Proposal of a new project

- **FASA – S. Avdeev**

- The main goal of the project is the study of space-time characteristics of hot nuclei formed in the collisions of light relativistic ions with heavy targets. The experiment is carried out using relativistic beams from the Nuclotron and the 4π–FASA detector. Its thirty telescopes will allow spectroscopic and correlation measurements in terms of relative angles (from 10° to 180°) or relative velocities of intermediate-mass fragments. Radial flow as a function of the fragment charge, thermalization in the hot spectator of the target, and the time of disintegration will be studied.

  Recommendation

  - The PAC notes that similar work on Multi-Fragmentation of Nuclei was carried out some 40 years ago at Fermilab, at CERN -PS and at the BEVATRON and BEVALAC.
  - The PAC requests the authors to sharpen their scientific case taking into account these earlier data and to present a convincing case on how they can solve the still open question of break-up or thermalization in the multifragmentation of nuclei.
  - The PAC looks forward to receiving an improved proposal with details on the target thickness, the identification power of their telescopes for He and Be isotopes, and a simulation of the performance of the experiment in comparison with theoretical predictions.

Recommendations of Itzhak Tserruya

(126 SC JINR, September 19, 2019).

1. *The PAC notes that similar work on Multi-Fragmentation of Nuclei was carried out some 40 years ago at Fermilab, at CERN - PS and at the BEVATRON and BEVALAC.*

   Answer.

   The process of multiple fragment emission is the main decay mode of hot nuclei at excitation energies exceeding 3 MeV per nucleon. Hot nucleus, expanding under thermal pressure, falls into the spinodal region, which is limited by equal to zero nuclear rigidity: $\partial p/\partial V=0$. It is followed by copious emission of intermediate mass fragments (IMF), which are heavier than alpha particles but lighter than fission fragments. The experimental information about the spinodal state of nuclear matter is gained by studies of nuclear multifragmentation. The process is interpreted as a "liquid-gas" phase transition occurring at a temperature 5-7 MeV. The nuclear multifragmentation process has been extensively studied in recent years following the advent of 4π detectors (TAMU, USA; GSI, Germany; INFN in Catania, Italy), provides a wealth of information on nuclear dynamics, on the properties of the nuclear equation of state and on the possible nuclear liquid-gas phase transition.

   The reaction mechanism is composed of three steps. The first step is the energy deposition step, when energetic nucleons and pions are emitted and the nuclear remnant is excited. This step is considered using the intranuclear cascade model (INC) to get the distribution of the nuclear remnants in charge, mass, and excitation energy. The second step is expansion driven by the thermal pressure in the hot remnant, which is described in the spirit of the Expanding Emitting Source model, EES. This process results in reducing the excitation energy. The final stage we describe by using the Statistical Model of Multifragmentation (SMM). Within this model the probabilities of different decay channels of the excited remnant are proportional to their statistical weights. The volume of the system from which emission of fragments occurs determines the Coulomb energy of the system.

Experiments on the relativistic beams of the Nuclotron accelerator using 4π–FASA device will provide information on the spinodal state of nuclear matter. The Project will answer key questions about the time scale of fragment emission (there is a sequential emission of fragments or simultaneous breakup of the system), about degree of thermalization of the system before the breakup, and about radial flow.

2. *The PAC requests the authors to sharpen their scientific case taking into account these earlier data and to present a convincing case on how they can solve the still open question of break-up or thermalization in the multifragmentation of nuclei.*

   Answer.

   For the experimental determination of the break-up time in the multifragmentation of nuclei, the correlation function between intermediate mass fragments was analyzed in respect to the relative angle. The correlation function exhibits a minimum at relative angles of zero arising from Coulomb repulsion between the coincident fragments. The magnitude of this effect drastically depends on the mean emission time, since the longer the time separation of the fragments, the larger their space separation and the weaker the Coulomb repulsion. The time scale of fragment emission is estimated by comparison the measured correlation function (Fig. 11 of the Project) to that obtained by the multi-body Coulomb trajectory calculations with break-up time as a parameter. In order to measure the IMF-IMF repulsion effect, the correlation function values at 26^0 was used (Fig. 12 of the Project).

One way of evaluating the degree of equilibration in a reaction, as well as determining the average source velocity, is through analysis of longitudinal versus transverse velocity of fragments along points of constant invariant cross section. Fig. 10 of the Project shows the longitudinal versus transverse velocity plots along points of constant invariant cross section for carbon fragments. The data for a given invariant cross section are isotropic; i.e., they can be described by a circle with fixed locus, corresponding to a single average source velocity. This suggests that the system thermalization take place prior to fragment emission.

3. *The PAC looks forward to receiving an improved proposal with details on the target thickness, the identification power of their telescopes for He and Be isotopes, and a simulation of the performance of the experiment in comparison with theoretical predictions.*

Answer.

Target – gold film with thickness of 1.5 mg/cm^2 is located in the center of the vacuum chamber (Page 3 of the Project).

Telescope identification power for He and Be clearly visible in figure 9 of the Project.

The INC + SMM model describes well the experimental data obtained at the Dubna superconducting accelerator NUCLOTRON. Thus, a comparative study of experimental data and theoretical calculations allows us to determine such characteristics of the system as the break-up time and radial flow (Fig. 12, 13, 10 of the Project).