Exploring Symmetry Energy with Heavy Ion Collisions
FRIB Equation of State Working Group
August 24, 2013

Low Energy Community Meeting
NSCL/MSU August 23-24, 2013

Betty Tsang, NSCL/MSU
Symmetry Energy Project

\[ S(\rho) \,(\text{MeV}) \]

\[ \text{Density } \rho/\rho_0 \]

TAMU, NSCL, RIKEN, FRIB, INFN

GSI

FAIR
Symmetry Energy Project

Improve constraints uncertainties

n/p, t/³He, TPC experiments

NSCL, RIKEN, TAMU, INFN

GSI

FAIR

S(ρ) (MeV)

Density ρ/ρ₀
ICNT—International Collaborations in Nuclear Theory
July 15-August 9, 2013

http://www.nucl.phys.tohoku.ac.jp/nusym13/

New results and new initiatives
Updated Constraints from NuSYM13

HIC constraints are consistent with nuclear structure constraints

1. Improve uncertainties with new experiments.
2. Apply lessons learned to high energy experiments.
Experiments to improve uncertainties

1. Isospin diffusions with RIB
2. New observables: projectile-like residue
3. NSCL--$^{112,118,124}$Sn+ $^{112,118,124}$Sn
4. RIKEN--$^{109}$In+$^{112}$Sn

Timing Scintillator  Target Ladder

Projectile-like residues ID

Multiplicity vs. ZID
From A. Pagano, INFN, Catania

Time scale of N/Z equilibrations

The ratio $E_{1-23}/E_{\text{COULOMB}}$ is calculated considering for the IMFs a dilute configuration with $r_0=1.8A^{1/3}$ fm (filled histogram corresponding to about 0.05 $\rho_0$) resulting from average values of SMF calculation ($\rho=0.05-0.06$ 1/fm$^3$)

E. De Filippo et al. INPC – florence-2013 conference (oral presentation)
experiment set up to measure $Y(n)/Y(p)$ and $Y(t)/Y(^3\text{He})$ to study the symmetry energy and nucleon effective masses

Neutron walls – neutrons
Forward Array – time start
Proton Veto scintillators

LASSA – charged particles
Miniball – impact parameter
Observation:
$M_{\text{NS}} \sim 2M_{\odot}$
$R_{\text{NS}} \sim 9 \text{ km}$

Equation of State
stiff EoS at high $\rho$
softening EoS at $\rho \sim 2\rho_0$
Astrophysics and Nuclear Physics

Neutron star (Rutledge, Gulliot)

AV14+UVII

Wiringa, Fiks, & Fabrocini 1988

Equation of State

softening

EoS

at \( r \sim 2\rho_0 \)

HIC at FRIB
HIC experiments

New observables: $\pi^-/\pi^+$ ratios
New detectors

HIC at FRIB

AV14+UVII
Wiringa, Fiks, & Fabrocini 1988

$E_\text{s}$ (MeV)

$\rho$ (fm$^{-3}$)
Successful Strategies used to study the symmetry energy with Heavy Ion collisions below E/A=100 MeV

- Vary the N/Z compositions of projectile and targets
  - $^{124}\text{Sn}+^{124}\text{Sn}, \quad ^{124}\text{Sn}+^{112}\text{Sn}, \quad ^{112}\text{Sn}+^{124}\text{Sn}, \quad ^{112}\text{Sn}+^{112}\text{Sn}$

- Measure isospin sensitive observables such as isotope distributions (isospin diffusion), n/p, $t/^{3}\text{He}$ ratios, flow

- Simulate collisions with transport theory
  - *Find the symmetry energy density dependence that describes the data. Constrain the relevant input transport variables.*

Successful Strategies used to study the symmetry energy with Heavy Ion collisions with RIB

- Vary the N/Z compositions of projectile and targets e.g. $^{132}\text{Sn}+^{124}\text{Sn}$, $^{132}\text{Sn}+^{112}\text{Sn}$, $^{108}\text{Sn}+^{124}\text{Sn}$, $^{108}\text{Sn}+^{112}\text{Sn}$

- Measure isospin sensitive observables such as isotope distributions (isospin diffusion), n/p, t/3He ratios, flow

- Simulate collisions with transport theory
  - Find the symmetry energy density dependence that describes the data.

Constrain the relevant input transport variables.

Heavy Ion Collisions at high density with RIB

Old data: Au+Au, E/A=150 to 1500 MeV

New Experiments at RIB facilities

<table>
<thead>
<tr>
<th>Beam</th>
<th>tgt</th>
<th>300 MeV &amp; 200 MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>N/Z(beam)</td>
</tr>
<tr>
<td>132Sn</td>
<td>124Sn</td>
<td>1.64</td>
</tr>
<tr>
<td>132Sn</td>
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</tr>
<tr>
<td>126Sn</td>
<td>112Sn</td>
<td>1.52</td>
</tr>
</tbody>
</table>

Similar RIB reactions can be used to study isospin diffusions.

\[ ID = \mathbf{j}_n - \mathbf{j}_p = -\rho D_\delta \nabla \delta \]

ID Increase with \( \nabla \delta \)

asymmetry gradient

6.5 days approved by June RIKEN PAC
SUMMARY

• Consistent constraints at low density $\Rightarrow$ HIC is a good probe to study symmetry energy.
• Improvement of uncertainties require RIB
• Next frontier is the high density region $\Rightarrow$ observation of small NS radius and high mass suggests a softening of SE at $\rho \sim 2\rho_0$
• Next experimental frontier: HIC at $E_{\text{beam}}/A \sim 100$-$400$ MeV with RIB beams
• Need theoretical support – transport model workshop scheduled in Jan, 2014 in China.