Dependence of Flow Observable in Heavy-Ion Collisions on the Isospin Dependent EoS of Nuclear Matter

D. Cozma, M. Petrovici (NIPNE, Bucharest, Romania)

HiDeSymE ESF Workshop

Zagreb, Croatia

October 16th, 2009

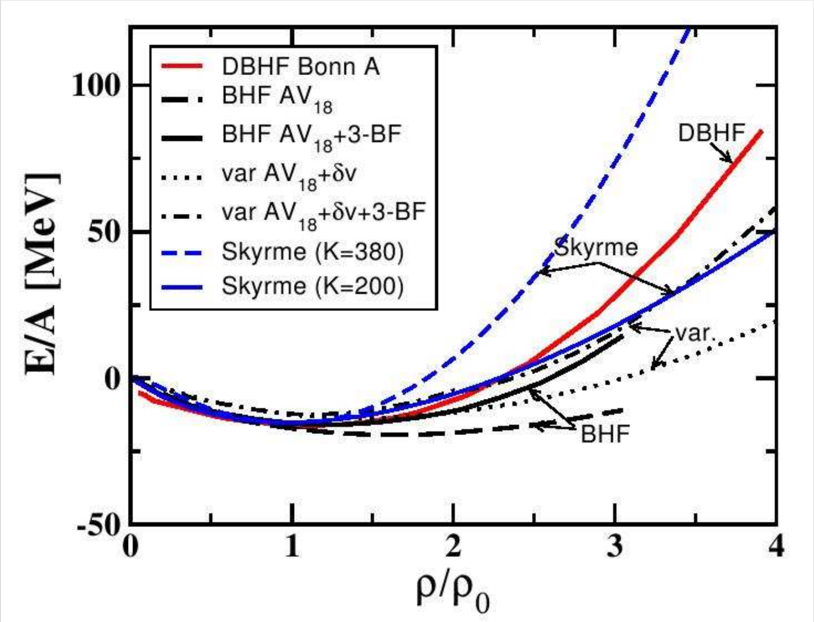
OVERVIEW

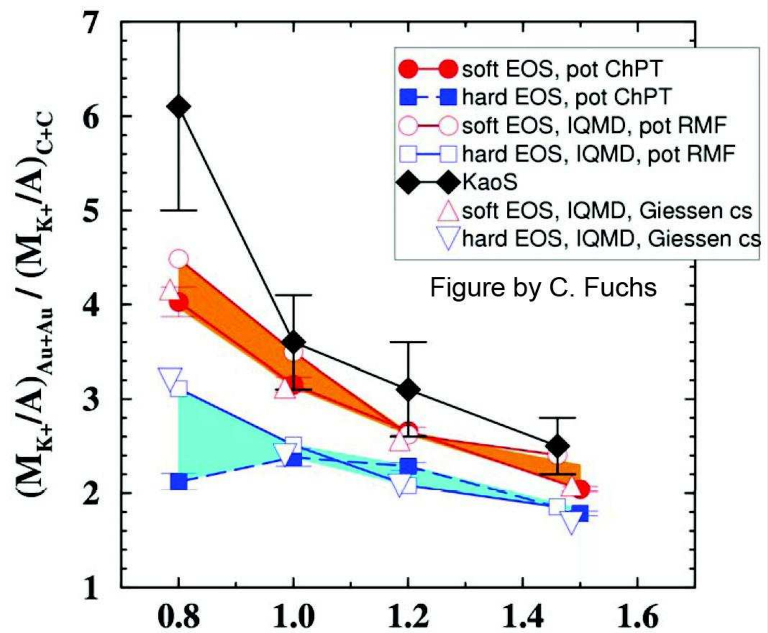
- **Introduction & Motivation**
- **HIC Model**
  - QMD transport model
- **In-medium Effects**
  - In-medium NN scattering
  - Isospin dependence of EoS
- **Flow observables**
  - Differential radial flow
  - Elliptic flow in Zr+Zr and Ru+Zr @ 400 MeV
- **Summary and Outlook**

Introduction

Nuclear Equation of State: E/A=$\mathcal{E}(\rho)$

sources: finite nuclei $\rho/\rho_0 \leq 1$
heavy-ions $\rho/\rho_0 \leq 3$
neutron stars $\rho/\rho_0 \leq 10$





Fuchs *et. al* PRL86, 1974

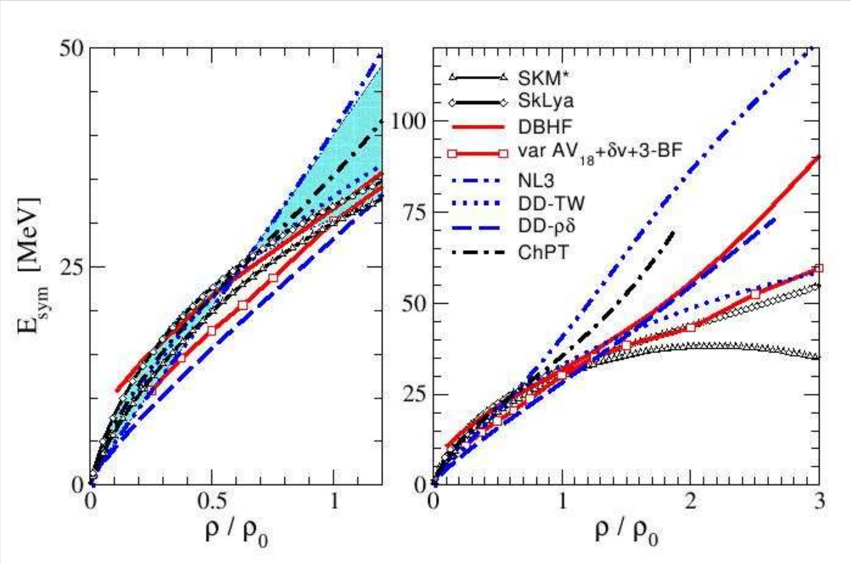
Introduction

Equation of State of asymmetric nuclear matter:
Symmetry energy:

$$\mathcal{E}(\rho,\beta) = \mathcal{E}(\rho) + \mathcal{E}_{sym}(\rho)\,\beta^2 + \cdots \qquad \beta = \frac{\rho_n - \rho_p}{\rho_n + \rho_p}$$

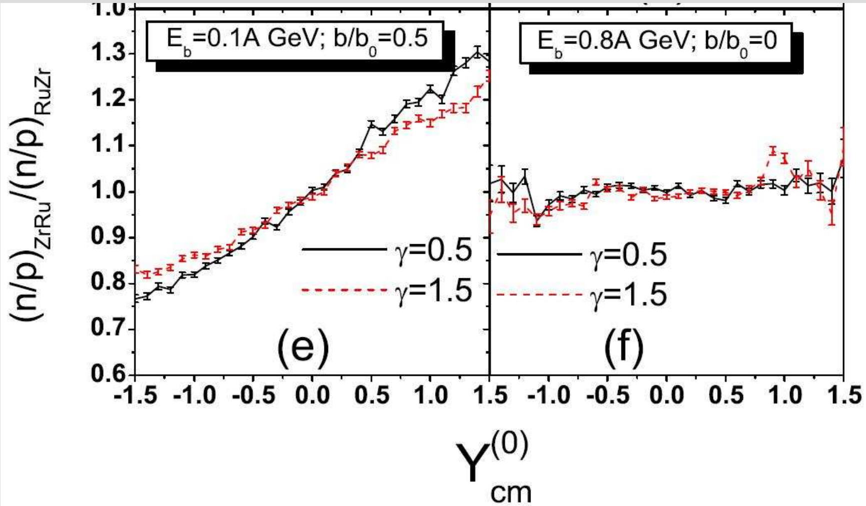
$$\mathcal{E}_{sym}(\rho) = \frac{1}{2}\,\frac{\partial \mathcal{E}(\rho,\beta)}{\partial \beta^2}|_{\beta=0} = a_4 + \frac{p_0}{\rho_0^2}(\rho - \rho_0)$$

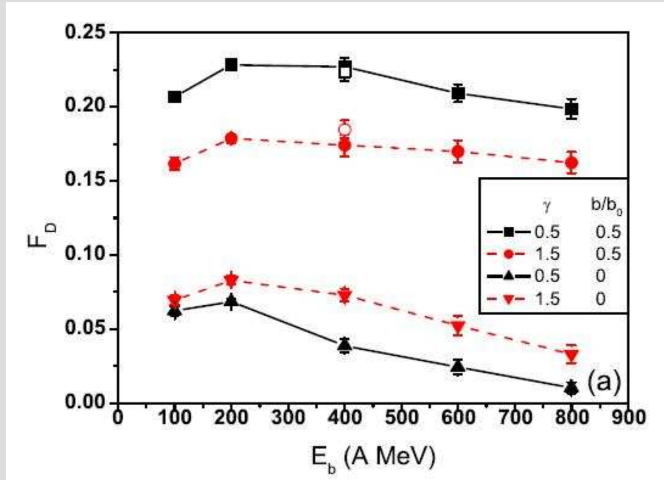
- phenomenological models constrained in the low ρ region diverge at high density



Observables

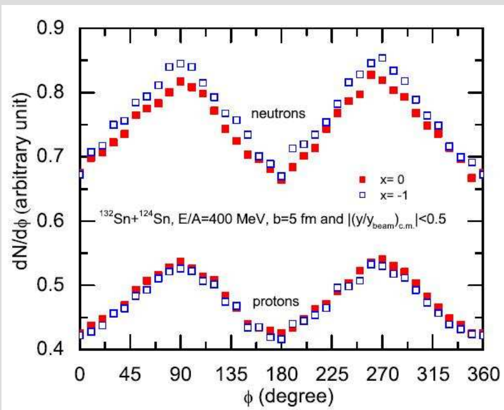
double neutron to proton ratio $(n/p)_{AB}/(p/n)_{BA}$

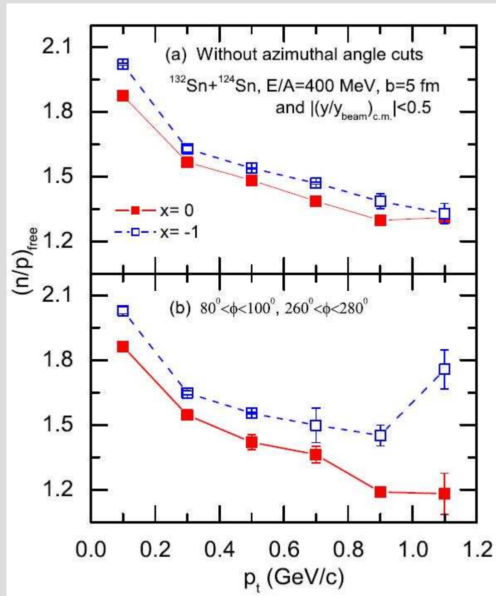




Li,Li, Stoecker PRC 73, 051601

neutron/proton ratio at midrapidity





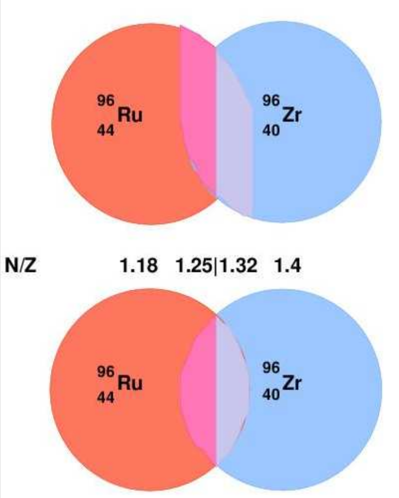
Yong, Li, Chen PLB 650, 344

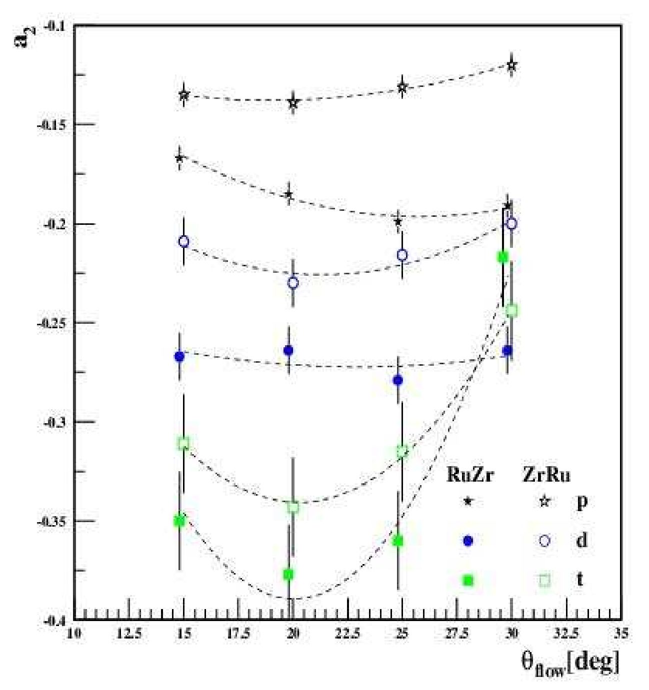
Motivation: FOPI Experiment

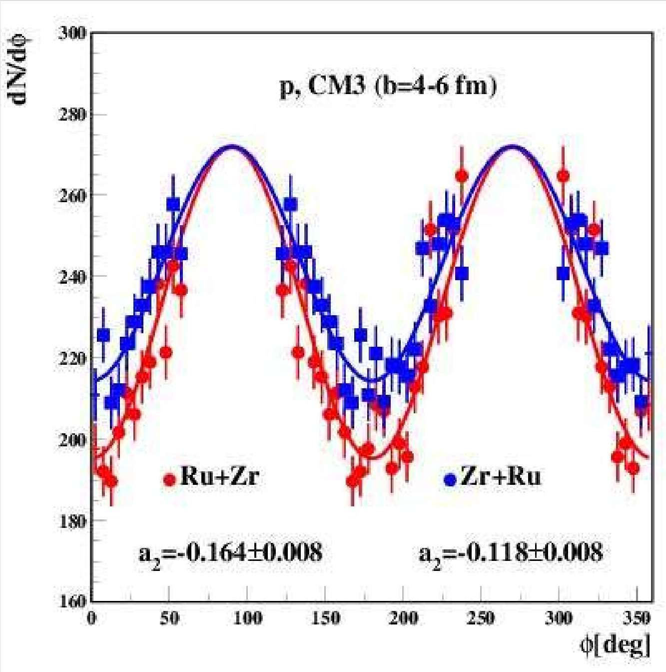
FOPI Collaboration: RuZr and AuAu @ 400 AMeV

Rami et al., PRL 84,1120

Hong et al., PRC 66, 034901







Transport Model

Transport model: **Quantum Molecular Dynamics**

Monte Carlo cascade + Mean field + Pauli-blocking

+ in medium cross section

all 4* resonances below 2 GeV - 10 Δ^* and 11 N^*

- included baryon-baryon collisions:

  all elastic channels

  inelastic channels $NN \to NN^\star$, $NN \to N\Delta^\star$, $NN \to \Delta N^\star$, $NN \to \Delta\Delta^\star$, $NR \to NR'$

- included pion-absorption $\rightleftharpoons$ resonance-decay channels:

  $\Delta \rightleftharpoons N\pi$, $\Delta^\star \rightleftharpoons \Delta\pi$, $\Delta^\star \rightleftharpoons N_{1440}\pi$, $N^\star \rightleftharpoons N\pi$, $N^\star \rightleftharpoons N\pi\pi$, $(N^\star \rightleftharpoons \Delta\pi$, $N^\star \rightleftharpoons N_{1440})$

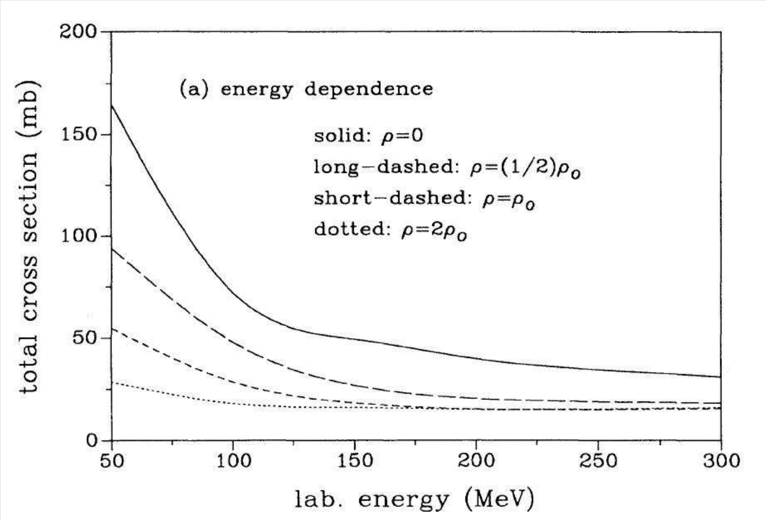
Nucleon-Nucleon Interaction

Vacuum NN Interaction: - microscopical OBE model (Bonn)

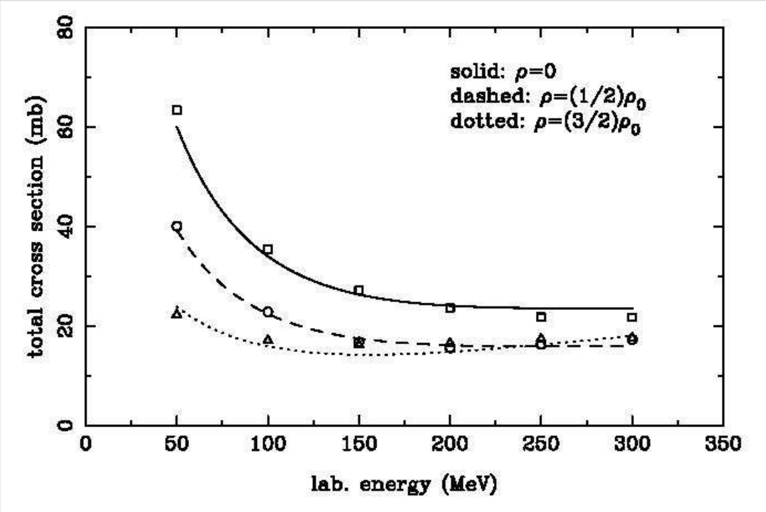
$$T(\vec{q}',\vec{q}) \quad = \quad V(\vec{q}',\vec{q}) + \mathcal{P}\int \frac{d^3k}{(2\pi)^3} V(\vec{q}',\vec{k}) \frac{m^2}{E_k^2} \frac{1}{2E_q - 2E_k} T(\vec{k},\vec{q})$$

In-Medium NN interaction: - Dirac-Brueckner approach

$$G(\vec{q}',\vec{q}|\vec{P},z) = V^*(\vec{q}',\vec{q}) + \mathcal{P}\int \frac{d^3k}{(2\pi)^3} V^*(\vec{q}',\vec{k}) \frac{m_*^2}{E^2_{1/2\vec{P}+\vec{k}}} \frac{Q(\vec{k},\vec{P})}{z - 2E_{1/2\vec{P}+\vec{k}}} G(\vec{k},\vec{q}|\vec{P},z)$$



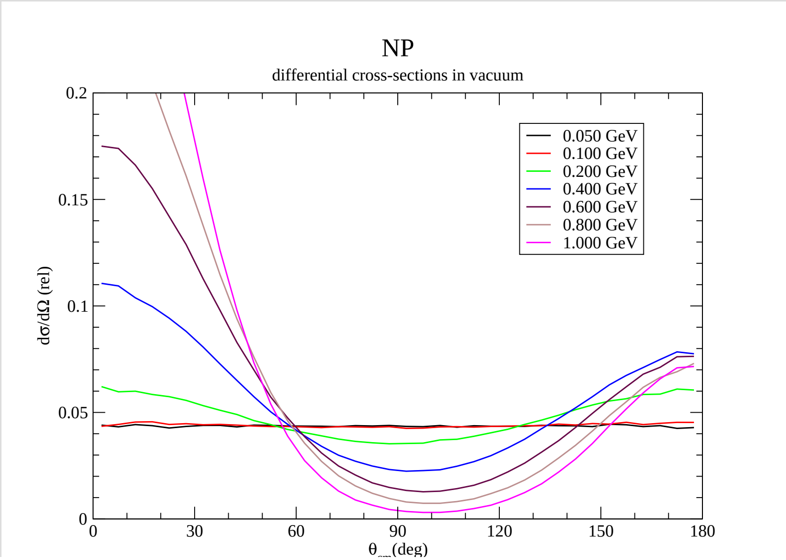
Li, Machleidt PRC 48, 1702

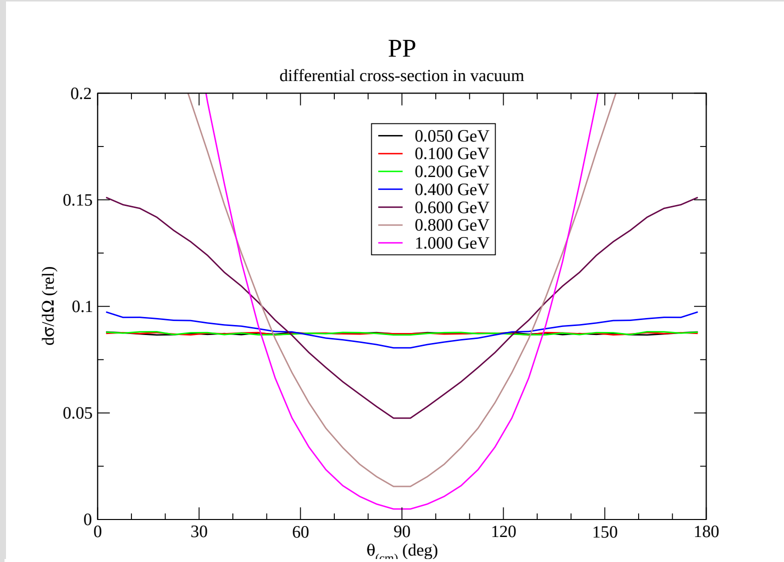


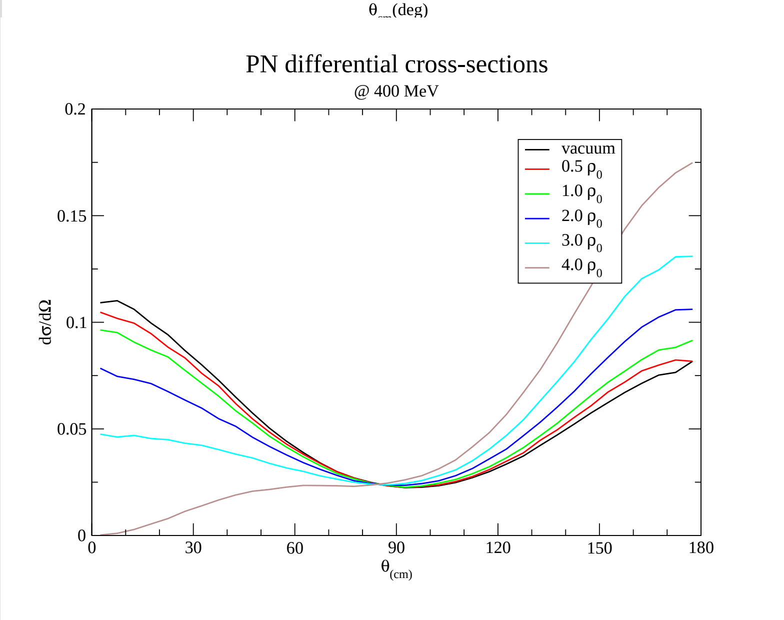
Li, Machleidt PRC 49, 566

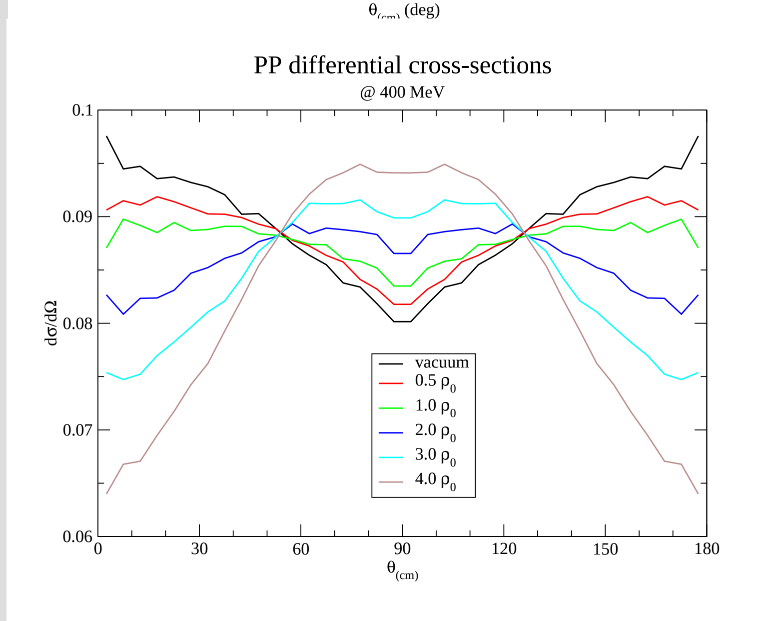
Nucleon-Nucleon Interaction

Li, Machleidt PRC 48, 1702; C. Fuchs, PRC 64, 024003









Isospin dependence of EoS

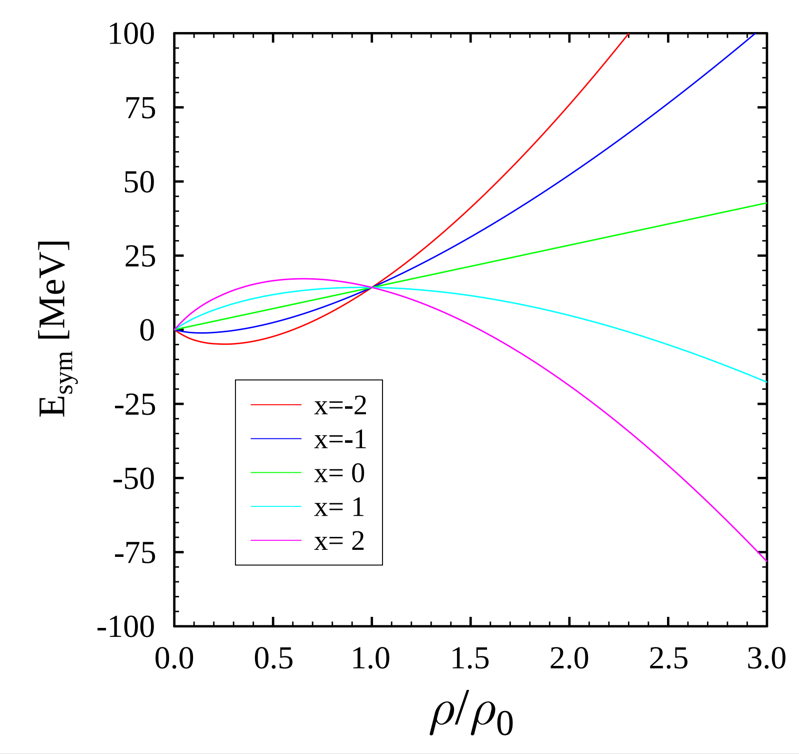
EoS of isospin asymmetric nuclear mater:

Das, Das Gupta, Gale, Li PRC67, 034611 (2003)

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

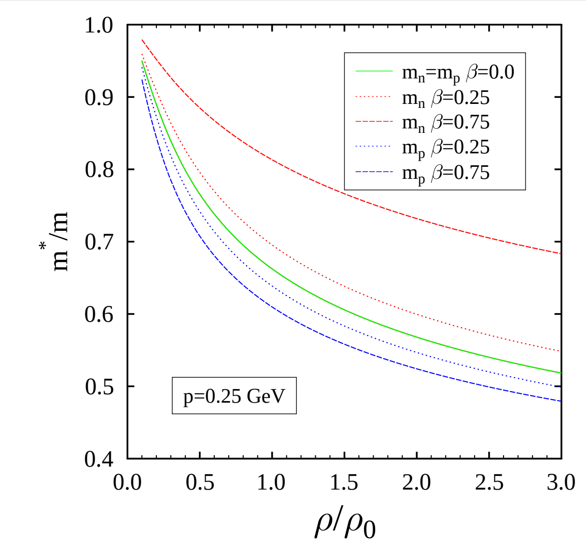
nucleons and resonances propagate in an isospin dependent mean field

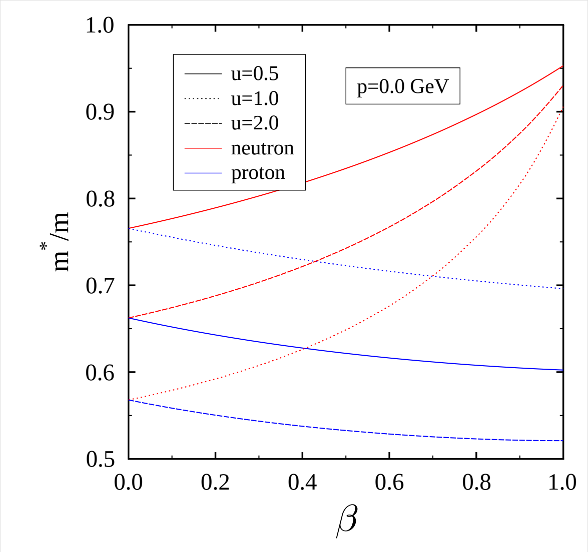
$$U_{asym}(n^*) = U_{asym}(\Delta^0) = U^n_{asym}$$
$$U_{asym}(p^*) = U_{asym}(\Delta^+) = U^p_{asym}$$
$$U_{asym}(\Delta^{++}) = 2U^p_{asym} - U^n_{asym}$$
$$U_{asym}(\Delta^-) = 2U^n_{asym} - U^p_{asym}$$



Consequences of isospin/momentum dependence

Effective Nucleon Masses





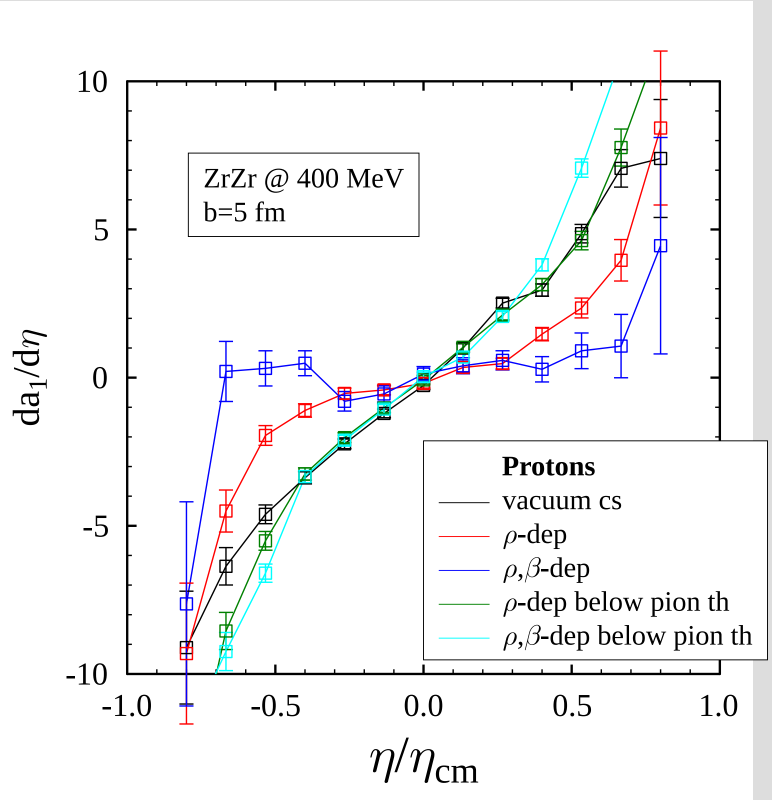
Isospin asymmetry dependence of NN cross-sections

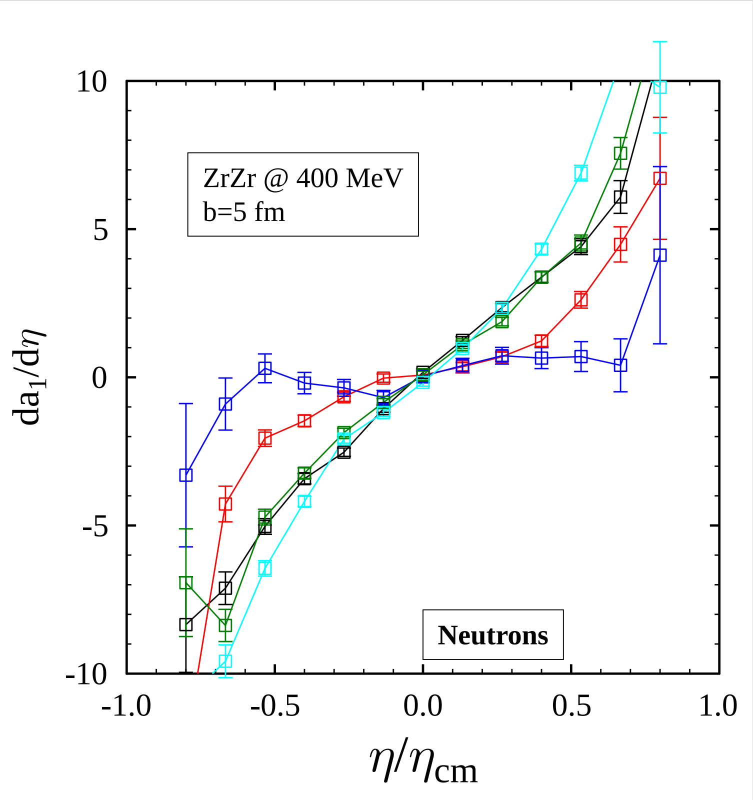
$$\sigma_{NN}(\rho,\beta) \quad = \quad \sigma_{NN}(\rho,\beta=0)\,\frac{m_1(\rho,\beta)\,m_2(\rho,\beta)}{m_1(\rho,\beta=0)\,m_2(\rho,\beta=0)}$$

Density dependence of NN cross-sections above pion production threshold

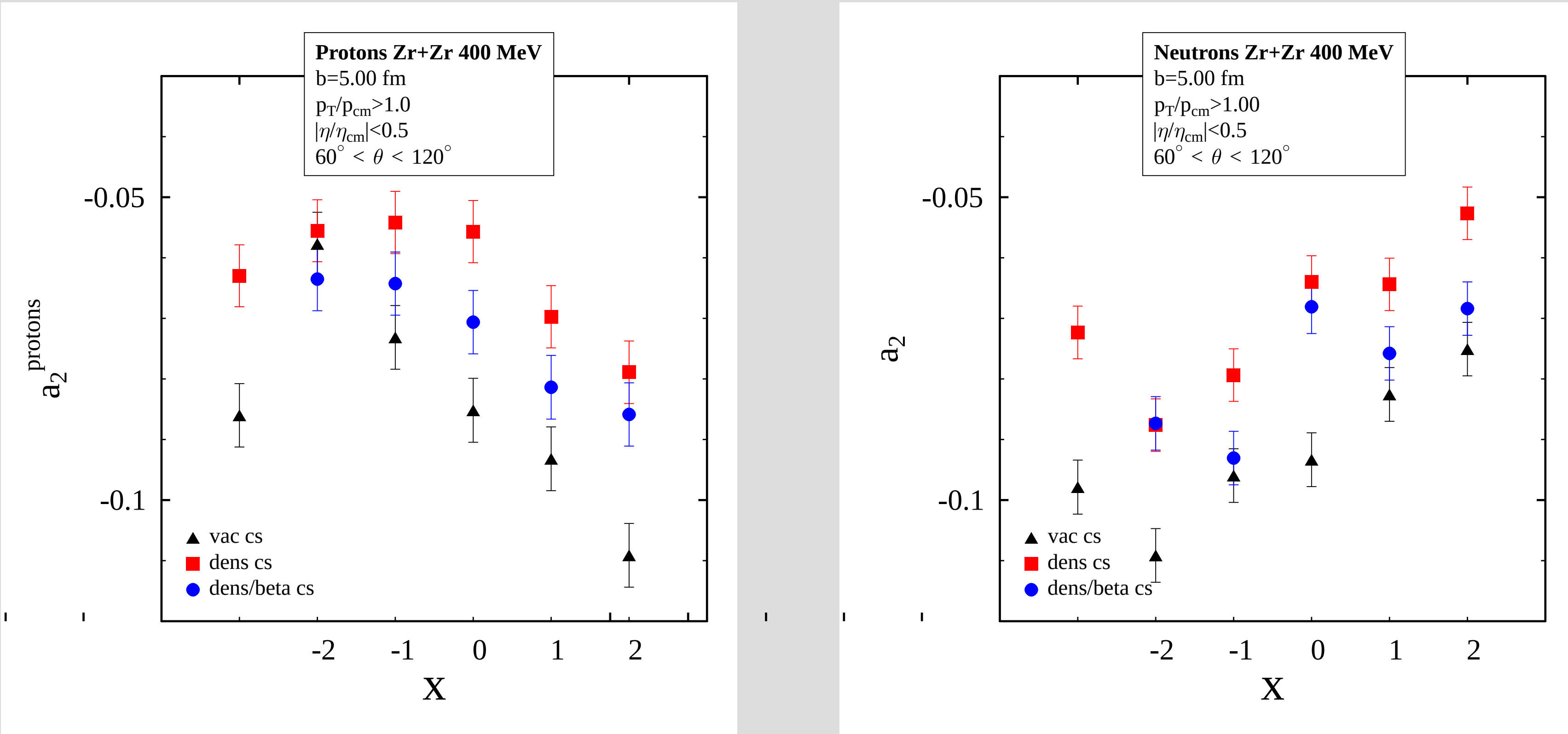
$$\sigma_{NN}(\rho,\beta) \quad = \quad \sigma_{NN}(\rho=0,\beta=0)\,\frac{m_1(\rho,\beta)\,m_2(\rho,\beta)}{m_N^2}$$

Differential radial flow

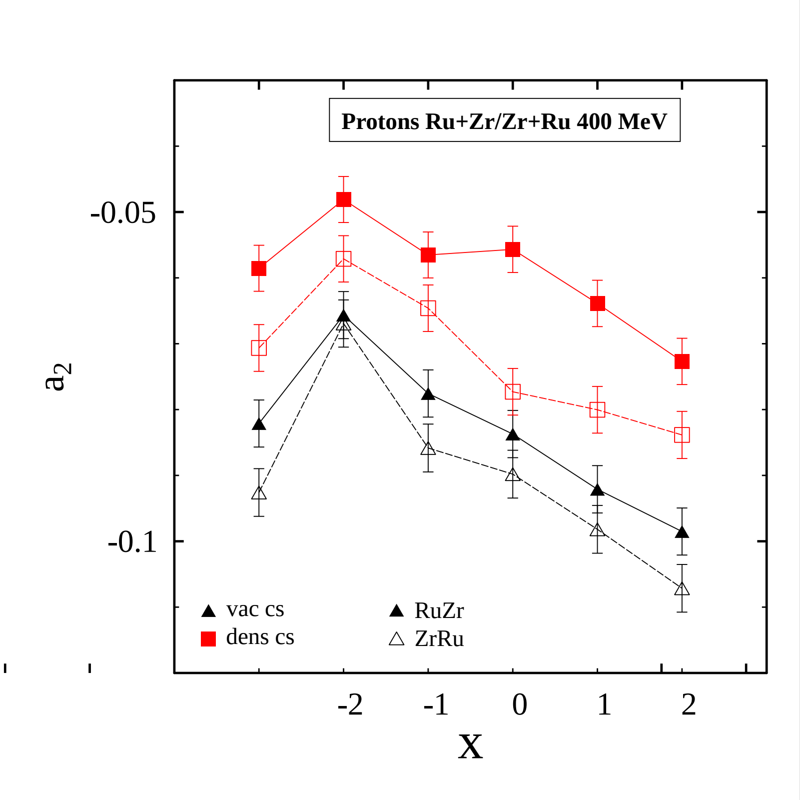


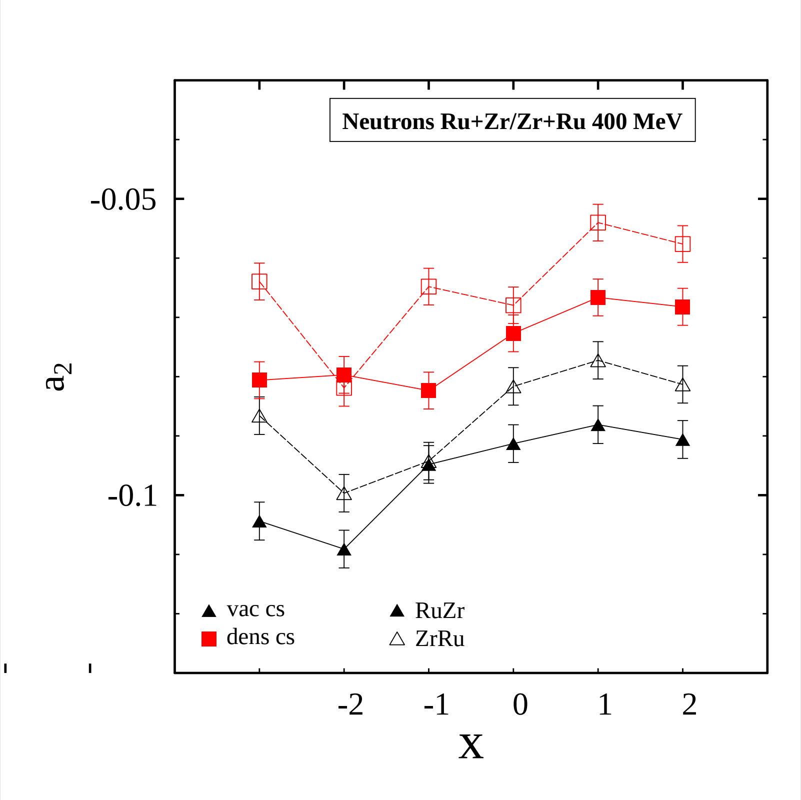


Elliptic flow: ZrZr



Elliptic flow: RuZr





Summary

- QMD: - accounts for isospin/momentum dependent EoS state and in-medium NN scattering
- Simulated collisions: - Ru+Ru, Zr+Zr and Ru+Zr @ 400 AMeV
- Conclusions:

- Important sensitivity of the flow observables on the NN interaction above pion production threshold
- Splitting of Ru+Zr and Ru+Zr values of a_2 determined by the isospin dependence of the NN interaction
- Value of elliptic flow parameter sensitive to the isospin dependent part of EoS; opposite behaviour for neutrons and protons
- Contraining the isospin dependent part of EoS from a_2 would require a good knowledge of the in-medium NN interaction