Measurements of charmonium production in p+p collisions at STAR

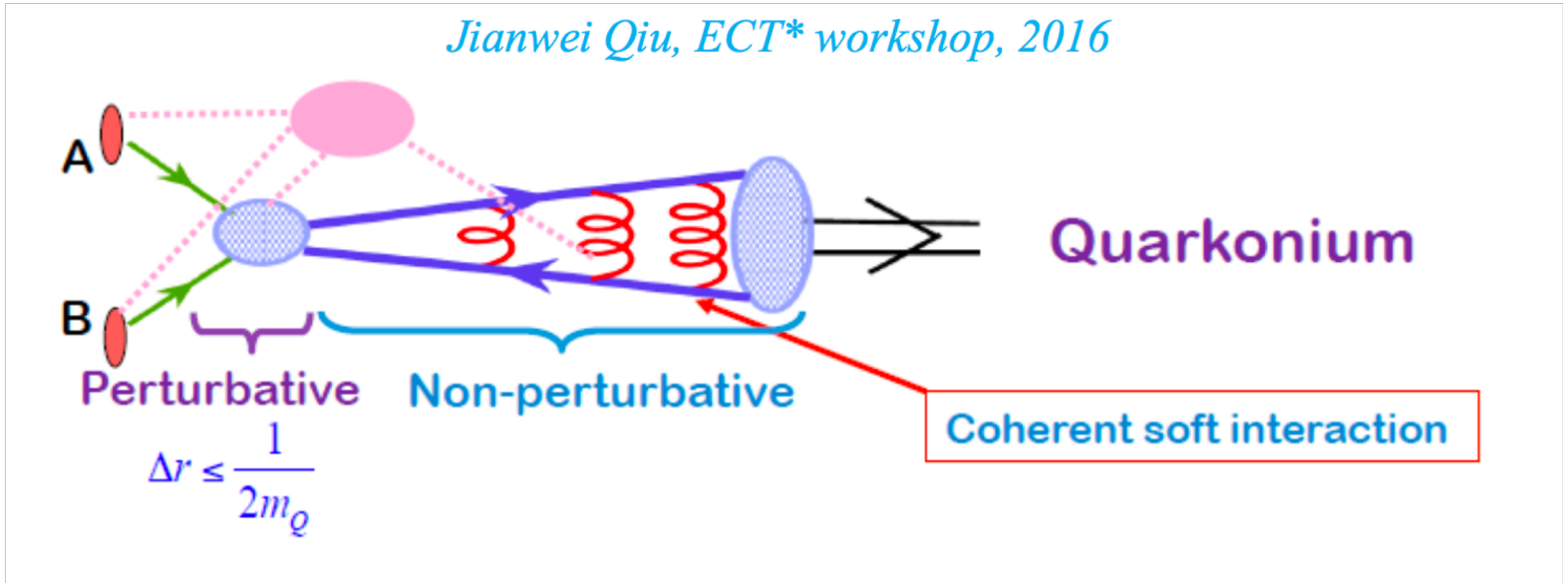
Zhen Liu

State Key Laboratory of Particle Detection and Electronics

University of Science and Technology of China

The 4th China LHC Physics Workshop, CCNU, 19th -22th Nov. 2018

Quarkonium in p+p collisions



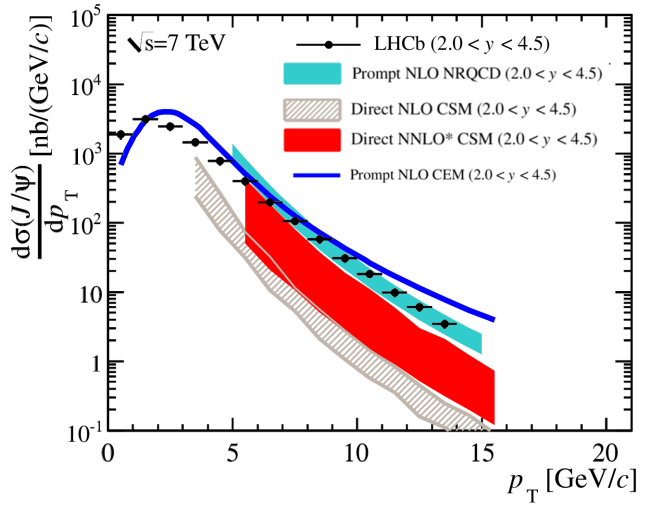
- Quarkonium production can be factorized into:
  - Perturbative: production of heavy $q\bar{q}$ pair
  - Non-perturbative: quarkonium formation; involves long distances and soft momentum scales

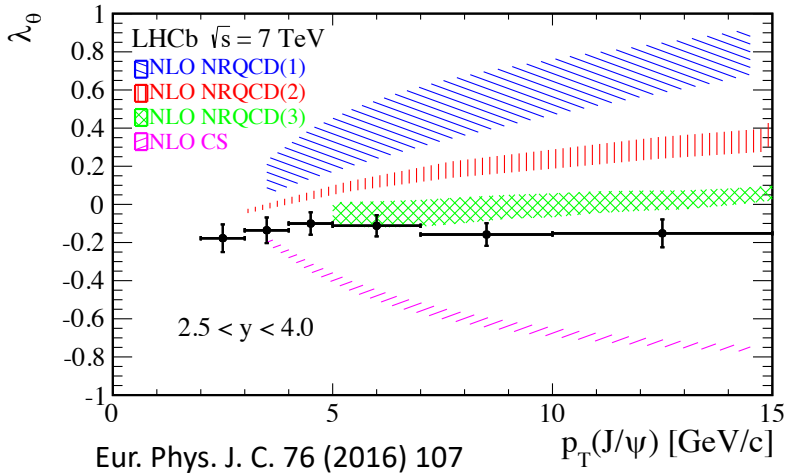
Charmonium production mechanism

Charmonium production mechanism in elementary collisions is not fully understood

- Models differ in the treatment of hadronization
  - Color Singlet Model
  - Color Evaporation Model
  - NRQCD approach (CGC+NRQCD)

- Measurements of charmonium polarization provide further constraints on production models



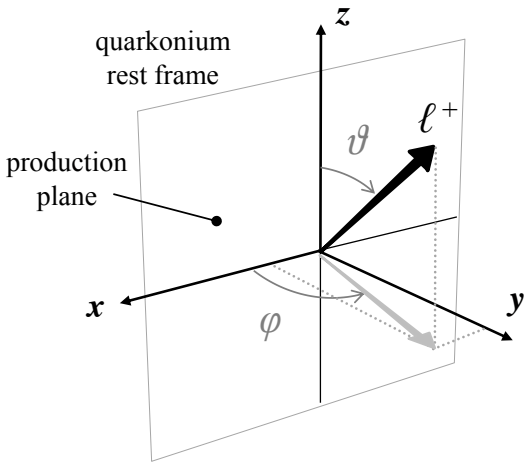


Eur. Phys. J. C. 76 (2016) 107

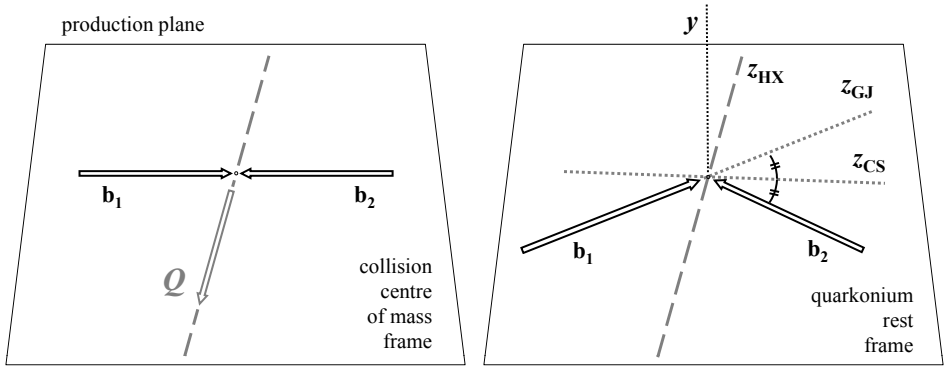
J/ψ polarization measurement

- J/ψ polarization can be analyzed via the angular distribution of the positively charged final-state lepton, which can be expressed as:

$$W(cos\theta, \varphi) \propto 1 + \lambda_\theta cos^2\theta + \lambda_\varphi sin^2\theta cos2\varphi + \lambda_{\theta\varphi} sin2\theta cos\varphi$$



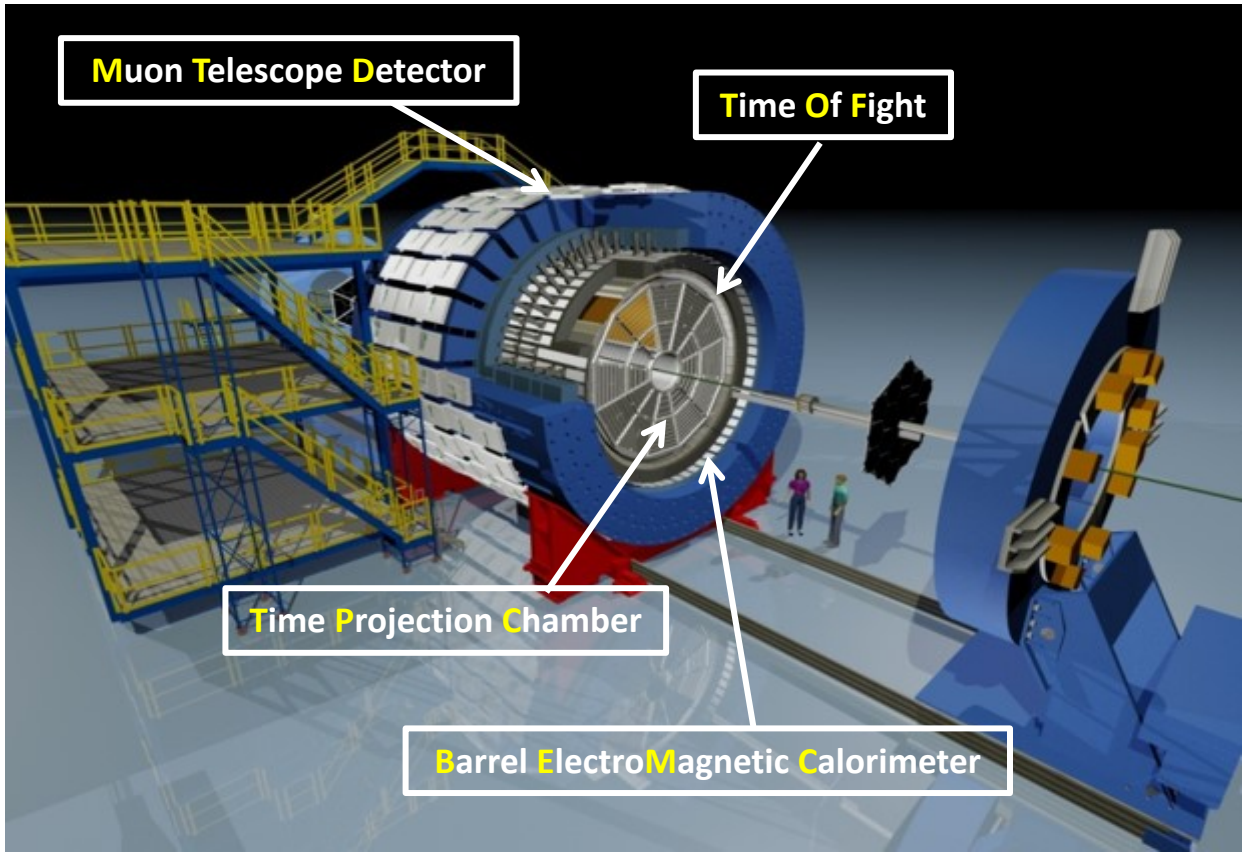
- θ - polar angle between momentum of a positive lepton in the J/ψ rest frame and the polarization axis z
- φ - corresponding azimuthal angle



- Polarization axis z
  - Helicity (HX) frame: along the J/ψ momentum in the center-of-mass frame of the colliding beams
  - Collins-Soper (CS) frame: bisector of the angle formed by one beam direction and the opposite direction of the other beam in the J/ψ rest frame

The Solenoid Tracker At RHIC (STAR)

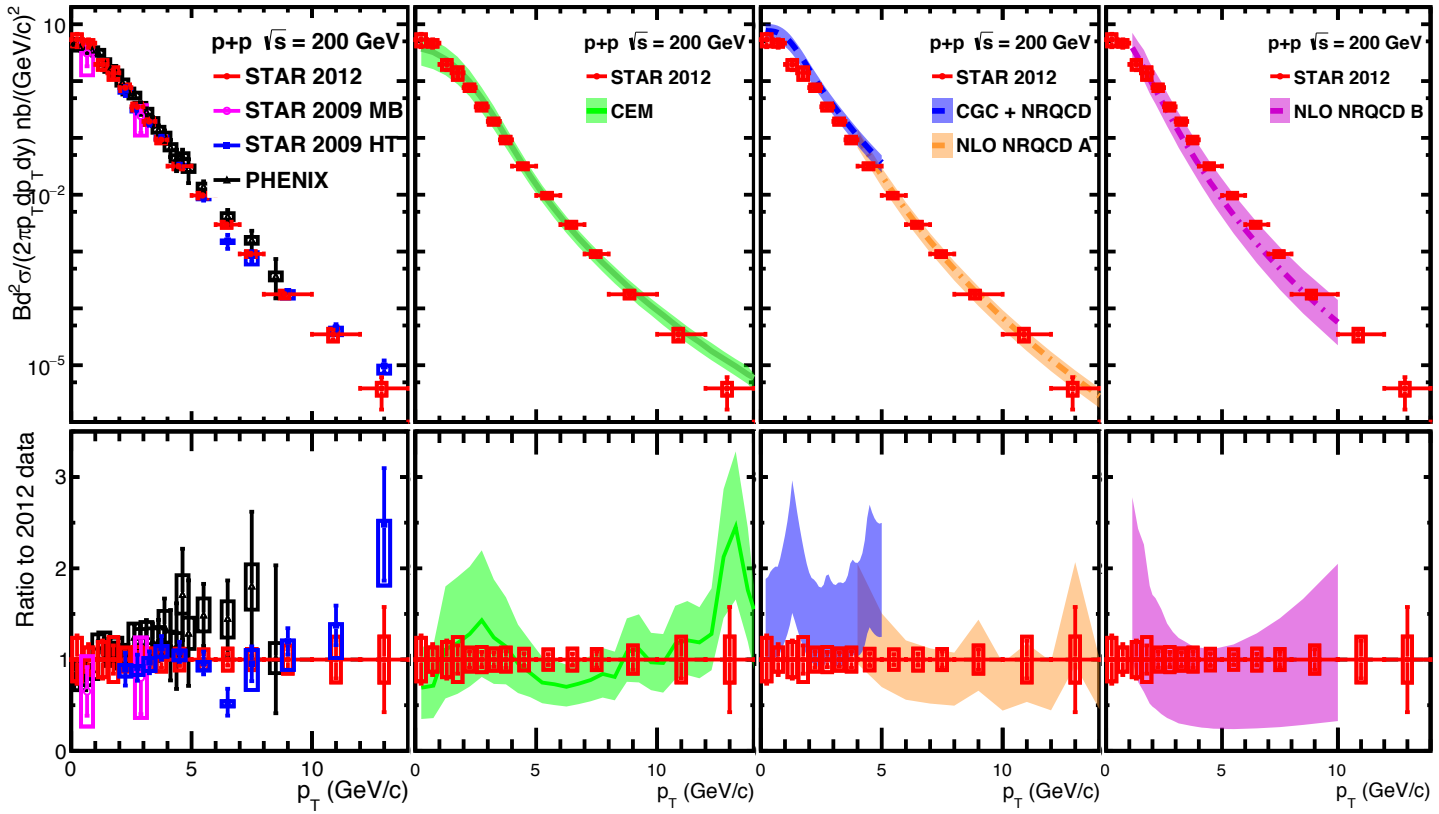
- Mid-rapidity detector: $|\eta| < 1$, $0 < \varphi < 2\pi$



- **TPC**: measure momentum and energy loss
- **TOF**: measure time of flight
- **BEMC**: trigger on and identify electrons
- **MTD** (45% in φ, $|\eta|<0.5$) : trigger on and identify muons
  - Timing measurement (σ~100 ps) and spatial resolution (~1 cm)
  - Reduced bremsstrahlung radiation compared to electrons

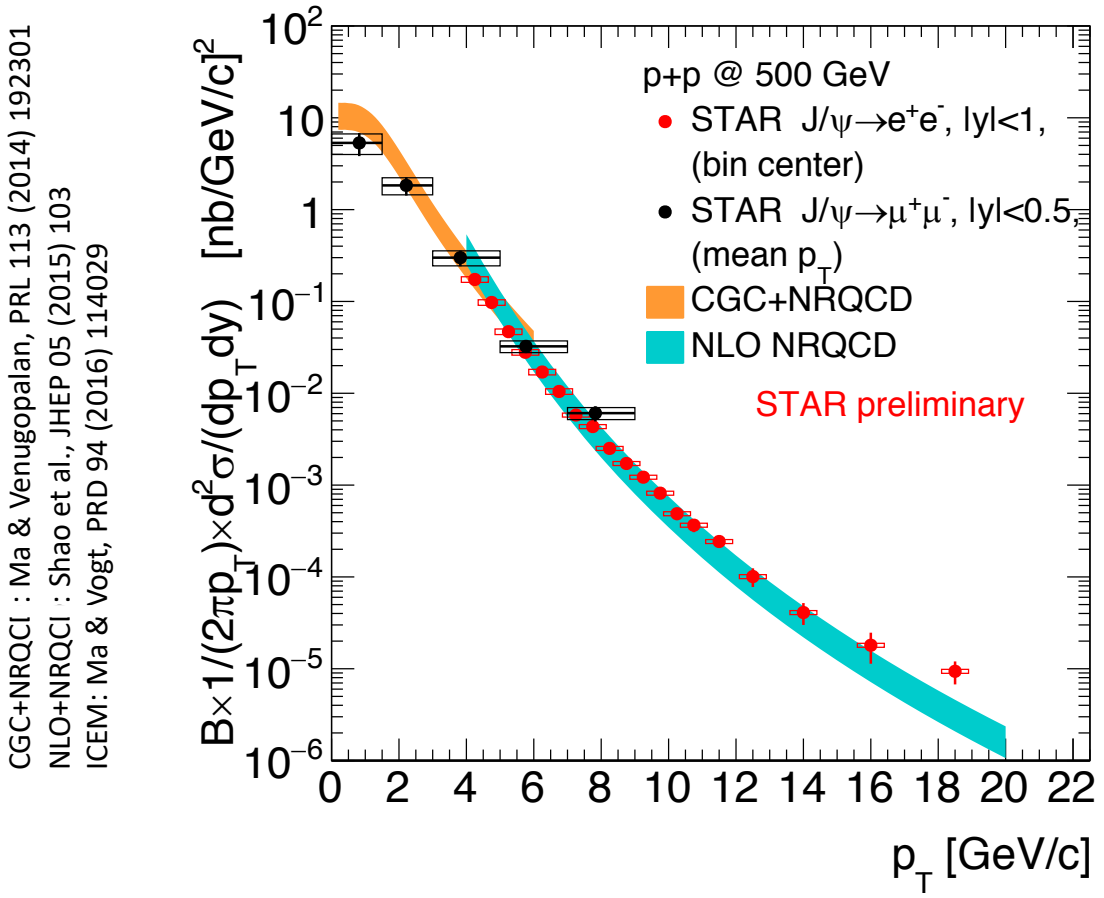
Inclusive J/ψ cross section at 200 GeV

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



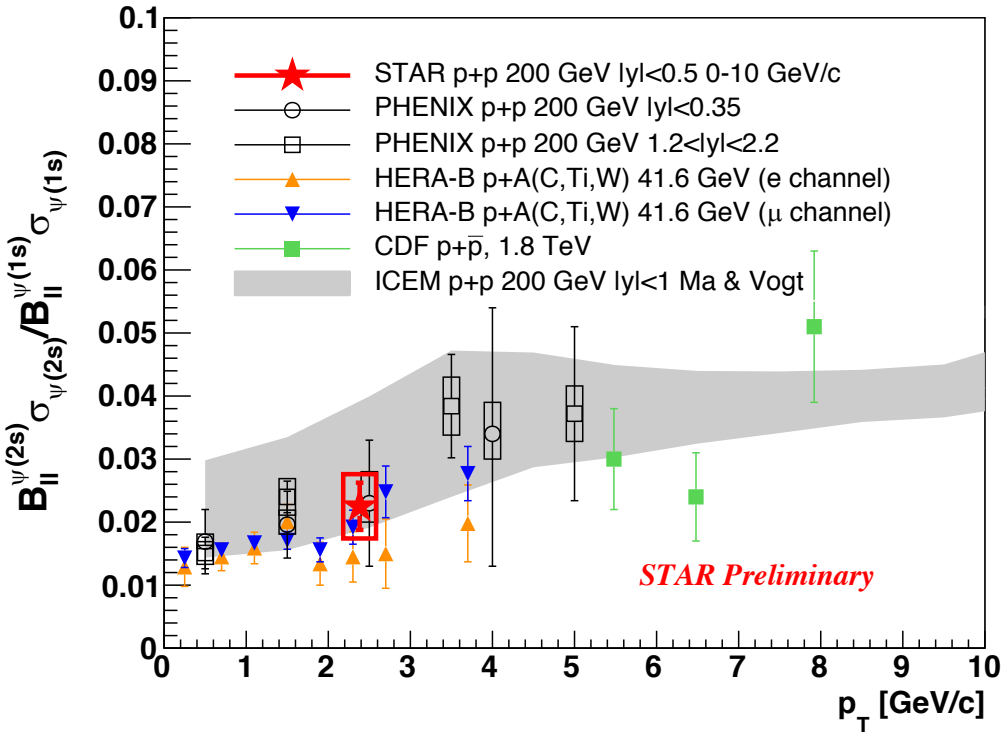
- The CEM model (direct J/ψ) and NLO NRQCD (prompt J/ψ) describe the data reasonably well for the applicable p_T ranges
- The data are close to the lower uncertainty boundary of the CGC+NRQCD calculations

Inclusive J/ψ cross section at 500 GeV



- Measurement at low p_T from dimuon channel and high p_T from dielectron channel
- Models describe the J/ψ production cross-section reasonably well

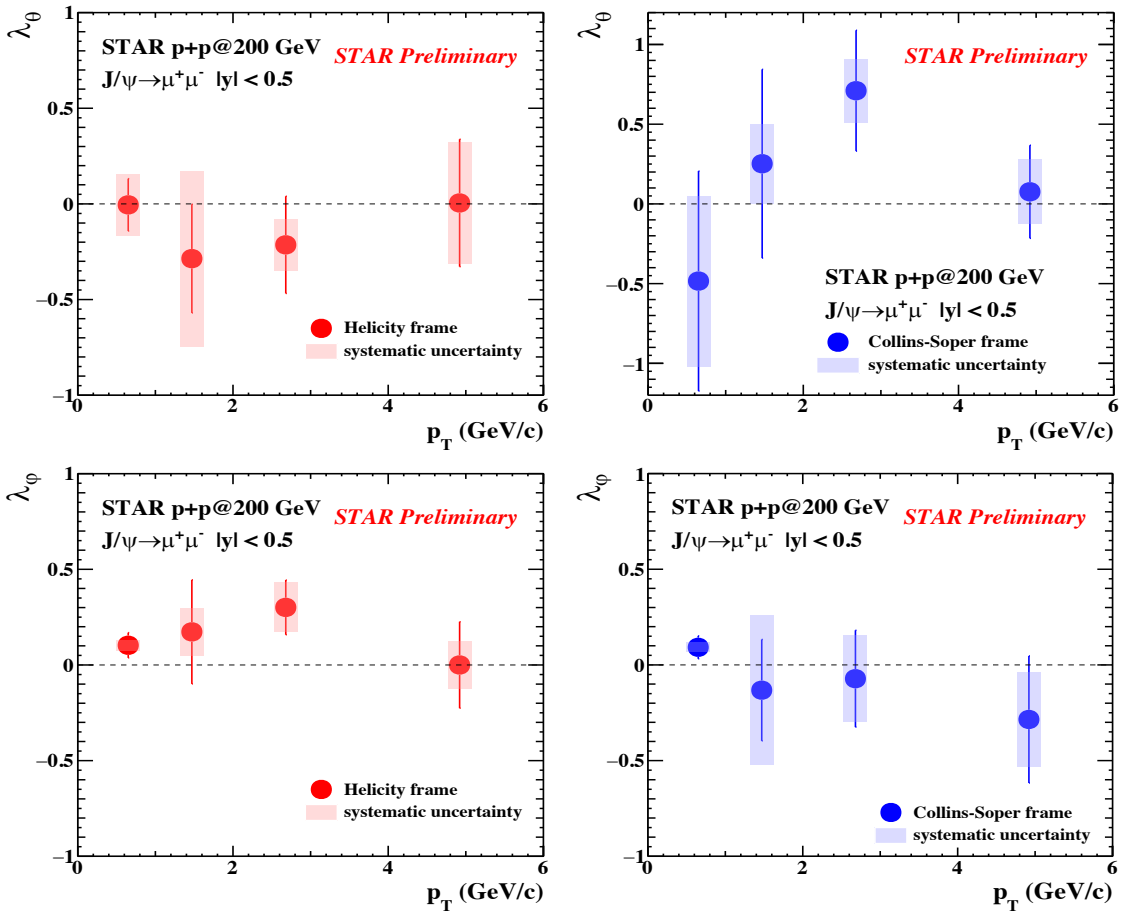
ψ(2S)/ψ(1S) ratio



HERA-B, EPJC 49, 545
PHENIX mid y, PRD 85 (2012) 092004
PHENIX forward y, PRC 95 (2017) 034904
CDF, 1.8TeV, PRL 79 (1997) 572
ICEM, Ma & Vogt, PRD 94 (2016) 114029

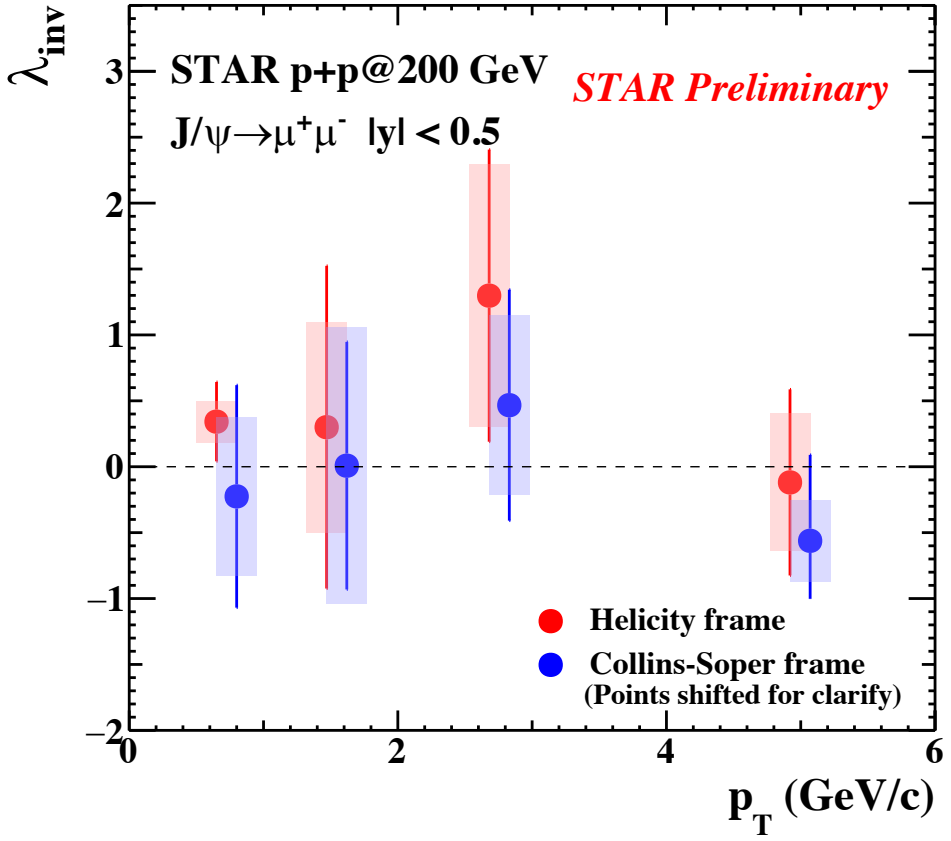
- Measured ψ(2S)/J/ψ ratio in 200 GeV p+p collisions is consistent with world-wide data
- The ICEM model describes the increasing trend

Inclusive J/ψ polarization at 200 GeV



- λ_θ and λ_φ parameters are consistent with 0 in HX and CS frames

Frame invariant quantity



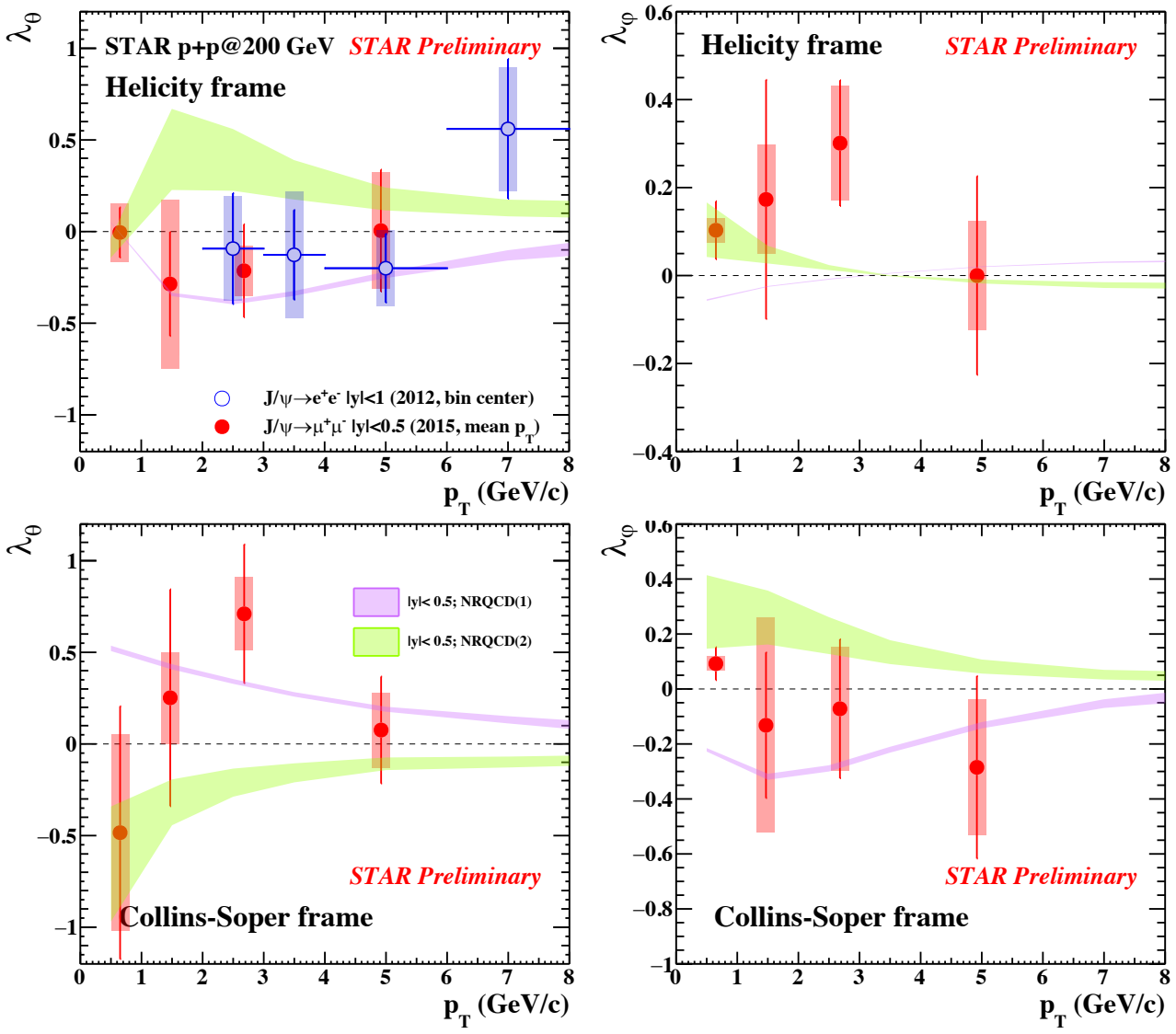
- Frame invariant quantity:

$$\lambda_{inv} = \frac{\lambda_\theta + 3\lambda_\varphi}{1 - \lambda_\varphi}$$

  - Any arbitrary choice of the experimental observation frame will give the same value of this quantity
  - Good cross-check on measurements performed in different frames

- λ_{inv} as a function of p_T are consistent between HX and CS frames

J/ψ polarization parameters vs. models



- J/ψ polarization parameters compared with NRQCD calculations using two sets of Long Distance Matrix Elements (LDMEs)
- NRQCD calculations are consistent with data within uncertainties
- J/ψ polarization at low p_T can be used to constrain the LDMEs

NRQCD1: Hong-Fei Zhang et al. Phys. Rev. Lett 114 (2015) 092006
NRQCD2: Bin Gong et al. Phys. Rev. Lett 110 (2013) 042002

Summary

- Inclusive J/ψ cross section is measured in p+p collisions
  - Models describe the J/ψ production cross-section reasonably well
- Inclusive J/ψ polarization is measured in the HX and CS frames for

  $0 < p_T < 5$ GeV/c
  - Both λ_θ and λ_φ parameters are consistent with 0 in the both frames
  - J/ψ polarization at low p_T can be used to constrain the LDMEs

Thank you!