Strangeness production (experiment)

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Outline

"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

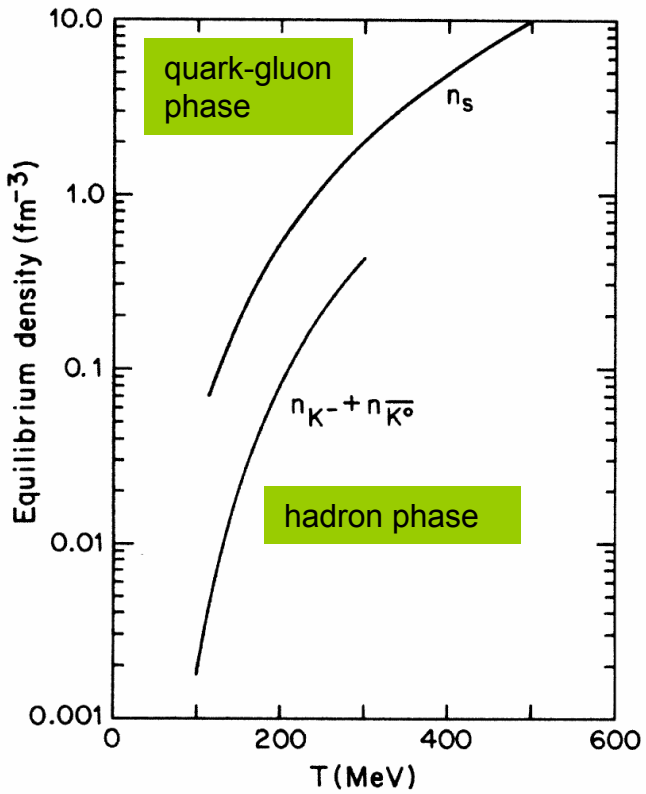
- energy dependence of strangeness production
- summary

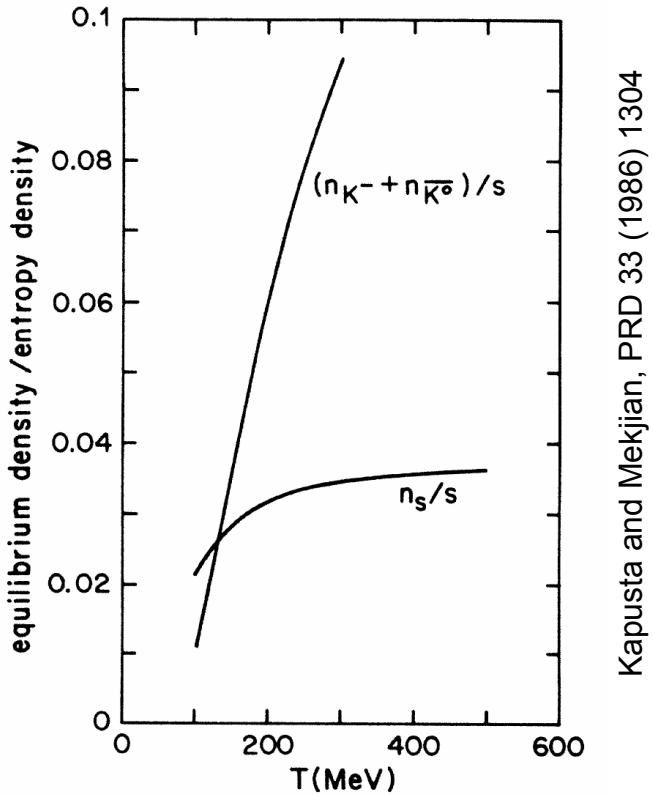
Motivation

• strange flavor not present at the beginning of the collision: newly produced!

→ study provides essential information about physical environment in which strangeness is created

→ however, can still be influenced by later interactions (difficult to entangle!)





Kapusta and Mekjian, PRD 33 (1986) 1304

Data on strangeness

SPS experiments

- NA49 K, ϕ, Λ, Ξ, Ω, (K^*, Λ^*)
- CERES ϕ, Λ, (K)
- WA97/NA57 K, Λ, Ξ, Ω
- NA50 ϕ
- NA60 ϕ

AGS experiments

- E-802, E-859, E-866, E-891, E-895, E-896, E-917,... K, Λ, Ξ

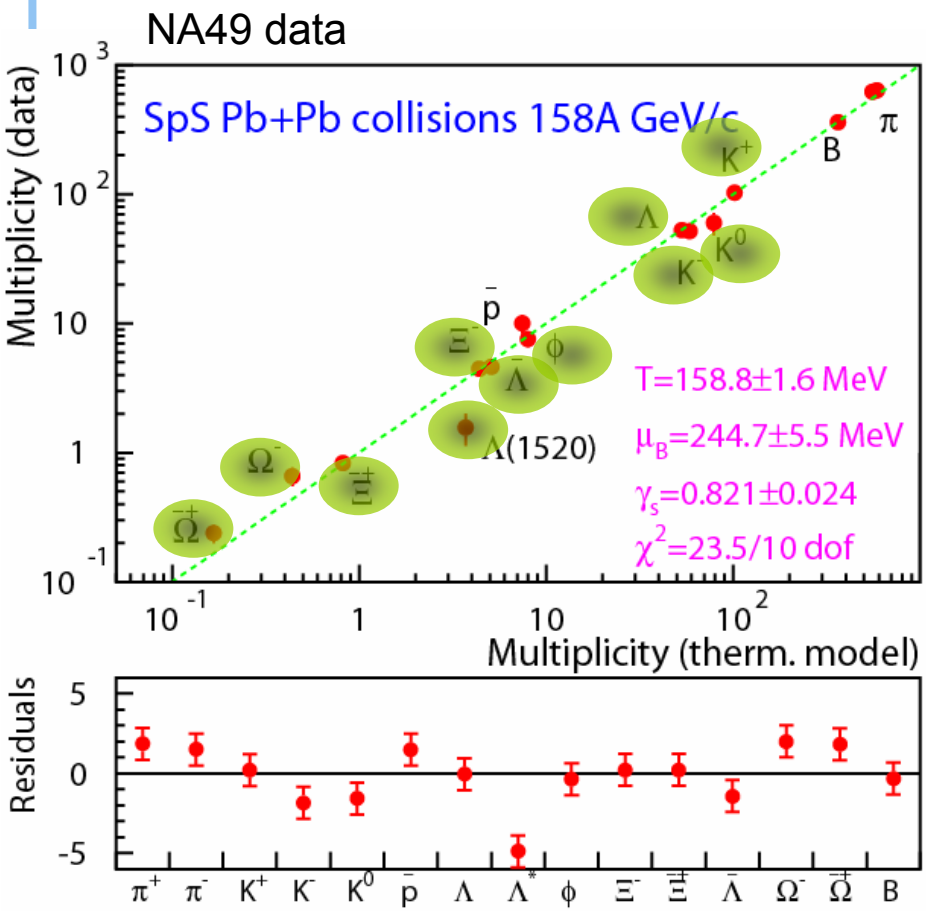
... list not exhaustive, mainly indicates what I used for this talk

central Pb+Pb

collisions at 158 AGeV

hadron production in central PbPb

- final state hadron yields: chemically equilibrated hadron gas



[Becattini et al., PRC 69, 024905 (2004)]

- freeze-out conditions:

$T_{chem} \approx 160$ MeV

$\mu_B \approx 240$ MeV

$(\gamma_s \approx 0.8)$

understanding strangeness production ↔

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

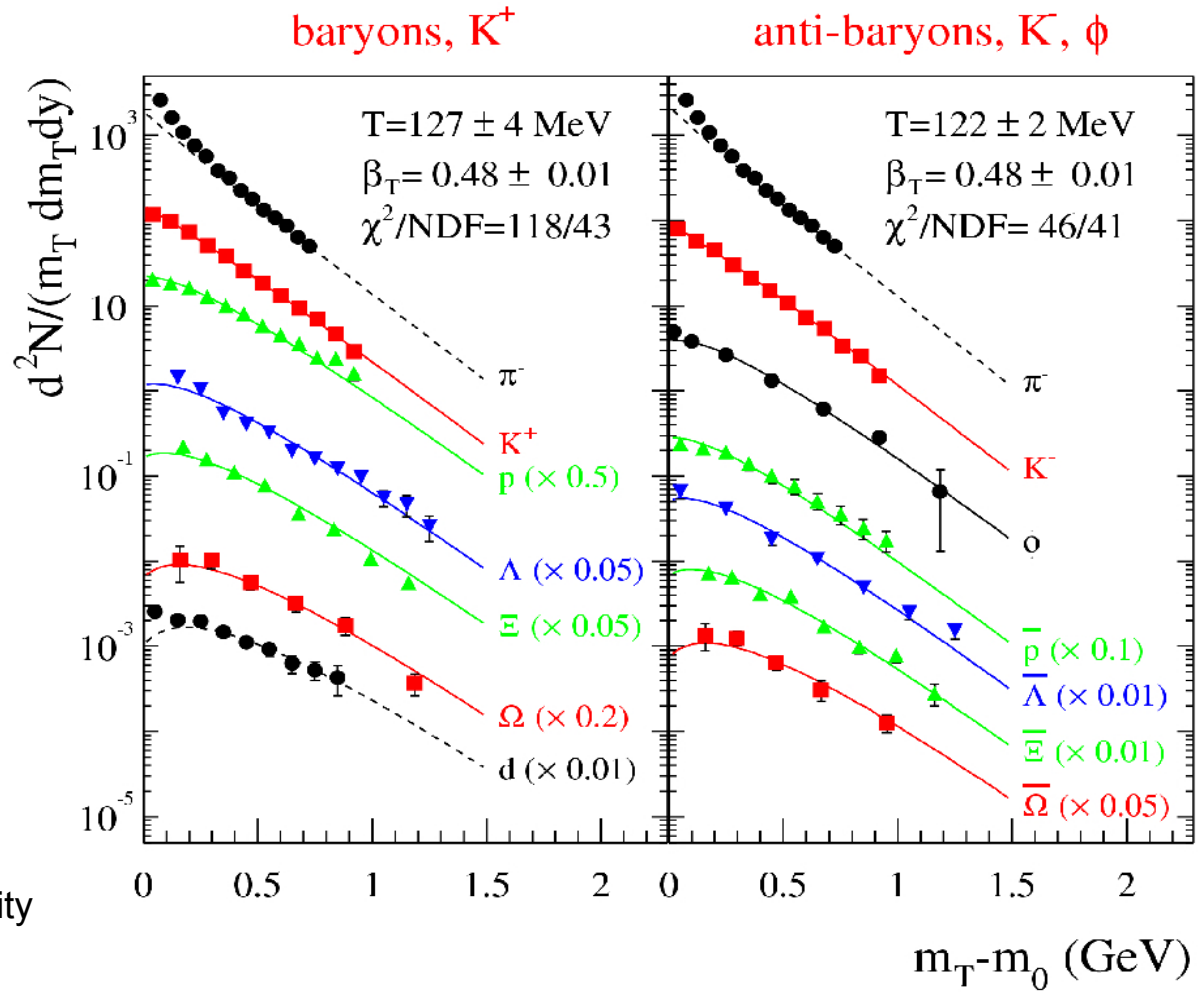
spectra at central Pb+Pb

- kinetic freeze-out from analysis of p_t-spectra

all particles seem to fit well to one freeze-out condition

however:

depends on assumptions in "blast wave model"



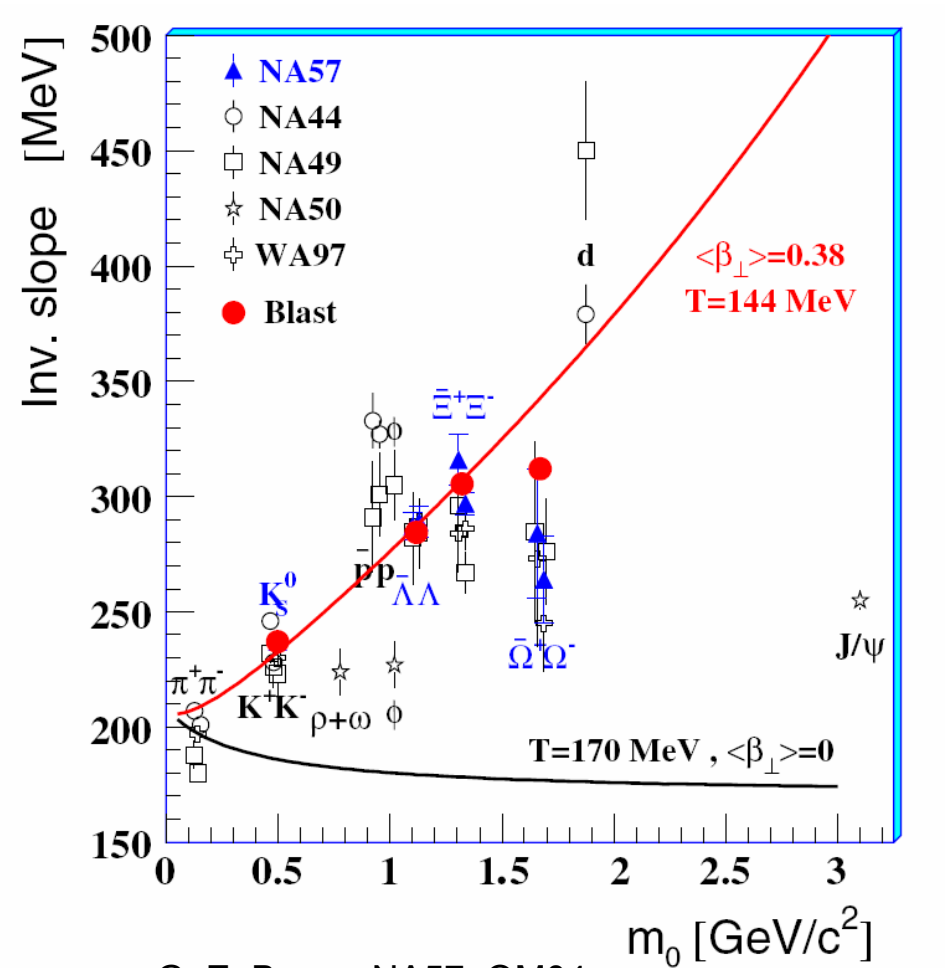
M. van Leeuwen, NA49, QM02

here: radial flow fit *
- β_T mean transverse flow velocity
- constant expansion velocity
- pions, deuterons not included in fit

* [Schnedermann, Sollfrank, Heinz, Phys. Rev. C48, 2462 (1993)]

spectra at central Pb+Pb (II)

- earlier freeze-out of multi-strange particles?



G. E. Bruno, NA57, QM04

spectra at central Pb+Pb (III)

hydrodynamical model with transversely expanding emission source,

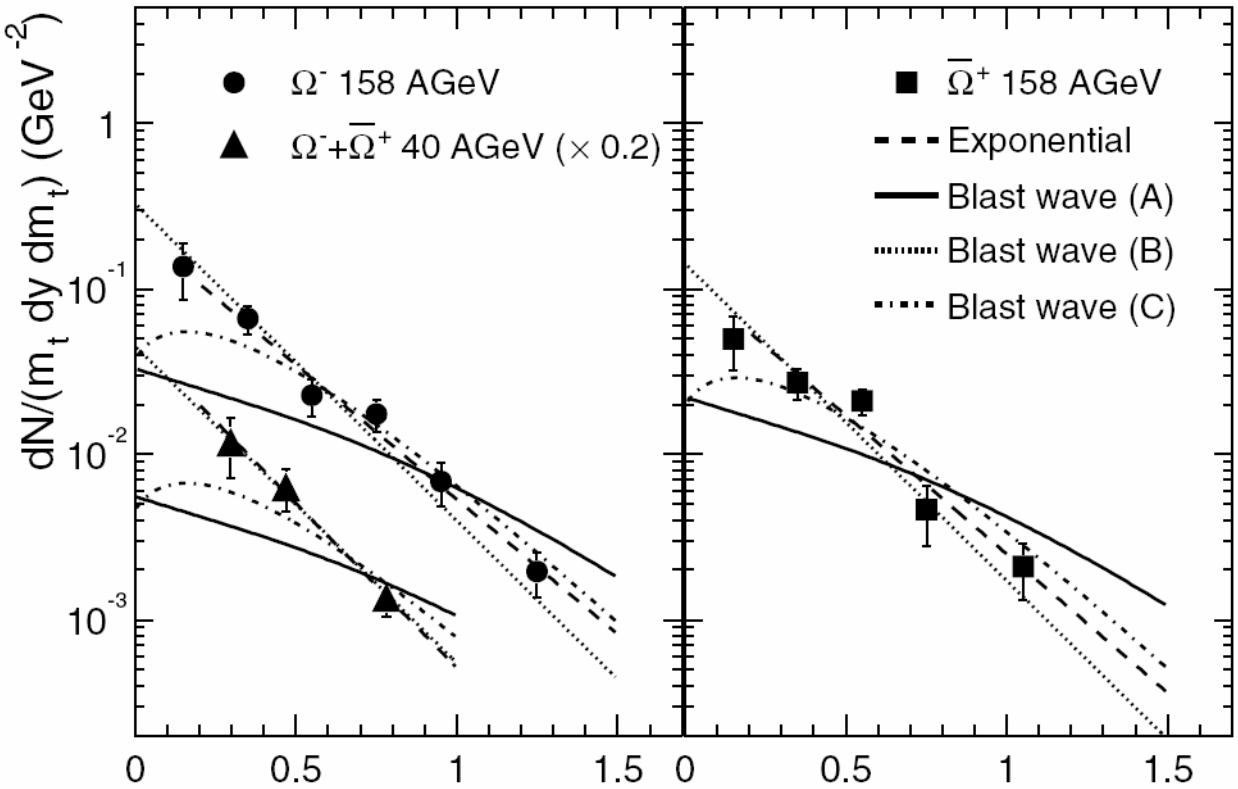
parameters: freezeout temperature T_f, transverse flow velocity β_s at the surface

linear velocity profile $\beta_t(r) = \beta_s r/R$

(A) "all" (no Ξ,Ω)
T_f = 90 MeV
$\langle\beta_t\rangle$ = 0.5

(B) "J/ψ"
T_f = 170 MeV
$\langle\beta_t\rangle$ = 0.2

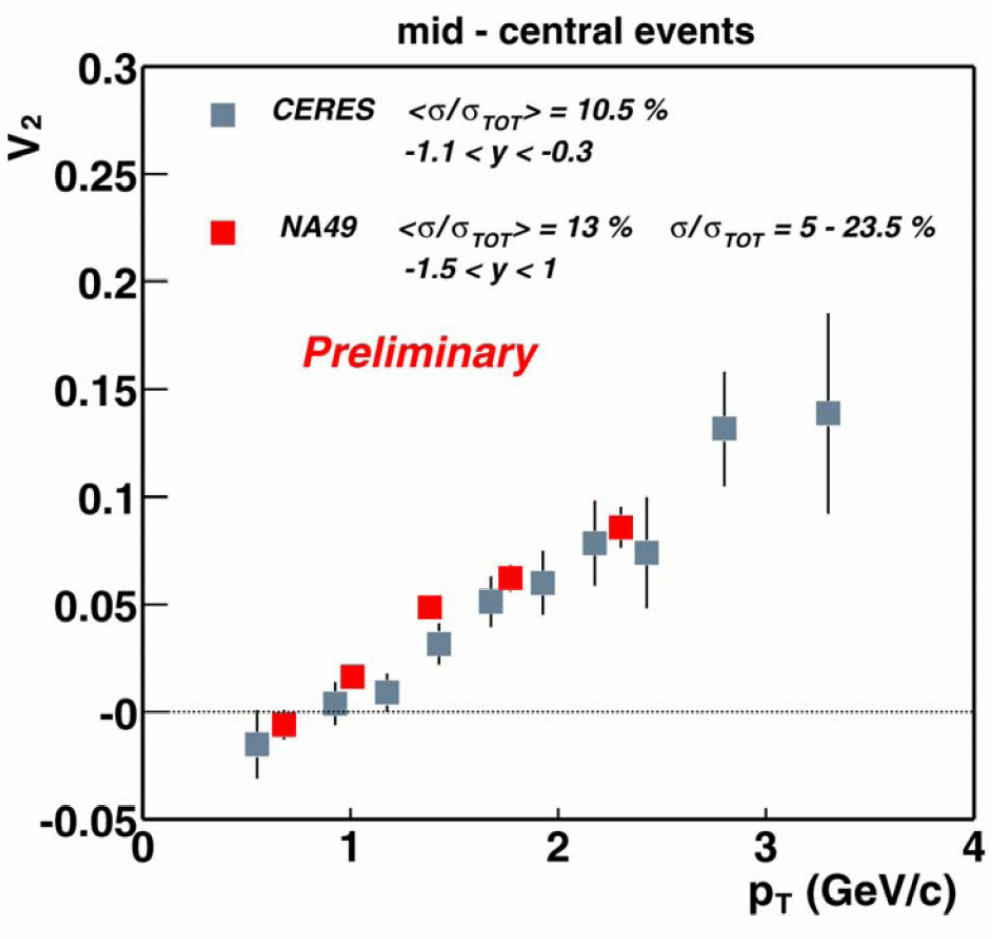
(C) constant expansion velocity, "all" (incl. Ξ,Ω)
T_f = 127 MeV
$\langle\beta_t\rangle$ = 0.5



NA49, PRL 94 (2005) 192301

Λ-flow

- substantial elliptic flow of Λ



very good agreement between CERES and NA49!

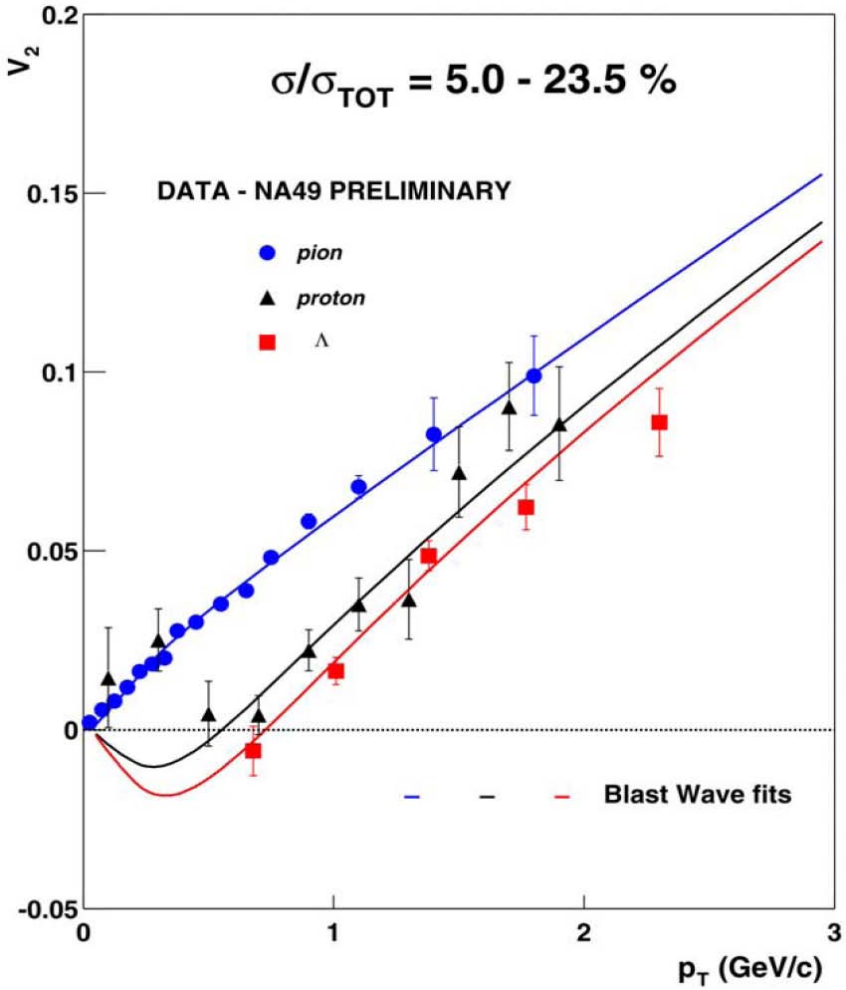
G. Stefanek, NA49, QM05

Λ-flow (II)

- smaller than for pions
- similar to protons

→ baryon/ meson effect similar to RHIC?

G. Stefanek, NA49, QM05



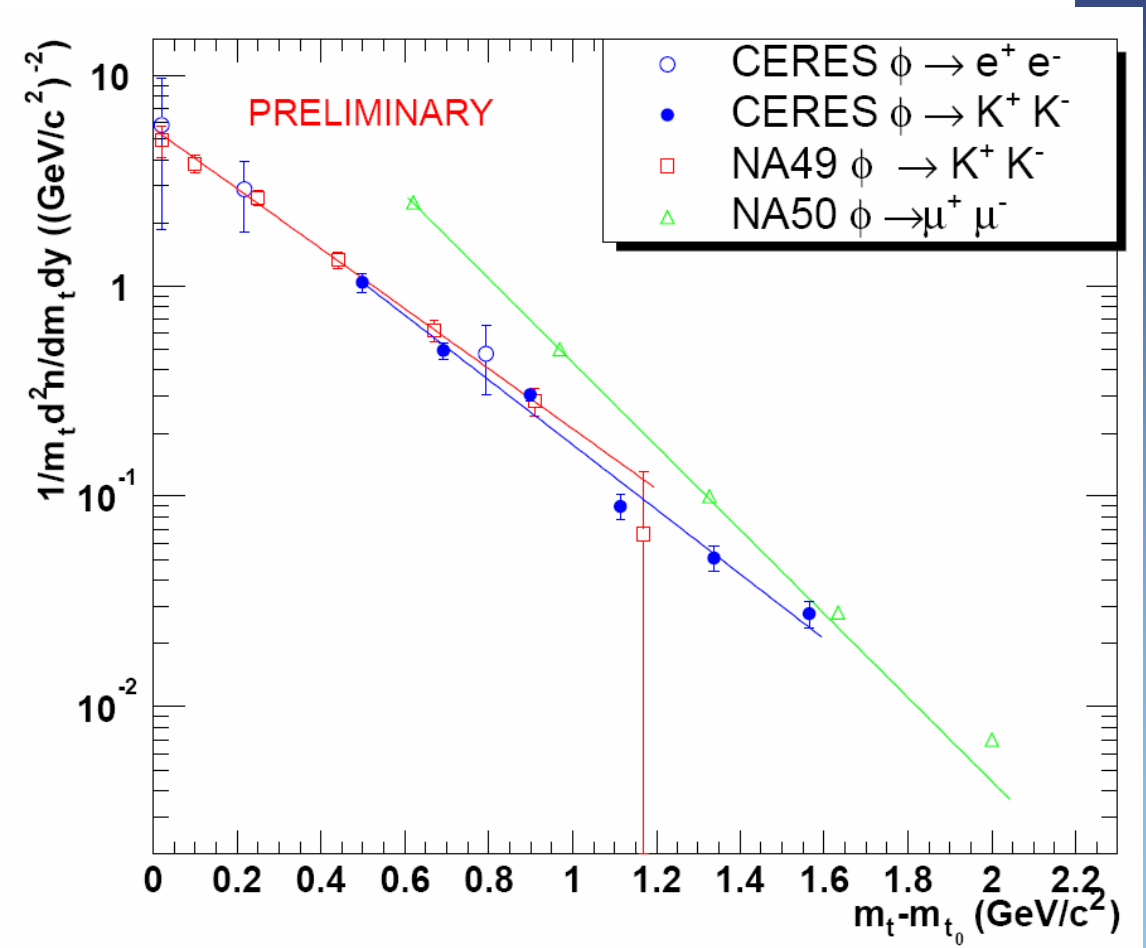
Future plans:

study v_2 of K^0_S, Ξ?

ϕ-meson

"ϕ-puzzle" in central Pb+Pb collisions at 158 AGeV basically solved:

discrepancy between NA49 and NA50 in yield and temperature for the ϕ-meson in central Pb+Pb collisions at 158 AGeV



D. Miskoviec, CERES, QM05

ϕ-meson (II)

NA50
branching ratio for $\phi \rightarrow \mu^+\mu^-$

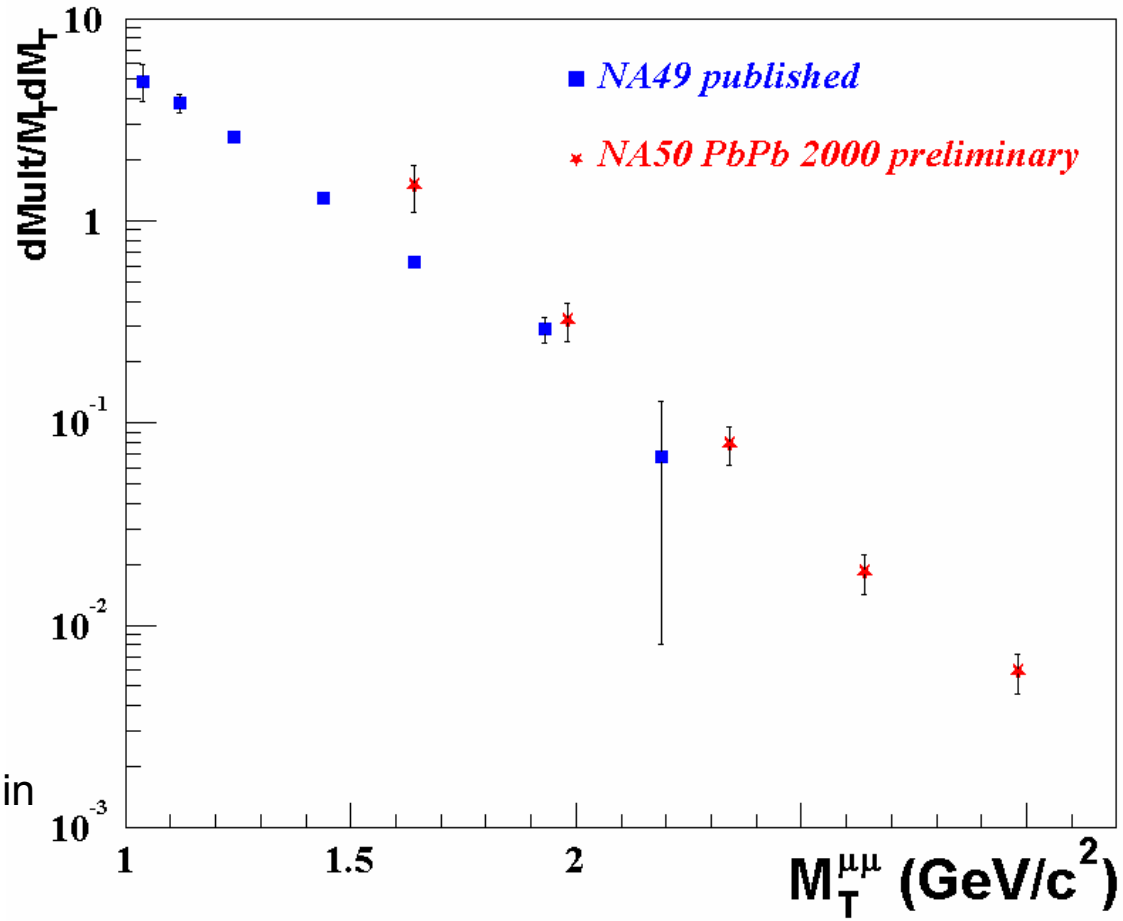
PDG 1998: $(2.5 \pm 0.4)\ 10^{-4}$
PDG 2004: $(2.85 \pm 0.19)\ 10^{-4}$

compare to $\phi \rightarrow e^+e^-$
PDG 1998: $(2.99 \pm 0.08)\ 10^{-4}$

assume same for $\mu^+\mu^-$
$\rightarrow$ 20% difference

discrepancy in slopes remains:
however, very different regions in m_t are fitted!

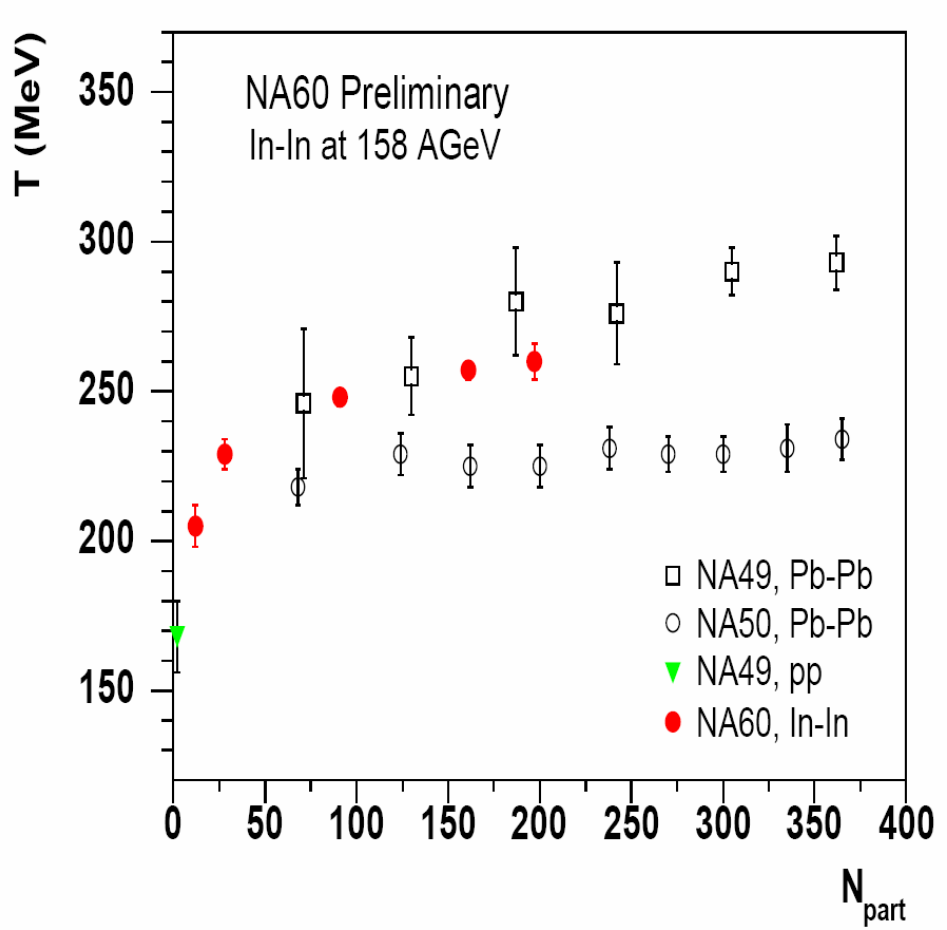
D. Jouan, NA50, SQM03



ϕ-meson (III)

new results from NA60 confirm the slopes measured by NA49

E. Scomparin, NA60, QM05



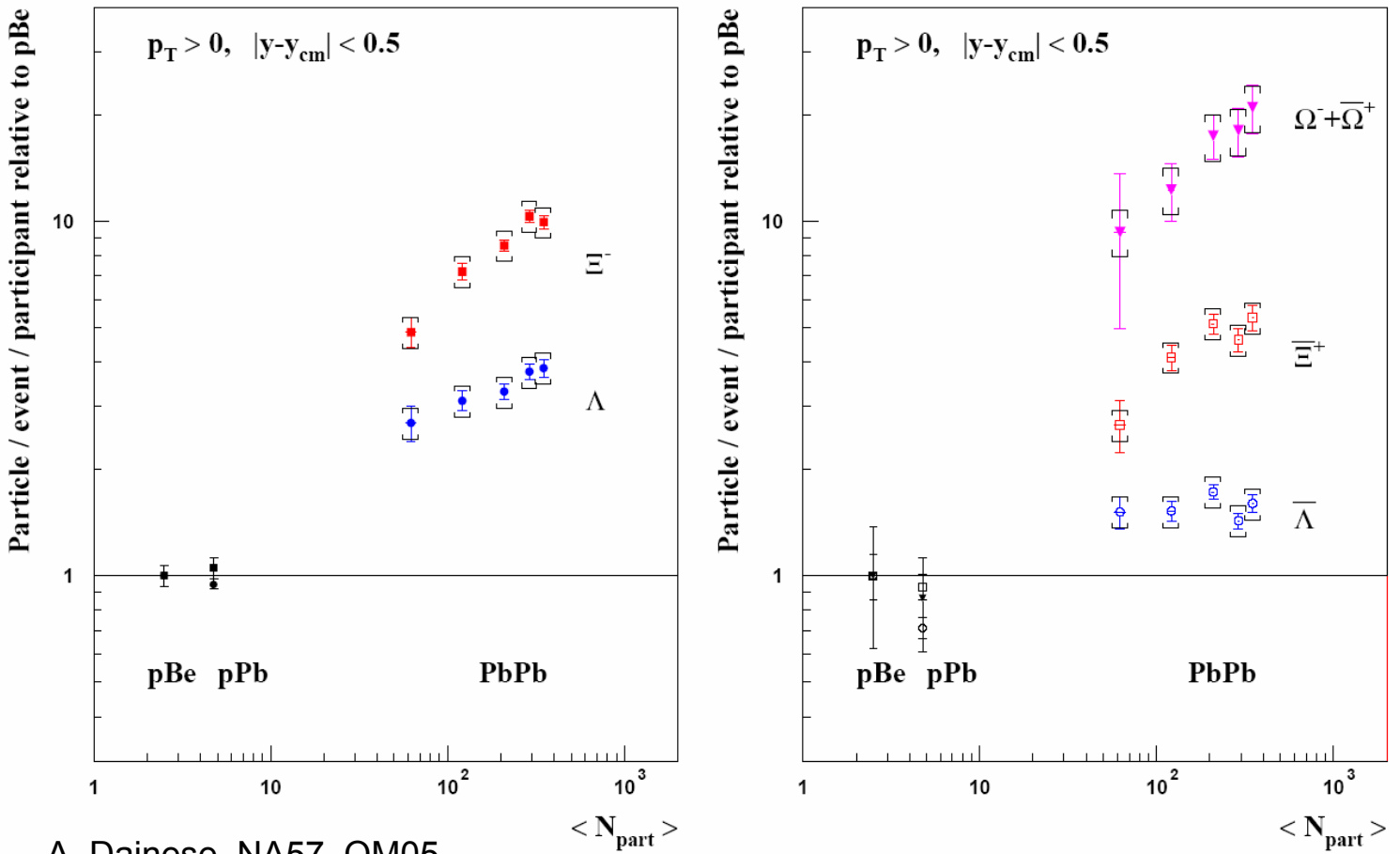
centrality dependent Pb+Pb collisions at 158 AGeV

and

central collisions of systems with smaller A

size dependence of s-production

- increase of s-production with system size
- s-hierarchy

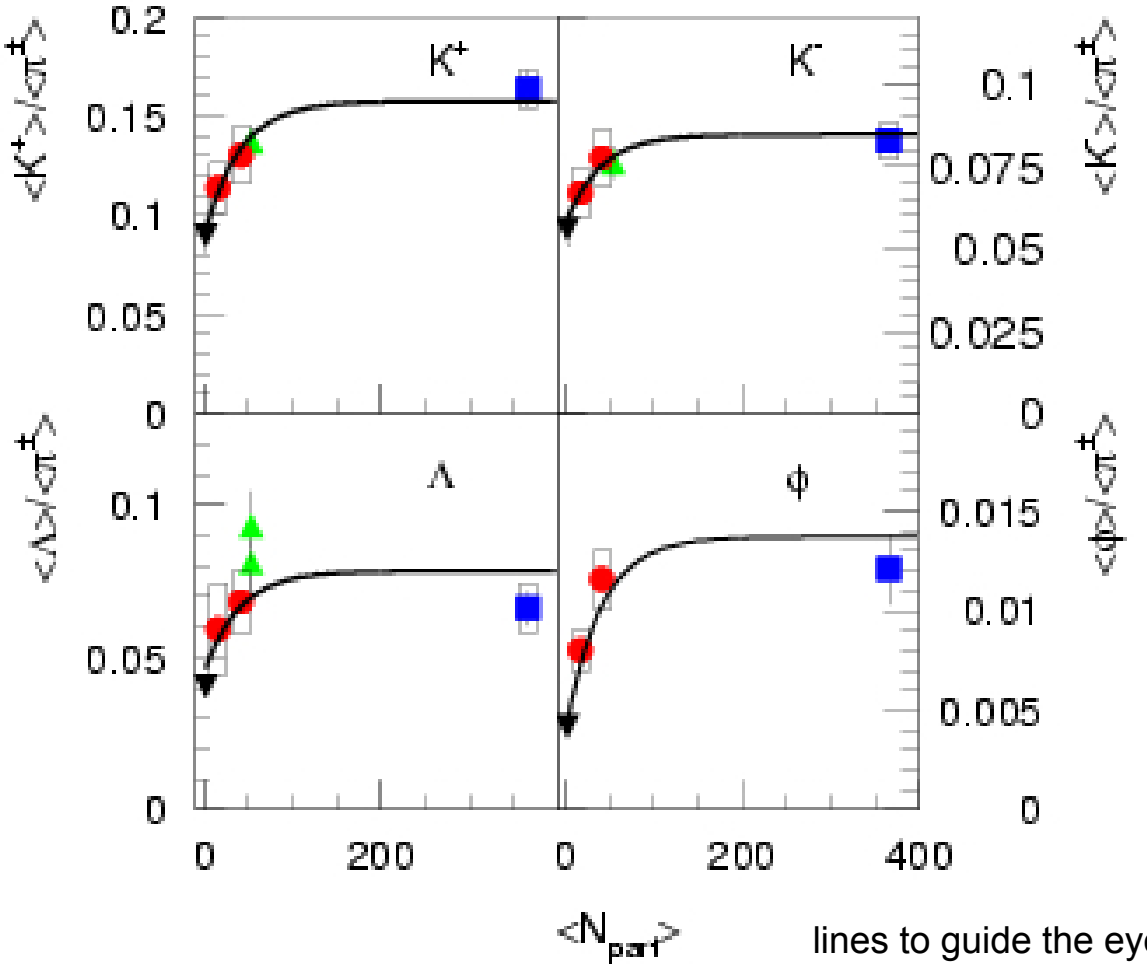


A. Dainese, NA57, QM05

size dependence of s-production (II)

- pp
- central CC, SiSi
- central SS
- central PbPb

[NA49, PRL 94, 052301 (2005)]



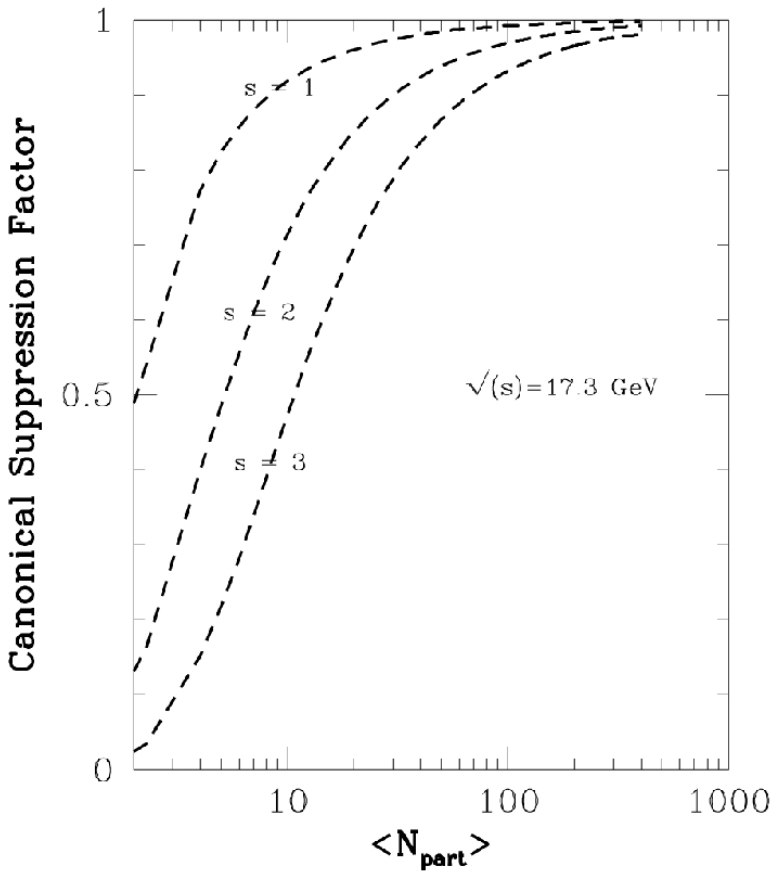
lines to guide the eye

- fast increase for small systems
- saturation from N_{part} > 60 on!

$$\langle \pi^{\pm} \rangle = 0.5 \cdot \left(\langle \pi^{+} \rangle + \langle \pi^{-} \rangle \right)$$

size dependence of s-production (III)

qualitatively explained by release of canonical s-suppression in large volumes

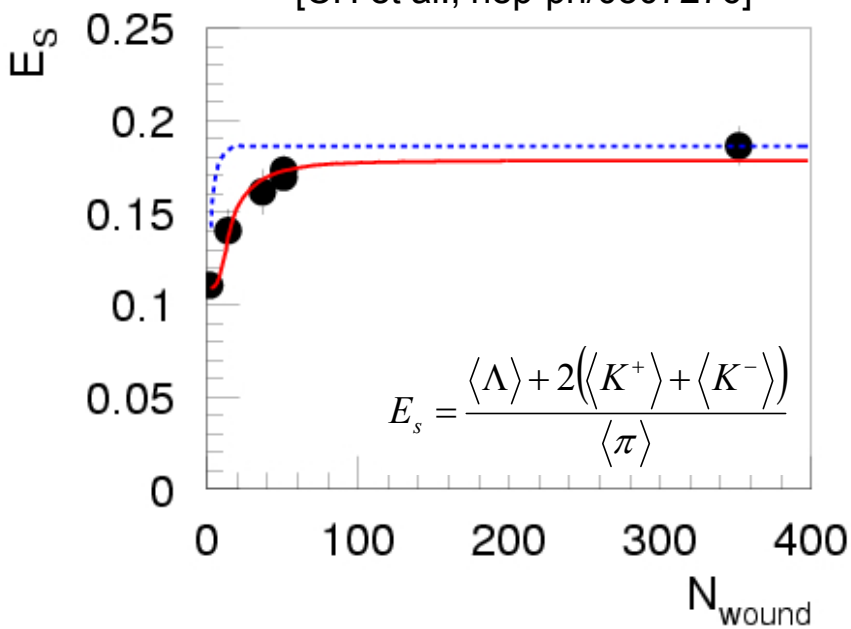


[Tounsi and Redlich, J. Phys. G: Nucl. Part. Phys 28 (2002) 2095]

quantitatively in disagreement with thermal models assuming $V=V_0 \cdot N_{part}/2$

percolation calculation with refined volume allowing for several smaller clusters in small systems: ok!

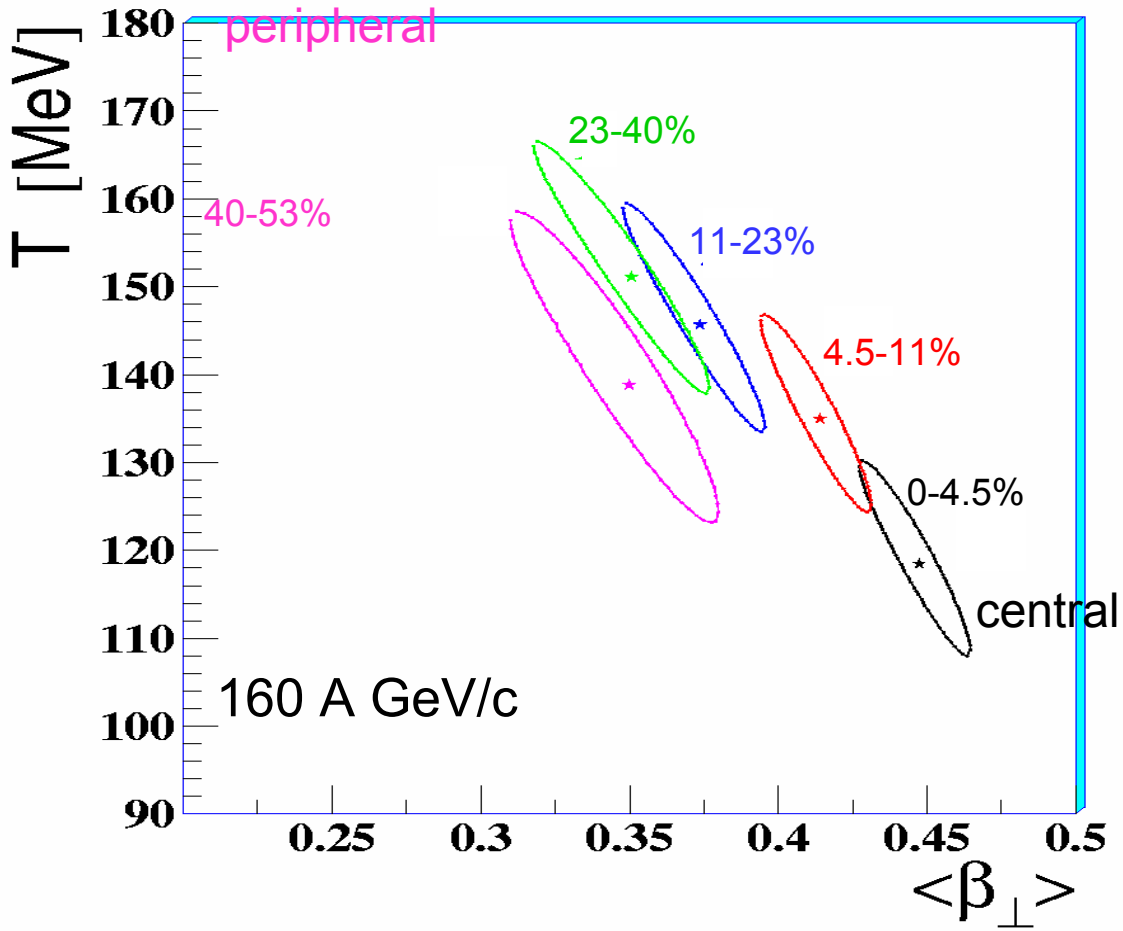
[CH et al., hep-ph/0507276]



Transverse mass spectra

- extract parameters for kinetic freezeout from spectra

→ earlier kinetic decoupling in peripheral collisions compared to central ones

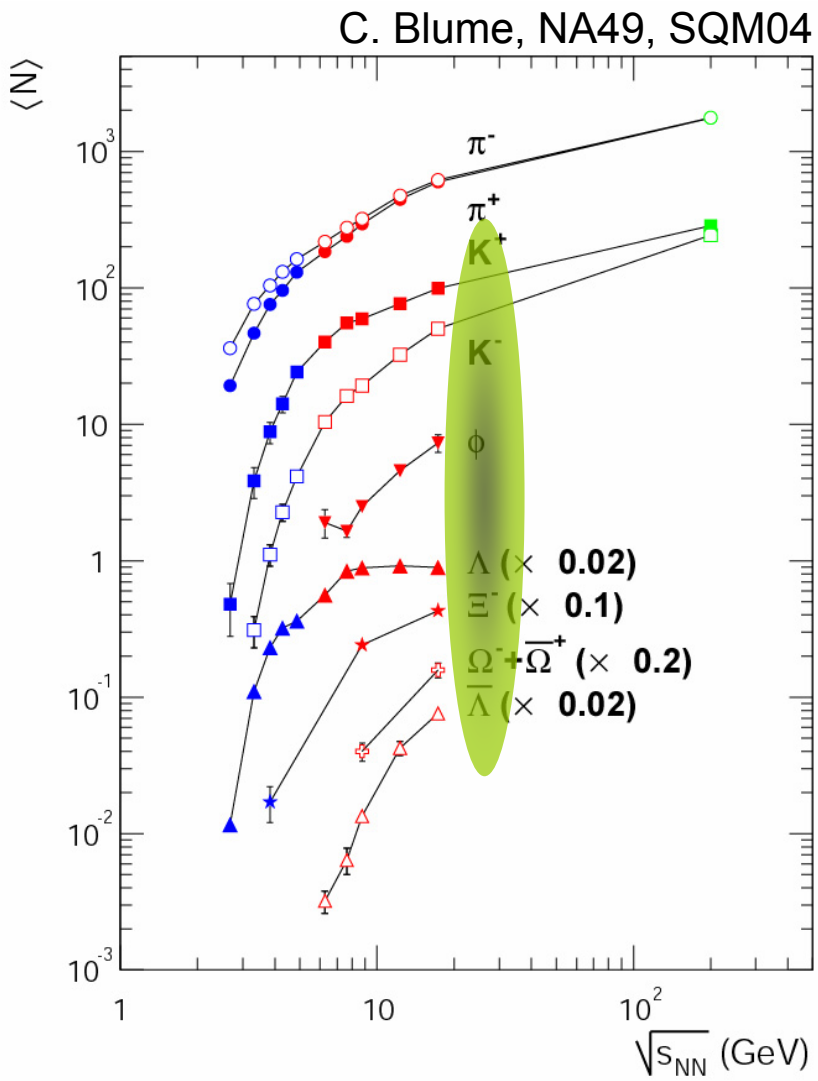


energy dependence of s-production

particle yields

- central Au+Au, Pb+Pb

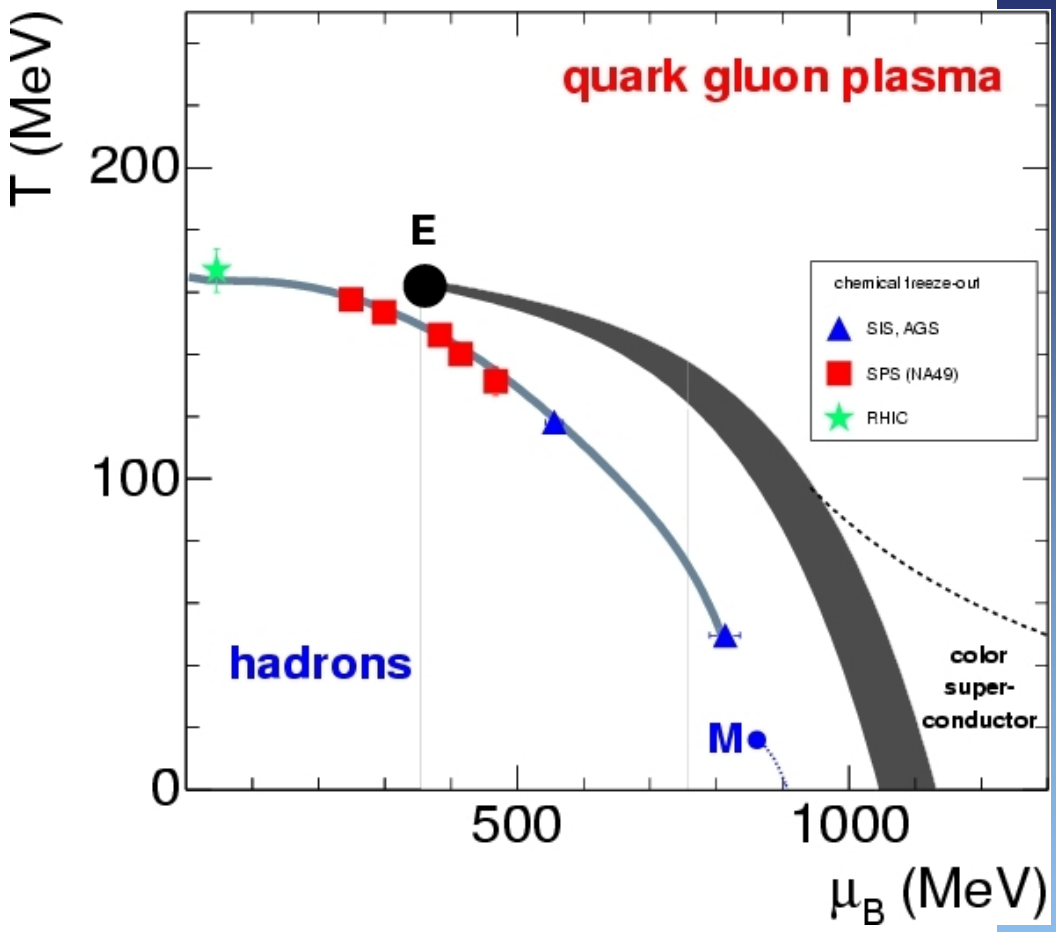
→ extract hadrochemical freezeout parameters (T, μ_B)



4π multiplicities only

Phase diagram

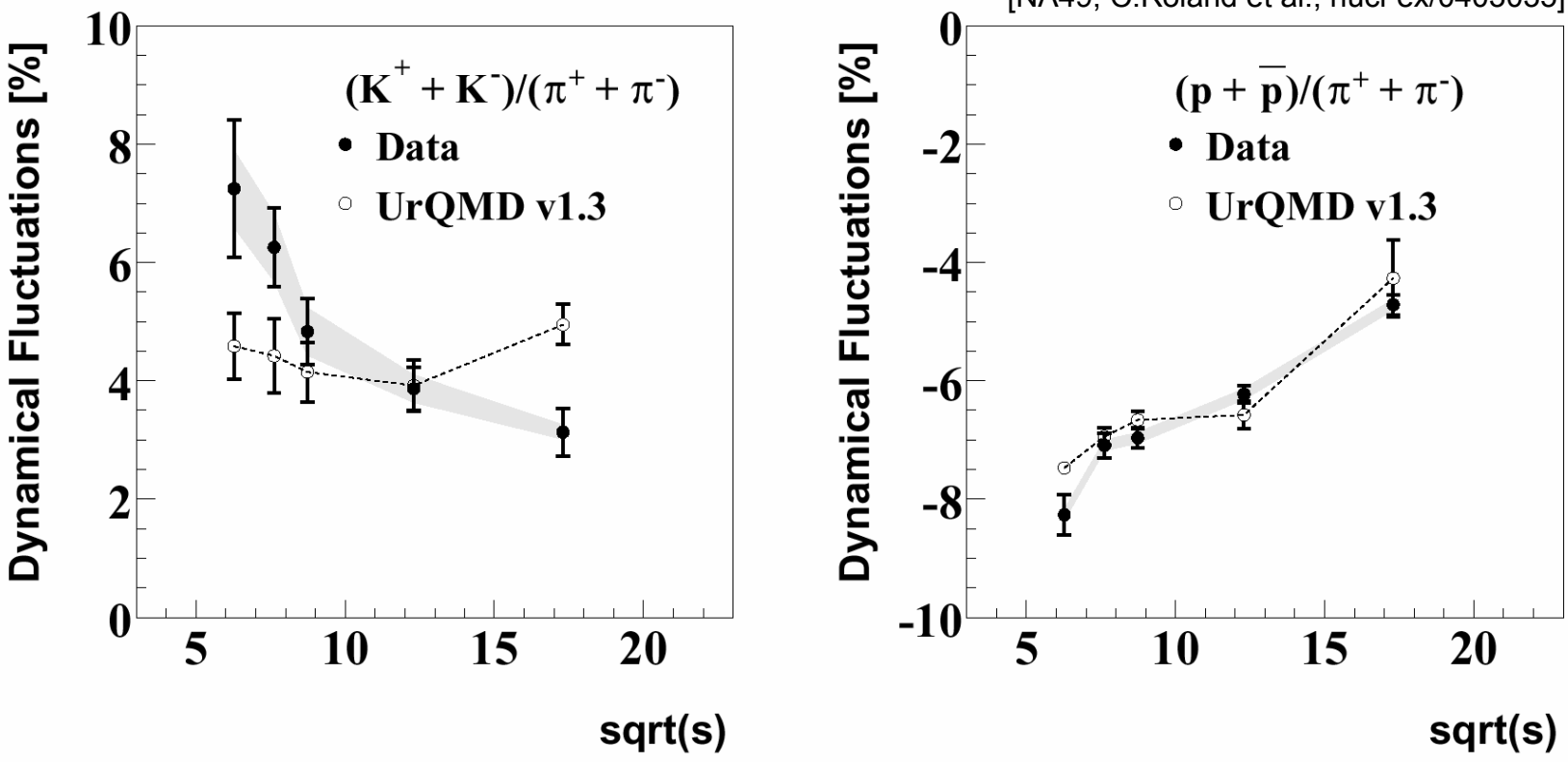
- deconfinement reached for top-SPS and RHIC?
- lower SPS energies
  - decreasing temperature increasing baryon density
  - (depart from phase boundary)



[Critical point (E): Fodor and Katz,
Hadron gas (γ_s): J. Manninen et al.,
grey band: 1st order phase transition]

fluctuations

[NA49, C.Roland et al., nucl-ex/0403035]

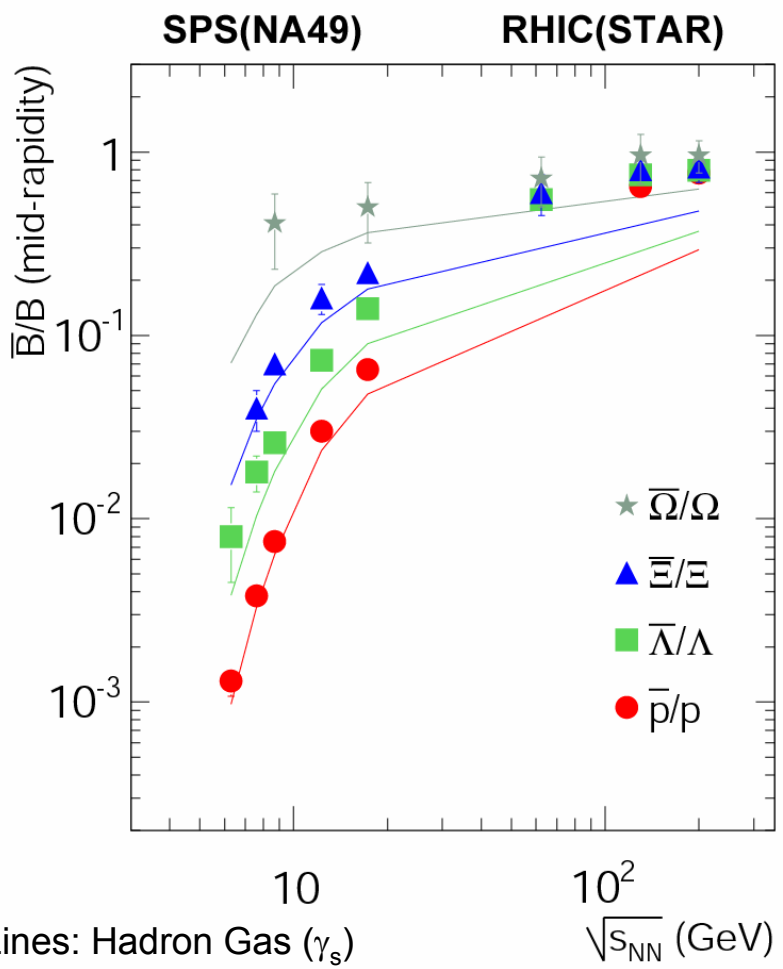


- dynamical fluctuations of the K/π ratio increasing towards lower energies
- p/π due to resonance decays, reproduced by UrQMD
- continuous rise? maximum at lower SPS energies? (acceptance effects?)

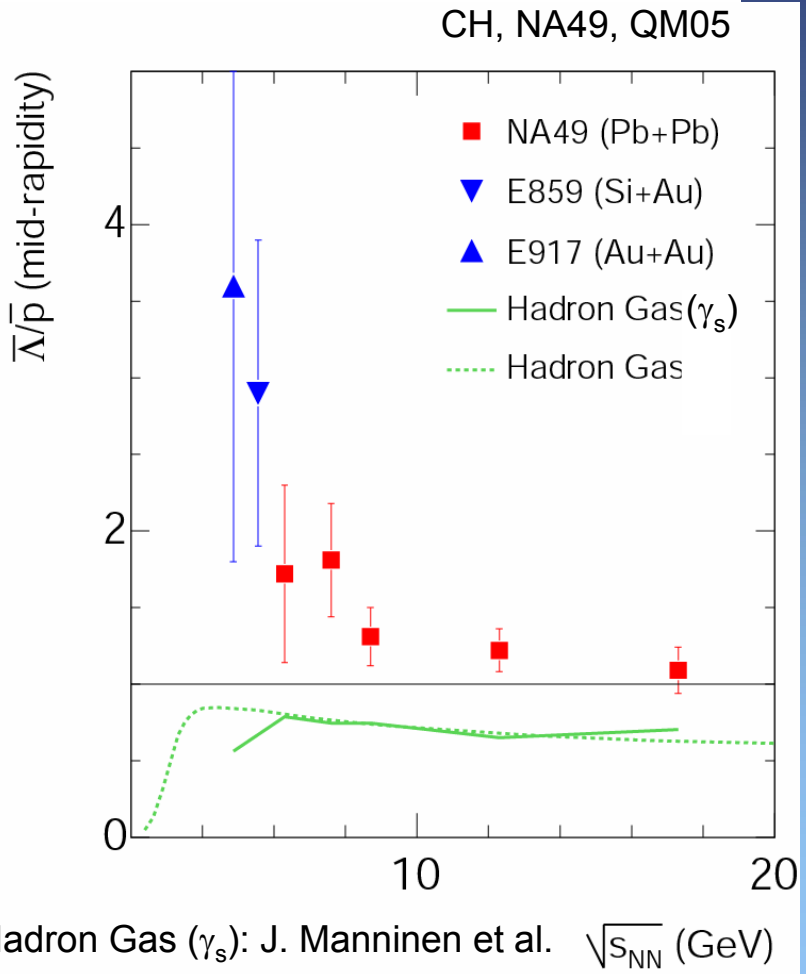
→ Energy dependence needed for larger range!

(Anti-)baryon production

- strongly decreasing $\bar{B}/B$ ratio — increasing baryon density!
- puzzle: $\bar{\Lambda}/\bar{p}$ ratio > 1 — strong $\bar{p}$ absorption?



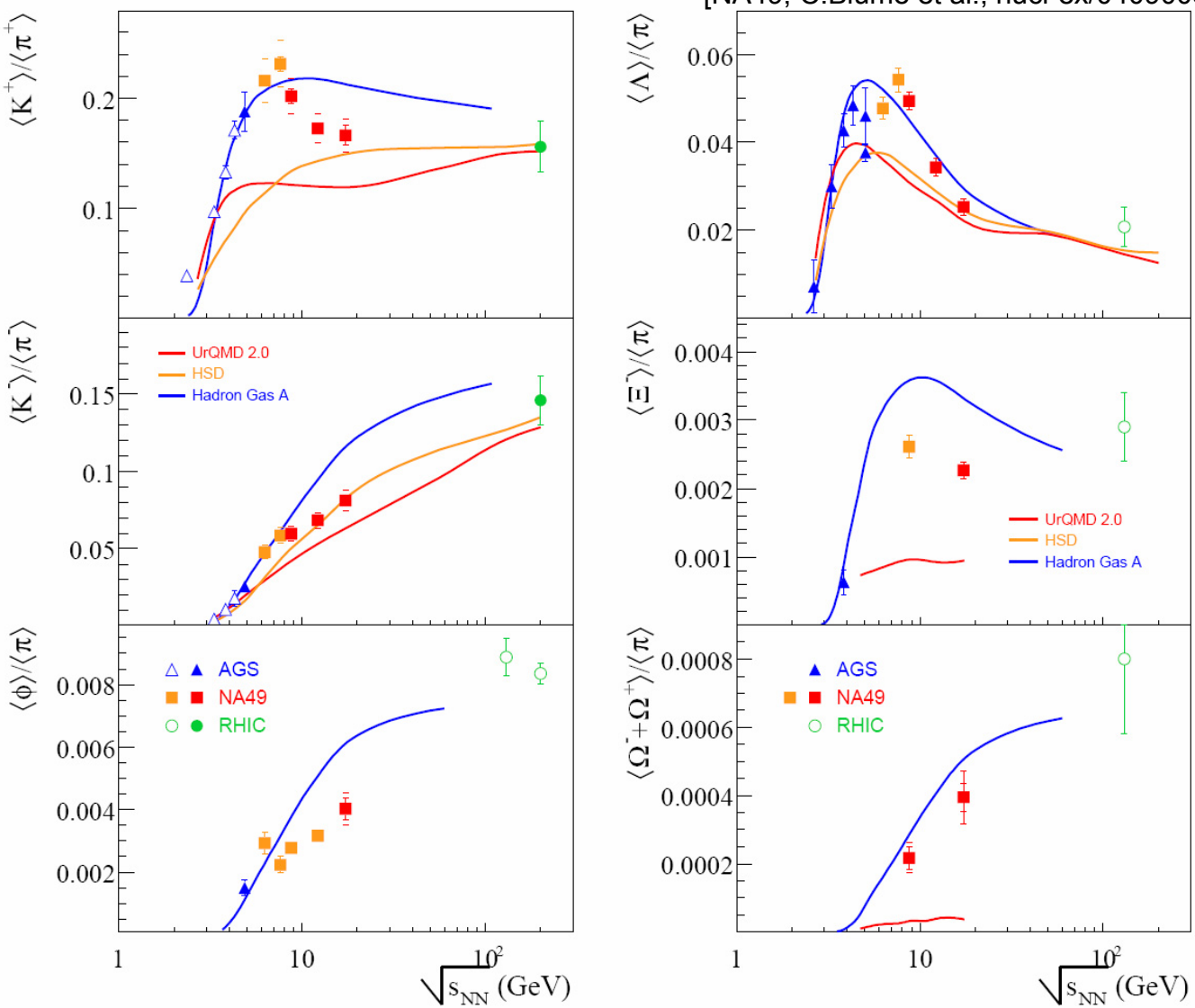
[Lines: Hadron Gas (γ_s)
J. Manninen et al. — Fit to 4π data!]



[Hadron Gas (γ_s): J. Manninen et al.
Hadron Gas: K. Redlich et al.]

relative s-production

[NA49, C.Blume et al., nucl-ex/0409008]



- maximum of relative strangeness production at 30 AGeV
- change from baryon to meson dominated matter
- s-production mechanism different in hadronic / partonic scenario

s-production

s-quark carriers:

K^-, $\overline{K^0}$

Λ (incl. Σ^0)

Ξ, Ω

$\Sigma^\pm$

$\overline{\text{s}}$-quark carriers:

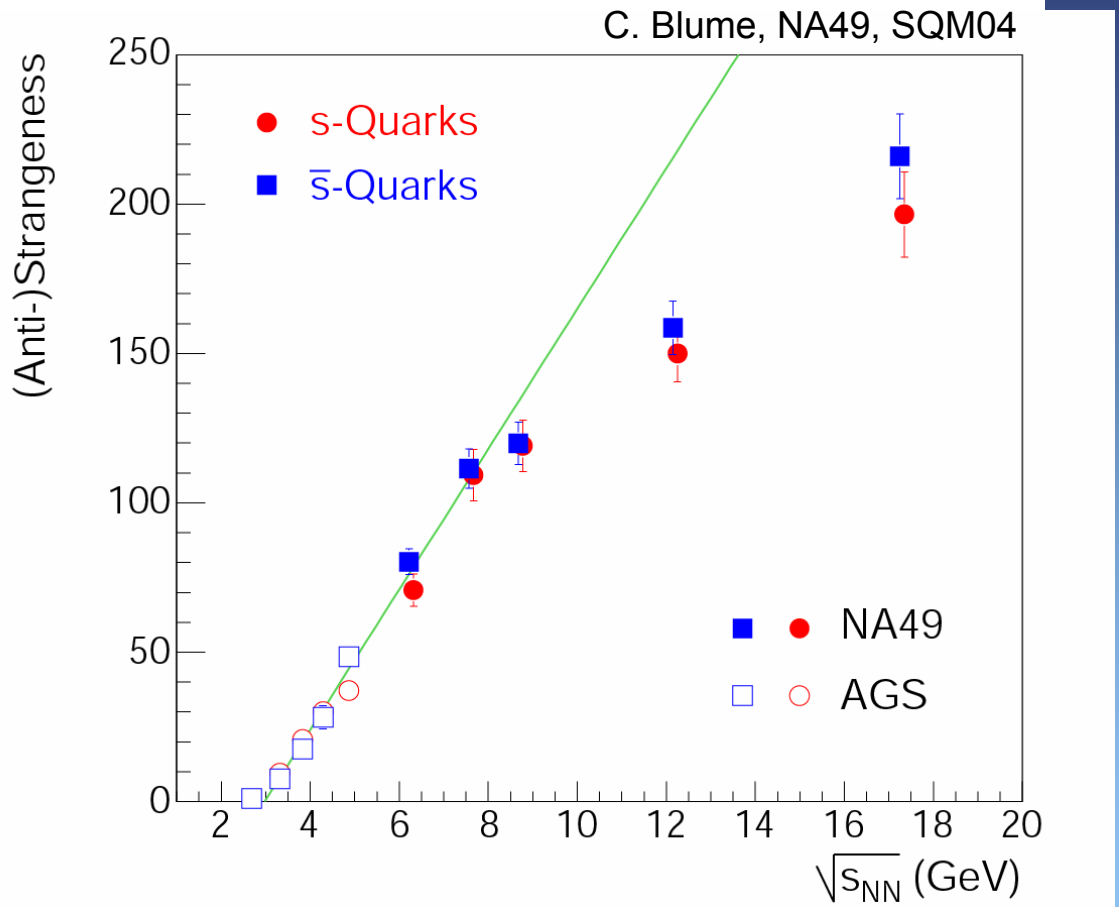
K^+, K^0

$\overline{\Lambda}$ (incl. $\overline{\Sigma^0}$)

$\overline{\Xi}$, $\overline{\Omega}$

$\overline{\Sigma^\pm}$

energy dependence of s-production weakens at ~30 *A*GeV

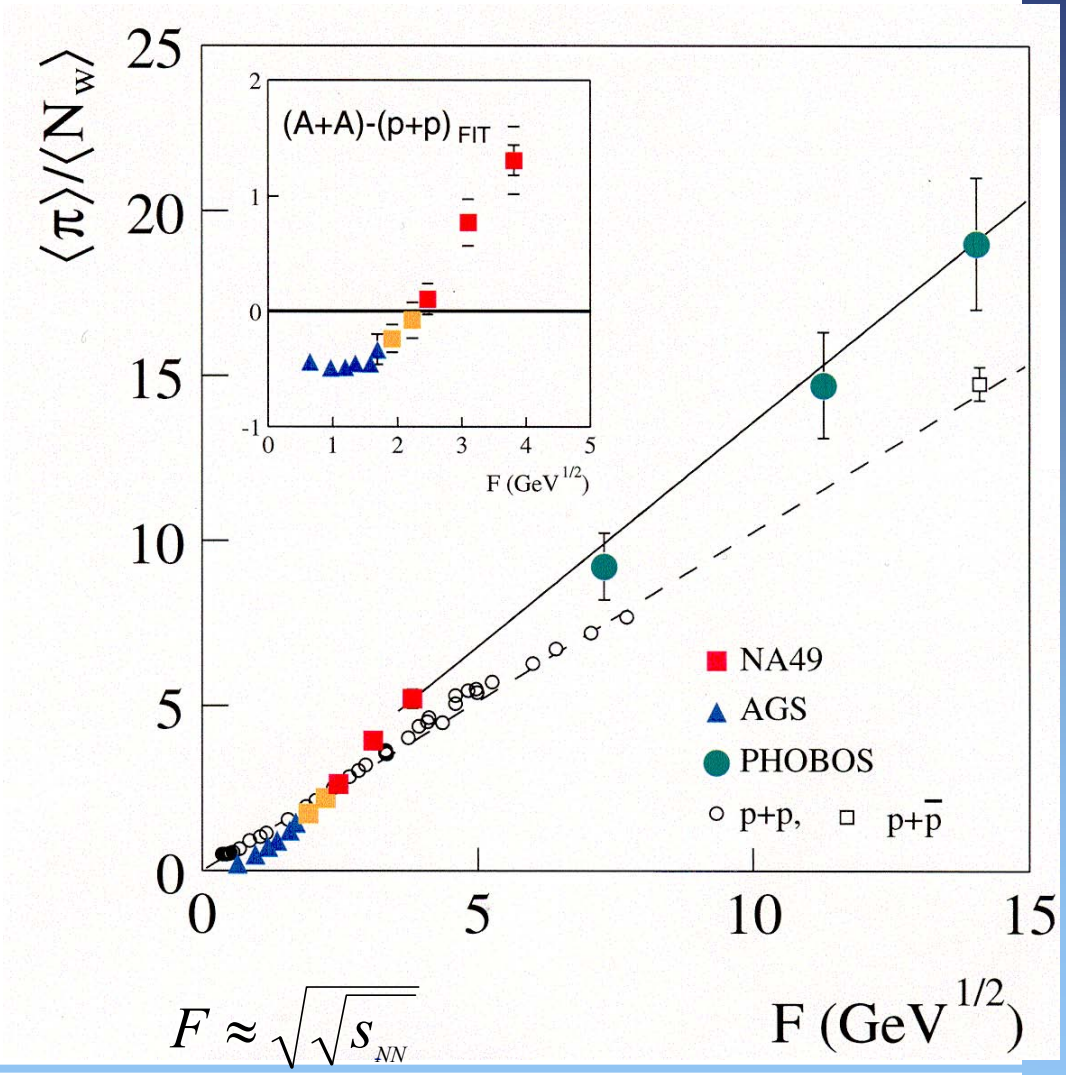


measured (at least partially)

extrapolated (isospin symmetry (K), hadron gas model (Ξ,Ω), empirical factor ($\Sigma^\pm$))

π-production

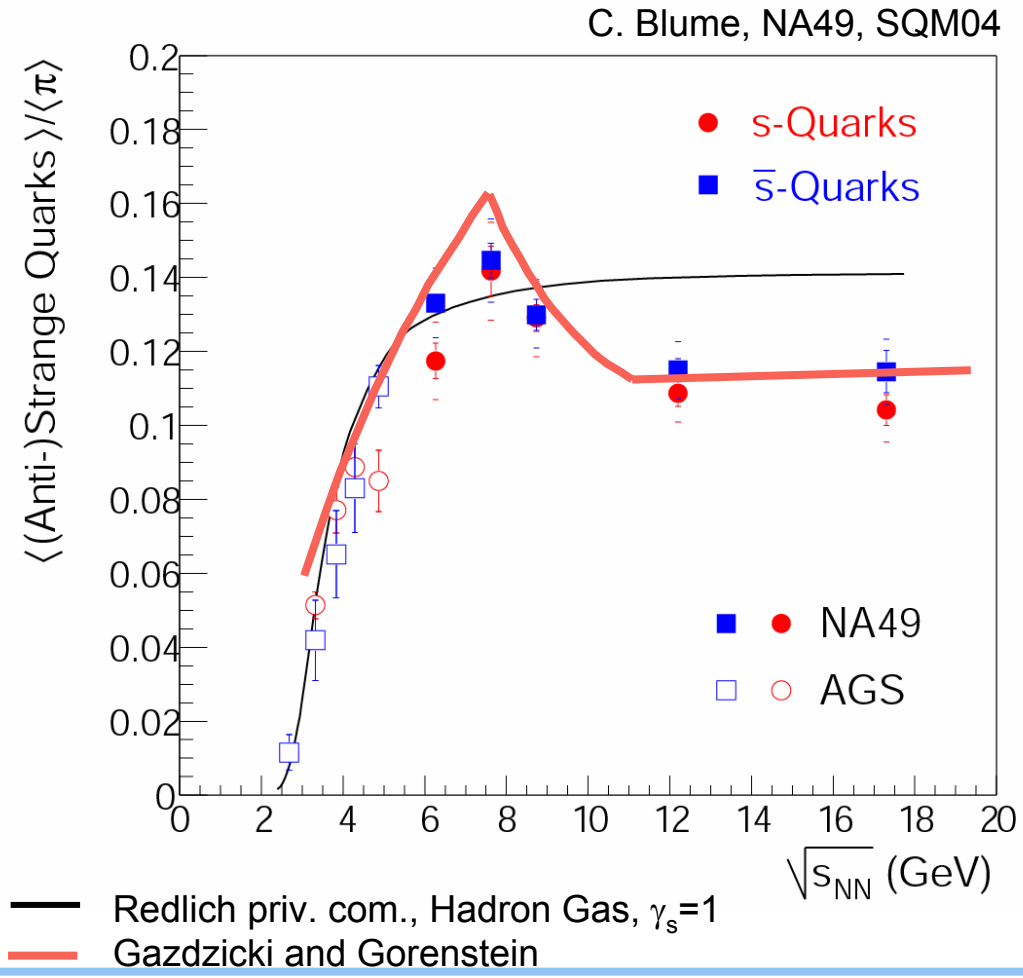
energy dependence of π-production changes at ~30 *A*GeV



relative s-production (II)

maximum in relative strangeness production at ~30 *A*GeV

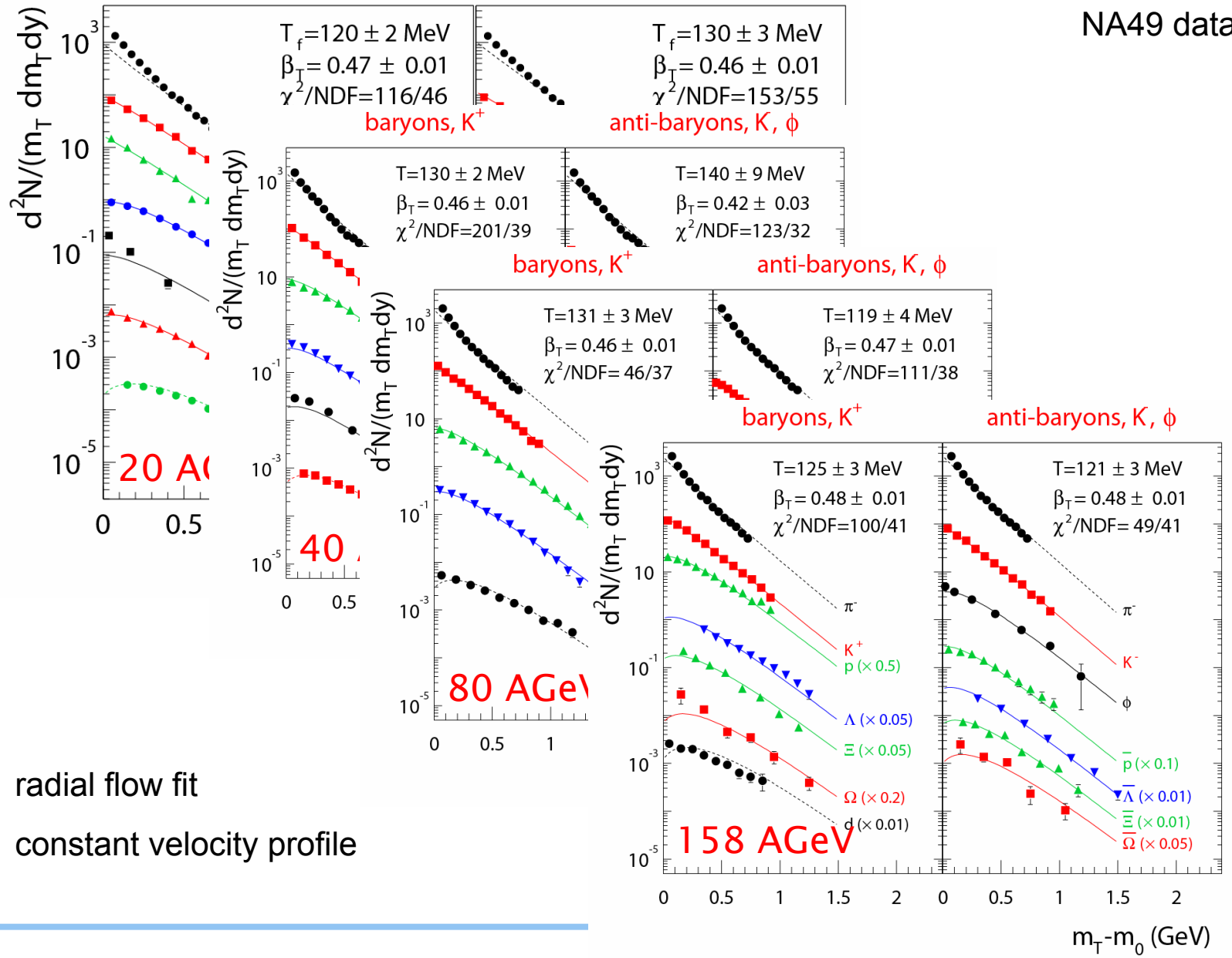
saturation for higher energies



- not explained by hadron gas models although the general feature is captured (baryon → meson dominated system)
- neither by UrQMD, HSD
  [E.L. Bratkovskaya et al., PRC 69, 054907 (2004)]
- predicted for a phase transition
  [Gazdzicki, Gorenstein, Acta. Phys. Polon. B30, 2705 (1999)]

spectra

NA49 data



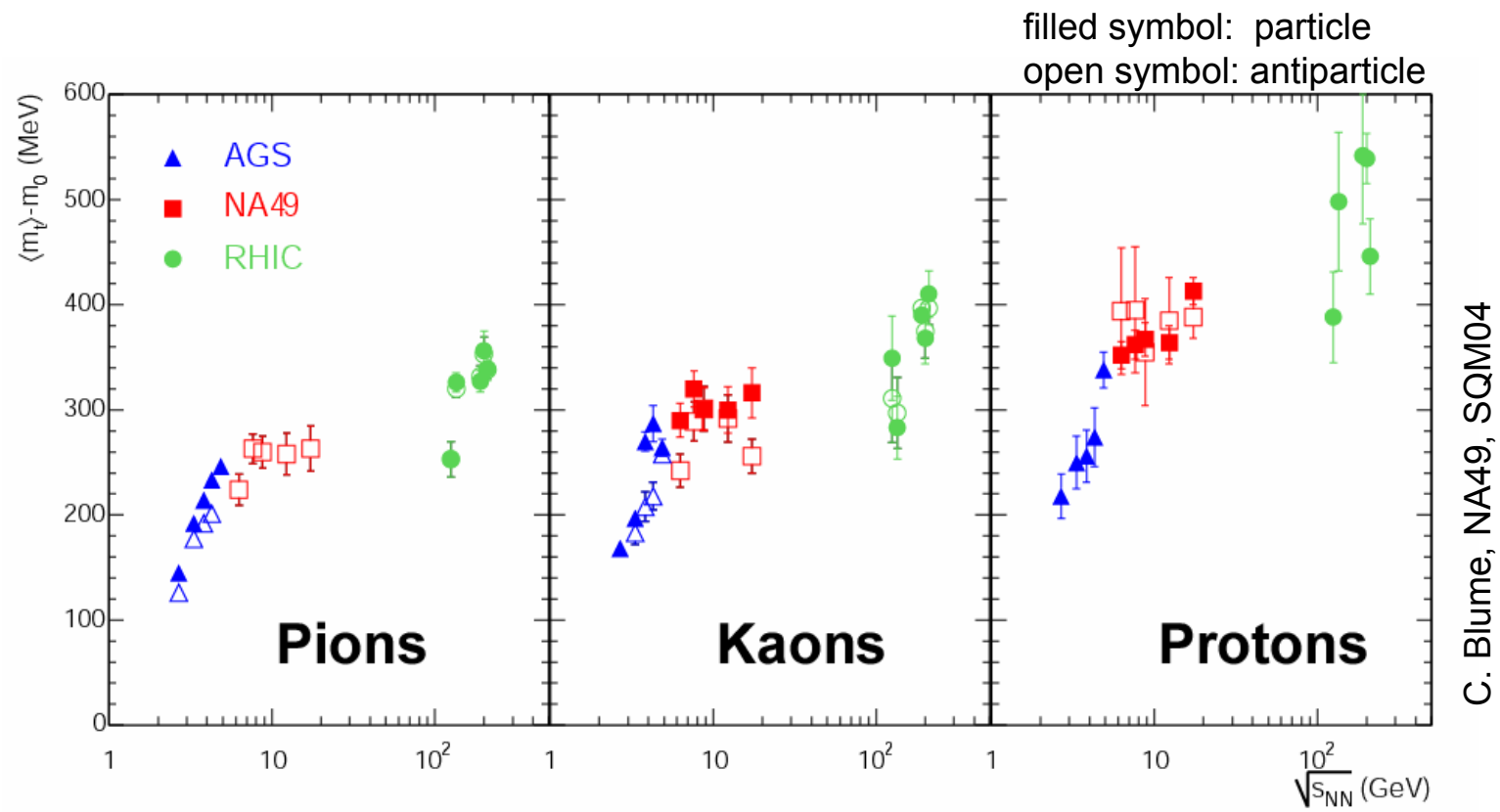
radial flow fit

constant velocity profile

Transverse-mass spectra (II)

energy dependence of $\langle m_t \rangle$ changes at lower SPS energies

seen for pions, kaons, protons and their antiparticles



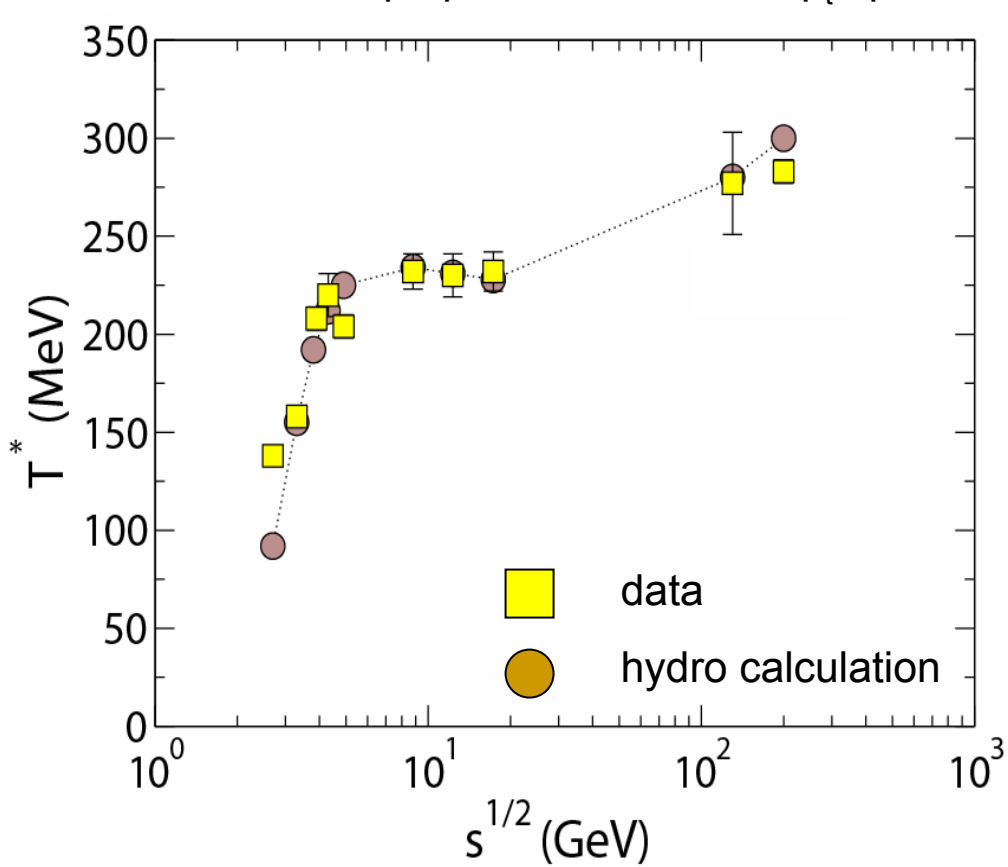
Transverse-mass spectra (III)

- not explainable by rescattering, Cronin effect from transport models (UrQMD, HSD, not shown)
[Bratkovskaya et al., PRC 69, 054907 (2004)]

→ early prehadronic/ partonic pressure needed!

- consistent with assuming a 1st order phase transition: change of EOS?
[Van Hove, PLB 118, 138 (1982); Gorenstein et al., PLB 567, 175 (2003)]

T* inverse slope parameter of kaon p_t-spectra



[Y. Hama et al., Braz. J. Phys. 34, 322 (2004)]

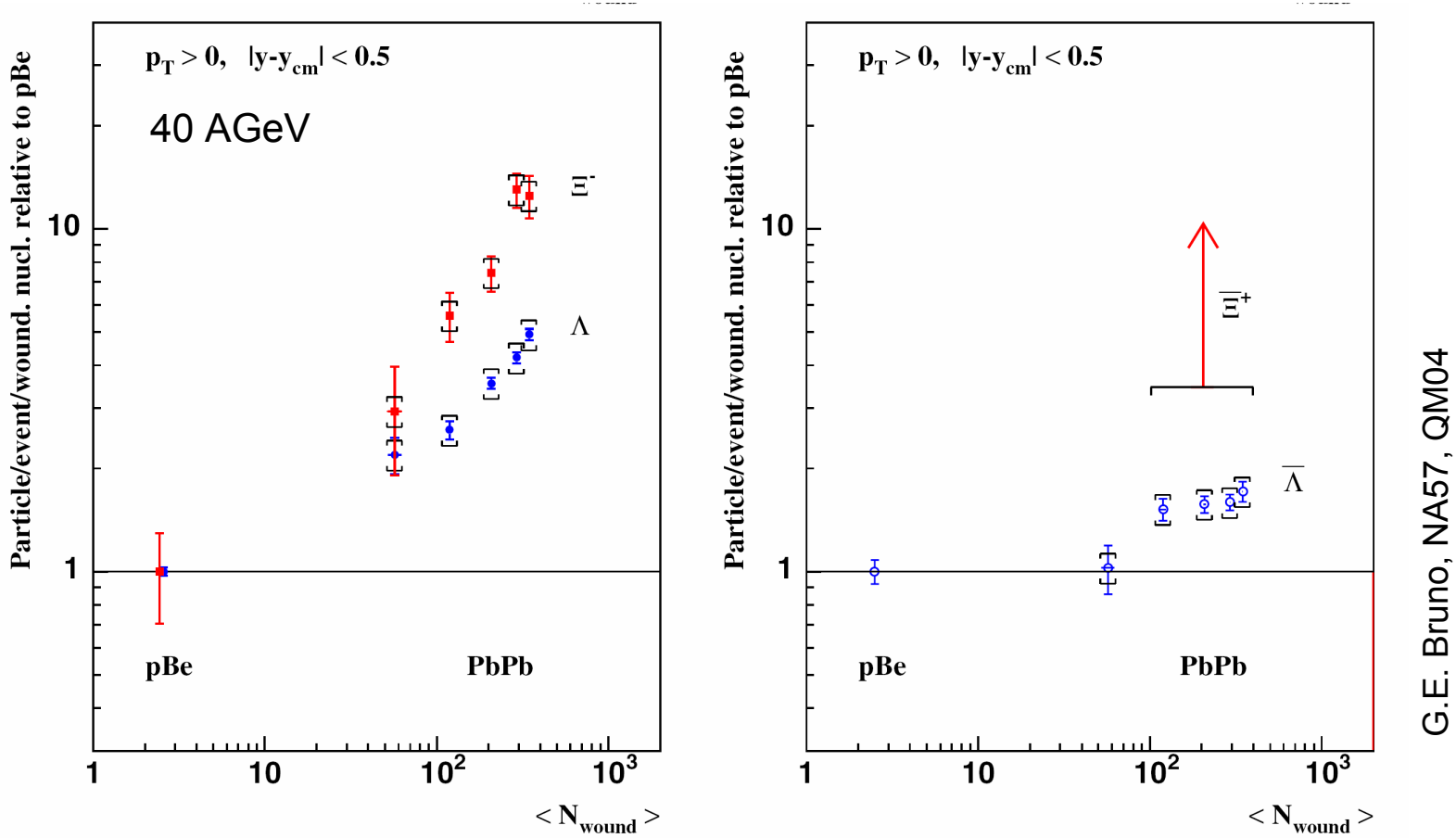
centrality dependent Pb+Pb collisions at 40 AGeV

and

central collisions of systems with smaller A

size dependence of s-production

- s-enhancement larger for central collisions compared to 158 AGeV
- increase with N_{wound} steeper than at 158 AGeV (s=1 "slower" saturation)
- s-hierarchy

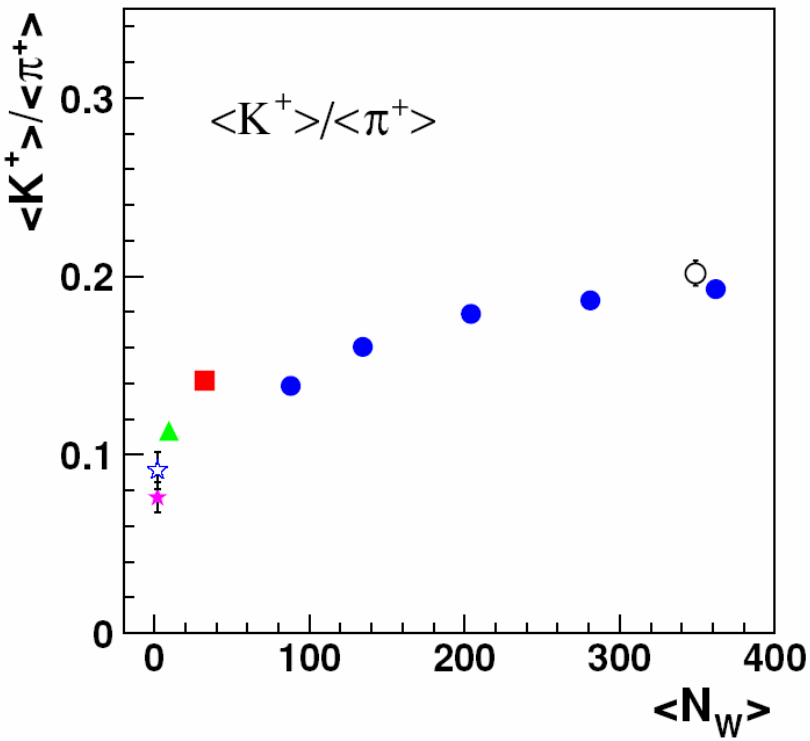


size dependence of s-production (II)

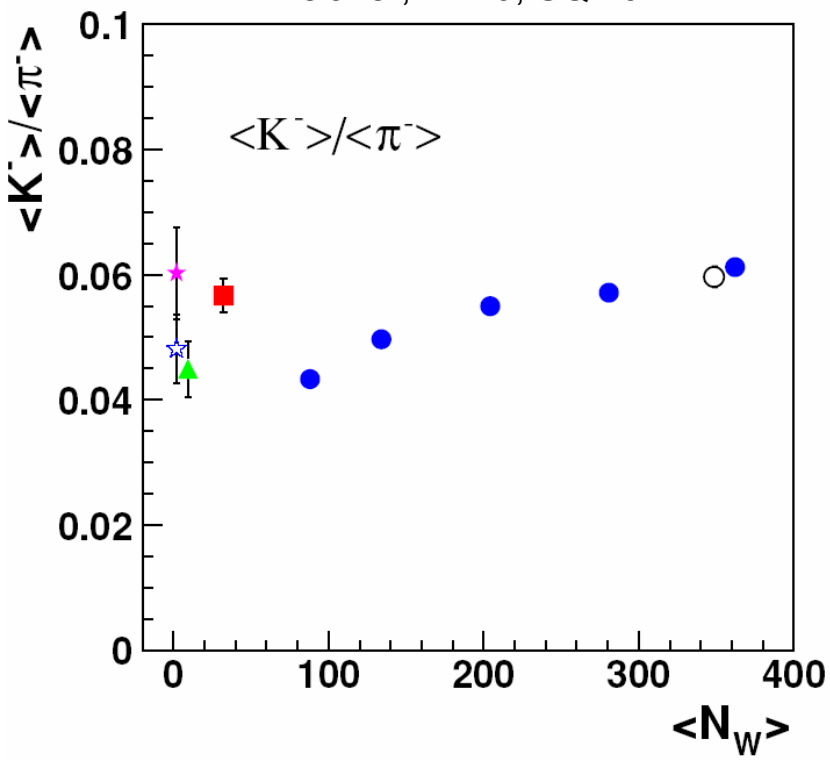
- stronger enhancement
- "geometry" effect comparing central collisions of small nuclei with peripheral Pb+Pb at the same N_{wound}

pp NN
semicentral CC
central SiSi
central PbPb

40 GeV beam energy



P. Dinkelaker, NA49, SQM04



size dependence of s-production (III)

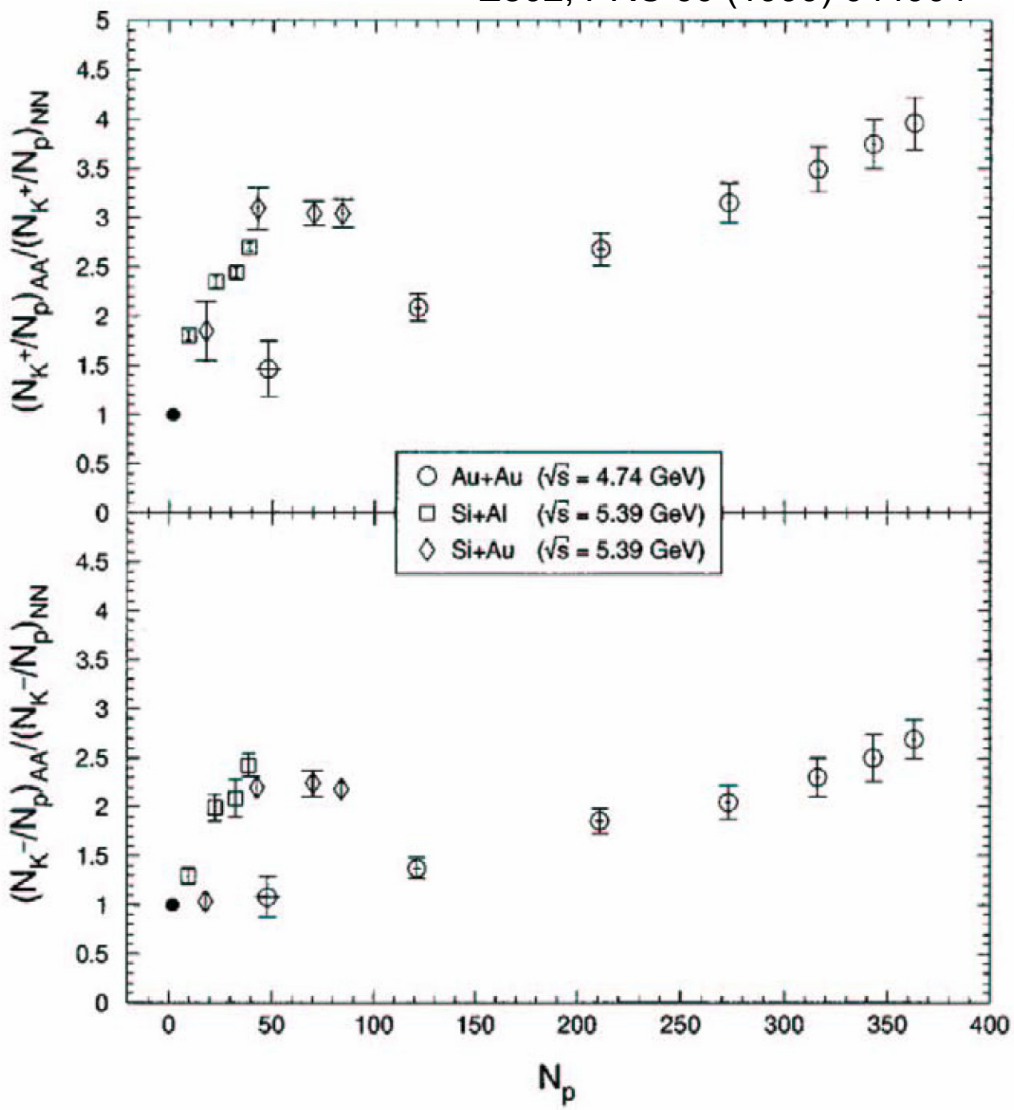
trend continues towards AGS:

- change from fast increase with saturation at rather low N_{part} to linear increase
- increasing differences between different collision geometries: central ↔ peripheral
- increasing s-enhancement compared to p+p

- RQMD: linear increase of relative s-production with centrality expected from hadronic rescattering

[Wang et al. PRC 61 (2999) 064904]

E802, PRC 60 (1999) 044904



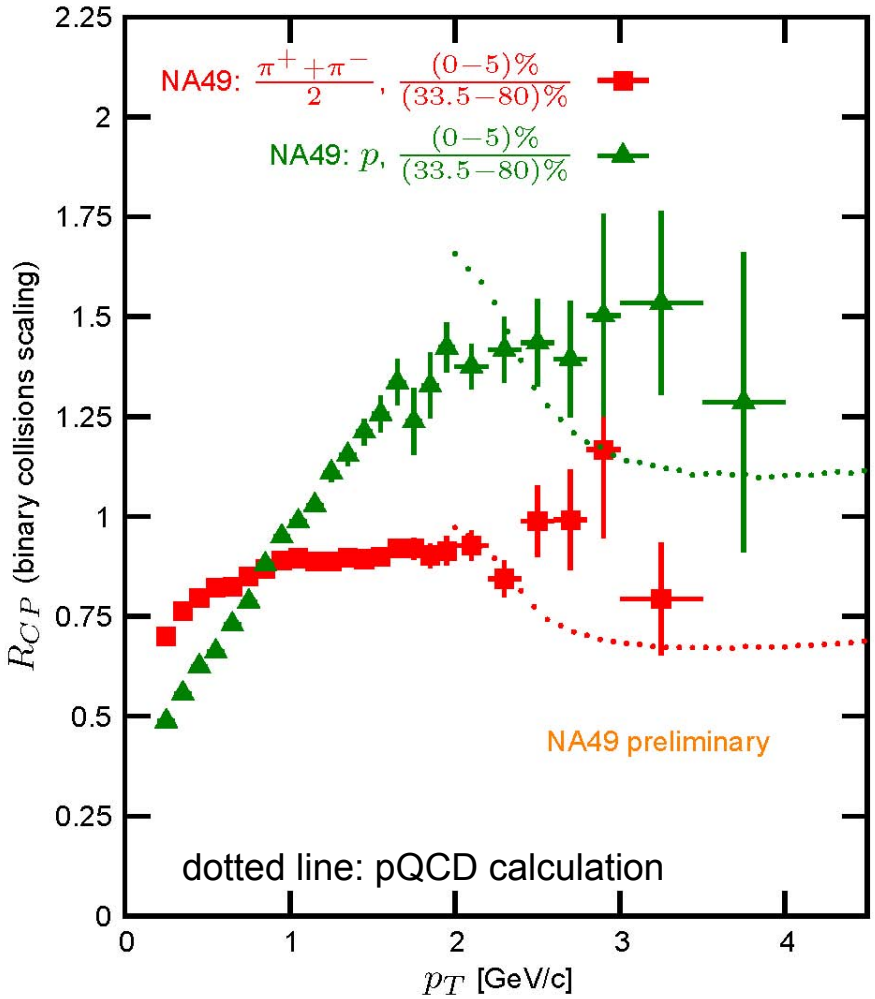
Summary

- (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

high-p_t phenomena

- saturation of R_{CP} for high p_t
- no Cronin enhancement for mesons at higher p_t
- baryon – meson difference

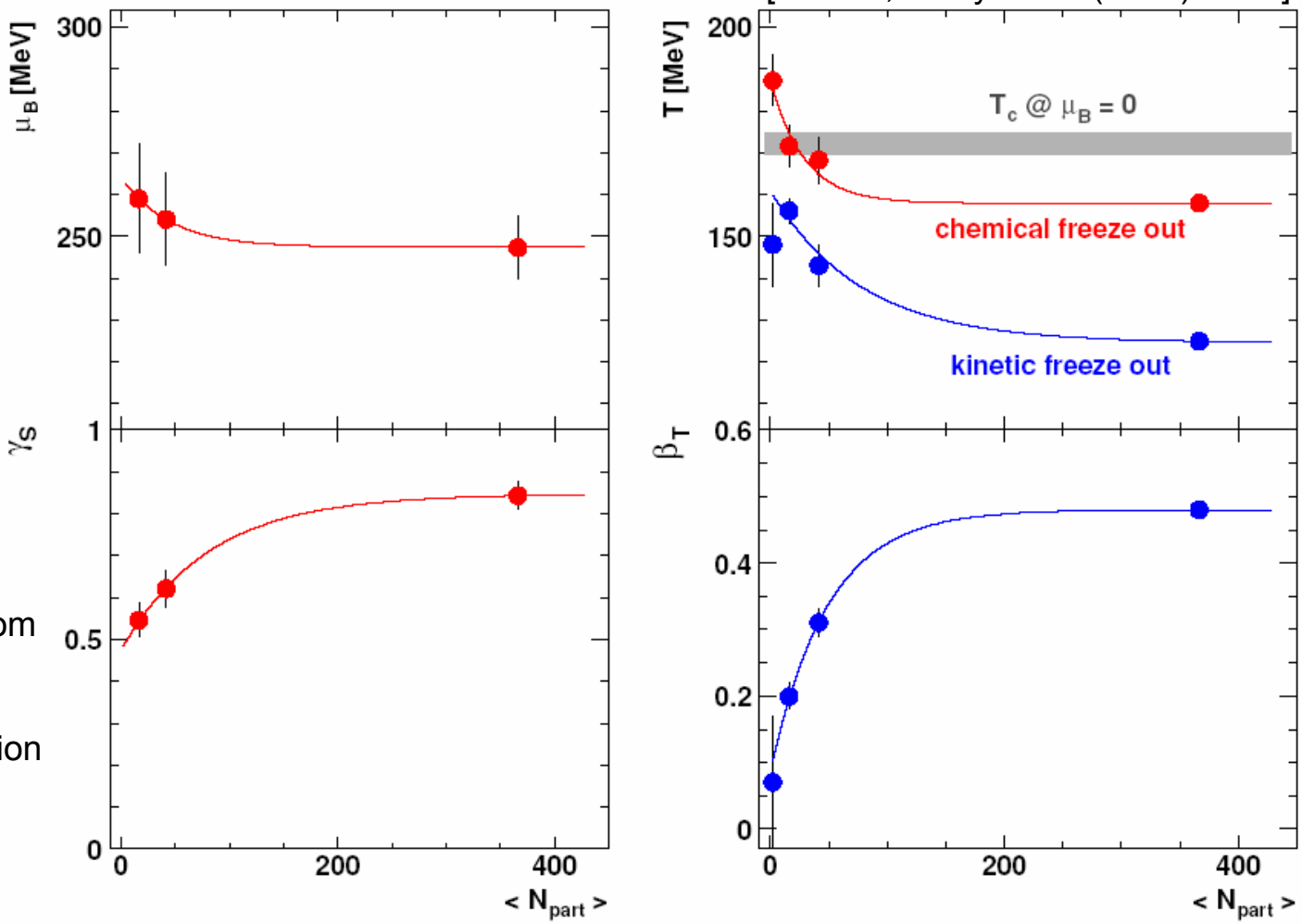
$\rightarrow$ enhancement of the baryon/meson ratio at high p_t



chemical / kinetic freeze-out

- „earlier“ freeze-out consistent with results from hadron gas model fits to smaller systems and radial-flow („blast-wave“) fits to p_t-spectra

[I.Kraus, J.Phys.G31 (2005) S147]



hadron gas model fits from Becattini, private communication (C+C, Si+Si Pb+Pb)