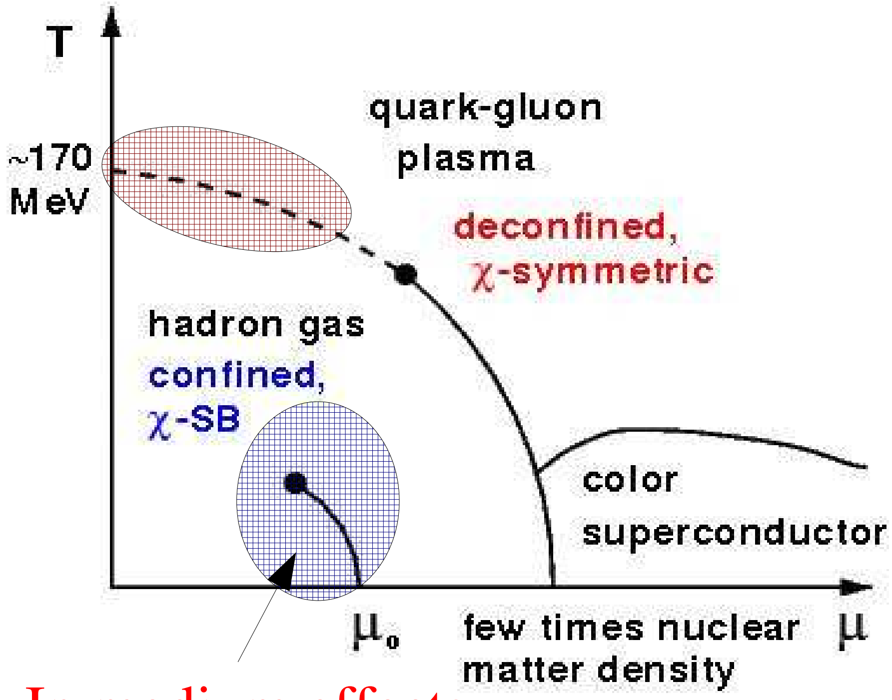
Strangeness in Heavy Ion Collisions

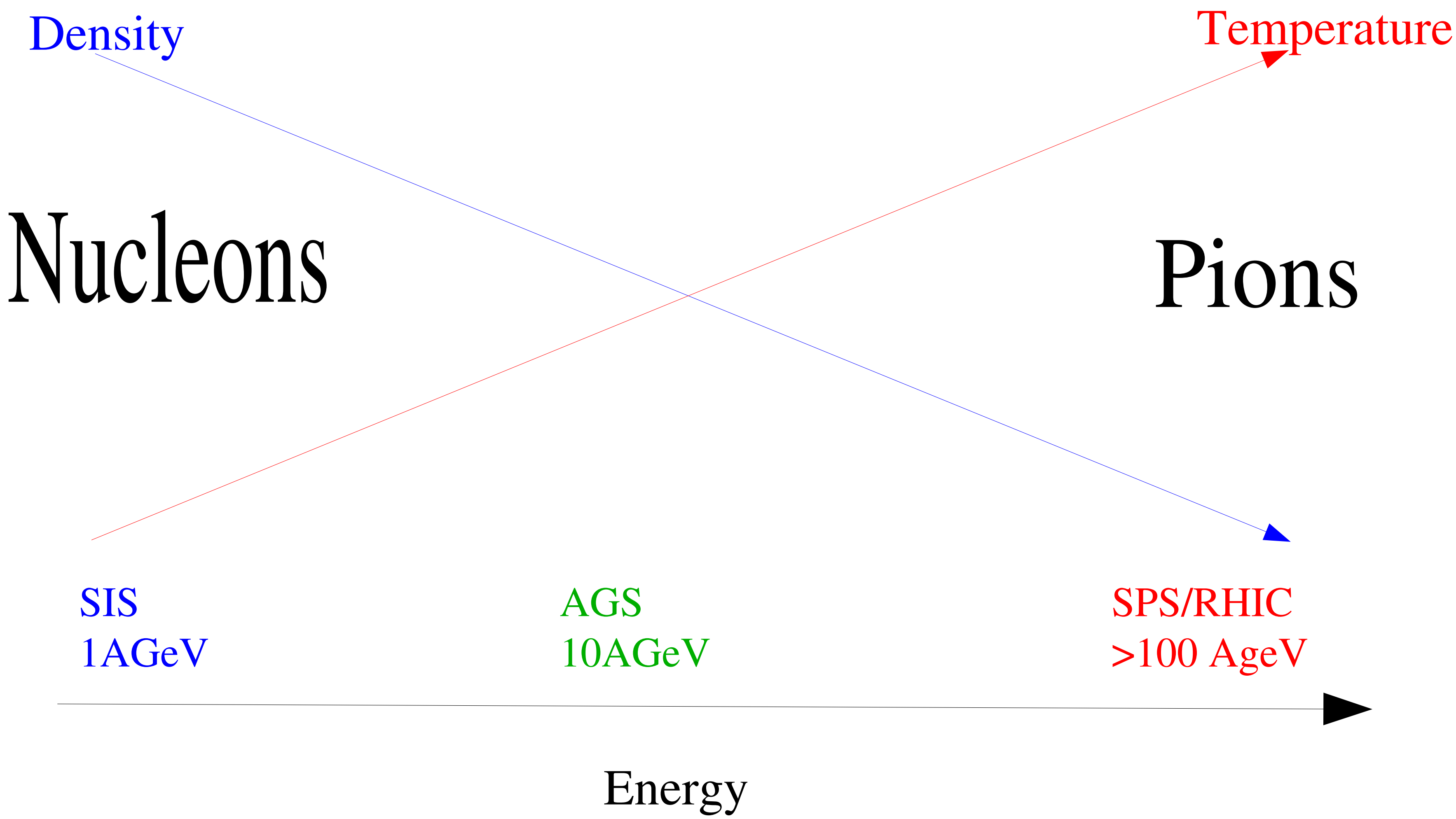
- The question(s)?
- Strangeness at low energies (SIS 1AGeV)
- Strangeness at very high energies (SPS/RHIC)
- Strangeness at intermediate energies (AGS/SPS)
- Conclusions

Why Heavy Ions



In medium effects

The different energies



What are the questions?

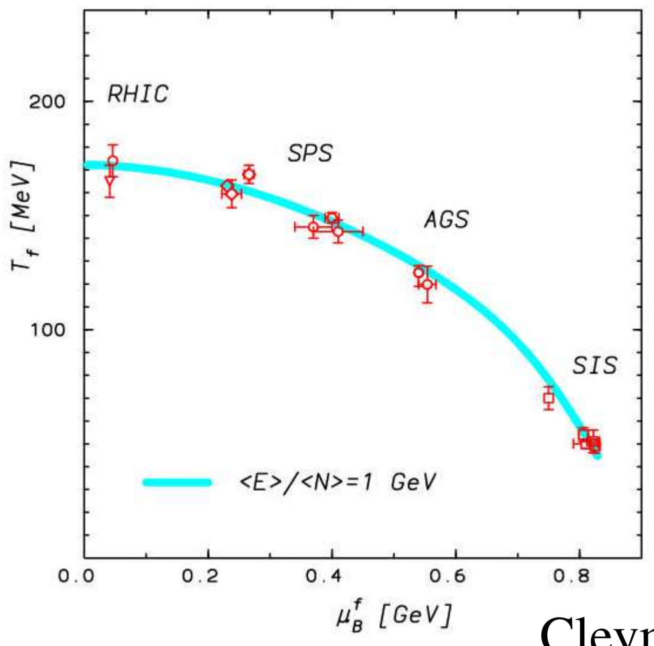
- In medium effects? (Neutron Stars)
- Symmetry breaking patterns
- Equation of state (Neutron Stars)
- Equilibrium, reaction dynamics
- .....

SIS (E_{cm}< 1AGeV)

SPS/RHIC (E_{cm}>20 AgeV)

- Quark Gluon Plasma
- In medium effects ???
- Reaction dynamics,, “rare” probe
- ....

Is it really all that different?



Cleymans et al.

In the statistical model, we simply have different Temperature and chemical potential

Explicit SU(3) breaking by nuclear matter

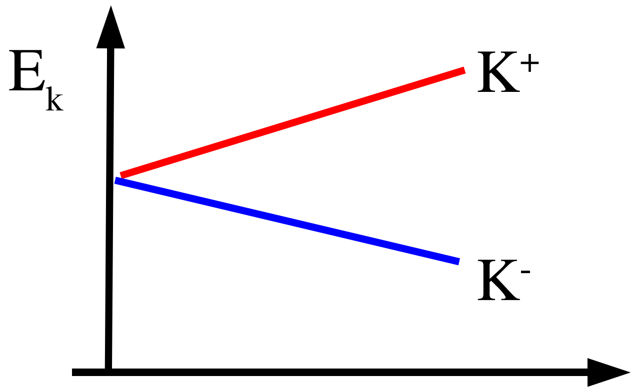
Kaplan & Nelson:
chiral SU(3)

$$\delta L = c_1 (\bar{N} \gamma_\mu N)(\bar{K} \partial_\mu K) + c_2 (\bar{N} N)(\bar{K} K)$$

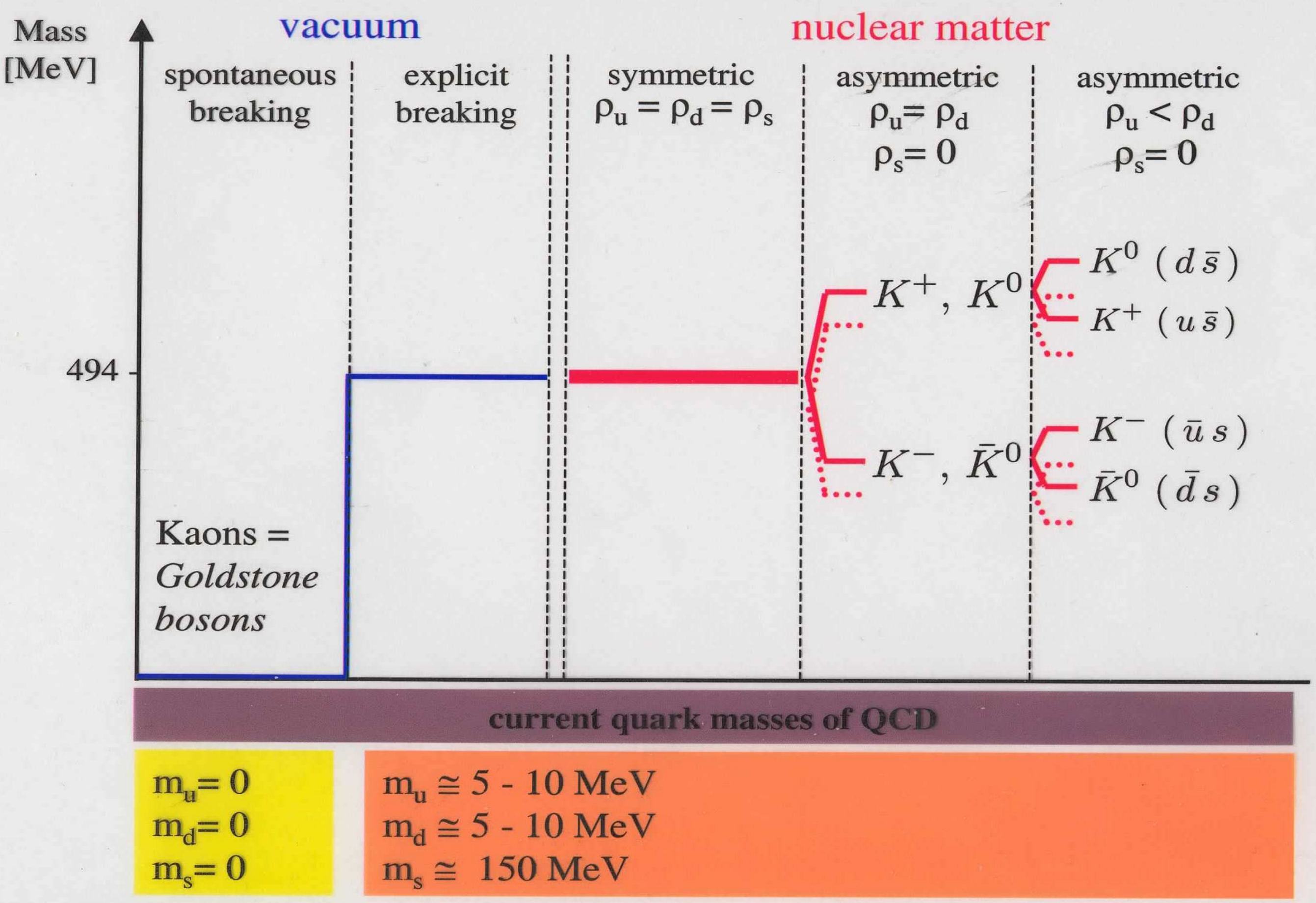
First term: $c_1 (\bar{N} \gamma_\mu N)(\bar{K} \partial_\mu K)$ (Weinberg Tomozawa) vector interaction
repulsive for kaons and
attractive for anti-kaons

Reason: Nuclear matter has no strange quarks
breaks SU(3) symmetry explicitly

NO splitting of the masses
in matter with equal number of
up, down and strange quarks



Pattern of chiral $SU(3)$ symmetry breaking



C. Sturm GSI Darmstadt

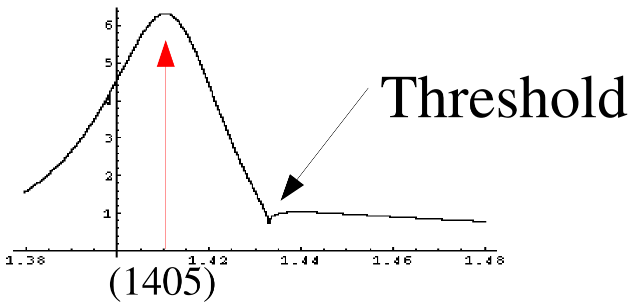
The difference between Kaons and Anti-kaons

- K-Nucleon NON-RESONANT
- mean field (impulse approximation)
- K+A consistent with K+N

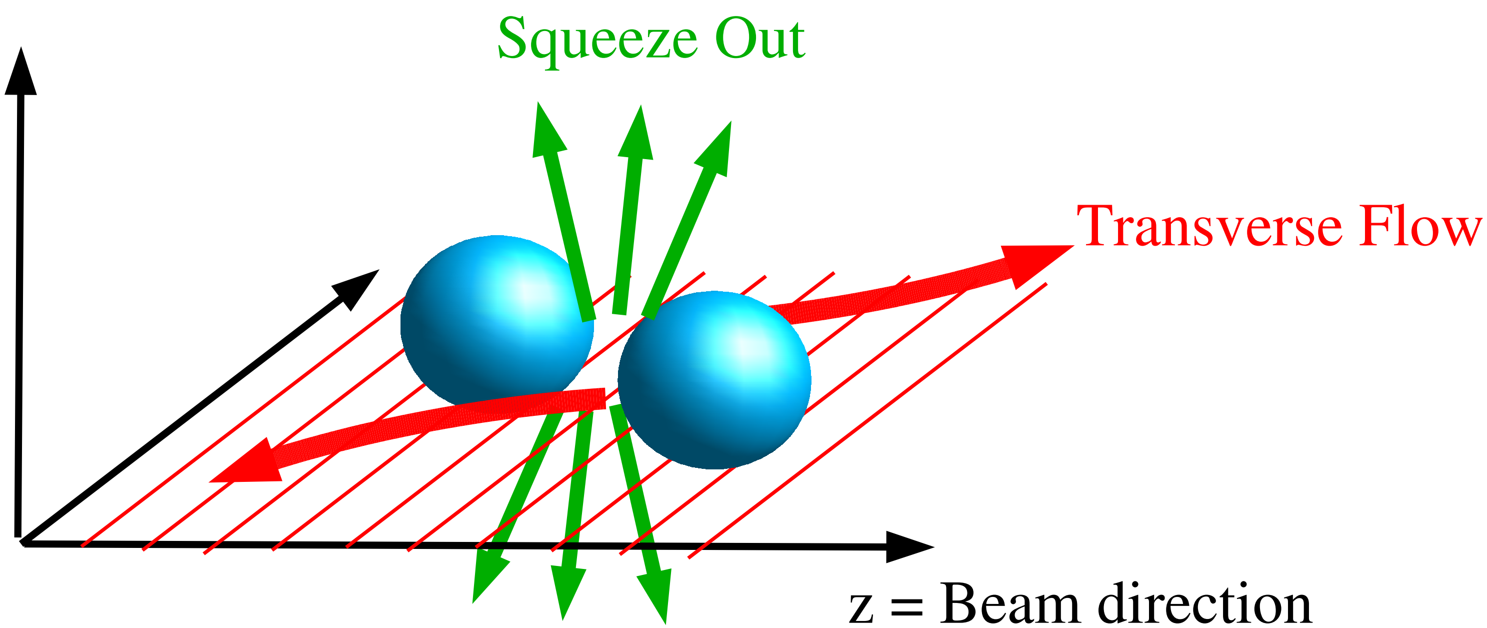
  (D.Ernst et al., Phys.Rev.C59,2627,(1999)
- expect repulsive mean-field

$$U_{opt} \approx 25 \frac{\rho}{\rho_0} \; MeV$$

- Anti-K-Nucleon RESONANT
- impulse approximation “fails”
- Anti-K+A different from Anti-K+N
  - Anti-K+N repulsive
  - Kaonic atoms attractive
- Lambda(1405)

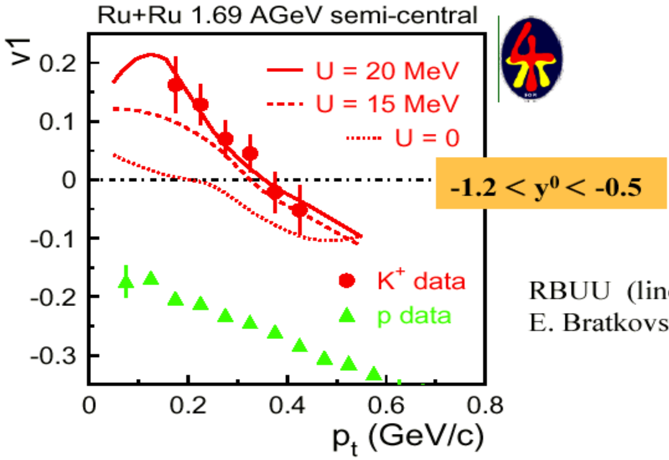


Flow as a probe of the mean field



Kaon Flow and “Squeeze out”

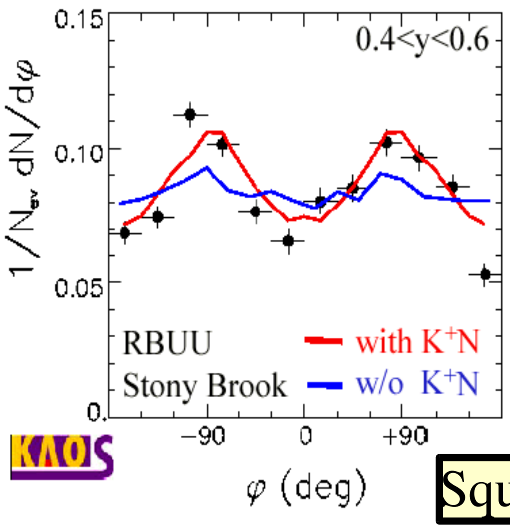
Repulsive potential:
Kaons should flow away from nucleons
predicted by C.M. Ko et al.
PRL 74, 238 (1995)



RBUU (lines)
E. Bratkovskaya , W. Cassing

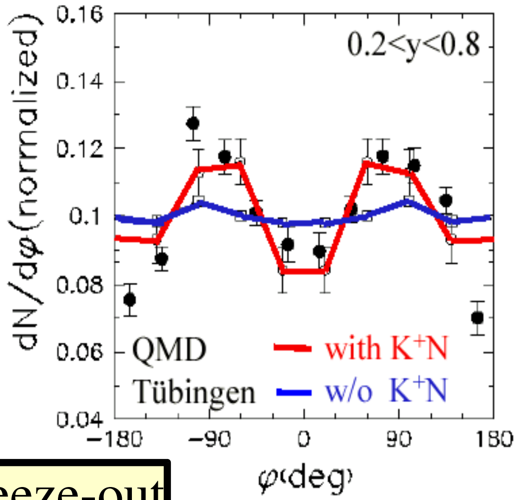
Y. Shin et al., PRL 81 (1998) 1576

G.Q.Li et al., PLB 381 (1996)

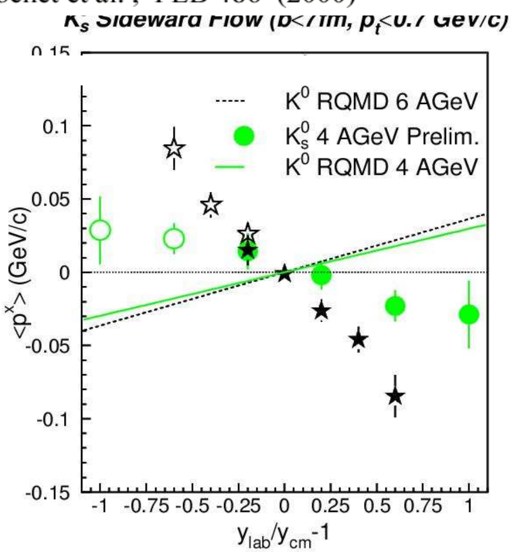


Squeeze-out

Z.S. Wang et al., EPJ A5 (1999) 275



P. Crochet et al. , PLB 486 (2000)



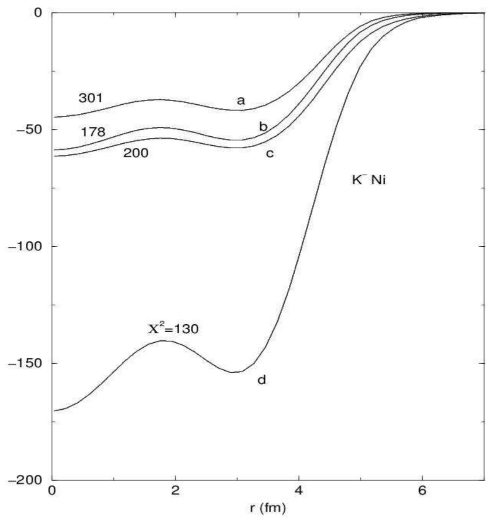
E895

Anti-Kaons
An interesting but complicated Story

Attractive Anti-Kaon potential may result in (Anti)Kaon-condensation in neutron stars
(Nelson, Kaplan; Brown, Prakash et al.)

However:
Neutron Stars and Kaonic atoms probe optical potential at T=0, p=0

Heavy ions: T > 0, p>0



Kaonic Atoms
Gal et al.

Can we extrapolate?

Kaonic atoms and Anti-Kaon Nucleon Scattering

Anti-K – Nucleon scattering:

Isospin=0: A_0= (-1.70 + I 0.68) fm repulsive

Isospin=1: A_1= (0.37 + I 0.60) fm attractive

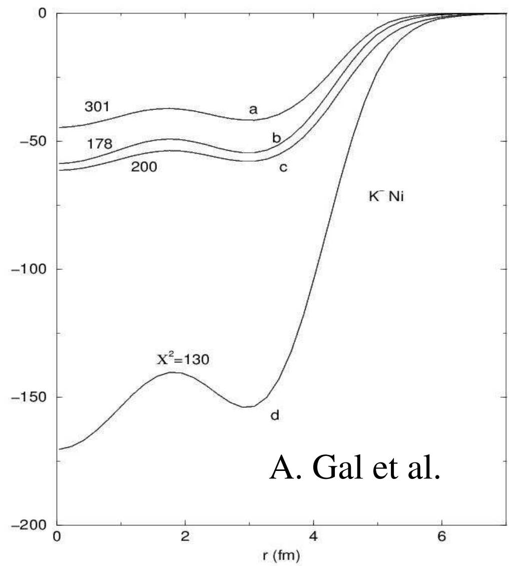
Isospin average: A = (-0.15 + I 0.62) fm repulsive

(Martin, 1980)

Chiral model: attractive?!

Kaonic Atoms:

Obviously attractive !?!

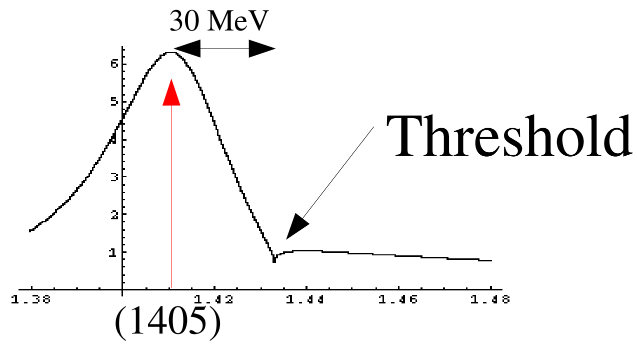


A. Gal et al.

Obviously impulse approximation does not work even at small densities

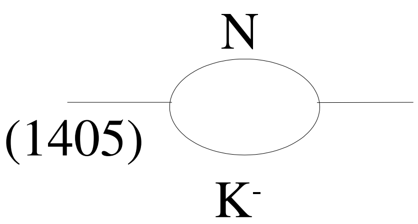
Coupled channels, Pauli Blocking etc.

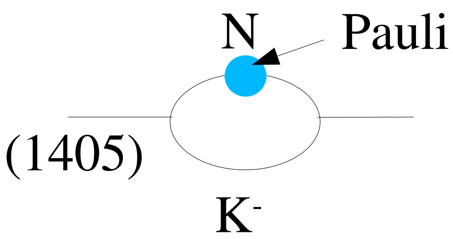
Presence of Lambda(1405) leads to repulsion in scattering amplitude



Analogy: p+n scatting in the deuteron channel

Hypothesis: If (1405) is weakly bound Anti-K – nucleon state, then it should dissolve in matter (Pauli blocking) and underlying attractive interaction appears
(V.K. 1994)





Coupled channels, Pauli Blocking etc.

Lambda(1405): Coupled channels!
Many refinements:

- chiral dynamics (Waas et al.)
- Self consistent (Lutz et al.; Oset et al.)
- many more resonances (Lutz et al.)
- Juelich potential (Tolos et al.)
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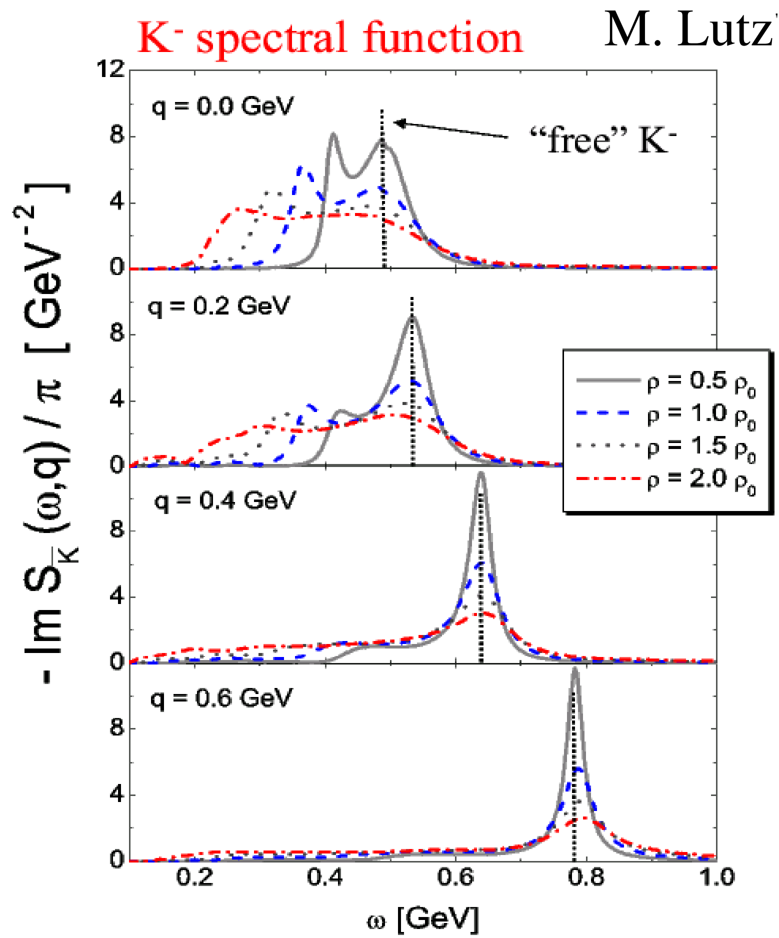
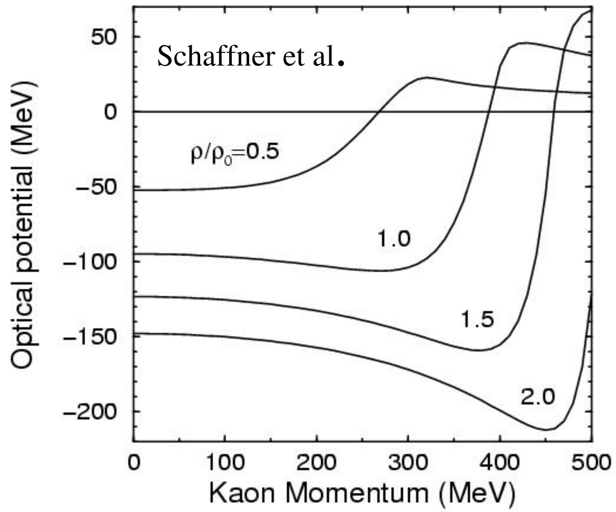
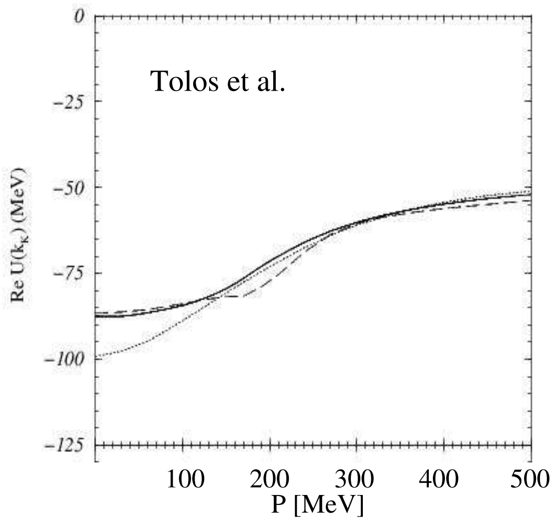
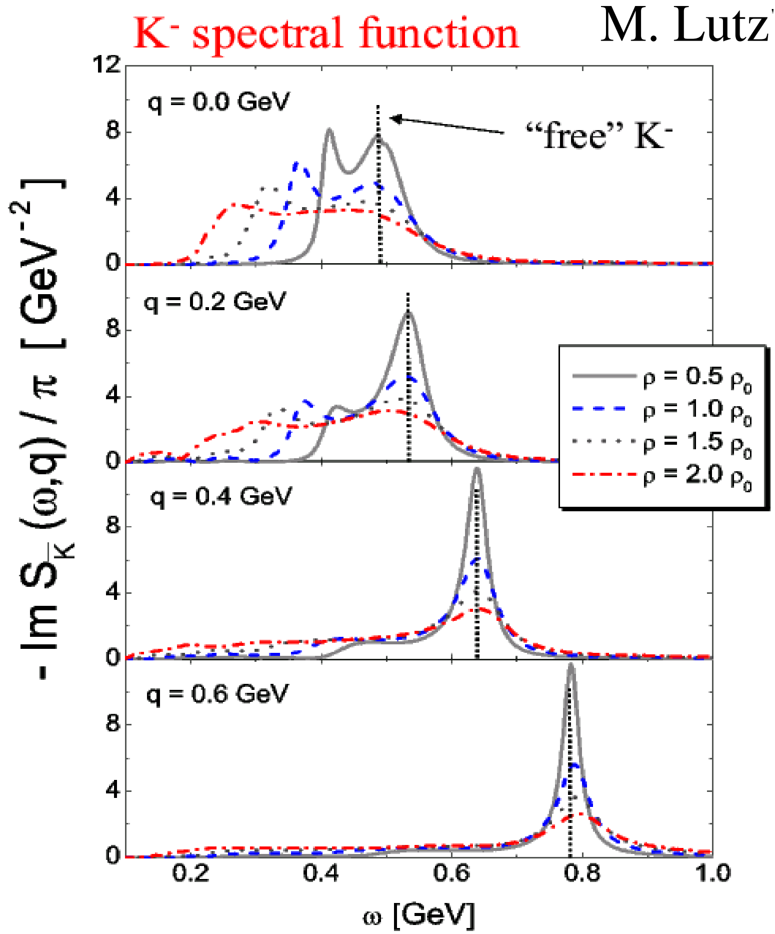


Momentum dependence

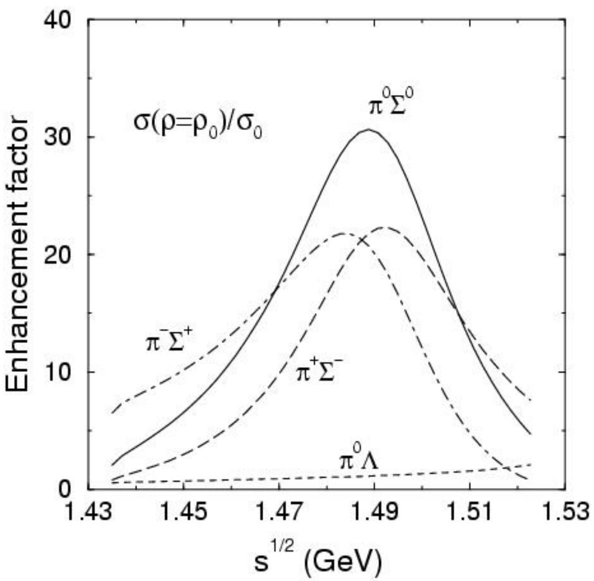




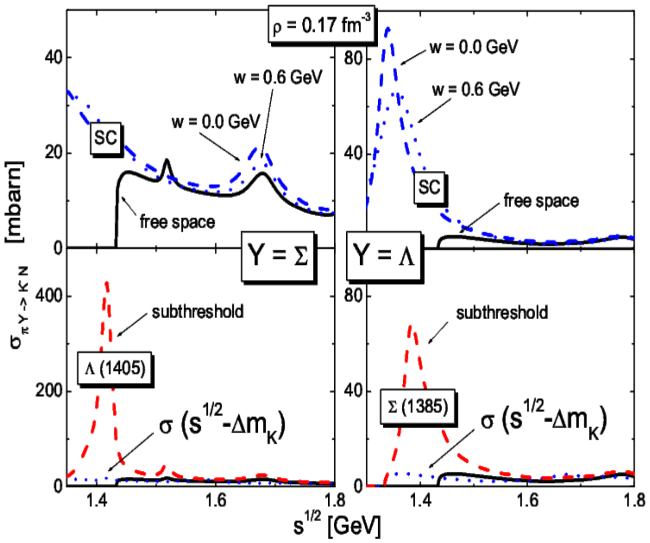


Cross Sections

In medium shifts/modifications of resonances induce changes in cross sections !



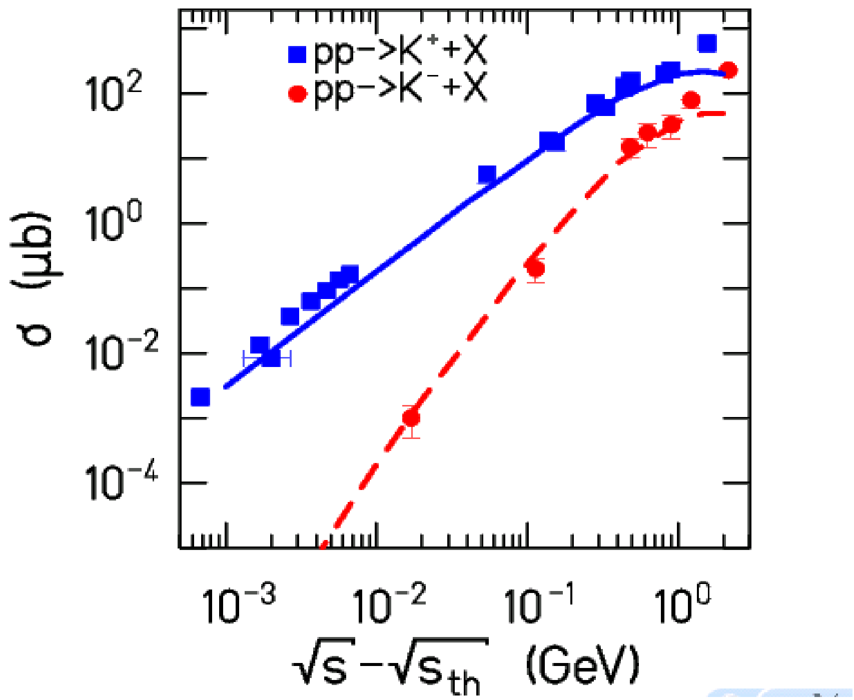
Schaffner et al. (2000)

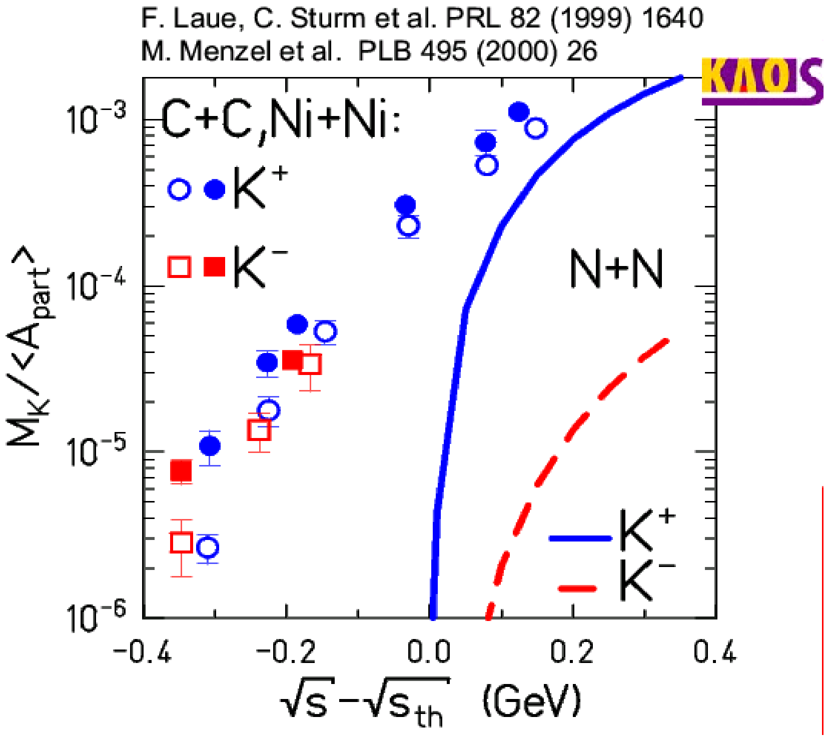


Lutz (2003)

A mean field description for the
interactions of
Anti-Kaons
may be too simplistic

Heavy Ion reactions





KAOS Collaboration

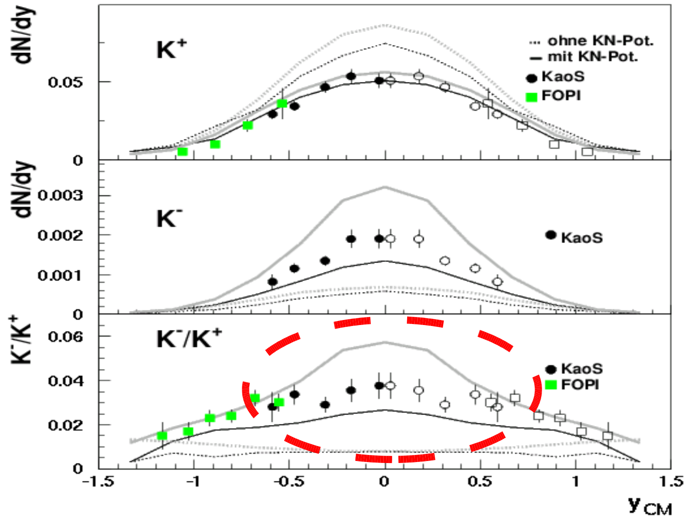
Theoretical interpretations

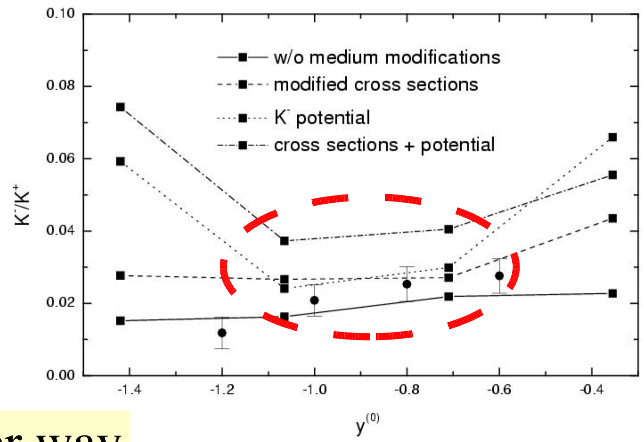
The "old story":
Attractive Anti-kaon potential increases yield

Cassing et al: 200-300% effect
similar to Ko et al.

However:
Does not work in
all transport models

Schaffner et. al.: 50 % effect
similar to Aichelin et al.

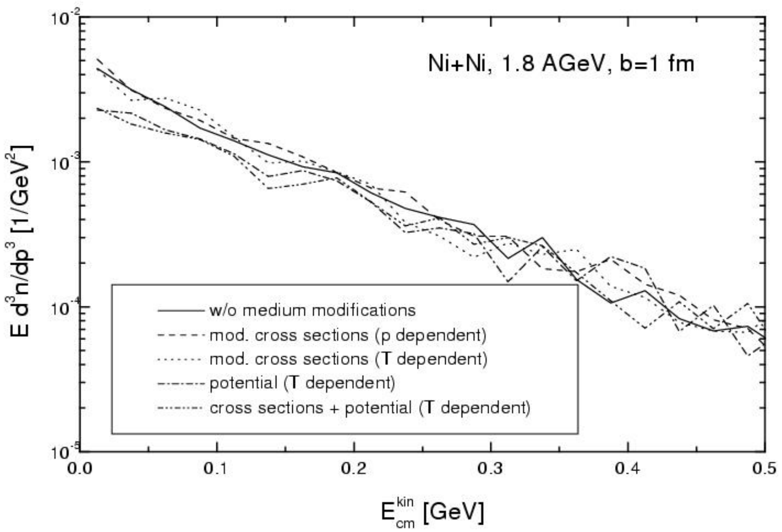




J. Aichelin: resolution under way

So what is going on?

Schaffner et al. (2000)

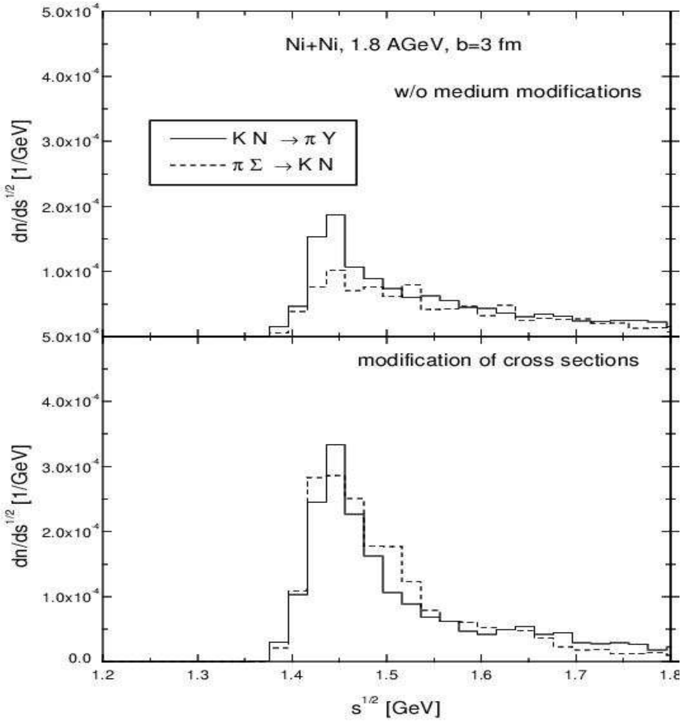


Apparently none of the in medium effects makes much of a difference!

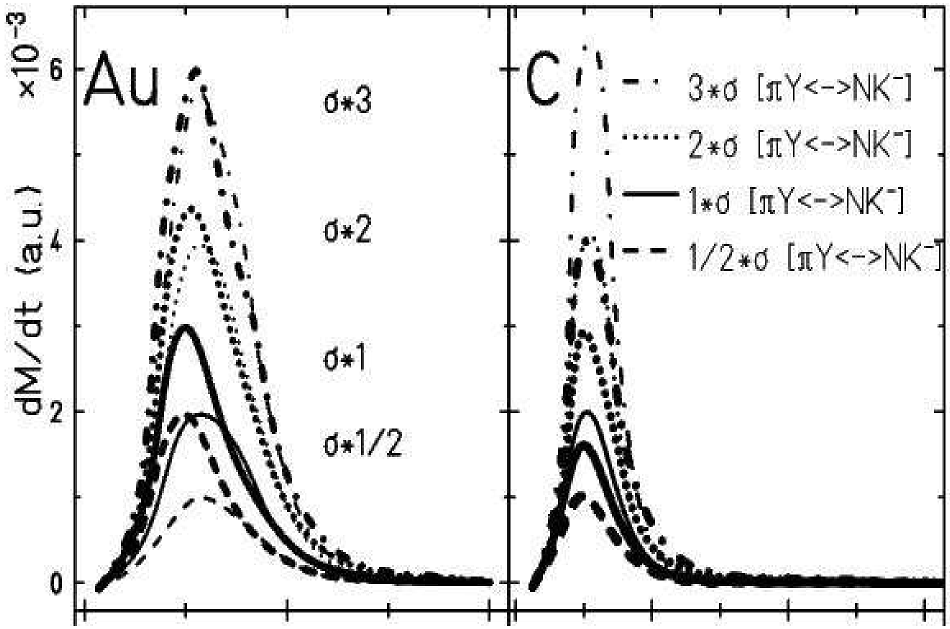
Equilibrium??????

Equilibrium?

Schaffner et al. (2000)



Hartnack et al, PRL in print



K^-+N ↔ + Y almost in balance!

Close to RELATIVE chemical equilibrium
between K^- and Y
even with normal cross sections

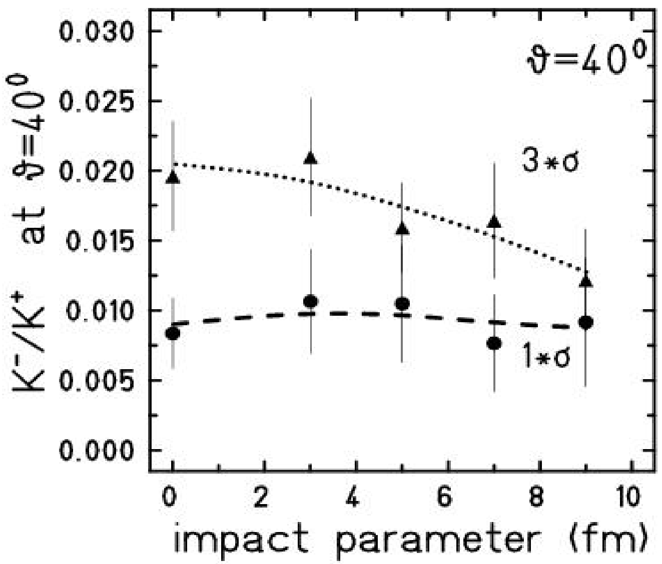
A simple picture

(H. Oeschler, Strangeness 2000)

1) Strangeness conservation: $N(Y) = N(K^+)$

2) Fast reaction $K^- + N \leftrightarrow \pi + Y$: $N(K^-)$ determined by $N(Y)$

3) $N(Y) \gg N(K^-)$: K^+ / K^- determined

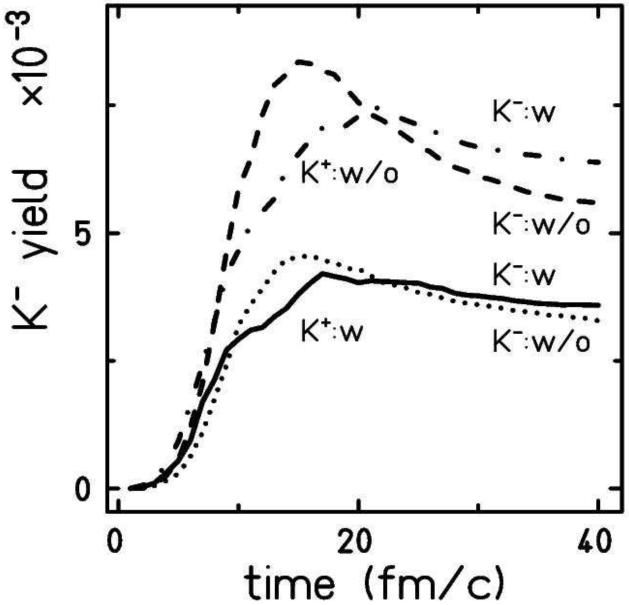


Hartnack et al., PRL in print

An amusing consequence

Anti- Kaon yield is determined by in medium effects on KAONS

Hartnack et al, PRL in print



Needed: more simple systems!

Anti-Kaon in medium is an interesting story

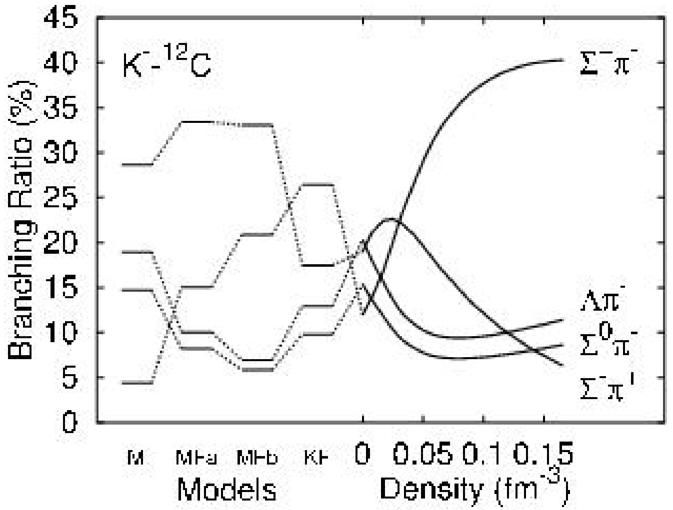
- In medium effects are there (Kaonic atoms)
- Relative “simple” many body problem
- coupled channels
- Nature of resonances (quark or bound state)
-
-

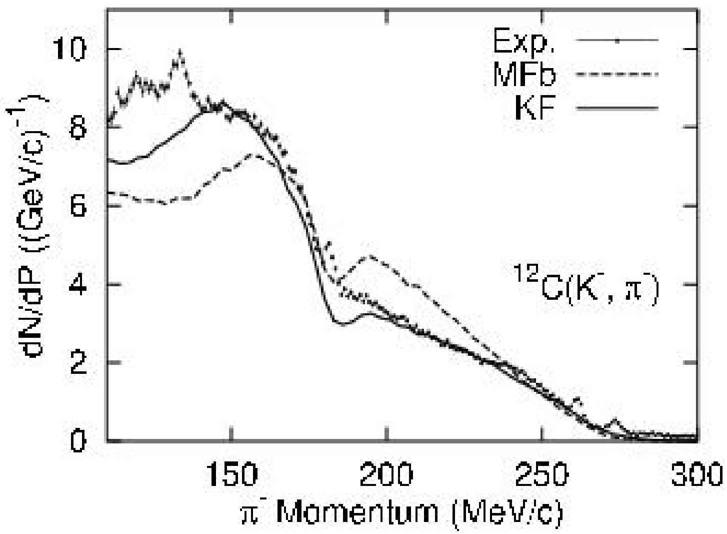
Heavy ions probably not the right place to make progress!

- K^-+N: resonance vs. background
- K^-+A: should reveal already many of the interesting effects

Example: stopped kaons

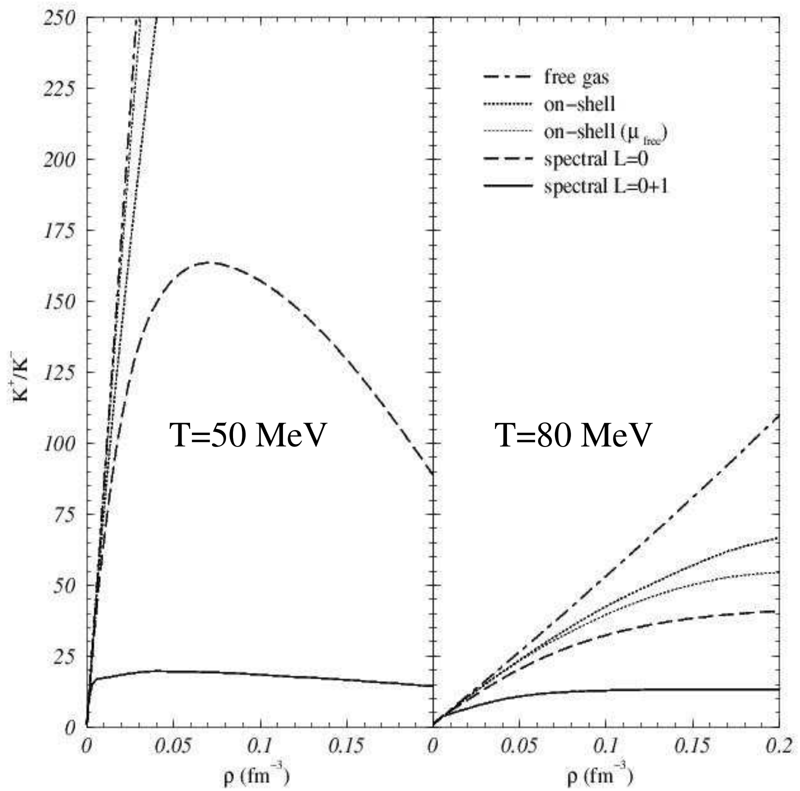
(Ohnishi et al, 1997)





Medium changes branching ratio of Hyperon (Sigma) decay

Equilibrium (Anti Kaons)



Tolos et al. (2003)

In medium spectral functions affect ratios

But is that what we measure?

Un-mixing of modes during expansion!

Strangeness and the QGP

- More strange quanta in a Quark Gluon Plasma (QGP) than in a hadron gas (HG)
- Equilibration time shorter in QGP than in hadron gas
  - gluon fussion
  - lower threshold

Strangeness enhancement as signal for QGP
(in particular strange ANTI-baryons)

Some definitions

- “strangeness” = strange + anti-strange
- “strangness suppression factor” $_s$

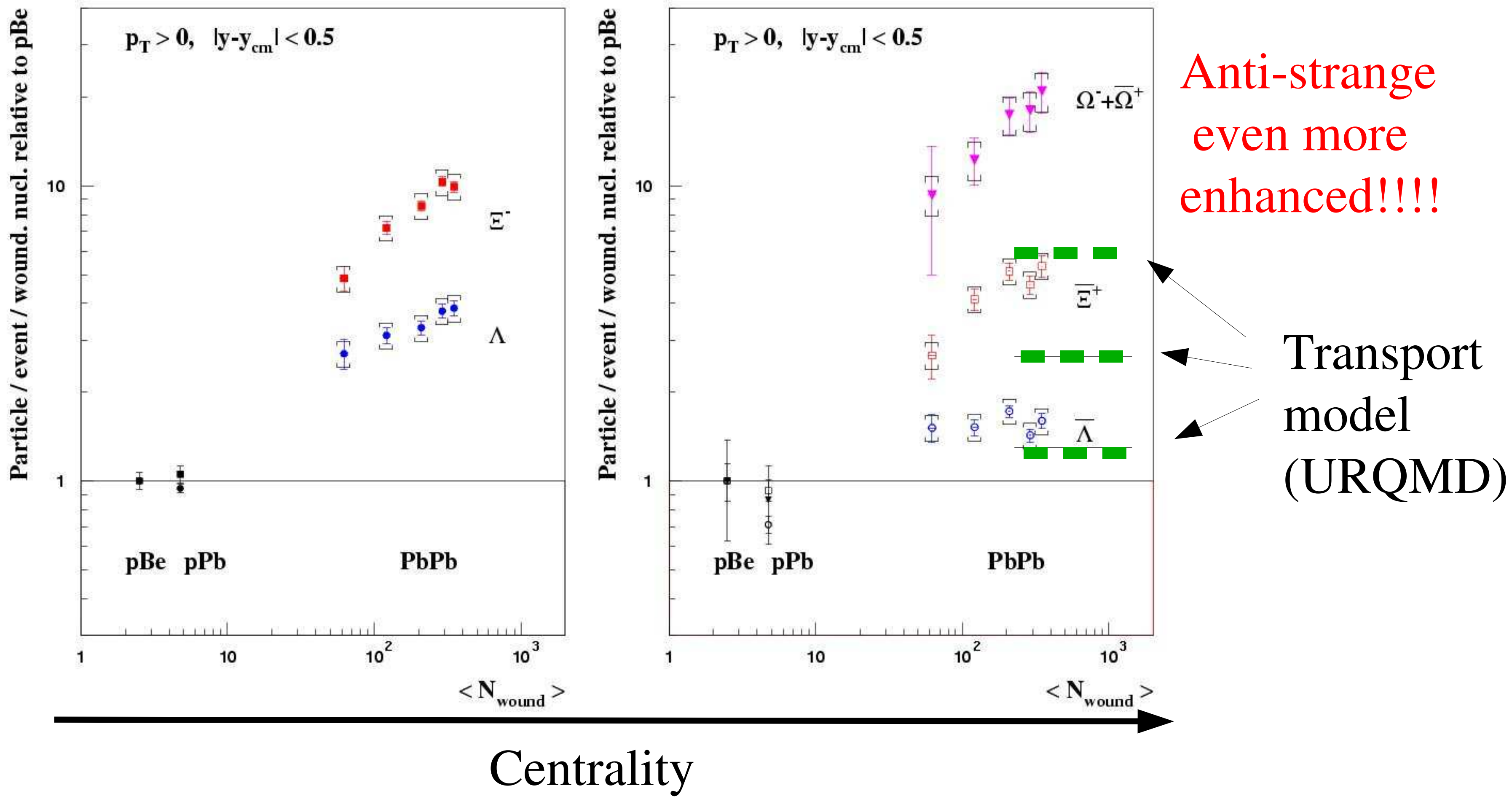
$$N_K = \gamma_s \int d^3 p \ \exp(-\beta(E_k + \mu_s))$$
$$N_\Lambda = \gamma_s \int d^3 p \ \exp(-\beta(E_\Lambda - \mu_s - \mu_B))$$

$_s > 1$ Strangeness enhancement

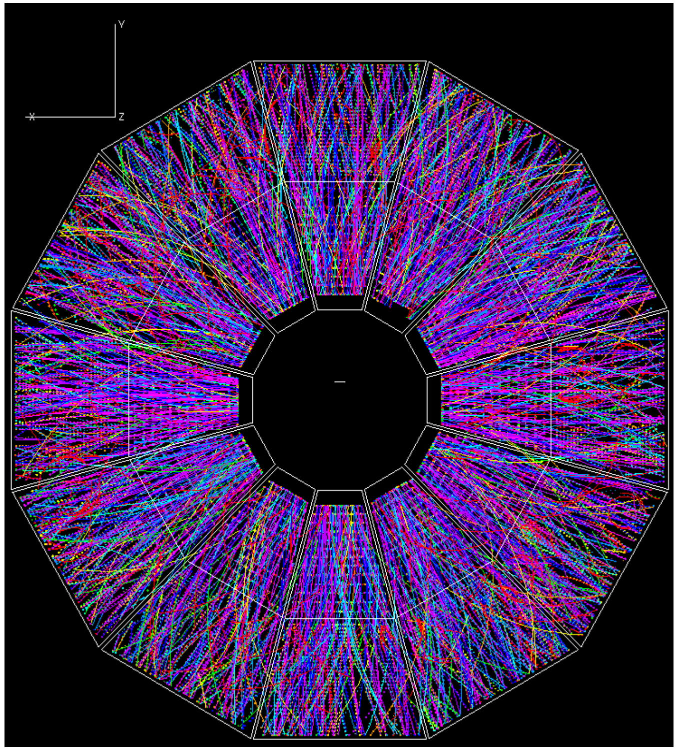
- “Wroblewski”-factor = (strange quarks)/(light quarks)

Strangeness enhancement?

NA57



Statistical approach



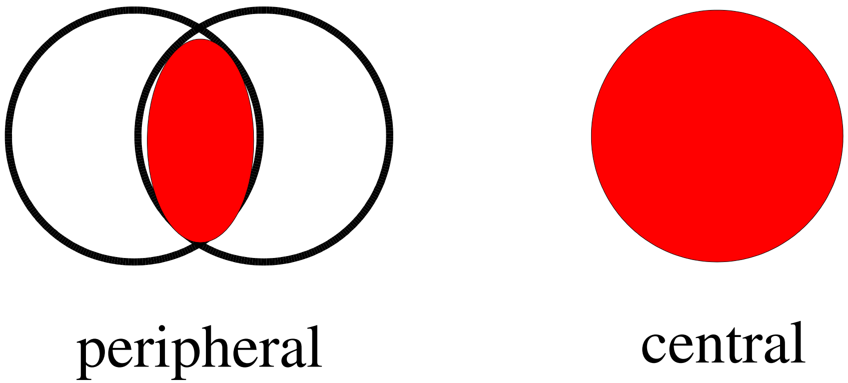
Au+Au

(STAR)

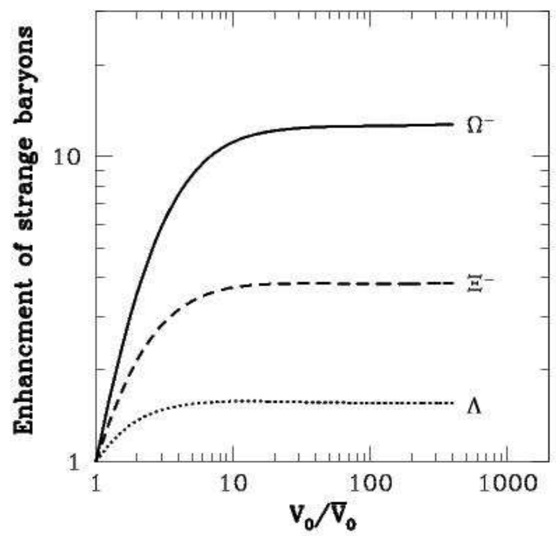
One simple explanation

Canonical "suppression" (Redlich et al)

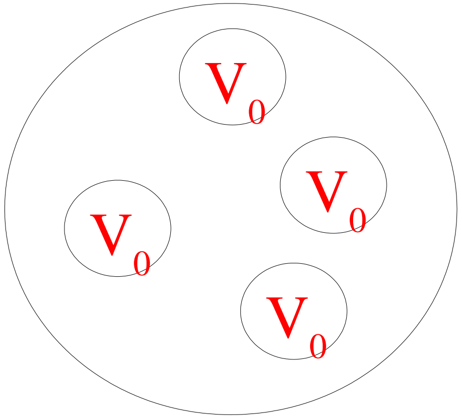
Explicit Strangeness conservation relevant for small systems



Redlich et al.



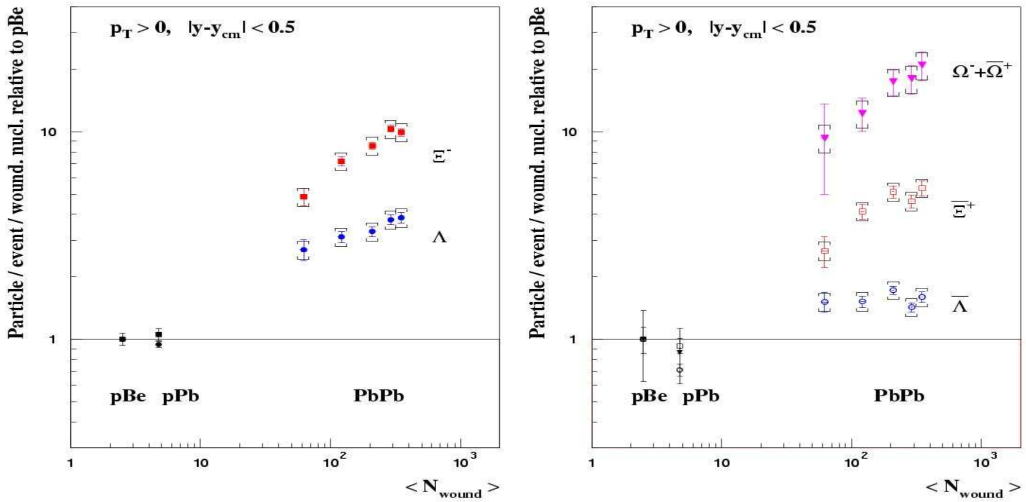
Strangeness equilibrium at SPS ?

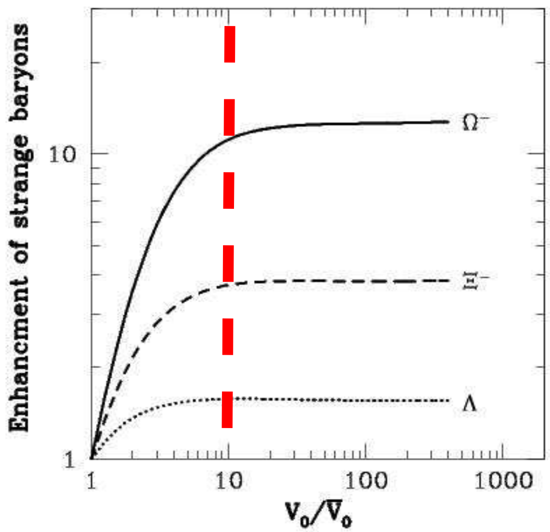


Canonical "suppression"
i.e. for small system strangeness conservation becomes relevant

Redlich et al.

NA57





A simple observation

(Leupold & Greiner)

Strange Anti-baryon production is FAST

Key channel: Multi-particle collisions

annihilation of anti-omega should have large cross section

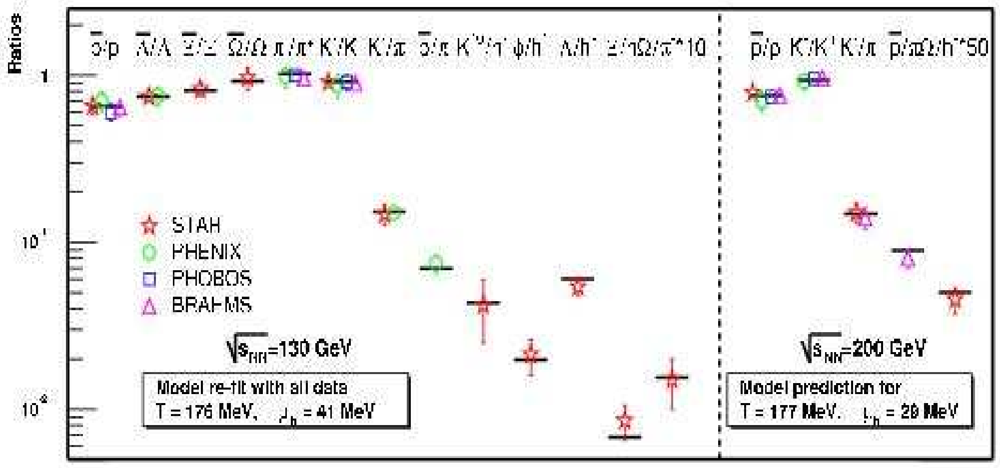
matrix element $M\left(\bar{\Omega}+N\rightarrow 3K^{-}+x\pi\right)$ is large

➡ inverse reaction should be fast as well due to detailed balance (phase-space just given by energy-conservation)

Leupold + Greiner estimate: = 1-2 fm

The end of a nice idea?

RHIC



$_s = 1$

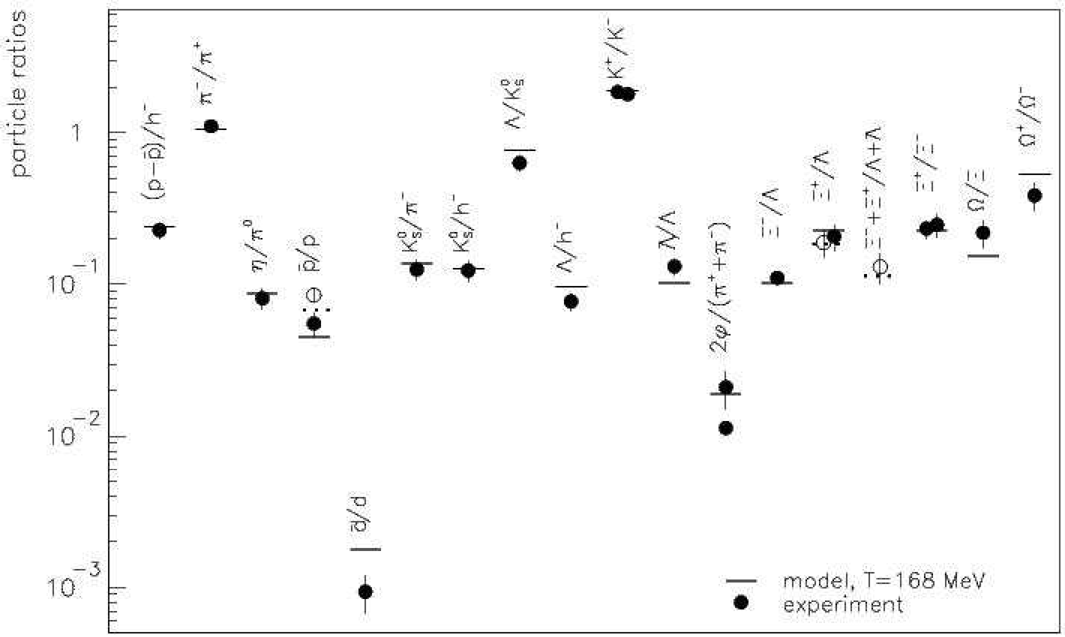
NOTE: $_s$=1 corresponds to a hadron gas in equilibrium

If QGP then $_s$ >1

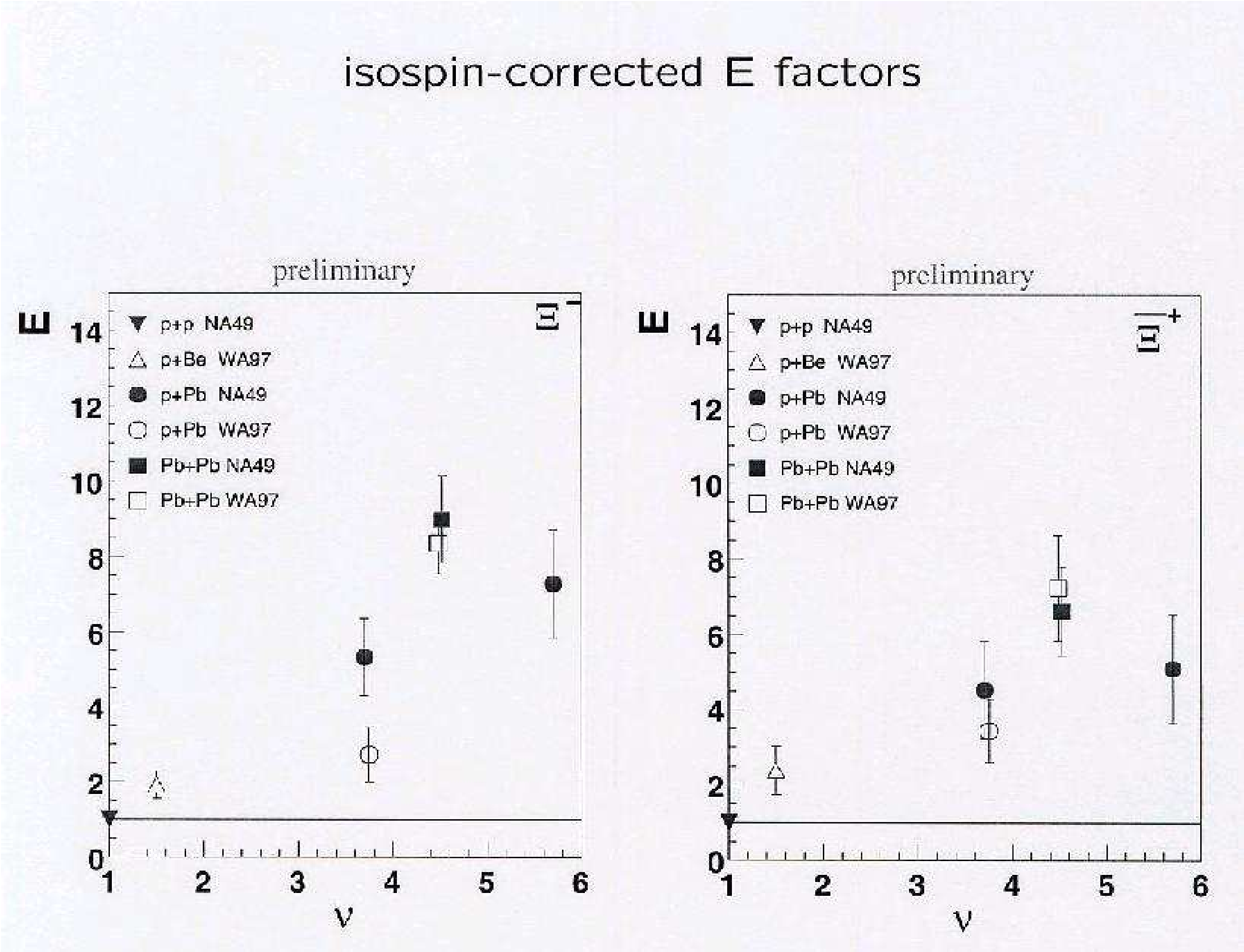
The end of a nice idea?

CERN SPS

$_s = 1$



Furthermore...



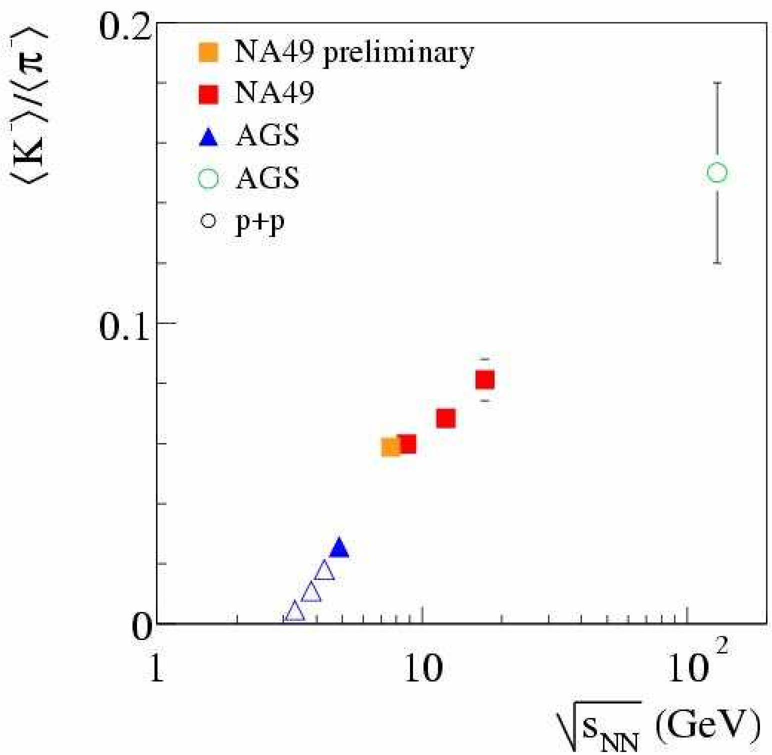
A. Rybicki (NA49)
SQM 2003

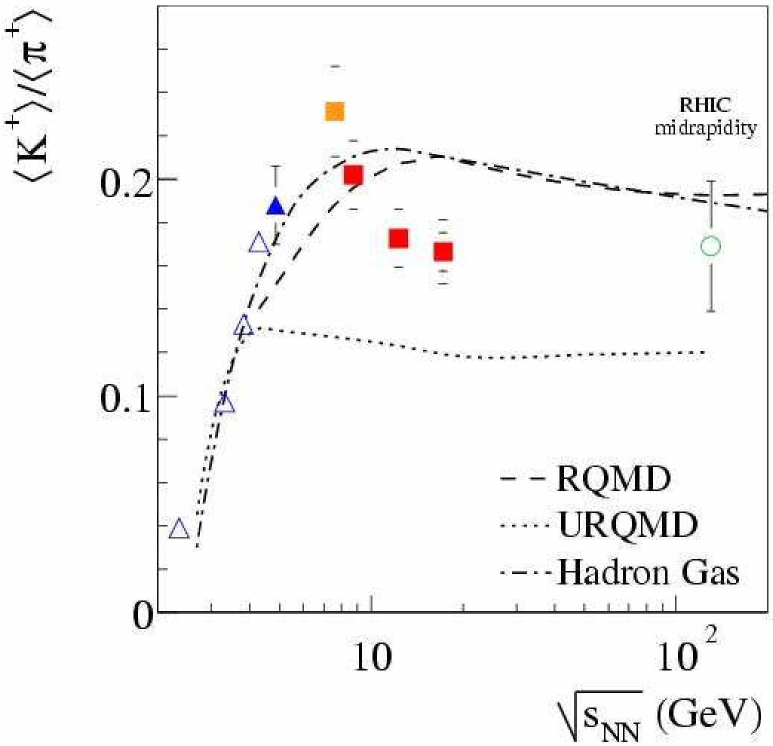
No difference between pA and AA

Not quite yet

NA49 has measured the
excitation function for
kaon production form (20) 30 -158 AGEV

Energy Dependence : Total K/π Ratios



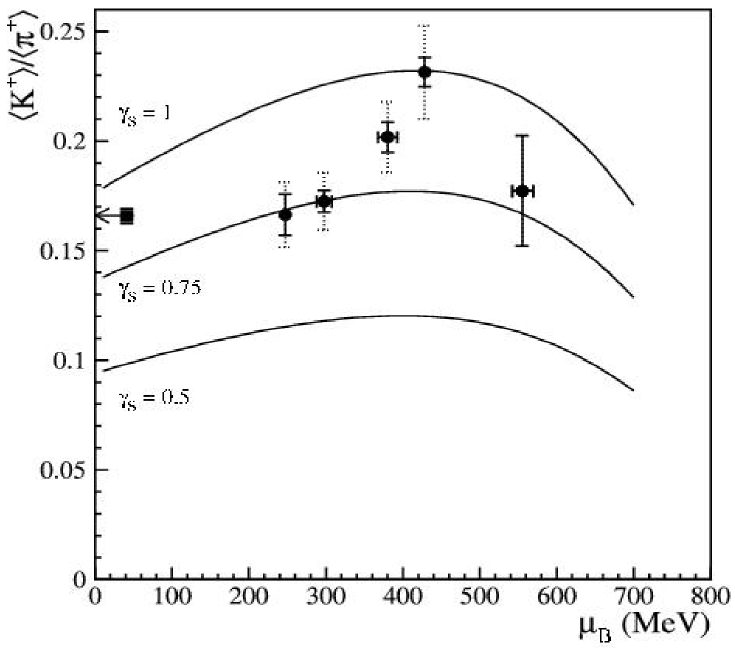


Sharp maximum for K^+/π^+ !

Indication for kink structure also for K^-/π^- ?

Thermal model

(Becattini et al)



Thermal model cannot describe data!
Here jump in $_s$ is needed

Isospin effect?
(A. Rybicki)

Other aspects

- Strange particles should have different cross sections in a pion gas
  - characterize the expansion dynamics
- Strange particles subject to additional conservation law
  - check on equilibrium
- Heavy ions are nice resonance factories -> Pentaquark??

Summary

- Equilibrium seems to dominate "simple" Heavy Ion observables!

- Low energies:
  - Kaon dynamics a perfect playground to study the symmetry breaking patterns in QCD
  - Anti-Kaon in matter: In medium modifications should be there!
    - But have we seen them in HI data?
  - Kaons in HI are "understood" and consistent with simpler systems
  - Kaons support notion of "soft equation of state"

- High energies:
  - No obvious strangeness enhancement
  - Rather interesting structure in excitation function of K/
  - Strangeness serves as tool to further characterize events

Outlook

- Anti-Kaon story needs to be fully settled
  - Transport
  - Measure simpler systems K^-+N, K^-+A
- Chance to pin down equilibrium question!
  - Kaon pairs
  - Omega pairs (up to SPS energies)
- The Phi!
- The "bump"