J/ψ production in Cu+Cu and Au+Au collisions at RHIC-PHENIX

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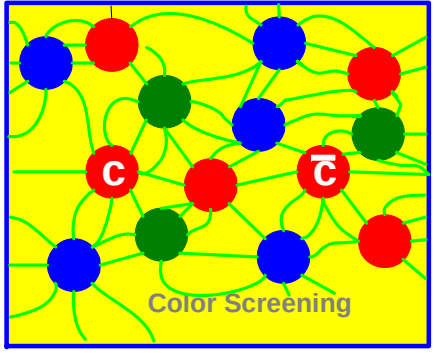
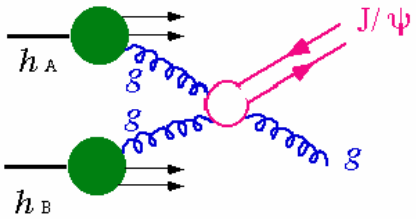
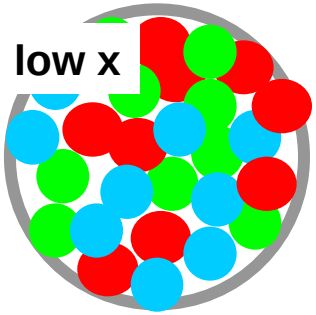
Physics motivation

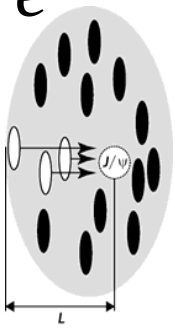
- J/ψ is one of the most important probes for quark gluon plasma study.
  - J/ψ will dissociate in QGP by Debye color screening.
  - Heavy quarks are created in initial hard collisions.
    - Mainly gluon fusion at RHIC energy
- Competing effects
  - Cold nuclear matter effects
    - Nuclear breakup, shadowing, CGC
  - Feed-downs from χ_c, ψ' and bottom
    - Sequential dissociation
  - Regeneration from uncorrelated charm quarks
- Need to experimentally disentangle these effects.

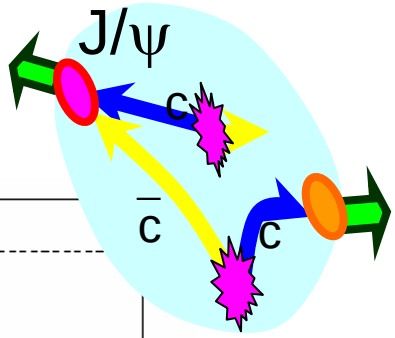


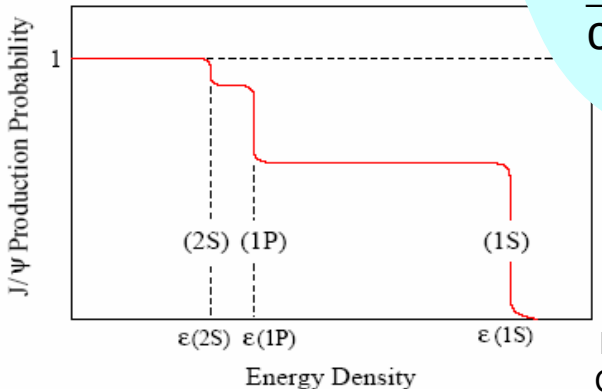




$e^{-L\rho\sigma_{abs}}$



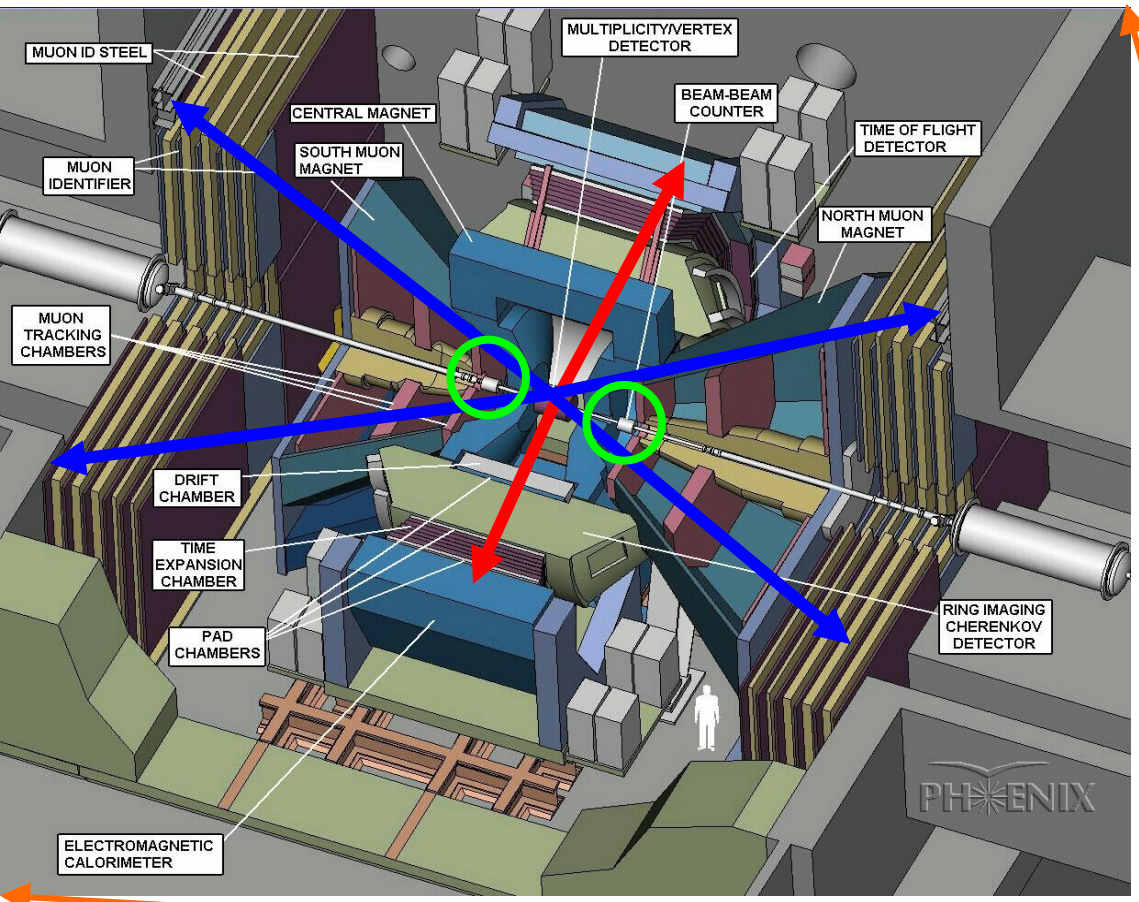




H. Satz, J. Phys. G 32, R25 (2006)

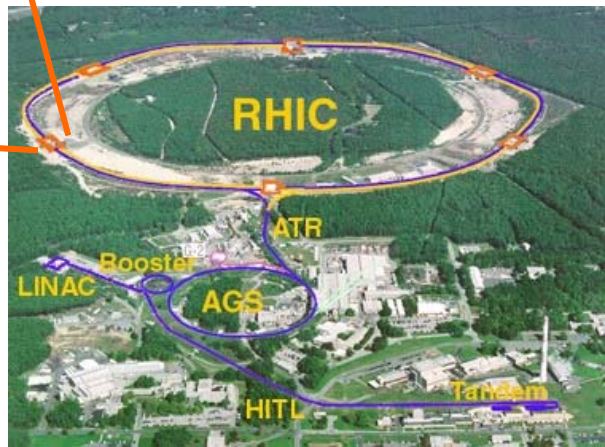
State	$J/\psi(1S)$	$\chi_c(1P)$	$\psi'(2S)$	$\Upsilon(1S)$	$\chi_b(1P)$	$\Upsilon(2S)$	$\chi_b(2P)$	$\Upsilon(3S)$
T_d/T_c	2.10	1.16	1.12	$\geq$4.0	1.76	1.60	1.19	1.17

PHENIX detector



- **Midrapidity**
  ($|y|<0.35$, e^+e^- pair, photon, hadron)
  - Tracking
    - DC, PC
  - PID
    - RICH, EMCal

- **Forward rapidity**
  ($1.2<|y|<2.2$, $\mu^+\mu^-$ pair)
  - Tracking
    - MuTr (MWPC)
  - PID
    - MuID (drift tube, absorber)



- **Vertex, centrality**
  - Timing, charged particle multiplicity
    - BBC
  - Spectator neutron
    - ZDC

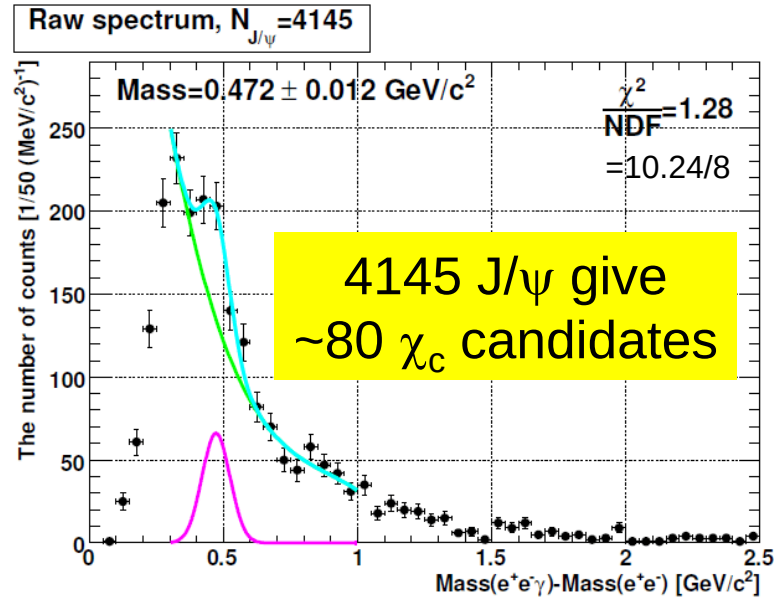
What PHENIX has done on quarkonia from QM06

- Final results
  - J/ψ in Cu+Cu collisions
    - This talk
    - arXiv:0801.0220 [nucl-ex]
  - Updated J/ψ in d+Au collisions
    - M. Wysocki's talk (VI-2, Tuesday, finished)
    - arXiv:0711.3917 [nucl-ex], to be published in Phys. Rev. C
- Preliminary results
  - χ_c in p+p collisions
    - This talk
  - ψ' in p+p collisions
    - M. Donadelli's poster (P127)
  - b quark in p+p collisions
    - Y. Morino's talk (XIV-5, Friday, finished)
  - J/ψ elliptic flow in Au+Au collisions
    - C. Silvestre's talk (XVIII-4, this session)
    - C.L. Silva's poster (P85)
- Ongoing analyses
  - ψ' and Υ in d+Au and Cu+Cu collisions
    - H. Liu's poster (P98)

Feed-downs into J/ψ are important to understand the J/ψ suppression

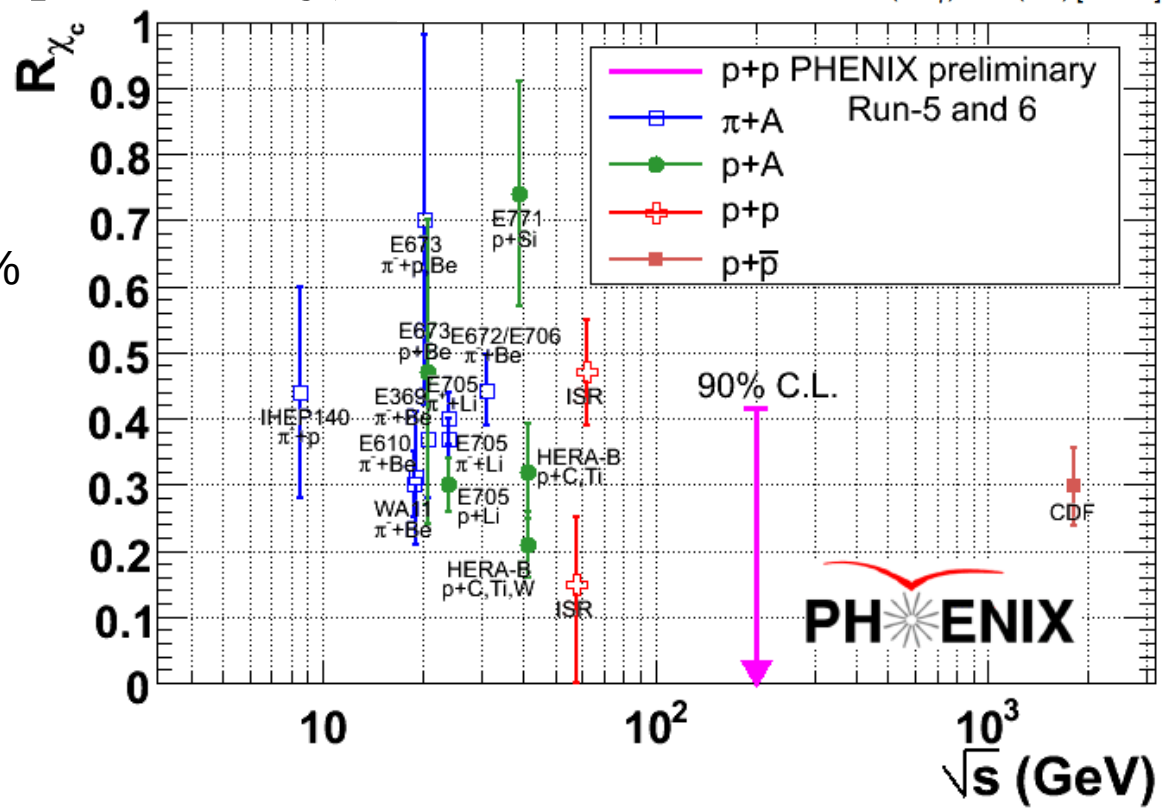
- The fractions of J/ψ sources from e.g. R. Vogt, Nucl. Phys. A700, 539 (2002) are
  - Direct production : ~58%
  - Decays from χ_{c0}, χ_{c1}, χ_{c2} : ~30%
  - Decays from ψ' : ~12%
  - Decays from b quarks : neglected
    - PHENIX currently does not have vertex detectors
- Inclusive J/ψ measurement in p+p collisions by PHENIX in Run-5 in 2005
  - BR(J/$\psi \rightarrow l^+l^-$)σ(J/ψ)=178 ± 3(stat) ± 53(syst) ± 18(norm) nb
  - Phys. Rev. Lett. 98, 232002 (2007), arXiv:hep-ex/0611020
- PHENIX separately measured these feed-down contributions in p+p collisions at midrapidity (|y|<0.35).

$\chi_c \rightarrow J/\psi+\gamma \rightarrow e^+e^-\gamma$ (p+p 200GeV, Run-5&6)



$$R_{\chi_c} = \frac{1}{\sigma(J/\psi)} \sum_{J=1}^{2} \sigma(\chi_{cJ}) BR(\chi_{cJ} \rightarrow J/\psi\,\gamma)$$

< 0.42 (90% C.L., PHENIX preliminary)

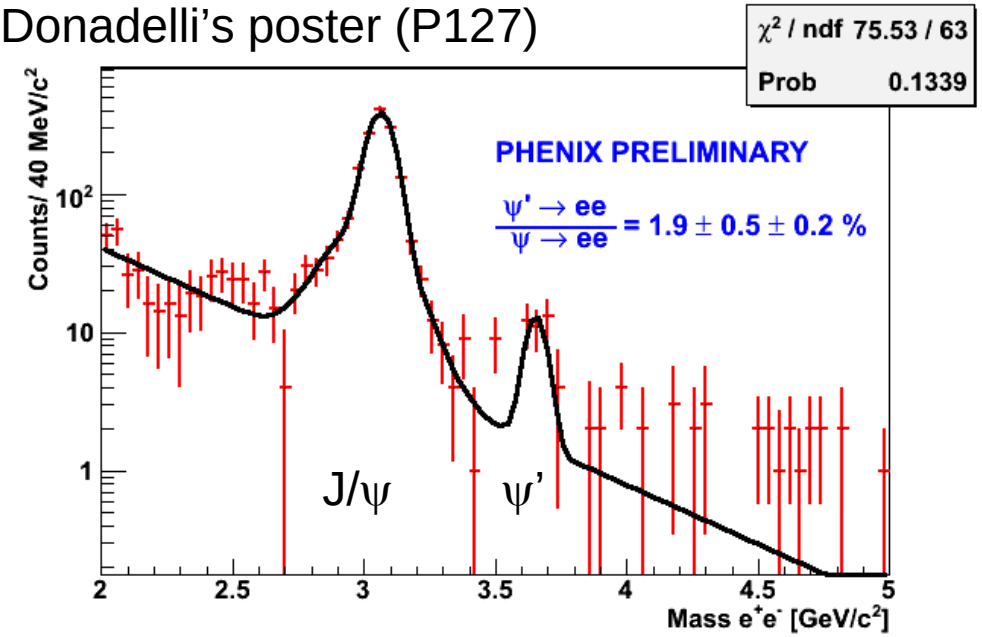


PDG 2007 values

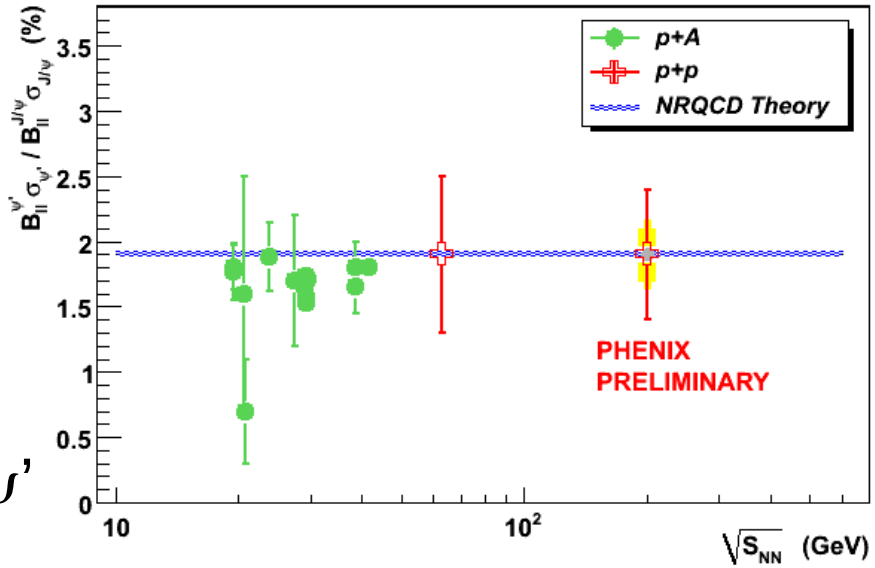
- $BR(\chi_{c0} \rightarrow J/\psi+\gamma)=1.32 \pm 0.11\%$
  - neglected
- $BR(\chi_{c1} \rightarrow J/\psi+\gamma)=35.9 \pm 1.9\%$
- $BR(\chi_{c2} \rightarrow J/\psi+\gamma)=20.3 \pm 1.0\%$

M. Donadelli's poster (P127)

$\psi' \rightarrow e^+e^-$ (p+p 200GeV, Run-6)

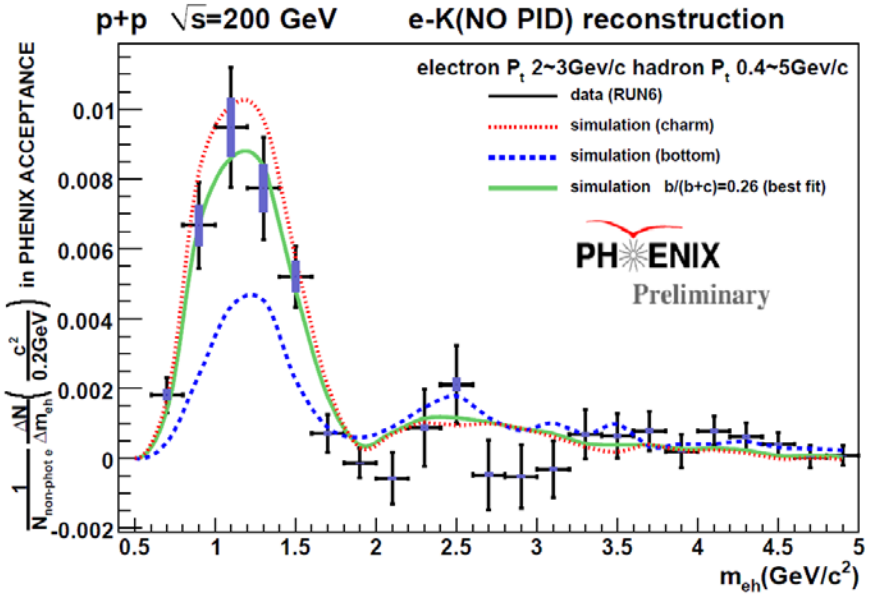


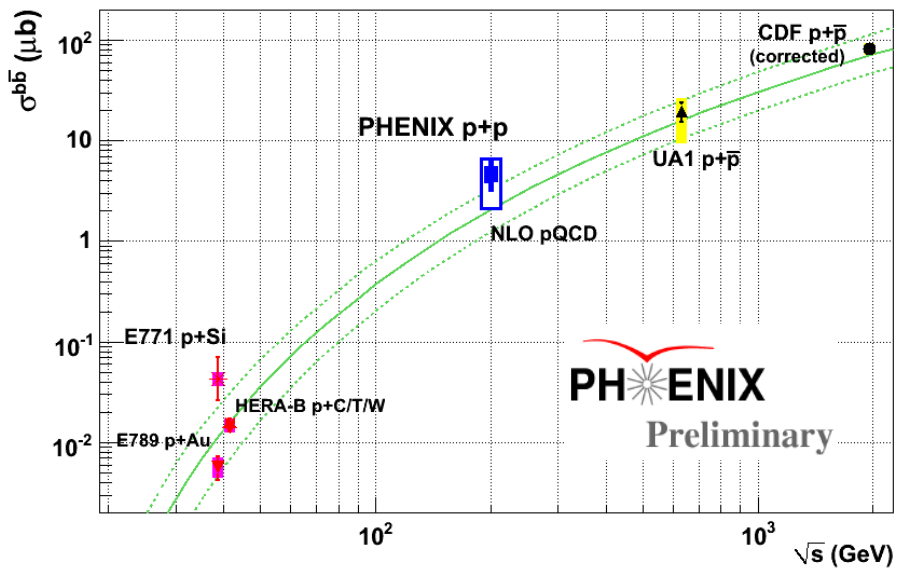
- PHENIX preliminary
  - $BR(\psi' \rightarrow e^+e^-)\sigma(\psi')/BR(J/\psi \rightarrow e^+e^-)\sigma(J/\psi)$ $=0.019 \pm 0.005$ (stat) ± 0.002 (syst)
- PDG 2007 values
  - $BR(J/\psi \rightarrow e^+e^-)=5.94 \pm 0.06\%$
  - $BR(\psi' \rightarrow e^+e^-)=0.743 \pm 0.018\%$
  - $BR(\psi' \rightarrow J/\psi+X)=56.9 \pm 0.9\%$
- $\sigma(\psi')/\sigma(J/\psi)=0.15 \pm 0.04$
- Feed-down fraction of J/ψ from ψ' is **0.086 ± 0.025**.



Y. Morino's talk (XIV-5, Friday, finished)

b-quark cross section obtained by electron-hadron correlation (p+p 200GeV, Run-5&6)

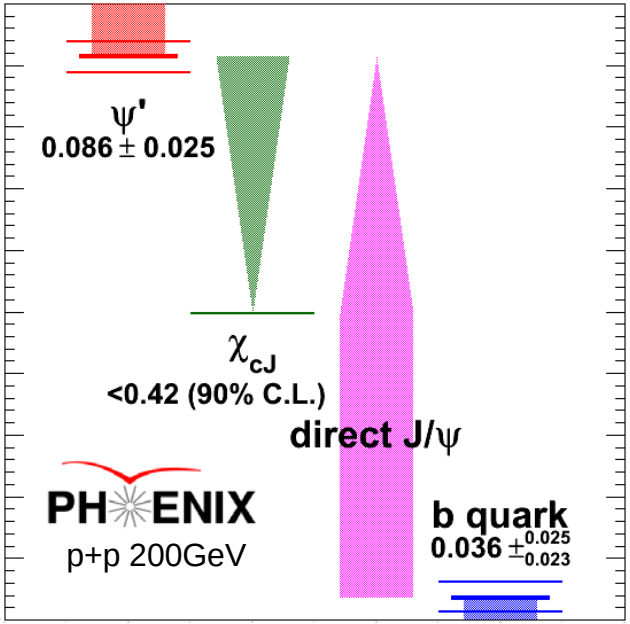




- PHENIX preliminary
  - $d\sigma^{bb\text{-}bar}/dy|_{y=0}=1.34 \pm 0.38(stat)\ ^{+0.74}_{-0.64}(syst)\ \mu b$
  - $\sigma^{bb\text{-}bar}=4.61 \pm 1.31(stat)\ ^{+2.57}_{-2.22}(syst)\ \mu b$
- PDG 2007 values
  - $BR(b \rightarrow J/\psi+X)=1.16 \pm 0.10\%$
- $BR(b \rightarrow J/\psi+X)\sigma^{bb\text{-}bar}=53\ ^{+34}_{-30}$ nb
- Feed-down fraction of J/ψ from b and b-bar quarks is **$0.036\ ^{+0.025}_{-0.023}$**.

Summary of feed-down measurements

- In p+p collisions at $\sqrt{s}$=200GeV, J/ψ is produced via
  - χ_{cJ}→J/ψ+γ decays : <42% (90% C.L.)
  - ψ'→J/ψ+X decays : 8.6 ± 2.5%
  - b quark→J/ψ+X decays : $3.6^{+2.5}_{-2.3}$%
  - Direct J/ψ production : the rest



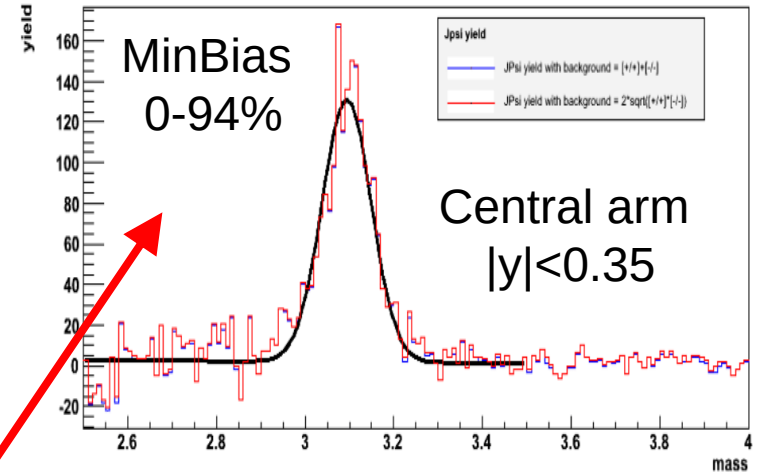
- Our knowledge of J/ψ production became much better.
  - R.Vogt's fractions are almost consistent with these measured fractions.

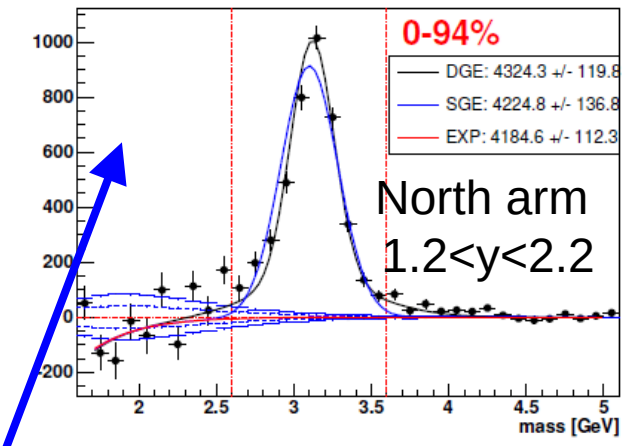
Motivation to measure J/ψ in Cu+Cu collisions at 200 GeV

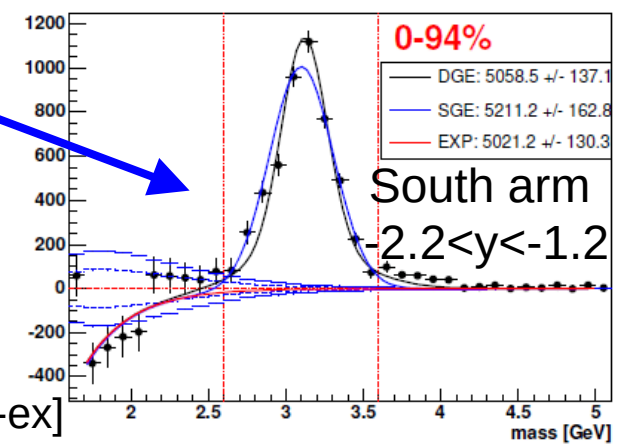
- More precise measurement in small N_{part} than in Au+Au collisions
  - Systematic measurement across entire N_{part} range
  - Cold nuclear matter effects might be dominant
  - Where is the starting point of J/ψ suppression?
- Higher luminosity gives higher statistics

Statistics of J/ψ in Cu+Cu 200 GeV running

- Run-5 Cu+Cu 200GeV
  - January 18, 2005-March 6, 2005
- Midrapidity (|y|<0.35)
  - 2.1 nb^{-1} (6.1B events)
  - 2000 J/ψ
- Forward rapidity (1.2<|y|<2.2)
  - 1.3 nb^{-1} (3.8B events)
  - 9000 J/ψ



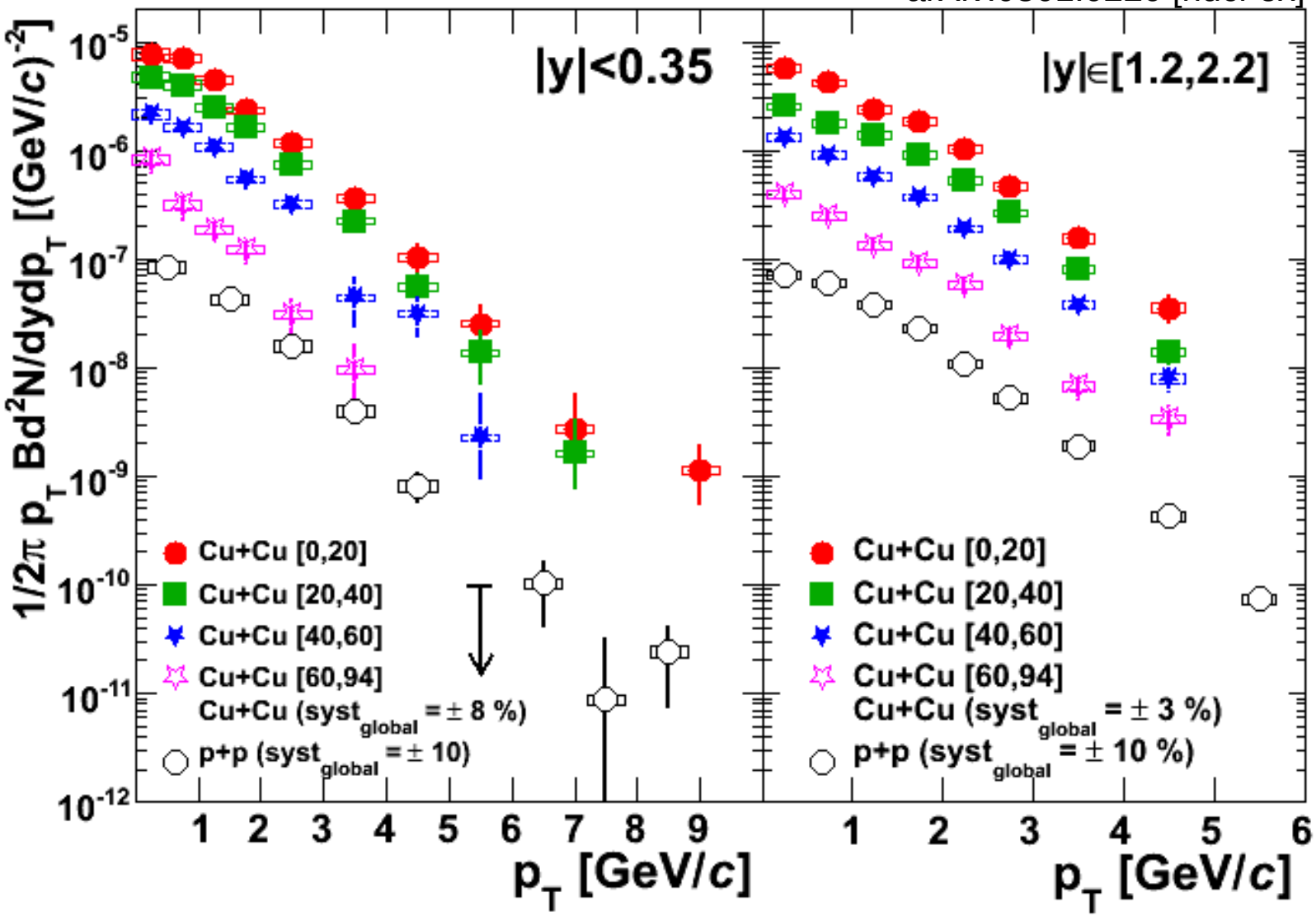




arXiv:0801.0220 [nucl-ex]

Invariant cross sections of J/ψ

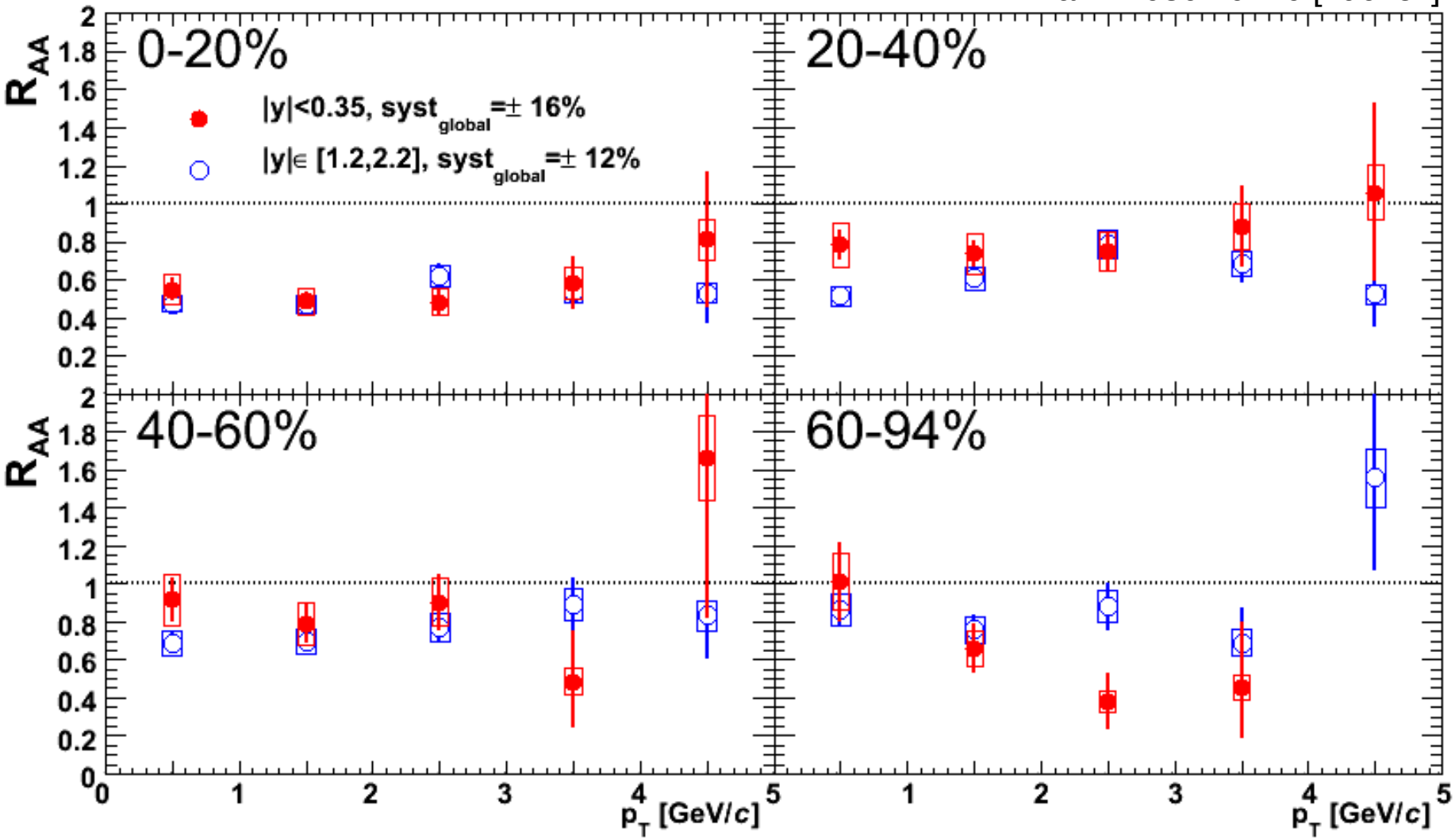
arXiv:0801.0220 [nucl-ex]



J/ψ was measured from p_T=0GeV/c to beyond p_T =5GeV/c.

R_{AA} vs p_T

arXiv:0801.0220 [nucl-ex]

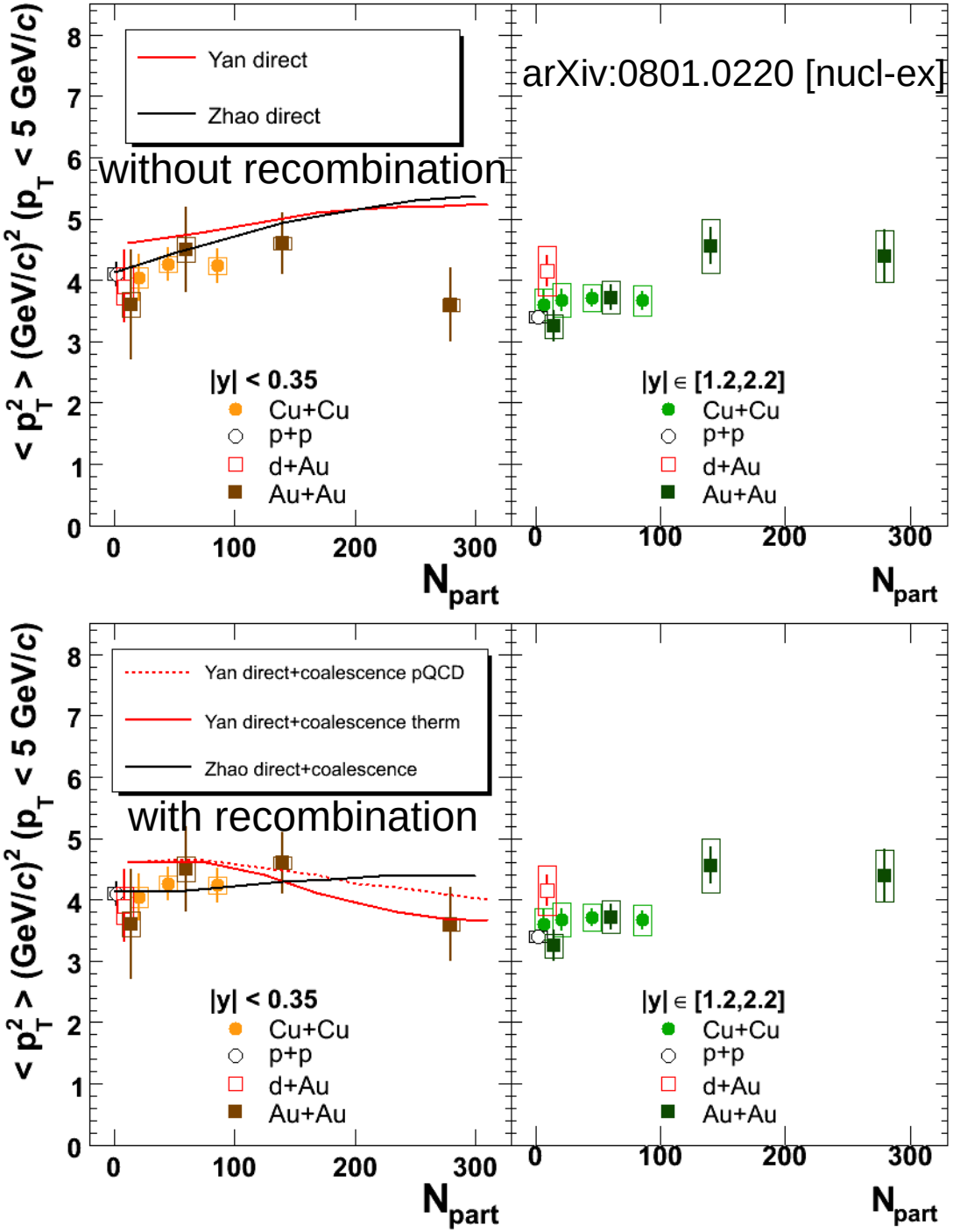


No strong p_T dependence. R_{AA} will be extended to >5GeV/c soon.

$<p_T^2>$ vs N_{part}

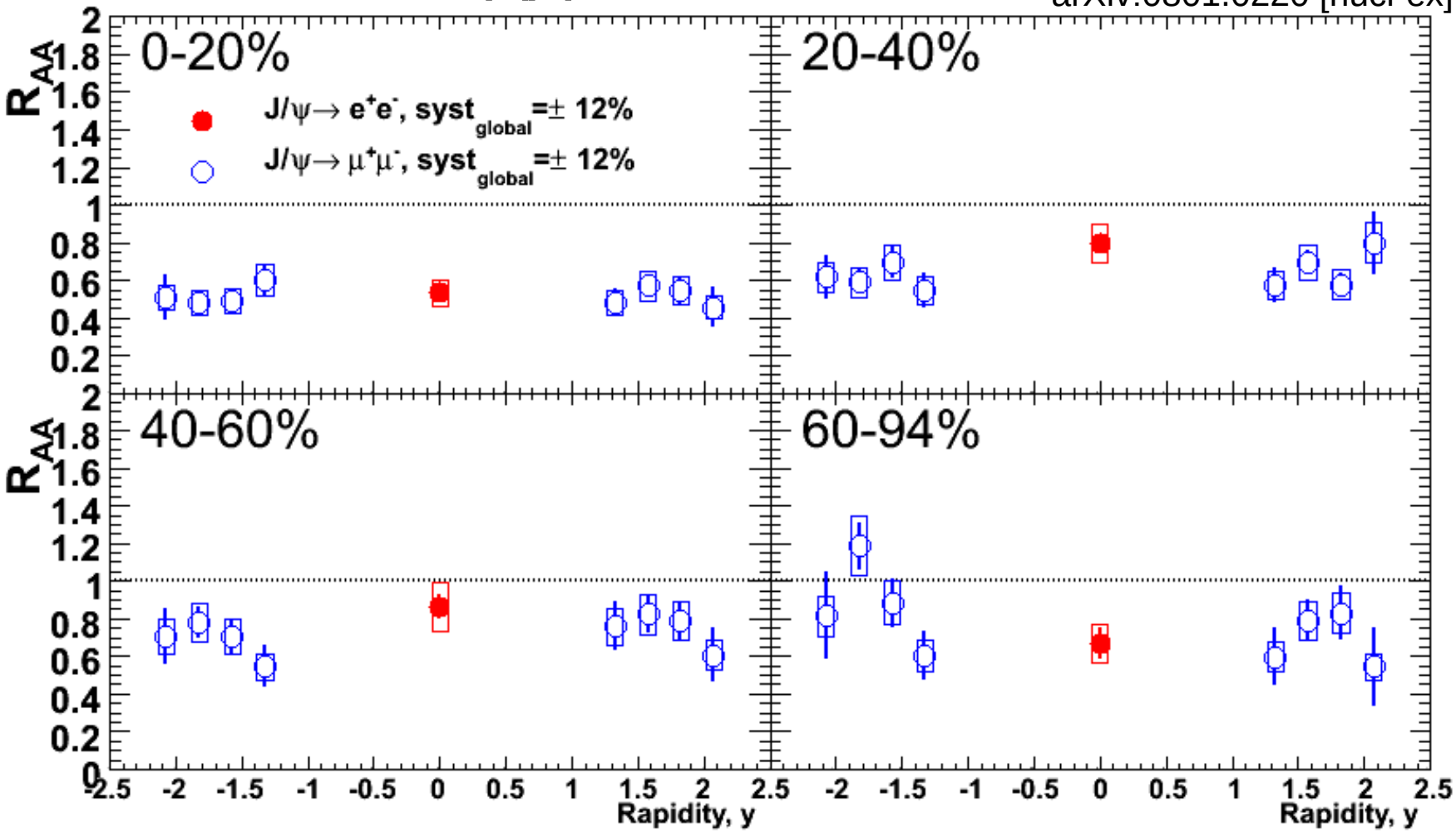
- Recombination of charm quarks could cancel the Cronin and leakage effects.
- Need more statistics to draw a conclusion.

- L. Yan, P. Zhuang and N. Xu, Phys. Rev. Lett. 97, 232301 (2006)
- X. Zhao and R. Rapp, arXiv:0812.2407 [hep-ph]



R_{AA} vs rapidity

arXiv:0801.0220 [nucl-ex]

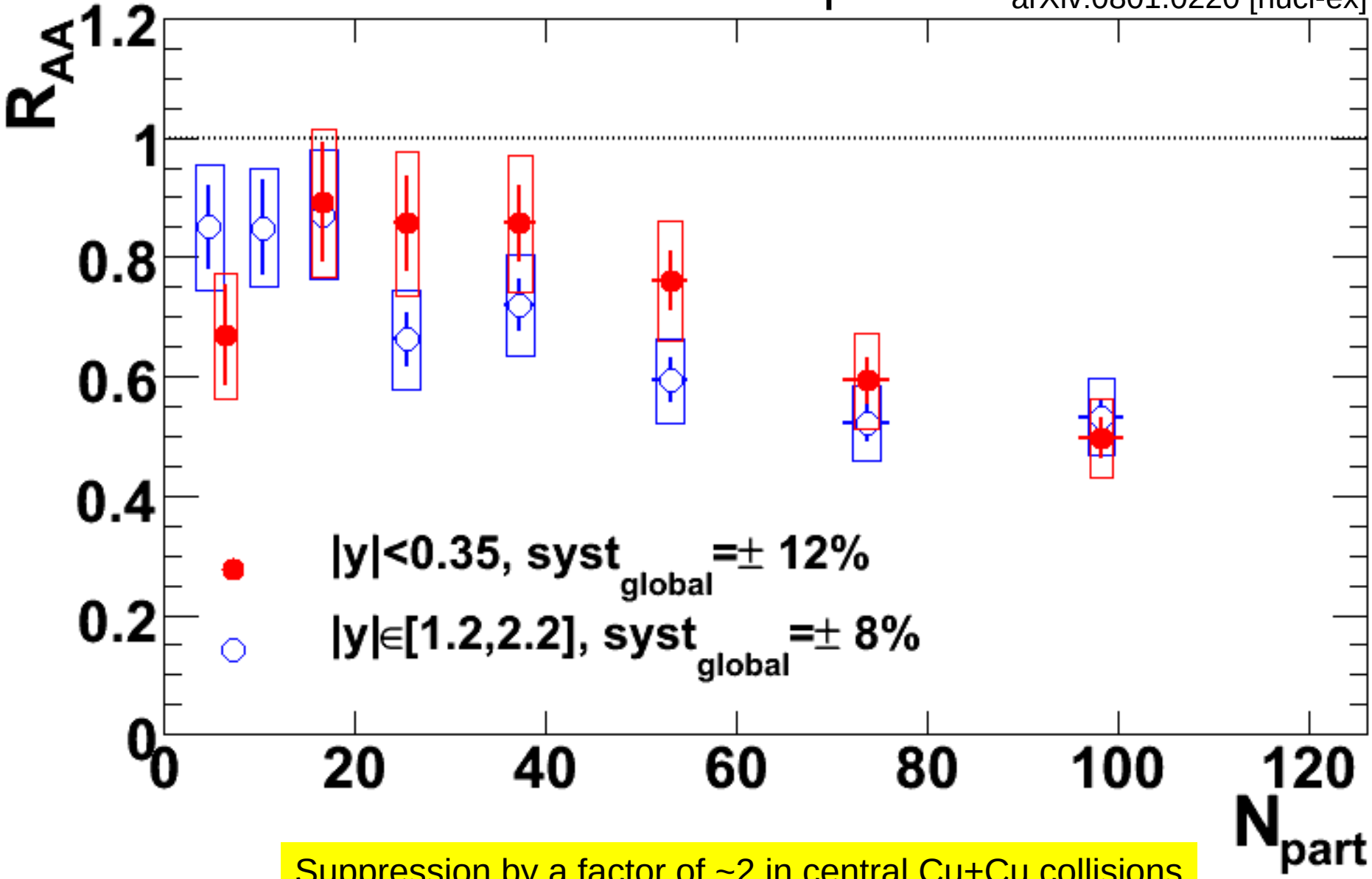


No strong rapidity dependence.

The RMS width of the rapidity distribution is identical within ~2-3% uncertainties in p+p and in all centrality classes for Cu+Cu collisions.

R_{AA} vs N_{part}

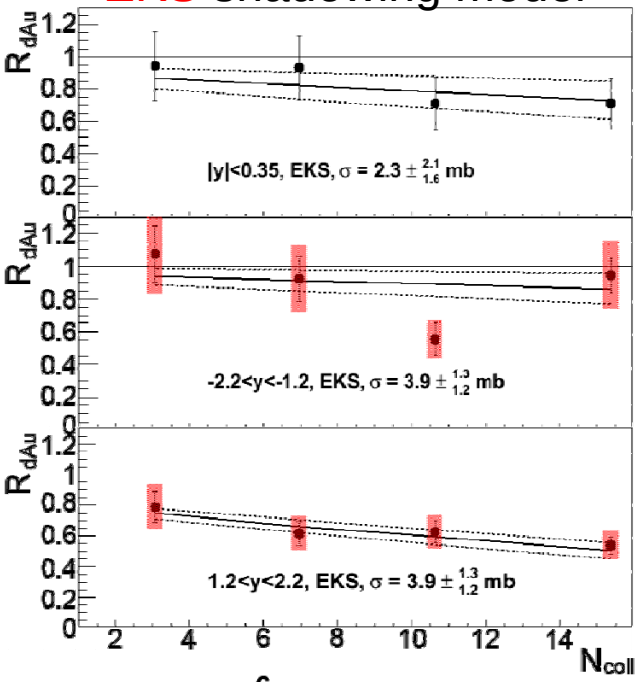
arXiv:0801.0220 [nucl-ex]



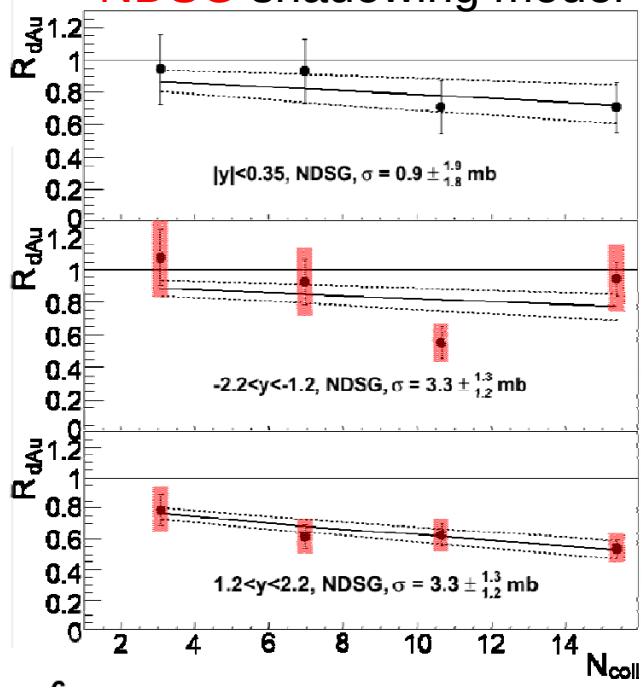
Suppression by a factor of ~2 in central Cu+Cu collisions

Rapidity dependent “effective” nuclear breakup cross sections from d+Au

EKS shadowing model



NDSG shadowing model

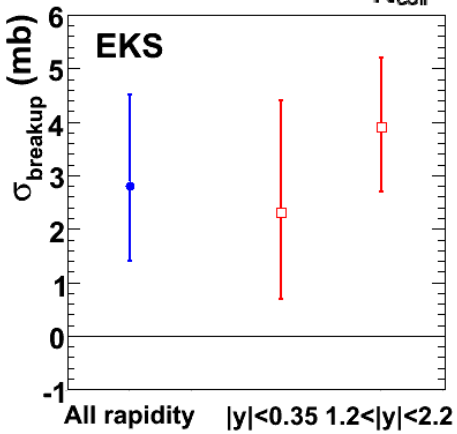


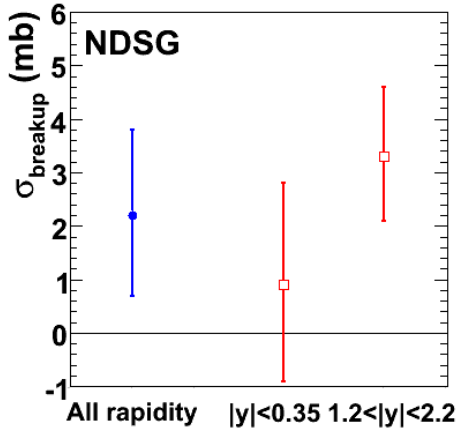
EKS: Eur. Phys. J. C 9. 61 (1999)
NDSG: Phys. Rev. D 69, 074028 (2004)

Midrapidity

Backward rapidity:
Au going direction

Forward rapidity:
d going direction



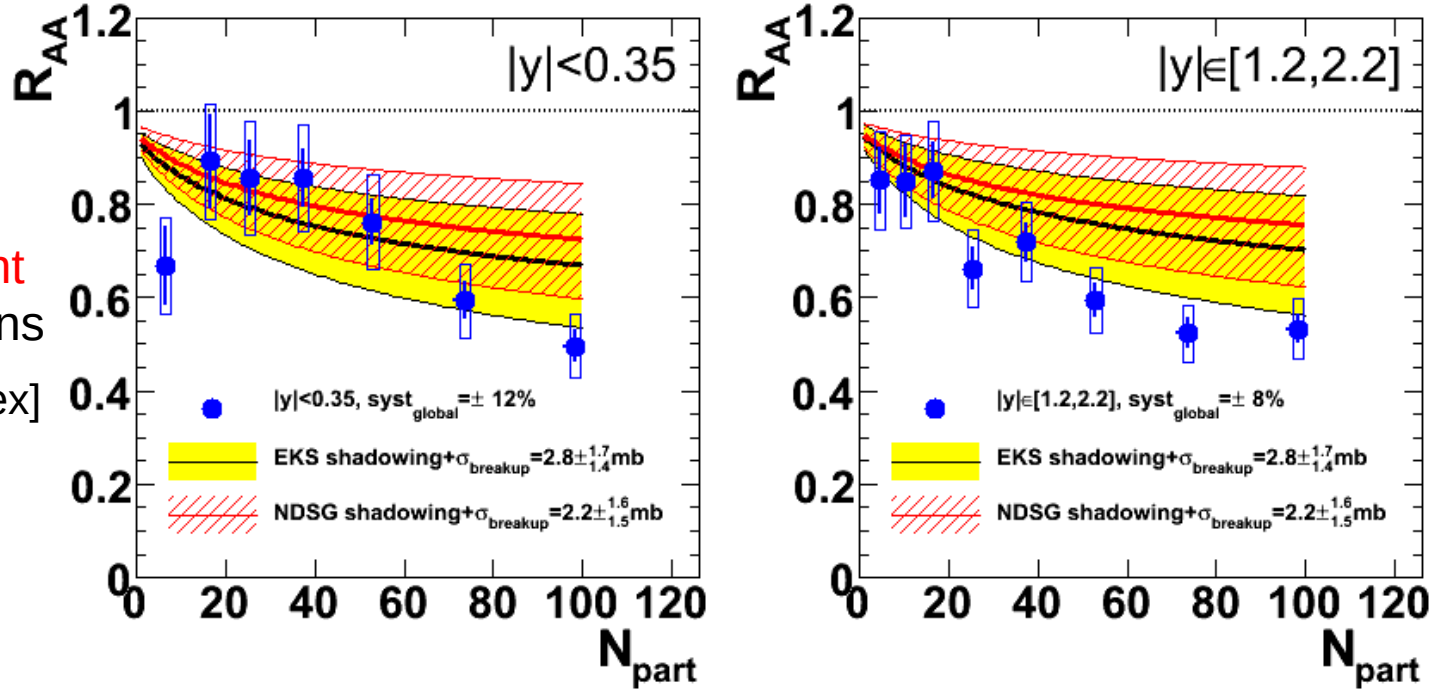


“Effective” breakup cross section is lager at forward rapidity than at midrapidity

arXiv:0801.0220 [nucl-ex]
arXiv:0711.3917 [nucl-ex]

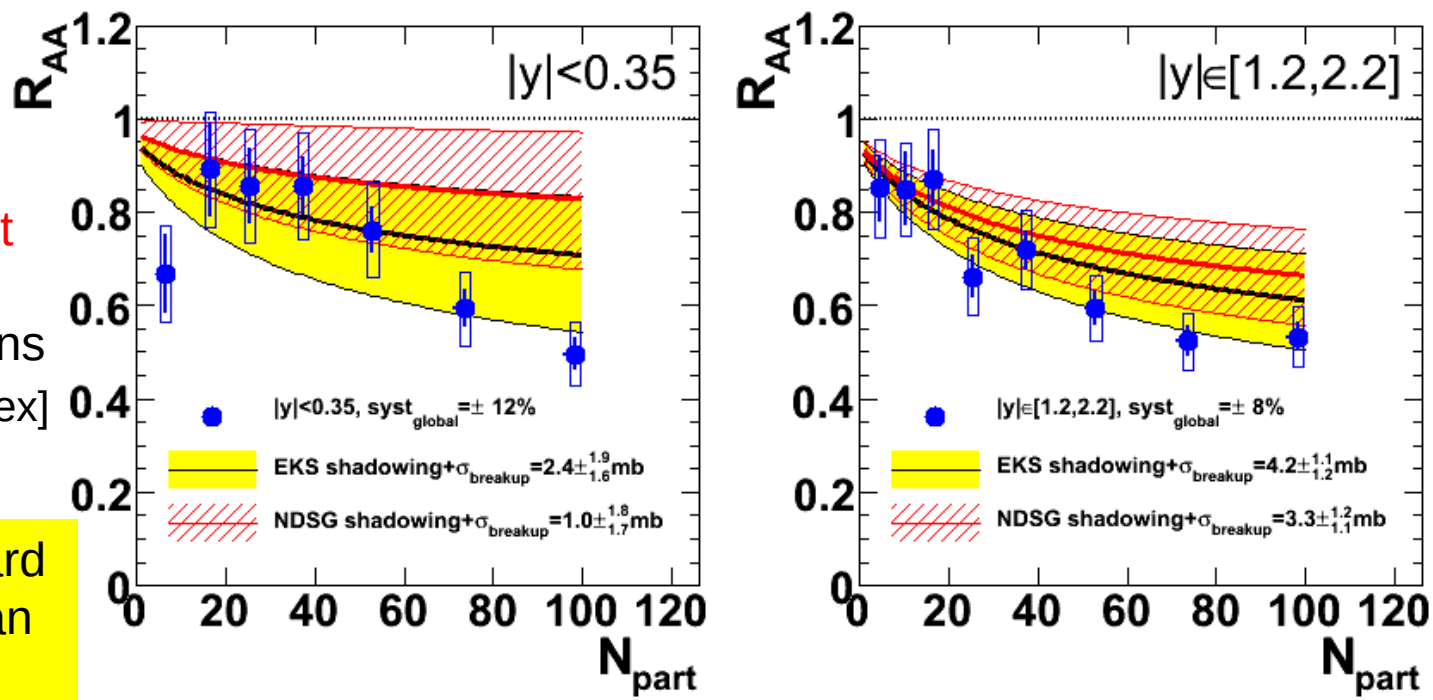
Rapidity independent
breakup cross sections

arXiv:0711.3917 [nucl-ex]



Rapidity dependent
"effective"
breakup cross sections

arXiv:0801.0220 [nucl-ex]



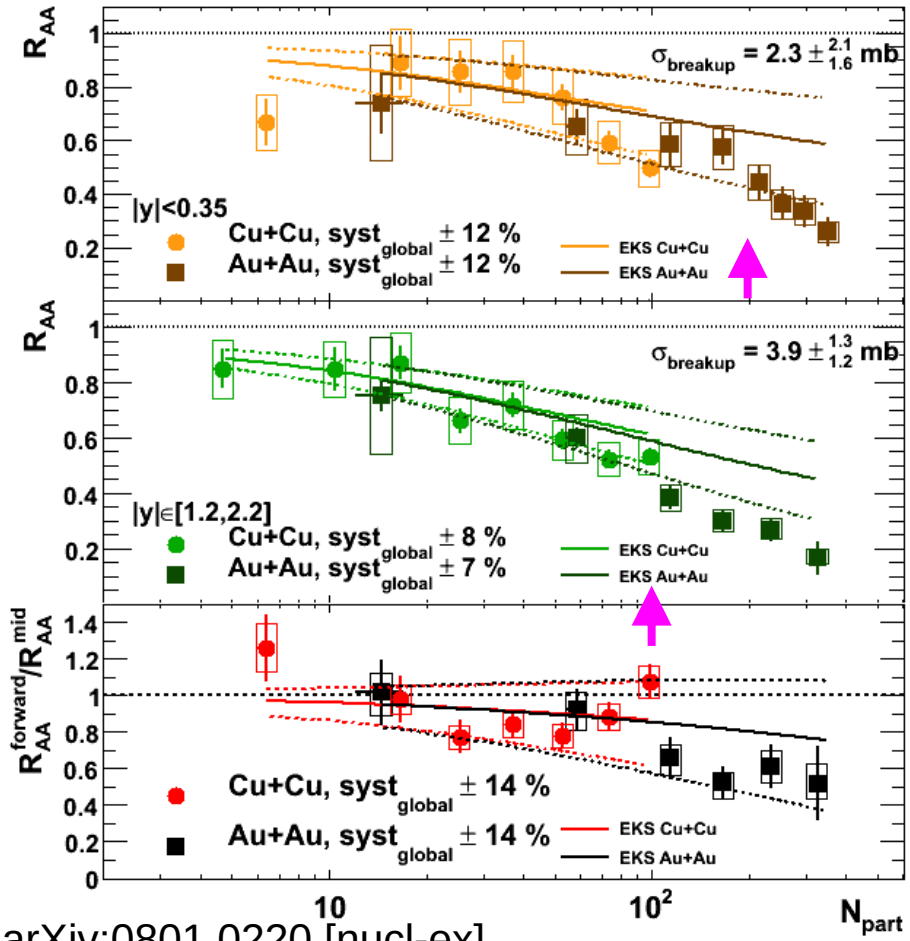
CNM effects at forward rapidity are lager than at midrapidity

Comparison with Au+Au results

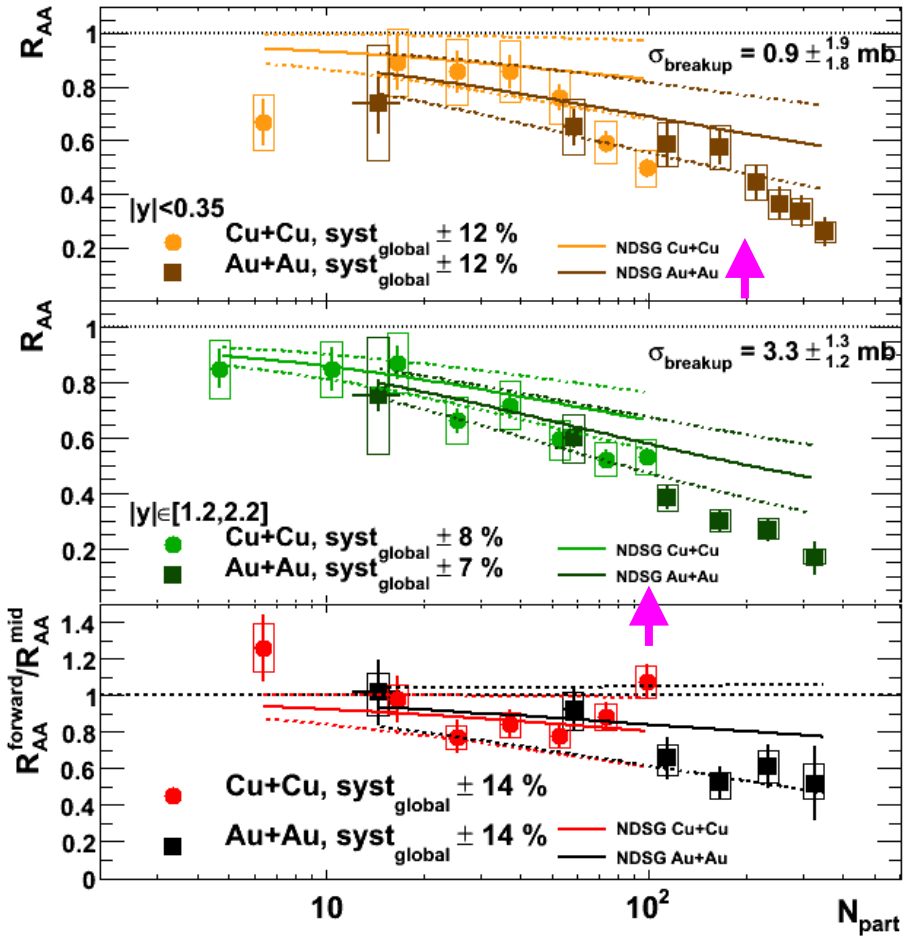
Phys. Rev. Lett. 98, 232301 (2007), arXiv:nucl-ex/0611020

With rapidity dependent "effective" breakup cross sections

EKS shadowing model



NDSG shadowing model



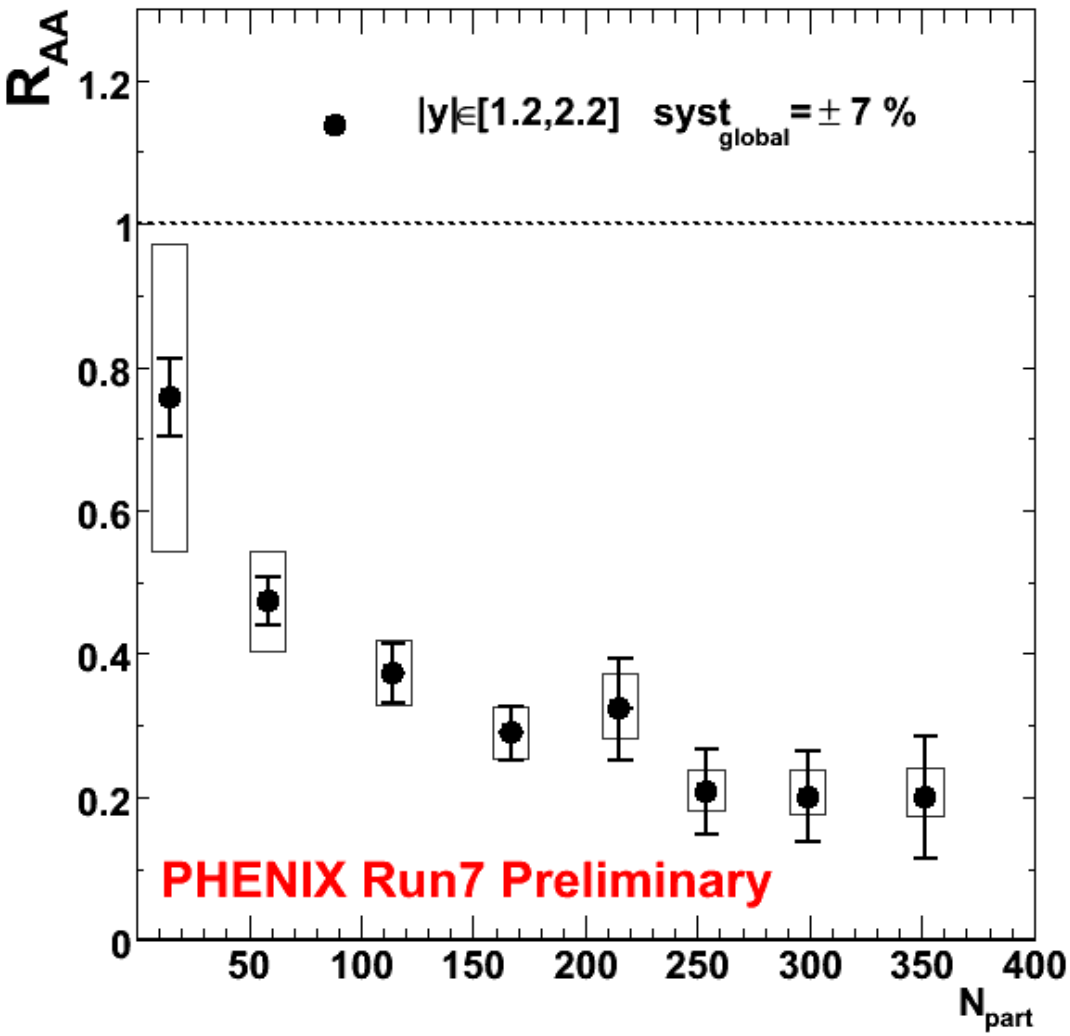
arXiv:0801.0220 [nucl-ex]

Cu+Cu and Au+Au data agree well.

J/ψ suppression below CNM effects seems to start at N_{part}~200/100 at mid/forward rapidity.

Rapidity narrowing in central Au+Au collisions is consistent with CNM effects.

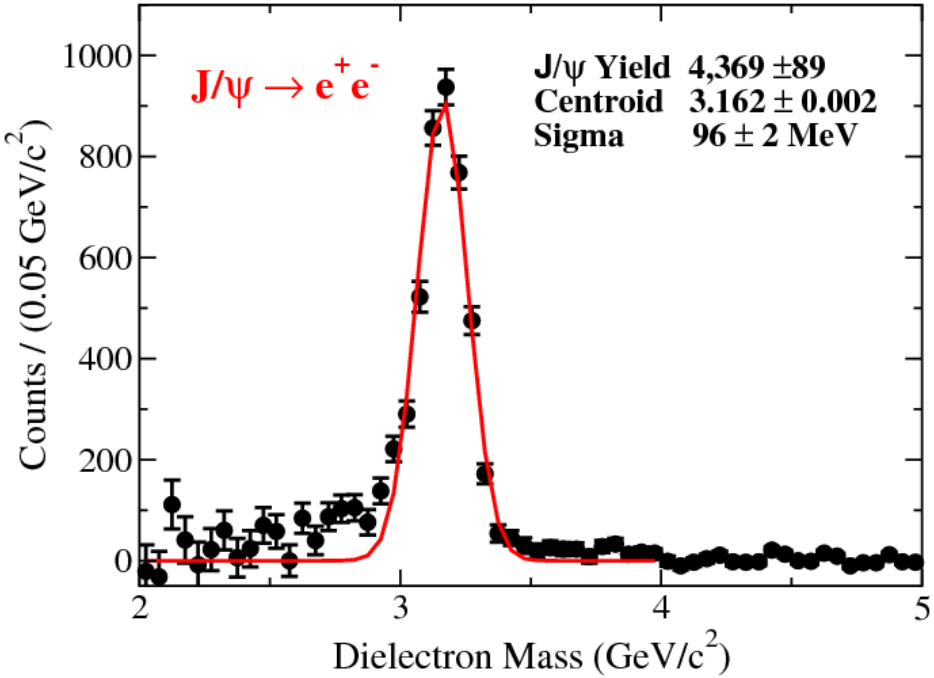
J/ψ at forward rapidity in Au+Au 200GeV with Run-7 data

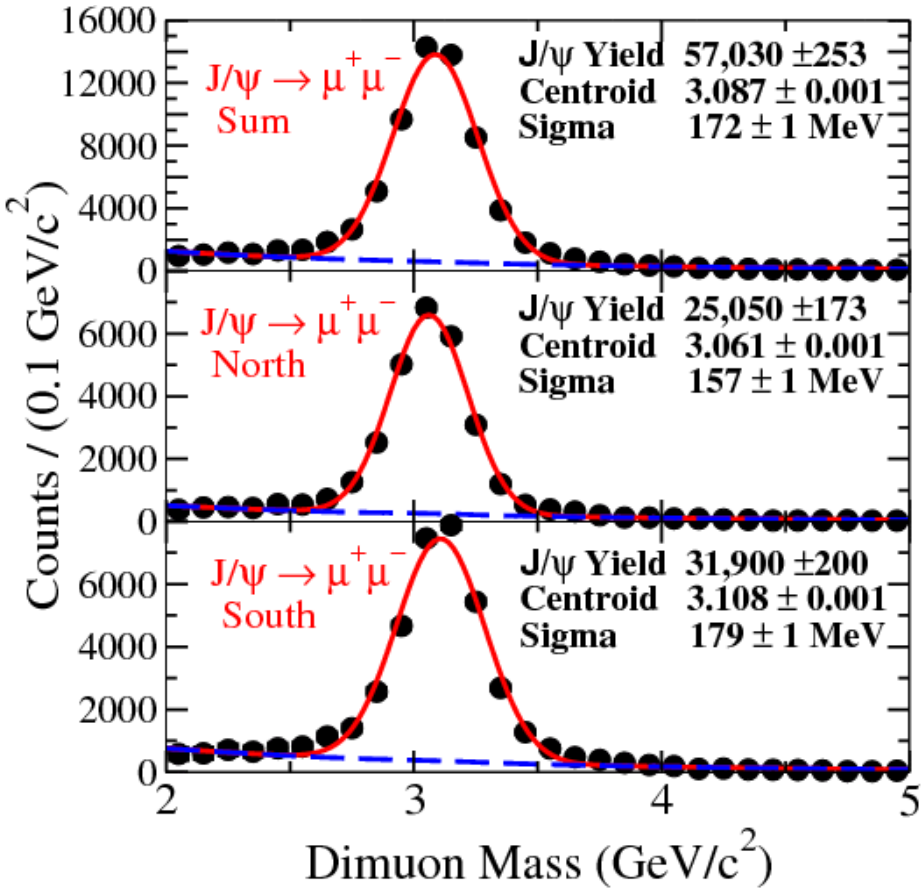


Statistics will increase by a factor of 3 from Run-4 data.

Preliminary Run-7 result at forward rapidity is consistent with published Run-4 result.

J/ψ in d+Au 200GeV with Run-8 data (2.7nb^{-1}(Run-3)→81nb^{-1})

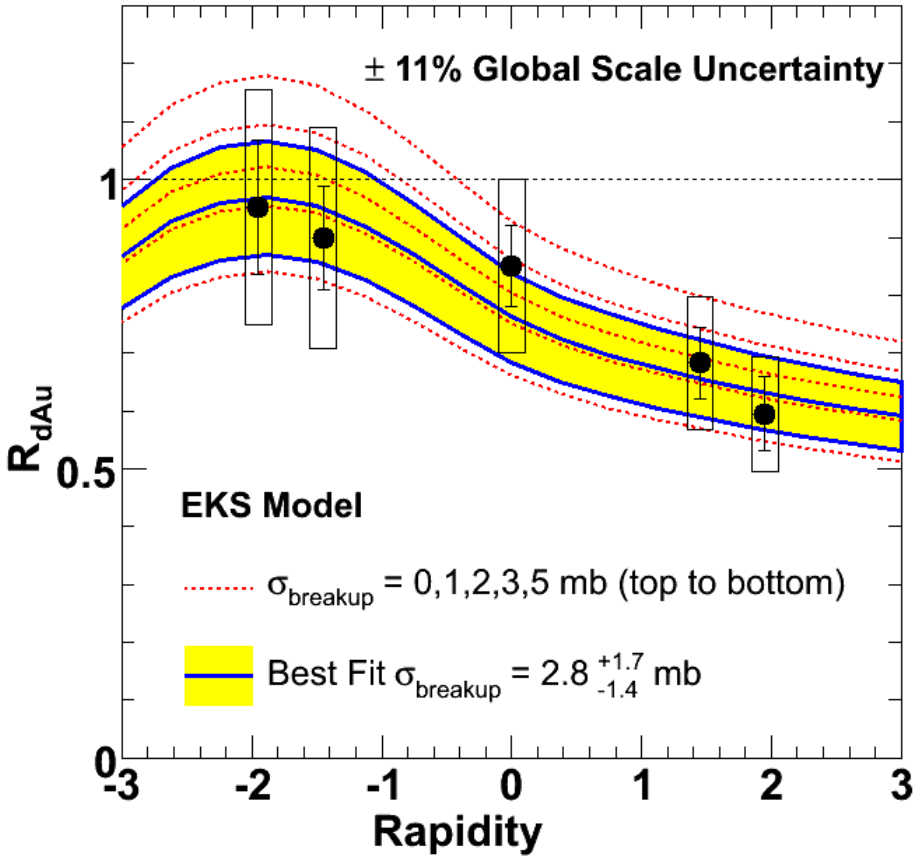
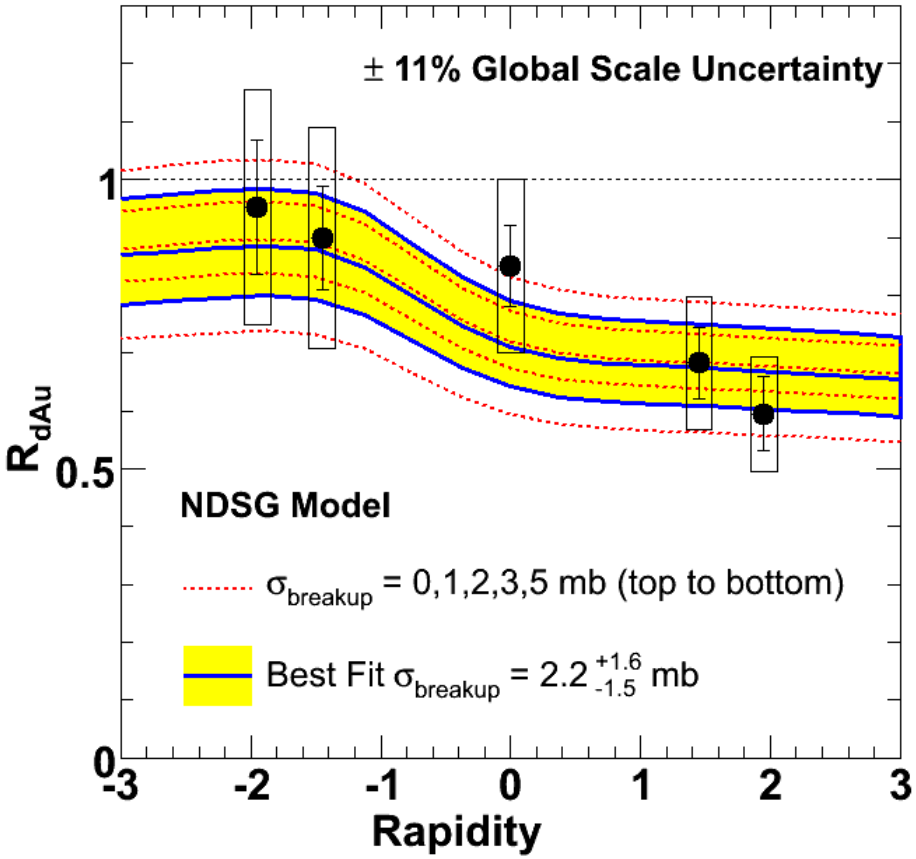




30 times larger statistics will reduce uncertainties of CNM effects.

Conclusion

- Feed-down fractions of J/ψ in p+p collisions have been measured.
- Precise Cu+Cu data has been obtained.
- Cu+Cu and Au+Au data has been compared to cold nuclear matter effects extrapolated from updated d+Au data.
  - CNM predictions agree with data in the small N_{part} region.
  - J/ψ suppression seems to start at N_{part}~200 at midrapidity and ~100 at forward rapidity.
- Although CNM uncertainties are still large, they will be reduced by Run-8 d+Au data.

Backup slides

Updated J/ψ in Run-3 d+Au