Arab J. Nucl. Sci. Appl., Vol. 52, 2, 1-6 (2019)

Arab Journal of Nuclear Sciences and Applications

ISSN 1110-0451 Web site: ajnsa.journals.ekb.eg (ESNSA)

Correlations of Singly and Doubly Charged Projectile Fragments with Secondary Charged Particles Produced in ^{32}S-Emulsion Interactions at 3.7A and 200A GeV

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Received 12th Aug. 2018
Accepted 3rd Oct. 2018

The multiplicity correlations amongst the singly (N_P) and doubly (N_{alpha}) charged projectile fragments and the secondary charged target fragments (black, grey and shower tracks) produced in ^{32}S–Emulsion interactions at 3.7A and 200A GeV are studied. This aims at shedding some light on the interface of spectator and participant region. The effect of changing the energy used for ^{32}S-Emulsion interactions is investigated as well, indicating that the values of $< N_P >$ and $< N_{alpha} >$ at both incident energies have the same values within experimental errors. The impact centrality is shown to be increased with the increasing number of singly charged projectile fragments N_P,. The correlation between the mean multiplicities of secondary charged particles and both of the singly and doubly charged projectile fragments are observed. The relation between the variation of mean values of black and heavy ionized particles is observed and found to be independent of the production of singly charged fragments.

Keywords: ^{32}S-Em Interactions/ Projectile Fragments/ Participant-Spectator Model/ Secondary Charged Particles

Introduction

In heavy ion collisions, multifragmentation is considered a good tool to understand nuclear structure and fragmentation properties [1-2]. In high energy physics, the nuclear emulsion detector technique plays an important role investigating nucleus-nucleus and nucleus-hadrons collisions, since it has the highest spatial resolution 4π, and excellent detection of relativistic particles. Furthermore the emulsion detector detects the projectile fragments and the target fragments which are used in the analysis of events.

Many workers have examined the multiplicity distributions and multiplicity correlations with evaporated recoil nucleons of target, produced mesons, helium and heavy ionizing charged particles [3-9], to help understand the interaction mechanism and particle production.

According to the participant-spectator model [10-13], the interacting system can be divided into three regions: a target spectator, a participant and a projectile spectator. The overlapping region of the two colliding nuclei is the region where violent collisions takes place which is the participant region, expecting that the local density and temperature to increase. After that, the participant region expands and cools down, producing single charged relativistic particles and rare isotopes which are mostly a mixture of pions, K- mesons and a lower ratio of fast protons. Target fragments are formed from the target spectator, since they are a combination of recoil proton and evaporated fragments. Projectile fragments are formed from projectile spectator. They are formed from highly

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DOI: **10.21608/ajnsa.2018.4838.1111**

excited projectile spectator residues through the evaporation.

There are relations between the participant and the spectator regions. It is expected that quark gulon plasma (quark matter) will be formed in the participant region at very high incident energies and a liquid –gas phase transition takes place in the spectator region [14].

In the present work, focus is made on investigating the relation between production of singly and doubly charged projectile fragments and average number of black, grey and shower particles. Moreover, the effect of energy for ^{32}S-Emulsion interactions at 3.7A and 200A GeV was investigated.

Experimental Technique

The present work was performed using two emulsion stacks of concentrations illustrated in Table (1). The first stack was horizontally exposed to the 3.7A GeV ^{32}S ions at the Dubna synchrophastron and the second one was tangentially irradiated by the 200A GeV ^{32}S ions of CERN-SPS (Exp. No. EMU03).

Table (1): The chemical composition of Br-2 and Fuji nuclear emulsions used for 3.7A and 200A GeV, respectively

Element	Number of atoms × 10^{22} (cm^{-3})	
	Br-2	Fuji
H	3.150	3.2093
C	1.412	1.3799
N	0.395	0.3154
O	0.956	0.9462
S	–	0.0134
I	–	0.00552
Br	1.031	1.0034
Ag	1.036	1.0093

To obtain a high scanning efficiency, the pellicles were scanned under 100X magnification by doubly scanning along the beam tracks, fast in the forward direction and slow in the backward one. The details about the irradiation and scanning are reported in earlier studies [15, 16]. Once an interaction is observed, the incoming track is carefully examined to ensure that it is indeed a beam track. In each interaction, the following visual features were recorded, the multiplicity of grey tracks (ng), black tracks (n_b), heavy ionized tracks (N_h= n_g+n_b) and the tracks of the produced shower particles (n_s).

The non-interacting projectile fragments, PFs (projectile spectators) are highly collimated tracks. The fragmentation cone [3] defined by a critical angle (this cone angle can be obtained from the primary beam energy of 3.7A and 200A GeV in conjunction with the fermi momentum) $\theta_{c\ \ i}$ = 44mrad at 3.7A GeV and θ_c = 1mrad at 200A GeV. The angles of PFs are measured using the coordinate method. The charge of the PFs was determined by the grain density, and δ-ray counting as discussed [17]. The projectile fragments PFs are classified according to their charges into:

1- Singly charged projectile fragments (z =1) their multiplicity is denoted by Np. According to El Nadi et al. [18] the relativistic hydrogen isotopes, protons, deuterons and tritons are produced in nuclear emulsion by the ratios 77.6%, 19.1% and 3.3% respectively.

2- Doubly charged projectile fragments (z =2), their multiplicity are denoted by N_{alpha} .

3- Multiply charged projectile fragments (z ≥ 3), their multiplicity are denoted by N_F.

Results and Discussion

Relation between projectile fragments and the secondary charged particles:

I-Singly charged projectile fragments dependence on secondary charged particle

The relation between singly charged projectile fragments Np and average number of showers, grey and black particles for ^{32}S-Em interactions at 3.7A and 200A GeV is compared and displayed in Table (2). It is noticed from this table that:

1) At the same Np,<n_s> values at 3.7A GeV are much smaller than that at 200A GeV.
2) For different Np and same energy, <n_g> values are nearly constant within experimental errors.
3) At the same N_P, <n_g> values at 3.7A GeV are higher than the corresponding values at 200A GeV.

4) For different N_P, $\langle n_b \rangle$ values within experimental errors show energy independence. So, the black particle production mechanism is different from that of N_P.
5) The mean value of doubly < Nalpha > charged particle shows energy independence for NP.

II-Doubly charged projectile fragments dependence on charged secondary particles

The relation between doubly charged projectile fragments N_{alpha} and average number of shower, grey and black particles for ^{32}S-Em interactions at 3.7A and 200A GeV is compared and displayed in Table (3). From Table (3), it is noticed that: 1) at the same N_{alpha}, $\langle n_s \rangle$ values at 3.7A GeV are much smaller than that at 200A GeV, while $\langle n_g \rangle$ values at 3.7A GeV shows higher values than 200A GeV. 2) $\langle n_b \rangle$ values are independent from different N_{alpha}. 3) $\langle n_s \rangle$ values decrease with increasing N_{alpha} at 3.7A GeV , while at 200A GeV, as a result of separation of grey and shower particles ,there are some contamination between the values of the grey particles with the values of shower ones, so the values fluctuate. 4) The mean value of singly < N_P > charged particle shows energy independence.

Table (2): Dependence of the singly charged PFs (N_P) on the mean values of secondary charged particles in ^{32}S-Em collisions at 3.7A and 200A GeV

N_P	1	2	3	4	5	6
$\langle n_s \rangle$ (3.7A GeV)	14.03±0.75	12.30±0.80	13.11±1.17	13.18±1.82	15.39±2.10	22.00±4.06
(200A GeV)	48.74±5.46	68.48±8.59	80.35±12.04	75.32±12.74	40.25±11.23	95.60±33.64
$\langle n_g \rangle$ (3.7A GeV)	3.74±0.25	3.64±0.30	3.53±0.43	4.64±0.83	4.22±0.82	6.00±2.73
(200A GeV)	2.10±0.27	2.02±0.31	2.28±0.39	2.32±0.68	2.13±0.99	2.80±1.63
$\langle n_b \rangle$(3.7A GeV)	6.69±0.43	7.28±0.54	6.23±0.63	6.79±1.10	7.78±1.56	4.17±1.62
(200A GeV)	5.13±0.57	6.06±0.65	6.80±0.93	4.78±1.02	3.75±0.90	4.60±1.65

Table (3): Dependence of the doubly charged PFs (N_{alpha}) on the mean values of secondary charged particles in ^{32}S-Em collisions at 3.7A and 200A GeV

N_{alpha}	1	2	3	4	5
$\langle n_s \rangle$ (3.7A GeV)	13.62±0.64	12.70±0.69	9.15±0.78	9.58±1.35	8.40±1.71
(200A GeV)	67.27±3.84	71.07±4.52	43.17±4.35	50.23±10.95	44.00±18.27
$\langle n_g \rangle$(3.7A GeV)	3.74±0.25	3.49±0.28	2.94±0.43	1.79±0.45	1.90±0.81
(200A GeV)	2.02±0.16	2.12±0.21	1.34±0.24	1.36±0.44	2.25±1.11
$\langle n_b \rangle$(3.7A GeV)	6.80±0.42	6.43±0.54	7.17±0.98	4.58±1.05	5.00±1.12
(200A GeV)	5.47±0.36	6.30±0.52	4.49±0.63	2.91±0.78	8.75±5.60

Projectile and secondary charged particles multiplicity correlations

The participant spectator model can explain the multiplicity correlations between the singly and doubly charged projectile fragments (Np, N_{alpha}) and the secondary charged particle multiplicities of n_s, n_g, n_b and N_h track particles. Figure (1) display the correlation between Np and mean secondary particles multiplicities$<n_s>$, $<n_g>$, $<n_b>$, $<N_h>$ and $< N_{alpha}>$ for ^{32}S-Em interactions at 3.7A and 200A GeV.

From these figures, a strong positive correlation is found between Np and both of $<n_s>$ and $<n_g>$. At the same time, the secondary particles such as black, heavy ionized charged particles and $< N_{alpha} >$ have shown weak correlation with the number of emitted proton projectile fragments Np. The emission rate of shower particle mean multiplicity shows strong dependence on the emitted number of Np. The showers firmly established that they are newly produced particles from the participants region of the collision. It indicates that the singly charged projectile fragment protons are coming from the spectator-participant region of projectile and target. The experimental data fits by a linear relation of the form:

$$<n_i>= a_i + b_i N_P \quad (1)$$

Where, i= s, g, b, h. The fitting parameters a_i and b_i and the values of χ^2/DoF are listed in Table (4).

From Fig. (1) and Table (2), it is noticed that: as the number of projectile spectator N_P increase, the impact centrality is increased, hence the production probability of shower $<n_s>$ and grey $<n_g>$ particles is increased. At 200A GeV the slope parameter for $<n_s>$ is the highest which indicates the strong dependence of Np on < ns>. The excitation of the target spectator is increased with increasing Np, so the production probability of black particles and heavily ionized tracks is increased. Because of the excitation of the target spectator is not directly related to the projectile spectator, N_P is weakly increased with $<n_b>$ and $<n_h>$. At 200A GeV, $<n_b>$ and $<n_h>$ values are increased first then, their values are weakly decreased.

On the other hand, with increasing the doubly charged projectile fragments, the production probability of singly charged PFs is initially increased, then tends to be constant because of the limited projectile spectator size.

Figure (2) show the correlation between N_{alpha} and each of $<n_s>$, $<n_g>$, $<n_b>$, $<n_h>$ and $<N_P>$ in the ^{32}S-Em at 3.7A and 200A GeV. From these figures, it is noticed that the negative correlation between N_{alpha} and each of $<n_s>$, $<n_g>$, $<n_b>$ and $<n_h>$. The experimental data is fitted by a linear relation of the form:

$$<n_i>= a_i + b_i N_{alpha} \quad (2)$$

Where i= s, g, b, h. The fitting parameters a_i and b_i and the values of χ^2/DoF are listed in Table (5). Although the production probability of the singly charged projectile fragments increases with $<n_s>$, $<n_g>$, $<n_b>$ and $<n_h>$, the production probability of the doubly charged projectile fragments decreases. This may be attributed to the limited projectile spectator size where, the singly charged PFs increases first and then tends to be constant.

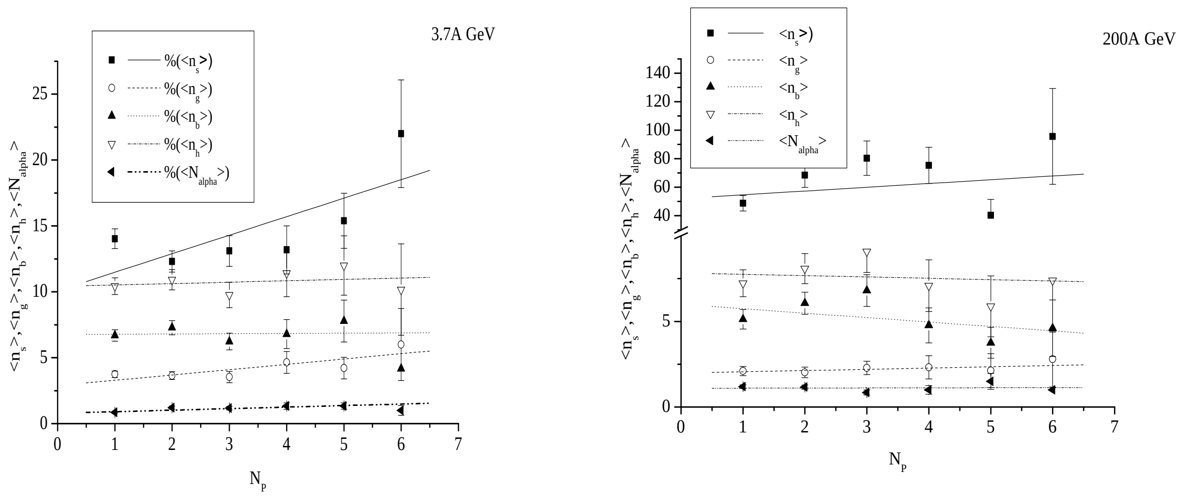

Fig. (1): Variations of $<n_s>$, $<n_g>$, $<n_b>$, $<n_h>$ and $<N_{alpha}>$ with N_P in the ^{32}S-Em interactions at 3.7A and 200A GeV

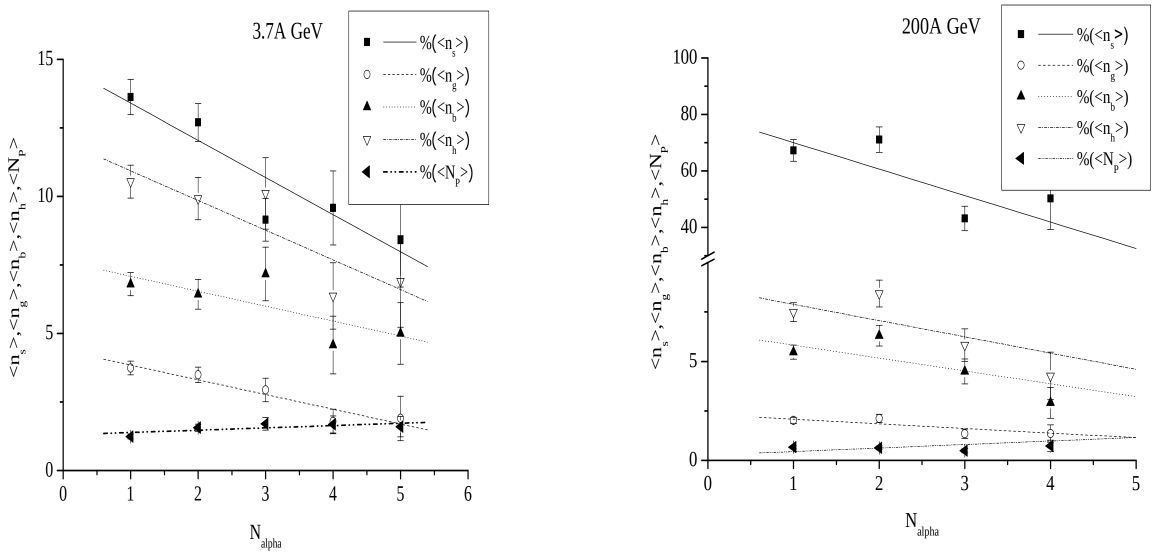

Fig. (2): Variations of $<n_s>$, $<n_g>$, $<n_b>$, $<n_h>$ and $<N_P>$ with N_{alpha} in the ^{32}S-Em interactions at 3.7A and 200A GeV

Table (4): Values of the best fitting parameters of equation (1) of the multiplicity correlations in ^{32}S-Em interactions

N_P	Energy (A GeV)	*a*	*b*	χ^2 / DoF
$<n_s>$	3.7	10.08±2.54	1.41±0.65	0.48
	200	53.66±19.80	4.13±5.09	4.16
$<n_g>$	3.7	2.88±0.57	0.40±0.15	0.08
	200	1.98±0.10	0.07±0.04	0.02
$<n_b>$	3.7	6.76±0.49	0.02±0.21	0.31
	200	6.00±0.78	-0.26±0.26	0.13
$<n_h>$	3.7	10.42±0.84	0.10±0.22	0.08
	200	7.83±0.80	-0.08±0.30	0.12
$<N_{alpha}>$	3.7	0.79±0.09	0.12±0.04	0.05
	200	1.09±0.24	0.01±0.06	0.04

Table (5): Values of the best fitting parameters of equation (2) of the multiplicity correlations in ^{32}S-Em interactions

N_{alpha}	Energy (A GeV)	*a*	*b*	χ^2 / DoF
$<n_s>$	3.7	14.76±1.06	-1.37±0.32	0.10
	200	79.39±9.97	-9.37±4.36	1.77
$<n_g>$	3.7	4.39±0.34	-0.54±0.10	0.05
	200	2.31±0.27	-0.23±0.13	0.22
$<n_b>$	3.7	7.63±0.91	-0.55±0.27	0.13
	200	6.47±0.86	-0.65±0.40	2.00
$<n_h>$	3.7	12.02±1.18	-1.08±0.36	0.15
	200	8.71±1.09	-0.82±0.52	1.88
$<N_P>$	3.7	1.30±0.16	0.08±0.05	0.02
	200	0.27±0.34	0.18±0.10	0.08

Conclusion

In the present work, a systematic investigation is carried out for the inelastic nuclear reactions induced by 3.7A and 200A GeV ^{32}S ions with emulsion nuclei. Nuclear emulsion has the highest (4π) spatial resolution compared with any other detector. Based on the findings of this study, the following conclusions can be drawn:

1-For ^{32}S projectiles, the values of $< N_P>$ and $< N_{alpha}>$ at both incident energies (3.7A and 200 A GeV) have the same values within experimental errors.

2-The correlations between the mean multiplicities of secondary charged particles and both of the singly and doubly charged projectile fragments are observed.

3-With an increasing number of singly charged projectile fragments N_P, the impact centrality is increased. Hence, a remarkable growth in the mean value of shower particles and slow growth in the mean value of grey particles is found.

4-Variation of the mean values of black and heavy ionized particles is found to be independent of the production of singly charged fragments.

Acknowledgement

The authors appreciate the guidance and advice given by Prof. Dr. A. Abdelsalm, head of Mohamed El–Nadi high energy Laboratory, Cairo University, where this work has been carried out. The authors would also like to express their gratitude to Vekseler and Baldin High Energy Laboratory, JINR, Dubna, Russia, for supplying us the photographic emulsion plates.

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