"The emergence of QCD is a wonderful example of the evolution from farce to triumph" David Gross, from his Nobel Lecture

Recent Results on (d,Au) Collisions from PHENIX

Richard Seto

for the

PHENIX

Experiment

RHIC/AGS User's meeting

Jun 6, 2009

Outline

- dAu collisions
  - Forward hadrons
  - forward J/psi
- a sort of Non Sequitur
  - An estimate of the NDOF (effective)
- Conclusions

dAu – forward hadrons II

J/ψ - an attempt to understand Cold Nuclear matter effects

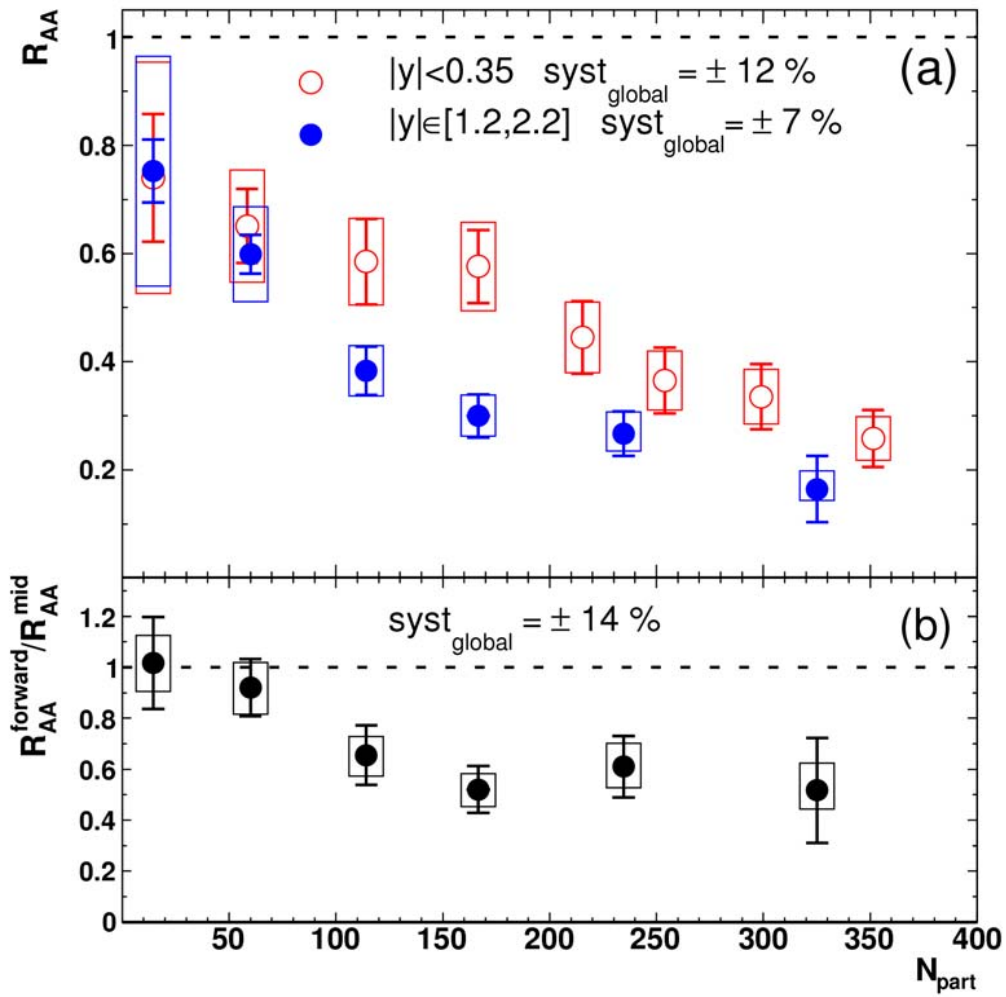
Tony Frawley, Mike Leitch, Ramona Vogt,
Alex Levy, Jamie Nagle, Darren McGlintey
Roberta Analdi

Au+Au R_{AA} - A "high y anomoly" (just kidding)

The stronger Au+Au suppression at forward/backward rapidity has generated considerable interest.

But what is the expected suppression due to **cold nuclear matter effects**?

PHENIX – reference here

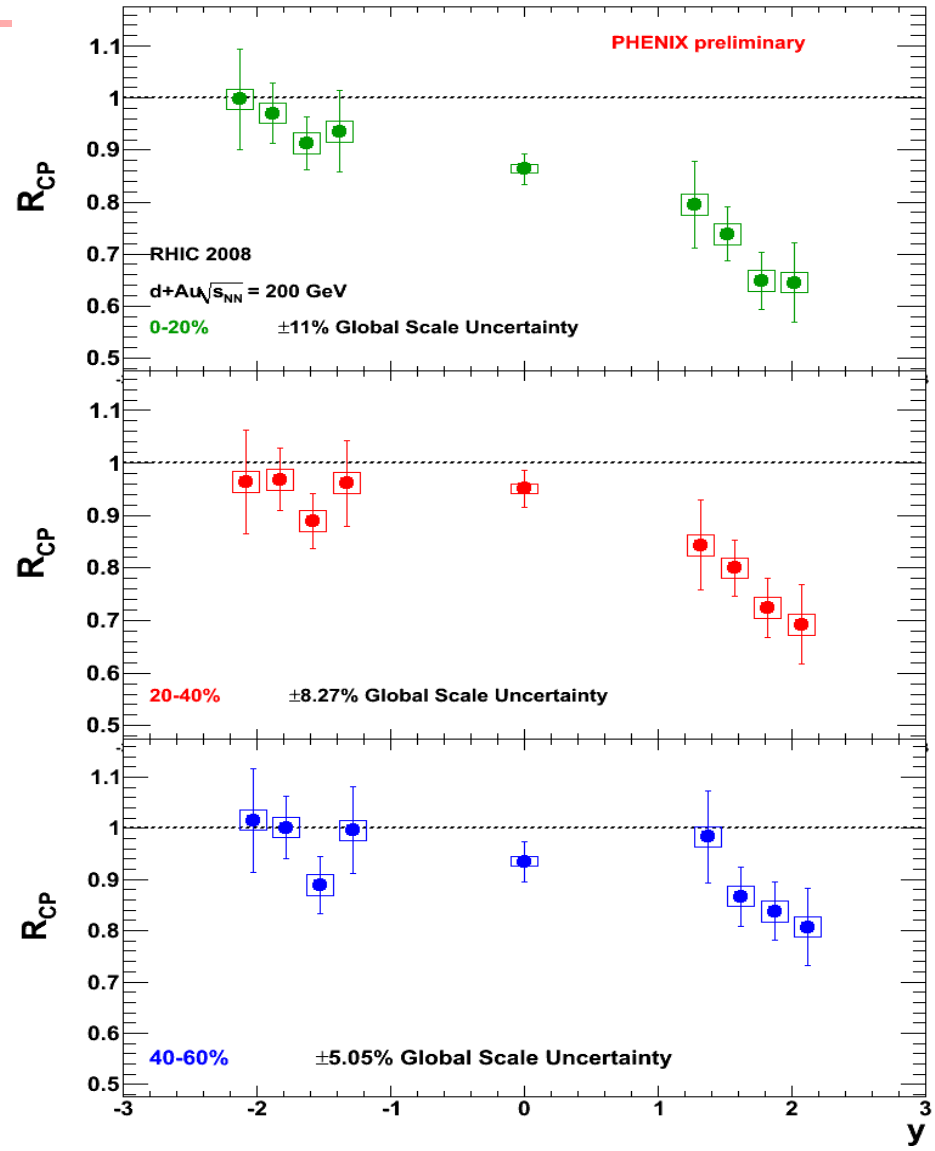


d+Au R_{CP}

The first results for d+Au from Run 8, shown at QM09.

Four centrality bins to make three R_{CP} points:

$$R_{CP} = \frac{\frac{dN}{dy}(0-20, 20-40, 40-60)}{\frac{dN}{dy}(60-88)}$$

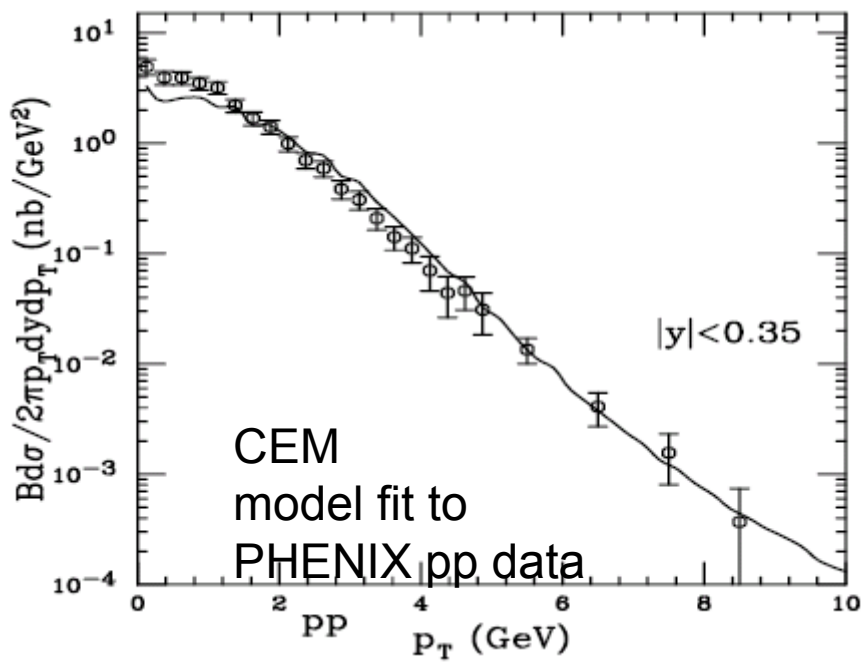


Fitting the Run 8 d+Au R_{CP}

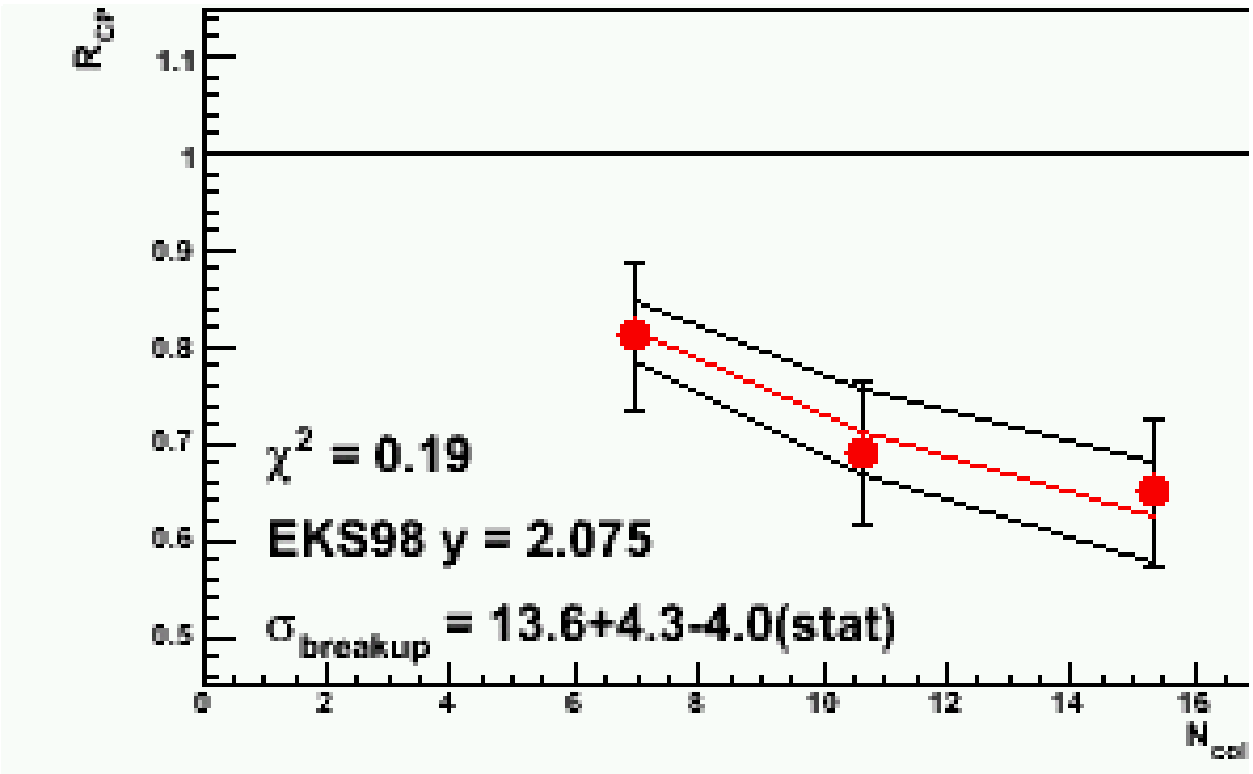
- **parameterize** d+Au R_{CP}
  - ➔ obtain AuAu R_{AA} with p+A physics divided out.

- Fit R_{CP} vs centrality **at each y** using calculations of R_{dAu} vs b
  - Color Evaporation Model (model of Ramona Vogt)
  - A shadowing PDF's – EKS98 and nDSg are used here.
  - $\sigma_{breakup}$ for collisions of (forming) J/ψ with nucleons (0-15 mb, 1 mb steps)
    - **$\sigma_{breakup}$ is allowed to vary with y**

- Convert R_{dAu} vs impact parameter to R_{dAu} vs centrality
  - use Glauber model

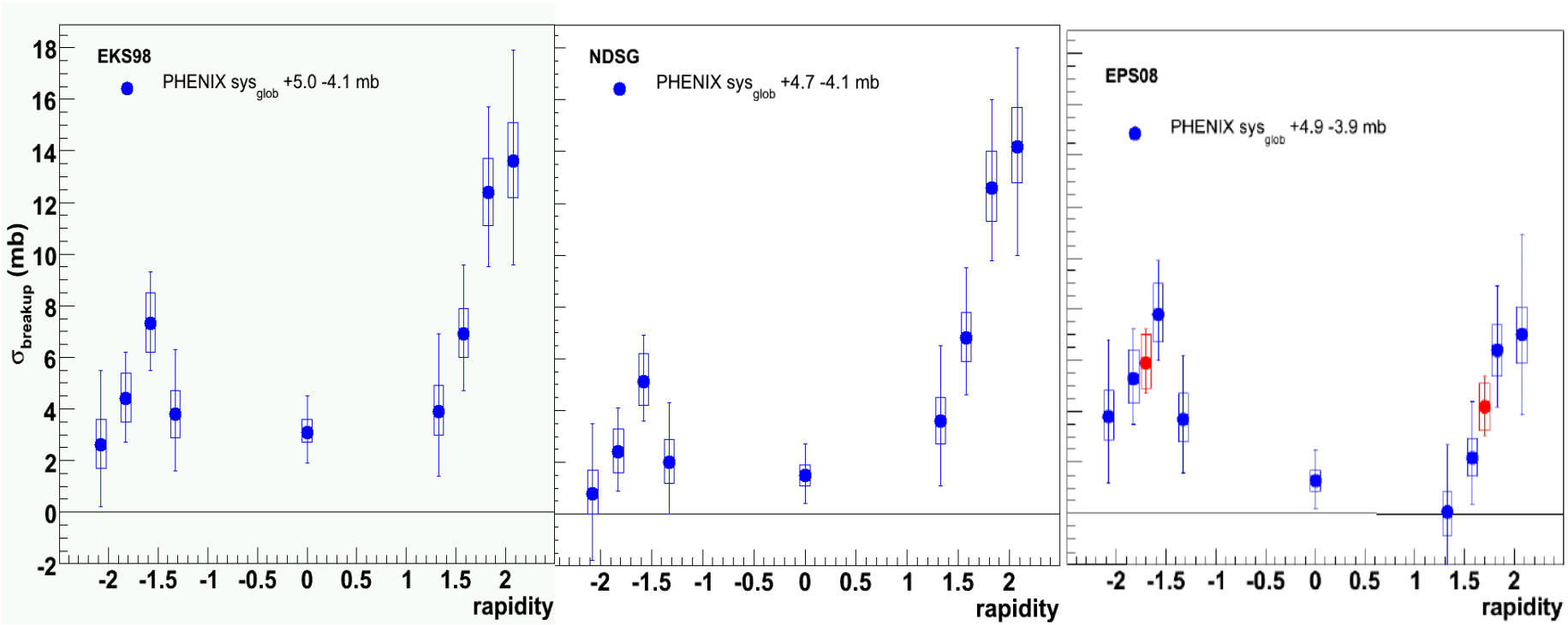


Fits to d+Au R_{CP} – example for EKS98



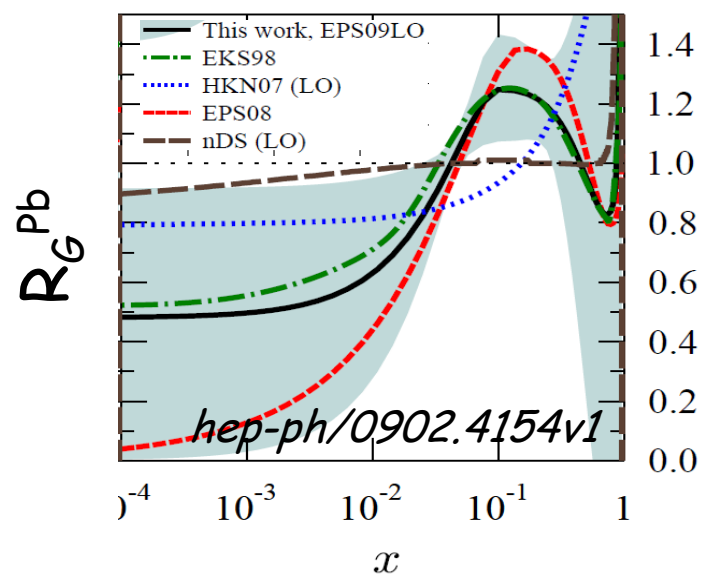
Au going -y ⟷ +y deuteron going

$\sigma_{breakup}$ vs y from d+Au R_{CP} fits with EKS98 and nDSg



$\sigma_{breakup}$ Dependent on PDF shadowing model

$\sigma_{breakup}$
effective cross section which might indicate physics not in the model
(e.g. initial state dE/dx…)

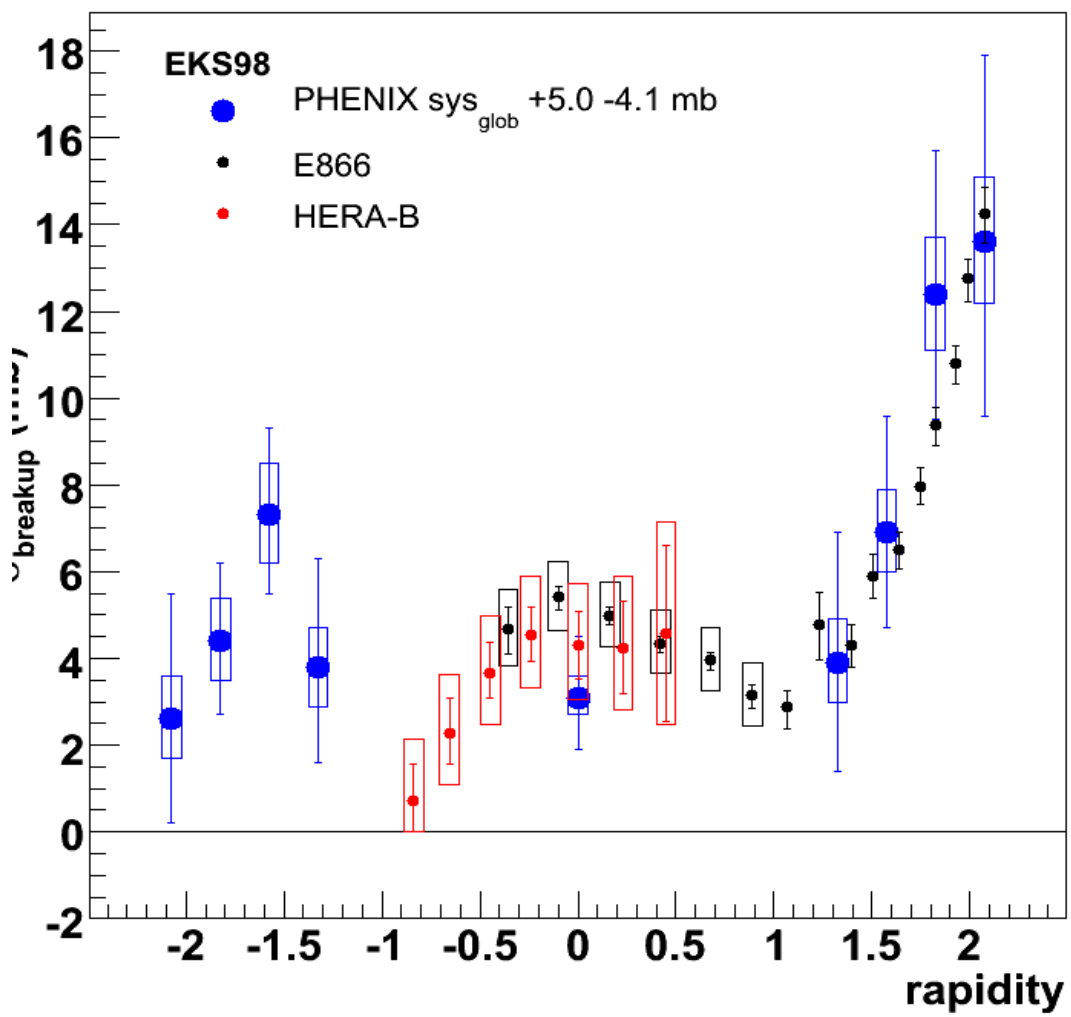


Comparison with lower energy data – EKS98 fits

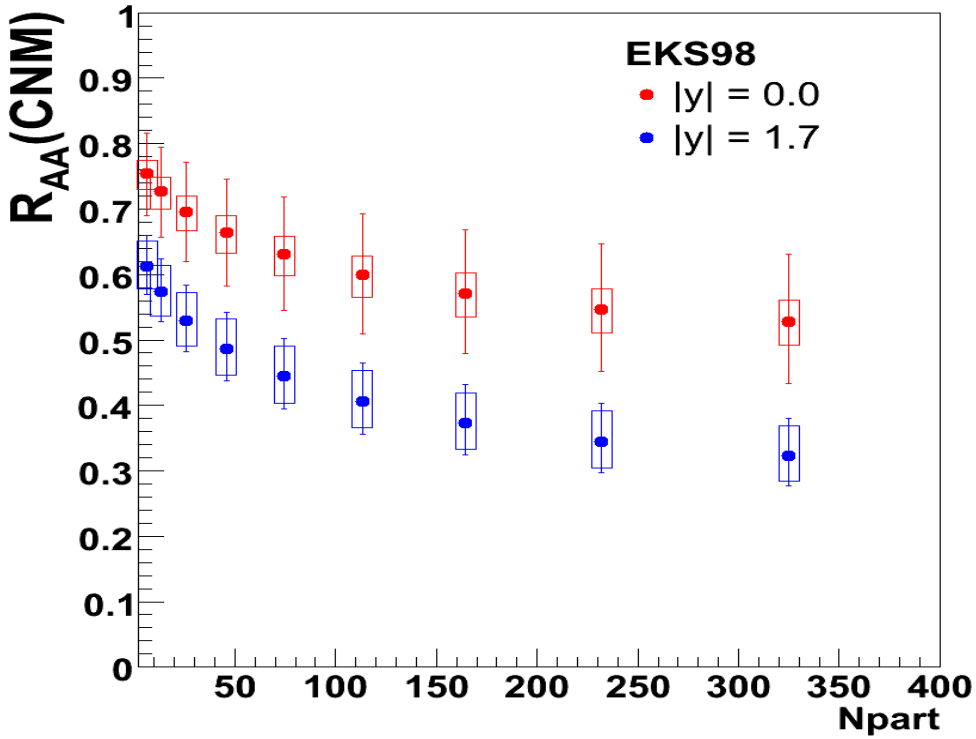
Lourenco, Vogt and Woehri (JHEP 02 (2009) 014) published the effective breakup cross section vs y from fits to E866 and HERA-B data.

Our results from 200 GeV are shown here compared with their results for the EKS98 case.

For **y > 1.2** the 200 GeV data follow the trend observed at lower energy remarkably closely!



Cold Nuclear Matter RAA for heavy ions



Now estimate RAA(CNM) using the results from the dAu RCP fits and a Glauber model

In the Glauber calculation:

Each nuclear collision is placed in a centrality bin according to Npart.

For each nucleon-nucleon collision:

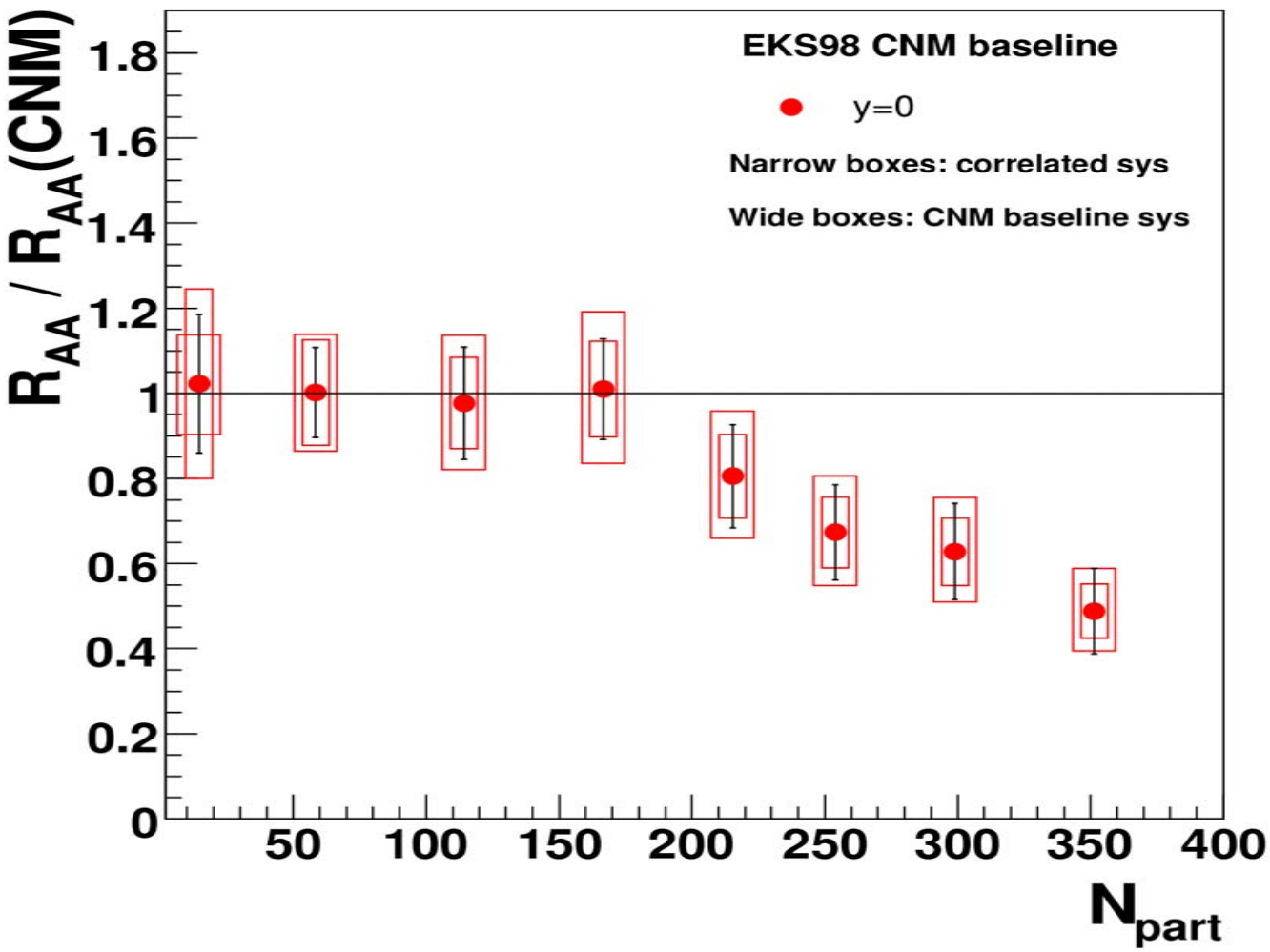
Determine impact parameter b1 of nucleon 1 in its target nucleus.

Determine impact parameter b2 of nucleon 2 in its target nucleus.

Add to the accumulated RAA: RdAu(b1,y=0) * RdAu(b2,y=0)

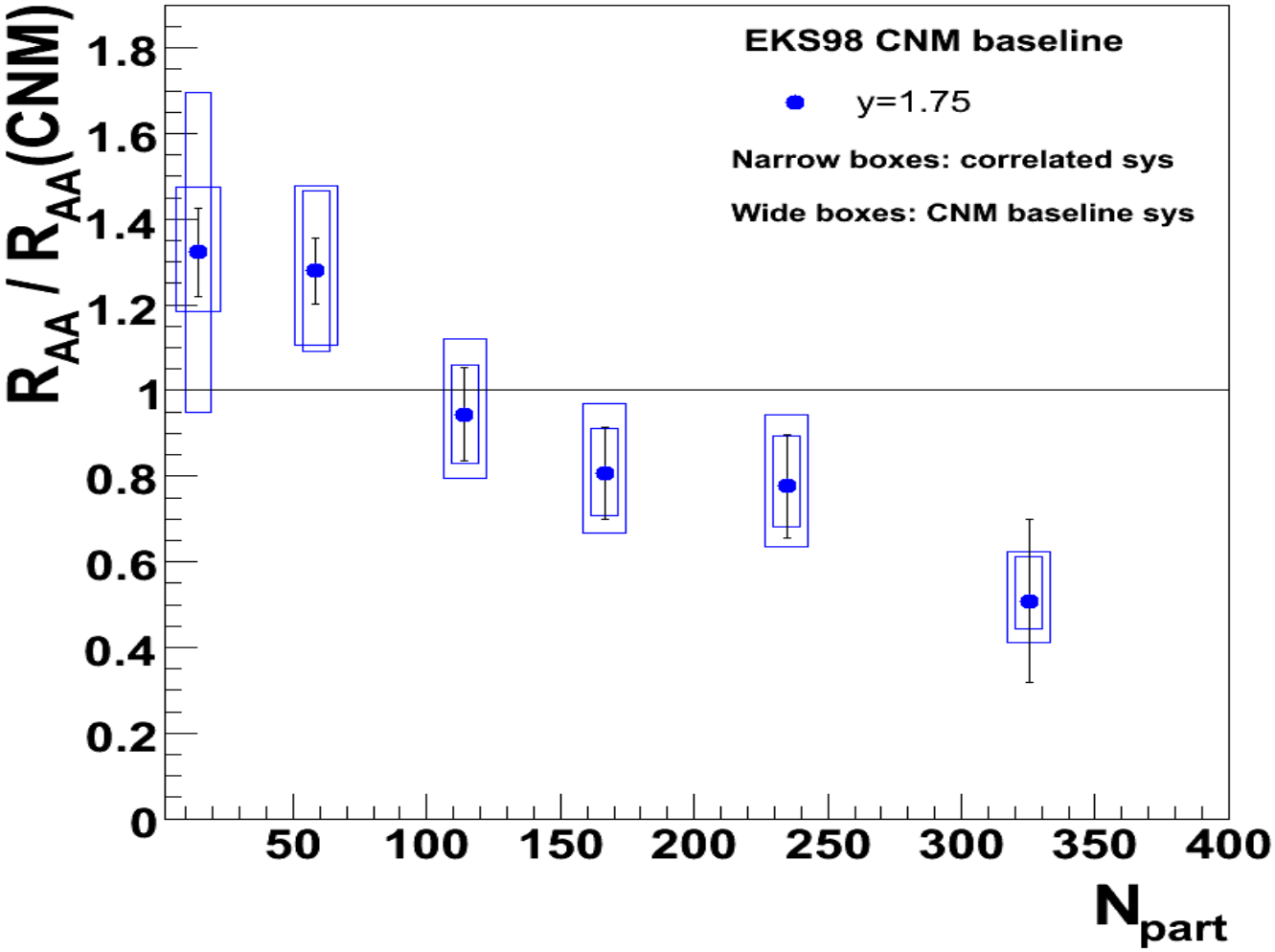
Add to the accumulated RAA: RdAu(b1,y=-1.75) * RdAu(b2,y=1.75)

Heavy ion "survival probability" at y=0 (EKS example)

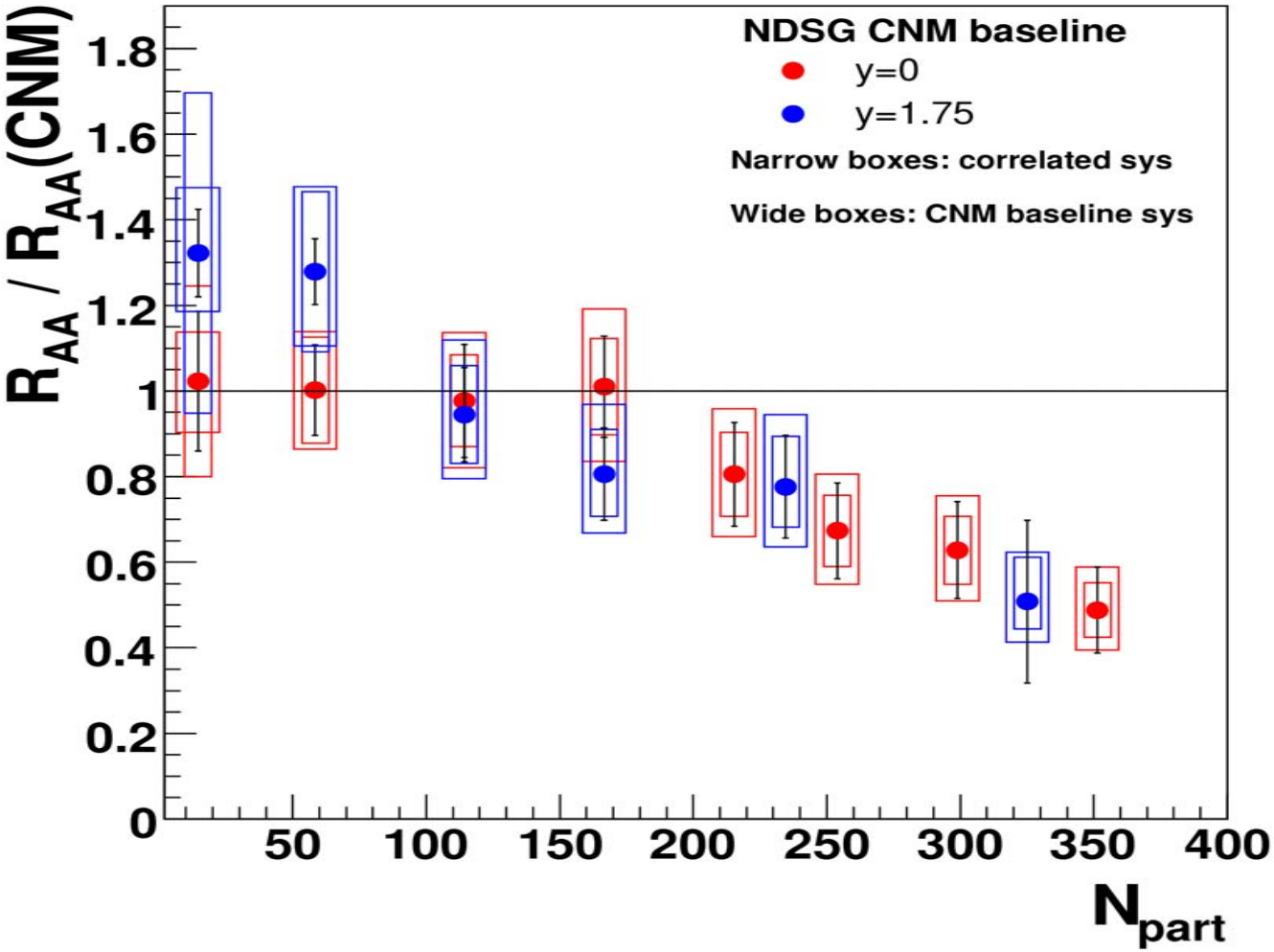


Now we can calculate the ratio RAA/RAA(CNM)

Heavy ion "survival probability" at |y| = 1.7 (EKS example)



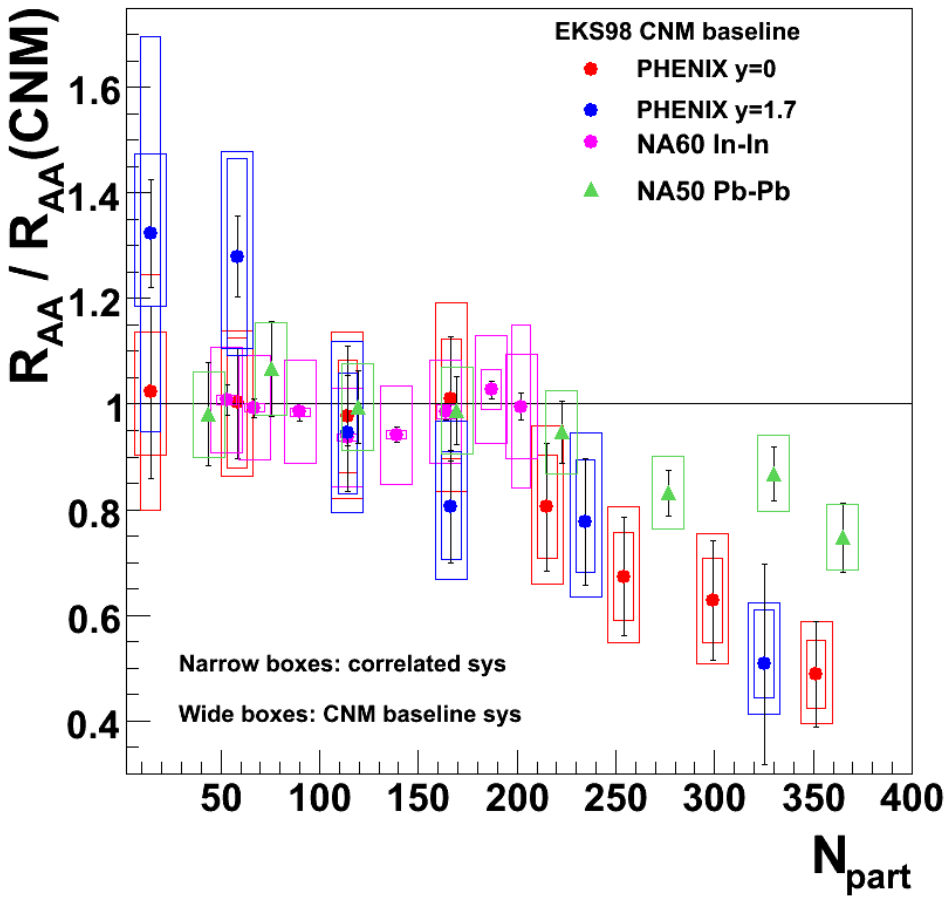
Heavy ion "survival probability" - EKS98 parameterization



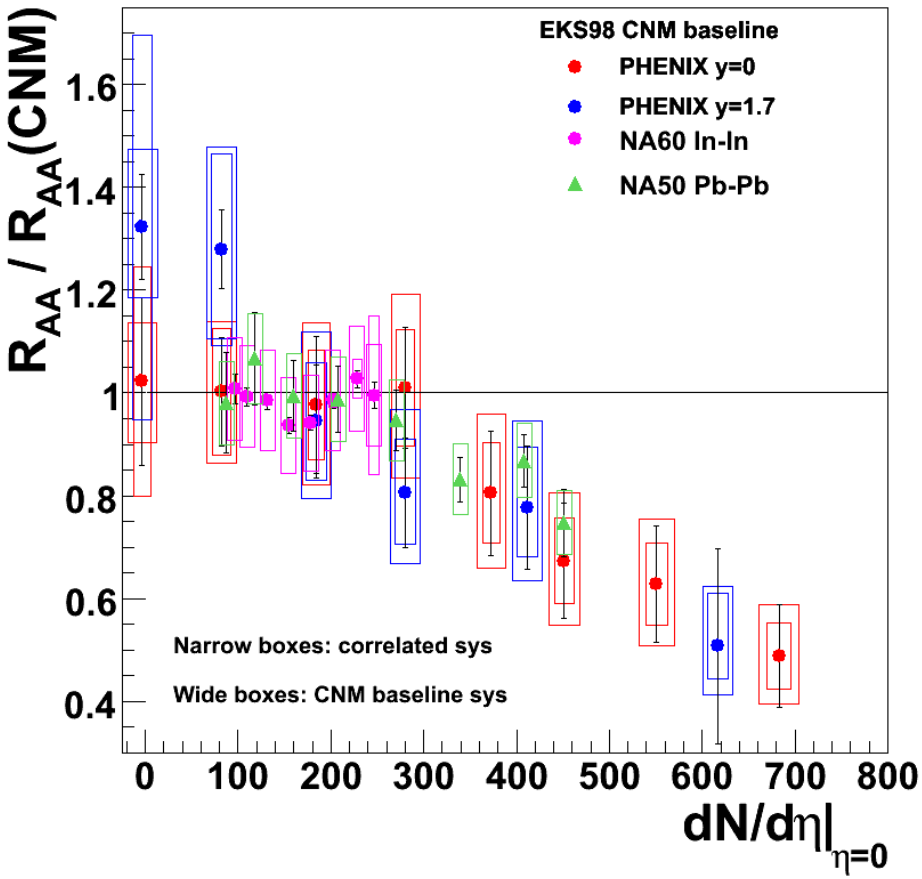
CNM effects explain the high y anomaly?

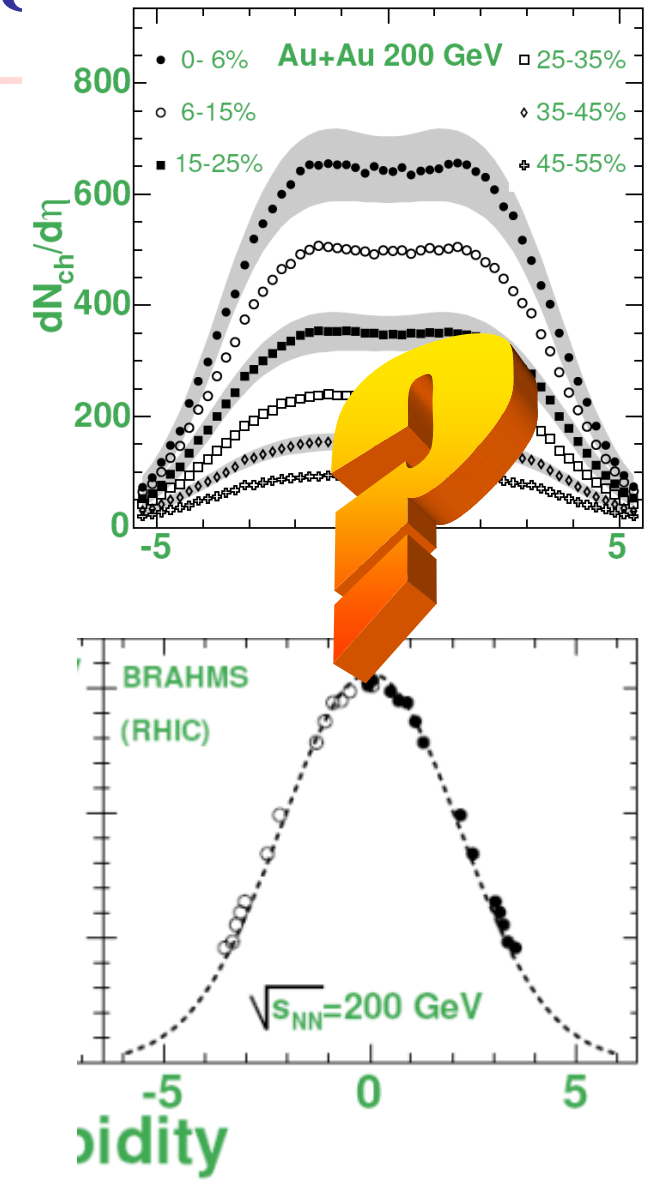
Any connections to NA50, NA60?

Roberta Analdi (ECT trento)



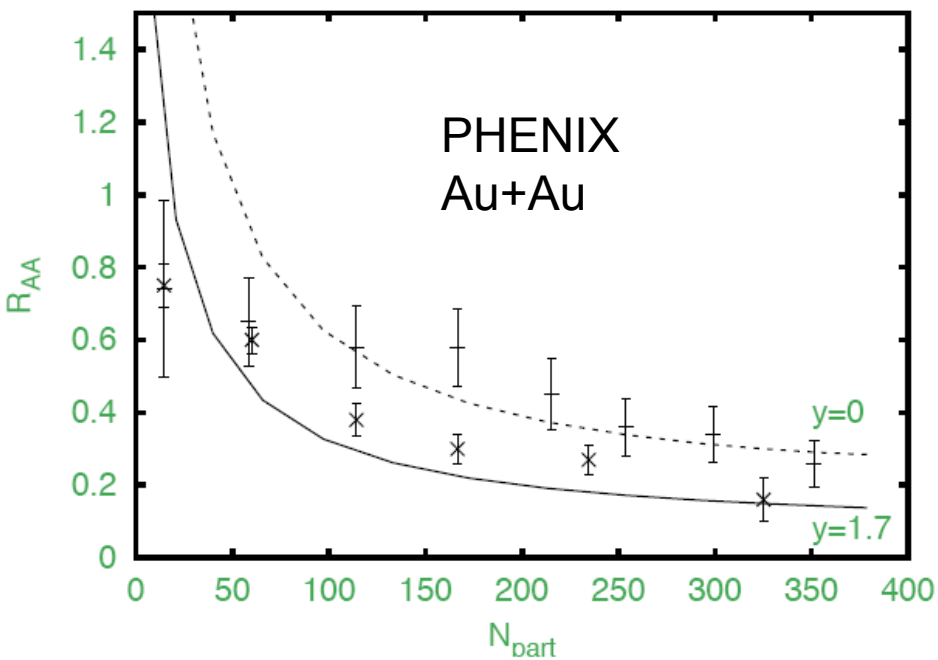
Plot now vs dN/dη ~ ε



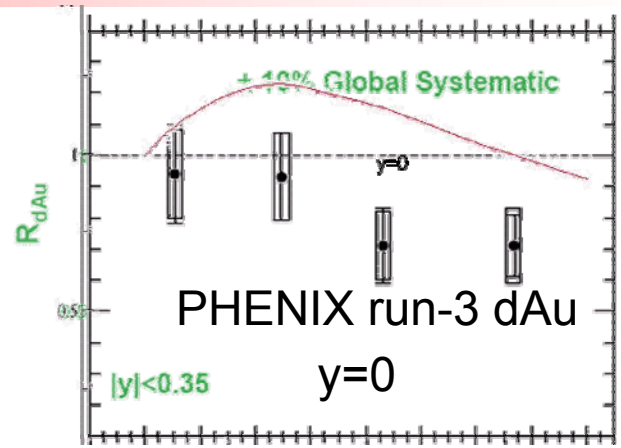


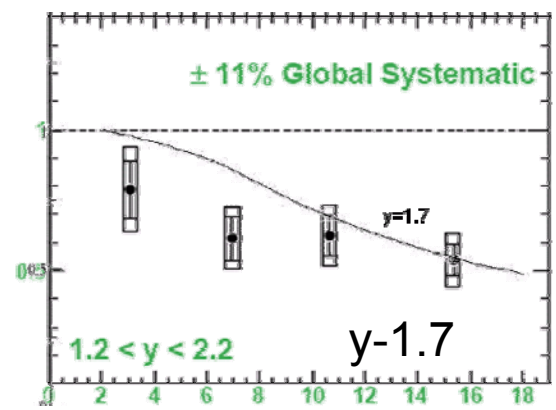
what about the CGC?

Cold J/ψ suppression



Physical mechanism of suppression:
diffusion in momentum space makes J/ψ formation less probable.





but does it fit dAu?

Note: from private communication
dAu model too crude, new results coming

Summary

The PHENIX d+Au data at 200 GeV seem to follow the trend observed at lower energy of a **rapid rise** in the **effective $\sigma_{breakup}$** at forward rapidity.

The effective $\sigma_{breakup}$ appears to be **roughly** constant below y ~ 1.25 at 200 GeV.

The R_{AA}(CNM) estimated from the fits to the R_{dAu} data show significantly **stronger suppression at |y|=1.7** than at y=0.

The measured suppression **beyond** the estimated R_{AA}(CNM) values, presumably due to **hot nuclear matter** effects, seems to be very similar at y=0 and |y|=1.7 at about 50%.

An attempt to estimate NDOF(effective)

really its

ε/T^4, $3s/4T^3$

Preliminaries : thermo

$$\varepsilon_g = \frac{1}{2\pi^2}\int \frac{p^3 dp}{e^{\beta p}-1} \qquad \Rightarrow \varepsilon_g = \frac{\pi^2 T^4}{30}$$

$$\varepsilon_q = \frac{1}{2\pi^2}\int \frac{p^3 dp}{e^{\beta(p+\mu)}+1} \qquad \Rightarrow \varepsilon_q + \varepsilon_{\bar{q}} = \frac{7\pi^2 T^4}{120} + \frac{\mu^2 T^2}{4} + \frac{\mu^4}{8\pi^2}$$

melt the hadrons and liberate quark and gluon DOF?

Energy density (entropy density) for "g" massless d.o.f. (bosons)

$$\varepsilon = g\frac{\pi^2}{30}T^4 \qquad TS = \varepsilon + p \Rightarrow \qquad s = g\left(\frac{4}{3}\right)\frac{\pi^2}{30}T^3$$

$$\varepsilon = 3\cdot\frac{\pi^2}{30}T^4$$

Hadronic Matter: quarks and gluons confined
For T ~ 200 MeV, **3** pions with spin=0

$$\varepsilon = \left\{2_s\cdot 8_g + \frac{7}{8}\cdot 2_s\cdot 2_a\cdot 2_f(3)\cdot 3_c\right\}\frac{\pi^2}{30}T^4$$

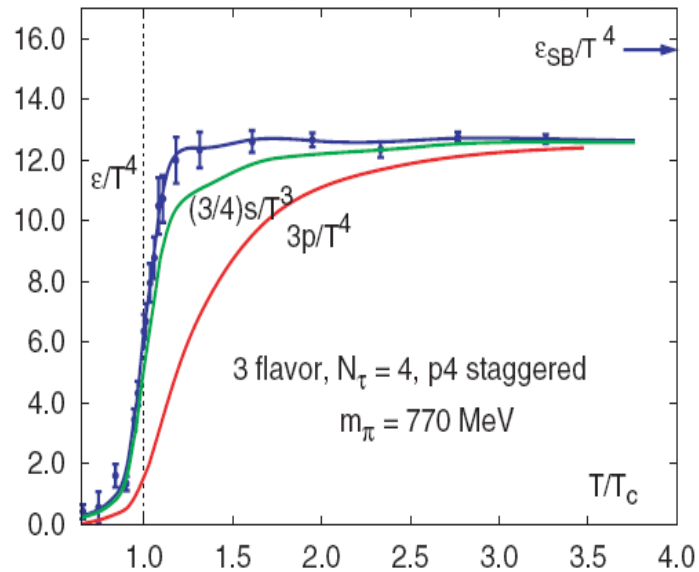
Quark Gluon Matter:
8 gluons;
2(3) quark flavors,
antiquarks,
2 spins, 3 colors

$$\varepsilon = 37(48)\cdot\frac{\pi^2}{30}T^4$$

Ndof~37 (48) !

Looking at ε/T^4, $3s/4T^3$ aka $NDOF_{effective}$

- PHENIX
  - energy density (ET)
  - T (photons)
  - entropy (dN/dy)
- Can we make a rough estimate from data of ε/T^4, $3s/4T^3$?
- For an ideal massless gas ε/T^4, $3s/4T^3 \sim NDOF$
- sQGP $\Rightarrow$ but we can look at the lattice for guidance

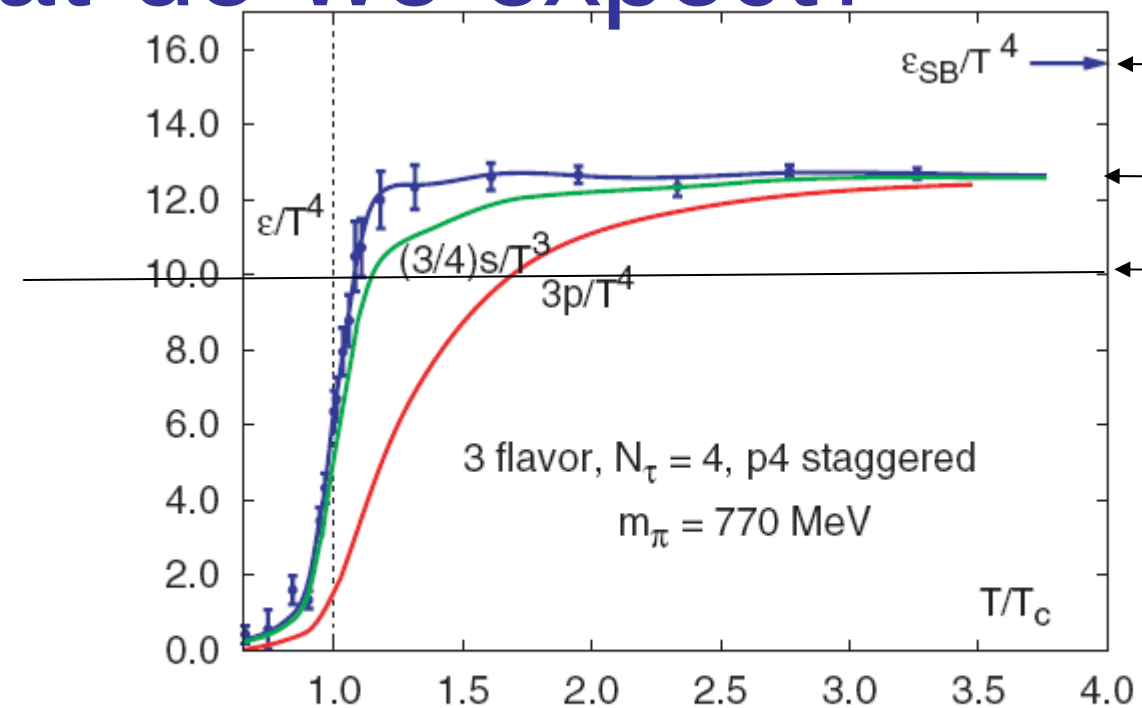


strategy~ fit ε, s, T a functions of τ

ref – see Enteria et al
Rajagopal, Mueller

what do we expect?

-



for 2 flavors

12 (ndof=37)

9.5 (ndof=29)

7.5 (ndof=23)

Figure 1 $\varepsilon(T)/T^4$, $P(T)/T^4$, and $s(T)/T^3$ for three light flavors of quarks on the lattice. SB, massless Bose field.

$$9.5\frac{30}{\pi^2} = 29 = ndof\,(effective)$$

37=ndof(effective 3 flavor)

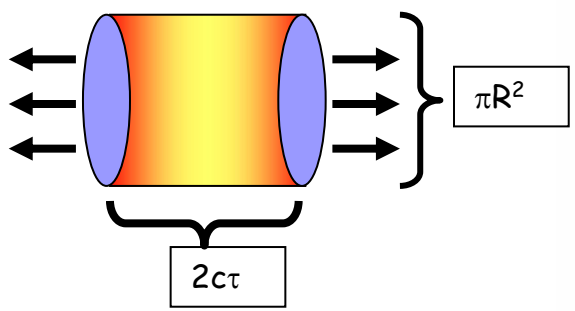
Expectaions								
	ndof(sb)	e/T^4(s	3s/4T^3(sb)	e/T^4(la	3s/4T^3(	ndof(effective)	3s/4T^3(near T	ndof(effective)
3 flavor	48	16.00	16	12.5	12.5	38.0	10.00	30.4
2 flavor	37	12.00	12	9.5	9.5	28.9	7.50	22.8

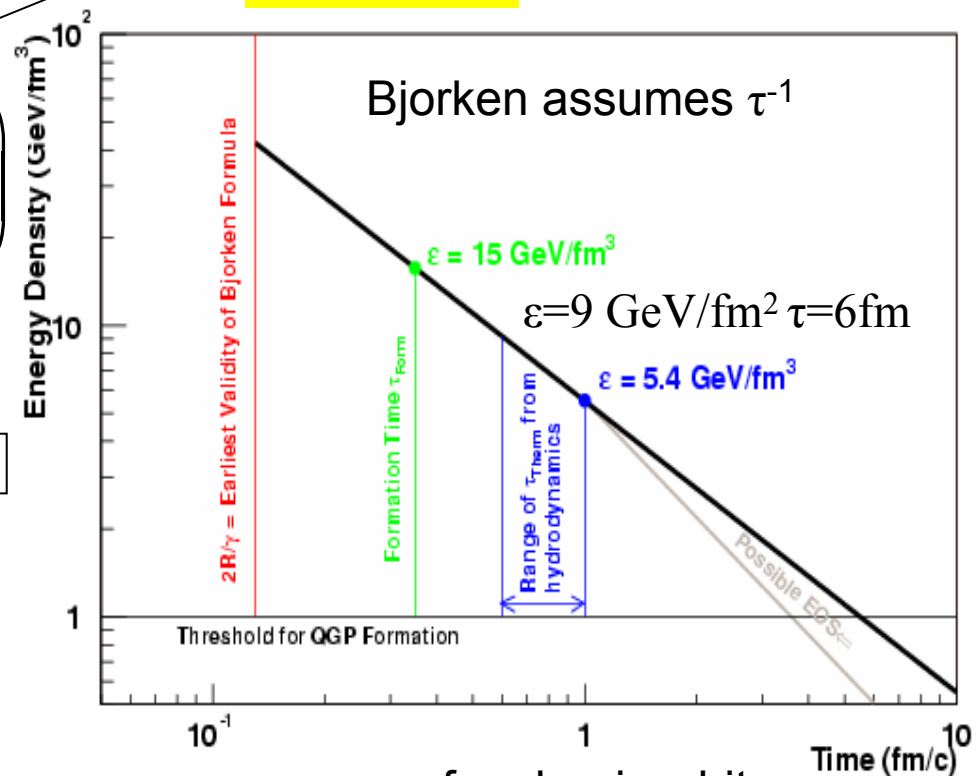
the data: Energy Density

$f(\tau) \sim \tau^{-1}$

$$\varepsilon_{Bj} = \frac{1}{\pi R^2} \frac{1}{2c\tau} \left(2 \frac{dE_T}{dy} \right)$$

R~6.3fm



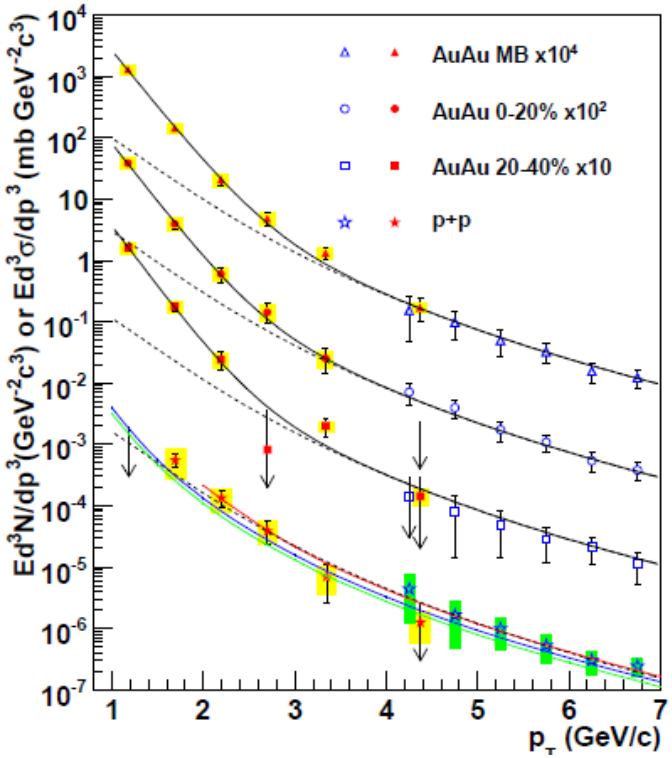


ref – phenix white paper

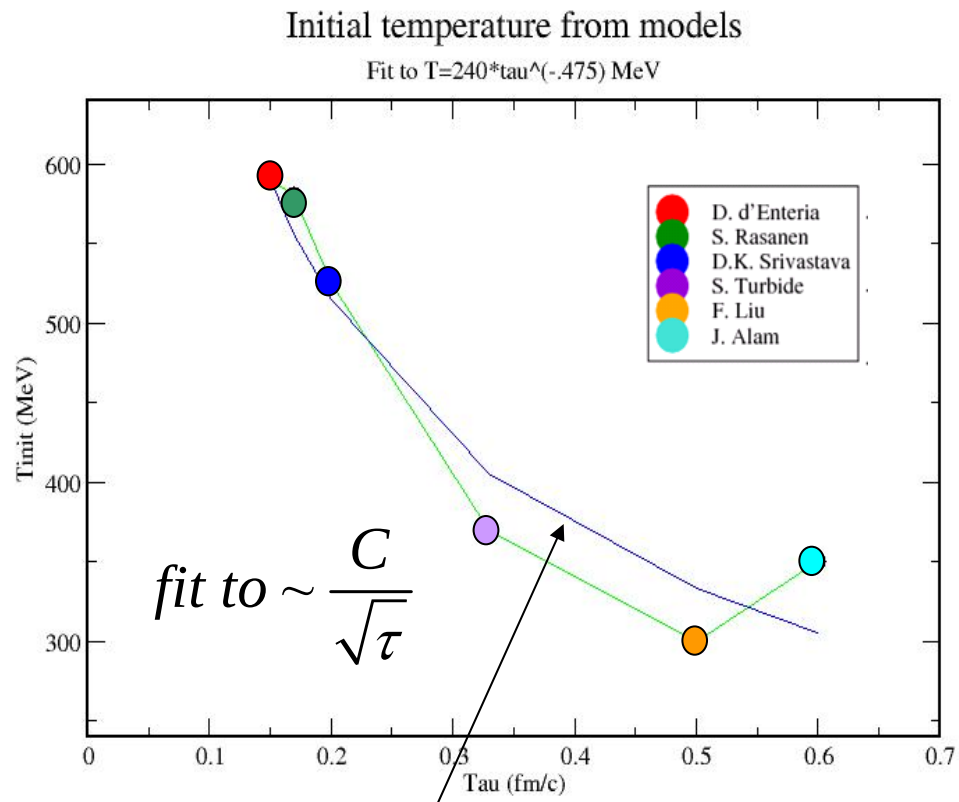
PHENIX: Central Au-Au yields

$$\left\langle \frac{dE_T}{d\eta} \right\rangle_{\eta=0} = 606 \pm 2 GeV \quad \Rightarrow \quad \left\langle \frac{dE_T}{dy} \right\rangle_{y=0} = 760 GeV$$

The data: Temperature - Photons



arXiv:0804.4168v1 [nucl-ex]



- Fit to the p_T slope in central collisions yields

  T_{avg} = 221 ±23 ±18 MeV

- Using models for the expansion

  T_{avg} = 221 → T_{init} > 300 MeV

fit to

$$T(GeV) = 0.240\tau^{-.475}\ GeV$$

The rough calculation
$NDOF_{effective}$ using ε/T^4 $3s/4T^4$

central

$$NDOF = \varepsilon \cdot \frac{30}{\pi^2 T^4} = \frac{1}{\pi R^2}\frac{1}{c\tau}\left(\frac{dE_T}{dy}\right)\frac{30(\hbar c)^3}{\pi^2 T^4} =$$

$$\frac{1}{\pi(6.6\,fm)^2}\frac{1}{\tau(\,fm)}(758GeV)\frac{30\,(0.197\,GeV\;\;fm)^3}{\pi^2(0.240\tau^{-.475}\;GeV)^4} = C\tau^{0.9}$$

$$NDOF = 39\tau^{0.9} \qquad dEt/dy = 760 \quad R = 6.6 = 1.18*(351/2)^{1/3}$$

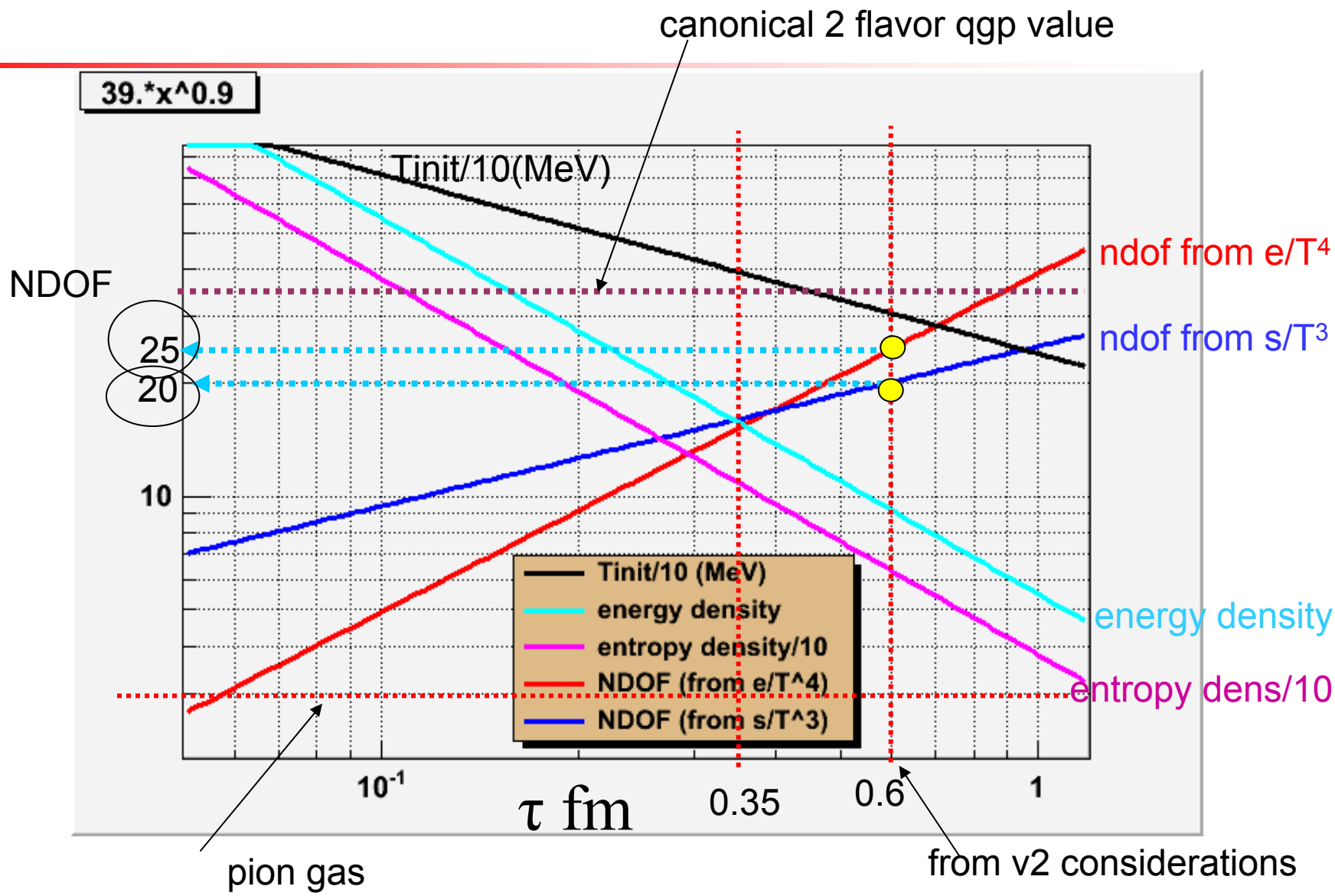
$$s = \frac{7.9}{\pi R^2}\frac{1}{c\tau}\left(\frac{dN_{ch}}{d\eta}\right)$$

from 1.1*7.25/1.04
ref –rajagopal/Mueller

$$NDOF = s\frac{45}{2\pi^2 T^3} = \frac{7.9}{\pi R^2}\frac{1}{c\tau}\left(\frac{dN_{ch}}{d\eta}\right)\frac{45\,(0.197\,GeV\;\;fm)^3}{2^2\pi^2(0.3\,GeV)^3} =$$

$$\frac{7.9}{\pi R^2}\frac{1}{c\tau}\left(\frac{dN_{ch}}{d\eta}\right)\frac{45\,(0.197\,GeV\;\;fm)^3}{2^2\pi^2(0.240\tau^{-.475}\;GeV)^3} = C\tau^{0.425}$$

$$NDOF = 25\tau^{0.425} \qquad dN/d\eta = 758 \quad R = 6.6 = 1.18*(350/2)^{1/3}$$

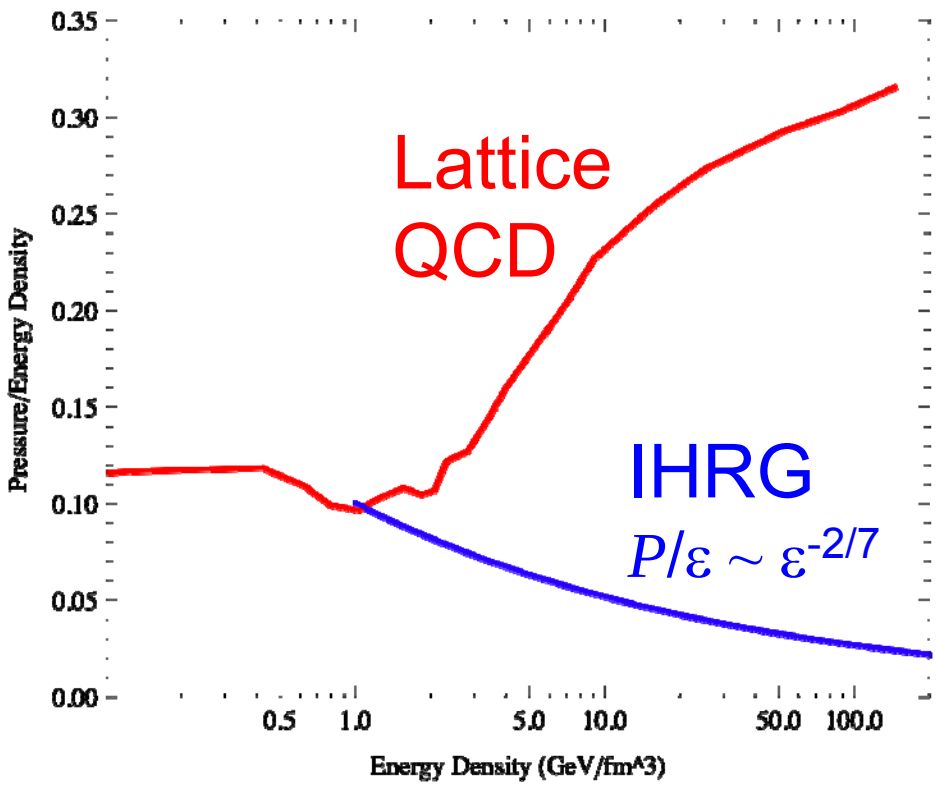


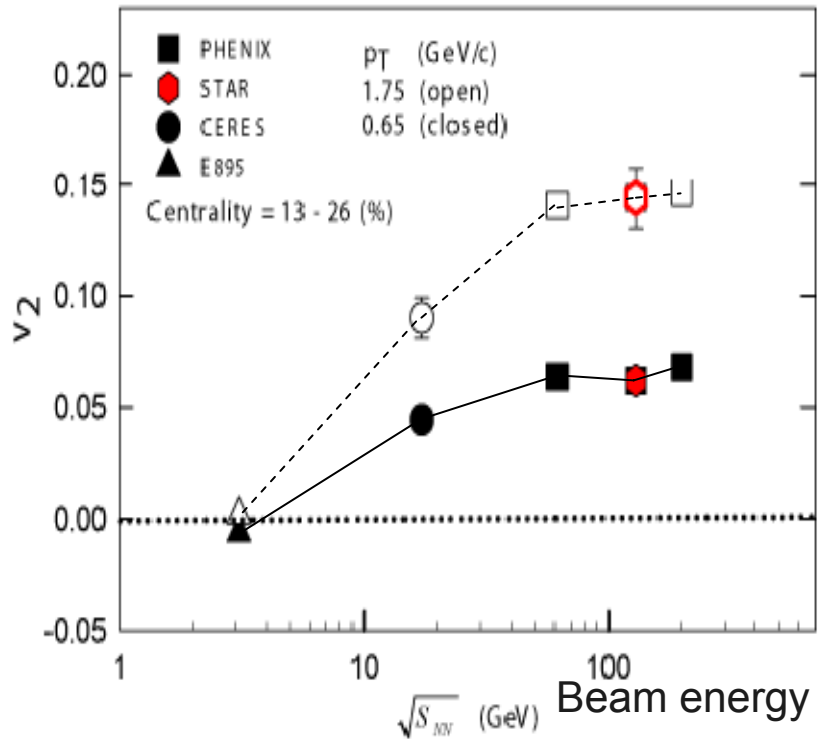
remember the expectations for 2 flavor QCD is 29(e/T^4) and 23(s/T^3)

What do we learn?

- Pretty hard to get NDOF=3 (i.e. need tau<0.1 fm)
- For reasonable tau ~0.35 to 1 fm (0.6 from v2 considerations) get NDOF= 25 using the energy density and 20 using the entropy
- a wQGP predicts ndof=37. If you use the lattice we see a value of 29 using the energy density. The entropy rises slower so right at Tc it would start out at about 23
- So what I would like to say is that
  - a) we see a e/T^4 and s/T^3 consistent (within the errors of this rough calculation) with the lattice
  - d) its much greater than 3
- This is a VERY rough estimate. Caveats about a hadron gas. But pressure arguments may be able to help
  - if the NDOF came from hadrons i.e. it would be the high mass stuff, then it would take a longer to equilibrate. But we have tau~0.6. also p/energy density from the lattice rises with energy density, as does our v2 – but it a hadron gas, a lot of the energy would be taken up in the mass (they particles would be moving slower, and the pressure would be less as compared to the energy density as the energy density rose

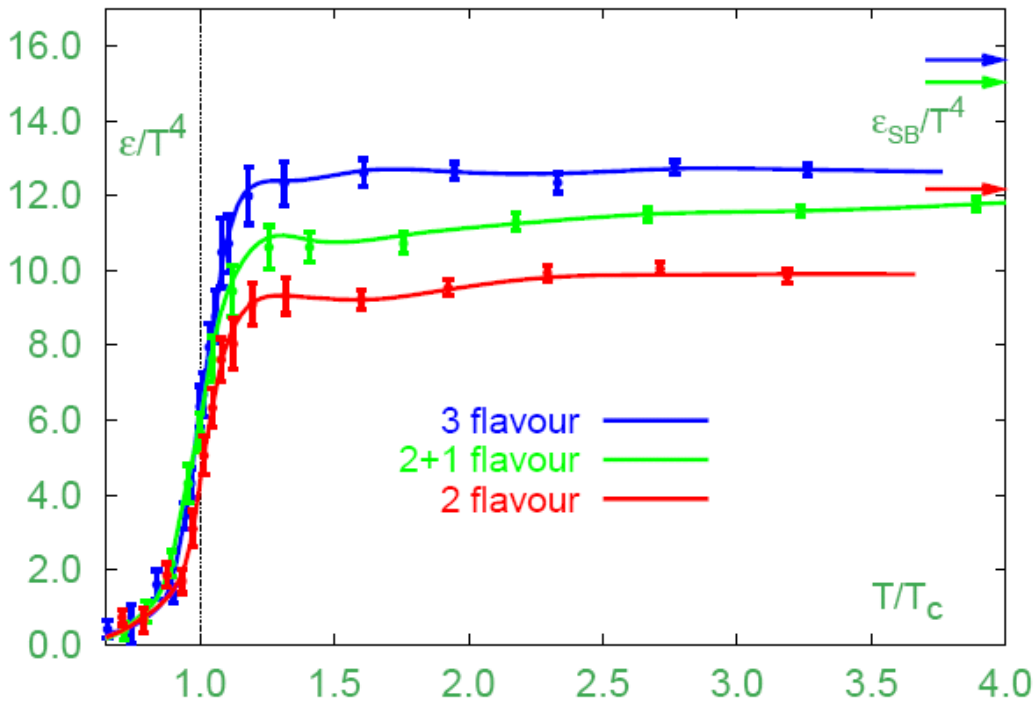
Pressure effects *increase* with energy density





A. Bazavov et al. (HotQCD), arXiv:0903.4379 [hep-lat]

Phys Rev Lett 94, 232302


16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
ε/T4
εSB/T4
3 flavour
2+1 flavour
2 flavour
T/Tc
1.0
1.5
2.0
2.5
3.0
3.5
4.0