NSAC Subcommittee on Relativistic Heavy Ions
BNL, June 2-6, 2004

Relativistic Heavy Ion Physics: the Next Step

D. Kharzeev

BNL

BROOKHAVEN
NATIONAL LABORATORY

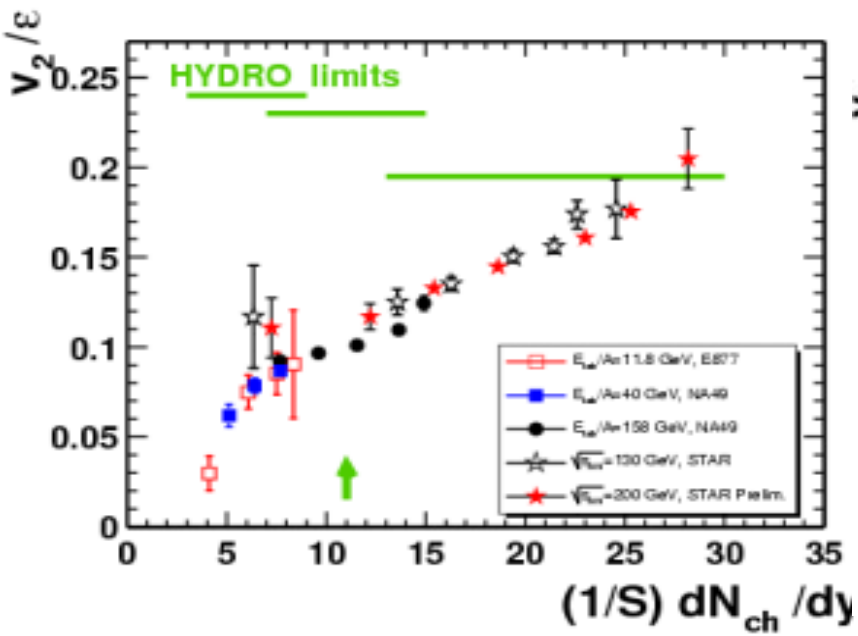
Four big questions:

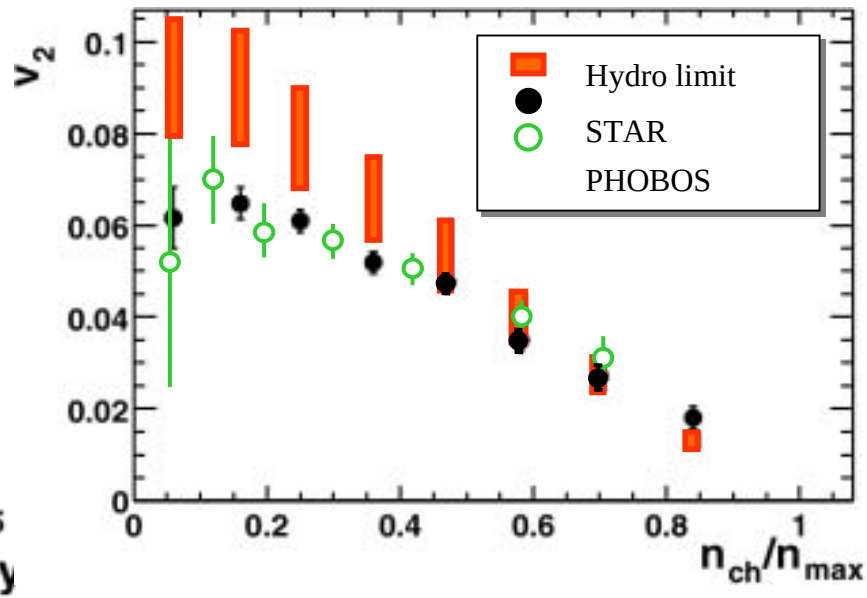
- What have we learned from RHIC so far?
- What do we still need to know?
- What has to be done?
- How should one do it?

What have we learned from RHIC so far ?

I. Collective flow =>

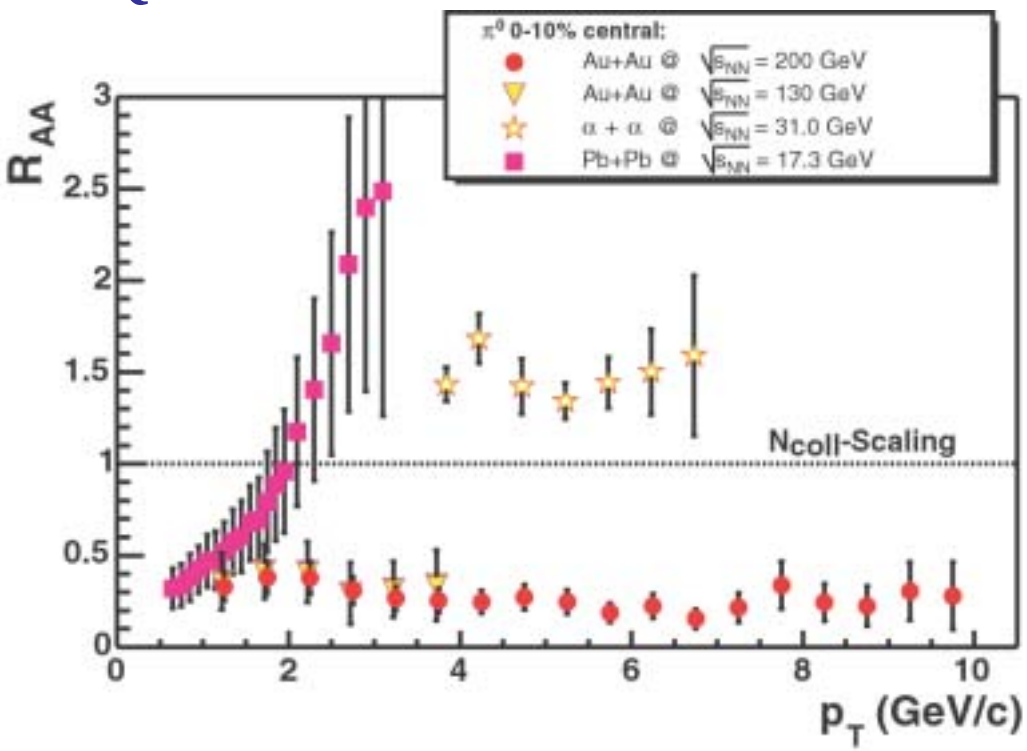
Au-Au collisions at RHIC produce strongly interacting matter





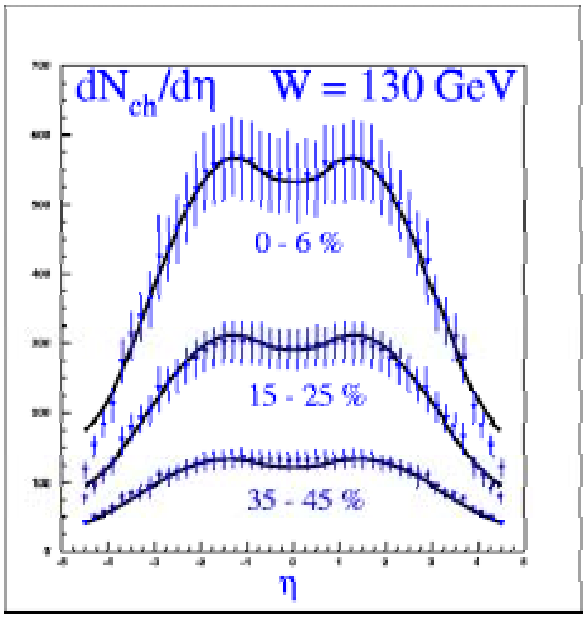
What have we learned from RHIC so far ?

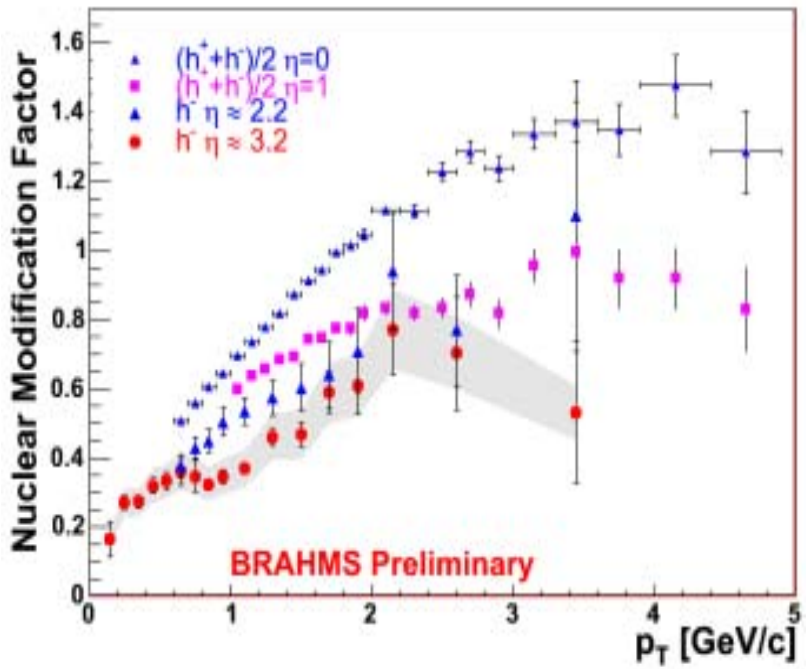
II. Suppression of high p_T particles =>
consistent with the predicted jet energy loss from induced gluon radiation in dense QCD matter



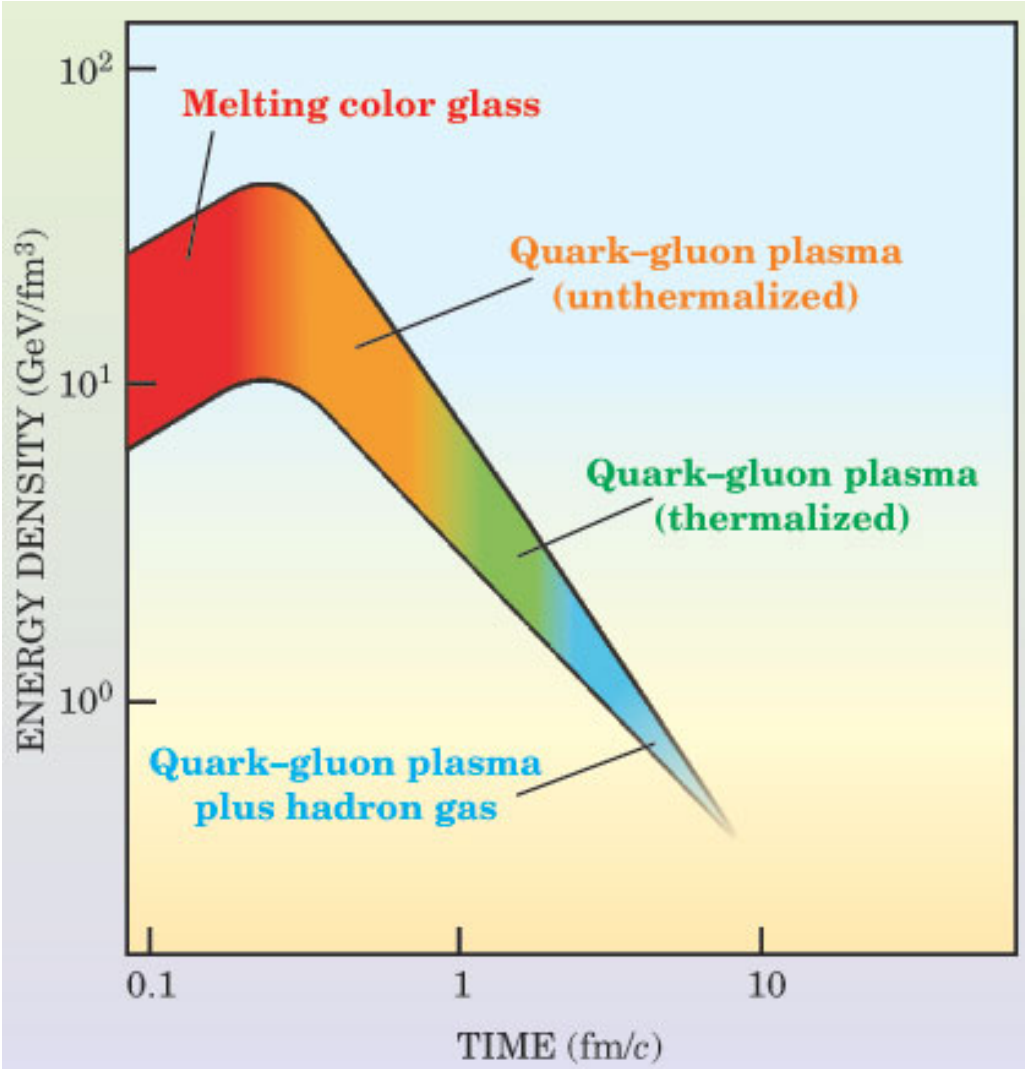
What have we learned from RHIC so far ?

III. “Small” hadron multiplicities +
suppression of high p_T particles at forward rapidities =>
coherent interactions in the initial state, consistent
with the presence of parton saturation/Color Glass Condensate





The emerging picture



T. Ludlam,
L. McLerran,
Physics Today
October 2003

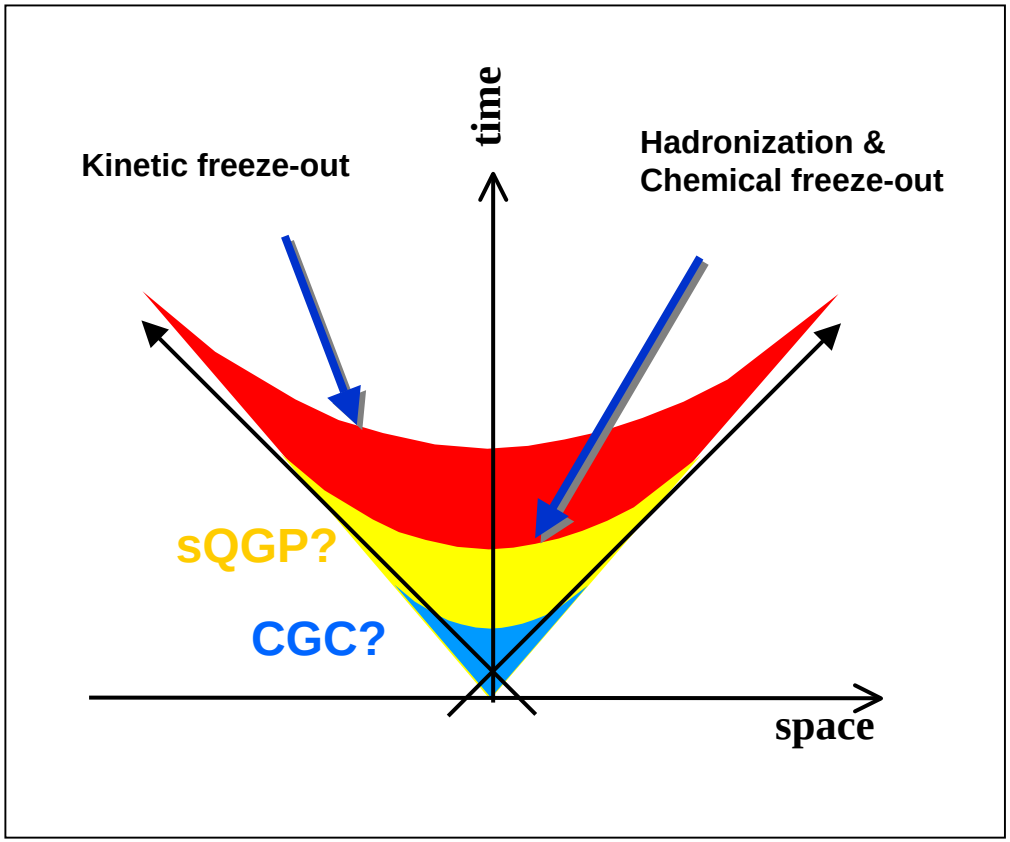
What we still need to know

- Is the produced matter a thermalized Quark-Gluon Plasma ?
  if yes, what are its properties ?

- Are the effects observed at forward rapidity due to parton saturation in the CGC ?

What do we still need to know?

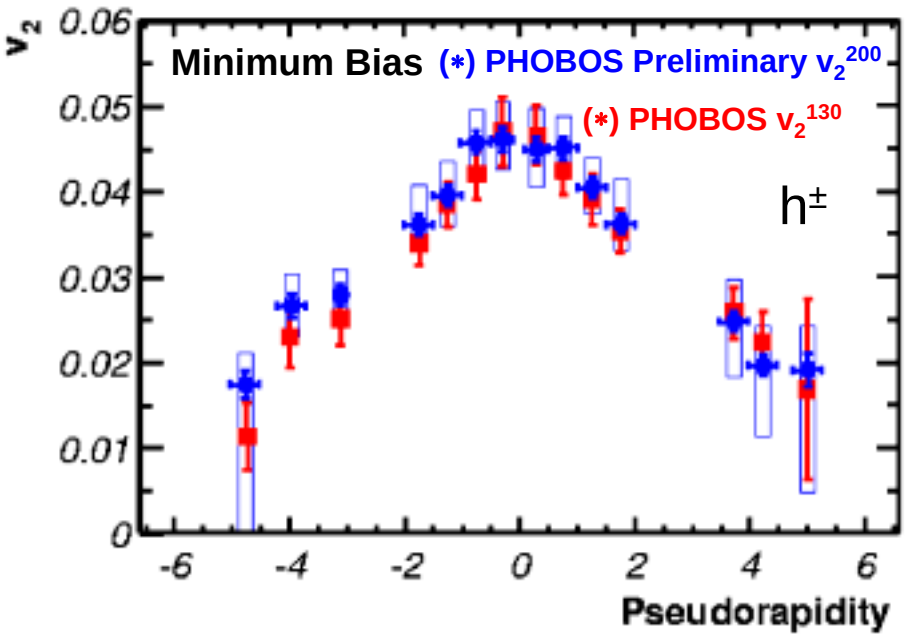
I. How does the sQGP evolve in space-time?

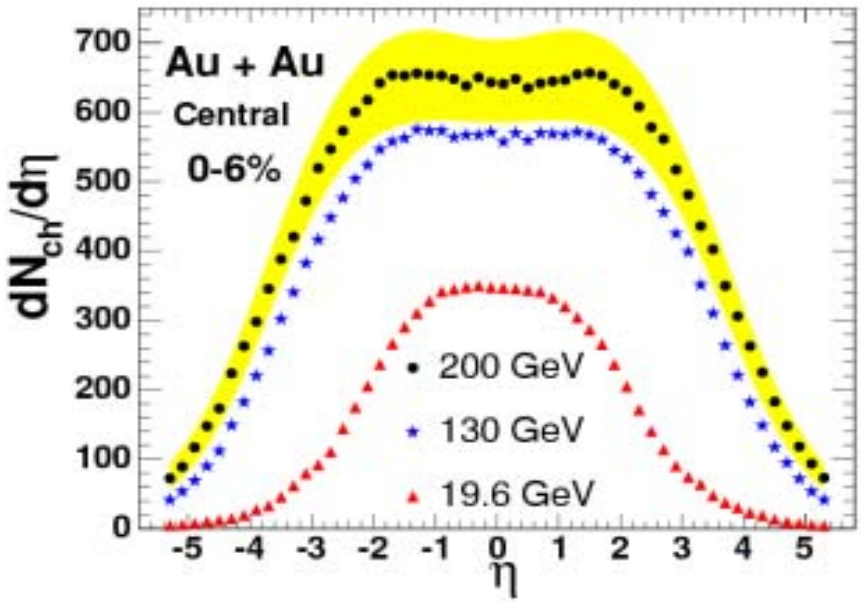


M.Baker

What do we still need to know?

I. How does the sQGP evolve in space-time?

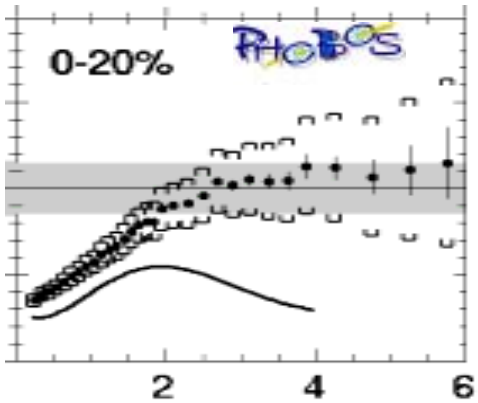


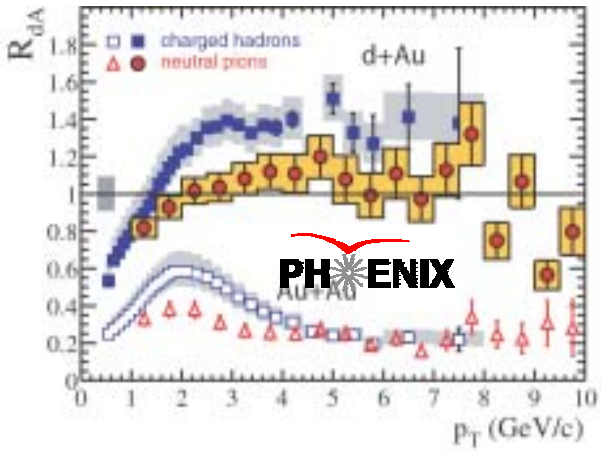


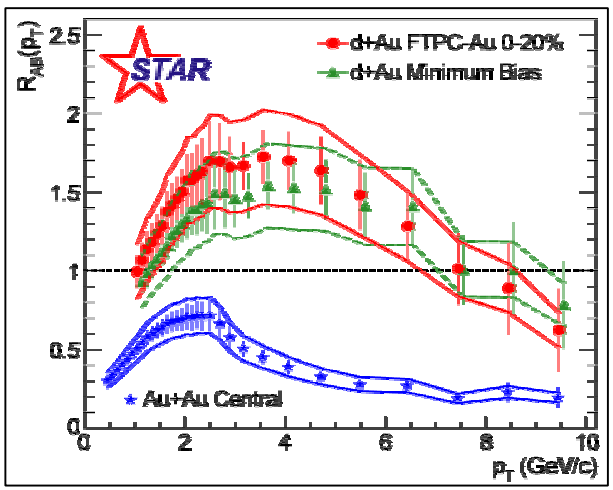
+ “HBT puzzle”

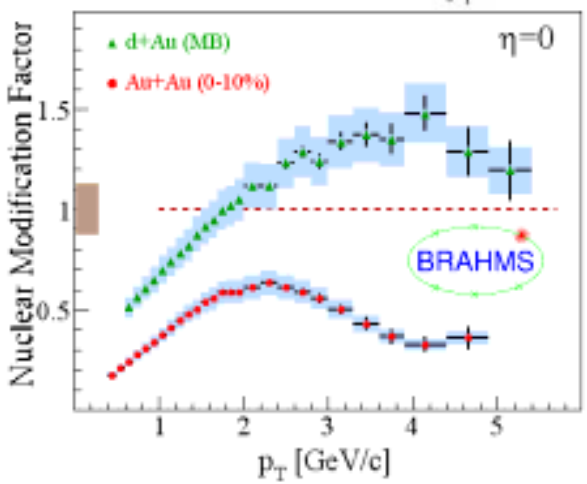
What do we still need to know?

II. d-Au experiments have shown that at y=0 the suppression of high p_T particles is a final-state effect:





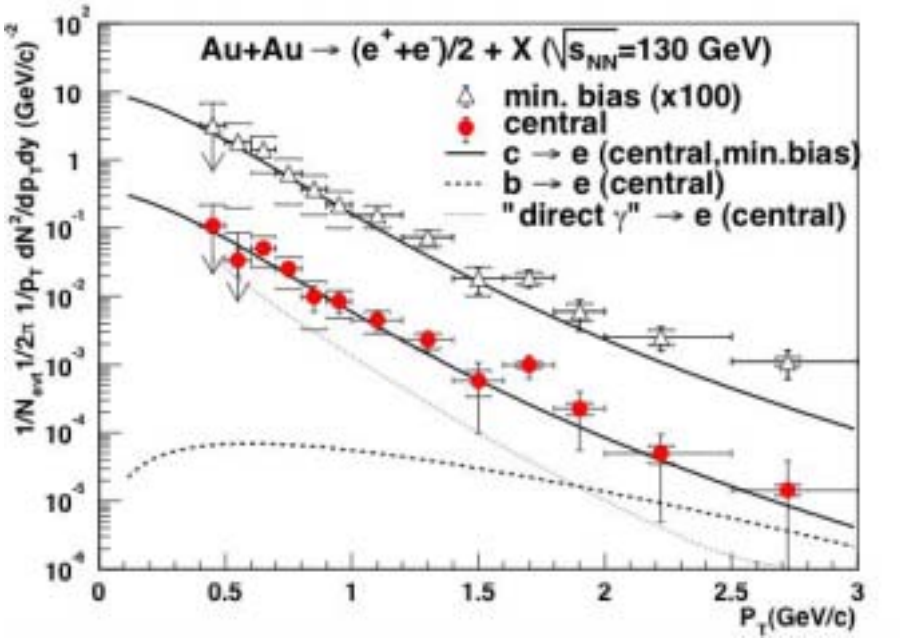


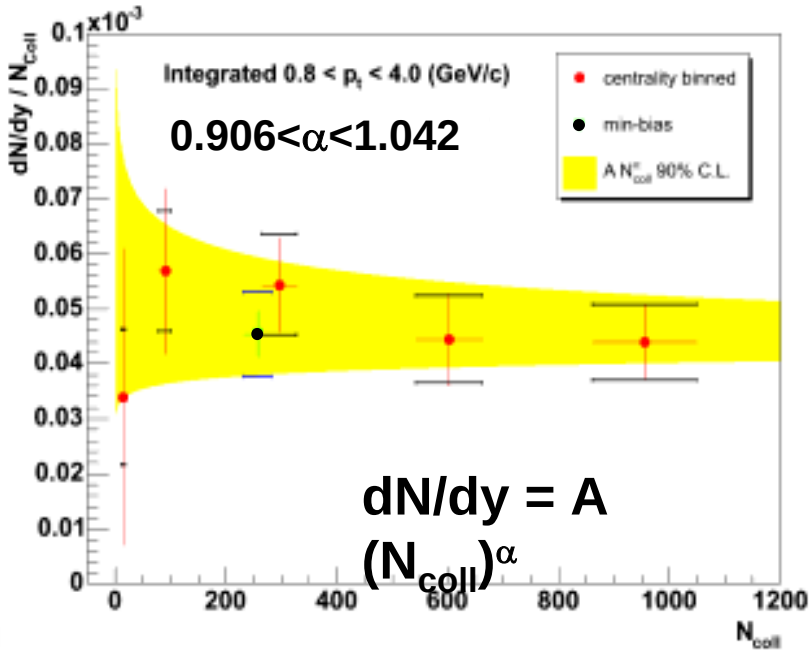


What do we still need to know?

II. can we prove that it is due to the radiative energy loss in sQGP?

induced radiation should be suppressed for heavy quarks; is it?



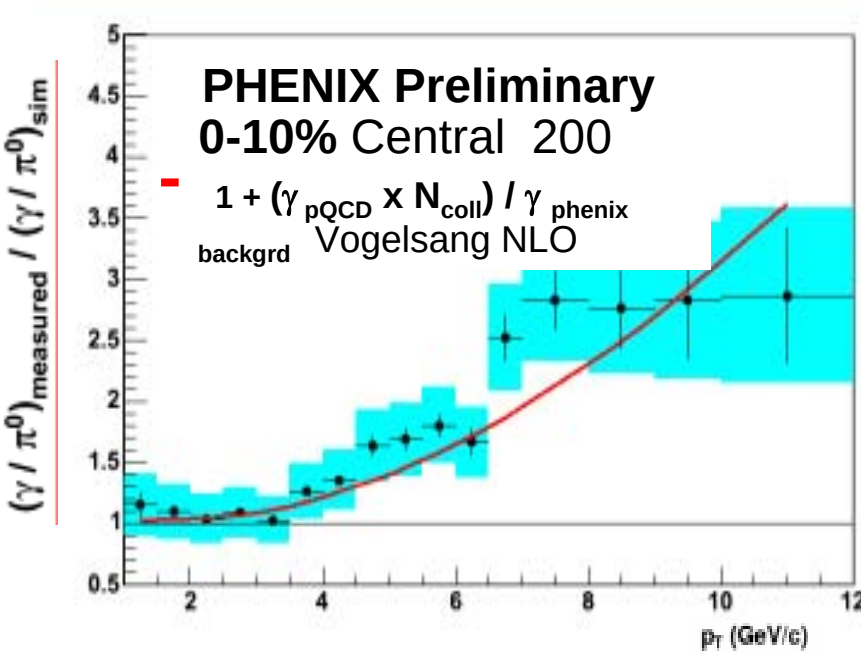


Data from PHENIX

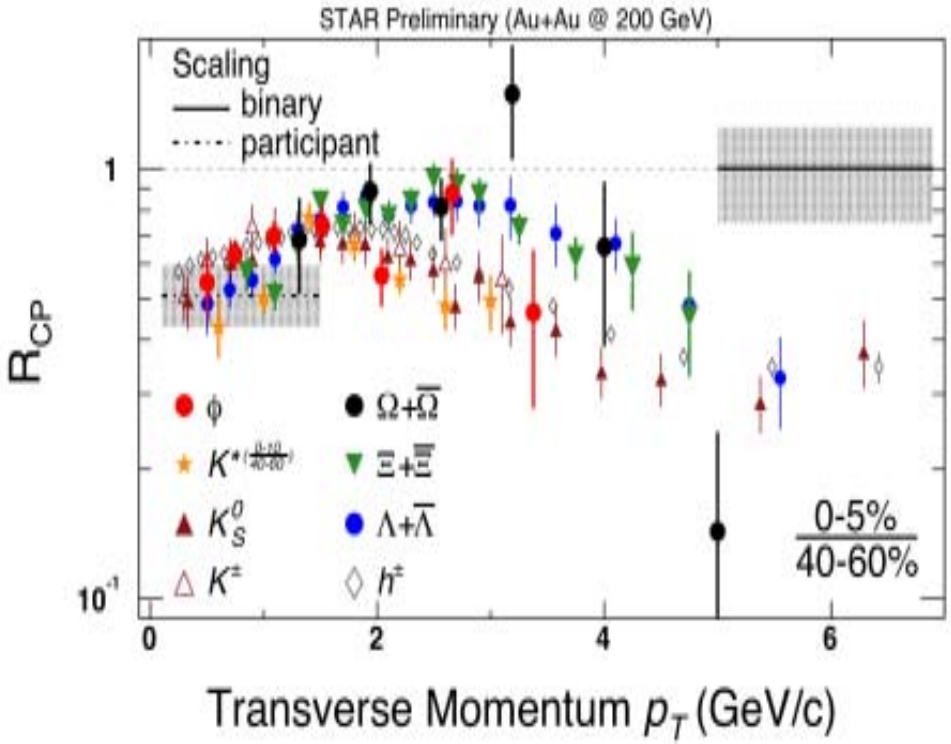
What do we still need to know?

II. can we prove that it is due to the radiative energy loss in sQGP?

Direct photons as a probe

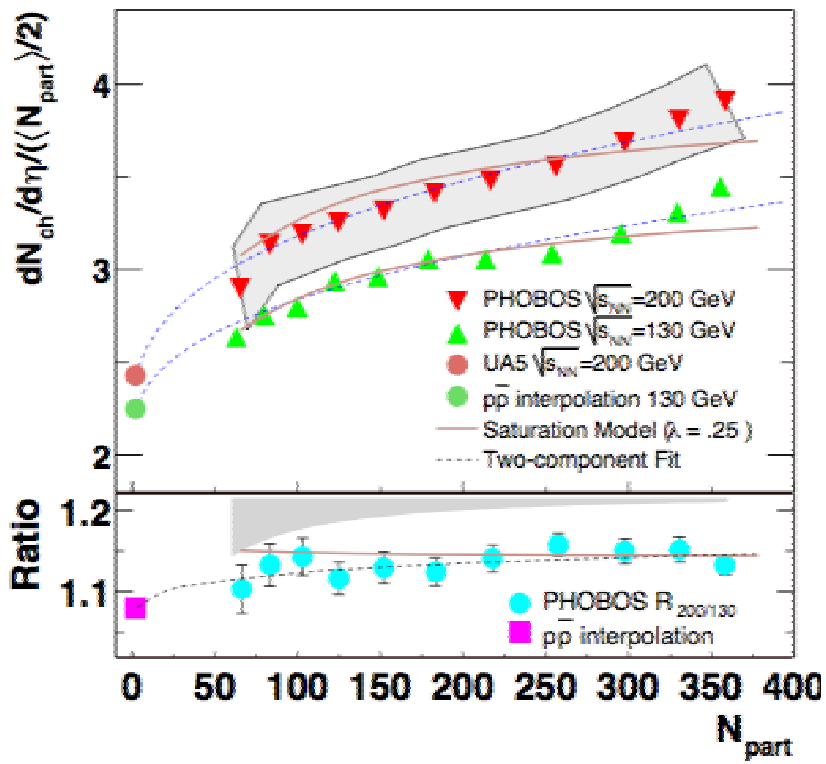


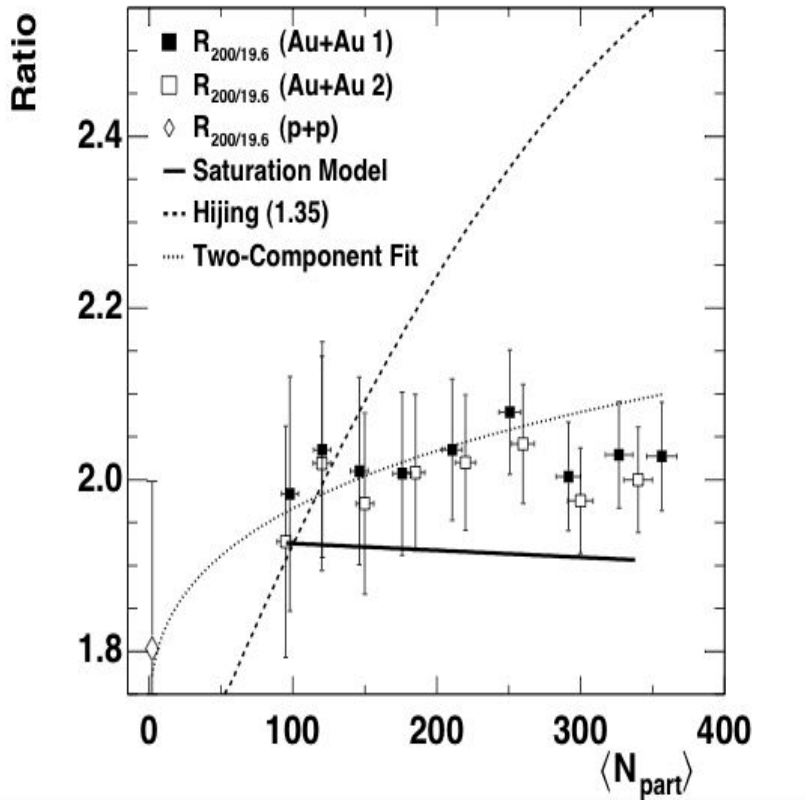
What is the origin of the "B/π puzzle"?



What do we still need to know?

III. The data on hadron multiplicities in Au-Au and d-Au collisions support the Color Glass Condensate picture:





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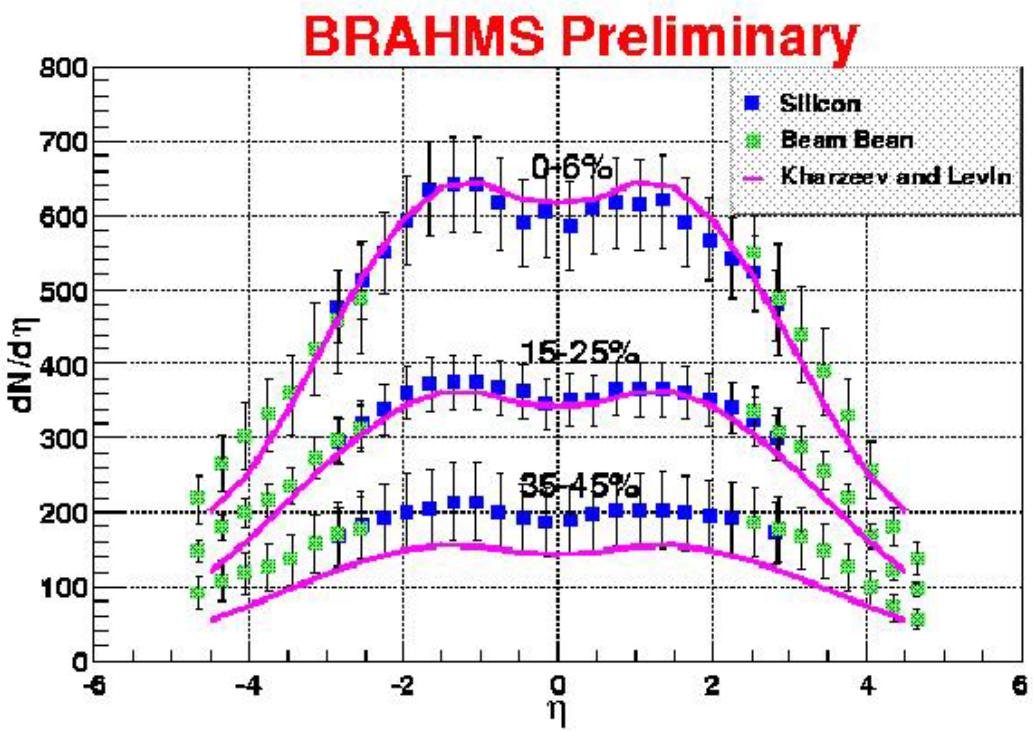
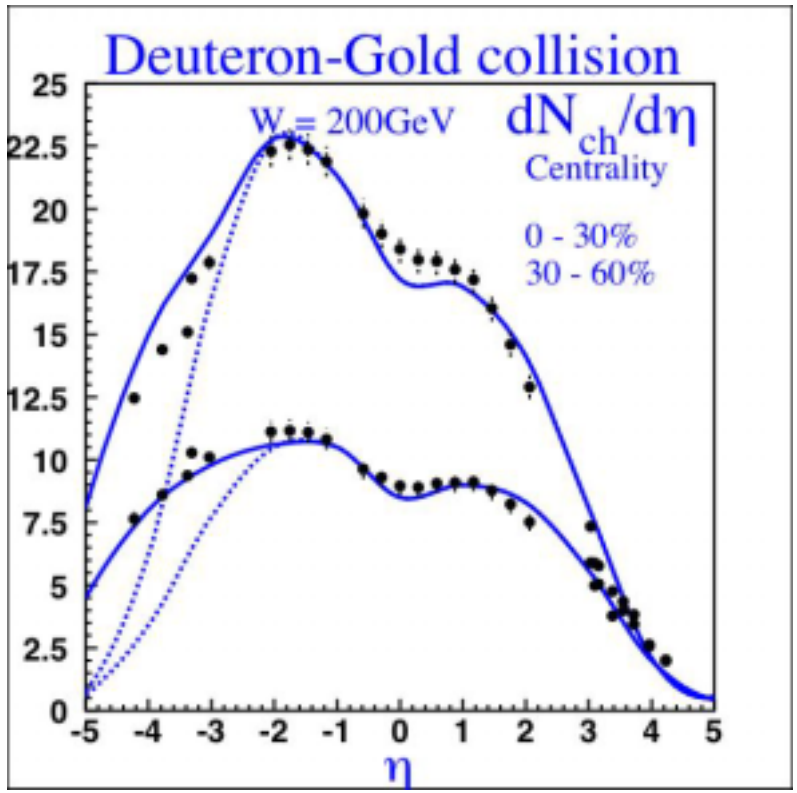
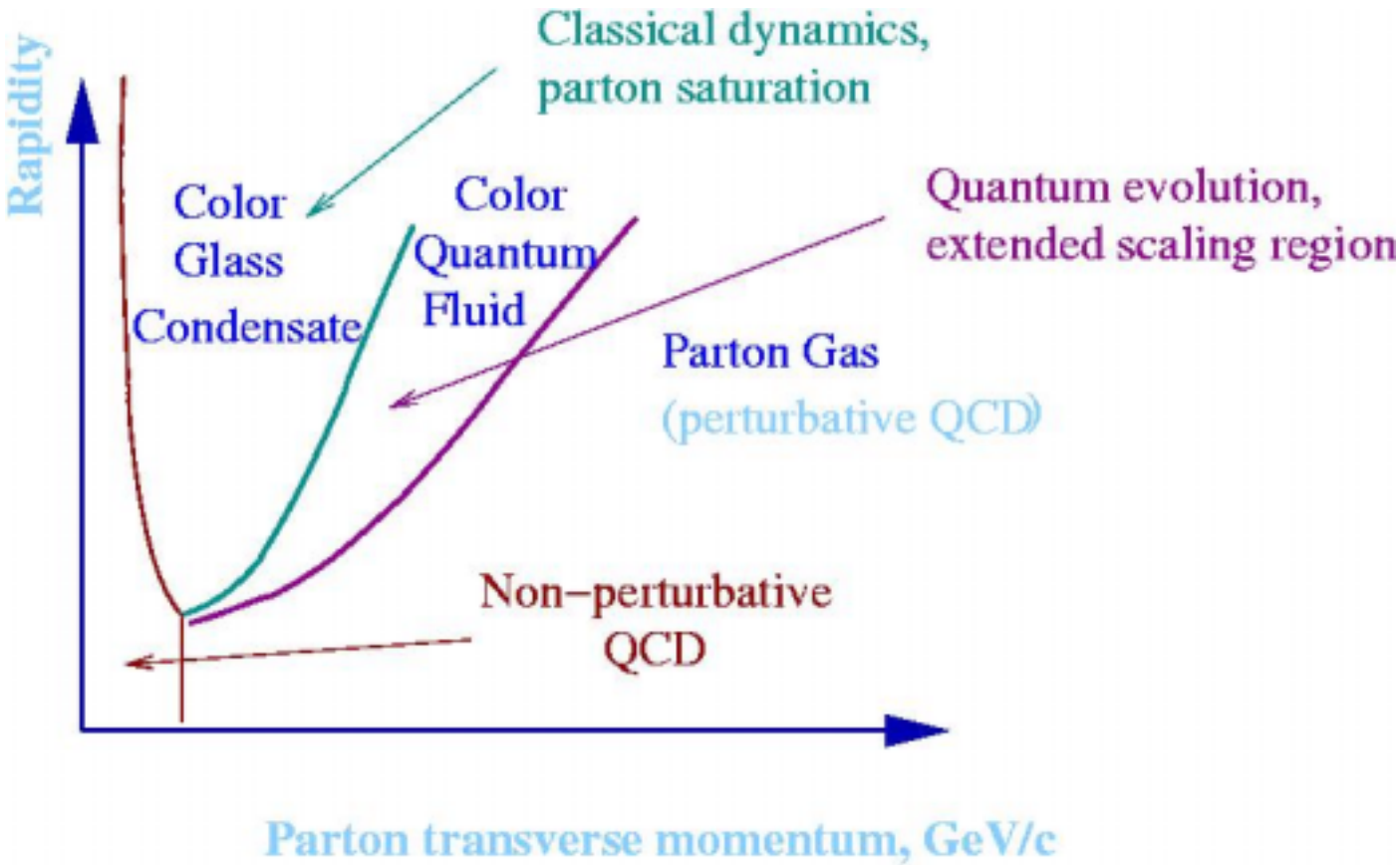




What do we still need to know?

III. can we prove that the CGC has been observed?
study (semi)hard processes at forward rapidities



Expectations for R_{dAu} at large rapidity

Agreement on the presence of suppression due to the quantum small x evolution in the CGC picture has been reached before the forward dAu data appeared:

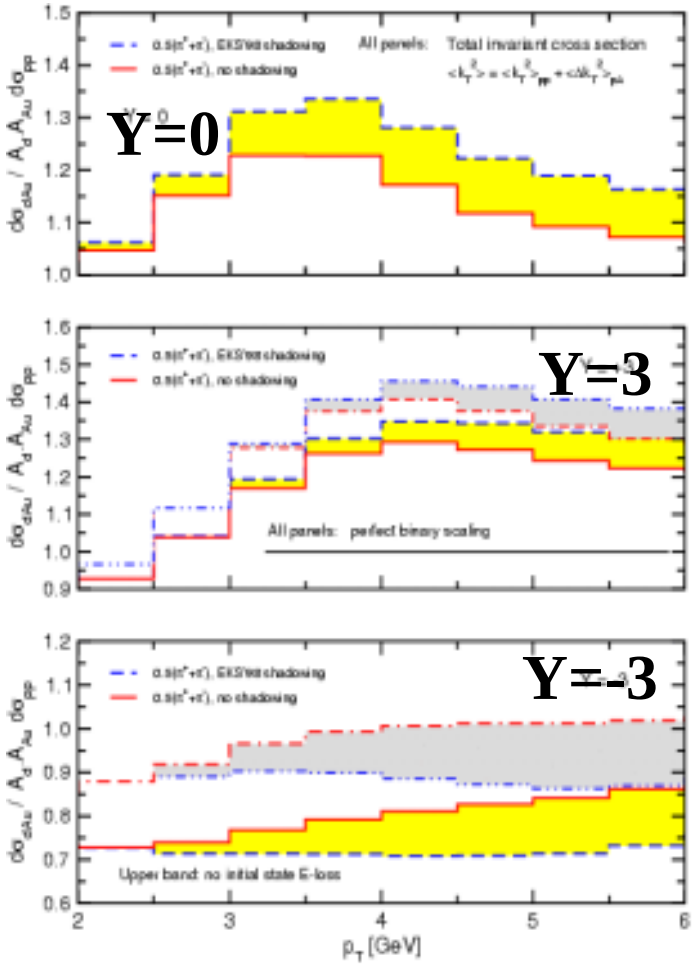
DK, E. Levin and L. McLerran, hep-ph/0210332;
DK, Yu.Kovchegov and K. Tuchin, hep-ph/0307037 v2
J. Albacete, N. Armesto, A. Kovner, C. Salgado,
U. Wiedemann, hep-ph/0307179;
R. Baier, A. Kovner, U. Wiedemann, hep-ph/0305265 v2

Agreement on the presence of Cronin effect in the classical approach and in the multiple scattering picture:

L.McLerran and R.Venugopalan; Yu.Kovchegov and A.H.Mueller;
J. Jalilian-Marian; A. Dumitru; J.-P. Blaizot; F. Gelis;…
X.N.Wang; M. Gyulassy; I. Vitev;…

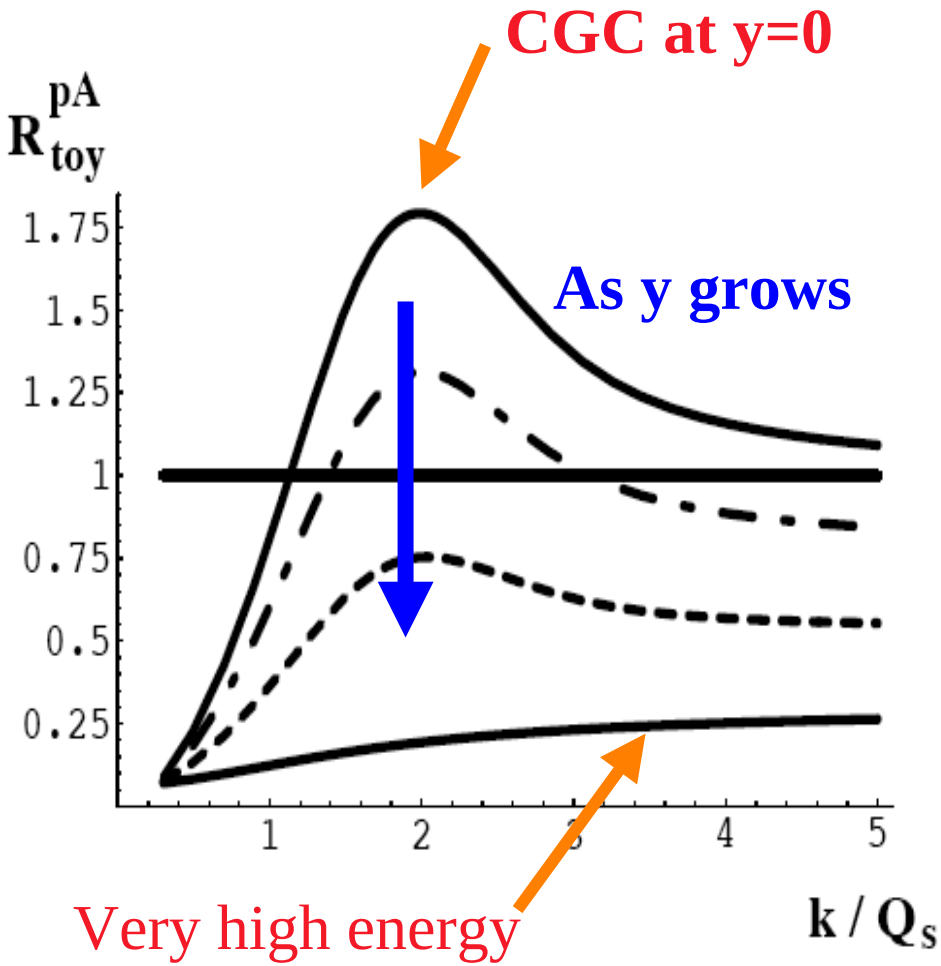
Model predictions

I. Vitev nucl-th/0302002 v2



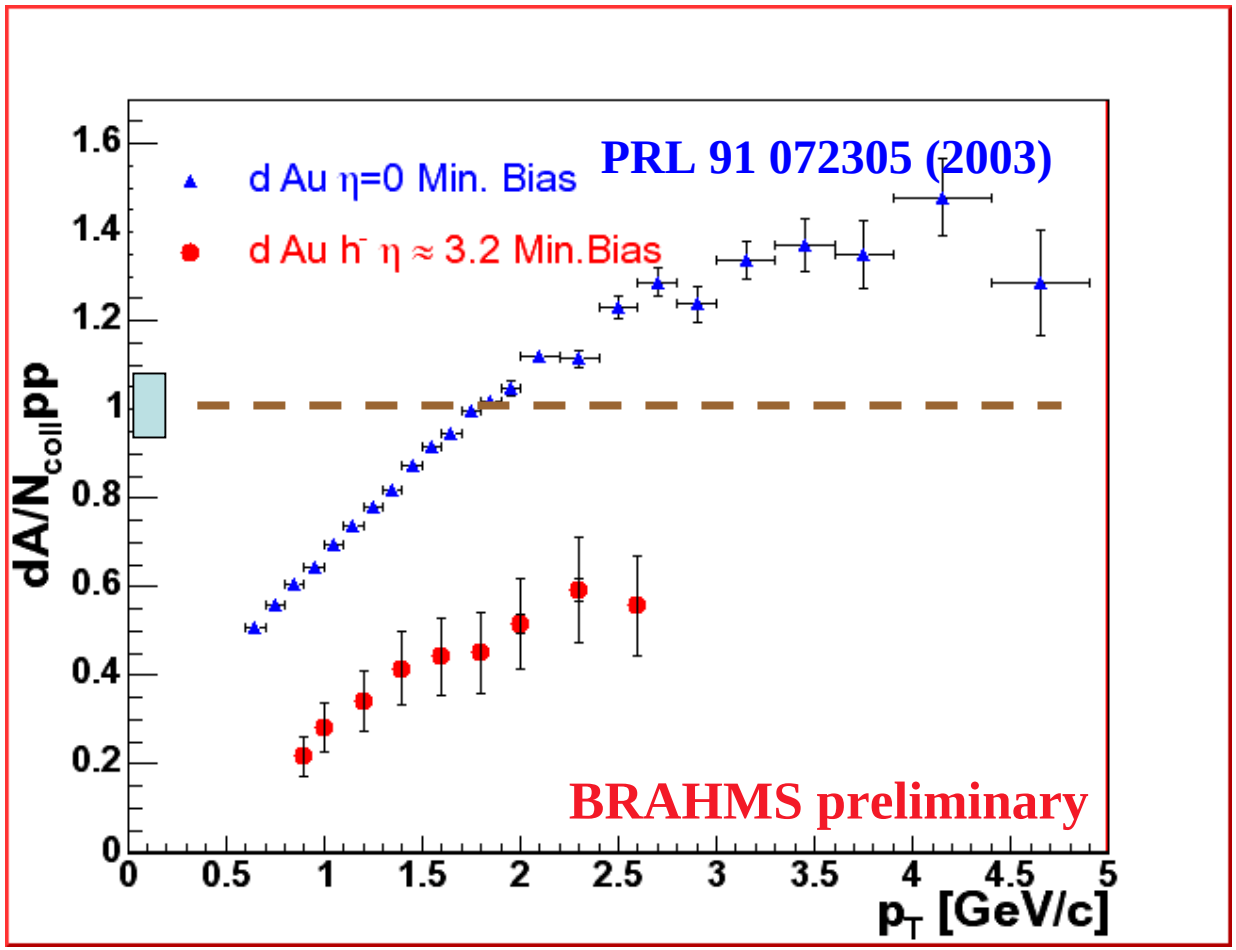
D. Kharzeev, Yu. Kovchegov and

K. Tuchin, hep-ph/0307037



R. Debbe, BRAHMS Coll., Talk at DNP Meeting, Tucson, November 2003

d-Au Nuclear Modification factor at η ~3.2



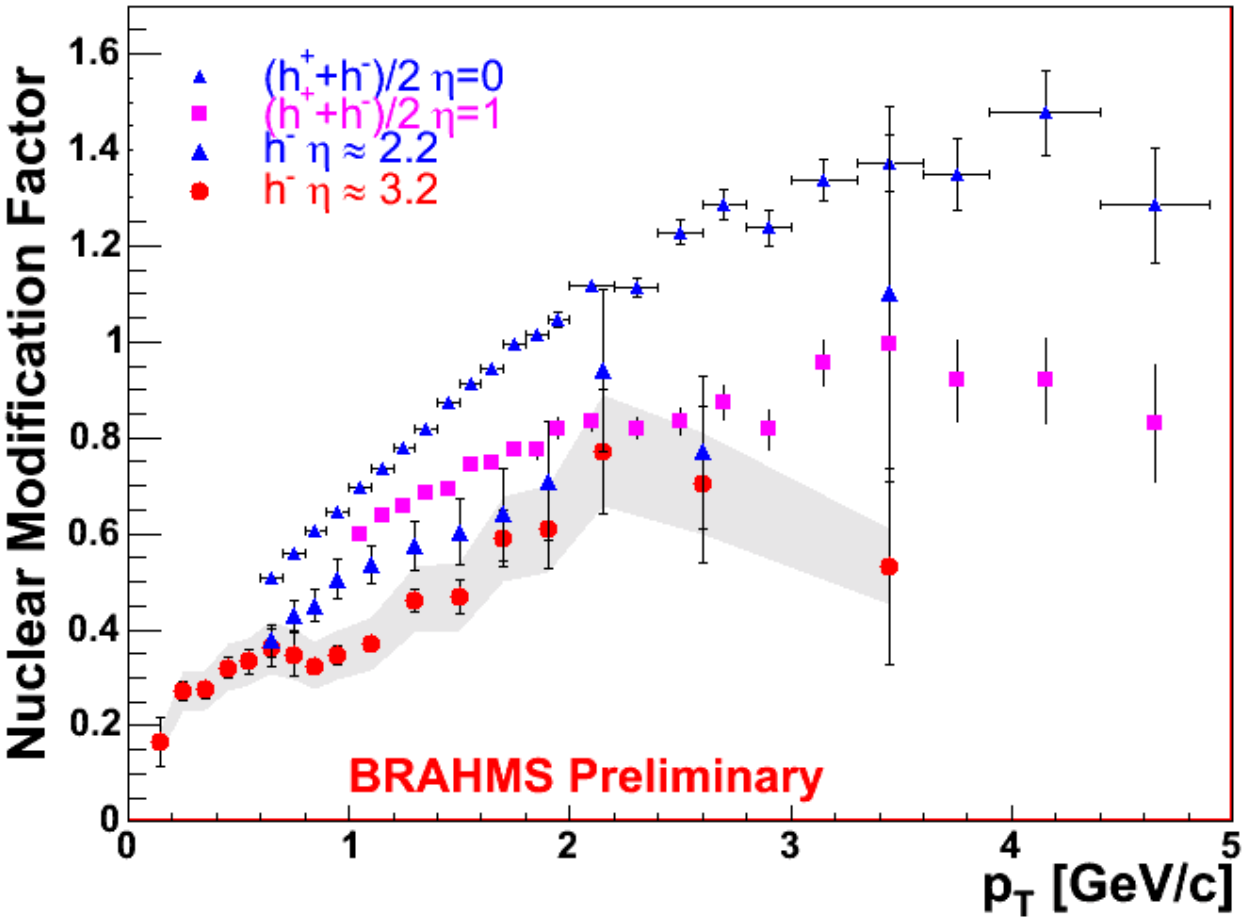
R. Debbe, BRAHMS Collaboration, Talk at the DNP Meeting, Tucson, November 2003

RdAu compares the yield of **negative particles** produced in dAu to the scaled number of particles with same sign in p-p

The scale is the number of binary collisions:

N_{coll}=7.2
(minimum biased)

R_{dAu} at different rapidities



All ratios extracted from minimum biased data samples

R.Debbe, BRAHMS, QM'04

Number of binary collisions in minimum biased events is estimated:

$N_{coll} = 7.2 \pm 0.3$

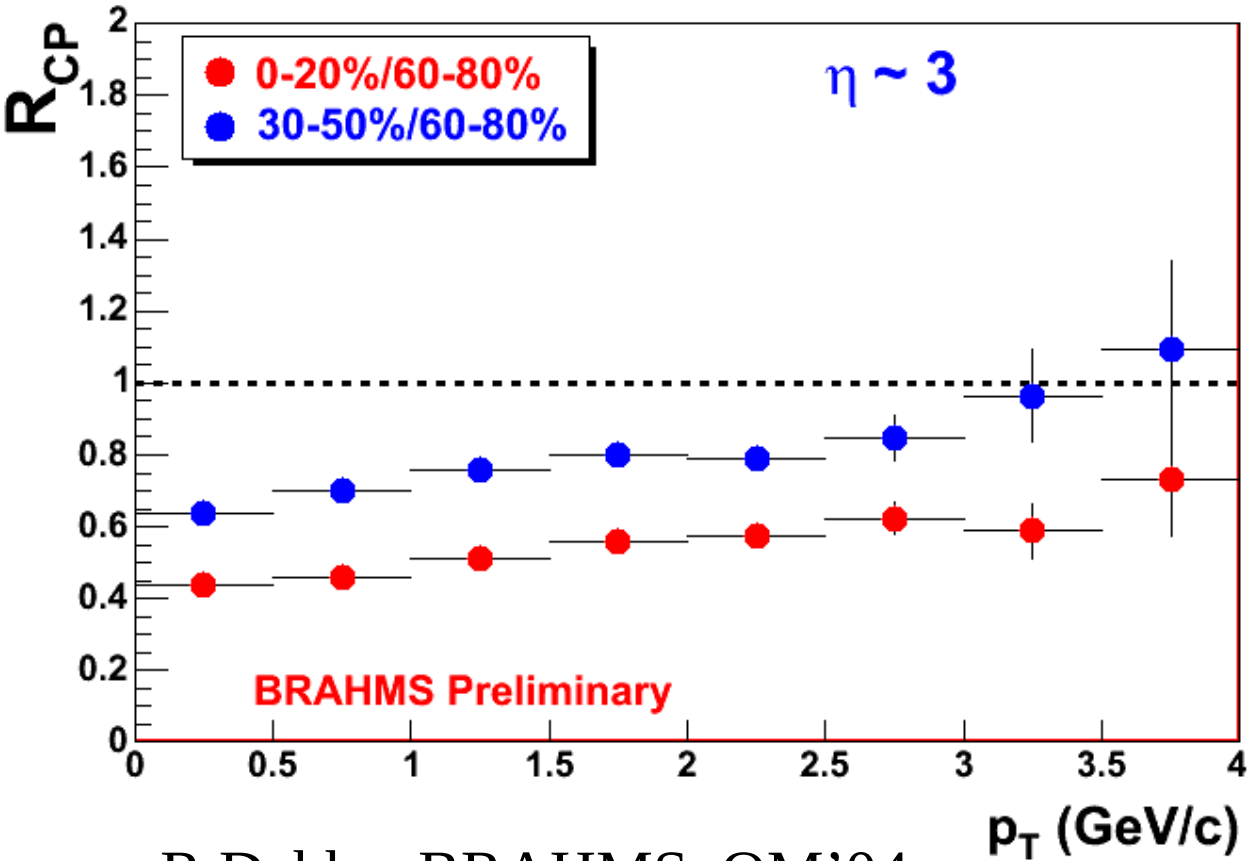
Statistical errors dominant over the systematic ones at η=2 and 3

Systematic error (not shown) ~15%

The values for η=0 were published in:

PRL 91 072305 (2003)

Centrality dependence



R.Debbe, BRAHMS, QM'04

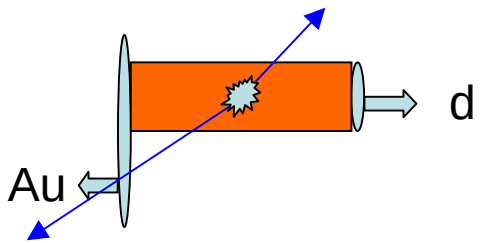
All numerators and denominator are scaled by the appropriate estimated number of binary collisions (HIJING + BRAHMS GEANT)

The ratios are corrected for trigger inefficiency.

All other corrections (acceptance, tracking efficiency..) cancel out.

Centrality Dependence of Particle Production @Fwd/Bwd Directions

1. Stopped hadrons
   - Mesons + Baryons
2. Light mesons
   - Pions + Kaons
3. Heavy flavors
   - Charm + Beauty

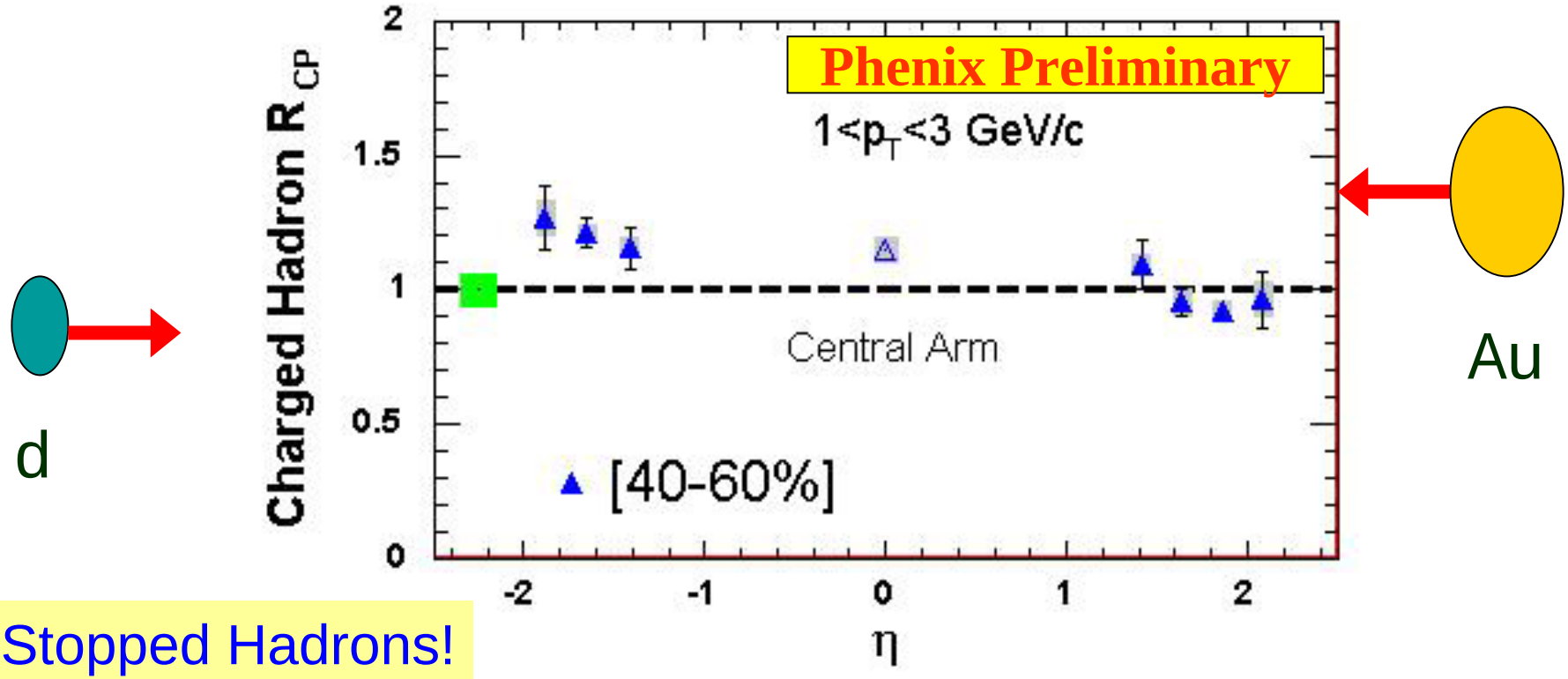


$$R_{CP}^{dAu}(P_T, y) \propto \frac{\dfrac{\Delta N^{cent-XX}}{< N_{coll} >}}{\dfrac{\Delta N^{60-88\%}}{< N_{coll} >}};$$

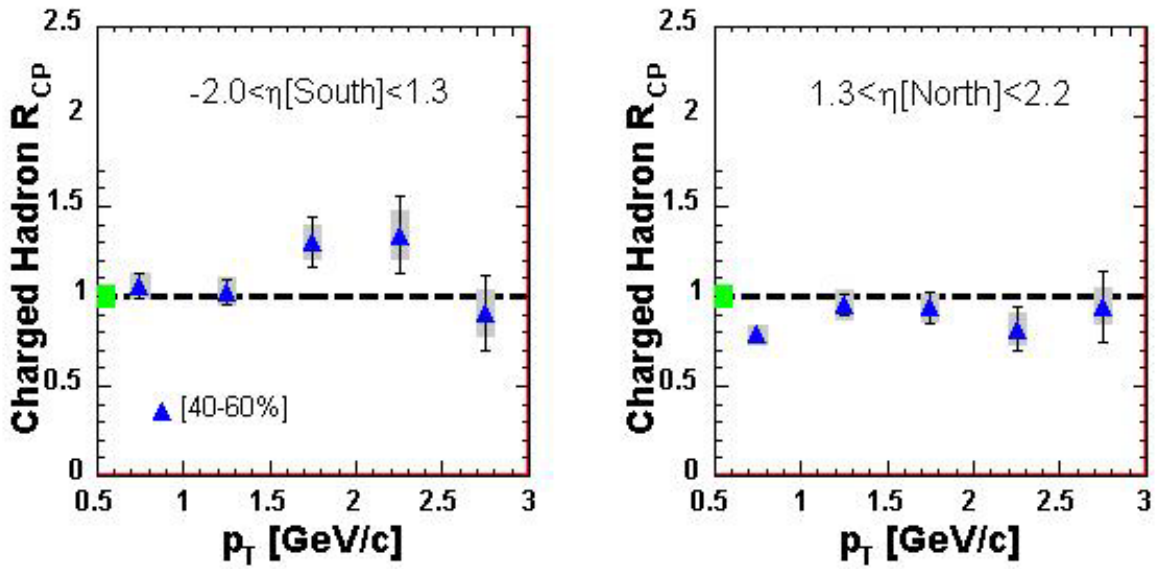
$$cent-XX = 0-20\%, 20-40\%, 40-60\%$$

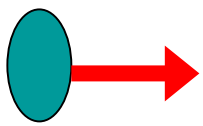
Ming Liu, PHENIX, QM'04

=> Talk by M. Liu

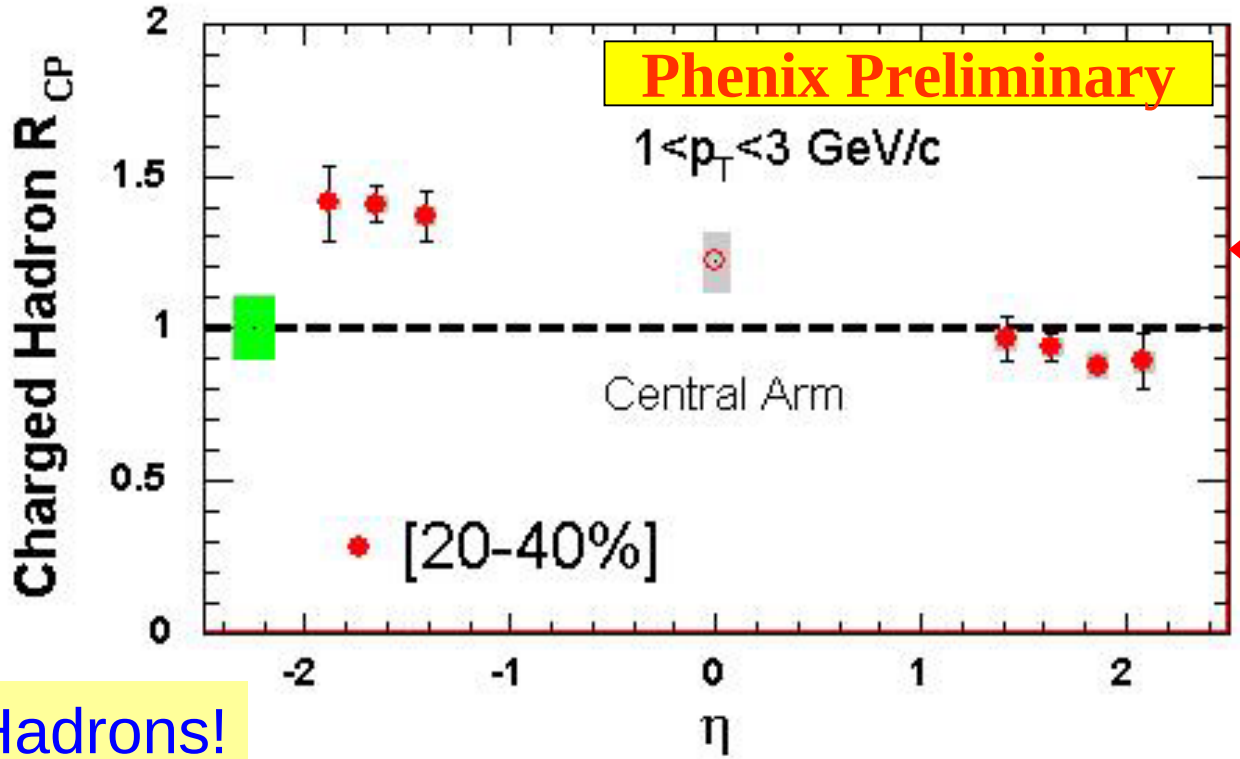


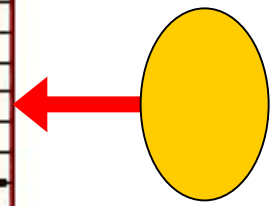
Stopped Hadrons!





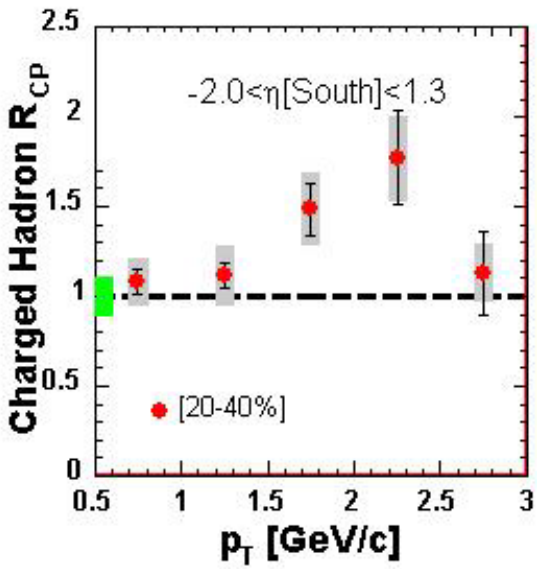
d

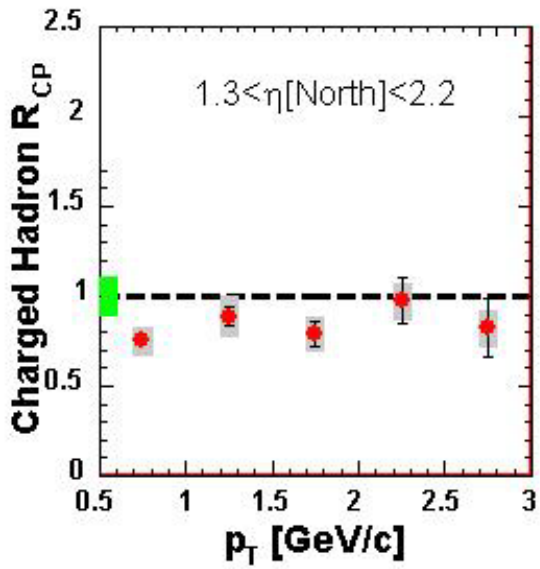


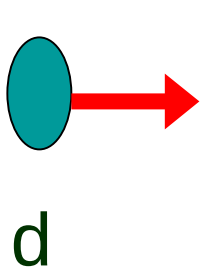


Au

Stopped Hadrons!







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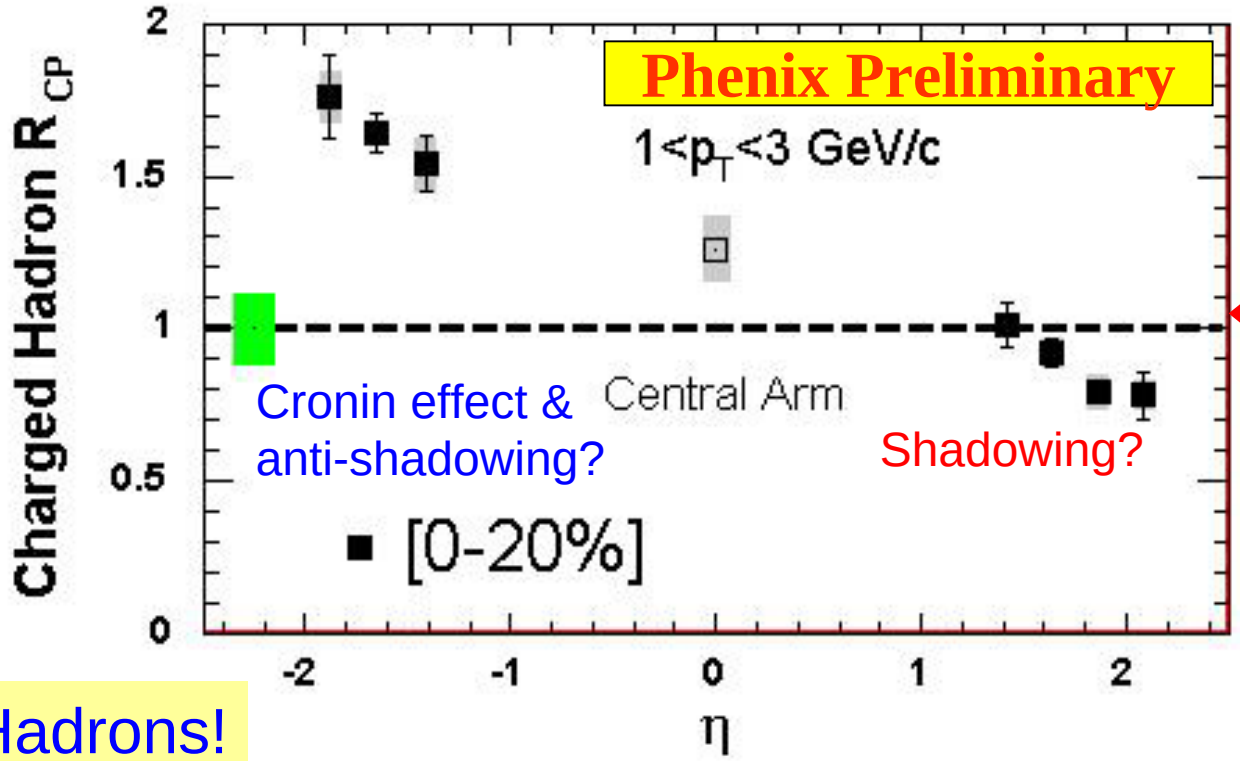

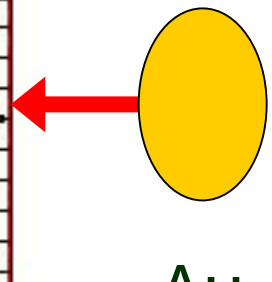

Au

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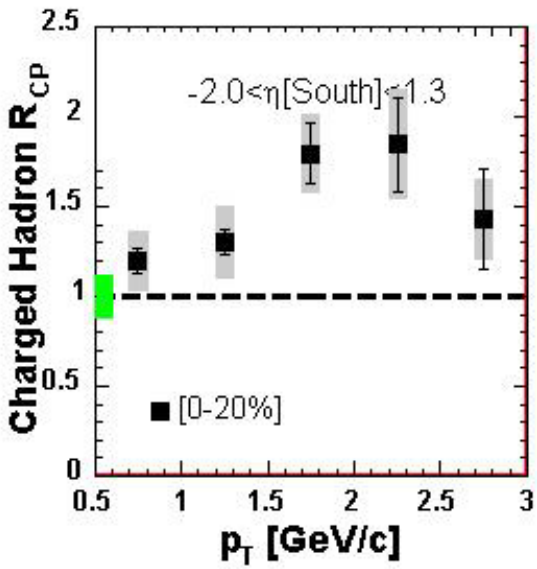
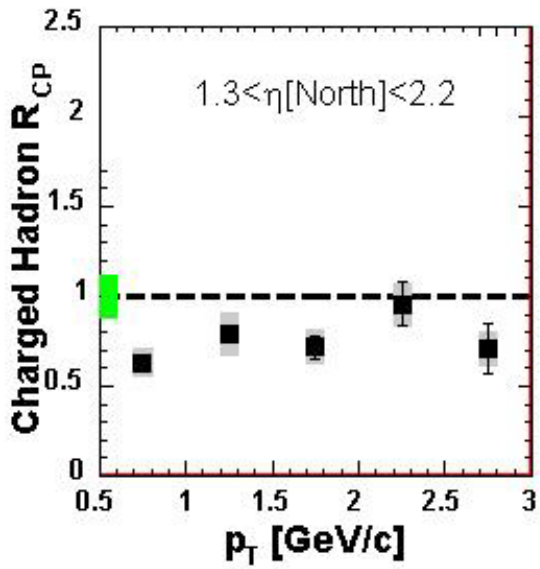
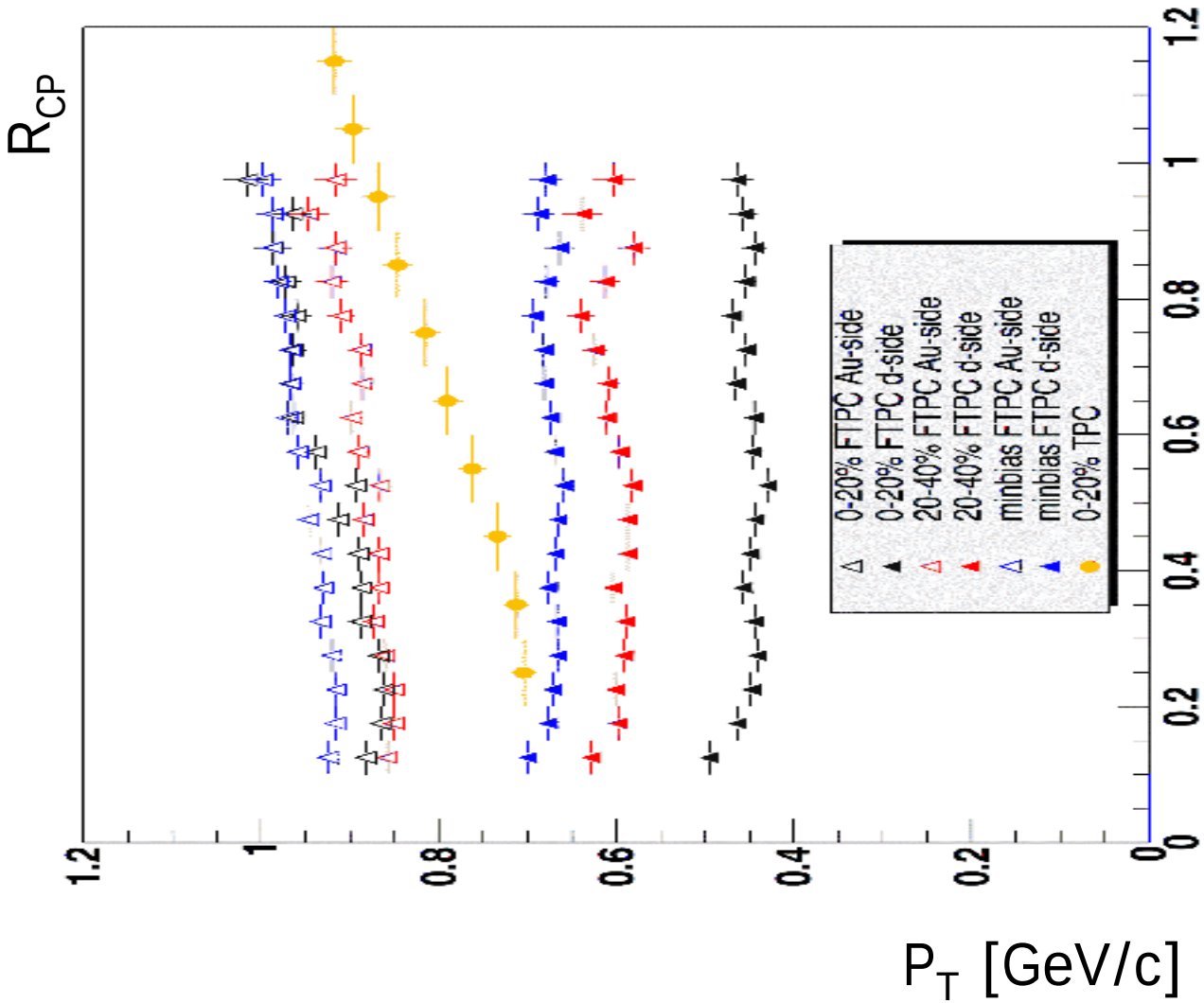




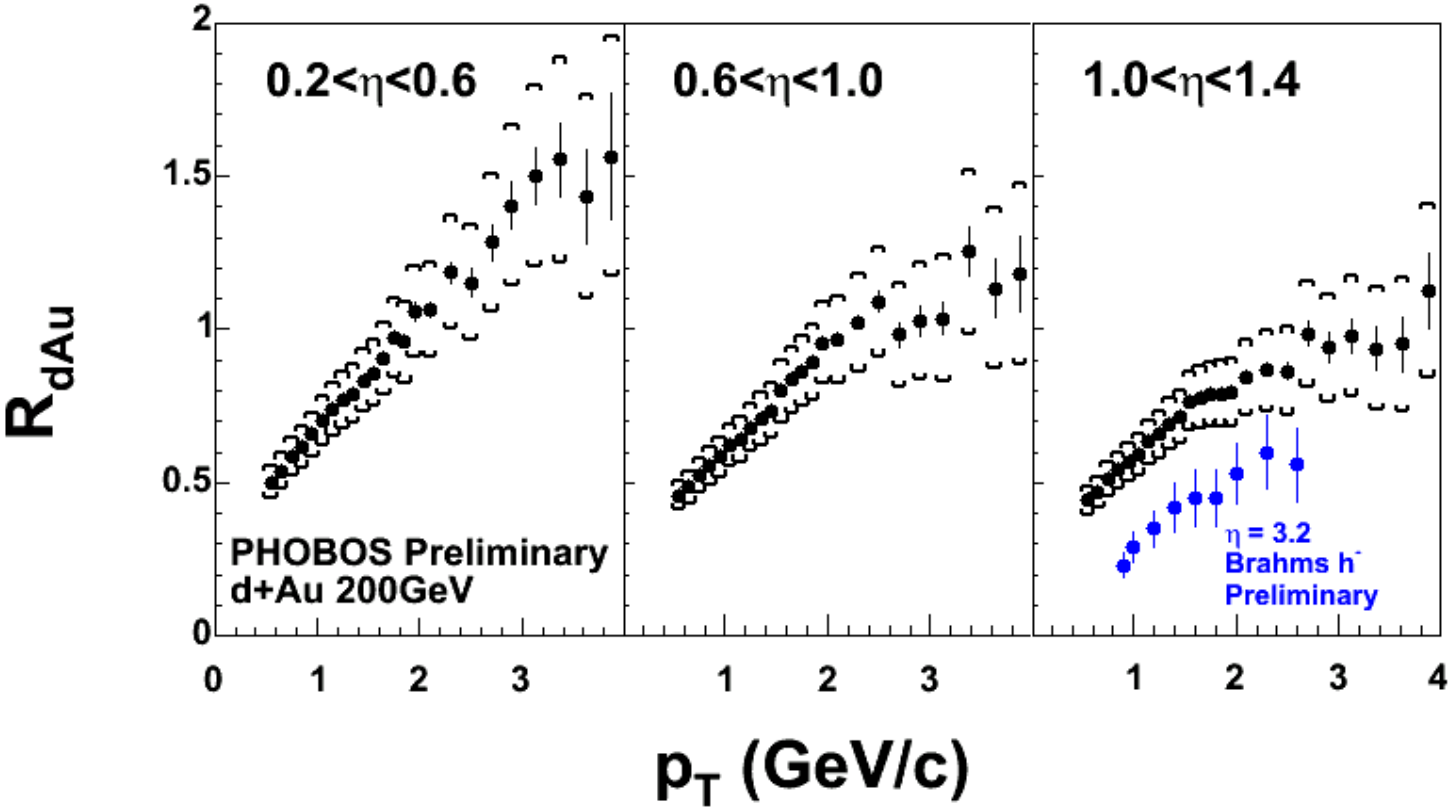
d+Au R_{CP} at forward rapidities



- Au-Side R_{CP} shows almost no variation with centrality
- d-side is interesting: more central is more suppressed

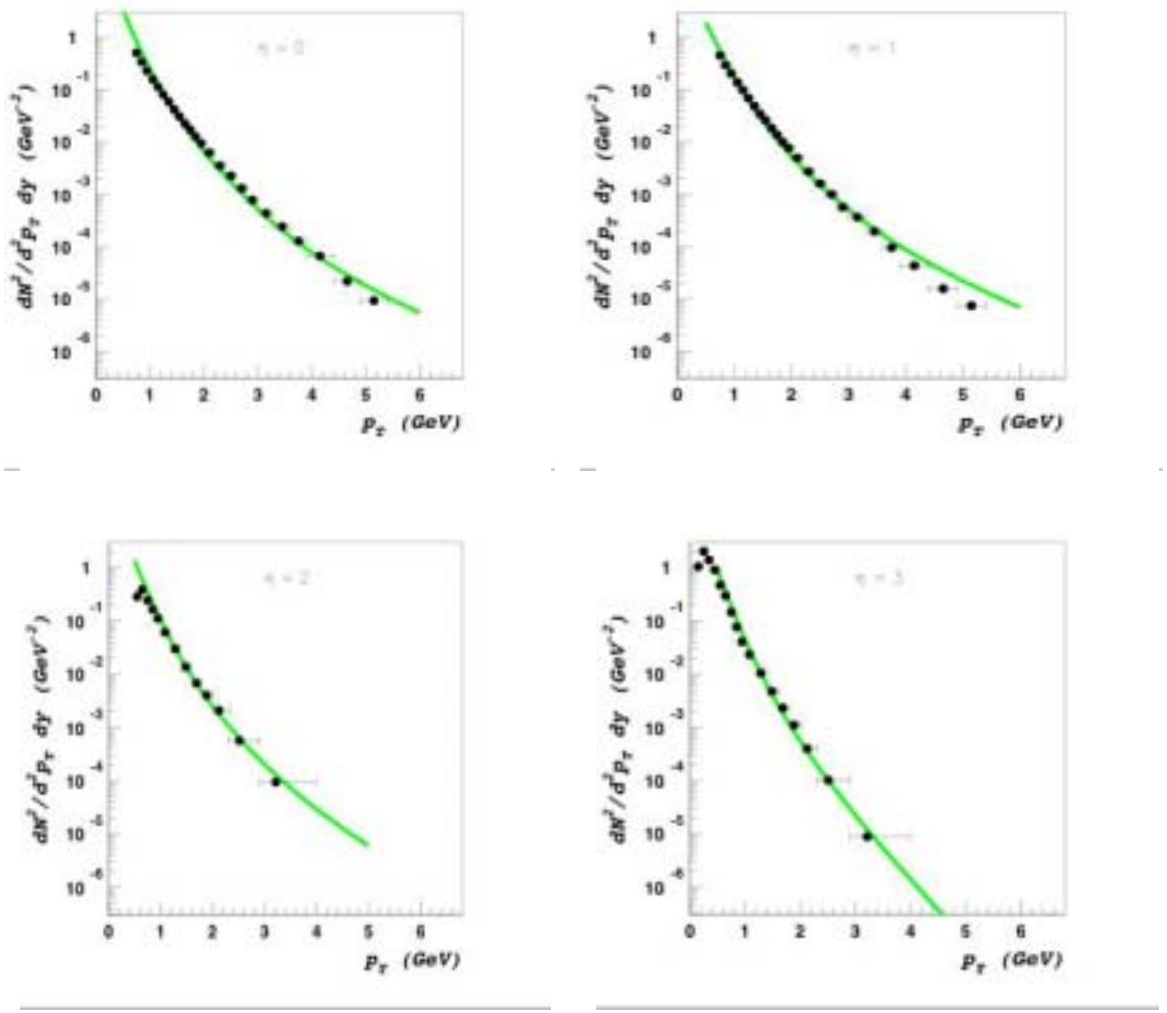
L.Barnby, STAR, QM'04

d Au spectra at (not so) forward rapidity



P. Steinberg, PHOBOS, QM'04

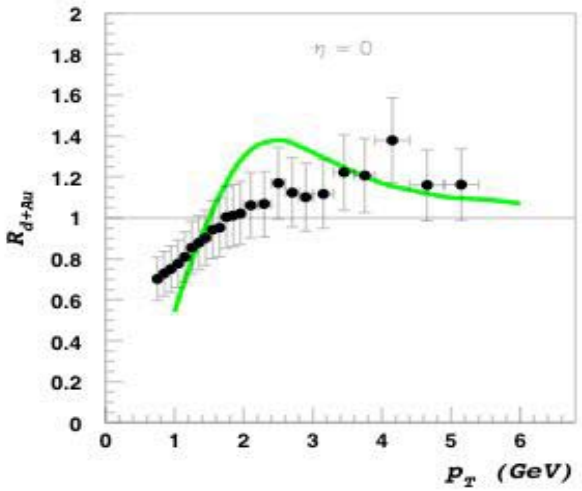
Color Glass Condensate: confronting the data I

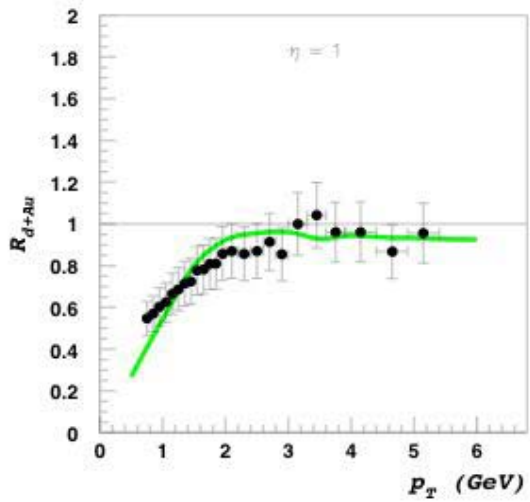


BRAHMS data,
$\eta = 0,\quad 1,\quad 2.2,\ 3.2$

DK, Yu. Kovchegov, K. Tuchin, hep-ph/0405045

Color Glass Condensate: confronting the data II





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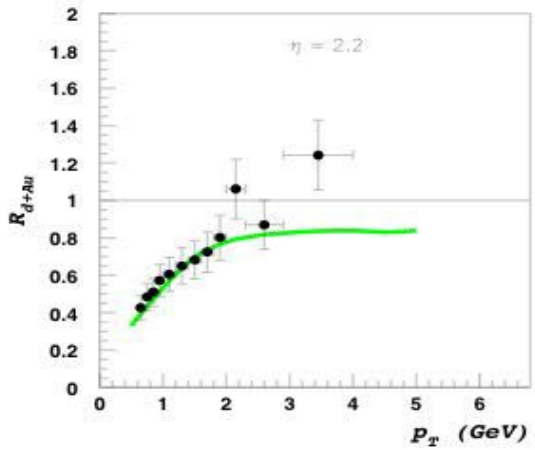
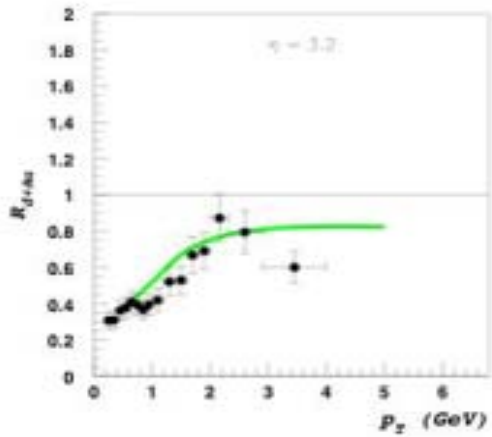
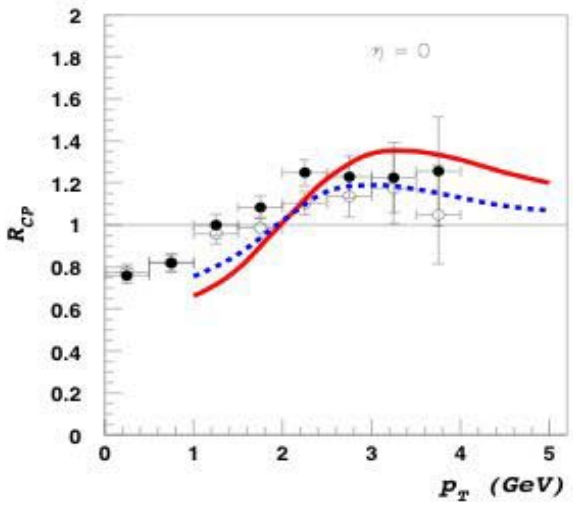
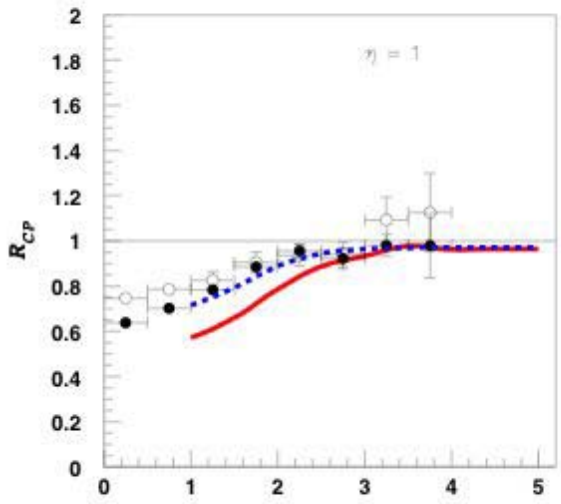




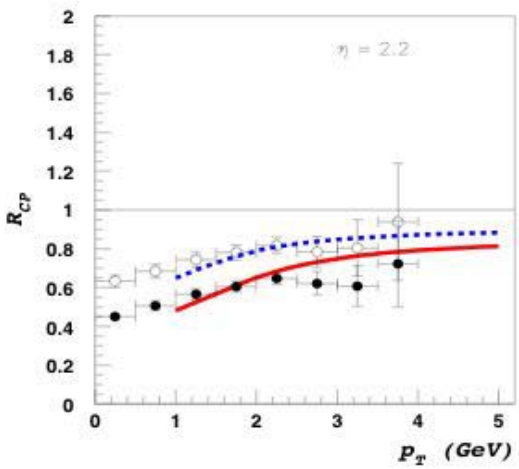
DK, Yu. Kovchegov, K. Tuchin, hep-ph/0405045

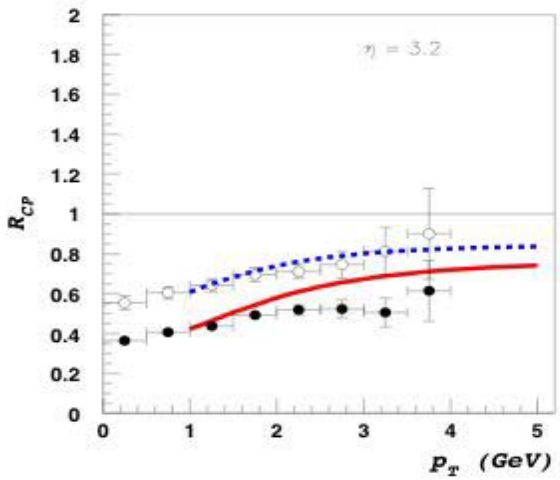
Color Glass Condensate: confronting the data III





BRAHMS data, R_{CP}
$\eta = 0,\quad 1,\quad 2.2,\ 3.2$





DK, Yu. Kovchegov, K. Tuchin, hep-ph/0405045

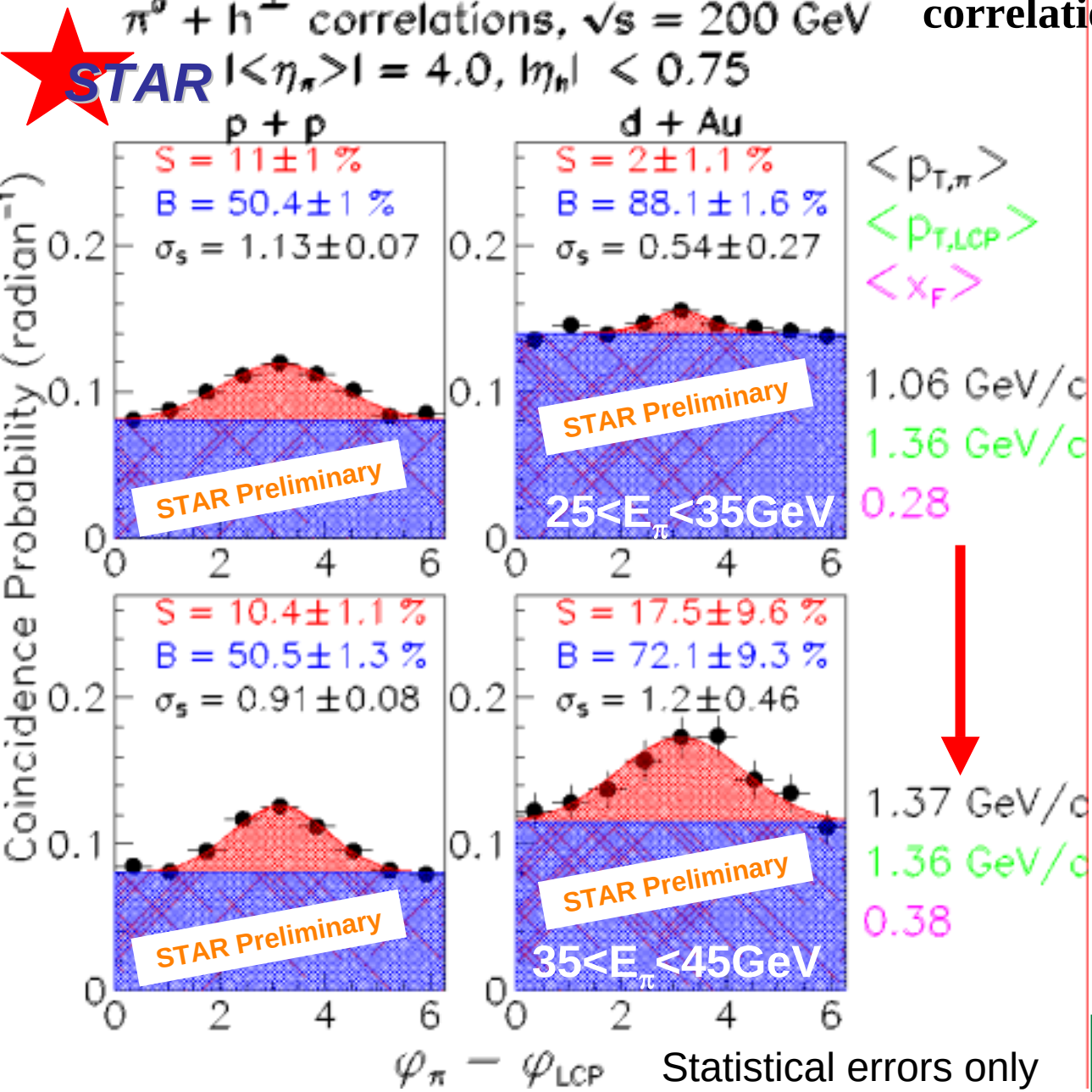
Are the effects observed at forward rapidity due to parton saturation in the CGC?

- Back-to-back correlations for jets separated by several units of rapidity are very sensitive to the evolution effects A.H.Mueller,H.Navelet, '87 and to the presence of CGC DK, E.Levin,L.McLerran, hep-ph/0403271

  Recent results from STAR: A. Ogawa, Talk at DIS'04

- Open charm, dileptons, photons in the forward region DK, K.Tuchin, hep-ph/0310..

  R.Baier,A.H.Mueller,D.Schiff, hep-ph/0403201;
  J.Jalilian-Marian, F. Gelis, R. Venugopalan



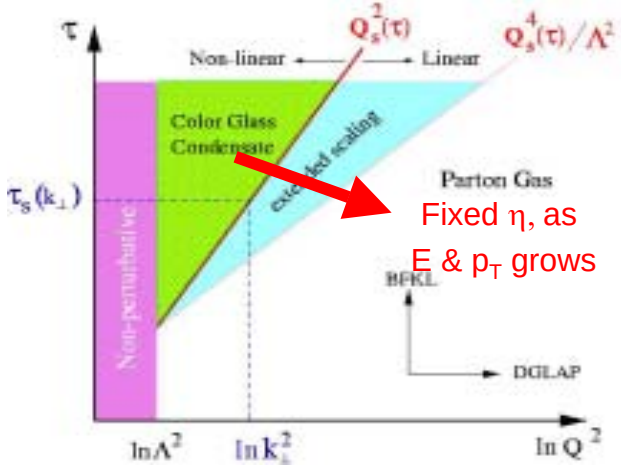
Statistical errors only

Large rapidity gap π^0+h$^\pm$ correlation data…

- **are suppressed in d+Au relative to p+p at small $<x_F>$ and $<p_{T,\pi}>$**

S_{pp}-S_{dAu}= (9.0 ± 1.5) %

Consistent with CGC picture

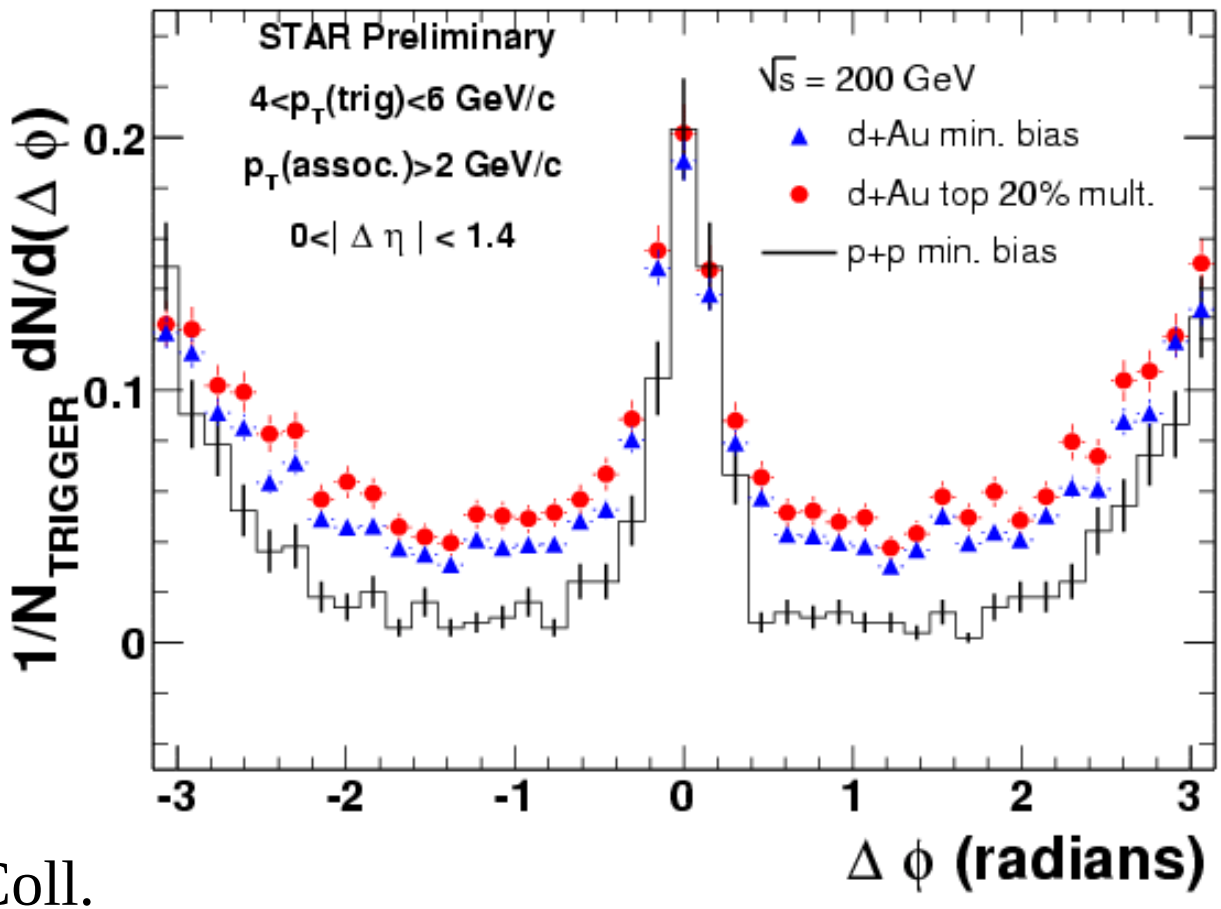


- **are consistent in d+Au and p+p at larger $<x_F>$ and $<p_{T,\pi}>$**

as expected by HIJING

p+p vs. d+Au

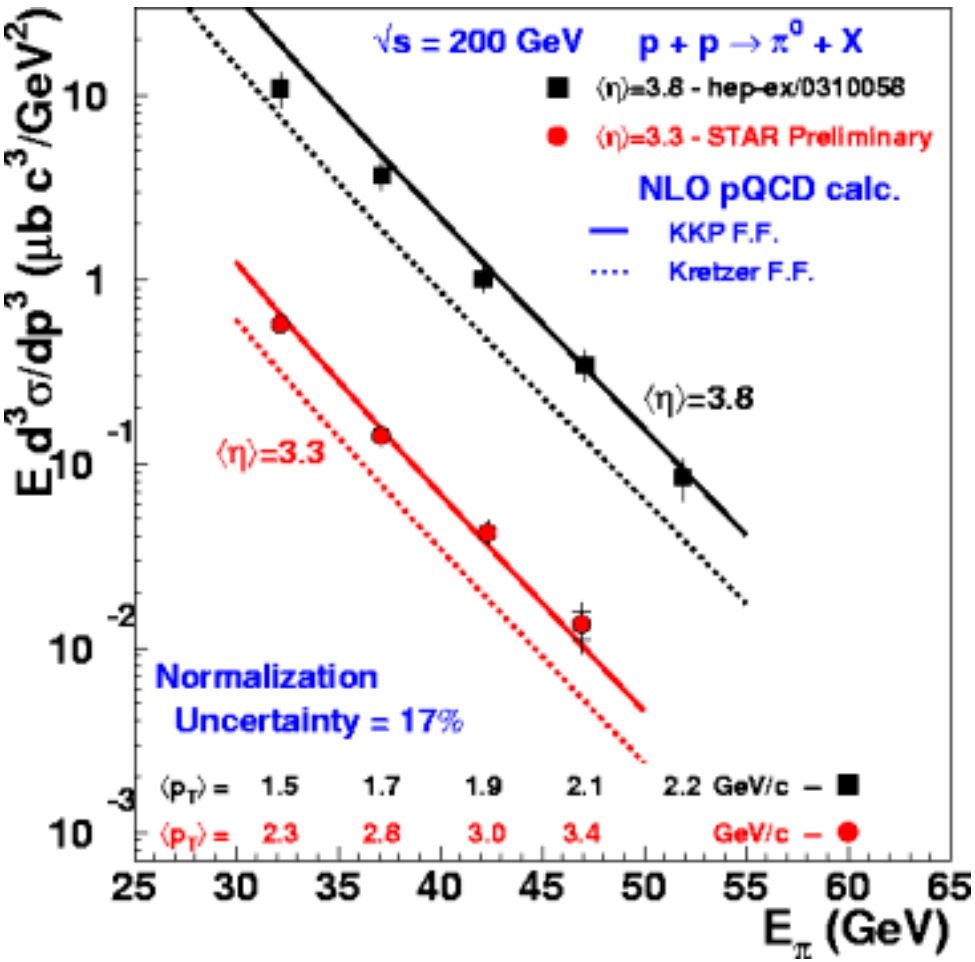
No “data manipulation”



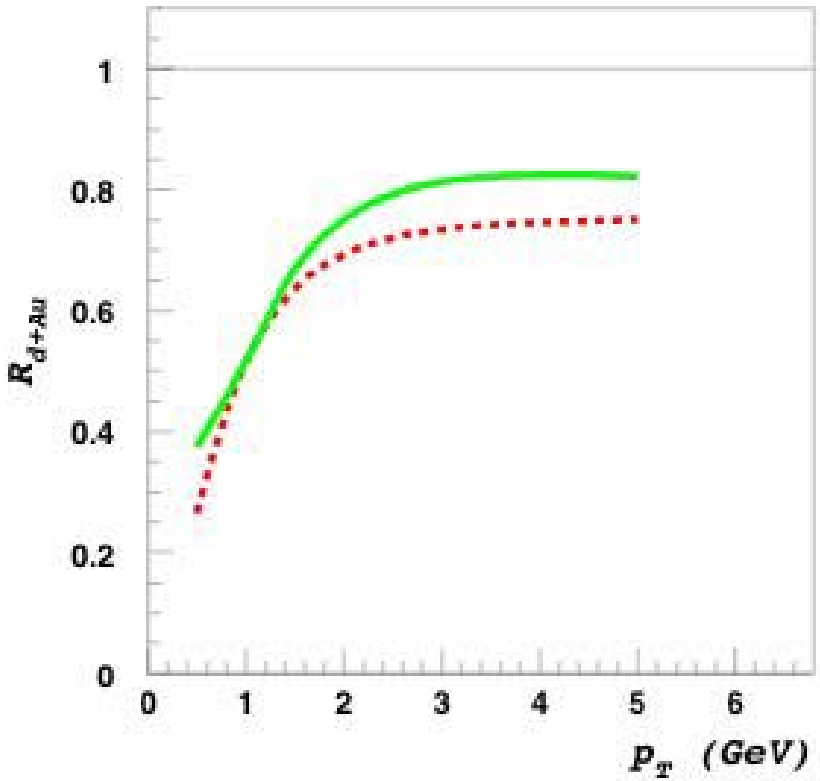
D. Hardtke, STAR Coll.

- Azimuthal correlations are *qualitatively* consistent
- Quantitative evaluation will constrain
  - o Nuclear k_T from initial state multiple scattering
  - o Shadowing
- Models that predict “monojets” due to initial state effects ruled out

pQCD works in forward pp



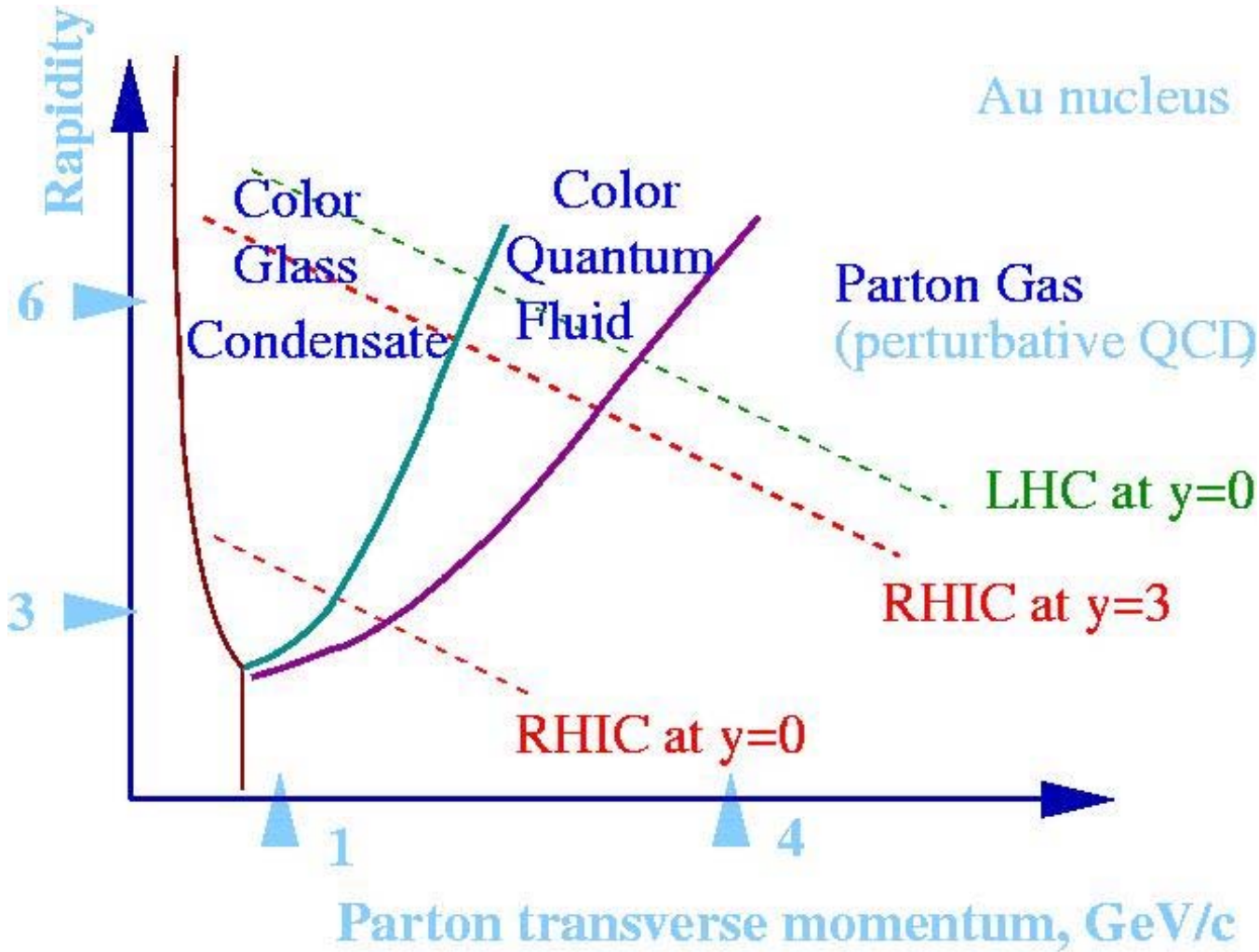
Color Glass Condensate at the LHC



At the LHC (red line), even the mid-rapidity, high p_T production will be dominated by the CGC

DK, Yu. Kovchegov, K. Tuchin, hep-ph/0405045

Phase diagram of high energy QCD



What has to be done?

To characterize the properties of the Quark Gluon Plasma, and to explore the Color Glass Condensate, we need to

I. Study hard processes in a wide range of rapidity and transverse momentum, with identified particles

(RHIC, RHICII, LHC, eRHIC)

heavy quark jets; jet (jet + γ, …) azimuthal correlations at large Δ y; heavy quarkonia; dileptons at high p_T

II. Study multi-particle correlations and fluctuations