BULK NUCLEAR PROPERTIES FROM PION YIELDS AND OTHER DATA

Jun Hong
Advisor: Pawel Danielewicz
International Collaborations in Nuclear Theory (ICNT)
8/2/2013

Outline

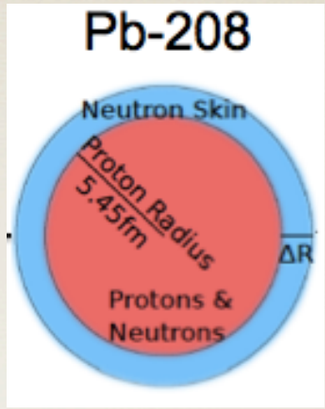
- Introduction
  - HIC and pion yields
  - Theoretical model
- Exploration of nuclear mean field
  - Challenges in predicting pion yields
  - Another observable: elliptic flow
- Exploration of symmetry energy
  - Puzzle: predictions of theoretical models
  - Our calculations
- Discussion & Conclusions

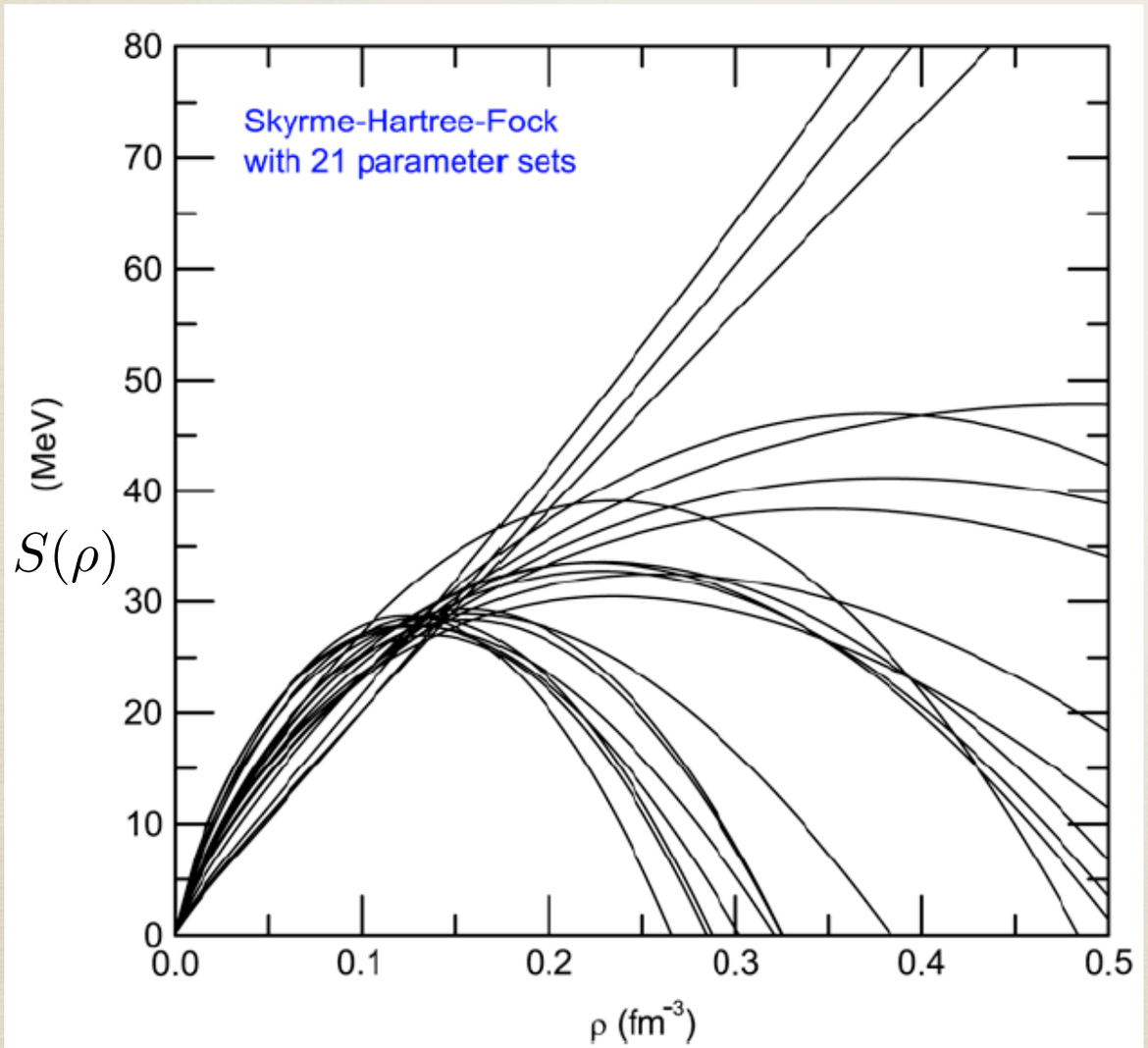
For *asymmetric* nuclear matter, EOS is not well established.

$$\frac{E}{A}(\rho,\alpha) = \frac{E}{A}(\rho,0) + S(\rho)\alpha^2 + O(\alpha^4) + \cdots$$

$$\alpha = \frac{\rho_n - \rho_p}{\rho_n + \rho_p}$$

symmetry energy





B.A. Li et al., Phys. Rep. 464.113(2008)

Heavy Ion Collision (HIC) and Pion Yields

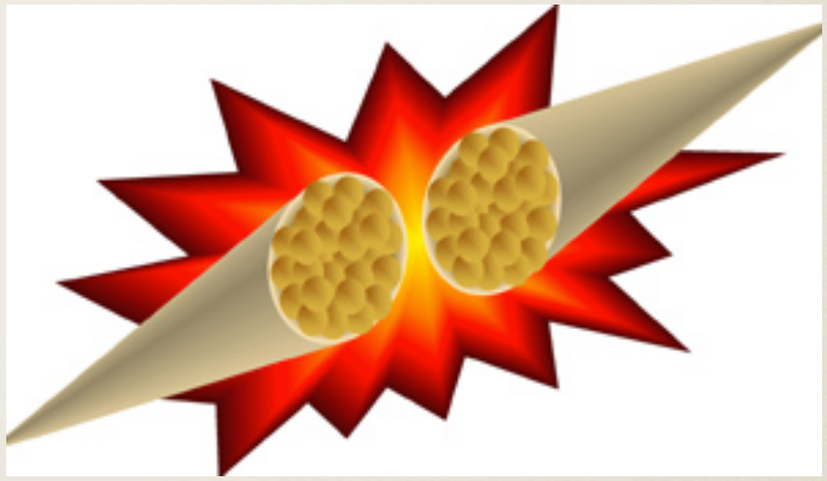
- Charged pion ratio has been proposed as a sensitive probe of high density behavior of symmetry energy.

B. A. Li, Phys. Rev. Lett. 88 (2002) 192701

$$NN \to N\Delta$$

$$\Delta \to N\pi$$

$$n \to \pi^- \qquad p \to \pi^+$$



$$(\pi^-/\pi^+)_{res} \equiv (5N^2 + NZ)/(5Z^2 + NZ) \approx (N/Z)^2_{dense}$$

BUU Transport Model

BUU transport model solves the Boltzmann equations for the space and momentum distribution f of all particles.

$$\frac{\partial f}{\partial t} + \frac{\partial \epsilon}{\partial \vec{p}} \frac{\partial f}{\partial \vec{r}} - \frac{\partial \epsilon}{\partial \vec{r}} \frac{\partial f}{\partial \vec{p}} = \mathcal{K}^{<}(1 \pm f) - \mathcal{K}^{>} f$$

$\mathcal{K}^{<}, \mathcal{K}^{>}$ are production and removal rates.

ϵ is the single particle energy.

$$\epsilon = \sqrt{p^2 + m^2} + U(p, \rho)$$

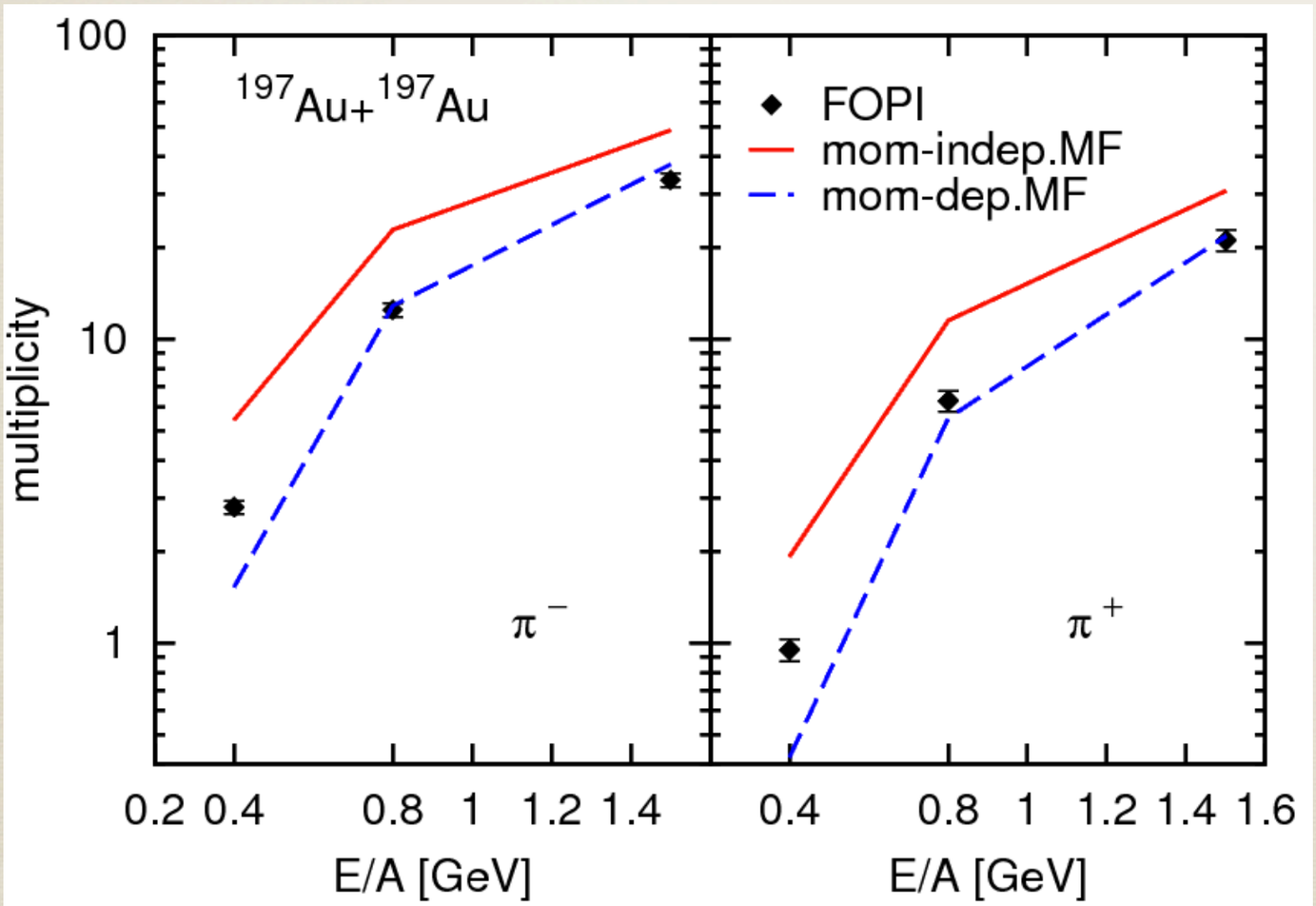
Momentum-dependent NMF in BUU

$$E = \int d\vec{r}\tilde{e} + E_S + E_T + E_{coul}$$

$$\tilde{e} = \int \frac{d\vec{p}}{(2\pi)^3} f(\vec{p})(m + \int_0^p dp' v^*(p', \rho)) + \int_0^\rho d\rho' U(\rho')$$

$$v^*(p') = \frac{p'}{\sqrt{p'^2 + m^2}}$$

$$v^*(p', \rho) = \frac{p'}{\sqrt{p'^2 + m^2/(1 + c\frac{\rho/\rho_0}{(1+\lambda p'^2/m^2)^2})^2}}$$

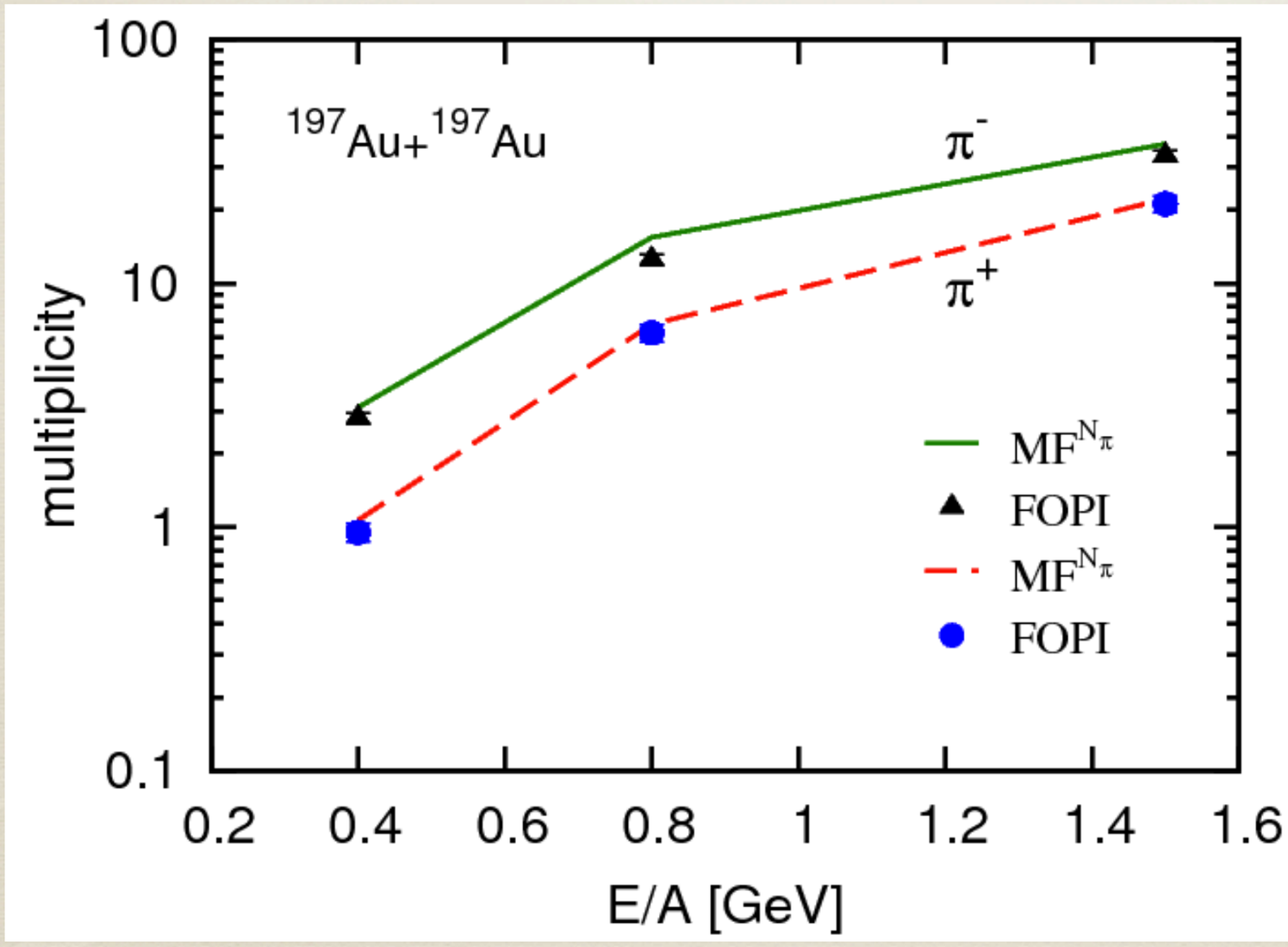


FOPI Collaboration, Nucl. Phys. A848,366(2010)

Pion Yields and Mom-dependent NMF

$$v^*(p',\rho) = \frac{p'}{\sqrt{p'^2 + m^2/(1 + c\frac{\rho/\rho_0}{(1+\lambda p'^2/m^2)^2})^2}}$$

We found that pion yields prefers a certain shape of the NMF.

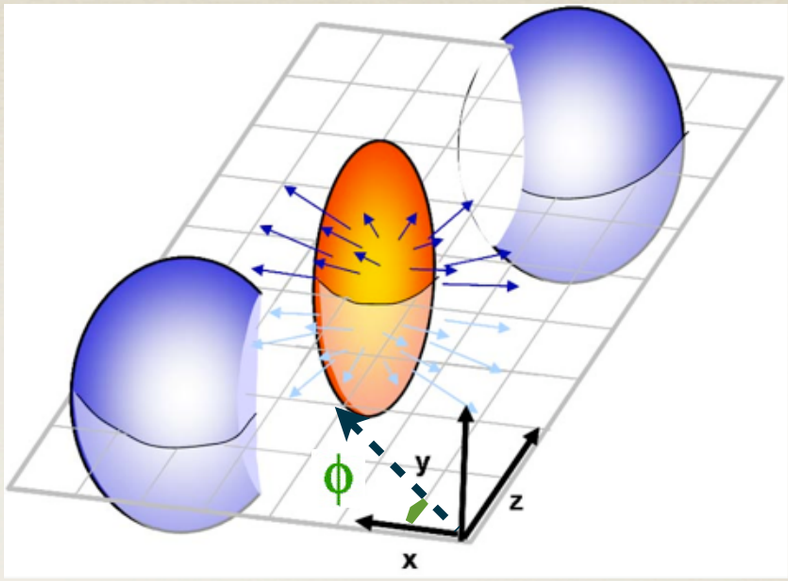


FOPI Collaboration, Nucl. Phys. A848,366(2010)

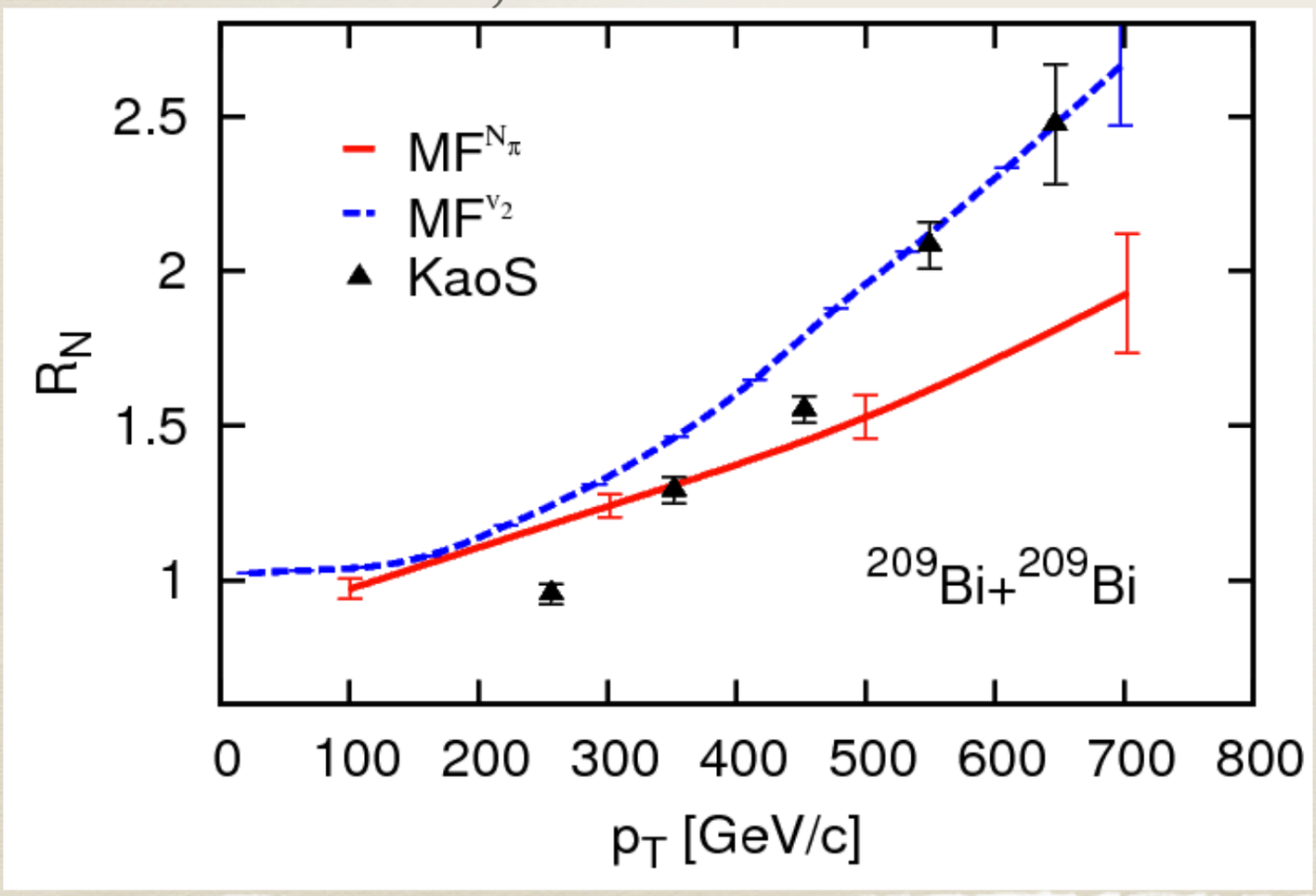
Elliptic flow

$$v_2 =< cos(2\phi) >= \frac{p_x^2 - p_y^2}{p_x^2 + p_y^2}$$

$$R_N = \frac{1 - v_2}{1 + v_2}$$



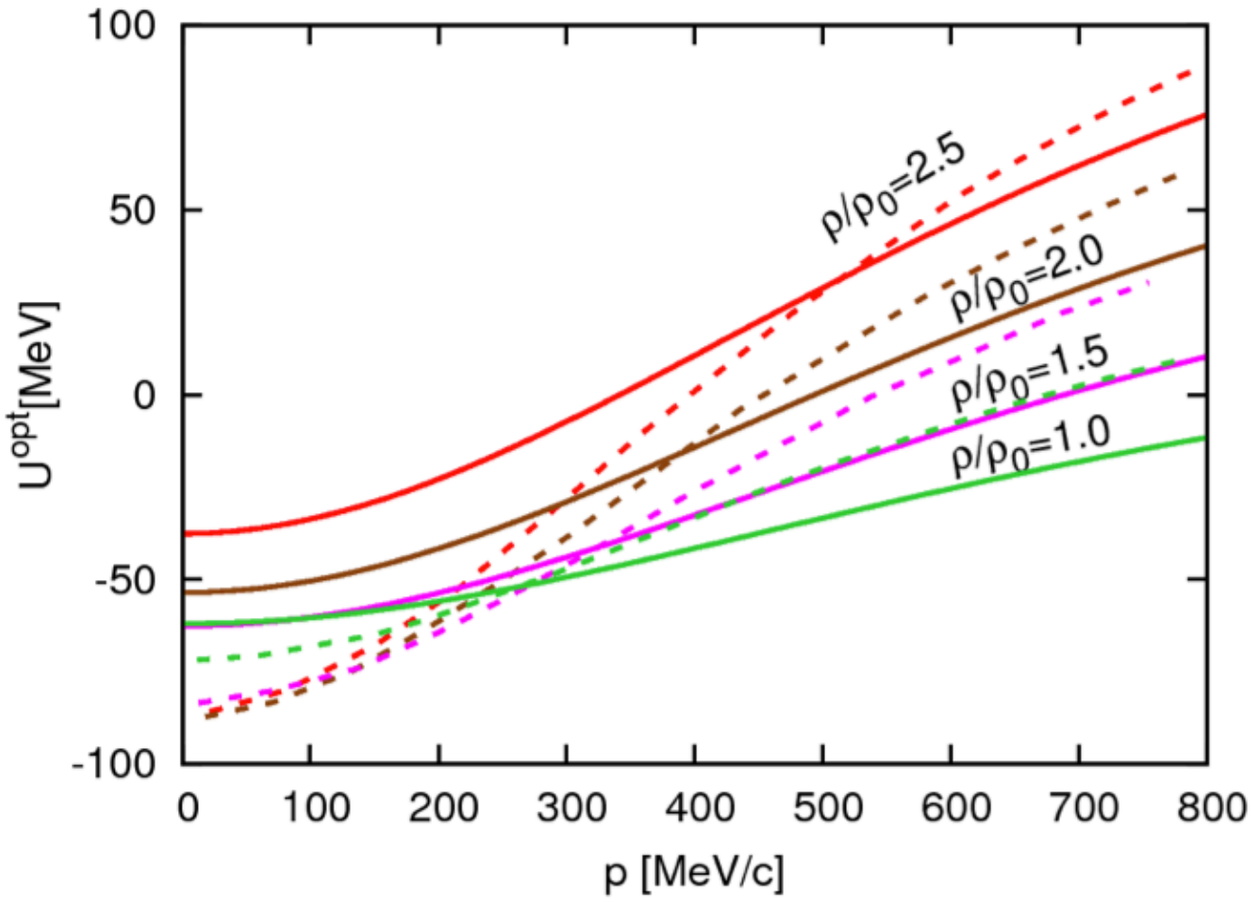
The previous mom-dependent NMF was fitted to reproduce flow data. Now, the new NMF?



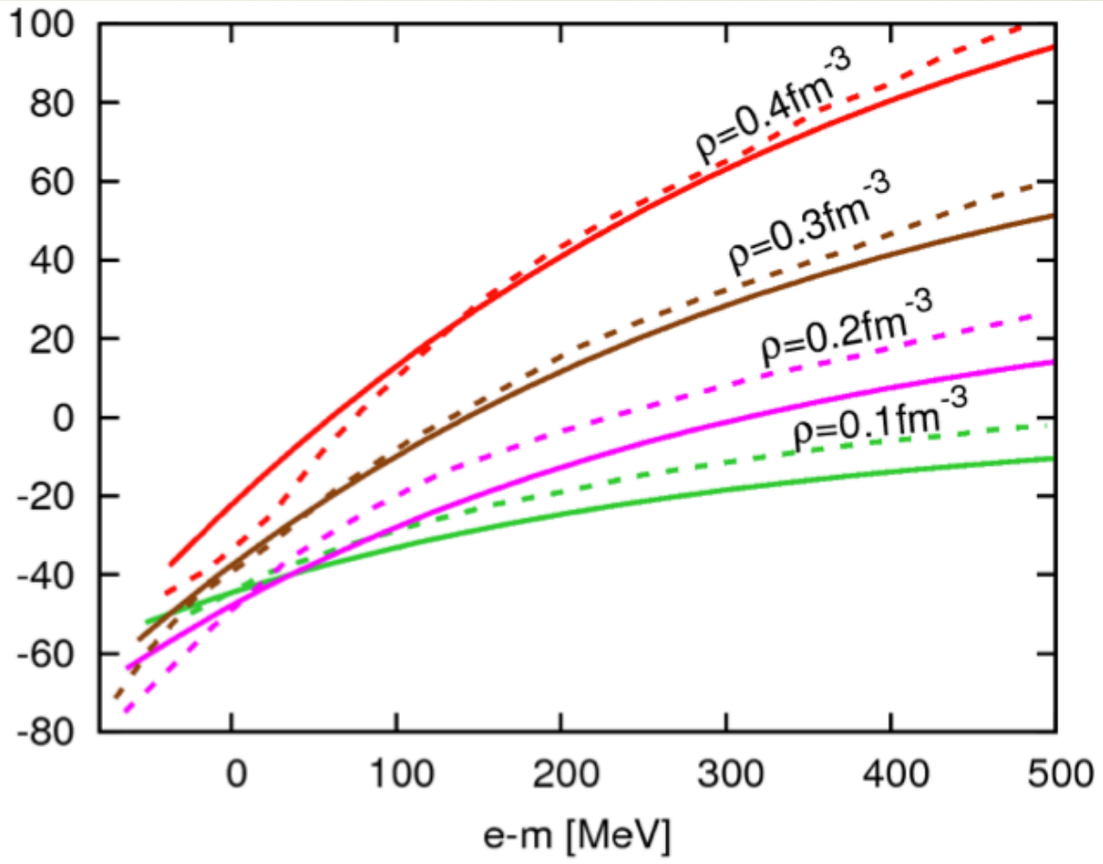
D.Brill et al., Z. Phys. A 355, 61 (1996)

Optical potential

$$U^{opt}(p) = \epsilon(p) - m - T(p)$$



Optical potential in nuclear matter at different densities as a function of momentum. Dashed and solid lines represent, respectively, the v_2- and N_π-optimized MFs.

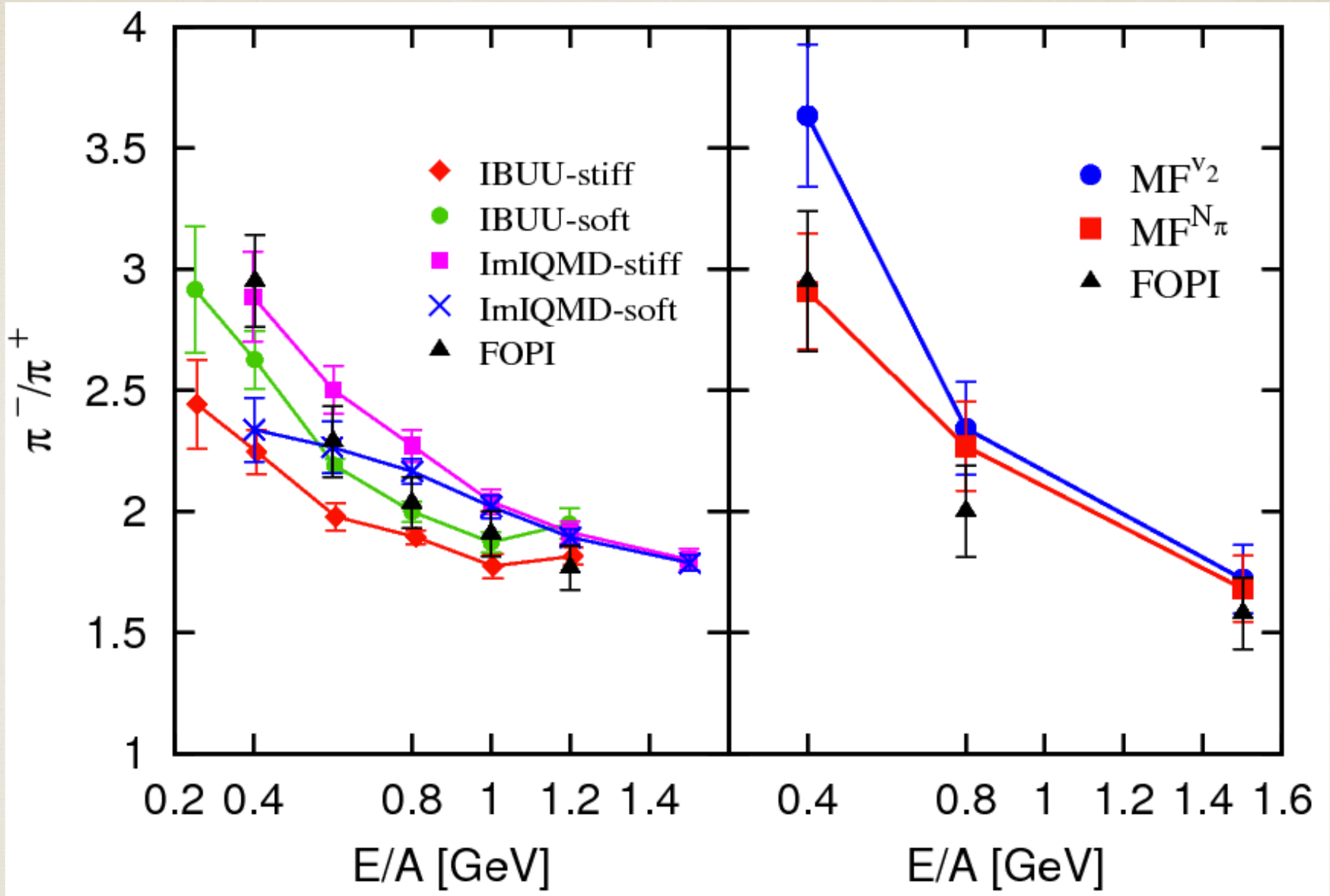


Optical potential in nuclear matter at different densities as a function of momentum. Dashed and solid lines represent, respectively, UV14+UVII variational calculations and our N_π-optimized MF.

Introduce anisotropy in the momentum dependence?

Christian H. Simon, P. Danielewicz, Phys. Rev. C 87(2013)054619

Symmetry Energy and Puzzle with Pion Ratio



IBUU favors a soft nuclear symmetry energy

Xiao et al, PRL 102,062502(2009)

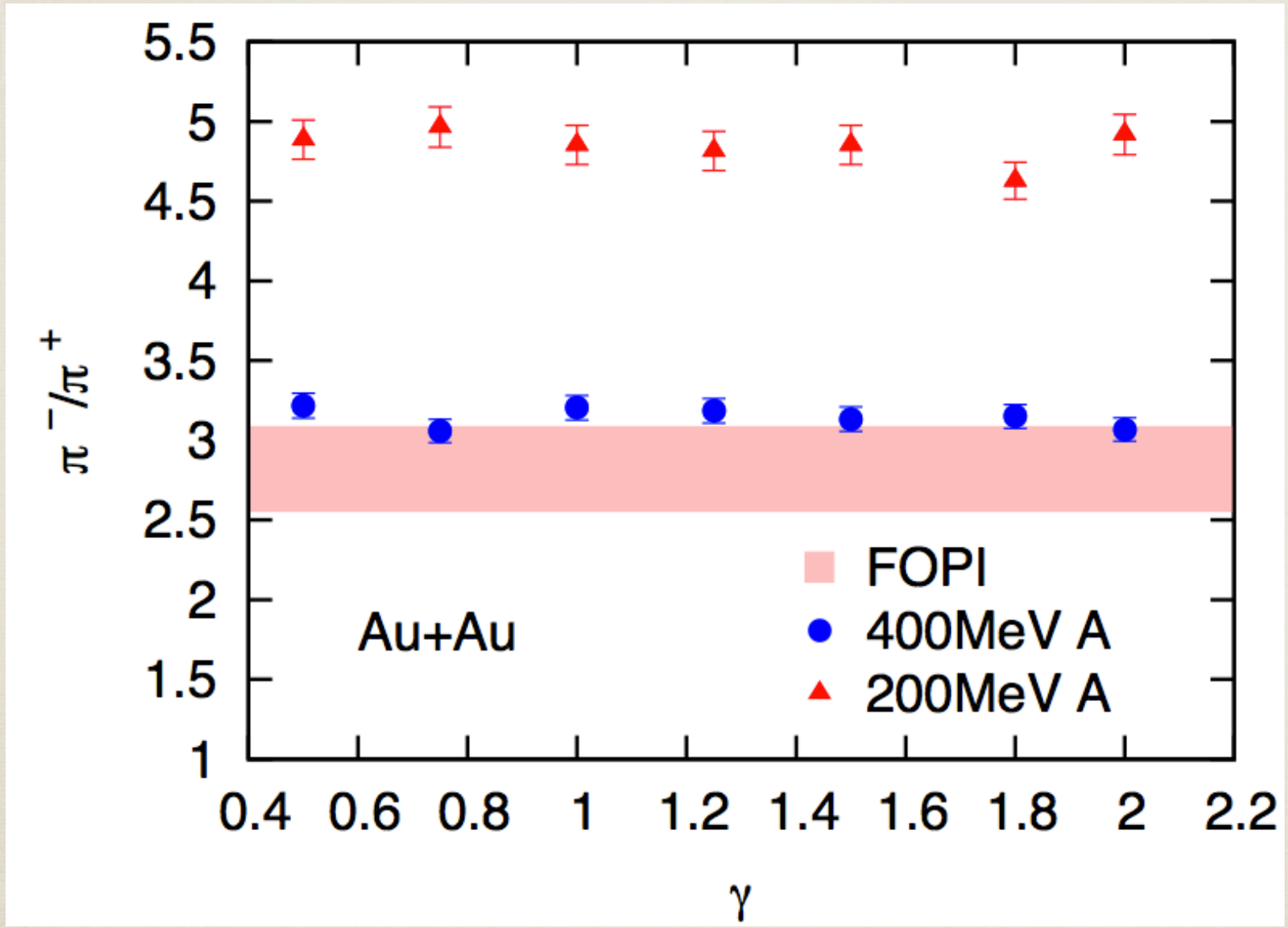
IQMD favors a stiff nuclear symmetry energy

Feng & Jin, PLB 683,140(2010)

$$S(\rho) = S_{kin0}(\frac{\rho}{\rho_0})^{\frac{2}{3}} + S_{int0}(\frac{\rho}{\rho_0})$$

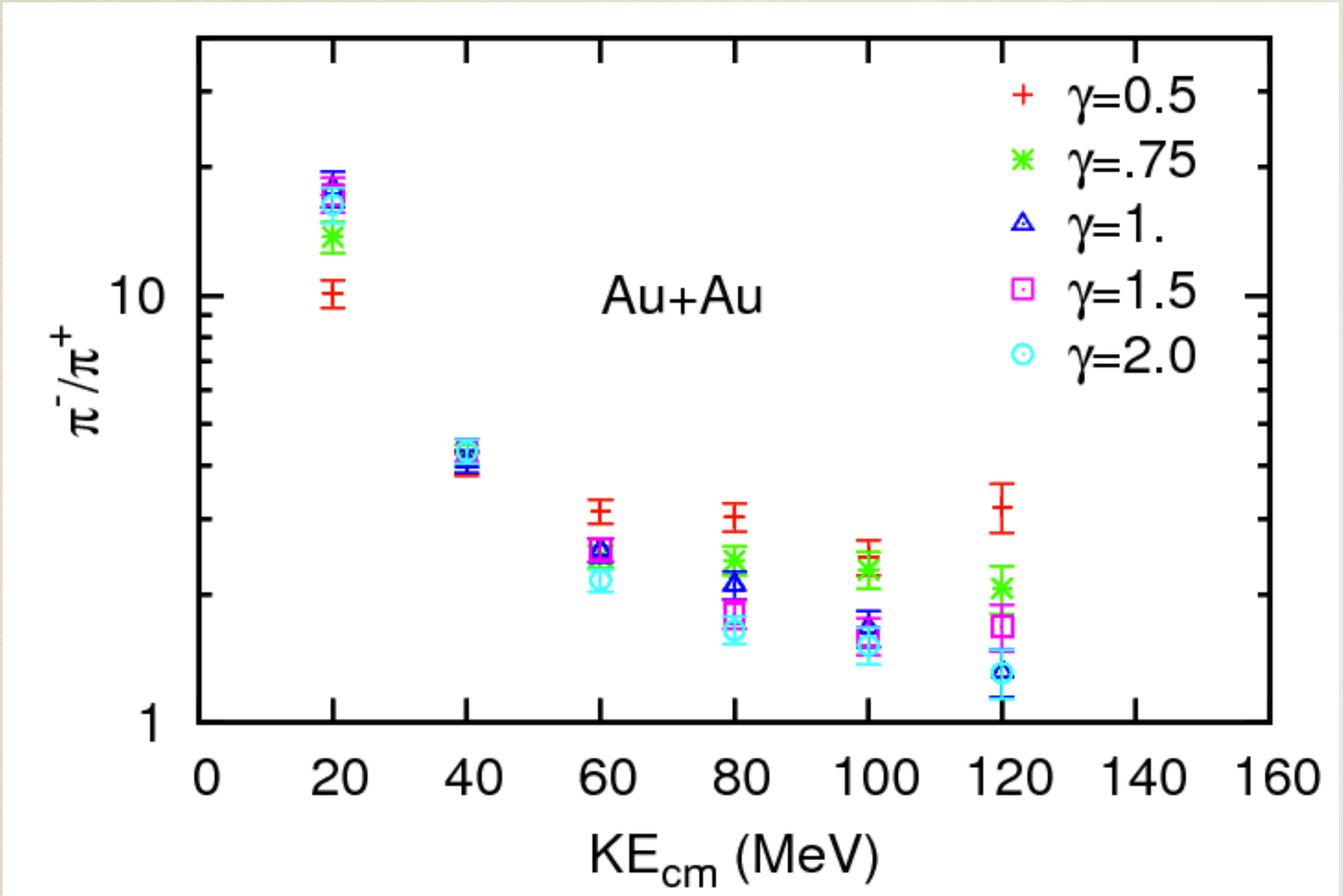
No Sensitivity to Symmetry Energy...

$$S(\rho) = S_{kin0}(\frac{\rho}{\rho_0})^{\frac{2}{3}} + S_{int0}(\frac{\rho}{\rho_0})^{\gamma}$$

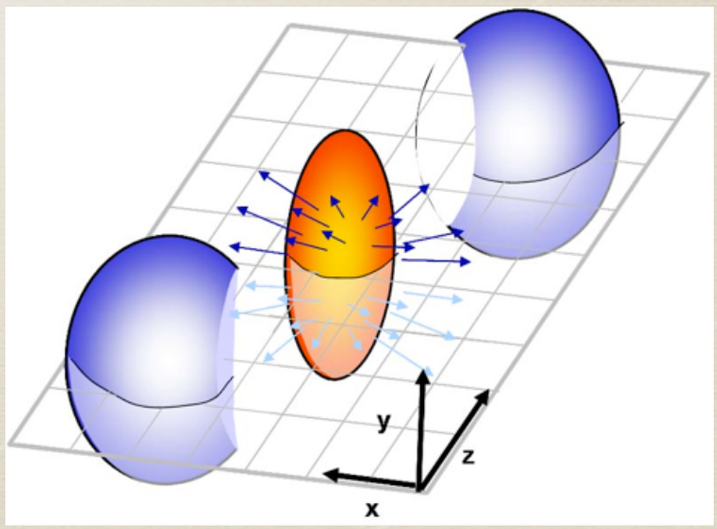


Disagree with IBUU & IQMD calculations!

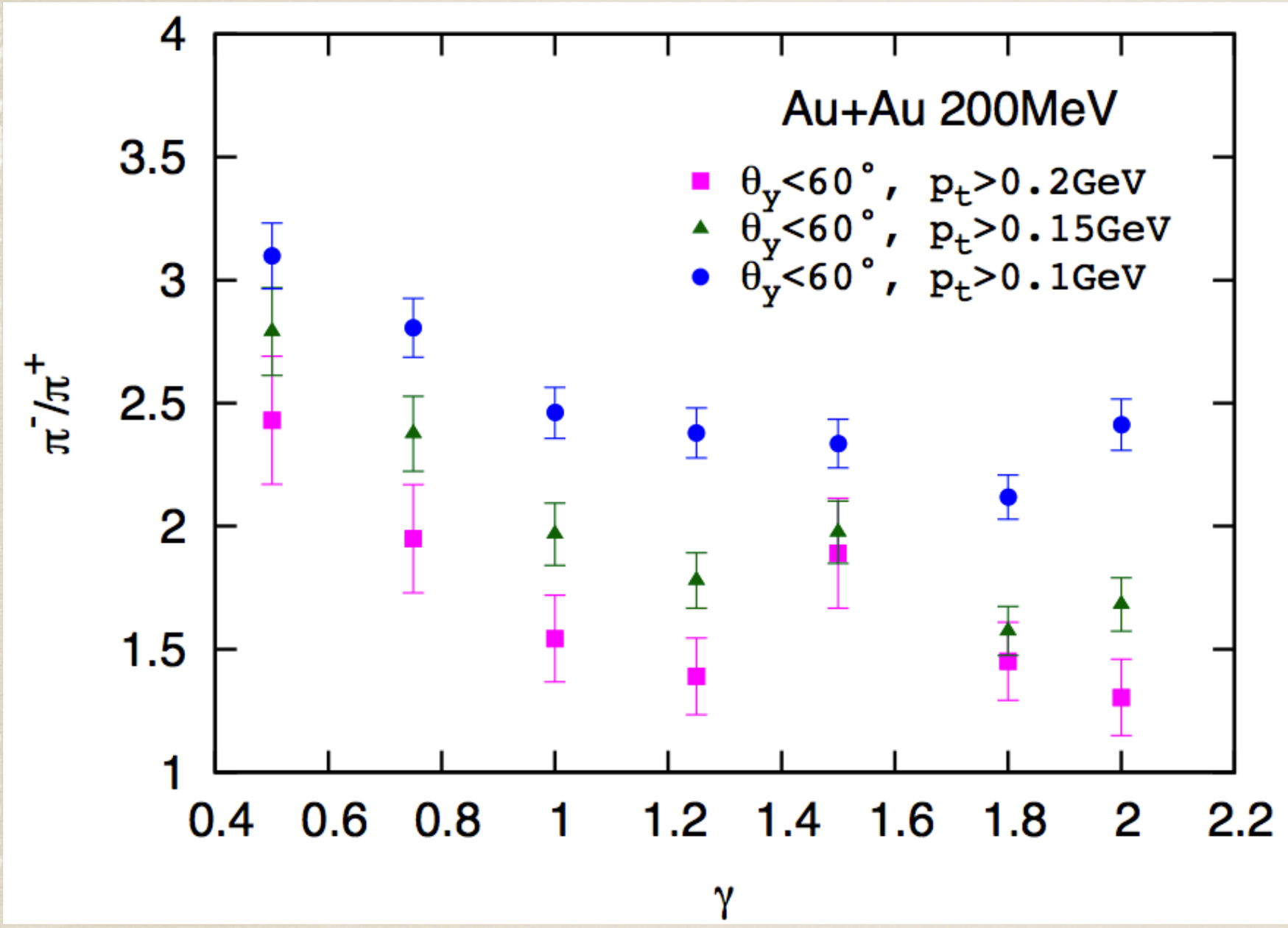
Excitation Function of Charged Pion Ratio

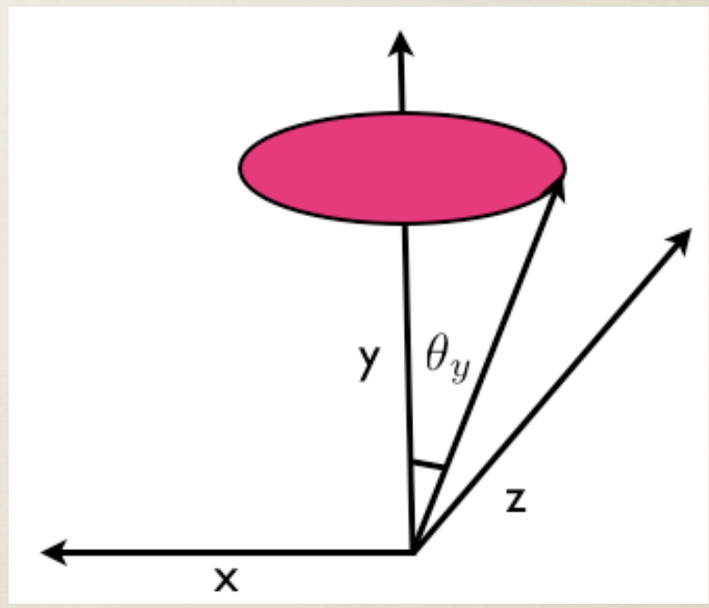


Kinetic energy of pion



Restore Sensitivity with Angular and Pt Cut

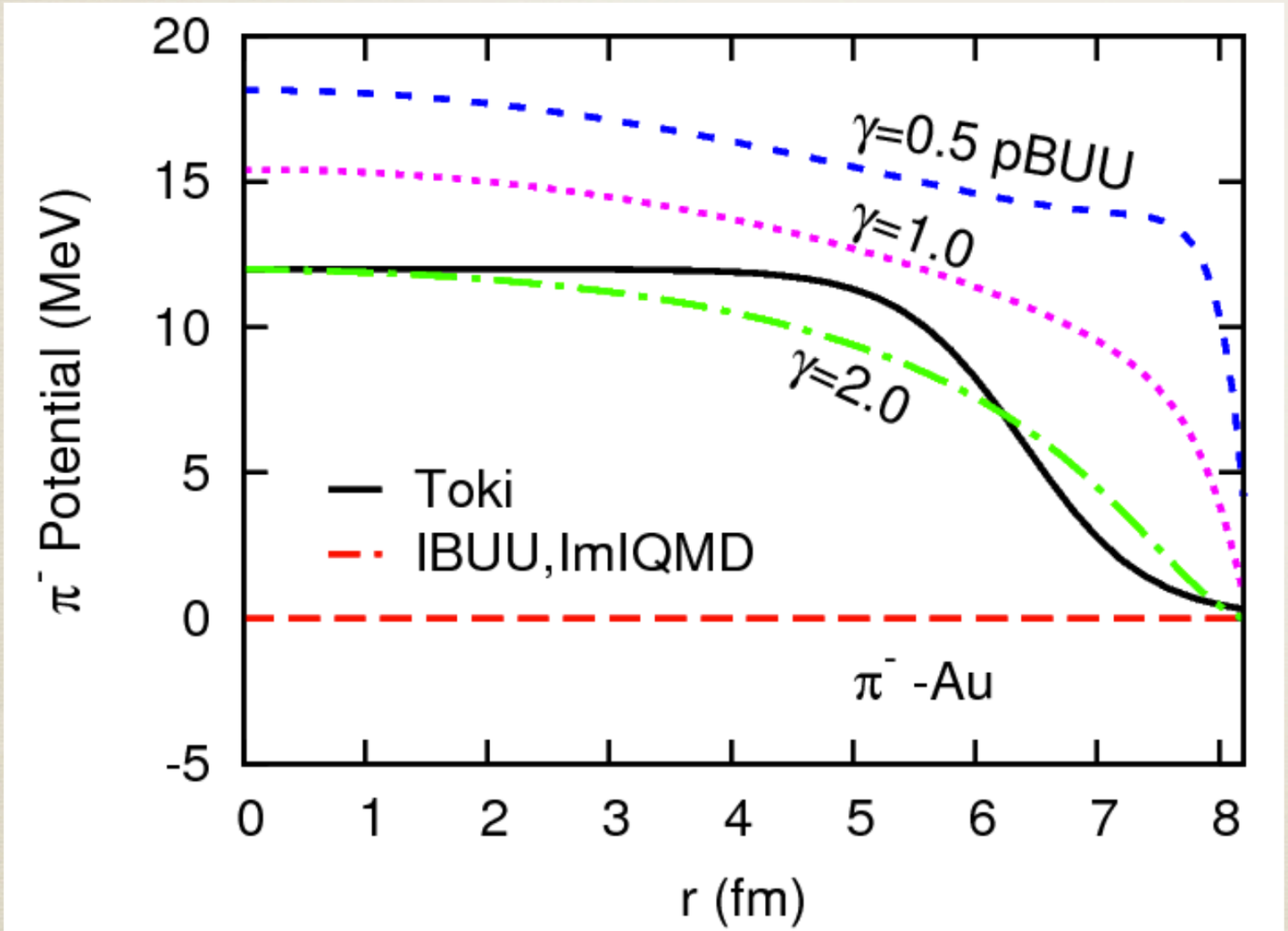




pion potential

One possible reason for the disagreement is: *pion potential*.
In IBUU and IQMD model, pion only feels Coulomb potential.

To describe deeply bound states for pionic atoms, Toki et al. constructed pion potentials in the nucleus.



$$U_{\pi^\pm} = \pm a_T \rho_T \frac{\rho^{\gamma-1}}{\rho_0^\gamma}$$

H. Toki et al, Nucl. Phys. A 501 (2009) 653

Conclusions

- We cannot find a momentum-dependent NMF to describe both total pion yields and flow data.
(may need to implement an anisotropic mom-dep. NMF)

- Our calculation for total charged pion ratio is not sensitive to HD behavior of symmetry energy. Different from calculations using IBUU model and IQMD model.

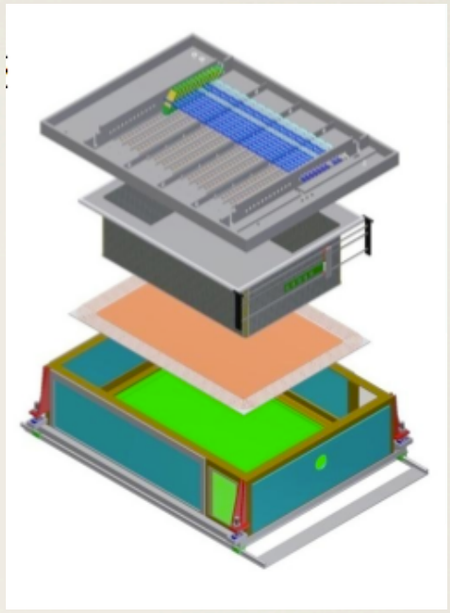
- We propose an angular and high transverse momentum cut for pion ratio, which can yield a good probe for experimentalists.

Thank you for your attention!

Constraints symmetry energy at $\rho > \rho_0$

SAMURAI-TPC collaboration(8 countries and 43 researchers): comparisons of π^-, π^+ and also n-p spectra and flows at RIKEN, Japan.

NSCL/MSU, Texas A&M Univ.,
Western Michigan Univ., Univ. Notre Dame,
GSI, Daresbury Lab, INFN/LNS,
Univ. Budapest, SUBATECH, GNIL,
China IAE, Brazil, RIKEN, Rikkyo Univ.,
Tohoku Univ., Kyoto Univ.



AT-TPC collaboration(U.S. & French), more measurements can be done at NSCL/FRIB, US.