Forward-backward multiplicity correlations in 4.5 A GeV/c silicon-nucleus interactions

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A detailed study of the mechanism of emission of pions and protons in the forward and backward hemispheres in 4.5 A GeV/c silicon-emulsion interactions has been carried out. For this purpose, a random sample comprising 1024 interactions caused by silicon nuclei is analyzed to examine the behavior of the emission characteristics of pions and protons emitted in the forward and backward hemispheres. The values of the forward-backward ratio and the asymmetry parameter as a function of the number of heavily ionizing particles are determined. The behavior of the angular distributions of pions and protons in the backward hemisphere and multiplicity correlations is also investigated. The results yield quite interesting information regarding the mechanism of production of pions and protons in the backward hemisphere.

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I. INTRODUCTION

Interest in the study of high-energy nucleus-nucleus interactions has received considerable growth in recent years. This is due to the possibility of the formation of collective nuclear matter at high density and the validity of scaling in the case of collisions of compound systems [1].

During the last few years [2–4], the backward production of particles scattered off nuclei has attracted much attention in the experimental side of the problem. But there is no theoretical model which can explain the salient features of particle production in the backward hemisphere and forward-backward multiplicity correlations.

The present paper is devoted mainly to the study of various characteristics of shower and gray tracks emerging in the forward ($\theta \leq 90°$) and backward ($\theta > 90°$) hemispheres in the case of silicon-nucleus interactions at 4.5 A GeV/c. Another objective of this paper is to examine whether the mechanism of particle production in the backward hemisphere is significantly different from the one operating in the production of particles in the forward hemisphere. This can help us solve some questions connected with the role of collective phenomena in the backward emission of particles from the nuclear targets.

II. EXPERIMENTAL DETAILS

Stacks of NIKFI-BR$_2$ nuclear emulsion were exposed to 4.5 A GeV/c silicon beam at the Joint Institute for Nuclear Research, Dubna, Russia. The volume of the stack is $16.9 \times 9.6 \times 0.06$ cm^3. Along the track double scanning, fast in the forward and slow in the backward direction, was carried out. The total length of the scanned tracks equals 202.83 m; 2224 inelastic interactions were picked up yielding a mean free path of 9.12 ± 0.19 cm. The events were chosen according to the following criteria: (i) all the beam tracks having projected angles $> 3°$ with respect to the mean primary direction were rejected; (ii) events produced within 30 μm from the top and the bottom of the emulsion pellicles have not been included for the analysis. For further analysis, 1024 inelastic interactions are used.

Secondary tracks emerging from each interactions are classified according to the emulsion experiment terminology, based upon their appearance in the microscope. These tracks are shower, gray, and black. The shower ($\beta \geq 0.7$) tracks correspond to singly charged relativistic particles, whereas gray ($0.3 \leq \beta < 0.7$) and black ($\beta < 0.3$) tracks are produced by comparatively slower particles emitted from the target nucleus. Gray tracks are mostly recoil protons with momenta lying in the interval 0.2–1.0 GeV/c, with less than a few percent admixture of low-momenta pions. The black tracks are due to slow particle and evaporated fragments. The numbers of shower, gray, and black tracks produced in an interaction are denoted by N_s, N_g, and N_b, respectively. Gray and black tracks taken together are referred to as the heavy tracks and their number in an event is designated by N_h ($=N_g + N_b$).

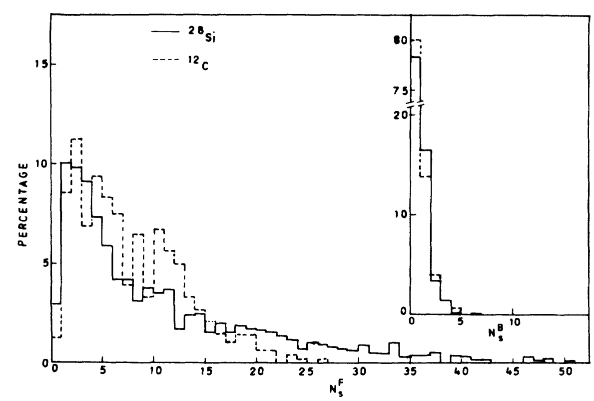

FIG. 1. Multiplicity distributions of shower tracks produced in the forward and backward hemispheres.

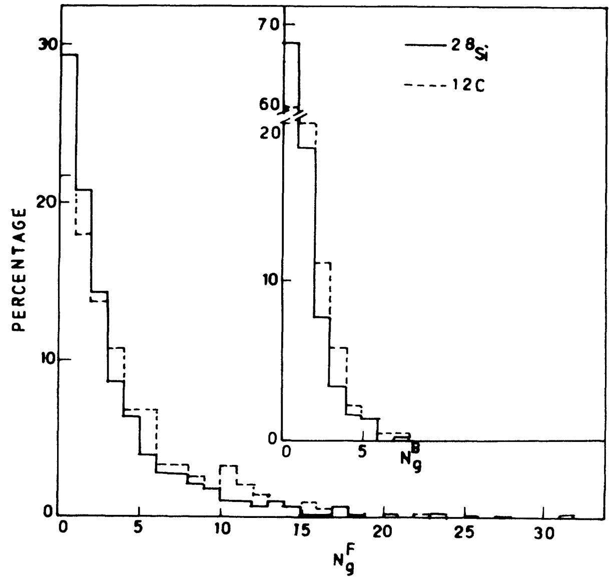

FIG. 2. Multiplicity distributions of gray tracks produced in the forward and backward hemispheres.

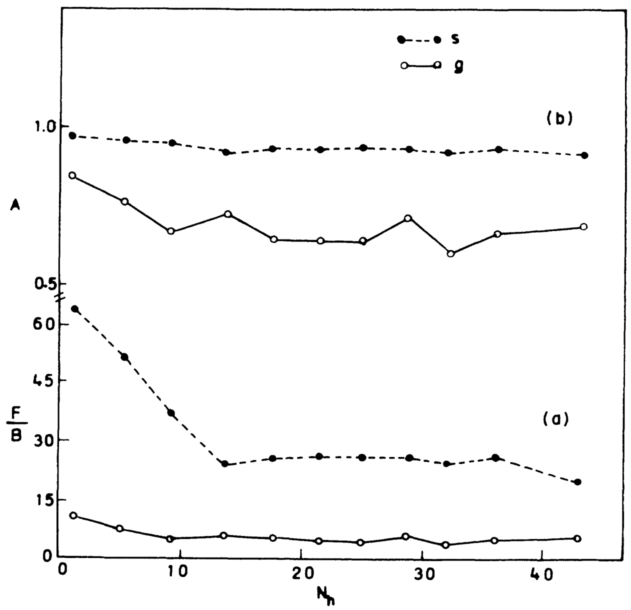

FIG. 3. (a) F/B ratios and (b) asymmetry parameter as a function of the number of heavily ionizing particles for both pions and protons.

III. EXPERIMENTAL RESULTS

A. Multiplicity distributions of shower and gray particles

Multiplicity distributions of shower and gray tracks in the forward and backward hemispheres produced in the interactions of carbon [5] and silicon nuclei are shown in Figs. 1 and 2. From these figures the multiplicity distributions of shower and gray tracks in the backward hemisphere are observed to be similar for both projectiles. However, in the forward hemisphere the distributions tend to become broader with increasing projectile mass. This shows that the particle production in the backward hemisphere is independent of the projectile mass.

Table I shows the values of average multiplicities of shower and gray tracks in the forward and backward hemispheres, the forward-backward ratio, and the asymmetry parameter. The average multiplicities of shower and gray tracks listed in Table I indicate that the probability of the forward emission is much higher than that for the backward emission. This fact is also reflected in the values of the forward-backward ratios. The asymmetry parameter defined as $A=(F-B)/(F+B)$ is relatively lower for gray tracks in comparison to shower tracks.

The forward-backward ratio for both shower and gray particles as a function of number of heavily ionizing particles (N_h) is plotted in Fig. 3(a). From the figure one might observe that the forward-backward ratio is seen to decrease with increasing value of N_h for shower particles. However, in the case of gray particles the forward-backward ratio changes very little with N_h. Figure 3(b) shows the asymmetry parameter for both shower and gray particles as a function of N_h. The negative slope for both the cases shows that the symmetry increases with N_h in the forward and backward hemispheres.

B. Angular characteristics of shower and gray tracks

Angular distributions of shower and gray tracks produced in the backward hemisphere ($\theta > 90°$) are displayed in Fig. 4 for carbon-emulsion [5] and silicon-emulsion interactions. It may be seen that the angular distributions of shower and gray tracks in the backward hemisphere are similar for both projectiles.

C. Multiplicity correlations

The backward hemisphere is intimately connected with the target fragmentation region, i.e., with that part of phase space where all single particle characteristics are most likely dependent on the projectile. Figures 5–8 show the multiplicity correlations in the forward and backward hemispheres. One may observe that the data may be fitted by a linear relation of the form

$$\langle N_i \rangle = aN_j + b, \quad i \neq j , \tag{1}$$

TABLE I. Values of average multiplicities of shower and gray particles in the forward and backward hemispheres, their F/B ratios, and asymmetry parameter.

	$\langle N_s^F \rangle$	$\langle N_s^B \rangle$	$\langle N_g^F \rangle$	$\langle N_g^B \rangle$	$(F/B)_s$	$(F/B)_g$	A_s	A_g
^{12}C	7.38±0.19	0.29±0.03	4.83±0.19	1.10±0.06	25.39±2.74	4.39±0.30	0.92	0.63
^{28}Si	10.95±0.31	0.29±0.02	7.34±0.13	1.43±0.03	37.76±2.83	5.13±0.14	0.95	0.67

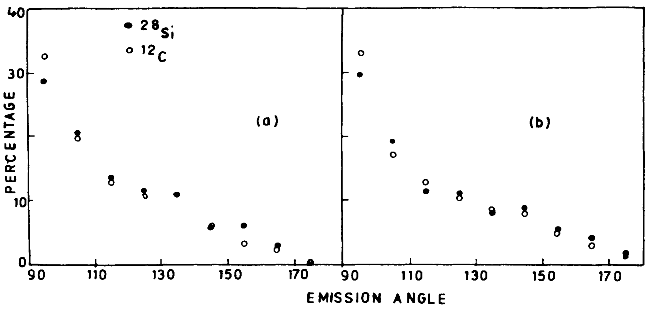

FIG. 4. Distribution of emission angle for (a) pions and (b) protons produced in the backward hemisphere.

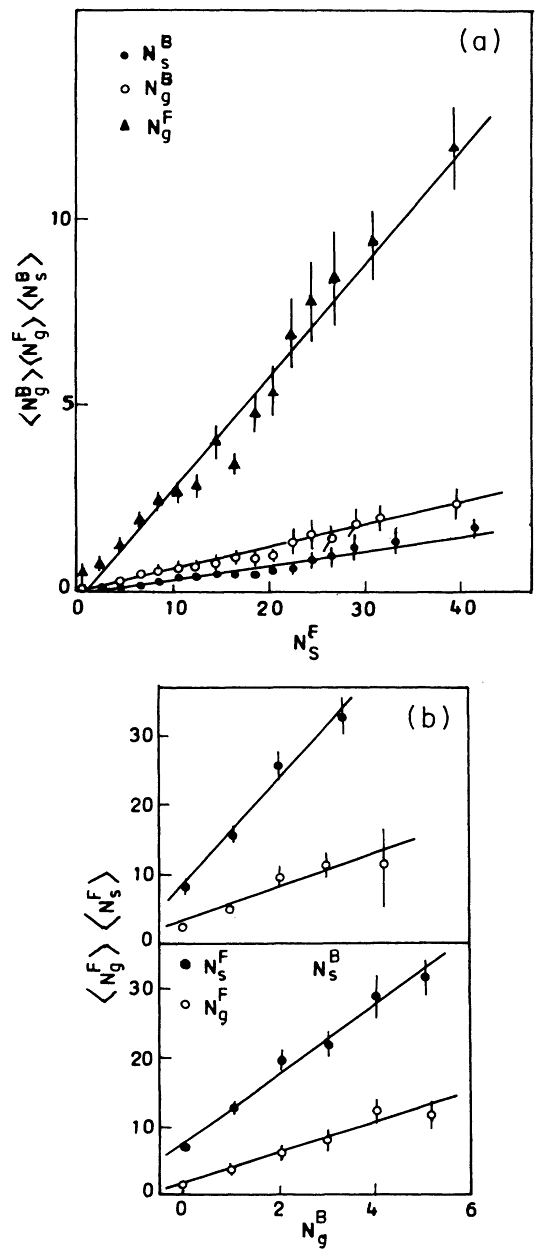

FIG. 5. (a) Variations of $\langle N_g^F \rangle$, $\langle N_g^B \rangle$, and $\langle N_s^B \rangle$ with N_s^F. (b) Forward-backward multiplicity correlations for pions and protons.

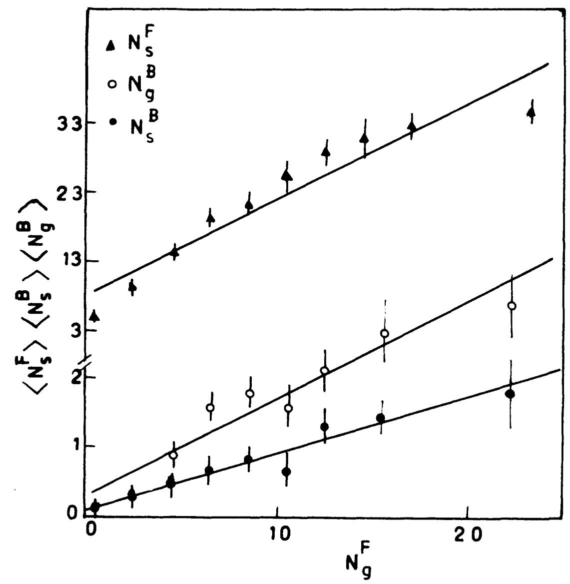

FIG. 6. Variations of $\langle N_s^F \rangle$, $\langle N_s^B \rangle$, and $\langle N_g^B \rangle$ with N_g^F.

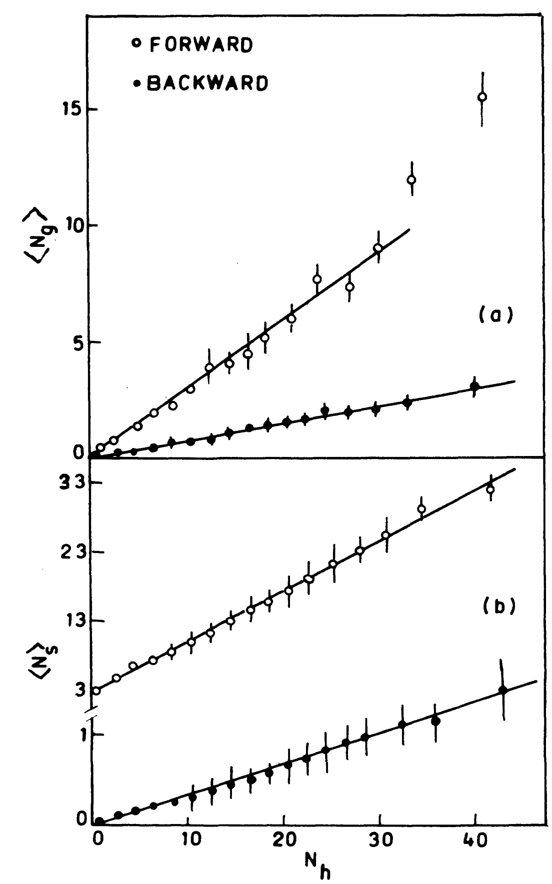

FIG. 7. Forward-backward mean multiplicity for (a) protons and (b) pions as a function of number of heavily ionizing particles.

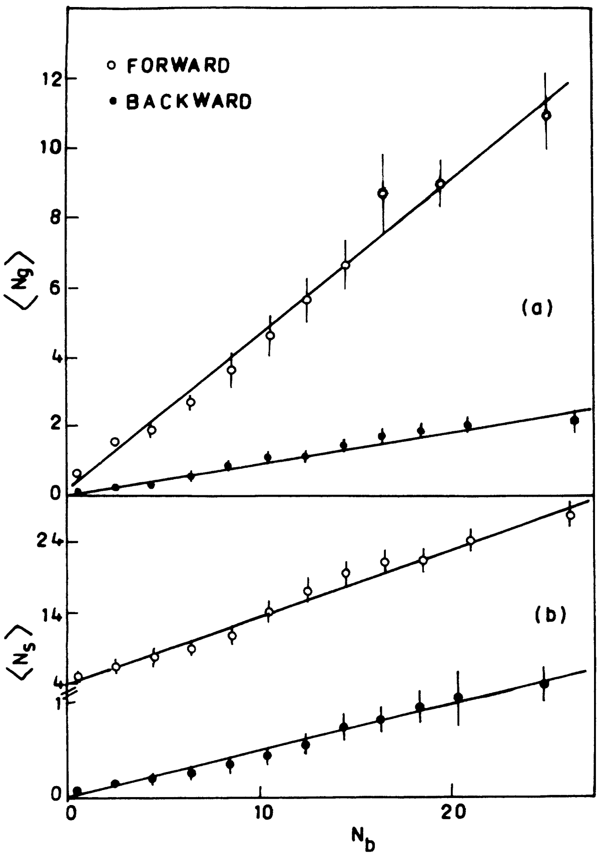

FIG. 8. Forward-backward mean multiplicity for (a) protons and (b) pions as a function of the number of black tracks.

where a is the slope parameter. The values of the slope parameter for all possible multiplicity correlations are given in Table II. From these figures, the following conclusions can be drawn: (i) The average numbers of shower and gray tracks in the forward and backward hemispheres increase with increasing values of N_b and N_h. (ii) The average values of shower and gray tracks in the forward hemisphere depend strongly on the number of gray and shower tracks in the backward hemisphere. However, the average number of gray and shower tracks in the backward hemisphere depends weakly on the number of gray and shower tracks in the forward hemisphere. This shows that the pions and protons produced in the backward hemisphere are somewhat different from those

TABLE II. Values of the slope and the constant in the possible forward and backward multiplicity correlations using Eq. (1).

Correlations	a	b
$\langle N_s^F\rangle - N_b$	0.978±0.041	3.680±0.581
$\langle N_s^B\rangle - N_b$	0.051±0.002	−0.019±0.029
$\langle N_s^F\rangle - N_h$	0.726±0.012	2.383±0.254
$\langle N_s^B\rangle - N_h$	0.034±0.001	−0.010±0.014
$\langle N_g^F\rangle - N_b$	0.449±0.021	0.125±0.274
$\langle N_g^B\rangle - N_b$	0.093±0.006	−0.003±0.082
$\langle N_g^F\rangle - N_h$	0.290±0.009	−0.018±0.154
$\langle N_g^B\rangle - N_h$	0.076±0.002	−0.123±0.052
$\langle N_g^F\rangle - N_s^F$	0.305±0.013	−0.291±0.255
$\langle N_s^F\rangle - N_g^F$	1.379±0.149	8.279±1.790
$\langle N_g^B\rangle - N_s^F$	0.061±0.002	−0.023±0.048
$\langle N_s^F\rangle - N_g^B$	4.991±0.317	7.831±0.959
$\langle N_s^B\rangle - N_s^F$	0.041±0.003	−0.121±0.052
$\langle N_s^F\rangle - N_s^B$	7.681±0.701	8.184±1.394
$\langle N_g^B\rangle - N_g^F$	0.139±0.014	0.296±0.158
$\langle N_g^F\rangle - N_g^B$	2.215±0.261	1.922±0.800
$\langle N_s^B\rangle - N_g^F$	0.083±0.007	0.075±0.075
$\langle N_g^F\rangle - N_s^B$	2.116±0.506	3.276±1.367

emitted in the forward hemisphere. (iii) The forward-backward multiplicity correlation is more pronounced in the case of pions than in the case of protons.

IV. CONCLUSIONS

From the exhaustive analysis of the data we conclude the following.

(i) The multiplicity distributions of shower and gray particles emitted in the backward hemisphere are stable with respect to the projectile mass. This shows that the backward hemisphere is independent of the projectile mass.

(ii) The angular spectra of shower and gray tracks produced in the backward hemisphere are independent of projectile mass.

(iii) The ratio F/B for shower and gray tracks approaches a constant value for $N_h \geq 14$.

(iv) The forward-backward multiplicity corrections are observed to be linear. These correlations exhibit that the energy transfer from the target fragmentation by the projectile increases with the increase in the number of backward pions and protons.

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