System Size and Beam Energy Effects on Probing the Nuclear Symmetry Energy with Pion Ratio

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Outline

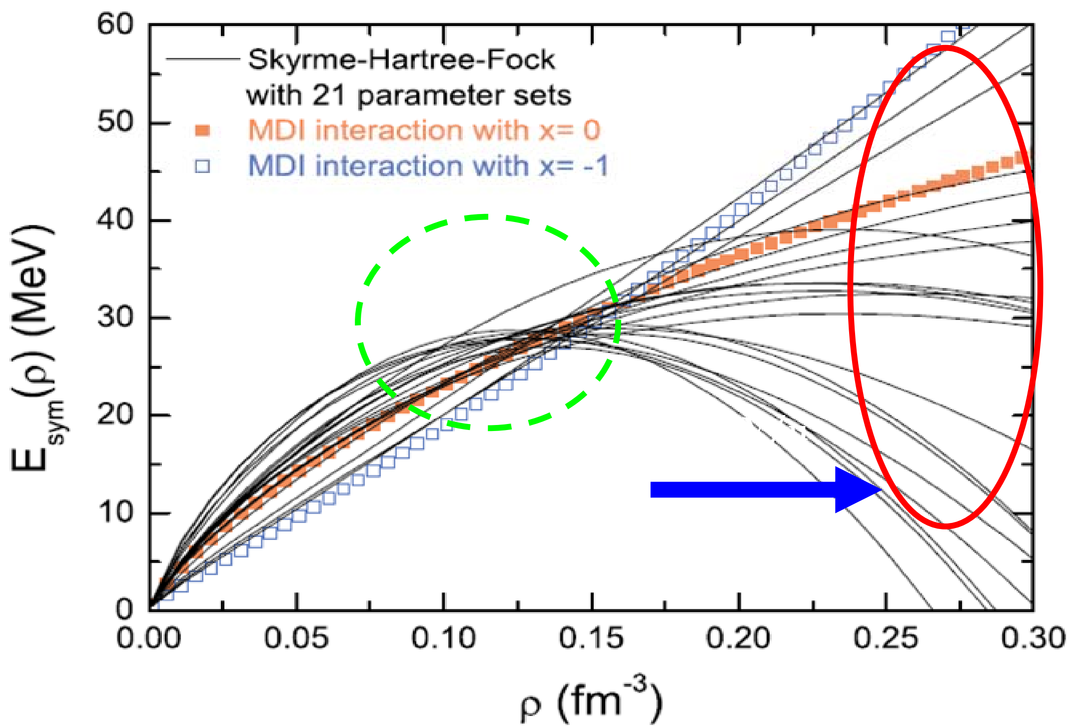
- Brief Introduction on nuclear symmetry energy
- π^-/π^+ probe to $E_{sym}(\rho)$ at high densities
- Main results and discussions
- Conclusion and further experiments

EOS of Asymmetric Nuclear Matter and Symmetry Energy

$$E(\rho,\delta)=E(\rho,0)+E_{\mathrm{sym}}(\rho)\delta^2+O(\delta^4),\quad \delta=(\rho_n-\rho_p)/\rho$$

$$E_{\mathrm{sym}}(\rho)\equiv\frac{1}{2}\frac{\partial^2 E(\rho,\delta)}{\partial\delta^2}$$

Most progress has been made to constrain the behavior of density dependence of symmetry energy at sub-saturation densities while little is know at supra-saturation densities!



A Conservative Conclusion about Symmetry Energy at Sub-saturation Densities

- ✓ **Isospin diffusion experiment at MSU**
- ✓ **Neutron skin in ^{208}Pb from hadronic probes**
- ✓ **Isoscaling in heavy-ion reactions**
- ✓ **Isospin dependence of giant monopole resonance**

$$31.6(\rho/\rho_0)^{0.69} \leqslant E_{sym}(\rho) \leqslant 31.6(\rho/\rho_0)^{1.05}$$

B.A. Li, L.W. Chen and C.M. Ko, Phys. Rep. 464 (2008) 113

A Promising Probe at Super-saturation Densities
π^-/π^+ ratio

Isobaric Model

$$\pi^-/\pi^+ = (5N^2+NZ)/(5Z^2+NZ) \approx (N/Z)^2_{dens}$$

Δ (1232) resonance model in first chance NN scattering (neglect re-scattering and re-absorption)

Thermal Model

$$\frac{\pi^-}{\pi^+} \propto \exp[2(\mu_n - \mu_p)/kT]$$

$$\mu_n - \mu_p = (V_{asy}^n - V_{asy}^p)\delta - V_{Coul} + kT\{\ln\frac{\rho_n}{\rho_p} + \sum_m \frac{m+1}{m} b_m (\frac{1}{2}\lambda_T^3)^m (\rho_n^m - \rho_p^m)\}$$

An Isospin and Momentum Dependent Transport Model

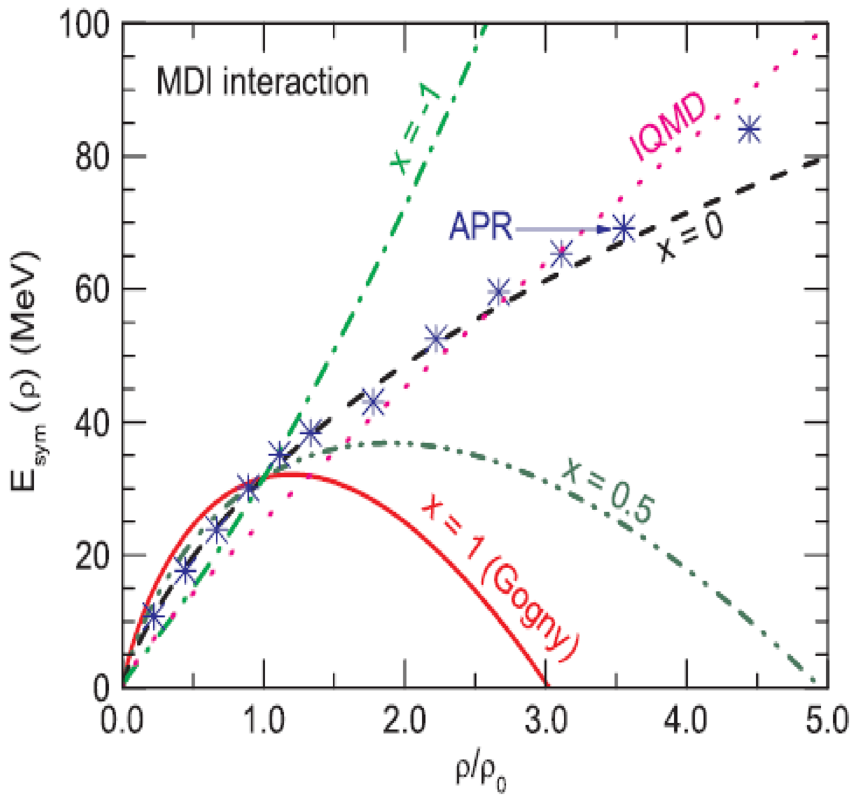
IBUU04

The isospin and momentum-dependent mean- field potential (MDI) is followed by:

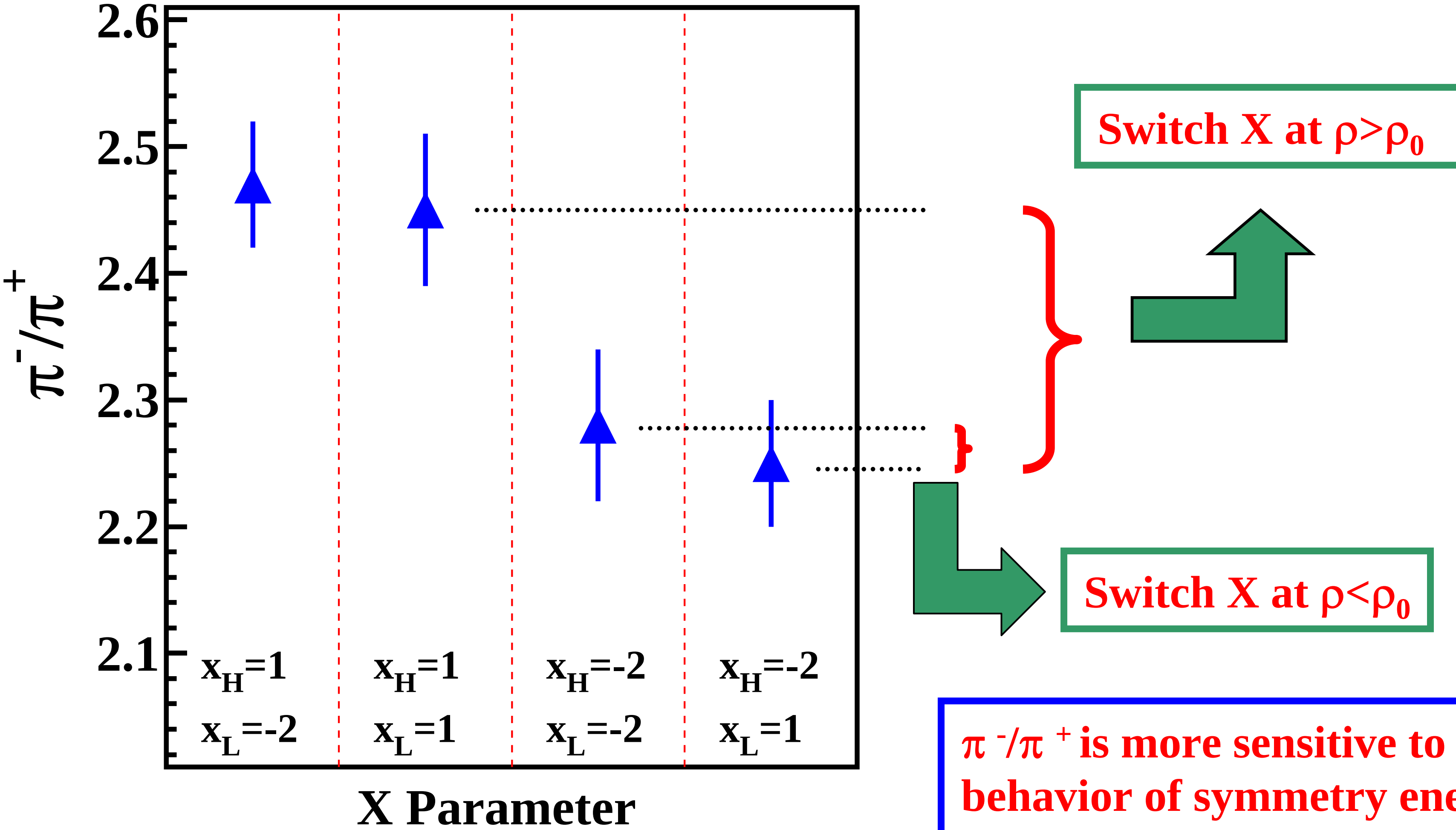
$$U(\rho, \delta, \mathbf{p}, \tau) = A_u(x)\frac{\rho_{\tau'}}{\rho_0} + A_l(x)\frac{\rho_\tau}{\rho_0} + B\left(\frac{\rho}{\rho_0}\right)^\sigma (1 - x\delta^2) - 8x\tau\frac{B}{\sigma+1}\frac{\rho^{\sigma-1}}{\rho_0^\sigma}\delta\rho_{\tau'} + \frac{2C_{\tau,\tau}}{\rho_0}\int d^3\mathbf{p}'\frac{f_\tau(\mathbf{r},\mathbf{p}')}{1+(\mathbf{p}-\mathbf{p}')^2/\Lambda^2} + \frac{2C_{\tau,\tau'}}{\rho_0}\int d^3\mathbf{p}'\frac{f_{\tau'}(\mathbf{r},\mathbf{p}')}{1+(\mathbf{p}-\mathbf{p}')^2/\Lambda^2}. \quad (1)$$

C. B. Das, S. Das Gupta, C. Gale, B. A. Li PRC67(2003) 034611

The parameter x above is introduced to mimic the density dependence of symmetry energy.

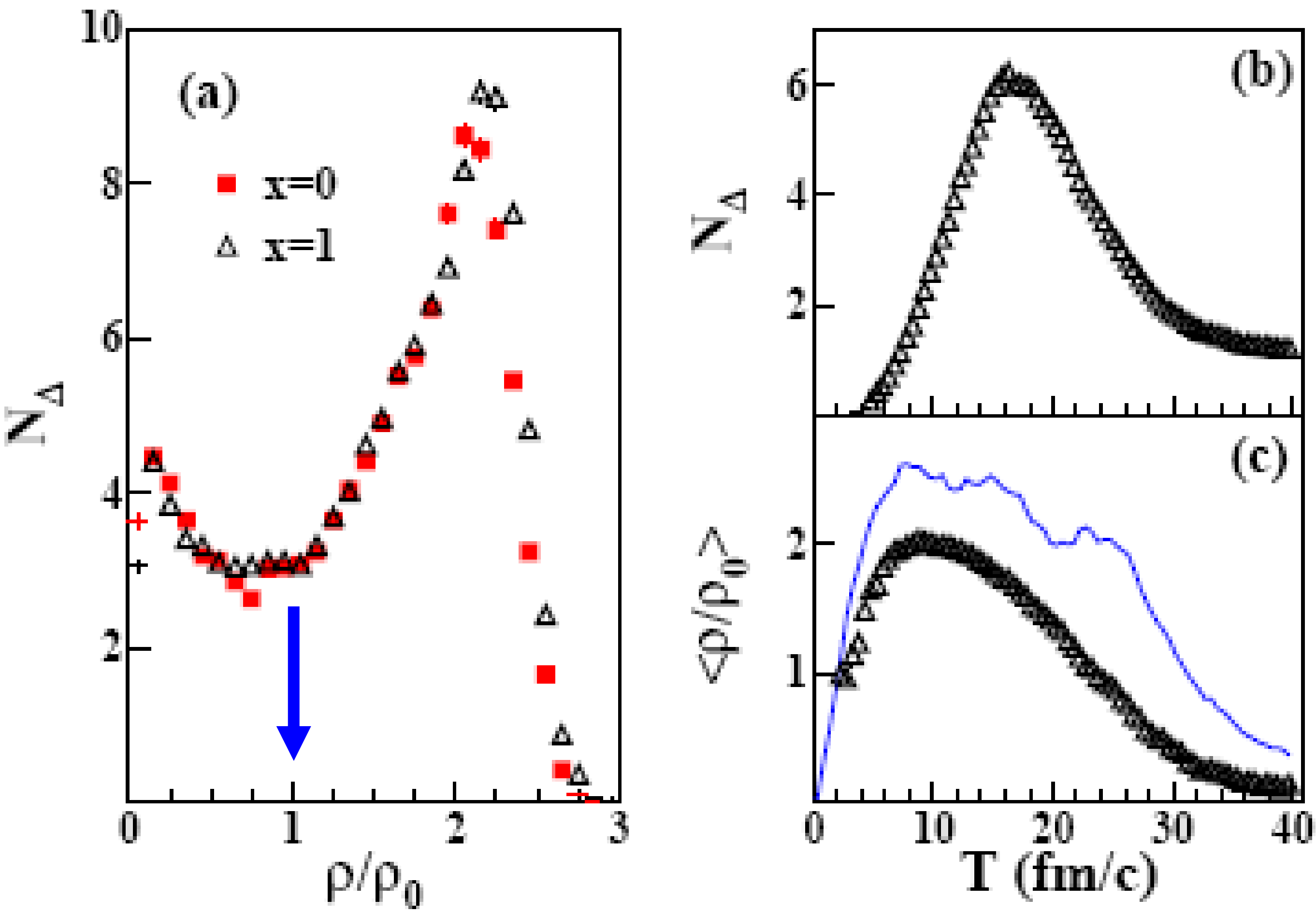


π^-/π^+ Probe the Behavior of Symmetry Energy at Supra-saturation Densities



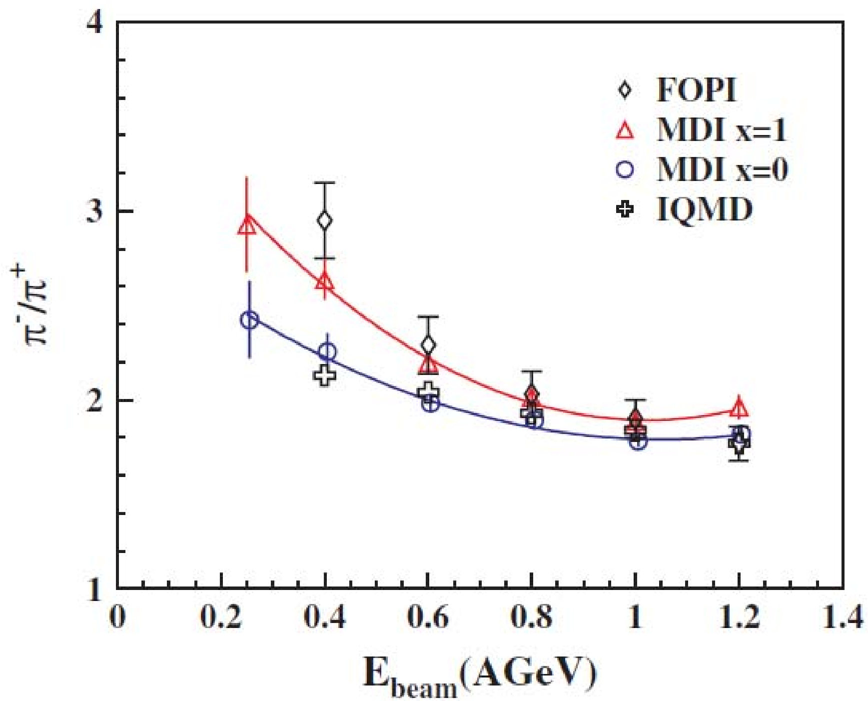
π^-/π^+ is more sensitive to the behavior of symmetry energy at supra-saturation densities !

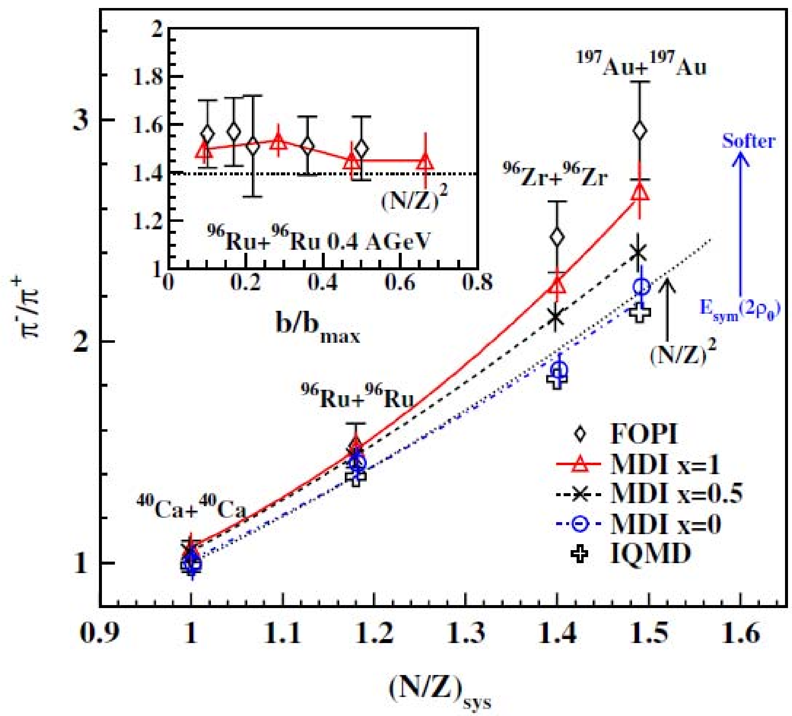
π^-/π^+ Probe the Behavior of Symmetry Energy at Supra-saturation Densities



Pions are mainly produced at higher densities !

Circumstantial Evidence for a Soft Nuclear Symmetry Energy at Supra-saturation Densities

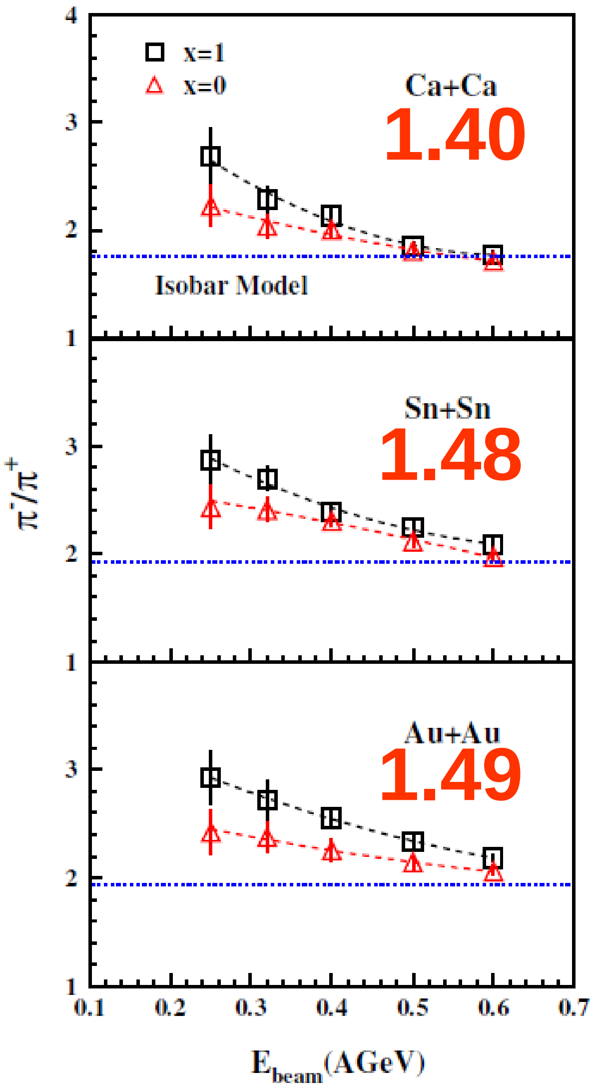




A rather soft nuclear symmetry energy is more favored to FOPI data!!!

Z.G. Xiao, B.A. Li, L.W. Chen, G.C. Yong and M. Zhang, Phys. Rev. Lett. 102 (2009) 062502

Probing the Behavior of Symmetry Energy with the Same Neutron/proton Ratio but Different Masses



$$R= (\pi^-/\pi^+)_{x=1} / (\pi^-/\pi^+)_{x=0}$$

1. The π^-/π^+ ratio increases with decreasing the beam energy and exceeds the isobar model prediction.

2. The sensitivity R decreases as the beam energy increases.

3. The sensitivity R increases from light to heavy system at a fixed beam energy.

Probing the Behavior of Symmetry Energy with the Same Neutron/proton Ratio but Different Masses

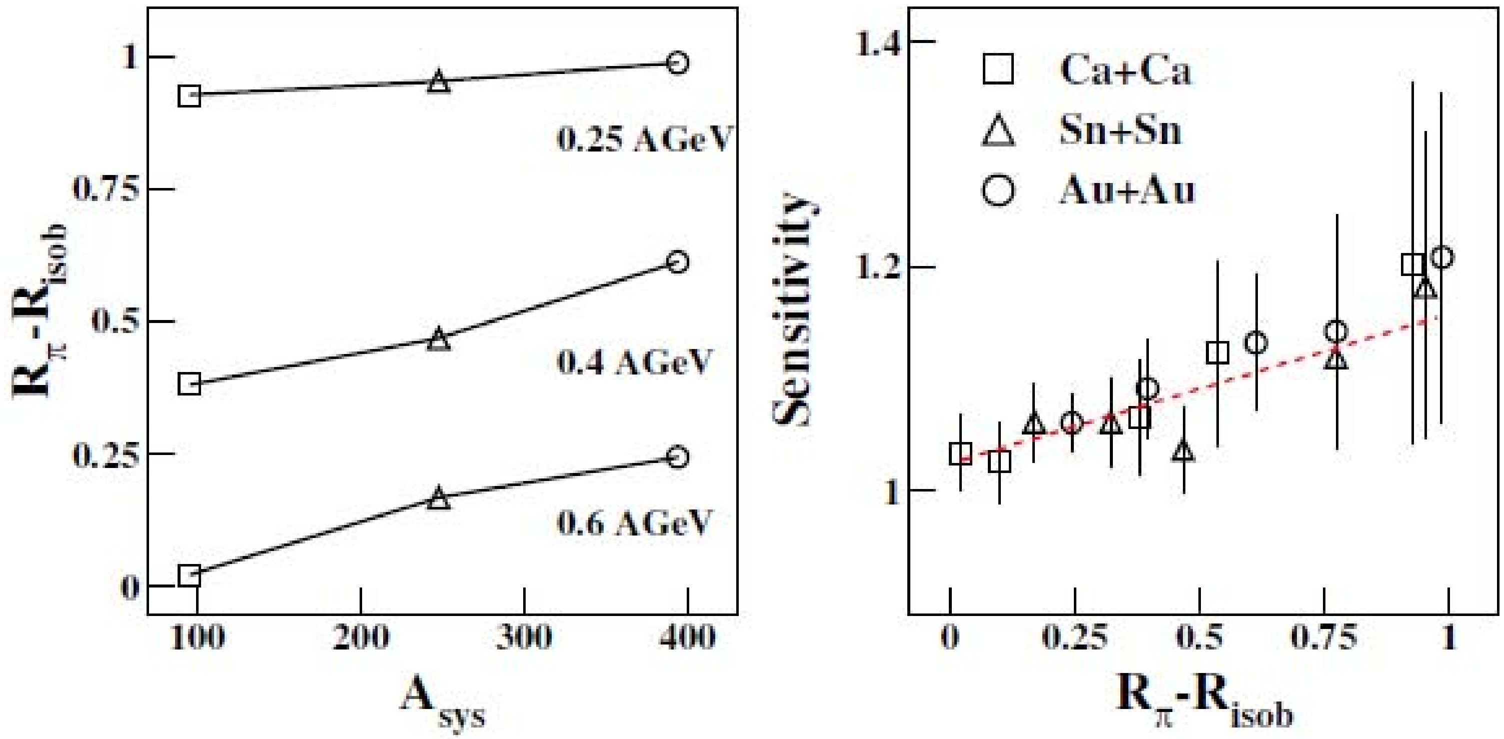
The sensitivity R is related to the degree of *isospin fractionation !*

***Definition*: the participant region is more neutron-rich (poor) if the value of the symmetry energy at high densities is lower (higher).**

√ Lower beam energy and lager system size can result in a higher central density, a much longer duration of the reaction thus a larger isospin fractionation.

Therefore, results suggest that heavy systems with larger *N*/*Z* are preferential to constrain the behavior of symmetry energy at supra-saturation densities with pion ratio near the threshold of pion production in experiment.

Quantitative Relation between Degree of Isospin Fractionation and Sensitivity



To the first order of approximation, we define the quality $R_\pi - R_{isob}$ to describe the degree of isospin fractionation.

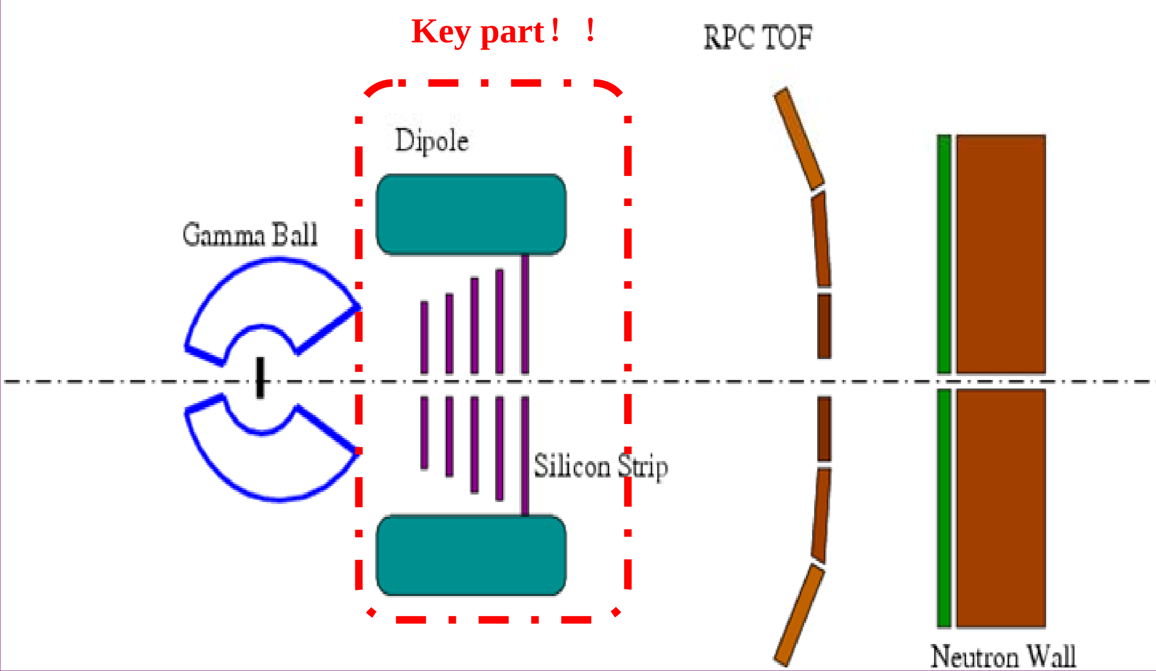
Conclusion and Further Experiment

- Heavy colliding systems are recommended in experiment to probe the behavior of symmetry energy at supra-saturation densities with the beam energy near the threshold of pion production.

- External Target Facility at HIRFL-CSR in China provide good opportunities to study EOS of asymmetric nuclear matter at sub-GeV energy regime.

External Target Facility — Phase Ⅰ- Ⅱ Complex at HIRFL-CSR

To be constructed within 4 years if approved.



NEW DETECTORS

- **γ-Ball**
  CsI (Tl) Array
- **MWPC**
  Inside Dipole
- **Si-Strip Array**
  Inside Dipole
- **TPC**
  Target Region

POSSIBLE PHYSICS

RIB Physics **√ EOS of Asymmetric Nuclear Matter** **High Baryon Density Matter**


清華園
Thank you !