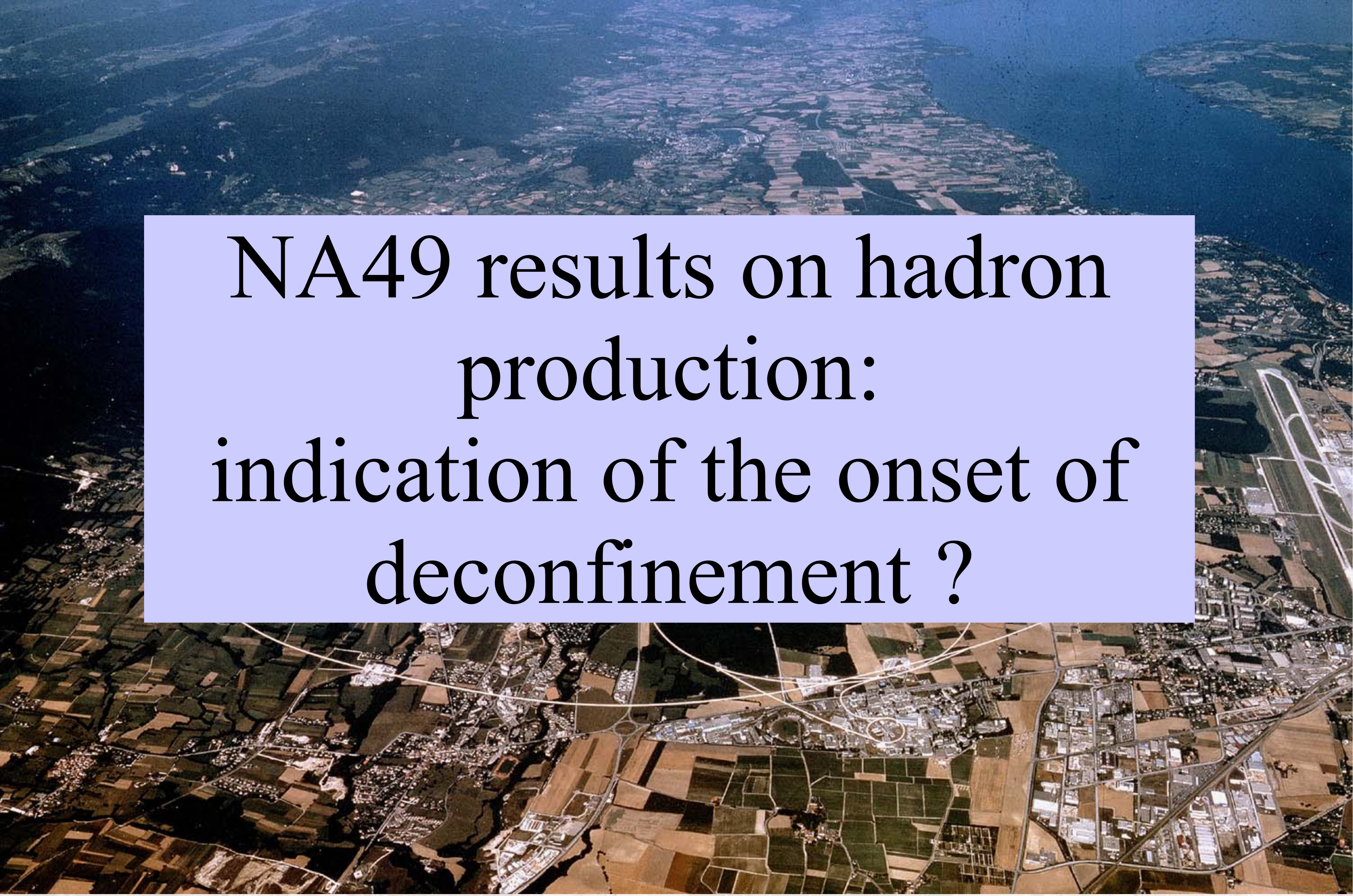
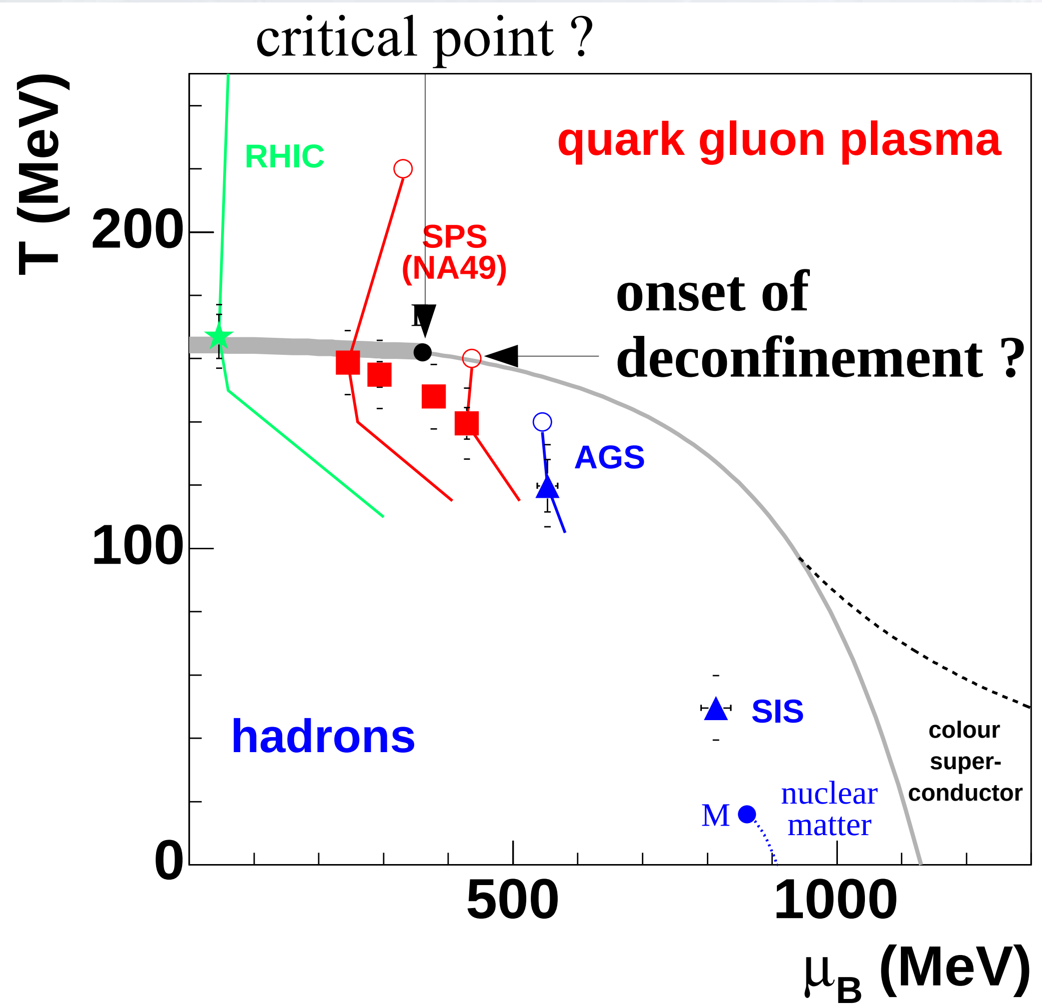


NA49 results on hadron production: indication of the onset of deconfinement ?

Benjamin Lungwitz

IKF Universität Frankfurt

Phase diagram



(baryon density)

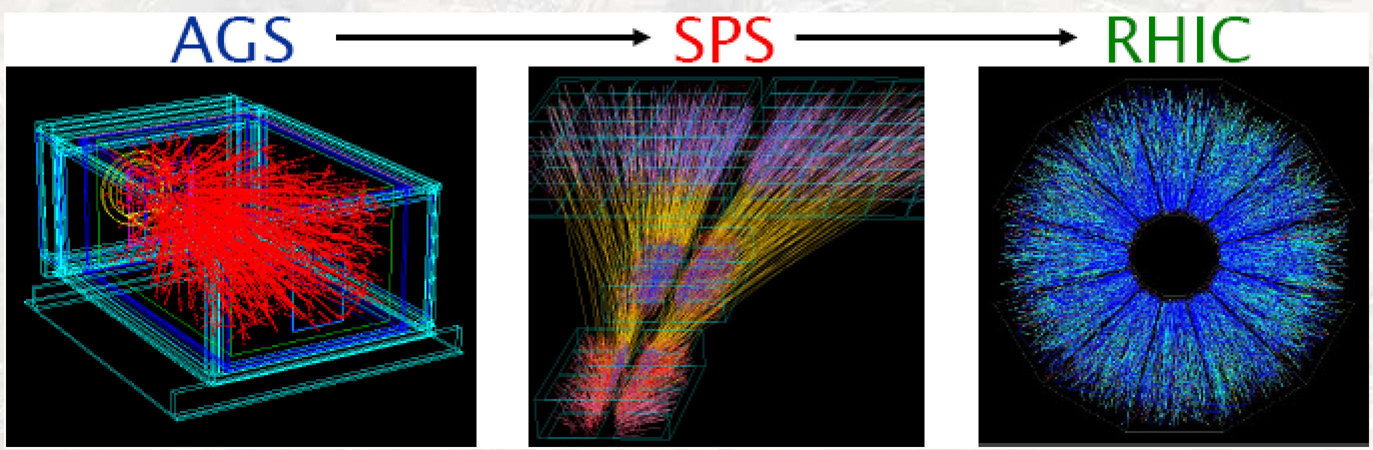
- Phase boundary separating hadron gas and QGP
- T=0: 1st order phase transition
- μ_b=0: a smooth cross over
- Critical point (2nd order phase transition)
- Chemical freeze out points from Hadron Gas Model, Becattini et al.
- **Is the onset of deconfinement seen in data ?**

Heavy ion experiments

Various heavy ion experiments cover a broad energy range:

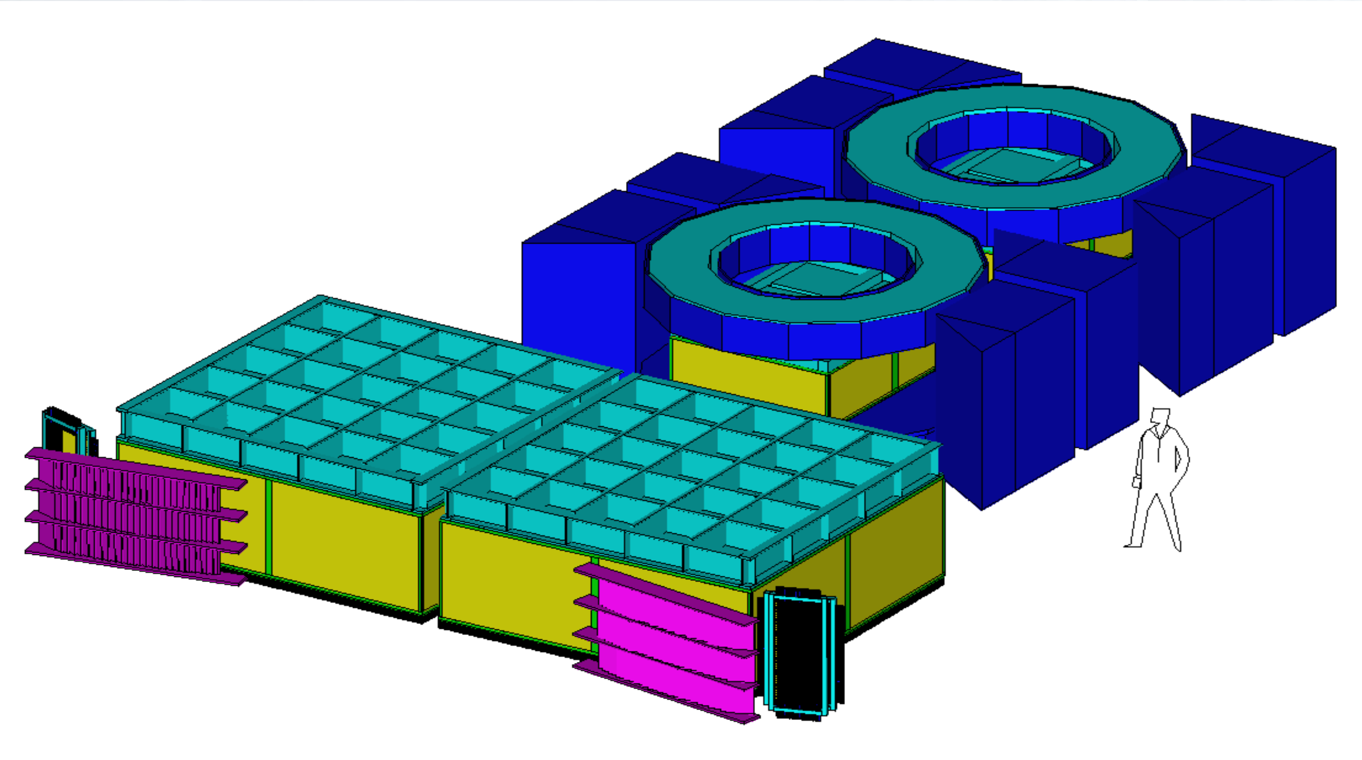
- AGS (E...)
- SPS (WA..., NA..., NA49)
- RHIC (Star, Phobos, Phenix, Brahms)
- LHC (Alice, CMS, Atlas)

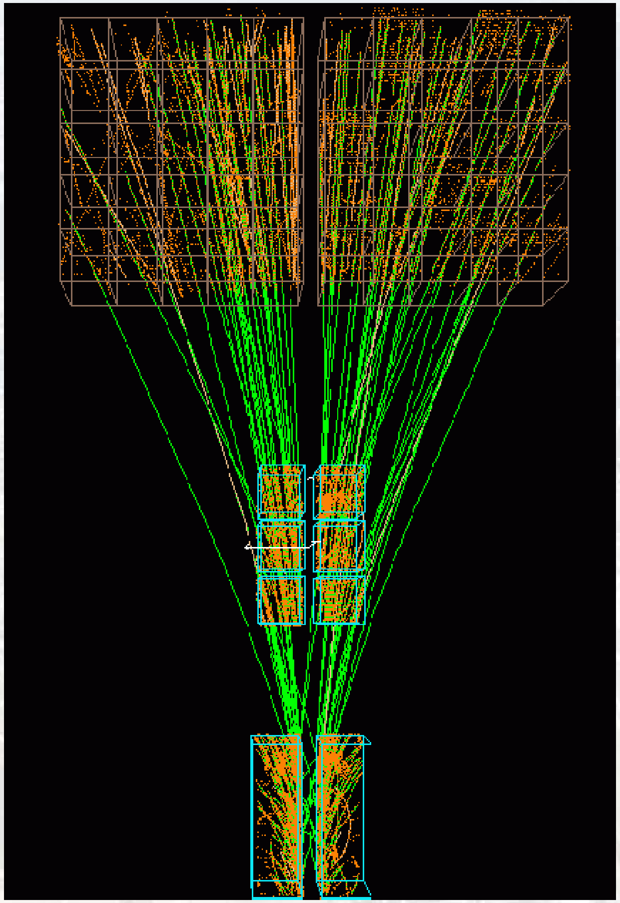
collision energy



EOS, E895 NA49 STAR

NA49 experiment

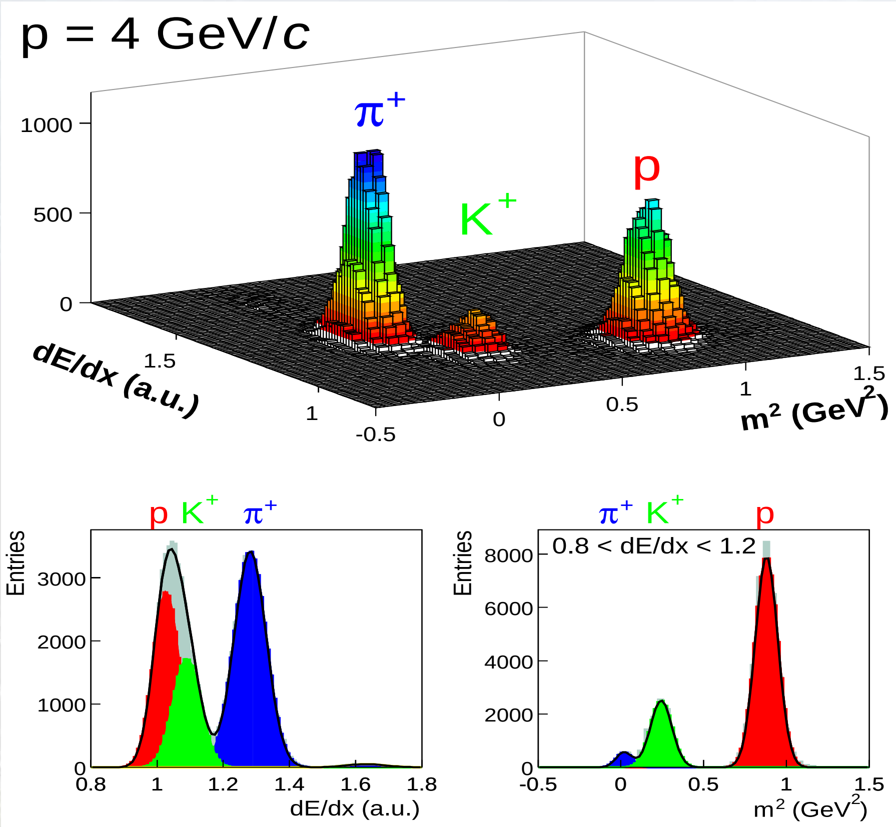


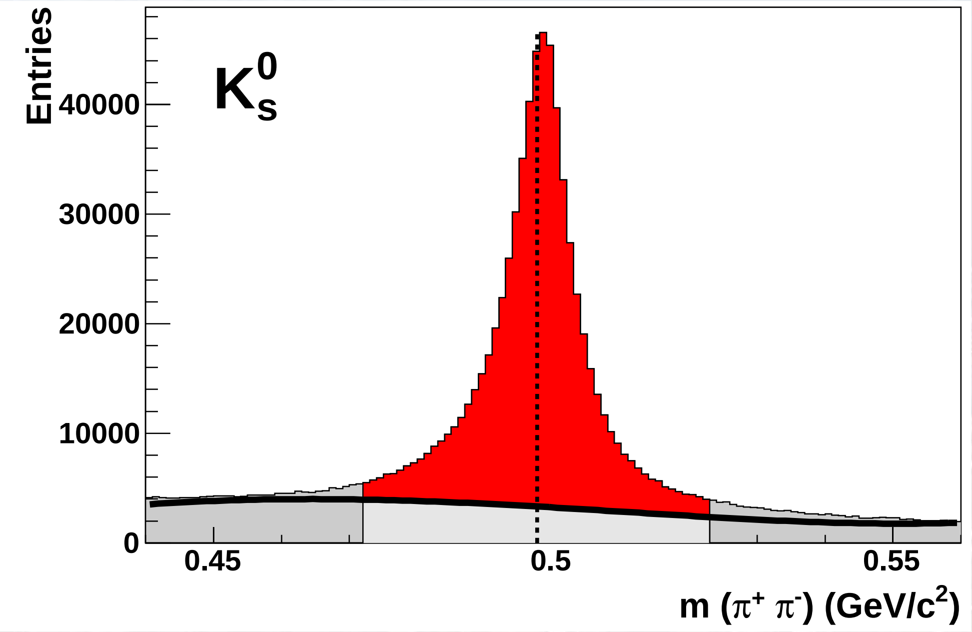


158*A* GeV
Si+Si

- Large detector acceptance for charged hadrons
- Energy range: 20-158*A* GeV
- Different collision systems: p+p, C+C, Si+Si, Pb+Pb, ...
- Centrality selection with veto calorimeter

Particle ID





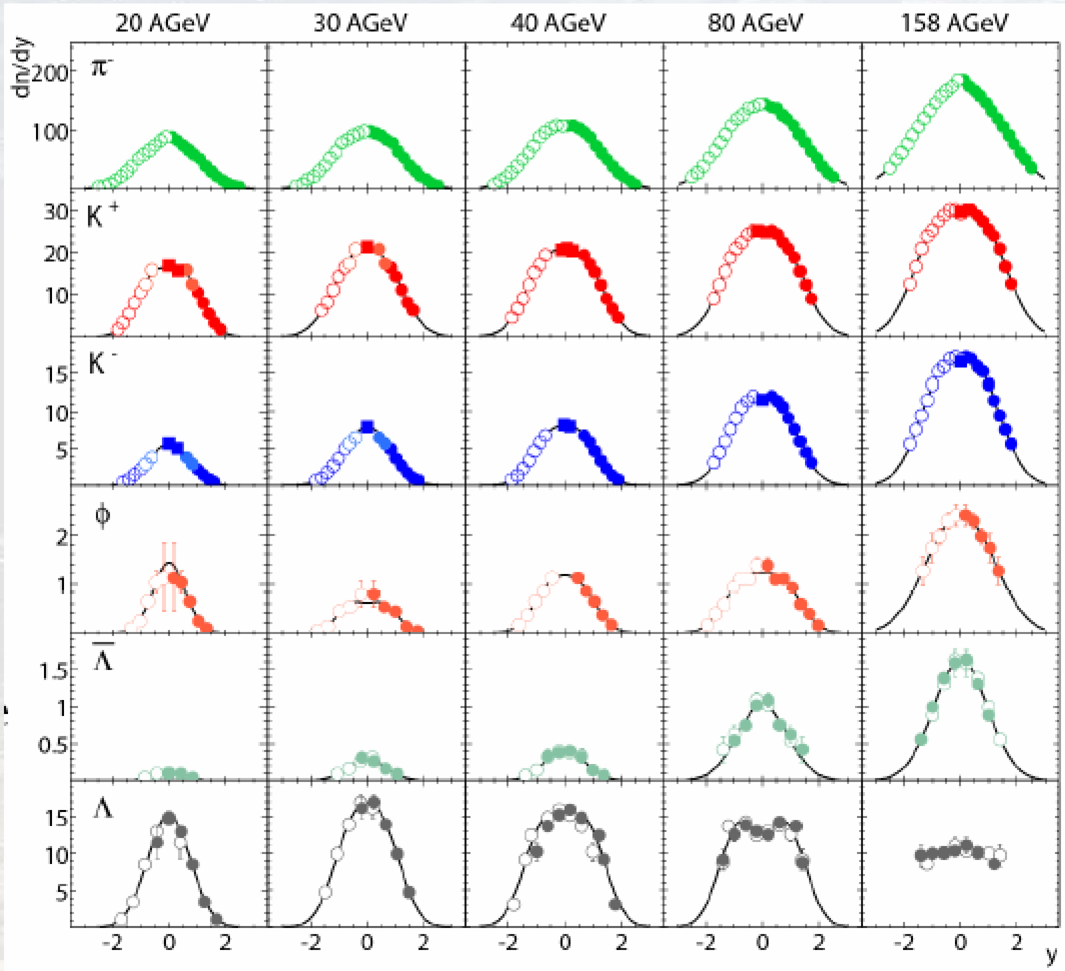
- dE/dx in TPCs and TOF (mid-rapidity) for $\pi^{\pm}$, $K^{\pm}$, p,d
- decay topology, invariant mass for K^0_S,Λ,Ξ,Ω,ϕ,...

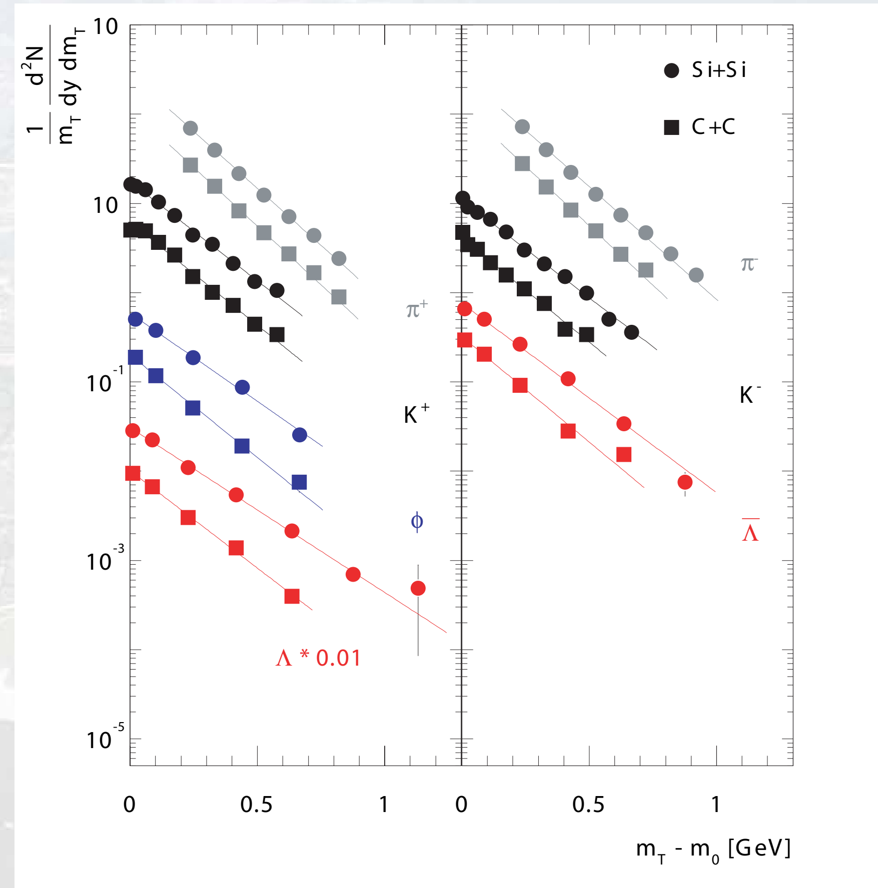
NA49 data examples

central Pb+Pb

C+C, Si+Si at 158*A* GeV

open symbols: reflected at midrapidity

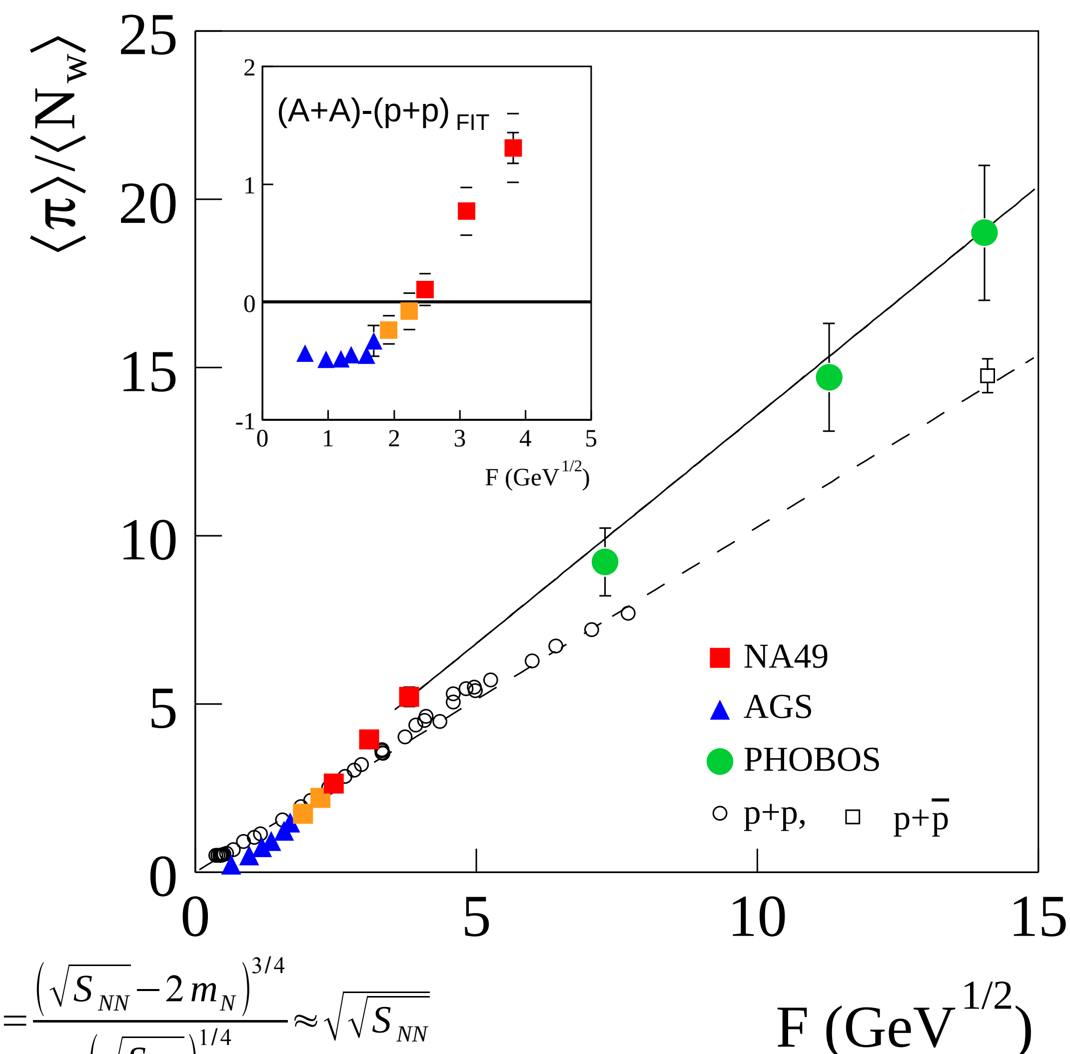




- Measuring of 4π yields

Compilation of NA49 data on hadron production:
http://na49info.cern.ch/na49/Archives/Data/NA49NumericalResults/na49_compil.pdf

Pions: energy dependence



$$F = \frac{\left(\sqrt{S_{NN}} - 2m_N\right)^{3/4}}{\left(\sqrt{S_{NN}}\right)^{1/4}} \approx \sqrt{\sqrt{S_{NN}}}$$

p+p and central Pb+Pb (Au+Au) collisions

p+p:

- π/N_W rises linearly with F

Pb+Pb:

- low energies: π/N_W smaller than in p+p
- high energies: π/N_W larger

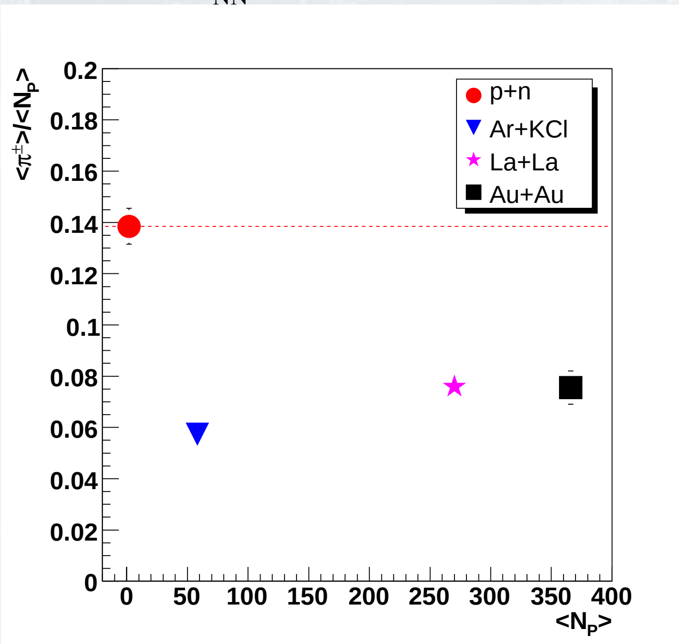
Possible explanation:

- Pion absorption in baryonic medium
- Pion enhancement in QGP (more degrees of freedom)
- Onset of deconfinement at ≈30A GeV (“Kink”) ?

Pions: system size dependence

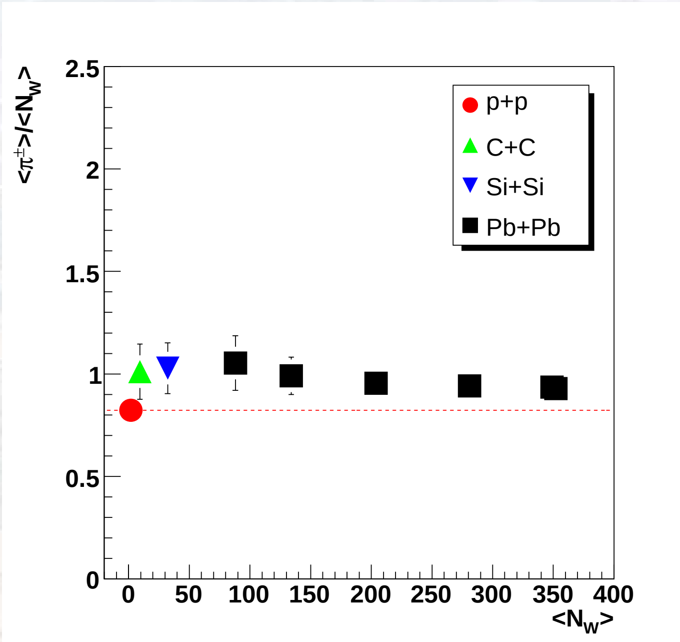
≈2A GeV

$\sqrt{s_{NN}} \approx 2.4$ GeV



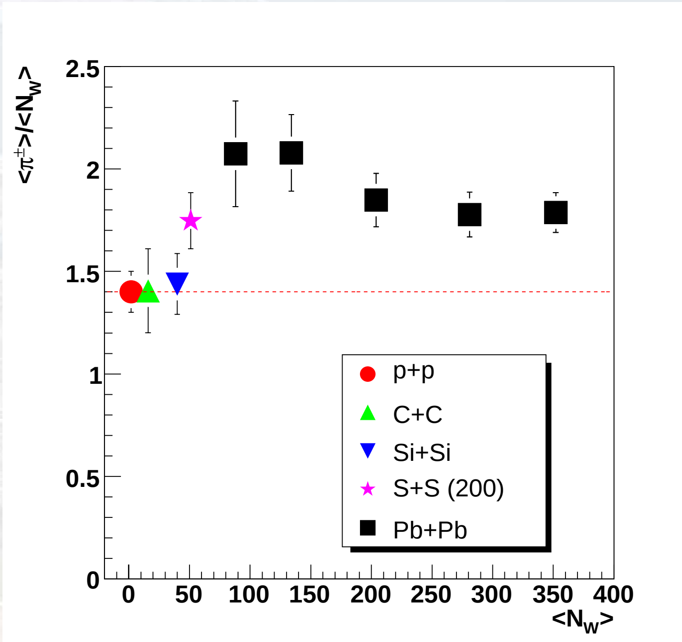
40A GeV

$\sqrt{s_{NN}} = 8.8$ GeV



158A GeV

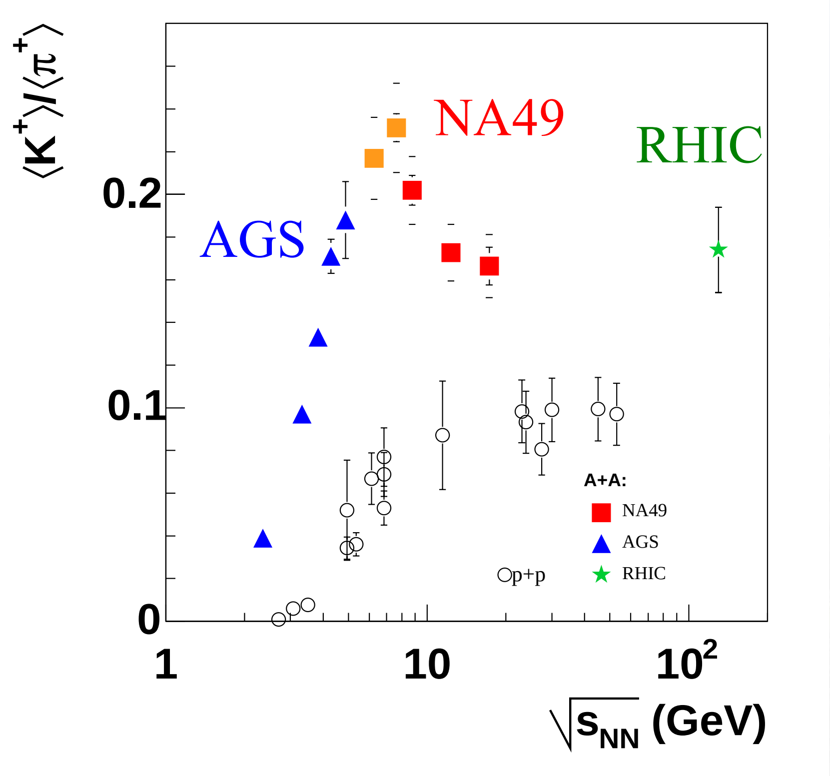
$\sqrt{s_{NN}} = 17.3$ GeV

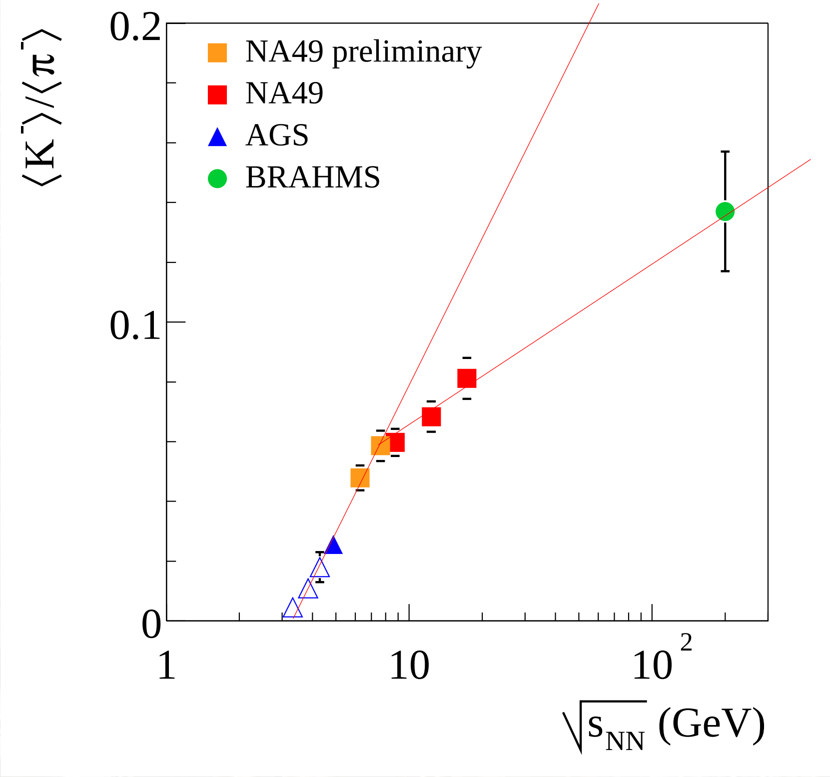


Pion yield per N_W:

- Absorption and enhancement rises quickly with system size

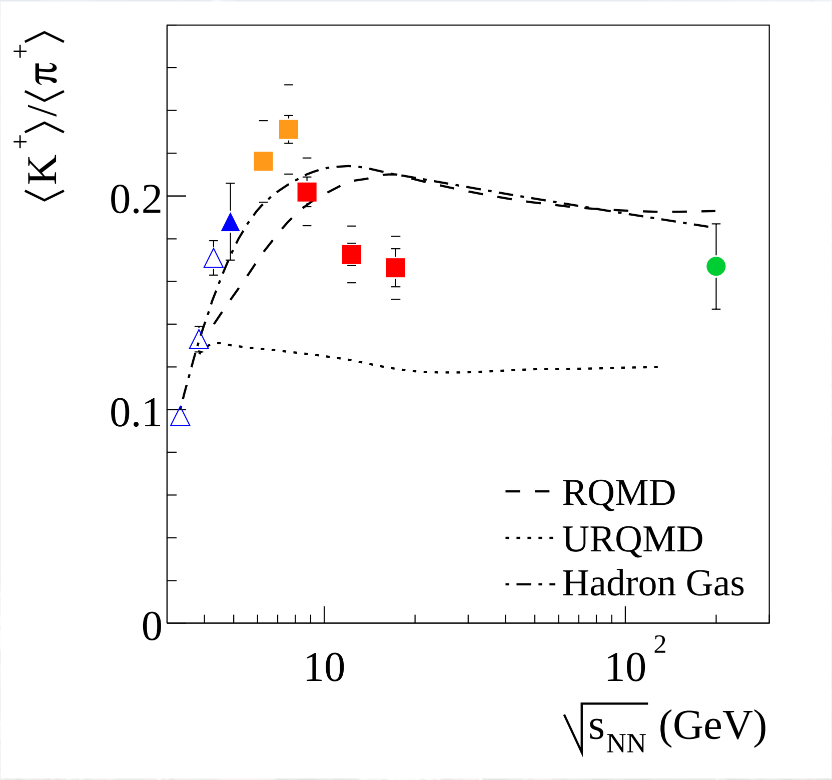
Kaons: energy dependence

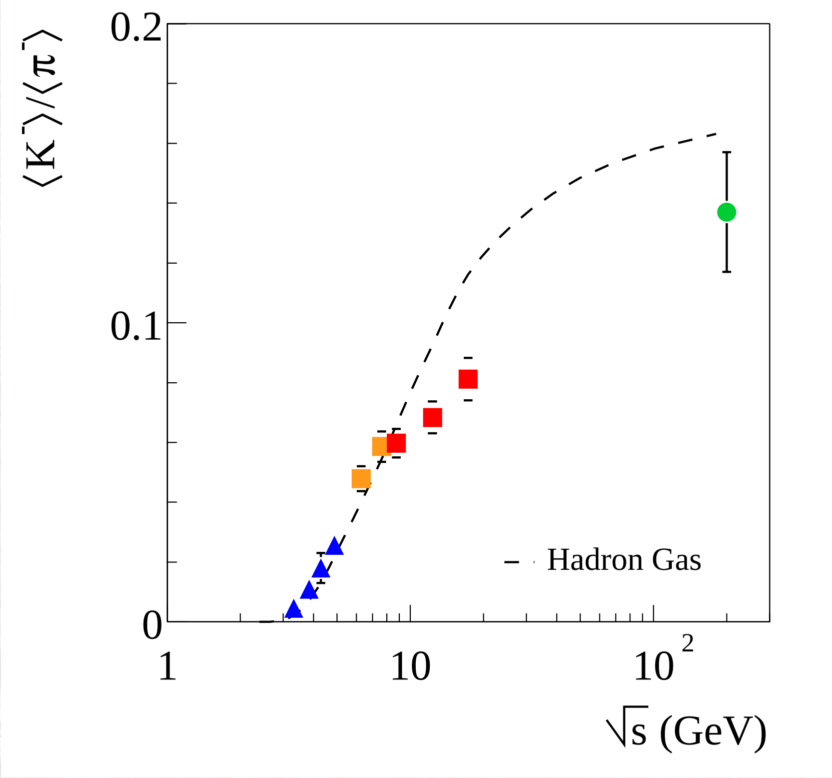




- K^+/π^+: maximum at 30A GeV (“Horn”)
- K^-/π^-: rises for lower energies faster than for higher energies

Kaons: energy dependence

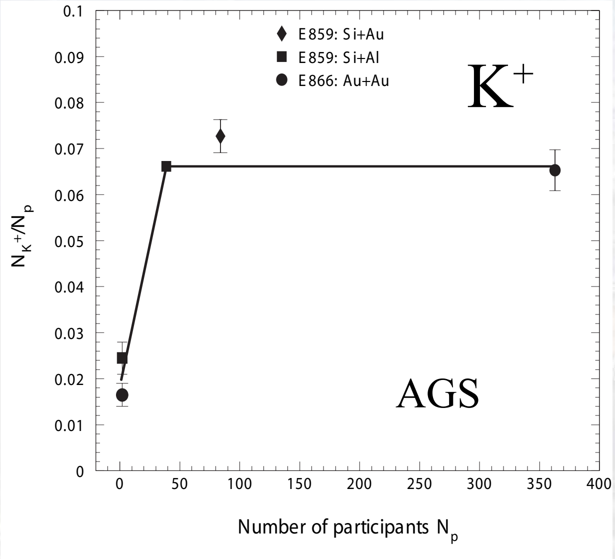




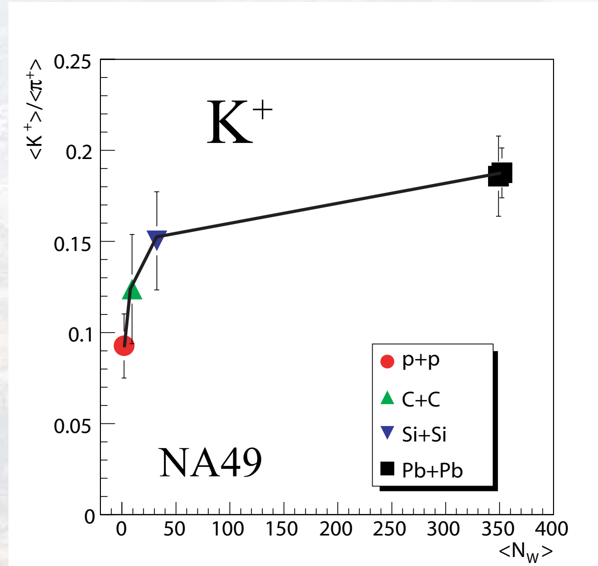
- K^+/π^+: maximum at 30A GeV ("Horn")
- K^-/π^-: rises for lower energies faster than for higher energies
- Shown hadronic models fail to describe data

Kaons: system size dependence

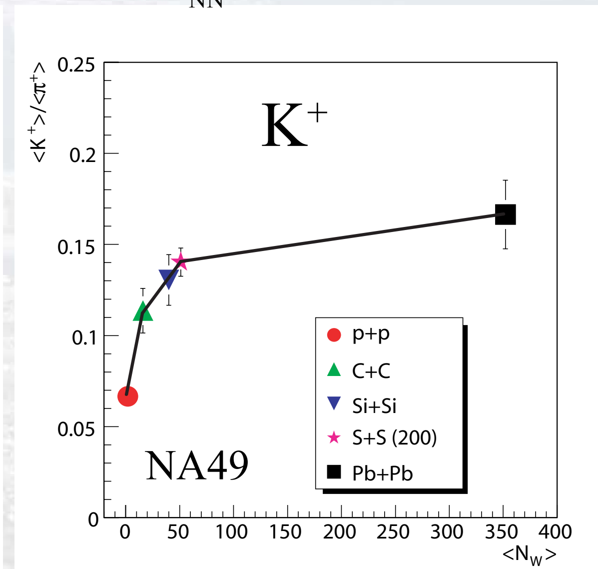
≈5A GeV
$\sqrt{s_{NN}}$≈3.4 GeV



40A GeV
$\sqrt{s_{NN}}$=8.8 GeV



158A GeV
$\sqrt{s_{NN}}$=17.3 GeV

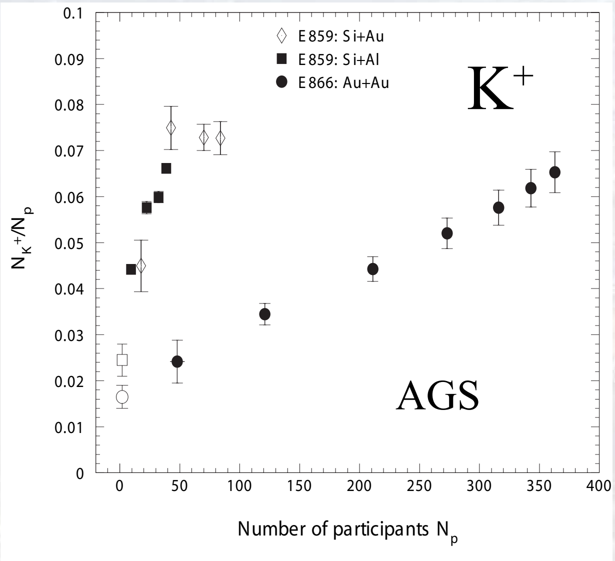


F. Wang, J.Phys.G27:283-300,2001

- Fast increase followed by a saturation for central collisions
  - Canonical suppression in small systems ?

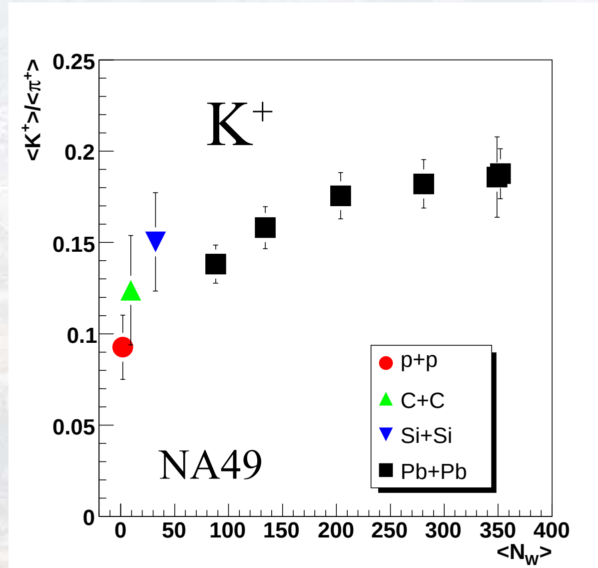
Kaons: system size dependence

≈5A GeV
$\sqrt{s_{NN}}$≈3.4 GeV

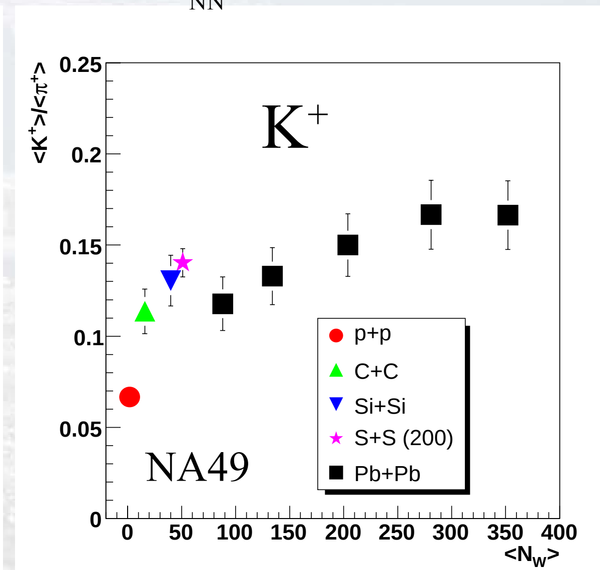


F. Wang, J.Phys.G27:283-300,2001

40A GeV
$\sqrt{s_{NN}}$=8.8 GeV



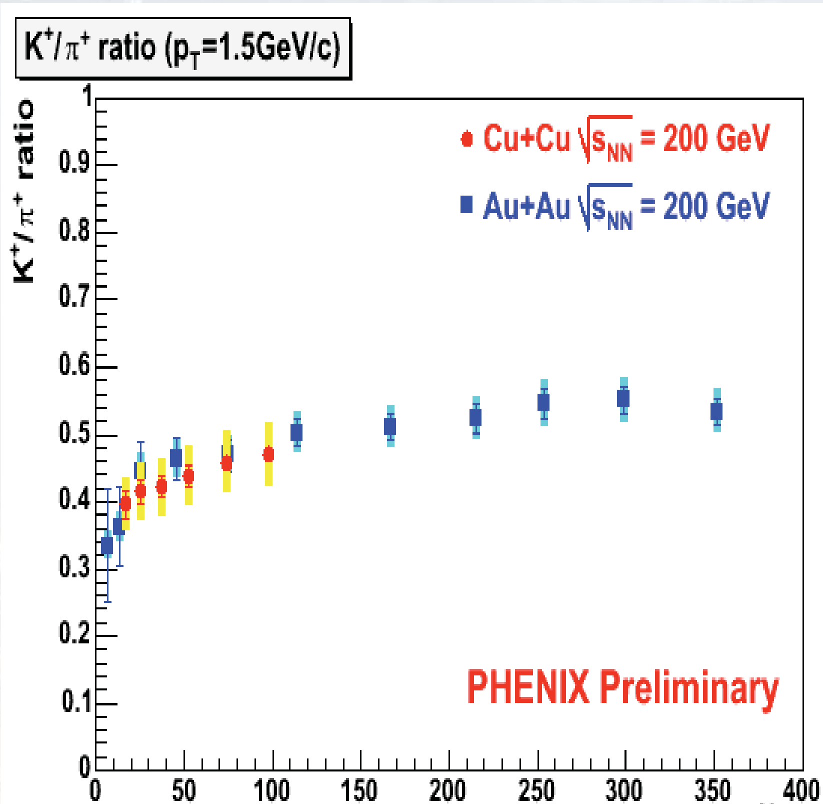
158A GeV
$\sqrt{s_{NN}}$=17.3 GeV



- Fast increase followed by a saturation for central collisions
  - Canonical suppression in small systems ?
- Increase with centrality, no saturation at AGS for centrality selected Au+Au collisions
- Similar behaviour of K^- (not shown here)

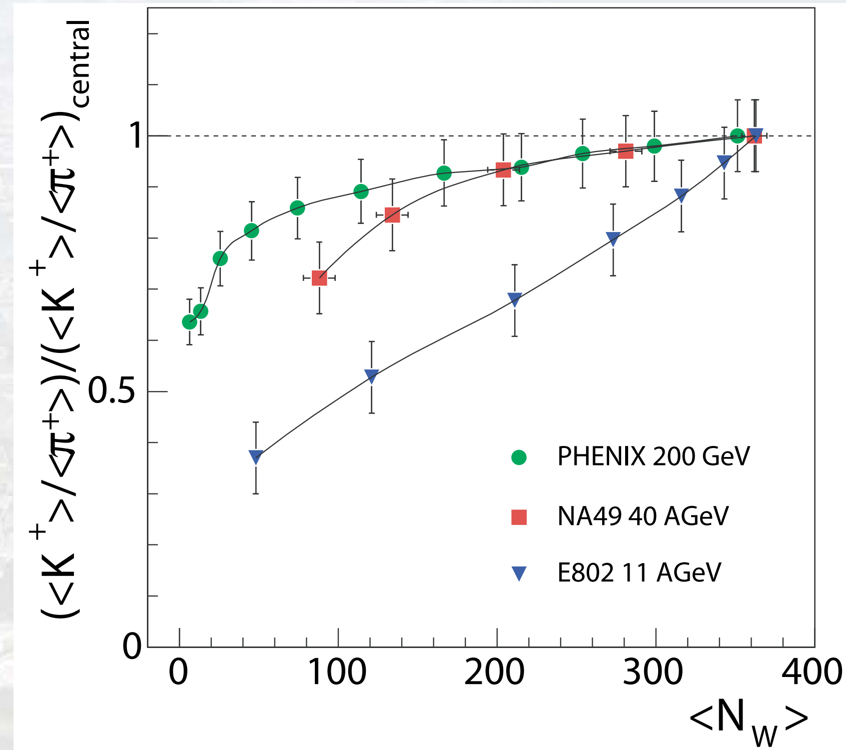
Kaons: system size dependence (2)

$\sqrt{s_{NN}}$=200 GeV



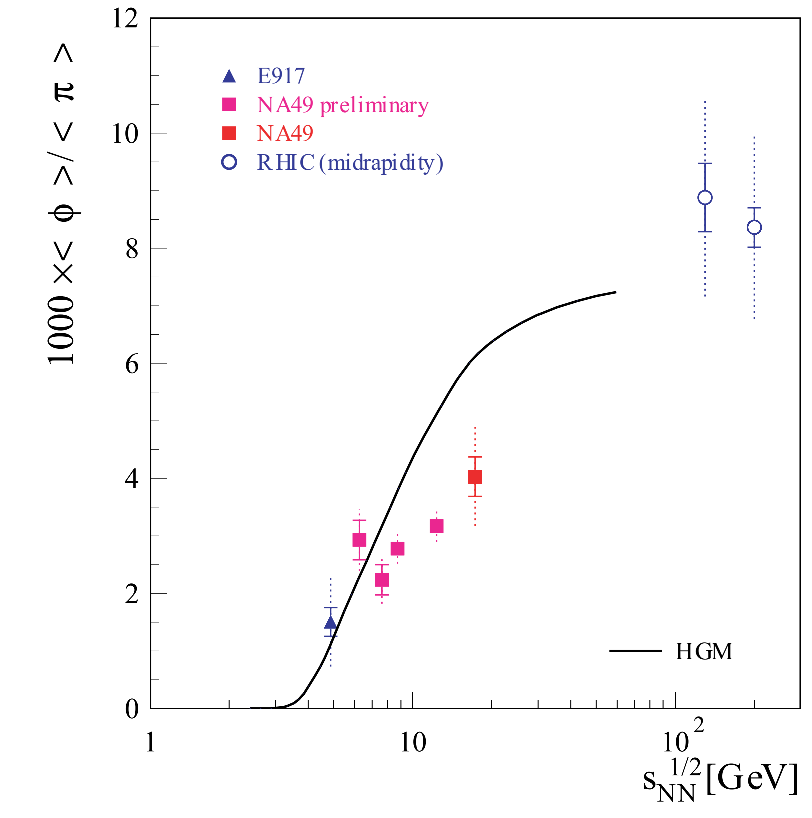
M. Konno, QM2005

Pb+Pb (Au+Au):



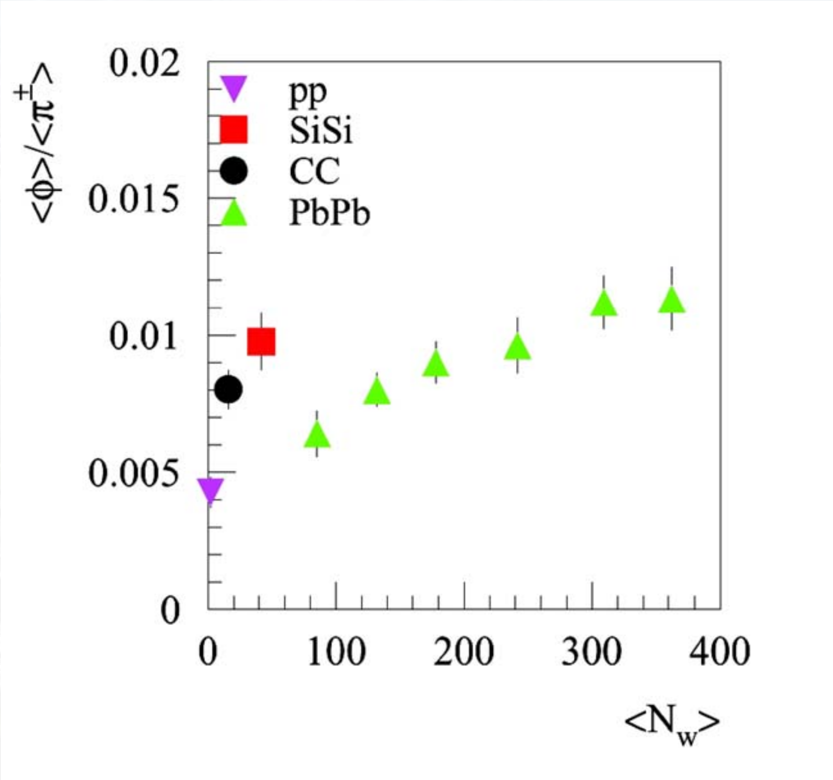
- RHIC: Cu+Cu = Au+Au at same N_P
- Earlier saturation with centrality for higher energies

ϕ- mesons



158A GeV

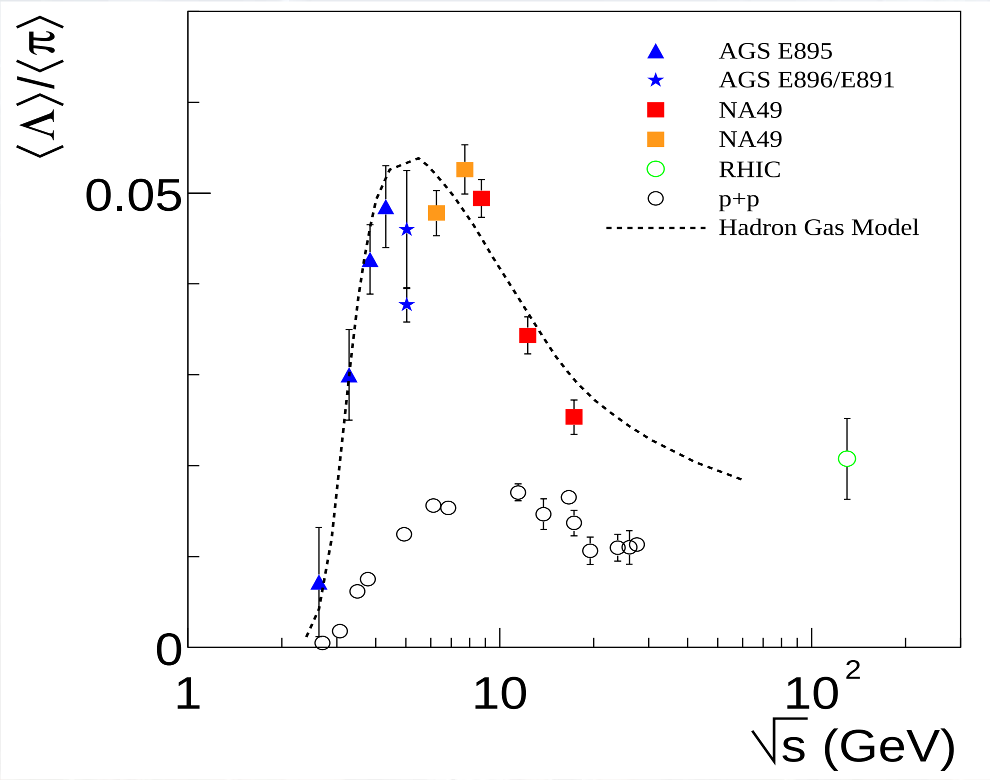
$\sqrt{s_{NN}}$=17.3 GeV



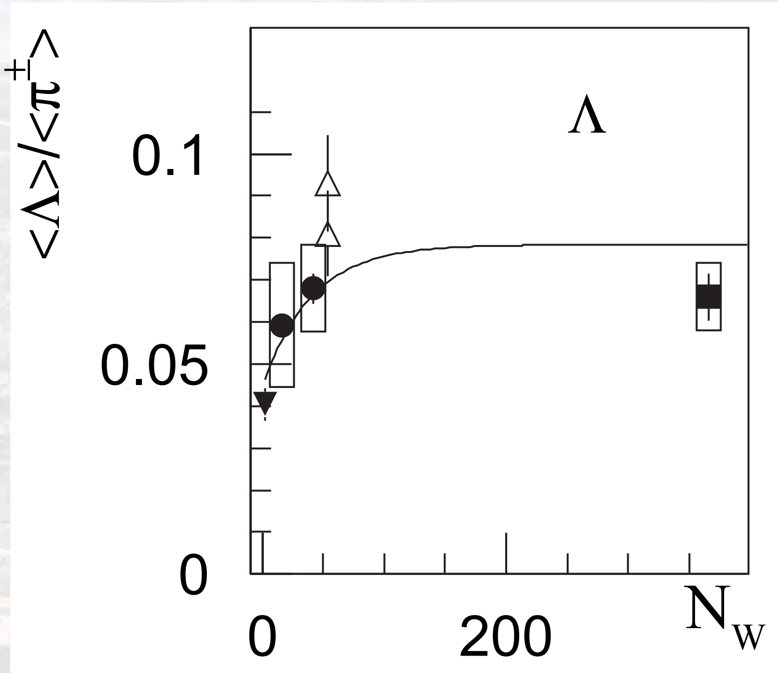
- Structure in energy dependence of ϕ/π ?

- Fast increase with N_W in central collisions
- Difference between central and peripheral collisions with same N_W

Λ- hyperons

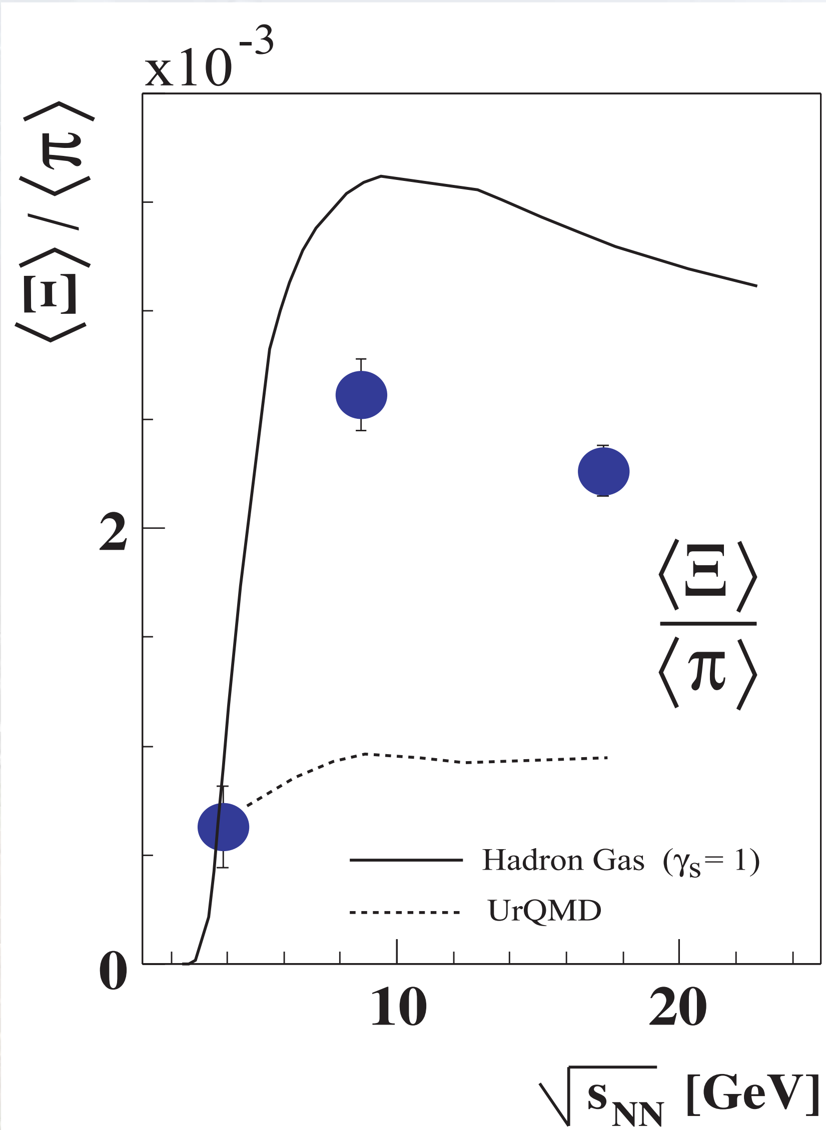


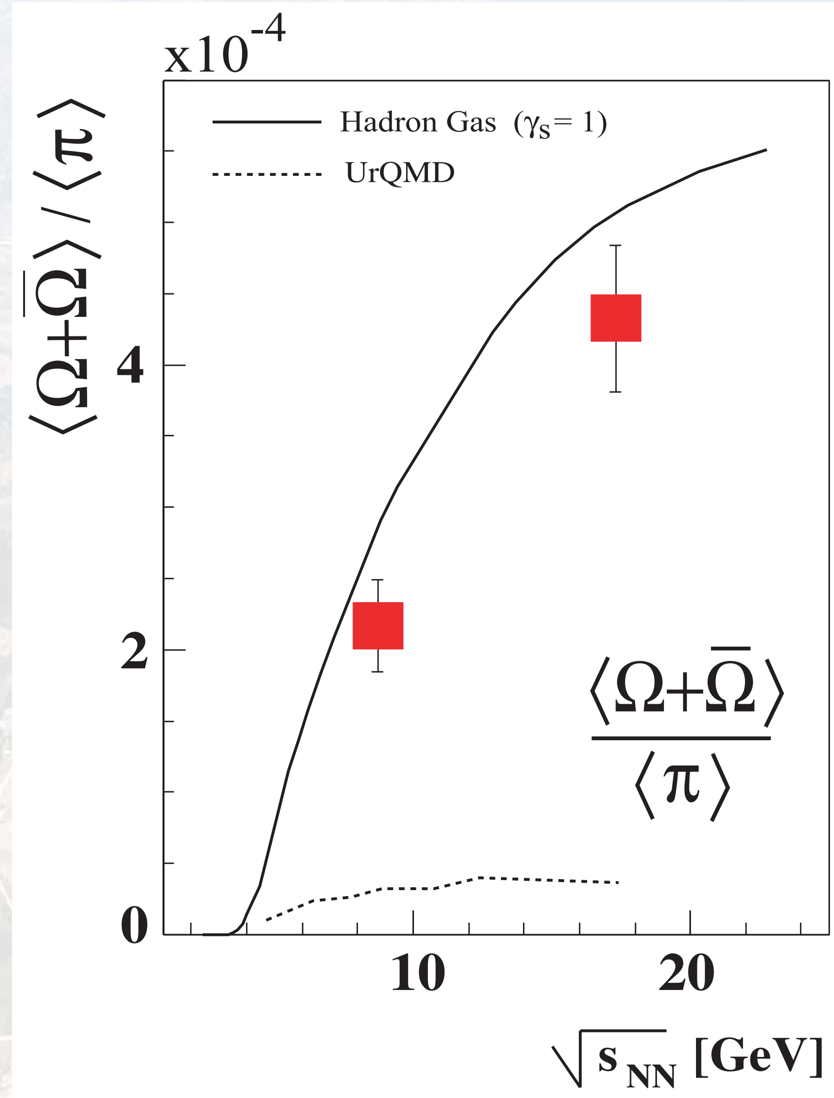
158A GeV
$\sqrt{s_{NN}}$=17.3 GeV



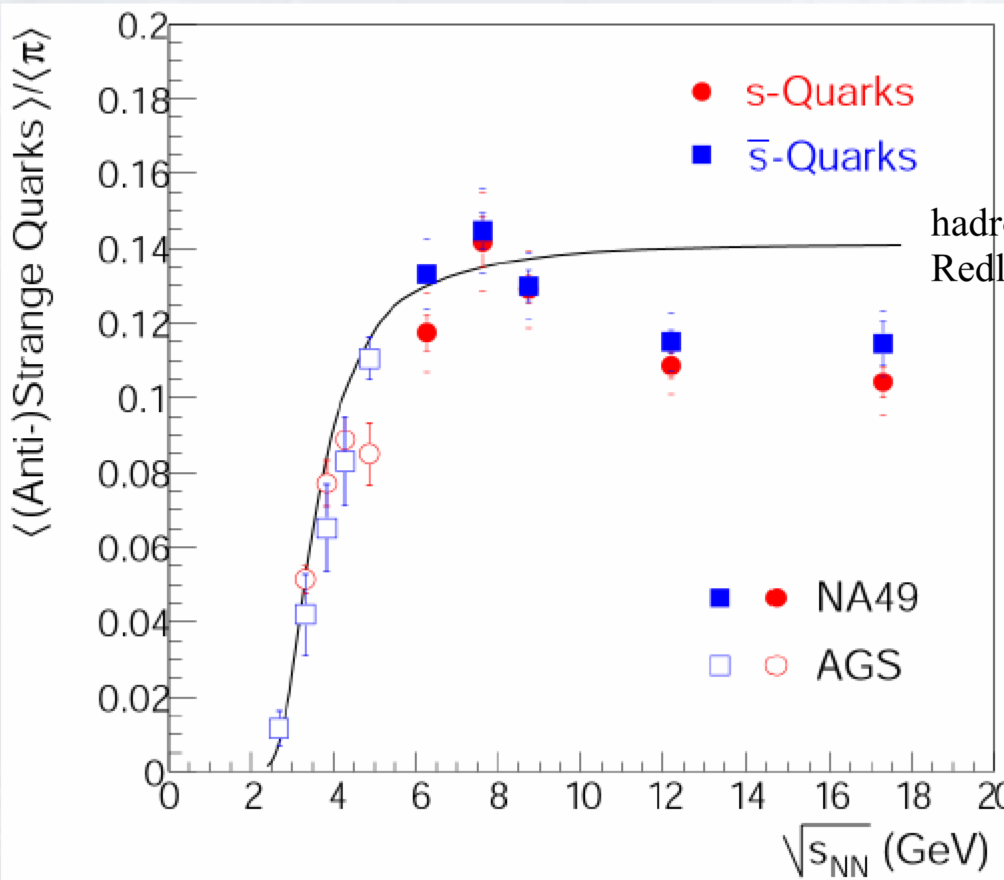
- Maximum of Λ/π at low SPS energies in A+A collisions
  - in agreement with Hadron Gas Model (Redlich et al.)
- System size dependence:
  fast increase from p+p to Si+Si, then saturation

Ξ and Ω- hyperons





Strangeness carriers



hadron gas model,
Redlich et al.

- strangeness carriers:
  - K^-, $\bar{K}^0$
  - Λ (incl. Σ^0)
  - Ξ, Ω
  - $\Sigma^\pm$
- anti-strangeness carriers:
  - K^+, K^0
  - $\bar{\Lambda}$ (incl. $\bar{\Sigma}^0$)
  - $\bar{\Xi}$, $\bar{\Omega}$
  - $\Sigma^\pm$

black: measured (at least partially)

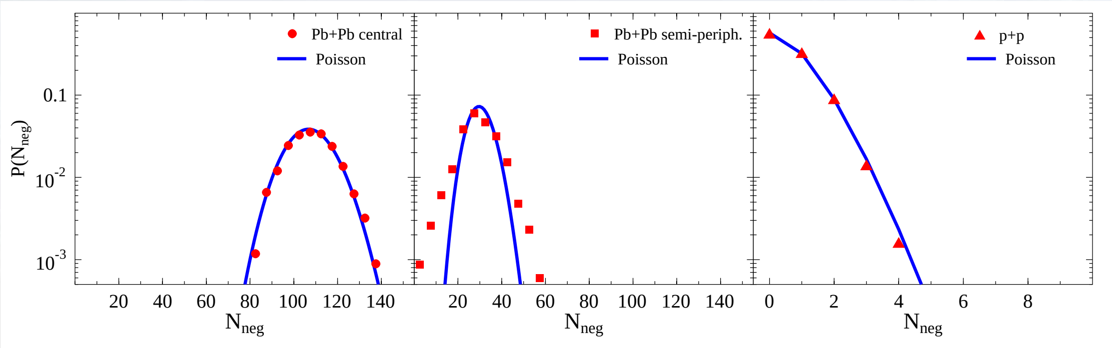
red: estimated by symmetries or empirical factors

- Data not described by hadronic models
- Consistent with phase transition

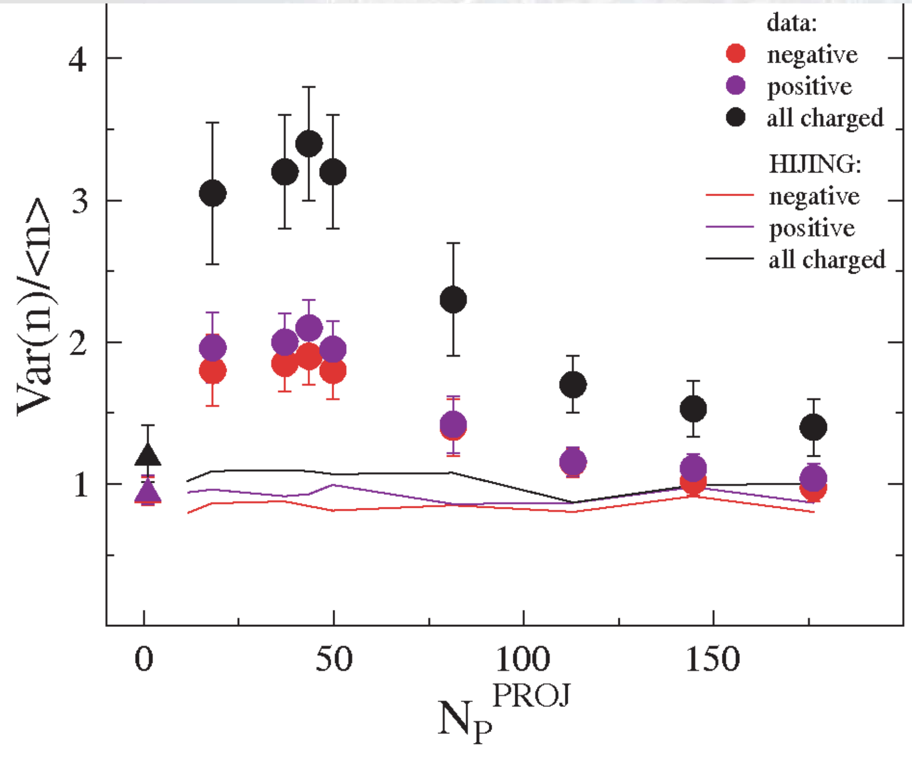
M. Gazdzicki, M. Gorenstein, Acta Phys.Polon.B30:2705,1999

- Strangeness conserved
- “Horn” also seen in s/π and $\bar{s}/\pi$

Multiplicity fluctuations

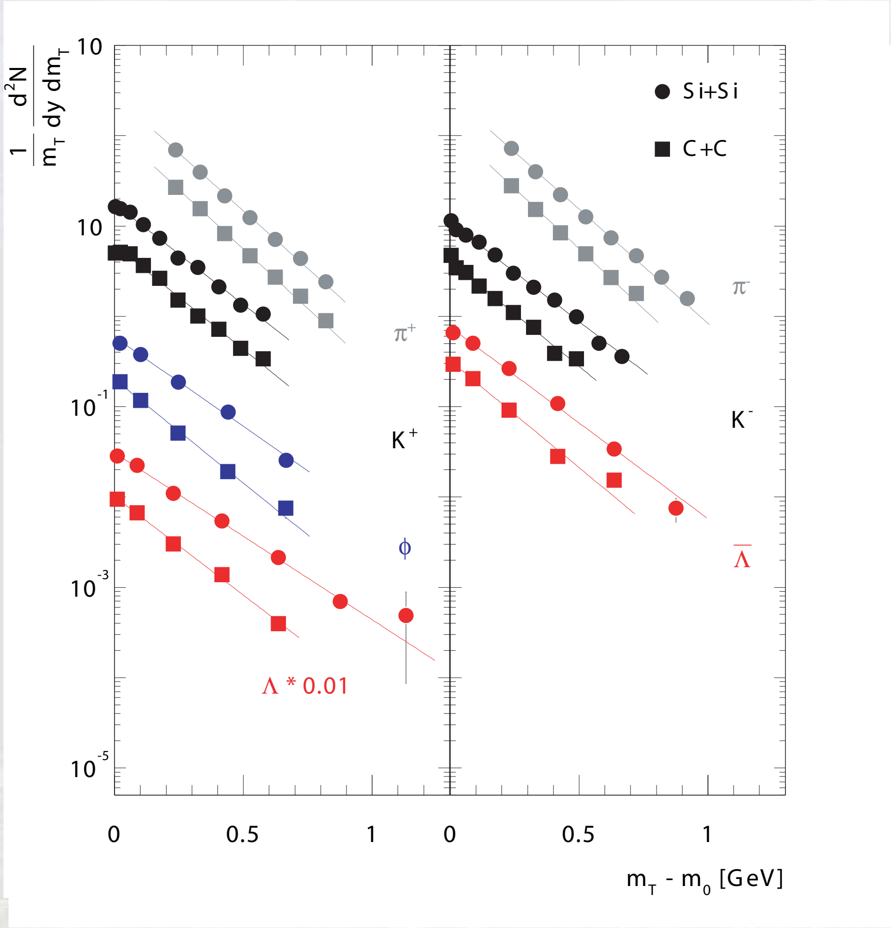


158A GeV, $\sqrt{s_{NN}}$=17.3 GeV



- Increase from central to peripheral collisions (also observed in other systems)
- $Var(h^+)/<h^+> \approx Var(h^-)/<h^->$ $< Var(h^\pm)/<h^\pm>$
- To come:
  - C+C and Si+Si
  - Energy dependence

Transverse mass spectra



$$m_T=\sqrt{p_T^2+m^2}$$

Commonly used measures:

- Inverse slope parameter T

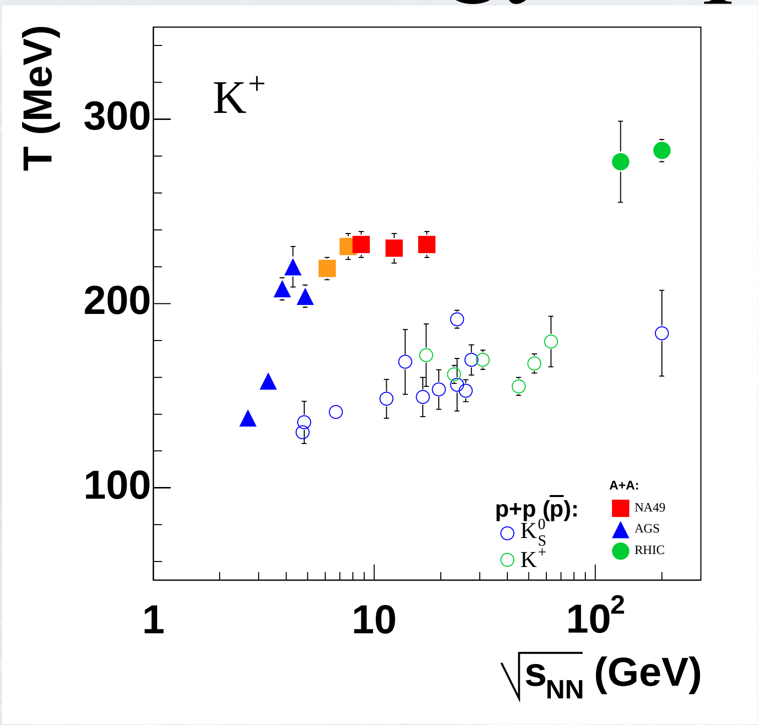
$$\frac{d^2n}{m_T\,dy\,dm_T}=C\cdot\exp\left(-\frac{m_T}{T}\right)$$

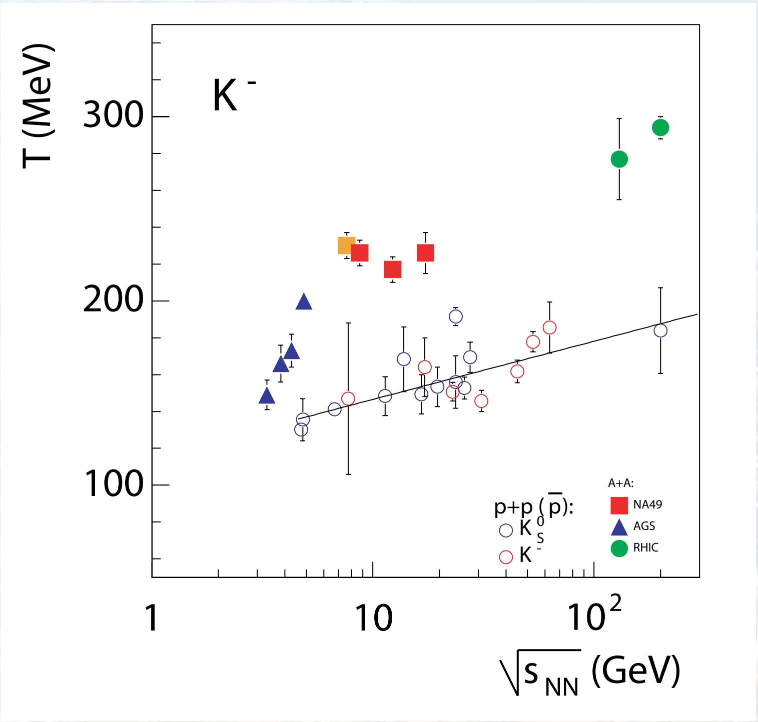
- Mean transverse mass $\langle m_T \rangle$

Determined by:

- Freeze-out- temperature
- Transverse expansion of the fireball

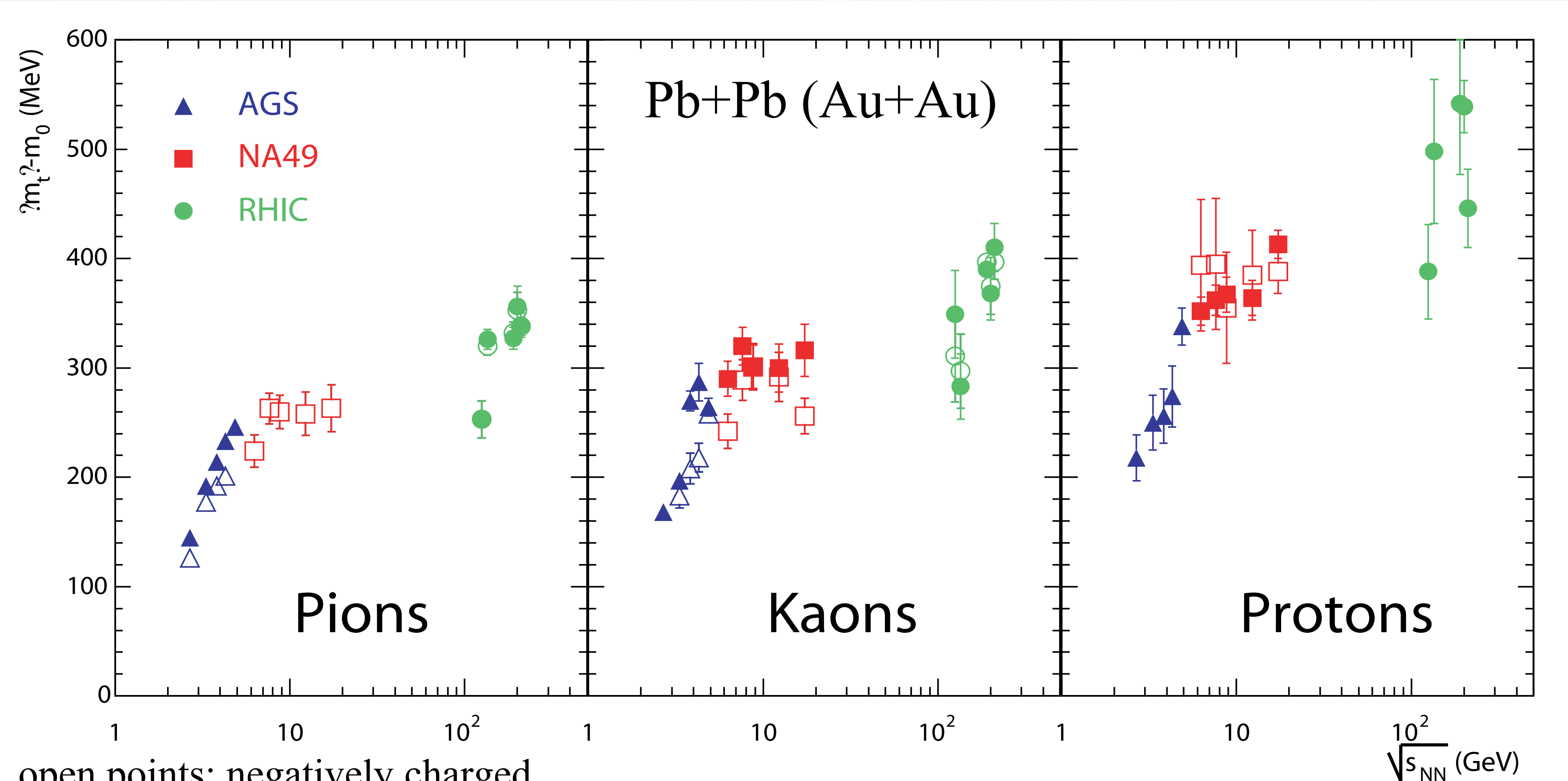
Energy dependence of T(K)





- A+A: T($K^{+/-}$) constant for SPS energies (“Step”)
  - Indication for phase transition (like heating curve of water)
  - Consistent with hydro calculation with 1st order phase transition
- p+p: Step not seen
- What about other particles ?

Energy dependence of $<m_T>$

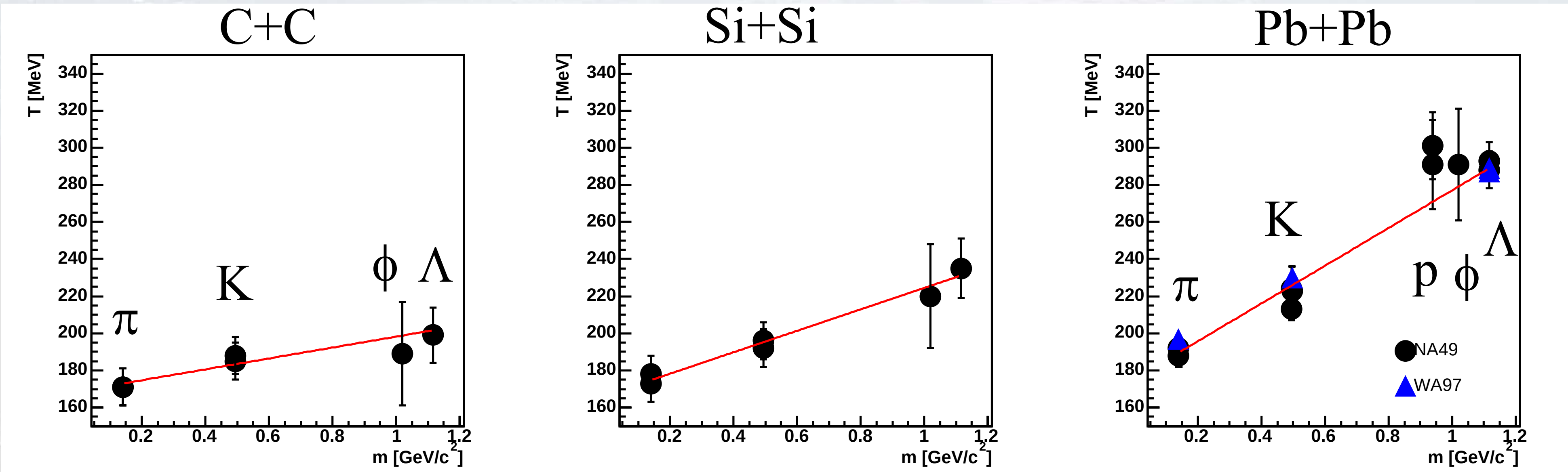


open points: negatively charged

- Kaons: $<m_T>$ similar to T
- “Step” also seen for other particles

Mass dependence of T

158A GeV, $\sqrt{s_{NN}}$=17.3 GeV



spectra fitted in intermediate m_T region

WA97: Eur.Phys.J.C14:633-641(2000)

- T increases with particle mass
  - Collective expansion more important for heavy particles
- Increase is stronger for larger systems

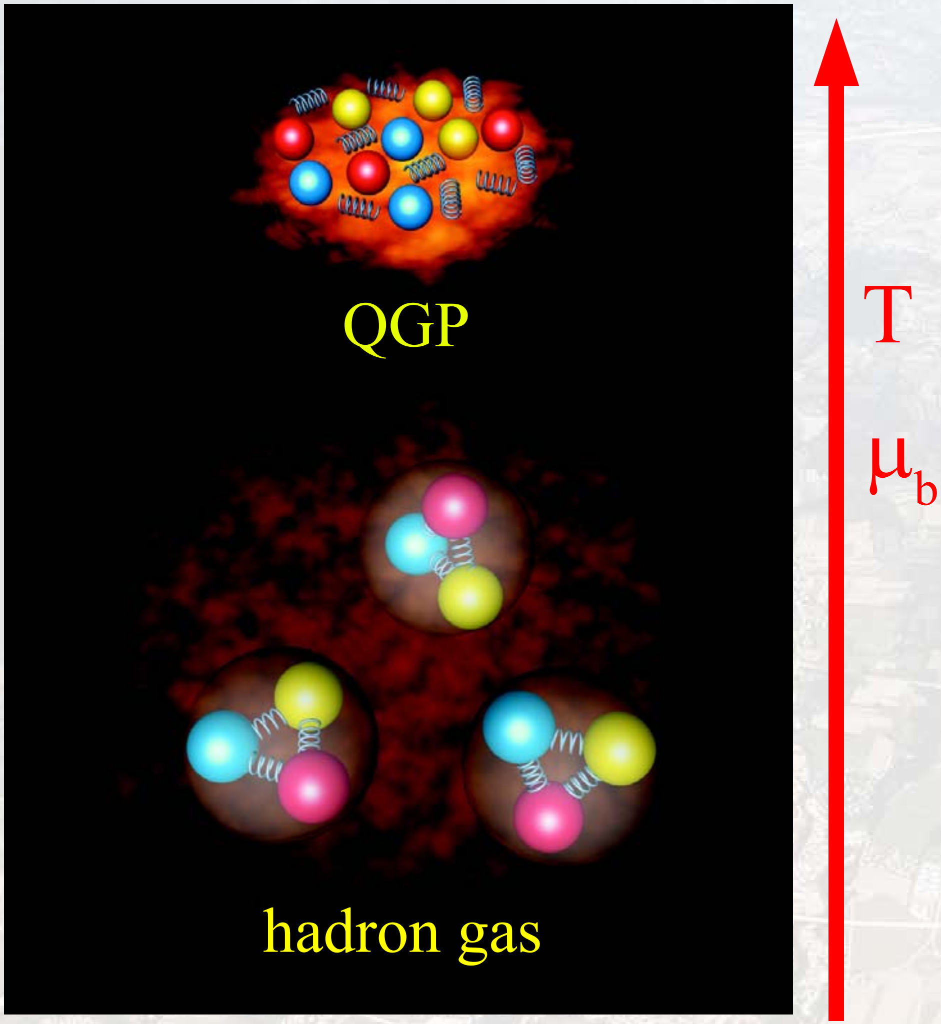
Summary

- NA49: Systematic studies of system size and energy dependence of various hadronic observables
- System size and centrality dependence:
  - Early saturation with system size for central collisions
  - No N_W scaling
- Anomalies in energy dependence of various observables in A+A collisions
  - pions: “Kink”
  - strangeness to pion ratio: “Horn”
  - inverse slope parameter and mean transverse mass: “Step”

Not described by hadronic models but consistent with onset of deconfinement at low SPS energies !

Backup

Phase transition in strongly interacting matter

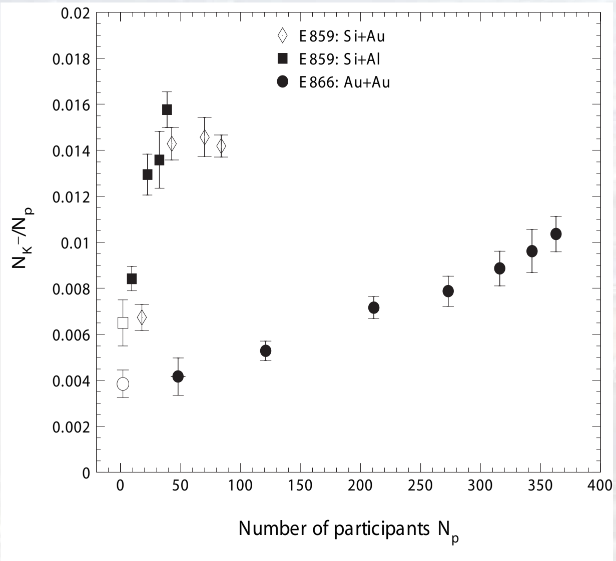


- Hadron gas:
  color neutral objects,
  confinement
- Quark-Gluon-Plasma:
  colored objects,
  deconfinement
- Heating / compression
  of hadronic medium:
  phase transition is
  expected

Kaons: system size dependence (2)

≈5A GeV

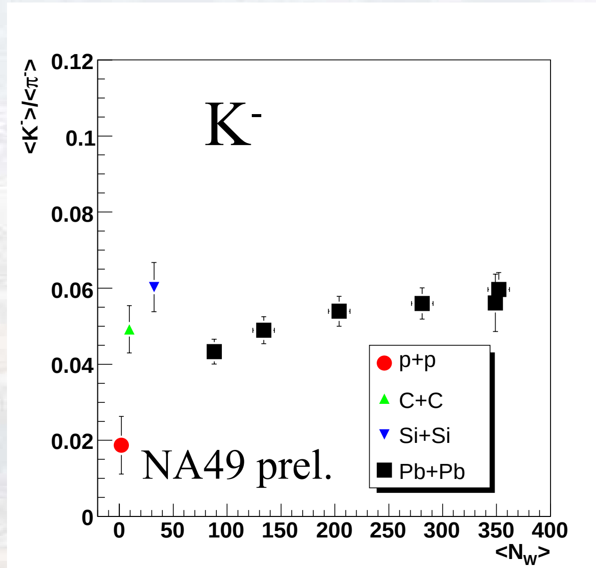
$\sqrt{s_{NN}} \approx 3.4$ GeV



AGS: F. Wang, arXiv: nucl-ex/0010002

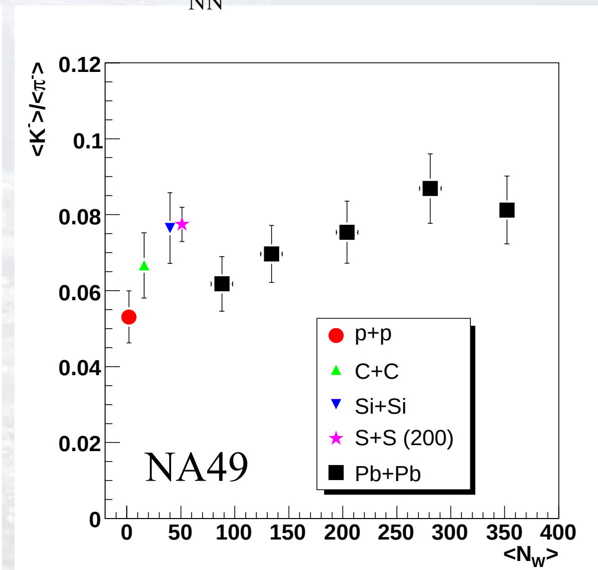
40A GeV

$\sqrt{s_{NN}}=8.8$ GeV



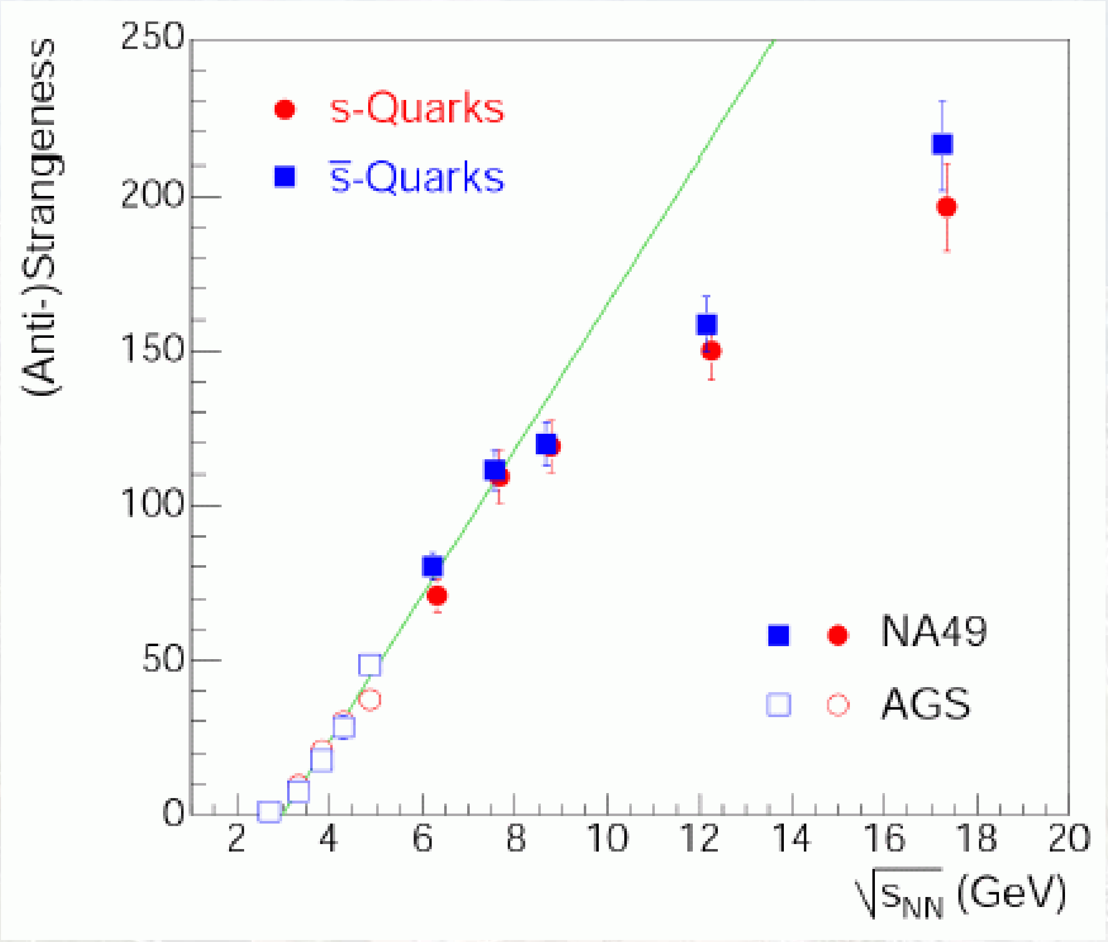
158A GeV

$\sqrt{s_{NN}}=17.3$ GeV



Strangeness carriers

- strangeness carriers:
  - K^-, $\overline{K}^0$ (a)
  - Λ (incl. Σ^0)
  - Ξ, Ω (b)
  - $\Sigma^\pm$ (c)
- anti-strangeness carriers:
  - K^+, K^0 (a)
  - $\overline{\Lambda}$ (incl. $\overline{\Sigma}^0$)
  - $\overline{\Xi}$, $\overline{\Omega}$ (b)
  - $\overline{\Sigma}^\pm$ (c)



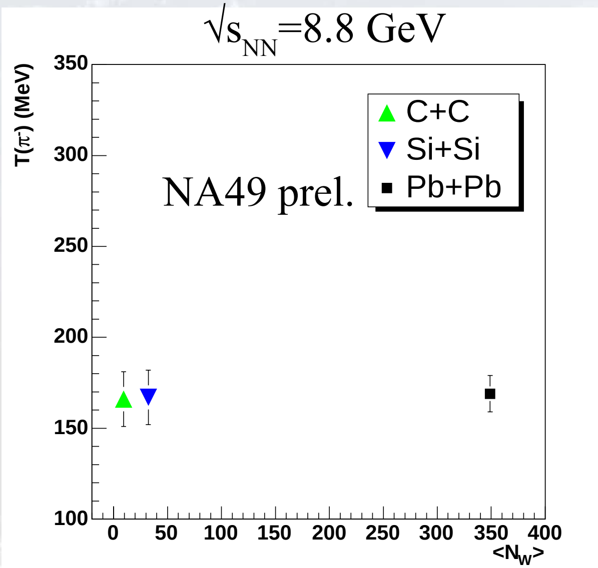
(a): obtained by isospin symmetry
(b): taken from hadron gas fit if not measured
(c): empirical factor of Σ/Λ assumed

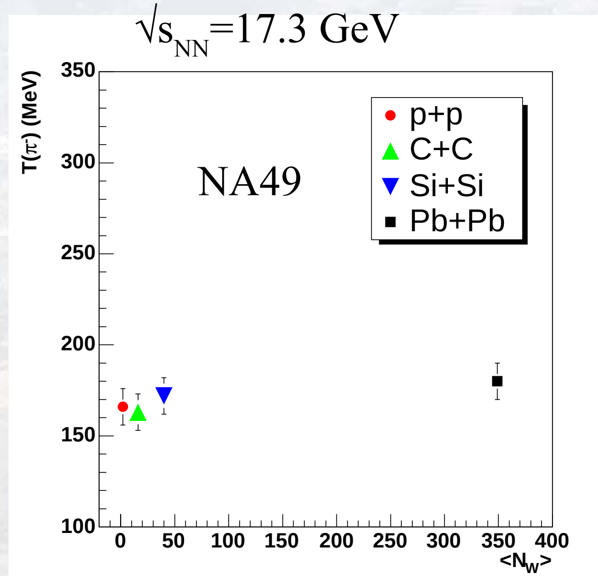
System size dependence of T

40A GeV $\sqrt{s_{NN}}=8.8$ GeV

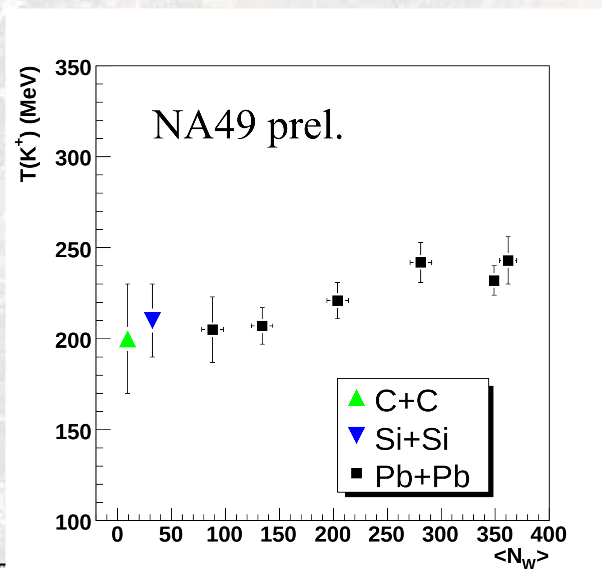
158A GeV $\sqrt{s_{NN}}=17.3$ GeV

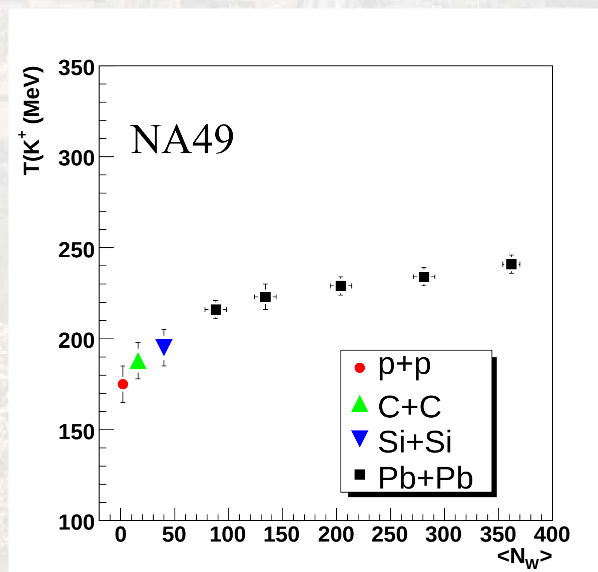
π^-





K^+



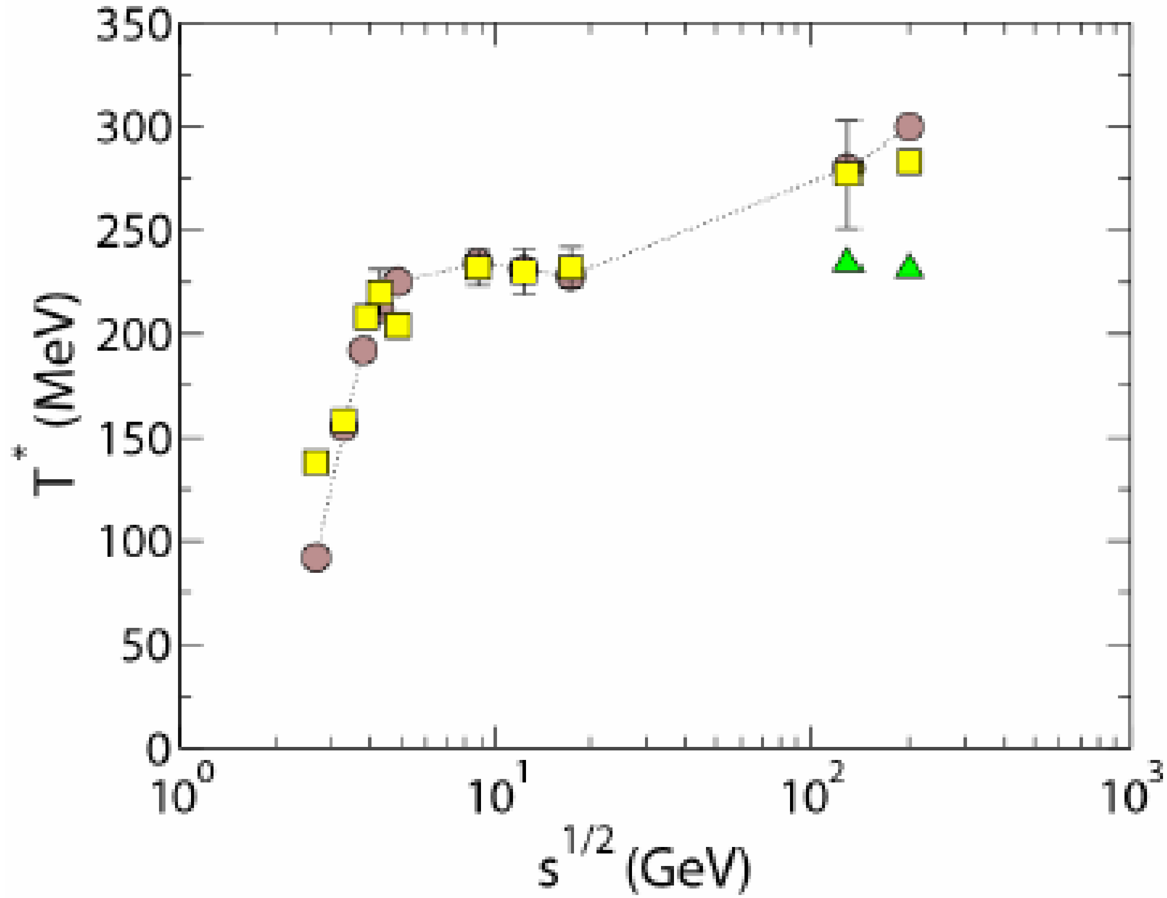


- $T(\pi)$ independent of system size
  - light particles less sensitive to collective expansion
- T(K) increases with system size
  - stronger collective expansion in heavier systems

Hydro calculation

Hydro calculation

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



Assuming 1st order phase transition

Initial conditions from NeXus

→ Change of EOS seen?