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PROJECTILE FRAGMENTATION PROCESSES IN ^{4}He - NUCLEUS INTERACTIONS AT 4.5 GeV/c PER INCIDENT NUCLEON

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Абдурахимов А.У. и др.   E1 - 12730

Фрагментация ядер ^4He с импульсом 4,5 ГэВ/с на нуклон

На установке СКМ-200 исследованы процессы фрагментации ядер ^4He с импульсом 18 ГэВ/с при их взаимодействии с ядрами Li, C, Al и Cu. Получены величины полных сечений фрагментации, инклюзивные сечения рождения фрагментов ^4He /^1H, ^2H, ^3H и ^3He /, а также сечения образования нескольких фрагментов в одном взаимодействии. Зависимость этих сечений от атомного веса ядра мишени (A_T) может быть представлена в виде A_T^α. Показано, что величина параметра α растет при увеличении числа нуклонов ^4He, провзаимодействовавших с мишенью (N_{int}). Представлена также A-зависимость множественностей ($\langle n_- \rangle$) и импульсов /$\langle p_T \rangle$ и $\langle p_L \rangle$ / π^--мезонов, рожденных в различных процессах фрагментации. Показано, что $\langle n_- \rangle$ при увеличении A_T практически не меняется, если $N_{int} \le 2$, и растет для $N_{int} > 2$, а $\langle p_T \rangle$ и $\langle p_L \rangle$ в пределах ошибок не зависят от A_T при любых N_{int}.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна 1979

Abdurakhimov A.U. et al.   E1 - 12730

Projectile Fragmentation Processes in ^4He-Nucleus Interactions at 4.5 GeV/c per Incident Nucleon

Fragmentation processes of ^4He nuclei on pure nuclear targets were studied in the SKM-200 streamer chamber. The cross sections for various fragmentation channels and their dependence on the target mass number, A_T, were studied. The correlation of the pion emission with fragmentation processes was studied, and the dependence of $\langle n_- \rangle$, $\langle p_T \rangle$, and $\langle p_L \rangle$ for pions accompanying various fragmentation processes on A_T was obtained. Some preliminary discussion of the obtained results is given.

The investigation has been performed at the Laboratory of High Energies, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna 1979

I. INTRODUCTION

Several experiments, devoted to the investigation of nuclear fragmentation at relativistic energies, have been performed during the last few years using the counter, nuclear emulsion and bubble chamber techniques[1].

In this paper we present the results of an analysis concerning the fragmentation processes of 18 GeV/c ^{4}He nuclei colliding with pure nuclear targets (Li , C , Al and Cu) inside a 2m streamer chamber (SKM-200). The experimental set-up (Section II) allowed one to register all charged secondaries in a 4π -geometry, thus yielding the possibility of studying such aspects of fragmentation processes as emission of more than one fragment of the projectile and production of charged secondaries (e.g., π^- -mesons) accompanying fragmentation processes.

II. EXPERIMENTAL SET-UP

The experimental set-up consisted of the 2m streamer chamber, placed in a magnetic field of 0.8 T, and a system of counters (see Fig.1, also ref.[2]). The streamer chamber

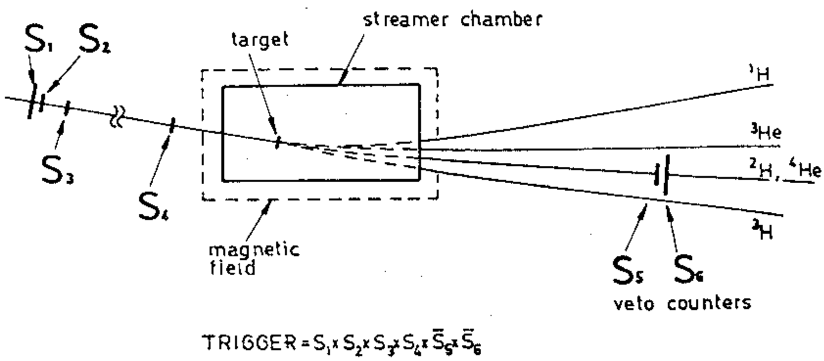

Fig. 1. Experimental set-up.

($200 \times 100 \times 60$ cm^3) used as a detector was filled with pure neon at atmospheric pressure and exposed to a beam of ^{4}He nuclei, accelerated up to a momentum of 4.5 GeV/c per incident nucleon. The triggering system of the set-up consisted of a beam telescope and a veto-counter system.

The targets made in the form of thin discs were mounted inside the fiducial volume of the chamber.

The films obtained during the exposures were scanned for the interactions of primary alphas with targets. All charged secondaries were registered during the scanning. The charge of positive relativistic secondaries was determined by visual examination of their ionization and by comparison with the ionization of primary tracks and other relativistic secondaries emitted within a narrow forward cone. Positive relativistic secondaries and all negative secondaries were measured, and geometrical reconstruction of the measured events was performed using the standard method based on the program GEOMSK [6].

The events for which the picture quality is unsatisfactory for measurements, for instance, due to the instability of the high voltage pulse in the streamer chamber, were rejected and were not used in the work for further analysis.

The numbers of measured events together with the typical errors in momentum and angular measurements are given in the Table. The sample of events on the lithium target yields better statistics and, moreover, smaller measurement errors than in the case of the other targets; the latter is due to a slightly different position of the lithium target in the chamber.

It should be noted that some corrections should be introduced into the primary data thus obtained because of the following effects:

a) The triggering system bias: a small fraction of events, for which a projectile fragment hits the veto-counter system (see fig. 1) and thus simulates a ^{4}He particle passing through the system, was lost in our detection set-up. The analysis of the geometry of the whole set-up and of the angular (e.g., azimuthal angular distributions) and momentum characteristics of observed fragments allows one to evaluate correction factors for "lost" events.

Table

Number of measured events and typical values of measurement errors

Target nucleus	Number of measured events	Typical values of errors		
		momentum measurements		emission angle measurements
		fragments*	pions	
Li	4024	3-9%	4%	2 mr
C	2151	5-16%		
Al	503			
Cu	590			

* The errors in momentum determination increase with the fragment mass.

b) The scanning bias against one-prong events: events with ^3He+n as only secondaries could not be reliably registered during the scanning. A special study of the frequency of such events was carried out, namely a sample of tracks passing through the chamber was measured and resolved into those due to one prong interactions and ^4He tracks passing through the chamber without interaction. In addition, the analysis of similar fragmentation channels involving two charged fragments (e.g., $^3H+{}^1H$) yielded an estimation of the frequency of such events.

c) The measurement bias against some negative secondaries: a small fraction of negative secondaries could not be measured and/or could not pass the geometrical reconstruction because of their unfavourable geometry or because of flares in the streamer chamber.

The correction factors, resulting from the above effects, were estimated and introduced into the data presented and discussed below.

A more detailed discussion of possible sources of errors and their estimation in the SKM-200 experiments has been given in /3/.

III. RESULTS AND DISCUSSION

1. Identification of Projectile Fragments; Momentum and Angular Distributions

In most cases projectile fragments consisting of two or more nucleons can be identified by their momentum (close to $\frac{p_{inc}}{4} \times A_{fr}$) and angular characteristics (strong forward collimation). In the case of ^{1}H fragments, however, their identification and even their definition is much less clear. This problem,in our opinion, has not been satisfactorily discussed in most of the previous experiments.

When dealing with a sample of single charged relativistic positive secondaries with momenta lower than those corresponding to $^{2,3}H$ nuclei, one has to remember than such a sample consists of several groups of particles. In fact, this sample contains projectile protons, stripped from the incident nuclei, projectile protons, undergone inelastic interaction with the target nuclei, knock-out protons (deuterons, tritons) from the target nuclei and, finally, some positive pions. The contribution of the pions to the sample, while negligible for small emission angles, increases for large emission angles. An experimental definition of what is to be called "fragmentation protons" and their extraction from the sample of positive relativistic secondaries is, therefore, not a trivial problem and unavoidably involves some arbitrariness.

In this experiment the approach to the problem was based on the analysis of momentum and angular distributions of positive relativistic secondaries.

The momentum spectra of positive relativistic secondaries were obtained for various cut-off values of emission angles. Examples of such spectra obtained experimentally are shown in Fig. 2 for the lithium target. The corrections for the biases discussed in section II have been taken into account in the further analysis.

The analysis of the shapes of the momentum distributions, and of the angular distributions (see Fig. 3) suggest a tentative definition of fragmentation protons as positive secondaries with a momentum of 2.5 GeV/c $<p<$ 6.5 GeV/c emitted at angles $\theta < 3°$. The choice of these cut-off values for the emission angle is, as indicated above, somewhat arbitrary; the same value has been used in other works [1b,d]. This definition is further used for identification of ^{1}H fragments in individual events (see below).

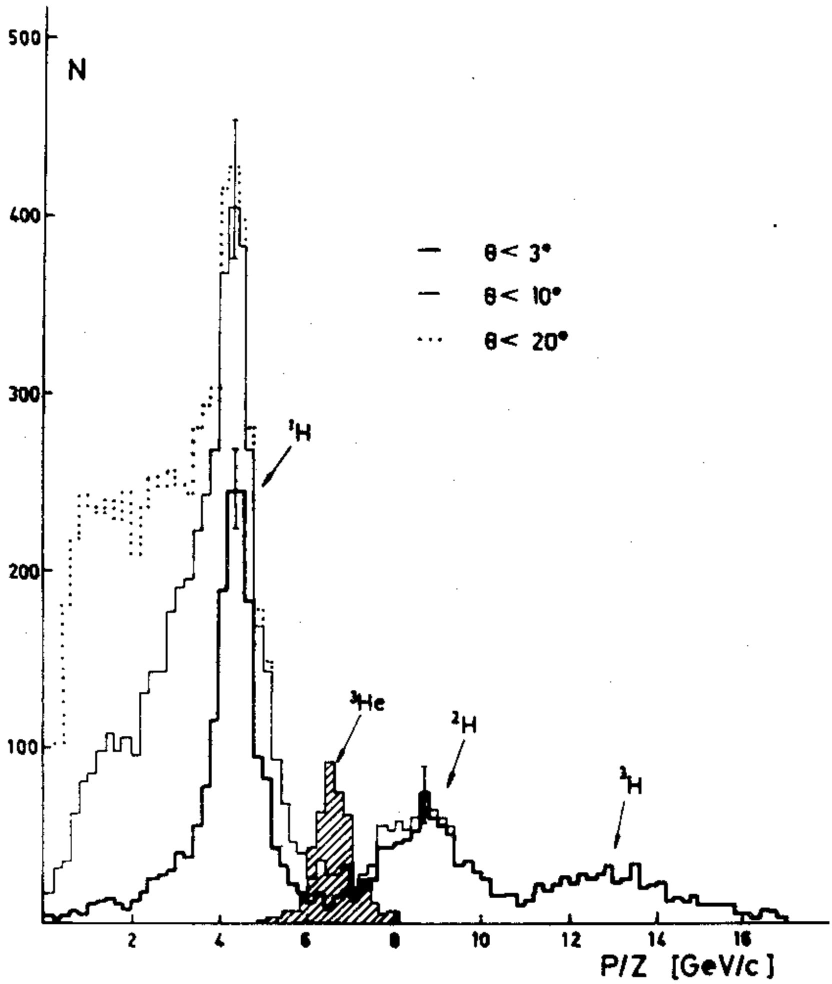

Fig. 2. p/z distribution of positive relativistic secondaries in ^{4}He−Li interactions for various cut-off values of emission angles θ. The hatched part of the spectrum consists of tracks with Z=2, selected in their ionization.

Angular distributions for heavier fragments of ^{4}He are also shown in Fig. 3 for the lithium target. Corresponding distributions for other targets are practically identical with those for the lithium target. The well-known effect

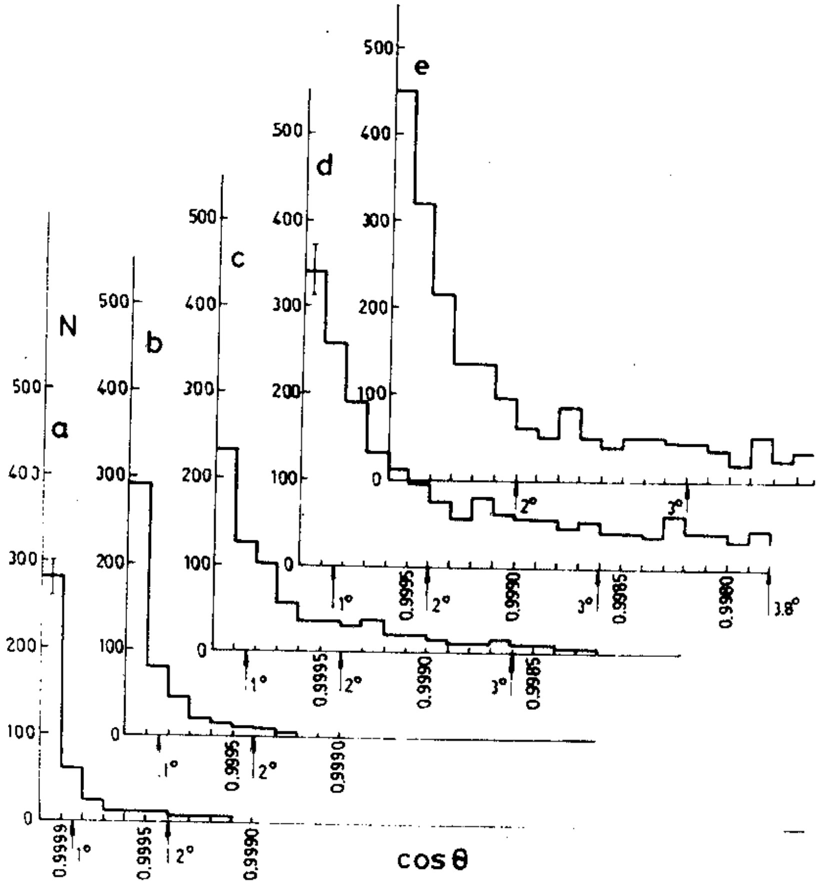

Fig. 3. Angular distributions of positive relativistic secondaries in ^4He–Li interactions. a) $Z = 2$ secondaries (^3He); b) $Z = 1$, $p > 10.8$ GeV/c secondaries (^3H), c) $Z = 1$, 6.5 GeV/c $< p <$ 10.8 GeV/c secondaries (^2H), d) $Z = 1$, 2.5 GeV/c $< p <$ 6.5 GeV/c secondaries (^1H), e) $Z = 1$, $p >$ 4.3 GeV/c secondaries (^1H - "right-hand" part of the momentum distribution).

of an increasing collimation with an increase of the fragment mass is clearly seen.

The analysis of momentum spectra allows one to resolve statistically the distributions for various nuclear targets into those corresponding to ^1H , ^2H , ^3H and ^3He fragments of the incident ^4He nuclei. In particular, the shapes of the momentum spectra of $Z=1$, $p>4.3$ GeV/c particles for various cut-off angles indicate that the sample is almost free from the contamination with non-fragmentation particles. The total number of fragmentation protons was therefore obtained from the number of $Z=1$, $p>4.3$ GeV/c particles under the assumption that the momentum spectrum of ^1H fragments is symmetrical with respect to its maximum.

Thus, the numbers of various fragments were obtained and further used whenever information on individual events had not been required.

Whenever individual events were analysed (for instance, from the point of view of fragmentation channels or pion production characteristics) the following criteria, based on the analysis of both momentum and angular spectra, were accepted:

a fragmentation proton	– $Z=1$ positive secondary emitted at an angle of $\theta<3°$ and with a momentum of 2.5 GeV/c $<p<$ $<$ 6.5 GeV/c,
a ^2H fragment	– $Z=1$ positive secondary with a momentum of 6.5 GeV/c $<p<$ $<$ 10.8 GeV/c,
a ^3H fragment	– $Z=1$ positive secondary with a momentum of $p>$ 10.8 GeV/c,
a ^3He fragment	– $Z=2$ secondary with a momentum of 5 GeV/c $<p/Z<$ 8GeV/c.

It should be noted that the events characterized by the reemission of the incident ^4He into the narrow forward cone were not registered in our experiment. The frequancy of such events, according to a rough estimate in an emulsion experiment /1,b/ is less than $\sim 3\%$.

2. Cross Section Values for Fragmentation Processes

Experimental data obtained in this experiment allow one to determine cross-section values for fragmentation processes of alpha particles incident on various nuclear targets. Four types of cross-sections were considered:

a) σ_{fr} – the cross-section for emission of at least one charged fragment of the incident nucleus,

b) $\sigma_{no\ fr}$ – the cross-section for interactions without charged fragments of the incident nucleus,

c) σ_x – the cross-section for emission of fragments of the type x (x being ^1H , ^2H ,^3H or ^3He);
σ_x is defined as

$$\sigma_x = \frac{\text{total number of fragments x}}{\text{total number of inelastic interactions}} \times \sigma^{inel}$$

d) σ_{chan} – the cross-section for interactions characterized by a given fragmentation channel.

For the evaluation of σ_x values, the statistical procedures of fragment identification were used, while the remaining cross-section values were obtained from the "individual" or "cut-off" criteria of fragment identification (section III). It should be noted, however, that when "individual identification" criteria are used, the tails of the momentum distributions are lost and corresponding cross-section values are slightly underestimated. A rough estimate is that an underestimation of cross section values is in most cases $\leq 10\%$. This systematical error is in most cases much lower than statistical errors involved.

Cross section values are normalized to σ^{inel} values[4]. The errors include statistical errors, uncertainties due to the correction procedures and those due to errors in σ^{inel} values.

Although the errors of the cross section values are in some cases rather large, an attempt to investigate the dependence of the cross sections on the target mass number, A_T, was undertaken. The corresponding plots are shown in Fig. 4, where the dependence of σ^{inel} on A_T[4] is also given for comparison. Within rather large errors the data are consistent with a power law $\sigma \sim A_T^{\alpha}$. The values of the parameter α depends on the fragmentation channel.

3. Characteristic of Pions Accompanying Fragmentation Processes

Since our experimental data yield information on all relativistic secondaries in individual events of ^{4}He-target nucleus interactions, an attempt was made to correlate data on pion production and on observed fragmentation processes. For this purpose only negative particles were used, since their sample consists of produced particles only.

Average multiplicities, transverse and longitudinal momenta of negative pions were obtained for groups of interactions, corresponding to various fragmentation characte-

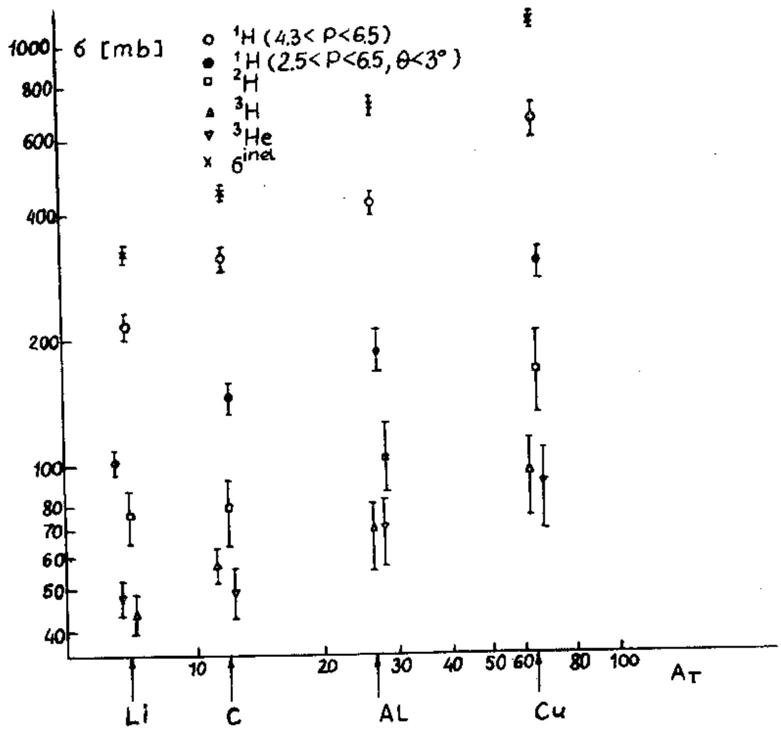

Fig. 4a. σ_x - the cross section for emission of charged fragment of a given type x versus A_T. • - ^1H fragment, o - ^1H fragment (^1H - "Right-hand" part of the momentum distribution taken twice), □ - ^2H fragment, Δ - ^3H fragment, ∇ - ^3He fragment, x - σ^{inel} /4/ .

ristics. The data are given in Figs. 5 and 6, where $\langle n_- \rangle$, $\langle p_T \rangle$, $\langle p_L \rangle$ are plotted versus $A_B^{1/3} + A_T^{1/3}$.

The data in Fig. 5 indicate that the multiplicity of mesons for fragmentation channels corresponding to only one or two projectile nucleons interacting with the target nucleus are practically independent of the target nucleus mass, while in the case of channels, corresponding to 2 or more projectile nucleons interacting with the target nucleus, the A_T-dependence is noticeable. For comparison, $\langle n_- \rangle$ values for average interactions (without any selection related to fragmentation processes) are plotted in the same figure .

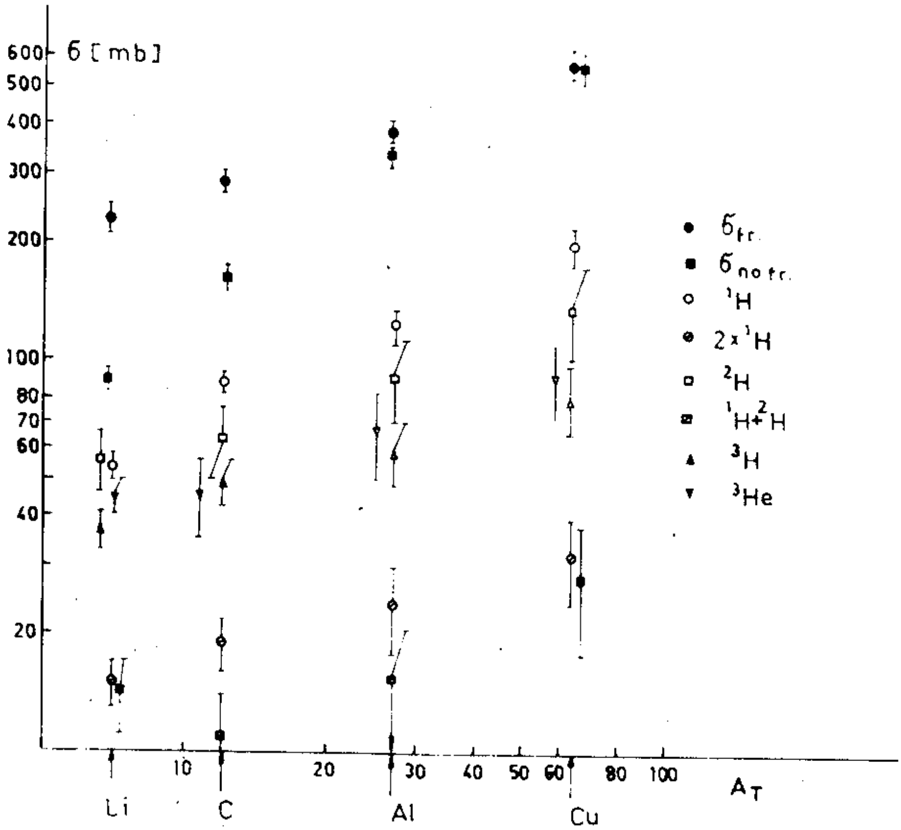

Fig. 4b. σ_{fr} , $\sigma_{no\ fr}$ and σ_{chan} values versus A_T. σ_{fr} - the cross section for emission of any fragment. $\sigma_{no\ fr}$ - the cross section for interaction without charged fragments, σ_{chan} - the cross section for interaction with a given fragmentation channel: o - exactly one ^1H fragment, ó - two ^1H fragments, □ - exactly one ^2H fragment, ⌀ - one ^1H and one ^2H fragment, Δ - exactly one ^3H fragment, V -exactly one ^3He fragment.

In Fig. 6 the behaviour of $\langle p_T \rangle$ and $\langle p_L \rangle$ versus the same variable is plotted.

Within rather large errors, $\langle p_T \rangle$ value seems to be independent of the target mass number, A_T, and of the accompanying fragmentation channel.

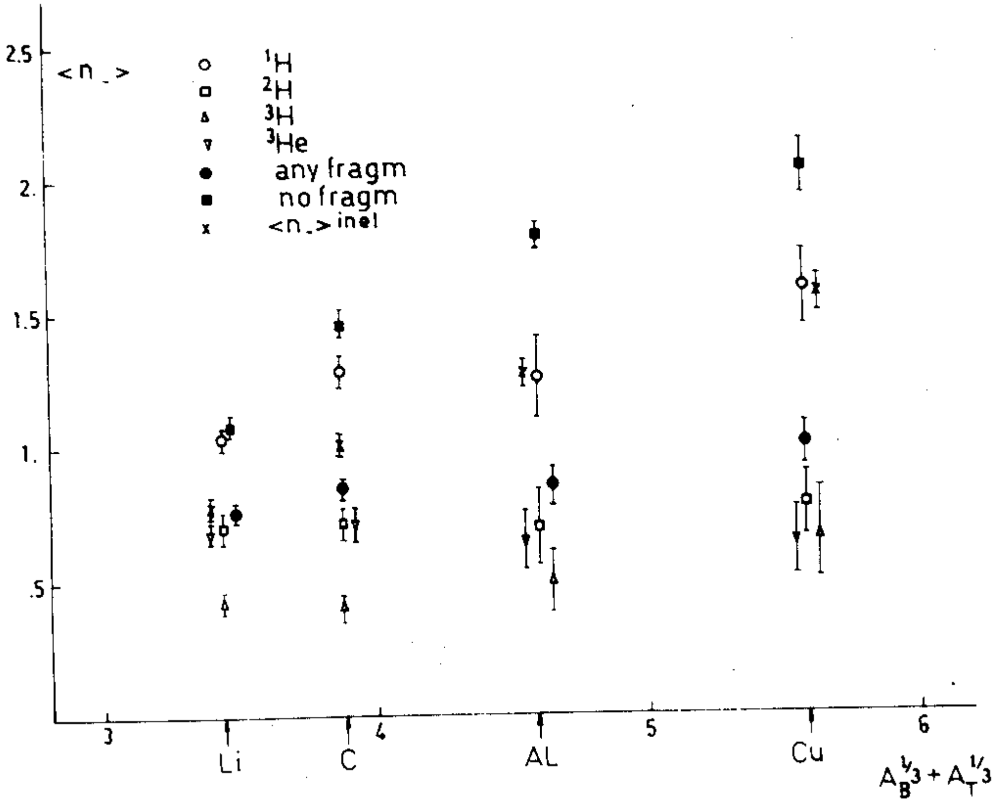

Fig. 5. Average values of the multiplicity of negative secondaries versus $A_B^{1/3} + A_T^{1/3}$ for various fragmentation channels.

IV. SUMMARY

The experimental results of an investigation of ^4He fragmentation in the collisions of alpha particles with Li , C , Al and Cu nuclei are presented.

1. Various channels of projectile fragmentation were observed and studied. Momentum and angular distributions were analyzed and used as a basis for the definition of fragmentation protons.

2. Cross section values for fragmentation processes and their dependences on the mass number of the target nucleus,

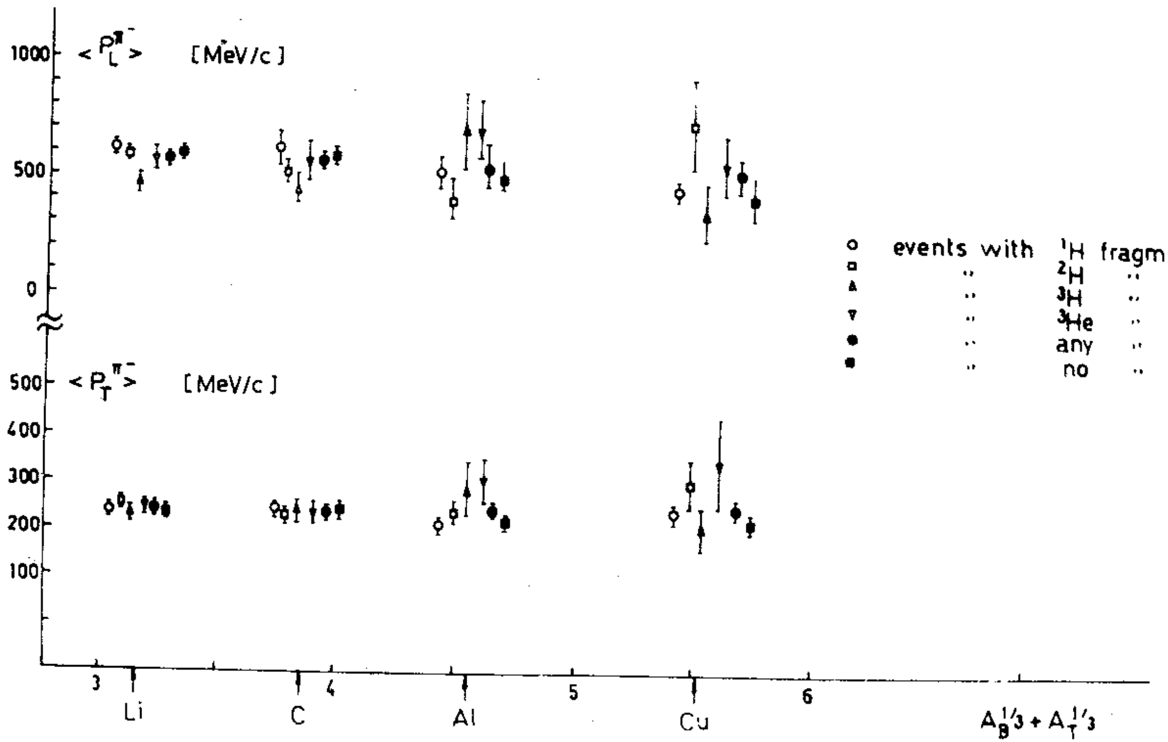

Fig. 6. Average values of $\langle p_T \rangle$ and $\langle p_L \rangle$ versus $A_B^{1/3} + A_T^{1/3}$ for various fragmentation channels.

A_T, were obtained. The data are consistent with a power-law, $\sigma \sim A^{\alpha}$; the parameter α increases with the number of incident nucleons which have interacted with the target nucleus, (N_{int}).

3. Characteristics of π^--meson production accompanying various fragmentation processes were studied. Average multiplicities, $\langle n_- \rangle$, transverse, $\langle p_T \rangle$, and longitudinal, $\langle p_L \rangle$, momenta of negative secondaries, and A_T dependences of these characteristics were obtained. The corresponding plots indicate a linear dependence of $\langle n_- \rangle$ on the variable $A_B^{1/3}+A_T^{1/3}$ with the slope increasing with N_{int}. The average transverse momenta, $\langle p_T \rangle$, are practically independent of A_T and of N_{int}. The average longitudinal momenta, $\langle p_L \rangle$, within rather large statistical errors do not allow one to exclude some weak dependence of $\langle p_L \rangle$ on A_T or/and on N_{int}.

4. Quantitative predictions of theoretical models in most cases cannot be tested by experimental data averaged over the impact parameter b [5]. In this experiment it has been possible to separate various channels of the projectile fragmentation into charged fragments. If the value N_{int} is taken as a measure of the impact parameter b, then the undesirable bluring of experimental data, due to the averaging of b, can be reduced by analyzing samples of events, corresponding to different N_{int} values.

5. The experimental results, summarized in items 2 and 3 together with consideration given in item 4, seem to be qualitatively consistent with the models using the hypothesis of independent nucleon-nucleon collisions in nucleus-nucleus interaction:

a) In the case of peripheral collisions (large b or low N_{int}) the interaction is expected to be insensitive to the target nucleus size (a weak dependence of cross sections and $\langle n_- \rangle$ values on A_T).

b) In the case of central collisions (small b or large N_{int}) the interaction involves more nucleons and is expected to be more sensitive to the target nucleus size (a significant dependence of cross sections and $\langle n_- \rangle$ values on A_T).

c) The observed $\langle p_T \rangle$ values for various energy available in the center of mass of colliding objects are constant within experimental errors.

The above considerations indicate that such an approach to the investigation of fragmentation processes in nucleus-nucleus collisions may yield new information to be compared with theoretical predictions, especially when a similar analysis for other primaries (e.g., ^{12}C) will be carried out.

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REFERENCES

1. a) Anderson L.M. (Jr.). Ph.D.thesis, Preprint LBL-6769, 1977. b) Shabratova G.S. et al. Acta Physica Slov., 1978, 28, p.132. c) Heckman H.H. et al. Phys.Rev., 1978, C17, p.1735. d) Abdrakmanov E.O. et al. JINR, E1-12548, Dubna, 1979. See also: Goldhaber A.S., Heckman H. Preprint LBL-6570, 1978. Schroeder L.S. Acta Phys.Pol., 1977, B8, p.355.
2. a) Anikina M.Kh. et al. JINR, 13-9030, Dubna, 1975. b) Abdurakhimov A.U. Pribory Tekhniki i Eksperimenta, 1978,5, p.53.
3. Aksinenko V. et al. JINR, E1-12472, Dubna, 1979.
4. Anikina M.Kh. et al. JINR, P1-10592, Dubna, 1977.
5. Gyulassy M. Preprint LBL-7141, 1978. Proc. of the Spec. Bev. Research Meeting, 1977.
6. Abdurakhimov A.U. et al. JINR, 10-10988, Dubna, 1977.

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