Symmetry Energy Effects in Particle Production

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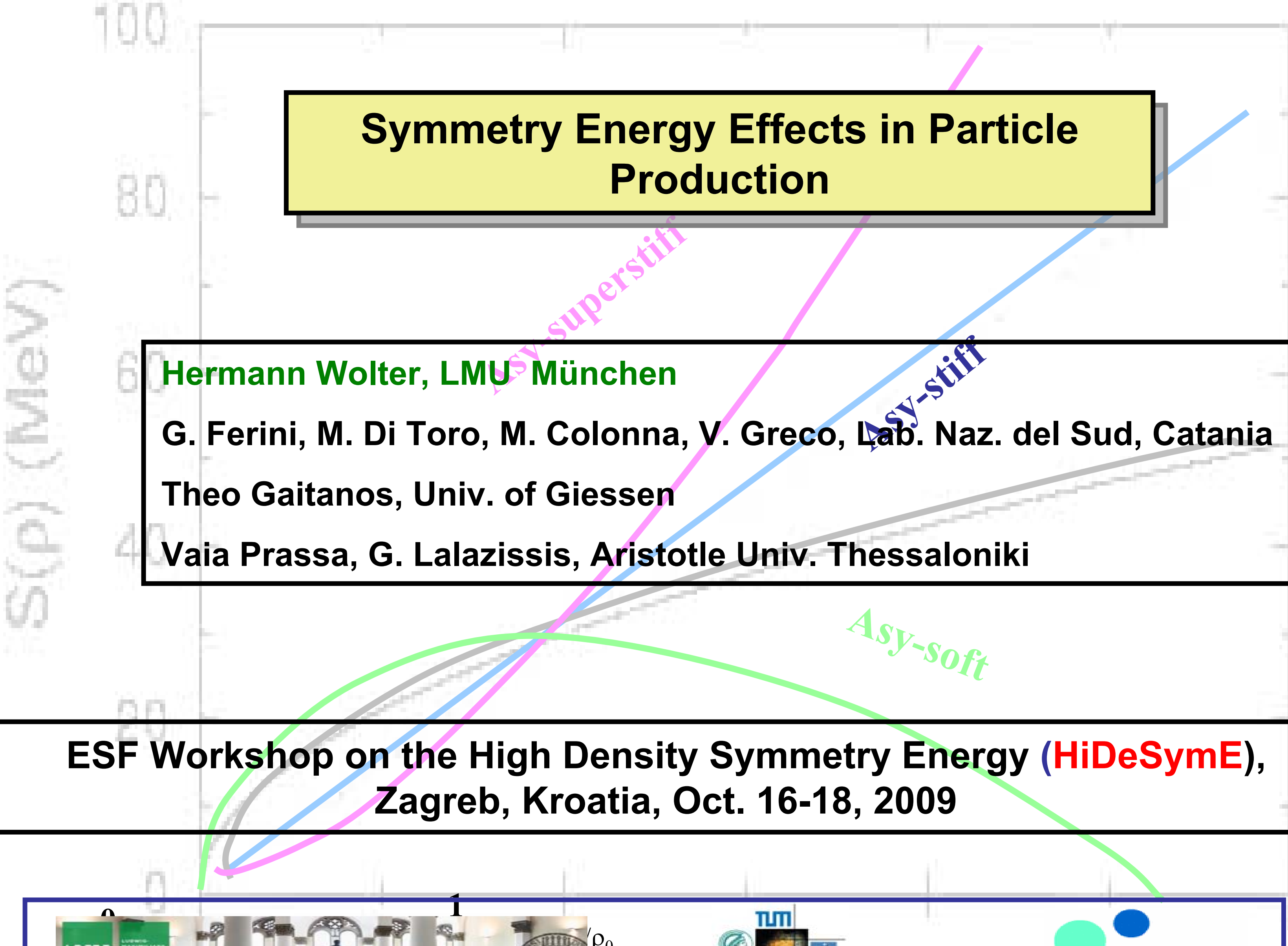
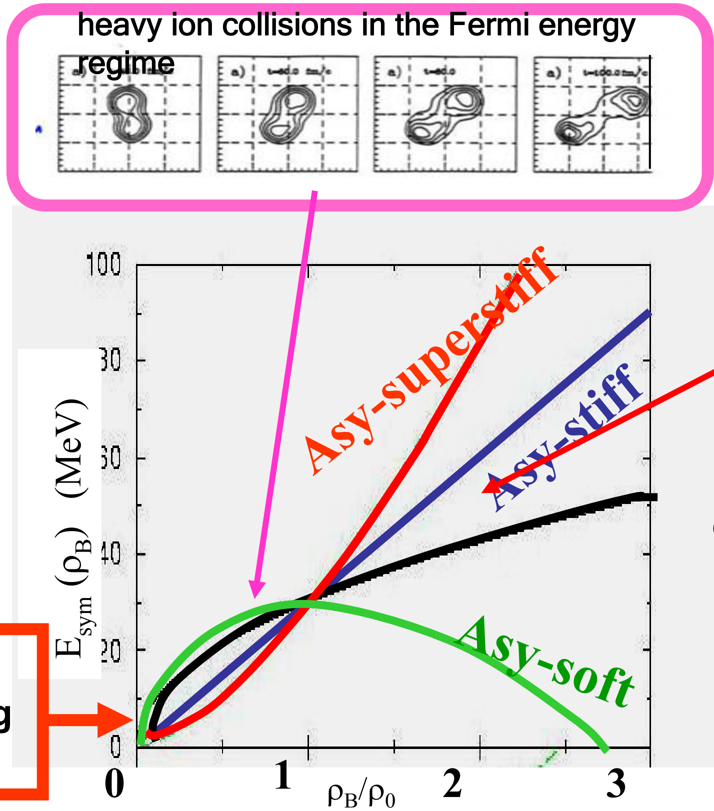
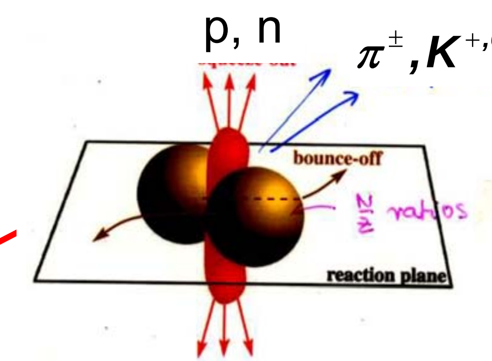


ESF Workshop on the High Density Symmetry Energy (HiDeSymE), Zagreb, Kroatia, Oct. 16-18, 2009

Symmetry Energy: Importance at different density ranges

$$E(\rho_B, I)/A = E(\rho_B) + E_{sym}(\rho_B) I^2 + O(I^4) + \dots \qquad I = \frac{N-Z}{N+Z}$$





Finite symmetry energy at zero energy due to clustering effects (G. Röpke, S. Typel)

High density: HIC at relativistic energies:

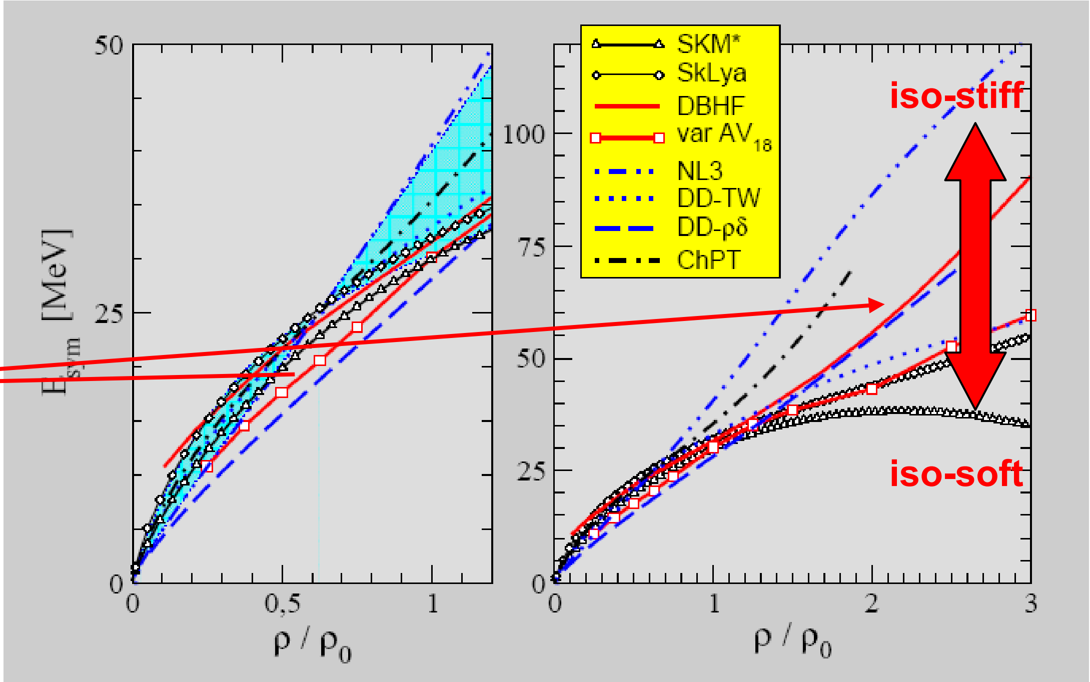
Differences in proton/neutron or light isobaric cluster flow

Ratio of isospin partners of produced particles:

- **→ pions $\pi+$ vs. $\pi-$**
- **→ strangeness K^+ vs. K^0**

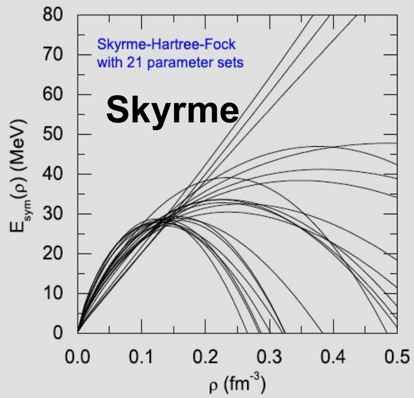
The Nuclear Symmetry Energy in different Models

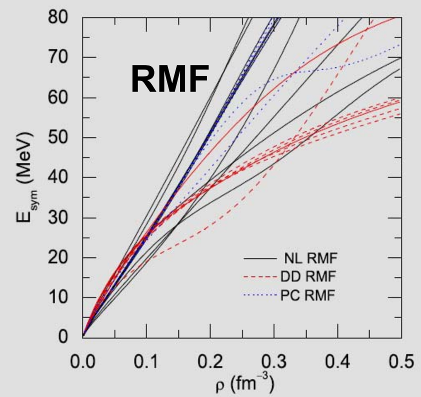
microscopic asy-EOS`s soft at low densities but stiff at high densities

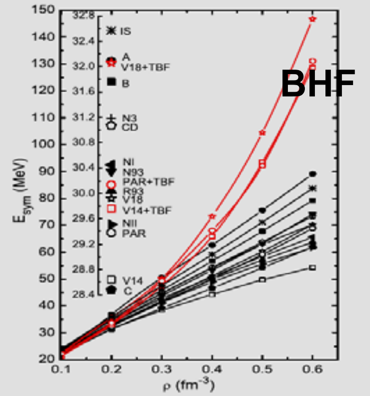


C. Fuchs, H.H. Wolter, EPJA 30(2006)5,(WCI book)

many more in: B.A. Li et al., Phys. Rep. 464 (2008)







Treatment of symmetry energy in RMF: ρ and δ meson

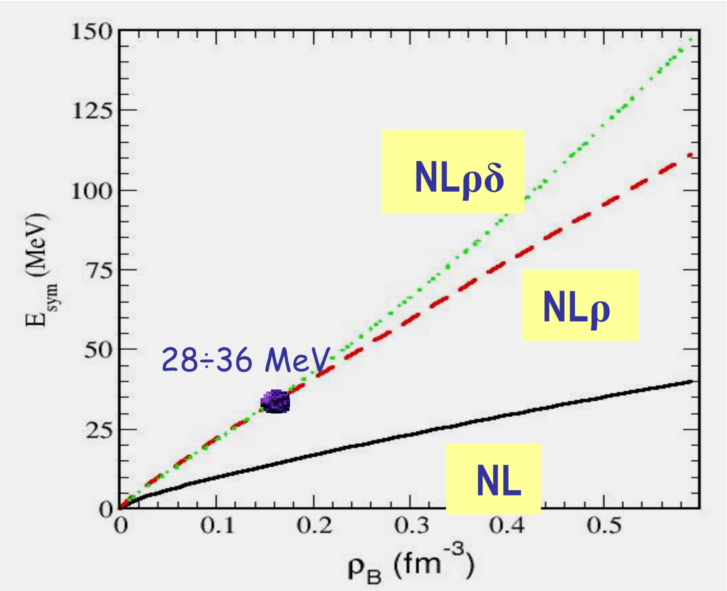
	isoscalar	isovector
scalar	σ	δ
vector	ω	ρ

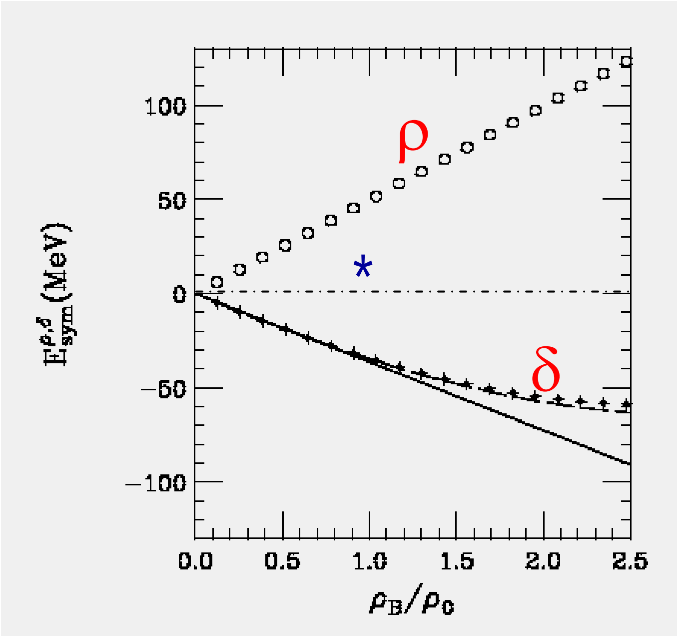
A cancellation between scalar and the isovector sector, similarly as for the isoscalar vector parts in potential

$$E_{sym} = \frac{1}{6}\frac{k_F^2}{E_F^{*2}} + \frac{1}{2}\left[f_\rho - f_\delta\left(\frac{M^*}{E^*}\right)^2\right]\rho_B$$

No δ → $f_\rho \cong 1.5\, f_\rho^{FREE}$ **NLρ**

$f_\delta = 2.5\ fm^2$ → $f_\rho \cong 5 f_\rho^{FREE}$ **NLρδ**

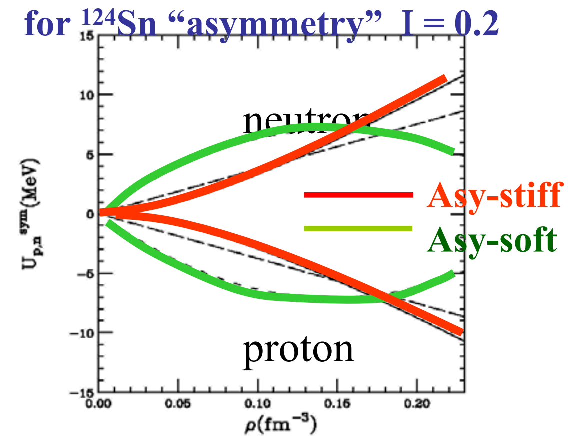




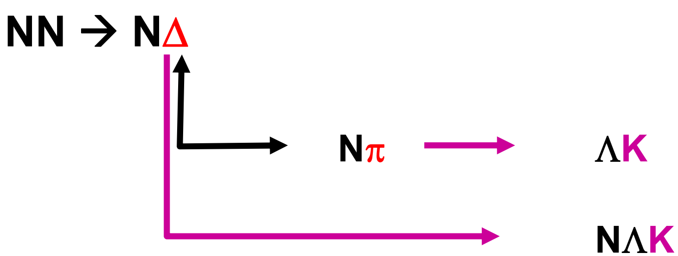
Liu, Greco, et al., PRC65(02)045201

Sensitivity to Symmetry Energy in Heavy Ion Collisions

Difference in neutron and proton potentials



1. „direct effects“: difference in proton and neutron (or light cluster) emission and momentum distribution → M. Di Toro
2. „secondary effects“: production of particles, isospin partners



1. Mean field effect: U_{sym} more repulsive for neutrons, and more for asystiff

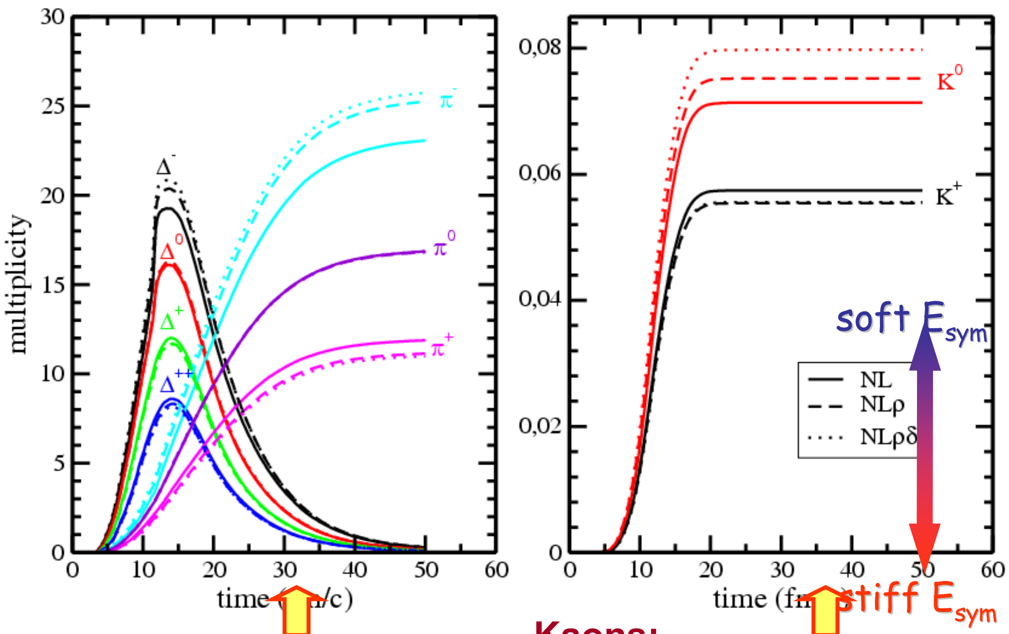
   → pre-equilibrium emission of neutron, reduction of asymmetry of residue

2. Threshold effect, in medium effective masses:

   → m^*_N, m^*_Δ, contribution of symmetry energy; m^*_K, models for K-potentials

Pion and Kaon production in “open” system (HIC)…

time dependence of Δ, π, and K production



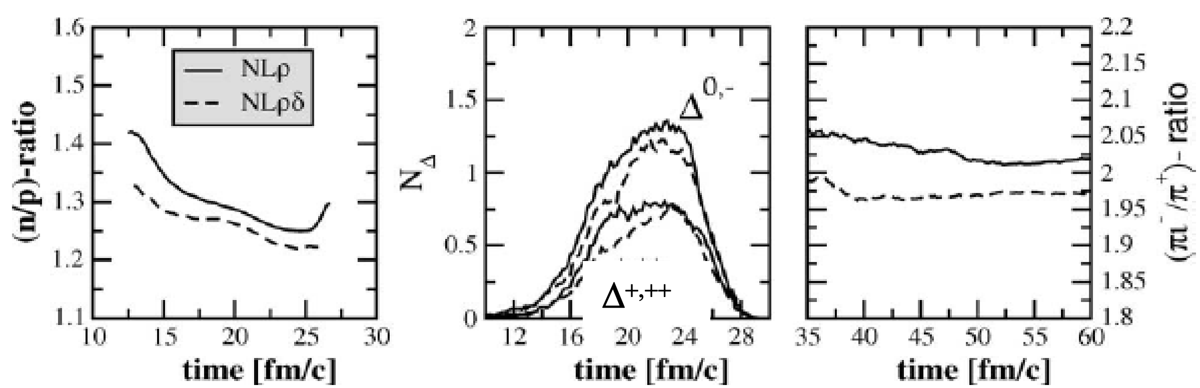
Au+Au@1AGeV

G.Ferini et al.,PRL 97 (2006) 202301

Pions: high and low density phase

Kaons:
- direct early production: high density phase
- isovector channel effects

Au+Au, 0.6AMeV, central



PION PRODUCTION

G.Ferini et al., NPA 762 (2005) 147, NM Box
PRL 97 (2006) 202301, HIC

Main mechanism $NN \Rightarrow N\Delta$, $\Delta \rightarrow \pi N$

nn → $p\Delta^-$ → $n\pi^-$; nn → $n\Delta^0$ → $p\pi^-$

pp → $p\Delta^+$ → $n\pi^+$; pp → $n\Delta^{++}$ → $p\pi^+$

$$\Rightarrow \frac{\pi^-}{\pi^+}$$

n→p "transformation"

1. Fast neutron emission: "mean field effect"

$$\frac{n}{p}\downarrow \Rightarrow \frac{Y(\Delta^{0,-})}{Y(\Delta^{+,++})}\downarrow \Rightarrow \frac{\pi^-}{\pi^+}\downarrow \; decrease: NL \rightarrow NL\rho \rightarrow NL\rho\delta$$

This should depend also on momentum dependence

2. C.M. energy available: "threshold effect"

$$\varepsilon_{n,p} = E^*_{n,p} + f_\omega \rho_B \mp f_\rho \rho_{B3}$$

Vector self energy + for n and - for p

$$s_{nn}(NL) < s_{nn}(NL\rho) < s_{nn}(NL\rho\delta)$$
$$s_{pp}(NL) > s_{pp}(NL\rho) > s_{pp}(NL\rho\delta)$$

$$\sigma = \sigma(s_{in} - s_{th})$$

$$\frac{\pi^-}{\pi^+}\uparrow \; increase\ NL \rightarrow NL\rho\delta$$

The Threshold Effect: nn→pΔ⁻ vs pp→nΔ⁺⁺

$$\sigma = \sigma\left(s_{in} - s_{th}\right)$$

nn→pΔ⁻

$$s_{in} = 4\left(E_n^* + \Sigma_n^0\right)^2 = 4\left(p_n^0\right)^2$$

↑ **Increasing with momentum**

$$s_{th} = \left[m_p - \Sigma_s(p) + \Sigma^0(p) + m_{\Delta-} - \Sigma_s(\Delta^-) + \Sigma^0(\Delta^-)\right]^2$$

$$\Sigma_i(\Delta^-) = \Sigma_i(n)$$
$$\Sigma_i(\Delta^0) = \frac{2}{3}\Sigma_i(n) + \frac{1}{3}\Sigma_i(p)$$
$$\Sigma_i(\Delta^+) = \frac{1}{3}\Sigma_i(n) + \frac{2}{3}\Sigma_i(p)$$
$$\Sigma_i(\Delta^{++}) = \Sigma_i(p) \quad ,$$

pp→nΔ⁺⁺

$$s_{in} = 4\left(E_p^* + \Sigma_p^0\right)^2 = 4\left(p_p^0\right)^2$$

↓

Compensation of Isospin Effects in s_{th}
due to simple assumption for S(D)

$$s_{th} = \left[m_n - \Sigma_s(n) + \Sigma^0(n) + m_{\Delta++} - \Sigma_s(\Delta^{++}) + \Sigma^0(\Delta^{++})\right]^2$$

Same thresholds → the s_{in}(NN) rules the relative yields
→ very important at low energies

$$\Rightarrow \frac{\pi^-}{\pi^+} \uparrow \text{ with } E_{sym}$$

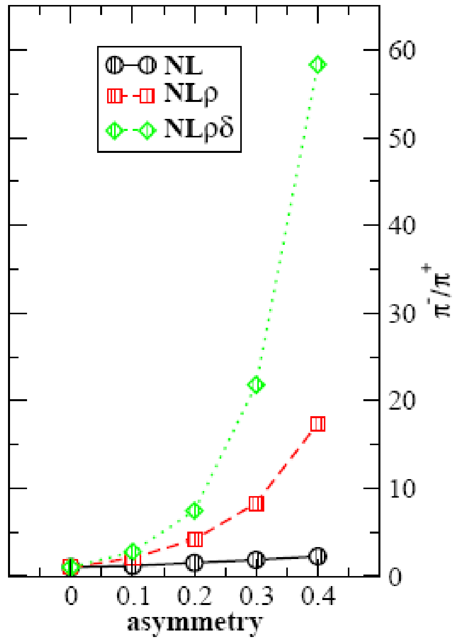
What is conserved is not the effective E*,p* momentum-energy but the canonical one.

Pion production

$$\frac{\pi^-}{\pi^+}$$

Ferini, NPA762(2005) 147

Equilibrium production
(box results)

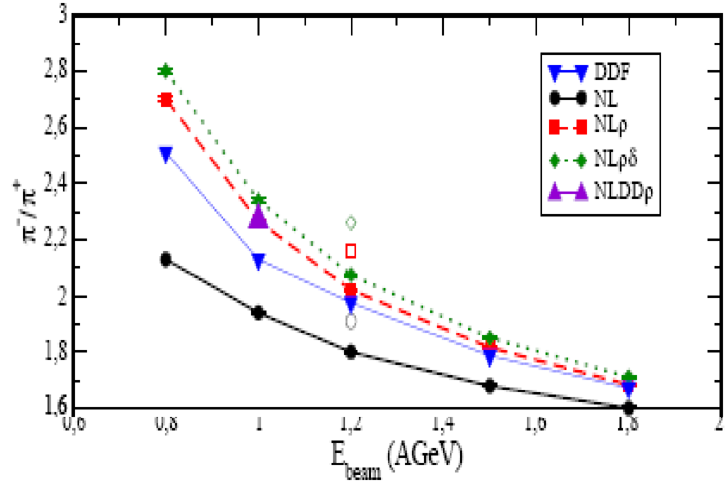


$$\frac{\pi^-}{\pi^+} = \frac{\sigma^{abs}_{\pi-}}{\sigma^{abs}_{\pi+}} \exp\left[2(\mu_n - \mu_p)/T\right]$$

~ 5 (NLρ) to 10 (NLρδ) at α~0.2

Finite nucleus simulation:

Au+Au, semicentral



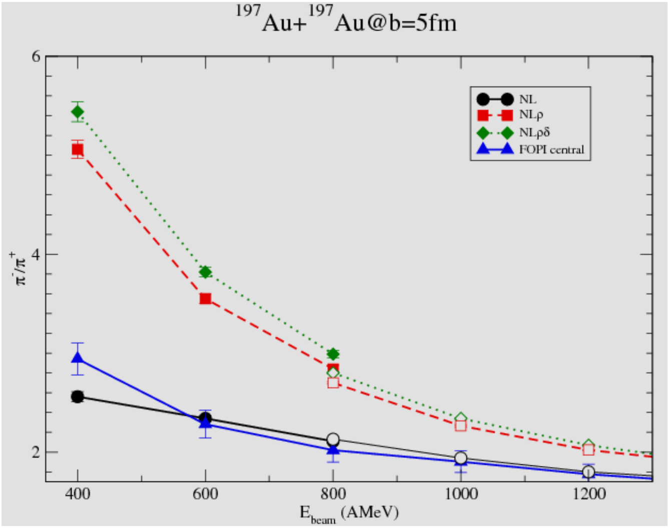
much below thermodynamic limit, non-equlibration

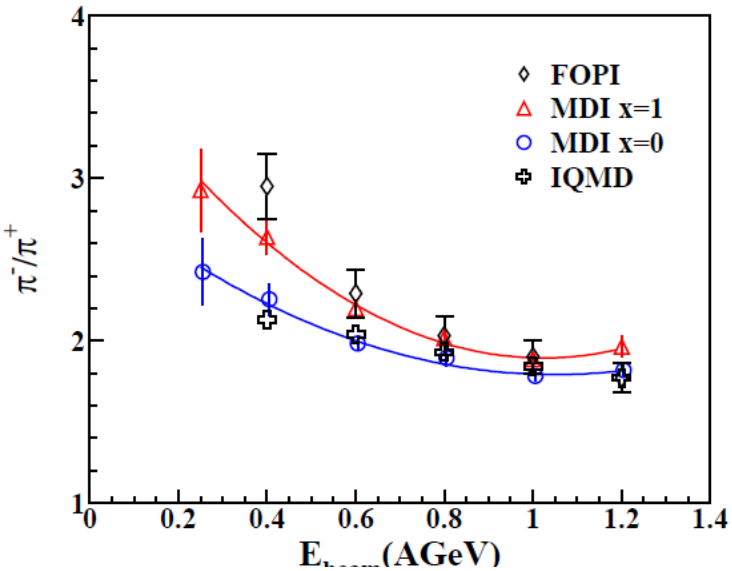
Pion ratios in comparison to FOPI data

W.Reisdorf et al.
NPA781 (2007) 459

Ferini, NPA762(2005) 147

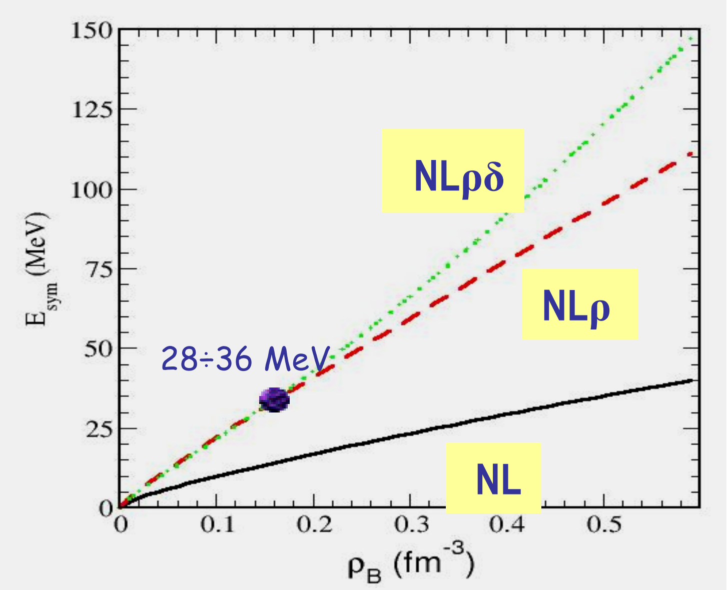
Zhigang Xiao et al.
PRL 102, 062502 (2009)

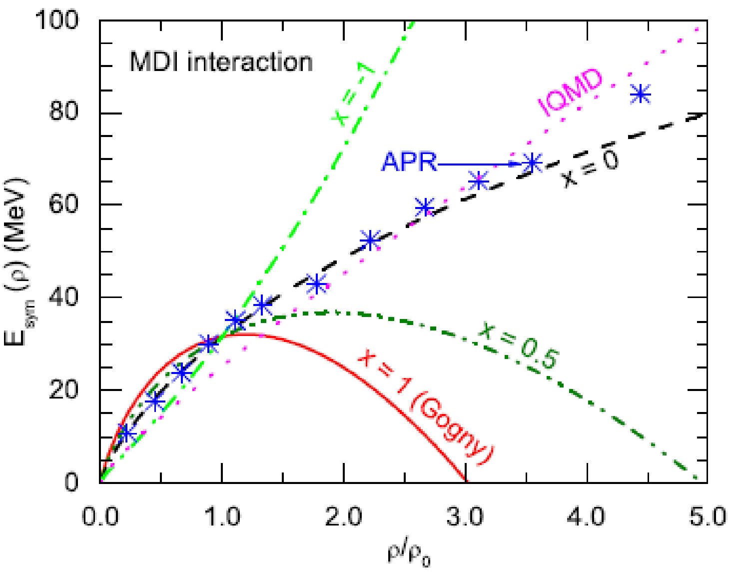




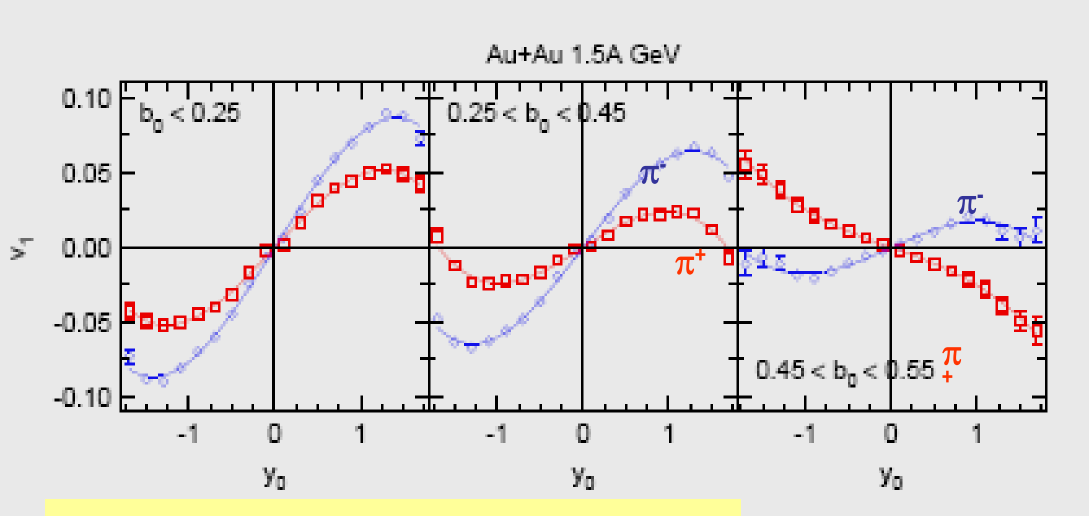
Agreement in the sense, that symmetry energy is small

Threshold effects very important!

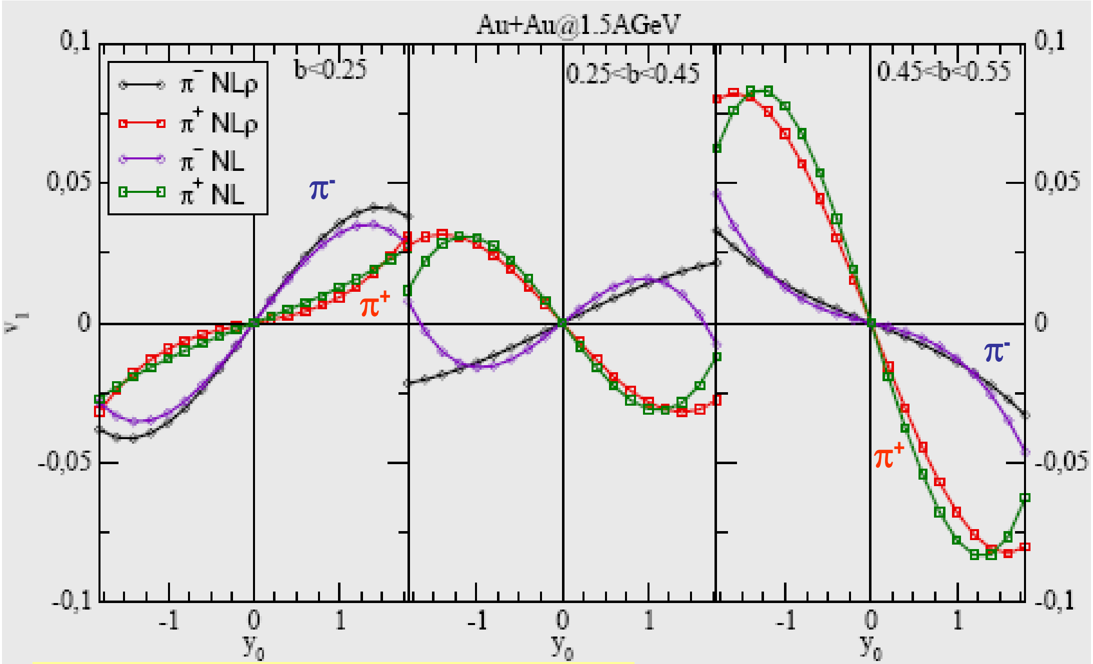




Transverse Pion Flows

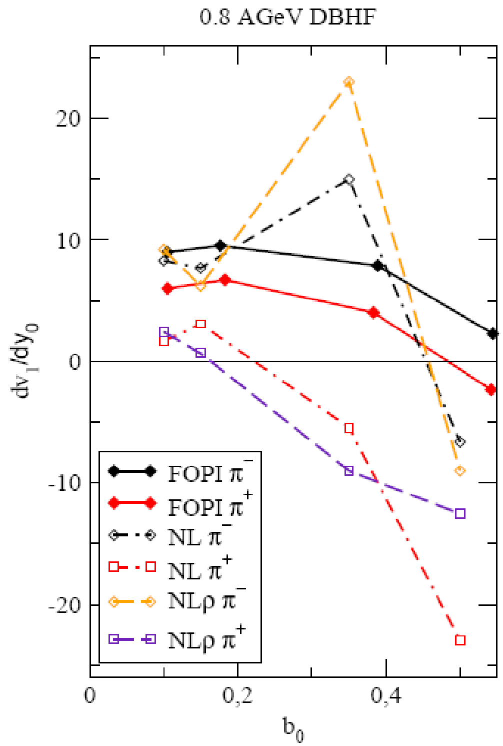


W.Reisdorf et al. NPA781 (2007) 459



Simulations: V.Prassa, PhD thesis 09

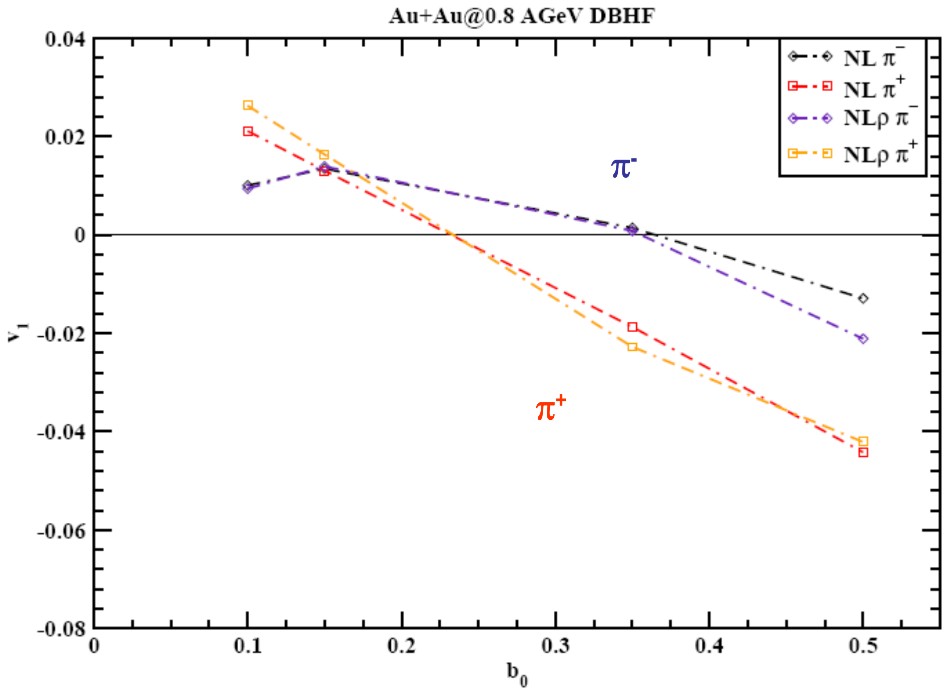
Antiflow: Decoupling of the Pion/Nucleon flows

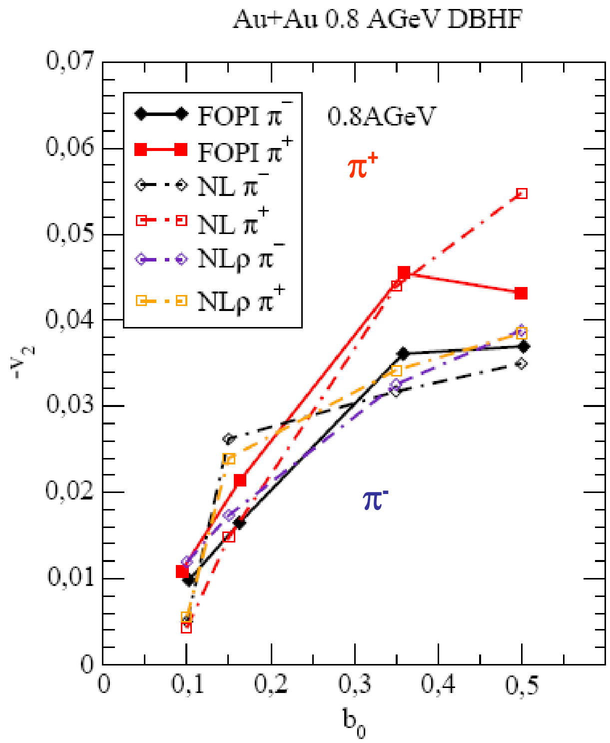


OK general trend.
but:
- smaller flow for both π- and π+
- not much dependent on iso-EoS

Directed and Elliptic Flow:

Au+Au, 0.8 AGeV, midrapidity, as function of centrality





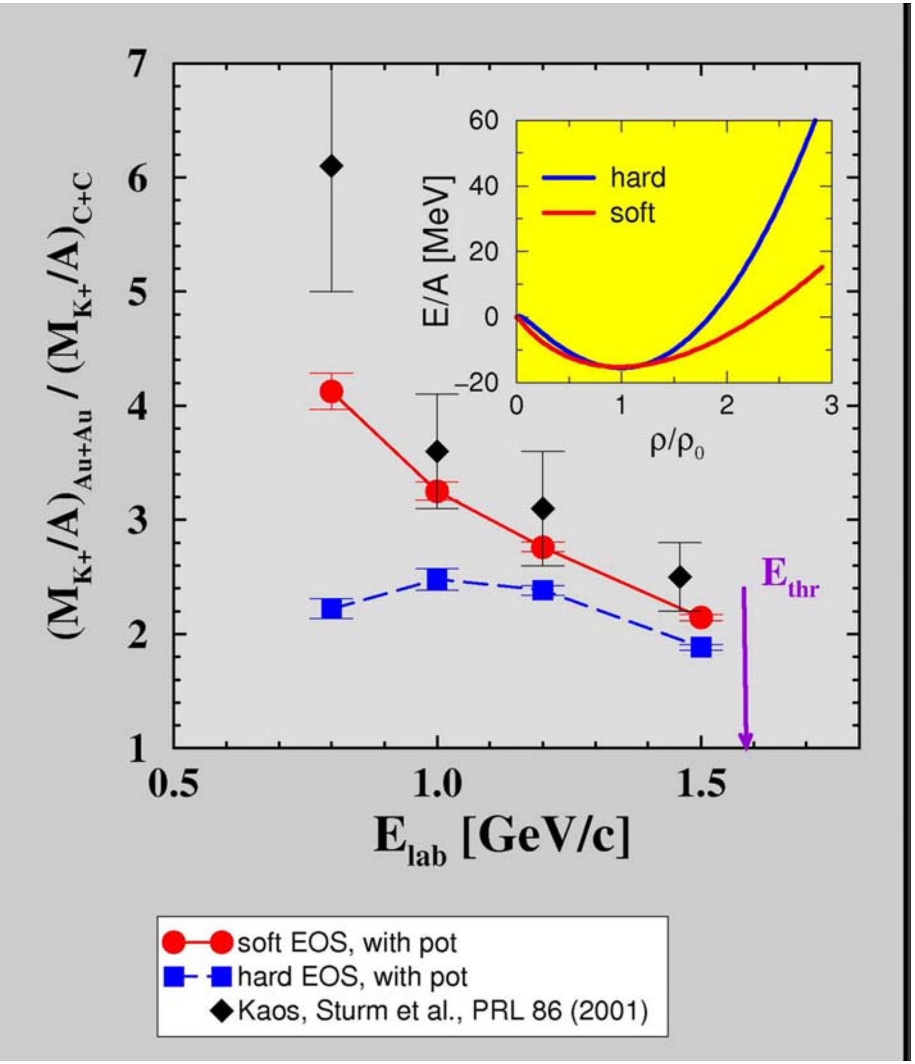
Kaon Production:

A good way to determine the symmetric EOS (C. Fuchs et al., PRL 86(01)1974)

Main production mechanism:

NN→BYK

πN→YK



Also useful for Isovector EoS?

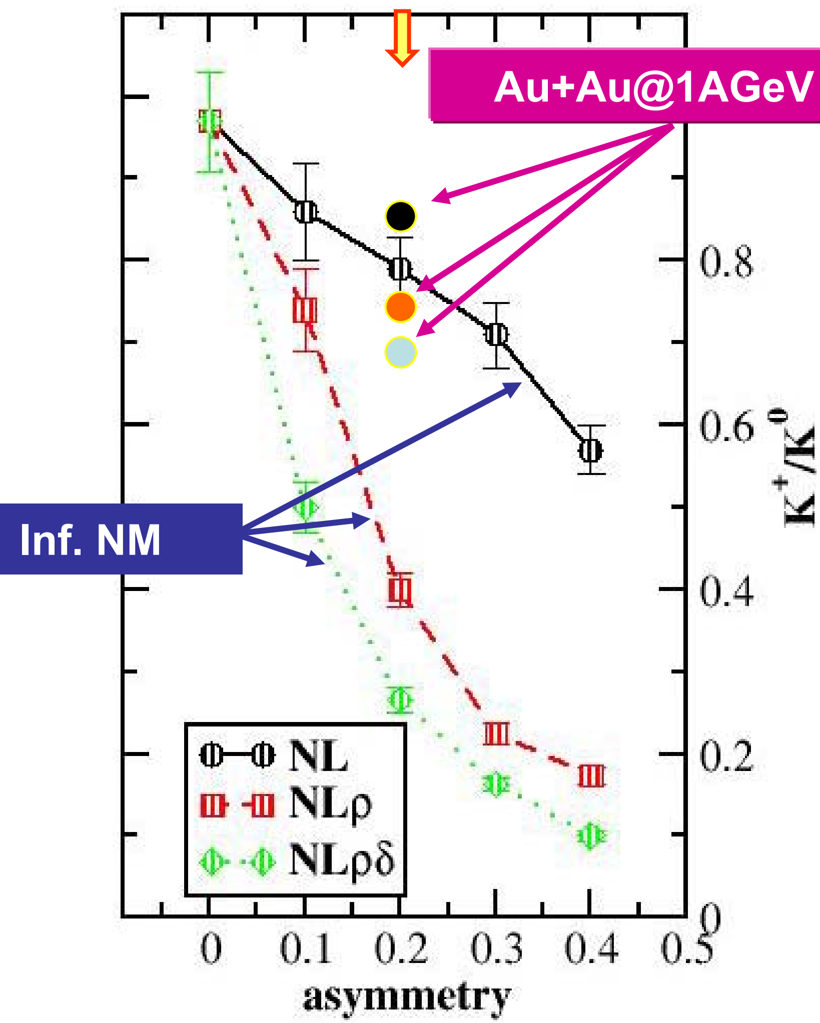
-charge dependent thresholds

- in-medium effective masses

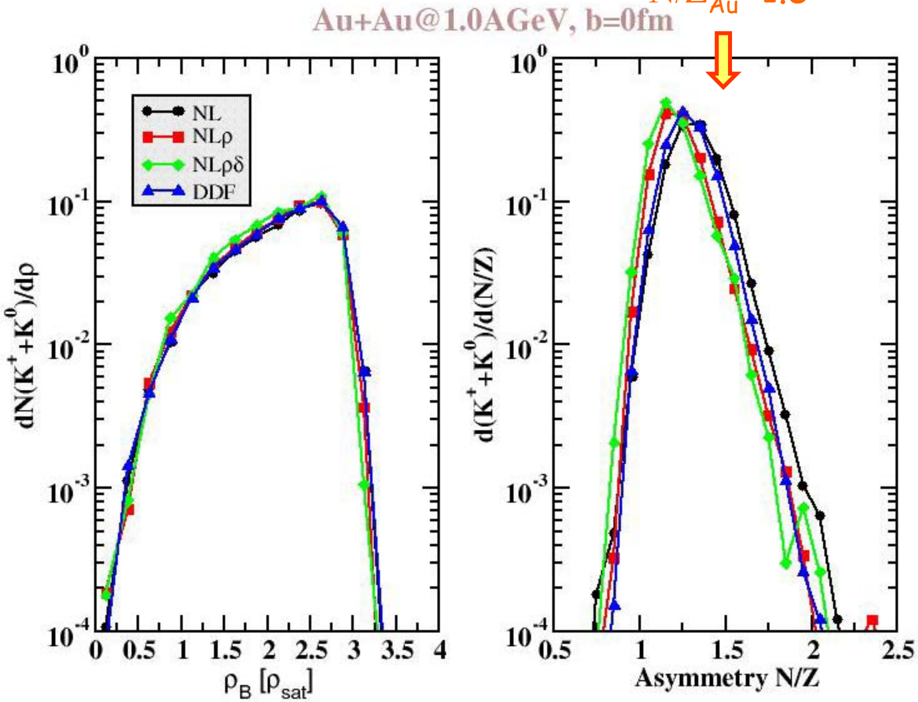
-Mean field effects

Strangeness ratio : Infinite Nuclear Matter vs. HIC

G. Ferini, et al., NPA762(2005) 147



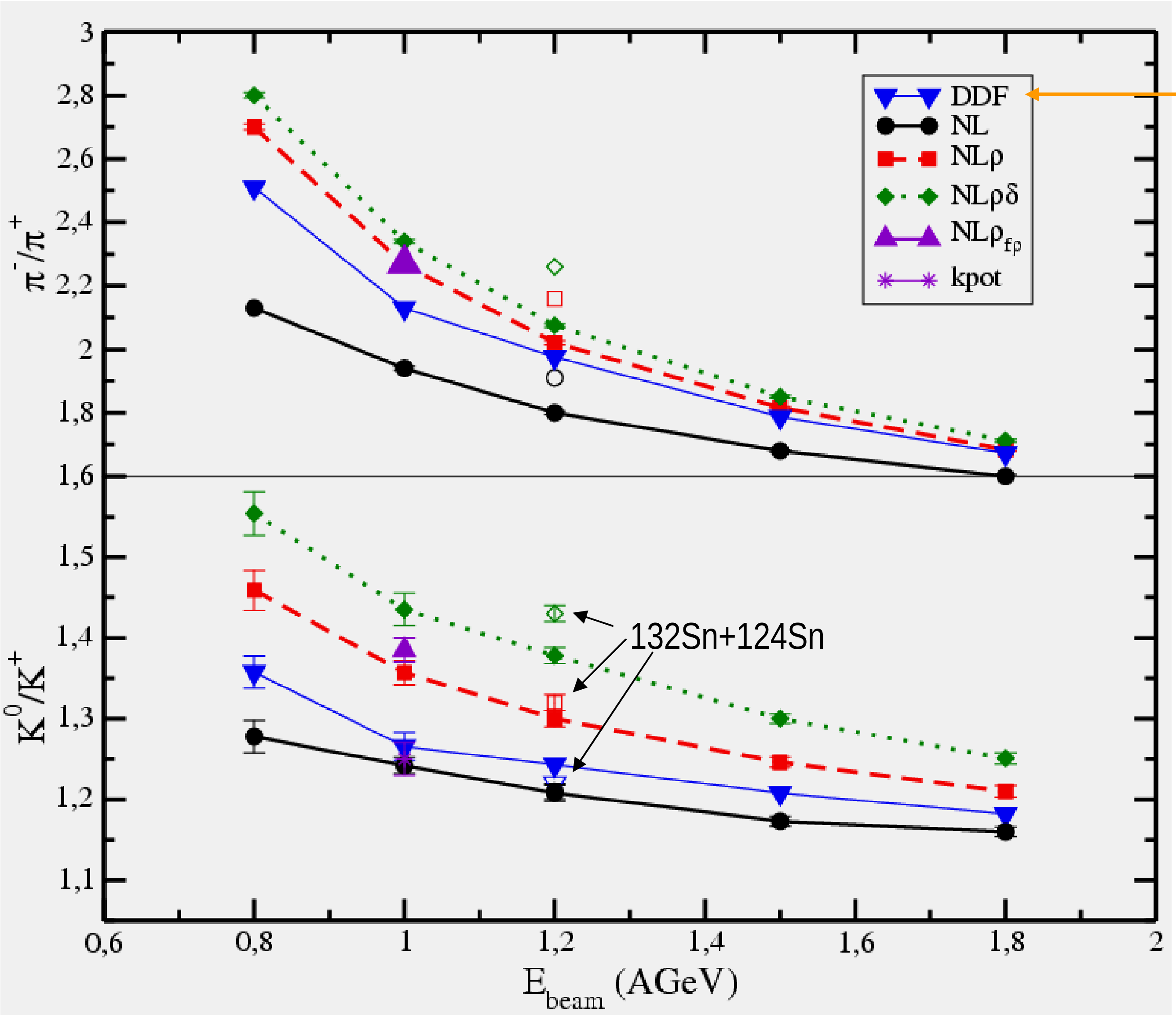
Density & asymmetry of the K-source



NL→ DDF→NLρ→NLρδ :
more neutron escape and more n→p *transformation*
(less asymmetry in the source)

Pre-equilibrium emission (mainly of neutrons) reduced asymmetry of source for kaon production → reduces sensitivity relative to equilibrium (box) calculation

Au+Au central: Pi and K yield ratios vs. beam energy



g_ρ decreasing with density

Kaons:
~15% difference between DDF and NLρδ

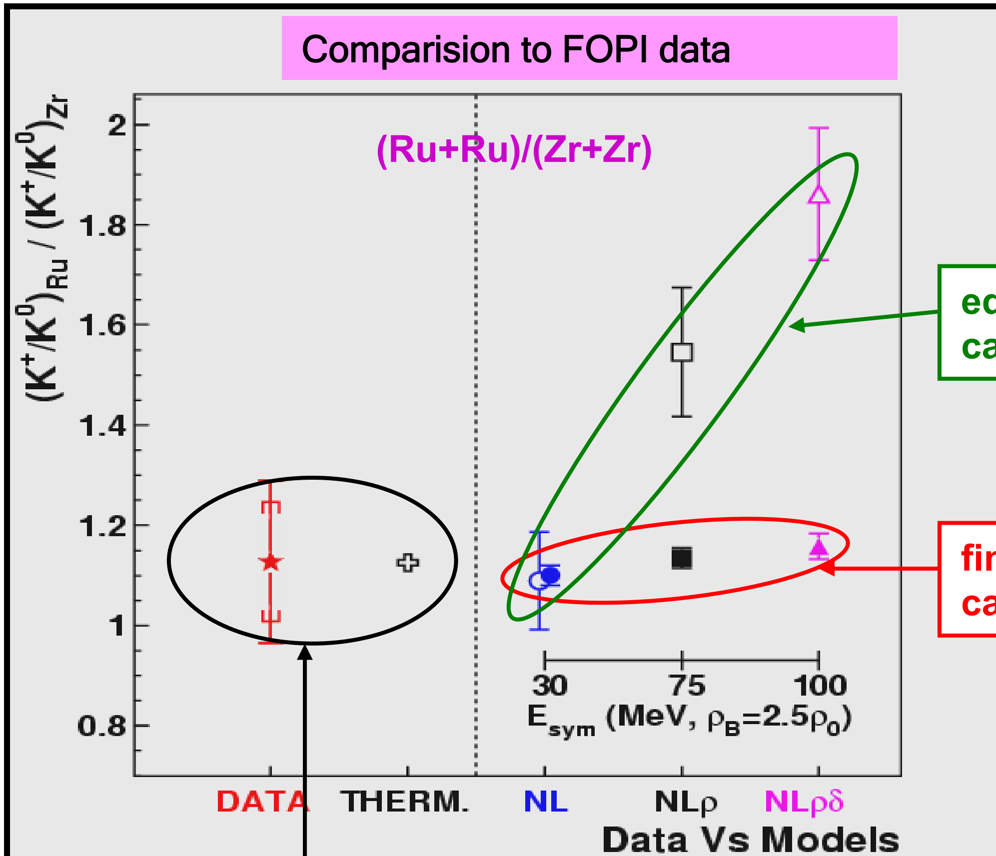
Inclusive multiplicities

Pions: less sensitivity ~10%, but larger yields

G.Ferini et al.,PRL 97 (2006) 202301

Kaon ratios: comparison with experiment

G. Ferini, et al., NPA762(2005) 147 and PRL 97 (2006) 202301



equilibrium (box) calculations

finite nucleus calculations

Data (Fopi)

X. Lopez, et al. (FOPI), PRC 75 (2007)

- sensitivity reduced in collisions of finite nuclei
- single ratios more sensitive
- enhanced in larger systems

Effect of kaon potentials

In-medium Klein-Gordon eq. for Kaon propagation:

$$\left[(\partial_\mu + iV_\mu)^2 + m_K^{*2}\right]\phi_K(x) = 0$$

Two models for medium effects tested:

Chiral perturbation (Kaplan, Nelson et al.)

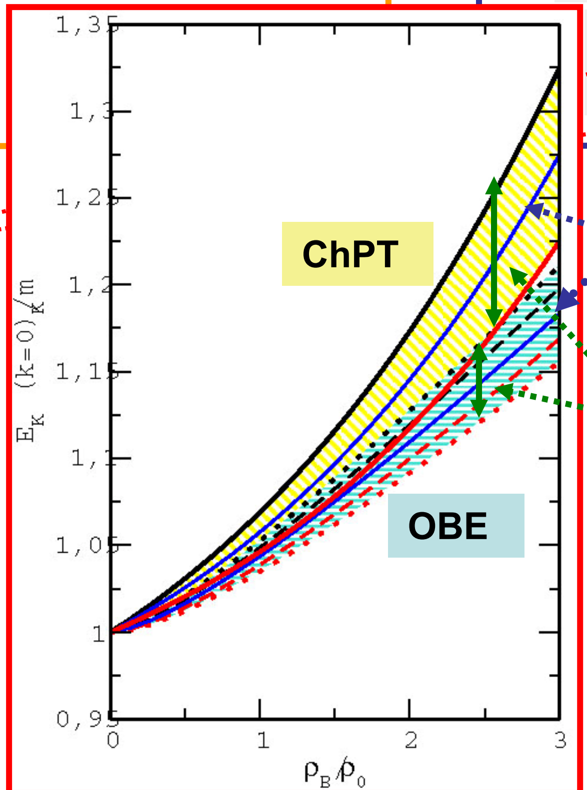
$$m_K^* = \sqrt{m_K^2 - \frac{\Sigma_{KN}}{f_\pi^2}\rho_s \mp \frac{C}{f_\pi^2}\rho_{s3} + V_\mu V^\mu} \qquad (upper\ sign,\ K^+)$$

$$V_\mu = \frac{3}{8f_\pi^{*2}} j_\mu \pm \frac{1}{8f_\pi^{*2}} j_{\mu 3}$$

One-Boson Exchange (Schaffner-Bielich et al.)

$$m_K^* = \sqrt{m_K^2 + \frac{m_K}{3}(g_{\sigma N}\sigma \mp f_\delta \rho_{S3})}$$

$$V^\mu = \frac{1}{3}(f_\omega^* j^\mu \pm f_\rho j_3^\mu)$$



Isospin-dependence

In-Medium K energy (k=0)

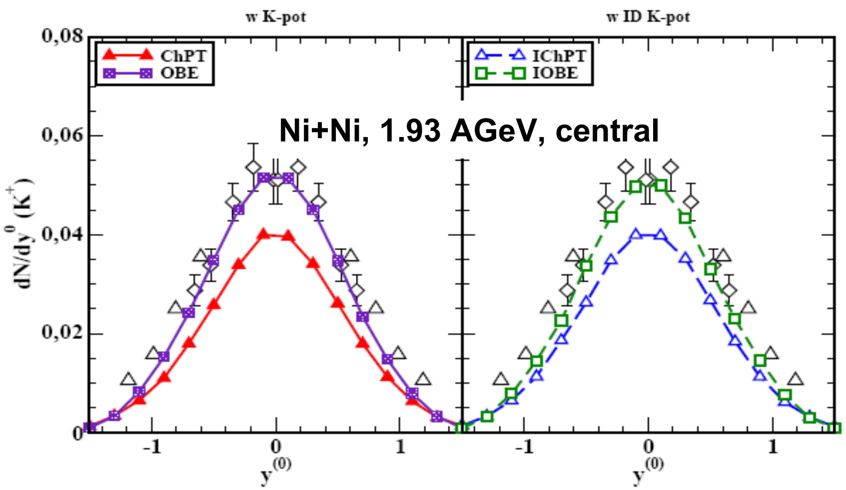
$$E_K(\mathbf{k}) = k_0 = \sqrt{\mathbf{k}^2 + m_K^{*2}} + V_0$$

Splitting for $K^{0,+}$

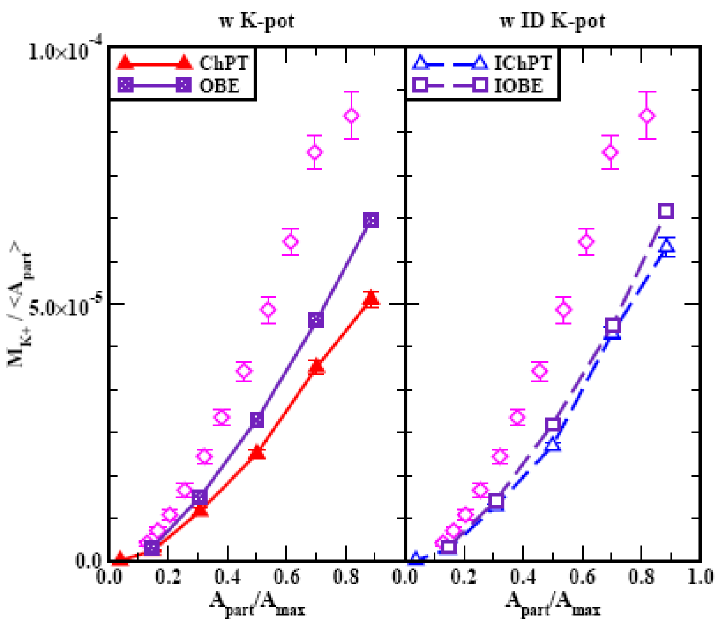
for NLρ and NLρδ

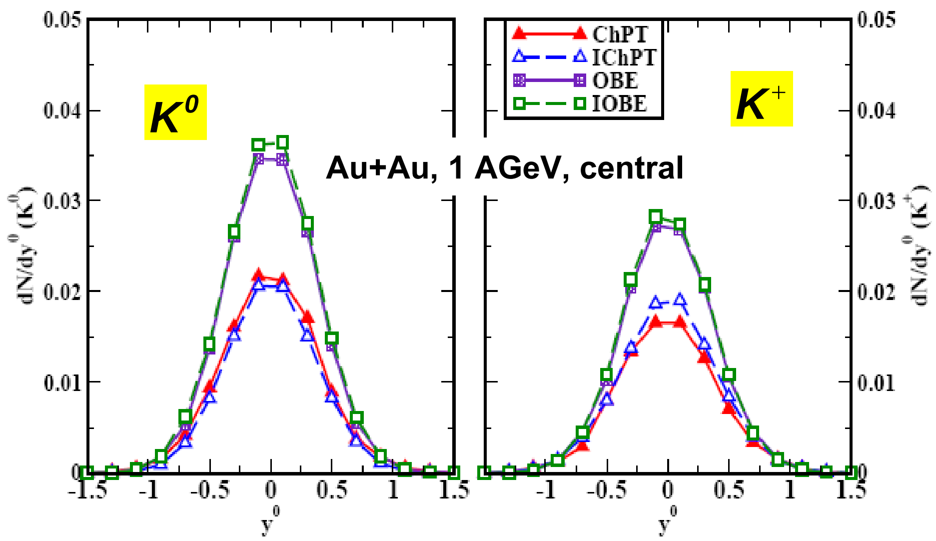
Kaon production and data (Kaos and FOPI)

Ni+Ni system



Au+Au system





Test of kaon potentials models

Two models for medium effects tested:

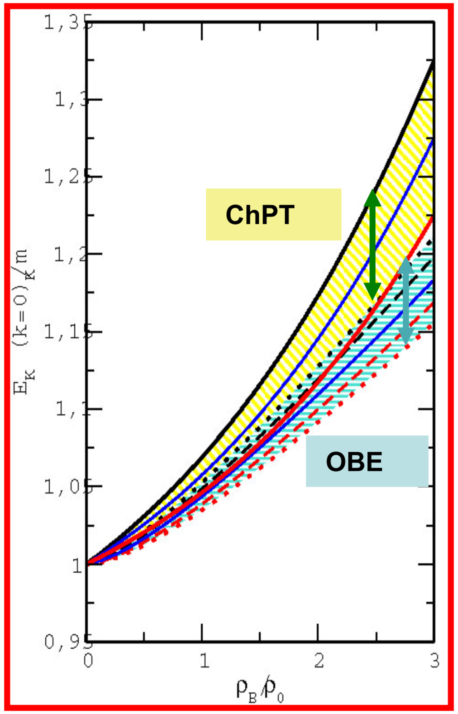
1.Chiral perturbation (Kaplan, Nelson, et al.) (ChPT)

2.One-boson-exch. (Schaffner-Bielich, et al.,) (OBE)

→density and isospin dependent

In-Medium K energy (k=0)

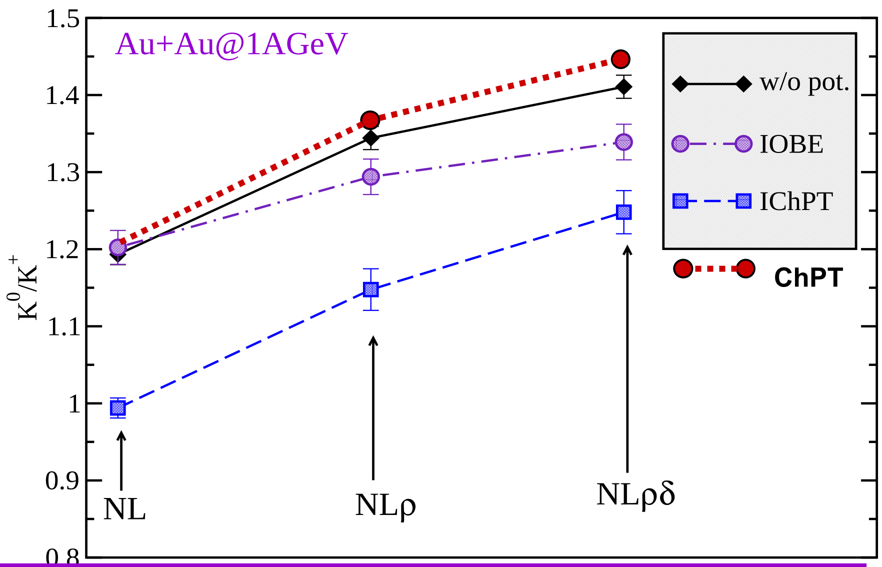
$$E_K(\mathbf{k}) = k_0 = \sqrt{\mathbf{k}^2 + m_K^{*2}} + V_0$$



Splitting for $K^{0,+}$

and NLρ and NLρδ

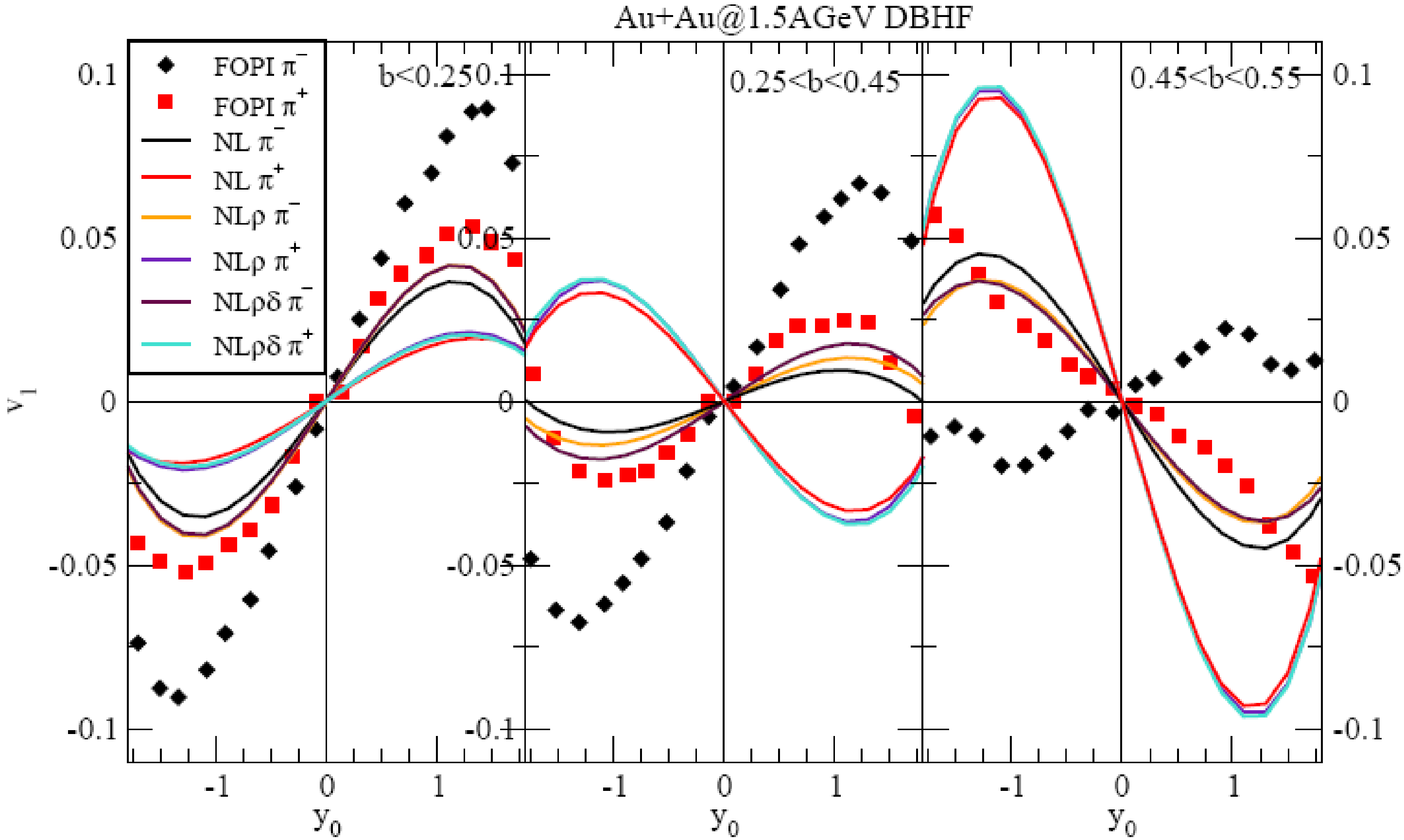
Ratios to minimze influence of σ_{eff} kaon potentials



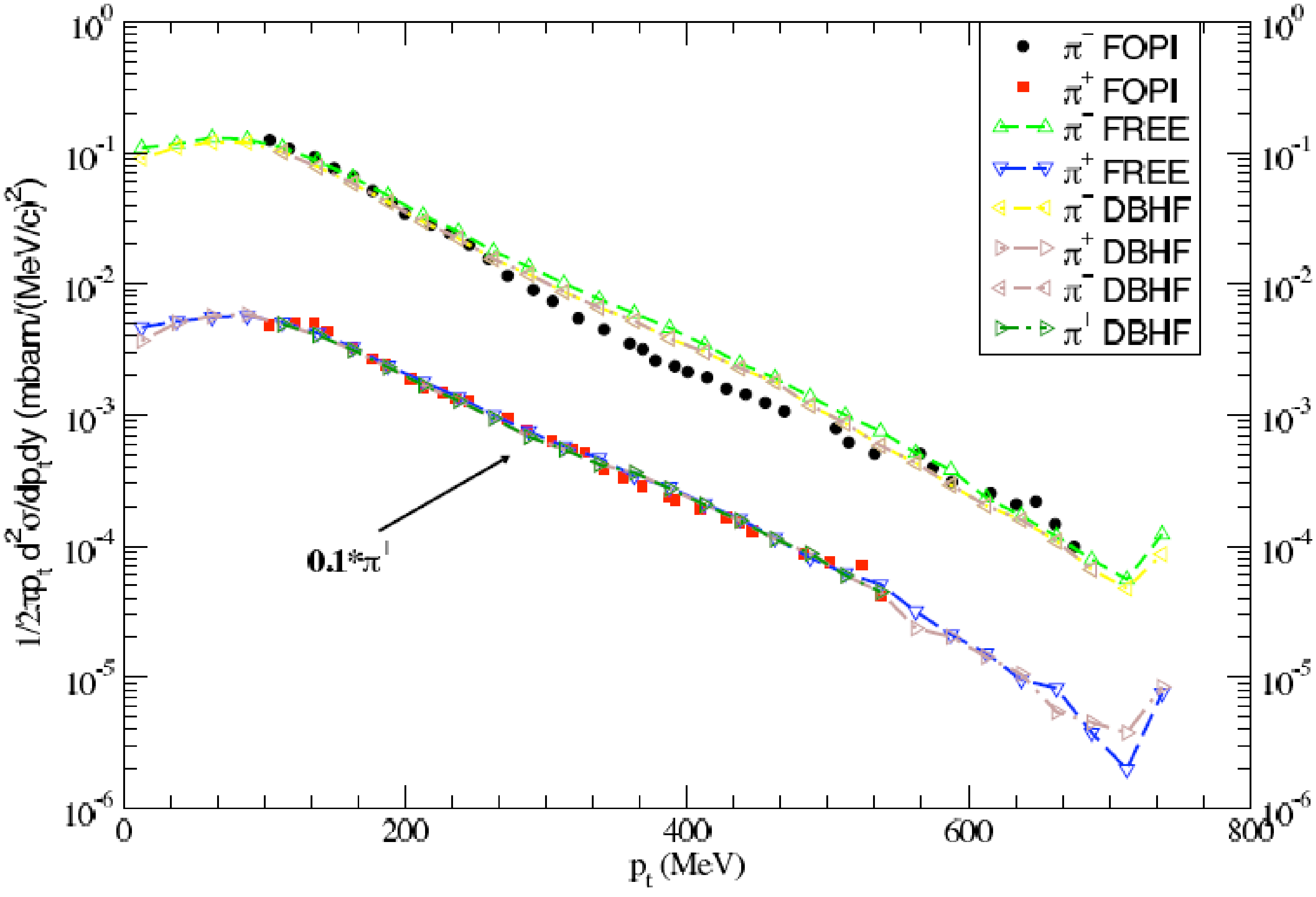
→ robust relative to K-potential, but dep.on isospin-dep part

Summary:

- particle production is an interesting alternative to the determination of the high density symmetry energy in heavy ion collisions
- the production is sensitive to to mean field and threshold effects, which depend on the symmetry energy, but also on the modelling of other input, as e.g. the Δ–sector
- thus question for the pion ratio must still be considered open.
- the strangeness sector is promising since the reaction mechanism is more transparent



Au+Au@1.5AGeV DBHF
FOPI π⁻
FOPI π⁺
NL π⁻
NL π⁺
NLρ π⁻
NLρ π⁺
NLρδ π⁻
NLρδ π⁺
b<0.25
0.25<b<0.45
0.45<b<0.55
v1
y0
0.1
0.05
0
-0.05
-0.1
-1
0
1



π⁻ FOPI
π⁺ FOPI
π⁻ FREE
π⁺ FREE
π⁻ DBHF
π⁺ DBHF
π⁻ DBHF
π⁰ DBHF
0.1*π⁰
1/2πp_t d²σ/dp_t dy (mbarn/(MeV/c)²)
p_t (MeV)

analysis of π-/π+ ratios in Au+Au
Zhigang Xiao, Bao-An Li et al.PRL 102, 062502 (2009)
FOPI data, W. Reisdorf et al.
NPA 781 (2007)