Quarkonium production at STAR

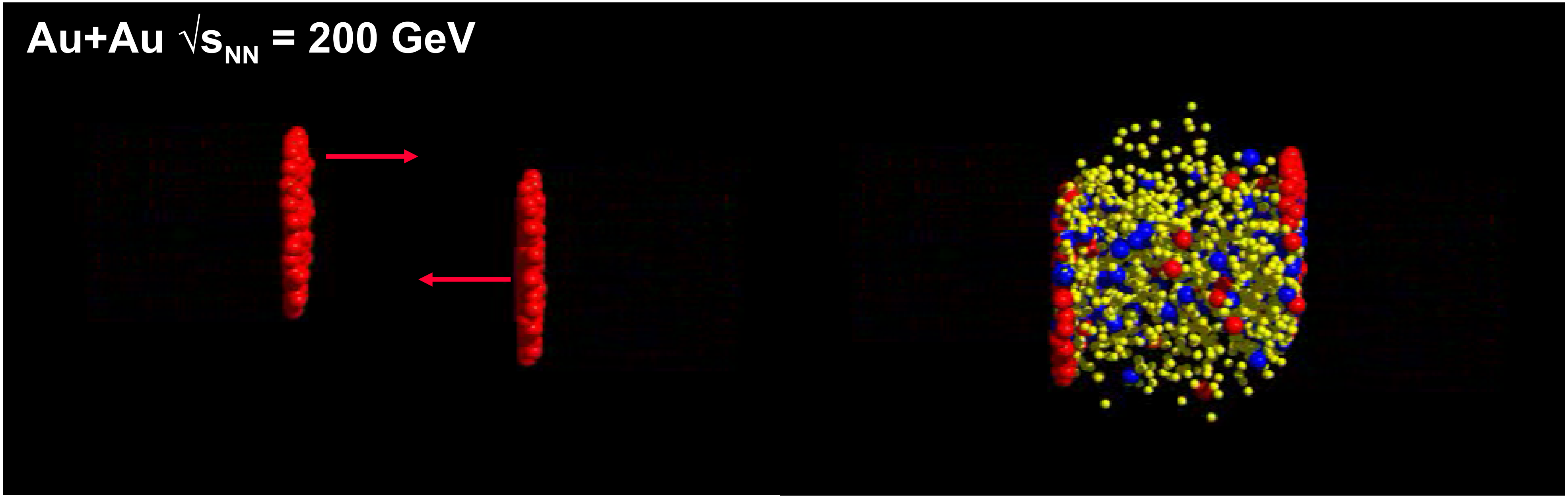
Daniel Kikoła for the STAR collaboration

PURDUE UNIVERSITY

- What can we learn?
- Issues and open questions
- STAR detector
- Results
  - J/ψ in p+p and A+A
  - Υ
- Near future

Why ?

Relativistic Heavy Ion Collisions



UrQMD Frankfurt

- **c, b** quarks produced early in the collision

  → good probe of created medium

- Quarkonium:
  - $c\bar{c}$ (J/ψ, ψ', χ_c …) $b\bar{b}$ (ϒ, ϒ', ϒ'' ...)

Matsui & Satz (1986):

Quark-Gluon Plasma

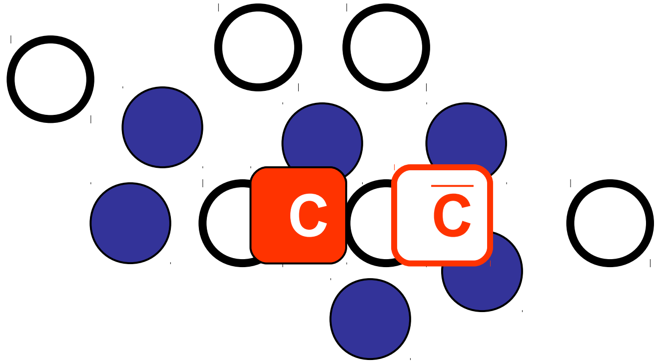
= J/ψ production suppression

c $\bar{c}$

Matsui & Satz (1986):

Quark-Gluon Plasma

= J/ψ production suppression



Matsui & Satz (1986):

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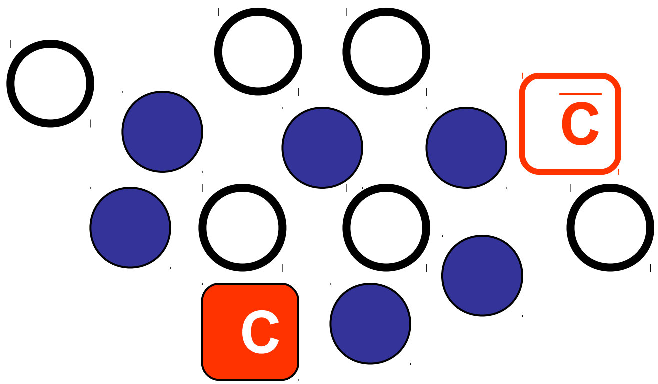

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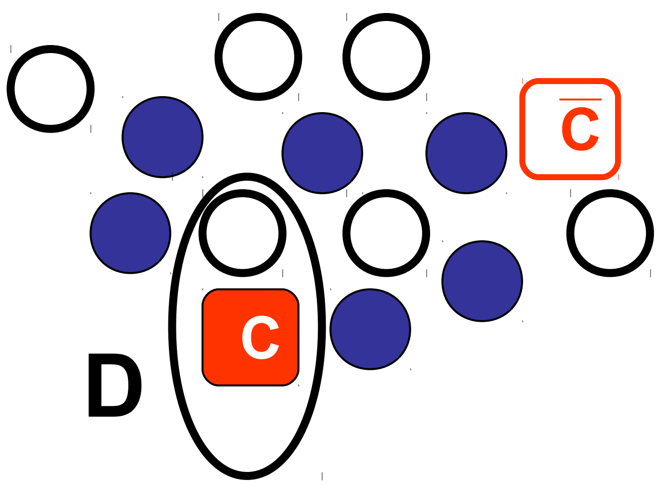
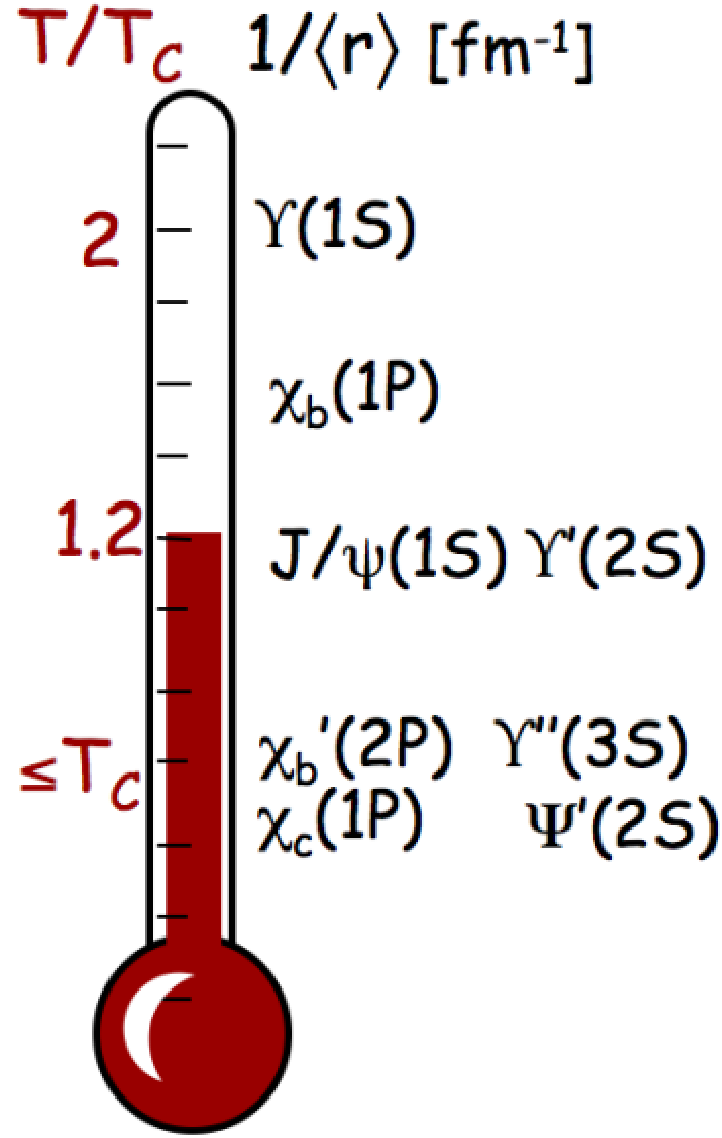


Sequential melting

→ Temperature of QGP

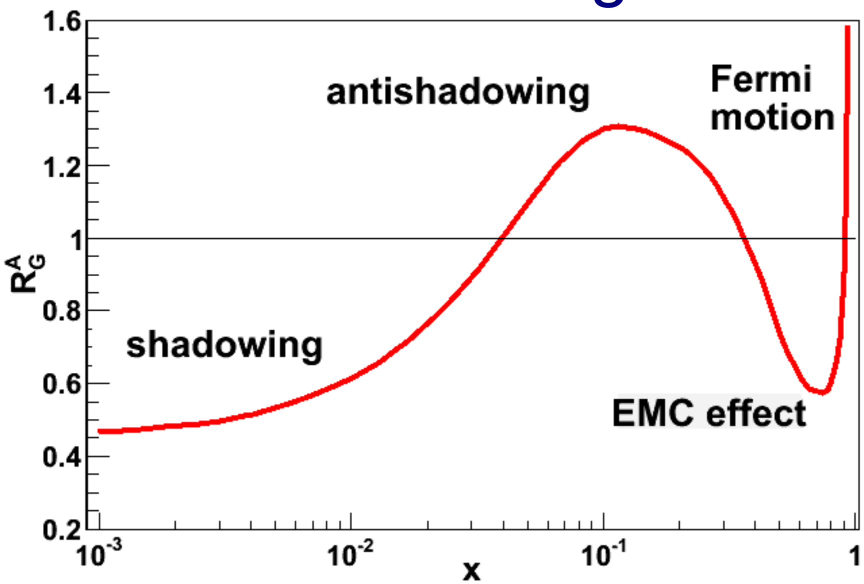


A. Mocsy Eur.Phys.J.C61:
705-710,2009

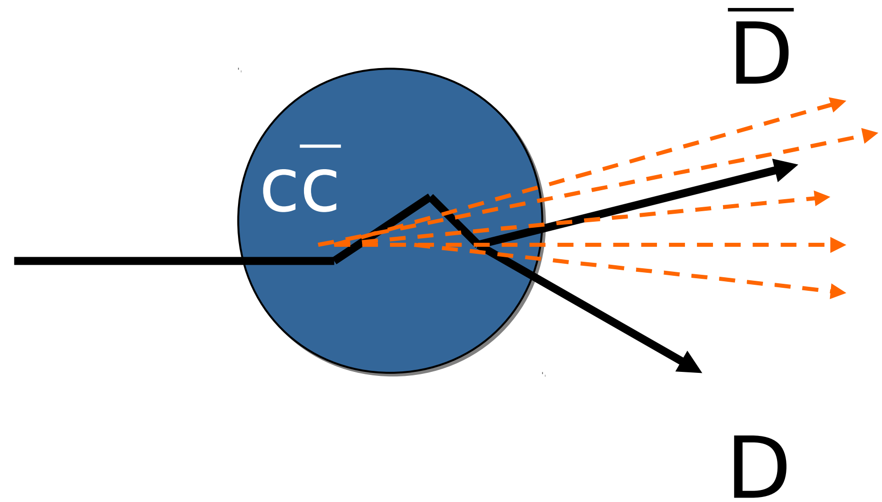
Complications

“Normal” suppression

Shadowing



Nuclear absorption



Co-mover absorption

....

Effects in QGP

- secondary production
- dissociation by gluons, energy loss

...

Issues &
Open questions

- Feed-down from excited states
    - same nuclear absorption and shadowing as 1s states?
- $B \rightarrow J/\psi$ feed-down
- Production mechanism
    - Color singlet or octet → is energy loss in QGP important?
    - Recombination of $c\bar{c}$ in QGP?
- Co-mover absorption

How to address these issues?

High-p_T J/ψ

- Helps to constrain B → J/ψ feed-down and production mechanism

ϒ

- Negligible co-mover abs. and recombination
- Less sensitive to nuclear absorption and shadowing

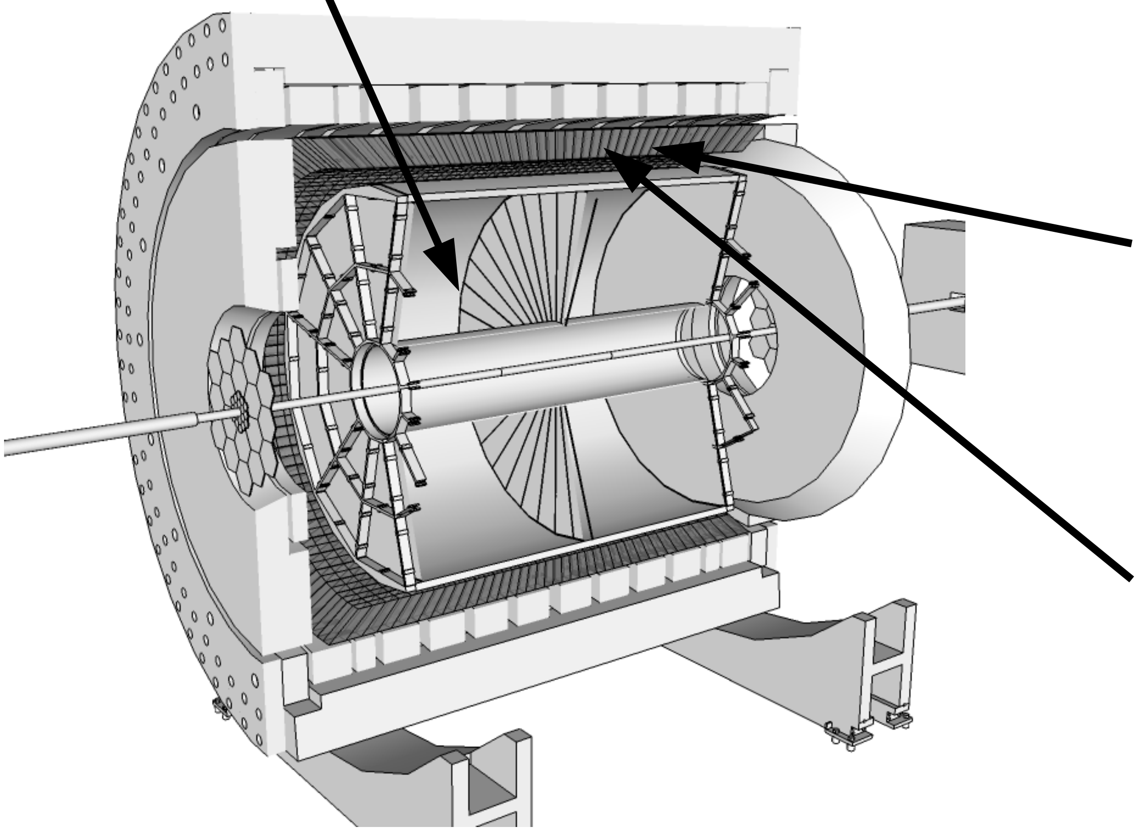
STAR detector
& analysis technique

STAR detector

Time Projection Chamber
Tracking: p_T, η, ϕ
PID via dE/dx

$J/\psi \rightarrow$ e+e-
$\Upsilon \rightarrow$ e+e-

- Large acceptance:
- full 2π coverage in ϕ
- $|\eta|< 1$



Barrel E-M Calorimeter
Electron ID via E/p
Fast Trigger

Shower Max Detector
Spatial resolution
Electron/hadron separation via shower shape

Experimental approach

1. baseline – **p+p**

2. "cold" nuclear matter effects – **d+Au**

$$R_{dAu} = \frac{1}{\langle N_{coll} \rangle} \frac{dN/dy^{dAu}}{dN/dy^{pp}}$$

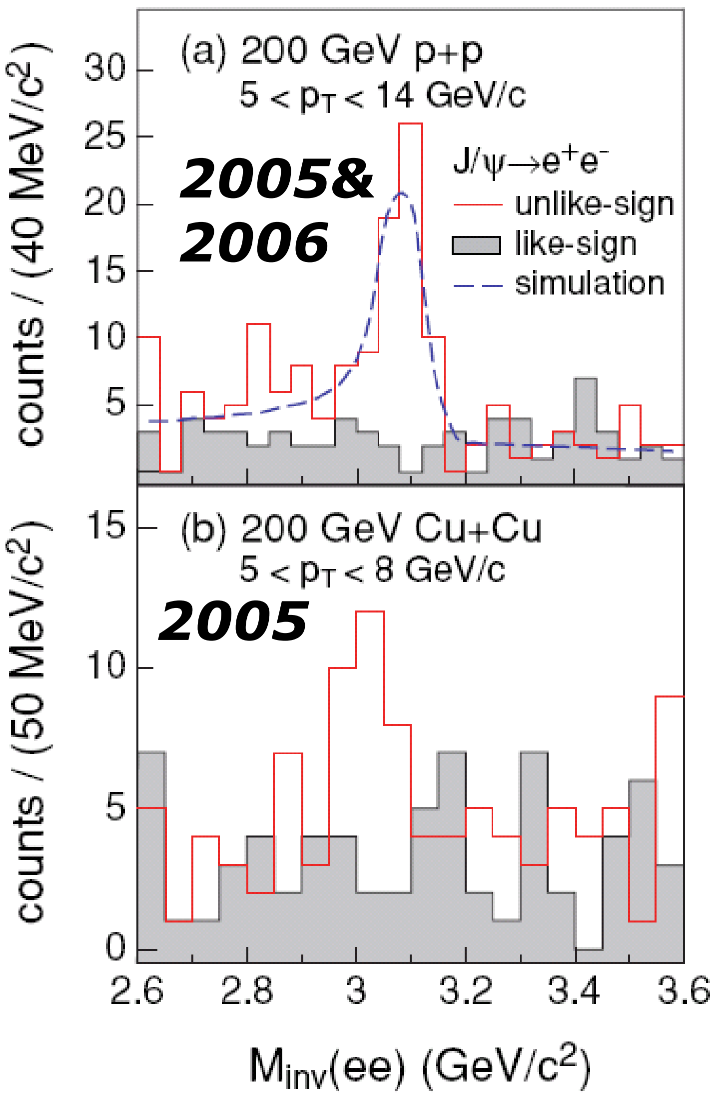
$R_{AA\ (dAu)} = 1$
if no modification in the medium

3. modification in the hot/dense medium – **Au+Au**

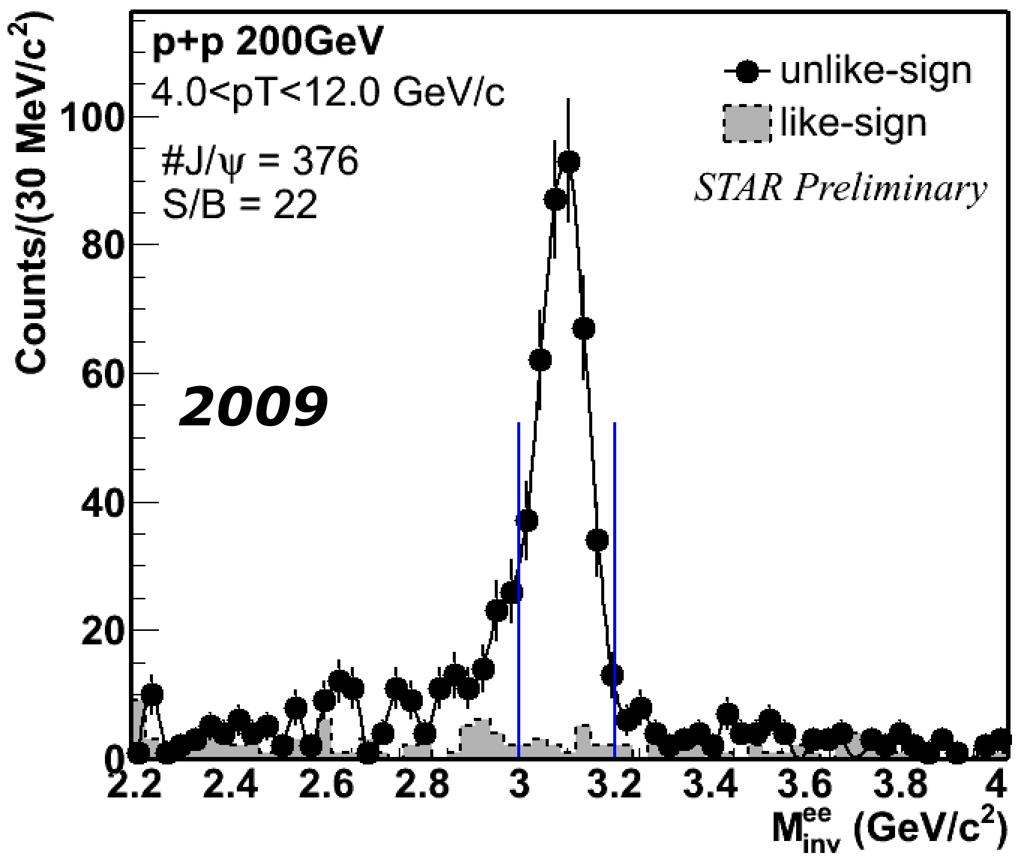
$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{dN/dy^{AuAu}}{dN/dy^{pp}}$$

High-p_T J/ψ

High-p_T J/ψ in p+p and Cu+Cu 200 GeV

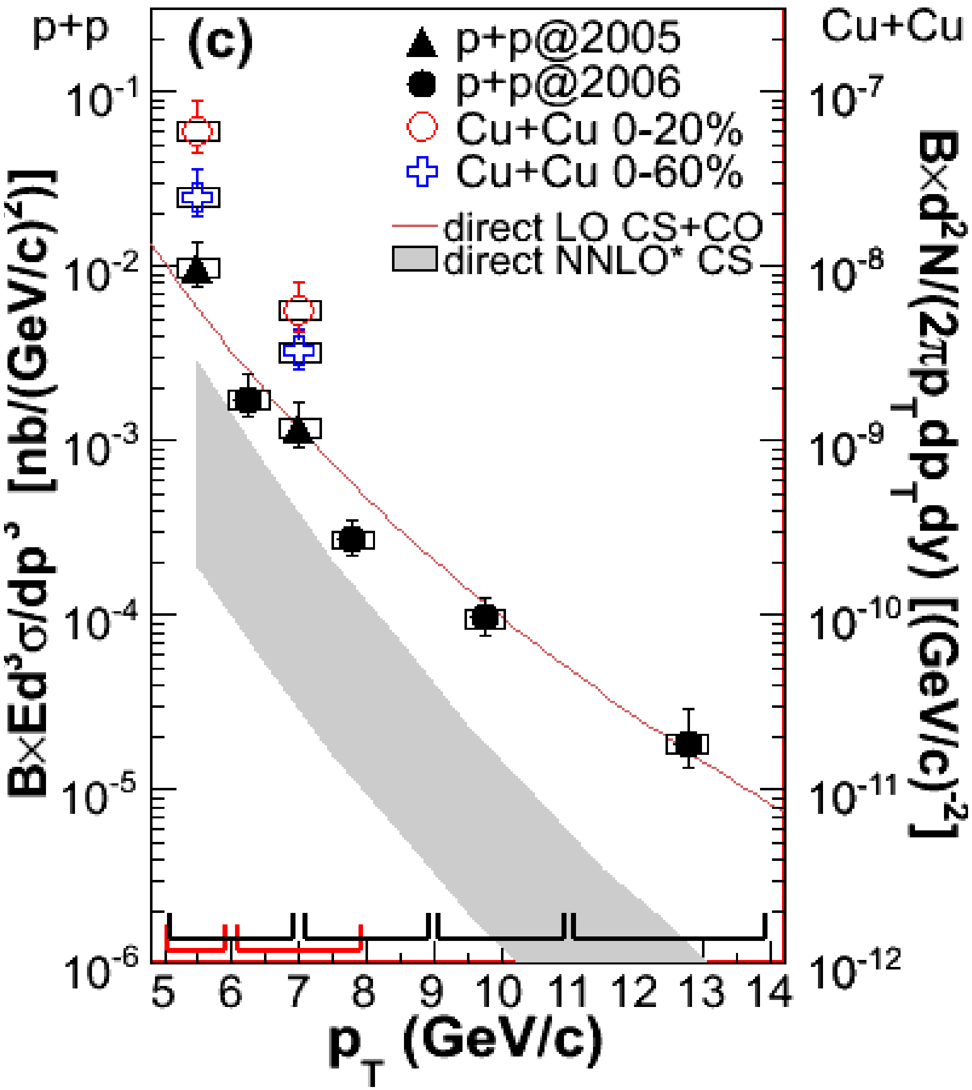


STAR, PRC80,041902(R), 2009



Tight cuts for correlation study

J/ψ production: p_T spectrum



NRQCD (LO Color-Octet + Color-Singlet) describes data well, little room for feed down

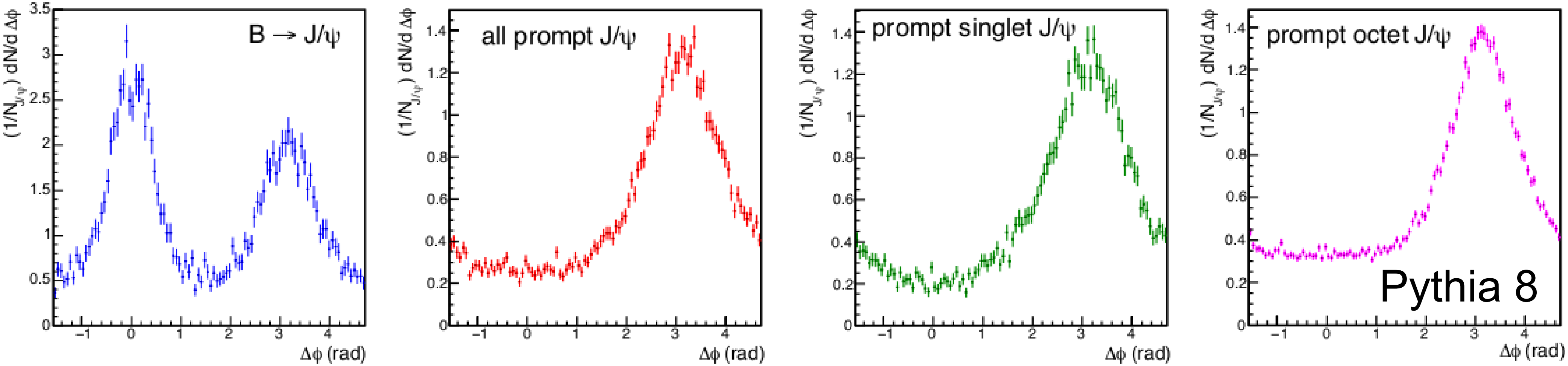
G. C. Nayak, M. X. Liu, and F. Cooper, Phys. Rev. D68, 034003 (2003), and private communication

NNLO Color-Singlet predicts a steeper p_T dependence

P. Artoisenet et al., Phys. Rev. Lett. 101, 152001 (2008), and J.P. Lansberg private communication

Phys.Rev.C80:041902,2009

Accessing B →J/ψ: J/ψ - h correlation

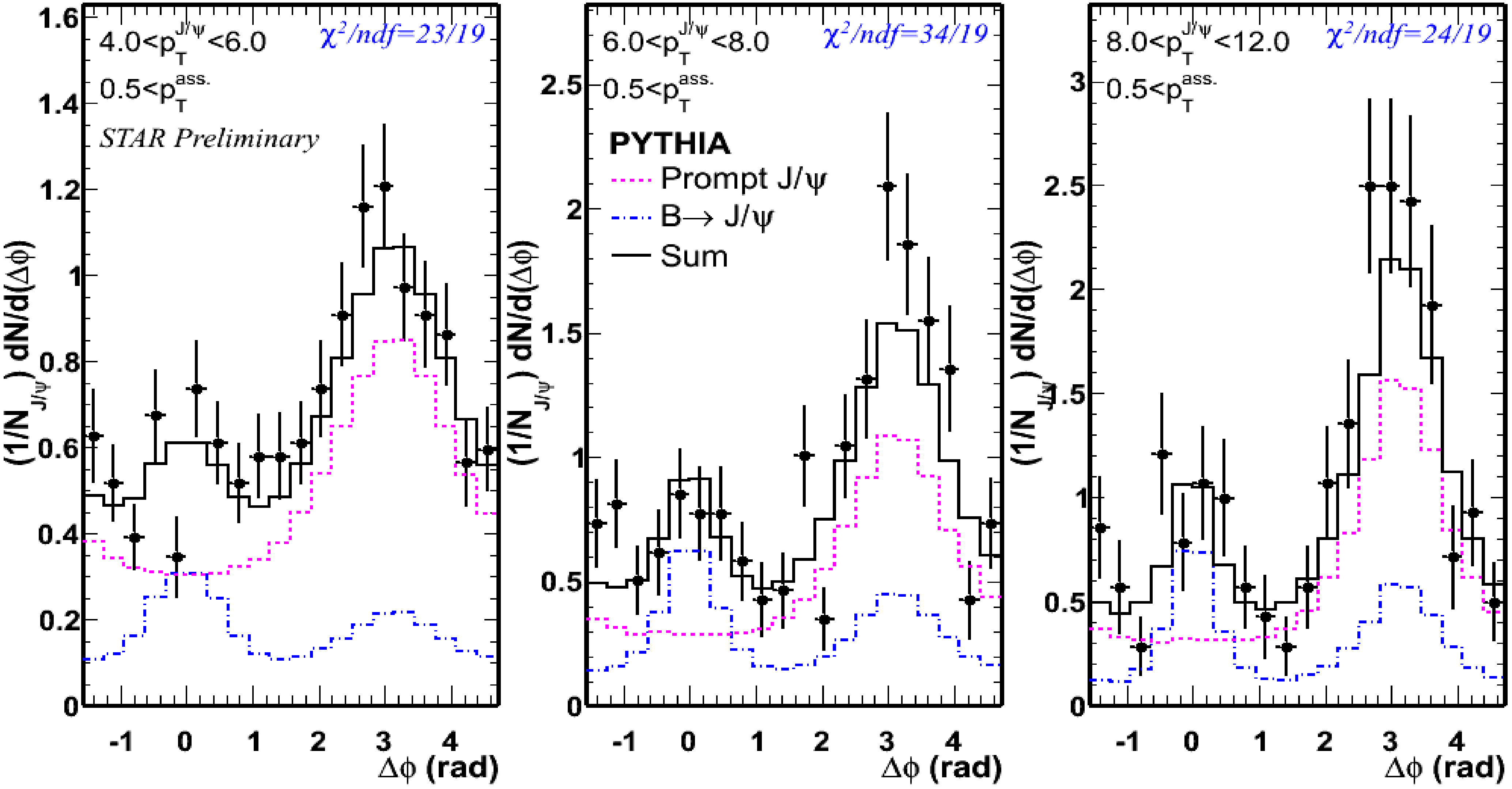


Thomas Ullrich, Workshop on Heavy Quark Production in HIC, Purdue Univ, 2011

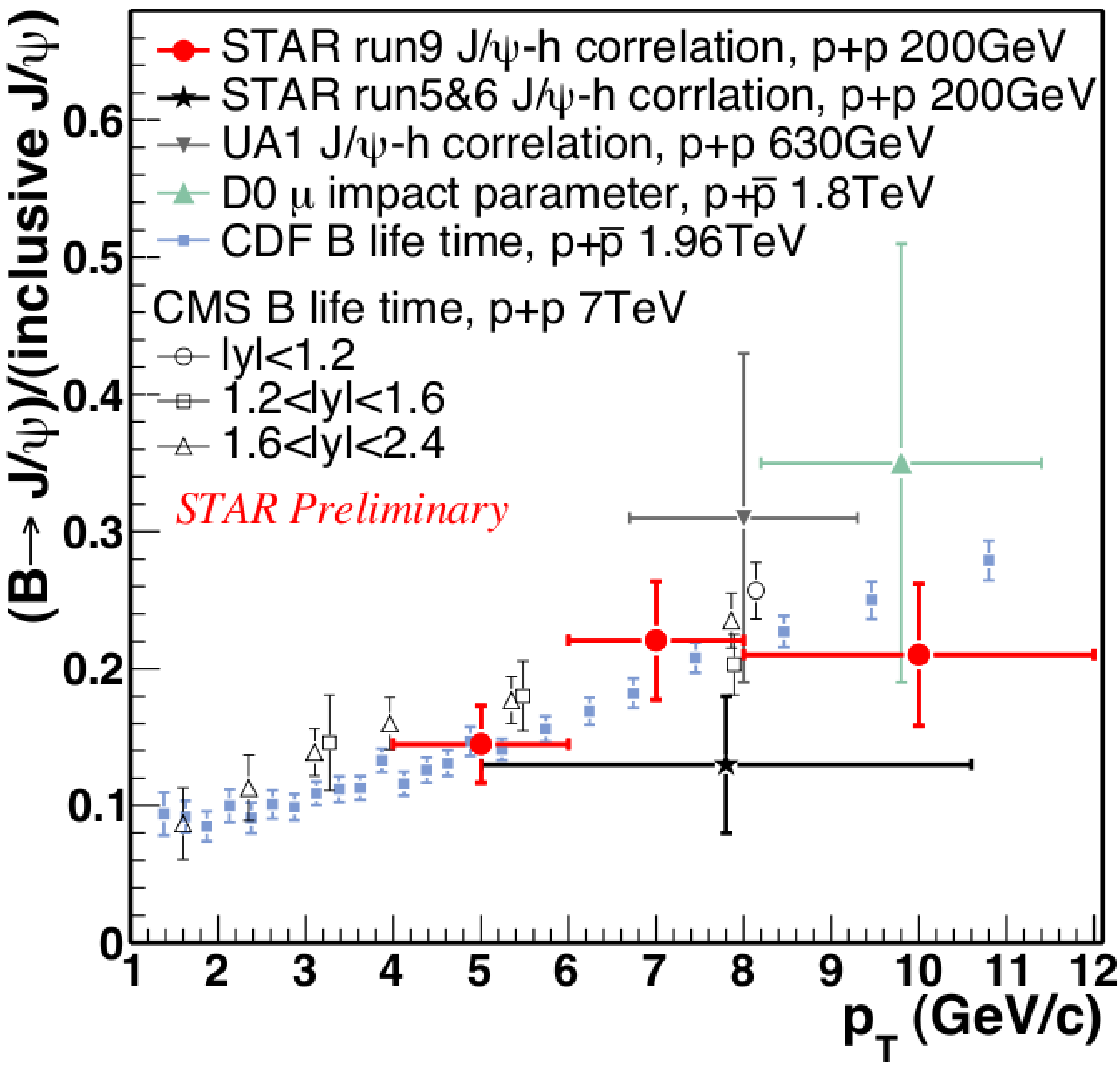
- If B → J/ψ then strong near side azimuthal corr.
- Model dependent: Pythia 8, LO NRQCD for prompt J/ψ production with ψ', χ_c, LO B production
- Little difference between CO and CS

High-p_T J/ψ - h correlation

p+p 200 GeV:



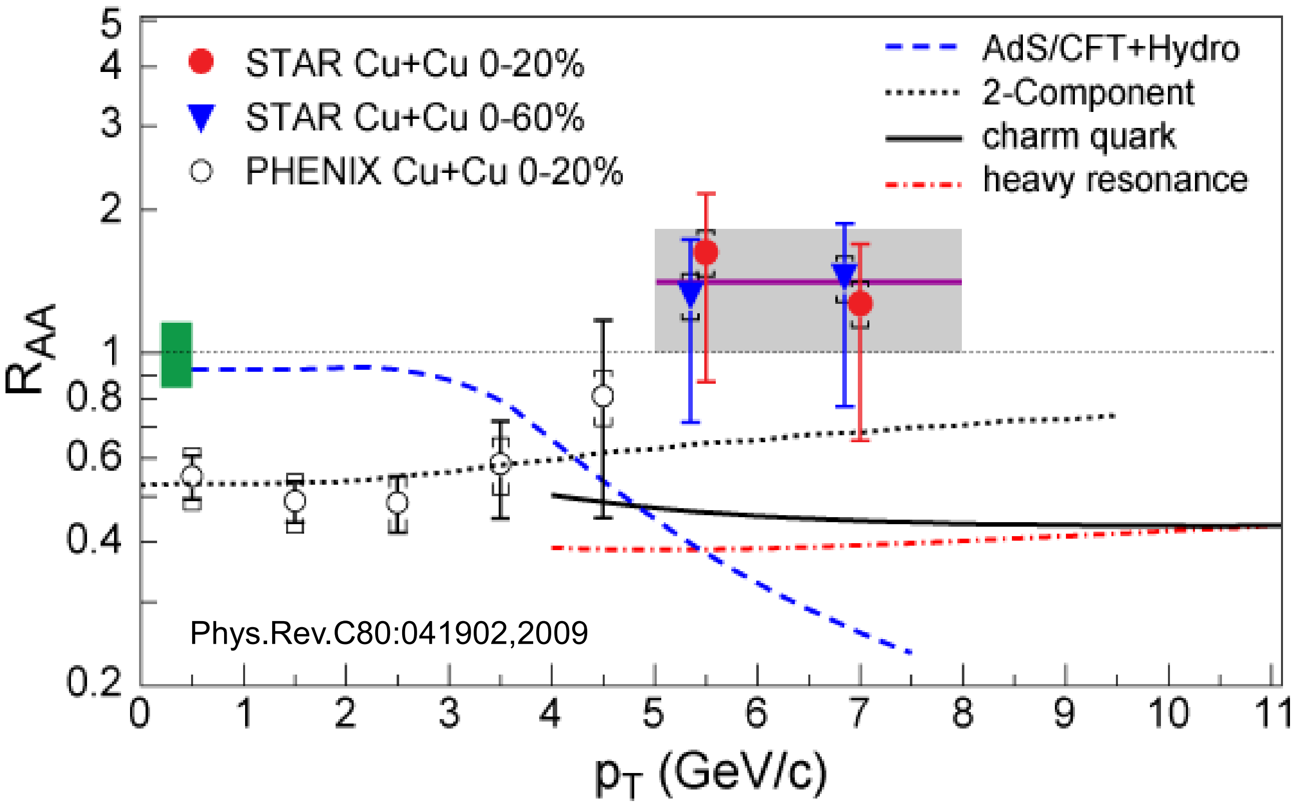
B →J/ψ feed-down in p+p



No significant beam energy dependence

High-p_T J/ψ in-medium interactions

Cu+Cu 200 GeV



No suppression at high p_T (p_T > 5 GeV/c):

R_{AA} = 1.4 ± 0.4 ± 0.2

- Contrast to open charm suppression: CS vs. CO?
- Trend reproduced when B feed-down and formation time effects included

Υ

Negligible co-mover abs. and recombination

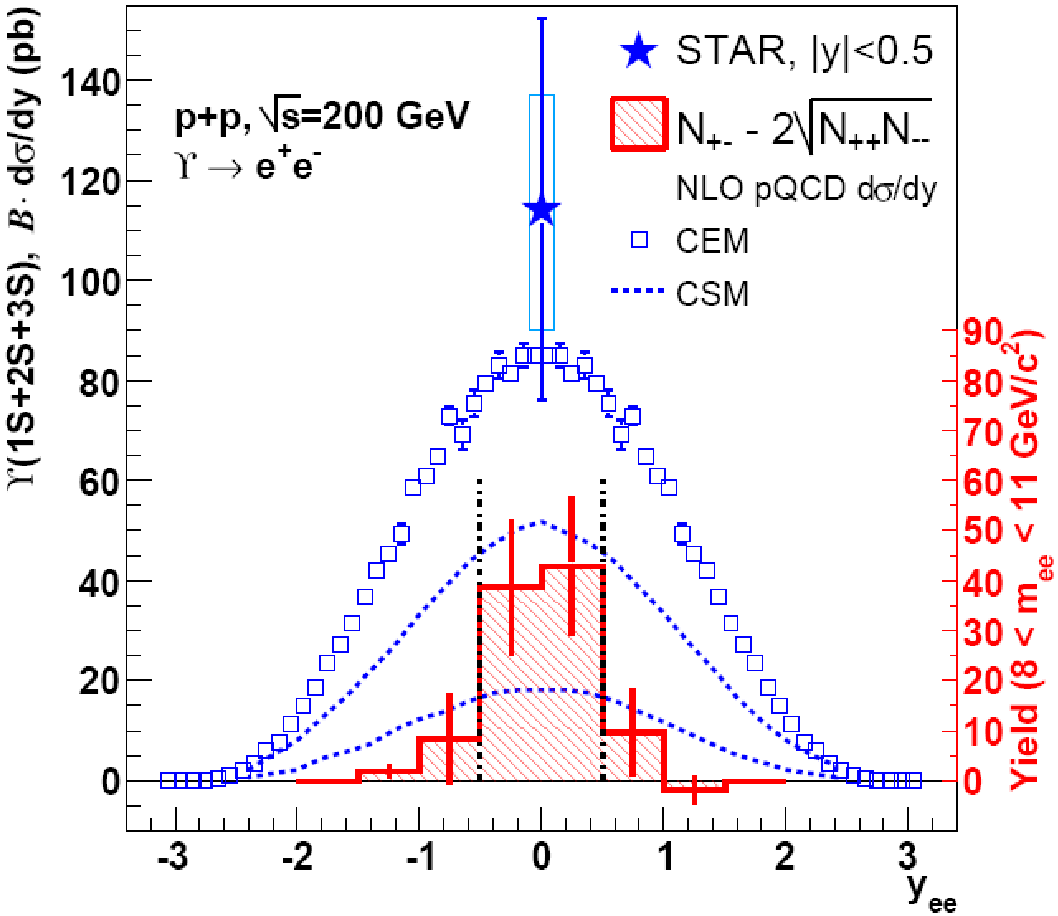
Less sensitive to nuclear absorption and shadowing

Small combinatorial background

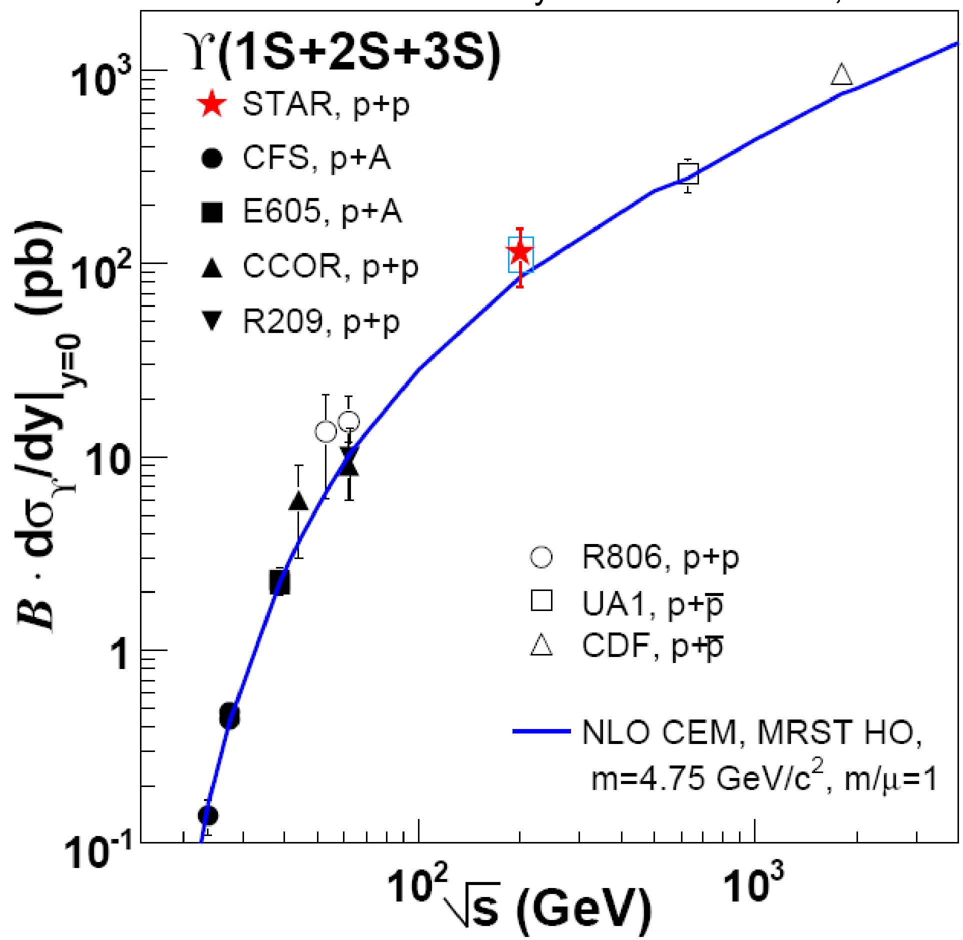
Υ is a challenge

Small cross-section → large luminosity required

Baseline: Υ in p+p 200 GeV



Phys.Rev.D82:012004,2010

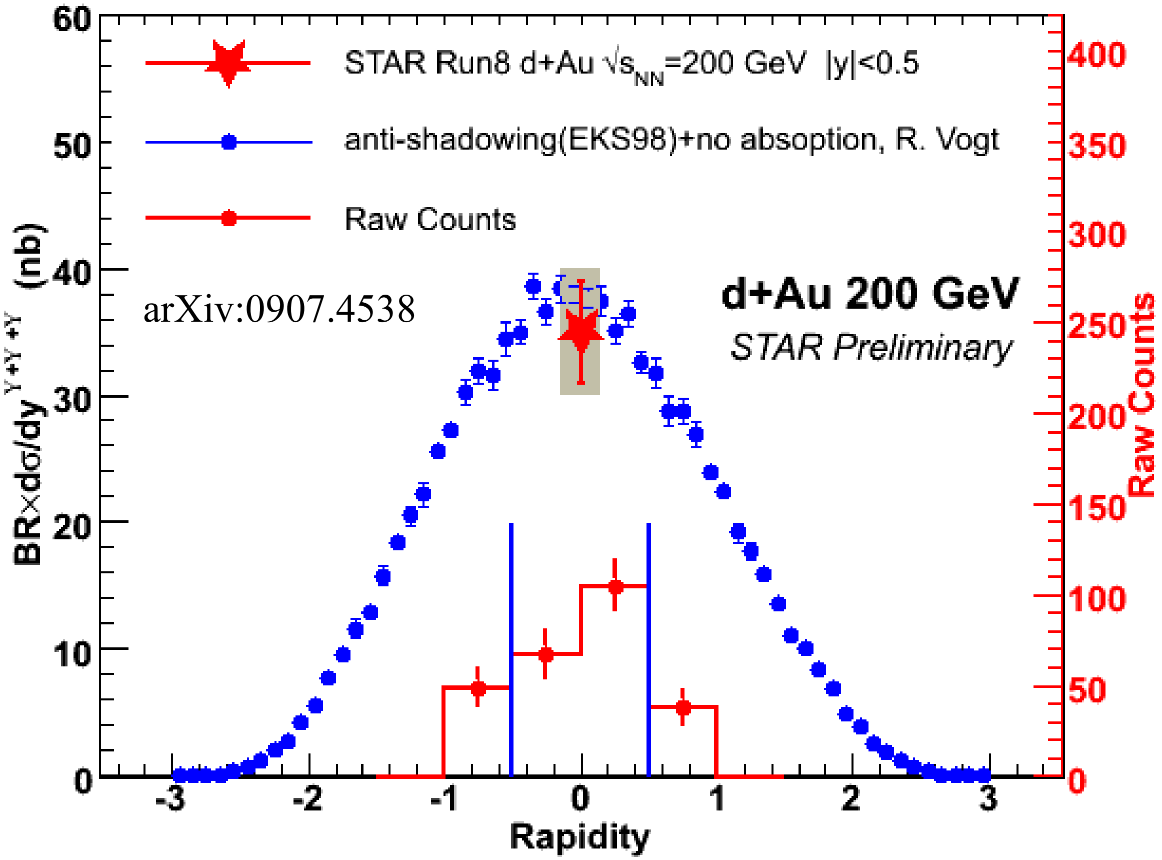


$$\sum_{n=1} \mathcal{B}(nS) \times \sigma(nS) = 114 \pm 38 \,^{+23}_{-24}\ \text{pb}$$

Consistent with CEM, (inconsistent with CSM: ~ 2σ)

Color Singlet Model (CSM)
PRL 100, 032006(2008),
Color Evaporation Model (CEM)
Phys. Rept. 462, 125 (2008)

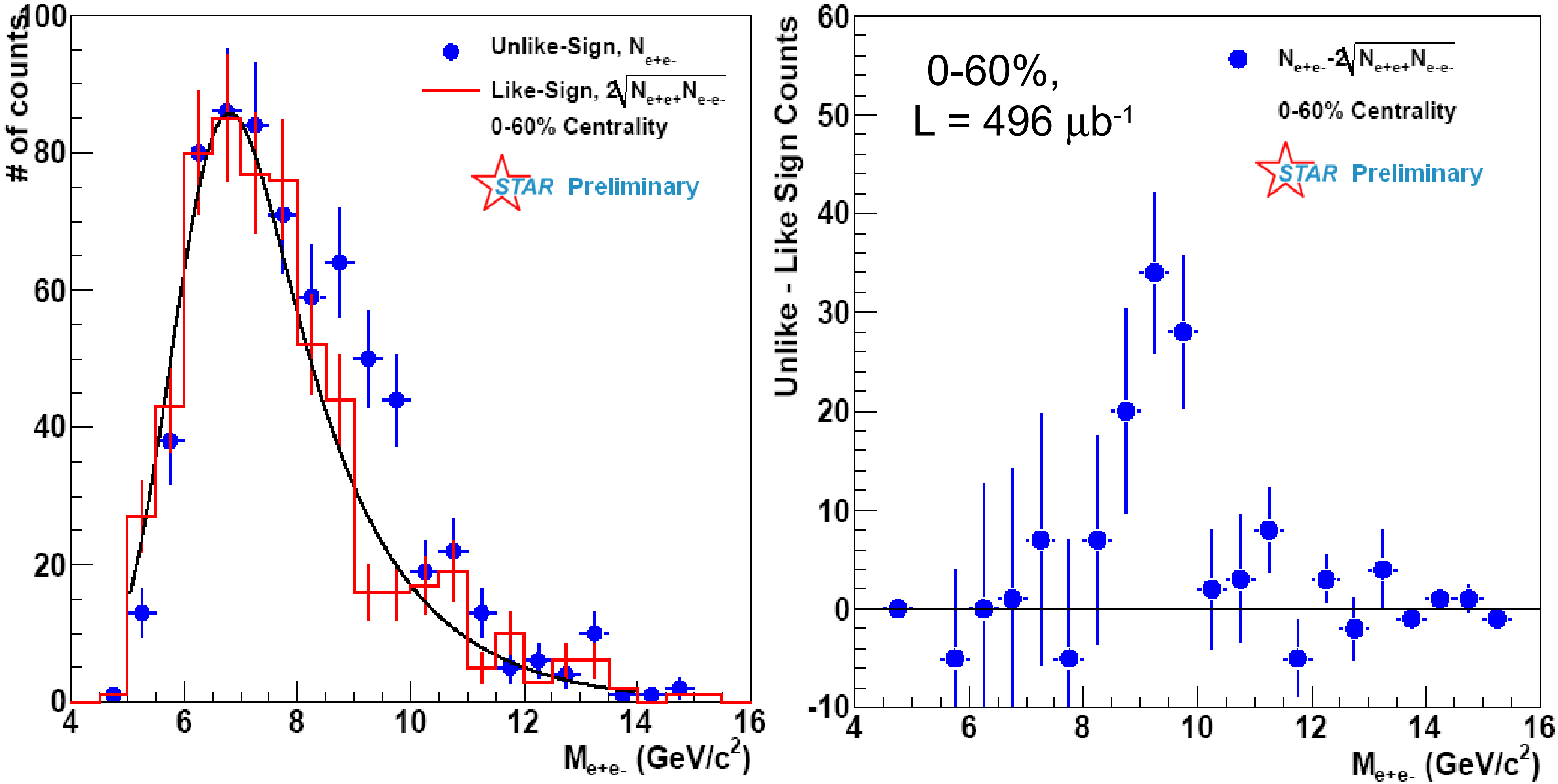
Cold nucl. matter: Υ in d+Au



$$R_{dA} = 0.78 \pm 0.28\,(\mathrm{stat.}) \pm 0.20\,(\mathrm{sys.})$$

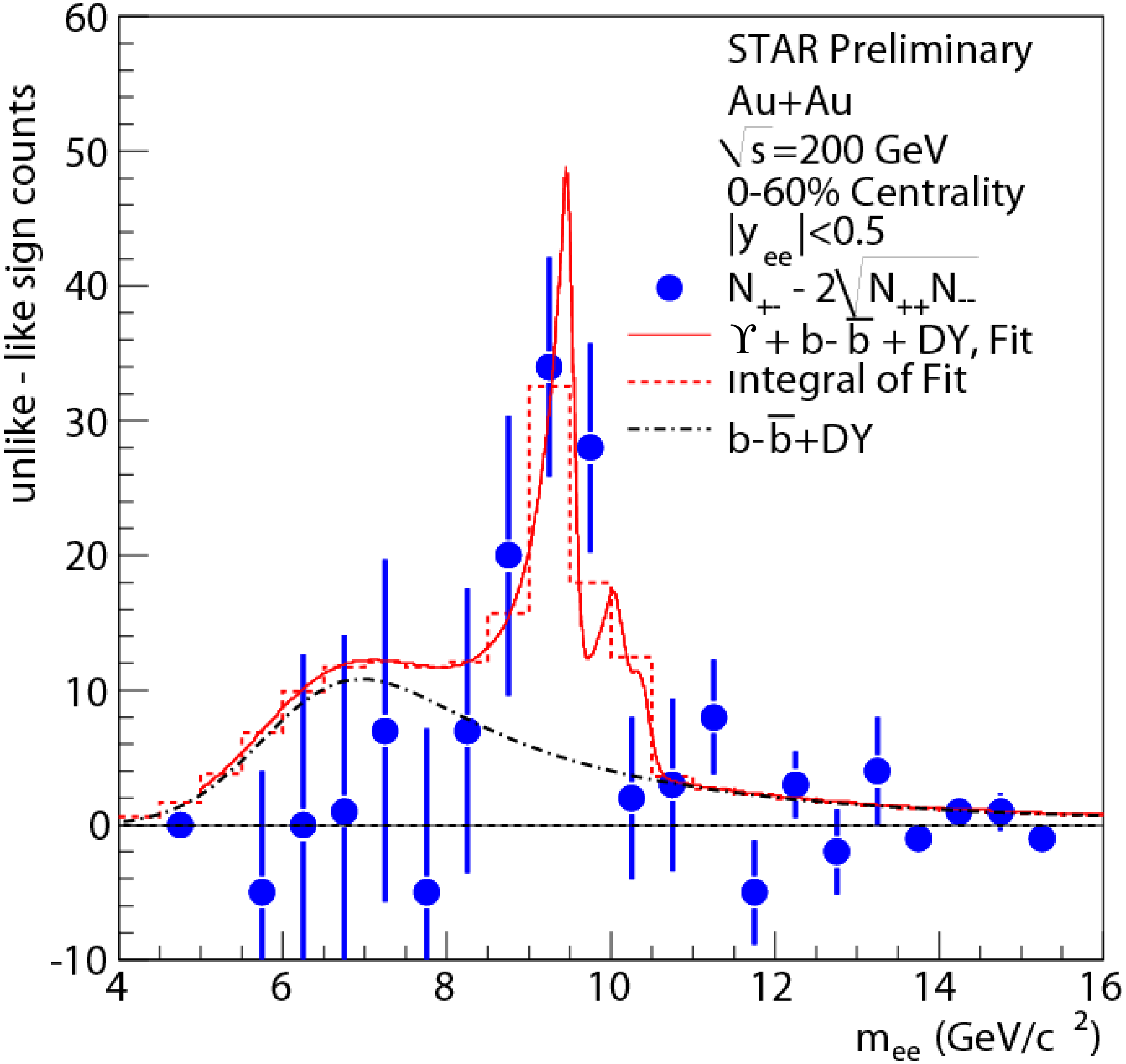
- Consistent with N_{bin} scaling
- Cold Nuclear Matter effects (shadowing) are rather small

ϒ in Au+Au 200 GeV



- 4.6σ significance, 95 Signal counts in 8 < m < 11 GeV/c^2
- Includes ϒ, Drell-Yan + $b\bar{b}$

Υ R_{AA} in Au+Au 200 GeV



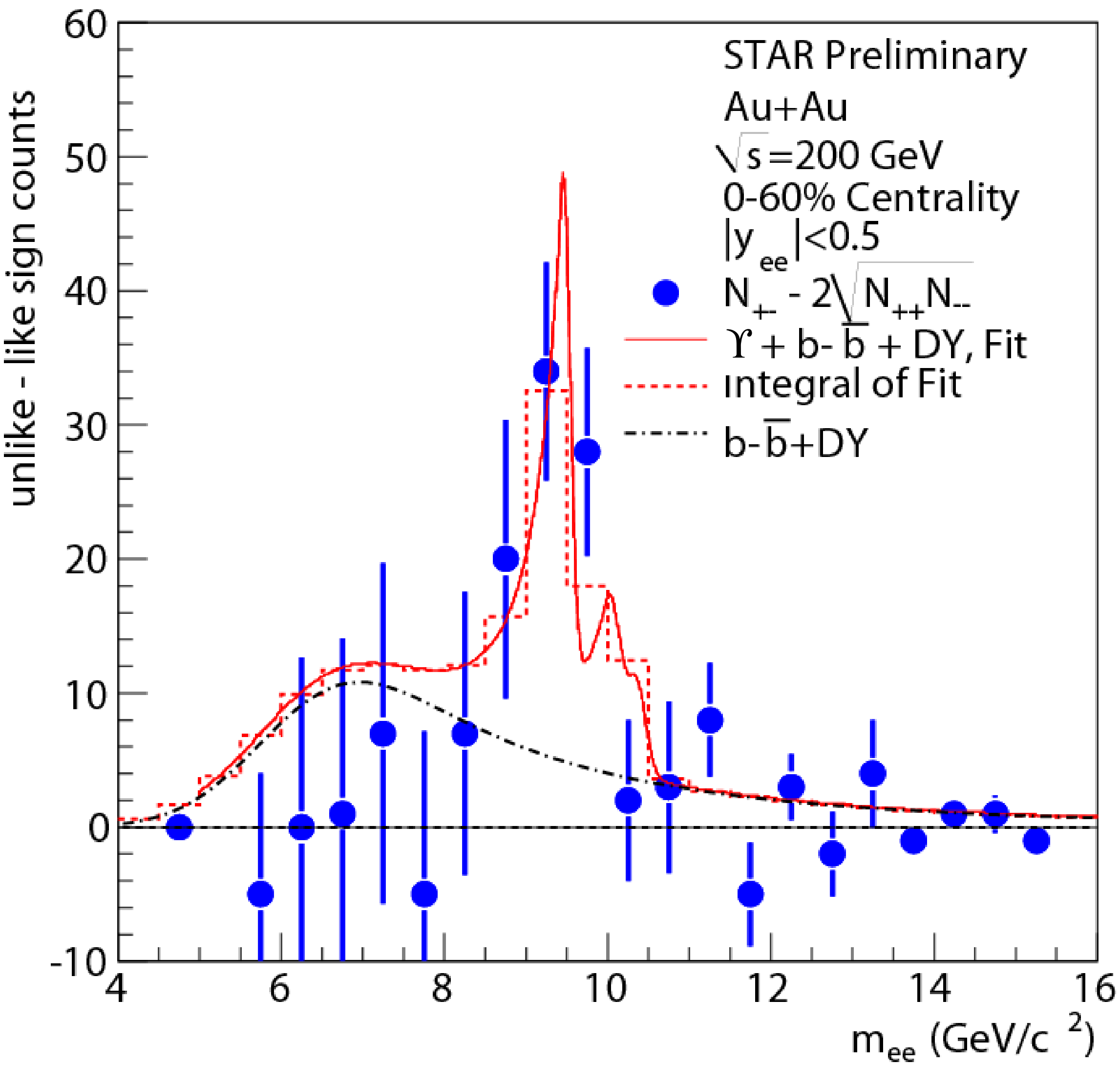
Υ(8.5<m<11 GeV) =

$N_{+-} - 2\sqrt{N_{++}N_{--}} - \int DY + b\bar{b}$

= 64±16(stat)± 25(sys)

R_{AA}= 0.78 ± 0.32(stat) ± 0.22(sys,Au+Au) ± 0.09(sys,p+p)

Υ R_{AA} in Au+Au 200 GeV



$\Upsilon(8.5<m<11 \text{ GeV}) =$

$N_{+-} - 2\sqrt{N_{++}N_{--}} - \int DY + b\bar{b}$

$= 64 \pm 16(\text{stat}) \pm 25(\text{sys})$

Need considerably more statistics to constrain theory

$R_{AA} = 0.78 \pm 0.32(\text{stat}) \pm 0.22(\text{sys,Au+Au}) \pm 0.09(\text{sys,p+p})$

Summary &
A look into the near future

Rich quarkonia program at STAR

- J/ψ: focus on high p_T
  - p_T spectra, B feed-down
  - R_{AA} in Cu+Cu at high-p_T consistent with unity
- Υ
  - first cross-section measurement in p+p at 200 GeV
  - d+Au: $R_{dAu} = 0.78 \pm 0.28(stat) \pm 0.20(sys)$
  - Au+Au:

    $R_{AuAu} = 0.78 \pm 0.32(stat) \pm 0.22(sys, Au+Au) \pm 0.09(sys, p+p)$

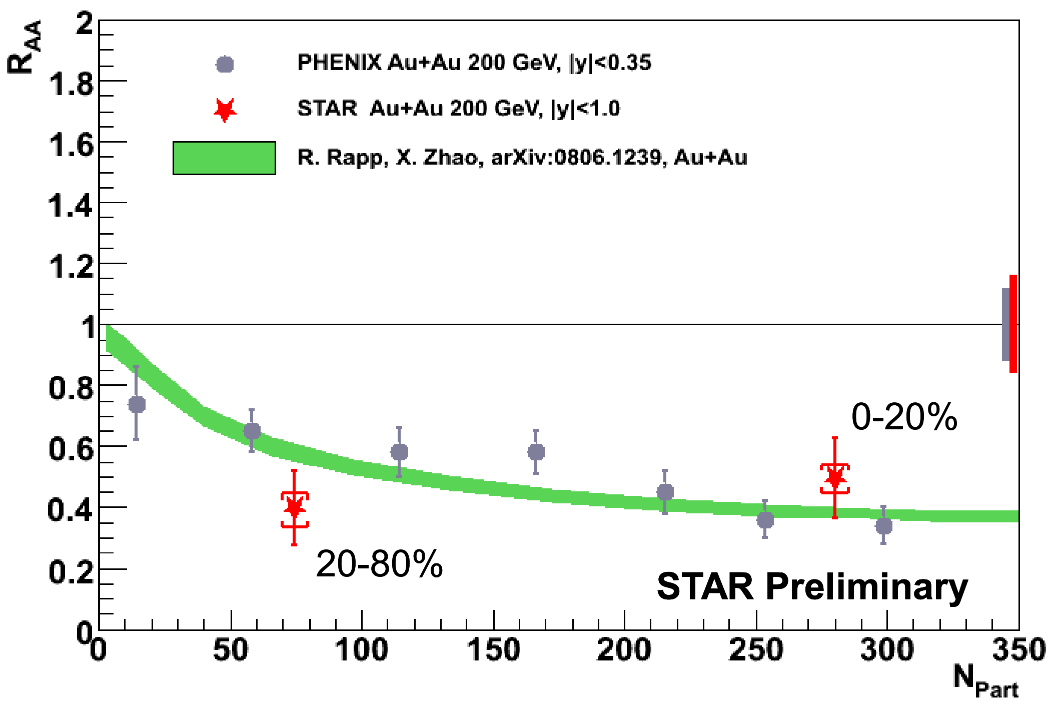
Near future

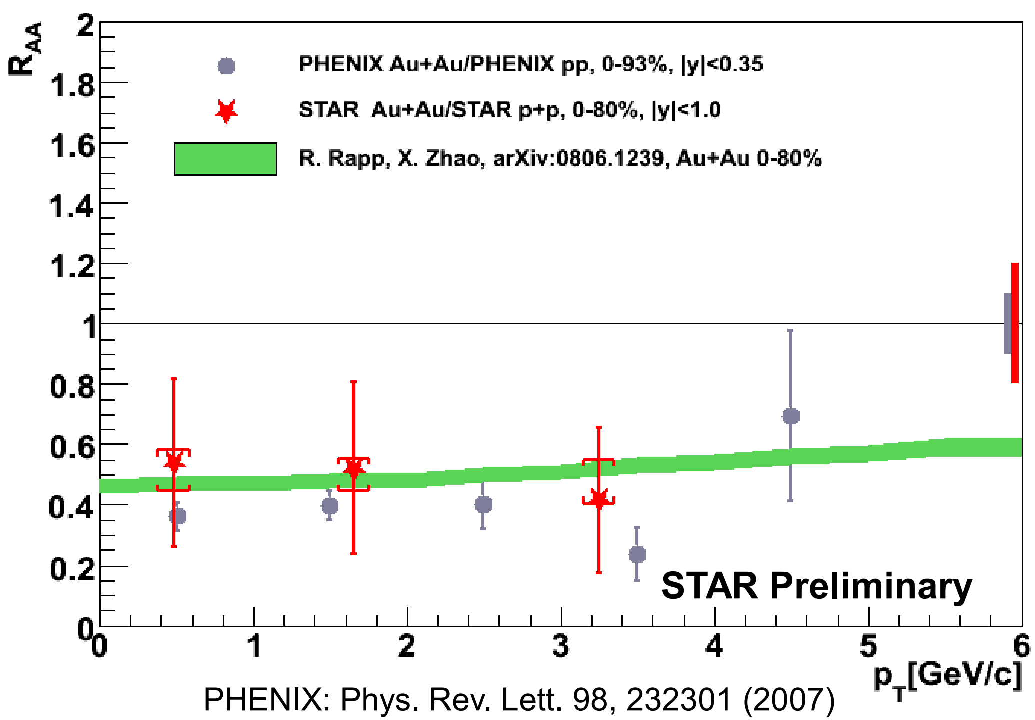
- J/ψ
  - Polarization measurements at high p_T
  - R_{AA} at high-p_T in Au+Au 200 GeV
  - J/ψ elliptic flow at 200 GeV
  - J/ψ from Beam Energy Scan
- ϒ
  - New cross-section measurements in p+p and Au+Au 200 GeV
  - R_{AuAu} vs centrality in Au+Au
  - Separation of ϒ from ϒ' and ϒ'' states


THE END
Filmed in
HOLLYWOOD, U.S.A.

Backup

Low-p_T J/ψ in Au+Au 200 GeV

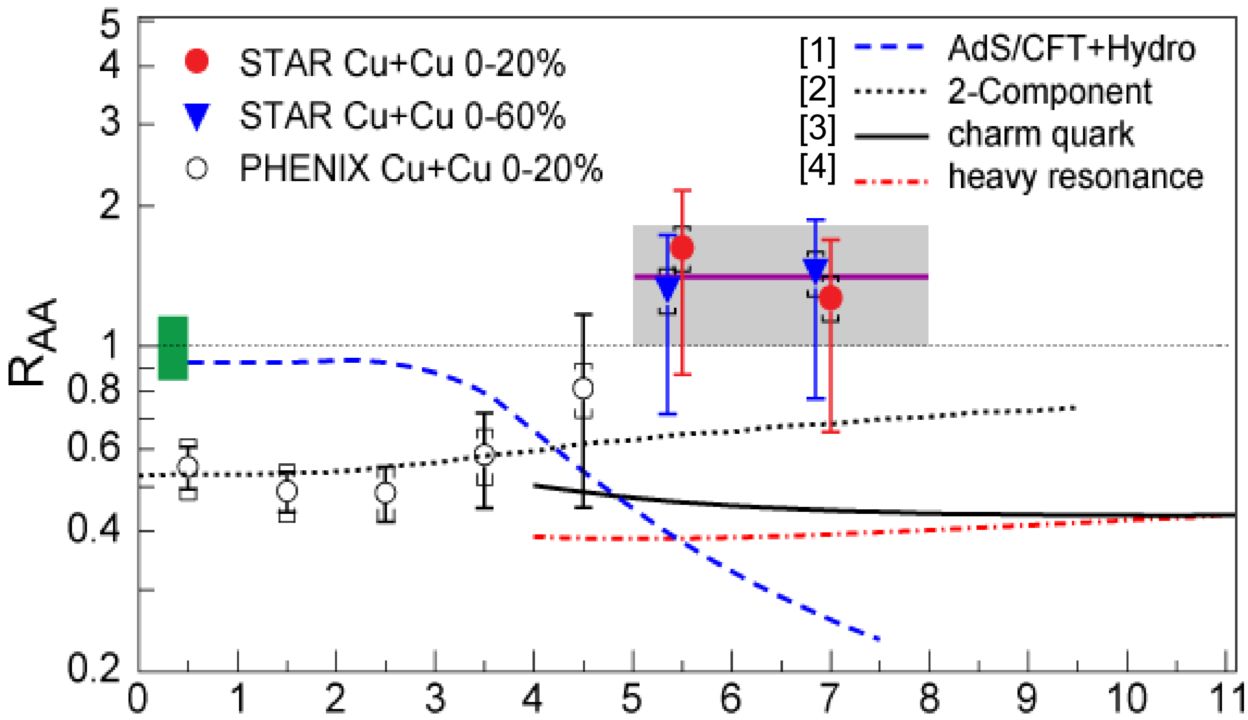




PHENIX: Phys. Rev. Lett. 98, 232301 (2007)

- Model (green band) includes: color screening in QGP, dissociation in hadronic phase, statistical recombination, B → J/ψ feed-down and formation time effects
- New Au+Au results with minimum inner material soon (5x higher statistics)

J/ψ production test: high-p_T



Phys.Rev.C80:041902,2009

$R_{AA}(p_T > 5$ GeV/c$) =$

1.4 ± 0.4 ± 0.2

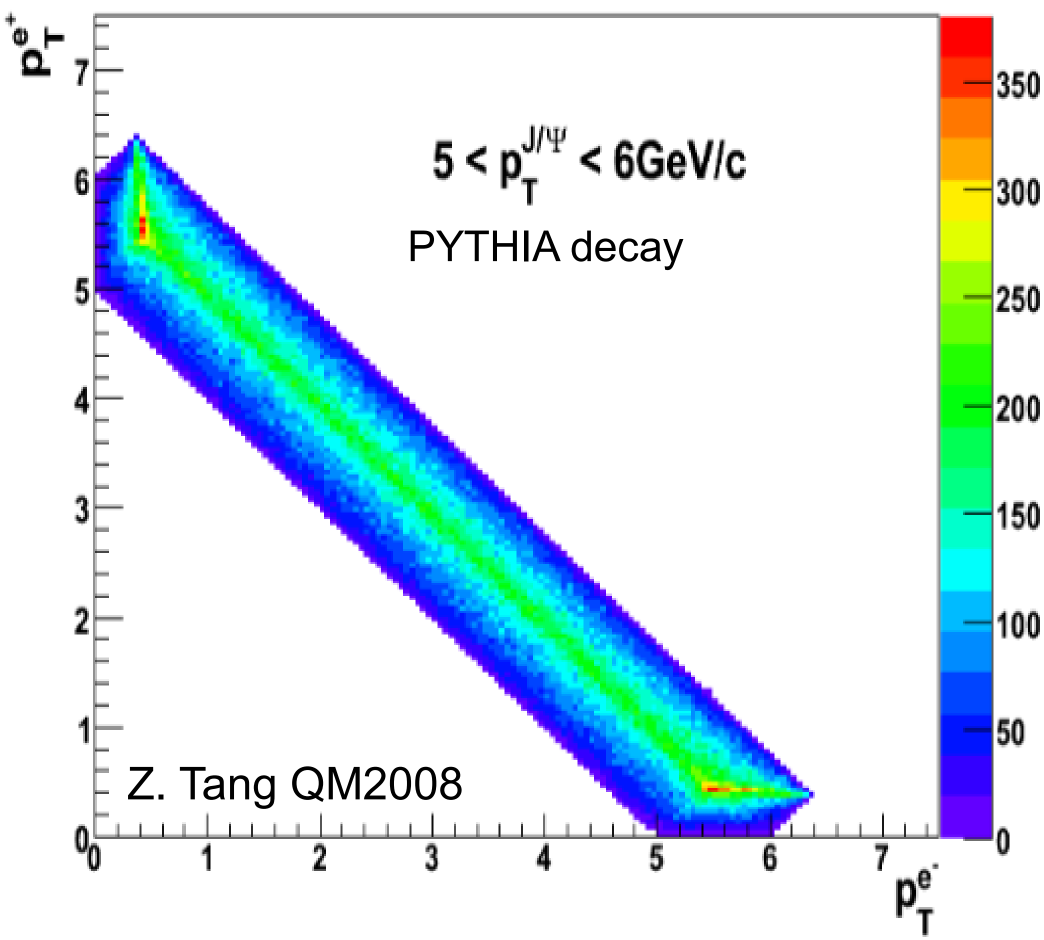
- Contrast to strong suppression of open charm

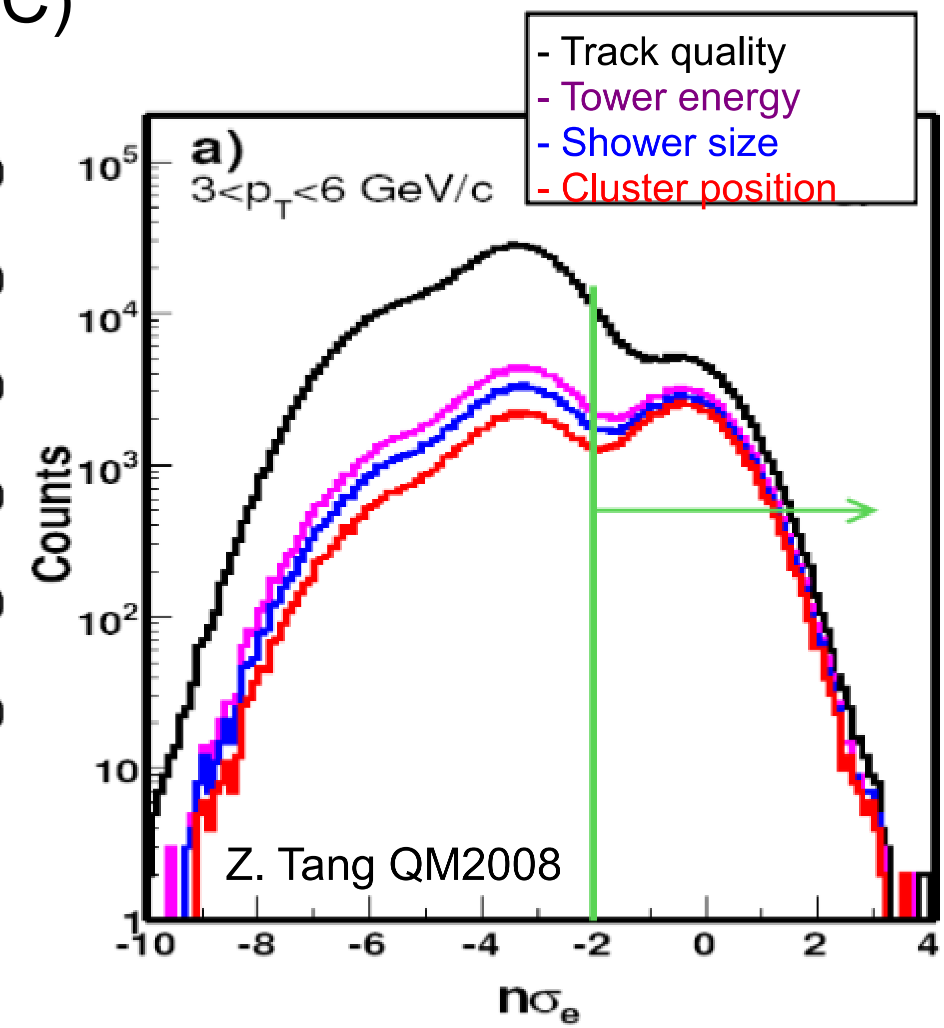
B.Abedev et al.,Phys.Rev.Lett. 98 (2007), 192301, S.Adler et al., Phys.Rev.Lett. 96(2006) 032301, [4] A. Adil and I. Vitev, Phys. Lett. B649, 139 (2007), and I. Vitev private communication; [3] S. Wicks et al., Nucl. Phys. A784, 426 (2007), and W. A. Horowitz private communication.

- Rising trend reproduced when B feed-down and formation time effects included [2] R. Rapp, X. Zhao, nucl-th/0806.1239

High p_T J/ψ at STAR

Single High Tower trigger for high p_T J/ψ
- Higher p_T electron: dE/dx (TPC) + EMC (p/E) + SMD (shower size and cluster position)
- Lower-p_T electron: dE/dx (TPC)





Heavy quarks = early production

Interpenetration time: $t \approx 2R/\gamma$

$m_c \approx 1.3\ \mathrm{GeV}$

SPS: $t \geqslant 1 fm$

$m_b \approx 4.2\ \mathrm{GeV}$

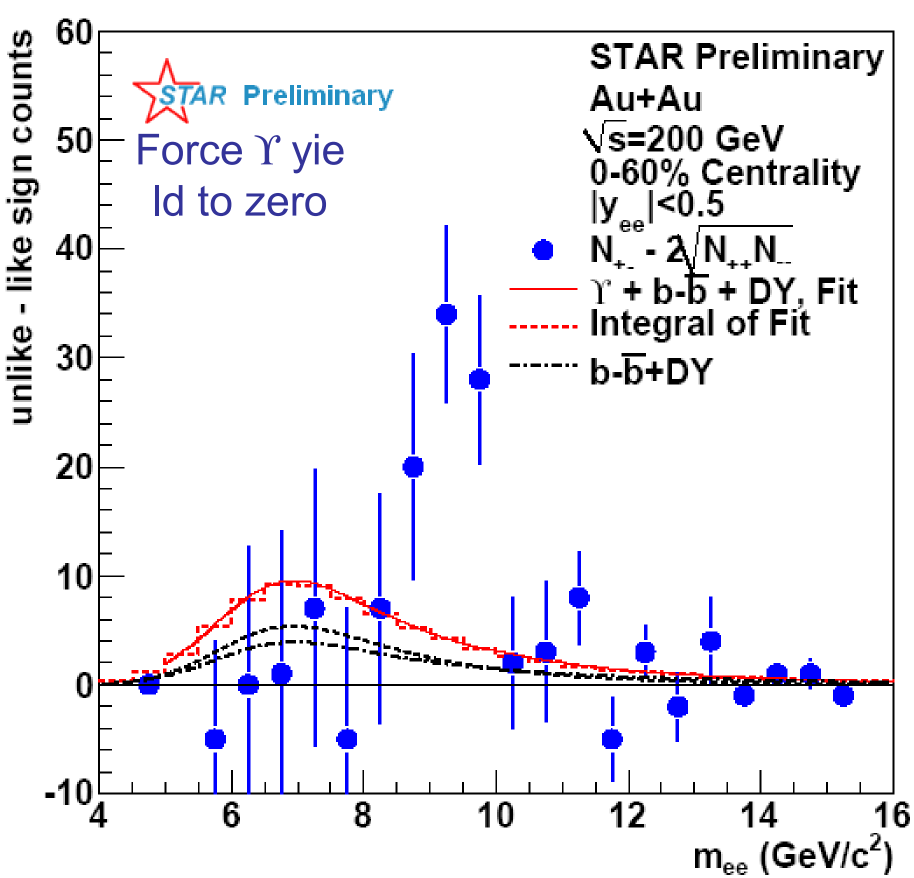
RHIC: $t \leqslant 0.2 fm$

$t_c^{production} = 1/2m_c \leqslant 0.1 fm$

LHC: $t \leqslant 5 \times 10^{-3} fm$

ϒ Yield Extraction 0-60% Centrality

- Do we see ϒ(1S+2S+3S) in 0-60% centrality?
  - Yes!



Raw yield of 0 is many sigma away from minimum χ^2