J/ψ polarization measurement in pp collisions and Pb−Pb collisions

Liang Dong

University of Science and Technology of China

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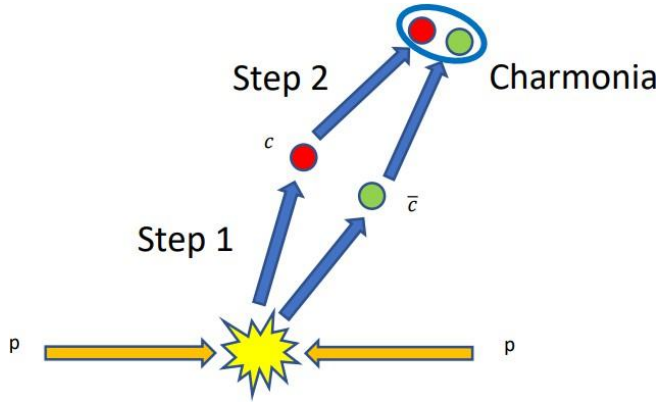
ALICE

Quarkonium in pp collisions

- **Quarkonium production**: perturbative + non-perturbative QCD.

- **Study quarkonium in pp**:
  - Distinguish among the quarkonium production mechanism; refine QCD based models such as: NRQCD, NRQCD+CGC, ICEM.
  - Reference for interpreting results obtained in Pb–Pb collisions.

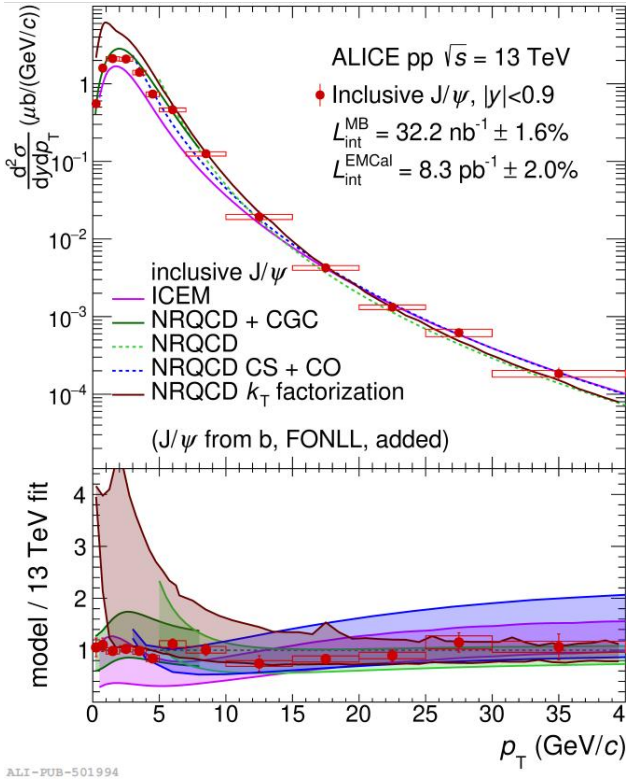


NRQCD: Phys. Rev. D51 (1995) 1125–1171
NRQCD+CGC: JHEP 01 (2014) 056
ICEM: Phys. Rev. D 94 no. 11, (2016) 114029

Motivation to study polarization

- Most theoretical models can reasonably describe the inclusive J/ψ production cross section, but they give **very different predictions** for the J/ψ polarization.

- J/ψ polarization serves as **a golden observable** for testing and refining quarkonium production models.



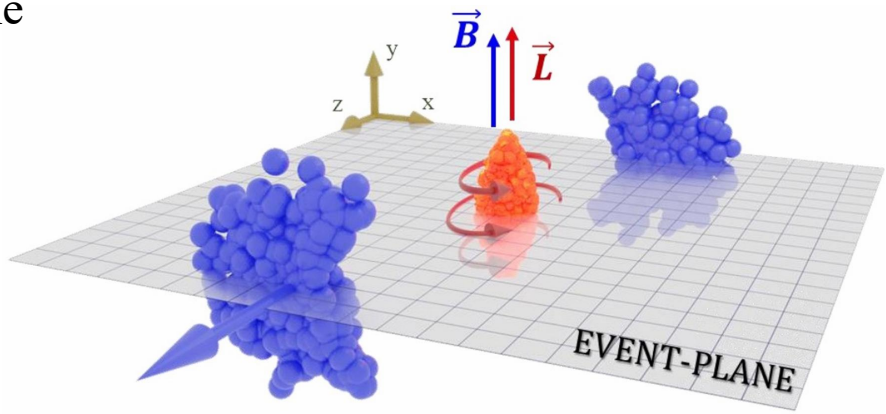
ALICE, Eur. Phys. J. C 81 (2021) 1121

Motivation to study polarization in Pb−Pb collisions

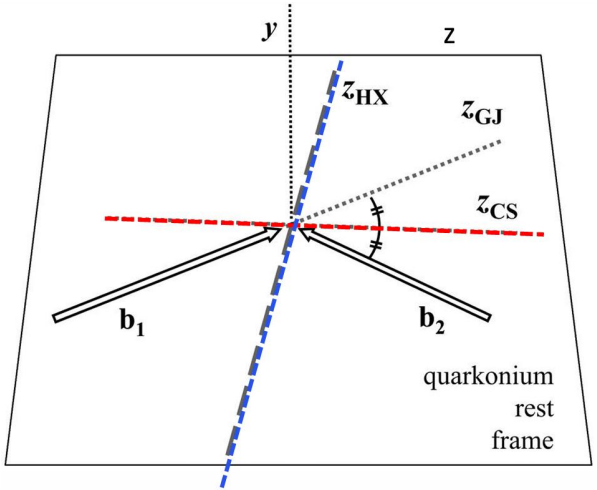
- Both the external magnetic field and the initial angular momentum produced in the non-central heavy-ion collisions may influence the quarkonium polarization.

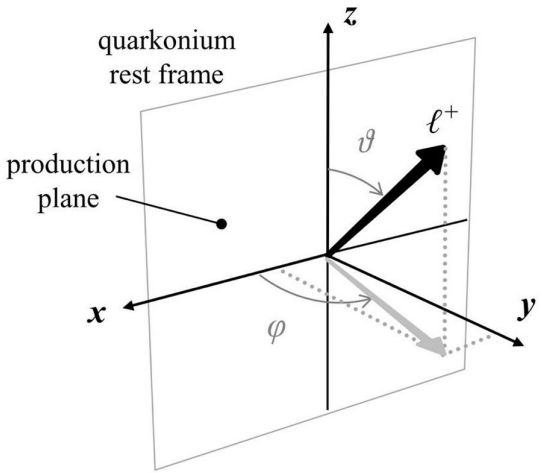
- The studies are also interesting in heavy-ion collisions to study quarkonium regeneration and suppression process in the QGP.

- The event plane, being perpendicular to the angular momentum and magnetic field, is ideal for observing polarization effects.



Introduction to polarization measurements





Polarization: the alignment of the particle spin with respect to a chosen quantization axis.

Polarization axis:

Helicity (HX): Direction of vector meson in the collision center of mass frame.

Collins-Soper (CS): The bisector of the angle between the beam and the opposite of the other beam, in the vector meson rest frame.

Production-plane(PP):Axis perpendicular to the production plane.

Event Plane based frame (EP): Axis perpendicular to the reaction plane.

Faccioli et. al, EPJC 69, 657 (2010)

Introduction to polarization measurements

Polarization is studied via measurement of angular distribution of particle decay products.

The angular distribution in dilepton decay:

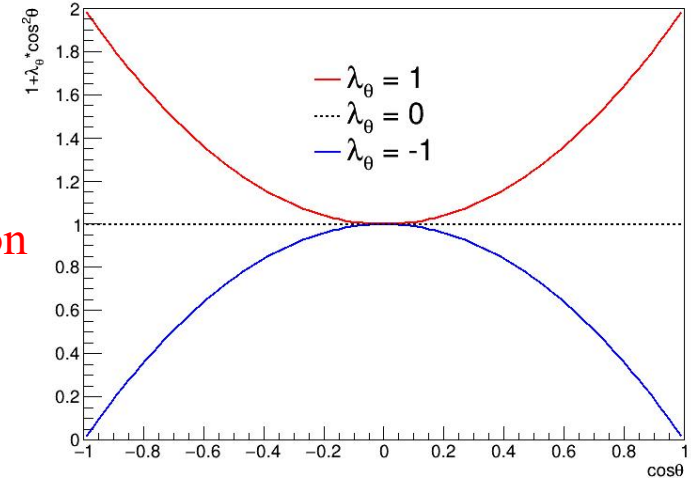
$$W(\theta,\phi) \propto \frac{1}{3+\lambda_\theta}\left(1+\lambda_\theta \cos^2\theta + \lambda_\phi \sin^2\theta \cos 2\phi + \lambda_{\theta\phi} \sin 2\theta \cos\phi\right)$$

Faccioli et. al, EPJC 69, 657 (2010)

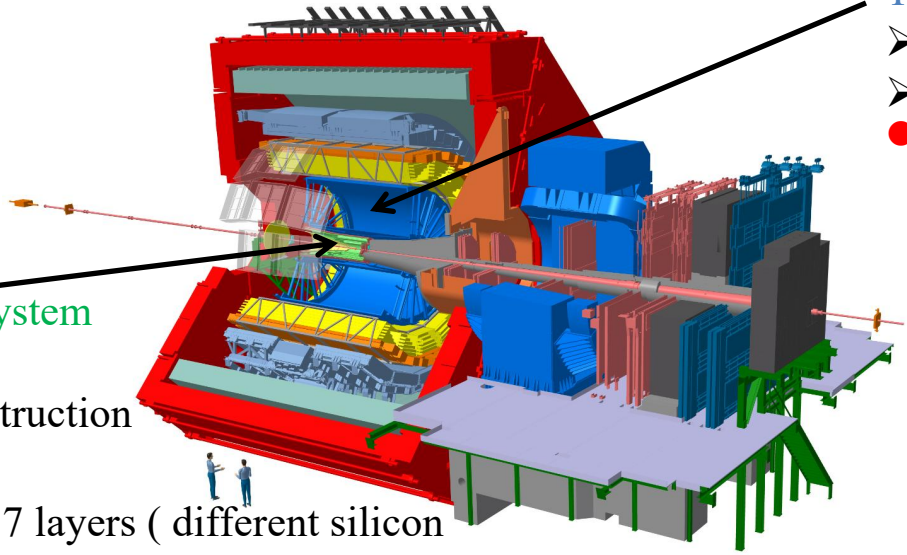
$(\lambda_\theta, \lambda_\phi, \lambda_{\theta\phi}) = (1,0,0)$ → Transverse polarization

$(\lambda_\theta, \lambda_\phi, \lambda_{\theta\phi}) = (-1,0,0)$ → Longitudinal polarization

$(\lambda_\theta, \lambda_\phi, \lambda_{\theta\phi}) = (0,0,0)$ → Unpolarized state



ALICE detector in Run3



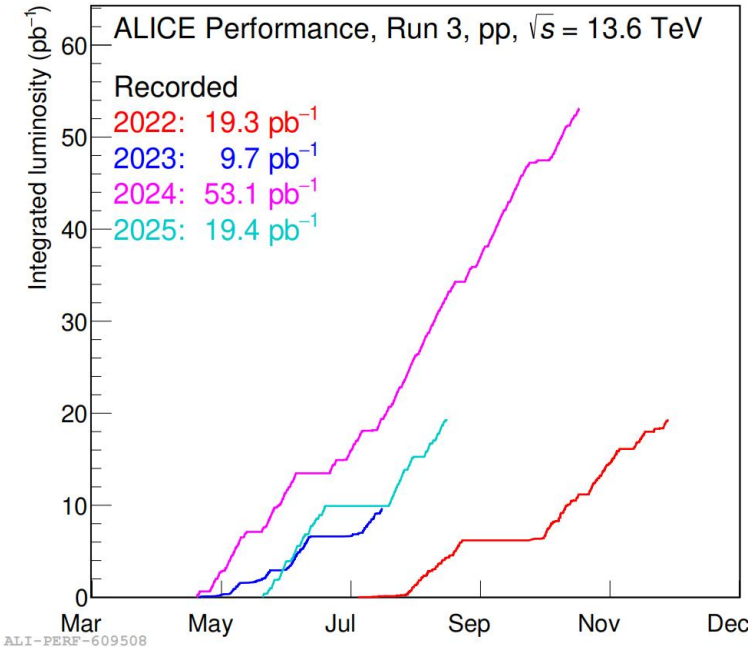
Time Projection Chamber

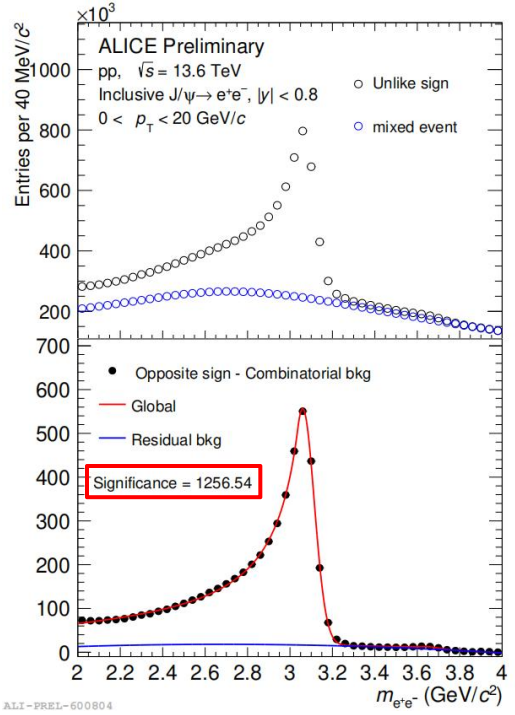
- ➢ Tracking
- ➢ Particle identification
- ● **Upgrade:**
  - ✓ Multi-Wire Proportional Chamber (MWPC) → Gas Electron Multiplier (GEM).
  - ✓ Enables continuous readout, allowing the collection of a significantly larger data sample.

Inner Tracking System

- ➢ Tracking
- ➢ Vertex reconstruction
- ● **Upgrade:**
  - ✓ 6 layers → 7 layers (different silicon technologies→ all silicon pixels)
  - ✓ Radius of innermost layer: 39 mm → 23 mm (**Improved track pointing resolution**)
  - ✓ Material budget for each of the 3 innermost layers: 1.15% → 0.35%. (**Reduction of conversion electrons**, one of the background sources in electron analyses.)

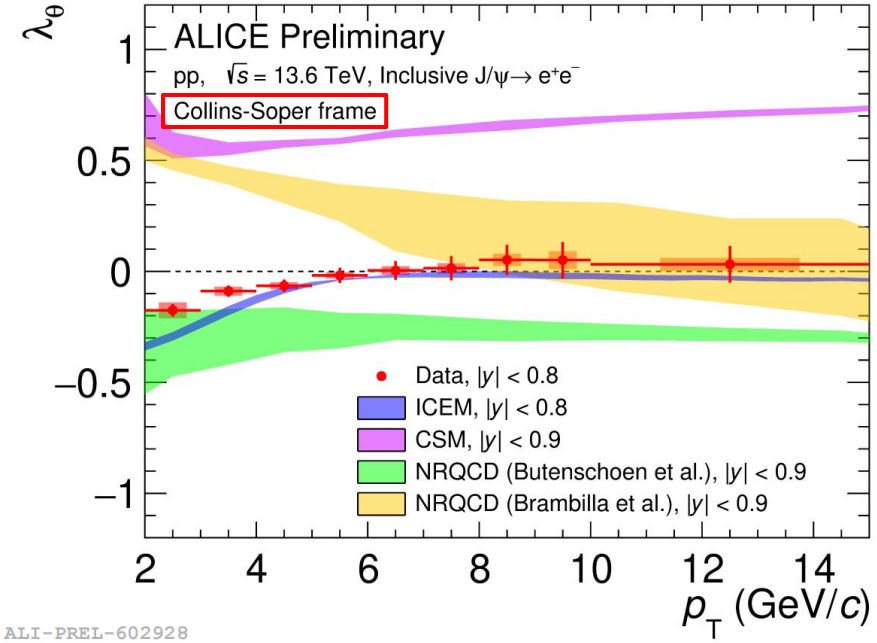
ALICE in Run3 data taken





- The pp collision data sample collected has increased by 10^4 compared to Run 2.
- The reconstructed J/ψ significance is greater than 1200.

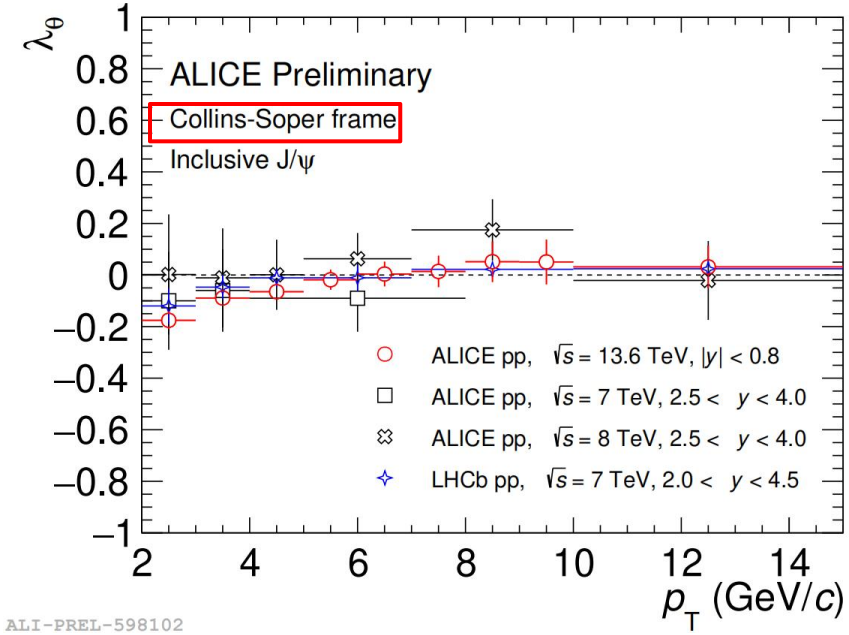
Quarkonium polarization in pp collision

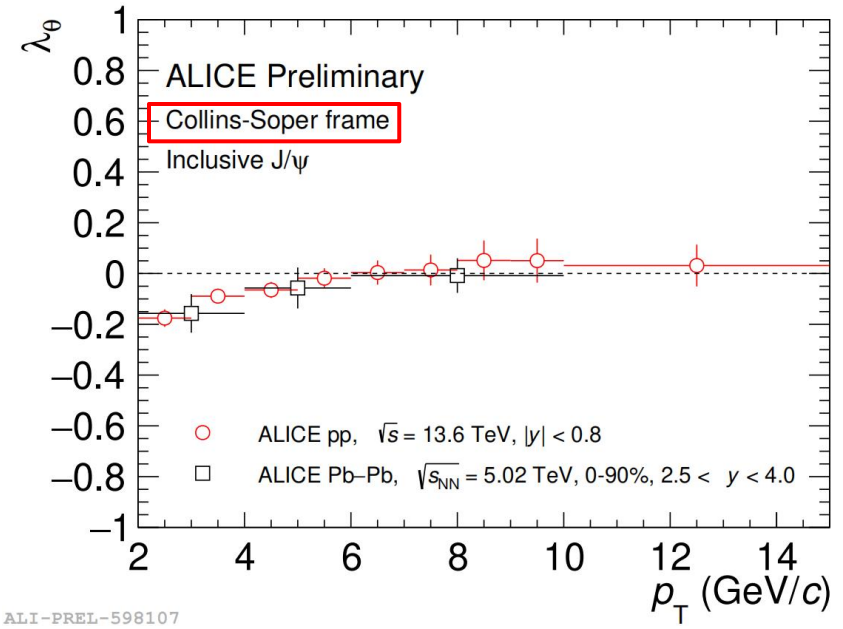


- The Run 3 statistics allow for the measurement of J/ψ polarization at midrapidity.
- Polarization measurements **provide an important constraint** on the LDME, which is crucial for understanding the J/ψ production mechanism in pp collisions.

ICEM: Phys. Rev. D 94 no. 11, (2016) 114029
CSM: Ann.Rev.Nucl.Part.Sci.60:463-489,2010

Quarkonium polarization in pp collision

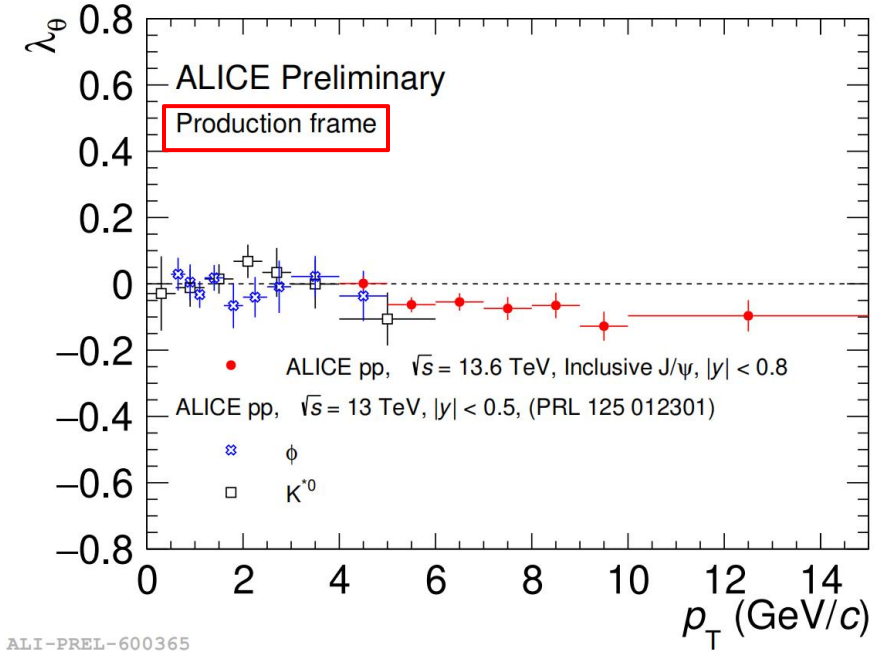




- The ALICE Run 3 Collins-Soper result is consistent with previous ALICE and LHCb results at forward rapidity, both in pp and Pb-Pb collisions.
- **No strong rapidity dependence or collision system dependence** observed in inclusive J/ψ polarization.

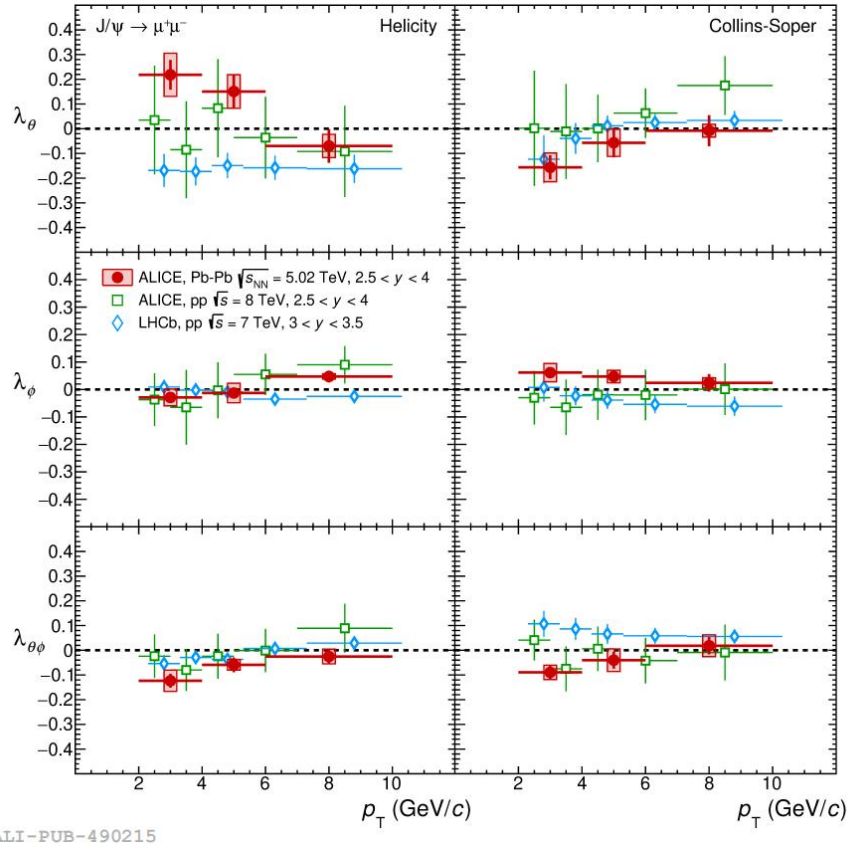
LHCb Collaboration, EPJC73, 2631 (2013)
ALICE Collaboration, EPJC78 (2018) 562
ALICE Collaboration, PLB815 (2021)136146
ALICE Collaboration, PRL108 (2012) 082001

Quarkonium polarization in pp collision



- The measured J/ψ polarization in Production frame is consistent with the previous ALICE results for ϕ and K^{*0}, shows no strong polarization.

Quarkonium polarization in Pb−Pb collision

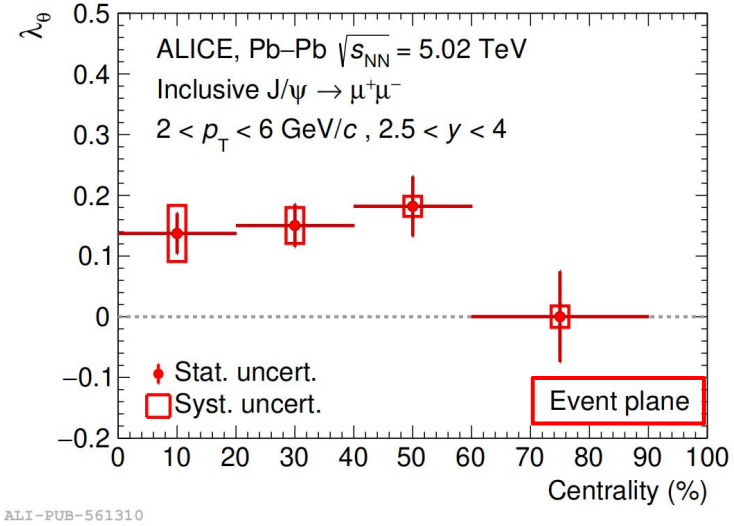


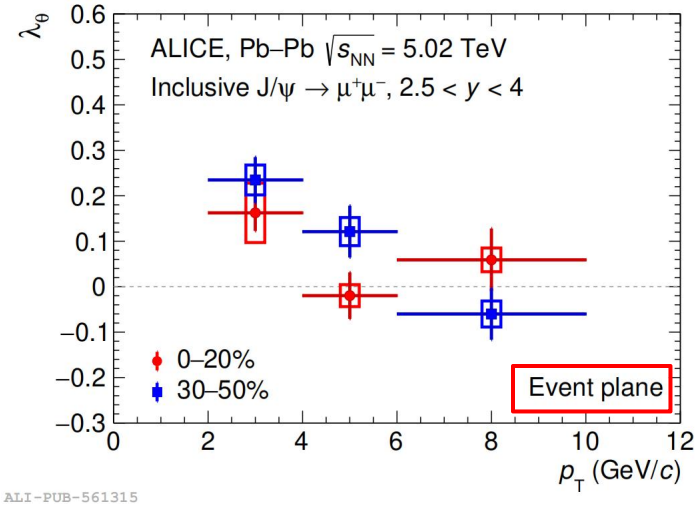
ALI-PUB-490215

- λ_θ indicates a slight transverse polarization at low p_T in HE, while a weak longitudinal polarization in CS frame.
- A significant difference (3.3σ) is found with respect to LHCb results at low p_T ($2 < p_T < 4$ GeV/c) in HE frame.
- Different polarization in Pb−Pb and pp may be a hint of different production mechanisms.

ALICE, PLB815 (2021)136146
LHCb, JHEP12 (2017) 110
ALICE, EPJC78 (2018) 562

Quarkonium polarization in Pb−Pb collision



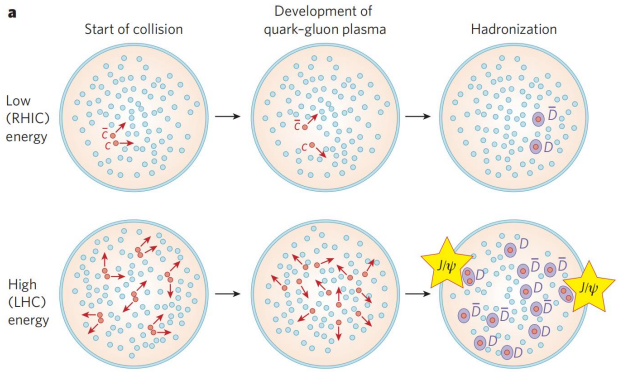


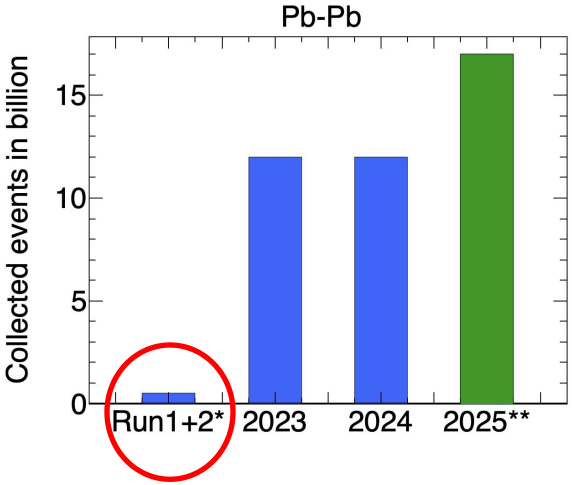
- First measurement of quarkonium polarization with respect to the event plane.
- **Finite polarization (~ 3.5σ)** of J/ψ in Pb−Pb collisions for (40−60)% centrality class with respect to the event plane.
- **Significant deviation (~ 3.9σ)** is observed for (30−50)% at low p_T ($2 < p_T < 4$ GeV/c).

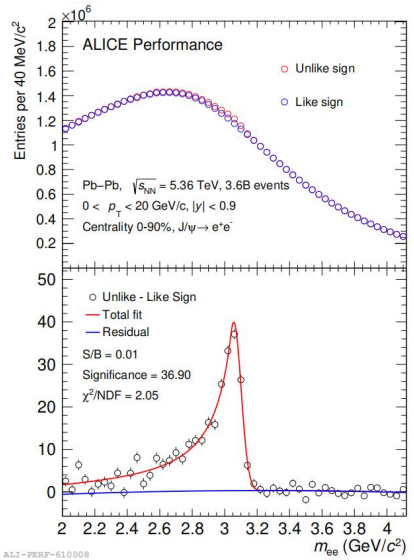
ALICE Collaboration, Phys. Rev. Lett.131, 042303 (2023)

J/ψ polarization in Pb–Pb collisions at midrapidity

P. Braun-Munzinger, J. Stachel, Nature 448 (2007) 302







- The measurement of J/ψ polarization at midrapidity is particularly important, as it provides direct insight into the dominant production mechanisms.
- Compared with RHIC energies, J/ψ production at the LHC is cleaner and less affected by competing processes.
- The Run 3 detector upgrade will enable precise measurements of J/ψ polarization at midrapidity and allow the separation of prompt and non-prompt contributions.

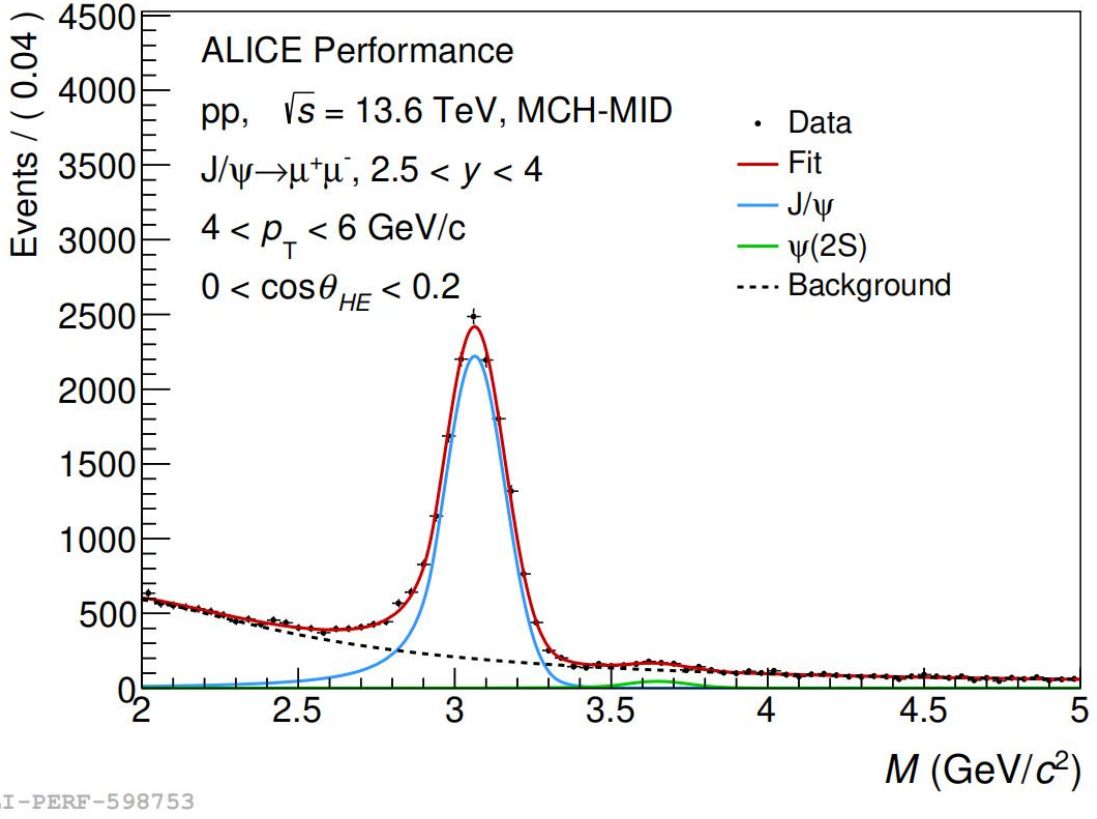
Summary

- **Quarkonium polarization in pp collision:**
  - J/ψ do not show strong polarization in Collins-Soper and production reference frames.
  - The results indicate there is no strong dependence of inclusive J/ψ polarization on rapidity, collision system or collision energy.
- **Quarkonium polarization in Pb-Pb collision:**
  - A small transverse (longitudinal) polarization in helicity(Collins-Soper) frame at 5.02 TeV.
  - Significant polarization of J/ψ is observed in event plane frame at 5.02 TeV.
- **Outlook:**
  - Precise measurement of J/ψ polarization is ongoing with improved statistics in Run 3.

Thanks

Backup

J/ψ signal extraction in pp collision at forward rapidity in Run3



Model

- **NRQCD**: Non-Relativistic QCD approach, long-distance matrix elements (LDME) fitted to experimental data.
- **NRQCD+CGC**: Color Glass Condensate effective theory coupled to leading order NRQCD calculations.
- **CSM**:The quarkonium is directly produced in a color-singlet state.
- **ICEM**: using the k_T-factorization approach to improve Color Evaporation Model (CEM).