Results from NA49

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for the NA49 collaboration (CERN)

NA49 data

- comprehensive set of data on hadron production in A+A collisions (data taking period 1994-2002, analysis still going on!)
- most extensively studied at the top SPS energy for central Pb+Pb, centrality controlled peripheral Pb+Pb, Si+Si, C+C, and p+p
- energy dependence over the entire SPS energy range

$\rightarrow$ nearly continuous energy dependence between threshold and RHIC available

$\rightarrow$ SPS energy range is a very interesting region!

main observables:

- hadron production, in particular strange hadrons
- 2-particle and charge correlations
- collective flow
- fluctuations
- d and $\bar{d}$ production
- high-p_t phenomena

parallel talks:

A. László, Aug.5th, session 1a: High-p_t spectra of identified particles

G. Stefanek, Aug.5th, session 2a: Elliptic flow of Λ hyperons

posters

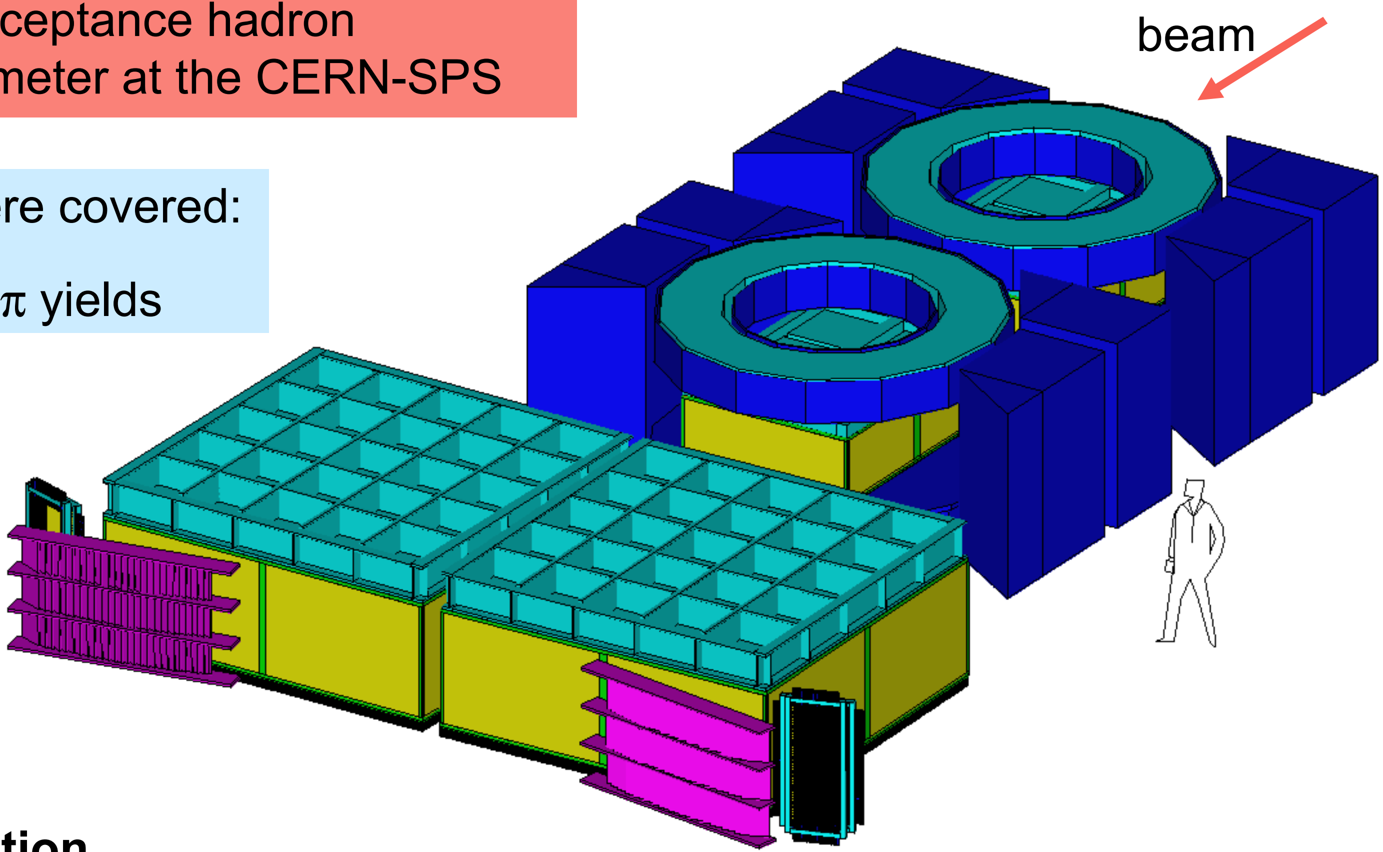
- **G. Melkumov, V. Kolesnikov:** Antideuteron and deuteron production
- **G. Melkumov, V. Kolesnikov:** Antiproton and proton production
- **P. Dinkelaker:** System-size dependence of s-production

The NA49 experiment

large acceptance hadron spectrometer at the CERN-SPS

forward hemisphere covered:

(y,p_t)-spectra $\rightarrow$ 4π yields



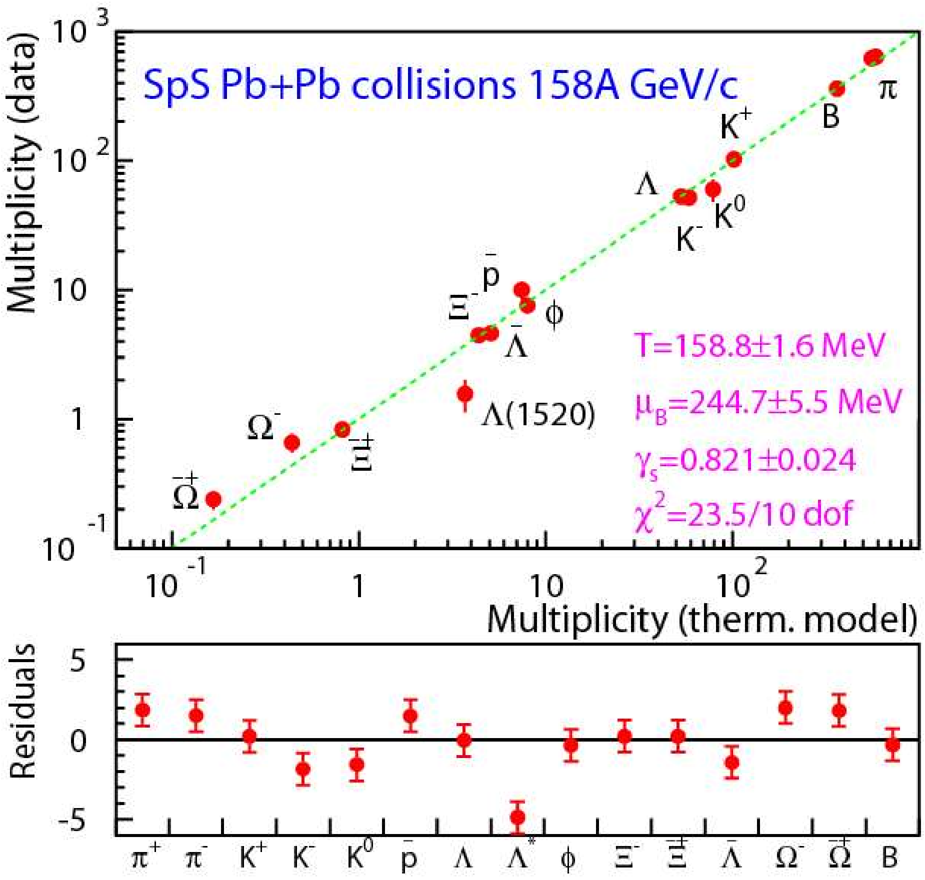
particle identification

- dE/dx (3-6% res.)
- TOF (60 ps res.) around midrapidity
- invariant mass + topology (5-10 MeV res.)

- energy of projectile spectators measured for centrality selection
- fragmentation beam for smaller nuclei

Hadron production in central PbPb

- initial stage: energy density $\varepsilon \approx 3$ GeV/fm^3 [NA49, PRL75, 3814 (1995)]
- 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

  ($\gamma_s \approx 0.8$)

- RHIC: $T_{chem} \approx 160$ MeV

  $\mu_B \approx 30\text{-}50$ MeV

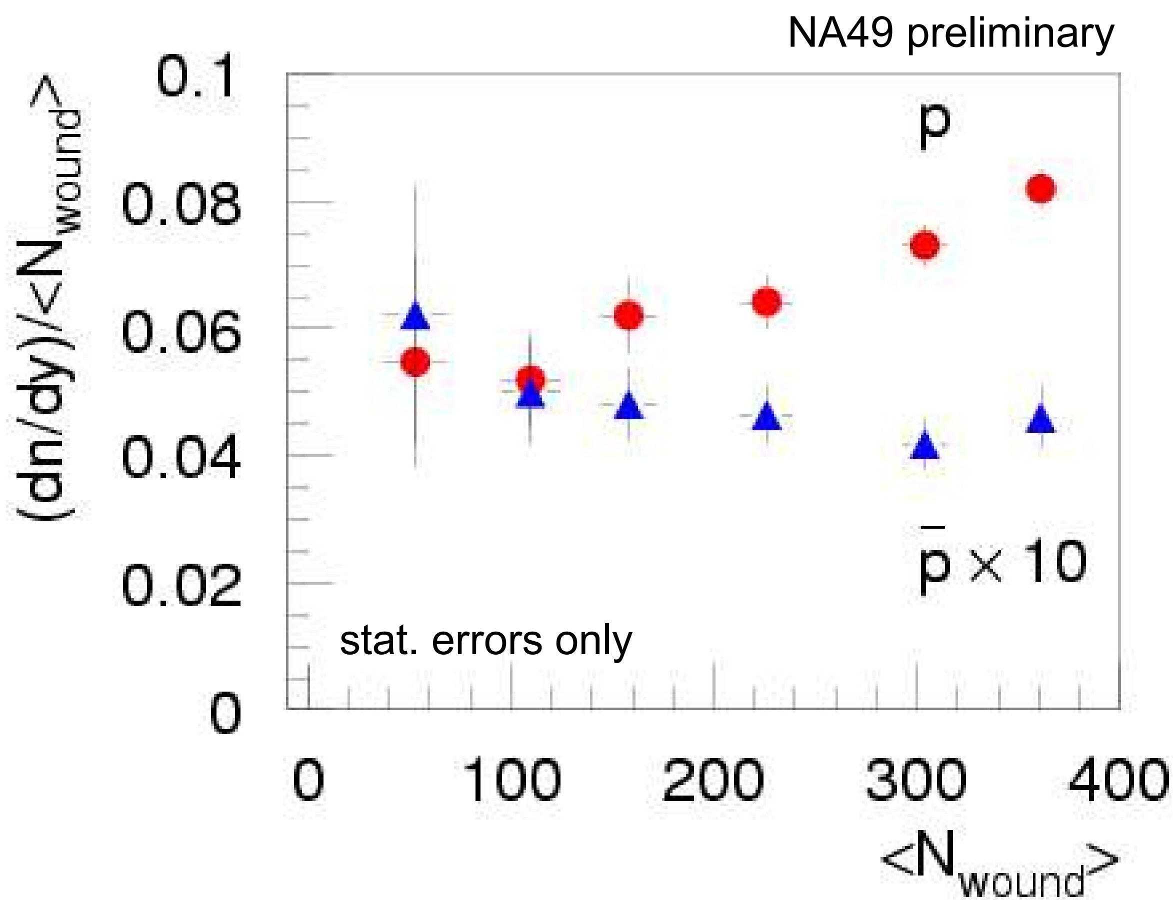
hadronization close to predicted phase boundary!

$\rightarrow$ deconfined system prior to freeze-out?

larger μ_B at SPS compared to RHIC

p and $\bar{p}$ production vs centrality

- protons at midrapidity: increased stopping for central collisions
- antiprotons: increasing absorption?!

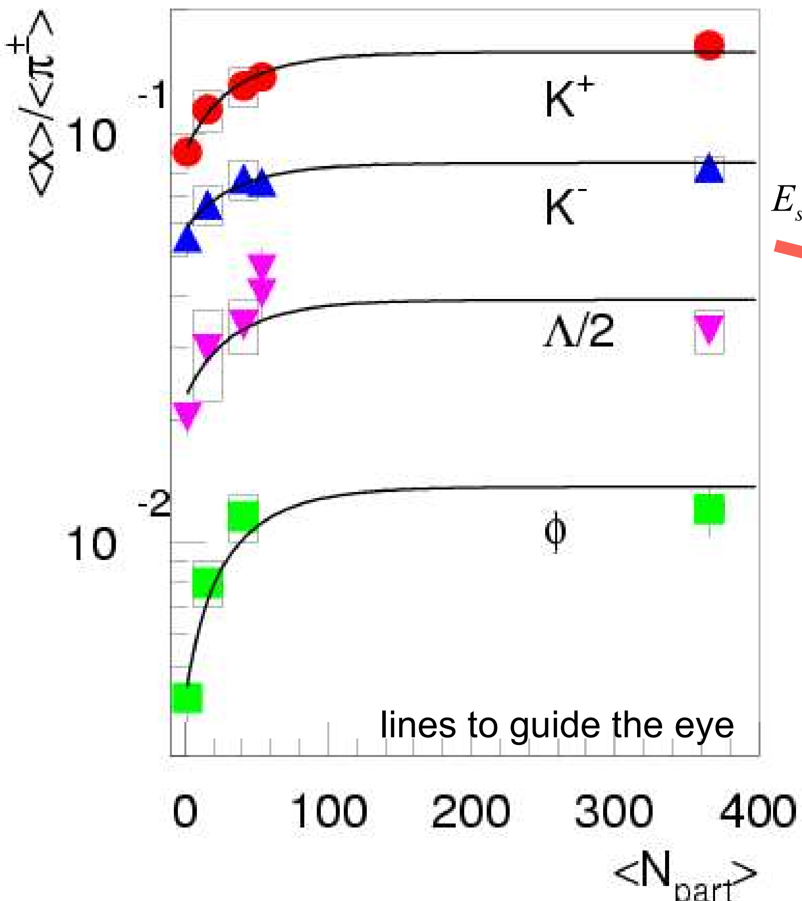


→ NA49 poster

s-production vs system-size

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

[NA49, PRL 94, 052301 (2005)]



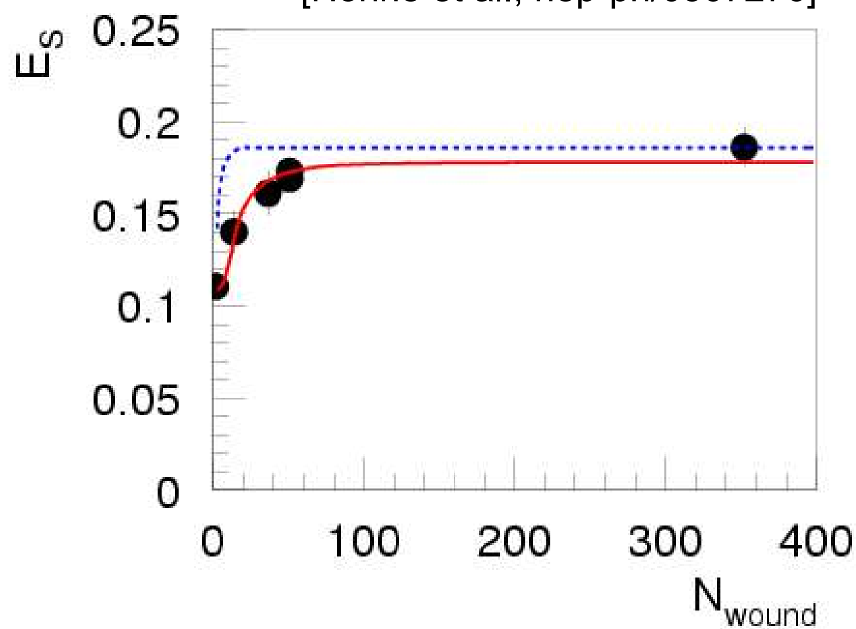
$$\langle\pi^{\pm}\rangle = 0.5\cdot\left(\langle\pi^{+}\rangle + \langle\pi^{-}\rangle\right)$$

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!

$$E_s = \frac{\langle\Lambda\rangle + 2\left(\langle K^+\rangle + \langle K^-\rangle\right)}{\langle\pi\rangle}$$

[Höhne et al., hep-ph/0507276]



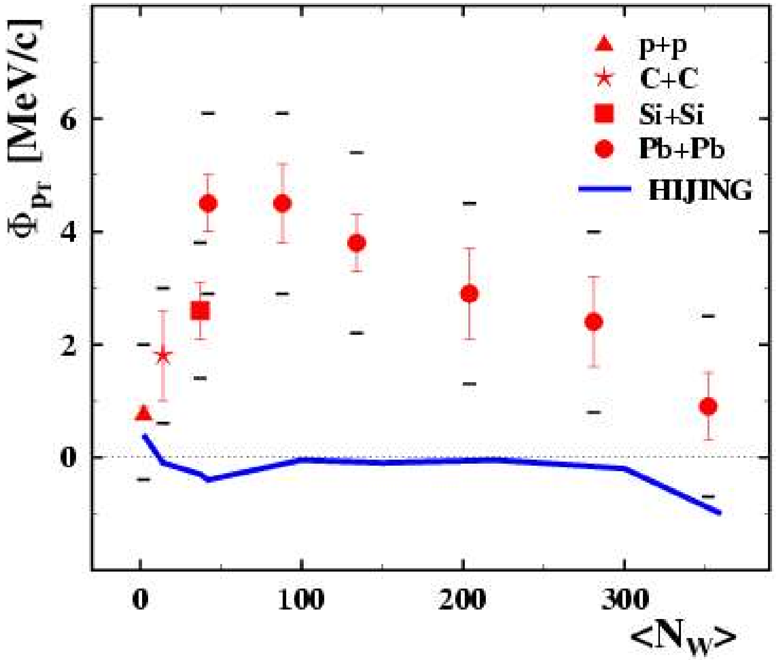
similar results at RHIC, e.g. [PHENIX, PRC 69, 034909 (2004)]

158 *A*GeV

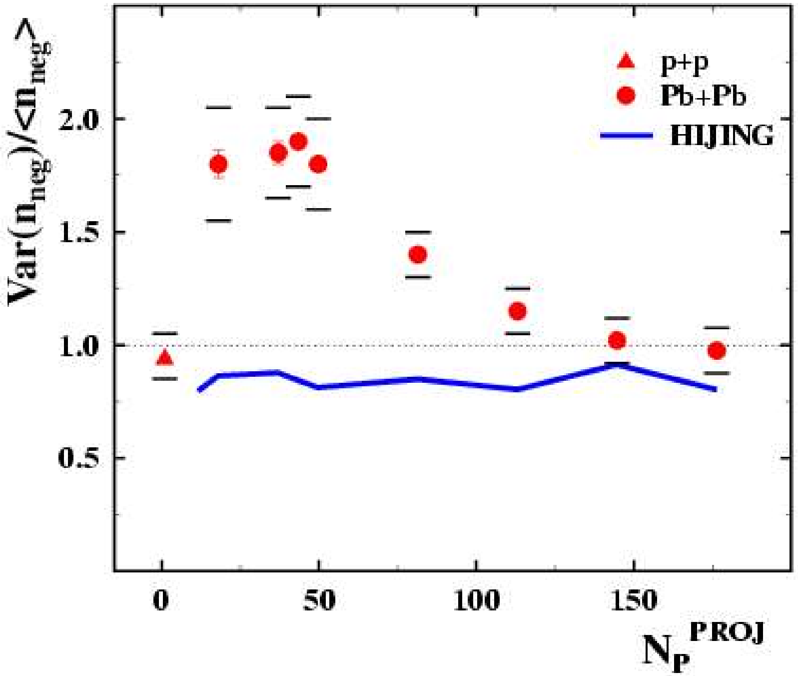
fluctuations vs centrality

all negatives, acceptance: $4 < y_\pi < 5.5$ and $0.005 < p_t < 1.5$ GeV/c

[NA49, PRC 70, 034902 (2004)]



NA49 preliminary



• fluctuations increase towards peripheral collisions

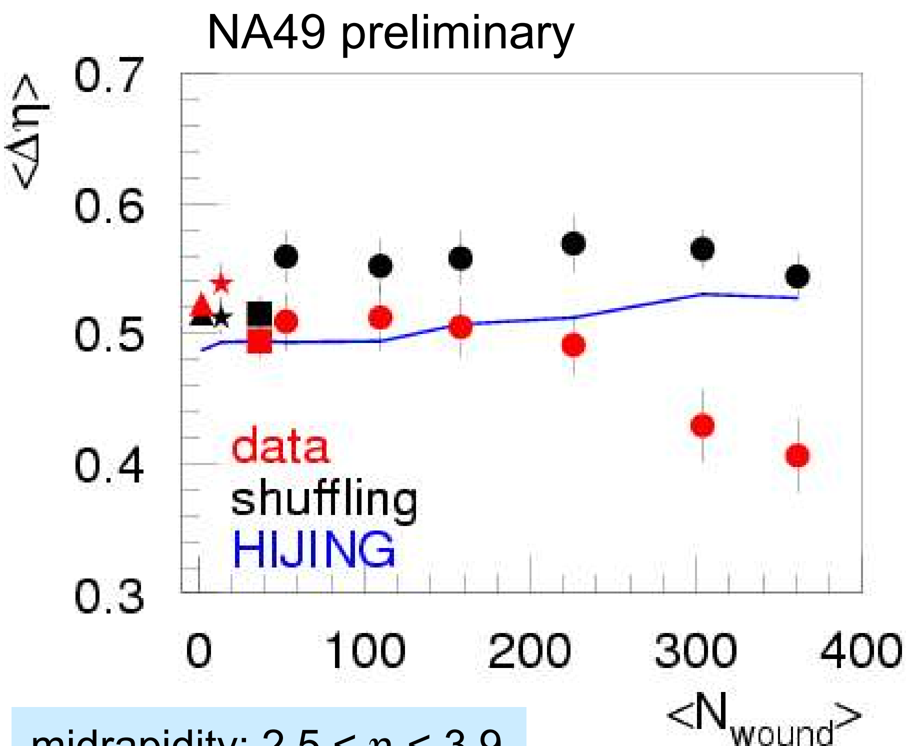
• consistent with percolation picture: fluctuations expected for systems where several clusters are present [Ferreiro et al., PRC 69, 034901 (2004)]

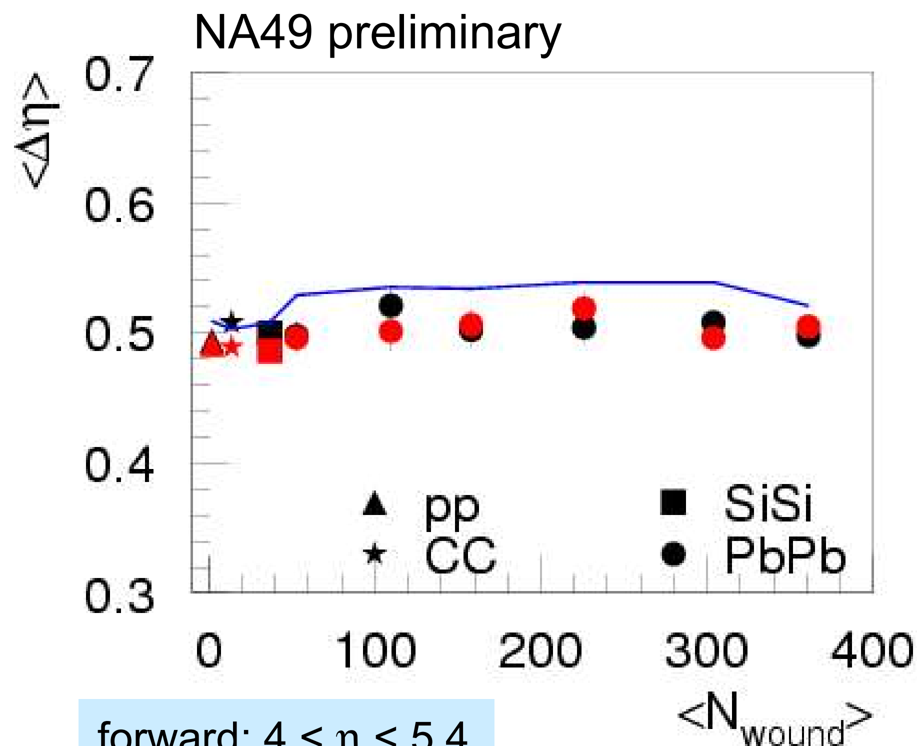
• $<p_t>$ and multiplicity fluctuations correlated
[Mrowczynski et al, PRC 70, 054906 (2004)]

similar results at RHIC, e.g. [PHENIX, PRL 93, 092301 (2004)]

balance function vs centrality

- analysis of balance function (all charged particles): consistent with delayed hadronization in central Pb+Pb [NA49, PRC 71, 034903 (2005)]
- **new**: effect of decreasing width located at mid-pseudorapidity





midrapidity: $2.5 < \eta < 3.9$

forward: $4 < \eta < 5.4$

$0.005 < p_t < 1.5$ GeV/c

similar results at RHIC, [STAR, PRL 90, 172301 (2003)]

Summary: PbPb @ 158 *A*GeV

- **central PbPb:** fireball of high energy density created
  hadron yields successfully described by hadron gas models
  $\rightarrow$ chem. freeze-out close to phase boundary
- **smaller A/ peripheral PbPb:** features can be explained assuming
  smaller/ several such sources, earlier freeze-out

(not shown: consistent with results from kinetic and chemical freeze-out analysis)

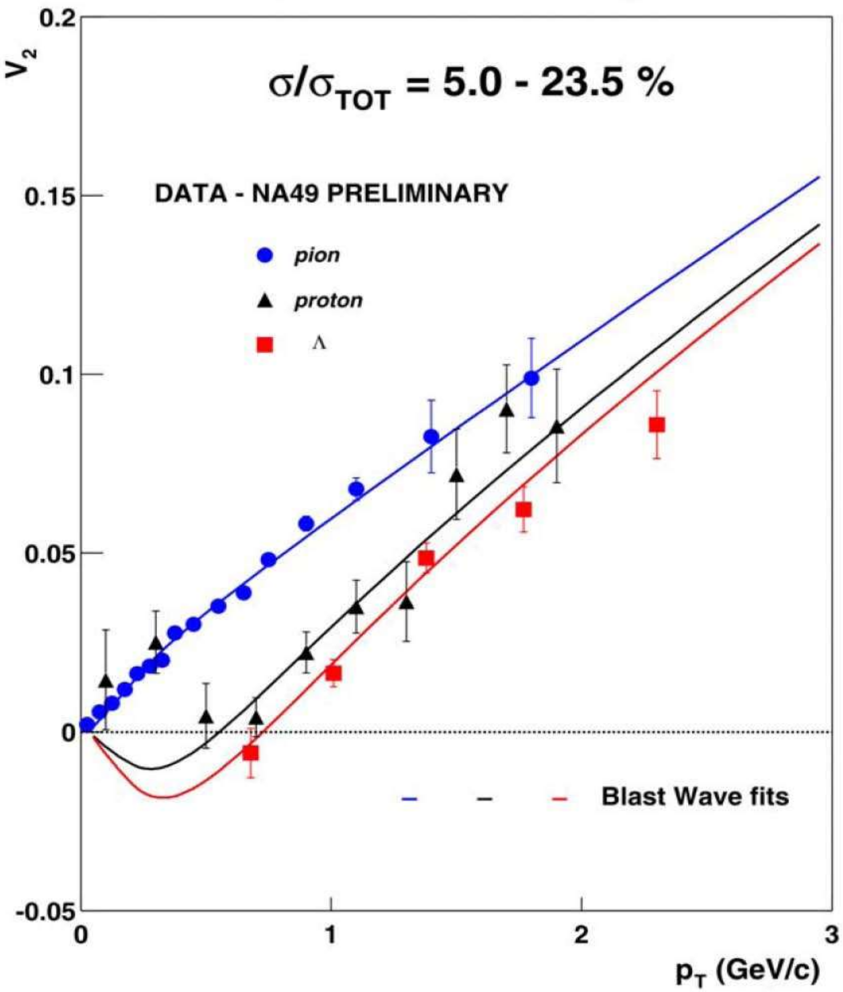
- **created matter shows similar behaviour at top-SPS and RHIC energies**
- **further similarities:** substantial elliptic flow (π, p, Λ)
  high-p_t phenomena

see NA49 talks on Λ-flow, and hadron production at high p_t

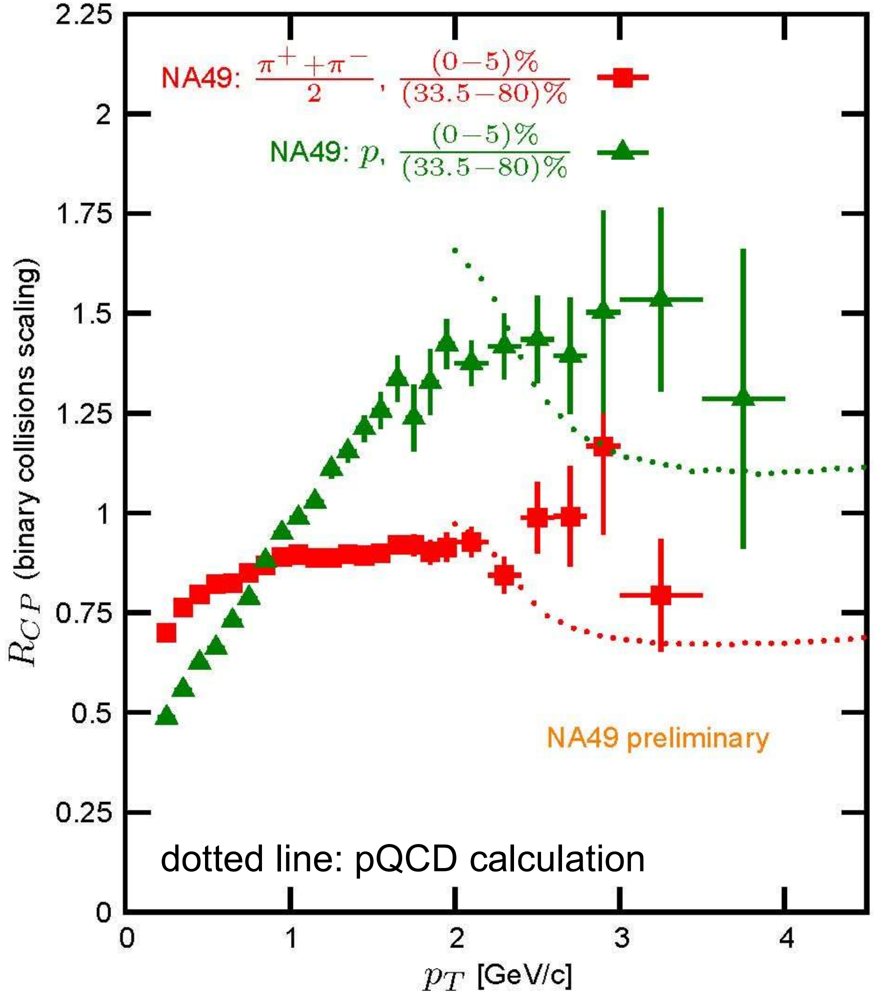
$\rightarrow$ **go down in energy and look for changes!**

158 *A*GeV — Highlights on Λ-flow and high-p_t

substantial elliptic flow of Λ



- saturation of R_{CP} for high p_t
- baryon – meson difference



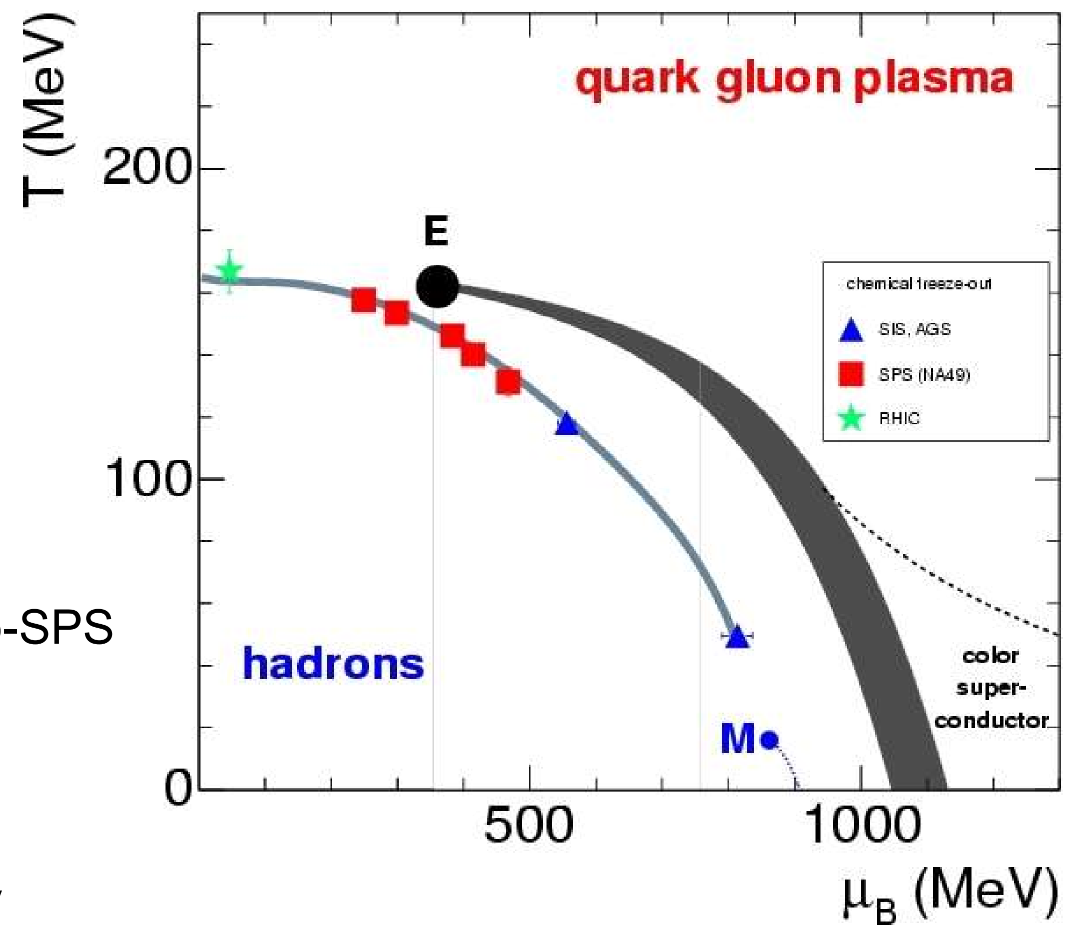
G. Stefanek, Aug.5th, session 2a

A. László, Aug.5th, session 1a

Phase diagram

hadron production measured from 20-158 *A*GeV

→ (T,μ_B) for hadrochemical freeze-out



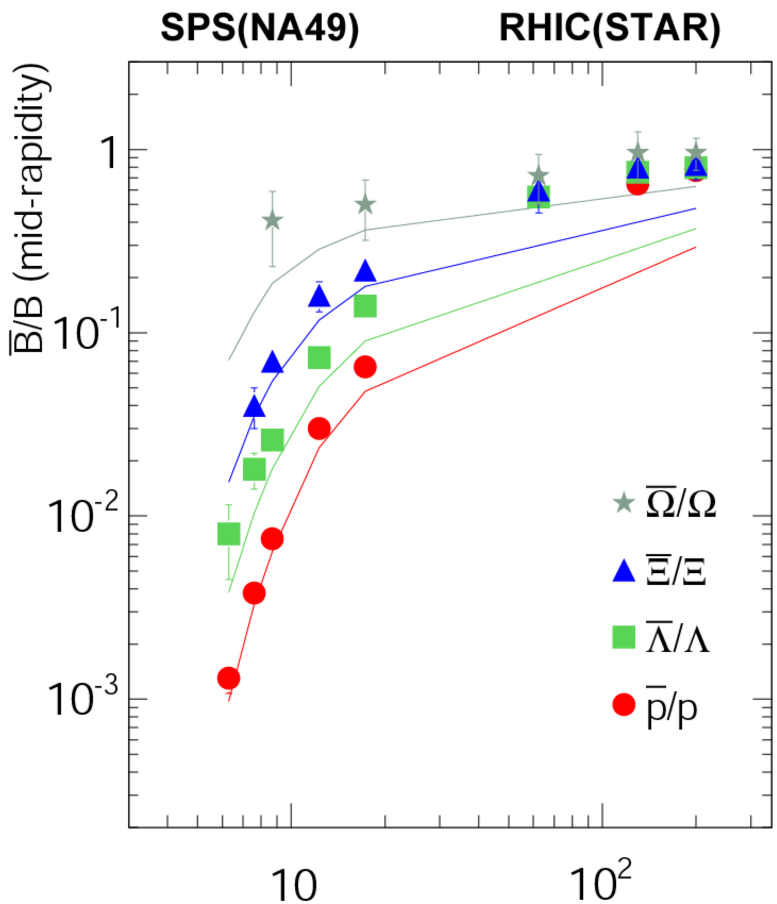
- deconfinement reached for top-SPS and RHIC?
- lower SPS energies
  - decreasing temperature increasing baryon density
  - (depart from phase boundary)

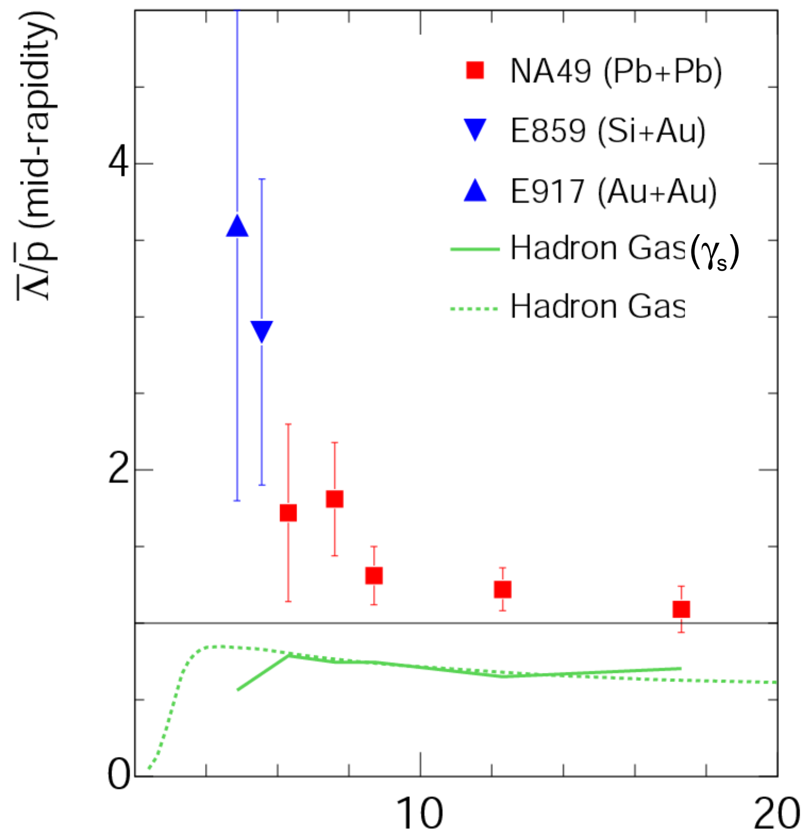
[Critical point (E): Fodor and Katz, Hadron gas (γ_s): J. Manninen et al., grey band: 1st order phase transition]

(Anti-)baryon production

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

→ NA49 poster





[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.]

s-production

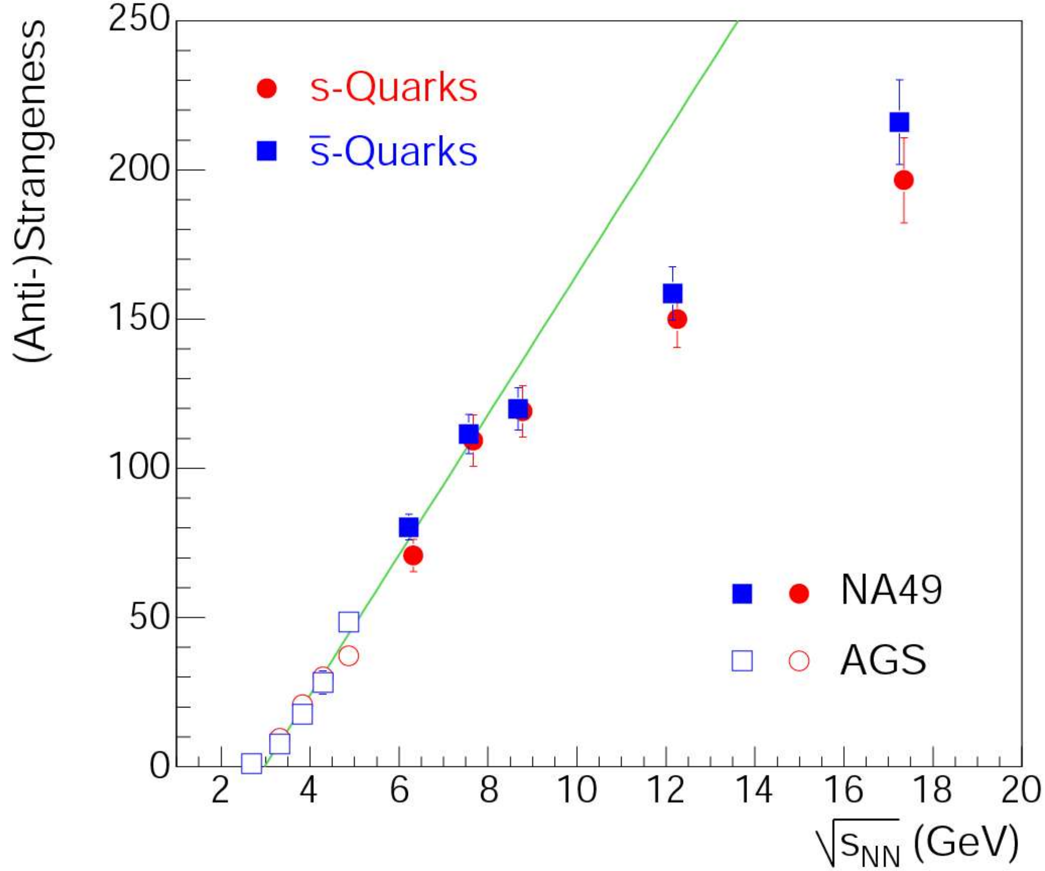
energy dependence of s-production weakens at ~30 *A*GeV

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. $\overline{\Sigma^0}$)
- $\overline{\Xi}$, $\overline{\Omega}$
- $\overline{\Sigma^\pm}$



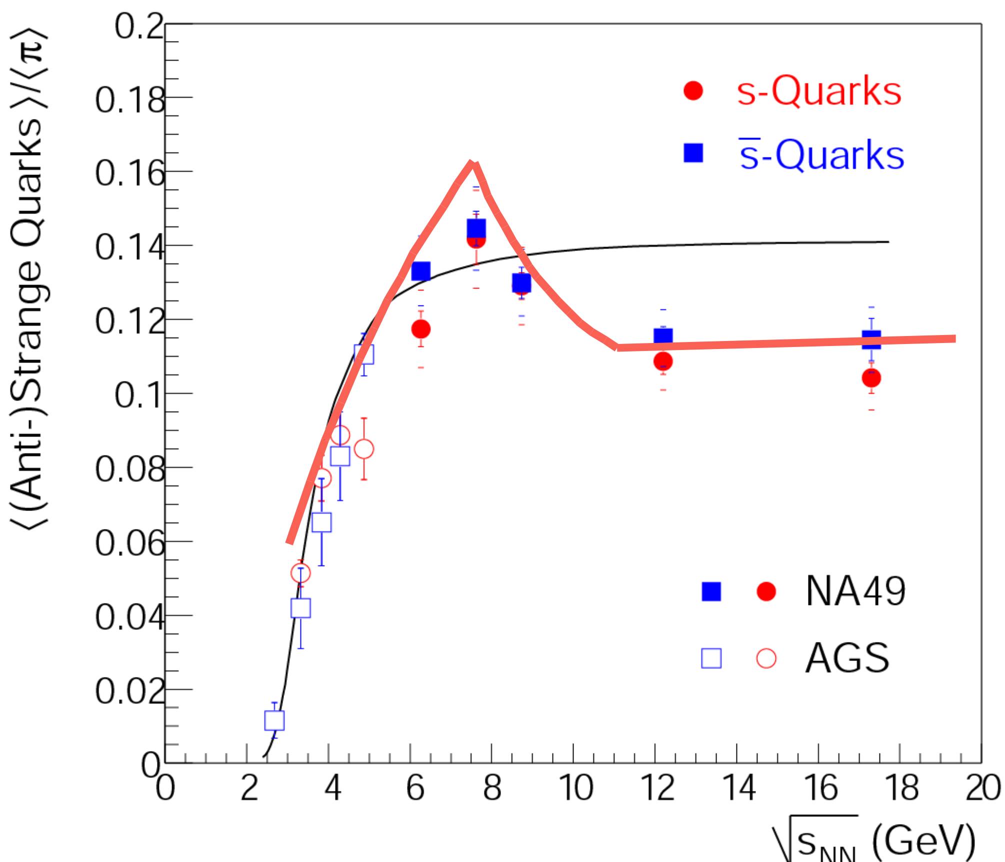
measured (at least partially)

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

relative s-production

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

saturation for higher energies



Redlich priv. com., Hadron Gas, γ_s=1

Gazdzicki and Gorenstein

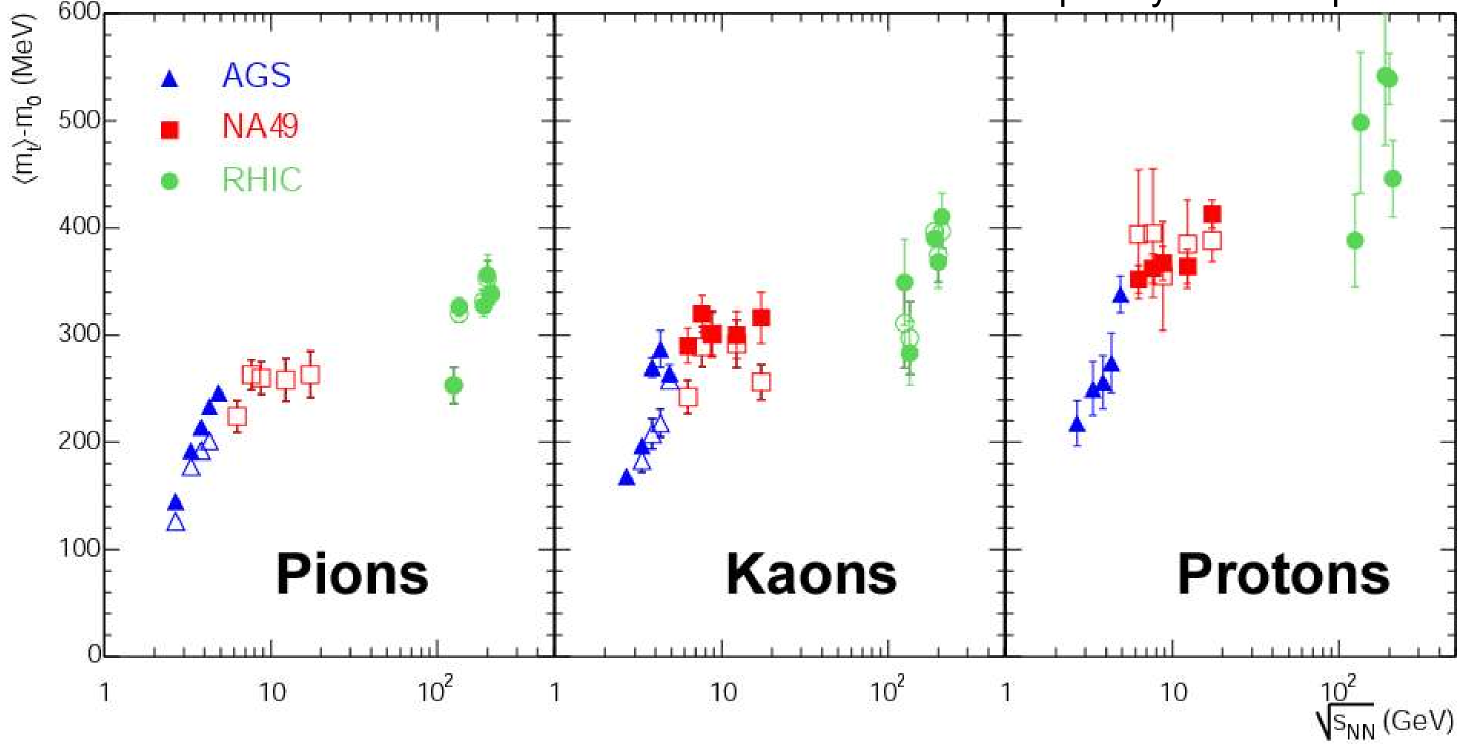
- not explained by hadron gas models although the general feature is captured (baryon → meson dominated system)
- neither by UrQMD, HSD [E.L. Bratkovskaya et al., PRC 69, 054907 (2004)]
- predicted for a phase transition [Gazdzicki, Gorenstein, Acta. Phys. Polon. B30, 2705 (1999)]

Transverse-mass spectra

energy dependence of $<m_t>$ changes at lower SPS energies

seen for pions, kaons, protons and their antiparticles

filled symbol: particle
open symbol: antiparticle



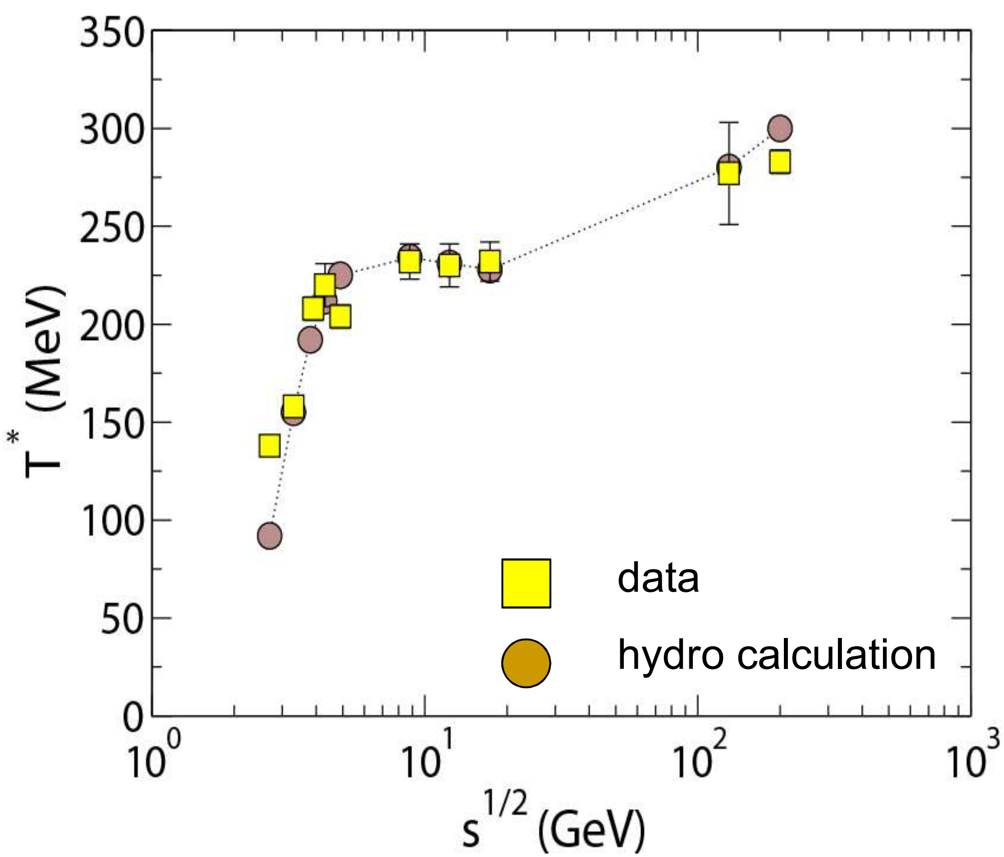
Transverse-mass spectra (II)

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

• not explainable by rescattering, Cronin effect from transport models

(UrQMD, HSD, not shown)
[Bratkovskaya et al., PRC 69, 054907 (2004)]

T* inverse slope parameter of kaon p_t-spectra



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

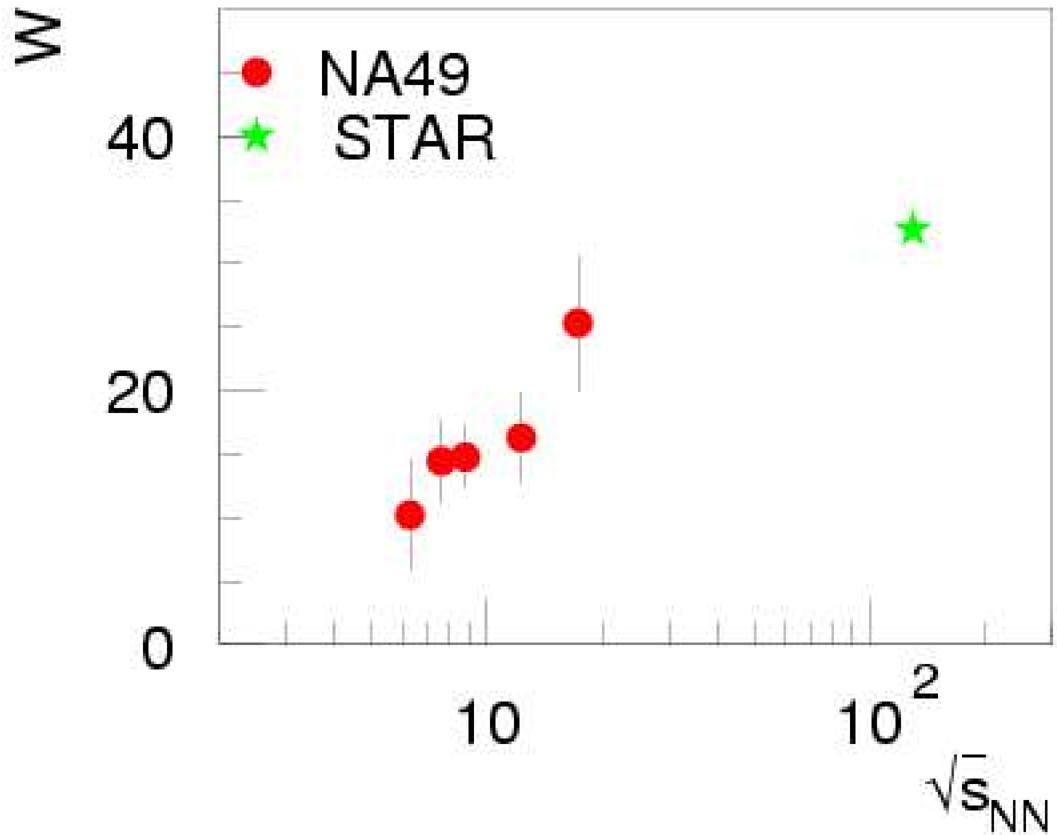
Balance function

all charged particles at midrapidity

- decreasing width of BF → delayed hadronization with increasing energy?
- **be careful:** different acceptance/ phase space window for different energies, in particular for STAR!

$$W = \left(\frac{\langle \Delta\eta \rangle_{shuffling} - \langle \Delta\eta \rangle_{data}}{\langle \Delta\eta \rangle_{shuffling}} \right) \cdot 100$$

NA49 preliminary



→ increase of W corresponds to decreasing width of the BF

[STAR, PRL 90, 172301 (2003)]

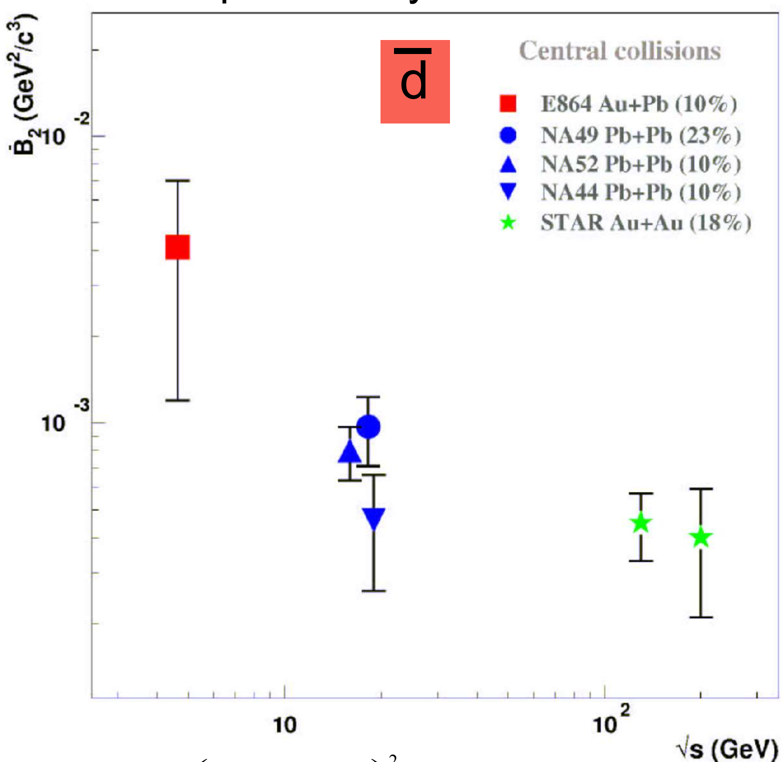
(anti-)protons and (anti-)deuterons

baryons:

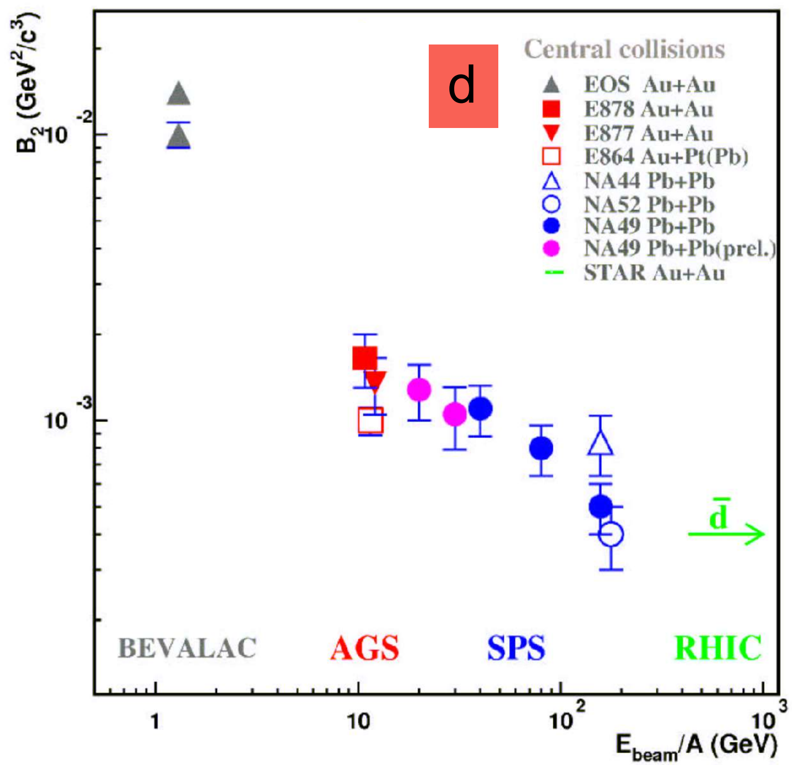
• coalescence analysis for d and $\bar{d}$ supports continuously increasing coherence volume towards higher energies

$$B_2 \propto \frac{1}{V_{coal}}$$

NA49 preliminary



NA49 preliminary



$$E_d \frac{d^3N_d}{dp_d^3} = B_2 \left(E_p \frac{d^3N_p}{dp_p^3} \right)^2$$

→ NA49 poster

Summary

- **Pb+Pb collisions at 158 *A*GeV**
  - **central PbPb**: fireball with high energy density created
    chem. freeze-out close to phase boundary
  - **smaller A/ peripheral PbPb**: behaviour consistent with assuming smaller/ several such sources, earlier freeze-out
  - **created matter shows similar behaviour at top-SPS and RHIC energies**
    (see also results on flow and high-p_t phenomena)

- **energy dependence of central Pb+Pb collisions: 20, 30, 40, 80, 158 *A*GeV**
  - **distinct changes with energy**: maximum of relative strangeness production at ~30 *A*GeV
    change of transverse expansion in SPS range
  - partially a result of the decrease of baryon density with energy
  - in detail best explained by models assuming explicitly a transition to a deconfined state at higher energy

→ **onset of deconfinement at lower SPS energies**

NA49 collaboration

C. Alt, T. Anticic, B. Baatar, D. Barna, J. Bartke, L. Betev, H. Bialkowska, C. Blume, B. Boimska, M. Botje, J. Bracinik, R. Bramm, P. Buncic, V. Cerny, P. Christakoglou, O. Chvala , J.G. Cramer, P. Csató, P. Dinkelaker, V. Eckardt, D. Flierl, Z. Fodor, P. Foka, V Friese, J. Gál, M. Gazdzicki, V. Genchev , G. Georgopoulos, E. Gladysz, K. Grebieszkow, S. Hegyi, C. Höhne, K. Kadija, A. Karev, M. Kliemant, S. Kniege, V.I. Kolesnikov, E. Kornas, R. Korus, M. Kowalski, I. Kraus, M. Kreps, A. Laszlo, M. van Leeuwen, P. Lévai, L. Litov, B. Lungwitz, M. Makariev, A.I. Malakhov, M. Mateev, G.L. Melkumov, M. Mitrovski, J. Molnár, St. Mrówczynski, V. Nicolic, G. Pálla, A.D. Panagiotou, D. Panayotov, A. Petridis, M. Pikna, D. Prindle, F. Pühlhofer, R. Renfordt, C. Roland, G. Roland, M. Rybczynski, A. Rybicki, A. Sandoval, N. Schmitz, T. Schuster, P. Seyboth, F. Siklér, B. Sitar, E. Skrzypczak, G. Stefanek , R. Stock, C. Strabel, H. Ströbele, T. Susa, I. Szentpétery, J. Sziklai, P. Szymanski, V. Trubnikov, D. Varga, M. Vassiliou, G.I. Veres, G. Vesztergombi, D. Vranic, A. Wetzler, Z. Wlodarczyk, I.K. Yoo, J. Zimányi

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parallel talks:

A. László, Aug.5th, session 1a
High-p_t spectra of identified particles

G. Stefanek, Aug.5th, session 2a
Elliptic flow of Λ hyperons

posters

G. Melkumov, V. Kolesnikov, session 1
- Antideuteron and deuteron production
- Antiproton and proton production

P. Dinkelaker, session 2
System-size dependence of s-production

backup slides

Data

• wealth of data collected! (data taking period from 1994 – 2002)

• analysis still ongoing, more to come!

• large statistics samples at top-SPS energy

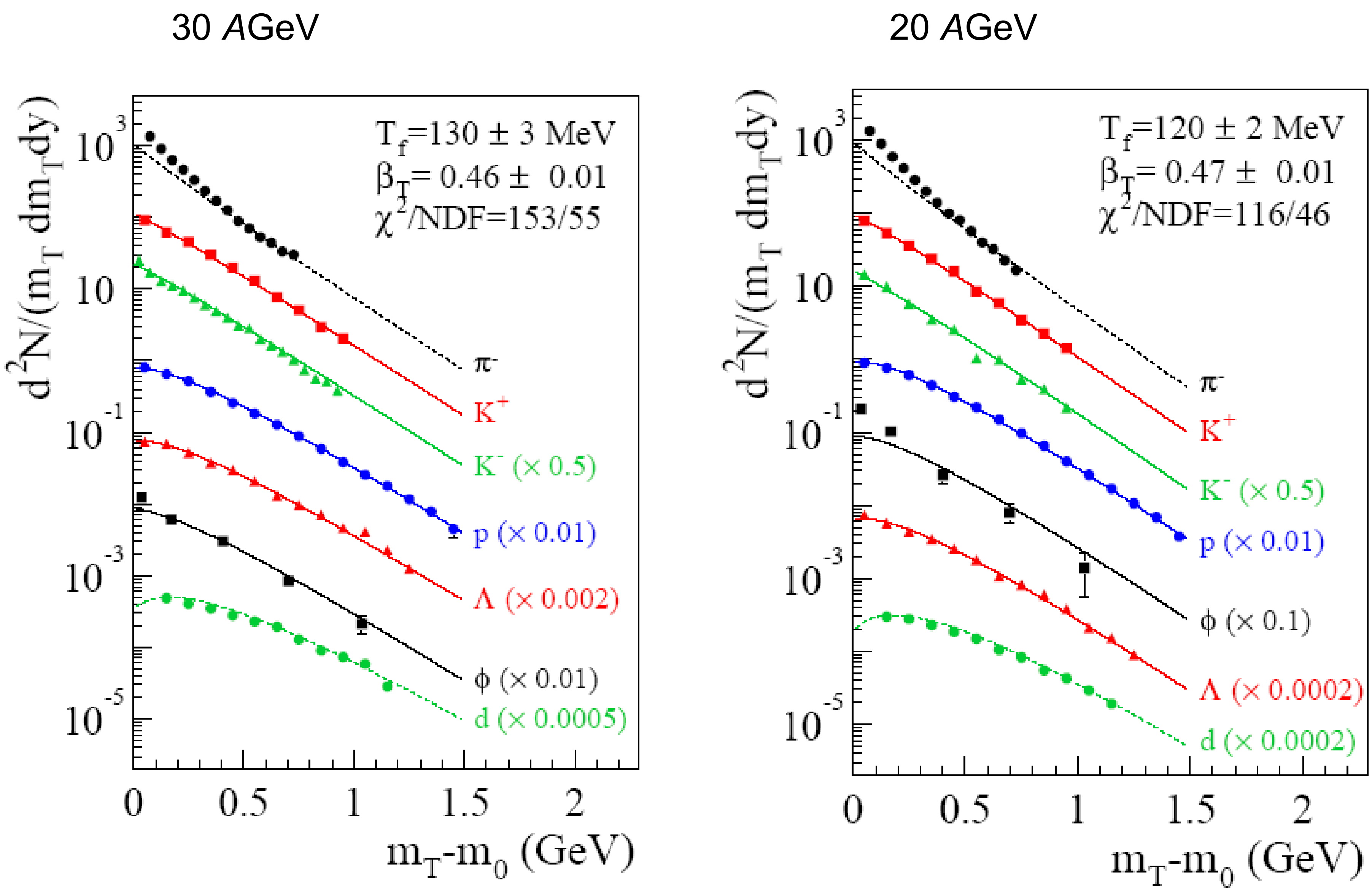
• centrality dependence and system-size dependence for 40 and 158 *A*GeV

• energy scan from 20 – 158 *A*GeV

• pp, pA data for comparison (not shown in table)

energy	system	centrality	statistics
158 *A*GeV	PbPb	10%, 23%	800k, 3000k
		minimum bias	410k
	CC, SiSi	15%, 12%	220k, 300k
80 *A*GeV	PbPb	7%	300k
40 *A*GeV	PbPb	7%	700k
		minimum bias	430k
	CC, SiSi	66%, 29%	240k, 130k
30 *A*GeV	PbPb	7%, 35%	440k, 230k
20 *A*GeV	PbPb	7%, 35%	360k, 330k

p_t-spectra

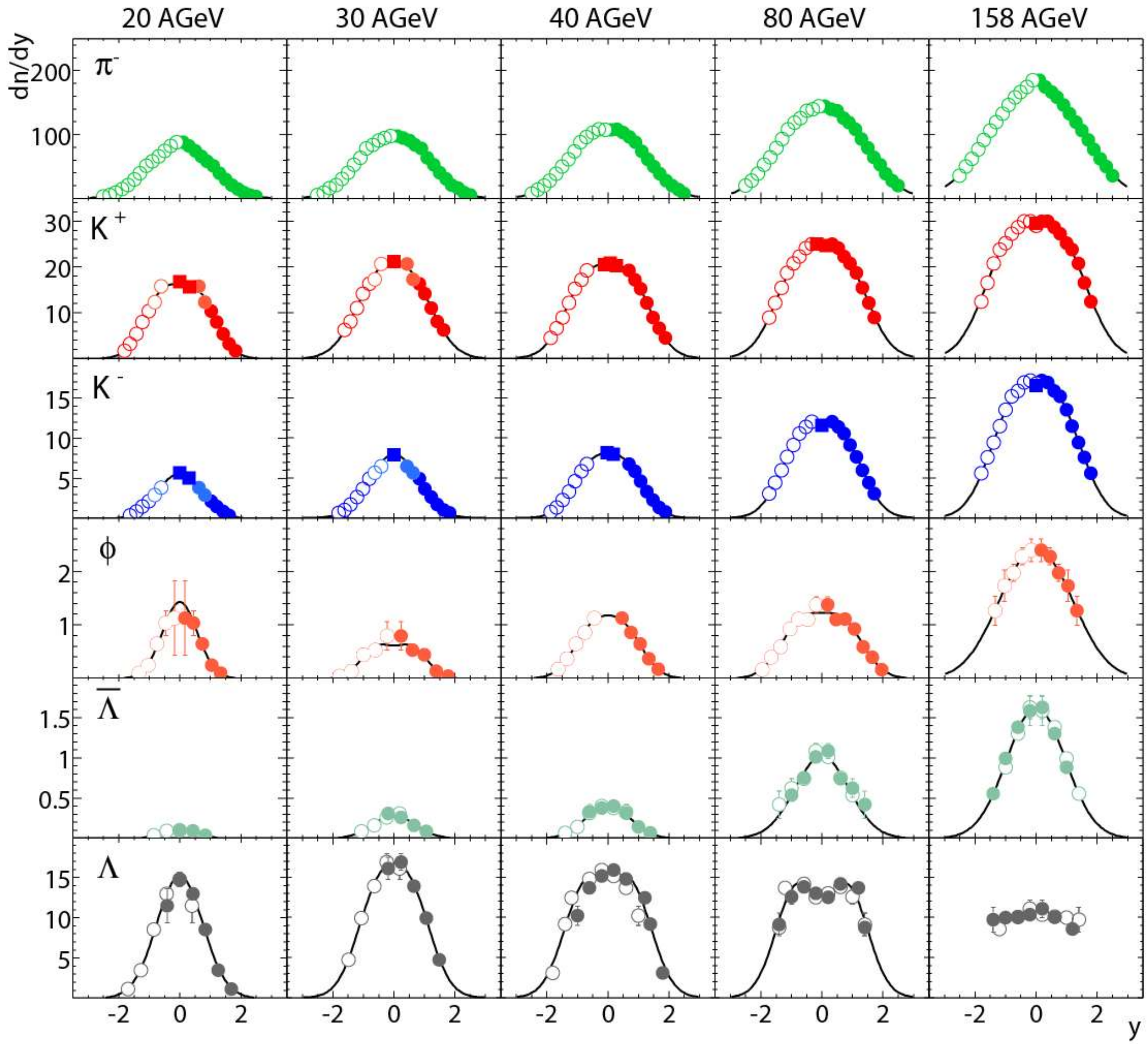


30 AGeV
20 AGeV
T_f=130 ± 3 MeV
β_T= 0.46 ± 0.01
χ^2/NDF=153/55
T_f=120 ± 2 MeV
β_T= 0.47 ± 0.01
χ^2/NDF=116/46
$d^2N/(m_T dm_T dy)$
m_T-m_0 (GeV)
π^-
K^+
K^- (× 0.5)
p (× 0.01)
Λ (× 0.002)
φ (× 0.01)
d (× 0.0005)
φ (× 0.1)
Λ (× 0.0002)
d (× 0.0002)

rapidity distributions

Central Pb+Pb
7% (20-80 *A*GeV)
5/10% (158 *A*GeV)

NA49



hadron production

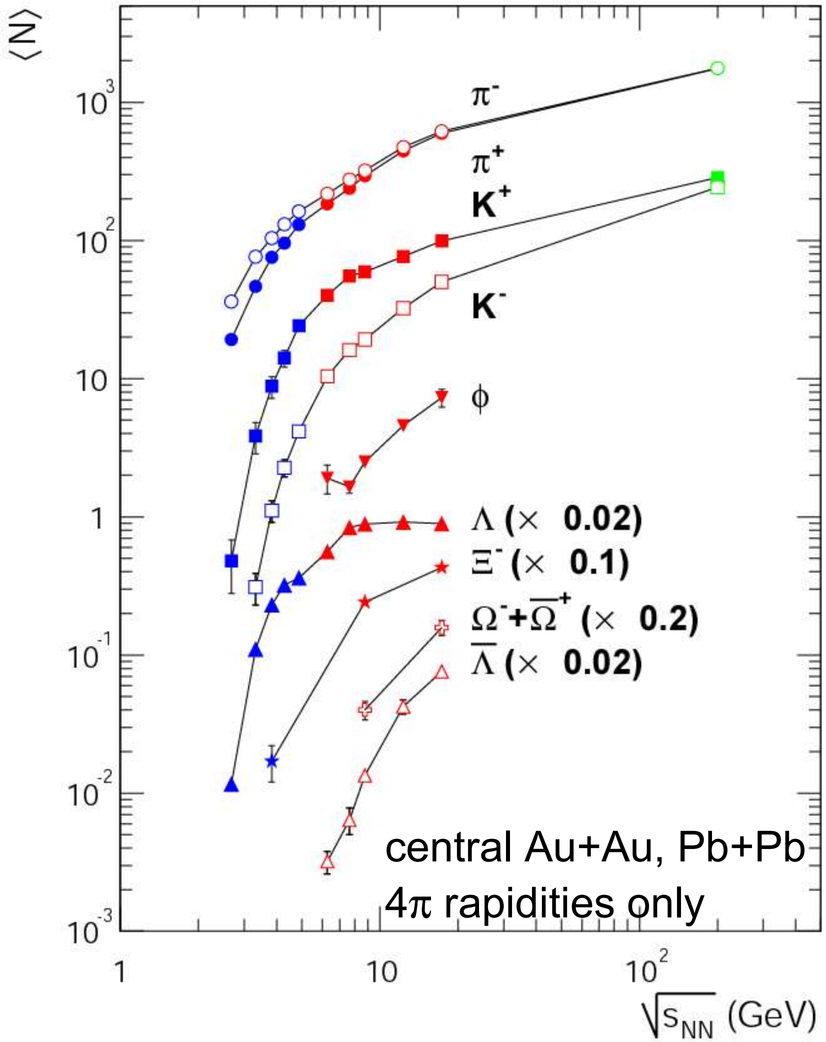
- (y,p_t)-spectra for large variety of hadrons measured from 20-158 *A*GeV

still adding data:

- Ξ and $\bar{\Xi}$
- K^0_S
- QM: $\bar{\Xi}/\Xi$ ratio at midrapidity

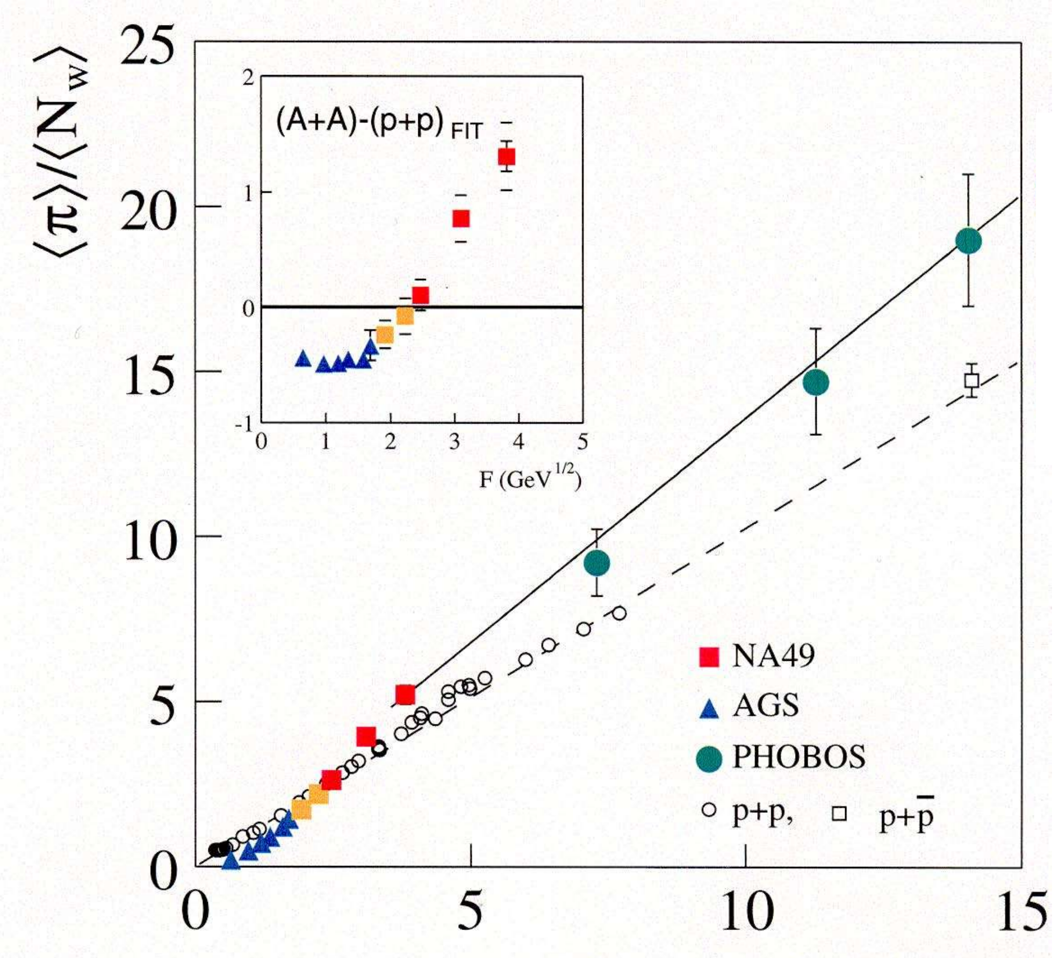
p, d, $\bar{p}$, $\bar{d}$ at midrapidity

AGS NA49 BRAHMS



π-production

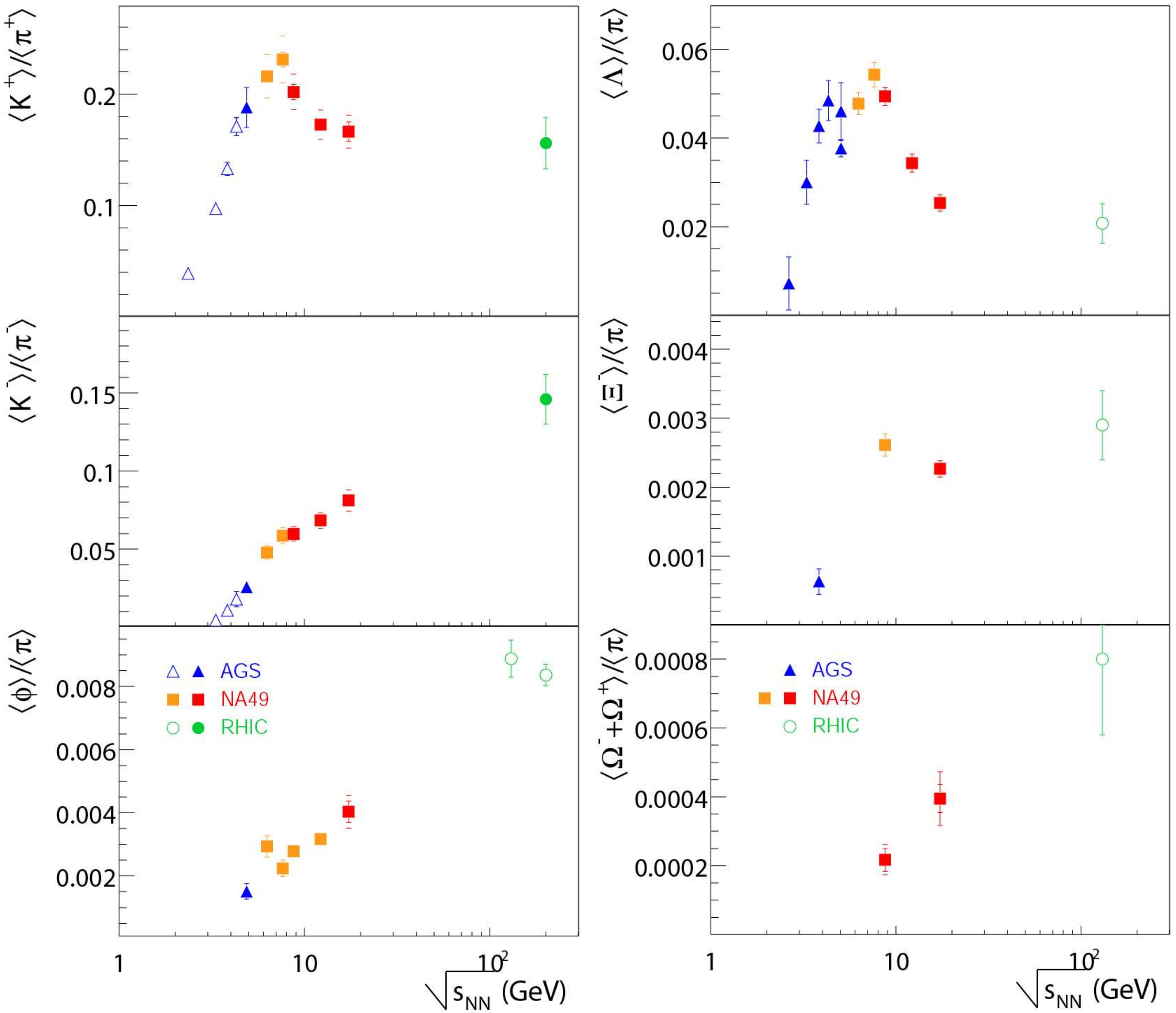
energy dependence of π-production strengthens at ~30 *A*GeV



$F \approx \sqrt{\sqrt{s_{NN}}}$

particle ratios: strangeness

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



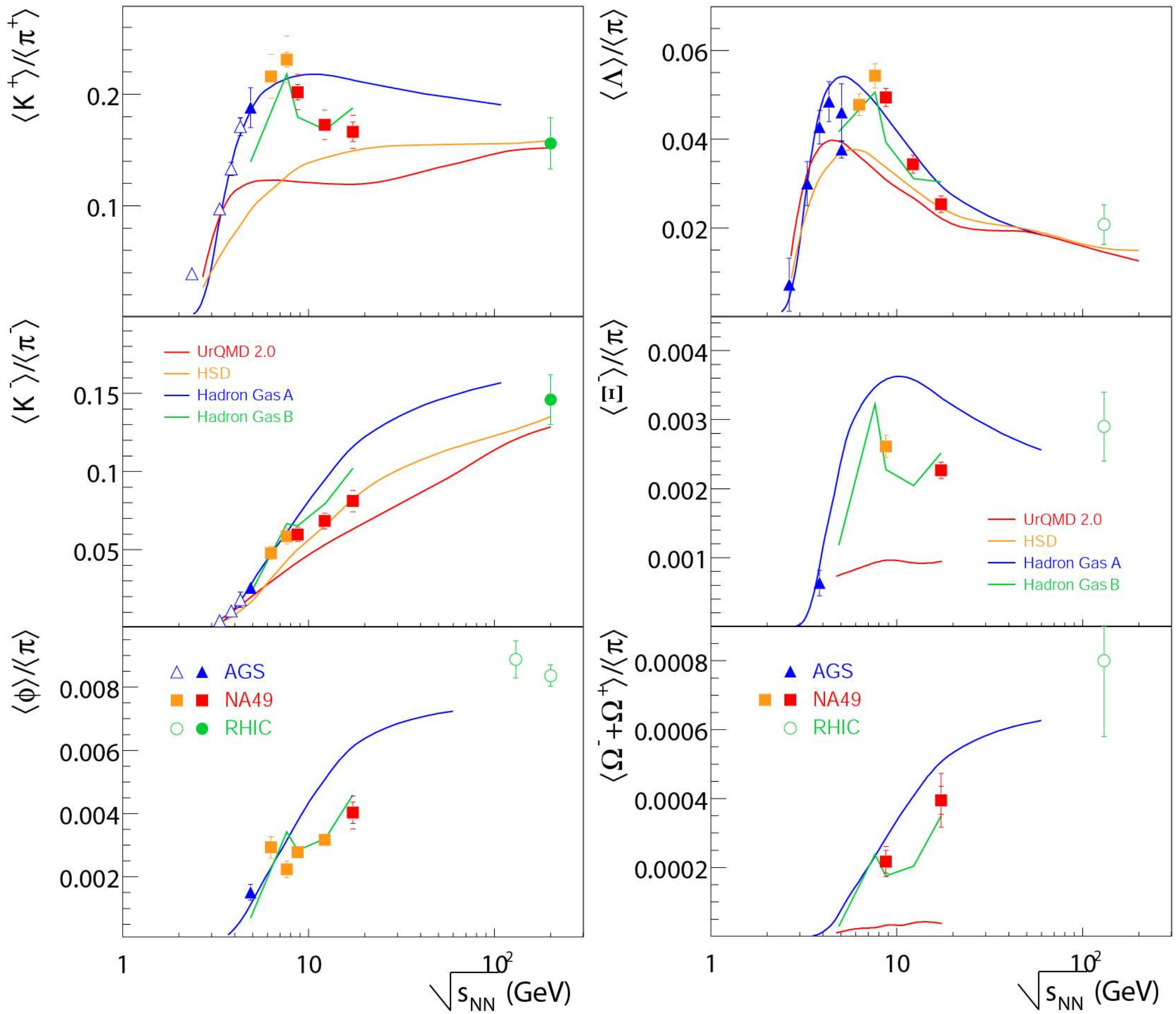
$$\langle\pi\rangle = 1.5\cdot\left(\langle\pi^+\rangle + \langle\pi^-\rangle\right)$$

particle ratios: strangeness (II)

- UrQMD, HSD [E.L. Bratkovskaya et al., PRC 69, 054907 (2004)]
- Hadron Gas [P. Braun-Munzinger et al., NPA 697, 902 (2002)]
- Hadron Gas (γ_s) [F. Becattini et al., PRC 69, 024905 (2004)]

- general features captured by models (baryon → meson dominated systems)
- models fail to describe the data in detail
- predicted for a phase transition [Gazdzicki, Gorenstein, Acta. Phys. Polon. B30, 2705 (1999)]

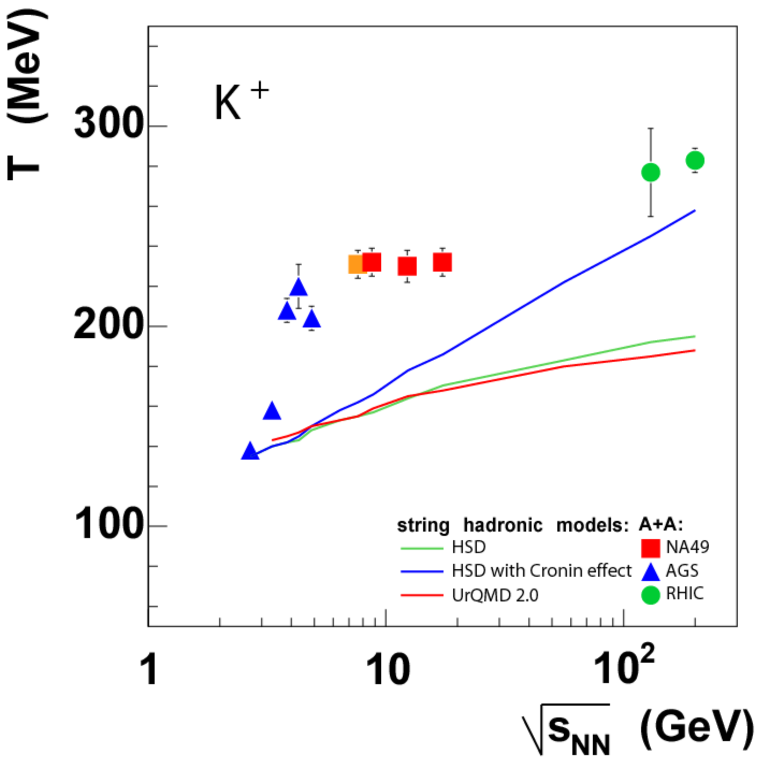
$$\langle\pi\rangle = 1.5\cdot\left(\langle\pi^+\rangle + \langle\pi^-\rangle\right)$$

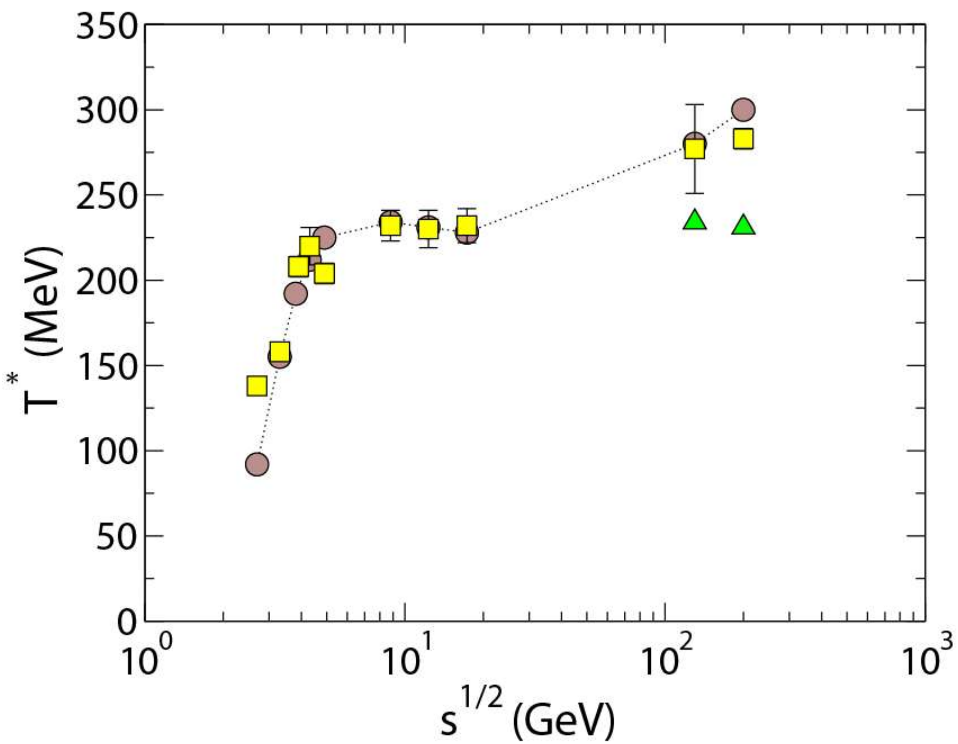


Transverse-mass spectra (II)

- not explainable with transport models: rescattering, Cronin effect
- consistent with assuming a 1st order phase transition: change of EOS?

[Van Hove, PLB 118, 138 (1982); Gorenstein et al., PLB 567, 175 (2003)]





[Bratkovskaya et al., PRC 69, 054907 (2004)]

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

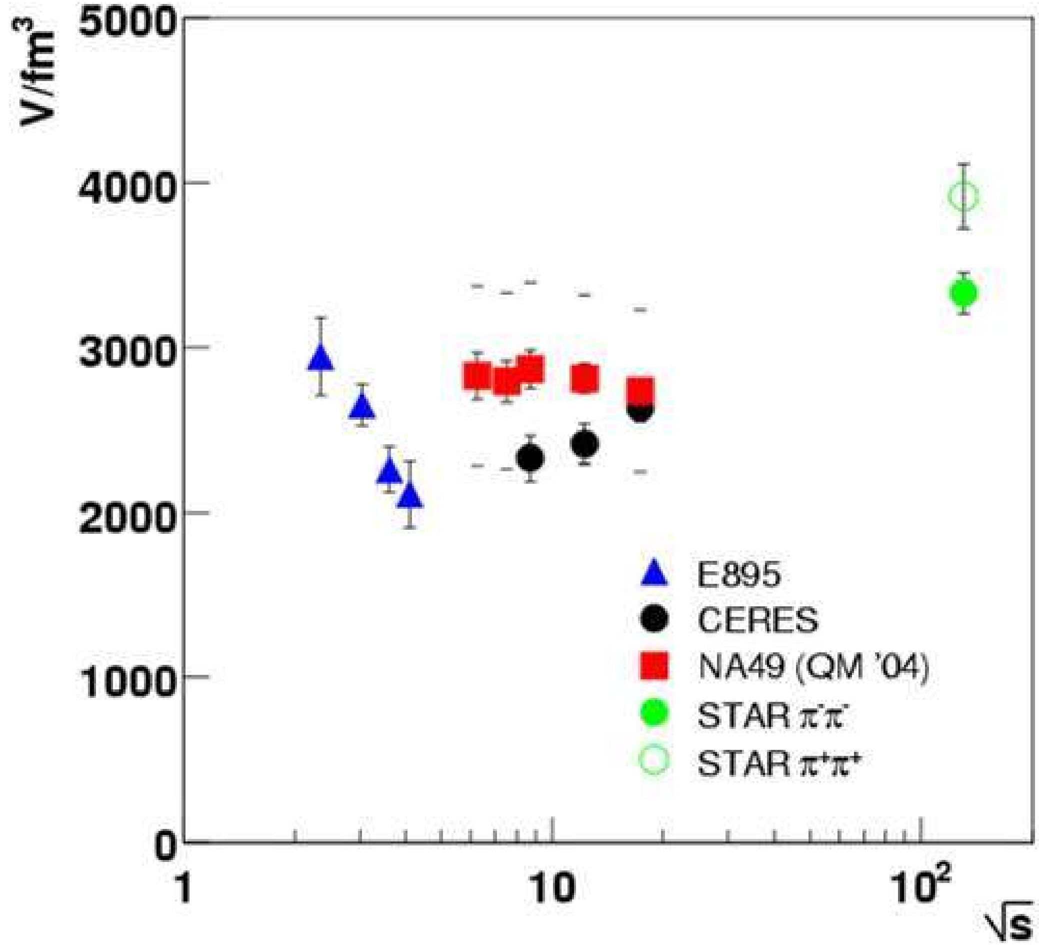
HBT

• p_t-spectra can be consistenly described together with results from π^--HBT analysis using an advanced "blast-wave parametrization", e.g. [Retiere and Lisa, PRC 70, 044907 (2004)]

• freeze-out conditions (radii, time, emission duration) similar at the higher energies

→ no strong change in freeze-out volume for pions seen

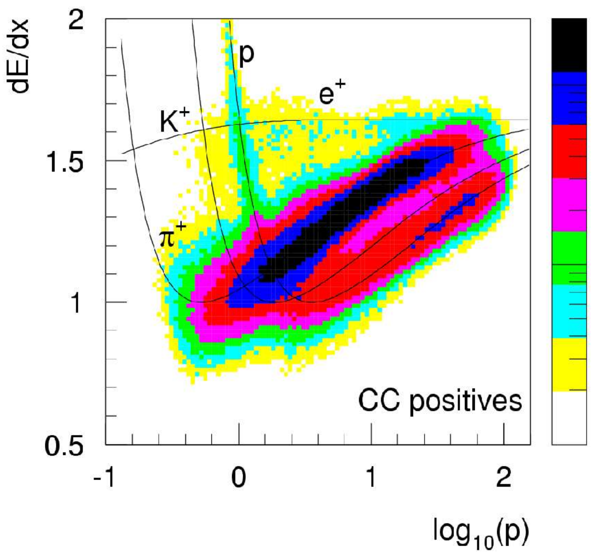
HBT analysis for negative pions

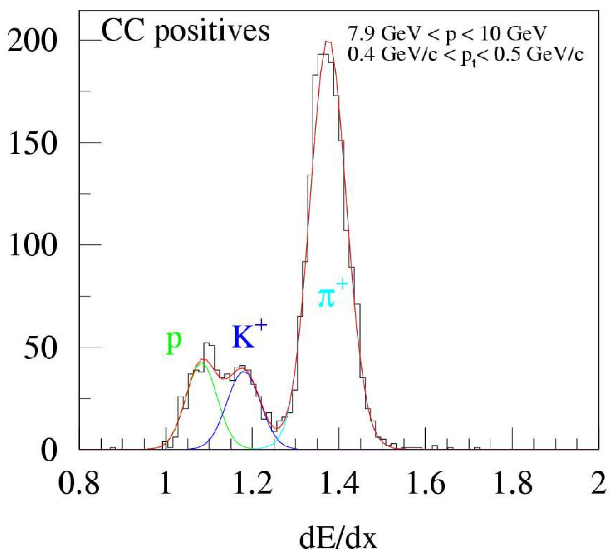


particle identification

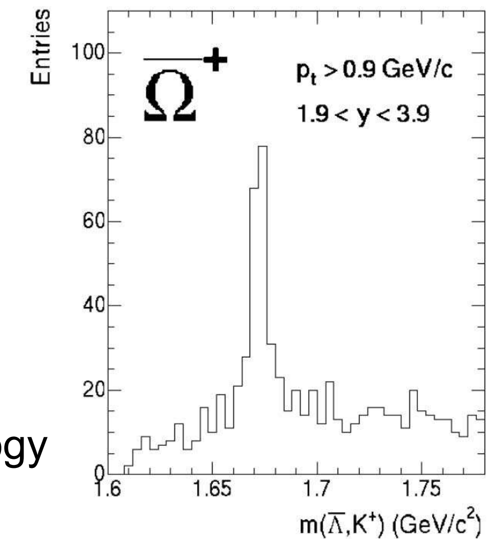
momentum

dE/dx





... + topology



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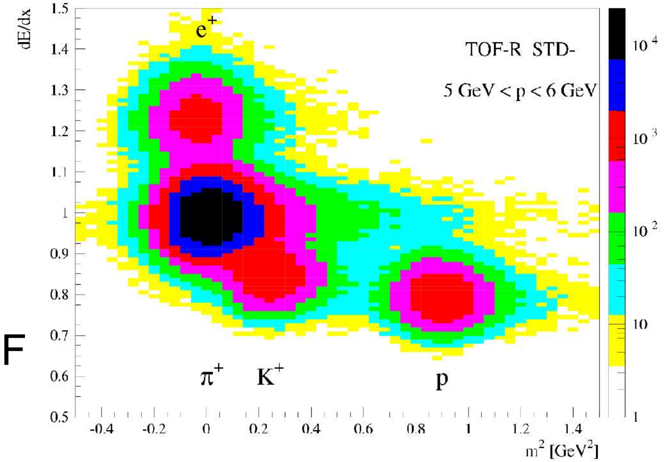

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