Review of BRAHMS experiment and results.

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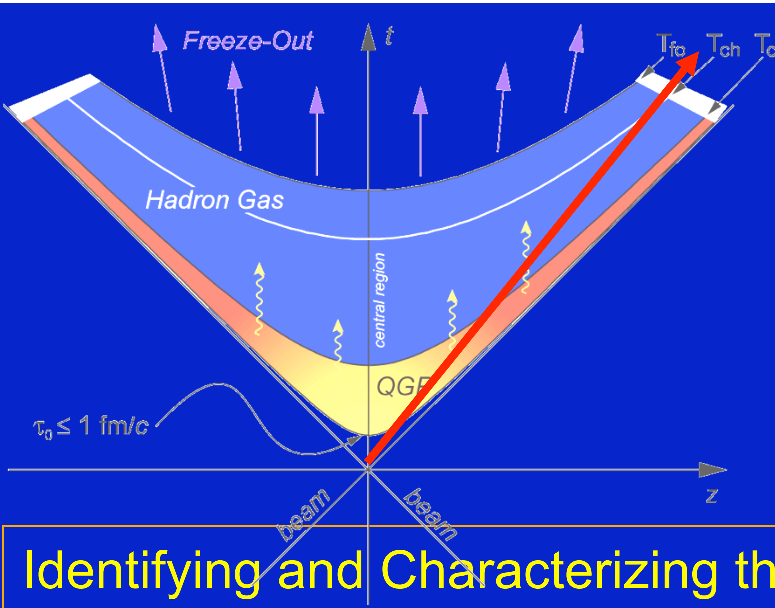
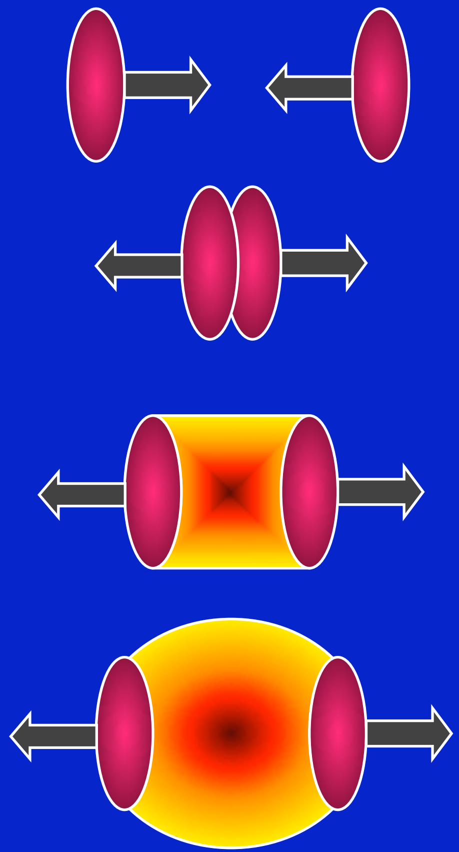
Motivation and Goals

- Stopping and energy transfer via measurements of net-baryon distribution.
- Reaction dynamics observed via particle production over wide rapidity
- Other goals were developed
  - Partonic media interactions via high-p_t suppression
  - Comparison to d+Au, looking for the CGC
  - *Transverse spin physics*

BRAHMS

Mapping space-time evolution with BRAHMS





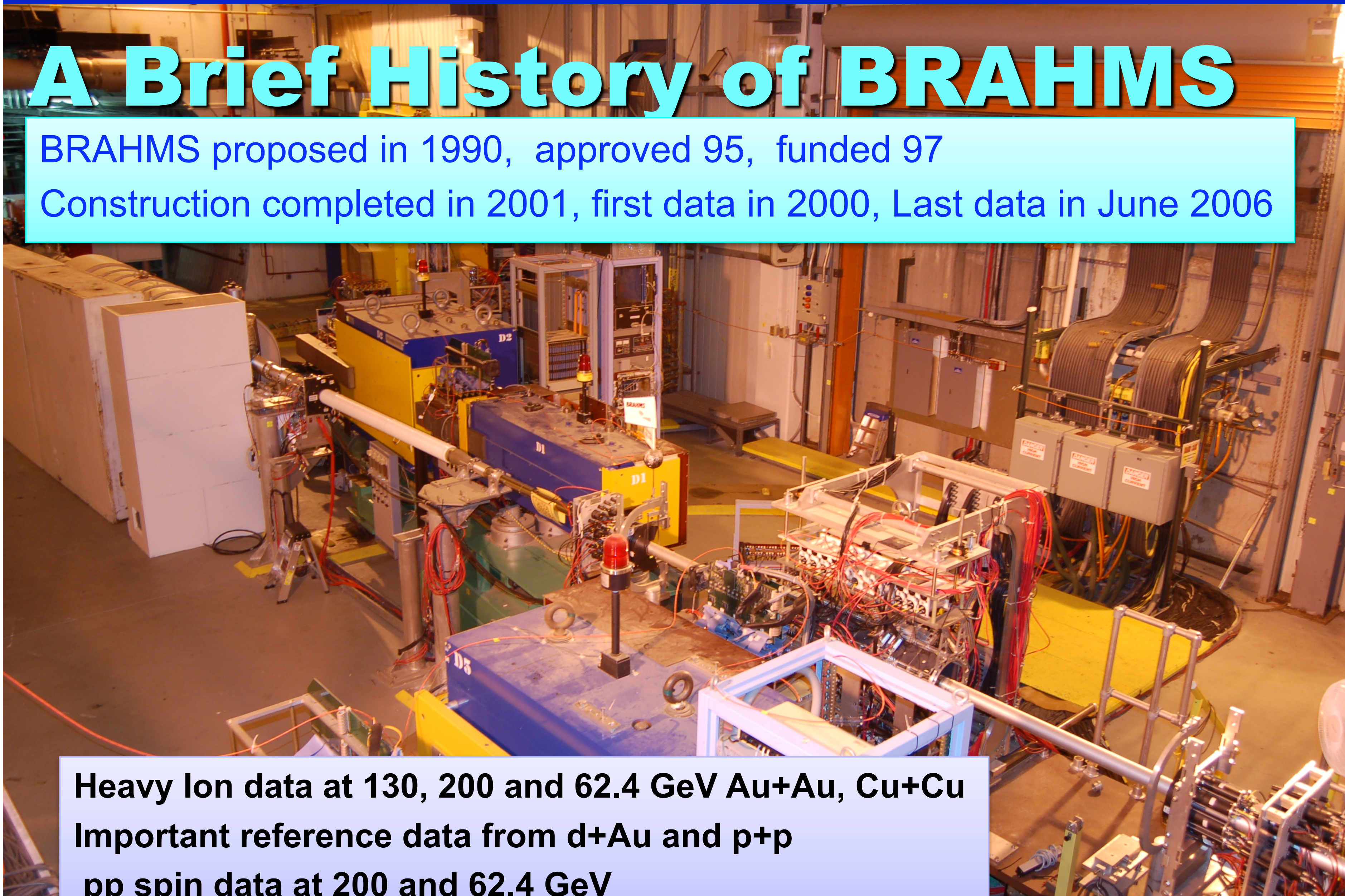
Identifying and Characterizing the Hot Matter

- - How does the system expand and evolve? Transverse and longitudinal dynamics
- Baryon Transport: Net-baryon vs y
- Bulk Properties: multiplicity, dN/dy
- Thermodynamic and freeze-out properties: Temperatures, Particle composition vs y
- Initial Conditions/Partonic Dynamics: high-p_T vs. y
- Constraints for theory

A Brief History of BRAHMS

BRAHMS proposed in 1990, approved 95, funded 97

Construction completed in 2001, first data in 2000, Last data in June 2006

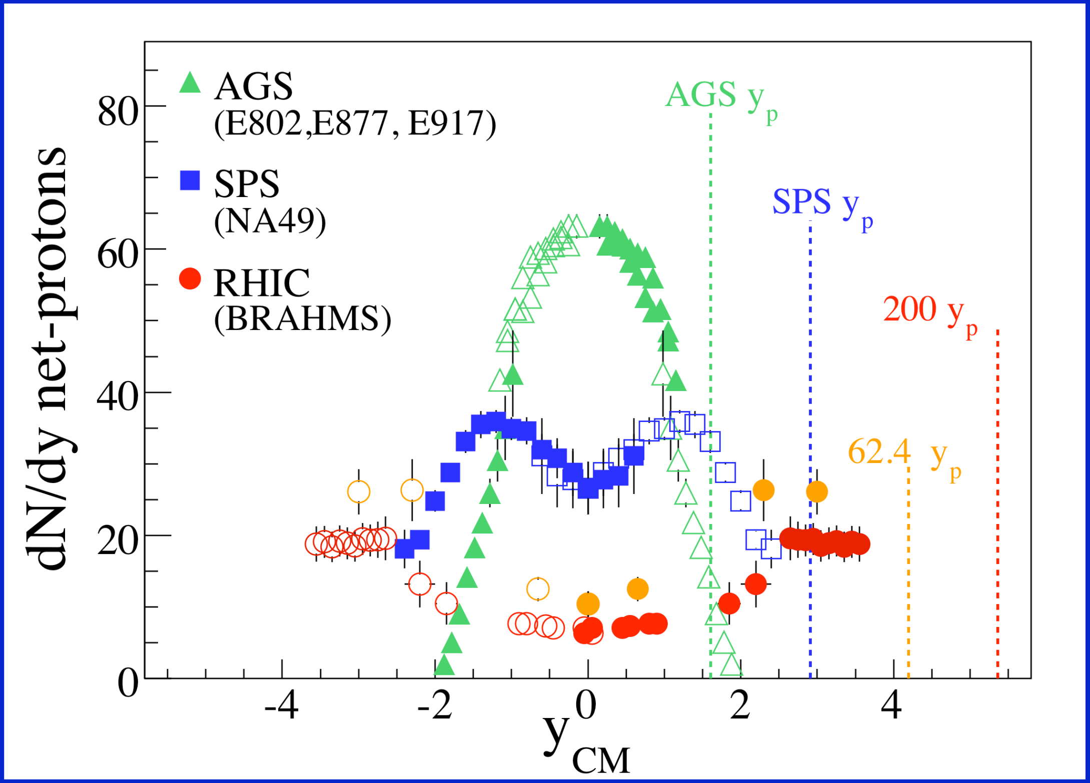


Heavy Ion data at 130, 200 and 62.4 GeV Au+Au, Cu+Cu

Important reference data from d+Au and p+p

pp spin data at 200 and 62.4 GeV

Baryon Transport: rapidity loss, energy available from the collision?



Central collisions Au,Pb

New data from 62 GeV (submitted PLB)

High rapidity preliminary 200 GeV data

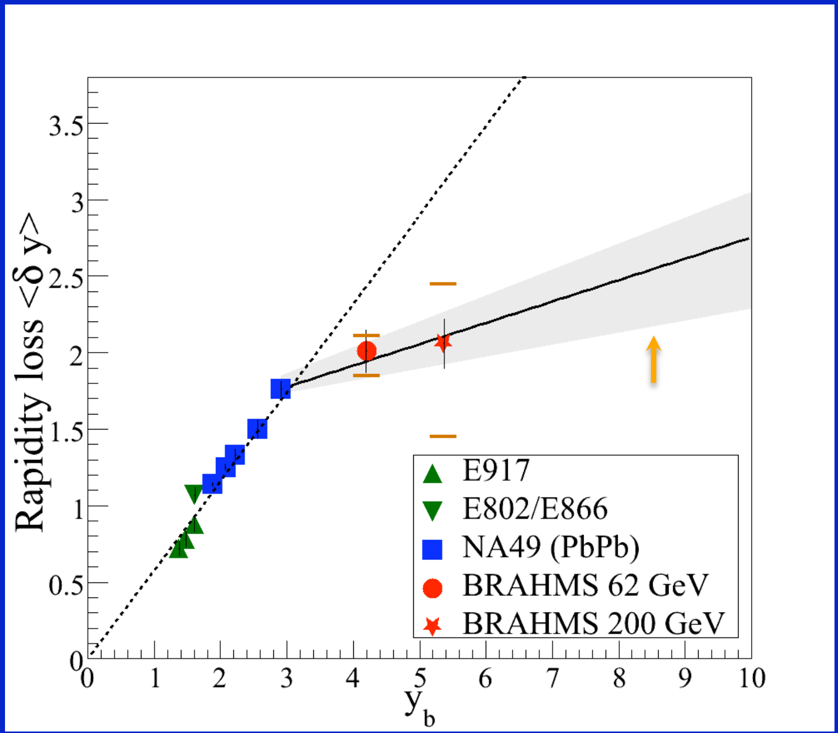
Quantifying rapidity Loss

$$\delta y = y_b - \frac{2}{N_{part}} \int_0^{y_b} y \cdot dN/dy \cdot dy$$

- Conversion to net-Baryon and accounting for un-measured region results in dy = 2.1 at 200 GeV , and 2.0 at 62.4 GeV
- The corresponding energy available for particle production and transverse longitudinal expansion is 72 and 22 GeV per participant nucleon.

Average Rapidity loss

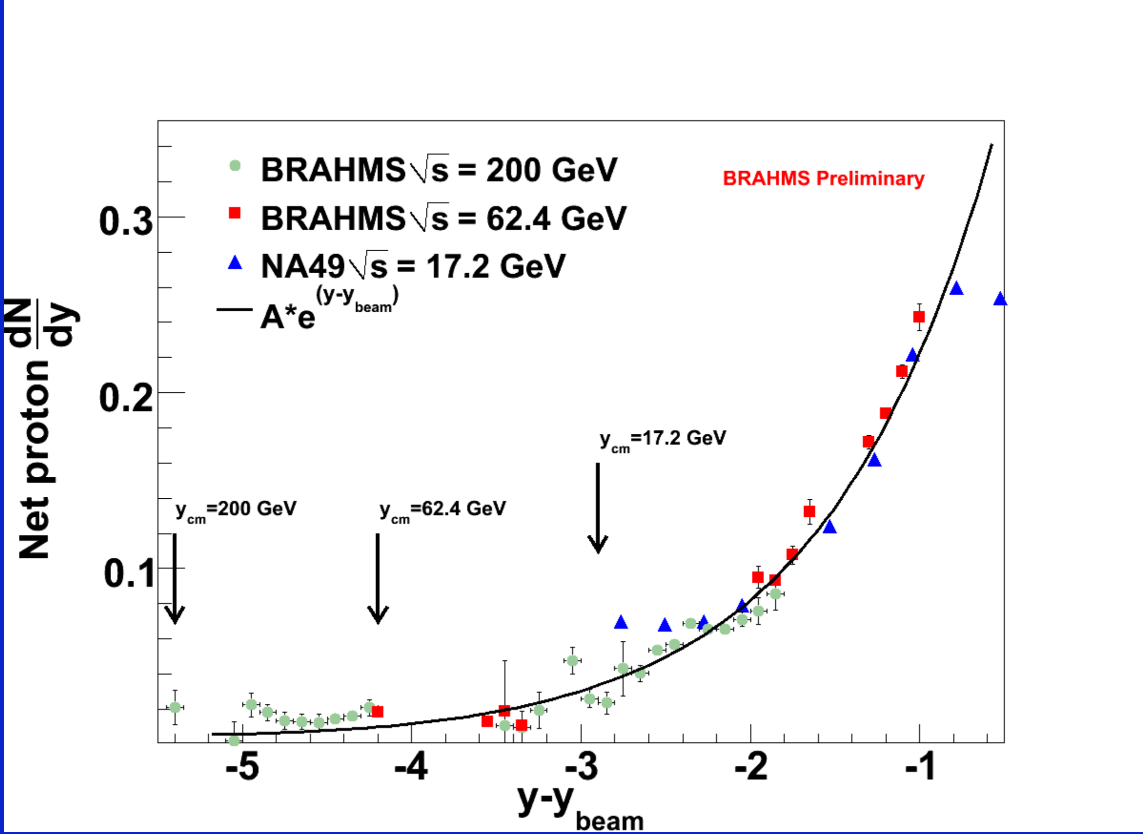
- The average rapidity loss from the 62 GeV data together with previous measurements from AGS,SPS and BRAHMS at 200 GeV
- Slowly increasing or flat trend above SPS energies.



See Hans Dalsgaard talk Friday 17:50

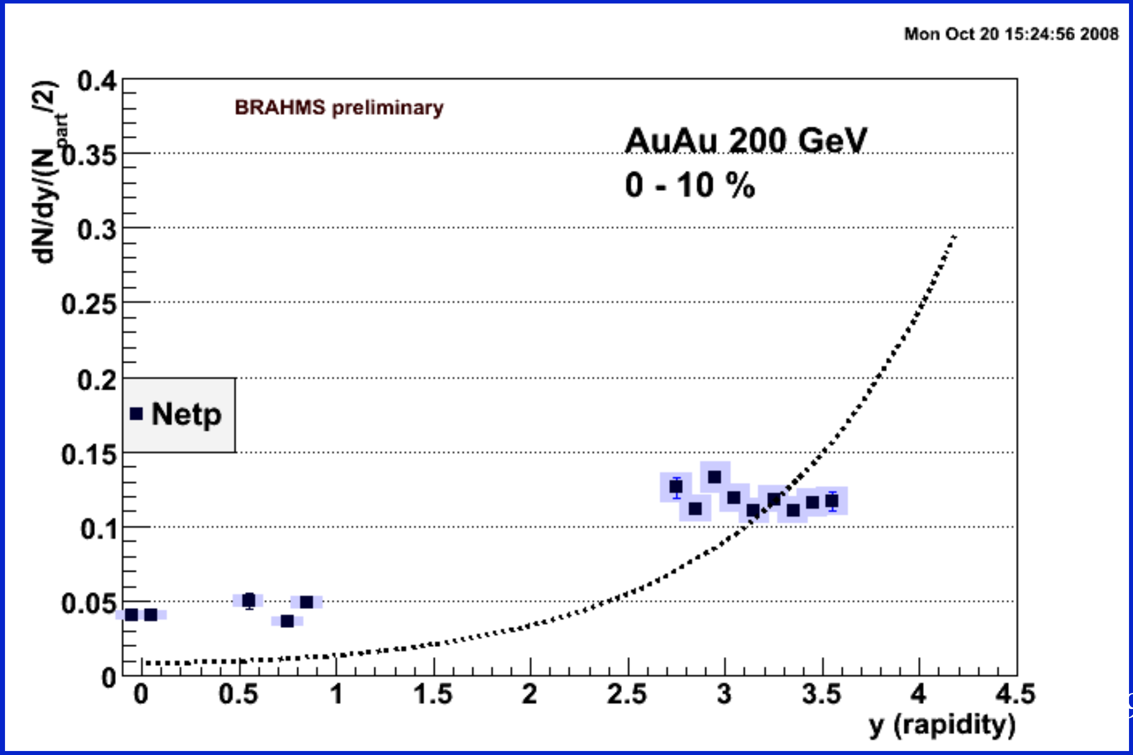
BRAHMS

Net-proton in pp is a reference



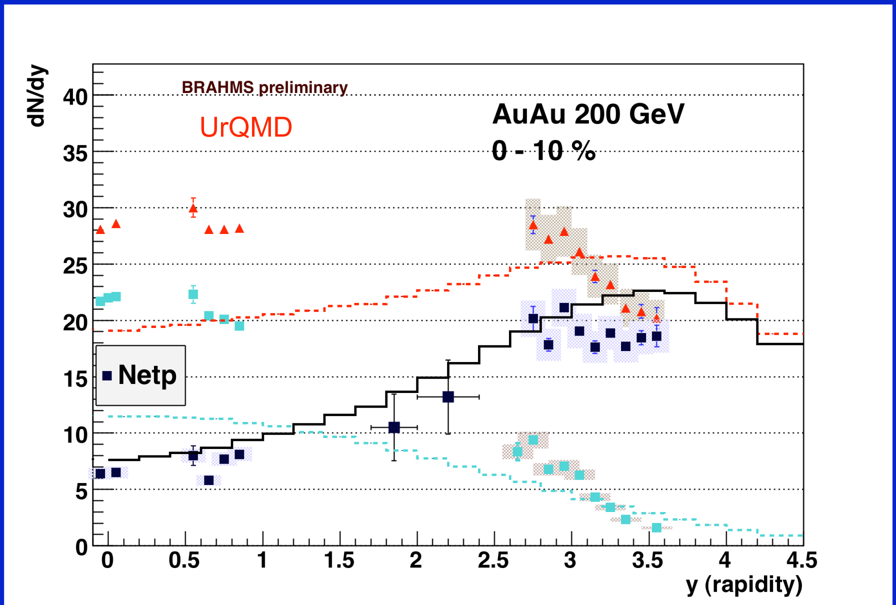
The pp Net-p distributions at 62 and 200 GeV exhibits same behaviour as the low energy data. Leaves little room for new mechanisms in pp stopping

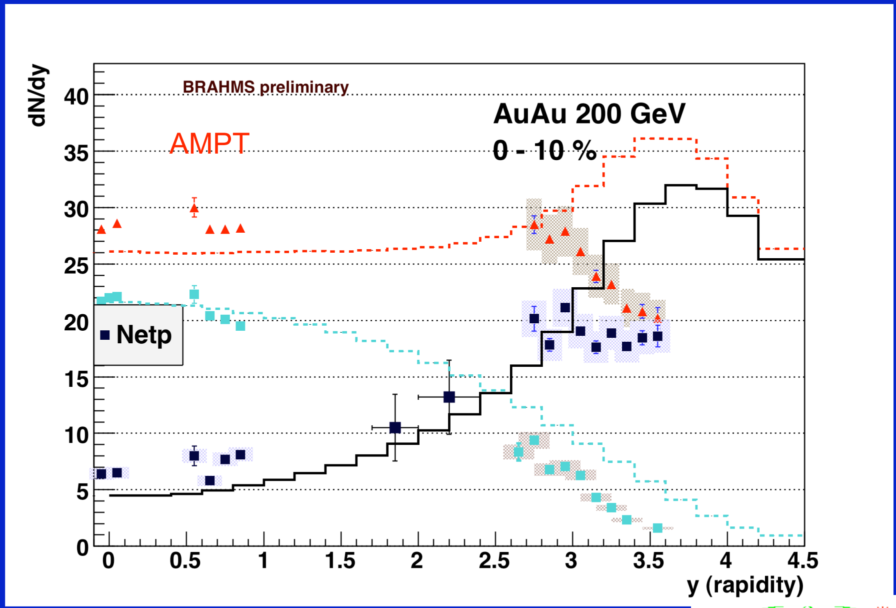
- Compare pp and AuAu centrality dependence
- Yield normalized to $N_{part}/2$
- Central collisions exhibits large transport of baryon to mid-rapidity number and energy toward y~0
- Peripheral collisions very similar to pp already from ~60%



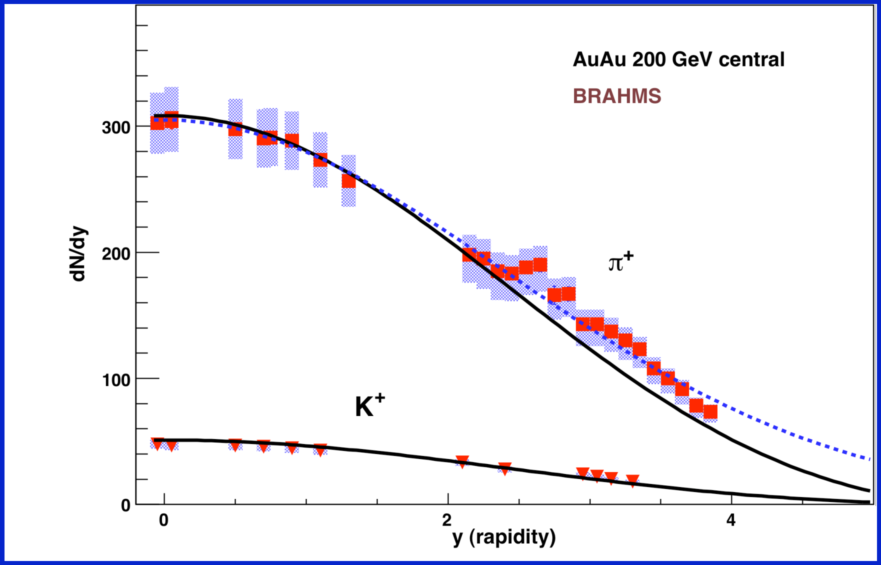
Model Comparisons

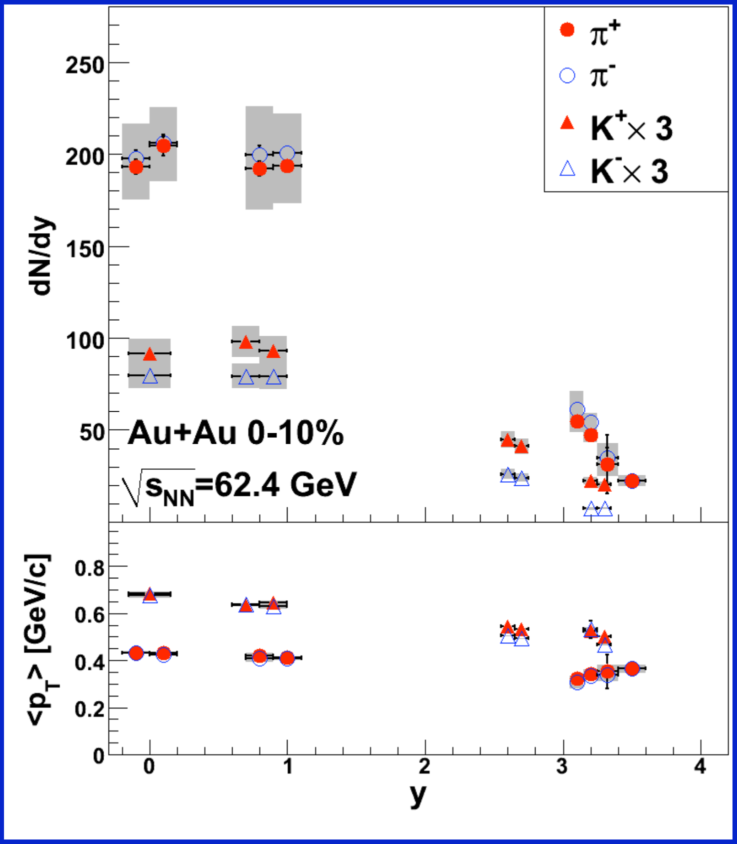
- A number of comparisons of other observables in the parallel talks and poster; Only example in this talk: net-p
- Event generators /transports model have varying success in describing the features of the HI reaction dynamics.





Produced Particles





AuAu 200 GeV 0-10% central

The dN/dy shape of pion is approx. Gaussian (blue)

The Landau hydro dynamic description as expanded by Wong give good description of dn/dy shape (black)

Why do Landau work ?

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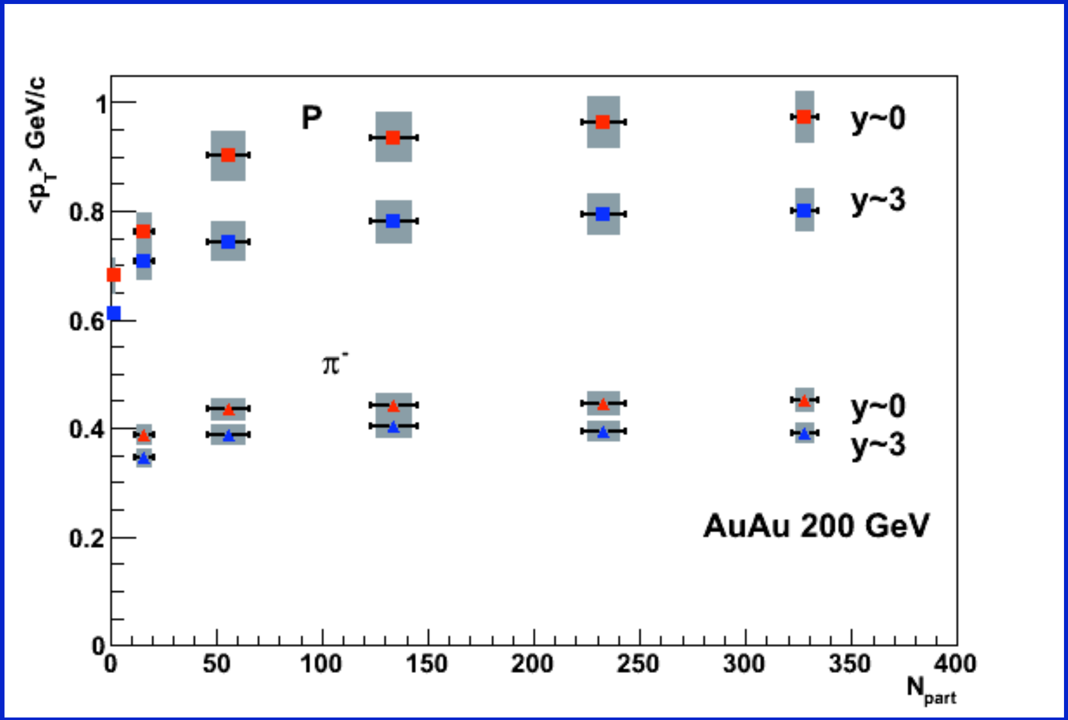
$<p_t>$: specie, rapidity and centrality



$<p_T>$ vs. centrality demonstrates increased transverse expansion for protons at y~0 and less at y~3

Weak dependence for pions

Reduced expansion and thus less medium effect at y~3

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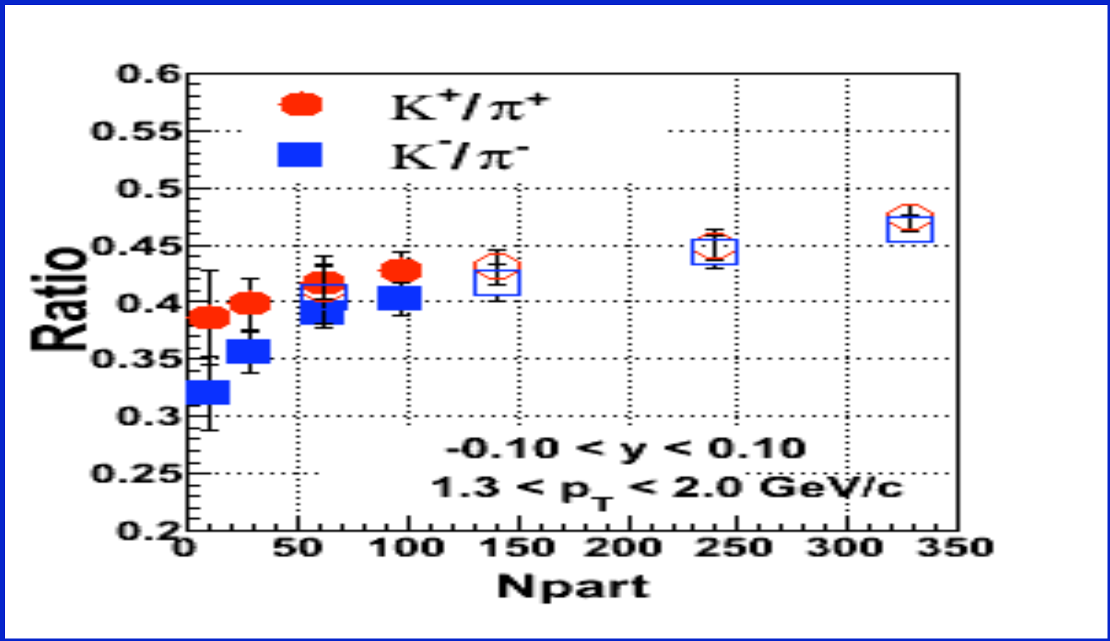
Inclusive Cu+Cu results

For the same number of participants (N_{part}) ratios in Cu +Cu are similar to those in peripheral Au+Au

Semi-inclusive physics quantities /bulk in CuCu are similar with AuAu peripherals results



Poster Selemon Bekele

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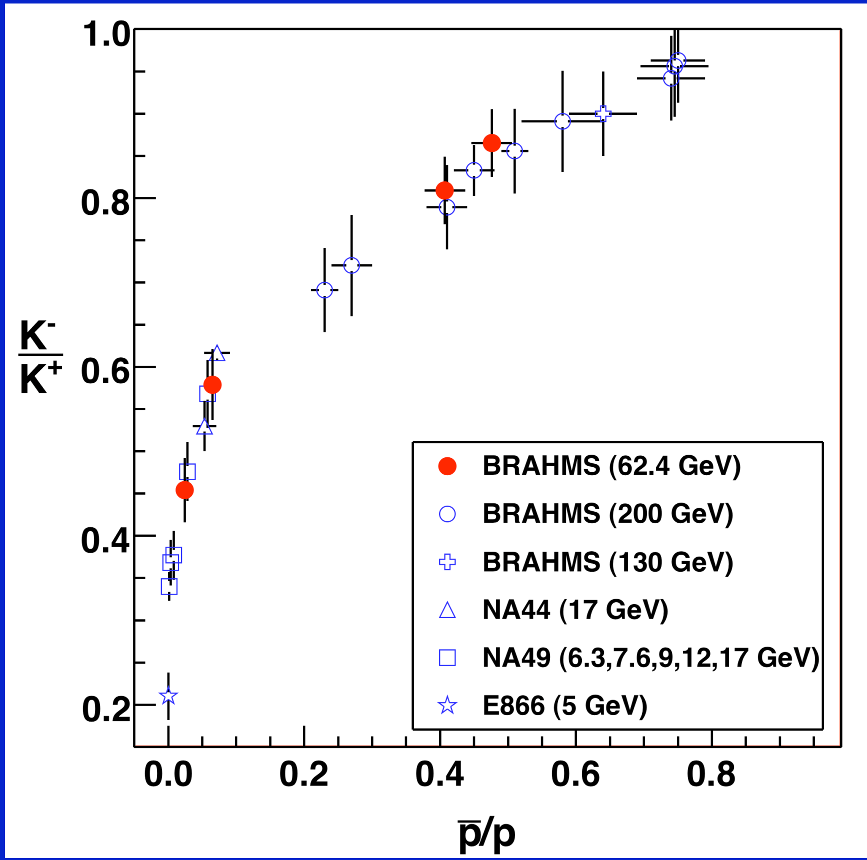
K^-/K^+ vs. pbar/p universal behaviour



Final data from 62 GeV

only μ_B controls the composition of bulk matter

Agrees with many statistical models with T~170MeV indicating local equilibrium

Baryon to Meson ratio vs. baryon chemical potential

The discovery at RHIC of Large Baryon to meson ratio in $1<p_t<5$ indication of quark coalescence.

Reflects hadronization scenario (recombination vs. fragmentation), radial flow of bulk medium

Energy and centrality dependence of p/π^+ and pbar/π^- and their evolution on rapidity may allow to verify the proposed scenarios

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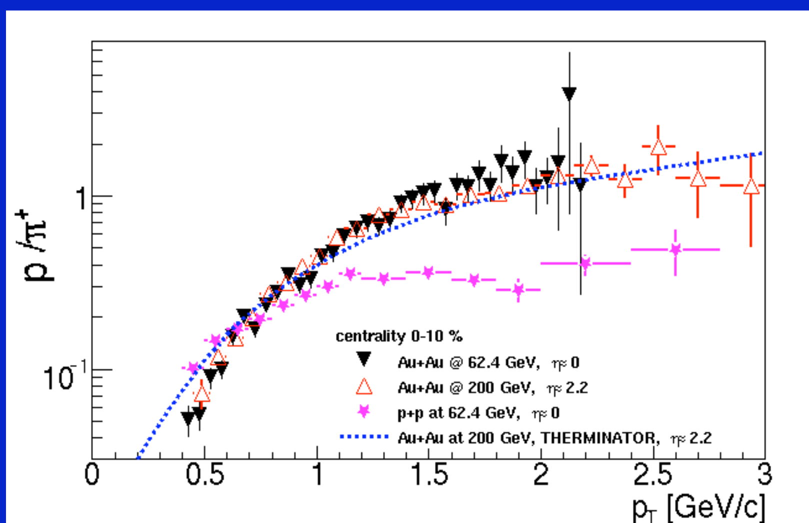
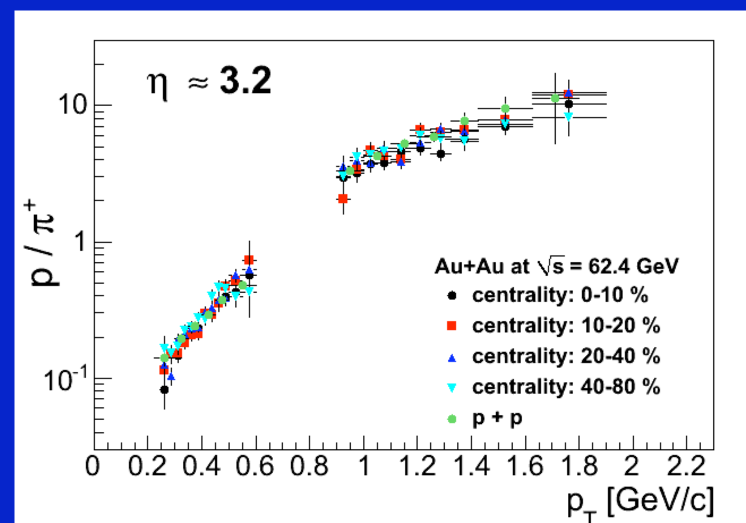
Energy systematics – 200 and 62

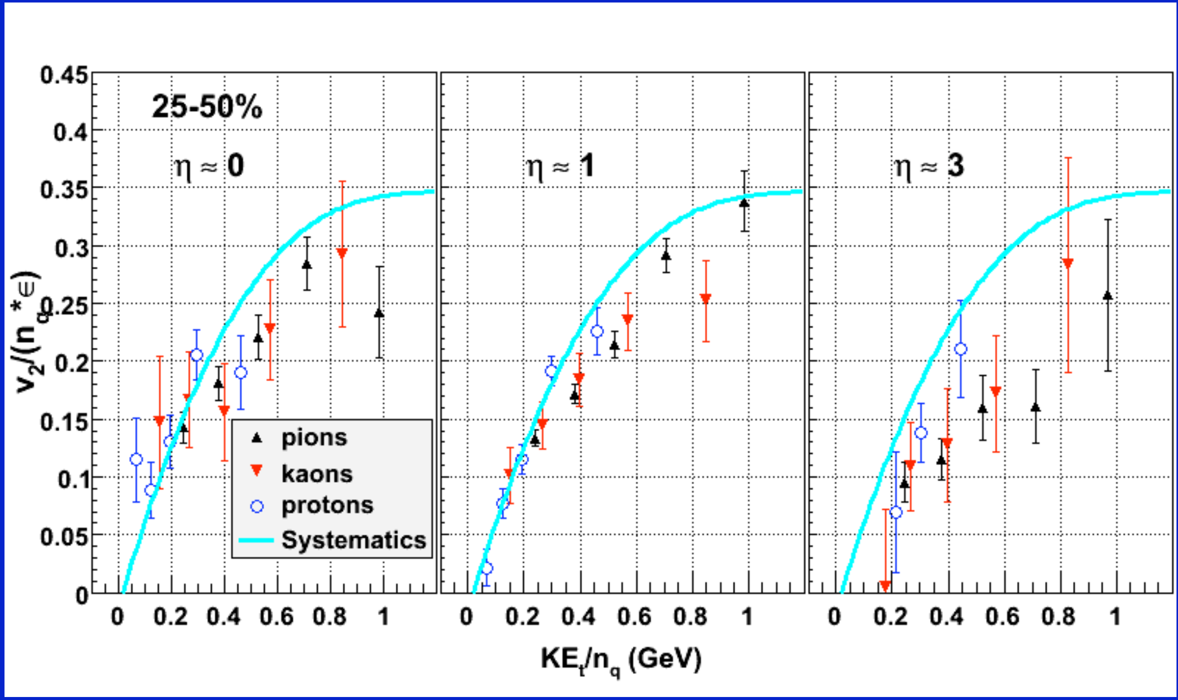
- Mid-rapidity 62 GeV similar to η~2.2 at 200 GeV with significant P/π ratios
- At y~0 and y~2.2 significant medium effects
- Close to beam rapidity (forward at 62 GeV) P/π exhibits no centrality dependence and is similar to pp indicating little influence from media (quark coalescence, hadronic re-scattering)





Talk by Pawel Statzel, Friday

Rapidity dependence of Elliptic flow for identified Hadrons



See Stephen Sanders talk in session Tuesday at 14:00

BRAHMS measurements at η~0,1 and 3 is compared to the universal systematics for scaled $v_2(p_T)$ from y~0

Dependence with rapidity observed (drop at y~3); less for 0-25%

This dependency together with the change in $\langle p_T \rangle$ make these measurements consistent the inclusive v_2 vs. y (from charged hadrons)

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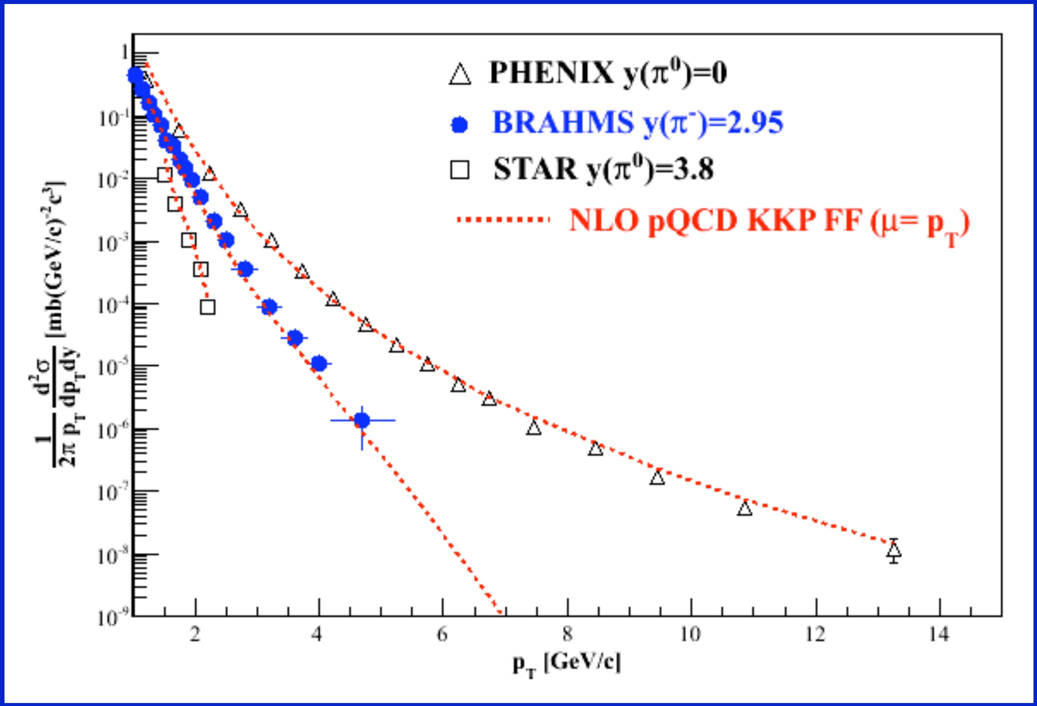
From bulk towards high p_T

At the RHIC energies, hard scattering processes at high-p_T become important.



200 GeV pp

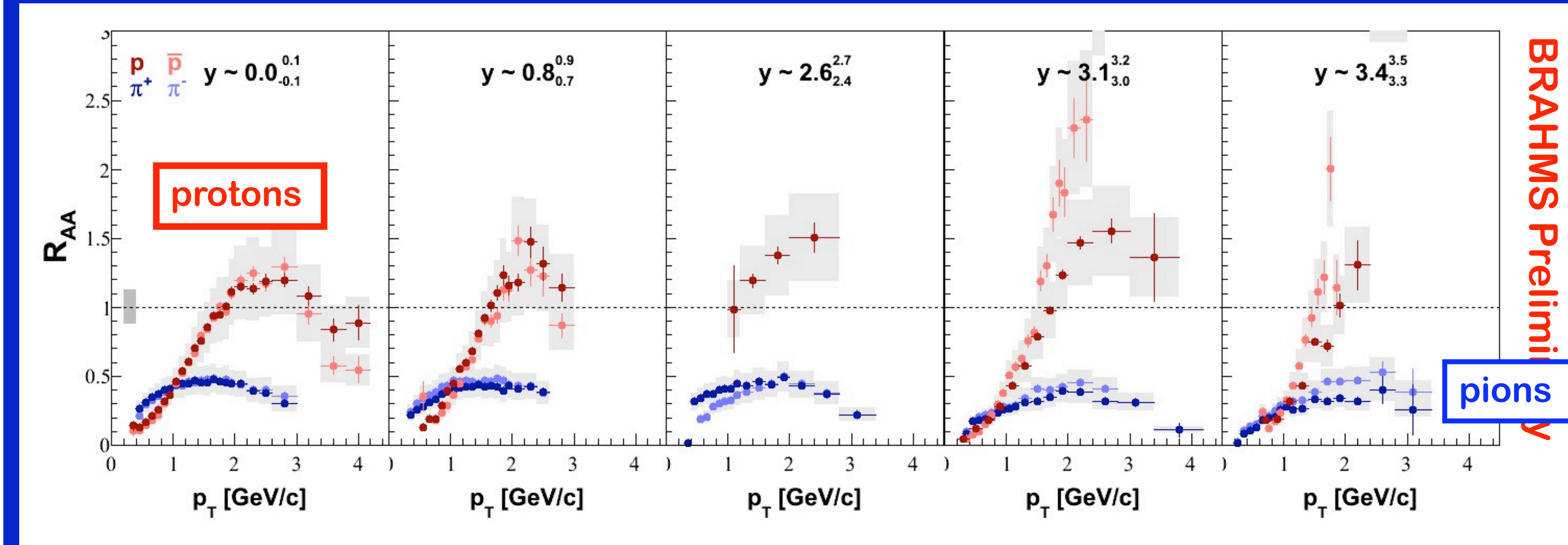
Partons are expected to loose energy in the dense matter

- Different rapidities provide varying density of the medium: Sensitive to the dynamics
- Largest medium effect at mid-rapidity

Initial and final state effects A+A, and d+Au

- Cronin Effect
  - Initial state multiple scattering leading to $R_{dA}>1$
- Nuclear Shadowing
  - Depletion of low-x partons (cold nuclei)
- Gluon Saturation
  - Depletion of low-x gluons (Color Glass Condensate)
- Other suppression at large y.
  - Dominance of valence quarks (large x_F)
  - Energy conservation…

R_{AA} for identified particles (AuAu 200GeV)



The charged pion yields are suppressed by a factor of ~ 2-3 as compared with binary scaled p+p pion yields.

- R_{AA} for pions is approximately independent of rapidity
- the proton and antiproton yields in central Au+Au at 200 GeV do not show suppression; baryon meson difference remains
- Several of the effects given can well be in play at large rapidity.

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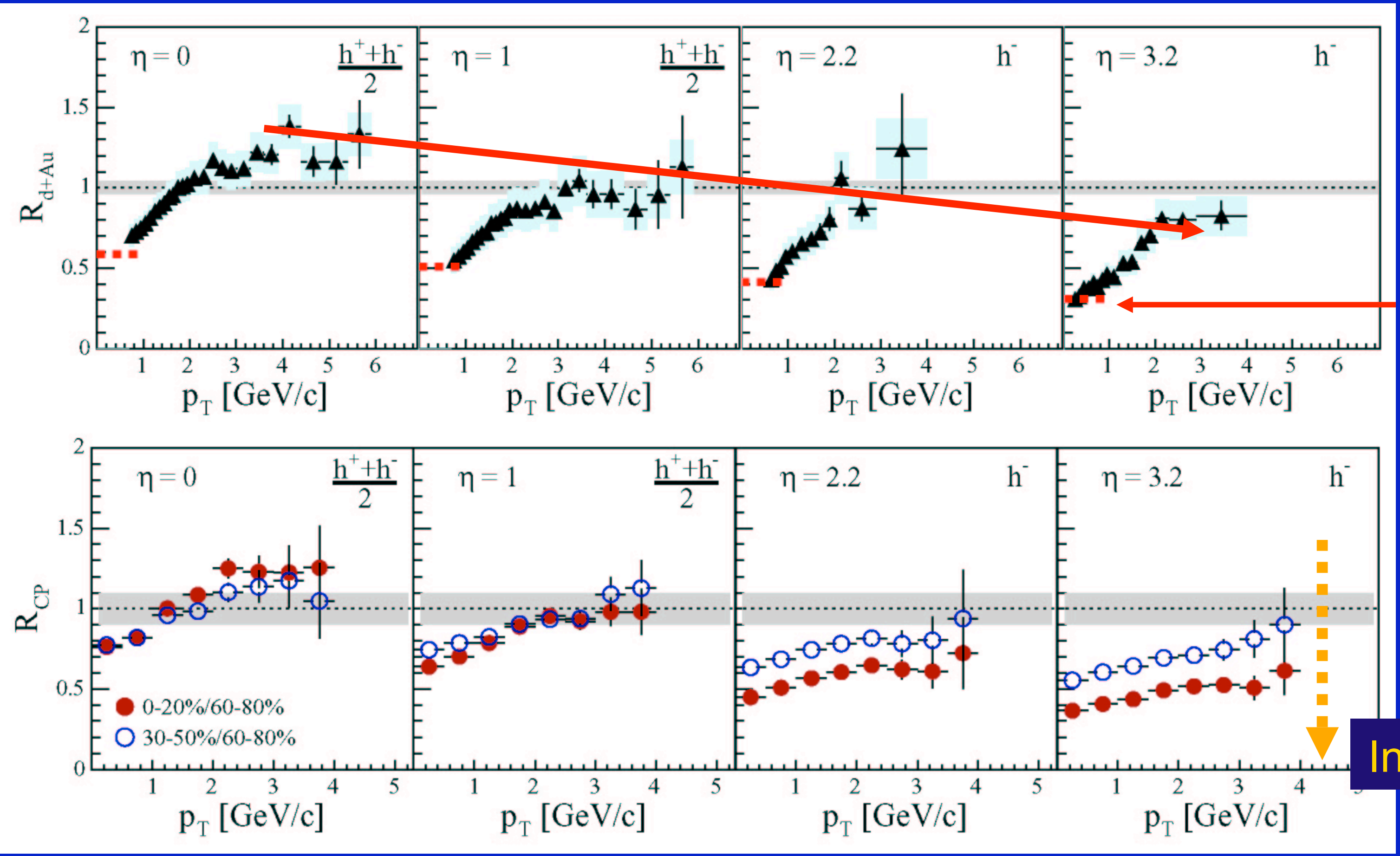
BRAHMS d+Au results as function of rapidity and centrality



$$R_{dAu} = \frac{Y_{dAu}}{N_{coll} Y_{pp}}$$

Normalized ratio of measured (integrated) dN/dη) Npart scaling

Increasing centrality

BRAHMS, PRL 93, 242303

The data have given rise to many interpretations and additional measurements. The behaviour is consistent with that of CGC, but presence at RHIC energies is not definitive and awaits additional correlation results

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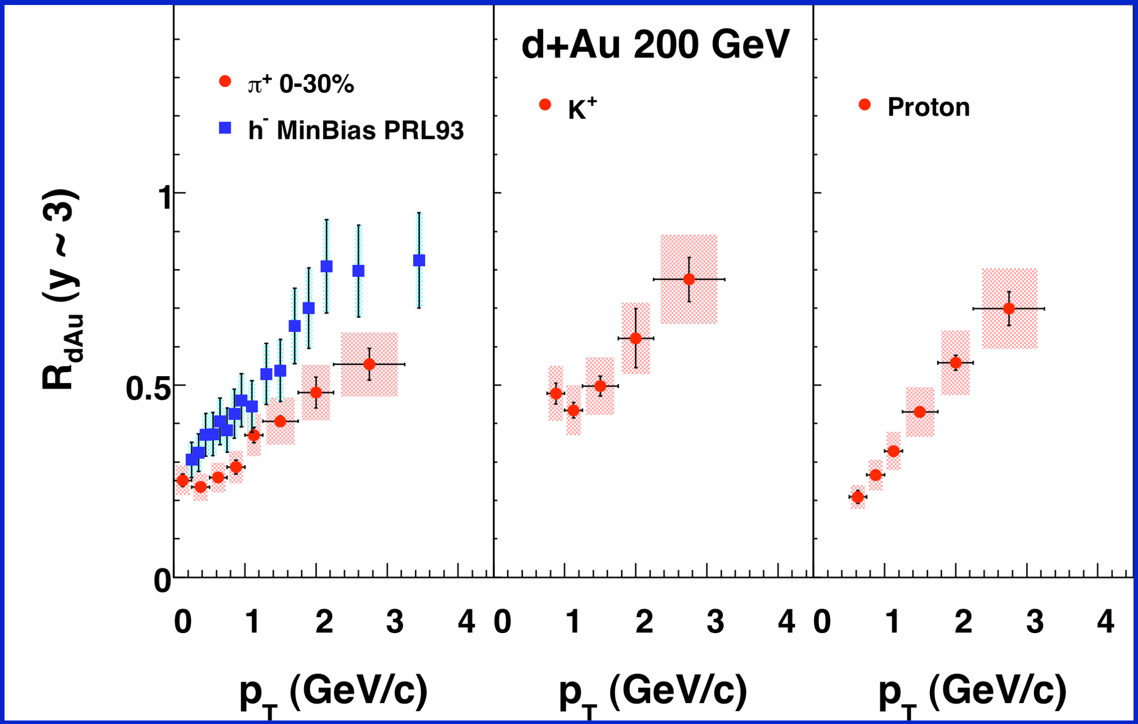
Identified Particle R_{dAu}



R_{dAu} for identified particle consistent with charged hadrons and all exhibiting R_{dA} <=1 for p_T<3 GeV/c

π+ the dominant meson exhibits clear suppression

BRAHMS

Summary

The BRAHMS experiment have provided unique physics results in the forward region, providing insight into several key questions,

"How does matter behave at very high temperature and/or density?"

- Jet-quenching suppression in AA, not d-A
- Au-Au, Cu-Cu, pp. Bulk properties energy dependence

"What is the nature of gluonic matter? and how does it behave inside of strongly interacting particles?"

- d-Au at high rapidities (low-x physics)

What did we learn

- The net-proton distributions in peripheral collisions are similar to pp.
- A clear change in net-proton rapidity shape takes place at ~ 60% centrality. Core dominates over corona shifting net-baryons to mid-rapidity.
- The near Gaussian shape of produced particles was a surprise
- The baryon chemical potential μ_B is the driving physics variable for many inclusive / bulk observables (Particle ratios vs. y, vs. p_t)
- $V_2(p_t)$ shows decrease towards forward rapidities.
- High p_t suppression at high rapidity via R_{AA} is open to interpretation.
- d-Au suppression observed at high rapidity has relevance for CGC and have inspired other newer measurements at RHIC.

BRAHMS

Collaboration

I.Arsene[7], I.G. Bearden[6], D. Beavis[1], S. Bekele[6] , C. Besliu[9], B. Budick[5],
H. Bøggild[6] , C. Chasman[1], C. H. Christensen[6], P. Christiansen[6], H.Dalsgaard, R.Debbe[1],
J. J. Gaardhøje[6], K. Hagel[7], H. Ito[10], A. Jipa[9], J. I. Jordre[9], E.B. Johnson[10],
C.E.Jørgensen[6], R. Karabowicz[3], N. Katryńska[3], E. J. Kim[4], T.M.Larsen[11], J. H. Lee[1],
Y. K. Lee[4], S.Lindal[11], G. Løvhøjden[2], Z. Majka[3], M. Murray[10], J. Natowitz[7], B.S.Nielsen[6],
C.Nygaard, D. Ouerdane[6],
D.Pald, R.Planeta[3], F. Rami[2], C. Ristea[6], O. Ristea[9], D. Röhrich[8],
S. J. Sanders[10], R.A.Sheetz[1], P. Staszel[3],
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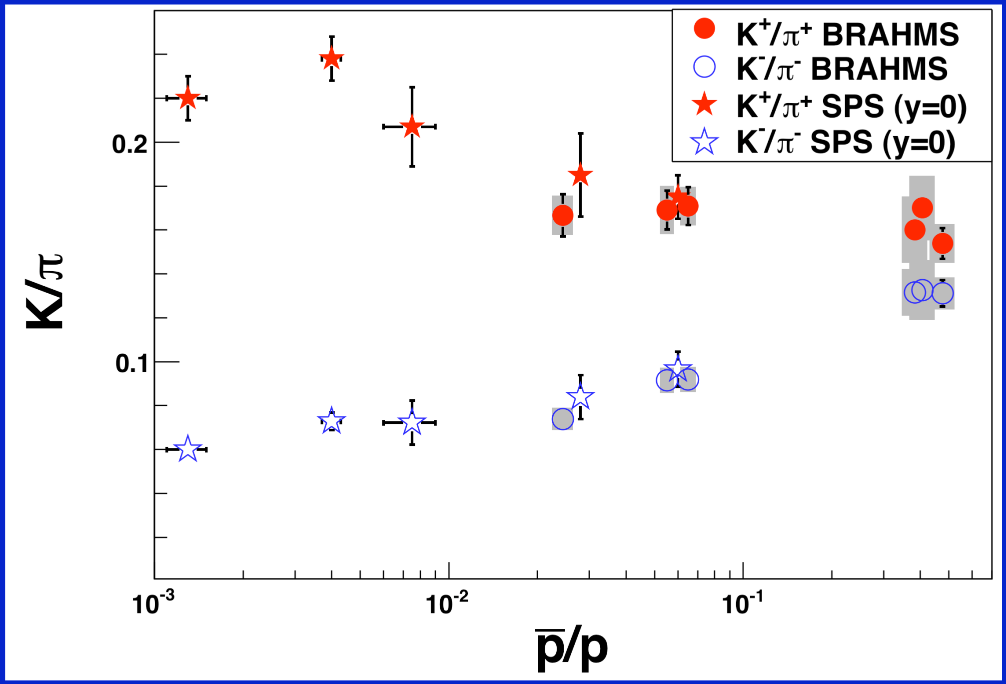
[7]Texas A&M University, College Station. USA, [8]University of Bergen, Norway
[9]University of Bucharest, Romania, [10]University of Kansas, Lawrence,USA
[11] University of Oslo Norway

BACKUP
and Surplus slides

K/pi vs u_B



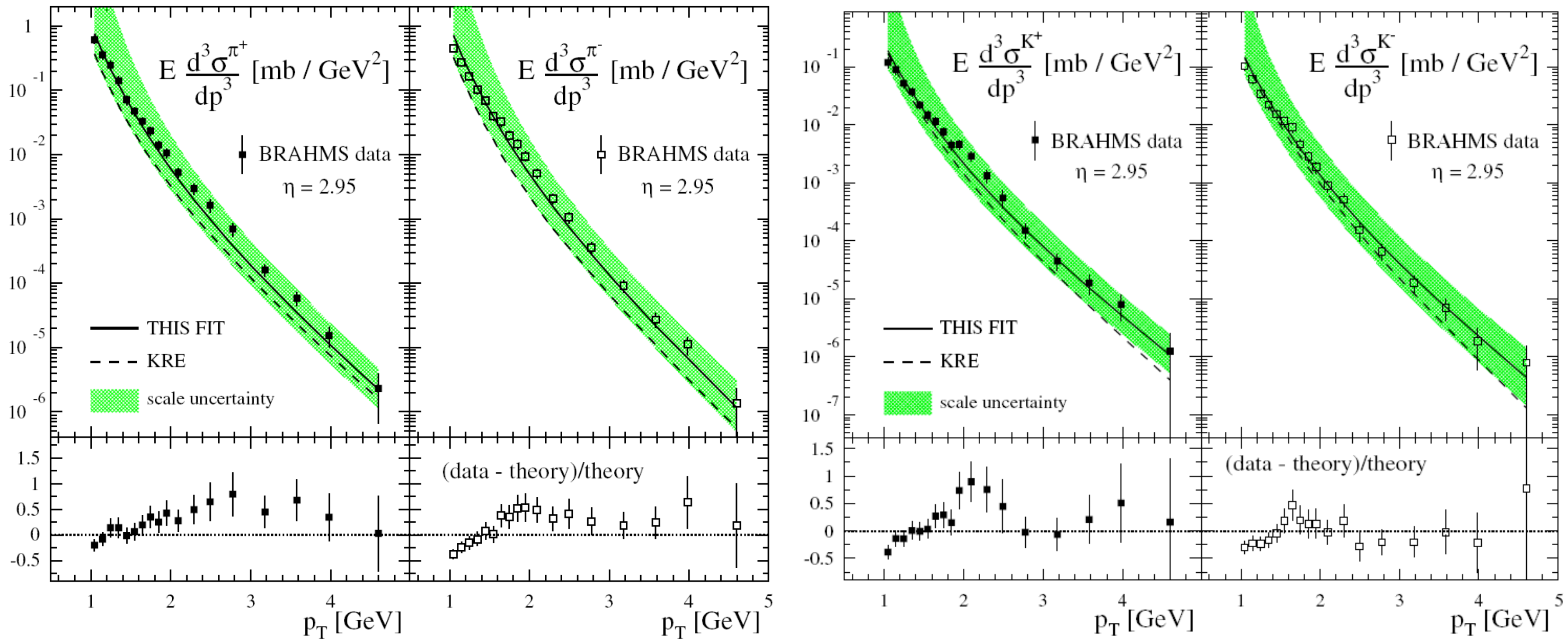
- K/pi energy dependence at low SNN at SPS of great interest This can be explored with the concept of muB driving bulk properties by going to forward rapidity at 62 GeV Au+Au.
- K/pi at the forward rapidity fall in same range as SPS data

BRAHMS

Global fits to data including BRAHMS large rapidity data

DSS, PRD **75,** 114010 (2007)

Brahms data: PRL 98, 252001 (2007)



Recently deFlorian, Sassot and Stratman performed a global fit including new data from Brahms at high rapidity. PRD **75,** 114010 (2007)

- Charged separated fragmentation functions
- Fragmentation functions significantly constrained compared to previous "state of the art" when adding RHIC data into fits.

Scaling in pp

- pp collision at lower energies exhibits a feature where dN/dx~c with an integral of ~0.6-0.7
- This implies for constant $<m_T>$ vs. rapidity that dN/dy~ exp(-y)
- The present data confirms this behavior at 200 GeV