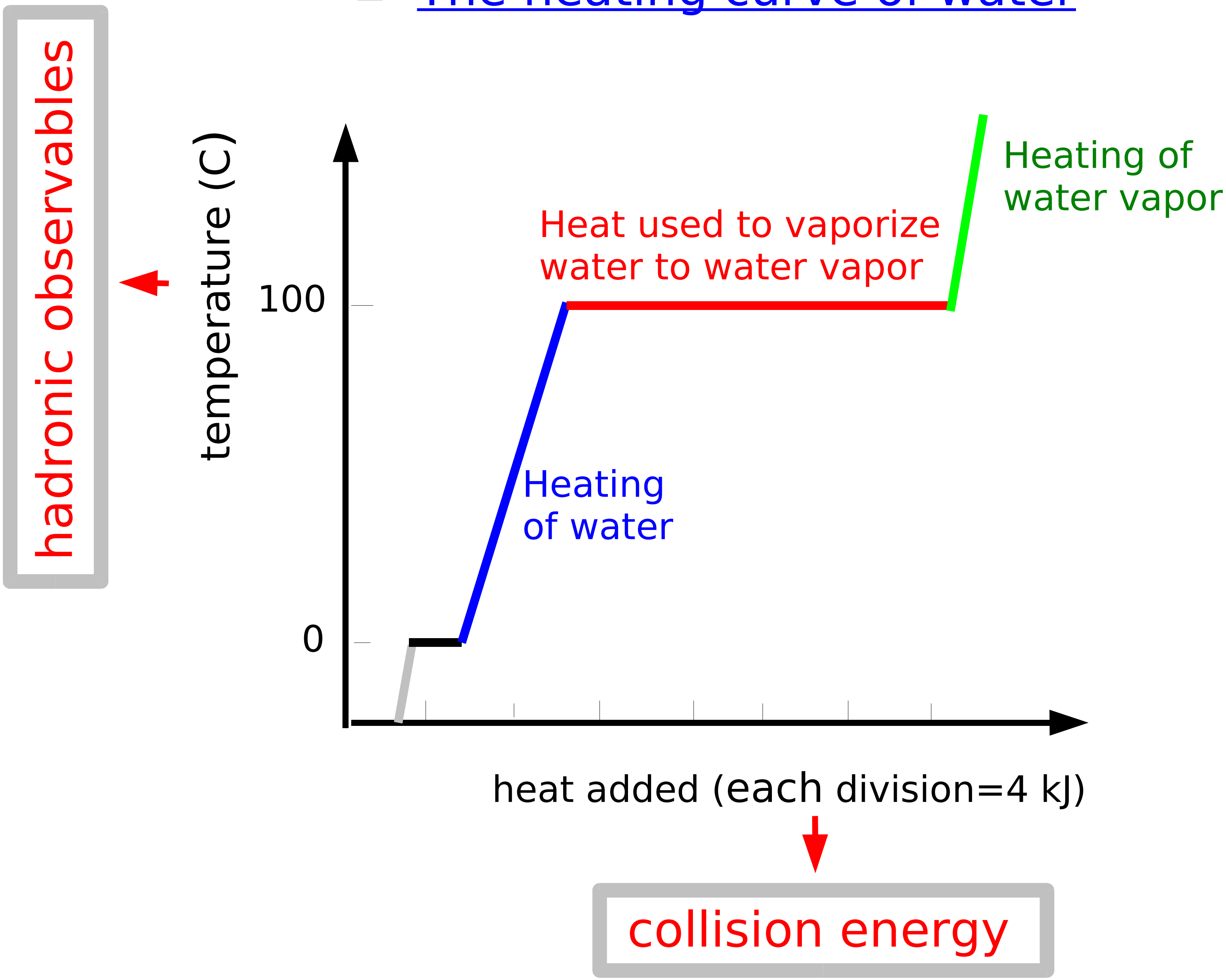
Energy dependence of strangeness production
and
Onset of deconfinement

M. Gazdzicki
Frankfurt, Kielce

- The basic idea
- Strangeness related effects
- To do list

The basic idea

The heating curve of water



■ ■ Heating curves of strongly interacting matter

1994-1998: Basic idea and predictions

Statistical Model of the Early Stage → Kink, Horn

M.G., Gorenstein 1994-1999

1998-2002: Pb+Pb collisions at low SPS energies (energy scan program at the CERN SPS)

Observation of the predicted effects in energy dependence of hadron production

NA49 at the CERN SPS

2002-now: Search for other effects, experimental tests

Step ..., more NA49 data ..., future measurements ...

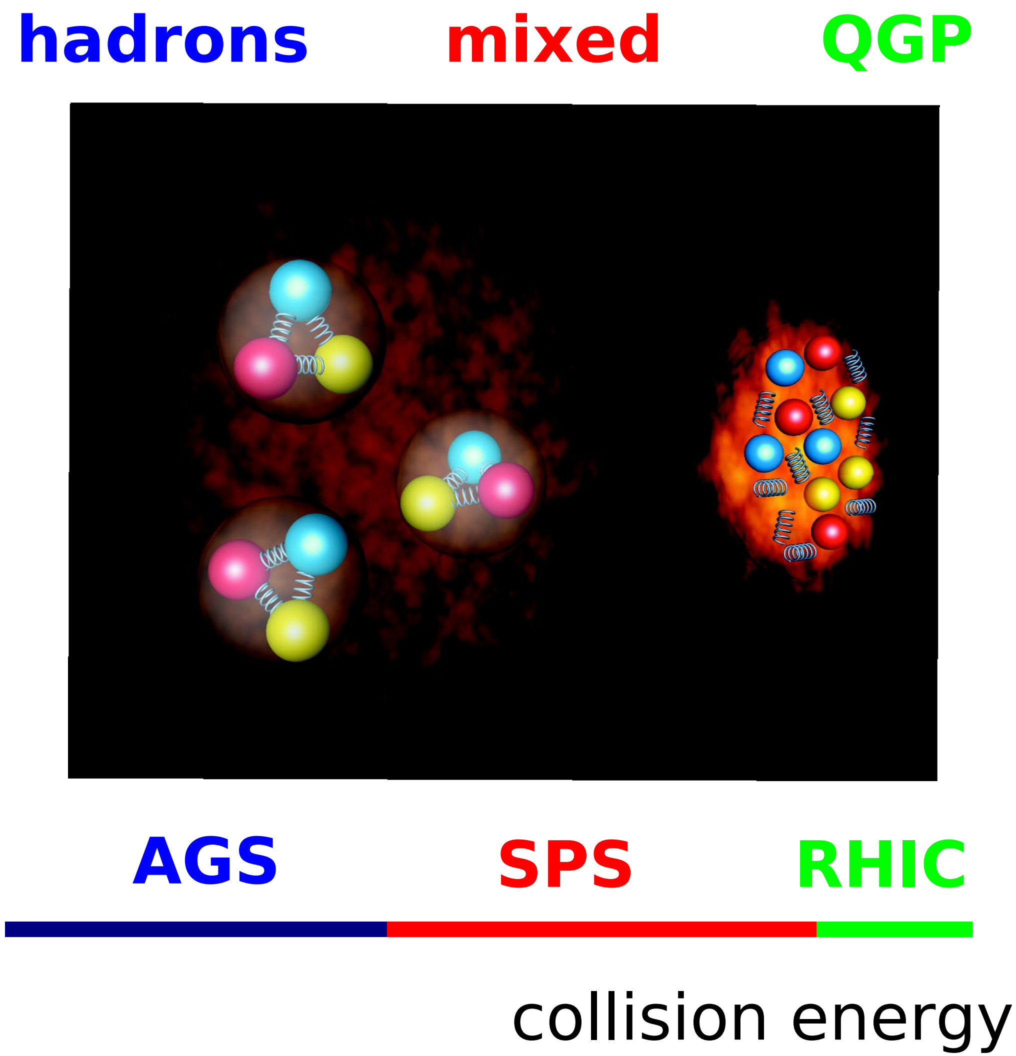
2006: Letter of Intend of NA49-future Collaboration

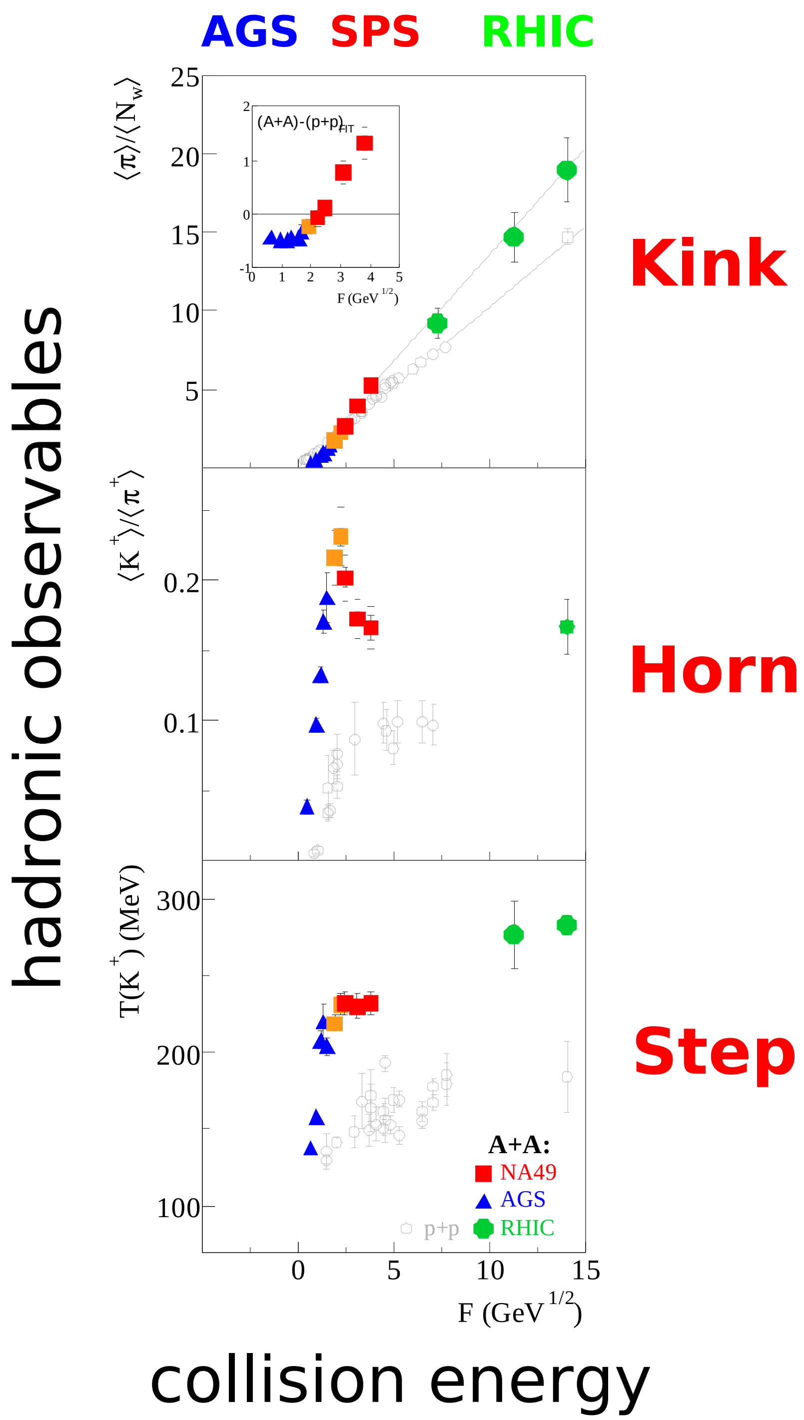
A new dedicated program with nuclear beams at the CERN SPS: study the onset of deconfinement and search for the critical point

Discussion on a possible RHIC program

BNL Workshop, March 9-10, 2006

Heating curves of strongly interacting matter





Strangeness related effects

Why strangeness?

- Step
- Horn
- Kaon/pion fluctuations

Why are strange hadrons important?

Rafelski, 1982 - ...

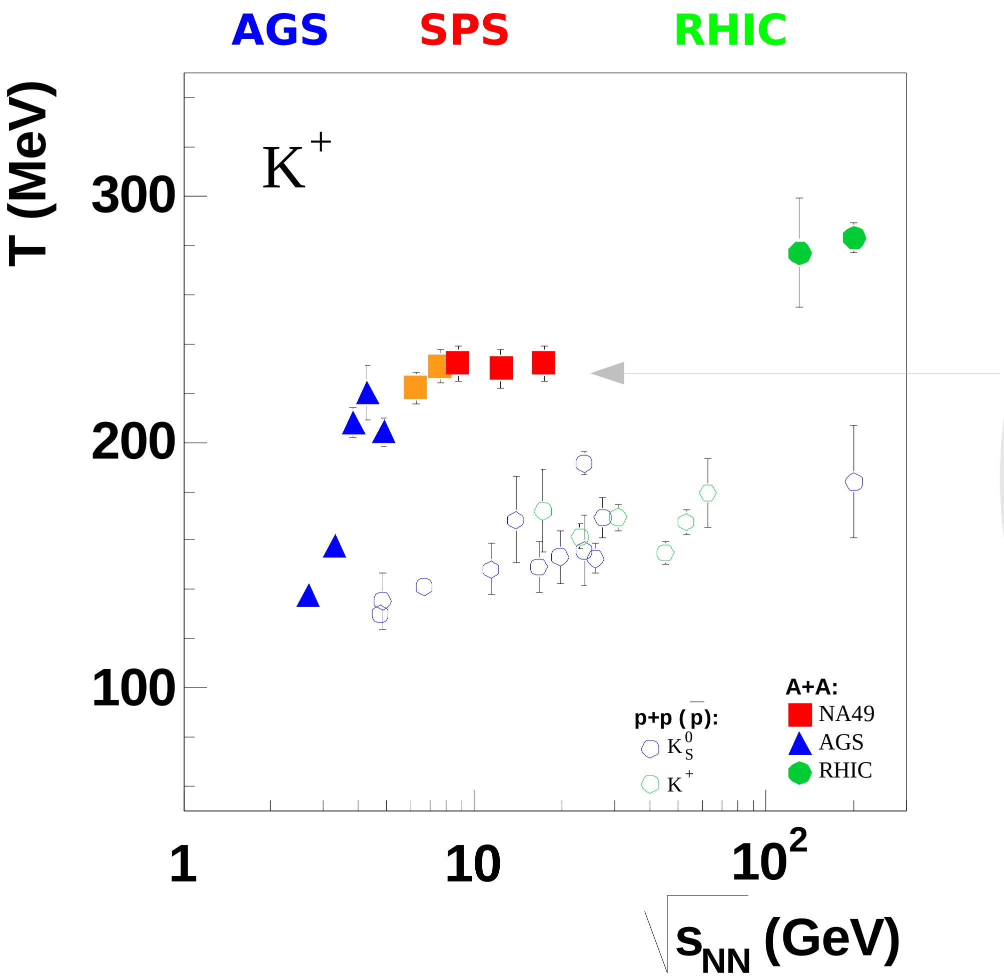
$m_S \leqslant T_C < m_K \quad \rightarrow$ copious but phase sensitive production of strange quarks and anti-quarks

Strangeness is conserved in strong interactions

Most of the measured identified hadrons are strange hadrons

...

The step in m_T slopes



Deconfinement

↓

Constant temperature and pressure in the mixed phase region

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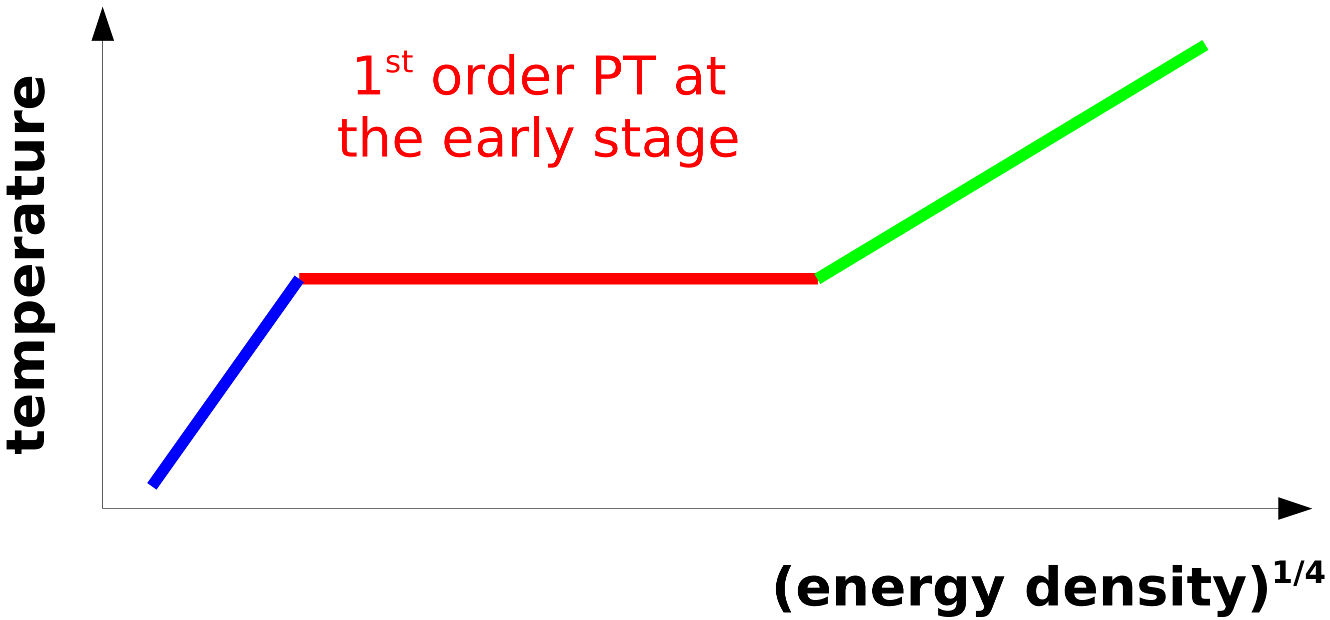
Weaker energy dependence of the shape of transverse mass spectra

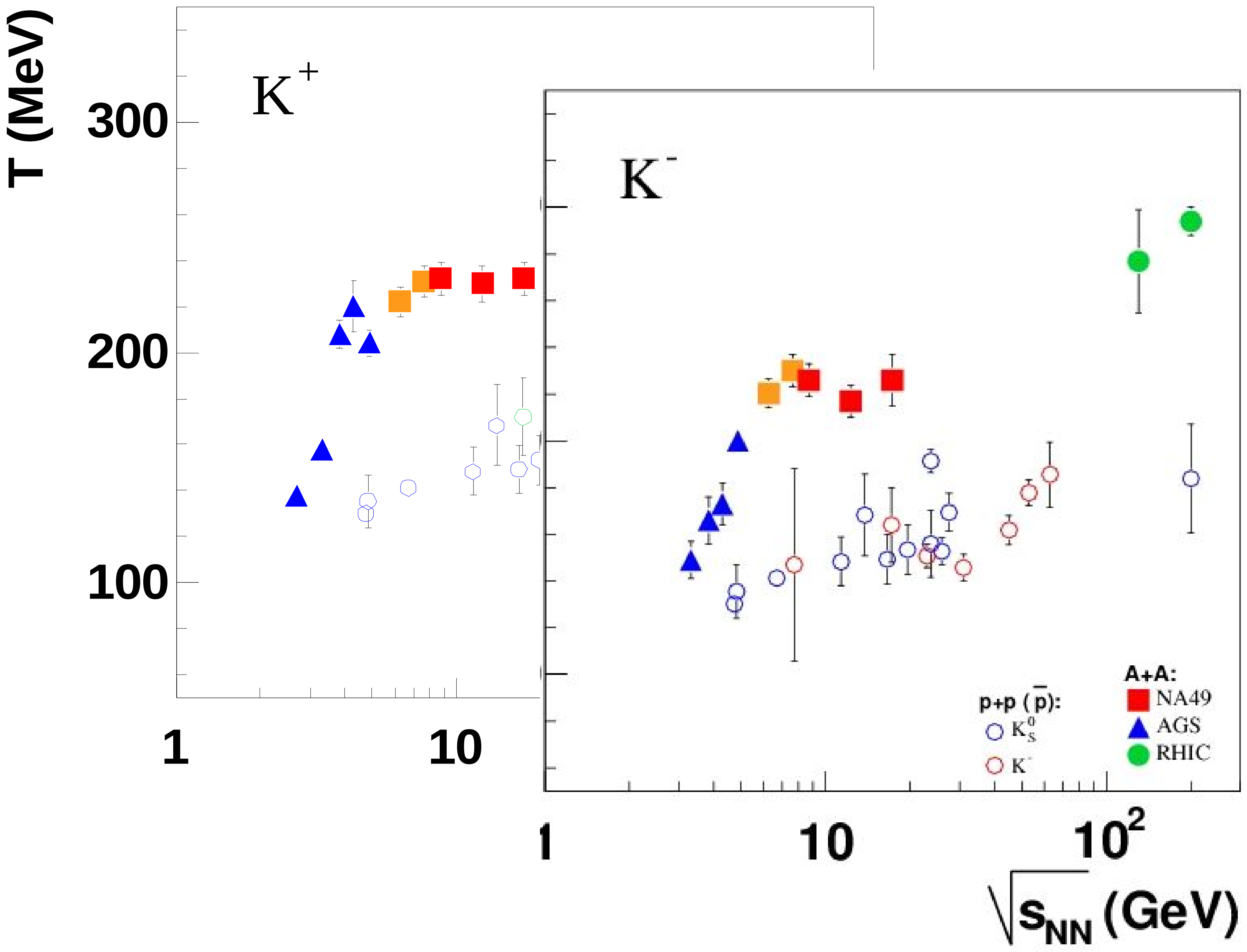
T – inverse slope parameter of transverse mass spectra

Gorenstein, M.G., Bugaev

The step – qualitative arguments

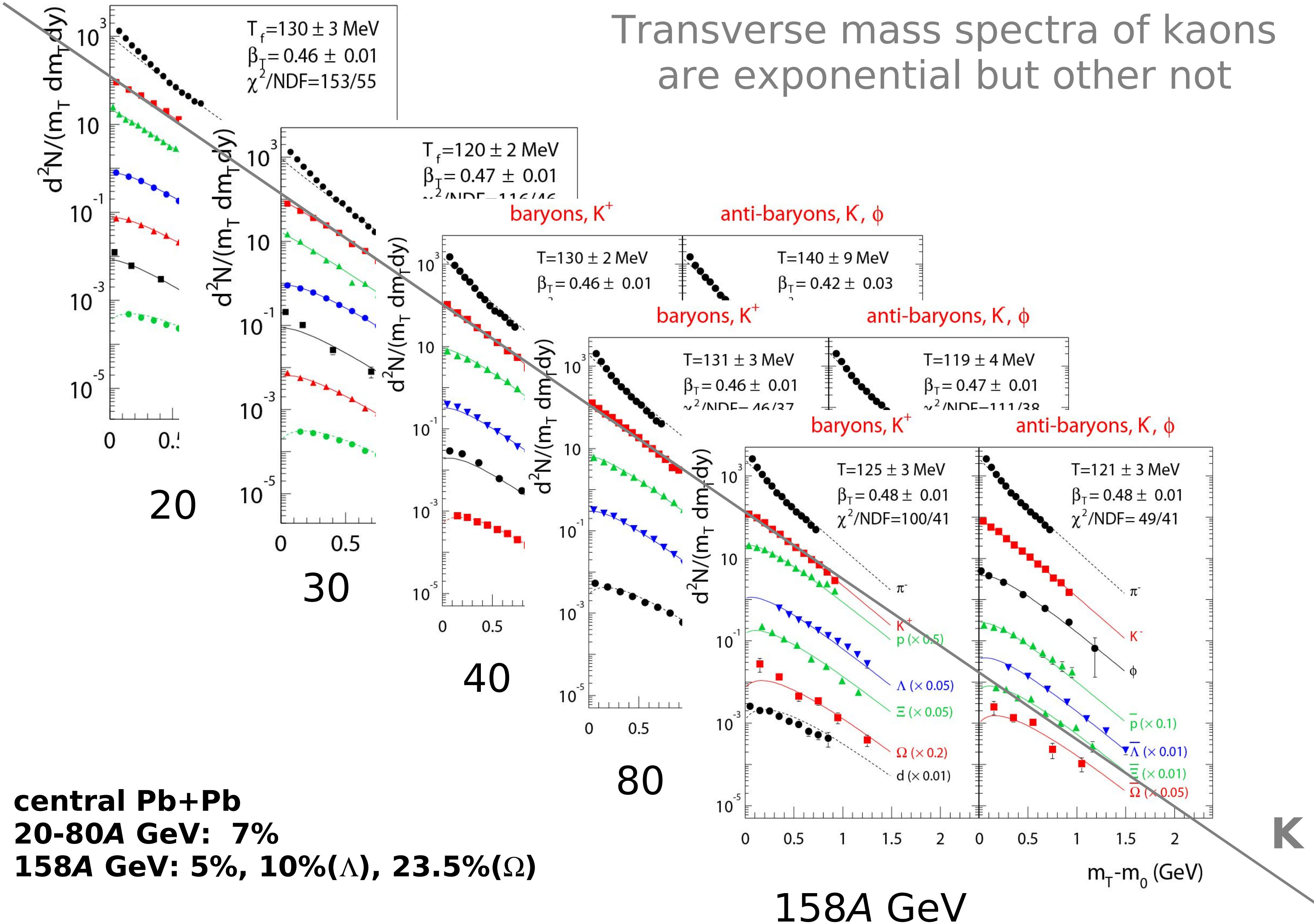


- Similar behavior for mean particle energy, <E>
- Assumption: Evolution conserves <E>
  (e.g. like in an ideal gas of massless particles)
- The early stage structure may be observed in the final state



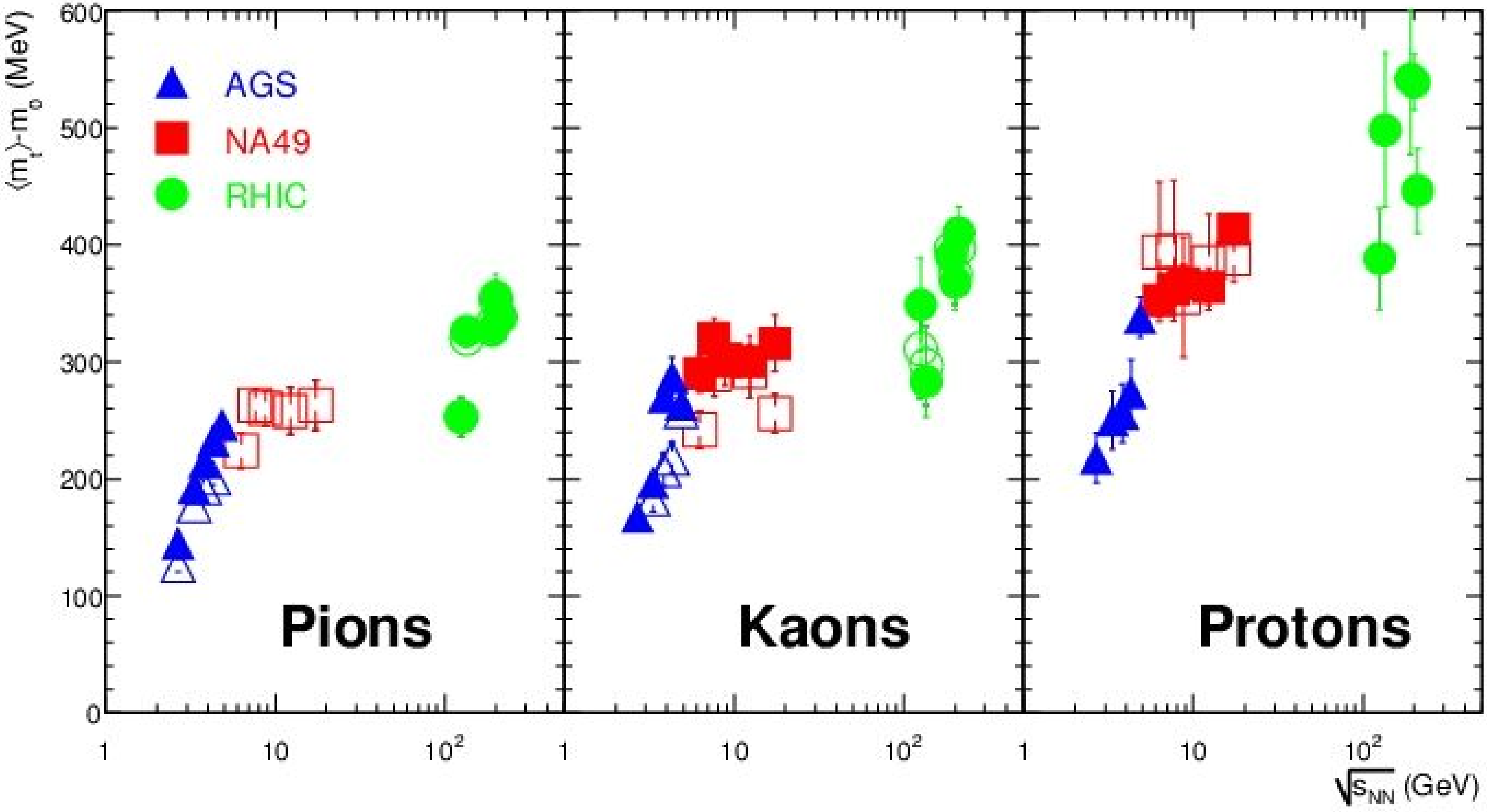
T (MeV)
300
200
100
1
10
K+
K-
1
10
10^2
√sNN (GeV)
p+p (p̄):
K0S
K-
A+A:
NA49
AGS
RHIC

Transverse mass spectra of kaons are exponential but other not



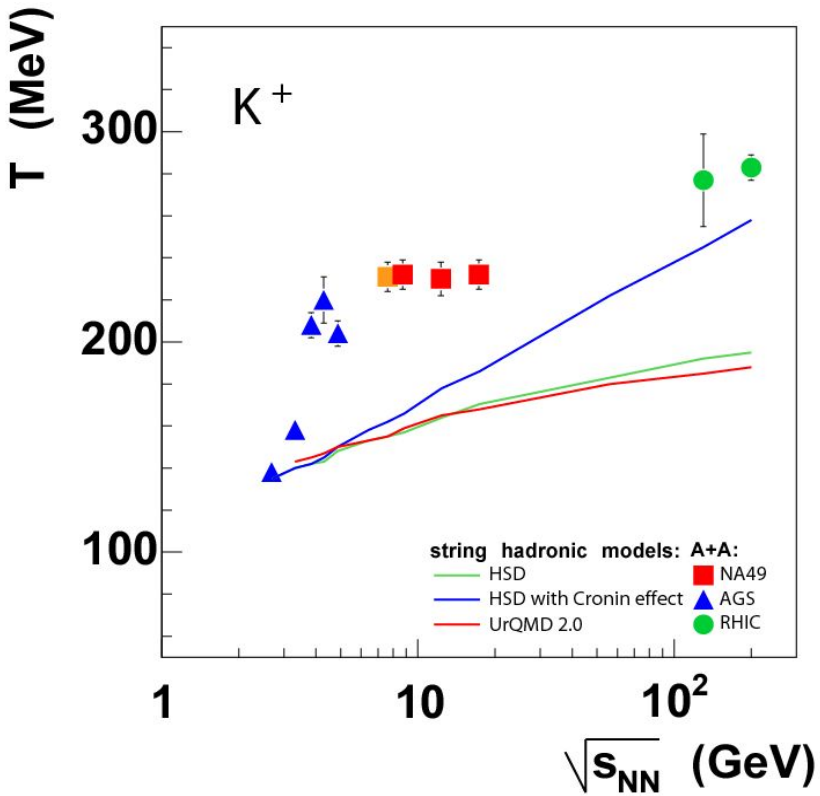
central Pb+Pb
20-80*A* GeV: 7%
158*A* GeV: 5%, 10%(Λ), 23.5%(Ω)

The step in <m_T> of various hadrons

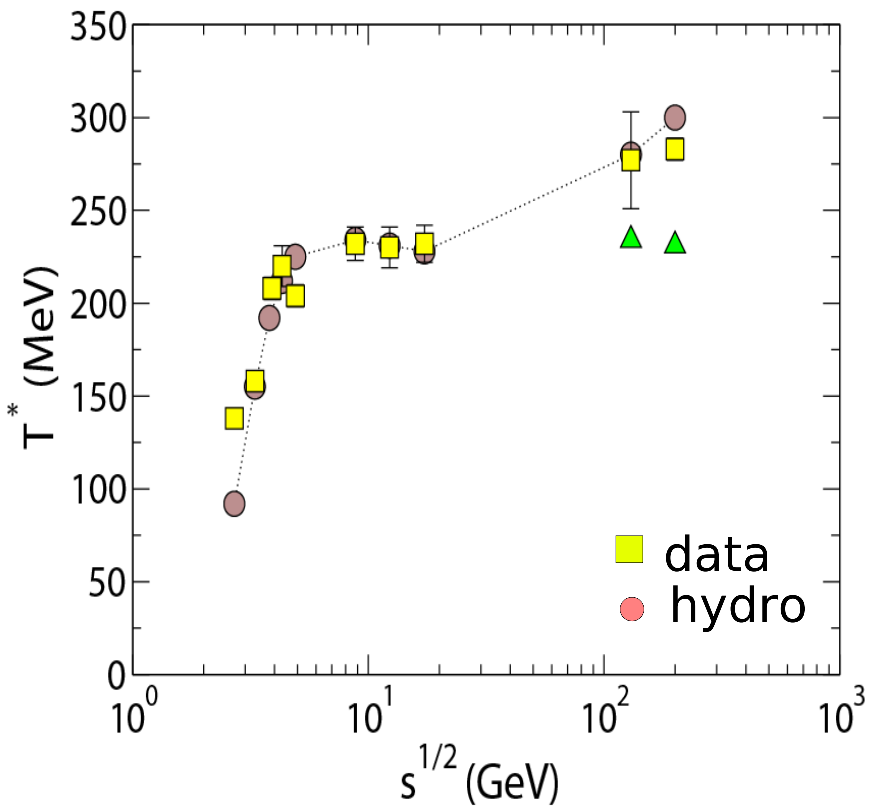


The step – quantitative models

String-hadronic models

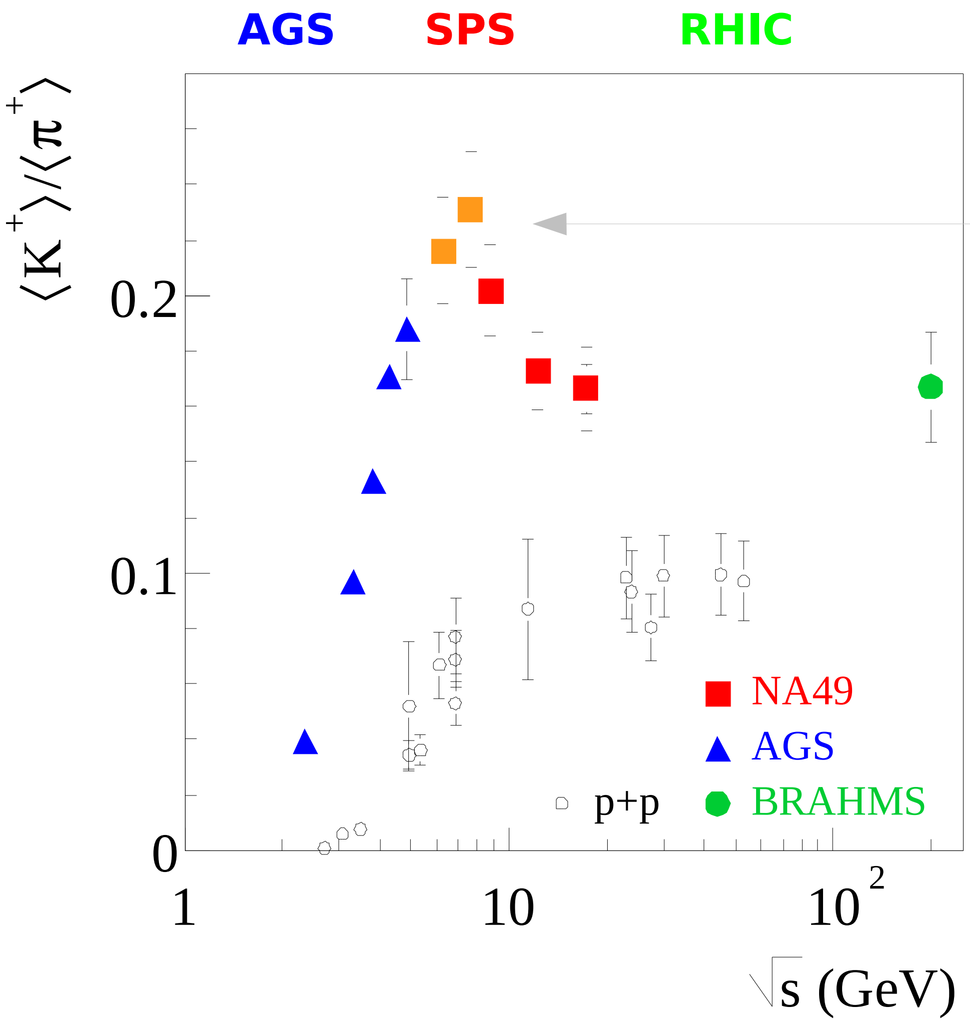


Hydro with the 1st order PT



Y. Hama. et al.
Braz. J. Phys. 34 (2004), 322,
hep-ph/0309192

The horn in strangeness yield



Deconfinement

↓

Decrease of masses of strangeness carriers and the number ratio of strange to non-strange degrees of freedom

↓

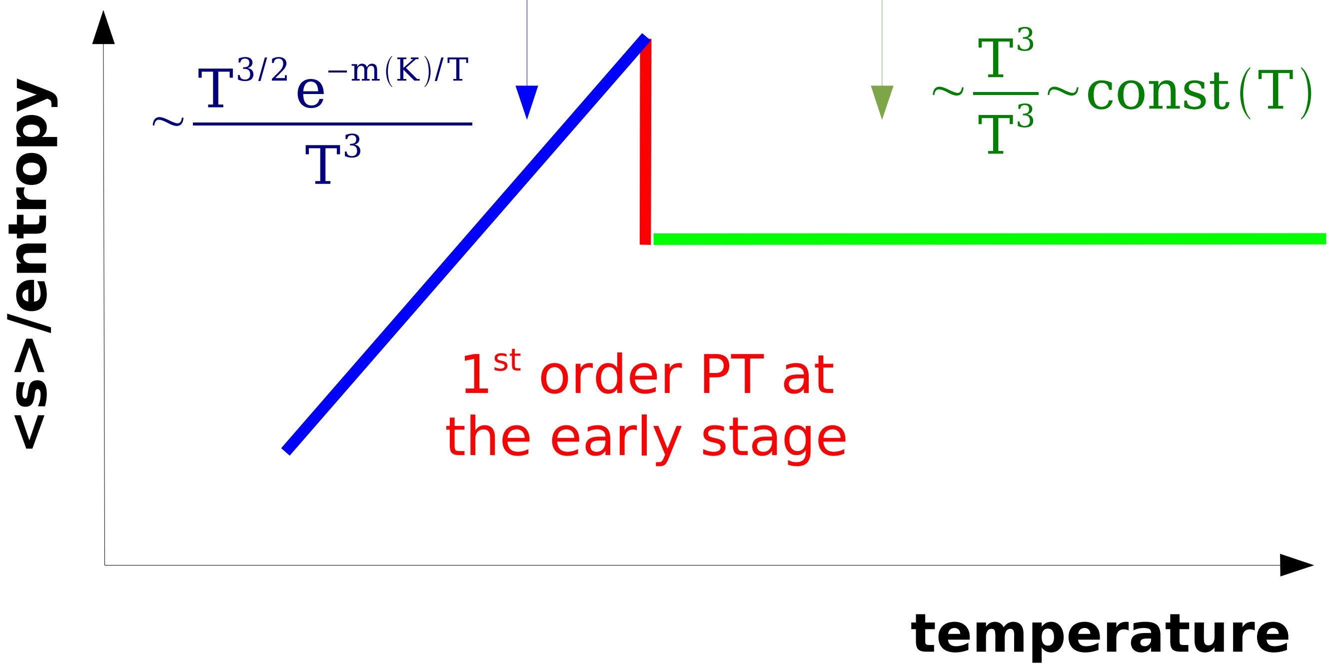
A sharp maximum in the strangeness to pion ratio

M.G., Gorenstein

The horn – qualitative arguments

Hadron Gas:
- heavy kaons (m(K) >> T_c)
- light pions (m(π) ≤ T_c)

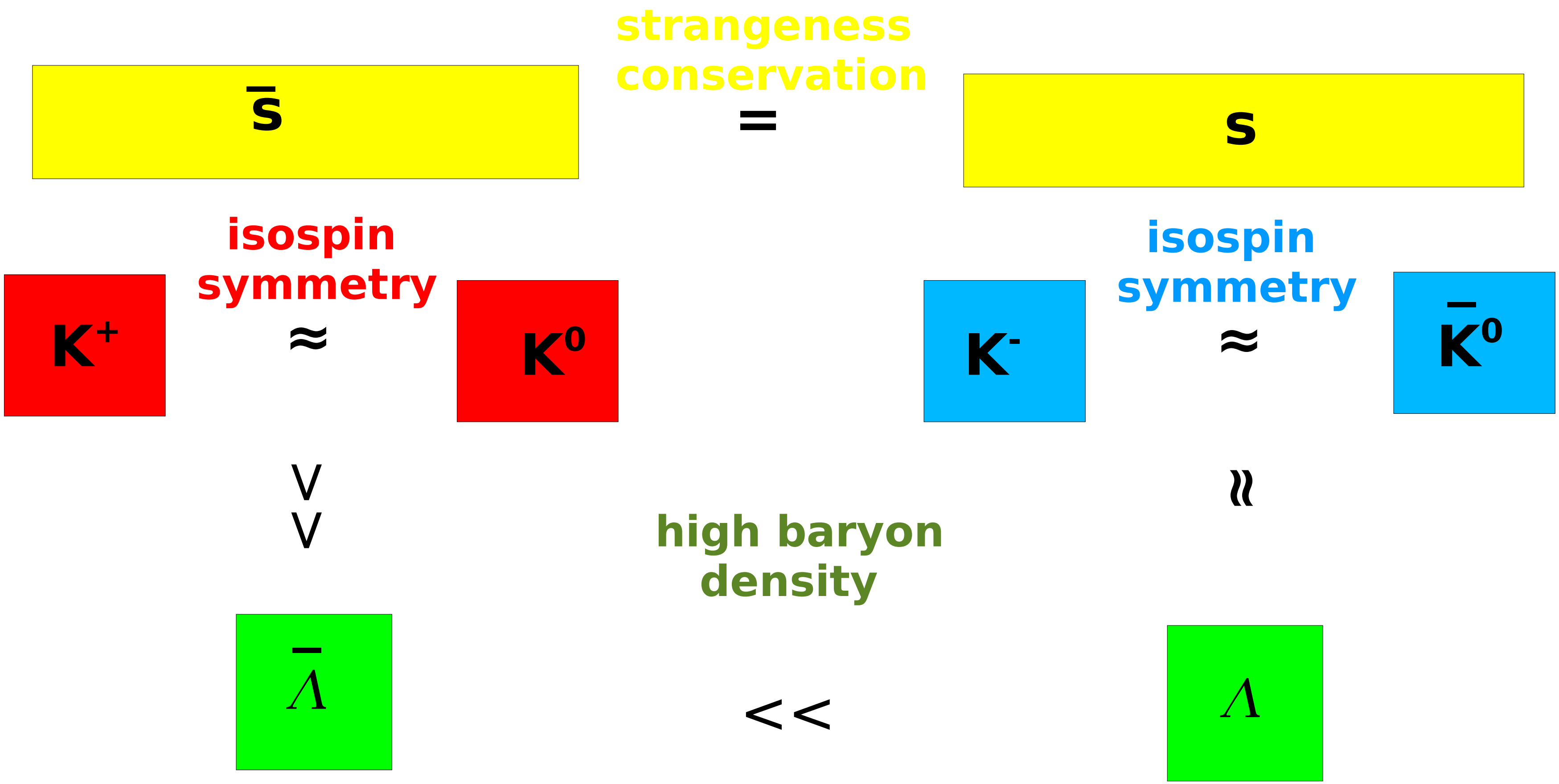
QGP:
- light s-quarks (m(s) ≤ T_c)
- light u, d and g (m(ns) << T_c)



→ Assumption: Evolution conserves entropy and <s>

→ The early stage structure may be observed in the final state

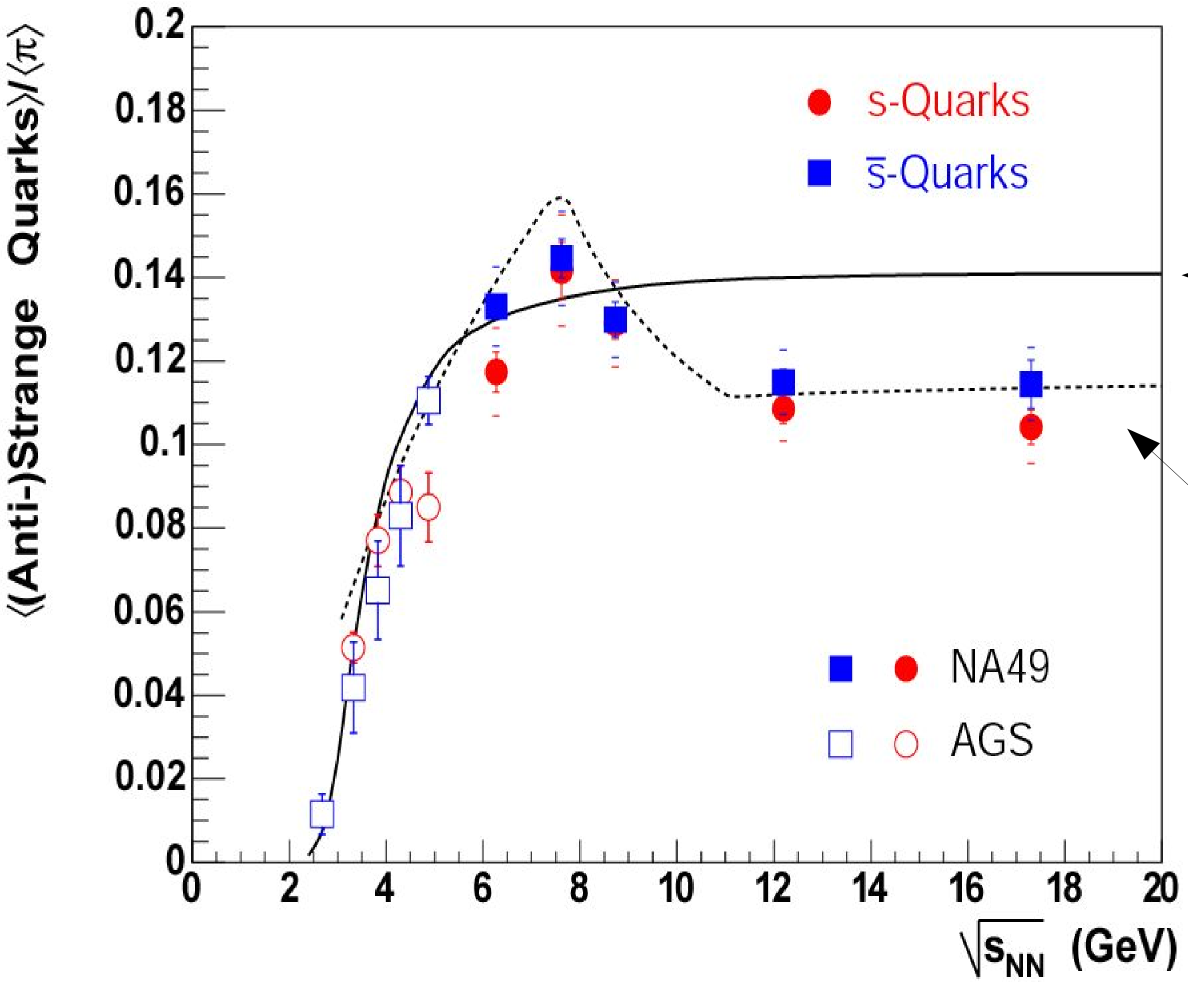
main strangeness carriers



sensitive to strangeness content only

sensitive to strangeness content and baryon density

The horn – quantitative models



-NA49 and AGS experimental data are consistent (<s>=<sbar>)

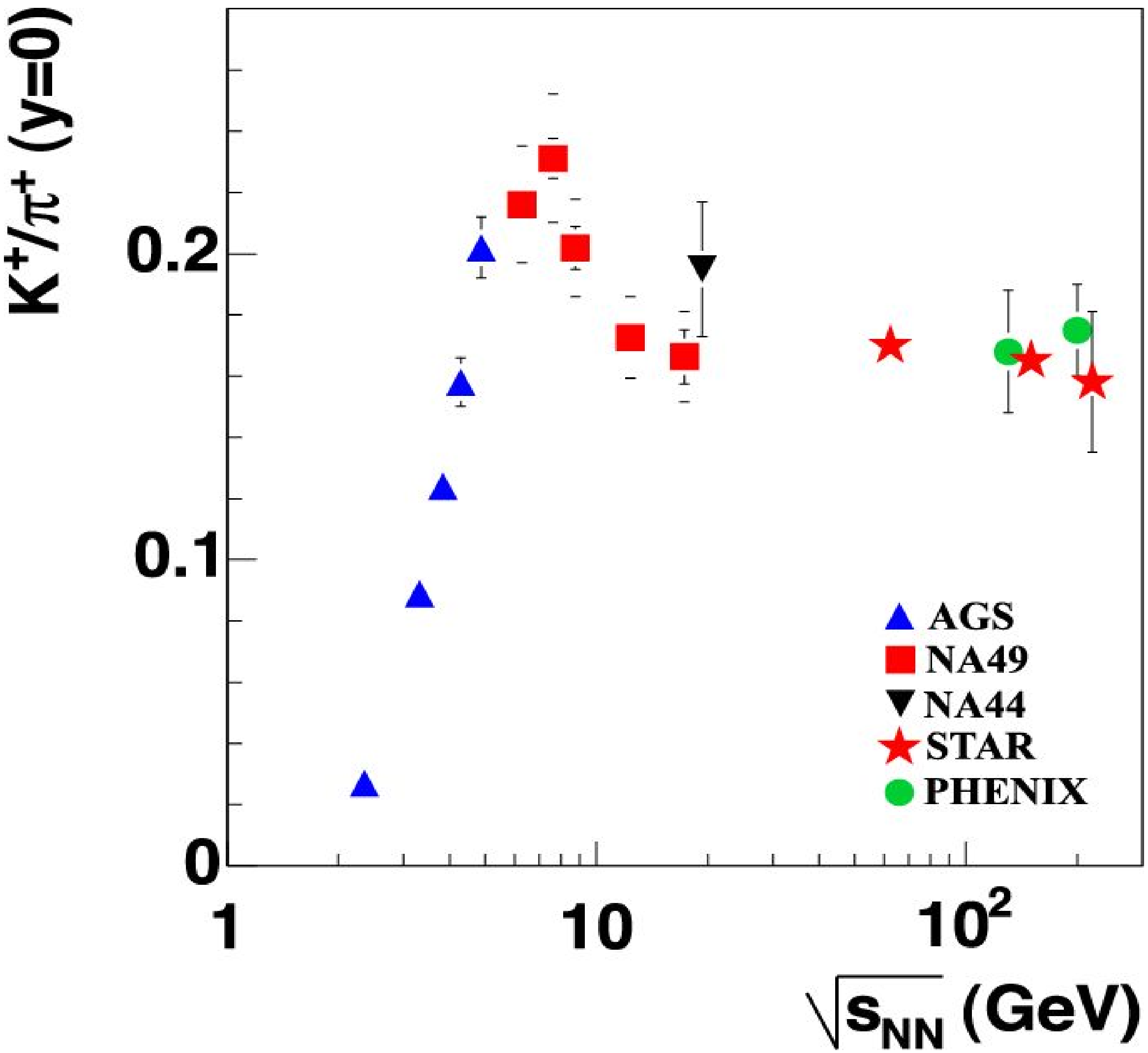
-difficult to parametrized within HG framework

Cleymans, Redlich

-agrees with the prediction for the onset of deconfinement

M.G., Gorenstein

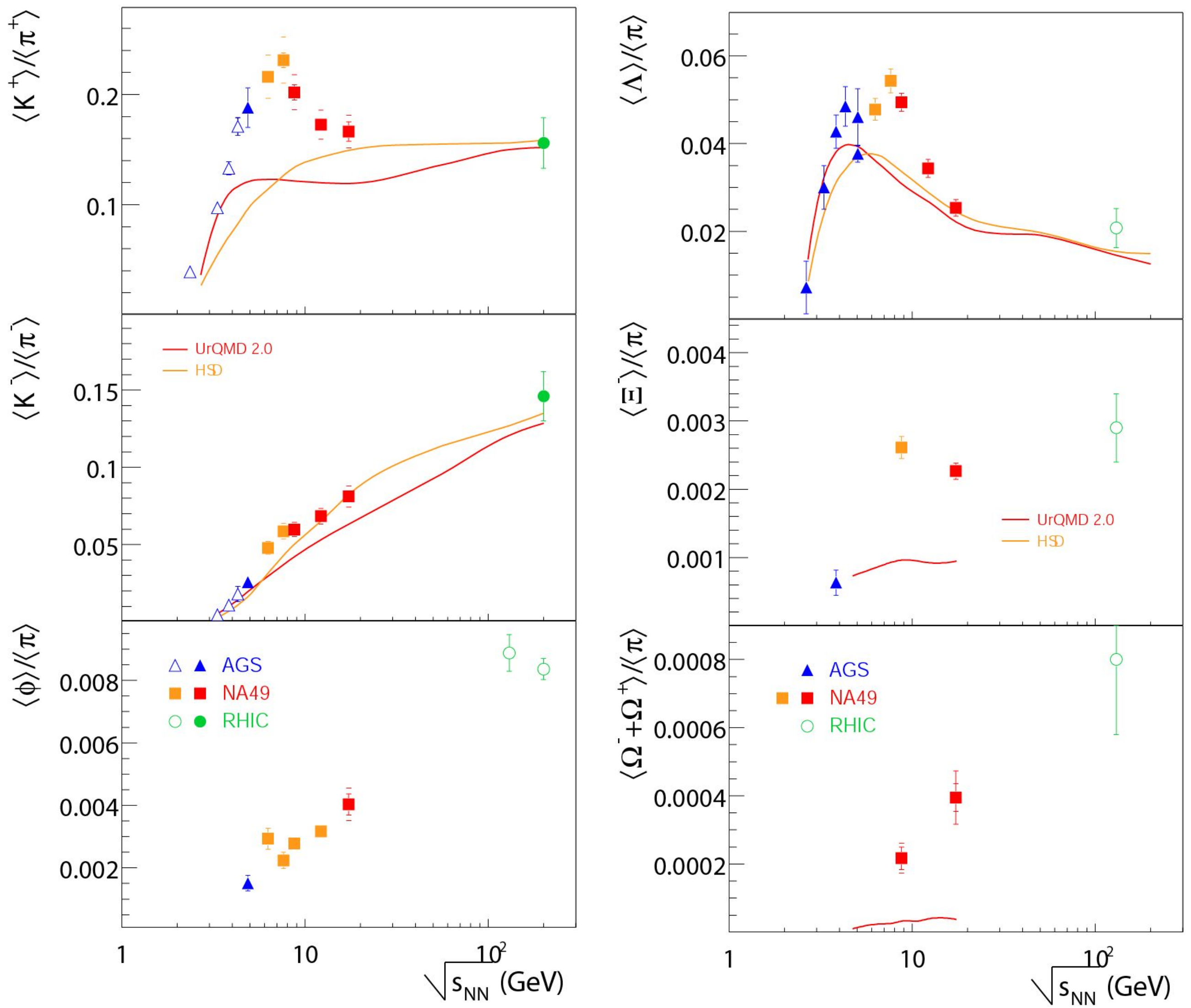
What about other experiments?



Overlapping measurements exist only for the mid-rapidity ratios

The results look consistent

energy dependence of various strange hadrons

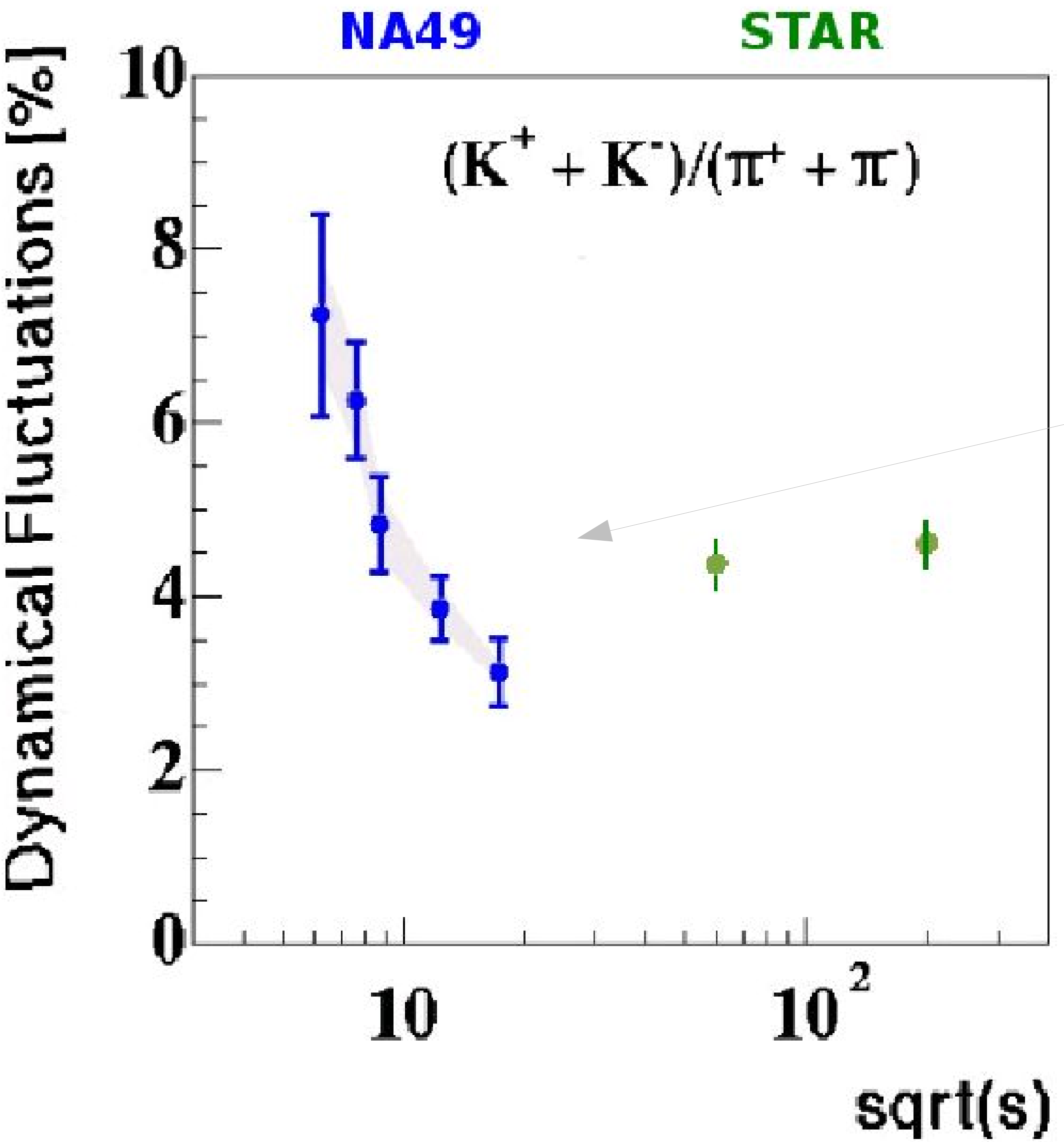


HSD, UrQMD:
E.L. Bratkovskaya et al., PRC 69 (2004), 054907

Mainly due to different sensitivity to baryon density different strange hadrons show different energy dependence

It is in general not explained by string-hadronic models

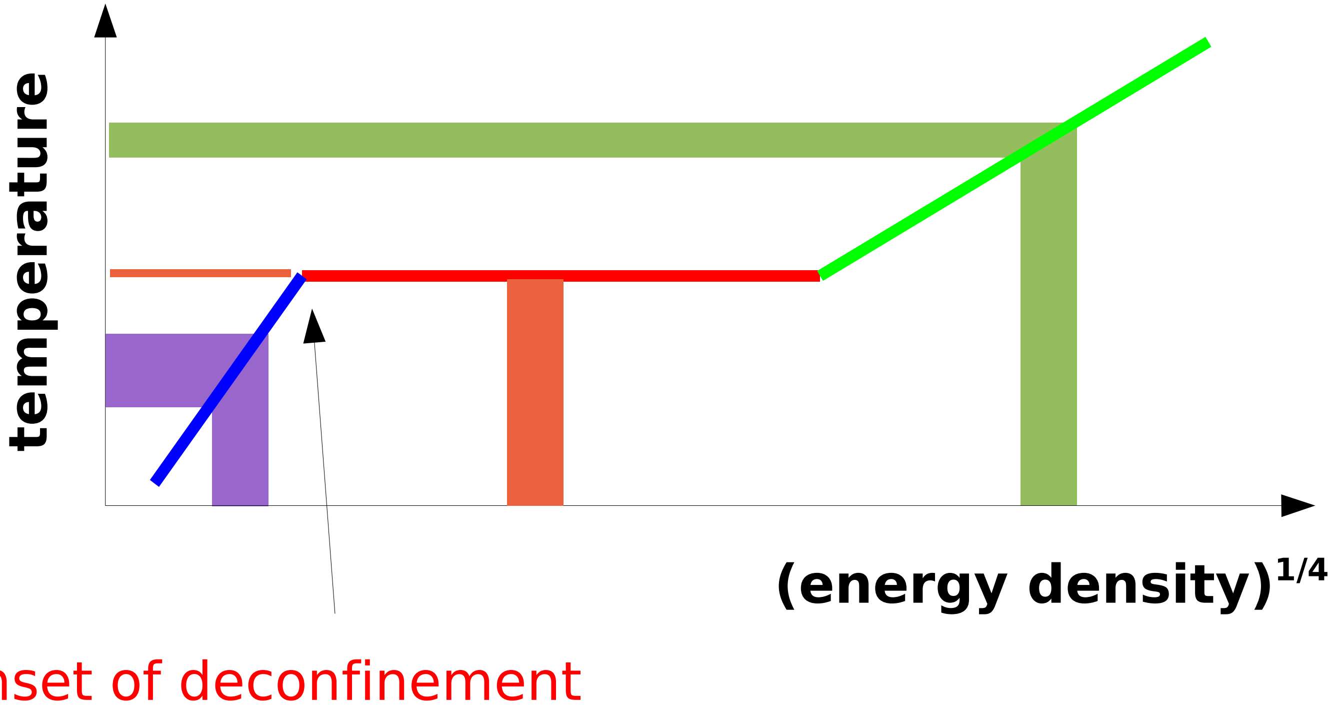
The kaon/pion fluctuations



Is the observed change in energy dependence related to deconfinement?

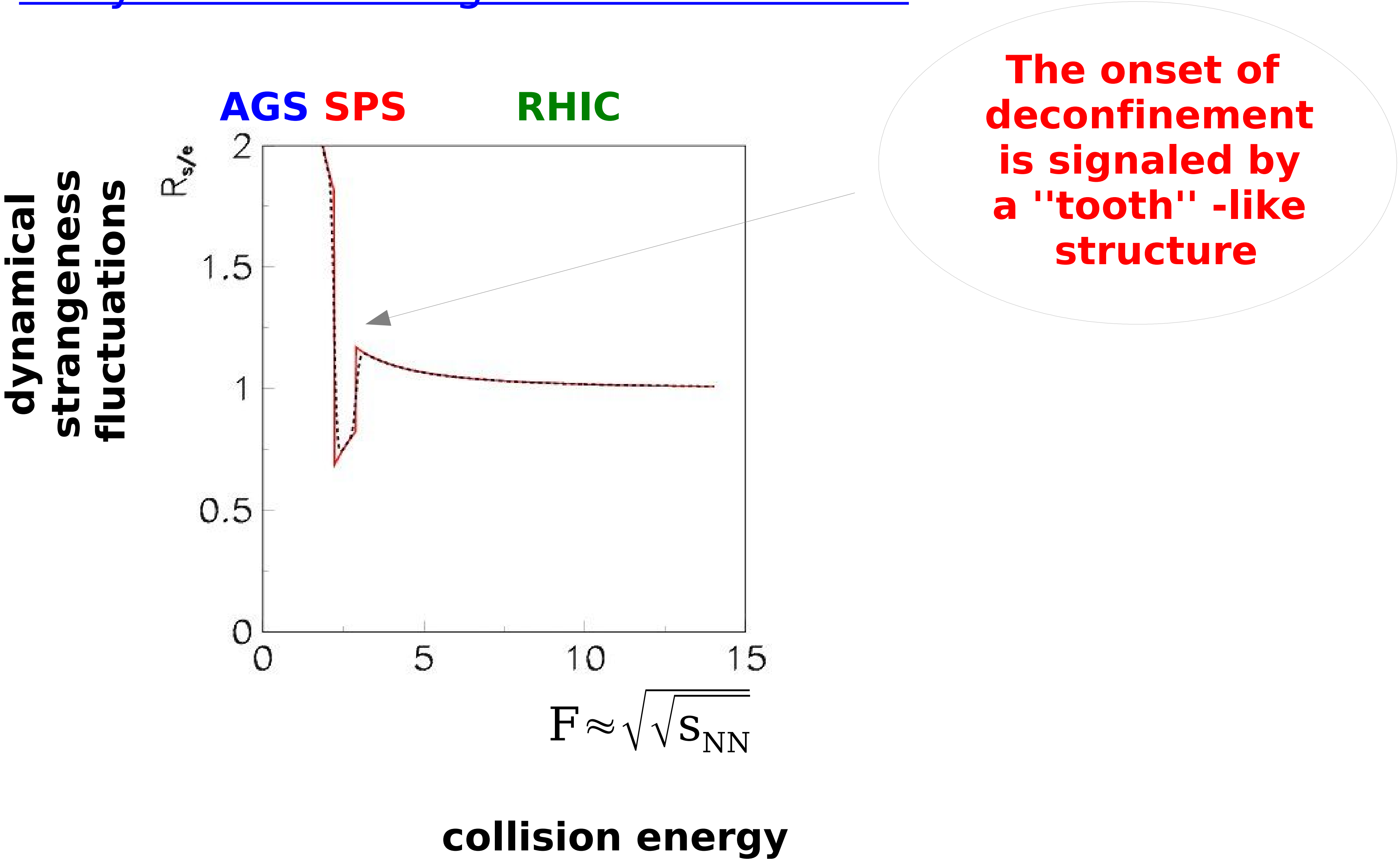
Strangeness fluctuation and onset of deconfinement

Response to the initial energy density fluctuations depends on the Equation of State at the early stage of the collisions

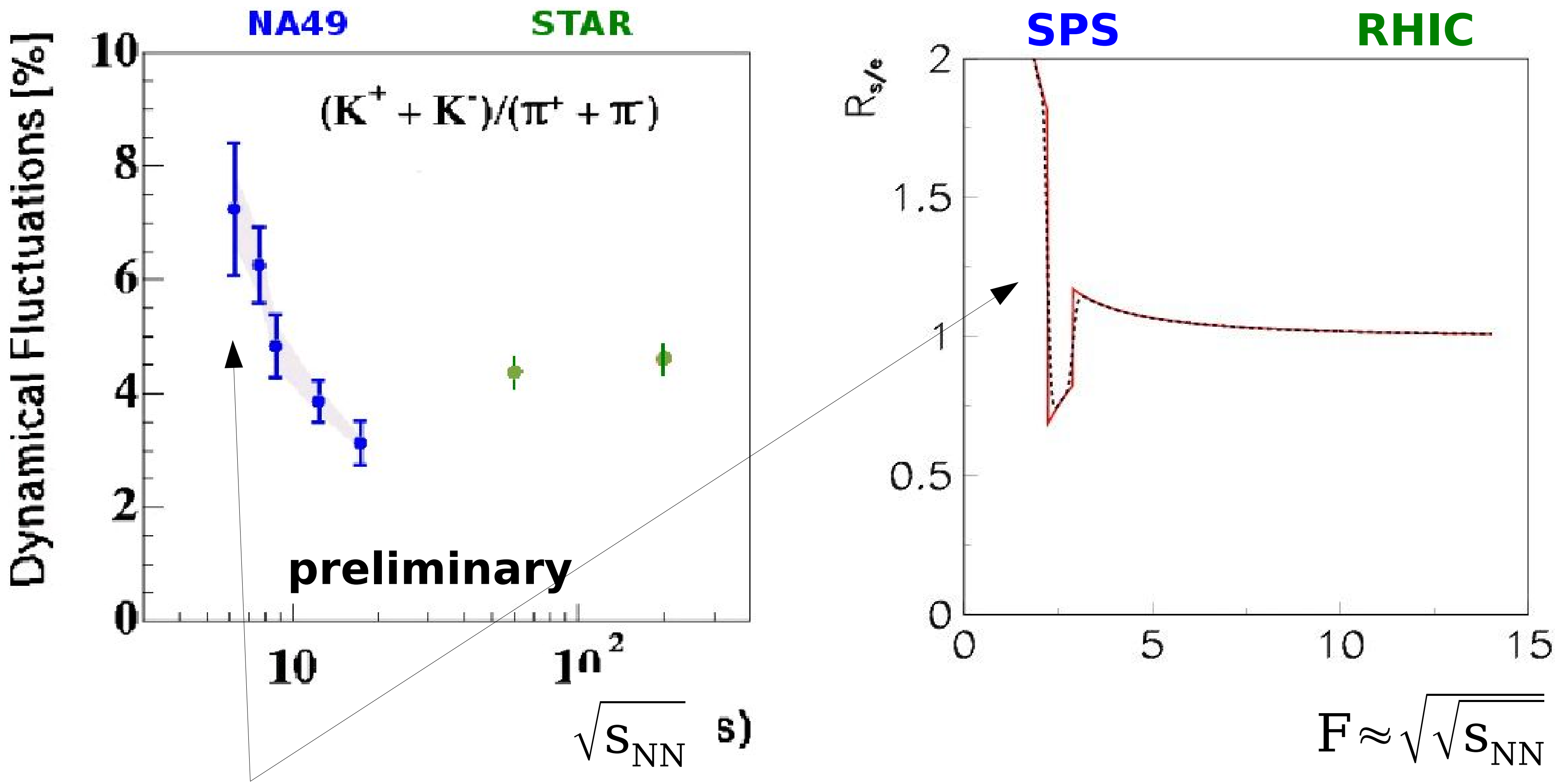


Gorenstein, M.G., Zozulya, PL B585:237, 2004

... and the energy dependence of dynamical strangeness fluctuations

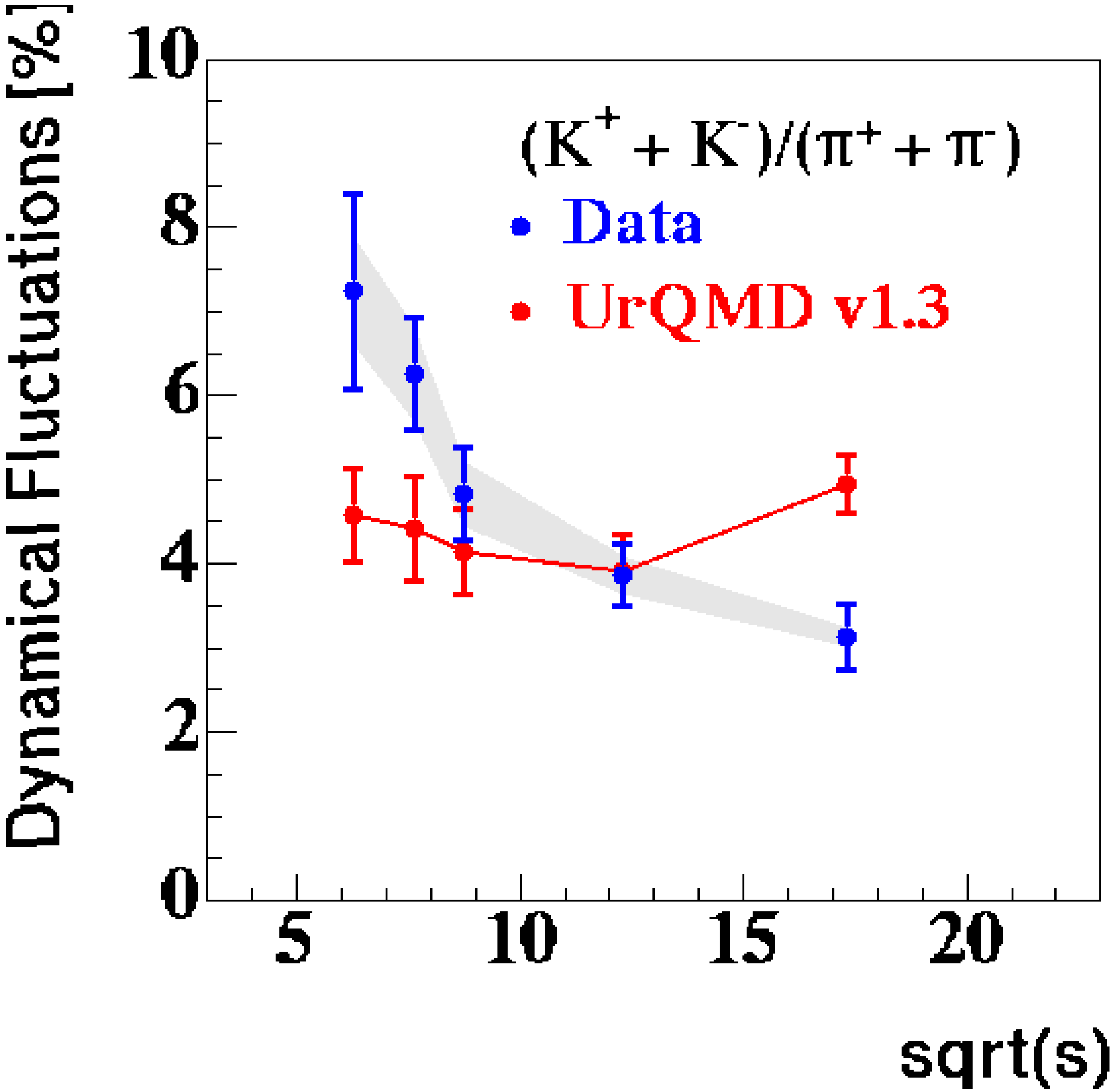


The NA49 data



Is the increase of fluctuations due to the onset of deconfinement?

Warning: a direct comparison is still impossible as different measures are used for data and model analysis central Pb+Pb at 20*A*-158*A* GeV

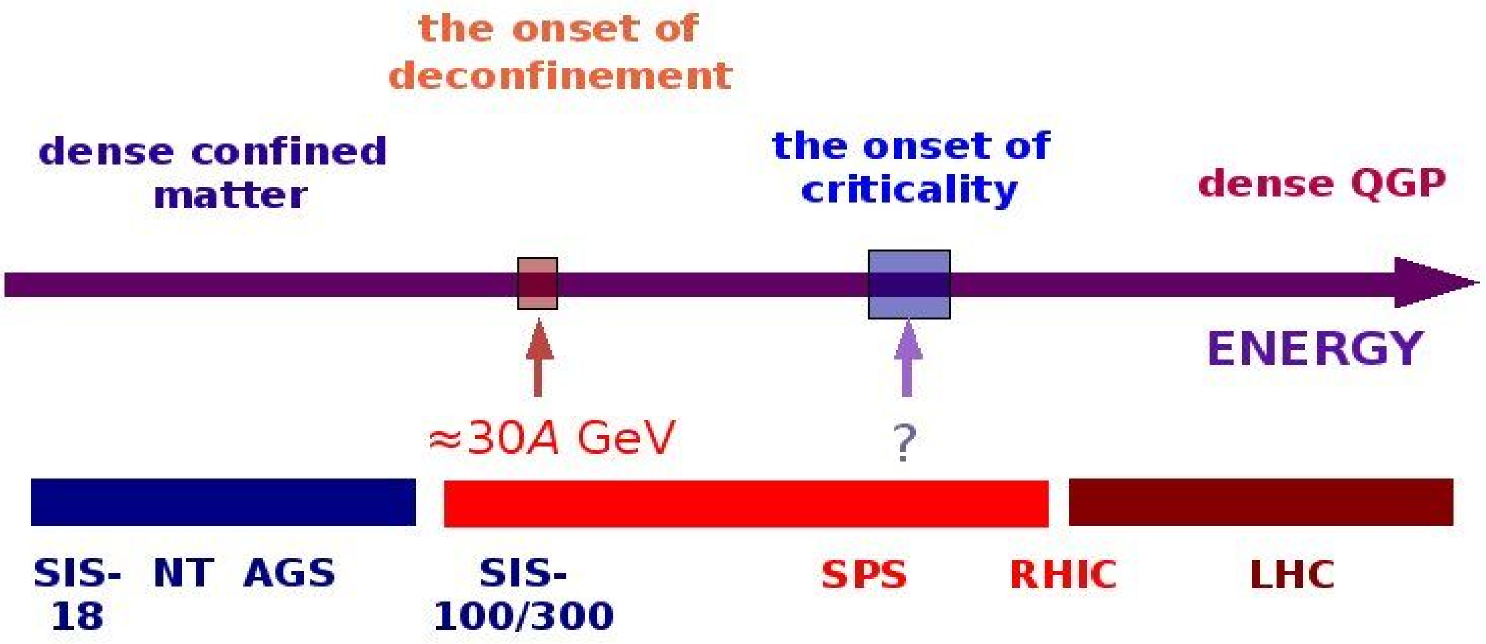


A string-hadronic model, UrQMD, does not reproduce the data

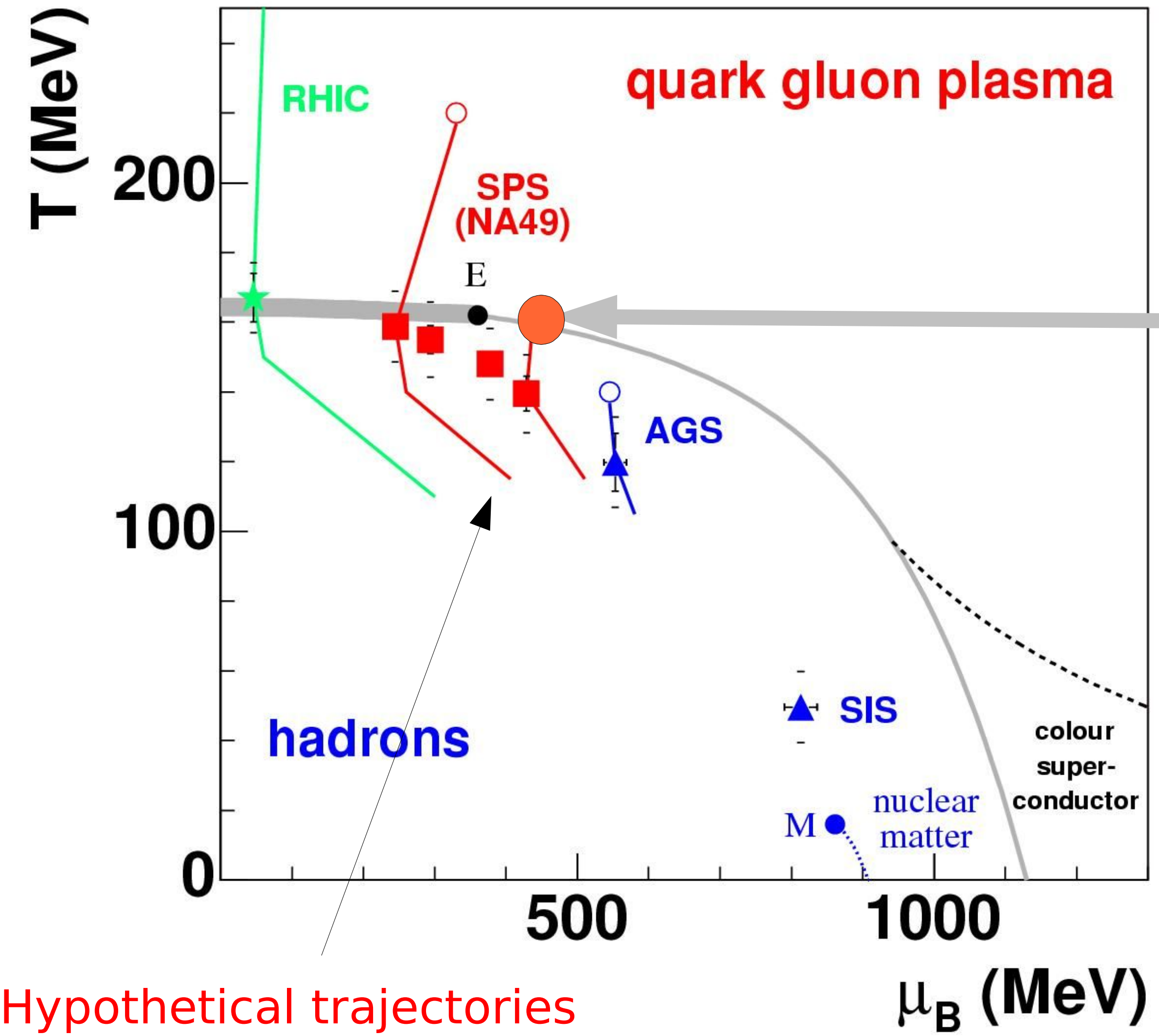
To do list : strangeness and deconfinement

Finish analysis of already taken data, in particular:
- -centrality dependence at 20A and 30A GeV,
- -particle fluctuations

Extend and confirm the NA49 results by new measurements:
- -in the near future: at RHIC and at SPS
- -in the far future: at FAIR



Phase diagram of strongly interacting matter - experiment



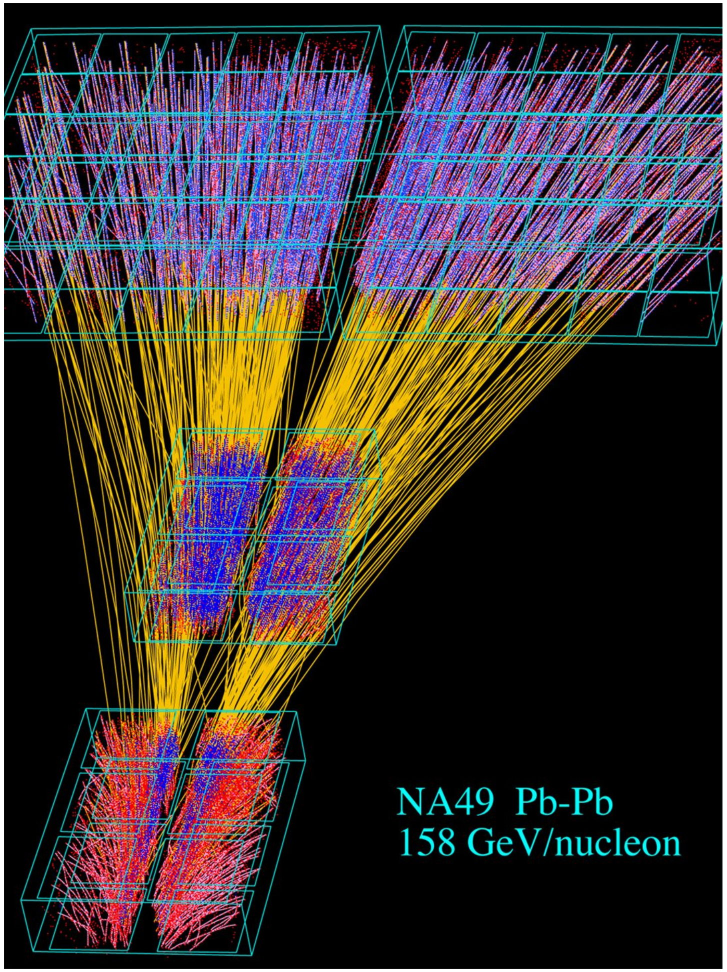
Horn, kink, step

Phase boundary reached at about 30*A* GeV

Hypothetical trajectories of the expanding matter

Additional slides

NA49 at the CERN SPS



→ A large acceptance: ≈50%

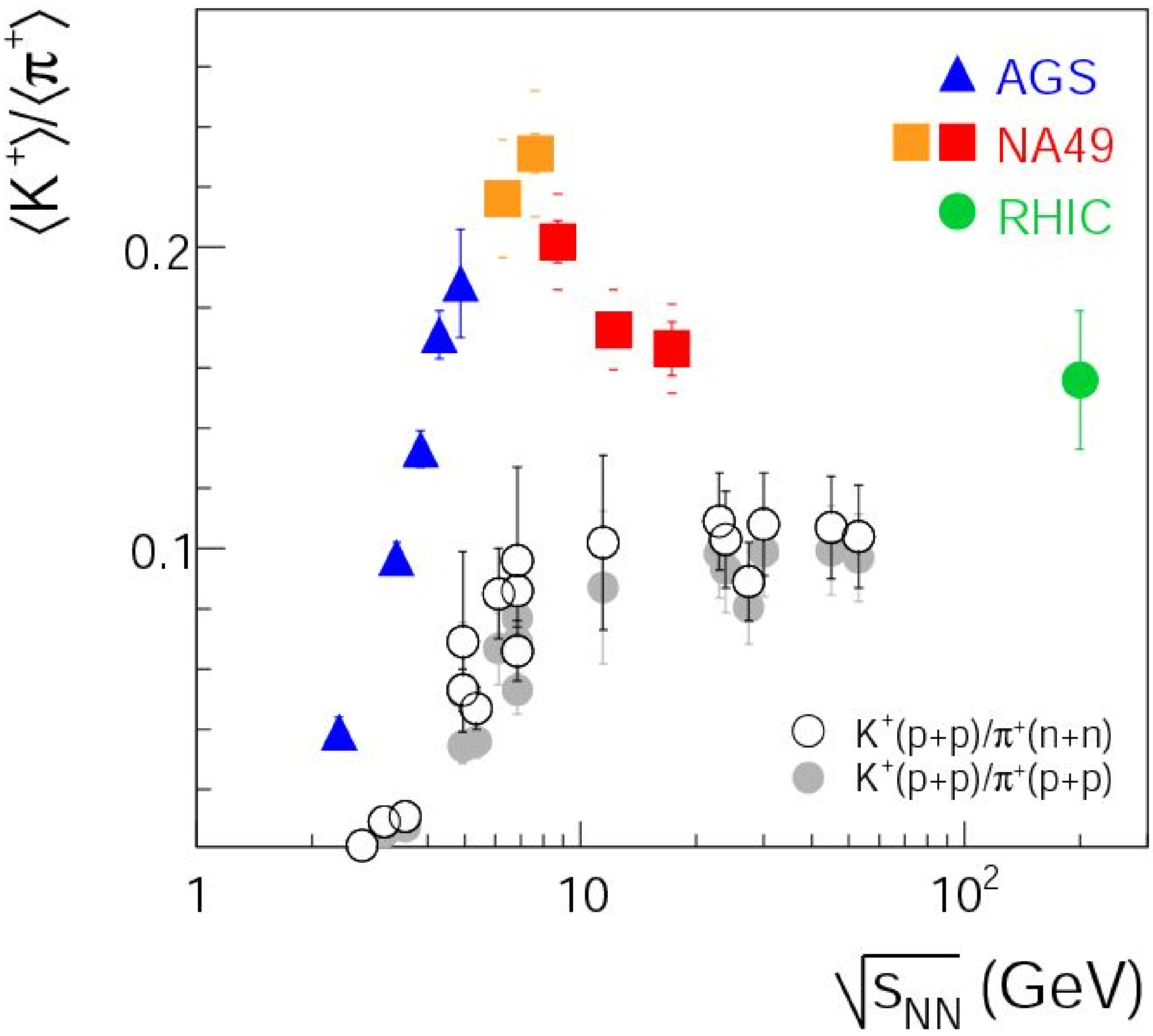
→ A high momentum resolution:

$$\sigma(p)/p^2 \approx 10^{-4} \quad ((\mathrm{GeV}/c)^{-1})$$

→ A good particle identification:

$$\sigma(\mathrm{TOF}) \approx 60\,\mathrm{ps},$$
$$\sigma(dE/dx)/\langle dE/dx \rangle \approx 0.04,$$
$$\sigma(m_{inv}) \approx 5\,\mathrm{MeV}$$

Effect of isospin differences



Event-by-event fluctuations of e.g. K/π

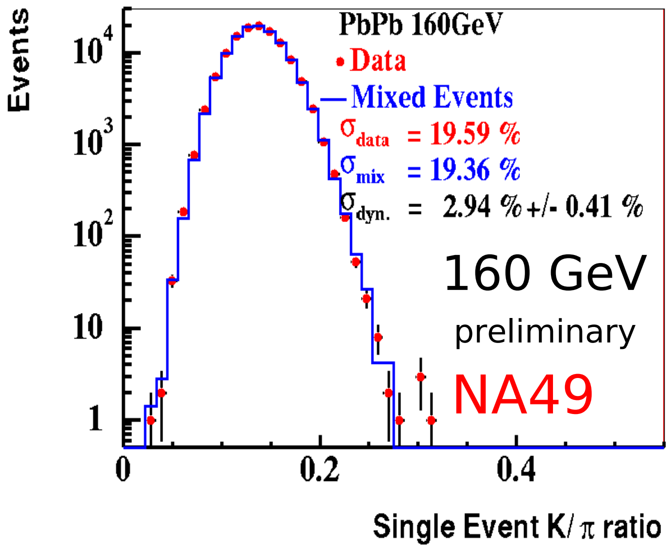
Compare to mixed event reference

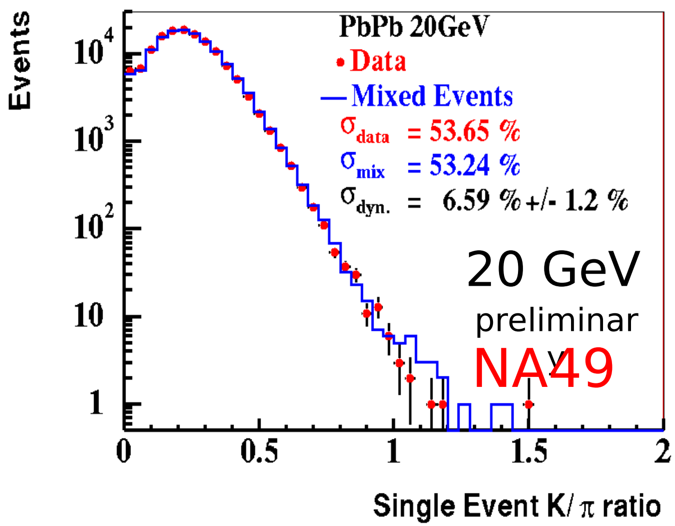
- Resolution
- Finite number statistics

→ Extraction of dynamical fluctuations

σ = RMS/Mean * 100 [%]

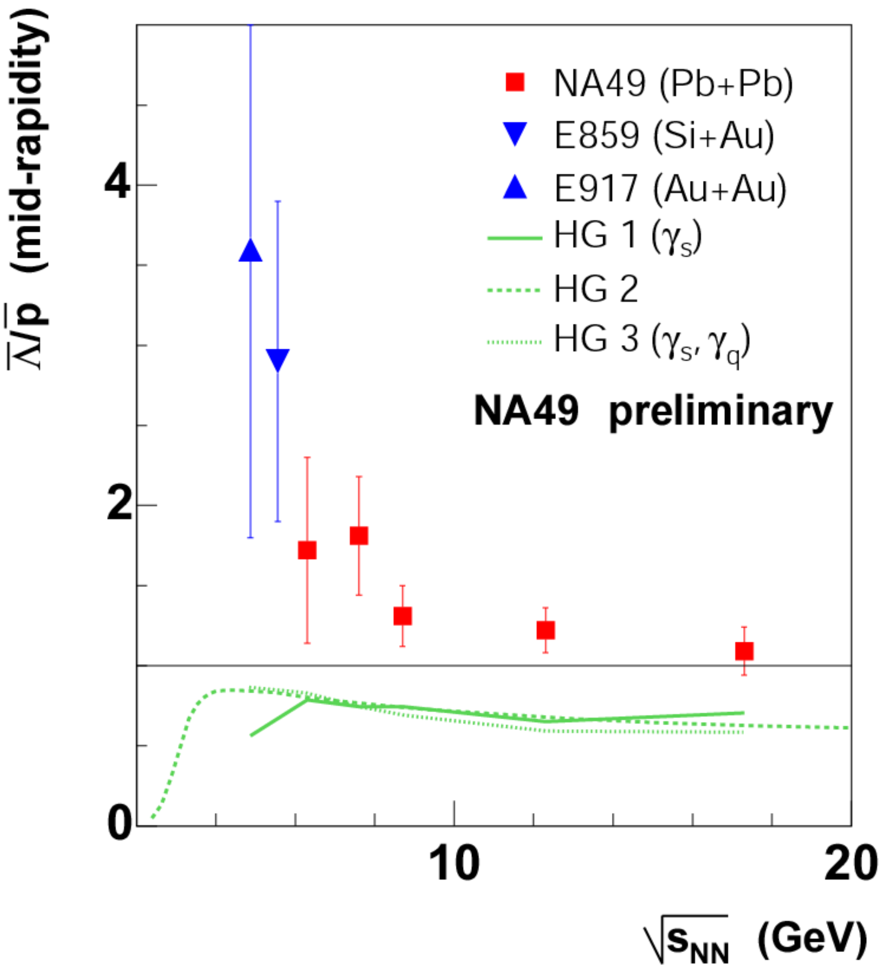
$\sigma^2_{dynamic} = \sigma^2_{data} - \sigma^2_{mix}$





Increase above 1 towards lower energies

consistent with recent NA49 data



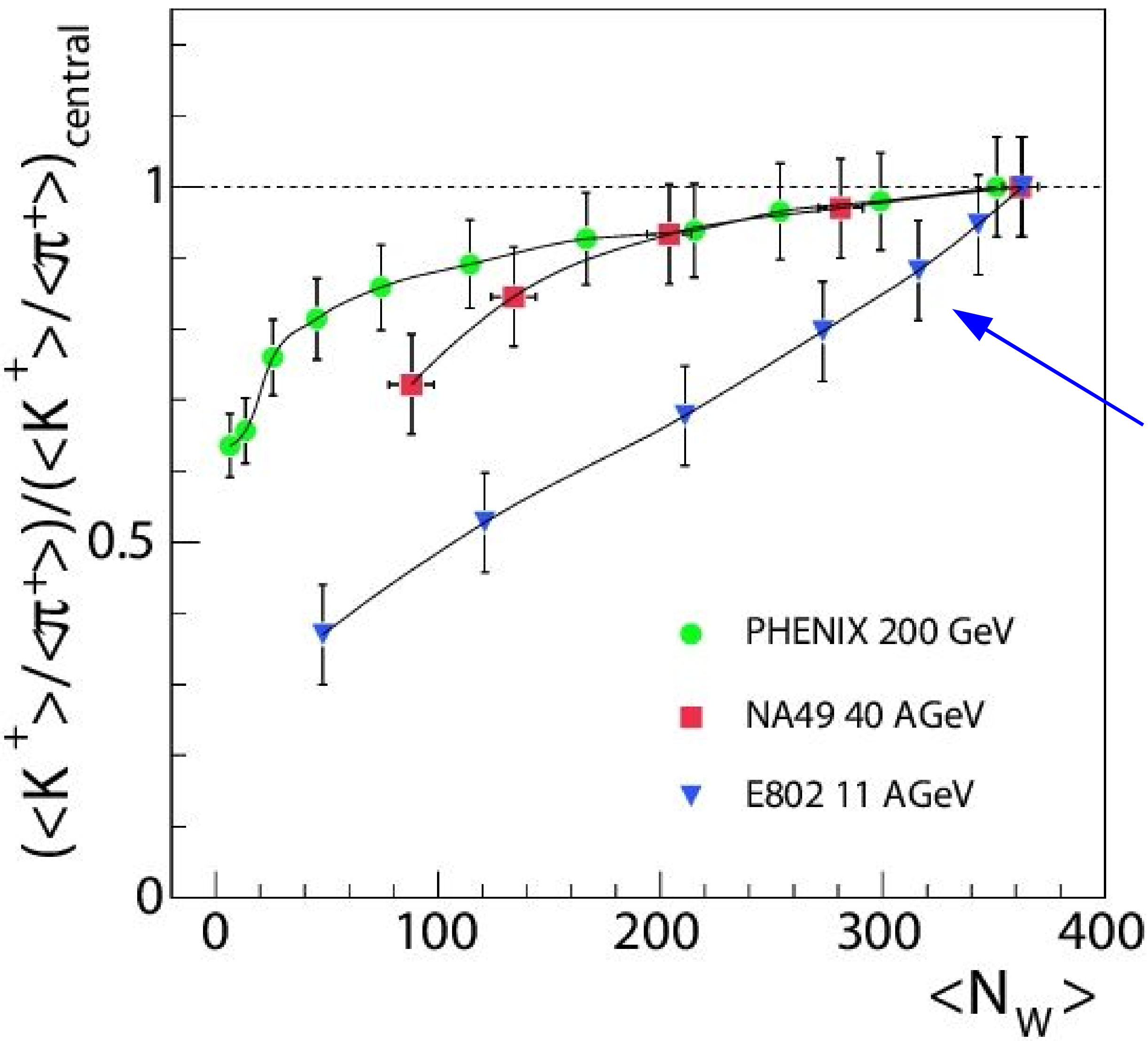
Models predict ratio < 1

Hadron Gas 1: J. Manninen et al.

Hadron Gas 2: K. Redlich et al.

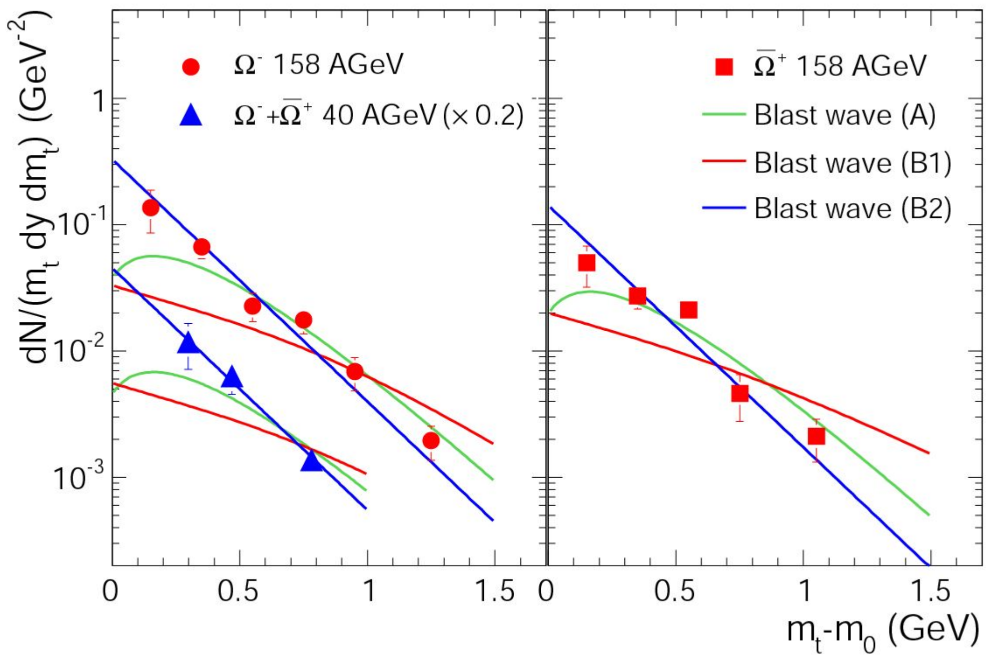
Hadron Gas 3: J. Rafelski et al.

How does the horn look in the thermodynamical limit?



The AGS data do not show saturation as a function of centrality

Evidence for early freeze-out of the Omega from blast wave fits?

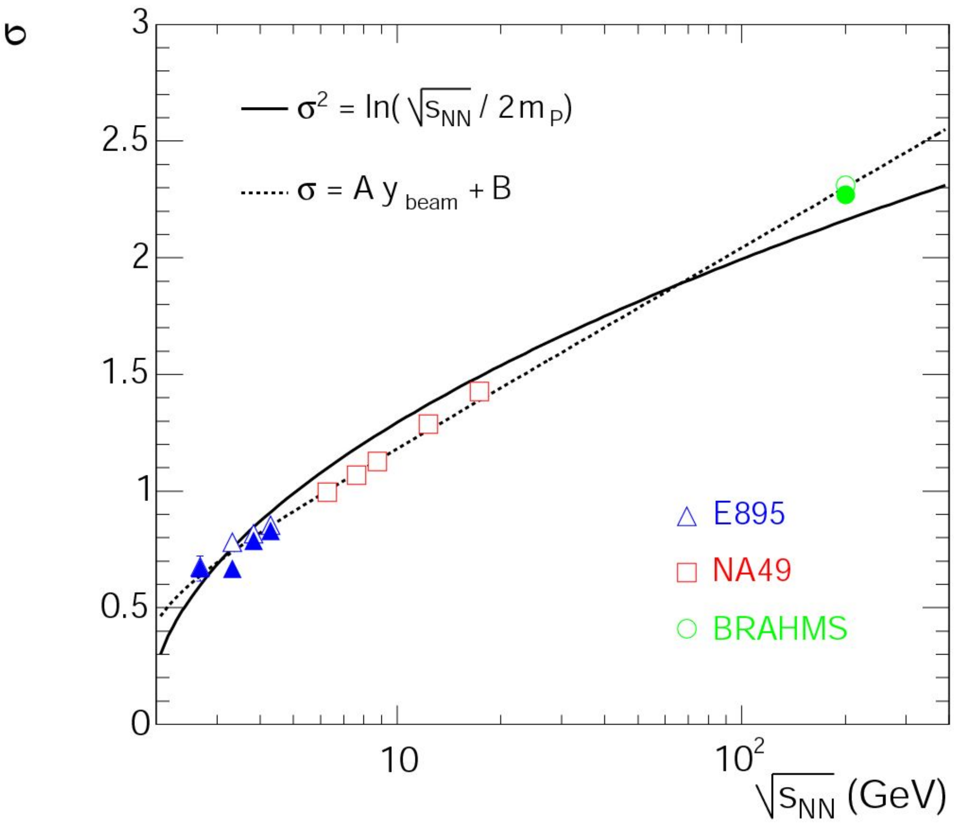


NA49 publication:
C. Alt et al., nucl-ex/0409004

Blast Wave Model	Velocity Profile	T_f (MeV)	$\langle \beta_t \rangle$	
A	constant	125	0.5	from fits shown before
B1	linear	90	0.5	Fit to K, p, φ, Λ
B2	linear	170	0.2	Fit to J/ψ and ψ′ (*)

(*) M.I. Gorenstein, K. A. Bugaev and M. Gazdzicki, PRL. 88 (2002), 132301.

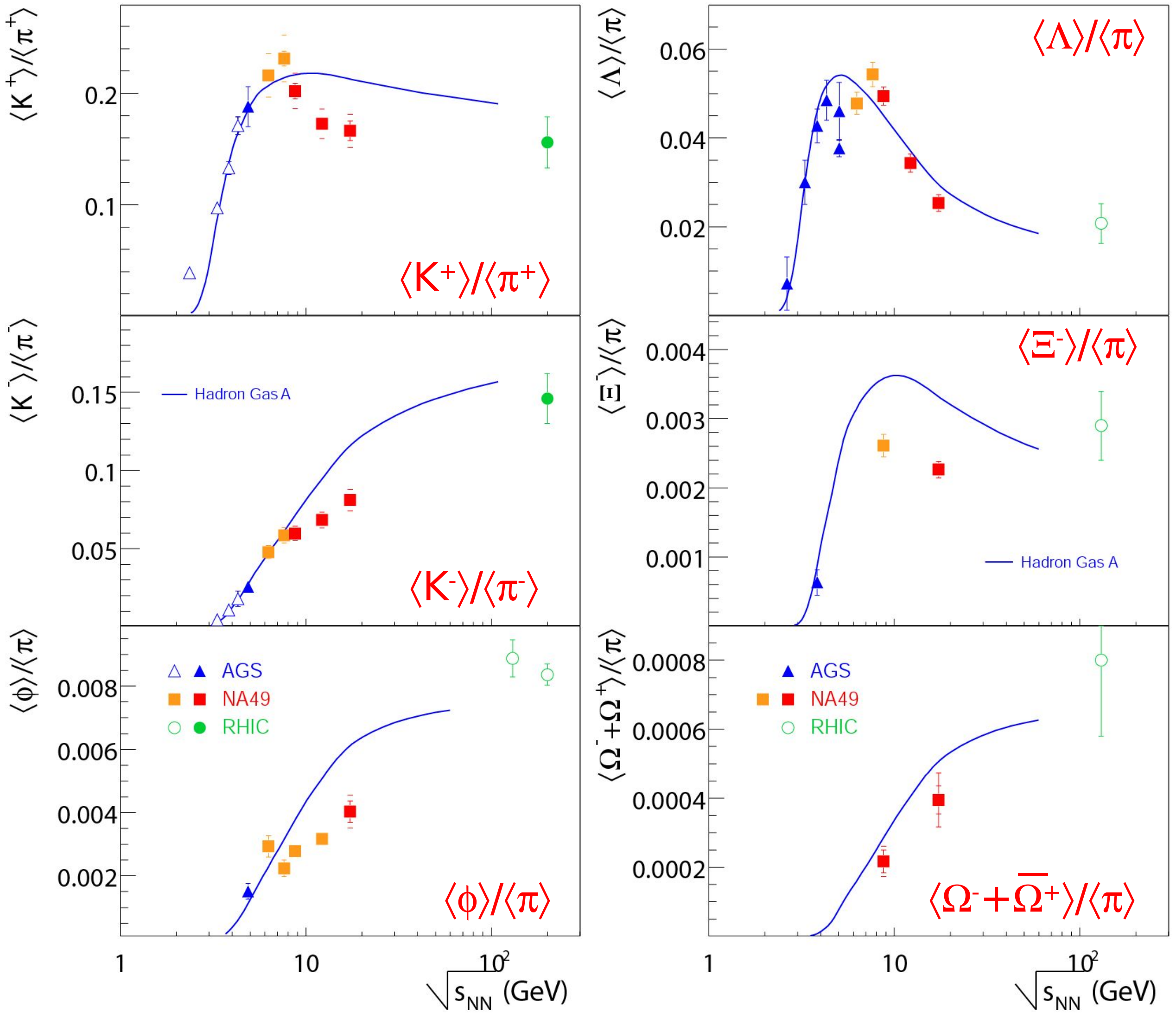
Pion widths are close to Landau prediction, but not perfectly



But: Perfect agreement to linear dependence on y_{beam}

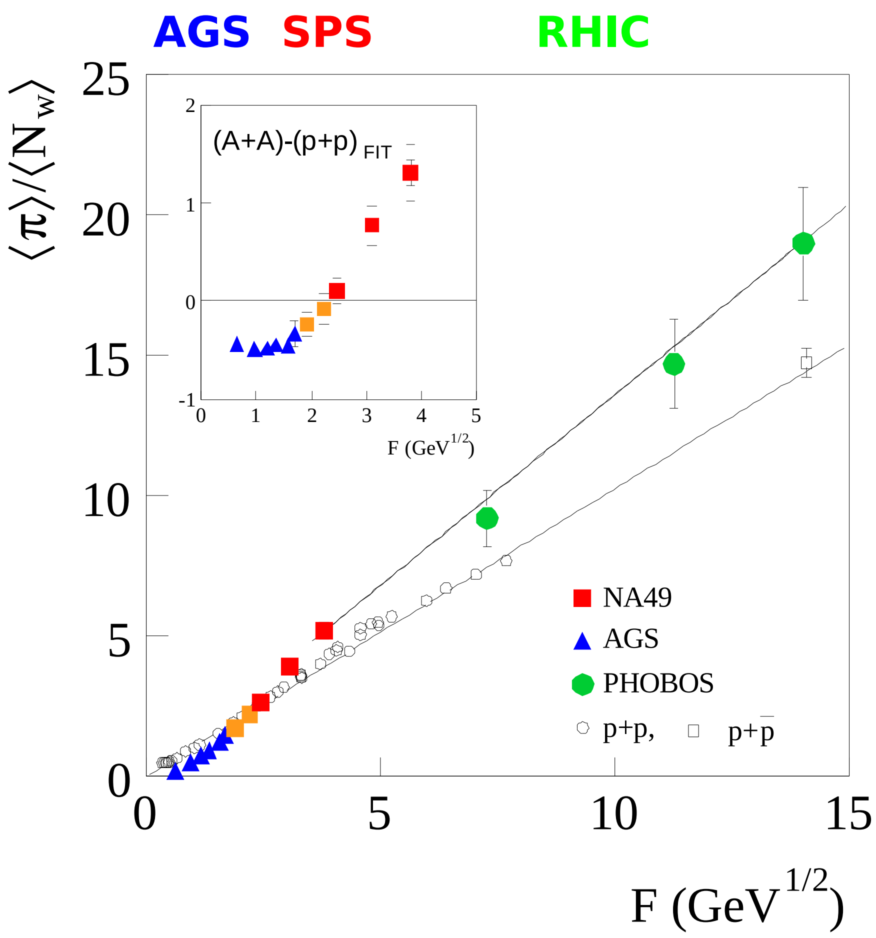
Statistical hadron gas model: $\gamma_s = 1$

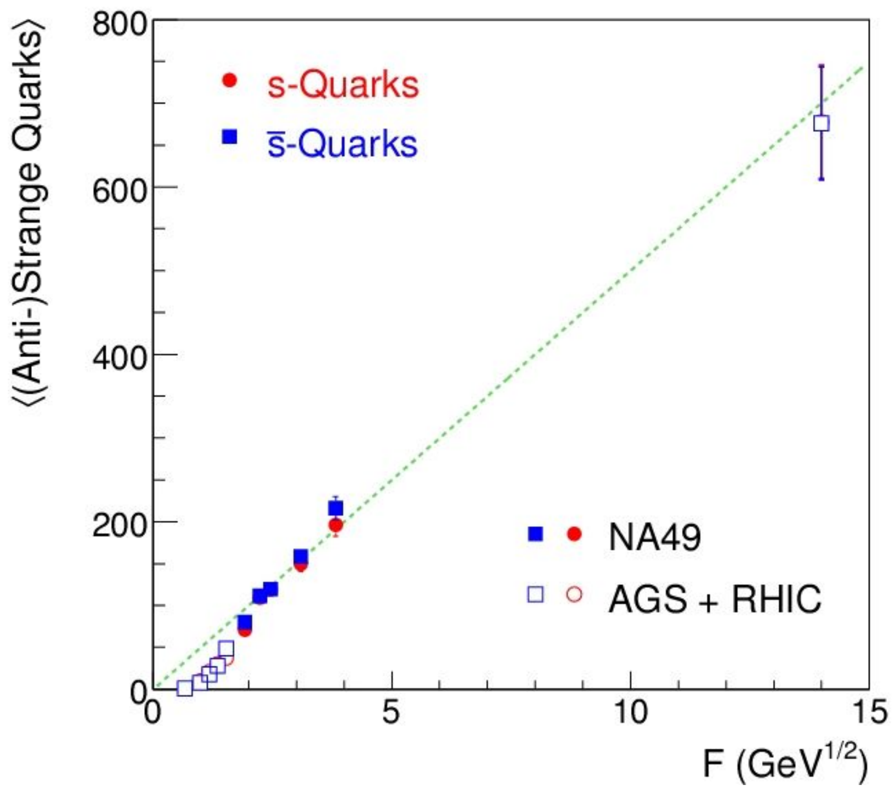
P. Braun-Munzinger,
J. Cleymans,
H. Oeschler,
and K. Redlich
Nucl. Phys. A697 (2002) 902



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

Is the horn because of pions or strangeness?





The answer is model dependent ...