

**Looking for the cold nuclear matter baseline for J/ψ
production at RHIC**

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May 26, 2009

Many thanks for contributions/help from:

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Mike Leitch

Alex Linden Levy

Jamie Nagle

Darren McGlinchey

The quarkonium plan

Species

Purpose

p+p

Quarkonium production mechanisms
Baseline cross sections for heavy ions

d+Au

Cold nuclear matter effects
Baseline CNM R_{AA} for heavy ions

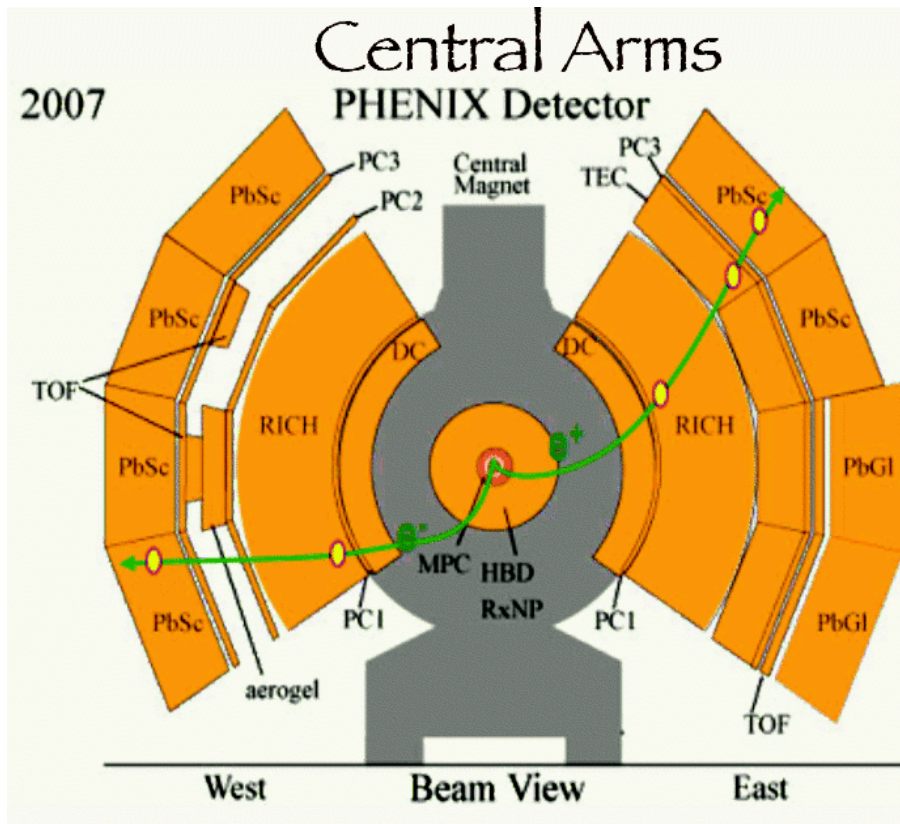
Cu+Cu

Hot nuclear matter effects near T_C

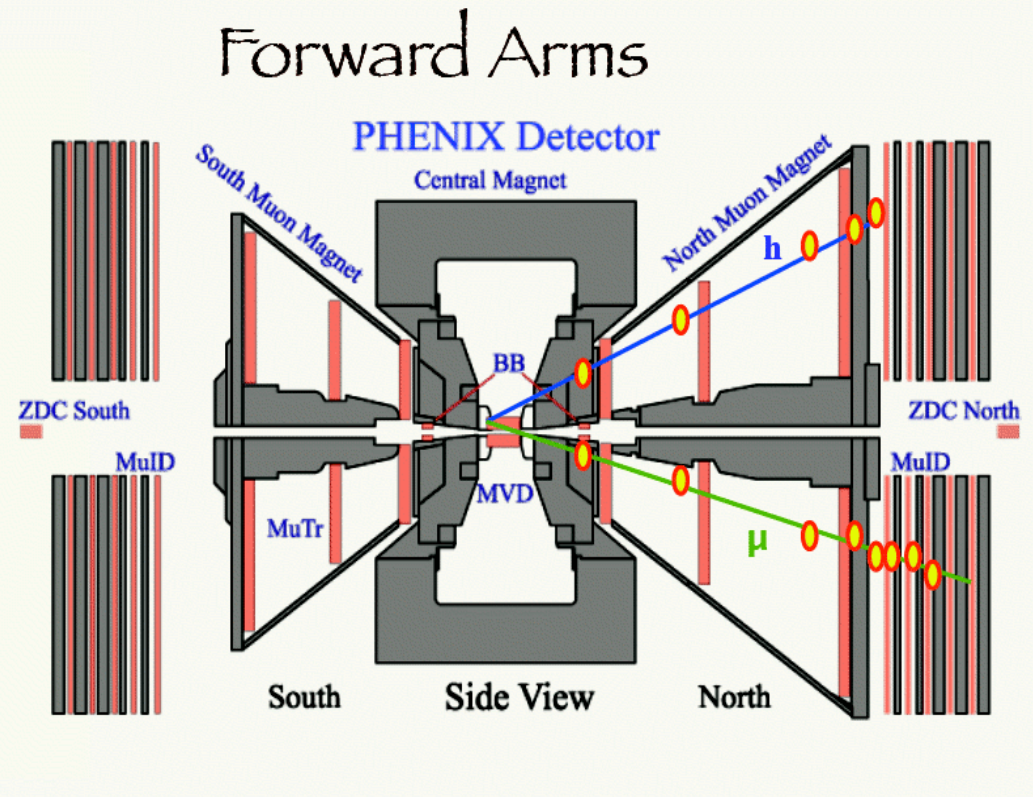
Au+Au

Hot nuclear matter effects well above T_C

The PHENIX Detector



$J/\psi \rightarrow e^+e^-$
 $-0.35 < y < 0.35$



$J/\psi \rightarrow \mu^+\mu^-$
 $1.2 < |y| < 2.2$

Brief review of the relevant J/ψ data

Au+Au R_{AA} Run 4 Au+Au + Run 5 p+p

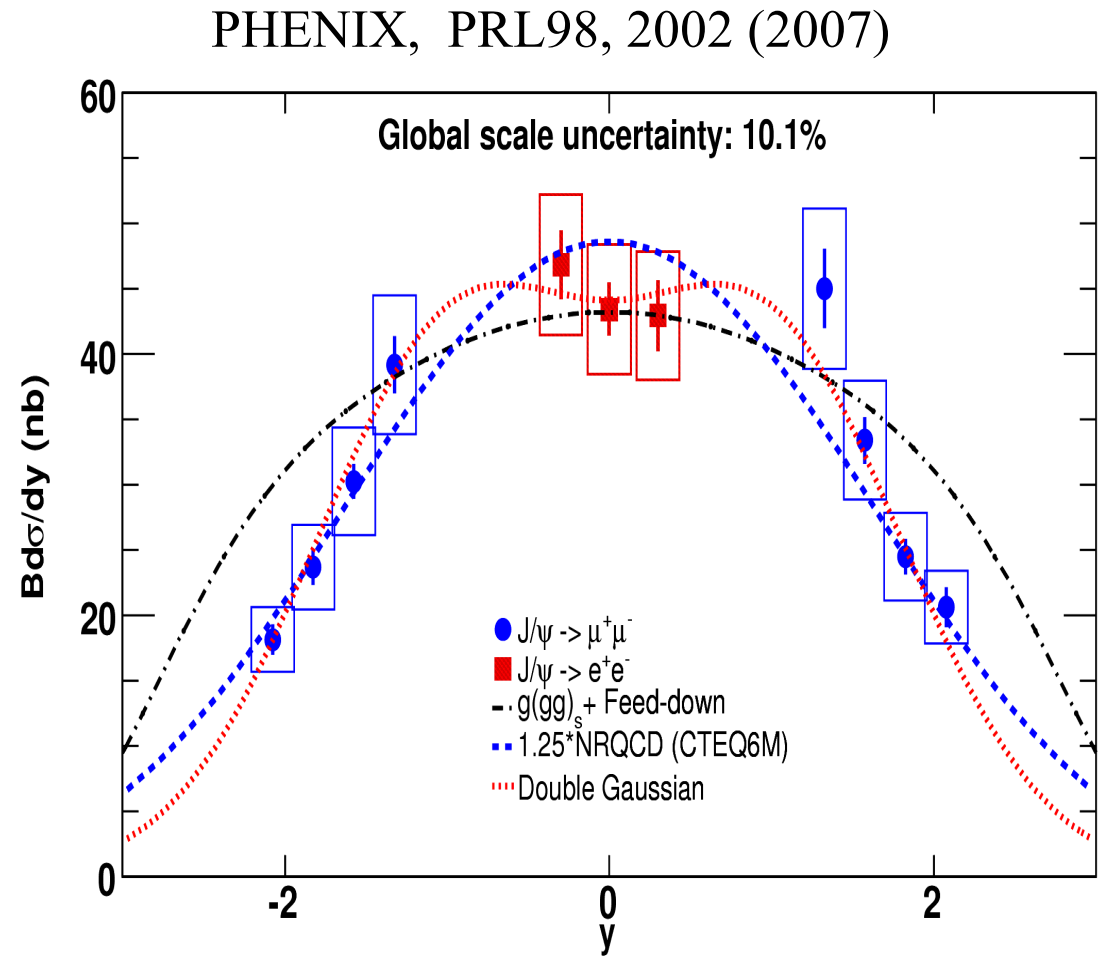
Cu+Cu R_{AA} Run 5 Cu+Cu + Run 5 p+p

d+Au R_{CP} Run 8 d+Au

To come: Run 8 R_{dAu} with Run 6 pp reference

Reference data – Run 5 p+p

This is the reference data set for **all** nuclear modification factors shown here.



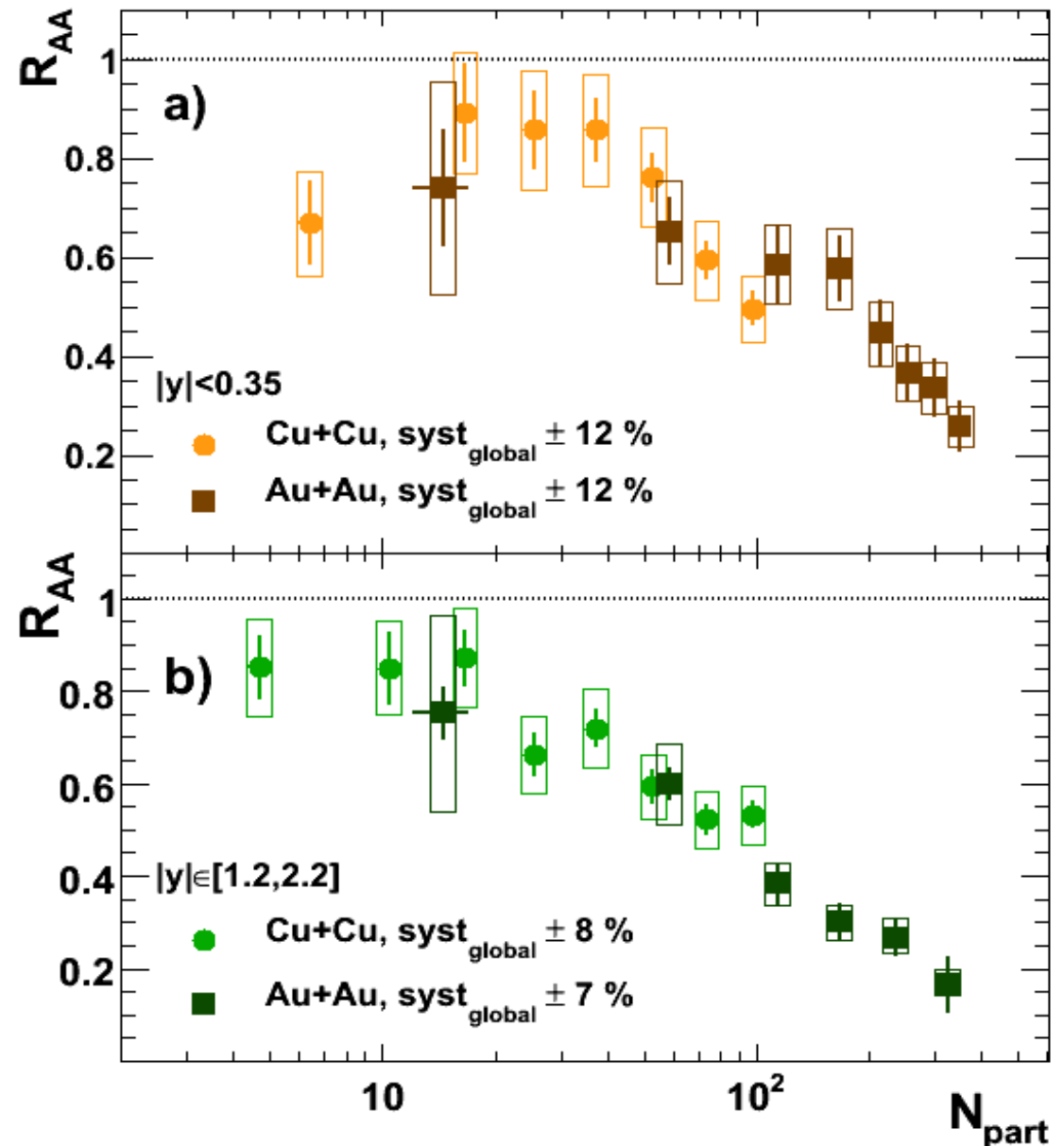
Cu+Cu and Au+Au R_{AA}

Phys. Rev. Lett. 101, 122301 (2008)

The N_{part} dependence of Au+Au and Cu+Cu is consistent.

Note the smaller systematic uncertainties for the Cu+Cu data. This is primarily due to smaller uncertainties on N_{coll} from the Glauber calculation.

Thus the Cu+Cu data will be much better for studying the **onset** of hot nuclear matter effects.

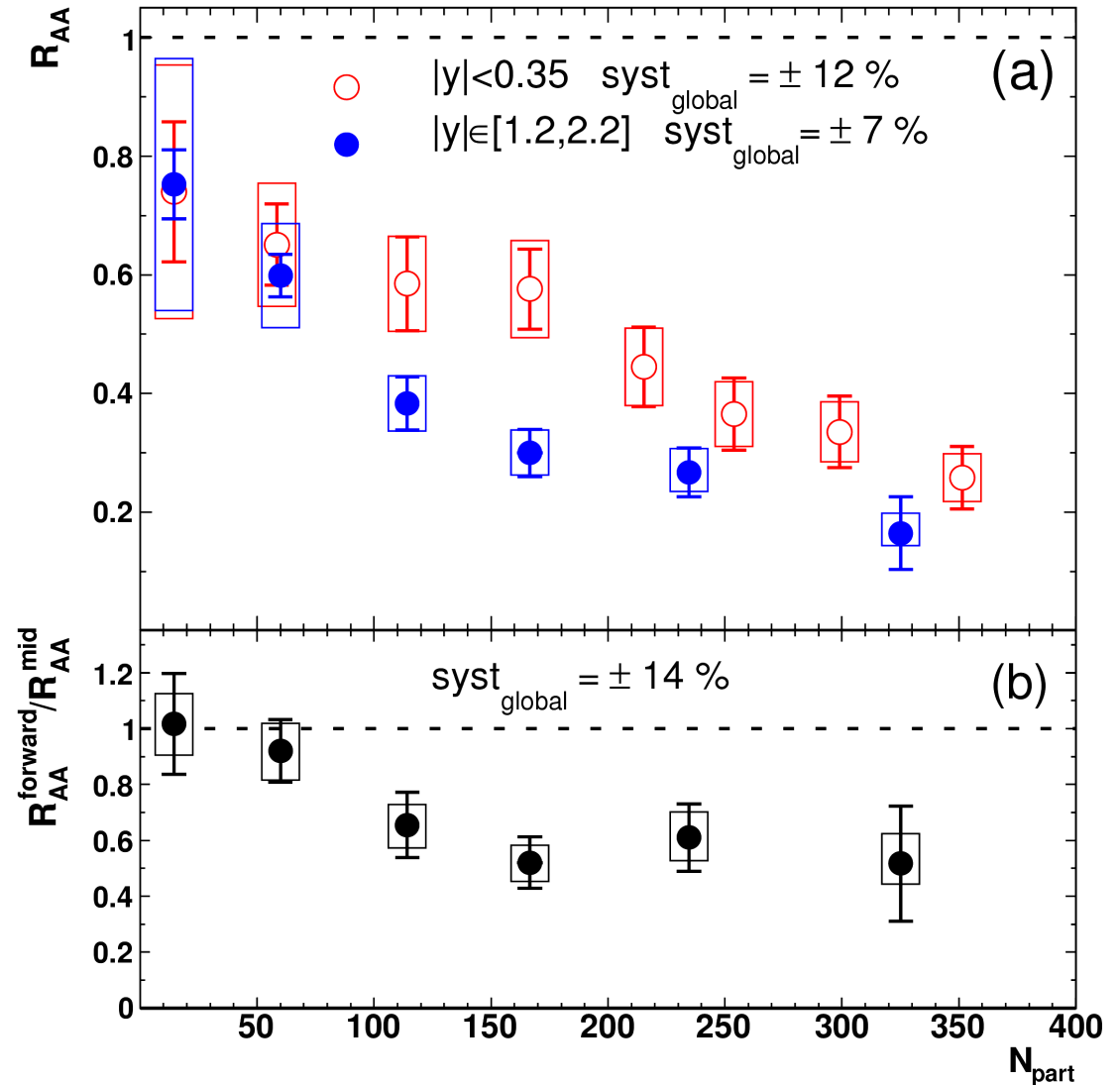


Au+Au R_{AA}

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

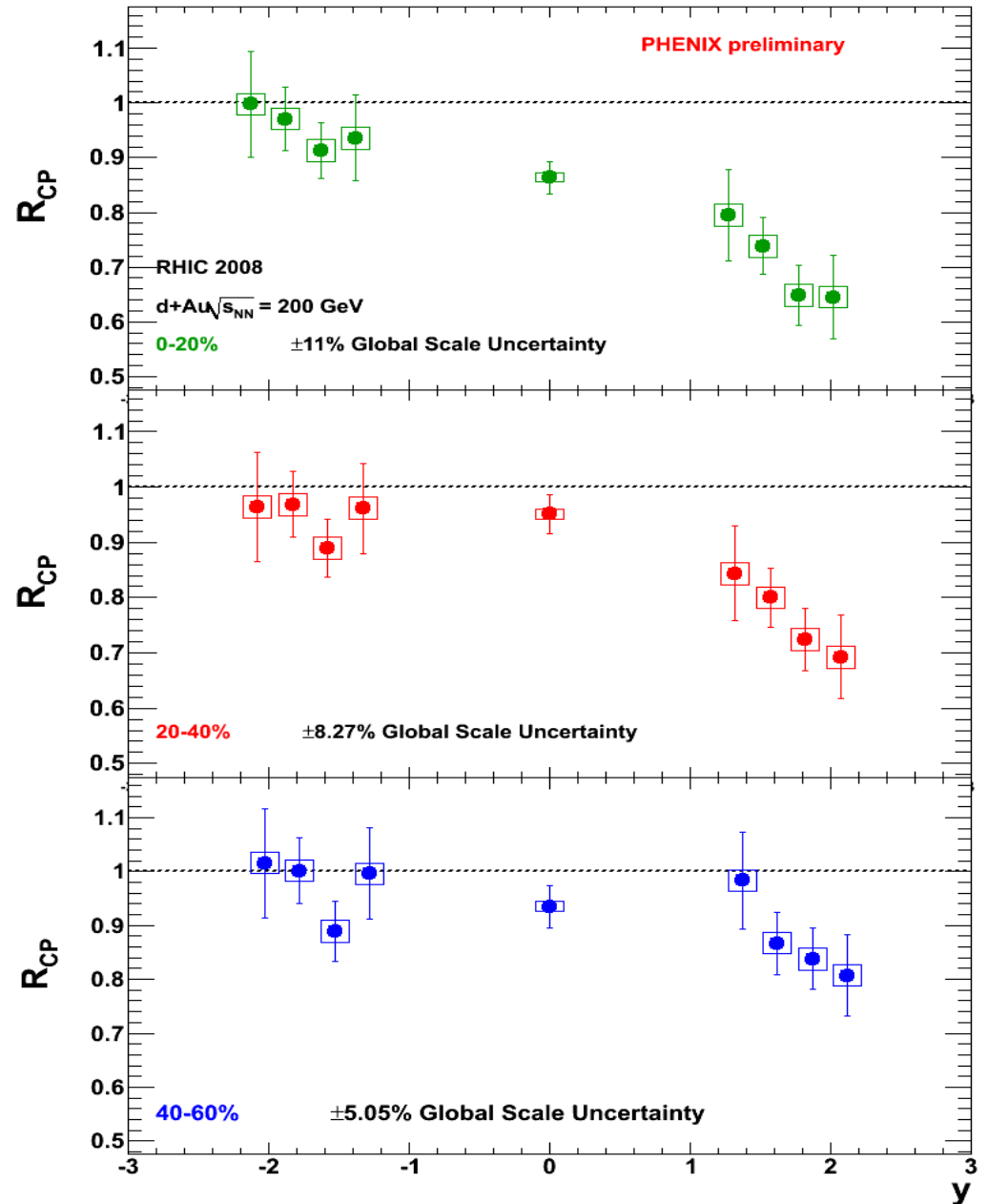


d+Au R_{CP}

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

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

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



What can we learn from the existing charmonium R_{AA} data?

The heavy ion charmonium data alone have not taught us as much as we would like, because of serious uncertainties caused by:

- 1) Poorly known initial state effects at RHIC:
 - Break up cross section for collisions with nucleons.
 - Shadowing.
 - Other effects? Initial state energy loss?

- 2) Poorly known open charm production cross sections.

Thus the trade-off between coalescence and destruction is difficult to illuminate experimentally.

To try to make inroads on 1), we start from the most recent d+Au data set:

– Run 8 d+Au

First we briefly review **previous attempts** to use **Run 3 d+Au** data for this.

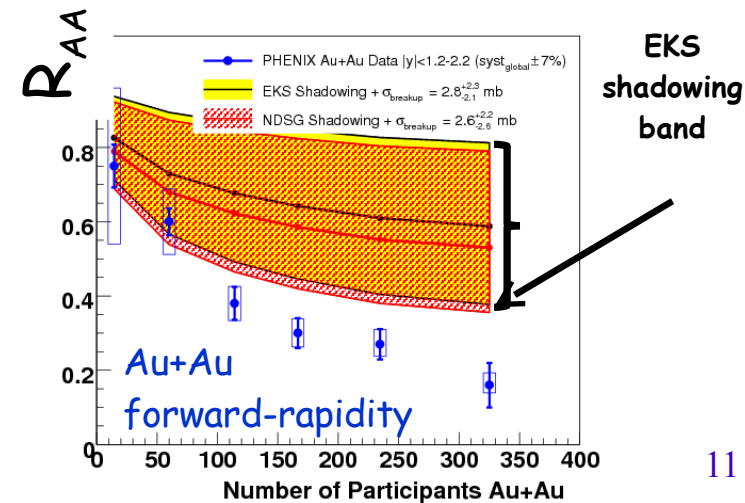
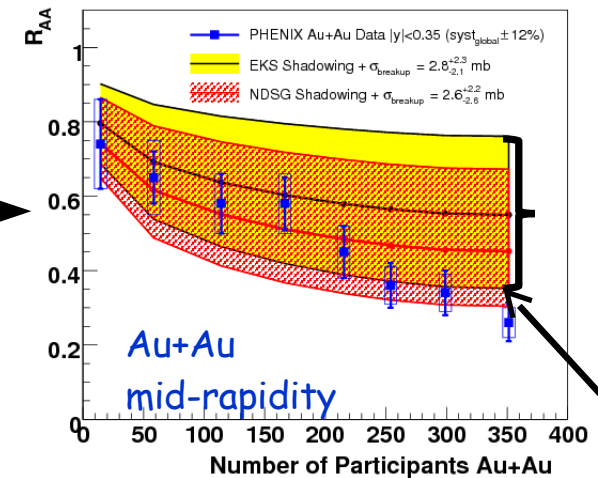
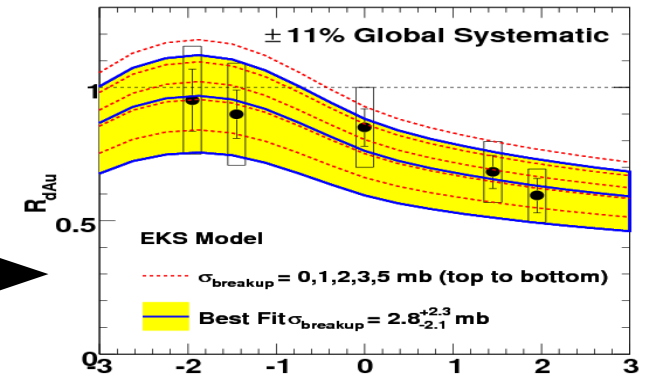
Estimating the CNM R_{AA} from Run 3 d+Au data - 1

This has been done before in **three ways**:

1) PHENIX (**Phys. Rev. C 77, 024912 (2008) and erratum arXiv:0903.4845**) fitted Run 3 R_{dAu} using a single σ_{breakup} at all rapidities + EKS98/nDSg shadowing calculations by Ramona Vogt.

The CNM R_{AA} was estimated using calculations of R_{AA} for Cu+Cu and Au+Au by Ramona, using the fitted σ_{breakup} + EKS98/nDSg.

However (**Phys. Rev. Lett. 101, 122301 (2008) PPG071**), when a single σ_{breakup} is used at all rapidities the **ratio** of the predicted $y=0$ to $|y|=1.7$ CNM R_{AA} values is just a **prediction of the shadowing model**. Therefore this is not a good way to use the R_{dAu} data to test if the increased suppression at $|y|=1.7$ is due to CNM effects.

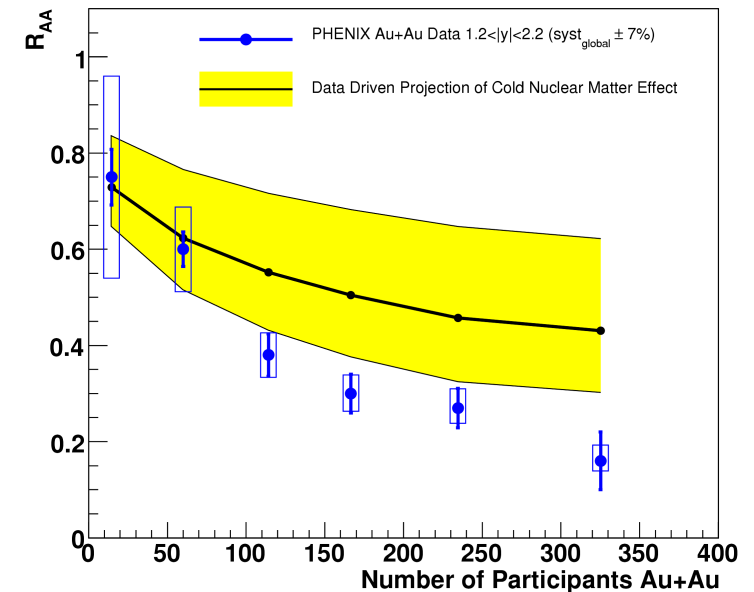
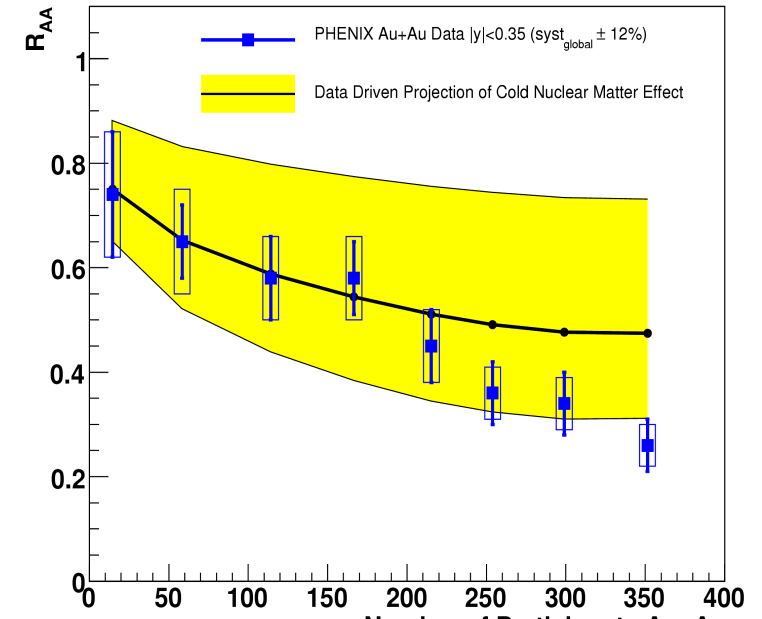


Estimating the CNM R_{AA} from Run 3 d+Au data - 2

2) Raphael Granier de Cassagnac (*J. Phys. G34, S955 (2007)*) used direct folding of the R_{dAu} data, with some assumptions, to predict the CNM R_{AA} for Au+Au. This works only for Au+Au, since R_{dAu} is used directly.

This approach produces **completely independent** CNM R_{AA} values at $y=0$ and $|y|=1.7$ – which is very good. But because of the low statistical precision of the Run 3 d+Au data, the results are inconclusive.

This approach **cannot** be used with d+Au R_{CP} data, nor can it be used to estimate a CNM R_{AA} baseline for Cu+Cu.



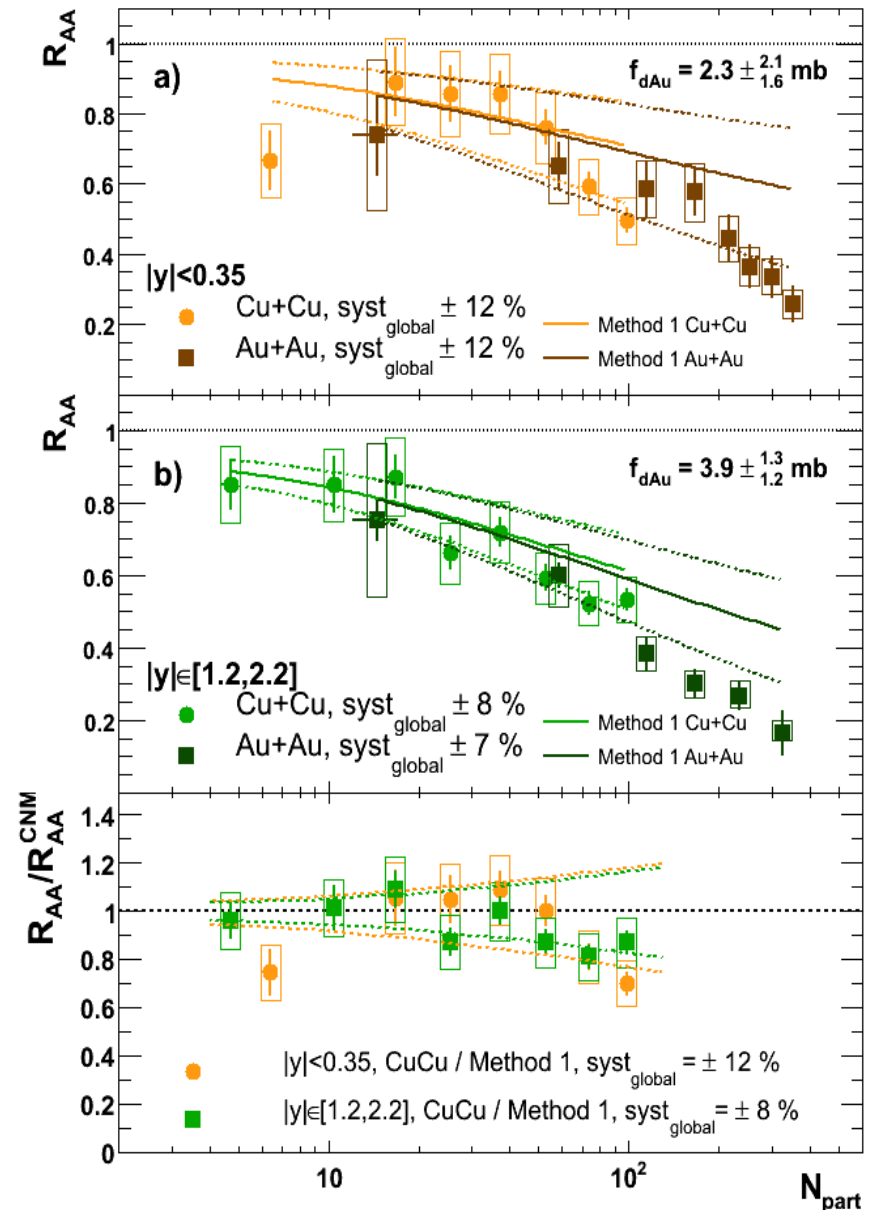
Estimating the CNM R_{AA} from Run 3 d+Au data - 3

3) The PHENIX R_{dAu} data were fitted **separately** at $y=0$ and $|y|=1.7$ with σ_{breakup} + EKS98/nDSg calculations by Ramona. The CNM R_{AA} was predicted for **Cu+Cu** and **Au+Au** independently at $y=0$ and $|y|=1.7$ using calculations by Ramona.

While this makes the ratio of the estimated CNM R_{AA} at $y=0$ and $|y|=1.7$ sensitive to the R_{dAu} data, it still assumes the forward and backward rapidity data have the **same** σ_{breakup} . We will see this is **not justified**.

NOTE: The uncertainty bands here are **underestimated** due to the fitting error that was corrected for 1). **Not fixed here yet!**

Phys. Rev. Lett. 101, 122301 (2008)



Fitting the Run 8 d+Au R_{CP}

We want to **parameterize** the d+Au R_{CP} data so that we can predict the heavy ion R_{AA} that would result from p+A physics only.

Fit R_{CP} vs centrality **independently at each rapidity** using calculations of R_{dAu} vs impact parameter by **Ramona Vogt** that include:

- σ_{breakup} for collisions of (forming) J/ ψ with nucleons (0-15 mb, 1 mb steps).
- A shadowing model – EKS98 and nDSg are used here.

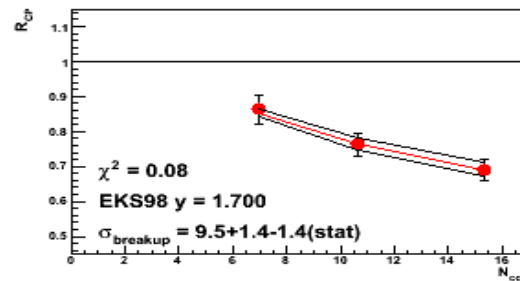
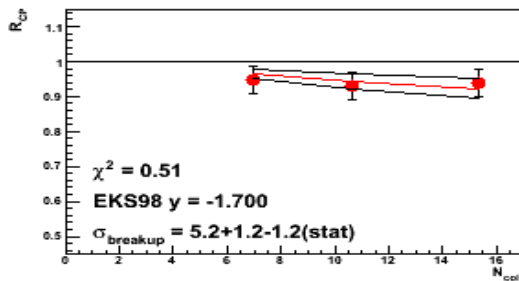
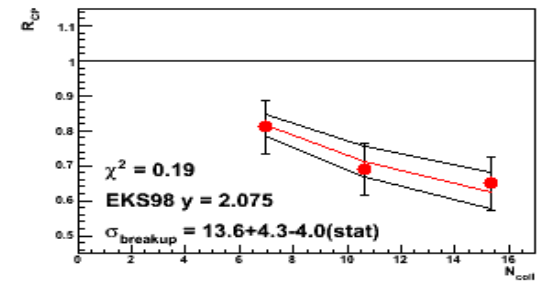
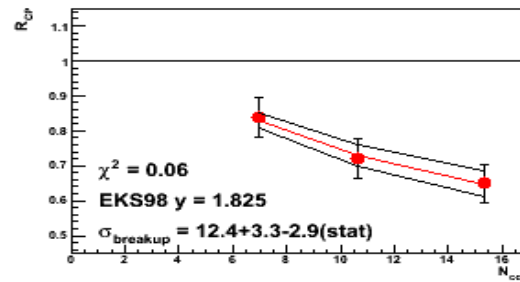
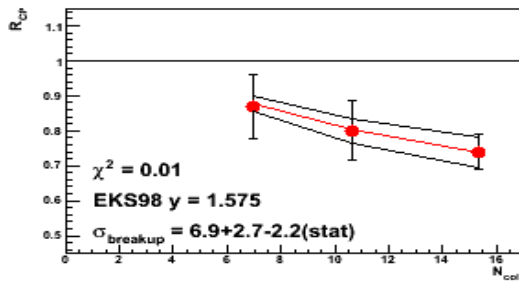
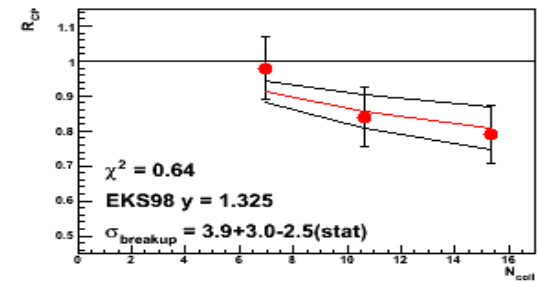
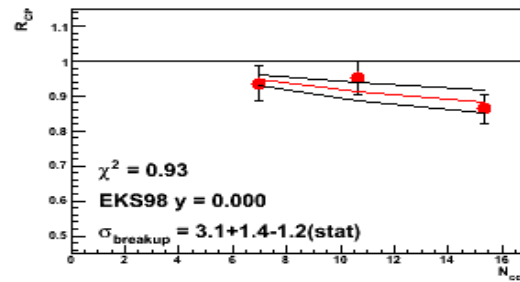
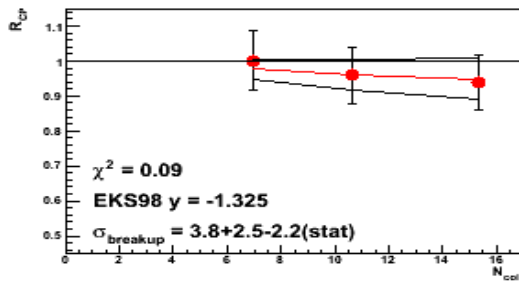
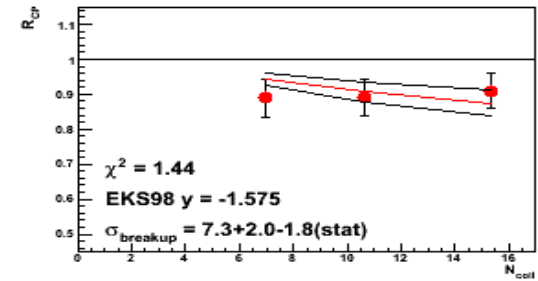
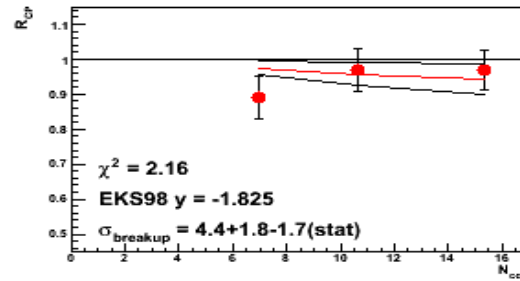
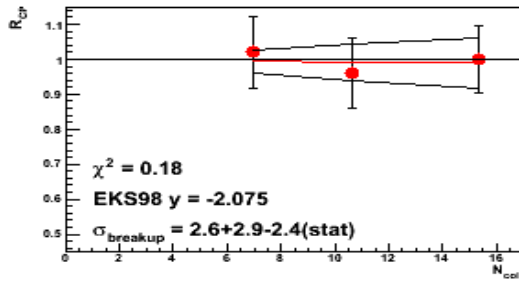
Convert R_{dAu} vs impact parameter to R_{dAu} vs centrality using PHENIX Glauber impact parameter distribution for each **dAu centrality bin**.

Fit procedure:

- Fit R_{CP} vs centrality using only uncertainties that are uncorrelated in rapidity.
- Vary R_{CP} by +/- 1σ in uncertainties that are correlated in rapidity, and refit.
- Vary R_{CP} by +/- 1σ in uncertainties that are global with rapidity and refit.

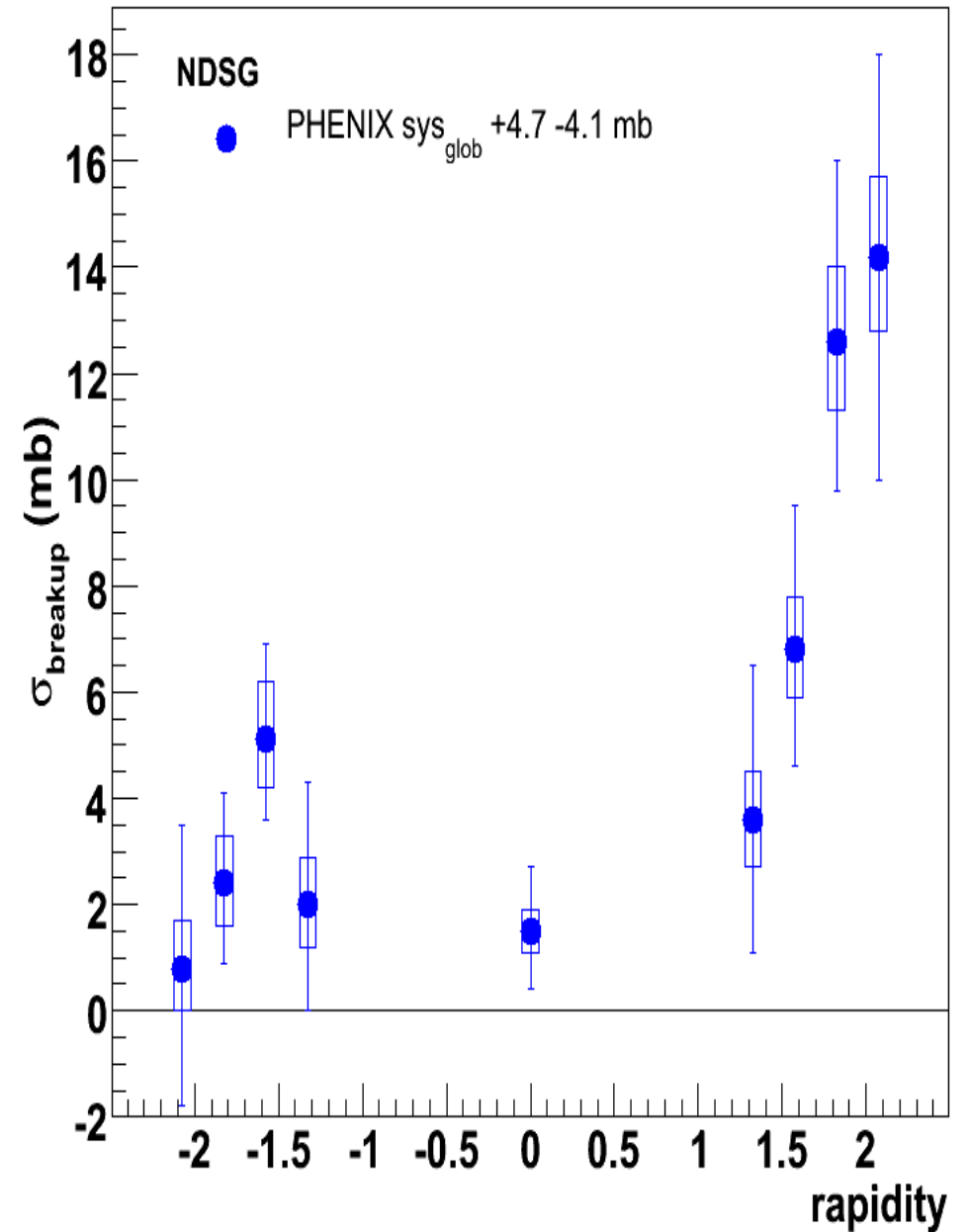
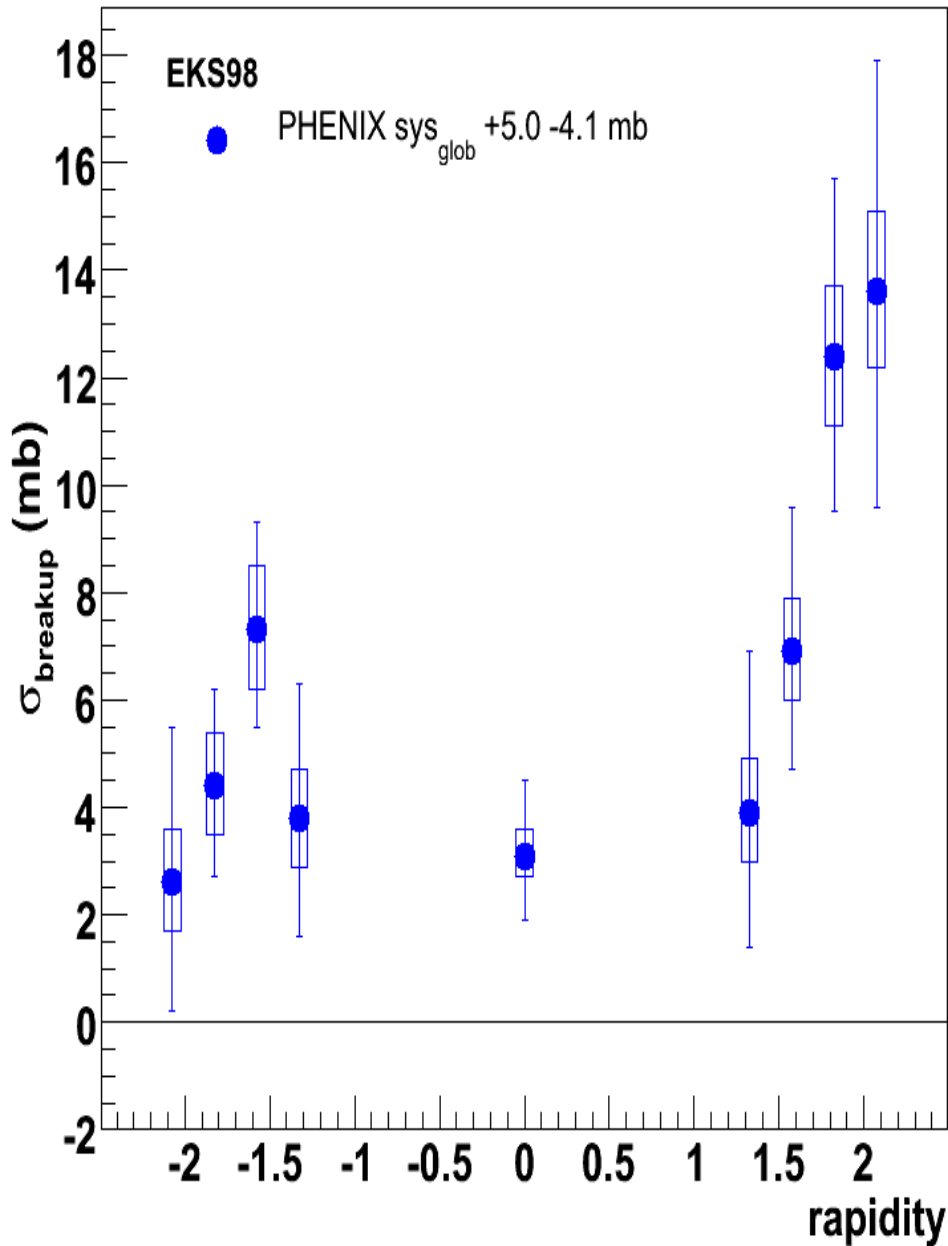
Uncertainties are shown respectively as **bars, boxes, and a global number**.

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



← Integrated for each muon arm

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

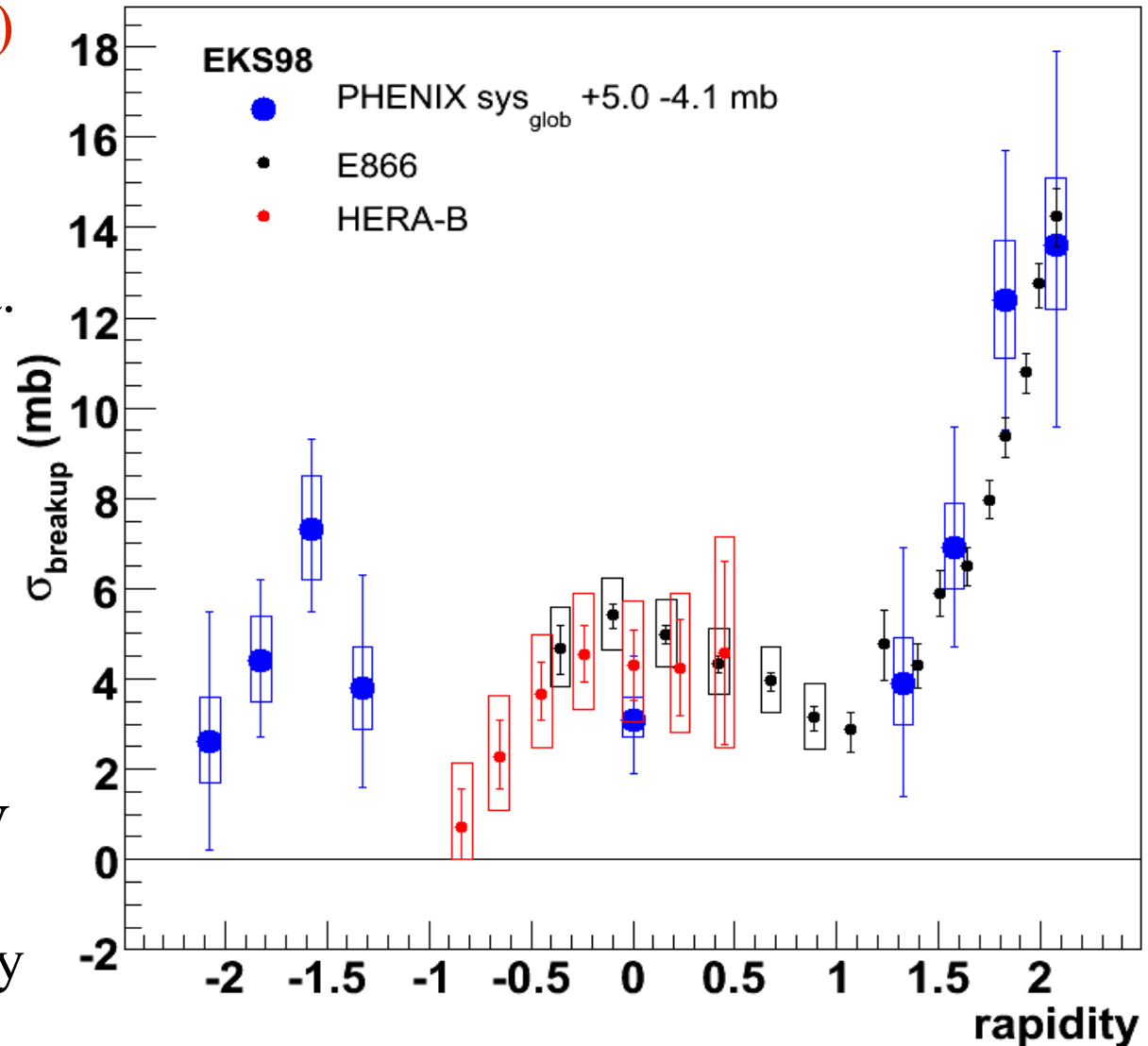


Comparison with lower energy data – EKS98 fits

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.

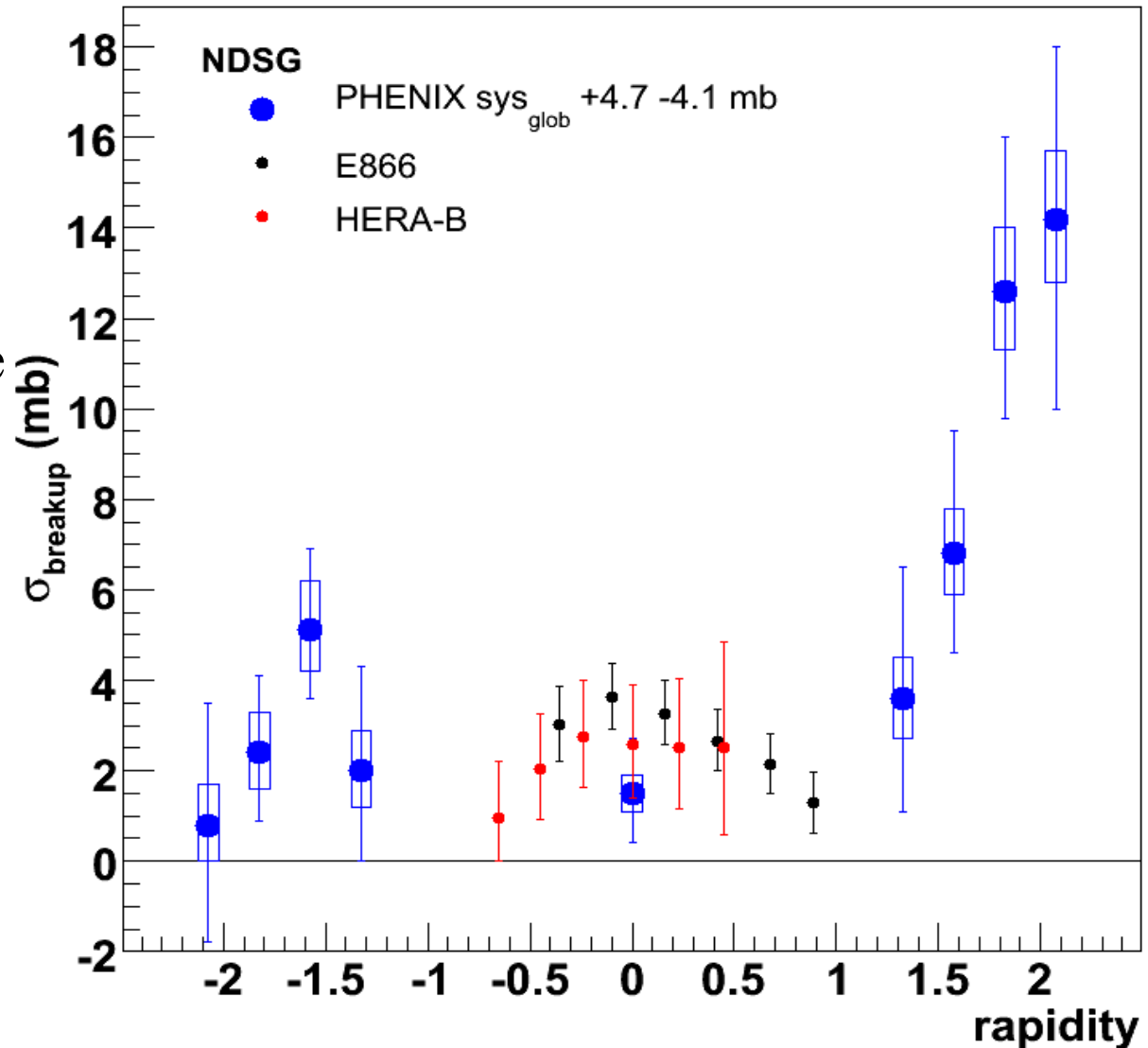
For $y > 1.2$ the 200 GeV data follow the trend observed at lower energy remarkably closely!



Comparison with lower energy data – nDSG fits

Note that the effective breakup cross section is significantly lower for $y < 1.2$.

But for $y > 1.2$ there is little difference from the EKS case.

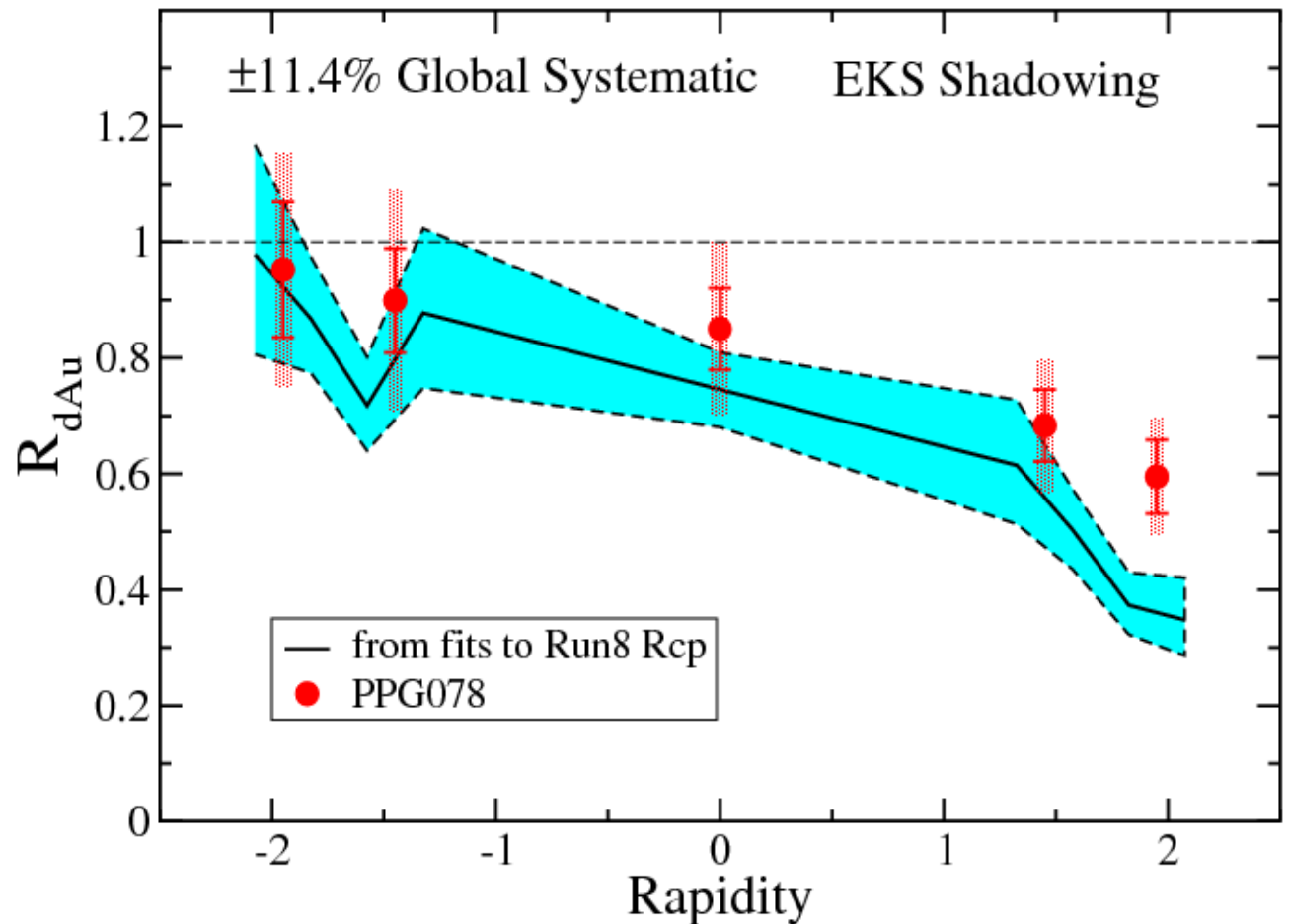


Sanity check! Comparison of new effective breakup cross section fits from R_{CP} to published 2003 d+Au R_{dAu} results

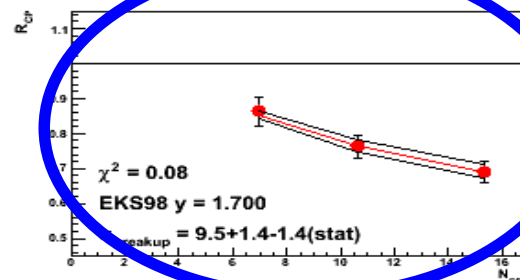
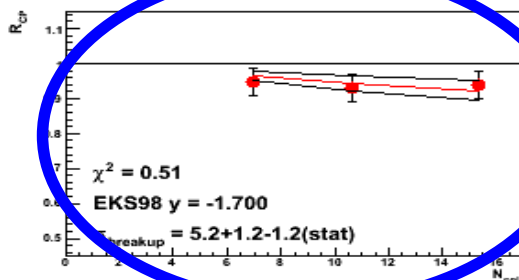
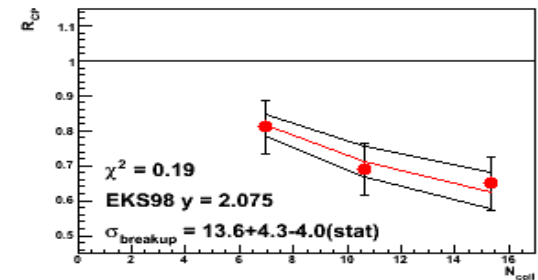
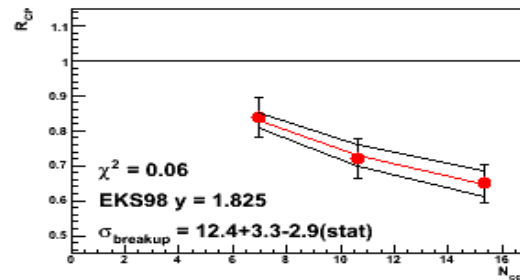
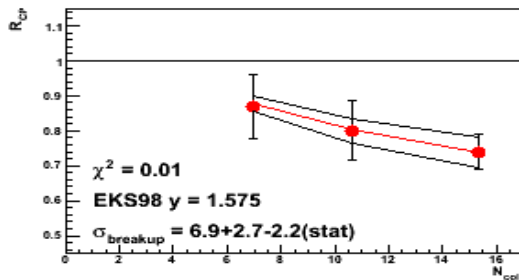
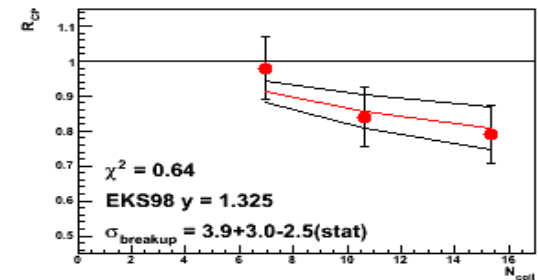
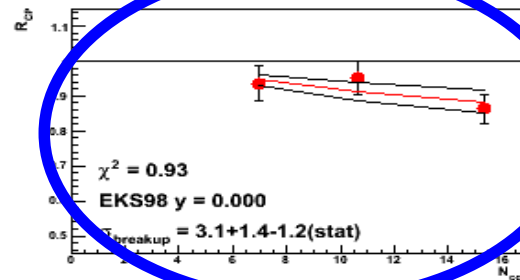
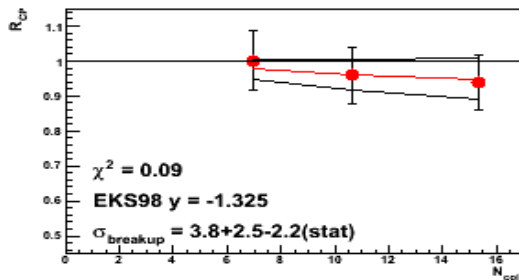
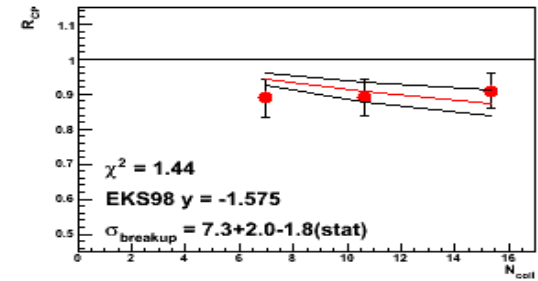
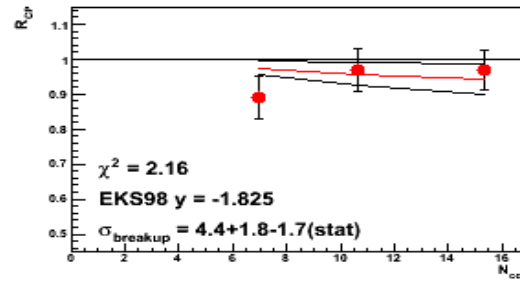
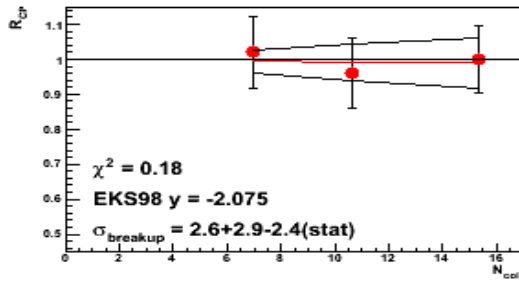
From the talk by Mike Leitch.

Fairly consistent with centrality integrated RdAu from old 2003 data

- *PRC* 77,024912(2008)

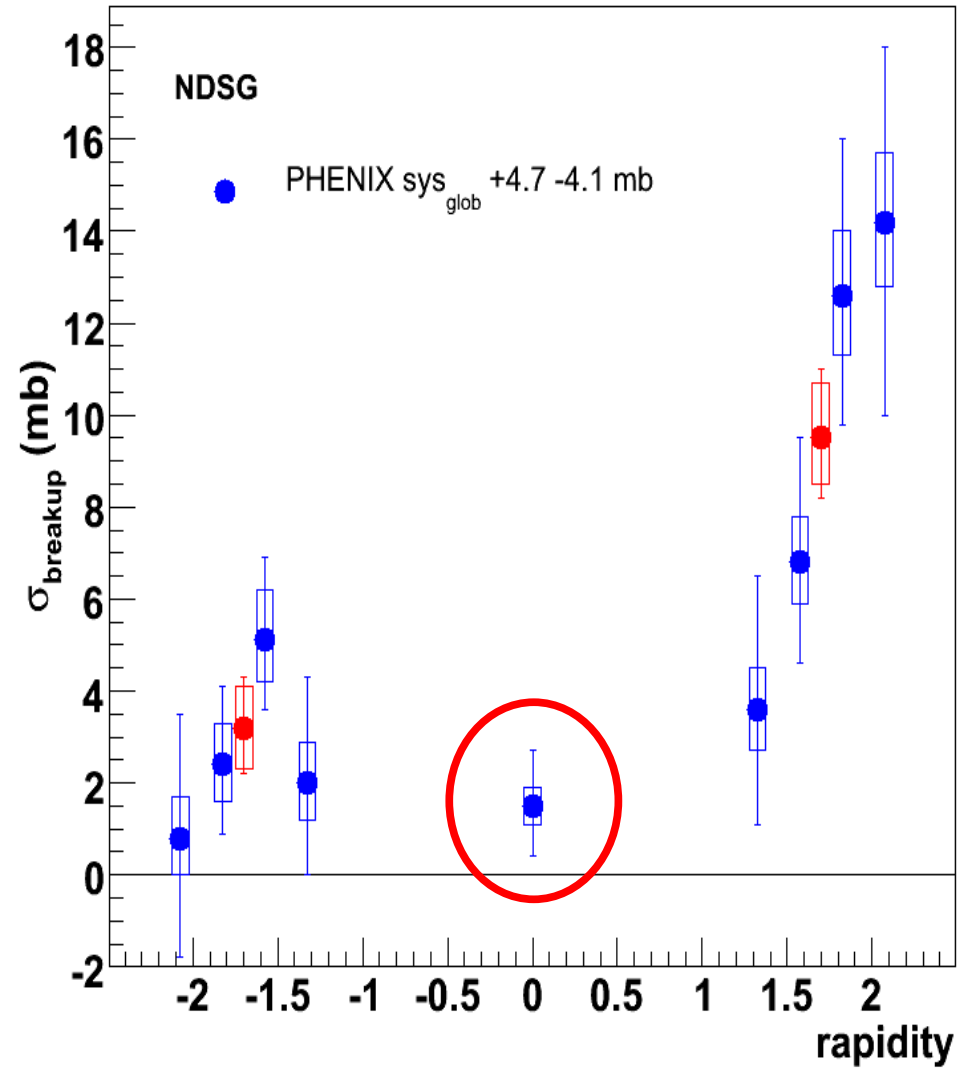
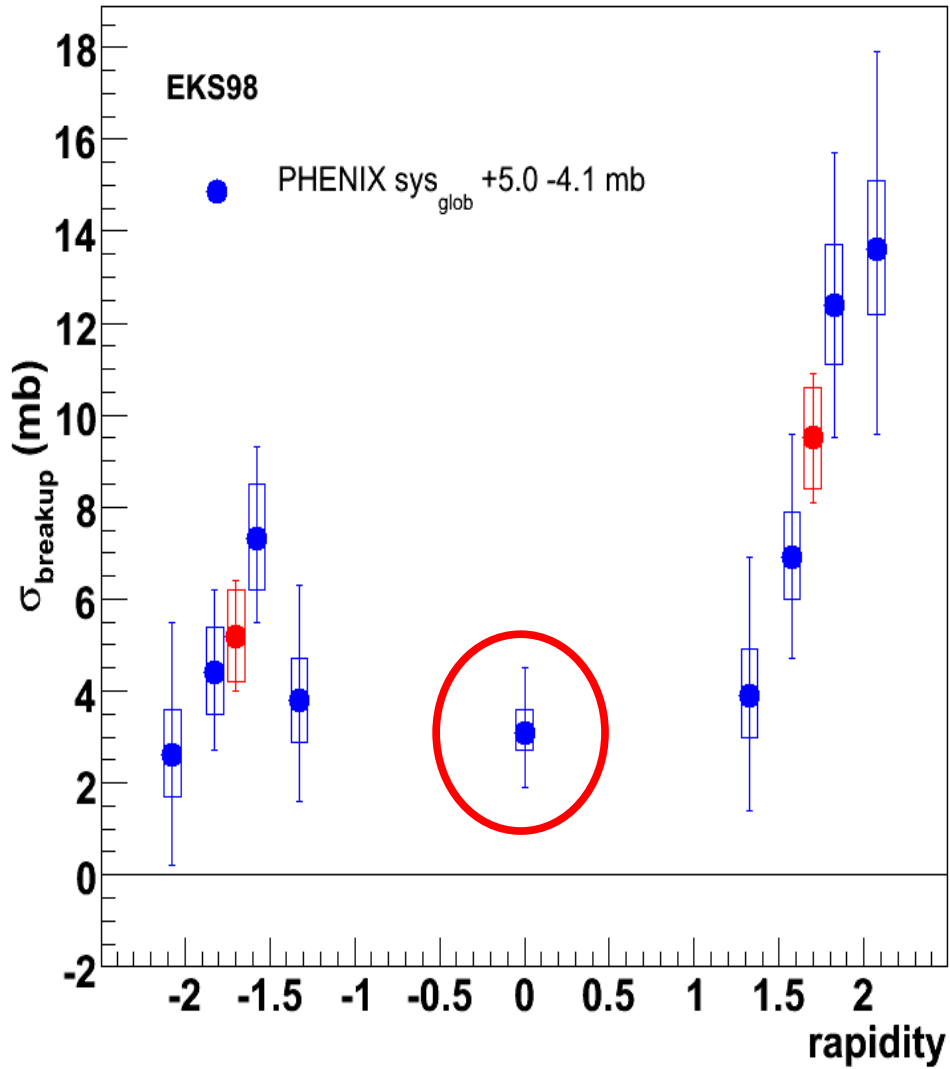


Parameterize d+Au R_{CP} at $|y|=0, 1.7$ – EKS98



Integrated for each muon arm

Effective σ_{breakup} used in Glauber calculations $|y| = 0, 1.7$



Cold Nuclear Matter R_{AA} for heavy ions

Having “calibrated” the Vogt calculations at each rapidity, we estimate the CNM R_{AA} using the results from the dAu R_{CP} fits.

To do this, we use a Glauber calculation for Au+Au that reproduces well the **average** N_{part} and N_{coll} values for the centrality bins used by PHENIX.

In the Glauber calculation:

Each nuclear collision is placed in a centrality bin according to N_{part} .

For each nucleon-nucleon collision:

Determine impact parameter b_1 of nucleon 1 in its target nucleus.

Determine impact parameter b_2 of nucleon 2 in its target nucleus.

Add to the accumulated RAA: $R_{dAu}(b_1, y=0) * R_{dAu}(b_2, y=0)$

Add to the accumulated RAA: $R_{dAu}(b_1, y=-1.75) * R_{dAu}(b_2, y=1.75)$

After processing all events, print out **at $y=0$ and $y=1.7$** for **centrality bin j** :

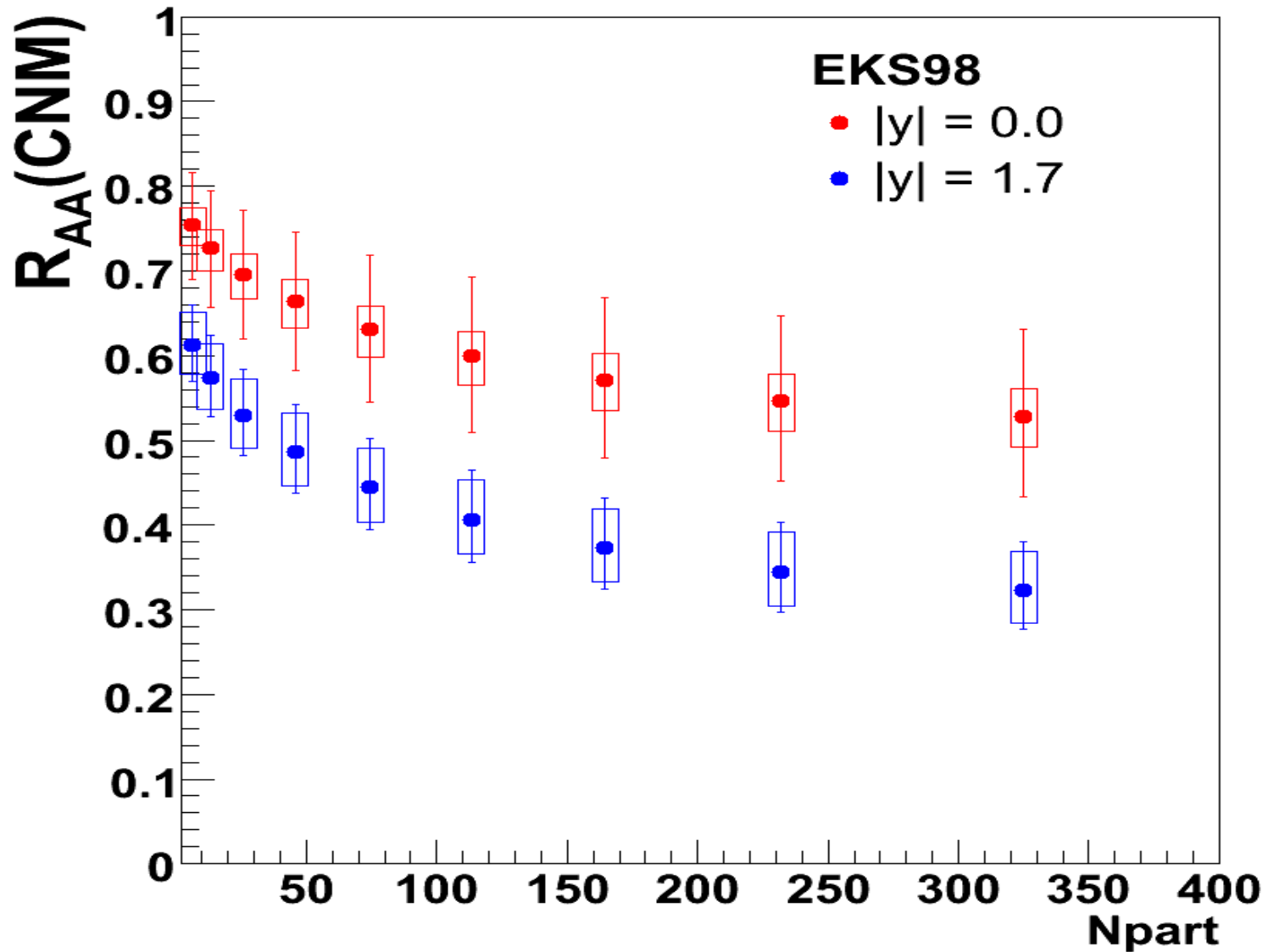
$N_{evts}[j]$, $\Sigma(RAA[j])/N_{evts}[j]$, $\Sigma(N_{coll}[j])/N_{evts}[j]$, $\Sigma(N_{part}[j])/N_{evts}[j]$

Estimation of uncertainties

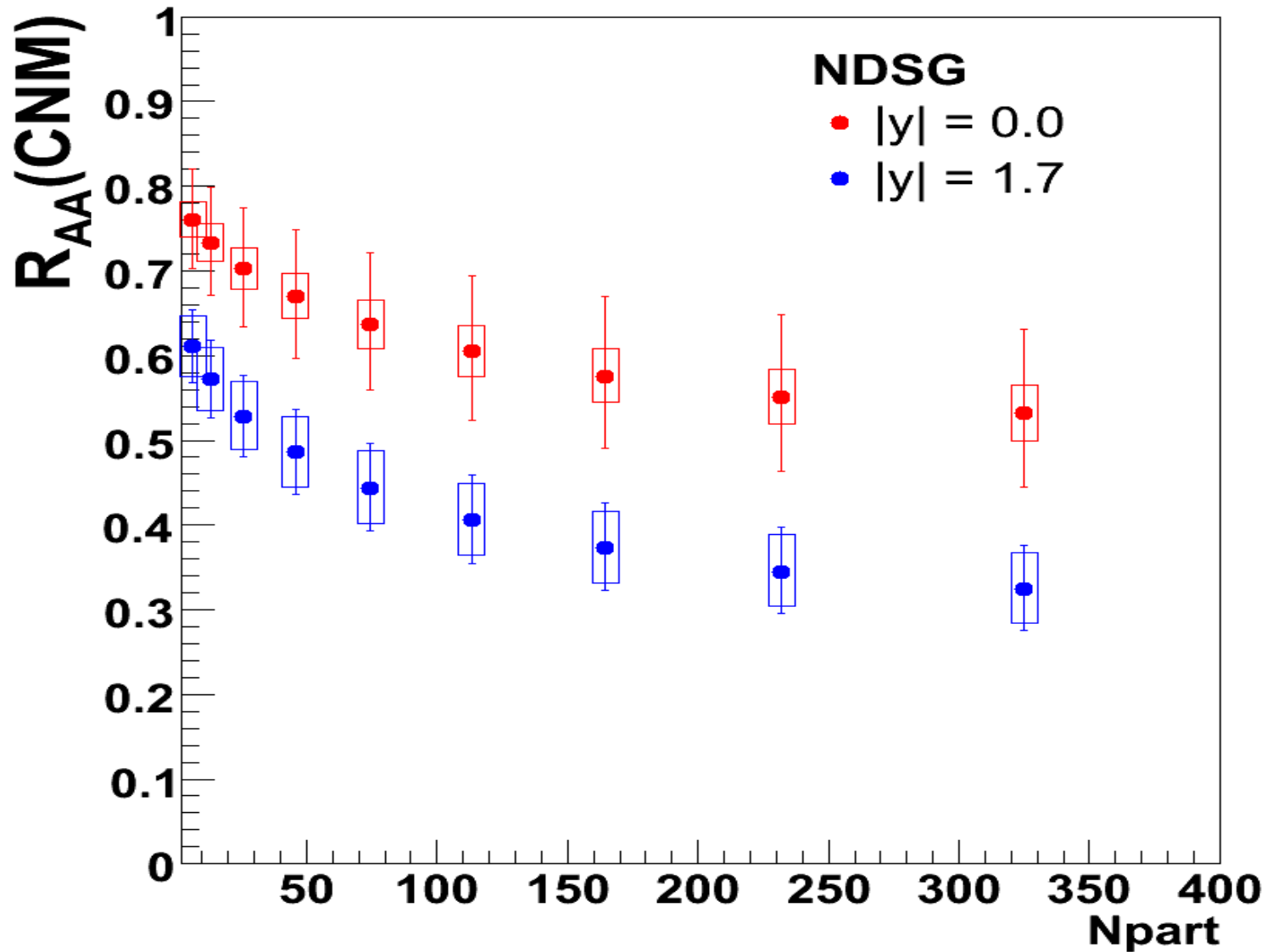
The CNM R_{AA} is calculated for the central fitted σ_{breakup} and for +/- 1σ in the type A (**uncorrelated in rapidity**) uncertainty and for +/- 1σ in the type B (correlated in rapidity) uncertainty.

The type A uncertainty is shown as a **vertical bar**, and the type B as a **box**.

Heavy ion CNM baseline R_{AA} – EKS98 parameterization



Heavy ion CNM baseline R_{AA} – nDSg parameterization

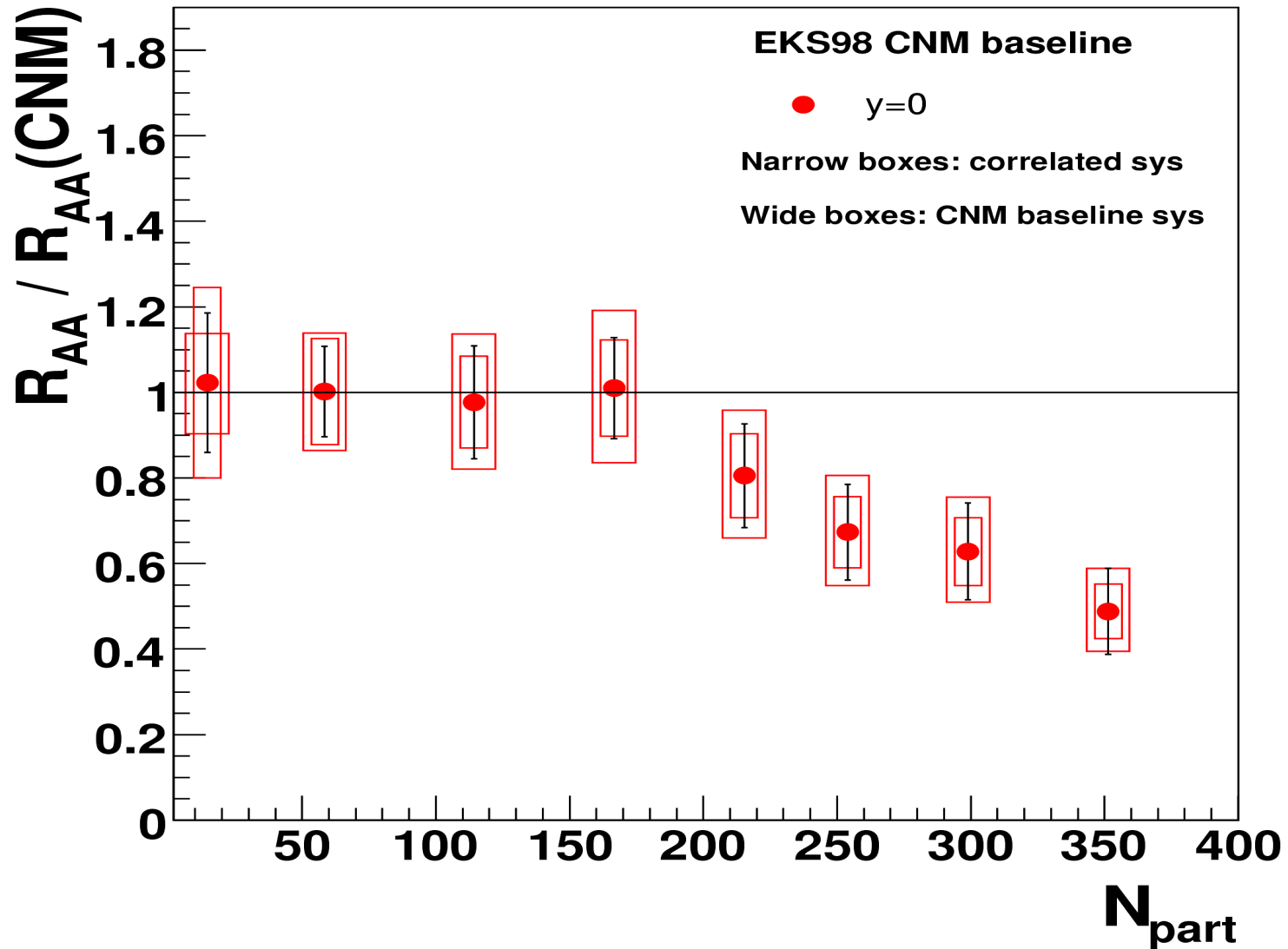


Calculating the heavy ion R_{AA} “survival probability”

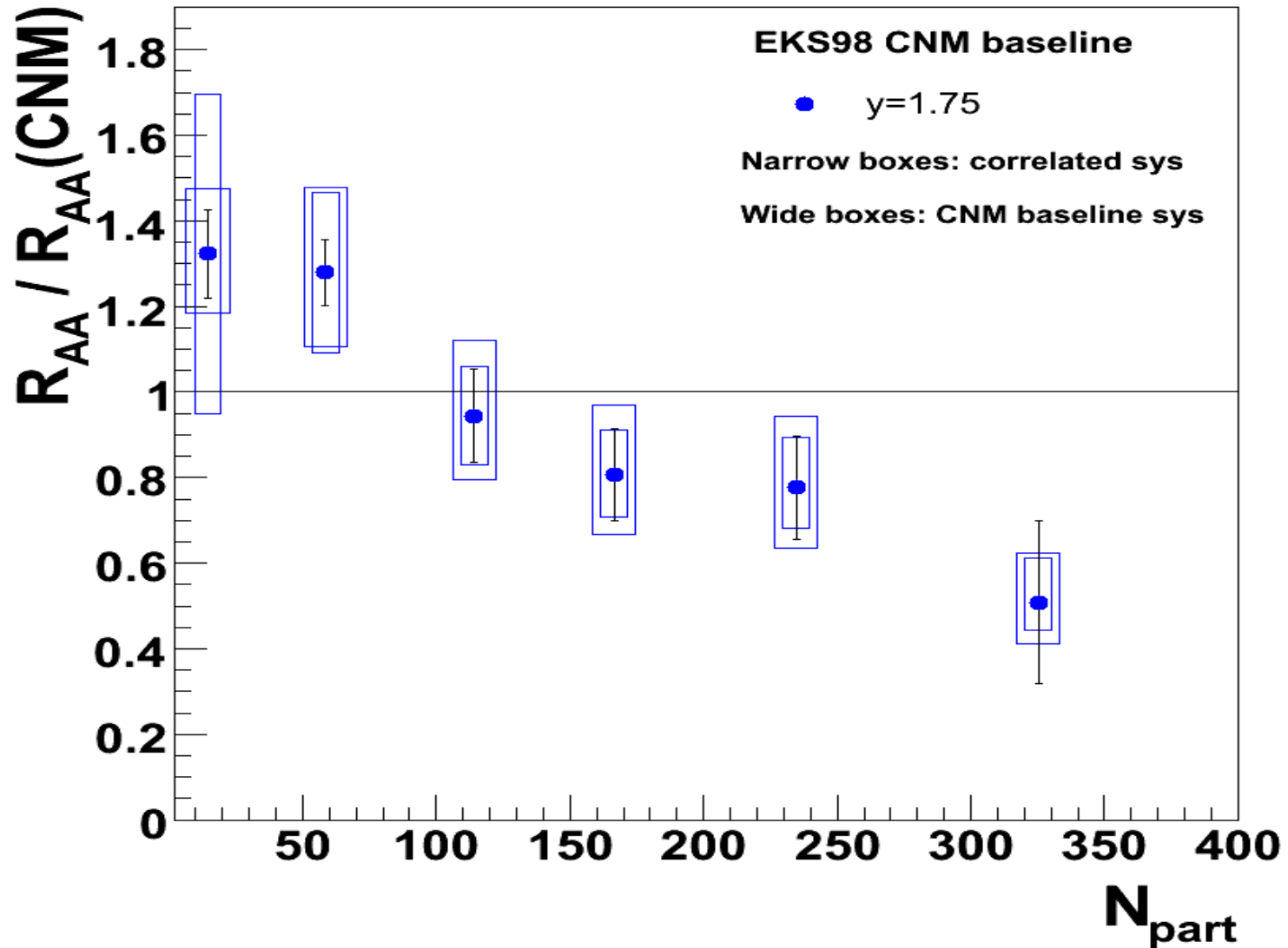
Now we can calculate the ratio $R_{AA}/R_{AA}(\text{CNM})$ from the measured R_{AA} and the estimated $R_{AA}(\text{CNM})$ shown on the previous slides.

In the following plots the uncertainty in $R_{AA}/R_{AA}(\text{CNM})$ due to the **uncorrelated** (mostly statistical) uncertainty in the measured R_{AA} is shown as a **bar**, the **correlated** uncertainty in the measured R_{AA} is shown as a **narrow box**, and the uncertainty due to the **estimated CNM R_{AA}** is shown as a **wider box**.

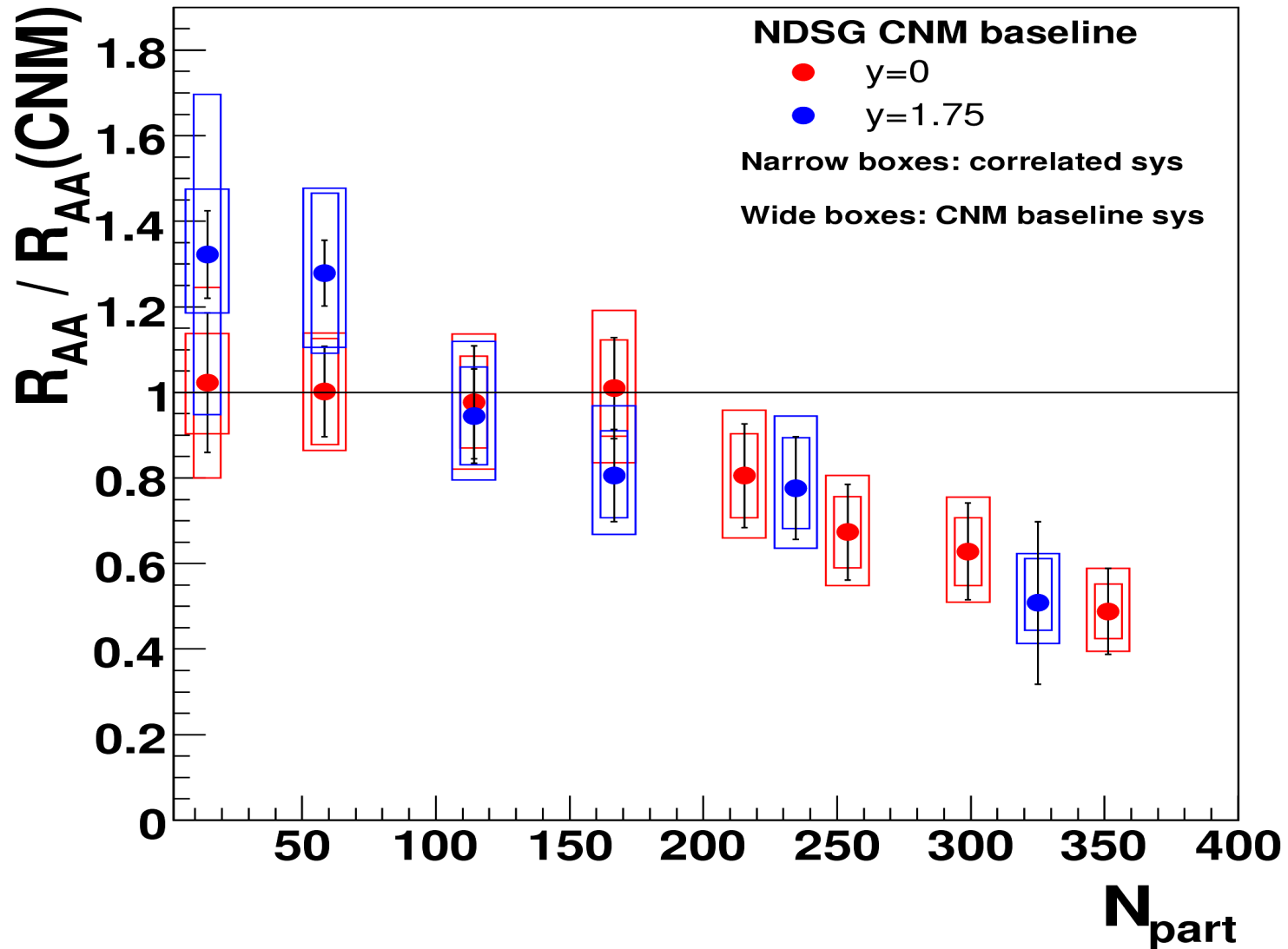
Heavy ion “survival probability” at $y=0$ (EKS example)



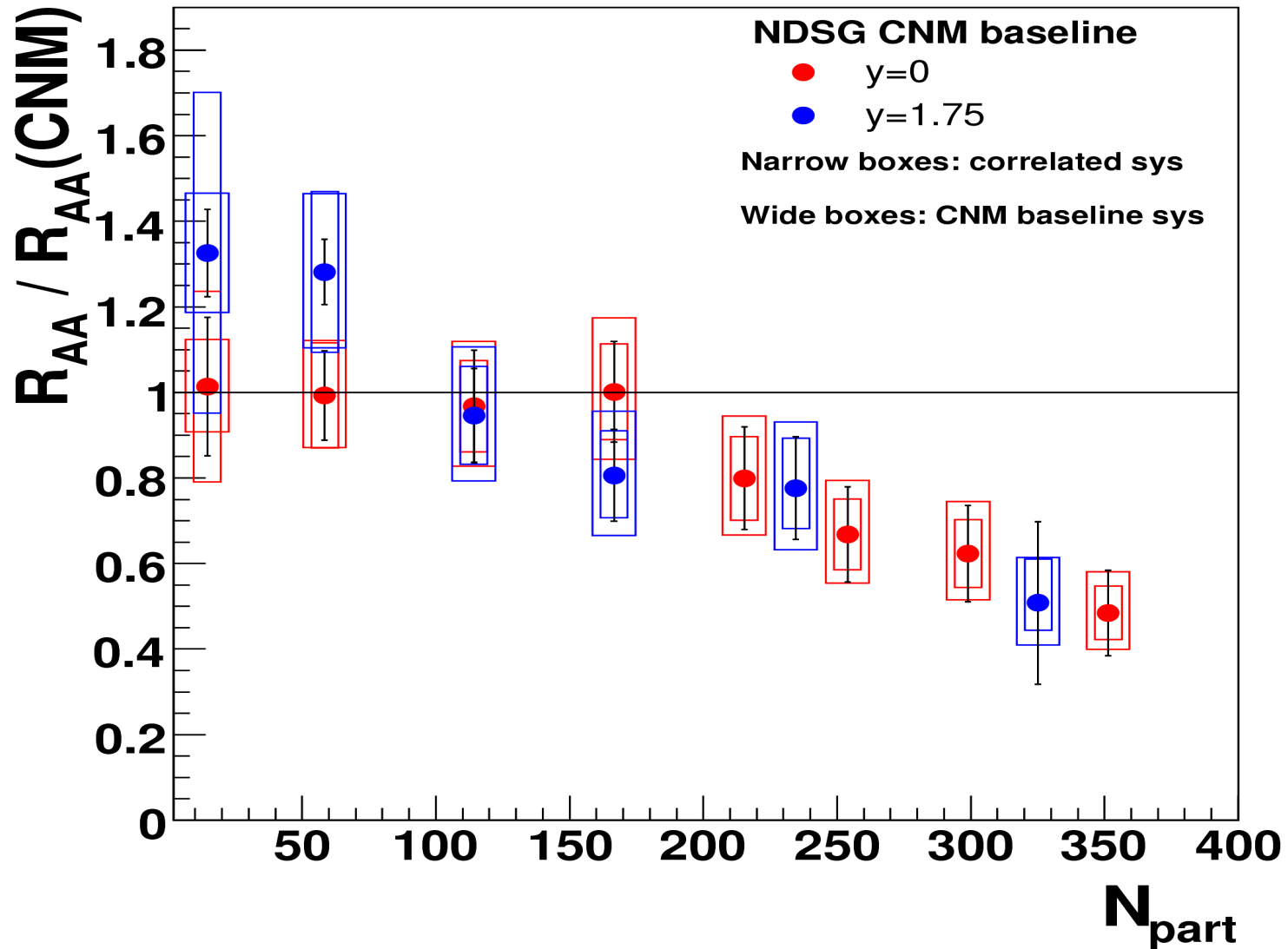
Heavy ion “survival probability” at $|y| = 1.7$ (EKS example)



Heavy ion “survival probability” - EKS98 parameterization



Heavy ion “survival probability” - nDSg parameterization



Comments

We are **just starting** to try to understand the d+Au data and their implications for heavy ions. Keep several things in mind about what was done here:

We assume that we can isolate hot nuclear matter effects by calculating R_{AA} due to a (Glauber guided) **superposition of d+Au collisions**. Perhaps not!

The role of Glauber uncertainties (mostly N_{coll}) needs to be understood in detail. The systematic uncertainties should be considered tentative until then.

We believe that fitting the R_{dAu} data, rather than R_{CP} , will provide greater precision when estimating the CNM baseline R_{AA} for Au+Au and Cu+Cu.

Although the parameterization at each rapidity is precise, it would be more satisfying if the model worked well over the full d+Au rapidity range!

We need to repeat this exercise for the **Cu+Cu data** (easy enough to do, did not have time yet).

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 σ_{breakup}** at forward rapidity.

The effective σ_{breakup} appears to be **roughly** constant below $y \sim 1.25$ 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%.

What next

Calculate $R_{AA}(\text{CNM})$ for **Cu+Cu**.

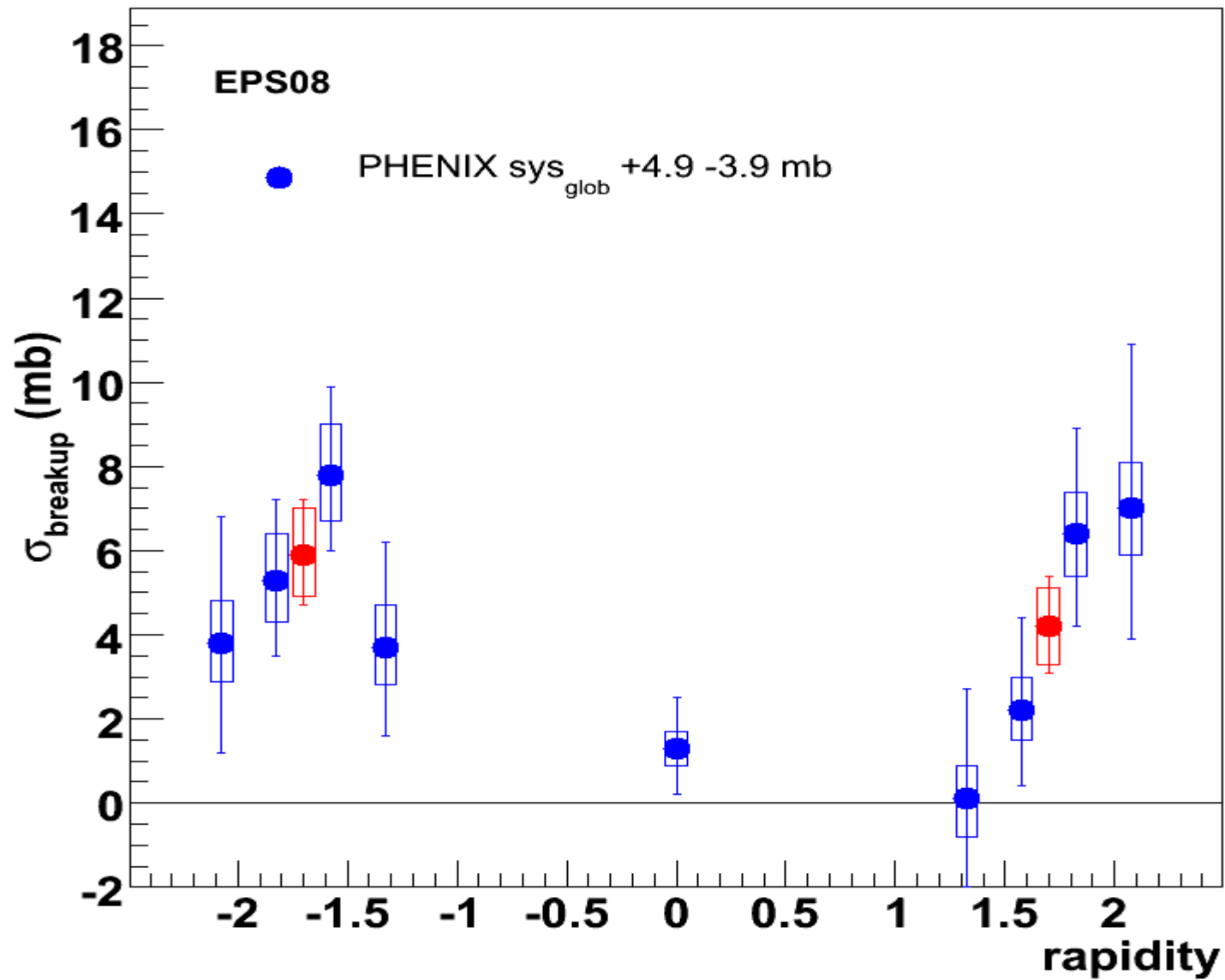
Investigate the **transverse momentum** dependence.

Understand the role of N_{coll} uncertainties better.

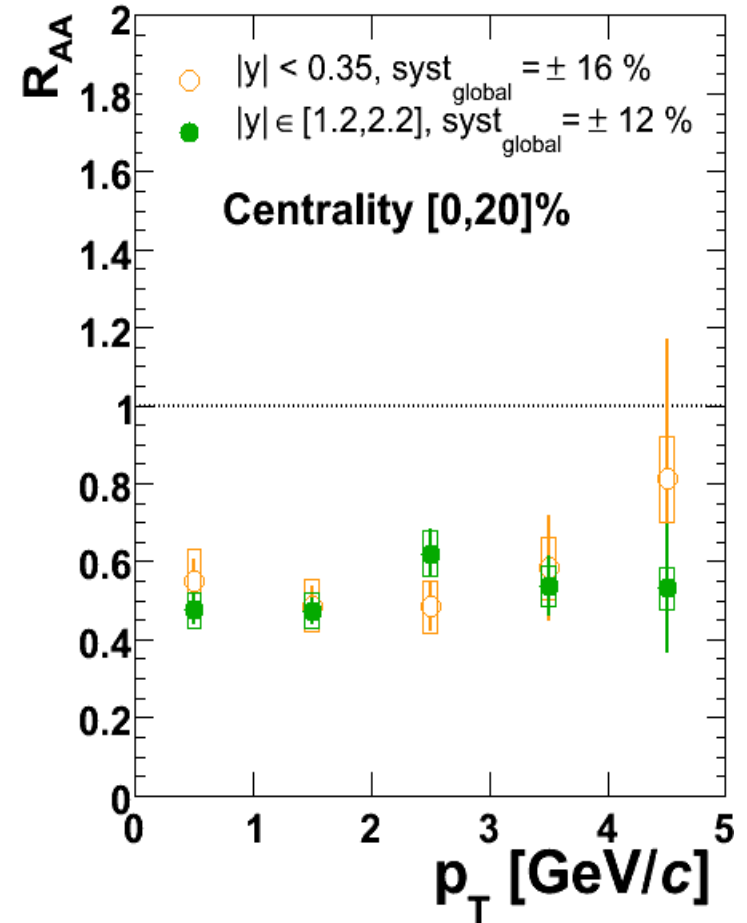
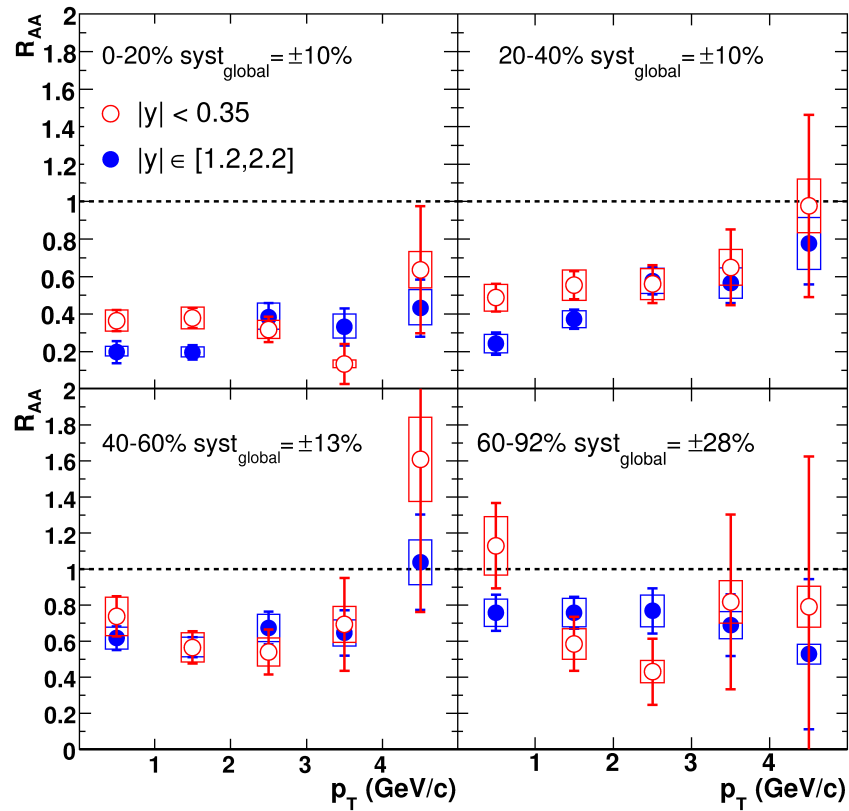
Do it all again with **R_{dAu}** instead of R_{CP} .

Backup

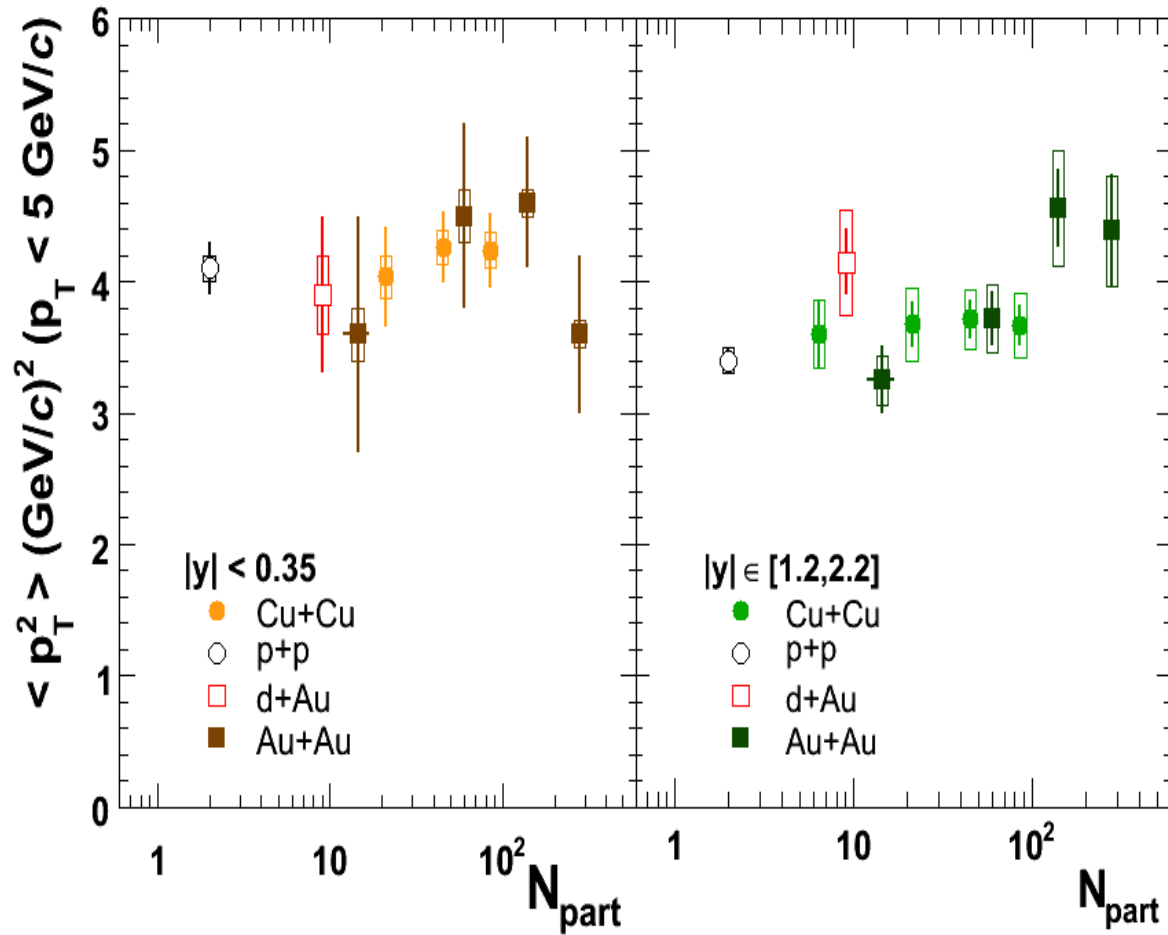
EPS08 parameterization



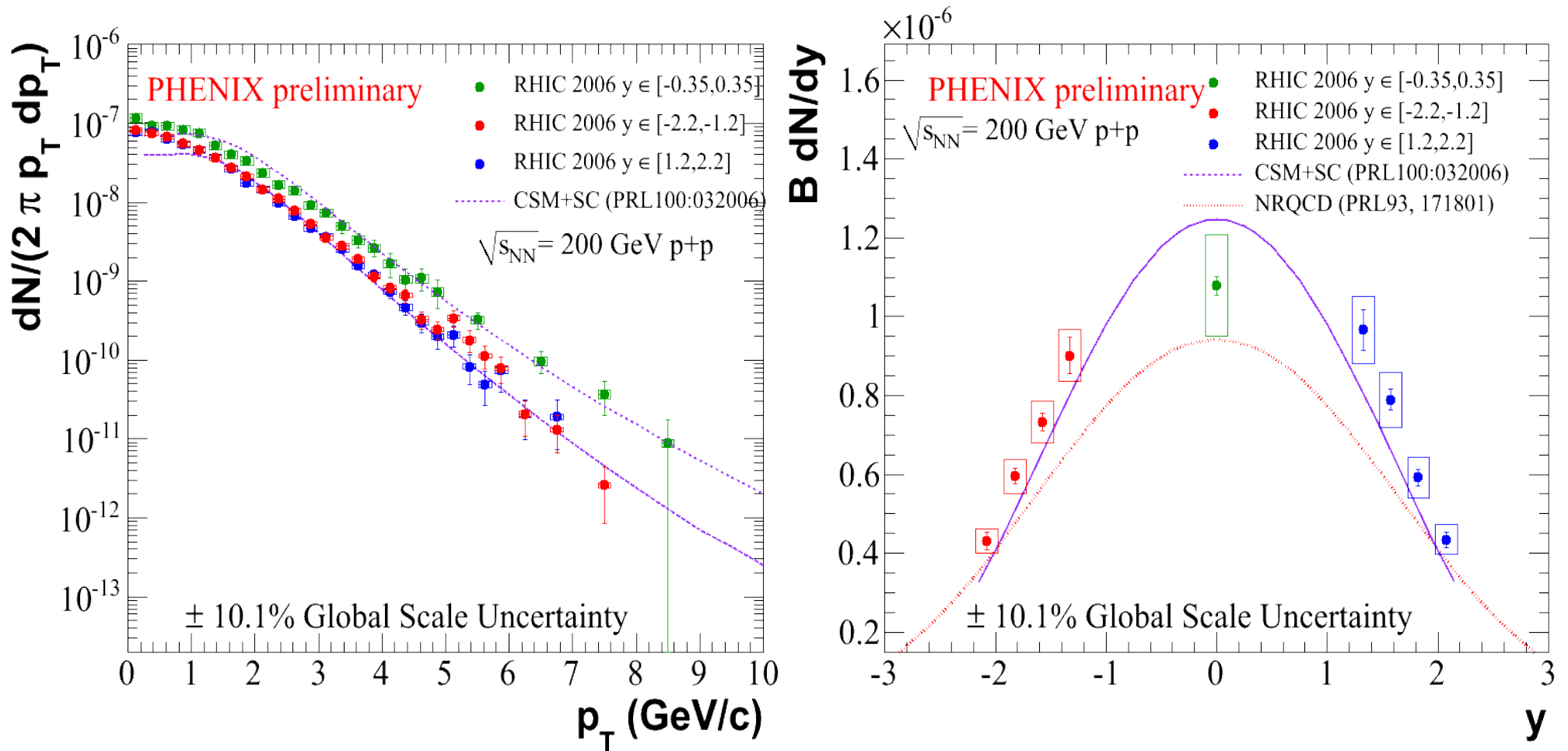
Existing RHIC Data - Au+Au



Existing RHIC Data - Cu+Cu



Reference data: Run 6 p+p will be used for R_{dAu}



The best p+p data set that has been analyzed so far is from Run 6.