Preliminary results from a study of isospin non-equilibrium

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Introduction and overview

The question of whether or not an excited nuclear system reaches equilibrium before decaying is of importance when trying to determine the events that occur in hot nuclear collisions just prior to fragment emission. One reason isospin of nuclear collisions is important is that it can give information about the origin of emitted fragments. Establishing the onset of isospin equilibrium will help to improve the accuracy of code predictions and deepen our understanding of the events occurring prior to fragment emission in hot nuclear matter.

This poster will show examples from previous, current and future studies of the role of isospin non-equilibrium in intermediate energy heavy ion nuclear collisions.

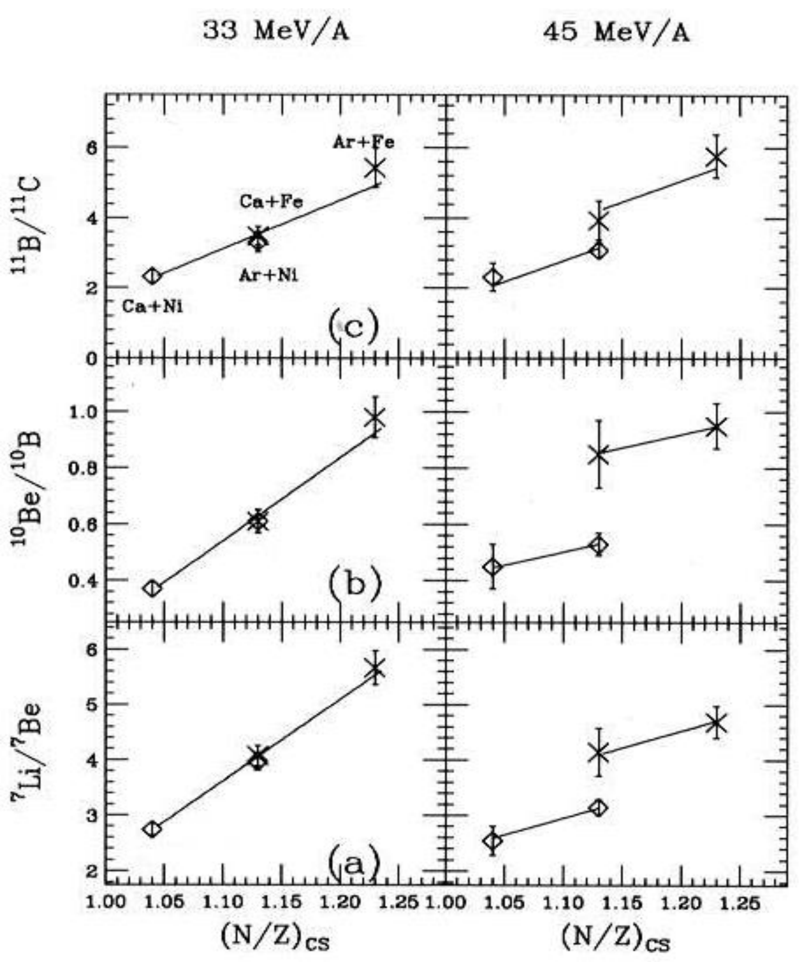

Fig. 1 H. Johnston. T. White, J. Winger, D. J. Rowland, B. Hurst, F. Gimeno-Nogues, D. O'Kelly, and S. J. Yennello, Phys. Lett. B **371**, 186 (1996).

Isobaric ratios show isospin equilibrium

The equilibration of isospin of ^{40}Ar, ^{40}Ca + ^{58}Fe, ^{58}Ni at the energies of 33 and 45 MeV/nucleon were investigated in figure 1. In the 33 MeV/nucleon data, the data suggest that fragments are emitted from an equilibrated source. On the other hand, in the 45 MeV/nucleon data, the data suggest fragments are being emitted from a non-equilibrated source. These data point out that the isospin equilibration is dependent on energy of the projectile and that the onset of non-equilibration for these systems lies between 33 and 45 MeV/nucleon.

Isobaric ratios show isospin equilibrium

The isospin non-equilibrium in heavy-ion collisions at intermediate energies is shown in figure 2 using the isospin dependent simulation code, BUU. The system of Ar on Ni at 25, 35, 45 and 55 MeV/nucleon are simulated in order to probe whether or not they achieve isospin equilibrium. By looking at the number of protons and neutrons in front of and behind the center of mass over time, it is predicted that isospin equilibrium is reached somewhere between 35 and 45 MeV/nucleon for the Ar on Ni system.

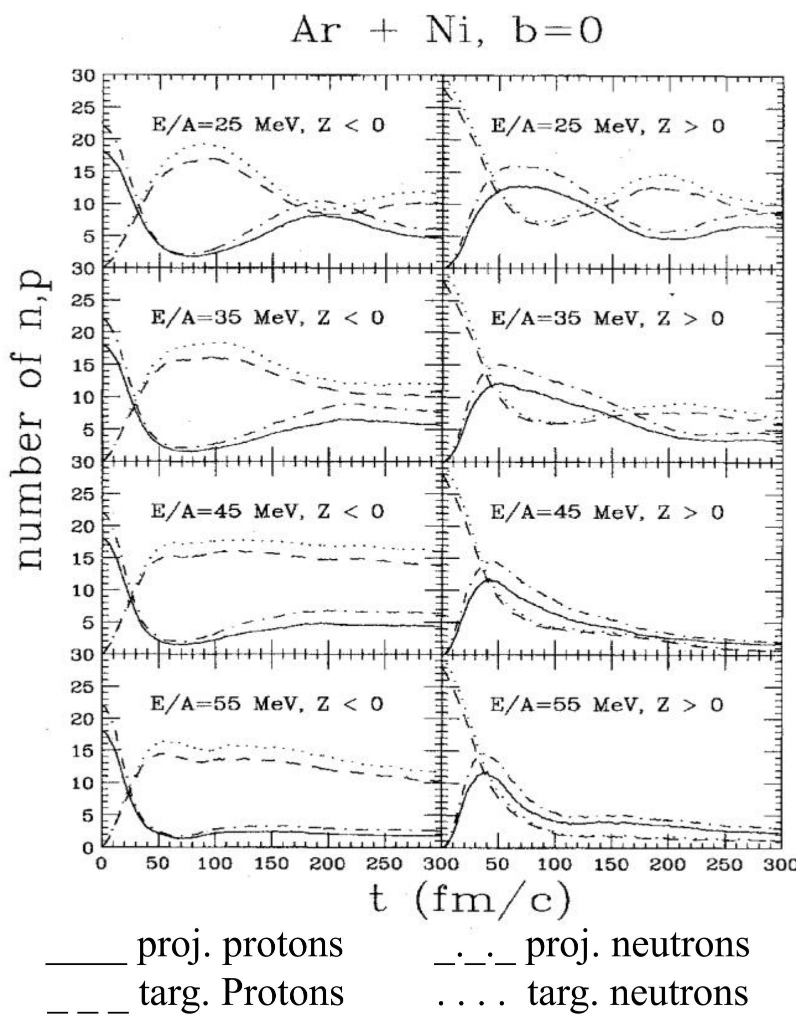

Fig. 2 Bao-An Li and Sherry J. Yennello, Phys. Rev. C **52**, R1746, (1995).

Rz factor shows isospin mixing

Isospin non-equilibrium is studied in figure 3 using the N/Z tracer method for the systems of 400 MeV/A ^{96}Ru, ^{96}Zr on ^{96}Ru, ^{96}Zr. The N/Z tracer method involves selecting a cell in momentum space and counting the number of protons within that cell. The authors came up with a value called R_Z, which measures the amount of mixing between projectiles and target nucleons. Using the symmetric systems as a calibration, the factor of R_Z is calculated to determine the degree of transparency. Z_{det} is the total number of protons detected in a selected space after a collision of a mixed system (Z), Zr on Zr (Z^{Zr}), or Ru on Ru (Z^{Ru}). In the symmetric systems, R_Z takes the value of +1 for the Zr on Zr and -1 for Ru on Ru. R_Z takes a value of zero when the emitting source is in full isospin equilibrium.

In figure 3, the Rz factor is shown to approach zero as the impact parameter becomes smaller, or the collision becomes more central. As the Rz factor gets closer to zero, more and more isospin mixing is occurring.

$$R_Z = \frac{2 \times Z - Z^{Zr} - Z^{Ru}}{Z^{Zr} - Z^{Ru}}$$

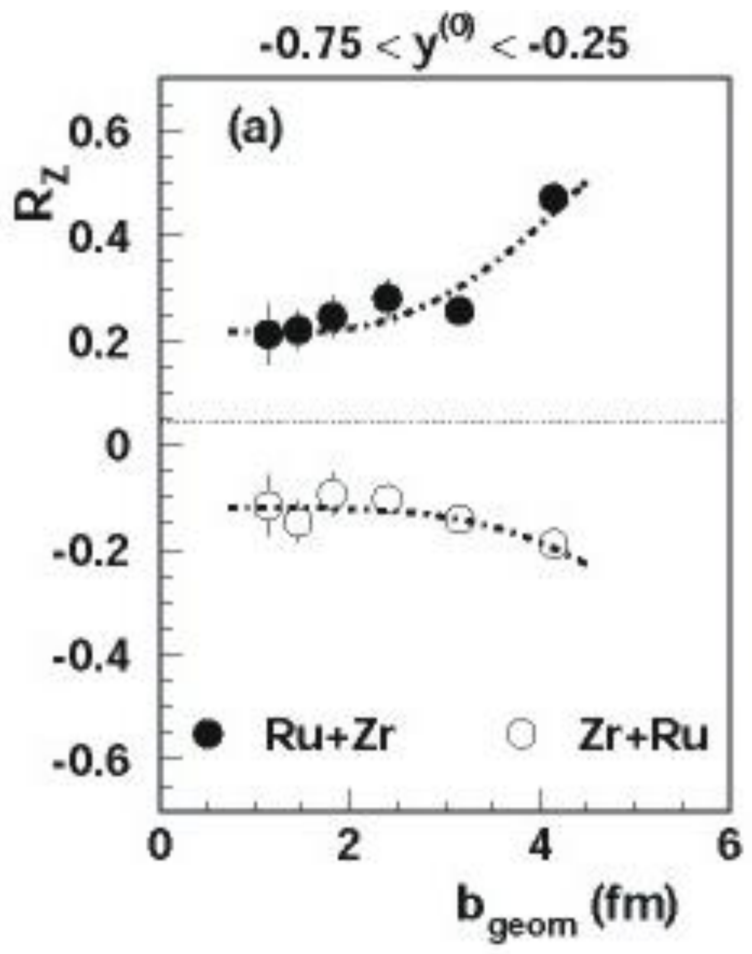

Fig 3. F. Rami, *et al.*, Phys. Rev. Lett. **84**, 1120 (2000).

NIMROD isospin study

Data has been collected for the following systems and energies at the Cyclotron Institute at Texas A&M University in order to study isospin non-equilibrium. The progress in calibration allows data from the systems in bold to be shown in this poster.

Energy	System	(N/Z)sys
35 MeV/A	^{58}Ni + ^{58}Ni	1.071
35 MeV/A	^{54}Fe + ^{58}Ni	1.074
35 MeV/A	^{54}Fe + ^{54}Fe	1.076
35 MeV/A	^{58}Fe + ^{58}Ni	1.148
35 MeV/A	^{58}Ni + ^{58}Fe	1.148
35 MeV/A	^{58}Fe + ^{54}Fe	1.154
35 MeV/A	^{58}Ni + ^{64}Ni	1.179
35 MeV/A	^{58}Fe + ^{58}Fe	1.231
35MeV/A	^{58}Fe + ^{54}Ni	1.259
35 MeV/A	^{64}Ni + ^{64}Ni	1.286
45 MeV/A	**^{58}Ni + ^{58}Ni**	**1.071**
45 MeV/A	**^{58}Ni + ^{58}Fe**	**1.148**
45 MeV/A	**^{58}Fe + ^{58}Ni**	**1.148**
45 MeV/A	**^{58}Fe + ^{58}Fe**	**1.231**

Preliminary analysis

In an effort to discern the number of emission sources, cuts on the charge particle multiplicity (mcp) are made for data taken at lab angle of 7 and 15 degrees. The top panel of figure 4 shows the slope of the energy spectra changing as the mcp increases. At low mcp, there are two sources seen in the two bumps of the spectra, while at high mcp, there is only one bump, indicating a single source. In the bottom panel of figure 4, the same cuts on mcp are taken on a more backward angle. The shift in spectra shape is less pronounced than the more forward data in the top panel of figure 4, indicating less feeding from multiple sources. Cuts on perpendicular and parallel velocity will be made in the future to better insure multiple sources are separated.

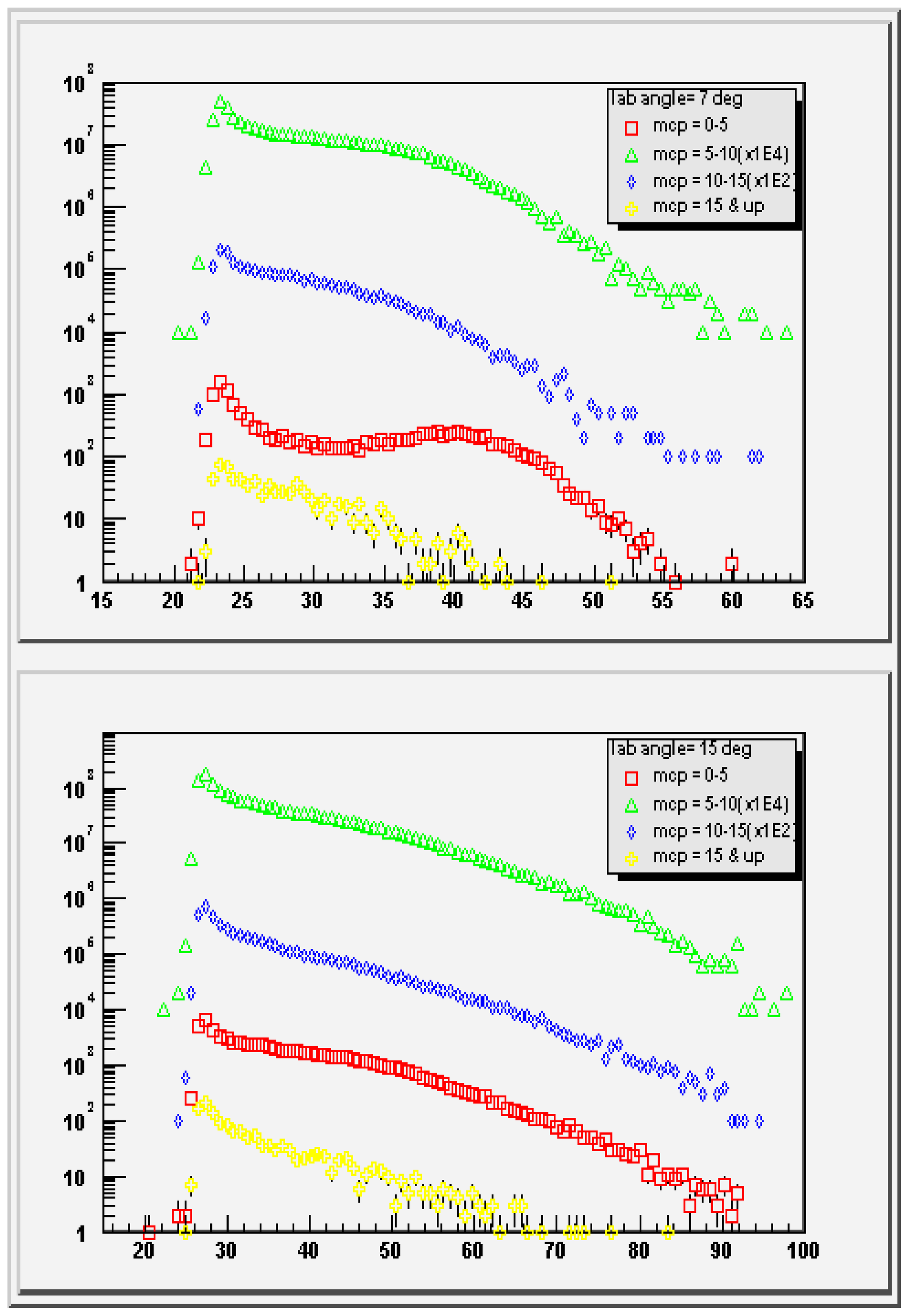

Fig. 4 Cuts on charge particle multiplicity for data taken at two angles is shown for alpha energy spectra. The yield is in arbitrary units and the energy is in MeV. The lines are scaled for separation purposes.

Preliminary data

In the spirit of the Gordon Conference, the first pertinent physics from the current data set is seen below. Figure 5 shows isotopic ratios as a function of the combined system isospin for data with a cut on mcp>10 taken at the lab angle of 15 degrees for systems with projectiles having 45 MeV/nucleon. The isotope ratios are comprised of the more neutron rich isotope yields divided by the less neutron rich yields. As the (N/Z) value of the system increases, the value of the ratio increases for each isotope. Or, in other words, as the neutron content of the combined system increases, the more neutron rich isotope's production is enhanced.

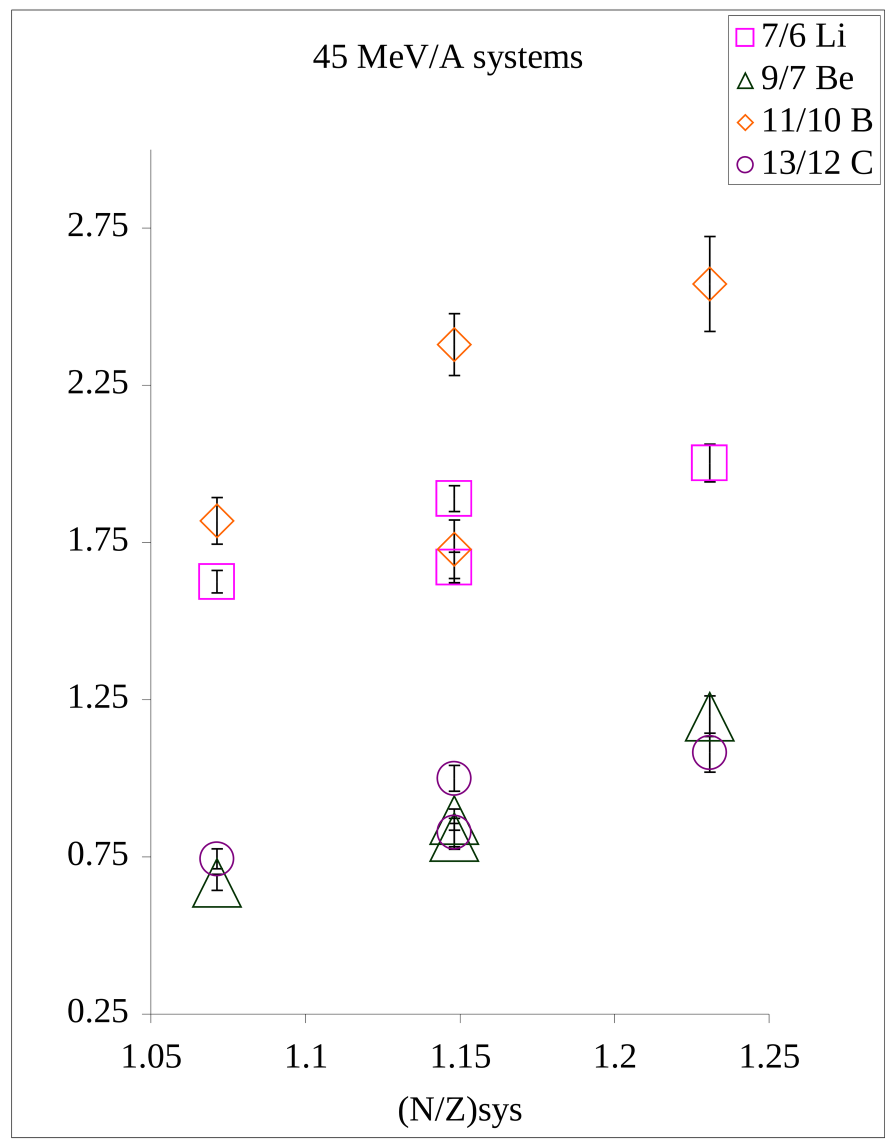

Fig. 5 Isotope ratios are shown plotted as a function of the (N/Z) of the compound system for data with projectiles having 45 MeV/A. The data shown have been cut for mcp>10 and are at a lab angle of 15 degrees.

Coming soon

Calibrations are nearing completion as of June 2002. More precise determination of centrality cuts will be done to give a firmer idea of the number of emission sources. The energy spectra will be fitted with a moving source code. Isotopic ratios from all systems and angles studied will be extracted. Also, the Rz factor for all systems will be studied. And, finally, the experiment will be simulated by and compared with isospin dependent modeling codes.