Research Journal of Recent Sciences ____ ISSN 2277-2502
Vol. **1 (ISC-2011),** 232-237 **(2012)** *Res.J.Recent Sci.*

Some Aspects of Secondary Charged Particles Produced in 4.5 A GeV/c ^{28}Si-Nucleus Interactions

Shaikh Sarfaraz Ali[1] and H.Khushnood[2]
Department of Physics, Jamia Millia Islamia, Jamia Nagar, New Delhi-110025, INDIA

Available online at, www.isca.in
(Received 15th October 2011, revised 10th January 2012, accepted 25th January 2012)

Abstract

Attempt has been made to study the characteristics of secondary charged particles produced in 4.5 A GeV/c ^{28}Si-nucleus interactions. The results reveal that the multiplicity correlations are not linear. These findings do not agree with those reported by several workers. However, these correlations may be reproduced quite well by second order polynomial. It is also observed that the dependence of mean normalized, R_A and reduced multiplicity, R_S on the multiplicity of different charged secondaries is linear up to a certain value and then acquire almost a constant value. Results also reveal that the k^{th} root of central moment increases with the increase of $\langle N_S \rangle$ and the values of normalized moments do not depend on the nature and energy of the projectiles. Finally, it is observed that the integral multiplicity distribution of heavily ionizing tracks provides a method for selecting the disintegration caused by the projectile due to different target nuclei of nuclear emulsion.

Keywords, Multiplicity correlations, mean normalized and reduced multiplicity, central moment, nuclear emulsion, etc.

Introduction

Study of relativistic heavy ion interactions has been carried out by several workers[1-9] during the recent years. One of the important feature of relativistic heavy ion reactions is the observation of collective behaviour of nuclear matter. However, the first goal for such studies is to investigate the correlations between the emitted particles in the nucleus-nucleus collisions.

In the present work an attempt has been made to investigate the characteristics of different secondary charged particles emitted in inelastic collisions of silicon nuclei with the nuclei of nuclear emulsion at the momentum of 4.5 A GeV/c. At the same time the nature of the dependence of various parameters on the mass number of the projectile and on the mass of the target nucleus are also studied. This will help us to understand the dynamics of hadronization of final stage charged secondaries produced in relativistic heavy ion interactions.

Material and Methods

In order to investigate the characteristics of secondary charged particles, a random sample of 498 events produced in 4.5 A GeV/c ^{28}Si-nucleus interactions, have been analyzed. All the relevant informations regarding the emulsion stacks, method of measurement, selection criteria, etc. may be found in our earlier publication[8]. All the secondary charged particles produced in these interactions may be classified in the following categories.

Black Particles: The tracks having relative velocity, b < 0.3 are termed as black tracks. The number of their tracks in an event is denoted by N_b. They are generally alpha particles and helium nuclei etc.

Grey Particles, The tracks with 0.3 £ b £ 0.7 are referred as grey particles. The number of grey particles in an integration is denoted by N_g. They are generally protons with a very little admixture of slow pions.

Heavily ionizing Particles, The black and grey tracks taken together are treated as heavily ionizing particles and denoted as N_h (= N_b +N_g).

Relativistic charged Particles, The tracks having b > 0.7 are considered as relativistic charged particles. The number of these particles in a star is represented by N_s. These are generally charged pions.

Results and Discussions

The integral multiplicity distributions of heavily ionizing particles, N_h, produced in 4.5 A GeV/c ^{28}Si-nucleus interactions is plotted in figure 1. It is interesting to note in the figure that the distribution has two different slopes with breaks approximately corresponding to CNO and Ag Br constituents of the emulsion nuclei. A similar behaviour of integral multiplicity distributions of heavily ionizing tracks is also observed in 4.5 A GeV/c ^{12}C-nucleus interactions[4]. It is reported that the multiplicity correlations between $\langle N_s \rangle$ - N_b, $\langle N_S \rangle$ - N_h and $\langle N_b \rangle$ - N_g acquire almost constant value beyond N_b ~ 9 and N_h ~ 31 and N_g ~ 20 in both hadron-nucleus and nucleus-nucleus collisions[2,10,11]. In order to understand the nature of the multiplicity correlations, an attempt has been made to investigate the multiplicity correlations between $<N_s>$ - N_b, $<N_S>$ - N_h and $<N_b>$ - N_g. For this purpose the regression of the type <Ni(Nj)>, where Ni, Nj = N_b, N_g, N_s and N_h and i ≠j. In the present work regression $<N_s (N_h)>$, $<N_s(N_b)>$ and $<N_b (N_g)>$ for ^{28}Si-nucleus reactions at 4.5 A GeV/c and their dependence on the nature of the projectile are studied. The dependence of $<N_s>$ with N_b, N_g and N_h and $<N_b>$ on N_g are displayed in figures 2-4. The multiplicity correlations obtained in ^{28}Si-nucleus collisions may be represented by the following second order polynomial quite well.

$$<N_s> = (5.47 \pm 3.11) + (0.41 \pm 0.35) N_h + (0.002 \pm 0.008) N_h^2 \quad \text{...(1)}$$

$$<N_s> = (6.85 \pm 1.82) + (0.69 \pm 0.56) N_b + (0.008 \pm 0.03) N_b^2 \quad \text{...(2)}$$

$$<N_b> = (0.92 \pm 0.02) + (1.41 \pm 0.38) N_g - (0.03 \pm 0.02) N_g^2 \quad \text{...(3)}$$

The continuous curve shown in figures corresponds to eqs. (1-3) for 4.5 A GeV/c ^{28}Si-nucleus interactions. It is reported that the multiplicity correlations between $<N_s>$ - N_h and $<N_S>$ -N_g in case of hadron-nucleus collisions in the energy range ~ (24-400) GeV[11]. and in 4.5 A GeV/c ^{12}C-nucleus reactions[4] may be represented by the second order polynomial. This indicates that the nature of the correlation $<N_s>$ - N_h is almost similar in both hadron-nucleus and nucleus-nucleus collisions.

The mean normalized multiplicity R_A defined as the ratio of average number of relativistic charged particles produced in hadron-nucleus and hadron-hadron collisions at the same projectile energy is one of the most important parameter to test the predictions of various theoretical models put forward for explaining the mechanism of hadronization of final stage charged particles produced in hadron-nucleus collisions. The study of R_A and its dependence on the nature and energy of the impinging hadron has been investigated by several workers in hadron-nucleus collisions at high energies[10]. However, a little attention has been paid to study this parameter in nucleus-nucleus interactions[3]. Thus, an attempt has been made to investigate the dependence of the mean normalized multiplicity, on the mass of the projectile and target nucleus. Mathematically, R_A may be given as;

$$R_A = <N_s>_{AA} / <N_{ch}>_{PP} \quad \text{...(4)}$$

Here $<N_s>_{AA}$ refers to to the average number of relativistic charged particles produced in nucleus-nucleus interactions and $<N_{ch}>_{PP}$ is the average number of charged particles emitted in Proton-Proton collisions at the same projectile energy. The reduced multiplicity, R_S is defined as the ratio of the average number of relativistic charged particles produced in nucleus-nucleus reactions, $<N_s>_{AA}$ and Proton-nucleus reactions $<N_{ch}>_{PP}$ at the same projectile energy

$$R_S = <N_s>_{AA} / <N_s>_{PA} \quad \text{...(5)}$$

It may be pointed out that the values of $<N_s>_{AA}$ have been calculated using the following relations[3].

$$<N_s>_{AA} = 2.34 <N_{ch}>_{PP} - 4.12 \quad \text{...(6)}$$

The values of R_A and R_S are estimated and their dependence with the number of black tracks, N_b produced in 4.5 A GeV/c ^{28}Si-nucleus interactions is shown in Fig.5. It is noticed in the figure that both R_A and R_S increase linearly with increasing the value of N_b up to N_b ~ 10. The experimental values of R_A and R_S are found to satisfy the following relationship, obtained by the method of least squares;

$$R_A = (0.219 \pm 0.07) N_b + (3.519 \pm 1.15) \quad \text{...(7)}$$

$$R_S = (0.330 \pm 0.114) N_b + (5.368 \pm 1.73) \quad \text{...(8)}$$

A similar behaviour of dependence of R_A and R_S with N_b is also observed in case of ^{12}C-nucleus reactions at 4.5 A GeV/c[3].

Figure 6 deals with the dependence of parameters R_A and R_S with the multiplicity of grey particles, N_g. It may be noted from the figure that the values of R_A and R_S increases with increasing value of N_g up to N_g ~ 9. The following relations obtained by the method of least square fit are found to satisfy the experimental data quite well,

$$R_A = (0.276 \pm 0.009) N_g + (3.321 \pm 1.32) \quad \text{...(9)}$$

$$R_S = (0.437 \pm 0.148) N_g + (4.860 \pm 2.08) \quad \text{...(10)}$$

A similar result has also been reported by Saleem et al [6] in the study of ^{12}C-nucleus collisions at 4.5 A GeV/c. An attempt has also been made to study the dependence of the parameters R_A and R_S with the multiplicity of heavily ionizing tracks, N_h. The variation of R_A and R_S with N_h for ^{28}Si-nucleus collisions is shown in figure 7. It is clear from the figure that R_A and R_S increase linearly with increasing value of N_h up to N_h ~ 28. The experimental value of R_A and R_S are found to satisfy the following fits obtained by the method of least squares.

$$R_A = (0.221 \pm 0.033) N_h + (1.721 \pm 0.762) \quad \text{...(11)}$$

$$R_S = (0.334 \pm 0.050) N_h + (2.601 \pm 1.149) \quad \text{...(12)}$$

The normalized moments of the multiplicity distributions of relativistic charged particles produced in high energy hadron-nucleus collisions has been investigated by several workers in the energy range ~ (50-400) GeV[12]. However, a little attention has been paid to study the normalized moments of the multiplicity distributions of relativistic charged particles produced in nucleus-nucleus interactions[1,3] . Thus, it was considered worthwhile to investigate the normalized moments of the distributions and their dependence on the mass of the projectile and struck nucleus. The normalized moments of the multiplicity distributions of relativistic charged particles is defined as;

$C_K = \langle N_S^K \rangle / \langle N_S \rangle^K$ ………………….(13)

where K is a constant and can have different values 2, 3, 4 etc. For studying the dependence of C_K on the size of the target nucleus, the values of C_2, C_3 and C_4 are calculated for different groups of emulsion nuclei in 4.5 A GeV/c ^{28}Si-nucleus interactions. The values of C_K obtained in 4.5 GeV/c ^{28}Si-nucleus reactions are listed in table-1 along with the results obtained in ^{12} C-nucleus reactions[1,3] at the same projectile energy.

It is interesting to note that the values of C_K in 4.5 A GeV/c ^{12}C-nucleus reactions and ^{28}Si-nucleus collisions are almost consistent with constant with the statistical limits. It may be further noted in the Table-1 that, the value of this parameter is observed to increase with increasing value of k. On comparing the findings of the present work with those obtained in 50 GeV and 400 GeV hadron-nucleus collisions[12], it may be observed that the value of C_K are very similar in both type of interactions. The k^{th} root of the central moment, m_K of the multiplicity distribution is also studied in 4.5 A GeV/c ^{28}Si-nucleus collisions. The parameter m_K is defined as,

$(m_K)^{1/2} = (\langle (N_S - \langle N_S \rangle)^K \rangle)^{1/2}$ ……………(14)

In figure 7 we have plotted $(m_2)^{1/2}$, $(m_3)^{1/2}$, $(m_4)^{1/2}$ as a function of $\langle N_S \rangle$ for ^{28}Si-nucleus interactions at 4.5 A GeV/c.

It may be seen in the figure that the solid line which represent the variation of the moments with $\langle N_S \rangle$ fits the experimental data quite well. On comparing these observation with those obtained in high energy hadron-nucleus collisions, it may be concluded that there is at least a qualitative similarity in the mechanism of hadronization in the final stage of high energy hadron-nucleus as well as nucleus-nucleus reactions.

Conclusion

On the basis of the study of the present work we draw some important conclusions which are summarized as follows, i. The multiplicity correlations amongst $\langle N_S \rangle$ - N_b, $\langle N_b \rangle$ - N_g, $\langle N_S \rangle$ - N_h are non-linear and may be represented quite well by the second order polynomial. Thus, our findings are in marked disagreement with those reported by other workers in both hadron-nucleus and nucleus-nucleus interactions. ii. The experimental values of R_A and R_S are found to increase linearly with increasing value of N_b, N_g and N_h up to $N_b \sim 10$, N_g up to $N_g \sim 9$, and N_h up to $N_h \sim 28$. iii. The values of normalized moments are found to remain almost constant. However, the value of this parameter increases with increasing value of k. iv. The results reveal that the k^{th} root of the central moment increases with increasing value of $\langle N_S \rangle$. v. On comparing the results obtained in 4.5 A GeV/c nucleus-nucleus interactions with those obtained in high energy hadron-nucleus collisions, we conclude that the results both in hadron-nucleus and nucleus-nucleus interactions are almost similar and the mechanism of hadronization of final stage charged particles operating in these reactions is perhaps the same.

Table-1
Values of normalized moments C_2, C_3 and C_4 in nucleus nucleus reactions at 4.5 A GeV/c

Type of Interactions	C_2	C_3	C_4	Reference
^{12}C-CNO	1.41 ± 0.10	2.42 ± 0.23	4.73 ± 0.58	6
^{28}Si-CNO	1.41 ± 0.01	2.44 ± 0.007	4.41 ± 0.003	Present work
^{12}C-Em	1.43 ± 0.05	2.51 ± 0.12	5.15 ± 0.33	6
^{12}C-Em	1.58 ± 0.07	2.67 ± 0.13	–	3
^{28}Si-Em	1.53 ± 0.01	3.06 ± 0.013	7.19 ± 0.01	Present work
^{12}C-AgBr	1.27 ± 0.06	2.20 ± 0.13	3.09 ± 0.24	6
^{12}C-AgBr	1.29 ± 0.26	2.48 ± 0.08	–	3
^{12}Si-AgBr	1.31 ± 0.007	4.56 ± 0.004	3.55 ± 0.35	Present work

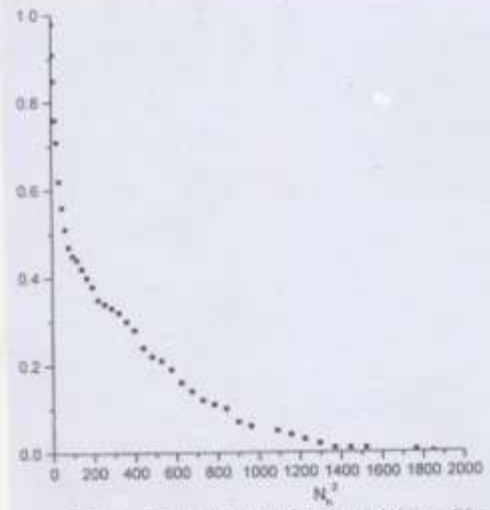

Fig. 1- Integral multiplicity distribution of heavily ionising particles produced in ^{28}Si-nucleus reactions at 4.5 A GeV/c

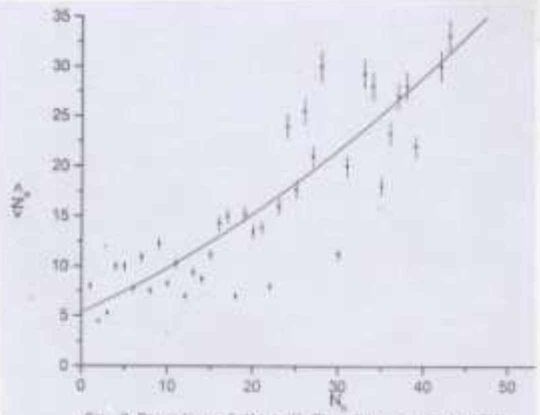

Fig. 2- Dependence of $<N_s>$ on N_h. The solid curve is the best fit for ^{28}Si-nucleus interactions at 4.5 A GeV/c.

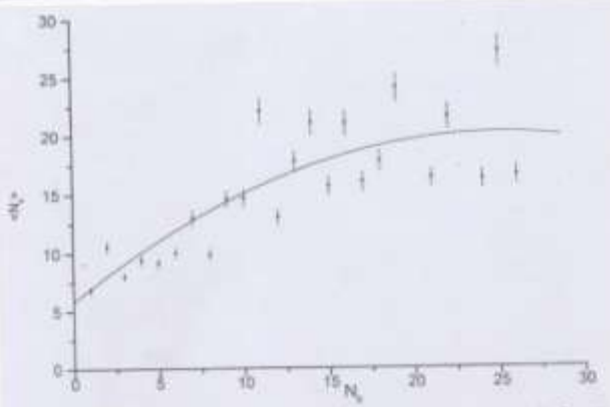

Fig. 3- Multiplicity correlation between $<N_s>$ and N_g. The curve shown in the figure is the best fit for ^{28}Si-nucleus interactions at 4.5 A GeV/c.

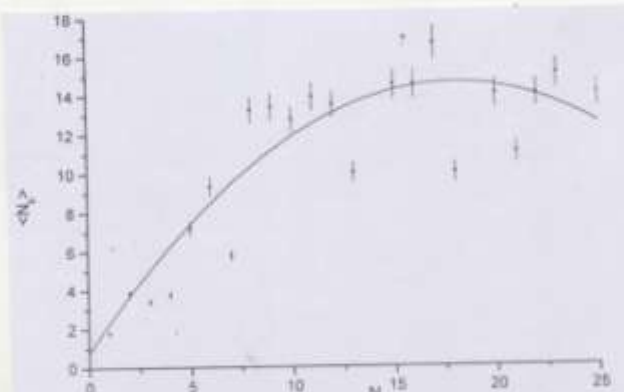

Fig. 4- Variation of $<N_s>$ with N_b. The continuous curve is the best fitting for ^{28}Si-nucleus collisions at 4.5 A GeV/c.

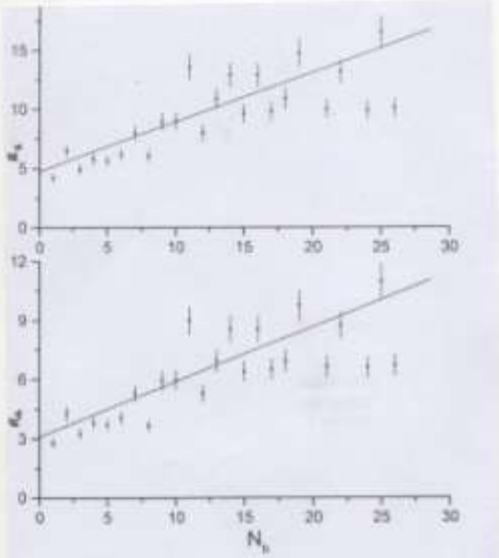

Fig. 5 Variation of R_s and R_A with N_h

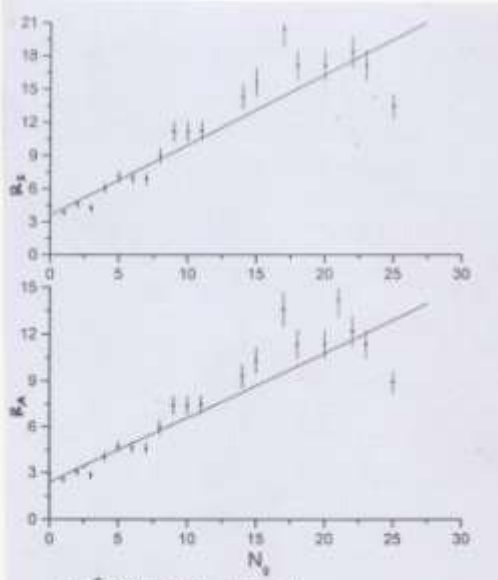

Fig. 6 Variation of R_s and R_A with N_g

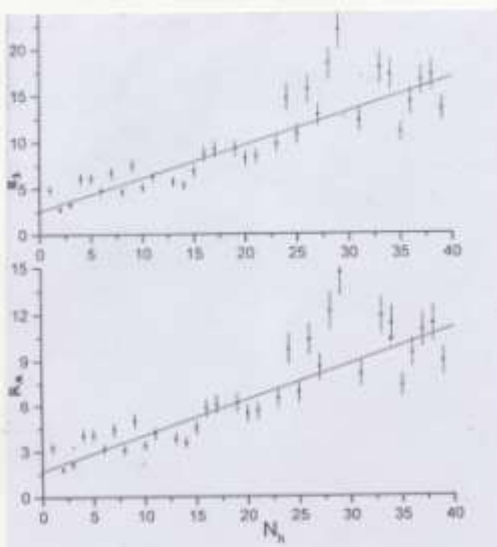

Fig. 7 Variation of R_s and R_A with N_h

Acknowledgment

The authors wish to thank to staff of all clinical laboratories of Valsad district, who gave their valuable support. The authors also wish to thank management and staff of Shree RamKrishna Institute of Computer Education and Applied Sciences, Surat; Dolat Usha Institute of Applied Sciences, Valsad.

References

1. Qasim Raza Khan M., Ph.D. Thesis submitted to Aligarh Muslim University, Aligarh **(1988)**

2. Saleem Khan et al M., Multiplicity characteristics of ^{12}C-nucleus interactions at 4.5 A GeV c^{-1}, Can. J. Phys. **74**, 651 **(1996)**

3. Saleem Khan et al M., Production of secondary charged particles in ^{12}C-nucleus reactions at 4.5 A GeV per nucleon, J. Phys. Soc. Jpn. **65**, 801 **(1996)**

4. Saleem Khan et al M., Study of disintegrations caused by 4.5 GeV carbon nuclei in nuclear emulsion, Nuovo Cimento A, **108**, 147 **(1996)**

5. Singh et al Prithipal, Features of relativistic charged particles produced in catastrophic destruction of heavy emulsion nuclei at 4.5 A GeV/c, Can. J. Phys. **76**, 559 (**1998**)

6. Abd Allah et al N. N., Non-statistical fluctuations of target fragments emitted in high energy nucleus-nucleus collisions, Can. J. Phys. **80**, 119 **(2002)**

7. El Naghy et al A., Comparative study for nucleus-nucleus interactions and modified cascade evaporation model at (4.1-4.5) A GeV/c, APHNS, Heavy Ion Phys.**15**, 131 **(2002)**

8. Sarfaraz Ali et al Shaikh, Study of totally disintegrated events caused by 4.5 A GeV/c ^{28}Si with heavy emulsion targets, Euro Phys. Lett. **65**, 773 **(2004)**

9. Khushnood et al H., Some aspects of multi particle production in 4.5 GeV ^{28}C-nucleus interactions, 6th International Conference on Physics and Astro Physics of Quark Gluon Plasma, Dec. 6-10,115 **(2010)** Goa, India

10. Khushnood et al H., A study of high energy hadron - nucleus interactions, Can. J. Phys. **61**, 1120 **(1983)**

11. Shakeel et al A., Multi particle production in 24, 50 and 400 GeV/c particle-nucleus interactions, Nuovo Cim. **76A**, 699 **(1983)**

12. Khushnood et al H., Some interesting features of charged particles produced in high energy hadron-nucleus collisions, Can. J. Phys. **68**, 67 **(1990)**