MATHEMATICAL MODELING OF EXPERIMENTS AT THE NUCLOTRON*

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Yield of nuclear fragments in Au+p, Au+Cu and Au+Au interactions for NICA (Nuclotron-based Ion Collider fAcility) energy range is estimated using LAQGSM and Geant4 FTF models.

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1. Introduction

At the future accelerator complex NICA [1], it is planned to investigate nucleus–nucleus interactions at energies from 3 to 11 GeV in the centre-of-mass energy of NN collisions. The ion beams will be created on the existing accelerator — NUCLOTRON, split and sent to the NICA storage rings. NUCLOTRON will produce extracted ion beams within the energy range of $E_{\rm lab} = 0.5$–$4.5\,A\,$GeV. It is also planned to accelerate nucleus from hydrogen to gold. Implementation of this program involves solving a number of technical problems, among which there is a task of cleaning the created and circulating beams.

2. Monte Carlo modeling of nuclear fragmentation

Theoretical Monte Carlo models of the multi-fragmentation of nuclei in hadron–nucleus collisions are rather widely represented in the literature. Among them, the most popular ones are a software package MCNP6 [2] and an INCL++ model [3] (Liège Intranuclear Cascade model). All of them for low and intermediate energies are based on the model of the intra-nuclear cascade. A high-energy model of quark–gluon strings (LAQGSM — Los Alamos Quark–Gluon String Model [4]) is integrated into the MCNP6 complex.

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The INCL++ model operates at energies up to 15 GeV per nucleon for incident nuclei with $A \leq 18$. INCL++ is presented in the widely available Geant4 software package [5]. The package also includes the Fritiof (FTF) model, which is used at energies above 3–5 GeV per nucleon for all combinations of colliding nuclei. The FTF model includes a nuclear destruction mechanism based on the Reggeon phenomenology — RTIM (Reggeon Theory Inspired Model) [6]. No use of the FTF model to assess the fragmentation of nuclei is known to us.

Recently, the extension of the well-known high-energy HIJING model to nuclear fragmentation processes was presented [7]. However, the range of applicability of the HIJING model (more than 20 GeV per nucleon, 20 GeV/u in the lab. system) does not cover the low-energy region at NICA. Therefore, we are forced to use MCNP6 (LAQGSM, INCL+ABLA) and Geant4 FTF and INCL++ models. Before presenting the results of simulations, we consider the application of FTF, INCL++ and LAQGSM models for nucleon–nucleus collisions. Figures 1, 2 show GSI experimental data and model calculations of fragmentations of iron and gold nuclei interacting with hydrogen — the distributions of the produced fragments on masses ($A_{\rm f}$) and charges ($Z_{\rm f}$). Total and nonelastic cross sections for normalization of the calculations were taken from [8].

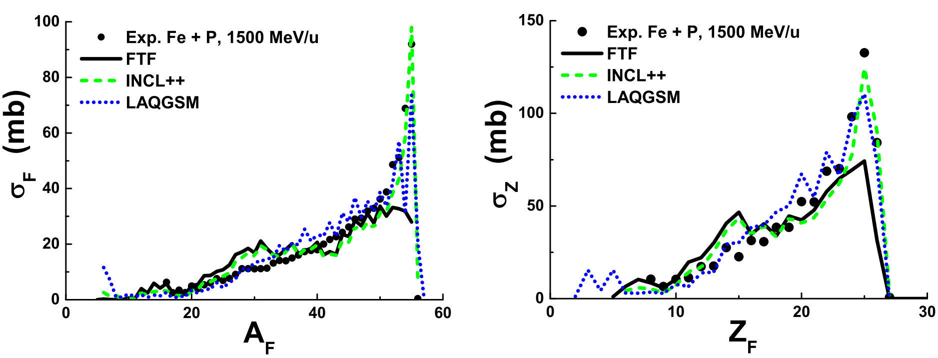

Fig. 1. Fragments distributions on masses and charges in the interactions of iron nuclei with hydrogen at 1.5 GeV/u. Points are experimental data [9]. Lines are model calculations.

As seen from Fig. 1, we have a good agreement between the experimental data and the calculations for the fragmentation of iron nuclei using all considered models. INCL++ gives the best results. LAQGSM reproduces general features of the data, but predicts too strong isotopic effects at $20 \leq Z_{\rm f} \leq 25$. FTF model underestimates the peak at $Z_{\rm f} \sim 26$.

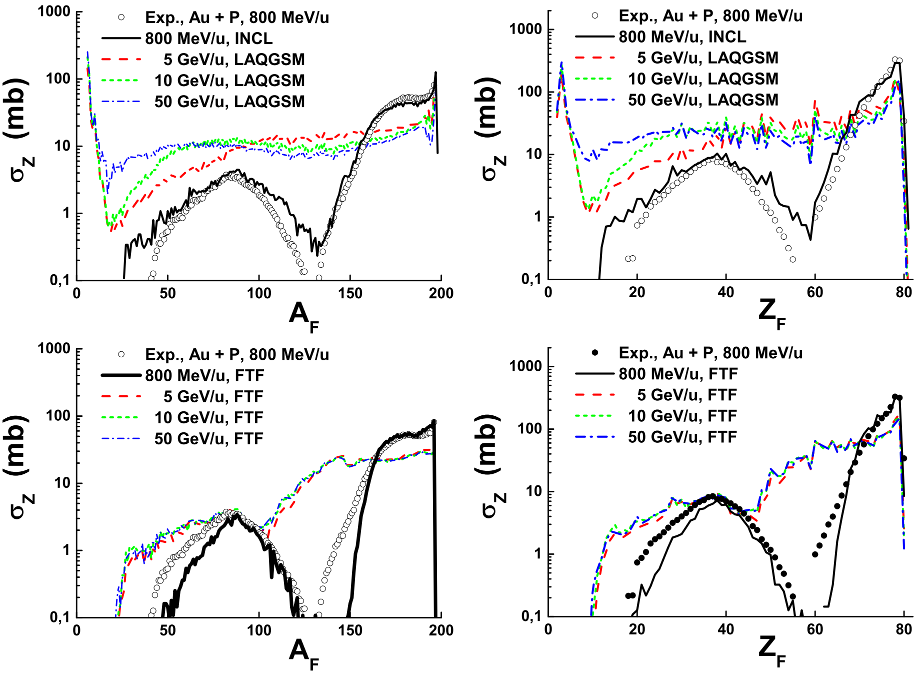

Fig. 2. Fragments distributions on masses and charges in the interactions of gold nuclei with hydrogen at 0.8, 5, 10 and 50 GeV/u. Points are experimental data [10]. Lines are model calculations.

INCL++ describes the peak at large $A_{\rm f}$, $Z_{\rm f}$, but predicts too large width of the fission peak for gold interactions (see Fig. 2). FTF model also describes the region of large $A_{\rm f}$, $Z_{\rm f}$ and gives the narrow width.

Figure 2 also demonstrates the energy evolution of the mass and charge spectra of fragments. LAQGSM predicts the main evolution at $A_{\rm f} \leq 100$. There is practically no evolution of the spectra at high energies according to the FTF model.

Figure 3 shows experimental data on the fragment charge distributions in Au+Cu and Pb+Cu interactions at high energies in comparison with model calculations. As seen, the models reproduce a general trend of the data. Though, there are some uncertainties in the calculation normalizations.

In Fig. 4, we present fragment mass and charge distributions in Au + Au interactions for the NICA energy range. The calculations were done using LAQGSM. FTF model calculations (not shown in the figure) are closed to the presented ones. As seen, there is no energy evolution of the spectra at sufficiently high energies. This means that for determination of the fragmentation of gold nuclei at high NICA energies, it is enough to make Nuclotron experiment with gold ions at 4.5 GeV/u only.

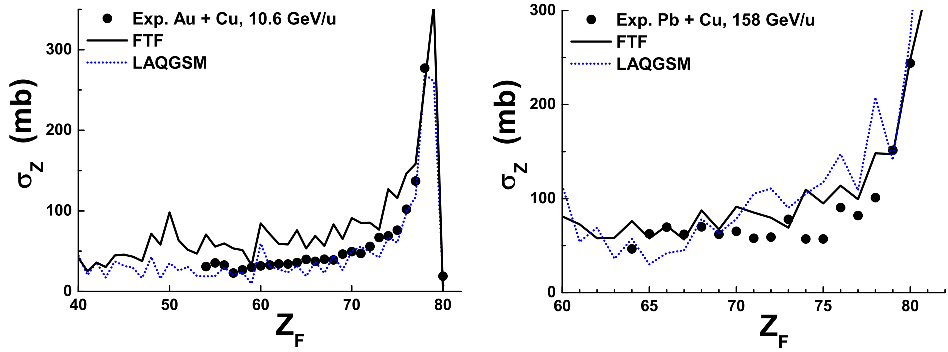

Fig. 3. Fragments distributions on charges in the interactions of gold and lead nuclei with copper at high energies. Points are experimental data [10, 11]. Lines are model calculations.

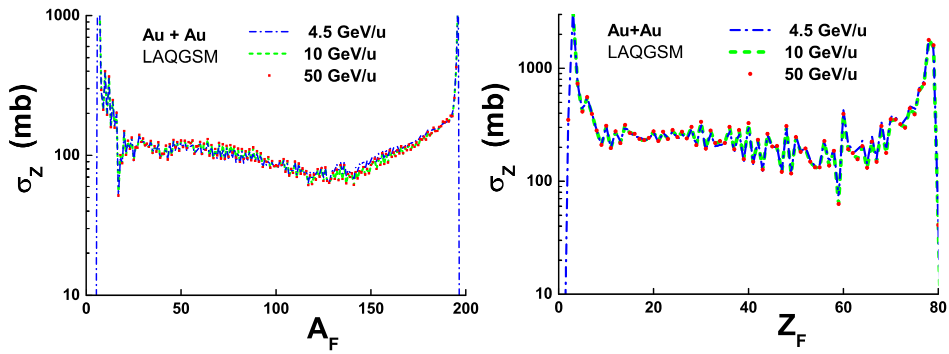

Fig. 4. Fragments distributions on masses and charges in the interactions of gold nuclei with gold at high energies. Lines are LAQGSM model predictions.

The main changes of the fragmentation can be at the energies below 4.5 GeV/u in Au+P or P+Au interaction. Experiments at BM@N — Baryonic Matter at Nuclotron, can verify these predictions.

REFERENCES

[1] http://nica.jinr.ru/

[2] https://mcnp.lanl.gov/

[3] A. Boudard *et al.*, *Phys. Rev. C* **87**, 014606 (2013); D. Mancusi *et al.*, *Phys. Rev. C* **90**, 054602 (2014).

[4] S.G. Mashnik *et al.*, LANL Report LA-UR-07-6198, `arXiv:0709.1736 [nucl-th]`; K.K. Gudima, S.G. Mashnik, A.J. Sierk, LANL Report LA-U R-01-6804, Los Alamos, 2001; N.S. Amelin, K.K. Gudima, V.D. Toneev, *Sov. J. Nucl. Phys.* **51**, 327 (1990) [*Yad. Fiz.* **51**, 512 (1990)]; **51**, 1093 (1990) [**51**, 1730 (1990)]; **52**, 1722 (1990) [**52**, 272 (1990)].

[5] J. Allison *et al.* [GEANT4 Collaboration], *Nucl. Instrum. Methods Phys. Res. A* **835**, 186 (2016).

[6] Kh. Abdel-Waged, N. Felemban, V.V. Uzhinskii, *Phys. Rev. C* **84**, 014905 (2011); Kh. Abdel-Waged, V.V. Uzhinsky, *Phys. Atom. Nucl.* **60**, 828 (1997) [*Yad. Fiz.* **60**, 925 (1997)]; Kh. Abdel-Waged, V.V. Uzhinskii, *J. Phys. G* **24**, 1723 (1998).

[7] Kh. Abdel-Waged, N. Felemban, *Phys. Rev. C* **91**, 034908 (2015).

[8] R.E. Prael, A. Ferrari, R.K. Tripathi, A. Polanski, Proceedings of the 4th Workshop on Simulating Accelerator Radiation Environments, Sept. 13–16,1998, Knoxville, TN; R.E. Prael, A. Ferrari, R.K. Tripathi, A. Polanski, Los Alamos National Laboratory, Report LA-UR-98-5843, December 1998.

[9] C. Villagrasa-Canton *et al.*, *Phys. Rev. C* **75**, 044603 (2007).

[10] L.Y. Geer *et al.*, *Phys. Rev. C* **52**, 334 (1995).

[11] C. Scheidenberger *et al.*, *Phys. Rev. C* **70**, 014902 (2004).