



HP2024
N A G A S A K I



Prompt/non-prompt J/ψ production in proton-proton and Pb–Pb collisions with ALICE

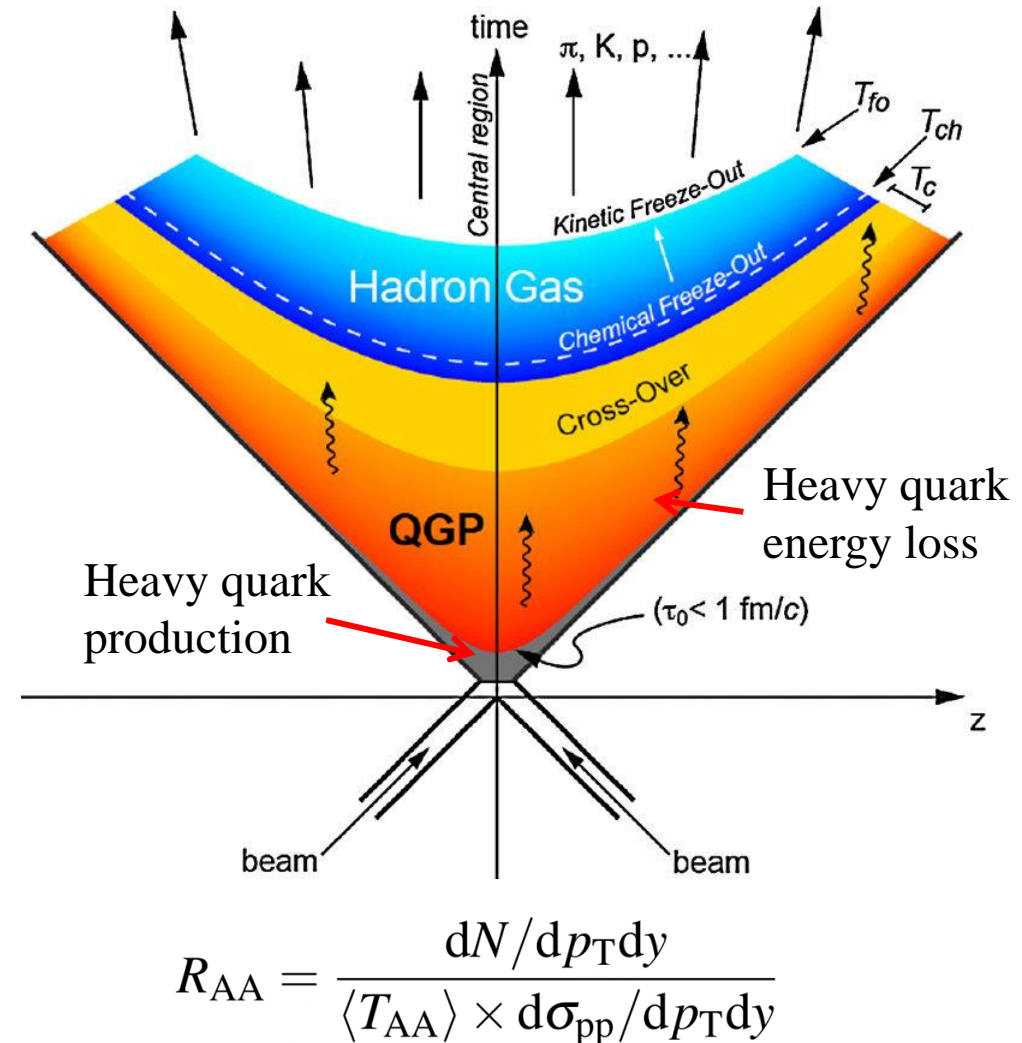
Yuan Zhang

For the ALICE Collaboration

University of Science and Technology of China

Introduction

- J/ψ is bound state of charm and anti-charm quark pair.
 - The simplest system in QCD: two-body problem
- Heavy quarks mostly produced in the early stages of Pb–Pb collisions.
 - Direct probes of QGP.
- **Prompt J/ψ :**
 - Direct production or feed-down from excited states.
 - **Suppression:** Color screen and dynamical dissociation.
 - **(Re-)generation:** Recombination of $c\bar{c}$ pairs in QGP.
- **Non-prompt J/ψ :**
 - Produced via **B-hadrons decay** through weak interactions.
 - Reflects the interaction between b-quark and QGP.
 - Can investigate the mass dependence of interaction between heavy-quarks and the QGP medium.



Quarkonium measurements with the ALICE detector (Run 2)

Inner Tracking System:

Tracking, vertex reconstruction,
Event Plane determination

Time Projection Chamber:

Tracking, particle identification

V0 Detector:

Centrality determination, triggering,
event plane measurement, and
background rejection

Muon Spectrum:

Trigger and tracking for muons

$$|y| < 0.9$$

$$J/\psi, \psi(2S) \rightarrow e^+e^-$$

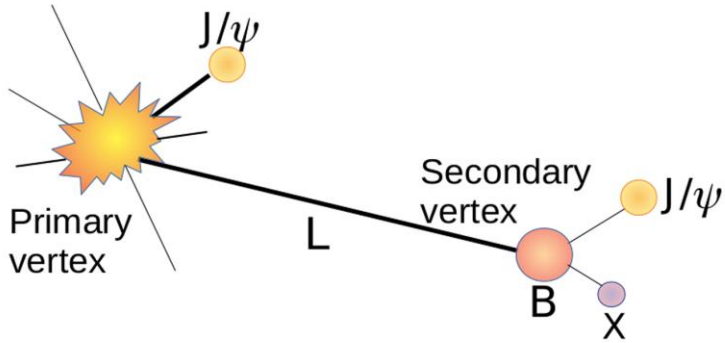
$$2.5 < y < 4$$

$$J/\psi, \psi(2S) \rightarrow \mu^+\mu^-$$

$$\Upsilon \rightarrow \mu^+\mu^-$$

- 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.

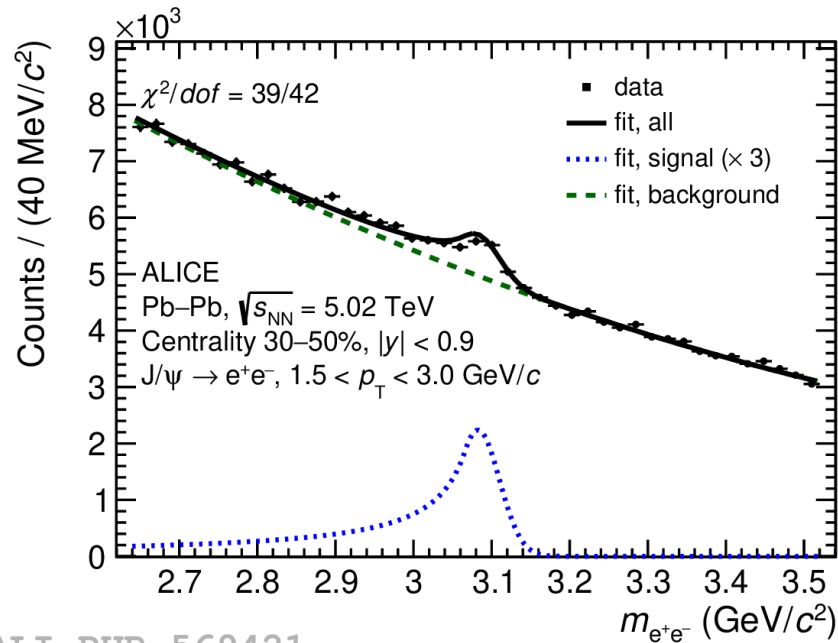
Separation of prompt and non-prompt J/ψ



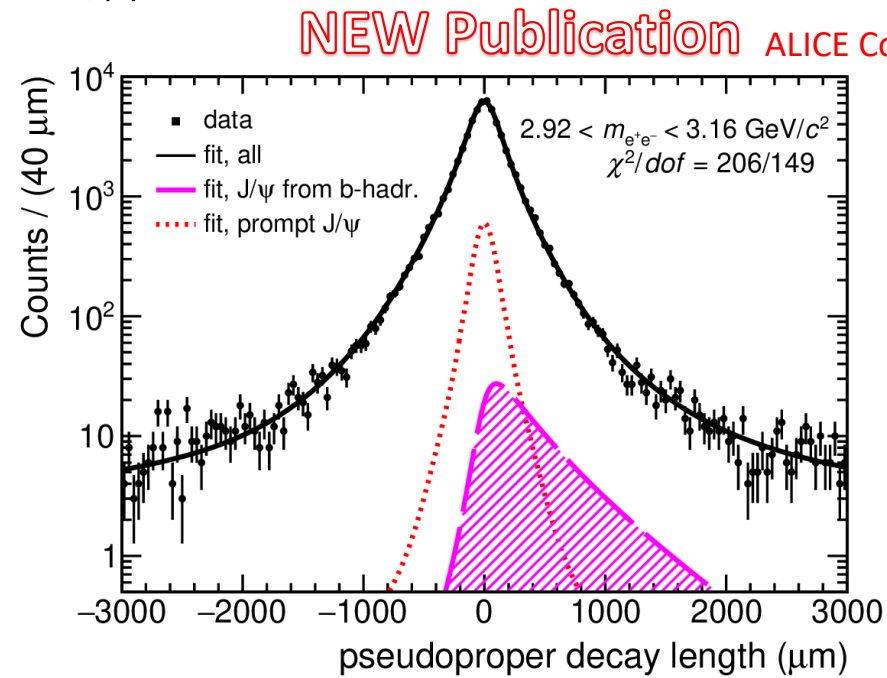
$$x = \frac{\vec{L} \cdot \vec{p}_T^{J/\psi}}{|\vec{p}_T^{J/\psi}|} \cdot \frac{m^{J/\psi} c}{|\vec{p}_T^{J/\psi}|}$$

$$f_B = \frac{\sigma^{J/\psi \leftarrow h_B}}{\sigma^{\text{inclusive } J/\psi}}$$

- Non-prompt J/ψ fraction (f_B) extracted by unbinned likelihood fit on invariant mass ($m_{e^+e^-}$) and **pseudo-proper decay length** (x) of e^+e^- pairs.
- Pseudo-proper decay length distribution for prompt and non-prompt J/ψ obtained from MC simulations.



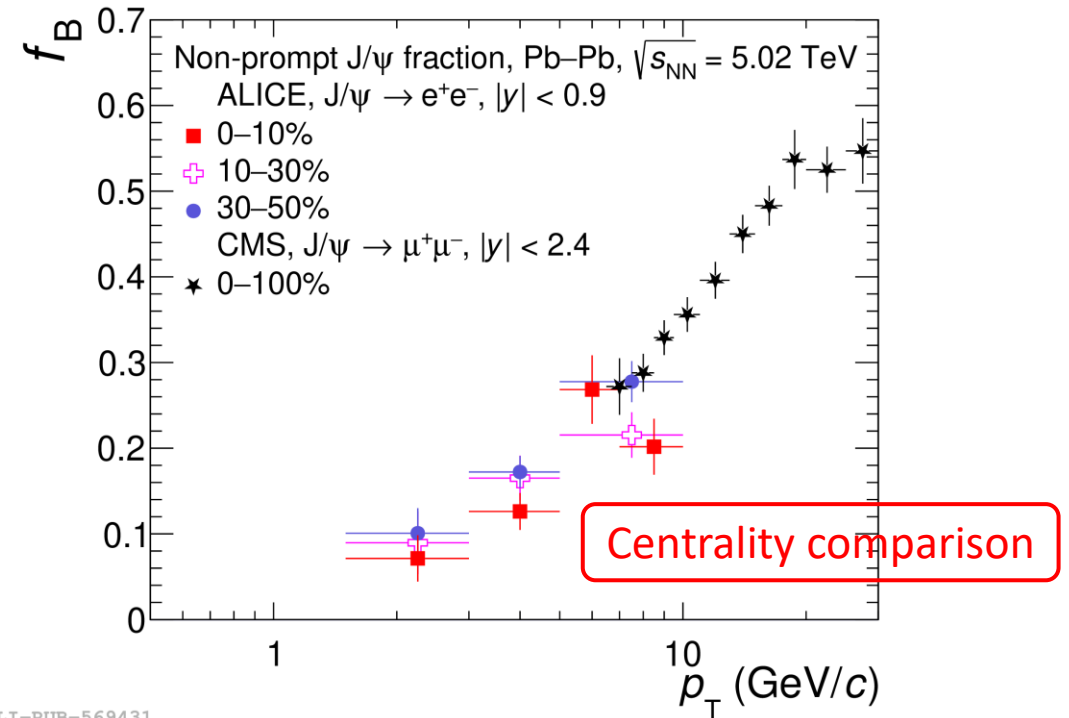
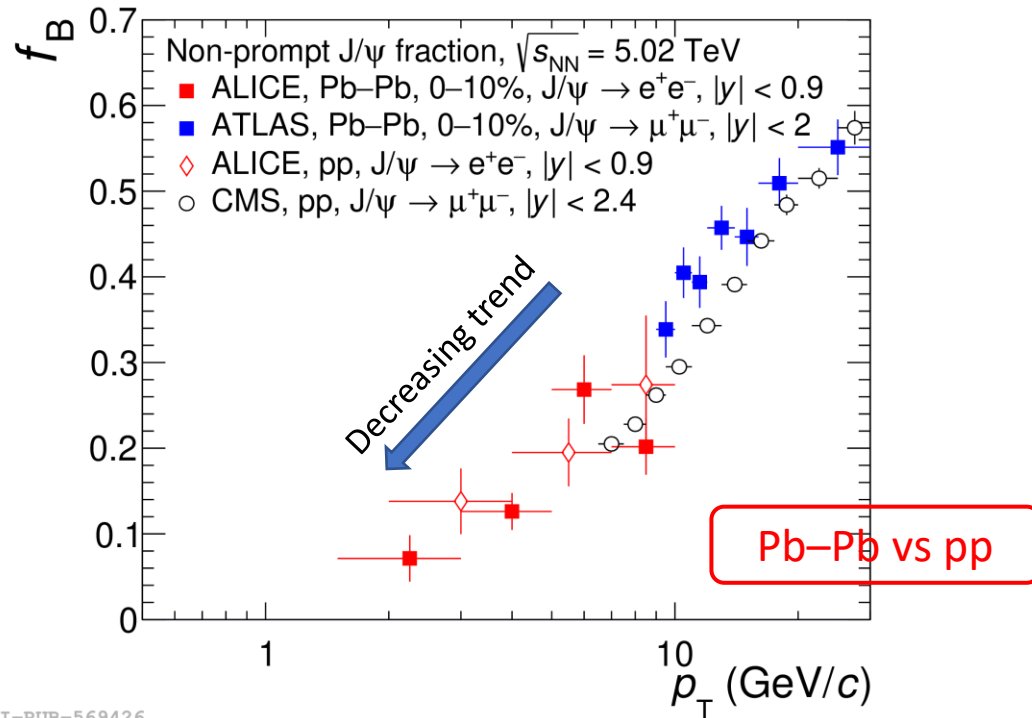
ALI-PUB-569421



NEW Publication ALICE Collaboration, *JHEP* 02 (2024) 066

Non-prompt J/ψ fraction vs p_T

NEW Publication ALICE Collaboration, *JHEP* 02 (2024) 066



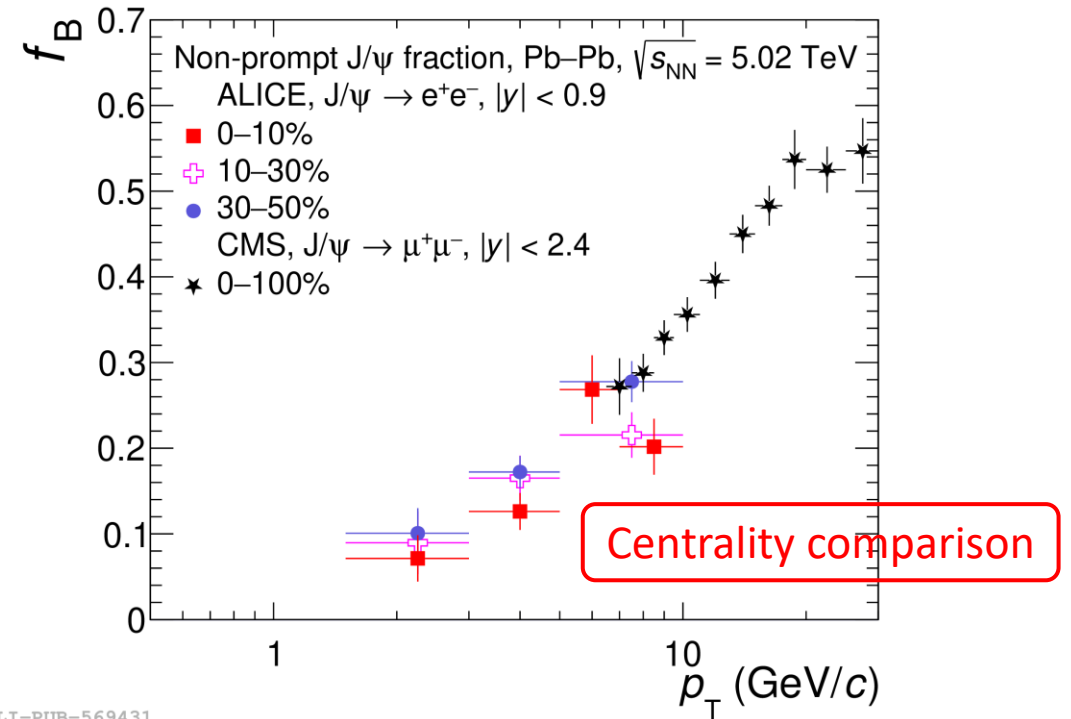
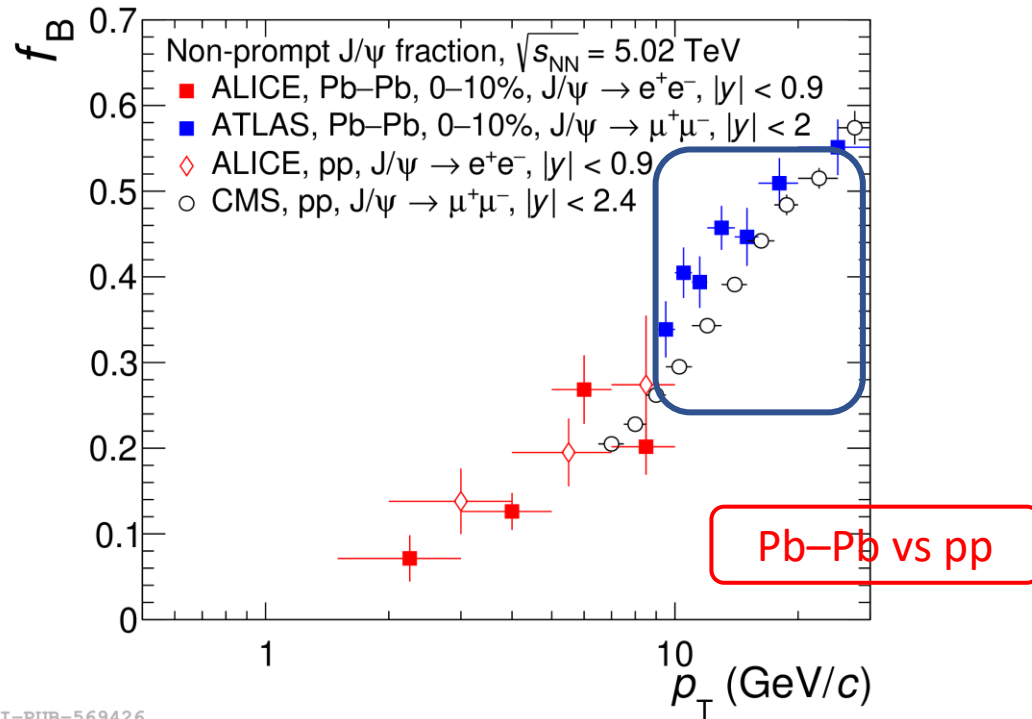
ALI-PUB-569426

ALI-PUB-569431

- f_B measurements extended down to $p_T = 1.5$ GeV/c, thanks to ALICE's unique capability to measure in low p_T .
 - **Consistent** with the results from ATLAS and CMS measurement in high p_T .
 - Matching the **decreasing trend** from high towards low p_T , similar in pp collisions.
- f_B in Pb–Pb collision is consistent with that in pp collisions within uncertainties, but slightly **higher** in high p_T .
 - Possibly suggesting a stronger nuclear suppression of prompt charmonia compared to beauty hadrons.
- Hint of mild **centrality dependence** in f_B measurements.

Non-prompt J/ψ fraction vs p_T

NEW Publication ALICE Collaboration, *JHEP* 02 (2024) 066



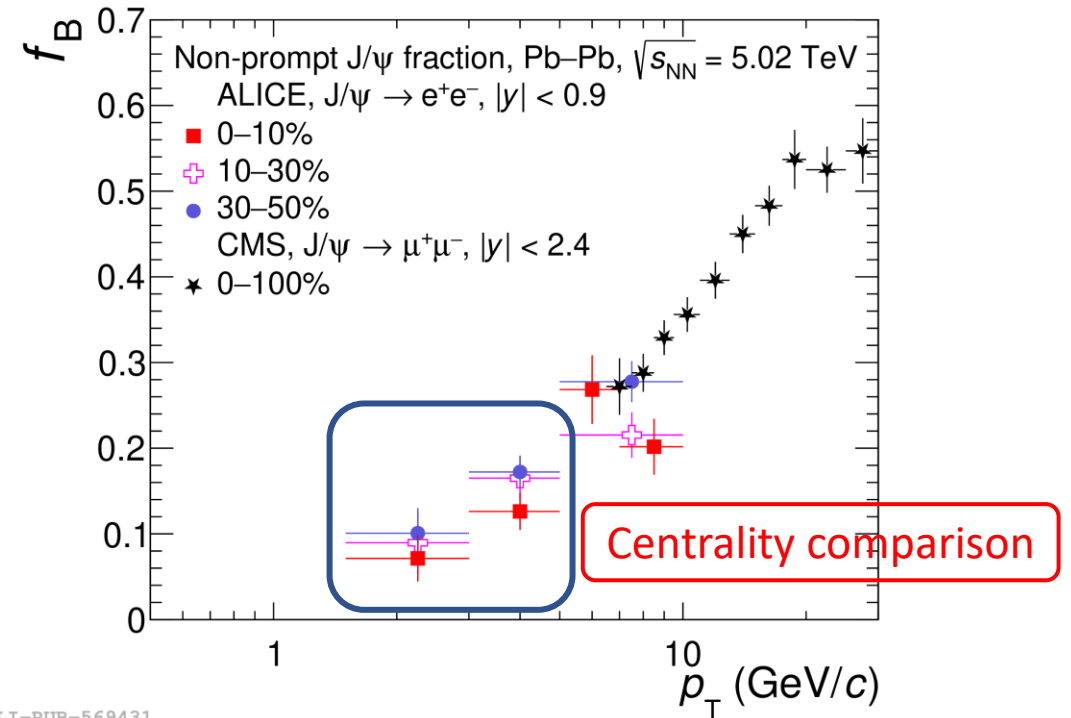
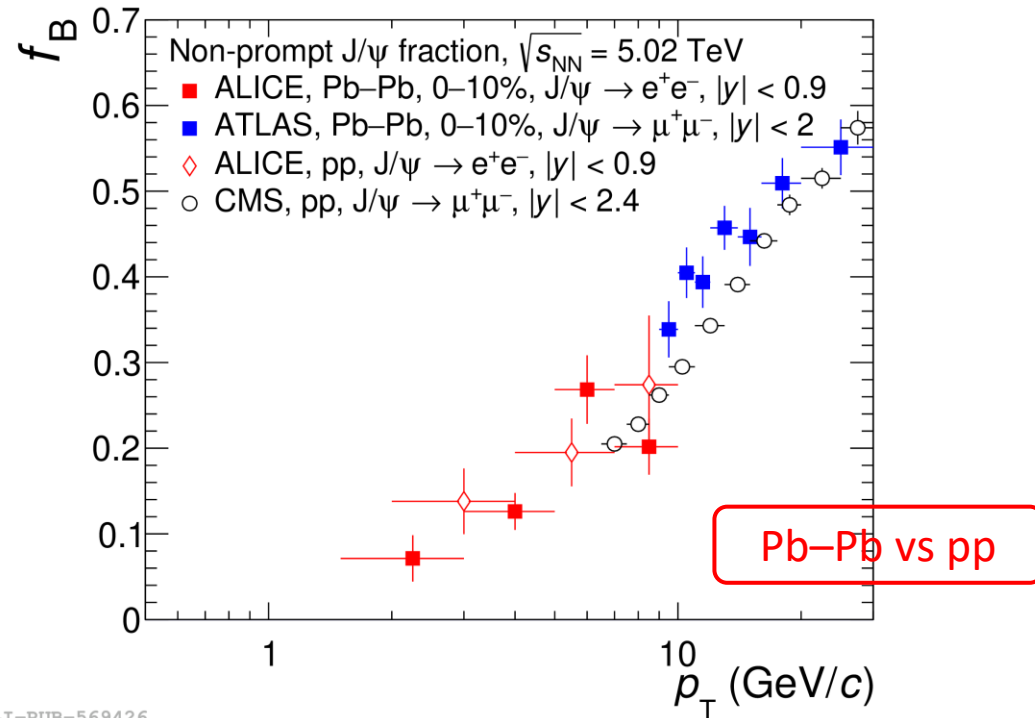
ALI-PUB-569426

ALI-PUB-569431

- f_B measurements extended down to $p_T = 1.5$ GeV/c, thanks to ALICE's unique capability to measure in low p_T .
 - **Consistent** with the results from ATLAS and CMS measurement in high p_T .
 - Matching the **decreasing trend** from high towards low p_T , similar in pp collisions.
- f_B in Pb–Pb collision is consistent with that in pp collisions within uncertainties, but slightly **higher** in high p_T .
 - Possibly suggesting a stronger nuclear suppression of prompt charmonia compared to beauty hadrons.
- Hint of mild **centrality dependence** in f_B measurements.

Non-prompt J/ψ fraction vs p_T

NEW Publication ALICE Collaboration, *JHEP* 02 (2024) 066



ALI-PUB-569426

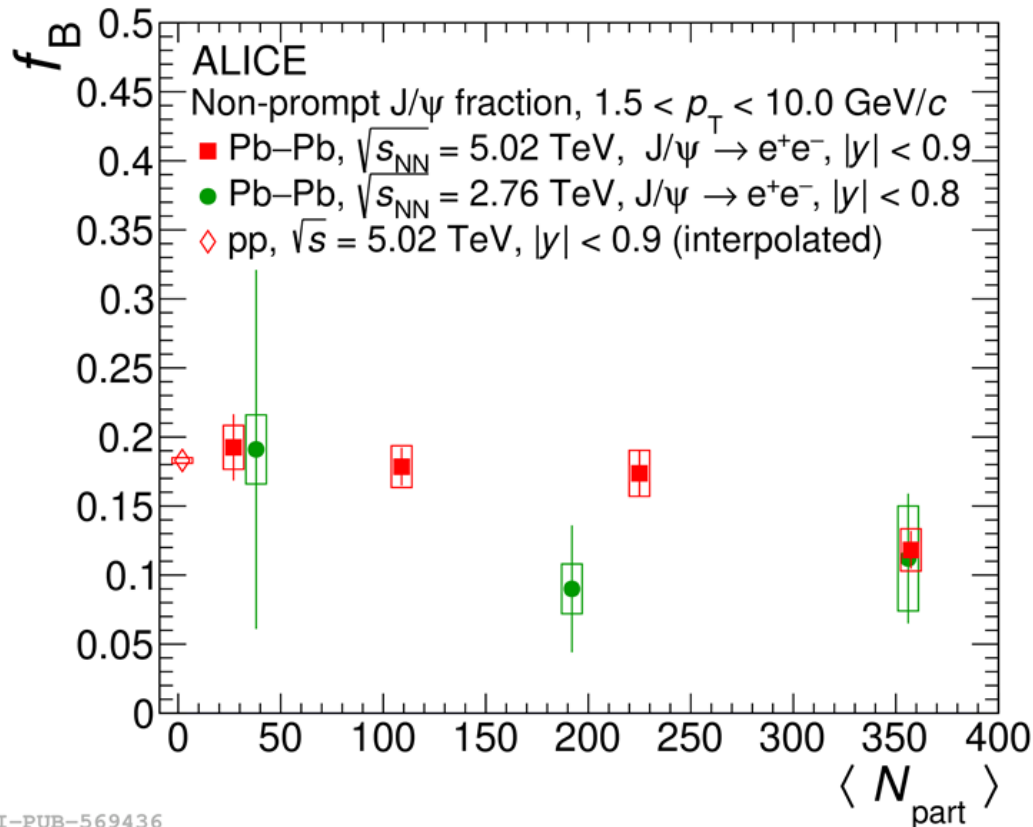
ALI-PUB-569431

- f_B measurements extended down to $p_T = 1.5$ GeV/c, thanks to ALICE's unique capability to measure in low p_T .
 - **Consistent** with the results from ATLAS and CMS measurement in high p_T .
 - Matching the **decreasing trend** from high towards low p_T , similar in pp collisions.
- f_B in Pb–Pb collision is consistent with that in pp collisions within uncertainties, but slightly **higher** in high p_T .
 - Possibly suggesting a stronger nuclear suppression of prompt charmonia compared to beauty hadrons.

□ Hint of mild **centrality dependence** in f_B measurements.

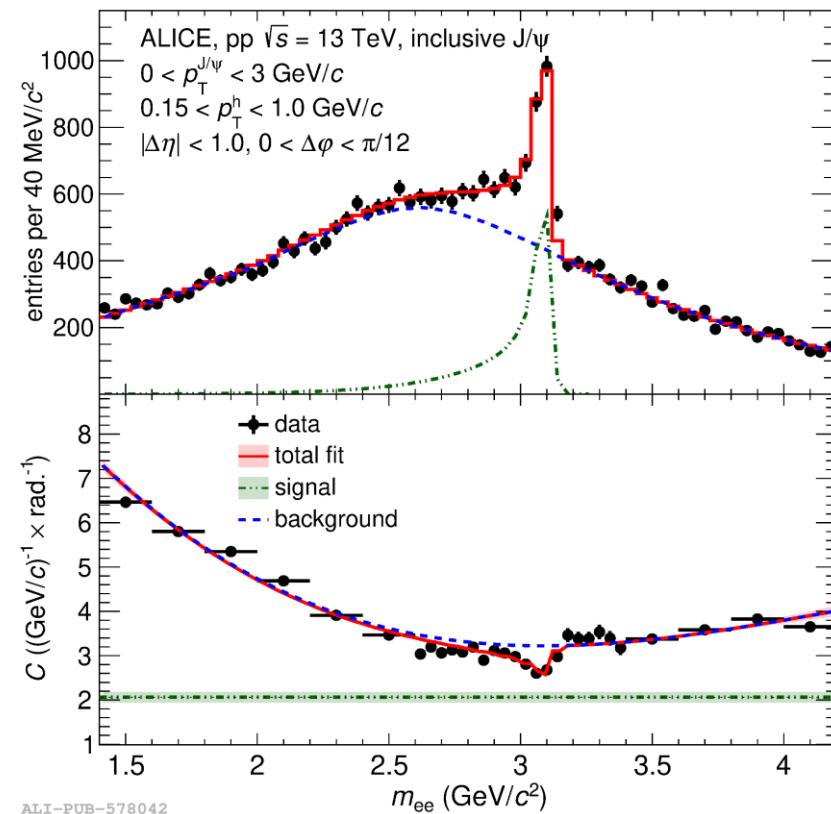
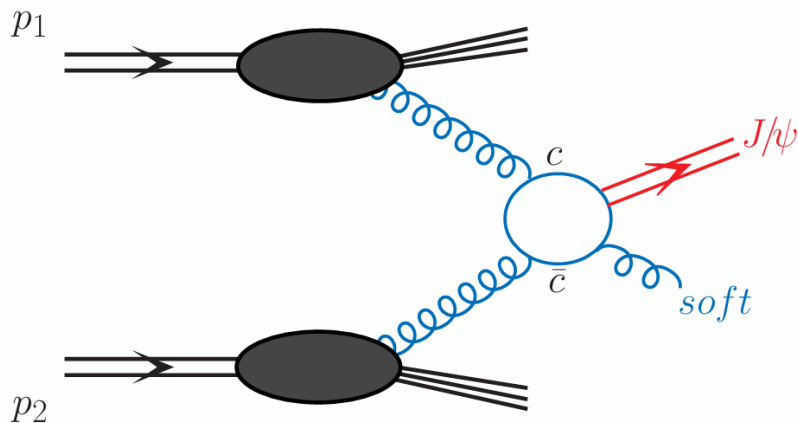
Non-prompt J/ ψ fraction vs centrality

NEW Publication ALICE Collaboration, *JHEP* 02 (2024) 066



- The statistical precision is significantly improved compared with earlier ALICE measurements at 2.76 TeV.
 - Thanks to the larger event sample available from LHC Run 2.
- **Small centrality dependence** is observed between peripheral and semi-central collisions.
- f_B in 0–10% most central collisions decreases.
 - Stronger contribution of prompt J/ ψ from **(re-)generation** in central collisions.

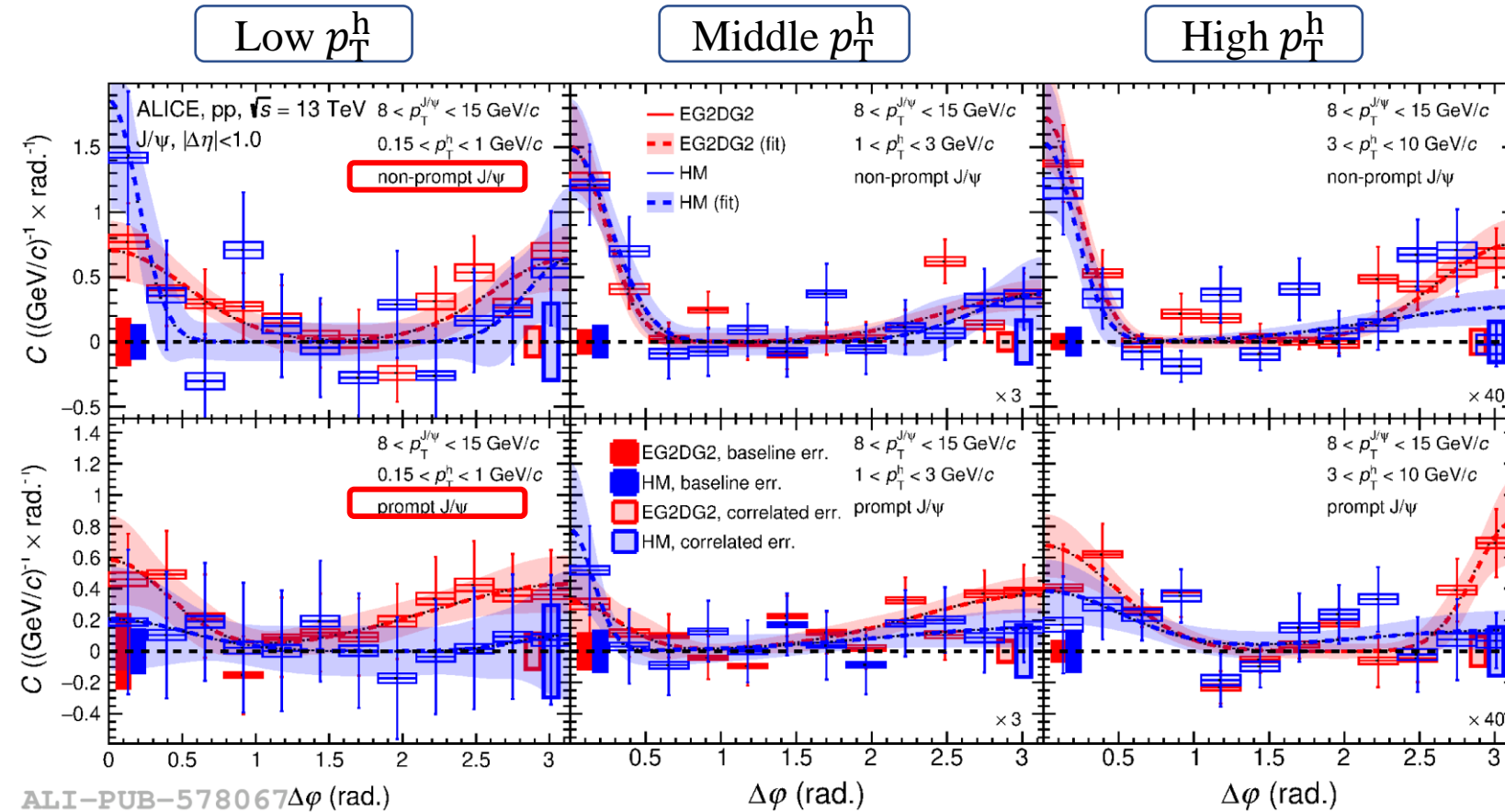
J/ψ-hadron correlations



- ❑ Soft gluon emissions when hadronization.
- ❑ Provides additional information for J/ψ production.

$$C(\Delta\eta, \Delta\phi; p_T^{J/\psi}, m_{e^+e^-}, p_T^h) = \frac{1}{N_{\text{trig}}} \cdot \frac{S(\Delta\eta, \Delta\phi)}{B(\Delta\eta, \Delta\phi)} \cdot B(0, 0)$$

J/ψ-hadron correlation



- Correlation functions for non-prompt and prompt J/ψ are shown with two triggers.
- Two correlation functions for different trigger show **compatible peak structures**.
- Correlation patterns on both the **near** and **away** sides.

$$C(\Delta\phi) = b + a_{NS} \times e^{-\frac{(\Delta\phi)^2}{2\sigma_{NS}^2}} + a_{AS} \times e^{-\frac{(\Delta\phi - \pi)^2}{2\sigma_{AS}^2}}$$

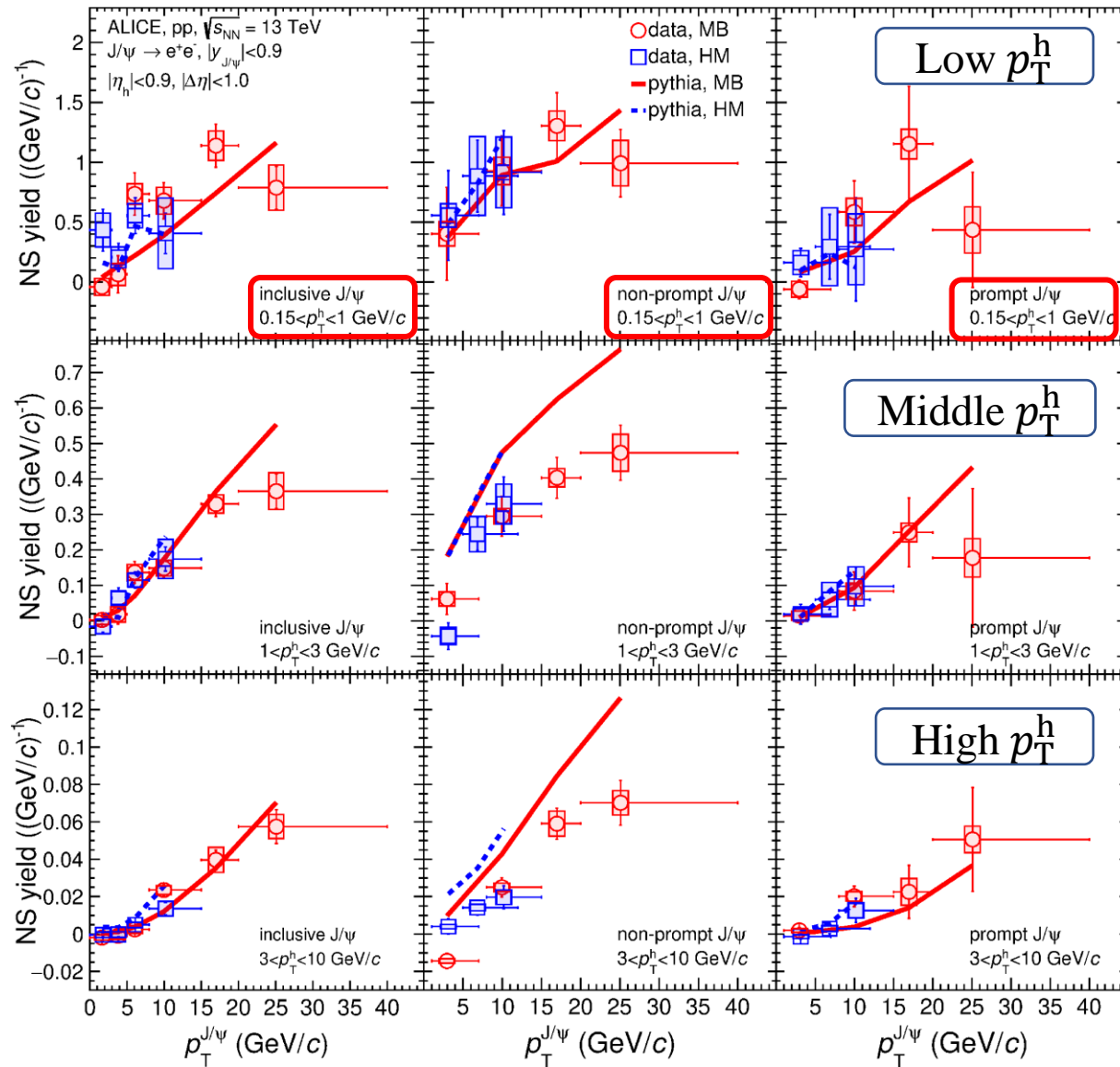
NEW Paper ALICE Collaboration, arXiv:2409.04364

Minimum Bias: Coincidence of signals in both V0 counters.

High Multiplicity: 0.1% events with the highest multiplicity in the V0 detector.

EG2DG2: The sum of energy in a sliding window (4×4 towers) in EMCAL above 4 GeV.

J/ ψ -hadron **near side** yield



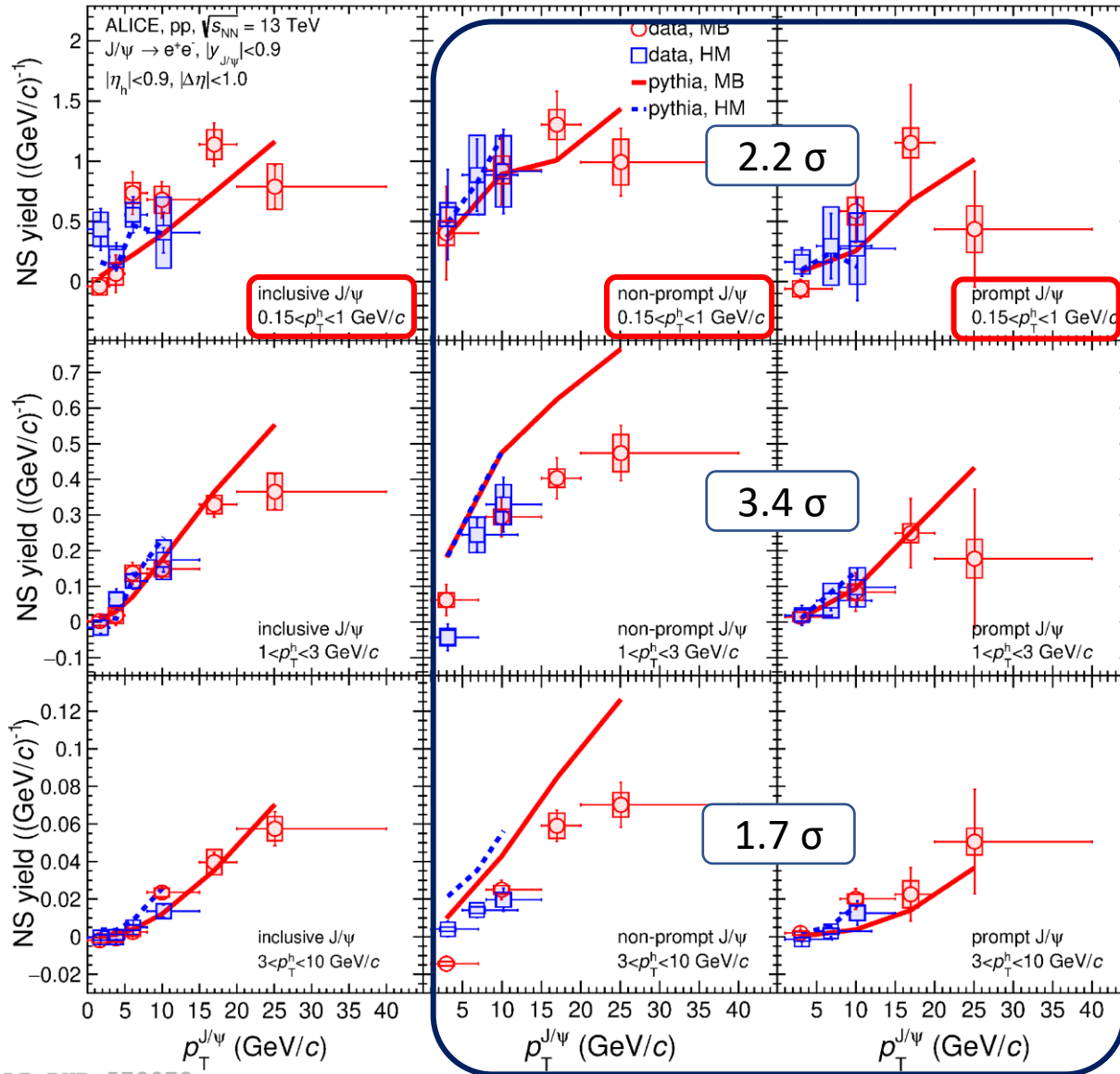
NEW Paper ALICE Collaboration, arXiv:2409.04364

- **Increasing trend** as a function of $p_T^{J/\psi}$.
- The NS yields associated with **non-prompt J/ ψ** are larger than those associated to prompt J/ ψ .
- A **good agreement** in the **HM and MB triggered** events within uncertainties both for inclusive, non-prompt and prompt J/ ψ .
 - No strong event multiplicity dependence observed in charm and beauty fragmentation.
- PYTHIA calculations are in **good agreement** with results, but **overestimate** hadron yields with $p_T > 1$ GeV/c associated with non-prompt J/ ψ .
 - Might point to **hadronization effects** which are not well reproduced in PYTHIA.

Skands, P., Carrazza, S. & Rojo, J., *Eur.Phys.J.C* 74 (2014) 3024

J/ ψ -hadron **near side** yield

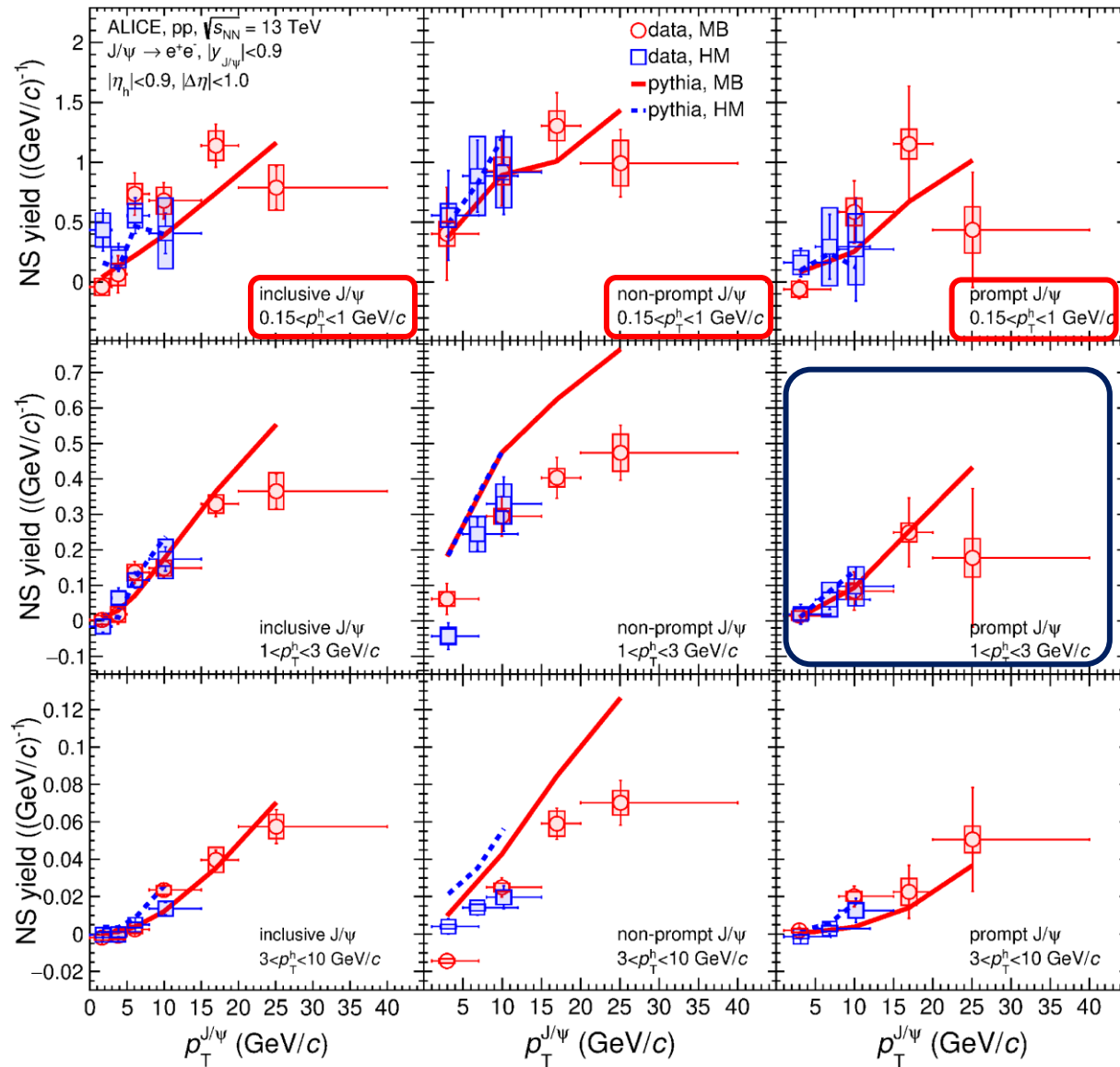
NEW Paper ALICE Collaboration, arXiv:2409.04364



- Increasing trend as a function of $p_T^{J/\psi}$.
- The NS yields associated with **non-prompt J/ ψ** are larger than those associated to prompt J/ ψ .
- A **good agreement** in the **HM and MB triggered** events within uncertainties both for inclusive, non-prompt and prompt J/ ψ .
 - No strong event multiplicity dependence observed in charm and beauty fragmentation.
- PYTHIA calculations are in **good agreement** with results, but **overestimate** hadron yields with $p_T > 1$ GeV/c associated with non-prompt J/ ψ .
 - Might point to **hadronization effects** which are not well reproduced in PYTHIA.

Skands, P., Carrazza, S. & Rojo, J., *Eur.Phys.J.C* 74 (2014) 3024

J/ ψ -hadron **near side** yield



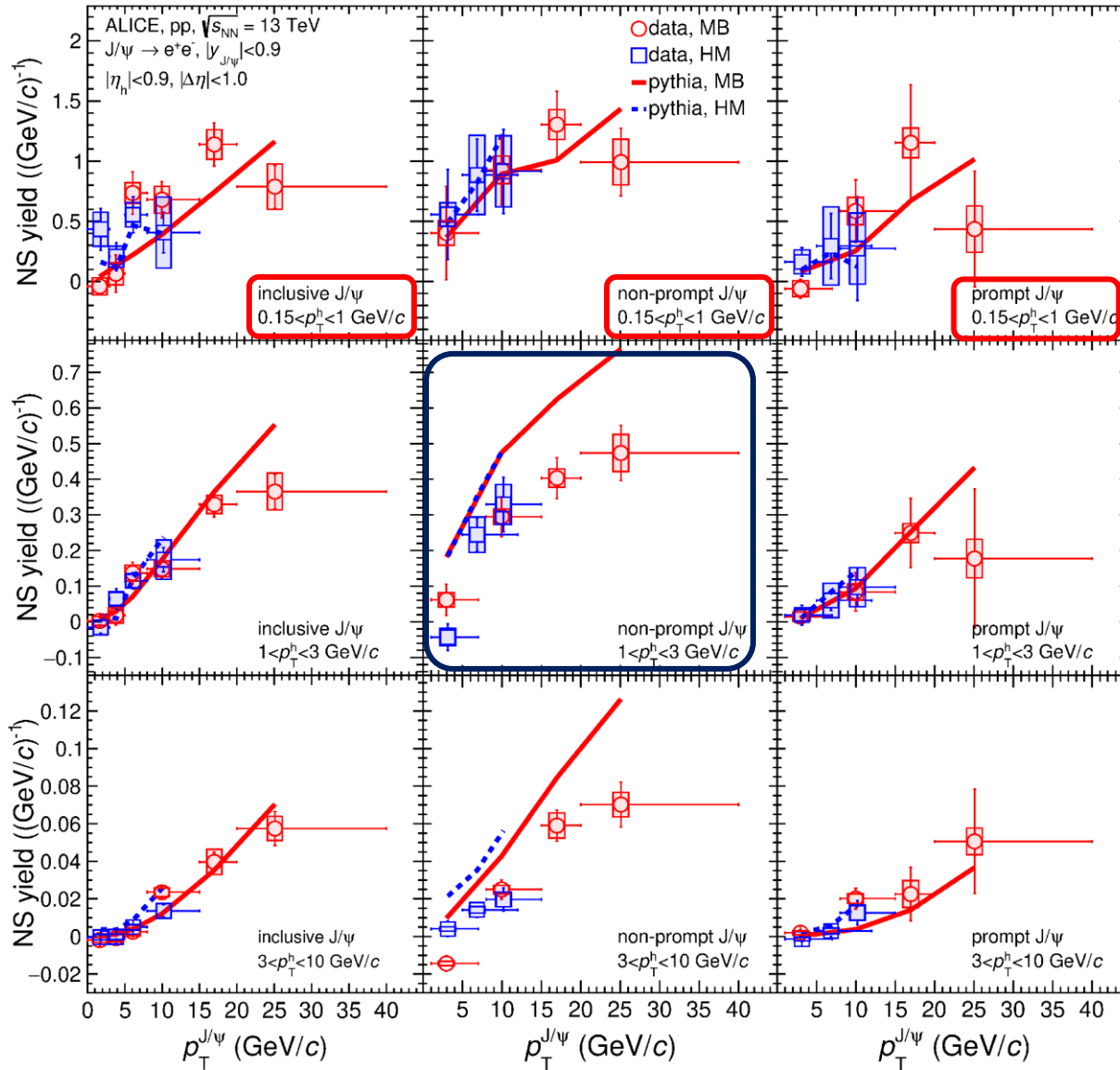
NEW Paper ALICE Collaboration, arXiv:2409.04364

- **Increasing trend** as a function of $p_T^{J/\psi}$.
- The NS yields associated with **non-prompt J/ ψ** are larger than those associated to prompt J/ ψ .
- A **good agreement** in the **HM and MB triggered** events within uncertainties both for inclusive, non-prompt and prompt J/ ψ .
 - No strong event multiplicity dependence observed in charm and beauty fragmentation.
- PYTHIA calculations are in **good agreement** with results, but **overestimate** hadron yields with $p_T > 1$ GeV/c associated with non-prompt J/ ψ .
 - Might point to **hadronization effects** which are not well reproduced in PYTHIA.

Skands, P., Carrazza, S. & Rojo, J., *Eur.Phys.J.C* 74 (2014) 3024

J/ ψ -hadron **near side** yield

NEW Paper ALICE Collaboration, arXiv:2409.04364

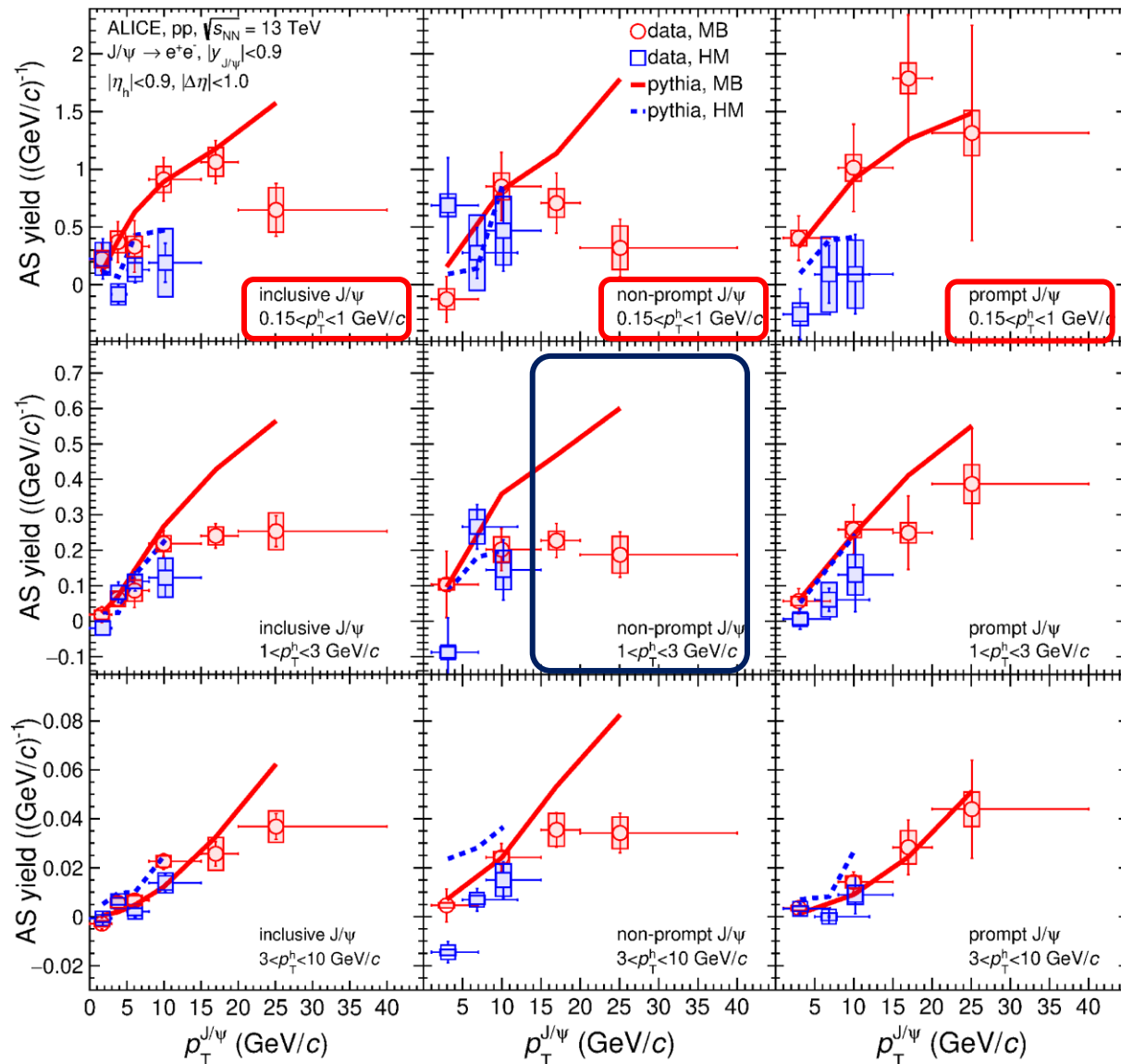


- **Increasing trend** as a function of $p_T^{J/\psi}$.
- The NS yields associated with **non-prompt J/ ψ** are larger than those associated to prompt J/ ψ .
- A **good agreement** in the **HM and MB triggered** events within uncertainties both for inclusive, non-prompt and prompt J/ ψ .
 - No strong event multiplicity dependence observed in charm and beauty fragmentation.
- PYTHIA calculations are in **good agreement** with results, but **overestimate** hadron yields with $p_T > 1$ GeV/c associated with non-prompt J/ ψ .
 - Might point to **hadronization effects** which are not well reproduced in PYTHIA.

Skands, P., Carrazza, S. & Rojo, J., *Eur.Phys.J.C* 74 (2014) 3024

J/ψ-hadron away side yield

NEW Paper ALICE Collaboration, arXiv:2409.04364



□ The PYTHIA calculations are in **good agreement** with the results of prompt J/ψ, but **overestimate** the results of non-prompt J/ψ for p_T above 15 GeV/c.

□ The correlated hadron yields in **HM** triggered events is **lower** than in **MB** events for prompt J/ψ in the $0.15 < p_T^h < 1.0$ GeV/c interval.
 ➤ Because of the bias introduced by the HM trigger.

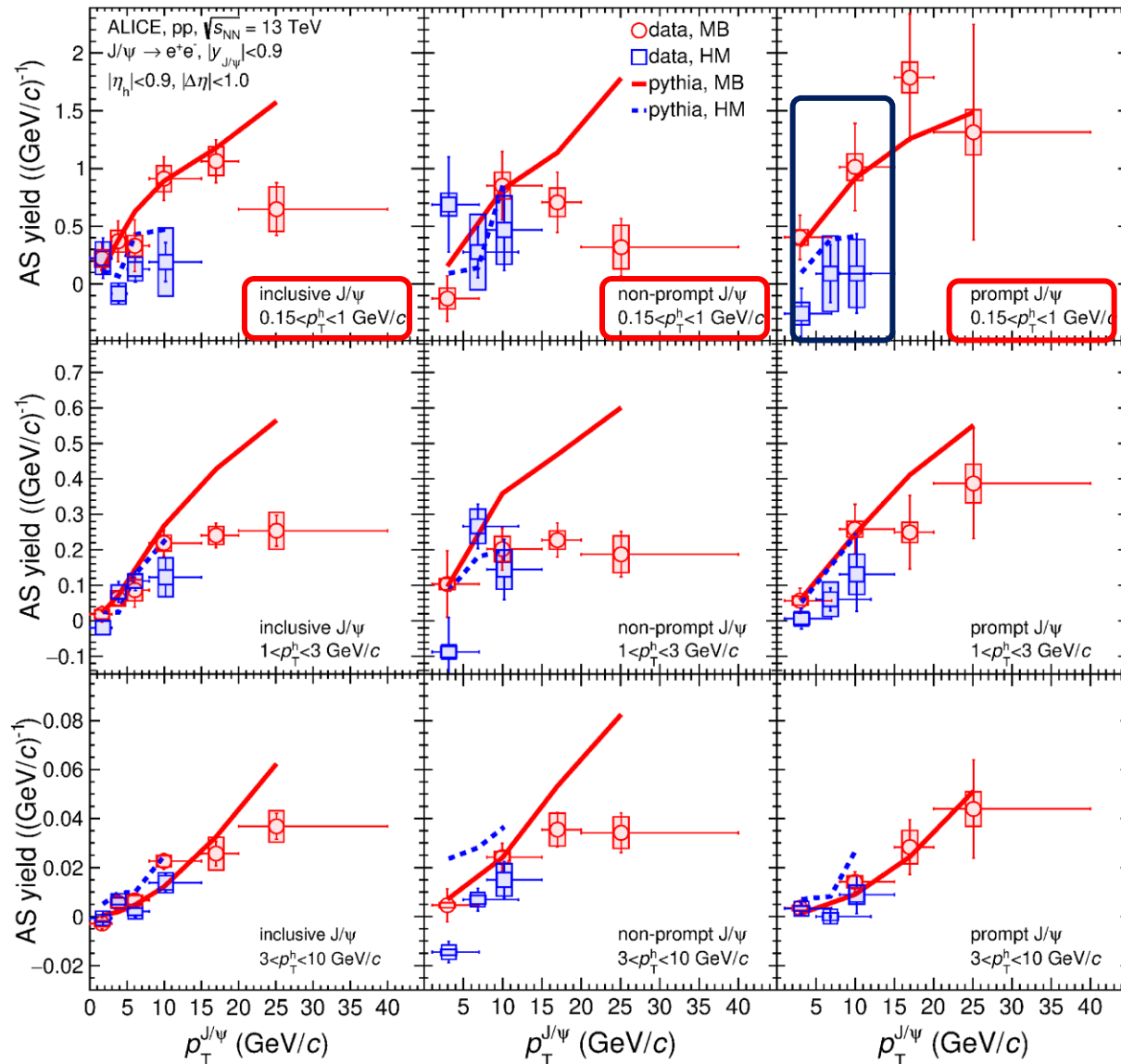


Requirement of a **high threshold on charged-particle multiplicity** in the **V0 detector acceptance**

Skands, P., Carrazza, S. & Rojo, J., *Eur.Phys.J.C* 74 (2014) 3024

J/ψ-hadron away side yield

NEW Paper ALICE Collaboration, arXiv:2409.04364



□ The PYTHIA calculations are in **good agreement** with the results of prompt J/ψ, but **overestimate** the results of non-prompt J/ψ for p_T above 15 GeV/c.

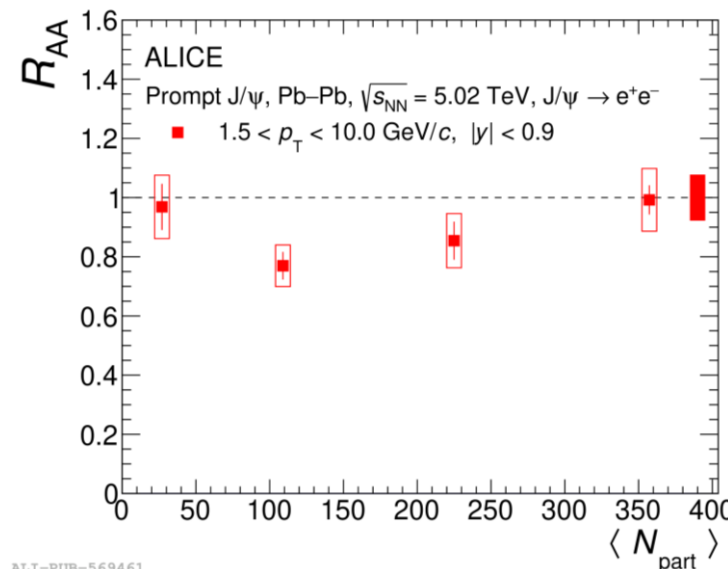
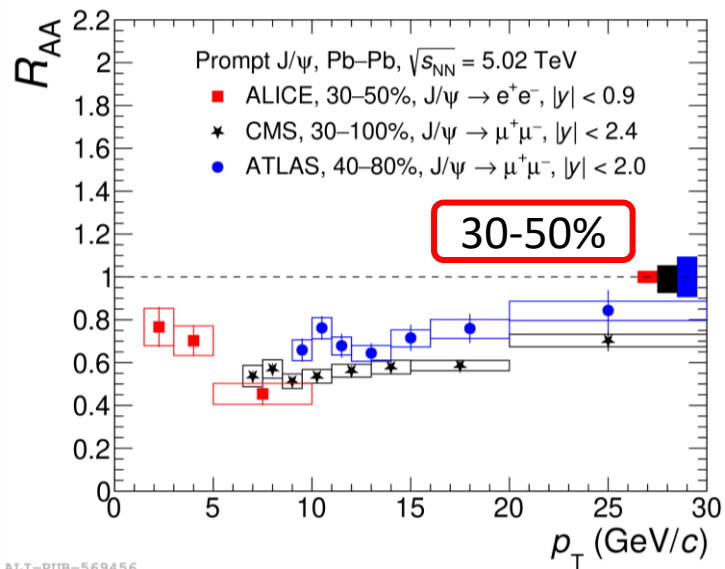
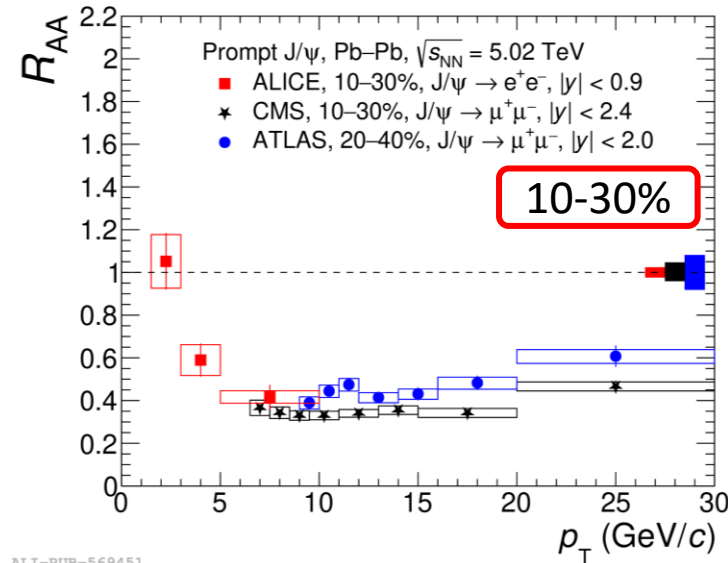
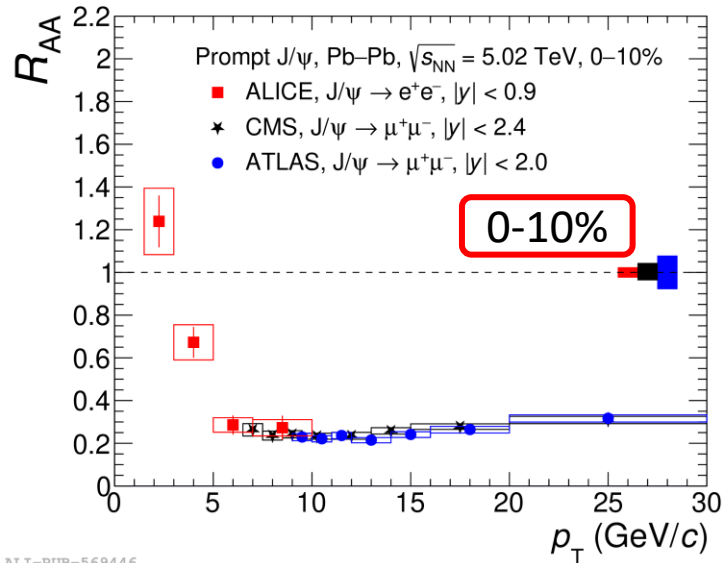
□ The correlated hadron yields in **HM** triggered events is **lower** than in **MB** events for prompt J/ψ in the $0.15 < p_T^h < 1.0$ GeV/c interval.
 ➤ Because of the bias introduced by the HM trigger.



Requirement of a **high threshold on charged-particle multiplicity** in the **V0 detector acceptance**

Skands, P., Carrazza, S. & Rojo, J., *Eur.Phys.J.C* 74 (2014) 3024

p_T and centrality dependence of prompt J/ψ R_{AA}



$$R_{AA}^{\text{prompt } J/\psi} = \frac{1 - f_B^{\text{Pb-Pb}}}{1 - f_B^{\text{PP}}} \times R_{AA}^{\text{inclusive } J/\psi}$$

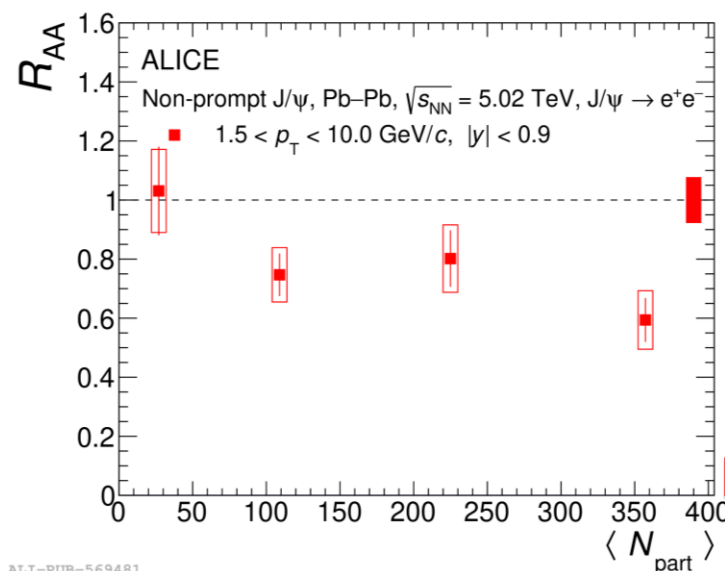
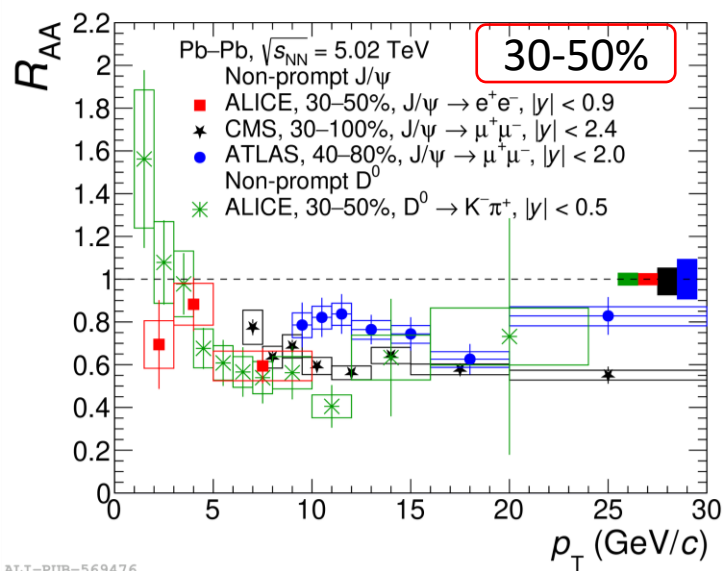
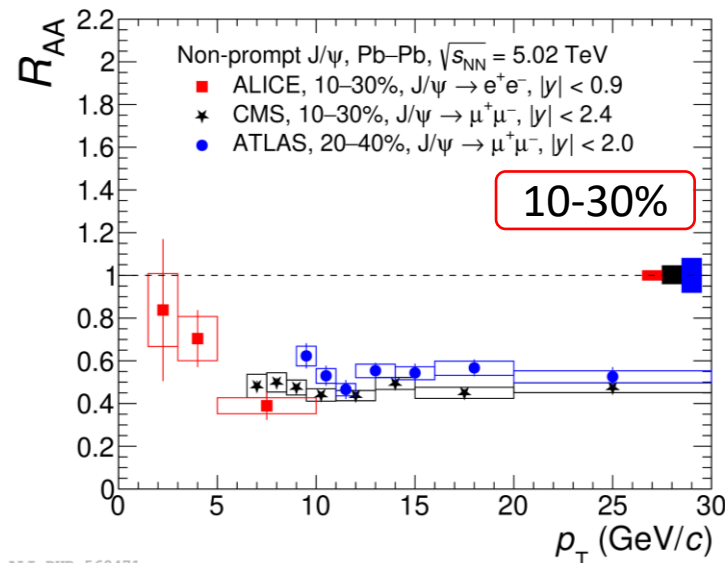
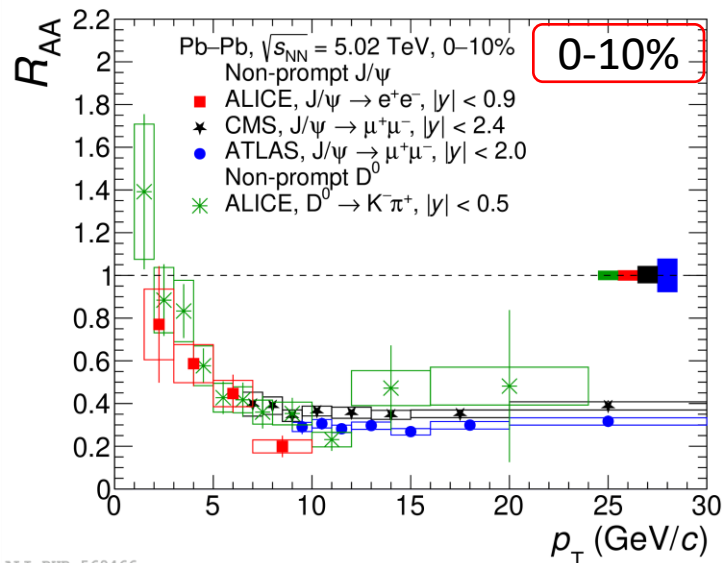
- In agreement with the CMS and ATLAS measurements in the overlapping p_T interval
 - More peripheral collision sample used in semi-central events in ATLAS.
- Suppression in $p_T > 5$ GeV/c
 - Stronger in central collisions.
- In $p_T < 5$ GeV/c, increases towards low p_T .
- p_T integrated R_{AA} rises towards most central collisions.



consistent with J/ψ (re-)generation scenario

NEW Publication ALICE Collaboration, *JHEP* 02 (2024) 066

p_T and centrality dependence of **non-prompt** J/ψ R_{AA}



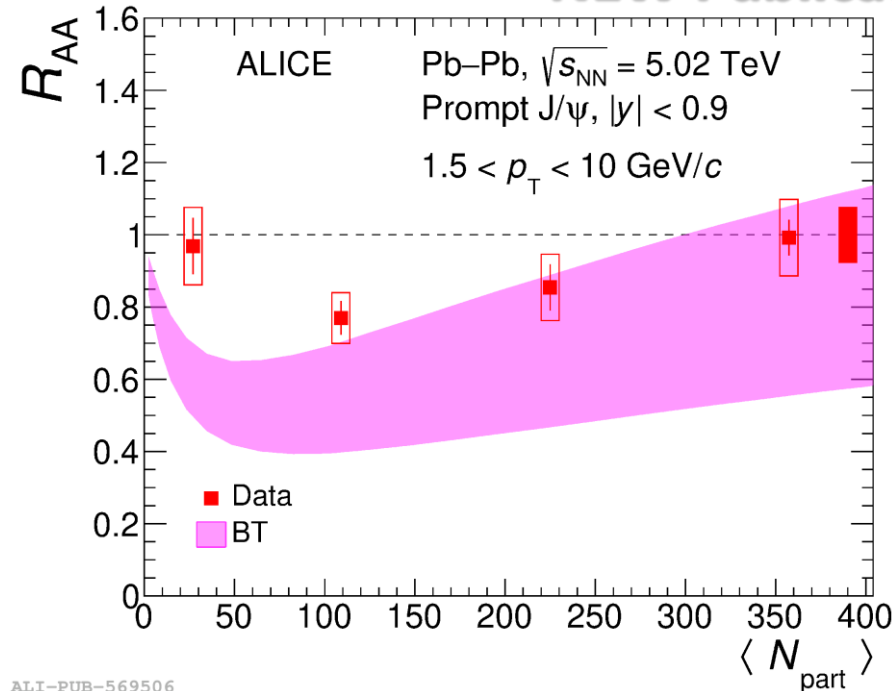
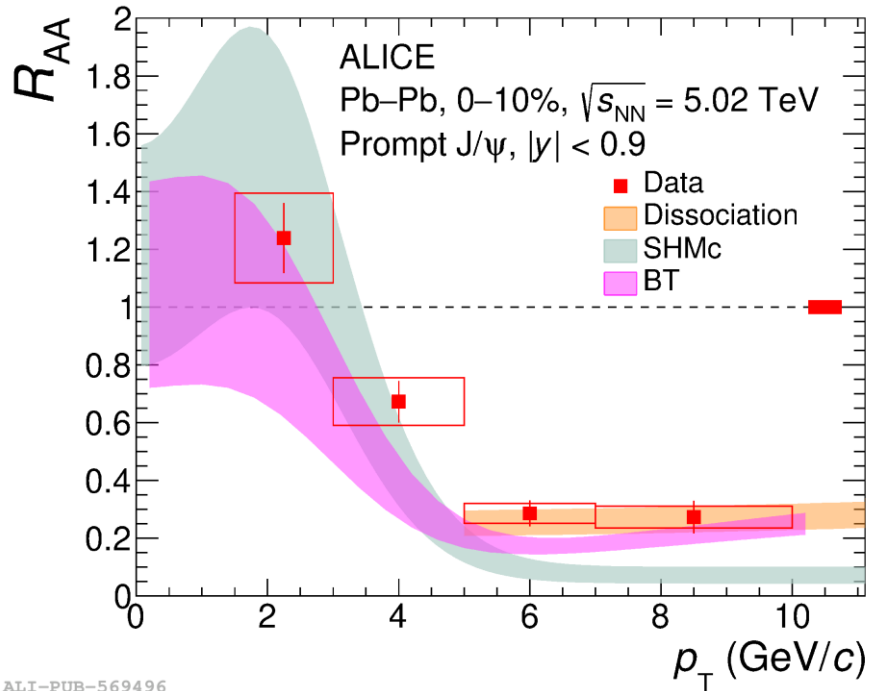
$$R_{AA}^{J/\psi \leftarrow h_B} = \frac{f_B^{Pb-Pb}}{f_B^{pp}} \times R_{AA}^{\text{inclusive } J/\psi}$$

- In agreement with the CMS and ATLAS measurements in the overlapping p_T interval
- Suppression in $p_T > 5$ GeV/c
 - Stronger in central collisions.
- R_{AA} is similar in different centrality classes for non-prompt J/ψ in $p_T < 5$ GeV/c.
- **Decreasing trend** towards more central collisions.
- Compatible with non-prompt D^0 results.
 - Difference might be caused by different decay kinematics.

NEW Publication ALICE Collaboration, *JHEP* 02 (2024) 066

Prompt J/ψ R_{AA} compared with models

NEW Publication ALICE Collaboration, *JHEP* 02 (2024) 066



SHMc: Charm quarks are **thermalized** inside the QGP and rapid freeze-out at the phase boundary.

BT: Use a Boltzmann-type transport equation to describe **dissociation and regeneration**.

Dissociation: Use rate equations to describe **collisional and thermal dissociation**.

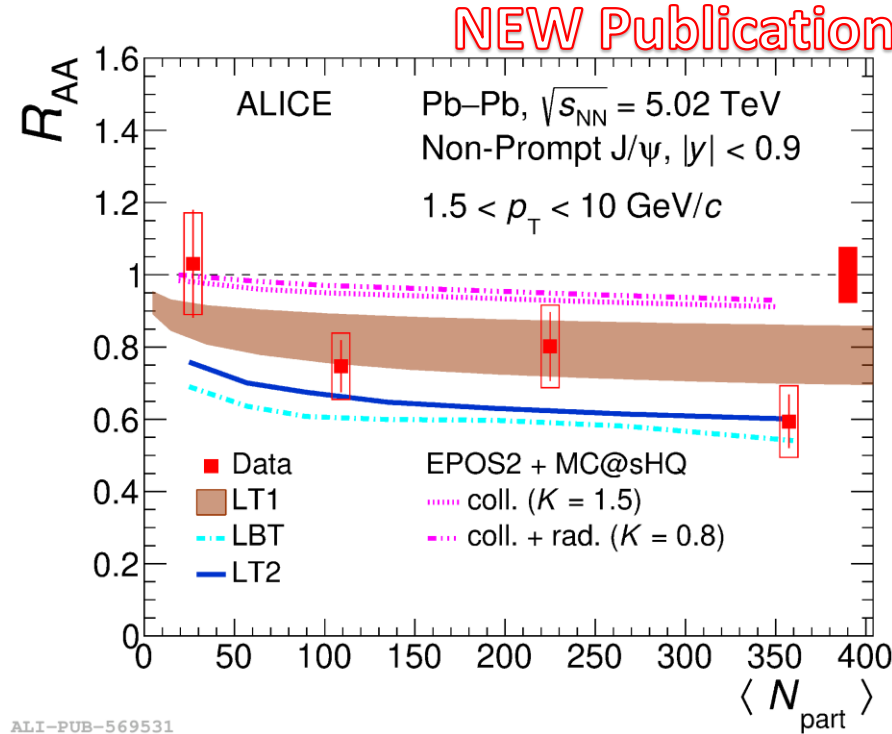
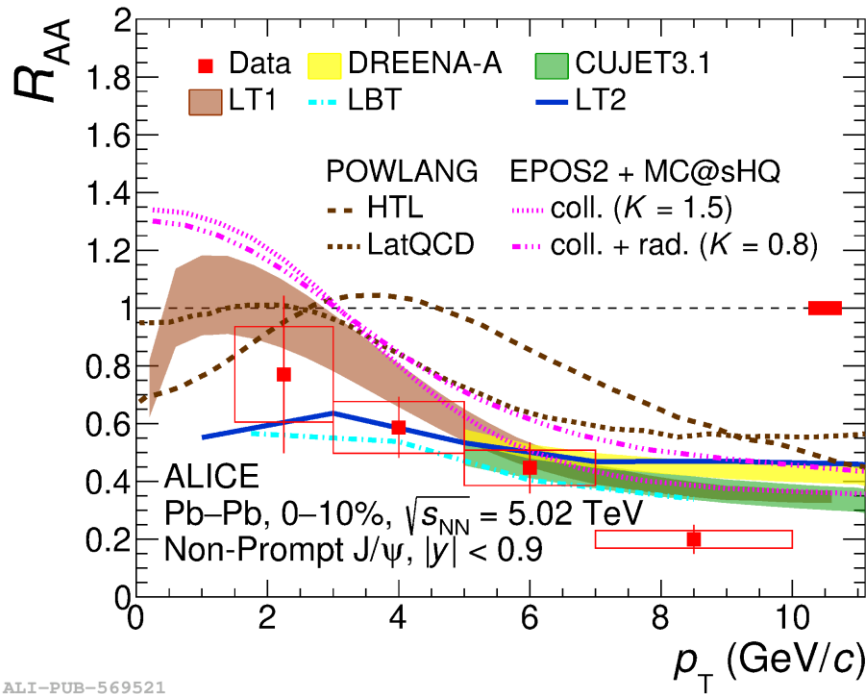
- ❑ The **SHMc model**^[1] reproduces the prompt J/ψ R_{AA} at low p_T , while significantly underpredict the data for $p_T > 5$ GeV/c.
 - In the SHMc model, most of the produced J/ψ are **thermalized**, only a small contribution from the collision corona.
- ❑ The **Dissociation model**^[3] provides a **good description** within uncertainties for $p_T > 5$ GeV/c.
- ❑ The **BT model**^[2] describes the trend of R_{AA} with number of participants.
 - In **good agreement** with data in 0–10% and 10–30% centrality classes.
 - **Underpredict** in peripheral collisions.

[1]A. Andronic, *et al. Phys. Lett. B* 797 (2019) 134836

[2]K. Zhou, *et al. Phys. Rev. C* 89 (2014) 054911

[3]S. Aronson, *et al. Phys. Lett. B* 778 (2018) 384–391

Non-prompt J/ψ R_{AA} compared with models



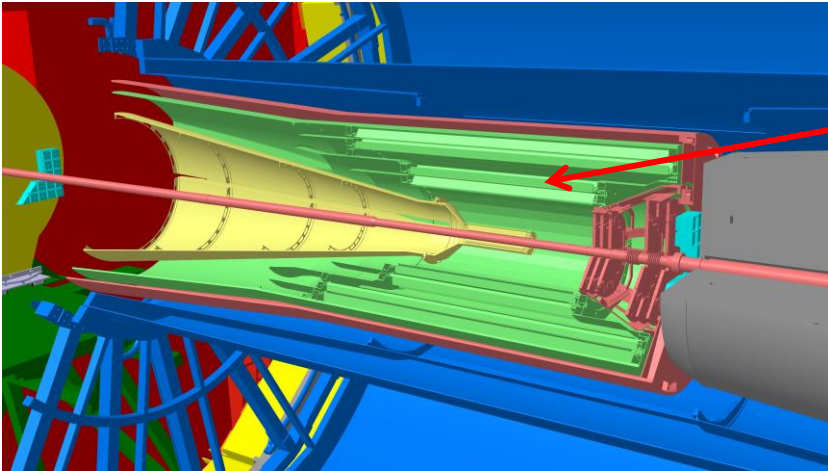
POWLANG: Energy loss solely via **collisional** processes.

Other models: Both **collisional and radiative** energy loss but with different hypotheses on transport dynamics, CNM effects, p_T distributions and hadronization.

- ❑ All models except **POWLANG**^[2] describe the data within uncertainties for $p_T > 5$ GeV/c.
 - Overprediction of **POWLANG** might be due to the lack of radiative energy loss contributions in model.
- ❑ **LBT**^[6] and **LT2**^[5] models are compatible with data within uncertainties in the full p_T .
- ❑ **LT1**^[1] model is compatible with data within uncertainties for all centrality classes.

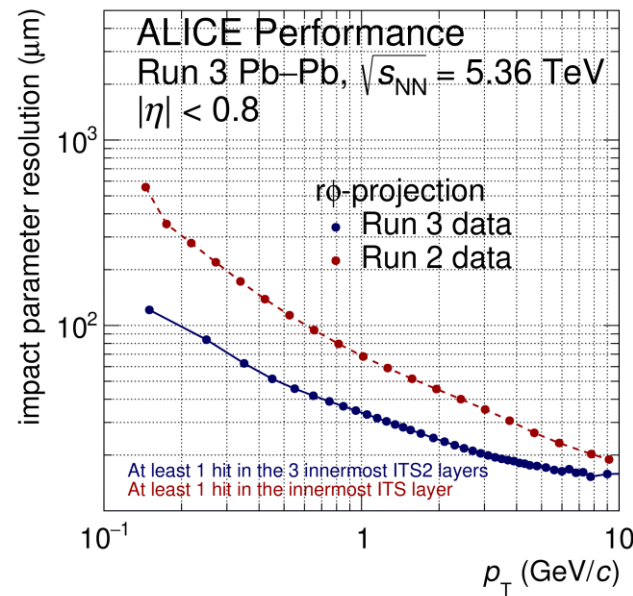
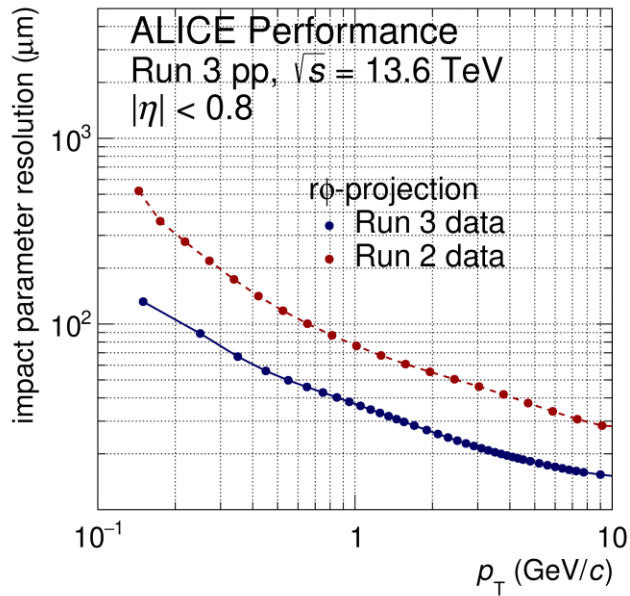
[1] M. Yang, et al. *Phys. Rev. C* 107 (2023) 054917
 [2] A. Beraudo, et al. *JHEP* 05 (2021) 279
 [3] S. Shi, et al. *Chin. Phys. C* 43 (2019) 044101
 [4] M. Nahrgang, et al. *Phys. Rev. C* 93 (2016) 044909
 [5] S.-Q. Li, et al. *Eur. Phys. J. C* 81 (2021) 1035
 [6] W.-J. Xing, et al. *Phys. Lett. B* 838 (2023) 137733
 [7] D. Zigic, et al. *Front. in Phys.* 10 (2022) 957019

ITS upgrades in Run 3



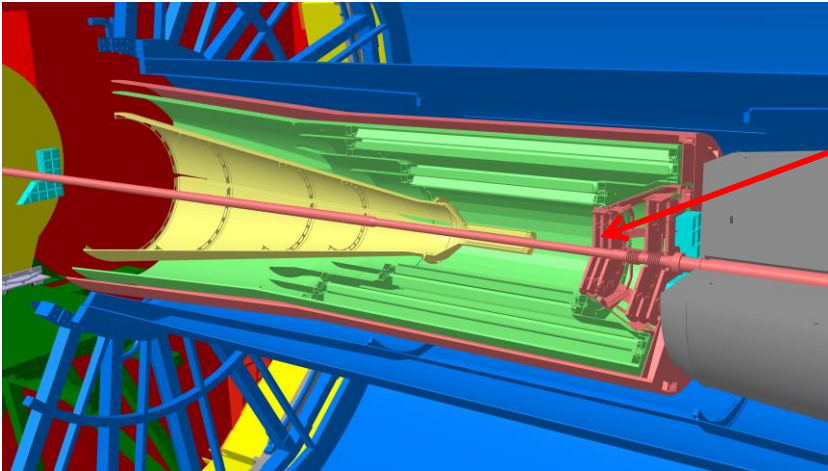
➤ ITS upgrade:

- 6 layers \Rightarrow 7 layers equipped with Monolithic Active Pixel Sensors (MAPS).
- Radius of innermost layer: 39 mm \Rightarrow 23mm.
- Material budget for each of the 3 innermost layers: 1.15% \Rightarrow 0.35%.

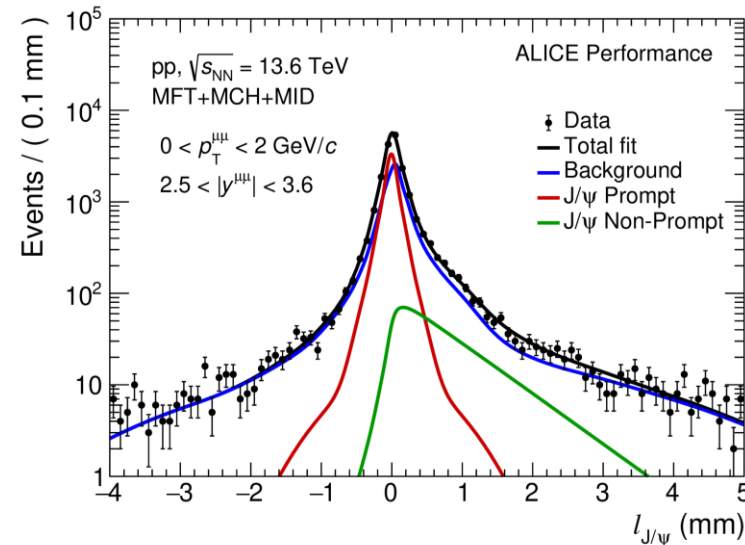
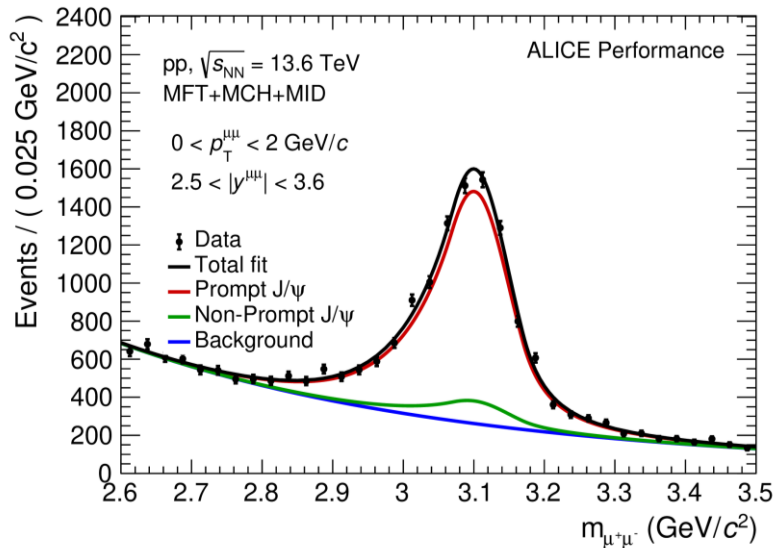


- The impact parameter resolution are largely reduced at midrapidity for Run 3 in both pp and Pb-Pb collisions thanks to the upgrade of ITS.

Measurement at forward rapidity in Run 3



- Muon Forward Tracker
 - Installed in Run 3.
 - 5 disks with MAPS.
 - Measures charged tracks with high spatial resolution.
 - Provides vertex capability, allowing to measure non-prompt decay.



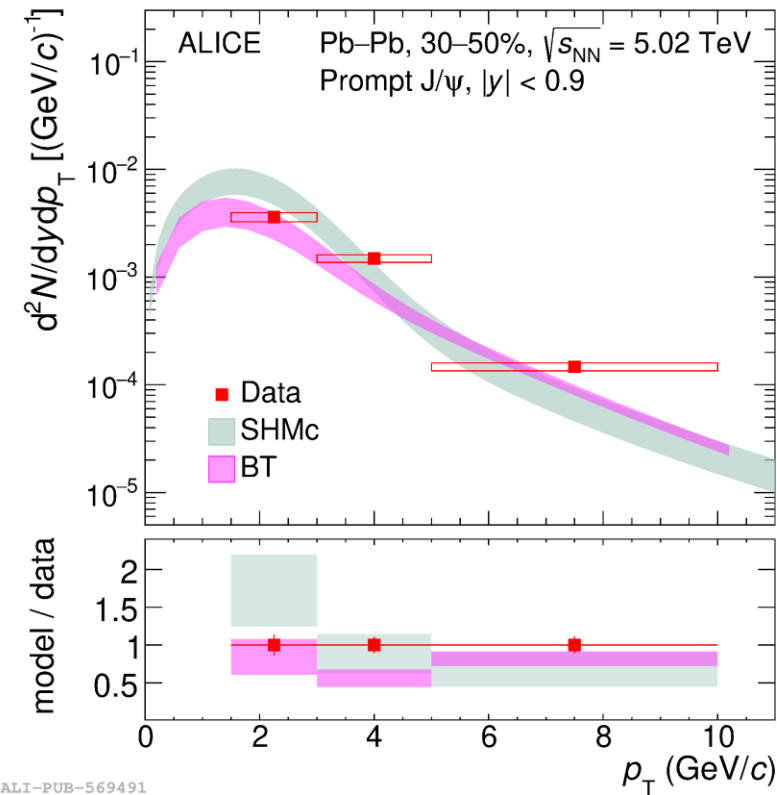
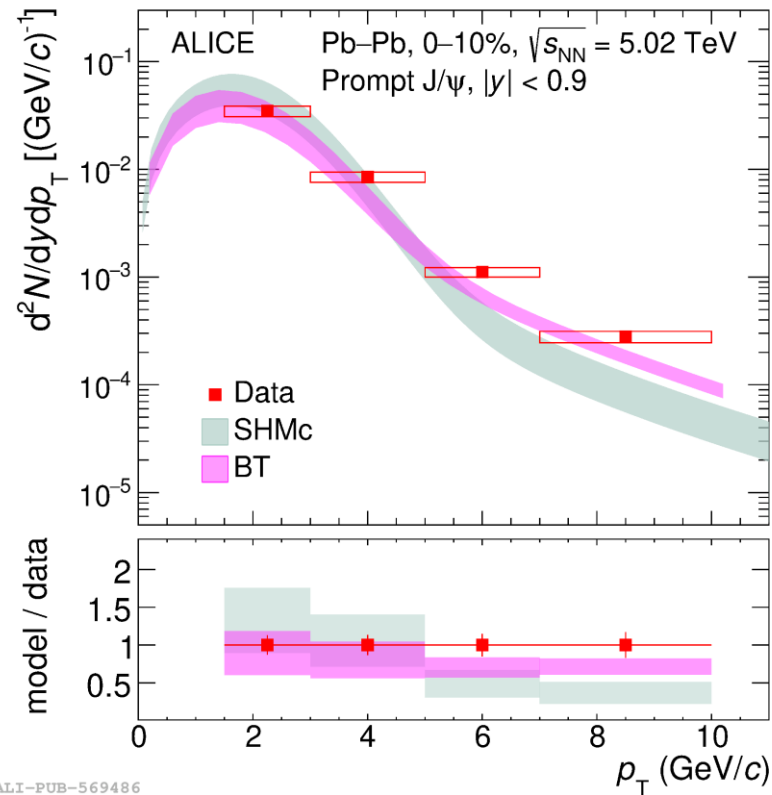
- Thanks to the installation of the new **muon forward tracker (MFT)**, the prompt/non-prompt charmonia separation is possible in LHC Run 3 also at **forward rapidity** ($2.5 < y < 4$).

Summary

- **J/ψ-hadron correlations in pp collisions**
 - Correlation patterns on both **near** and **away** sides.
 - Near-side yields associated with non-prompt J/ψ are larger than those associated to prompt J/ψ.
 - **No strong multiplicity dependence** observed in charm and beauty fragmentation.
- **R_{AA} of prompt/non-prompt J/ψ in Pb–Pb collisions**
 - Increase towards low p_T and most central collisions for prompt J/ψ caused by **(re-)generation**.
 - R_{AA} of prompt J/ψ can be described by models considering **(re-)generation** in low p_T . The models with **energy loss** in medium can describe the R_{AA} of non-prompt J/ψ.
- **Outlook:**
 - The impact parameter **resolution** is largely **reduced** at midrapidity for Run 3 because of the **upgrade of ITS**.
 - Prompt/non-prompt charmonia separation is possible in LHC Run 3 also at **forward rapidity** thanks to the new installed **MFT detector**.

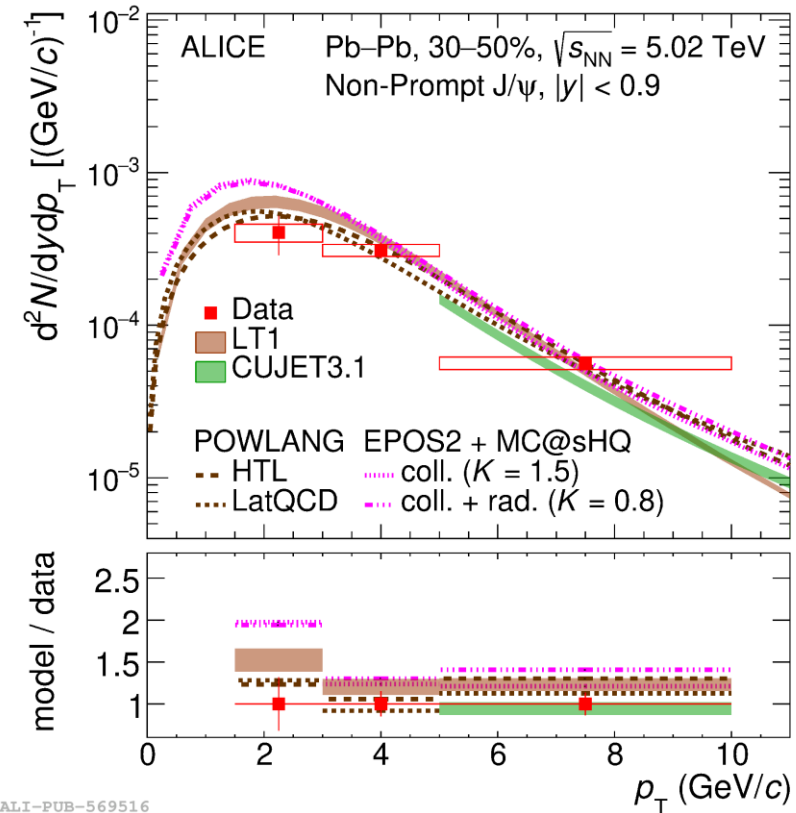
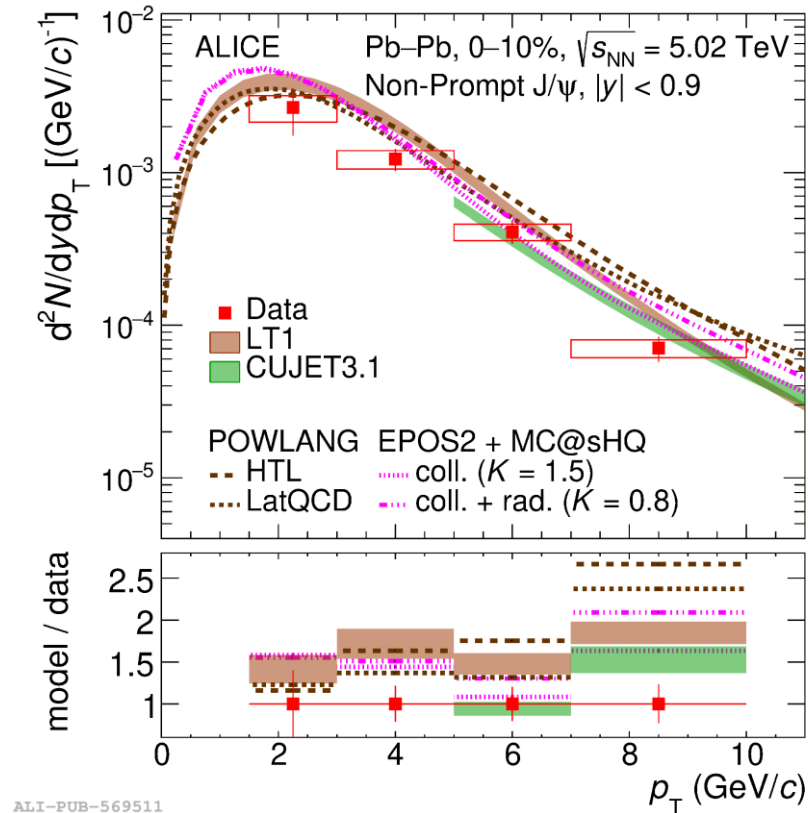
BACK UP

Prompt J/ψ production



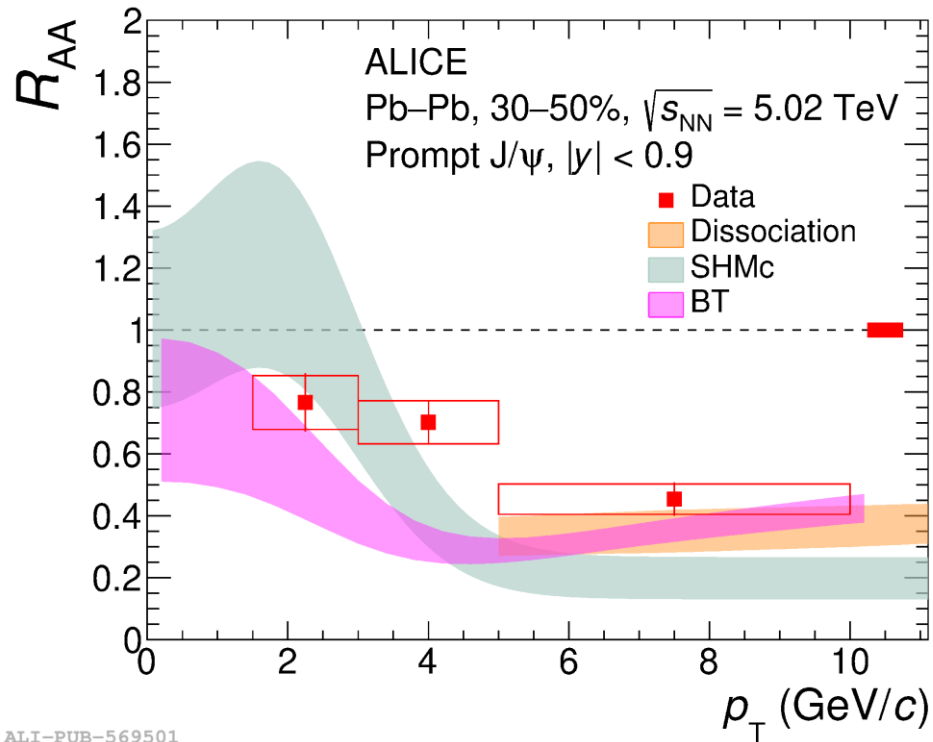
- Both two models show an overall good agreement with data within uncertainties, in particular for p_T below 5 GeV/c.
- At higher p_T , both models tend to underpredict the data, with the SHMc model showing a larger discrepancy.
 - In the SHMc model most of the produced J/ψ are **thermal**, with only a small contribution from the collision corona.

Non-prompt J/ ψ production

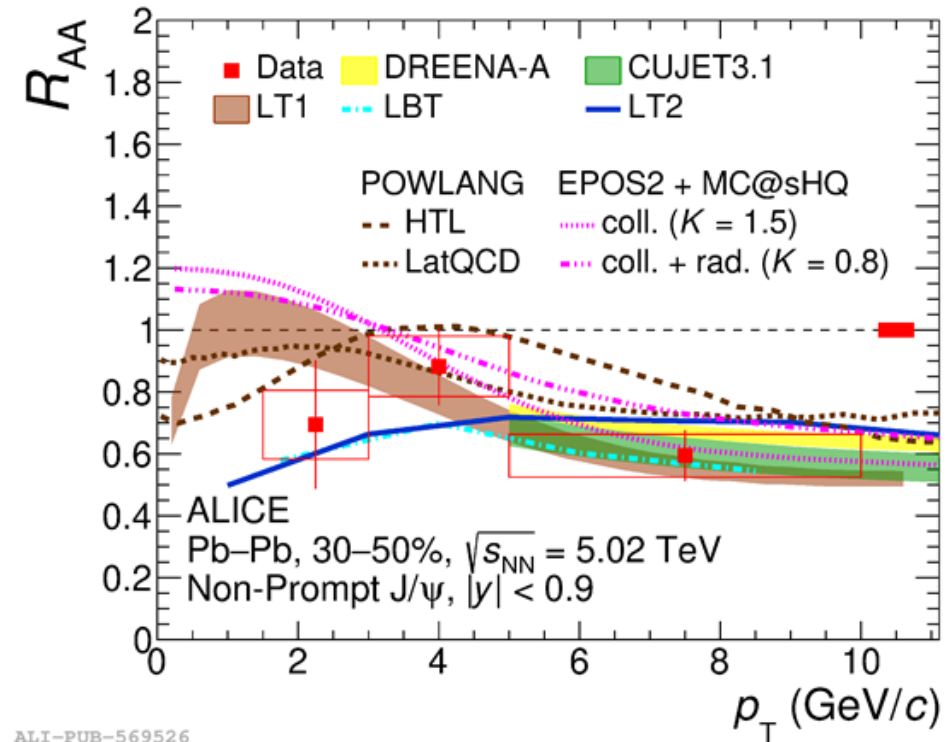


- ❑ Models show systematically **higher** values compared to data.
 - Discrepancy larger for POWLANG, could be related to the absence of **radiative processes** in this model.
- ❑ CUJET3.1 is **compatible** with data within uncertainties for $p_T > 5$ GeV/c.

R_{AA} in semicentral collisions



ALI-PUB-569501



ALI-PUB-569526