Overview of recent charmonium measurements with ALICE at the LHC

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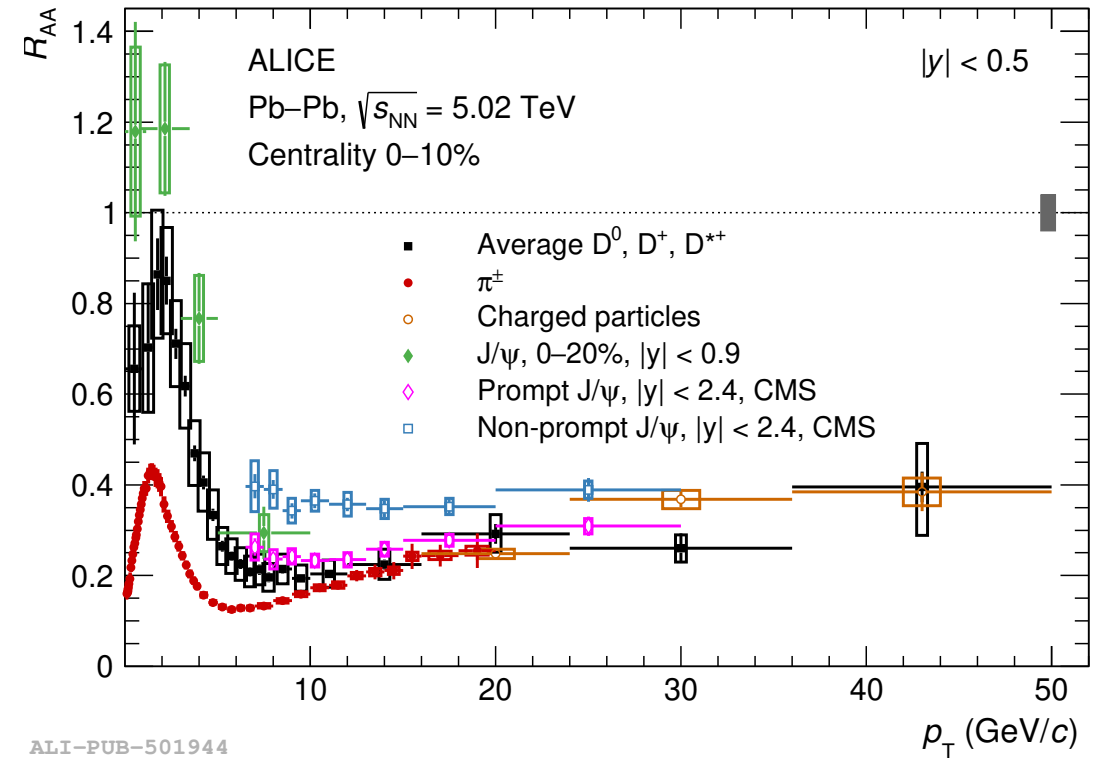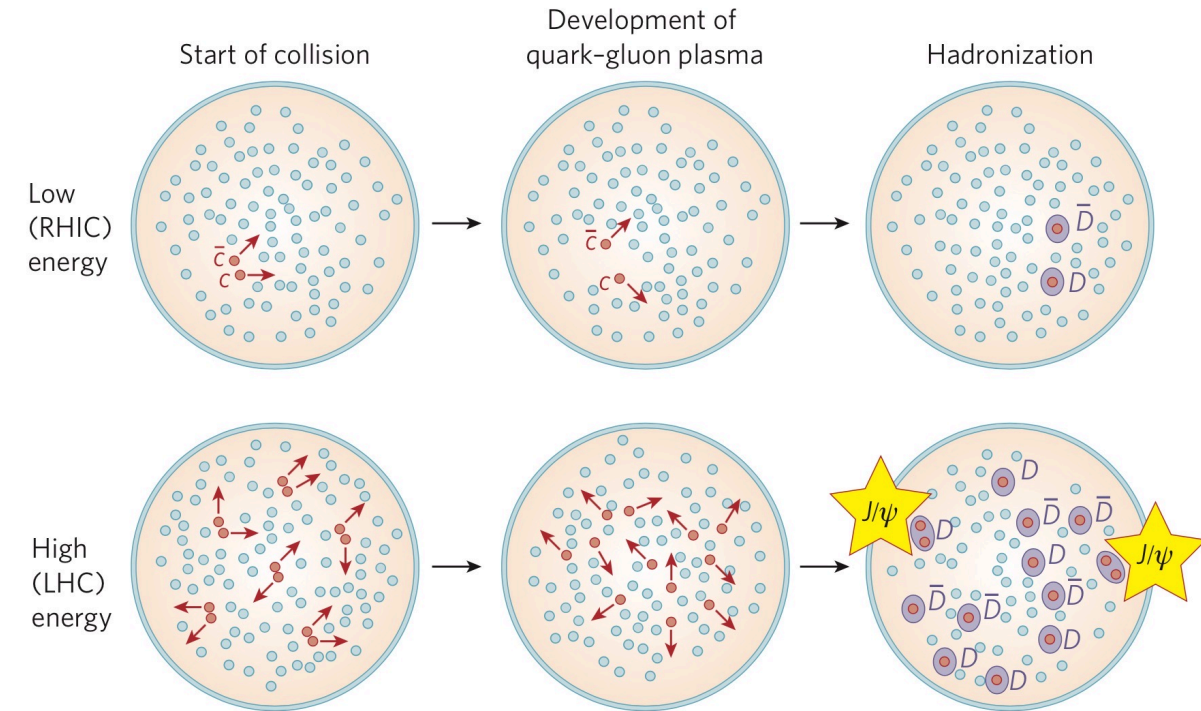
Hiroshima, Japan, 24-27 Apr. 2023

➢ Introduction and motivation

➢ Results in Pb─Pb collisions at 5.02 TeV

- Inclusive, prompt and non-prompt J/ψ production

- ψ(2S) production and ratio to J/ψ

- J/ψ polarization w.r.t event plane

➢Summary and outlook

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

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- 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/ψ is significantly higher than at RHIC

- Measurement of the non-prompt J/ψ can contribute to the study of the mass dependence of parton energy loss
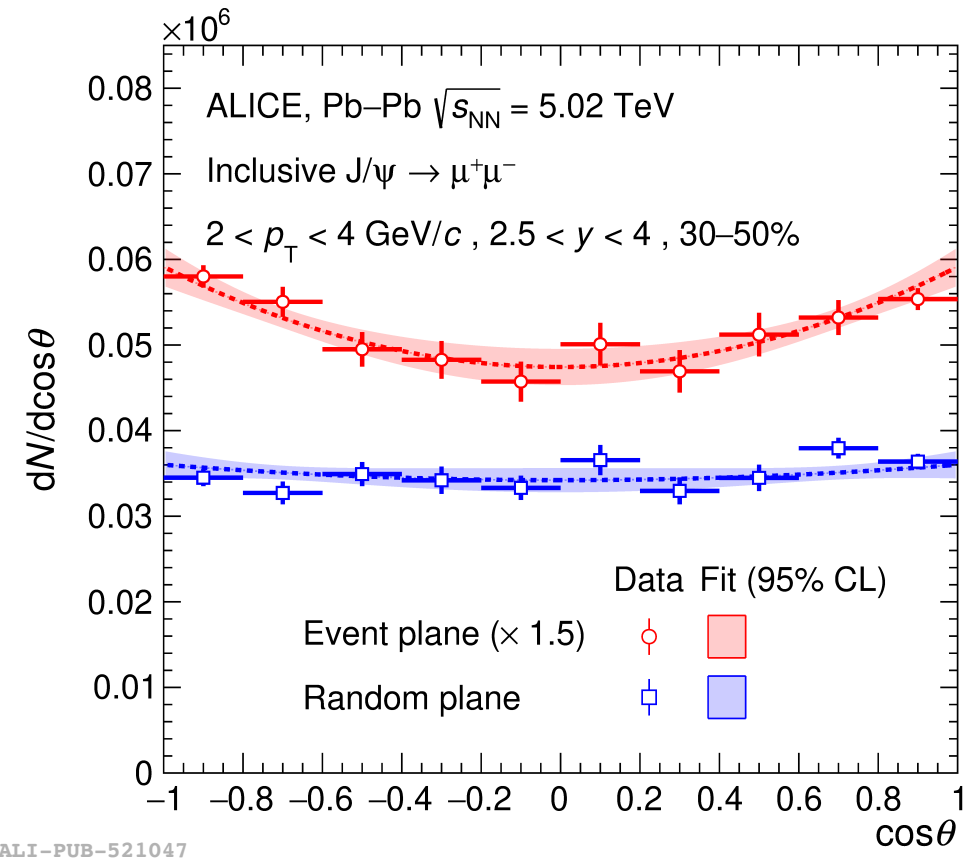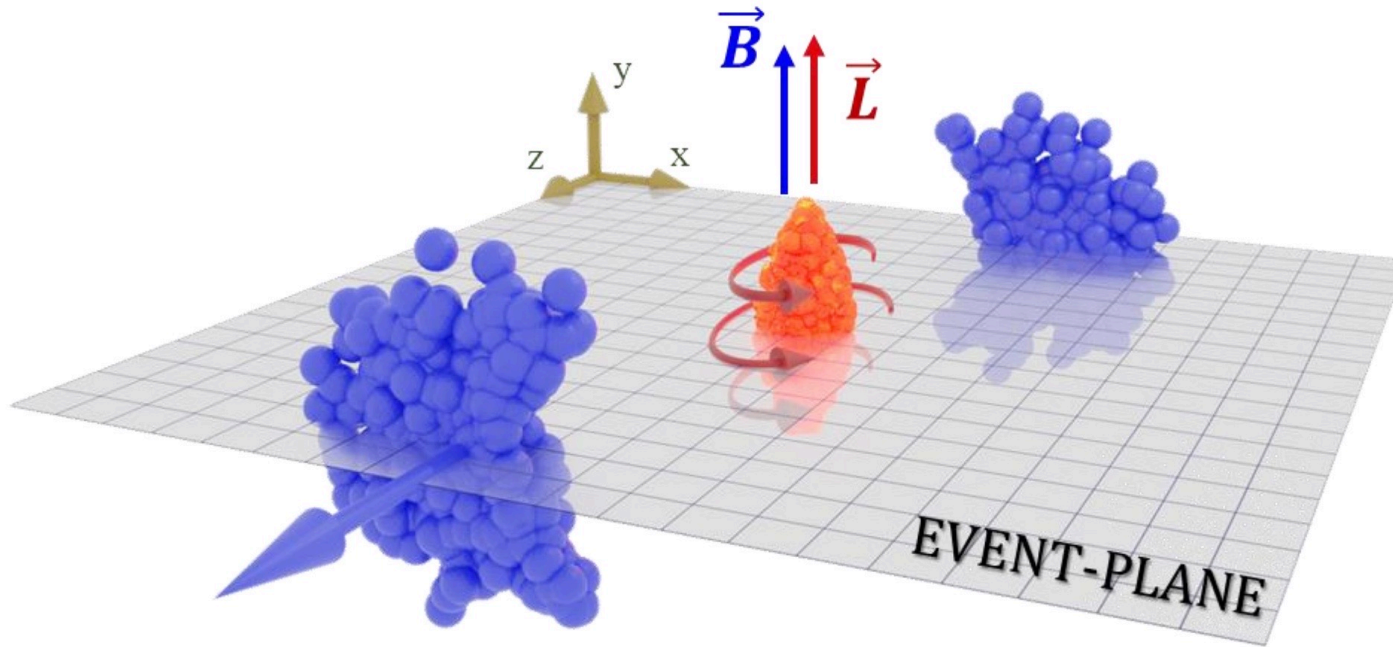
Heavy quark pairs are produced in the earlier stage of AA collision and can experience both the short living **B** and the **L** of the rotating medium, can affect J/ψ polarization w.r.t a chosen axis (event plane)
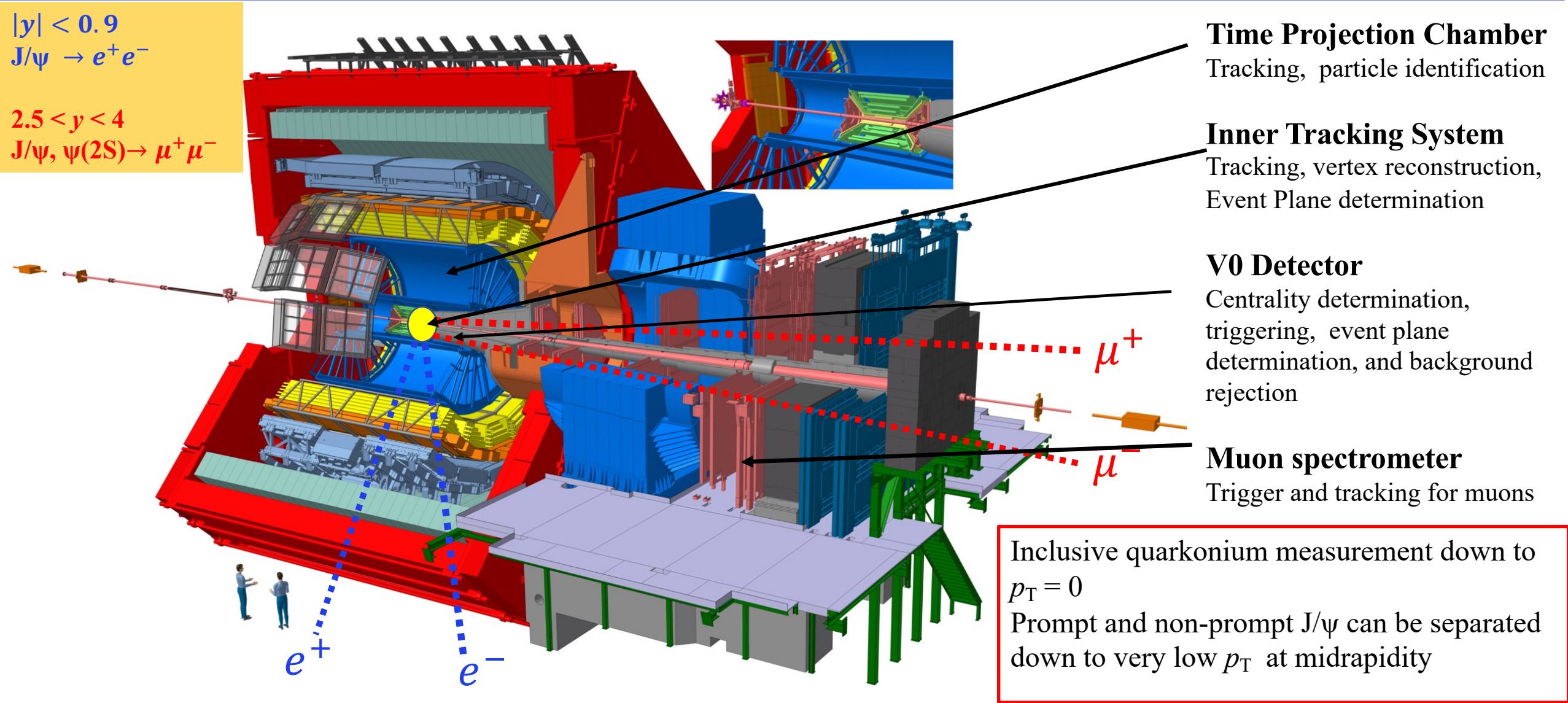
$|y| < 0.9$
$J/\psi \rightarrow e^+ e^-$

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

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

μ^+

μ^-

Muon spectrometer
Trigger and tracking for muons

e^+

e^-

Inclusive quarkonium measurement down to
$p_T = 0$
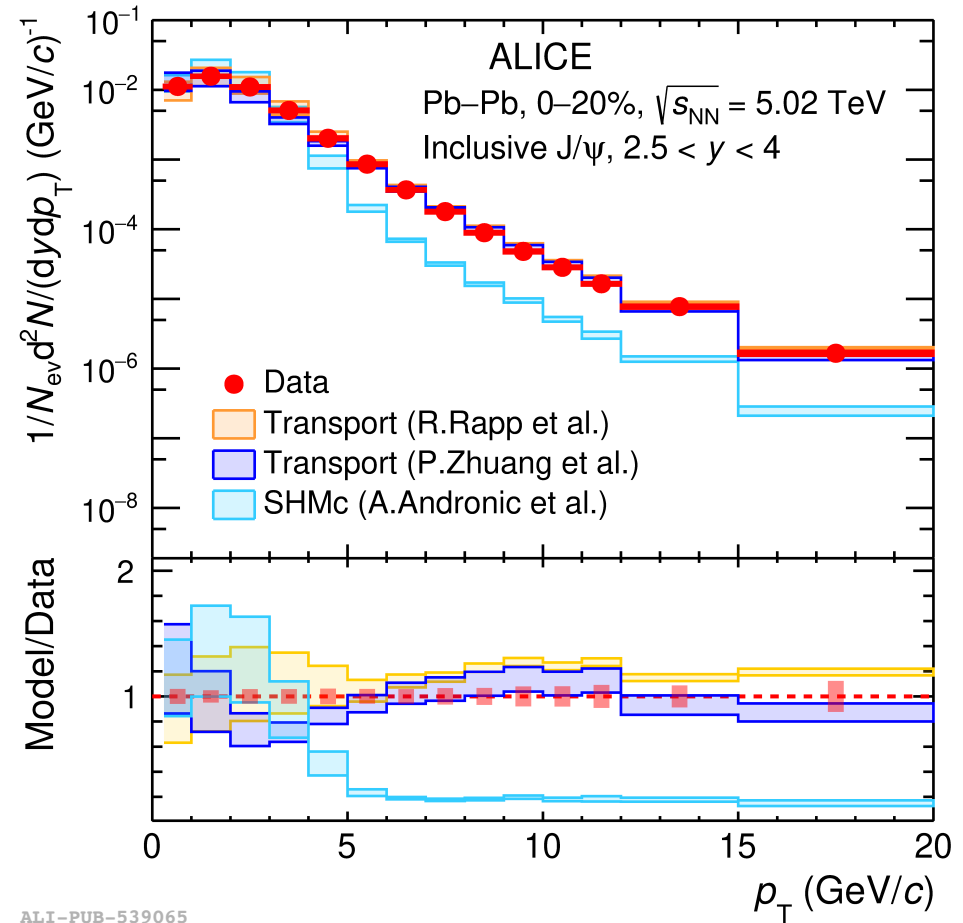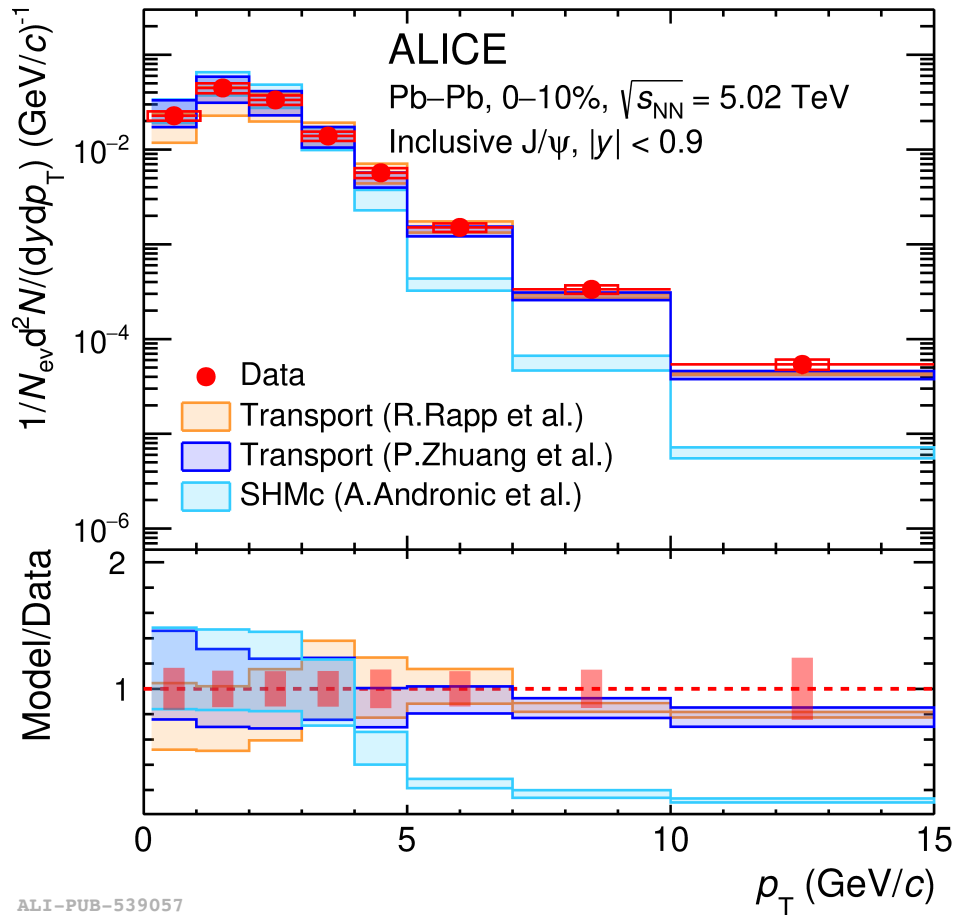Prompt and non-prompt J/ψ can be separated
down to very low p_T at midrapidity
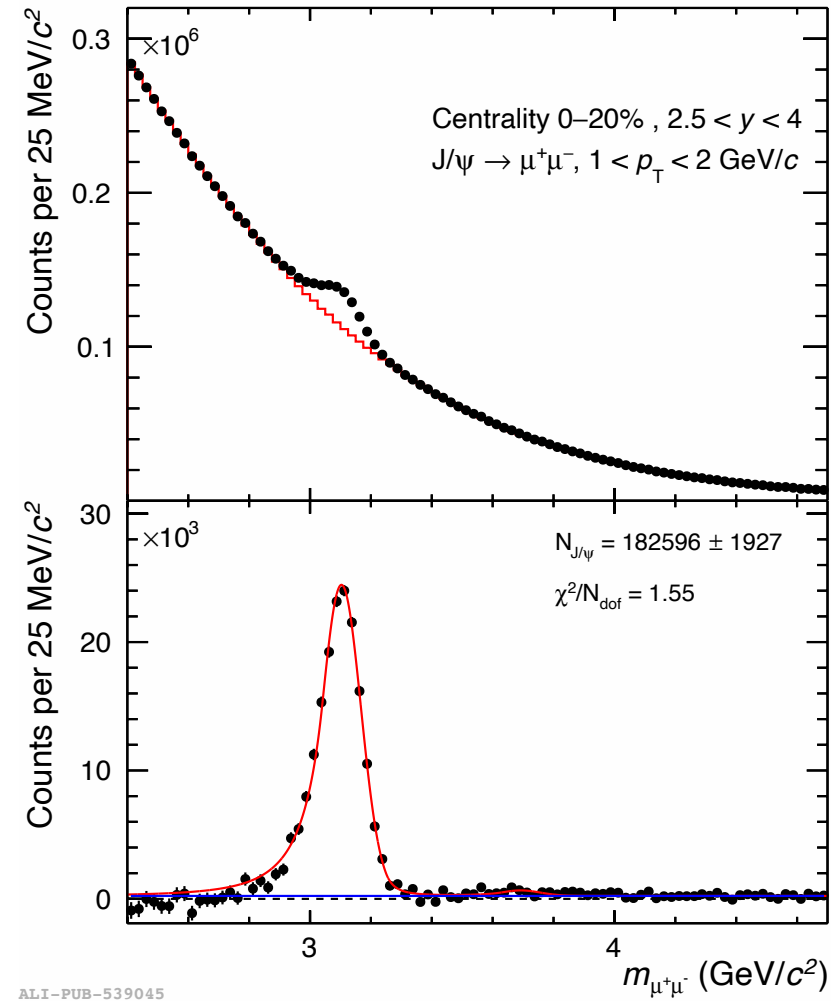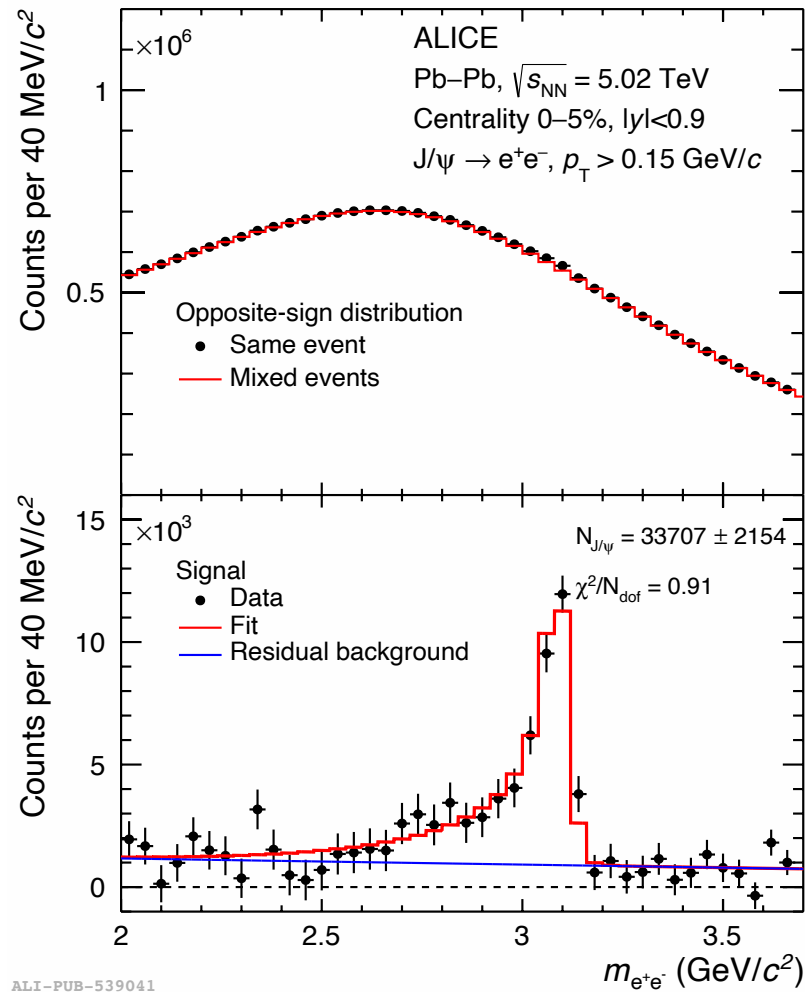
arXiv:2303.13361

J/ψ are reconstructed via dielectron (left) and dimuon (right) decay channels at mid- and forward rapidity, respectively.

Inclusive J/ψ yield in Pb−Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

ALI−PUB−539057

ALI−PUB−539065

New paper

➢ Inclusive J/ψ yields are shown as a function of p_T at mid- (left) and forward (right) rapidity
➢ Two transport models describe the data within uncertainties
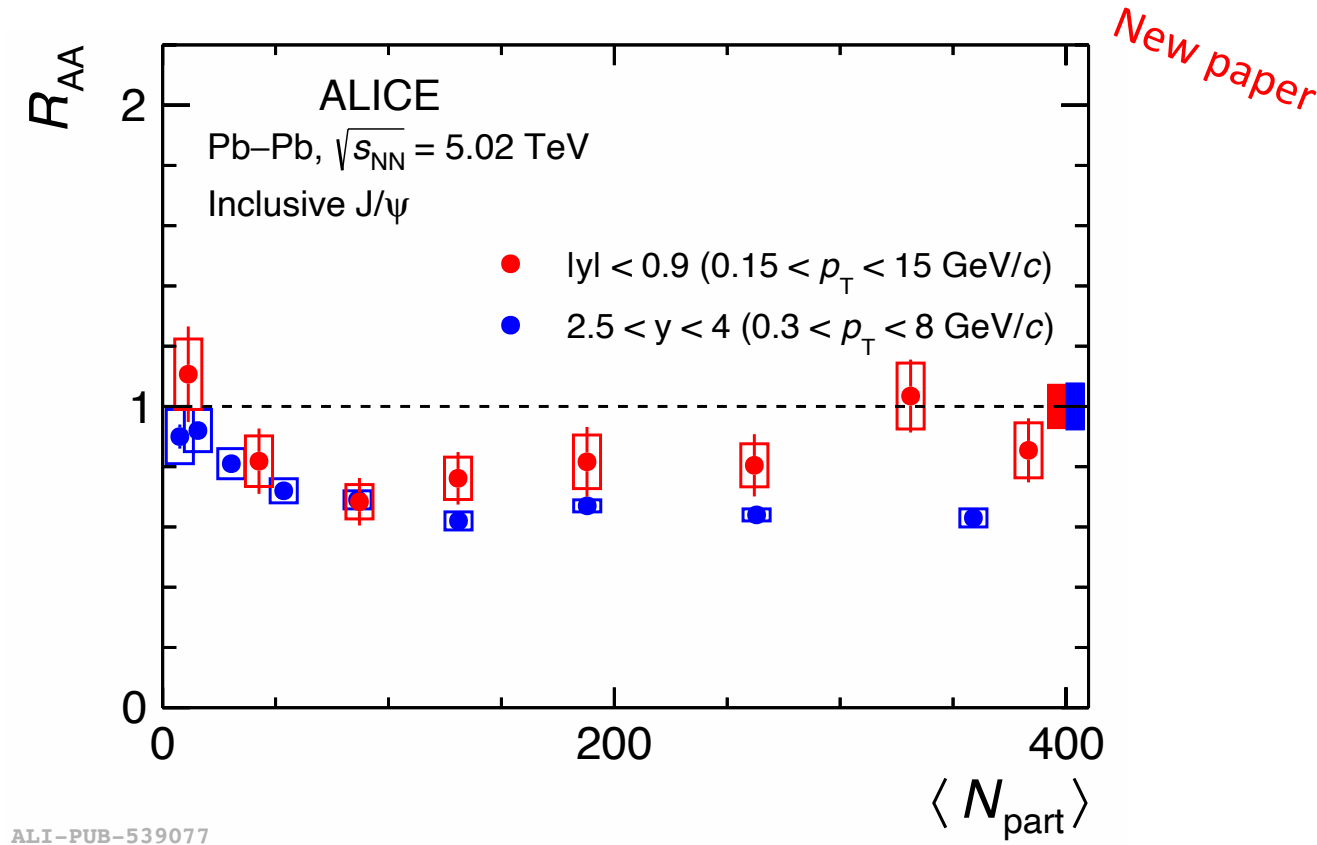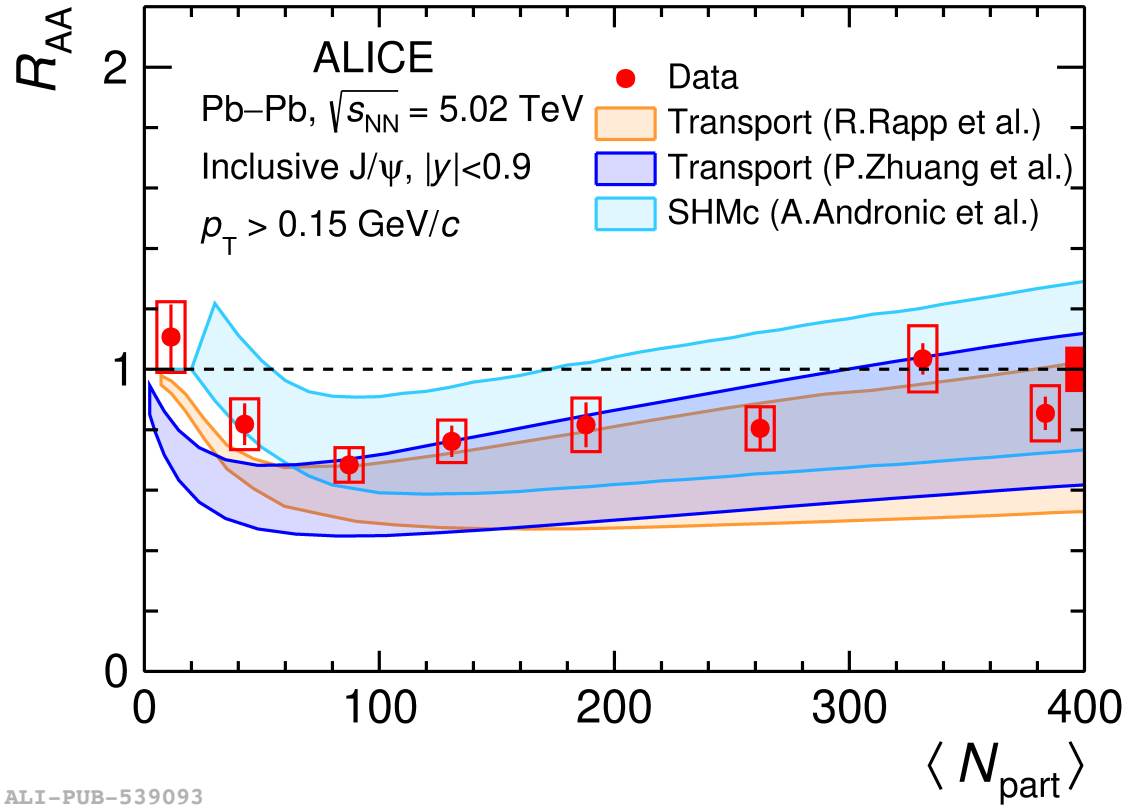➢ SHMc agrees with data at low p_T, and underestimates the measurement at high p_T

arXiv:2303.13361
Du, X. et al., NPA 943, 147–158 (2015)
Zhou, K., et al., PRC 89, 054911 (2014)
Andronic, A, et al, PLB 797, 134836 (2019)

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

New paper

ALICE
Pb–Pb, $\sqrt{s_{NN}}$ = 5.02 TeV
Inclusive J/ψ, |y|<0.9
p_T > 0.15 GeV/c

Data
Transport (R.Rapp et al.)
Transport (P.Zhuang et al.)
SHMc (A.Andronic et al.)

ALI-PUB-539093

ALICE
Pb–Pb, $\sqrt{s_{NN}}$ = 5.02 TeV
Inclusive J/ψ

|y| < 0.9 (0.15 < p_T < 15 GeV/c)
2.5 < y < 4 (0.3 < p_T < 8 GeV/c)

ALI-PUB-539077

- Evidence for J/ψ (re-)generation in central collisions, with a larger contribution at midrapidity compared to forward rapidity
- All models can describe the data but suffer from large uncertainties related to inputs used in calculations (eg. charm cross section, shadowing).
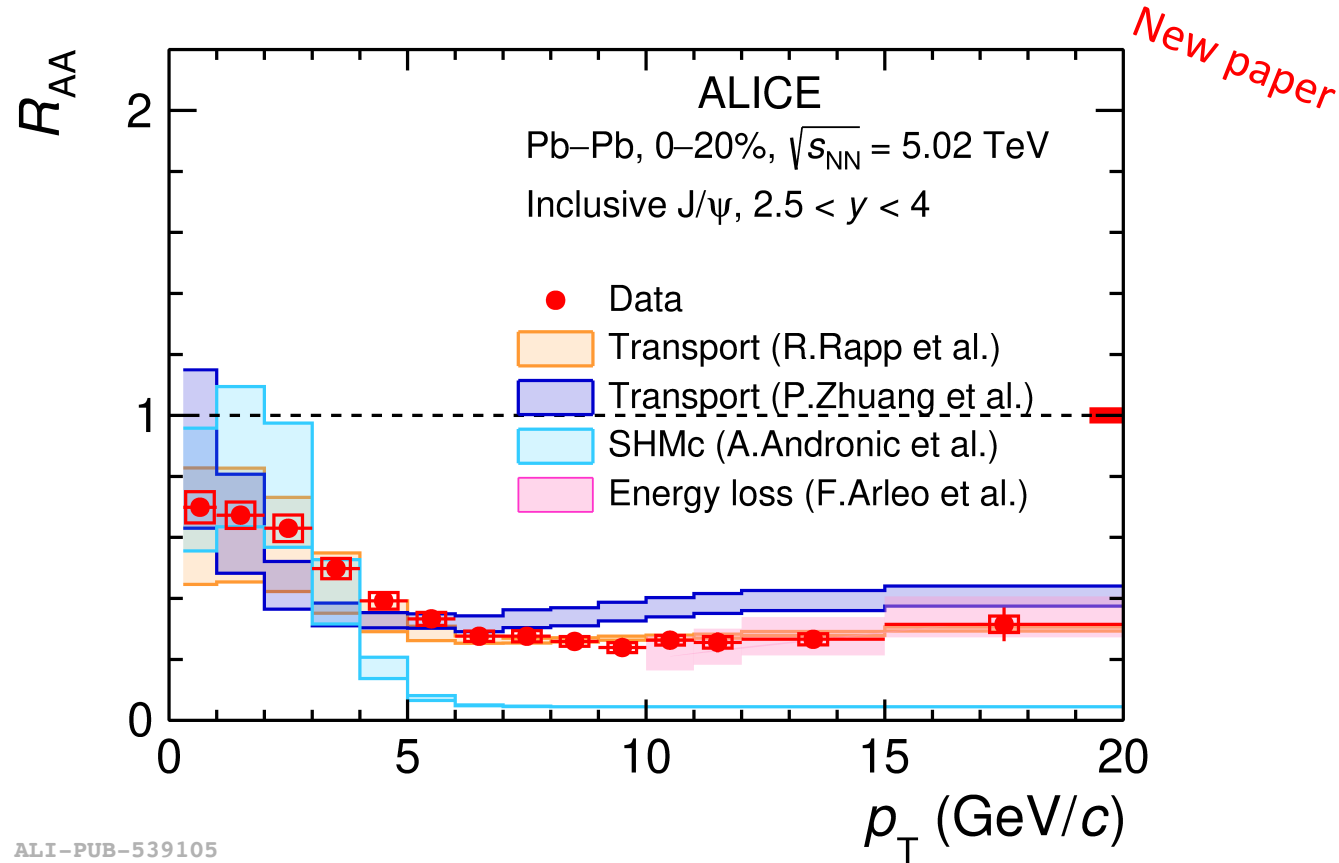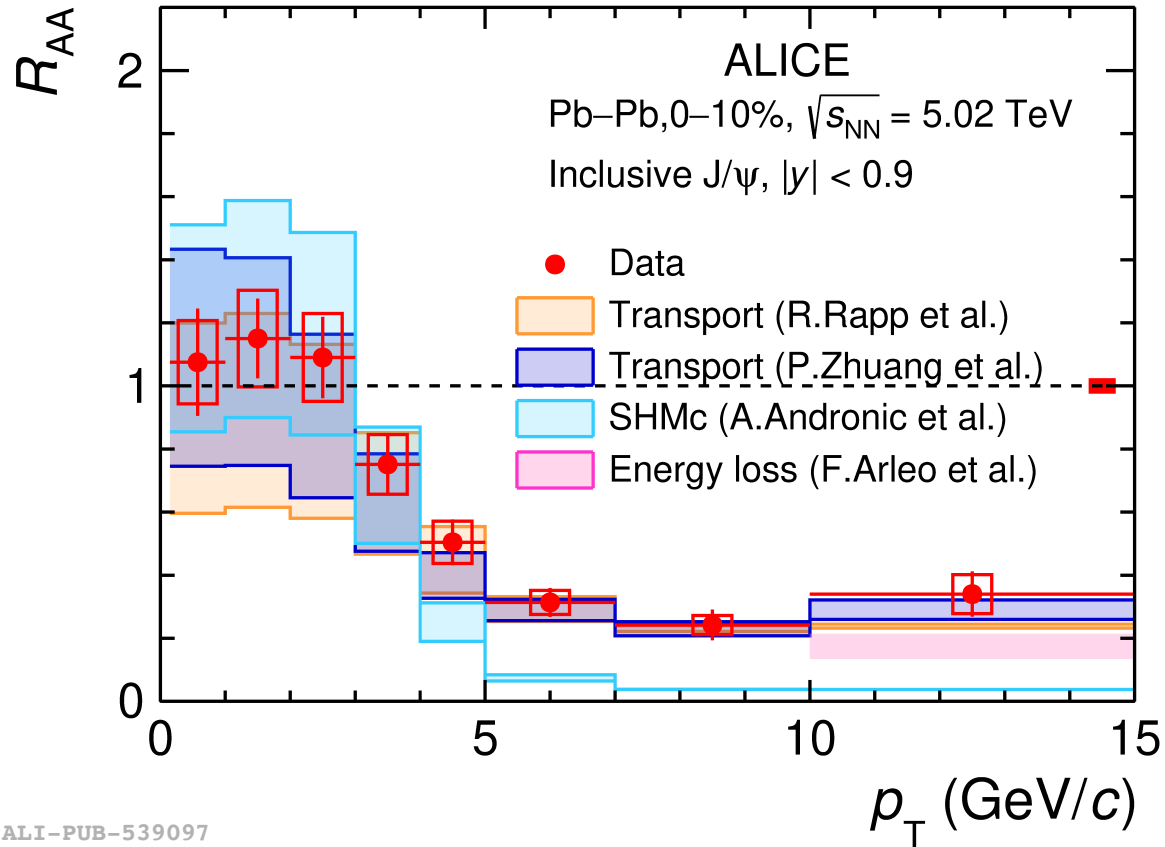
arXiv:2303.13361
Du, X. et al., NPA 943, 147–158 (2015)
Zhou, K., et al., PRC 89, 054911 (2014)
Andronic, A, et al, PLB 797, 134836 (2019)

ALI−PUB−539097

ALI−PUB−539105

New paper

➤ Evidence for J/ψ (re-)generation at low p_T

➤ Transport and SHMc models describe data at low p_T, while SHMc underestimates the measurement at high p_T. The energy loss model agrees with data at high p_T
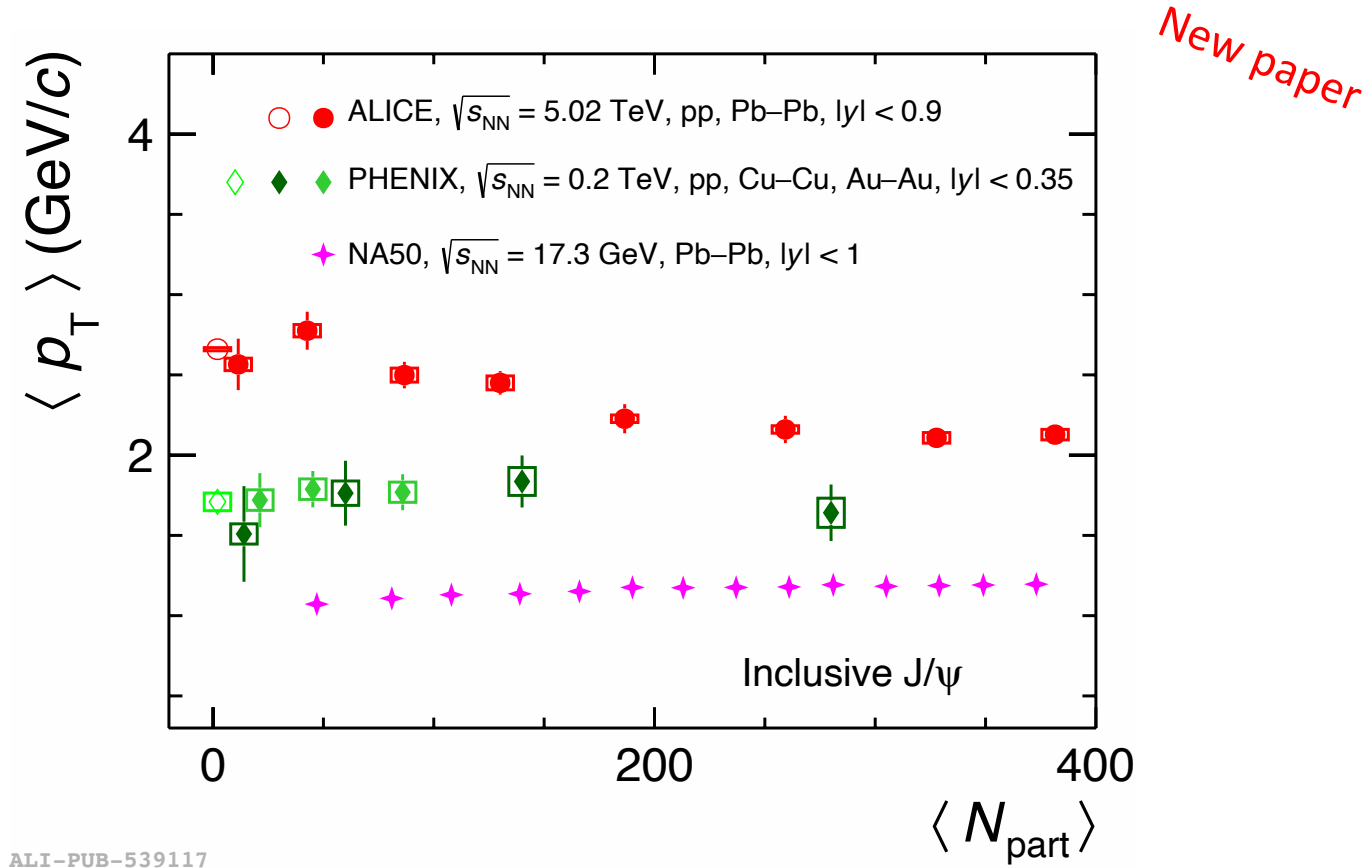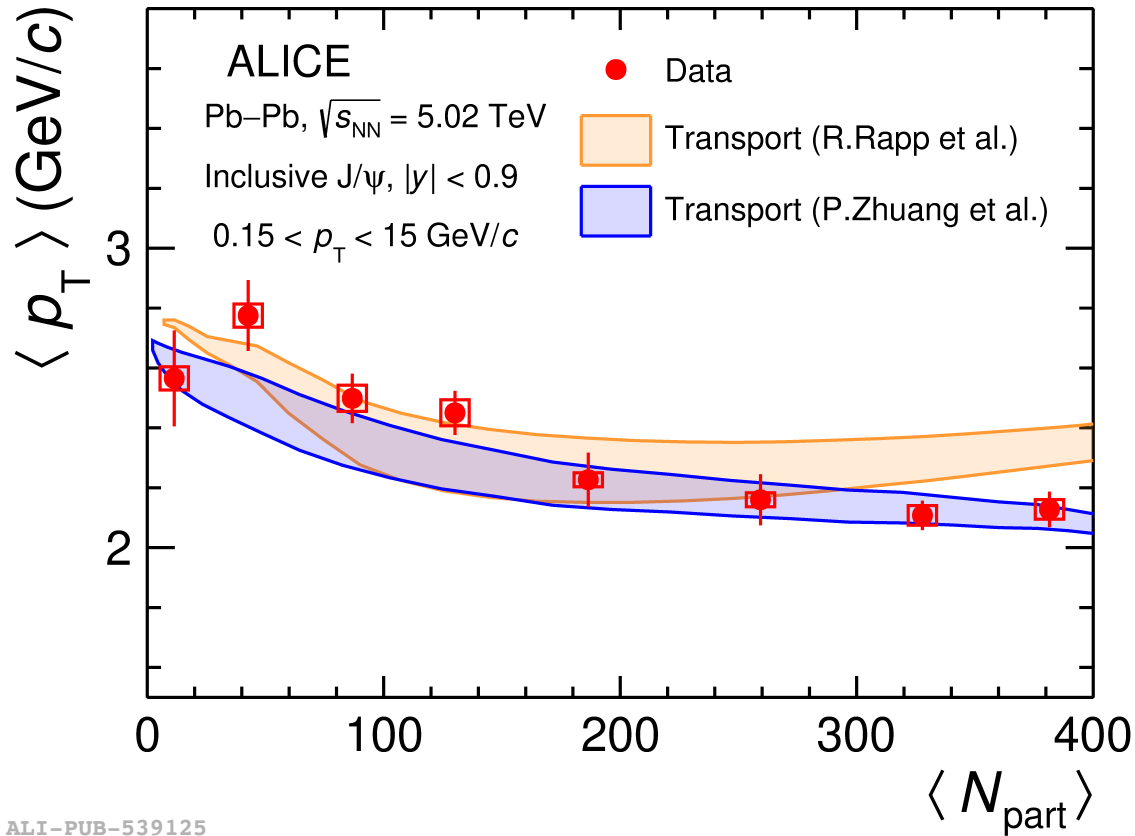
arXiv:2303.13361
Du, X. et al., NPA 943, 147−158 (2015)
Zhou, K., et al., PRC 89, 054911 (2014)
Andronic, A, et al, PLB 797, 134836 (2019)
Arleo. F, PRL119, 062302 (2017)

New paper

ALICE
Pb−Pb, $\sqrt{s_{NN}}$ = 5.02 TeV
Inclusive J/ψ, |y| < 0.9
0.15 < p_T < 15 GeV/c

- Data
- Transport (R.Rapp et al.)
- Transport (P.Zhuang et al.)

ALI−PUB−539125

- ALICE, $\sqrt{s_{NN}}$ = 5.02 TeV, pp, Pb−Pb, |y| < 0.9
- PHENIX, $\sqrt{s_{NN}}$ = 0.2 TeV, pp, Cu−Cu, Au−Au, |y| < 0.35
- NA50, $\sqrt{s_{NN}}$ = 17.3 GeV, Pb−Pb, |y| < 1

Inclusive J/ψ

ALI−PUB−539117

➤ Two transport models describe the decreasing trend of J/ψ ⟨p_T⟩ toward central collisions
➤ Decreasing trend with centrality indicates a softening p_T shape due to the large (re-)generation contribution at low p_T, the behavior is different from low energy collisions

arXiv:2303.13361
Du, X. et al., NPA 943, 147–158 (2015)
Zhou, K., et al., PRC 89, 054911 (2014)

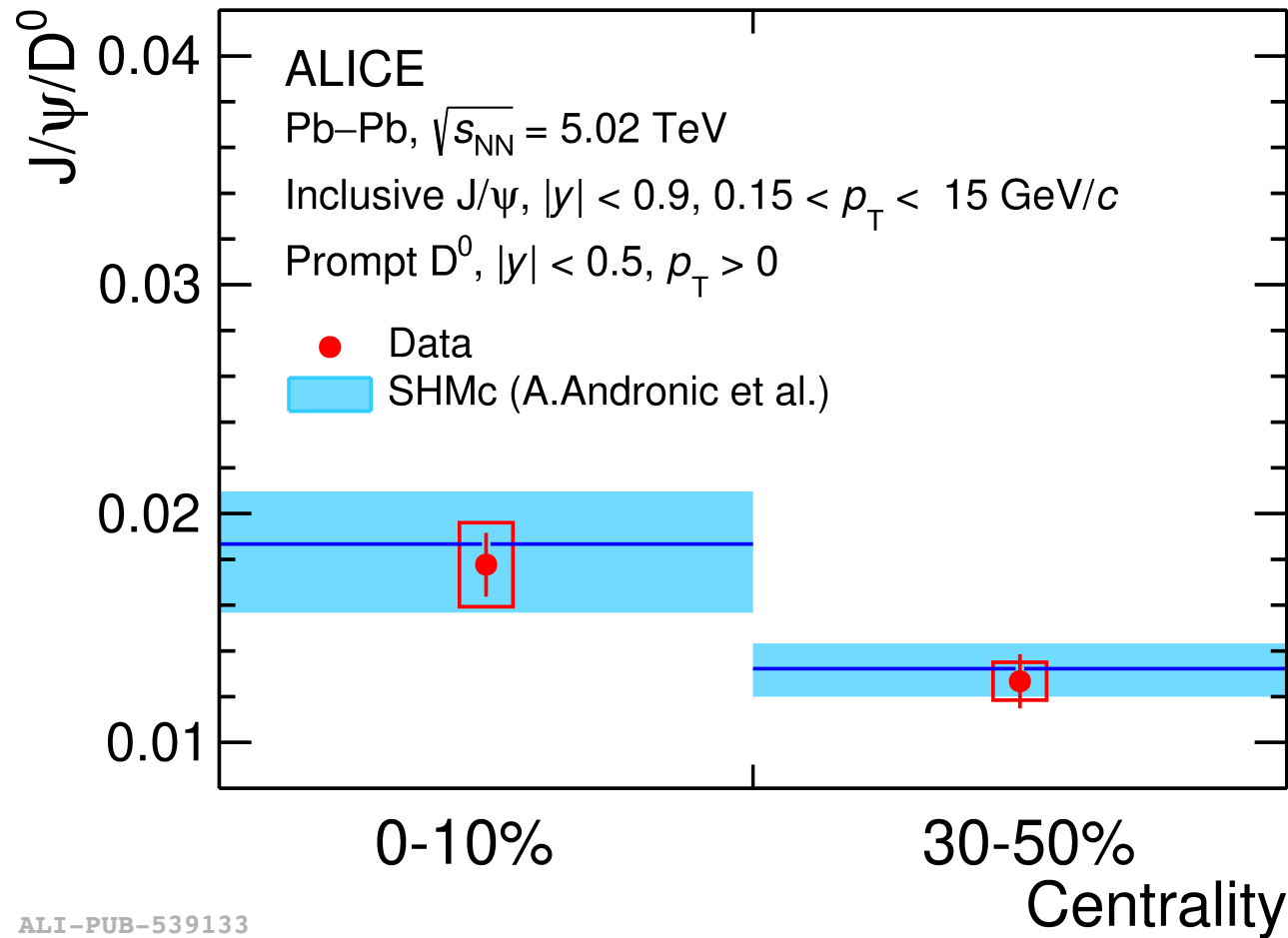# Inclusive J/ψ r_{AA} in Pb−Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

ALI−PUB−539129

ALI−PUB−539121
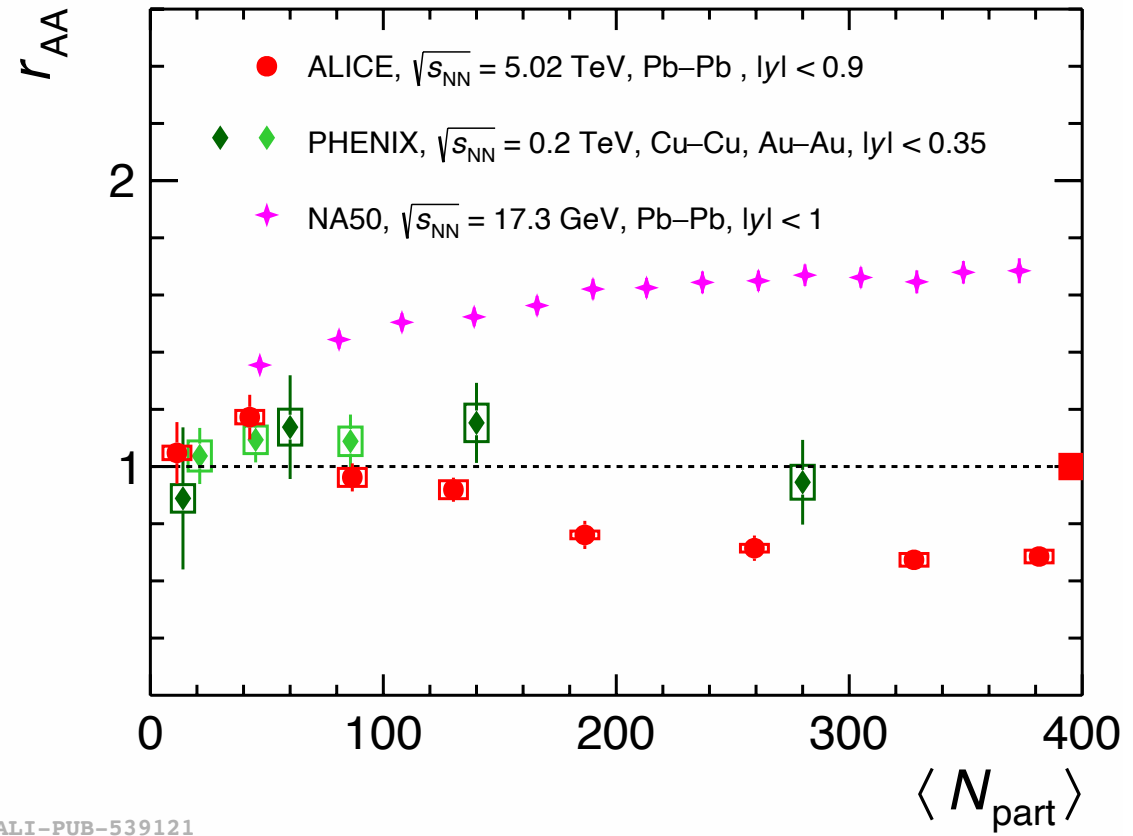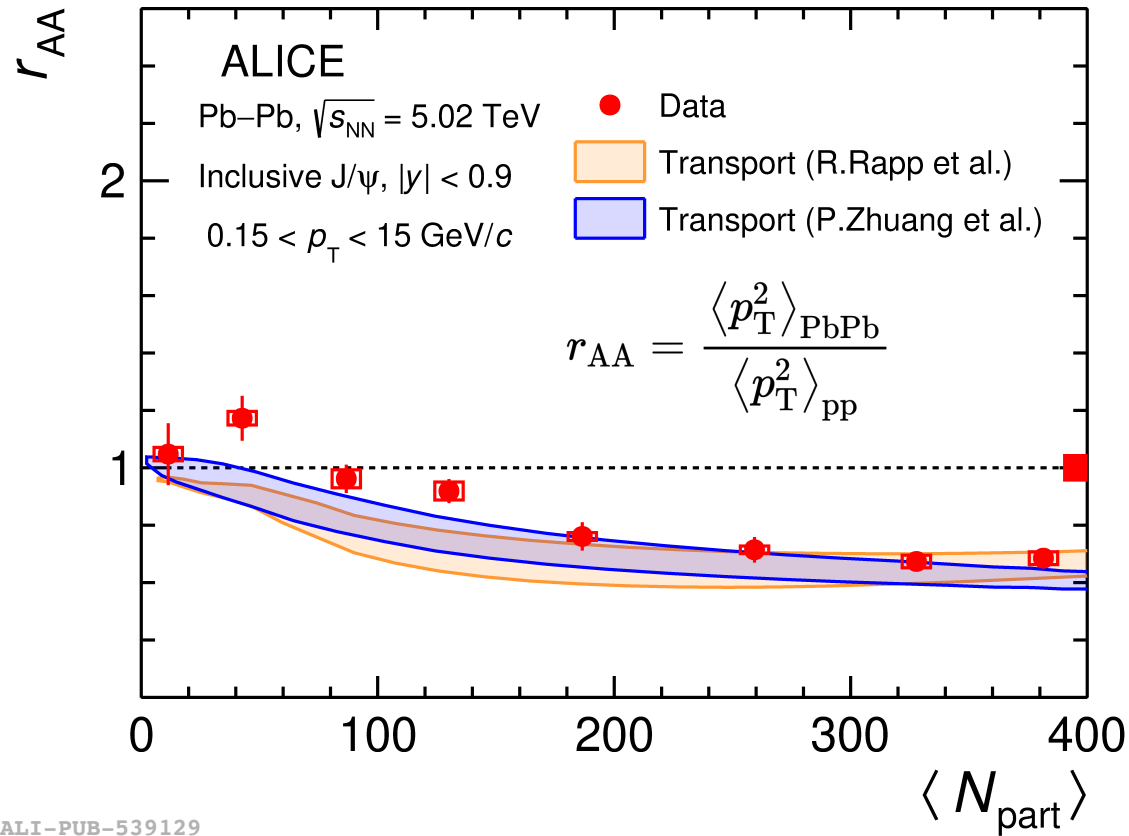
arXiv:2303.13361
Du, X. et al., NPA 943, 147–158 (2015)
Zhou, K., et al., PRC 89, 054911 (2014)

➤ Similar decreasing trend for r_{AA} from semicentral toward central collisions

➤ r_{AA} below unity indicates a softening J/ψ p_T shape in Pb−Pb collisions compared to pp collisions

ALICE
Pb–Pb, $\sqrt{s_{NN}}$ = 5.02 TeV
Inclusive J/ψ, $|y| < 0.9$, $0.15 < p_T < 15$ GeV/c
Prompt D^0, $|y| < 0.5$, $p_T > 0$

- Data
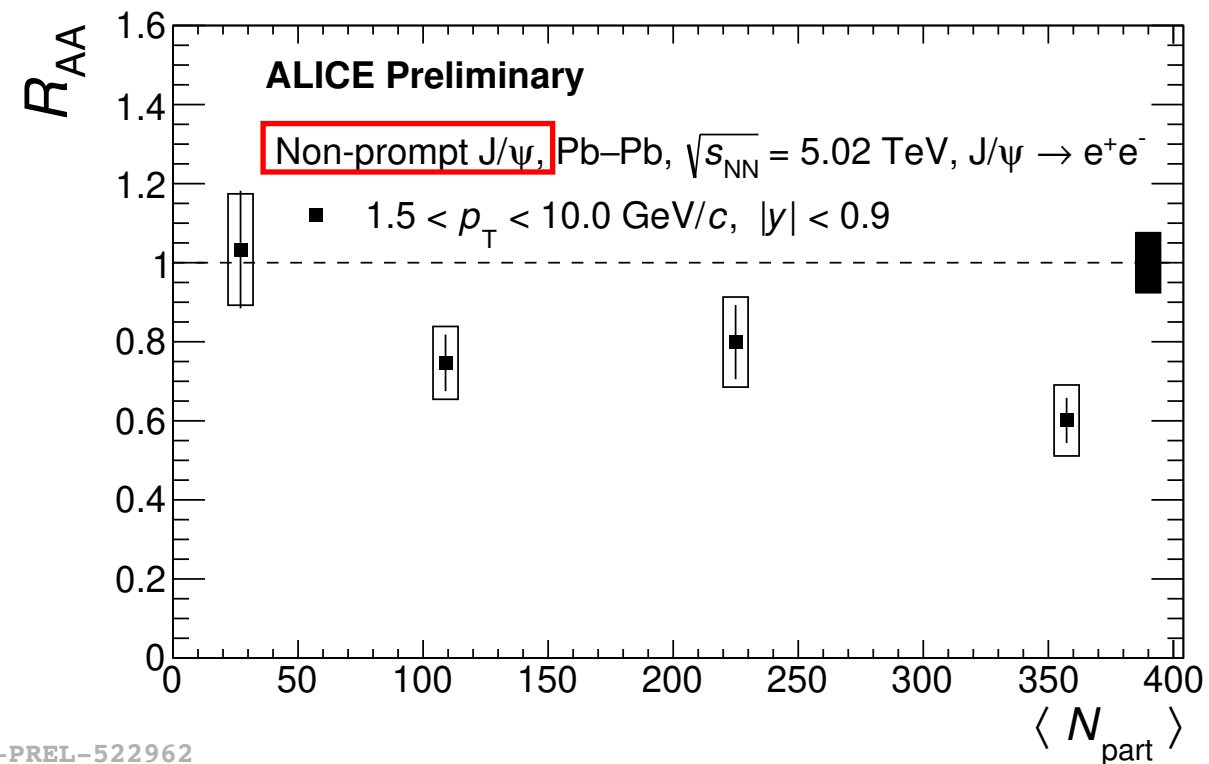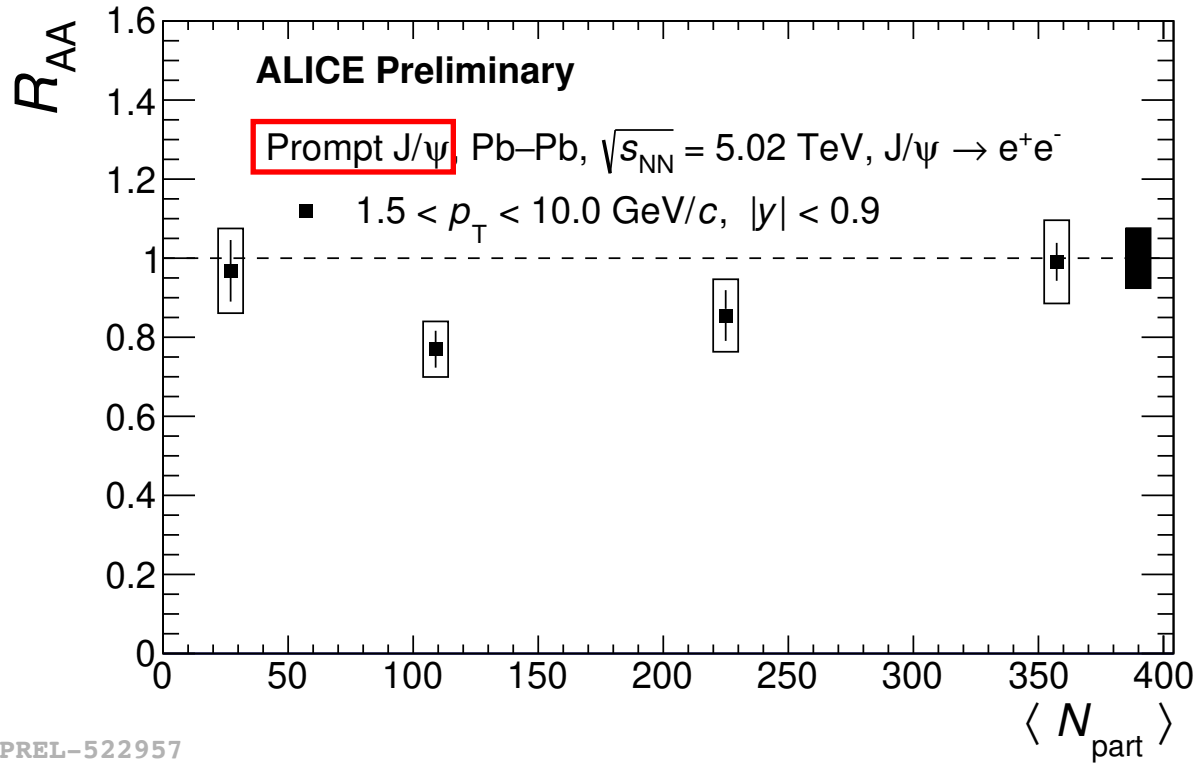- SHMc (A.Andronic et al.)

0-10%   30-50%   Centrality

ALI–PUB–539133

- ➤ Sensitive to hadronization mechanisms for open and hidden charm hadrons

- ➤ The centrality dependent trend of the D^0 to J/ψ ratio can be explained by the increase of charm fugacity towards most central collisions according to SHMc prediction

New paper

ALI-PREL-509352

ALI-PREL-509342
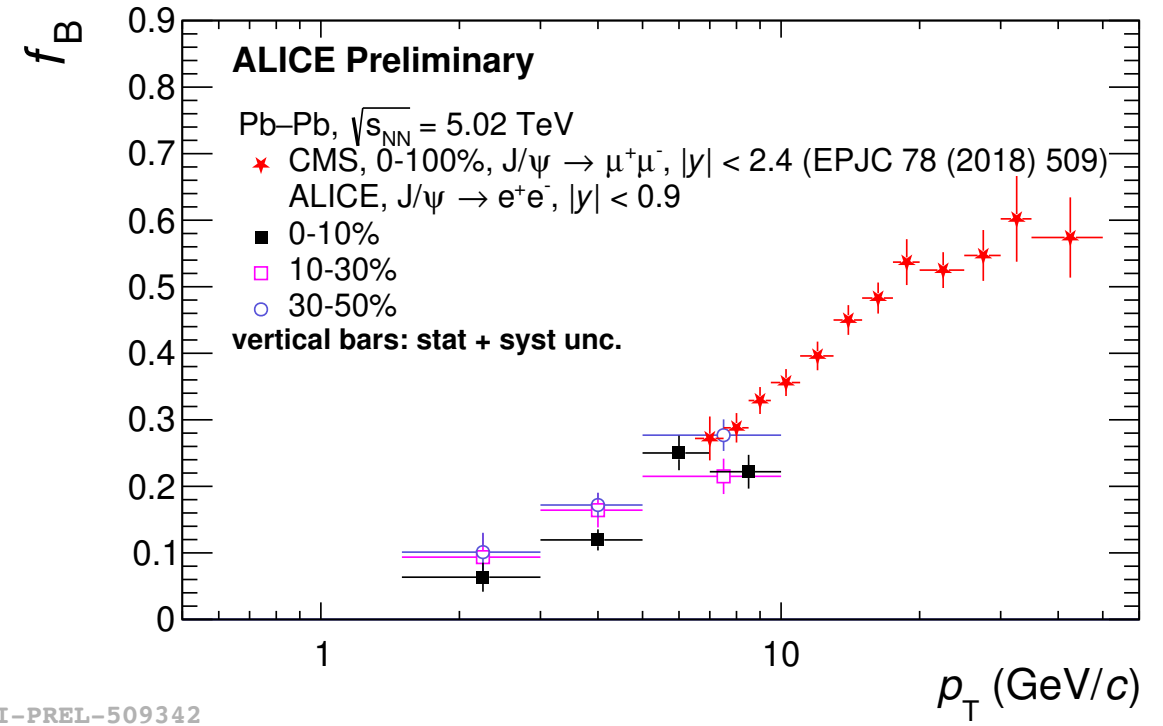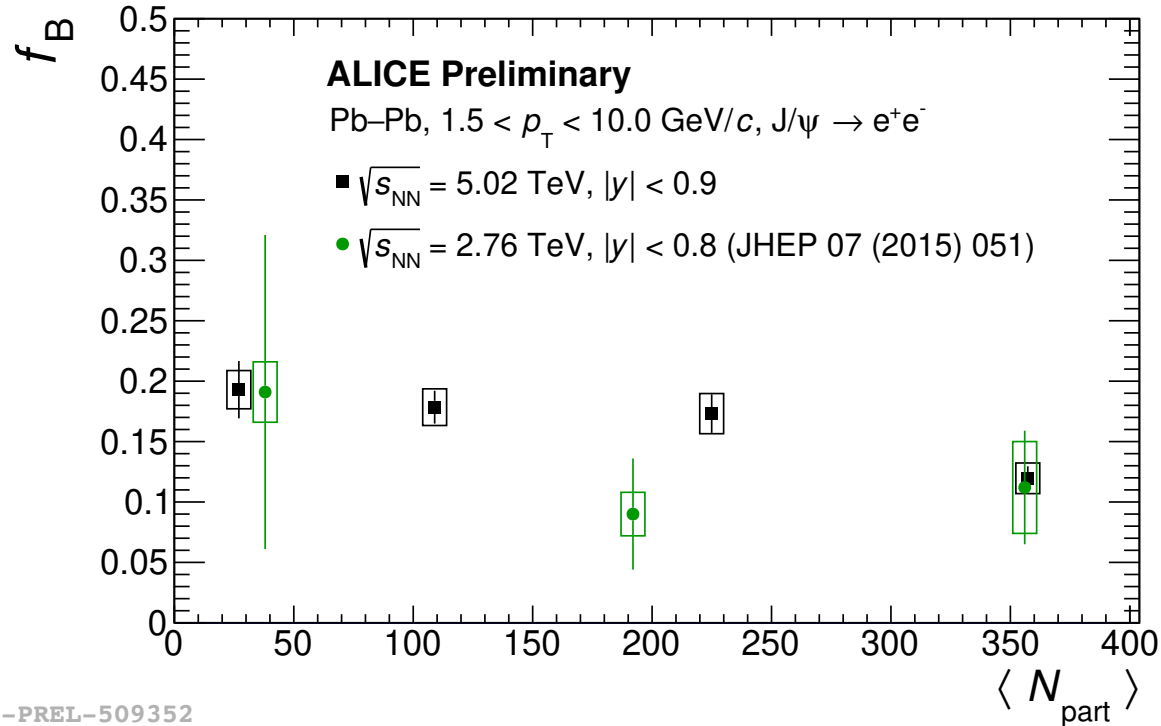
➢ The precision of the new measurement is significantly improved compared to LHC Run 1 results
➢ The slight centrality dependence hints at an increasing contribution from (re-)generation towards most central collisions for prompt J/ψ
➢ ALICE extends non-prompt J/ψ measurement at the LHC down to p_T = 1.5 GeV/c at midrapidity

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

# p_T and centrality dependence of prompt and non-prompt J/ψ


ALI−PREL−512458

ALI−PREL−512468
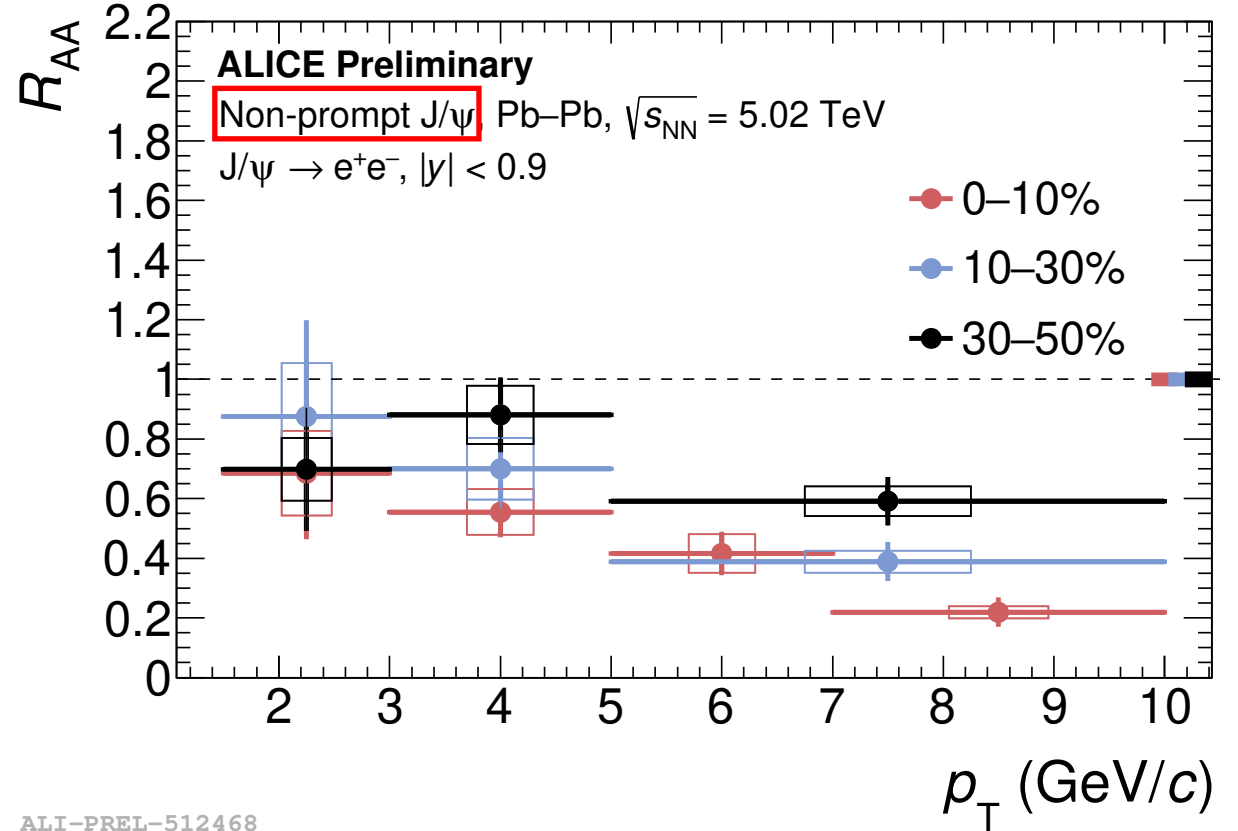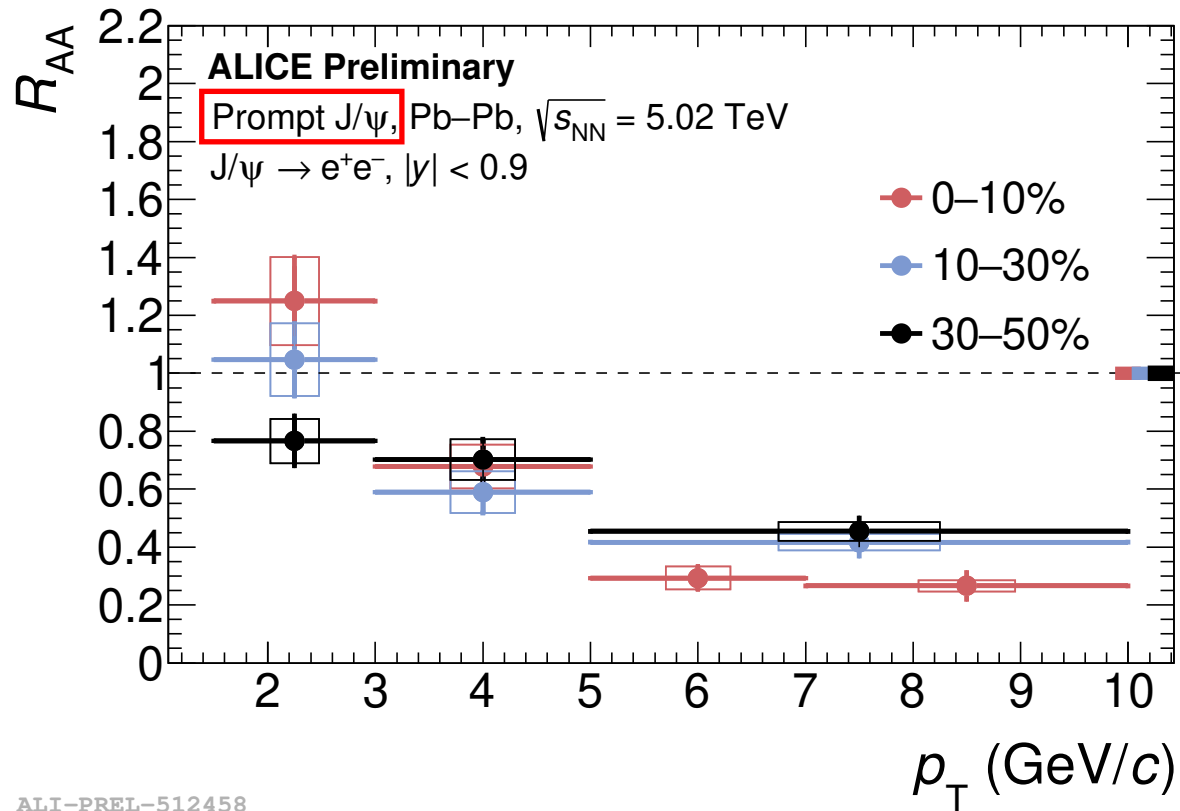
- ➤ Prompt J/ψ R_{AA} increases from semicentral to central collisions in the lowest p_T intervals
- ➤ The suppression seems stronger in central collisions compared to semicentral at high p_T for both prompt and non-prompt J/ψ R_{AA}

J/ψ R_{AA} comparison with models

ALI-PREL-509400

ALI-PREL-509383
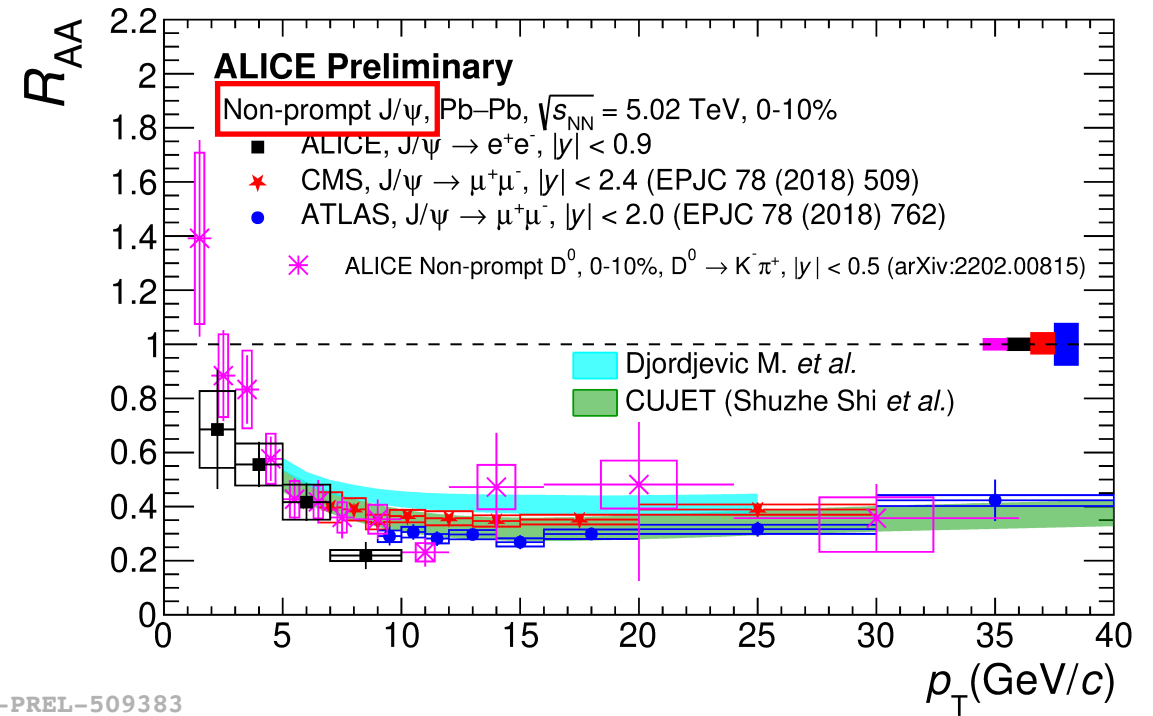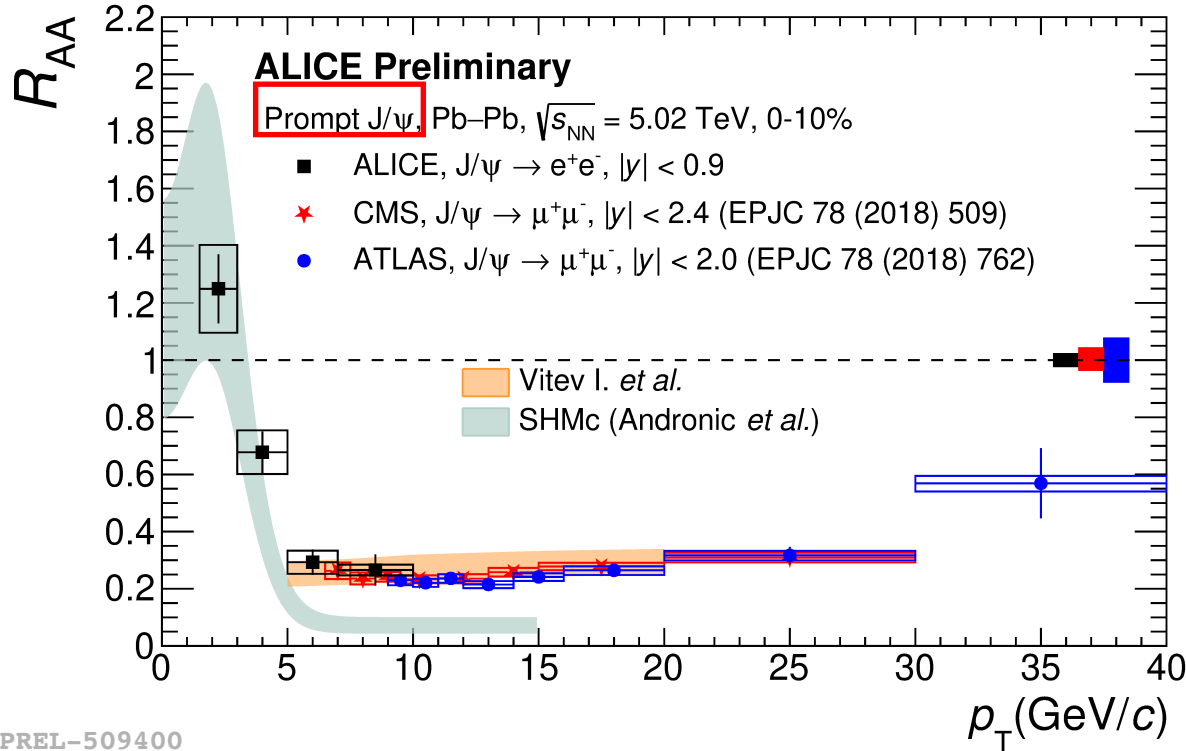
➢ R_{AA} extended down to p_T =1.5 GeV/c and compatible within uncertainties with ATLAS and CMS measurements in common p_T range

➢ 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
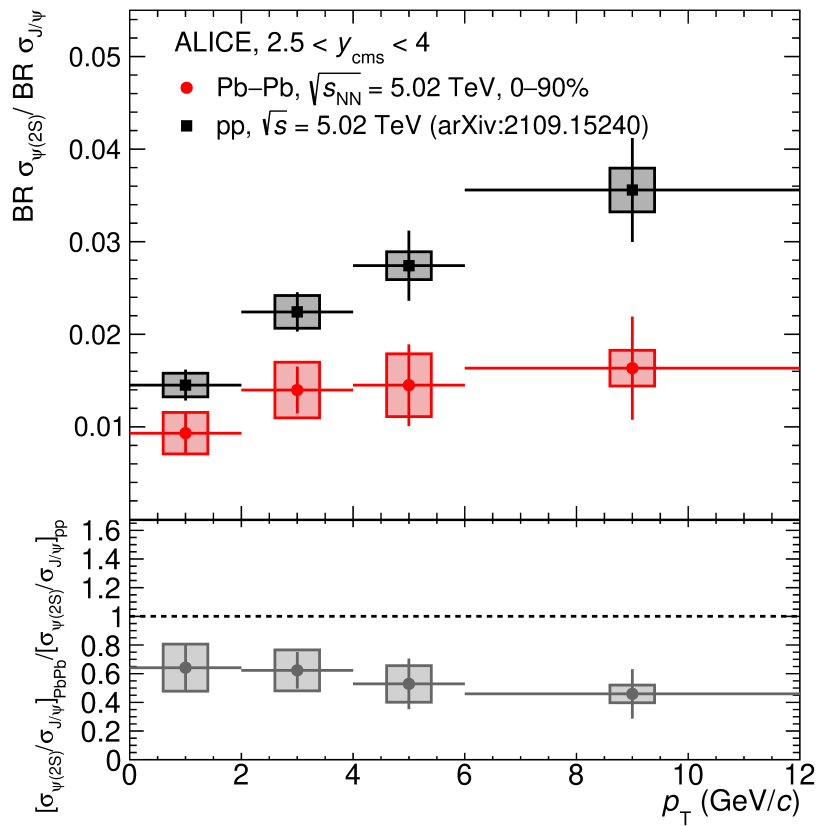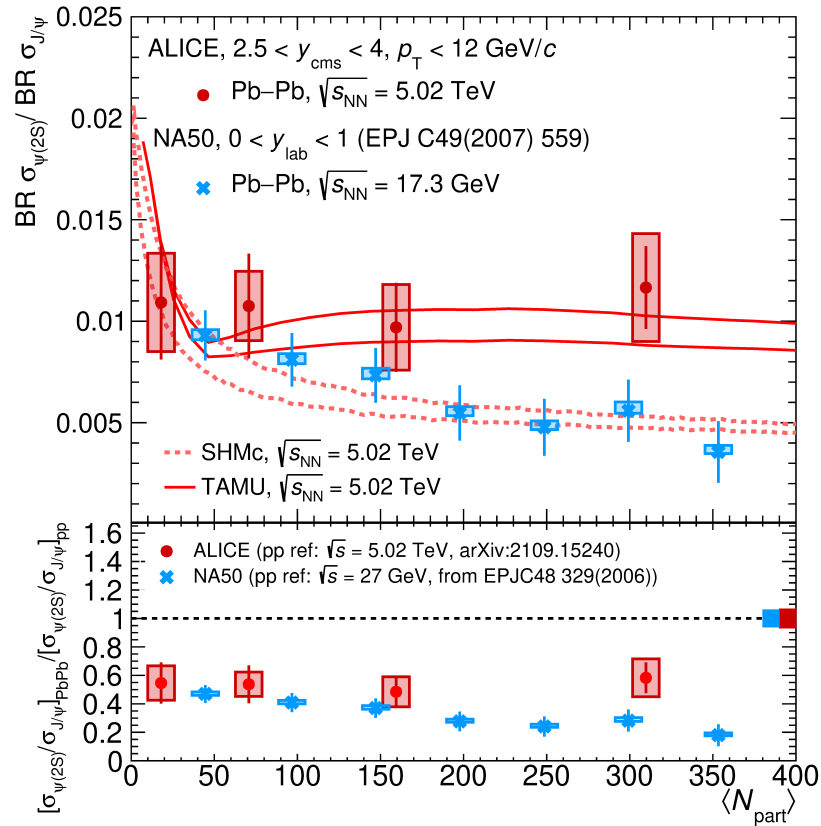
Andronic, A, et al, PLB 797, 134836 (2019)
A. Adil, I. Vitev, Phys. Lett. B 649, 139 (2007)
S. Shi, et al., Phys. C 43, 044101 (2019)
S. Stojku et al., PRC 105, L021901 (2022)

ψ(2S) R_{AA} in Pb−Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV
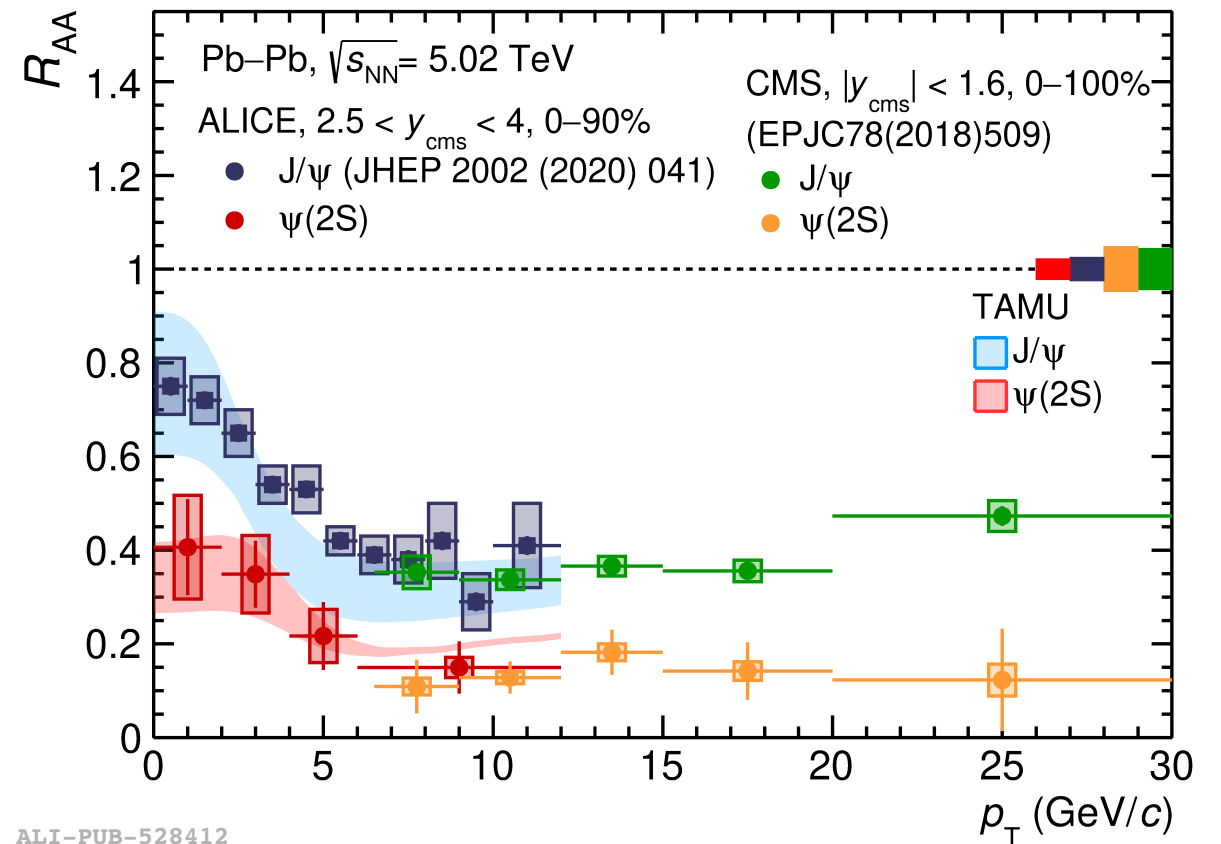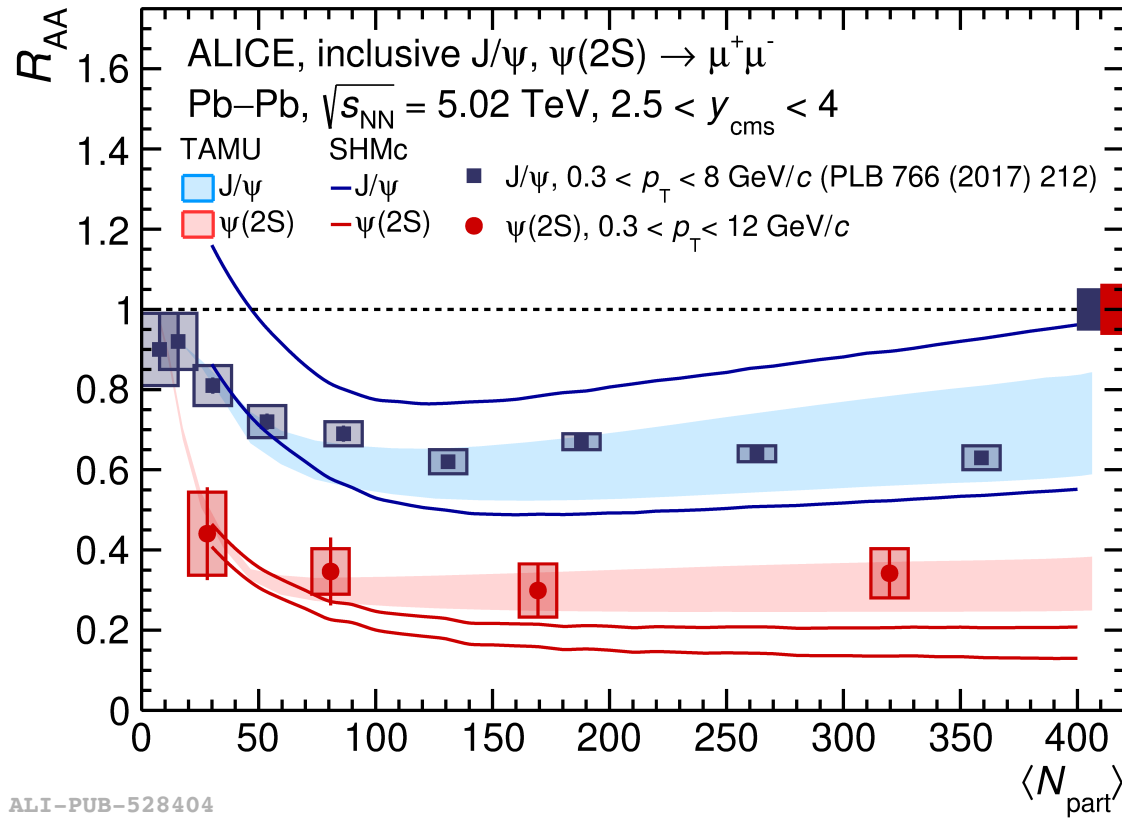
- ➤ A larger suppression of the ψ(2S) with respect to the J/ψ is observed
- ➤ The ψ(2S) R_{AA} increases at low p_T , which is a hint ψ(2S) regeneration
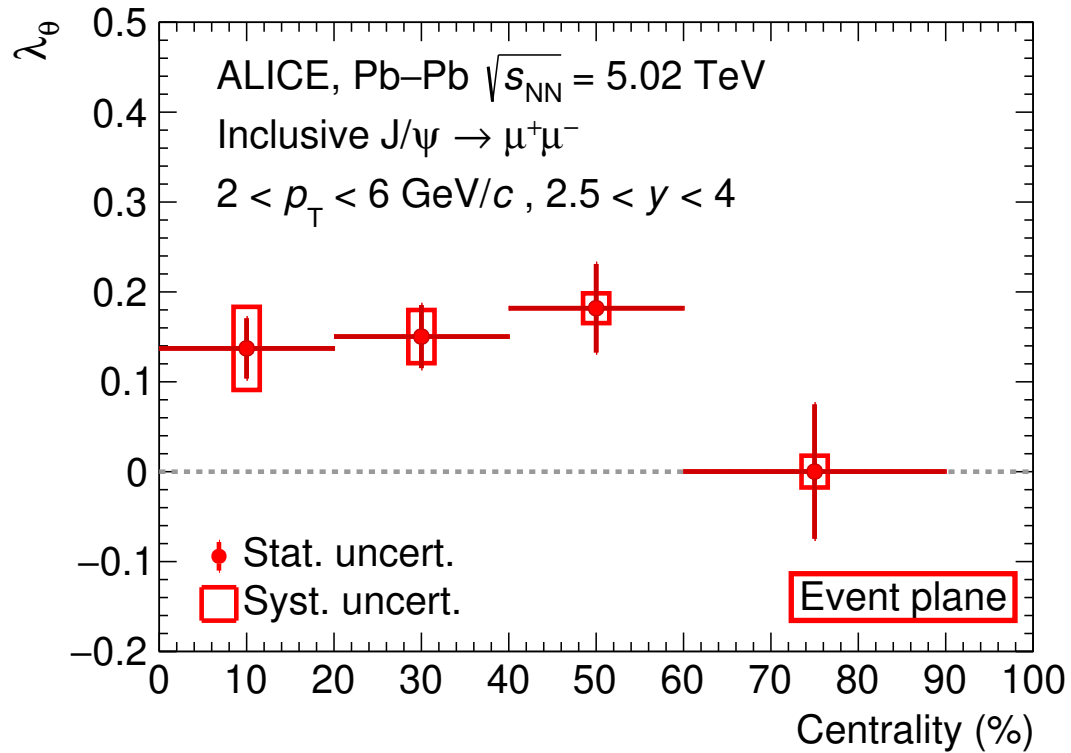- ➤ The TAMU model describes data slightly better than SHMc

ALI-PUB-528400

ALI-PUB-528408

➤ The ratio of ψ(2S) and J/ψ cross section shows no significant centrality and p_T dependence at 5.02 TeV, which is different from low energy collisions

➤ The TAMU model describe data slightly better than SHMc in central collisions
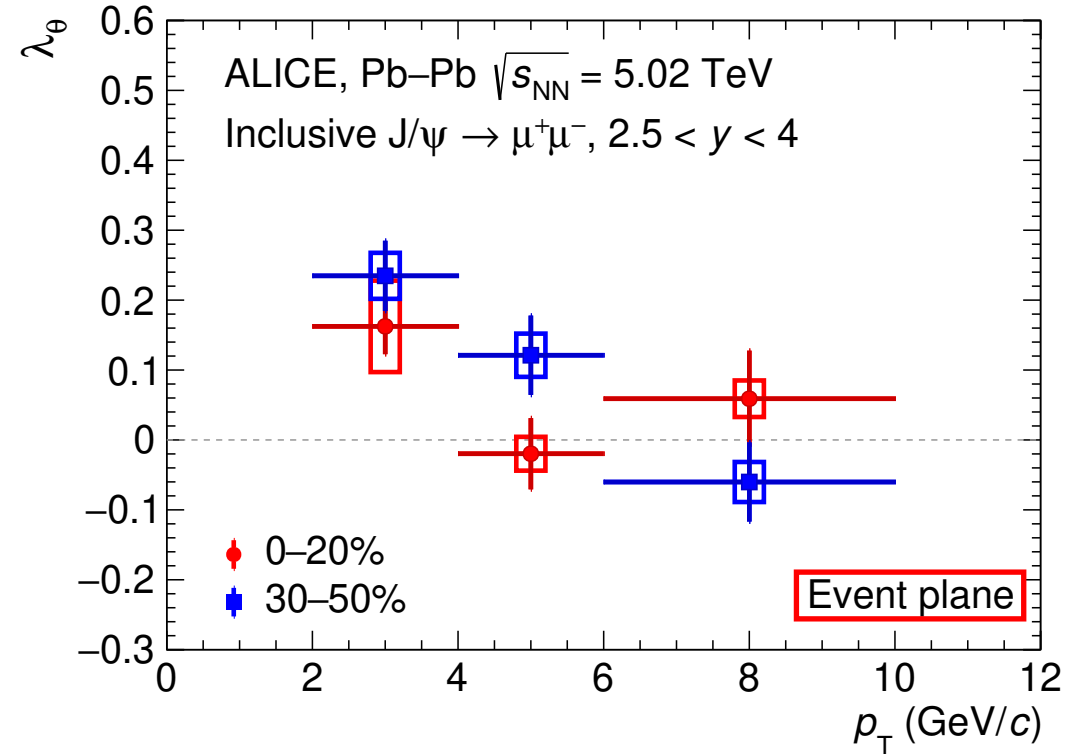
arXiv:2210.08893
(TAMU) X. Du, et al.,NPA943,147-158(2015)
(SHMc) A. Andronic, et al.,PLB797,134836(2019)

ALI−PUB−521052

ALI−PUB−521057

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

arXiv:2204.10171

Summary and outlook

➤ **J/ψ and ψ(2S) production in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV**

- Dominant contribution from (re-)generation in central collisions and low p_T for inclusive and prompt J/ψ

- Strong suppression observed for non-prompt J/ψ, described by energy loss models

- A larger suppression of the ψ(2S) with respect to the J/ψ is observed

- Significant non-zero J/ψ 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/ψ at forward rapidity.

Thanks