15th France China Particle Physics Network/Laboratory workshop (FCPPN/L2024)

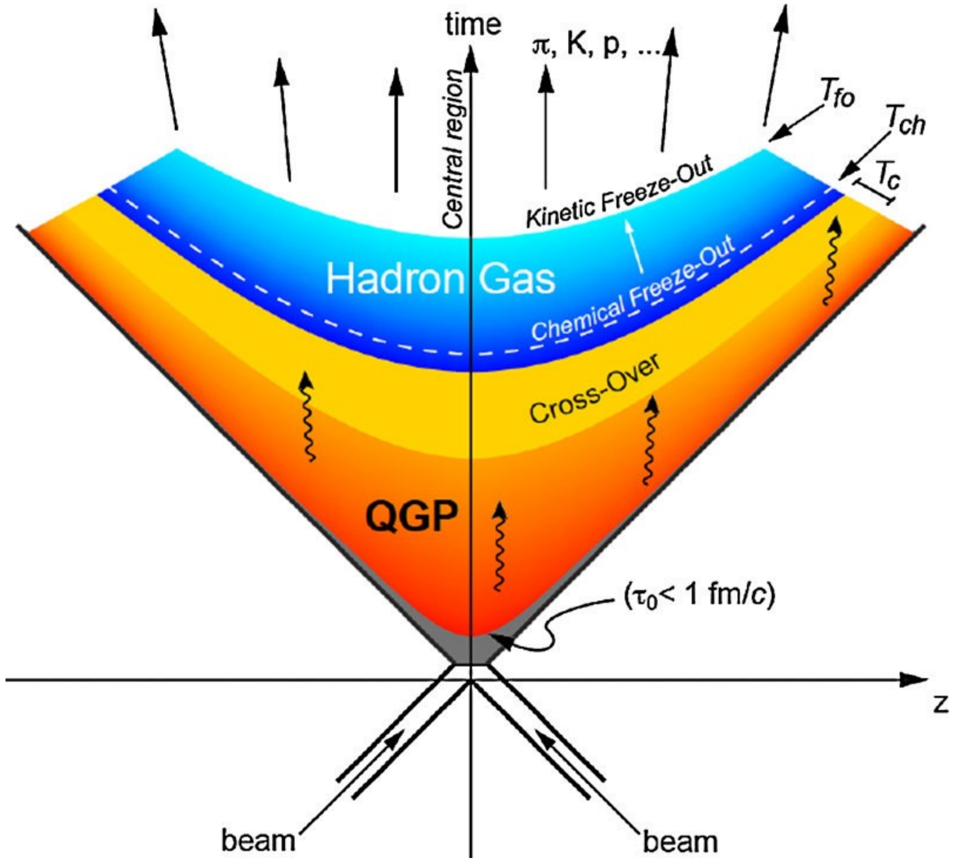
Heavy-flavour polarisation measurements with ALICE at the LHC

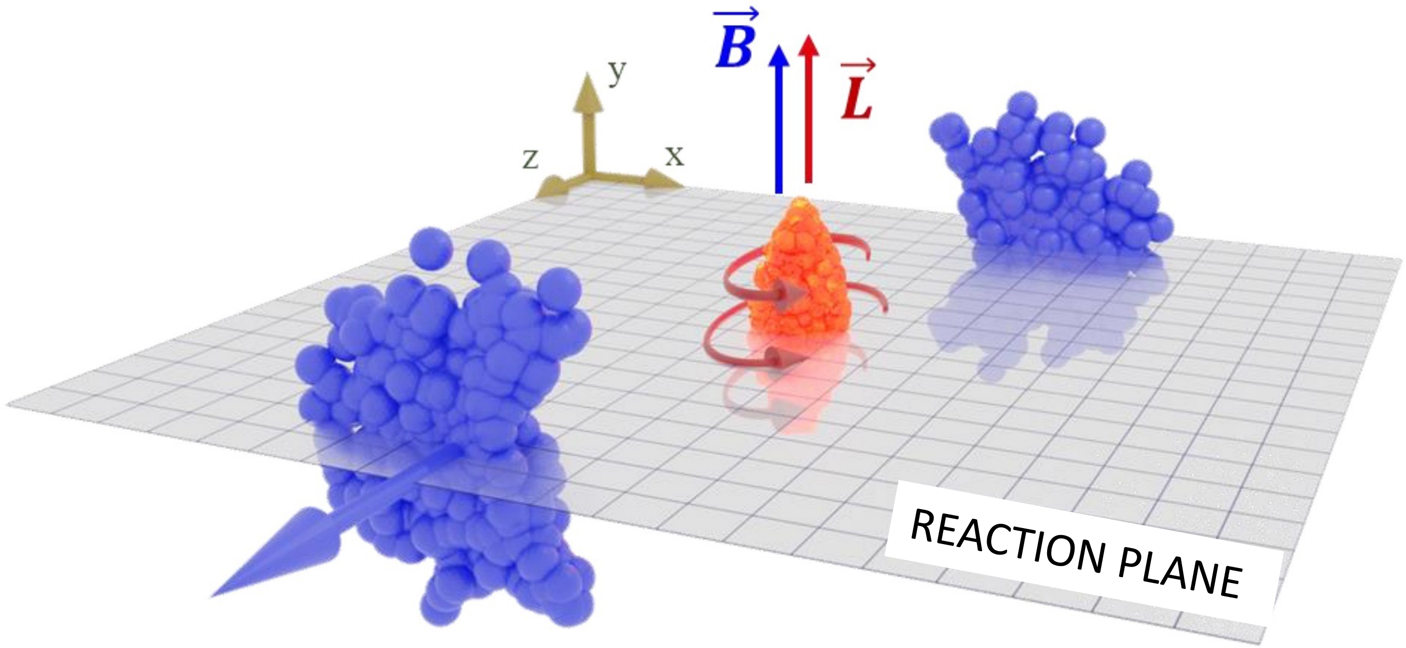
Xiaozhi Bai

University of Science and Technology of China

Bordeaux France, Jun 10 – 14, 2024

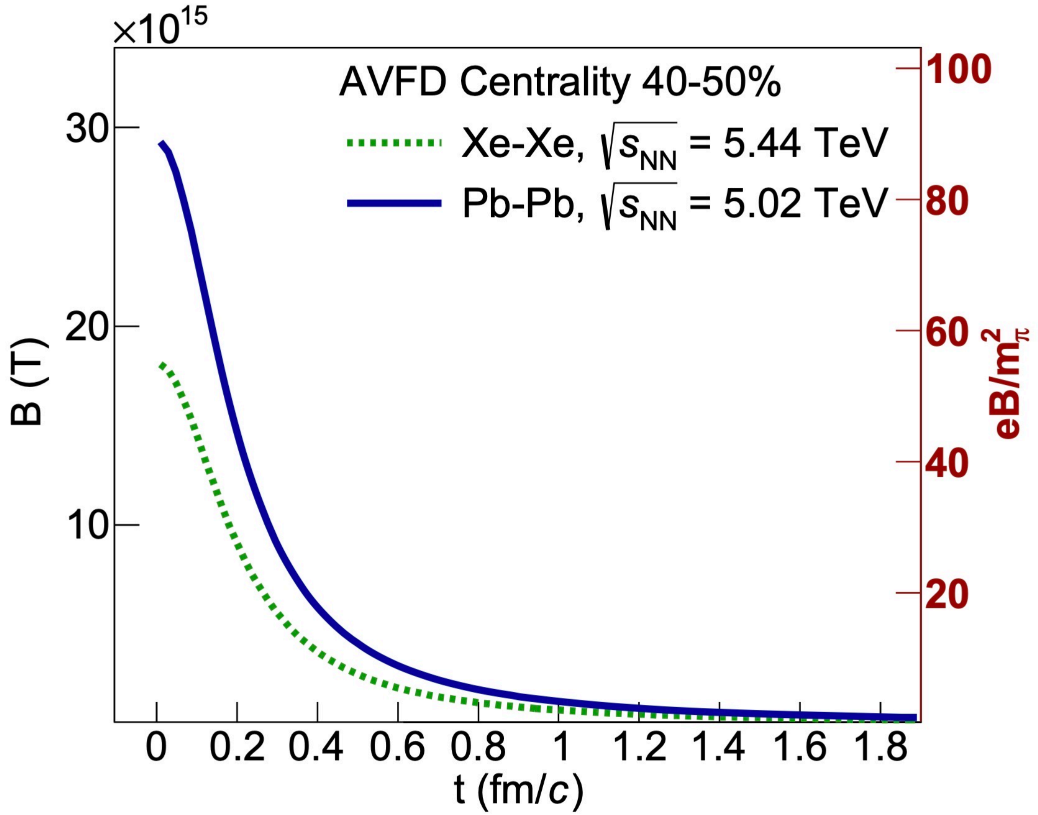
Introduction to heavy-ion collisions



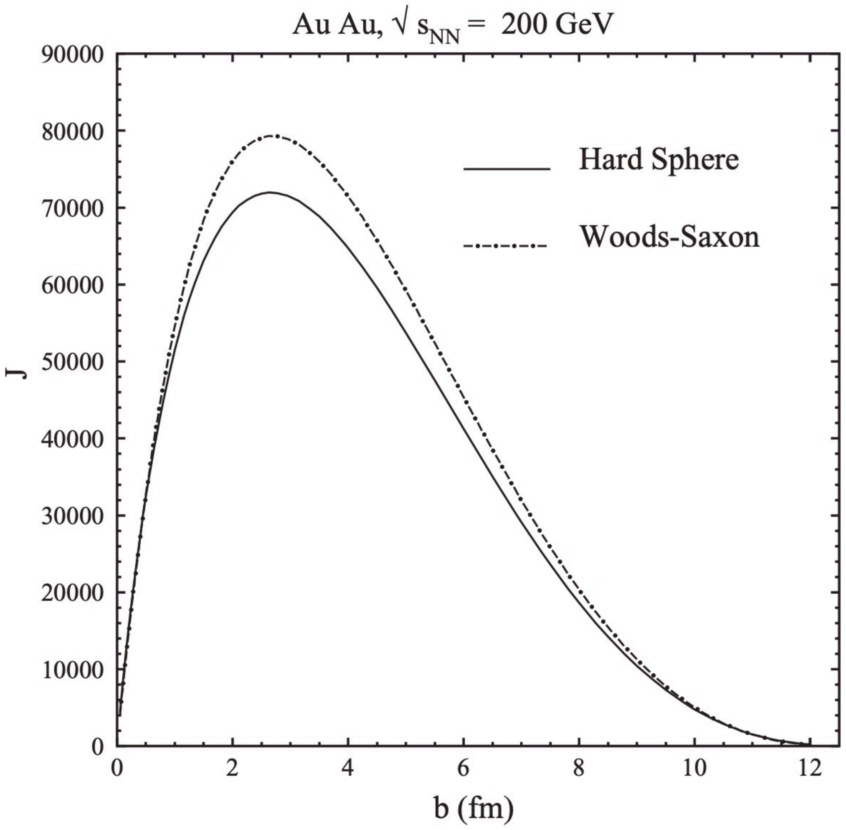


- In non-central heavy-ion collisions, short-lived magnetic fields (***B***) and very strong orbital momentum (***L***) are expected to be produced.
- They can influence the global polarization of the produced particles.

Strong magnetic field and orbital momentum



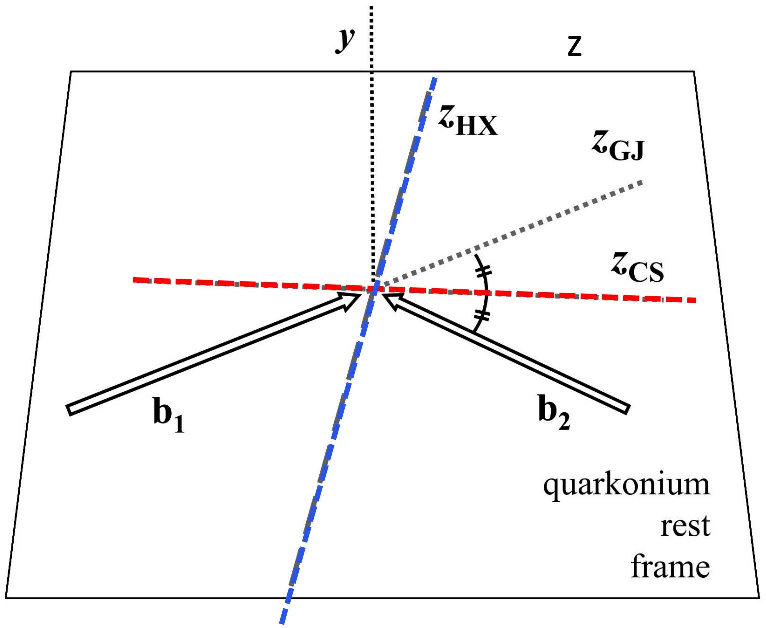
Christakoglu et al., EPJC (2021) **81**: 717

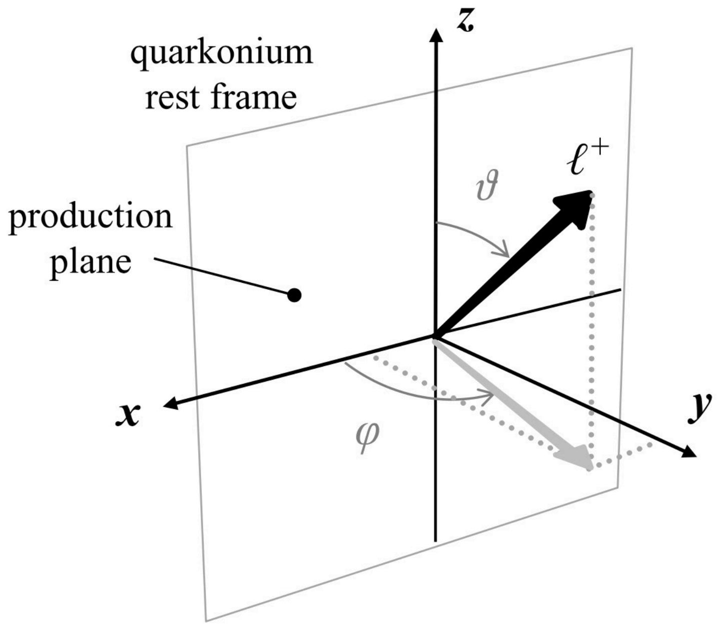


F. Becattini et al., PRC 77 (2008)

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

Motivation for polarization measurements

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

- **Recombination** of polarized quark (antiquark) during the hadronization

$$\rho_{00} = \frac{1 - P_q \cdot P_{\bar{q}}}{3 + P_q \cdot P_{\bar{q}}} = \begin{cases} \lessgtr 1/3^{*} \Rightarrow \vec{\mathrm{B}} \\ < 1/3 \Rightarrow \vec{\mathrm{L}} \end{cases}$$

$$^{*} > 1/3 \mathrm{q} = 0, < 1/3 \mathrm{q} \neq 0$$

P_q is global quark polarization

- Polarized quark (antiquark) **fragmentation**

$$\rho_{00} = \frac{1 + \beta \cdot P_{\bar{q}}^2}{3 - \beta \cdot P_{\bar{q}}^2} > 1/3$$

Quarkonia measurements:

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

$\lambda_\theta =$ polarization parameter

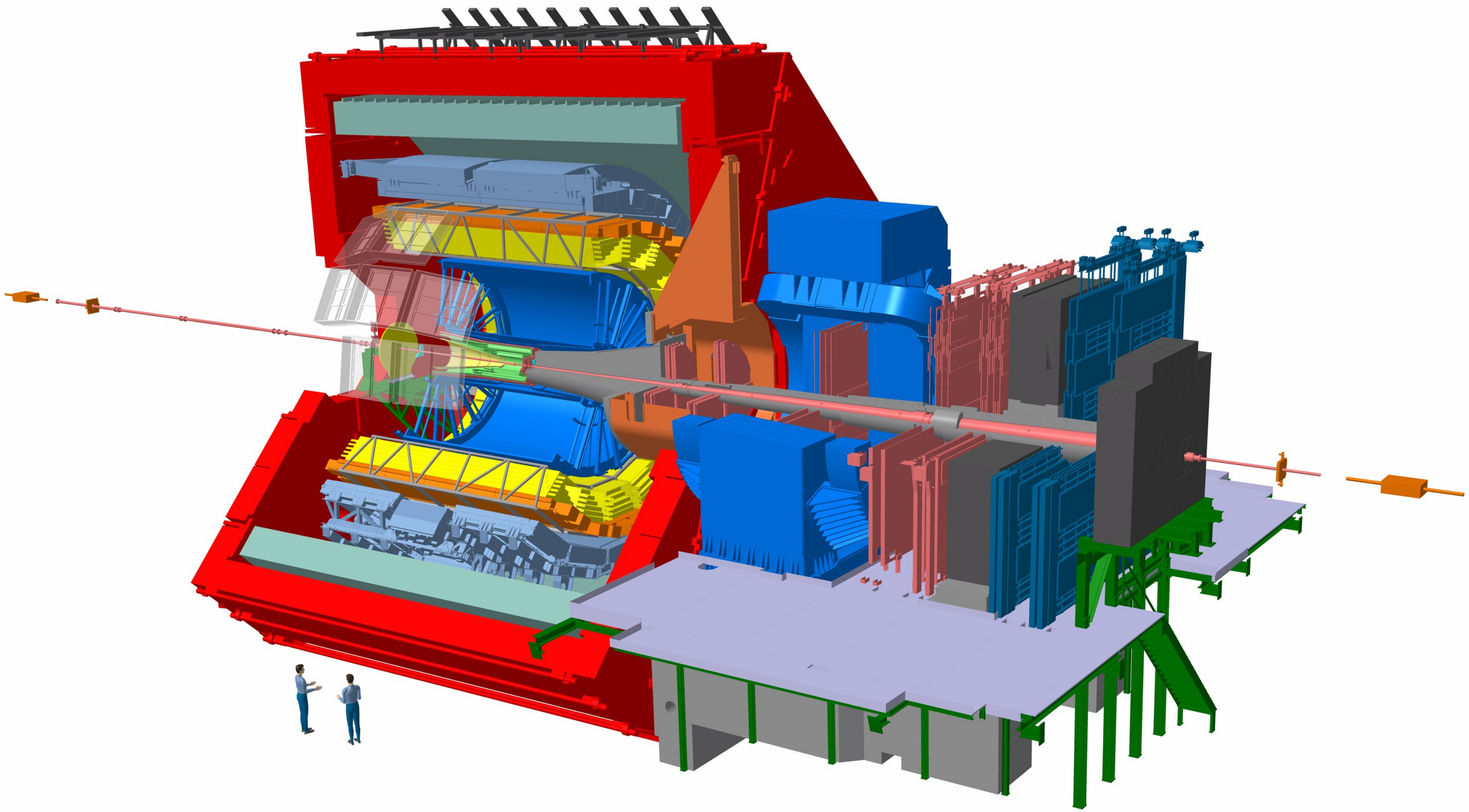
$\lambda_\theta = 0$ no spin alignment

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

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

- **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.

ALICE Detector



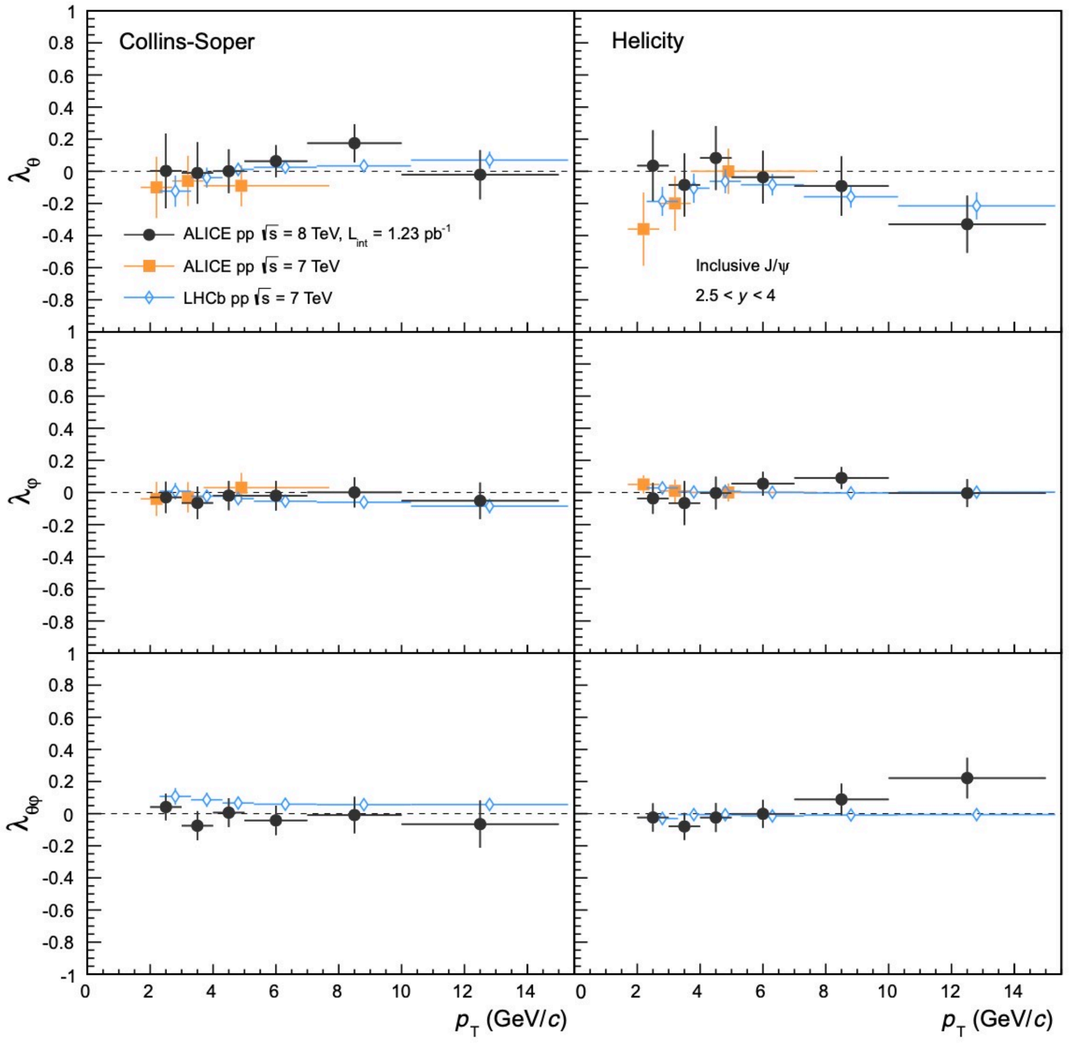
- **Time Projection Chamber**
  Tracking, particle identification

- **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

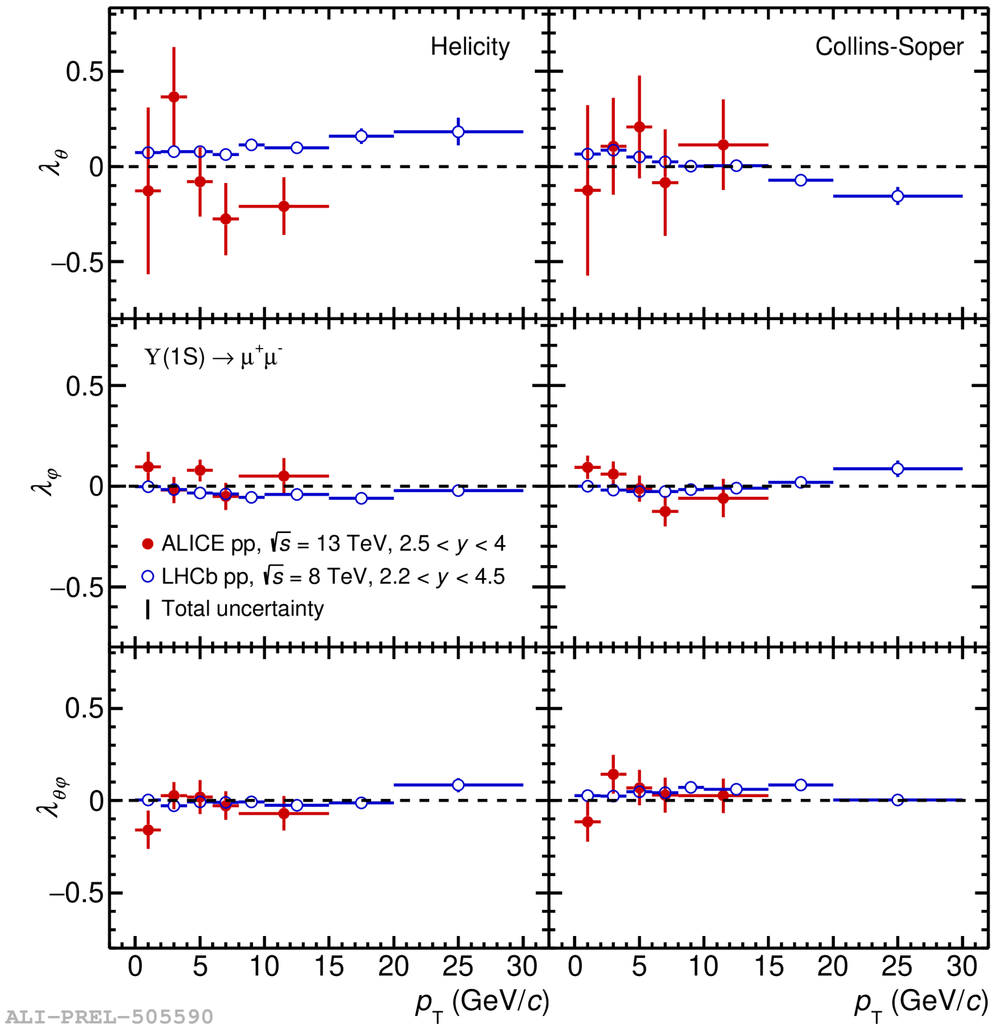
J/ψ polarization measurements in pp collisions



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** by ALICE at forward rapidity up to p_T = 15 GeV/c

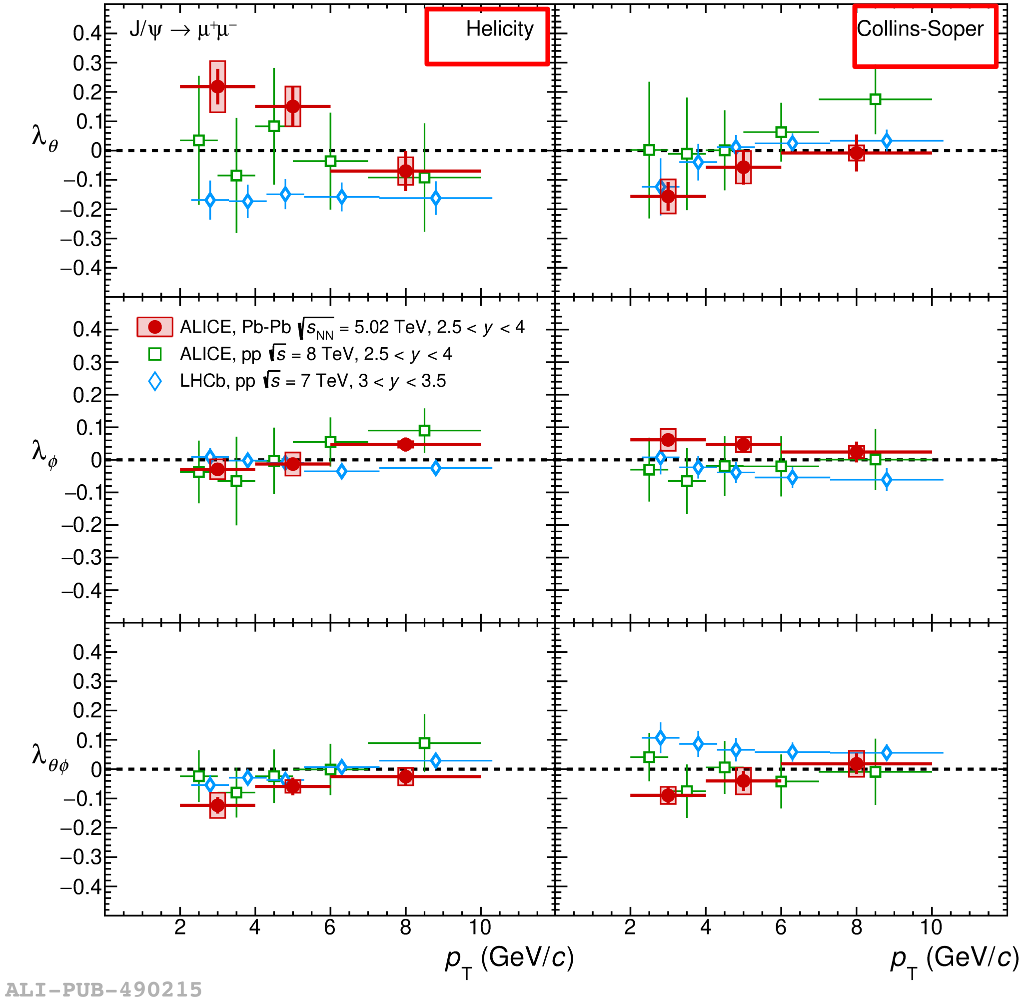
Υ(1S) polarization measurements in pp collisions



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

λ_θ, λ_ϕ, $\lambda_{\theta\phi}$ are compatible with zero in Helicity and Collins-Soper reference frames

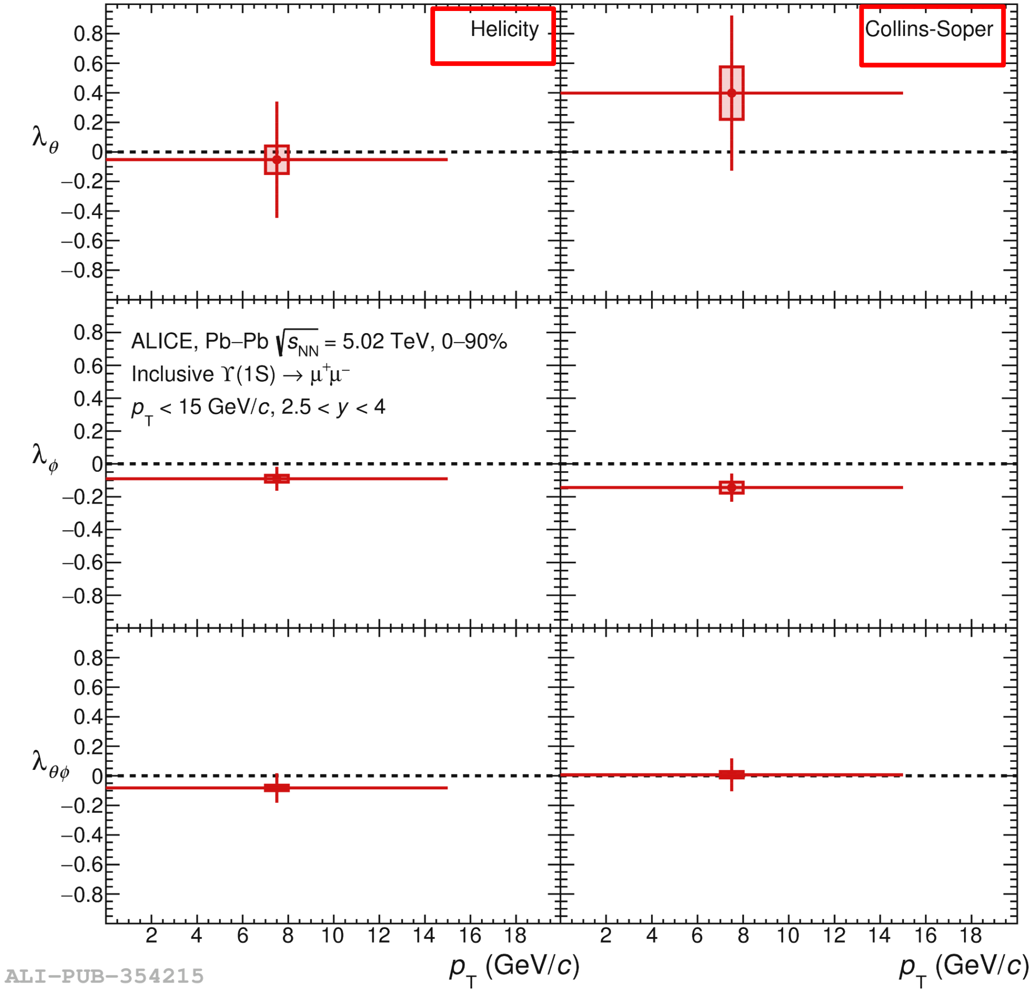
J/ψ polarization measurements in heavy-ion collisions



- λ_θ, λ_ϕ, $\lambda_{\theta\phi}$ close to zero in Helicity and Collins-Soper reference frames
- **Maximum deviation from zero is 2.1σ, and 3.3σ w.r.t higher precision LHCb results from pp** at low p_T

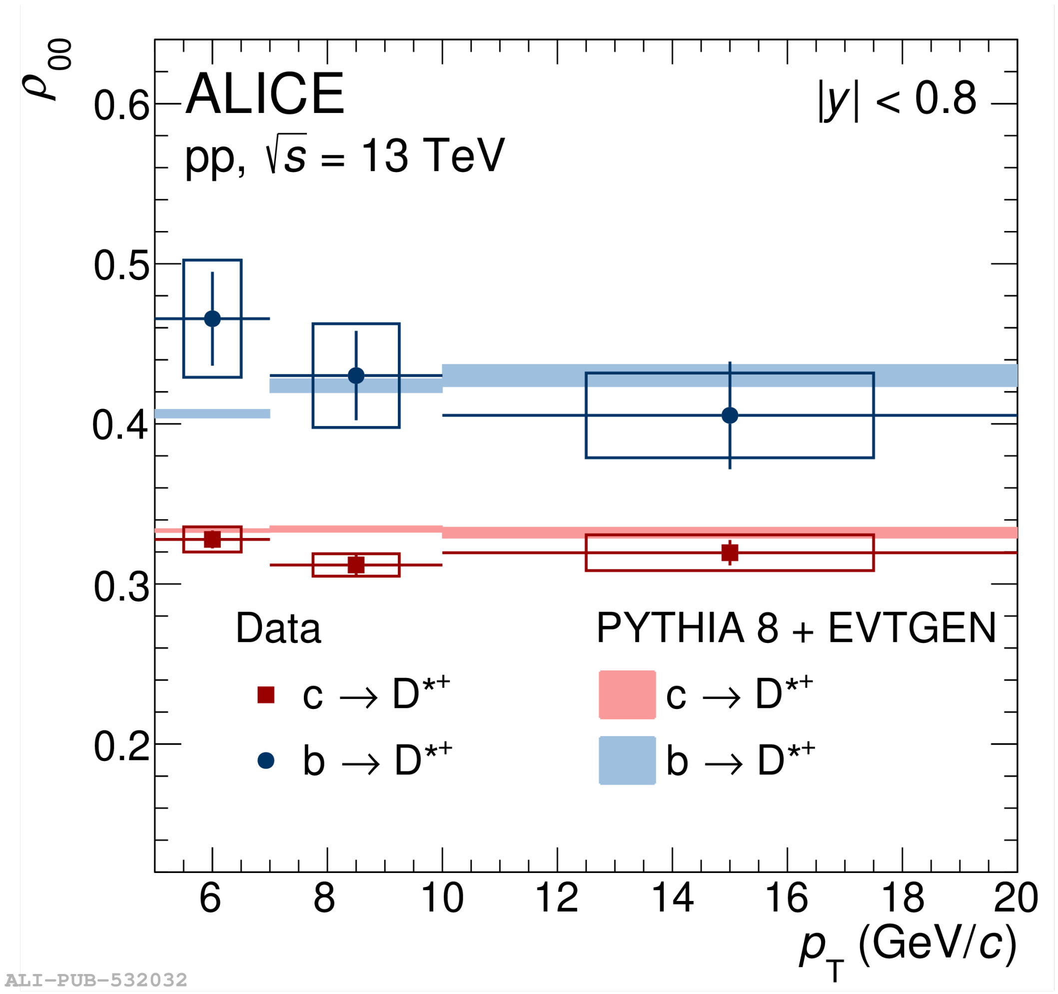
ALICE, PLB 815 (2021) 136146
LHCb, JHEP12 (2017) 110
ALICE, PLB 815 (2021) 136146

ϒ(1S) polarization measurements in heavy-ion collisions



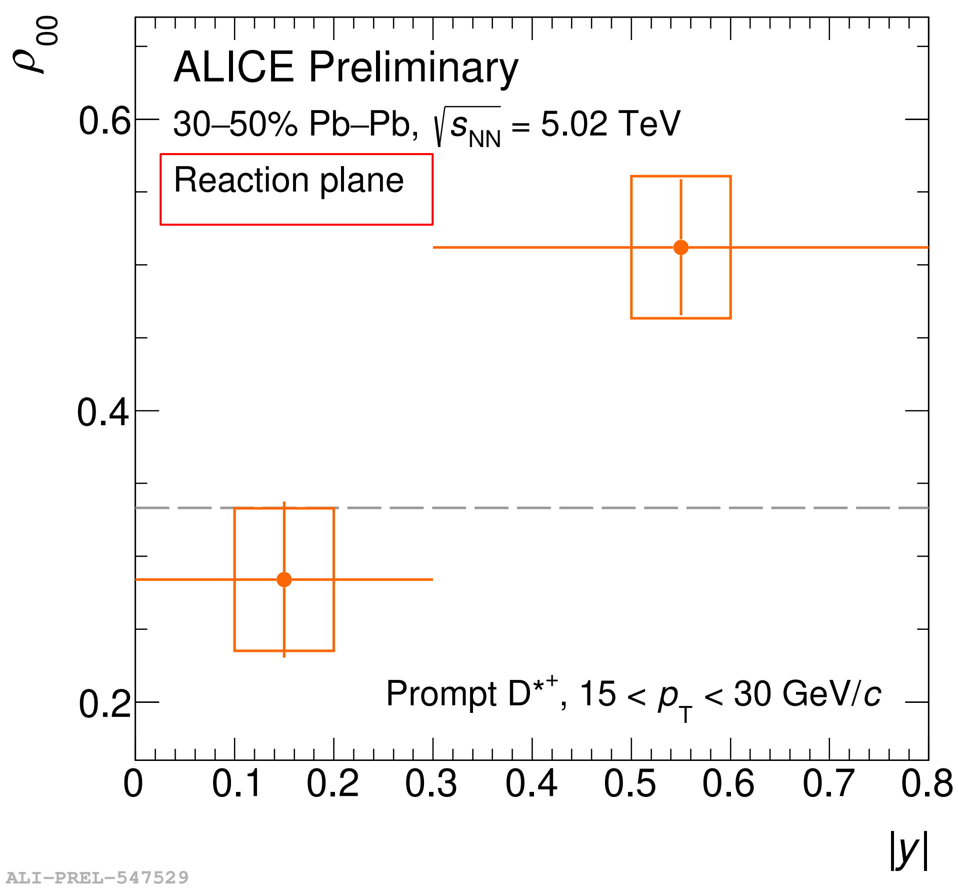
No strong polarization is observed for **ϒ(1S)** although there are substantial uncertainties

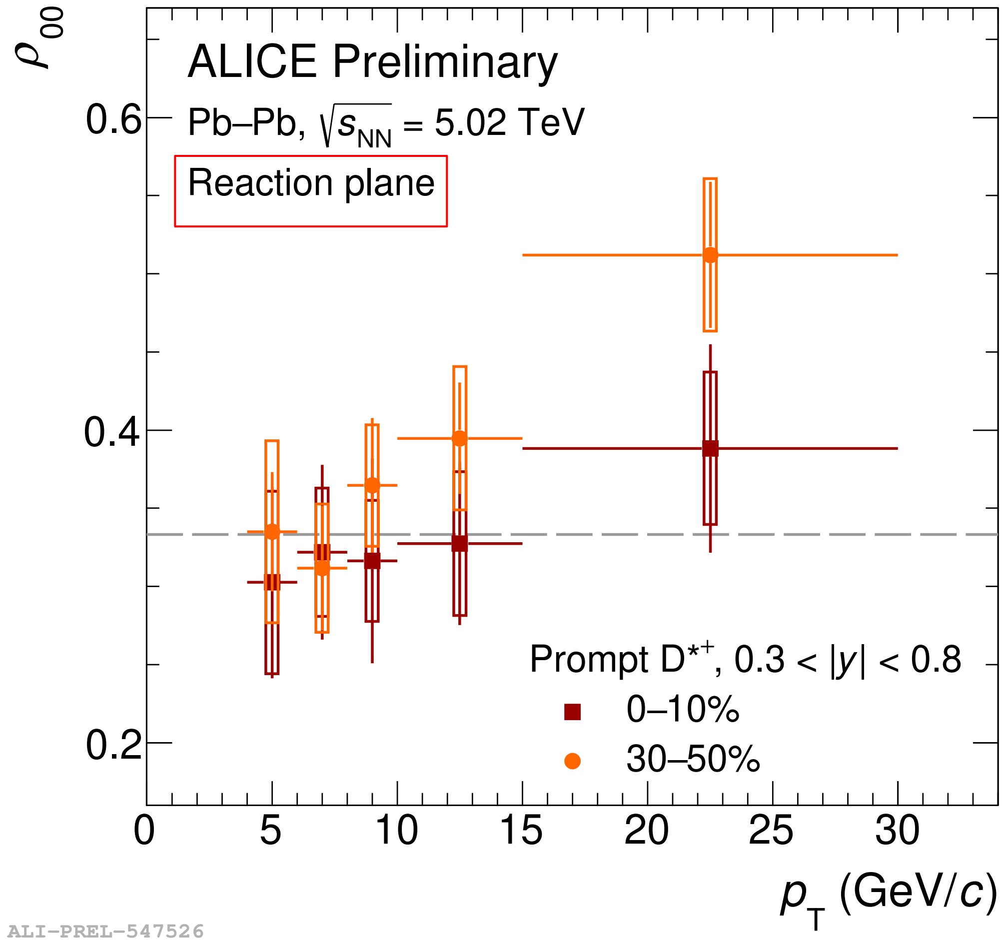
The prompt and non-prompt D^{*+} polarization in pp collisions



- Measurement performed with respect to the helicity reference frame
- Prompt $\mathbf{D}^{*+}$ ρ_{00} compatible with 1/3 within uncertainties (no polarization)
- Non-prompt $\mathbf{D}^{*+}$ $\rho_{00} > 1/3$ due to the helicity conservation of the beauty hadrons decay
- The charm quarks are either produced unpolarised or their polarization is washed out during the hadronization process
- An important baseline for future spin alignment measurements of D^{*+} vector mesons in heavy-ion collisions

D^{*+} global polarization in Pb–Pb collisions

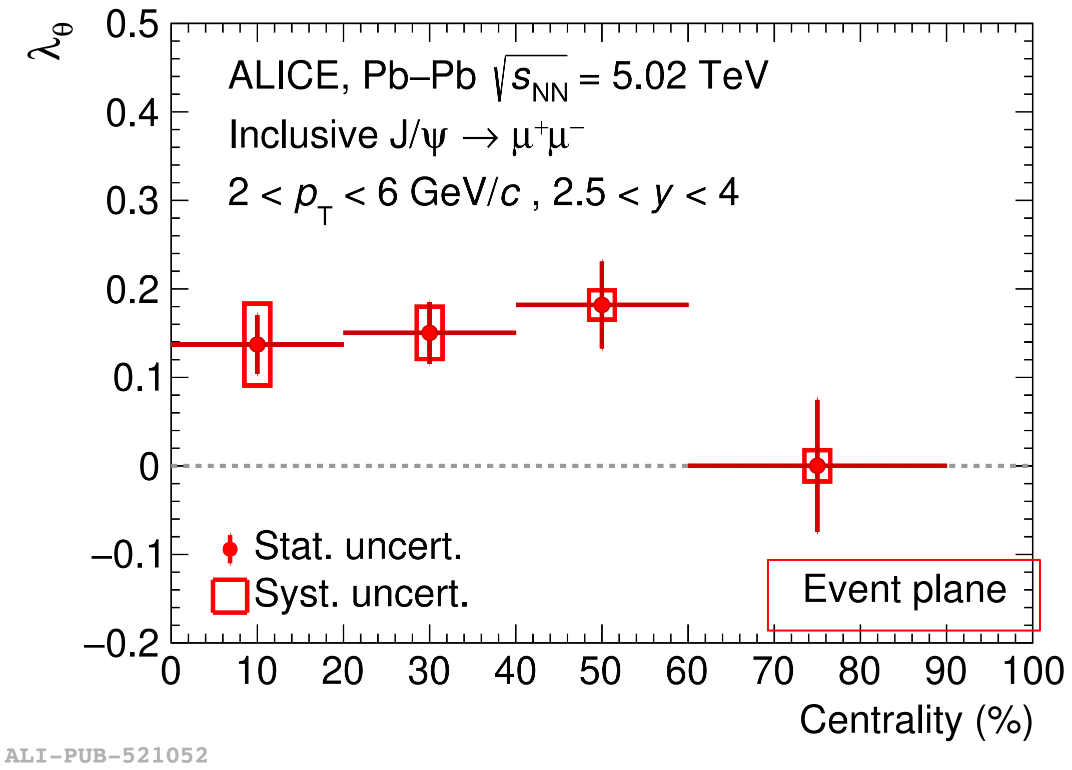


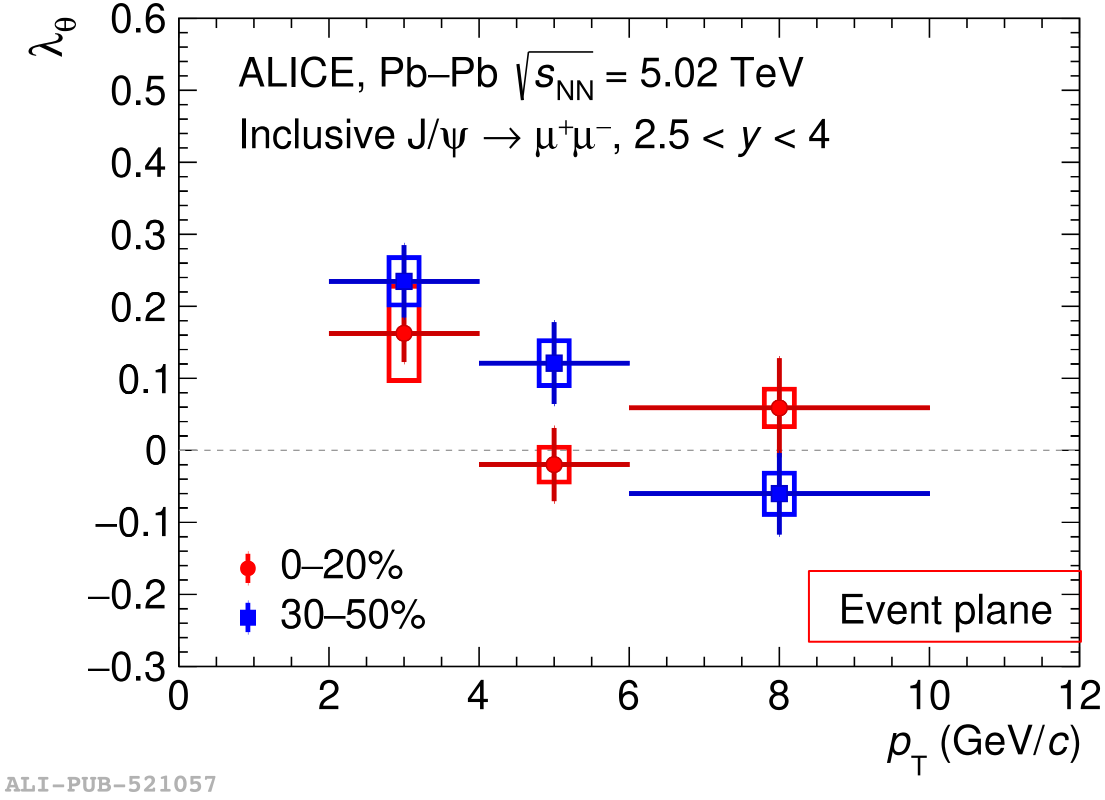


- 0 – 10% : ρ_{00} compatible with 1/3 , 30 – 50% : $\boldsymbol{\rho_{00}}$ > 1/3 at high p_T
- Significant deviation at larger rapidity (0.3 < |y| < 0.8) than at midrapidity (|y| < 0.3)

J/ψ polarization in Pb−Pb collisions

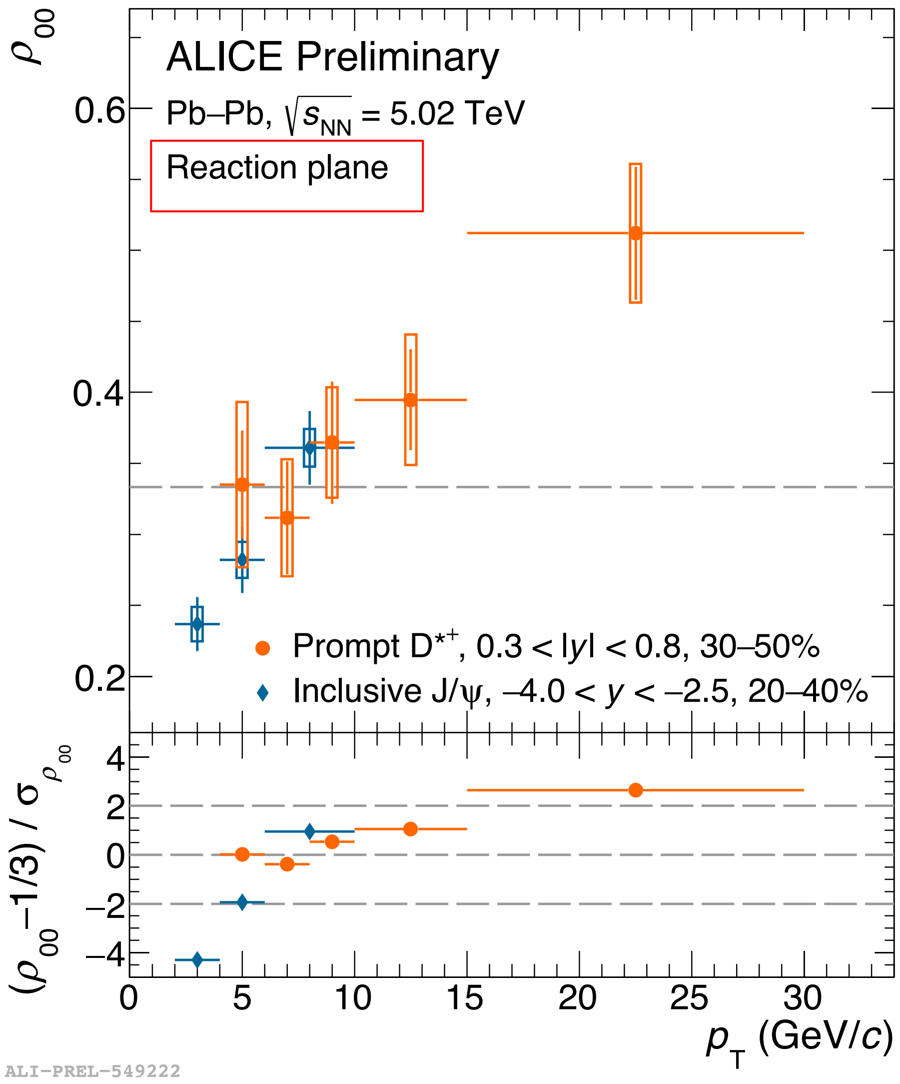
PRL 131 (2023) 4, 042303





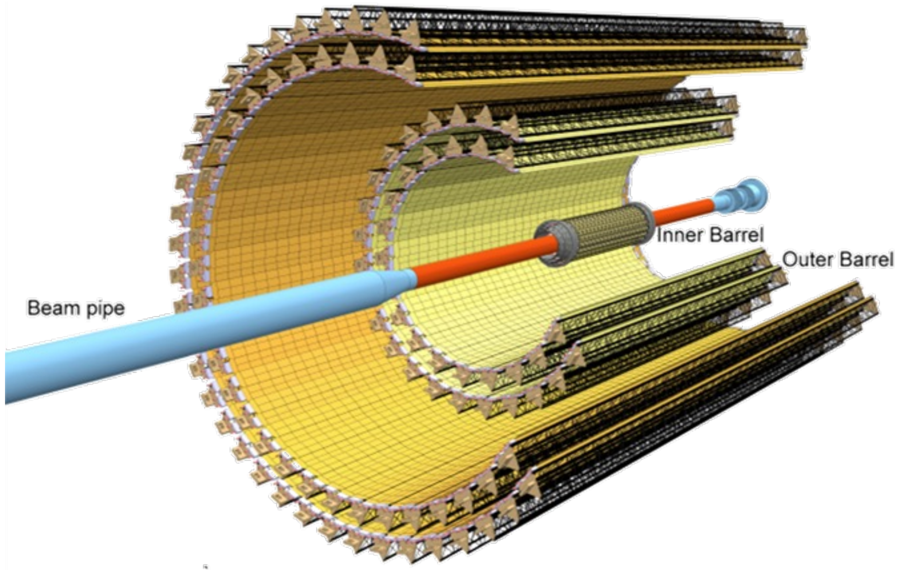
- First measurement of quarkonium polarization **with respect to the event plane**
- **Significant polarization (~3.5σ)** observed in semicentral collisions (40-60%) in 2 < p_T < 6 GeV/c
- The significance of the polarization reaches **~3.9σ** at low p_T (2 < p_T < 4 GeV/c) in 30-50%
- Interpretation of results requires inputs from theoretical models

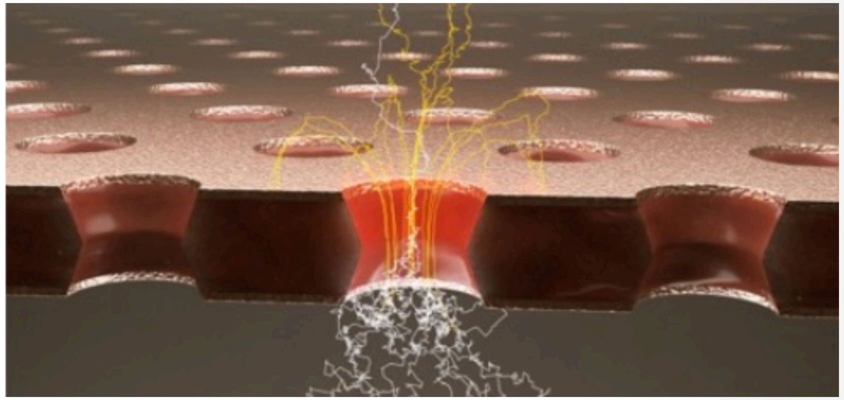
Comparison of the D*+ and J/ψ polarization

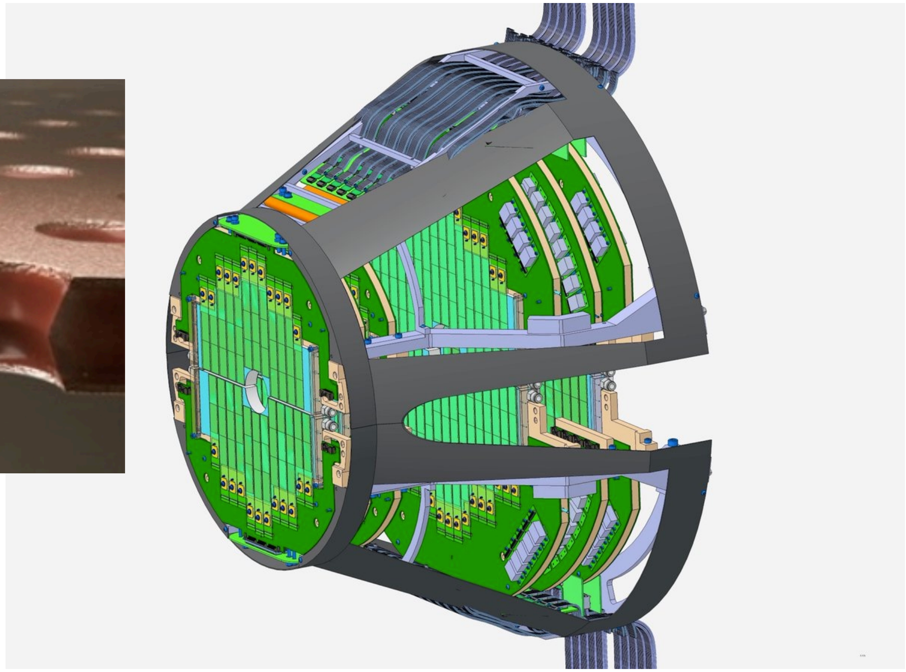


- Agreement with the:
  - $\rho_{00} < 1/3$ quark recombination at low p_T
  - $\rho_{00} > 1/3$ quark fragmentation at high p_T
- At high p_T the fragmentation of heavy quarks polarized by the magnetic field translates to $\rho_{00} > 1/3$?
- Theory guidance needed!

The detector upgrade on Run 3



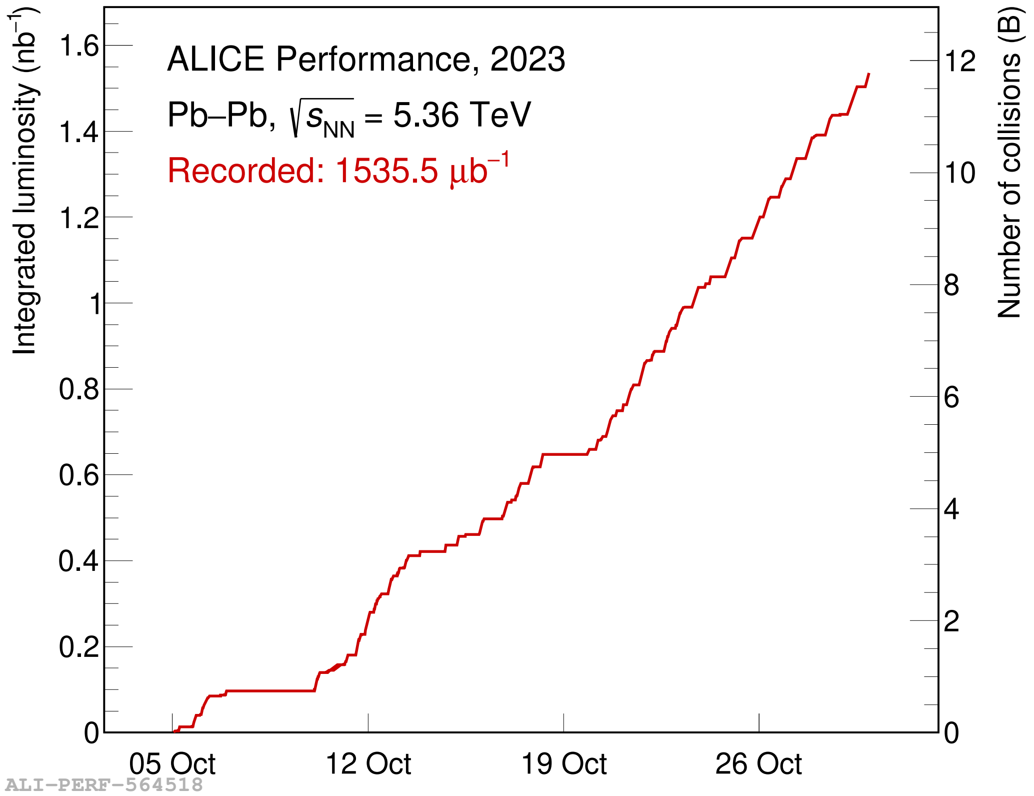


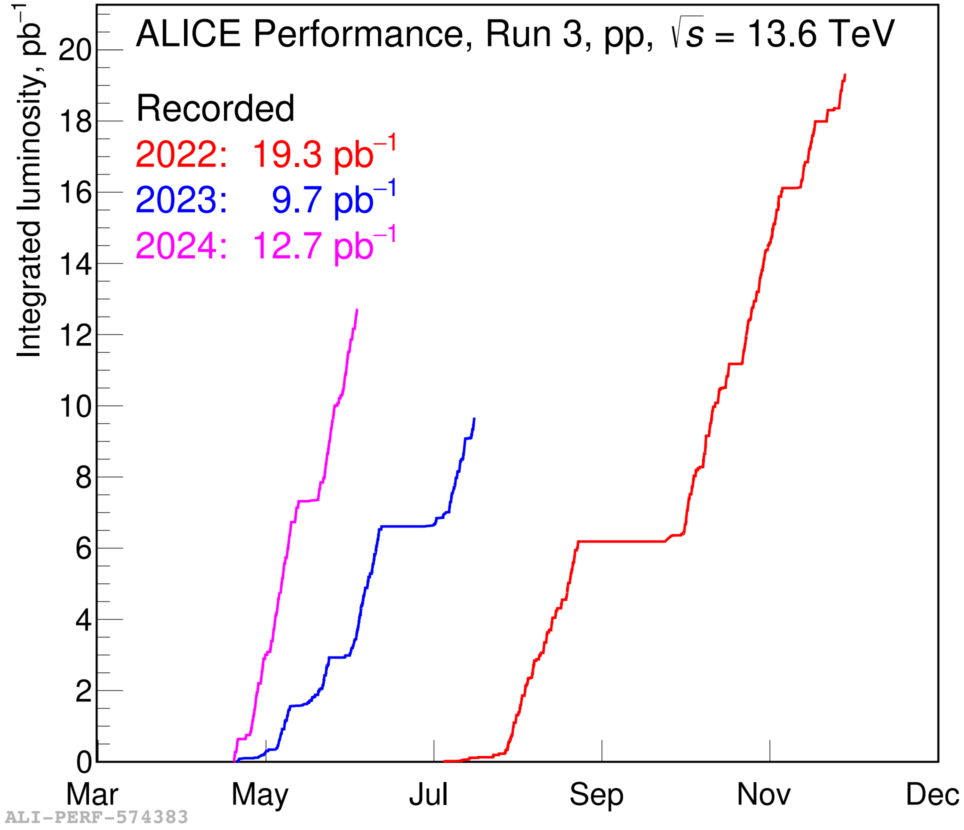


The main upgrades

- Inner tracking system (3 to 6x improvement in pointing resolution)
- Continuous readout at high rate for TPC (GEM readout, 50x increase in readout rate)
- New forward interaction trigger (Secondary vertexing for forward muons)

Run 3 data taking

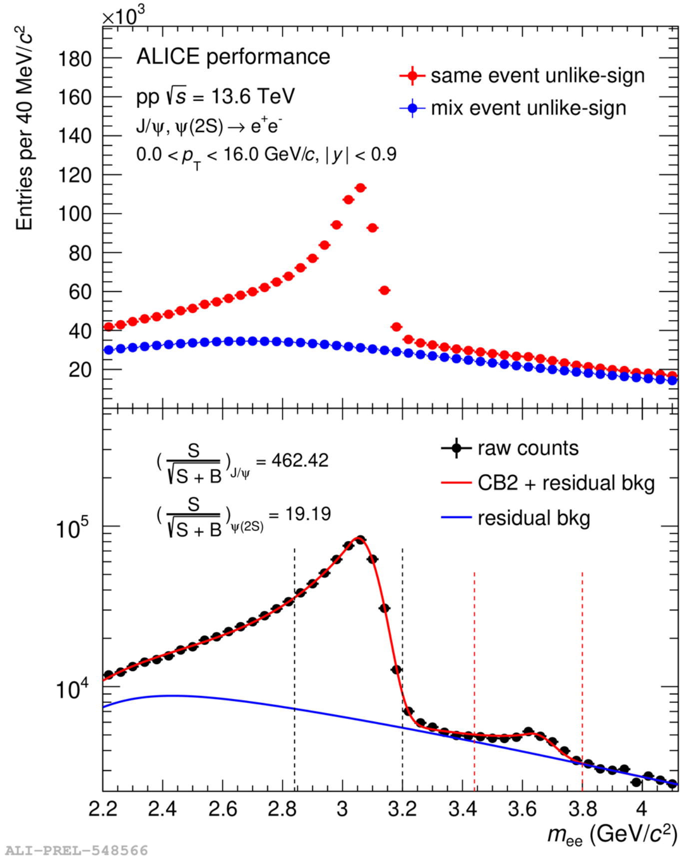


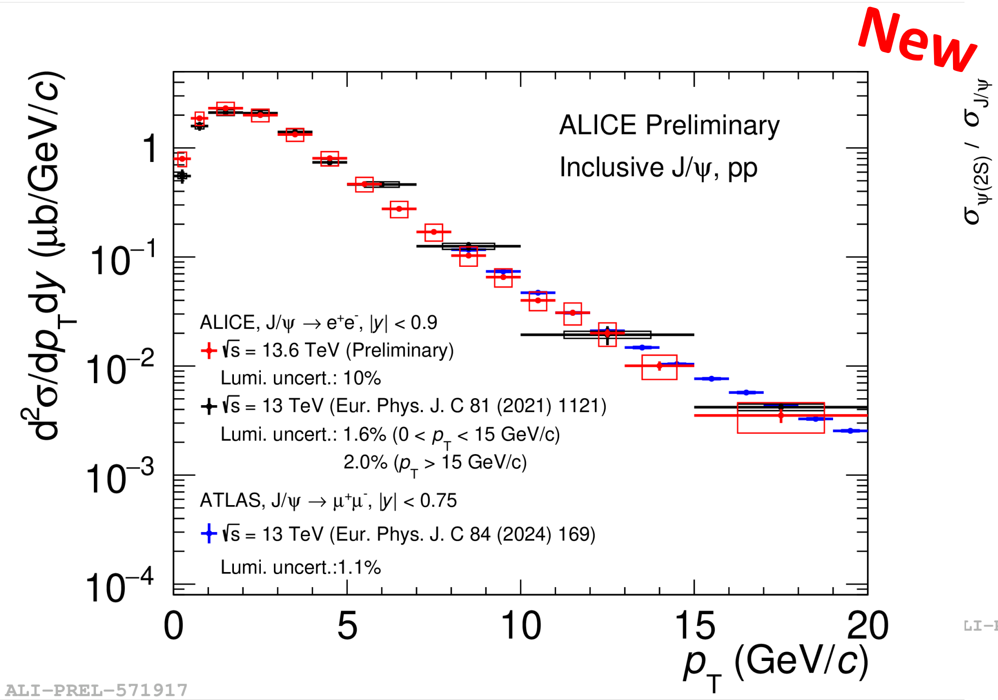


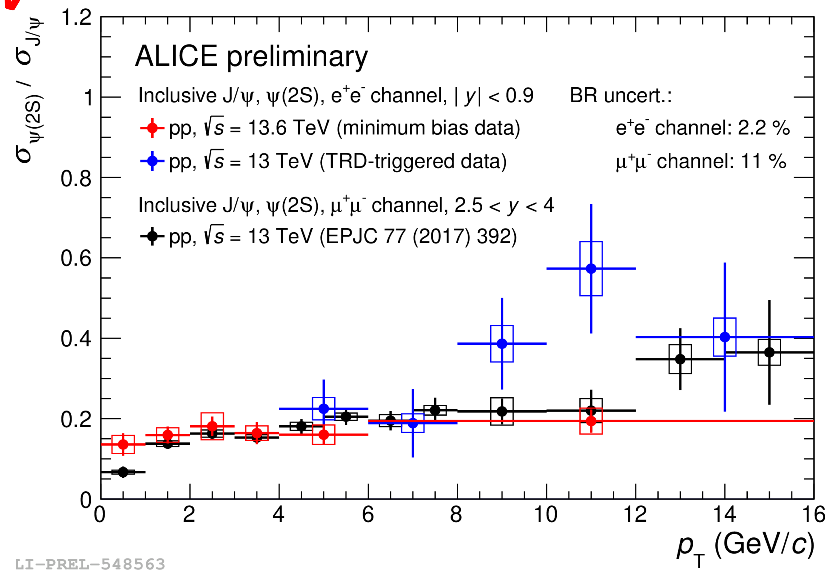
- Pb-Pb data taking 50 kHz
- Collected approx. 12 B minimum bias events

- pp data taking at 500 kHz
- 42 pb^{-1} minimum bias events are recorded

Inclusive J/ψ cross section

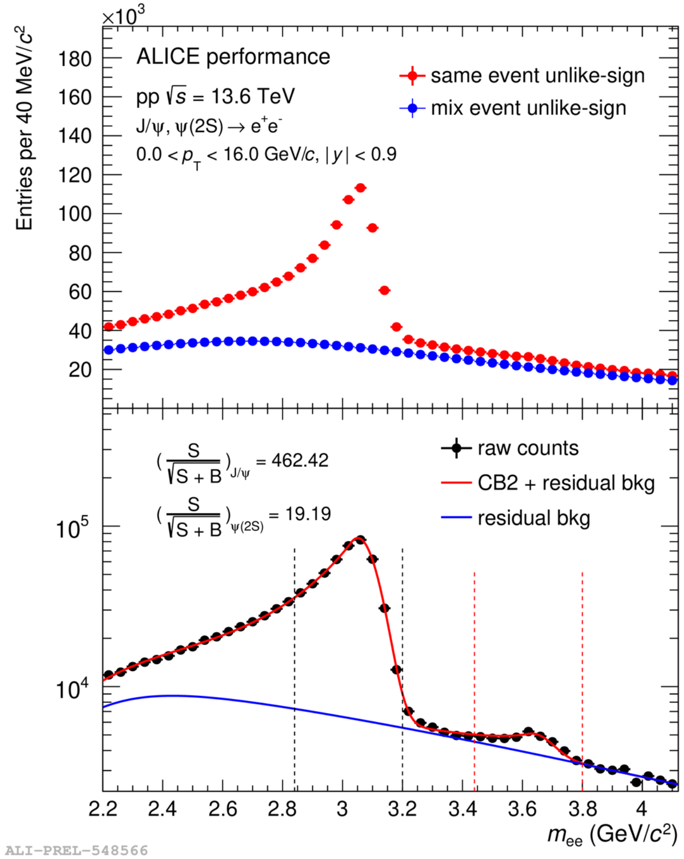


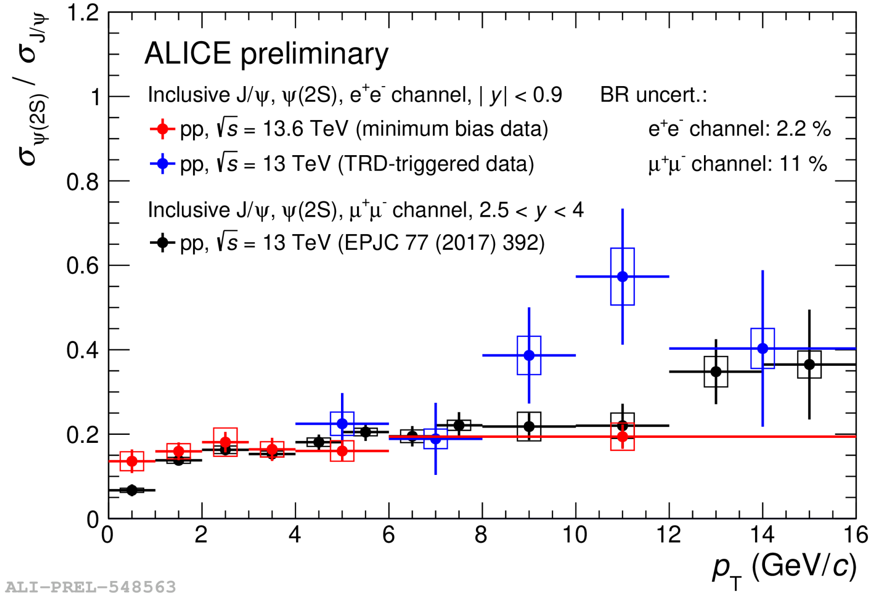




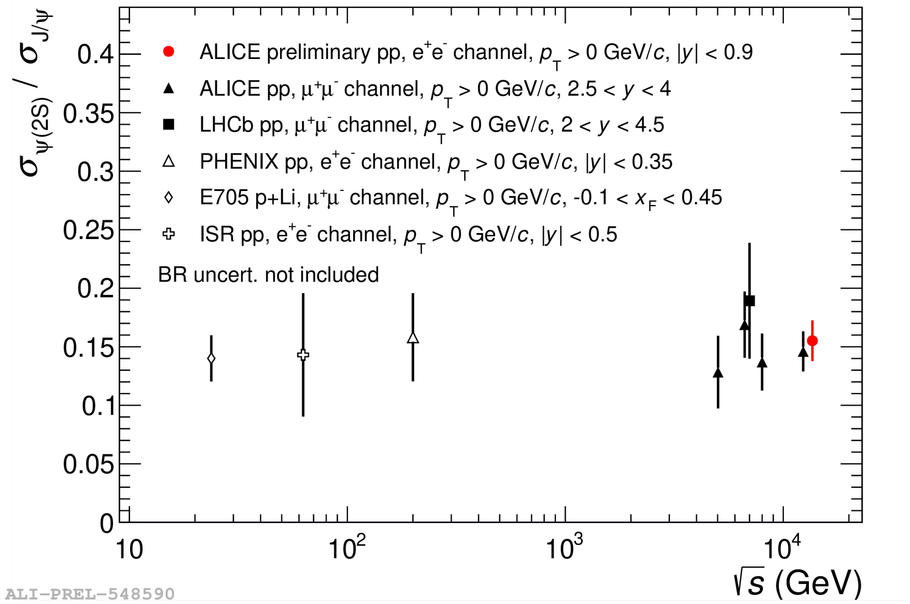
- The new J/ψ and ψ(2s) measurements through e^+e^- decays with **Run 3 data**
- Cover down to pT = 0 with excellent precision
- Important input to quarkonia production models

ψ(2s) to J/ψ ratio



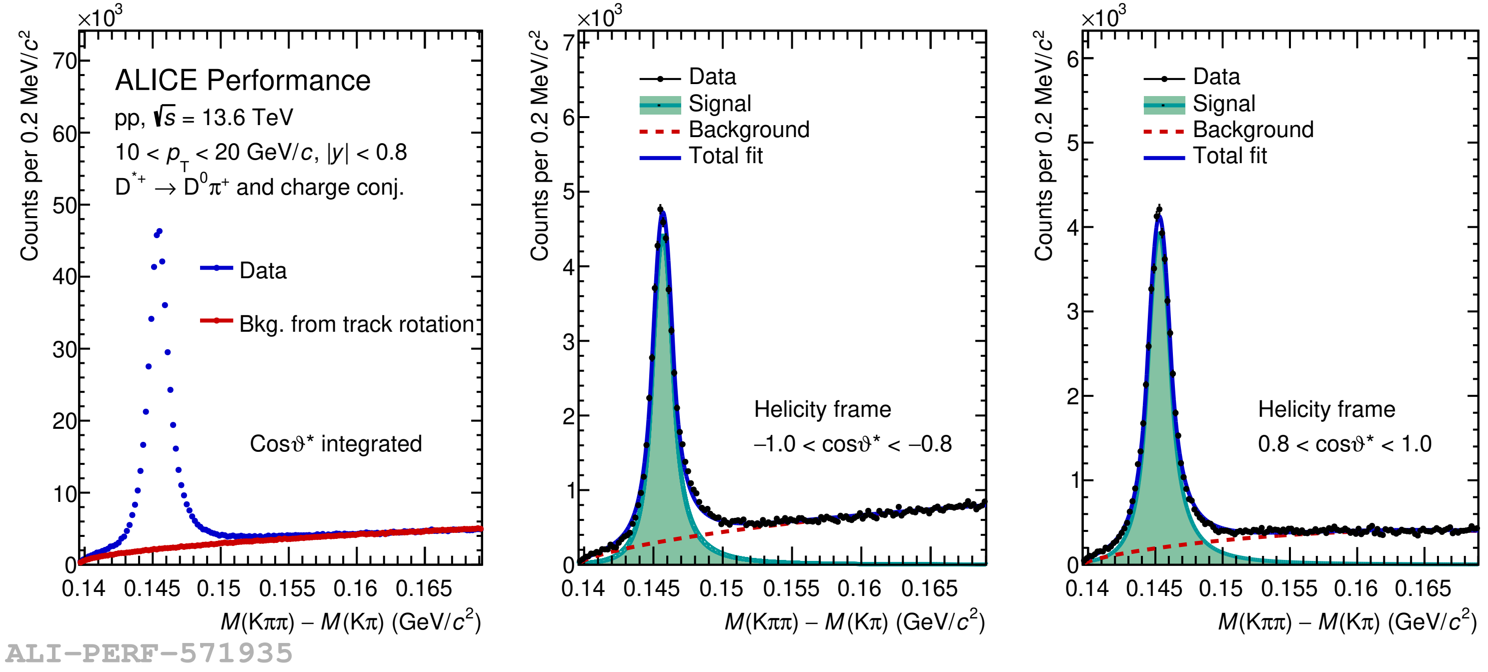


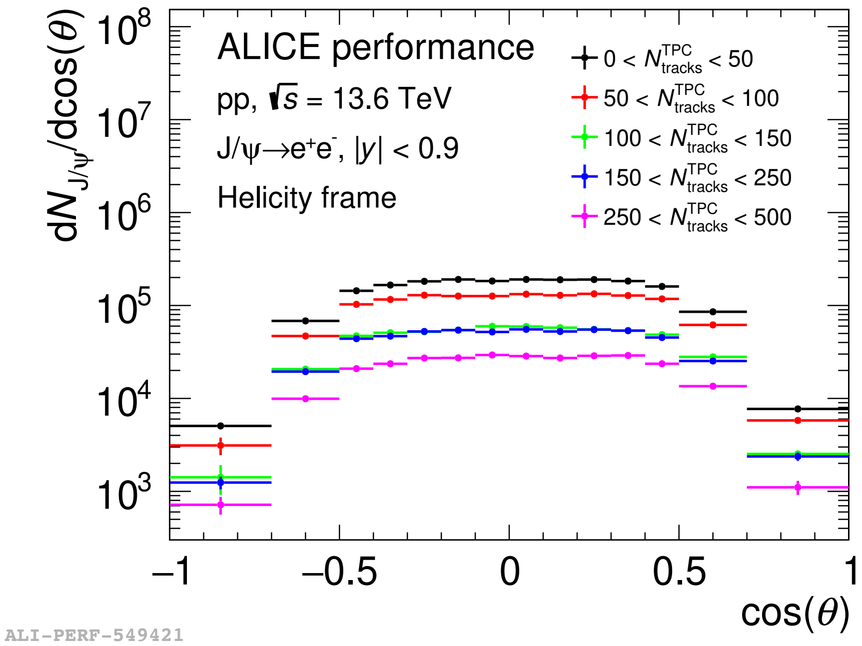
New



- The ψ(2s) to J/ψ ratio are measured through e^+e^- decays with Run 3 data
- cover down to $p_T = 0$ with excellent precision
- Important input to quarkonia production models

Heavy-flavour polarization measurements in Run 3





- The precision of the D^{*+} polarization measurements will be improved significantly in Run 3
- The measurement of the J/ψ polarization is performed through dielectron channel at the midrapidity

Heavy flavour polarization measurements with ALICE

	K^{*0}	ϕ	D^{*+}	J/ψ	ϒ(1S)
pp	ρ_{00} ~ 1/3 (production plane)	ρ_{00} ~ 1/3 (production plane)	ρ_{00} ~ 1/3 (HX)	ρ_{00} ~ 1/3 (HX and CS)	ρ_{00} ~ 1/3 (HX and CS)
Pb-Pb	ρ_{00} < 1/3 low p_T (RP)	ρ_{00} < 1/3 low p_T (RP)	ρ_{00} > 1/3 high p_T (RP)	ρ_{00} < 1/3 (low p_T) (RP)	ρ_{00} ~ 1/3 (HX and CS)

Summary and outlook

➢ pp collisions:

- The measured **J/ψ, Υ(1S) , D^{*+}** , polarization are closer to 0

➢ Pb−Pb collisions

- **J/ψ and Υ(1S)** polarization consistent with zero in helicity and collins-soper reference frames, but significant polarization (~$\mathbf{3}.9\boldsymbol{\sigma}$) observed w.r.t the reaction plane for J/ψ
- D^{*} polarization depends on the centrality, p_T and rapidity

➢ Outlook for Run 3

- The run3 data alignment and calibrations are ready for physics analysis
- More precise results can be expected from Run 3

Thanks