

Strangeness Production Signal of QGP?

Theoretical predictions => SPS data

Model description: UrQMD, Statistical models



Canonical strangeness conservation &
Multistrange baryons enhancement

Unified Freeze-out curve: from GSI (SIS) => RHIC

- energy and centrality dependence of particle yield
- K, \bar{K} excitation function
- K/\bar{K} and K/π ratios
- particle spectra

Conclusions

QGP- strangeness characteristics

Low threshold for s-quark production => B. Müller, J. Rafelski, et al..

large s-quark density

$g+g \rightarrow s+\bar{s}$, $q+\bar{q} \rightarrow s+\bar{s}$: threshold $2m$

compare with: most efficient conventional reactions

$p+p \rightarrow p + K + \Lambda$, $\pi^- + \pi^+ \rightarrow K + K$: threshold 0.7GeV

- * $\langle \bar{s} \rangle$ more abundant than $\langle \bar{q} \rangle$
- * Short equilibration time of $\langle s \rangle$ in QGP L. McLerran, et.al.....
- Long -//- in HG P. Koch, et al..
- However: in HG multiparticle interactions



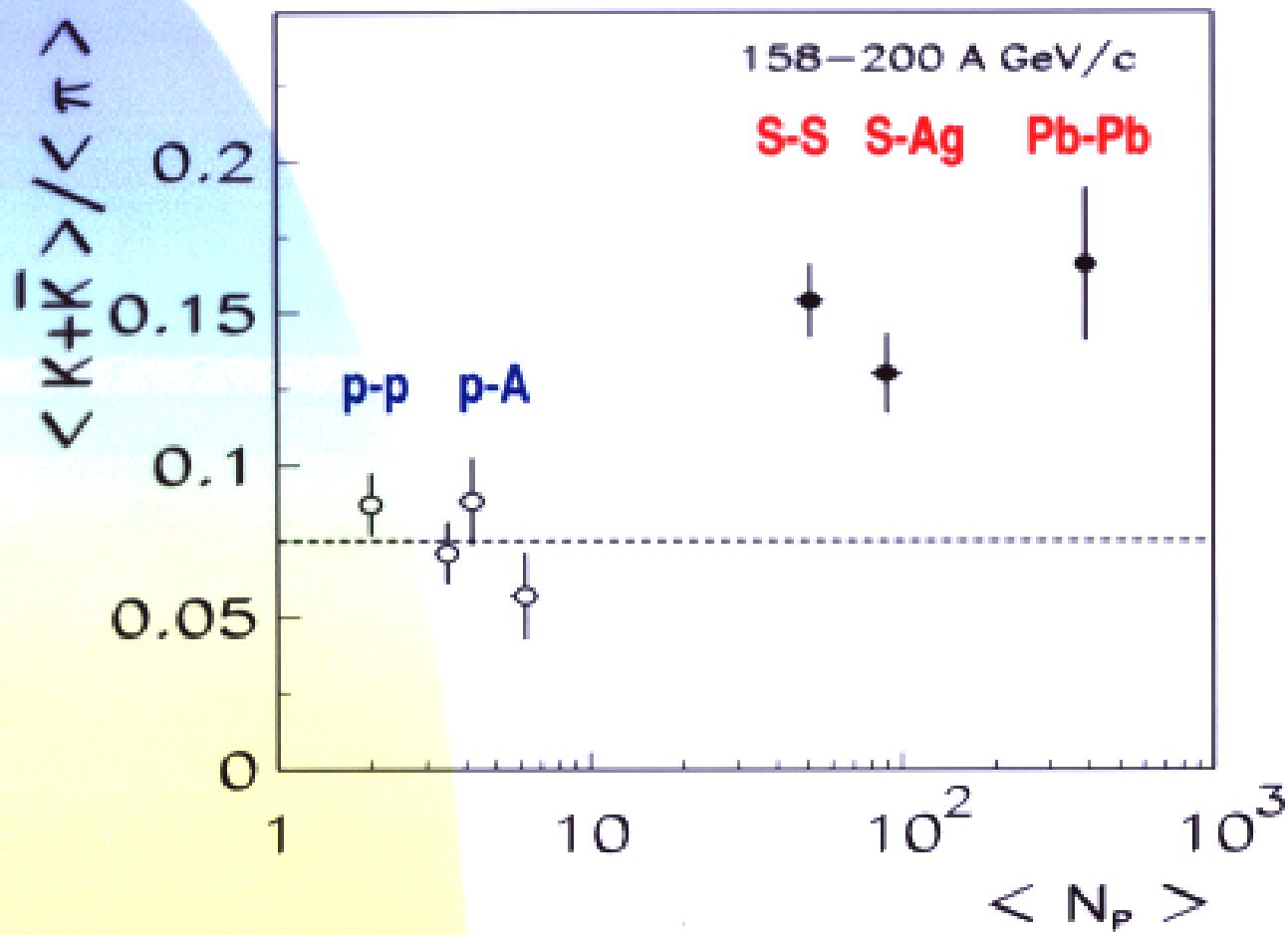
can substantially speed-up chemical equilibration

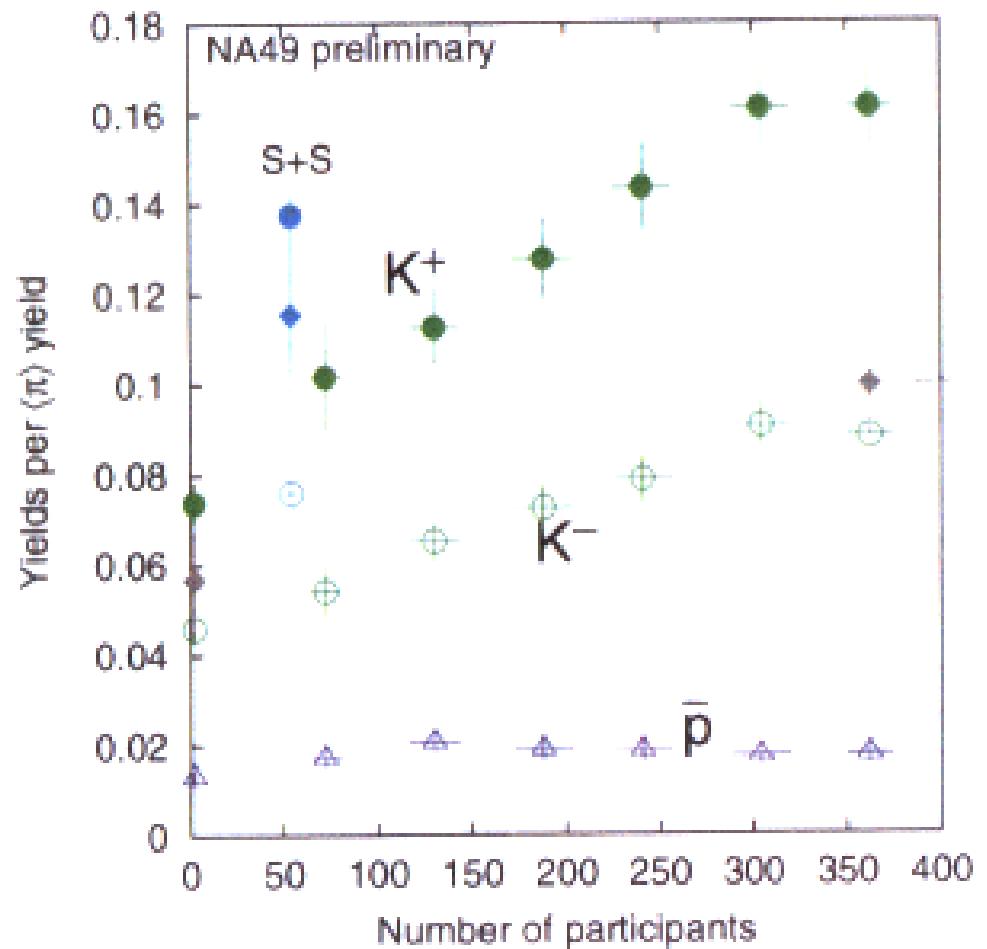
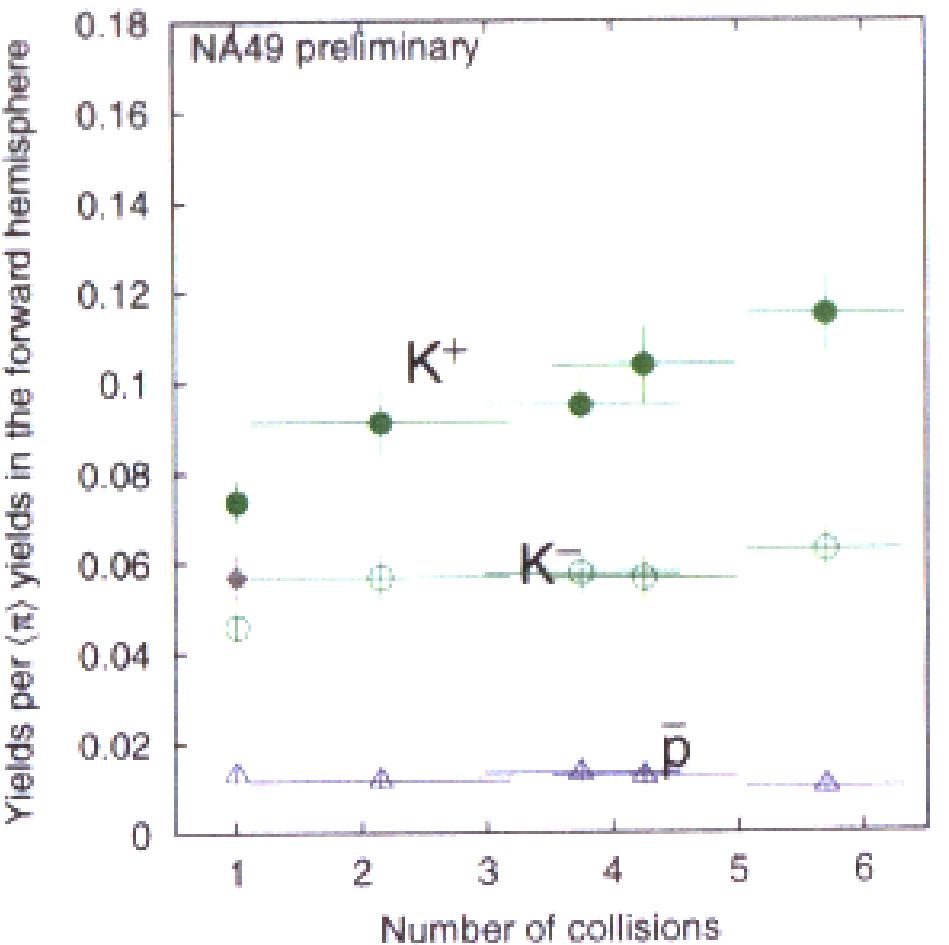
R. Rapp, E. Shuryak & C. Greiner, S. Leupold

Experimental Implications

- Global strangeness enhancement from $p-p,p-A \Rightarrow A-A$ (P. Koch, B. Müller, J. Rafelski)
strangeness content measured by: $\langle s\bar{s} \rangle / \langle \text{part.} \rangle$,
 $\langle s\bar{s} \rangle / (\langle u\bar{u} \rangle + \langle d\bar{d} \rangle)$
- (Multi)-strange baryons and antibaryons
enhancement increasing with strangeness
content (J. Rafelski)
- Plasma hadronisation \Rightarrow chemical equilibrium
of hadronic phase-space
(J. Kapusta et al.; P. Koch, et al.; B. Friman et al.;
T. Biro; R. Stock,)

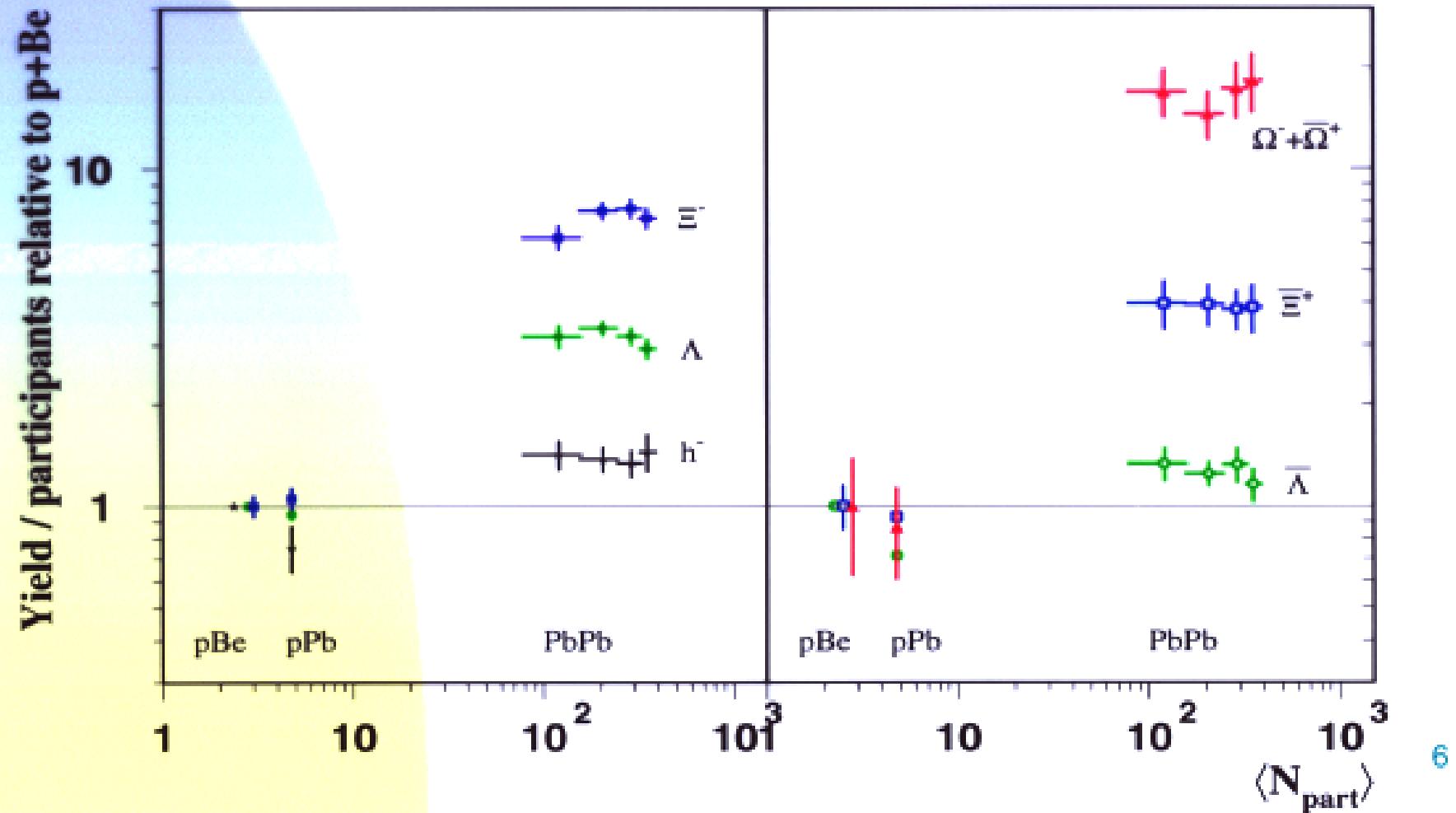
Global Strangeness Enhancement NA35 & NA49



Centrality dependence $\text{Pb} + \text{Pb}$  $\text{p} + \text{A}$ 

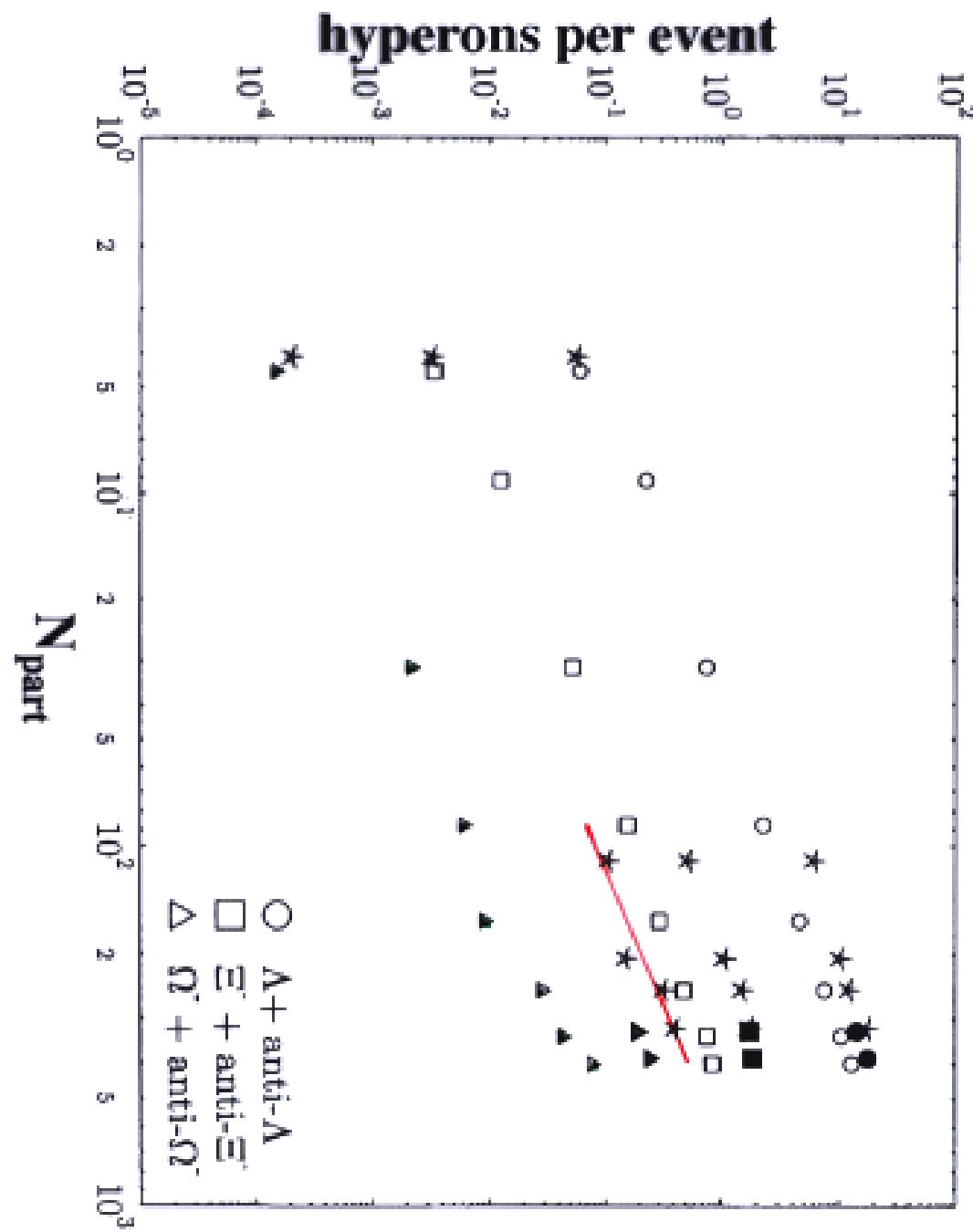
(Multi) Strange Baryons Enhancement

WA97



UrQMD : Sven Soff et al.

$p_{\text{p}} \text{Pb} (158 \text{ A GeV}) \text{ Pb}$



$$\gamma_s = \frac{P(s\bar{s})}{P(q\bar{q})} = \exp\left(-\frac{\pi(m_s^2 - m_q^2)}{2\kappa}\right)$$

constituent quark mass:

$m_q = 10 \text{ MeV}$ $m_s = 230 \text{ MeV} = D$ $\gamma_s = 0.65$

current quark mass:

$\gamma_s' = 0.3$

Statistical-Thermal Models

- At freeze-out: the available particle phase space is occupied according to statistical laws
-> thermal distribution
- Chemical freeze-out: particle abundances are frozen in
- Thermal freeze-out: particle spectra are frozen in

Test of equilibration required to specify:

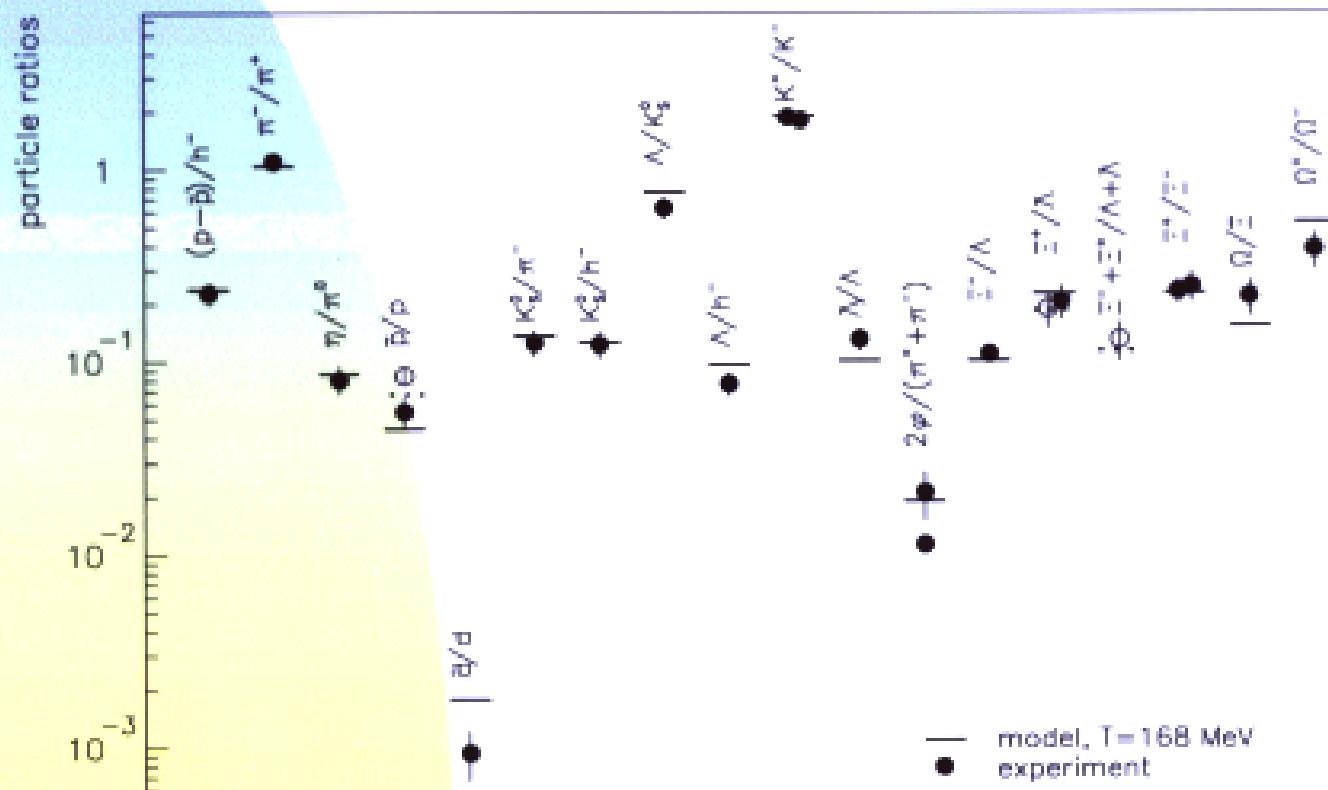
- i) level of observation: (multiplicities, spectra, correlations,...)
- ii) Statistical operator:

$$Z^{GC}(T, \vec{\mu}, V) = \text{Tr}[e^{-\beta(H - \mu_B B - \mu_S S - \mu_Q Q)}]$$

Test of chemical equilibrium for Pb-Pb at SPS

P. Braun-Munzinger, I. Heppe, J. Stachel

$$\varepsilon \approx 0.6 \text{GeV} / \text{fm}^3, \rho_B \approx 0.16 / \text{fm}^3$$



Modelling statistical operator

Equilibrium description

$T \sim 0.17 \text{ GeV}$, $\mathcal{E} \sim 0.6 \text{ GeV/fm}^3$, $\rho_B \sim 0.16 \text{ fm}^{-3}$

non-equilibrium

(J.Letessier, J. Rafelski)

QGP-explosion

2-phase -space oc. par.

in-medium effects

(D.Zschiesche, et al.)

SU(3) chiral Lagrangian

$M(T)$

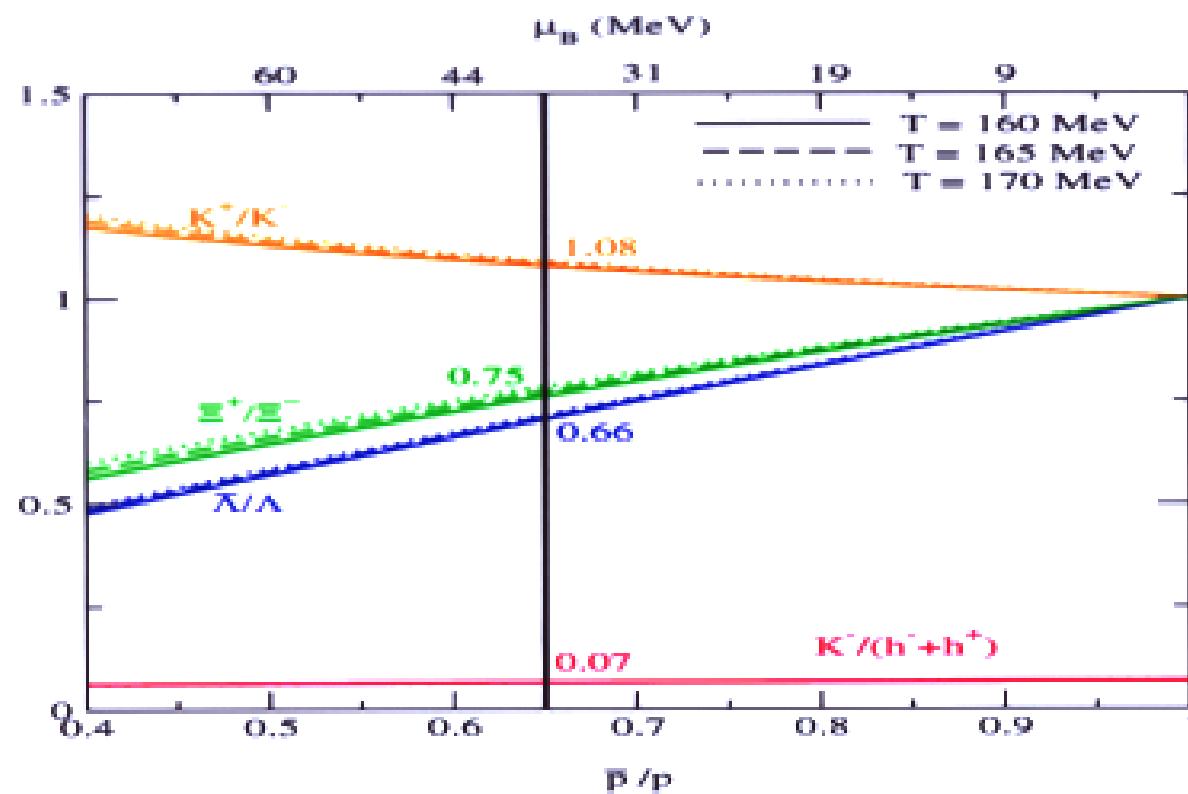
$T = 144 \text{ MeV}$

Problems: ?

- Omega yield
- fluctuations
- dileptons

Thermal Model at RHIC

F. Becattini, J. Cleymans, A. Keranen, E. Suhonen, K. R



Strangeness suppression – kinetic approach

C.M. Ko, V. Koch, Z. Lin, M. Stephanov, Xin-Nian Wang, K.R.

Example:



Rate equation:

$$\frac{d\langle N_K \rangle}{dt} = \frac{G}{V} \langle N_\pi \rangle^2 - \frac{L}{V_0} \langle N_K \rangle^2$$

$$\langle N_K^2 \rangle = \langle N_K \rangle^2 + \langle \delta N_K^2 \rangle$$

$$\downarrow \\ \langle N_K \rangle$$

Size of fluctuations



Equilibrium limit

$$\langle N_K \rangle \ggg 1$$

$$\langle N_K \rangle \lll 1$$

$$n_{K^+} \approx m_{K^+}^2 T K_2 \left(\frac{m_{K^+}}{T} \right) \times$$

$$V_0 m_{K^-}^2 T K_2 \left(\frac{m_{K^-}}{T} \right)$$

$$n_{K^+} \approx m_{K^+}^2 T K_2 \left(\frac{m_{K^+}}{T} \right)$$

(Multi) Strange Particle Multiplicities

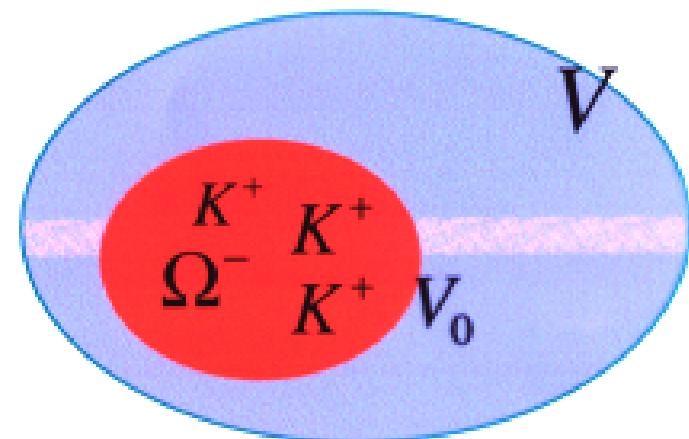
Hamieh, Tounsi, et al..

Consider : baryon free and charge neutral system
of volume V and temperature T

Impose : strangeness neutrality condition

$$\frac{\langle N_S \rangle}{V} \approx w_S \frac{I_S(2V_0 w_{S=1})}{I_0(2V_0 w_{S=1})}$$

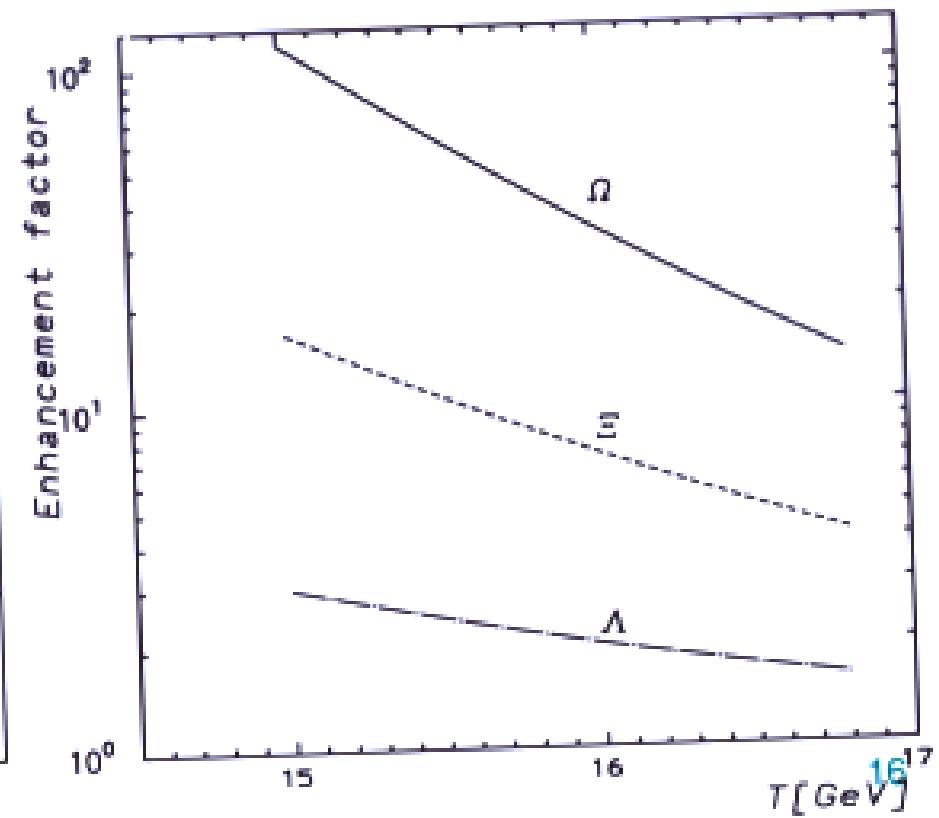
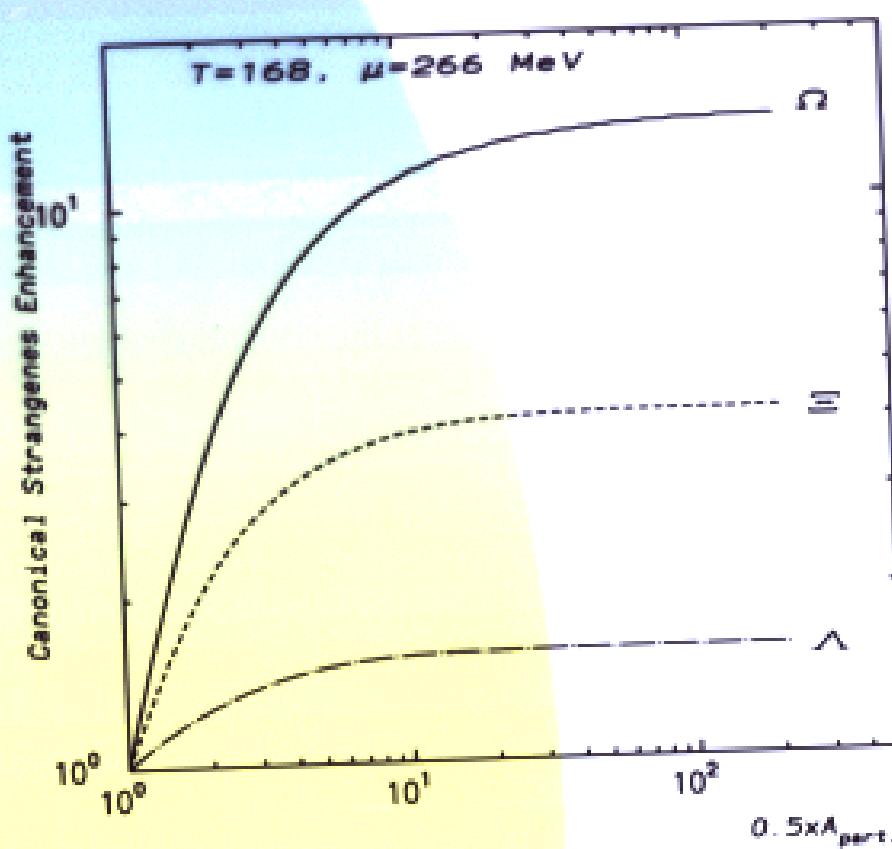
$$w_S \sim \int d^3 p e^{-\beta E_S}$$



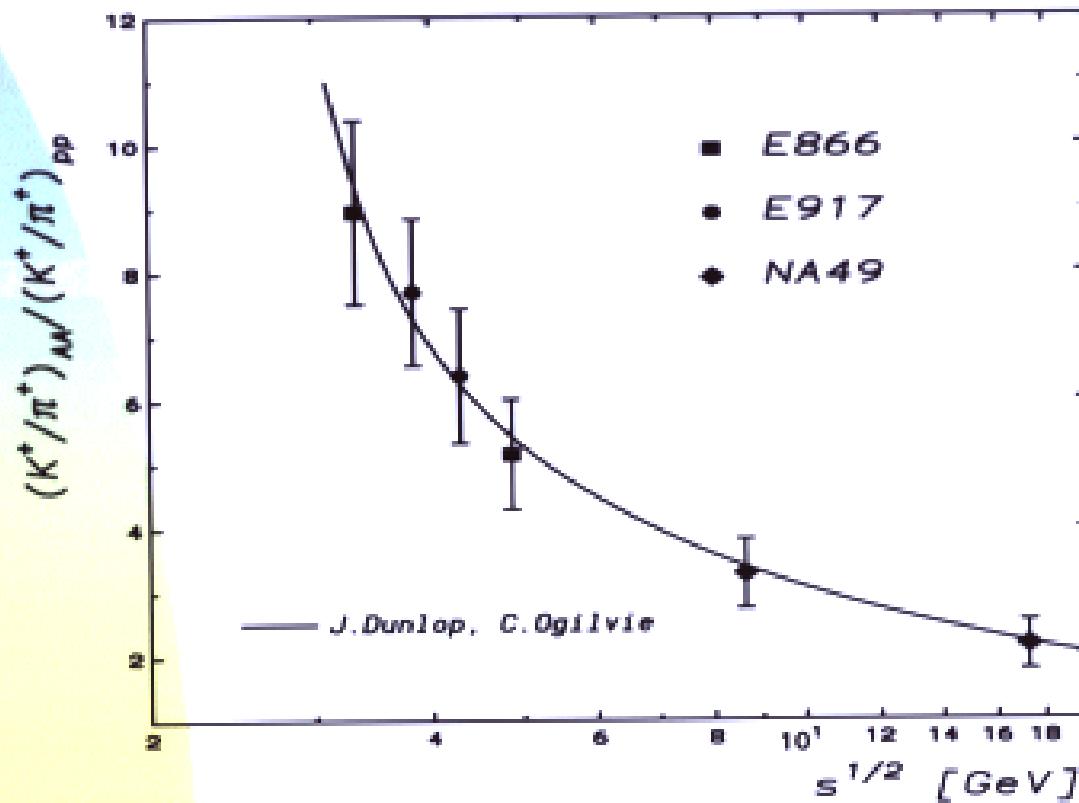
$$\frac{\langle N_S \rangle^C}{V} \approx \begin{cases} V_0 w_{S=1} \gg 1: & w_S \\ V_0 w_{S=1} \ll 1: & w_S \{ [V_0 w_{S=1}]^{|S|} + \dots \} \end{cases}$$

Statistical Model – Centrality Dependence

approaching asymptotic -
grand canonical limit

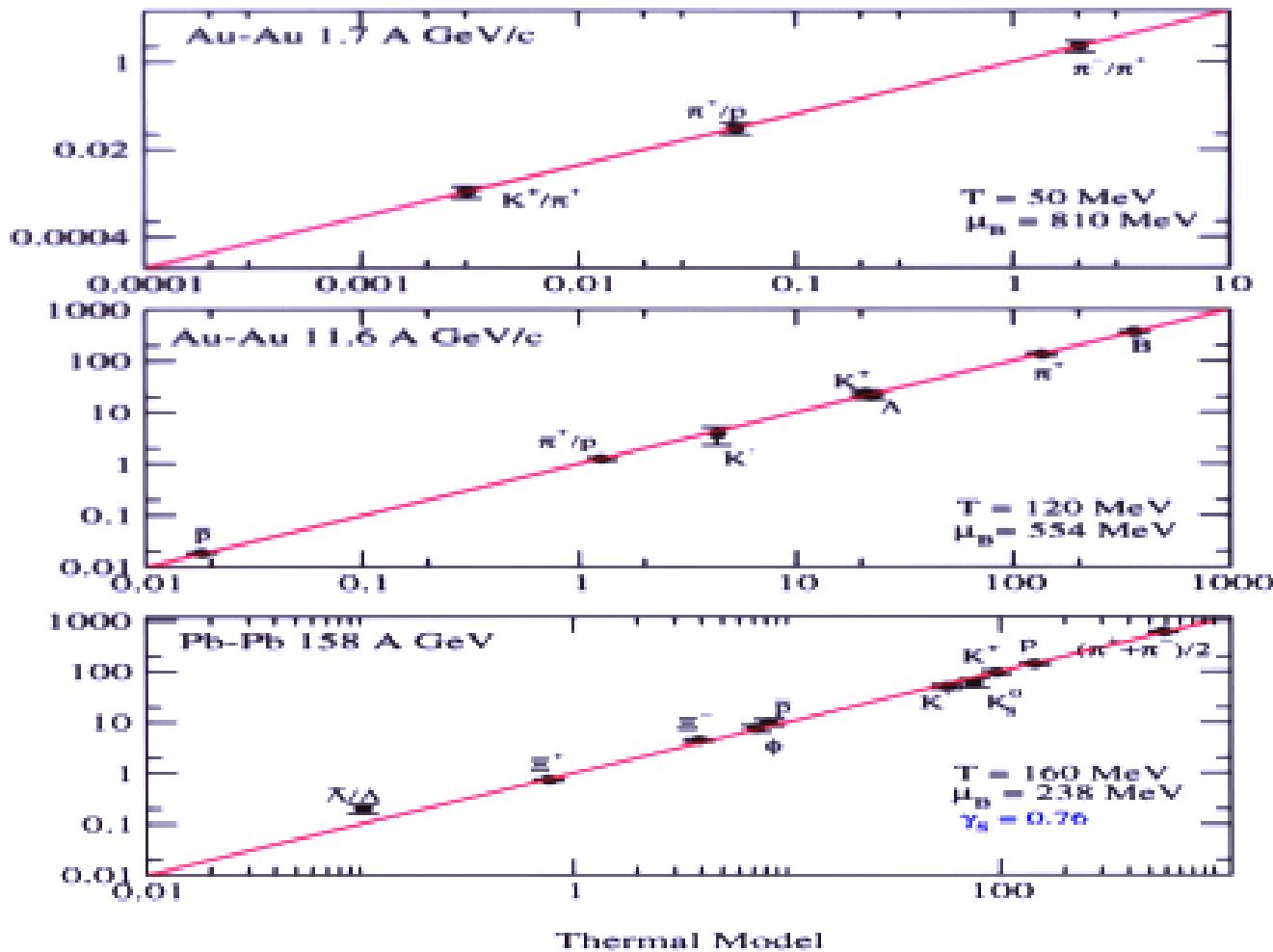


Strangeness enhancement pp => AA energy dependence



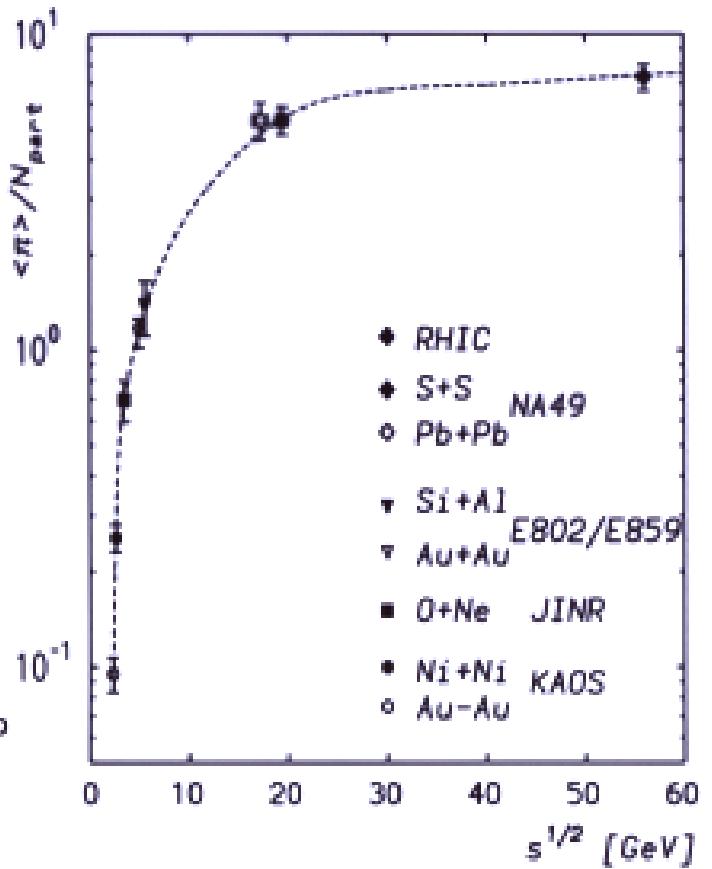
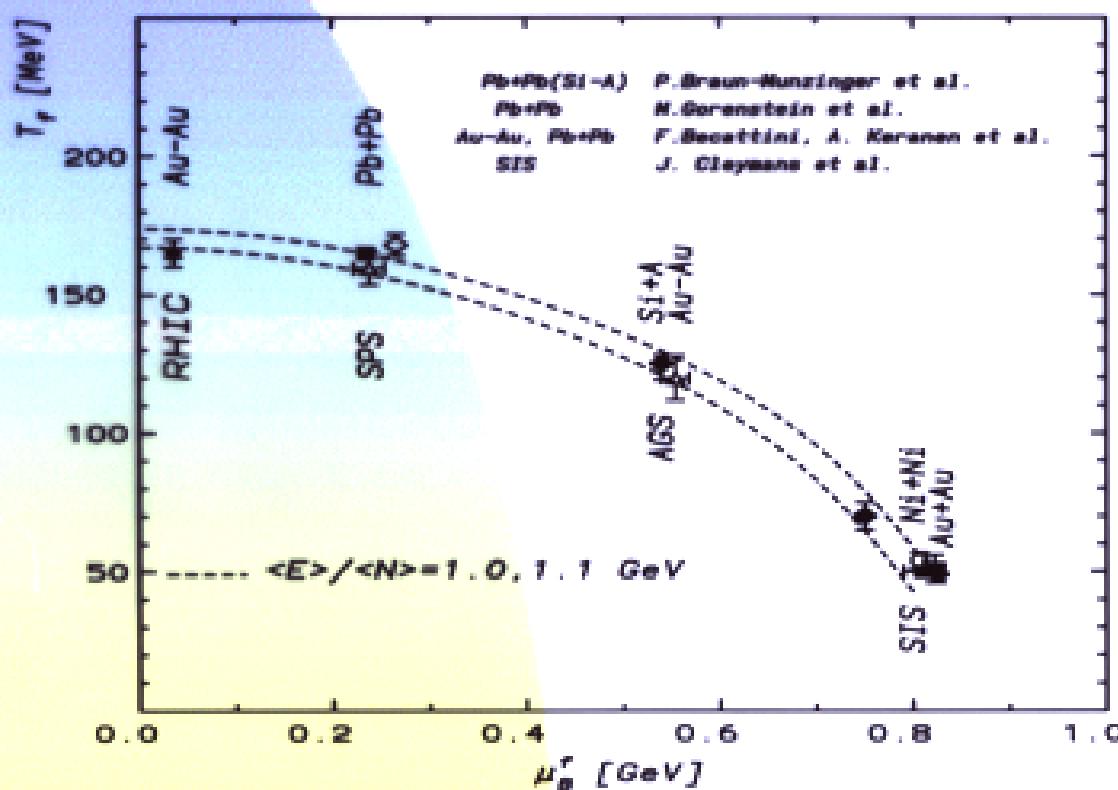
Chemical Equilibrium SIS - AGS - SPS

F. Becattini, J. Cleymans, A. Keranen, H. Oeschler, E. Suhonen, et al..



Unified freeze-out curve from SIS => RHIC

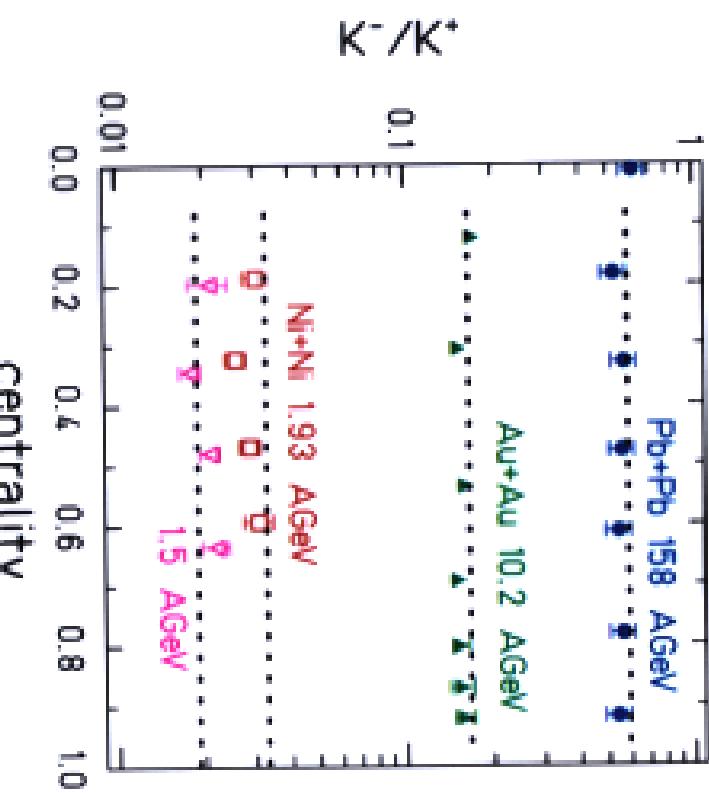
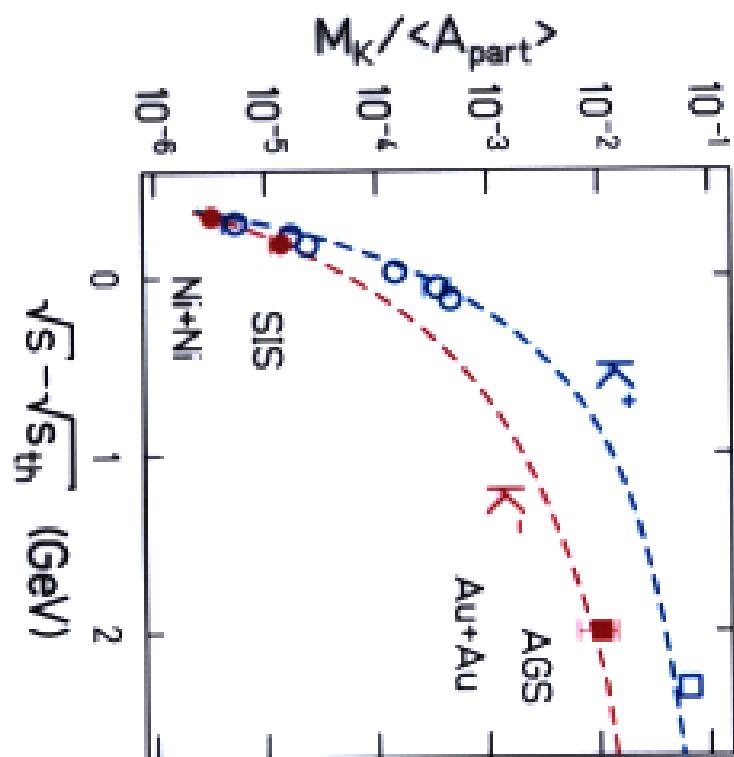
J. Cleymans, K.R



$$\langle E \rangle / \langle N \rangle = \langle m \rangle + 3T/2$$

Kaon Production from SIS to SPS

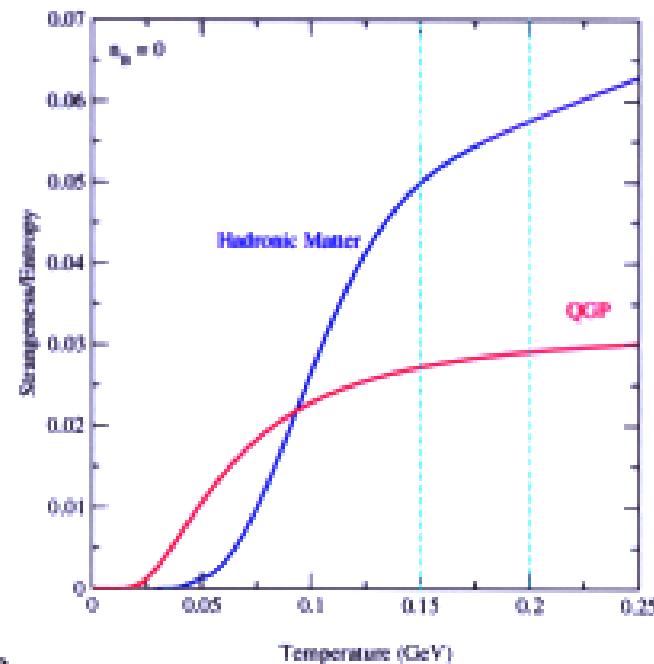
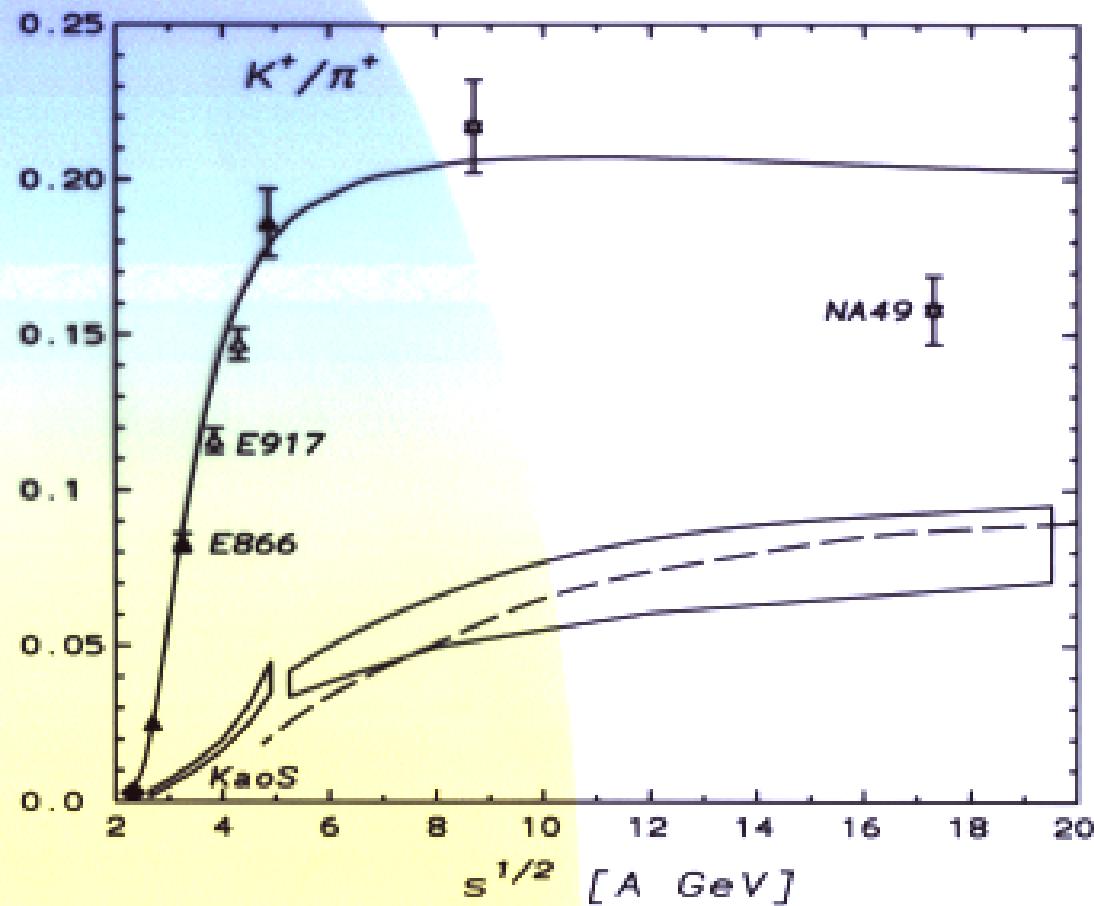
H. Oeschler et al.



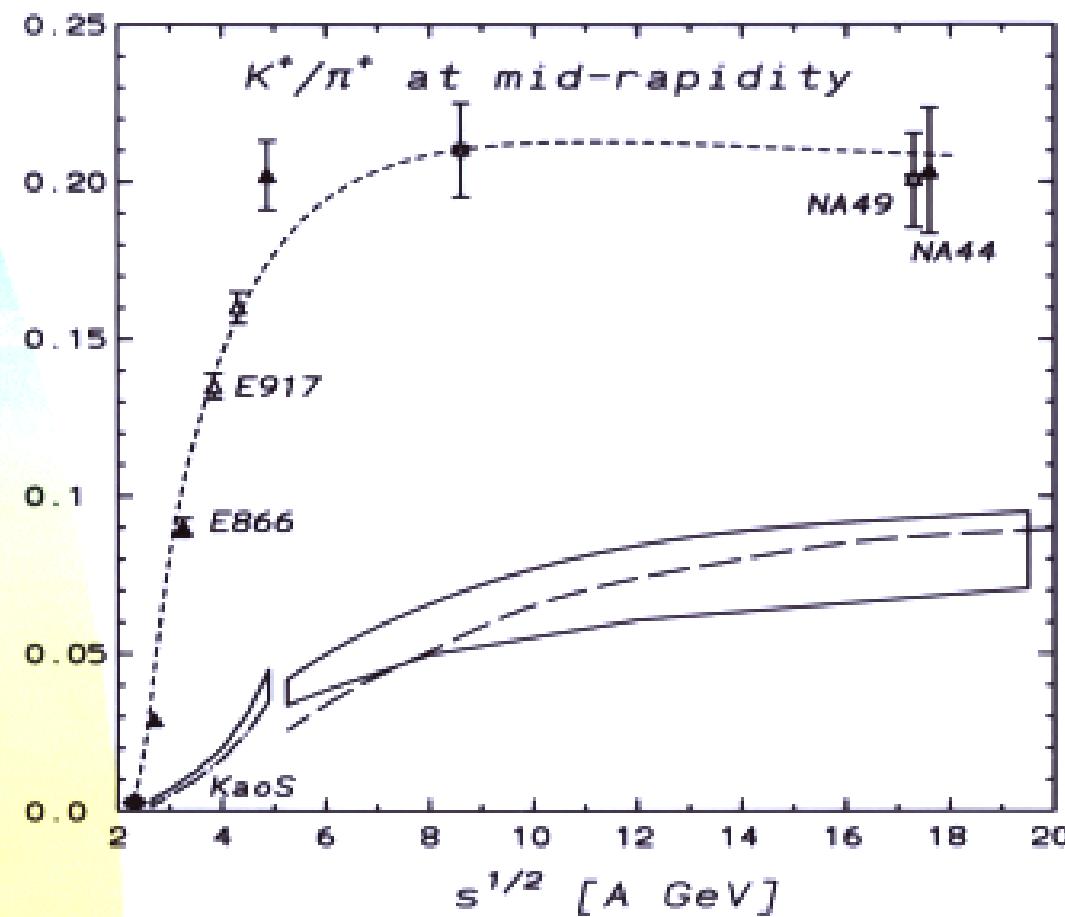
Strangeness suppression from 40 – 158 AGeV

4π data

model predictions by:
M. Gazdzicki, D. Roehrich



Mid-rapidity K^+/π^+ data do not show suppression from 40 =>158GeV



Conclusions

SPS data are consistent with the predictions of QGP

However: these predictions **are not a unique signal for deconfinement:**

- Chemical equilibrium population of hadronic yields observed in A-A collisions from SIS, AGS, SPS to RHIC
- Strangeness enhancement already appears in p-A
- Enhancement (K^+/π^+) from p-A to A-A collisions increases with decreasing \sqrt{s}
the above also expected for multistrange baryons?

- Suppression of K^+/π^+ (NA49 4π data) from 40 \Rightarrow 158 AGeV Pb-Pb collisions could signal new dynamics