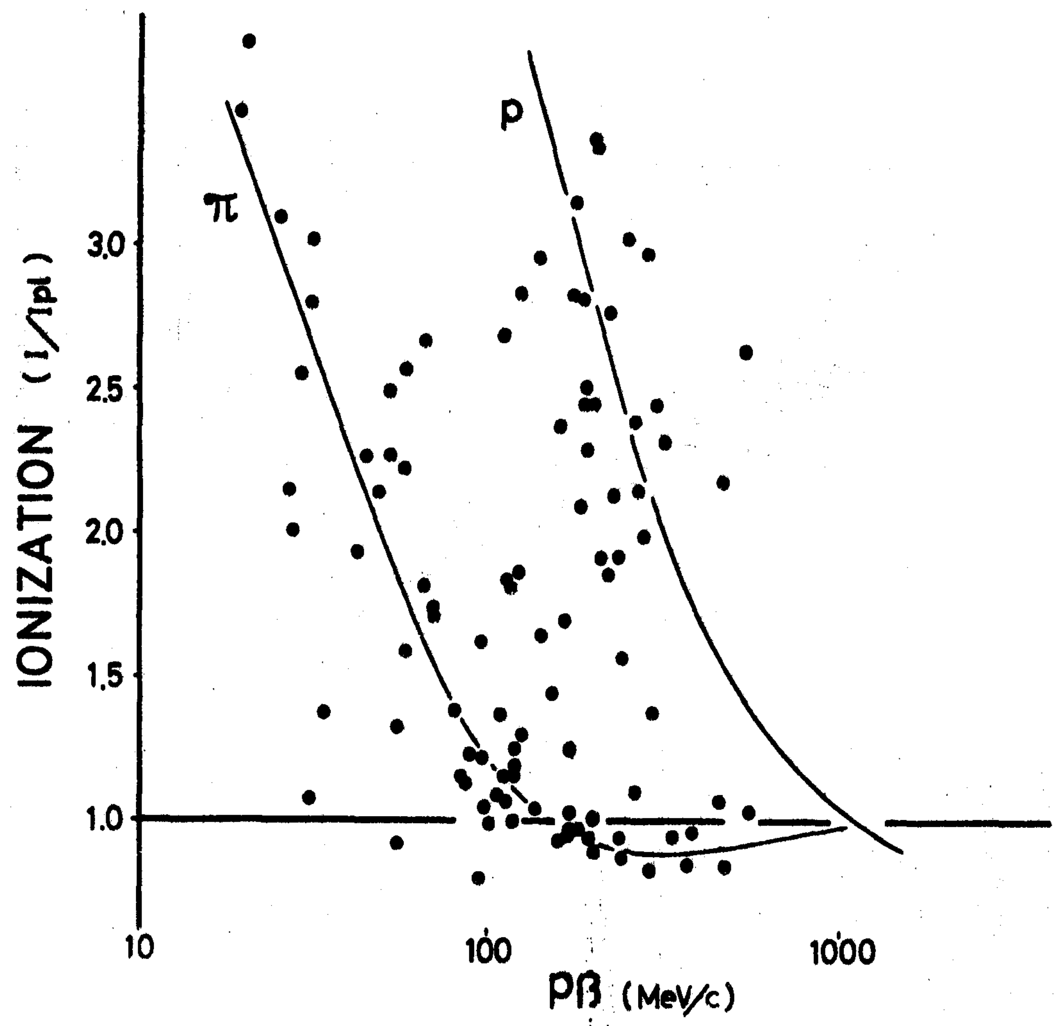

Fig. 2