Strangeness production at AGS and SPS

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Outline – December 2005

"Strangeness is a vast subject." F.Antinori, proceedings QM04

- motivation
- data FAIR
  - (SIS), AGS, SPS, (RHIC)
  - particle yields, spectra, flow, fluctuations, (high-p_t, correlations)
- strangeness production at top SPS energy (158 AGeV)
  - system-size dependence

largest amount of data

- energy dependence of strangeness production
- summary

Outline

- summary december
- new data (see SQM06): yields (+ rapidity and p_t-distributions)
  elliptic flow
  fluctuations

- yields
  → hadron gas model fits: s-undersaturation at 158 AGeV (no γ_s)?
  → ... s-oversaturation at lower SPS energies (γ_s)?
  → inhomogeneous freeze-out?
  → equilibration?
- energy dependence of size-dependence of relative s-production
- elliptic flow
- particle ratio fluctuations (K,π)

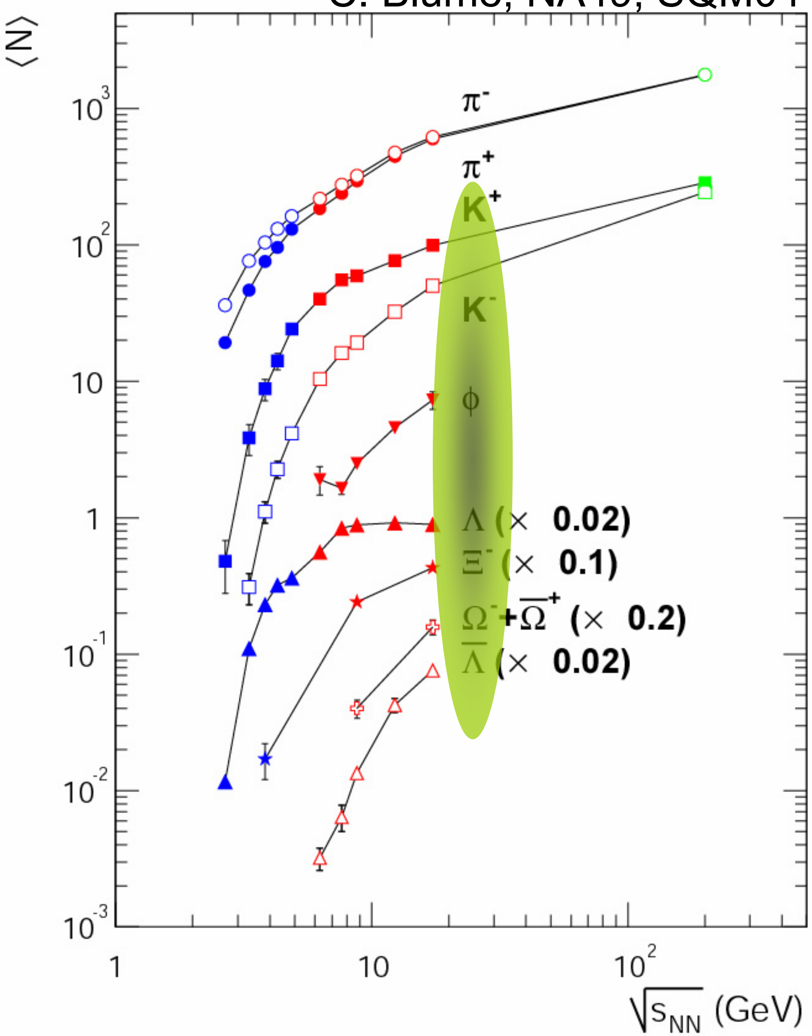
Summary – December 2005

- (selected) overview on strangeness production from AGS, SPS experiments
- "most" of the particles are strange:
  understanding strangeness production → learn about "bulk" hadron production
- particle yields/ ratios well described by (~) chemically equilibrated hadron gas
  for smaller systems take smaller hadronization volume into account (properly !)
  → strangeness enhancement due to release of canonical s-suppression
  interesting: change of "shape" of s-increase with centrality for lower energies!
- distinct features observed in energy dependence of (strange) particle production
  maximum in relative s-production at ~30 AGeV
  step-like structure in $\langle m_t \rangle$-values in SPS energy range
- strong common transverse flow: earlier kinetic decoupling in peripheral Pb+Pb?
  earlier decoupling of Ω in central Pb+Pb?
  "ϕ-puzzle" solved: no difference between hadronic and leptonic decay channel
  elliptic flow of Λ
  K/π fluctuations

Particle yields

• central Au+Au, Pb+Pb

→ extract hadrochemical freezeout parameters (T, μ_B)

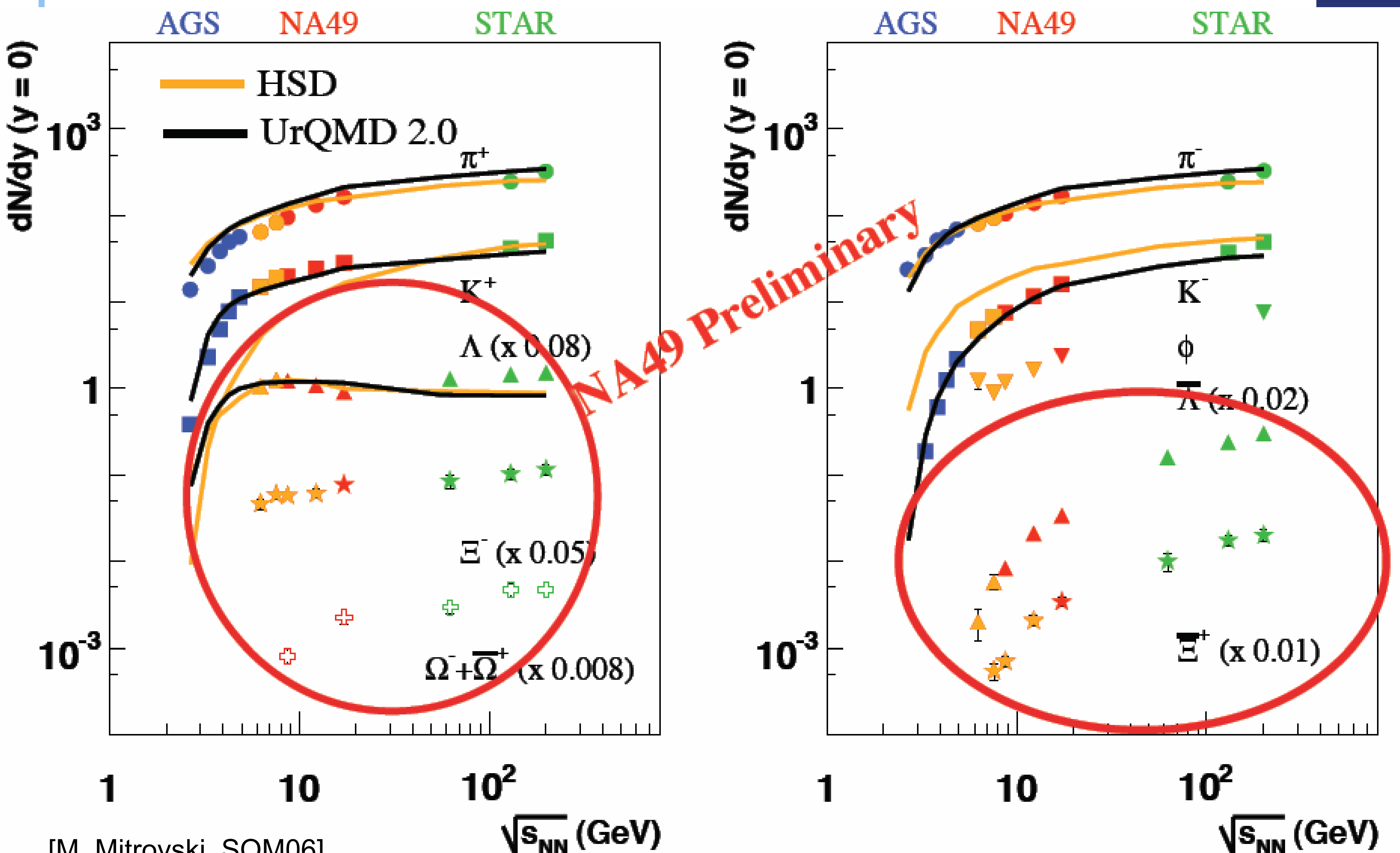


understanding strangeness production ↔

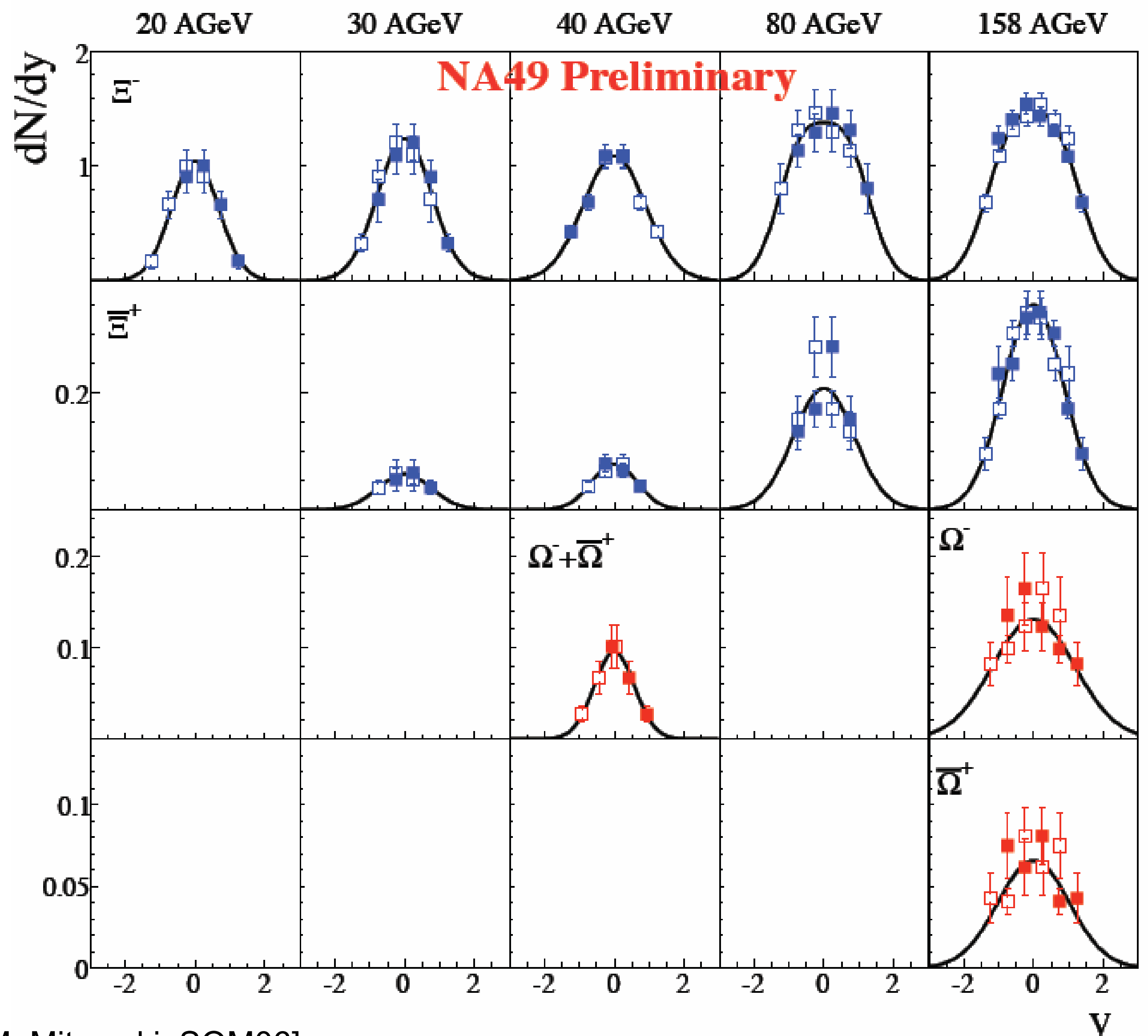
understanding (bulk) hadron production: mechanism, environment, ...

4π multiplicities only

New data on Ξ production from NA49



[M. Mitrovski, SQM06]

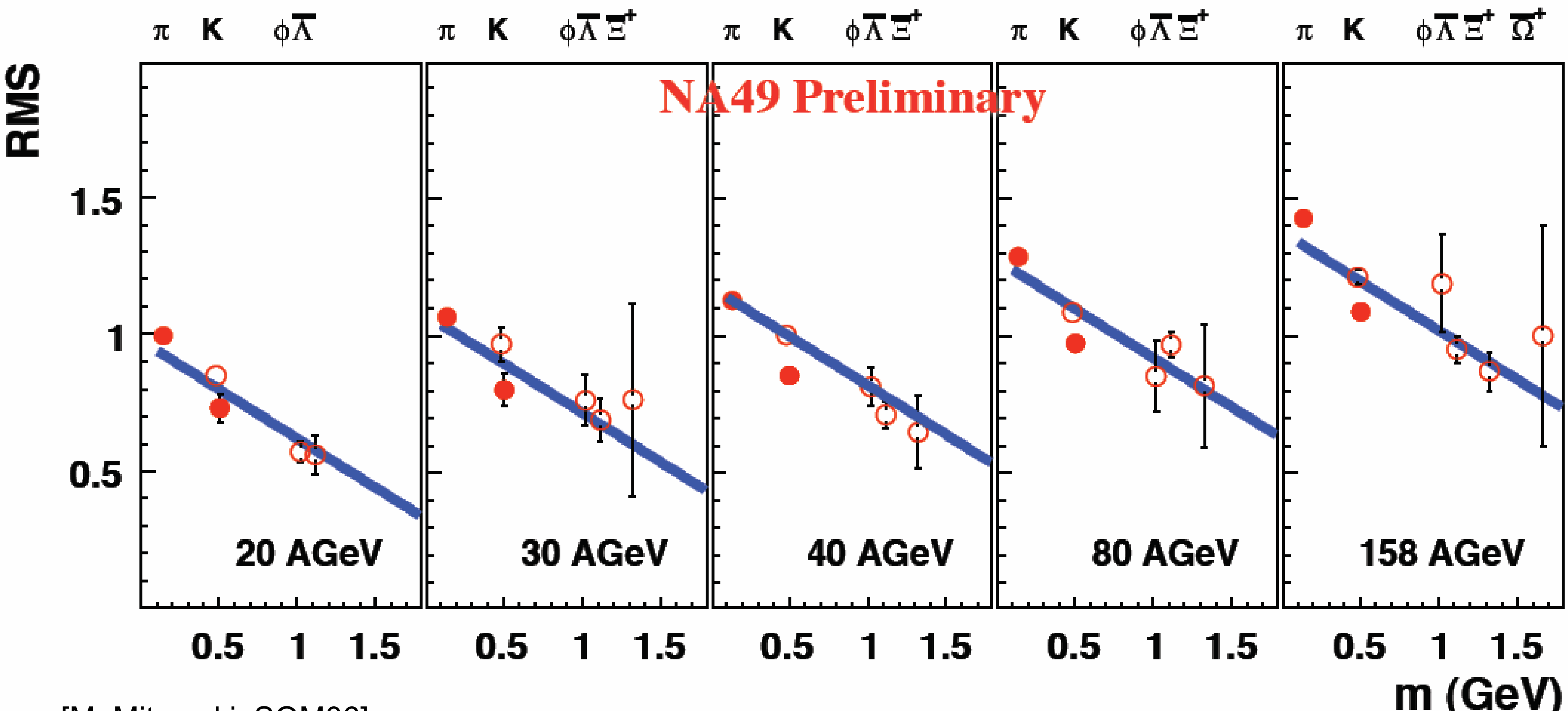


approximately gaussian shape

[M. Mitrovski, SQM06]

Mass dependence of rapidity width

- ~ linear dependence on particle mass for mesons and antibaryons
- similar slope at all SPS energies
- explainable by hydro-inspired models?

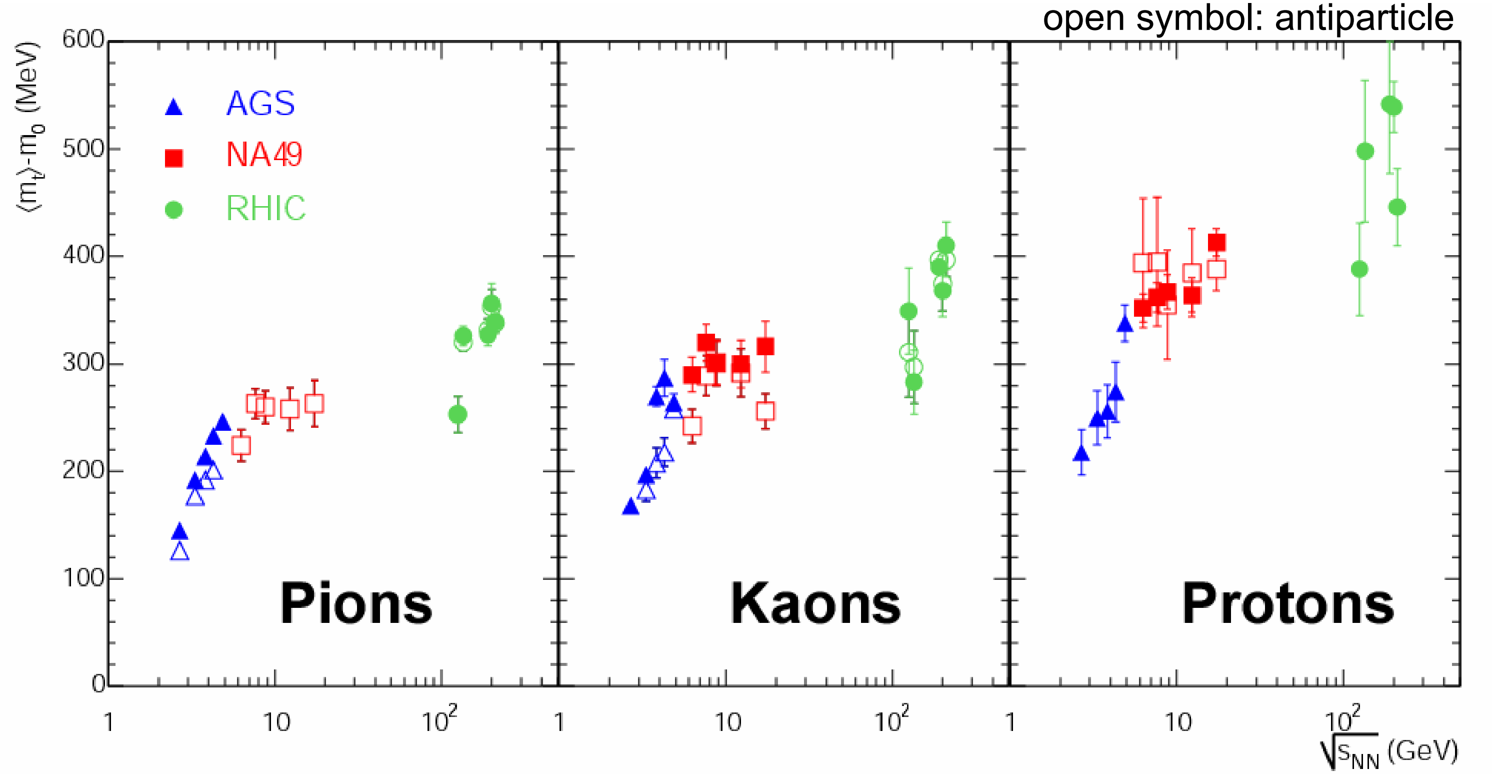


[M. Mitrovski, SQM06]

Mean transverse momenta vs. energy

- energy dependence of $<m_t>$ changes at lower SPS energies
- not described by HSD, UrQMD but by Hydro models with phase transition
- seen for pions, kaons, protons and their antiparticles ...

filled symbol: particle
open symbol: antiparticle

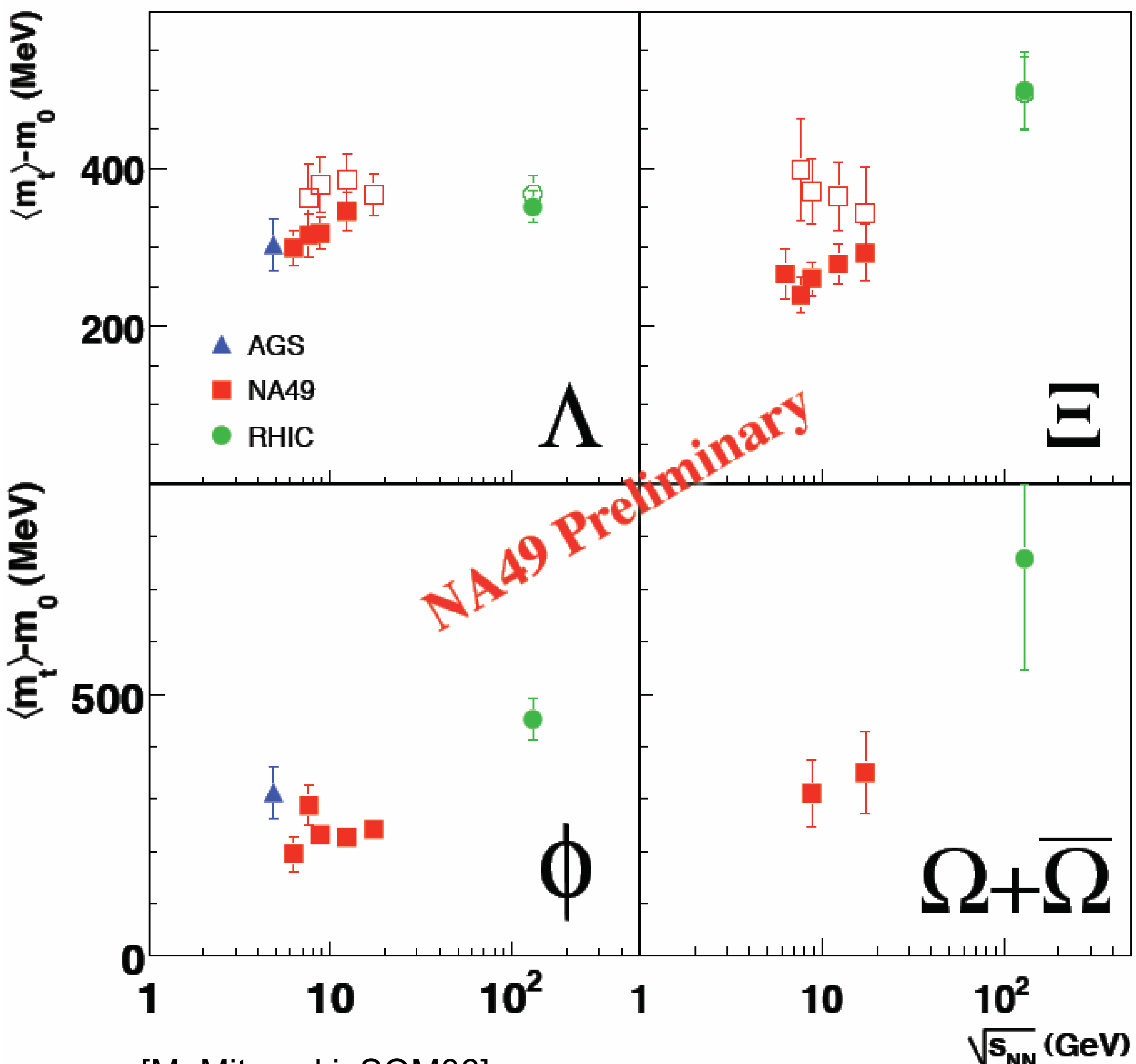


C. Blume, NA49, SQM04

Mean transverse momenta vs. energy (II)

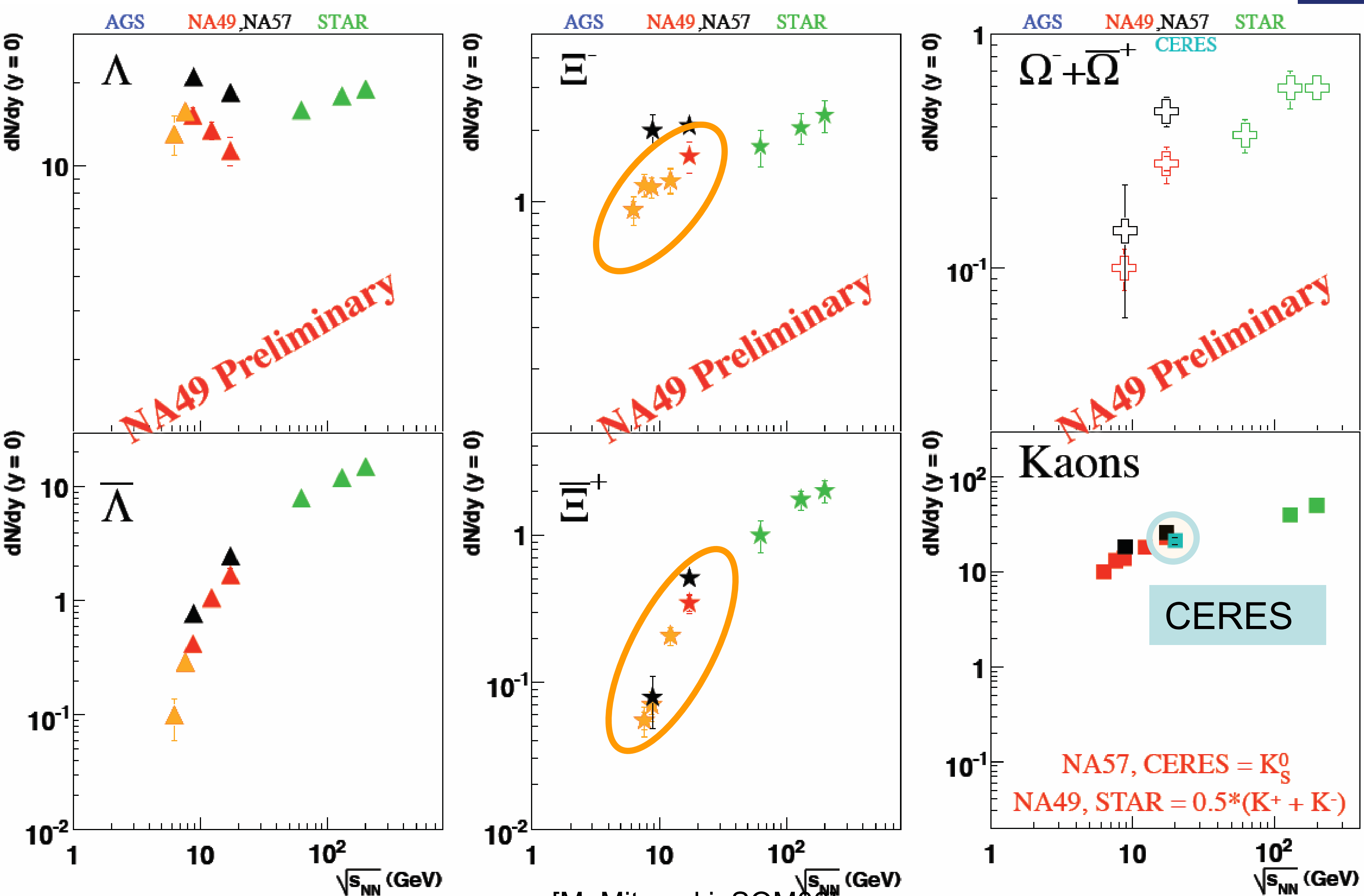
... and (more or less) seen for other strange particles as well!

- AGS measurements missing for complete picture!



[M. Mitrovski, SQM06]

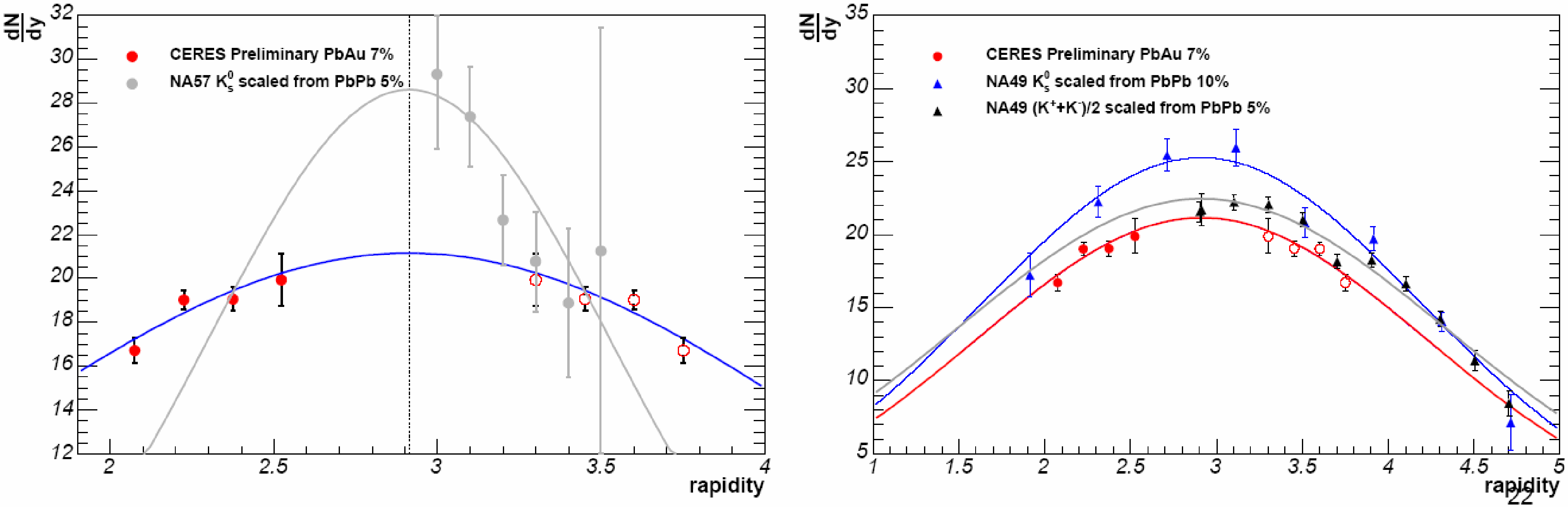
Midrapidity yields vs. energy



[M. Mitrovski, SQM06]

K^0_S at 158 AGeV from CERES

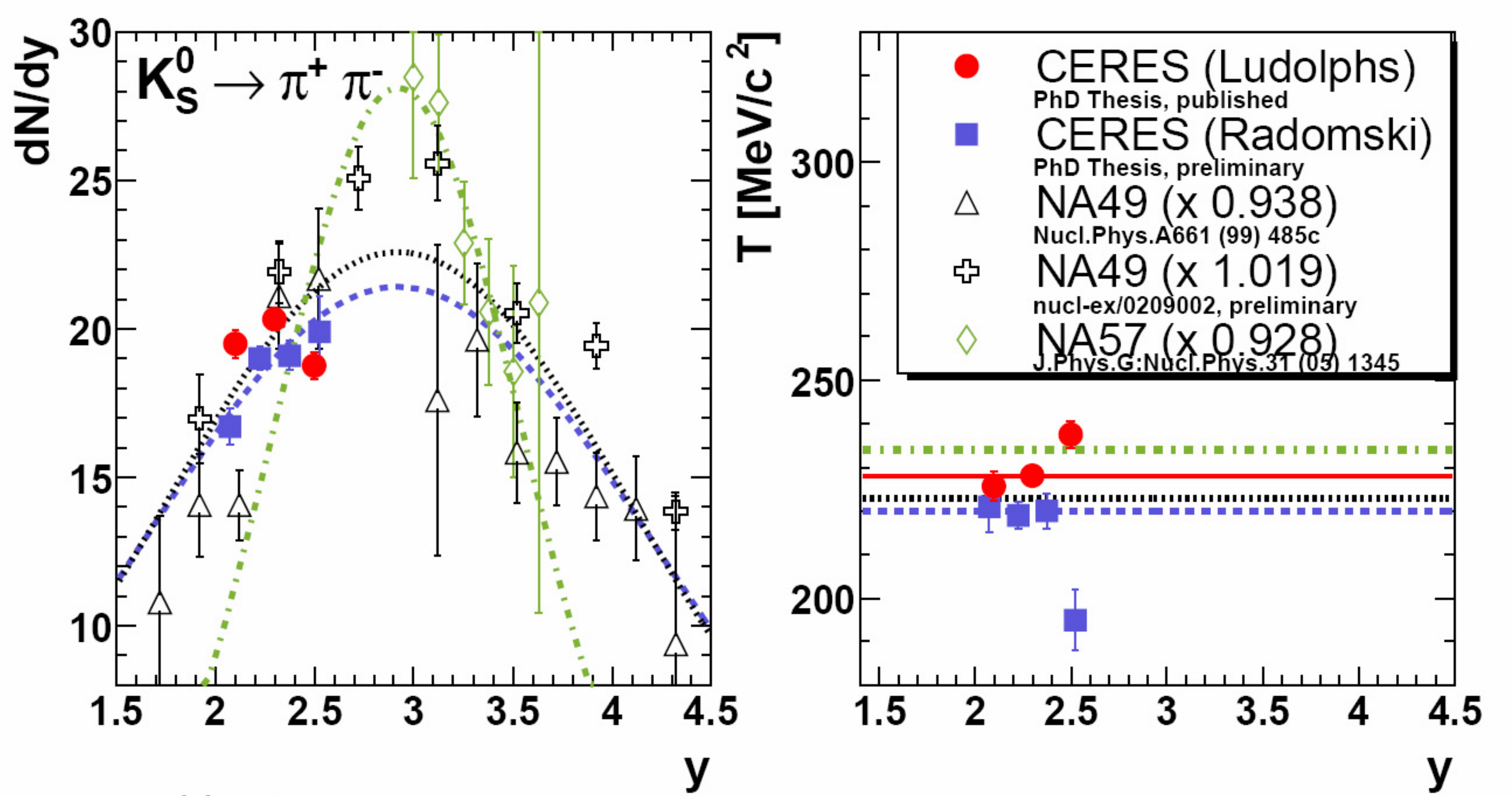
- 2 independent K^0_S analysis for 7% central Pb+Au collisions from CERES
  - reconstruction without PID and 2nd vertex reconstruction
  - reconstruction without PID but with 2nd vertex reconstruction
- ~ agreement with NA57 for same y-bins but disagreement in fit
- rather good agreement to NA49 ($K^+ + K^-$) data (5% difference only)!



[J. Milosevic, SQM06]

K^0_S at 158 AGeV from CERES (II)

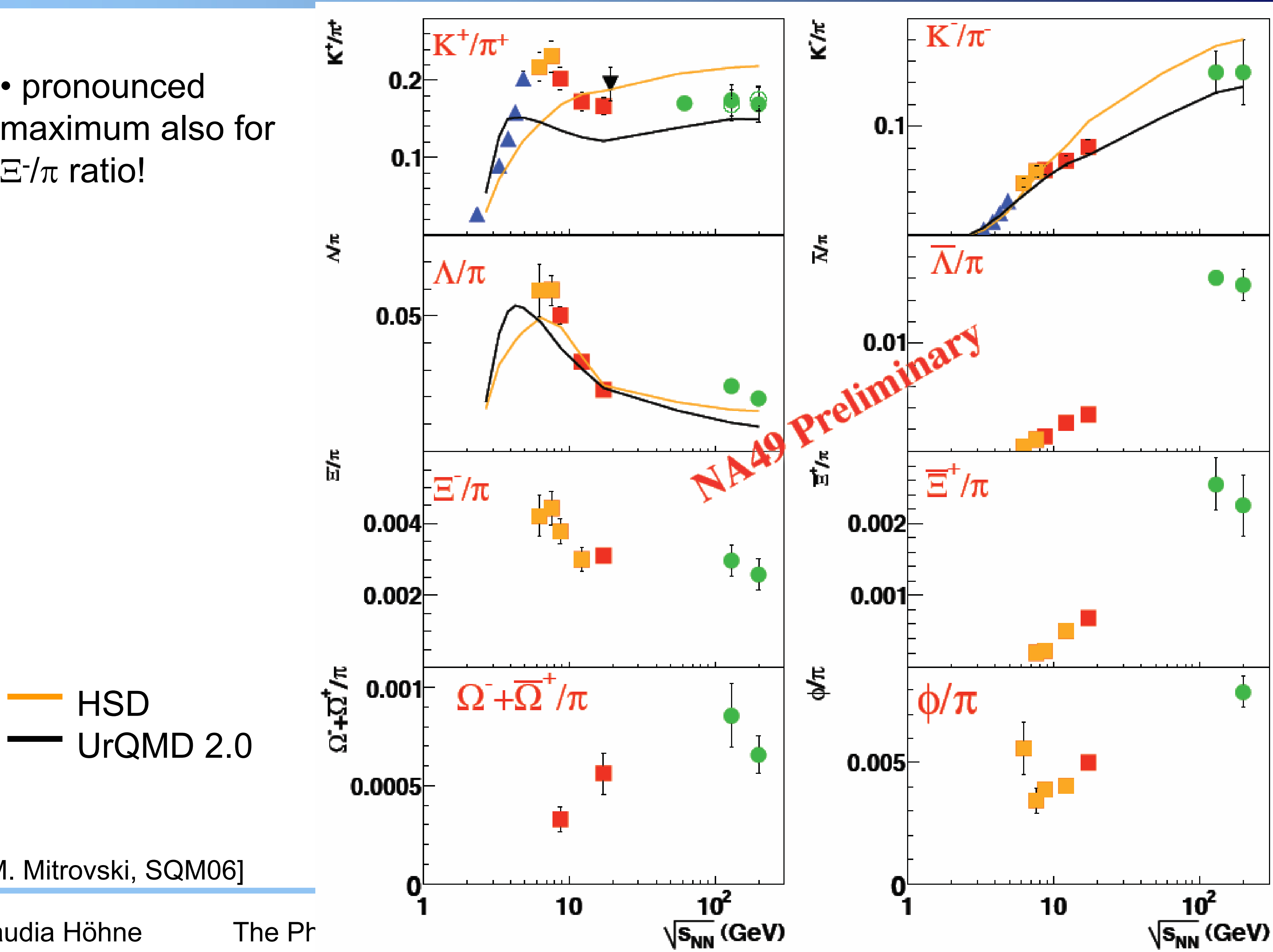
- good agreement of the 2 CERES analysis
- same temperatur as for NA49 (T = 230 MeV)



[J. Milosevic, SQM06]

Ratios – midrapidity yields

• pronounced maximum also for Ξ^-/π ratio!

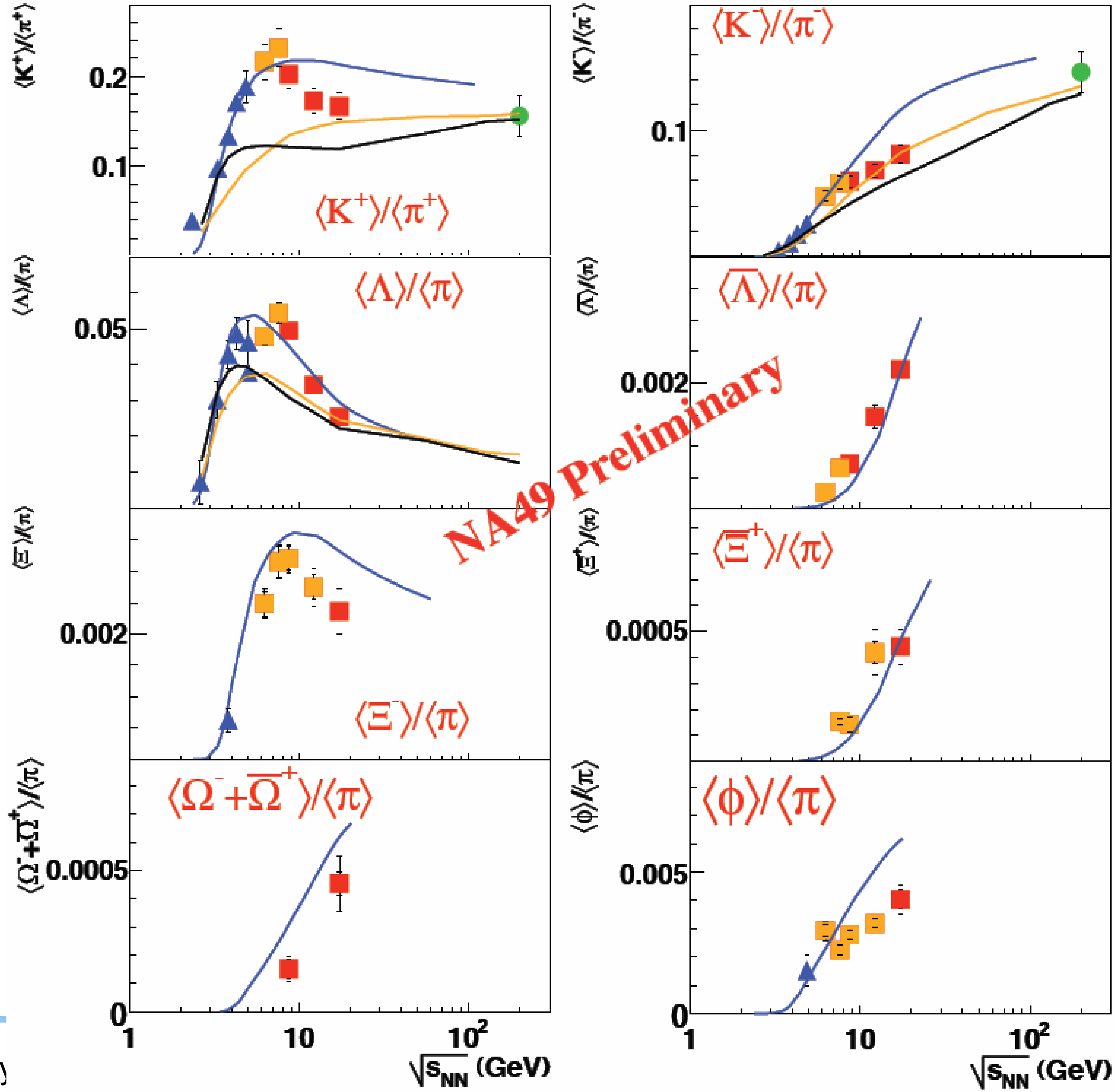


[M. Mitrovski, SQM06]

Ratios – 4π yields

- pronounced maximum also for Ξ^-/π ratio!
- disagreement with HSD/ UrQMD in particular at lower SPS energies
- disagreement to HGM in particular at higher SPS energies!

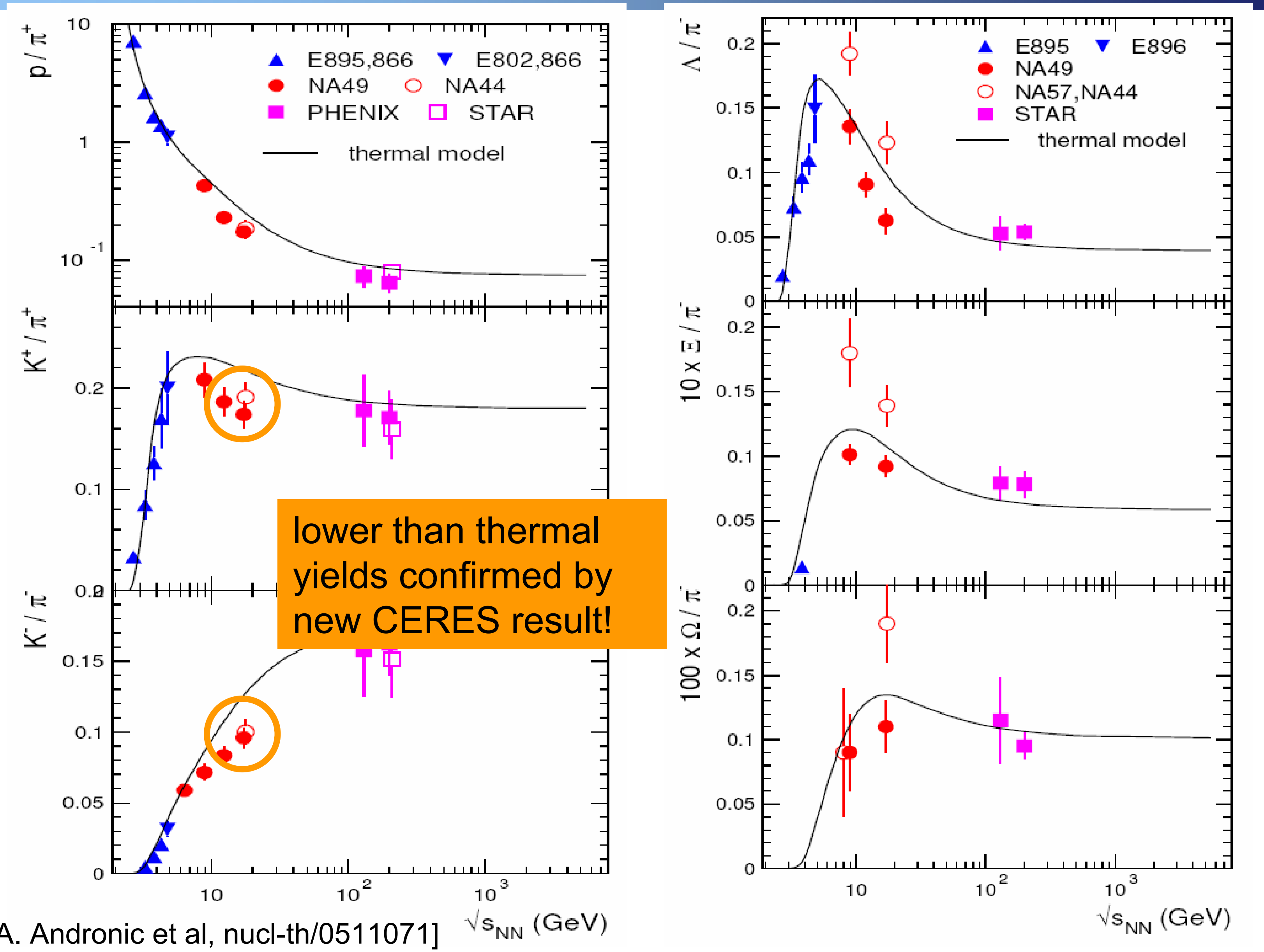
"s-undersaturation"



HSD
UrQMD 2.0
HGM

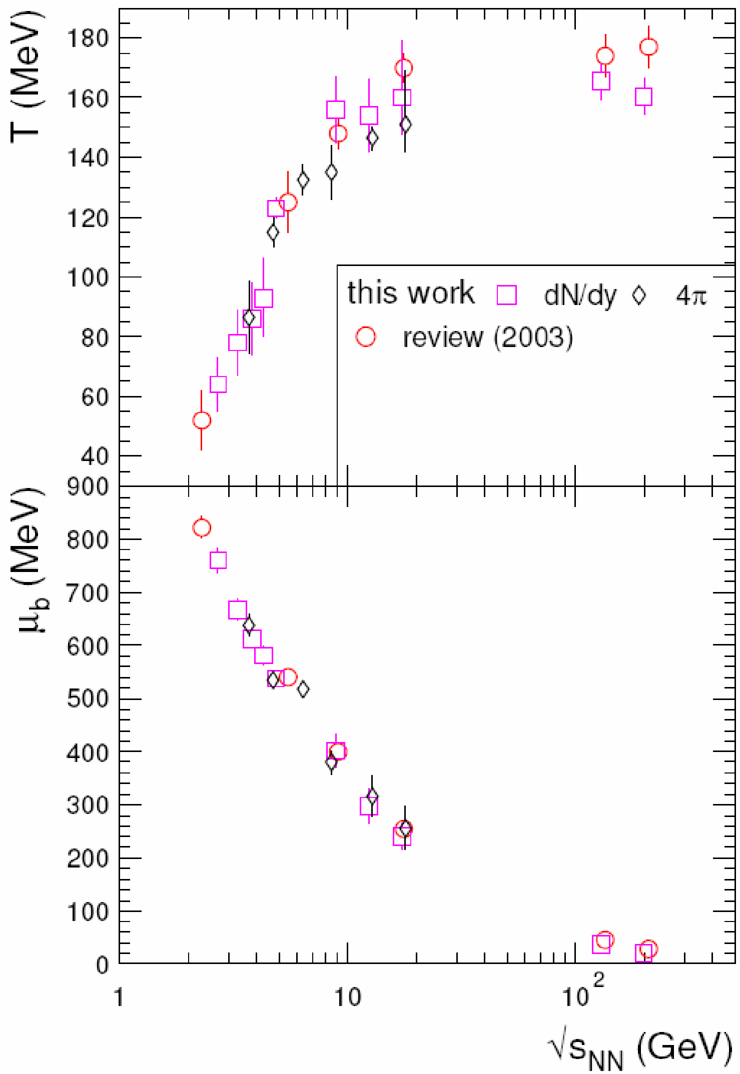
[M. Mitrovski, SQM06]

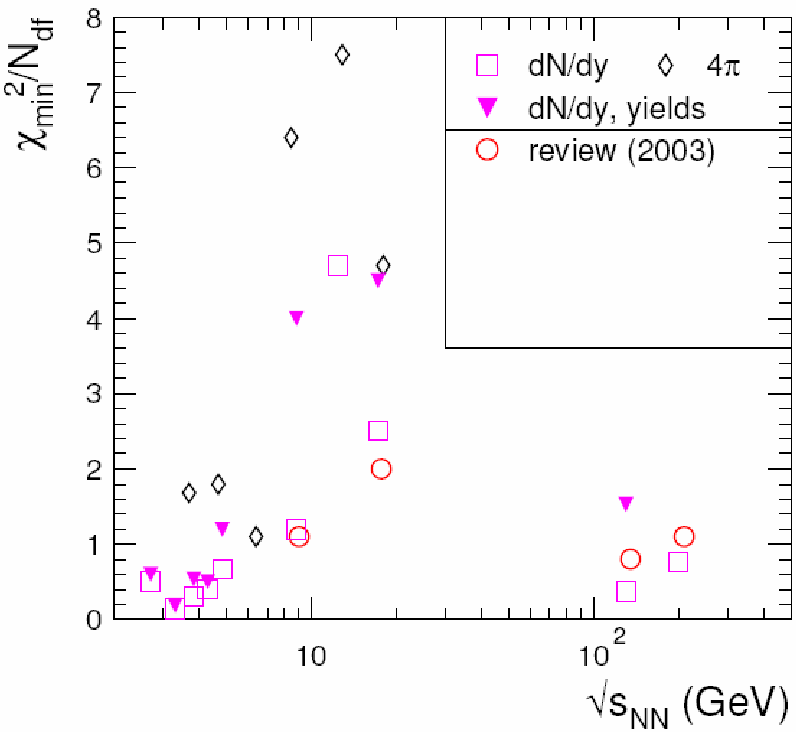
Particle ratios at midrapidity (HGM)



[A. Andronic et al, nucl-th/0511071]

Energy dependence of T,μ_B (HGM)

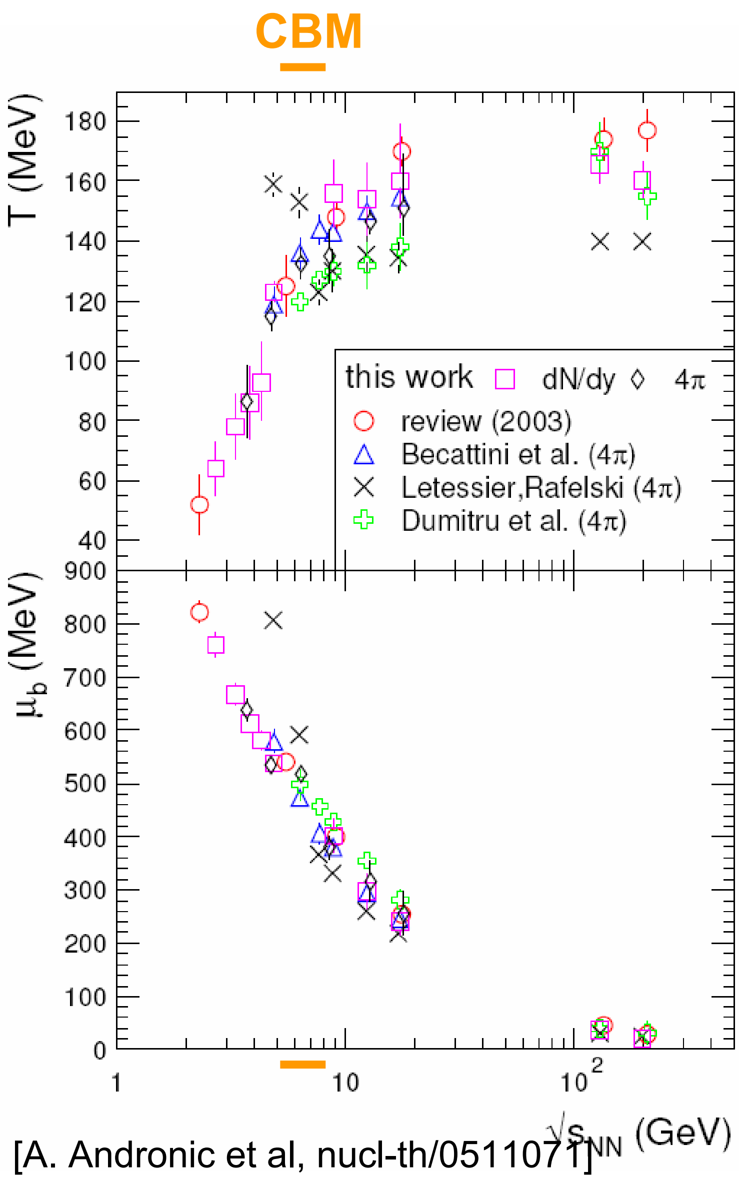




problems with fit quality at higher SPS energies

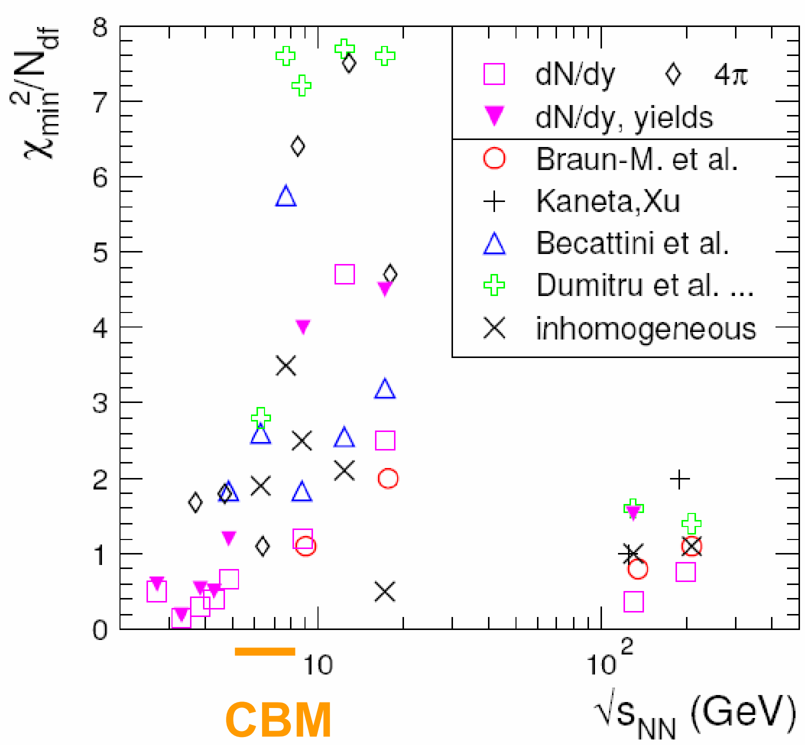
[A. Andronic et al, nucl-th/0511071]

Energy dependence of T, μ_B (HGM) (II)



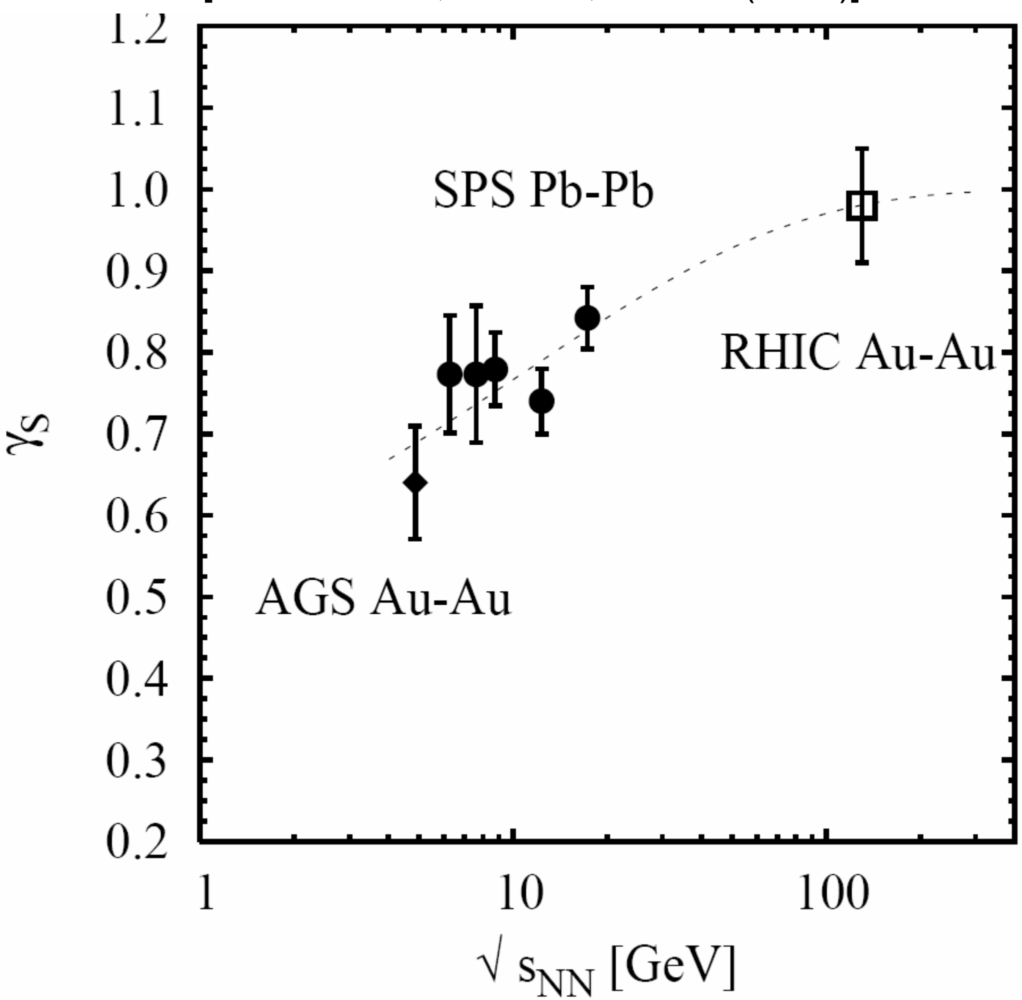
[A. Andronic et al, nucl-th/0511071]

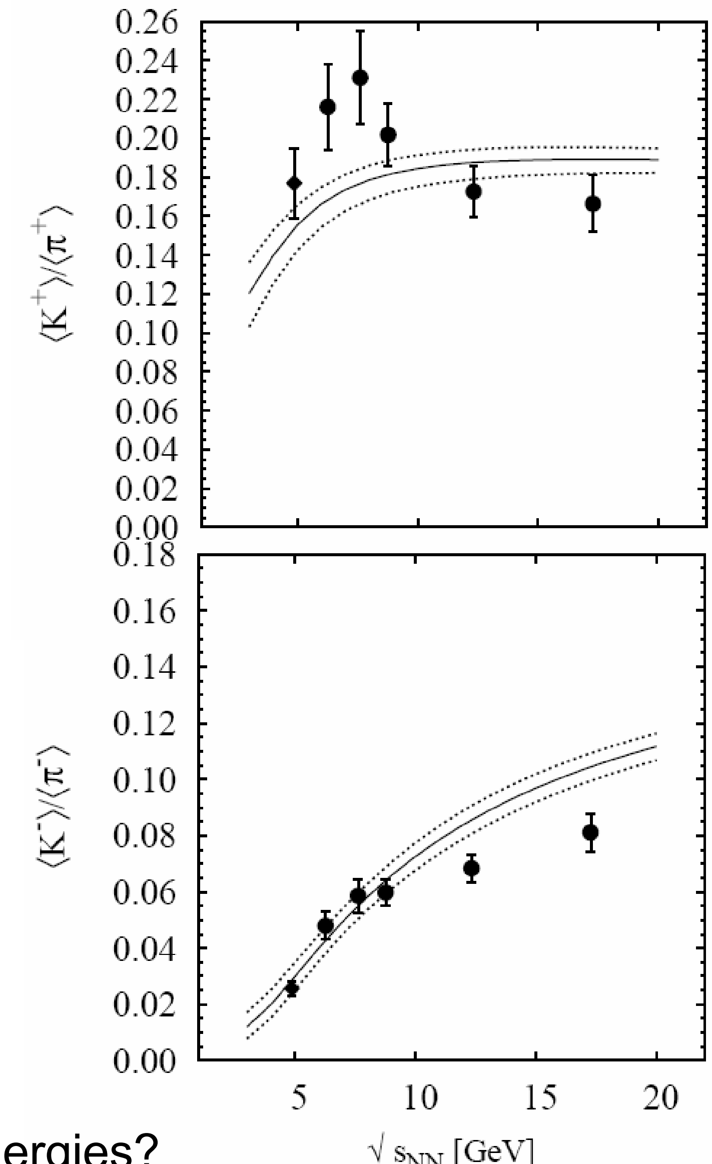
- Becattini et al.: $+\gamma_S$ (V) - hep-ph/0511092
- Rafelski et al.: T, V, $\gamma_{S,q}$, λ_{q,S,I_3} - nucl-th/0504028
  γ_S=0.18,0.36,1.72,1.64,...
  γ_q=0.33,0.48,1.74,1.49,1.39,1.47...
- Dumitru et al.: inhom. $(\delta T, \delta\mu_B)$ - nucl-th/0511084



Strangeness undersaturation parameter γ_s

[Becattini et al, PRC 73, 044905 (2006)]





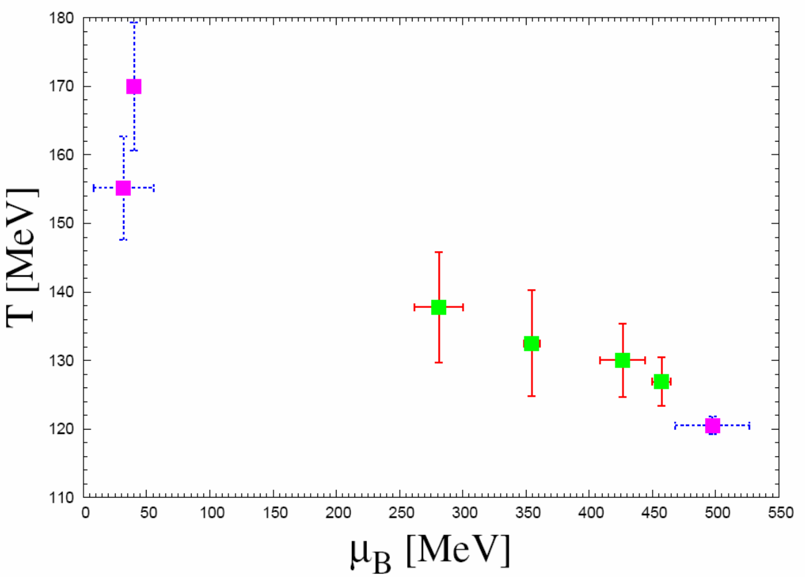
• lesson to learn from s-undersaturation at lower energies?

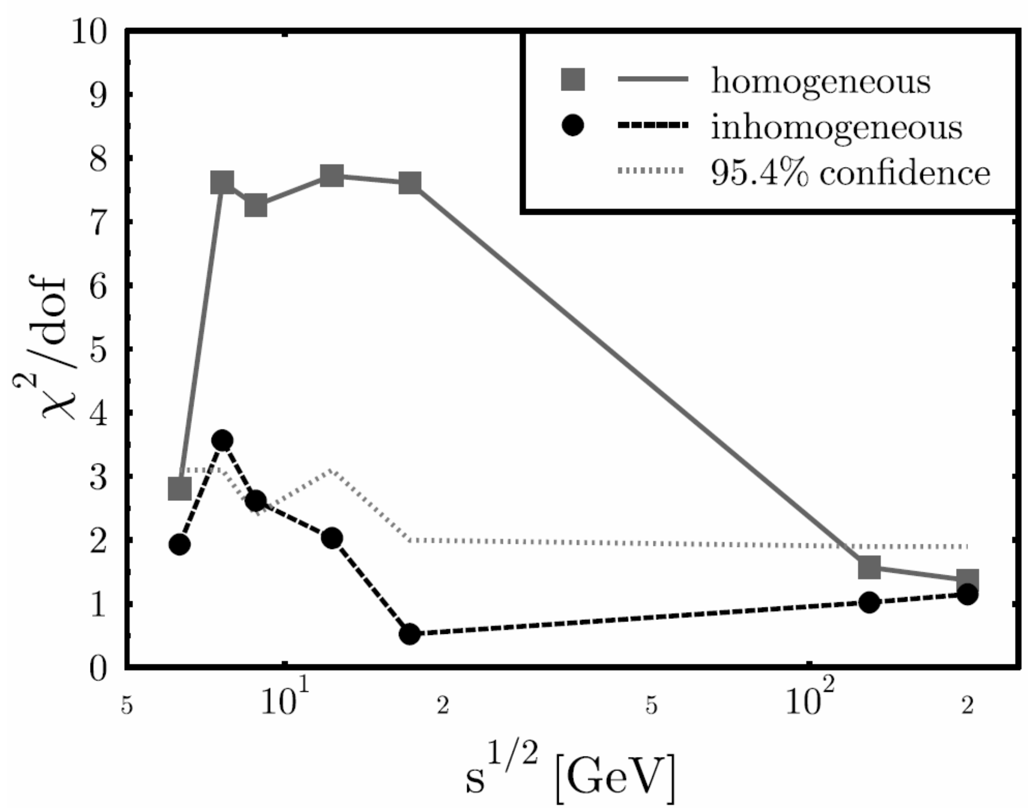
Inhomogenous scenario?

- Is there something to learn from these deviations? (equilibrium??)
- interesting ansatz: Dumitru el al, nucl-th/0511084
- allow for an inhomogenous fireball at chemical decoupling ($T, \delta T, \mu_B, \delta\mu_B$)

→ significant improvement in fit quality for 30 – 158 AGeV beam energy

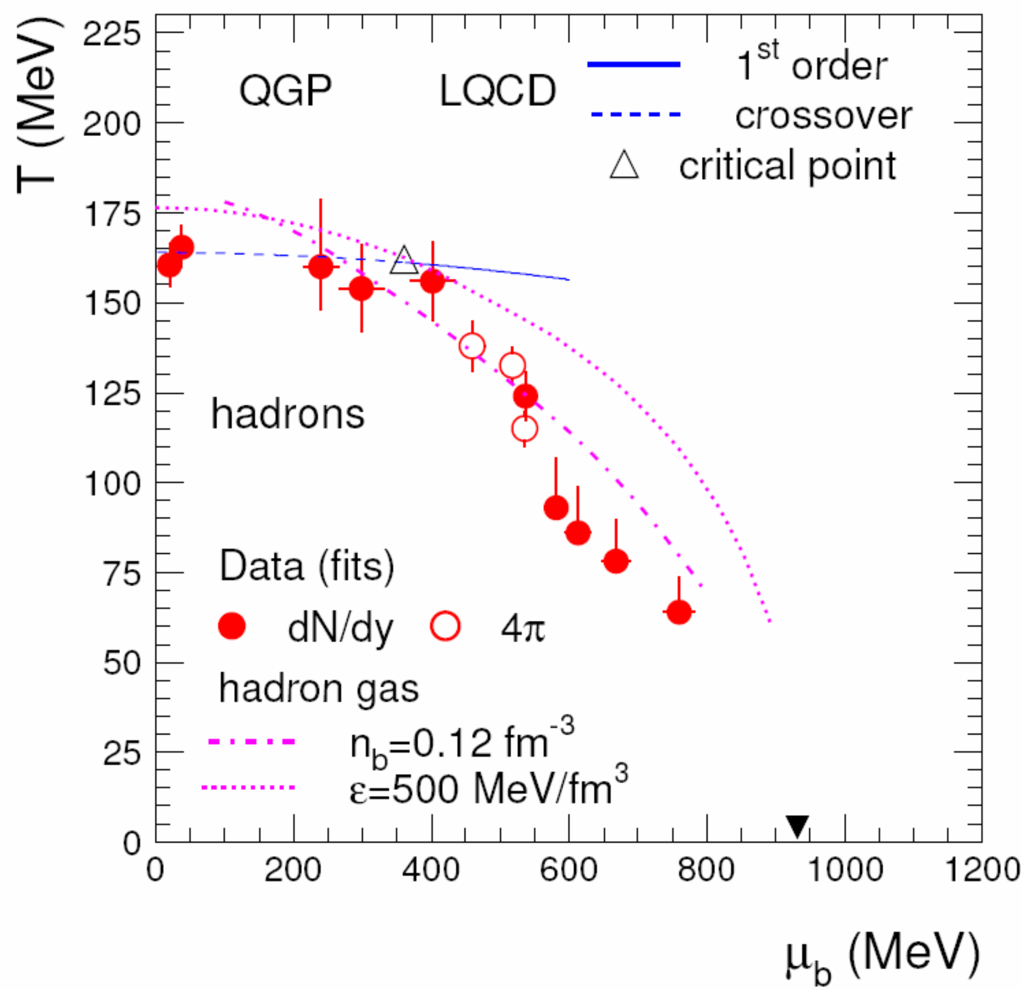
- relation to 1st order phase transition?





[Dumitru et al, Nucl-th/0511084]

QCD phase diagram



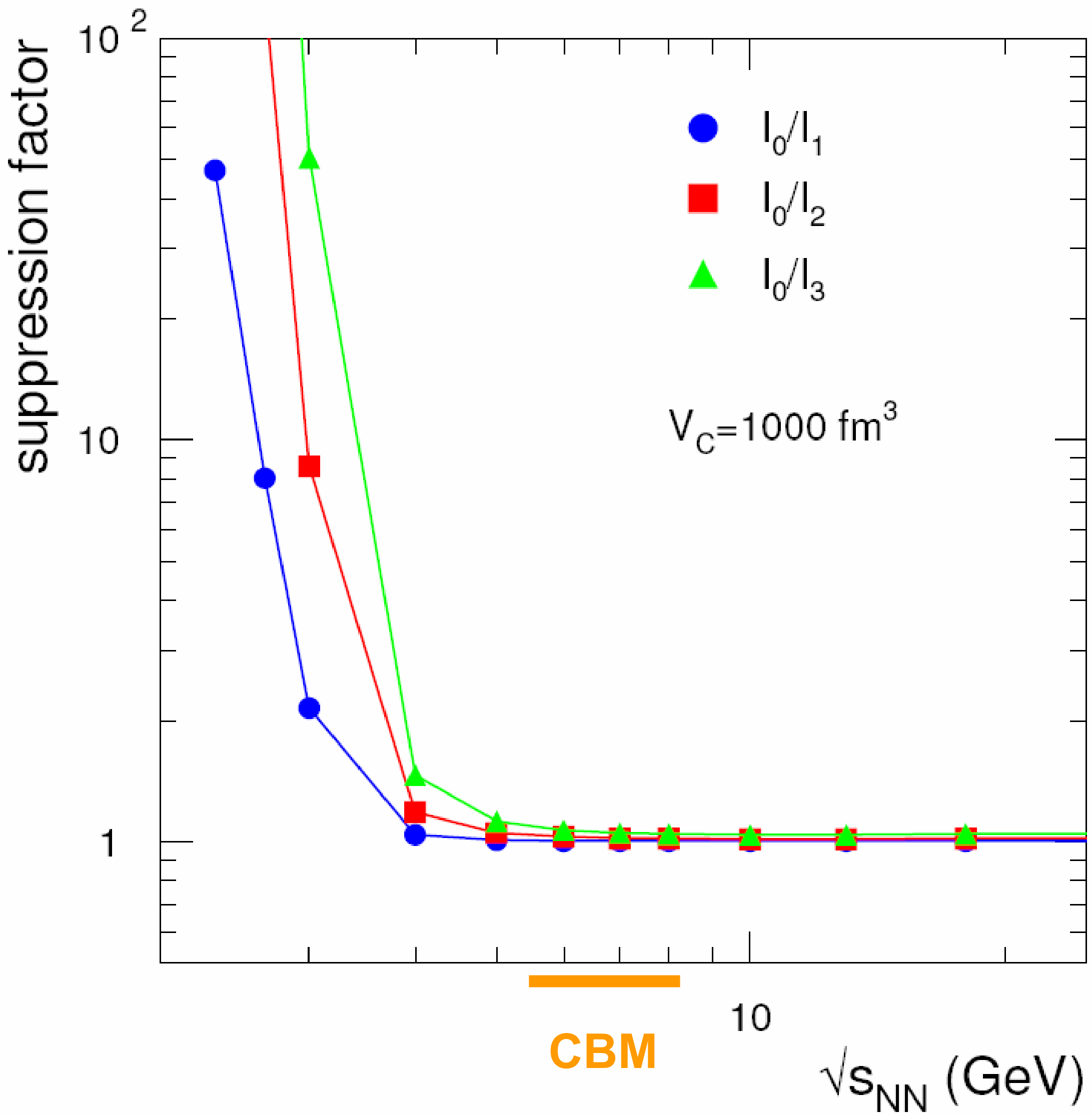
[A. Andronic et al, nucl-th/0511071]

- statistical model only way to put points on the QCD phase diagram
- different approaches agree rather well on (T,μ_B)

Canonical s-suppression

- (very low) energies: well defined case for s-undersaturaion
- for central Au+Au grand canonical ensemble applicable for CBM energies

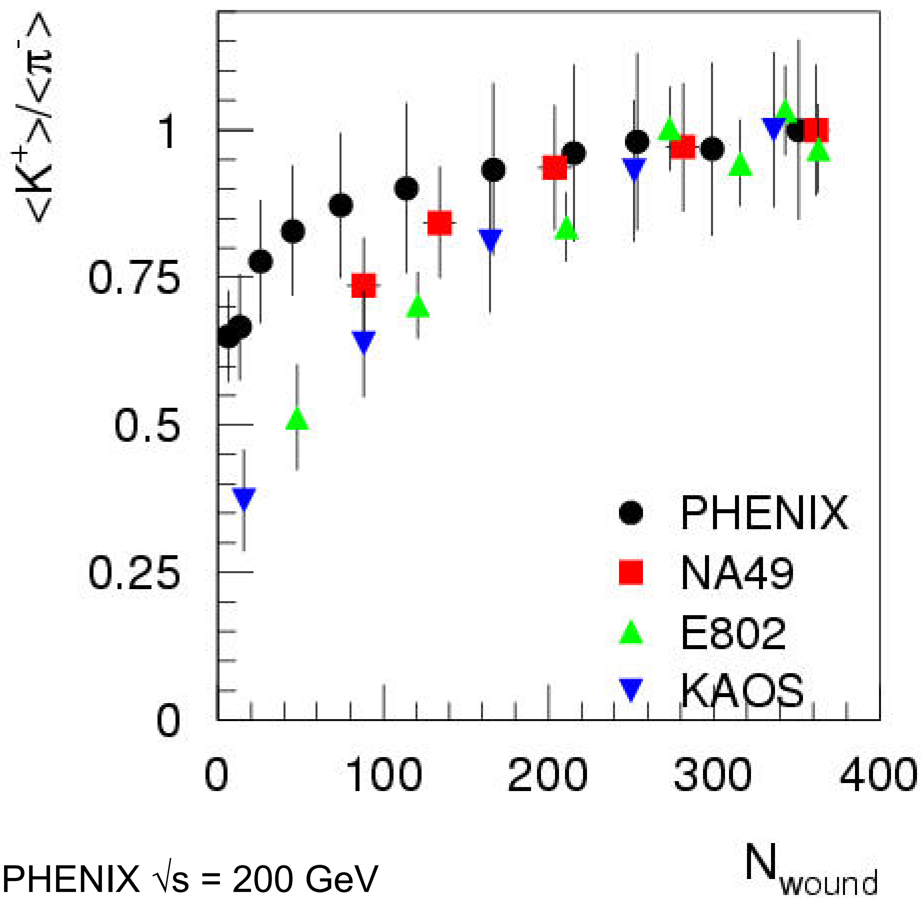
→ saturation of relative s-production expected with centrality/ size

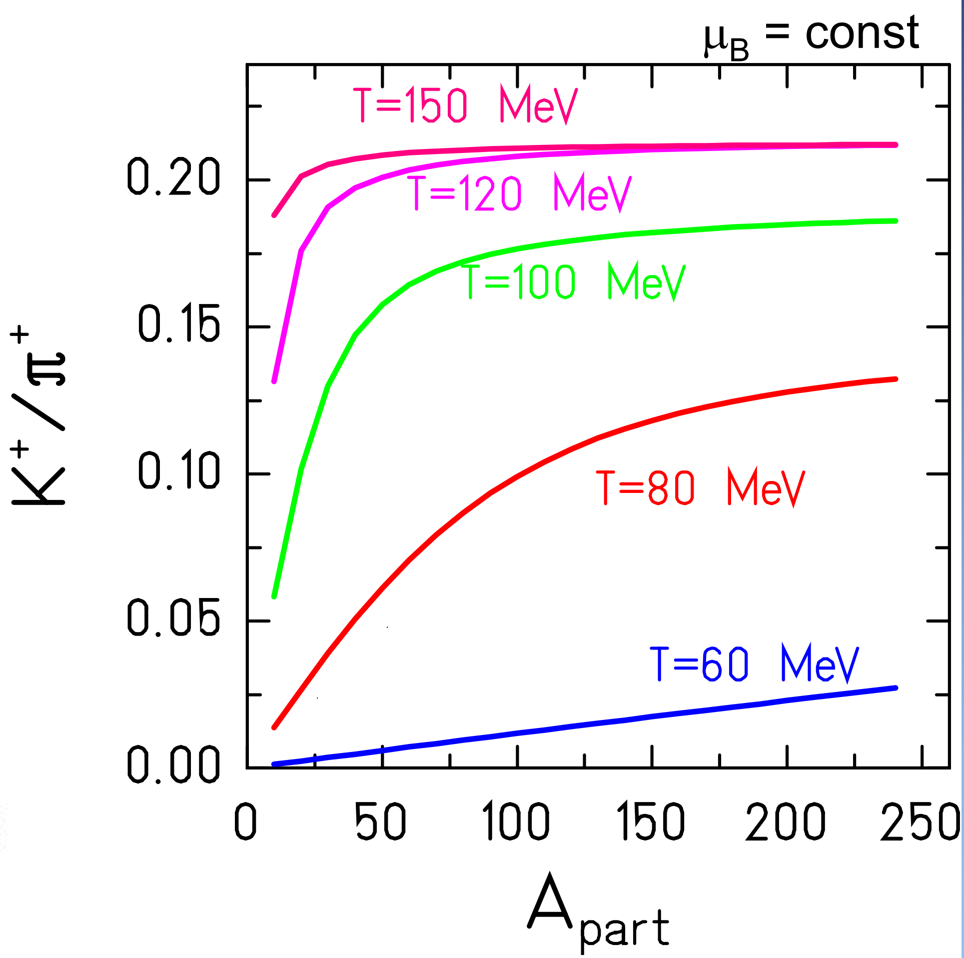


[A. Andronic et al, nucl-th/0511071]

Energy dep. of centrality dep. of rel. s-prod.

- earlier saturation for higher energies, saturation also for KAOS?
- shape explainable by release of can. s-suppression alone?





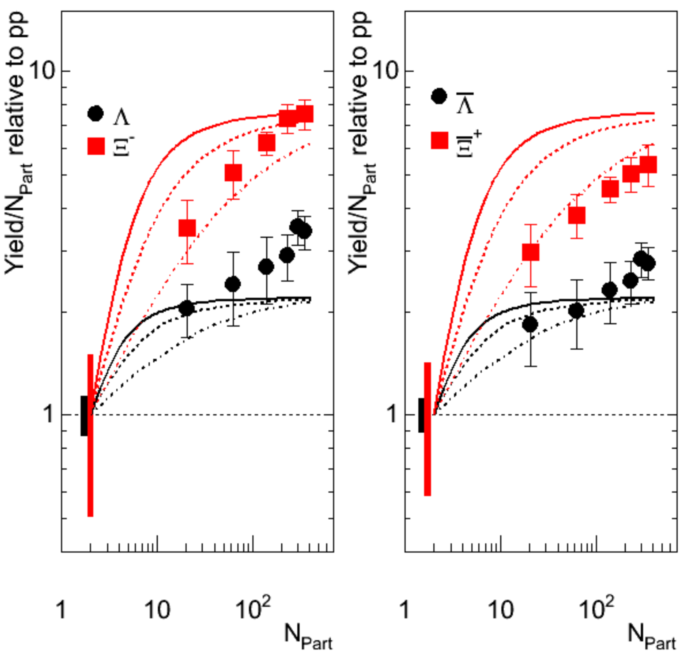
[H. Oeschler, priv. com.]

PHENIX $\sqrt{s}$ = 200 GeV
NA49 E_{beam} = 40 AGeV
E802 E_{beam} = 11.1 AGeV
KAOS E_{beam} = 1.5 AGeV

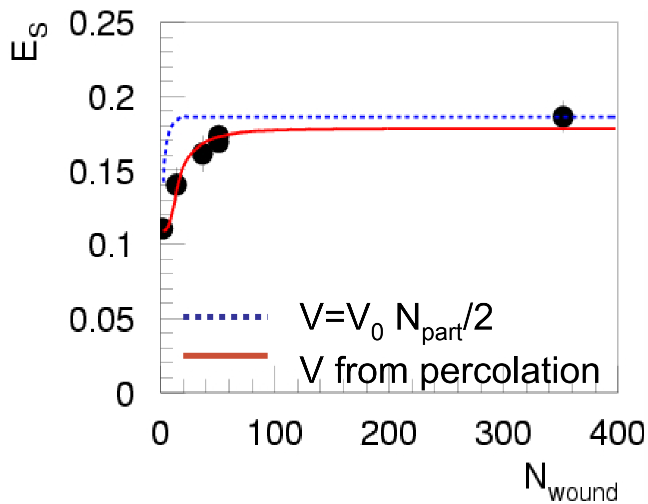
Size-dependence of relative s-production

- non-linear dependence of volume on Npart
  - $V=V_0(N_{part}/2)^{\alpha}$ (α=1, 2/3, 1/3)
  - V from percolation
- include additional s-undersaturation factor γ_s

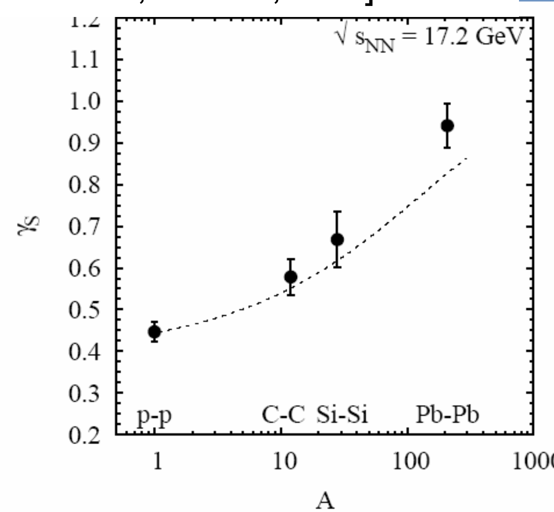
[H. Caines, SQM06]



[CH, hep-ph/0507276]

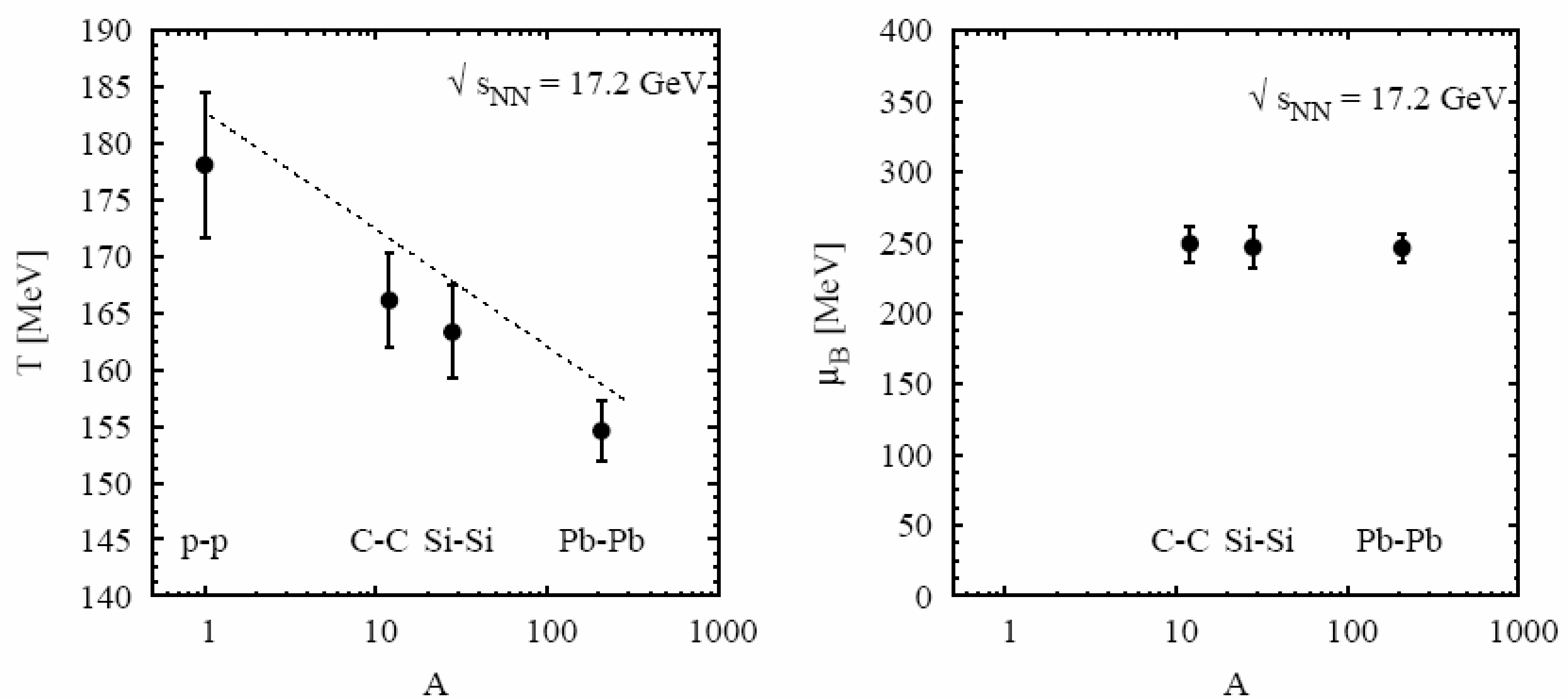


[Becattini, PRC73,044905,2006]



Size dependence of rel. s-production (II)

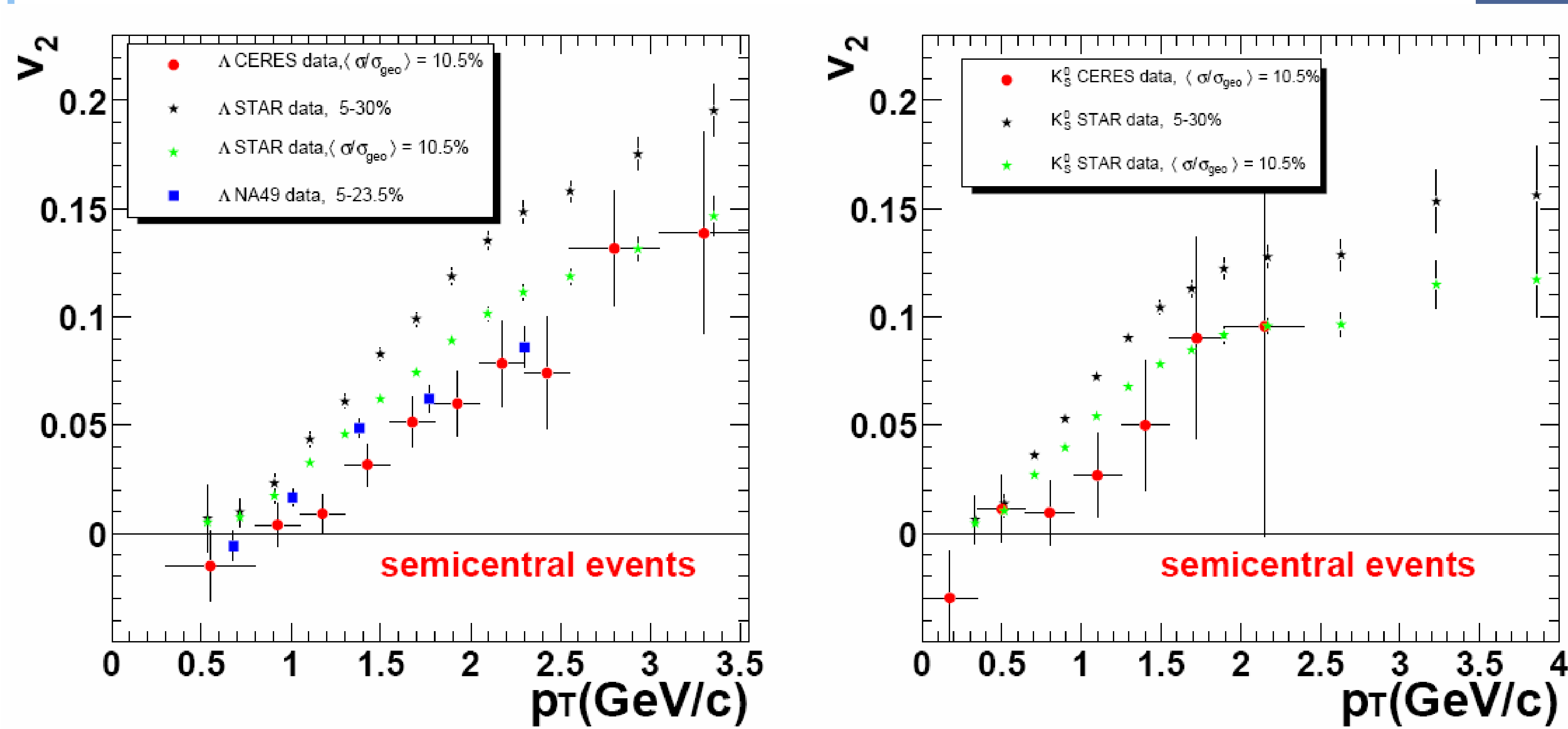
- model including γ_s: (T,μ_B) vary with size → smaller systems freeze-out closer to phase boundary?
- ... or (T,μ_B) constant?



[Becattini, PRC73,044905,2006]

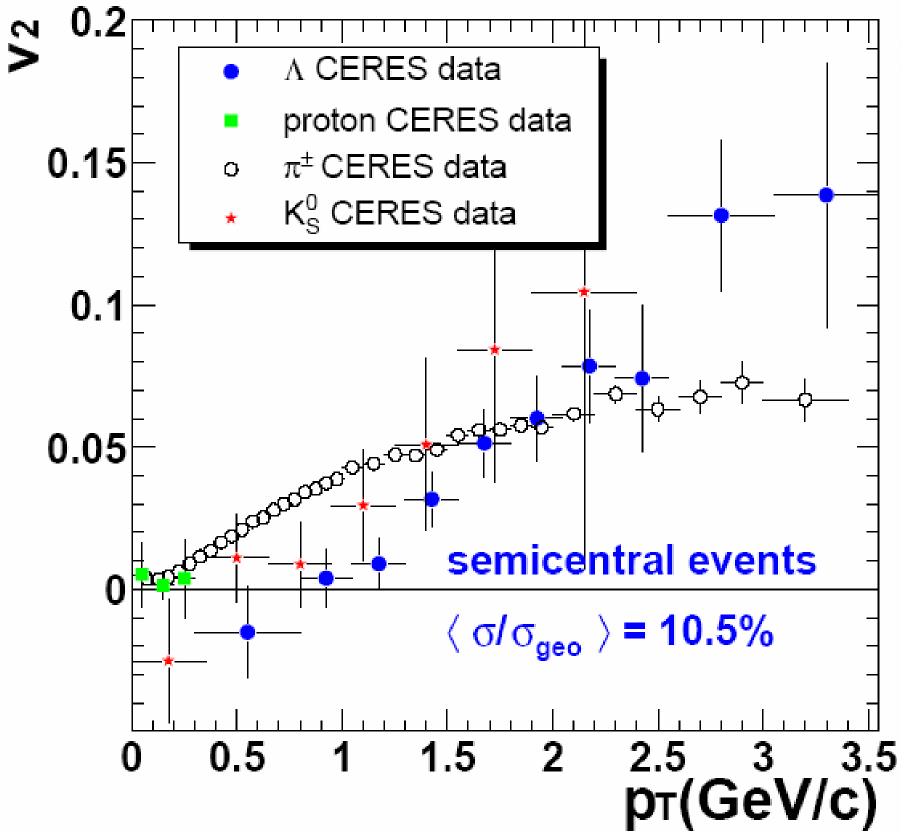
Elliptic flow of strange particles

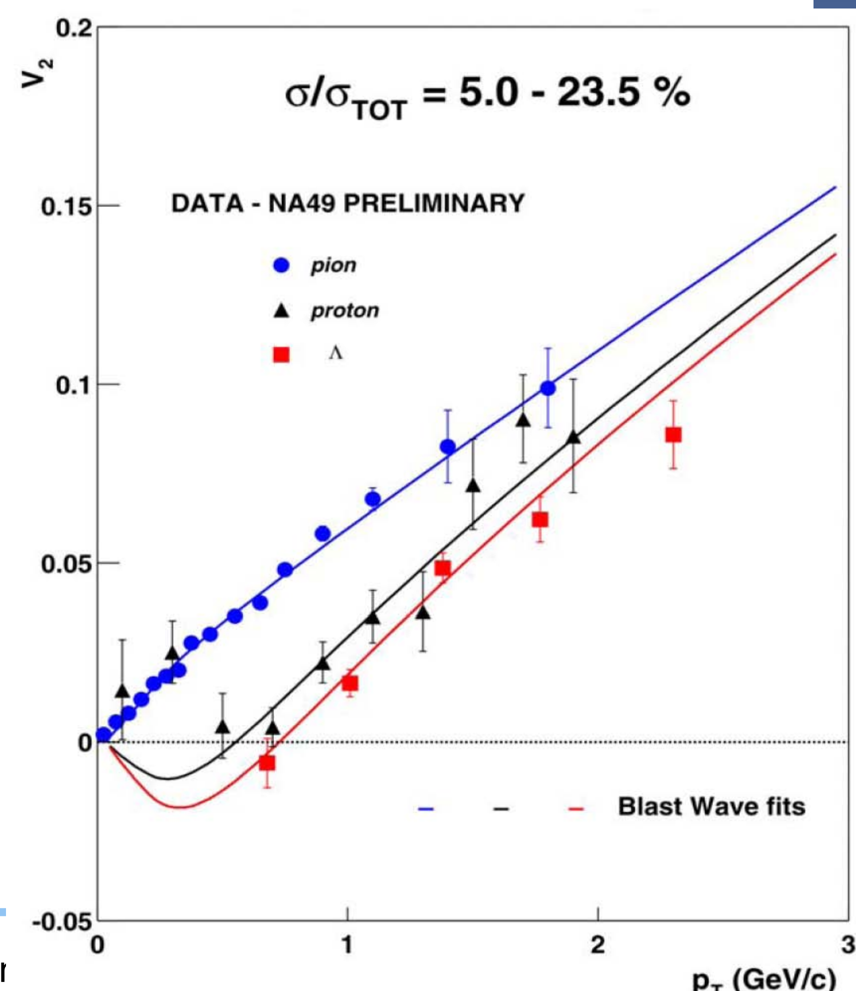
- strangeness (s=1) flows at top-SPS energies!
- v_2 at RHIC (rescaled to same centrality) larger due to higher beam energy



Elliptic flow of strange particles (II)

- mass ordering for p_t < 1.5 GeV, opposite above
- meson – baryon difference as for RHIC?
  NCQ scaling works only appr. for p_t/nq > 0.5 GeV





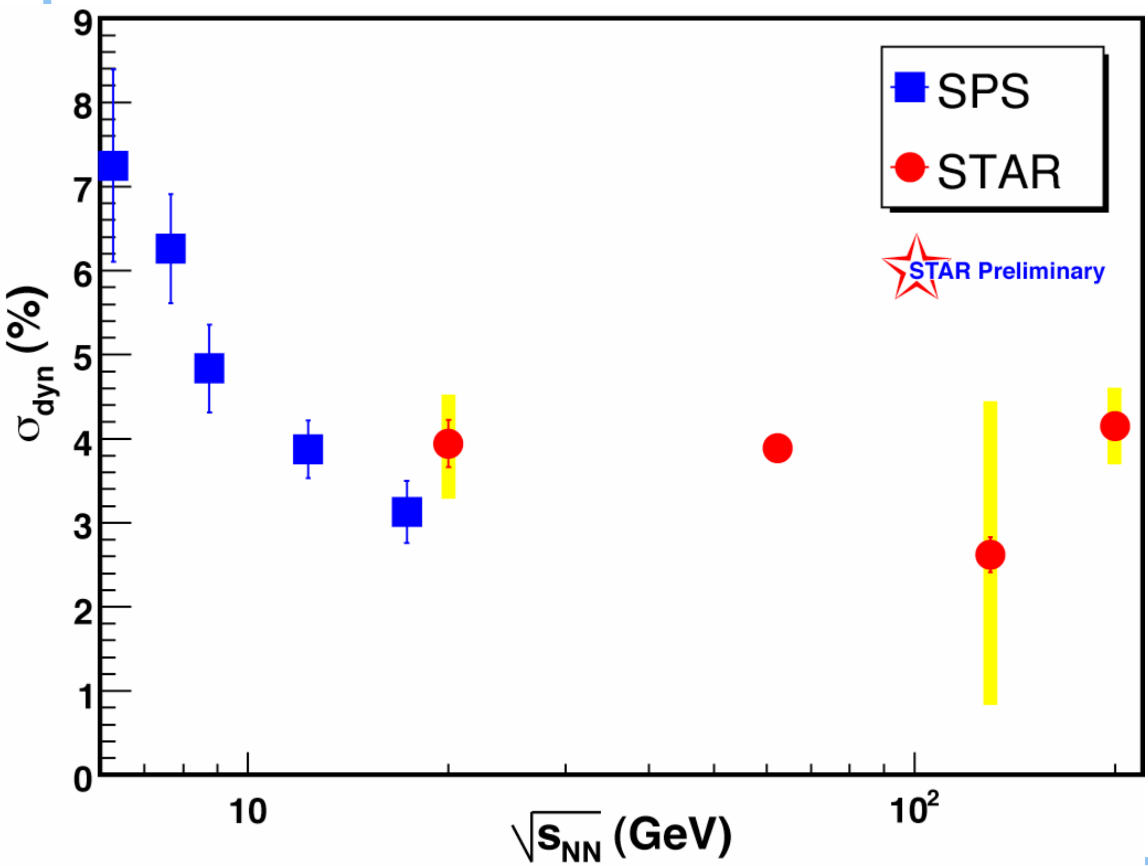
K/π fluctuations

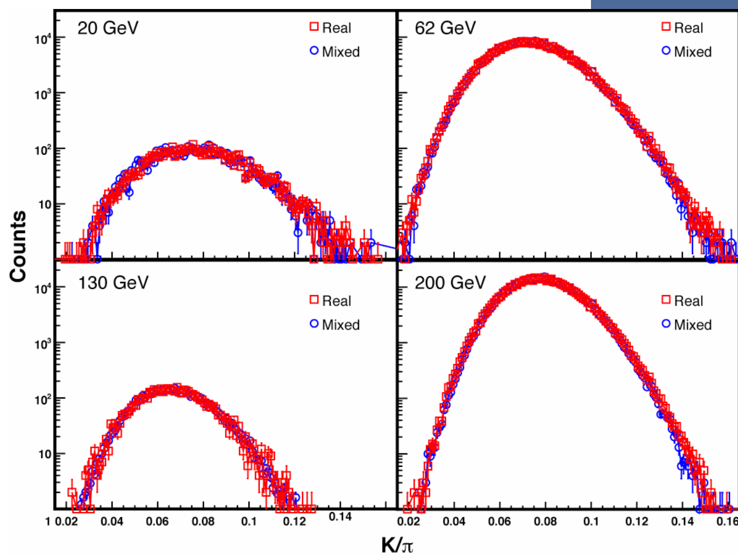
- role of resonance decays?
- acceptance effects?
- alternative measurement?

K*

very good agreement between top SPS – low RHIC

$\nu_{dyn,K\pi}$



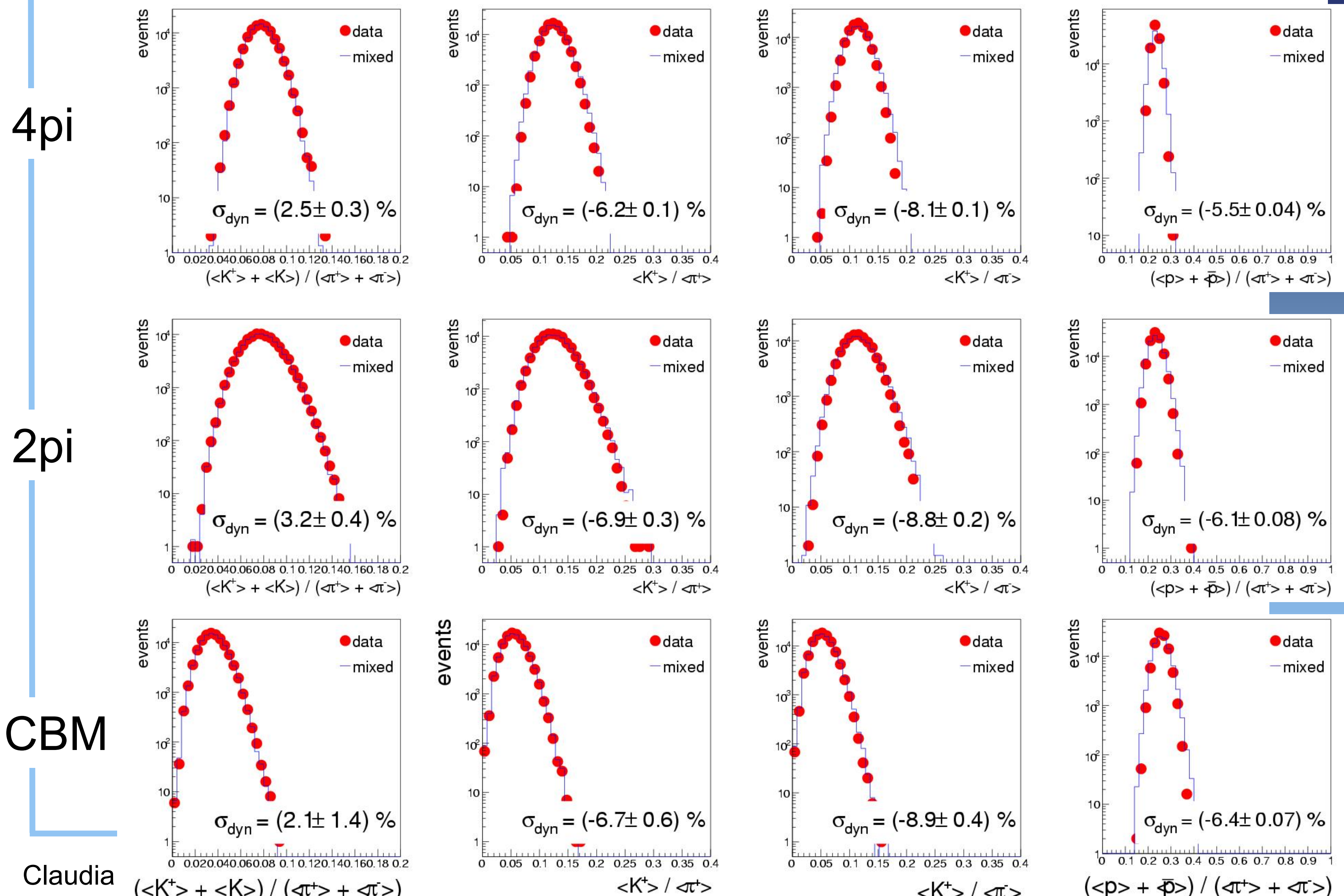


$$\sigma_{dyn} = \sqrt{\sigma_{data}^2 - \sigma_{mixed}^2}$$

[S. Das, SQM06]

Role of resonances for K/π fluc. (UrQMD) ?

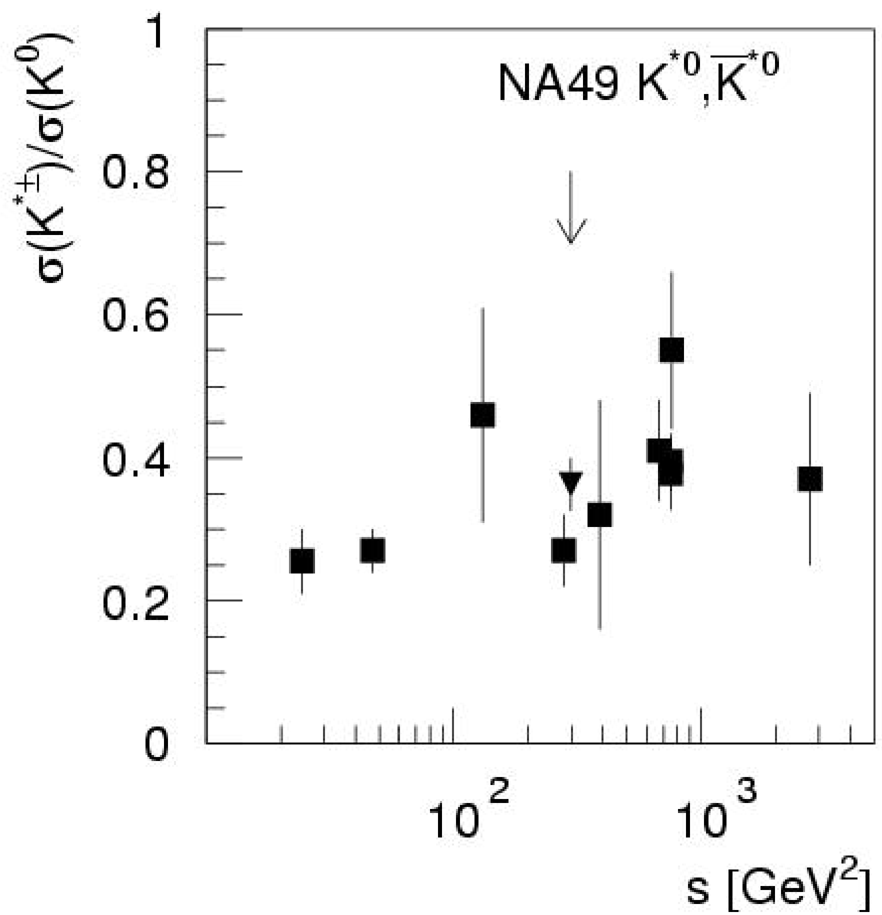
Simulations by D. Kresan (GSI), M. Bleicher (Frankfurt): Au+Au 25 AGeV



Claudia

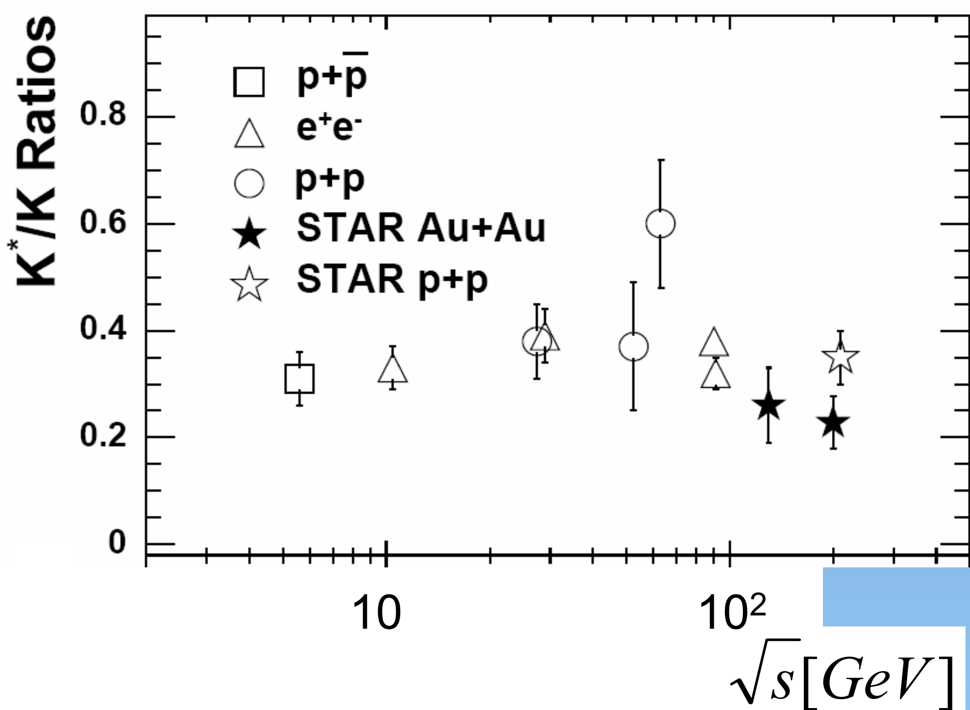
K*/K versus energy (pp)

- K*/K ratio rater constant with energy in pp
- A+A: suppression towards central collisions – energy dependent?



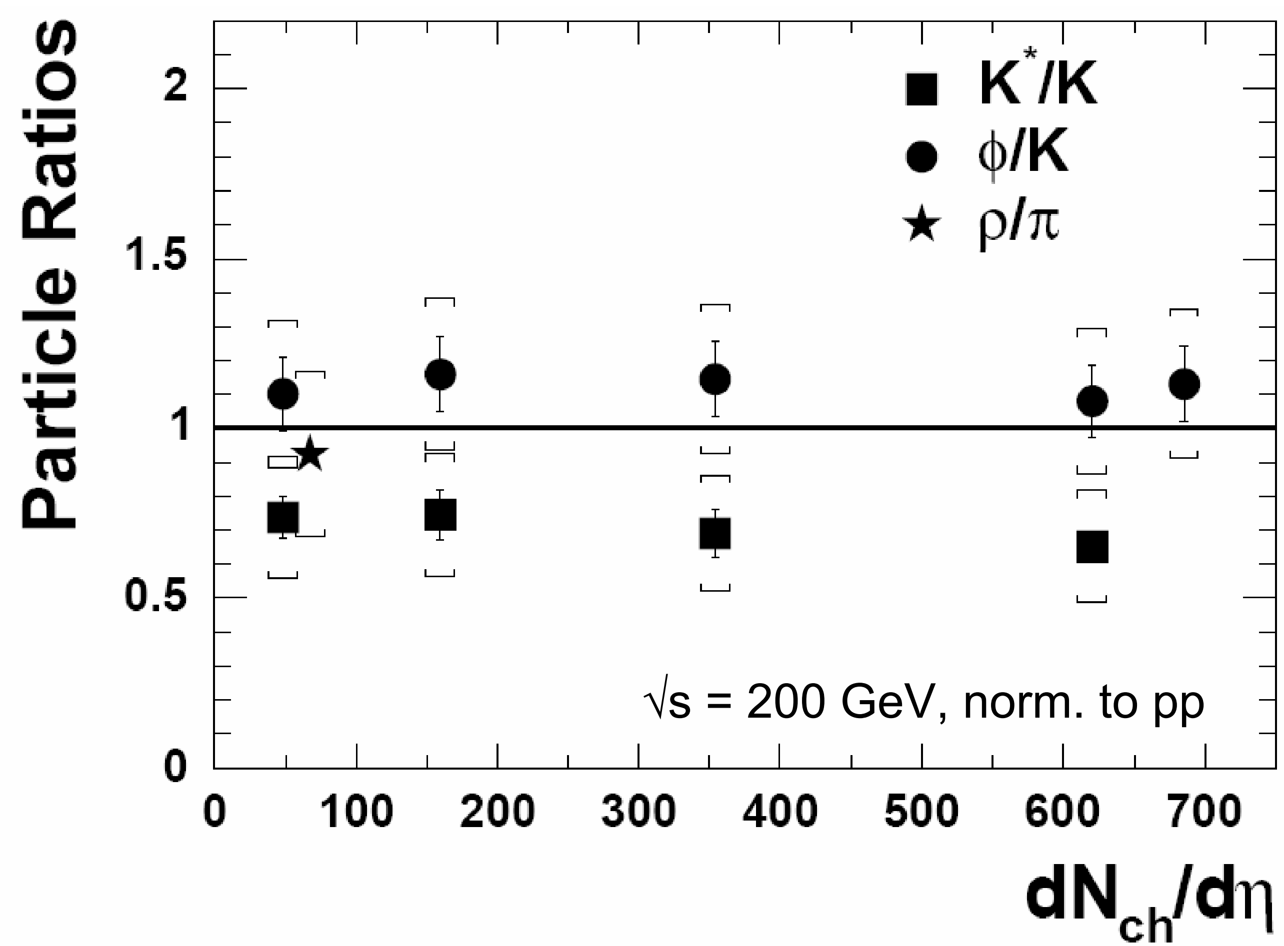
[CH, PhD thesis]

[STAR. PRC 71. 064902 (2005)]



K*/K versus centrality (STAR)

- energy dependence? ("length" of rescattering phase)



How to measure best?

The use of σ_{dyn} is problematic because it involves event-by-event fluctuations of a ratio

A better measure is $\nu_{dyn,K\pi}$

$$\nu_{dyn,K\pi} = \frac{\langle N_K (N_K - 1)\rangle}{\langle N_K\rangle^2} + \frac{\langle N_\pi (N_\pi - 1)\rangle}{\langle N_\pi\rangle^2} - 2\frac{\langle N_K N_\pi\rangle}{\langle N_K\rangle\langle N_\pi\rangle}$$

First proposed by Pruneau, Gavin and Voloshin PRC 66 (2002)
Used in STAR Net Charge fluctuation paper – PRC 68 (2003)

- **Insensitive to efficiency**
- **Properly deals with small multiplicities**
- **Centrality studies**

We will use $\nu_{dyn,K\pi}$ for our systematic studies of K/π fluctuations

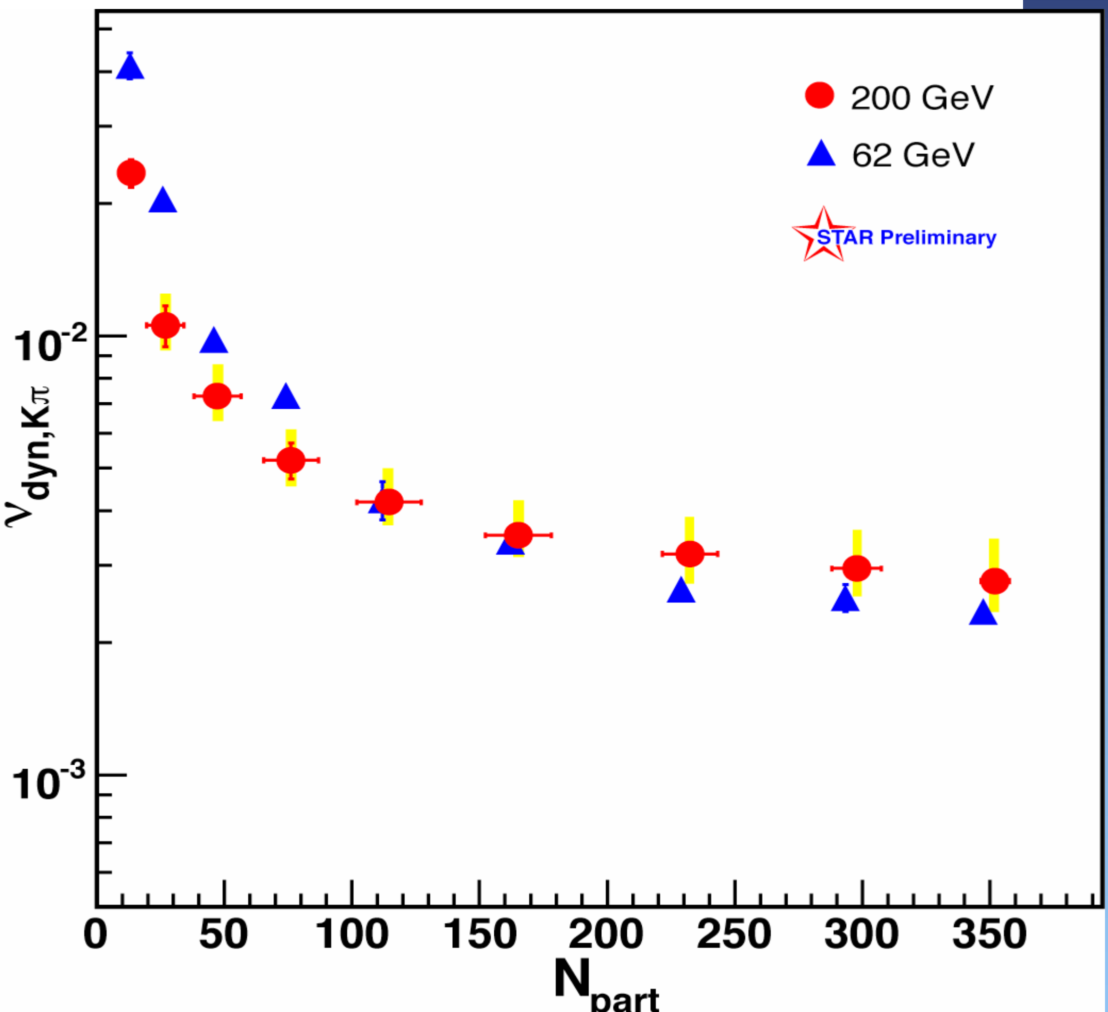
[S. Das, SQM06]

Centrality dependence of K/π fluc.

- continous rise towards the most peripheral Au+Au collisions

(similar to $<p_t>$ - fluctuations from STAR)

- influence of centrality determination or acceptance?



[S. Das, SQM06]

Summary

• new data on Ξ and K^0_S production at SPS!

• "step" in mean transverse masses vs. energy also for Λ, Ξ, Ω, ϕ

... however, AGS data missing!

• s-undersaturation at higher SPS energies? (no γ_s)

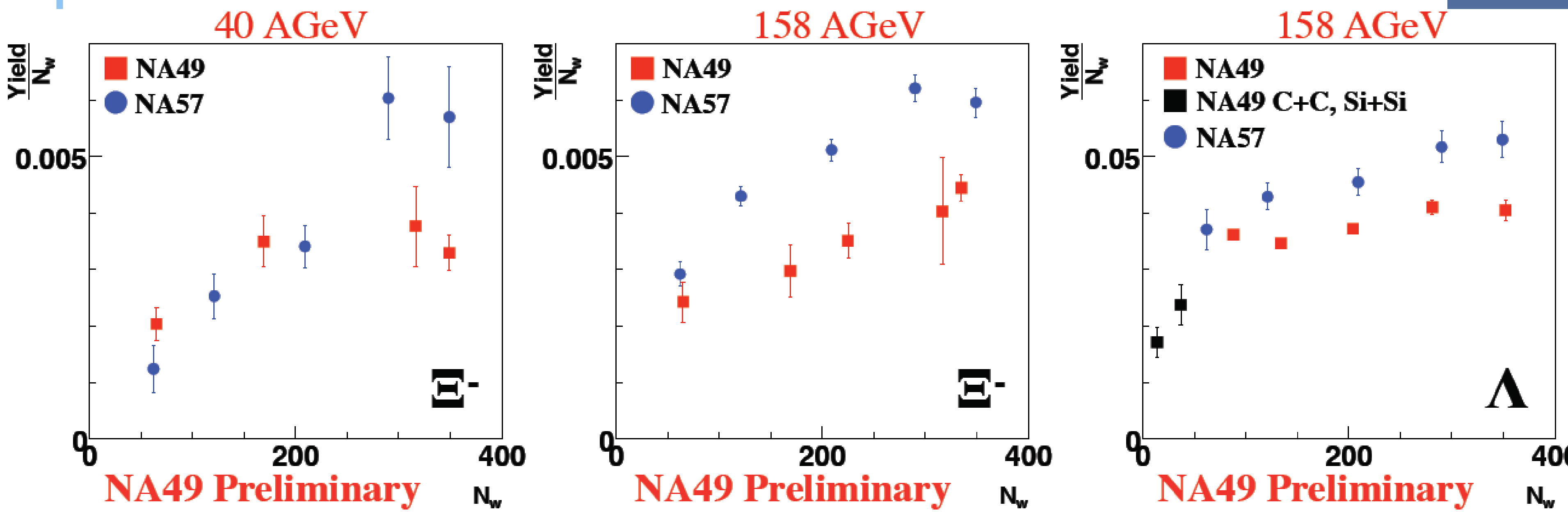
• can we learn something from deviations of the data from hadron gas model fits: anything beyond thermal?

• smaller systems: freeze-out closer to phase boundary?

• strangeness (s=1) flows at top SPS!

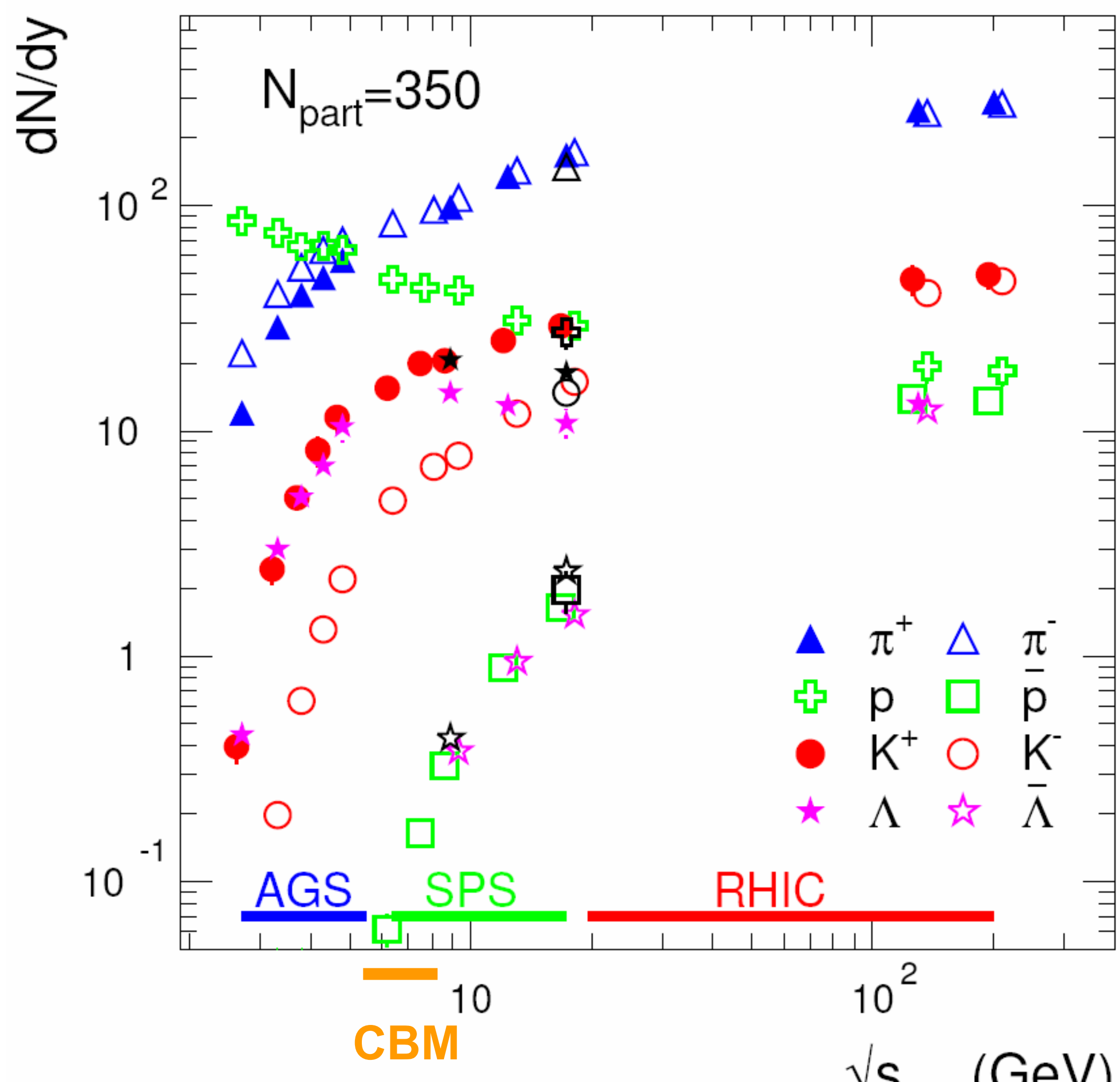
• K/π fluctuations: more understanding needed ...

better data on K* production in A+A at lower energies!



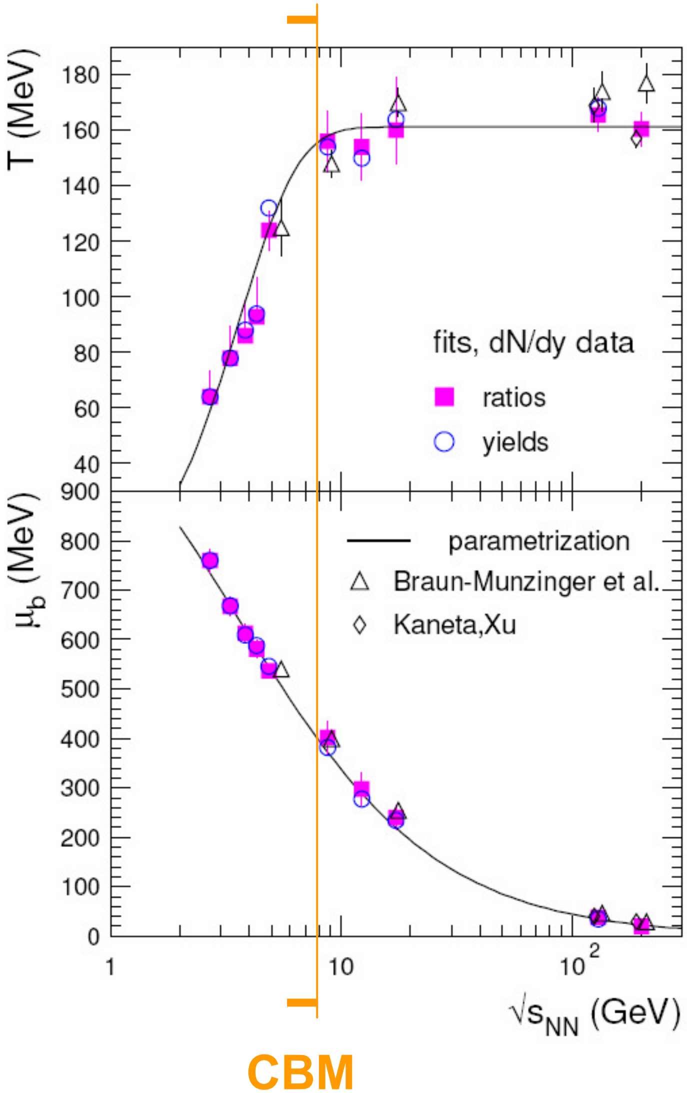
[M. Mitrovski, SQM06]

Particle yields at midrapidity



[A. Andronic et al, nucl-th/0511071]

Parametrization of energy-dep.



$$T[\mathrm{MeV}] = T_{lim}\left(1 - \frac{1}{0.7 + (\exp(\sqrt{s_{NN}}(\mathrm{GeV})) - 2.9)/1.5}\right)$$

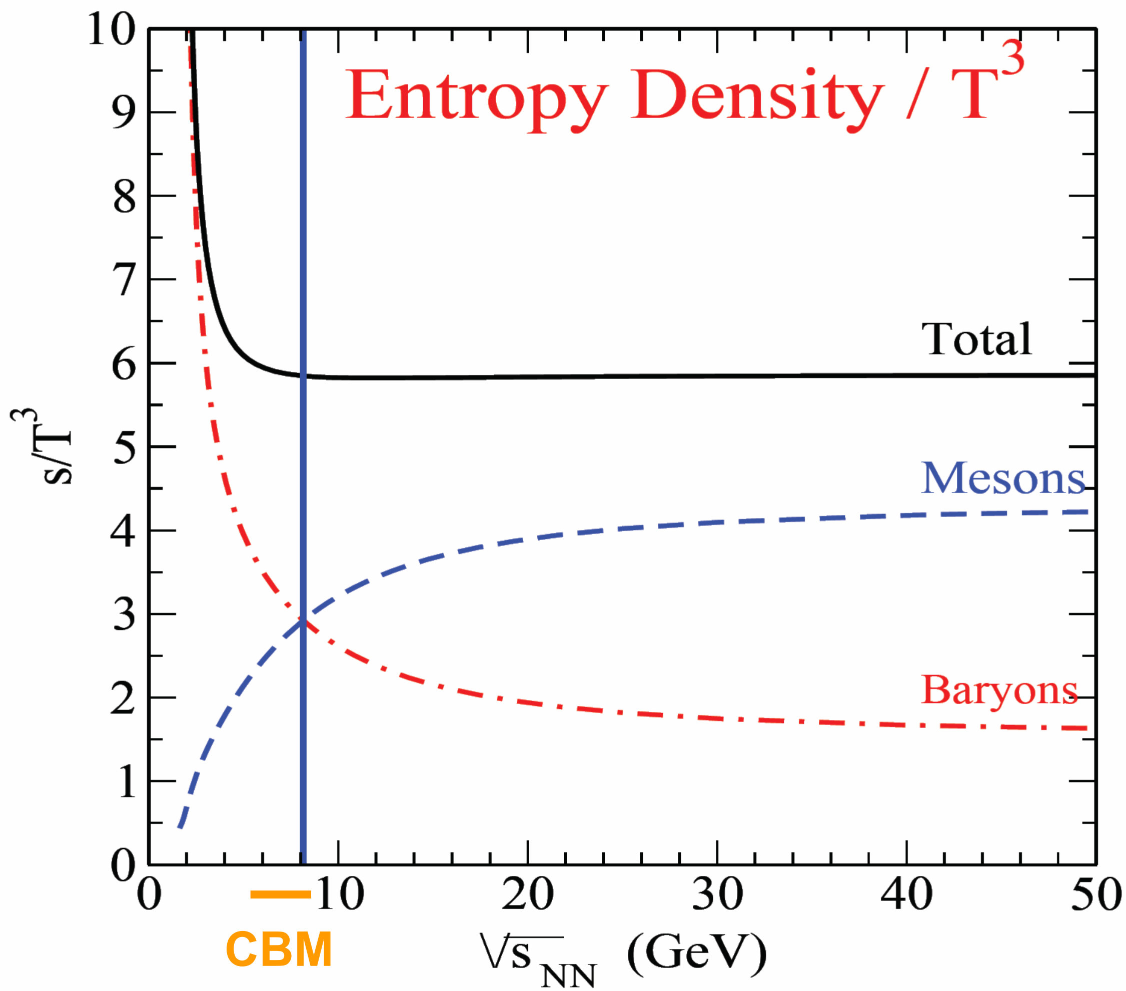
$$T_{lim} = 161 \pm 4\ \mathrm{MeV}\ (\chi^2/N_{df}{=}0.3/3)$$

$$\mu_b[\mathrm{MeV}] = \frac{a}{1 + b\sqrt{s_{NN}}(\mathrm{GeV})}$$

$$a = 1303{\pm}120\ \mathrm{MeV},\ b = 0.286{\pm}0.049\ \mathrm{GeV}^{-1}\ (\chi^2/N_{df}{=}0.5/8)$$

[A. Andronic et al, nucl-th/0511071]

Baryon → Meson dominance



J. C., H. Oeschler, K. Redlich and S. Wheaton, Physics Letters B615 (2005) 50-54.
A. Tawfik, J. Phys. G Nucl. Part. Phys. G31 S1105 (2005).