Measurement of J/ψ polarization in p+p collisions at √s = 200 GeV through the dimuon channel at STAR

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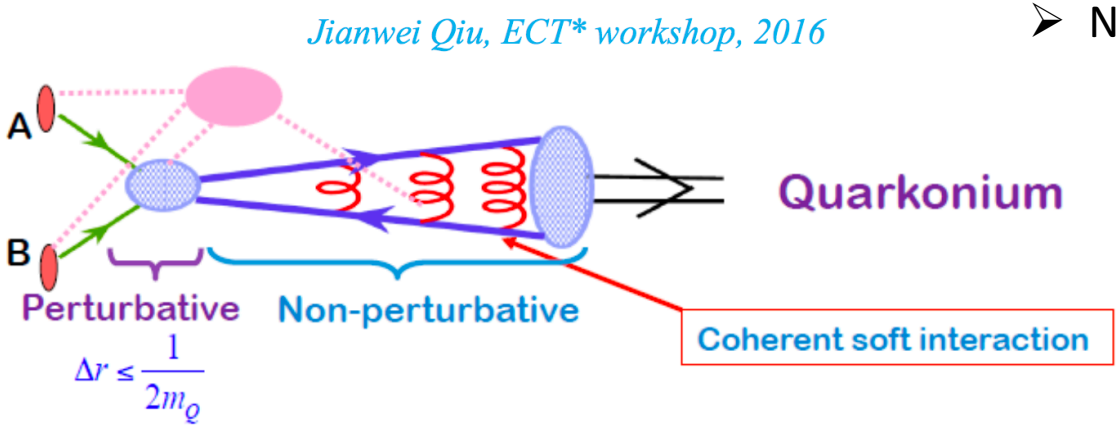
J/ψ production mechanism

J/ψ production mechanism in elementary collisions is not fully understood.



- No full-QCD description
  - Production of the $c\bar{c}$ pair: perturbative
  - Evolution of the $c\bar{c}$ pair into the physical quarkonium state: non-perturbative
    - Model dependent

- Three popular models on the market
  - Color Evaporation Model
    - All pairs with mass less than open heavy flavor threshold
  - Color Singlet Model
    - Assume physical color singlet state, quantum numbers are conserved
  - NRQCD approach (Color Octet Model)
    - $c\bar{c}$ pair is produced in color octet state or singlet state

J/ψ production puzzle

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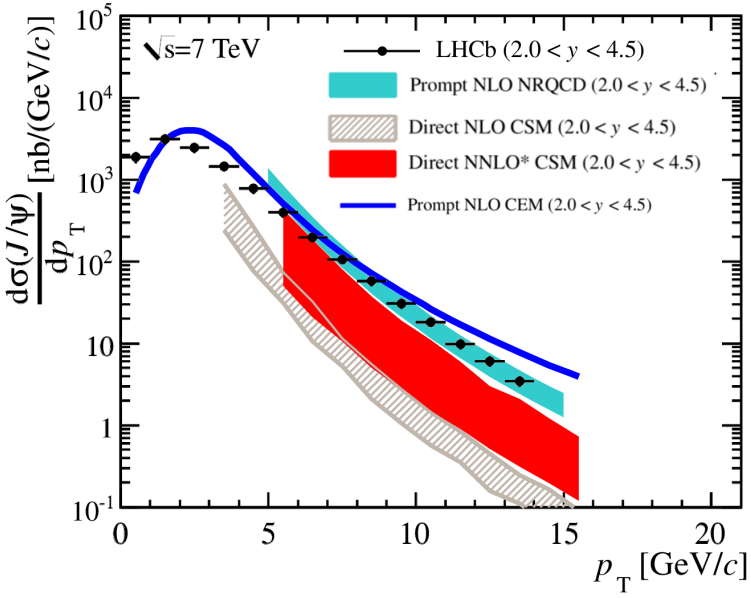
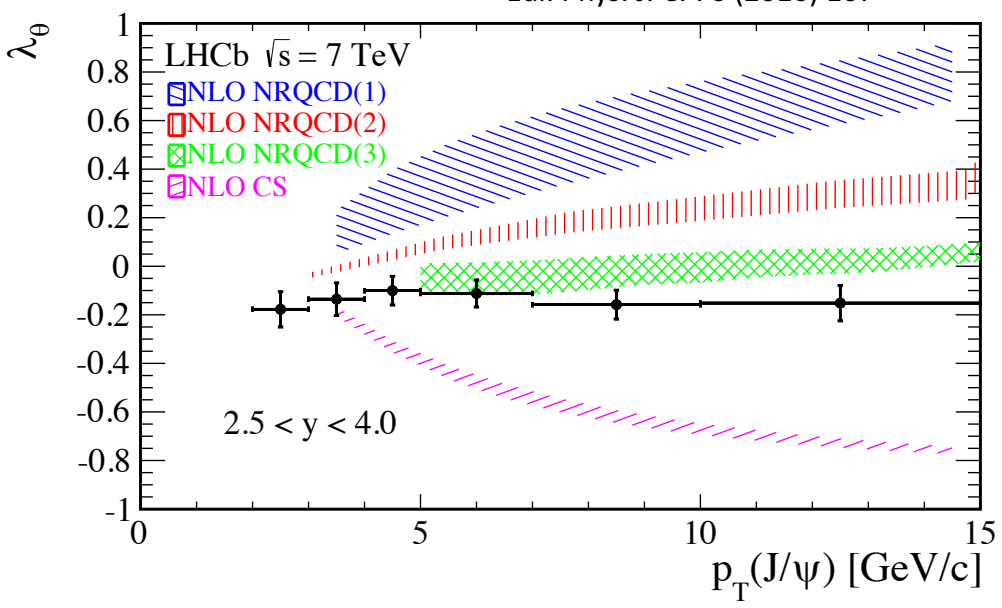
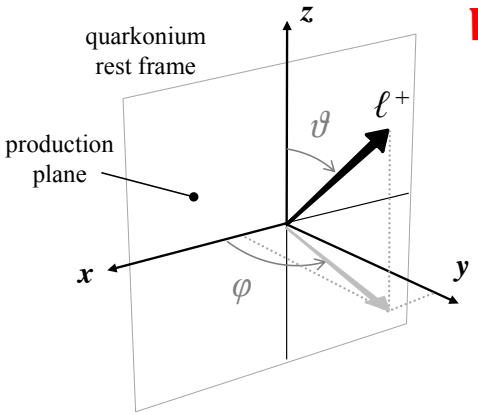




- Measurements of J/ψ polarization provide further constraints on production models
  - Competing theoretical approaches predict similar production cross-sections, but different polarizations

J/ψ polarization measurement

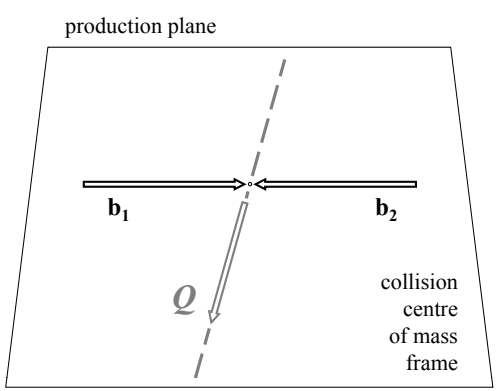
- J/ψ polarization can be analyzed via the angular distribution of the decay lepton pair

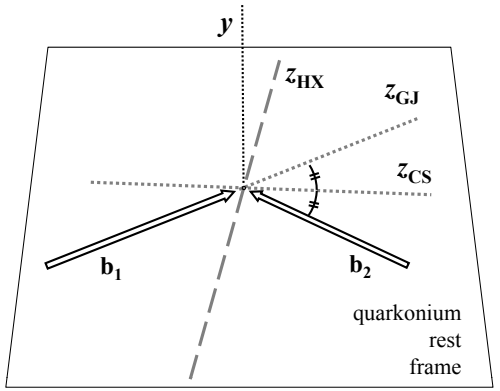


$$W(cos\theta, \varphi) \propto 1 + \lambda_\theta cos^2\theta + \lambda_\varphi sin^2\theta cos2\varphi + \lambda_{\theta\varphi} sin2\theta cos\varphi$$

- θ - polar angle between momentum of a positively charged 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 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



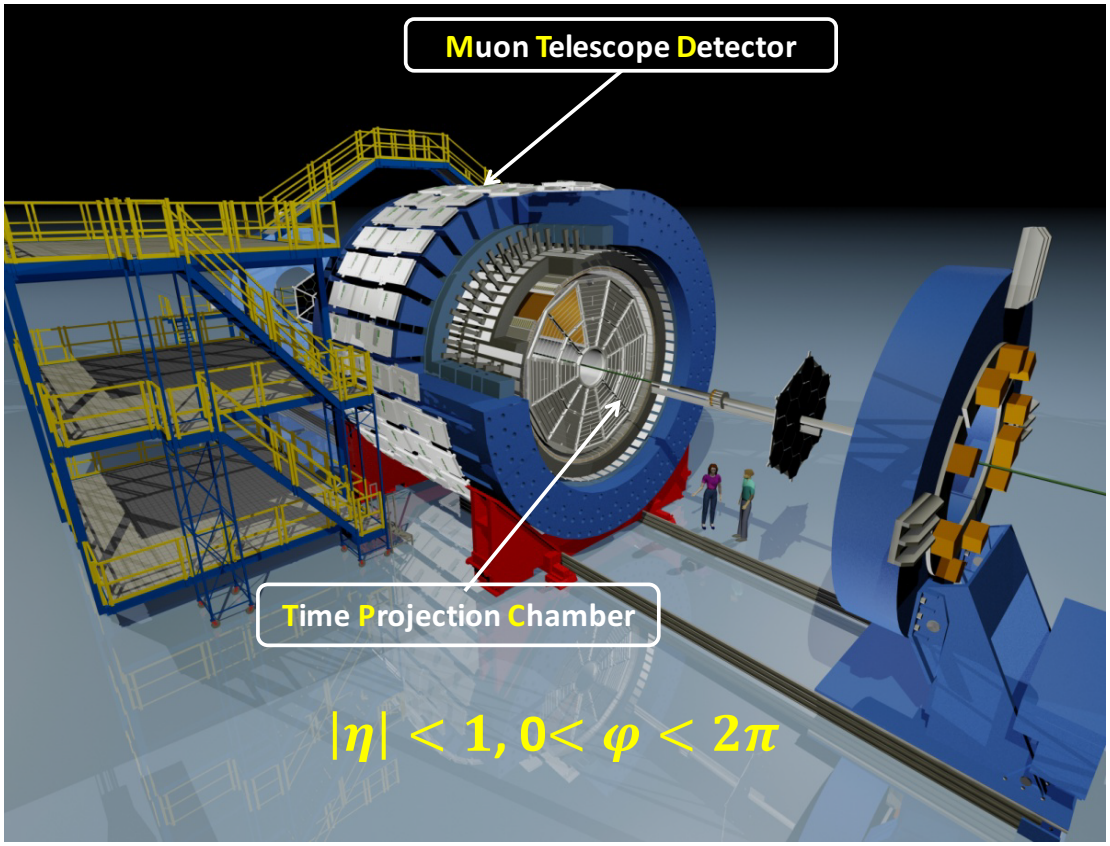


- Frame invariant quantity:

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

- Good cross-check

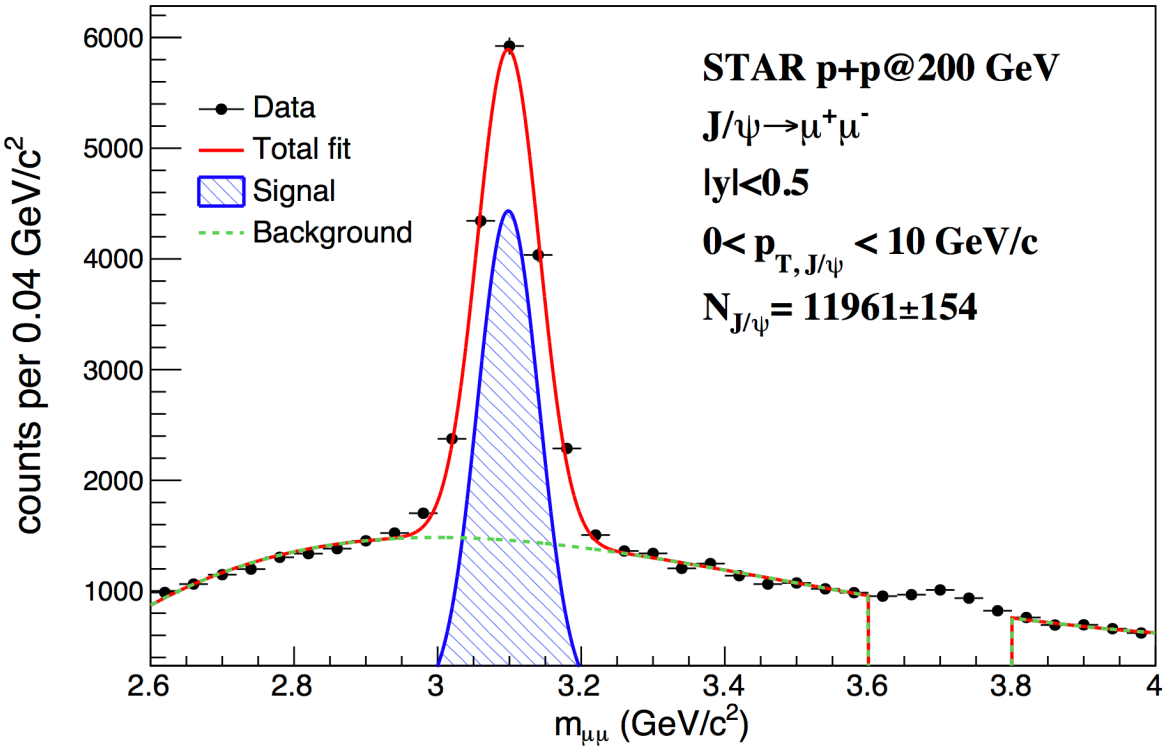
The Solenoid Tracker At RHIC



- **TPC**: measure momentum and energy loss
- **MTD (45% φ, $|\eta| < 0.5$)**: Multi-gap Resistive Plate Chamber (MRPC) technology
  - Precise timing measurement ($\sigma \sim 100ps$)
  - Spatial resolution (~1-2 cm)
  - ✓ Dimuon trigger improves low p_T J/ψ measurement precision
  - ✓ Muon identification

The MRPC modules for TOF and MTD are mainly developed and produced by USTC and Tsinghua.

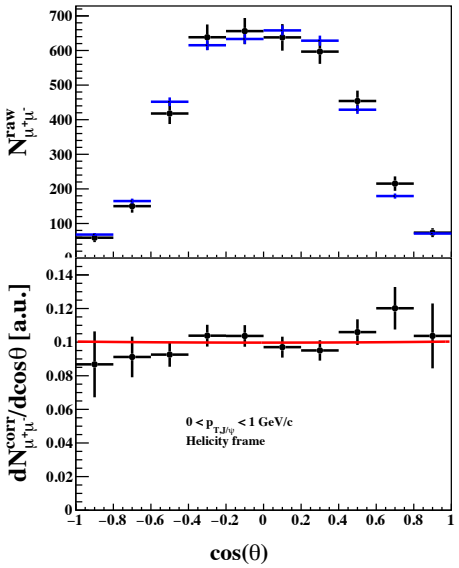
Signal extraction

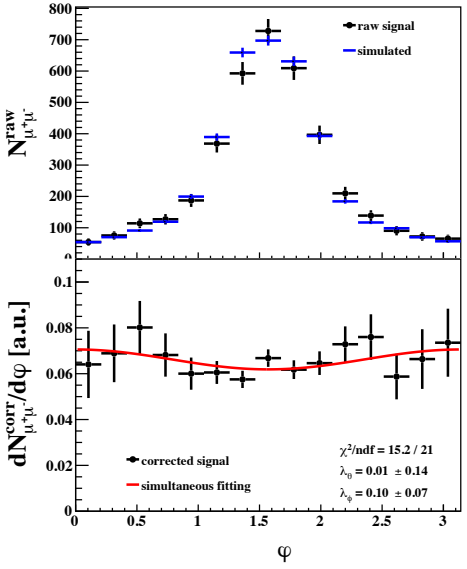


- The study was performed in four J/ψ p_T bins, in each p_T bins:
  - 10 bins for the cosθ variable from -1 to 1
  - 15 bins for the $|\varphi|$ varible from 0 to π

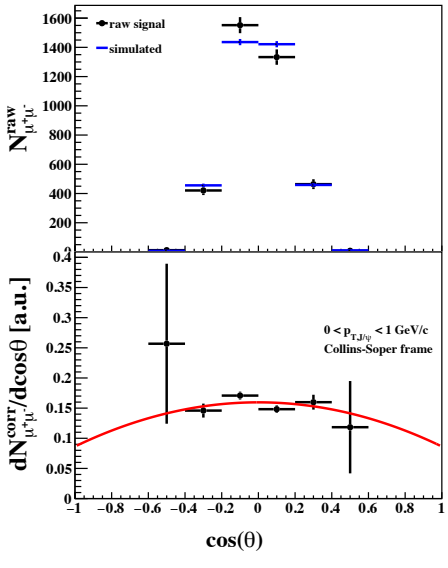
Polarization parameters extraction

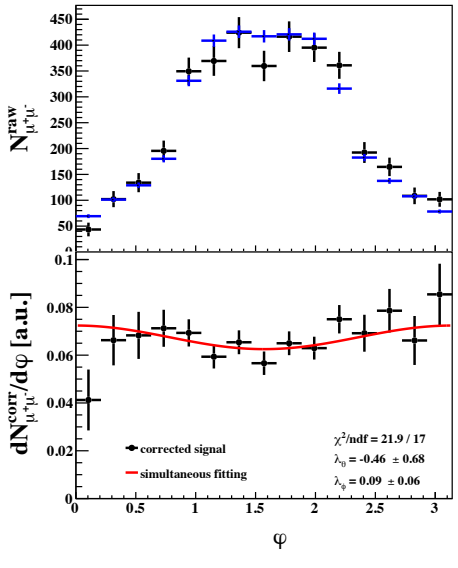
Helicity frame





Collins-Soper frame



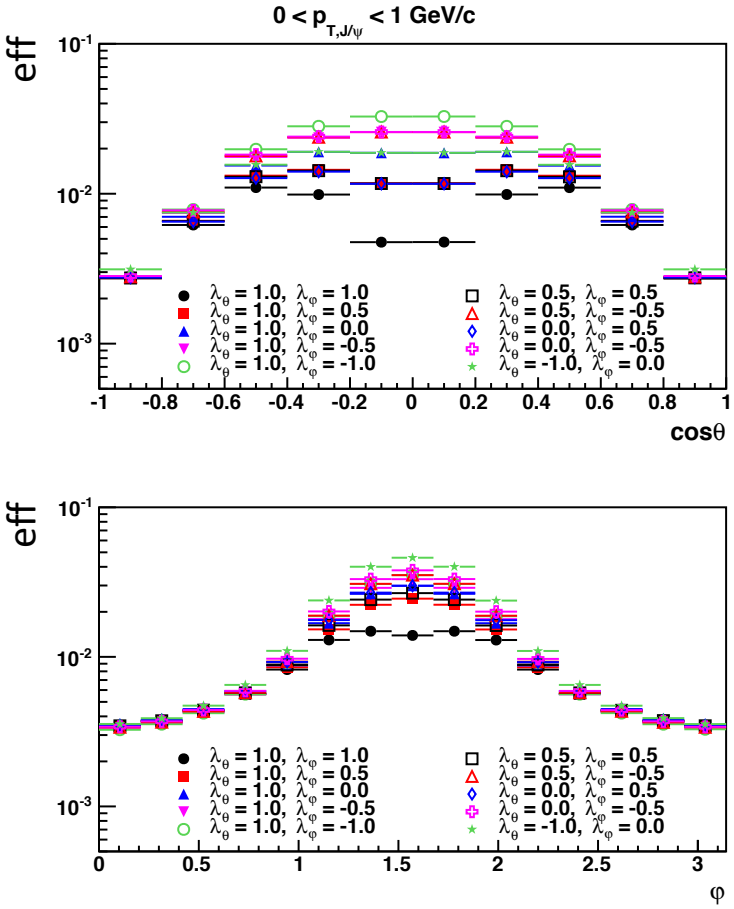


Fitting function: $W(cos\theta) \propto 1 + \lambda_\theta cos^2\theta \quad W(\varphi) \propto 1 + \frac{2\lambda_\varphi}{3+\lambda_\theta} cos2\varphi$

- An example of the correction and fitting procedure for $0 < p_T < 1$ GeV/c.

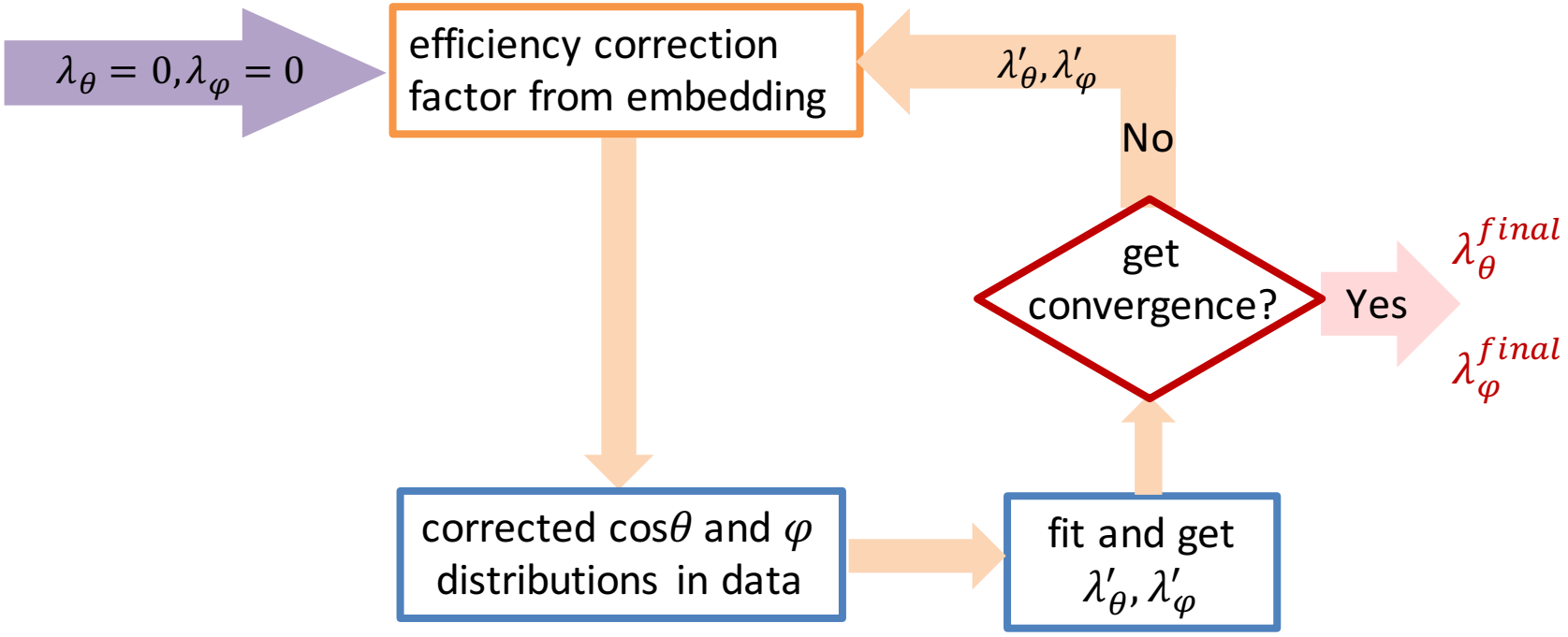
Dependence of correction on $\lambda_\theta^{input}, \lambda_\varphi^{input}$

Analysis	
Data	Embedding
Polarized (unknown)	*Input* $\lambda_\theta, \lambda_\varphi$
Acceptance*efficiency	*Acceptance*efficiency*



- The cosθ and φ acceptances are strongly correlated and depend on λ_θ and λ_φ
- The λ_θ and λ_φ are unknown

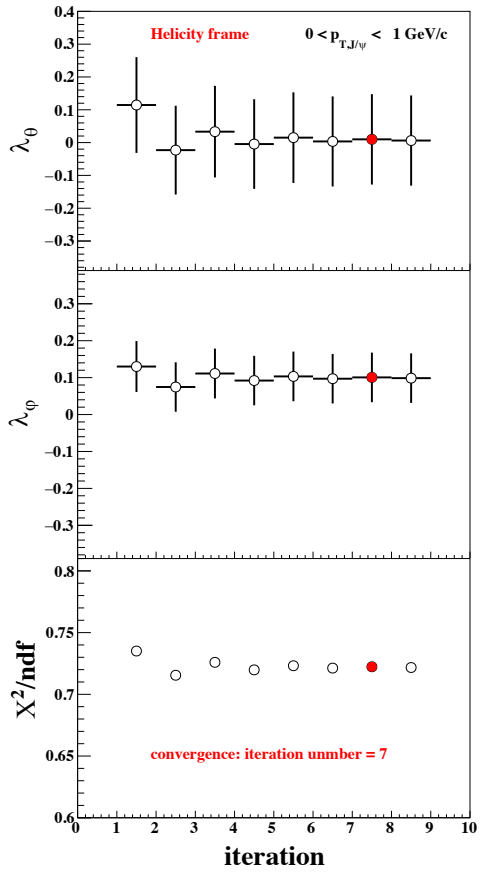
An iterative procedure



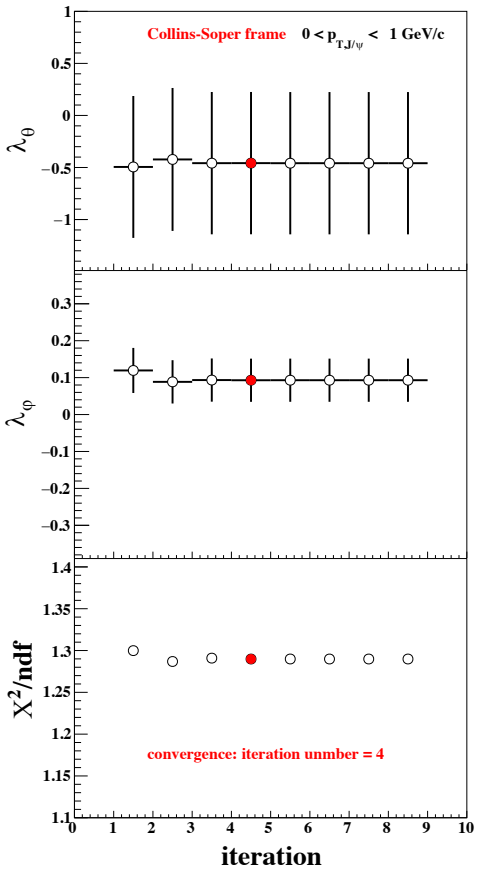
- Repeat until convergence is reached
  - The extracted polarization parameters do not vary by more than 0.01 between two successive iterations

Extract polarization parameters via iterative procedure

Helicity frame

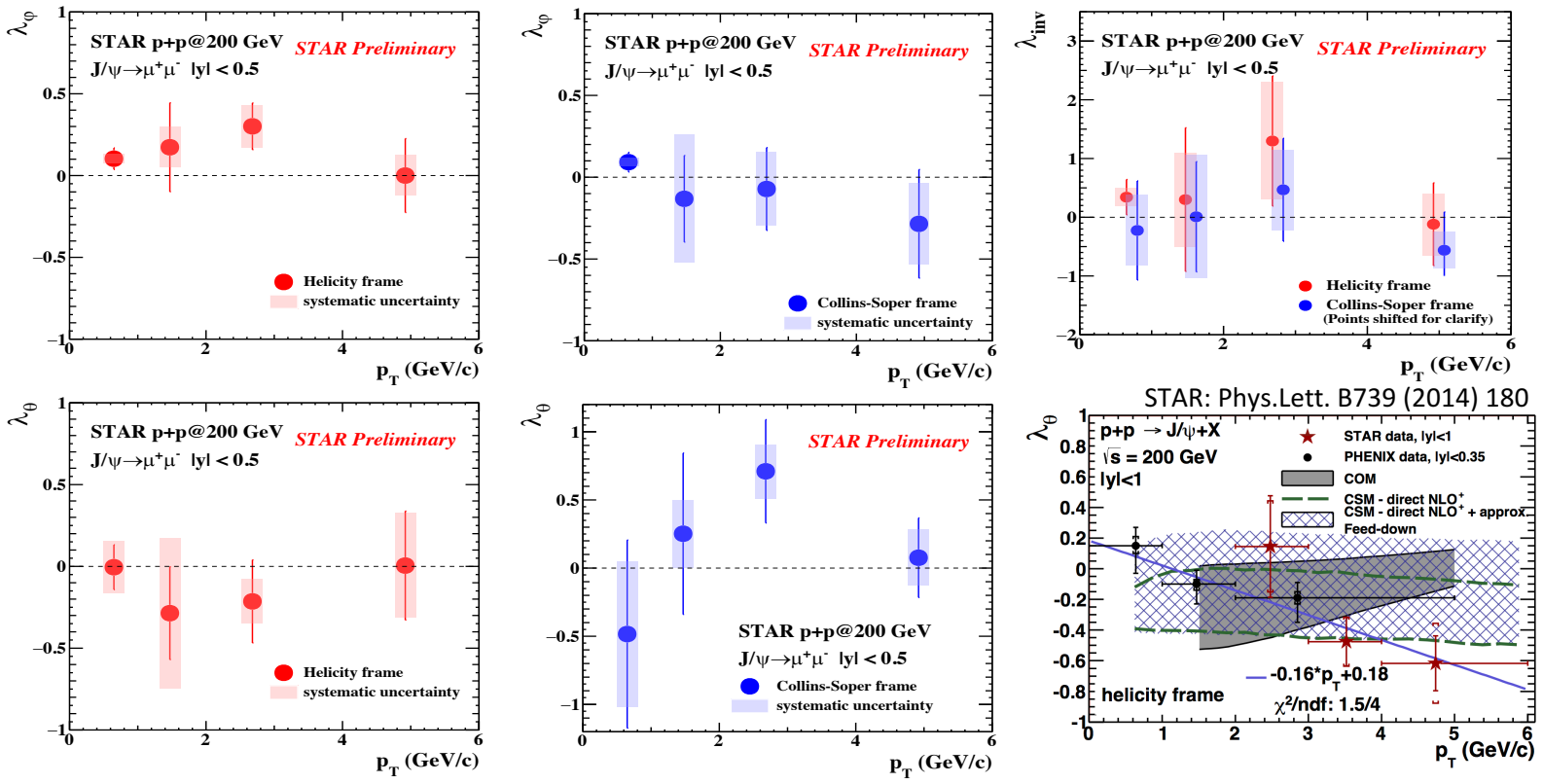


Collins-Soper frame



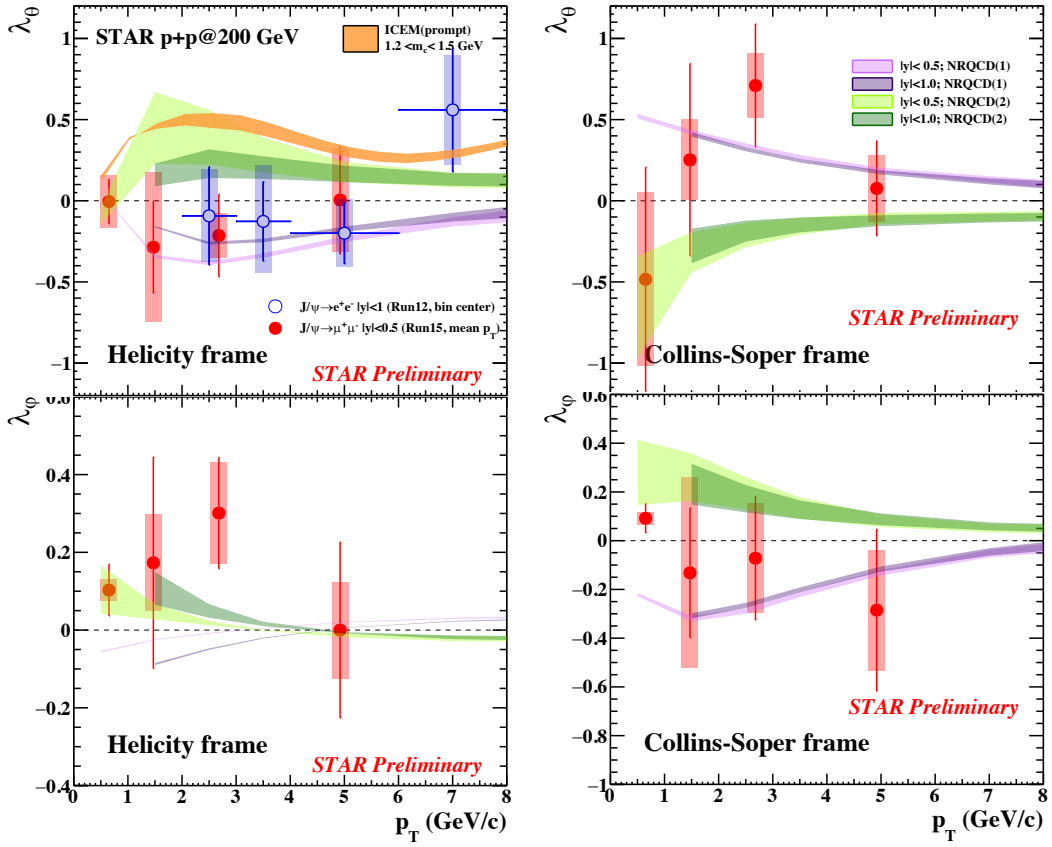
- The $\lambda_\theta, \lambda_\varphi$ and χ^2/ndf as a function of iteration number for $0 < p_T < 1$ GeV/c

J/ψ polarization parameters in p+p collisions



- J/ψ polarization measurement for $0 < p_T < 5$ GeV/c
- λ_θ and λ_φ parameters are consistent with 0 in HX and CS frames
- λ_{inv} as a function of p_T are consistent in both frames
- Without strong p_T dependence

J/ψ polarization vs. Model calculations



NRQCD (1): Phys. Rev. Lett. 114 (2015) 092006
NRQCD (2): Phys. Rev. Lett. 110 (2013) 042002
Hongfei Zhang's private contribution
ICEM: Phys. Rev. D 96 (2017) 054014
Ramona Vogt's private contribution;

- Improved CEM (prompt J/ψ) calculation is touching the upper limit of some data points
- NRQCD (prompt J/ψ) calculations are consistent with data with in uncertainties
  - Different kinematic regions (|y| < 0.5 and |y| < 1)
  - Two sets of Long Distance Matrix Elements (LDMEs).

Summary

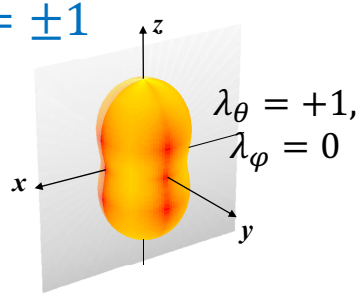
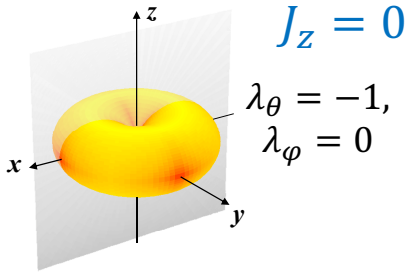
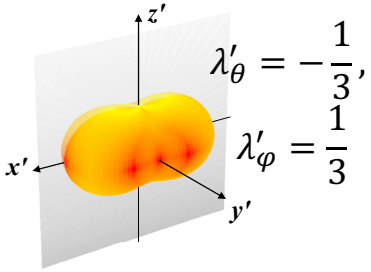
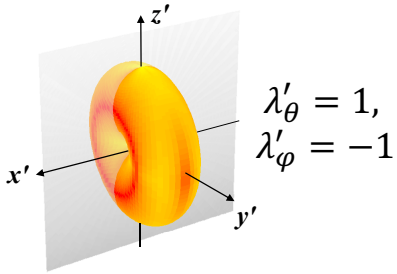
The first measurement for inclusive J/ψ polarization via dimuon decay channel in p+p collisions at √s = 200 GeV at STAR

- Develop iterative procedure to improve efficiency correction
- The polarization parameters $\lambda_\theta, \lambda_\varphi$ and λ_{inv} are 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, without strong p_T dependence
  - λ_{inv} is consistent in both frames
  - Can provide further constrains to model calculations

Back up

J/ψ polarization measurement

$$W(cos\theta,\varphi) \propto \frac{1}{3+\lambda_\theta} \cdot (1+\lambda_\theta cos^2\theta + \lambda_\varphi sin^2\theta cos2\varphi + \lambda_{\theta\varphi} sin2\theta cos\varphi)$$

	transverse polarization $J_z = \pm 1$	longitudinal polarization $J_z = 0$
natural frame		
frame rotated by 90°		

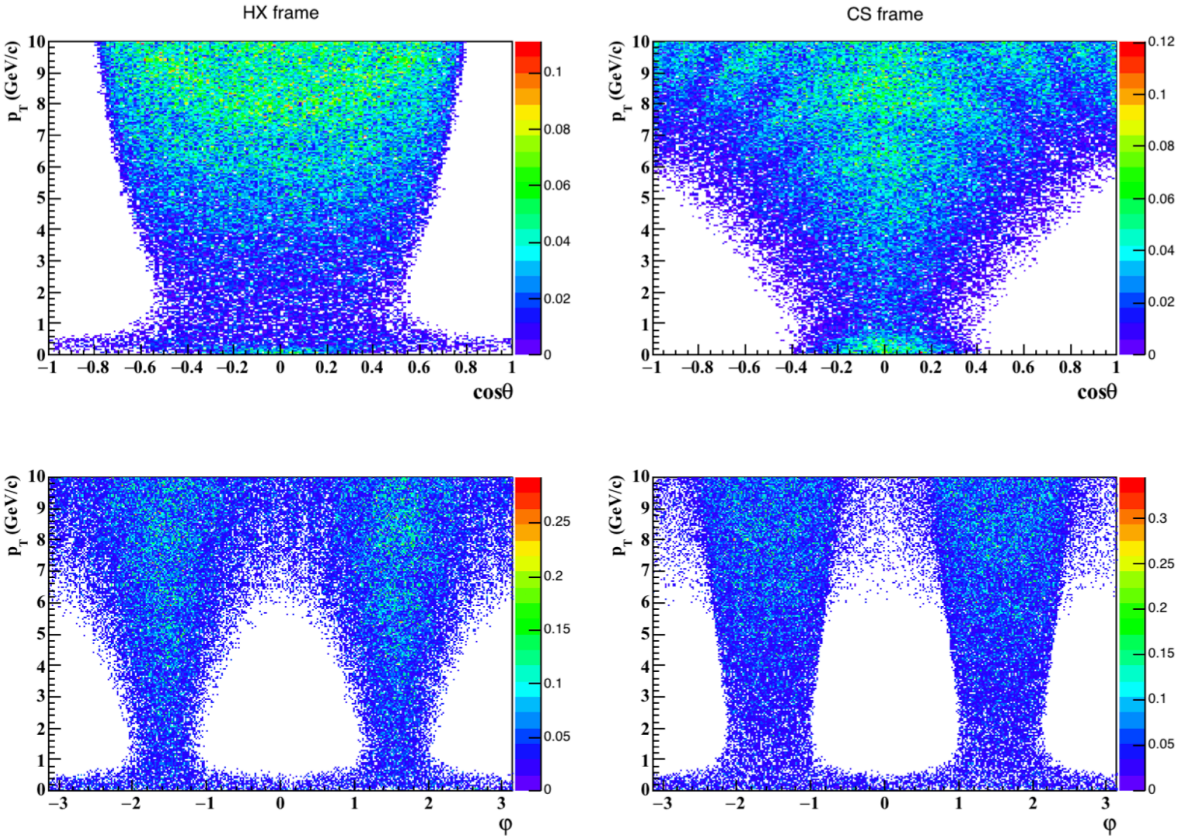
➢ Frame invariant quantity:

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

- The same value of this quantity
- Good cross-check

P. Faccioli, et al., Eur. Phys. J. C 69, 657 (2010)

Efficiency evaluation: embedding



- Raw J/ψ distributions have to be corrected
- A Monte Carlo simulation is used (J/$\psi \rightarrow \mu^+\mu^-$ embedding)
  - Simulated J/ψ passing through GEANT simulation
  - Embedded into a real event