Mean free paths of multiple helium fragments produced by ^{32}S at 6.4 TeV

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We report the measurements on interaction mean free paths of the multiple He fragments produced by the collisions of ^{32}S ions at 200 GeV/nucleon in nuclear emission. Within experimental errors, the mean free paths have been found to be independent of the He multiplicity and the size of the target nucleus.

With the availability of relativistic heavy-ion projectiles from accelerator facilities such as the Super Proton Synchrotron (SPS) at the CERN Geneva, the Bevalac at the Lawrence Berkeley Laboratory, and the Synchrophastron at the Joint Institute for Nuclear Research Dubna, numerous experiments have been done to study the mean-free-path (MFP) values of the secondary He (Refs. 1–8) projectile fragments (PF's) produced in heavy-ion interactions within a few centimeters from the production points. On the MFP's of He fragments in nuclear emulsion, only two experiments have yielded the positive evidence for the existence of anomalons,[7,8] while the others contradict them.[1–6] To explain the possible existence of anomalons, various theoretical models have appeared in the literature.[9]

In a recent investigation[1] of the mean free paths of the projectile He fragments produced in ^{16}O- and ^{32}S-induced interactions at 200 GeV nucleon in nuclear emulsion, we observed that the MFP's of He fragments (i) did not depend upon the distance from their production points for the white star events ($N_h \leq 1$) and (ii) were found to be independent of the distance when the data were combined for all the targets ($N_h > 0$). In Ref. 1, the dependences of MFP's on the He fragment multiplicity and on the size of the target nucleus were not investigated. The purpose of the present investigation is to study the MFP's of multiple He fragments produced in ^{32}S-induced interactions at 200 GeV/nucleon on the basis of the He multiplicity and the target size. We are also interested in studying the variation of He MFP's of the emitted He fragments in electromagnetic dissociated events (ED's) as a function of the distance from their production points. In general, the detection of He fragments is quite definite due to their distinctive grain density in nuclear emulsion.

This experiment (EMU 08) was performed in a stack consisting of 36 Ilford G5 nuclear emulsions exposed horizontally to the 200 GeV/nucleon ^{32}S ions at the CERN SPS. Details of experimental setup, scanning of the pellicles, and event classification can be found in Ref. 10. A total of 1354 events of ^{32}S nuclei was picked up by following 127.38 m of the primary track length, giving rise to a mean free path of ^{32}S nuclei in emulsion $\lambda = 9.41 \pm 0.26$ cm. Out of 1354 events, 1157 events were due to inelastic interactions and the rest were due to ED's. Among 1157 inelastic events, 923 events were found to be peripheral. Peripheral events are always associated with noninteracting spectator fragments of charge $Z \geq 2$ in the very forward cone.[10] For this Brief Report, only those peripheral events were employed which were accompanied by at least one or more He fragments in the forward cone. The He fragments were identified by counting the grain density/gap density or the number of δ rays as discussed in Ref. 3. A total of 1110 He tracks were selected in 640 inelastic peripheral events. The He tracks were followed with utmost care, under 100× oil objectives on digitized stage microscopes, from pellicle to pellicle until they either interacted or escaped from the stack. By following 104.55 m of the He track length, 497 secondary inelastic interactions were recorded. In Table I, we present the characteristics of the primary inelastic events along with the MFP's of the secondary He tracks on the basis of different He multiplicity. In Table II, we have given the

TABLE I. Topologies of primary inelastic interactions of ^{32}S having different He multiplicity and the mean free paths of the He fragments produced in these events.

Information of the primary events				Information of the secondary events			
He multiplicity	No. of events	$\langle n_s \rangle$	$\langle N_h \rangle$	No. of events	Total track length followed (m)	λ (cm) $L \leq 3$	λ (cm) $L > 3$
1	347	58.0±3.1	7.3±0.4	154	32.34	18.18±2.55	22.40±2.21
2	172	48.1±3.7	5.1±0.4	150	31.43	19.85±2.93	21.44±2.10
3	81	44.1±4.9	6.5±0.7	106	23.18	19.86±3.46	22.77±2.67
4	28	33.3±6.3	5.3±1.0	61	10.58	17.80±4.32	17.17±2.59
4,5,6	40	28.8±4.6	4.1±0.06	87	17.60	20.91±4.36	19.98±2.50
All He	640	51.8±2.0	6.4±0.3	497	104.55	19.45±1.57	21.74±1.72

TABLE II. Topologies of primary inelastic interactions of ^{32}S with different targets in emulsion, having at least one He fragment and the mean free paths of the He fragments produced.

Information of the primary events				Information of the secondary events			
Target/event kind	No. of events	$\langle n_s \rangle$	$\langle N_h \rangle$	No. of He tracks followed	Total track length (m)	No. of inelastic events	λ (cm)
Emulsion	640	51.8±2.0	6.4±0.3	1110	104.55	497	21.04±0.94
CNO	267	36.4±2.2	3.8±0.2	468	42.96	215	19.98±1.36
AgBr	205	91.3±6.4	14.9±1.0	328	30.23	146	20.71±1.71
ED	82			124	12.13	49	24.76±3.54

overall features of the primary and secondary inelastic events used in this work. The errors quoted in Tables I and II are of statistical origin.

The mean free paths (λ_i) of the He fragments can be determined in different path lengths by the relation $\lambda_i = L_i / N_i$, where N_i is the number of events observed in that interval. This parameter λ, as a function of the distance (L) from the production point, is plotted in Figs. 1(a)–1(d) for ^{1}He, ^{2}He, ^{3}He, and (^{4}He+^{5}He+^{6}He) multiplicity events, respectively. Within their statistical errors, the observed MFP's do not seem to depend upon the He multiplicity in all the path lengths. The same conclusion can be drawn from Table I where we have calculated the MFP's of He fragments in different He multiplicity events for the distances $L \leq 3$ cm and $L > 3$ cm. It has been pointed out in Ref. 9 that the mean free paths of the secondary fragments may be shorter than the normal ones in the few cm from their production for more peri-

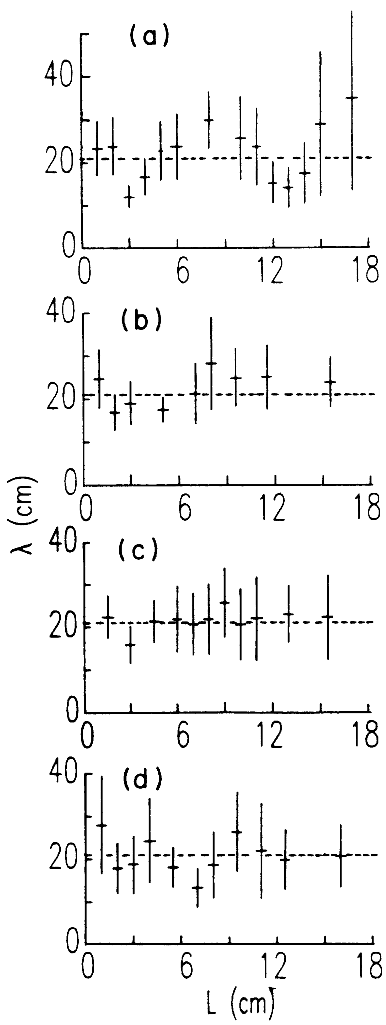

FIG. 1. Interaction mean free path λ as function of the distance L from their points of production for (a) ^{1}He, (b) ^{2}He, (c) ^{3}He, and (d) (^{4}He+^{5}He+^{6}He) multiplicity events. The dashed lines in these figures represent the He overall MFP for inelastic events.

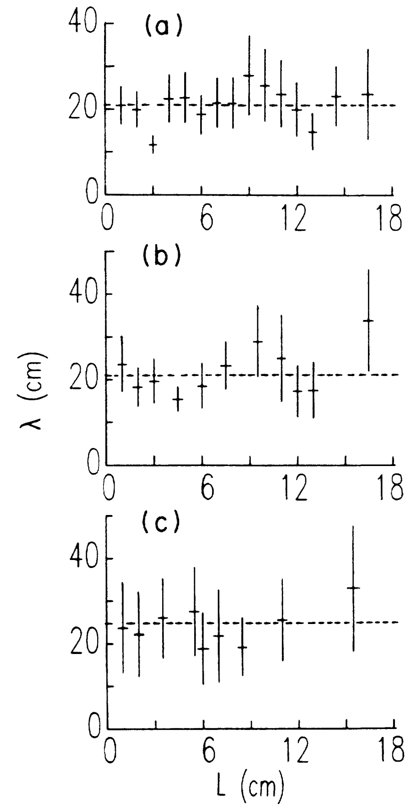

FIG. 2. Distribution of the mean free path λ in different path lengths for (a) CNO targets and (b) AgBr targets in nuclear emulsion. (c) The same as that of (a) and (b) but for the He fragments emitted in the electromagnetic dissociations. The dashed lines in (a) and (b) represent the He overall MFP's in inelastic events while that in (c) represents the same for ED's.

pheral events. In general, the events with a lesser number of produced shower particles ($\langle n_s \rangle$) are considered to be more peripheral. This is apparent from Table I where the primary events with He multiplicity ≥ 4 are more peripheral in nature, since $\langle n_s \rangle$ decreases as the He multiplicity increases. Even these very peripheral events do not show any anomalous behavior of the mean free paths of produced He fragments at the highest available beam energy.

In order to investigate the dependence of the MFP's on the basis of the target size, we divide the inelastic events into two categories: (i) light targets (CNO) with $2 \leq N_h \leq 7$ and (ii) heavy targets (AgBr) with $N_h > 7$, where N_h refers to the sum of black and grey tracks ($N_b + N_g$) produced in the primary events due the excitation of the target nucleus. In the former category of events, if the track length of a black track produced from the excitation of the target nucleus is less than 65 μm,[11] the interaction is deemed to be involved with the light targets (CNO) of nuclear emulsion. For more details of separation of the events into different categories such as CNO and AgBr targets in nuclear emulsion, one may refer to Ref. 11. Table II depicts the salient features of the primary peripheral events caused by the ^{32}S beam at 200 GeV/nucleon and the inelastic secondary events produced by He tracks in nuclear emulsion. In Figs. 2(a) and 2(b), we plot the variation of λ as a function of distance L from the production points. It is interesting that we do not find any target-dependent anomaly in the MFP's of the He fragments. Average values of the interaction mean free paths for the CNO and AgBr targets, within their statistical errors, are very close to the overall mean free path of the whole data sample (21.04±0.94 cm). Similar results were also reported earlier[4] by our laboratory at 60 GeV/nucleon ^{16}O emulsion interactions.

As far as we know, the MFP's of the secondary projectile He fragments produced in the electromagnetic dissociations at ultrarelativistic energies have not been investigated as a function of the distance from their production points prior to the present work. These electromagnetic events are extremely peripheral and are produced in electromagnetic collisions involving impact parameters larger than the range of the nuclear force. Extremely strong electromagnetic fields from the heavy target nuclei are produced for the short time at the projectile; such events typically consist of PF's, which proceed essentially in the direction of the incident projectile nucleus. Further details on the selection of ED's are discussed in Ref. 10. In this experiment, we observed 197 ED's out of a sample of 1354 primary events. Among 197 ED's, 82 were found to be associated with the production of one or more He fragments. In Table II, we have presented the characteristics of secondary inelastic events caused by the He fragments emitted in 82 ED's. In Fig. 2(c), we show the distribution of th MFP's of the He fragments as a function of the distance. Once again, our experimental data do not show any anomalous effects, although the electromagnetic events involve entirely different production mechanism. The overall MFP of the He fragments emerged in ED's is comparable to that of the inelastic He events (Table II).

From the above discussion, we conclude that the mean free paths of the He fragments produced in collisions of ^{32}S projectiles at the highest available energy are independent of the He multiplicity, the target size (CNO or AgBr) and their production mechanism (ED's). These findings are in line with the previous results on He fragments produced at different energies with various incident heavy-ion projectiles[1–6] and are in contradiction to the results of Ghosh *et al.*[7] and El-Nadi *et al.*[8] It is interesting to point out here that with the same projectile at the same energy/nucleon, the recent results of Khan *et al.*[6] do not agree with the results of Ghosh *et al.*[7] and El-Nadi *et al.*[8]

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