Measurement of J/ψ polarization in p+p collisions at $\sqrt{s}$ = 200 GeV through the di-muon channel at STAR

Zhen Liu, for the STAR Collaboration

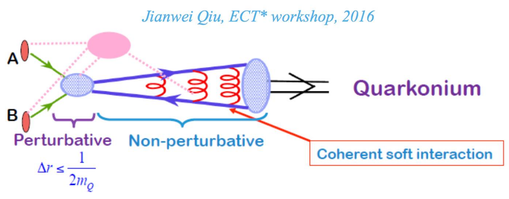
University of Science and Technology of China

State Key Laboratory of Particle Detection and Electronics

Abstract

Quarkonium production mechanism in elementary collisions has not been fully understood. Experimental data on the J/ψ cross section in p+p collisions can be described relatively well by several models that are currently available on the market. However, these models differ in their predictions for the J/ψ polarization. Therefore precise measurements of J/ψ polarization can provide further constraints on the production models. During the RHIC 2015 run, the STAR experiment recorded a large sample of p+p collisions at $\sqrt{s}$ = 200 GeV triggered by the Muon Telescope Detector for charmonium studies via the di-muon decay channel. In this poster, we will present the J/ψ polarization measurement in the helicity and Collins-Soper reference frames utilizing this data set. The polarization parameters λ_θ and λ_φ are extracted from simultaneous fit to 1-dimensional polar and azimuthal angular distributions of decayed μ^+ in the J/ψ transverse momentum range of 0-5 GeV/c in both frames. The results will be compared with similar measurements in higher transverse momentum region as well as with model calculations.

Motivation and Introduction



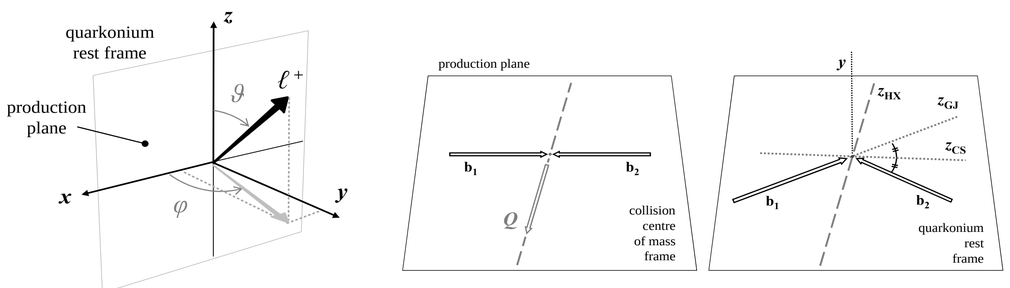
QCD factorization:
- Long distance process: no full-QCD description of quarkonium formation,
  - Model dependent;
  - Input from experiments needed.

- J/ψ polarization can be analyzed via the angular distribution of the decayed positively charged leptons[1], which can be expressed as:

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

$$|\lambda_\theta| < 1, \qquad |\lambda_\varphi| \leq \frac{1}{2}(1+\lambda_\theta)$$

- λ_θ and λ_φ can be extracted from simultaneous fit to 1-dimensional angular distributions,
  - $\lambda_{\theta\varphi}$ vanishes in both integrations.



- $\boldsymbol{\theta}$ - polar angle between momentum of positive lepton in J/ψ rest frame and polarization axis z.
- $\boldsymbol{\varphi}$ - corresponding azimuthal angle.

- Polarization axis z,
  - **Helicity (HX) frame:** along J/ψ momentum in center-of-mass frame of 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:

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

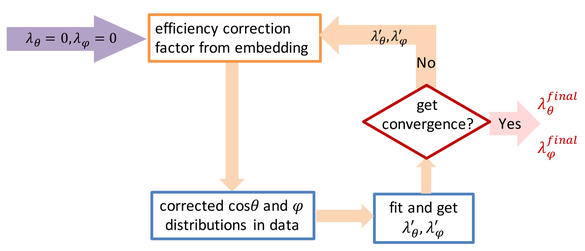
  - Any arbitrary choice of the experimental observation frame should give the same value of λ_{inv};
  - Good cross-check on measurements performed in different frames.

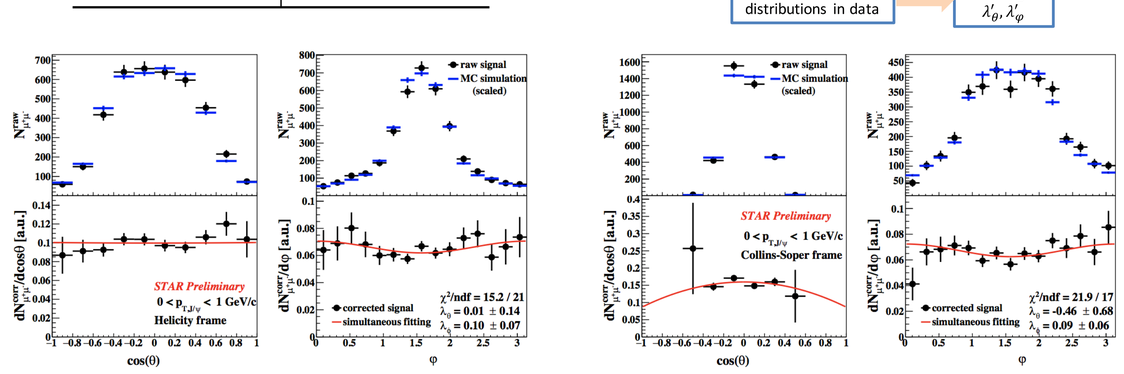
Efficiency and Acceptance Corrections

- Raw J/ψ distributions have to be corrected for the STAR detector acceptance and efficiency.
- The complication is that the acceptance correction is sensitive to the J/ψ polarization parameters, which are not known a priori.
- An iterative procedure is used to overcome this complication.

Analysis

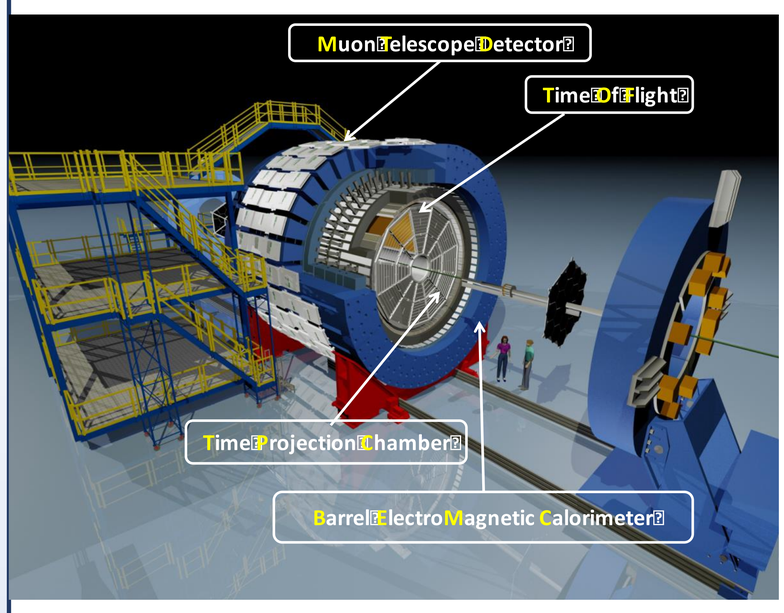
Data	Embedding
Polarized (unknown)	*Input*: $\lambda_\theta, \lambda_\varphi$
Acceptance*efficiency	*Acceptance*efficiency*

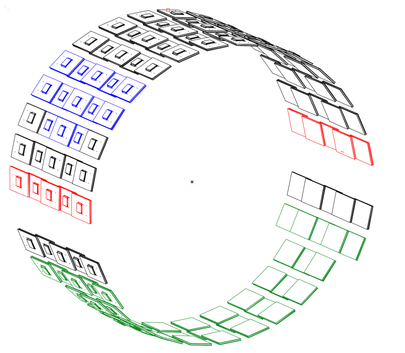


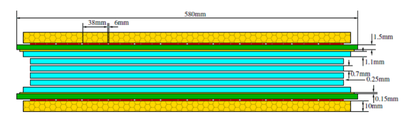


- An example of the last iteration for 0 < p_T < 1 GeV/c.

STAR Experiment

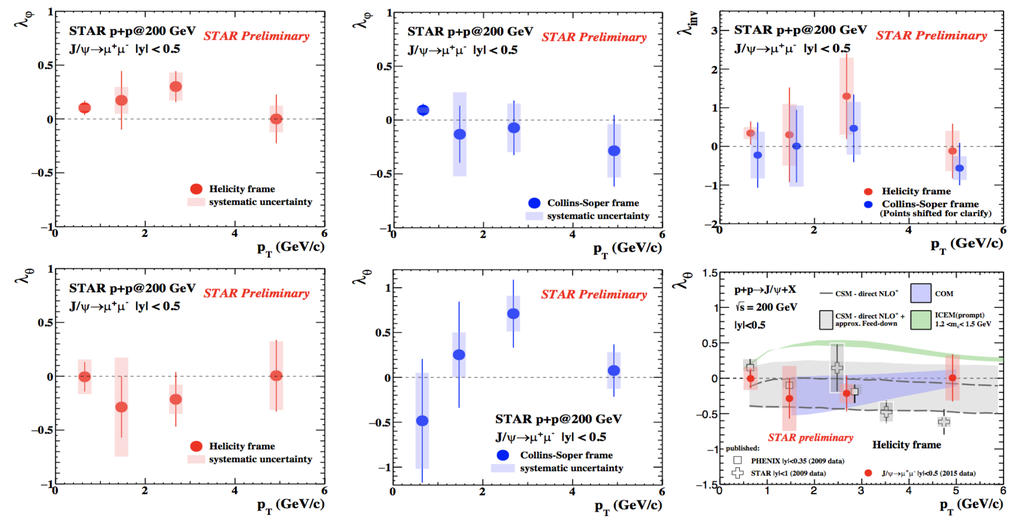




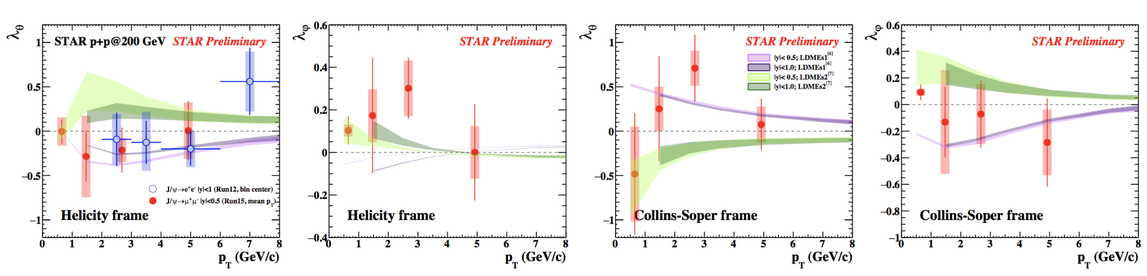


- Top right: A schematic view of the entire Muon Telescope Detector (MTD) system. MTD covers 45% in φ and $|\eta| < 0.5$. It is used to trigger on and identify muons which emit less Bremsstrahlung radiation compared to electrons.
- Bottom right: A schematic side-view of the Multi-gap Resistive Plate Chambers with long readout strips (LMRPC) used in the MTD design: time resolution ~100 ps and spatial resolution ~1-2 cm[2].

Results and Conclusions



The measured inclusive J/ψ polarization:
- 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 between HX and CS frames.
- Newly measured λ_θ parameter is consistent with the previous results[3, 4], even though the trends seem a bit different at high p_T.
- Color Singlet Model (CSM) calculation[3] (direct J/ψ) and Color Octet Model[4] (COM) calculation (direct J/ψ) are in agreement with data while an improved Color Evaporation Model[5] (prompt J/ψ) calculation is touching the upper limit of some data points.



Comparison with NRQCD approach[6] :
- Model calculations for different kinematic regions (|y| < 0.5 and |y| < 1) using two sets of Long Distance Matrix Elements (LDMEs).
- Theoretical calculations are in agreement with data within uncertainties. The substantial difference in J/ψ polarization at low p_T when different LDMEs are used, points to the potential of constraining the LDMEs with J/ψ polarization measurements of better precision in the future.

References

[1] P. Faccioli *et al.* (2010) *Eur. Phys. J.* C 69, 657
[2] C. Yang *et al.* (2014) *Nuclear Instruments and Methods in Physics Research A* 762: 1–6
[3] L. Adamczyk *et al.* (STAR) (2014) *Physics Letters B* 739 : 180-188
[4] A. Adare *et al.* (PHENIX) (2010) *Phys. Rev. D* 82, 012001
[5] B.A. Kniehl et al. (2017) *Phys. Rev. D* 96, 054014 (use the matrix elements)
[6] Hong-Fei Zhang *et al.* (2015) *Phys. Rev. Lett* 114, 092006
[7] Bin Gong *et al.* (2013) *Phys. Rev. Lett* 110, 042002

Acknowledgement

This work was supported in part by the National Natural Science Foundation of China (Grant No.11675186, the sub-topic of the 973 project. (HH2030040069)

U.S. DEPARTMENT OF ENERGY | Office of Science

The STAR Collaboration
drupal.star.bnl.gov/STAR/presentations

BROOKHAVEN NATIONAL LABORATORY