

# 15<sup>th</sup> workshop on QCD Phase Transition and Relativistic Heavy Ion Collisions

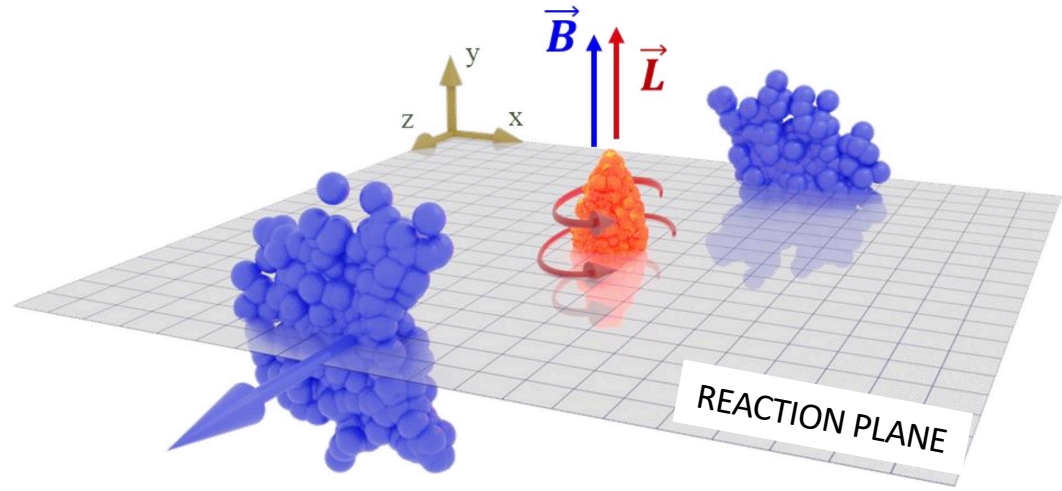
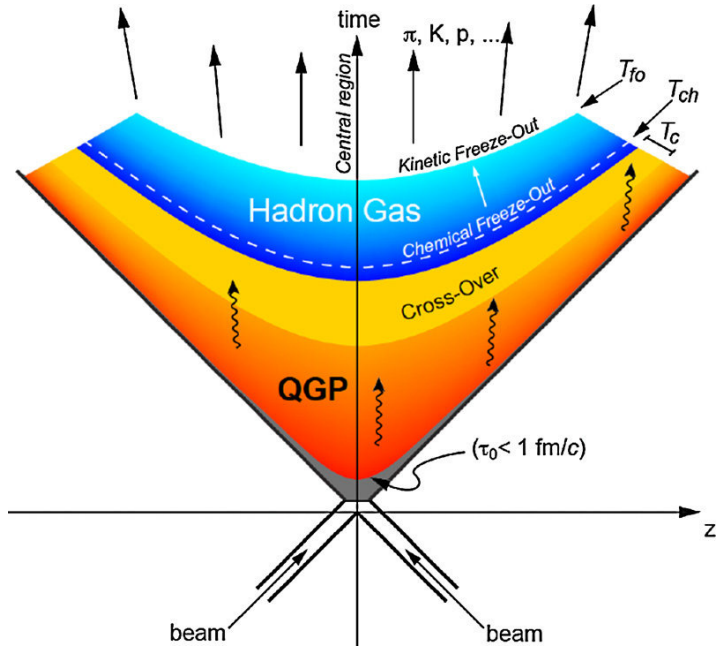
## Vector meson polarization measurements in pp and Pb-Pb collisions with ALICE at the LHC

Xiaozhi Bai (白晓智)

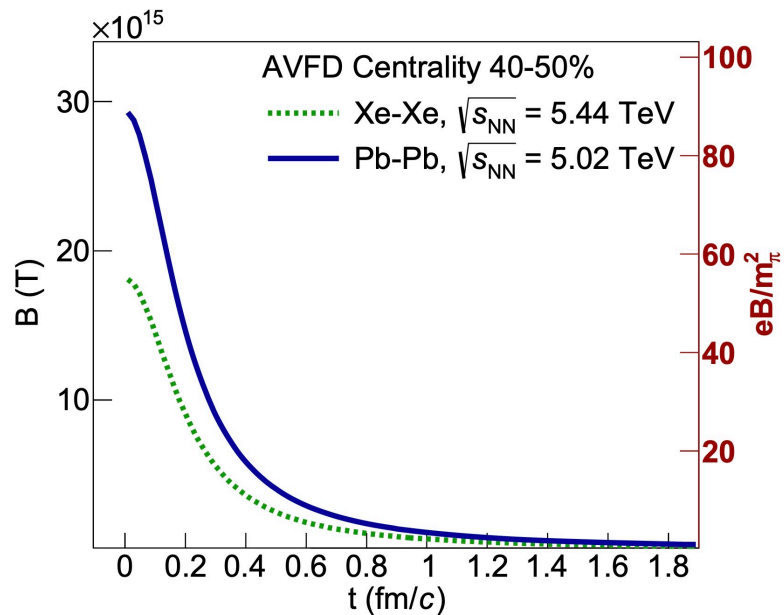
University of Science and Technology of China

Zhuhai China, 17th Dec. 2023

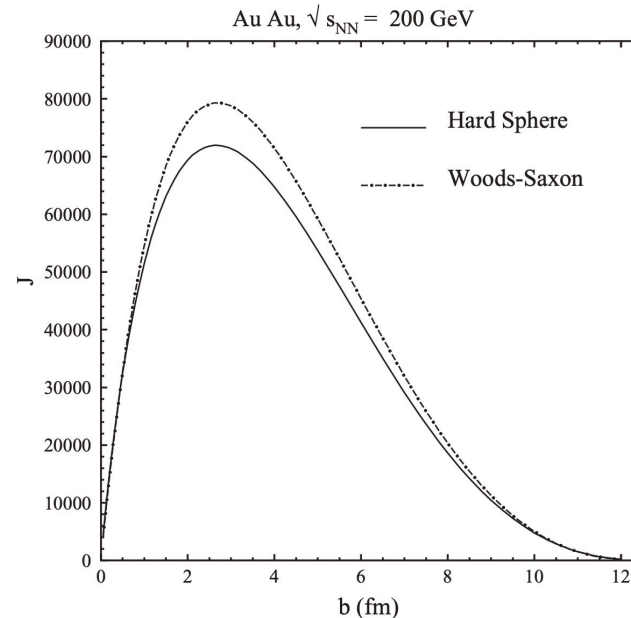




- In non-central heavy-ion collisions, short-lived magnetic fields ( $\vec{B}$ ) and very strong orbital momentum ( $\vec{L}$ ) are expected to be produced.
- They can influence the global polarization of the produced particles.

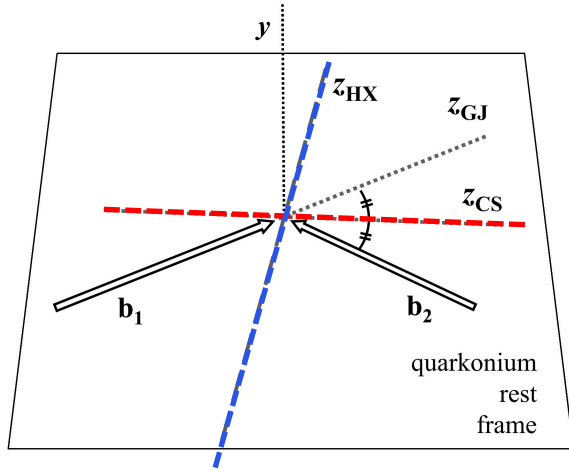


Christakoglu et al., EPJC (2021) 81: 717

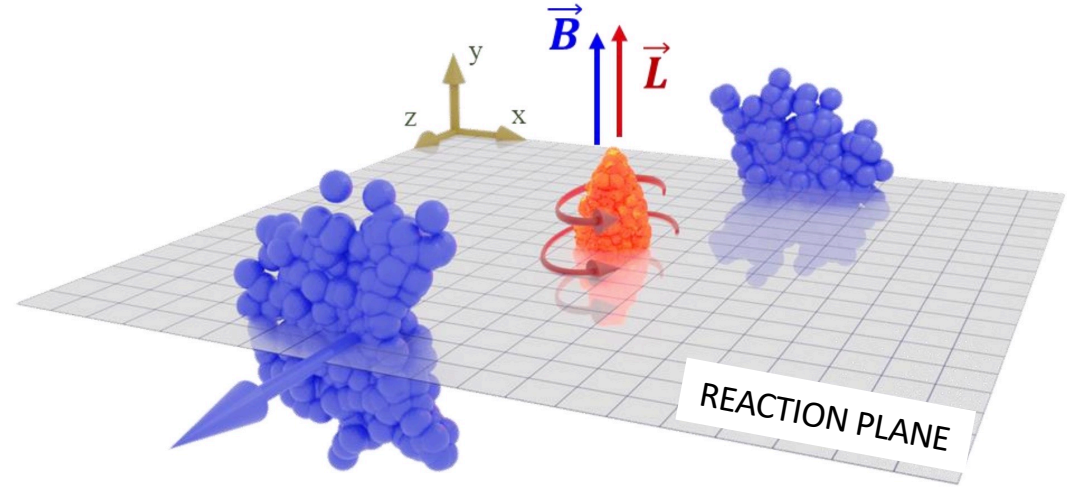


F. Becattini et al., PRC 77 (2008)

- Lifetime increases from mid to forward rapidity, and decreasing quickly with time
- Angular momentum strongly depends on impact parameter ( $b$ )



$z$



## 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

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

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

**Quarkonia measurements:**

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

$\lambda_\theta =$  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

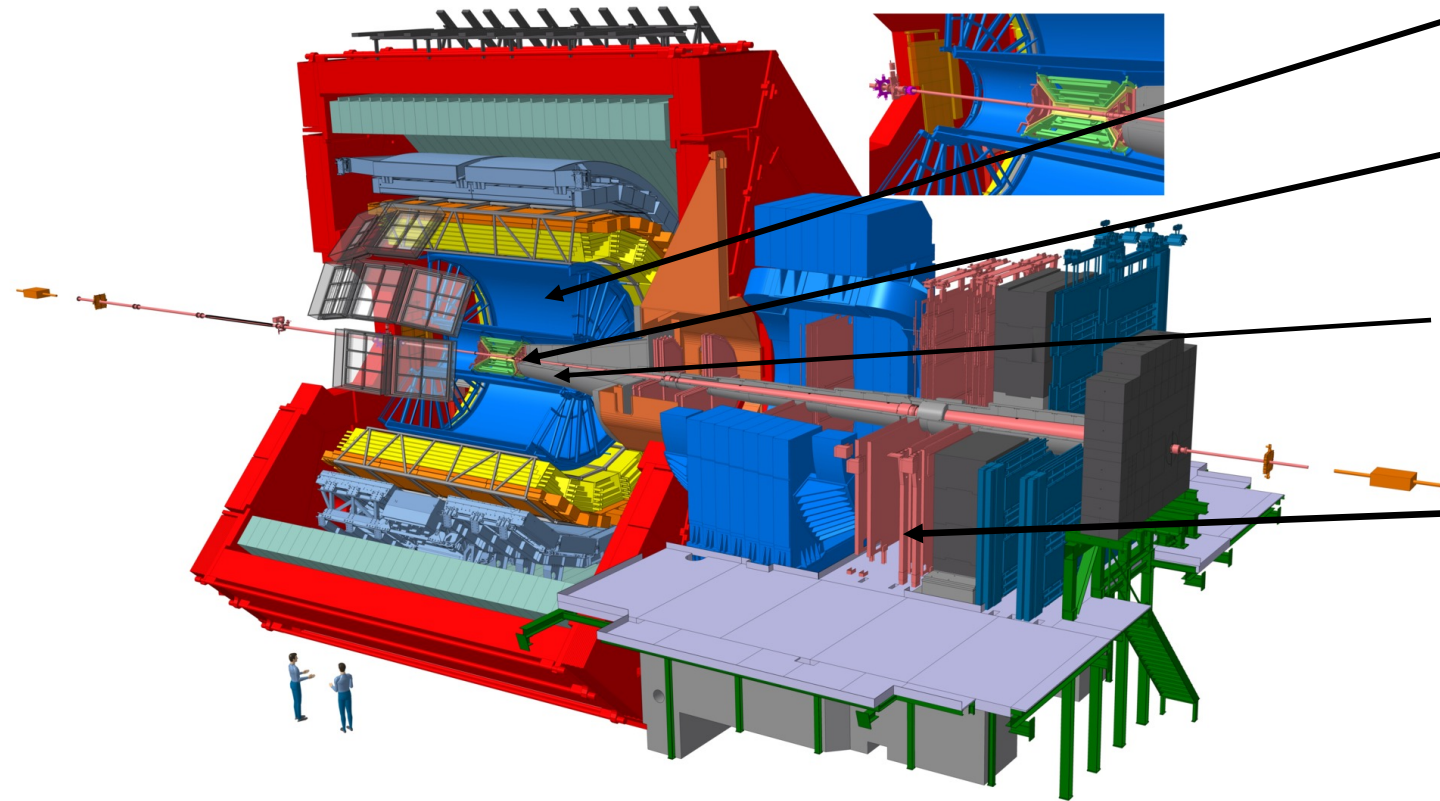
Y. Yang, et al., Phys. Rev. C 97, (2018)034917

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, hadronization mechanisms, and strong force field...

# ALICE detector (Run 2)



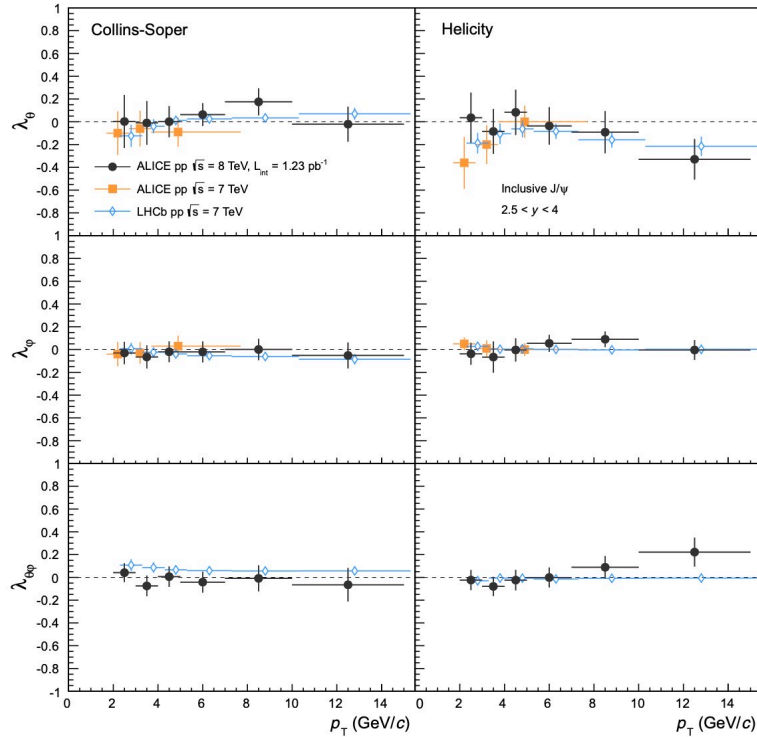
**Time Projection Chamber**  
Tracking, particle identification

**Inner Tracking System**  
Tracking, vertex reconstruction,  
event plane determination

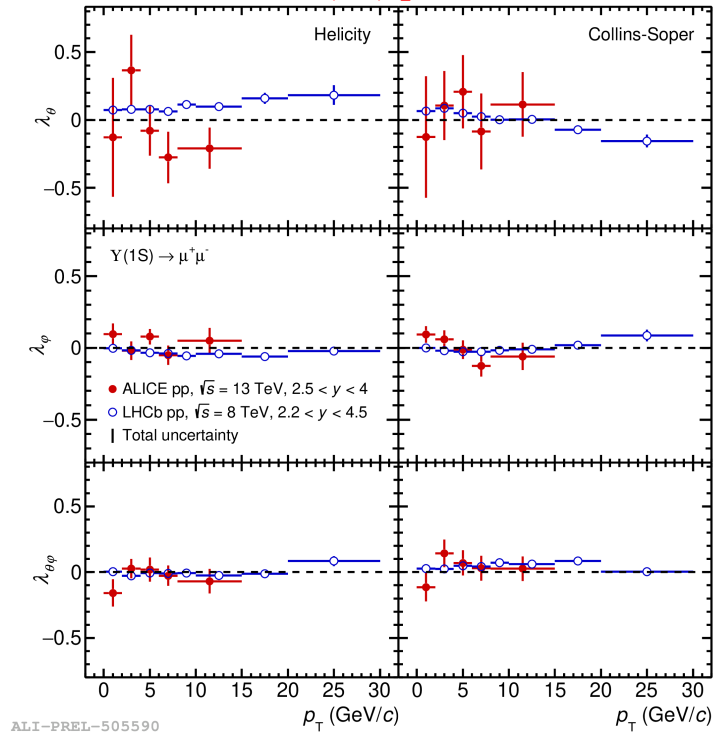
**V0 Detector**  
Centrality determination,  
triggering, event plane  
determination, and background  
rejection

**Muon spectrometer**  
Trigger and tracking for muons

## J/ψ polarization



## Υ(1S) polarization

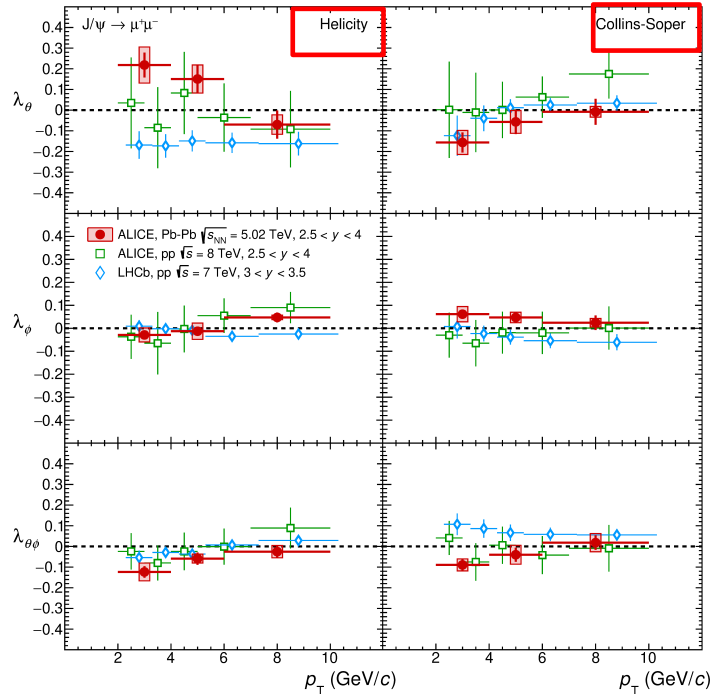


ALI-PREL-505590

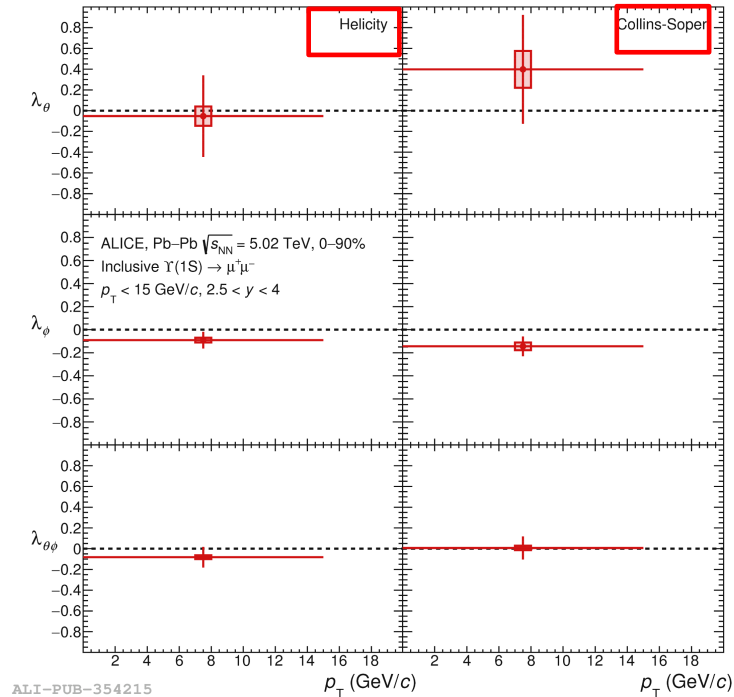
ALICE, PRL 108 (2012) 082001  
 ALICE, EPJC 78 (2018) 562  
 LHCb, JHEP,12(2017) 110  
 LHCb: JHEP 12 (2017) 110

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

## J/ψ polarization



## Υ(1S) polarization



ALI-PUB-490215

ALI-PUB-354215

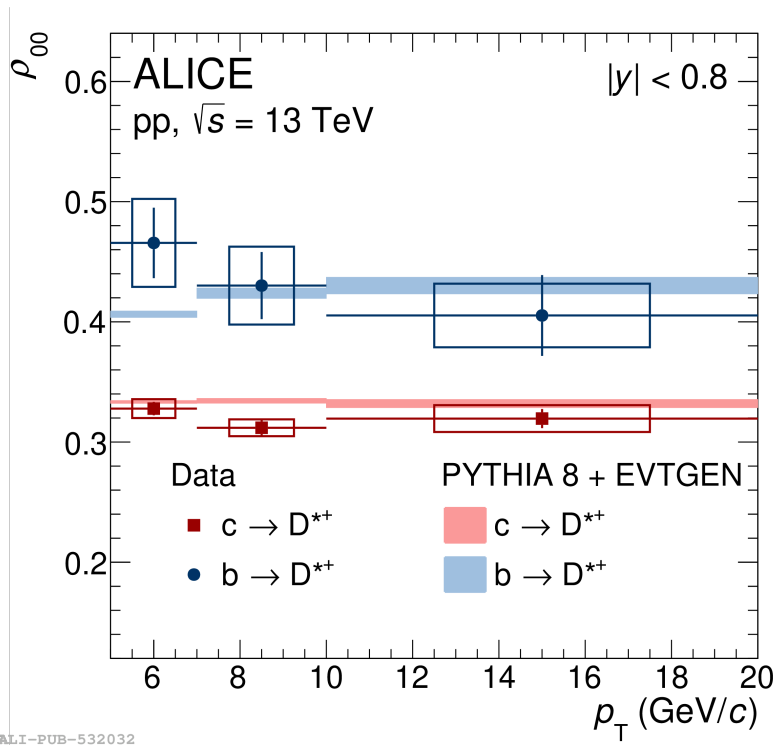
- **No strong polarization** is observed for  $\Upsilon(1S)$  although there are substantial uncertainties.
- Maximum deviation from zero is  $2.1\sigma$  in the low  $p_T$  bin for  $J/\psi$  in Helicity reference frame

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



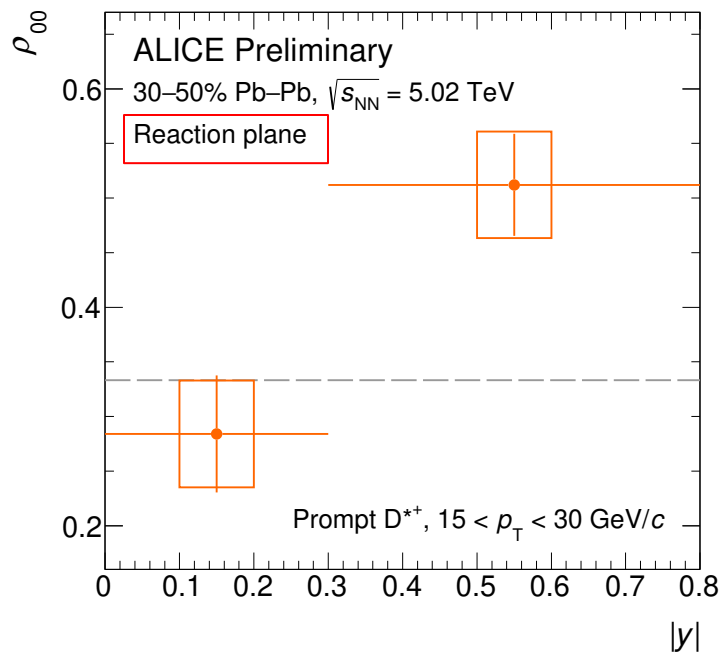
# The prompt and non-prompt $D^{*+}$ polarization in pp collisions

ALICE, *Phys.Lett.B* 846 (2023) 137920

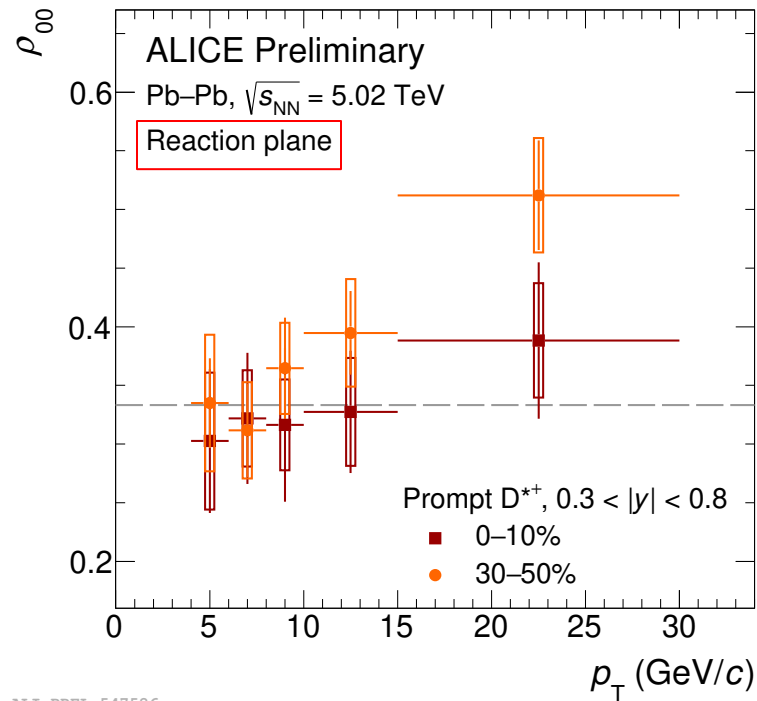


ALI-PUB-532032

- Measurement performed with respect to the helicity reference frame
- Prompt  $D^{*+}$   $\rho_{00}$  compatible with 1/3 within uncertainties (no polarization)
- Non-prompt  $D^{*+}$   $\rho_{00} > 1/3$  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



ALI-PREL-547529

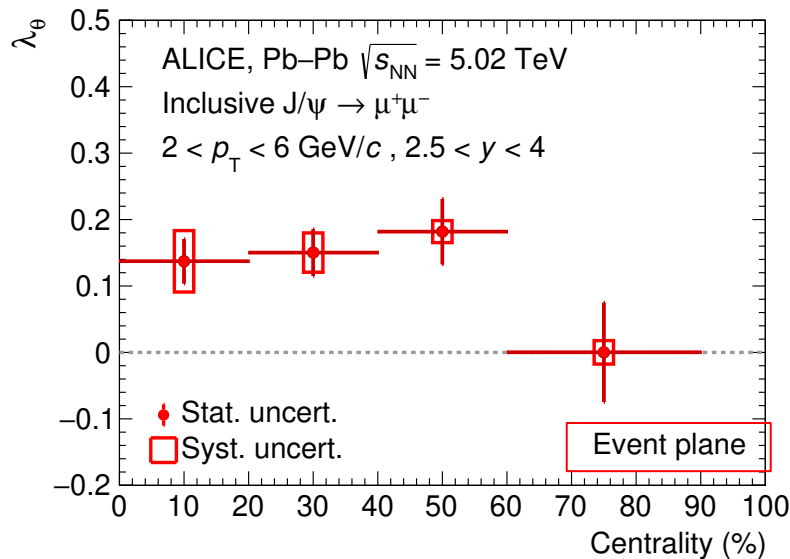


ALI-PREL-547526

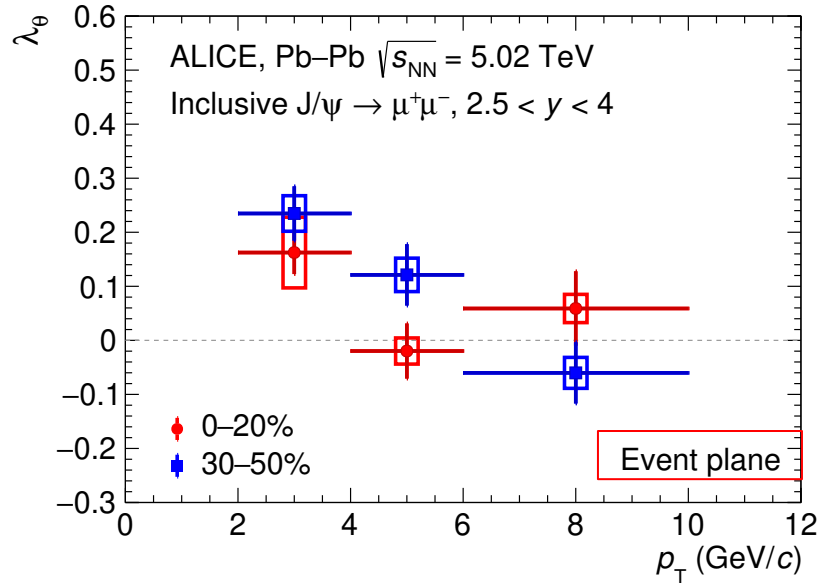
- 0 – 10% :  $\rho_{00}$  compatible with  $1/3$  , 30 – 50% :  $\rho_{00} > 1/3$  at high  $p_T$
- Significant deviation at larger rapidity ( $0.3 < |y| < 0.8$ ) than at midrapidity ( $|y| < 0.3$ )

# J/ψ polarization in Pb–Pb collisions

ALICE, PRL 131 (2023) 4, 042303

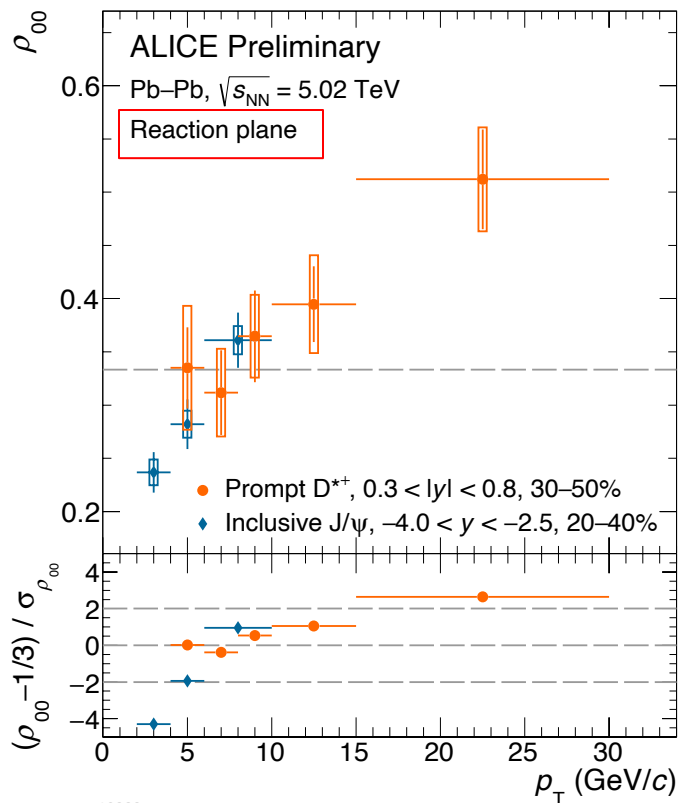


ALI-PUB-521052



ALI-PUB-521057

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



ALI-PREL-549222

➤ Agreement with the:

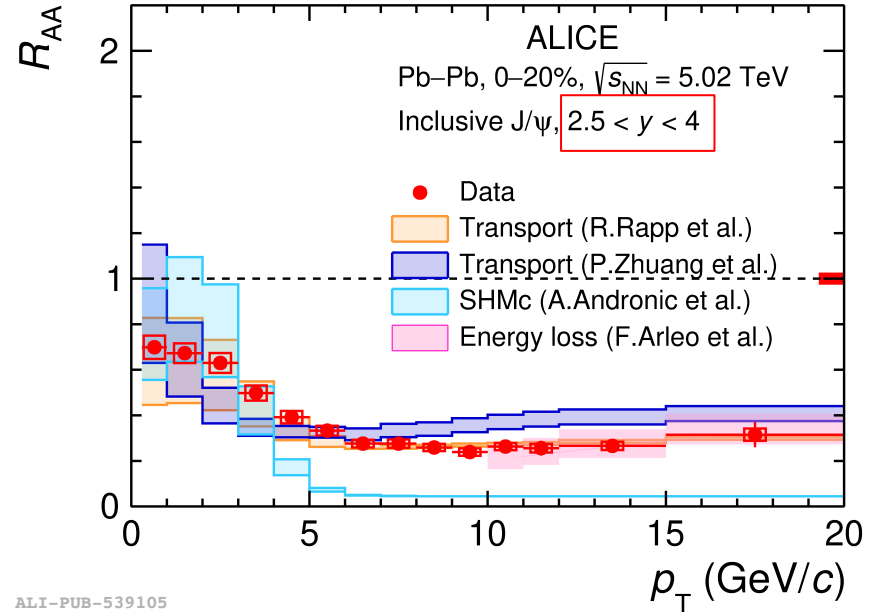
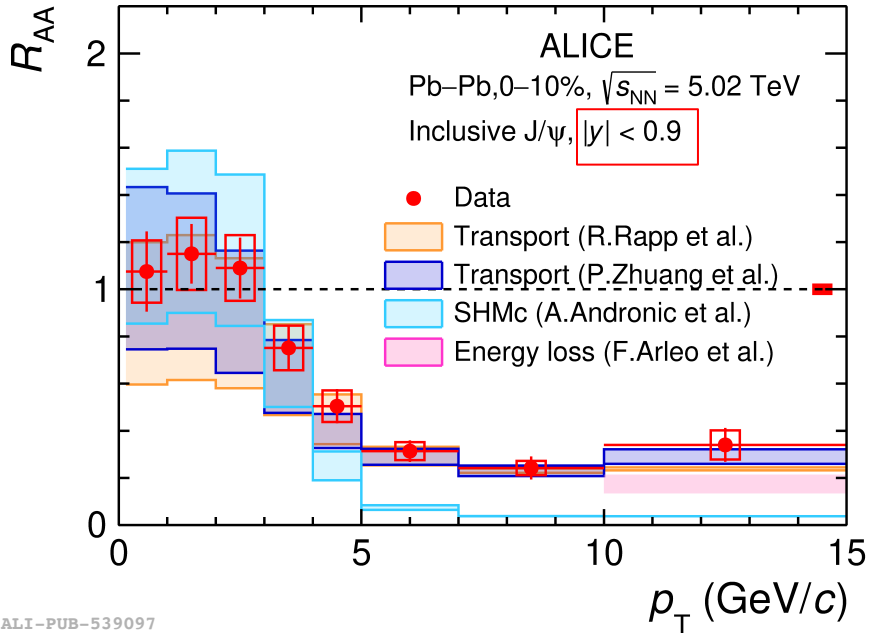
- $\rho_{00} < 1/3$  quark recombination at low  $p_T$
- $\rho_{00} > 1/3$  quark fragmentation at high  $p_T$

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

➤ Theory guidance needed!

# J/ψ production via recombination

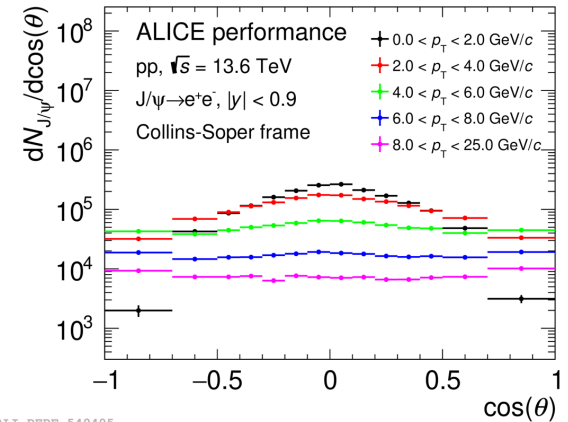
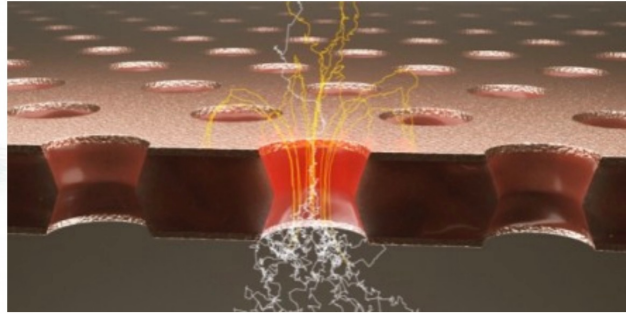
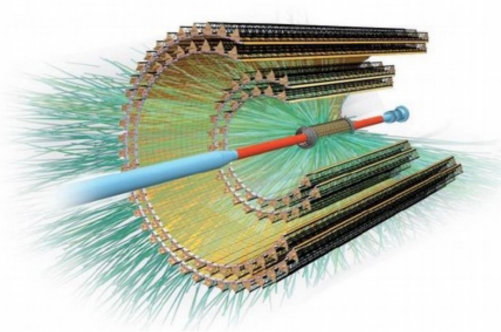
ALICE, arXiv:2303.13361



- The **recombination is a dominate process** for the J/ψ production **at low  $p_T$  and midrapidity**
- Is the J/ψ global polarization inherited from polarized charm quarks via uncorrelated charm and anticharm recombination?

More details in poster by Senjie Zhu, on Dec. 15<sup>th</sup> at 14:00

	$K^{*0}$	$\phi$	$D^{*+}$	$J/\psi$	$\Upsilon(1S)$
pp	$\rho_{00} \sim 1/3$ (production plane)	$\rho_{00} \sim 1/3$ (production plane)	$\rho_{00} \sim 1/3$ (HX)	$\rho_{00} \sim 1/3$ (HX and CS)	$\rho_{00} \sim 1/3$ (HX and CS)
Pb-Pb	$\rho_{00} < 1/3$ low $p_T$ (RP)	$\rho_{00} < 1/3$ low $p_T$ (RP)	$\rho_{00} > 1/3$ high $p_T$ (RP)	$\rho_{00} < 1/3$ (low $p_T$ ) (RP)	$\rho_{00} \sim 1/3$ (HX and CS)



- The  $J/\psi$  spin alignment will be measured via dielectron decay channel at midrapidity, for prompt and non-prompt  $J/\psi$  separately.
- The newly installed MFT enables the separation between prompt and non-prompt charmonium at forward rapidity

More details in two posters by Zhenjun Xiong, and Yuan Zhang on Dec. 15<sup>th</sup> at 14:00

# Summary

## ➤ pp collisions:

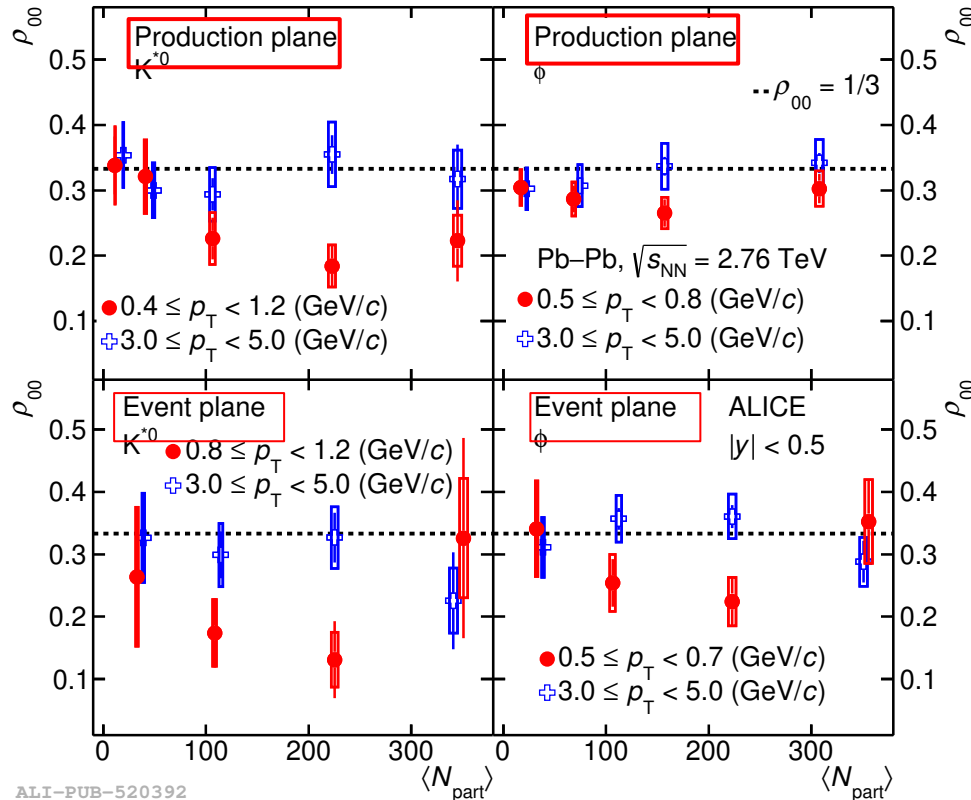
- The measured  $J/\psi$ ,  $Y(1S)$ ,  $D^{*+}$ ,  $K^{*0}$  and  $\phi$ , do not exhibit strong polarization

## ➤ Pb–Pb collisions

- $J/\psi$  and  $Y(1S)$  do not show strong polarization in Helicity and Collins-Soper reference frames, but significant polarization ( $\sim 3.9\sigma$ ) observed w.r.t the reaction plane for  $J/\psi$
- $D^{*+} \rho_{00}$  depends on the centrality,  $p_T$  and rapidity
- Theory guidance is needed to interpret the data



# Thanks



## Low $p_T$

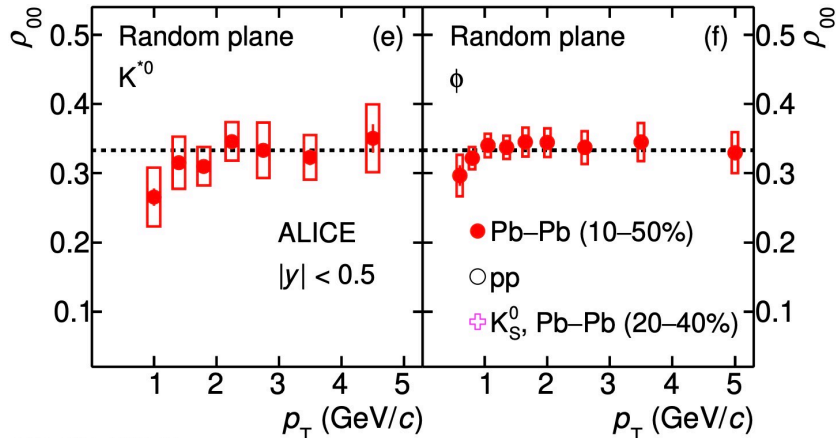
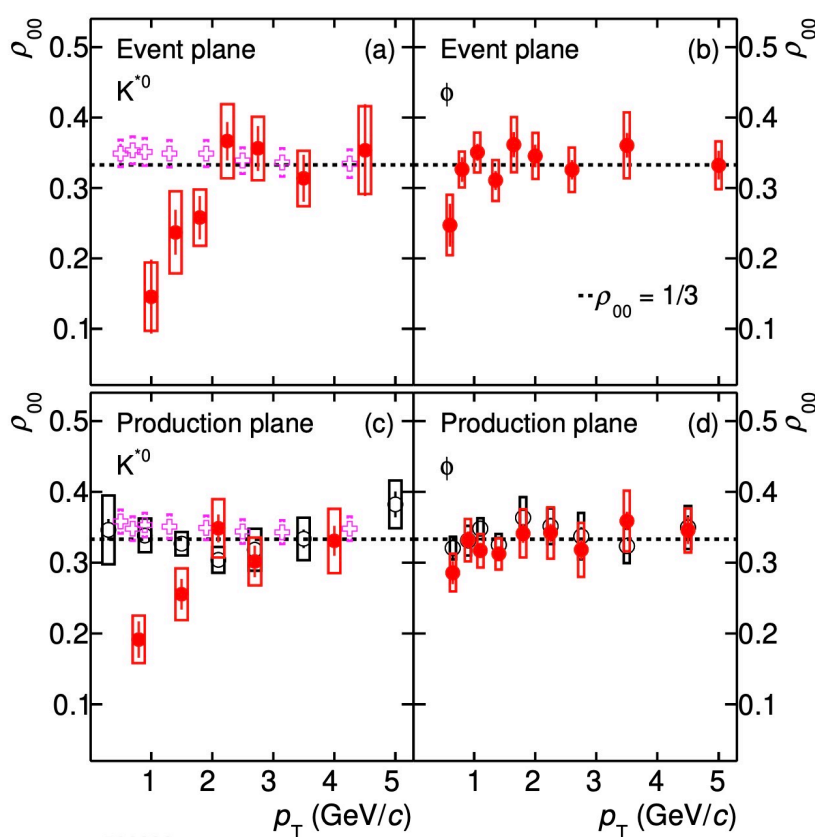
- Maximum deviation of  $\rho_{00}$  in semicentral collisions
- Deviation from 1/3
  - $K^{*0}$ : 3.2  $\sigma$  (PP) and 2.6  $\sigma$  (EP)
  - $\phi$ : 2.1  $\sigma$  (PP) and 1.9  $\sigma$  (EP)
- Larger effect than observed in  $\Lambda$  polarization [ALICE, *Phys.Rev.C* 105 (2022) 2, 029902]

## High $p_T$

No centrality dependence and results are consistent with 1/3

PRL 125(2020) 012301

# $K^{*0}$ and $\phi$ polarization in pp and Pb–Pb collisions



ALI-PUB-520388

## pp collisions:

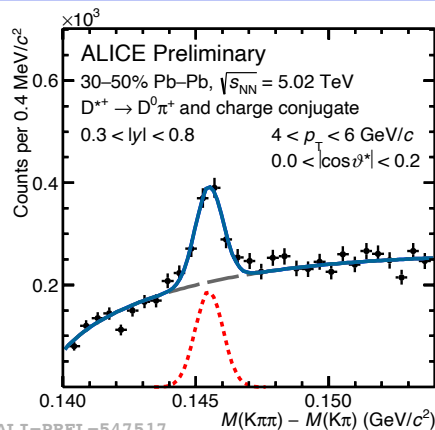
- $\rho_{00}$  consistent with 1/3 for both  $K^{*0}$  and  $\phi$  in production plane in pp collisions

## Pb-Pb collisions:

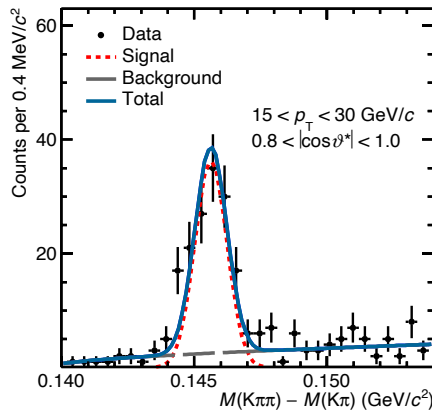
- $\rho_{00}$  for  $K_S^0$  (spin=0) consistent with 1/3
- $\rho_{00} < 1/3$  for  $K^{*0}$  and  $\phi$  at low  $p_T$
- $\rho_{00}$  consistent with 1/3 at high  $p_T$  ( $K^{*0}$ :  $p_T > 2$  GeV/c,  $\phi$ :  $p_T > 0.8$  GeV/c)

ALICE, PRL 125(2020) 012301

ALI-PUB-520388



ALI-PREL-547517

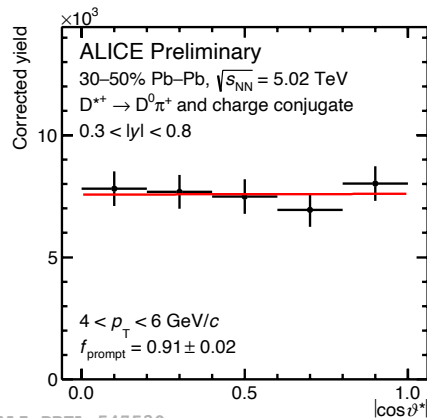


➤ First measurement of  $D^{*+}$  polarization with respect to the reaction plane

➤ Multiclass classification algorithm based on BDT used to reduce the combinatorial background and distinguish among prompt and non-prompt components

➤  $\rho_{00}$  extracted taking into account:

- Event plane finite resolution
- B-hadron feed-down contribution



ALI-PREL-547520

