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STRANGENESS PRODUCTION
Lessons from IQMD
or
A strange mixture of something old, something new and something borrowed

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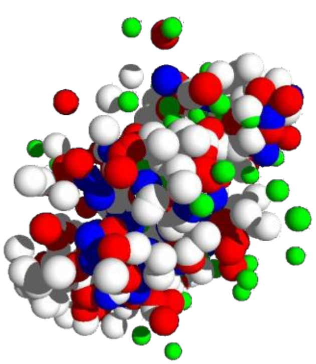
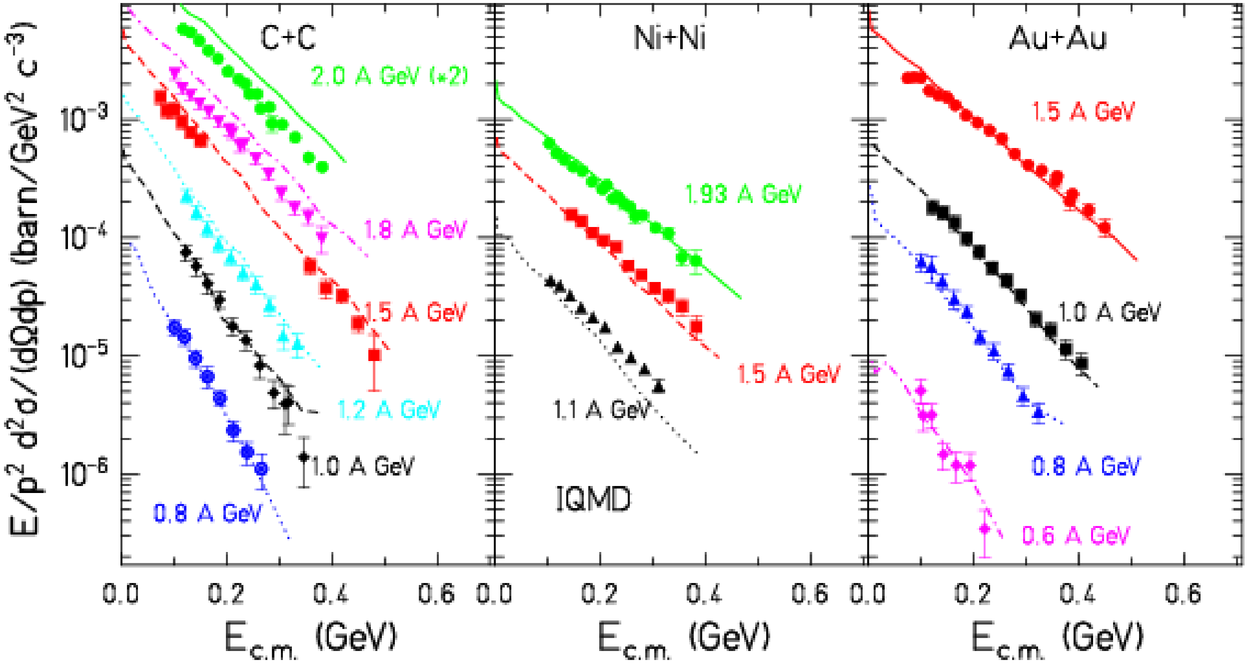


Outline

- Strangeness production in IQMD
- Some « wellknown » results
  - Mdi, eos, rescattering, strangeness echange
- And if we scaled our cross sections ?
- K-/K+   - thermal behaviour or law of mass action ?
- π/A – a happy coincidence ?
- How to get the Φ into the game ?
- K- and Φ
- Conclusion



Our tool: IQMD

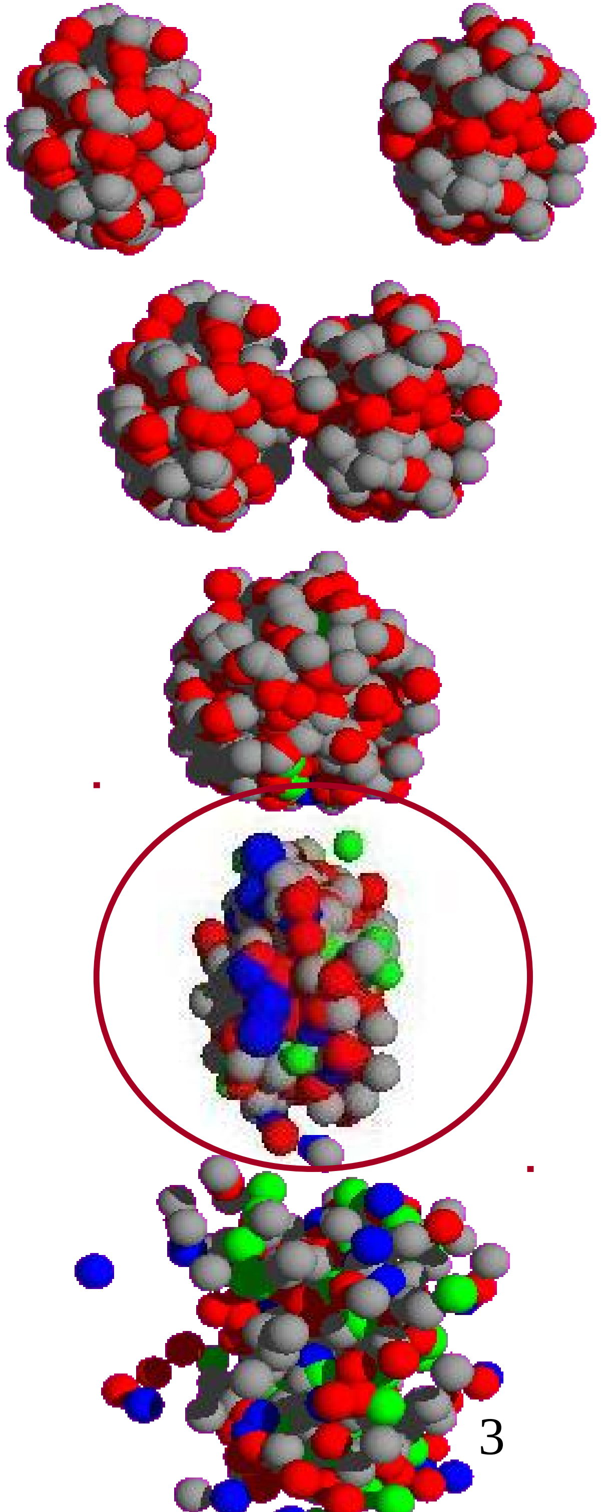
Isospin-Quantum Molecular Dynamics model

- **Semiclassical dynamical N-body model with quantum features based on 2 body interactions**

- **Microscopic calculation of heavy ion collisions on an event-by-event-basis**

- **includes N, Δ, π with isospin d.o.f.**

- **strange particles treated virtually**



Allows for a « photo » of the high density phase and for a look inside …

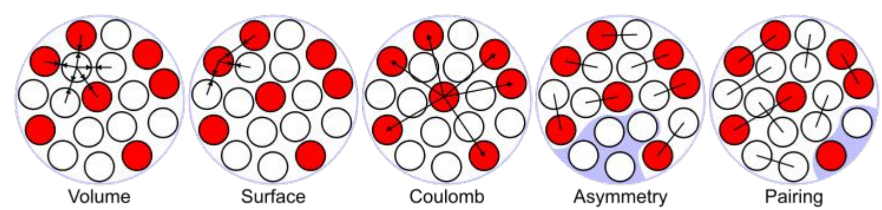
Definition of the potentials

2 body interactions **(no equilibrium required)**

$$
\begin{aligned}
V^{ij} &= G^{ij} + V^{ij}_{\mathrm{Coul}} \\
&= V^{ij}_{\mathrm{Skyrme}} + V^{ij}_{\mathrm{Yuk}} + V^{ij}_{\mathrm{mdi}} + V^{ij}_{\mathrm{Coul}} + V^{ij}_{sym} \\
&= t_1\delta(\vec{x}_i - \vec{x}_j) + t_2\delta(\vec{x}_i - \vec{x}_j)\rho^{\gamma-1}(\vec{x}_i) + t_3\frac{\exp\{-|\vec{x}_i - \vec{x}_j|/\mu\}}{|\vec{x}_i - \vec{x}_j|/\mu} + \\
&\quad t_4 \ln^2(1 + t_5(\vec{p}_i - \vec{p}_j)^2)\delta(\vec{x}_i - \vec{x}_j) + \frac{Z_i Z_j e^2}{|\vec{x}_i - \vec{x}_j|} + \\
&\quad t_6 \frac{1}{\varrho_0} T_3^i T_3^j \delta(\vec{r}_i - \vec{r}_j)
\end{aligned}
$$

Λ:Only Skyrme *2/3

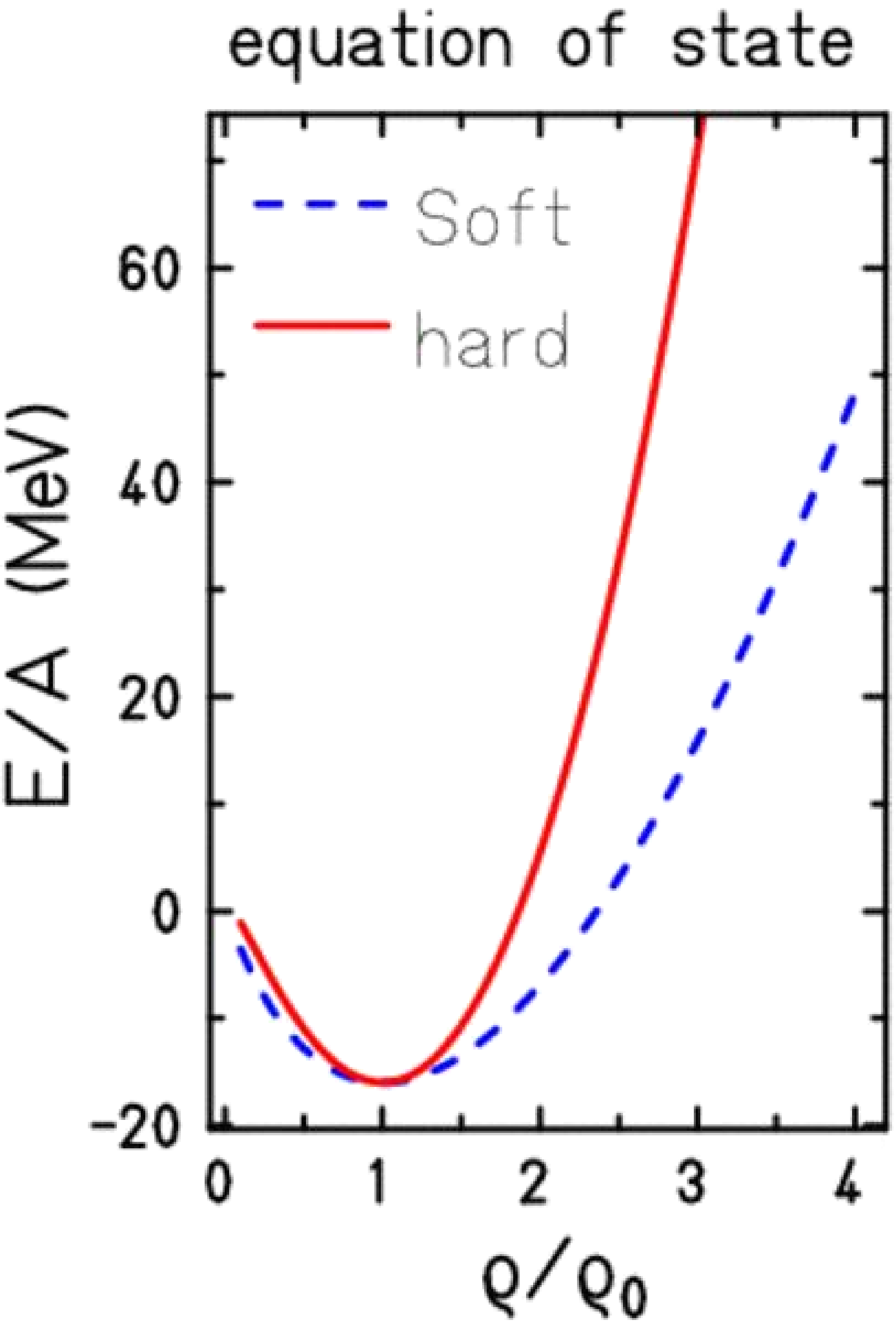
Bethe Weizsaecker –mass formula:



Volume term **+Surface term** **+Coulomb term** **+symmetry term**

(nucl. eos) **(+pairing term not included in dynamics)** **(asy- eos)**

The static part (our «eos») : Skyrme



$$U = \alpha \cdot \left(\frac{\rho_{int}}{\rho_0}\right) + \beta \cdot \left(\frac{\rho_{int}}{\rho_0}\right)^{\gamma}$$

3 parameters, 2 ground state condit.

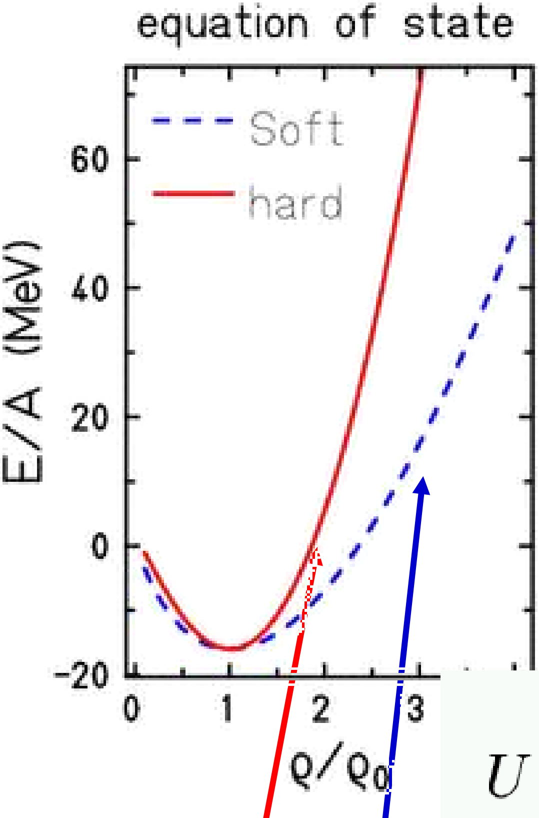
1 remaining d.o.f.: compression mod.

Artificial link between curverture at ground state and high density behaviour.

Compression modulus K>170 MeV

Problems of causality for high densities $\rho > 5\text{-}7\ \rho_0$

Caution when extrapolating to high densities



The eos in IQMD

after the convolution of the Skyrme type potentials supplemented by momentum dependent interactions (mdi) for infinite saturated nuclear matter at equilibrium

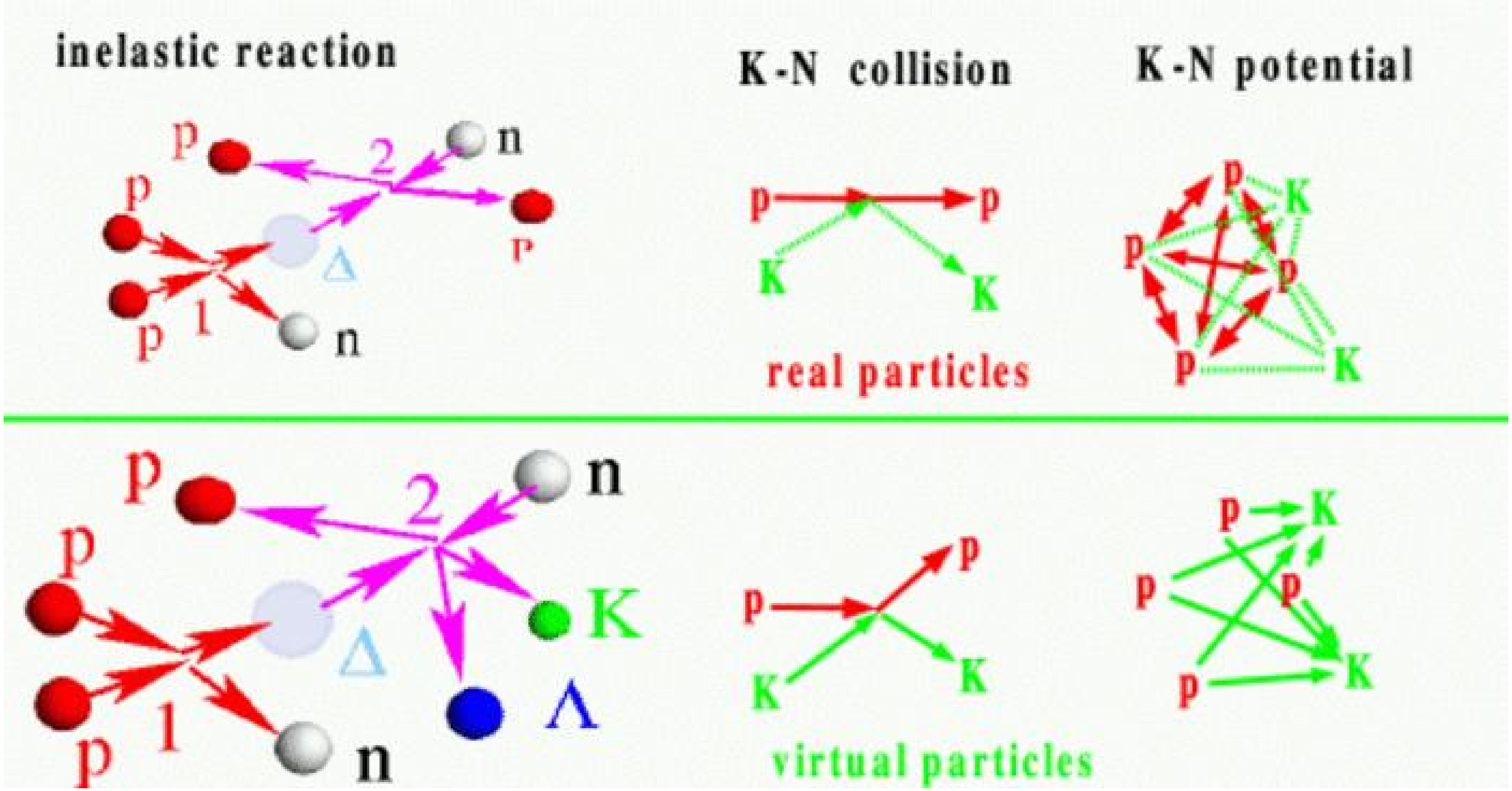
$$U = \alpha \cdot \left(\frac{\rho_{int}}{\rho_0}\right) + \beta \cdot \left(\frac{\rho_{int}}{\rho_0}\right)^{\gamma} + \delta \cdot \ln^2\left(\varepsilon \cdot (\Delta\vec{p})^2 + 1\right) \cdot \left(\frac{\rho_{int}}{\rho_0}\right)$$

	α (MeV)	β (MeV)	γ	δ (MeV)	$\varepsilon\ \left(\frac{c^2}{\mathrm{GeV}^2}\right)$	κ (MeV)
S	-356	303	1.17	—	—	200
SM	-390	320	1.14	1.57	500	200
H	-124	71	2.00	—	—	376
HM	-130	59	2.09	1.57	500	376
INT	-157	103	1.58	—	—	284
VH	-110	56	2.40	—	—	456

soft: S, SM

hard: H, HM

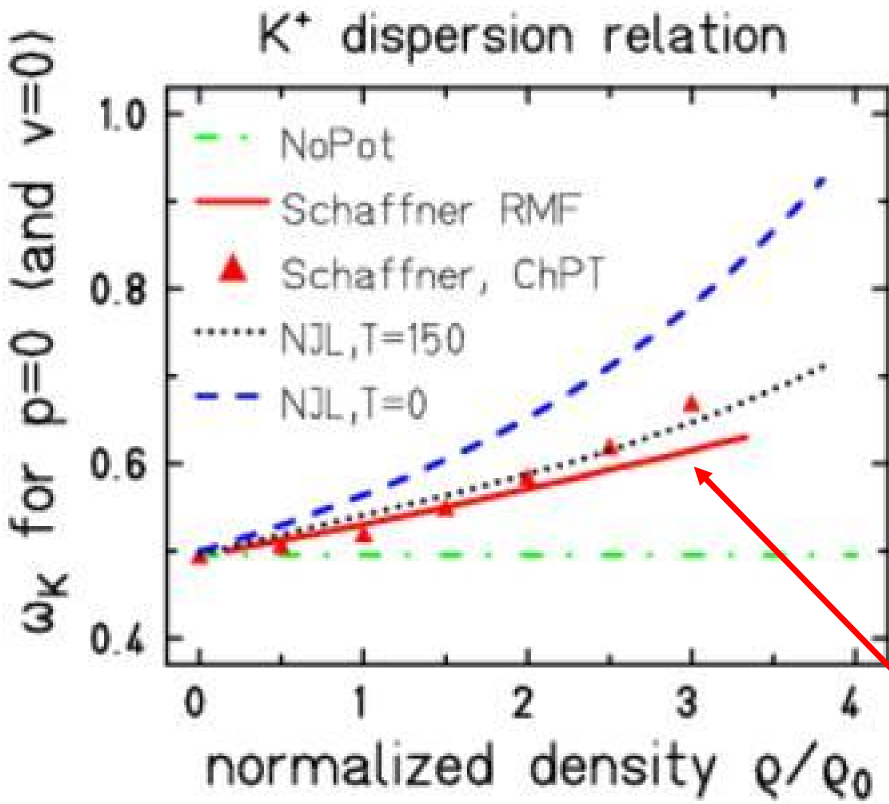
Kaons : « virtual » propagation

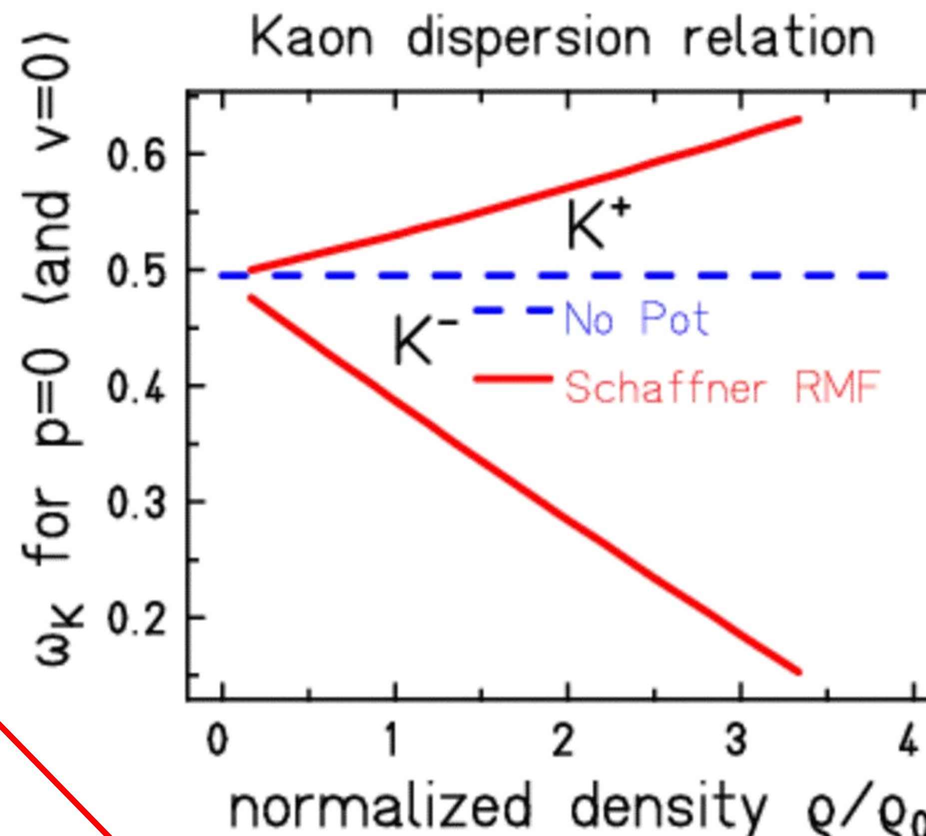


« Real world » particles do not see virtual particles, but

- Virtual particles scatter on real particles
- Virtual particles feel potentials from real particles

Our optical potential for kaons



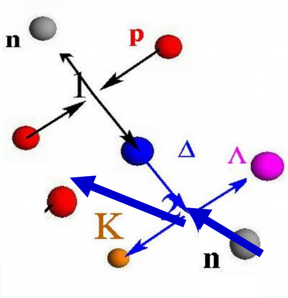


Several parametrizations exist & are implemented

Analogously for K-

Use of Schaffner-Bielich RMF results as standard

$$U_{opt}^K = \sqrt{(\vec{k} - g_v\vec{\Sigma}_v)^2 + m_K^2 + m_K g_s \Sigma_s} + g_v \Sigma_v^0 - \sqrt{k^2 + m_K^2}$$



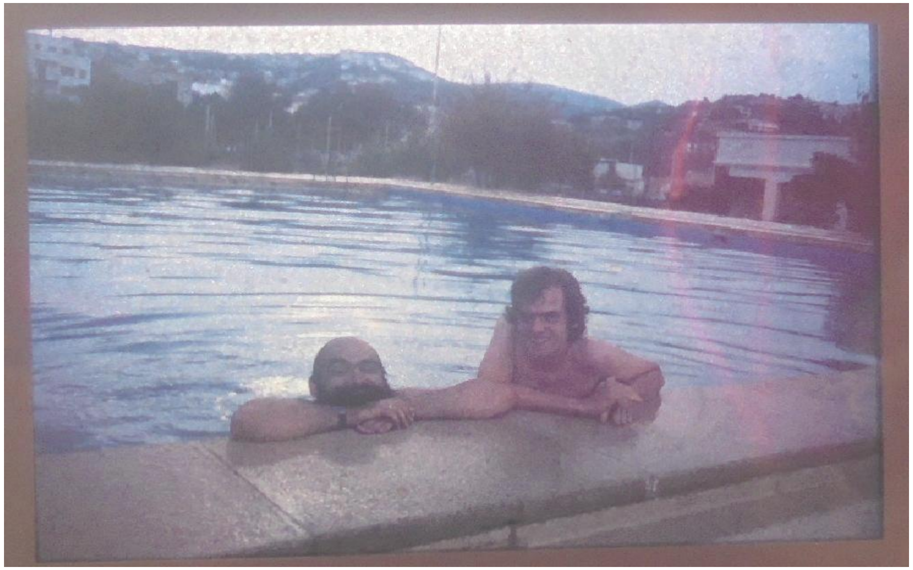
Production channels implemented in IQMD

$NN \to N\Lambda K^+$	$NN \to N\Sigma K^+$	$NN \to \Delta\Lambda K^+$	$NN \to \Delta\Sigma K^+$
$N\Delta \to N\Lambda K^+$	$N\Delta \to N\Sigma K^+$	$N\Delta \to \Delta\Lambda K^+$	$N\Delta \to \Delta\Sigma K^+$
$\Delta\Delta \to N\Lambda K^+$	$\Delta\Delta \to N\Sigma K^+$	$\Delta\Delta \to \Delta\Lambda K^+$	$\Delta\Delta \to \Delta\Sigma K^+$
$\pi N \to \Lambda K^+$	$\pi N \to \Sigma K^+$	$\pi\Delta \to \Lambda K^+$	$\pi\Delta \to \Sigma K^+$
$NN \to NNK^+K^-$	$N\Delta \to NNK^+K^-$	$N\Delta \to N\Delta K^+K^-$	$\Delta\Delta \to NNK^+K^-$
$\Delta\Delta \to \Delta\Delta K^+K^-$	$\pi N \to NK^+K^-$	$\pi\Delta \to NK^+K^-$	

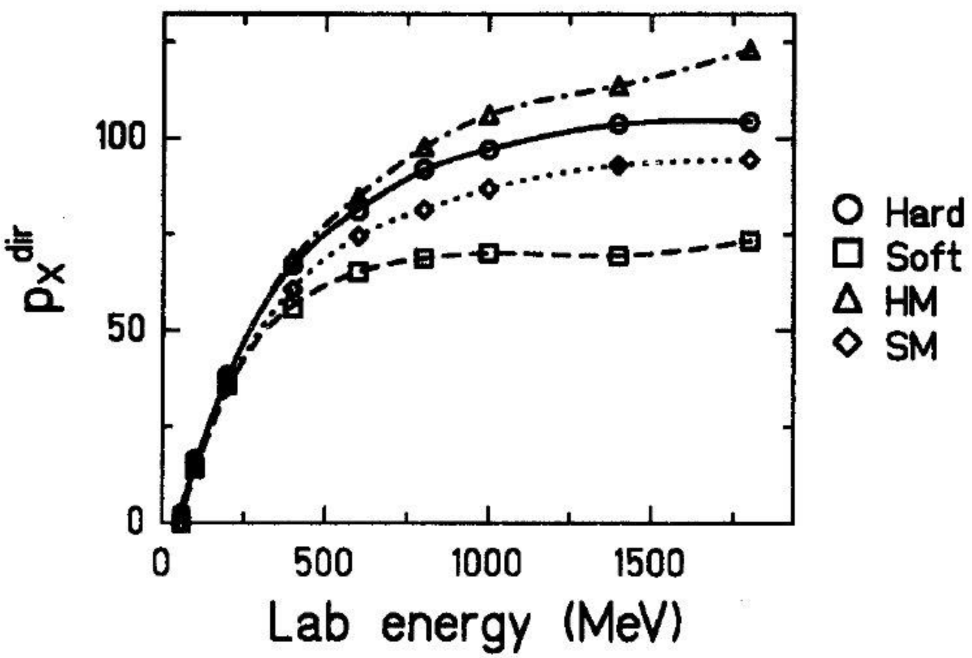
- **Each channel contains isospin subdivisions**
- **Only few channels (like pp→pLK$^+$) are measured by the experiment (even incomplete infos)**
- **Significant incertainties from parametrization of unknown channels or isospin subdivisions**

Lessons, part 1 : very long ago...

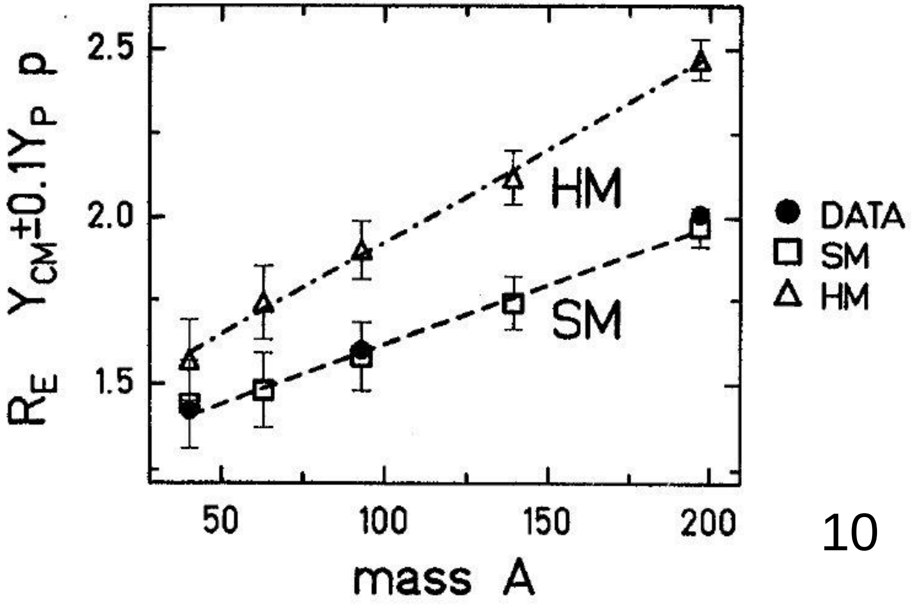
- Equation of state is more than only Skyrme
- You need momentum dependent interactions (mdi) for the correct description of the centrality dependence
- We had to change our vote for the hard eos...



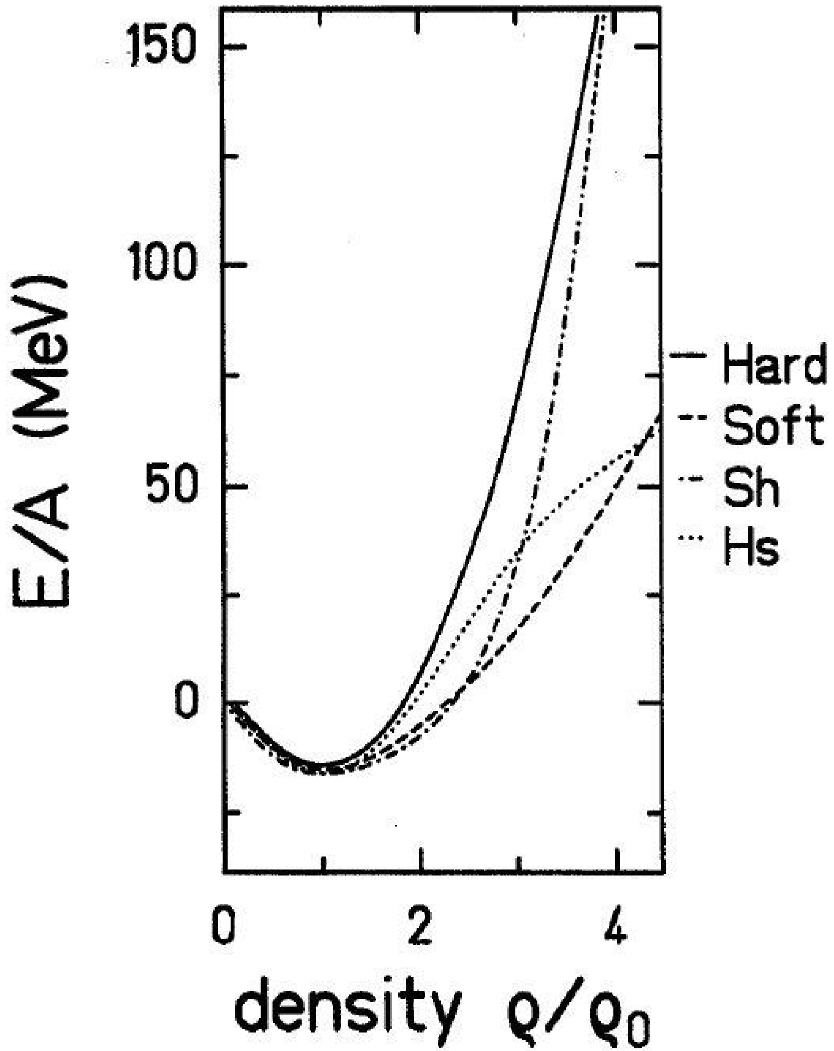
Au+Au b=3fm QMD

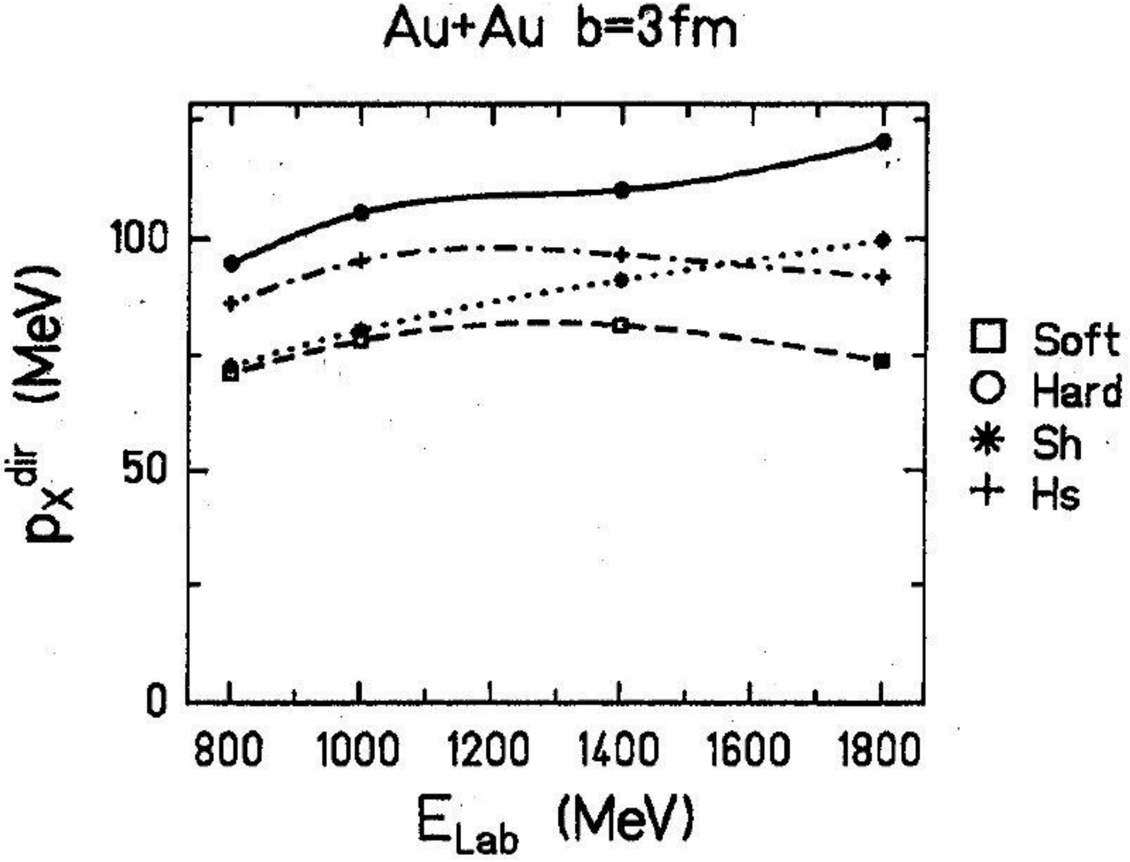


$^AX(400MeV)+^AX$ b = 0.25 b_{max}



Eos : much more is possible





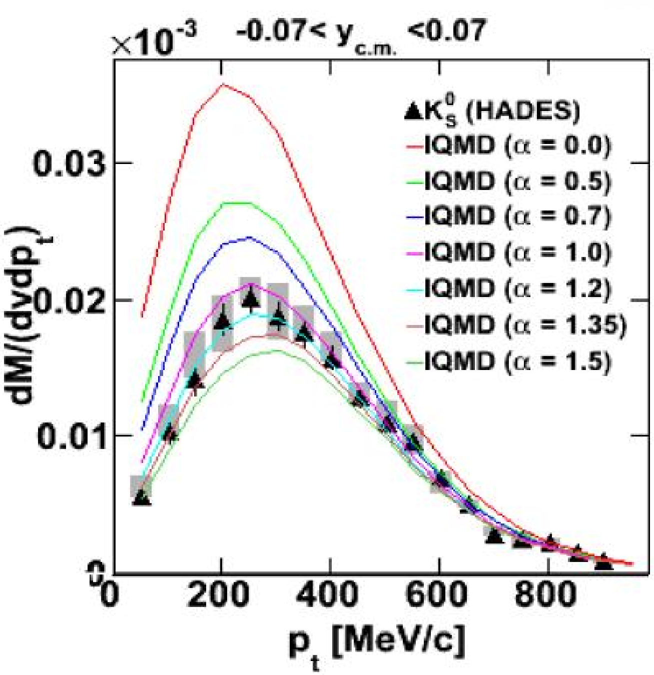
- **The connection of compressibility and high density behaviour is only an artifact of a simple parametrization**

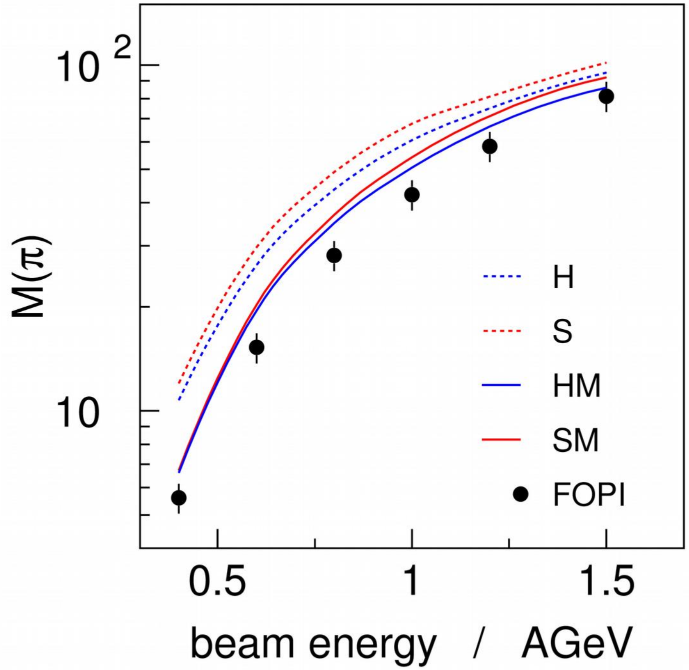
Lessons, part 2 : more recent

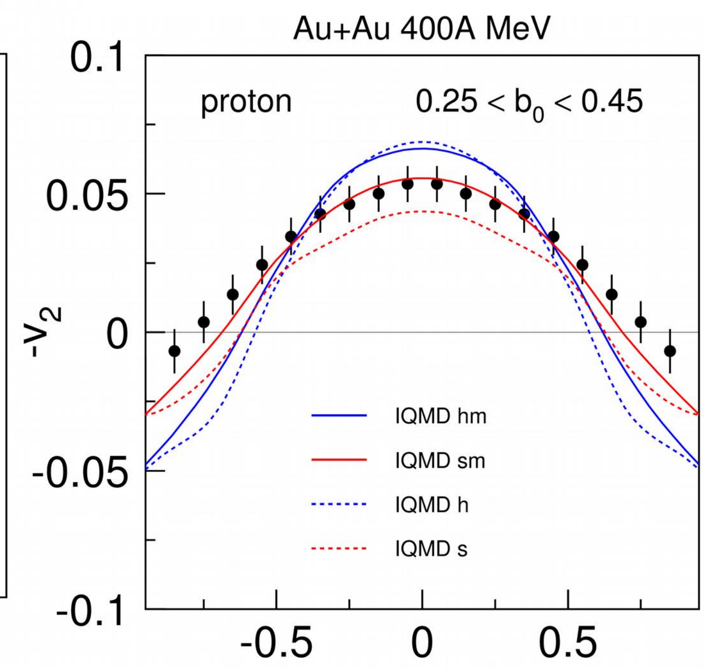
- HADES data indicate KN potential around 40 MeV at ρ_0.
- FOPI pion data can only be explained by IQMD when using mdi
- Need for simulations to explain all important experimental observables (and not only the preferred ones…)
- Need for experiment for good normalisations when calibrating measurements in different areas (e.g. Schnetzer et al.)

A+A	E (AGeV)	Θ_{lab} (deg)	$4\pi \times d\sigma/d\Omega$ (mb)	T (MeV)	Ref.
Ne+NaF	2.0	44	20±10	79±6	[52]
Ne+NaF	2.1	15 - 80	23±8	122	[129]

- KaoS and FOPI data best be explained using a soft eos plus mdi

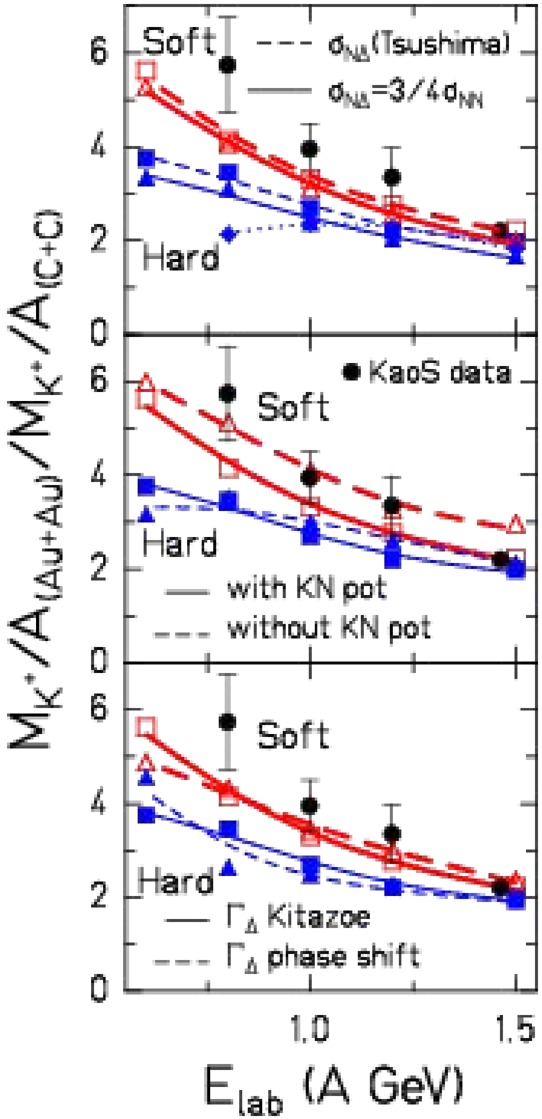


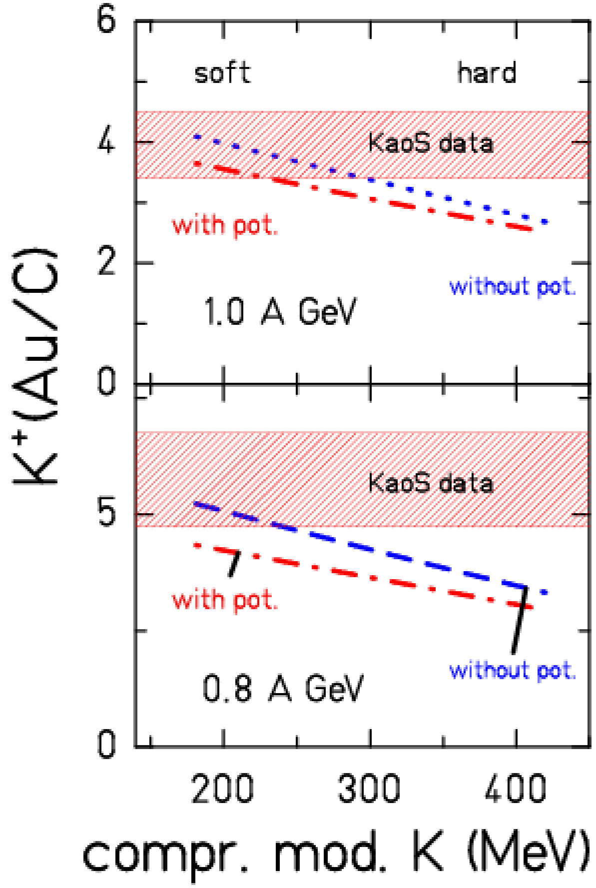


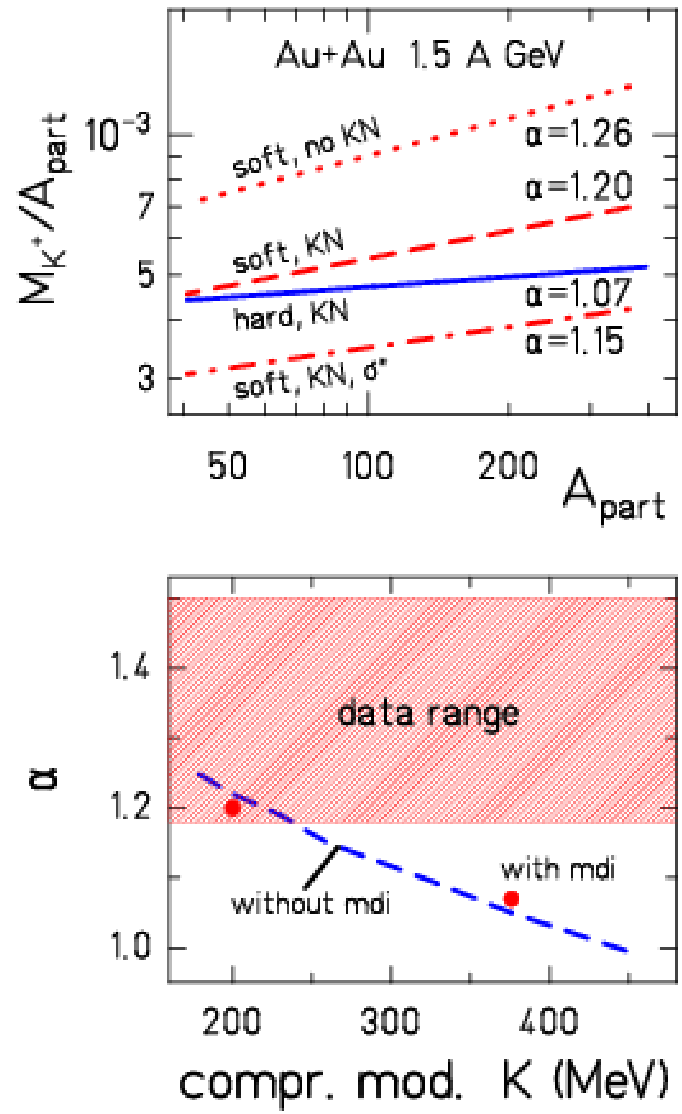


y_0

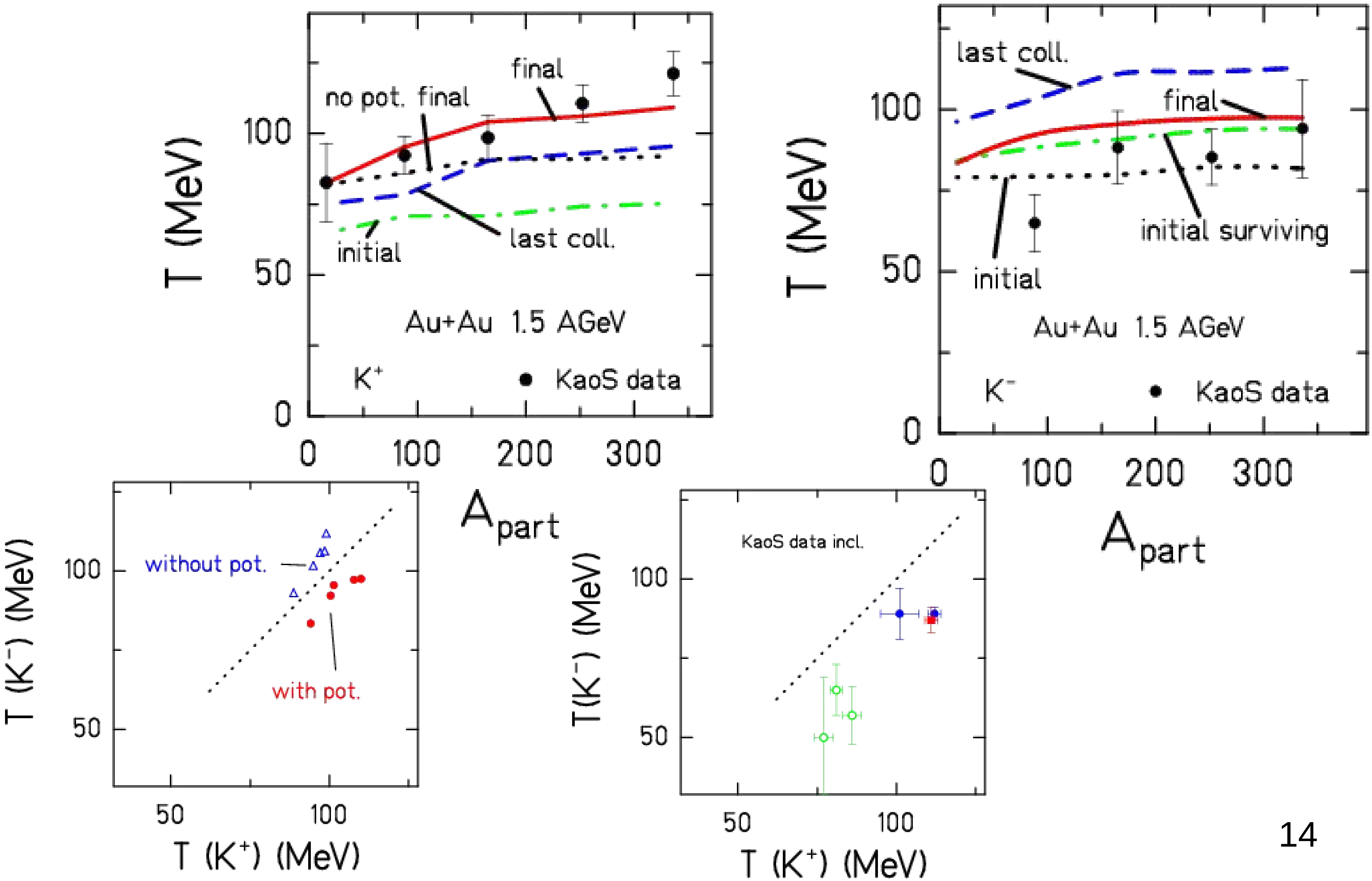
Equation of state : soft+mdi



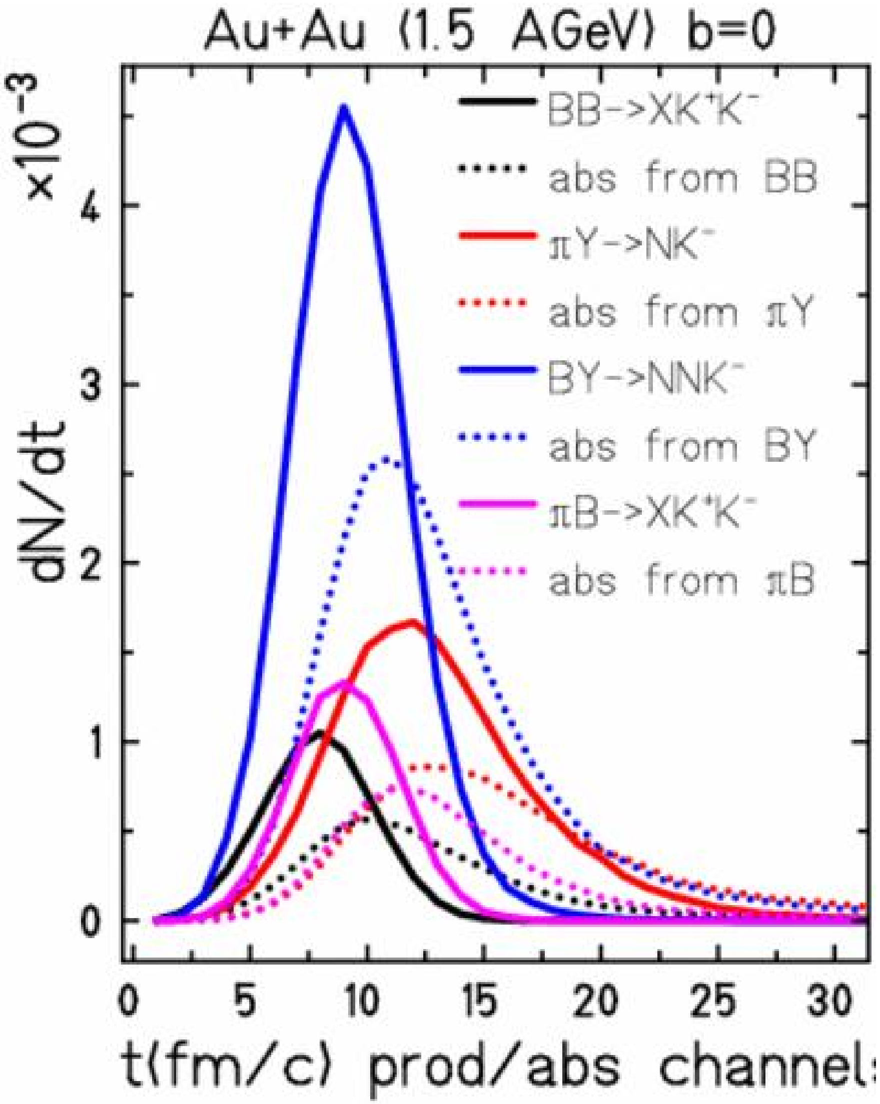


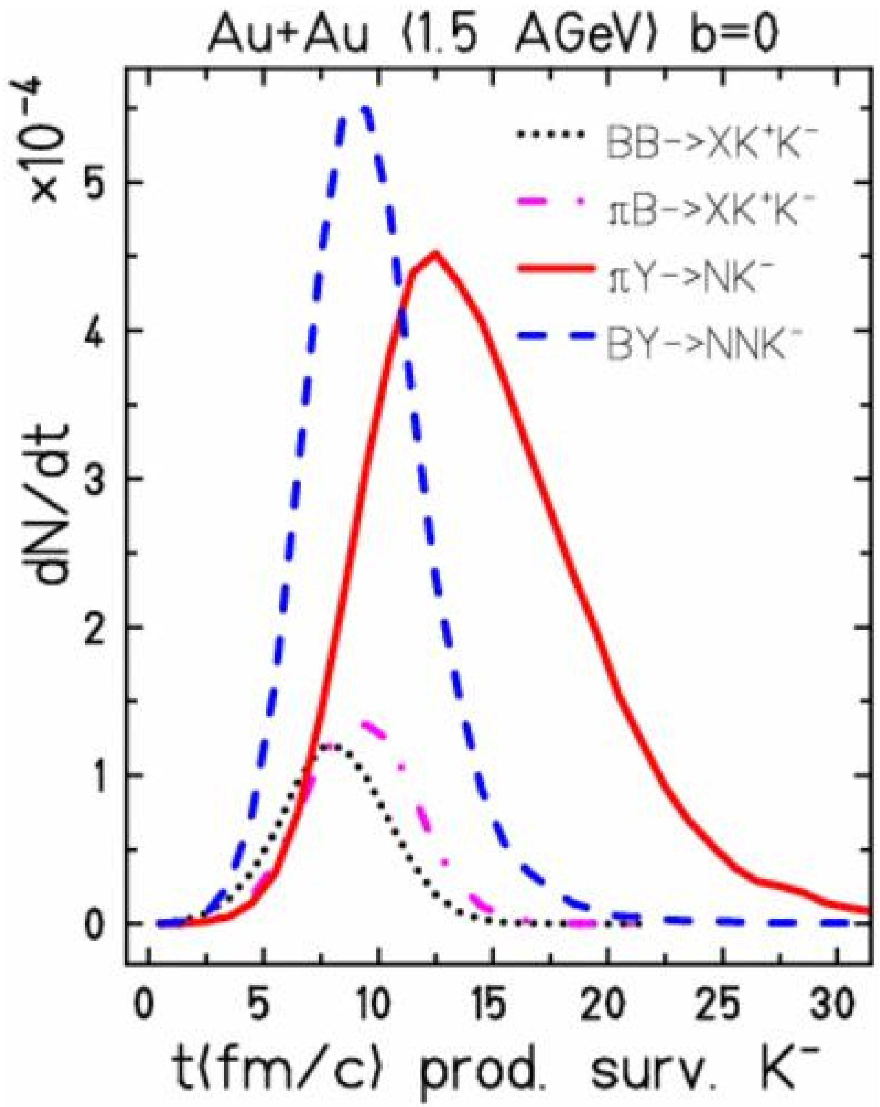


Kaon temperatures : potential+rescattering

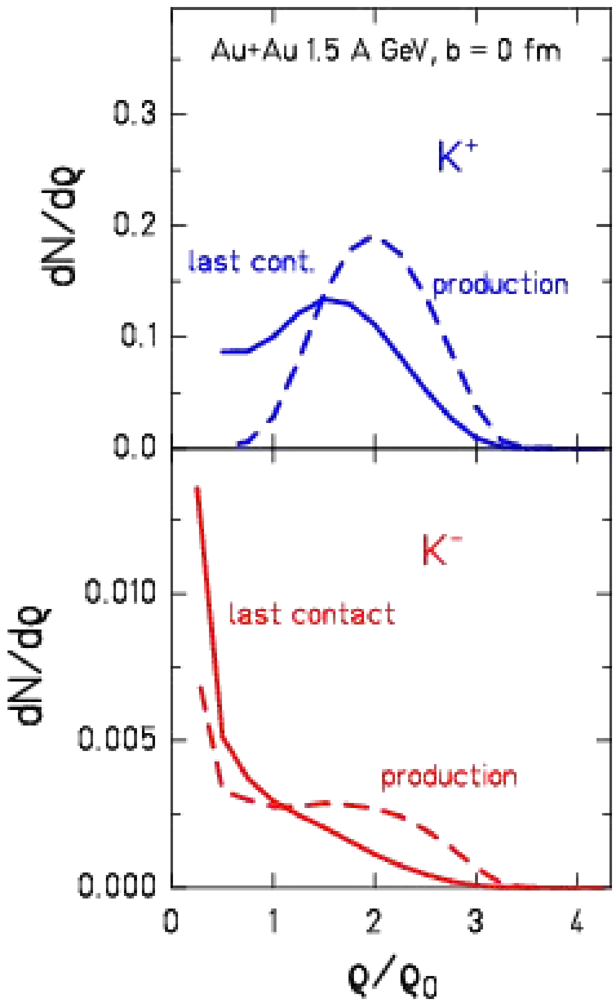


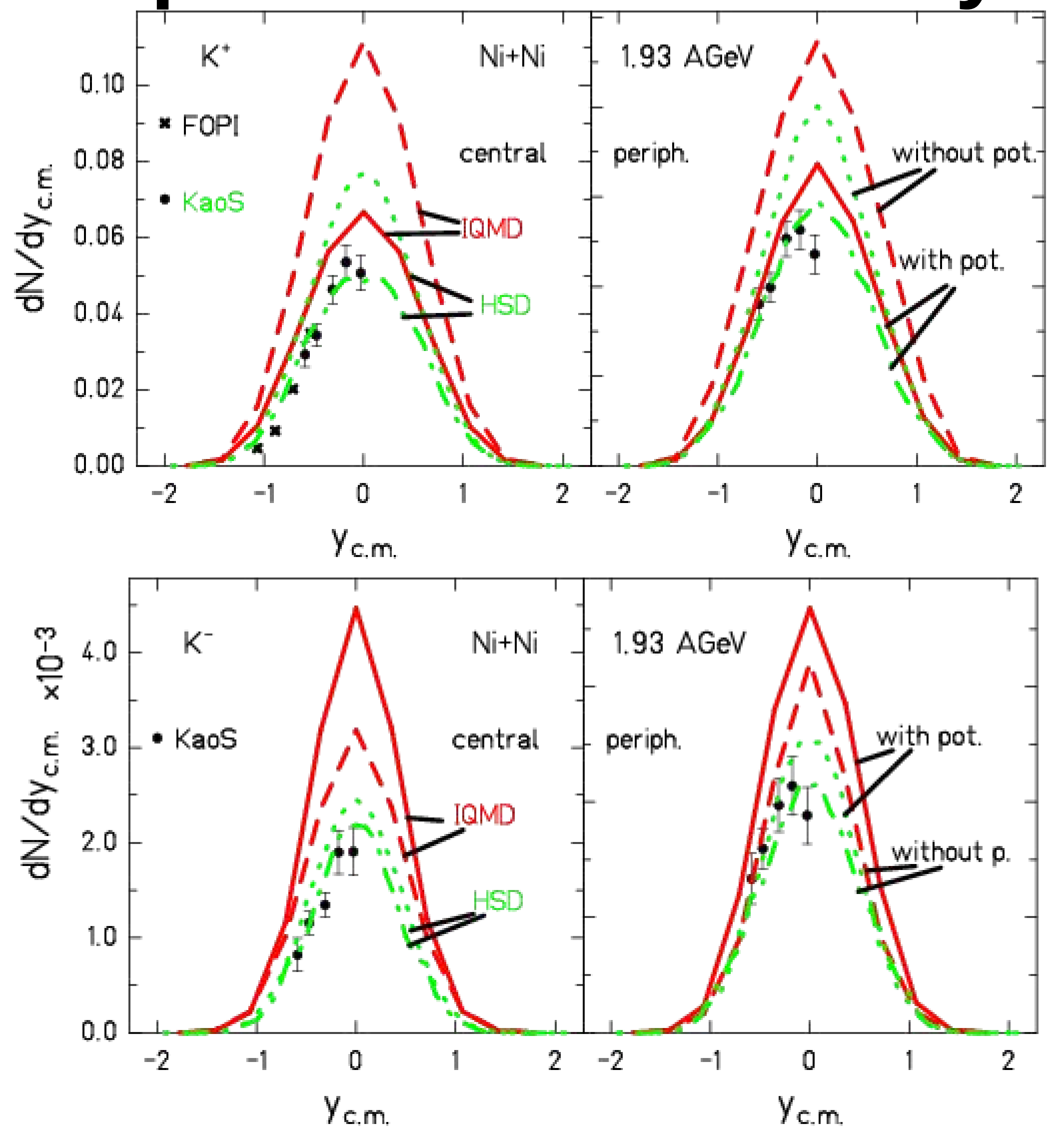
K-: dominance of $Y\pi \leftrightarrow NK^-$





K- stem from strangeness exchange : low density signal & paradoxal effect on yields





K- coupled to K+ by BB→NYK+, πY→NK-

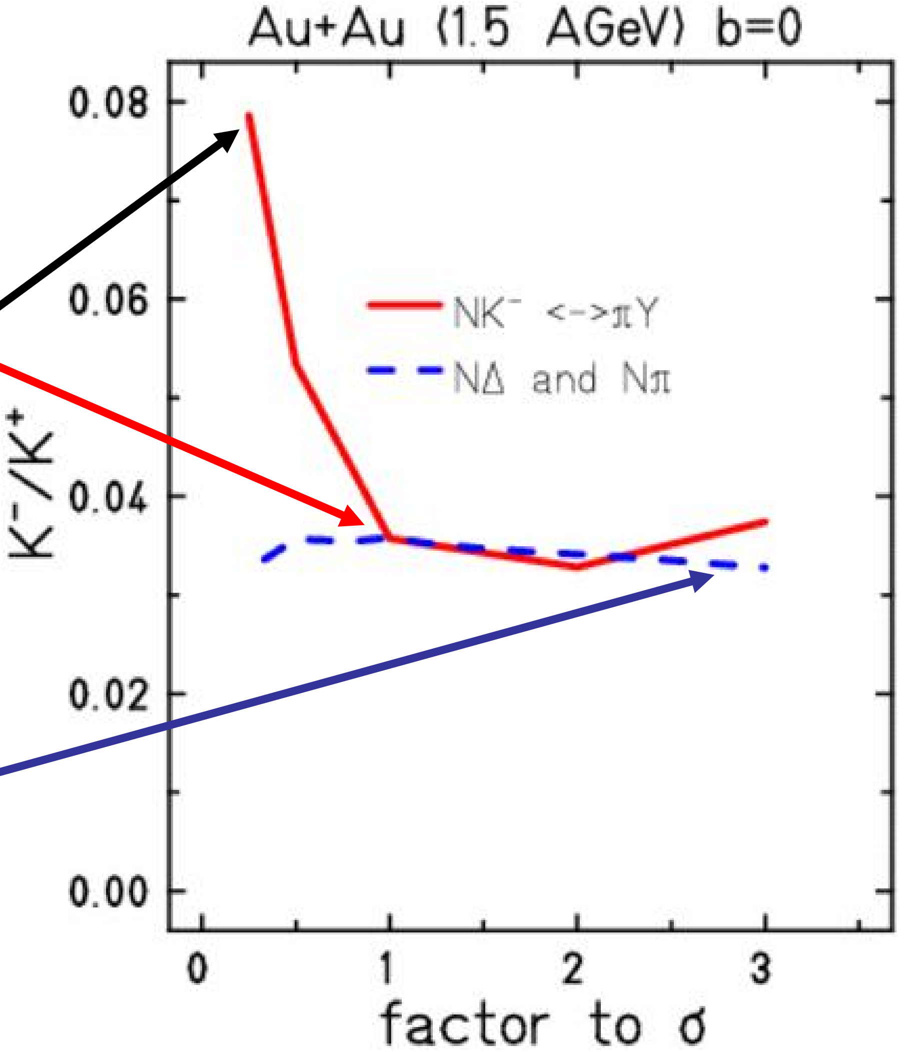
Insensitivity of K^-/K^+ to $Y\pi \leftrightarrow NK^-$

The antikaon production follows the law of mass action: The yield becomes insensitive to the cross section.

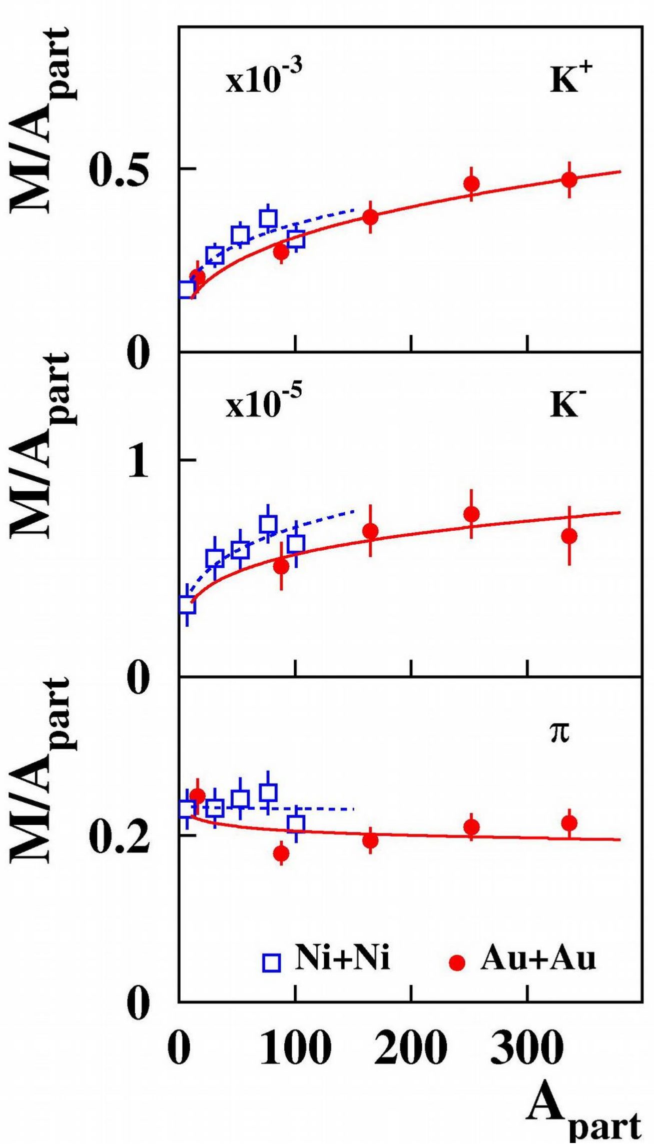
For small cross section other channels take over the dominance (especially BY).

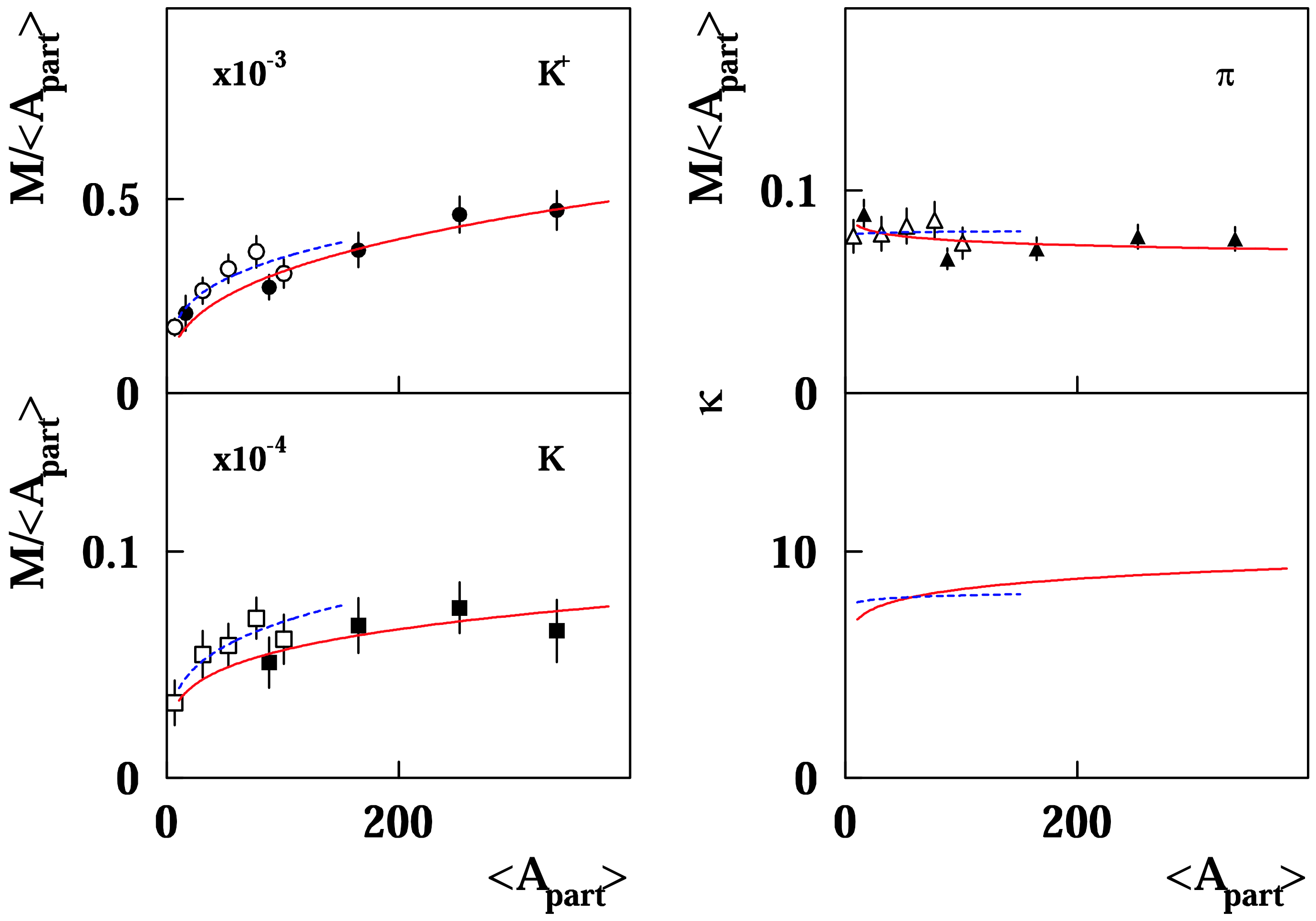
NN↔NΔ and Nπ→Δ do not show any influence neither

Since 2N(K+)≈N(Y) we get K-/K+ ~ K-/Y ~ π/A



Explaining same A_{part} dependence of K+ and K-



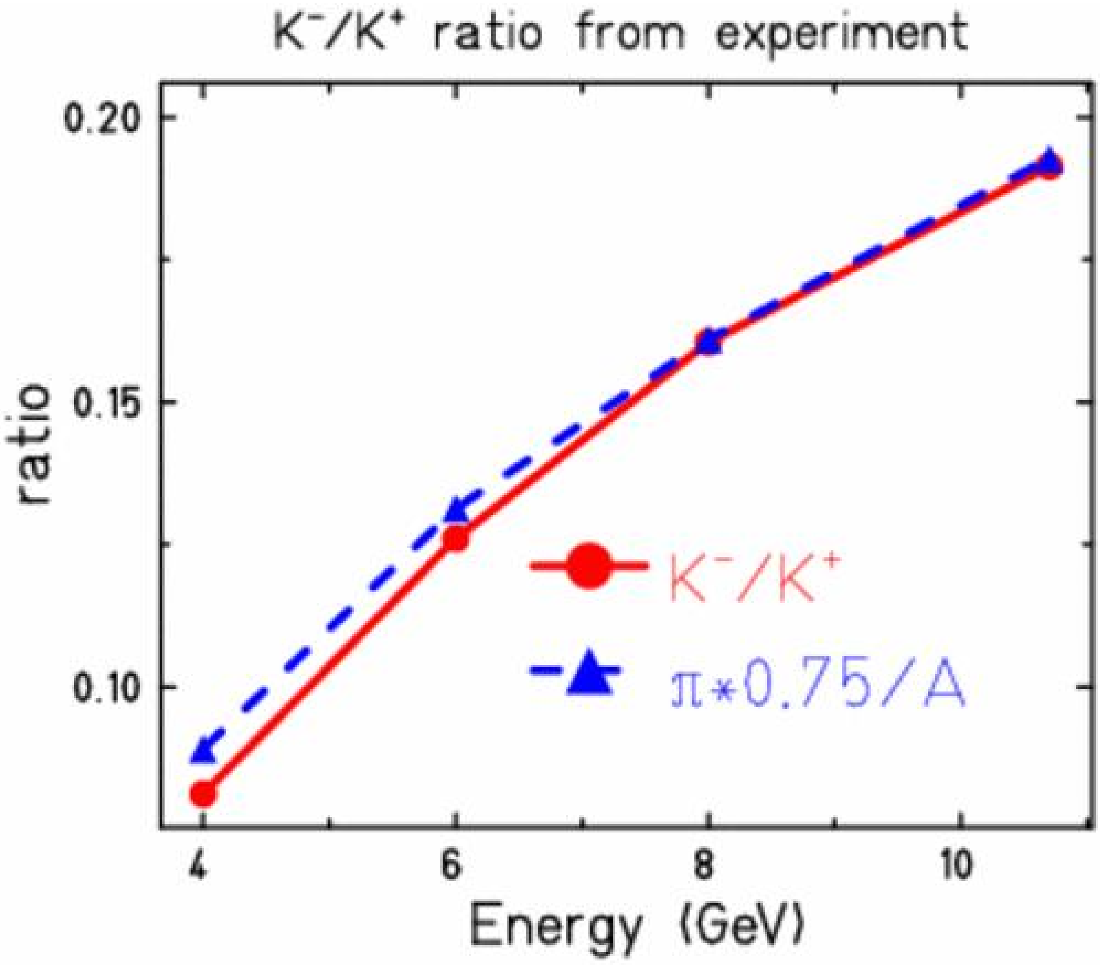


Reproduced by Thermus

$\kappa = ([\pi]\,[Y])/([K^-]\,[N])$

J.Cleymans et al;PLB603(2004)146

Assumption confirmed by experiment

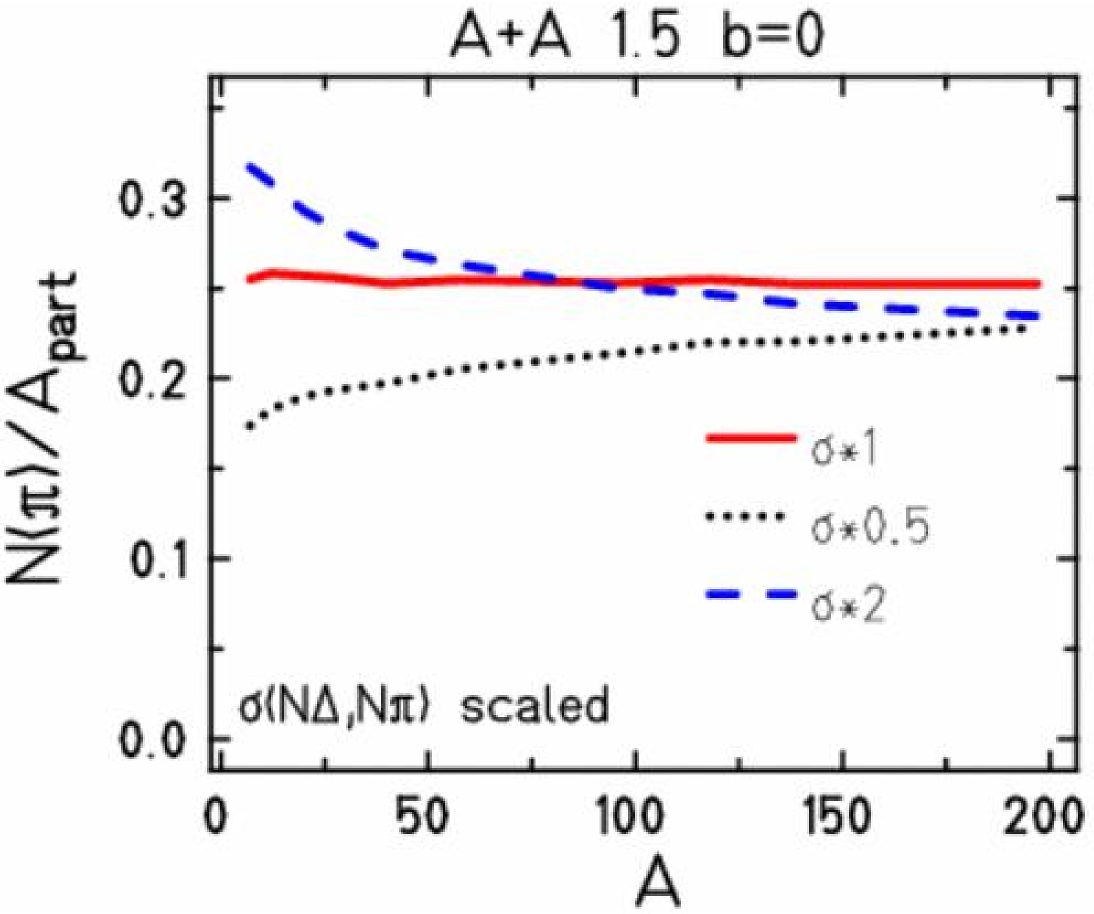


Analysis of the data of pions, kaons and antikaons at AGS confirms this behaviour:

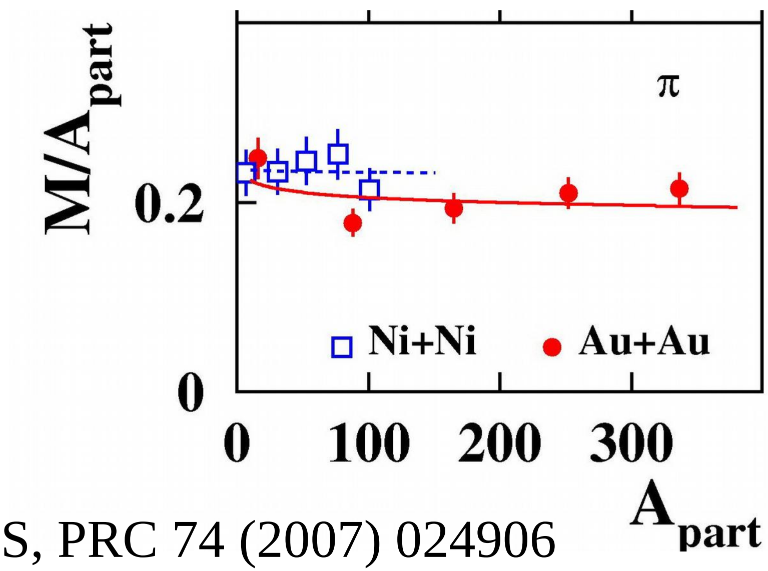
Application of the law of mass action

H. Oeschler, SQM 01 and J. Phys. G: Nucl. Part. Phys. 27 (2001) 257

By the way : π/A is constant, by chance ?



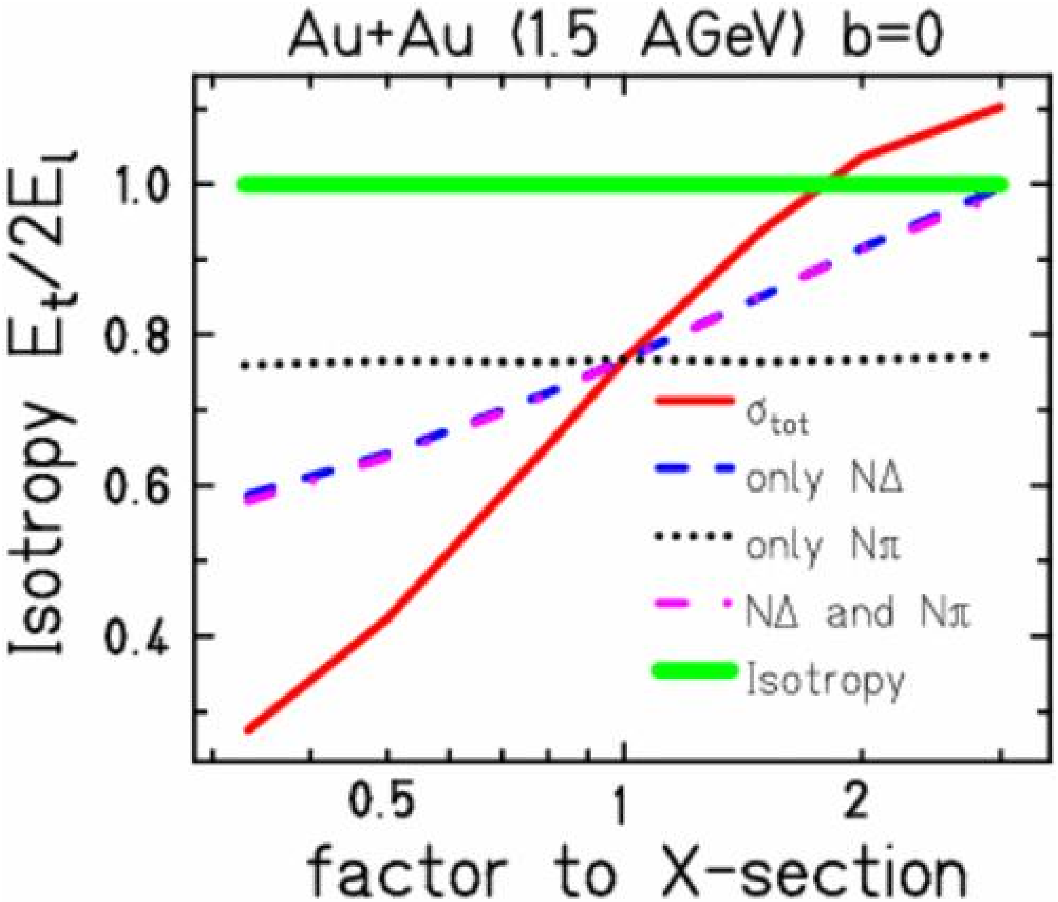
The constant ratio of π/A can only be achieved with the actual free cross sections.

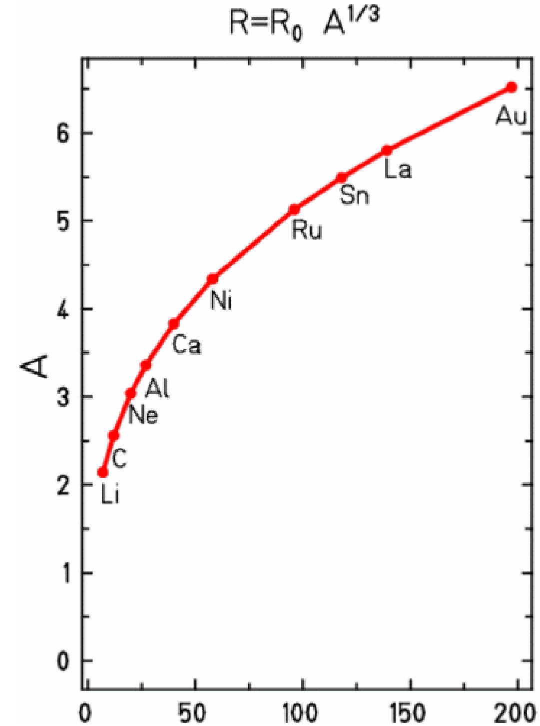


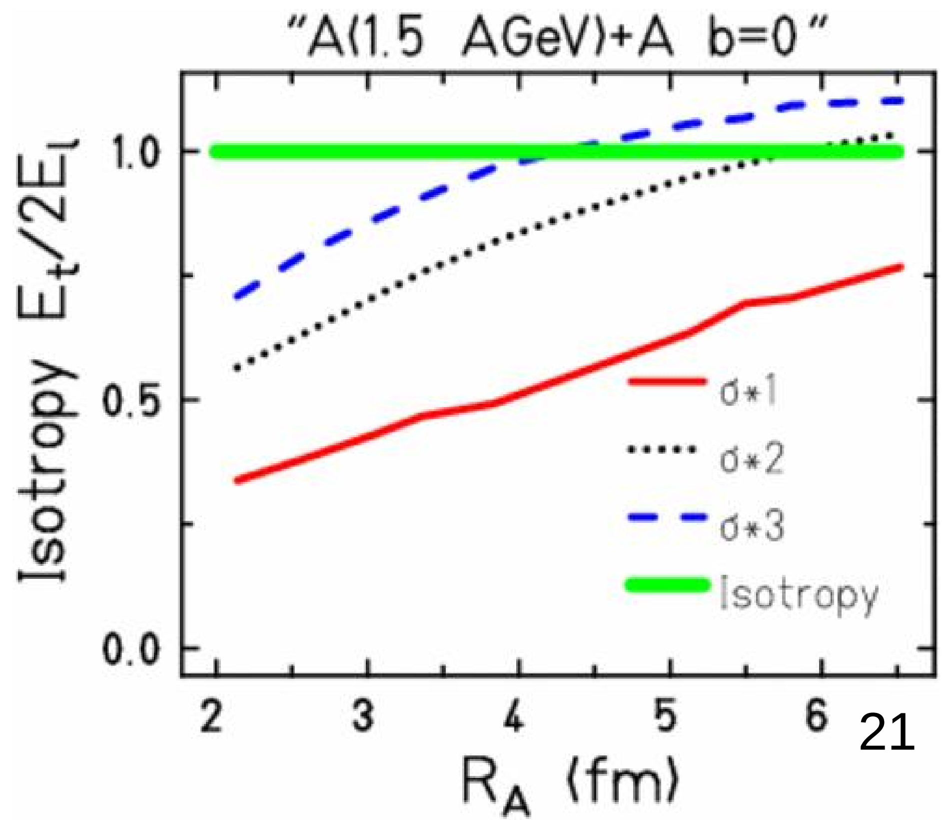
KaoS, PRC 74 (2007) 024906

A happy coincidence for the use of thermal models?

Useless to say that we are not equilibrated



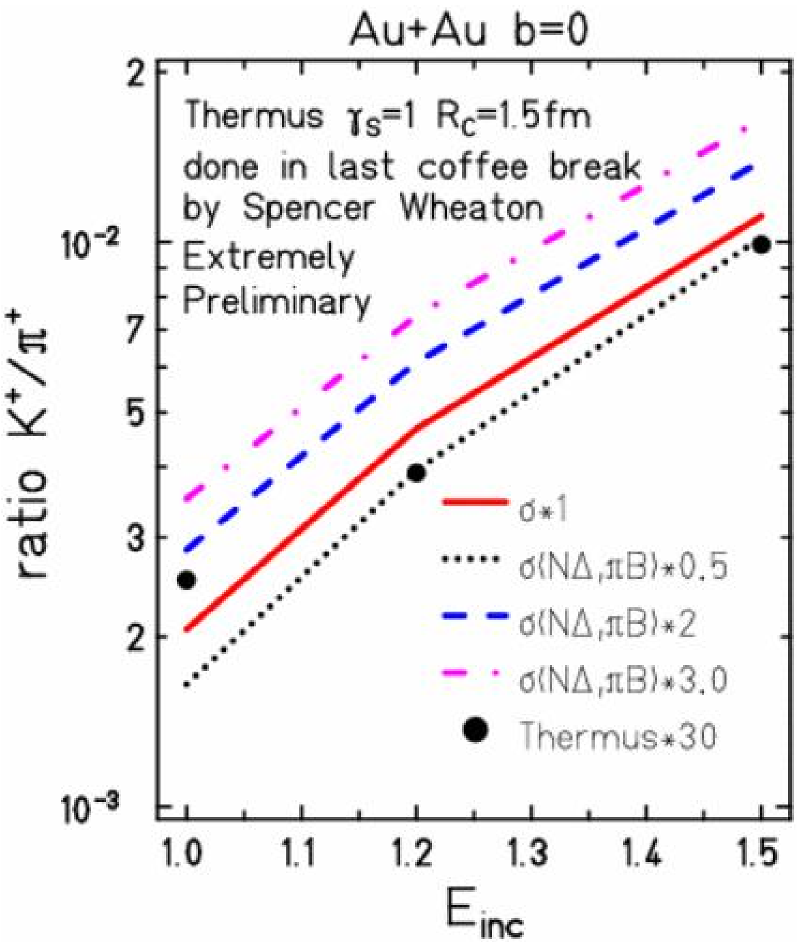


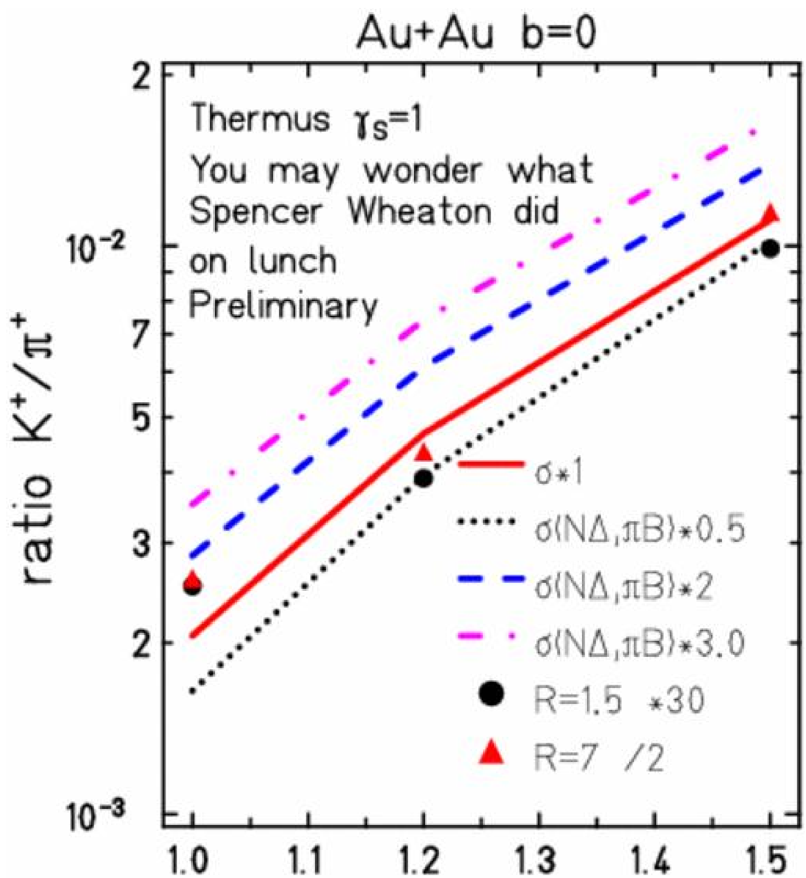


Nearly factor 2 needed for Au+Au

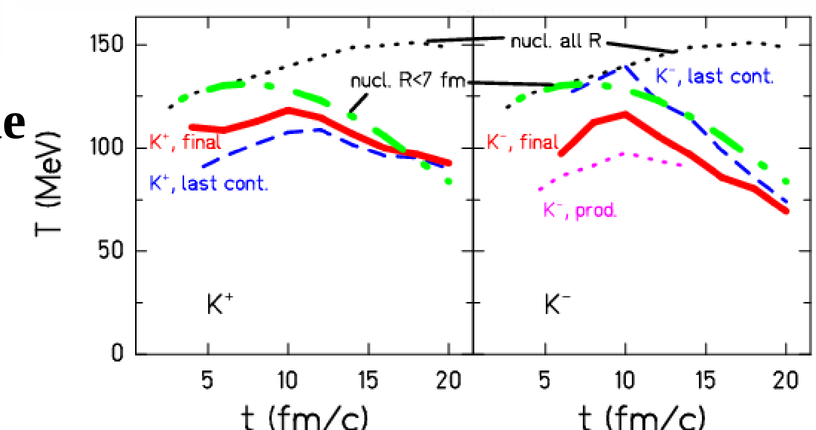
Much more for smaller systems

K/π, effects of radius in Thermus





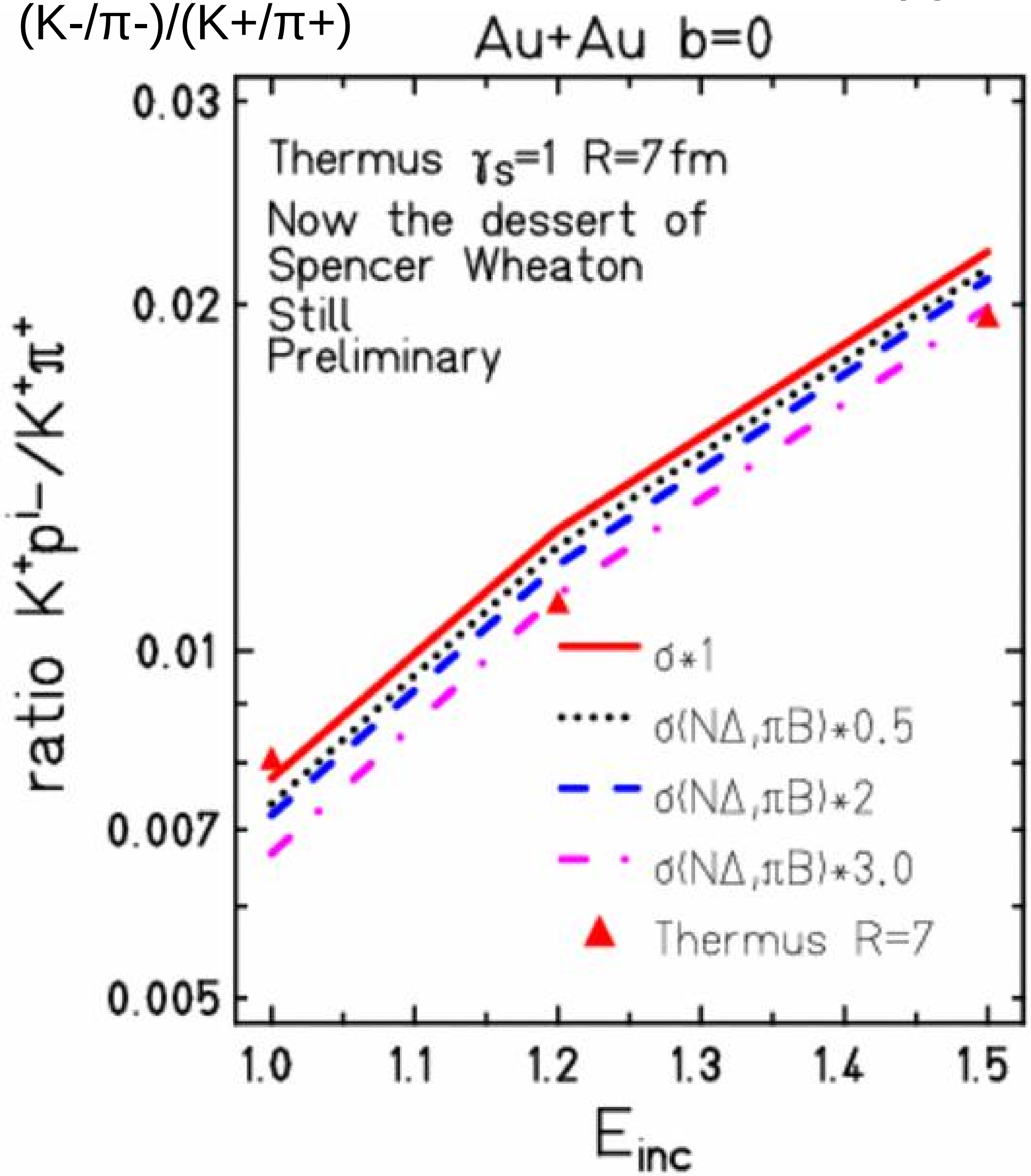
Sorry, for the comments in the figures, this was just taken from my DM2010 talk...



R=7fm motivated by freezeout temperatures

But when coming back to K-/K+ all problems vanish

(K-/π-)/(K+/π+)



- **Agreement without any correction factor**

Thermus run by Spencer Wheaton with R=7fm

Since Thermus could not run K-/K+ directly, we used $(K^-/\pi^-)/(K^+/\pi^+) = K^-\pi^+/\pi^-K^+$

Some word on the phi

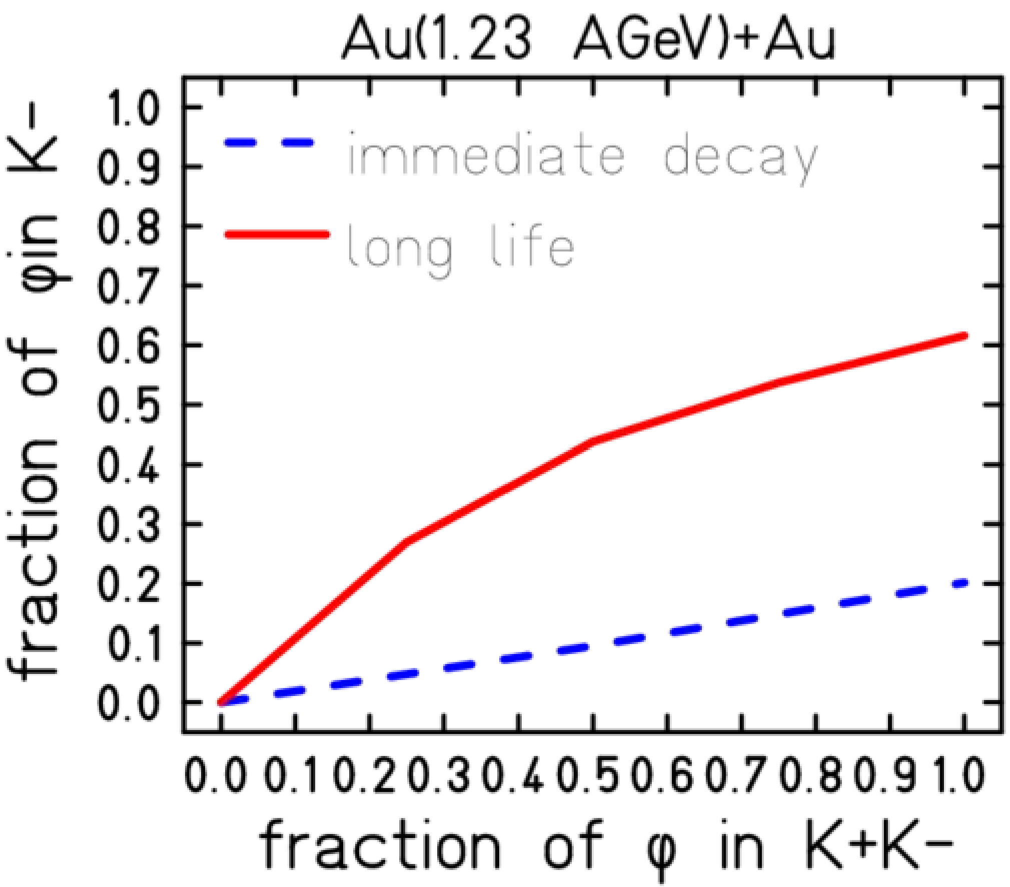
- **The only simple way in IQMD to include a Φ is an additional branching in the channels leading to K+K- :**
  BB→ NNK+K- and πB→ NK+K-
- **We use two extreme cases : immediate decay and very long lifetime**
- **The results are VERY PRELIMINARY**

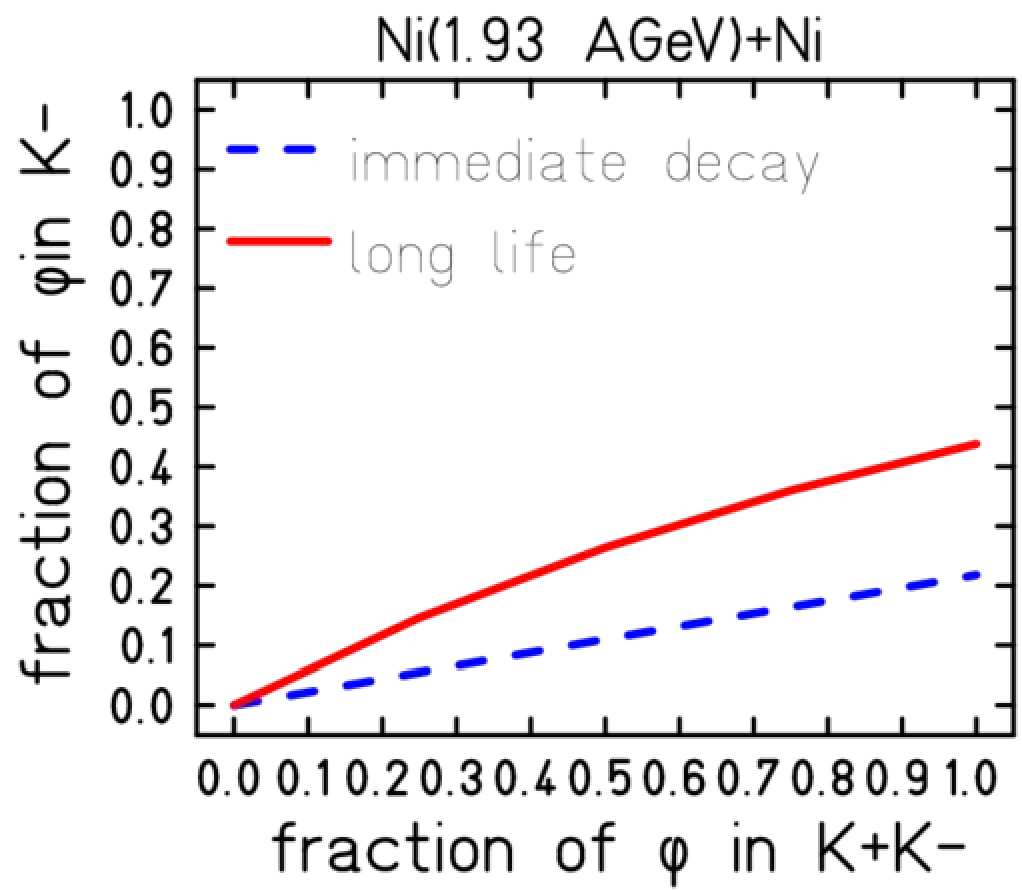
$NN \to NNK^+K^-$ $N\Delta \to NNK^+K^-$ $N\Delta \to N\Delta K^+K^-$ $\Delta\Delta \to NNK^+K^-$

$\Delta\Delta \to \Delta\Delta K^+K^-$ $\pi N \to NK^+K^-$ $\pi\Delta \to NK^+K^-$

Dominating channels

Effect on the relative contribution



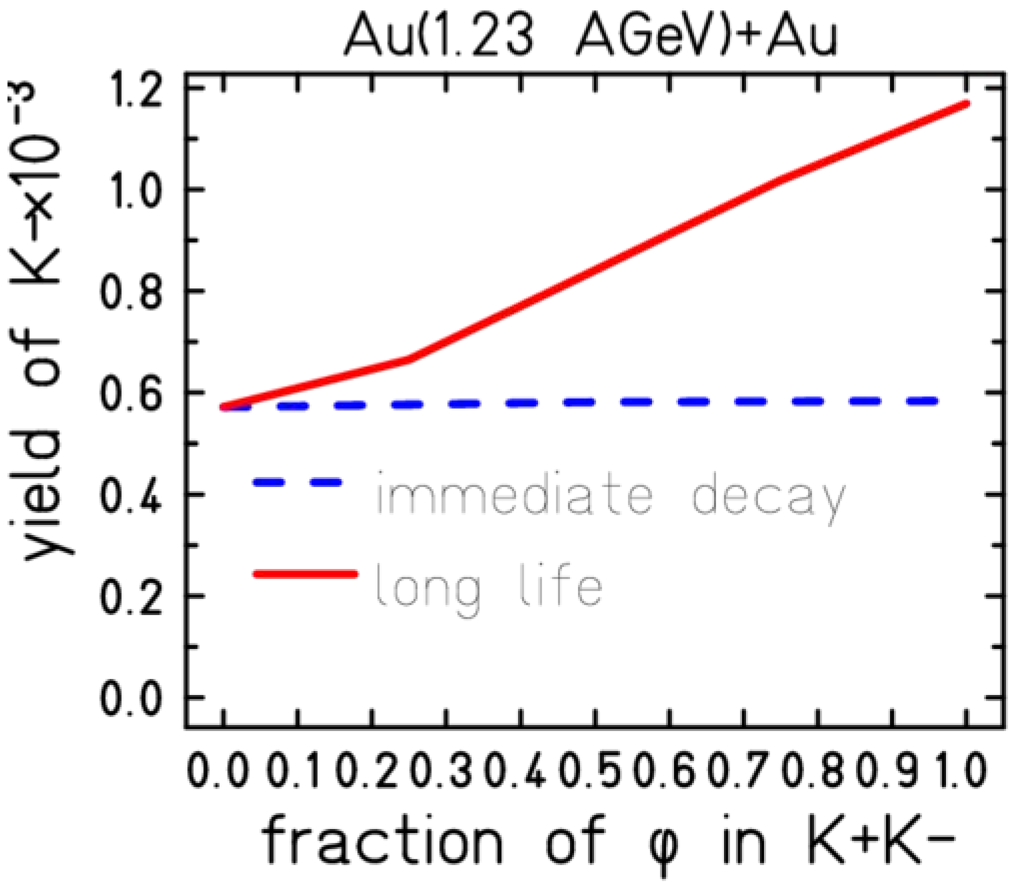


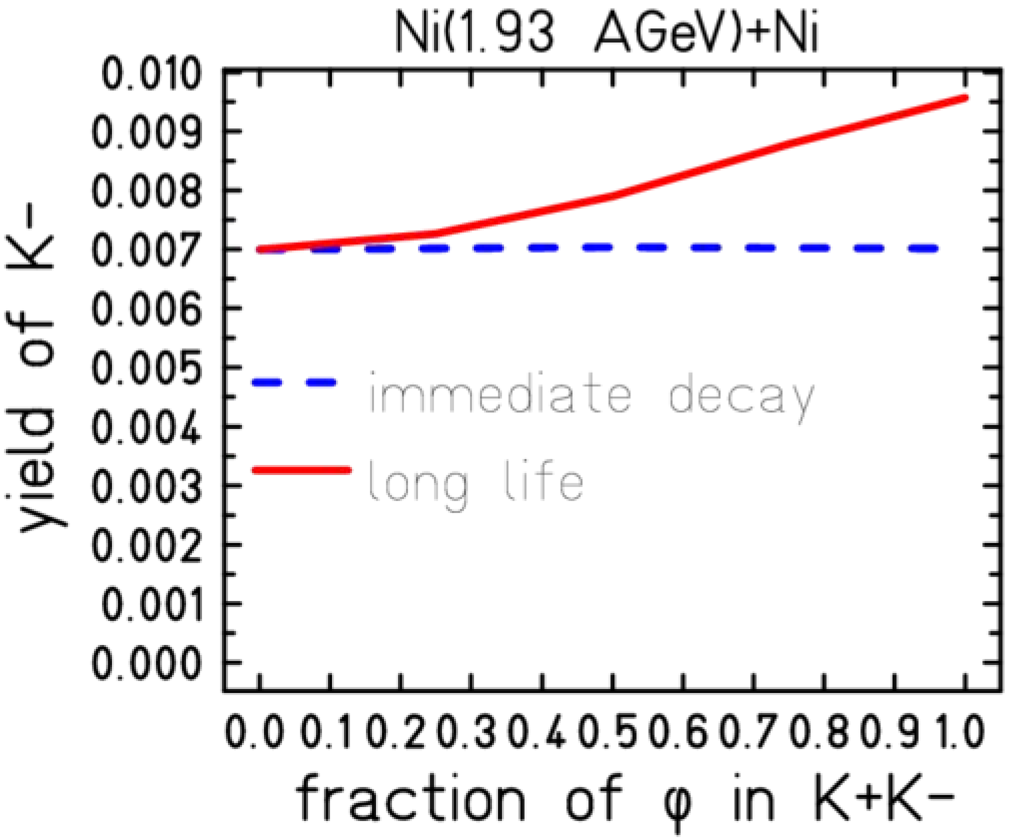
Immediate decay :
Modest change corresponding to the contribution of the K+K- channels

Long lifetime :
Strong contribution due to the absence of absorption in the phi channel

Preliminary

Effect on the absolute yield



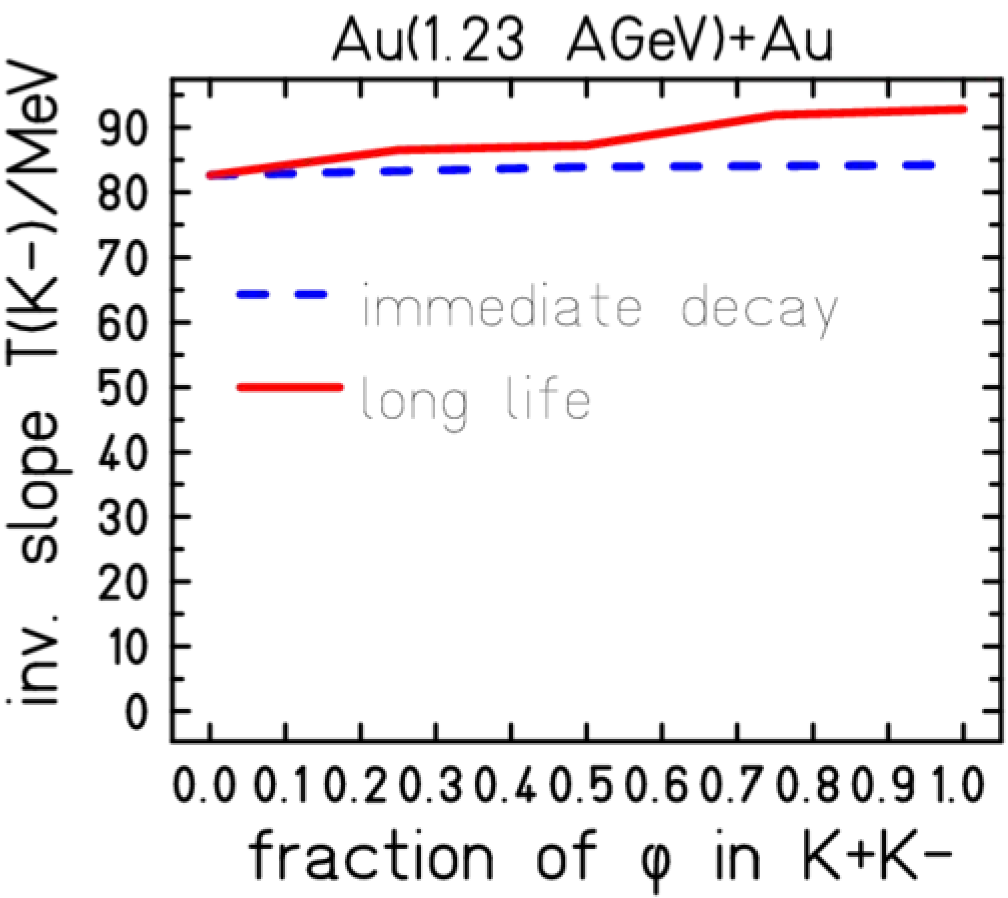


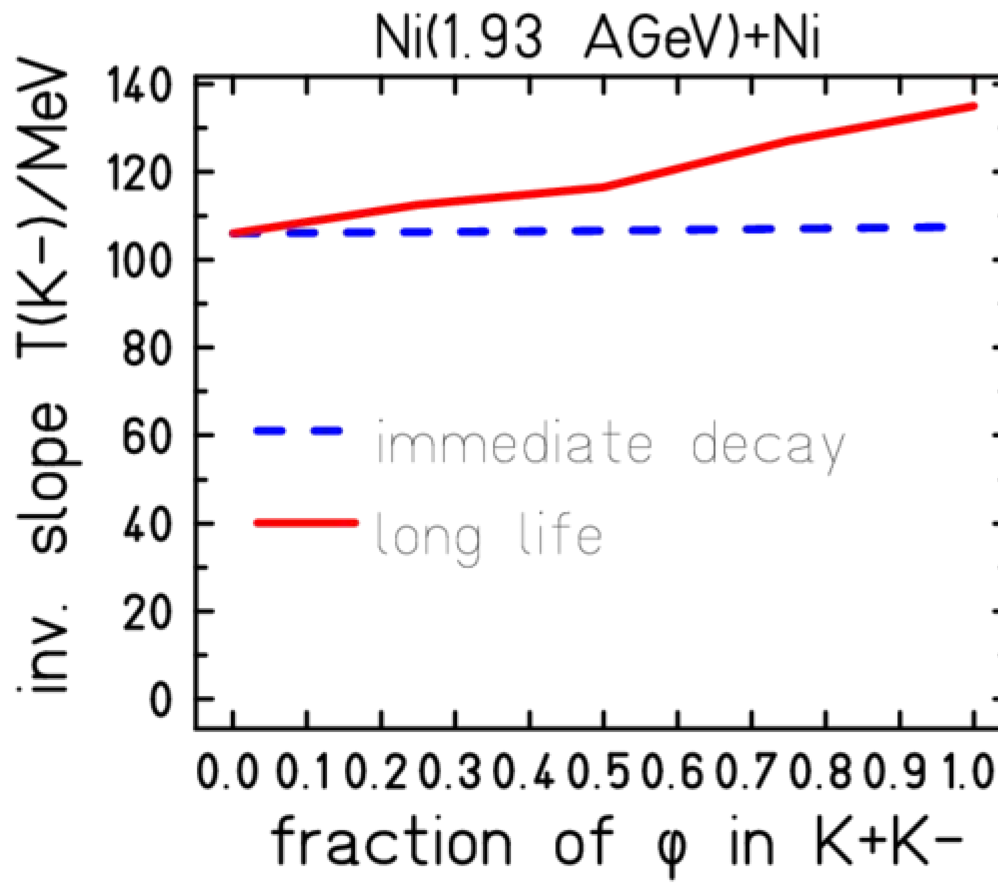
Immediate decay :
The yields stay practical constant

Long lifetime :
Yields rise significantly due to the absence of absorption in the phi channel

Preliminary

Effect on the inverse slope



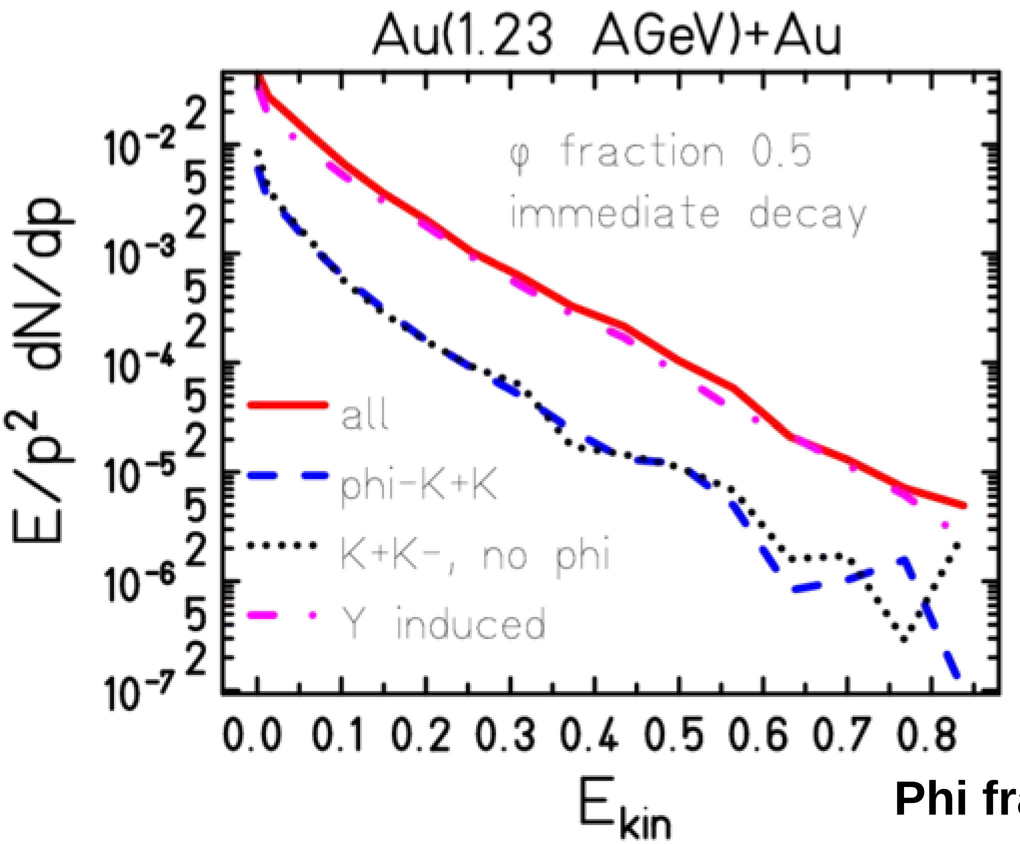


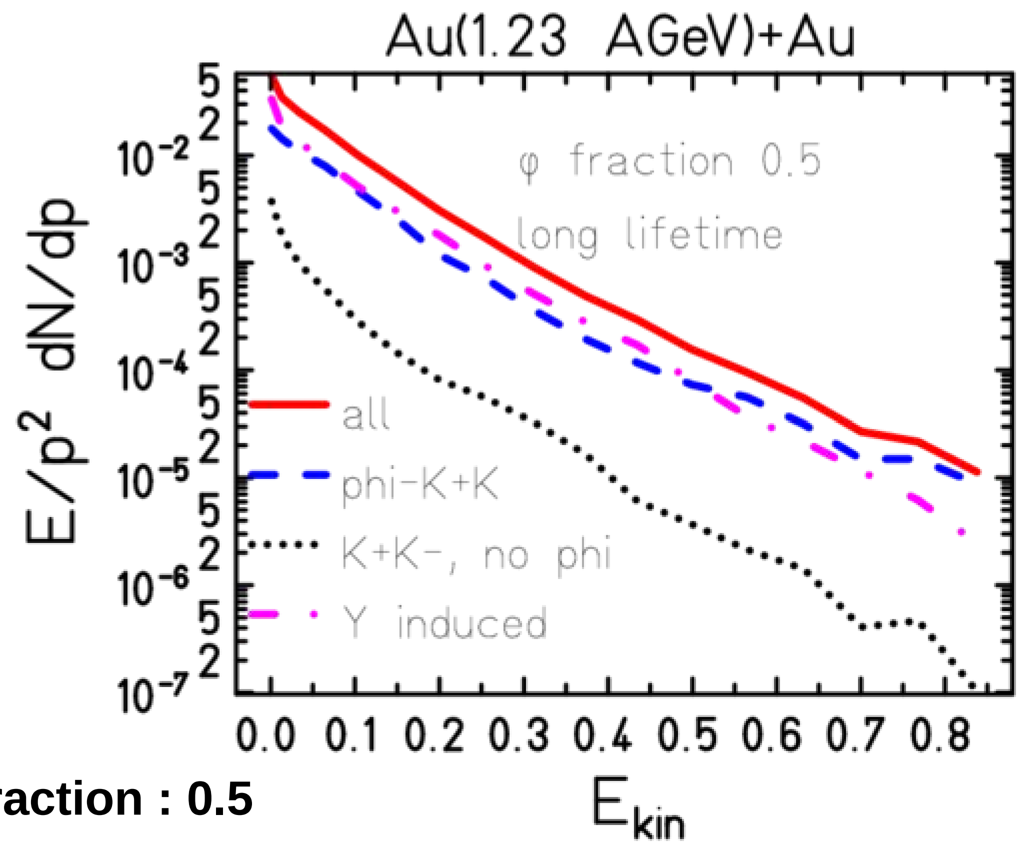
Immediate decay :
The temperatures stay constant

Long lifetime :
The phi channels adds a high temperature component.

Preliminary

Inverse slope of contributions





Phi fraction : 0.5

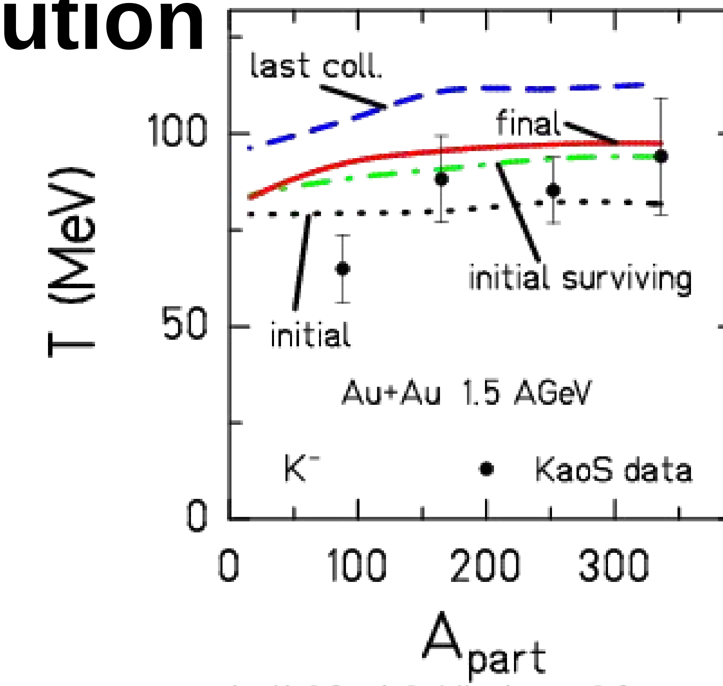
Immediate decay :
The total yield is dominated by the Y-induced channel.
Phi-induced and non-phi induced K+K- channels show similar behaviour

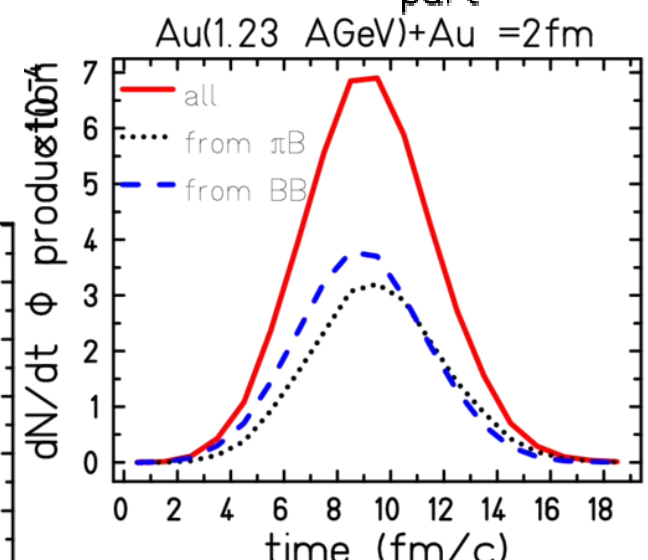
Long lifetime :
The total yield is dominated by the Y-induced and Phi-induced channels.
The latter shows a higher temperature.
Non phi-induced K+K- channels contribute only marginally.

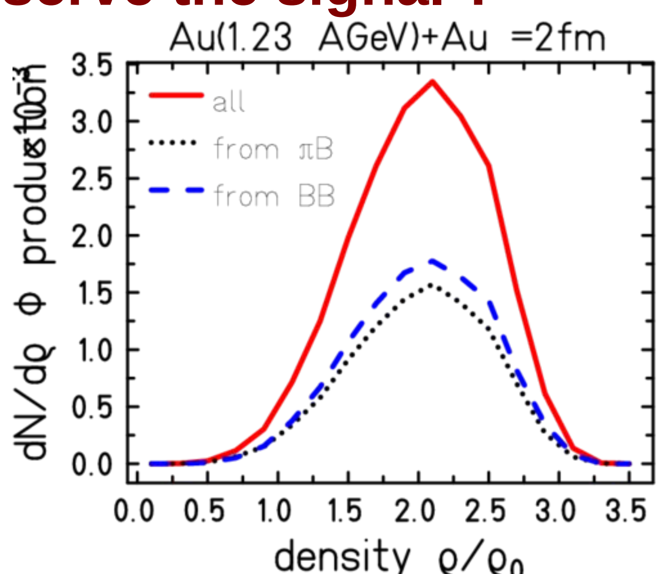
Preliminary

Effects+words of caution

- Strong effects visible for long lifetime
  - Lifetime to be more explicited
- Suppression of absorption at this channel
  - Directly visible in yields
- No « cooling » by regaining mass
  - Medium effects on phi ?
- Seemingly differences in phi channels (not shown) BB→BBΦ and πB→BΦ
  - To be investigated in detail
- Φ are produced in early stage and at high densities. Do the K- conserve the signal ?
  - Question of transport of Φ in medium







Preliminary

Conclusions

- **Simulation models should rely first on the configuration which describes the majority of global observables**
  - **For IQMD this clearly requires soft eos+mdi + KN potentials**
- **Rescattering of (anti)kaons play an important role on the spectra, but they are supplemented by potential effects**
  - **Rescattering : high energy part, Potential : low energy part**
- **Thermal models will probably be able to REPRODUCE particle yields at that energy but this does not mean that the system is thermal**
  - **Interplay in the NN↔NΔ, Δ↔πN, πΛ↔NK- channels with NΔ →NΛK+**
- **Strongly interacting particles like the K- (but probably also the Ξ) may have their origin in the high density phase but they are strongly related to the late phase of interaction**
  - **K- dominated by late strangeness exchange**
- **The role of the Φ needs to be clarified**

Thank you !

If we shadows have offended,
Think but this, and all is mended,
That you have but slumber'd here
While these visions did appear.
And this weak and idle theme,
No more yielding but a dream
Gentles, do not reprehend:
if you pardon, we will mend.

W. Shakespeare: A midsummer night's dream