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Light fragments from (C + Be) interactions at 0.6 GeV/nucleon

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Abstract

Nuclear fragments emitted at 3.5° in ^{12}C fragmentation at 0.6 GeV/nucleon have been measured. The spectra obtained are used for testing the predictions of four ion-ion interaction models: INCL++, BC, LAQGSM03.03 and QMD as well as for the comparison with the analytical parametrization in the framework of thermodynamical picture of fragmentation.

1 Introduction

The study of emission of light fragments is important to understand the nature of ion-ion interactions. Different reaction mechanisms contribute to this rather complicated process which can hardly be described in analytical way. For this reason we tested a few Monte-Carlo transport codes against the data of the FRAGM experiment [1–3].

2 The FRAGM experiment and the test of the models of ion-ion interactions

In the FRAGM experiment at ITEP TWA heavy ion accelerator, we have measured the fragment yields from the reaction

$$^{12}\mathrm{C} + ^{9}\mathrm{Be} \rightarrow \mathrm{f} + X \tag{1}$$

with a beamline spectrometer set at 3.5° to carbon beam. Here f stands for all fragments from protons up to isotopes of projectile nucleus. The projectile kinetic energies were T_0= 0.2−3.2 GeV/nucleon. In this report we present data at T_0= 0.6 GeV/nucleon for fragments: hydrogen, helium and two lithium (^{6}Li, ^{7}Li) isotopes. The fragments were measured at a wide momentum region which include the midrapidity, the fragmentation peak and the cumulative regions. In the last one the fragment momenta per nucleon are much higher than momentum per nucleon of the projectile. This gives a good testing ground for a comparison with predictions of different ion-ion interaction models.
The fragment yields were measured by scanning the beamline spectrometer momentum with a step of 50−100 MeV/c and counting the number of events corresponding to different fragments and normalizing to the monitor. The fragments were well separated on time-of-flight *vs* dE/dx plots. The relative cross sections $d^2\sigma/(d\Omega dp)$, where p is the fragment momentum in a laboratory frame, were calculated. They are shown for hydrogen, helium and lithium isotopes in comparison with the calculations by four models: INCL++ (Fig. 1(a)), BC (Fig. 1(b)), LAQGSM (Fig. 1(c)) and QMD (Fig. 1(d)). We used the INCL++, BC and QMD models from a GEANT4-package.

Our measurements cover three-to-six orders in the cross section magnitude, depending on the fragment. Qualitatively, all the models reproduce well the energy dependence of the differential cross sections of the fragment yields. Model prediction for the cross section at fragmentation peak maxima differ by no more than 2−3 times[1]. The largest differences are observed for the QMD model, which predicts smaller width for the fragmentation peaks. LAQGSM reproduces the energy dependence of the cross sections at high energy part of the fragmentation peaks, but underestimates the cross section in the low-energy part. The predictions of BC and INCL++ models are very

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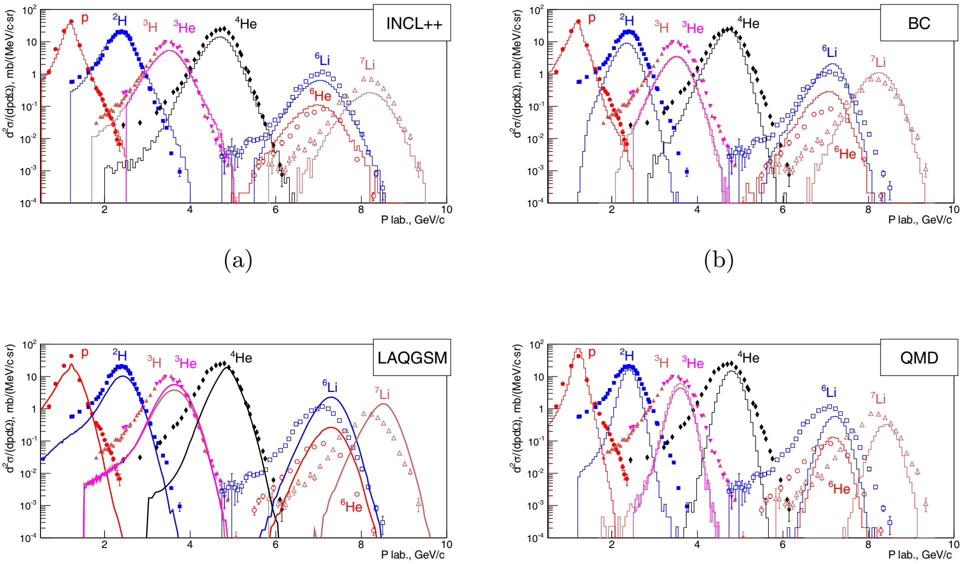
[1] The data of the FRAGM experiment were normalized to BC calculations at the maximum of the proton peak. This normalization factor was used in all figures.



(a) (b)

(c) (d)

Figure 1: Relative yields of H, He and Li isotopes in ^{12}C + ^{9}Be interaction at 0.6 GeV/nucleon and at 3.5° as a functions of fragment laboratory momenta. Data (points), model calculations (histograms/lines): (a) INCL++ model [7], (b) BC model [4], (c) LAQGSM model [5], (d) QMD model [6].

close, but INCL++ gives better description of the experimental data, which is especially noticeable in the areas far from the fragmentation peak maxima.

3 Slope parameters from kinetic energy spectra

In the framework of thermodynamical picture of nuclear fragmentation, the fragment kinetic energy (T) distribution in the rest frame of the carbon nucleus should be of Maxwell-Boltzmann type and not depend on the fragment type. The distributions of invariant cross section for fragment yields $Ed^3\sigma/d^3p = (E/p^2)d^2\sigma/(d\Omega dp)$, where E is a total energy, are shown in Fig. 2 as function of T. Both experimental data and model calculations are presented. The INCL++ model gives a good description of the experimental data much better than the others. The spectra were parameterized by a sum of two Maxwell-Boltzmann distributions

$$Ed^3\sigma/d^3p = E(A_S exp(-T/T_S) + A_C exp(-T/T_C)), \qquad (2)$$

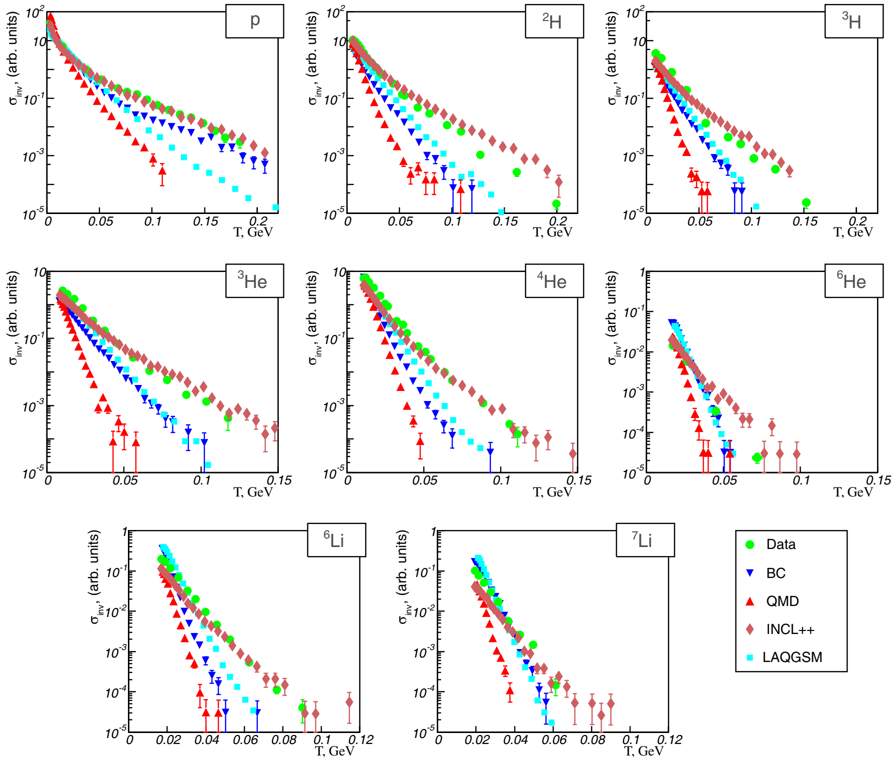


Figure 2: Invariant cross sections as functions of fragment kinetic energies in the ^{12}C rest frame: measured data *vs* model calculations.

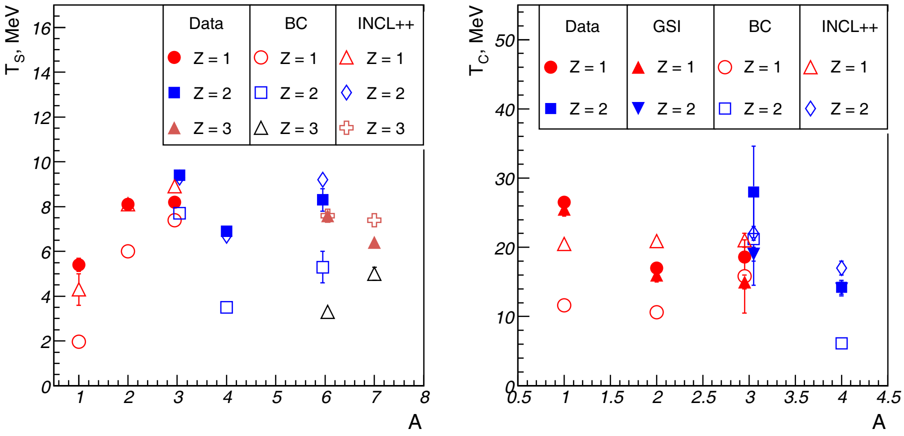


Figure 3: Temperature parameters T_S (left) and T_C (right) as a function of fragment atomic number. Closed points are ours, and GSI results are from [9], open points are calculations in INCL++ and BC models.

where A_S and A_C are normalization factors for low and high energy regions, and the slope parameters T_S and T_C are "temperatures" defined in these regions. The function (2) gives a good description of both the data and the calculations for all models and all fragments. The obtained values of T_S and T_C are shown in Fig. 3. The T_S values are in a reasonable agreement with those obtained in [8] for 1−2 GeV/nucleon carbon ions. The experimental results for T_C from [9] obtained at GSI at 1 GeV/nucleon for ^{197}Au + ^{197}Au collisions are in a reasonable agreement with our results. The INCL++ model describes the data on T_S well and better than the other models.

4 Conclusion

Fragment yields from the reaction ^{9}Be(^{12}C, f)X (f − fragments from p to ^{7}Li) at 0.6 GeV/nucleon were measured and compared to prediction of four models of ion-ion interactions. The INCL++ describes all momentum spectra rather well, both in the region of fragmentation peak and in the cumulative region while all other models underestimate the experimental results in the cumulative (high momentum) region. Kinetic energy spectra in the projectile rest frame can be parameterized as $E(A_S \exp(-T/T_S) + A_C \exp(-T/T_C))$, where both T_S and T_C values are in satisfactory agreement with the predictions of the INCL++ model. Other models strongly underestimates the data at high kinetic energies; T_C values are higher for protons than for other fragments.

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