



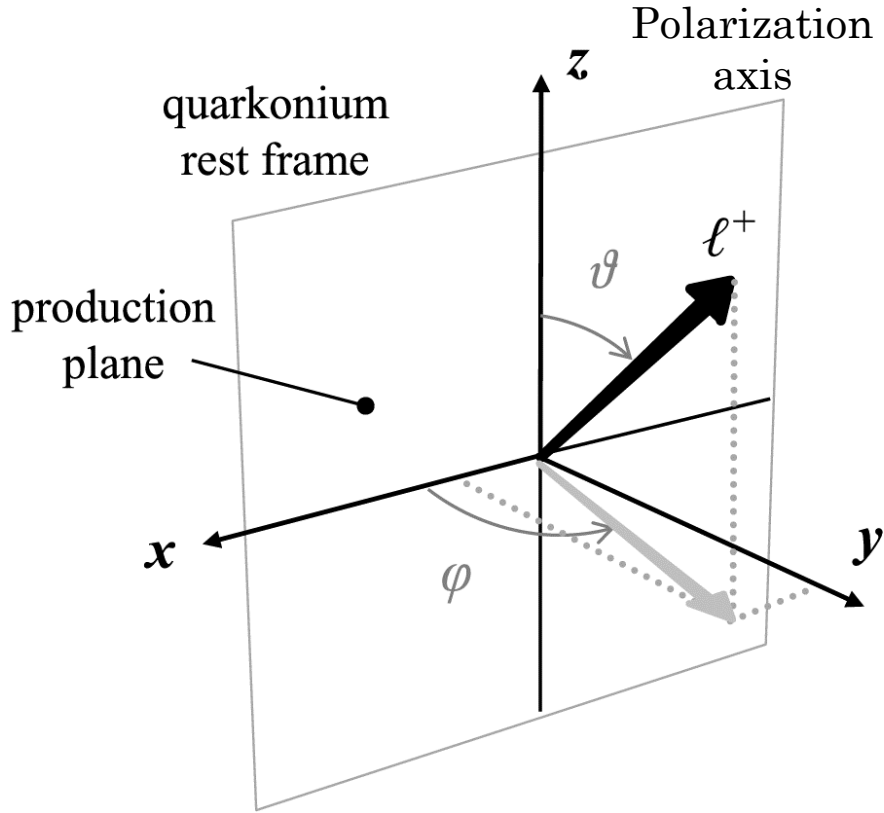
# Quarkonium polarization in hadronic collisions with ALICE

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University of Science and Technology of China

The 12<sup>th</sup> International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions

Nagasaki, Japan



For the decay of vector meson into dilepton, in rest frame of vector meson

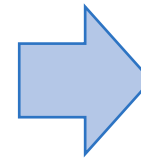
$$W(\cos \theta, \phi) \propto \frac{1}{3 + \lambda_\theta} \cdot (1 + \lambda_\theta \cos^2 \theta + \lambda_\phi \sin^2 \theta \cos 2\phi + \lambda_{\theta\phi} \sin 2\theta \cos \phi)$$

For these polarization parameters.

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

$$(\lambda_\theta, \lambda_\phi, \lambda_{\theta\phi}) = (+1, 0, 0)$$

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



No polarization

Transverse polarization

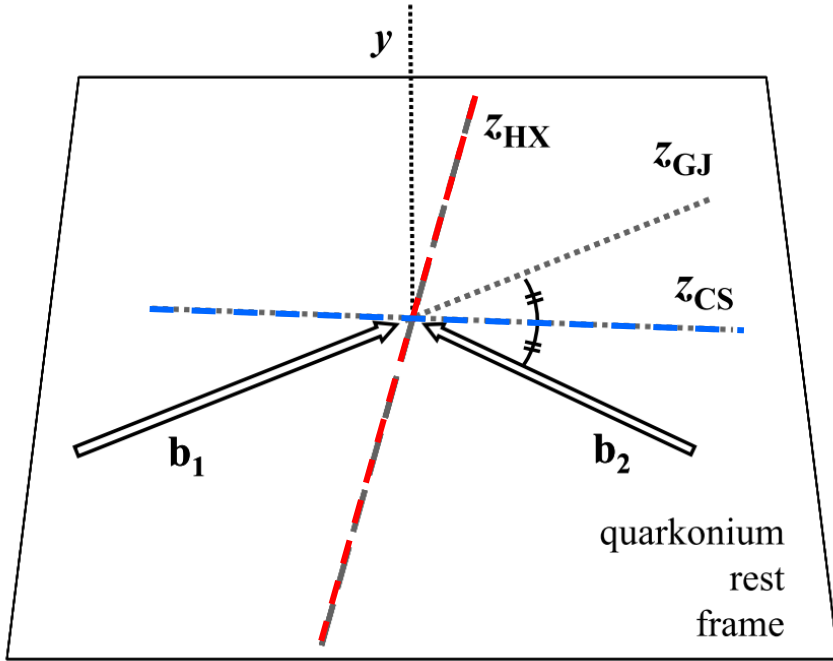
Longitudinal polarization

Sometimes the spin density matrix is also used directly to represent

$$W(\cos \theta) \propto (1 - \rho_{00}) + (3\rho_{00} - 1) \cos^2 \theta$$

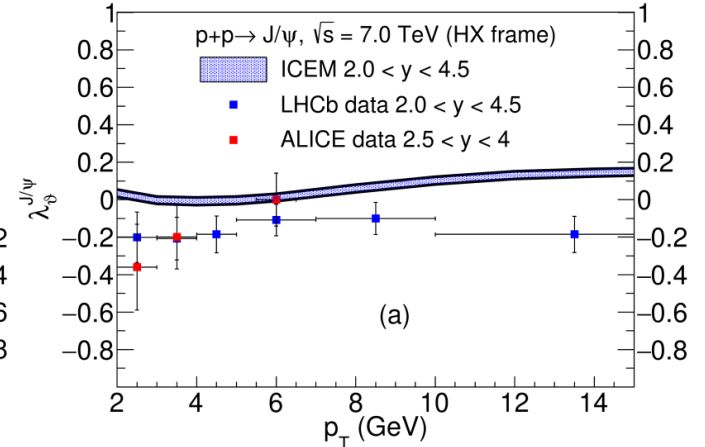
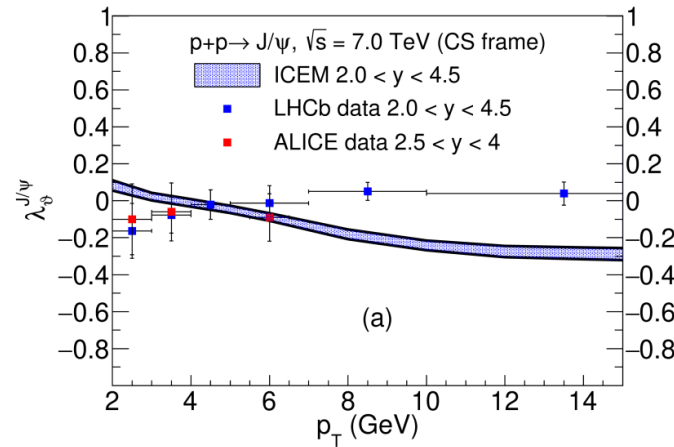
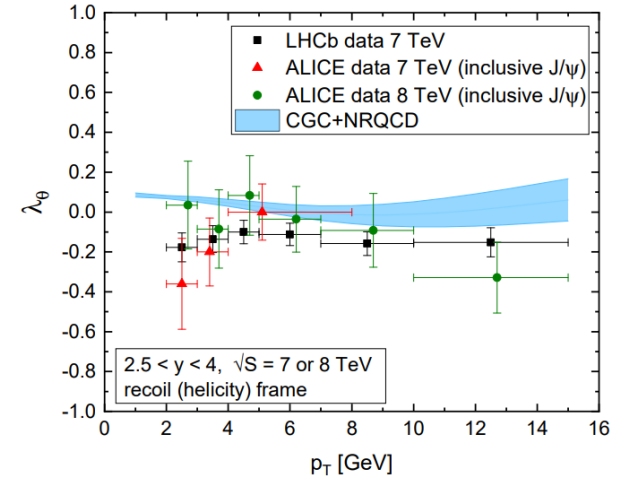
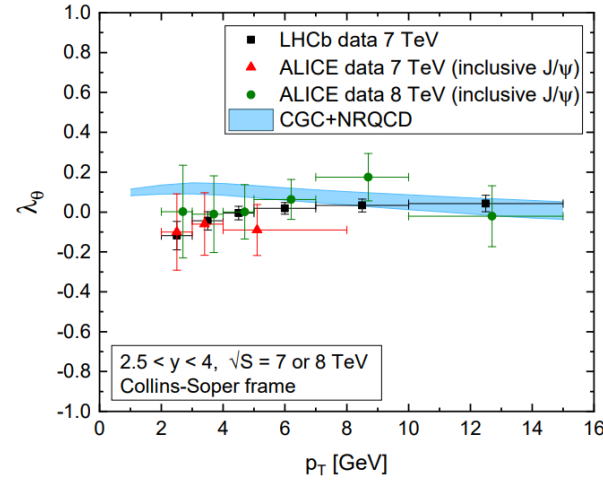
- Polarization is defined as the alignment of spin along a chosen direction.
- Measured through the anisotropy of the angular distribution of the decay products.

# Quarkonium polarization in pp collisions



Faccioli et al, Eur. Phys. J. C (2010) 69: 657–673

- **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.



➤ Golden observable to constrain quarkonium production mechanism.

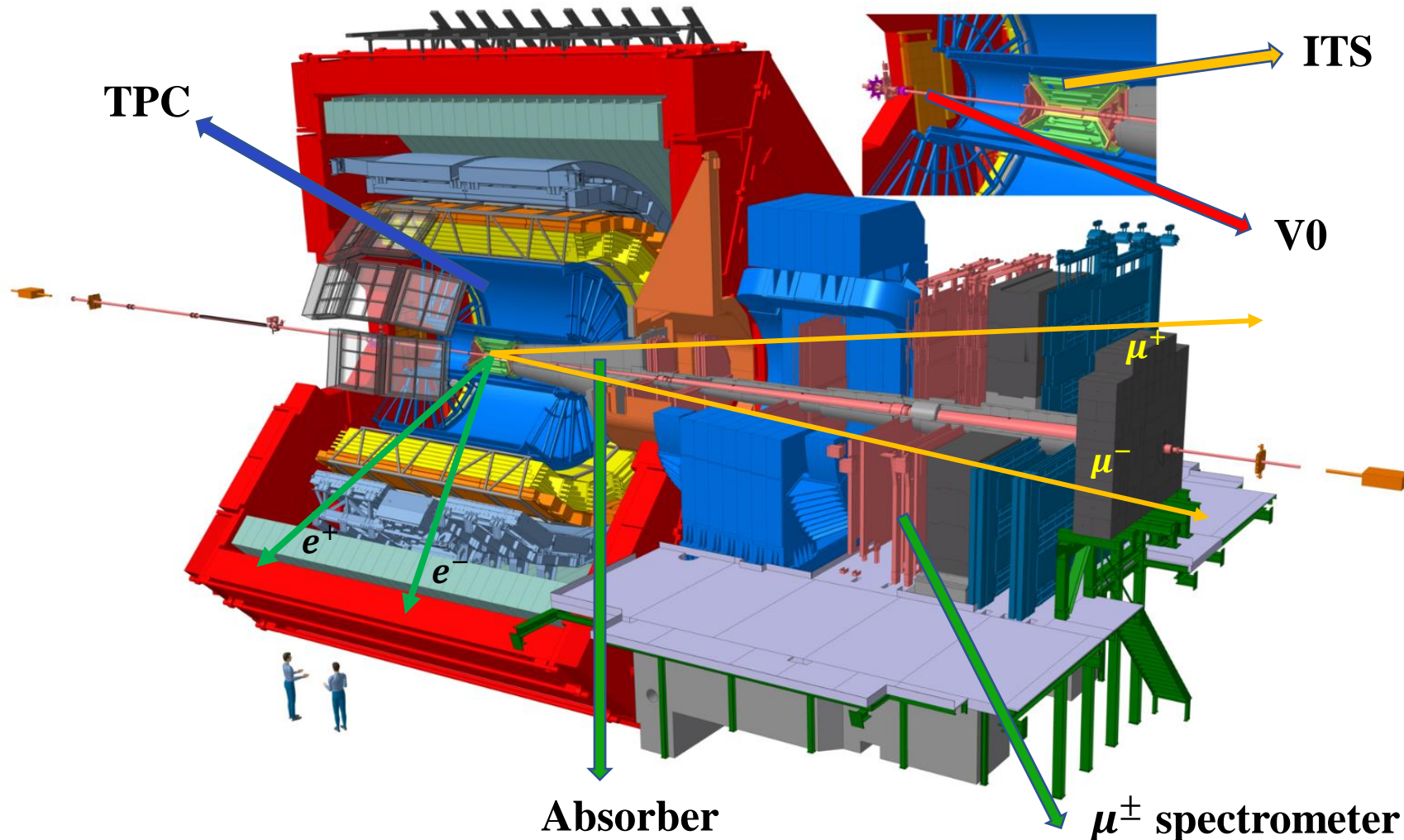
- Color singlet: longitudinal polarization
- NRQCD: transverse polarization

① Yan-Qing Ma et al, JHEP 12, 057 (2018)  
 ② Vincent Cheung and Ramona Vogt, PRD 104, 094026 (2021)

# ALICE detector

Forward ( $2.5 < y < 4.0$ )

Central barrel ( $|y| < 0.9$ )



- ◆ V0 detector
  - ✓ Centrality determination
  - ✓ Trigger
  - ✓ Background rejection
- ◆  $\mu^\pm$  spectrometer
  - ✓ Trigger
  - ✓  $\mu^\pm$  tracking
- ◆ Time Projection Chamber
  - ✓ Tracking, Particle identification
- ◆ Inner Tracking System
  - ✓ Tracking, Vertex reconstruction

Run 3 updates:

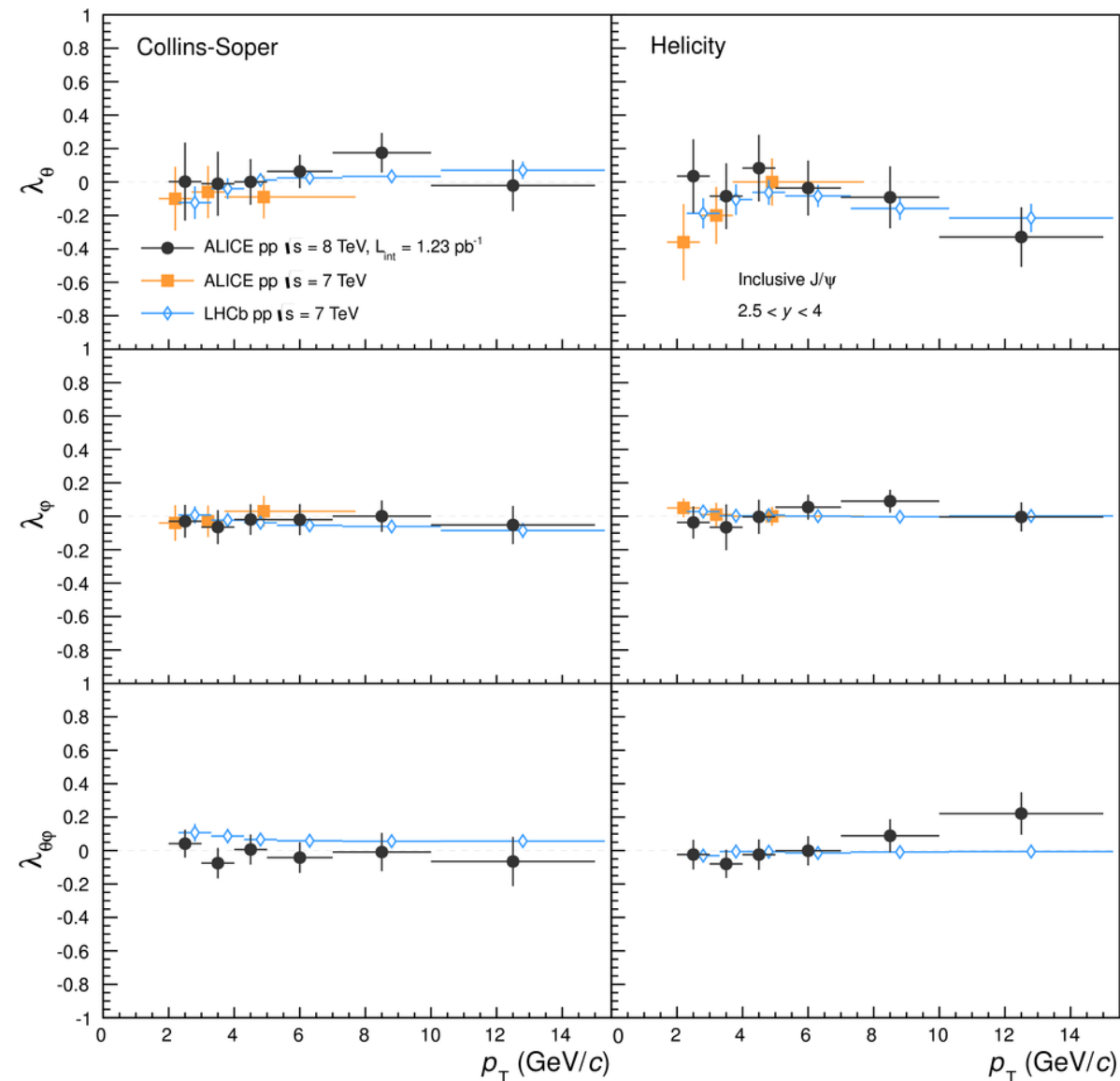
Upgraded:

- TPC
- ITS

New:

- FIT
- MFT

# J/ψ polarization in pp collisions

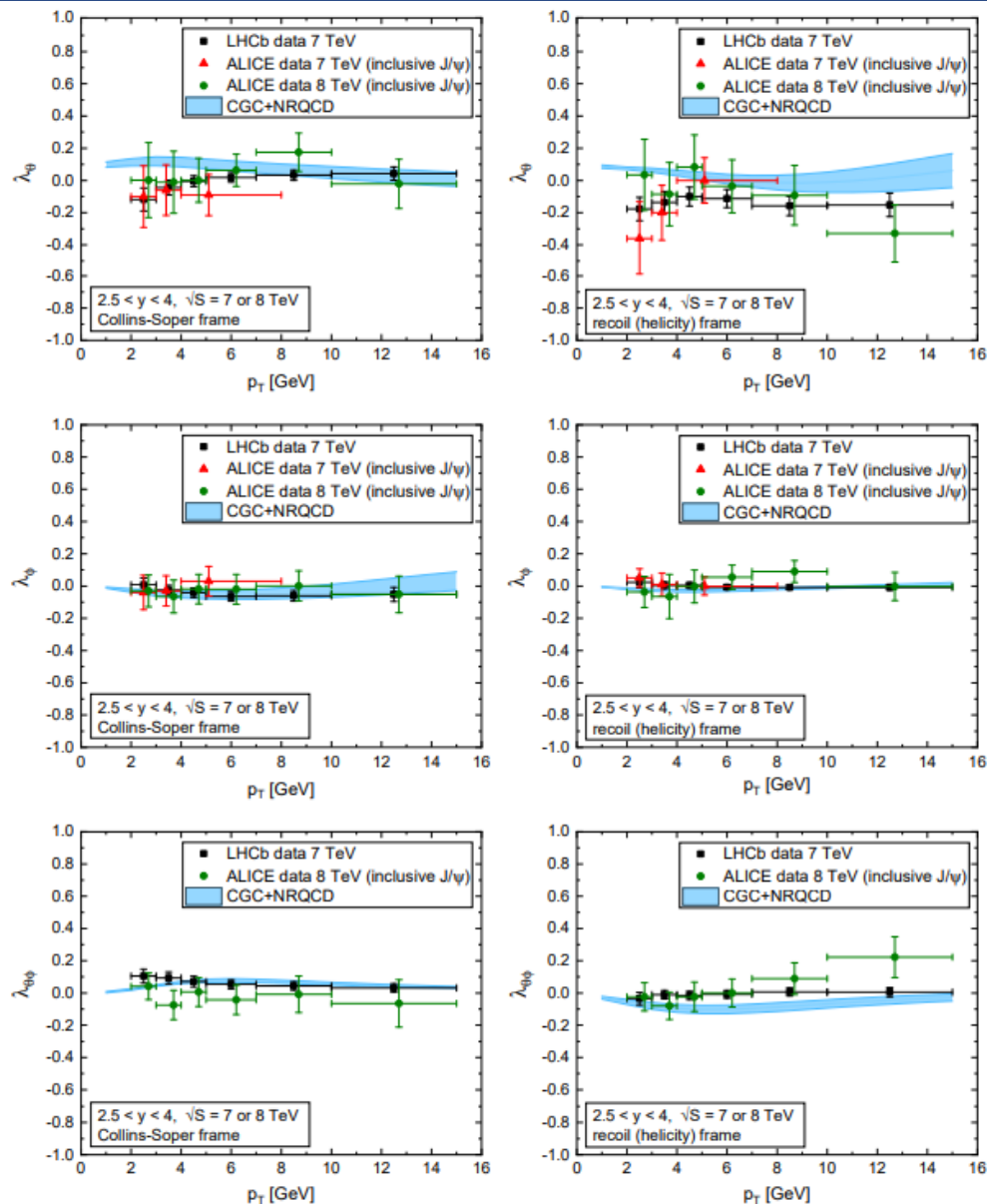


➤ The J/ψ polarization measurements from ALICE at forward rapidity are close to zero up to  $p_T = 15$  GeV/c.

- The measurements from ALICE are compatible to that from LHCb.

- ① ALICE Collaboration, PRL 108, 082001(2012)
- ② ALICE Collaboration, EPJC 78, 562 (2018)
- ③ LHCb Collaboration, EPJC 73, 2631 (2013)

# J/ψ polarization in pp collisions



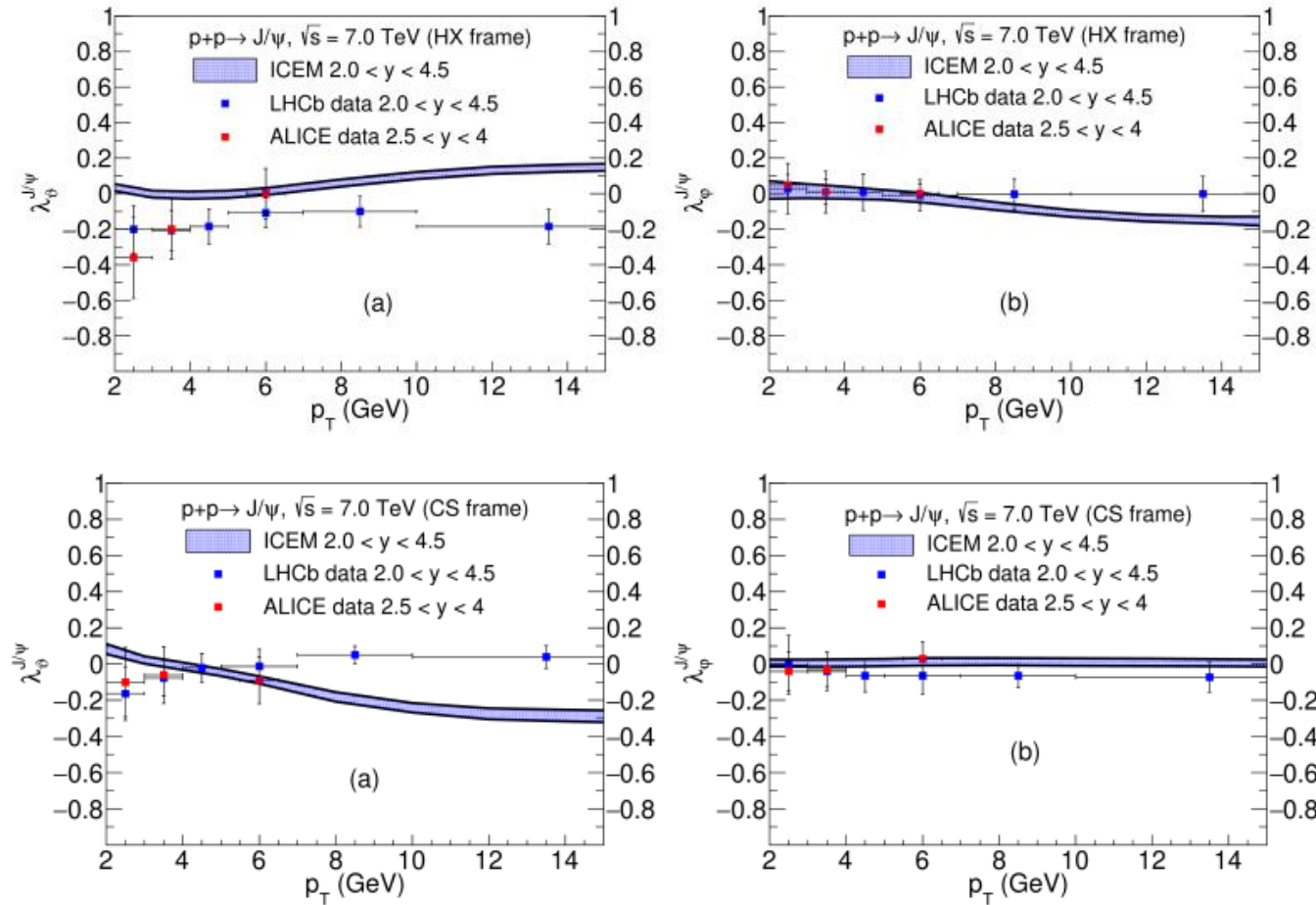
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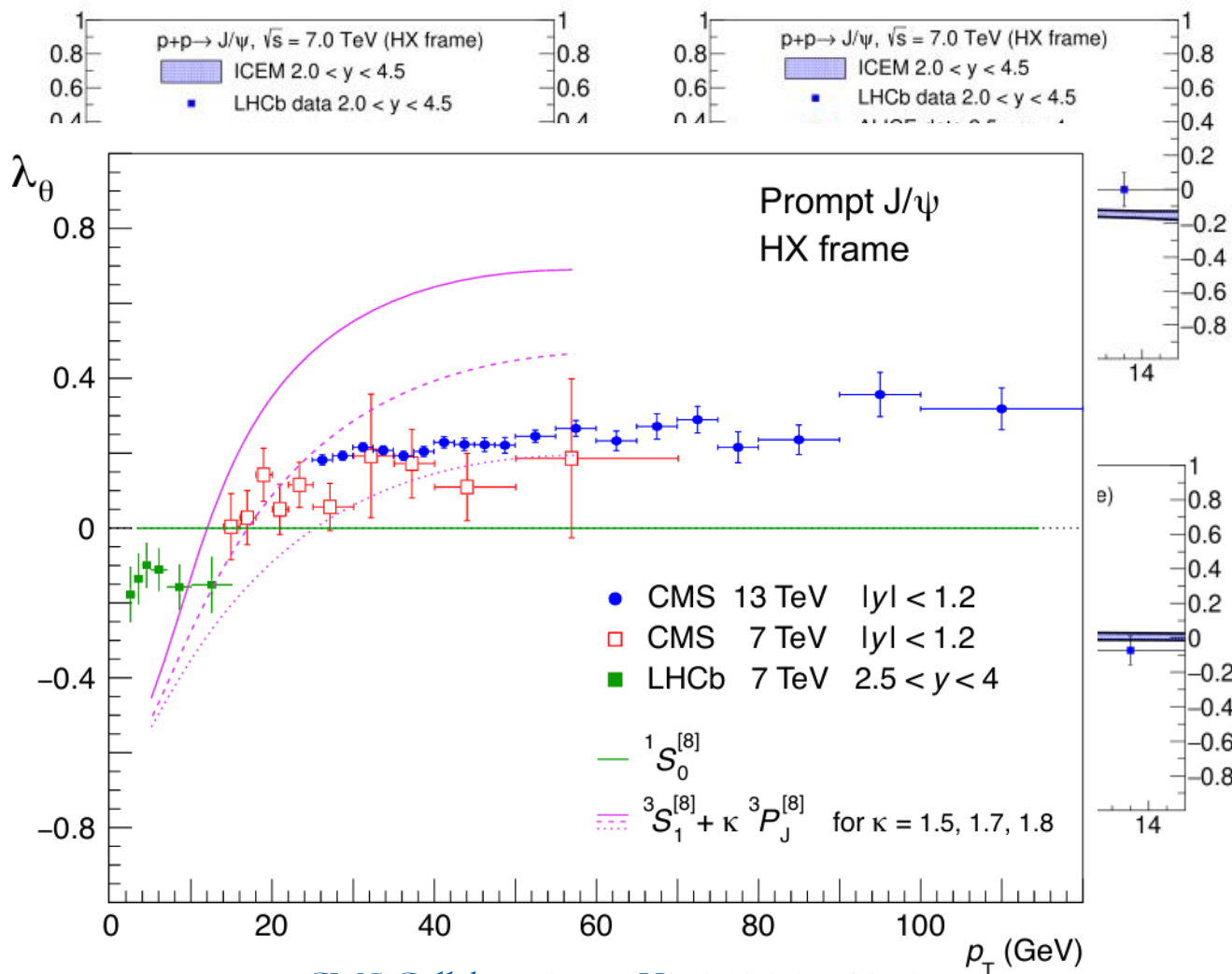
# J/ψ polarization in pp collisions



- The  $J/\psi$  polarization measurements from ALICE at forward rapidity are close to zero up to  $p_T = 15$  GeV/c.
  - The measurements from ALICE is compatible to that from LHCb.
- The CGC + NRQCD can describe data well.
- The ICEM predicts a small  $J/\psi$  polarization but the trend of  $\lambda_{\theta}$  is the opposite to the measured one..

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# J/ψ polarization in pp collisions

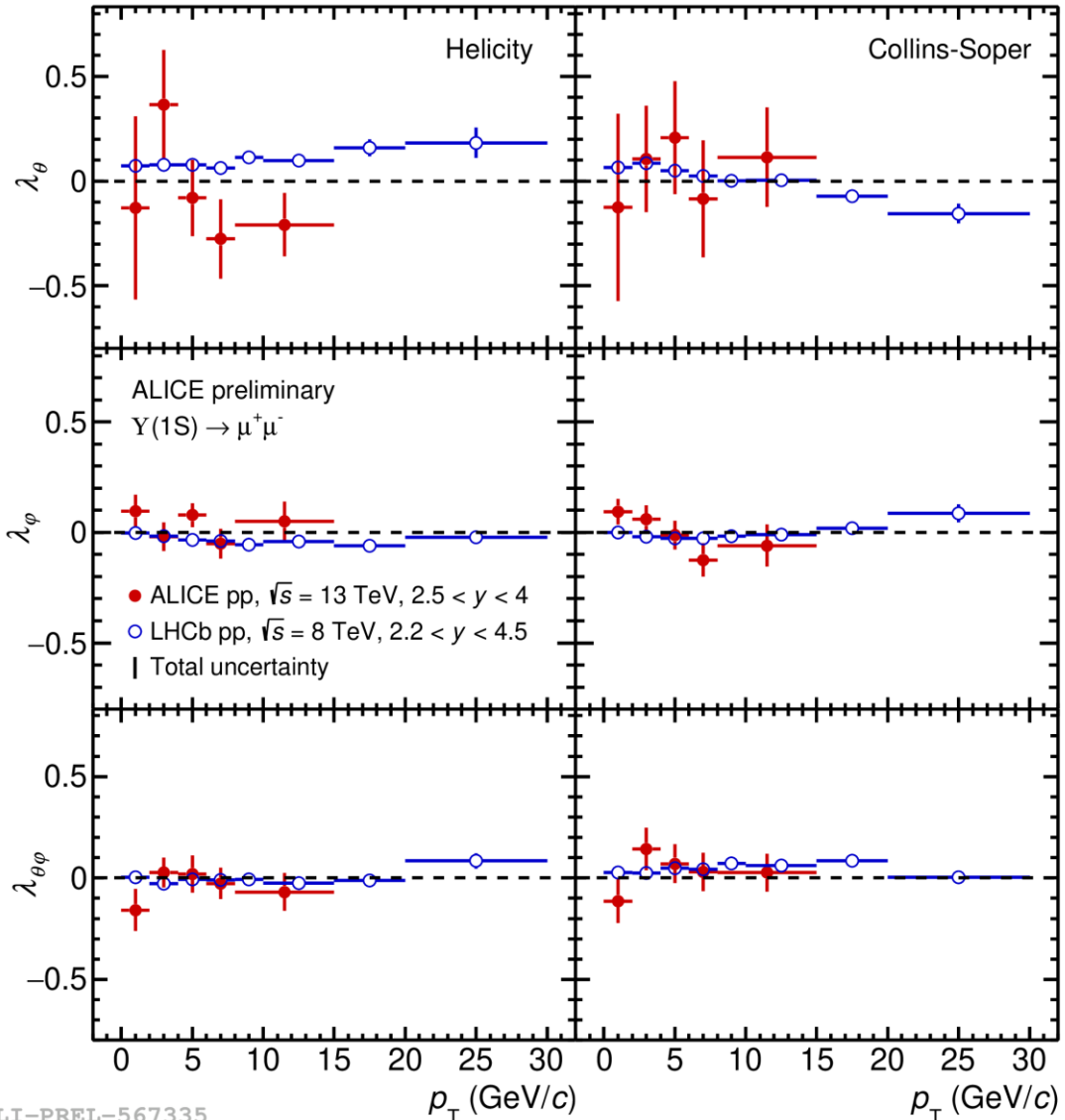


CMS Collaboration, arXiv:2406.14409v1

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  - The measurements from ALICE is compatible to that from LHCb.
- The CGC + NRQCD can describe data well.
- The ICEM predicts a small J/ψ polarization but the trend of  $\lambda_\theta$  is the opposite to the measured one.
- A new measurement from CMS shows a significant transverse polarization ( $\lambda_\theta \approx 0.2$ ) at  $p_T > 20$  GeV/c.



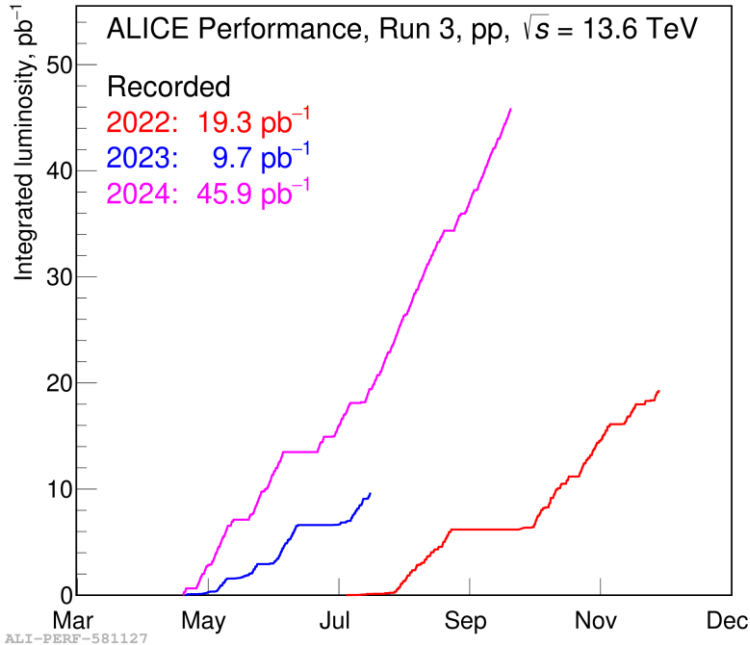
# $\Upsilon(1S)$ polarization in pp collisions



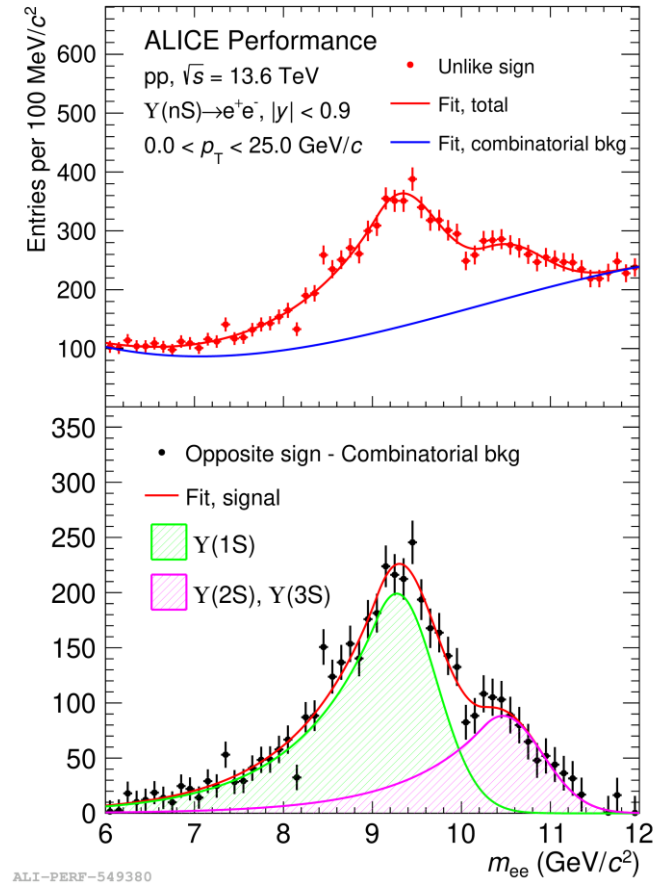
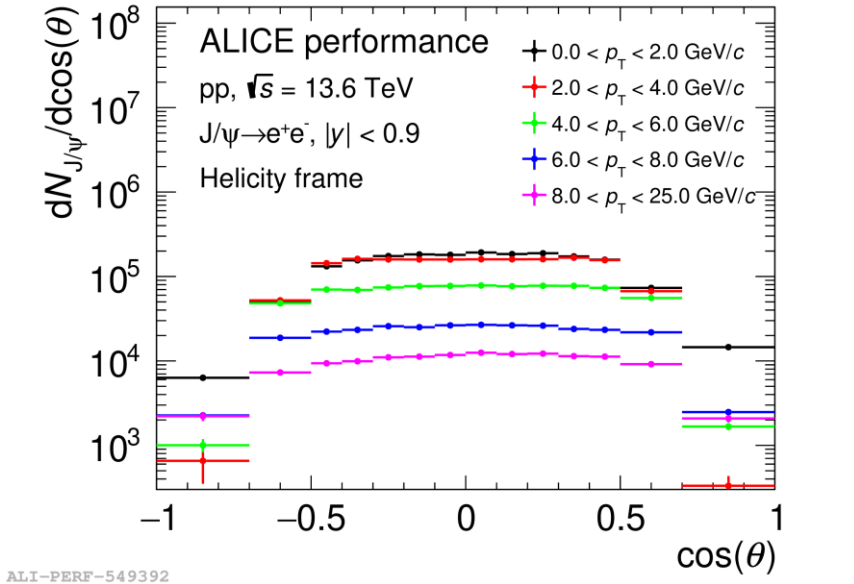
- First measurements of  $\Upsilon(1S)$  polarization at ALICE forward rapidity.
  - All polarization parameters evaluated down to  $p_T = 0$ .
  - All polarization parameters are compatible with zero within uncertainties in HX and CS frames.
- Results compatible within uncertainties with LHCb measurements at  $\sqrt{s} = 8$  TeV.

① LHCb Collaboration, JHEP 12, 110 (2017)  
② Bin Gong, et al, PRL 112, 032001 (2014)

# ALICE Run 3 Performance in pp collisions



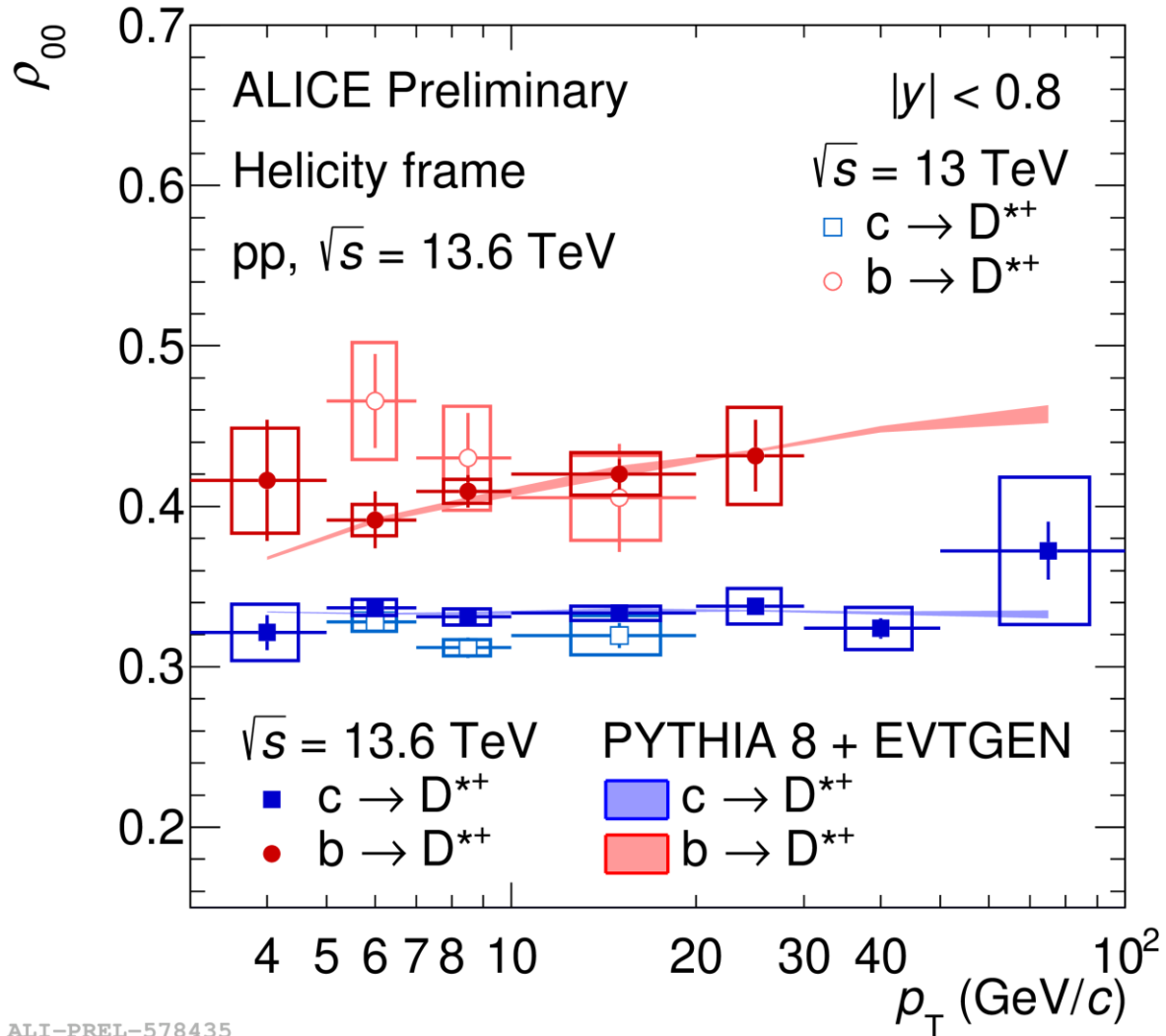
With 2022 data only



- The statistical sample in ALICE Run 3 is  $10^3$  times larger than in Run 2 at midrapidity, thanks to the continuous readout system.
- The increased statistics allow ALICE to measure the polarization of  $J/\psi$  at midrapidity for the first time, in different  $p_T$  and multiplicity region.
- The measurement of  $Y(1S)$  polarization in the midrapidity region may also be possible.

# D<sup>\*+</sup> polarization in pp collisions

**New preliminary !**

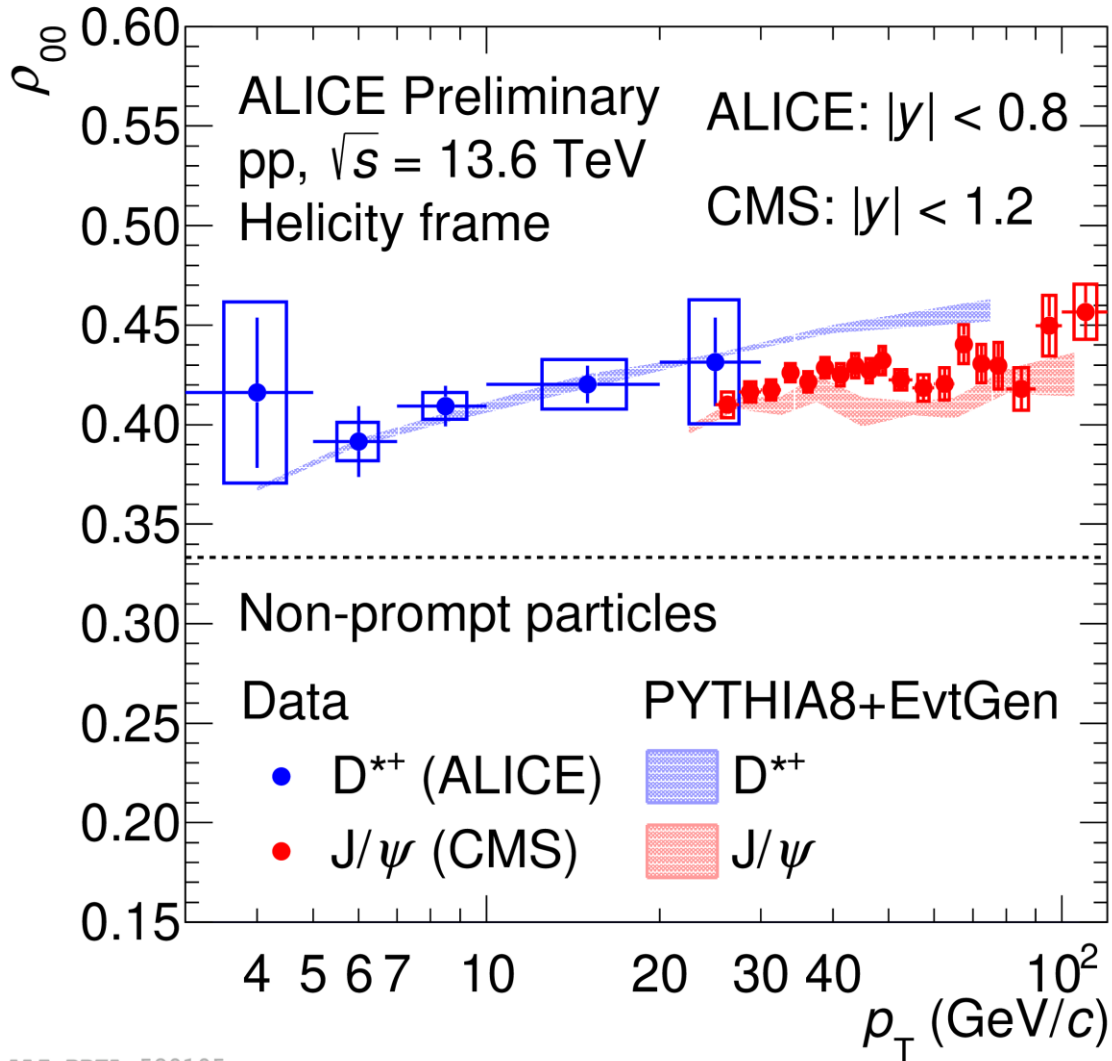


- The prompt D<sup>\*+</sup> polarization measurements from ALICE at midrapidity are close to 1/3 up to  $p_T = 20$  GeV/c.
- The non-prompt D<sup>\*+</sup> polarization measurements shows a transverse polarization ( $\rho_{00} \approx 0.45$ ).

$\rho_{00} > 1/3$  (transverse polarization)  
 $\rho_{00} = 1/3$  (no polarization)  
 $\rho_{00} < 1/3$  (longitudinal polarization)

① ALICE Collaboration, PLB 846 137920 (2023)

**New preliminary !**

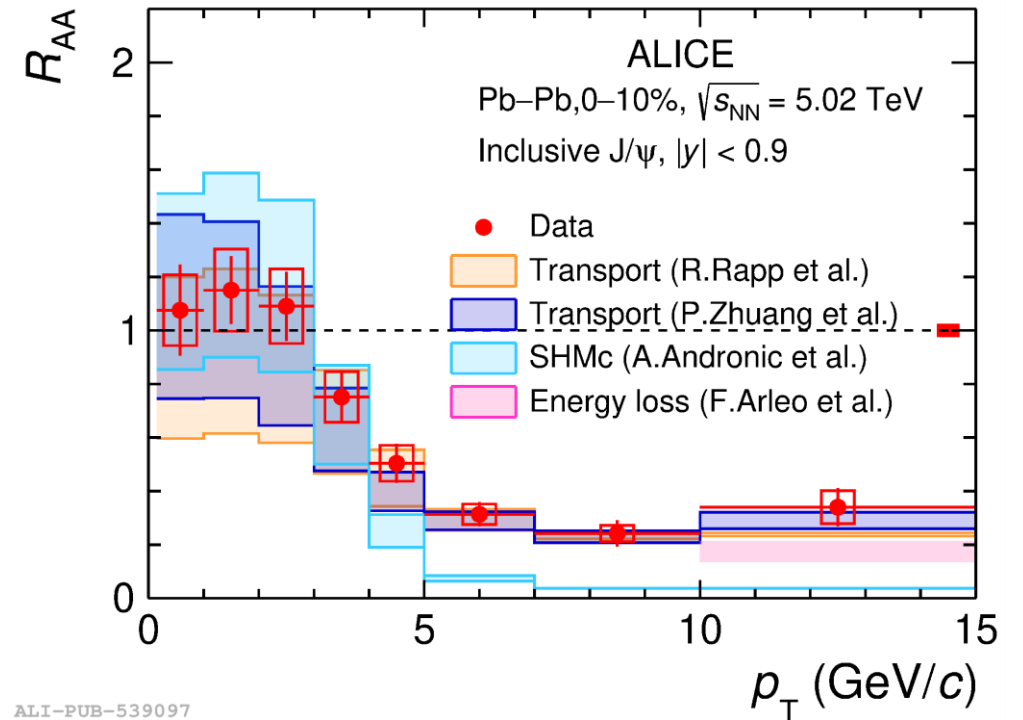
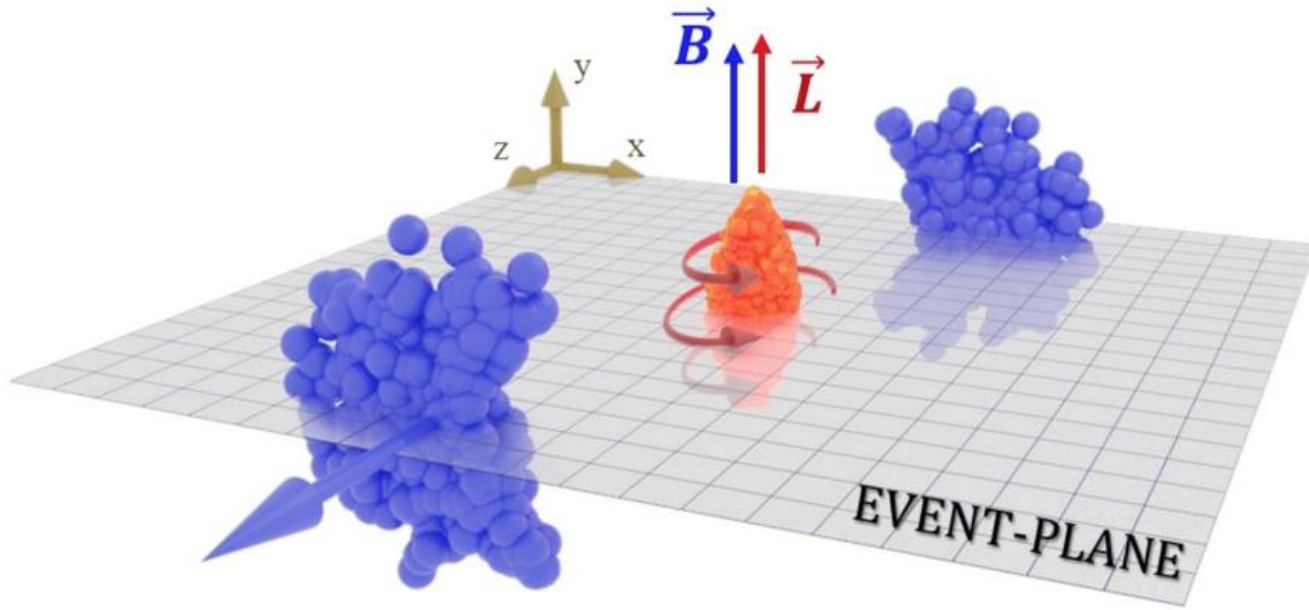


- The prompt D<sup>\*+</sup> polarization measurements from ALICE at mid rapidity are close to 1/3 up to  $p_T = 20$  GeV/c.
- The non-prompt D<sup>\*+</sup> polarization measurements shows a transverse polarization ( $\rho_{00} \approx 0.45$ ).
- The PYTHIA8 + EVTGEN prediction agrees with the ALICE measurement, indicating that the polarization of non-prompt J/ $\psi$  and D<sup>\*+</sup> arises from helicity conversion.

$\rho_{00} > 1/3$  (transverse polarization)  
 $\rho_{00} = 1/3$  (no polarization)  
 $\rho_{00} < 1/3$  (longitudinal polarization)

① ALICE Collaboration, PLB 846 137920 (2023)

# Quarkonium polarization in Pb–Pb collisions

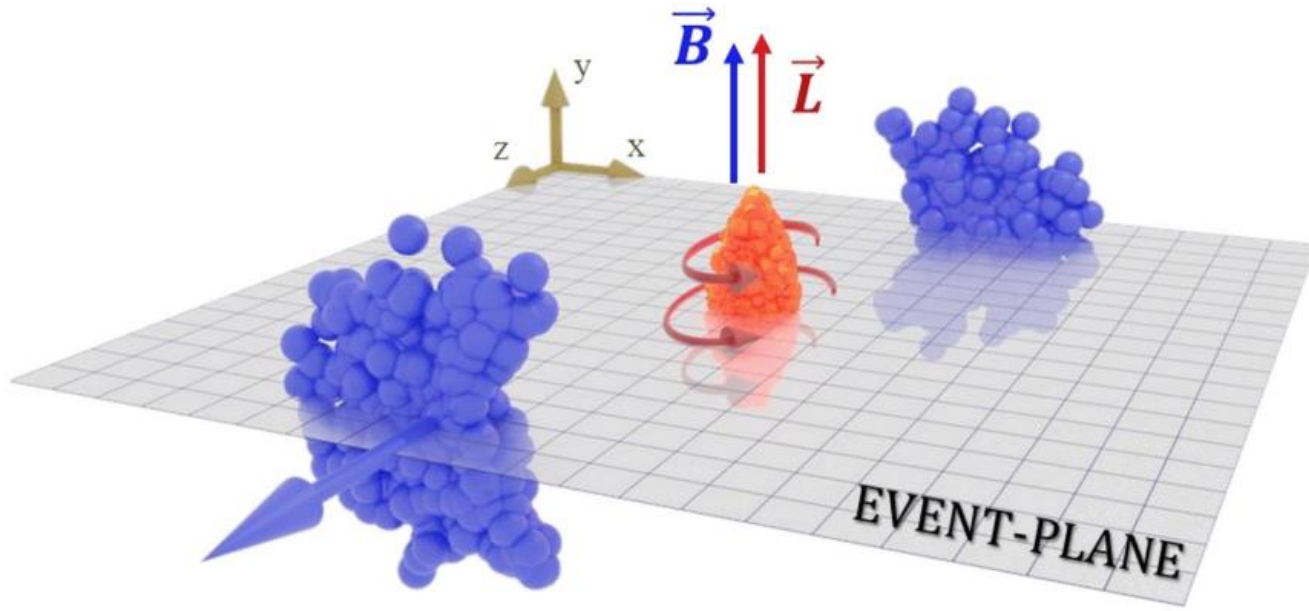


ALI-PUB-539097

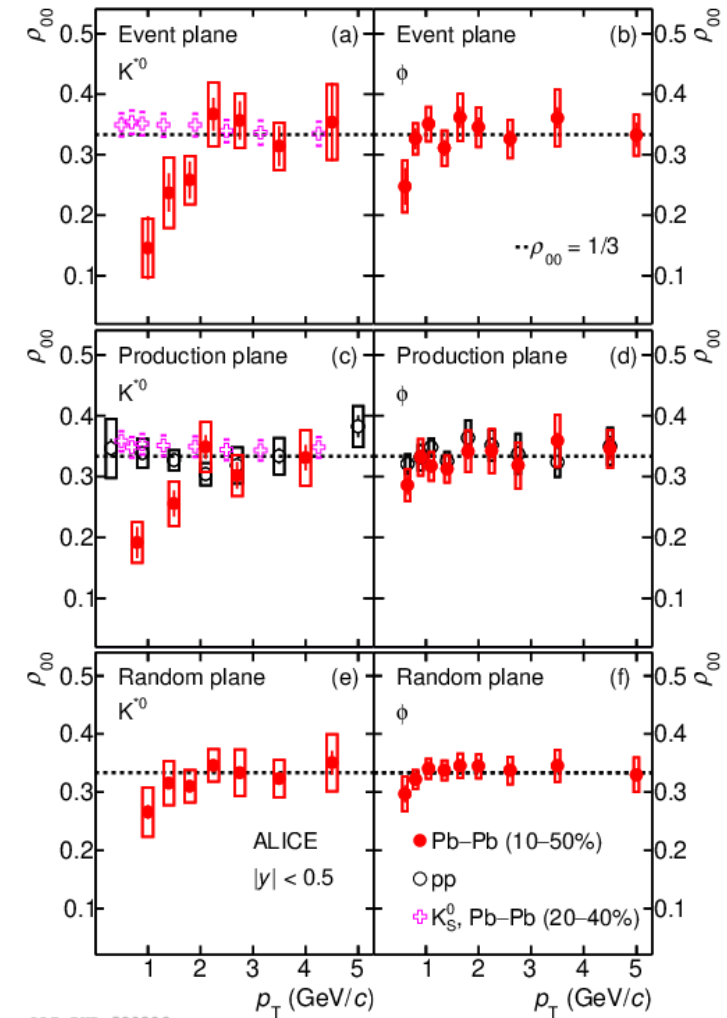
ALICE Collaboration, PLB 849 138451 (2024)

- A deconfined medium (QGP) is created in AA collisions.
- Large angular momentum and huge magnetic field due to the medium rotation is predicted, affecting the spin distribution of quarks thermalized in the medium.
- Contribution of (re)generation and suppression plays an important role at the LHC energies.

# Quarkonium polarization in Pb–Pb collisions

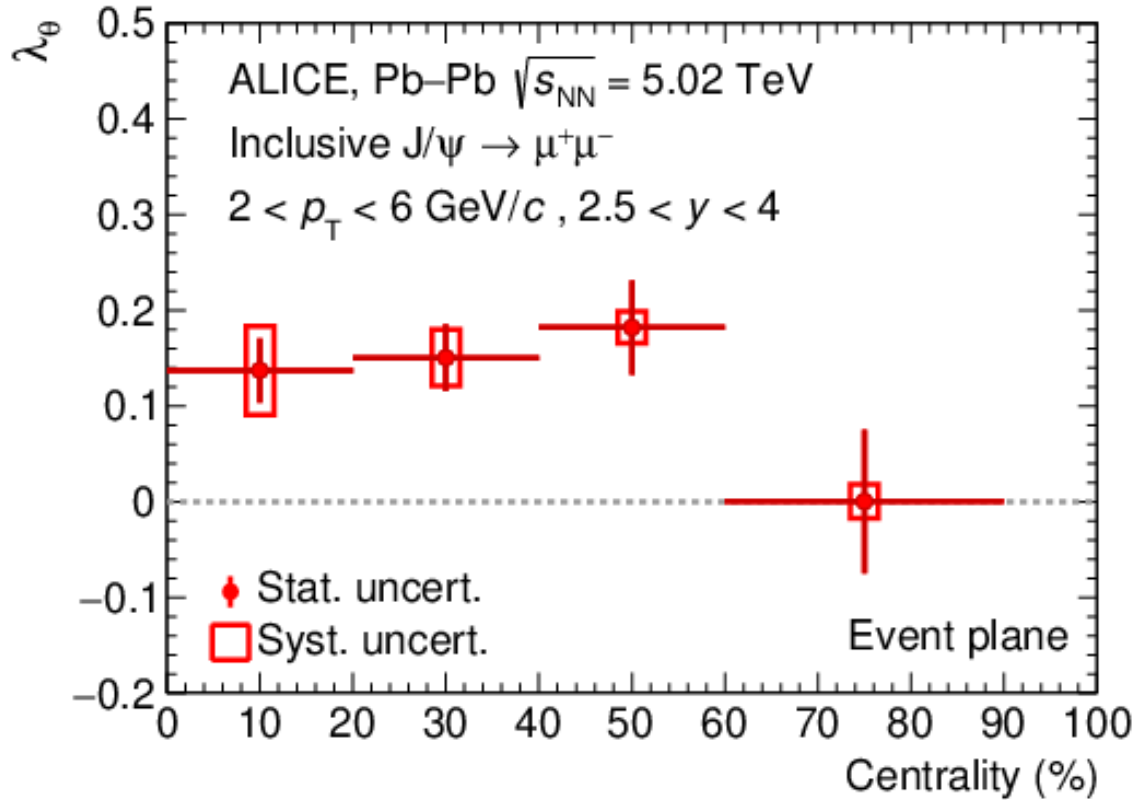


- The event plane, being perpendicular to the angular momentum and magnetic field, is ideal for observing polarization effects.



ALI-PUB-520388

ALICE Collaboration, PRL. 125, 012301 (2020)

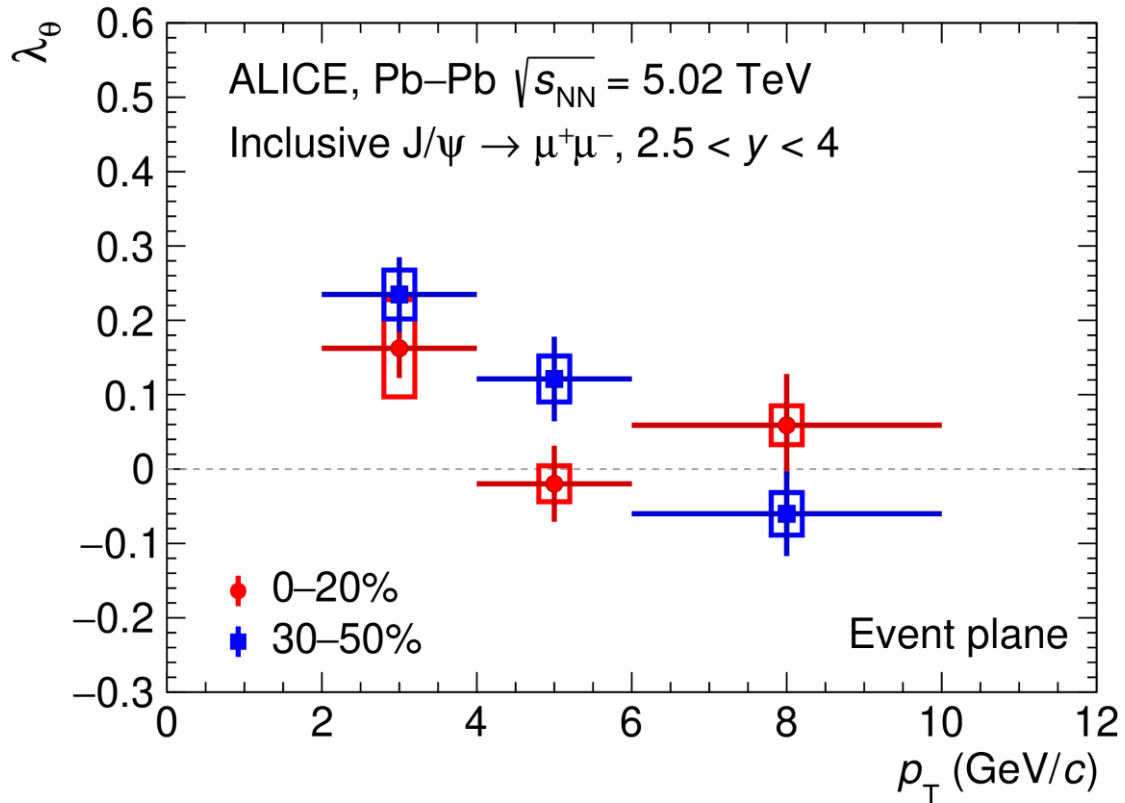


ALI-PUB-521052

## ➤ Centrality dependence

- Small but significant ( $3.5 \sigma$ ) polarization observed in 40-60% and  $2 < p_T < 6$  GeV/c.
- The polarization is compatible with 0 in the 60-90% centrality.

① ALICE Collaboration, PRL. 131 042303 (2023)



ALI-PUB-561315

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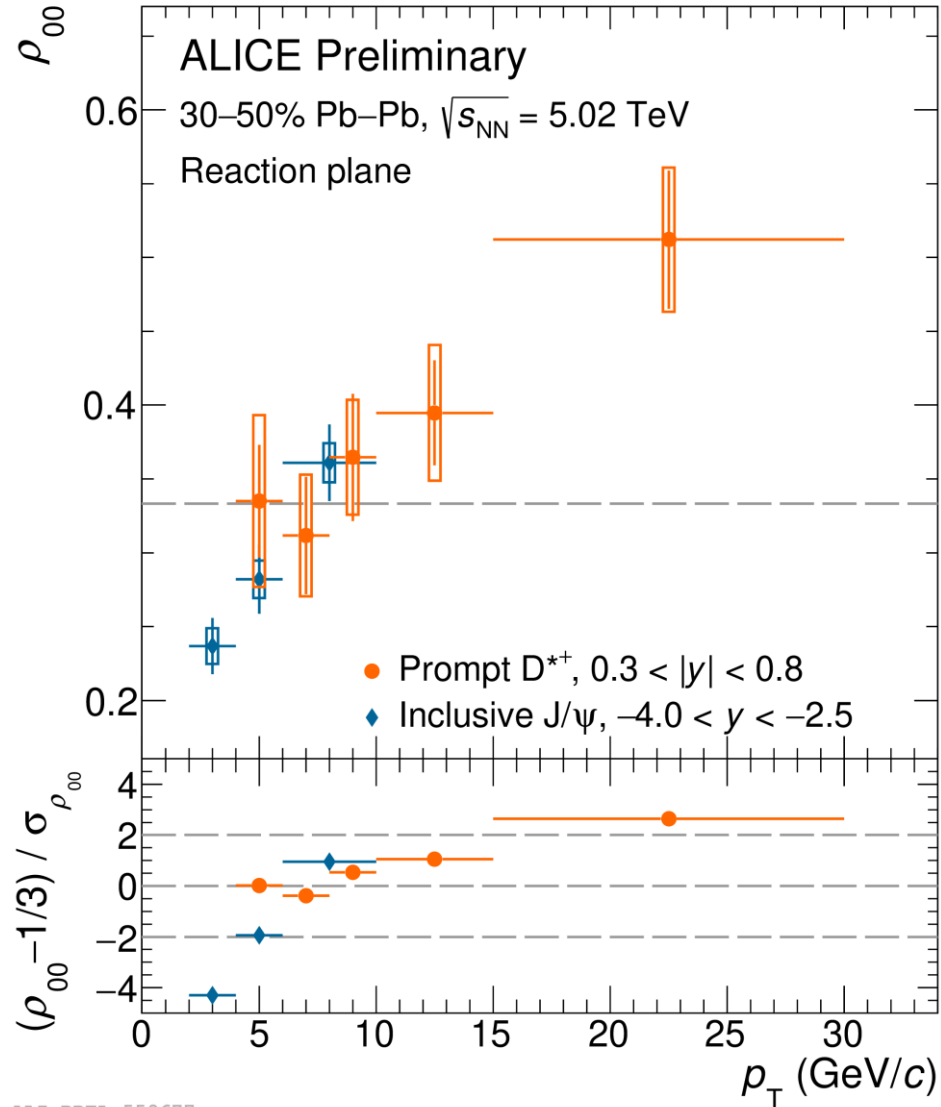
## ➤ $p_T$ dependence

- Significant deviation ( $3.9 \sigma$ ) at low transverse momentum.

① ALICE Collaboration, PRL. 131 042303 (2023)

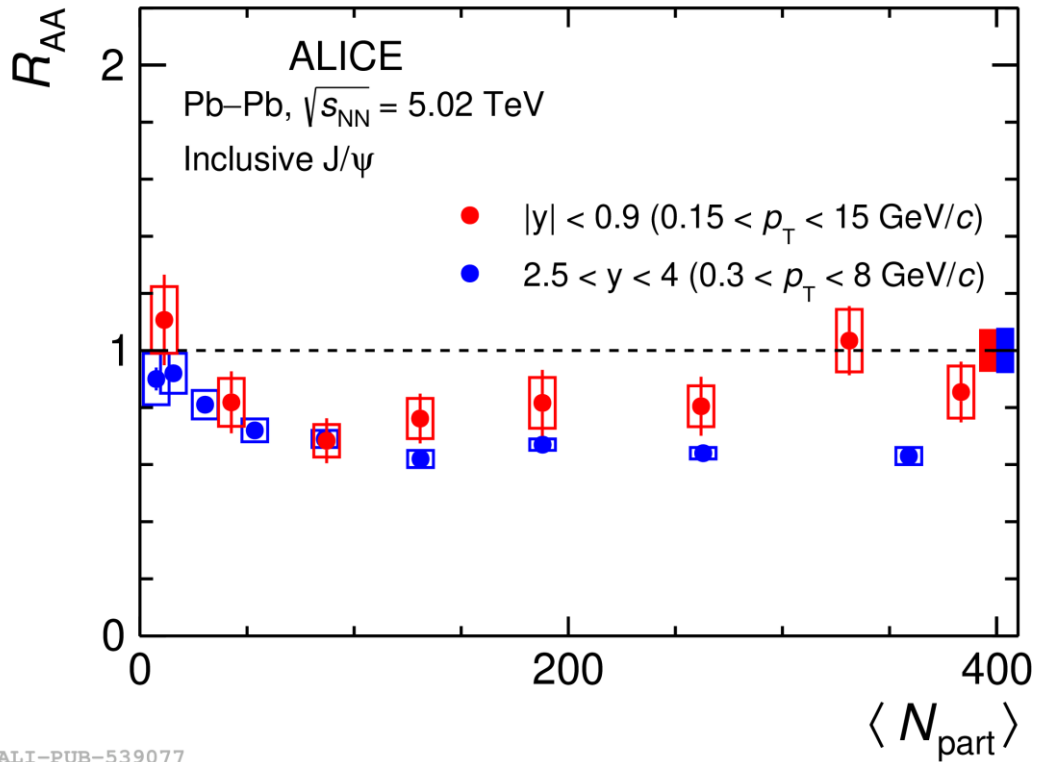


**New preliminary !**



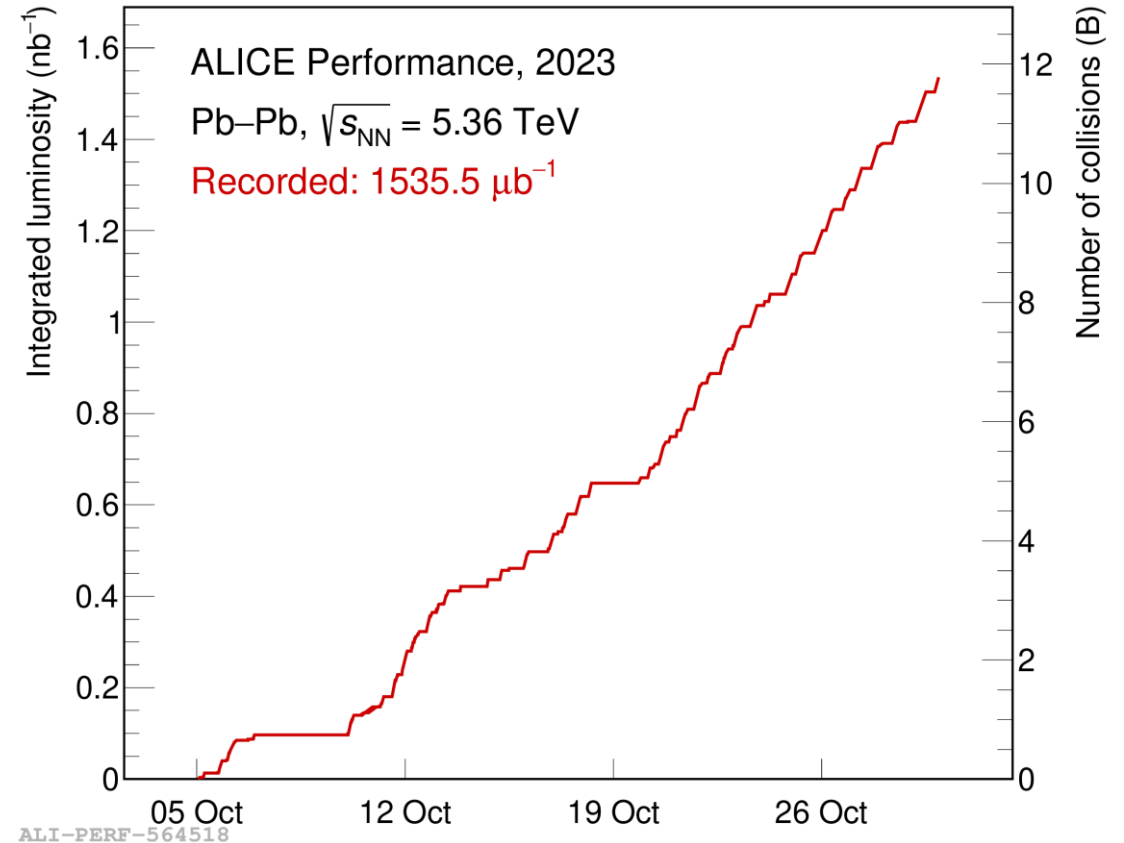
➤ In semi-central collisions, the  $\rho_{00}$  of D<sup>\*+</sup> increases with increasing  $p_T$ .

More detail can be find in  
Mingze's talk (Next)



ALI-PUB-539077

ALICE Collaboration, PLB 849 138451 (2024)



ALI-PERF-564518

- J/ $\psi$  regeneration with a larger contribution at mid-rapidity.
- The statistics from ALICE Run 3 enable the possibility of measuring the global polarization of J/ $\psi$  at mid-rapidity.

- The measurement of  $J/\psi$  and  $\Upsilon(1S)$  polarization in pp does not exhibit polarization up to 15 GeV/c.
- The measurement of  $J/\psi$  global polarization in Pb–Pb shows a significant signal at low transverse momentum and semi-central collisions.
- More precise polarization measurements ( $J/\psi$ ,  $\Upsilon(1S)$ ...) can be expected from the upgraded detector and higher statistics in ALICE Run 3.

*Thank  
You*