Produzione di particelle come osservabile per l'equazione di stato ad alta densità barionica

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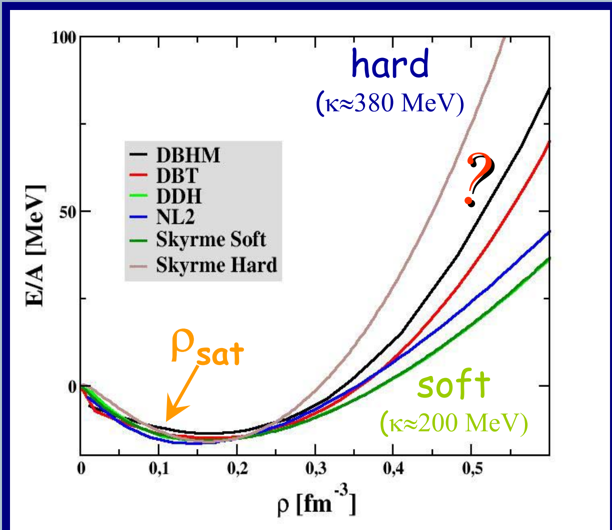
- Introduzione: l'equazione di stato (EoS)
- Particelle prodotte in collisioni ad energie relativistiche (1-2 AGeV)
- Pioni e kaoni come osservabili per l'EoS
- La fase di alta densità in una reazione ad energie del GeV
- Conclusioni

Otranto, 29 Maggio-3 Giugno 2006

The Nuclear EOS Uncertainties

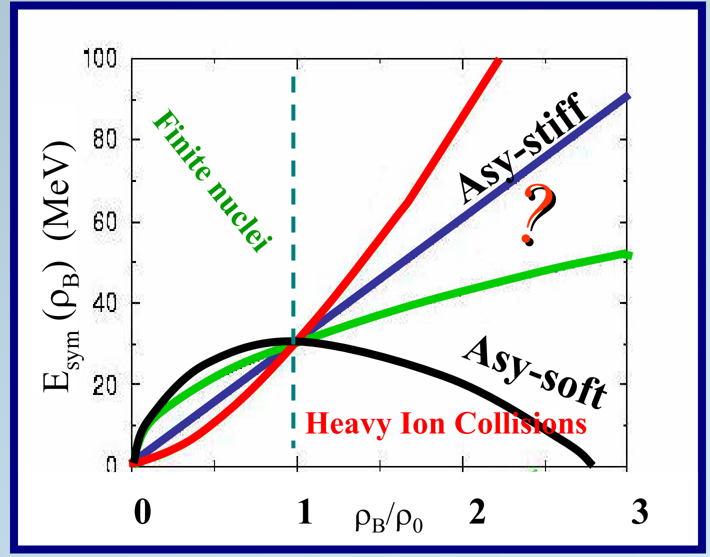
…iso-scalar sector



$$K = 9\rho_0^2 \left(\frac{\partial^2 E}{\partial \rho_B^2} \right) \Big|_{\rho_B = \rho_0}$$

- Particle multiplicity
- Nucleon collective flows (sideward, elliptic)

…iso-vector sector



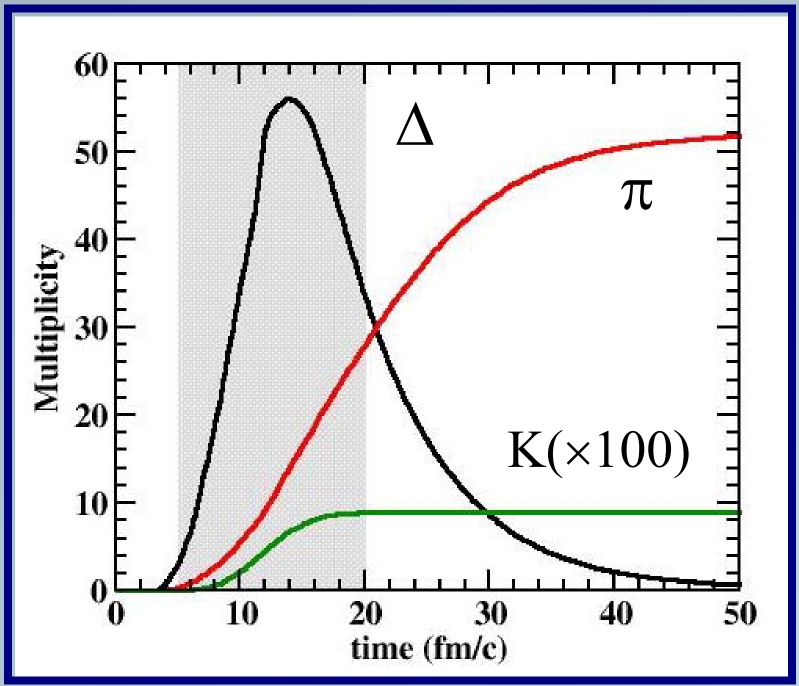
$$\varepsilon_{sym} \equiv \frac{E_{sym}}{A}(\rho) = a_4 + \frac{L}{3}\left(\frac{\rho - \rho_0}{\rho_0}\right) + \frac{K_{sym}}{18}\left(\frac{\rho - \rho_0}{\rho_0}\right)^2$$

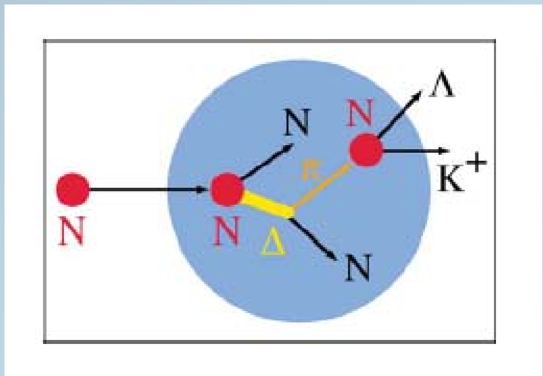
$$L \equiv 3\rho_0 \left(\frac{d\varepsilon_{sym}}{d\rho}\right)_{\rho=\rho_0} = \frac{3}{\rho_0} P_{sym}(\rho_0) \qquad K_{sym} \equiv 9\rho_0^2 \left(\frac{d^2\varepsilon_{sym}}{d\rho^2}\right)_{\rho=\rho_0}$$

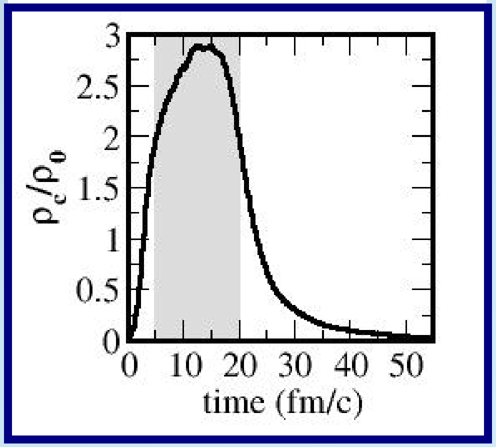
Slope parameter   Curvature parameter

- Neutron-proton differential flow
- Isospin equilibration
- Pion flow
- Isospin ratios (π^-/π^+, K^0/K^+)

Pion and kaon production at GeV energies





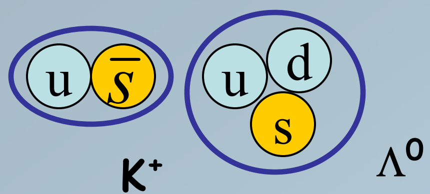


- ✓ pions freeze out late (at low density)
- ✓ kaons freeze out early

K mesons probe the high density phase

Produzione di kaoni

Conservazione di stranezza



- Produzione associata K + Y
- E_{thresh}~1.56 AGeV
- No riassorbimento per i K
- λ_k~7 fm

$BB \rightarrow BYK$ $(B \equiv N,\Delta)$

$\pi B \rightarrow YK$ $(Y \equiv \Lambda,\Sigma)$

$BK \rightarrow BK$

"emissione diretta"

Produzione sotto soglia:

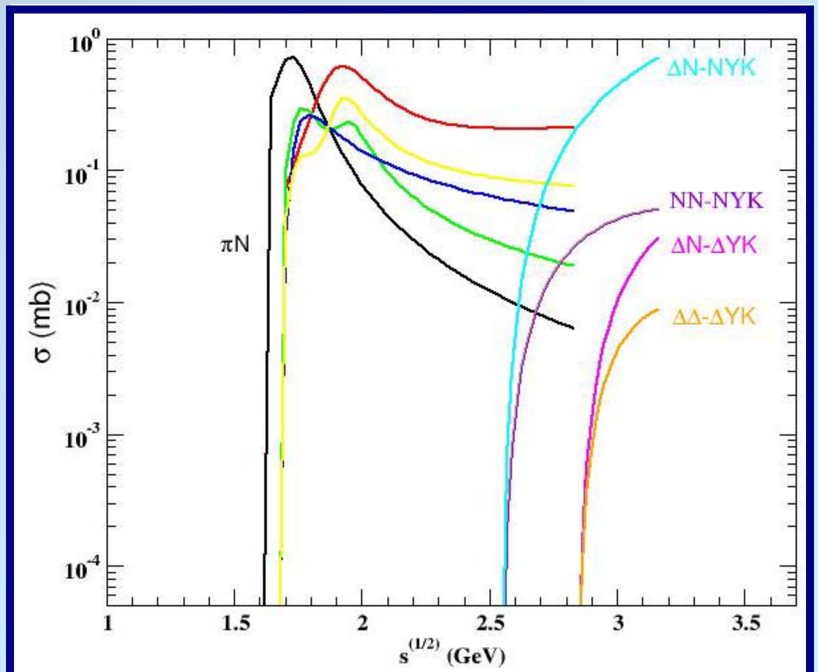
moto di Fermi + processi "multi-step"

K prodotti ad alta densità

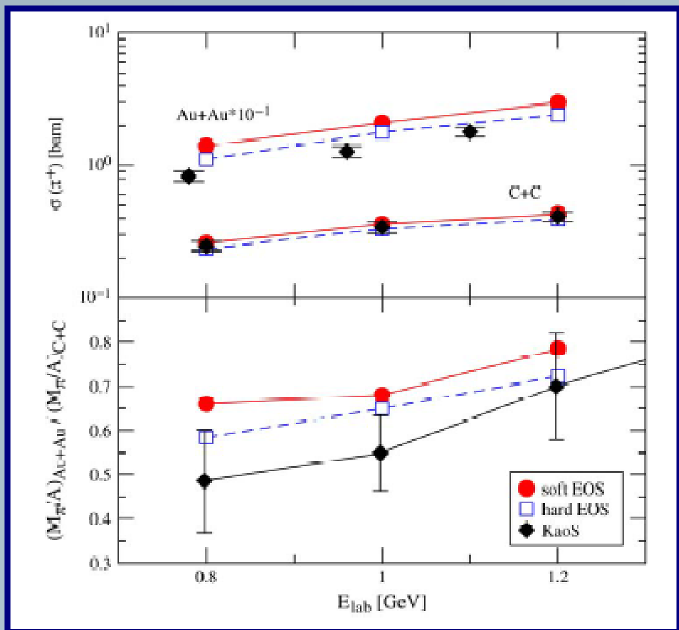
$\sigma_{BB \rightarrow K}$ ⑥ $\sigma_{BB \rightarrow X}$

<u>Metodo perturbativo:</u> i kaoni non influenzano la dinamica del sistema

0.8-2AGeV ⟶ $\sigma_{BB \rightarrow K}$ < 1 mb!

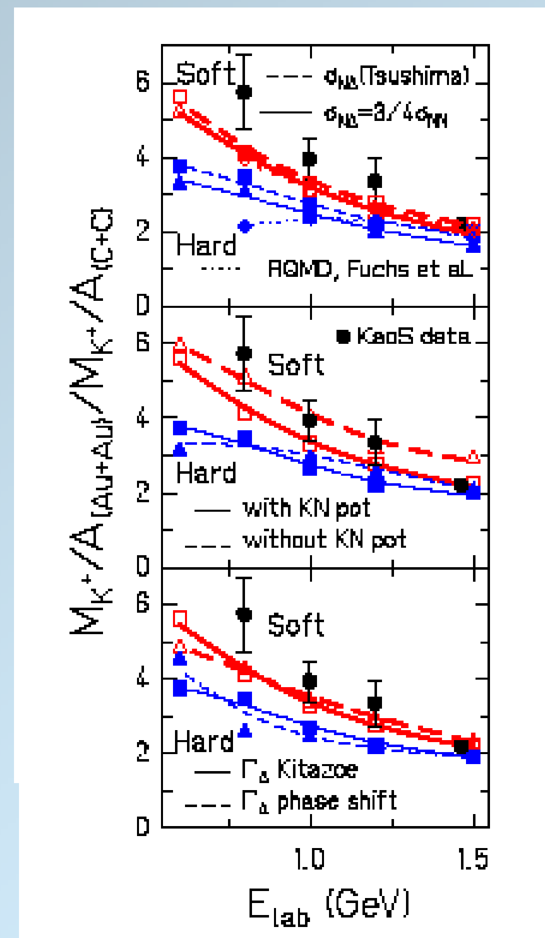


(Isoscalar) EoS from pion and kaon production



π yield does NOT constrain the (isoscalar) EoS

Kaon data only compatible with a soft EoS, even varying:



NΔ cross section

KN potential

Δ lifetime

- F. Laue et al. (KaoS Coll.), PRL 82 (1999), 1640.
- C. Sturm et al. (Kaos Coll.), PRL 86 (2001), 39.
- C. Fuchs, Prog. Part. Nucl. Phys. 56 (2006), 1.
- Ch. Hartnack et al., PRL 96 (2006), 012302.

Effects of the symmetry energy

$$\Sigma^\mu(p,n) = f_v j^\mu \mp f_\rho j_3^\mu$$

Baryon current

$$j_{3\mu}(x) = j_\mu^p(x) - j_\mu^n(x)$$

Vector self energy more repulsive for neutrons (-) and more attractive for protons (+)

a) Neutrons pushed out from the high density stage of the reaction

b) Neutrons converted into protons during the high density stage of the reaction

Consequences on

$$\frac{\pi^-}{\pi^+} \quad \text{and/or} \quad \frac{K^0}{K^+} \quad ???$$

nn → $p\Delta^-$ → $n\pi^-$

nn → $n\Delta^0$ → $p\pi^-$

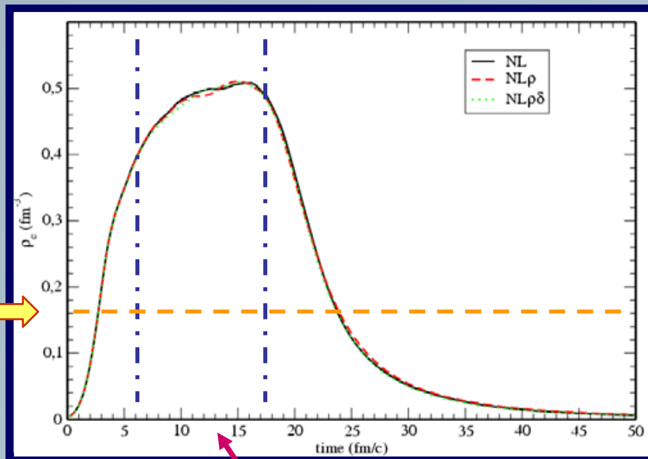
pp → $p\Delta^+$ → $n\pi^+$

pp → $n\Delta^{++}$ → $p\pi^+$

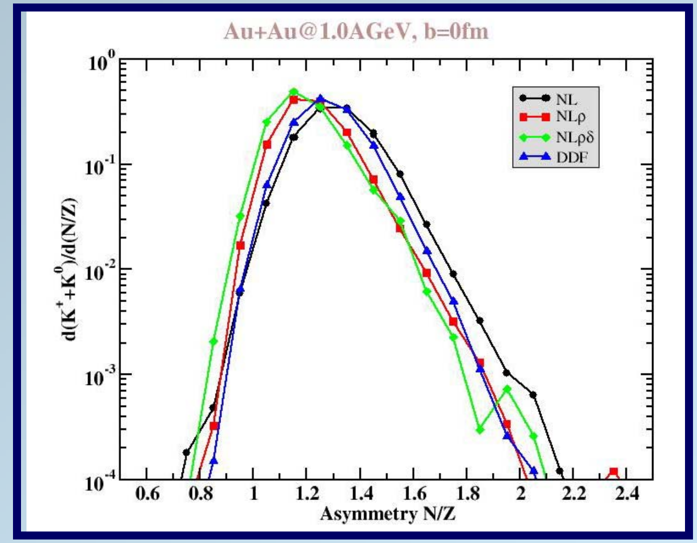
$p\pi^-$, $n\pi^+$ → K^0, K^+

Au+Au 1AGeV: density and isospin of the Kaon source

"central" density

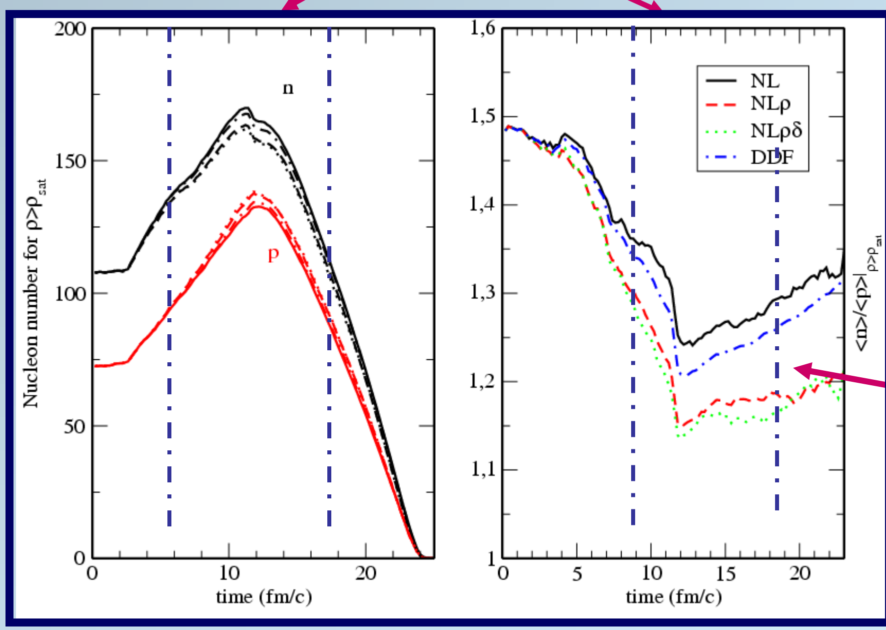


Time interval of Kaon production



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

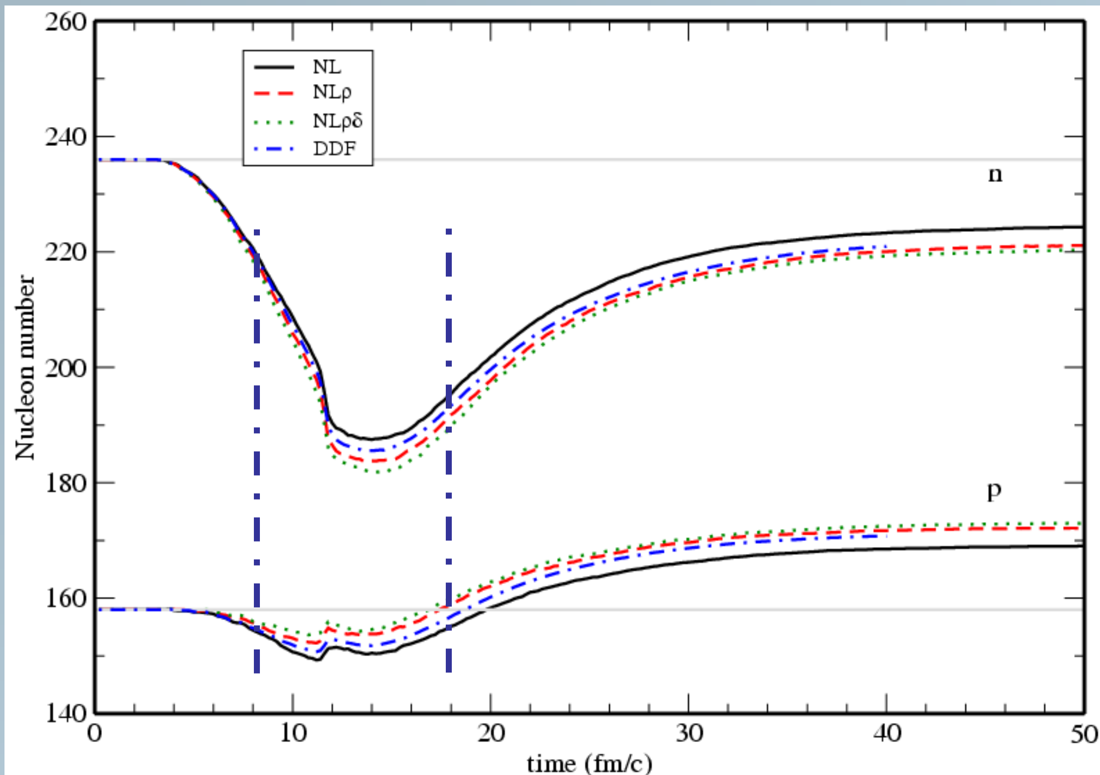
n,p at High density



n/p at High density

Drop:
Competition of fast neutron emission
and
Inelastic channels:
n→p *transformation*

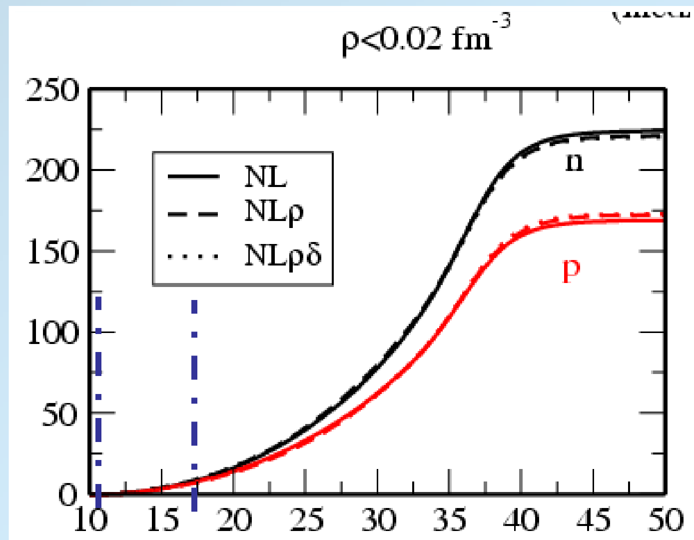
Au+Au@1AGeV: time evolution of the total number of nucleons



Large n→p transformation
at early times:
Less asymmetry in the Kaon source

f_ρ increasing sequence
NL<DDF<NLρ<NLρδ

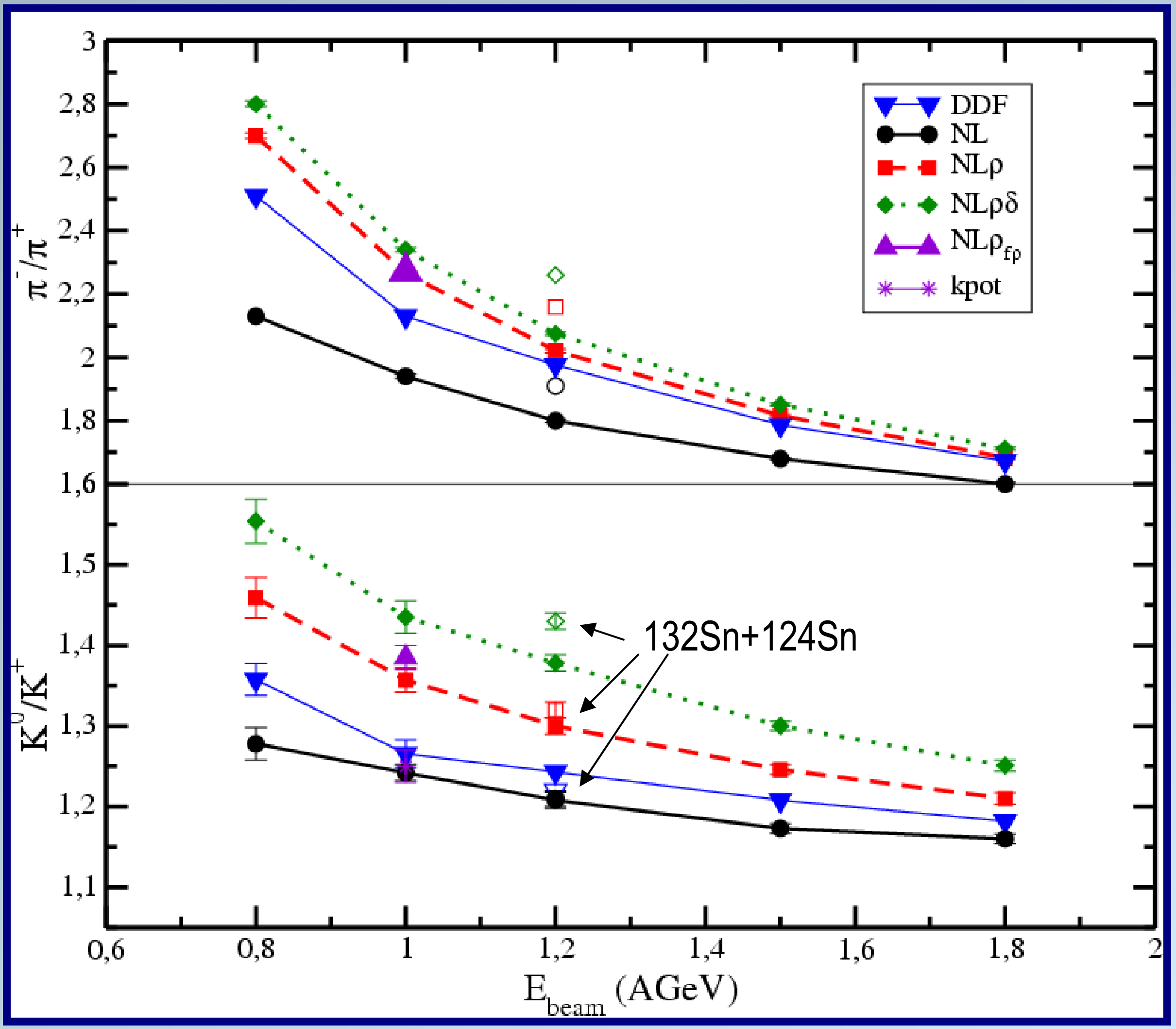
Free nucleons



Check:
π^-/π^+, n/p, K^0/K^+ vs
emission time (P_t)

→ Different behavior at lower energies,
reduced inelastic competition

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



Kaons:
~15% difference between DDF and NLρδ

No sensitive to the KN potential

Inclusive multiplicities

Pions: less sensitivity ~10%, but larger yields

Conclusions

➢ Isoscalar sector:

- Nucleon flow data and K^+ multiplicities give indication of a SOFT EoS

➢ Isovector sector:

- E_{sym} reduces the asymmetry in the high density phase of the reaction
- A stiffer E_{sym} (i.e. with greater f_ρ) favours the neutron to proton conversion through inelastic collisions
- π^-/π^+ and K^0/K^+ ratios are affected by E_{sym}
- In the 1-2 AGeV range K^0/K^+ ratio is more sensitive to E_{sym}, in terms of the strength of the isovector channel
- The effect is enhanced in colliding systems with large asymmetry

Produzione di K in prossimità della soglia

Esperimenti

GSI

$0.8 < E_{beam}(AGeV) < 2$

FOPI

$^{197}Au+^{197}Au$, $^{40}Ca+^{40}Ca$,
$^{96}Ru(Zr)+^{96}Ru(Zr)$

- Molteplicità K^+
- Flussi collettivi K^+, Λ
- K^+/K^0 per (α=0.08, 0.16)

$^{96}Ru+^{96}Ru$ @1.5 AGeV

$^{96}Zr+^{96}Zr$@1.5 AGeV

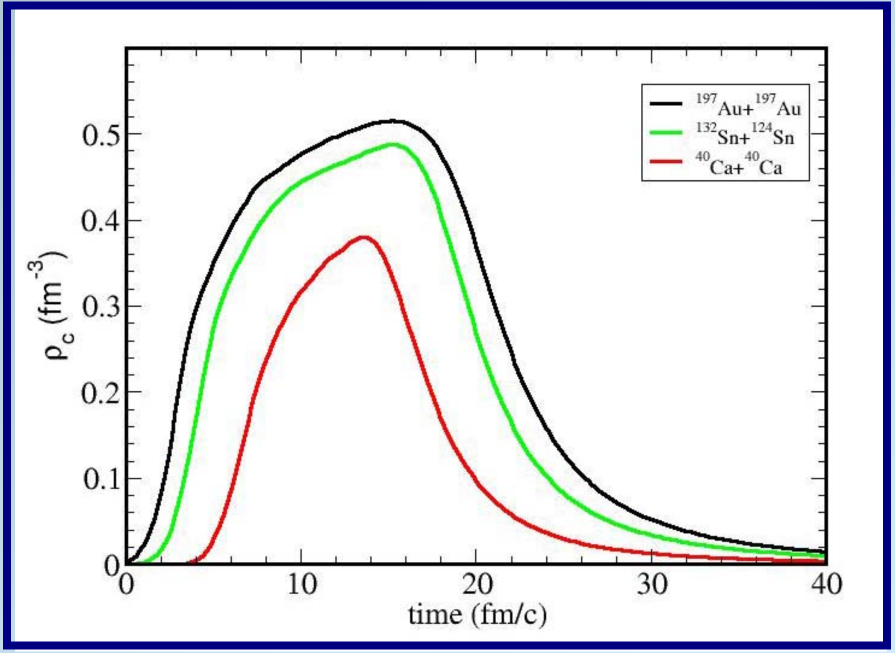
KaoS

$^{197}Au+^{197}Au$, $^{12}C+^{12}C$,
$^{56}Ni+^{56}Ni$

- Molteplicità K^+
- Flussi collettivi K^+, Λ
- Rapporto molteplicità K^+ $(^{197}Au+^{197}Au)/(^{12}C+^{12}C)$

System size dependence

	N_π/A	N_K/A
$^{40}Ca+^{40}Ca$	0.17	1.4×10^{-4}
$^{132}Sn+^{124}Sn$	0.14	2.3×10^{-4}
$^{197}Au+^{197}Au$	0.13	3.2×10^{-4}



Heavy systems ⟺
- More collisions
- More stopping
- Higher density

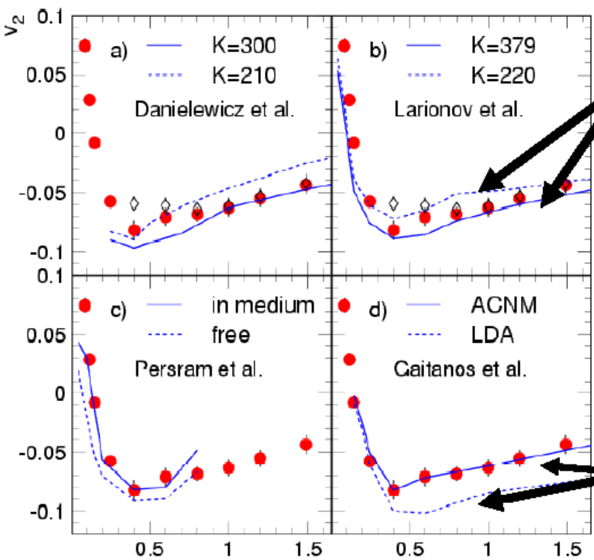
⇓

✓ Pions more easily reabsorbed

✓ Kaons more easily produced

Andronic nucl-ex 0411024

Different in medium cross sections K=210



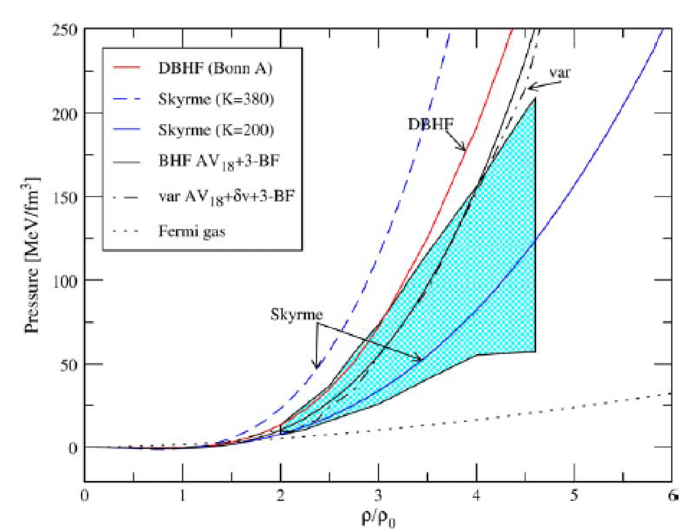
Different EOS same range of V_{NN}

Different ranges of V_{NN} same EOS

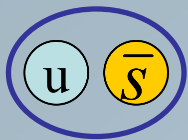
Elliptic flow

Sideward + elliptic flows data rule out supersoft (K=167 MeV) and hard (K>300 MeV) EoS

Soft Eos (K≈200 MeV)



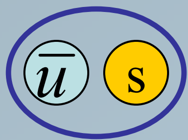
I kaoni: generalità



K^+

$$K^+ \to \mu^+ + \nu_\mu\,, \qquad K^+ \to \pi^+ + \pi^0$$

$(\tau \sim 1\times 10^{-8}\ \mathrm{s})$



K^-

$$K^- \to \mu^- + \nu_\mu\,, \qquad K^- \to \pi^- + \pi^0$$

K^0 è una combinazione di coppie $d\bar{s}$ e $\bar{d}s$ e può decadere in 2 modi:

$$K^0_S \to \pi^+ + \pi^- \qquad K^0_S \to \pi^0 + \pi^0 \qquad (\tau \sim 9\times 10^{-11}\ \mathrm{s})$$

$$K^0_L \to \pi^+ + \pi^- + \pi^0 \qquad K^0_L \to \pi^0 + \pi^0 + \pi^0 \qquad (\tau \sim 5\times 10^{-8}\ \mathrm{s})$$

massa
$$\begin{cases} m_{k+} = m_{k-} \approx 494\ \mathrm{MeV}/c^2 \\ m_{k^0} \approx 498\ \mathrm{MeV}/c^2 \end{cases}$$

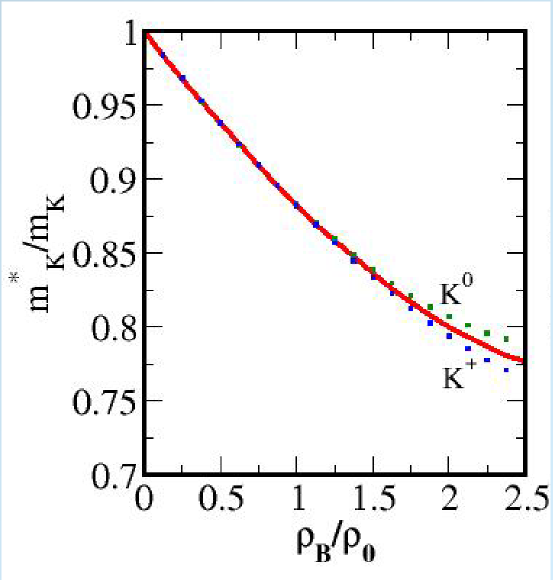
Il potenziale e gli effetti del mezzo sui kaoni

Effetti osservabili:

- ✓Distribuzione azimutale
- ✓Flusso trasverso
- ✓Soglia di produzione

Approcci:

- ✓CPT (Chiral Perturbation Theory)
- ✓BEM (Boson Exchange Model)



Relazioni di dispersione:

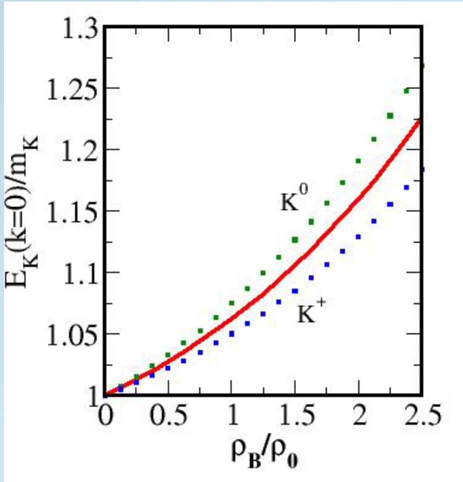
$$\omega_{K^+} = \left[m_K^2 + k^2 - g_{\sigma K} m_K \phi + (g_{\omega K} V_0)^2\right]^{1/2} + g_{\omega K} V_0$$

$$\omega_{K^-} = \left[m_K^2 + k^2 - g_{\sigma K} m_K \phi + (g_{\omega K} V_0)^2\right]^{1/2} - g_{\omega K} V_0$$

Massa efficace:

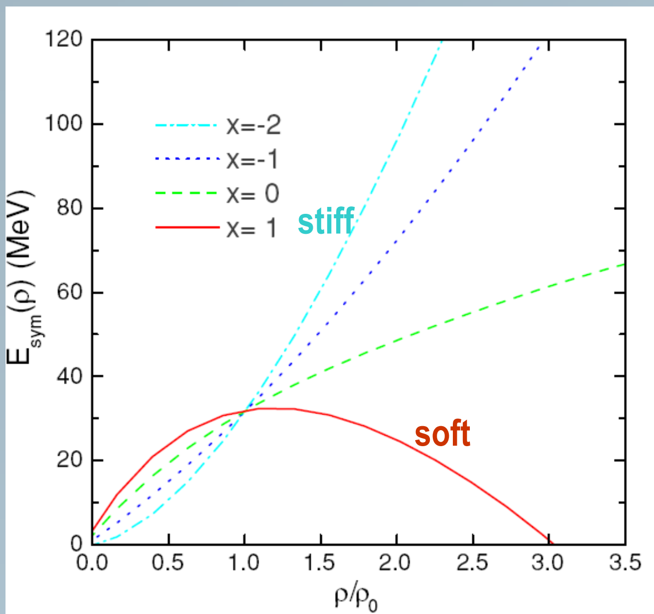
$$m^*_{k^{+,-}} = \sqrt{\left(m_k^2 - \frac{\Sigma_{KN}}{f_\pi^2}\rho_s + V_\mu V^\mu\right)}$$

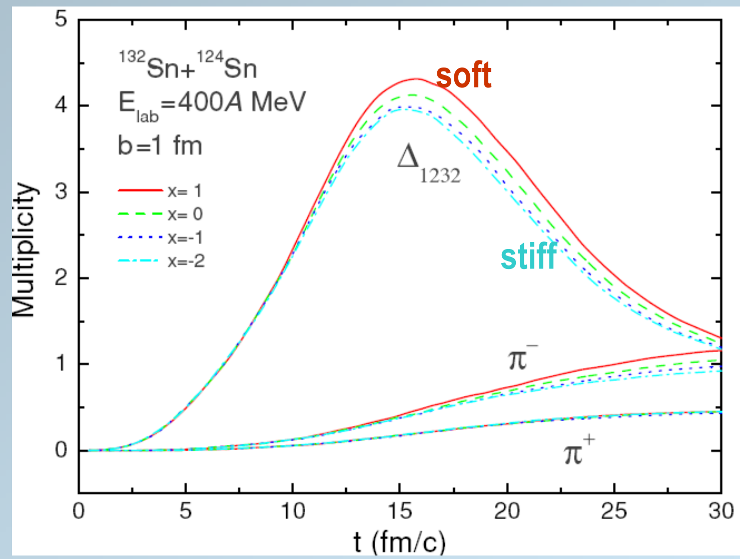
$$V_\mu = \frac{3}{8 f_\pi^2} j_\mu$$



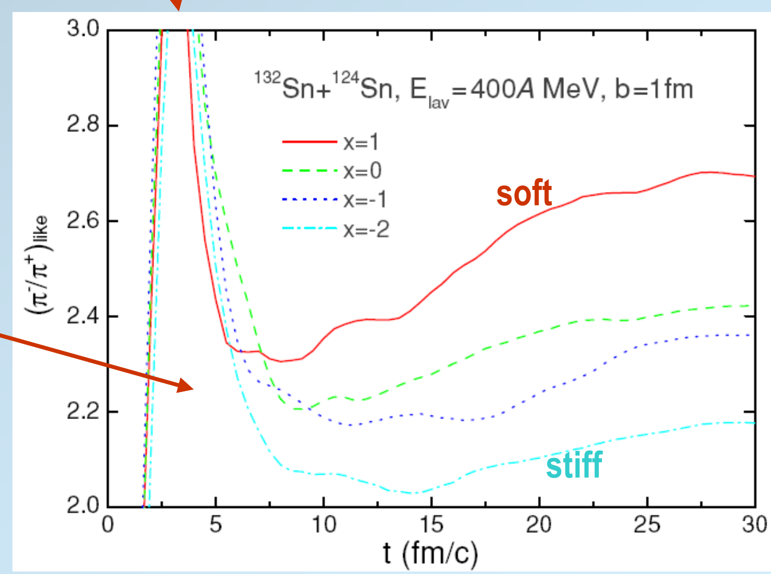
IBUU : not covariant symmetry term

132Sn+124Sn at 0.4AGeV





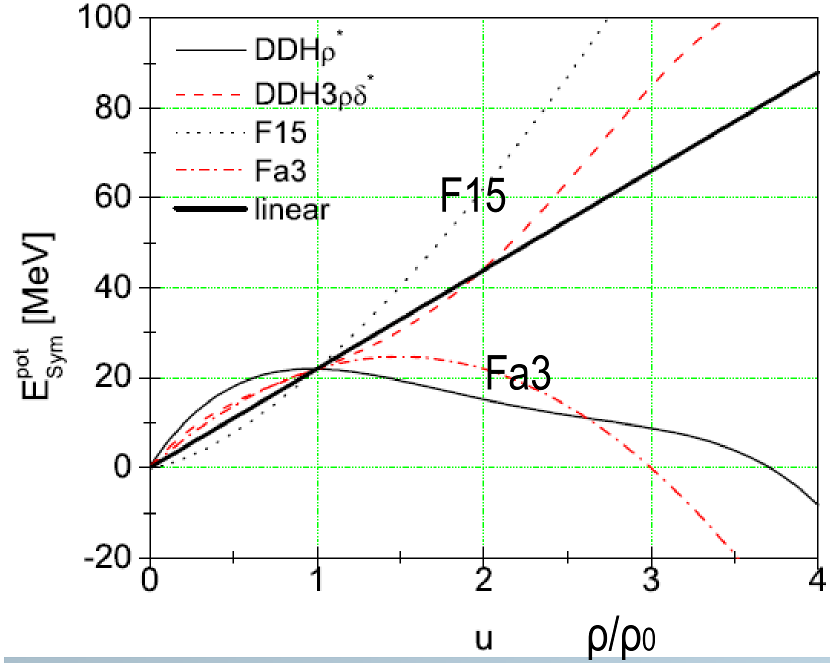
fluctuations



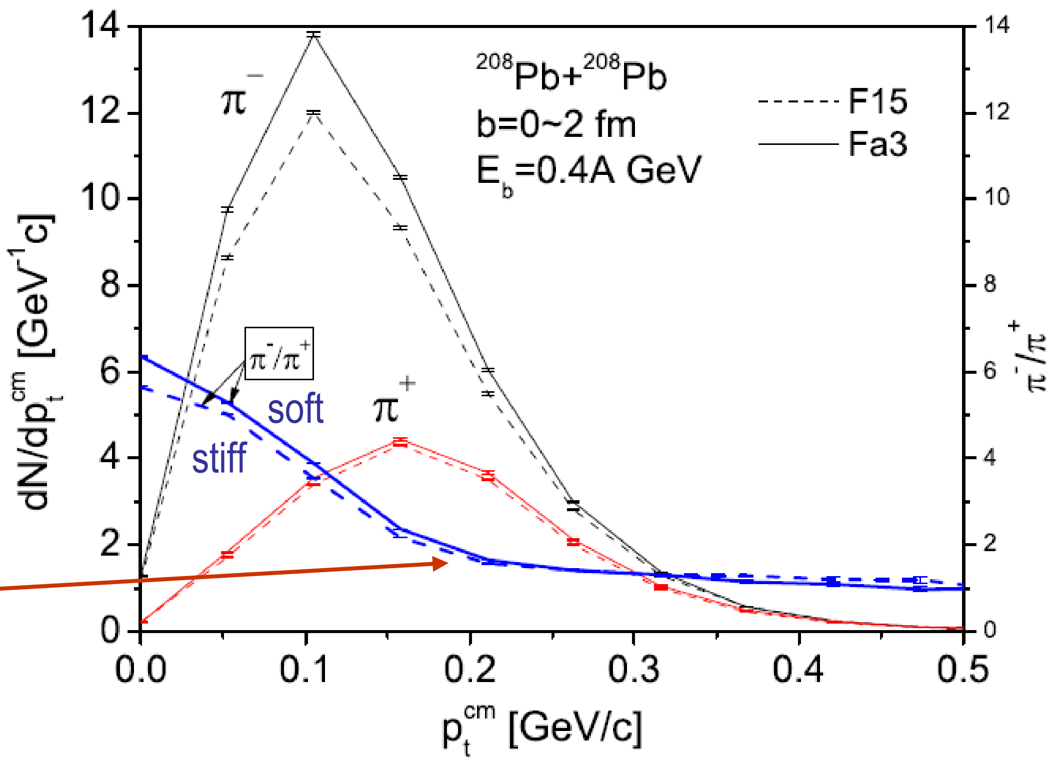
π(-)/π(+) always decreasing with the iso-stiffness?

Bao-An Li PRC 71 (2005) 014608

UrQMD : not covariant symmetry term

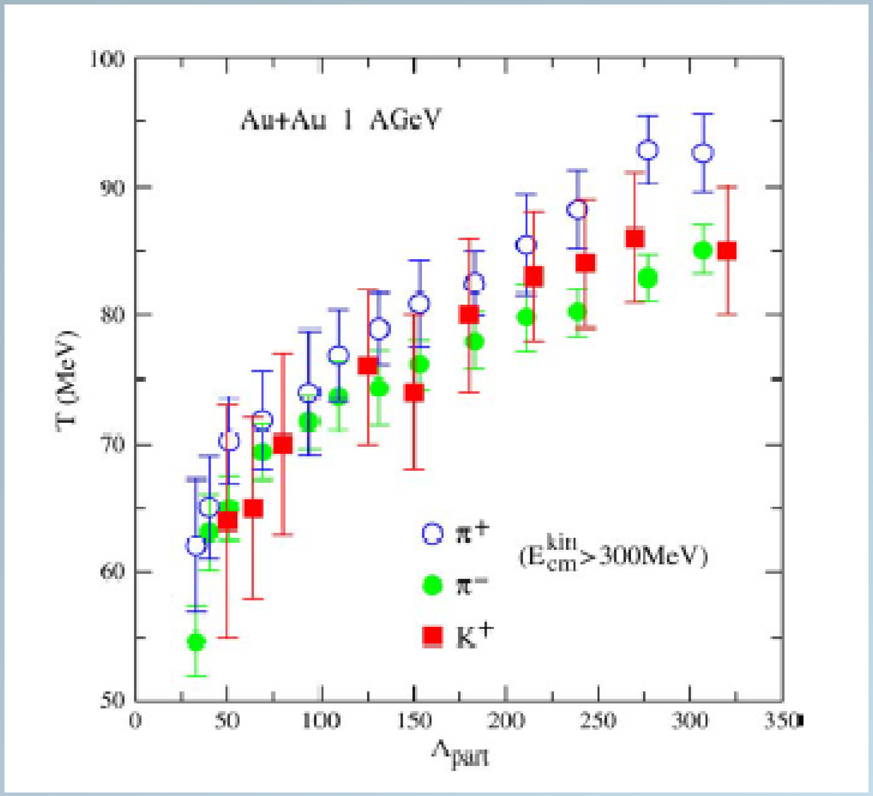


208Pb+208Pb at 0.4AGeV



Inelastic channels less important but still crossing at high p_t

Q.Li et al. PRC 72 (2005) 034613



Kaons behave like high energy pions

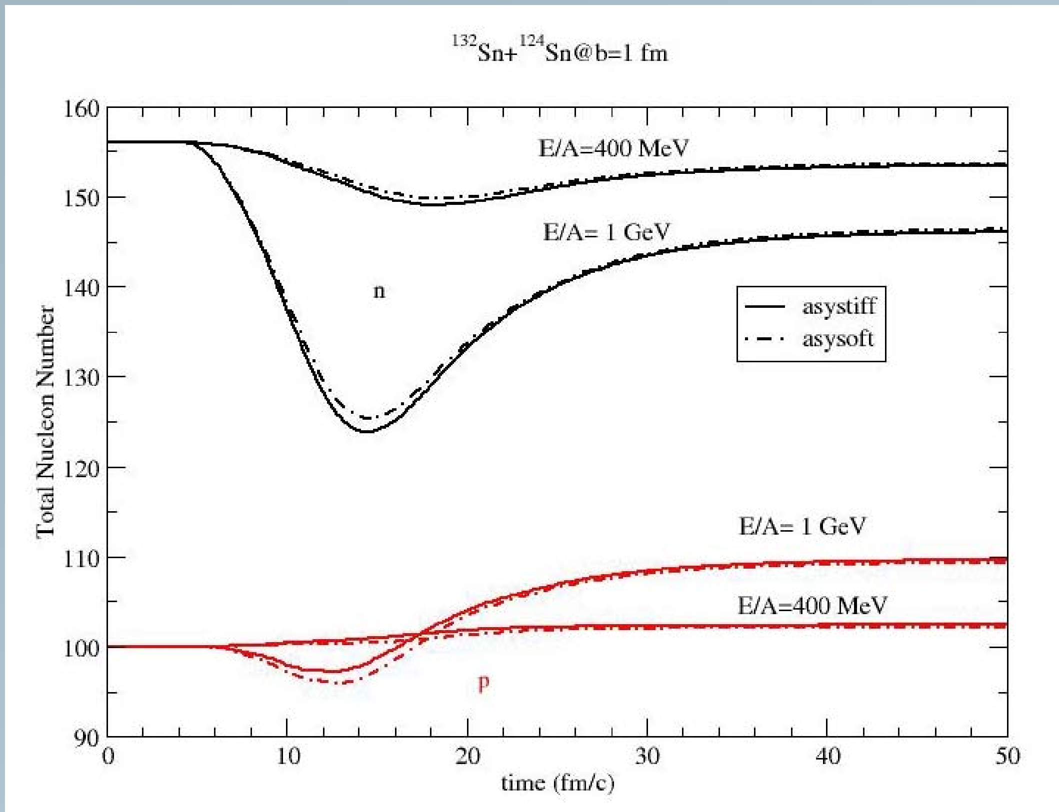
P. Senger, H. Stroebele,J. Phys. G 25 (1999) R59

D Best et al, Fopi , NPA 625 (1997), 307

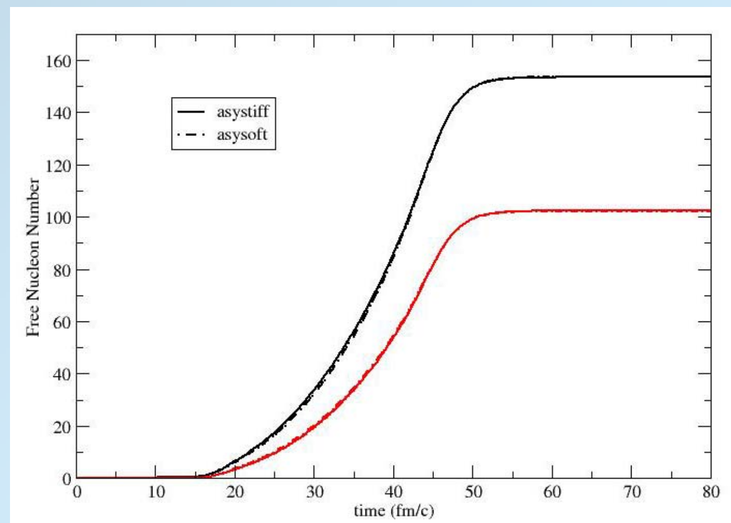
Bass et al, PRC 51 (1995), 3343

Wagner et al, kaos, PLB 420 (1998), 20

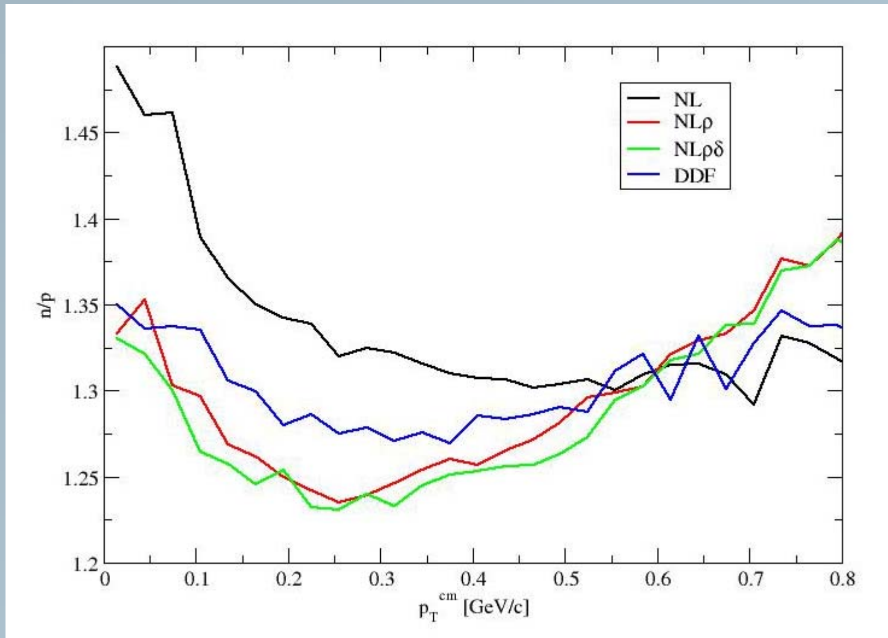
Wagner et al., kaos, PRL 85 (2000), 18



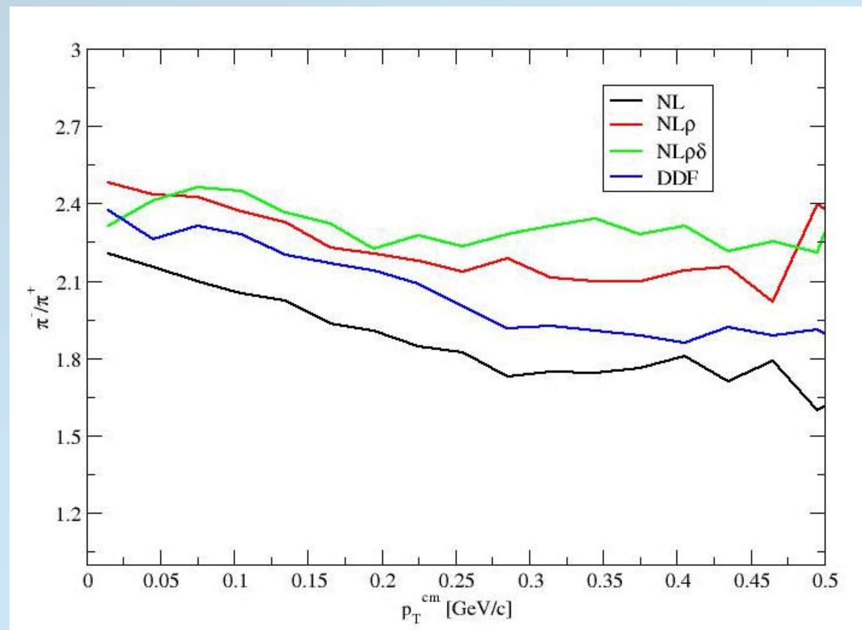
132Sn+124Sn@b=1 fm
E/A=400 MeV
E/A= 1 GeV
n
asystiff
asysoft
E/A= 1 GeV
E/A=400 MeV
p
Total Nucleon Number
time (fm/c)



asystiff
asysoft
Free Nucleon Number
time (fm/c)



n/p
p_T^{cm} [GeV/c]
NL
NLρ
NLρδ
DDF



π^-/π^+
p_T^{cm} [GeV/c]
NL
NLρ
NLρδ
DDF

$$\langle p_x(y)\rangle = \frac{1}{N(y)}\sum_i p_{xi}(y)$$

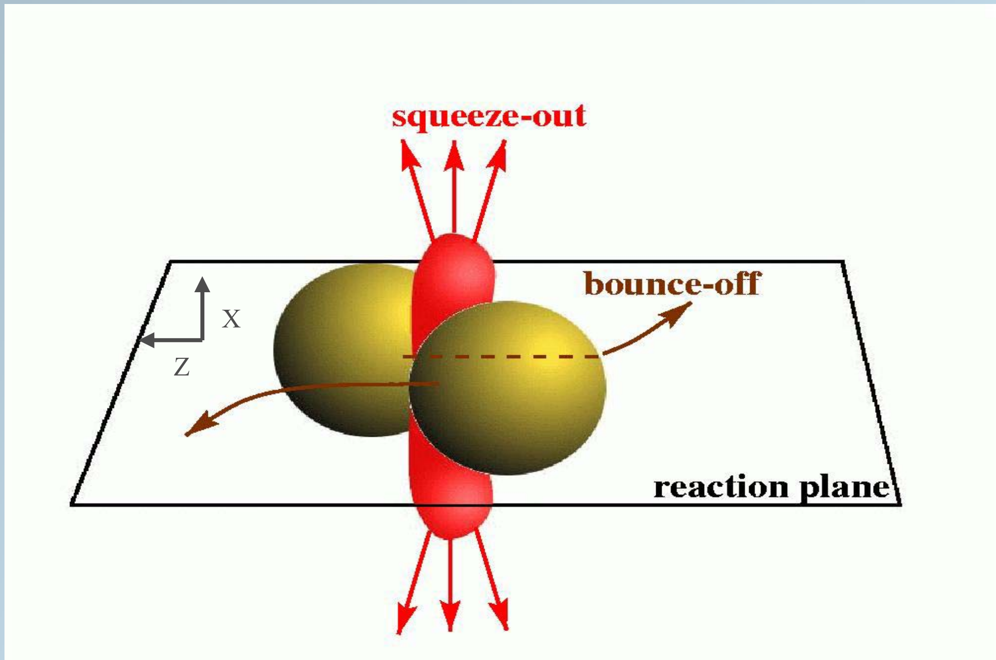
Bounce-off

(in-plane flow)

$$\mathrm{V}_2(p_t) = \left\langle \frac{p_x^2 - p_y^2}{p_x^2 + p_y^2} \right\rangle$$

Squeeze-out

(elliptic flow)



$$F^{p-n}(y) = \frac{1}{N(y)}\sum_i p_{xi}(y)\tau_i$$ ⟸ Isospin ⟹ $$\mathrm{V}_2^{\mathrm{p\text{-}n}}(p_t) = \mathrm{V}_2^{\mathrm{p}}(p_t) - \mathrm{V}_2^{\mathrm{n}}(p_t)$$

Differenze tra NLρ e NLρδ

(V. Greco et al., PLB 562 (2003), 215)