Rapidity dependence of of Particle Production

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Outline

- Collision Geometry and rapidity distribution.
- Brahms Setup and experimental methods.
- Proton Anti-proton distributions (Net baryons, stopping)
  - Transverse momentum spectra and rapidity distributions
  - Determining net-proton distribution and rapidity loss.
- Produced hadrons (Kaons, pions)
  - Transverse momentum spectra and rapidity distributions
  - Energy systematic
- Thermodynamic properties
  - Chemical and kinetic expansion and freeze-out
- Summary

- Initial scattering of two contracted relativistic Nuclei.
- (z,ct) picture –
  - initial parton cascading (ct~1 fm)
  - Hydro development
  - Chemical freeze out, kinetic freeze-out
  - The freezeout surfaces are reflected in rapidity/angular distribution
- Bjorken Picture dN/dy flat, transparent, properties independent of frame (y).
- How far in rapidity is the systems thermalized..

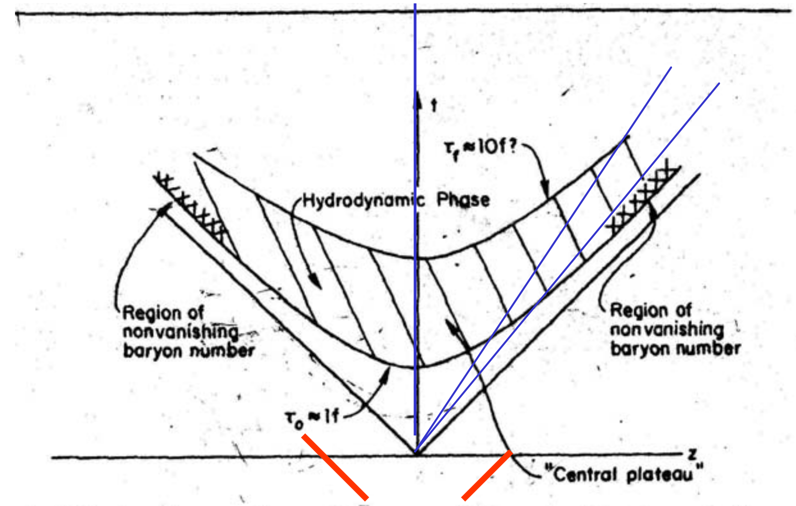


FIG. 3. Space-time diagram of longitudinal evolution f the quark-gluon plasma.

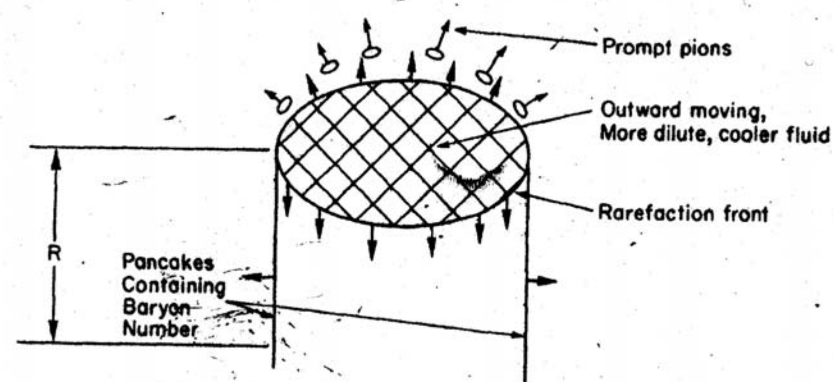


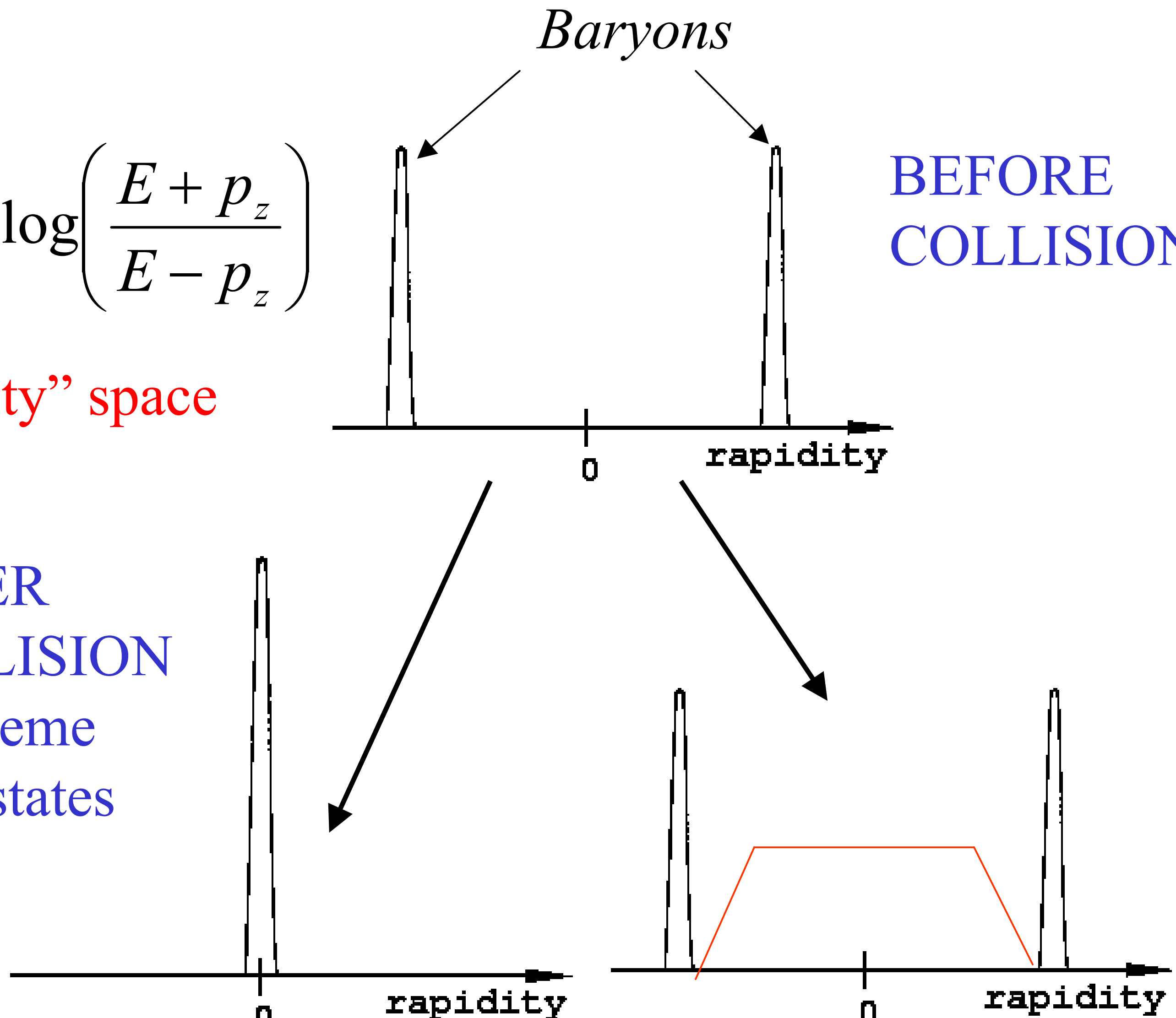
FIG. 4. Geometry of fluid expansion near the edge of the nuclei.

J.D.Bjorken,PRD 27,140 (1983)

$$y = \frac{1}{2}\log\left(\frac{E + p_z}{E - p_z}\right)$$

"Velocity" space

BEFORE COLLISION

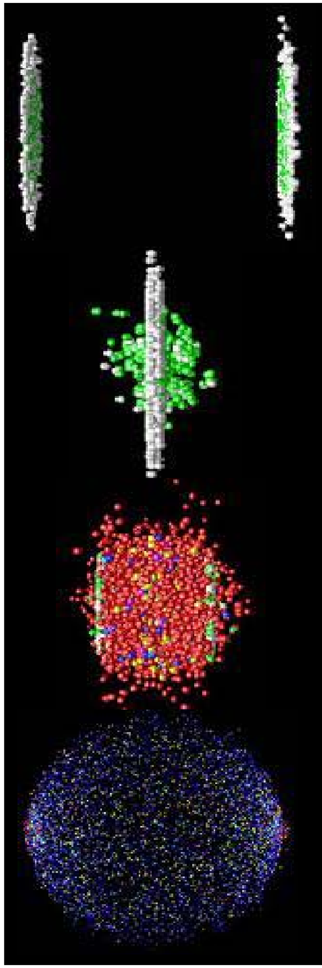


AFTER COLLISION
2 extreme final states

Full stopping

Full transparency

Physical space

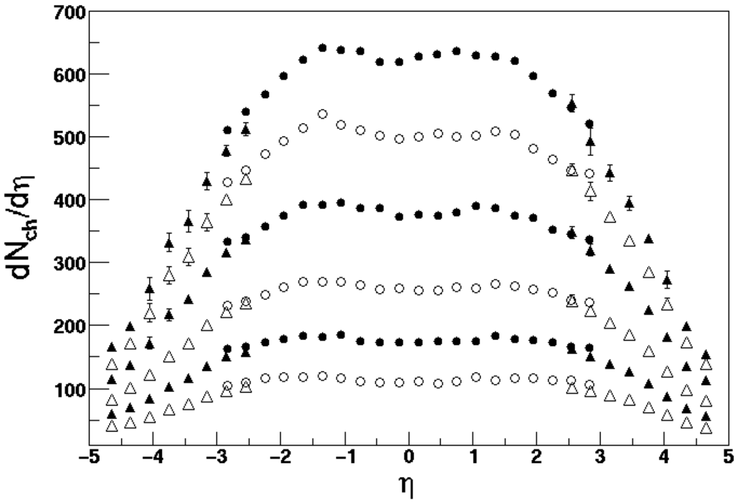


VNI sim.

Charged particle η - distributions

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

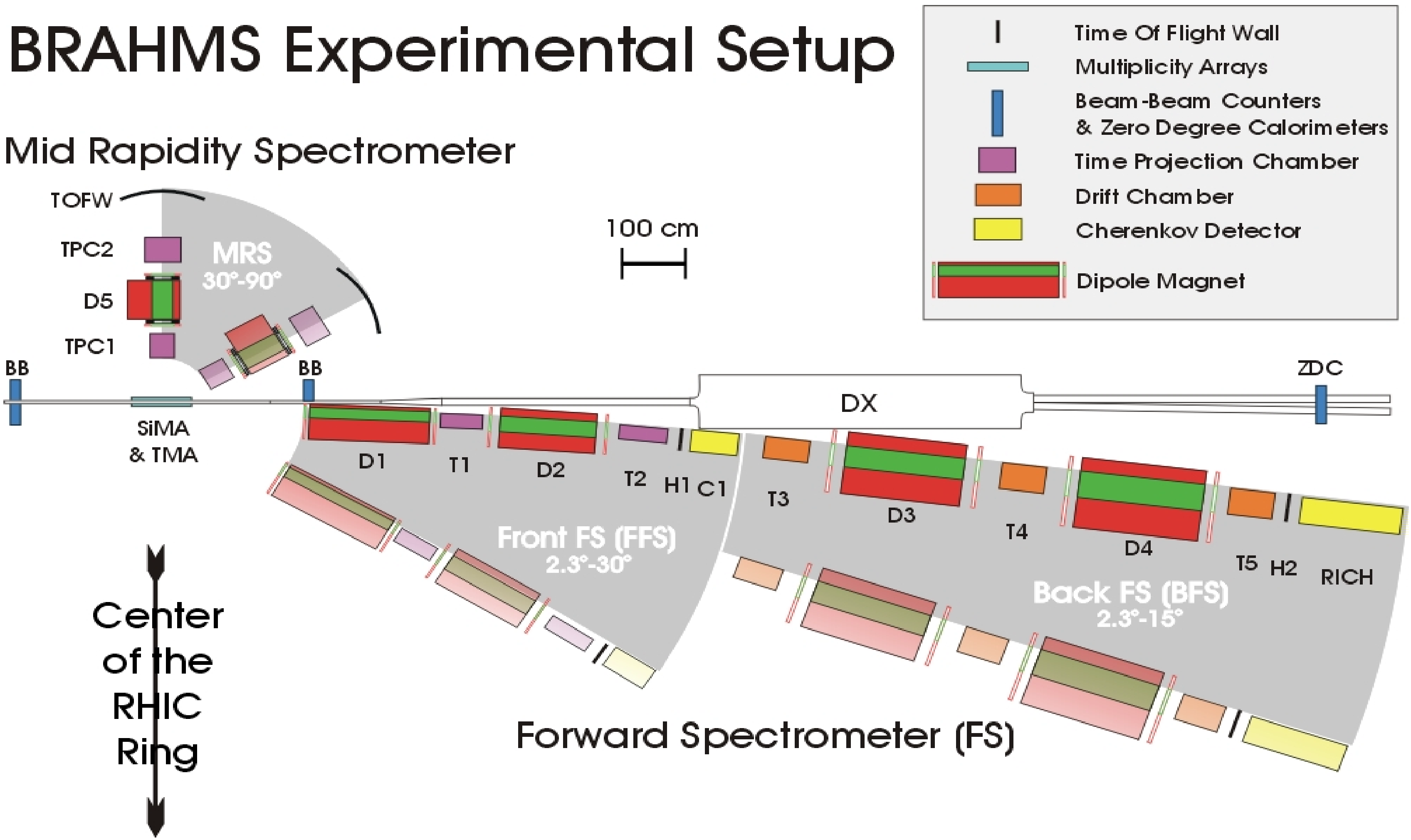
- dN/dη ‘flattish’ (as discuss earlier today)
- Part of the shape is effected by the use of η rather the y.
- Following data are for central collisions



I. G. Bearden et al.(BRAHMS Collaboration) Phys. Rev. Lett. **88**, 202301 (2002)

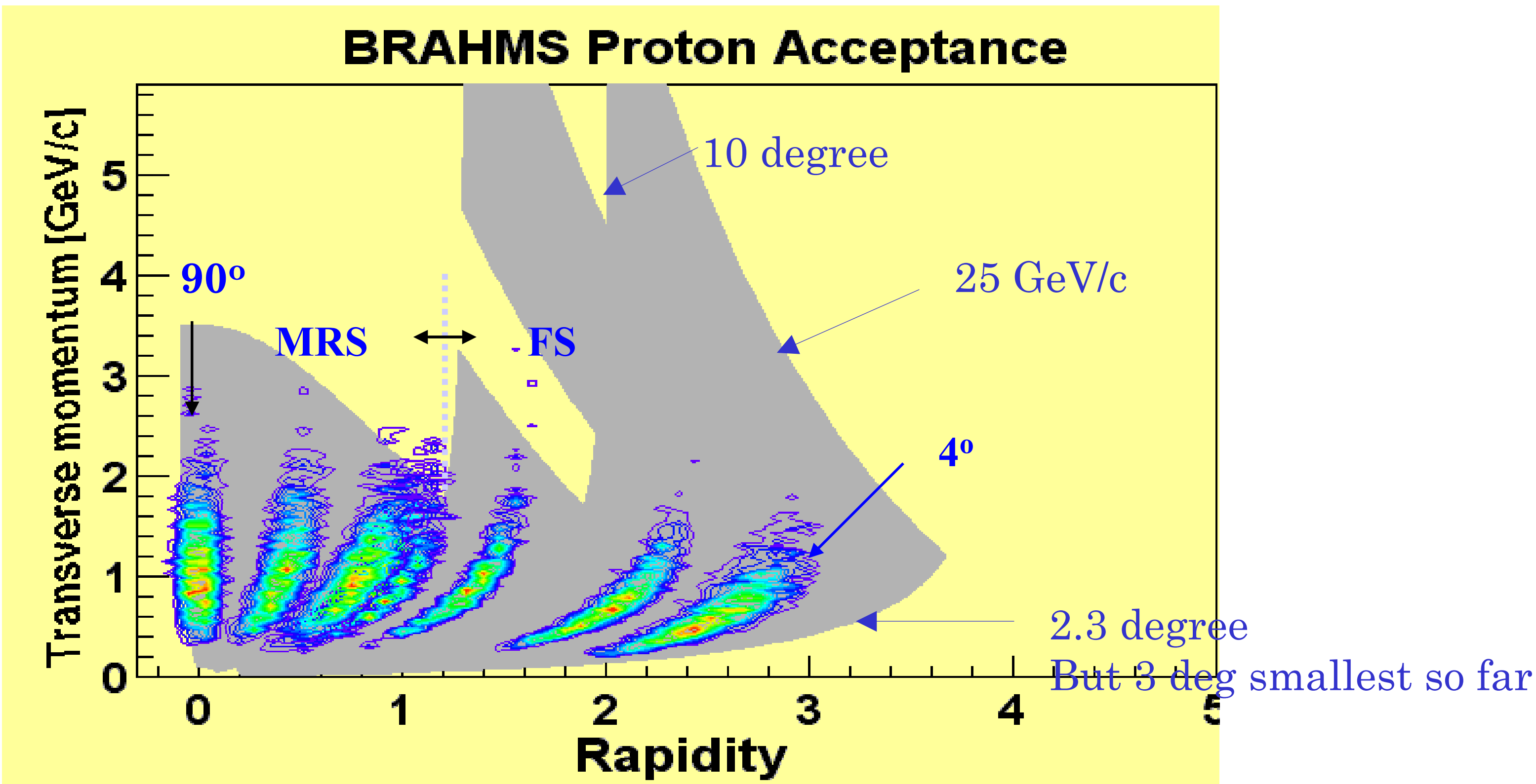
The BRAHMS experiment

Setup for Au+Au data in 2001-2002

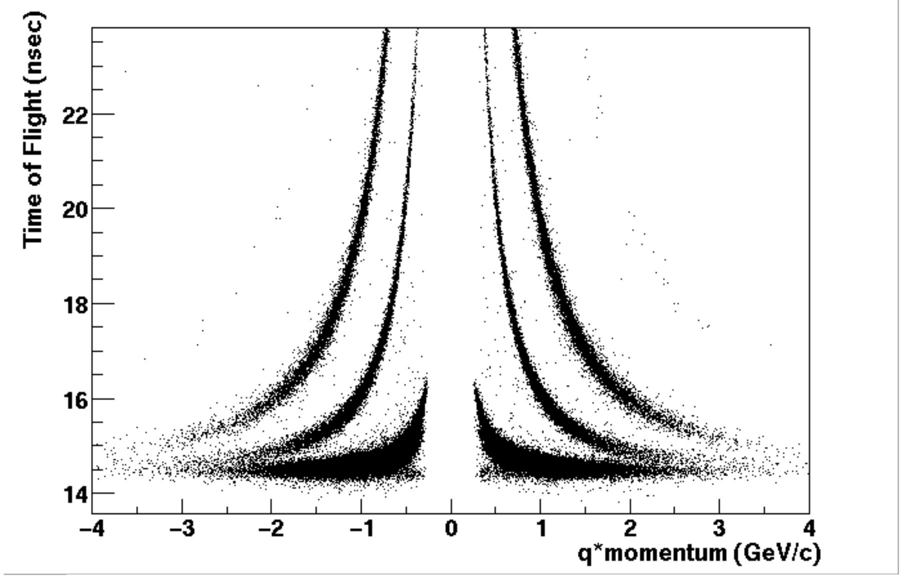


BRAHMS Acceptance

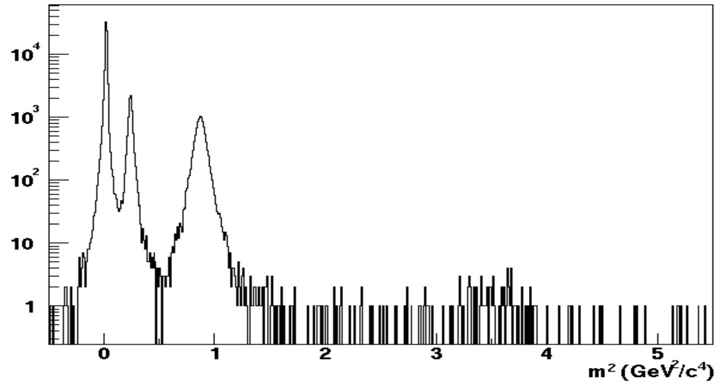
A wide range of y and pt is covered
by rotating two spectrometers with various magnetic fields.

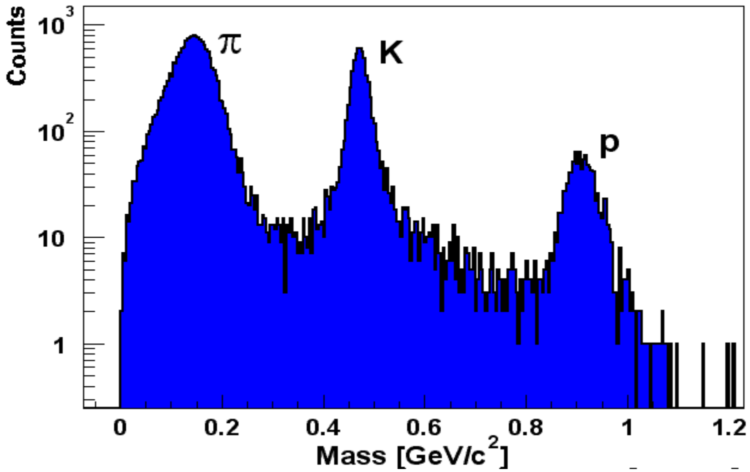


Particle identification.



- 125 slats: time of flight resolution ~ 75*p*sec
- pi/K separation ~ up to 2.5 GeV/c
- K/p separation ~ up to 4 GeV/c
- RICH at high P in FS.

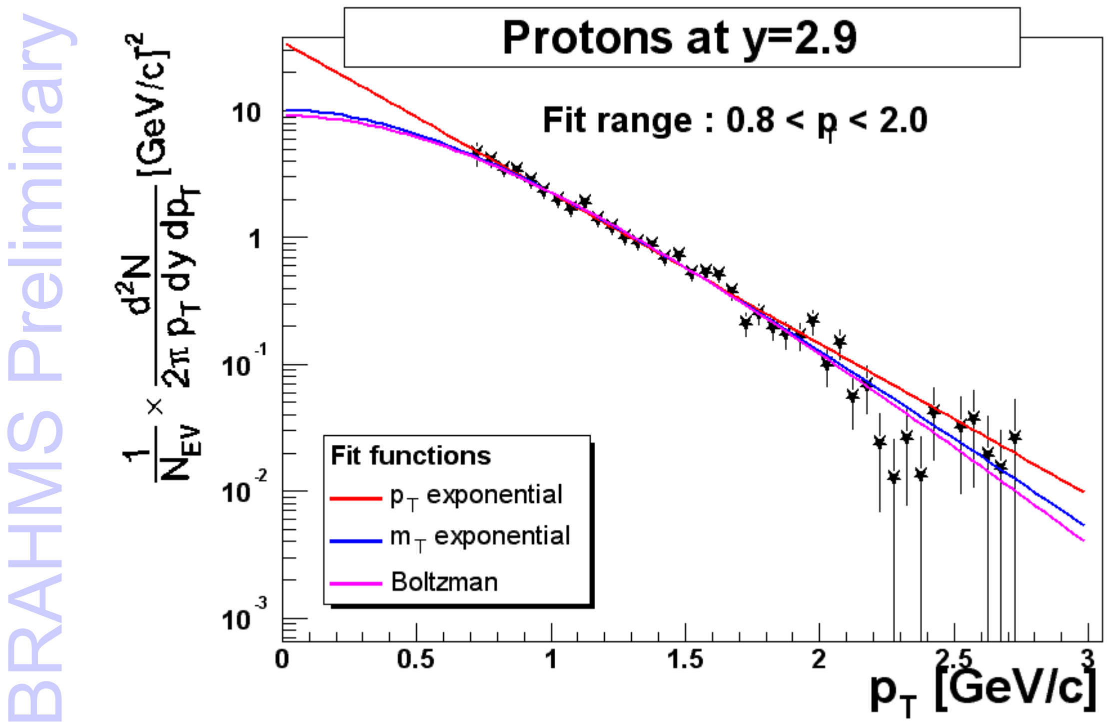




Proton , and Net-Proton Distributions

- The net-baryon rapidity distributions are though to reflect the initial re distribution of baryonic matter in the very first moment of the collisions. Due to the large mass subsequent expansion and re-scattering will not result in a significant rapidity change.
- It is important to consider net-Protons i.e. N(B)-N(B-bar) since there is a significant 'pair' production at high energy.
- The net-p is used as a measure for the net-baryon which is only accessible via a measurement of the neutrons too.

Depenence on assumed spectral shapes



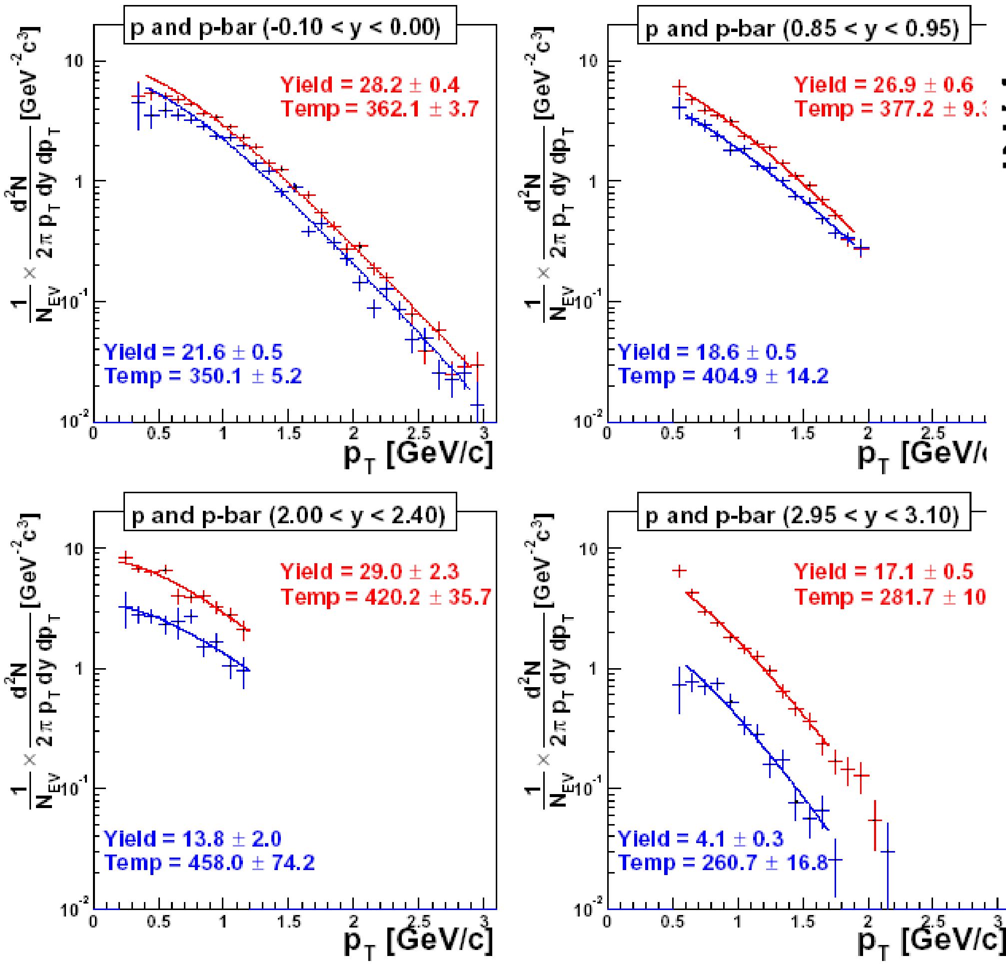
There is a 20% yield difference between p_T and m_T exponentials, =

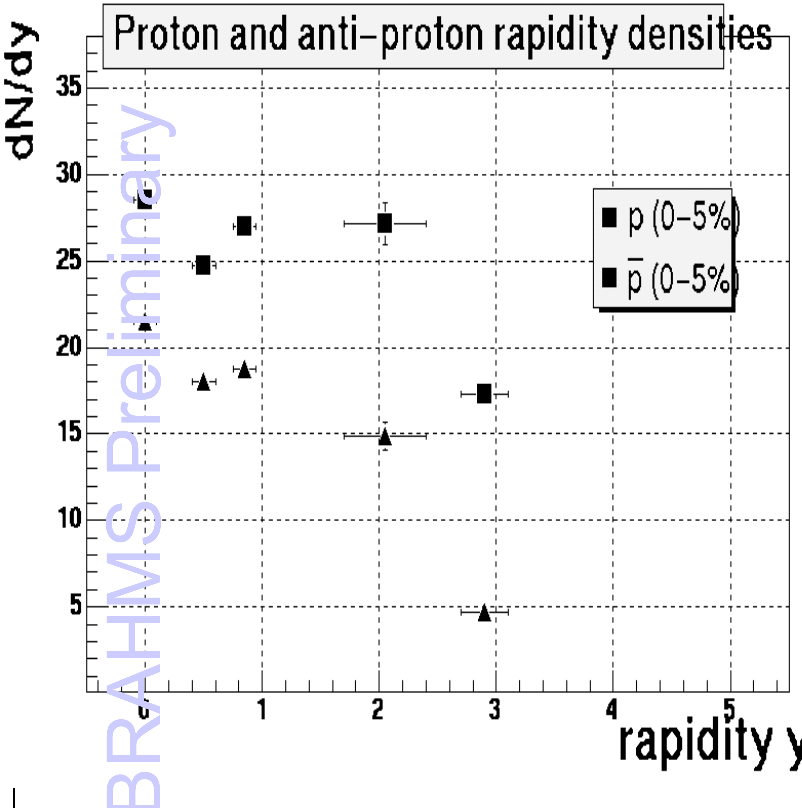
At lower y exponential m_t or Boltzman distributions are prefered. In the /T)

following exponential m_t fits are used. $dN/dy\ m_t dm_t \sim exp(- m_t /T)$,

$m_t = sqrt(m^2 + p_t^2)$

p,pbar Spectra at 0-5% Central at y=0 - 3

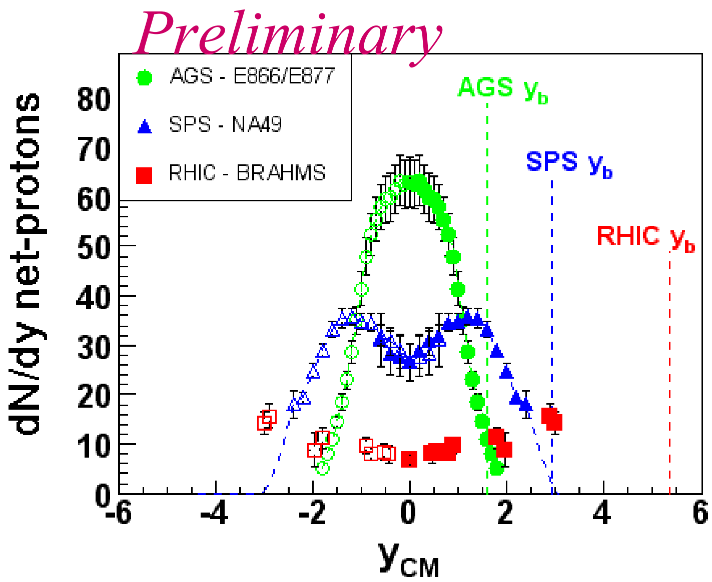




Net-p energy systematic

The shape of the net-proton distribution measured at RHIC is different from what is observed at lower energies.

At RHIC the mid-rapidity region is almost net-proton free. Pair production dominates at RHIC.

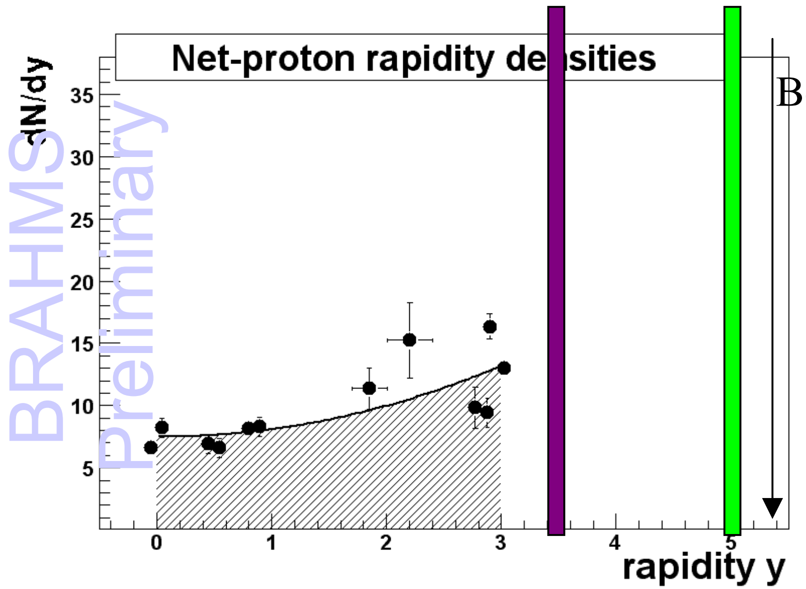


- AGS->RHIC : Stopping -> Transparency
- Net proton peak > y ~ 2

Estimate of amount of stopping

- Even though we do not have measurements in 3-5.4,we may extend another .4 units in future, how can we estimate rapidity loss right now.
- Interested in evaluating $\delta y = \int (yb-y)\, dN/dy \,/\, \int dN/dy$, as has been done for lower energy data.
- Baryon conservation tells us Net(p) ~ 68 for N_{part}~340 (0-10%) or ~85 in the case of full proton/neutron equilibration.
- Only small corrections are expected due contributions from Λ decays.

Rapidity Loss Estimates



All net-protons at y = 3.5
Maximal rap. loss = 2.6

All net-protons at y = 5.0
Minimal rap. loss = 1.75

29 net-protons measured (0 < y <3)

Estimate total :

350 participants 140 initial protons

n→p and p→Λ etc. (equilibrium?)

Assume 140 total ⇒ 41 outside acc.

Example of processes :

$p+p \rightarrow n+p+\pi^+$ (p→n)

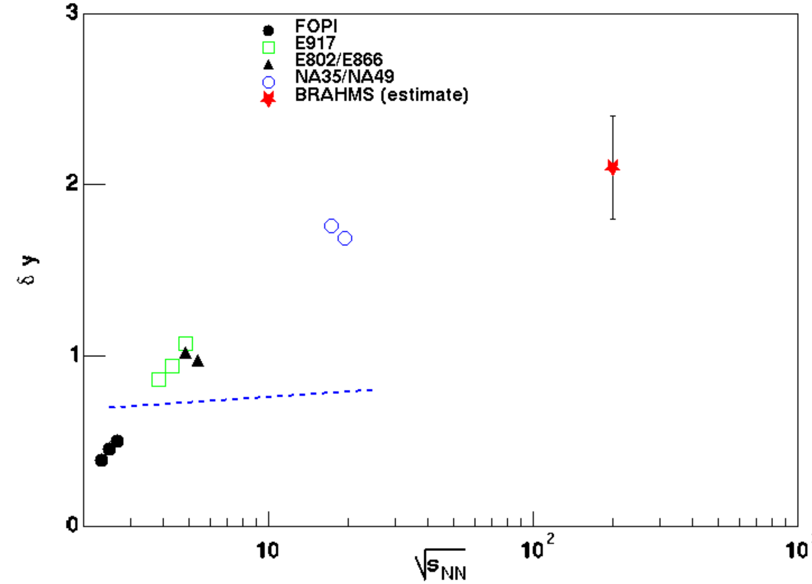
$n+n \rightarrow n+p+\pi^-$ (n →p)

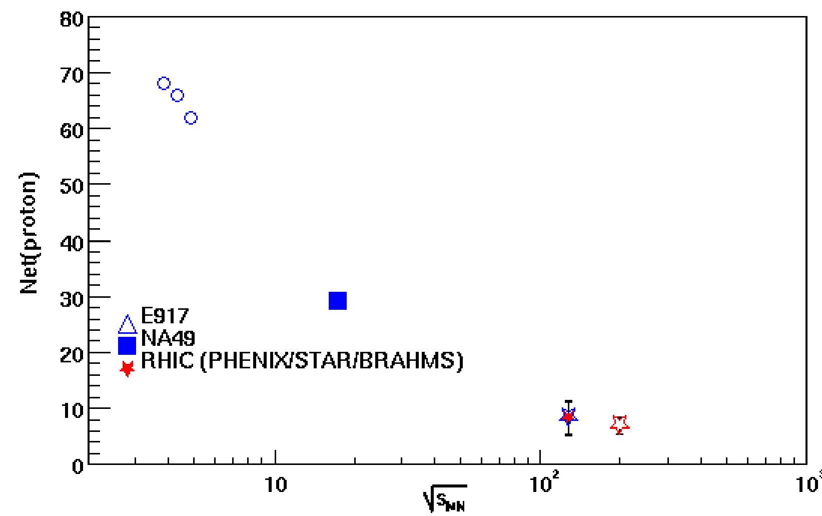
$p+N \rightarrow \Lambda + K^+ + N$ (p→ Λ)

$\Lambda \rightarrow p + \pi^-$ (Λ →p)

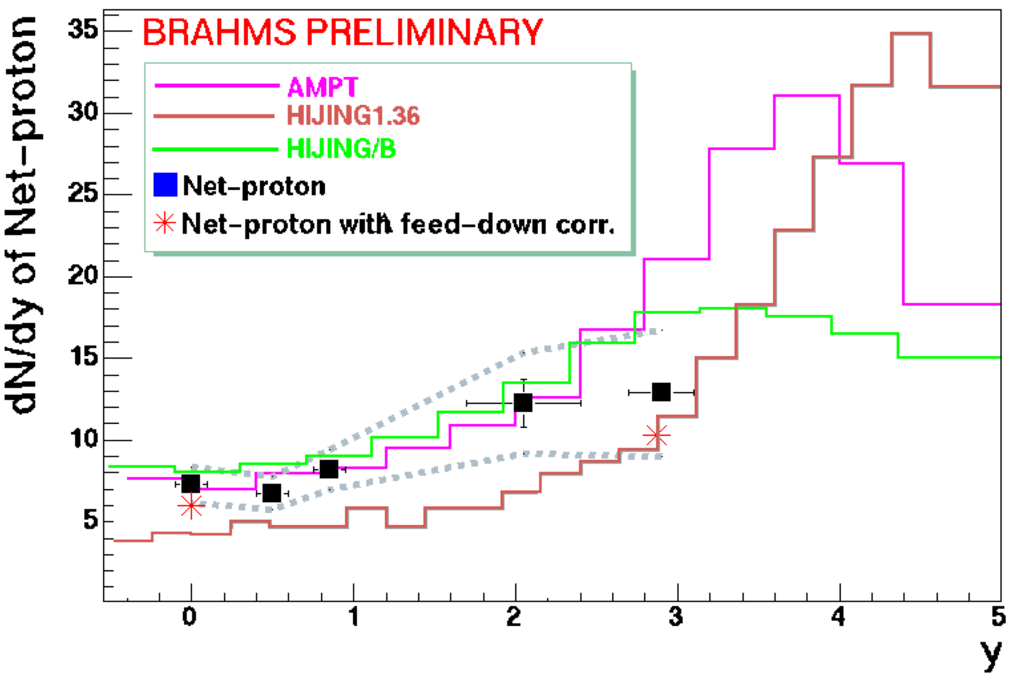
Energy systematic of Rapidity loss and Net-Proton

- Earlier compilations of δy and relative rapidity loss from SIS,AGS and SPS data have been made (ref. OH/FV PhysRevC)
- These data showing the ‘increase’ in δy for AA, while pp is approximately constant.
- The estimated value at RHIC is consistent with a continuous increase of δy.
- This implies that 84-90% of the initial energy is stopped and emerges as internal energy, produced particles and at end of reactions in longitudinal and transverse momentum distributions.
- Net-protons at y~0 continuously decrease with energy.





dN/dy of Net-proton and Models for 0-10% central



"Plateau" at |y| < ± 1

the yields by 18, 20% at y=0,2.9

- Net-baryon at y =0: ~16

  (if N(proton)/N(neutron) ≈ 1

  N(net-L)=0.9N(net-proton))
- Hyperon feed down correction decrease yields 16-20%
- A range of models is still allowed with these data.

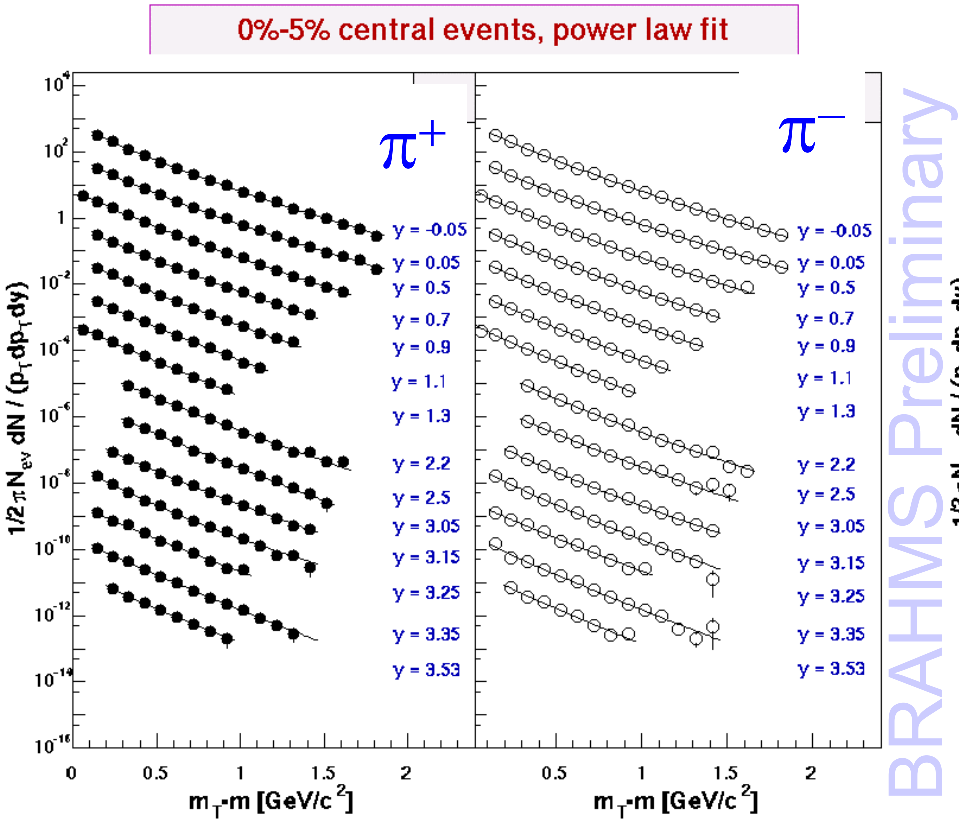
Conclusions

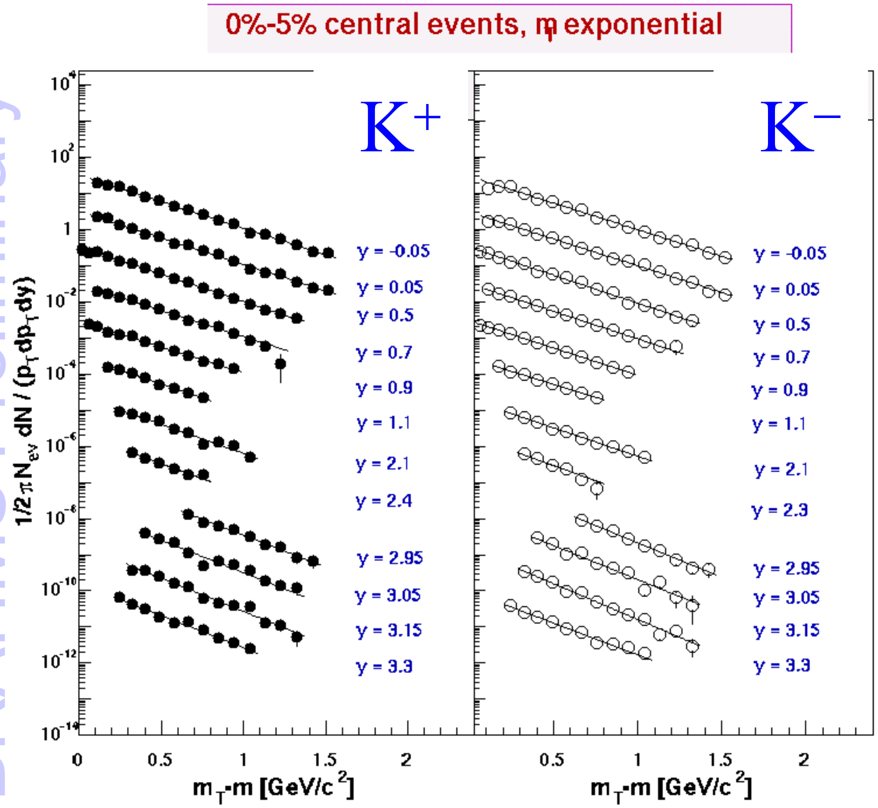
- The observed net-proton yield increases from 7.3±0.5(stat.) ±1.0(syst.) at y = 0 to at 12.9±0.4(stat.) ±1.6(syst.) at y=3.
- The collisions exhibits a large degree of transparency. This has not been observed in collisions at lower energies.
- The rapidity loss is estimated to be in the range 1.8-2.4 for central collisions.

Pions and Kaons.

- The produced particles are expected to be dominate at mid-rapidity. The issue of interest is their transverse momenta distributions, and their rapidity distributions which reflect the dynamical development.
- Analysis of spectra is similar to that of protons, though spectral shapes are different.

Pion and Kaon spectra in y = 0 – 3.5 for 0-5% central Au+Au





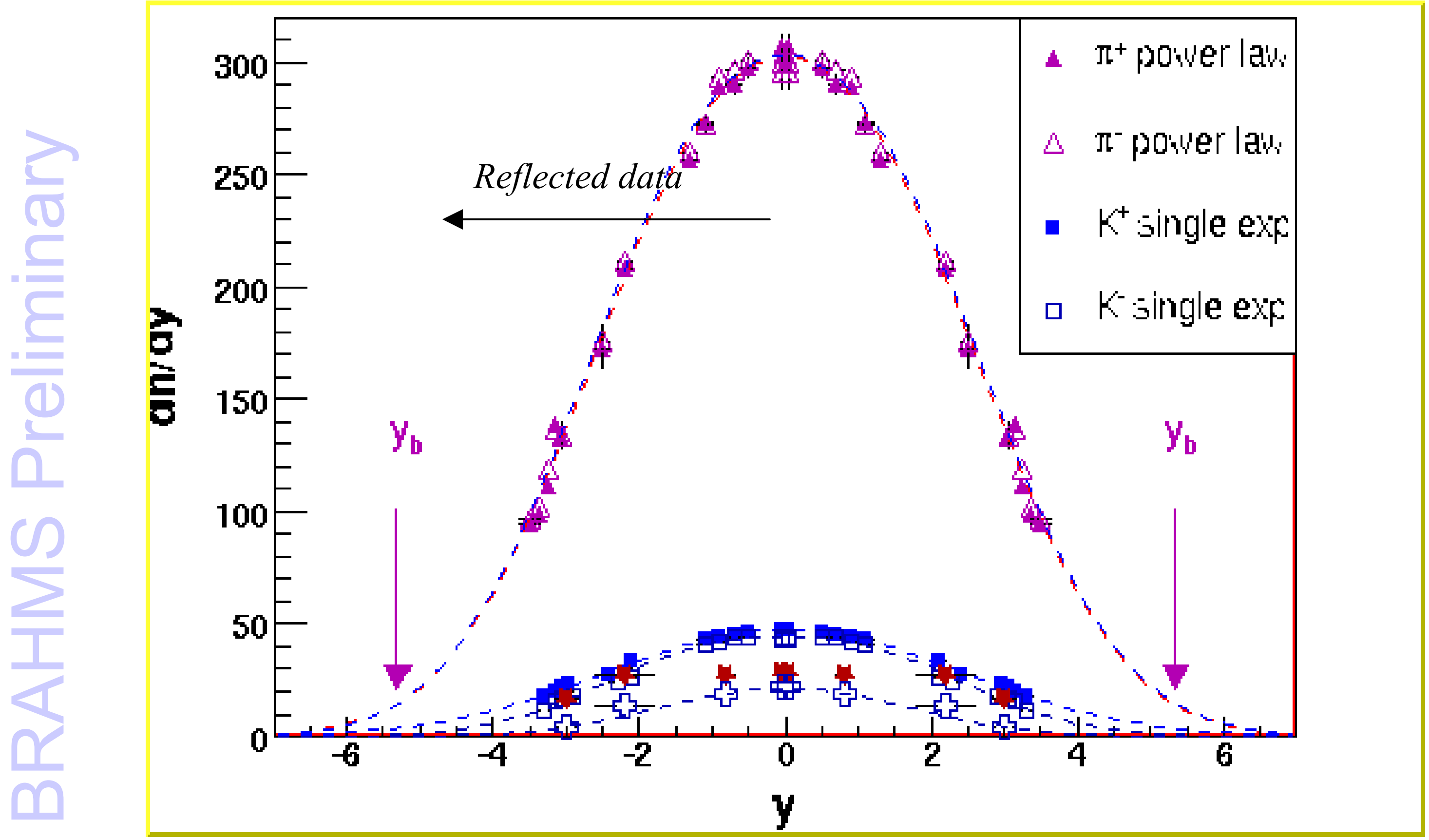
Pion: Power law fit

Kaon: m_T single exponential fit

$A(pt/p0+1)^{-n}$

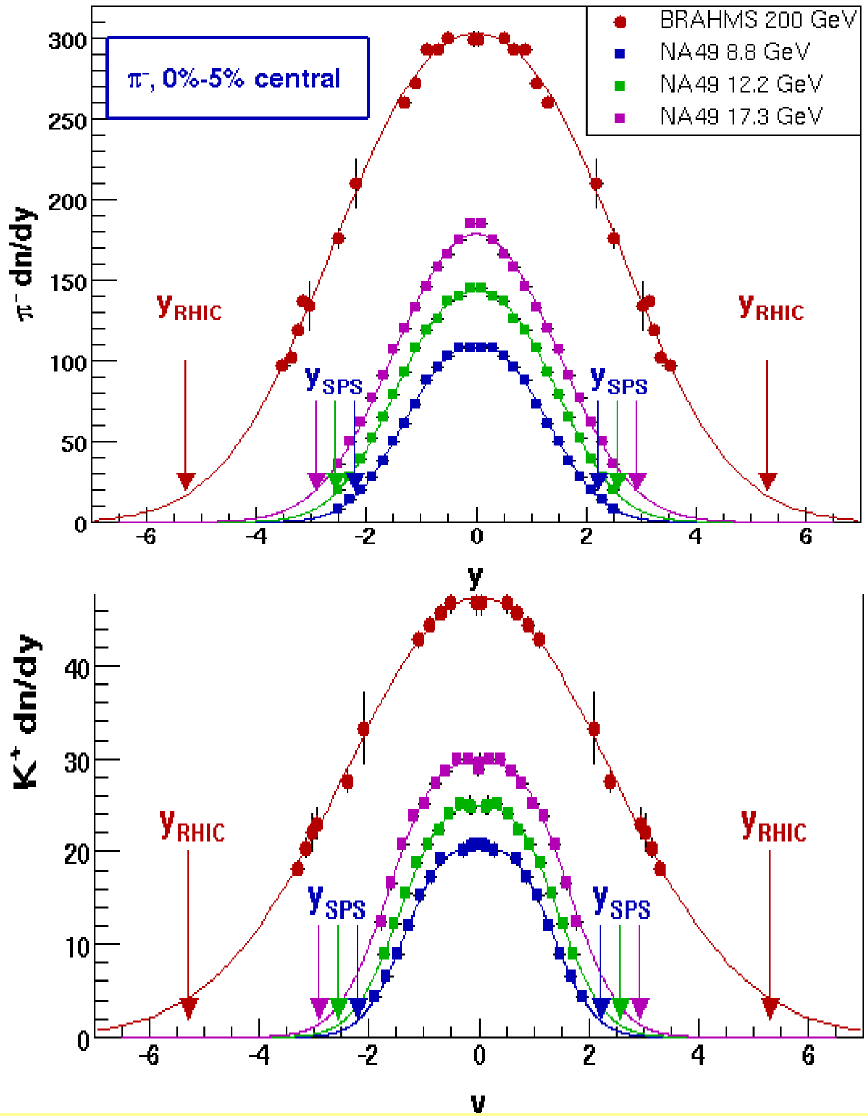
D. Ouerdane (NBI) Thesis

dN/dy of pion and Kaon for 0-5% Central Au+Au at $\sqrt{S_{NN}}$=200 GeV



- No clear "plateau" observed
- Rapidity dendities : Close to a Gaussian shape ($\sigma(\pi +)$ =2.35 ~ σ(K+) =2.39)
- Yield is extrapolated from a double Gaussian (better description of data).
- Total yield in agreement with pulished dN/dη measurements from multiplicity detectors

Comparison with SPS data



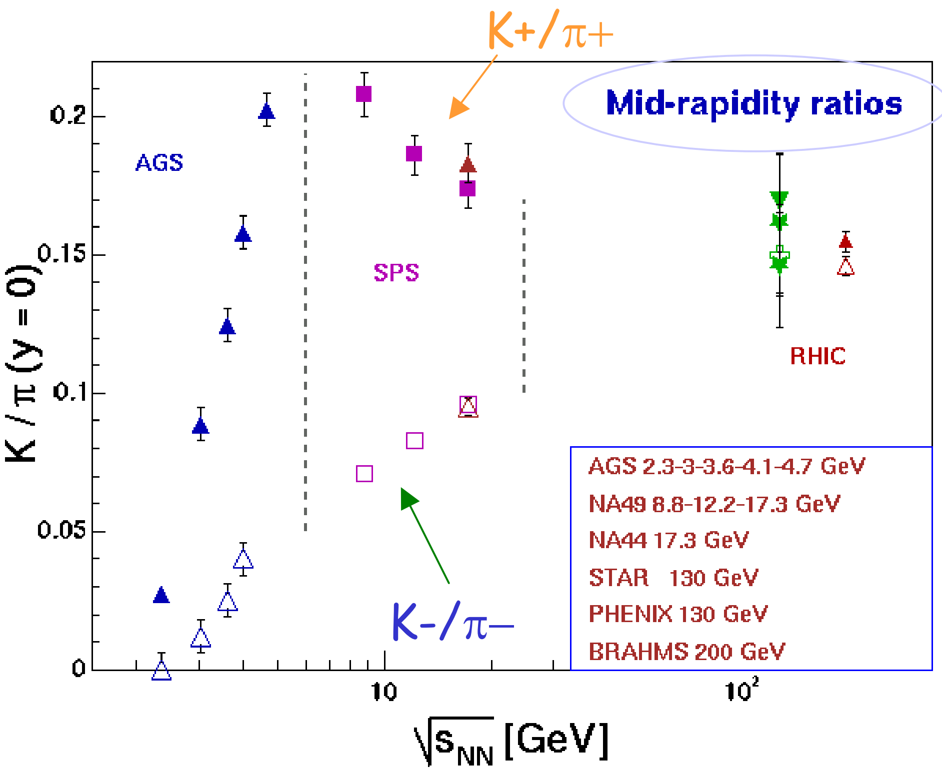
π+

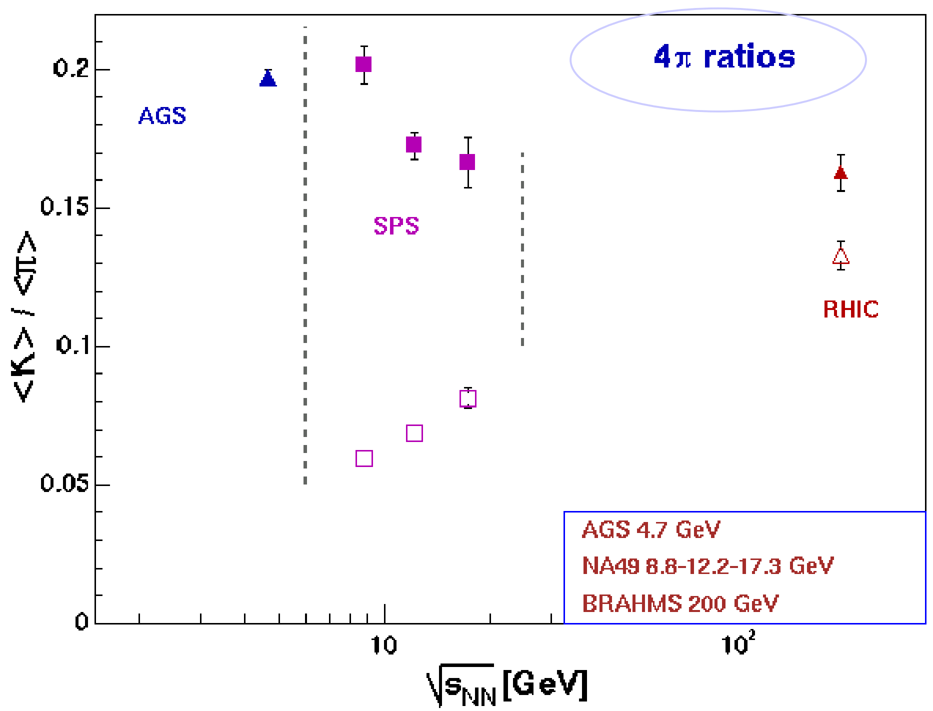
K+

M

Rapidity density changes differently for π + and K+ from SPS to RHIC

Strangeness : K/π systematics



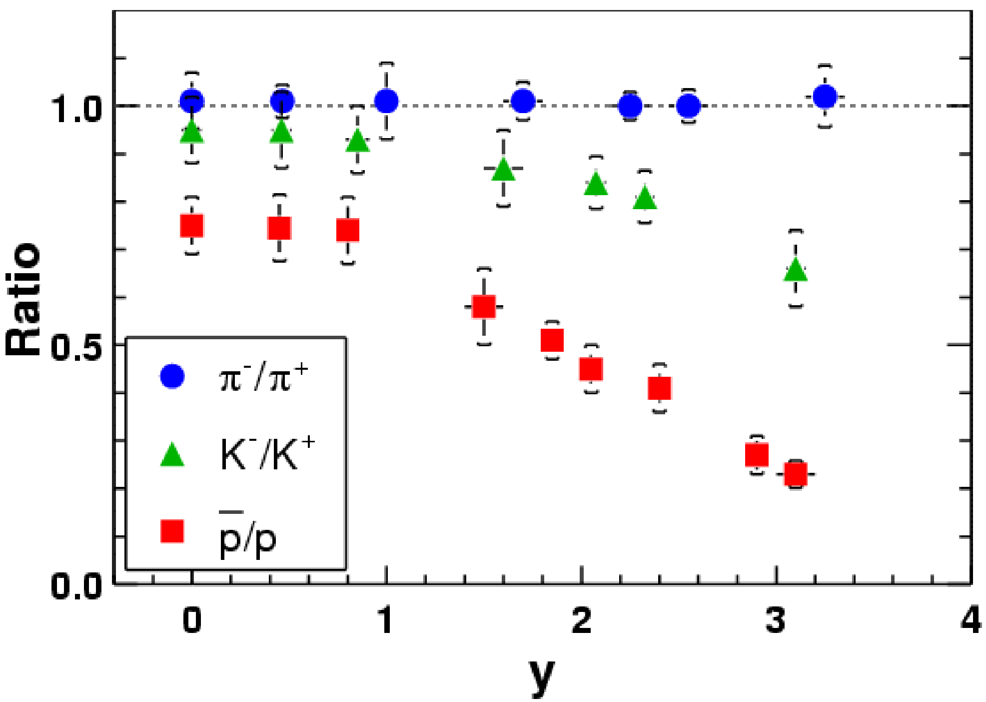


- K^+/π^+ ratio flattens at RHIC energy at y=0 and for integrated yield
- K^+/π^+ at y~3: similar to SPS (Pb+Pb Central at 17 GeV)
- K^-/π^- increases with energy

Thermodynamical properties

- Understanding properties of the dynamic system require us to analyze chemical and kinetic properties of the reaction.
- This can be done in terms of statistical models and in terms of ‘flow’ models; These later are inspired by a hydro-dynamical view point, namely that the initial system is thermal equilibrium, and expands transversely.
- Two specific transitions are thought, namely Chemical after which time particle composition is fixed, and and the kinetic freeze-out where interactions between particles ceases.

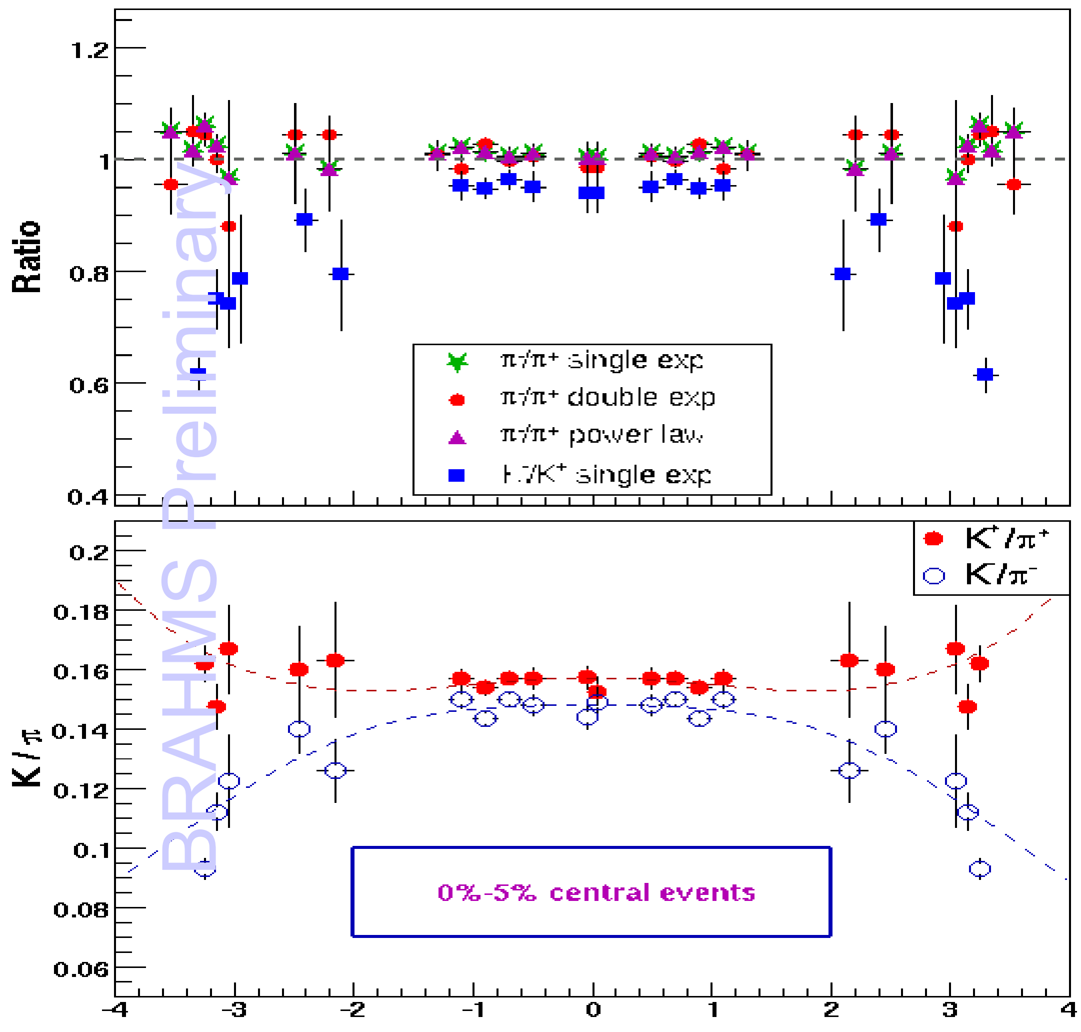
Anti-particle/particle ratios vs. rapidity at $\sqrt{S_{NN}}$=200 GeV



PRL 90 102301 (Mar. 2003)

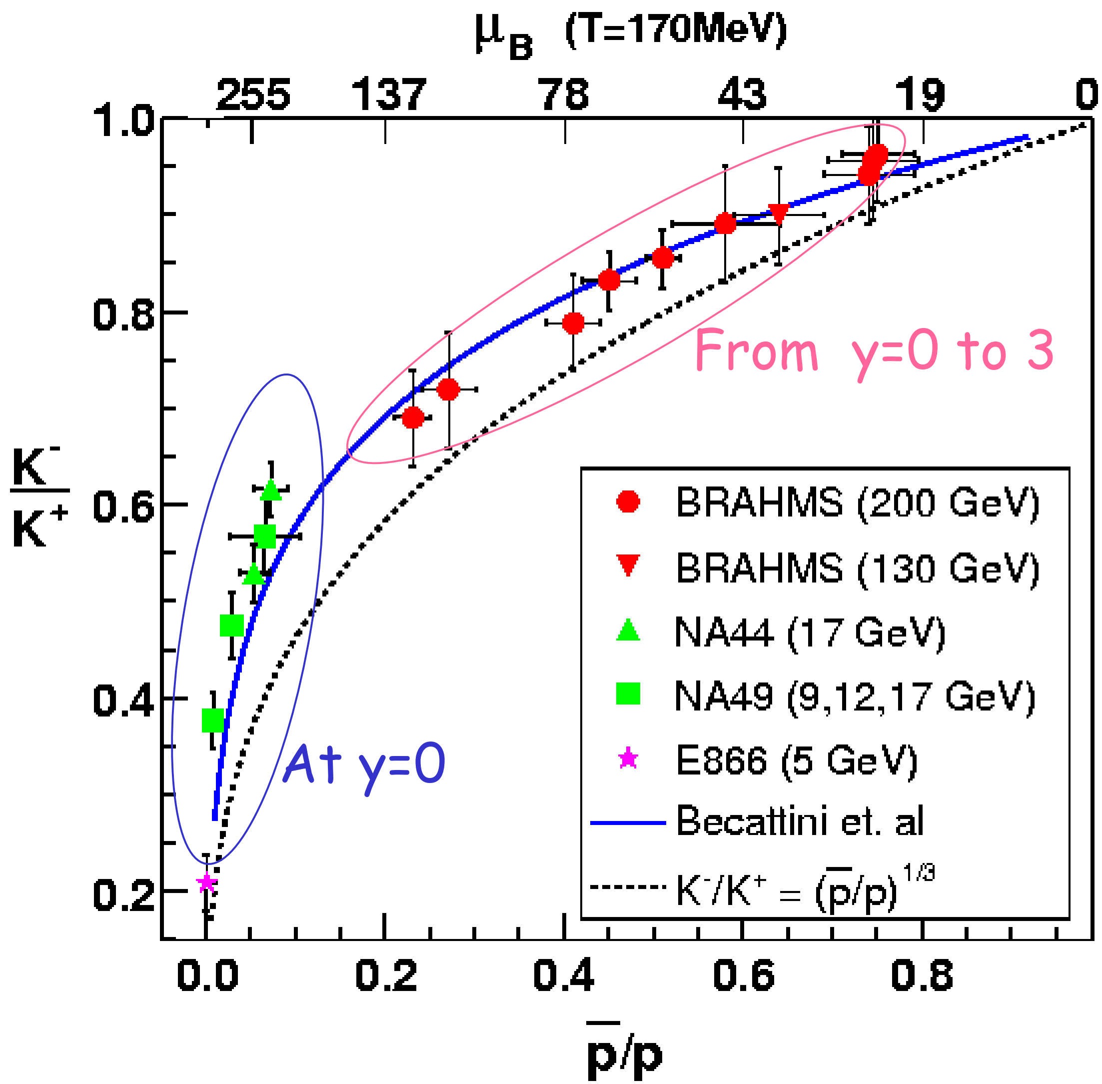
- At y=0 (20% central)
  pbar/p = 0.75 ±0.04
  K^-/K^+ = 0.95 ±0.05
  p^-/p^+ = 1.01 ±0.04
- Highest pbar/p ratio but still incomplete transparency (~17% increase from 130 GeV)
- Ratios ~identical over +-1 unit around mid-rapidity.
- Weak centrality and p_T dependence (not shown here)
- No Hyperon feed down correction applied: less then 5% correction
- Dynamical (cascade, string) models do NOT describes rapidity dependent ratios correctly

Ratios



- π -/ π +, K-/K+: in agreements with BRAHMS published results
- K-/ π - decrease with y while K+/ π + shows no significant rapidity dependence

"Universal" Correlation in K^-/K^+ vs pbar/p?

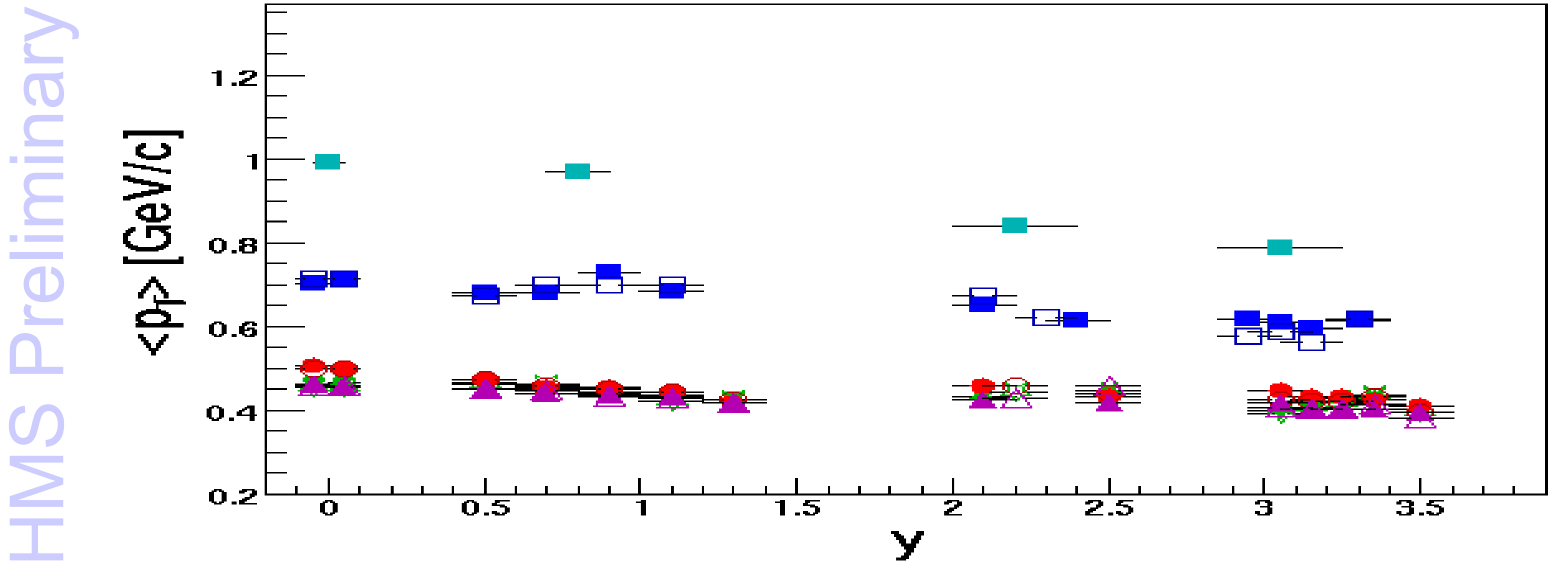


- By simple quark counting in quark recombination K^-/K^+
  $= \exp(2m_s/T)\exp(-2m_q/T)$
  $= \exp(2m_s/T)(\text{pbar}/p)^{1/3}$
  $= (\text{pbar}/p)^{1/3}$
  by assuming local (in y) strangeness conservation
- $K^-/K^+ = (\text{pbar}/p)^a$
  a = 0.24±0.02 for BRAHMS
  a = 0.20±0.01 for SPS
- Good agreement with the statistical-thermal model prediction by Becattini et al. (PRC64 2001): Based on SPS results and assuming T=170 MeV

PRL 90 102301 Mar. 2003

S. V. Afanasiev *et al.*, NA49 Collaboration, nucl-ex/0205002, nucl-ex/0208014; M. Van Leeuwen, Proc. Quark Matter 2002. P. Seyboth, private comm.
I. G. Bearden *et al.*, NA44 Collaboration, Phys. Rev. C66, 044907 (2002).

<pt> vs rapidity for p and K



<pt> (and inverse slope) for p and K decrease slowly

with rapidity (0-3: 10-15% decrease).

Thermal source with transverse flow

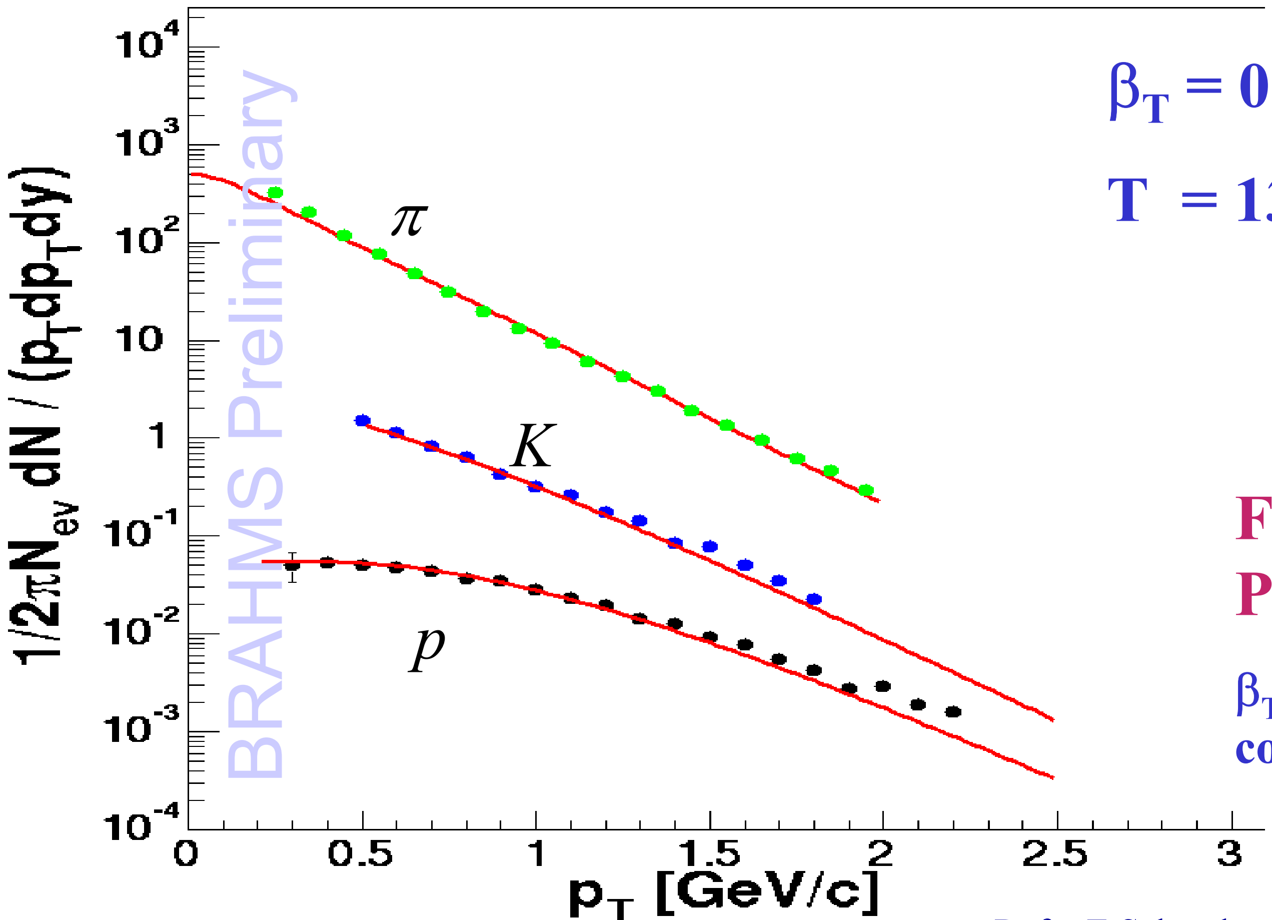
$$E\frac{d^3N}{d^3p} = \int_\sigma \frac{p^\lambda d\sigma_\lambda}{e^{(U^\nu p_\nu - \mu)/T} + 1}$$

Distributions of particles are assimilated to the counting of particles traversing a hyper-surface σ beyond which the system decouples

Changing to a Boltzman distributions. And integrating over y and φ produces the following function to fit the measured spectra. ($\beta_T = \tanh \rho$)

$$\frac{dN}{p_T dp_T} = Am_T \int_0^R I_0\left(\frac{p_T \sinh \rho}{T}\right) K_1\left(\frac{m_T \cosh \rho}{T}\right) r dr$$

Transverse flow at y=0



$\beta_T = 0.53$

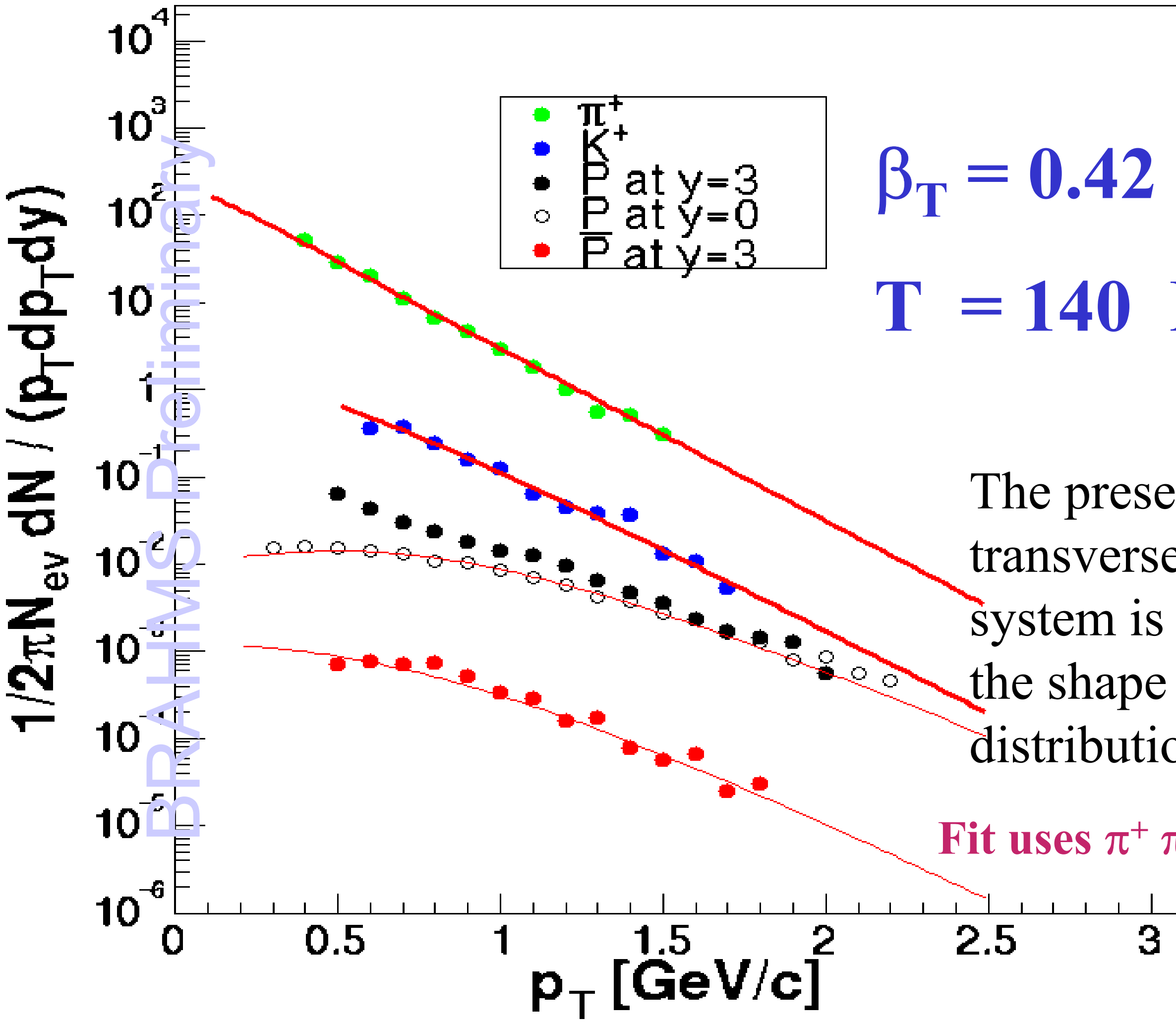
$T = 138$ MeV

Fits $\pi^+\ \pi^-\ K^+$ P Pbar.

β_T and T are correlated.

Ref. : E.Schnedermann et al, PRC48 (1993) 2462

Transverse flow at y~ 3



β_T = 0.42

T = 140 MeV

The presence of transverse flow in the system is most evident in the shape of the proton distribution.

Fit uses π^+ π^- K^+ Pbar.

Summary (Au+Au at $\sqrt{S_{NN}}$=200 GeV)

In this talk I have review BRAHMS measurements of the rapidity dependence (y =0 – 3.5) in Central Au-Au Collisions at RHIC.

- Rapidity densities dN/dy for produced hadrons π and K: ~Gaussian distribution σ(π +) ~ σ(K+)
- This questions the strict validity of the Bjorken lonitudinal expansion often assumed in Hydrodynamical calculations.
- The Chemical composition of the system is though approximately constant over ±1 unit of rapidity, and over the complete range is consistent with an equilibrated system with a T~170 MeV and with a changing Baryon chemical potential μ_B from ~20 to ~140 MeV.
- <pt> and Inverse slope decreases with rapidity (10-15% from y=0 to 3) also reflected in the change in transverse expansion velocities β from 0.53 to 0.42 at large rapidities.

- Transverse expansion present at all rapidities but reduced at high y.
- The observed net-proton yield increases from 7.3±0.5(stat.) ±1.0(syst.) at y = 0 to at 12.9±0.4(stat.) ±1.6(syst.) at y=3.
- The collisions exhibits a large degree of transparency. This has not been observed in collisions at lower energies. The rapidity loss is estimate to be in range1.8-2.6.
- Thus the Au-Au collisions has the behavior of an highly excited and expanding thermalized system over 3 units of rapidity.

Acknowledgements

The Brahms Collaboration

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