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Measurements of charmonium production in p+p collision at the STAR experiment

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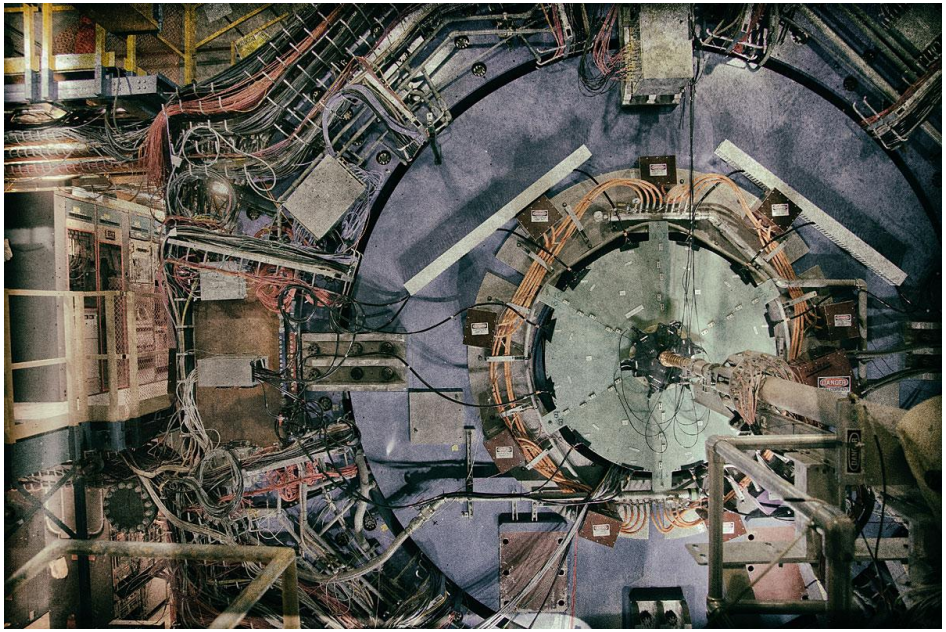
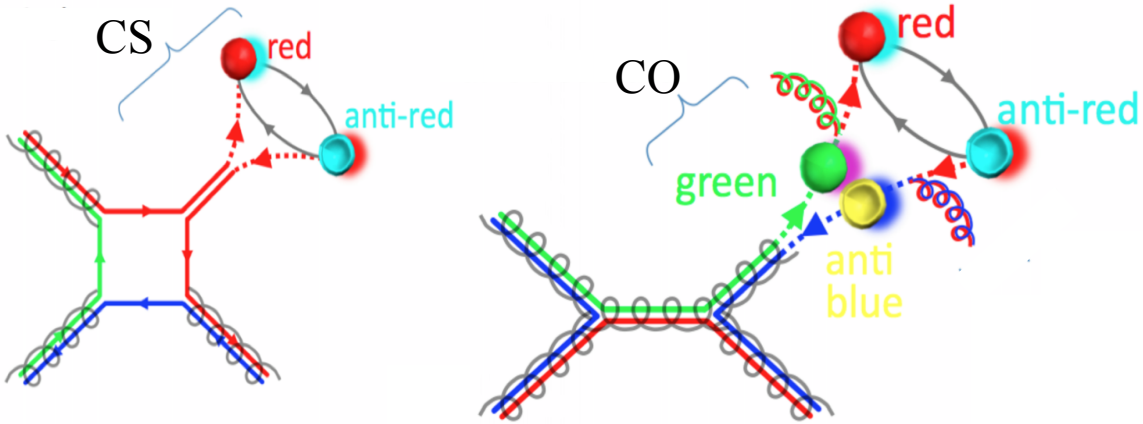
Outline

- Motivation
- Relativistic Heavy Ion Collider (RHIC)
- The STAR detector
- Measurements of charmonium production in p+p collision
- Summary

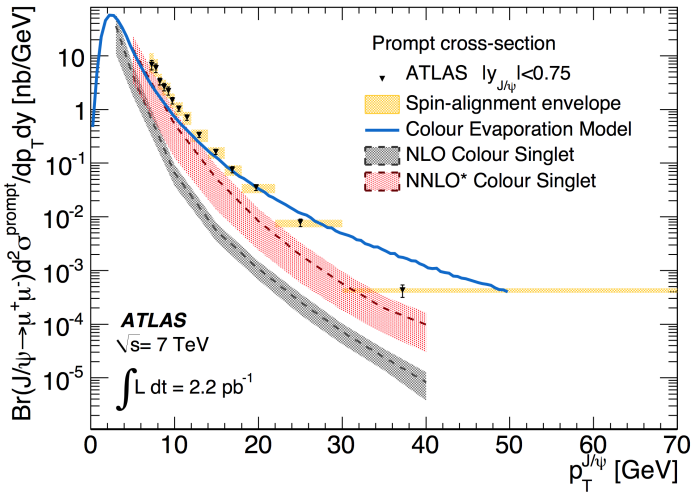


Motivation

- The production mechanism of heavy quarkonium is not fully understood in hadron-hadron collisions
- Models existing on the market:
  - Color Singlet Model (CSM)
  - Color Octet Mechanism (COM)
  - Non-relativistic QCD (NRQCD)
    - + Color Glass Condensate effective theory (CGC)
  - Color Evaporation Model (CEM) / Improved CEM



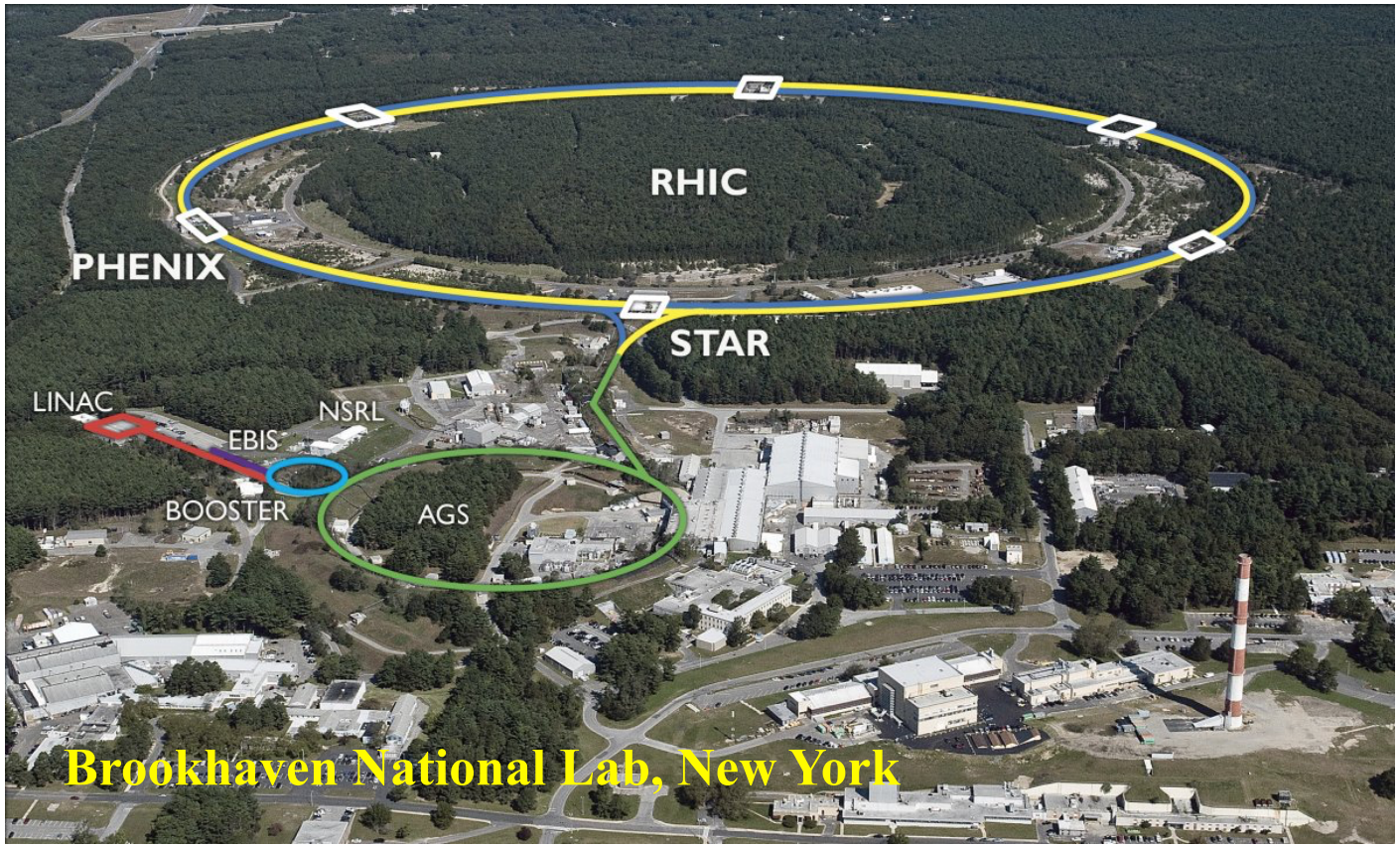
From Cristina Biino's Talk (FPCP2013)



Nucl. Phys. B 850 (2011) 387-444

Relativistic Heavy Ion Collider (RHIC)

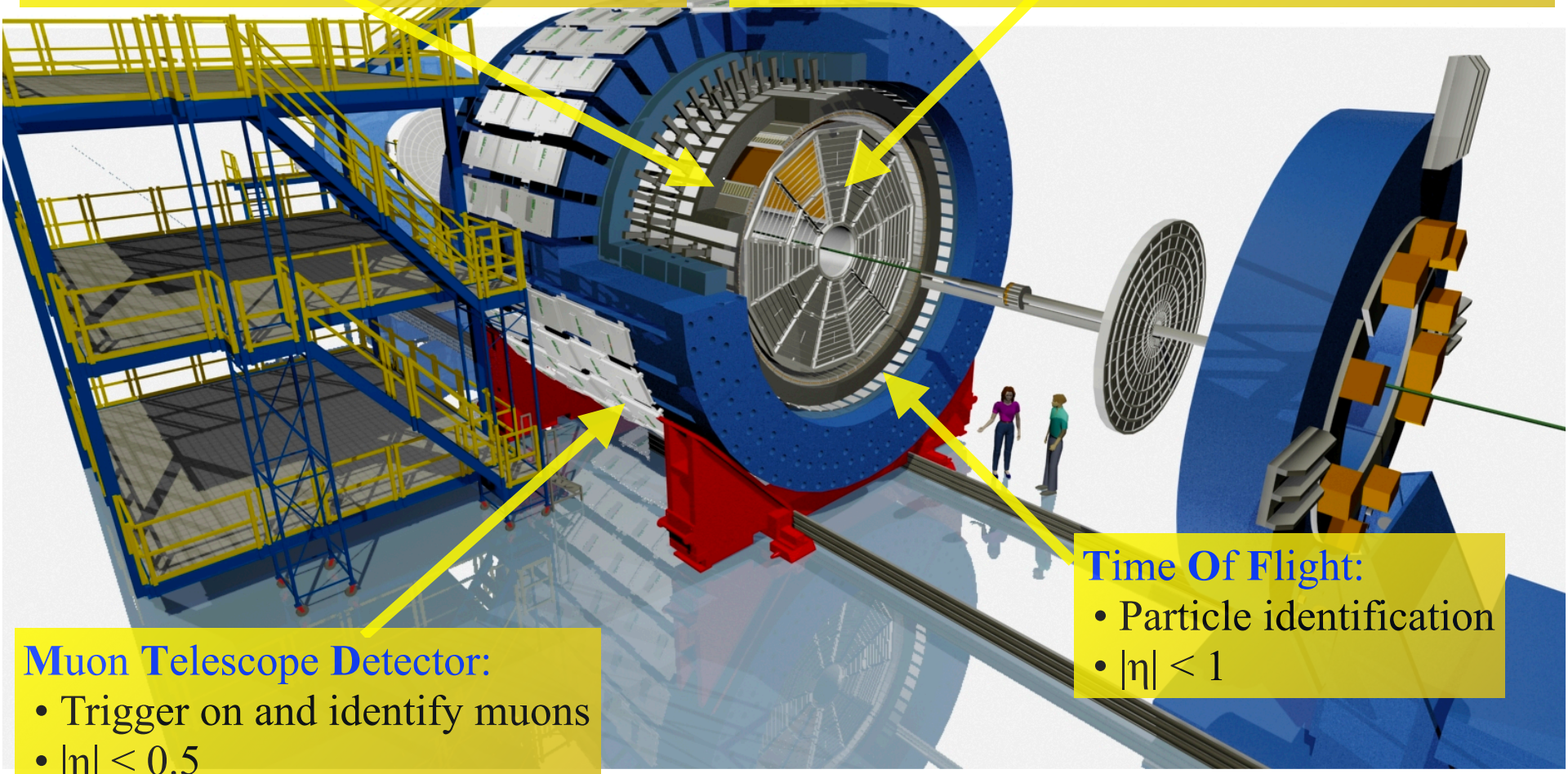
- One of the most versatile particle colliders in the world!
  - The world's only collider with polarized proton beam
  - Several different type of collisions: p+p, Au+Au, p+Au, d+Au, U+U, …
  - Different collision energy: 3.3 (fixed-target mode) – 200 GeV for Au+Au, and up to 510 GeV for p+p



The STAR detector

Barrel ElectroMagnetic Calorimeter:
- Trigger on and identify electrons
- $|\eta| < 1$

Time Projection Chamber:
- Precise momentum and dE/dx measurement
- $|\eta| < 1$

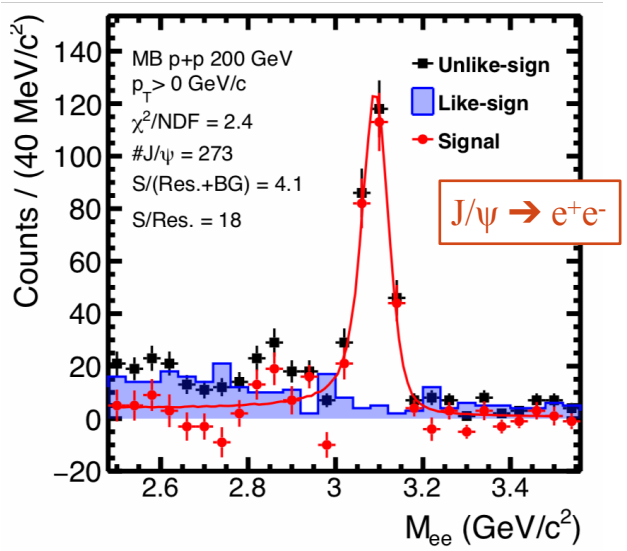


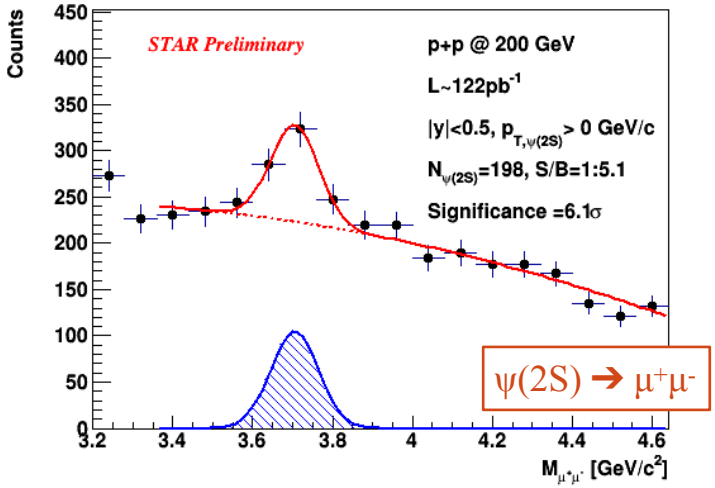
Time Of Flight:
- Particle identification
- $|\eta| < 1$

Muon Telescope Detector:
- Trigger on and identify muons
- $|\eta| < 0.5$

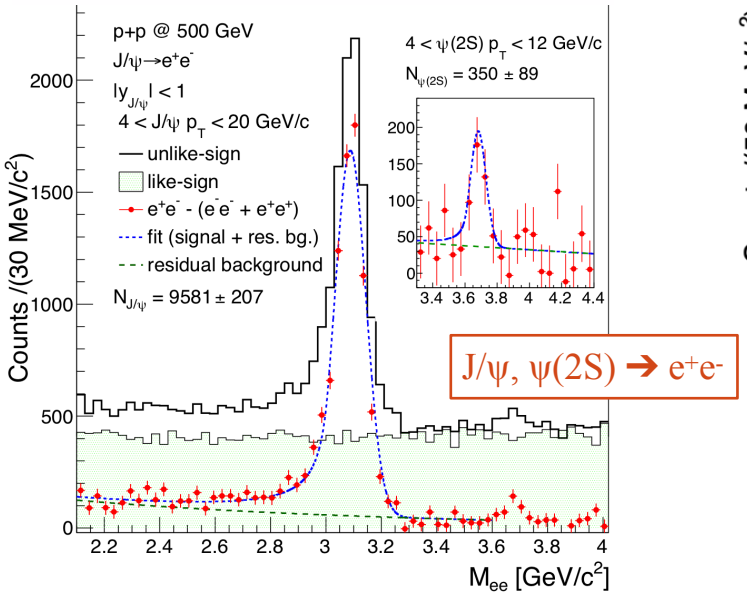
J/ψ and ψ(2S) in p+p @ 200 and 500 GeV

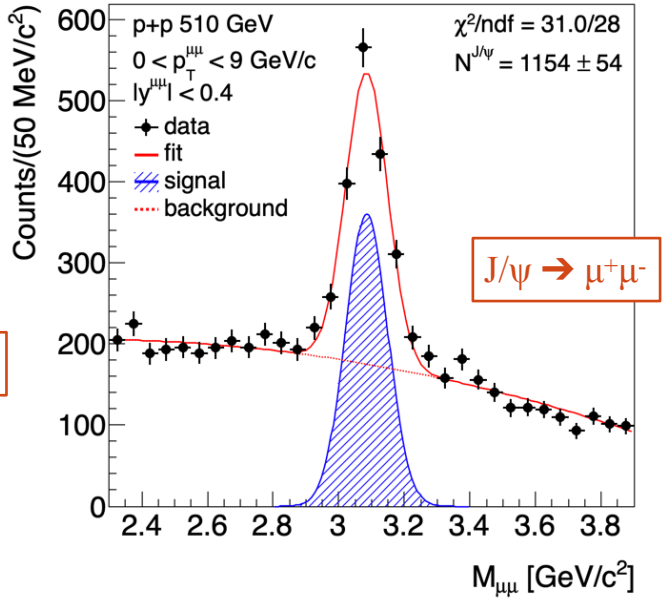
p+p @ 200 GeV



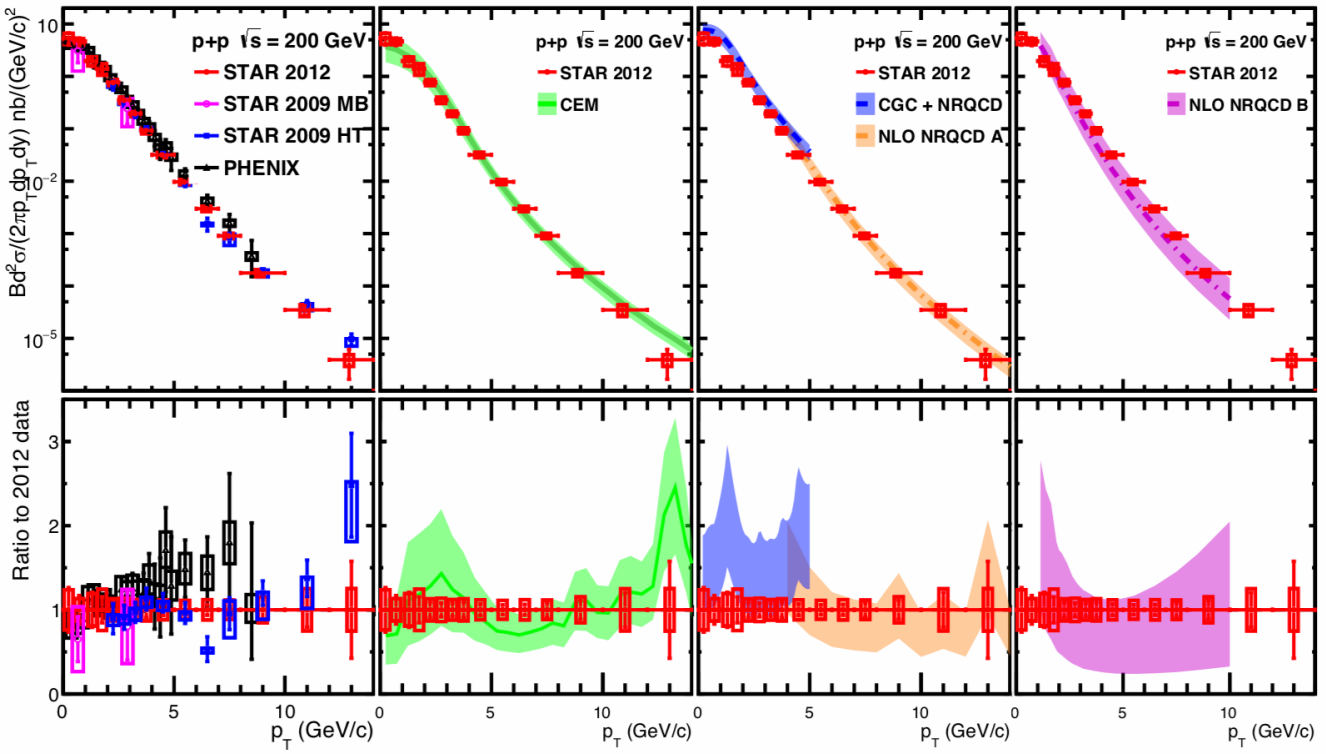


p+p @ 500 GeV





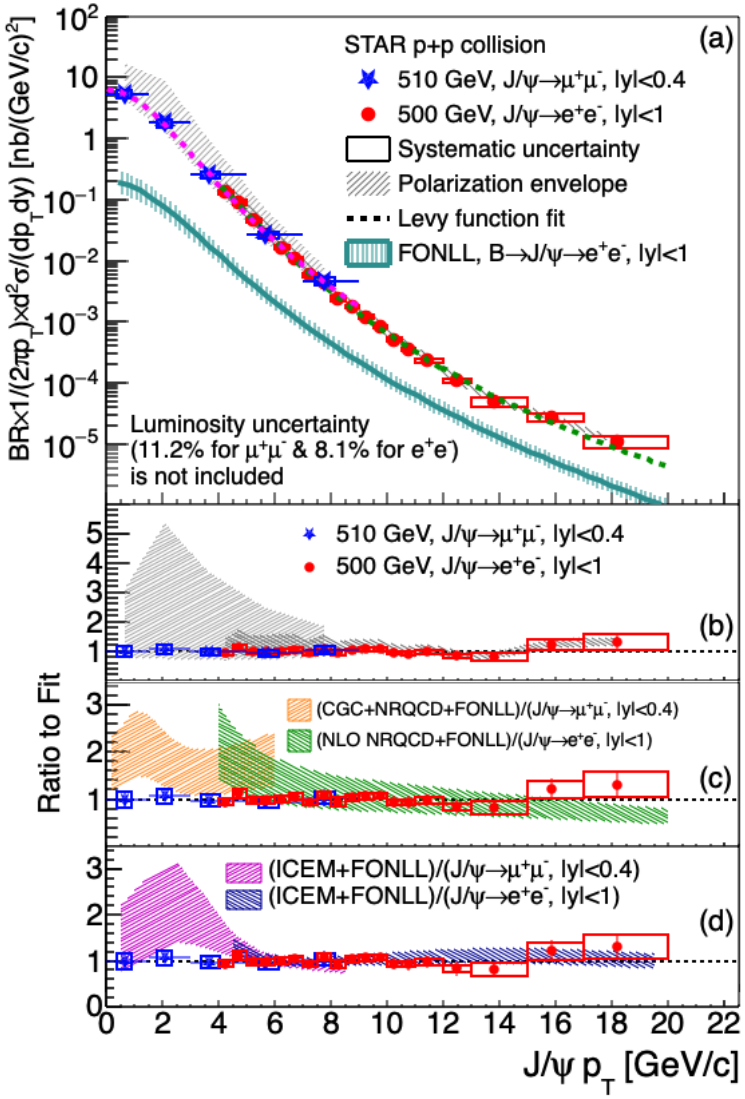
J/ψ cross-section in p+p collisions @ 200 GeV

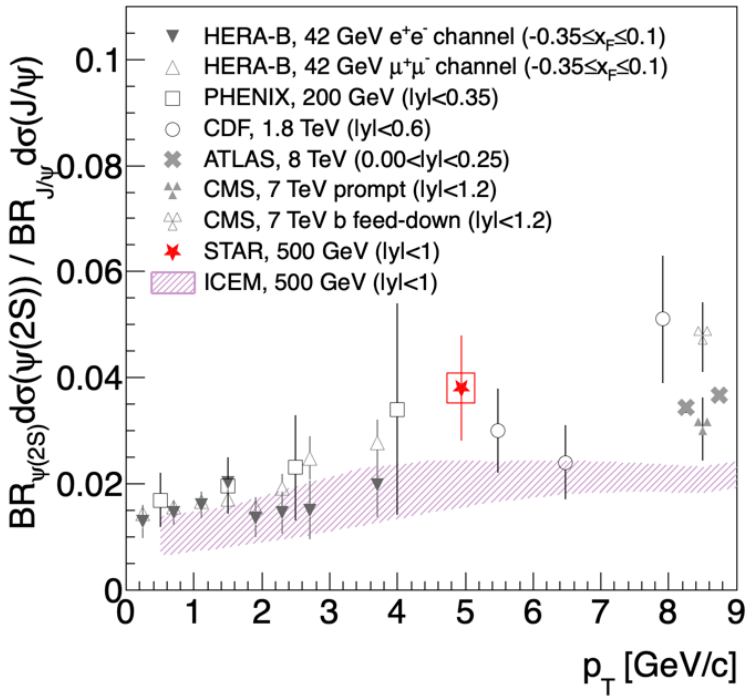


- Precise measurements of inclusive J/ψ cross-section covering J/ψ p_T from 0 to 14 GeV/c
- Consistent with CEM (direct production only) and NLO NRQCD (prompt production only) calculations
- CGC+NRQCD (prompt production only) calculation above the data, but on the edge of uncertainties

STAR 2012: PLB 786 (2018) 87-93
STAR 2009: PLB 722 (2013) 55;
PRC 93 (2016) 064904
PHENIX: PRD 82 (2010) 012001
CEM: Phys. Rept. 462 (2008) 125;
R. Vogt private communication (2009)
NLO+NRQCD A: PRD 84 (2011) 114001
CGC+NRQCD: PRL 113 (2014) 192301
NLO+NRQCD B: PRL 108 (2012) 172002

J/ψ cross-section in p+p collisions @ 500 GeV

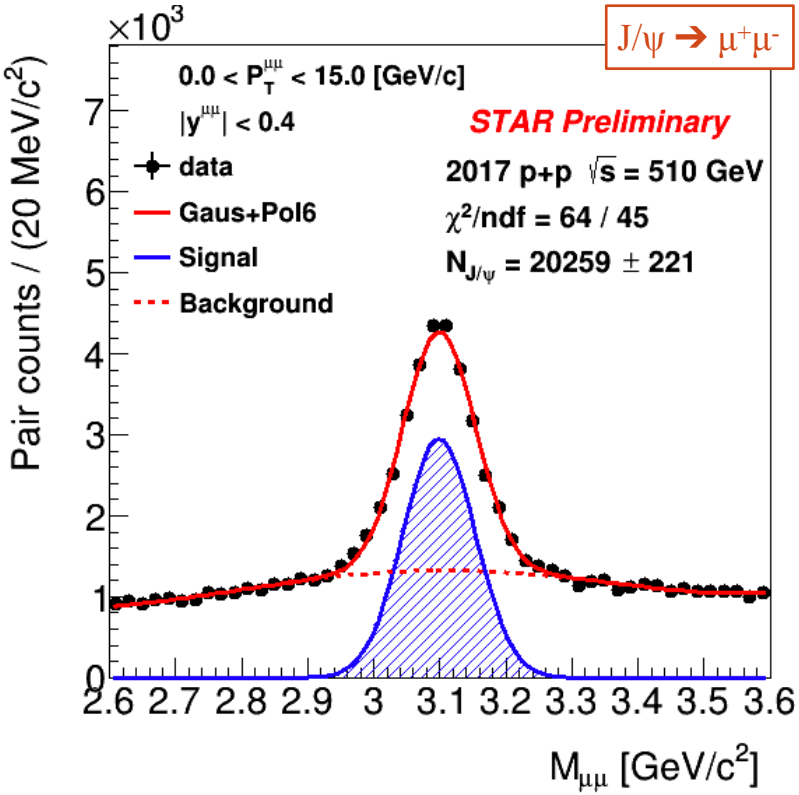


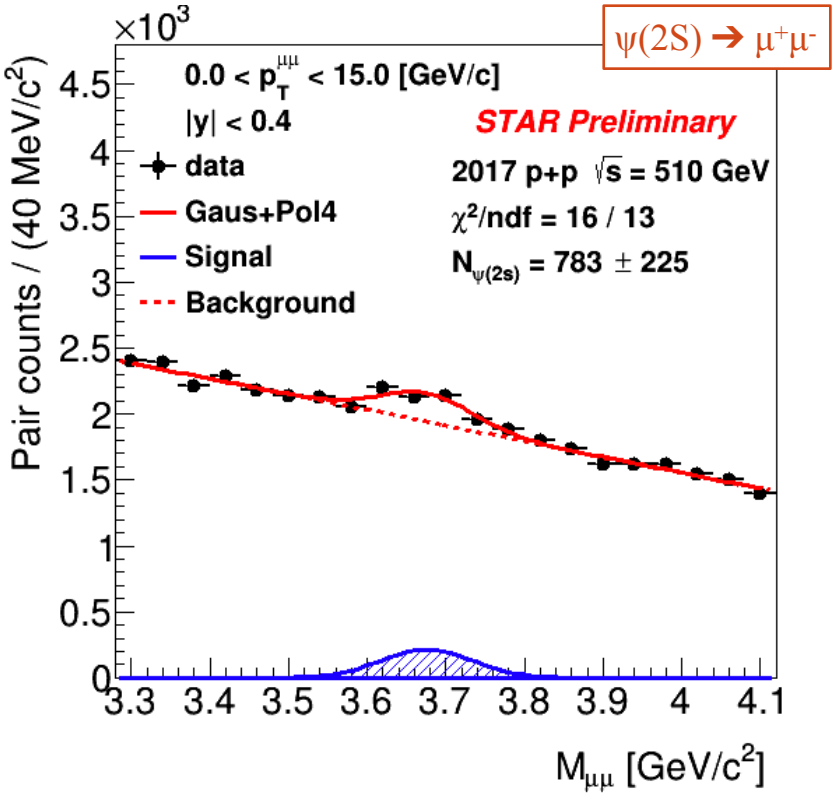


- Precise measurements of J/ψ cross-section covering J/ψ p_T from 0 to 20 GeV/c
- Consistent with CGC+NRQCD, NLO NRQCD, and ICEM calculations (B feed-down from FONLL included) with a small tension at low p_T
- ψ(2S) to J/ψ ratio follow the world trend

STAR: PRD 100, 052009 (2019)

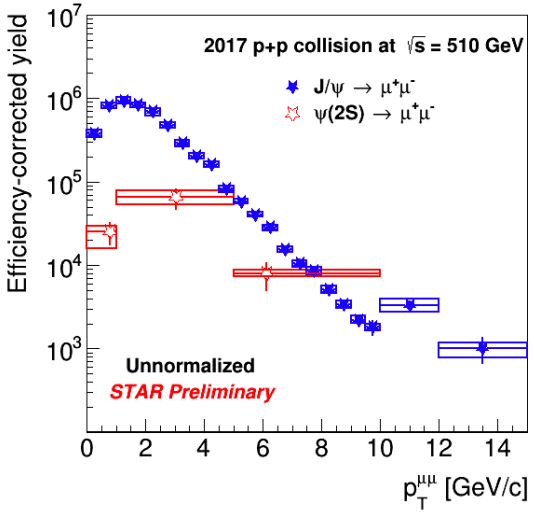
J/ψ and ψ(2S) in p+p @ 510 GeV with 2017 data

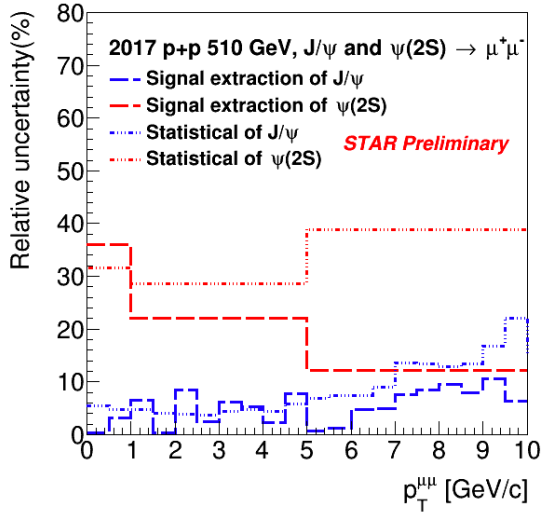


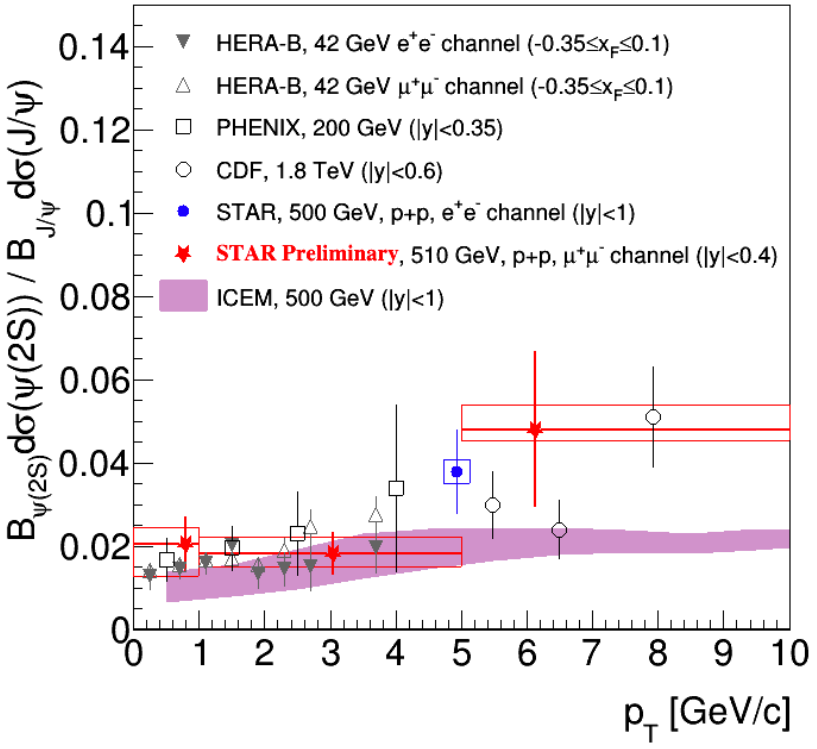


- In 2017, STAR collected a large data set of p+p collisions at 510 GeV (integrated luminosity ~187 pb^{-1} for dimuon trigger)
- More than ten times the number of J/ψ with dimuon trigger than 2013 data
- Enough number of ψ(2S) for differential analysis

ψ(2S) to J/ψ ratio @ pp 510 GeV with 2017 data







- Analysis using high statistics data set collected in 2017 is being finalized.
- For the first time, we can measure p_T differential cross section of ψ(2S) at STAR
- p_T differential ψ(2S) to J/ψ ratio follows world-wide trend

Summary

- Inclusive J/ψ production cross-section for p+p @ 200 GeV can be described by CEM (direct J/ψ) and NLO NRQCD (prompt J/ψ), while CGC+NRQCD (prompt J/ψ) calculation above the data, but on the edge of uncertainties
- Inclusive J/ψ production cross-section for p+p @ 500 GeV can be described by CGC+NRQCD, NLO NRQCD, and ICEM model (non-prompt J/ψ estimated using FONLL) with a small tension at low p_T region.
- First p_T differential measurement of ψ(2S) to J/ψ ratio at STAR and follows the world-wide trend.
- First p_T differential measurement of cross section of ψ(2S) at STAR is under the way.

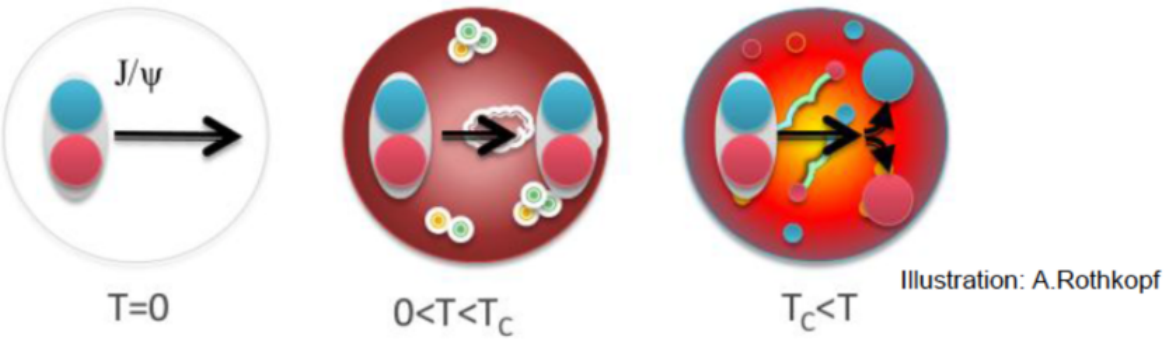
Backup

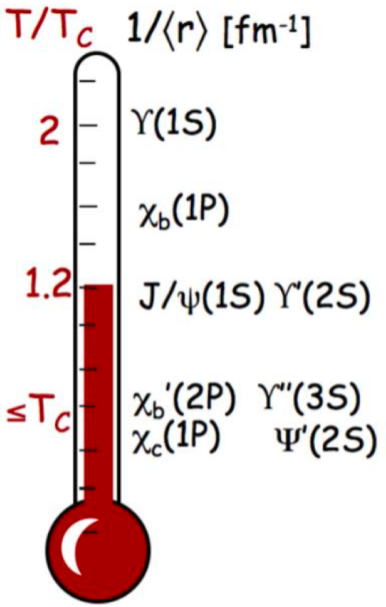
Study QGP using heavy flavor

- Heavy quarks (open heavy flavor, quarkonia) are good probes for studying QGP in heavy-ion collisions
  - $m_{c,b} >> T_C, \Lambda_{QCD}, m_{u,d,s}$: produce dominantly by high-Q^2 scatterings in the early stage

  ➜ Good candidates to study the evolution of QGP

- Quarkonium suppression is one of smoking guns of QGP formation (by T. Matsui and H. Satz PLB 178 (1986) 416)
- Color-screening: Quarkonium dissociates in the medium
- Sequential melting: different states dissociate at different temperature





A. Mocsy, EPJ C61 (2009) 705

Study QGP using quarkonium

Interpretation of quarkonium suppression is complicated:

- Hot nuclear matter effects
  - Dissociation
  - Regeneration from deconfined quarks in the medium
  - Energy loss in the medium
  - Formation time effect
- Cold nuclear matter effects
- Feed-down from excited states and B-hadrons