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Carbon fragmentation at 300 MeV/nucleon vs transport codes

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Abstract. Momentum spectra of all long-lived fragments from ^{12}C fragmentation at 3.5^o have been measured. Differential cross sections span up to five orders of its magnitude. The preliminary results are compared with predictions of two transport codes: INCL++ and LAQGSM03.03. Both models give a good description of the data except few items which are discussed.

1 Introduction

The study of nucleus-nucleus interactions is one of the main aims of the modern nuclear physics. During last years, apart from an investigation of fundamental properties of these interactions, special attention has been paid to precise phenomenological description of these processes used in applications such as heavy-ion therapy where fragmentation is a main source of irradiation behind the Bragg peak. On this way a few simulation programs for nucleus-nucleus interactions has been created. They demand an experimental verification as well as refinement of their basic approaches. One of the aims of the FRAGM experiment performed at TWA (Tera Watt Accumulator) heavy-ion facility at ITEP was to obtain high precision data on nuclear fragmentation in the energy range accessible at this accelerator. In the framework of this experiment the data has been taken for carbon ion fragmentation in low-energy region. This work is a continuation of carbon fragmentation performed for higher energy [1] and for light fragments [2], [3]. In this publication we give preliminary results on all long-lived nuclear fragment emissions from 300 MeV incident carbon ion and compare them with the predictions of two transport codes.

2 Experiment

The experiment was carried out at the heavy-ion complex TWA at ITEP which includes an ion laser source, a linac, a booster and an accelerator-accumulator ring. Ions of 200-1000 MeV/n could be accumulated in this ring for successive use in experiments on the high-energy-density physics or

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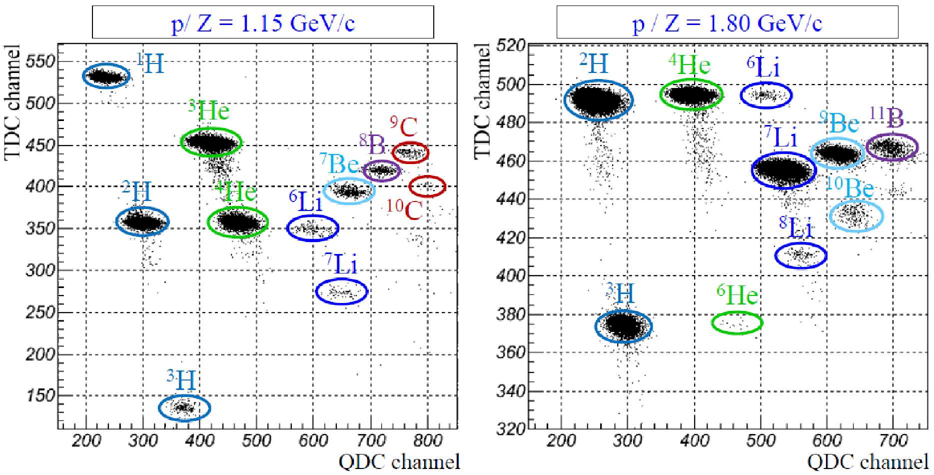

Figure 1. Two-dimensional plots QDC vs TOF channels for two rigidities of the beam-line spectrometer demonstrate good identification of the fragments.

accelerated to maximal energy of 4 GeV/nucleon. During our measurements each four seconds the carbon ions C^{+4} were accelerated in the booster up to 300 MeV/nucleon. Then while injection to the accelerator-accumulator ring they were totally stripped and captured in the ring. After that the beam was steered to the internal target of 50 μm Be foil strip providing the spill. It made simultaneously possible to have both a high luminosity due to multiple passage of the ions through the target and a small size of the source needed for a high momentum resolution of the subsequent magnetic analysis. The products of the carbon nucleus fragmentation outgoing at 3.5^o were momentum analyzed by the double-focus beam-line spectrometer of 42 meters long. Sets of few scintillation counters were placed at intermediate and final focuses for multiple measurements of ionization losses (dE/dx) and time of flight (TOF). The set up has been described in more details in [2]. Fragments with different charge and mass were unambiguously selected on two-dimensional plots dE/dx vs TOF. Two examples of this selection are given in figure 1 for different rigidities of the beam-line. The left is for 1.15 GeV/c that is near maximal emission of fragments with A/Z = 1.5 such as ^{3}He and ^{9}C. The right is for 1.80 GeV/c that is near the maximal yield of fragments with A/Z = 2.3 such as ^{7}Li, ^{9}Be and ^{11}B. The fragment momentum spectra were obtained by beam line energy scan in steps of 50 MeV/c. As a monitor we used a telescope of three scintillation counters that viewed the target at 2°. The preliminary results are presented in figure 2 normalized to INCL++ model predictions at the proton peak maximum.

3 Comparison of model predictions with experimental data

One of the aims of the FRAGM experiment is to test different models of ion-ion interactions. On this way it was possible for us to test three models from GEANT4 package supported by CERN: BC (Binary Cascade)[4], INCL++(C++ version of the Liege Intranuclear Cascade model)[5] and QMD (Quantum Molecular Dynamics)[6] as well as LAQGSM03.03 (the Los Alamos version of the Quark Gluon String Model)[7]. The last one is a main part of MCNP6 [8] transport code, supported and updated by LANL, USA. Only for two of them the results of the test will be given in this short

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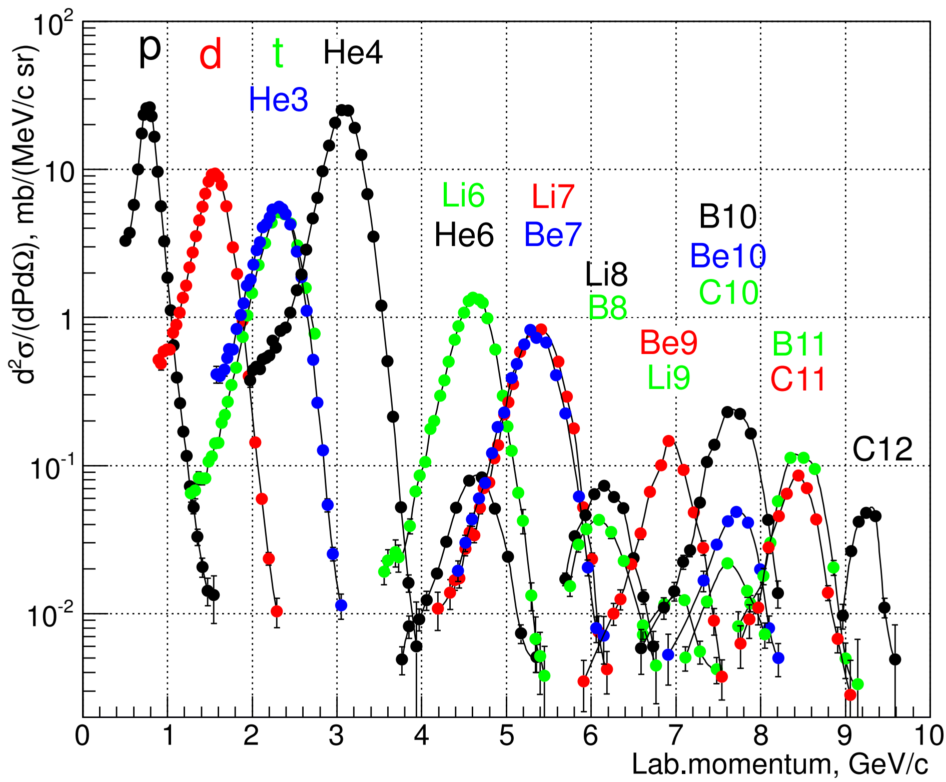

Figure 2. Laboratory momentum spectra of the fragments emitted at 3.5^o from the carbon fragmentation at 300 MeV/nucleon. Smooth lines are drawn though the data points just to guide the eye.

publication. In figure 3 and figure 4 our data from figure 2 are compared with predictions of INCL++ and LAQGSM models, respectively, for fragments with the even atomic numbers and protons. The experimental data are given by red and magenta points and the model predictions by blue and light blue points. The agreement between INCL++ and data for protons, deuterons, ^{4}He, ^{6}Li and ^{10}B is perfect. The yields of ^{6}He,^{8}Li and ^{10}Be are overestimated by the model by a factor of 2-3 while the shapes of fragmentation peaks are reproduced well. INCL++ predicts very low cross section for ^{8}B emission and it cannot be seen in the scale of figure 3. The shape and value of the ^{12}C peak are different from the data. But it has to be mentioned here that ^{12}C emission can be connected with other mechanisms different from usually used in the fragmentation processes. The LAQGSM model (see figure 4) reproduces well the shapes of all fragmentation peaks, but positions of these peaks are slightly moved to higher momentum. The model predictions are in good agreement with the data for ^{8}B emission. This model does not give predictions for ^{12}C yield for above mentioned reasons.

4 Conclusion

The comparison performed shows a large potential of modern transport codes to describe the new high precision data on fragmentation in ion-ion interactions. The authors are grateful to operating

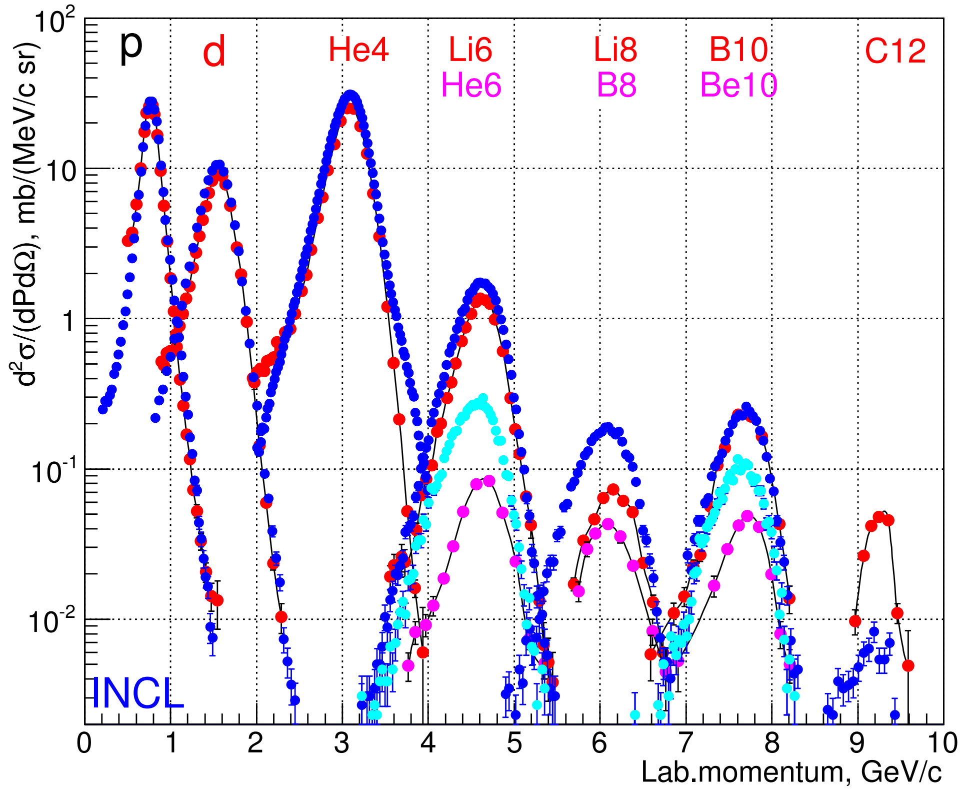

Figure 3. The same experimental data as in figure 2 but in comparison with the predictions of the INCL++ model.

personnel of ITEP TWA and to technicians of the FRAGM experiment for a large contribution in carrying out the measurements. Part of the work, performed at LANL, was carried out under DOE Contract No. DE-AC52-06NA25396. This work has been supported by Russian Foundation for Basic Research (grant RFBR 15-02-06308).

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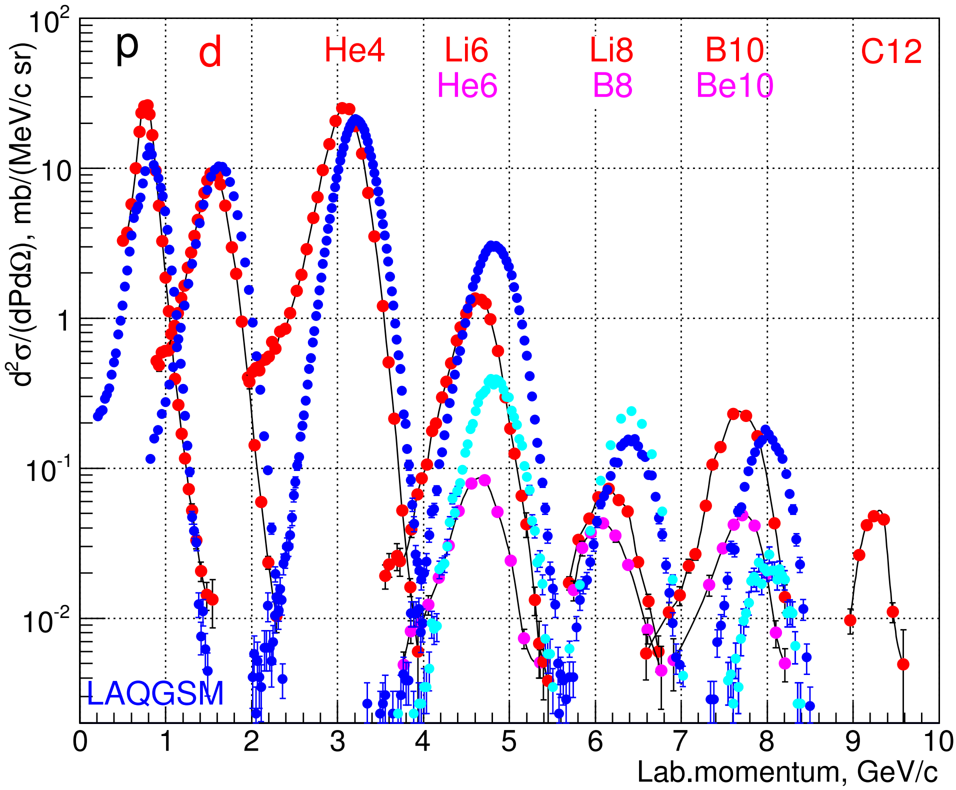

Figure 4. The same experimental data as in figure 2 but in comparison with the predictions of the LAQGSM03.03 model.

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