Modeling the EOS

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Outline

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- Overview models

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- Symmetric nm

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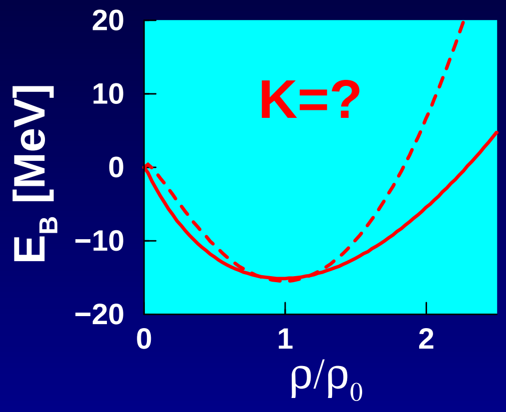
- Constraints from HICs

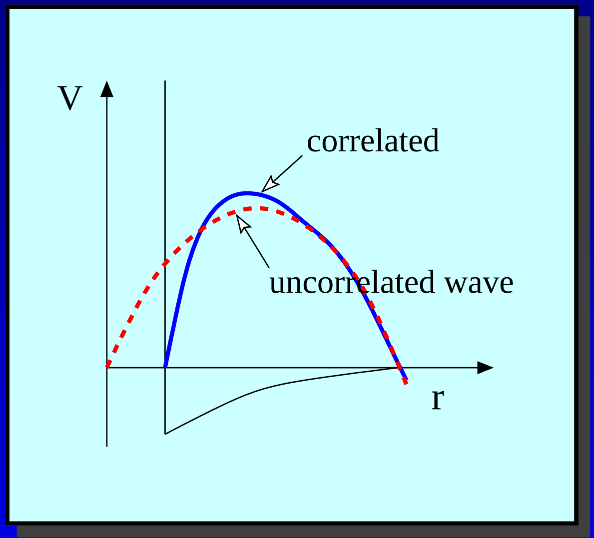
Overview models

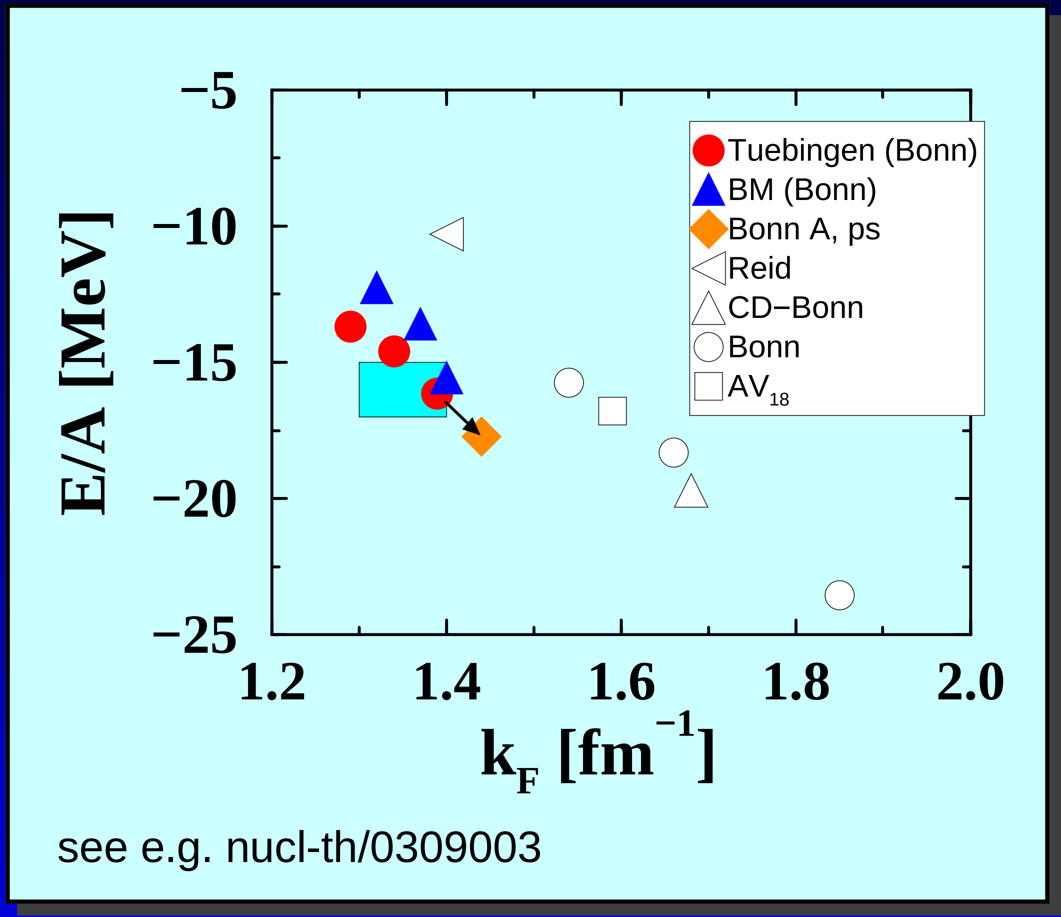
- Ab inito approaches
  Brueckner: BHF (Catania,..), DBHF (T¨ubingen,..),
  variational appr. (Urbana)
  realistic NN-interaction, no parameters
- Effective field theory
  Density functionals (Furnstahl, Serot,...), ChPT (Weise)
  peturbativ, scale arguments ($m_\pi/M, k_F/M$), few parameters (< 2)
- Empirical density functionals
  Skyrme, Relativistic Mean Field
  many parameters (6-10), high precison fits to finite nuclei

Saturation of Nuclear Matter

DBHF: realistic NN force, no parameter







Coester line $\Longrightarrow$ relativistic!

Hadronic many-body theory

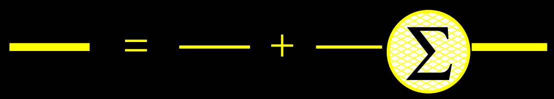
Relativistic Brueckner: N+OBEP ($V = \sigma, \omega, \pi, \rho, \eta, \delta$)

$\Longrightarrow$ 2-N correlations in hole-line expansion

$\Longrightarrow$ self-consistent sum of ladder diagrams

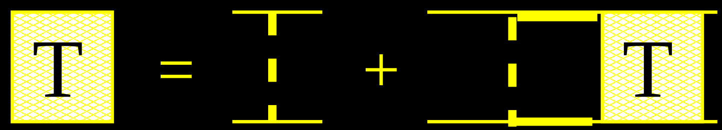
Dyson-Equation:

$G = G_0 + G_0 \Sigma G$



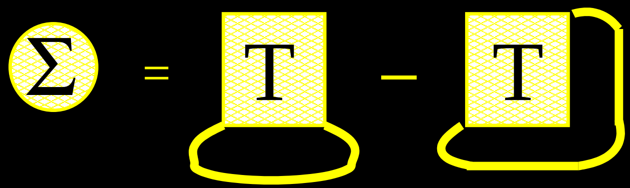
Bethe-Salpeter-Equation:

$T = V + i \int VGGQT$



Self Energy (Hartree-Fock):

$$\Sigma(\rho, k) = \sum_{q \epsilon F} < q|T(q,k)|q >= \Sigma_S - \gamma_0 \Sigma_0 + \vec{\gamma} \cdot \vec{k} \Sigma_V$$



Saturation mechanism

- Non-relativistic:

  tensor force essential

  2nd order $1-\pi-$exchange: large and attractive

  Pauli-blocking $\Longrightarrow$ saturation

- Relativistic:

  tensor force quenched Banerjee & Tjon NPA 708 (2002) 303

  cancellation of large scalar and vector fields

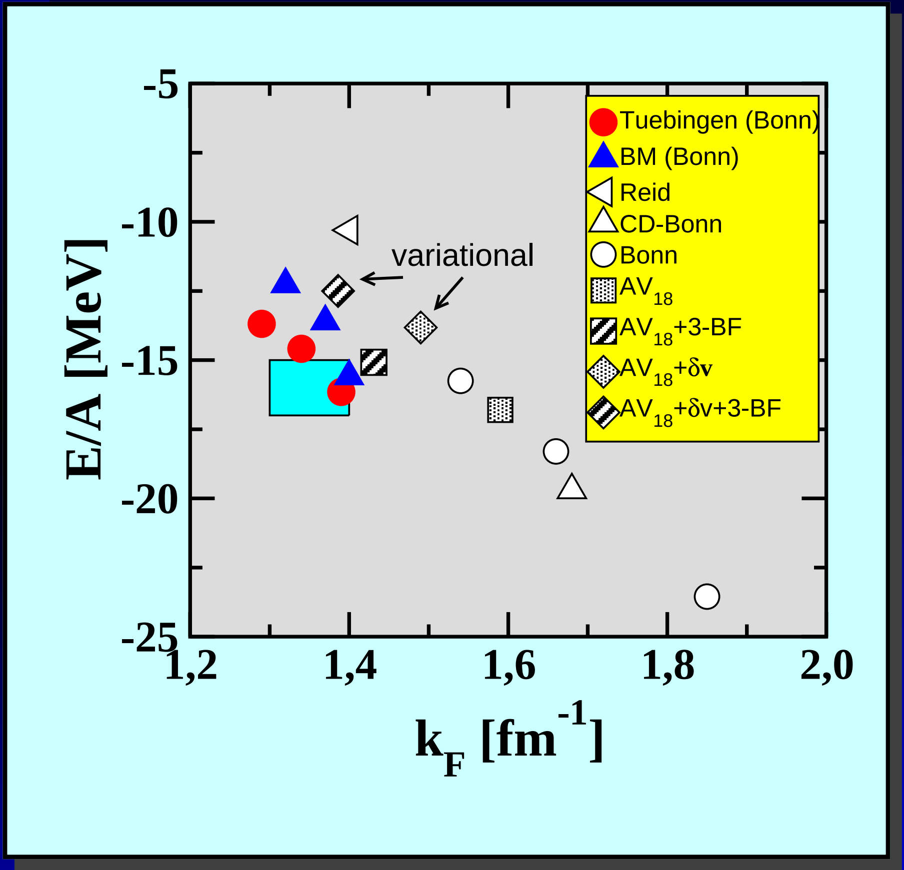
  difference of vector and scalar density $\Longrightarrow$ saturation

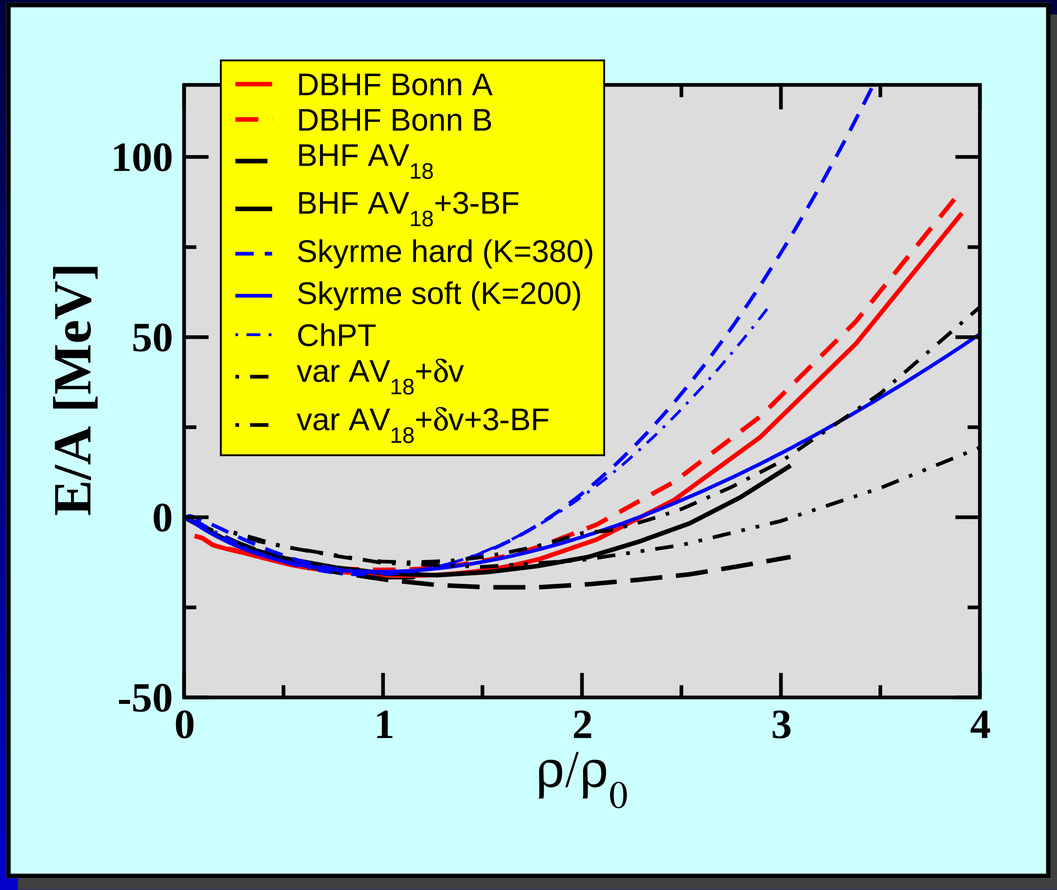
  principally similar to RMF theory

  C.F., Lect. Notes Phys. 641 (2004) 119

BHF versus DBHF

BHF: 3-body forces necessary (Zuo et al., NPA 706 (2002) 418)





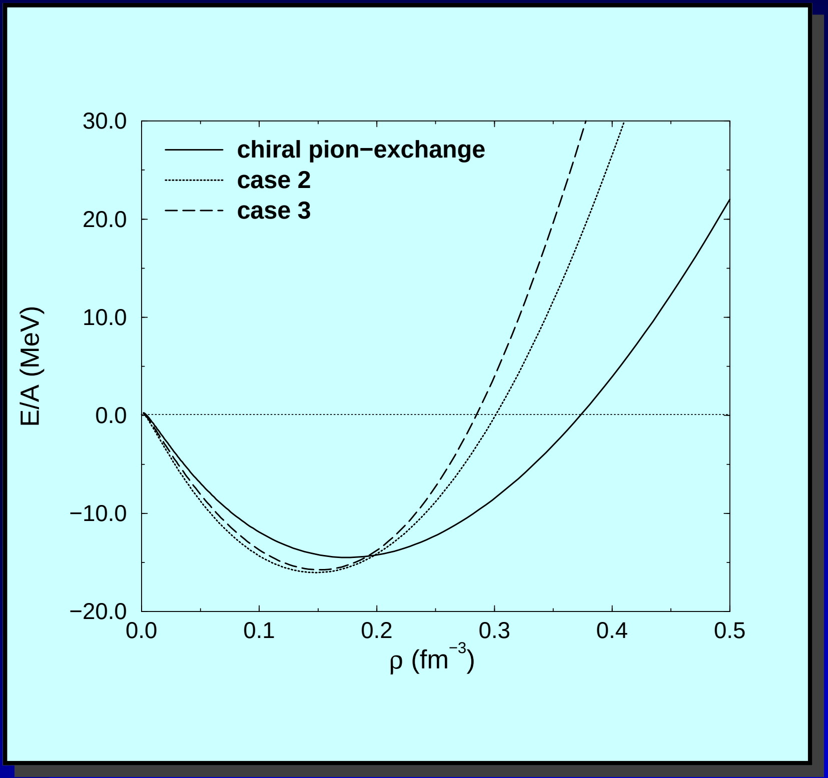
All microscopic EOS are soft !

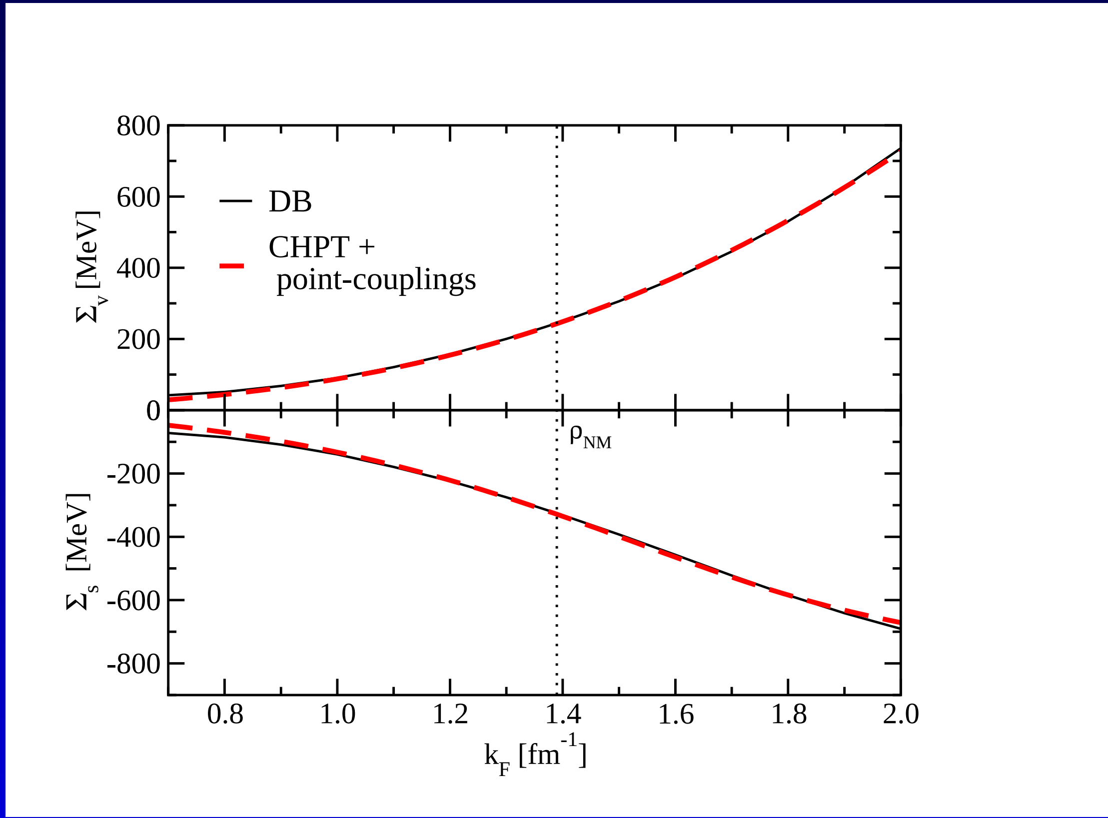
Example for EFT: ChPT

ChPT: pion dynamics + cut-off $\Longrightarrow$ expansion in k_F:

$\Longrightarrow$ soft EOS

fine tunig to finite nuclei: $\Longrightarrow$ hard EOS

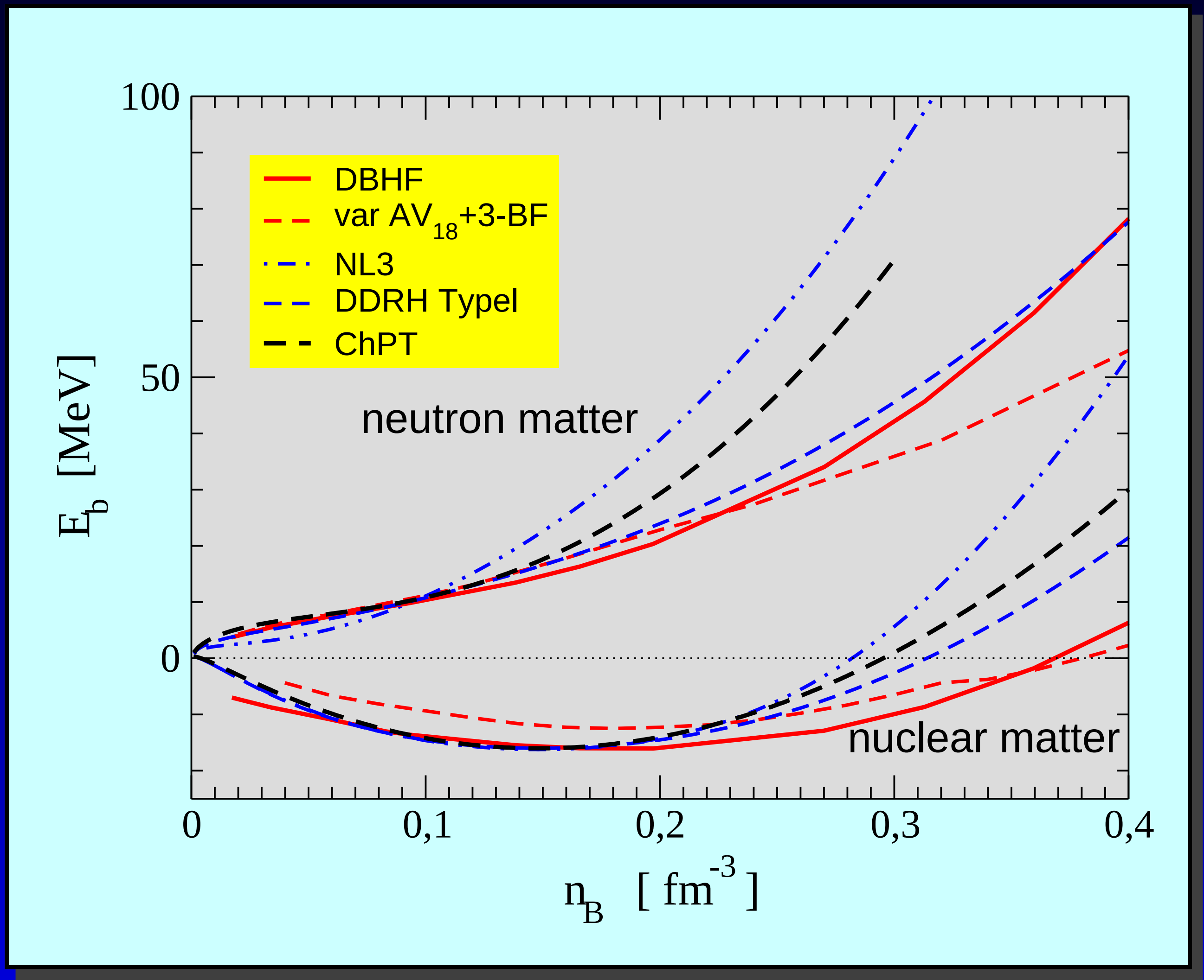




ChPT: Finelli et al. NPA 735 (2004) 449

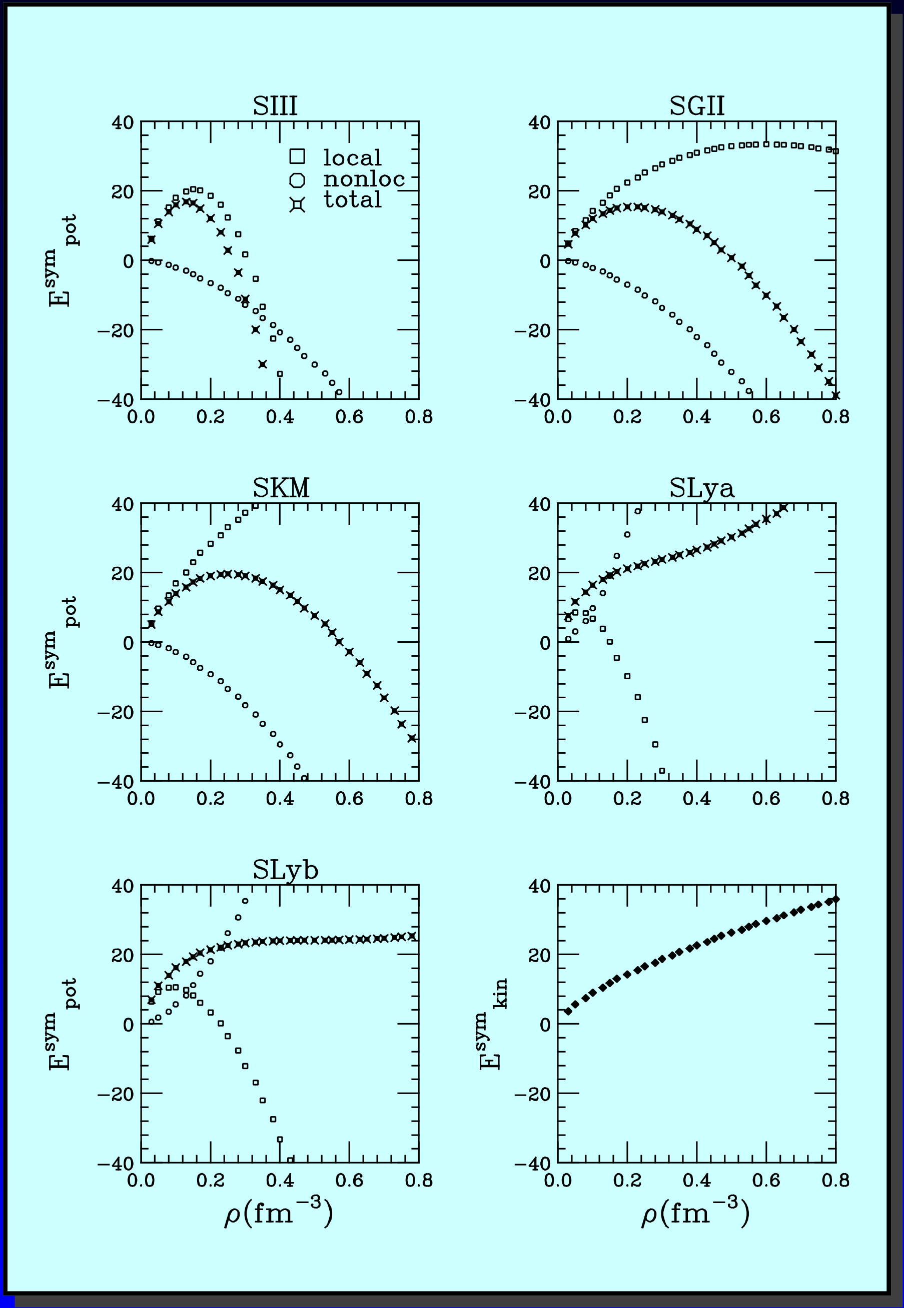
DBHF: Gross-Boelting, C.F., Faessler, NPA 648 (1999) 105

Neutron matter EOS



DBHF EOS is soft (K=230 MeV); but asy-stiff

Symmetry energy from Skyrme



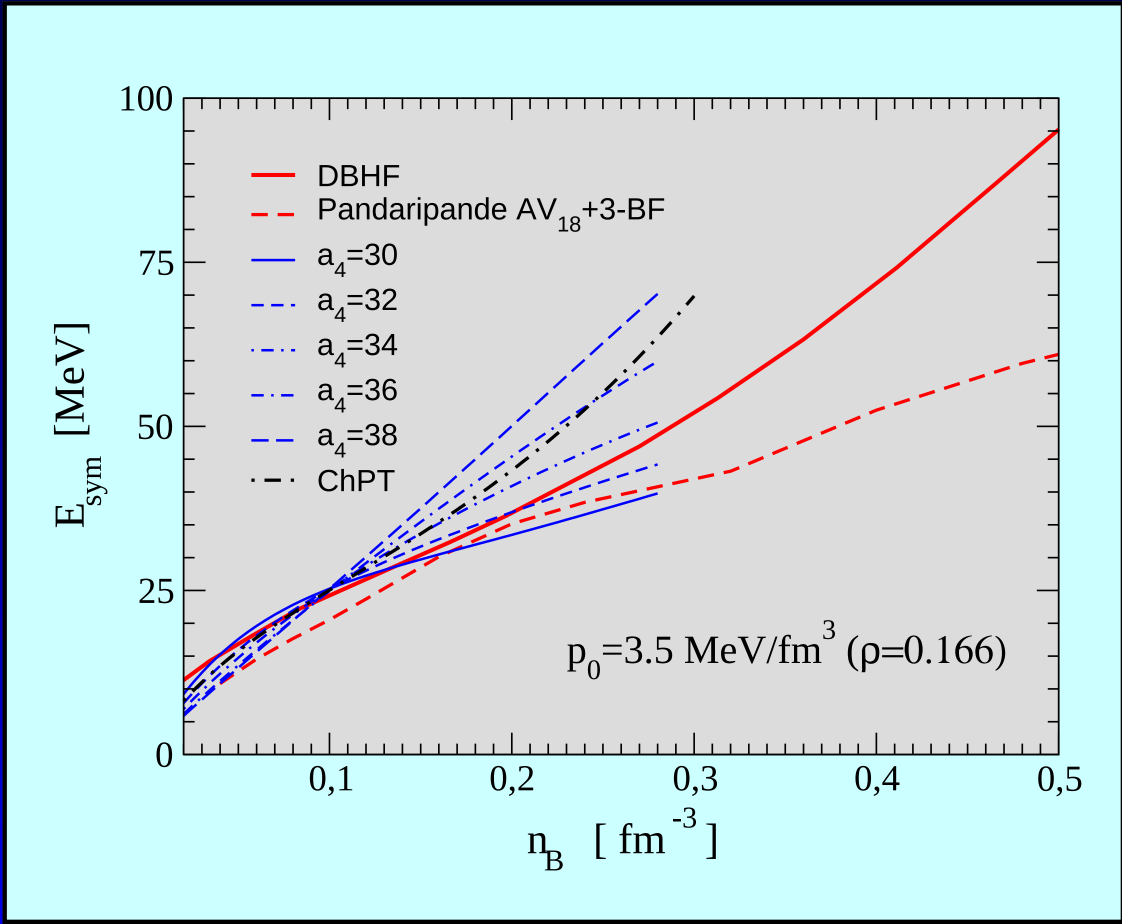
Baran, Di Toro et al.
nucl-th/0412060

Symmetry energy

$$E_{\rm sym}(n_B) = \frac{1}{2}\left[\frac{\partial^2 E_b(n_B,\beta)}{\partial\beta^2}\right]_{\beta=0} \simeq E_b(n_B,\beta=1) - E_b(n_B,\beta=0)$$

$$\beta = Y_n - Y_p$$

model	$E_{\rm sym}$ [MeV]
Skyrme	<30
Skyrme (SkLy)	32
RMF	32-36
DBHF (Bonn A)	34.4
Lenske (Bonn C)	28
ChPT (Finelli et al.)	34



RMF: Vretenar et al., PRC 68 ('03) 024310

Neutron-proton mass splitting

Comparison of different approaches $\Longrightarrow$ careful !

Many different defnitions of effective masses are used!

Non-relativistic mass:

$$m^*_{NR} = \left[M + \frac{1}{k}\frac{d}{dk} U_{s.p.} \right]^{-1}$$

Dirac mass:

$$m^*_D = M + \Sigma_S$$

Relativistic: $U_{s.p.} \simeq \frac{m^*_D}{E^*}\Sigma_S + \Sigma_0$

Neutron-proton mass splitting

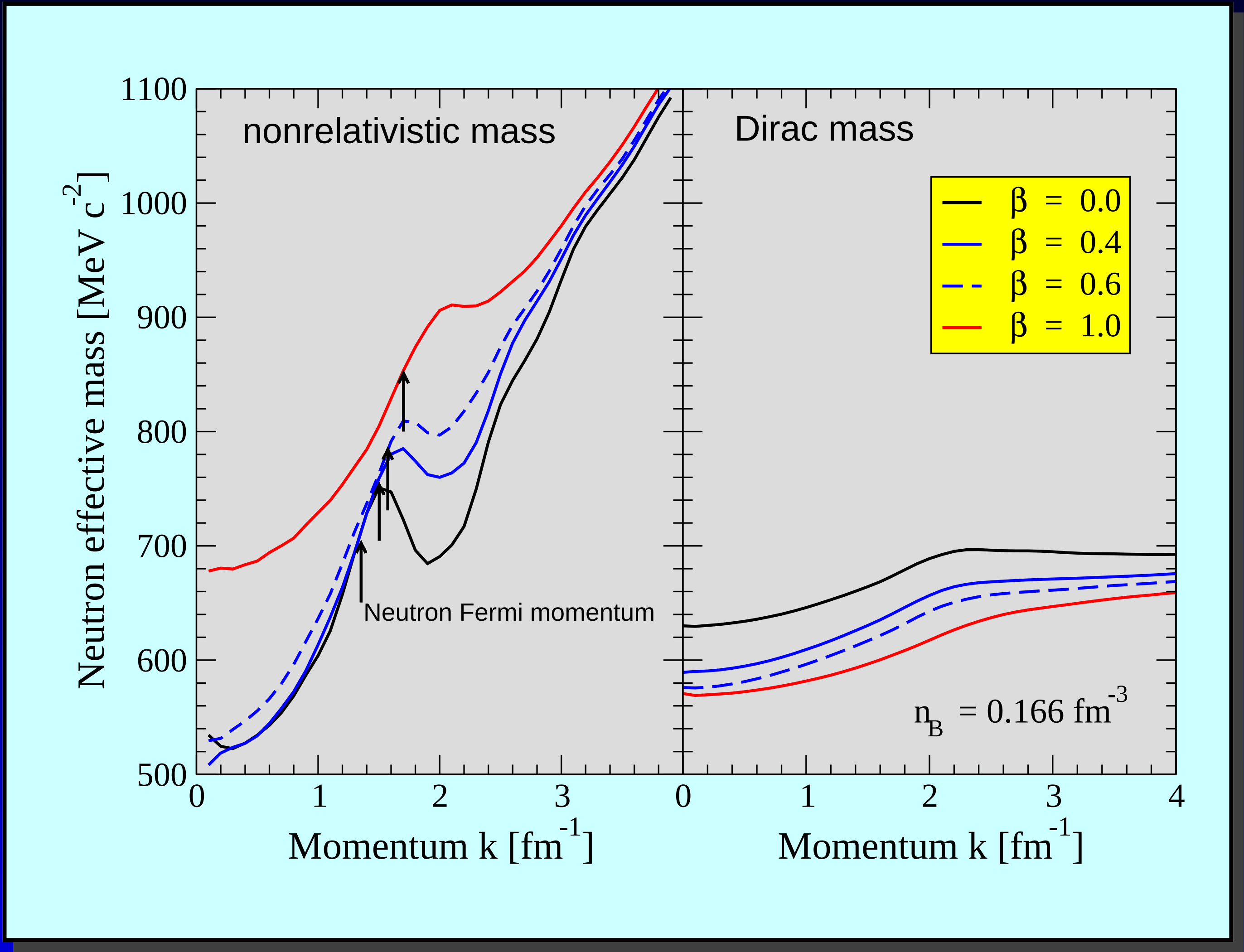
- BHF: $m^*_{NR,n} > m^*_{NR,p}$
- RMF: $m^*_{D,n} < m^*_{D,p}$; $m^*_{NR,n} < m^*_{NR,p}$ $(\rho + \delta)$

  Baran, Di Toro et al. nucl-th/0412060
- DBHF with Σ extracted by fit method: $m^*_{D,n} > m^*_{D,p}$

  Alonso & Sammarunca, nucl-th/0301032
- DBHF with projection method: $m^*_{D,n} < m^*_{D,p}$

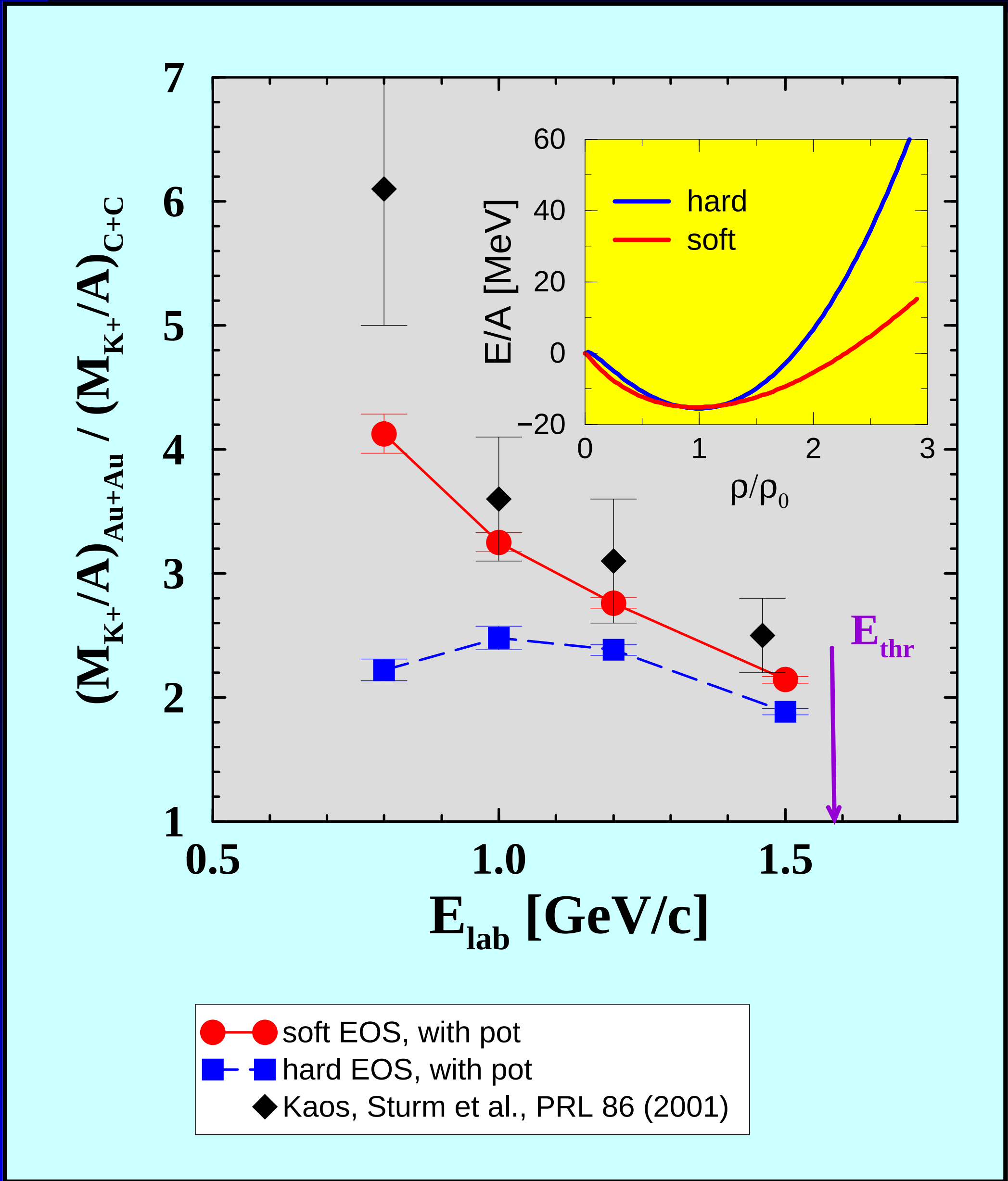
  de Jong & Lenske, PRC 58 ('98) 890, van Dalen, C.F., Faessler, NPA 744 ('04) 227
- non-rel. mass in DBHF: $m^*_{NR,n} > m^*_{NR,p}$

Neutron-proton mass splitting



DBHF: van Dalen, C.F., Faessler in preparation

Constraints from HICs: Kaons



Symmetric part of EOS: Subthreshold K^+ production

Far subthreshold: highly sensitive to collective effects

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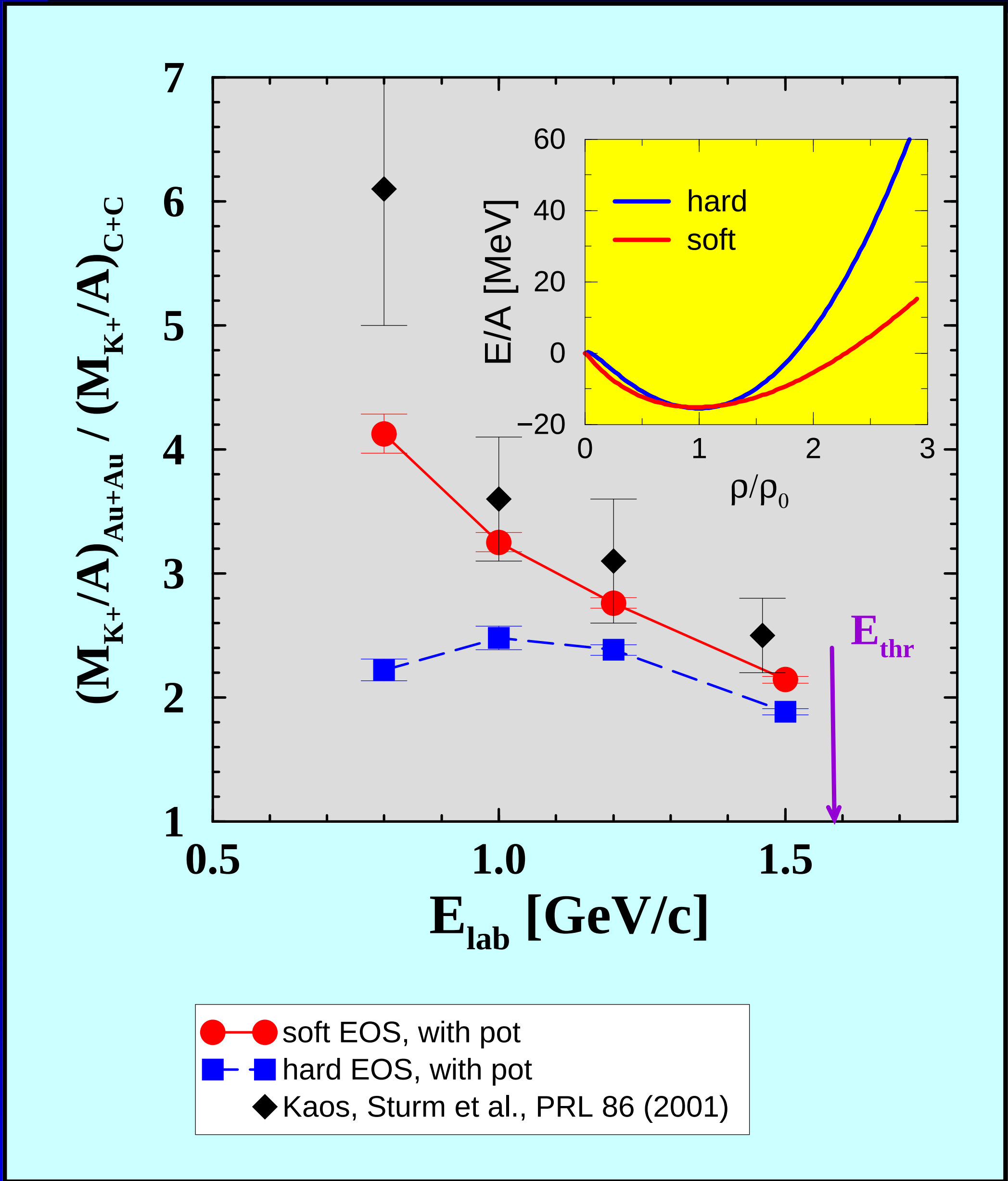


Symmetric part of EOS: Subthreshold K^+ production

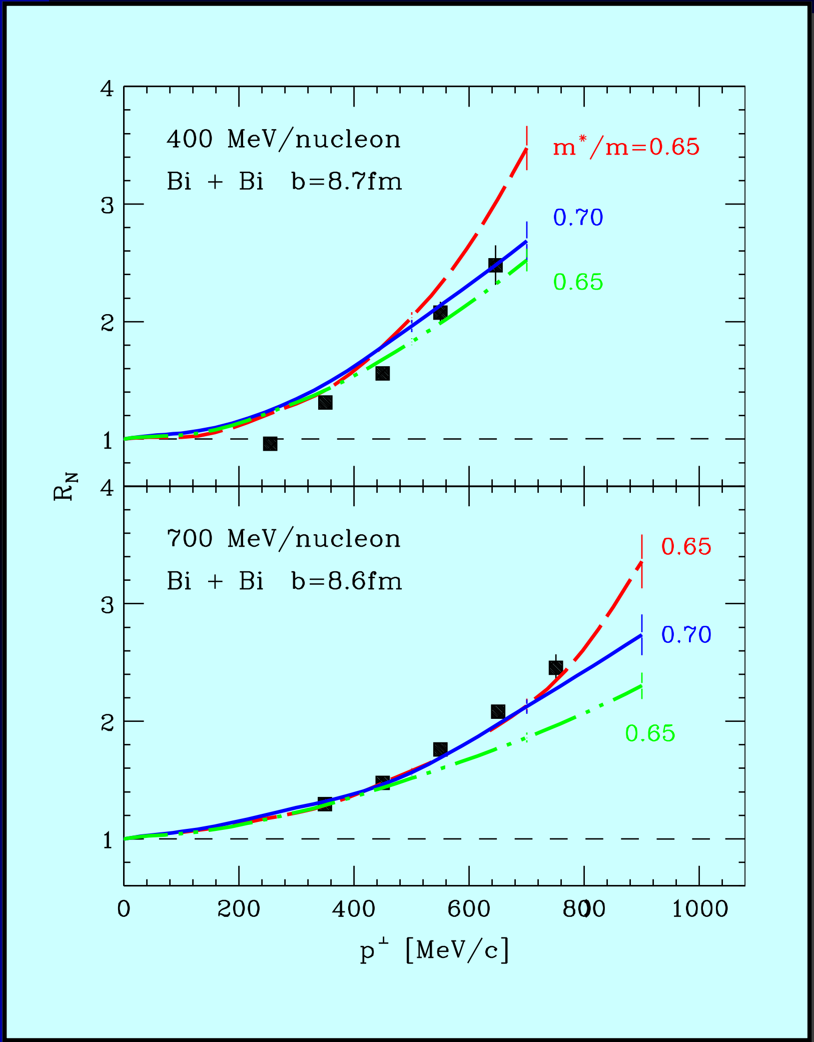
Far subthreshold: highly sensitive to collective effects

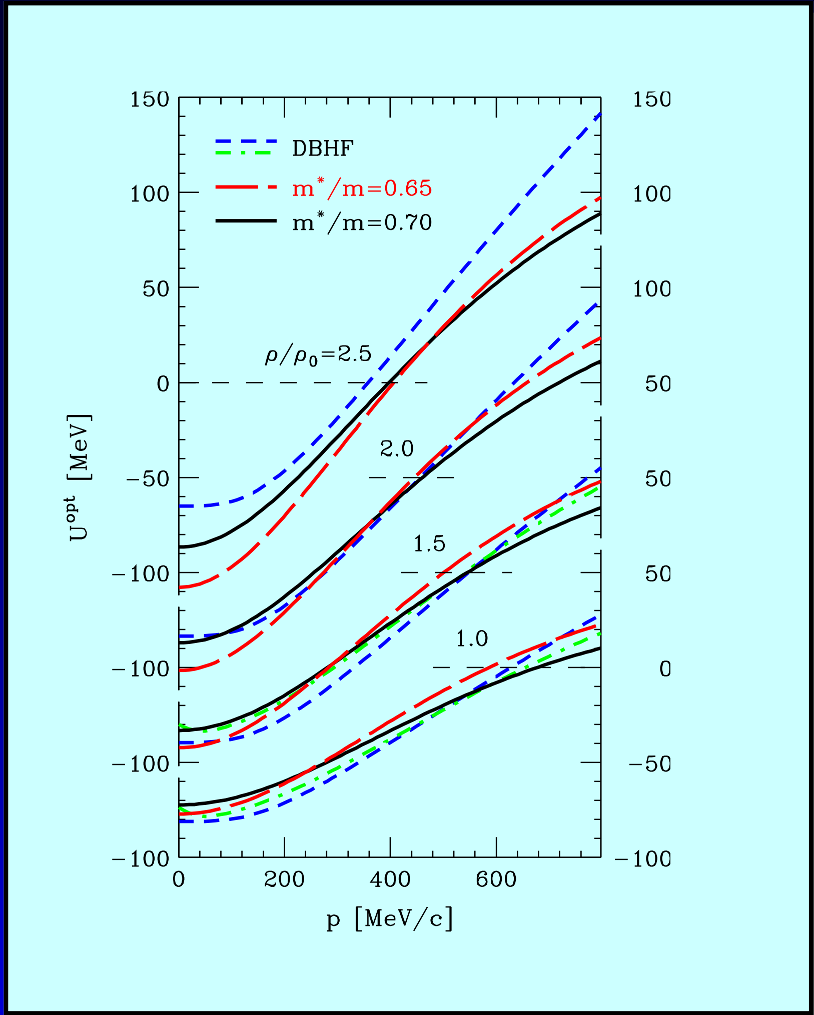
$\Downarrow$

KaoS data $\Longrightarrow$ soft EOS!

C.F. et al., PRL 86 (2001) 1974

Constraints from HICs: Flow





K=210 MeV ($m^*/m = 0.7/0.65$) and K=380 MeV (ruled out)

Danielewicz, NPA 673 (2000) 375

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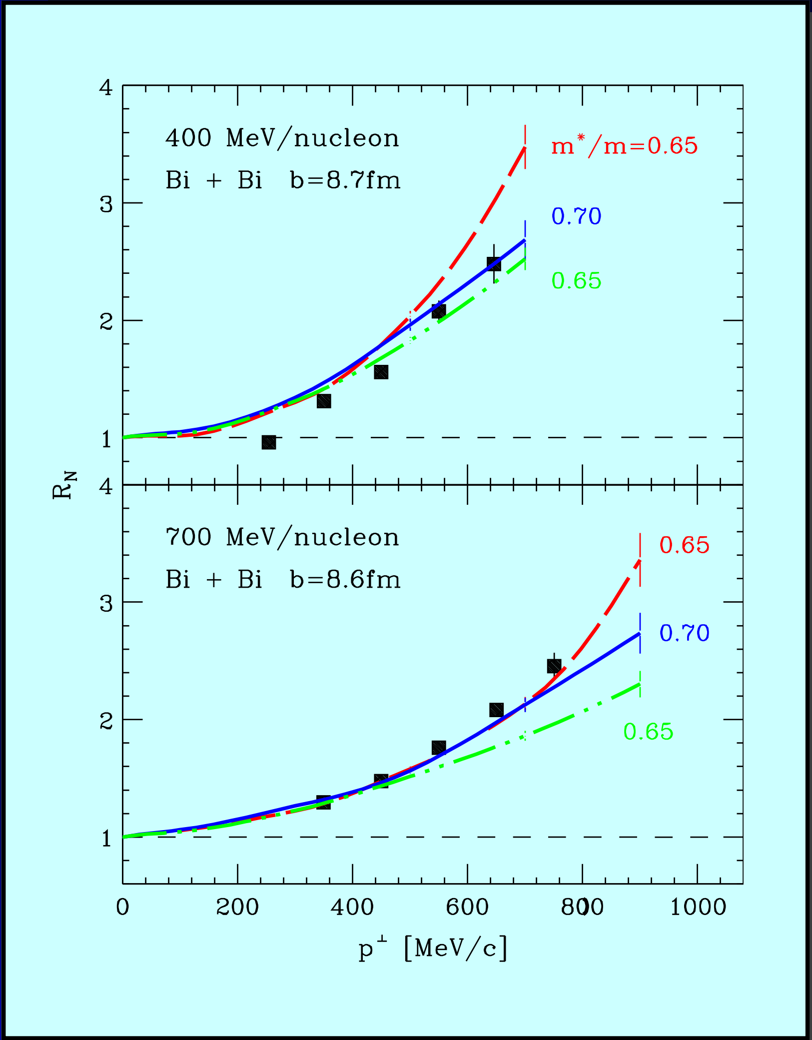

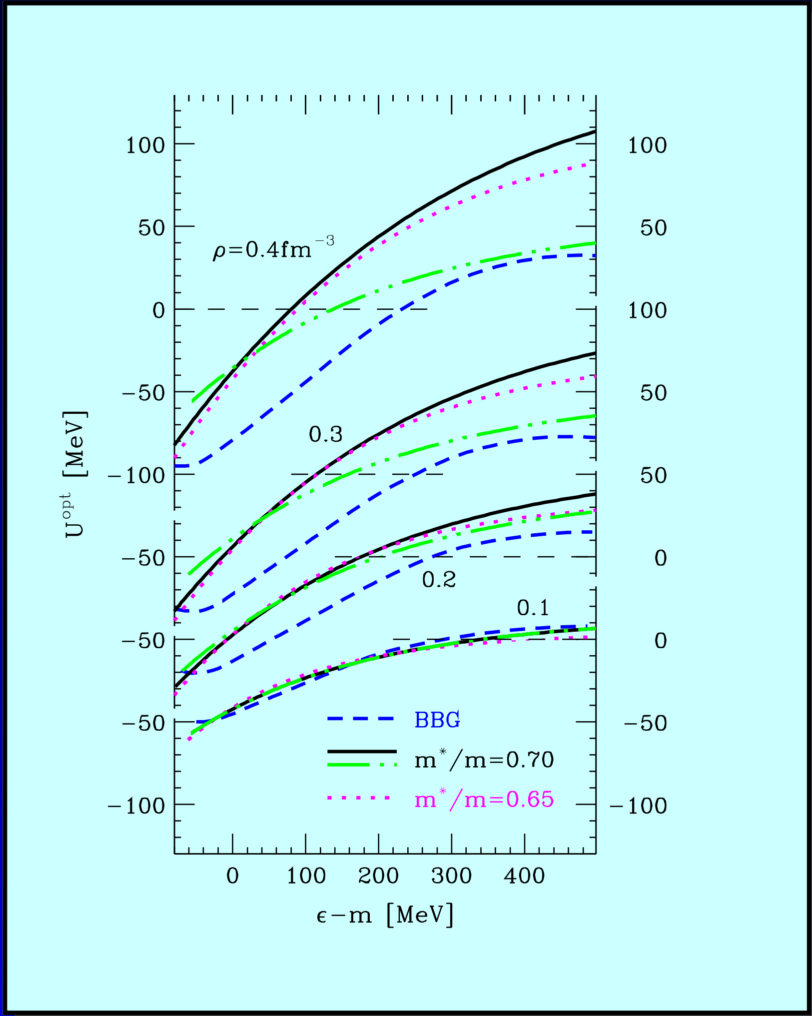

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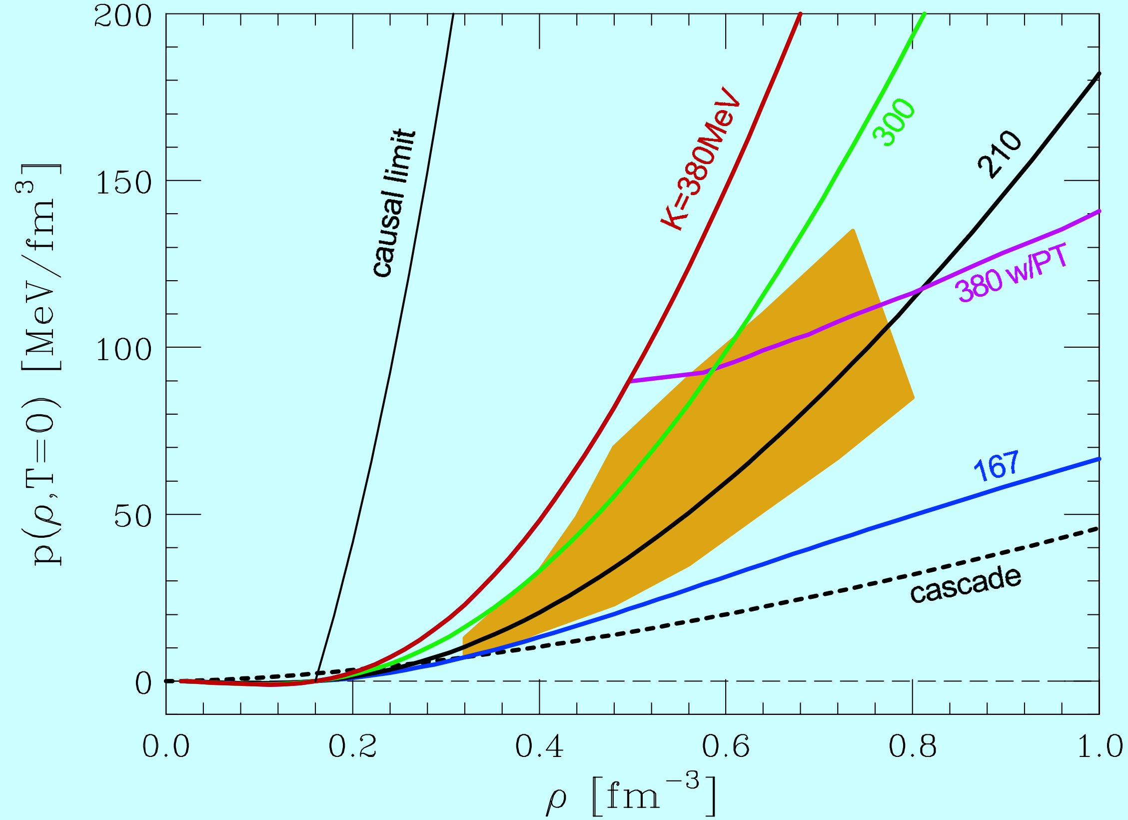
- elliptic flow $\Longrightarrow$ density dependence



Danielewicz, NPA 673 (2000) 375

Constraints from HICs: Flow

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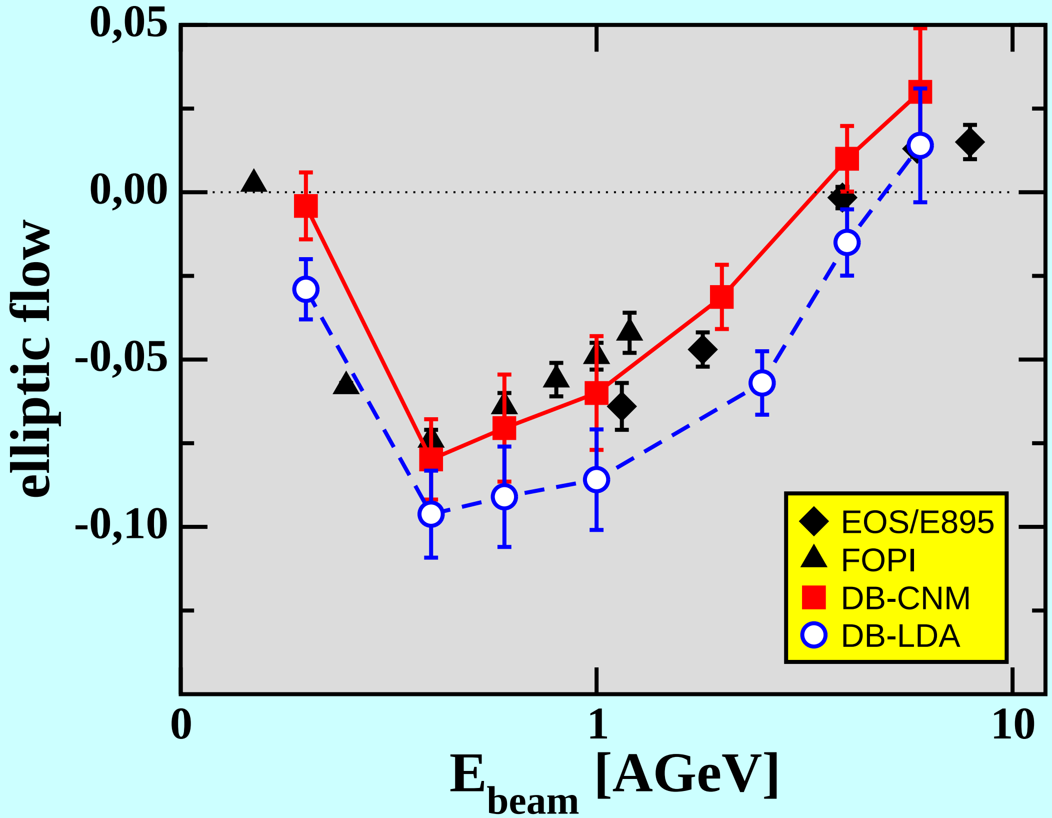


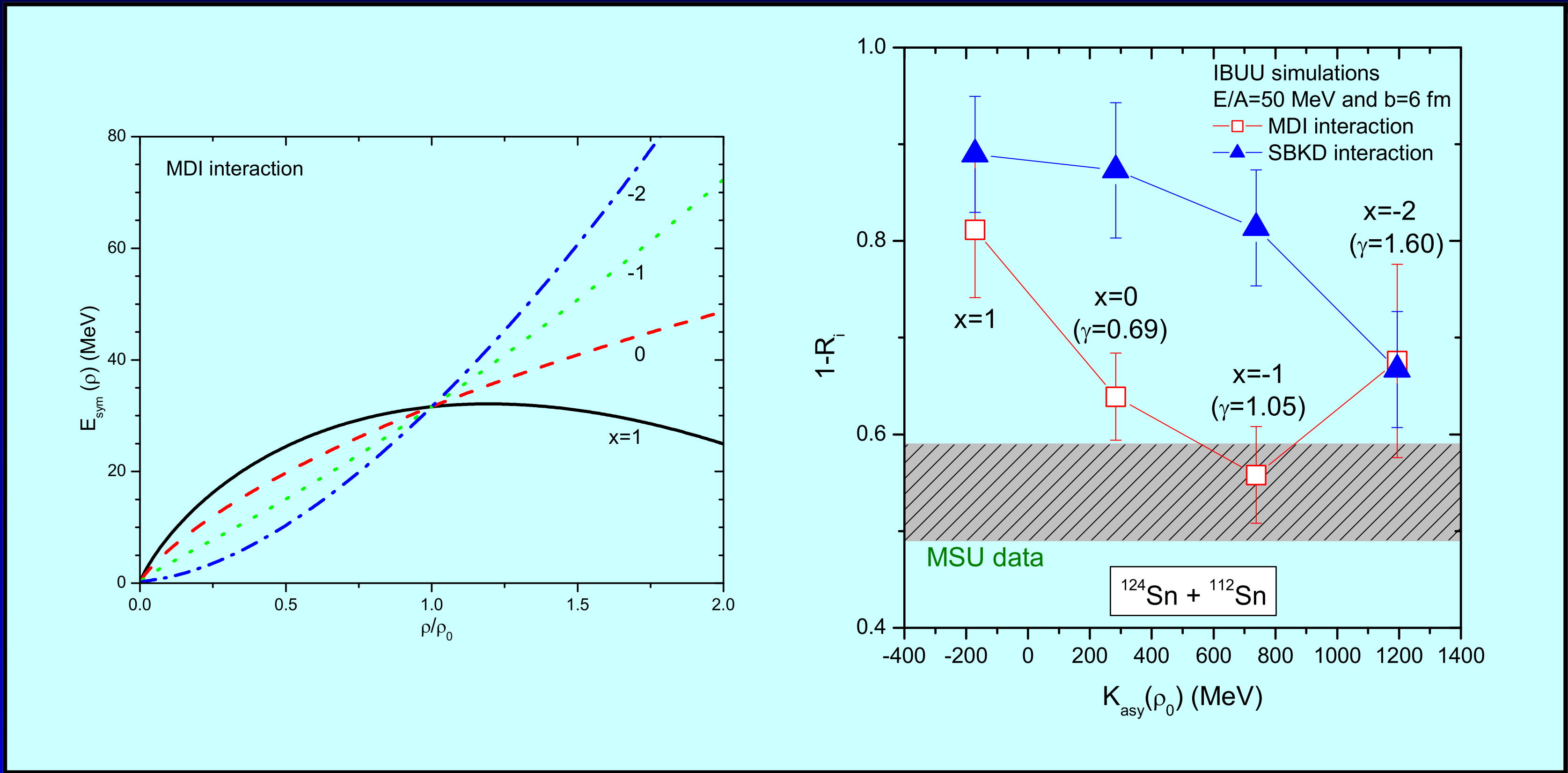
C.F., Gaitanos, NPA 714 (2003) 643

Gaitanos, C.F., Wolter, EPJA 12 (2001) 421; NPA 650 (1999) 97

Constraints from HICs

Isospin dependence: HICs with equal mass isotopes

$\Longrightarrow$ isospin diffusion: GSI (FOPI), MSU data



BUU: Chen, Ko, B-A Li, nucl-th/0407032, $E_{\rm sym} = 31.6(\rho/\rho_0)^\gamma$

Preliminary Summary

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- Consistent with information from hics