

26th International Symposium on Spin Physics

Measurement of the J/ψ polarization in pp and Pb–Pb collisions with ALICE at the LHC

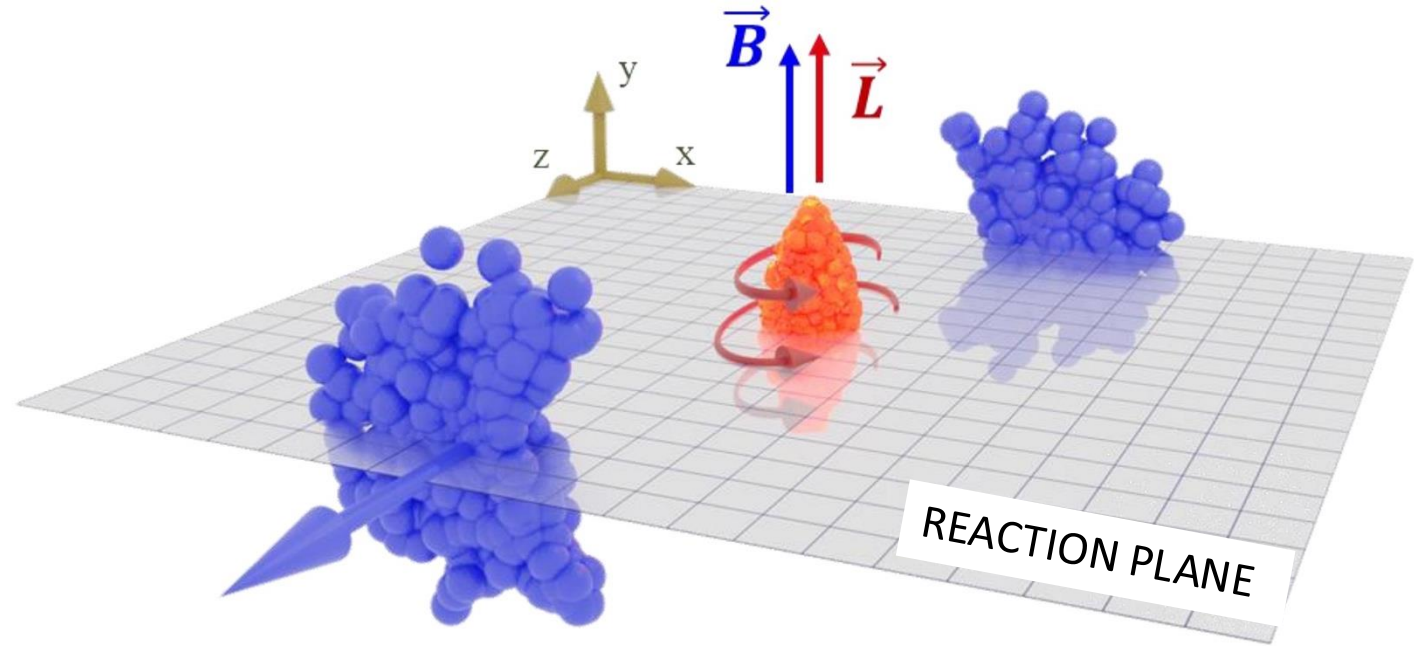
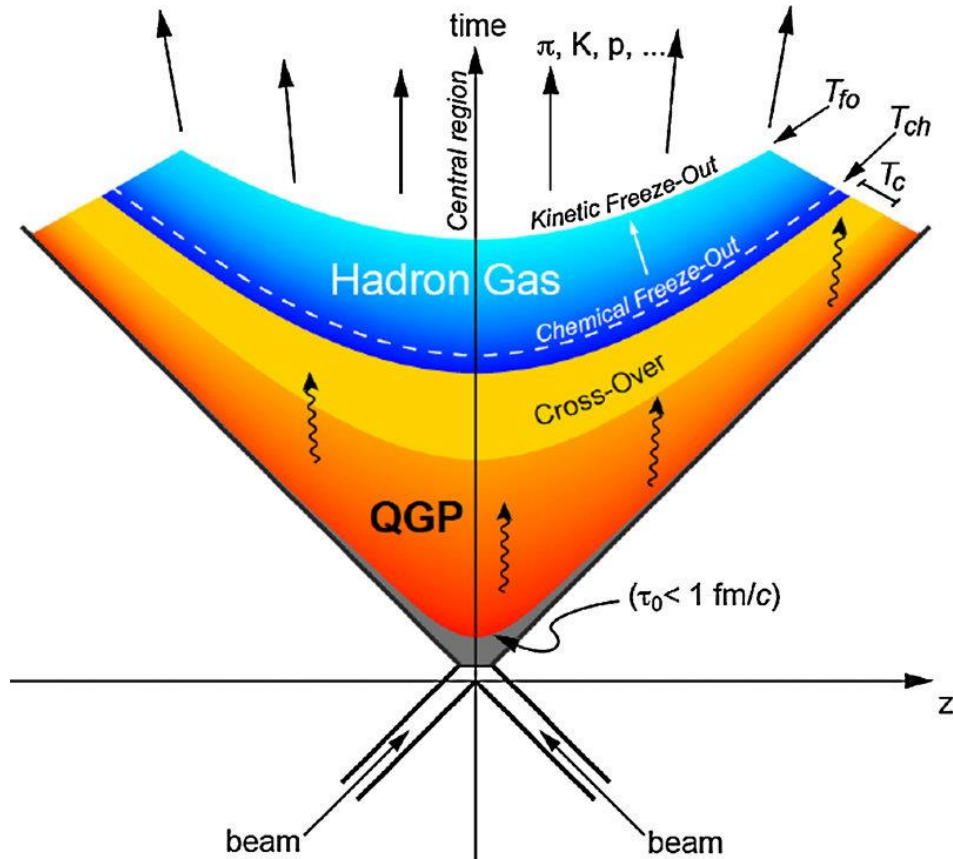
Xiaozhi Bai for the ALICE Collaboration

University of Science and Technology of China

Qingdao, 21-26 Sep. 2025

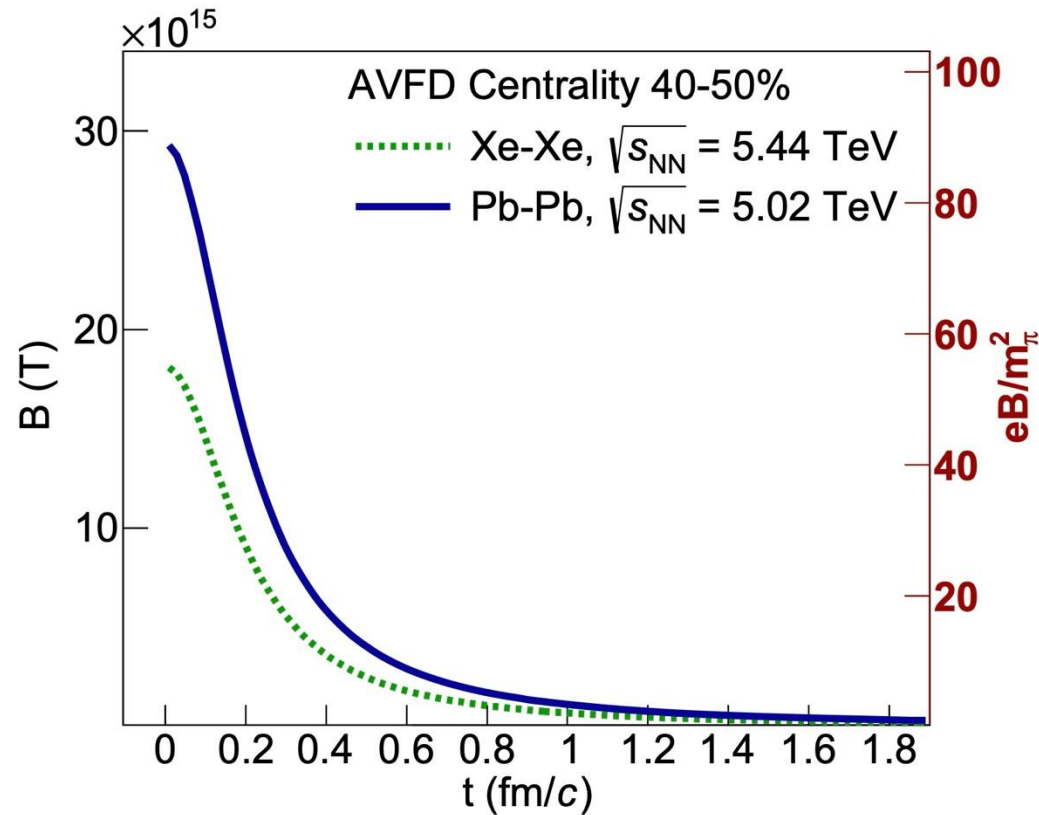


Introduction to heavy-ion collisions

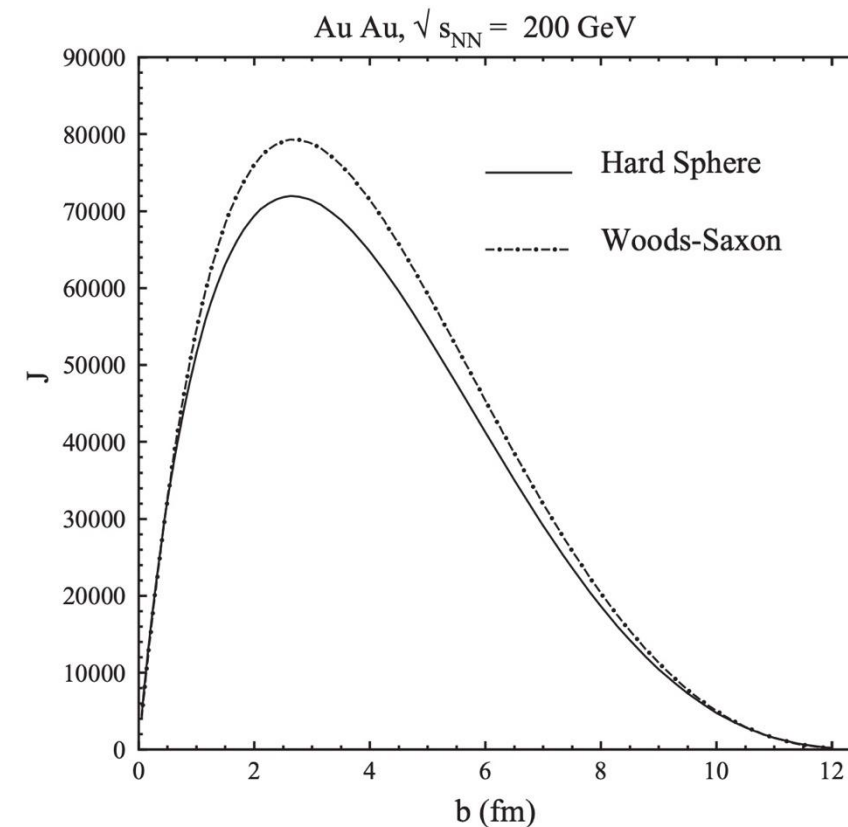


- In non-central heavy-ion collisions, short-lived magnetic fields (\vec{B}) and very strong orbital momentum (\vec{L}) are expected to be produced.
- They can influence the global polarization of the produced particles.

Strong magnetic field and orbital momentum



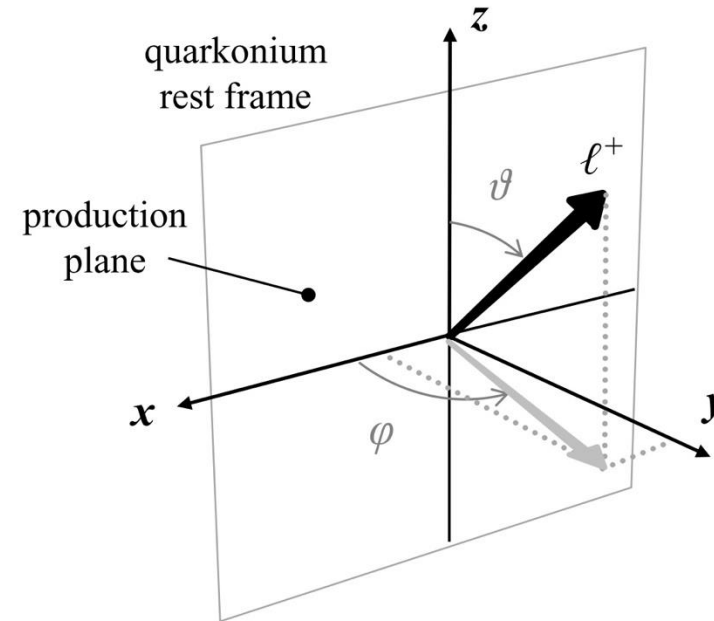
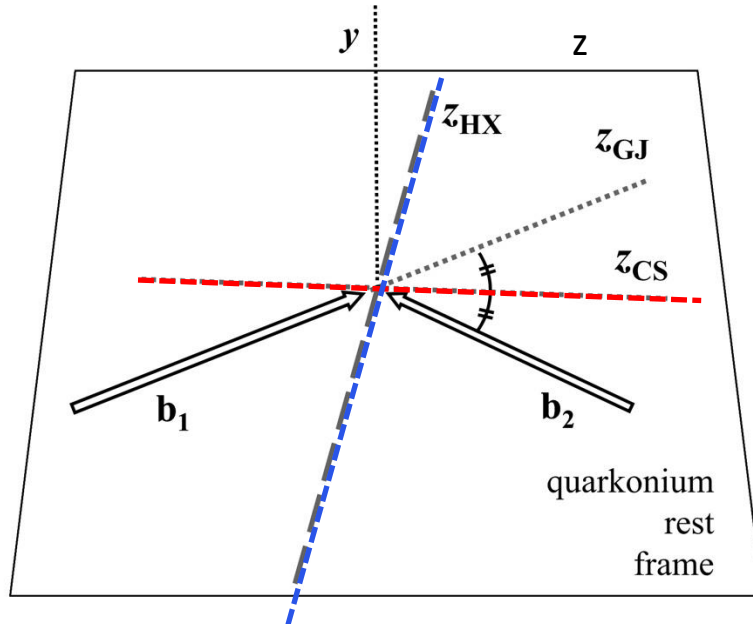
Christakoglu et al., EPJC (2021) 81: 717



F. Becattini et al., PRC 77 (2008)

- The most intense magnetic field in nature! [STAR Collaboration, Nature 548, 62 (2017)]
- Lifetime expected to increase from mid to forward rapidity [Das et al., PLB 768 (2017) 260]
- Angular momentum strongly depends on impact parameter (b)

Introduction to polarization measurements



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

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

Event Plane based frame (EP): axis orthogonal to the reaction plane in the collision center of mass frame

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

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

$\rho_{00} (\lambda_\theta)$ spin density matrix element (polarization parameter)
 $\rho_{00} = 1/3$ ($\lambda_\theta = 0$) no spin alignment

Quarkonium decay to dilepton:

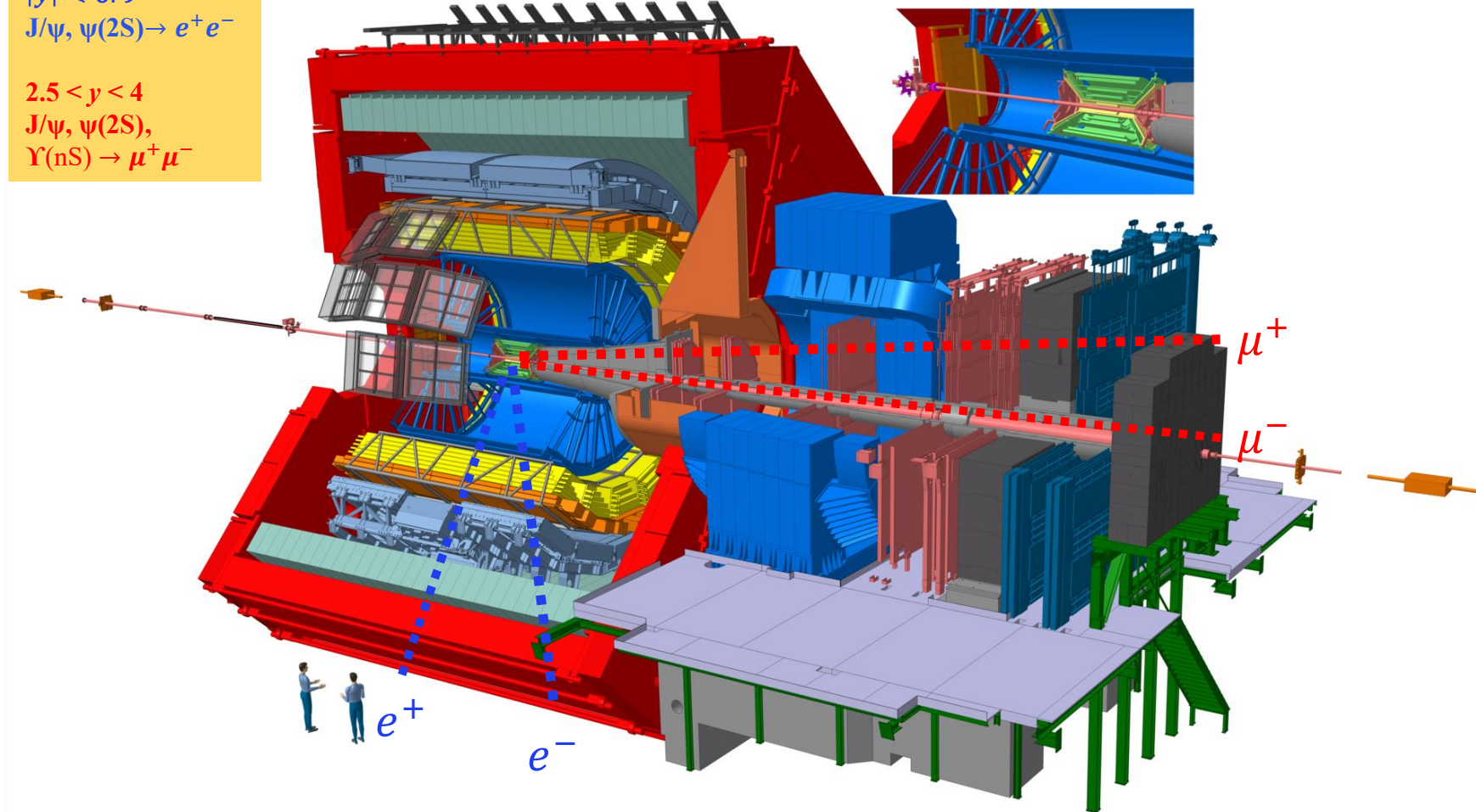
$$\lambda_\theta = \frac{1 - 3\rho_{00}}{1 + \rho_{00}} \quad \begin{cases} \lambda_\theta > 0 \rightarrow \rho_{00} < 1/3 \\ \lambda_\theta < 0 \rightarrow \rho_{00} > 1/3 \end{cases}$$

- **pp collisions:** Important to constrain quarkonium production mechanisms in hadronic collisions
- **AA collisions:** Polarization measurements gives access to different time scales and mechanisms, like the early-produced magnetic field, angular momentum, and hadronization mechanisms.

Z. Liang, X. Wang, PLB 629 (2005) 20-26
 Y. Yang, et al. ,Phys. Rev. C **97**, (2018)034917
 P. Faccioli et al. EPJ C69 (2010) 657-673
 X. Sheng, et al., PRL 131 (2023) 4, 042304

Quarkonium measurements with the ALICE

$|y| < 0.9$
 $J/\psi, \psi(2S) \rightarrow e^+e^-$
 $2.5 < y < 4$
 $J/\psi, \psi(2S),$
 $\Upsilon(nS) \rightarrow \mu^+\mu^-$



Time Projection Chamber
 Tracking, particle identification

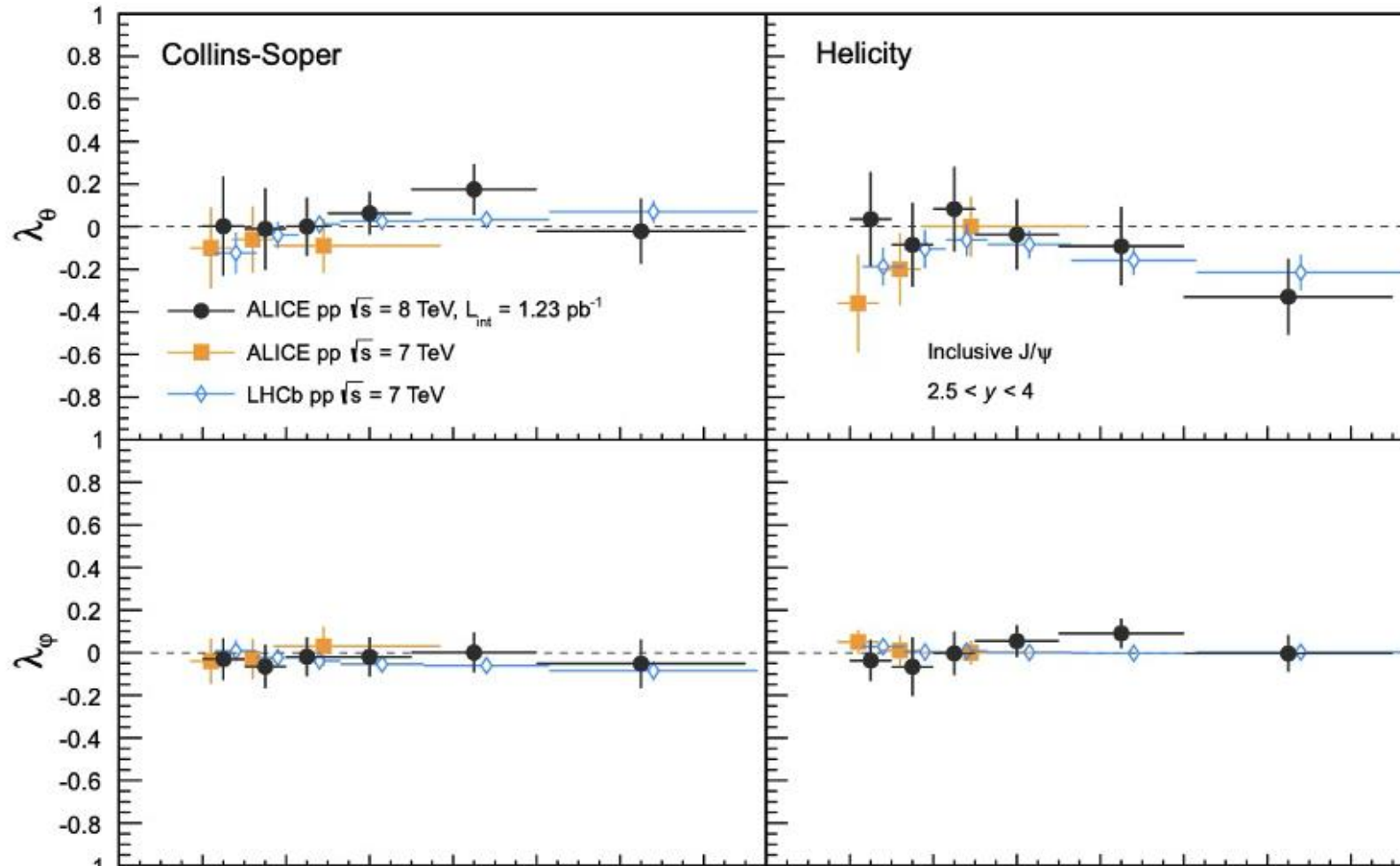
Inner Tracking System
 Tracking, vertex reconstruction, Event plane determination

V0 Detector
 Centrality determination, triggering, event plane determination, and background rejection

Muon spectrometer
 Trigger and tracking for muons

Charmonium measurement down to $p_T = 0$, run 3 upgraded detectors allow to measure the $\psi(2S)$, $\Upsilon(nS)$ at midrapidity

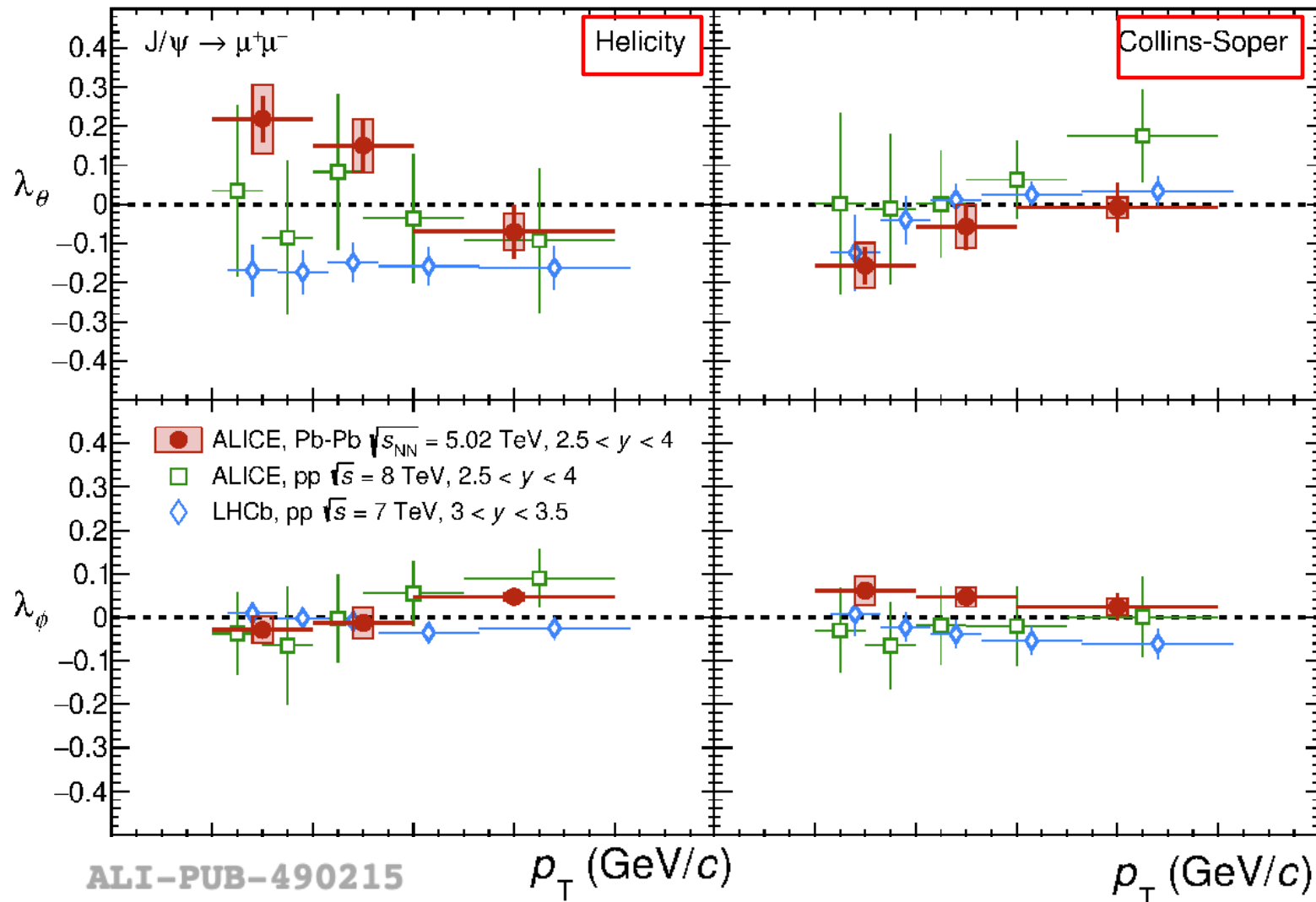
J/ψ polarization measurements in pp collisions



ALICE, PRL 108 (2012) 082001
 ALICE, EPJC 78 (2018) 562
 LHCb, JHEP,12(2017) 110
 LHCb: JHEP 12 (2017) 110

No strong polarization is observed for **J/ψ** and **Υ(1S)** by ALICE at forward rapidity up to $p_T = 15 \text{ GeV}/c$

J/ψ polarization measurements in Pb–Pb collisions



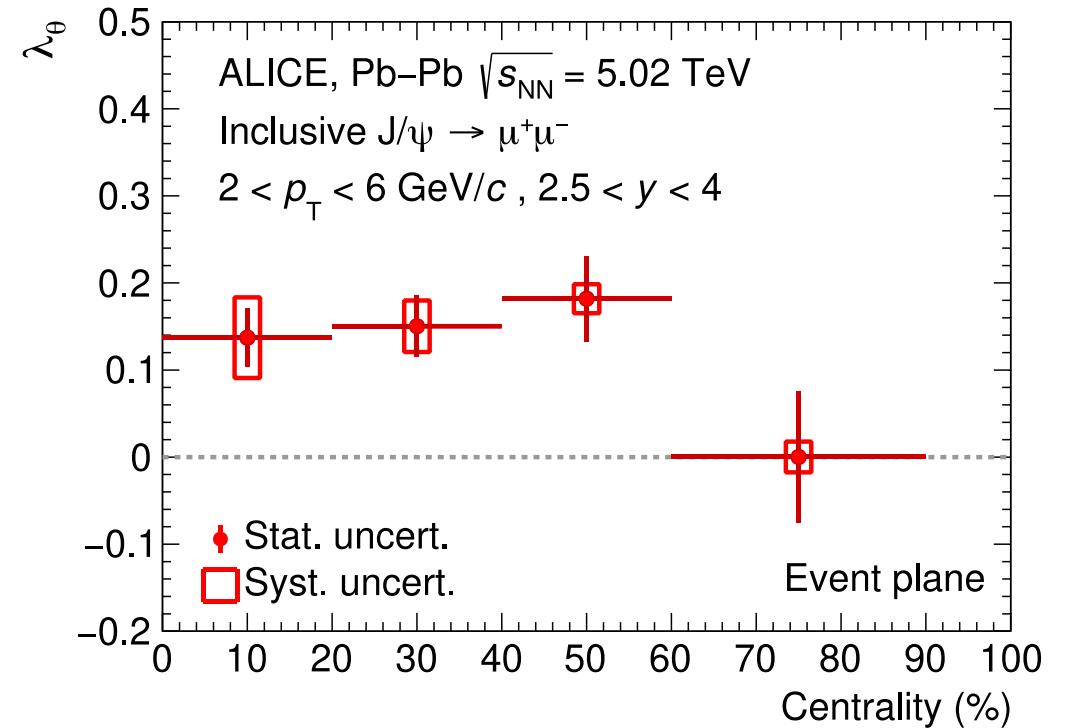
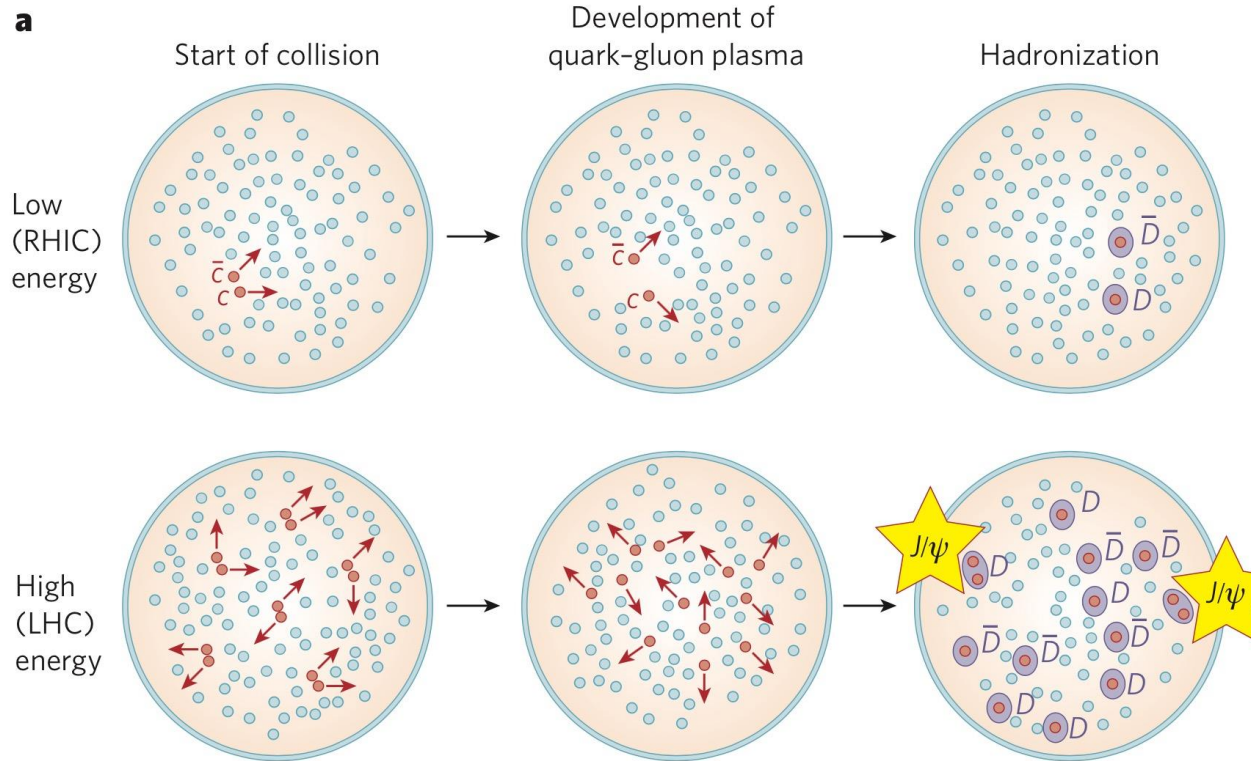
Maximum deviation from zero is 2.1σ in the low p_T bin for J/ψ in Helicity reference frame

ALICE, PLB 815 (2021) 136146
LHCb, JHEP12 (2017) 110
ALICE, PLB 815 (2021) 136146

J/ψ (re)generation in Pb–Pb collisions

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

ALICE, PRL 131 (2023) 4, 042303

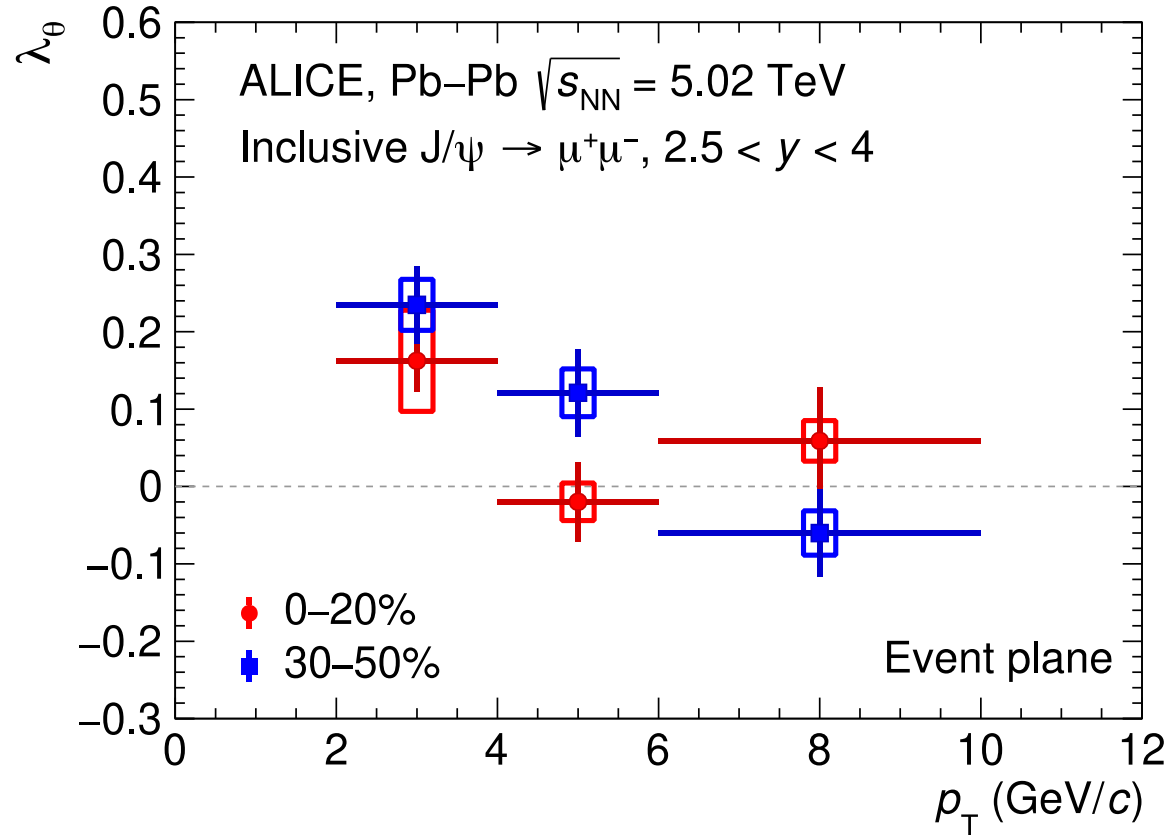


$$W(\cos \theta, \phi) \propto \frac{1}{3 + \lambda_\theta} \cdot (1 + \lambda_\theta \cos^2 \theta + \dots)$$

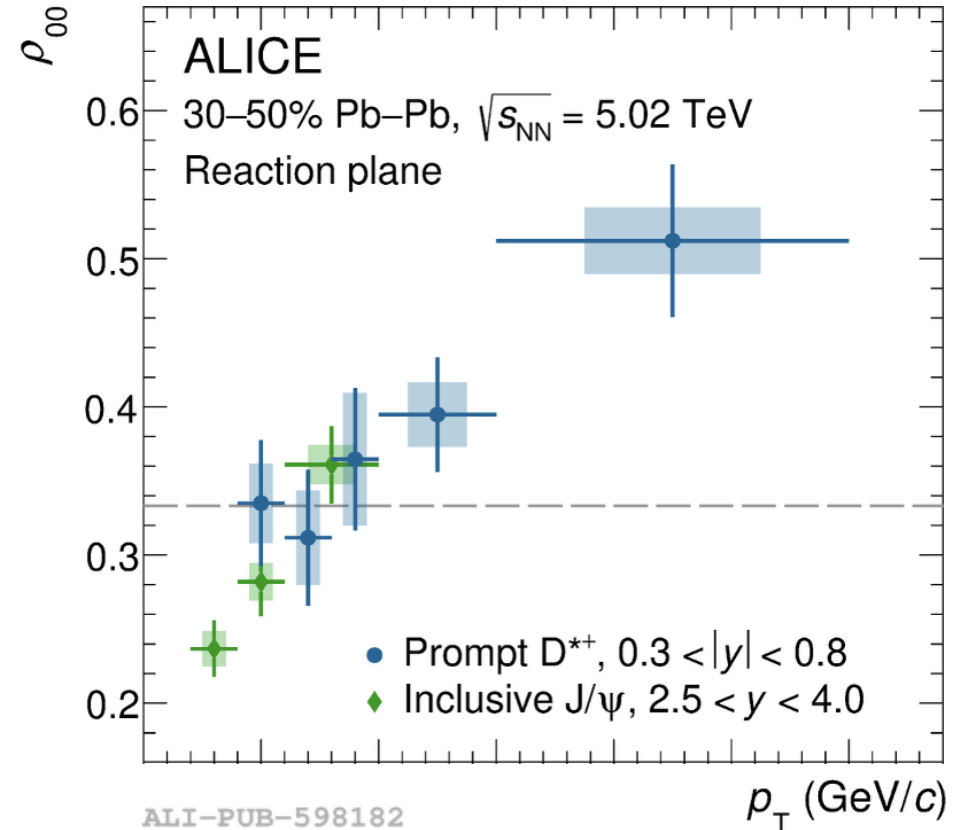
- First measurement of quarkonium polarization **w.r.t the event plane**
- Significant polarization ($\sim 3.9\sigma$) observed in semicentral collisions
- Significant polarization possibly related to the J/ψ from (re)generation, but theory guidance needed

J/ψ and D*⁺ spin alignment in Pb–Pb collisions

ALICE, PRL 131 (2023) 4, 042303



arXiv:2504.00714



➤ Evidence (3.1σ) of spin alignment $\rho_{00} > 1/3$ at $p_T > 15$ GeV/c and $0.3 < |y| < 0.8$

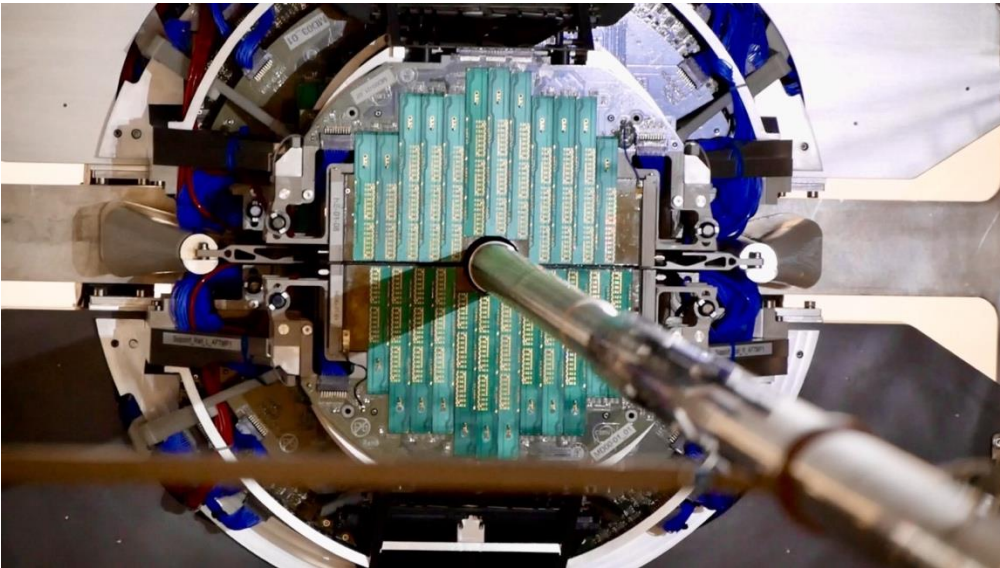
$$\lambda_\theta = \frac{1 - 3\rho_{00}}{1 + \rho_{00}} \quad \begin{cases} \lambda_\theta > 0 \rightarrow \rho_{00} < 1/3 \\ \lambda_\theta < 0 \rightarrow \rho_{00} > 1/3 \end{cases}$$

➤ Inclusive J/ψ seems to feature a common increasing trend at the overlapping p_T (theoretical guidance is needed)

Y. Zhao. JHEP 08 (2024) 070 : see the talk by Defu Hou (Tue 9:25)

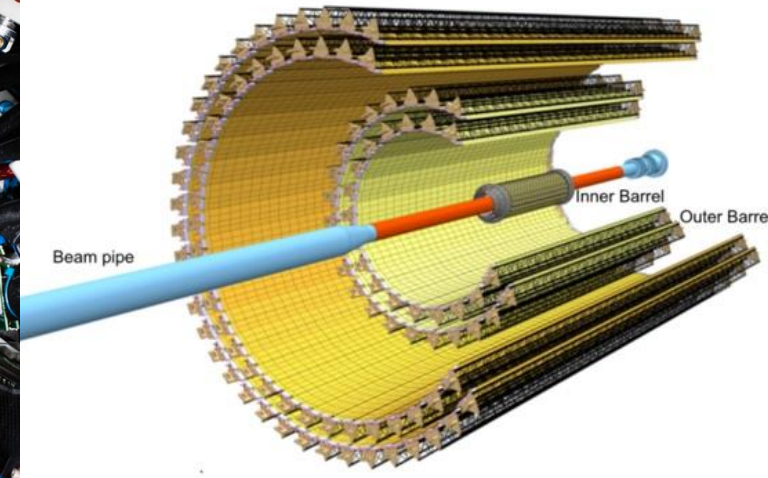
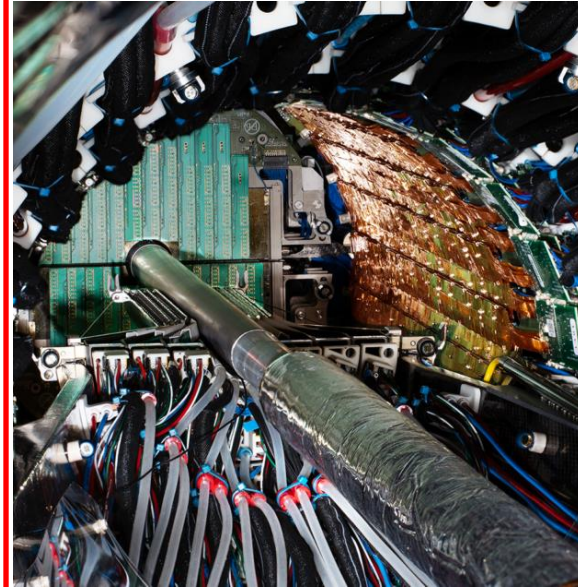
ALICE in Run 3 (MFT and ITS2)

New Muon Forward Tracker

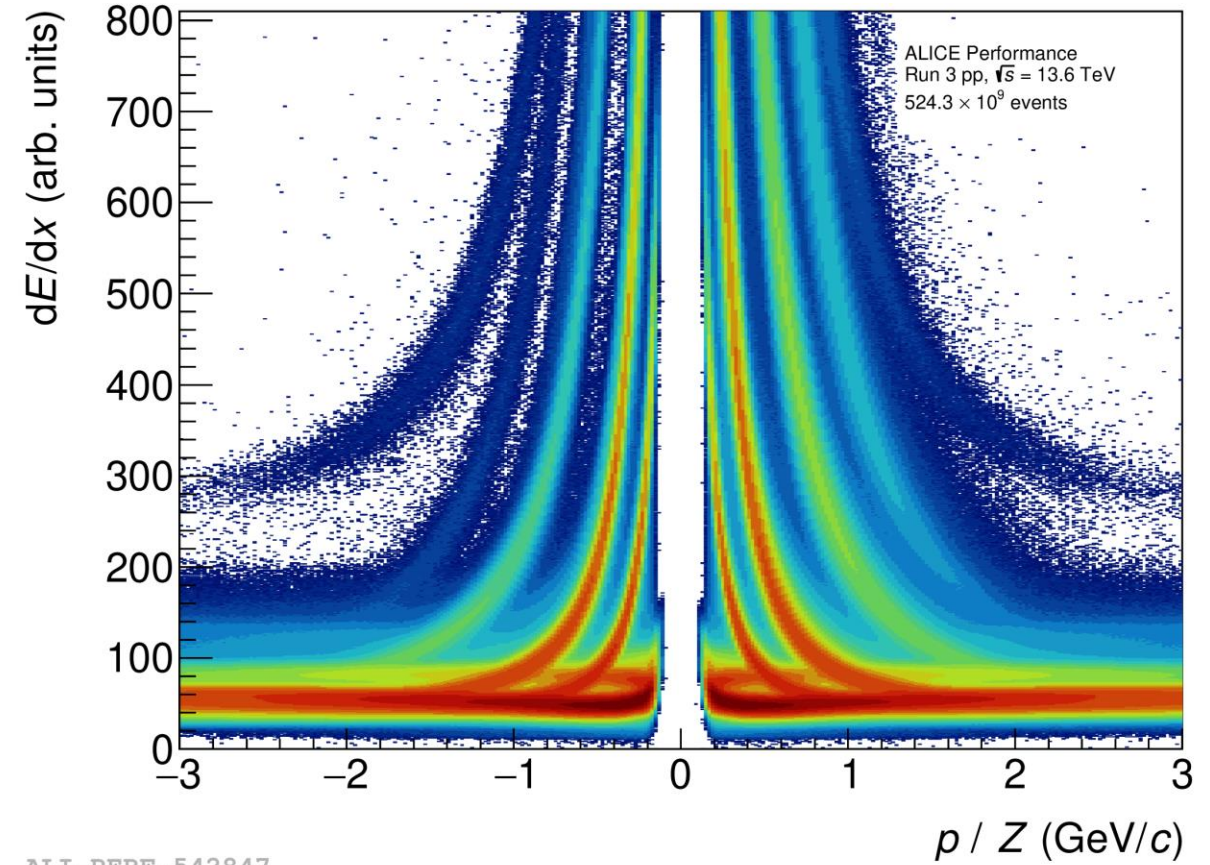
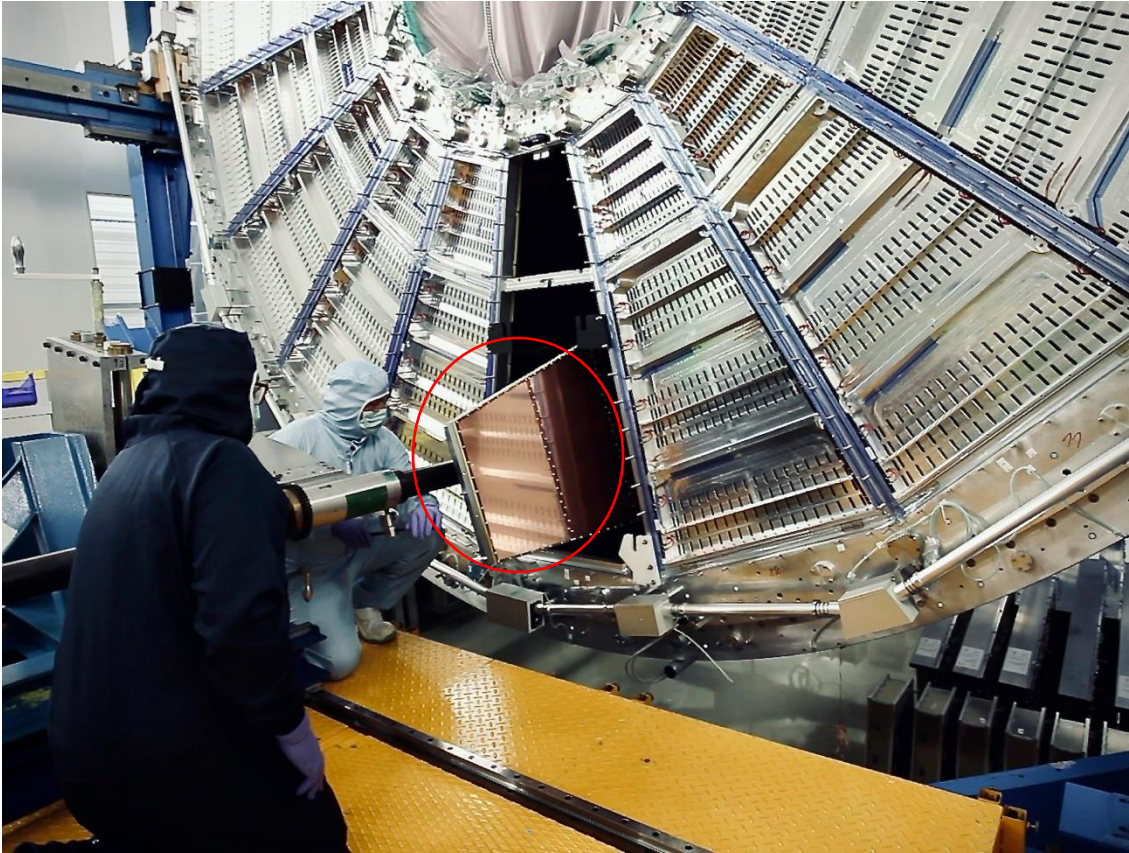


- Monolithic Active Pixel Sensor technology
- Spatial resolution: 5 μm
- Pixel size: 27 μm x 29 μm
- Integration time: 5 μs

Upgraded Inner Tracking System



- 3 layers in inner barrel (IB), 4 in outer barrel (OB)
- Get closer to IP: from 39 mm to 23 mm
- Reduced material budget: from 1.14% X_0 to 0.36% X_0 per layer
- Reduced pixel size: from 50 x 425 μm^2 to 29 x 27 μm^2

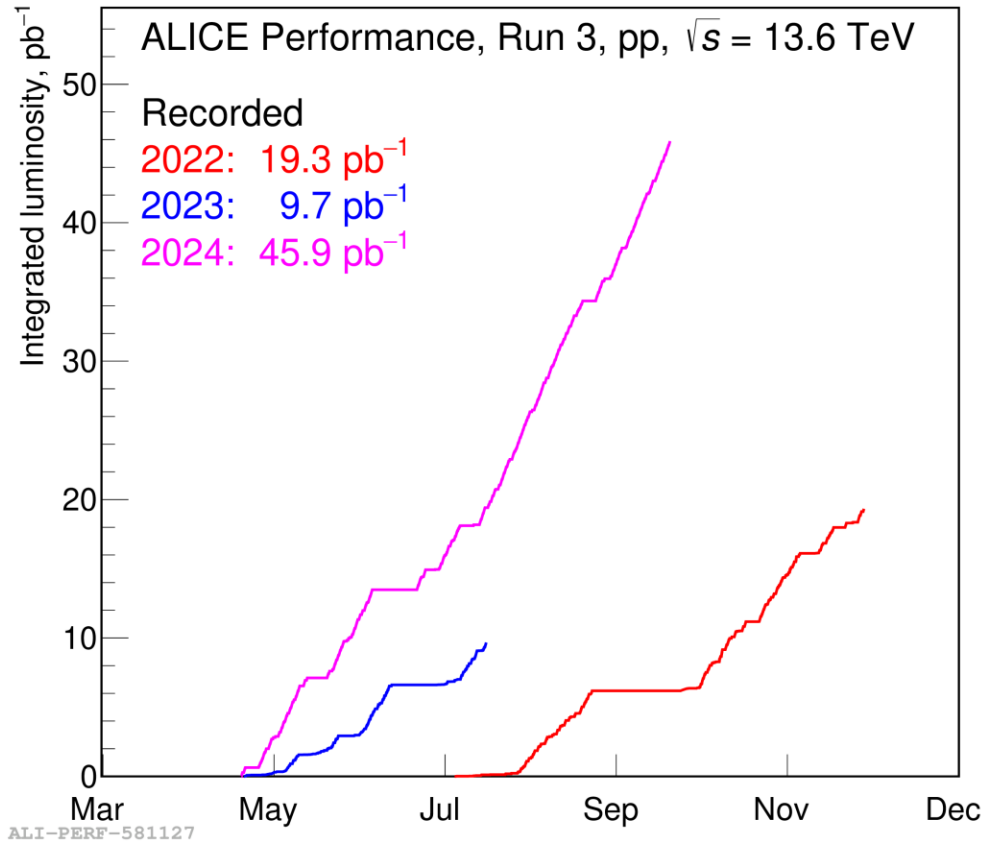


TPC continuous readout (GEM)

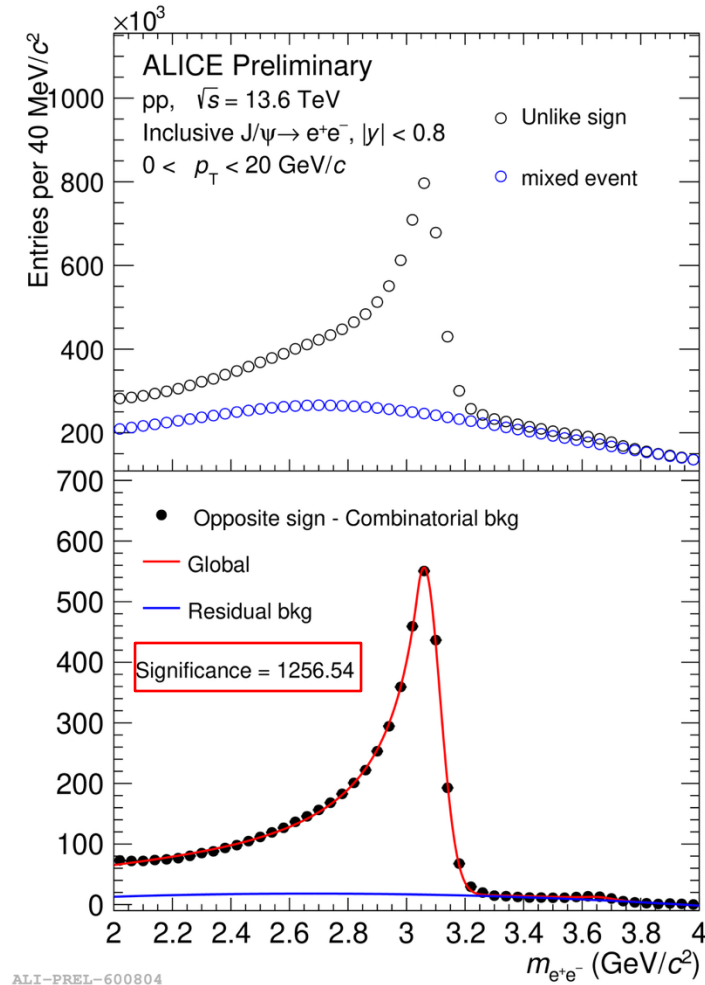
- pp data taking at 500 kHz
- Pb-Pb data taking at 50 kHz

ALICE in Run 3 data taken

pp @13.6 TeV

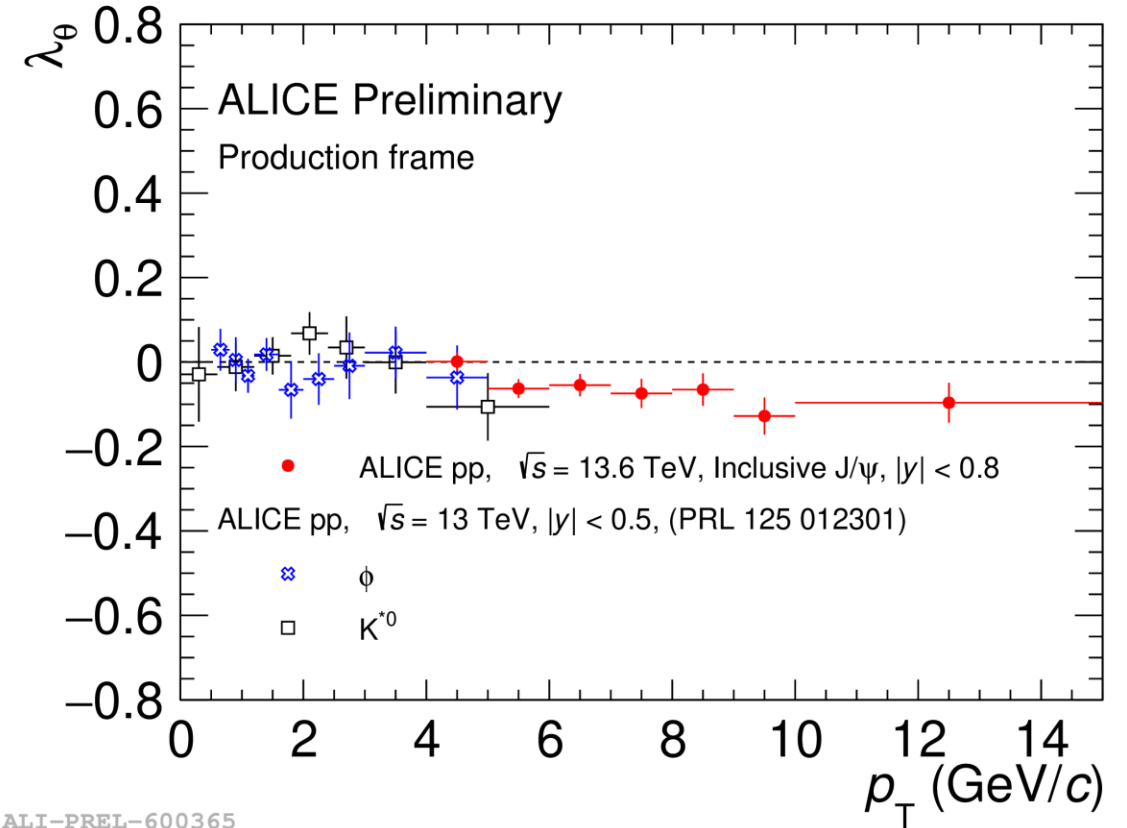
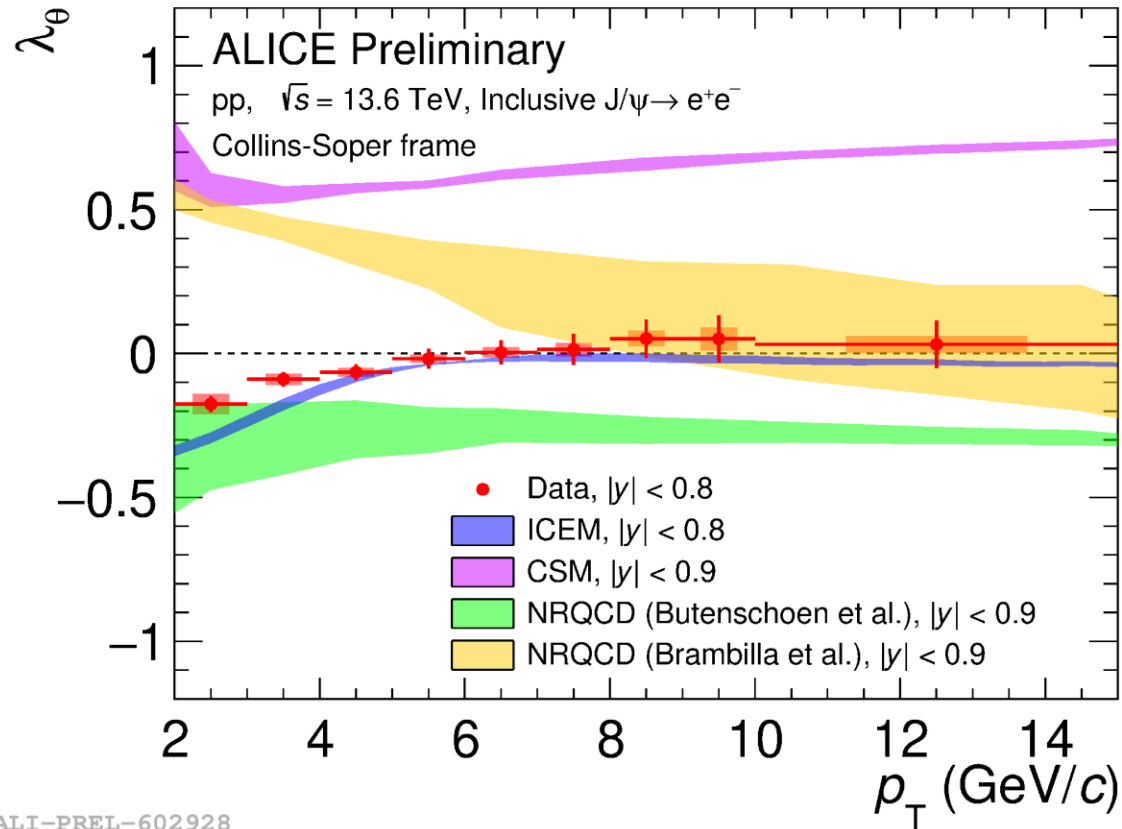


- Record all the minimum bias (MB) events during the data taken
- Collected approx. **2000B MB** events **pp** collisions
- The reconstructed J/ψ significance is **greater than 1200**



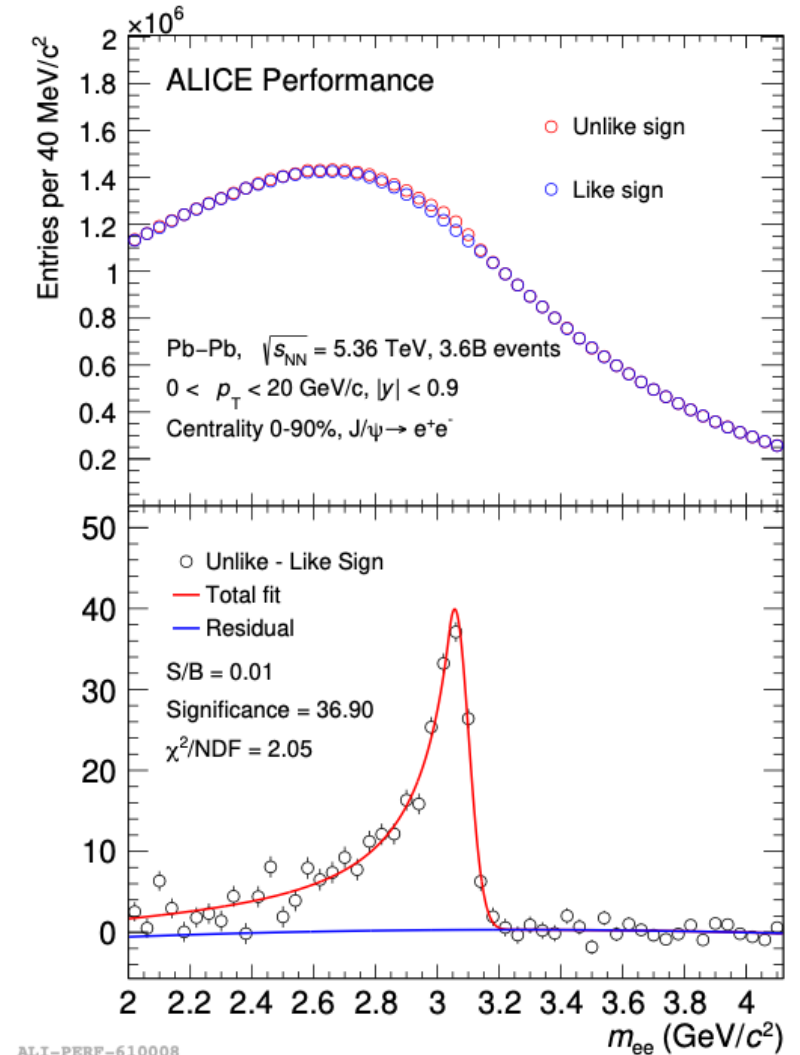
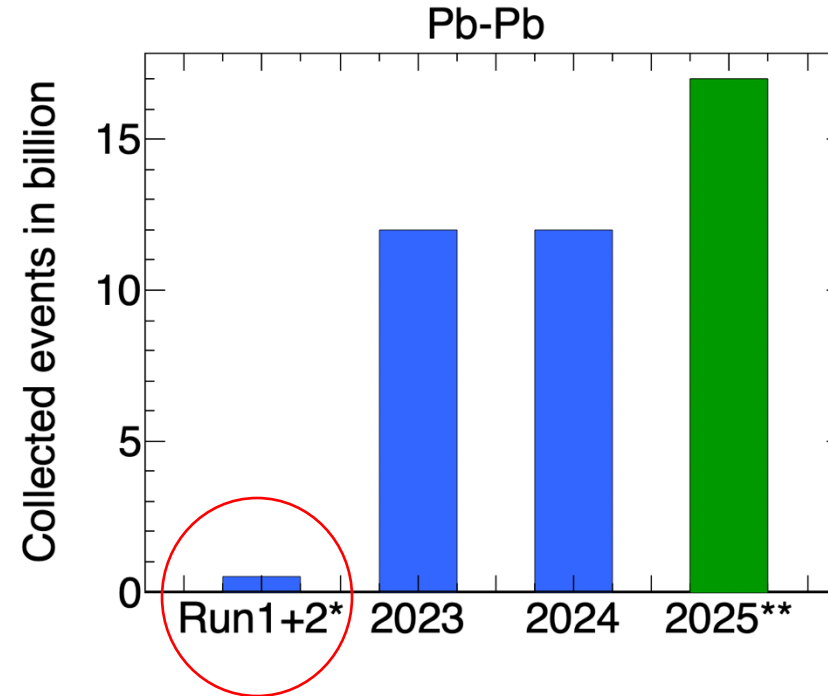
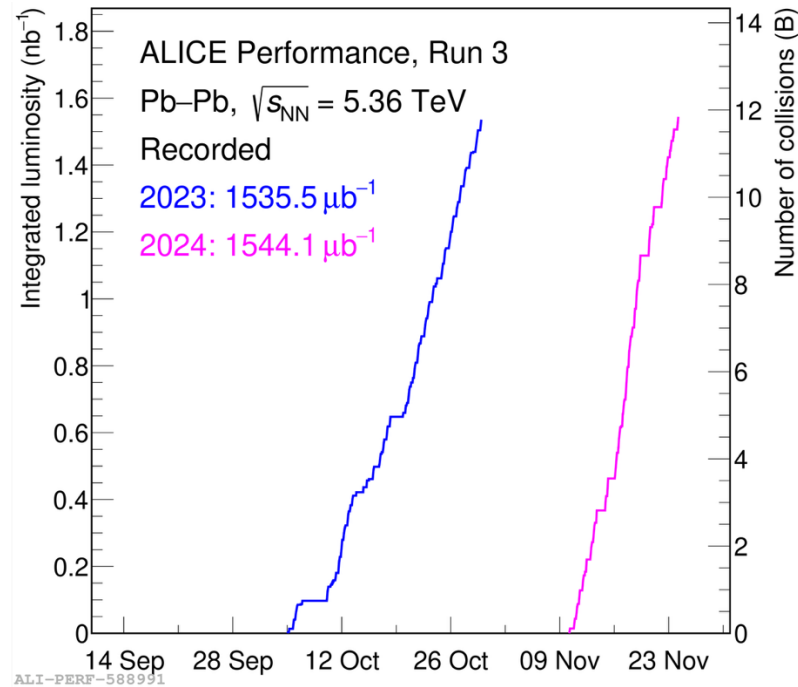
Charmonia polarization in pp collisions

New Preliminary



- 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 proton-proton (pp) collisions

J/ψ spin alignment in Pb–Pb collisions at midrapidity



- Collected approx. **24B MB** events in Pb-Pb
- J/ψ spin alignment in Pb–Pb collisions at midrapidity is ongoing

Summary

- **J/ψ do not show strong spin alignment in Helicity and Collins-Soper reference frames in pp collisions**
- **Significant polarization ($\sim 3.9\sigma$) observed w.r.t the reaction plane**
- **The Run 3 detector upgrade allows for the measurement of spin alignment at midrapidity**
- **Theory guidance is needed to interpret the data**

Thanks