MULTIPARTICLE PRODUCTION IN NUCLEUS-NUCLEUS INTERACTIONS AT HIGH ENERGIES

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We present and discuss results on multiplicity and angular distributions of shower particles produced in silicon-nucleus collisions at 4.5 A GeV/c. These results are compared with those obtained for different values of impact parameter. Shower width distribution has also been investigated.

1 Introduction

Studies on nucleus-nucleus interactions at high energies have been attracting more and more interest recently. It is believed [1-3] that these interactions may provide various information about the nuclear matter under extreme conditions of high temperature and densities. For this purpose, it is obviously necessary to obtain a considerable amount of experimental information on diverse characteristics of such interactions; this applies particularly to the multiple production of particles in the collisions of relativistic nucleus-nucleus collisions with relatively larger mass numbers of the incident nuclei.

In the present work we present and discuss results on the characteristics and angular distributions of relativistic singly charged particles produced in silicon-nucleus collisions at 4.5 A GeV/c. These results are compared with those involving carbon-nucleus collisions [4] at the same incident beam momentum.

2 Experimental Detail

The experimental data has been obtained by investigating a NIKFI-BR2 nuclear photo-emulsion plates of dimension(16.9 × 9.6 × 0.06) cm³ irradiated by 4.5 A GeV/c silicon beam at Dubna Synchrophasotron. 1524 interactions were collected by double, fast in the forward and slow in the backward direction, scanning of tracks under 15X eyepieces and each interaction was looked at under 95X oil immersion objectives.

Secondary charged particles produced in each interaction are classified into shower, grey and black tracks; the division of tracks into three distinct groups correspond to different physical processes through which they are envisaged to be produced. The shower tracks have very large range and ioniza-
tion less than $1.4g_0$, where $g_0$ represents the plateau density of a singly charged particles and equals 29.6 grains per 100 micron. The grey tracks have ranges greater than 3 mm and their ionizations lie in the range $1.4g_0$-$10g_0$. The black tracks have ranges less than 3 mm and the ionization greater than $10g_0$. The number of shower, grey and black tracks produced in an event are denoted by $N_s$, $N_g$ and $N_b$ respectively. Grey and black tracks together are referred to as the heavily ionizing particles or heavy tracks in an event and their number is represented by $N_h(=N_g+N_b)$.

Emission angles of all these tracks were measured by taking the space coordinates $(x,y,z)$ at three consecutive points on the same track and at three other points on the incident beam track. Also, the space coordinates $(x_0,y_0,z_0)$ of the production point were noted.

3 Method of Target Identification

It is quite difficult to identify the exact nature of the target because emulsion consists of H, C, N, O, Ag and Br nuclei. However, various methods have been tried by several authors [5-8] to identify the targets on the basis of the distribution of heavily ionizing tracks, $N_h$. Usually, the events with $N_h \leq 1$ are taken to be due to H targets; interactions characterized by $2 \leq N_h \leq 6$ may be due to CNO and AgBr targets and the events with $N_h \geq 7$ are exclusively due to AgBr targets. This method of separation of targets in the experiment is more accurate in hardron-nucleus interactions because in that case the interactions are induced by very light nuclei. For the case of nucleus-nucleus interactions, this method is crude. The events having $N_h > 8$ satisfy the condition for AgBr, but for $N_h \leq 8$ events, there is an admixture of interactions due to CNO and peripheral collisions with AgBr targets. However, a method was suggested by Jakobsson and Kullber[7] for the separation of AgBr events from the interactions having $N_h \leq 8$ by the distribution of short-range tracks. This distribution reveals that there are practically no tracks for the interactions with AgBr targets in the emulsion having ranges between(10-50) µm in the interval of $N_h = 2 - 8$. The events due to AgBr nuclei with $N_h \leq 8$ and having at least one short track of 10 µm are due to recoil nuclei.

In this paper, an attempt has been made to separate the targets using the following criteria for the case of nucleus-nucleus interactions.

CNO events: $2 \leq N_h \leq 8$ and no track with range $\leq 10$ µm

AgBr events: (i) $N_h > 8$, (ii) $N_h \leq 8$ and at least one track with range $\leq 10$ µm and no track with $10 \leq R \leq 50$ µm

H events: $N_h \leq 1$, but do not fall in the above categories.
Table 1 gives the results using the above criteria along with the results of other similar efforts [4,9-11]. It may be seen from the table that the probability of events due to AgBr nuclei increases with increasing projectile mass.

| Momentum per Nucleon (GeV/c) | Projectile | H  | CNO | AgBr | Ref. |
|-----------------------------|------------|----|-----|------|------|
| 3.0                         | P          | 18.00 | 49.50 | 32.50 | 9    |
| 4.5                         | α          | 21.03 | 40.42 | 38.55 | 10   |
| 4.5                         | C          | 21.29 | 30.87 | 47.84 | 4    |
| 4.5                         | Si         | 15.29 | 33.79 | 50.92 | Pers. work |
| 1.8                         | Fe         | 23.13 | 22.64 | 54.23 | 11   |

Table 2. Mean multiplicity and dispersion of relativistic charged particles produced in carbon- (1st row) and silicon- (2nd row) nucleus collisions at 4.5 A GeV/c.

| < N_s > | D(N_s) | < N_s > | D(N_s) | < N_s > | D(N_s) |
|---------|--------|---------|--------|---------|--------|
| 2.18 ± 0.18 | 1.74 ± 0.13 | 5.04 ± 0.21 | 3.66 ± 0.15 | 8.92 ± 0.25 | 5.17 ± 0.18 |
| 3.15 ± 0.19 | 2.98 ± 0.13 | 7.00 ± 0.26 | 5.93 ± 0.18 | 16.30 ± 0.27 | 10.95 ± 0.27 |

4 Experimental Results

The values of mean multiplicities and dispersion of the relativistic charged particles produced in the interactions of silicon nuclei with emulsion nuclei and the groups of events with N_h ≤ 1, 2 ≤ N_h ≤ 8 and N_h > 8 are presented in Table 2. These results are compared with the values obtained for carbon-nucleus interactions [4]. It is interesting to note that the mean multiplicity of the relativistic charged particles grows rapidly with the increase in the mass of the projectile and target nuclei.

Figure 1 shows the multiplicity distributions of shower particles obtained for the interactions of 28Si and 12C nuclei with emulsion for the three different targets. In Fig. 2, we have plotted the multiplicity distributions of relativistic charged particles produced in 28Si-nucleus collisions for different targets and these distributions are compared with 12C-nucleus collisions. It may be seen that the distribution changes most rapidly with increasing projectile and target mass; its broadening changes its shape.

In order to examine the dependence of mean shower particle multiplicity on target mass, the correlation between the mean multiplicity of shower and heavily ionizing particles has been investigated.

Figure 3 shows the correlation dependences < N_s(N_h) > and < N_h(N_s) > for 28Si-nucleus interactions. We note that these dependences can be represented nicely by the following Linear relation with positive slopes.

\[
< N_s > = (0.81 ± 0.02)N_h + (2.05 ± 0.52)(1)
\]
\[ < N_s > = (0.75 \pm 0.02) N_s + (1.88 \pm 0.58) (2) \]

For each group of \( N_h \), the \( N_h \) were accumulated into a composite star and the forward \( F \) to backward \( B \) asymmetry of this star, \( A = (F - B)/(F + B) \) was determined. Results for different \( N_h \) groups are shown in Fig. 4. From this figure, it is clear that the asymmetry \( A \), which is a measure of the four-momenta transfer to the target, is greater for smaller \( N_h \) values (peripheral collisions), whereas the results involving the whole data show relatively large momentums as well as "bounce off, side-splash" effects in the case of non-peripheral collisions that characterizes the collective flow observed in heavy ion experiment.

The angular distribution of shower particles have been analyzed in terms of the rapidity parameter, which at high energies reduces to \( \eta = -\ln \tan \theta/2 \), where \( \theta \) is the emission angle of a shower particle with respect to the mean beam direction in the laboratory frame. Figure 5 shows pseudorapidity distribution of relativistic charged particles produced in \(^{28}\text{Si}\)-nucleus interactions for the three different \( N_h \) groups. From this figure, it is observed that the centroid of the \( \eta \)-distribution shifts towards higher values of \( \eta \) with increasing impact parameter. Furthermore, the excess of particles arising due to the decreasing value of the impact parameter tends to appear only in the central region of the rapidity space.

The variations of \( < \eta > \) and rapidity dispersion \( D(\eta) \) with \( N_h \) are exhibited in Fig. 6. It is interesting to note from the figure that \( < \eta > \) decreases monotonically with increasing \( N_h \) values. We notice that \( < \eta > \) decreases slowly due to the loss of the projectile energy with increasing number of collisions. The energy is believed to be shared by more and more particles having relatively lower energies. This observation is incompatible with the predictions of tube type models [12]. Furthermore, it may be noted from this figure that there is no systematic variation in the rapidity dispersion distribution \( D(\eta) \) with increasing \( N_h \), except in the region of very small values of \( N_h \), where a large part of the cross-section is envisaged to be governed by the peripheral collision with probably one intranuclear nucleon.

The rapidity width (\( R \)) of an event is calculated using the following relation, \( R = \eta_H - \eta_L \), where \( \eta_H \) and \( \eta_L \) are respectively the maximum and minimum pseudorapidity values in an interaction. In order to investigate the dependence of the rapidity width distribution on target size, the data have been divided into different \( N_h \)-intervals. The shower width distributions for various \( N_h \)-intervals are displayed in Fig. 7. It may be noticed in this figure that the peaks of the \( R \)-distribution shift towards the lower values of \( R \) with increasing impact parameter. This feature can be explained in terms of the
fact that shower particles produced with relatively larger angles would tend to appear in the target fragmentation region.

5 Conclusion

The following conclusions may be drawn from the results of the present work:

1- Multiplicity distribution of relativistic charged particles depends on both projectile and target mass.

2- A linear dependence between the mean multiplicities of relativistic charged and heavy particles is observed.

3- Angular distribution of shower particles depends strongly on the impact parameter.

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Figure Captions

Fig. 1 Multiplicity distributions of shower particles for (a) silicon and (b) carbon

Fig. 2 Multiplicity distributions of relativistic particles for (a) H (b) CNO (c) AgBr

Fig. 3 $\langle N_s \rangle$ vs. $N_h$ and $\langle N_h \rangle$ vs. $N_s$

Fig. 4 Asymmetry parameter vs. $N_h$

Fig. 5 Pseudorapidity distributions of relativistic particle produced in 4.5 GeV/c Si interactions

Fig. 6 Dependence of $\langle \eta \rangle$ and $D(\eta)$ on $N_h$

Fig. 7 Shower width distributions in Si-nucleus interactions
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