Cold nuclear matter effects on J/ψ production

Tony Frawley
Florida State University

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Session on heavy quarkonia

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The quarkonium plan

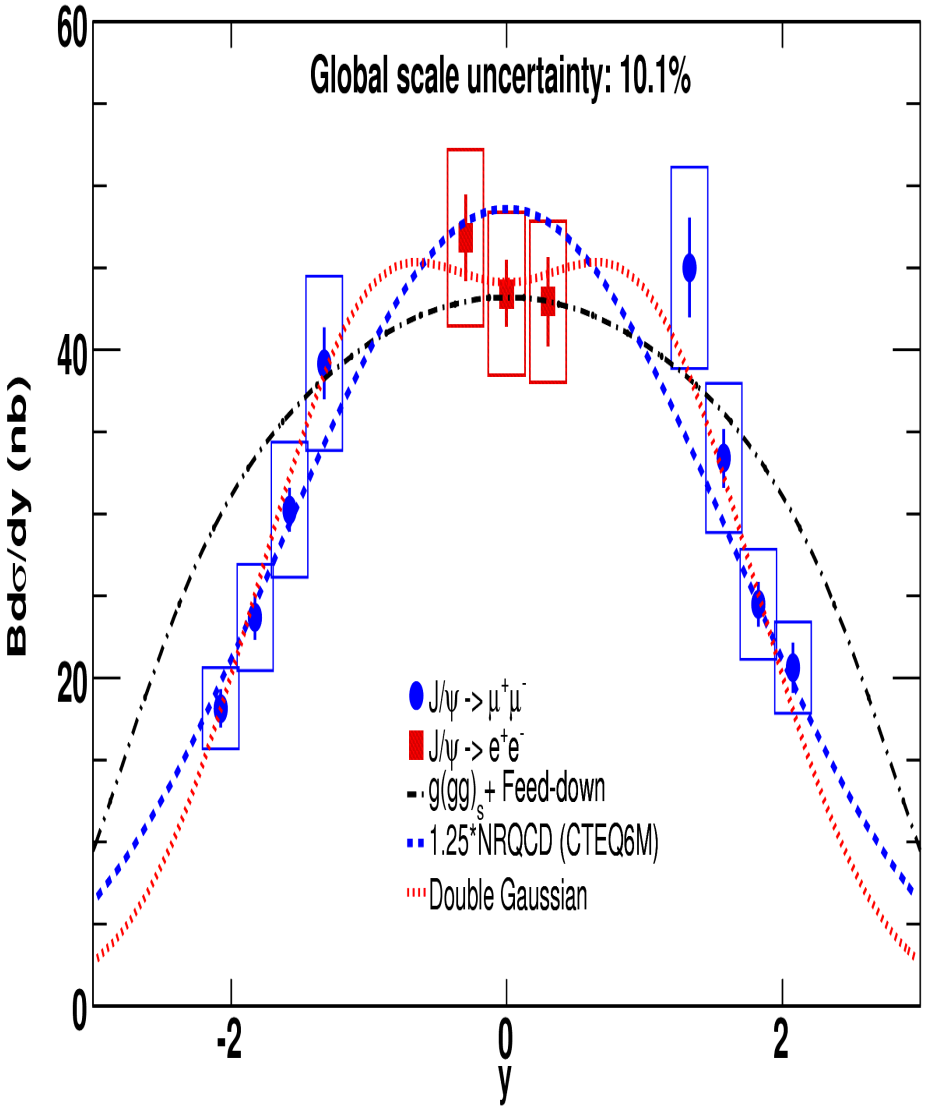
Species	Purpose
p+p	Quarkonium production mechanisms Baseline cross sections for heavy ions
d+Au	Cold nuclear matter effects Baseline CNM R_{AA} for heavy ions
Cu+Cu	Hot nuclear matter effects near T_C
Au+Au	Hot nuclear matter effects well above T_C

All measured with the same collision energy and kinematics.

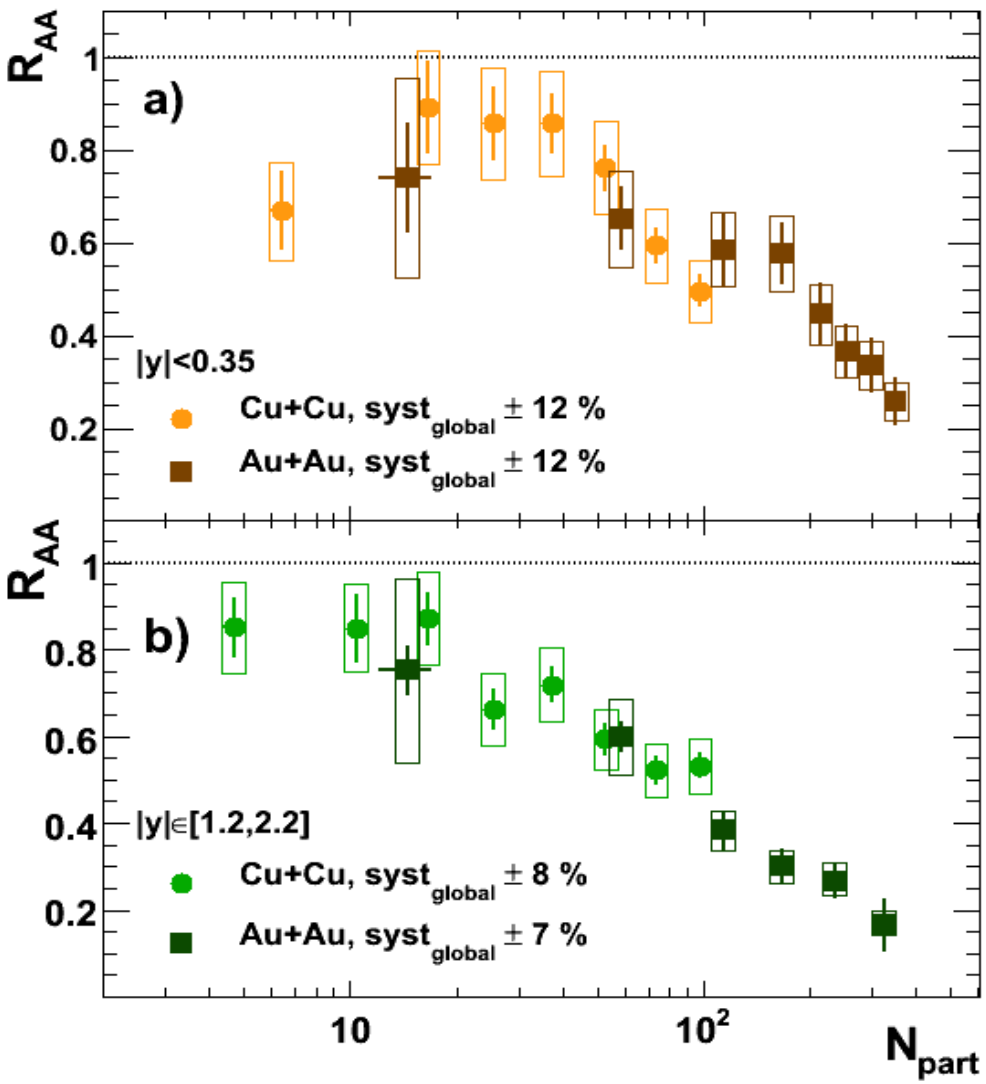
The data

p+p, Cu+Cu and Au+Au J/ψ data

Phys. Rev. Lett. 98, 232002 (2007)



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

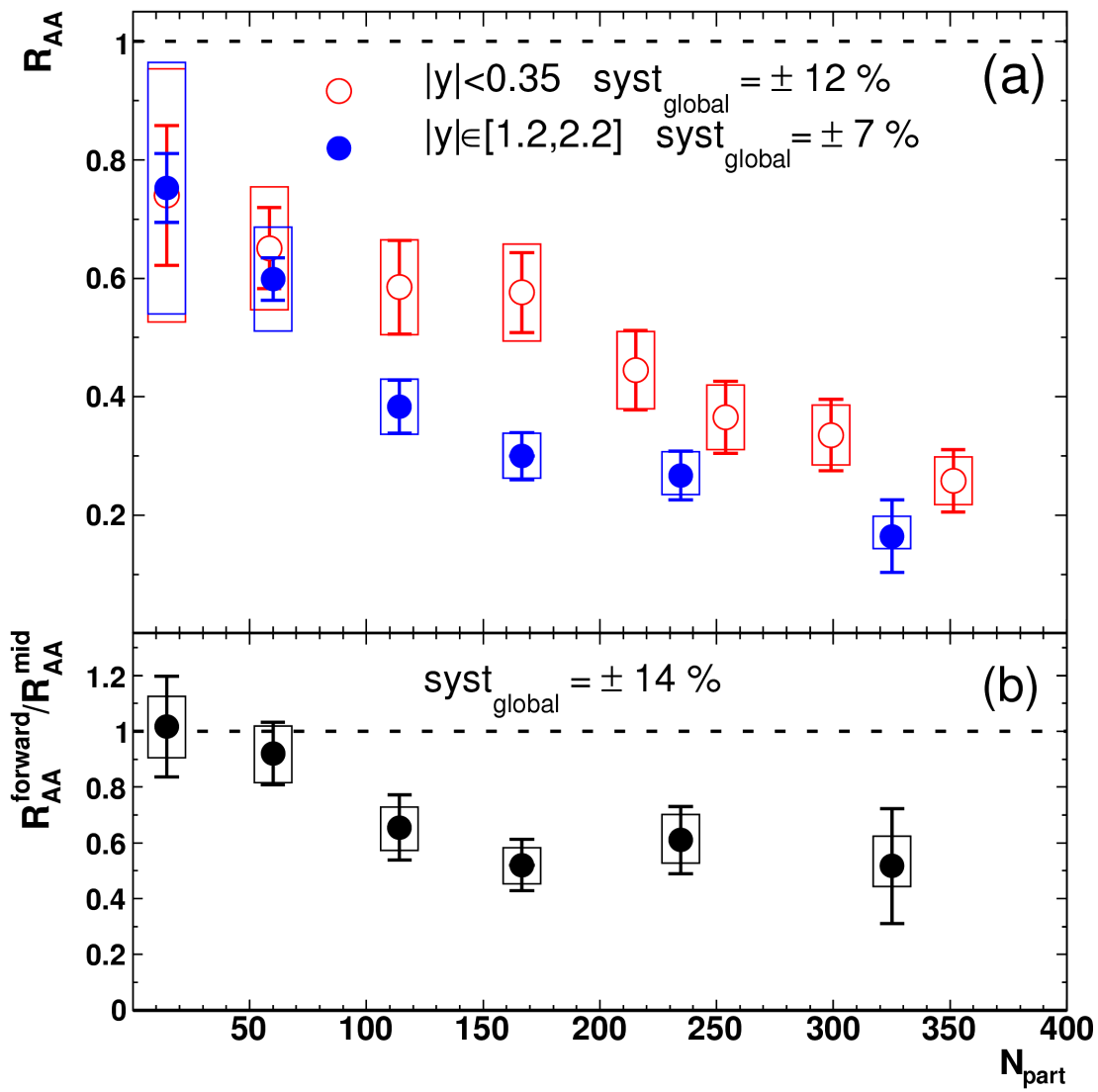


Au+Au R_{AA}

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

But what does it mean?

Phys. Rev. Lett 98, 232301 (2007)



The problem:

The heavy ion J/ψ 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**

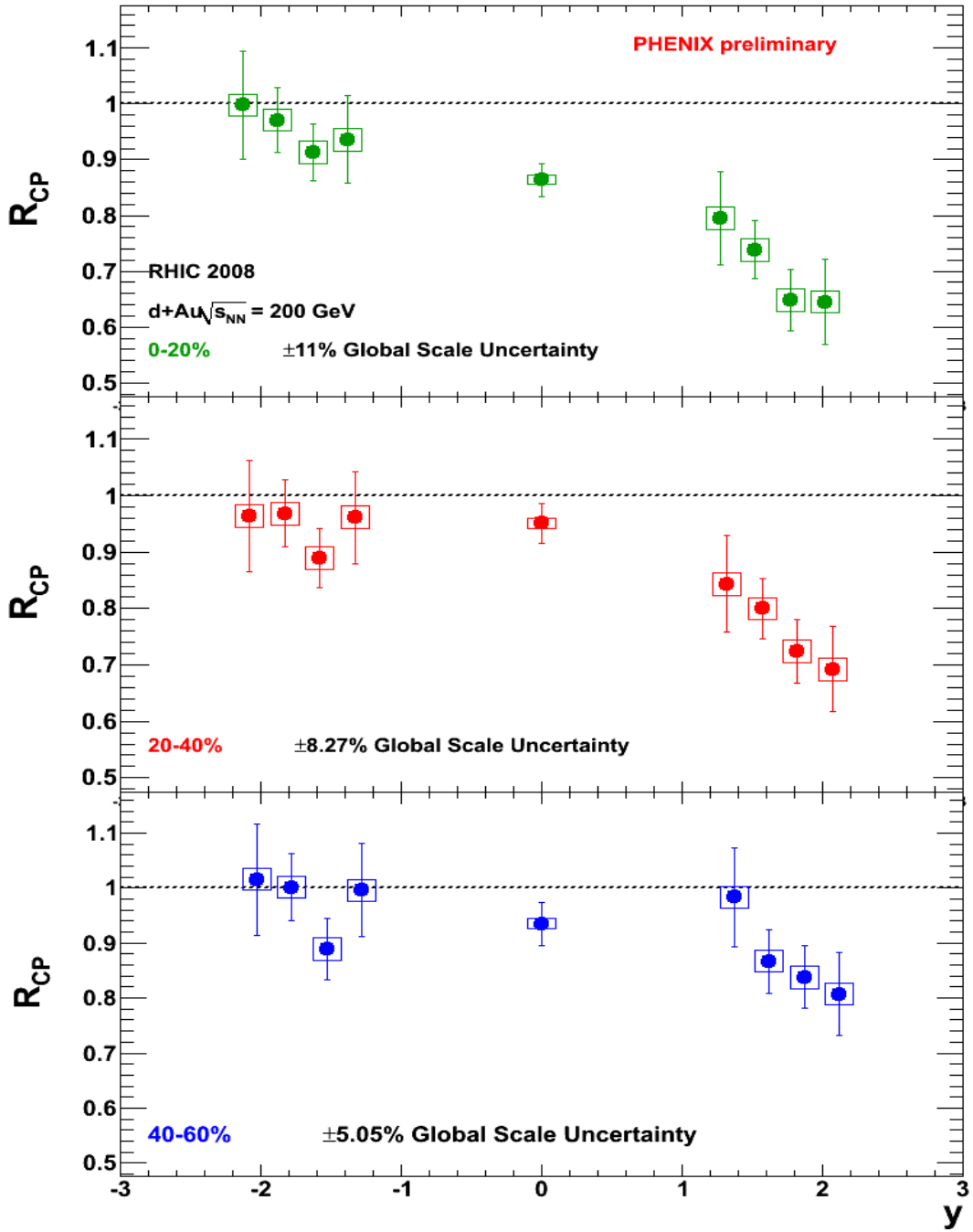
and try to understand what the Au+Au R_{AA} would look like without hot nuclear matter effects.

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}

We want to **parameterize** the d+Au R_{CP} data so that we can predict the heavy ion R_{AA} that would result from folded 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:

- $\sigma_{breakup}$ for collisions of (forming) J/ψ with nucleons (0-20 mb, 1 mb steps).
- A shadowing model – EKS98, EPS09 and nDSg are used here.

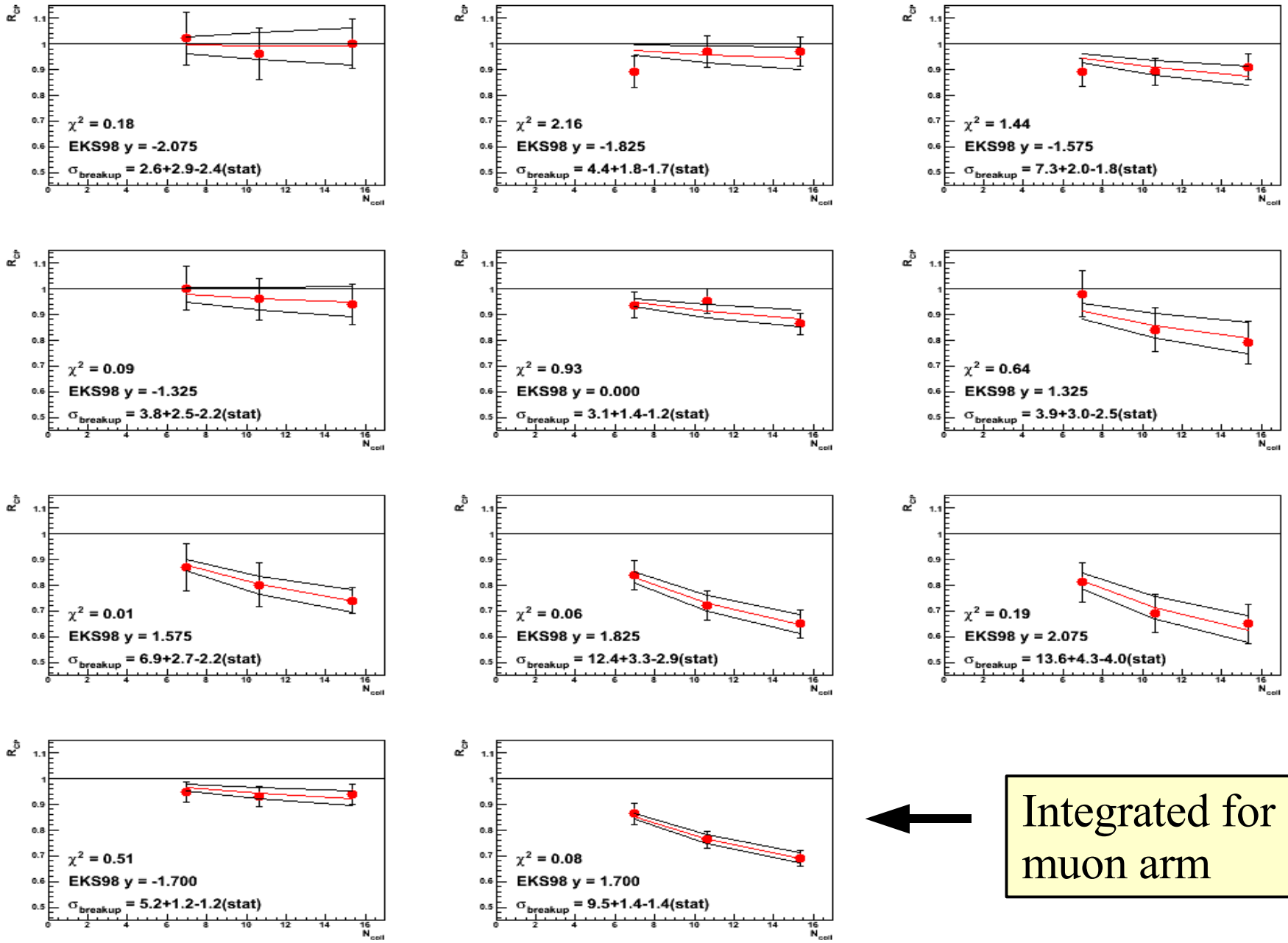
Convert R_{dAu} vs impact parameter to R_{dAu} vs centrality using the PHENIX Glauber impact parameter distribution for each **dAu centrality bin**.

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**.

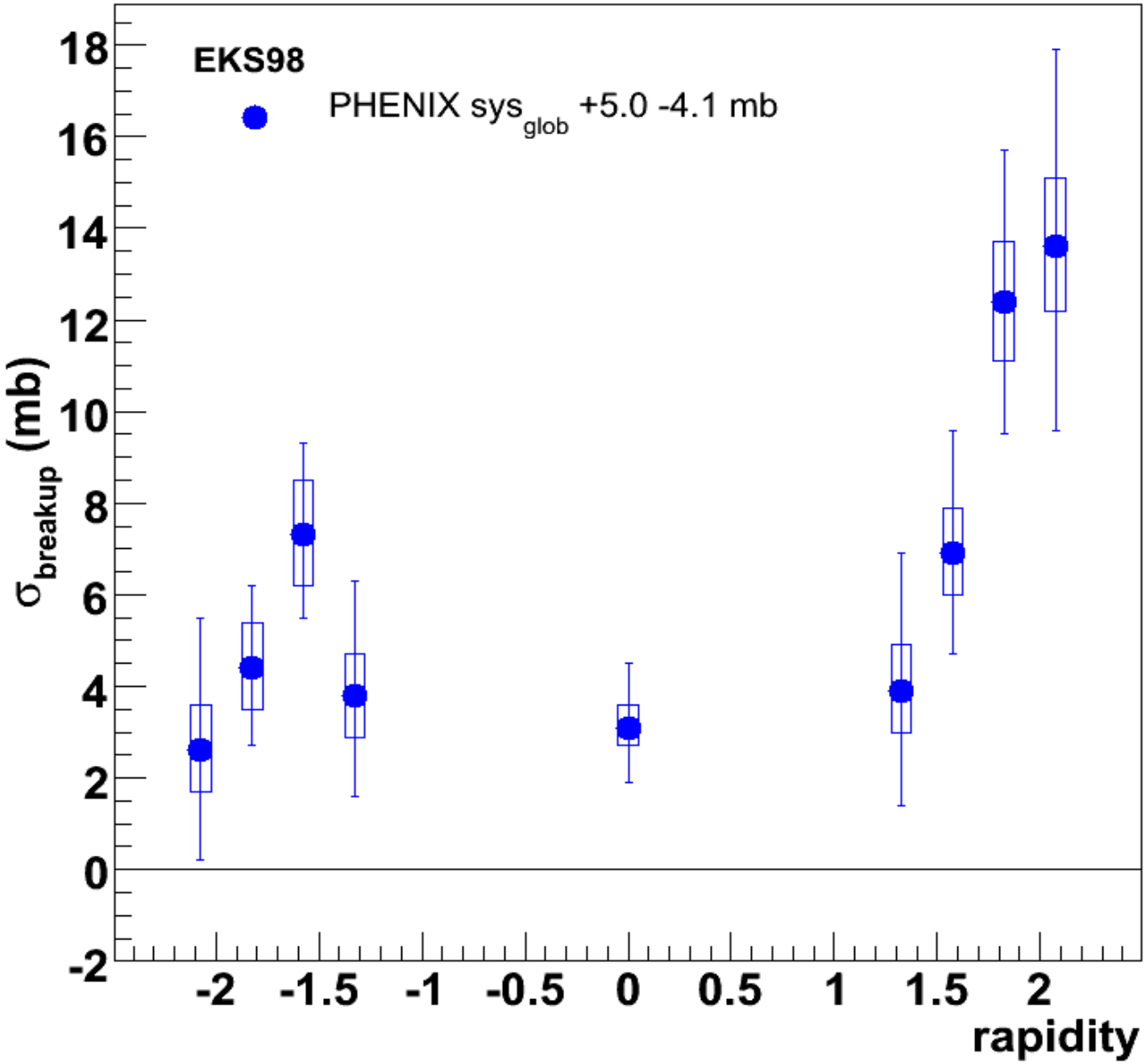
Fits to d+Au R_{CP} – example for EKS98



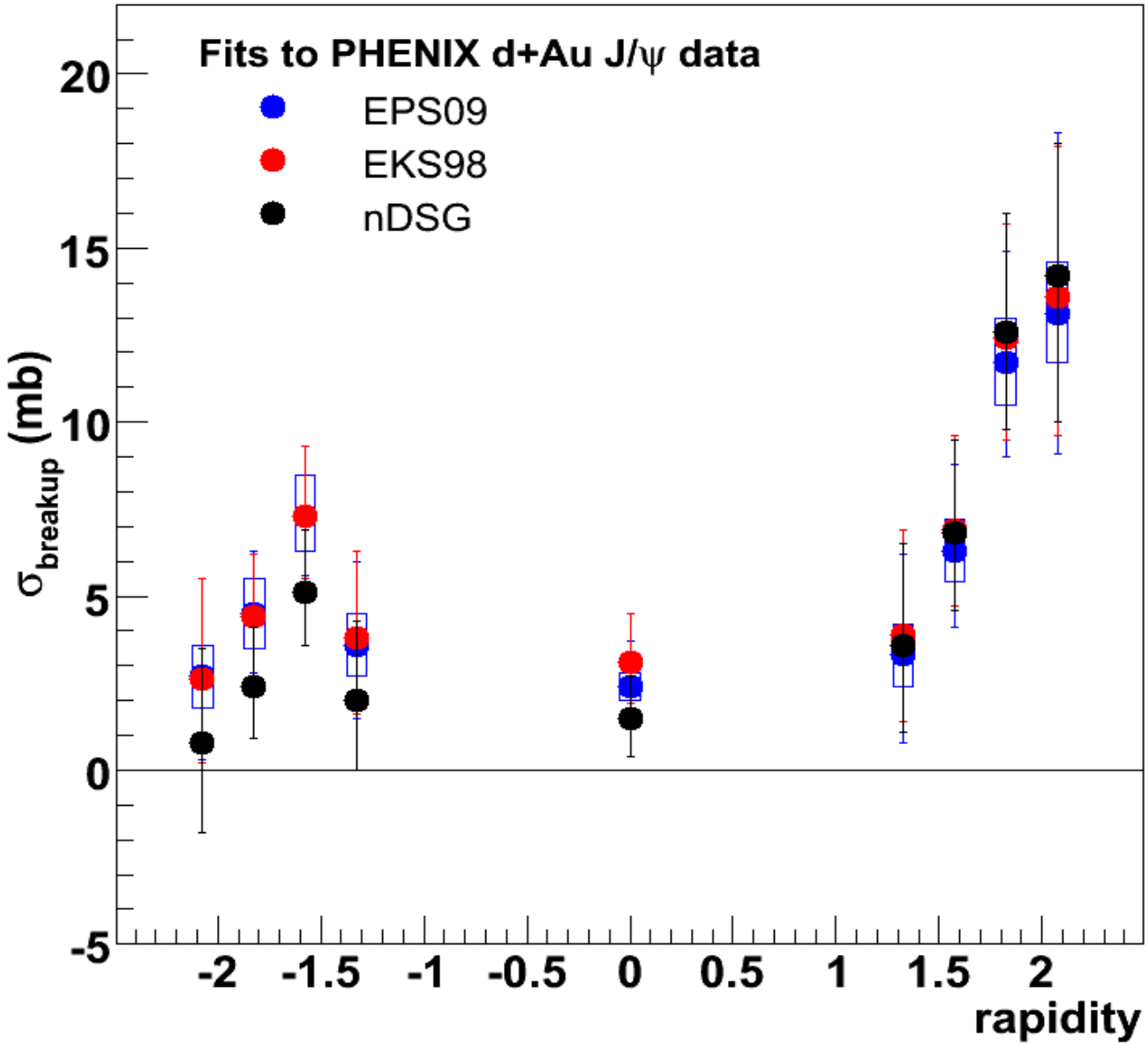
Integrated for each muon arm

$\sigma_{breakup}$ vs y from d+Au R_{CP} - example for EKS98

Uncertainties are uncorrelated (bars), correlated (boxes), and global (number).



Comparison of fits with EPS09, EKS98 and nDSg shadowing

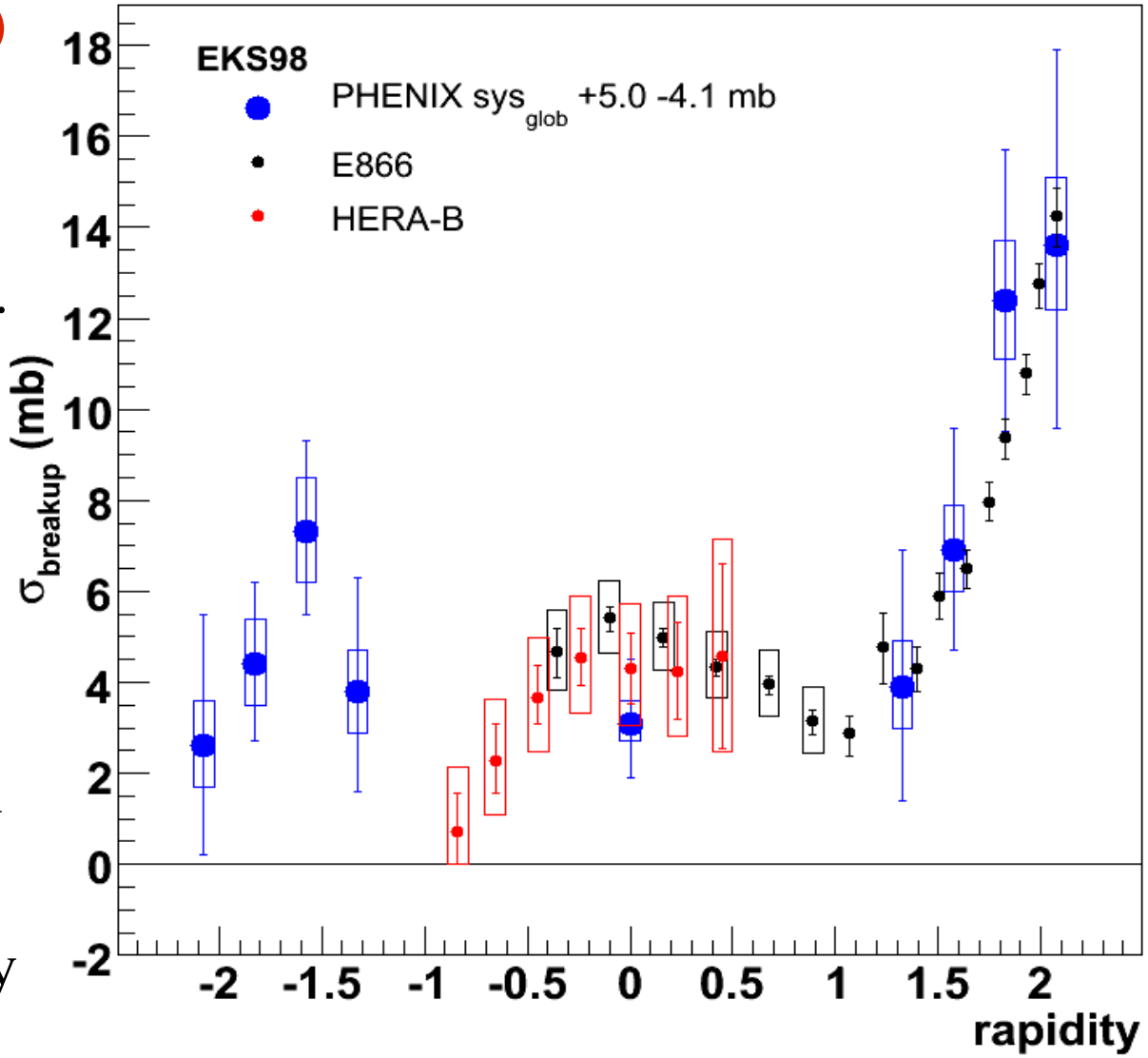


Comparison with lower energy data – EKS98 fits

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

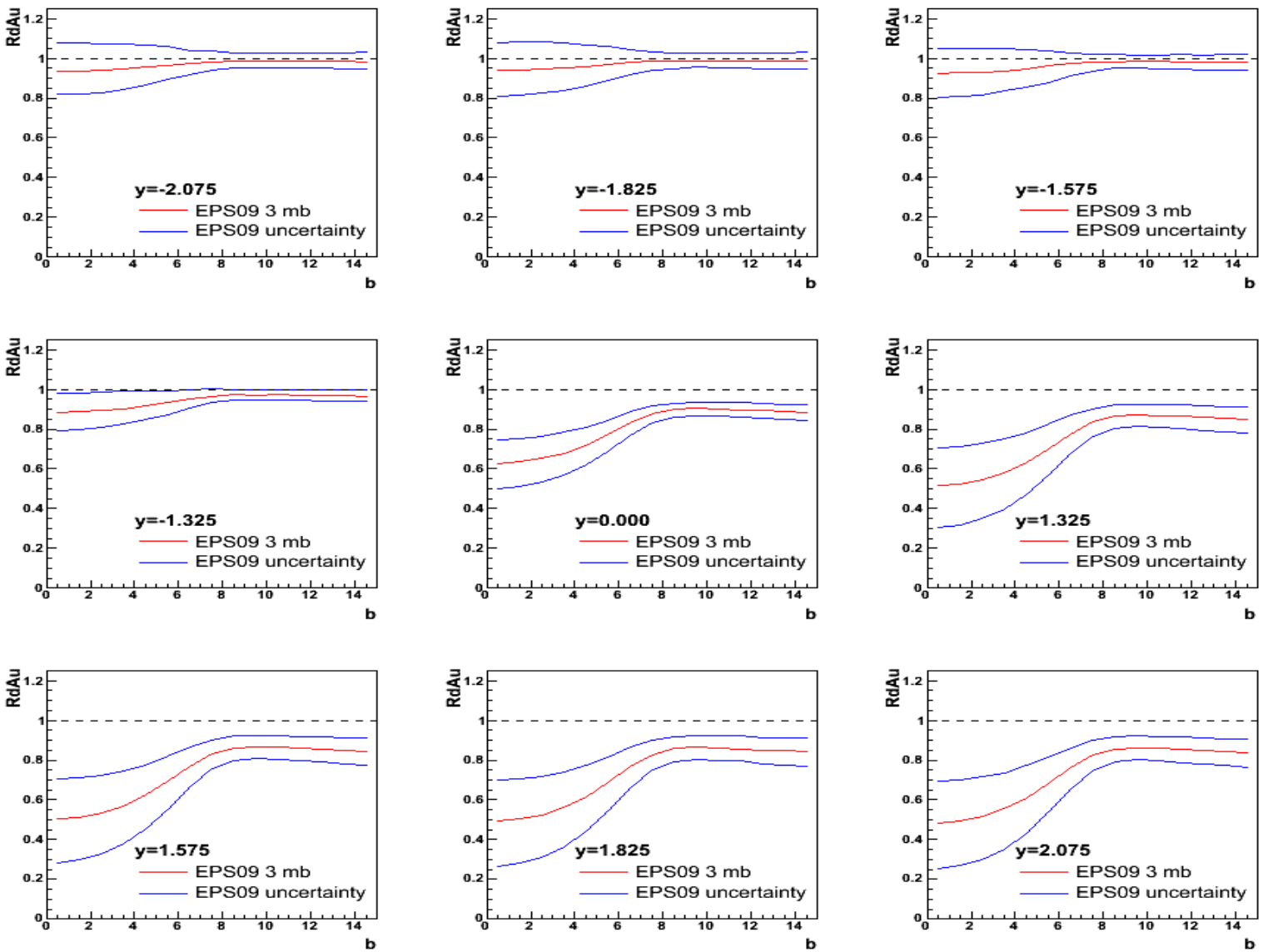
Our results from 200 GeV are shown here compared with their results, both for the EKS98 case.

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



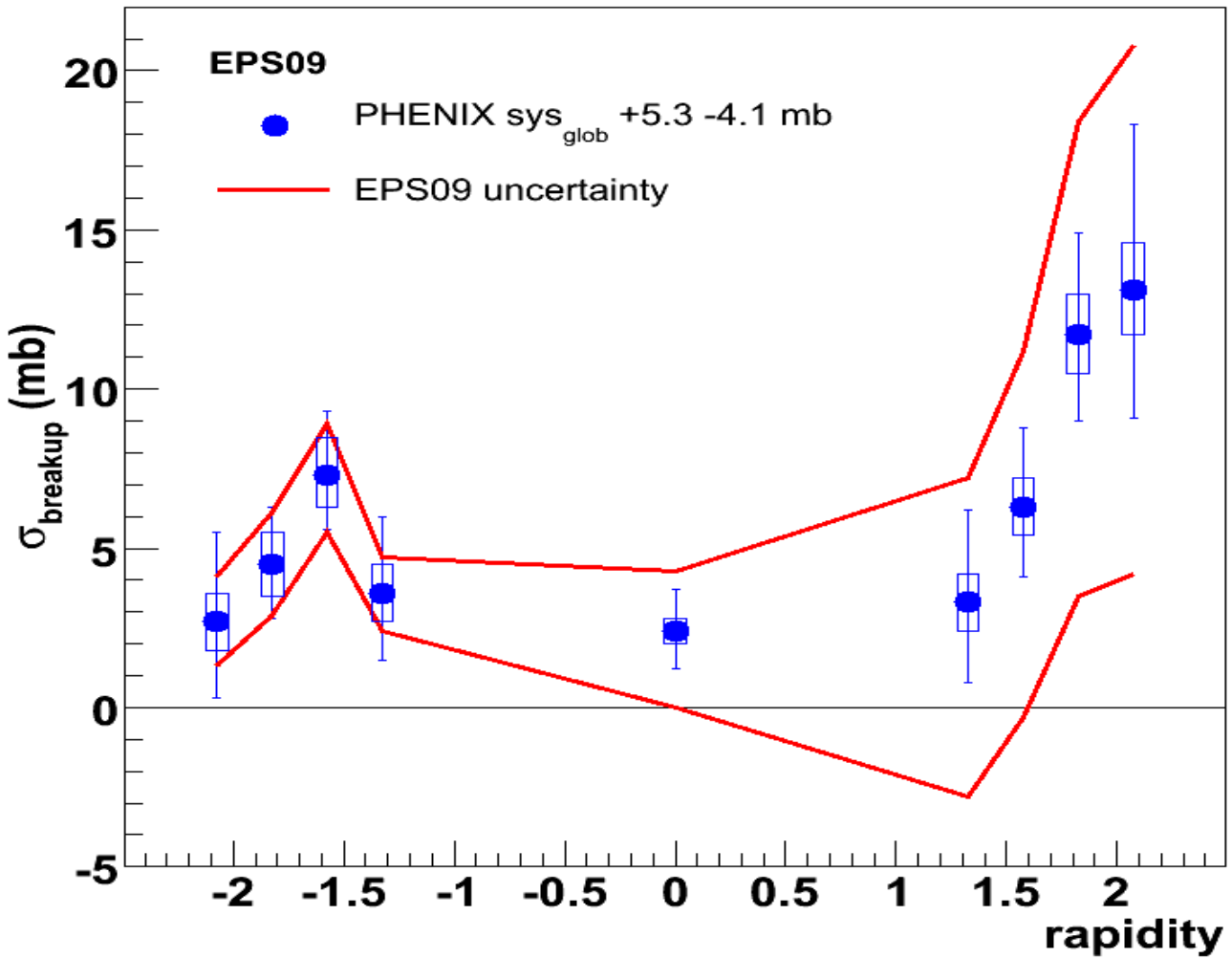
Is it clear that the rise at forward rapidity is not shadowing?

Ramona Vogt has made calculations of R_{dAu} using EPS09 shadowing, which has **systematic uncertainties**. This is an example of the R_{dAu} uncertainty bands for $\sigma_{breakup}$ = 3 mb obtained by me from Ramona's calculations.



Fitted $\sigma_{breakup}$ for EPS09 (with uncertainty band)

The data points are from fits with the EPS09 central values, the red lines are fits using the EPS09 values on the theoretical uncertainty bands. Clearly, the shadowing parameters are less well defined at forward rapidity, where we probe lower x_2.

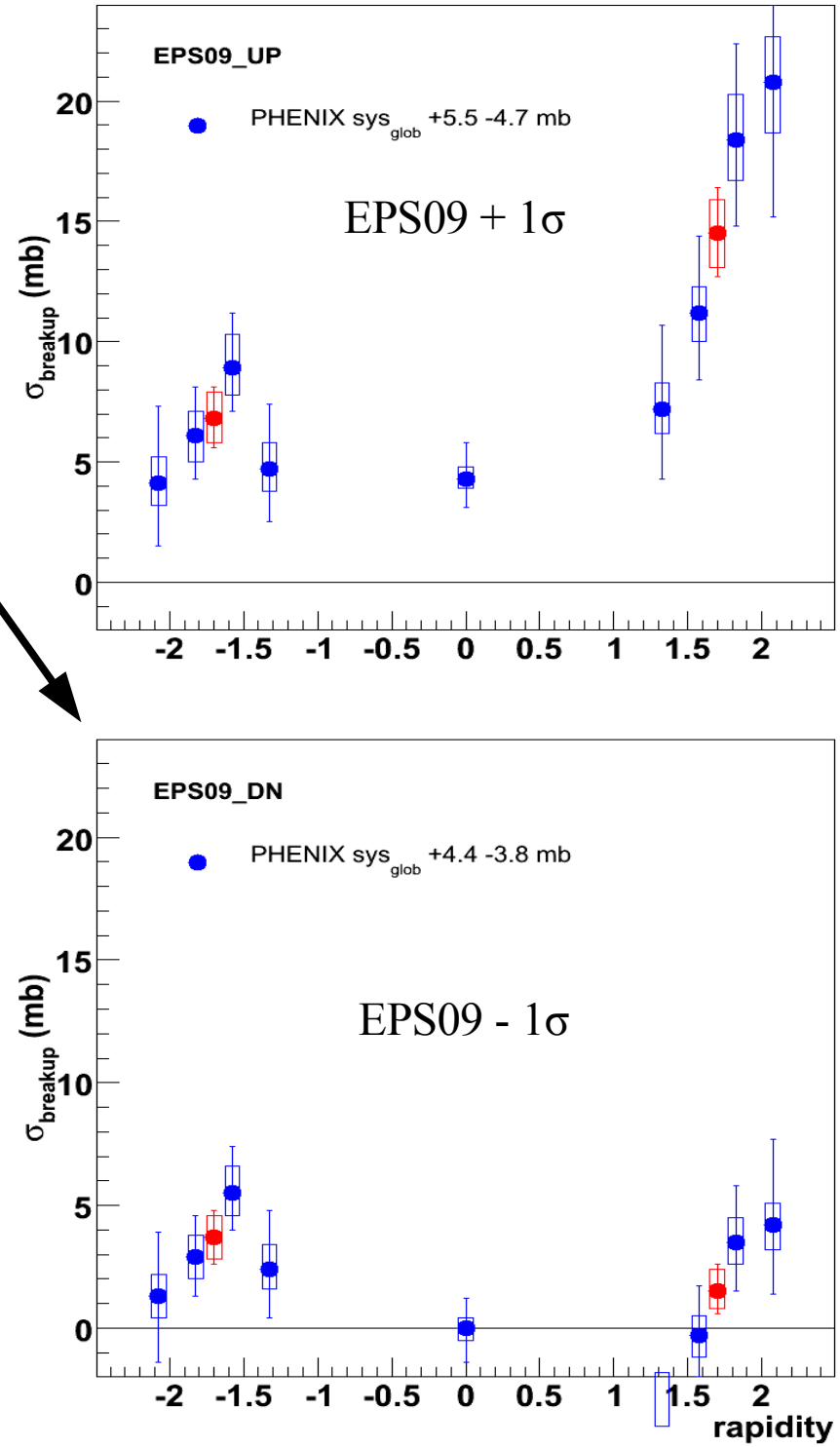


Conclusion:

At the lower EPS09 theoretical uncertainty, the strong rise in $\sigma_{breakup}$ at forward rapidity is **gone**.

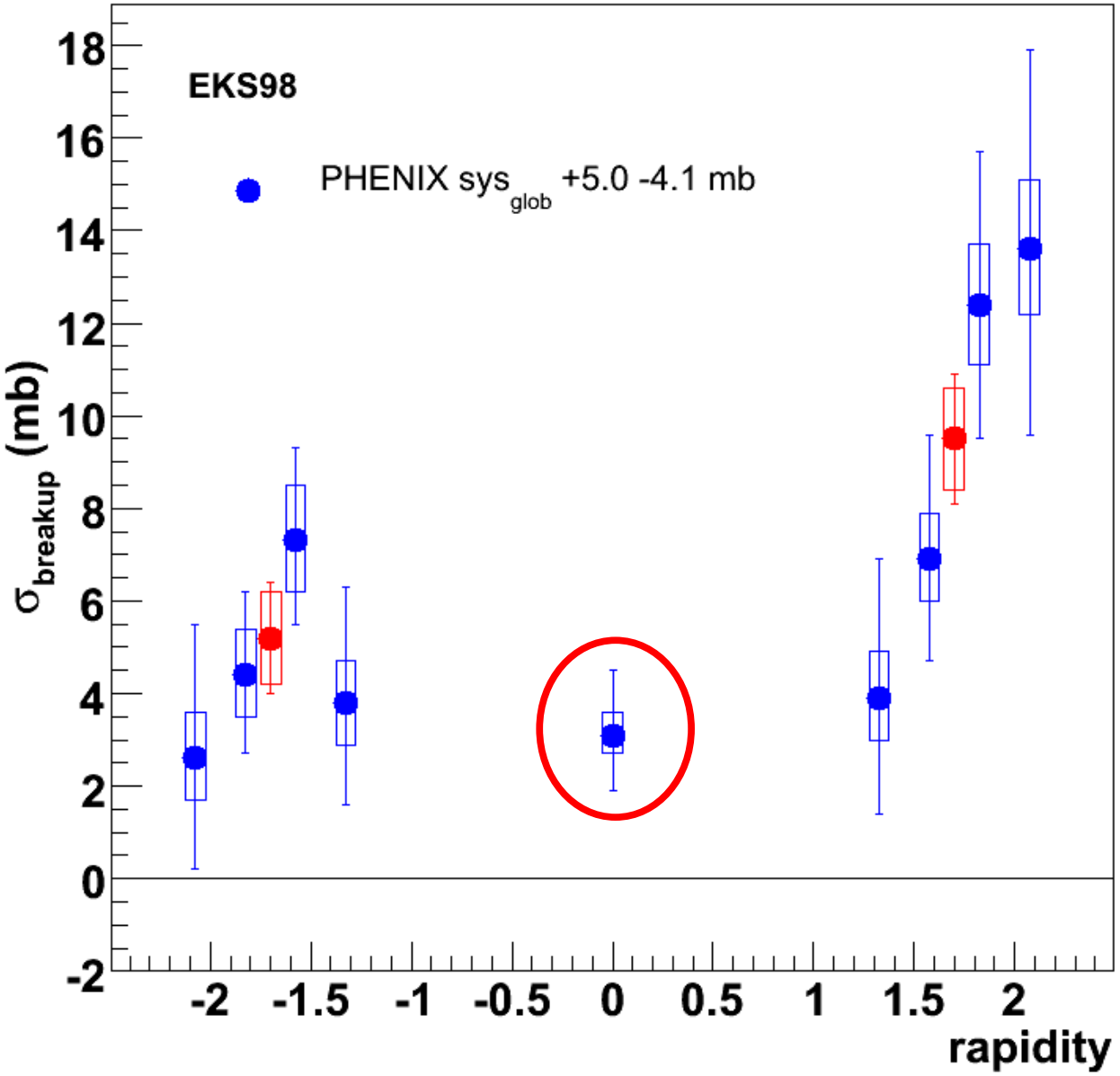
So the theoretical uncertainties are large enough to cast doubt on any conclusion that the strong rise at forward rapidity is due to **new physics**.

But how would this look at E866 energies?



Get effective $\sigma_{breakup}$ for use in Glauber calculations |y| = 0, 1.7

The red points are the effective $\sigma_{breakup}$ values for the muon arms as a whole.



Cold Nuclear Matter R_{AA} for heavy ions

Having "calibrated" the Vogt R_{dAu} calculations at each rapidity, we estimate the CNM R_{AA} using the $\sigma_{breakup}$ results from the dAu R_{CP} fits with a set of **R_{pAu} calculations** from Ramona.

To do this, we use a Glauber calculation for Au+Au that reproduces well the **average** Npart and Ncoll values for the centrality bins used by PHENIX.

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: RpAu(b1,y=0) * RpAu(b2,y=0)

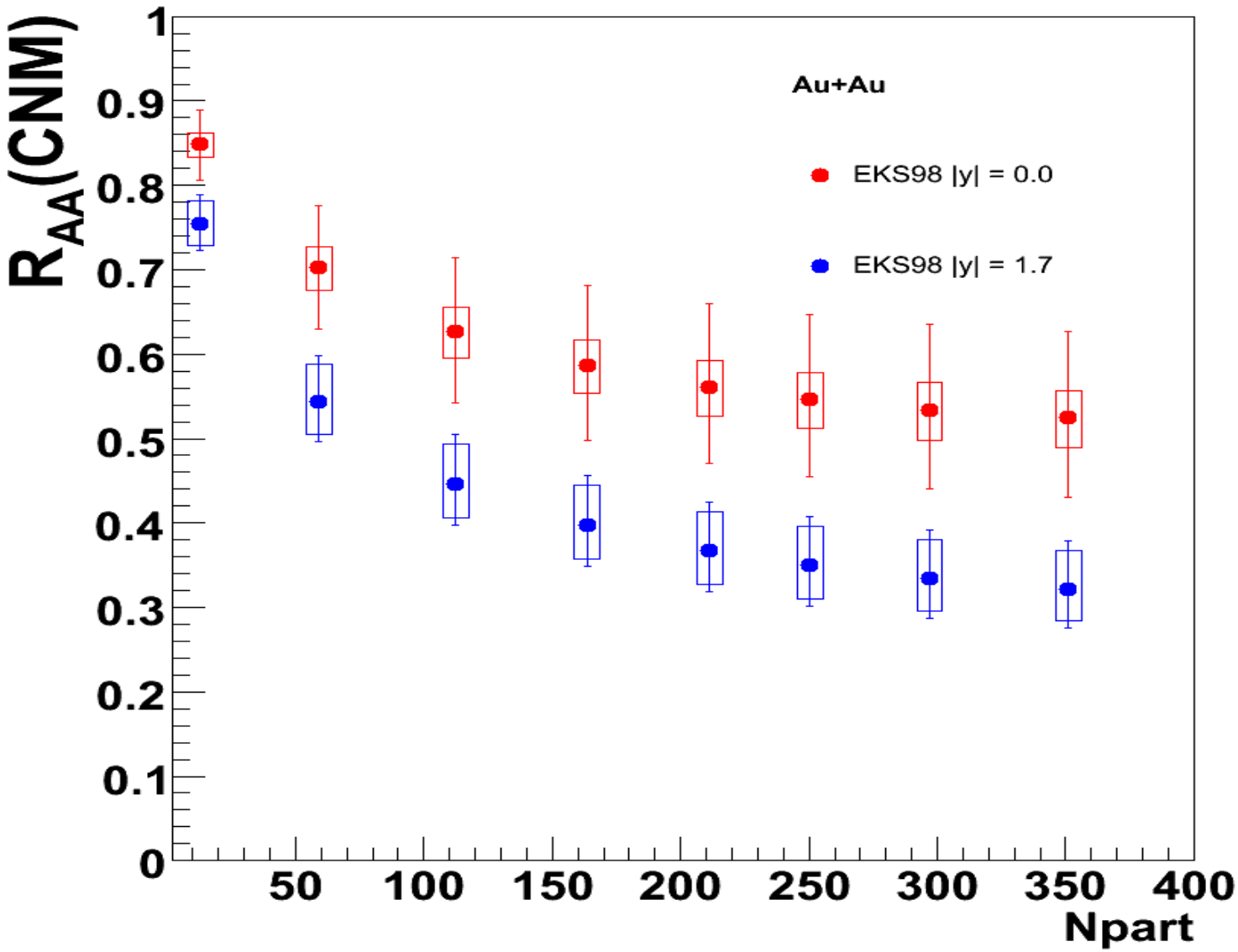
Add to the accumulated RAA: RpAu(b1,y=-1.75) * RpAu(b2,y=1.75)

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

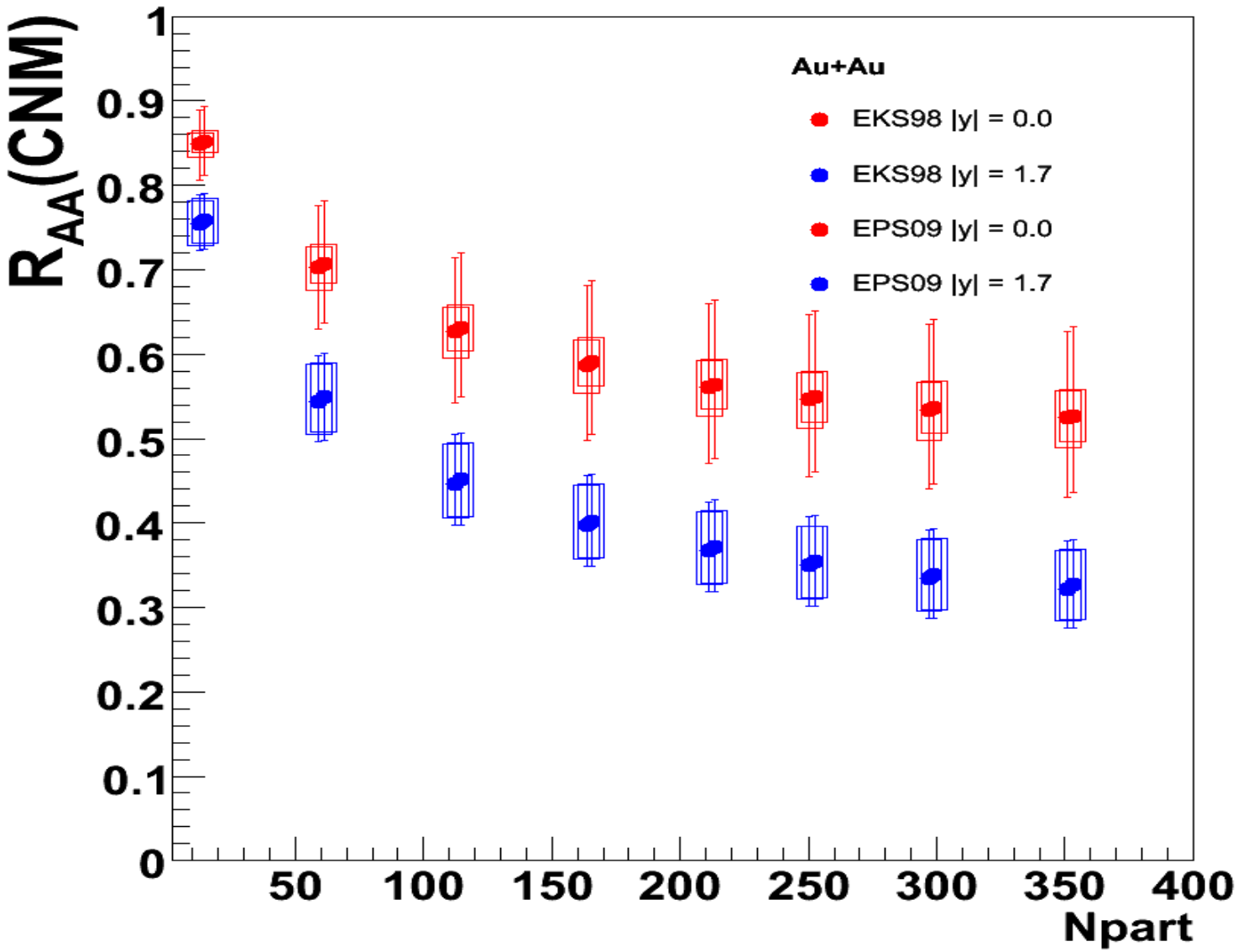
Nevts[j], Σ(RAA[j])/Nevts[j], Σ(Ncoll[j])/Nevts[j], Σ(Npart[j])/Nevts[j]

R_{AA}(CNM) for Au+Au with **EKS98** shadowing model and the d+Au best fit breakup cross sections.

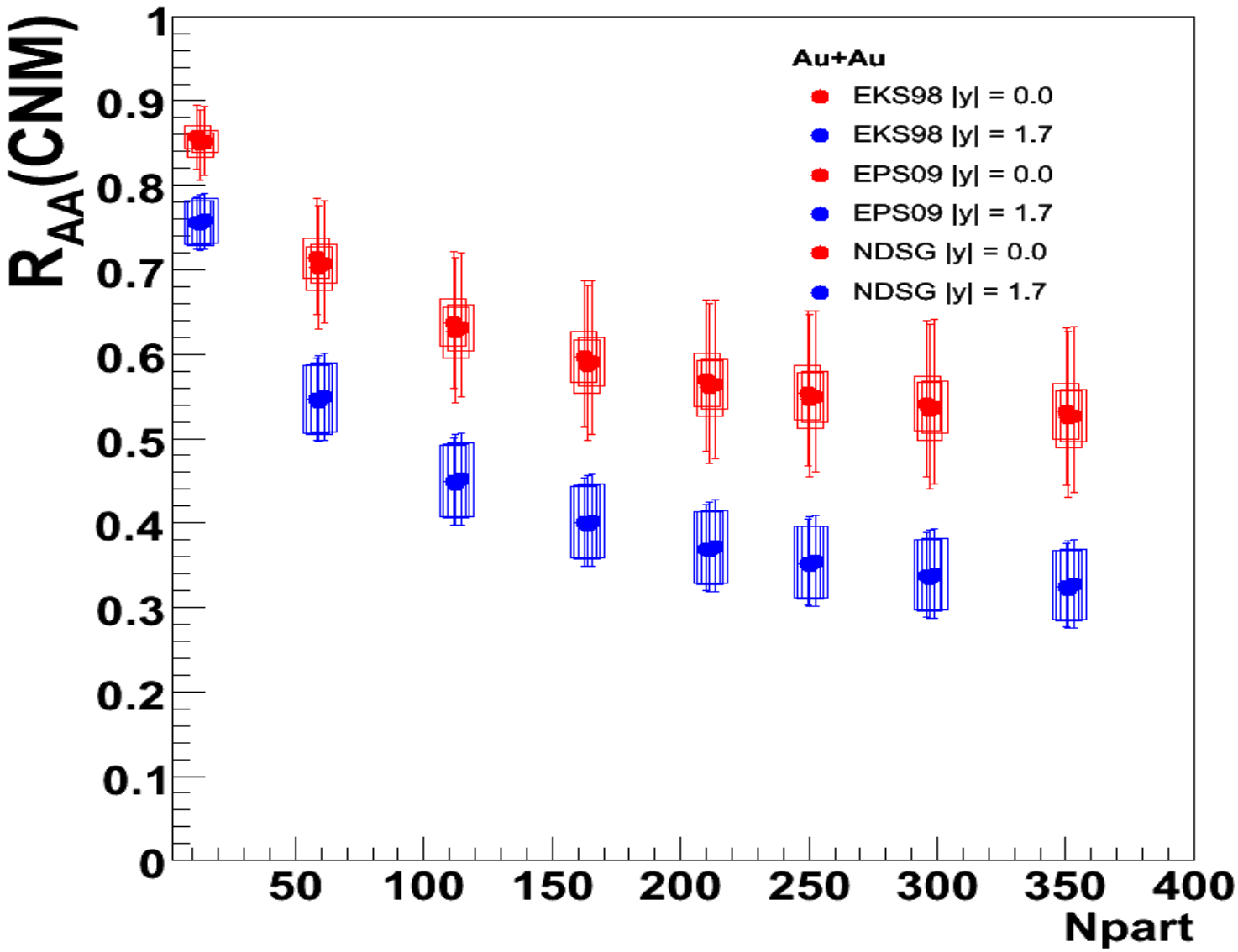
How does this depend on the shadowing model?



R_{AA}(CNM) for Au+Au with **EKS98/EPS09** shadowing model and the d+Au best fit breakup cross sections.

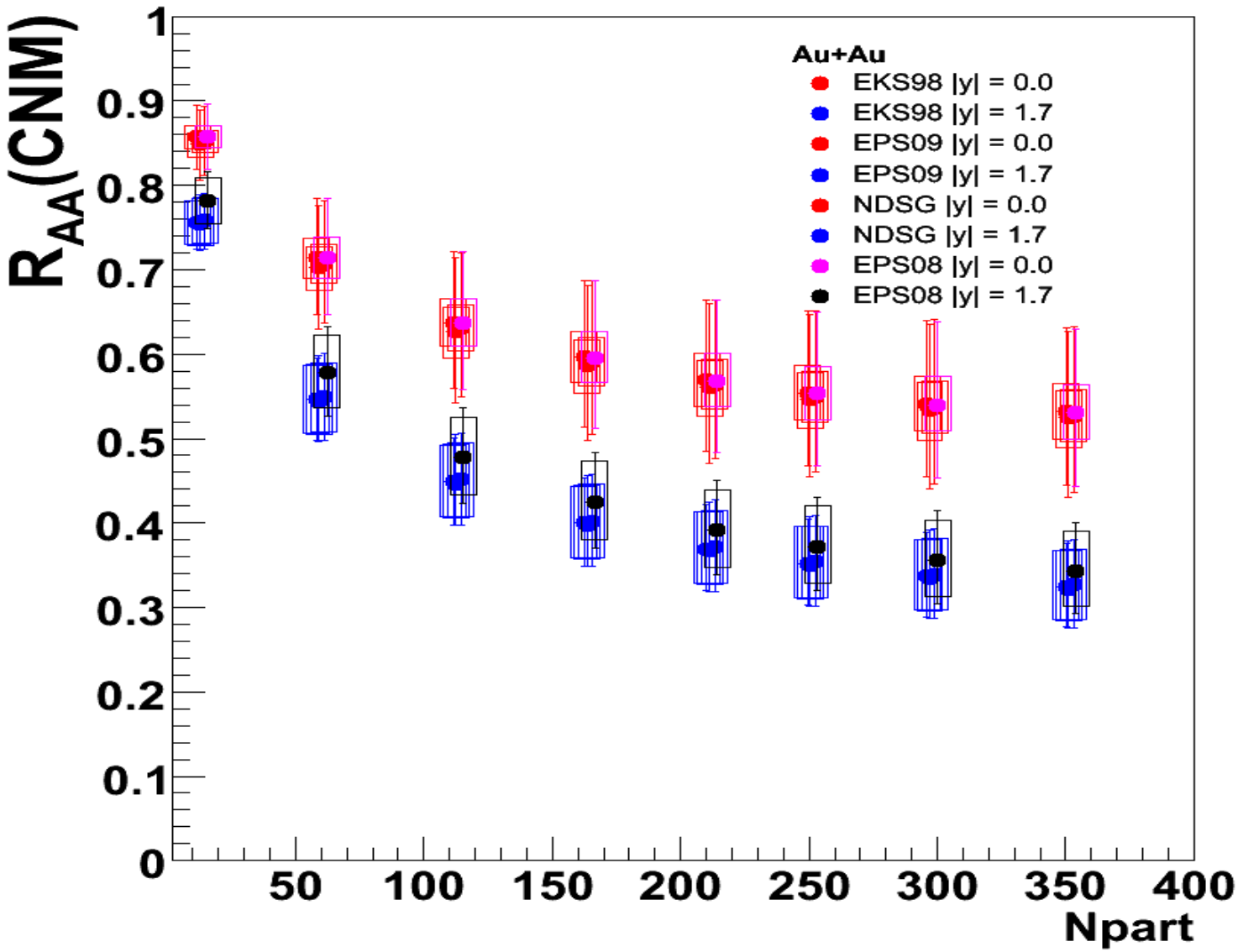


R_{AA}(CNM) for Au+Au with **EKS98/EPS09/nDSG** shadowing model and the d+Au best fit breakup cross sections.



R_{AA}(CNM) for Au+Au with **EKS98/EPS09/nDSG/EPS08** shadowing model and the d+Au best fit breakup cross sections.

Not much dependence on the shadowing model



Results for "survival probability"

The R_{AA}(CNM) values shown on slides 7 and 8, calculated with the EKS98 parameterization of the d+Au data, have been used to make plots of **R_{AA}/R_{AA}(CNM)** for the published PHENIX J/ψ R_{AA} data:

PHENIX **Au+Au** data: Phys. Rev. Lett. 98, 232301 (2007).
PHENIX **Cu+Cu** data: Phys. Rev. Lett. 101, 122301 (2008).

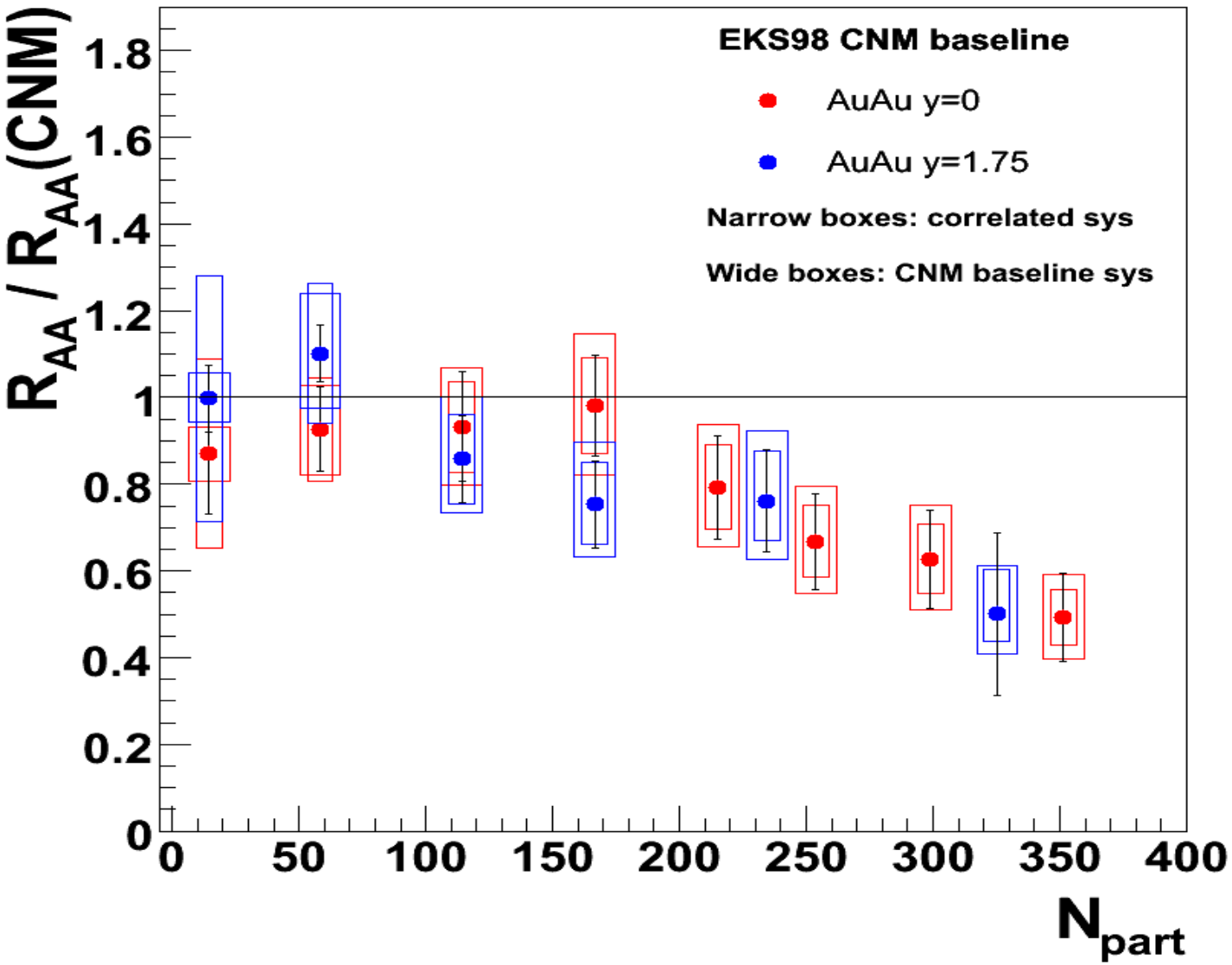
Of course, calling it a **"survival probability"** implies a particular mechanism for J/ψ production that may not be correct or complete.

It is more accurate to think of R_{AA}(CNM) as **"folded pA"** - an estimate of what we would see if there were no additional effects in AA collisions.

BUT: If the rapidity dependence of the effective absorption cross section in d+Au is due to changes in **charm pair** production (as distinct from destruction of forming J/ψ), the R_{AA}(CNM) reference will work as the baseline for any production mechanism – including statistical hadronization.

Results for Au+Au for the EKS98 case

The suppression beyond CNM effects is found to be similar at y=0 and at y=1.7. There is essentially **no** dependence on the shadowing model used to parameterize the d+Au R_{CP}.



Aside

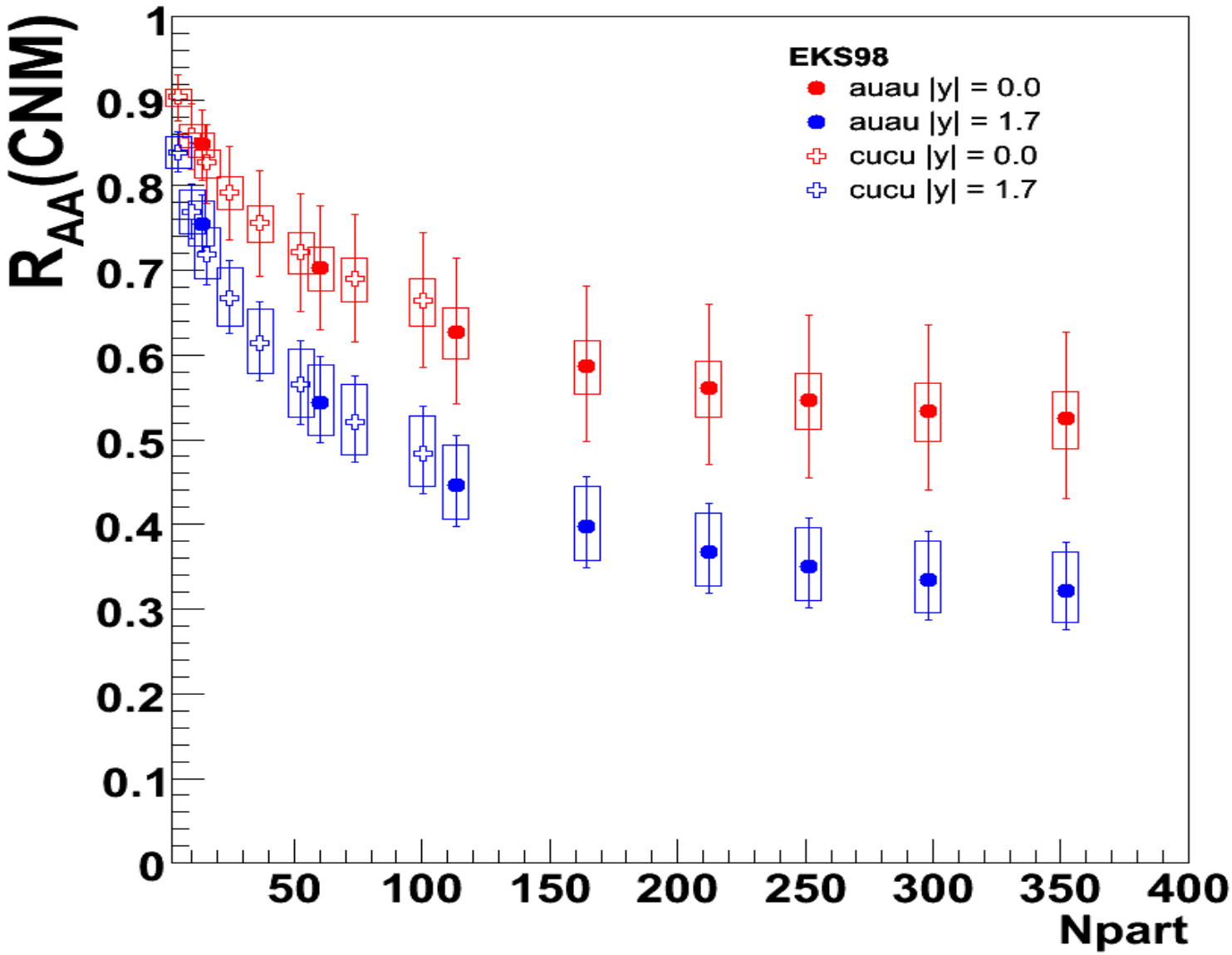
If a larger fraction of the ψ' and χ_c are destroyed by **cold nuclear matter effects**, which seems very likely, then the $R_{AA}/R_{AA}(CNM)$ will not reflect the destruction of those mesons – they are **already** gone in our d+Au measurements.

We should try to **quantify** this at RHIC using our d+Au data.

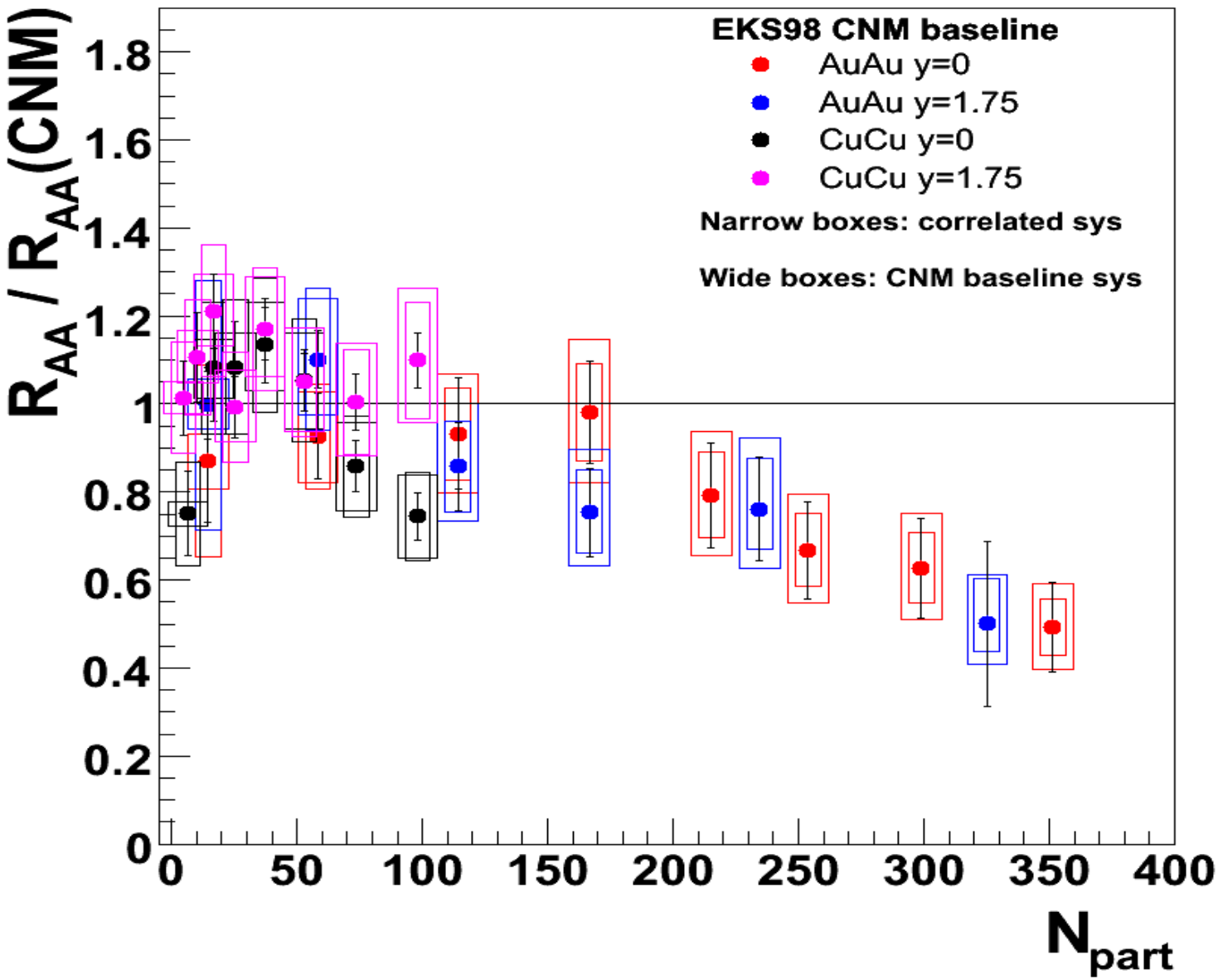
My point is: be careful about looking for evidence of excited charmonia destruction in $R_{AA}/R_{AA}(CNM)$.
$\rightarrow$ in the limit where they were **all** destroyed in the initial collision, they would have **no** effect in $R_{AA}/R_{AA}(CNM)$.

R_{AA}(CNM) for Au+Au and **Cu+Cu** made with the **EKS98** shadowing model for **RpCu** from Ramona and the d+Au best fit breakup cross sections.

Nice agreement of the Npart dependence between CuCu and AuAu!

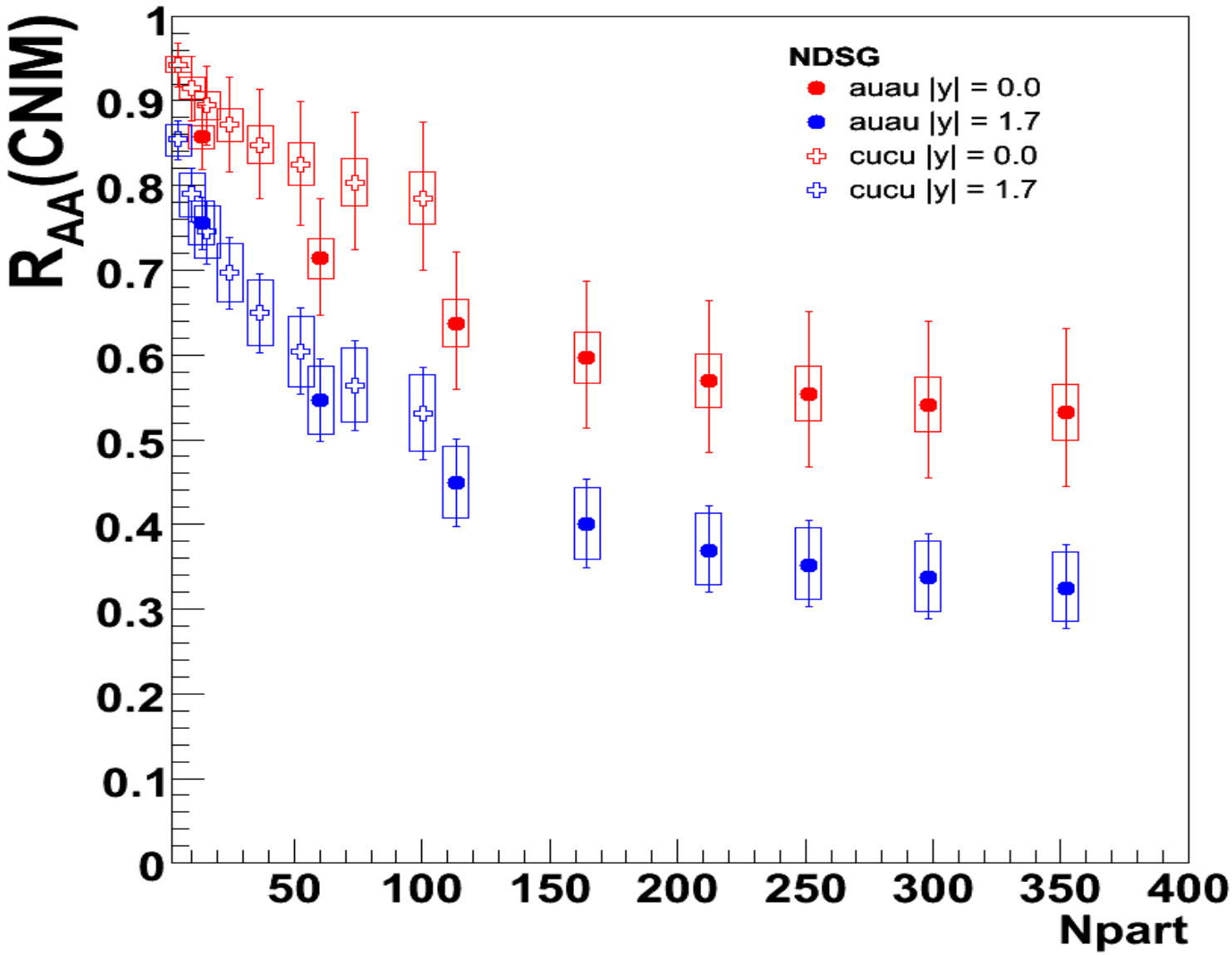


Results for Au+Au and Cu+Cu for the EKS98 case



BUT: R_{AA}(CNM) for Au+Au and **Cu+Cu** made with the **nDSg** shadowing model for **RpCu** from Ramona and the d+Au best fit breakup cross sections.

Difference in Npart dependence for AuAu and CuCu for the nDSg case!



Summary and conclusions

The suppression **beyond "folded pA"** is **very similar** for y=0 and y=1.7, even though R_{AA} is quite different.

There is very little dependence of R_{AuAu}(CNM) on the shadowing model used in the parameterization of d+Au. Not surprising, since the d+Au R_{CP} was fitted with a **Au** shadowing model.

But caution: There is significant model dependence of the calculated R_{CuCu}(CNM) when using a parameterization of **d+Au** data. Even though the EKS98 R_{CuCu}(CNM) looks **reasonable** next to the R_{AuAu}(CNM) it is important to remember that there is still some model dependence there – the data were fitted using a Au shadowing parameterization, **not** a Cu one, since we do not have d+Cu data.

Finally, I should stress that these are **my conclusions** - I am not speaking for PHENIX here.

Backup

What happens to the large global systematic uncertainty on $\sigma_{breakup}$?

I argue that the global systematic uncertainty on $\sigma_{breakup}$ cancels in the calculation of the R_{AA}(CNM) as follows:

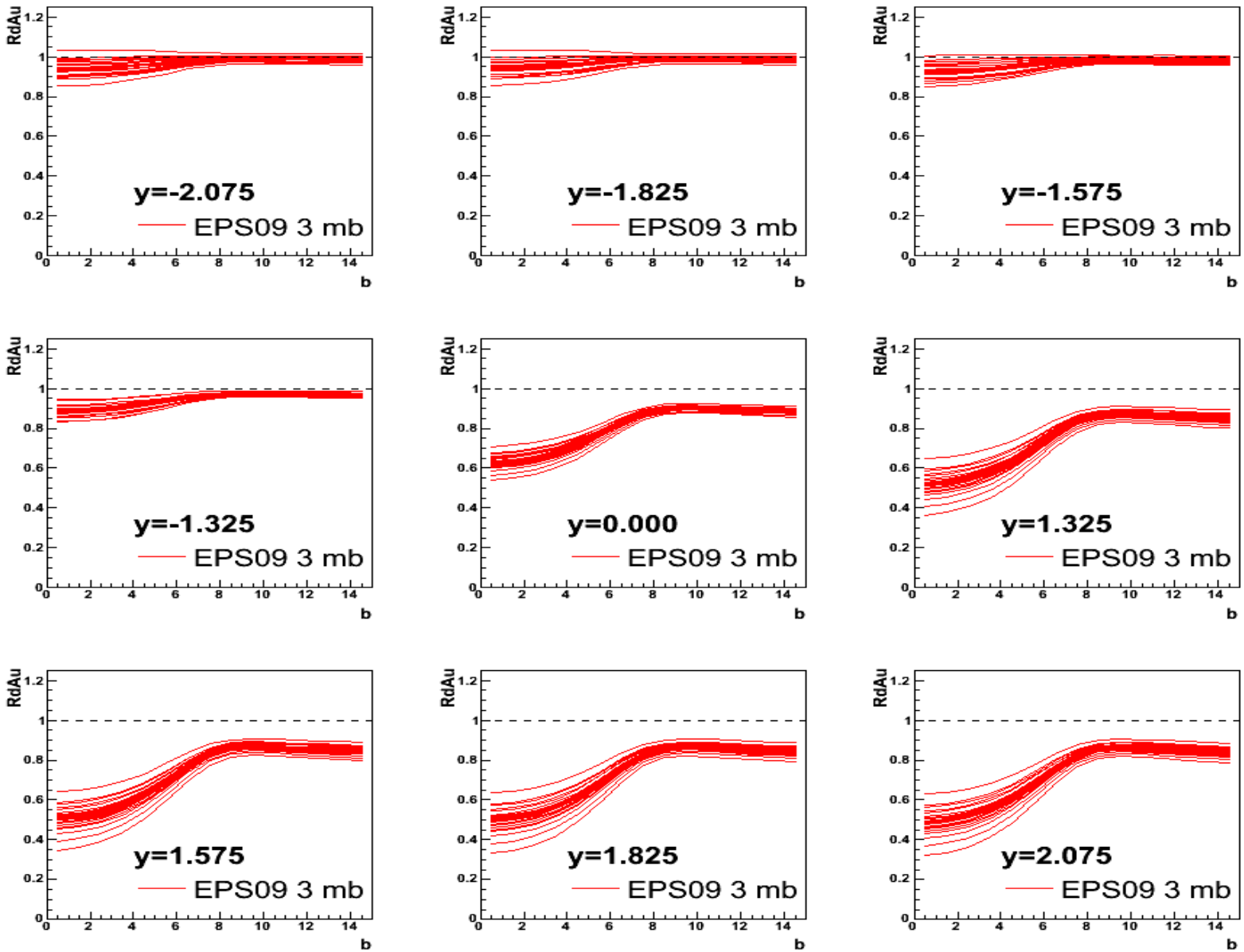
The global uncertainty on $\sigma_{breakup}$ is due to the uncertainty in the Glauber calculation of average Ncoll used in calculating the centrality dependence of the data.

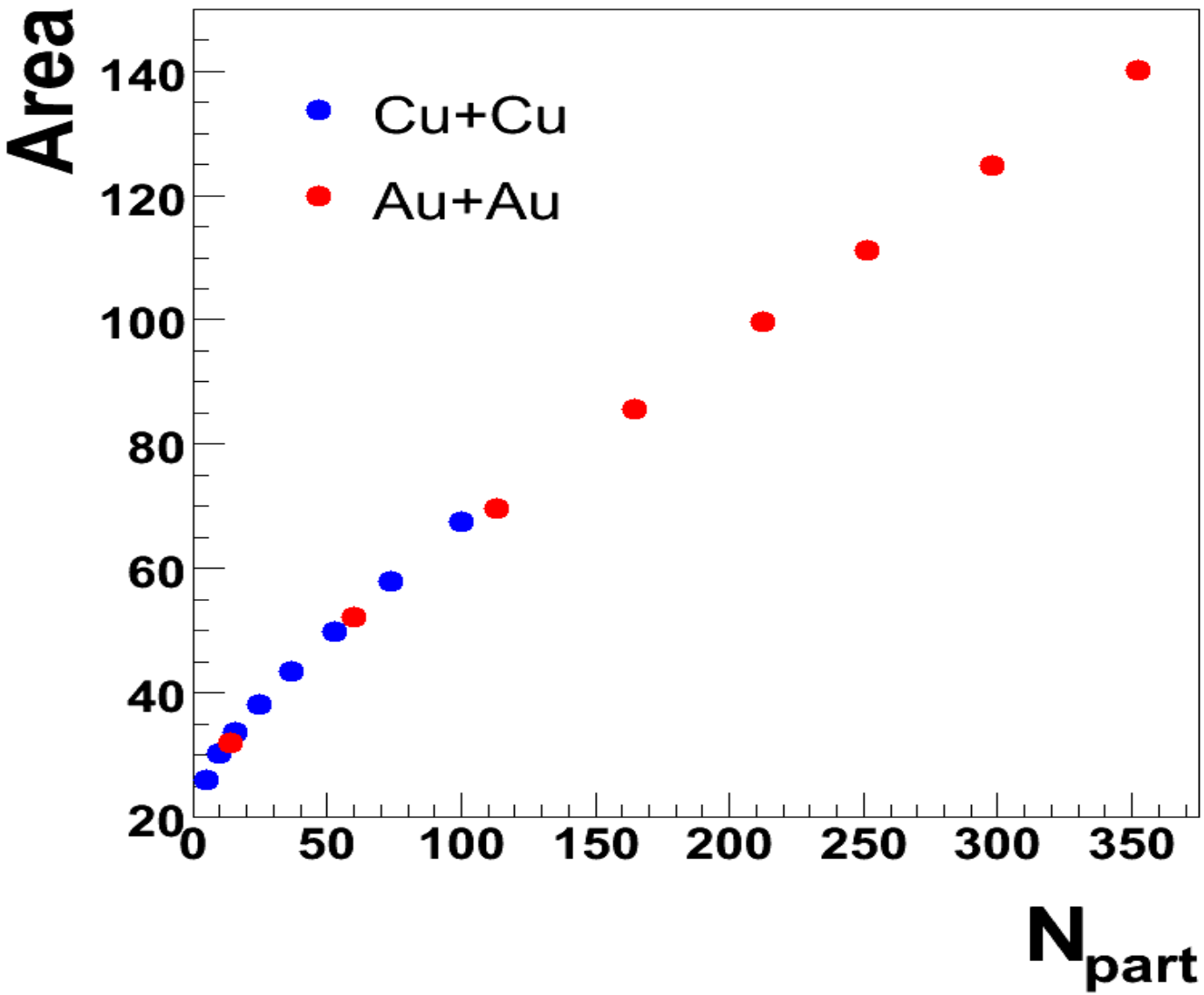
The fitted $\sigma_{breakup}$ is used to calculate RAA(CNM) in the **same** Glauber model as was used to estimate average Ncoll for the data.

Thus the fitted $\sigma_{breakup}$ has uncertainties in its **absolute value** due to the Ncoll estimation used for the centrality dependence of the data, but that uncertainty does not carry over into RAA(CNM) because the same model is used to estimate Ncoll there.

Look at this with EPS09 (which has theoretical uncertainties)

Ramon Vogt has calculated the R_{dAu} values from all 31 EPS09 calculations for $\sigma_{breakup}$ = 0-20 mb. An example is shown here for $\sigma_{breakup}$ = 3 mb.



Calculation of overlap areas vs Npart in Glauber model

The overlap area as a function of Npart for Cu+Cu and Au+Au from a Glauber calculation.