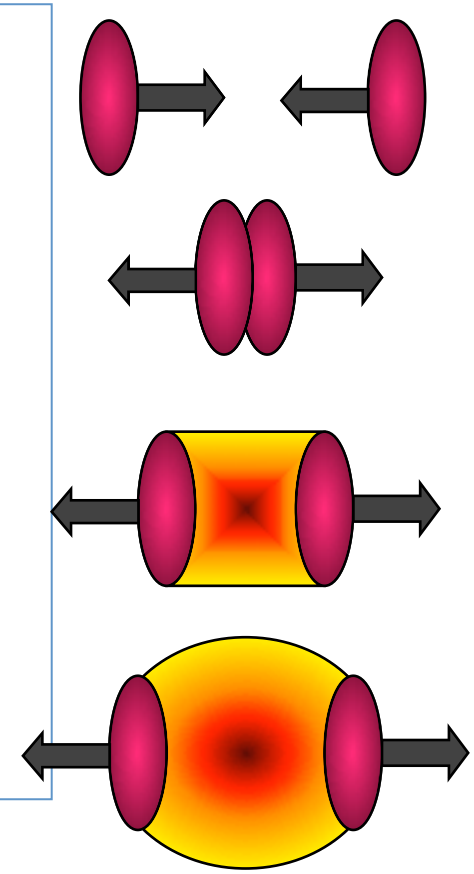
Reaction Dynamics in Relativistic HI collisions

Flemming Videbæk
Physics Department
Brookhaven National lab

Mapping space-time evolution

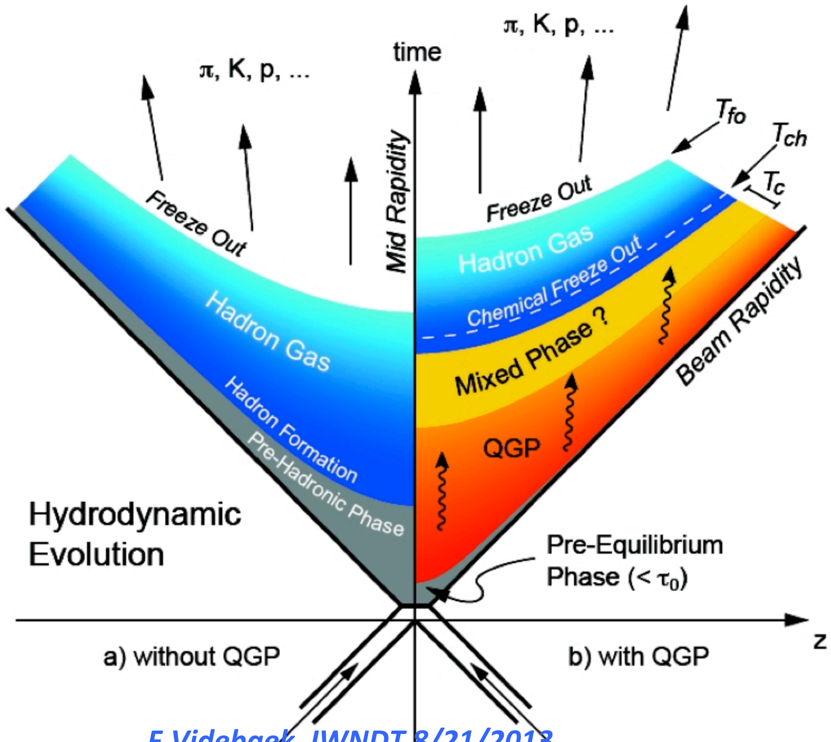
Identifying and Characterizing the Hot Matter

- - 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

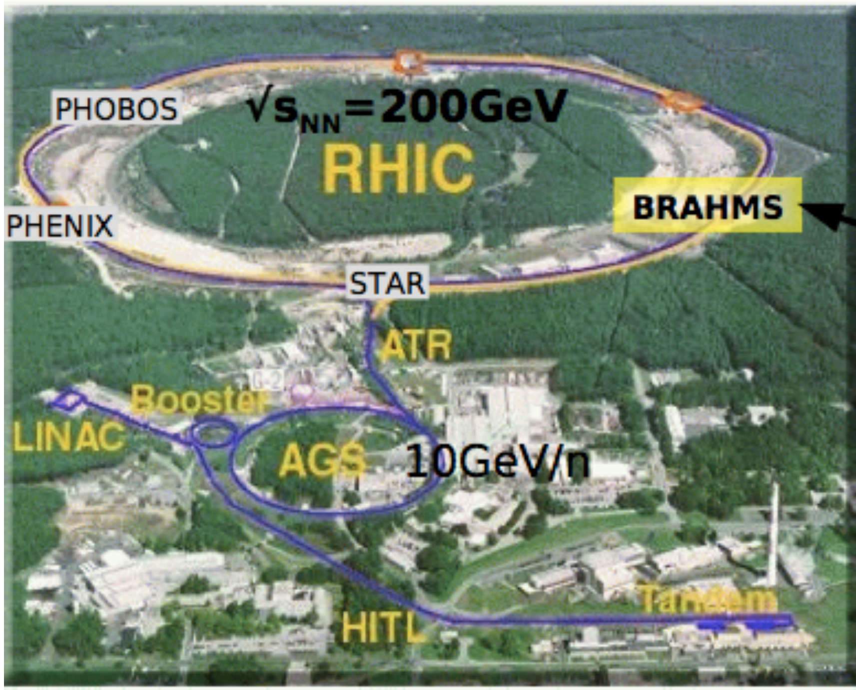


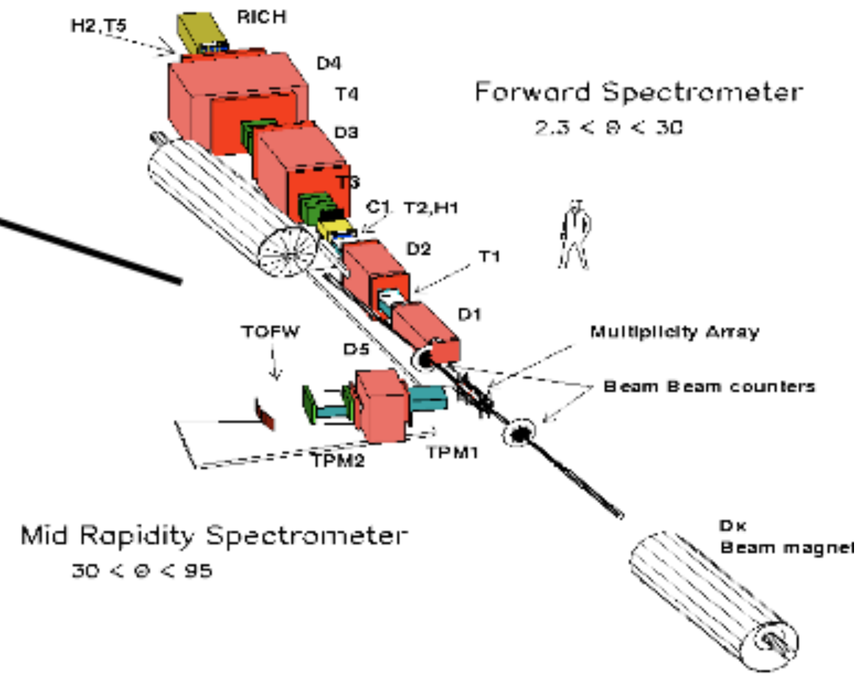
Space-Time view

- Short transition time (10^{-23} sec) freeze-out nuclear configuration
- Formation of hot dense media
- Expansion equilibration

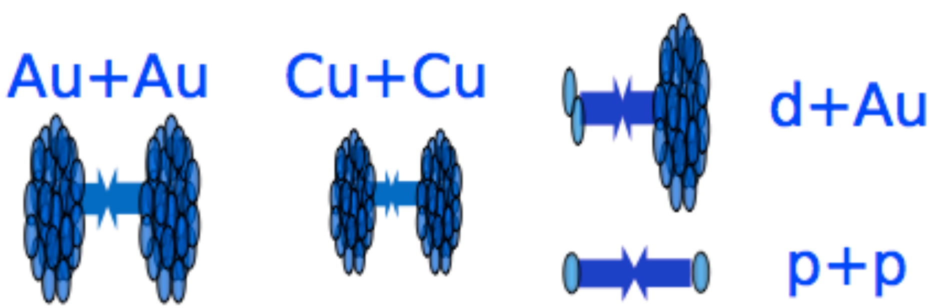


RHIC & BRAHMS

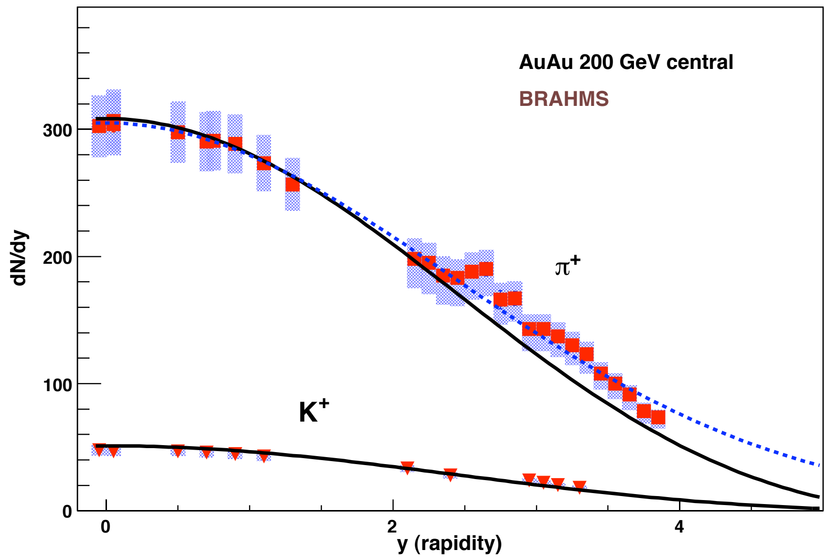




Energies:
$\sqrt{s_{NN}}$=62GeV,
$\sqrt{s_{NN}}$=130GeV,
$\sqrt{s_{NN}}$=200GeV



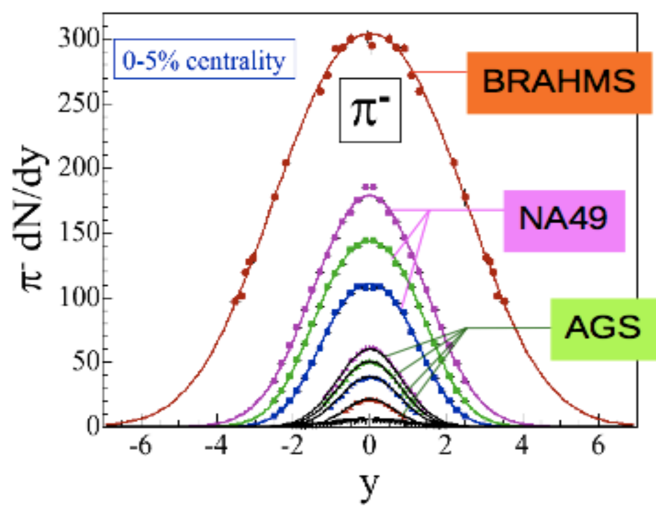
Produced Particles



AuAu 200 GeV 0-10% central

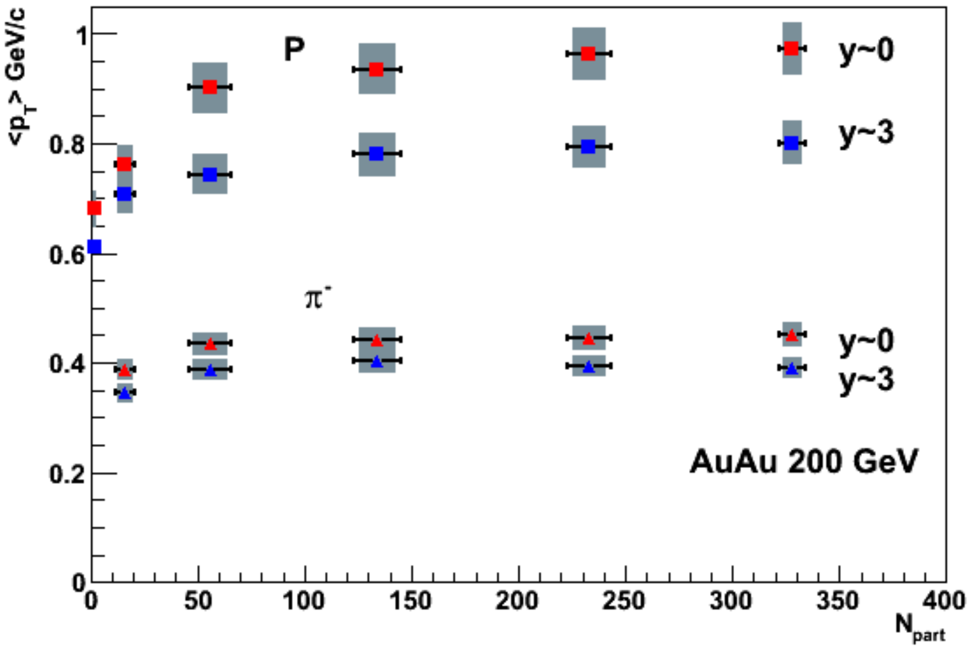
The dN/dy shape of pion is approx. Gaussian (blue)

The Landau hydro dynamic description give good description of dn/dy shape (black)



$<p_t>$: specie, rapidity and centrality

peripheral central



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

Weak dependence for pions

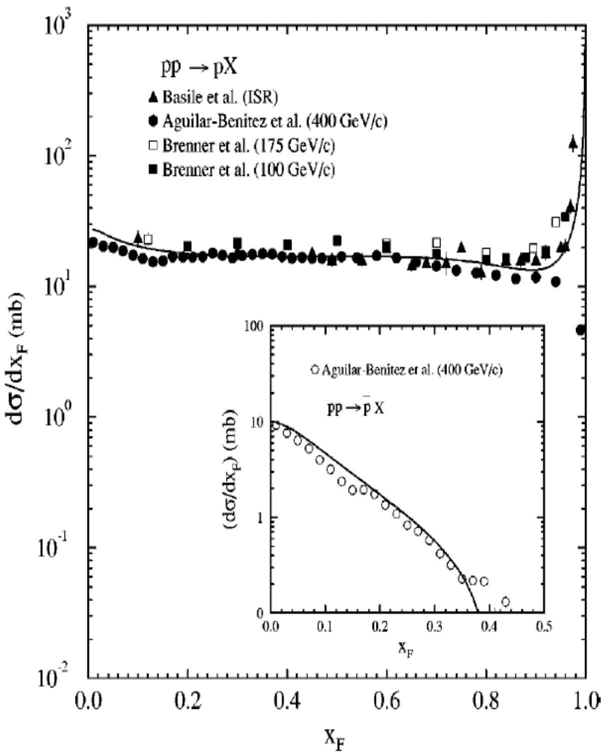
Reduced expansion and thus less medium effect at y~3

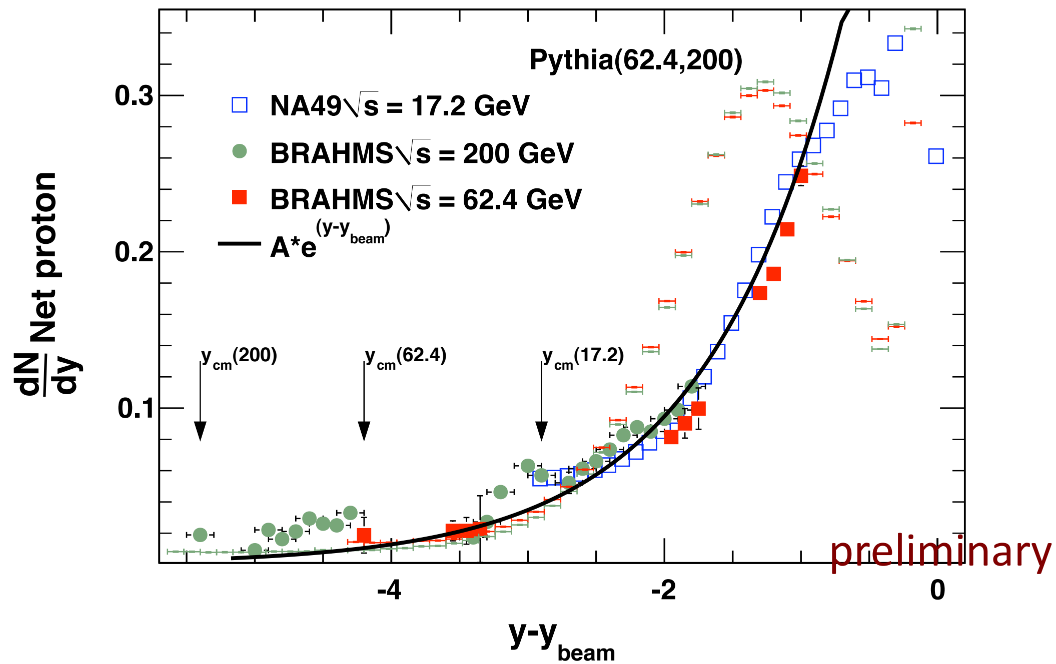
Stopping, Energy transfer

- During the reaction the energy in the projectile baryon (quarks) will be transferred.
- The natural process is that as energy is transferred, the baryon number is also transported away from the projectile rapidity.
- Baryon number is hard to measure so the net proton distribution is taken as a proxy for the baryon distributions
- dN/dy(net-B)= dN/dy(proton)-dN/dy(p-bar)

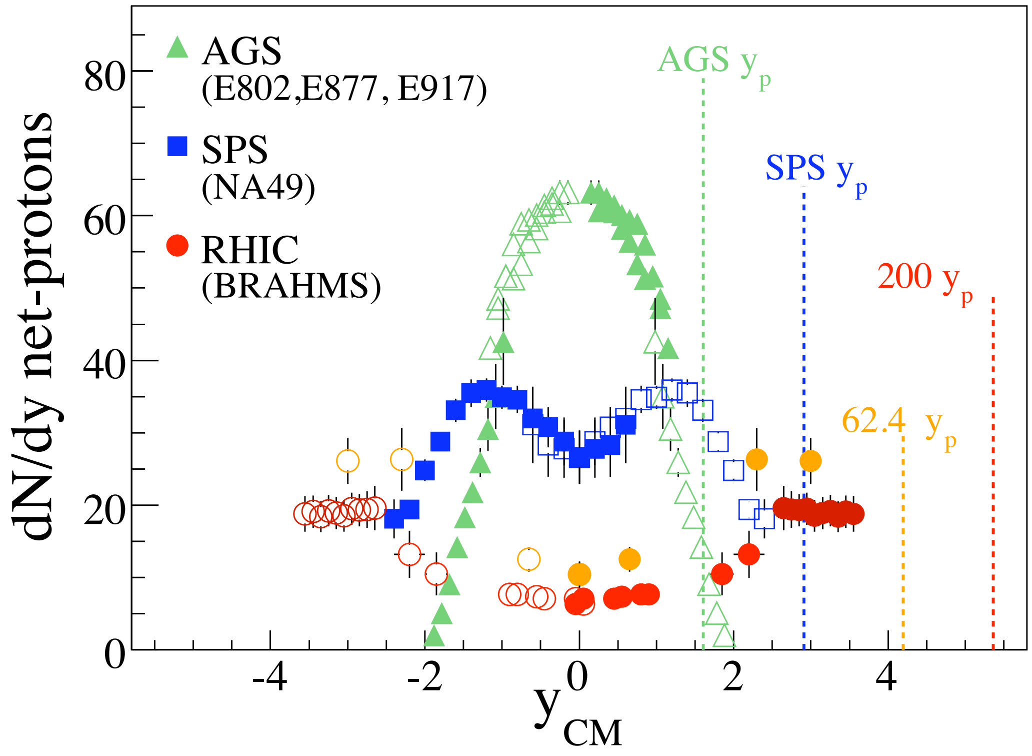
Net-proton Distributions

- pp collision at lower energies exhibits a feature where dN/dx~constant 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. No hint of additional baryon transport from 17->200 GeV.





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



Central collisions Au,Pb

High rapidity preliminary 200 GeV data

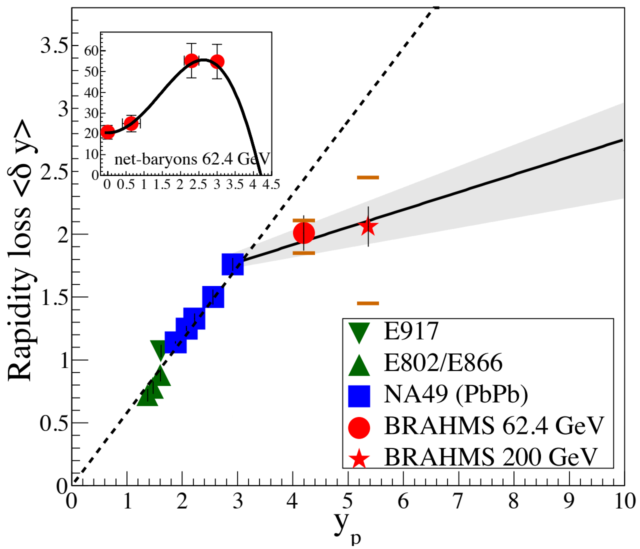
Quantifying rapidity Loss

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

- 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

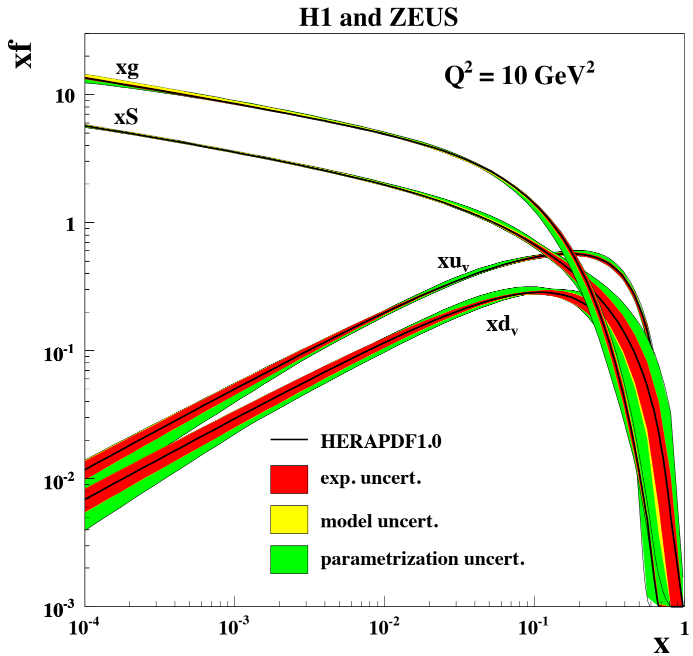
- The average rapidity loss from the 62 GeV data together with previous measurements from AGS,SPS and BRAHMS at 200 GeV
- Slowly increasing or flat trend above SPS energies.

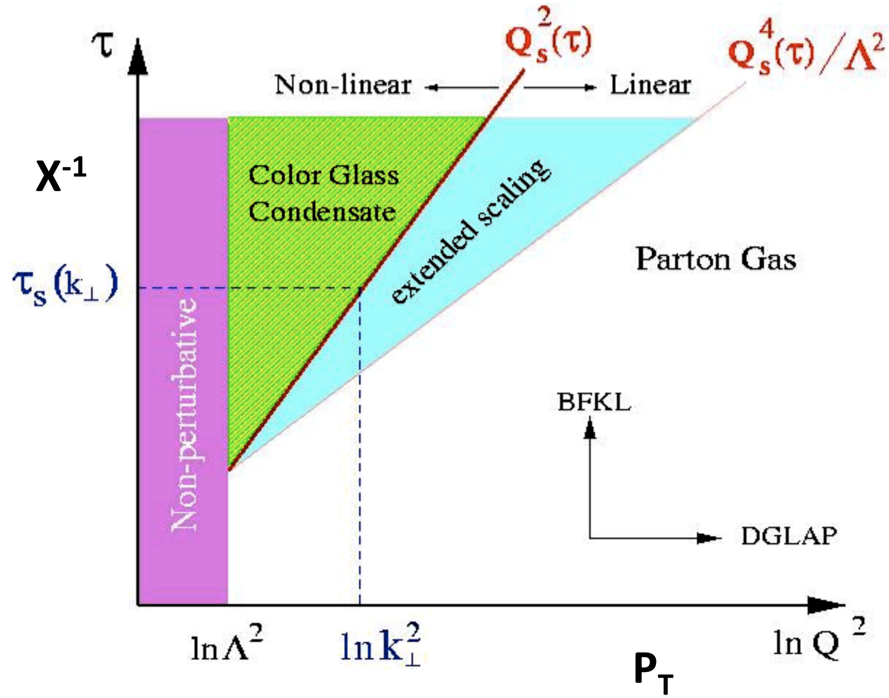


Initial and final state effects
A+A, and d+Au

- 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…

Gluon density dominates at x<0.1

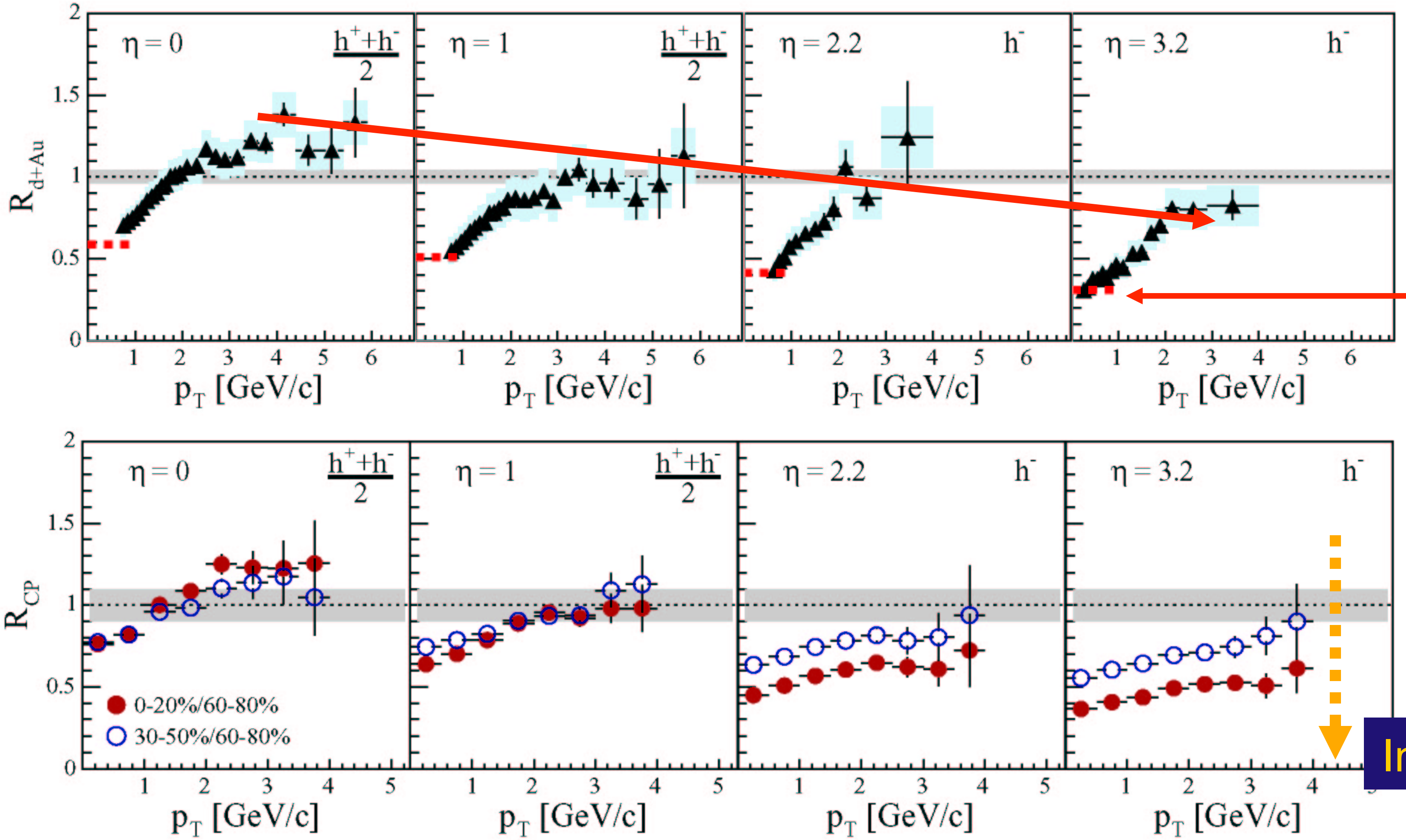




- Rapid rise in gluons described naturally by linear pQCD evolution equations
- This rise cannot increase forever - limits on the cross-section

→ non-linear pQCD evolution equations provide a natural way to tame this growth and lead to a saturation of gluons, characterized by the saturation scale $Q^2_s(x)$

BRAHMS d+Au results as function of rapidity and centrality



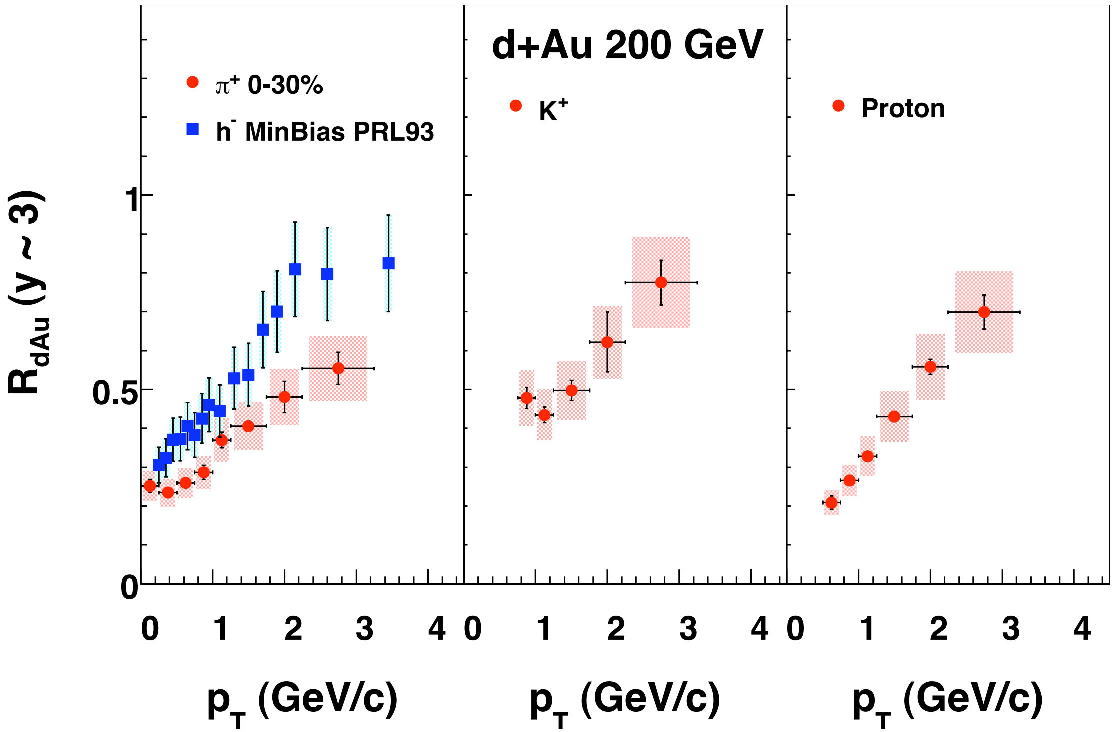
$$R_{dAu} = \frac{Y_{dAu}}{N_{coll} Y_{pp}}$$

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

The data have given rise to many interpretations and additional measurements. The behaviour is consistent with that of CGC,

BRAHMS, PRL 93, 242303

Identified Particle R_{dAu}



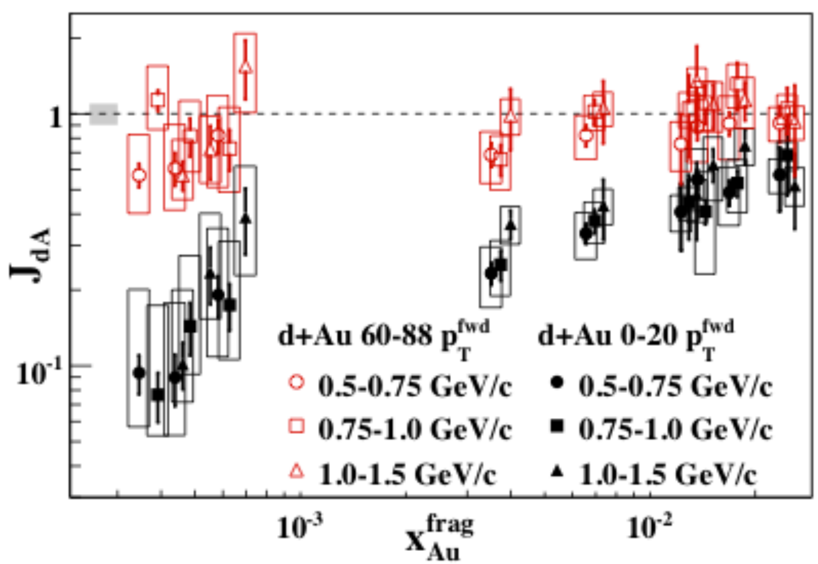
R_{dAu} for identified particle consistent with charged hadrons and all exhibiting R_{dA} <=1 for p_T<3 GeV/c

π+ the dominant meson exhibits clear suppression

Correlation studies

Further studies of di- parton (hadron) correlation can shed more light on process. Using forward-forward and forward-midrapidity correlations comparing d-A with pp

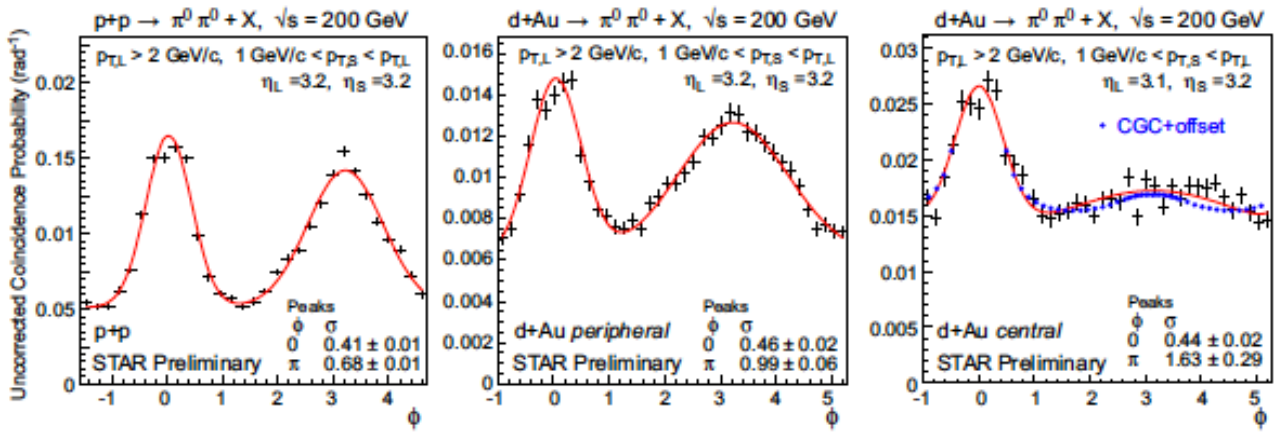
The X(Au) ~ $(p_t^1 e^{-y1} + p_t^2 e^{=y2})$/ sqrt(S) in a 2-2 process



Peripheral Collisions

Central Collisions

Phenix: Phys. Rev. Lett. 107, 172301 (2011)

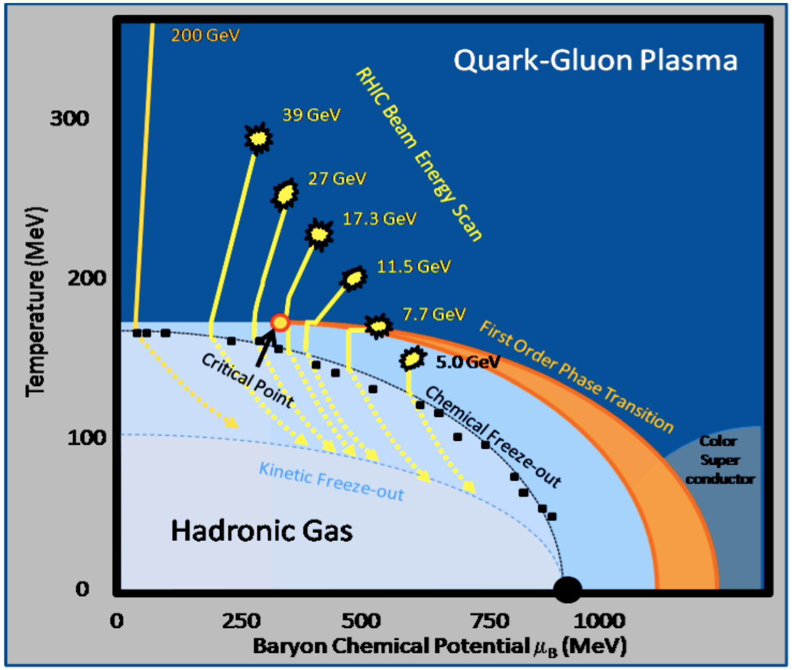


E. Braidot for the STAR Collaboration, arXiv:1008.3989 [nucl-ex].

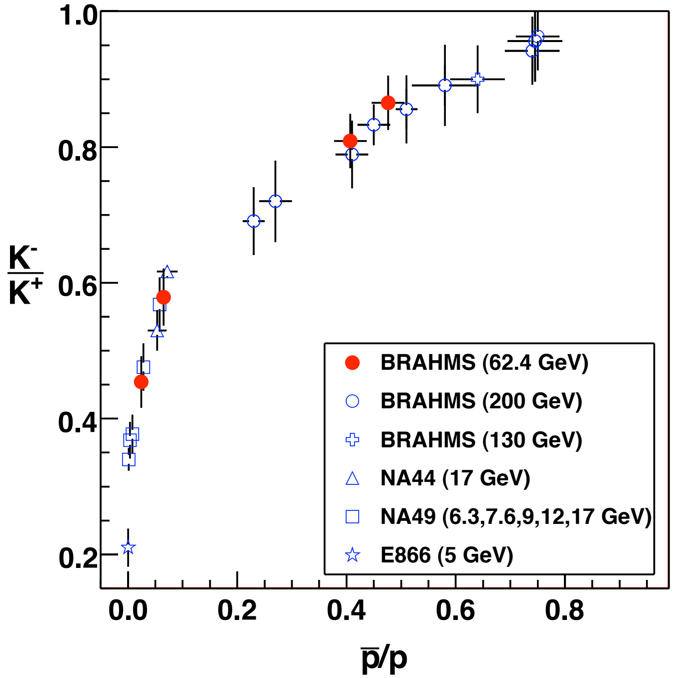
Uncorrected coincidence signal versus azimuthal angle difference between two forward neutral pions in *p*+*p* collisions (left) compared to peripheral (center) and central *d*+Au collisions (right)

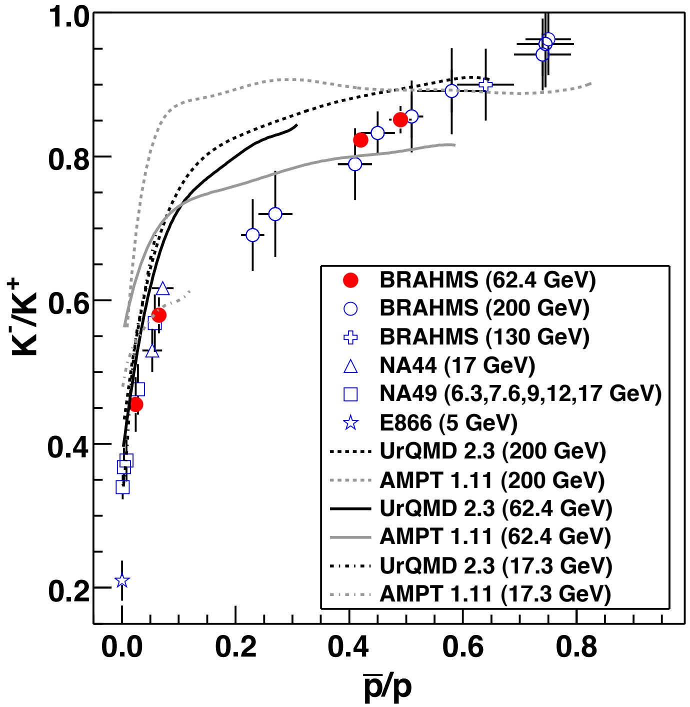
Nuclear Phase Diagram

Want to get access to the nuclear phase diagram by measurement yields and kinetic properties of produced particles.



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



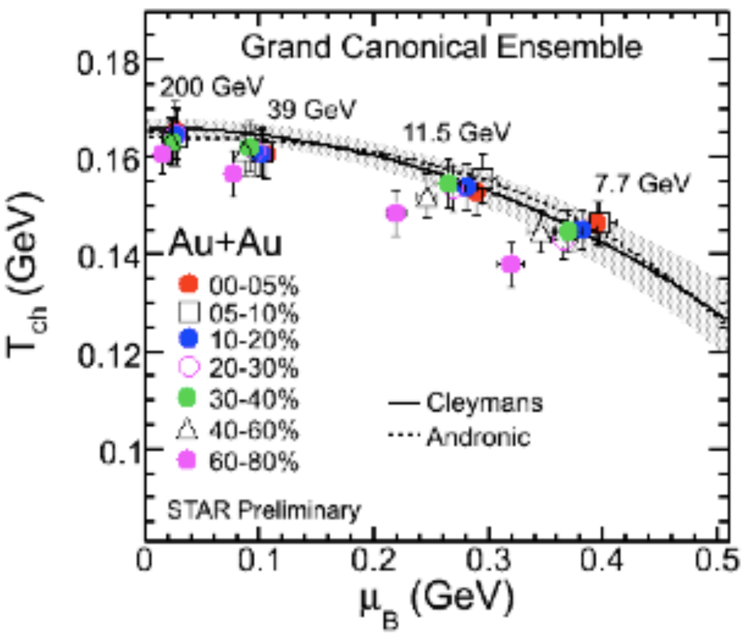


only μ_B controls the composition of bulk matter

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

Chemical Analysis

As example of analysis being done is shown result from STAR Beam Energy Scan using particle yields of many particles at mid-rapidity



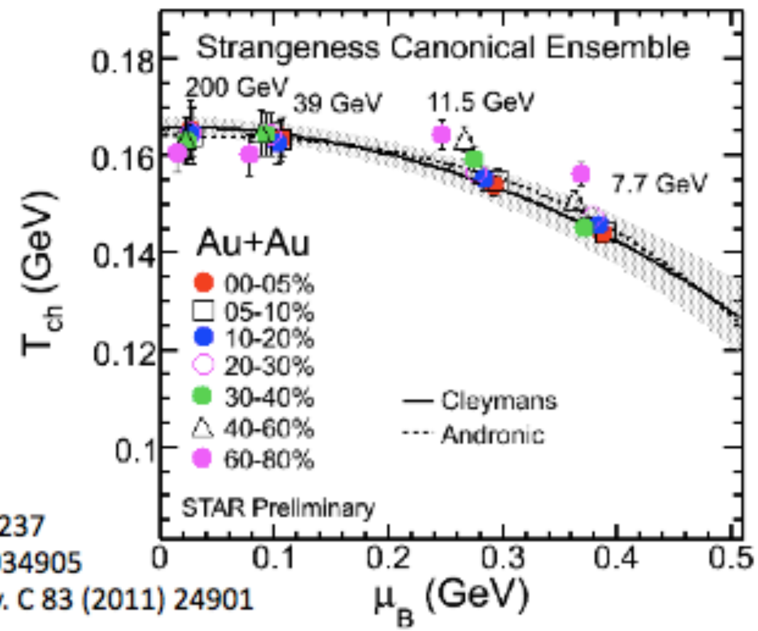
Particles used:

π, K, p, Λ, K^0_s, Ξ

THERMUS Model:

T_{ch} and μ_B

Chemical

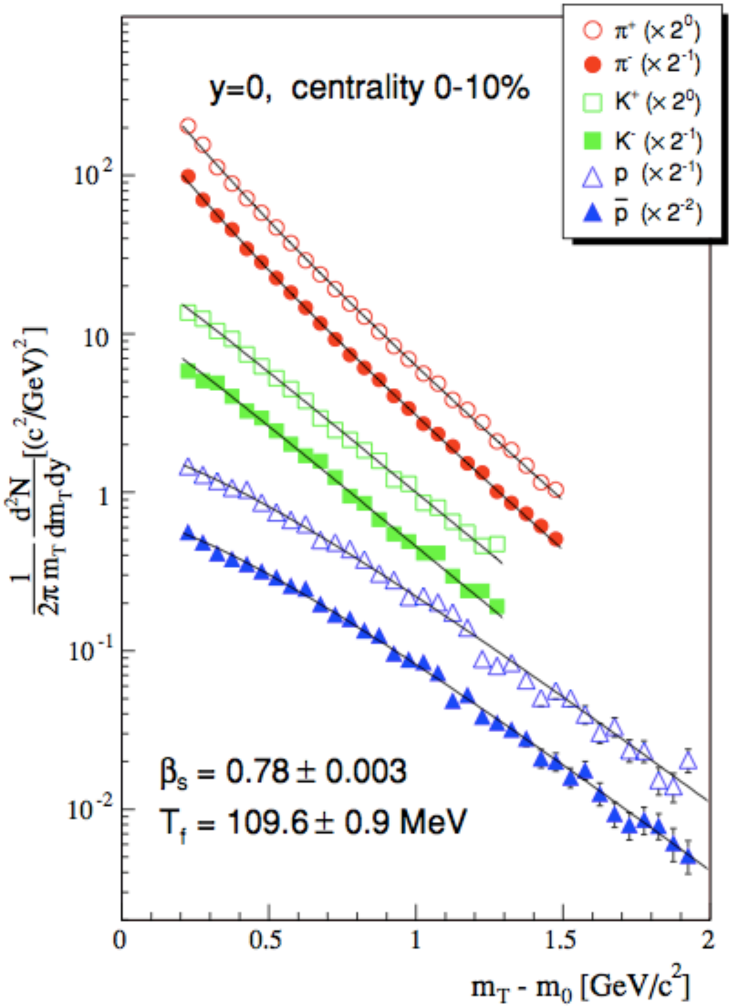


Andronic: NPA 834 (2010) 237

Cleymans: PRC 73 (2006) 034905

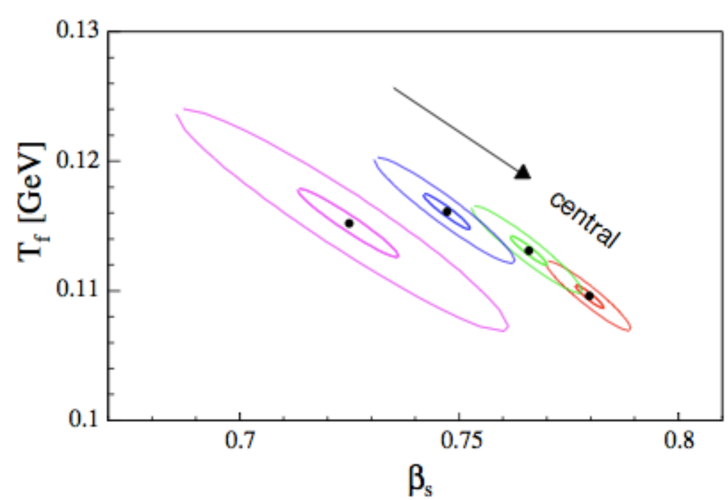
Au+Au 200 GeV : Phys. Rev. C 83 (2011) 24901

Kinetic Analysis



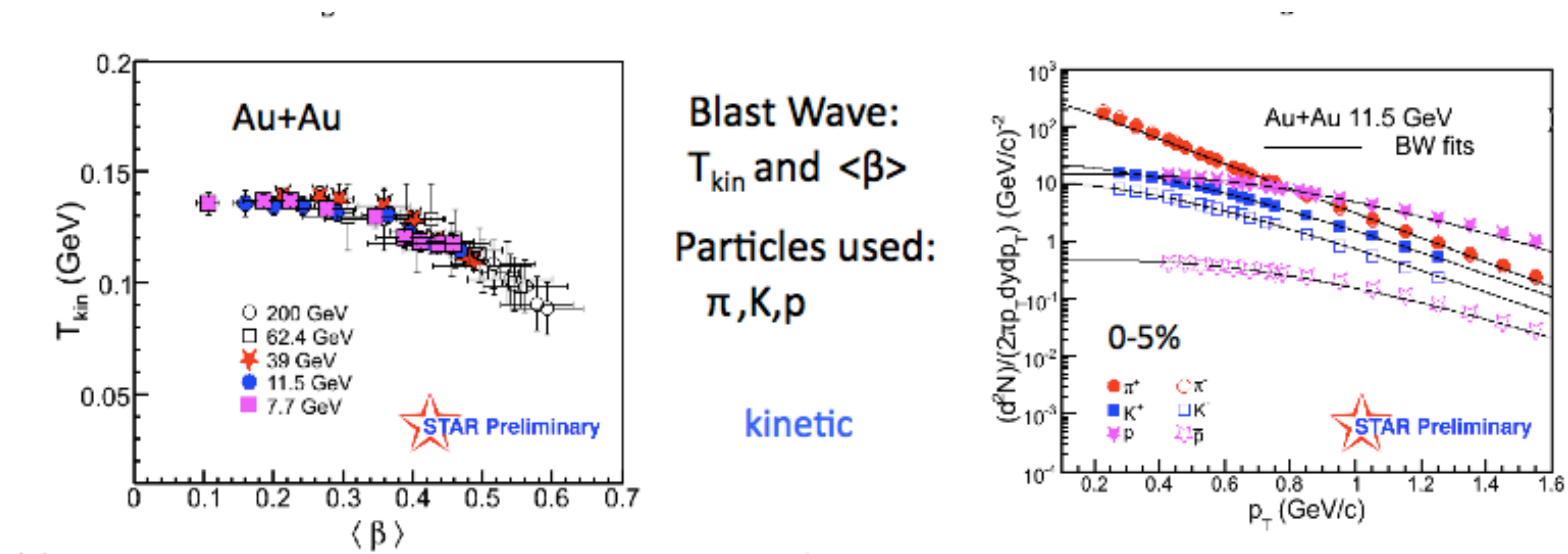
Analysis is often done within framework of blast-wawe assuming constant Tf with a collective transverse flow characterized by a surface velocity βs

$$\frac{dN}{m_T dm_T} \propto \int_0^{R_{\max}} r\, dr\, m_T I_0\left(\frac{p_T \sinh\rho}{T_f}\right) K_1\left(\frac{m_T \cosh\rho}{T_f}\right),$$



Energy systematics

As example of analysis being done is shown result from STAR Beam Energy Scan using particle spectra of many particles at mid-rapidity



Summary

- Significant stopping in AA collisions. About 75% of energy available for particle production.
- The near Gaussian shape of produced particles
- The baryon chemical potential μ_B is the driving physics variable for many inclusive / bulk observables (Particle ratios vs. y, vs. p_t)
- d-Au suppression observed at high rapidity has relevance for CGC and with newer results points to significant suppression at low parton x in the heavy nucleus

BRAHMS and TAMU contribution

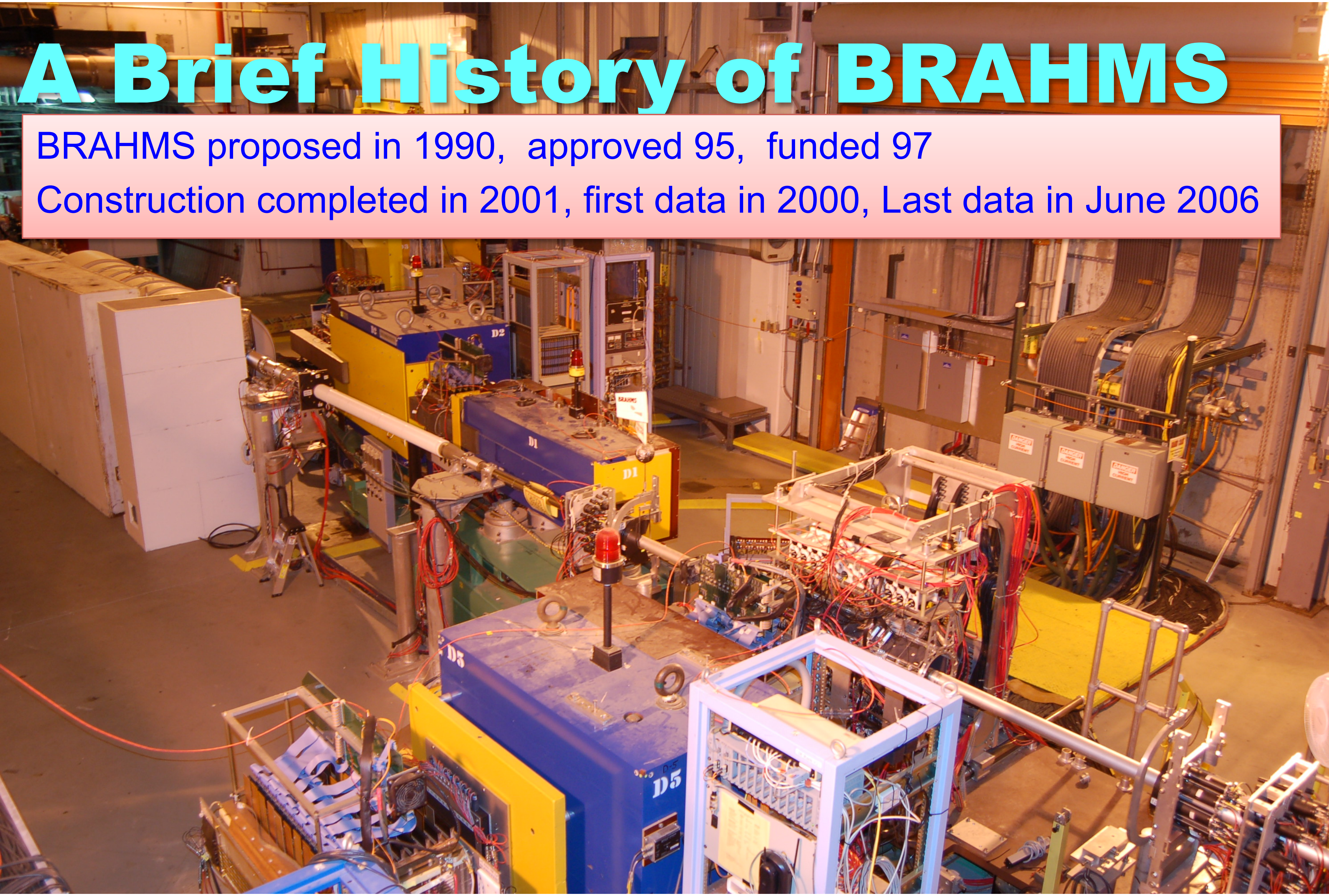
Quark Gluon Plasma and Color Glass Condensate at RHIC? The perspective from the BRAHMS experiment.

I. Arsene[j], I. G. Bearden[g], D. Beavis[a], C. Besliu[j], B. Budick[f], H. Bøggild[g], C. Chasman[a], C. H. Christensen[g], P. Christiansen[g], J. Cibor[c], R. Debbe[a], E. Enger[ℓ], J. J. Gaardhøje[g], M. Germinario[g], O. Hansen[g], A. Holm[g], A. K. Holme[ℓ], K. Hagel[h], H. Ito[a], E. Jakobsen[g], A. Jipa[j], F. Jundt[b], J. I. Jørdre[i], C. E. Jørgensen[g], R. Karabowicz[e], E. J. Kim[a,k], T. Kozik[e], T. M. Larsen[g,ℓ], J. H. Lee[a], Y. K. Lee[d], S. Lindahl[ℓ] G. Løvhøiden[ℓ], Z. Majka[e], A. Makeev[h], M. Mikelsen[ℓ], M. J. Murray[h,k], J. Natowitz[h], B. Neumann[k], B. S. Nielsen[g], D. Ouerdane[g], R. Płaneta[e], F. Rami[b], C. Ristea[g,j], O. Ristea[j], D. Röhrich[i], B. H. Samset[ℓ], D. Sandberg[g], S. J. Sanders[k], R. A. Scheetz[a], P. Staszel[g], T. S. Tveter[ℓ], F. Videbæk[a], R. Wada[h], Z. Yin[i], I. S. Zgura[j],

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



Closing

- Joe brought his group into BRAHMS with important contributions
  - Zero Degree Calorimeter First at RHIC
  - Online and analysis framework and software
  - Ideas and analysis on thermalization
- He also got Z.Majka and the Krakow group involved
  - In Drift Chamber construction and analysis
- Enjoy the future