对称能高密行为与重离子碰撞中同位旋灵敏观测量

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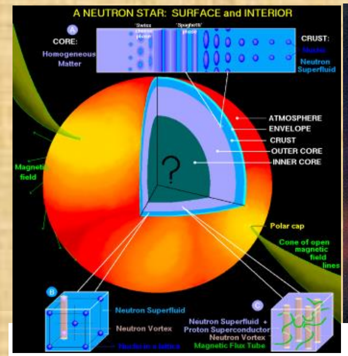
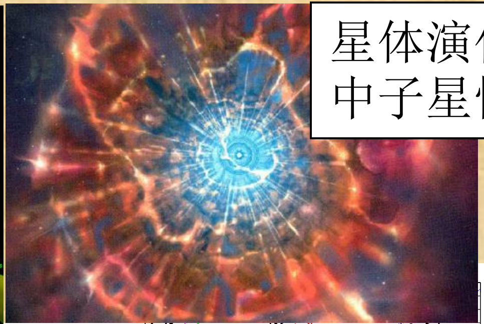
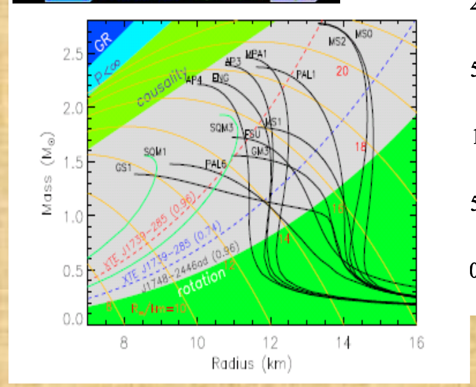
报告内容

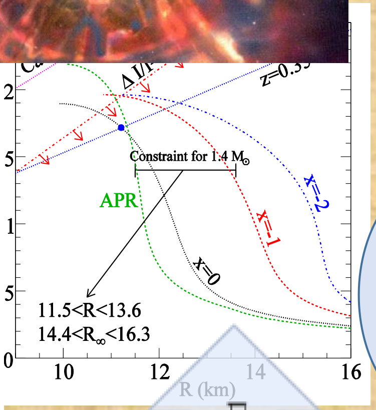
1. 研究动机与现状
2. 研究结果
3. 总结





星体演化,超新星爆炸，
中子星性质等

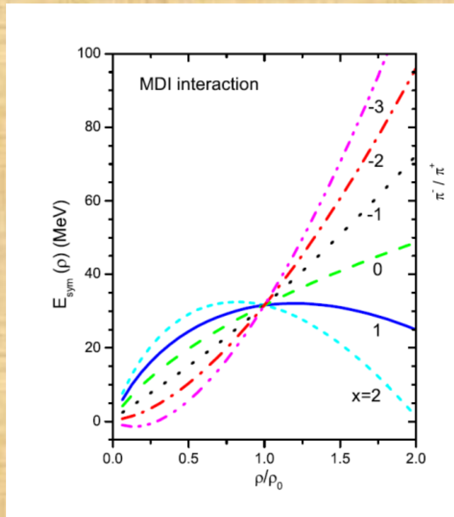


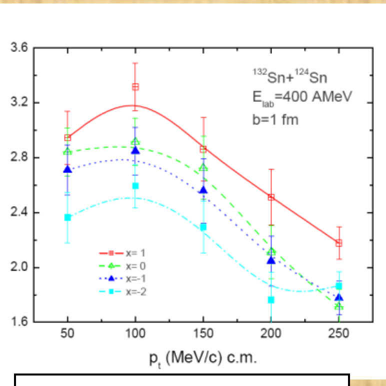


中子星性质

$$E_A(\rho,\beta)=E_A(\rho,0)+E_{sym}(\rho)\beta^2+O(\beta^4)$$

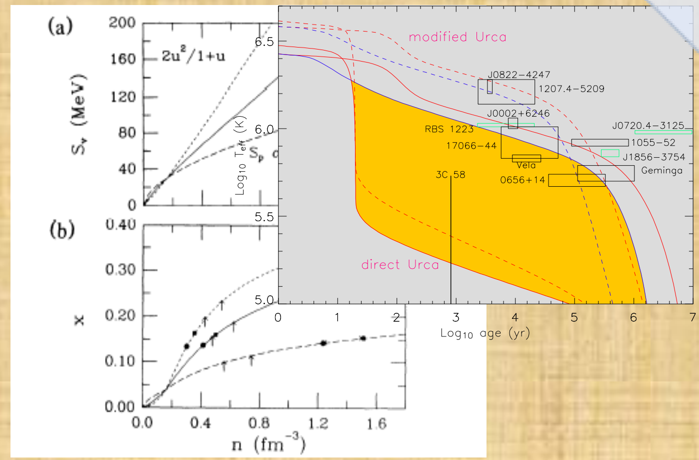
对称能密度依赖性 $E_{sym}(\rho)$





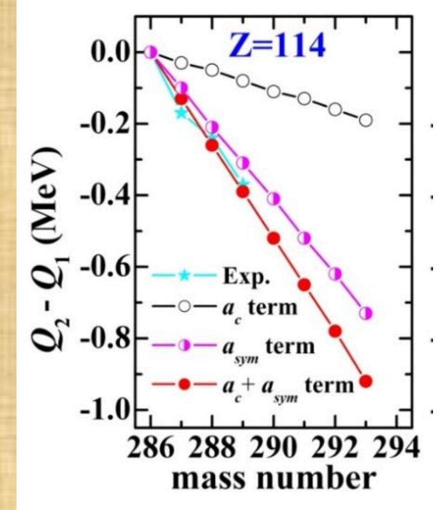
同位旋输运相关新物理现象

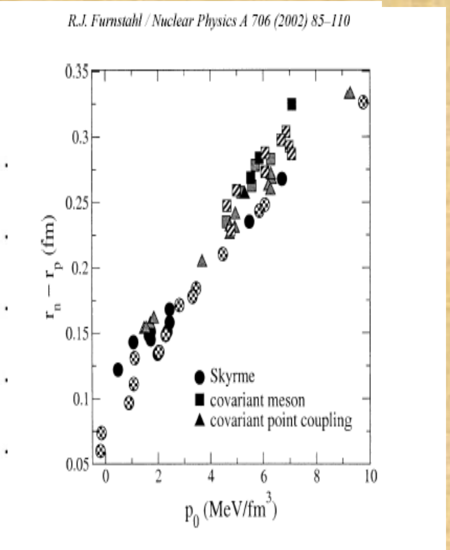
丰中子核、重核以及超重核性质



核子-核子强相互作用本质
检验和发展原子核多体理论

核介质中核子-核子有效相互作用



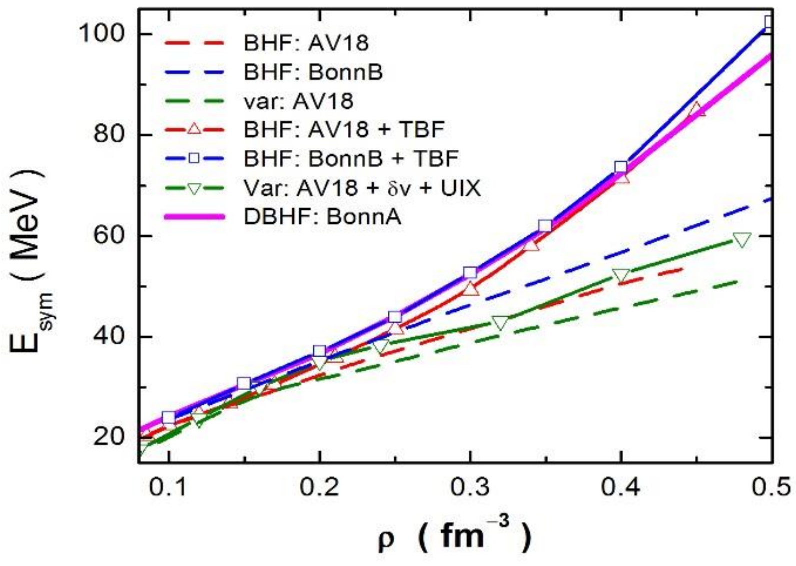


对称能的多体理论预言

- Skyrme-Hartree-Fock Approach
- Relativistic Mean Field Theory
- Relativistic Hartree-Fock

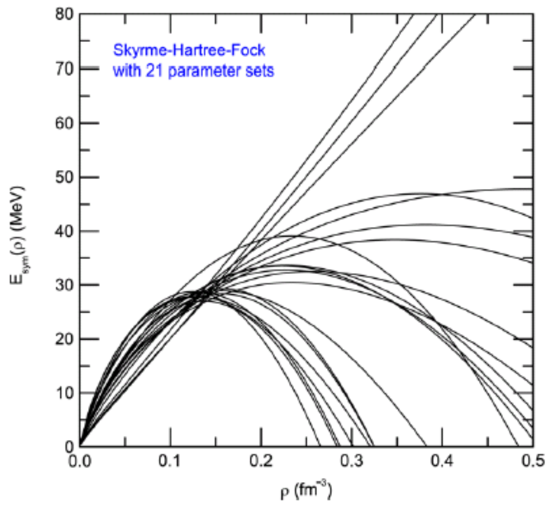
- Variational Approach
- Green’s Function Theory
- Brueckner Theory
- Dirac-Brueckner Approach
- Effective Field Theory

各种微观理论预言的对称能高密行为存在很大分歧

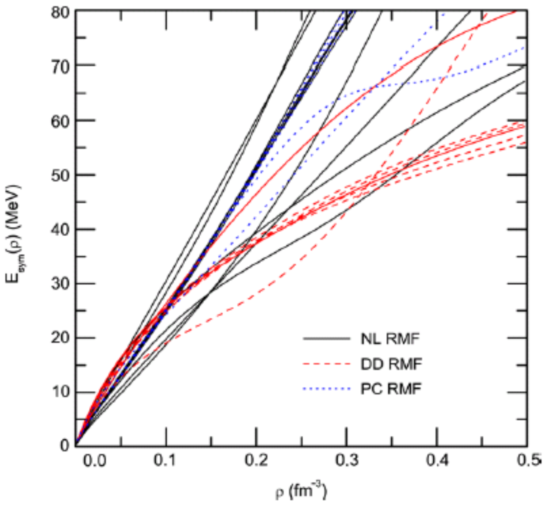


微观多体理论：
多体变分法
微观BHF多体理论

Skyrme-Hartree-Fock



相对论平均场理论



饱和密度附近对称能密度依赖性

在饱和密度附近，通常将对称能作泰勒展开：

$$S(\rho)=S_0+\frac{L}{3}\left(\frac{\rho-\rho_0}{\rho_0}\right)+\frac{K_{\mathrm{sym}}}{18}\left(\frac{\rho-\rho_0}{\rho_0}\right)^2+\mathcal{O}\left[\left(\frac{\rho-\rho_0}{\rho_0}\right)^3\right]$$

斜率参数 *L*

$$L=3\rho\left.\frac{\partial E_{sym}(\rho)}{\partial\rho}\right|_{\rho_0}$$

曲率参数 K_{sym}

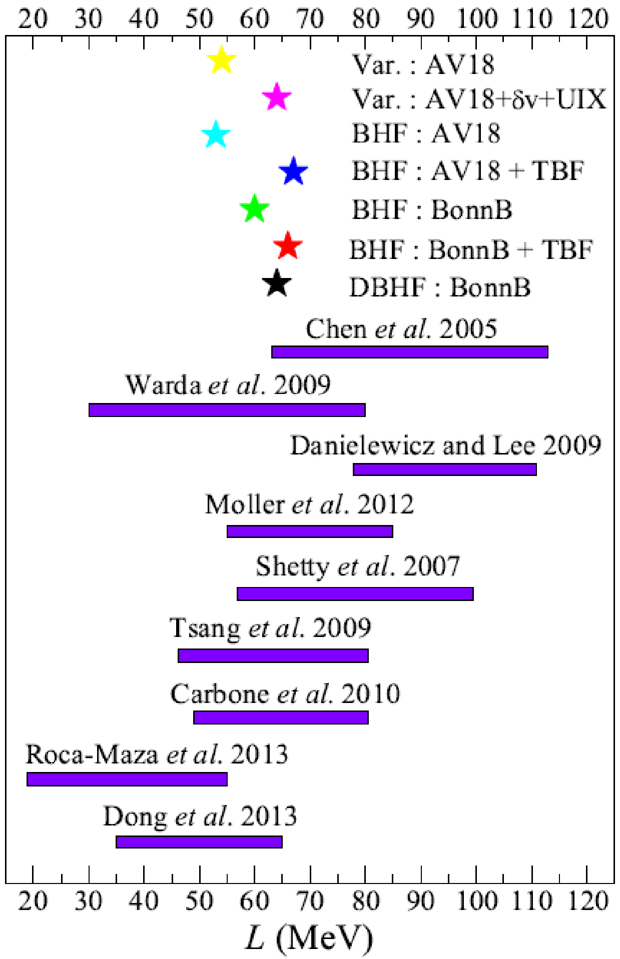
$$K_{sym}=9\rho^2\left.\frac{\partial^2 E_{sym}}{\partial\rho^2}\right|_{\rho_0}$$

Experimental constraints:

$$20\mathrm{MeV}<L<120\mathrm{MeV}$$

Microscopic predictions:

$$50\mathrm{MeV}<L<70\mathrm{MeV}$$



Microscopic predictions

Neutron skin thickness

Surface symmetry energy

Nuclear mass

Isospin diffusion & isoscaling

Pymgy dipole resonance

IVGQR

β-decay energy of heavy nuclei

Zuo *et al.*, EPJA 50 (2014) 12

对称能灵敏观测量

At sub-saturation densities

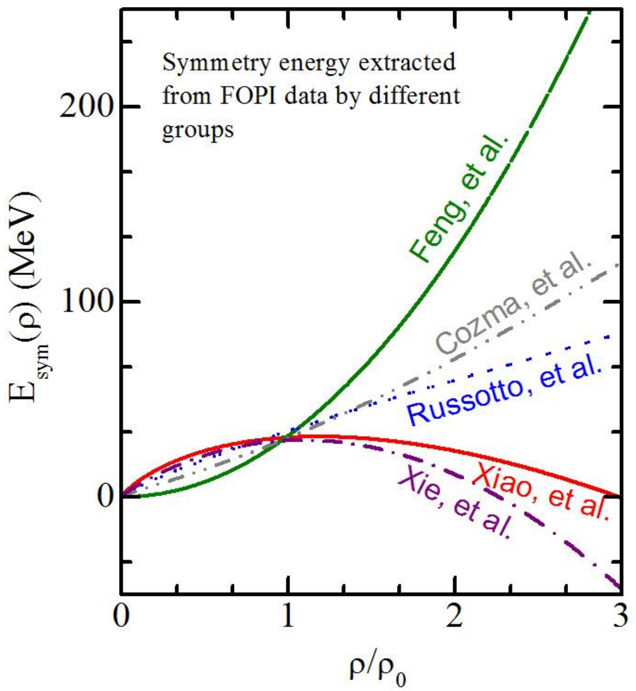
- Sizes of n-skins of unstable nuclei from total reaction cross sections
- Proton-nucleus elastic scattering in inverse kinematics
- Parity violating electron scattering studies of the n-skin in ^{208}Pb
- n/p ratio of FAST, pre-equilibrium nucleons
- Isospin fractionation and isoscaling in nuclear multifragmentation
- Isospin diffusion/transport
- Neutron-proton differential flow
- Neutron-proton correlation functions at low relative momenta
- t/^{3}He ratio

Towards high densities reachable at FAIR/GSI, RIA, RIKEN and CSR/China

- π^-/π^+ ratio, K^+/K^0 ?
- Neutron-proton differential transverse flow
- n/p ratio at mid-rapidity
- Nucleon elliptical flow at high transverse momenta

通过重离子碰撞约束对称能高密行为

高密区对称能



德国GSI的Au+Au实验

超硬

PLB 683 (2010) 140 (QMD)

介于软和硬之间

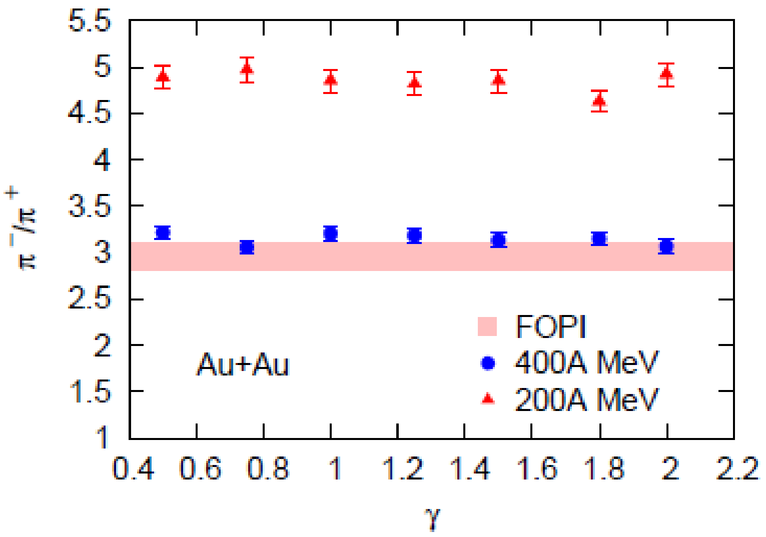
PRC 88 044912 (2013)

PLB. 697(2011)471 (rQMD)

超软

PRL 102(2009)062502 (BUU)

PLB 718 (2013) 1510 (BLV)



不敏感

Hong and Danielewicz,

ArXiv: 1307.7654 2013 (pBUU)

现状：实验上，相关实验研究和实验数据极端缺乏

理论上，对称能灵敏观测量的模型依赖性

关键理论问题：高密对称能灵敏观测量的模型依赖性

不同类型输运理论模型导致的模型依赖性

输运理论模型中各种不确定因素导致的模型依赖性：

介质中NN弹性散射截面和非弹性散射截面

介质中Δ性质

介质中阈值效应

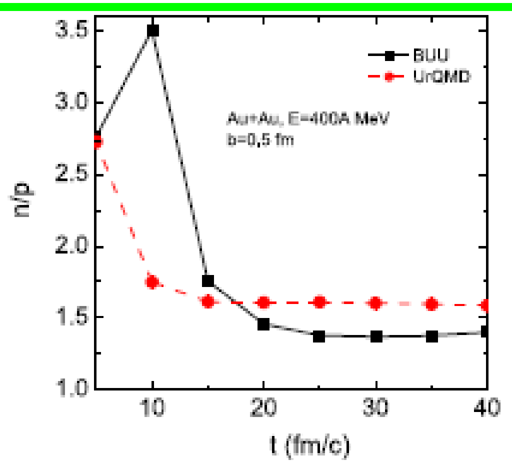
π介子势

……

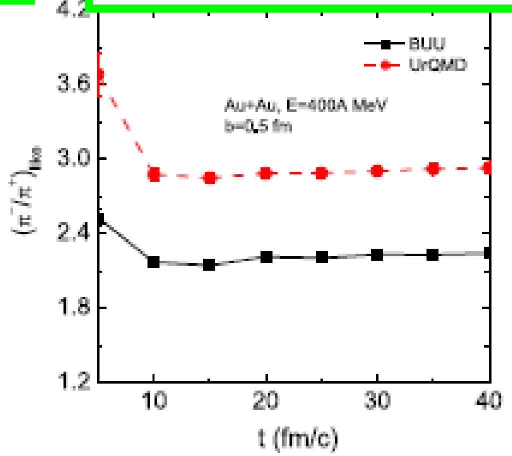
高密对称能灵敏观测量的模型依赖性（BUU模型与QMD模型）

W.M. Guo et al., **PLB726 (2013) 211**

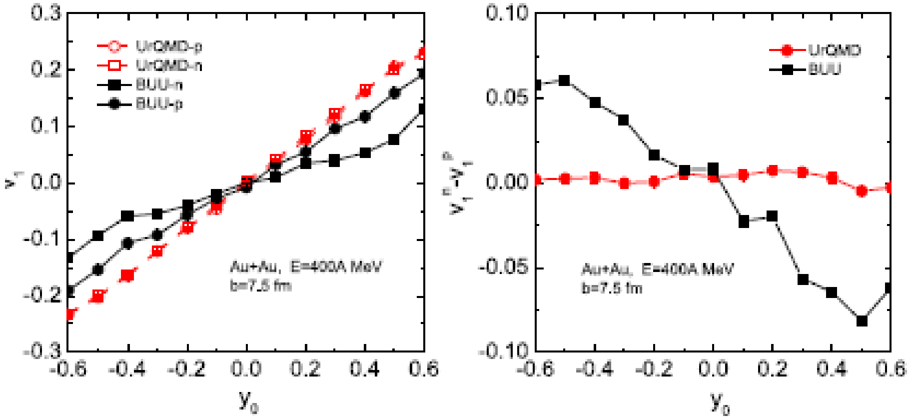
自由核子发射n/p比



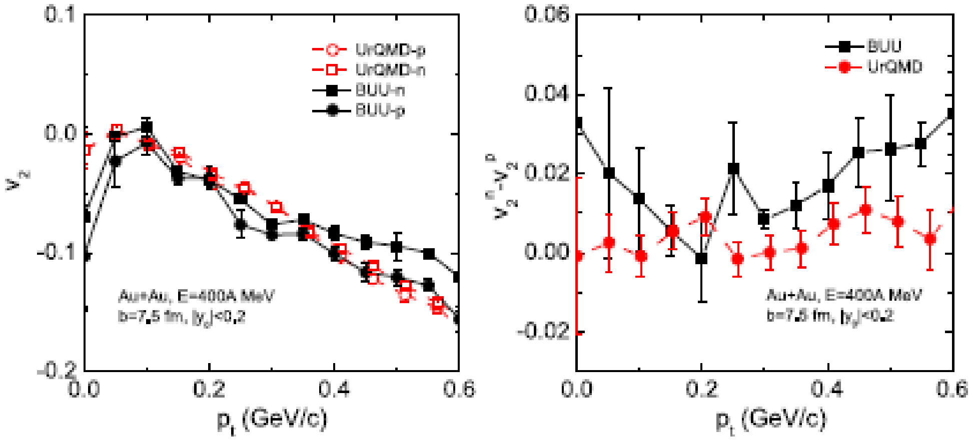
荷电π介子产额比



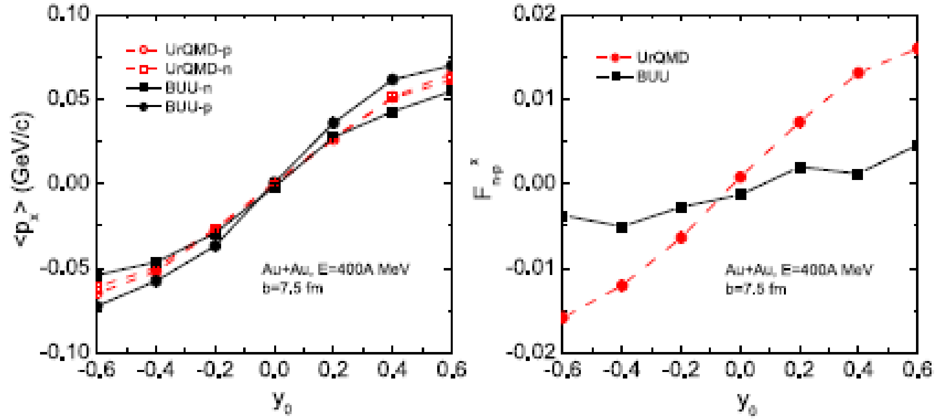
中子与质子直接流



中子与质子微分椭圆流



中子与质子微分横向流



非对称核介质中NN弹性散射截面效应

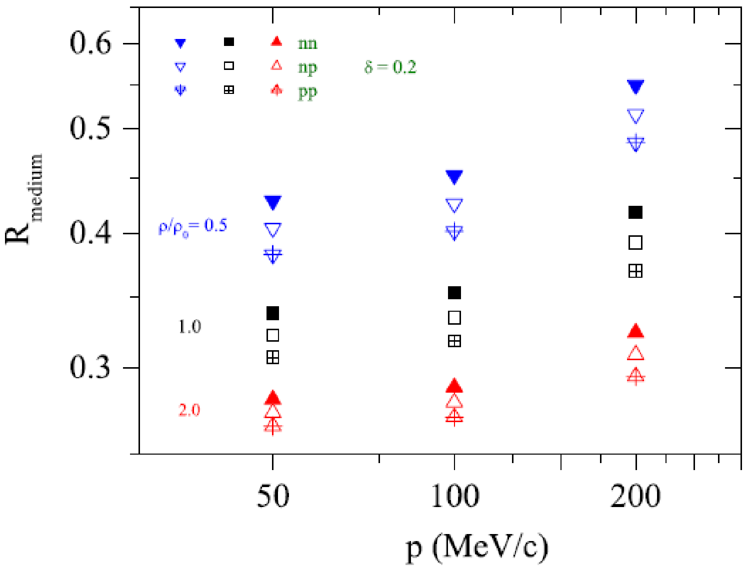
W.M. Guo et al., PRC90 (2014) 044605

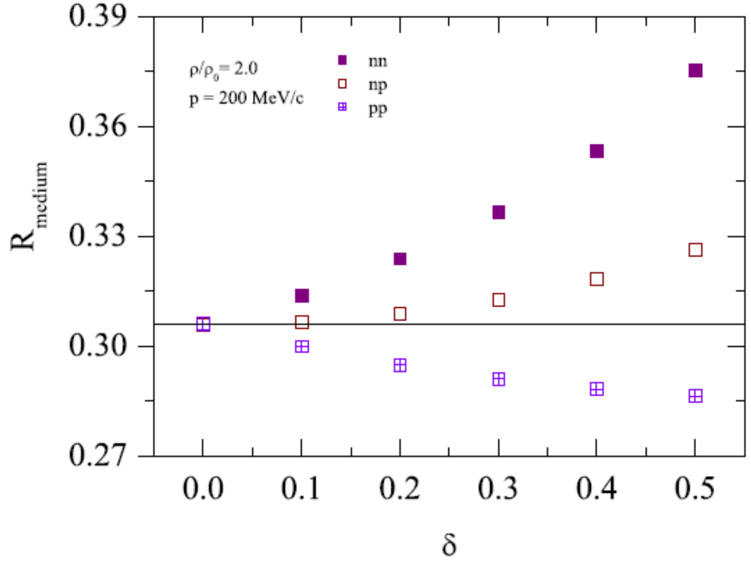
in-medium NN elastic cross section, which is from the scaling model according to nucleon effective masses [25–28]

$$
\begin{aligned}
R_{medium}(\rho, \delta, \vec{p}) &= \sigma^{medium}_{NN_{elastic}} / \sigma^{free}_{NN_{elastic}} \\
&= (\mu^*_{NN} / \mu_{NN})^2,
\end{aligned}
\tag{3}
$$

where μ_{NN} and μ^*_{NN} are the reduced masses of the colliding nucleon pair in free space and medium, respectively. And the effective mass of nucleon in isospin asymmetric nuclear matter is given by

$$
m^*_\tau = \{1 + \frac{m_\tau}{p}\frac{dU_\tau}{dp}\}^{-1} m_\tau. \tag{4}
$$

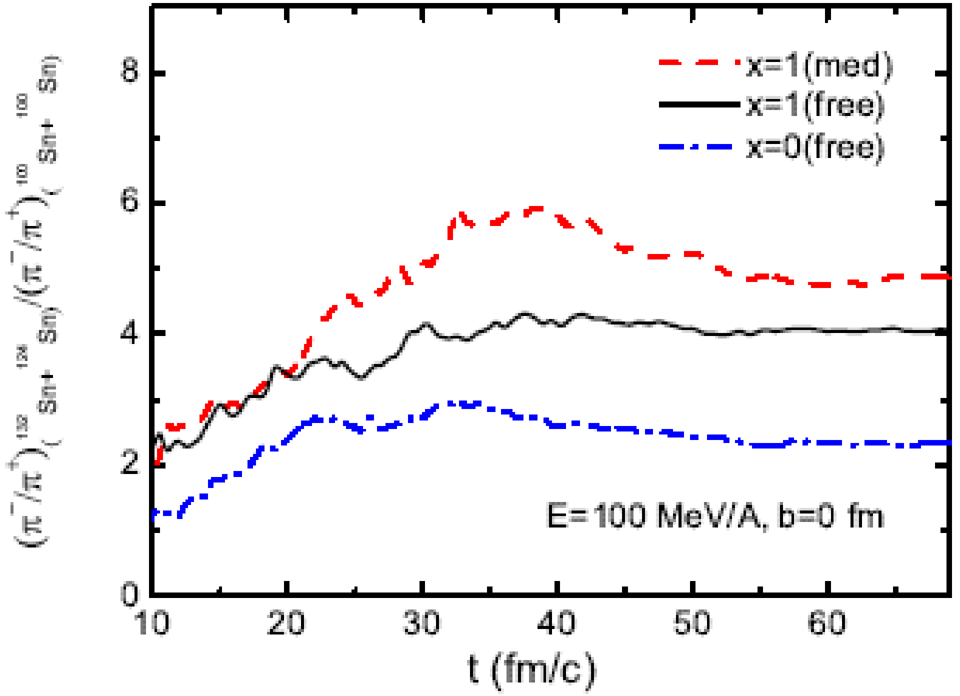




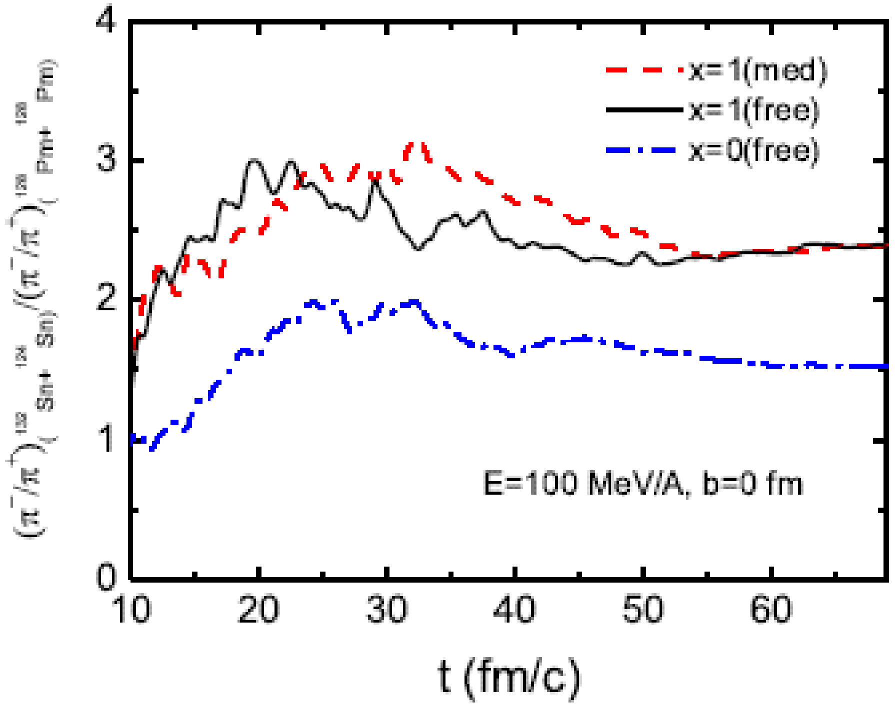
非对称核介质中NN弹性散射截面效应

W.M. Guo et al., PRC90 (2014) 044605

双反应系统荷电π介子双比：$\dfrac{(\pi^-/\pi^+)_{\text{丰中子系统}}}{(\pi^-/\pi^+)_{\text{缺中子系统}}}$



丰中子系统^{132}Sn+^{124}Sn与缺中子系统^{100}Sn+^{100}Sn



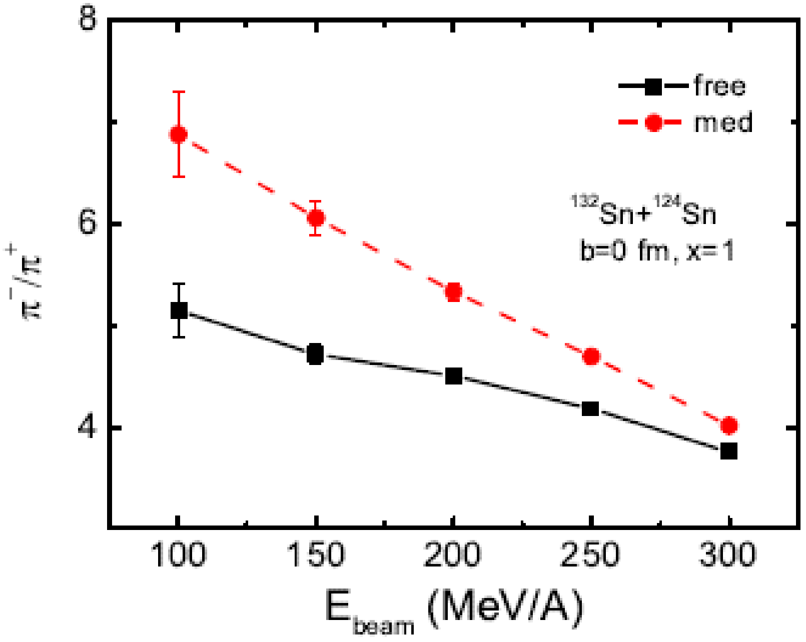
丰中子系统^{132}Sn+^{124}Sn与缺中子系统^{128}Pm+^{128}Pm

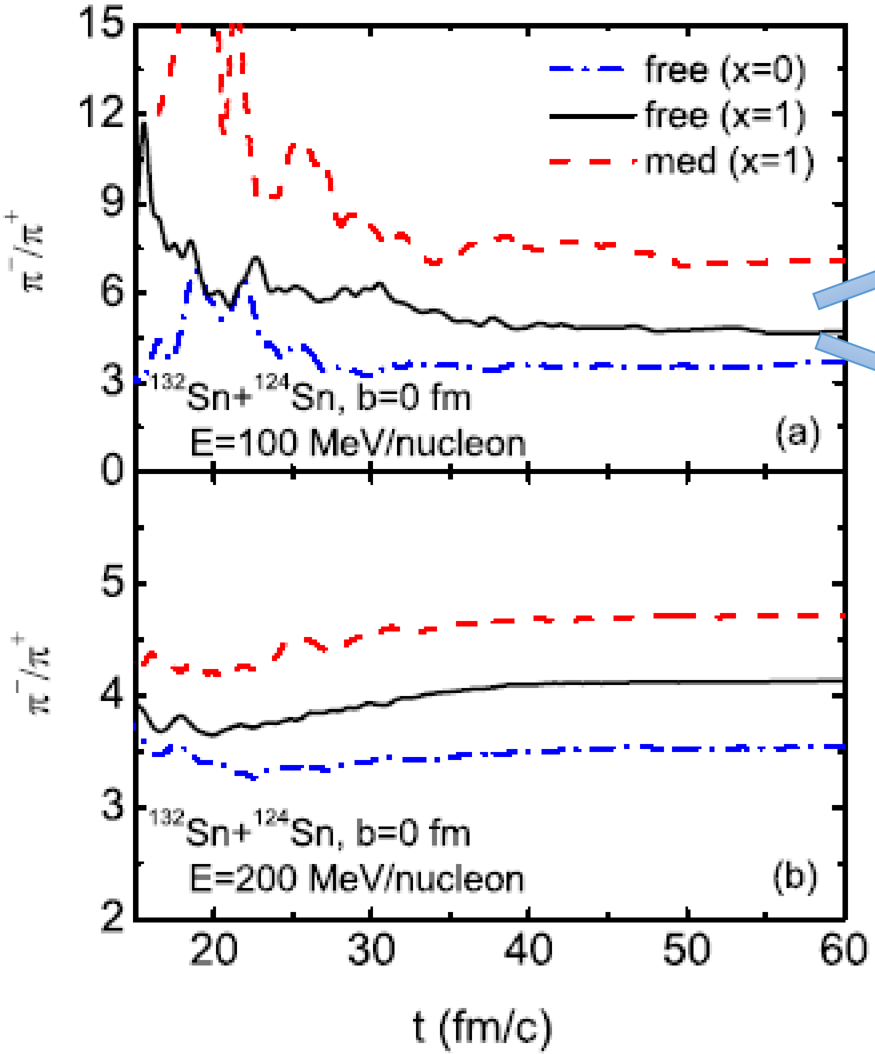
有望解决通过荷电π介子比探测对称能高密行为时遇到的介质中NN弹性散射截面的不确定性问题。

非对称核介质中NN弹性散射截面效应

W.M. Guo et al., PRC90 (2014) 044605

$^{132}Sn + ^{124}Sn$碰撞系统





NN截面效应

对称能效应

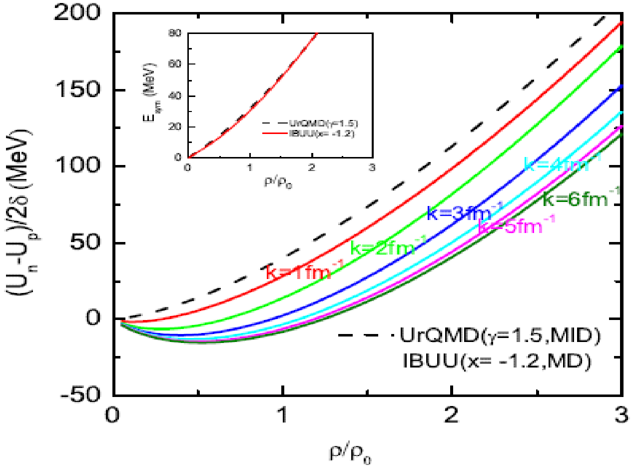
介质中NN截面效应对重离子碰撞中π^-/π^+比有显著影响

如何减弱或消除由于介质中NN散射截面的不确定性造成的对于同位旋灵敏观测量的影响?

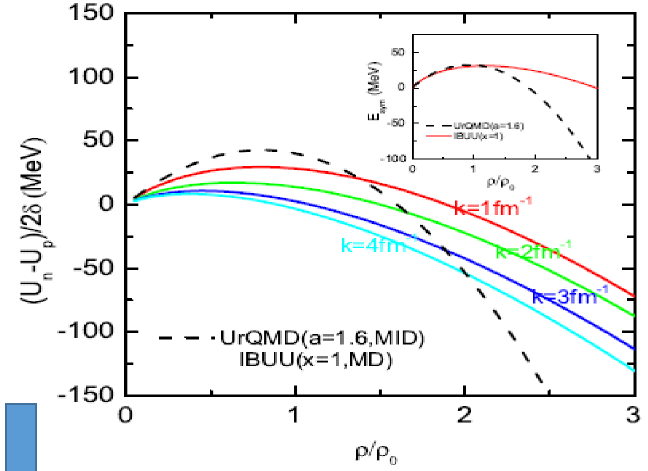
同位旋分馏: 定性探测对称能高密行为的模型无关灵敏观测量

W.M. Guo et al., **PLB738 (2014) 397**

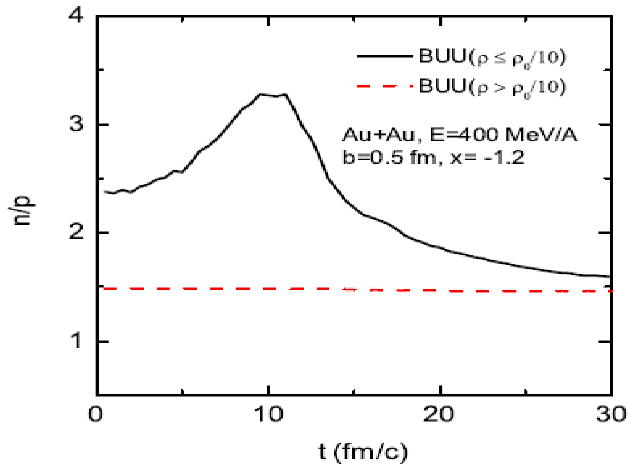
超硬对称能高密行为



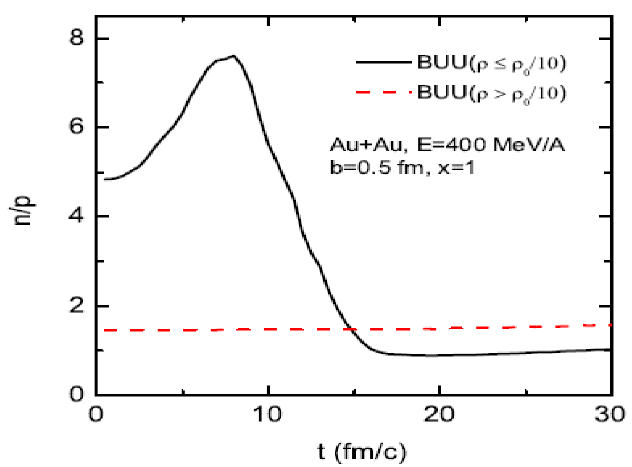
超软对称能高密行为



正常同位旋分馏



反常同位旋分馏



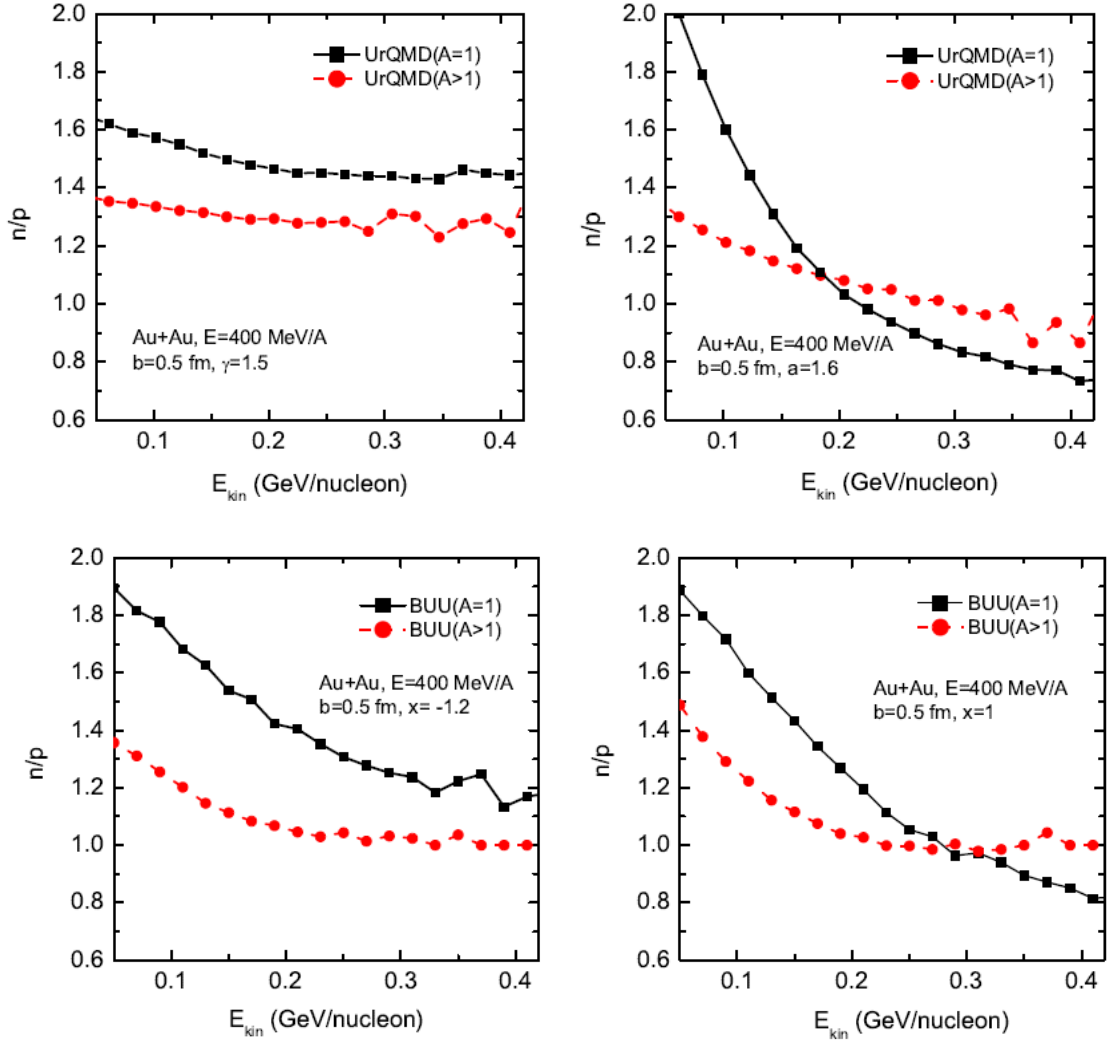
正的对称势：对中子具有排斥性，对质子具有吸引性，导致正常同位旋分馏（汽相n/p比大于液相n/p比）

负的对称势：对质子具有排斥性，对中子具有吸引性，导致反常同位旋分馏（汽相n/p比小于液相n/p比）

同位旋分馏: 定性探测对称能高密行为的模型无关灵敏观测量

W.M. Guo et al., **PLB738 (2014) 397**

超硬对称能高密行为　　超软对称能高密行为



QMD

BUU

重离子碰撞中正常或者反常的同位旋分馏可以作为定性探测对称能高密行为的模型无关的灵敏观测量

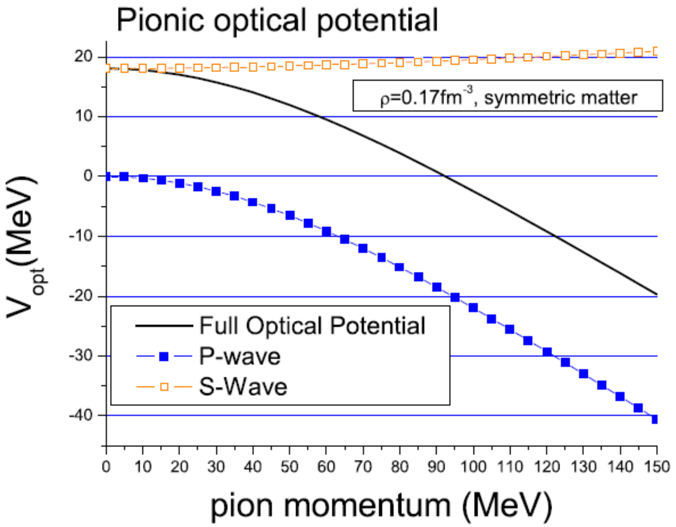
π势对荷电π介子比率的影响

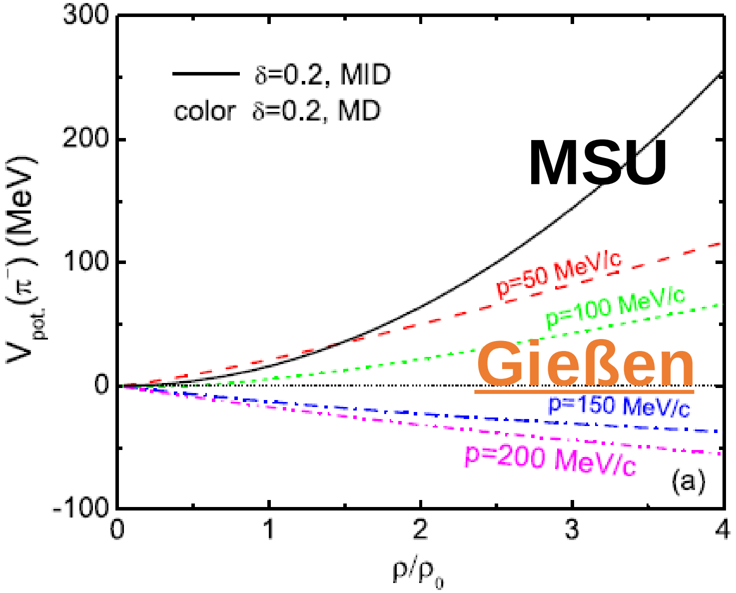
MSU π势: [J. Hong & P. Danielewicz, PRC 90, 024605 (2014)]

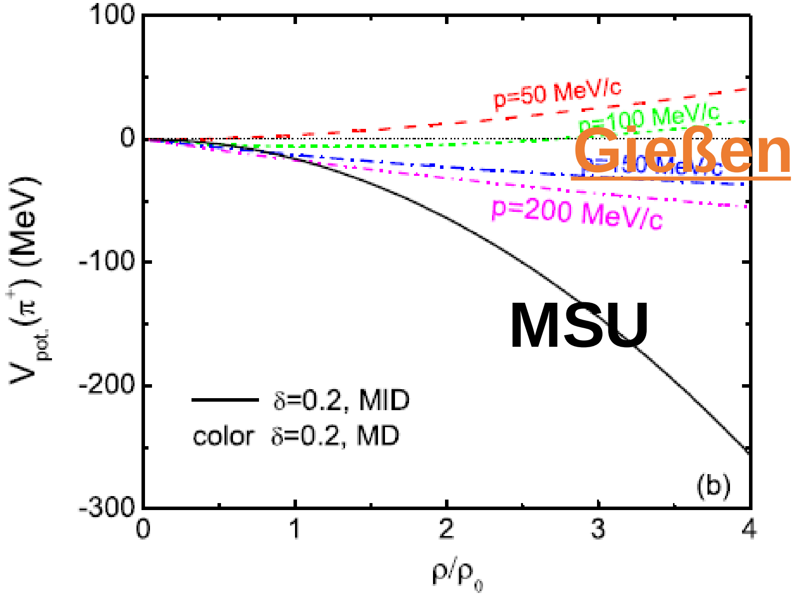
$$U_{\pi^{\pm}} = \mp 8 S_{int0} \rho_T \frac{\rho^{\gamma-1}}{\rho_0^{\gamma}}$$

(仅考虑s波贡献，动量无关，对π^-排斥，对π^+吸引，)

Gießen π势 [O. Buss, diploma thesis]

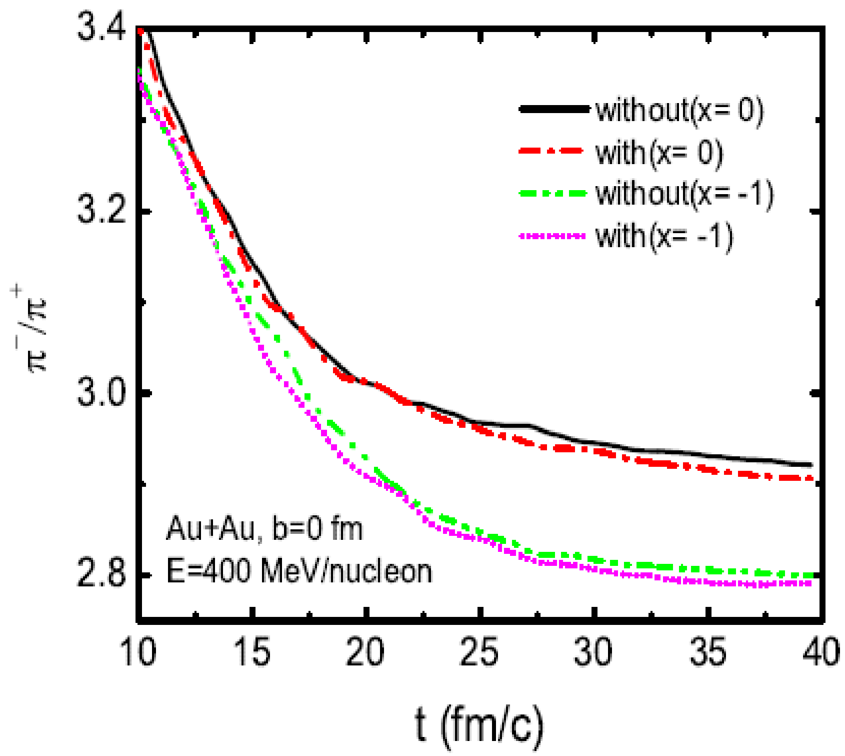




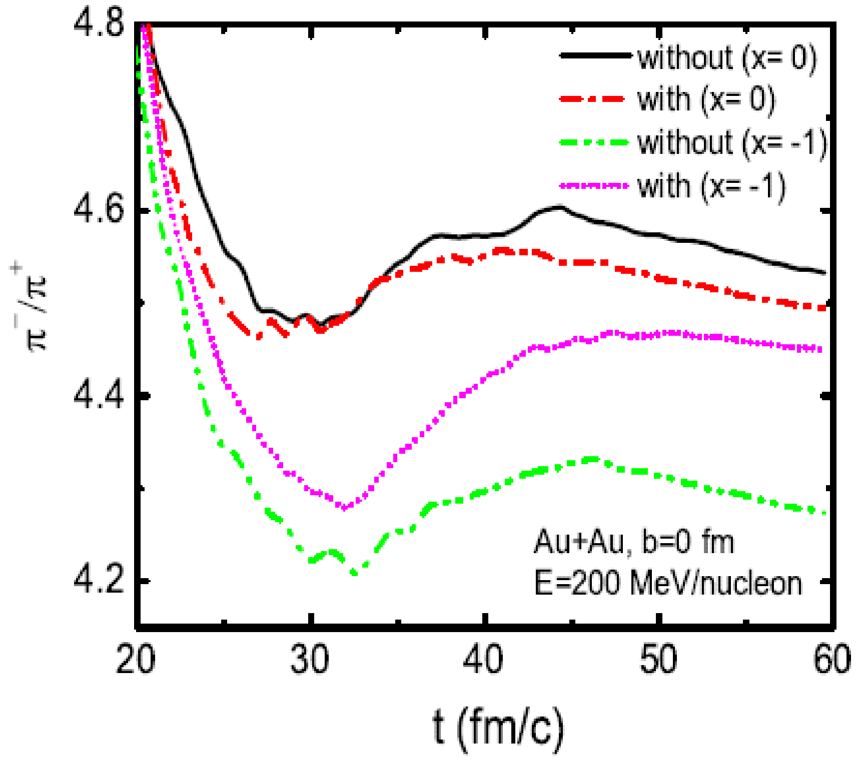


π势对荷电π介子比率的影响

入射能量：每核子400MeV



入射能量：每核子200MeV



入射能量较高时，pion势的影响较小

入射能量较低时，pion势有显著影响，其作用会减弱荷电pion介子比的对称能敏感性

总结

探索了对称能灵敏观测量的模型依赖性

提出了定性探测对称能高密行为的模型无关灵敏观测量

提出解决通过荷电π介子比探测对称能高密行为时介质中NN弹性散射截面不确定性问题的方案

研究了pion势对重离子碰撞中荷电 pion介子比值的影响；在低束流能量下抵消重离子碰撞荷电pion介子比值的对称能效应

谢谢大家！