Study of nuclear multifragmentation induced by ultrarelativistic μ-mesons in nuclear track emulsion

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Abstract. Exposures of test samples of nuclear track emulsion were analyzed. The formation of high-multiplicity nuclear stars was observed upon irradiating nuclear track emulsions with ultrarelativistic muons. Kinematical features studied in this exposure of nuclear track emulsions for events of the muon-induced splitting of carbon nuclei to three alpha particles are indicative of the nuclear-diffraction interaction mechanism.

Crystal of silver-bromide - 0.2 μm

Atom - 10^{-4} μm

Proton - 10^{-9} μm

60 μm

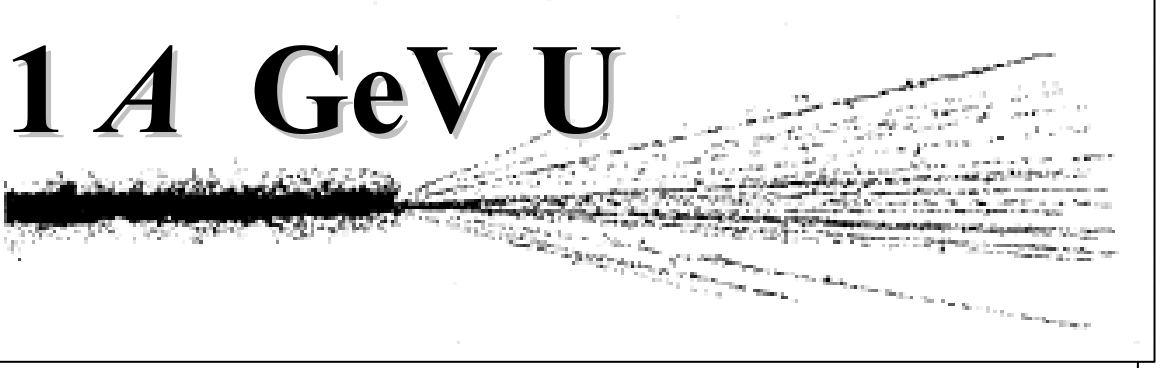
The spatial resolution of nuclear emulsion BR-2 (Russia) is 0.5 μm, and its sensitivity ranges from the most highly charged relativistic ions to singly charged relativistic particles. These features can be estimated in the photograph combining pictures of interaction of relativistic sulfur nucleus and human hair thickness of 60 μm . Both images were obtained under identical conditions using a microscope and a digital camera. It can be argued that nuclear emulsion gives the best projection of the events that occurred on microcosm scale.

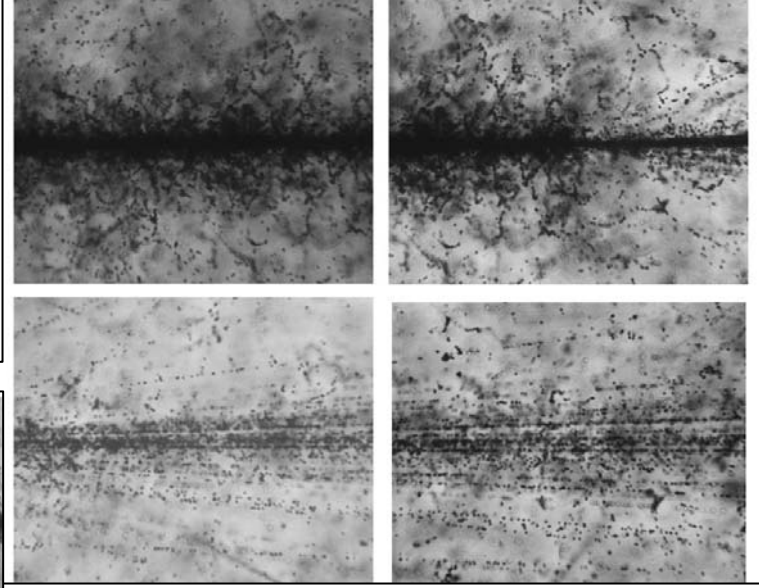
Test track-emulsion samples manufactured by the MICRON production unit of the Slavich Company JSC are being presently irradiated within the Becquerel project. The samples in question are created by casting emulsion layers 50 to 200 μm thick onto glass substrates.

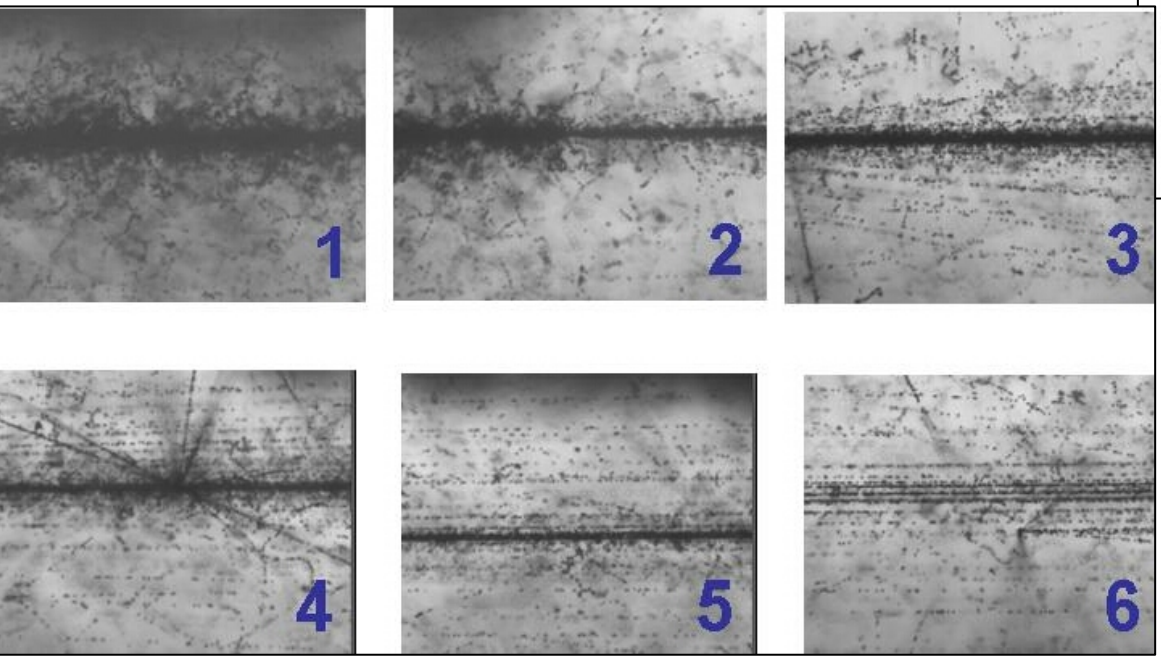
The basic properties of this nuclear track emulsion are close to those of BR-2 nuclear track emulsions, which are sensitive to relativistic particles. The production of BR-2 nuclear track emulsions had been performed for more than four decades and was completed about ten years ago. The product emulsion has already been used in the range-based spectrometry of alpha particles.

Test irradiations were aimed primarily at a general quality control and a control of the emulsion sensitivity to relativistic particles, as well at a comparison of ranges of slow nuclei that have strongly ionizing low energies with the values calculated on the basis of the SRIM simulation code. The present article combines the results obtained by analyzing recent exposures of nuclear track emulsions to ultrarelativistic muons.

So wide a variety of experimental implementations became possible owing to the use of the new nuclear track emulsion, whose properties permitted applying the same strategy to coordinate measurements for tracks of length between several microns and several tens of microns.



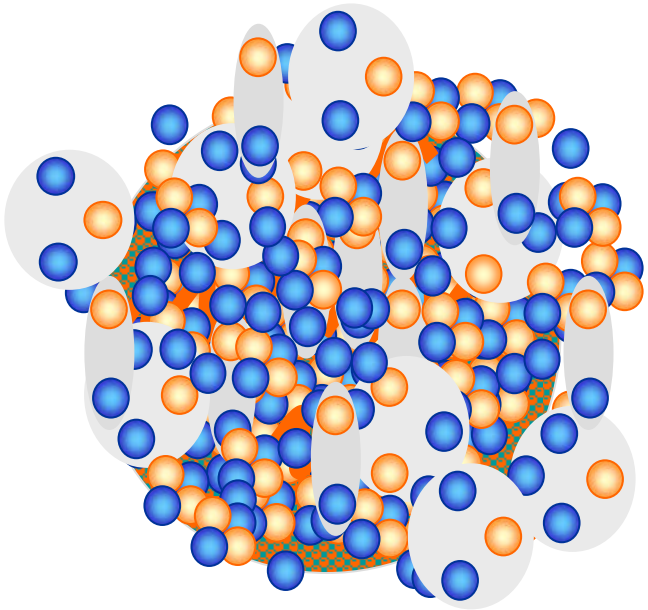


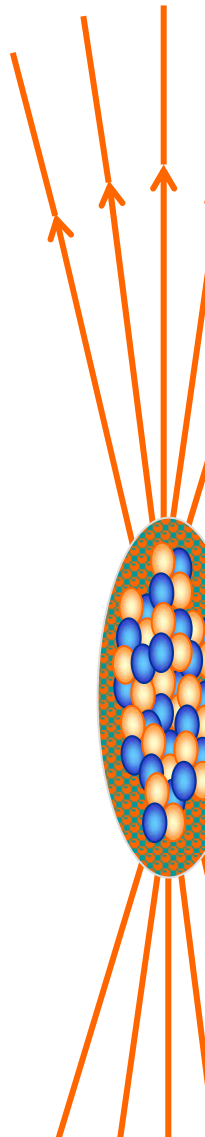


10 *A* GeV Au

160 *A* GeV Pb

The studies of light nuclei are only the first steps toward complex cluster-nucleon ensembles He – H – n produced in the dissociation of heavy nuclei. The question that has to be answered is what kind of physics underlies the "catastrophic" destruction shown in Fig. Events of multiple fragmentation of relativistic nuclei down to a complete destruction into the lightest nuclei and nucleons without visible excitation of target nuclei were reliably observed in NTE for Au and Pb and even U projectile nuclei. The existence of this phenomenon is certain. It is possible that it confirms the essential role of the long-range quantum electrodynamics interaction. The charges of heavy nuclei make possible multiphoton exchanges and transitions in many-particle states.





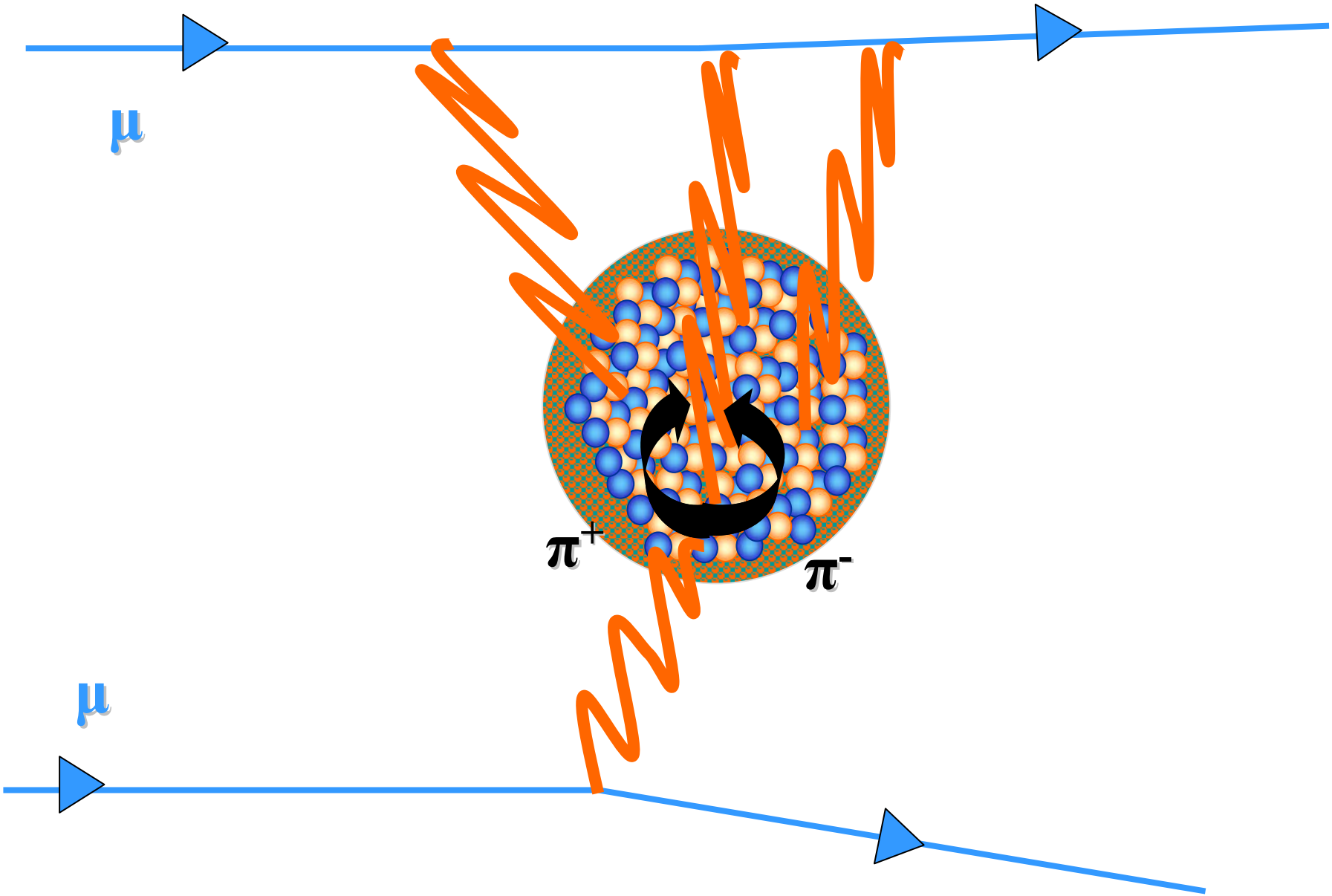
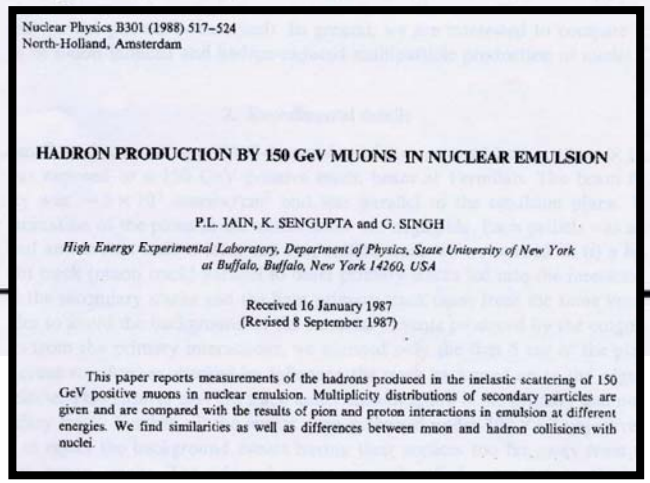

μ
μ
π+
π-

TABLE 1

Multiplicity distribution of secondary tracks produced in interactions of 150 GeV muons with emulsion

n \ N_b	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	0	0	12	20	25	14	8	4	8	0	1	4	0	0	0	0	0	0	0
2	0	3	14	27	22	16	11	7	5	0	1	1	0	0	1	0	0	0	0
3	1	3	10	16	7	3	5	9	6	5	2	1	0	2	2	0	0	0	0
4	0	0	0	10	5	3	7	3	2	6	0	1	0	0	0	0	0	1	0
5	0	1	2	1	3	5	4	3	1	2	2	1	2	1	1	0	2	0	0
6	0	0	1	1	2	1	5	2	3	1	1	1	0	0	0	2	0	0	0
7	0	0	0	0	1	1	1	1	0	2	0	1	0	0	1	1	1	0	0
8	0	0	0	0	0	0	1	0	1	0	2	0	1	0	0	0	1	0	0
9	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
11								1	0	0	0	0	0	0	0	0	0	0	0
12								0	0	0	0	0	1	0	0	0	0	0	0
13								0	0	0	0	0	0	0	0	0	0	0	0
14								0	0	0	0	0	0	0	0	0	0	0	0
15								0	0	0	0	0	1	0	0	0	0	0	1



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HADRON PRODUCTION BY 150 GeV MUONS IN NUCLEAR EMULSION

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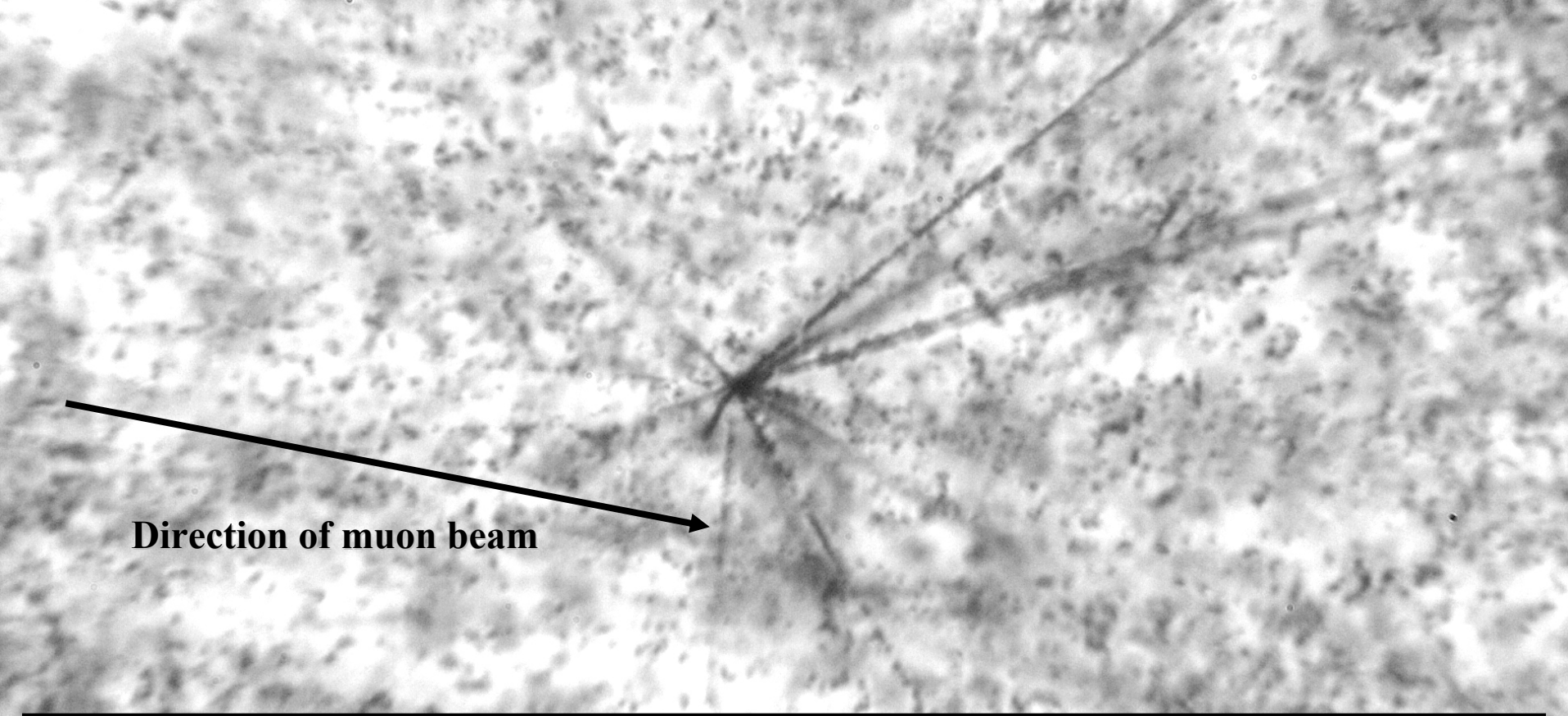
This paper reports measurements of the hadrons produced in the inelastic scattering of 150 GeV positive muons in nuclear emulsion. Multiplicity distributions of secondary particles are given and are compared with the results of pion and proton interactions in emulsion at different energies. We find similarities as well as differences between muon and hadron collisions with nuclei.

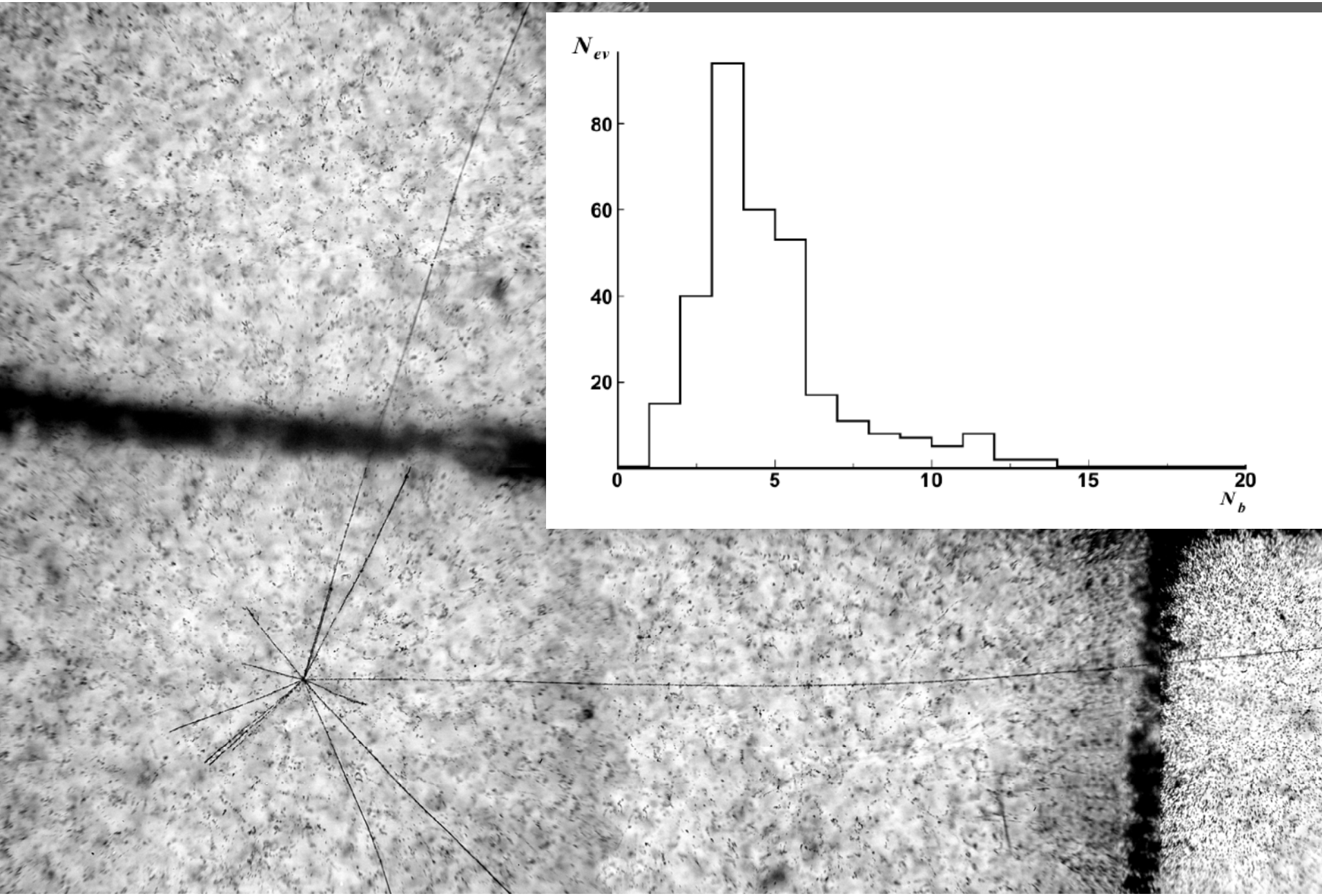


The deep-inelastic scattering of ultrarelativistic muons is a commonly recognized means for studying the parton structure of nucleons and nuclei. The irradiation of track emulsions with these particles makes it possible to study concurrently the multifragmentation of nuclei under the effect of a purely electromagnetic probe. Multiphoton exchanges or transitions of virtual photons to vector mesons may serve as a fragmentation mechanism.

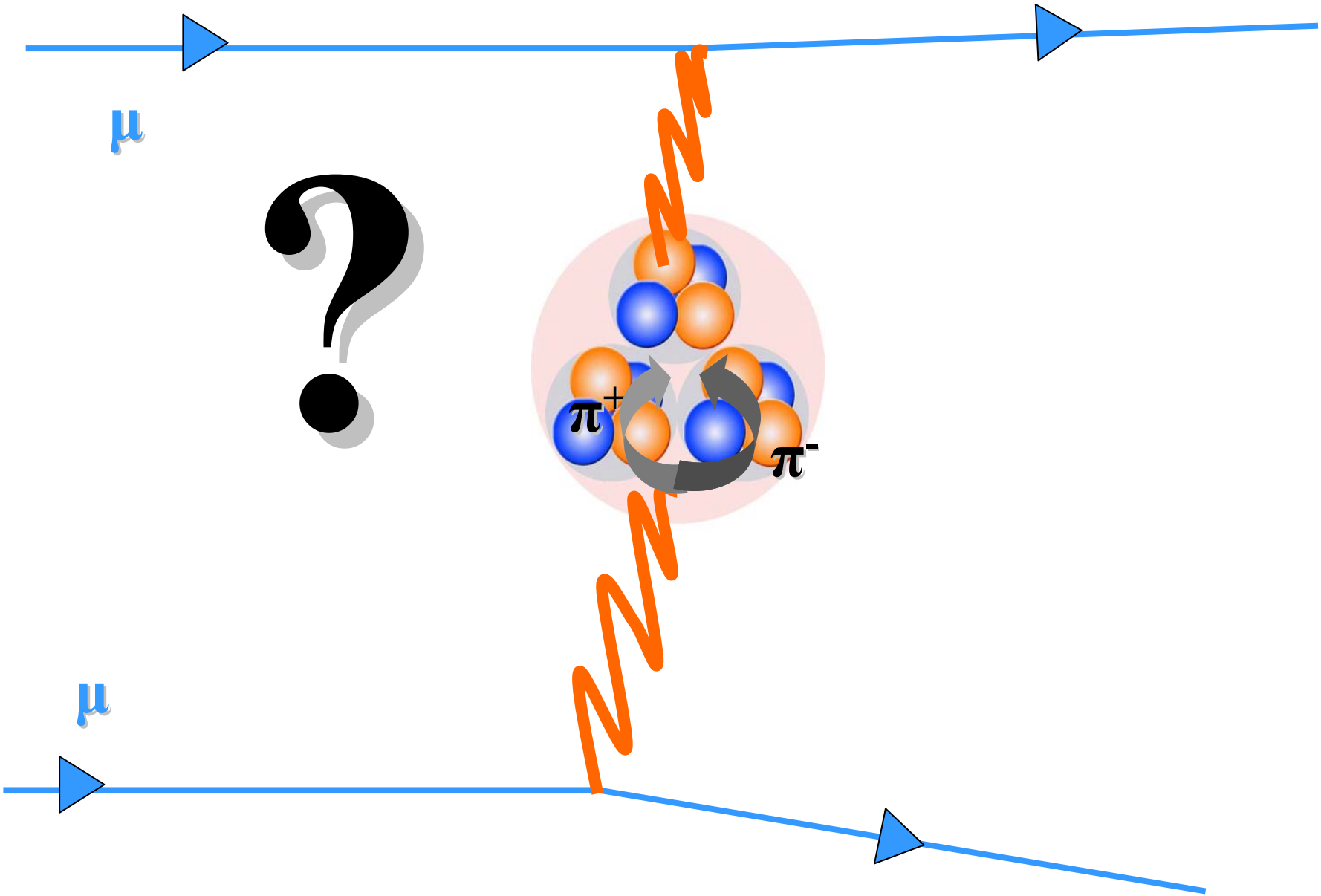
At CERN, a track-emulsion sample was exposed to 160-GeV muons. Earlier, comparable analysis was performed for NTE longitudinally exposed to 150 GeV. The objective of the exposure described here was to study experimental loads in the vicinity of the beam axis and to assess preliminarily the character of muon interactions.

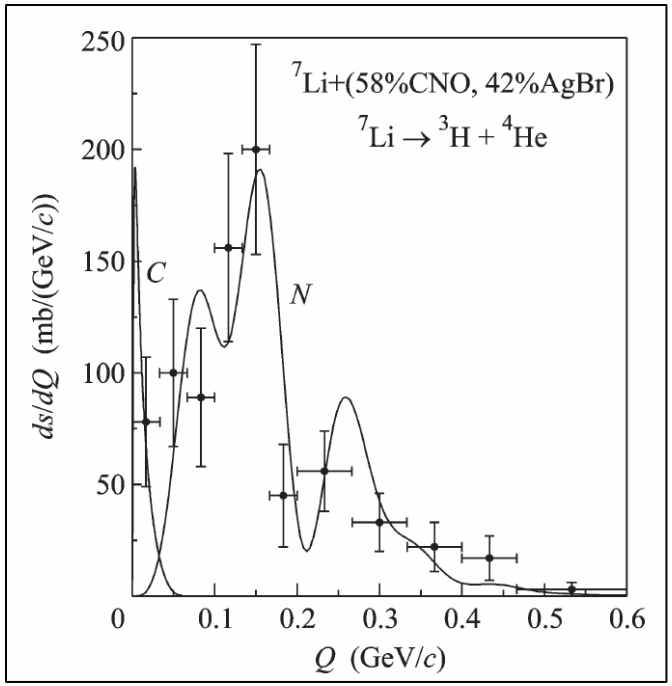
A nine-hour irradiation in the case of the transverse orientation proved to be the most favorable for our analysis. So long-term an irradiation was possible owing to the smallness of the cross section for muon interaction and to a small effect of beam ionization in relation to the longitudinal arrangements of layers. The duration of the irradiation run was constrained for fear of overloads with tracks from interactions in the glass substrate. In principle, this duration could be increased by two orders of magnitude without causing complications for the ensuing analysis.

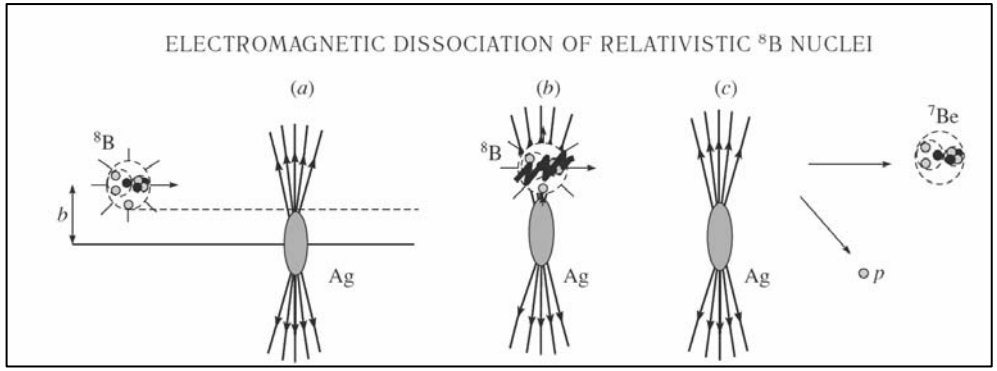
Scanning led to finding, in irradiated track emulsions, about 300 stars containing not less than three target fragments. The topology of stars was determined by the number of strongly ionizing b particles. Figure shows the distribution of N_b. Although the solid angle within which tracks could be observed was limited, the formation of high-multiplicity stars involving almost one-half of the charge of heavy nuclei in the composition of the emulsion could be proven.


N_{ev}
80
60
40
20
0
5
10
15
20
N_b

Seventy-two stars containing only triples of *b* particles stopped in the track emulsion were associated with the breakup process $^{12}C \rightarrow 3\alpha$. Alpha-particle ranges and spatial emission angles were determined on the basis of coordinate measurements for tracks. The mean α-particle range was 23.1 ± 0.6 μm (RMS 8.4 μm). The alpha-particle energy was estimated on the basis of the SRIM model. Its mean value proved to be 5.3 ± 0.1 MeV (RMS 1.3 MeV).


μ
?
π+
π−
μ





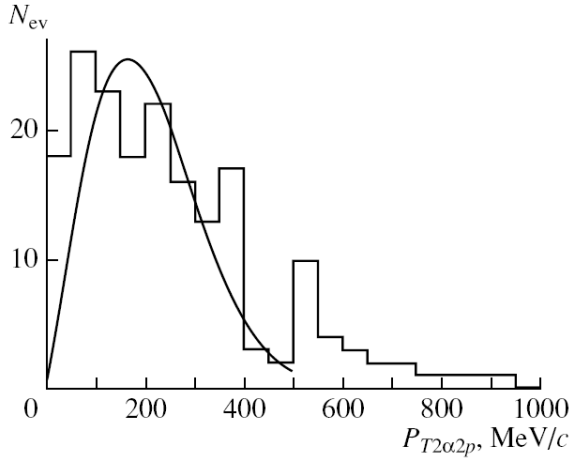
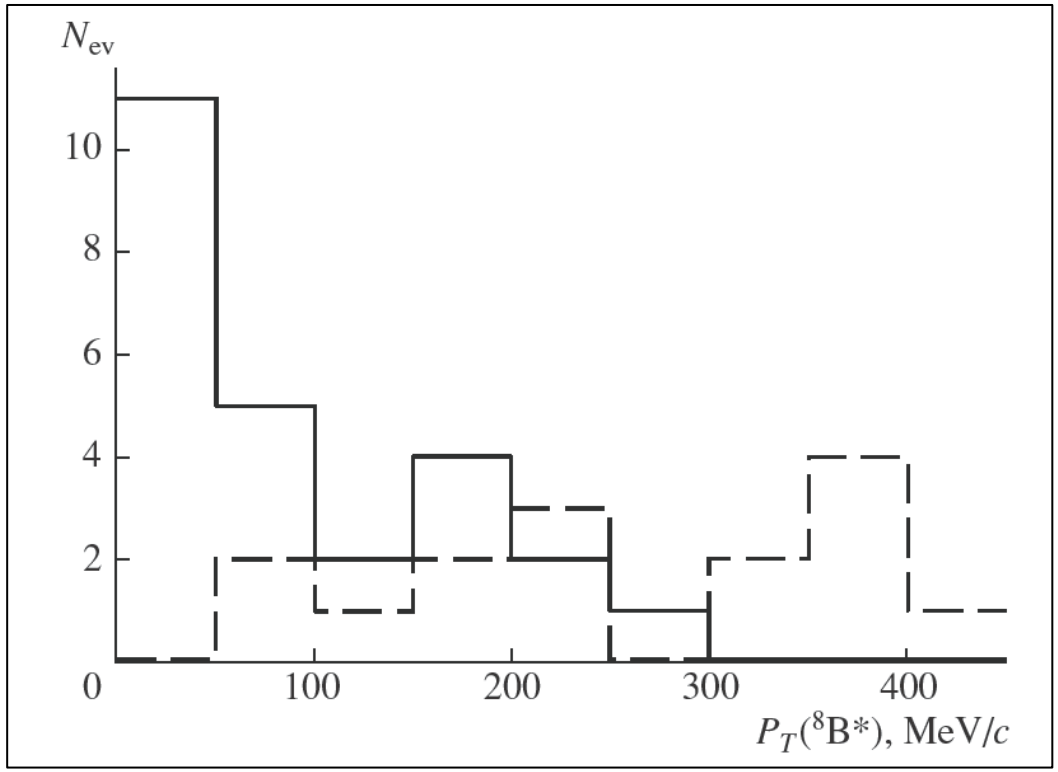
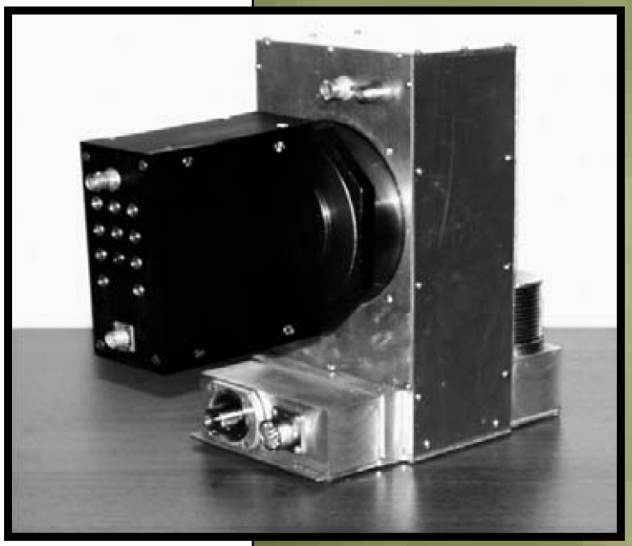
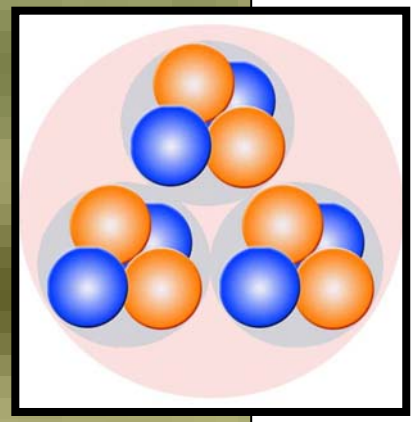


Fig. 5. Distribution of events of the channel $^{10}C \to 2\alpha + 2p$ with respect to the total transverse momentum $P_{T2\alpha2p}$. The curve represents the respective Rayleigh distribution.



Correlations of α-particles in splitting of ^{12}C nuclei by 14.1 MeV neutrons





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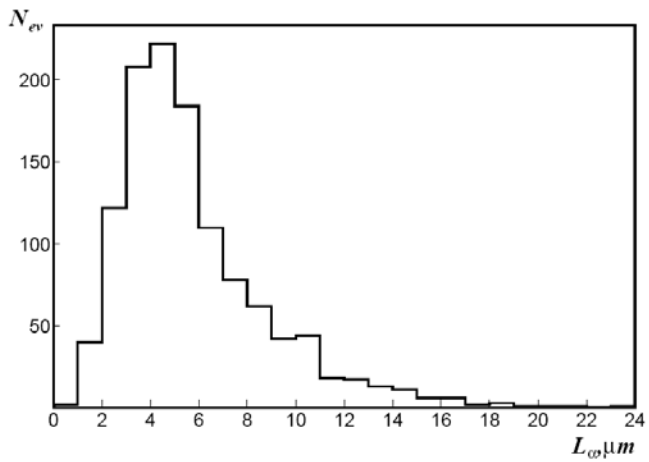


FIG. 1: Distribution of α-particles over ranges L_α.

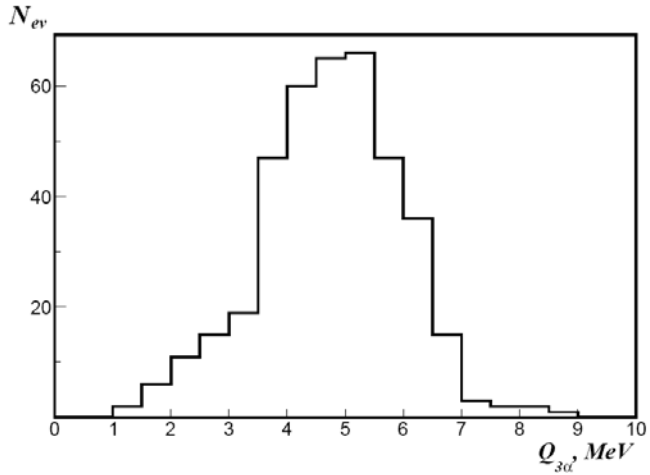


FIG. 3: Distribution triples of α-particles over energy $Q_{3\alpha}$.

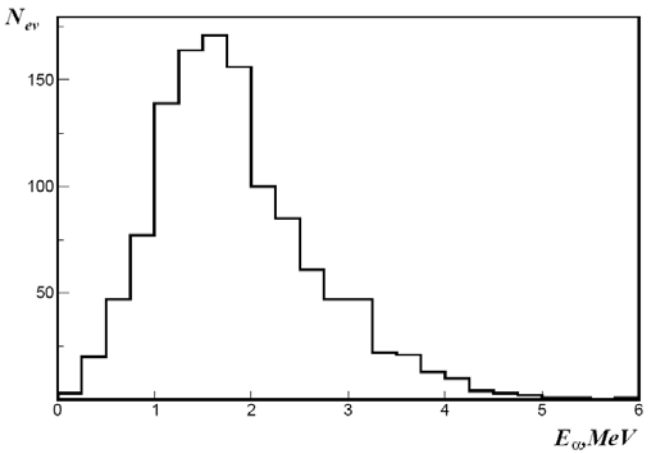


FIG. 2: Distribution of α-particles over energy E_α.

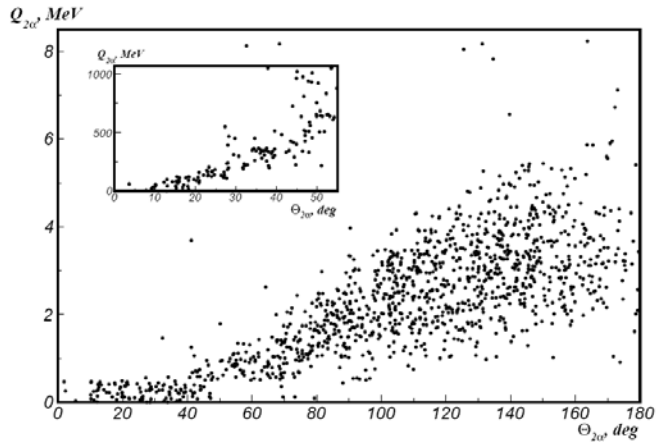
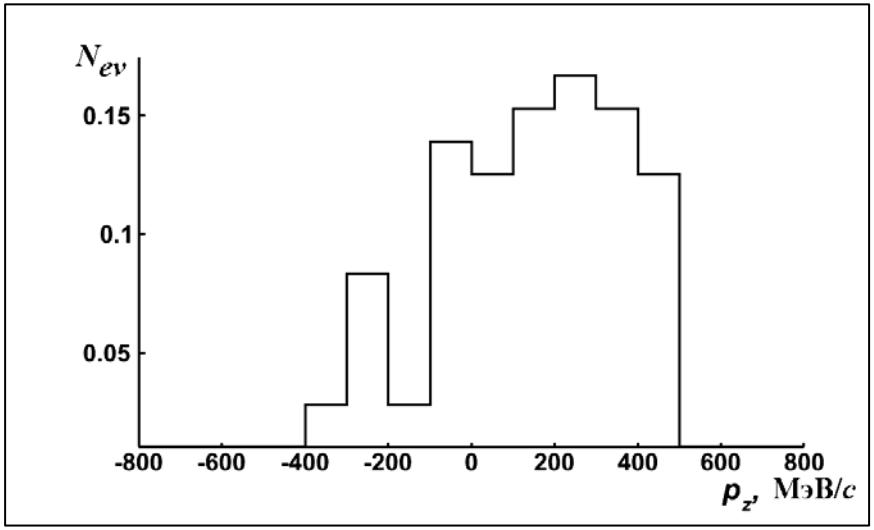
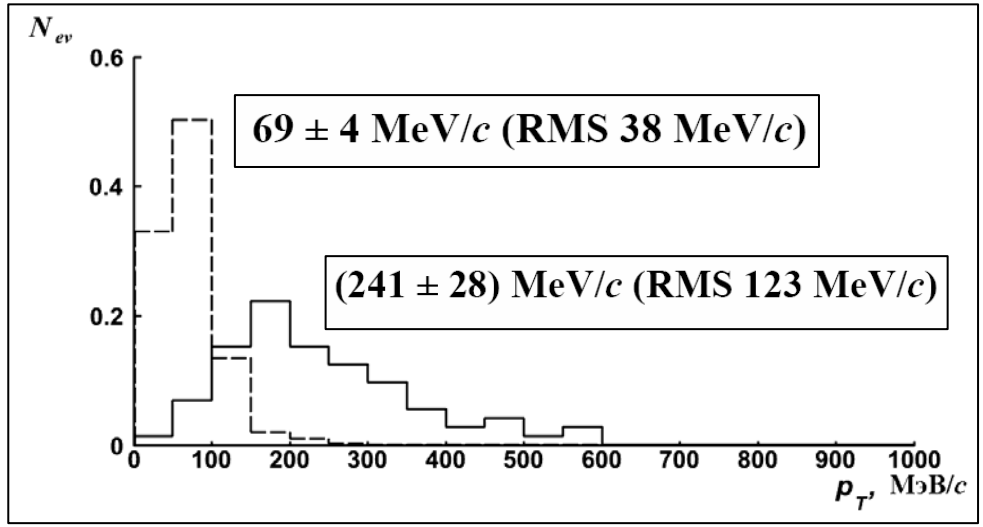
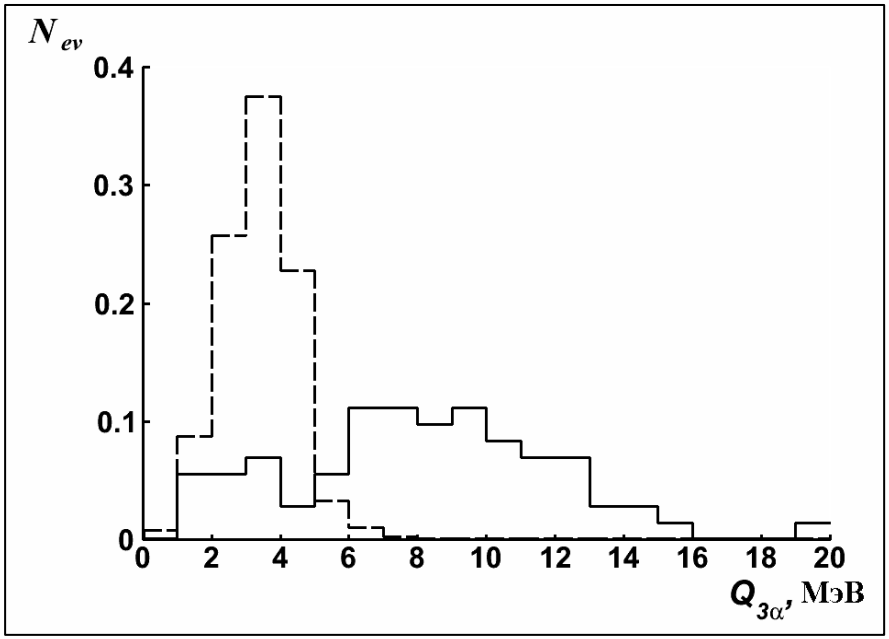
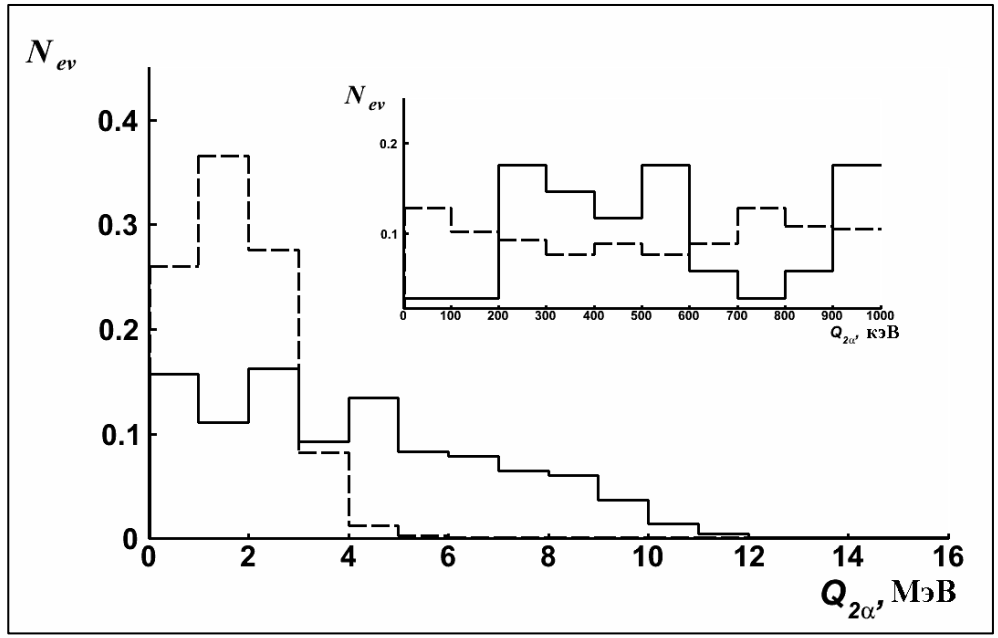


FIG. 4: Correlation over energy $Q_{2\alpha}$ and opening angles $\Theta_{2\alpha}$ in α-particle pairs.









72 stars containing only a triple of *b*-particles stopped in NTE are assigned to the disintegration μ + ^{12}C → 3*α* and compared with the case *n*(14.1 MeV) + ^{12}C → 3*α* + *n*.

The P_T ,$Q_{3\alpha}$ and $Q_{2\alpha}$ distributions for the irradiation of nuclear track emulsions with muons are indicative of a hard character of the process without manifestations of the well-known structural features of the ^{12}C nucleus, including the formation of alpha-particle triples in the continuum region.

We emphasize that the contribution of ^{12}C breakup with a threshold of 7.36 MeV should have inevitably manifested itself in the channel being discussed ($N_b = 3$). However, the circumstance that it is the nuclear diffraction mechanism rather than the soft electromagnetic mechanism that manifests itself for this channel, which possesses the minimum threshold, seems unexpected and deserves a theoretical analysis.

These observations, which are of a preliminary character, indicate that a full-scale investigation of a complete muon-induced disintegration of nuclei on the basis of multilayered assemblies from thick layers of substrate-free nuclear track emulsion is highly promising. In order to interpret reliably data obtained upon exposing track-emulsion layers to muons, it is necessary to test the hadron-background level at the places where the emulsion layers were irradiated.

Data from such an irradiation could be used in planning experiments based on silicon detectors or on a time-projection chamber. Investigation of the muon-induced fragmentation of nuclei is of practical interest for developing approaches to the separation of muons and pions on the basis of the distinctions between the stars created by them. Moreover, this is useful for testing models of physics processes for lepton-nucleus colliders.