# J/ψ Production in Proton+Proton and Heavy-Ion Collisions at STAR

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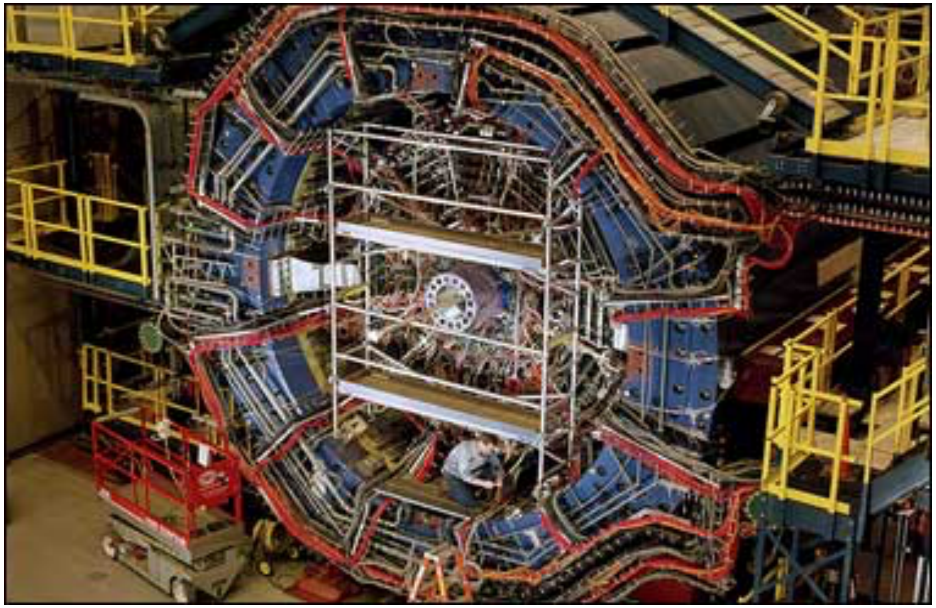
# Outline

- Motivation
- Relativistic Heavy Ion Collider
- The STAR detector
- J/ψ production in p+p collisions at $\sqrt{s}$ = 200 & 500 GeV
- J/ψ production in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV
- Summary



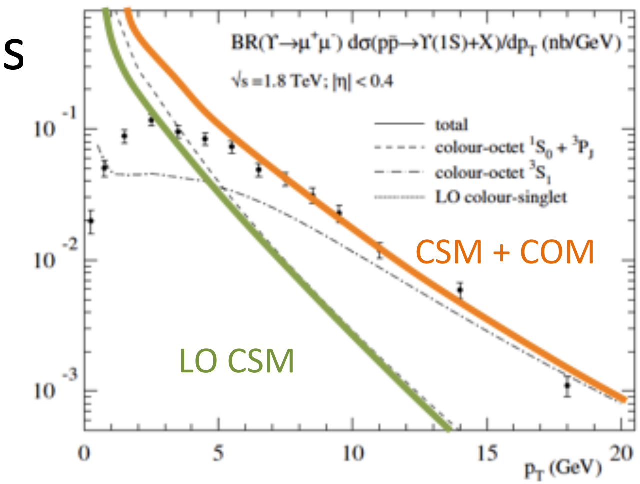
# Motivation

- Quarkonium production mechanisms are still not fully understood in p+p collisions

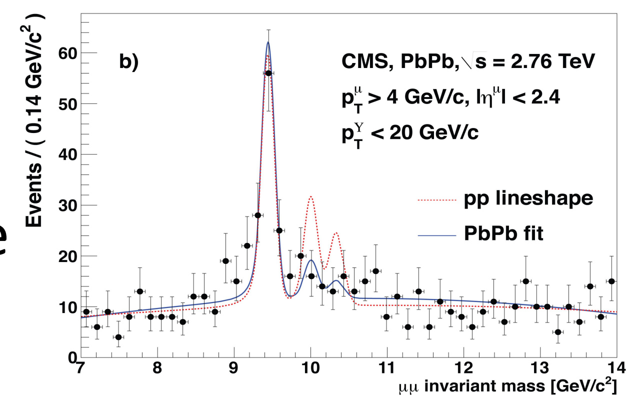
- Some popular models on the market:
  - Color Singlet Model (CSM)
  - Color Octet Mechanism (COM) / NRQCD
  - Color Evaporation Model (CEM)
  - $k_T$ factorization
  - …

- Studying the suppression of quarkonium states in heavy-ion collisions can provide deep insights into the properties of QCD and Quark-Gluon Plasma

CDF ϒ(1S) result



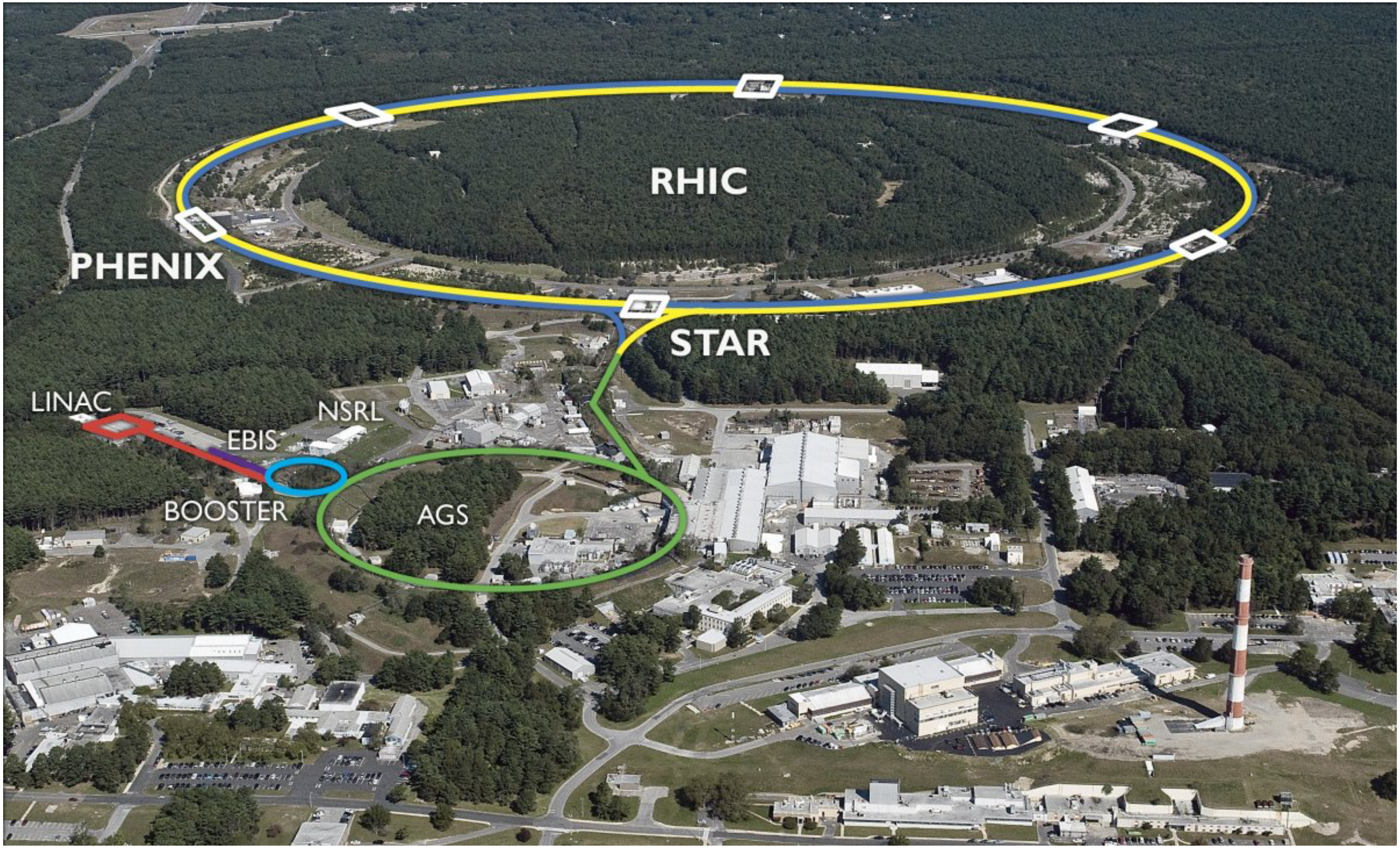

M. Kramer, Prog. Part. Nucl. Phys. 47, 141 (2001).



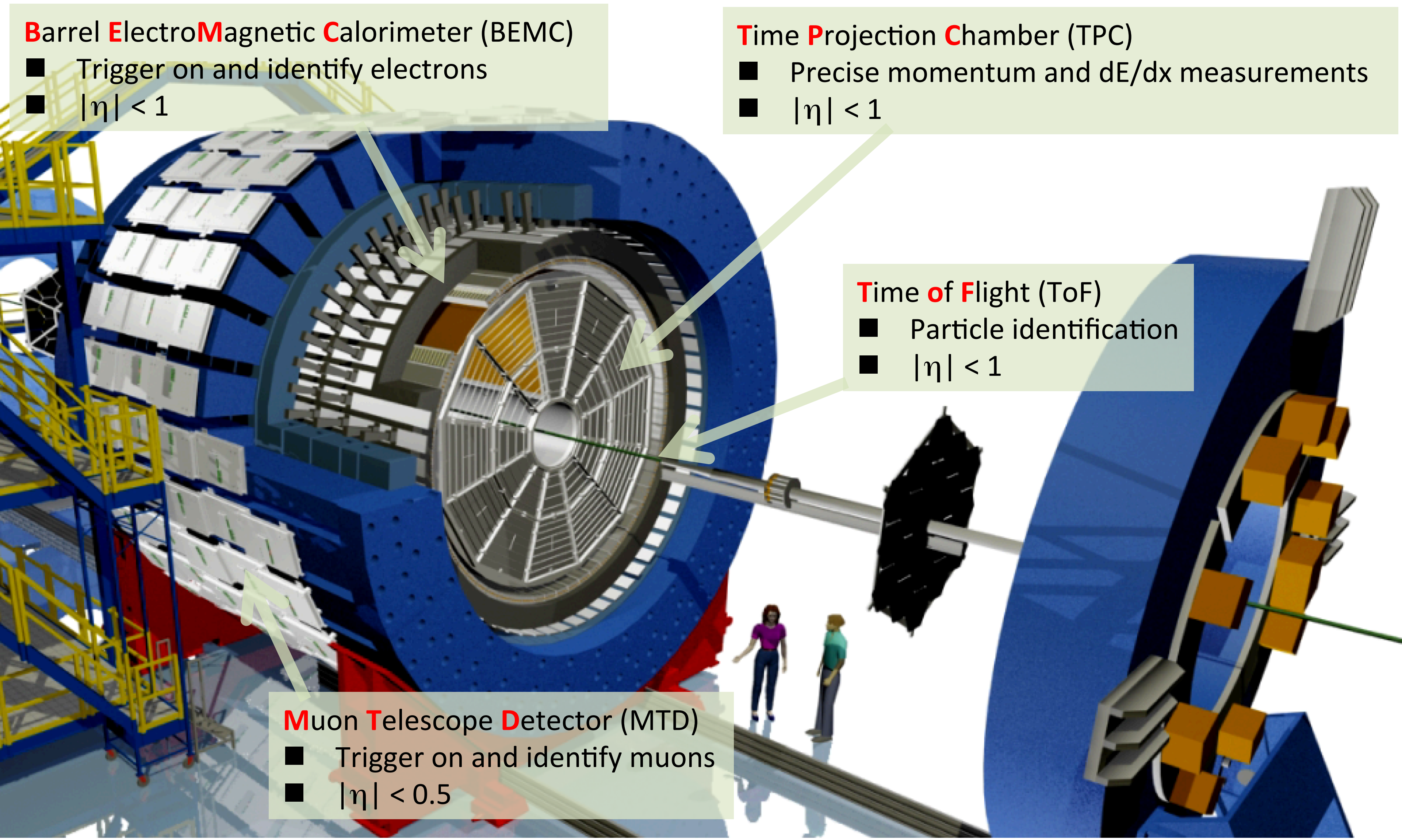

CMS Collaboration, Phys Rev Lett 107 052302,2011

# Relativistic Heavy-Ion Collider

- One of the most powerful heavy-ion colliders in the world!

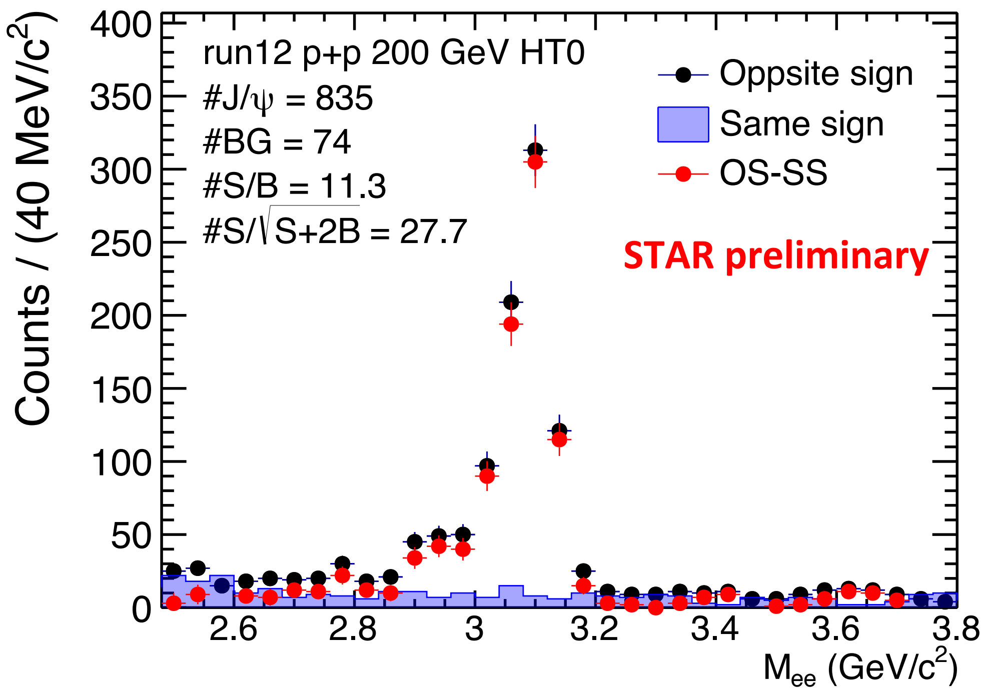


# The STAR Detector



# $J/\psi \rightarrow e^+e^-$ in p+p @ 200 GeV

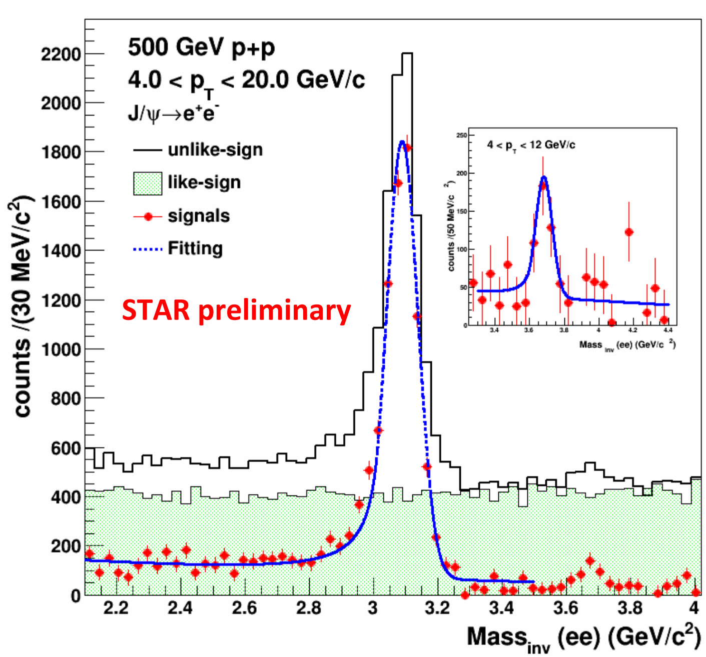
- Luminosity: 25.4 $pb^{-1}$ (2012 Run)
- Track selection:
  - Basic track qualities
  - $p_T$ > 2.5/3.6/4.3 GeV/c for trigger electrons from $J/\psi$
  - $p_T$ > 0.2 GeV/c for partner electrons from $J/\psi$
  - $|\eta_e| < 1$
  - $|y_{J/\psi}| < 1$

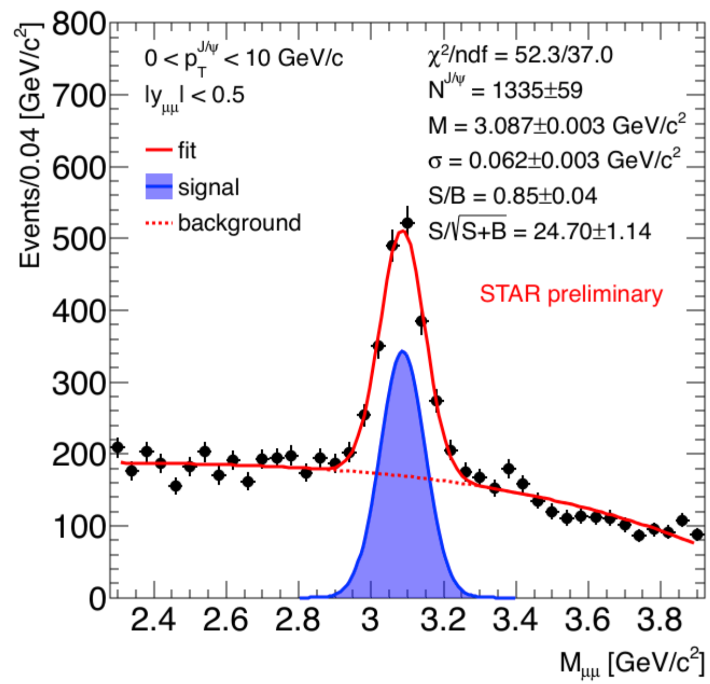


# $J/\psi \rightarrow e^+e^-/\mu^+\mu^-$ in p+p @ 500 GeV

- **Dielectron:**
  - Luminosity: 22 $pb^{-1}$ (2011 Run)
  - Track selection:
    - Basic track qualities
    - $|\eta| < 1$
    - $p_T > 1$ GeV/c for electrons from $J/\psi$
- **Dimuon:**
  - Luminosity: 28 $pb^{-1}$ (2013 Run)
  - Track selection:
    - Basic track qualities + MTD matching
    - $|\eta| < 0.5$
    - $p_T > 1.3$ GeV/c for muon candidates
    - Additional muon ID seletion

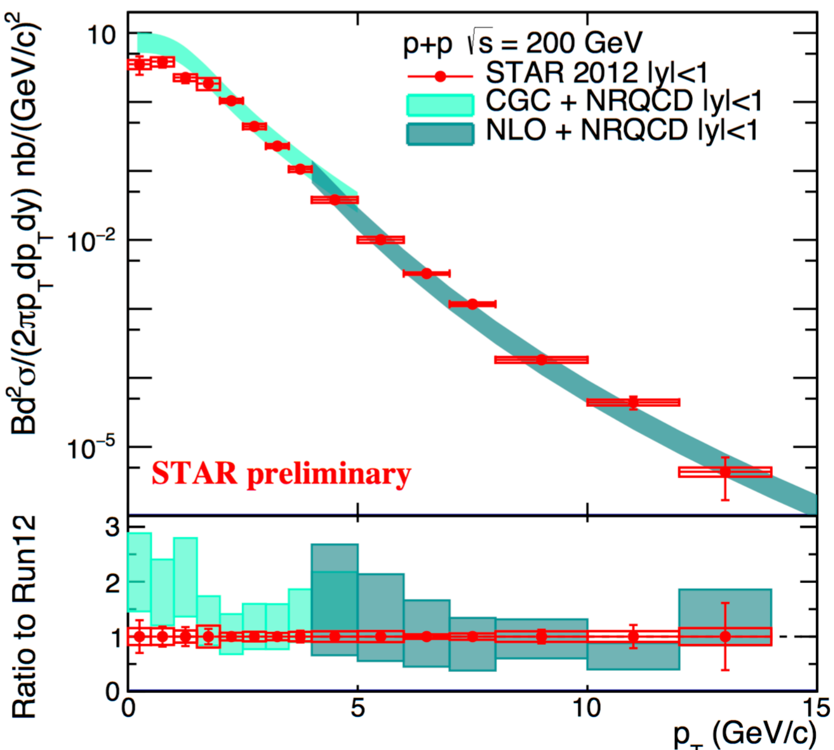
(More details can be found in T.C. Huang's poster)



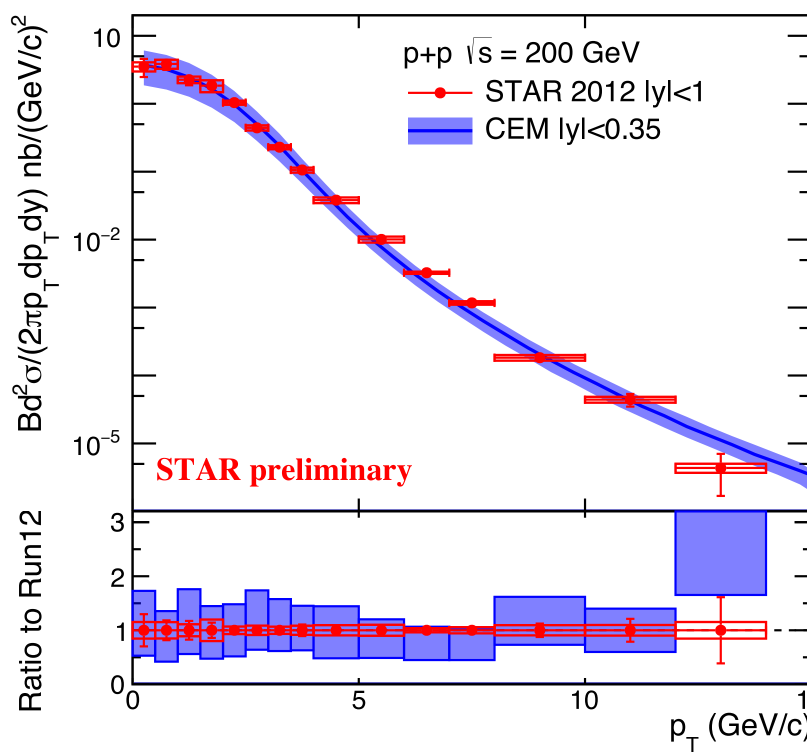



# J/ψ Invariant Cross-Section in p+p @ 200 GeV

- Precision measurement of J/ψ production cross-section from 0 to 14 GeV/c of $p_T^{J/\psi}$
- Data are in a good agreement with CGC+NRQCD & NLO+NRQCD calculations, except that model calculations seem to be above data at low $p_T$
- CEM can describe data very well



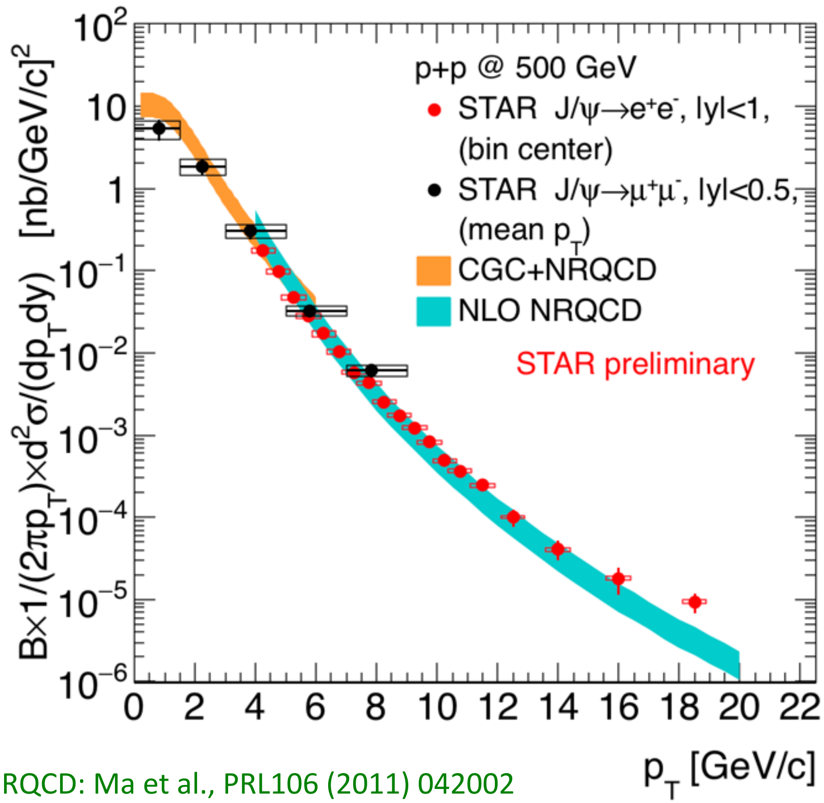

NLO NRQCD: Ma et al., PRL106 (2011) 042002
CGC+NRQCD: Ma, Venugopalan, PRL**113** (2014) 192301

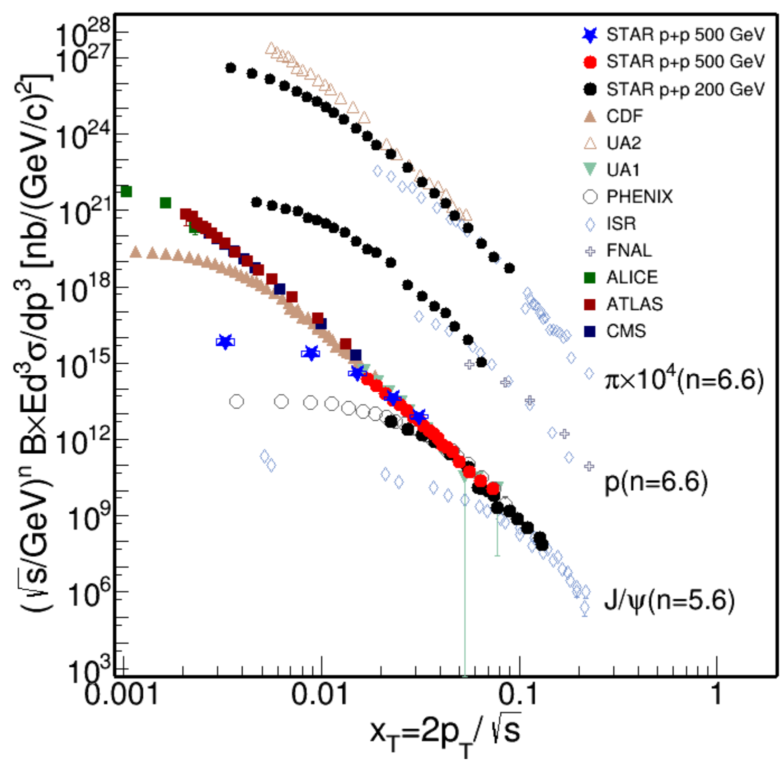



CEM: Nelson, Vogt, Frawley, PRC **87** (2013) 014908

# J/ψ Invariant Cross-Section in p+p @ 500 GeV

- Precision measurement of J/ψ production cross-section from 0 to 20 GeV/c of $p_T^{J/\psi}$ (μμ for low $p_T$ and ee for high $p_T$)
- Consistent with CGC+NRQCD & NLO NRQCD calculations. Similar discrepancy at low $p_T$ as seen in p+p @ 200 GeV
- Broken scaling at low $x_T$ is due to soft processes



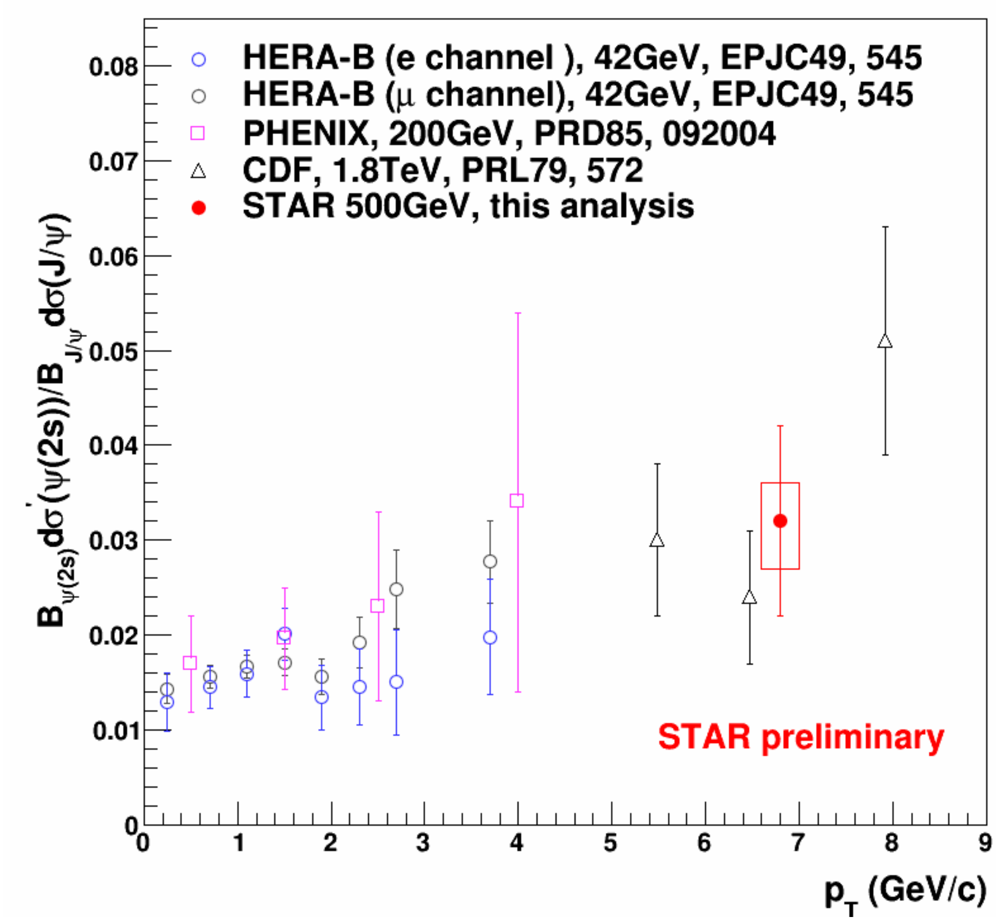

NLO NRQCD: Ma et al., PRL106 (2011) 042002

CGC+NRQCD: Ma, Venugopalan, PRL**113** (2014) 192301

PRC **80** (2009) 041902

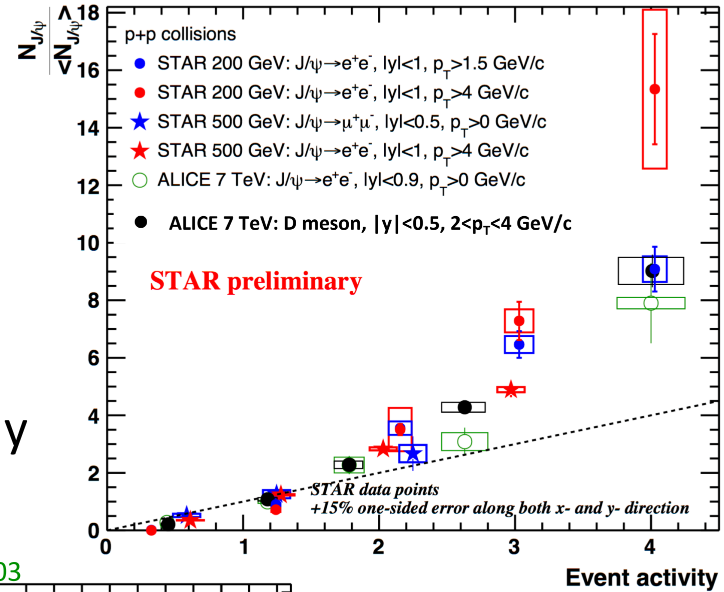
# $\psi(2s)$ to $J/\psi$ Ratio

- To help determine the feed-down contribution of $\psi(2s)$ to $J/\psi$
- Result from STAR is consistent with other experiments
  - ➔ No obvious collision energy dependence



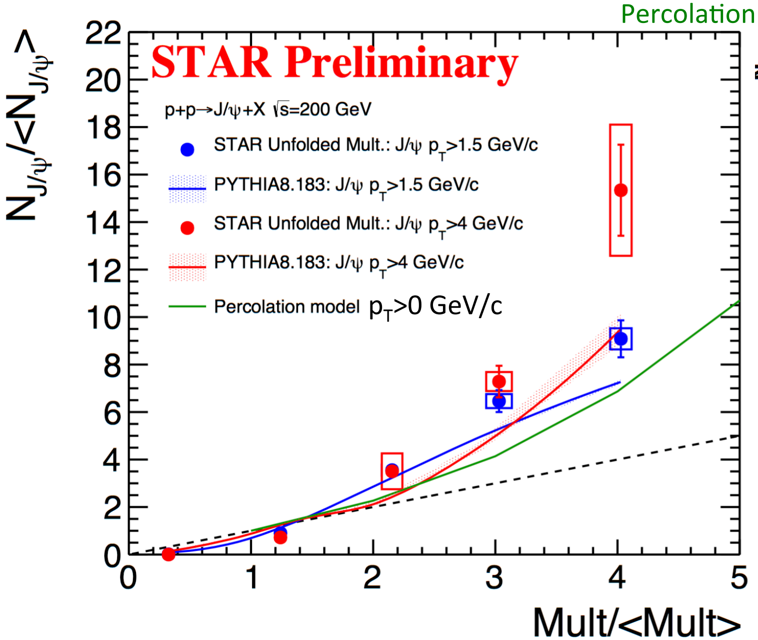
# J/ψ Yield vs. Event Activity

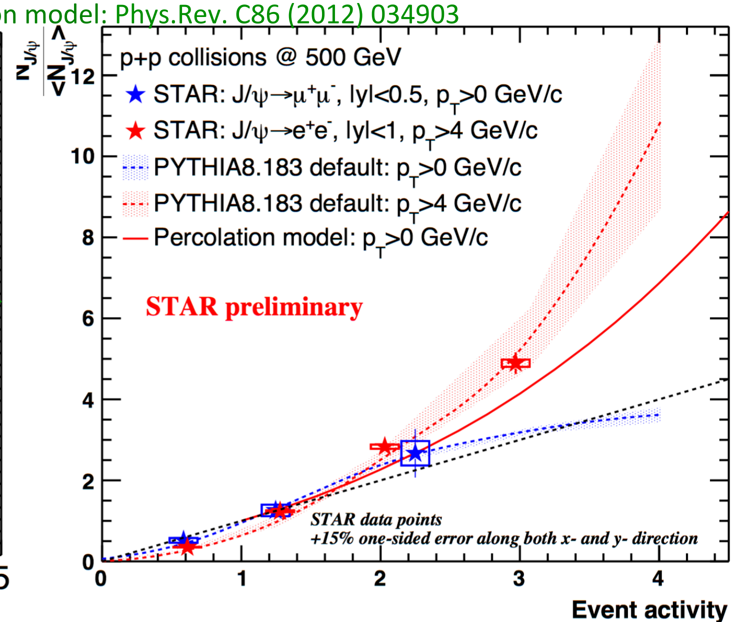
- Event activity = charged-particle multiplicity
- Relative J/ψ yield rises faster than a linear function
  - ➔ Similar global trend at different collision energies and as for the D meson
- PYTHIA and Percolation model can qualitatively describe the rising behavior




ALICE: JHEP 09 (2015) 148

Percolation model: Phys.Rev. C86 (2012) 034903

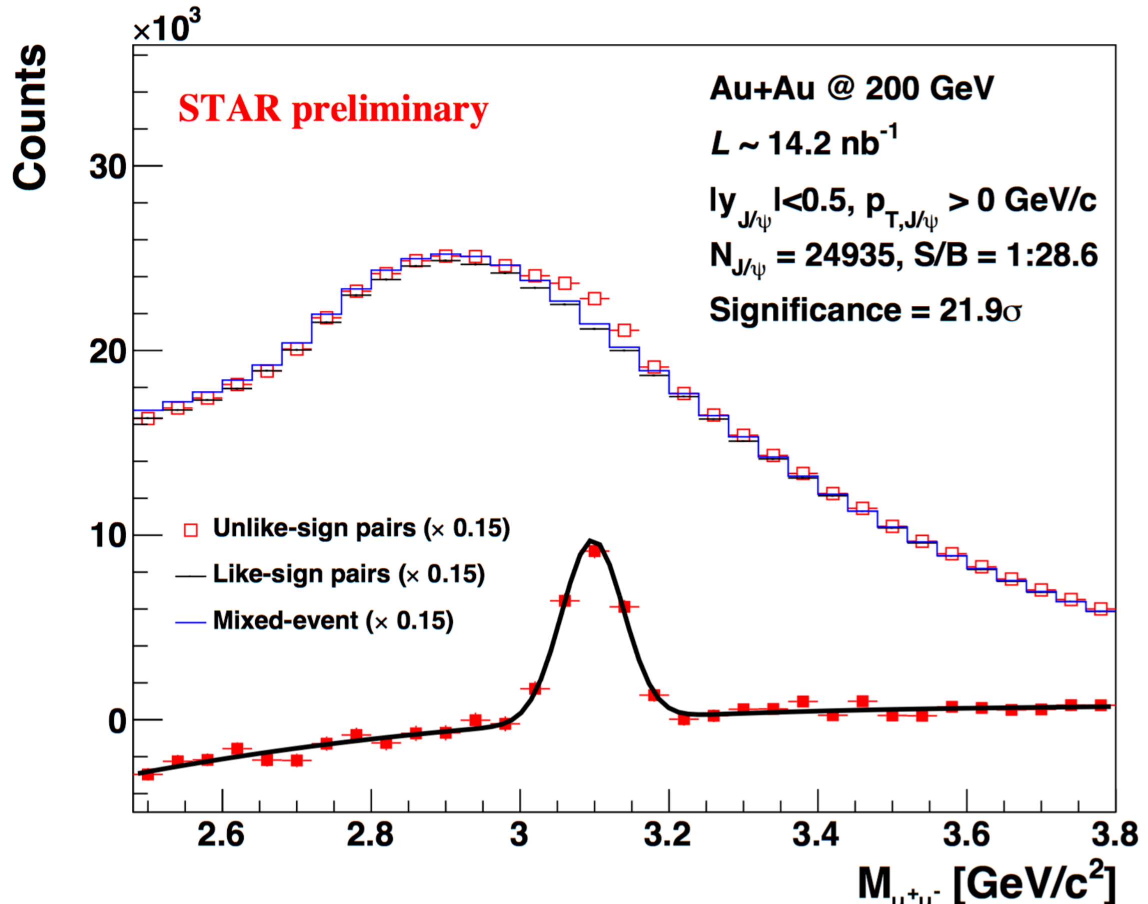



* $p_T$ > 0.2 GeV/c for tracks

# $J/\psi \rightarrow \mu^+\mu^-$ in Au+Au @ 200 GeV

- Luminosity: 14 $nb^{-1}$ (2014 Run)
- Track selection:
  - Basic track qualities + MTD PID
  - $|\eta| < 0.5$
  - $p_T^{leading} > 1.5$ GeV/c
  - $p_T^{subleading} > 1.2$ GeV/c

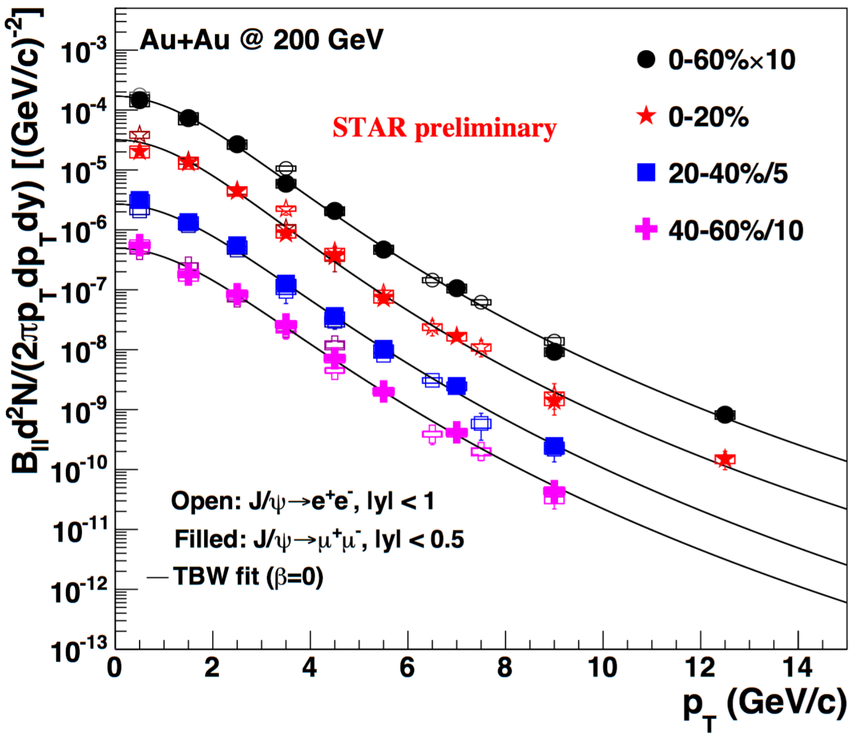


# J/ψ Invariant Yield

- First precision measurement of J/ψ invariant yield via the dimuon channel at mid-rapidity covering $0 < p_T < 15$ GeV/c at STAR
- Consistent with published results from the dielectron channel.

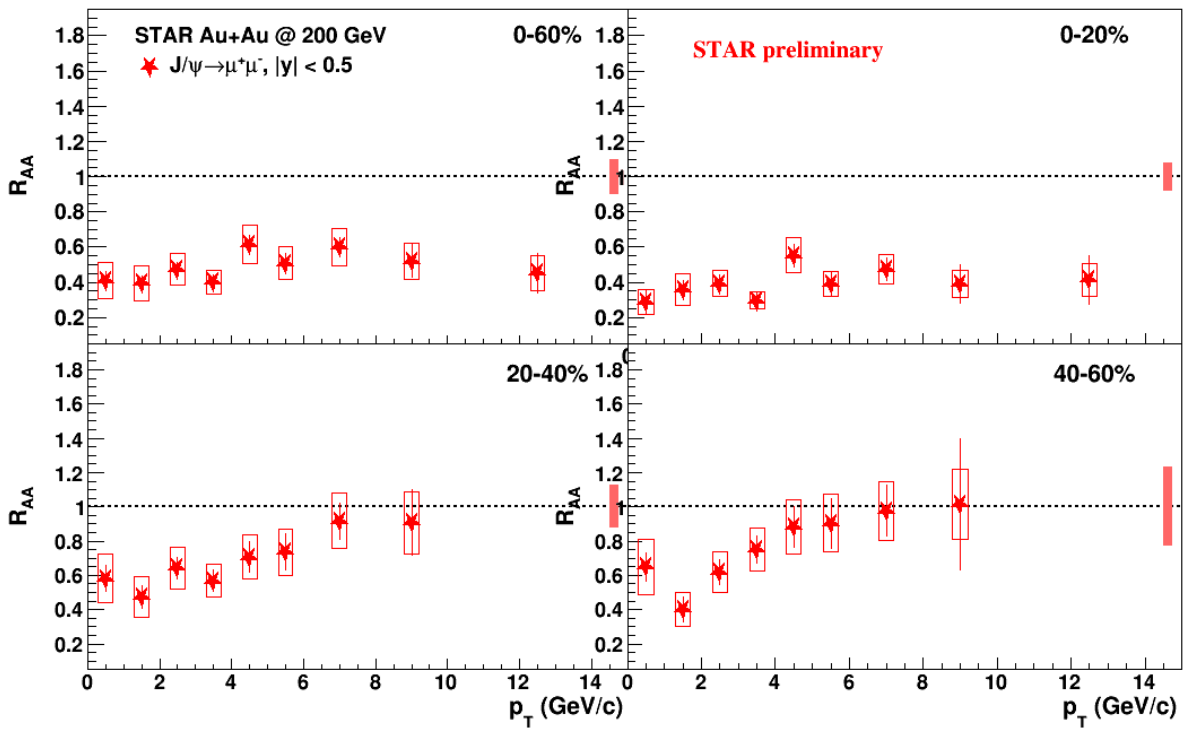
(STAR Collaboration Phys Lett B722 55-62, 2013)

  - Tsallis Blast-wave (TBW) function with the assumption of zero J/ψ velocity can describe data very well (Ref: Phys. Rev. C **79** 051901, 2009)



# $J/\psi$ $R_{AA}$ vs. $p_T$

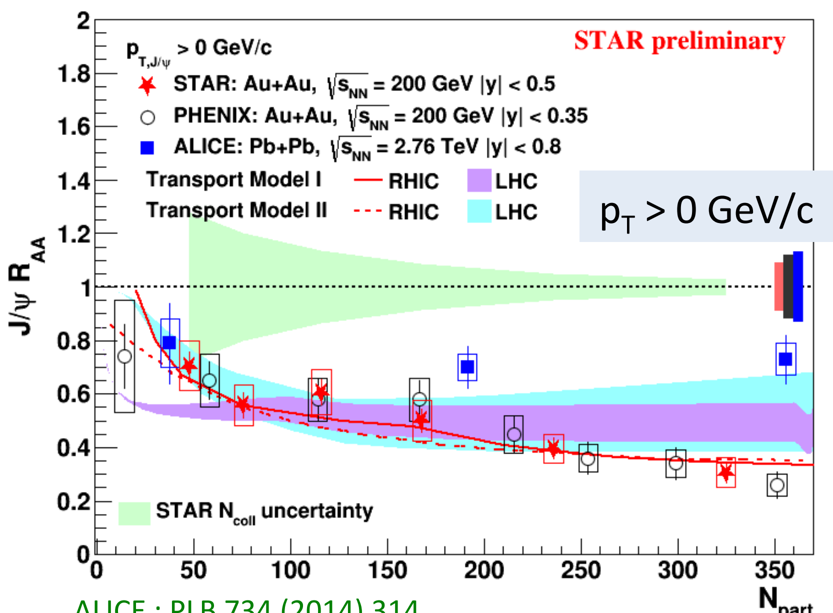
- No obvious $p_T$ dependence in $R_{AA}$ in 0 - 20% centrality bin
- Rising $R_{AA}$ with $p_T$ in 20 - 40% and 40 - 60% centrality bins
- Suppression at low $p_T$: dissociation, Cold Nuclear Matter (CNM) effect, regeneration
- Rising trend at high $p_T$ could be due to formation time effects, B-hadron feed-down
- Strong suppression at high $p_T$ in central collisions is a clear sign of dissociation since regeneration contribution and CNM effects are small



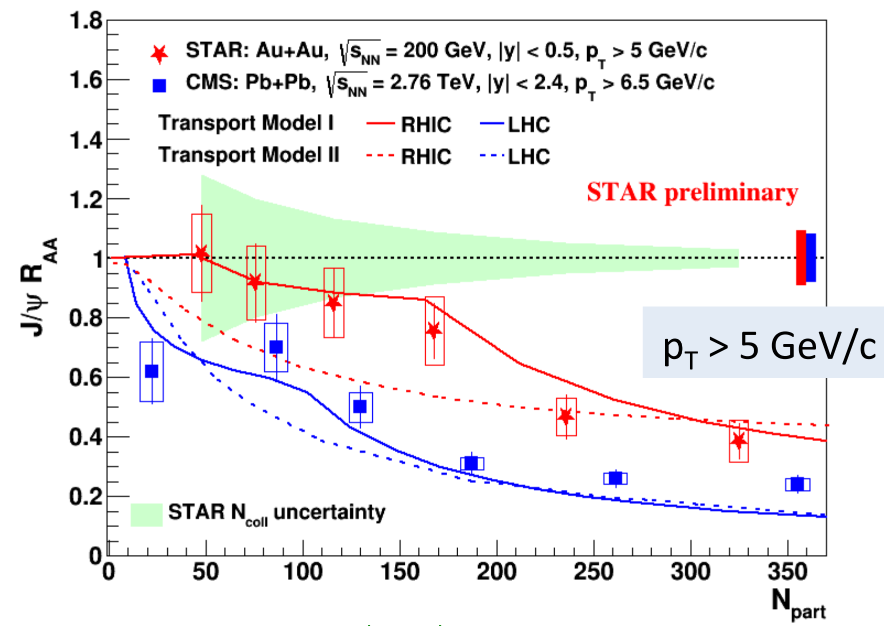
# J/ψ $R_{AA}$ vs. $N_{part}$

Transport model:
Model I at RHIC: PLB 678 (2009) 72
Model I at LHC: PRC 89 (2014) 054911
Model II at RHIC: PRC 82 (2010) 064905
Model II at LHC: NPA 859 (2011) 114

- RHIC vs. LHC
  - $p_T$ > 0 GeV/c: less suppressed in central collisions at the LHC
    ➔ larger regeneration contribution due to higher charm quark cross-section
  - $p_T$ > 5 GeV/c: more suppressed in central collisions at the LHC
    ➔ larger dissociation rate due to higher medium temperature
- Data vs. transport models (dissociation + regeneration effects)
  - $p_T$ > 0 GeV/c: both models can describe the centrality dependence at RHIC, but tend to overestimate suppression at LHC
  - $p_T$ > 5 GeV/c: there is tension among data and models




ALICE : PLB 734 (2014) 314
PHENIX : PRL 98 (2007) 232301

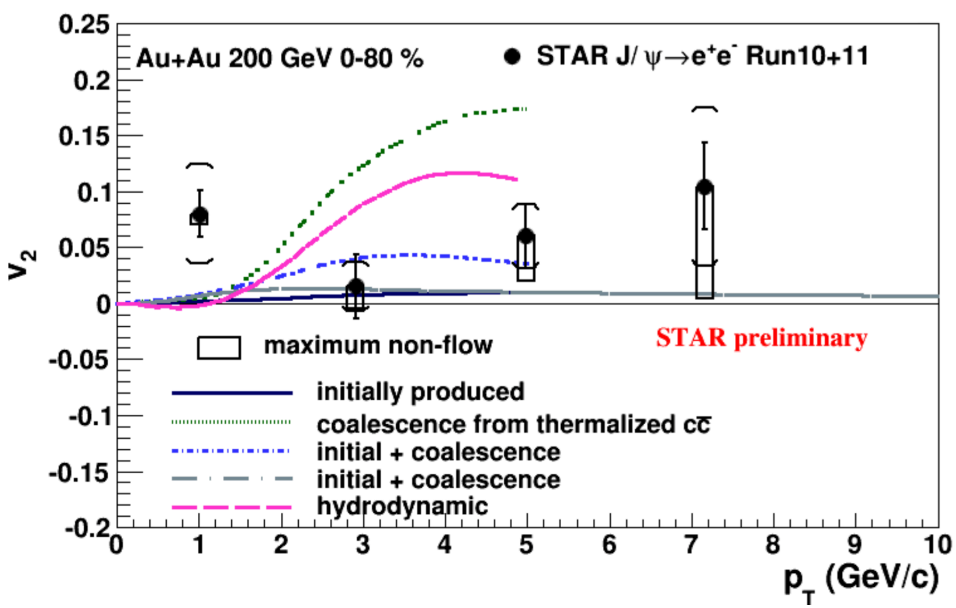


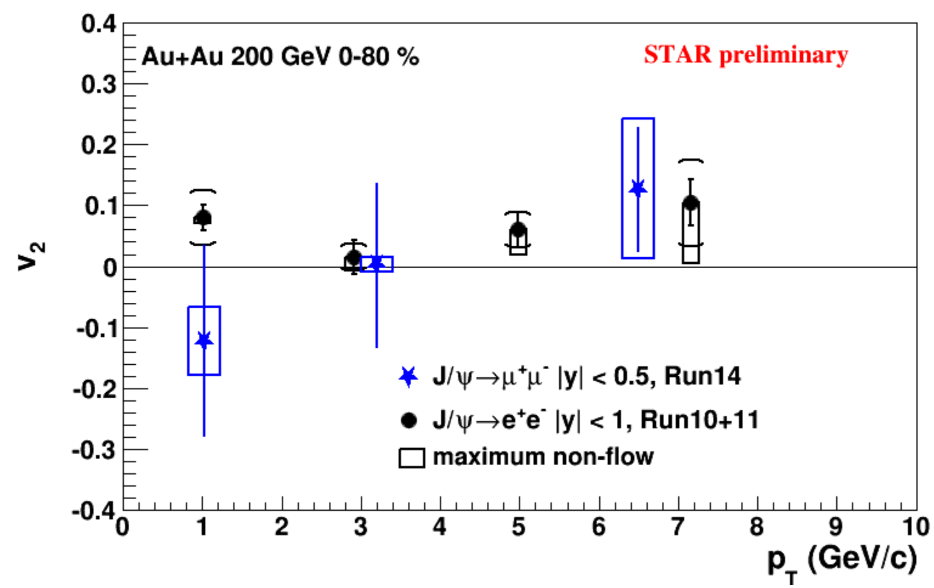

CMS: JHEP 05 (2012) 063

# J/ψ Elliptic Flow ($v_2$)

STAR, PRL 111 (2013) 052301
L. Yan, P. Zhuang, and N. Xu, PRL 97 (2006) 232301
V. Greco, C.M. Ko, and R. Rapp, PLB 595 (2004) 202
X. Zhao and R. Rapp, arXiv: 0806.1239
Y. Liu, N. Xu and P. Zhuang, NPA 834 (2010) 317
U.W. Heinz and C. Shen, (private communication)

- **Two main production mechanisms for J/ψ:**
  - Primordial: close to zero $v_2$
  - Regenerated: inherit $v_2$ from constituent charm quarks
- **First measurement of J/ψ $v_2$ in dimuon decay channel in STAR**
  - Consistent with the dielectron channel
- **For $p_T$ above 2 GeV/c, $v_2$ is consistent with zero**
  - ➔ Contribution of regenerated J/ψ is small



# Summary

- **The MTD allows STAR to study J/ψ production over a broad kinematic range down to zero $p_T$ via the dimuon decay channel in both p+p and Au+Au collisions**
- **J/ψ production in p+p @ 200 & 500 GeV**
  - Differential J/ψ invariant cross-section from 0 – 20 GeV/c of $p_T^{J/\psi}$ is consistent with CEM, CGC + NRQCD and NLO NRQCD predictions
  - ψ(2s) to J/ψ ratio is consistent with other experiments and no obvious dependence on collision energy is seen
  - J/ψ yield vs. charged-particle multiplicity increases faster than a linear function
- **J/ψ production in Au+Au @ 200 GeV**
  - Differential J/ψ → $\mu^+\mu^-$ invariant yield is consistent with J/ψ → $e^+e^-$ result
  - Strong J/ψ suppression at high $p_T$ in central collisions
    → dissociation in effect
  - Transport models including dissociation and regeneration contributions can describe centrality dependence at RHIC for $p_T$ > 0 GeV/c, but there is tension among models and data for $p_T$ > 5 GeV/c
  - J/ψ $v_2$: consistent with 0 above 2 GeV/c, favoring the scenario of small regeneration contribution
- **Stay tuned for more J/ψ results from STAR**