Density Dependence of the Symmetry Energy through Emitted Protons and Neutrons

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Motivation

The density dependence of the EOS has been constrained for symmetric nuclear matter, but the asymmetric term is not. Specifically, the direction of the trend is poorly constrained at high densities.

$$E_{sym}(MeV) \approx 12.5(\rho/\rho_0)^{2/3} + 17.6(\rho/\rho_0)^{\gamma}$$

$$\frac{E}{A}(\rho,\delta) = \frac{E}{A}(\rho,0) + E_{sym}(\rho)\delta^2 \qquad \delta = \frac{\rho_n - \rho_p}{\rho_n + \rho_p}$$

It has been shown that the ratio of emitted neutrons to protons from a central, heavy ion collision is a strong, independent, straight forward method for probing the symmetry energy

We examine the (n/p) Double Ratio as an experimental observable that allows for a simpler treatment of the neutron detection efficiencies using BUU simulations. The Double Ratio is defined as DR=^{124}R(n/p)/^{112}R(n/p).

Simulation Progression

The following are a set of simulations showing the time evolution of a collision of ^{124}Sn on ^{124}Sn at 50 MeV/u, each with a different set of input parameters.
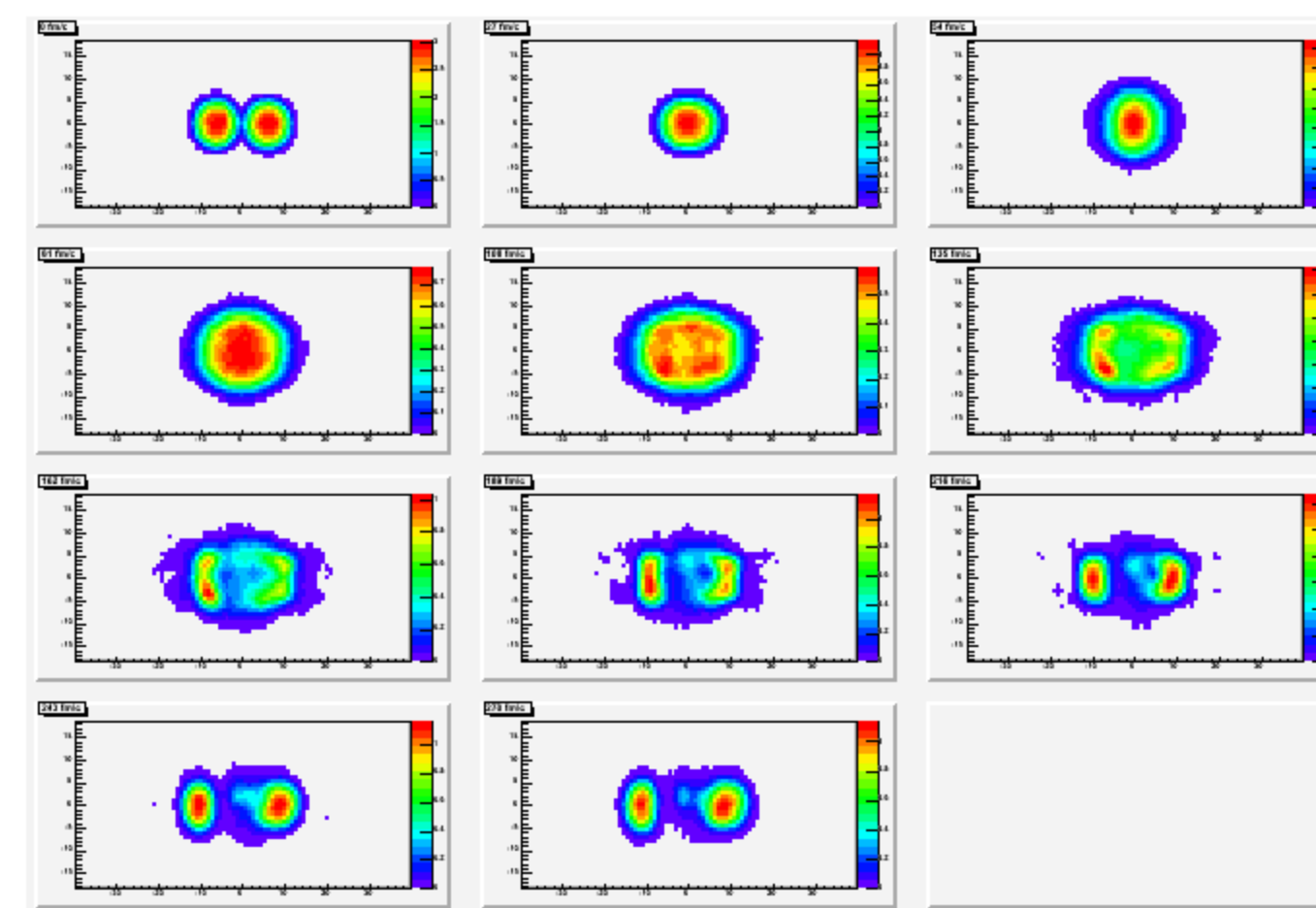
BUU simulation with a momentum independent mean field with no cluster particles. Each plot represents a progression of 27 fm/c.
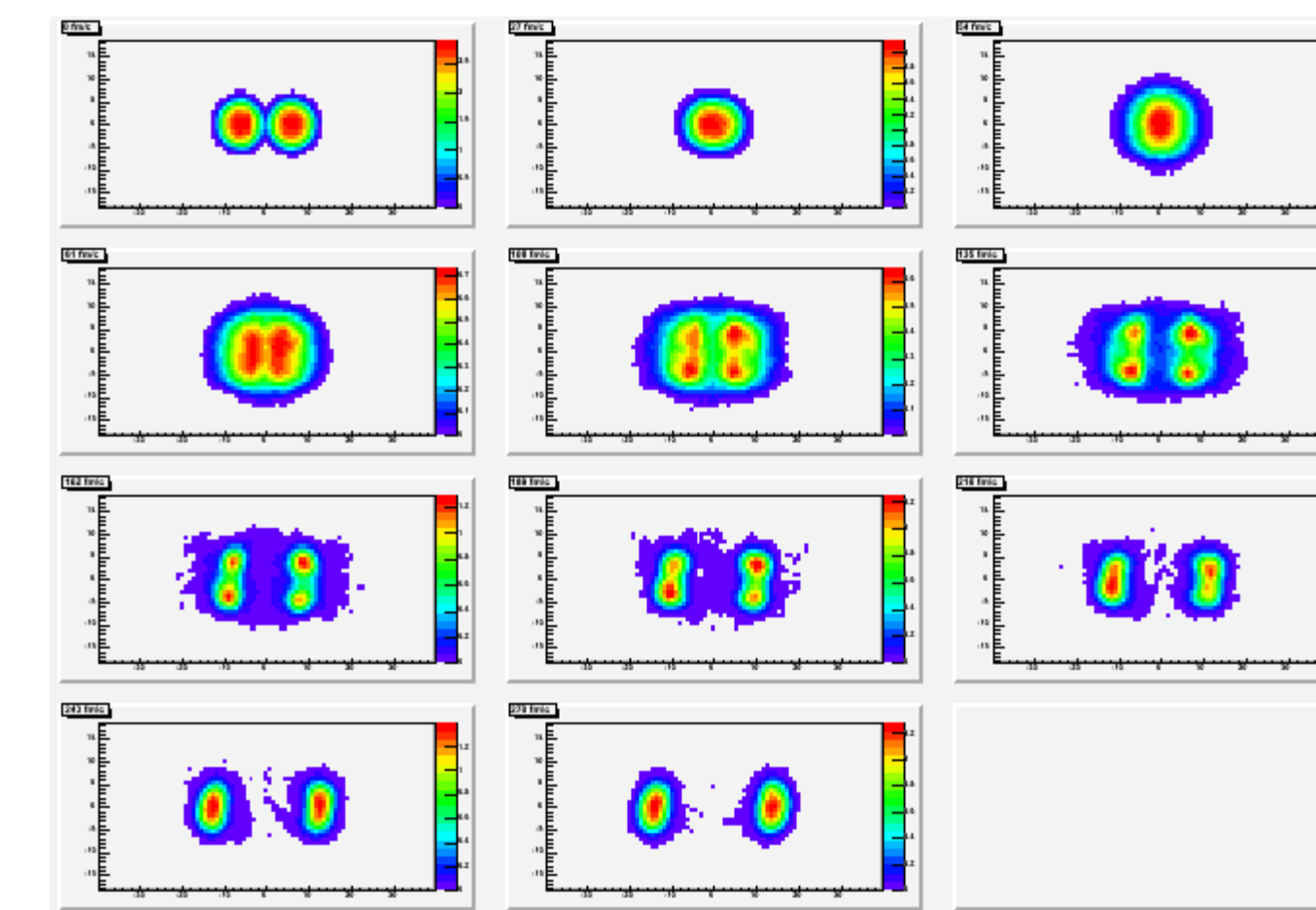
BUU simulation with a momentum dependent mean field without clusters shows that the momentum dependence adds extra pressure to the system forcing the two residues to separate at an earlier time.
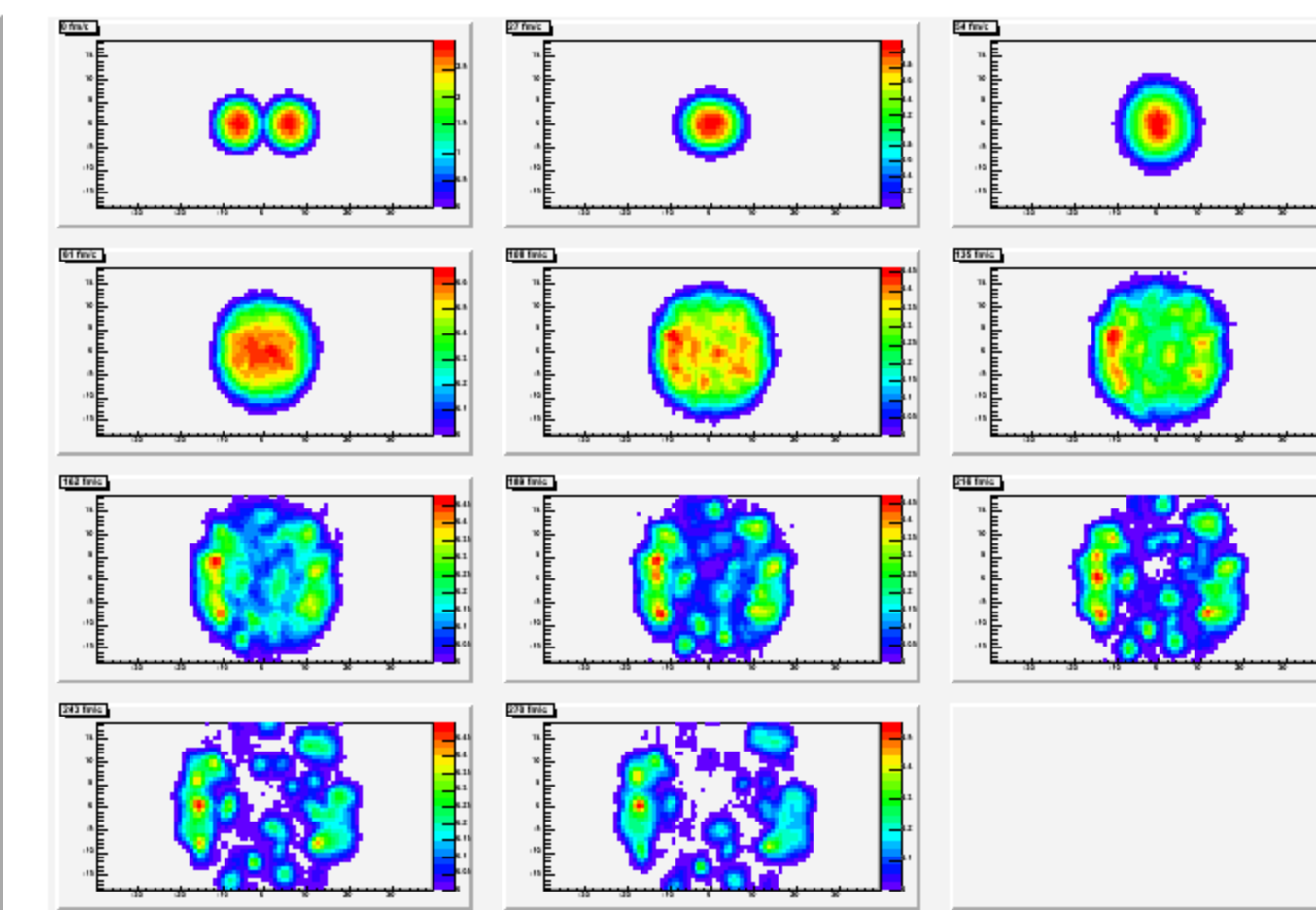
BUU simulation with a momentum dependent mean field with clusters, A<3, particles. The cluster formation leads to a much more complex set of residues.

BUU Simulations

Boltzmann-Uehling-Uhlenbeck (BUU) transport codes are used to simulate the collisions between two nuclei. In this case we use a well documented pBUU.

Danielewicz, NPA**673**, 375 (2000)

BUU simulations involve a number of input parameters in order to correctly predict and reproduce data. Observables, such as the Double Ratio, have been shown to be sensitive to these parameters.

An in depth analysis of this sensitivity involves looking at the dependence on cluster production, test particle numbers, stiffness of the symmetry energy, momentum dependence, and mean field compressibility among others.

Double Ratio Calculation

The following figures represent the calculated n/p Double Ratios with a number of input parameters, as well as a comparison to current data. Each Double Ratio is calculated from 50 MeV/A symmetric reactions of ^{124}Sn & ^{112}Sn.
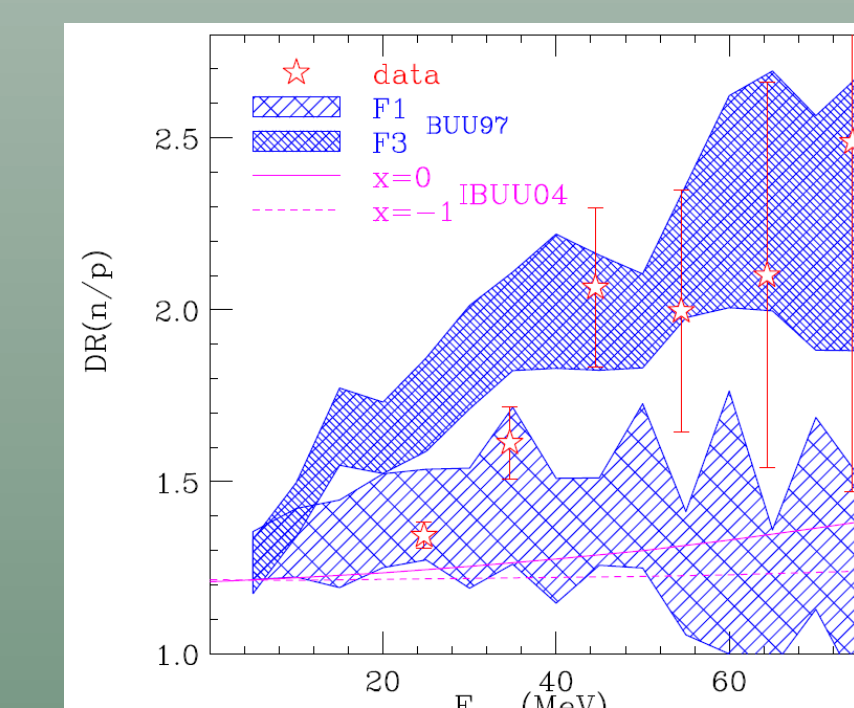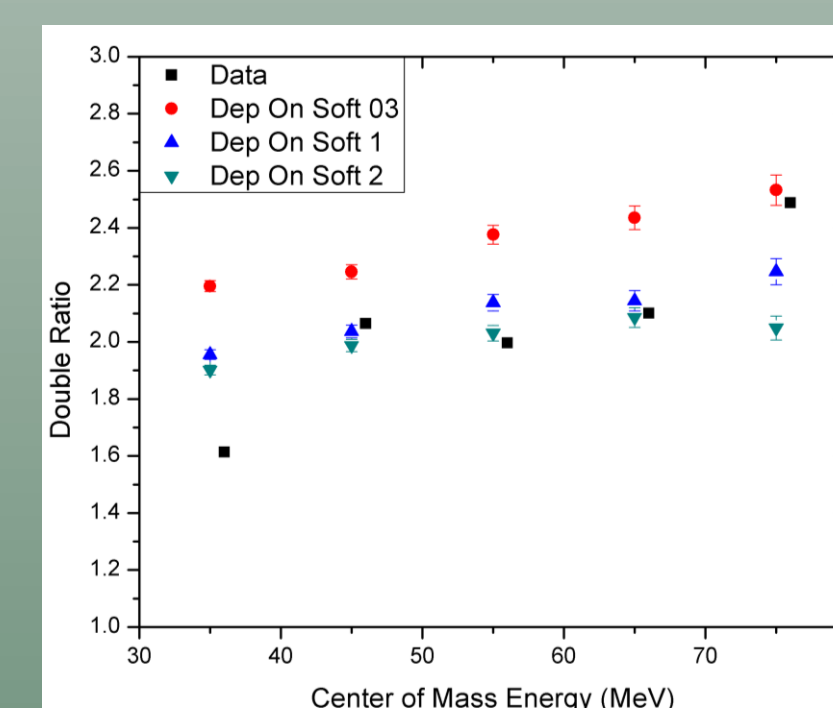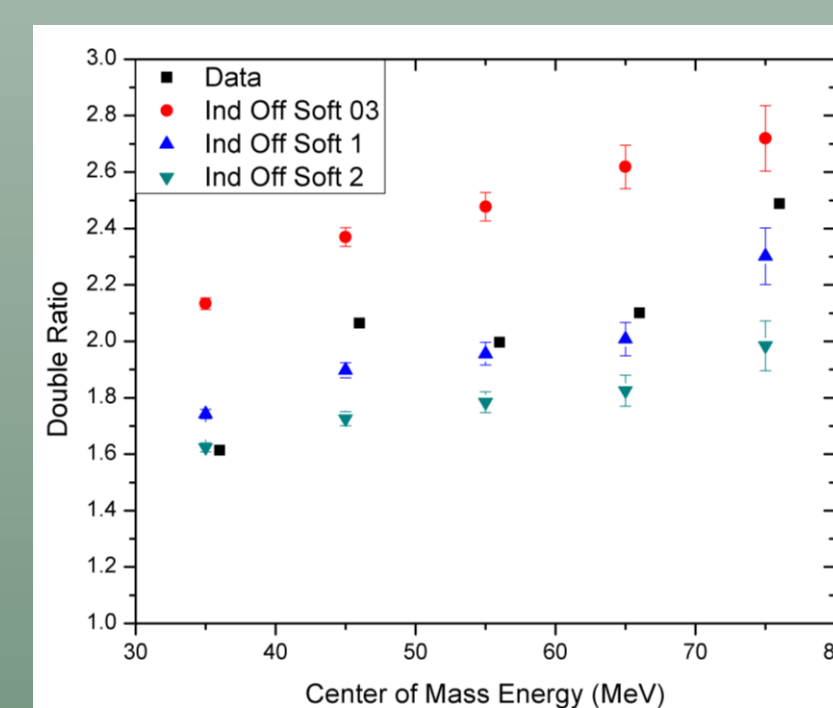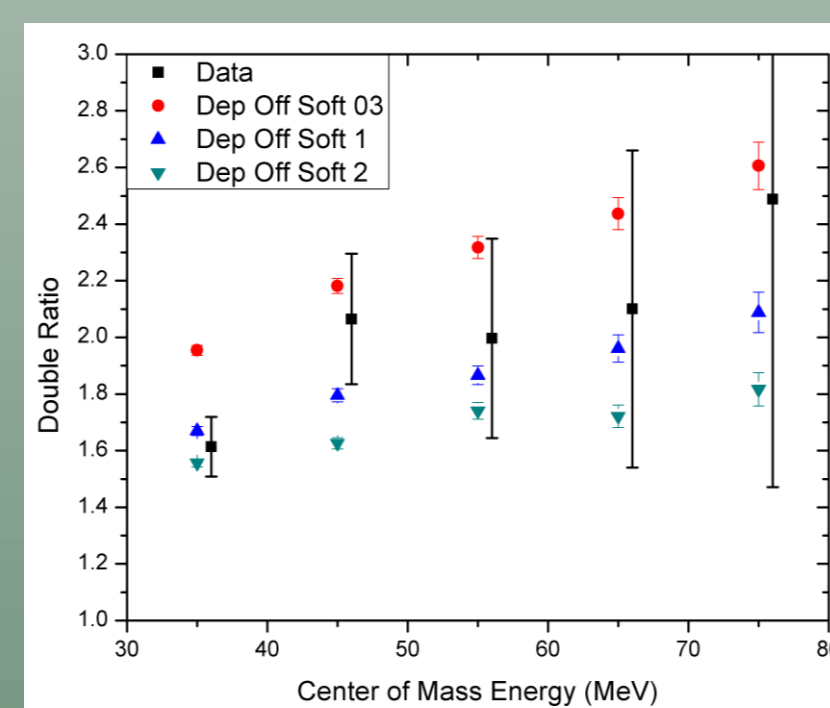
Momentum Dependent reactions where the stiffness of the density dependence of the symmetry energy is varied, show a large variance in the calculated Double Ratio. In general, the softer the symmetry energy, the larger the Double Ratio.

By switching to a Momentum Independent model, we see similar trends in the simulated values, as one would expect.

Clustering effects also cause a change in the Double Ratios. Cluster effects seem to decrease the sensitivity to the Double Ratio.

Other transport models have been used to predict the Double Ratios, including these simulations using BUU97 and iBUU04. We see a similar trend showing the softer symmetry energy having a larger Double Ratio.

Zhang, et al., PL B664(08) 145

Experimental Comparison
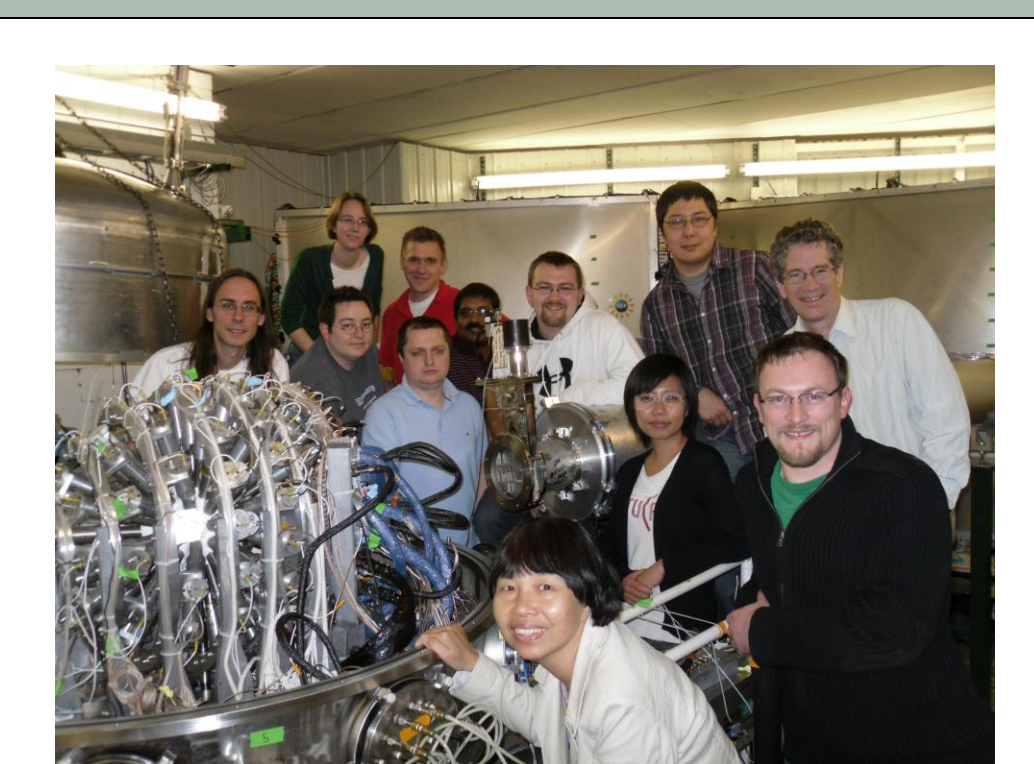
Experiment 09042, which was completed in December 2009, will help to constrain the stiffness of the symmetry energy through the measurement of neutron and proton energy spectra from symmetric ^{124}Sn and ^{112}Sn reactions at 50 and 120 MeV/u.

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