Proceedings of ICRC 2001: 1366 © Copernicus Gesellschaft 2001

ICRC 2001

Forward-backward particle caracteristics in the interactions of ^{3}He and ^{4}He with emulsion nuclei at 3.7A GeV

M. El-Nadi[1], A. Abdelsalam[1], M. S. El-Nagdy[2], E. A. Shaat[1], N. Ali-Mossa[3], Z. Abou-Moussa[1], S. Kamel[4], N. Rashed[5], M. E. Hafiz[5], and B. Badawy[1]

[1] Physics Department, Faculty of Science, Cairo University, Giza, Egypt.
[2]Physics Department, Faculty of Science, Helwan University, Ain Helwan, Cairo, Egypt.
[3]Basic Science Department, Faculty of engineering, Zagazig University, Banha Branch, Egypt.
[4]Physics Department, Faculty of Education, Ain Shams University, Cairo, Egypt.
[5]Physics Department, Faculty of Science, Cairo University, Fayoum Branch, Fayoum, Egypt.

ABSTRACT Experimental data on relativistic (shower) and fast (grey) hadrons emitted in the forward ($\theta < 90^o$) and backward ($\theta \geq 90^o$) hemispheres in the interactions of 3.7A GeV helium isotopes (^{3}He and ^{4}He) with emulsion nuclei are presented and analyzed. The dependence of the probabilities of the interactions accompanied by backward relativistic ($n_s^b > 0$) and fast ($N_g^b > 0$) hadrons on the projectile and target sizes are studied. The multiplicity distributions and mean values of both forward and backward shower and grey particles are investigated for the total samples as well as for events having $n_s^b > 0$, $N_g^b > 0$ and different projectile spectator charges. The data showed that while the values of the average muliplicity of the produced forward shower particles are strongly dependent on the projectile mass number, A_p, those of the backward ones are nearly independent of A_p. Consequently, the present study yields quite interesting information regarding the mechanism of the backward particle production in heavy ion interactions.

1 INTRODUCTION:

One of the important aspects in hadron–nucleus (h-A) and nucleus-nucleus (A-A) interactions is the emission of relativistic and fast hadrons in the backward hemisphere (BHS). The importance of investigating such backward emission may be attributed to the fact that, in free nucleon–nucleon (N-N) collisions, the hadron production in the BHS is kinematically restricted. The emission of energetic backward hadrons beyond the kinematic limit may be an evidence for exotic production mechanisms like production from clusters (Frankfurt and Strikman, 1979; Burov et al., 1977; Gorenstein and Zinovjev, 1977; Baldin et al. , 1978; and Mathis and Meng Ta-Chung, 1978). Therefore, the emission of these hadrons in heavy ion collision supplies interesting information on nuclear effects such as the internal motion of nucleons inside the nucleus. Baldin et al. (1978) thought that simple Fermi motion could not account for the production of the relativistic hadrons in the BHS. They stated that the dominant mechanism for such production was an interaction between the incident nucleons from the projectile and multinucleon clusters in the target, referring to this mechanism as the cumulative production (Baldin, 1980). The experimental data of Lawrence Berkeley Laboratory (LBL) (Schroeder et al., 1979; Schmidt and Blankenbecler, 1977; Harris, 1980) supported a model called the effective target model (Mathis and Meng Ta-Chung, 1978). However until now, there is no theoretical explanation for the experimental features of particle production in the BHS. The present work is a continuation of our program (El-Nadi et al., 1994; 1996; 1998) for studying the characteristics of backward production in the interactions of various projectiles with emulsion nuclei. This work reports the experimental data on various characteristics of events characterized by the emission of relativistic and fast hadrons in the BHS

Correspondence to: S. Kamel (Email: sayedks @ hotmail.com)

($\theta_{lab} \geq 90^O$) produced from the interactions of helium isotopes (^{3}He and ^{4}He) with emulsion nuclei at 3.7 A GeV. This paper is also concerned with examining, whether or not the mechanism of particle production in the BHS is significantly different from that responsible for the production of particles in the forward hemisphere, FHS, ($\theta < 90^O$).

2 EXPERIMENTAL DETAILS:

Two Br-2 nuclear emulsion stacks were exposed to two helium isotopes (^{3}He and ^{4}He) beams at the Dubna Synchrophasatron, Russia. The dimensions of each pellicle are 20cmx10cmx60 µm (undeveloped emulsion). Along the track double scanning fast in the forward direction and slow in the backward one was carried out. In total lengths of 332.6m and 217.6m of scanned tracks, 1685 and 1092 inelastic interactions were picked up giving mean free paths of 19.74±0.48cm and 19.93±0.60cm for ^{3}He and ^{4}He projectiles, respectively.

Secondary tracks emerging from each detected interaction are classified according to the emulsion experimental terminology. Such terminology is based upon the velocity $\beta = v/c$, the range L in the emulsion and the relative ionization $I^* = I/I_O$ (where I is the ionization of the particle track and I_O is the plateau ionization for singly charged minimum ionizing particles. These secondary tracks are categorized as follows:-shower particles, s, (mainly pions) with $I^* \leq 1.4$ and $\beta \geq 0.7$, grey particles, g, (recoil nucleons) having $1.4 < I^* \leq 10$, $0.3 \leq \beta < 0.7$ and L≥3mm and black particles, b, (slow target fragments) with $I^* > 10$, $\beta < 0.3$ and $L < 3$ mm.

The multiplicities of these three kinds of particles are denoted by n_s, N_g and N_b, respectively. The sum of N_g and N_b is referred to as the heavily ionizing particles N_h while that of n_s and N_g is called the compound multiplicity N_c. The singly and doubly charged and projectile fragments emitted within $\theta \leq 3^O$ were carefully excluded from the above shower and grey multiplicities (Adamovich et al., 1977, Marine et al., 1979). The grey particle emitted within $\theta \leq 3^O$ and having $L < 3$ mm is considered as helium projectile fragment of Z = 2.

3 RESULTS AND DISCUSSIONS:

3.1 Projectile and target size dependences:

The probabilities of observing events accompanied by the emission of backward particles ($n_s^b>0$, $N_g^b>0$ and $N_c^b>0$) in the interactions of ^{3}He and ^{4}He ions at 3.7 A GeV with emulsion nuclei are presented in table 1. The probability of these events for two different target sizes ($N_h \leq 8$ and $N_h > 8$) as well as for different values of projectile spectator charges (Q=0,1 and 2) are also presented in table 1. Events having $N_h \leq 8$ are due to the interactions of the projectile with CNO nuclei and peripheral interactions with AgBr nuclei, whereas the events having $N_h > 8$ are due to quasi-central collisions and central collisions with AgBr nuclei. From the data presented in table 1 one can observe for both helium projectiles that:

1) The ratio of the probabilities of the two different target sizes ($N_h>8/N_h\leq 8$) for the production of events accompanied by the emission of shower and compound particles in the BHS ($n_s^b>0$ and $N_c^b>0$) is nearly equal three while this ratio for events with $N_g^b>0$ is about five .

2) The probabilities for the production of events having $n_s^b>0$, $N_g^b>0$ and $N_c^b>0$ increase with increasing the degree of centrality of collisions. It should be noticed that the value of Q characterizes the degree of centrality, which is an indication of the impact parameter.

3.2 Effects of projectile and target participants:

Table 2 displays the values of the mean multiplicities of shower and grey particles emitted in both FHS and BHS together with their corresponding ratios, $(F/B)_{s,g}$, at different target sizes ($N_h \leq 8$ and $N_h > 8$) and different Q-values (Q=0, 1 and 2) for ^{3}He–Em and ^{4}He–Em interactions. For the two used helium isotopes, this table shows that:

(1) The ratio $< n_s >_{N_h>8} / < n_s >_{N_h \leq 8}$ is about two in the FHS and four in the BHS. On the other hand $< N_g >_{N_h>8} / < N_g >_{N_h \leq 8}$ is about four and eight in the FHS and BHS, respectively. This reflects the

Table 1: The probabilities of the number of events accompanied by the emission of backward shower ($n_s^b>0$), grey ($N_g^b>0$) and compound ($N_c^b>0$) particles for ^{3}He-Em and ^{4}He-Em interactions at different target sizes ($N_h \leq 8$ and $N_h > 8$) and Q-values.

Interaction		Total	$N_h \leq 8$	$N_h > 8$	Q=0	Q=1	Q=2
^{3}He	$n_s^b > 0$	23.3	12.3	42.6	37.7	17.0	13.2
	$N_g^b > 0$	36.4	16.0	72.1	55.3	28.7	21.4
	$N_c^b > 0$	46.7	26.2	82.5	68.3	37.7	30.7
^{4}He	$n_s^b > 0$	26.5	16.3	50.2	37.7	24.8	13.2
	$N_g^b > 0$	34.2	15.5	77.8	52.0	29.8	17.0
	$N_c^b > 0$	46.5	29.0	87.2	65.0	43.6	26.1

Table 2: Mean multiplicities of shower and grey particles emitted due to the interactions with emulsion nuclei of 3.7A GeV ^{3}He and ^{4}He in the FHS and BHS together with their corresponding ratios at different target sizes and different Q values.

Interaction		$<n_s^f>$	$<n_s^b>$	$<N_g^f>$	$<N_g^b>$	$<N_C^b>$	$(F/B)_s$	$(F/B)_g$
^{3}He	**Total**	3.68±0.07	0.29±0.01	1.92±0.06	0.61±0.03	0.90±0.03	12.90	3.12
	$N_h \leq 8$	2.80±0.07	0.13±0.01	0.91±0.03	0.18±0.01	0.31±0.02	21.23	5.15
	$N_h > 8$	5.44±0.12	0.55±0.03	3.99±0.10	1.38±0.05	1.93±0.07	09.87	2.90
	$Q = 0$	5.51±0.12	0.47±0.03	3.28±0.11	1.06±0.06	1.53±0.02	11.65	3.10
	$Q = 1$	3.09±0.08	0.21±0.02	1.40±0.07	0.43±0.03	0.64±0.02	14.71	3.26
	$Q = 2$	1.97±0.10	0.14±0.02	0.83±0.07	0.28±0.03	0.42±0.01	14.07	2.96
^{4}He	**Total**	4.19±0.10	0.35±0.02	1.92±0.07	0.67±0.04	1.02±0.05	12.00	2.96
	$N_h \leq 8$	3.02±0.09	0.18±0.02	0.77±0.04	0.19±0.02	0.37±0.02	16.78	4.07
	$N_h > 8$	6.91±0.19	0.74±0.05	4.57±0.15	1.78±0.09	2.53±0.11	09.31	2.55
	$Q = 0$	6.34±0.17	0.54±0.04	3.12±0.14	1.13±0.08	1.67±0.10	11.74	2.76
	$Q = 1$	3.74±0.14	0.31±0.03	1.56±0.11	0.54±0.05	0.85±0.03	12.06	2.89
	$Q = 2$	1.99±0.12	0.16±0.02	0.81±0.07	0.24±0.03	0.40±0.02	12.43	3.38

dependence of the emission of backward shower and grey particles on the target size.

(2) For both FHS and BHS, the degree of centrality has nearly the same effect on the shower and grey average values.

(3) The values of both $(F/B)_s$ and $(F/B)_g$ decrease with increasing the target size while the degree of centrality has nearly no effect on these values.

3.3 Multiplicity distributions of forward and backward particles

As we have stressed earlier (El-Nadi et al., 1994; 1996; 1998; 1998) that the particle produced in the BHS is intimately connected with the target fragmentation region i.e. with that part of phase space where all single particle characteristics are most safe from being dependent on the projectile. Therefore, it is desired in this section to compare the total multiplicities of shower and grey particles emitted in FHS and BHS for 3.7A GeV ^{3}He-Em interactions with the corresponding data for ^{4}He-Em at the same energy per nucleon.

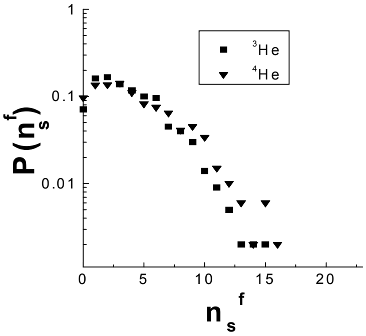


Fig. 1:The He-Em normalized multiplicity distributions of the forward shower particles.

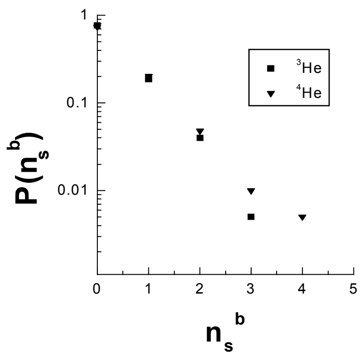


Fig. 2:The He-Em normalized multiplicity distributions of the backward shower particles.

The multiplicity distributions of these particles are represented in Figs. 1-4. From these figures one observes that changing projectile nucleus from ^{3}He to ^{4}He does not lead to a noticeable increase in the high multiplicity events, which reflects the slight increase in the mean values of the different emitted particles in the FHS and BHS (see table 2).

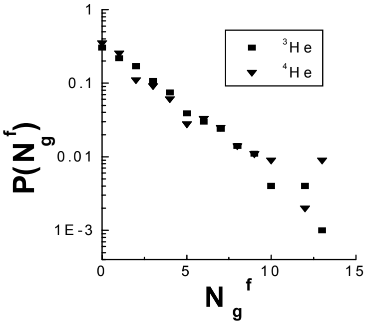


Fig. 3:The He-Em normalized multiplicity distributions of the forward grey particles.

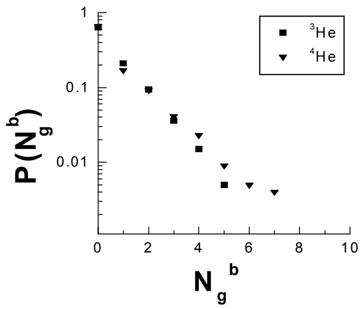
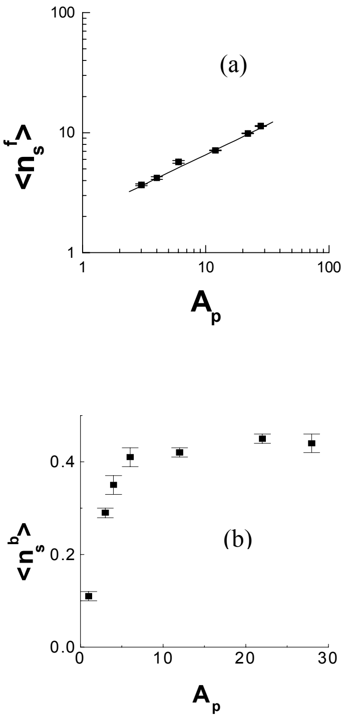


Fig. 4:The He-Em normalized multiplicity distributions of the backward grey particles.

It is interesting now to investigate at 3.7A GeV the relation between the mean shower values, $<n_s>$, and the mass number of the projectile nucleus A_P in both FHS and BHS. In Fig. 5a., the experimental data of different $<n_s^f>$ of ^{3}He, ^{4}He, ^{6}Li, ^{12}C, ^{22}Ne and ^{28}Si versus A_P have been fitted with a power law of the form:

$<n_s^f>=\alpha A_P^{\beta}$ where $\alpha \approx 2.09\pm1.05$ and $\beta \approx 0.50\pm0.02$

Such relation supports the independence picture of multiparticle production in the FHS.



Figs. 5:The mean value of the forward (a) and the backward (b) shower particles as a function of the projectile mass number, A_p, at 3.7A GeV.

On the other hand, in Fig. 5b. $<n_s^b>$ reaches a limiting value for $A_p \geq 6$ i.e. becomes independent of the projectile size (≈0.4).

4 CONCLUSIONS

The present data of backward particle production (shower and grey) in the inelastic interactions of 3.7A GeV helium isotopes (^{3}He and ^{4}He) with emulsion nuclei lead to the following conclusions:

1- In both the FHS and BHS, the overall multiplicity distributions as well as the mean multiplicities of the the projectile size (helium isotopes).

2- The probabilities of the interactions accompanied with shower, grey or compound particles flying in the BHS increase with increasing both of the target size and the degree of centrality.

3- The dependence of the mean multiplicities of shower and grey particles emitted in the BHS on the target size is stronger than that in the FHS.

4- It is interesting to observe that $<N_g^b>/<n_s^b>\simeq 2$ in the BHS and 0.5 in the FHS.

5- While the forward-backward ratios of the shower and grey particles $(F/B)_{s,g}$ decrease with increasing the target size, such ratios are nearly unaffected by the degree of centrality.

ACKNOWLEDGEMENT The authors are grateful to the director and the staff of the Synchrophastron at JINR, Dubna, for supplying us with the irradiated emulsion plates.

REFERENCES:

Frankfurt L.L. and Strikman M.J., Phys.Lett.B,83,497, 1979.

Burov V.V., Lukyanov V.K. and Titov A.I., Phys.Lett.B,67, 46, 1977.

Gorenstein M.I. and Zinovjev G.M., Phys.Lett.B,67 ,100, 1977.

Mathis H.B. and Meng Ta-Chung, Phys.Rev.C,18,952, 1978.

Baldin A.M. et al. Preprint JINR-P1-11302 Dubna, 1978.

Baldin A.M., Proceedings of the International Conference of Extreme State in Nuclear System , Dresden, 1980.

Schroeder L.S. et al., Phys. Pev. Lett.43,1787, 1979.

J.W.Harris, Proceedings of the Workshop on Nuclear Dynamics, California, March 17-21, 1980.

Schmidt I.A. and Blankenbecler R., Phys. Rev. D,15,3321, 1977.

El-Nadi M. et al. Int. J. Mod. Phys.E,3 , 811, 1994.

El-Nadi M. et al., Rad. Phys.Chem,47, 681, 1996.

El-Nadi M. et al., IL Nuovo Cimento A,110 ,1255, 1998.

El-Nadi M. et al., Eur. Phys.J.A,3,183, 1998.

Adamovich M. I. et al., JINR, EI-10838, Dubna, 1977.

Marine A. et al.,Yad.Fiz.,29,105, 1979.