Decomposition of sensitivity of the symmetry energy observables

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Helei Liu, Gaochan Yong and Dehua Wen, arXiv:1406,6504

Outline

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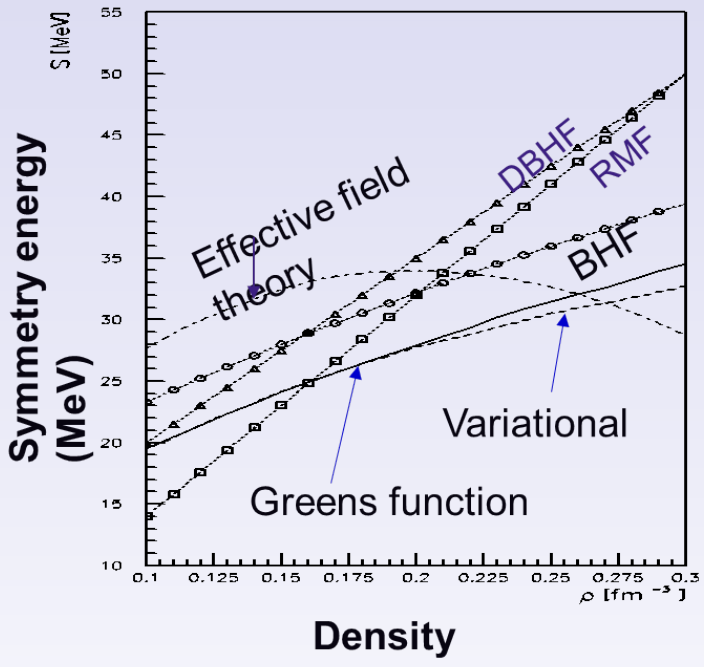
Why study symmetry energy

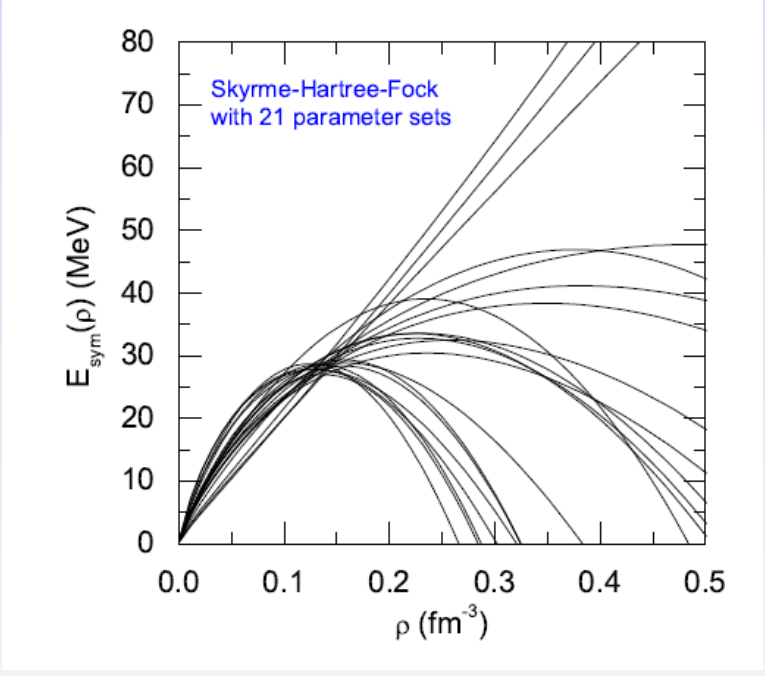
- Crucial roles of nuclear symmetry energy in astrophysics and nuclear physics
  - Determines the structure of a neutron star, governs its thermal evolution...
  - Understanding the structure of radioactive nuclei
  - The reaction mechanism of heavy-ion collisions
  - ...

Why study symmetry energy

- Contradictory results of different calculations



From different many-body theories

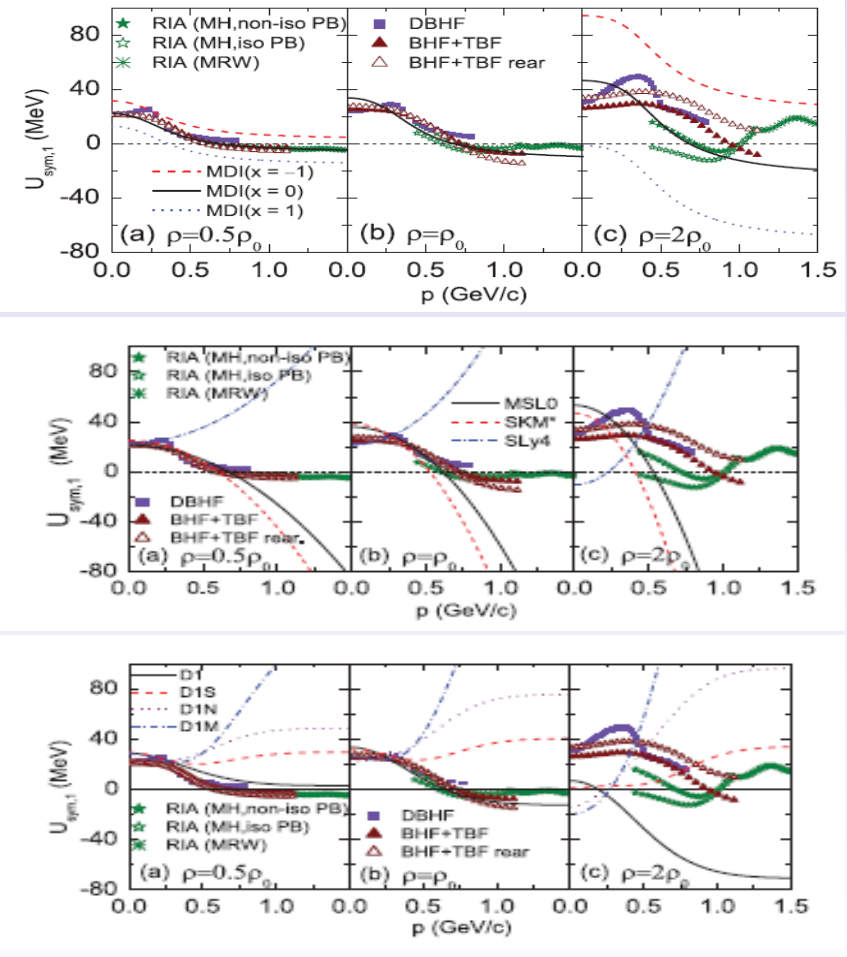


From one approach but different parameters

B.A.Li, L.W.Chen, Che Ming Ko, Phys. Rep. 464, 113 (2008)

Why study symmetry energy

- large uncertainties of symmetry potential



Poorly known especially at high density and high momentum

Reducing the uncertainties on the constrains of $E_{sym}(\rho)$ is thus of critical importance and remains a big challenge!

R.Chen, B.Cai, L.W.Chen, B.A.Li, Phys.Rev.C85,024305(2012)

How to study SE in HIC

We use isospin dependent Boltzmann-Uehling Uhlenbeck model(IBUU)

$$(\frac{\partial}{\partial t} + \frac{\vec{p}}{m}\nabla_r U \cdot \nabla_p) f(\vec{r}, \vec{p}, t) = I(f)$$

Collision term:

$$\begin{aligned} I(f) =& \frac{4}{(2\pi)^3} \int\int d\vec{p}_2 d\vec{p}_3 \int d\Omega |\nu_{12}| \frac{d\sigma}{d\Omega}(\vec{p}_2 - \vec{p}_4)\delta(\vec{p}_1 + \vec{p}_2 - \vec{p}_3 - \vec{p}_4)\times \\ & \{f(\vec{r}, \vec{p}_3, t) f(\vec{r}, \vec{p}_4, t)[1 - f(\vec{r}, \vec{p}_1), t][1 - f(\vec{r}, \vec{p}, t)] - \\ & f(\vec{r}, \vec{p}_1, t) f(\vec{r}, \vec{p}_2, t)[1 - f(\vec{r}, \vec{p}_3), t][1 - f(\vec{r}, \vec{p}_4, t)]\} \end{aligned}$$

observables of density-dependent SE

- Pre-equilibrium n/p ratio
- Neutron-proton differential transverse flow
- Proton differential elliptic flow
- Double neutron-proton differential transverse flow
- Isospin fractionation
- Isospin diffusion
- π yields and π^-/π^+ ratio

.....

Outline

Single particle potential

isospin-dependent single particle potential:

$$U(\rho,\delta,\tau) = U_0(\rho) + U_{sym}(\rho,\delta,\tau)$$

isoscalar potential:

$$U_0(\rho) = -356u + 303u^{7/6}$$

G.F.Bertsch et al, PRC, 29, 673 (1984)

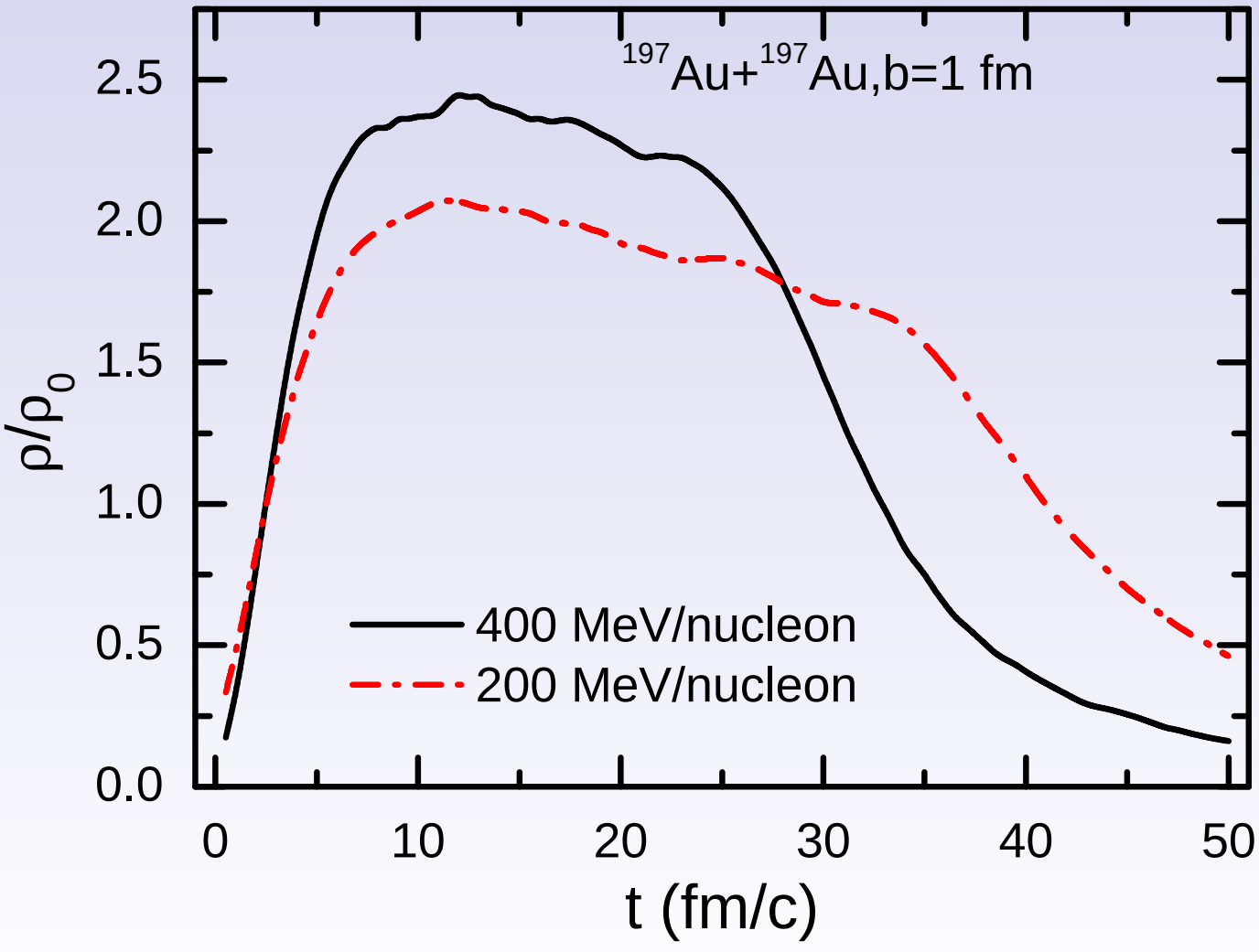
isovector potential:

$$\begin{aligned} U_{sym}^{x=1}(\rho,\delta,\tau) =& 4\tau\delta(3.08 + 39.6u - 29.2u^2 + 5.68u^3 - 0.52u^4) \\ & - \delta^2(3.08 + 29.2u^2 - 11.4u^3 + 1.57u^4) \end{aligned}$$

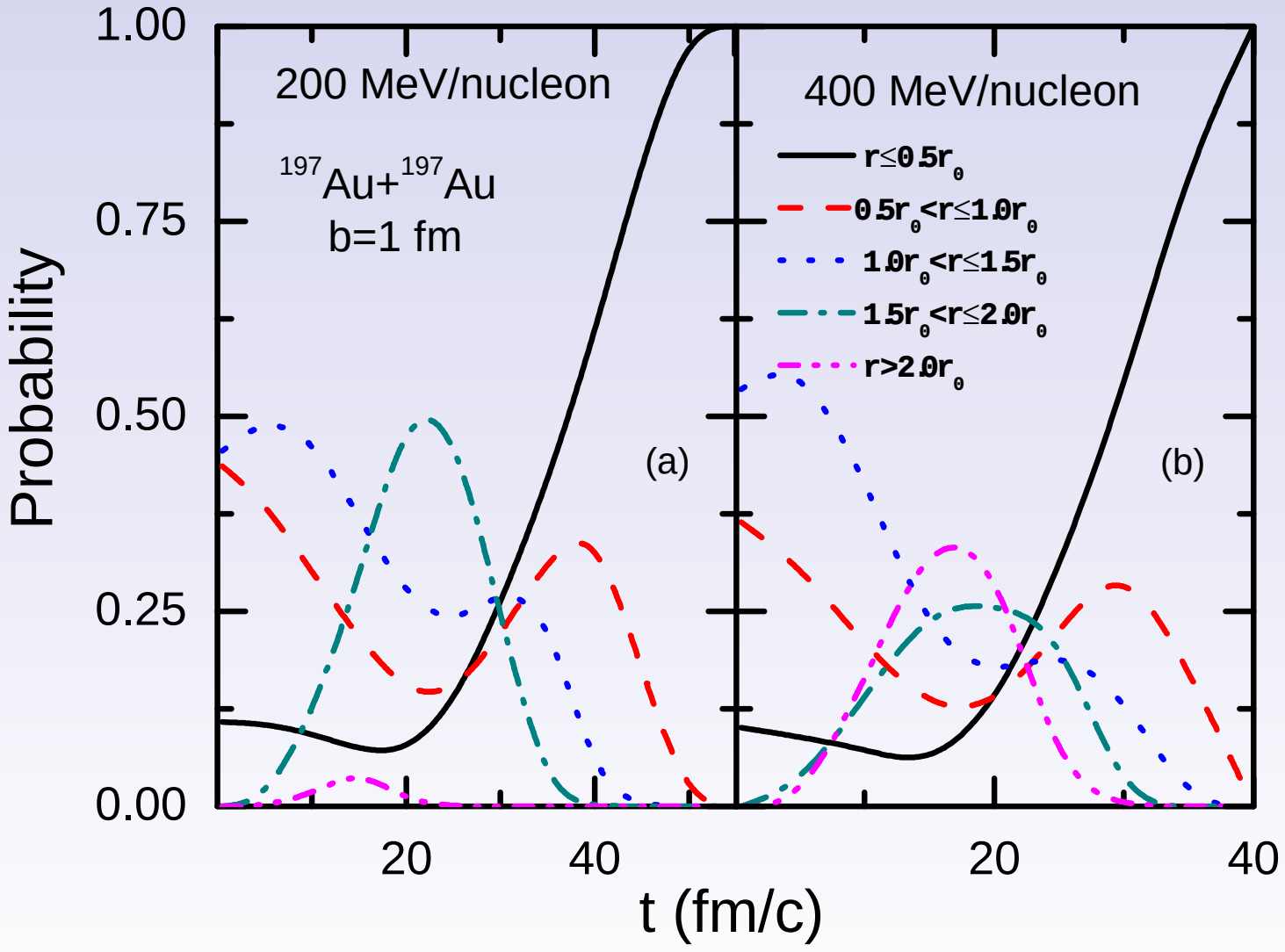
$$\begin{aligned} U_{sym}^{x=0}(\rho,\delta,\tau) =& 4\tau\delta(1.27 + 25.4u - 9.31u^2 + 2.17u^3 - 0.21u^4) \\ & - \delta^2(1.27 + 9.31u^2 - 4.33u^3 + 0.63u^4) \end{aligned}$$

B.A.Li et al., PRC, 69, 011603 (2004)

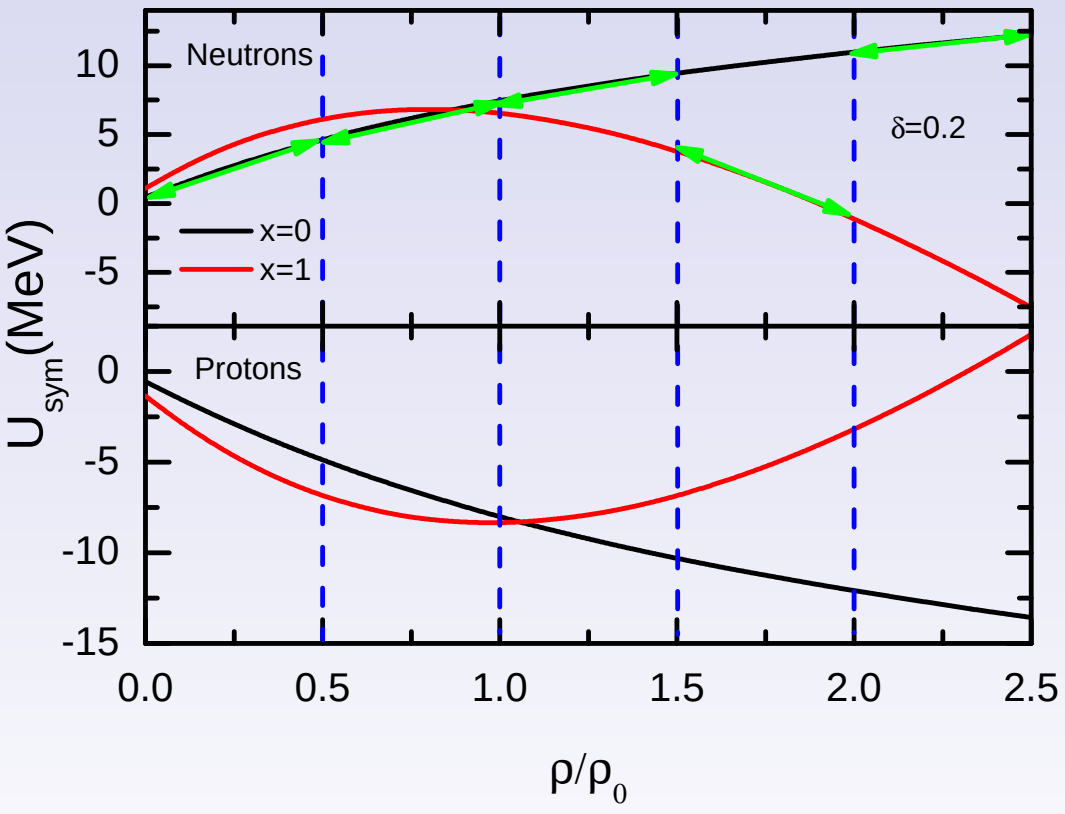
Evolution of baryon density



Distribution probability of baryon



Methodology



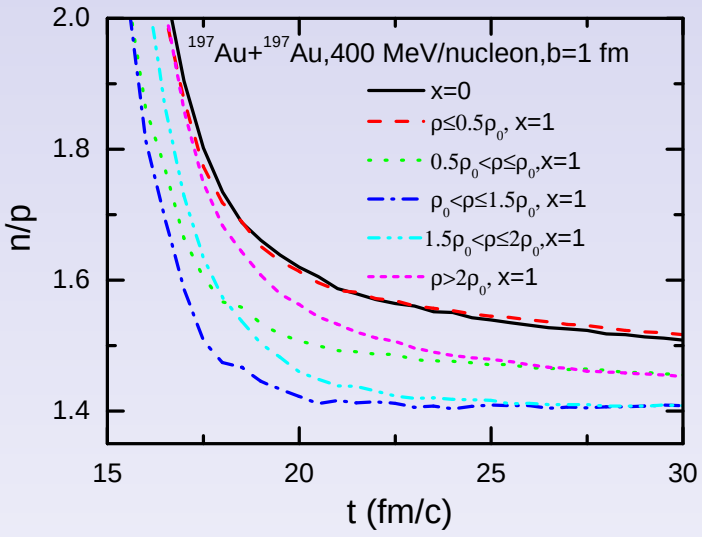
R_0: the standard value from $x = 0$.

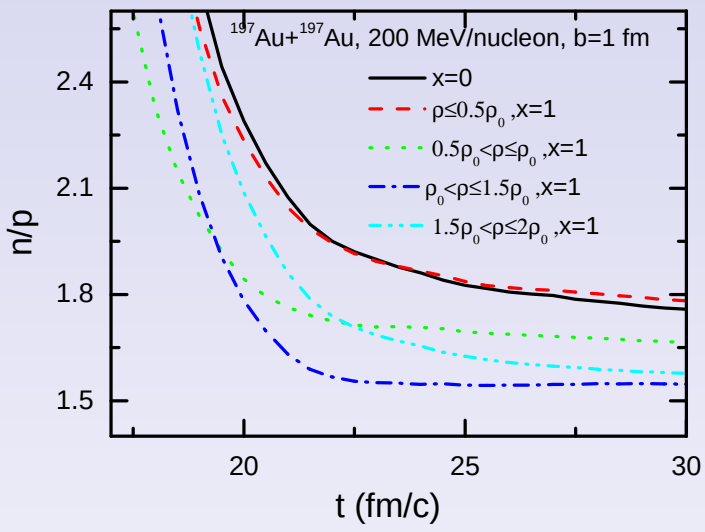
R_i: the value for switching the symmetry potential in certain density region.

$(R_i - R_0)/R_0$ stands for the sensitivity.

Outline

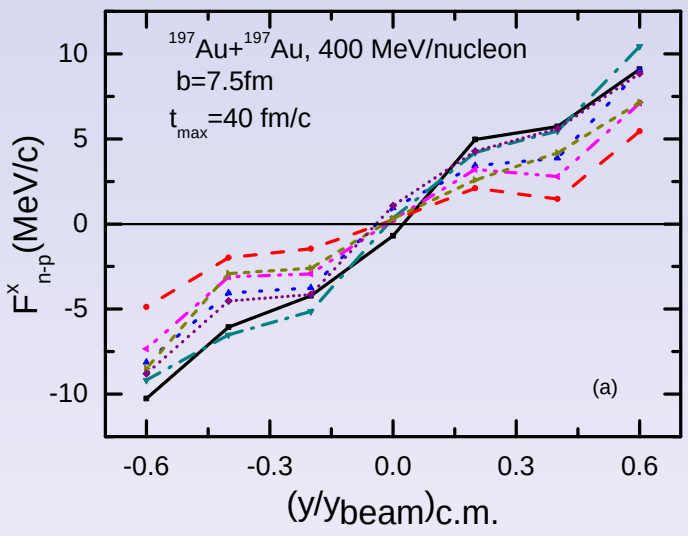
Decomposition of sensitivity: free n/p

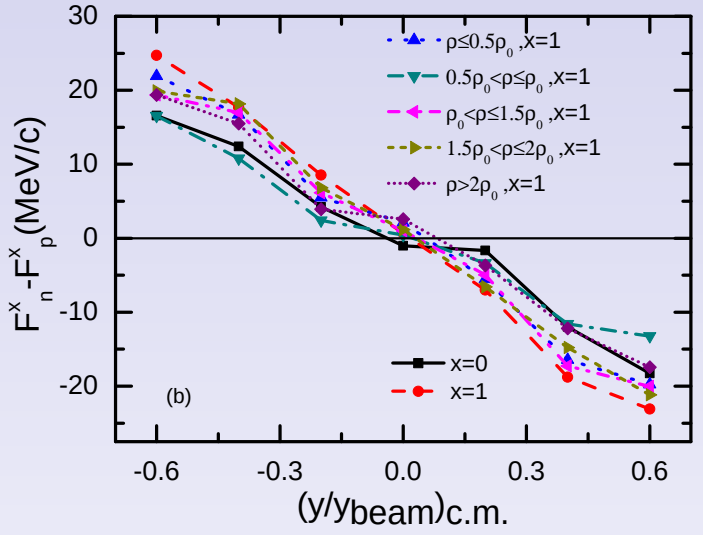




Most sensitive density points are about $1.5\rho_0$ for n/p at 400 or 200 MeV per nucleon beam energies

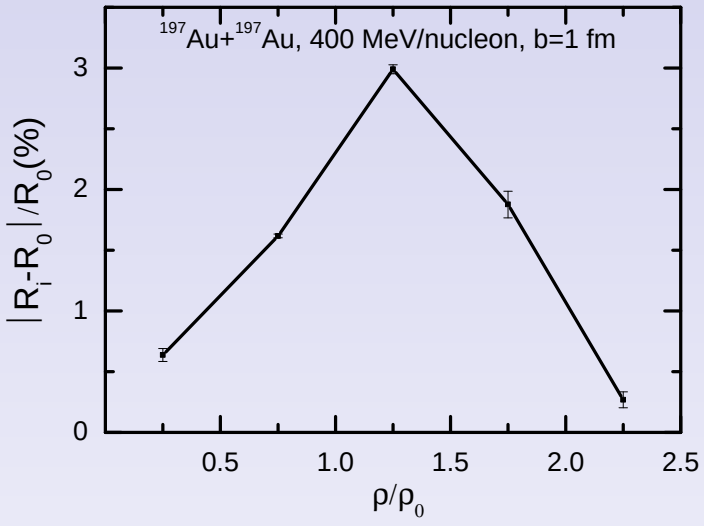
Decomposition of sensitivity: flow

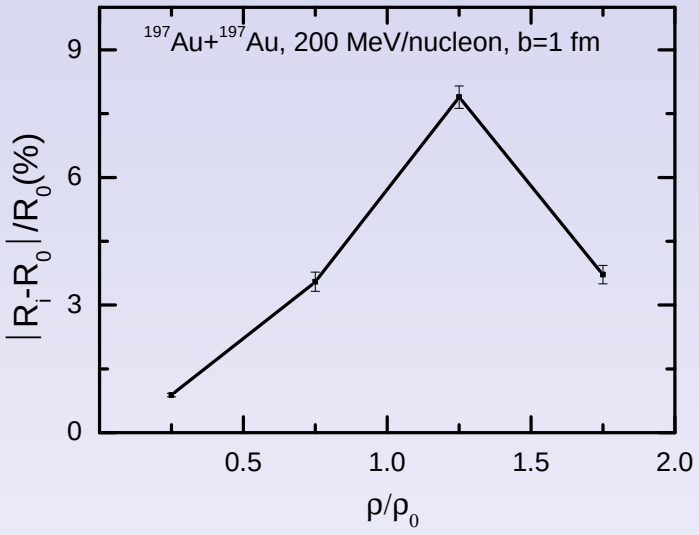




Neutron-proton differential transverse flow is most sensitive at $1 \sim 1.5\rho_0$

Decomposition of sensitivity: pion ratio





Most sensitive density points are about $1.5\rho_0$ for pion at 400 or 200 MeV per nucleon beam energies

Outline

Conclusions

- Can not probe SE at maximal density
- Both pion and nucleon emissions are affected by low-density SE
- Most sensitive density points are about $1.5\rho_0$ for pion and nucleons at 400 or 200 MeV per nucleon beam energies.

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Outlook

- There should be more methods to probe the sensitivity of symmetry energy observables, our way is not unique
- Only the density region have been explored, the sensitivity for symmetry energy observables in momentum region is also urgent need us to work out
- The analytical sensitivity of the symmetry energy observables decomposition are expected to be useful for extracting reliable information about the symmetry energy of neutron-rich nuclear matter from experimental data

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Thank you very much !