Energy dependence of transverse particle production, from SPS to RHIC

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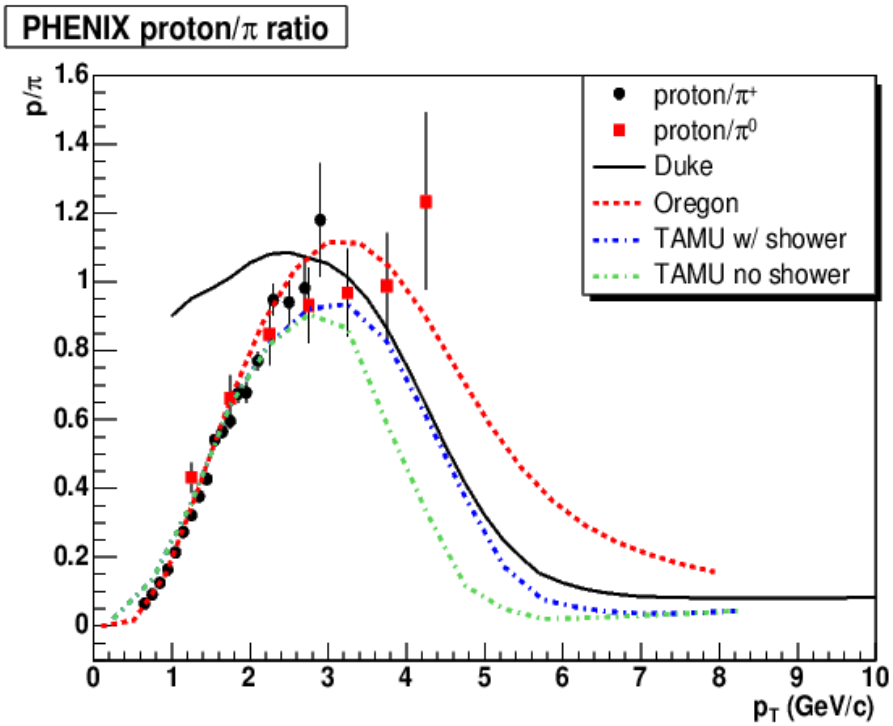
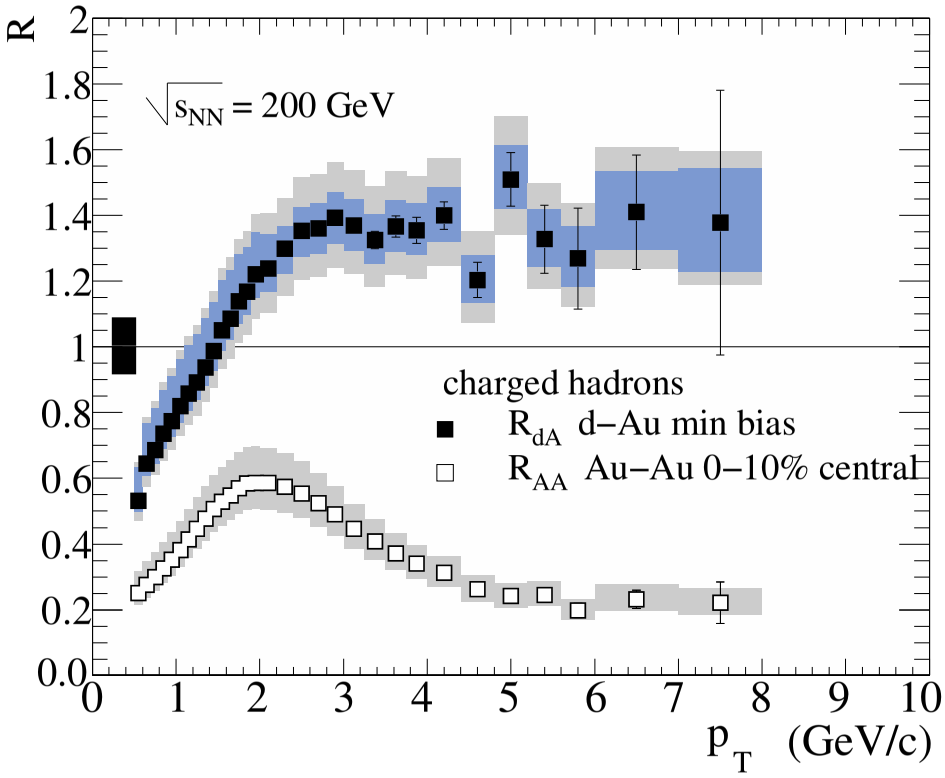
- Physics motivation: energy dependence.
- Data sets, centrality selection.
- Charged hadron analysis.
- Hadron yield ratios.
- Nuclear modification for identified charged hadrons.
- Summary.

Physics motivation: energy dependence





Baryon/meson ratio at RHIC

Increasing with p_T, may bend down

Described by coalescense

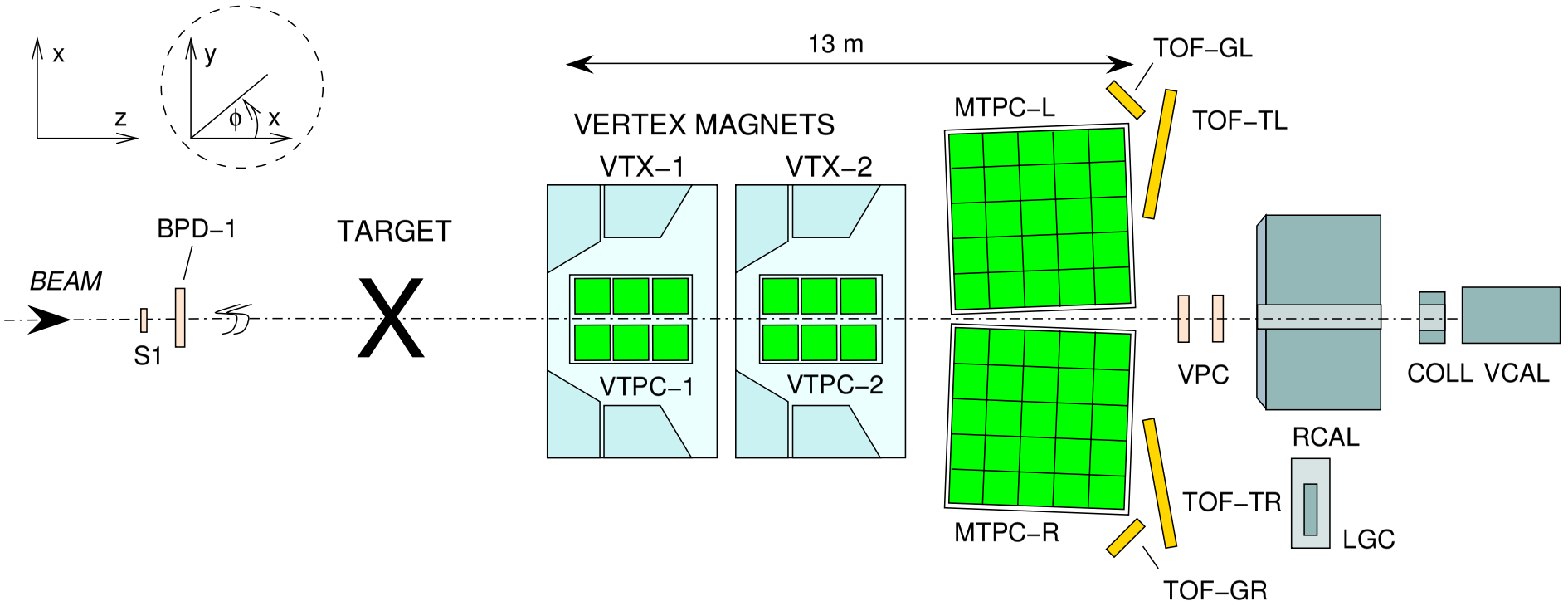
R_{AA} at RHIC

Suppression of high p_T particles

Described by jet-quenching

What is the energy dependence of these effects?

Pb+Pb at $\sqrt{s_{NN}} = 17.3\,\mathrm{GeV}$ c.m. energy, CERN-NA49 (maximal Pb+Pb SPS energy).



Data sets from 1996:

minimum-bias $(406\mathrm{k})$

10% most central $(930\mathrm{k})$

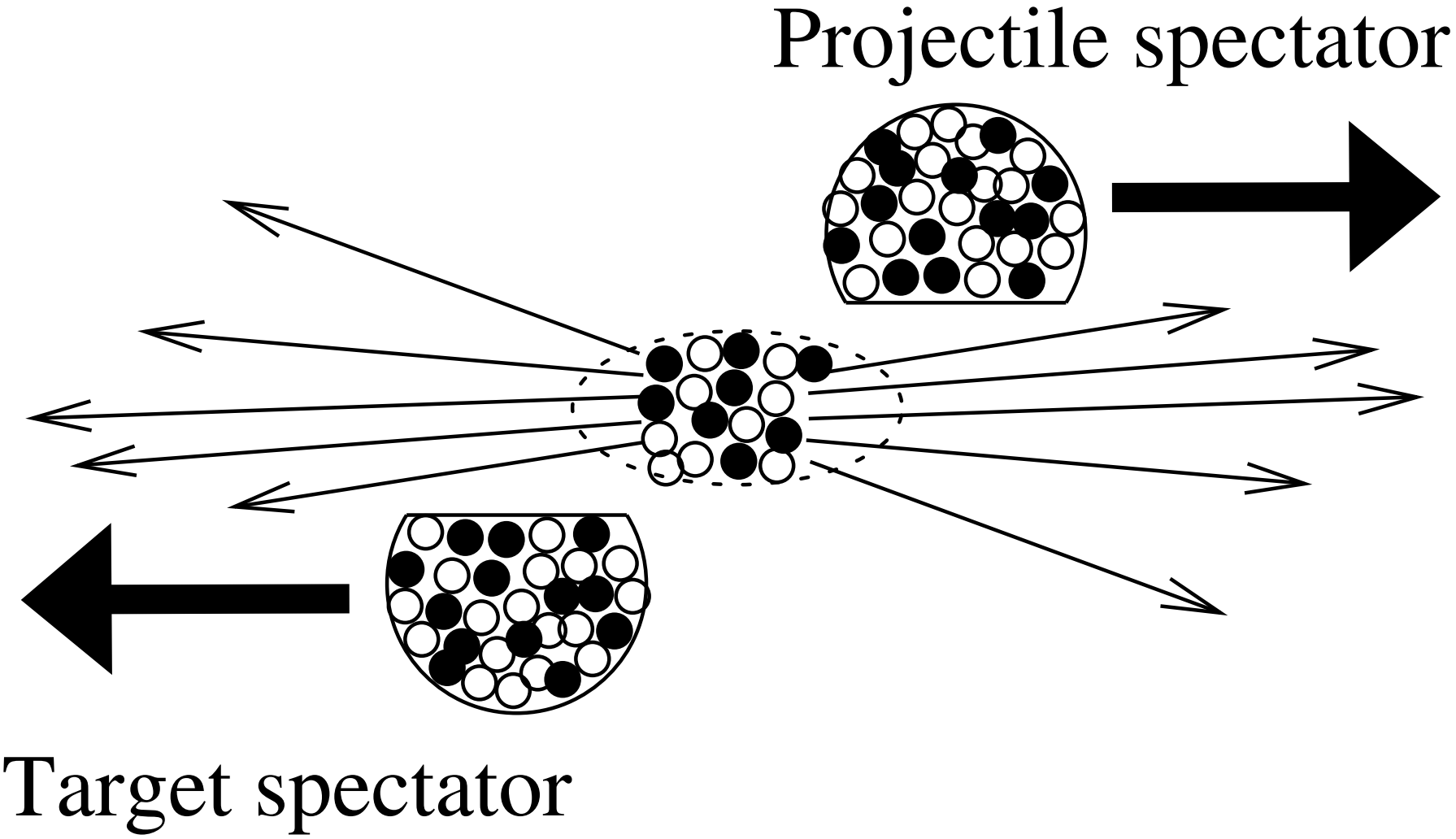
Data sets from 2000:

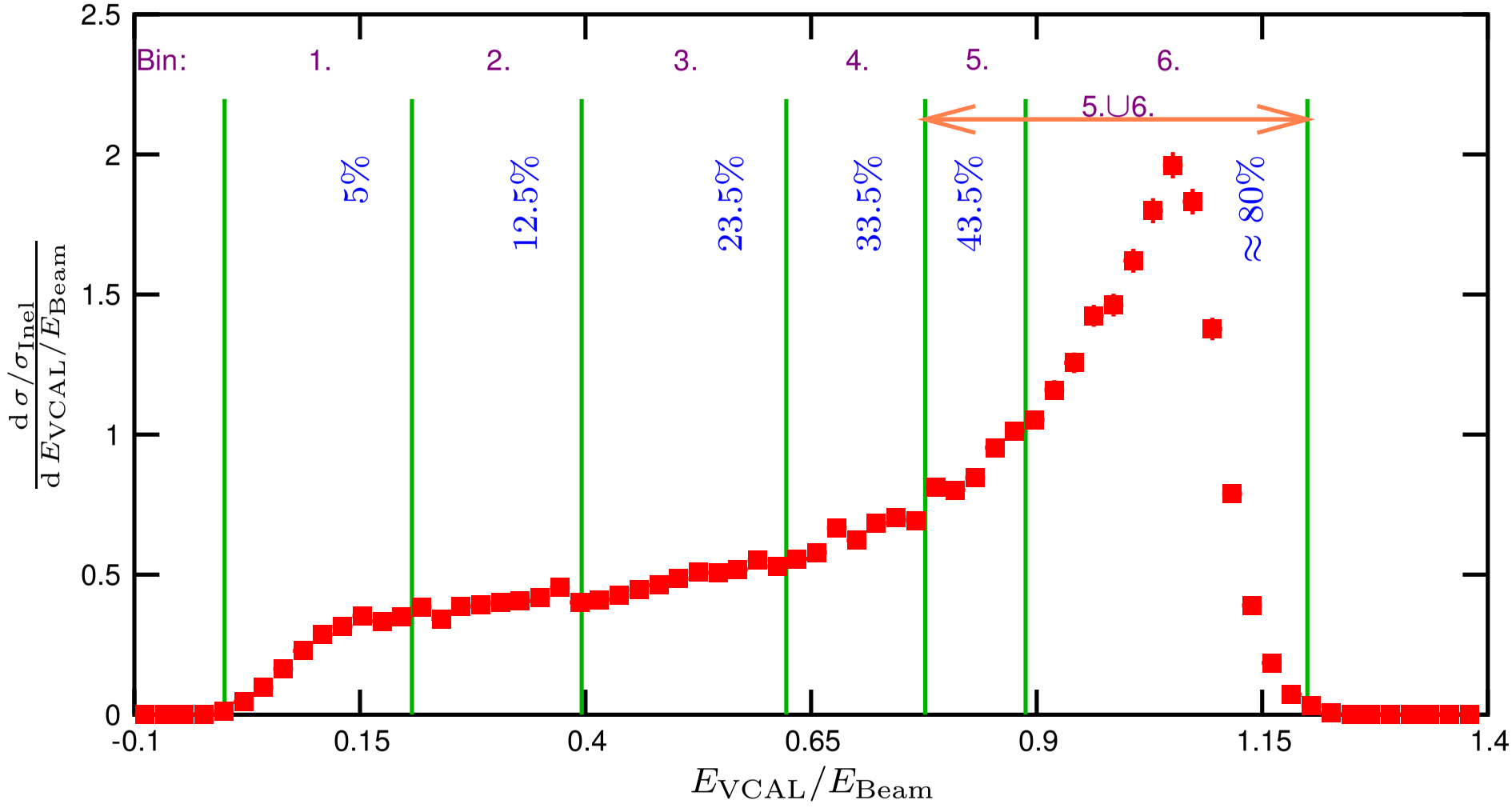
minimum-bias $(340\mathrm{k})$

24% most central $(3\mathrm{M})$

Method of centrality selection: measuring projectile spectator energy.

In center-of-mass system:





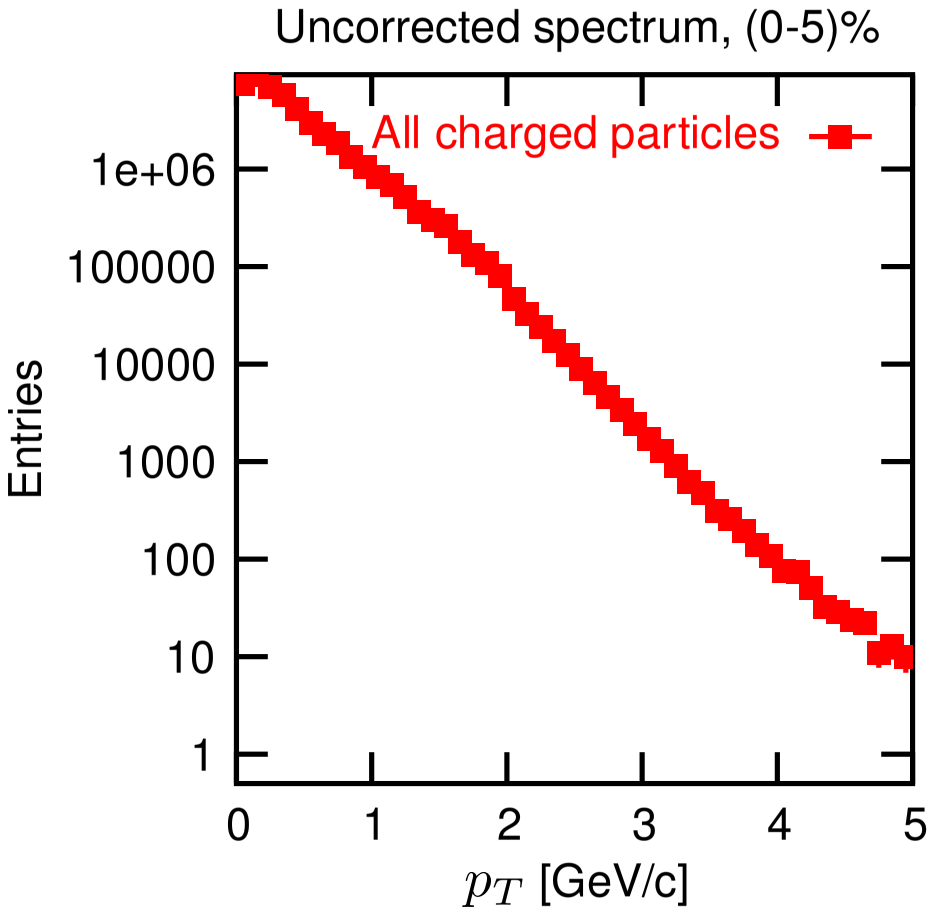
Centrality bins defined by: $\%$ of total inelastic cross section $(7.15\mathrm{mb})$.

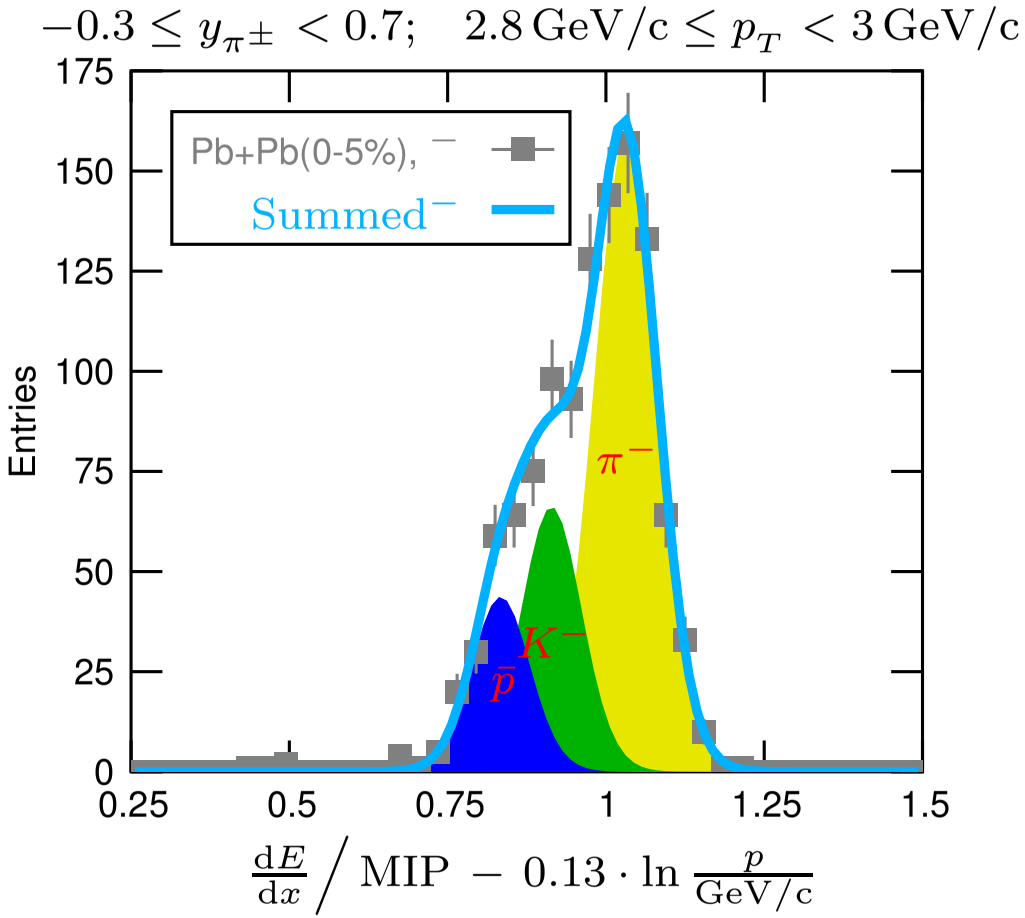
N_W (wounded nucleons), N_{BC} (number of binary collisions) calculated by VENUS

+ empiric Veto Calorimeter energy distribution.

Charged hadron analysis

Rapidity domain: $-0.3 \leq y \leq 0.7$. Centrality: (0-5)%, (12.5-23.5)%, (33.5-80)%.





Good statistics. Tracking efficiency $> 95\%$.

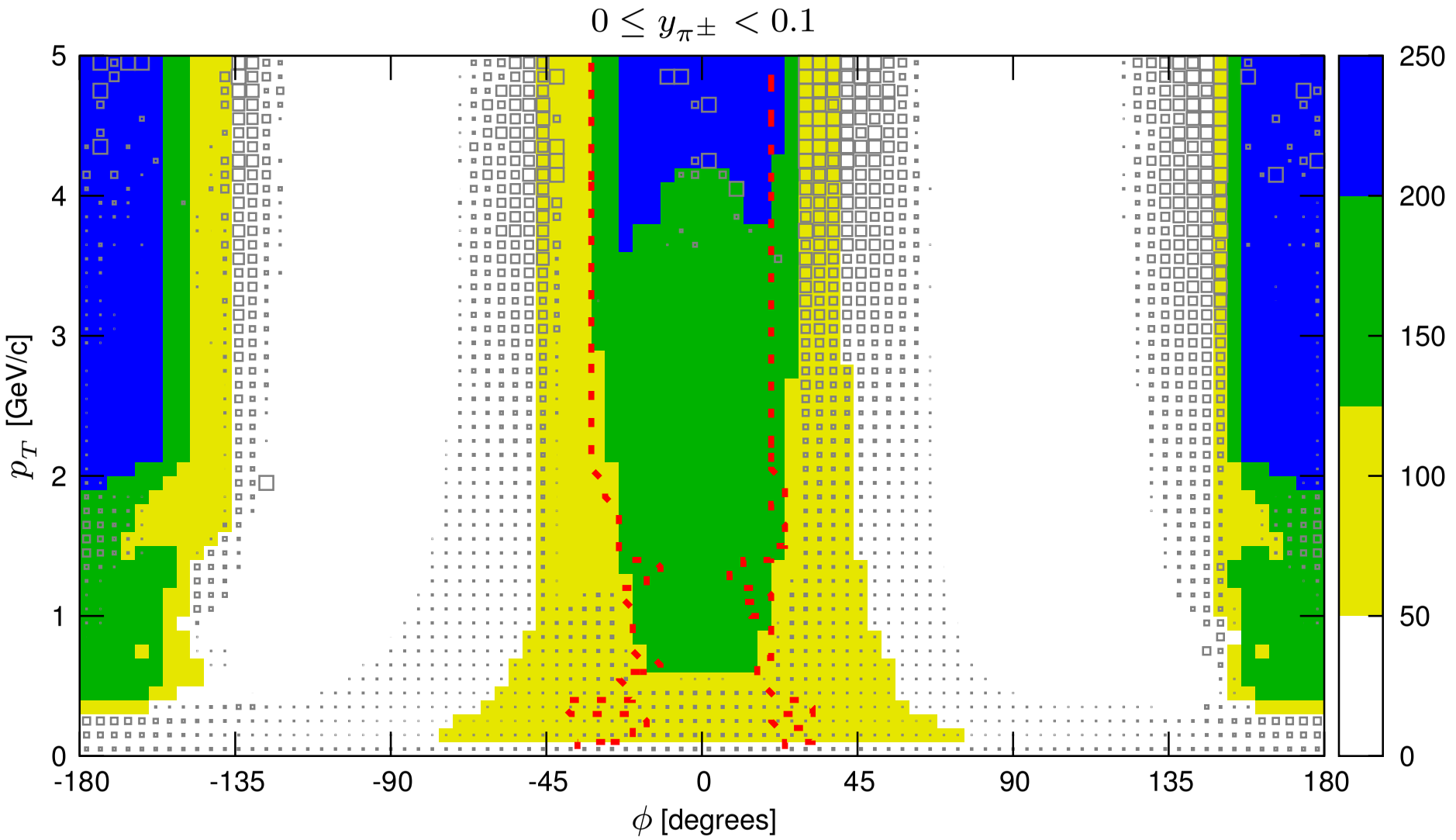
Efficient fake track rejection.

Typ. mom. resolution: $\frac{\sigma(p)}{p^2} \approx 10^{-4} \frac{1}{\mathrm{GeV/c}}$

Good $\frac{\mathrm{d}E}{\mathrm{d}x}$ resolution.

Typ. $\frac{\mathrm{d}E}{\mathrm{d}x}$ resolution: $3 - 6\%$

Key ingredients of the analysis: rejection discontinuous tracks.



A 3 dimensional acceptance cut after it.

High p_T results

Practically 0% fake track contamination, momentum space resolution better than 1% overall, momentum scale uncertainty less than 0.1%.

Corrected for:

- geometrical acceptance,
- tracking inefficiency (below 10%),
- decay loss (from 20 to 0%),
- feed-down ($5 - 30\%$),
- non-target contamination (5%).

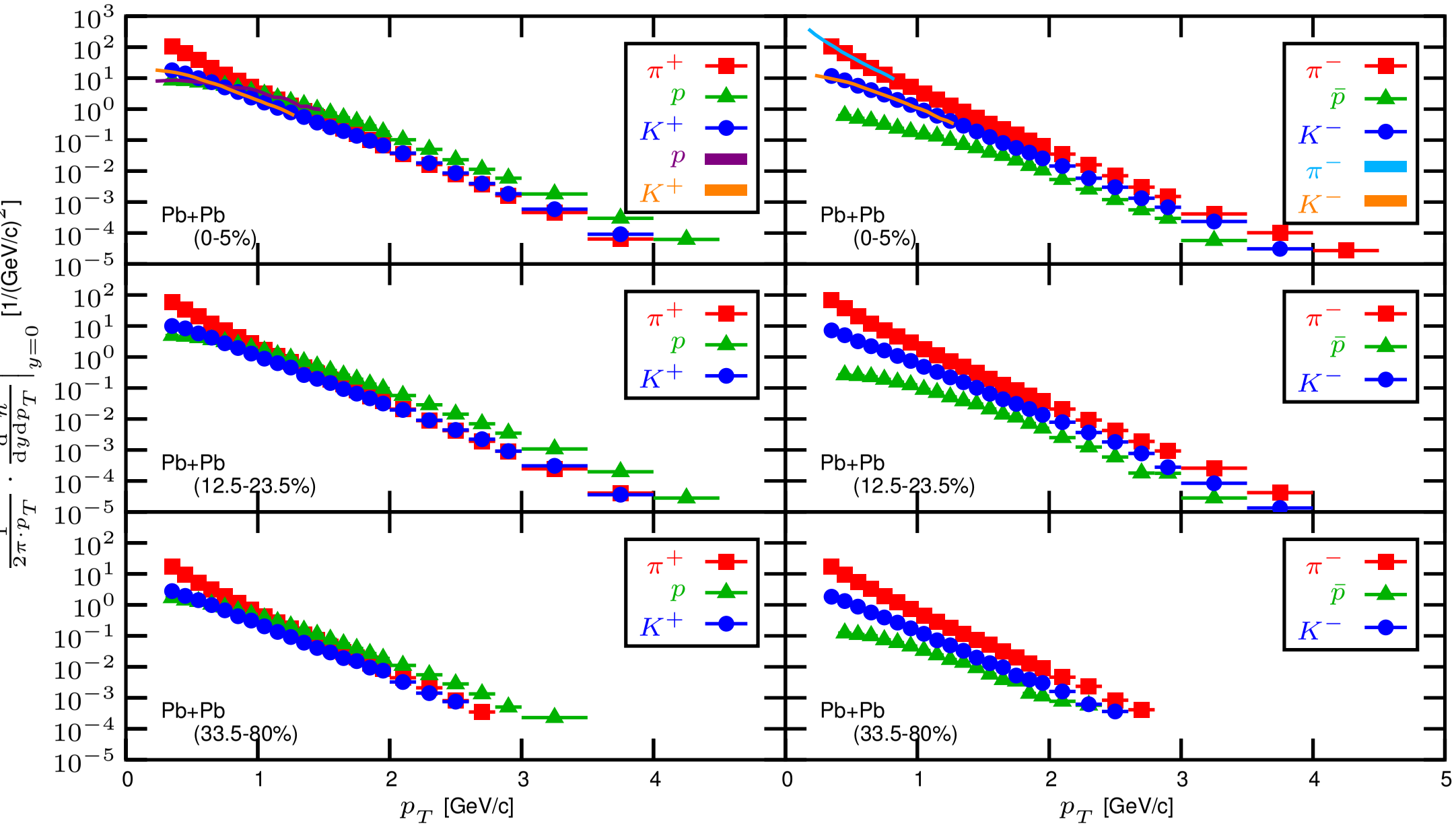
Estimated ystematic errors: 2.2% ($\pi^{\pm}$, K^{-}), 3.7% (p), 4.5% (K^{+}), 6.5% ($\bar{p}$).

Published in:

C. Alt *et al.* (the NA49 Collaboration):

High transverse momentum hadron spectra at $\sqrt{s_{NN}} = 17.3\,\mathrm{GeV}$ in Pb+Pb and p+p collisions;

Physical Review **C** (2007) accepted [arXiv:0711.0547].


$\frac{1}{2\pi \cdot p_T} \cdot \frac{d^2n}{dy dp_T}\Big|_{y=0}$ [1/(GeV/c)^2]
p_T [GeV/c]
Pb+Pb (0-5%)
Pb+Pb (12.5-23.5%)
Pb+Pb (33.5-80%)
π^+
p
K^+
p
K^+
π^-
$\bar{p}$
K^-
π^-
K^-

Comparison to models and higher energy data

- Blast-Wave (BW) paramerization of the combined data on m_T spectra and HBT, fitted simultaneously at low p_T.

  At low p_T: good (fitted). At high p_T: does not describe data as expected.

  (F. Retiere, M. A. Lisa: Phys. Rev. **C70** (2004) 044907.)

- pQCD-based energy loss models.

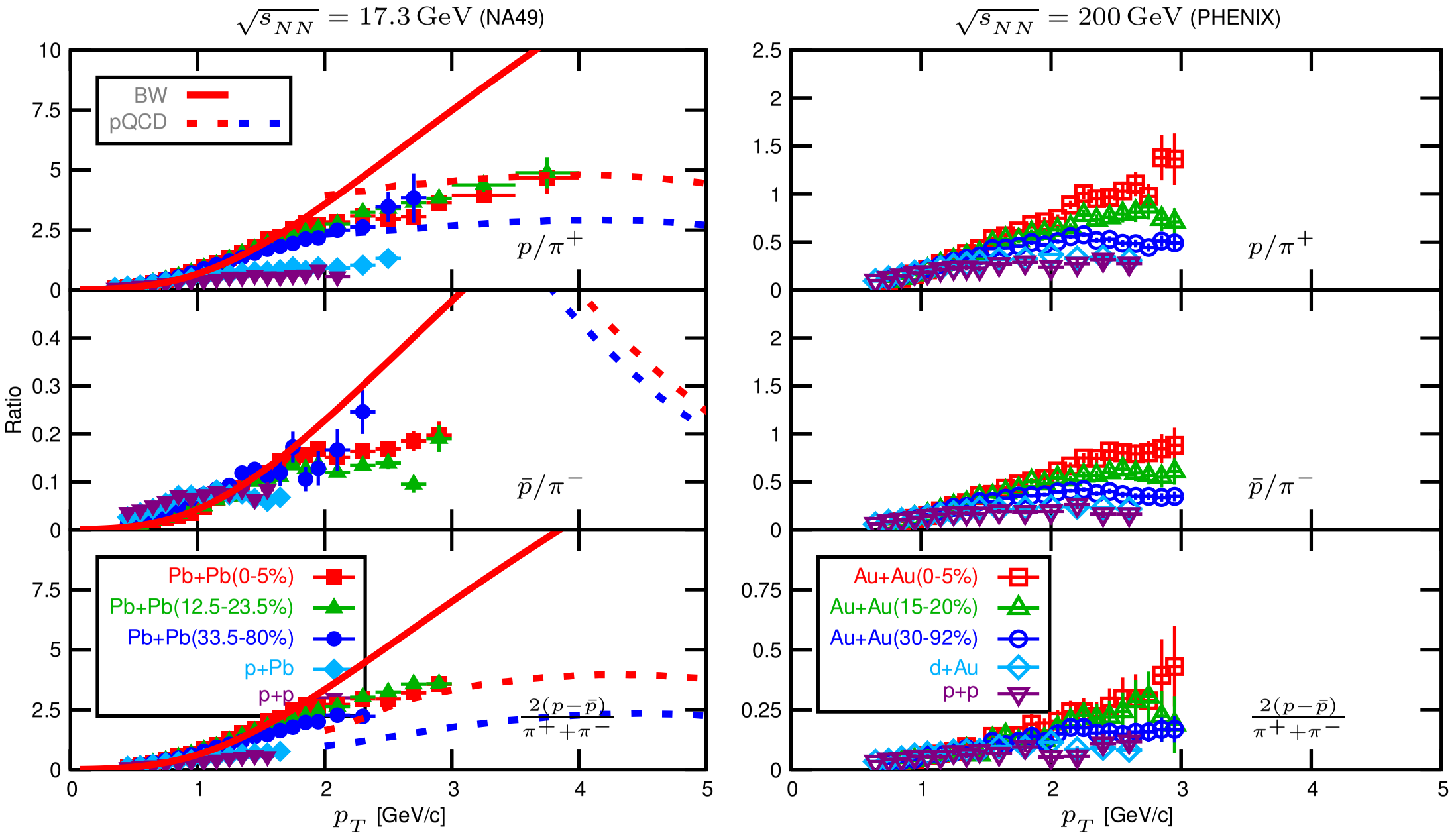
  Does not describe produced-baryon/meson ratios. Not perturbative regime?

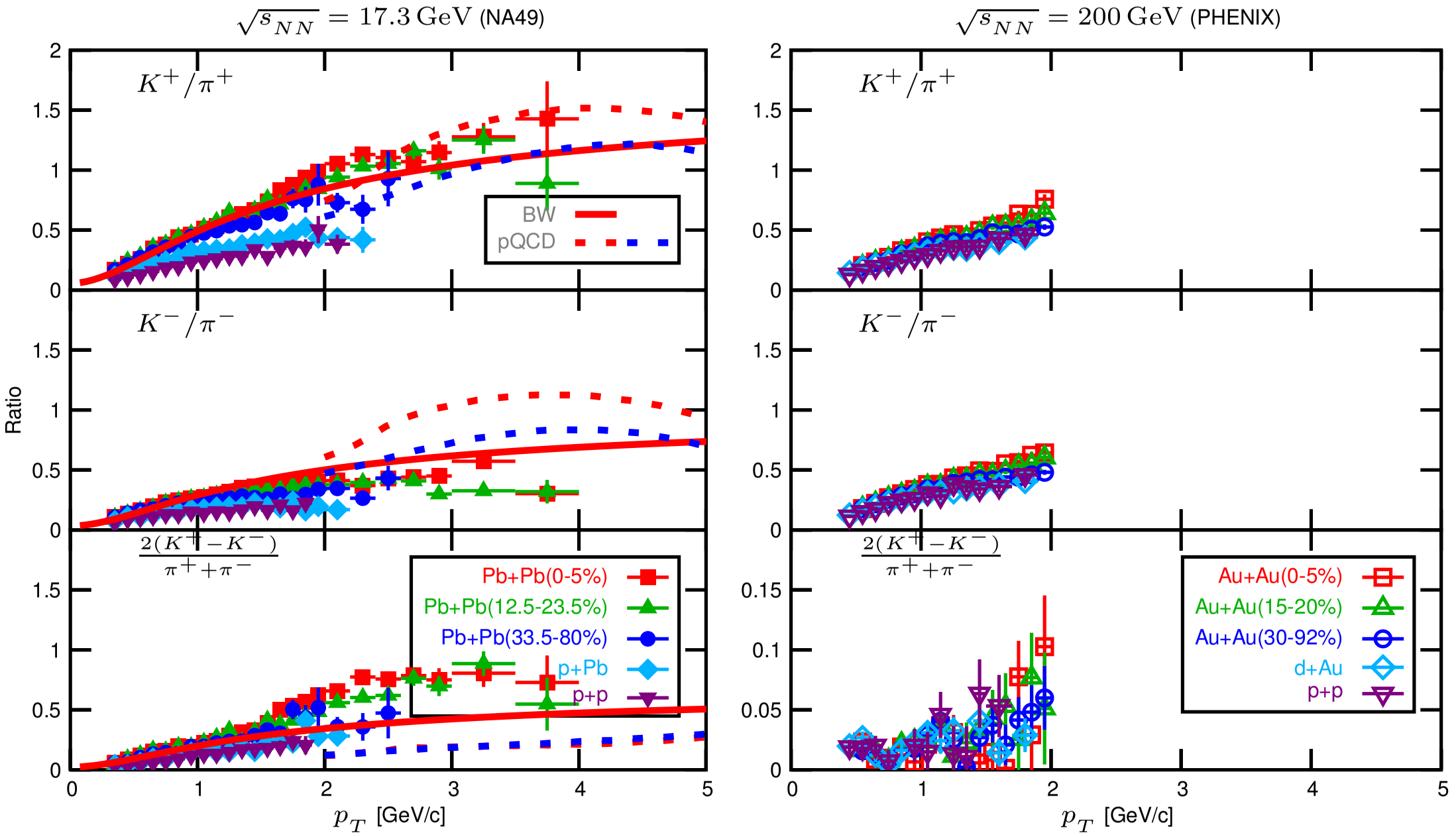
  (X.-N. Wang: Phys. Lett. **B595** (2004) 165.)

- Energy dependence. Decreased role of net-baryon production at higher collision energies.

  (S. S. Adler *et al.* (PHENIX Coll.): Phys. Rev. **C69** (2004) 034910,

  S. S. Adler *et al.* (PHENIX Coll.): Phys. Rev. **C69** (2006) 024904.)


$\sqrt{s_{NN}} = 17.3$ GeV (NA49)
$\sqrt{s_{NN}} = 200$ GeV (PHENIX)
BW
pQCD
p/π^+
$\bar{p}/\pi^-$
$\frac{2(p-\bar{p})}{\pi^+ + \pi^-}$
Pb+Pb(0-5%)
Pb+Pb(12.5-23.5%)
Pb+Pb(33.5-80%)
p+Pb
p+p
Au+Au(0-5%)
Au+Au(15-20%)
Au+Au(30-92%)
d+Au
p+p
Ratio
p_T [GeV/c]


$\sqrt{s_{NN}} = 17.3$ GeV (NA49)
$\sqrt{s_{NN}} = 200$ GeV (PHENIX)
K^+/π^+
K^-/π^-
$\frac{2(K^+ - K^-)}{\pi^+ + \pi^-}$
Ratio
BW
pQCD
Pb+Pb(0-5%)
Pb+Pb(12.5-23.5%)
Pb+Pb(33.5-80%)
p+Pb
p+p
Au+Au(0-5%)
Au+Au(15-20%)
Au+Au(30-92%)
d+Au
p+p
p_T [GeV/c]

Failure of blast-wave picture at high p_T because of non-thermal spectra.

pQCD failing to describe produced particle ratios? $(\bar{p}/\pi^-, K^-/\pi^-)$

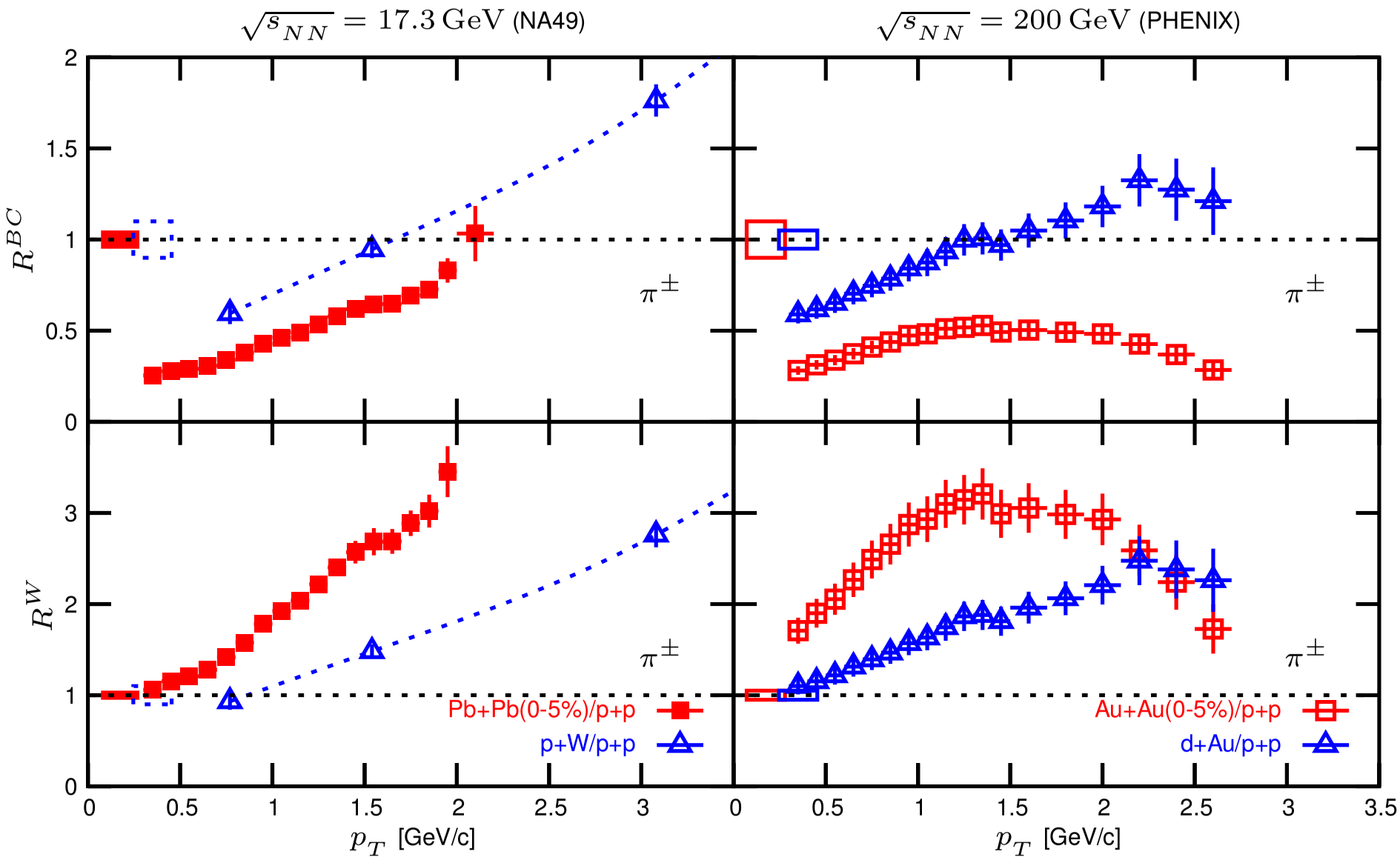
Nuclear modification factors

Defined by:

$$R_{A+B/C+D} := \frac{N(C+D)}{N(A+B)} \cdot \frac{\text{Yield}(A+B)}{\text{Yield}(C+D)}.$$

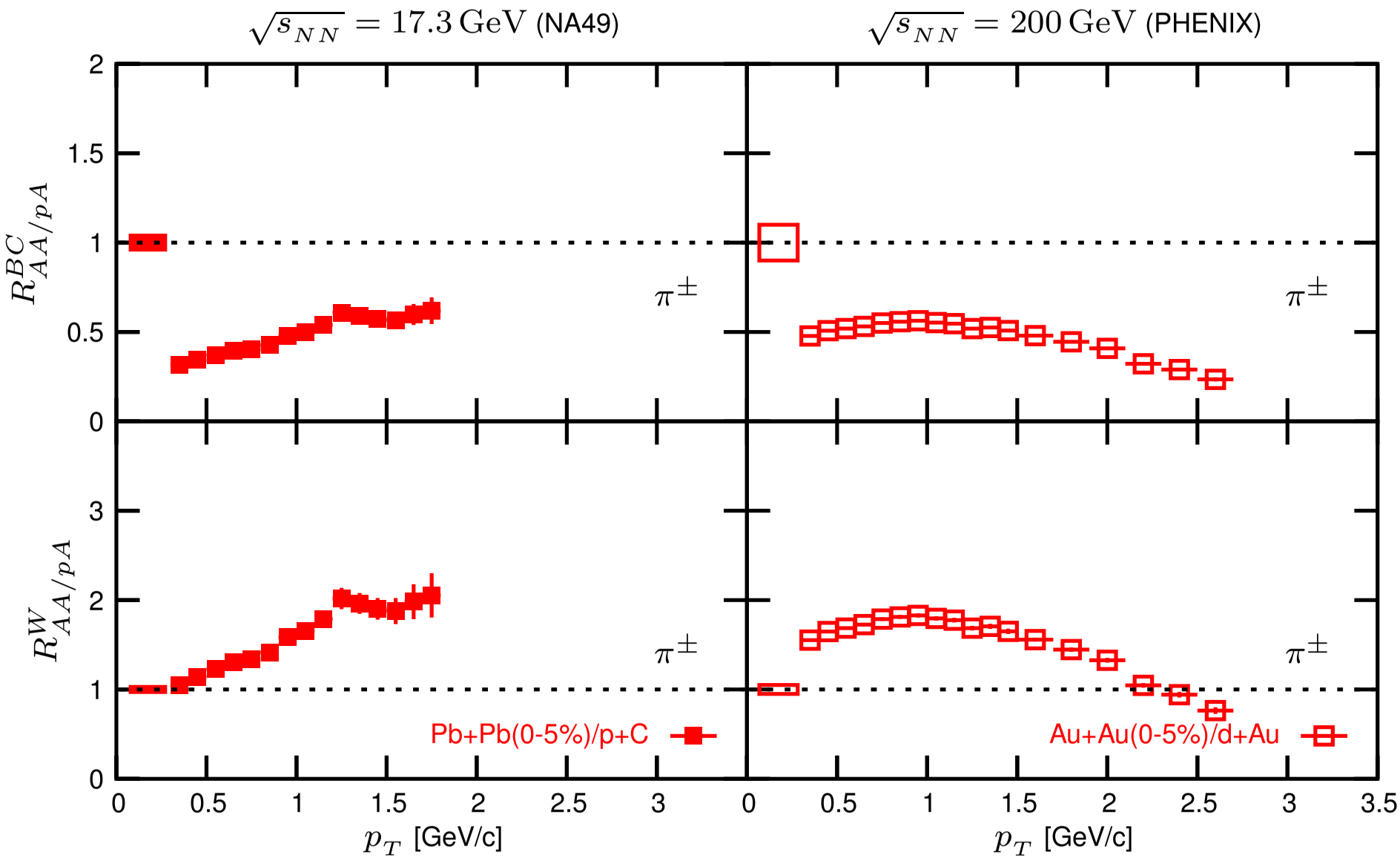
Here N can be either the calculated value of the number of binary collisions, or the calculated value of the number of wounded nucleons, in the given centrality range, for the given collisions A+B and C+D.

Energy dependence of R_{AA}. p+W/p+p: D. Antreasyan *et al*, Phys. Rev. **D** (1979) 764.

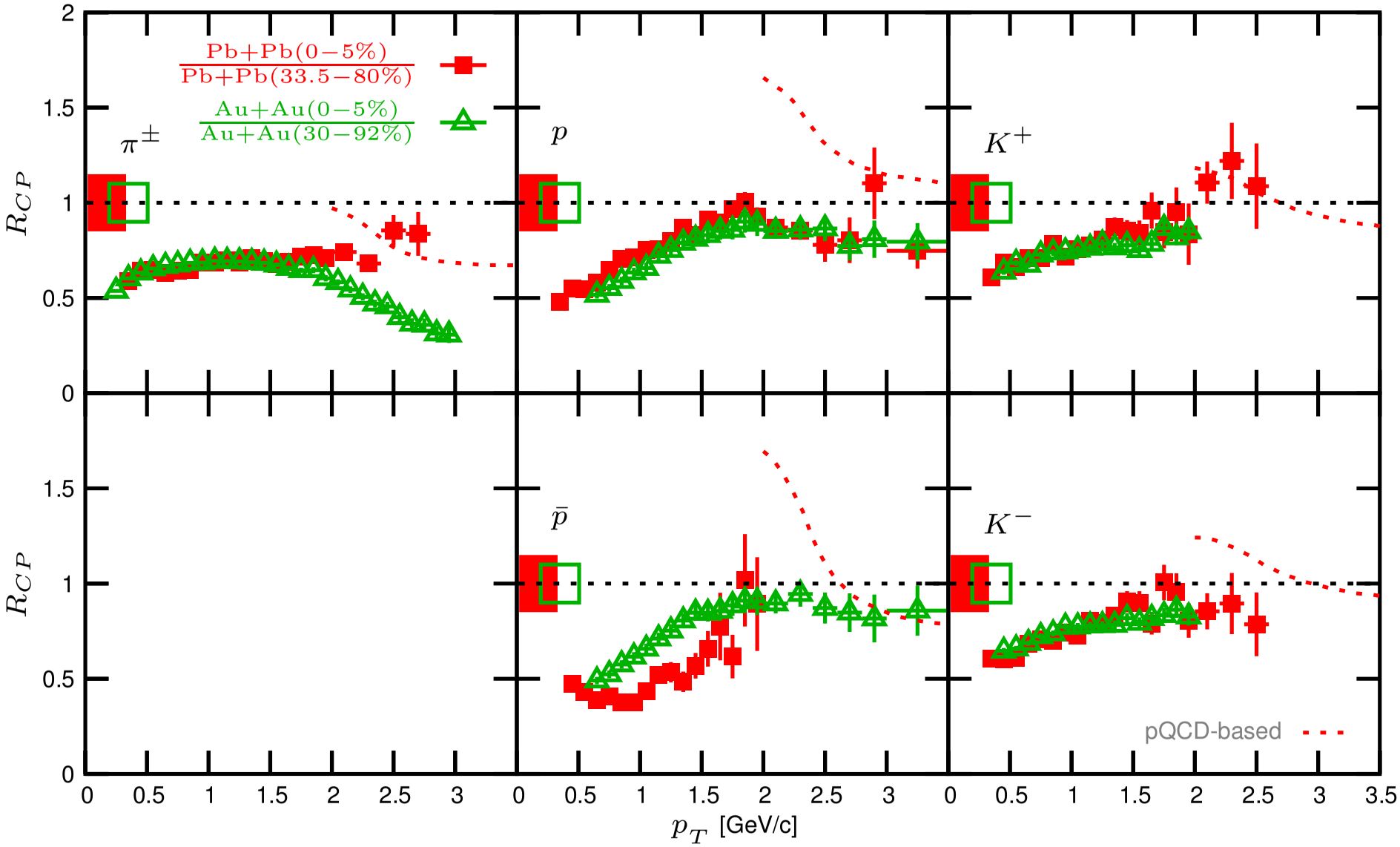


Energy dependence of $R_{AA/pA}$.

p+C: C. Alt *et al*, Eur. Phys. J. **C49** (2007) 897.



Energy dependence of R_{CP}.



Summary

- Published NA49 results on yields at $2\mathrm{GeV/c} \leq p_T < 4.5\mathrm{GeV/c}$, around midrapidity.

- Monotonic increase of baryon/meson and Kaon/pion ratios with centrality and p_T.
- The blast-wave model seems not to describe baryon/meson ratios at high p_T as expected.
- The pQCD-based energy loss model does not seem to describe the produced-baryon/meson ratios at high p_T.

- In the $R_{AA/pA}$ or R_{CP} curves, no Cronin enhancement observed for mesons, with binary collisions scaling.
- pQCD-based energy loss model seems to describe the R_{CP}.
- Strong energy dependence at high p_T for $\bar{p}$ (however: higher systematics).
- For other particles, the R_{CP} curves are very similar at the two very different energies, although for $\pi^{\pm}$ there is a detectable deviation at high p_T.