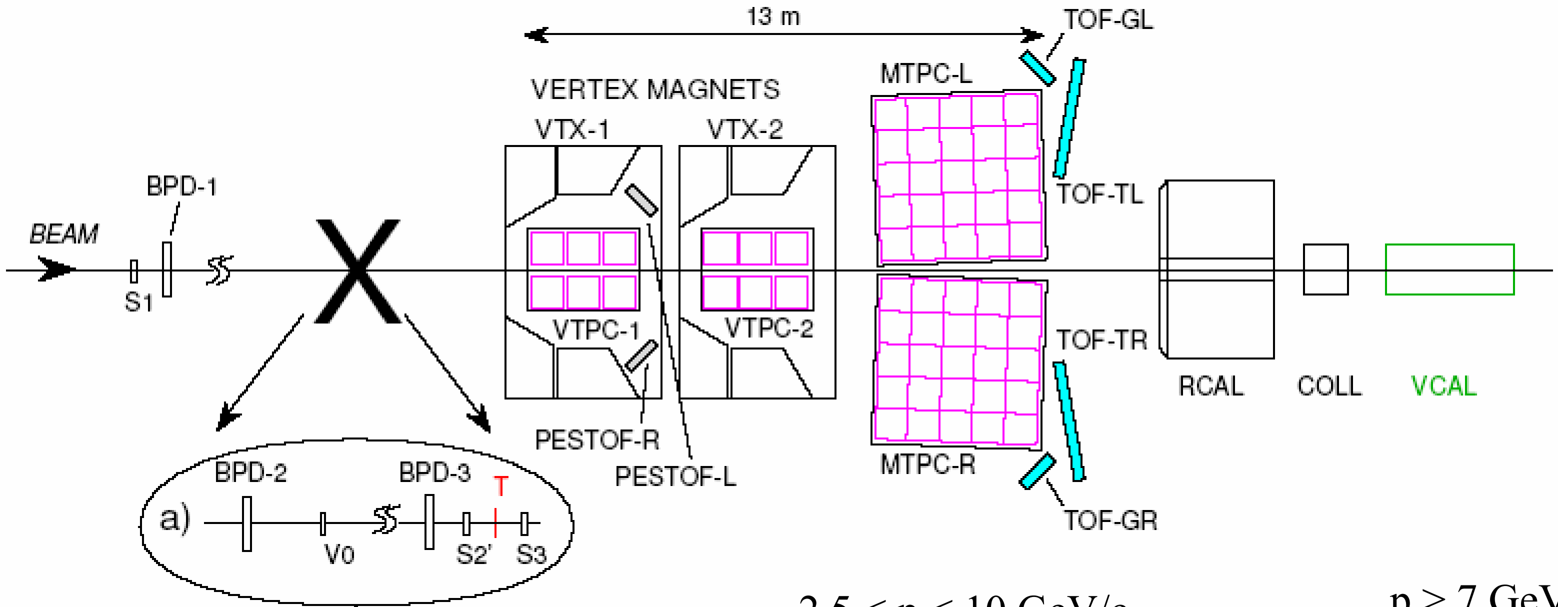
NA49 Results from Pb+Pb Collisions at the CERN SPS

P.Seyboth, Max-Planck-Institut für Physik, Munich
and Świętokrzyska Academy, Kielce
for the NA49 collaboration

- NA49 experiment - Introduction
- ^{3}He, tritium production (V.Kolesnikov)
- Balance function (P.Christakoglou)
- Status of fluctuation measurements

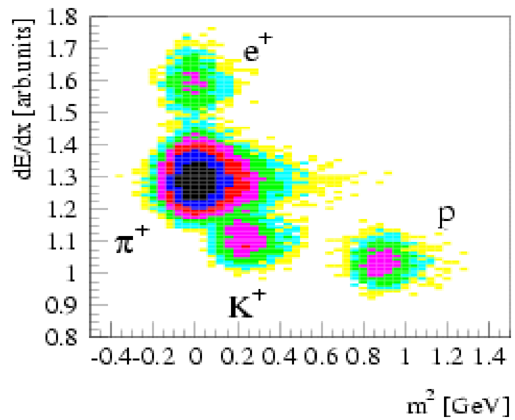
  (K.Grebieszkow, M.Rybczynski, B.Lungwitz, C.+G.Roland)
- Future plans

The NA49 Detector

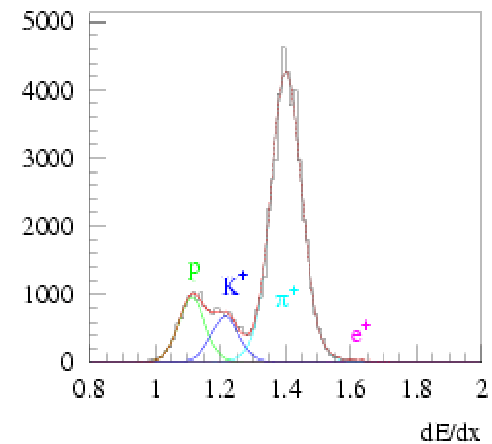


Target: Pb foil, 20 cm liquid H_2
VCAL detects projectile spectators
$\Delta p/p^2$ = 7 (0.3) • 10^{-4} $(GeV/c)^{-1}$
(VTPC-1, VTPC+MTPC)
Particle identification:
dE/dx (3 – 6 %), TOF (~ 60 ps)
decay topology (K^0_s , Λ, Ξ, Ω)
$\sqrt{s_{NN}}$ = 6.3, 7.6, 8.7, 12.3, 17.3 GeV

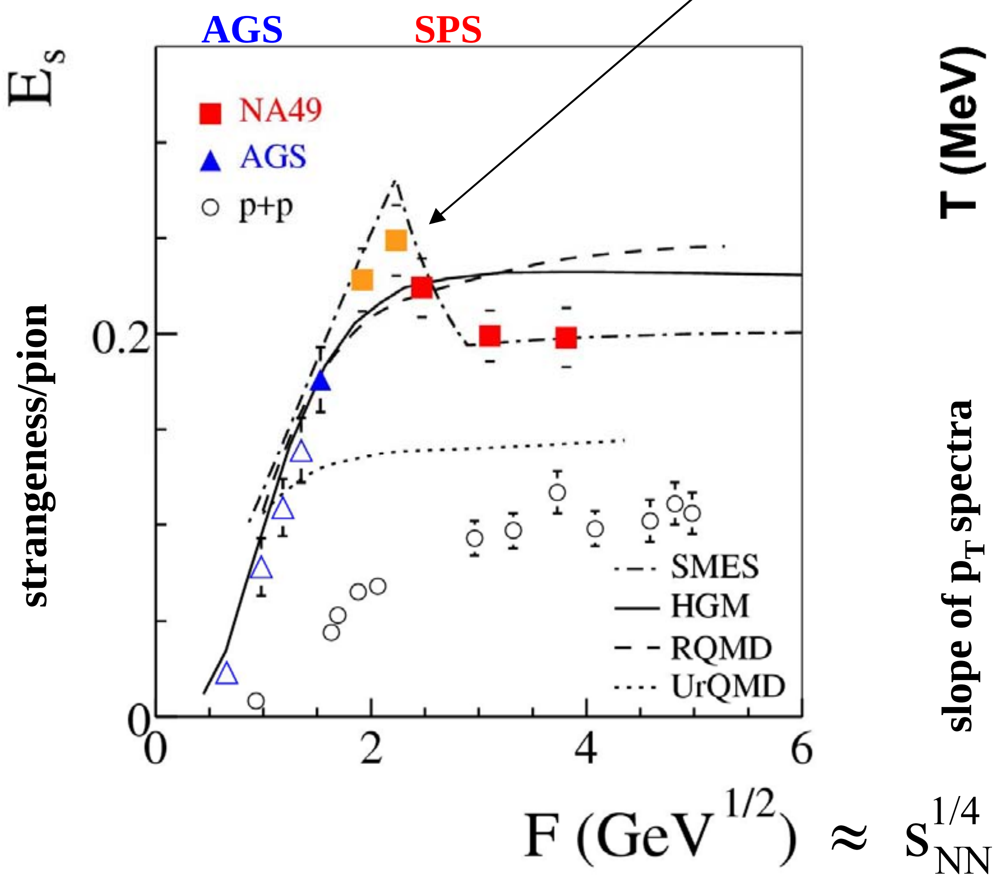
2.5 < p < 10 GeV/c
TOF + dE/dx
at midrapidity

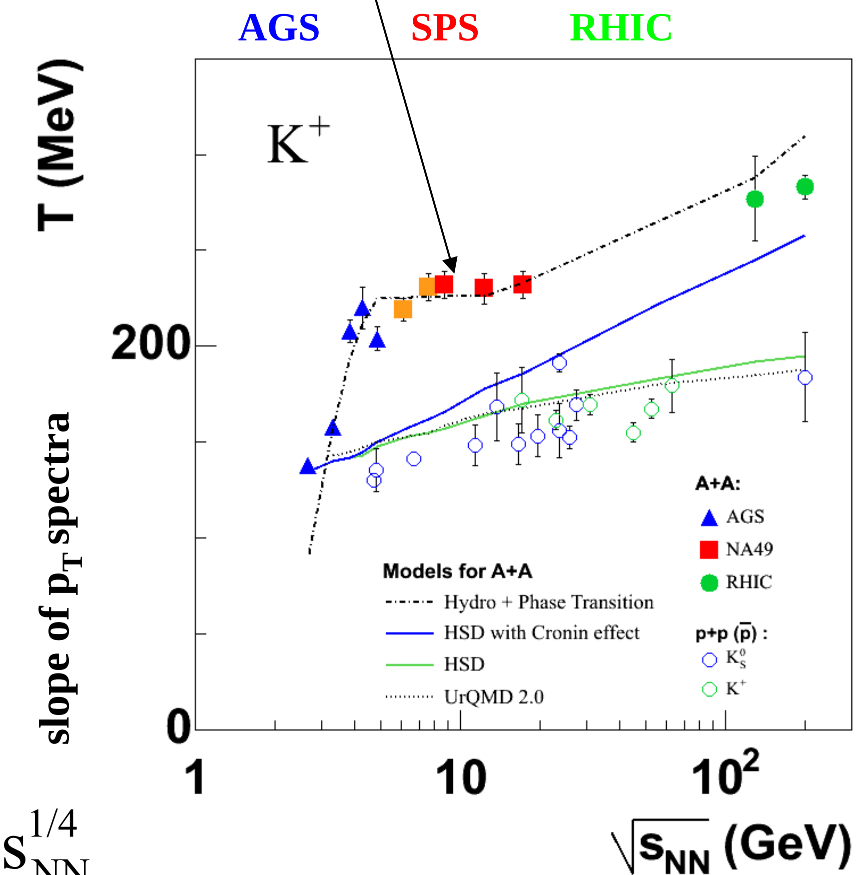


p > 7 GeV/c
dE/dx
forward rapidity

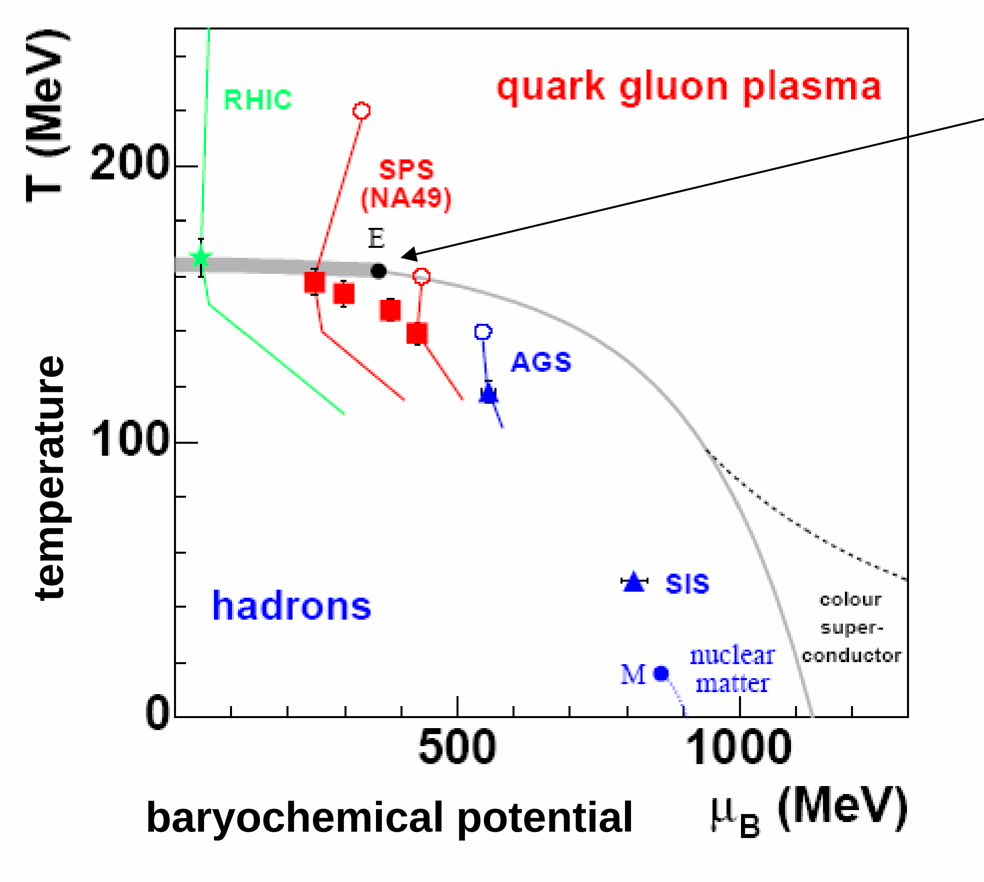


Changes of hadron production properties in central Pb+Pb collisions at the CERN SPS energies are not reproduced by models without onset of deconfinement at low SPS energies





Freeze-out parameters determined from hadron yields for central Pb+Pb collisions at the CERN SPS are close to the predicted phase boundary between hadron gas and quark-gluon plasma



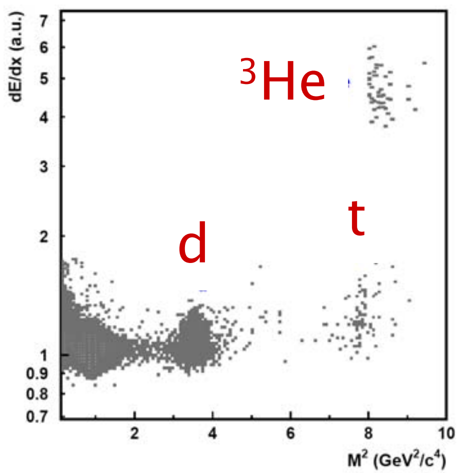
A critical point of strongly interacting matter is predicted by QCD. It may be discovered as a maximum of fluctuations in a comprehensive energy and system size scan at the CERN SPS and low energy RHIC

hadron gas analysis:
F.Becattini et al., PRC73(2006)044905

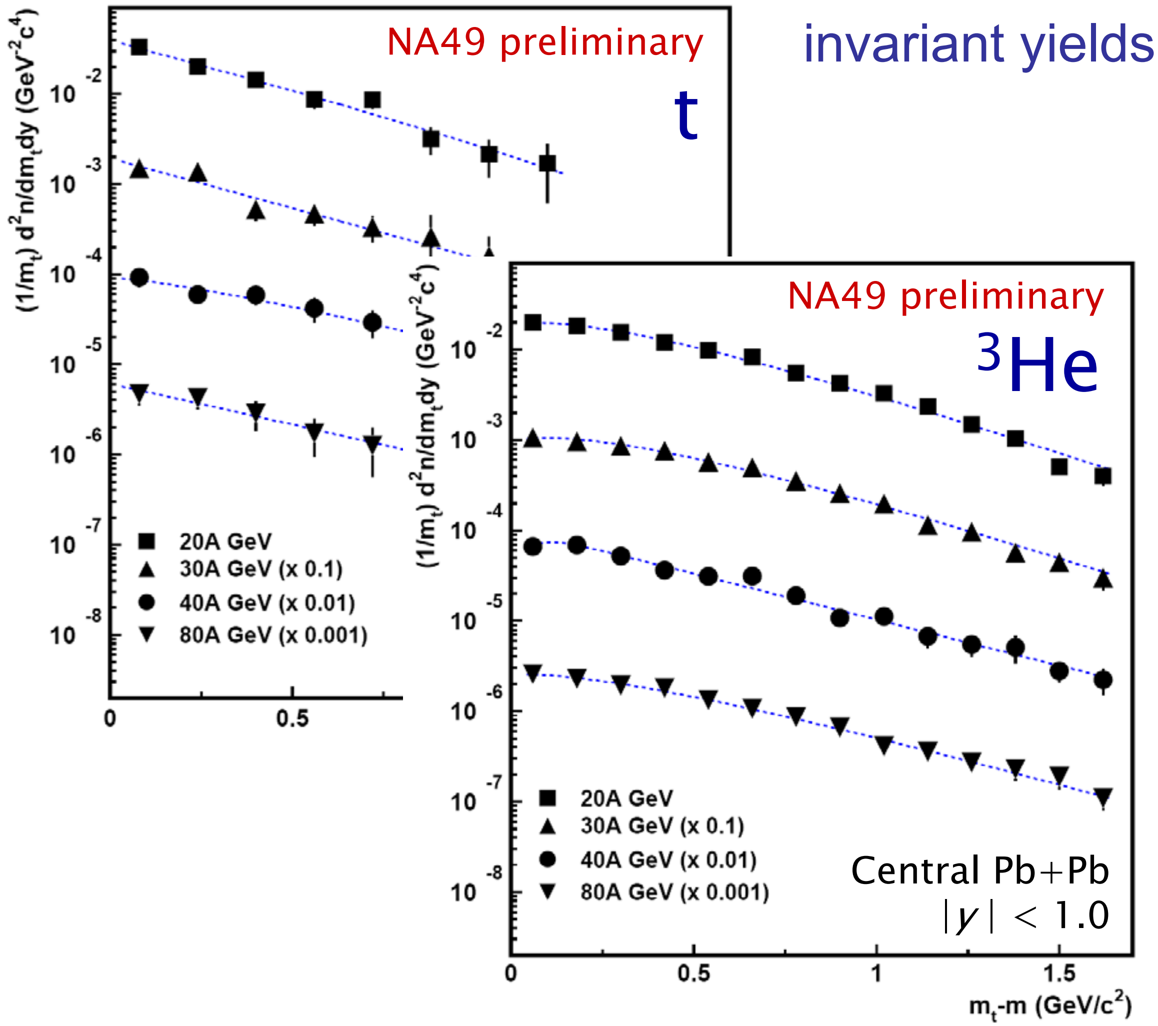
lattice QCD results:
Z.Fodor and S.Katz, JHEP 04(2004)050

light fragments (1)

^{3}He identification:
dE/dx + TOF
(at 40A GeV)

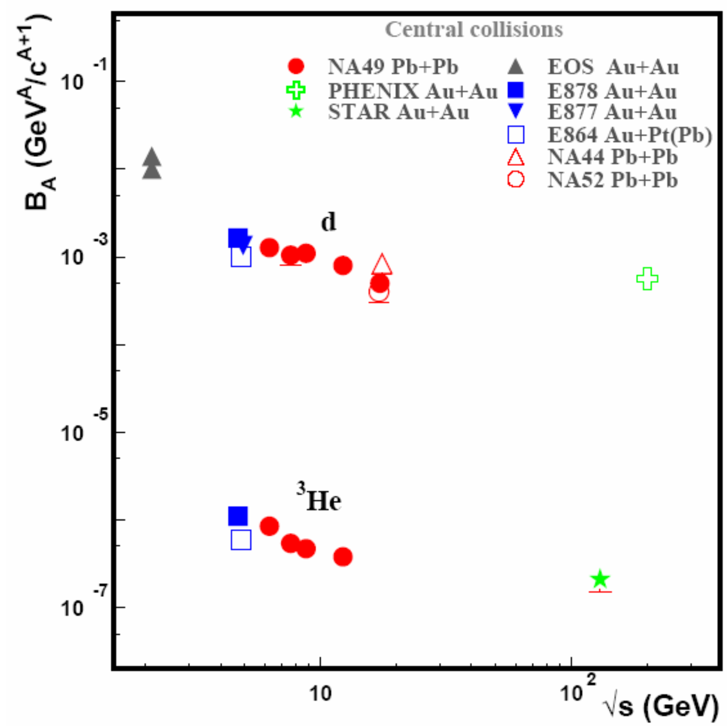


differential
invariant yields



light fragments (2)

coalescence paramater (p_T= 0)

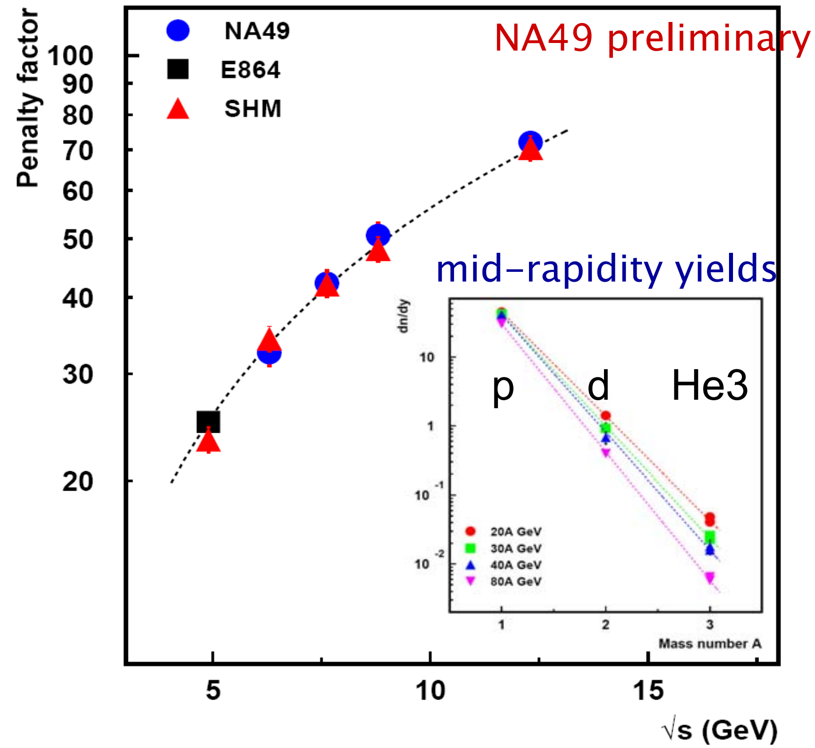


computed using p spectra:

$$E_A \frac{d^3 N_A}{dP_A^3} = B_A \left(E_p \frac{d^3 N_p}{dP_p^3} \right)^A \quad , \quad P_A = A \cdot P_p$$

gradual decrease with energy

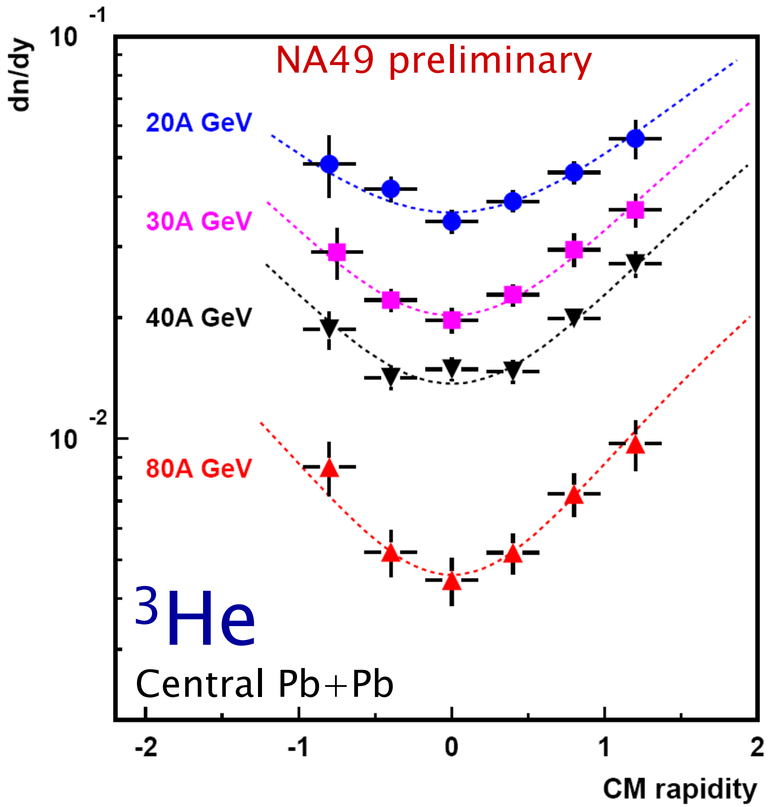
penalty factor (using dn/dy)

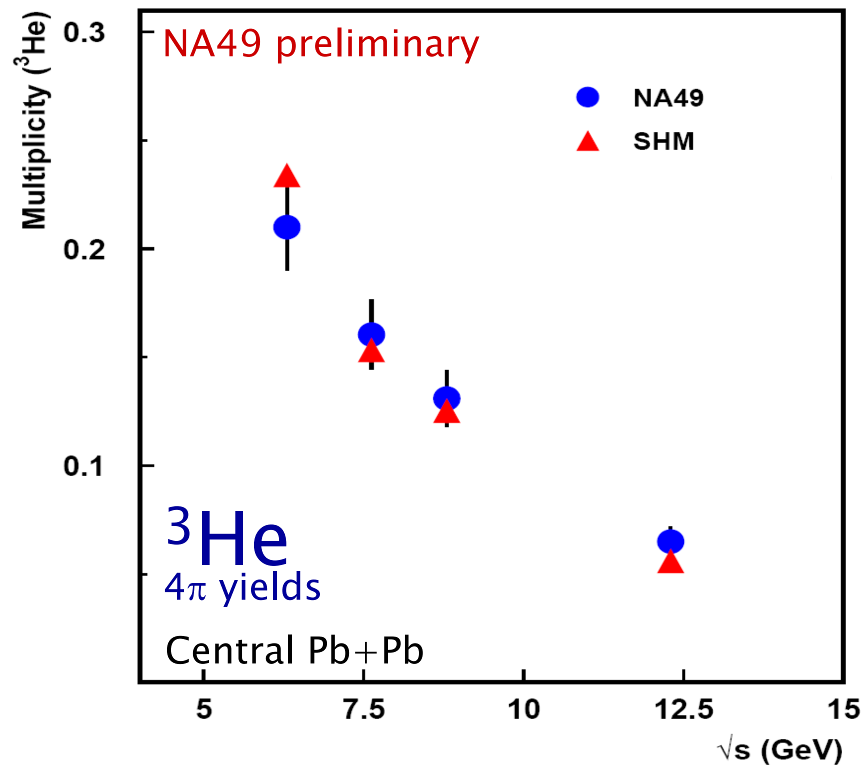


$$\frac{dn(A)}{dy} \sim \text{const}/p^{A-1}$$

agrees with statistical hadron gas prediction

light fragments (3)





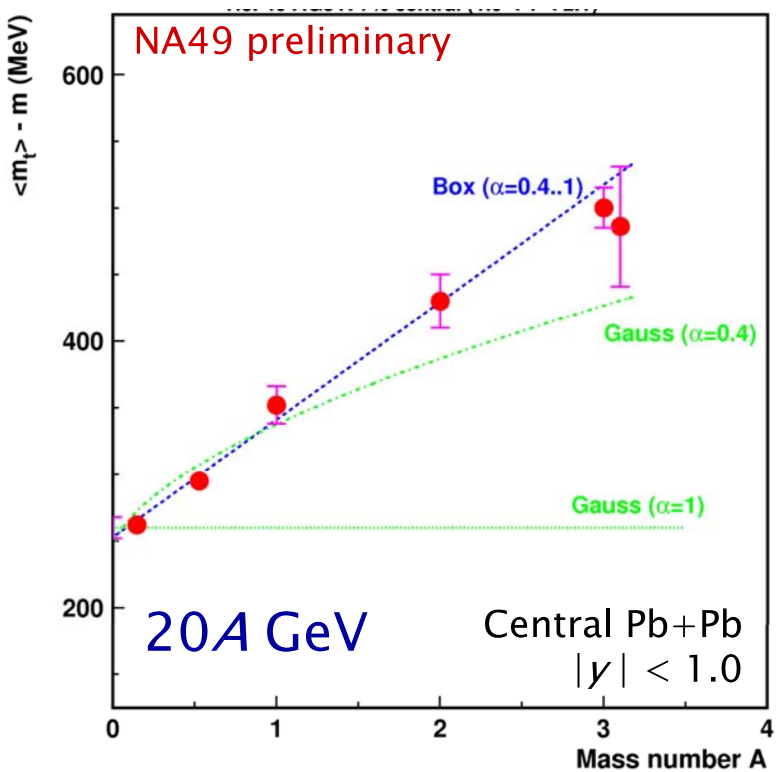
total yields estimated from parabolic fits up to $|y_{beam}|$ (motivated by RQMD)

yields show surprising agreement with statistical hadron gas model

F.Becattini et al., PRC73 (2006) 044905

light fragments (4)

coalescence model



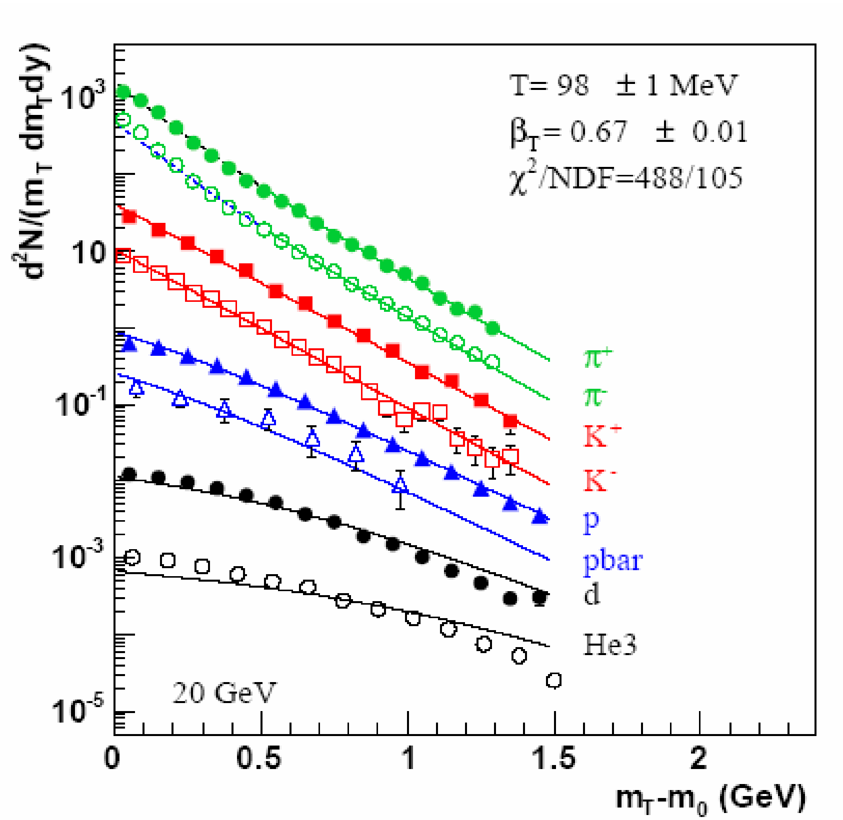
constant density, $v(r) = v_f\,(r/R_f)^{\alpha}$

$\rightarrow \quad \langle m_T \rangle - m \;\sim A^{1-\alpha}$

(A.Pollieri et al., PLB419 (1998) 19)

linear velocity increase ok

blast wave model



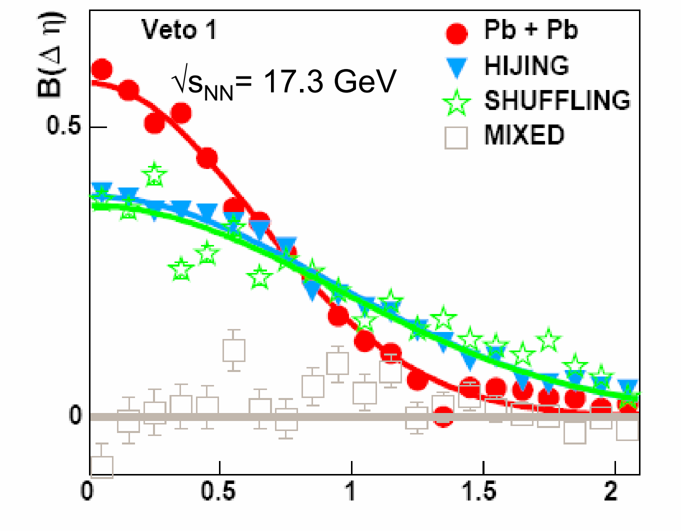
d,^{3}He require smaller T, <β_T>

<u>Balance Function:</u> charge correlations in pseudo-rapidity

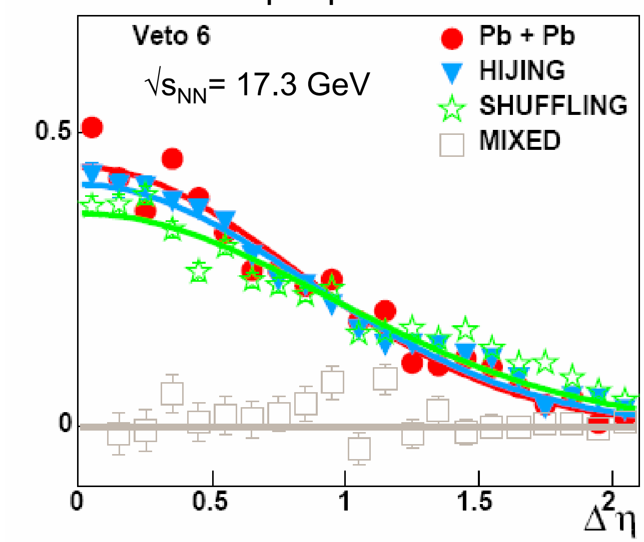
$$B(\delta\eta) = \frac{1}{2}\left(\frac{N_{(+-)}(\delta\eta) - N_{(--)}(\delta\eta)}{N_{-}} + \frac{N_{(-+)}(\delta\eta) - N_{(++)}(\delta\eta)}{N_{+}}\right)$$

narrowing of the balance function proposed as QGP signature (delayed hadronisation due to phase coexistence)

central



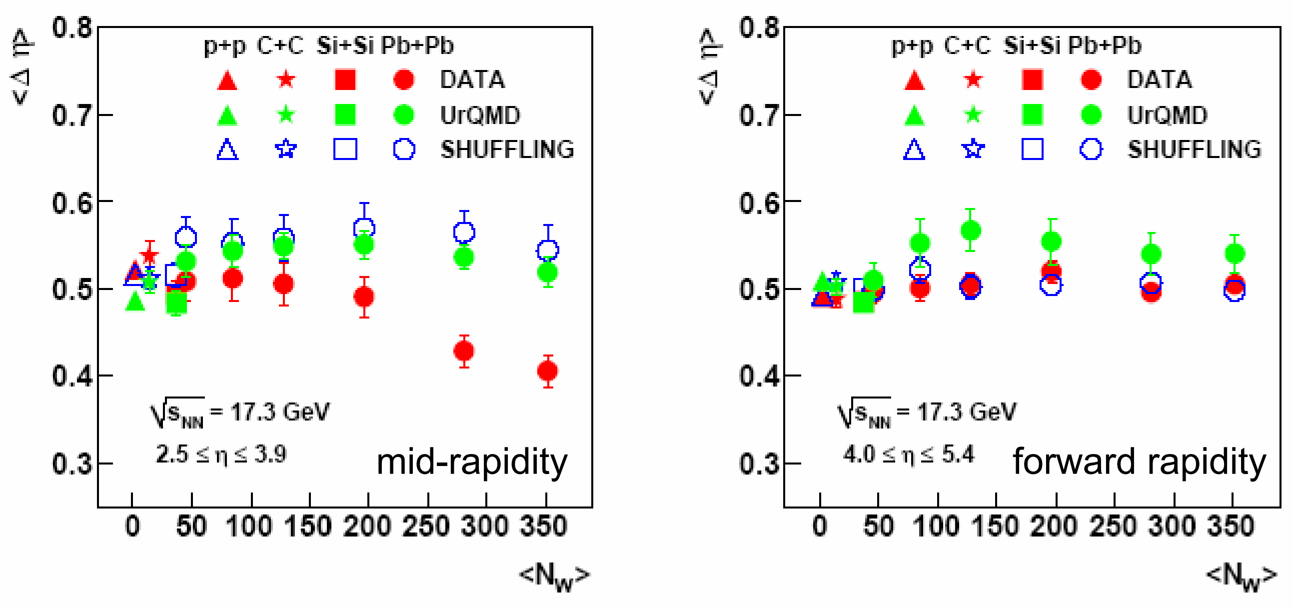
peripheral



data compared to shuffled events (scrambling of rapidities, retention of global charge conservation)

narrowing of BF in central Pb+Pb collisions

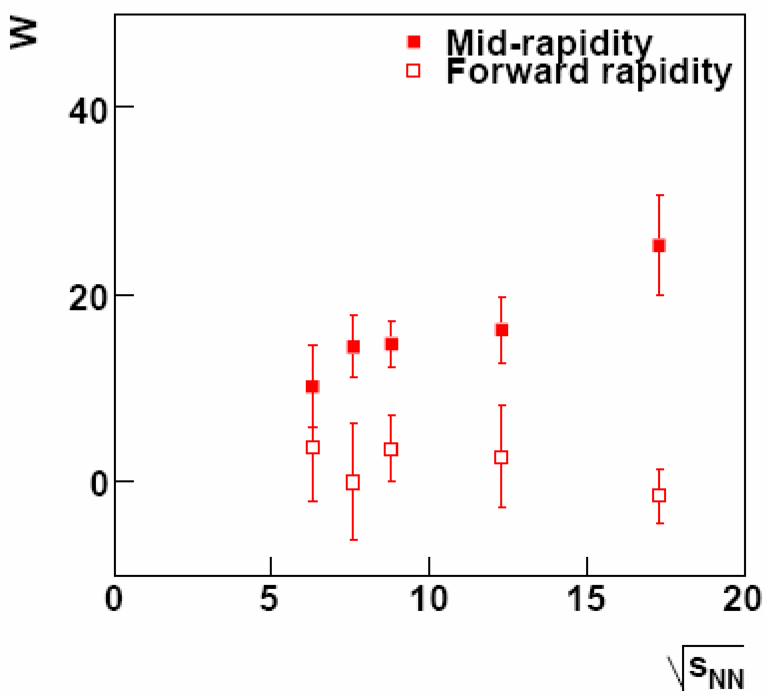
- width decreases ≈ 17 % at SPS and RHIC from peripheral to central collisions
- narrowing only at central rapidity at SPS

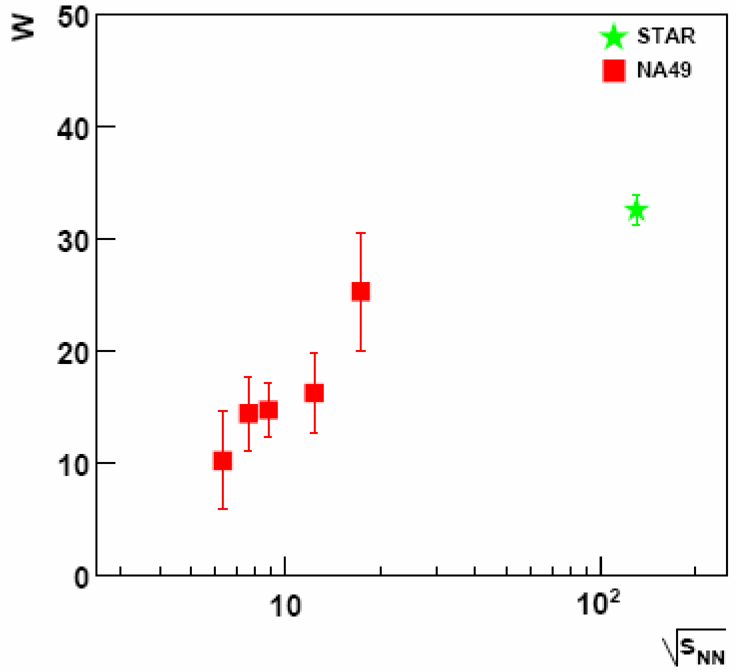


BF: energy dependence of the range of charge correlations

shuffled events used as reference:

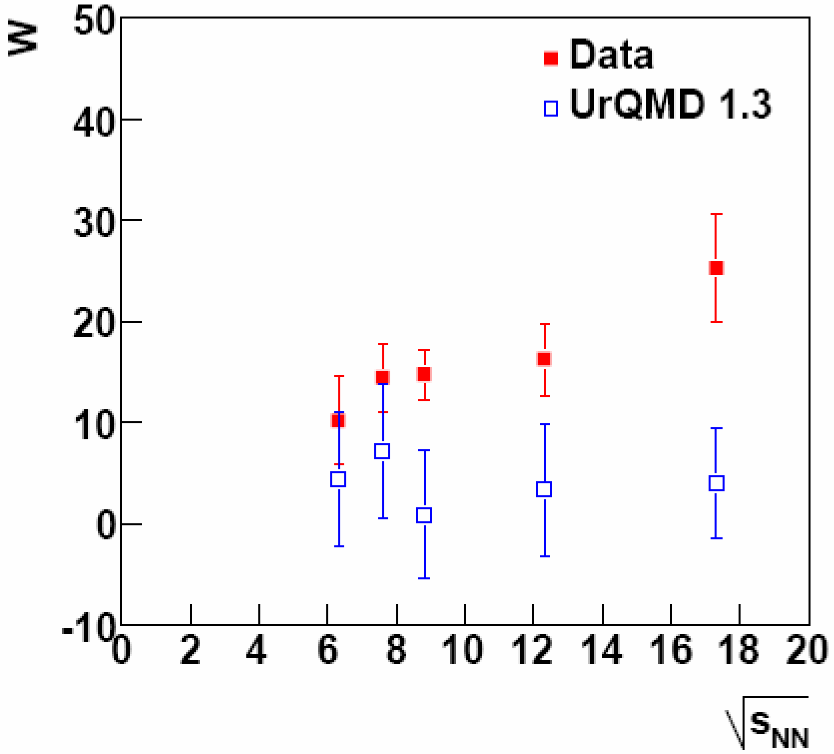
$$W = (\langle\Delta\eta\rangle_{shuff} - \langle\Delta\eta\rangle_{data}) / \langle\Delta\eta\rangle_{shuff} \cdot 100$$

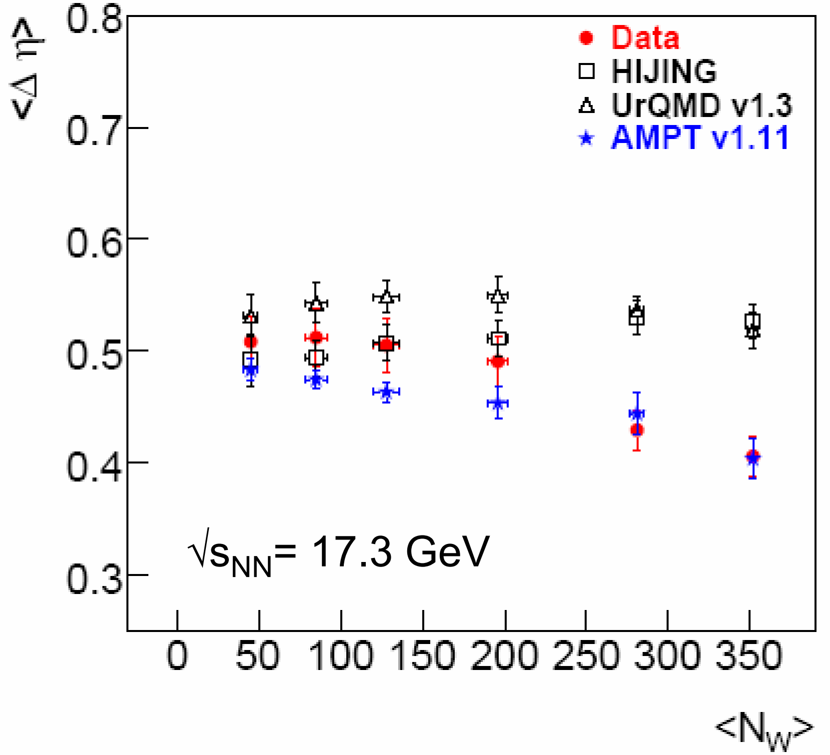




normalised narrowing parameter W increases smoothly with energy

BF: model comparisons at midrapidity

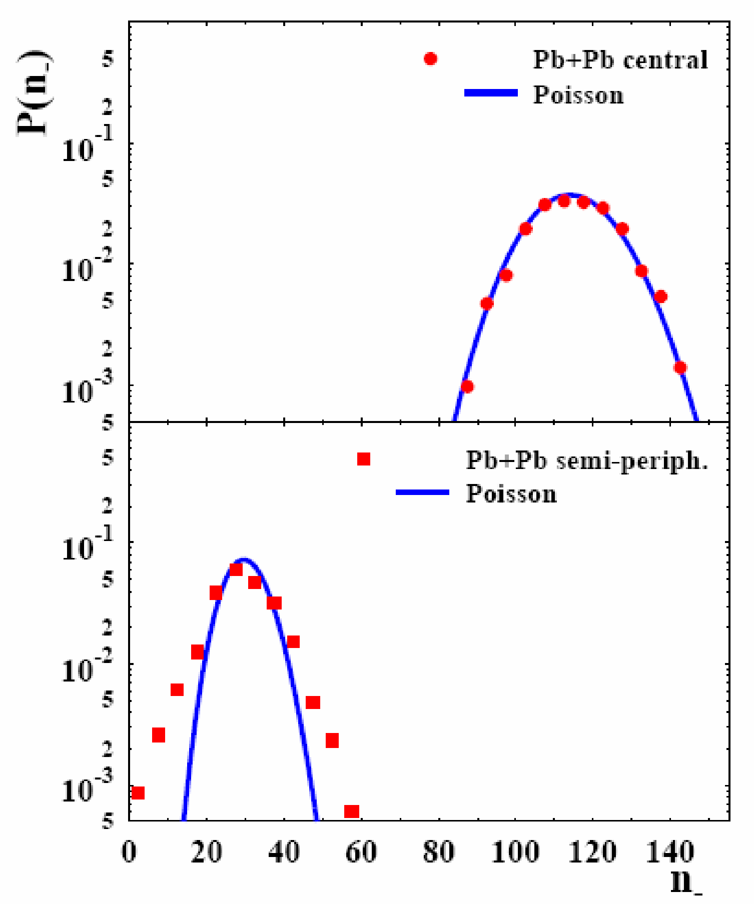




- effects due to local charge conservation and radial flow may dominate (Pratt, Bialas)
- microscopic model AMPT has deconfined phase and gets BF narrowing

Event-by-event fluctuations of negative hadron multiplicity

Pb+Pb at 158AGeV, $1.1 < y_\pi < 2.6$

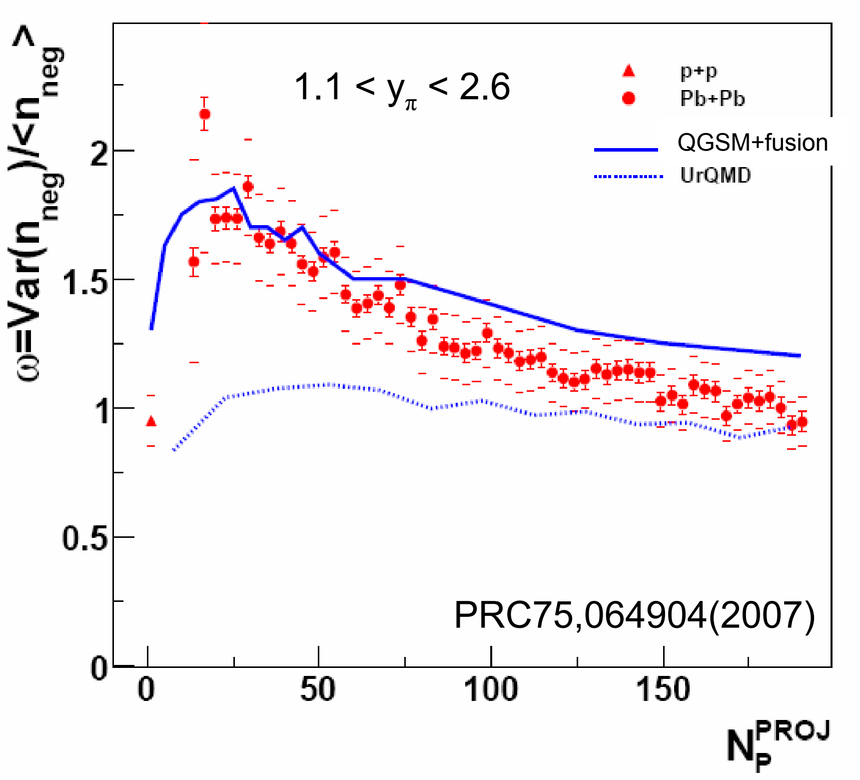


- fluctuations measured at forward rapidity ($1.1 < y_\pi < 2.6$) where azimuthal acceptance is best
- number of projectile participants fixed by projectile spectator energy cut; no restriction on target participants
- central collisions: fluctuations nearly Poissonian (independent emission)
- peripheral collisions: fluctuations exceed Poissonian

measure: $\omega = Var(n\_)/<n\_>$

Event-by-event fluctuations of negative hadron multiplicity

system size dependence at 158A GeV



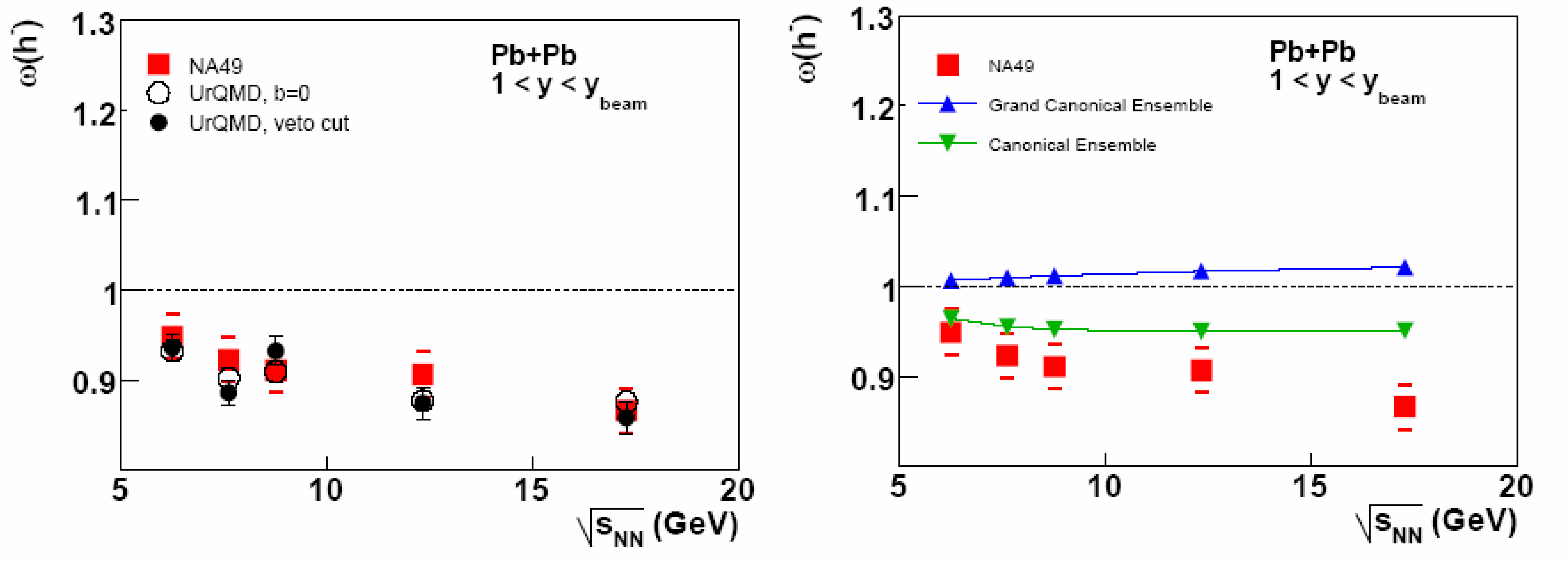
- rise due to effect of fluctuating target participants ?
- reproduced by string models with string fusion (QGSM+fusion)

L.Cunqueiro et al.,PRC69(2005)024907

Event-by-event fluctuations of negative hadron multiplicity

energy dependence (forward rapidity)

(Na49 preliminary)

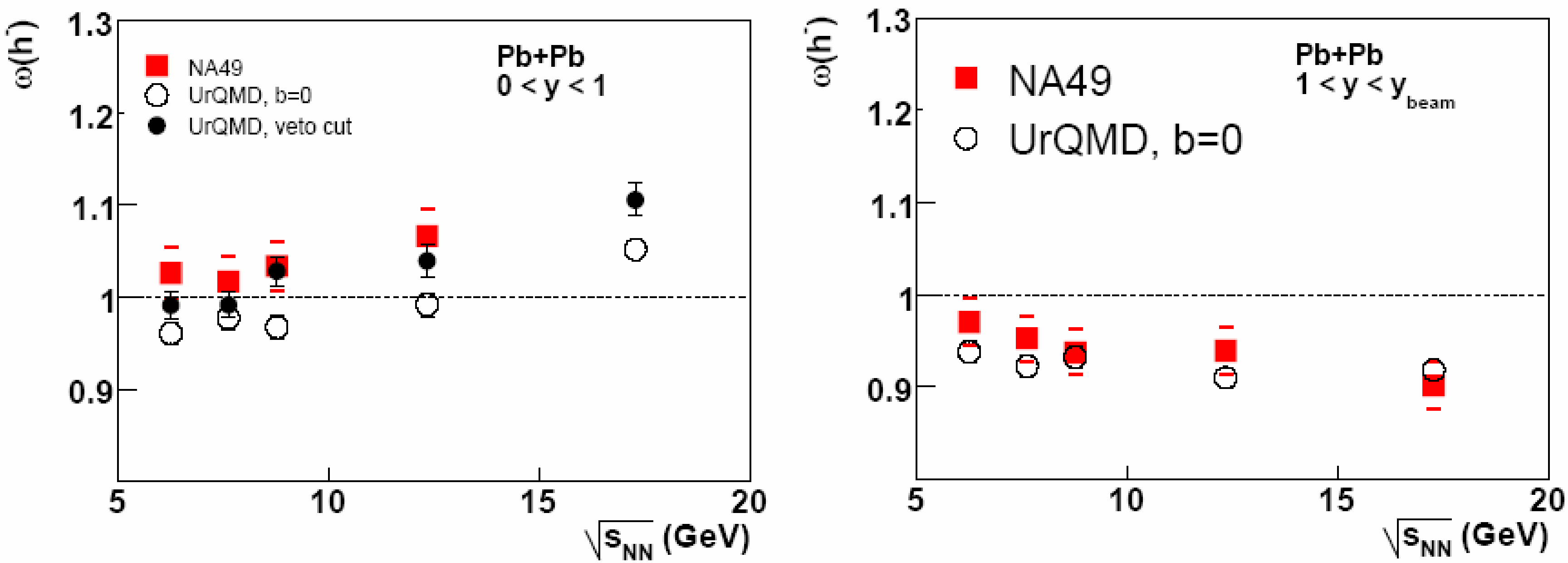


- fluctuations in central Pb+Pb collisions small, no anomalies
- results close to UrQMD and statistical model predictions

Event-by-event fluctuations of negative hadron multiplicity

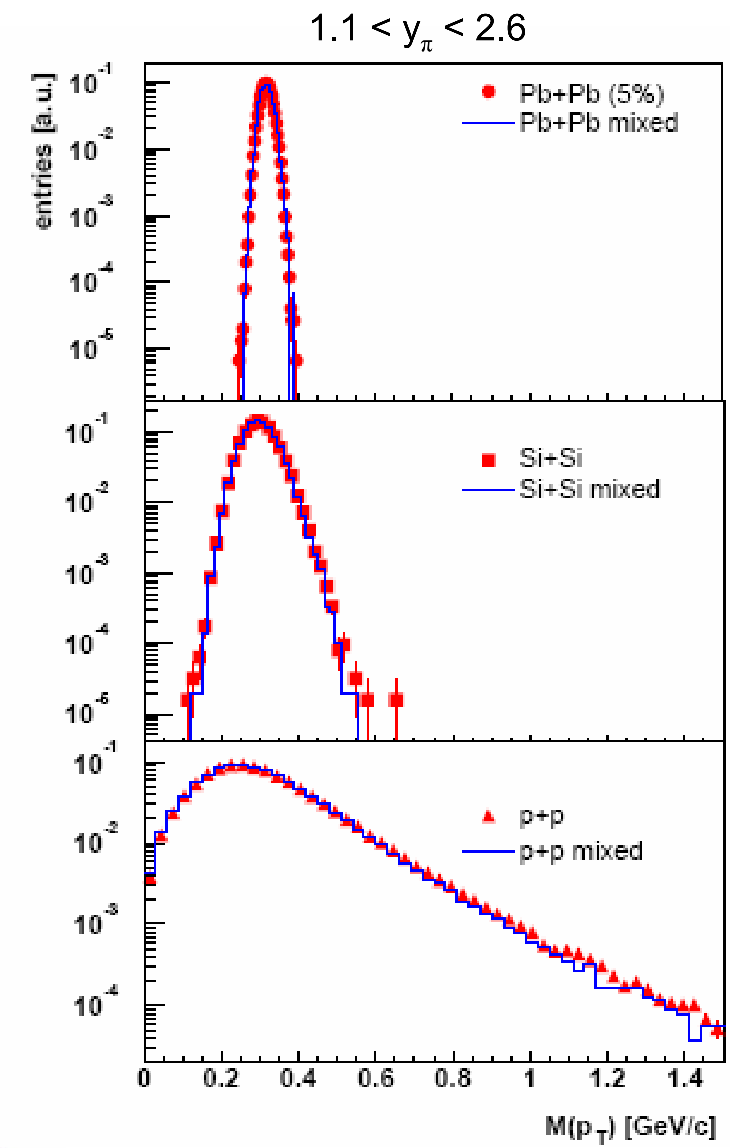
similar observations

near midrapidity for $p_T <$ 500 MeV/c



(Na49 preliminary)

Event-by-event fluctuations of <p_T> (negative hadrons)



- distributions of <p_T> similar for real and mixed events
- no evidence for distinct event classes
- non-statistical (dynamical) fluctuations are small, < few %

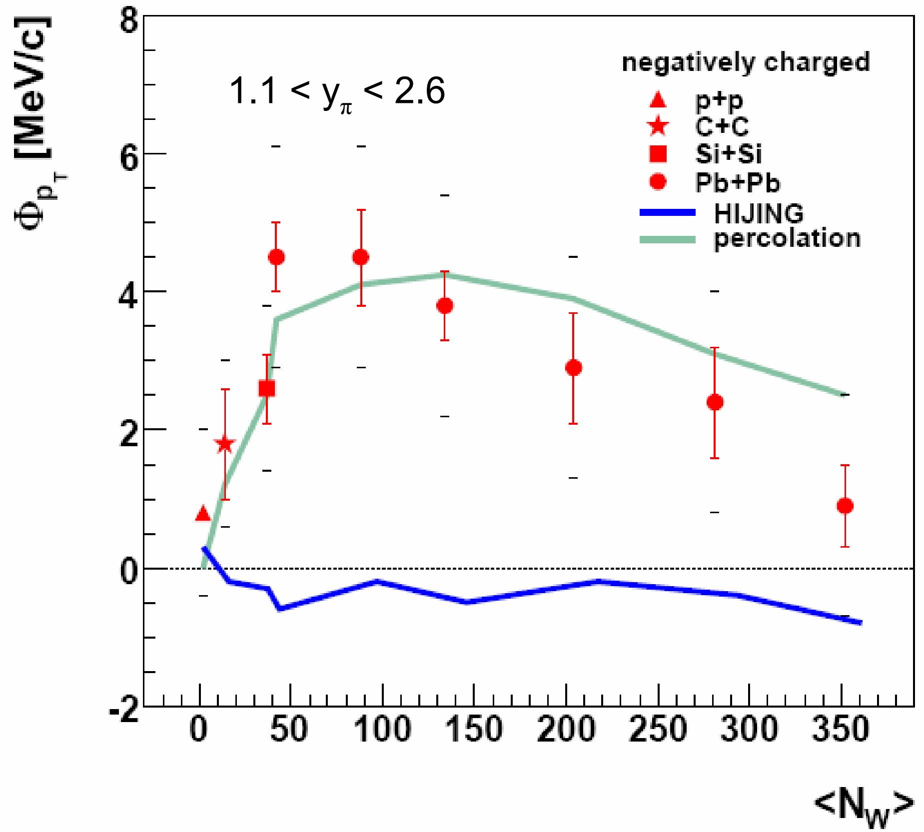
measure: Φ_{pT}

$$\Phi p_T = \sqrt{\frac{< Z^2 >}{< N >}} - \sqrt{< z^2 >}$$

$$z = p_T - <p_T> \qquad Z = \sum_{i=1}^{N} (p_T^i - <p_T>)$$

Event-by-event fluctuations of <p_T> (negative hadrons)

system size dependence at 158A GeV



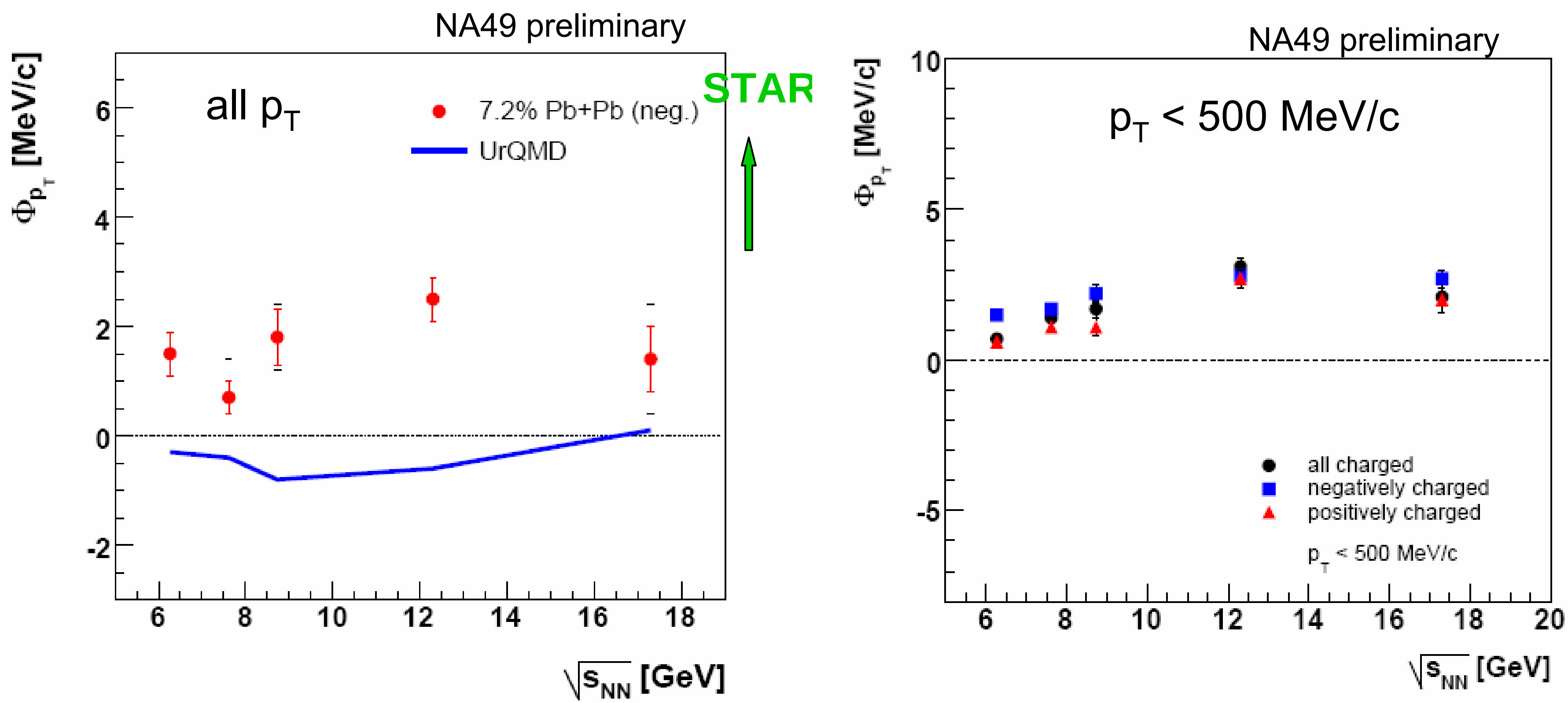
PRC70,034902(2004)

decrease towards central collisions; effect of string fusion ?

(E.Ferreiro et al, PRC 69, 034901 (2004))

Event-by-event fluctuations of <p_T> (negative hadrons)

energy dependence (1.1 < y_π < 2.6)

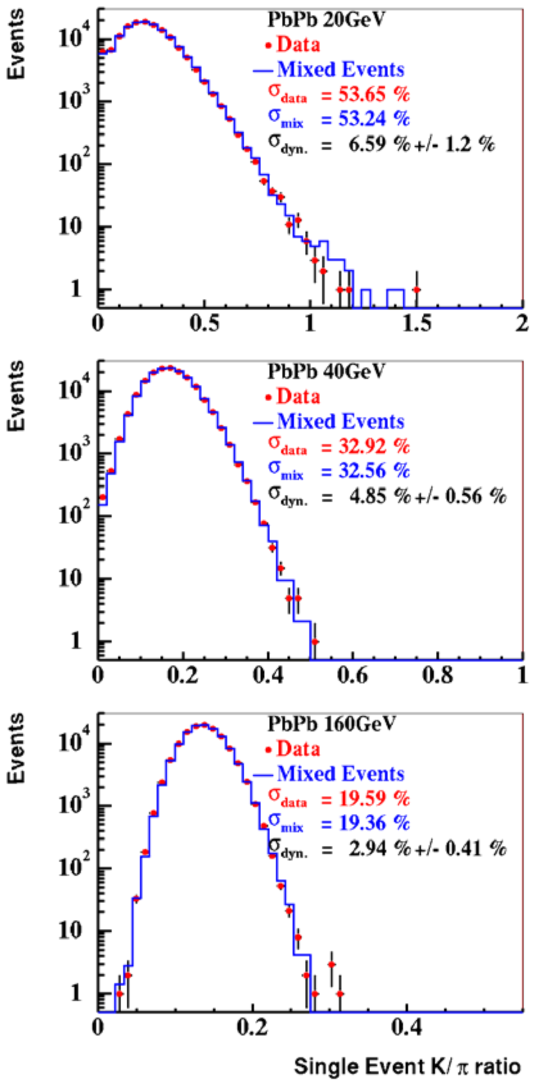


- no significant change with energy at SPS for central Pb+Pb collisions
- no indication of critical point (maximum of ≈ 8 MeV/c predicted)

(M. Stephanov)

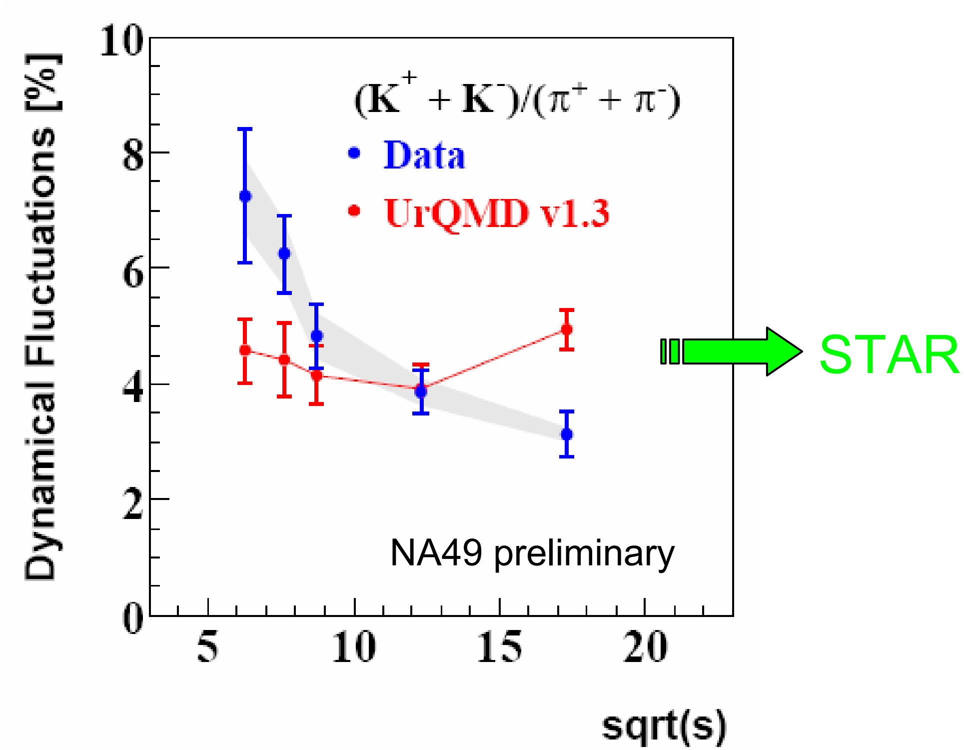
The Event-by-Event K/π ratio

Beam Energy



maximum likelihood fit for each event

$$\sigma^2_{dyn} = \sigma^2_{data} - \sigma^2_{mixed}$$



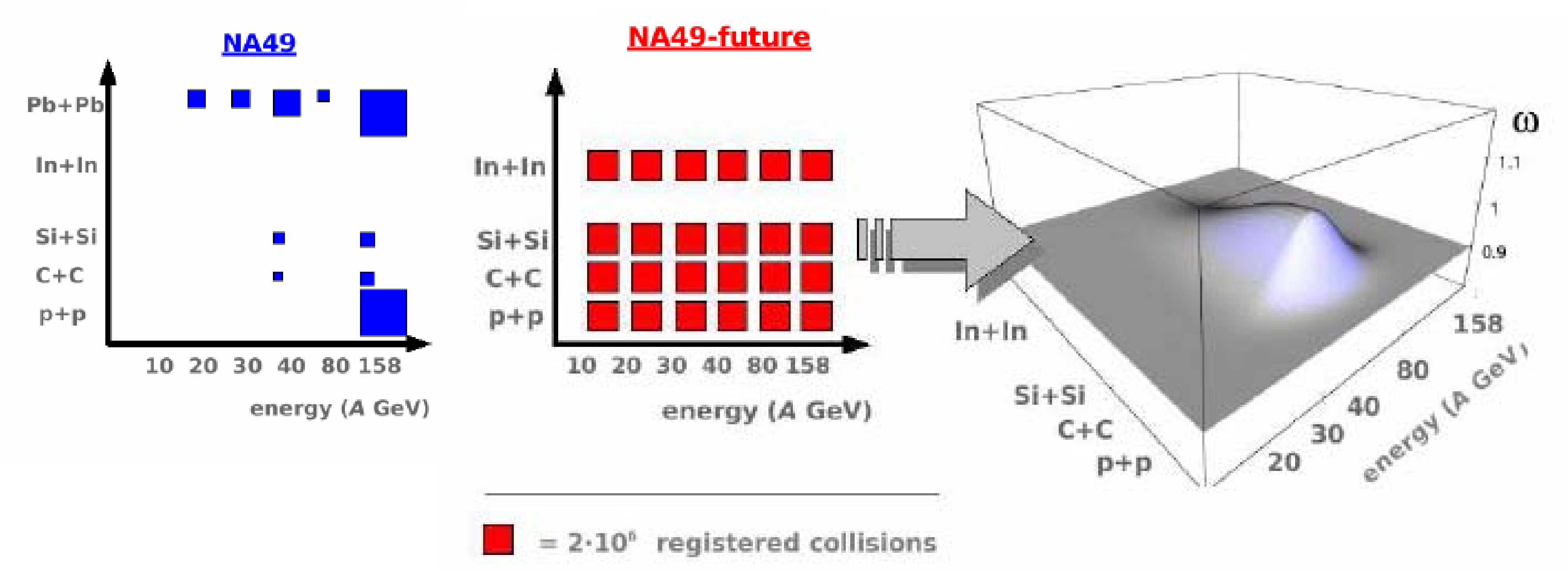
Fluctuations increase at lower energy
effect of onset of deconfinement ?

M.Gorenstein et al.,PLB585(2004)237

Future Plans

- Search for the QCD critical point in fluctuations
- Study details of the onset of deconfinement

  → scan SPS energies with smaller size nuclei



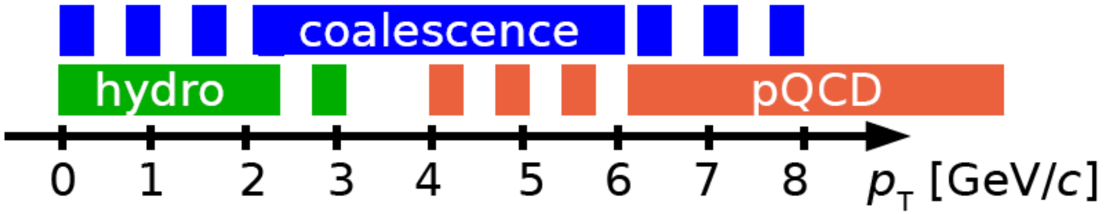
Experiment NA61 (upgraded NA49 detector) will start data taking with protons this year and with S ions in 2009

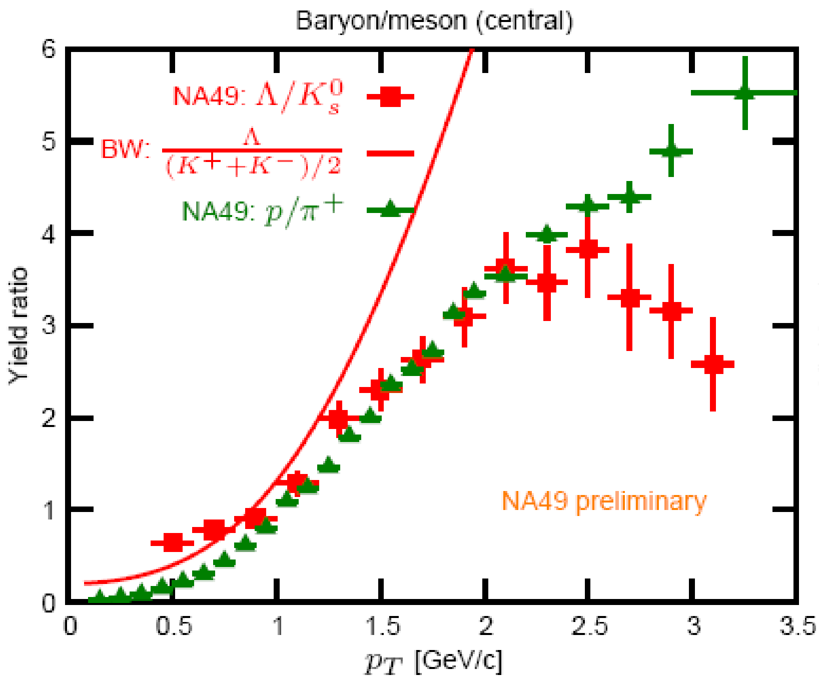
The NA49 Collaboration

C. Alt, T. Anticic, B. Baatar, D. Barna, J. Bartke, L. Betev, H. Białkowska, C. Blume, B. Boimska, M. Botje, J. Bracinik, R. Bramm, P. Bunčić, V. Cerny, **P. Christakoglou**, P. Chung, O. Chvala, J.G. Cramer, P. Csató, P. Dinkelaker, V. Eckhardt, D. Flierl, Z. Fodor, P. Foka, V. Friese, J. Gál, M. Gaździcki, V. Genchev, G. Georgopoulos, E. Gładysz, **K. Grebieszkow**, S. Hegyi, C. Höhne, K. Kadija, A. Karev, D. Kikola, M. Kliemant, S. Kniege, **V.I. Kolesnikov**, E. Kornas, R. Korus, M. Kowalski, I. Kraus, M. Kreps, **A. Laszlo**, R. Lacey, M. van Leeuwen, P. Lévai, L. Litov, **B. Lungwitz**, M. Makariev, A.I. Malakhov, M. Mateev, G.L. Melkumov, A. Mischke, M. Mitrovski, J. Molnár, S. Mrówczyński, V. Nicolic, G. Pálla, A.D. Panagiotou, D. Panayotov, W. Peryt, M. Pikna, J. Pluta, D. Prindle, F. Pühlhofer, R. Renfordt, **C. Roland, G. Roland**, **M. Rybczyński**, A. Rybicki, A. Sandoval, N. Schmitz, **T. Schuster**, P. Seyboth, F. Siklér, B. Sitar, E. Skrzypczak, M. Slodkowski, **G. Stefanek**, R. Stock, C. Strabel, H. Ströbele, T. Susa, I. Szentpétery, J. Sziklai, M. Szuba, P. Szymanski, V. Trubnikov, D. Varga, M. Vassiliou, G.I. Veres, G. Vesztergombi, D. Vranić, A. Wetzler, Z. Włodarczyk, A. Wojtaszek, and I.K. Yoo

Backup Slides

Intermediate p_T results (1)



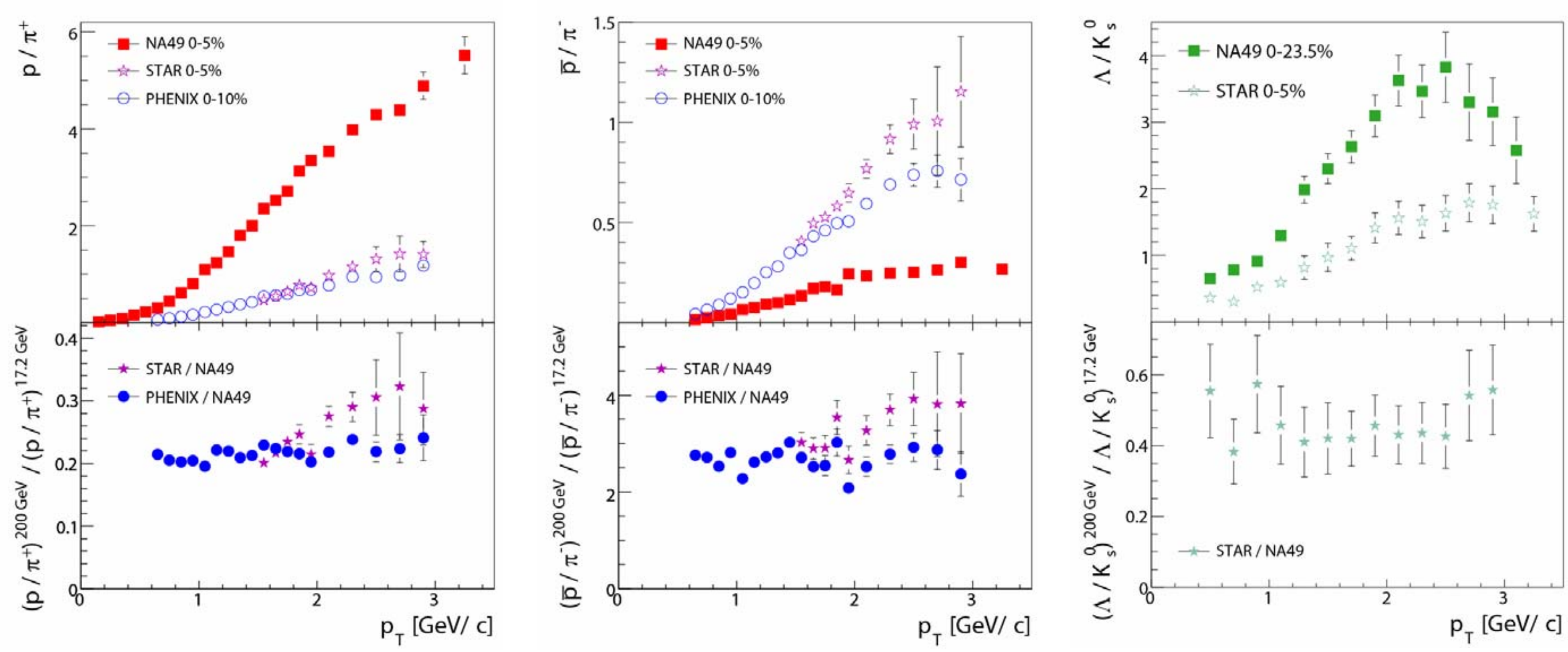


baryon/meson ratio

- rises rapidly with p_T
- deviates from blast-wave (hydro) for p_T > 1.2 GeV/c as at RHIC
- SPS data reach coalescence range but end below pQCD region

Intermediate p_T results (2)

Baryon/meson ratio at SPS vs RHIC



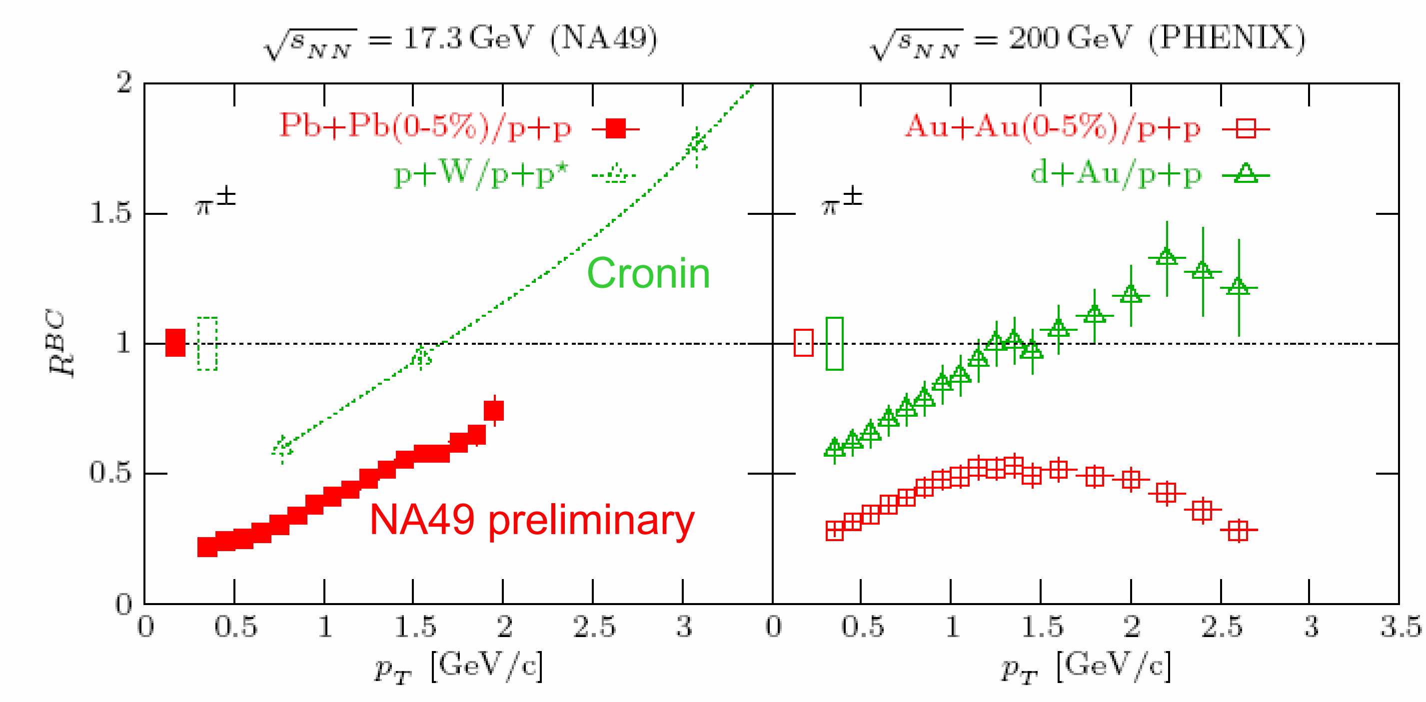
SPS: central Pb+Pb at $\sqrt{s}$= 17.3 GeV
RHIC: central Au+Au at $\sqrt{s}$= 200 GeV

- same relative increase with p_T at SPS and RHIC

Intermediate p_T results (3)

nuclear modification factor of pions at SPS and RHIC

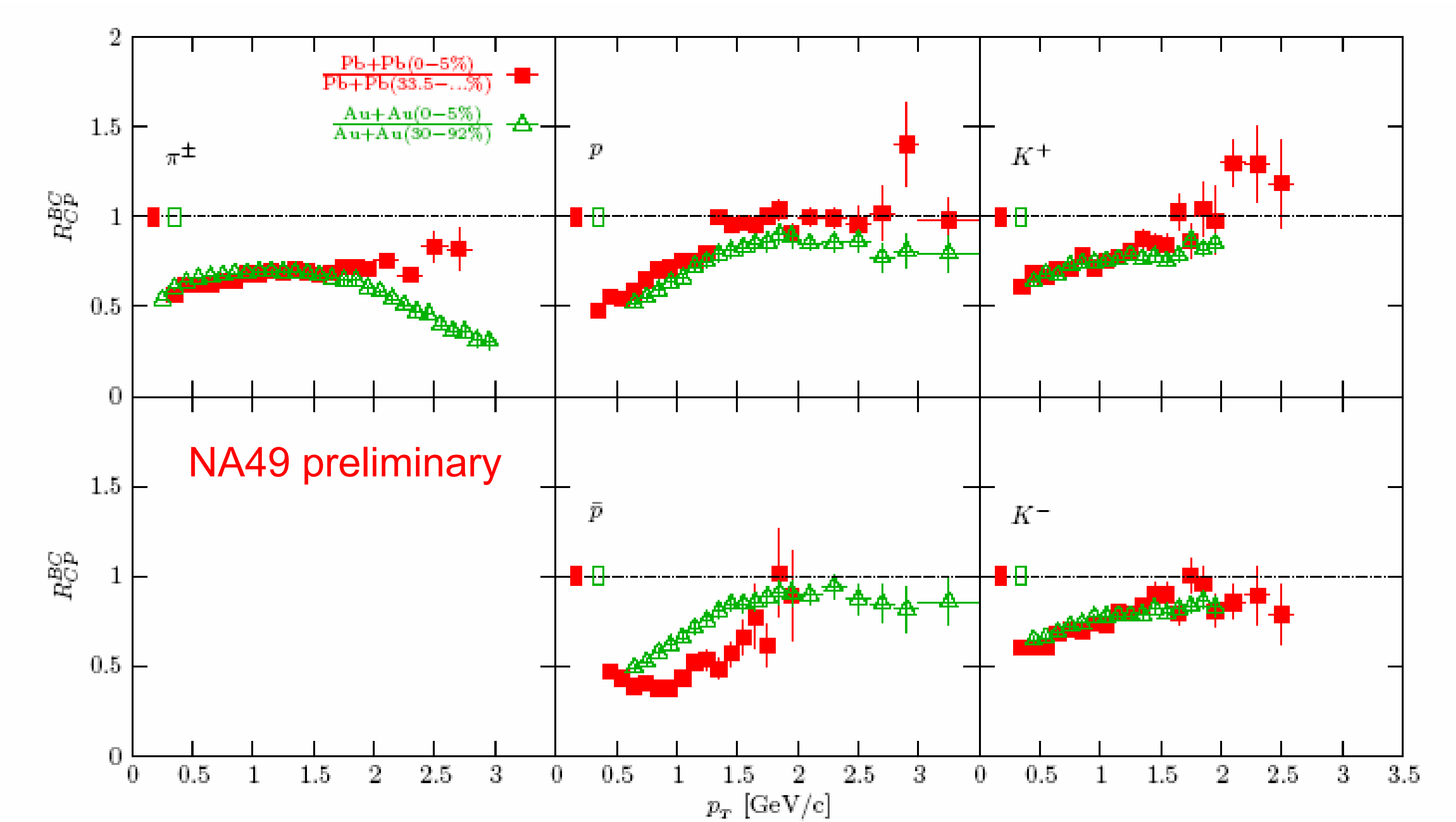
$$R_{AB}(p_t) = \frac{1}{\langle N_{coll}(AB)\rangle} \frac{d^2N_{AB}/(dp_t\,dy)}{d^2N_{pp}/(dp_t\,dy)} \qquad R_{CP}(p_t) = \frac{\langle N^P_{coll}(AA)\rangle}{\langle N^C_{coll}(AA)\rangle} \frac{d^2N^C/(dp_t\,dy)}{d^2N^P/(dp_t\,dy)}$$



- similar increase of ratio at SPS in pPb and PbPb (Cronin effect)
- R_{PbPb} stays below binary scaling like R_{AuAu} at RHIC

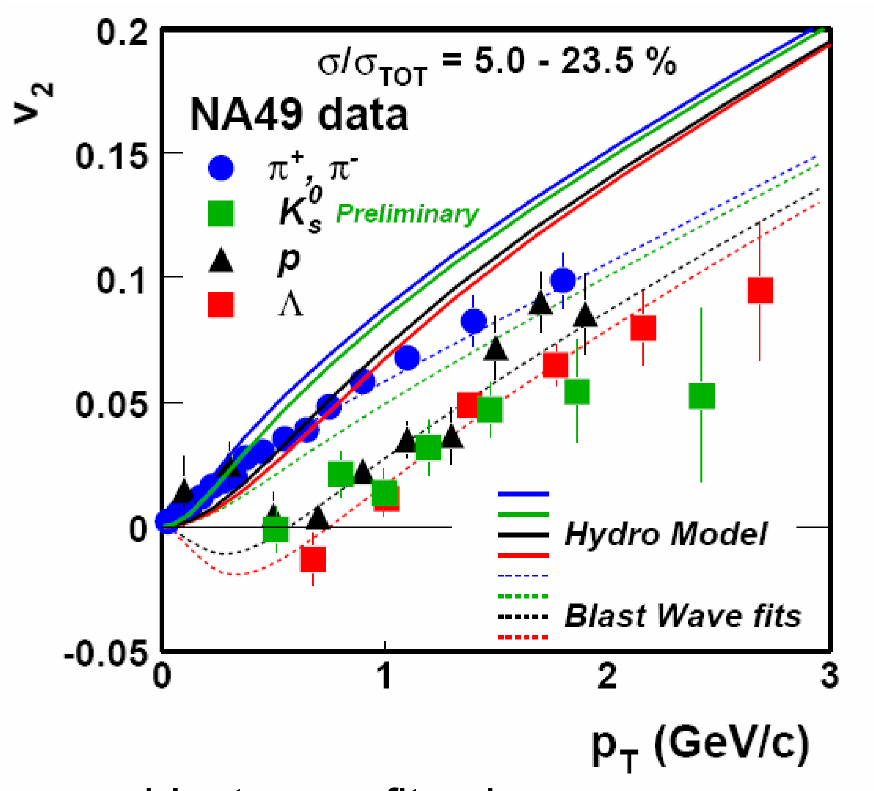
Intermediate p_T results (4)

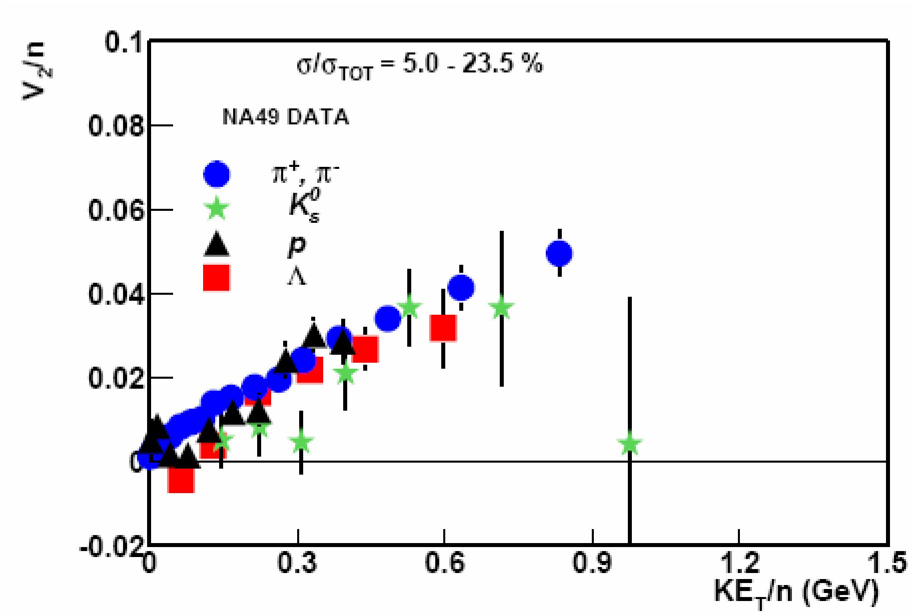
nuclear modification factor R_{CP} at SPS and RHIC



- trends of R_{CP} quite similar at SPS and RHIC
- p_T range at SPS not yet sufficient to establish suppression

elliptic flow v_2 in Pb+Pb collisions at 158AGeV





$KE_T = m_T - m$

(A.Adare et al.,PRL 98 (2007) 162301)

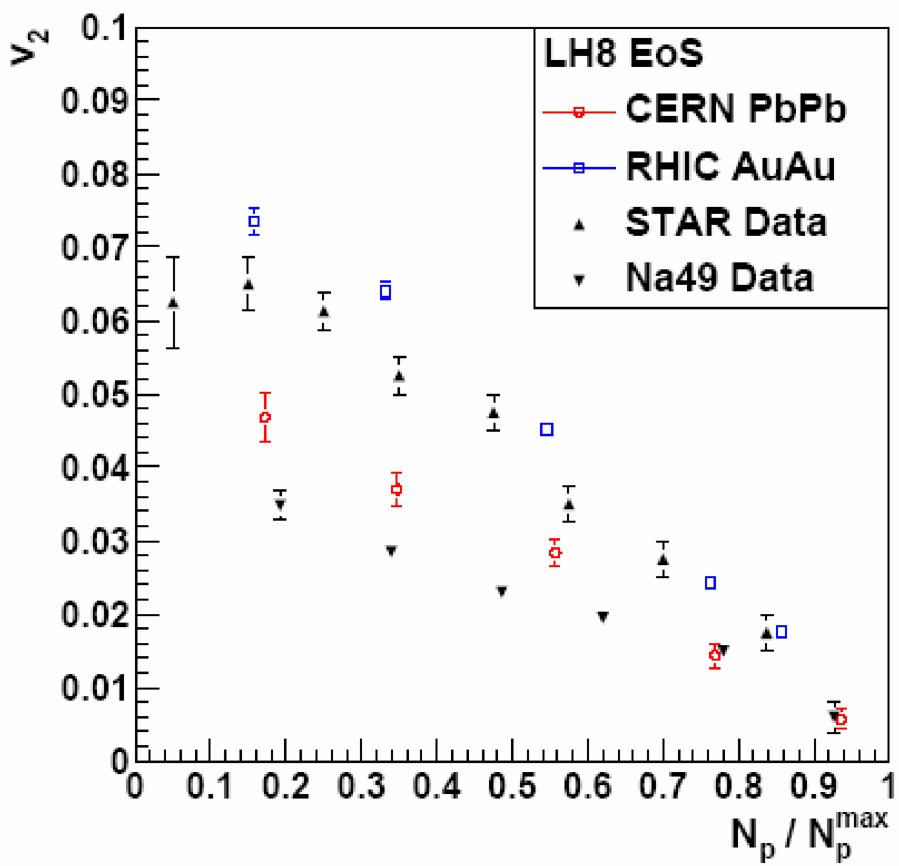
- blast wave fits ok
- overprediction by pure hydro model
- preliminary K^0_s unexpectedly low

- reasonable scaling also at SPS
- coalescence region not reached

more realistic freeze-out model

- QGP + hydro model expansion
- statistical hadronisation
- hadronic re-scattering stage (RQMD)

Teaney, Lauret, Shuryak
PRL 86 (2001) 4783

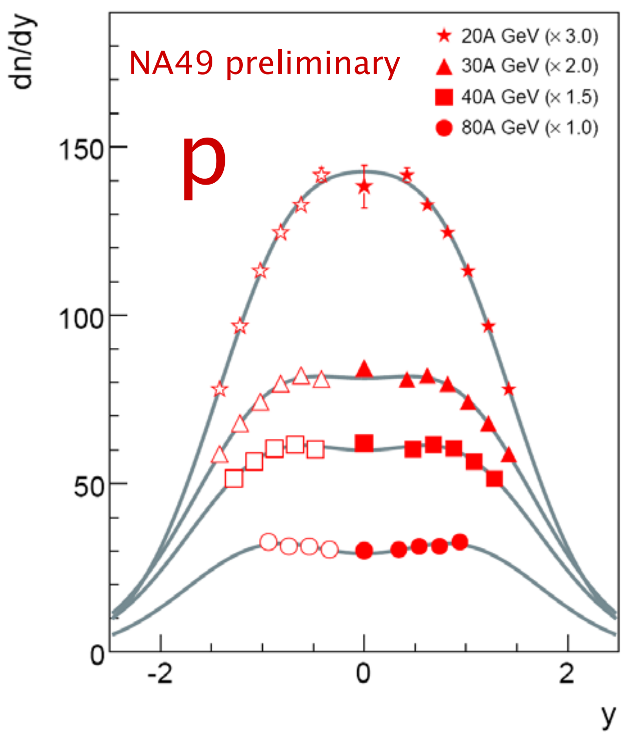


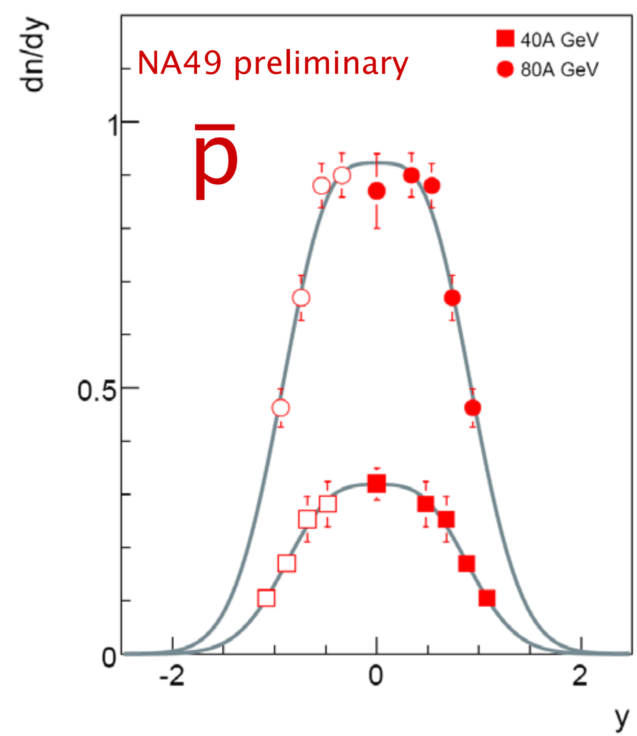
fair description
of SPS and RHIC data

Baryon stopping (1)

Proton and antiproton rapidity spectra in central Pb+Pb collisions

- new results from dE/dx analysis at forward rapidities
- published results from TOF analysis at midrapidity (PRC73(2006)044910)



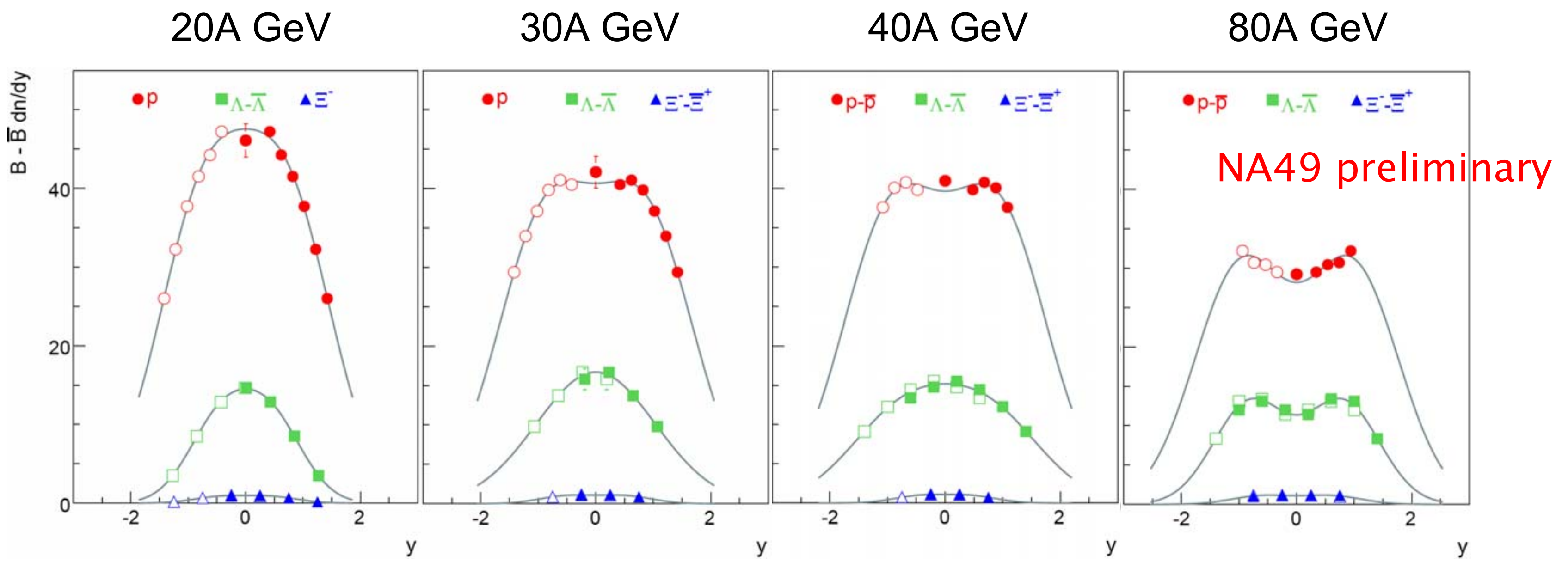


evolution of shape, decrease of yield

Gaussian shape, increase of yield

Baryon stopping (2)

net-baryon distributions in central 7% Pb+Pb collisions



construction of net-baryon distributions:

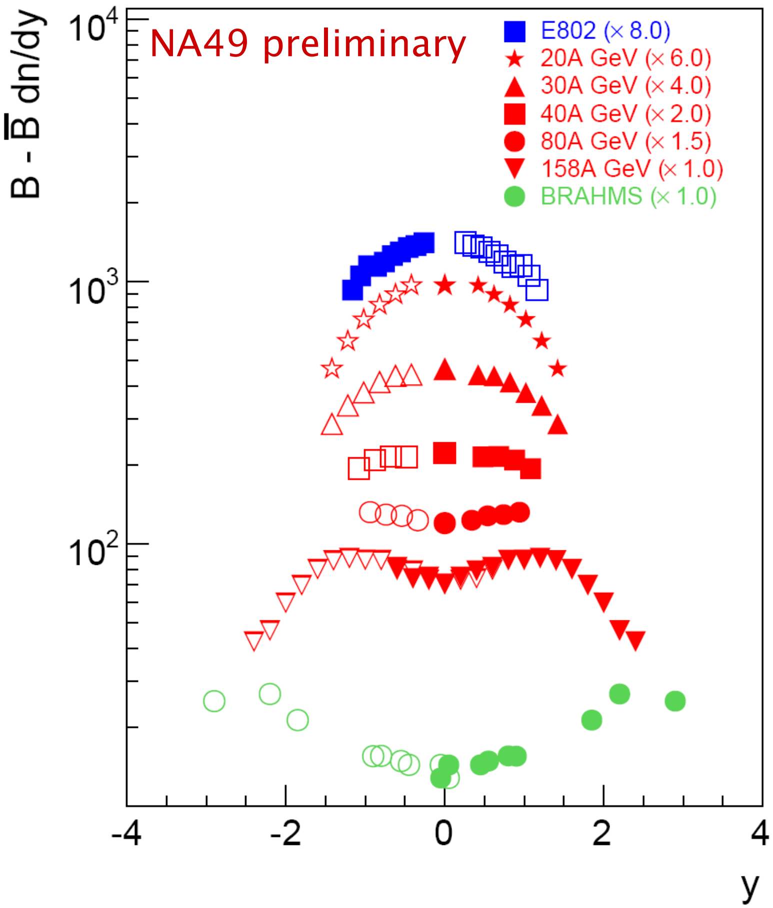
$$N(B-\overline{B}) = S_n \cdot (p-\overline{p}) + S_{\Sigma^\pm} \cdot (\Lambda-\overline{\Lambda}) + S_{\Xi^0} \cdot (\Xi^- - \overline{\Xi}^+)$$

scaling factors taken from statistical model fits

F.Becattini et al., PRC73 (2006) 044905

Baryon stopping (3)

evolution of net-baryon rapidity distributions

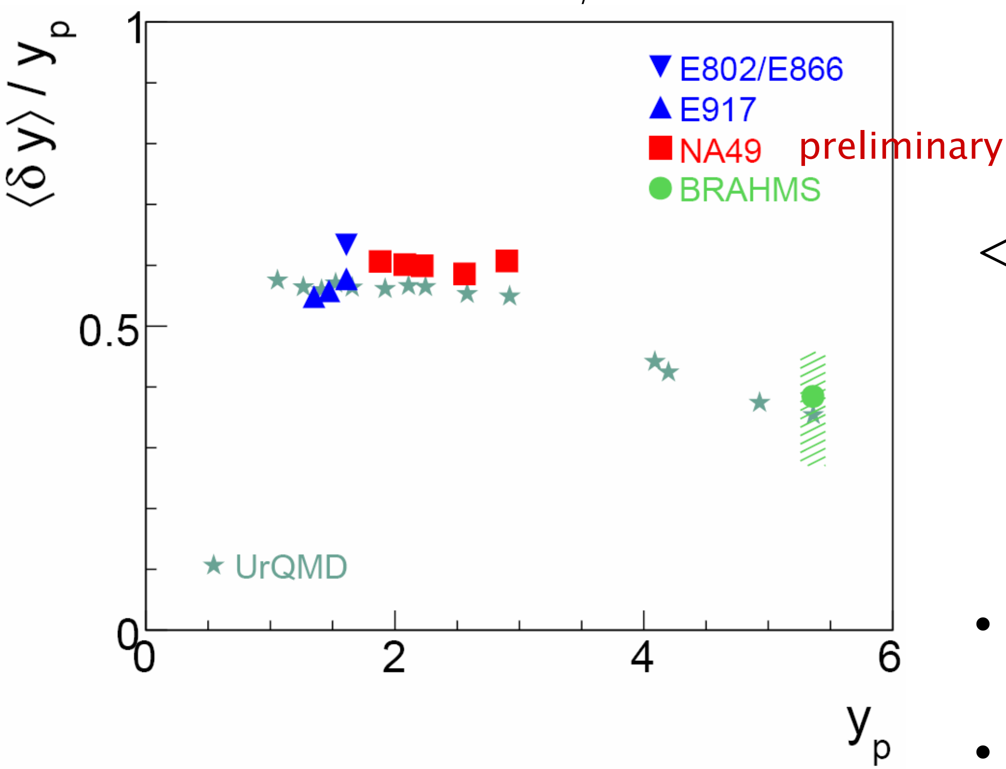


- pronounced change of shape at SPS energies
  peak → dip structure
- net-baryon density decreases rapidly at mid-rapidity

Baryon stopping (4)

energy dependence of projectile rapidity loss $<\delta y>/y_p$

Central Pb+Pb/Au+Au



$$< \delta y > \; = y_p - <y>$$

$$= y_p - \frac{2}{N_{part}} \int_0^{y_p} y \frac{dN_{B-\bar{B}}}{dy} dy$$

- at AGS, SPS constant ≈ 0.6
  decrease at RHIC energies
- reproduced by UrQMD $<x_F>$≈ 0.38

(UrQMD: M.Bleicher, Florence Workshop)

Baryon stopping (5)

energy dependence of inelasticity K

Energy of single net-baryon:

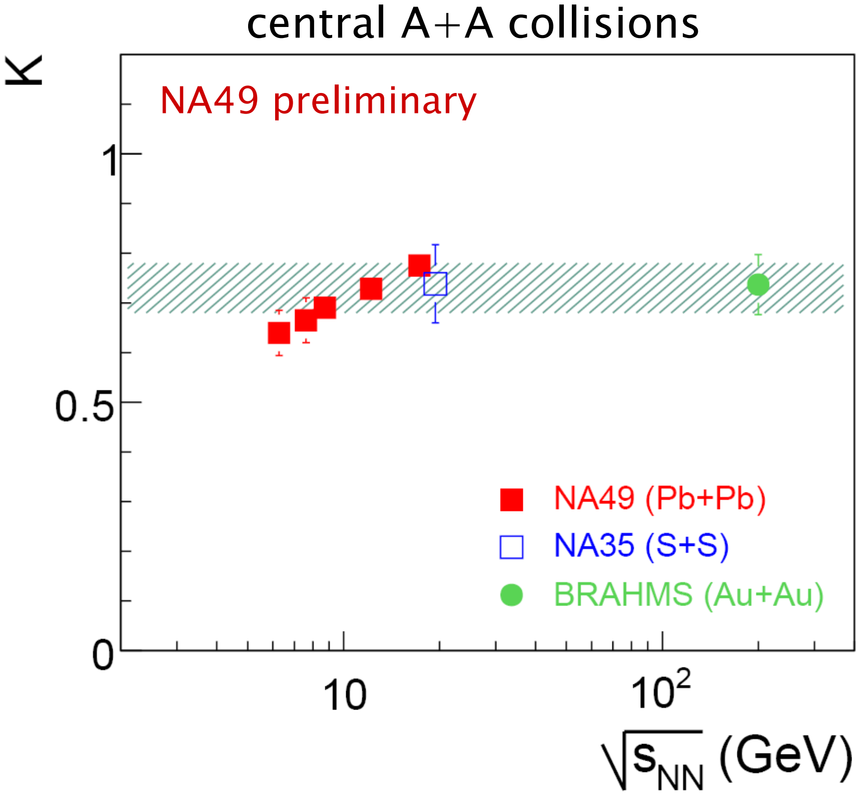
$$E_{B-\bar{B}} = \frac{1}{N_{B-\bar{B}}} \int_{-y_p}^{y_p} \langle m_T \rangle_y \frac{dN_{B-\bar{B}}}{dy} \cosh(y)\, dy$$

Total inel. energy per net-baryon:

$$E_{inel} = \frac{\sqrt{s_{NN}}}{2} - E_{B-\bar{B}}$$

Inelasticity:

$$K = \frac{2\,E_{inel}}{\sqrt{s_{NN}} - 2m_p}$$

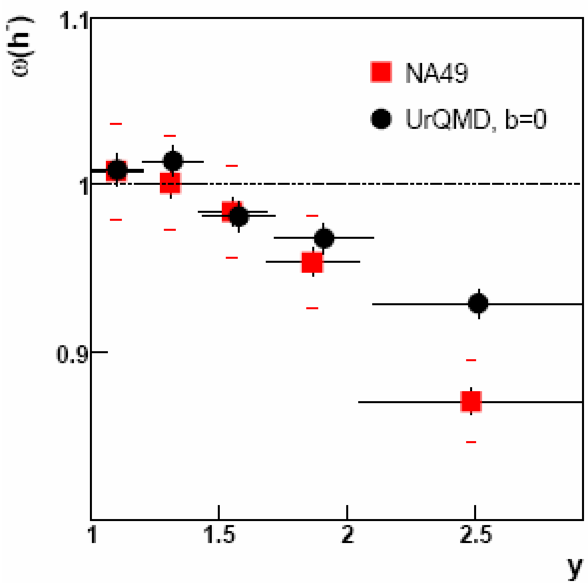


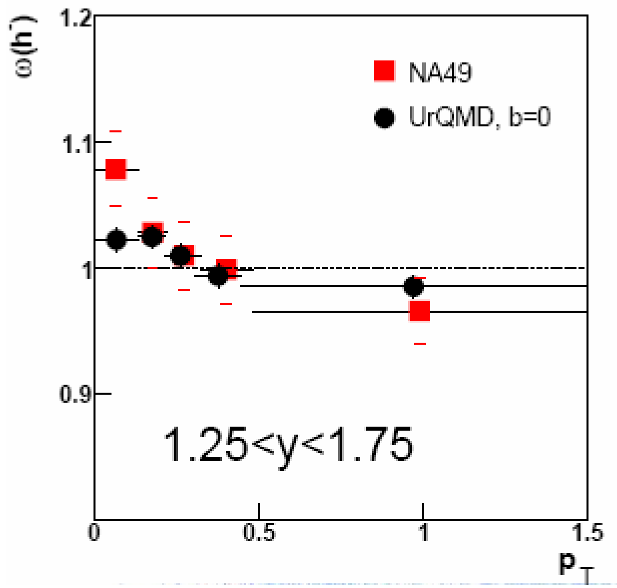
Inelasticity saturates at K = 0.7-0.8 above SPS

Event-by-event fluctuations of negative hadron multiplicity

rapidity and p_T dependence at 158A GeV

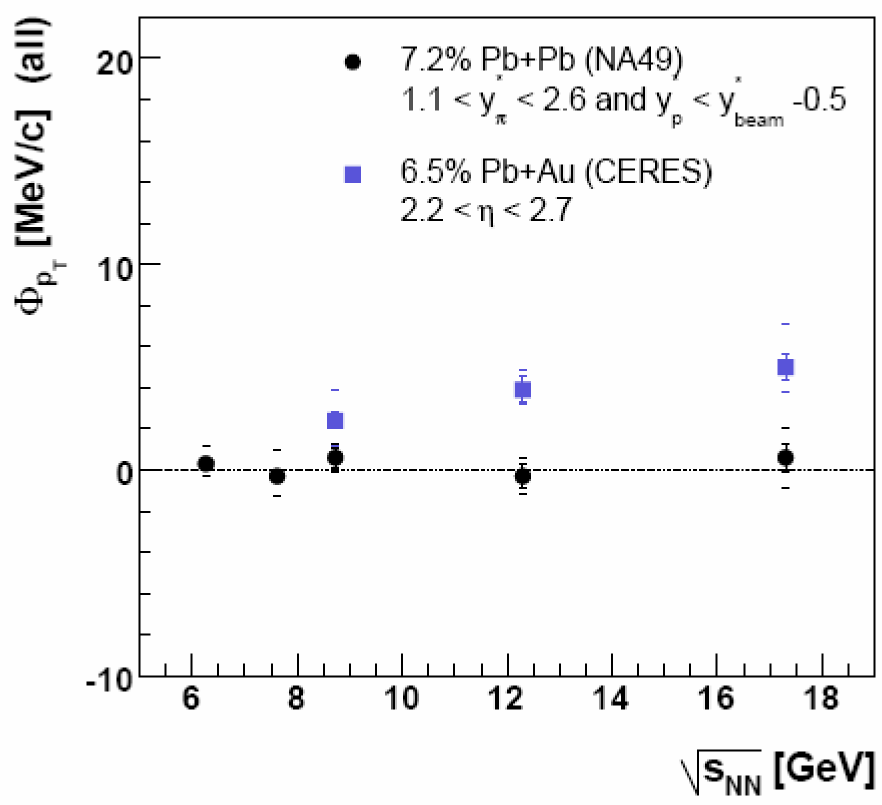
NA49 preliminary



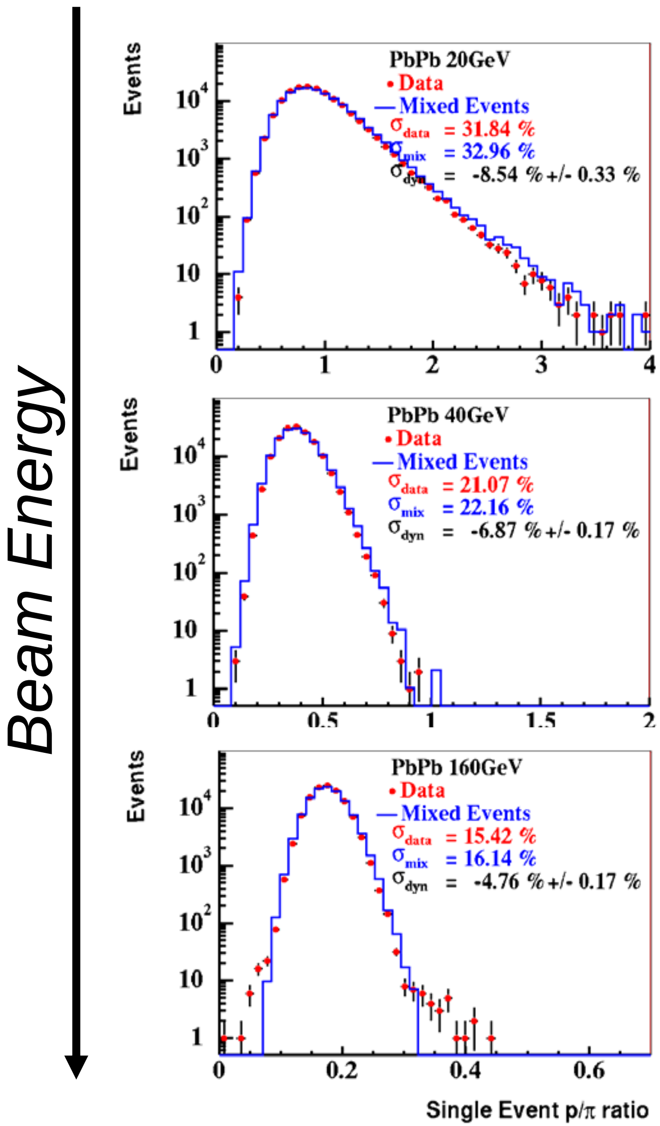


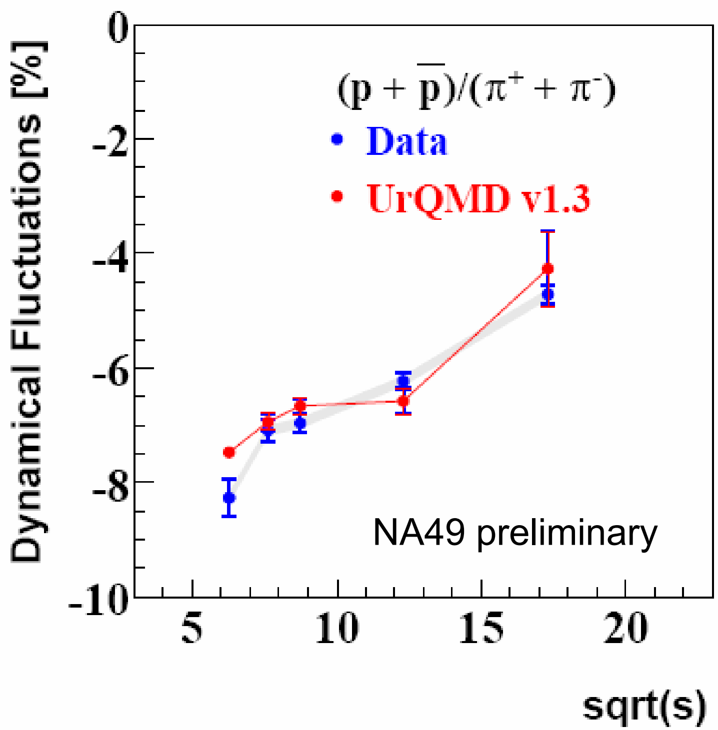
rapidity and p_T dependence reproduced by the UrQMD model

Event-by-event fluctuations of $<p_T>$ at SPS



The Event-by-Event $(p + \overline{p})/\pi$ ratio





The distribution of the E-by-E p/π ratio is narrower for data than mixed events.
Effect of baryon resonance decay ?

Pb+Pb collisions at top SPS energy

- Initial energy density exceeds the critical value predicted by lattice QCD (≈ 1 GeV / fm^3)
- Strong collective behavior
  - anisotropic and radial flow
  - transverse expansion of the matter droplet by factor 2
- Proposed signatures for deconfinement observed
  - strangeness enhancement
  - J/Ψ,Ψ' yield suppression
  - di-lepton enhancement, ρ^0 modification

  (circumstantial evidence for a new state of matter (2000)

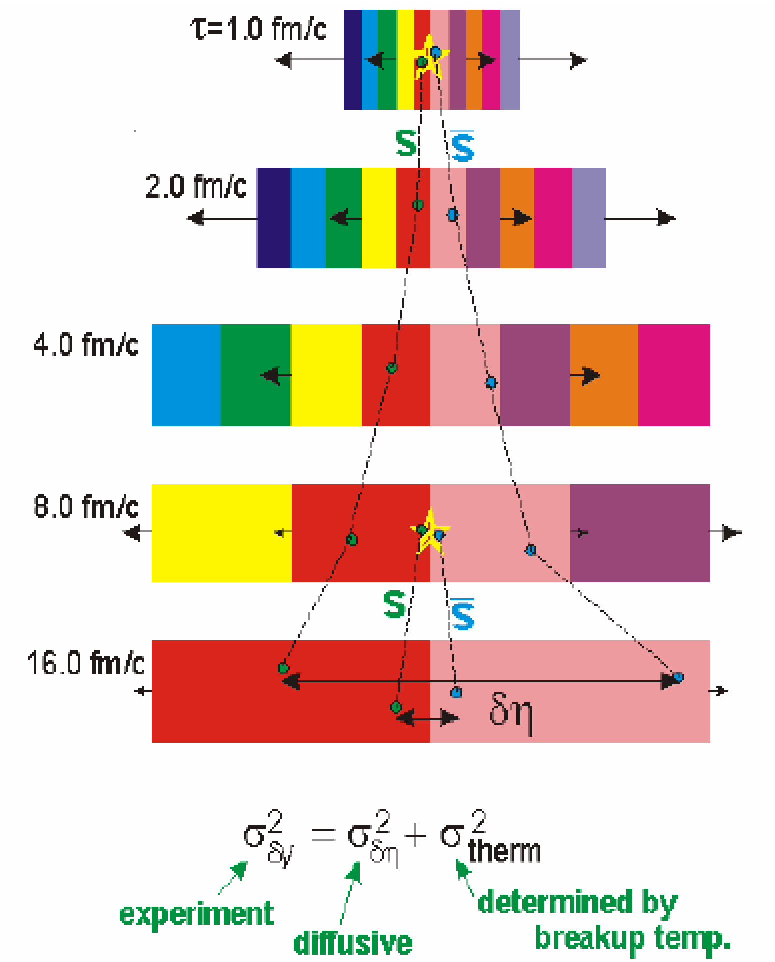
➢ Validate by a search for a threshold in the largest collision system (central Pb+Pb reactions)

➢ SPS energy scan: 20, 30, 40, 80, 158 GeV/nucleon

($\sqrt{s_{NN}}$ = 6.3, 7.6, 8.7, 12.3, 17.3 GeV)

Balance Function

Bass,Danielewicz,Pratt: PRL 85,2689(2000)



- oppositely charged particles created at the same point in space – time
- particles get separated in rapidity by thermal motion (rescattering) and developing collective flow
- early produced pairs are separated more in rapidity than late produced pairs
- separation δη quantified by the balance function:

$$B(\delta\eta) = \frac{1}{2}\left(\frac{N_{(+-)}(\delta\eta) - N_{(--)}(\delta\eta)}{N_-} + \frac{N_{(-+)}(\delta\eta) - N_{(++)}(\delta\eta)}{N_+} \right)$$

delayed hadronisation =
narrowing of balance function
predicted as signature of
first order phase transition