12th Edition of the Large Hadron Collider Conference

Heavy-flavour polarization measurements

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for the ALICE, ATLAS, CMS, LHCb Collaborations

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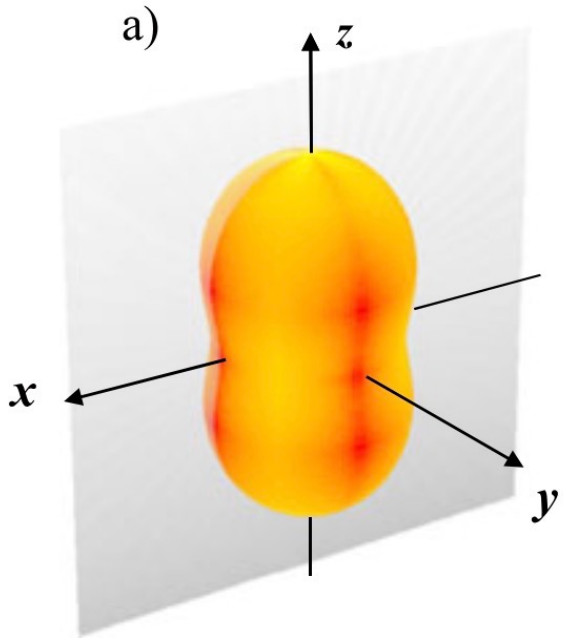
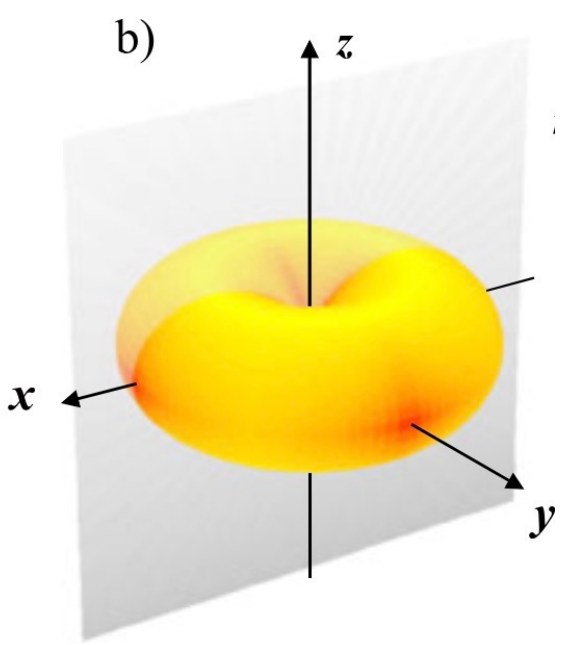
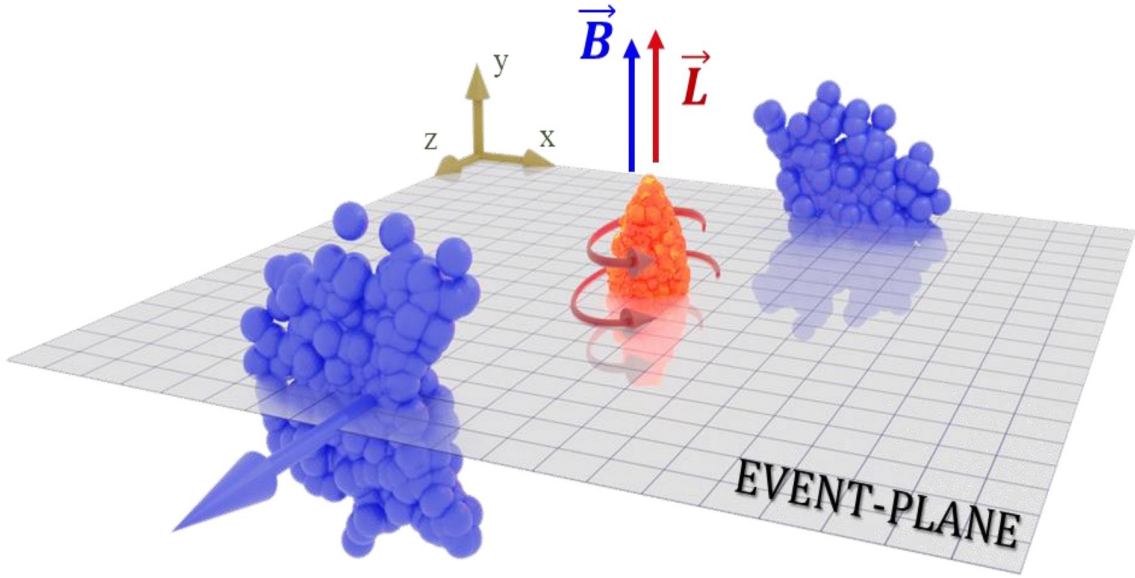
Motivation



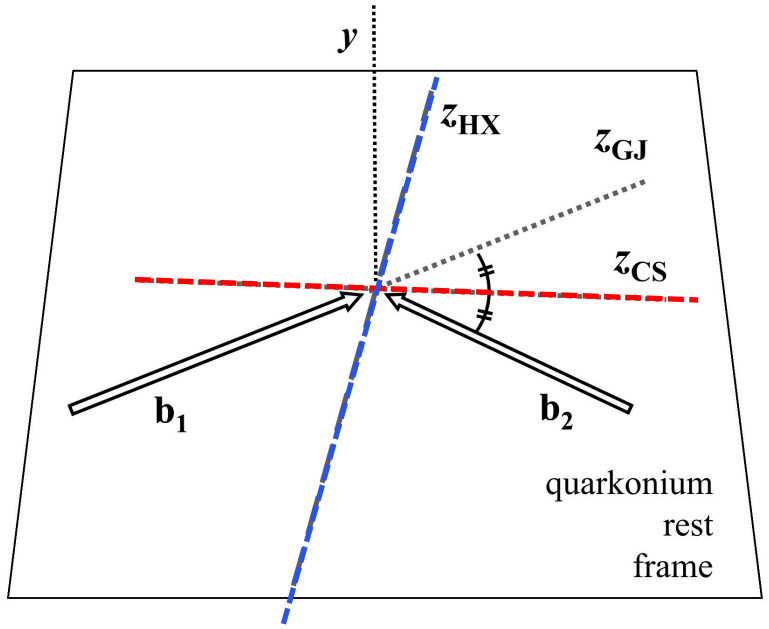


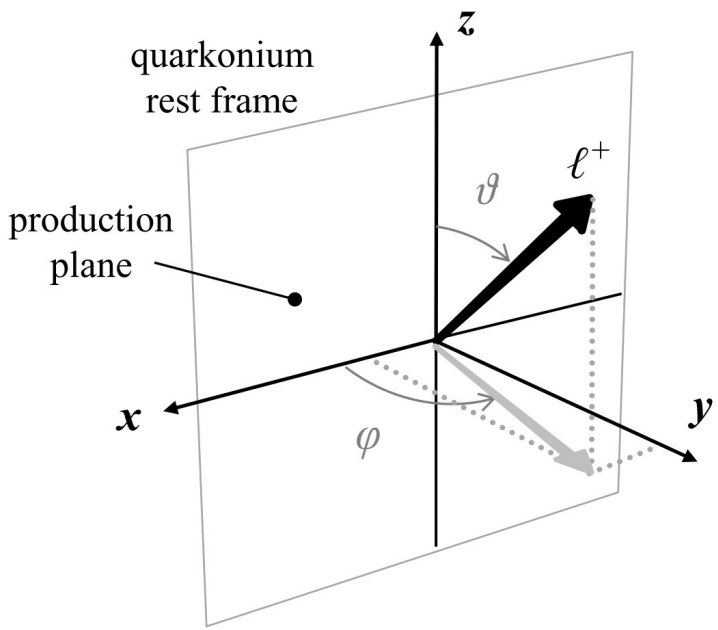


Z. Liang, X. Wang, PLB 629 (2005) 20-26
P. Faccioli et al. EPJ C69 (2010) 657-673
F. Becattini et al., PRC 77 (2008)
Christakoglu et al., EPJC (2021) **81**: 717

- **pp collisions**: Important to study the production of vector mesons in hadronic collisions, and also needed to provide **a reference** for Pb–Pb measurements
- **AA collisions**: Polarization measurements give access to different time scales and mechanisms, like the early-produced magnetic field, angular momentum, and hadronization mechanisms

Introduction of the reference frames





$$W(\cos\theta,\phi) \propto \frac{1}{3+\lambda_\theta}\cdot\left(1+\lambda_\theta\cos^2\theta+\lambda_\phi\sin^2\theta\cos 2\phi+\lambda_{\theta\phi}\sin 2\theta\cos\phi\right) \quad \lambda_\theta=\frac{1-3\rho_{00}}{1+\rho_{00}} \quad \begin{cases}\lambda_\theta>0\rightarrow\rho_{00}<1/3\\ \lambda_\theta<0\rightarrow\rho_{00}>1/3\end{cases}$$

Polarization axis:

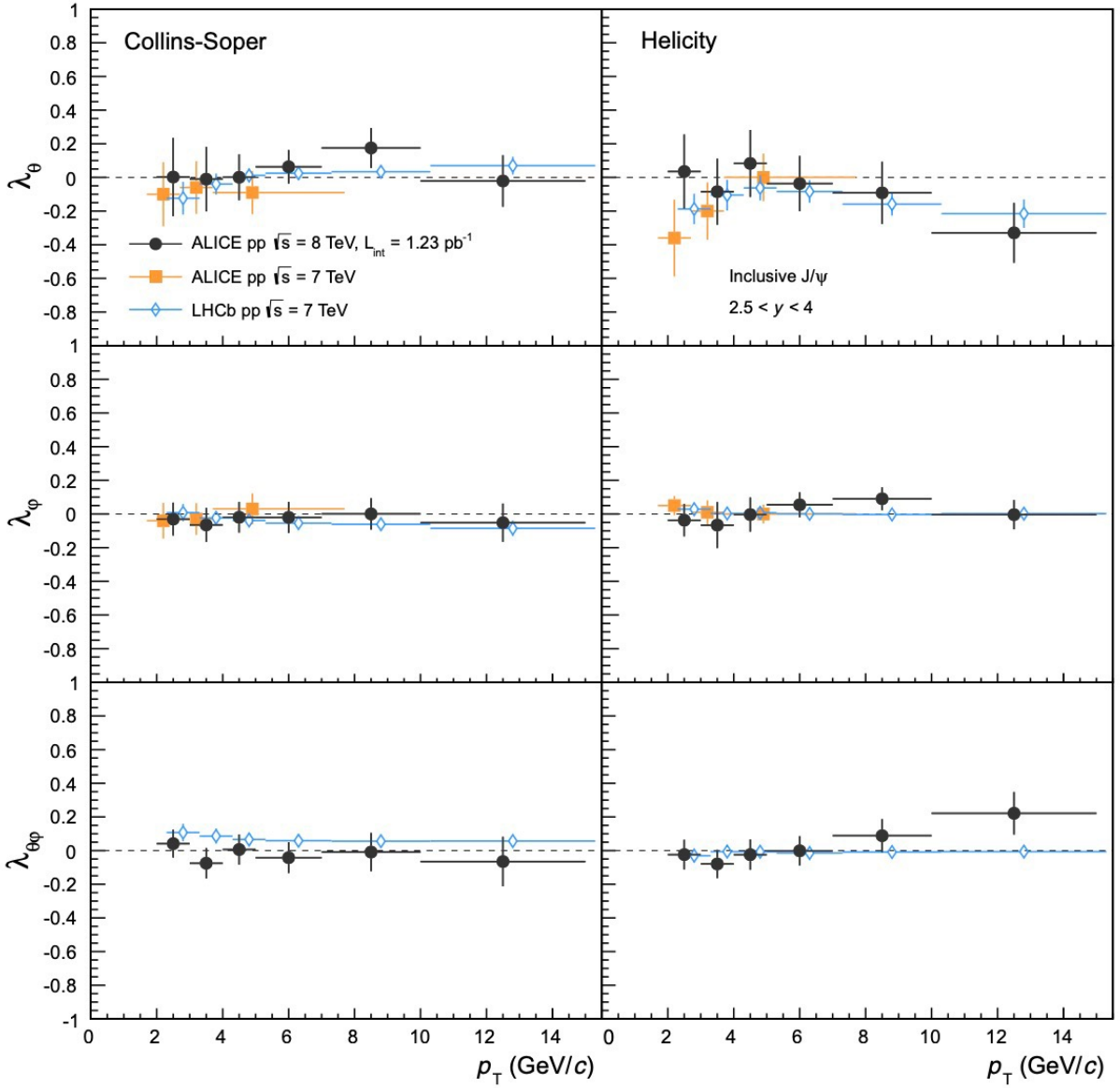
P. Faccioli et al. EPJ C69 (2010) 657-673

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

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

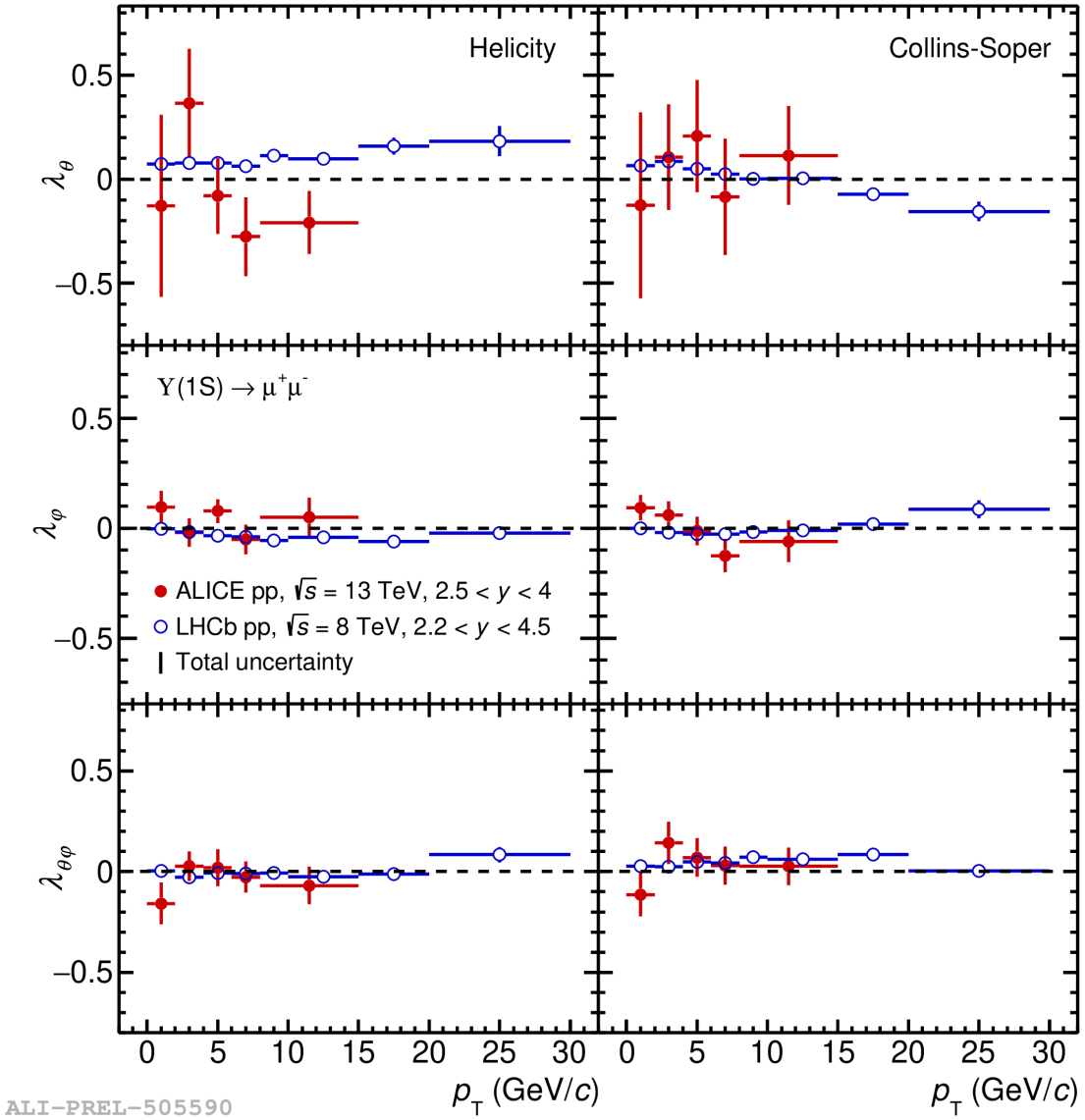
J/ψ polarization in pp collisions



- No strong J/ψ polarization is observed by ALICE at forward rapidity up to p_T = 15 GeV/c
- Results compatible within uncertainties with LHCb measurements at 7 TeV

ALICE, PRL 108 (2012) 082001
ALICE, EPJC 78 (2018) 562
LHCb, Eur. Phys. J. C (2013)
V. Cheung, JHEP 12 (2018) 057
Y, Mang, Phys.Rev.D 104 (2021) 9, 094026

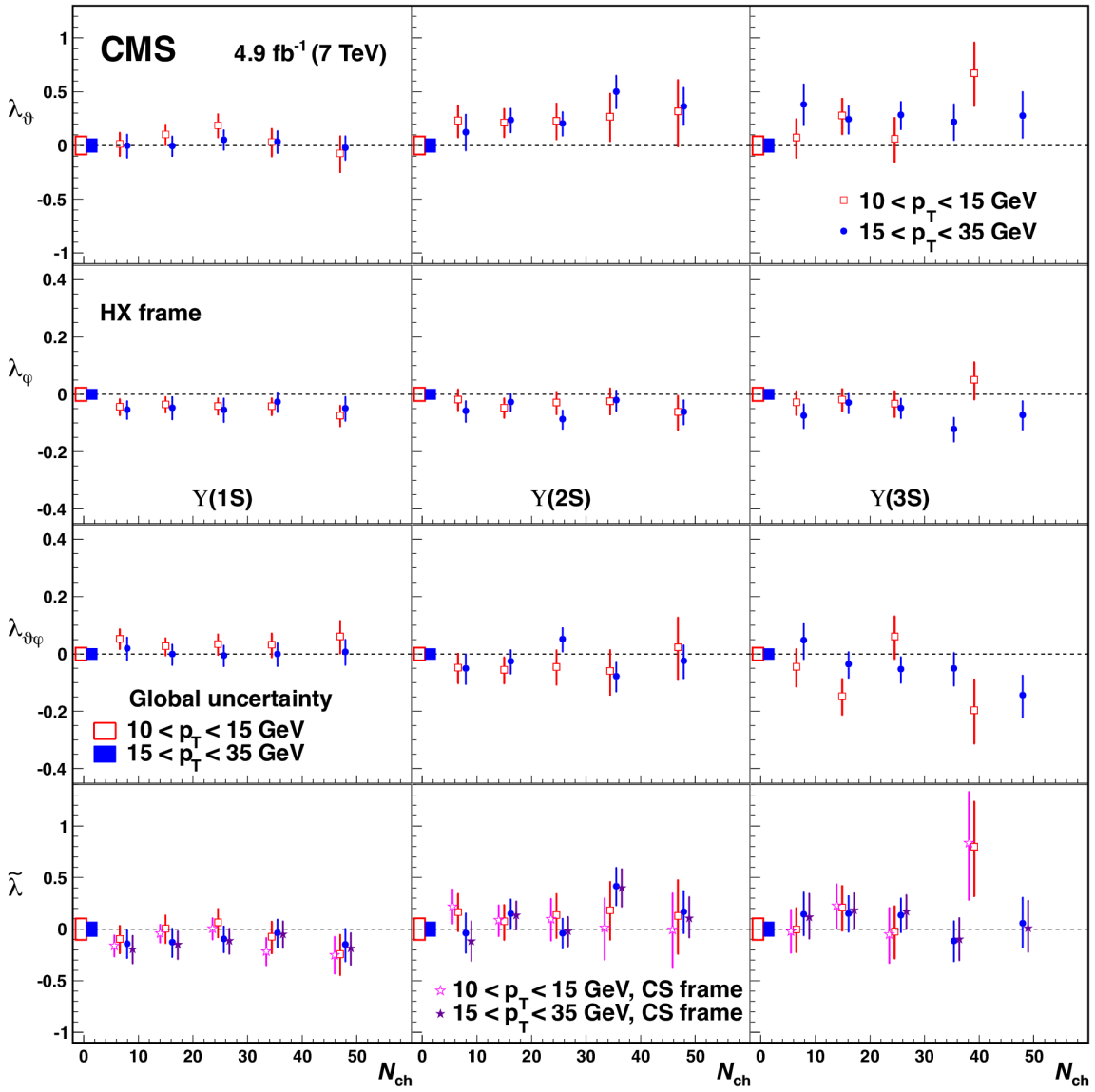
Υ(1S) polarization in pp collisions



- λ_θ, λ_ϕ, $\lambda_{\theta\phi}$ are compatible with zero in Helicity and Collins-Soper reference frames, ALICE does not observe a significant p_T dependence within the uncertainties
- λ_θ, λ_ϕ, $\lambda_{\theta\phi}$ evaluated down to zero p_T
- Results compatible within uncertainties with LHCb measurements at 8 TeV

LHCb, JHEP 12 (2017) 110

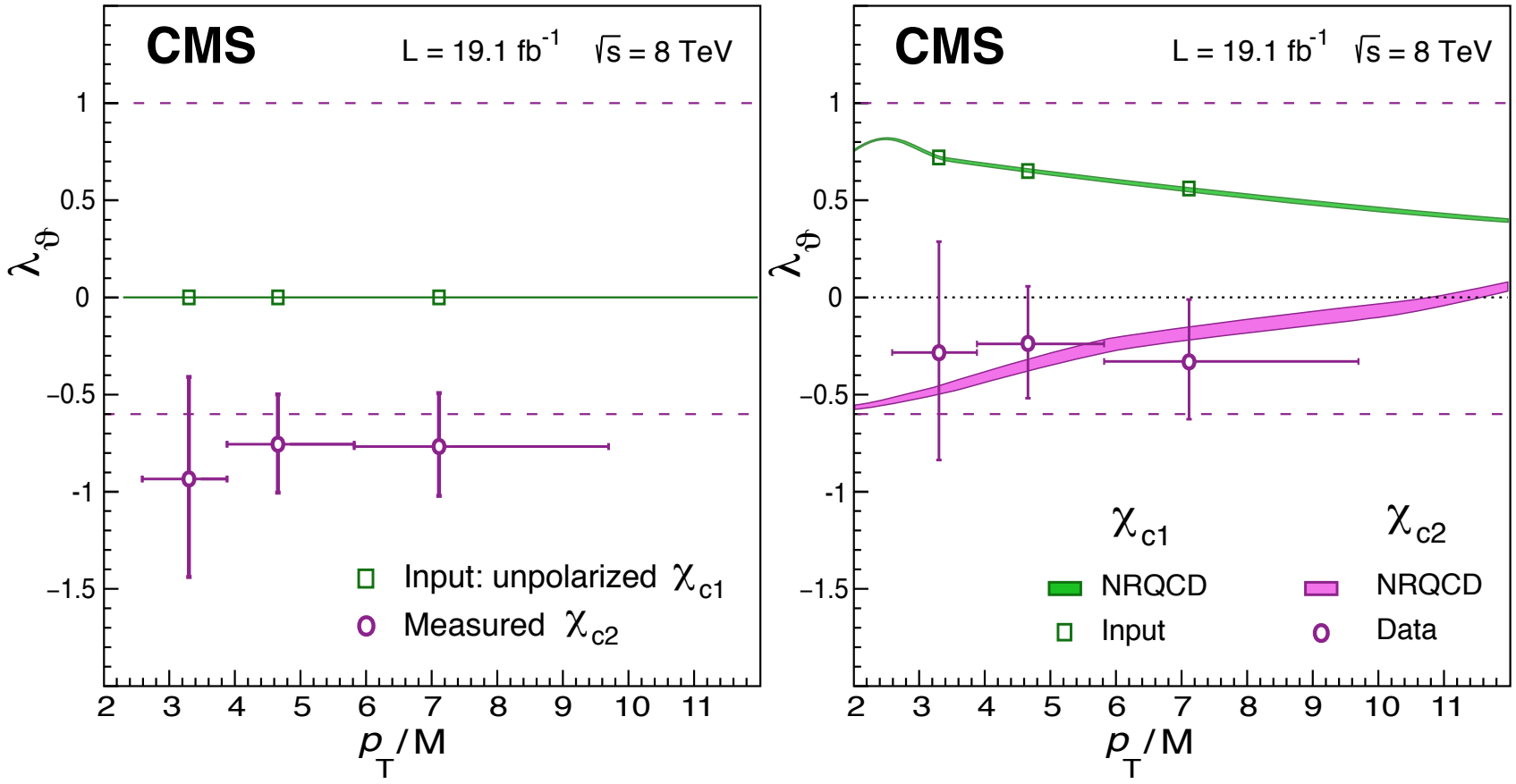
Υ(nS) polarization in pp collisions at CMS



- λ_θ, λ_ϕ, $\lambda_{\theta\phi}$, and $\tilde{\lambda}$ are closer to zero in Helicity and Collins-Soper reference frames.
- Does not observe a significant multiplicity and p_T dependence within the uncertainties

CMS, Phys. Rev. D 97 (2018) 072010

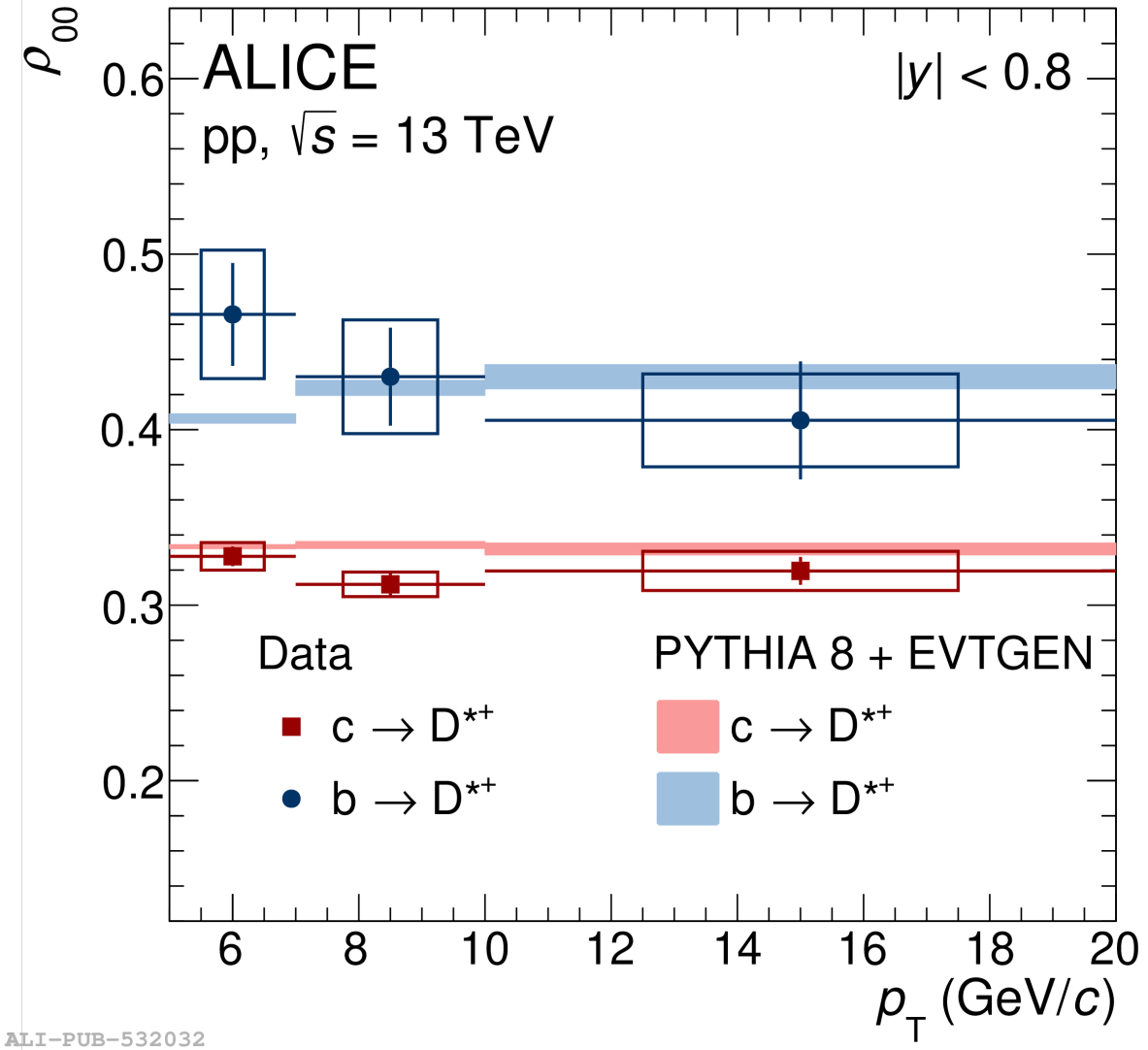
χ_{c1} and χ_{c2} polarisations in pp collisions



- A significant difference between χ_{c1} and χ_{c2} in the helicity frame is observed.
- An agreement with the NRQCD prediction

CMS, Phys. Rev. Lett. 124 (2020) 162002
P. Faccioli, et al, Eur. Phys. J. C 78, 268 (2018)

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

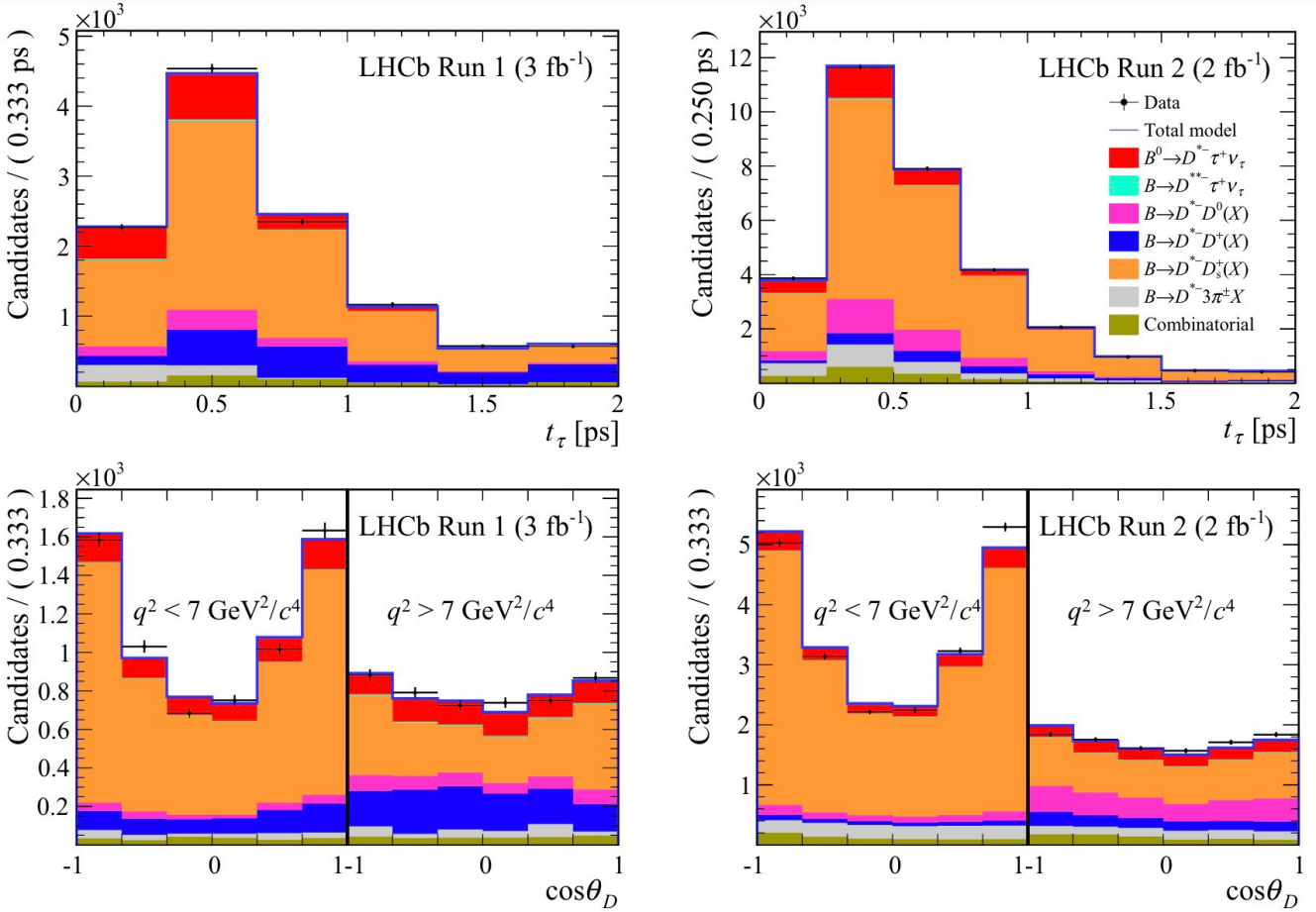


- Measurement performed with respect to the helicity reference frame
- Prompt $\mathbf{D}^{*+}$ ρ_{00} compatible with 1/3 within uncertainties (no polarization)
- Non-prompt $\mathbf{D}^{*+}$ $\rho_{00} > 1/3$ due to the helicity conservation of the beauty hadrons decay
- The charm quarks are either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

$$\frac{\mathrm{d}N}{\mathrm{d}\cos\theta^*} \propto \left[1 - \rho_{00} + (3\rho_{00} - 1)\cos^2\theta^*\right]$$

ALICE, Phys.Lett.B 846 (2023) 137920
T. Sjöstrand et al., CPC 191 (2015) 159-177

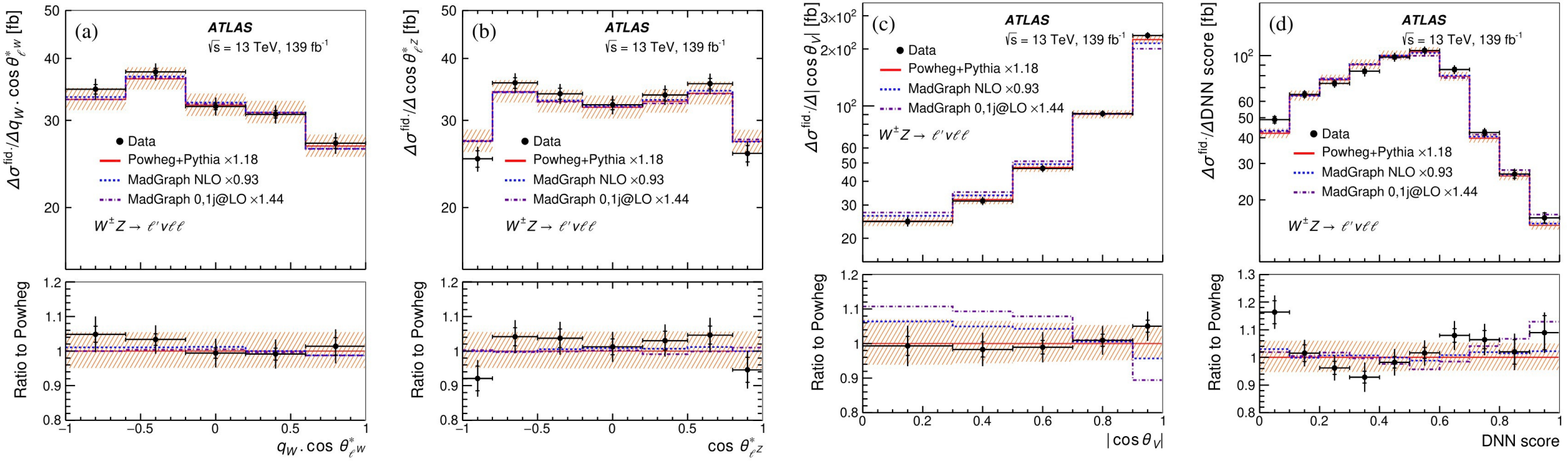
Measurement of the D^{*+} longitudinal polarization fraction



LHCb, arXiv:2311.05224

- First measurement of the **D^{*+}** longitudinal polarization fraction via $B^0 \to D^{*-}\tau^+\nu_\tau$ decay
- These measurements are compatible with SM predictions and with the results obtained by the Belle experiment

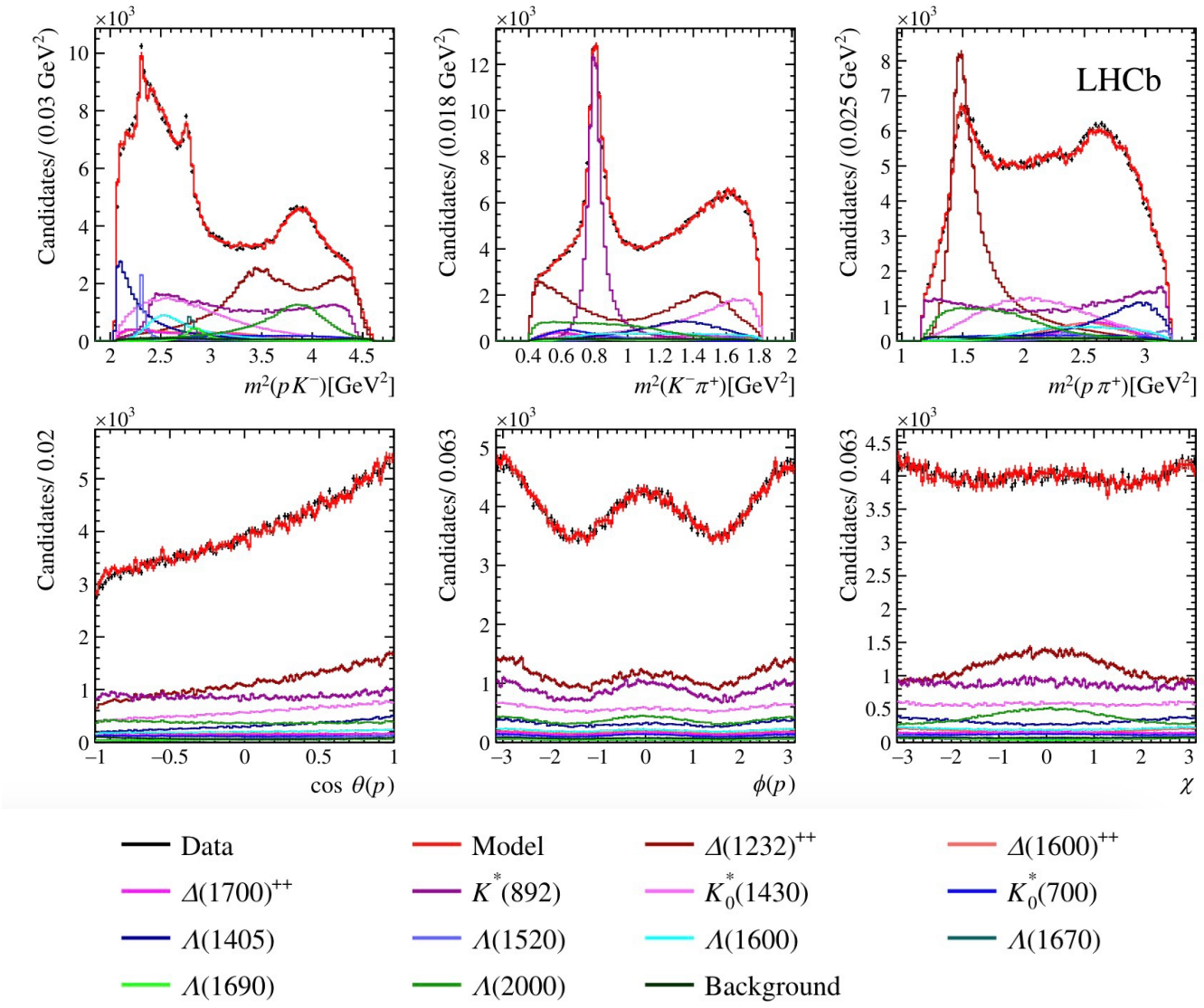
First observation of joint-polarization of $W^{\pm}Z$



- First observation of joint-polarization of $W^{\pm}Z$
- The measured values agree with the SM predictions and are consistent with the measured joint helicity fractions when neglecting interference among polarisation states

ATLAS, Phys. Lett. B 843 (2023) 137895
M. Grazzini, JHEP 05 (2017) 139

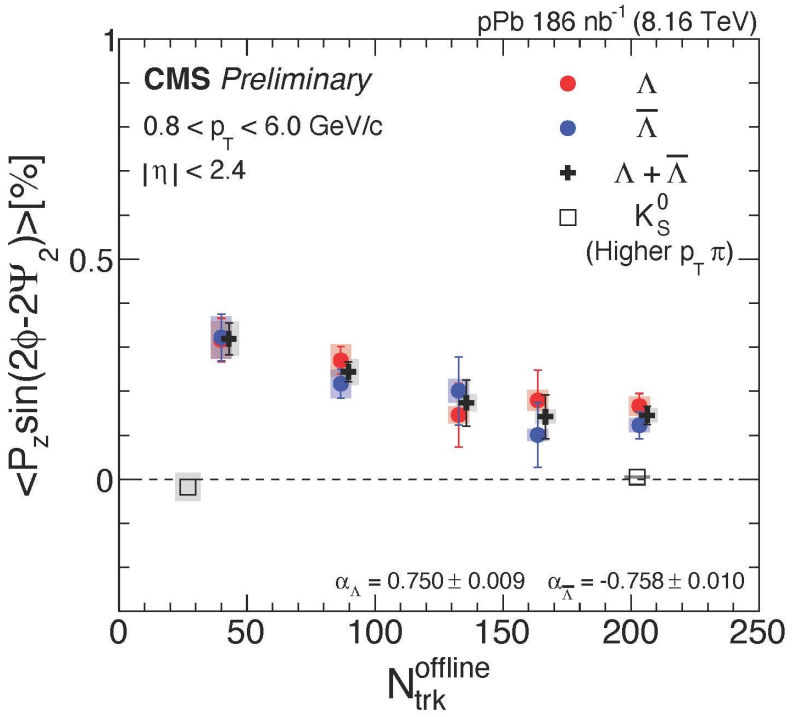
Λ_c^+ baryon polarization measurement

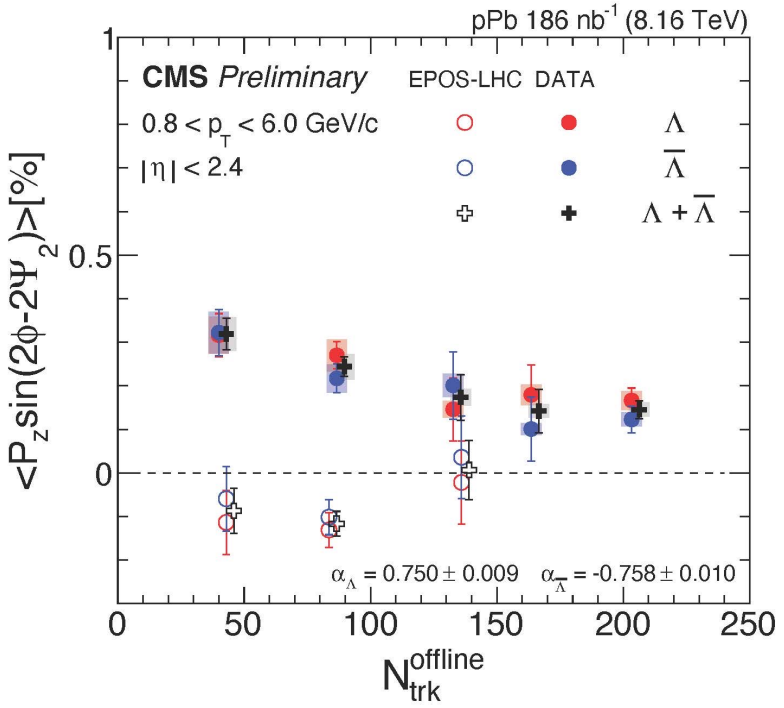


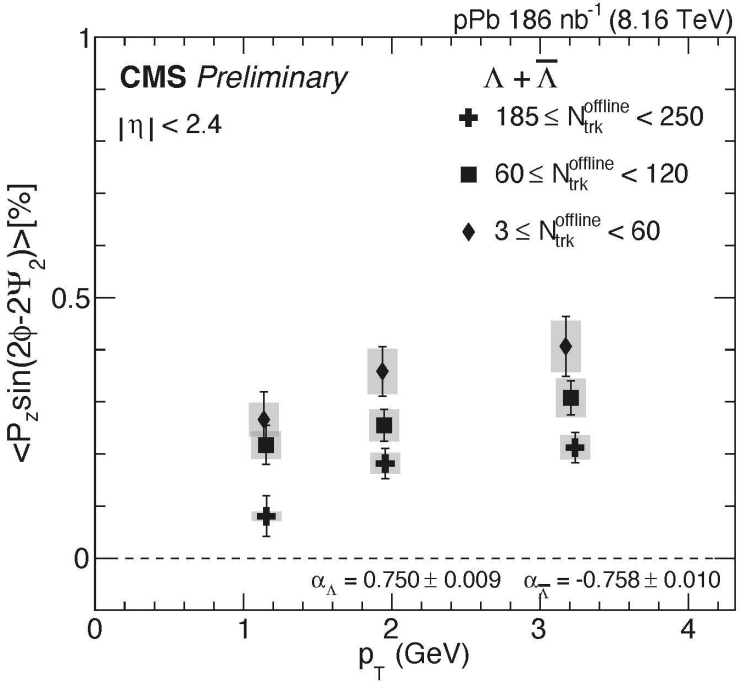
- Λ_c^+ polarization was measured via $\Lambda_c^+ \to pK^-\pi^+$, large Λ_c^+ polarization is found, measured with absolute uncertainties of order 1%.
- The normal polarization, sensitive to time-reversal violation effects and final-state interactions, is compatible with zero

LHCb, PhysRevD.108.012023

Azimuthal dependence of hyperon polarization

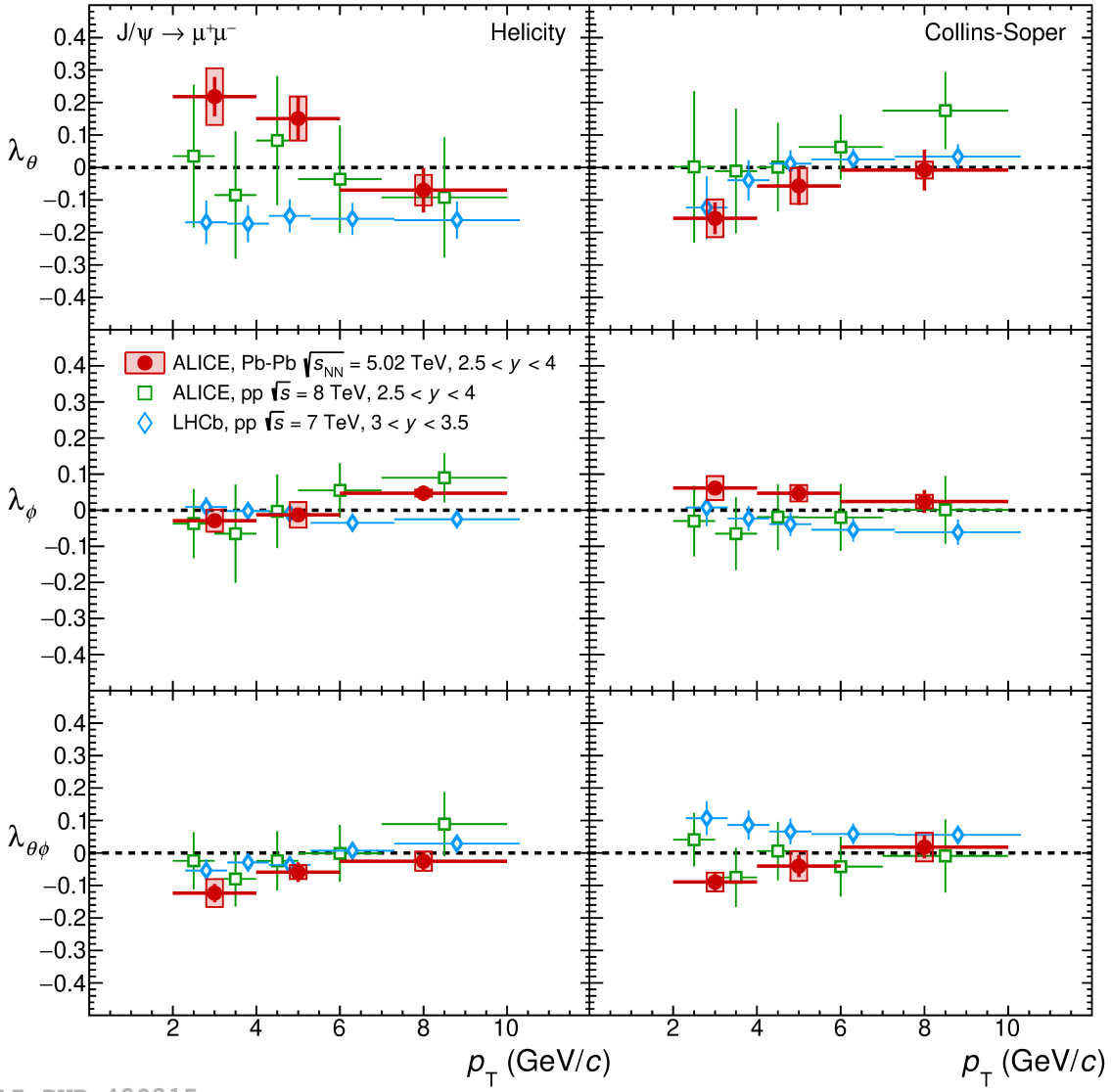






- First observation of the Λ polarization along the beam direction in p–Pb collisions
- Multiplicity dependence does not fully agree with vorticity expectation
- It remains to see if other polarisation mechanism is the origin, e.g. polarisation fragmentation functions

Charmonium polarization results in heavy-ion collisions

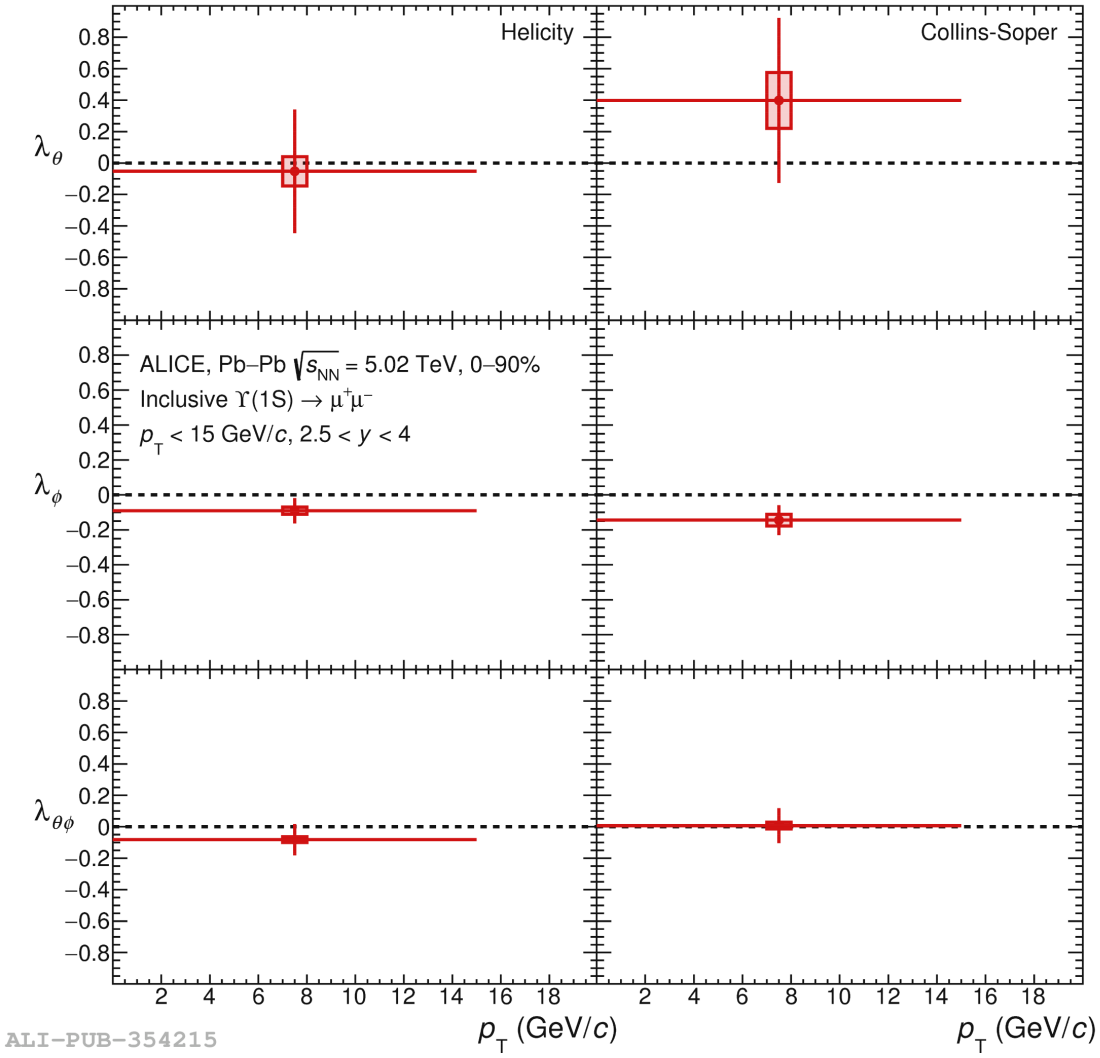


ALI-PUB-490215

- 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** at low p_T.
- Comparable with ALICE results at 8 TeV in pp collisions within uncertainties.

ALICE, Phys.Lett.B 815 (2021) 136146
ALICE, Eur. Phys. J. C78 no. 7, (2018) 562
LHCb, JHEP 12 (2017) 110

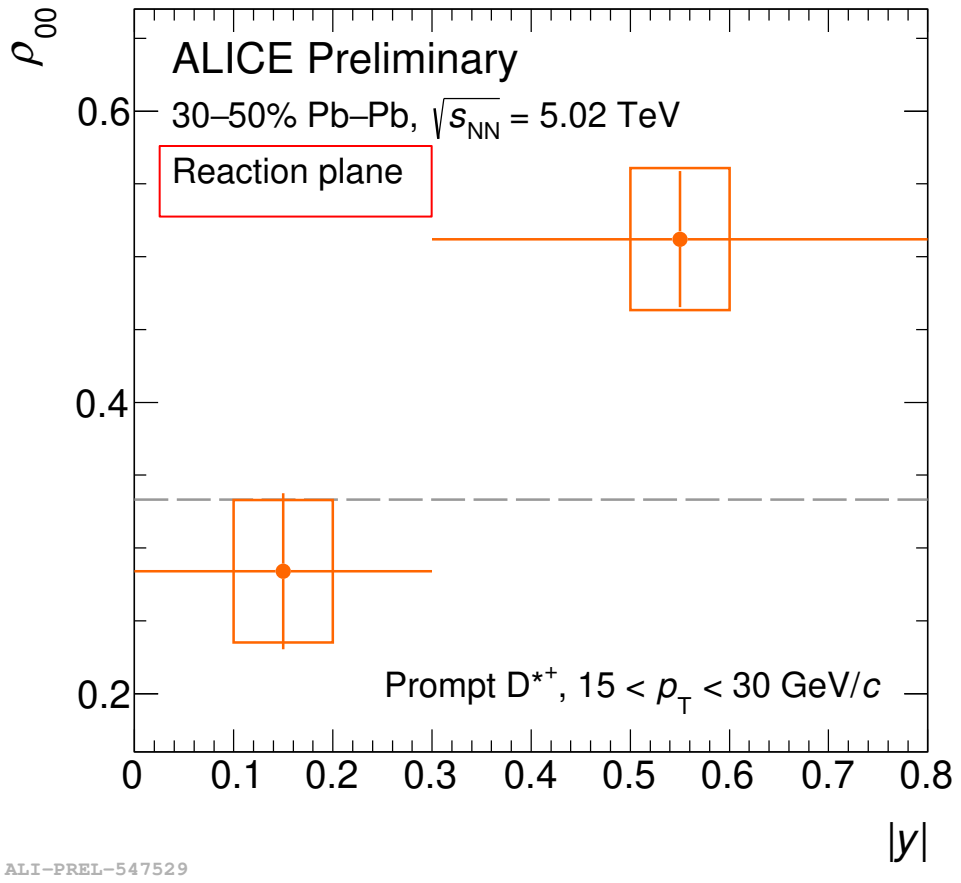
Bottomonia polarization results in heavy-ion collisions

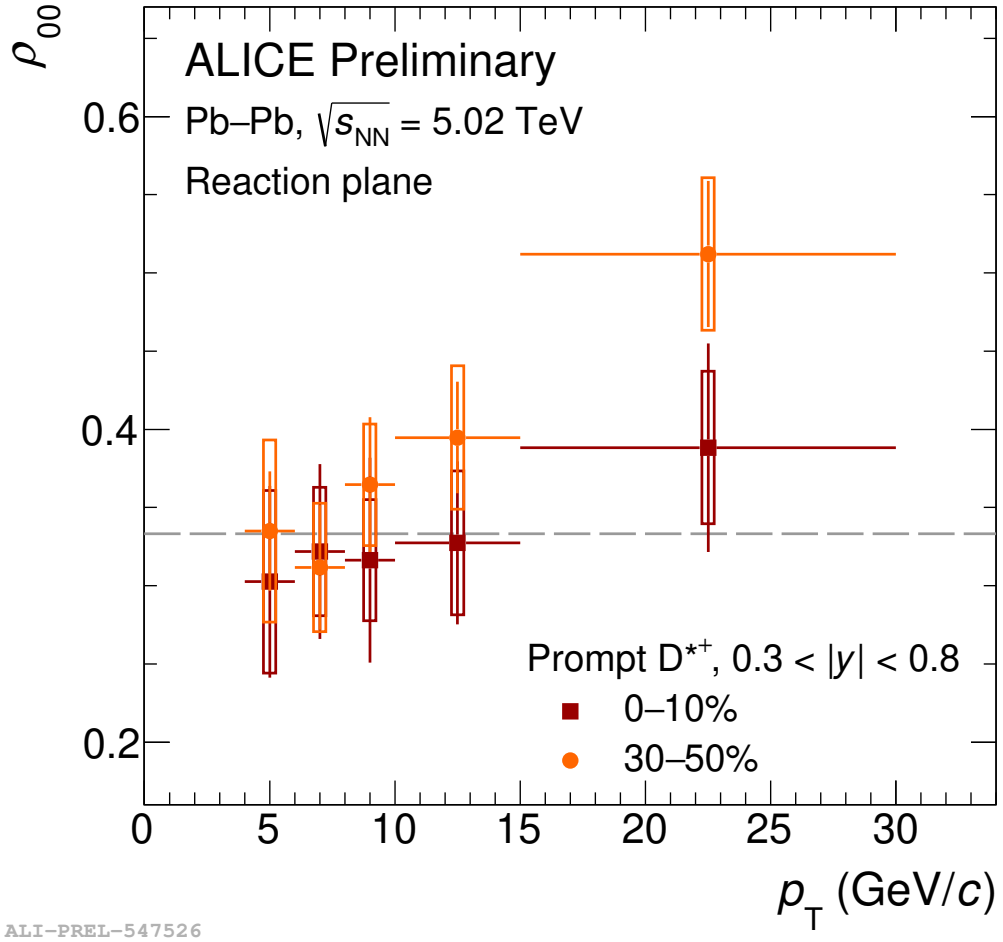


- Measuring bottomonia , early production of the beauty quarks, significantly lower contribution via (re-)generation
- The $\Upsilon(1s)$ polarization was measured in Helicity and Collins-Soper reference frames
- λ_θ, λ_ϕ, $\lambda_{\theta\phi}$ all compatible with zero but the measurement is still strongly limited by the statistics

ALICE, Phys.Lett.B 815 (2021) 136146

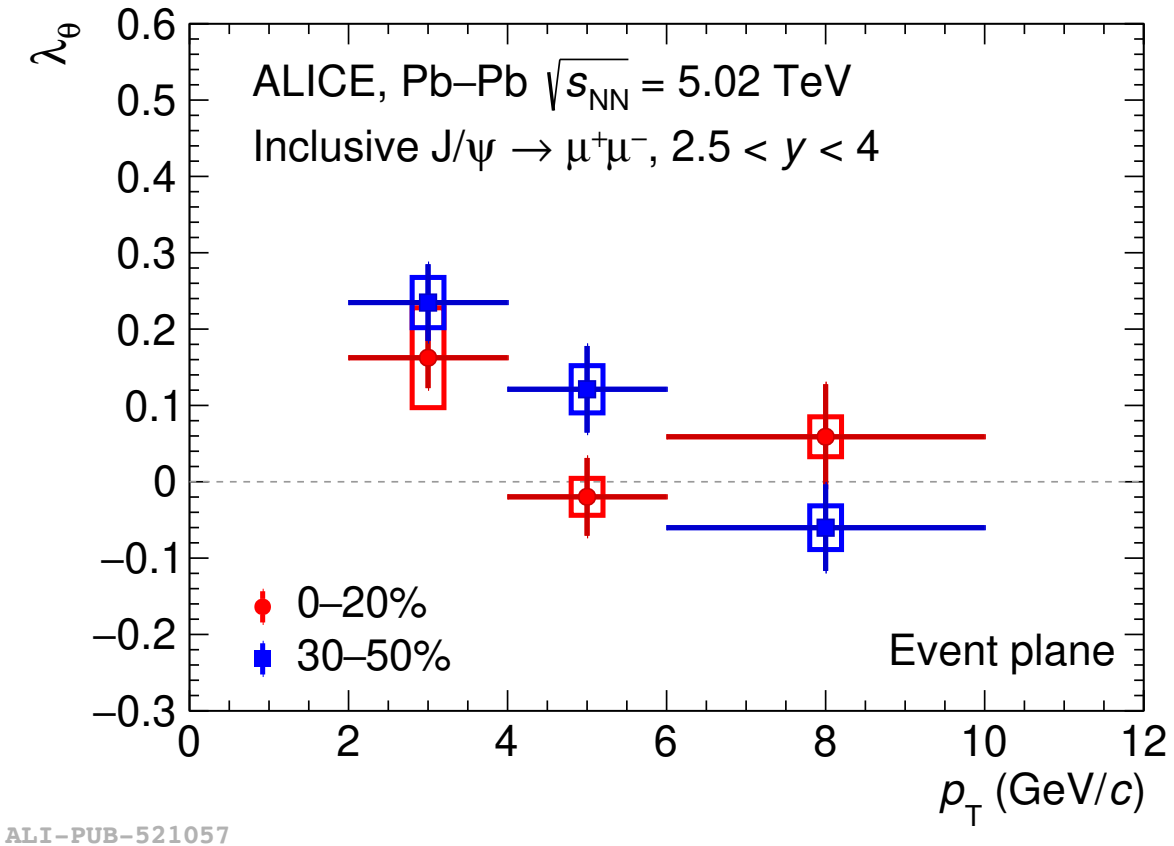
D^{*+} global polarization in Pb–Pb collisions

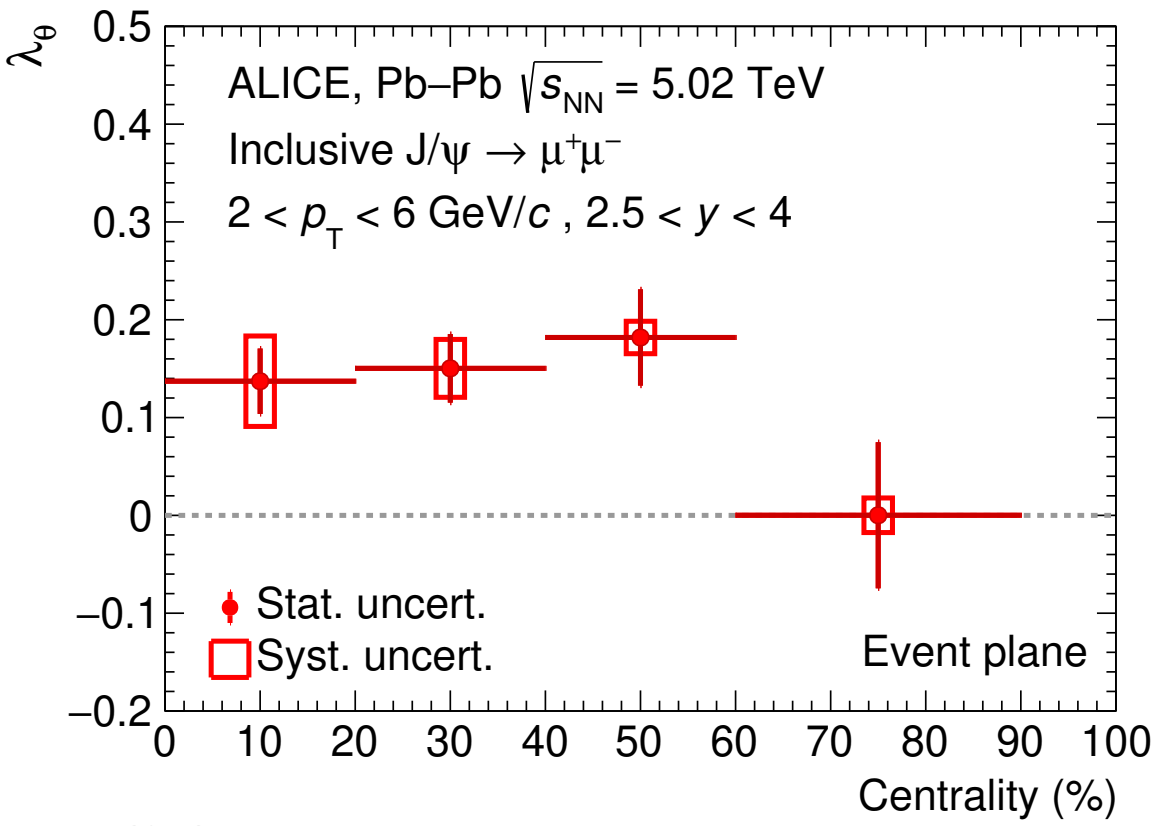




- 0 – 10% : ρ_{00} compatible with 1/3 , 30–50% : $\boldsymbol{\rho_{00}}$ > 1/3 at high p_T
- Significant deviation at larger rapidity (0.3 < |y| < 0.8) than at midrapidity (|y| < 0.3)

J/ψ global polarization in Pb–Pb collisions

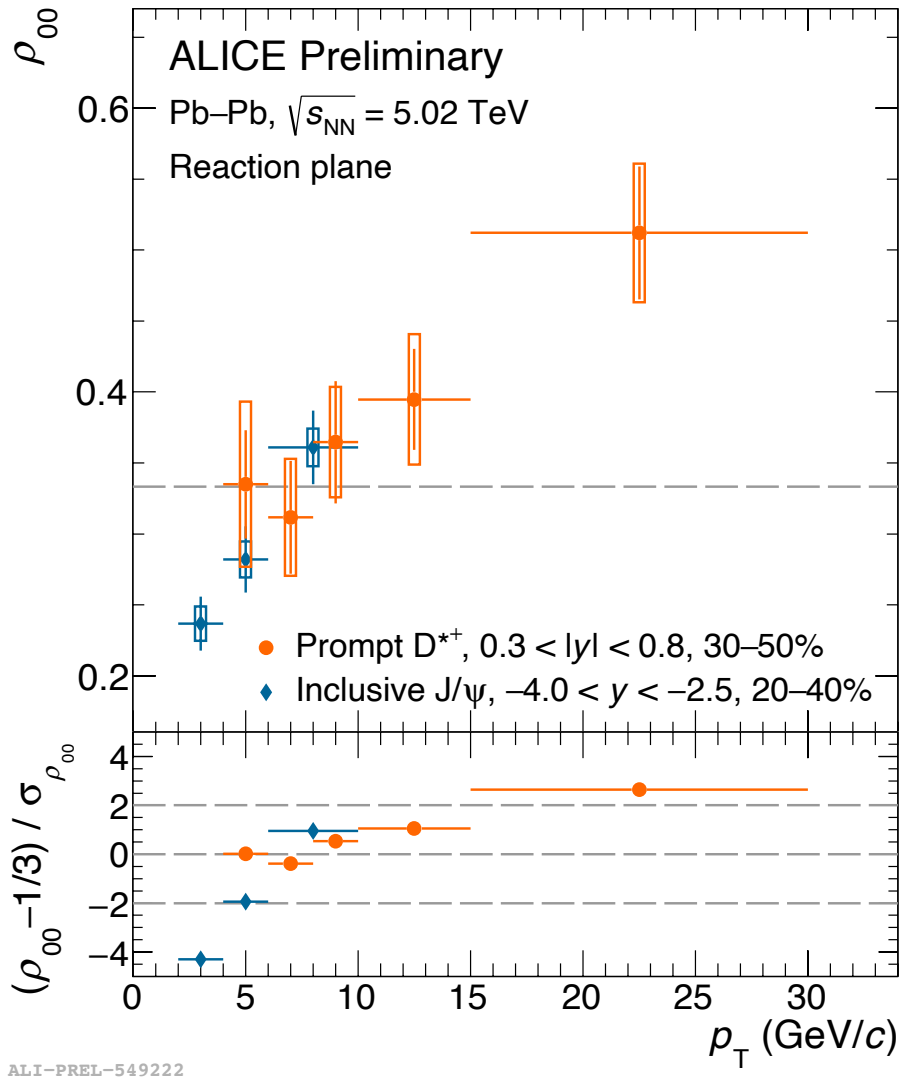




- The λ_θ deviation reaches ~$\mathbf{3.9\sigma}$ at low p_T ($2 < p_T < 4$ GeV/c) in 30-50%
- Significant polarization (~$\mathbf{3.5\sigma}$) observed in semicentral collisions (40-60%) in $2 < p_T < 6$ GeV/c
- In LHC Run 3 ALICE will be able to study polarization at midrapidity via the dielectron channel

ALICE, PRL 131 (2023) 4, 042303

J/ψ and D^{*+} global polarization comparions



- Agreement with the:
  - $\boldsymbol{\rho_{00}} < 1/3$ quark recombination at low p_T
  - $\boldsymbol{\rho_{00}} > 1/3$ quark fragmentation at high p_T

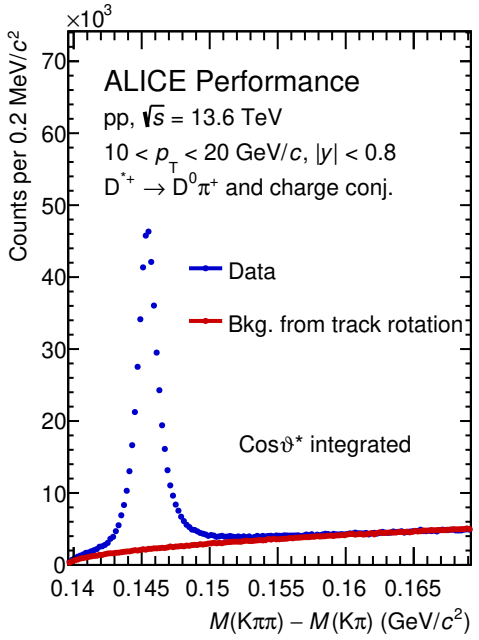
$$\lambda_\theta = \frac{1-3\rho_{00}}{1+\rho_{00}} \quad \begin{cases} \lambda_\theta > 0 \rightarrow \rho_{00} < 1/3 \\ \lambda_\theta < 0 \rightarrow \rho_{00} > 1/3 \end{cases}$$

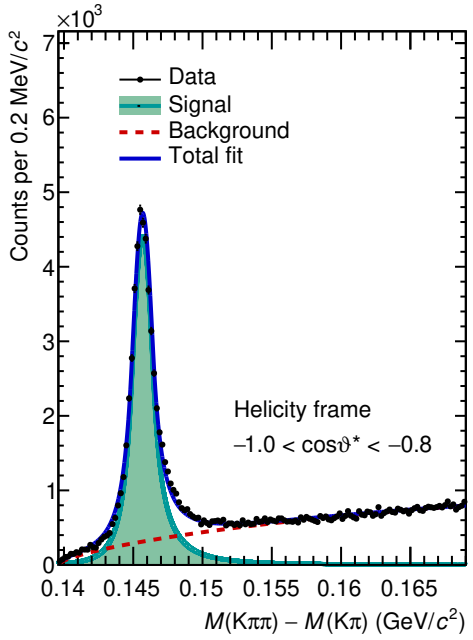
Z. Tang, X. Wang, Phys.Lett. B 629 (2005) 20-26

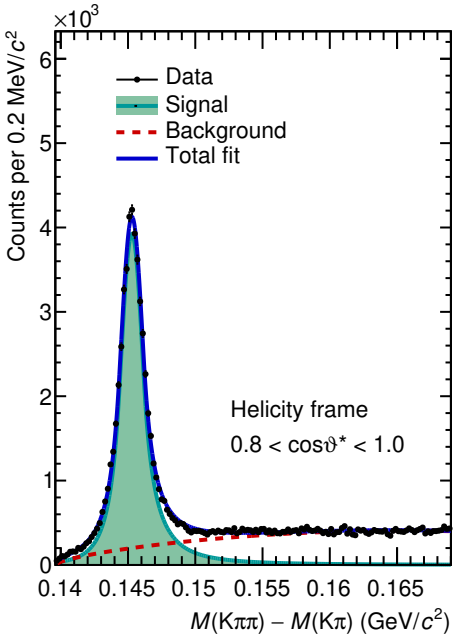
- At high p_T the fragmentation of heavy quarks polarized by the magnetic field translates to $\boldsymbol{\rho_{00}} > 1/3$?

- Theory guidance needed!

Heavy-flavour polarization measurements in Run 3







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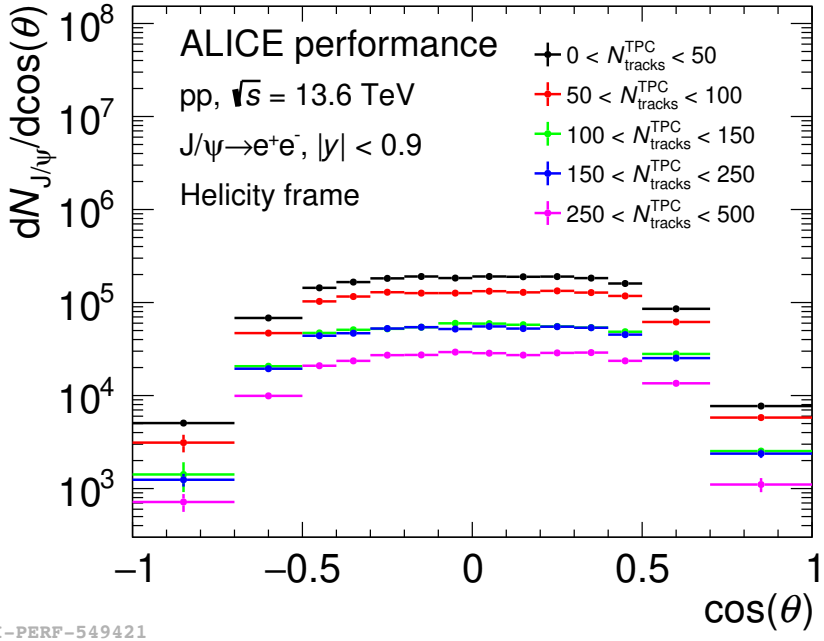

ALI-PERF-549421

- 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.

Summary

➢ pp and p–Pb collisions:

- The measured **J/ψ, Y(nS) , and prompt D^{*+}** polarization are closer to 0.
- A significant difference between $\boldsymbol{\chi_{c1}}$ **and** $\boldsymbol{\chi_{c2}}$ in the helicity frame is observed
- A significant Λ polarization is observed in p–Pb collisions, which depends on multiplicity and p_T
- More precise results can be expected from Run 3

➢ Pb–Pb collisions

- **J/ψ and Y(1S)** polarization consistent with zero in Helicity and Collins-Soper reference frames, but significant polarization (~$\boldsymbol{3.9\sigma}$) observed w.r.t the reaction plane for J/ψ
- D^{*+} polarization depends on the centrality, p_T and rapidity
- **Theory guidance is needed to interpret the data**

Thanks