

# SQM 2022

The 20th International Conference on Strangeness in Quark Matter  
13-17 June 2022 Busan, Republic of Korea

## Measurement of quarkonium production and polarization in pp and Pb–Pb collisions with ALICE



**ALICE**

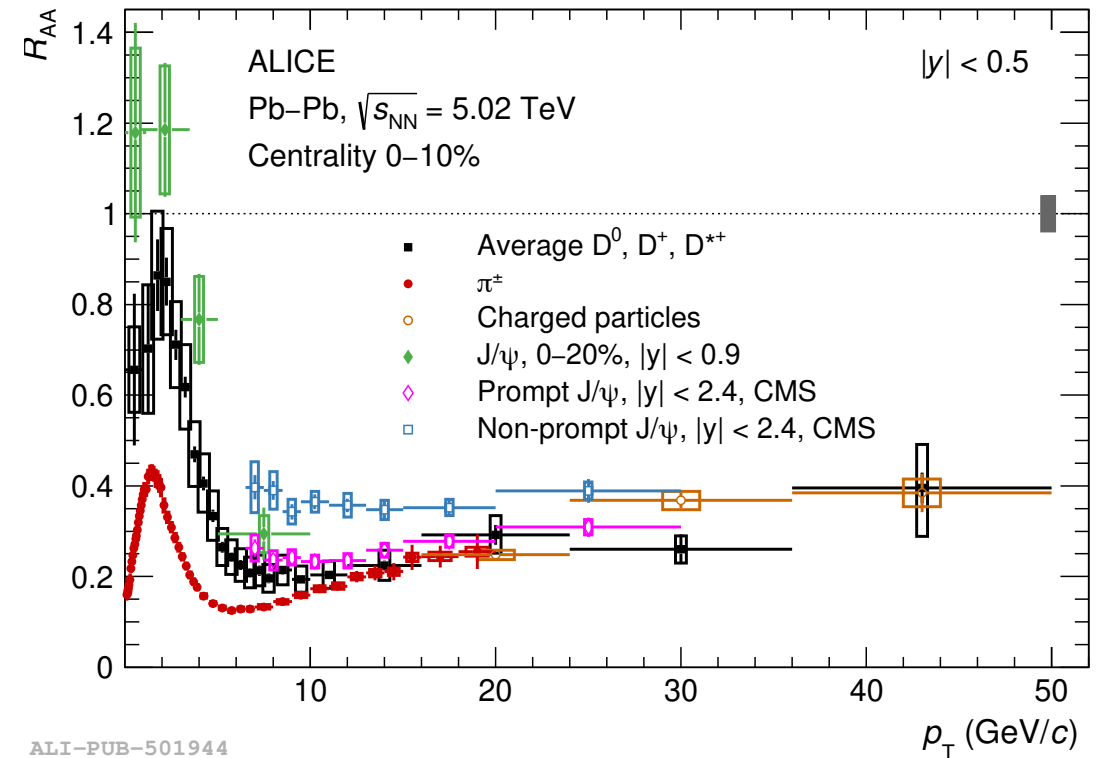
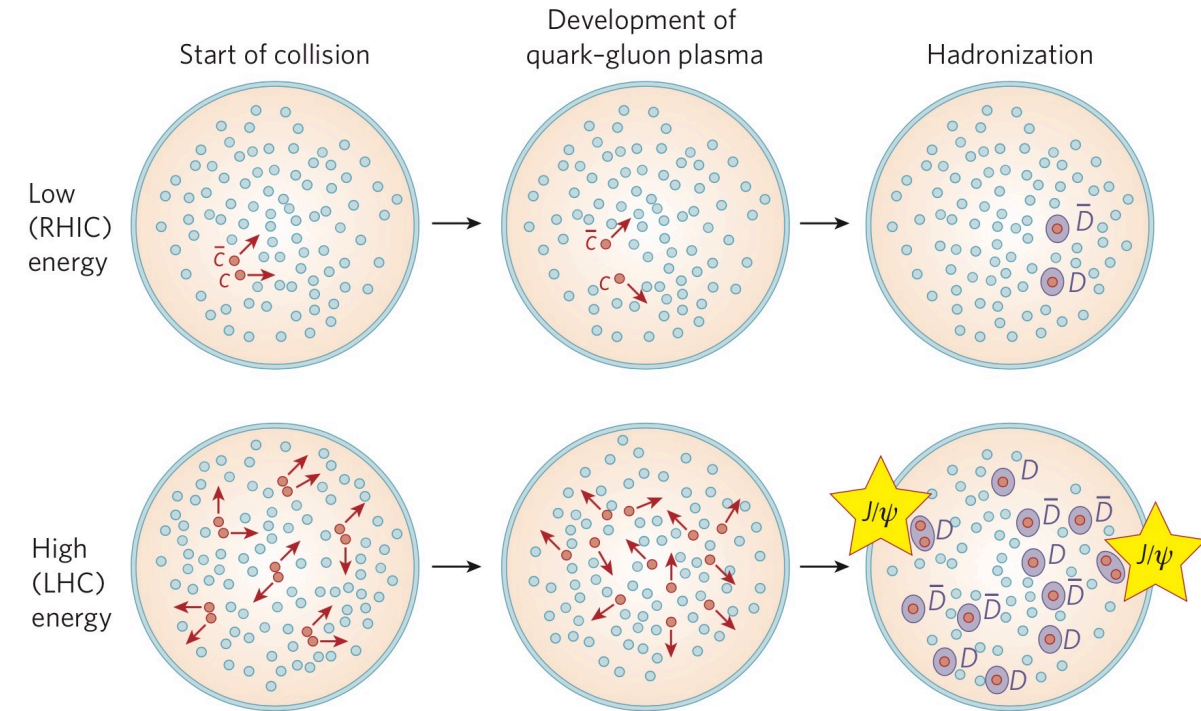
**Xiaozhi Bai**  
on behalf of the **ALICE Collaboration**

University of Science and Technology of China



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

JHEP 01 (2022) 174



ALI-PUB-501944

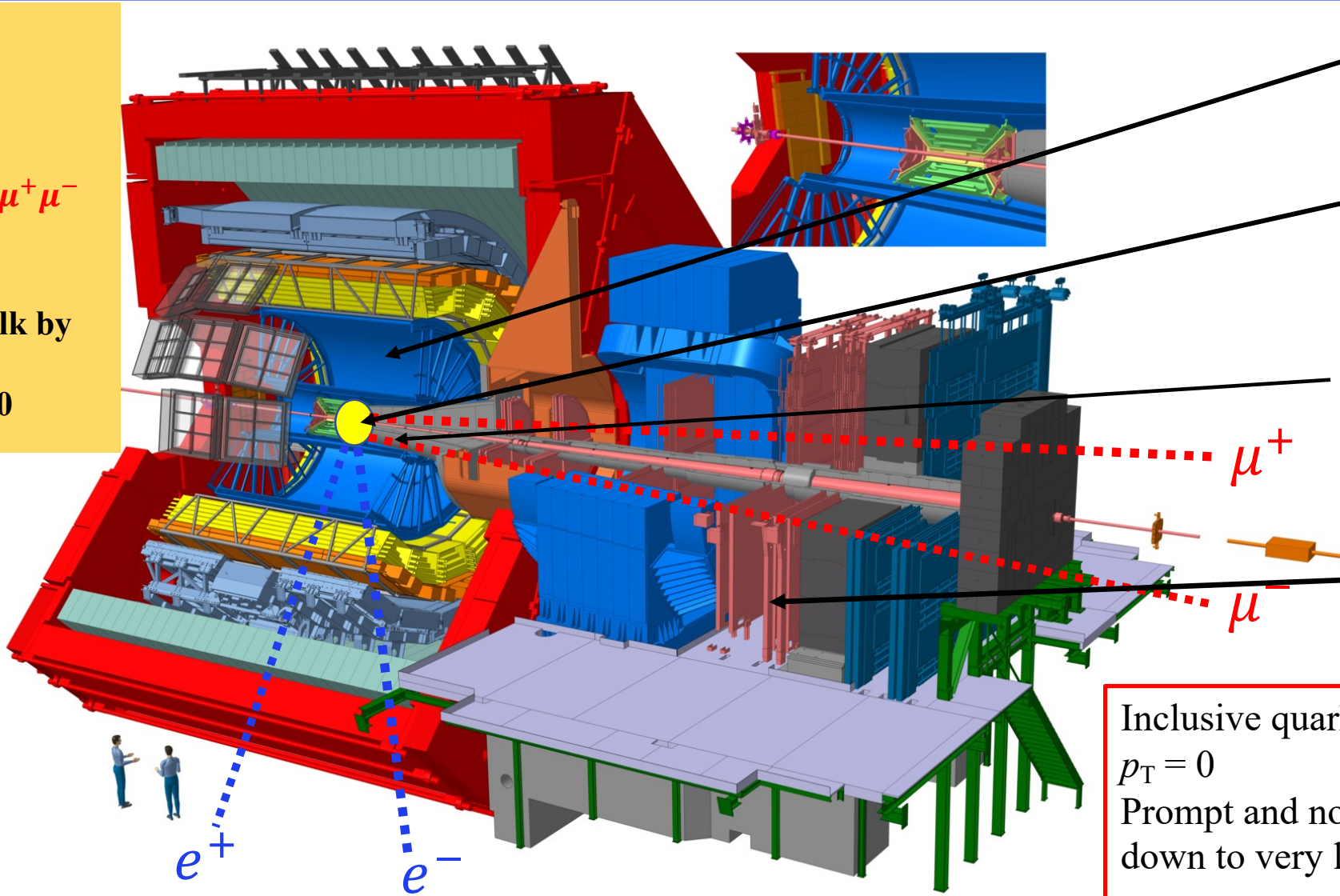
- Suppression of the direct charmonium due to colour screening and dissociation
- Charm quark ( $c$  and  $\bar{c}$ ) production cross section at the LHC is larger compared to RHIC energies, and the (re-)generation contribution to the  $J/\psi$  is significantly higher than RHIC
- Measurement of the non-prompt  $J/\psi$  can contribute to the study of the mass dependence of parton energy loss

# Quarkonium measurements with the ALICE detector

$|y| < 0.9$   
 $J/\psi \rightarrow e^+e^-$

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

$\psi(2S)$ , see talk by  
 Hushnud  
 on Tue 10:00



**Time Projection Chamber**  
 Tracking, particle identification

**Inner Tracking System**  
 Tracking, vertex reconstruction,  
 Event Plane determination

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

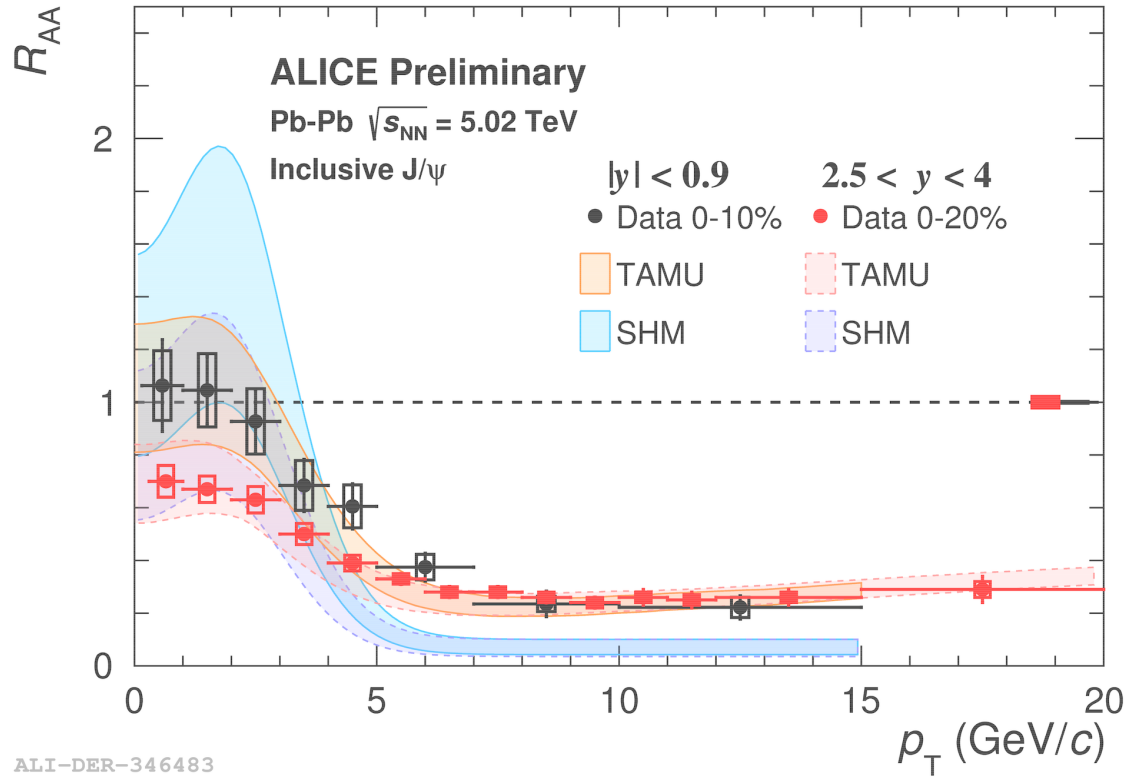
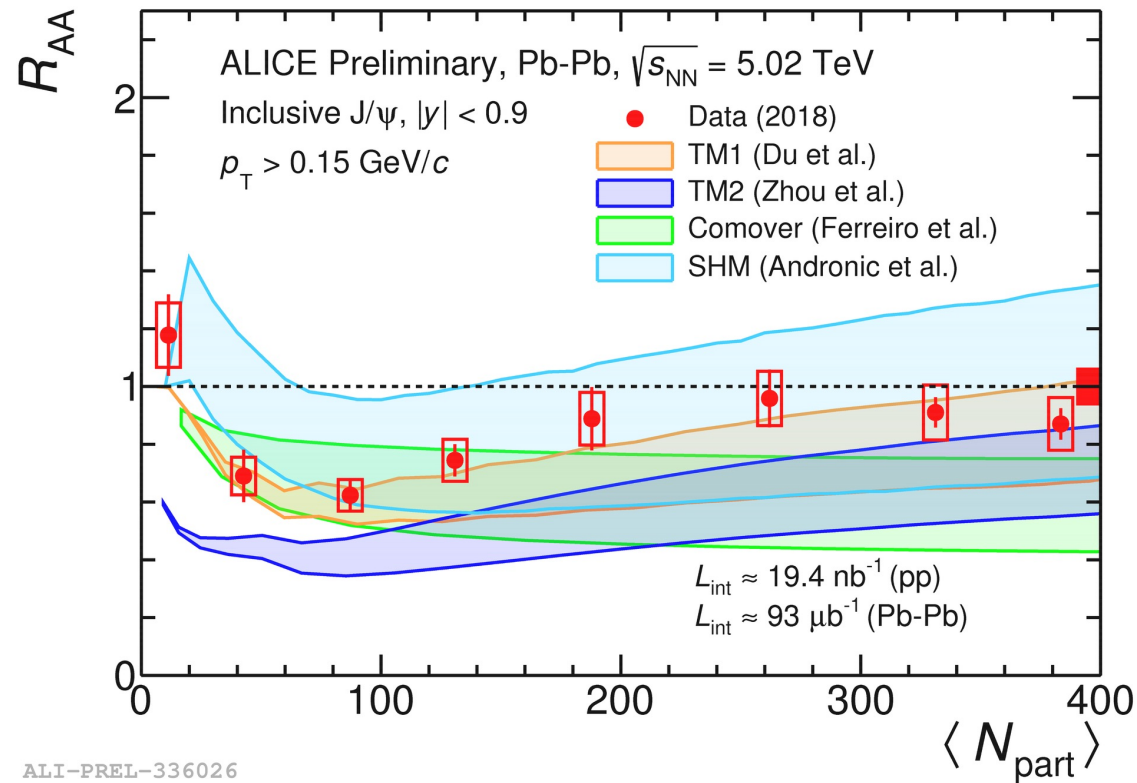
**Muon spectrometer**  
 Trigger and tracking for muons

Inclusive quarkonium measurement down to  $p_T = 0$   
 Prompt and non-prompt  $J/\psi$  can be separated  
 down to very low  $p_T$  at midrapidity

# Quarkonium production



# J/ψ $R_{AA}$ in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

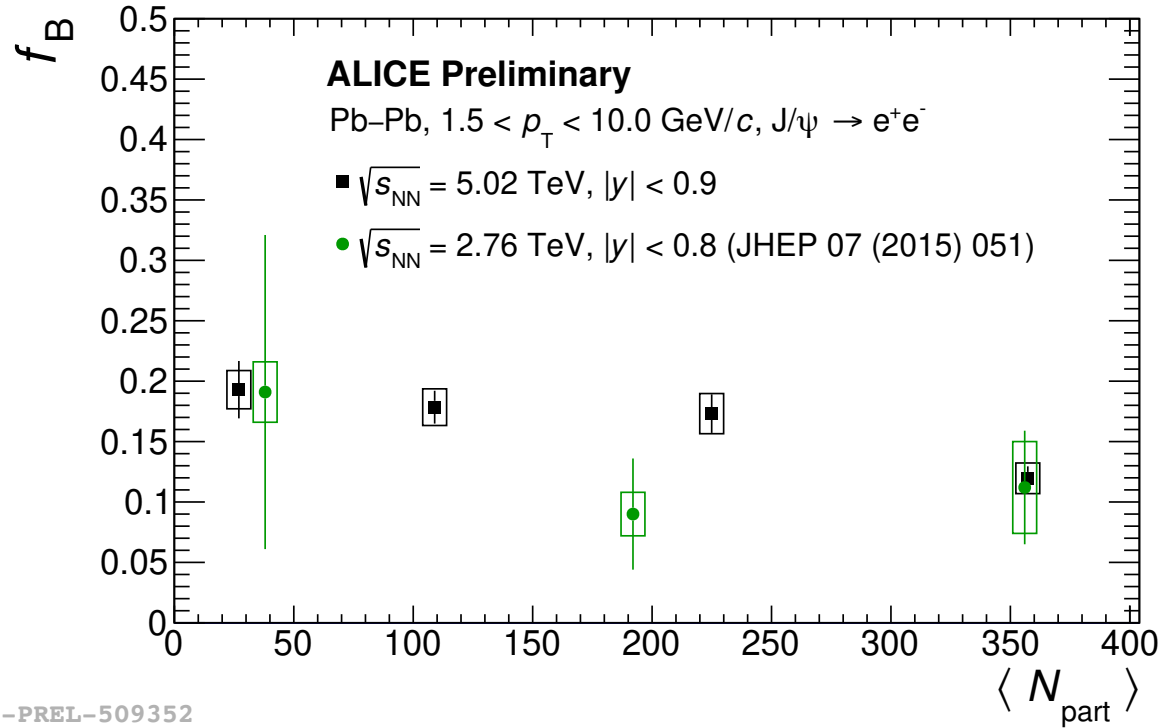


TM1: Du X. and Rapp R., NPA 943 (2015) 147-158  
 TM2: Zhou et al., PRC 89, 054911 (21 May 2014)  
 SHM: Andronic A. et al., PLB 797 (2019) 134836  
 Comover: Ferreiro E. et al., PLB 731 (2014) 57

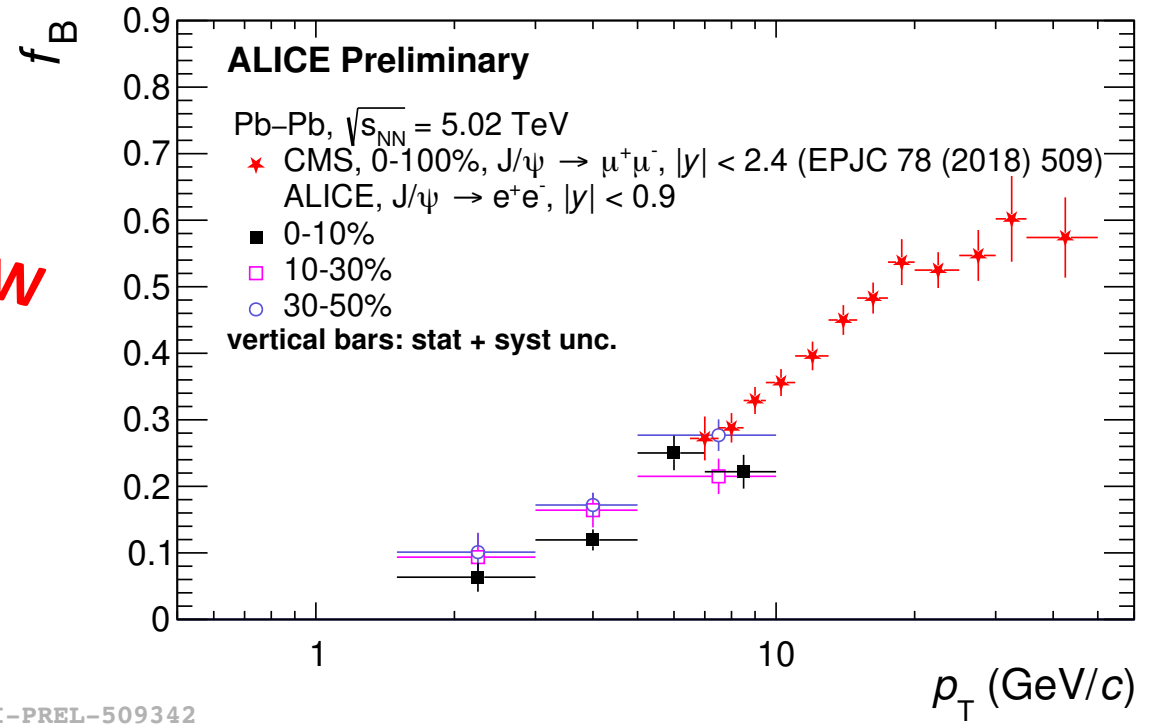
ALI-PREL-336026

ALI-DER-346483

- Evidence for J/ψ (re-)generation at low  $p_T$  and in central collisions, with larger contribution at at midrapidity compared to forward rapidity
- The statistical hadronization model can describe the data at low  $p_T$ , while the transport model agrees with data in the whole measured  $p_T$  ranges

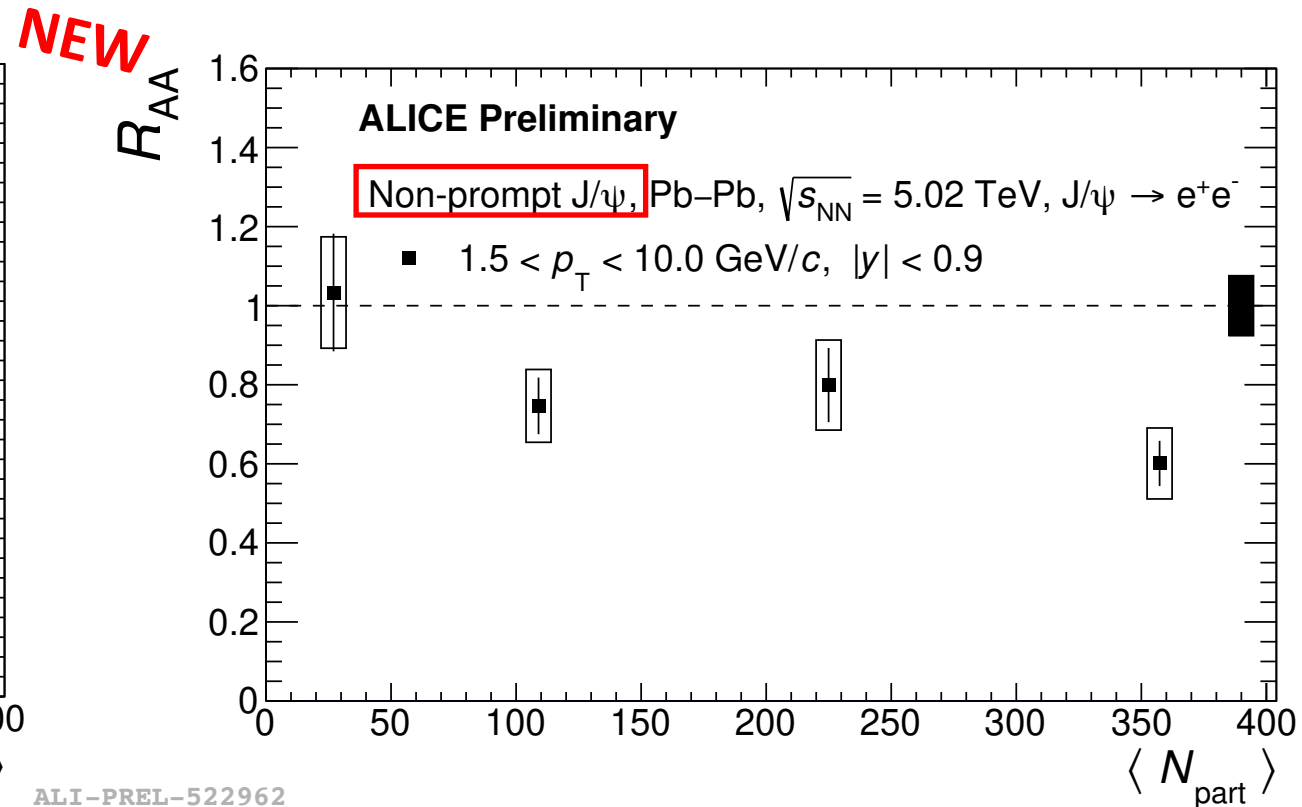
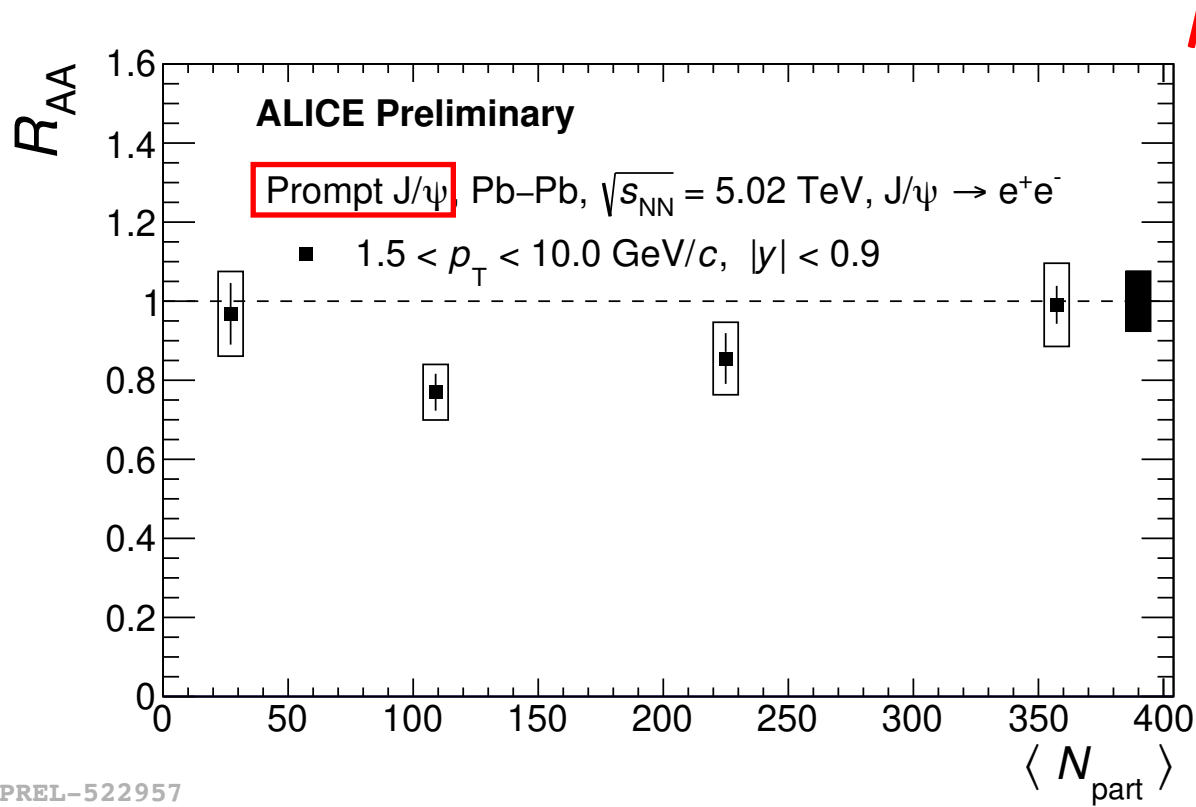


**NEW**

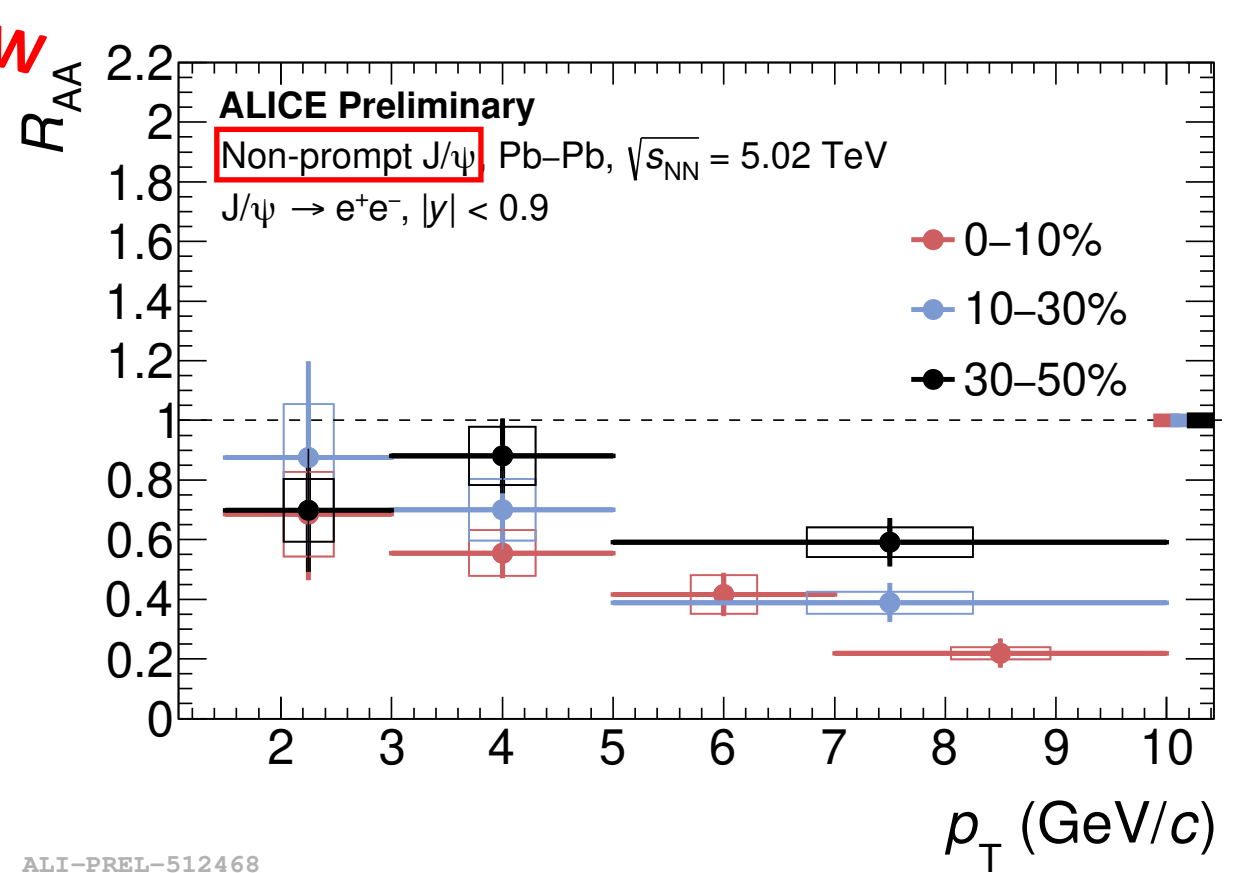
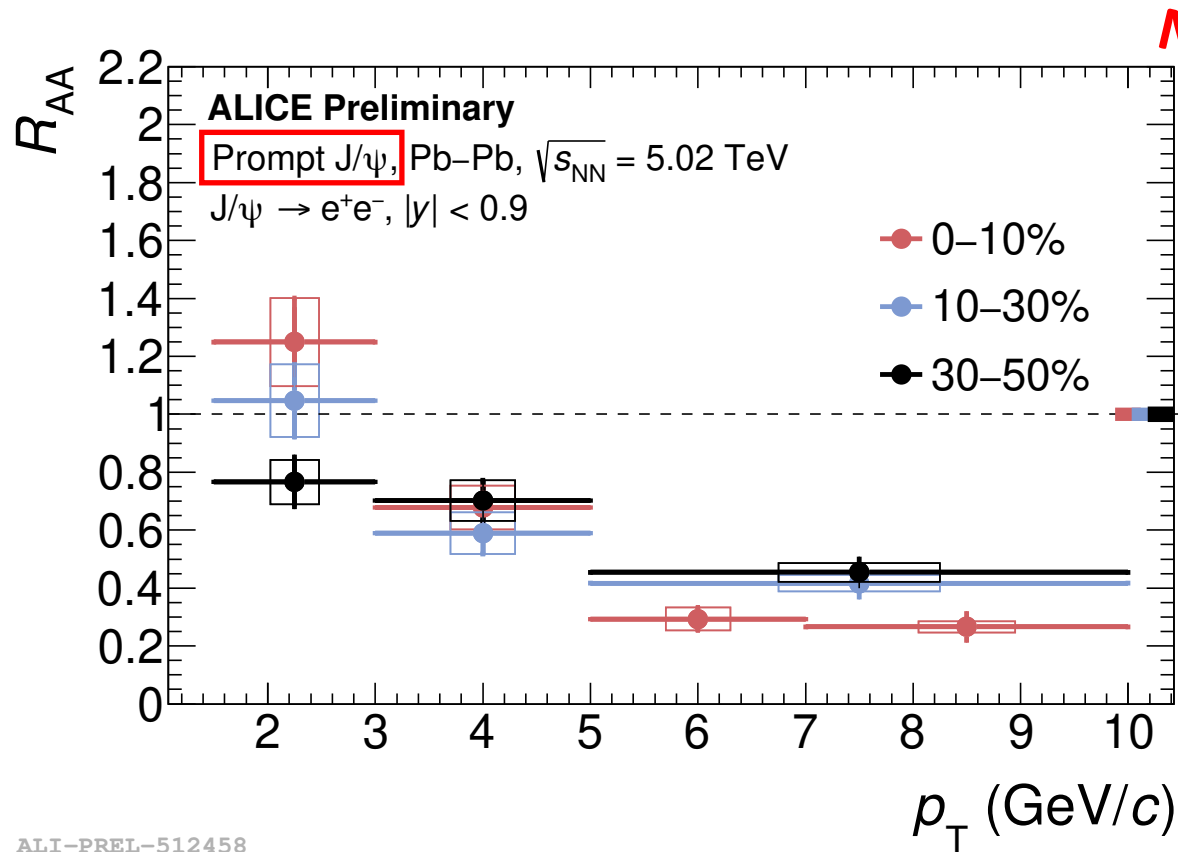


- The precision of the new measurement is significantly improved compared to Run 1 results
- The slight centrality dependence hints at an increasing contribution from (re-)generation towards most central collisions for prompt  $J/\psi$
- ALICE extends non-prompt  $J/\psi$  measurement at the LHC down to  $p_T = 1.5$  GeV/c at midrapidity

# Centrality dependence of prompt and non-prompt $J/\psi$ $R_{AA}$

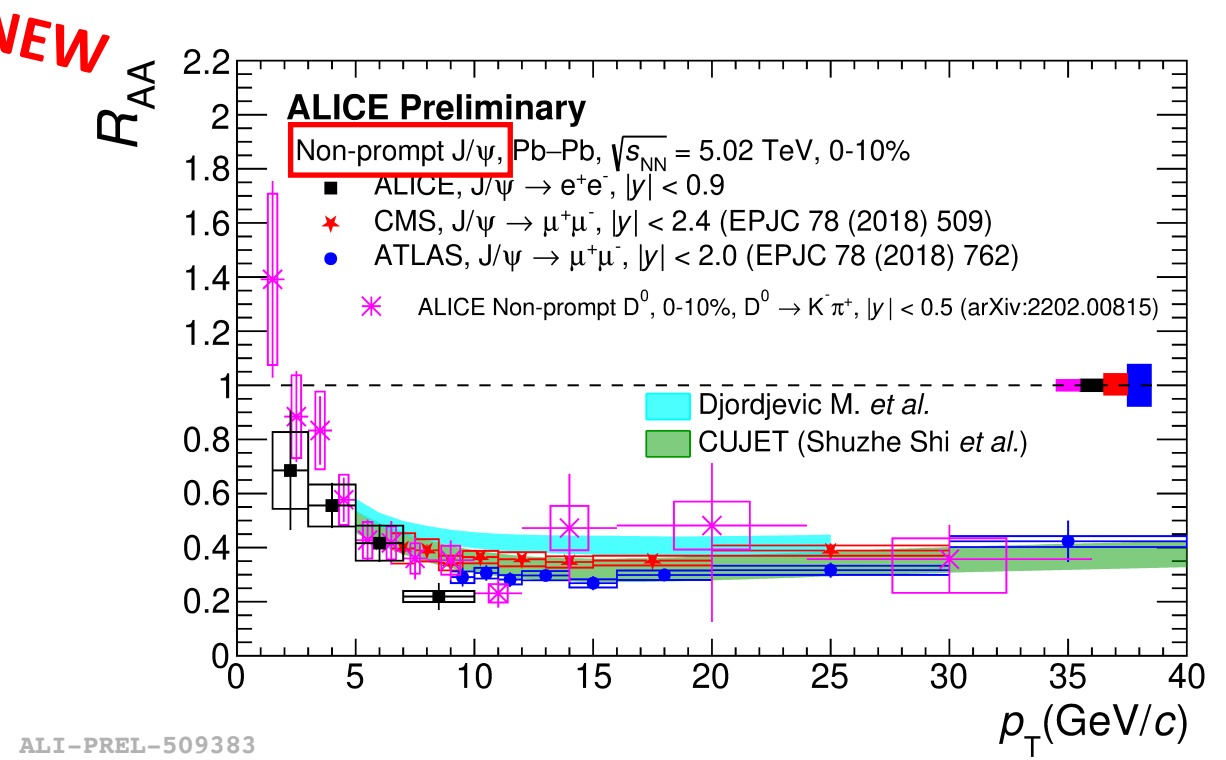
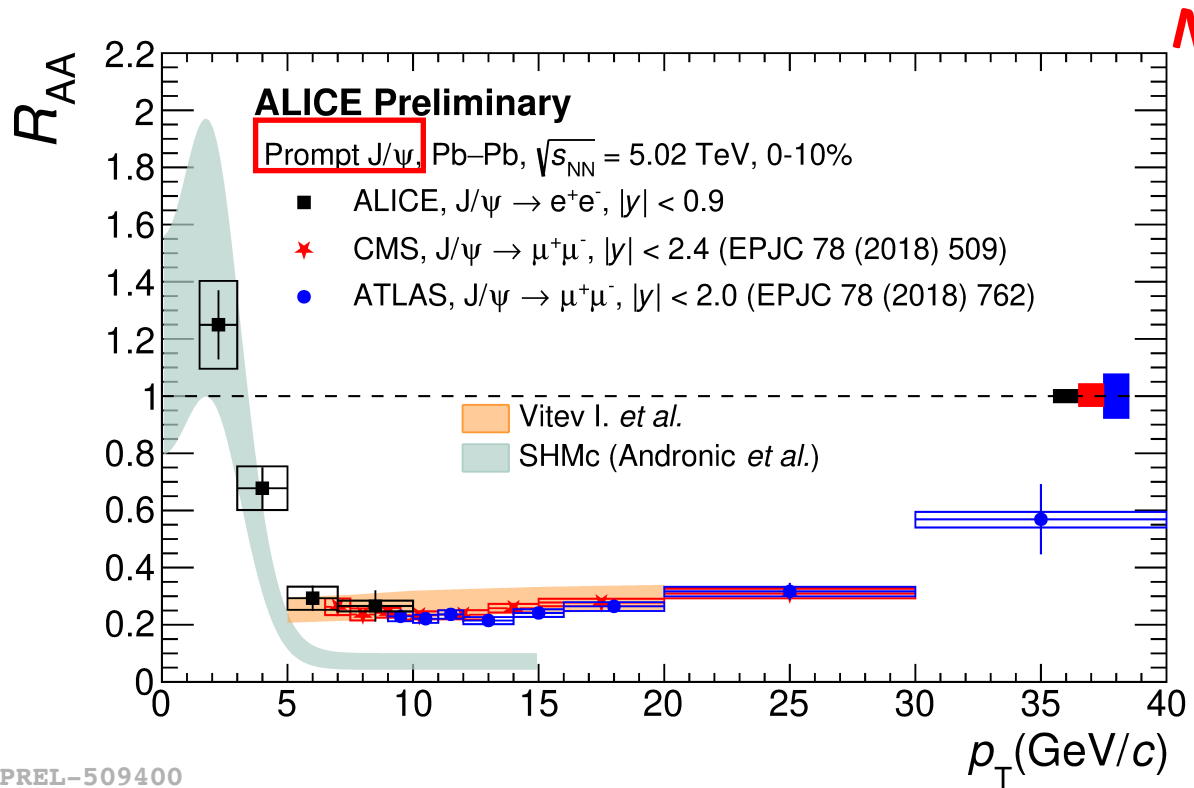


- Prompt  $J/\psi$   $R_{AA}$  increases towards more central collisions, points to an increasing contribution from (re-)generation
- Non-prompt  $J/\psi$  is more suppressed in central collisions, expected from heavy quark energy loss in the medium



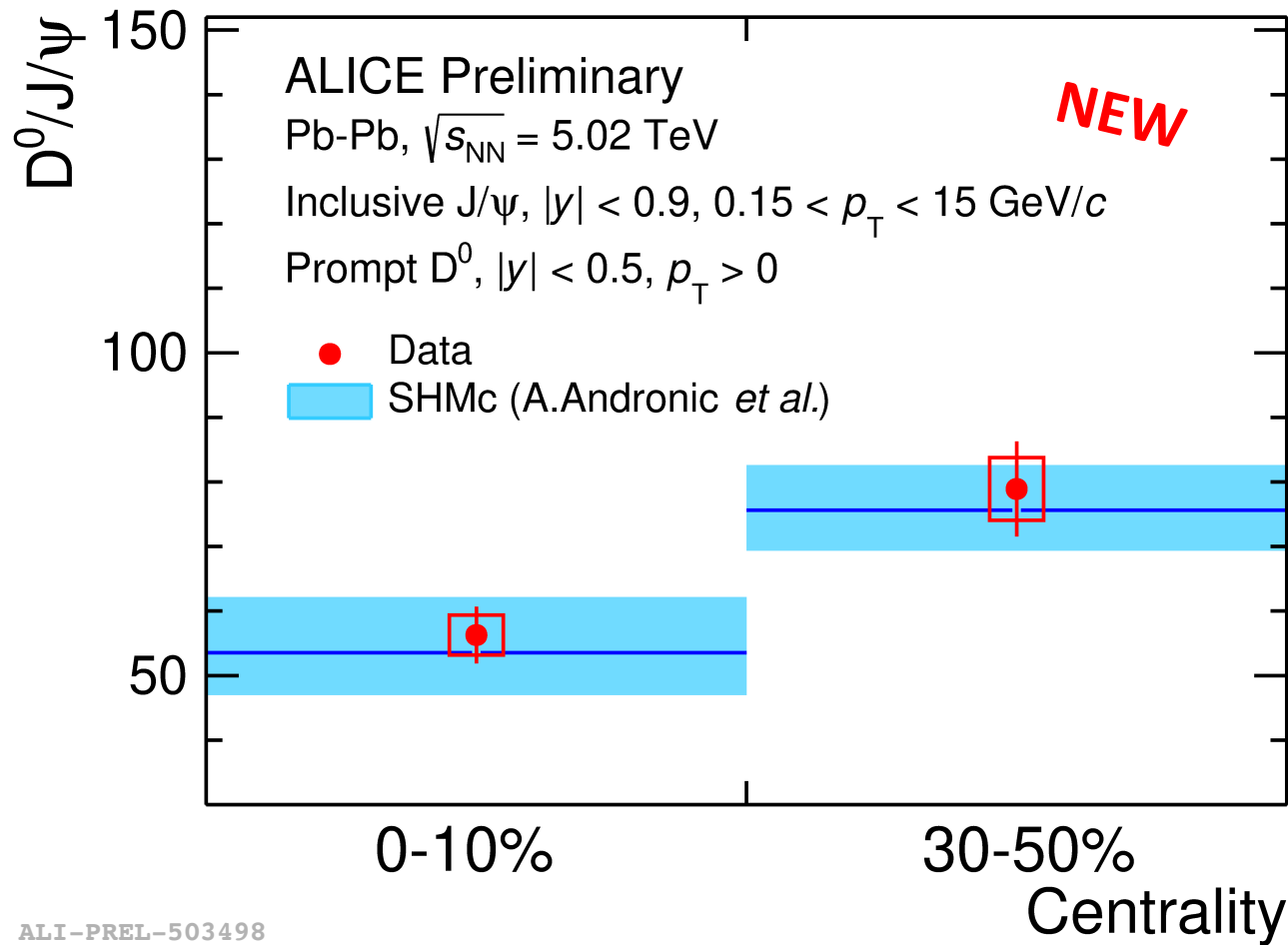
- Prompt  $J/\psi$   $R_{AA}$  increases from semicentral to central collisions in the lowest  $p_T$  intervals
- The suppression seems stronger in central collisions compared to the semicentral at high  $p_T$  for both prompt and non-prompt  $J/\psi$   $R_{AA}$





- $R_{AA}$  extended down to  $p_T = 1.5$  GeV/c and compatible within uncertainties with ATLAS and CMS measurements at high  $p_T$
- Similar trends for non-prompt J/ψ and non-prompt D<sup>0</sup>  $R_{AA}$  (small difference could arise from the different decay kinematics)
- Non-prompt J/ψ  $R_{AA}$  described by models implementing collisional and radiative energy loss for  $p_T > 5$  GeV/c, while the prompt J/ψ  $R_{AA}$  agrees with the SHMc prediction at low  $p_T$

# D<sup>0</sup>-to-J/ψ ratio in Pb–Pb collisions



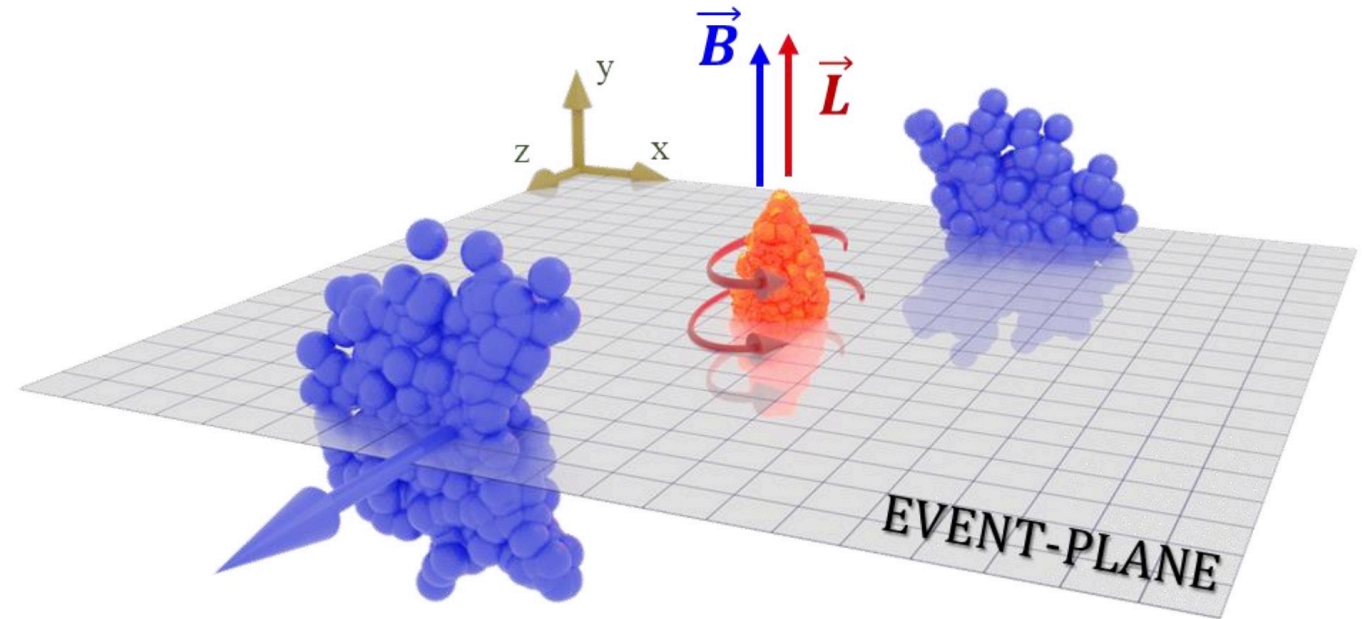
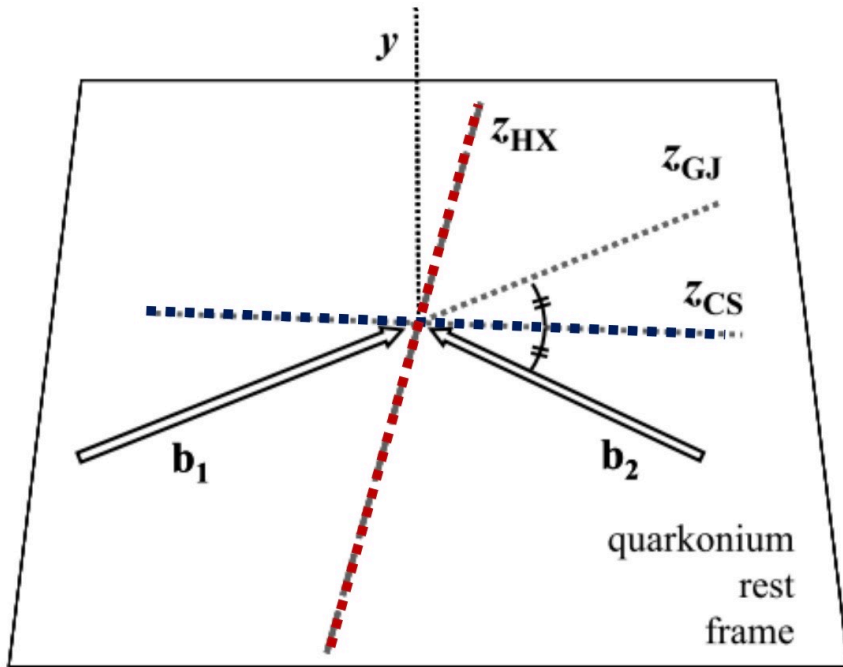
- Sensitive to hadronization mechanisms for open and hidden charm hadrons
- The centrality dependent trend of the D<sup>0</sup> to J/ψ ratio can be explained by the increase of charm fugacity towards most central collisions according to SHMc prediction

ALI-PREL-503498

A. Andronic *et al.*, JHEP07 (2021) 035

# Quarkonium polarization

# Quarkonium polarization

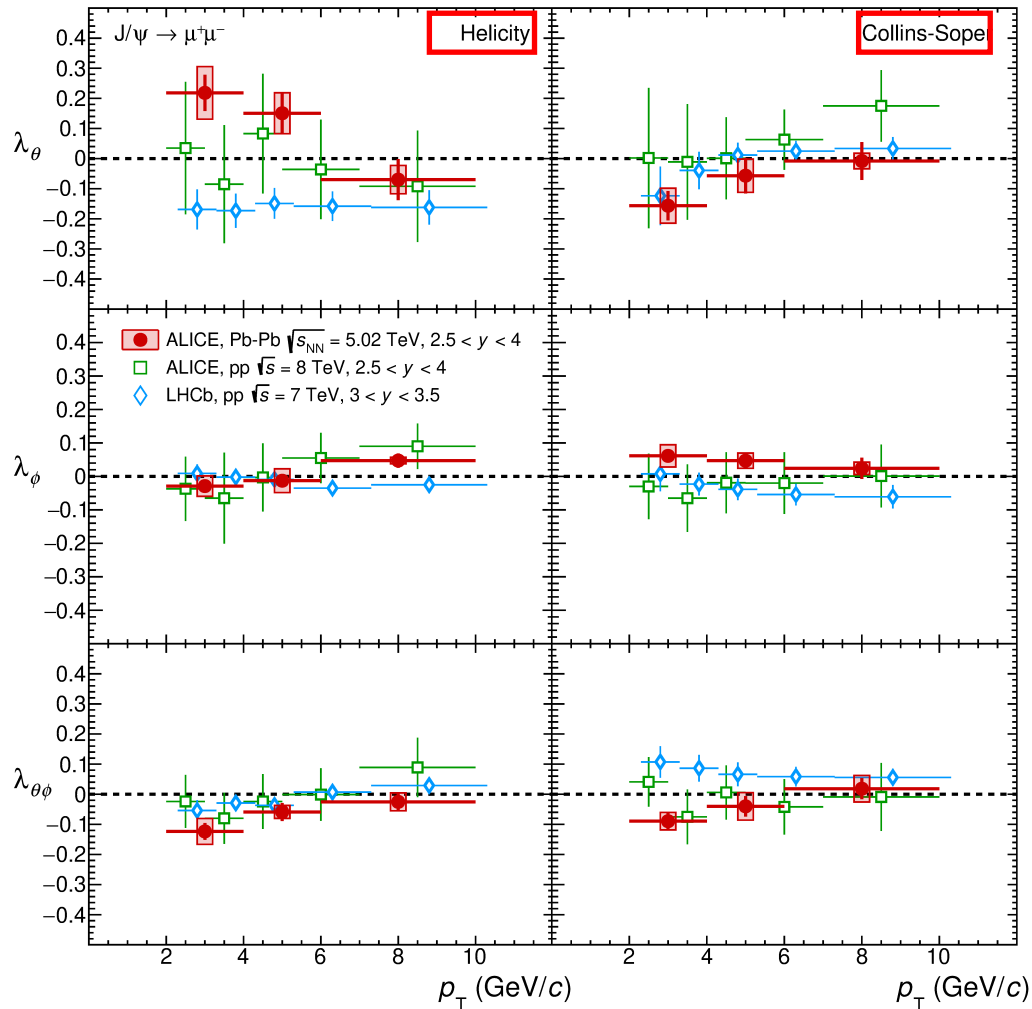


Figures from P. Faccioli et al. EPJ C69 (2010) 657-673

- Constrains quarkonium production mechanism in pp collisions.
- Probe of the dissociation/regeneration in QGP
- Heavy quark pairs are produced in the earlier stage of AA collision and can experience both the short living  $B$  and the  $L$  of the rotating medium, can affect  $J/\psi$  polarization w.r.t a chosen axis (event plane)

# J/ψ polarization in Pb–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

PLB 815 (2021) 136146

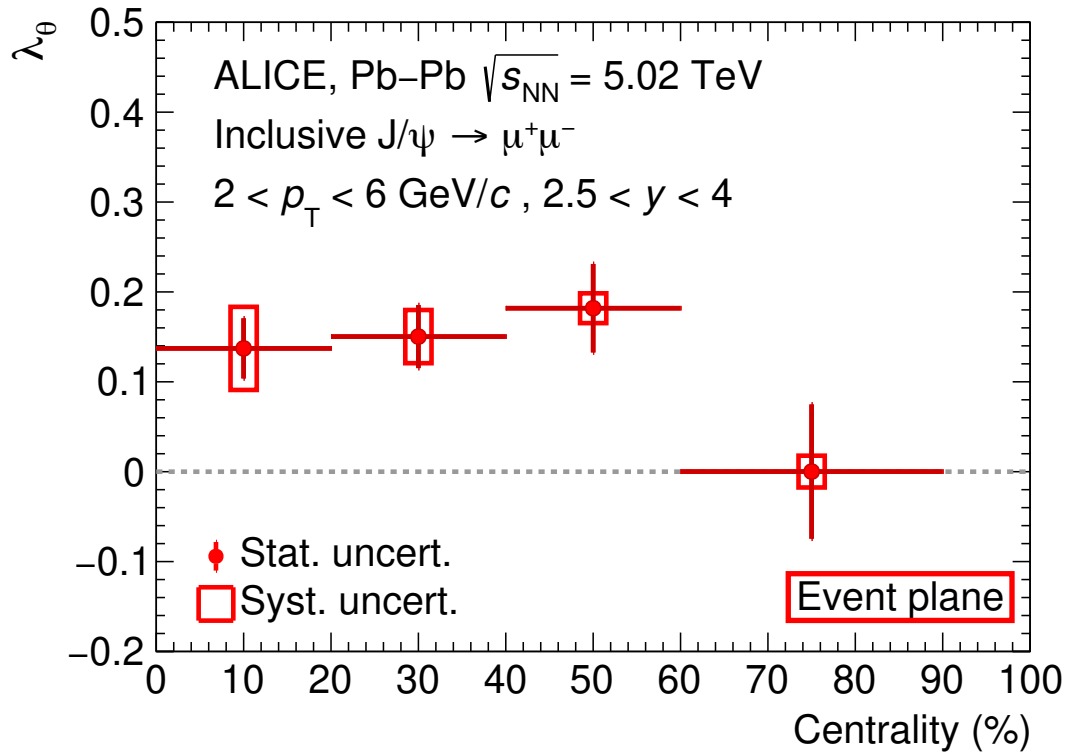


- First measurement of J/ψ polarization in Pb–Pb collisions at LHC
- $\lambda_\theta$  shows a maximum  $2\sigma$  deviation w.r.t zero in HE and CS for  $2 < p_T < 4$  GeV/c,  $3\sigma$  difference w.r.t LHCb in pp collisions in the HE reference frame
- Different behaviours in Pb-Pb compared to pp collisions due to the suppression/regeneration?

LHCb, EPJC 73 (2013) 11  
 ALICE, EPJC 78 (2018) 562

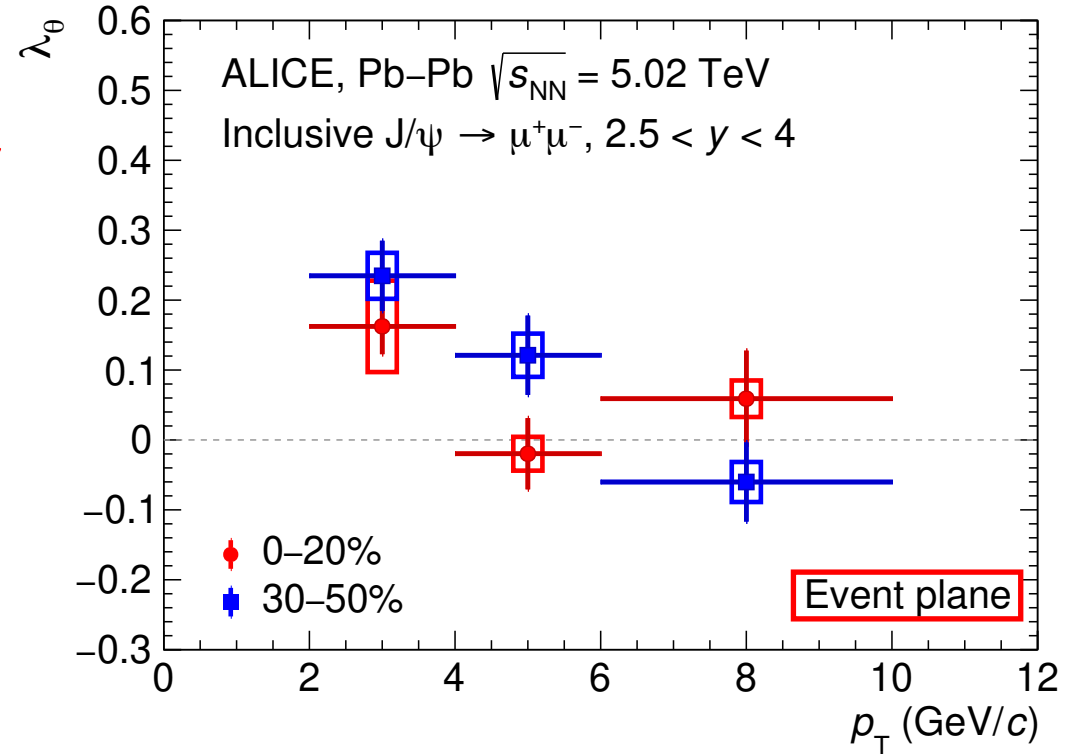


arXiv:2204.10171



ALI-PUB-521052

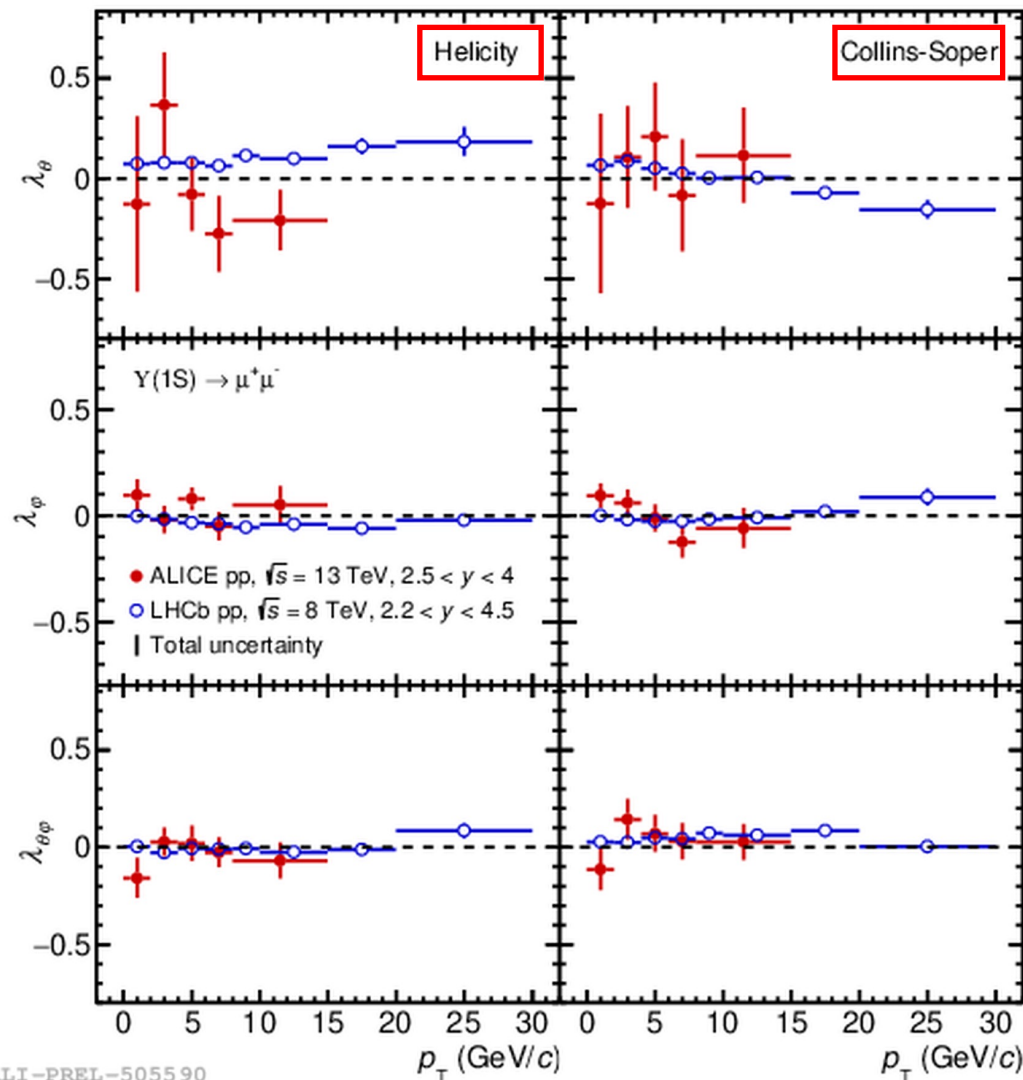
NEW



ALI-PUB-521057

- First measurement of quarkonium polarization w.r.t the event plane
- Significant polarization ( $\sim 3.5\sigma$ ) observed in semicentral collisions (40-60%) in  $2 < p_T < 6$  GeV/c
- The deviation 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

# $\Upsilon(1S)$ polarization in pp collisions at $\sqrt{s} = 13$ TeV



**NEW**

- $\lambda_\theta, \lambda_\phi, \lambda_{\theta\phi}$  measured down to  $p_T=0$  at forward rapidity
- $\lambda_\theta, \lambda_\phi, \lambda_{\theta\phi}$  are all compatible with zero in pp both HE and CS reference frames.
- Results compatible within the uncertainties with LHCb measurements at  $\sqrt{s} = 8$  TeV (LHCb Collaboration, JHEP 12 (2017) 110)
- Qualitatively in agreement with NLO NRQCD (Gong et al, PRL 112, 032001 (2014))

# Summary and outlook

## ➤ Nuclear modification of $J/\psi$ in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

- Dominant contribution from (re-)generation in central collisions and low  $p_T$  for prompt  $J/\psi$
- Strong suppression observed for non-prompt  $J/\psi$ , described by the energy loss models

## ➤ Quarkonium polarization in pp and Pb-Pb collisions

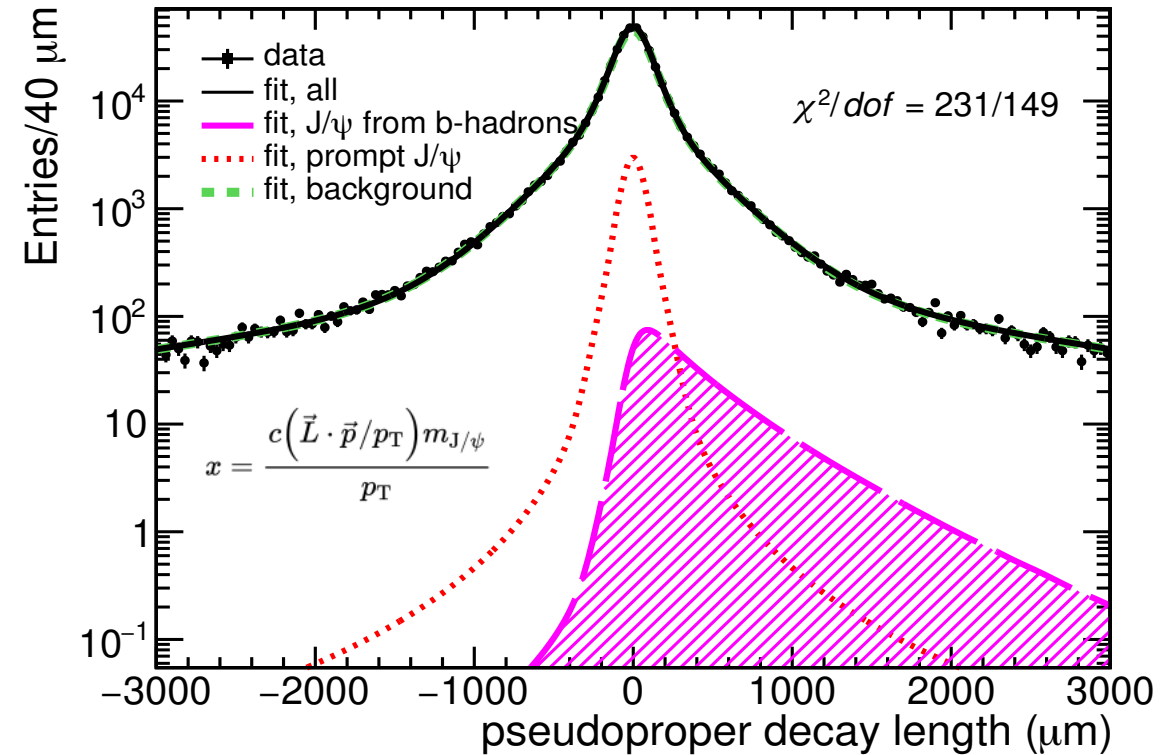
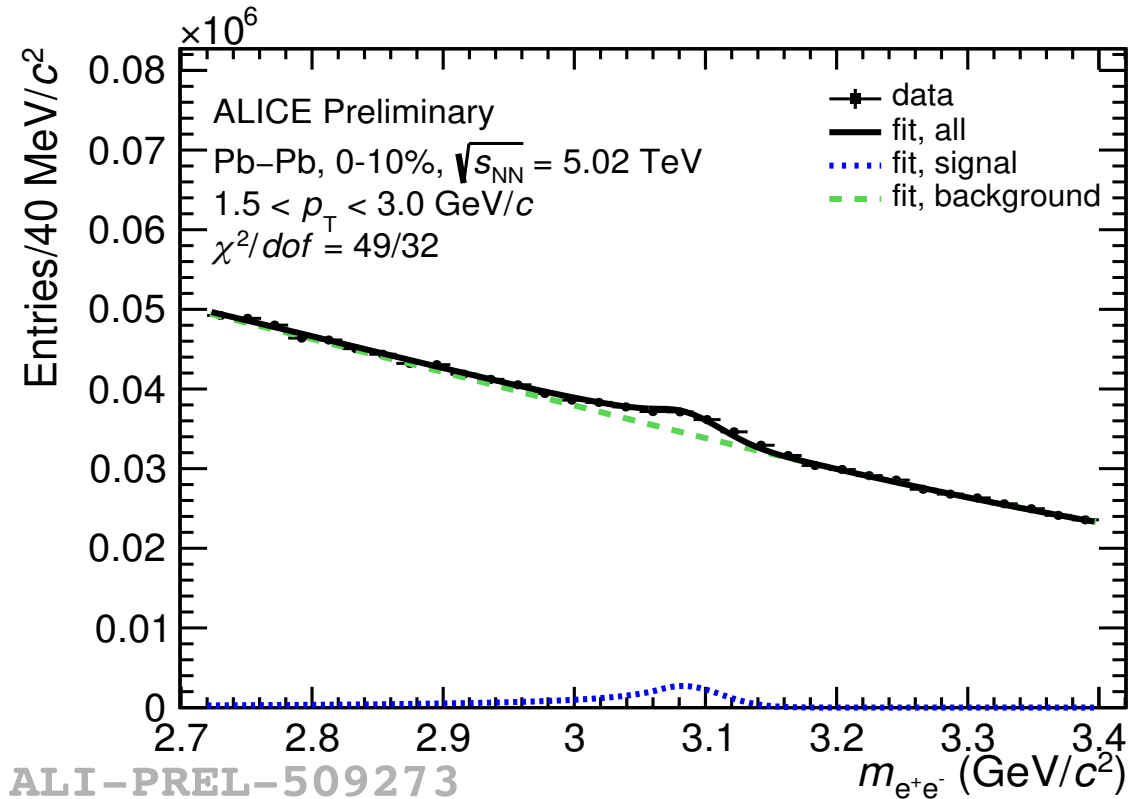
- $\Upsilon(1S)$  polarization parameters are all compatible with zero for pp collisions
- Significant non zero  $J/\psi$  polarization observed w.r.t event plane in semicentral Pb-Pb collisions at low  $p_T$

## ➤ Detector upgrade for Run 3

- More precise measurements can be expected from high statistics
- The newly installed MFT enables the separation between prompt and non-prompt  $J/\psi$  at forward rapidity.

# Thanks

# Non-prompt J/ψ fraction in Pb–Pb collisions



- The non-prompt J/ψ fraction is extracted through an unbinned two-dimensional likelihood fit of the dielectron pair invariant mass and pseudoproper decay length
- The main challenge is the very low signal-to-background ratio, in particular in central collisions and at low  $p_T$