# Heavy quarkonia measurements at STAR

**Outline**

1. Motivations
2. STAR Detectors
3. Triggers & Technique
4. Results
5. Summary


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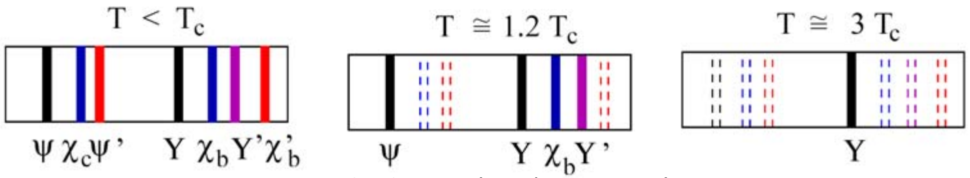
***For the STAR Collaboration***

# Motivation: J/ψ in heavy ion collisions




*H. Satz, Nucl. Phys. A (783):249-260(2007)*

- **J/ψ suppression at low $p_T$ maybe only from excited stats (ψ', $\chi_c$)**

F. Karsch, D. Kharzeev and H. Satz, PLB 637, 75 (2006)

- **Hot wind dissociation → high $p_T$ direct J/ψ suppression**

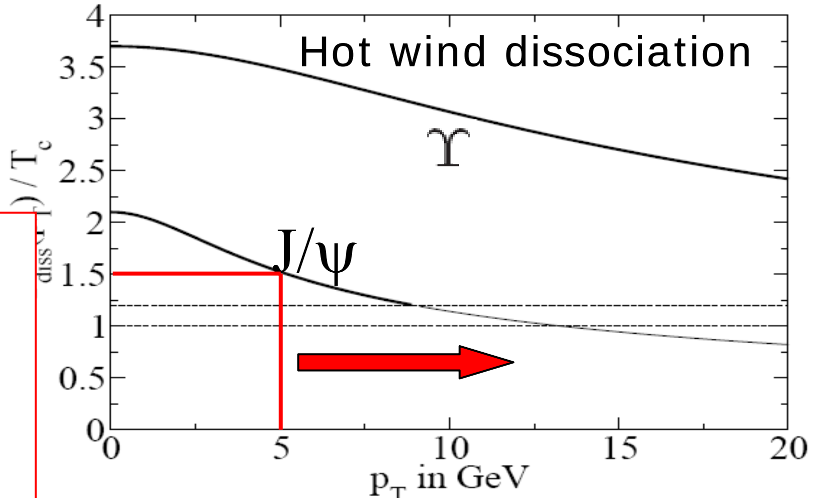
- **2-component approach: dissociation + recombination**

$R_{AA}$ decreases slightly or flat with $p_T$ X. Zhao and R. Rapp, hep-ph/07122407

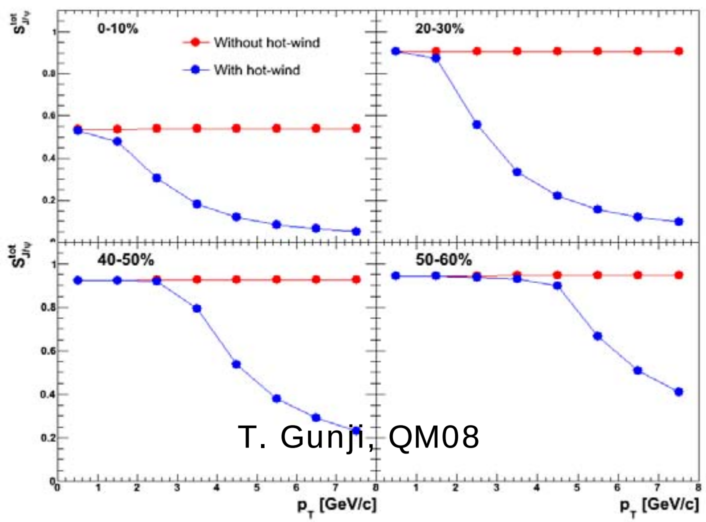
$R_{AA}$ increase slightly with $p_T$ including formation time and B decay X. Zhao, WWND2008

- **Color singlet model:**

$R_{AA}$ increase with $p_T$ (formed out of medium) *F. Karsch and R. Petronzio, PLB 193(1987), 105 ; J.P. Blaizot and J.Y. Ollitrault, PLB 199(1987),499*




H. Liu, K. Rajagopal and U.A. Wiedemann
PRL 98, 182301(2007) and hep-ph/0607062
M. Chernicoff, J. A. Garcia, A. Guijosa hep-th/0607089



# J/ψ production mechanism in p+p

**What's the production mechanism at RHIC energy?**

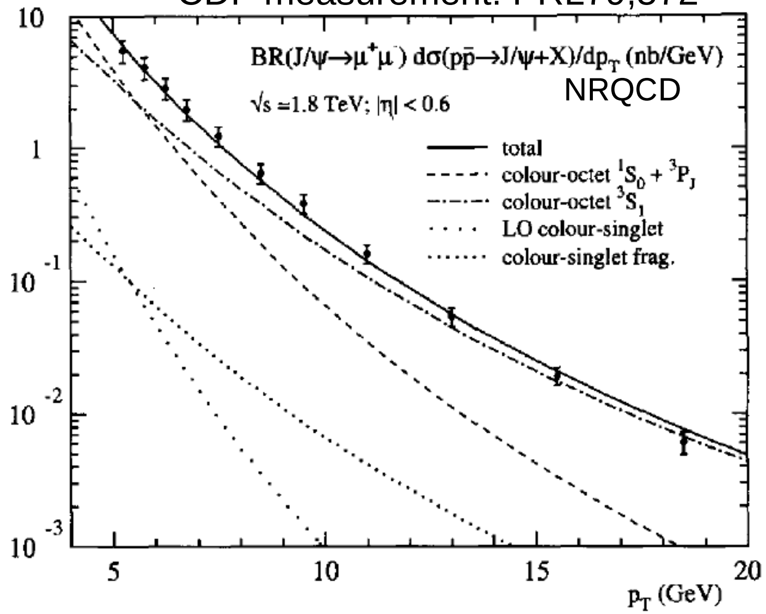
1. Color singlet model (CSM) [1] → pQCD
2. Color octet model (COM) [2] → Non-Relativistic QCD (NRQCD)
3. Color evaporation model (CEM) [3]
4. …

Contribution might be from:

- Gluon fusion
- Heavy quark fragmentation [4]
- Gluon fragmentation [5]
- Decay feed-down
- …

How do we distinguish different production mechanism and different source contribution?

CDF measurement: PRL79,572



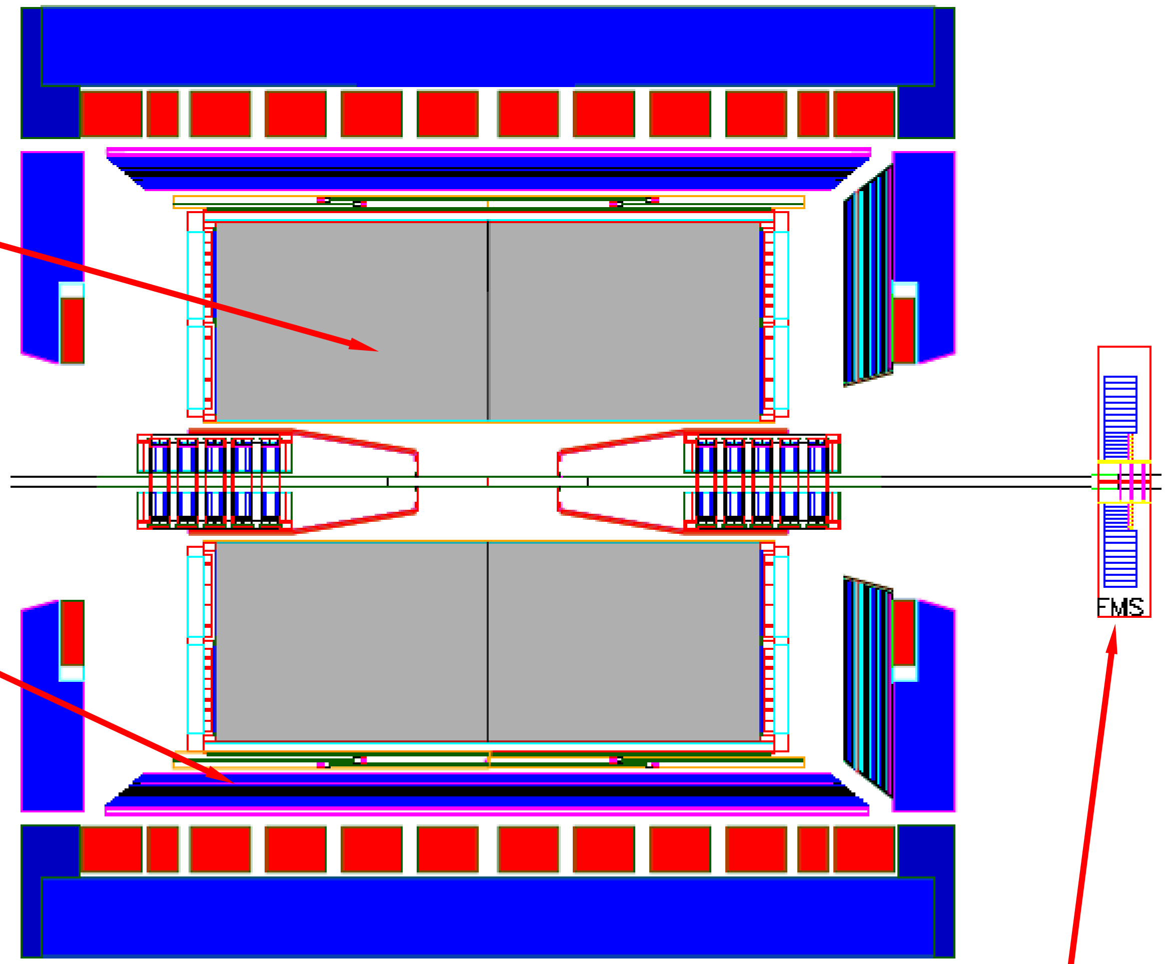


1) R. Baier et al., PLB 102, 364 (1981)
2) M. Kramer, Progress in Particle and Nuclear Physics 47, 141 (2001)
3) H. Fritzsch, PLB 67, 217 (1977)
4) Cong-Feng Qiao, hep-ph/0202227
5) K. Hagiwara et al., hep-ph/0705.0803

# STAR detector for quarkonia measurements

- TPC
  - Acceptance: $|\eta| < 1$ , $0 < \phi < 2\pi$
  - Tracking => momentum
  - e ID: ionization energy loss

- BEMC
  - Acceptance: $|\eta| < 1$ , $0 < \phi < 2\pi$
  - e ID : E/p, shower size
  - High-energy tower trigger



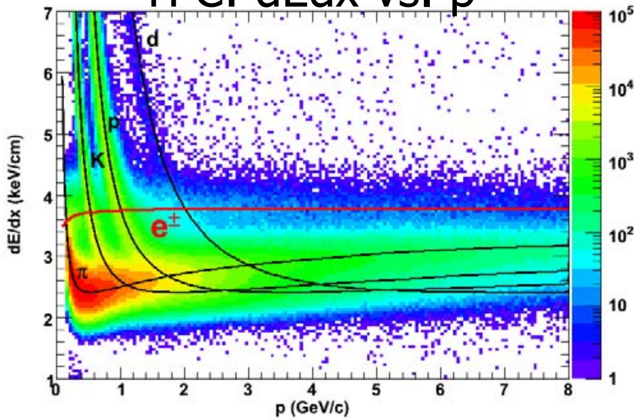

Forward Meson Spectrometer

# STAR triggers for quarkonia measurements

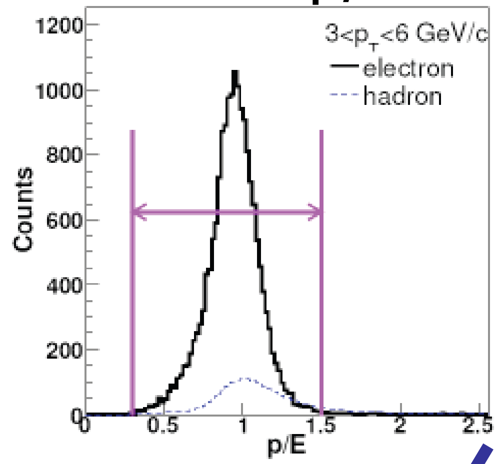
- Minimum Bias trigger
  - BBC; ZDC; VPD
- Cascade high energy tower triggers (hardware)
  - different thresholds for $E_T$
  - Help sampling full luminosity
- L2 trigger (software)
  - Tower Clustering
  - Further select on the high towers topology
  - Use CTB/TOF to reject photon
  - Large rejection factor

# eID capability at STAR

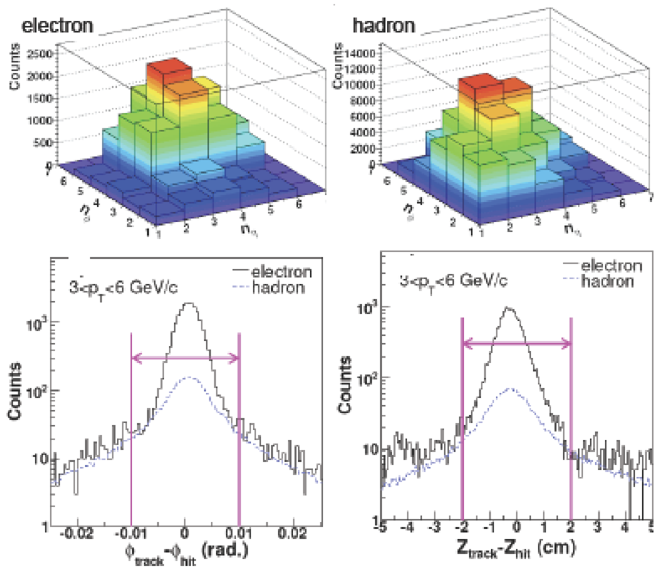
TPC: dEdx vs. p

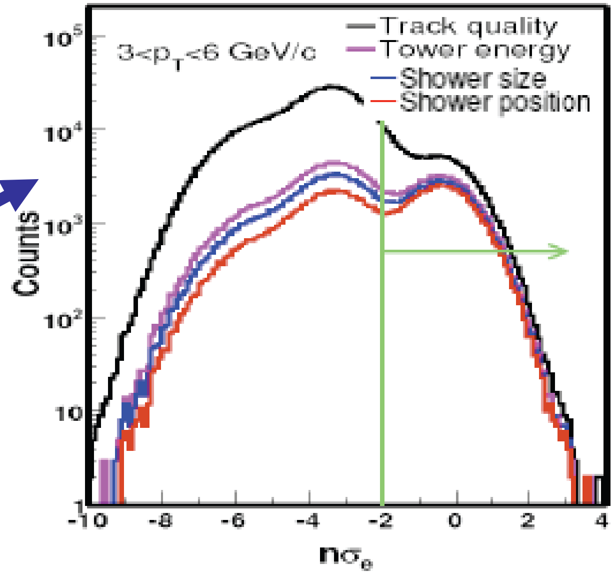



EMC: p/E




BSMD: shower size for e(h)

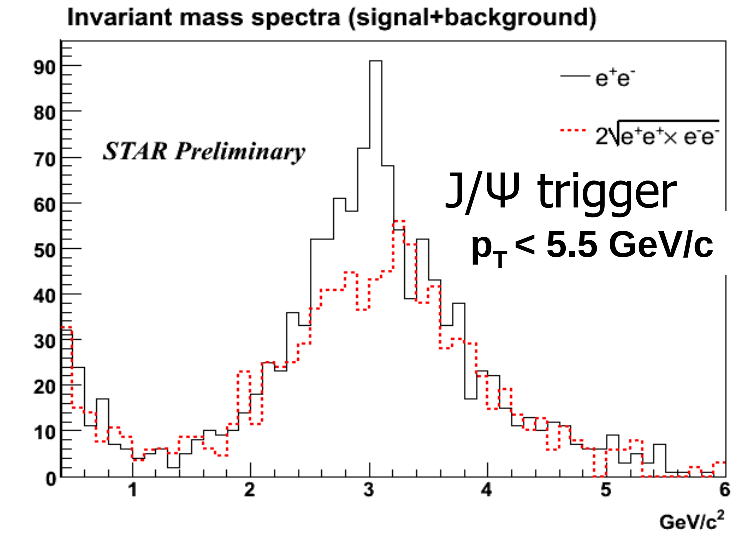


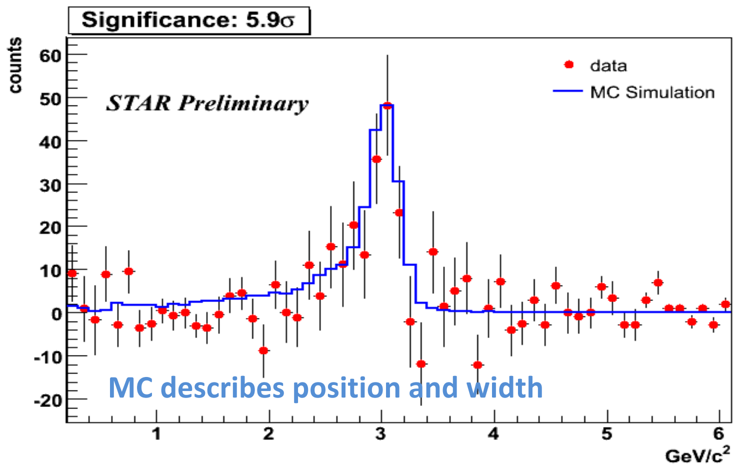



# J/$\psi$ production at STAR
# (mid-rapidity region)

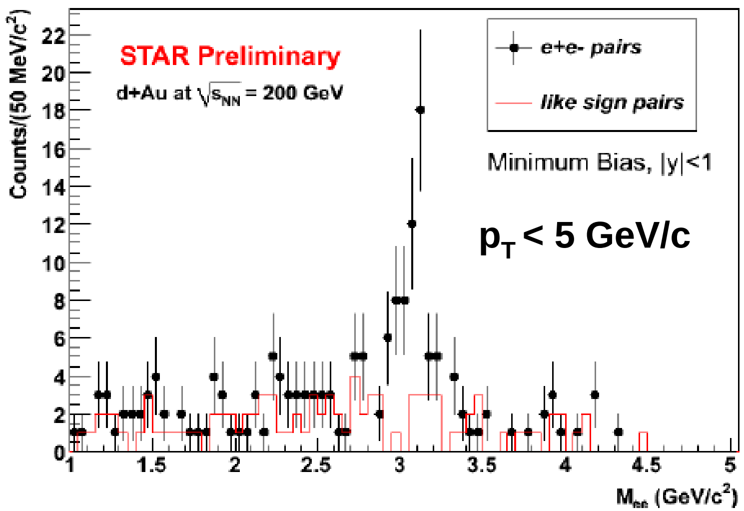
# Low $p_T$ J/ψ in p+p & d+Au

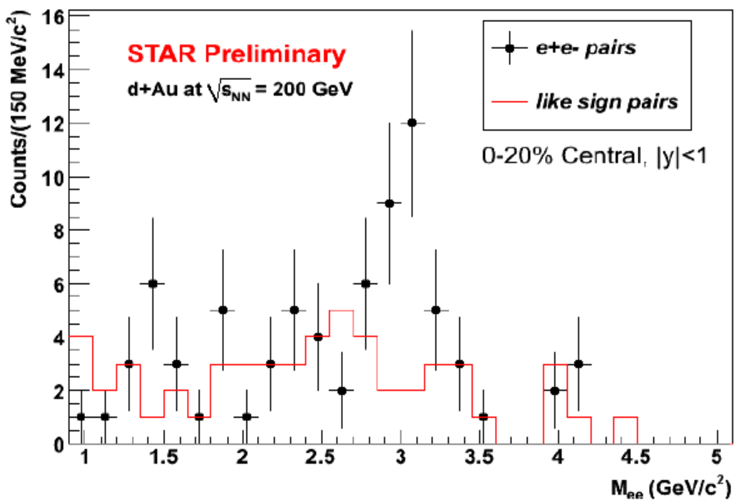
## p+p 200 GeV



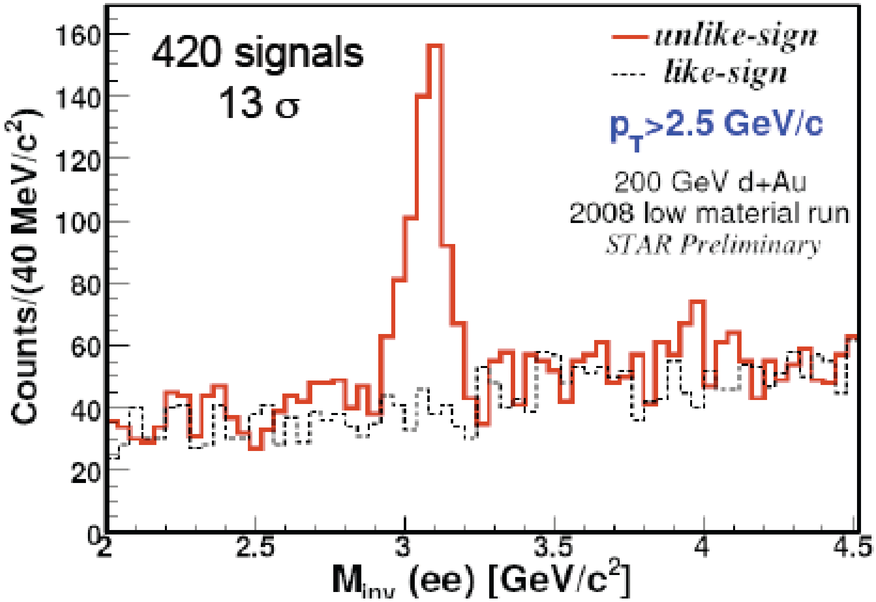



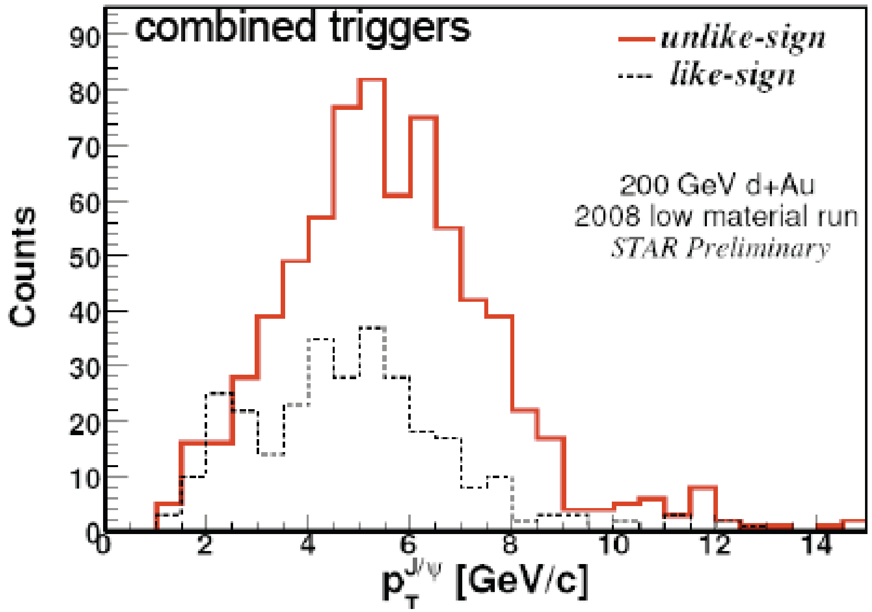

## d+Au 200 GeV



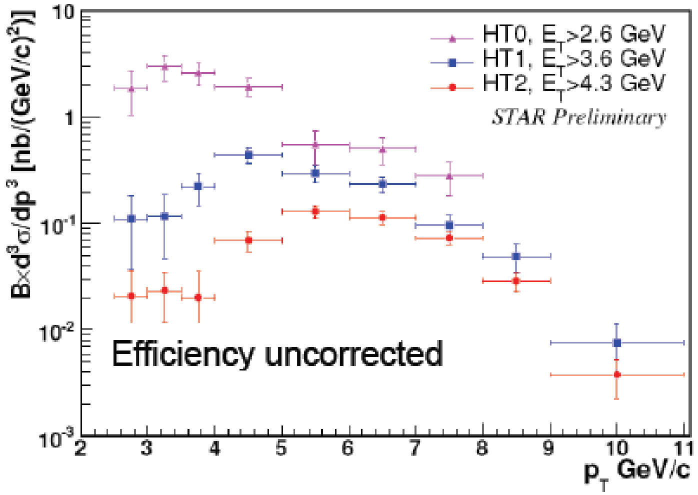



# high pt J/Psi in dAu




Efficiency corrected spectra study is in progress

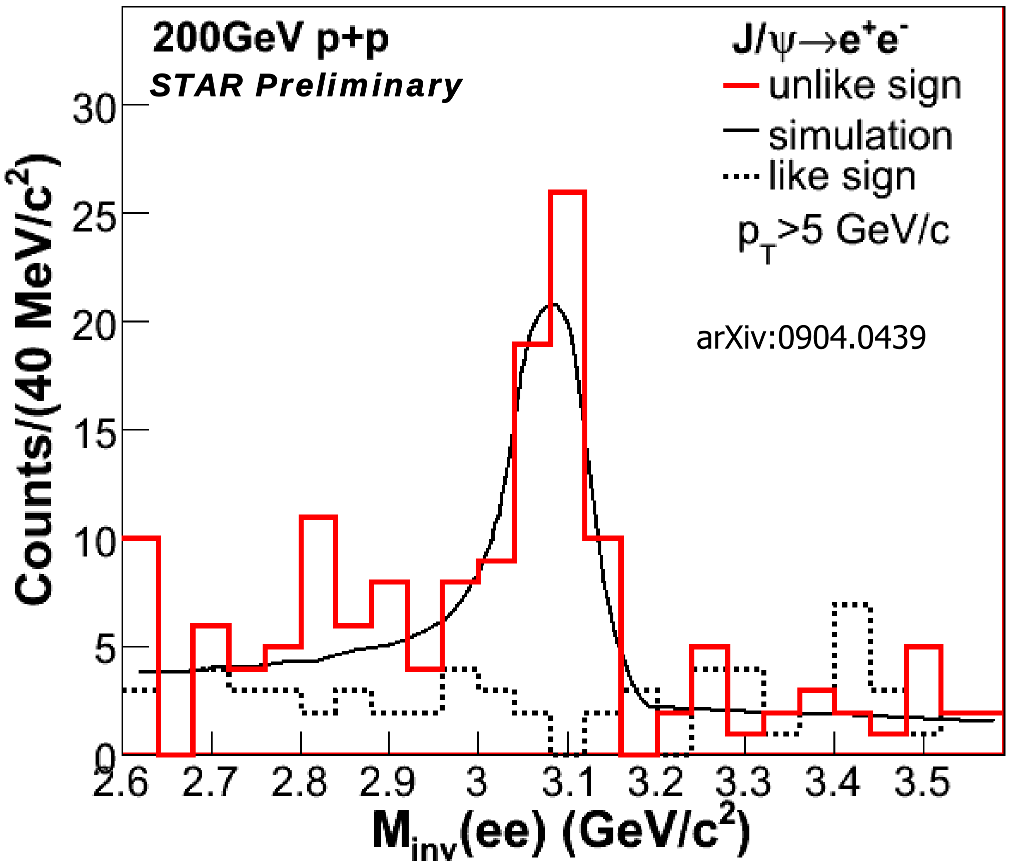


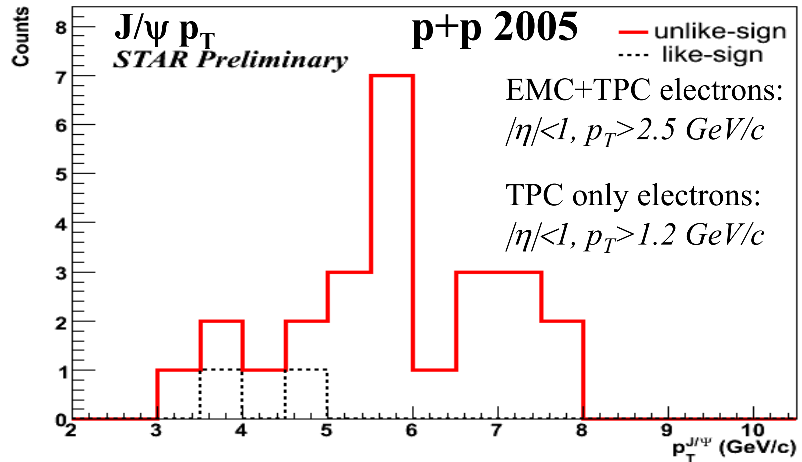

**$p_T$ up to 11 GeV/c**

# High $p_T$ J/ψ in p+p

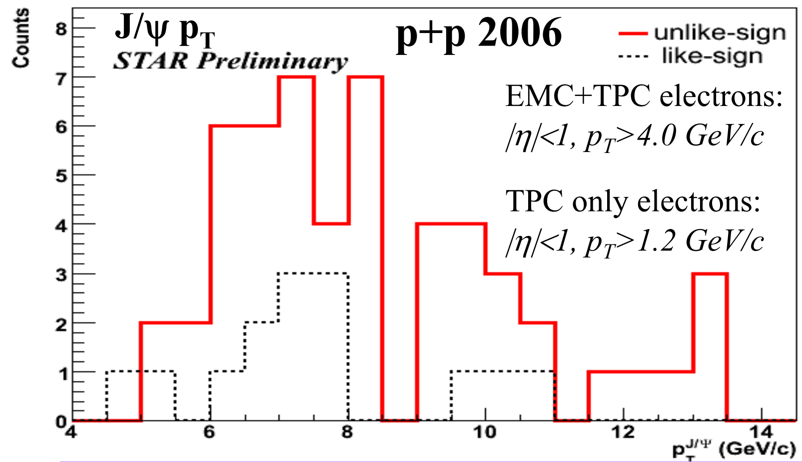
**EMC (High Tower) trigger:**

$5 < p_T < 14$ GeV/c



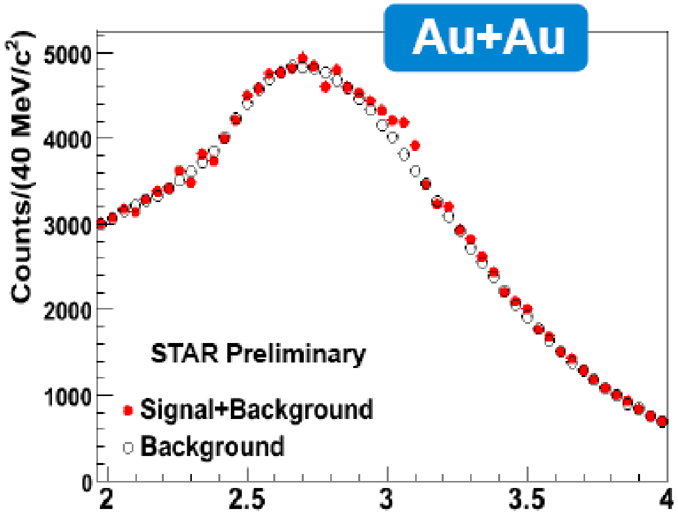



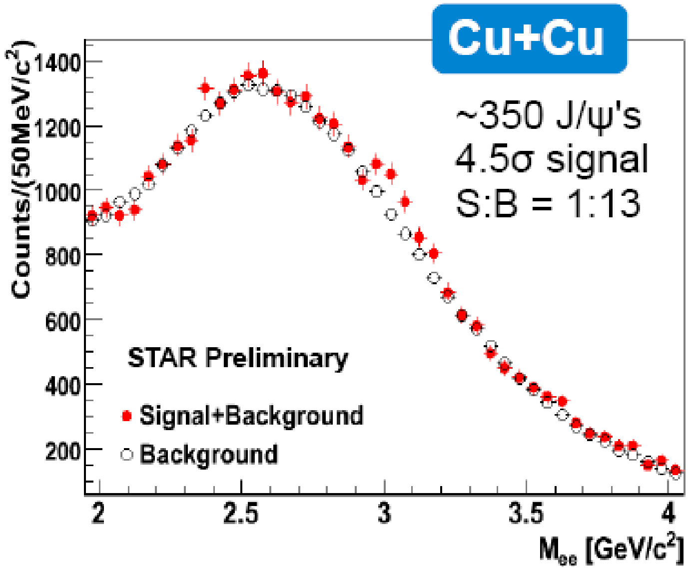

No background at $p_T$>5 GeV/c



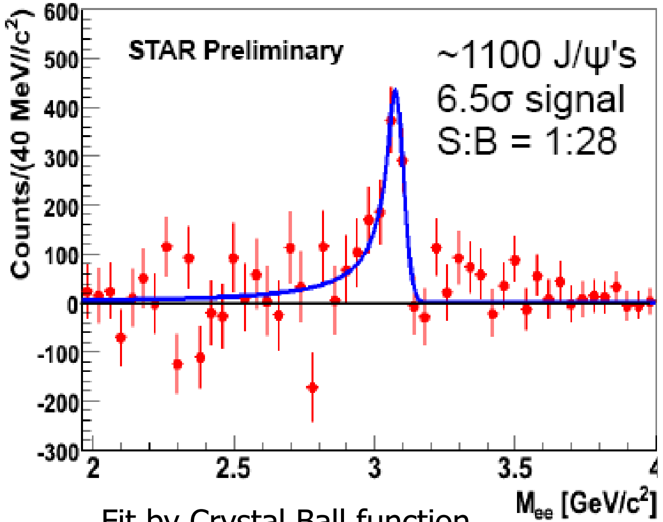

Reach higher $p_T$ (~14 GeV/c)

# J/ψ in heavy-ion collisions




Low $p_T$

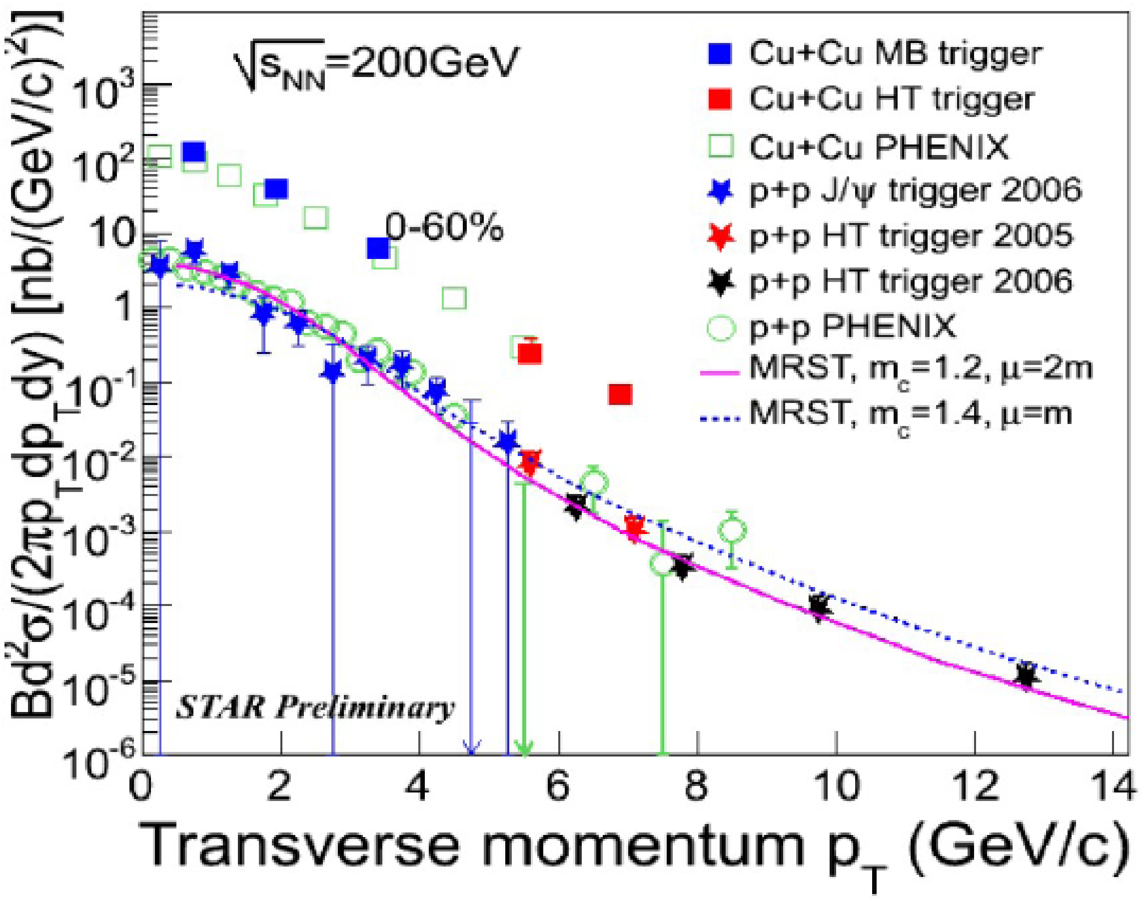



Fit by Crystal Ball function

High $p_T$

| | $p+p$ (2005) | $p+p$ (2006) | Cu+Cu |
|---|---|---|---|
| MB trigger | BBC | BBC | ZDC |
| $E_T$ (GeV) | $> 3.5$ | $> 5.4$ | $> 3.75$ |
| Sampled int. lumi | 2.8 $pb^{-1}$ | 11.3 $pb^{-1}$ | 860 $\mu b^{-1}$ |
| $p_{T1}$ (GeV/$c$) | $> 2.5$ | $> 4.0$ | $> 3.5$ |
| $p_{T2}$ (GeV/$c$) | $> 1.2$ | $> 1.2$ | $> 1.5$ |
| $J/\psi$ $p_T$ (GeV/$c$) | 5-8 | 5-14 | 5-8 |
| $J/\psi$ counts | $32 \pm 6$ | $51 \pm 10$ | $23 \pm 10$ |
| S/B | 9:1 | 2:1 | 1:4 |

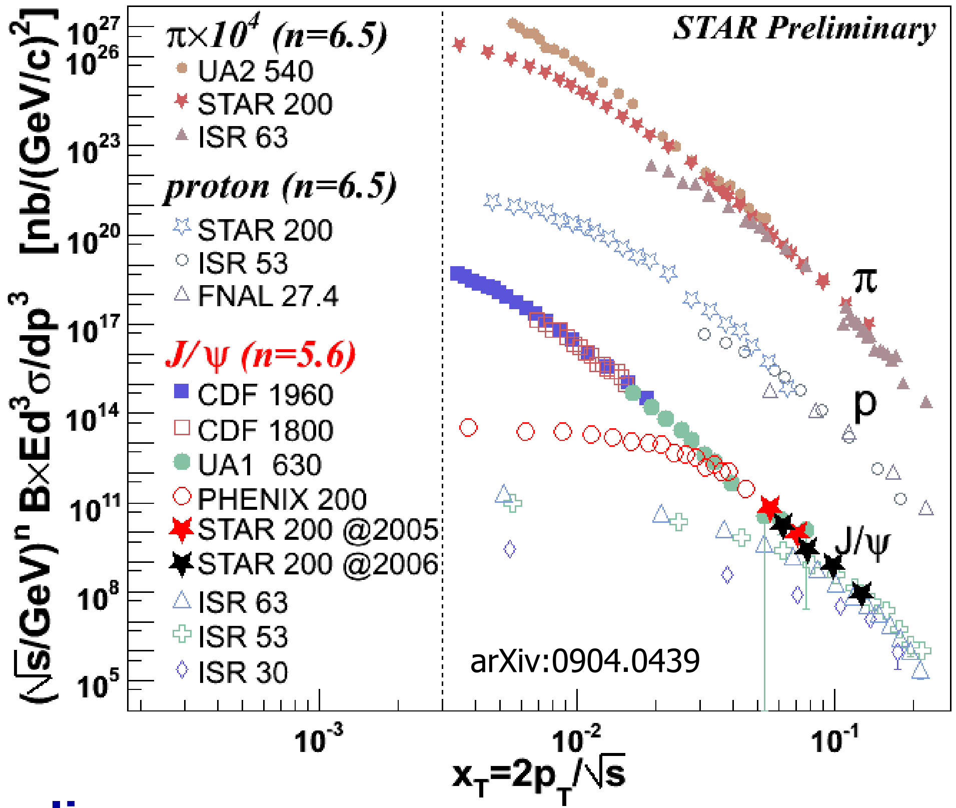
# J/ψ spectra in p+p and Cu+Cu at 200 GeV




- **Significantly extend $p_T$ range of previous measurements in p+p at RHIC to 14 GeV/c, which allows to distinguish different theoretical calculations**

- **Consistent with Color-Evaporation calculations (R. Vogt, Private communication)**

# $x_T$ scaling in p+p collisions




$$E\frac{d^3\sigma}{dp^3} = \frac{g(x_T)}{s^{n/2}}$$

**n is related to the number of point-like constituents taking an active role in the interaction**

## $x_T$ scaling:

1. π and proton at $p_T$>2 GeV/c: n=6.5±0.8
   *(PLB 637, 161(2006))*
2. J/ψ at $p_T$>5 GeV/c: **n=5.6±0.2**
3. Soft processes affect low $p_T$ J/ψ production

**n~6**

**Color Octet**

*(Nayak PRD68 034003 (2003))*

**Color-Evaporation**

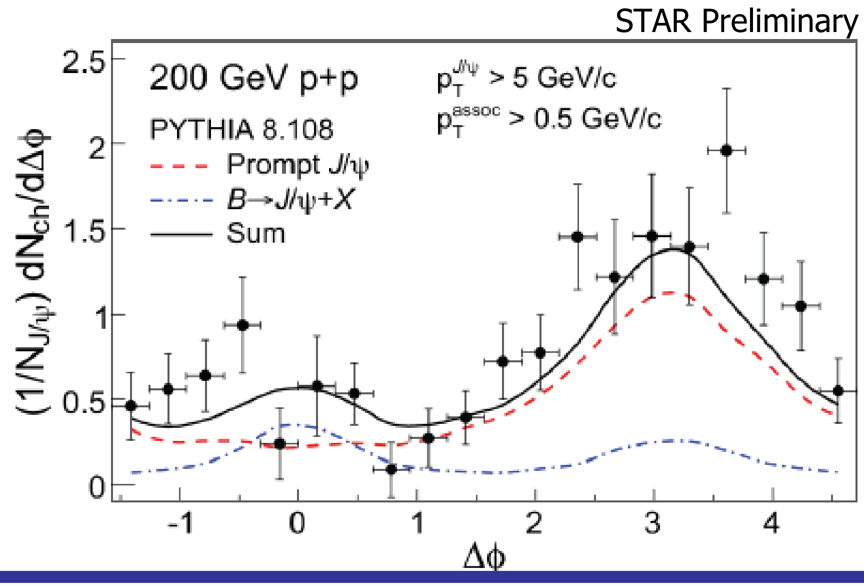
*(Vogt private communication)*

**n~8**

**(NNLO*) Color Singlet**

*(Artoisenet PRL 101, 152001 (2008))*

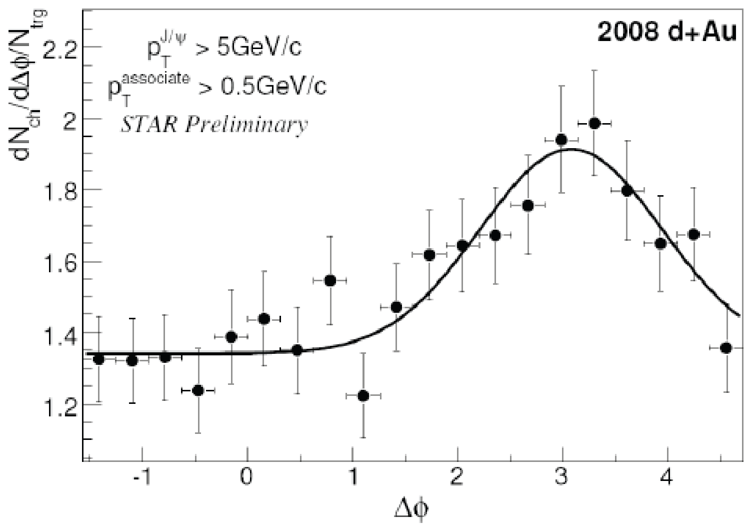
# J/ψ - hadron correlation in pp & dAu




p+p

$$\frac{B->J/\Psi}{inclusive} = (13 \pm 5)\% \quad (p_T^{J/\psi} > 5\,GeV/c)$$

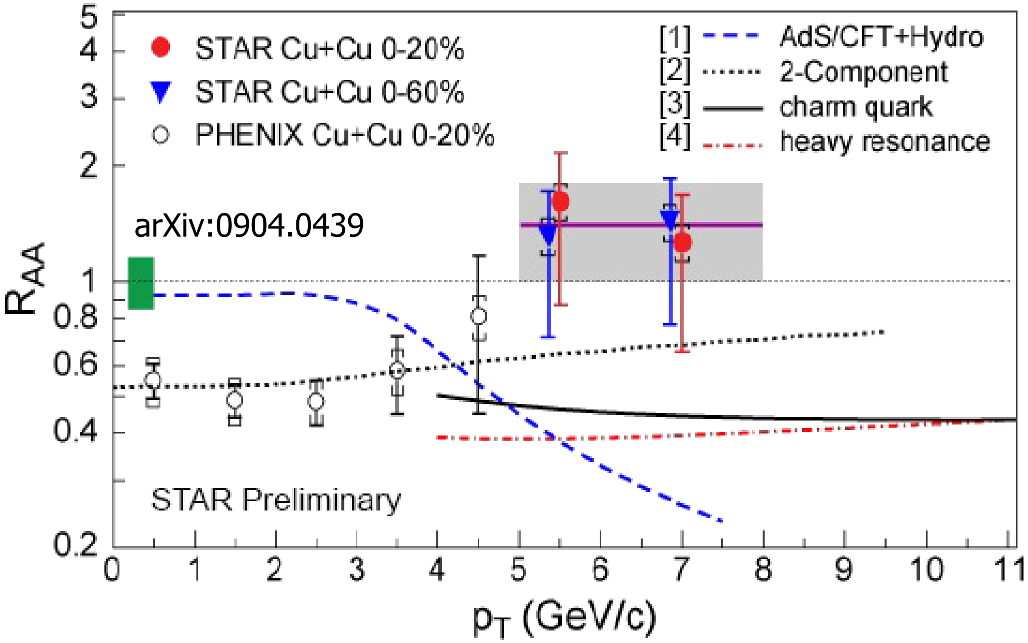
arXiv:0904.0439




d+Au

Need further efficiency correction to constrain the contribution from B mesons

# J/ψ $R_{AA}$ at high $p_T$




At $p_T$ > 5 GeV/c

$$R_{AA}^{0\sim20\%} = \mathbf{1.4 \pm 0.4(stat.) \pm 0.2(sys.)}$$

J/ψ is the only hadron measured in RHIC HI collisions that doesn't exhibit significant high $p_T$ suppression

[1] Ads/CFT+ hydro (hot wind) : J/ψ is embedded in a hydrodynamic model and the $T_{diss}$ decreases with the increasing of relative velocity (hot wind) *(Liu PRL 98, 182301(2007) & Gunji JPG 25, 104137 (2008))*

[2] 2-Component model includes color screening, hadronic phase dissociation, stat. ccbar coalescence at the hadronization transition, J/ψ formation time effects and B-meson feeddown *(Zhao and Rapp arXiv:0712.2407)*

[3] & [4] are open charm $R_{AA}$ calculation by WHDG model *(Wicks NPA 784, 426 (2007))* and a GLV model *(Adil and Vitev PLB 649, 139 (2007))*

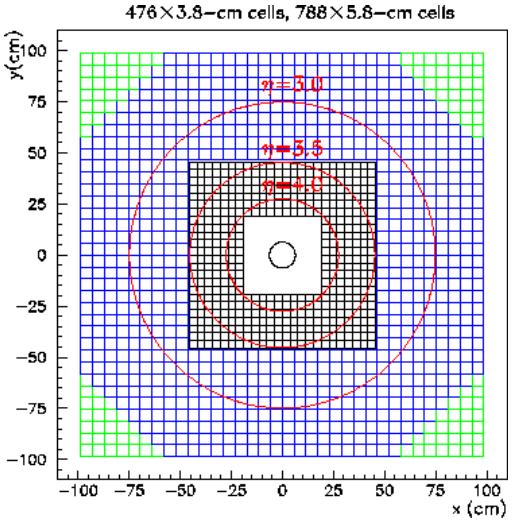
# J/$\psi$ production at STAR
# (forward-rapidity region)

# J/ψ production at forward region in p+p

High-$x_F$ J/ψ measurement provides insight regarding intrinsic heavy flavor within the proton

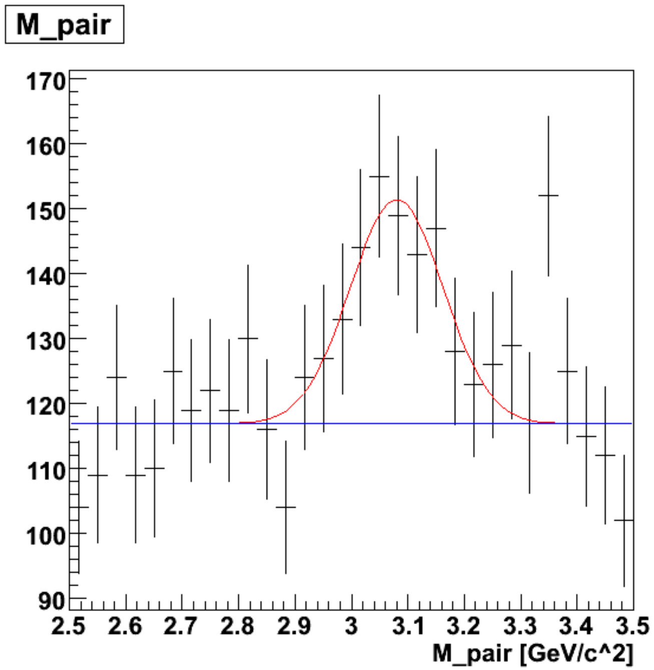
**Forward Meson Spectrameter (FMS)**
Full azimuthal coverage for 2.5 < $\eta$ < 4

STAR Preliminary




**Trigger in p+p:**
FMS High Tower + BBC Minbias
(~ 6 $pb^{-1}$ Sampled Luminosity)

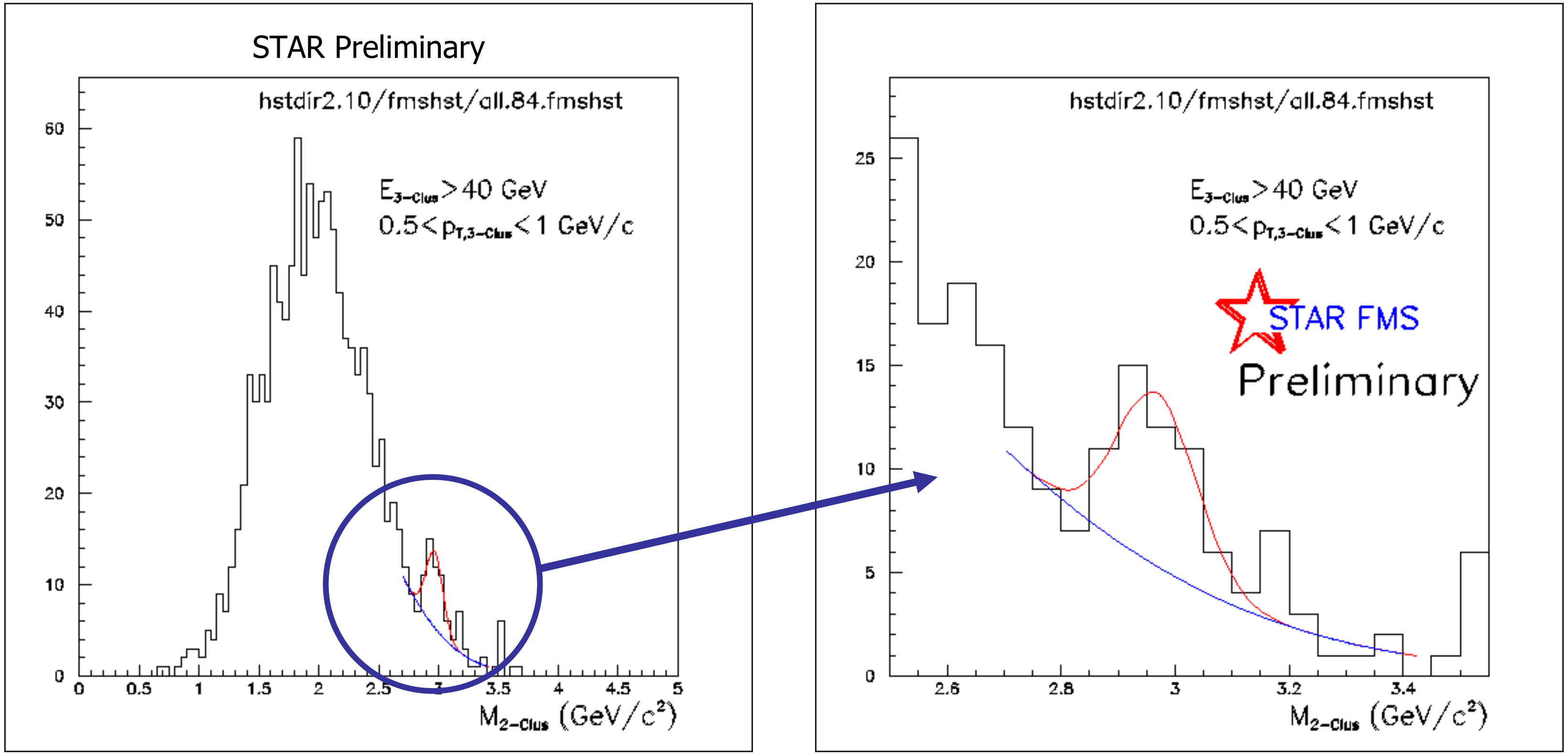
Reconstructed 2-cluster invariant mass




Signal significance ~ 4.5 σ

# $X_c$->J/ψ+ γ at forward region in p+p

3-cluster analysis

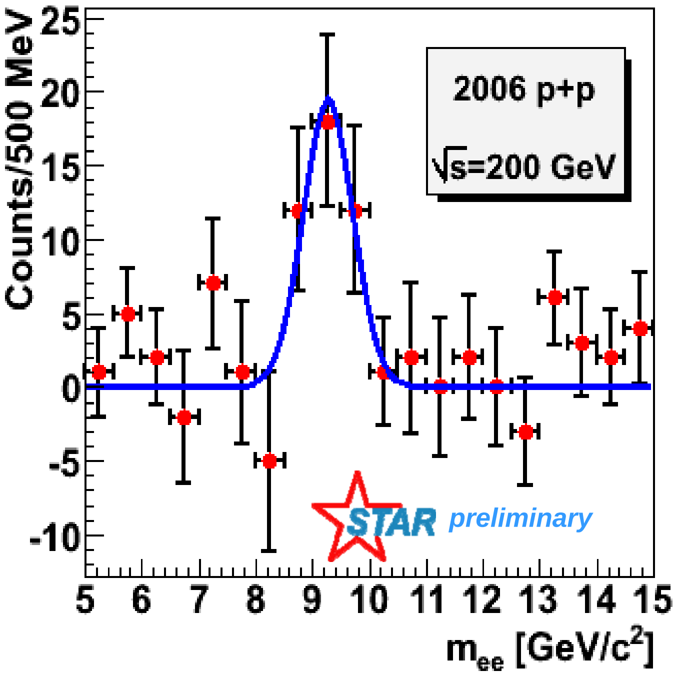



Signal significance ~ 2.9 σ

# $\Upsilon$ production at STAR
# (mid-rapidity region)

- $\Upsilon$ is a cleaner probe compared to J/psi
  - co-mover absorption → negligible
  - recombination → negligible

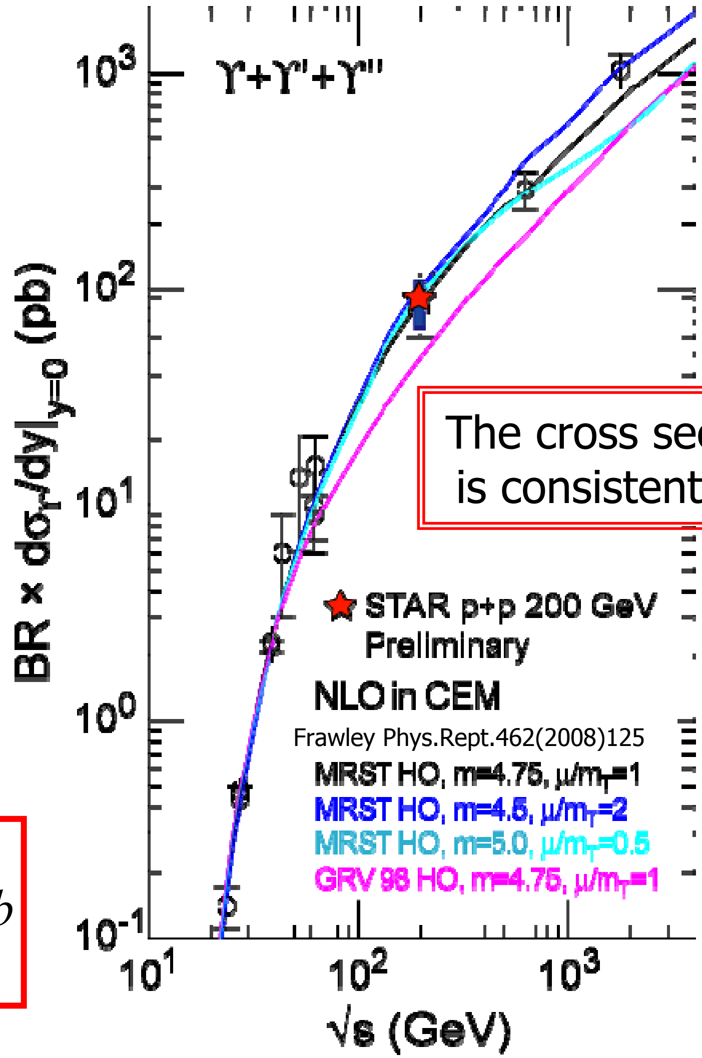
# $\Upsilon$ Measurements in p+p




Signal significance ~ 3σ

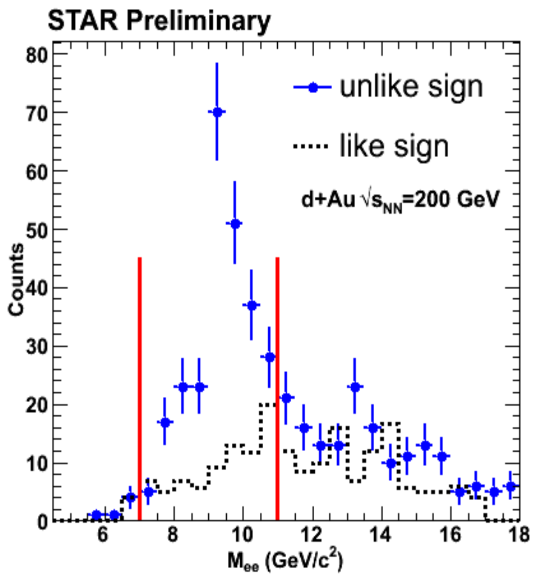
$$B_{ee} \times \left(\frac{d\sigma}{dy}\right)_{y=0}^{Y+Y'+Y''} = 91 \pm 28(stat.) \pm 22(syst.)\ pb$$

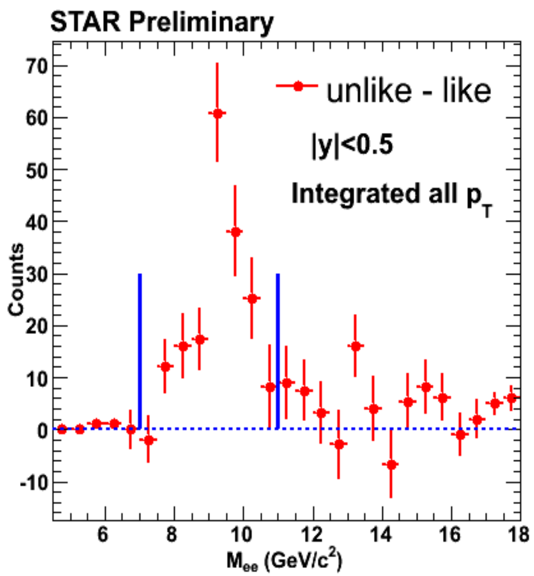
*J. Phys. G: Nucl. Part. Phys. 34(2007)S947*

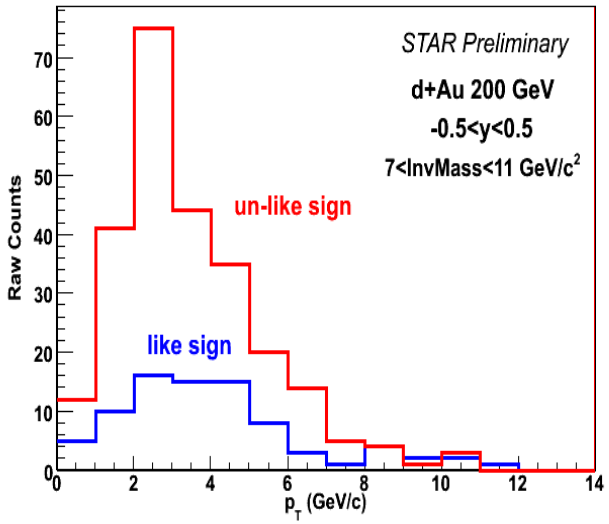



The cross section in p+p is consistent with pQCD

# ϒ Measurements in d+Au



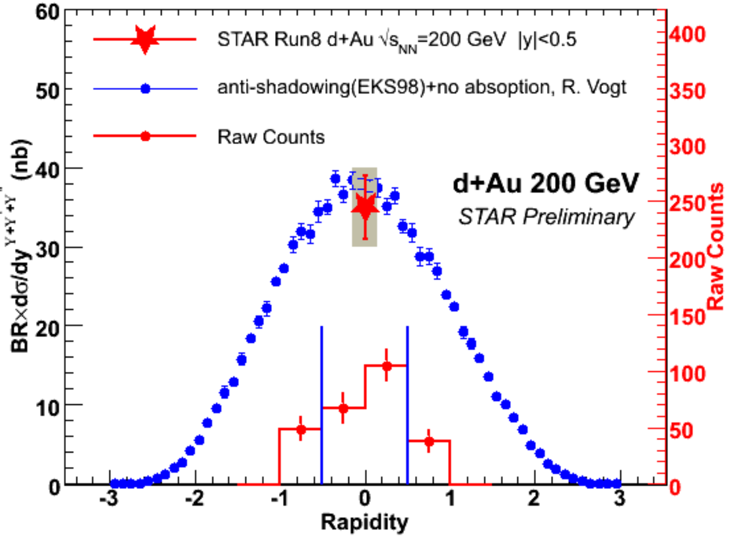




- Signal + Background ⇒ unlike-sign electron pairs
- Background ⇒ like-sign electron pairs
- ϒ(1S+2S+3S) total yield: integrated from 7 to 11 GeV from background-subtracted $m_{ee}$ distribution
  - Raw Yield: 172 +/- 20 (stat.)
  - Strong signal (8σ significance)

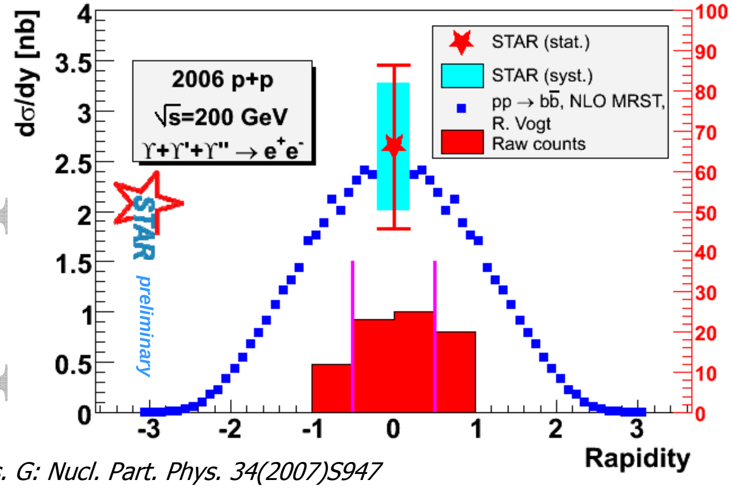
$$B_{ee} \times \left(\frac{d\sigma}{dy}\right)_{y=0}^{Y+Y'+Y''} = 35 \pm 4(stat.) \pm 5(syst.)\, nb$$

# Nuclear modification factor

d+Au




p+p




J. Phys. G: Nucl. Part. Phys. 34(2007)S947

$p+p$

$$B_{ee} \times \left(\frac{d\sigma}{dy}\right)_{y=0}^{\Upsilon+\Upsilon'+\Upsilon''} = 91 \pm 28(stat.) \pm 22(syst.)\, pb$$

$d+Au$

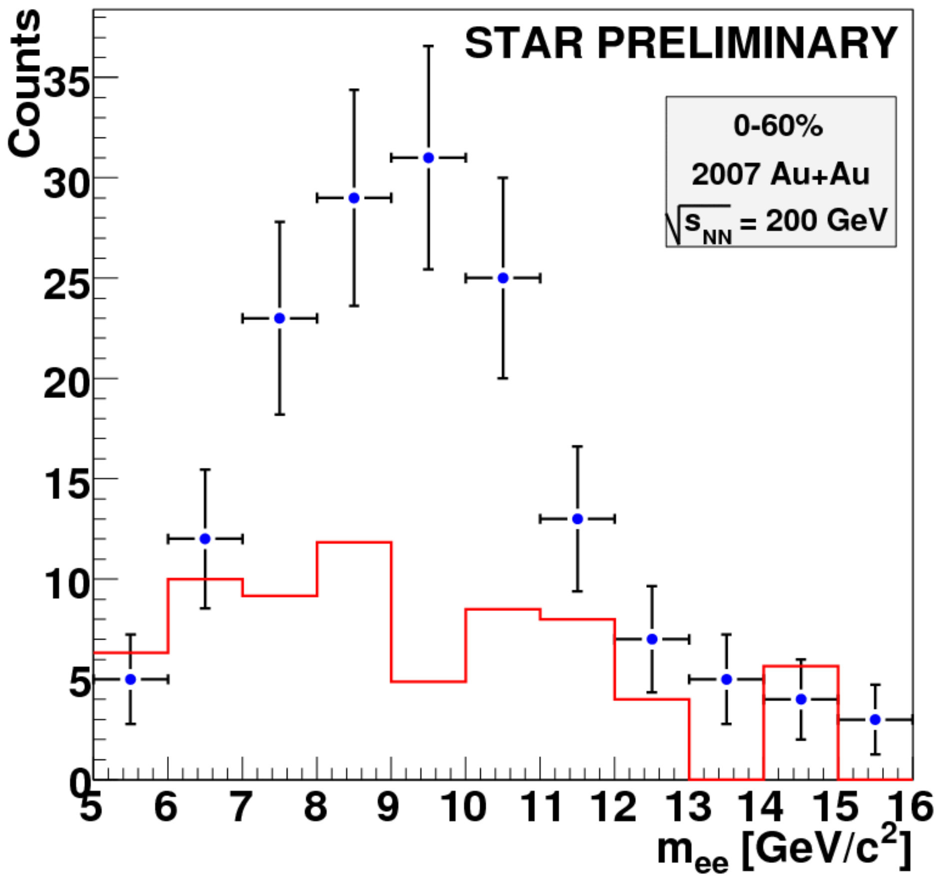
$$B_{ee} \times \left(\frac{d\sigma}{dy}\right)_{y=0}^{\Upsilon+\Upsilon'+\Upsilon''} = 35 \pm 4(stat.) \pm 5(syst.)\, nb$$

$$R_{dAu} = 0.98 \pm 0.32\ (\text{stat.}) \pm 0.28\ (\text{sys.})$$

*Error is dominated by the stat. in pp*
*STAR has taken 21 pb$^{-1}$ data in the 2009 pp run*

**$R_{dAu}$ is consistent with $N_{bin}$ scaling**

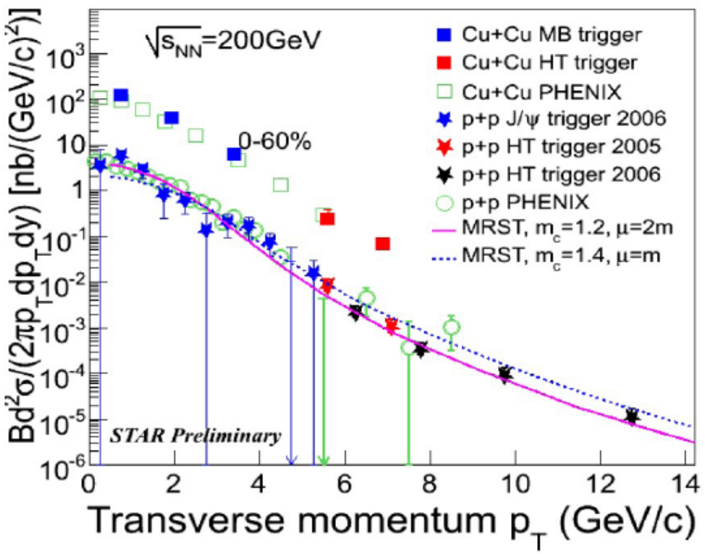
# Υ signal observation in Au+Au

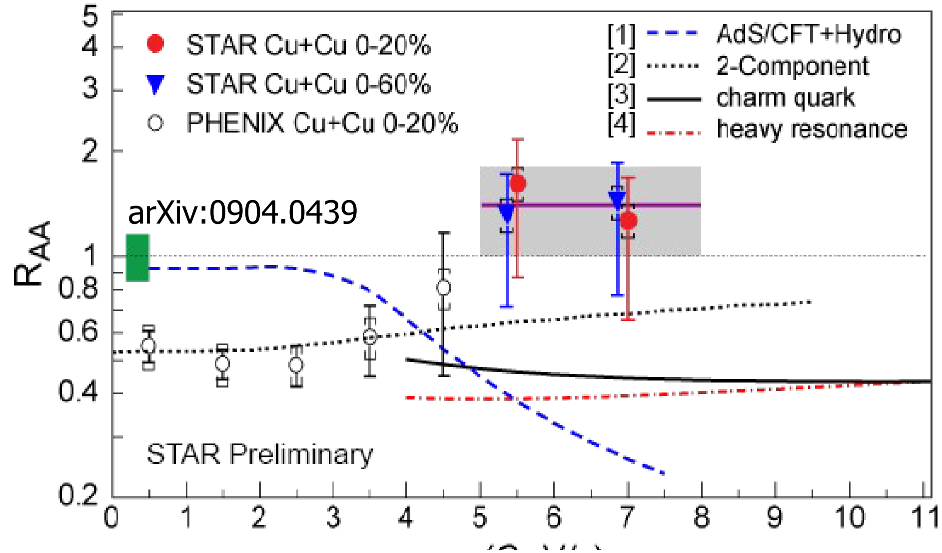



Cross section calculation is in progress

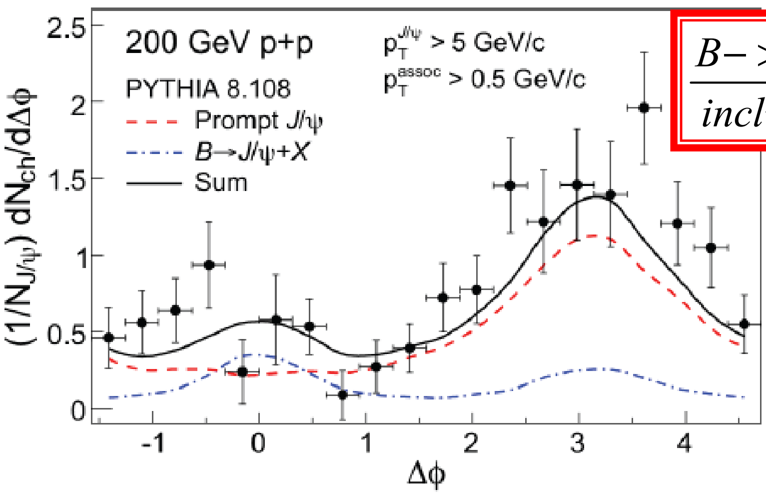
*J. Phys. G: Nucl. Part. Phys. 35(2008)104153*

# Summary (money plots reminder)

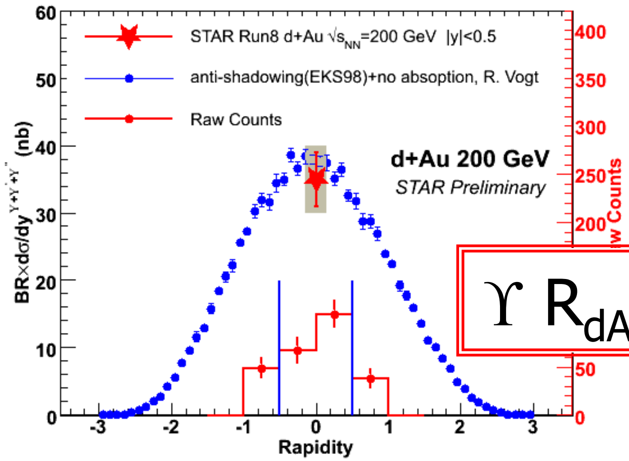



arXiv:0904.0439




$$\frac{B->J/\Psi}{inclusive}=(13\pm5)\%$$




$\Upsilon$ $R_{dAu}$~1

# Summary

**J/ψ in p+p, dAu and A+A collisions:**

$p_T$ spectra in p+p:
- **extended to ~14 GeV/c**
- **follows $x_T$ scaling with n=5.6 at $p_T$>5 GeV/c, deviates from scaling at low $p_T$**

J/ψ-hadron correlation in p+p & d+Au:
- **no significant near side correlation constrain the contribution from B→J/ψ+X**

J/ψ $R_{AA}$
- **indication of $R_{AA}$ increasing at high $p_T$**

production mechanisms:
- **described by CEM and CSM**
- **soft processes affect low $p_T$ production**

- **constrain decay contribution**
- **constrain production mechanism: CSM or COM**

- **medium properties**

**Υ in p+p, d+Au and Au+Au collisions:**

The X-section is measured:

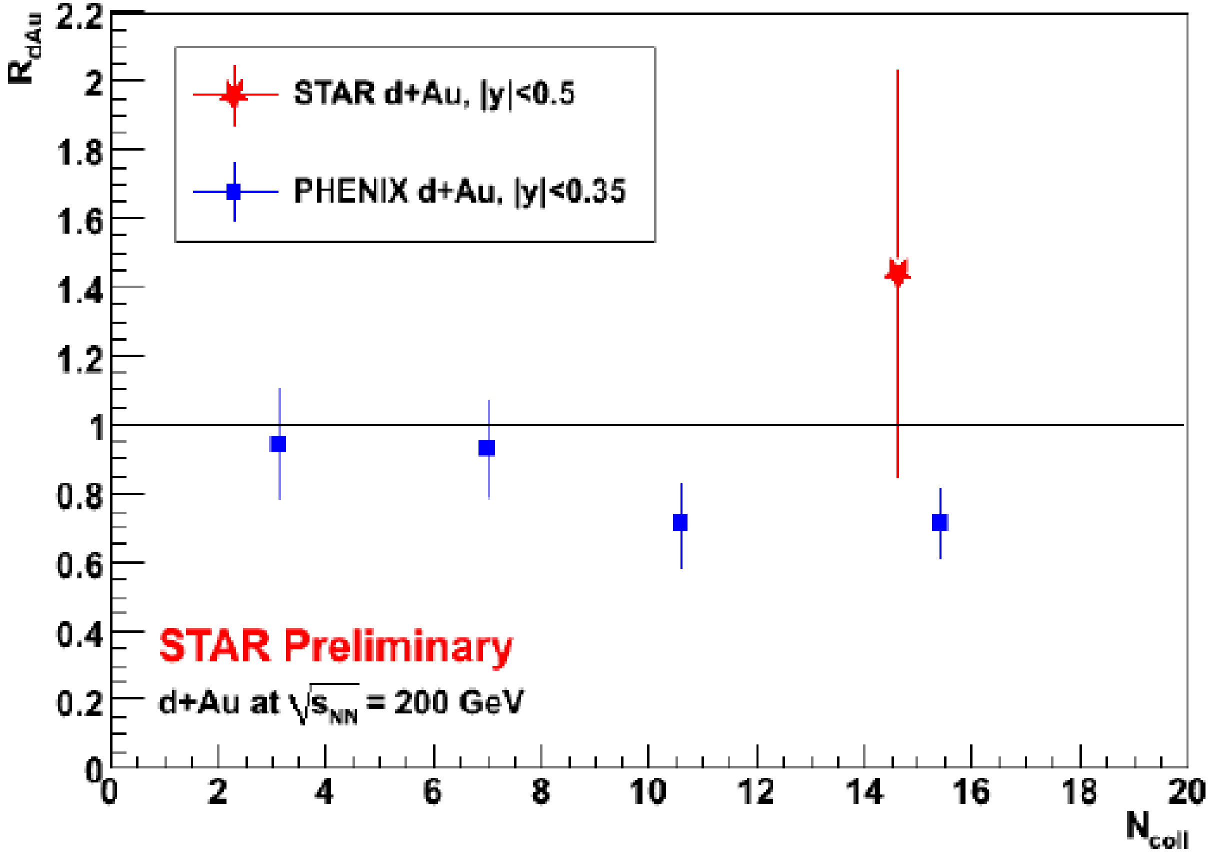
p+p $B_{ee}\times(d\sigma/dy)_{y=0}$=91±28(stat.)±22(sys.)pb

d+Au $B_{ee}\times(d\sigma/dy)_{y=0}$=35±4(stat.)±5(sys.)nb

$R_{dAu}$ =0.98±0.32(stat.)±0.28(sys.)

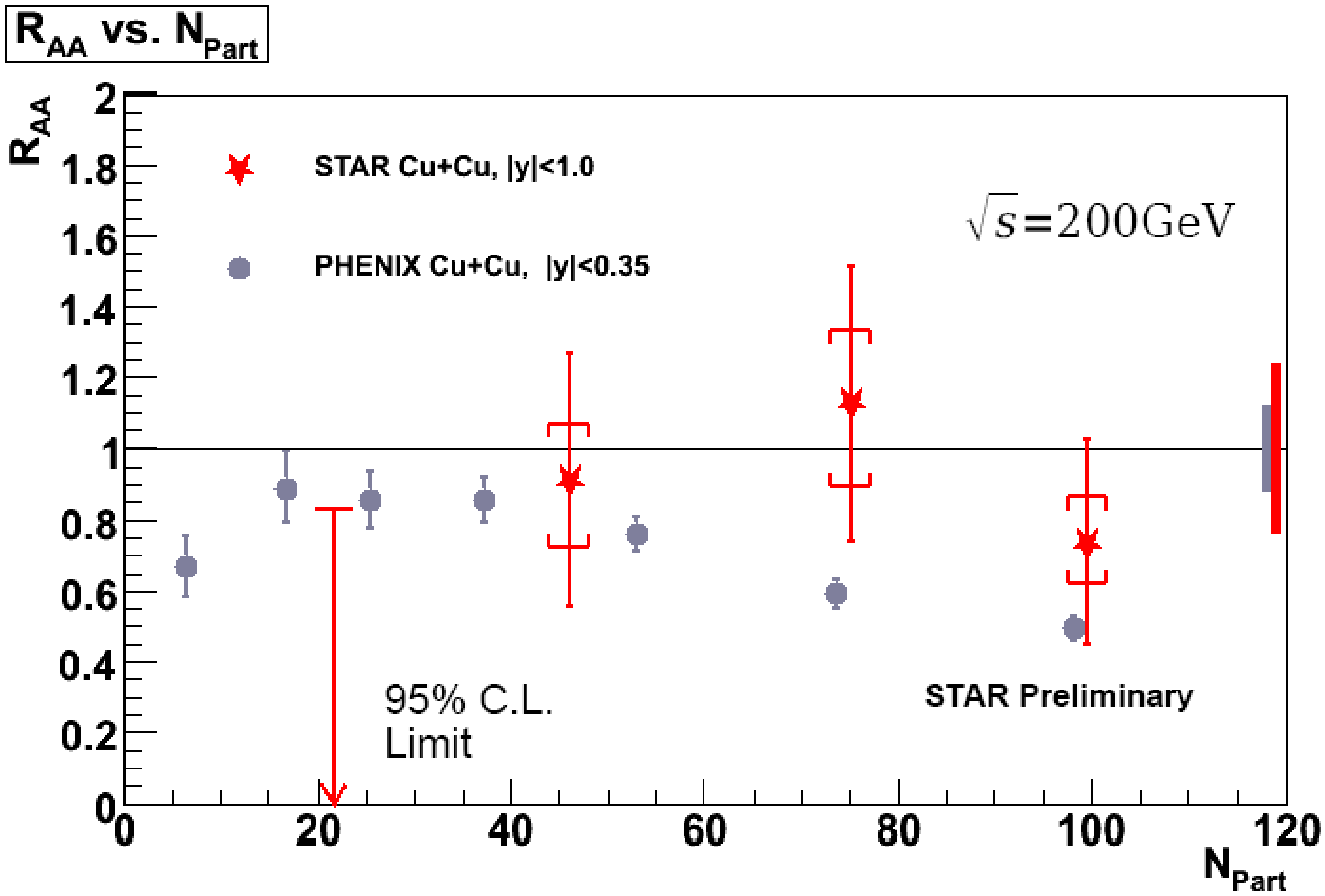
# Back up

# Low $p_T$ J/ψ in p+p & d+Au



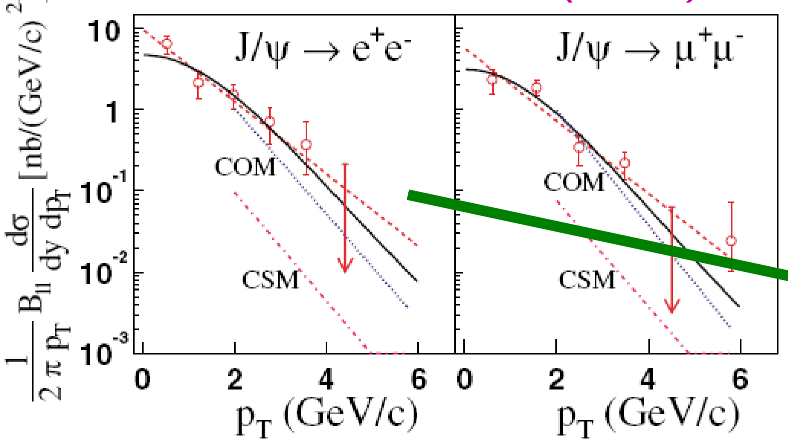

$$R_{dAu} = \frac{dN^{dAu}/dy}{N_{coll} dN^{pp}/dy} = 1.4 \pm 0.6$$

# Cu+Cu – $R_{AA}$ vs. $N_{part}$

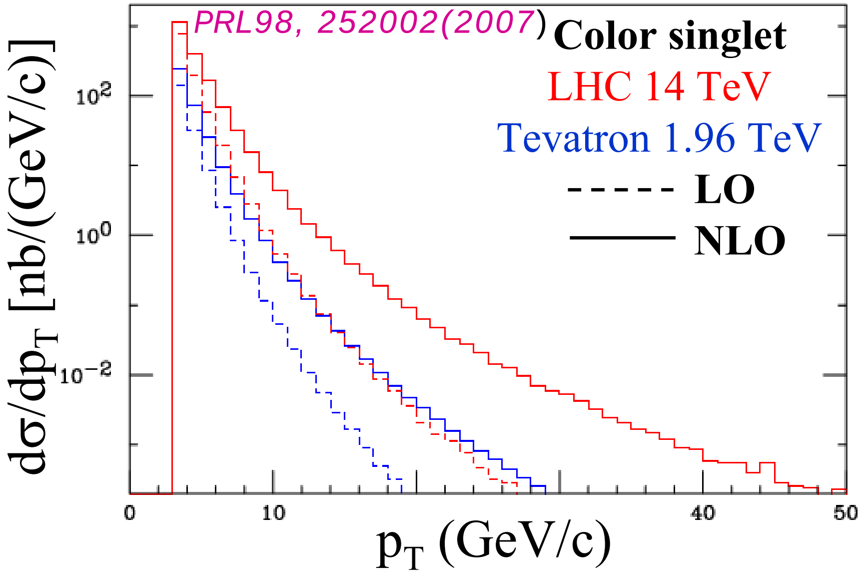


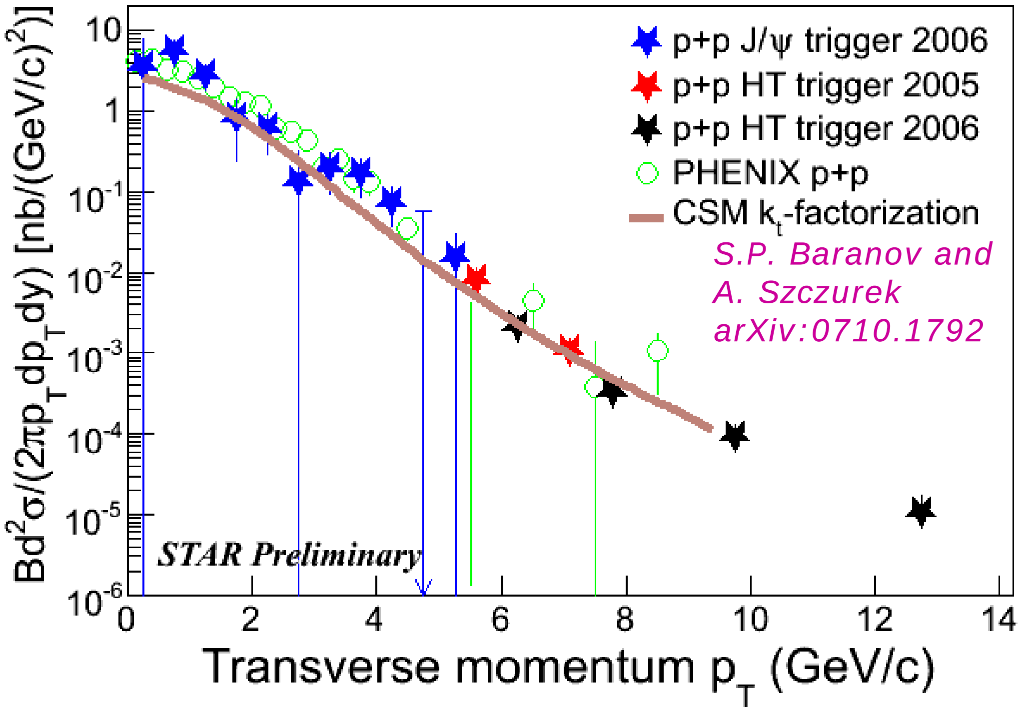
# NLO correction on spectra

*PHENIX, PRL 92, 05180 (2004)*



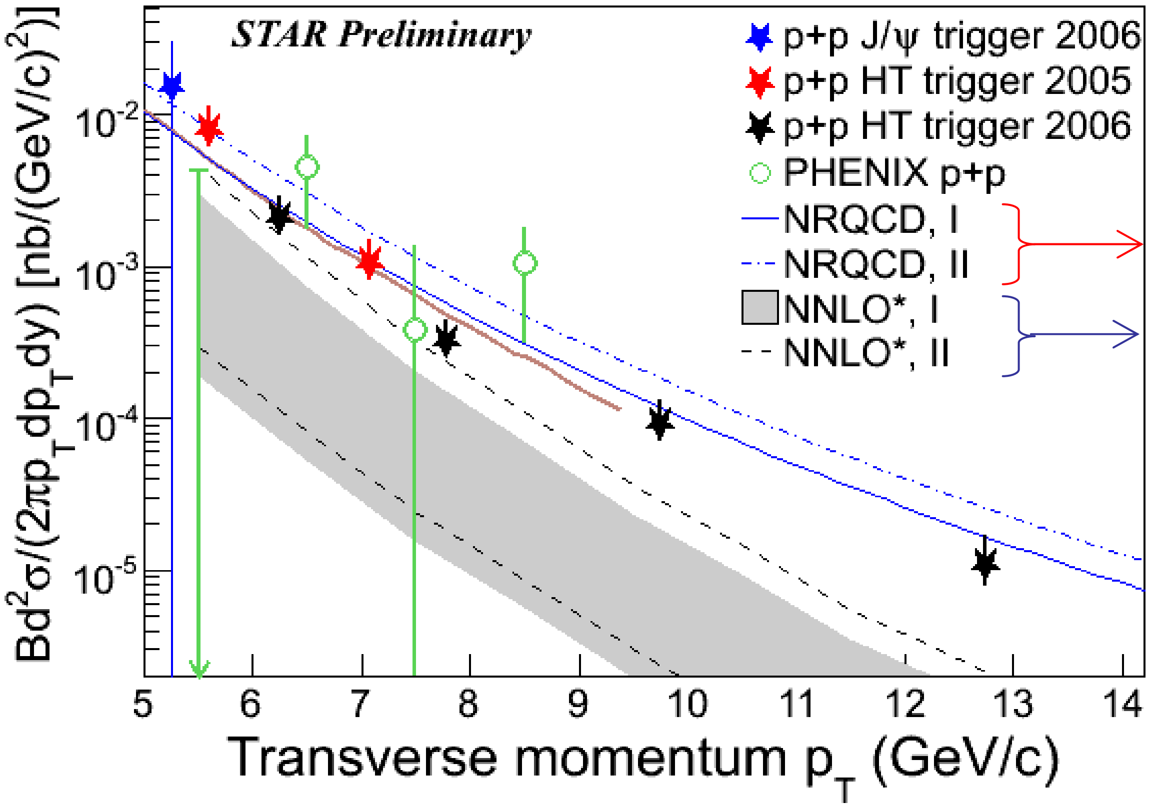

CSM can also describe the data with some improvement like the $k_t$-factorization approach




**CSM NLO correction is huge**

# Compare to pQCD and NRQCD



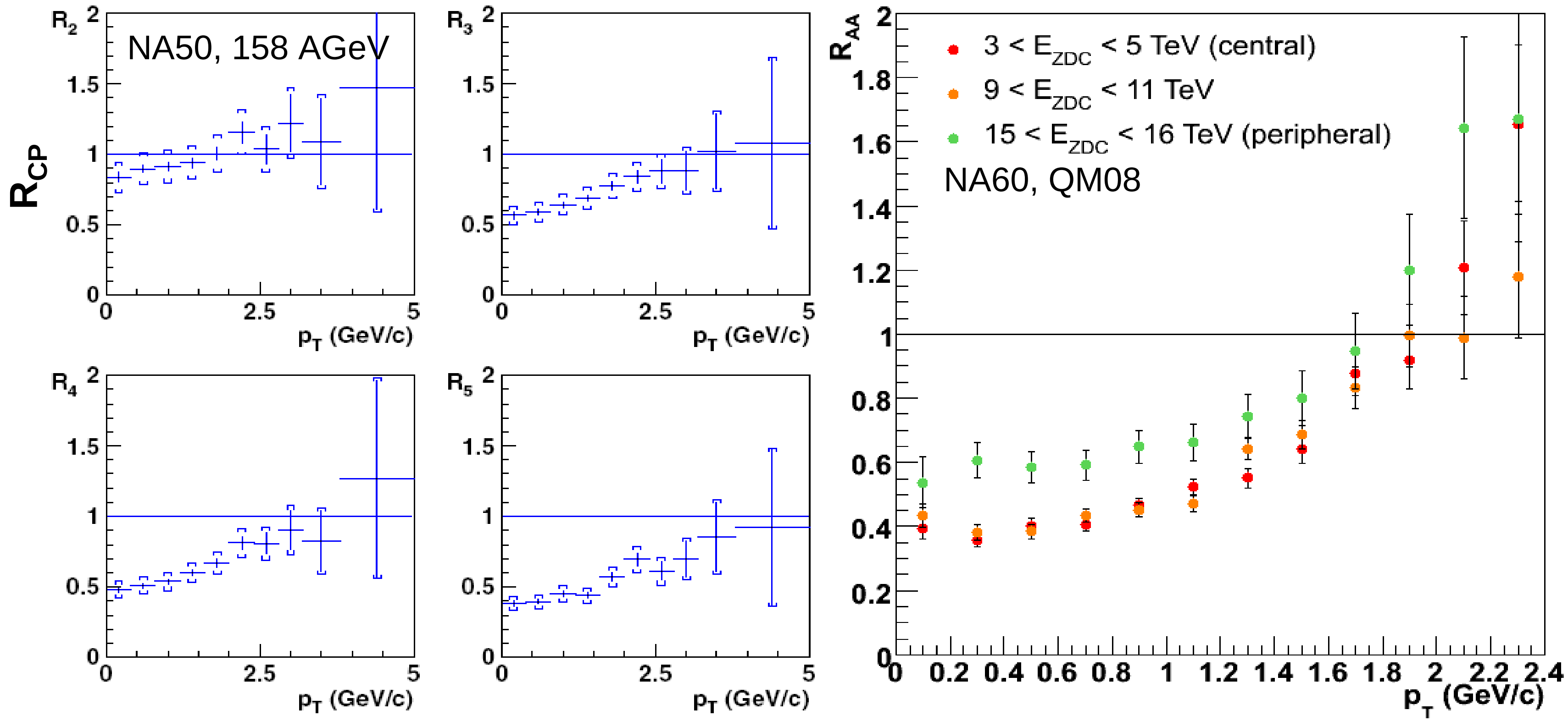

**I: prompt production**
**II: include $\chi_c$ and $\psi'$ feed-down**

P. Artoisenet et al., PRL 101, 152001
J.P. Lansberg private communications

G.C.Nayaket al., PRD 68, 034003
and private communications

- NRQCD leave little room from parton fragmentation and B feed-down
- NNLO* under-predict at the highest $p_T$ bin

# Compare to SPS




RHIC: Cu+Cu, $\sqrt{s_{NN}} = 200 GeV$ , consistent with no suppression at $p_T > 5$ GeV/c

SPS: In+In, $\sqrt{s_{NN}} = 17.3 GeV$ , consistent with no suppression at $p_T > 1.8$ GeV/c

Similar trend also observed at SPS, might from different physics origin