The symmetry energy at high densities and pion ratio

Gao-Chan Yong

NuSYM16@Tsinghua University

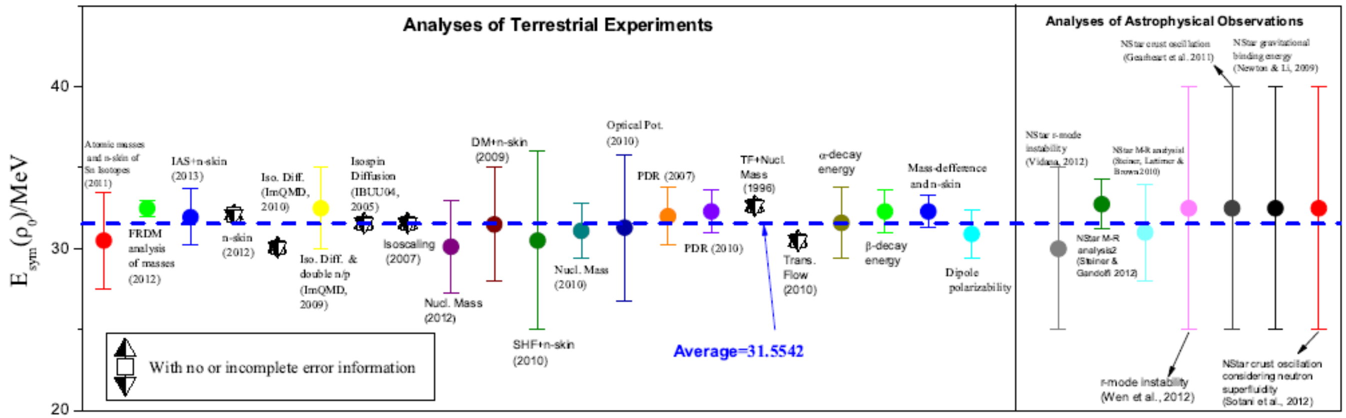
2016-6-14

Outline

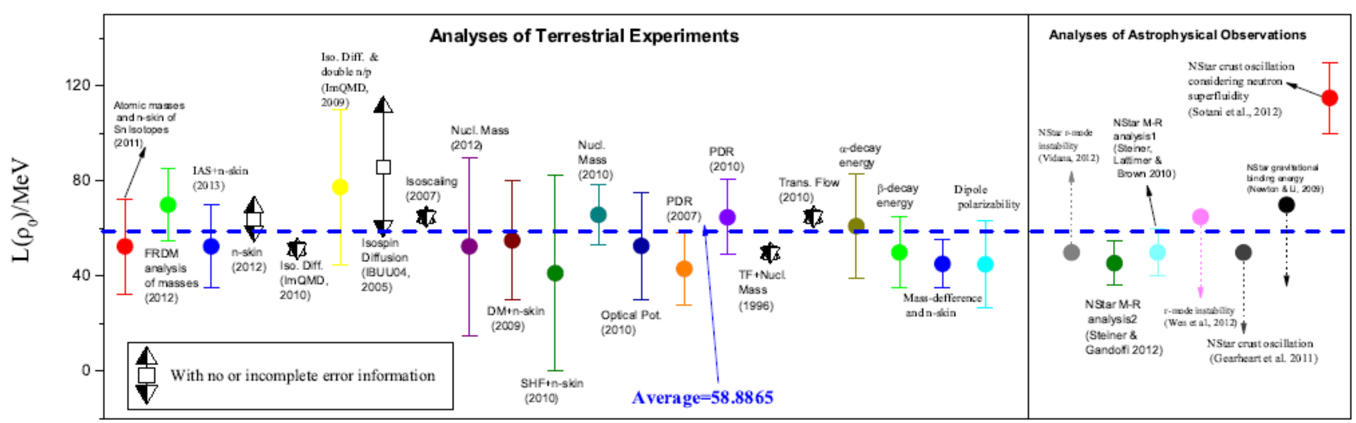
- Background
- Pion ratio and pion potential
- Pion ratio and In-medium BB cross section
- Pion ratio and NN Short-Range Correlations
- Density region probed by pion ratio
- Summary

Why high densities

Around saturation density:

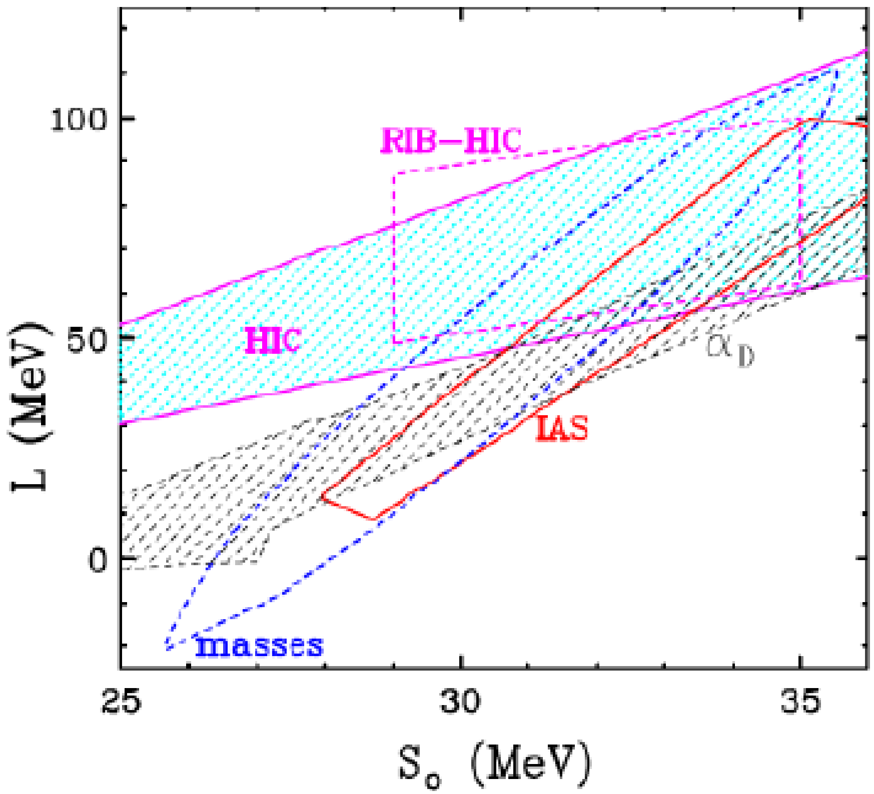


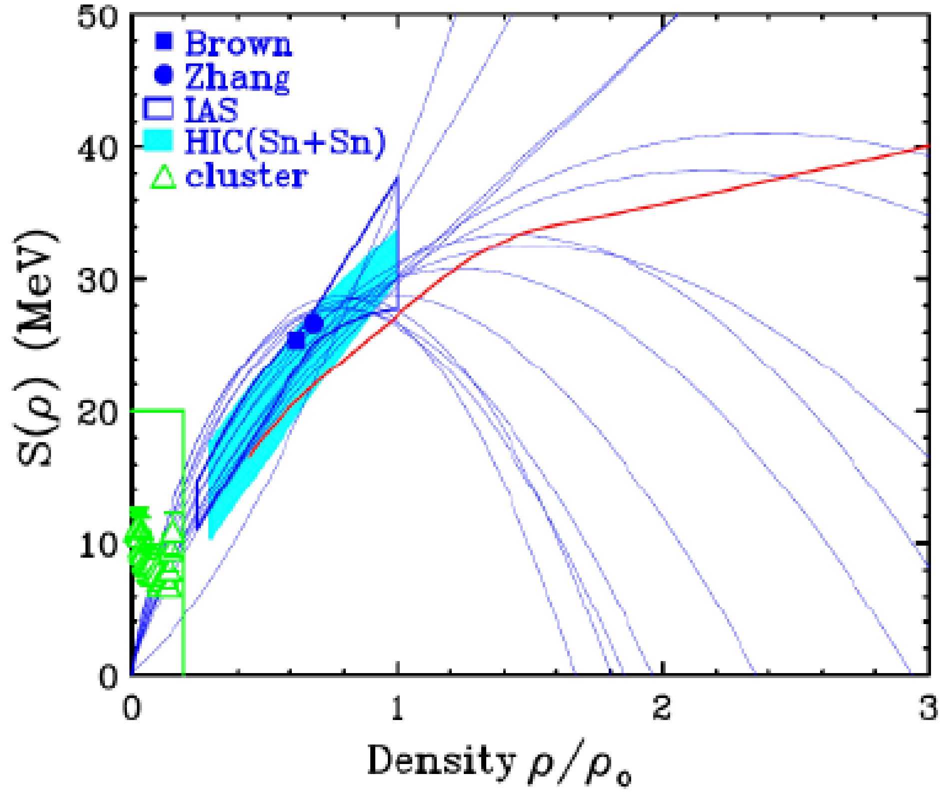
NuSYM roughly constrained based on model analyses of experimental and observational data



Bao-An Li, Xiao Han, Phys. Lett. B727, 276 (2013)

Updated Constraints with credible error bars from NuSYM13





$$L(\rho_0) \equiv [3\rho(\partial E_{\rm sym}/\partial\rho]_{\rho_0}$$

There is larger uncertainty at supradensities!

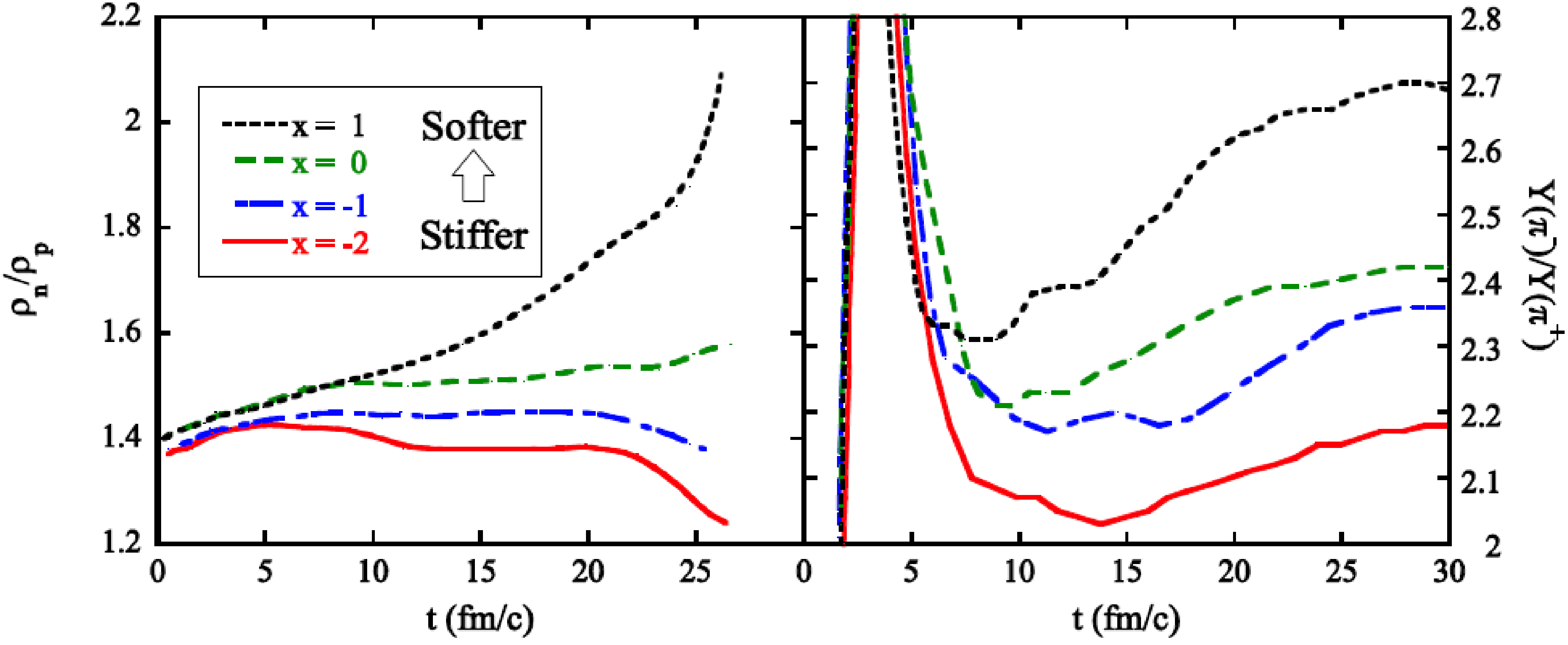
C. J. Horowitz, et al., J. Phys. G: Nucl. Part. Phys. 41 (2014) 093001

Why pion ratio

Proposal for Nuclear Physics Experiment at RI Beam Factory

(RIBF NP-PAC-12, 2013)

pion ratio proposed as a potential probe of the symmetry energy at high densities



https://groups.nscl.msu.edu/hira/sepweb/pages/home.html.

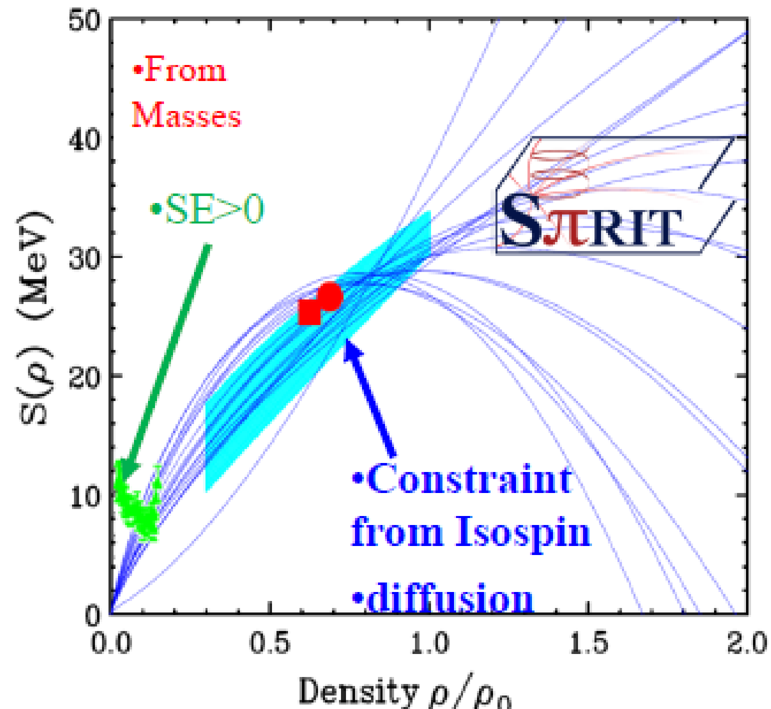
Bao-An Li, Gao-Chan Yong, Wei Zuo, Phys.Rev.C71:014608,2005

Upcoming Experimental Plans with *SπRIT*

Determination of the density and momentum dependence of EOS (m*)
at supra-saturation density

Observables:
π^+/π^-, n/p, t/^{3}He ratios,

13.5 days approved by NP-PAC in 2013.



^{238}U primary beam (^{132}Sn, ^{124}Sn beams)

^{124}Xe Primary beam (^{108}Sn beams)

Beam	Target	E_{beam}/A	δ_{sys}	Goal	Days
^{132}Sn	^{124}Sn	300	0.22	Probe maximum δ	3
^{124}Sn	^{112}Sn	300	0.15	Probe intermed. δ, σ_{np}, σ_{nn}	3
^{108}Sn	^{112}Sn	300	0.09	Probe minimum δ	3
^{108}Sn	^{124}Sn	300	0.15	Probe intermed. δ, σ_{np}, σ_{nn}	3

U.S. DEPARTMENT OF ENERGY Office of Science

Jonathan Barney for SπRIT TPC Collaboration
1/11/2016

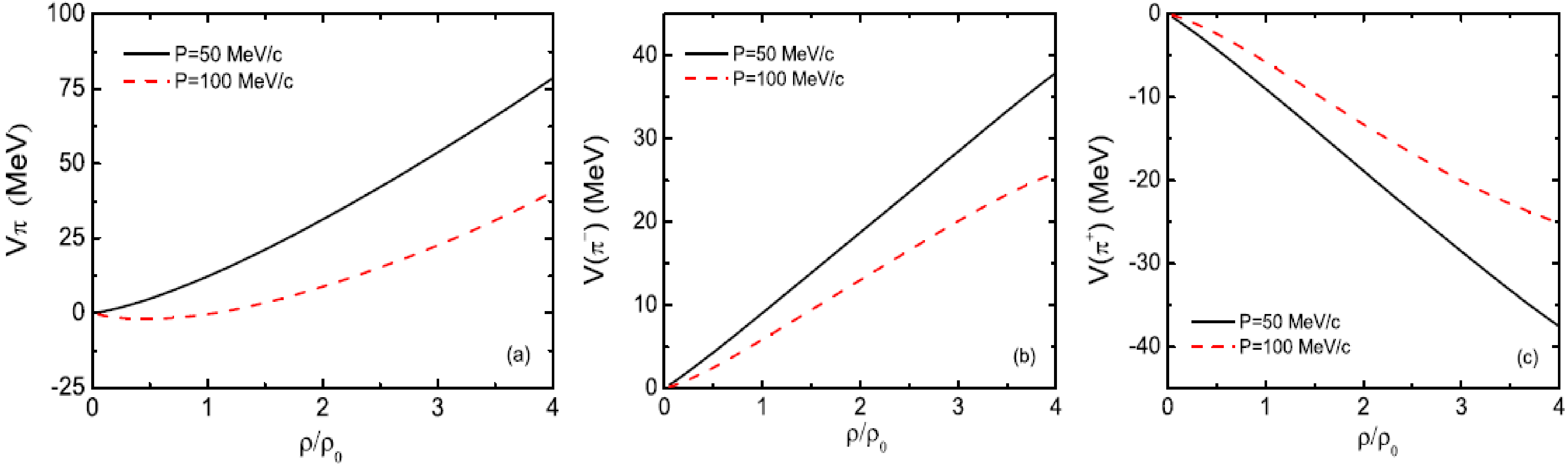
SπRIT

(1). Pion potential and pion ratio

- Jun Hong, P. Danielewicz, Phys. Rev. C 90, 024605 (2014)
- Wen-Mei Guo, Gao-Chan Yong, Hang Liu, Wei Zuo, Phys. Rev. C 91, 054616 (2015)
- M.D. Cozma, arXiv:1603.00664
- Zhao-Qing Feng, arXiv:1606.01083
- Jun Xu, Lie-Wen Chen, Che Ming Ko, Bao-An Li, Yu-Gang Ma, Phys.Rev.C87:067601,2013

(1). Pion potential and pion ratio

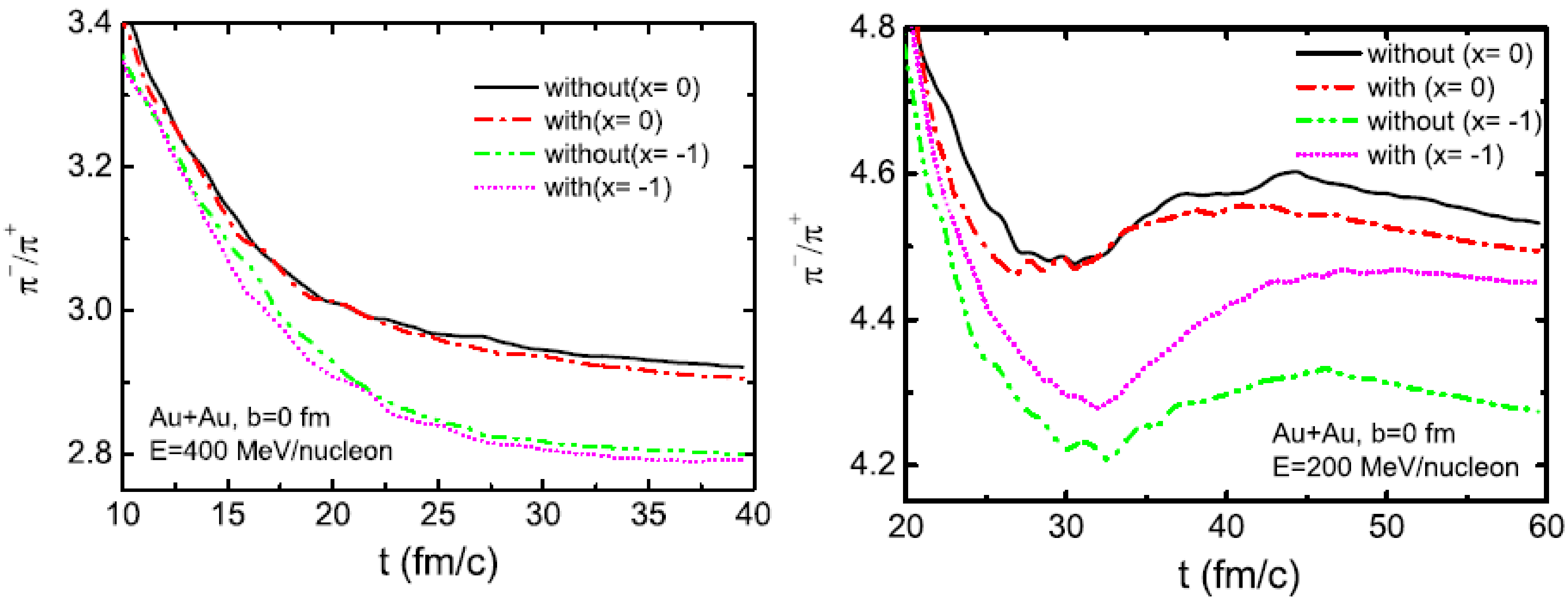
Isoscalar and isovector potentials of pions (asymmetry =0.2)



More repulsive for pion minus

O. Buss, diploma thesis, Justus-Liebig-Universit ¨ at Gießen, 2004 (unpublished), https://gibuu.hepforge.org/trac/wiki/Paper#Diplomatheses.

(1). Pion potential and pion ratio



Pion potential and symmetry potential have opposite effects on pion minus; thus Pion potential partly cancels out the effect of symmetry energy on the pion ratio

Wen-Mei Guo, Gao-Chan Yong, Hang Liu, Wei Zuo, Phys. Rev. C 91, 054616 (2015)

(2). In-medium BB cross section and pion ratio

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

$$U_B^{\Delta^-} = U_n,\quad U_B^{\Delta^0} = \tfrac{2}{3}U_n + \tfrac{1}{3}U_p,\quad U_B^{\Delta^+} = \tfrac{1}{3}U_n + \tfrac{2}{3}U_p,\quad U_B^{\Delta^{++}} = U_p$$

Reduction of in-medium BB cross section

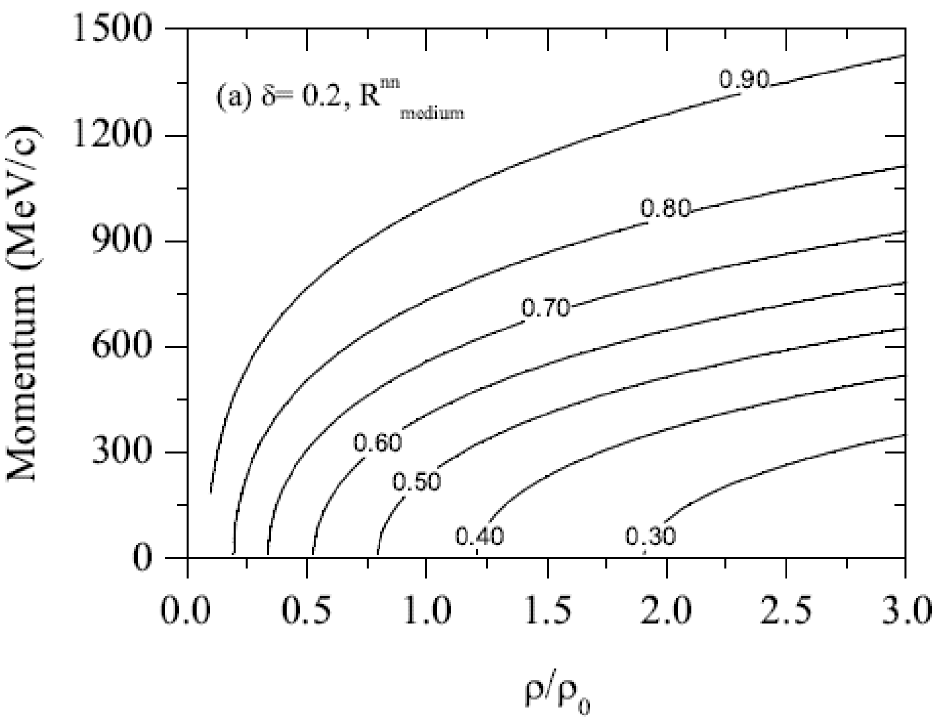
$$R^{BB}_{\text{medium}}(\rho,\delta,\vec{p}) \equiv \sigma^{\text{medium}}_{BB_{\text{elastic,inelastic}}}/\sigma^{\text{free}}_{BB_{\text{elastic,inelastic}}} = (\mu^*_{BB}/\mu_{BB})^2,$$

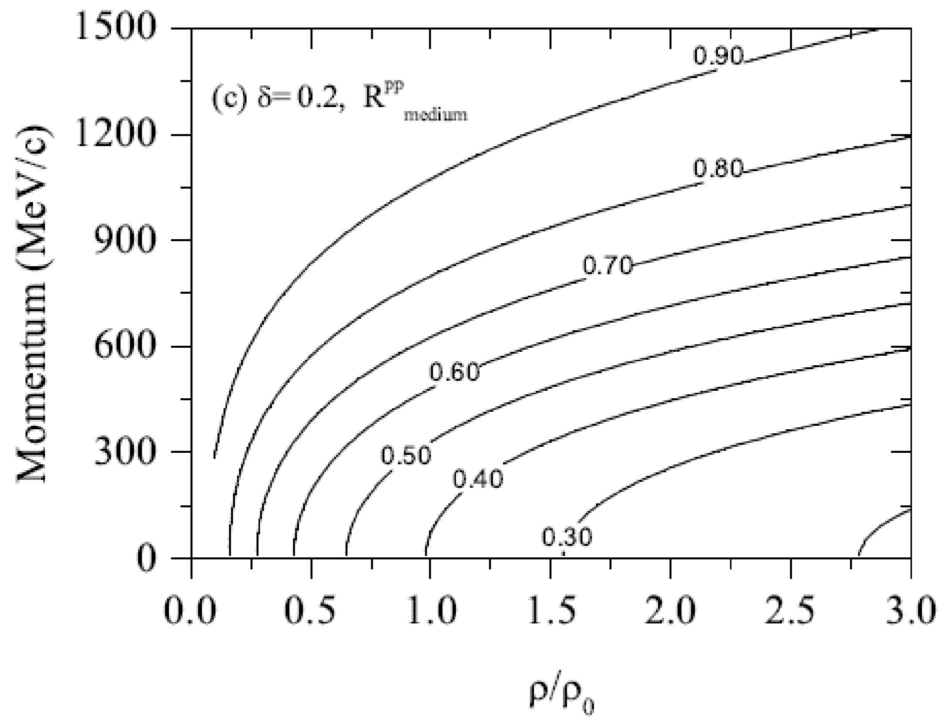
reduced mass of colliding pair

$$\frac{m_B^*}{m_B} = \left\{1 + \frac{m_B}{p}\frac{dU_B}{dp}\right\}$$

Gao-Chan Yong, Phys. Rev. C 93, 044610 (2016),
M.D. Cozma, Phys.Lett. B753 (2016) 166-172
Bao-An Li, Lie-Wen Chen, Phys.Rev.C72:064611,2005

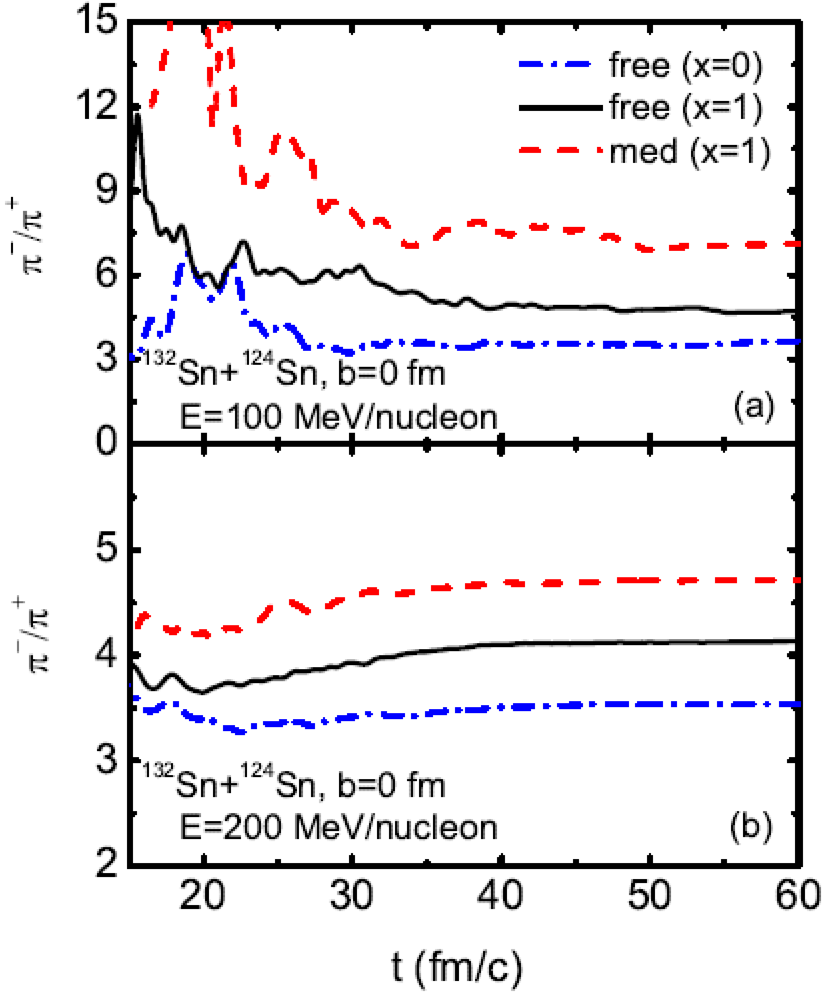
(2). In-medium NN cross section and pion ratio



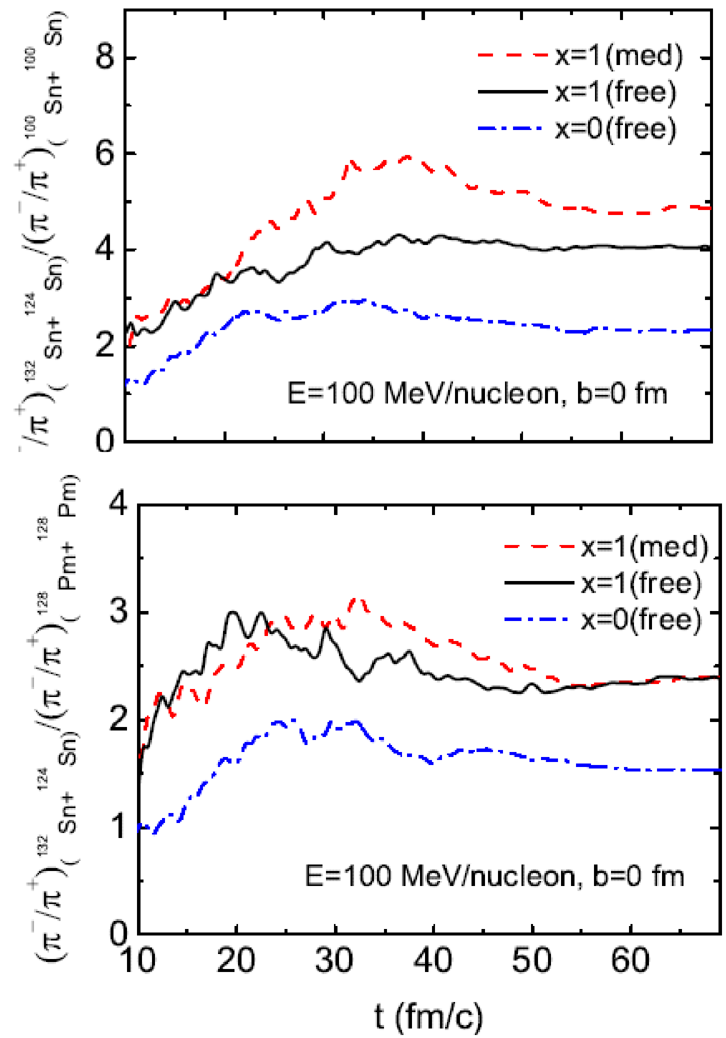


Cross section of pp in medium reduced larger than nn

(2). In-medium NN elastic cross section and pion ratio

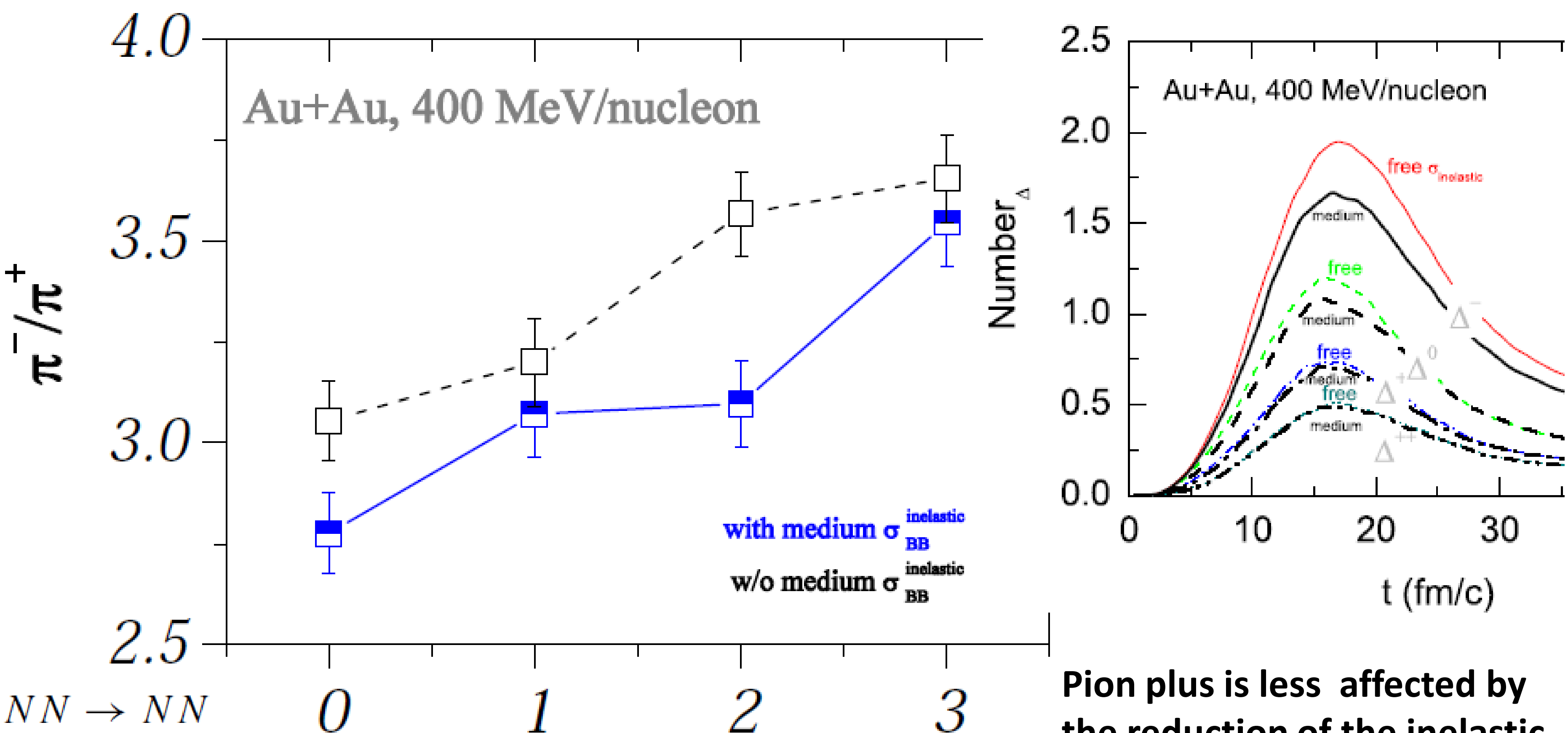


with the same mass number of system, the effects of in-medium NN elastic scattering cross section are canceled



Wen-Mei Guo, Gao-Chan Yong, Wei Zuo, Physical Review C 90, 044605 (2014)

(2). In-medium BB inelastic cross section and pion ratio



$NN \rightarrow NN$

$N\Delta \rightarrow N\Delta$

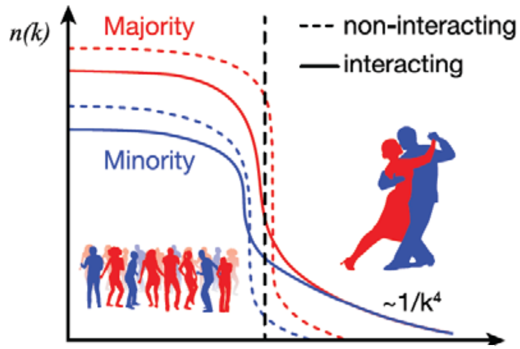
$\Delta\Delta \rightarrow \Delta\Delta$

$NN \rightleftharpoons N\Delta$ **X**

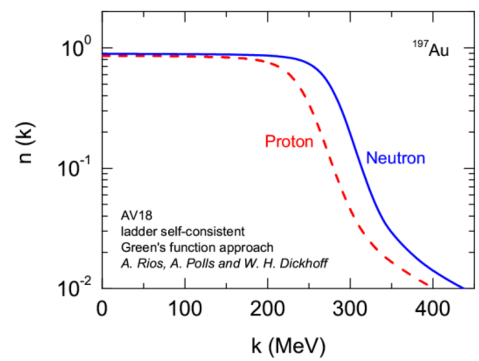
Pion plus is less affected by the reduction of the inelastic Xsection.

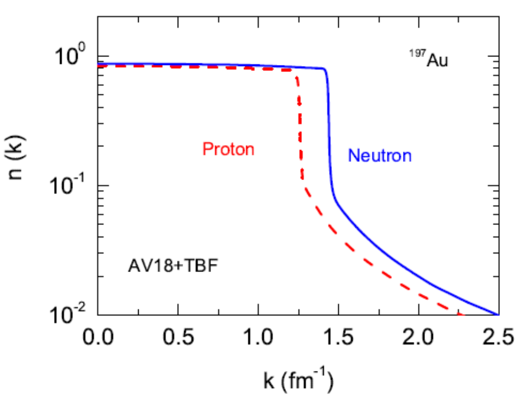
Gao-Chan Yong, Phys. Rev. C 93, 044610 (2016)

(3). Short-Range Correlations and pion ratio



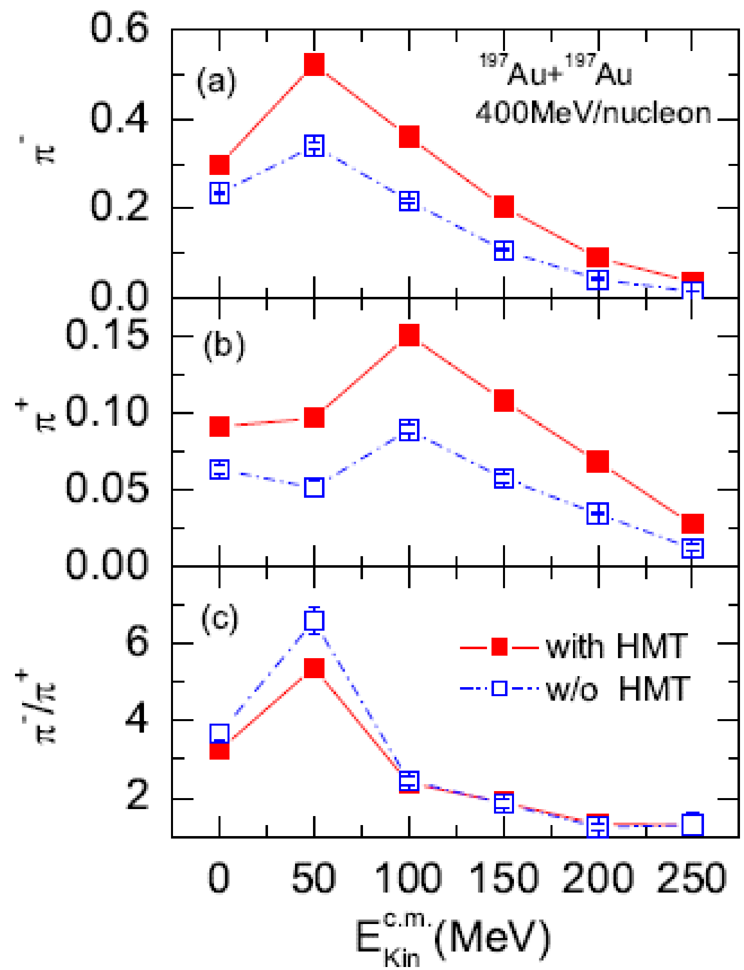
O. Hen et al, Science 346, 614 (2014)





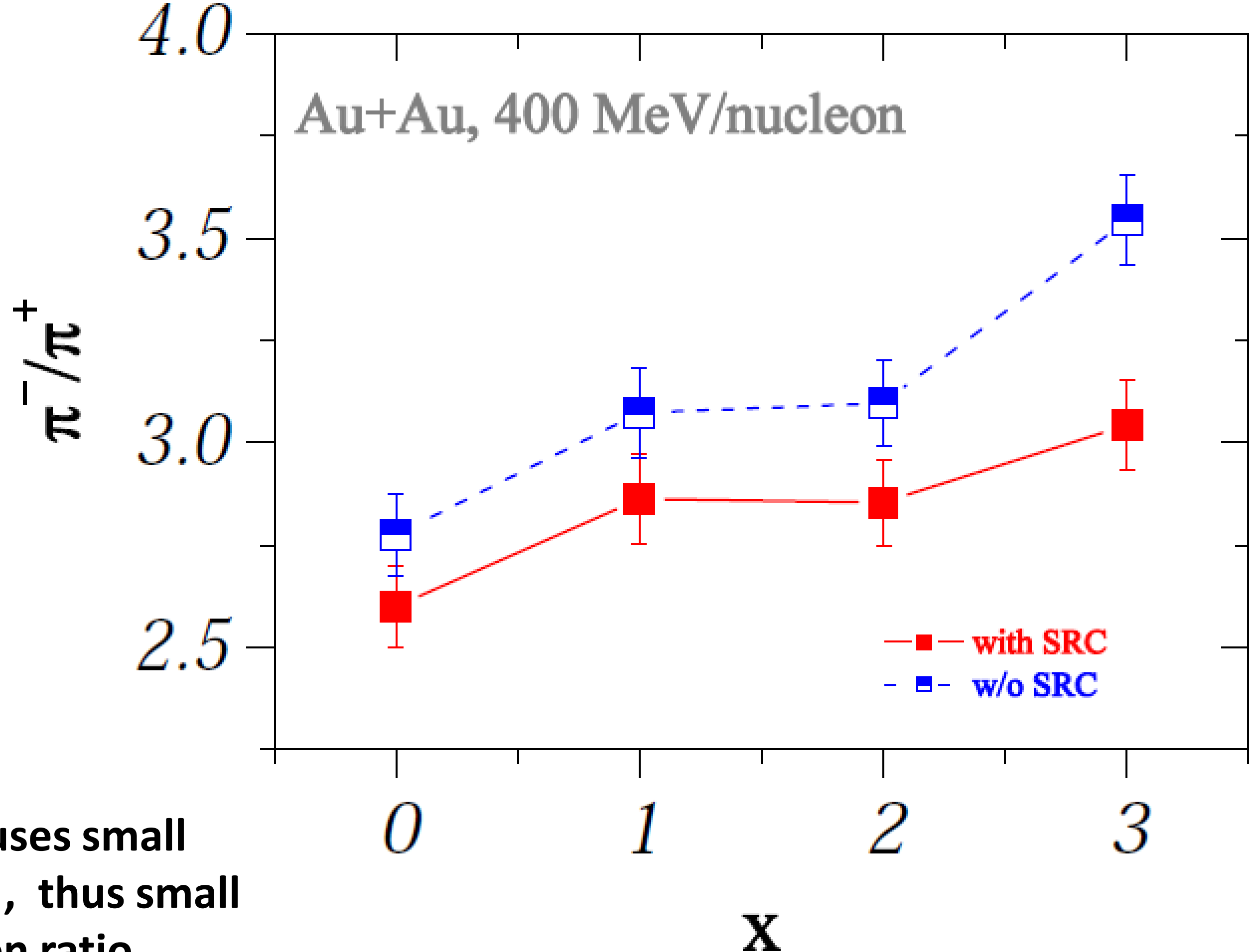
SRC increases the kinetic energies of neutrons and protons

proton has larger probability than neutron to have larger momentum



Fang Zhang, Gao-Chan Yong, arXiv:1605.03656

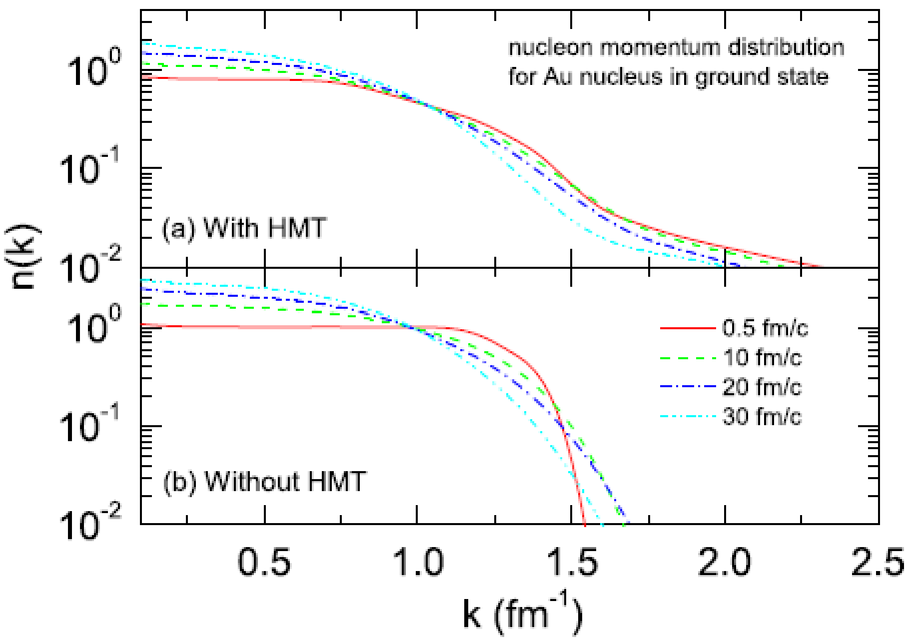
(3). Short-Range Correlations and pion ratio



The SRC causes small asymmetry , thus small value of pion ratio.

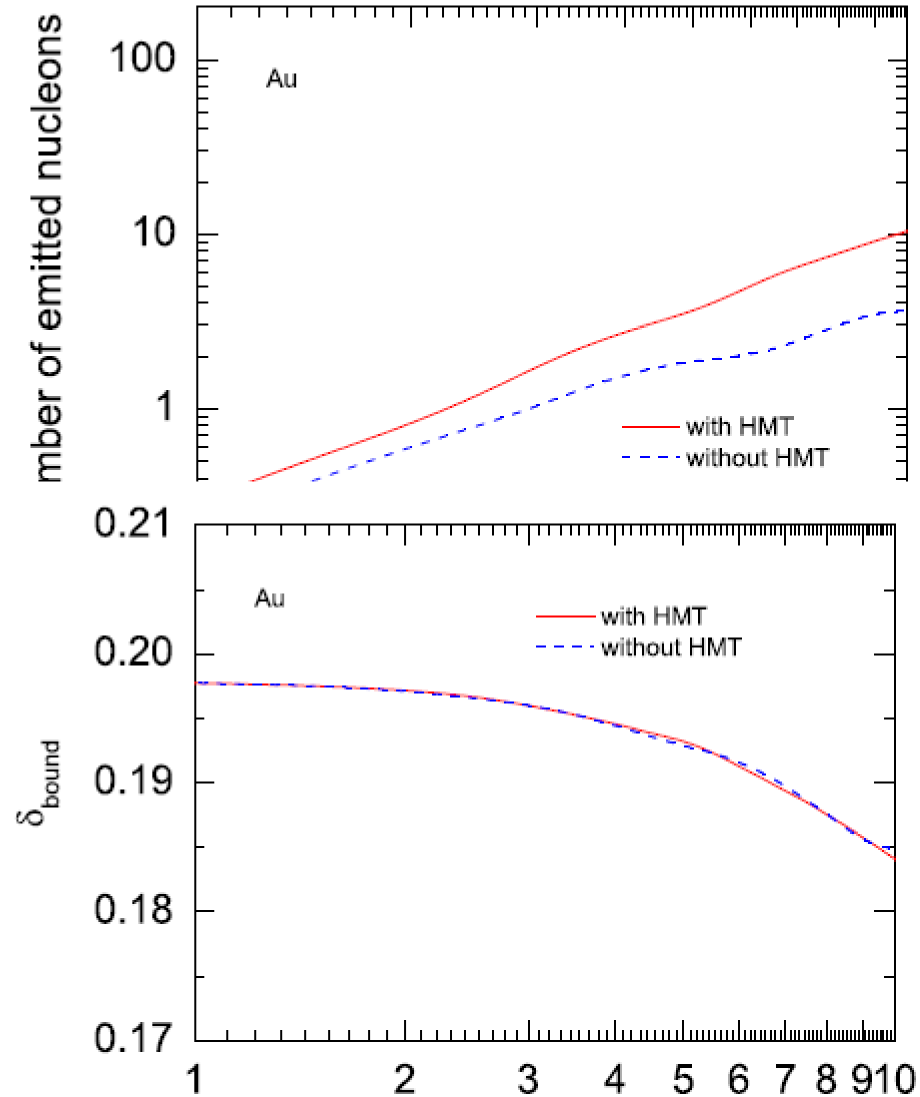
Gao-Chan Yong, Phys. Rev. C 93, 044610 (2016)

(3). On the stability



shape of the mom distribution is well kept in Au197

asymmetry of bound nucleons in the system is also well kept

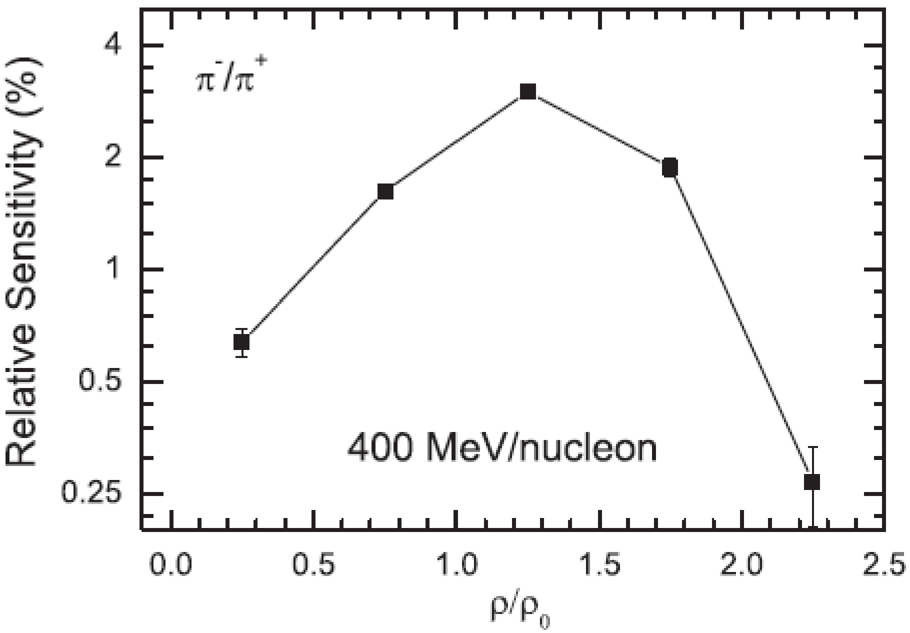


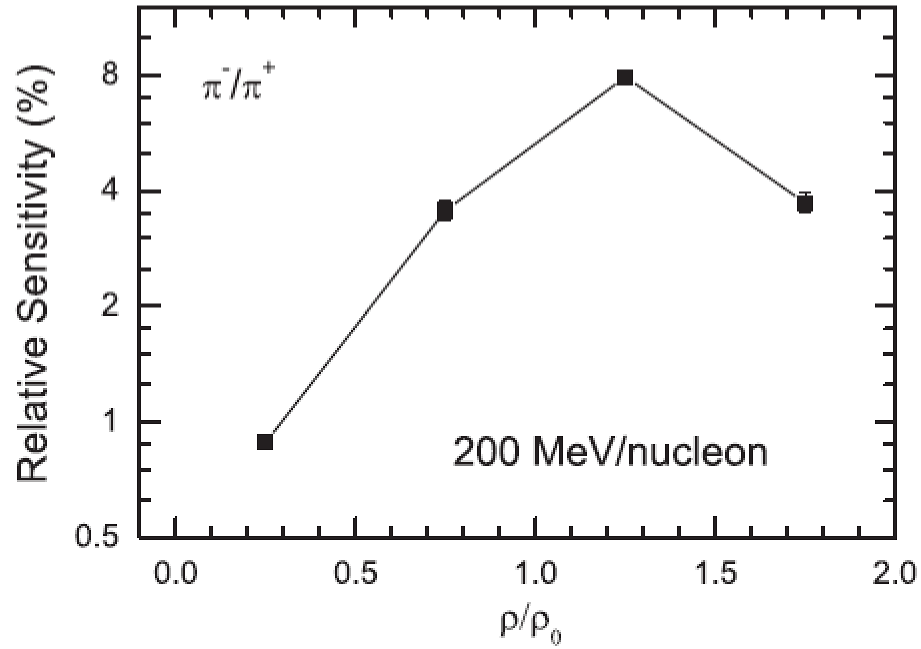
Gao-Chan Yong, Phys. Rev. C 93, 044610 (2016)

t (fm/c)

(4). Density region probed by pion ratio

197Au +197Au, b = 1 fm





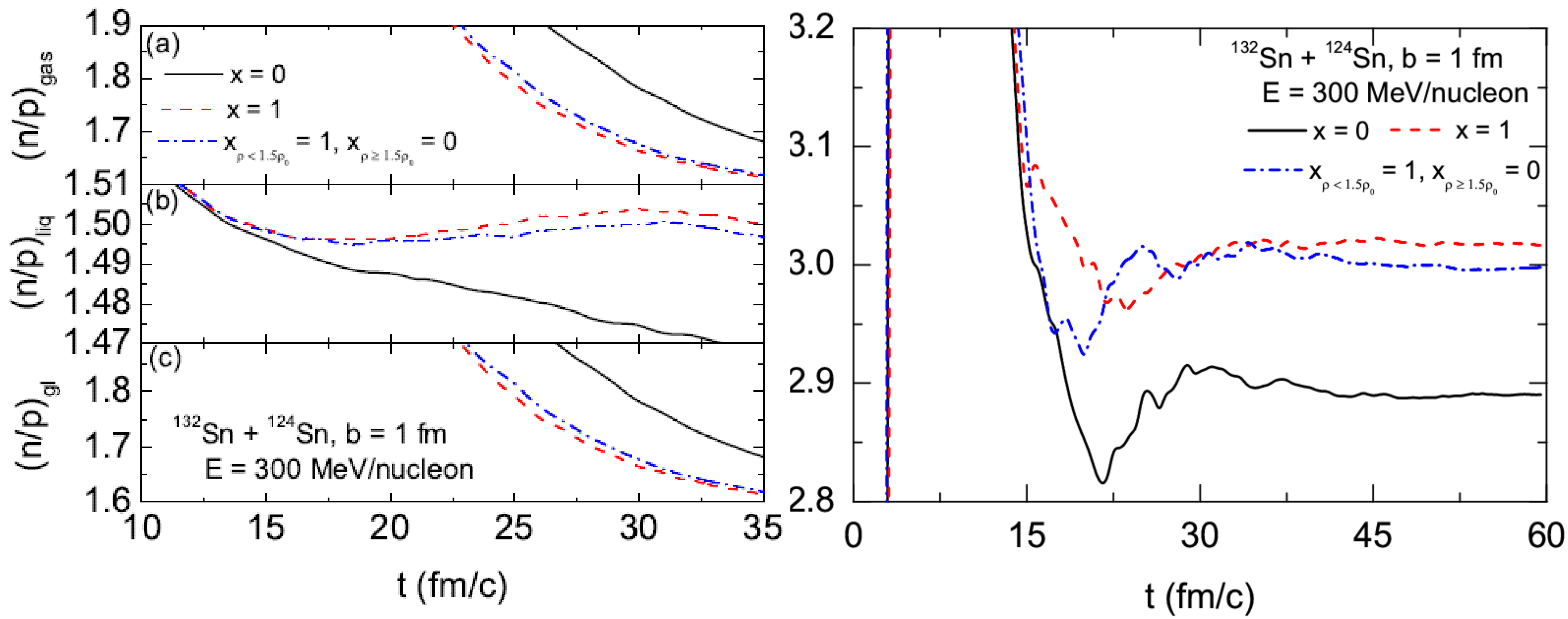
Symmetry energy at low densities also affects the pion ratio, thus

Probing the density-dependent symmetry energy around 1.25ρ0

He-Lei Liu, Gao-Chan Yong, De-Hua Wen, Physical Review C 91, 044609 (2015)

(4). Density region probed by pion ratio

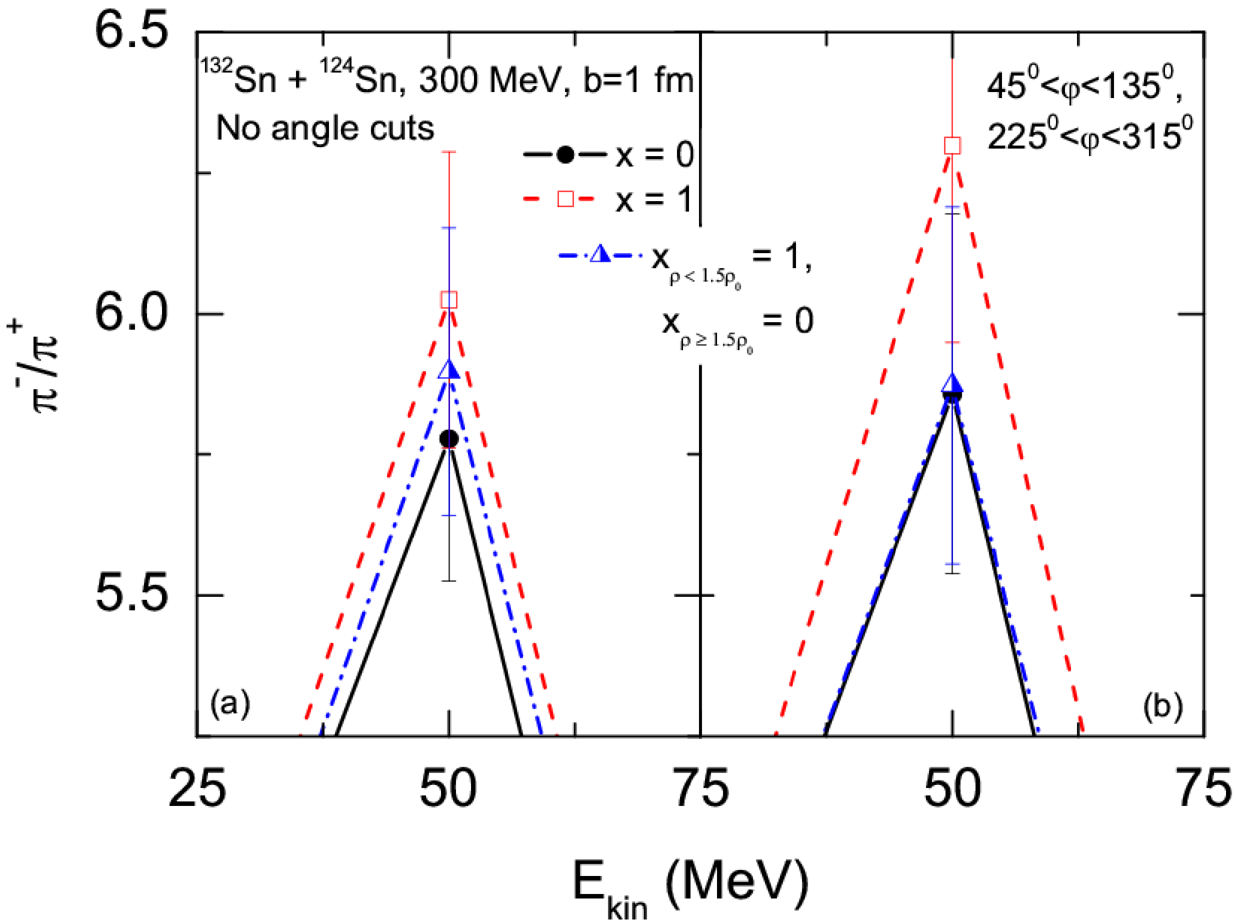
132Sn + 124Sn, b = 1 fm, 300 MeV/nucleon

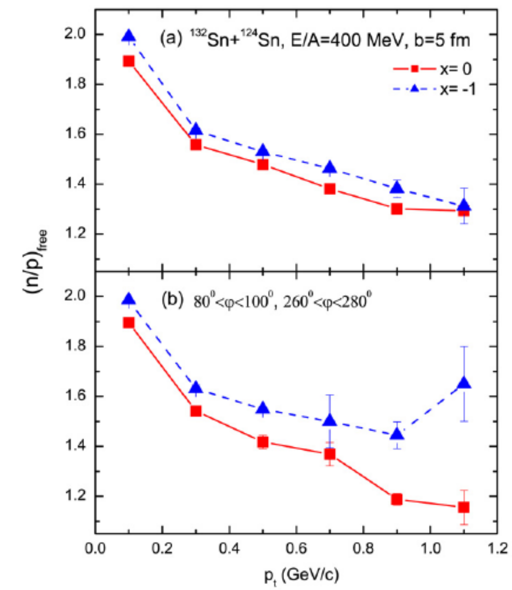


mainly probe the symmetry energy in the density region 1-1.5 times saturation density

Shan-Jing Cheng, Gao-Chan Yong, De-Hua Wen, arXiv:1605.03701

(4). How to probe NuSYM at high densities





Gao-Chan Yong, Bao-An Li, Lie-Wen Chen, Phys. Lett. B650 (2007) 344

making azimuth and kinetic energy cuts may probe the Esym at high density

Shan-Jing Cheng, Gao-Chan Yong, De-Hua Wen, arXiv:1605.03701

Summary

NuSYM probe-pion ratio may be affected by:

- pion potential
- In-medium elastic/inelastic BB cross section
- NN Short-Range Correlations

The density region that pion ratio probed may be not as high as expected.