Topics of discussions:
1. Remaining challenges of the symmetry energy constraints at low density.
   - Experiments at MSU and Riken
   - Theory uncertainties
2. Proposed Experiments to probe the high density region
   - TPC in Riken & MSU
   - GSI experiment
3. Theoretical developments in high density observables
   - What are the model uncertainties in productions of pion?
   - Are there strong correlations between t/3He and n/p ratios?
4. Can we learn from existing experimental data on pions?
5. Investigations of different observables such as particle correlations,
Lessons learned from LE measurements:

1. HI collision dynamics are complex but proved to be sensitive to density dependence of symmetry energy.

2. Problems still remain, e.g.
   - How to extract results to T=0;
   - Control of input parameters in transport models.

3. Calcs are important for paper and for PAC approval.

4. However, promising observables may not be predicted by calc’s. Experiments need to cast a wide net.

5. We benefit a lot from statistical calcs to provide insights in the beginning. What roles can statistical calculations play in higher energy HIC?

6. To create high density nuclear matter on earth, HIC is the only game in town. Before FRIB, there is Riken!
Heavy ion collisions:

\[ \frac{E}{A} (\rho, \delta) = \frac{E}{A} (\rho,0) + \delta^2 \cdot S(\rho) \quad \delta = \frac{\rho_n - \rho_p}{\rho_n + \rho_p} = \frac{N-Z}{A} \]

Results obtained in transport model simulations of Au+Au collisions to reproduce the flow ($E/A \sim 1-8$ GeV) measurements. Transport models include constraints in momentum dependence of the mean field and NN cross-sections.
\[ S = 12.5 \left( \frac{\rho}{\rho_0} \right)^{2/3} + C_{s,p} \left( \frac{\rho}{\rho_0} \right)^{\gamma_i} \]

\[ 0.4 \leq \gamma_i \leq 1 \]

\[ \text{ImQMD} \]

\[ S(\rho) \sim 31.6 \left( \frac{\rho}{\rho_0} \right)^{\gamma} \]

\[ 0.69 \leq \gamma \leq 1.05 \]

\[ \text{IBUU04} \]

\[ S = S_o + \frac{L}{3} \left( \frac{\rho_B - \rho_0}{\rho_0} \right) + \frac{K_{sym}}{18} \left( \frac{\rho_B - \rho_0}{\rho_0} \right)^2 + \ldots \]

\[ L = 3\rho_0 \left. \frac{\partial E_{sym}}{\partial \rho_B} \right|_{\rho_B=\rho_0} = \frac{3}{\rho_0} P_{sym} \]
\[ S = 12.5 \left( \frac{\rho}{\rho_0} \right)^{2/3} + C_{s,p} \left( \frac{\rho}{\rho_0} \right)^{\gamma_i} \]

\[ S(\rho) \sim 31.6 \left( \frac{\rho}{\rho_0} \right)^{\gamma} \]

Are the differences coming from model dependence?

MSU transport simulation group
Examine:

1. Momentum dependence of mean field.
2. NN Cross-section dependence.
3. Effects of effective nuclear masses, $m_n^*$ and $M_p^*$.
4. Effects of cluster formation – very important in energy near Fermi energy.
5. Production of $\pi^+$, $\pi^-$ in various codes and predictions.
Au+Au

Wed afternoon discussions
Inconsistencies in the constraints on symmetry energy at high and low density?
International Collaborations

Sn+Sn, E/A=50 MeV

RIBF

Isospin diffusions for fragments and residues with RIBF, ~2010

Riken TPC & to measure $\pi^+/$, t/3He, p/n (Nebula), spectra ratios

GSI : Land+Chimera+miniball → measure p,n spectra ratios and differential flow. ~2011
## International Collaborations

<table>
<thead>
<tr>
<th>Site</th>
<th>Probe</th>
<th>Device</th>
<th>$E_{lab/A}$ MeV</th>
<th>Main Focus</th>
<th>Reactions</th>
<th>$?$</th>
<th>FY</th>
<th>density</th>
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</thead>
<tbody>
<tr>
<td>RIBF RIKEN</td>
<td>$\pi^+\pi^-, p, n, t, ^3\text{He}$</td>
<td>TPC NEBULA</td>
<td>200-300</td>
<td>$E_{sym}$</td>
<td>$^{132}\text{Sn}+^{124}\text{Sn}, ^{108}\text{Sn}+^{112}\text{Sn}, ^{52}\text{Ca}+^{48}\text{Ca}, ^{36}\text{Ca}+^{40}\text{Ca}$</td>
<td>Y</td>
<td>2013-2015</td>
<td>$\approx 2\rho_0$</td>
</tr>
<tr>
<td>RIBF RIKEN</td>
<td>$\pi^+\pi^-, p, n, t, ^3\text{He}$</td>
<td>TPC NEBULA</td>
<td>200-300</td>
<td>$\sigma_{nn}, \sigma_{pp}, \sigma_{np}$</td>
<td>$^{100}\text{Zr}+^{40}\text{Ca}, ^{100}\text{Ag}+^{40}\text{Ca}, ^{107}\text{Sn}+^{40}\text{Ca}, ^{127}\text{Sn}+^{40}\text{Ca}$</td>
<td>Y</td>
<td>2016-2017</td>
<td>$\approx 2\rho_0$</td>
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<tr>
<td>GSI</td>
<td>$p, n$</td>
<td>LAND, FOPI, Miniball CHIMERA</td>
<td>400-800</td>
<td>$E_{sym}$</td>
<td>$^{124,112}\text{Sn}+^{124,112}\text{Sn}$</td>
<td>Y</td>
<td>2011</td>
<td>2.5-3$\rho_0$</td>
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<tr>
<td>NSCL</td>
<td>$\pi^+\pi^-$</td>
<td>AT-TPC</td>
<td>120-170</td>
<td>$E_{sym}$</td>
<td>$^{124,112}\text{Sn}+^{124,112}\text{Sn}$</td>
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<td>2014-2016</td>
<td>1-2$\rho_0$</td>
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<tr>
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<td>$p, n$</td>
<td>LASSA N-wall</td>
<td>50-150</td>
<td>$E_{sym}$</td>
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<td>2009-2012</td>
<td>0.5-1.6$\rho_0$</td>
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<tr>
<td>NSCL</td>
<td></td>
<td></td>
<td>35-70</td>
<td>$E_{sym}$</td>
<td>$^{124,112}\text{Sn}+^{124,112}\text{Sn}, ^{108,112,124,132}\text{Sn}+^{124,112}\text{Sn}, ^{56,58,64,68}\text{Ni}+^{58,64}\text{Ni}, ^{40,48}\text{Ca}+^{40,48}\text{Ca}$</td>
<td>N</td>
<td>2009-2012</td>
<td>$\approx 0.5\rho_0$</td>
</tr>
</tbody>
</table>
International Collaborations; cross-disciplinary, theorists + experimentalists

USA
NSCL MSU, USA: Betty Tsang, Bill Lynch, Abigail Bickley, Gary Westfall, Pawel Danielewicz, Edward Brown, Andrew Steiner
Western Michigan University: Michael Famiano
Texas A&M University: Sherry Yennello
Smith College USA: Malgorzata Pfabe

Japan
Kyoto University: Tetsuya Murakami
Riken: Hiroshi Sakurai, Shunji Nishimura, Yoichi Nakai, Atsushi Taketani
Rikkyo University: Jiro Murata, Kazuo Ieki
Tohoku University: Akira Ono

Western Europe
GSI, Germany: Wolfgang Trautmann, Yvonne Leifels, Marcus Bleicher
Daresbury Laboratory, United Kingdom: Roy Lemmon
INFN Catania, Italy: Giuseppe Verde, Angelo Pagano, Paulo Russotto, Massimo di Toro, Maria Colonna, Aldo Bonasera, Vincenzo Greco
GANIL, France: Abdou Chbihi, John Frankland, Jean-Pierre Wieleczko
SUBATECH FR: Christoph Harnack

China
China Institute of Atomic Energy: Yingxun Zhang, Zhuxia Li
Brazil:
Sergio Souza, Paul Donangelo, Brett Carlson
Isospin diffusions for fragments and residues with RIBF, ~2010

Riken TPC & to measure $\pi^+/\pi$, t/3He, p/n (Nebula), spectra ratios