HP2024
NAGASAKI

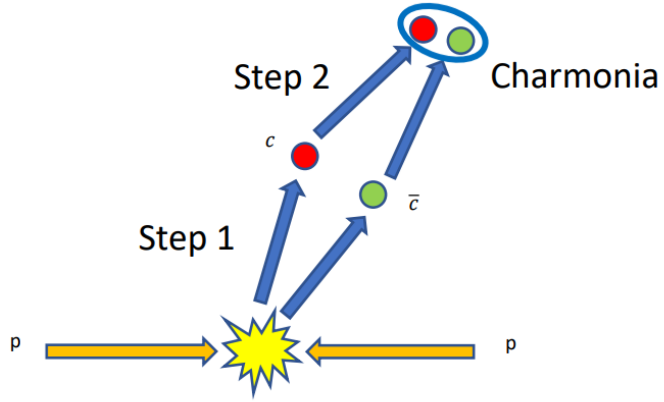
Quarkonium production in proton-proton and Pb−Pb collisions with ALICE

Yiping Wang on behalf of the ALICE Collaboration
University of Science and Technology of China

12th Int Conf on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions

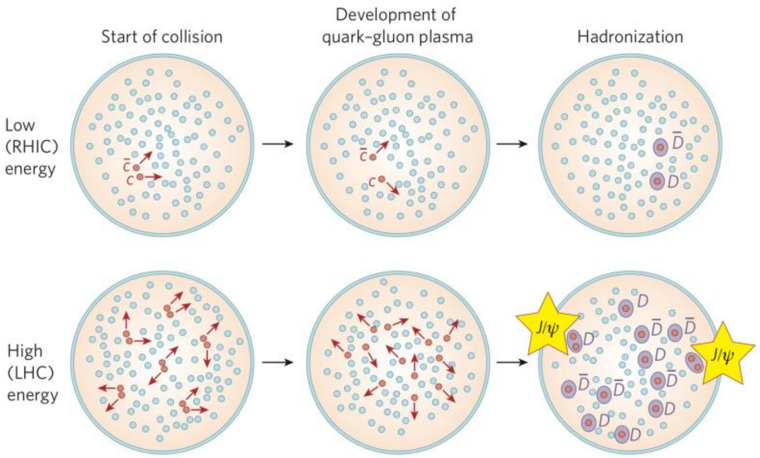
Quarkonium in pp collisions

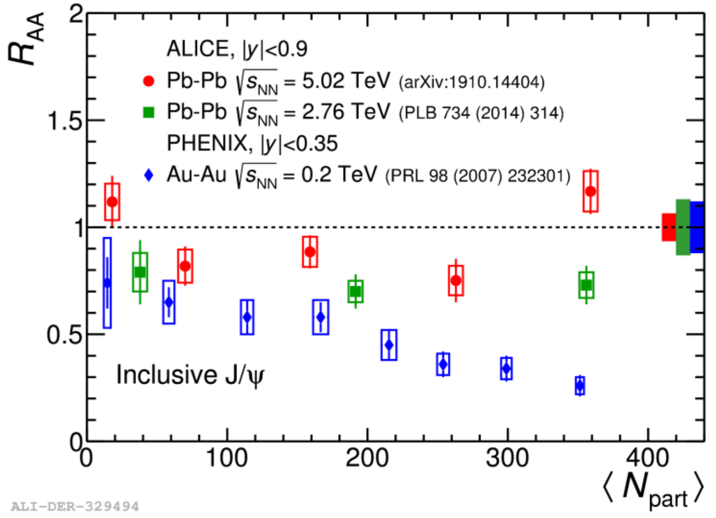
- **Study quarkonium in pp**:
- Distinguish among the quarkonium production models in pp; refine QCD based models :
  - **NRQCD**: Non-Relativistic QCD approach, long-distance matrix elements (LDME) fitted to experimental data.
  - **NRQCD+CGC**: Color Glass Condensate effective theory coupled to leading order NRQCD calculations.
  - **ICEM**: using the k_{T}-factorization approach to improve Color Evaporation Model (CEM).
- Reference for interpreting results obtained in Pb–Pb collisions.



NRQCD: Phys. Rev. D51 (1995) 1125–1171
NRQCD+CGC: JHEP 01 (2014) 056
ICEM: Phys. Rev. D 94 no. 11, (2016) 114029

Quarkonium as a probe of QGP in Pb−Pb





Phys. Lett.B 178 (1986) 416–422
Phys. Rev. Lett. 92 (2004) 212301
Phys. Lett. B 490 (2000) 196–202
Phys. Rev. D 64 (2001) 094015
Nucl. Phys. A 943 (2015) 147–158

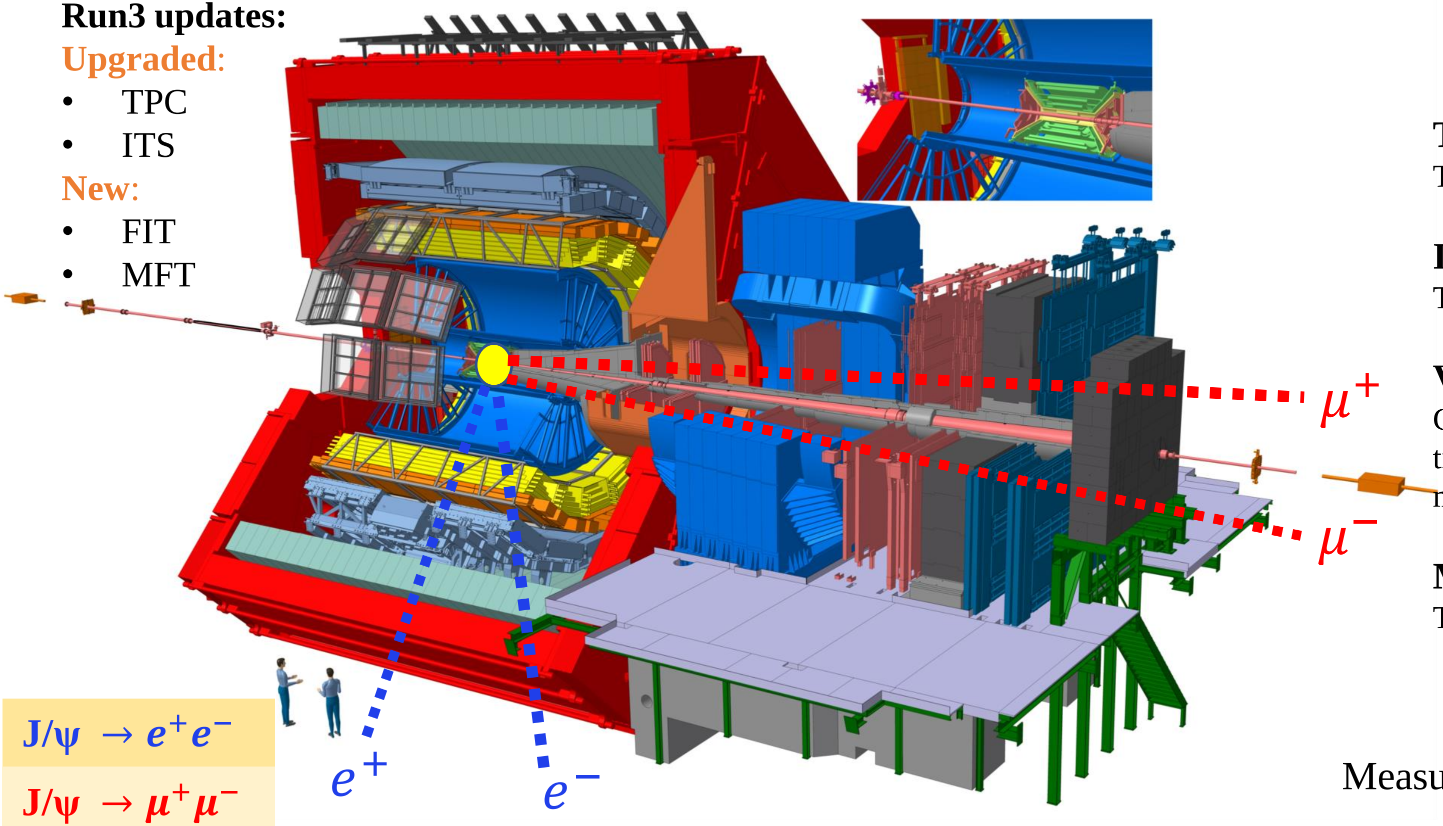
- Suppression of the direct charmonium due to color screening and dissociation.
- Recombination enhanced the charmonium production close to the transition at LHC energies.
- ψ(2S) production relative to J/ψ in Pb−Pb collisions has a strong discriminating power between different regeneration scenarios.

Quarkonium measurements with ALICE detector

Run3 updates:

Upgraded:
- TPC
- ITS

New:
- FIT
- MFT



$J/\psi \rightarrow e^+e^-$

$J/\psi \rightarrow \mu^+\mu^-$

Time Projection Chamber
Tracking, particle identification

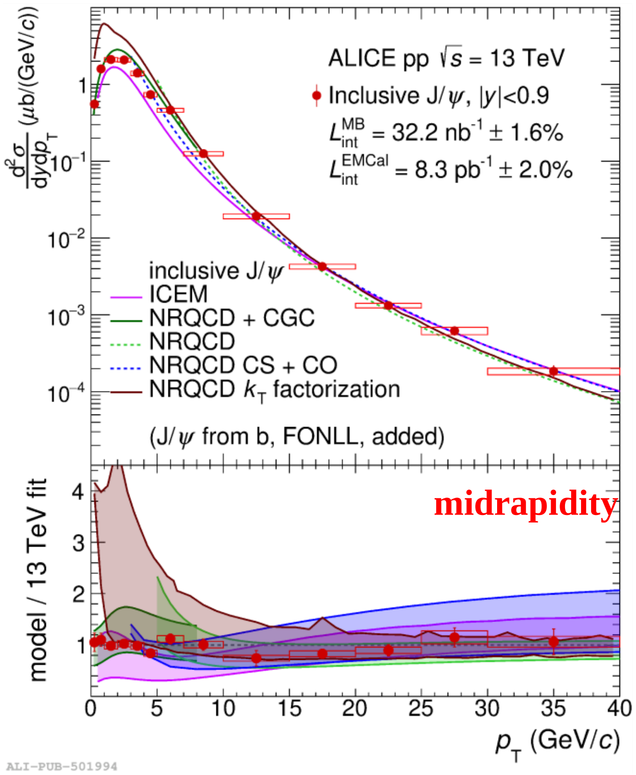
Inner Tracking System
Tracking, vertex reconstruction

V0 Detector
Centrality determination triggering, and reaction plane measurement

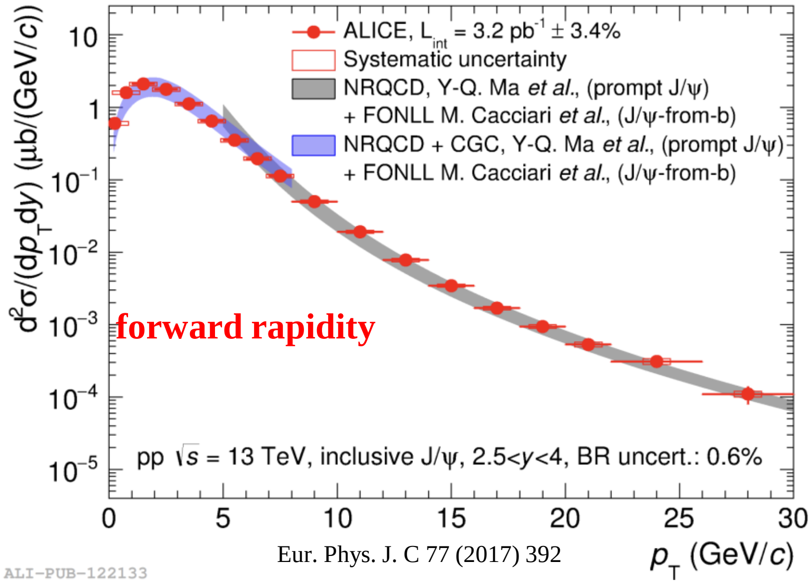
Muon spectrometer
Trigger and tracking for muons

Measured p_{T} can be down to 0

J/ψ p_T spectrum in pp collisions at $\sqrt{s}$ = 13 TeV



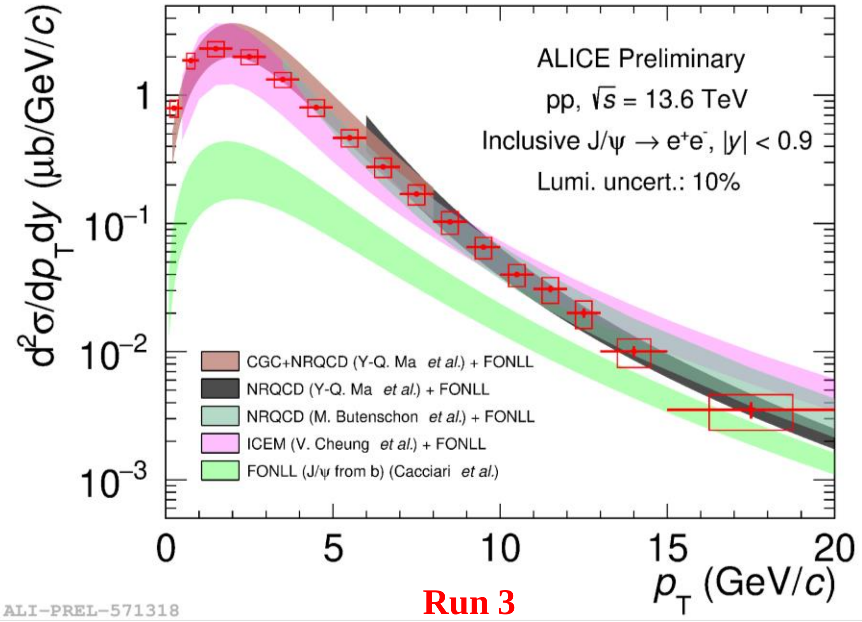
Eur. Phys. J. C 81 (2021) 1121



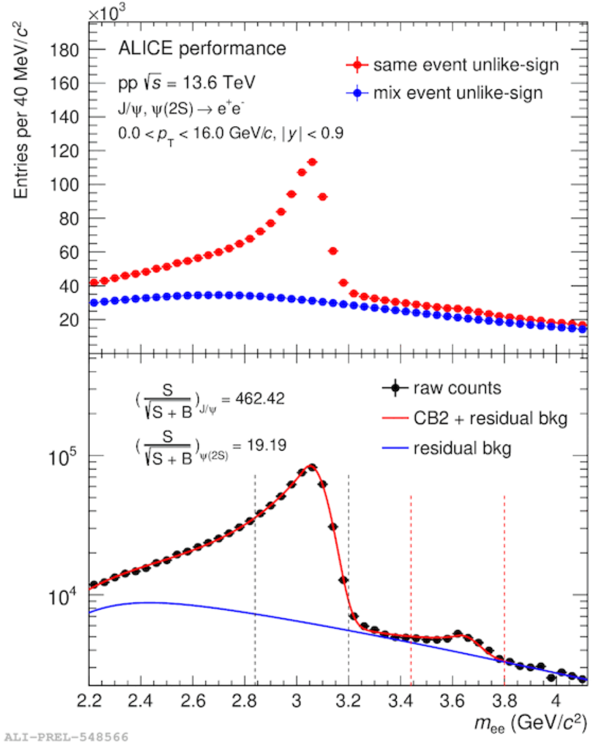
Eur. Phys. J. C 77 (2017) 392

- Precise measurements of inclusive J/ψ production at pp 13 TeV at both midrapidity and forward rapidity, p_T down to 0.
- FONLL is used to calculate non-prompt contribution.
- Measurement uncertainty is lower than most model uncertainties. All models describe data reasonably.

J/ψ p_T spectrum in pp collisions at $\sqrt{s}$ = 13.6 TeV



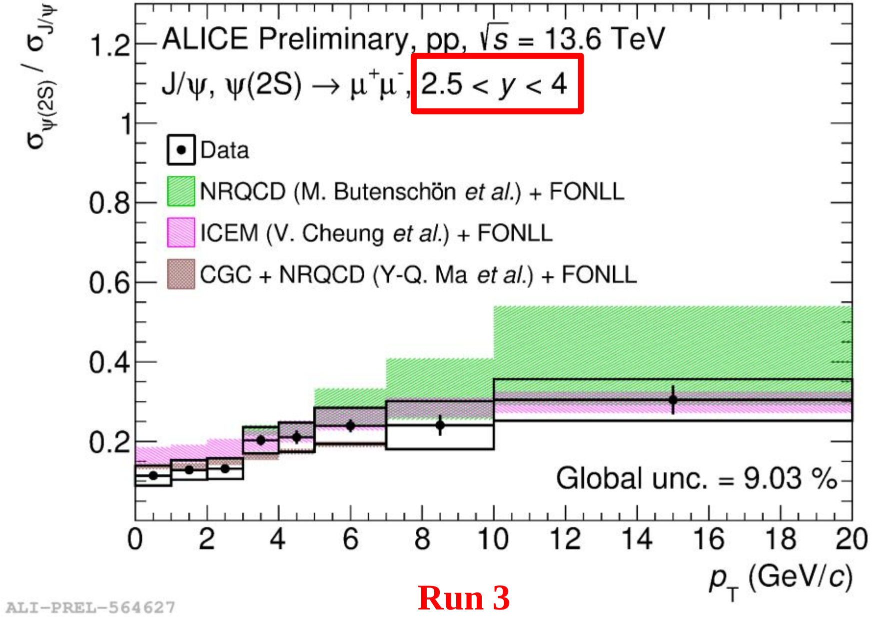
Run 3

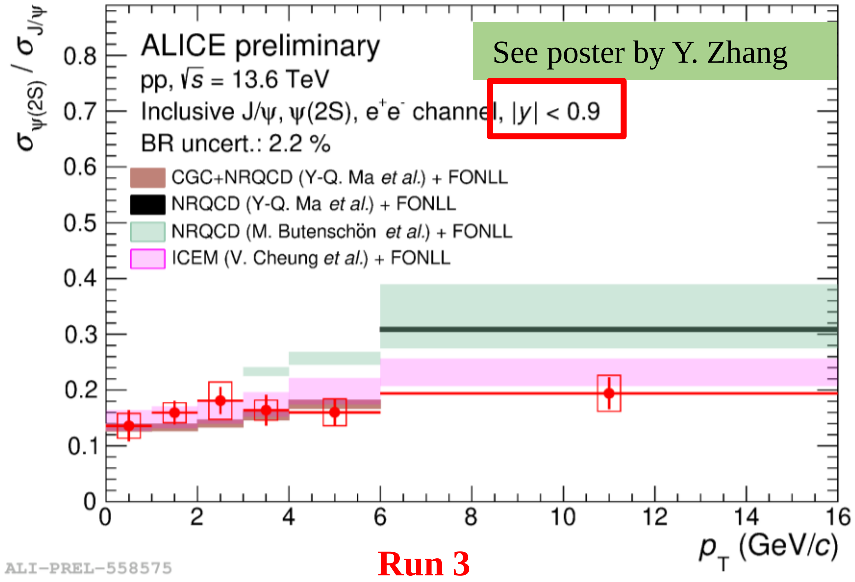


- Measurement of inclusive J/ψ production in pp 13.6 TeV collisions at midrapidity, p_T down to 0.
- Significant improvement in statistics for Run 3.
- All models describe data reasonably.

See poster by Y. Zhang

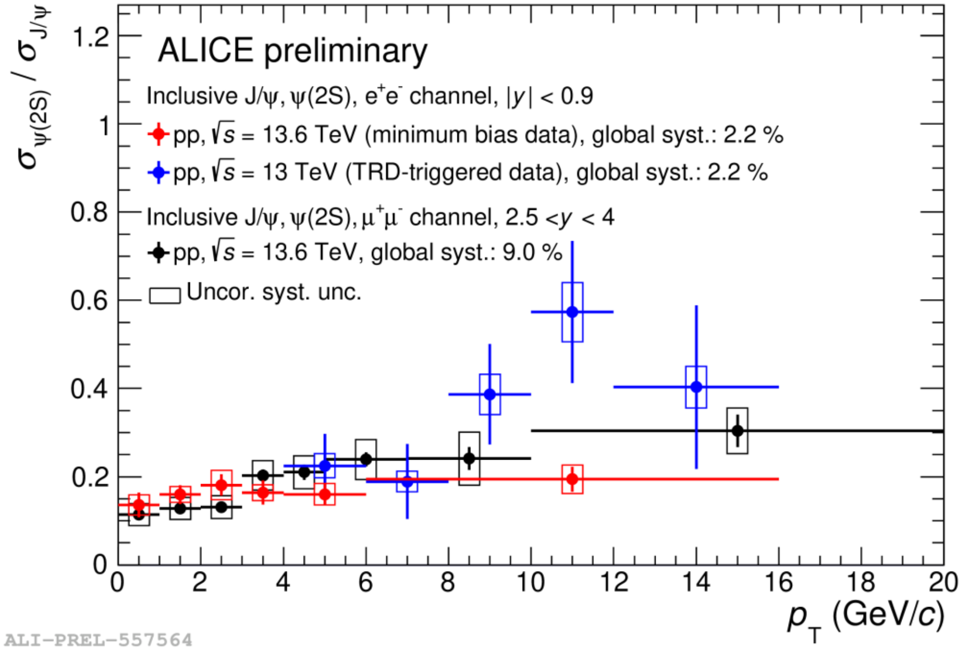
ψ(2S)-to-J/ψ ratio in pp collisions at $\sqrt{s}$ = 13.6 TeV





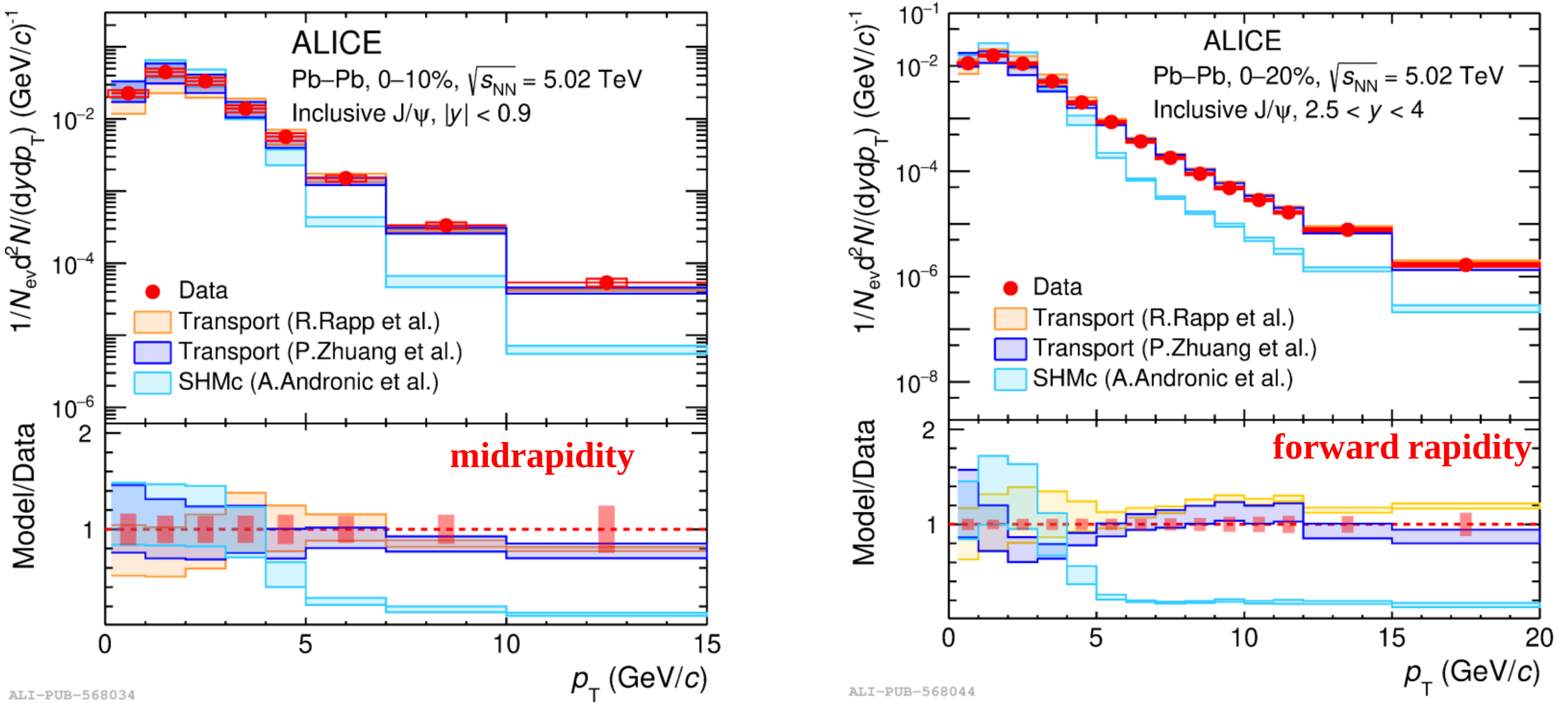
- **First measurement** of ψ(2S) in central barrel in ALICE.
- ψ(2S)-to-J/ψ ratio measurements at midrapidity and forward rapidity.
- ICEM reproduce measurements reasonably over full p_T range.

ψ(2S)-to-J/ψ ratio in pp collisions at $\sqrt{s}$ = 13.6 TeV



- The results from different energies and rapidity intervals are consistent.

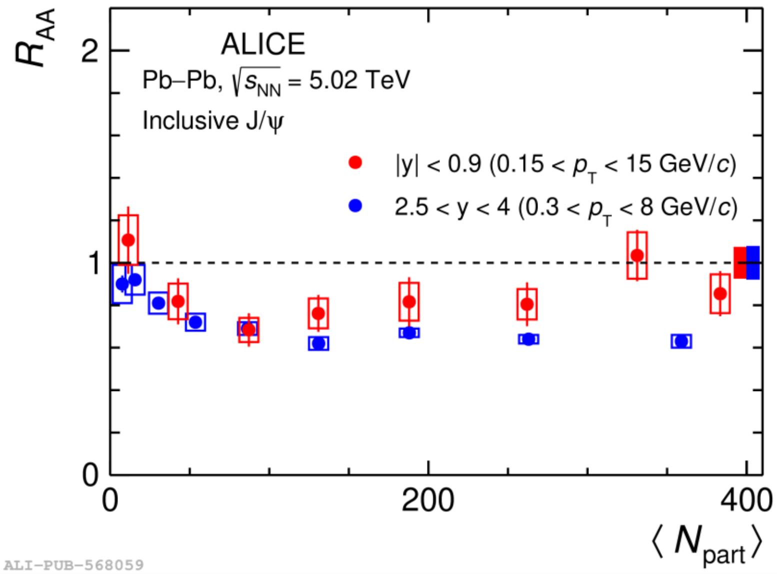
J/ψ p_T spectrum in Pb−Pb collisions $\sqrt{s_{NN}}$ = 5.02 TeV

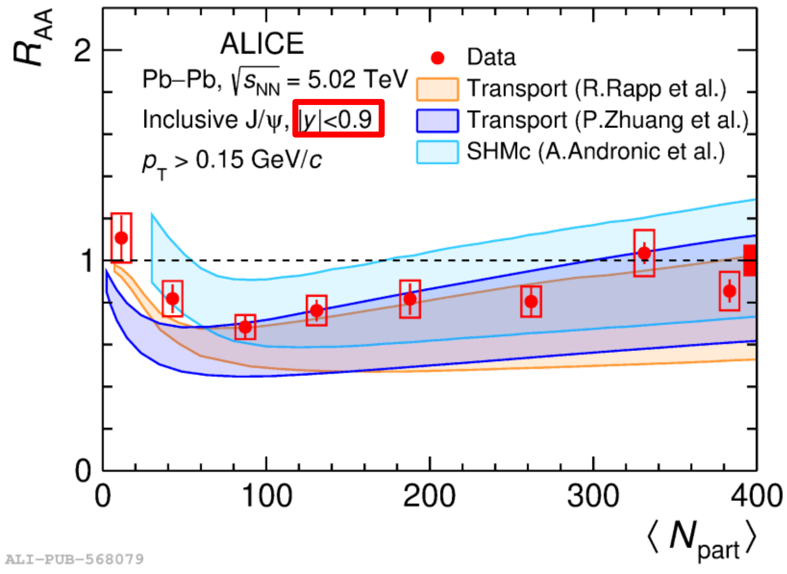


Phys. Lett. B 849 (2024) 138451

- Measurement of inclusive J/ψ production at Pb−Pb 5.02 TeV, p_T down to 0.
- SHMc underestimates data at high p_T; two transport model agree with data over full p_T range.

Centrality dependence of J/ψ R_{AA} in Pb−Pb collisions



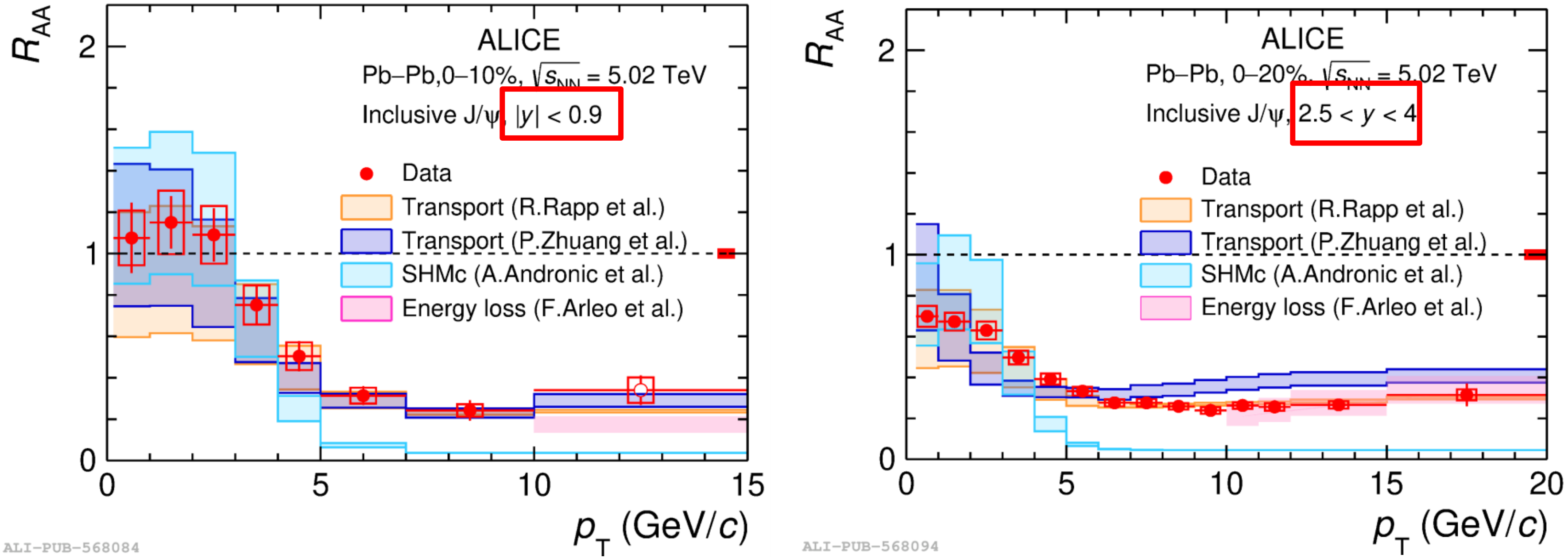


Phys. Lett. B 849 (2024) 138451

- **Stronger regeneration** in central collisions at midrapidity.
- All three model calculations show good agreement with data at midrapidity.
- More precise experimental inputs (total charm cross-section/shadowing) are needed to constrain models.

$$R_{AA} = \frac{1}{\langle T_{AA}\rangle}\frac{d^2N_{AA}/dydp_T}{d^2\sigma_{pp}/dydp_T}$$

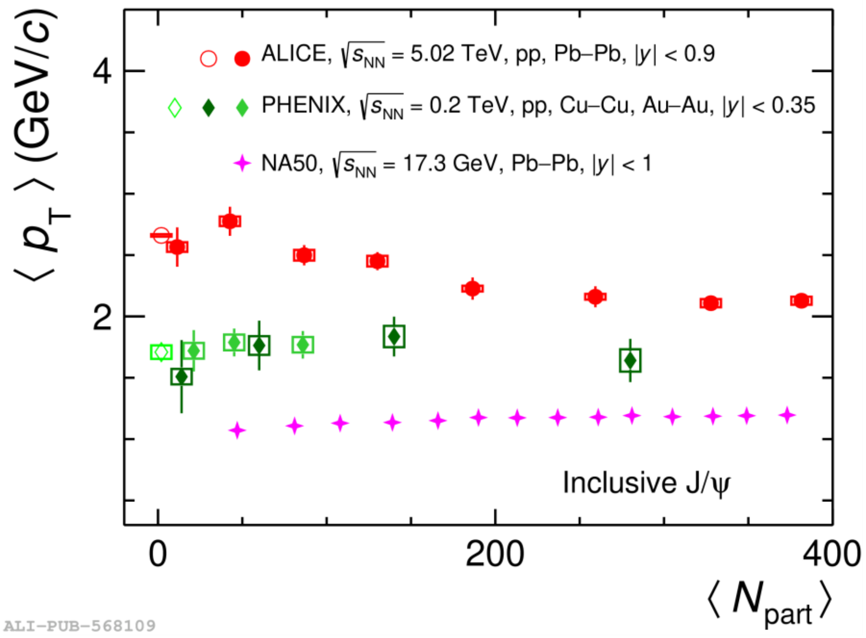
p_T dependence of J/ψ R_{AA} in Pb−Pb collisions

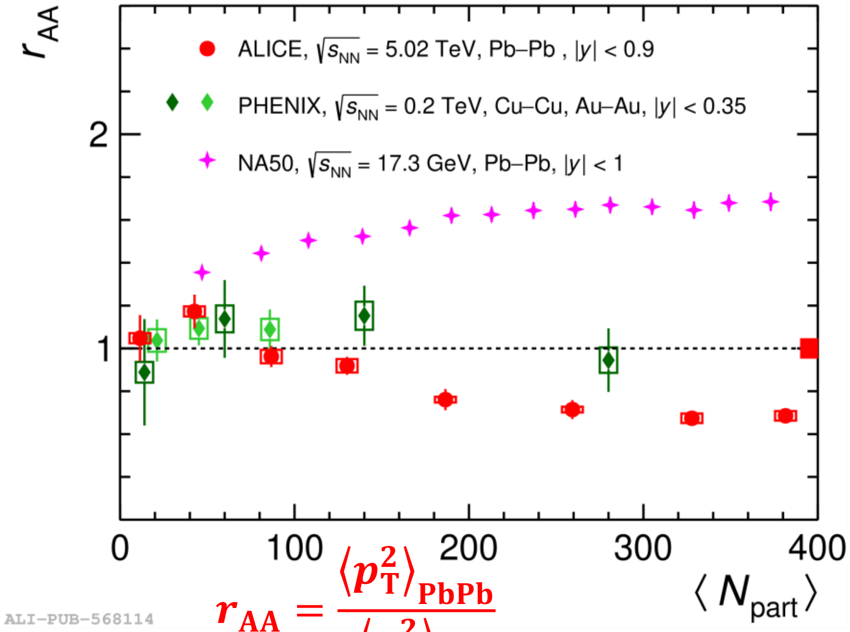


Phys. Lett. B 849 (2024) 138451

- Significant suppression at p_T > 5 GeV/c for both forward and midrapidity.
- Stronger **regeneration** at midrapidity in low p_T range in central collisions.
- More precise experimental inputs (total charm cross-section/shadowing) are needed to constrain models at low p_T.

J/ψ $\langle p_T \rangle$ and r_{AA} in Pb–Pb collisions $\sqrt{s_{NN}}$ = 5.02 TeV



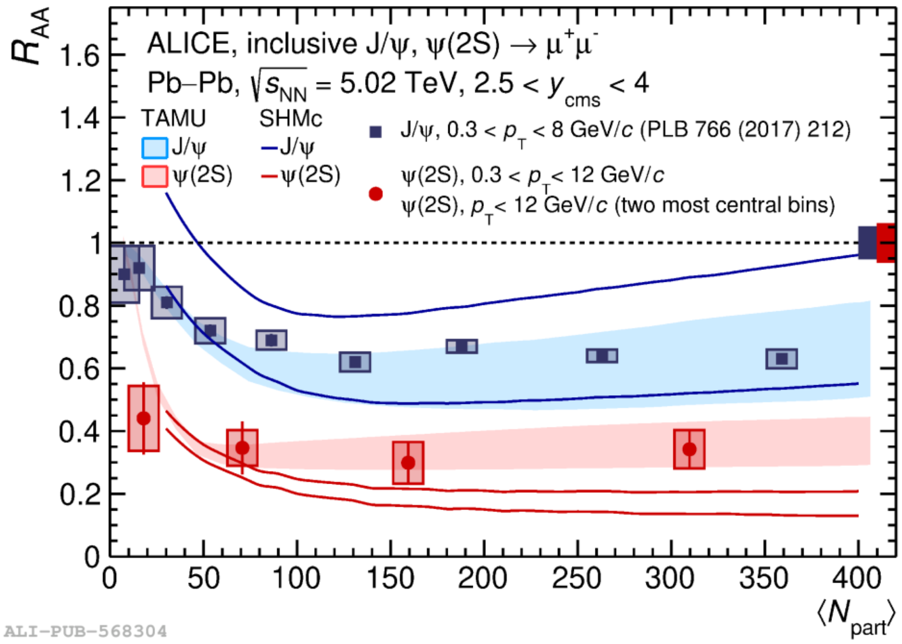


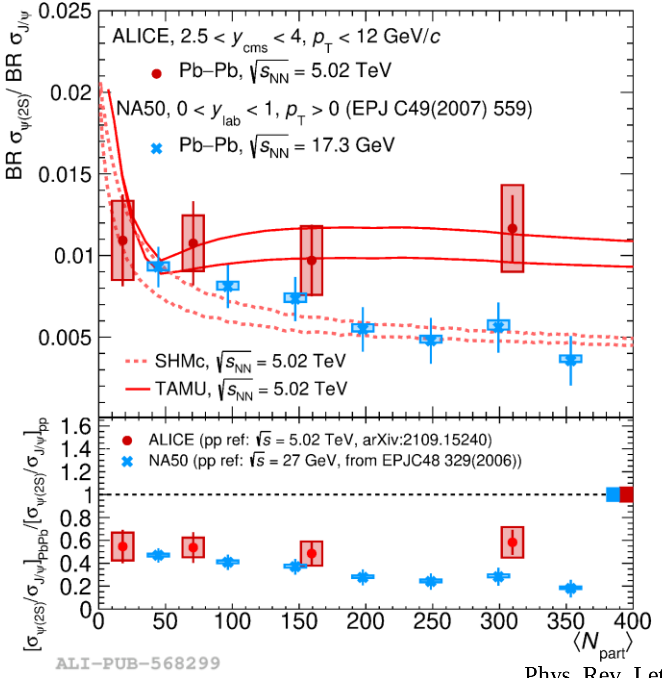
$$r_{AA} = \frac{\langle p_T^2 \rangle_{PbPb}}{\langle p_T^2 \rangle_{pp}}$$

Phys. Lett. B 849 (2024) 138451

- Decreasing trends of $\langle p_T \rangle$ and r_{AA} from peripheral to central with ALICE → **Regeneration at low p_T**
- $\langle p_T \rangle$ increases with collision energy.
- r_{AA} below unity indicates a softening J/ψ p_T shape in Pb–Pb collisions compared to pp collisions.

Centrality dependence of R_{AA} and double ratio of ψ(2S)-to-J/ψ

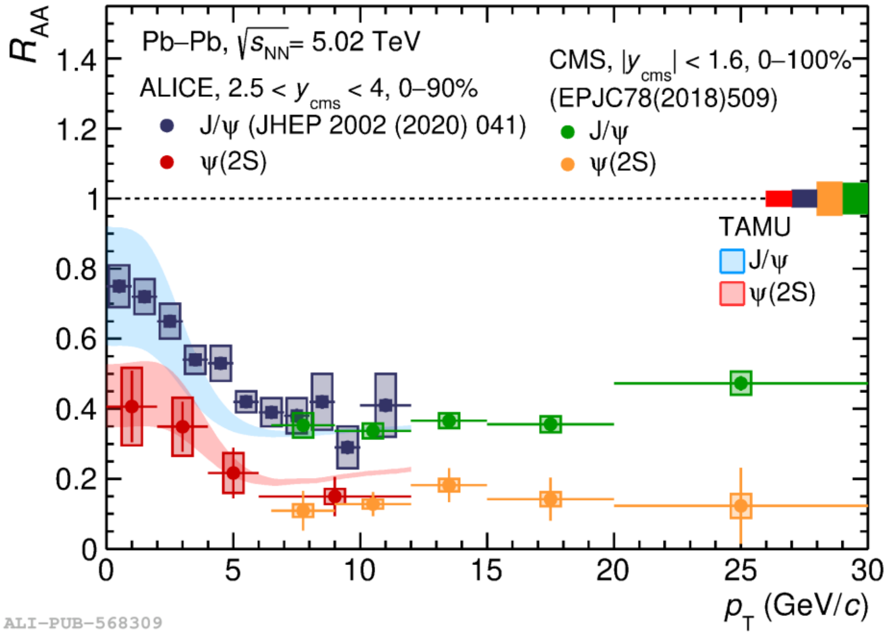


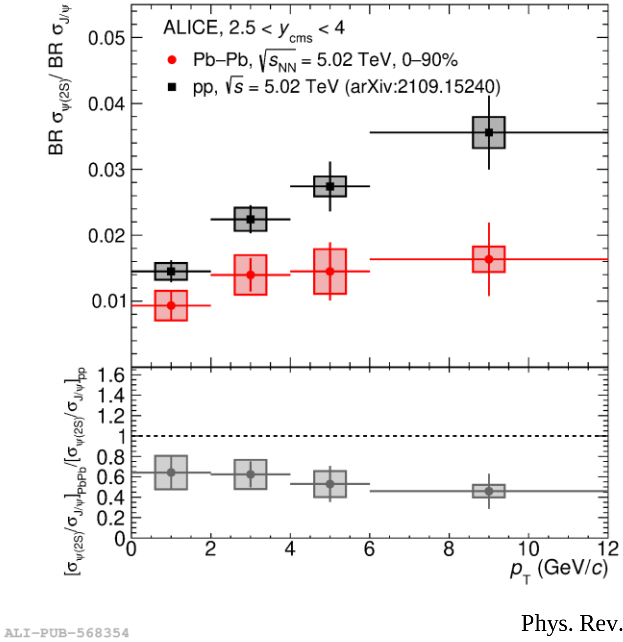


Phys. Rev. Lett. 132 (2024) 042301

- Flat centrality dependence for both ψ(2S) R_{AA} and ψ(2S)-to-J/ψ (double) ratio at the LHC.
- ψ(2S) is more suppressed.
- SHMc underestimates the ψ(2S) R_{AA} and ψ(2S)-to-J/ψ ratio in central collisions; TAMU agrees with data.

p_T dependence of R_{AA} and double ratio of ψ(2S)-to-J/ψ

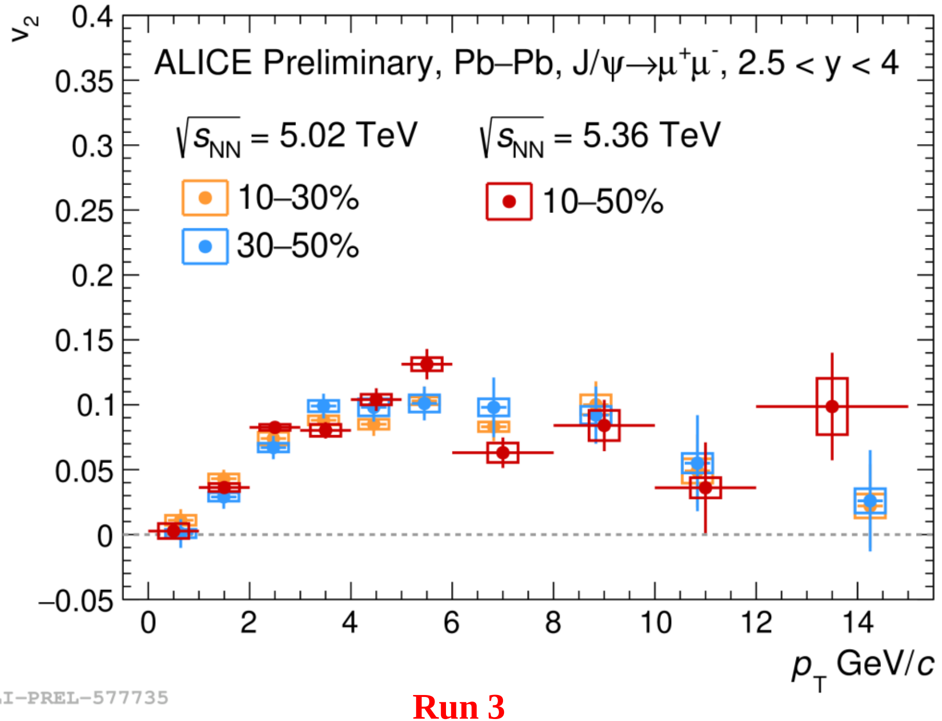




Phys. Rev. Lett. 132 (2024) 042301

- ψ(2S) shows a stronger suppression over the full p_T range.
- Lower suppression at low p_T → regeneration.
- Measurements agree with CMS measurements and TAMU model.

J/ψ v_2 in Pb−Pb collisions at $\sqrt{s_{NN}}$ = 5.36 TeV



Run 3

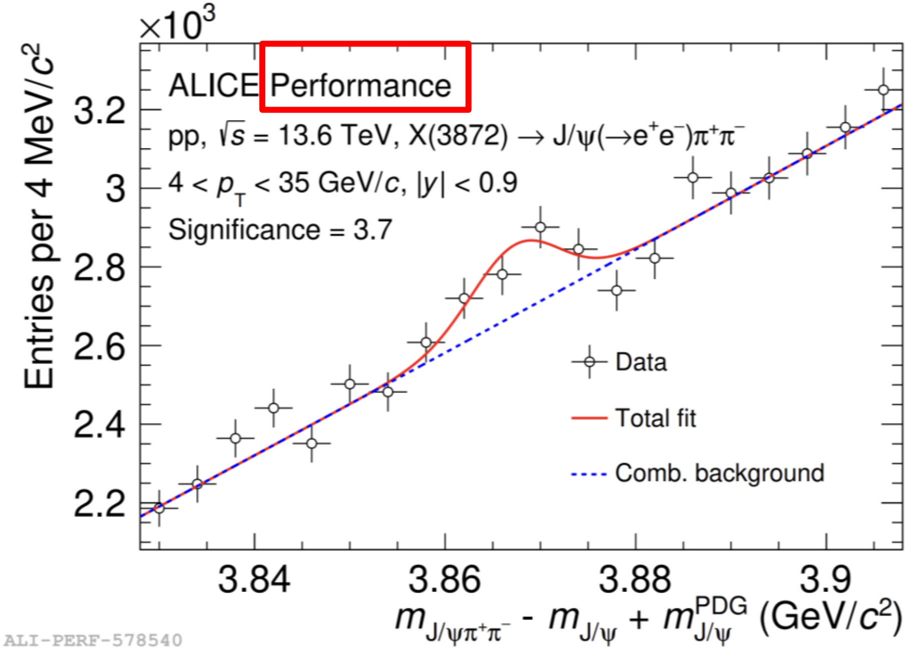
- inclusive J/ψ v_2 vs. p_T using Event-Plane at forward rapidity in ALICE Run 3.
- v_2 results are compatible within uncertainties between the two energies.

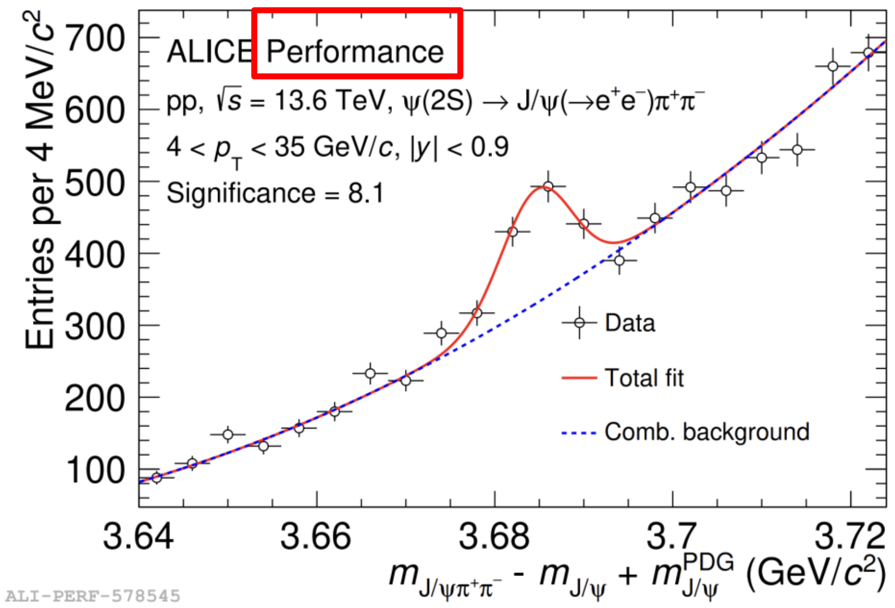
Event-Plane:

$$v_n = <\cos[n(\varphi - \Psi_n)]>/R_n\{EP\}$$

See poster by C. Zhang

ψ(2S) and X(3872) in pp collisions at $\sqrt{s}$ = 13.6 TeV





~ 40% pp 13.6TeV data

- First look of X(3872) at low p_{T}.
- ψ(2S) and X(3872) using J/ψ$\pi^+\pi^-$ channel at pp 13.6 TeV with ALICE Run 3.

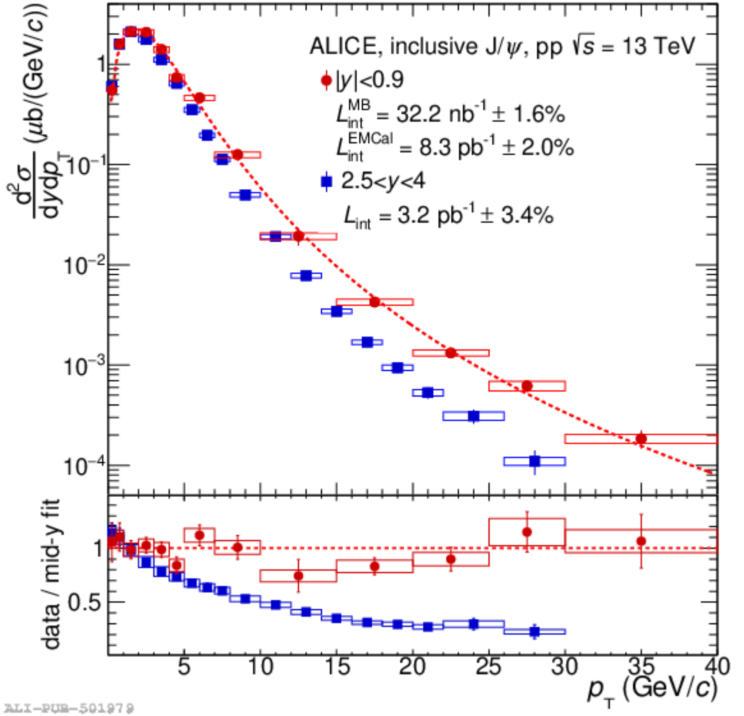
Summary

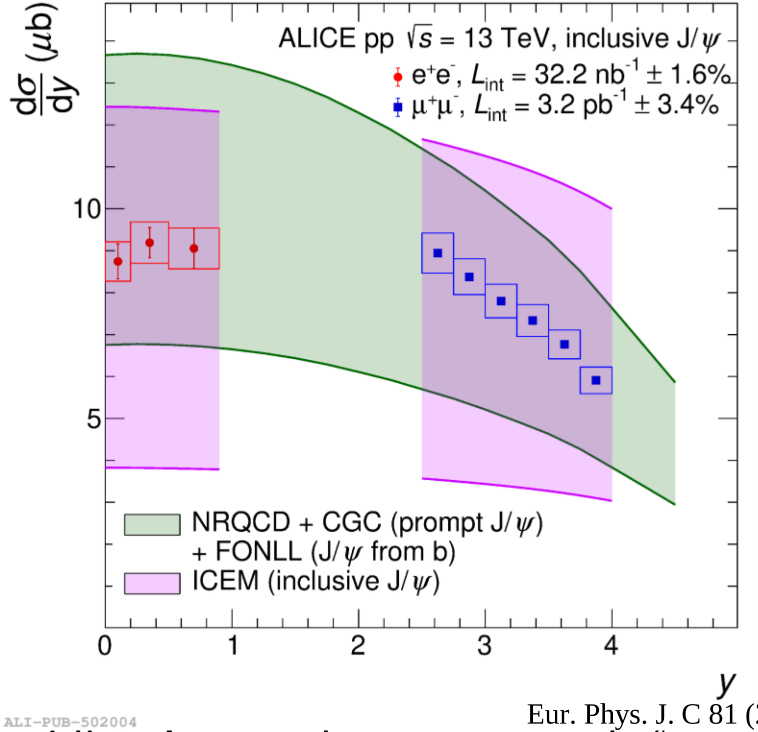
- **Inclusive J/ψ in pp and Pb−Pb:**
  - Provides important constraints to QCD models and a reference for investigating the QGP.
  - Stronger regeneration observed in low p_{T} in Pb−Pb.
- **Double ratio of ψ(2S)-to-J/ψ:**
  - Stronger suppression of ψ(2S) compared to J/ψ, by a factor ~ 2.
  - TAMU model describes data well; SHM model qualitatively agree with data.
- **Outlook:**
  - There is going to be more precise measurements in Run 3.
  - **First look** of **X(3872)** at low p_{T} for the first time with ALICE.

Thanks

Backup

Comparison of J/ψ yield between mid and forward rapidity



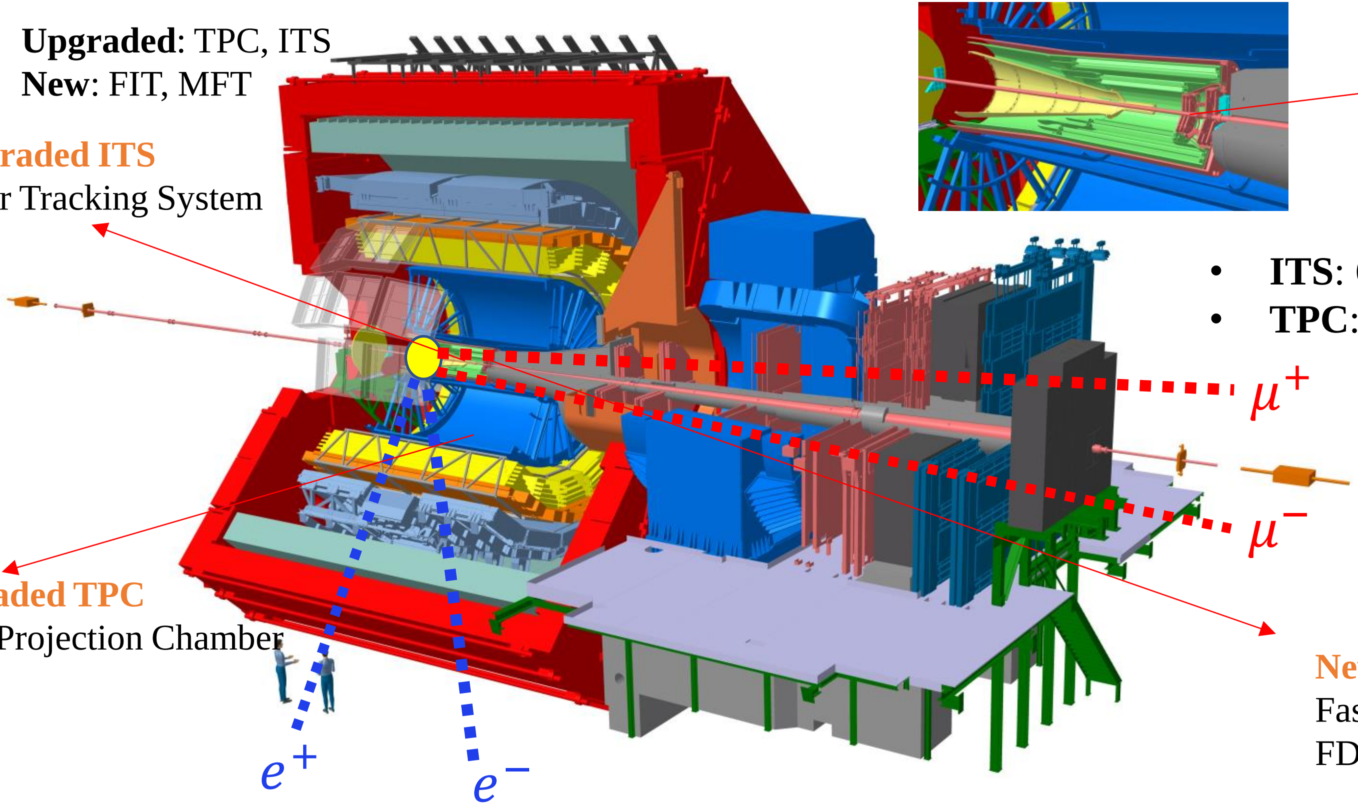


Eur. Phys. J. C 81 (2021) 1121

- Larger J/ψ production at high p_T at mid-rapidity. A steep decrease towards forward rapidity
- Both NRQCD+CGC and ICEM models are compatible due to large uncertainties.

Quarkonia measurements with ALICE detector

- **Upgraded**: TPC, ITS
- **New**: FIT, MFT



Upgraded ITS
Inner Tracking System

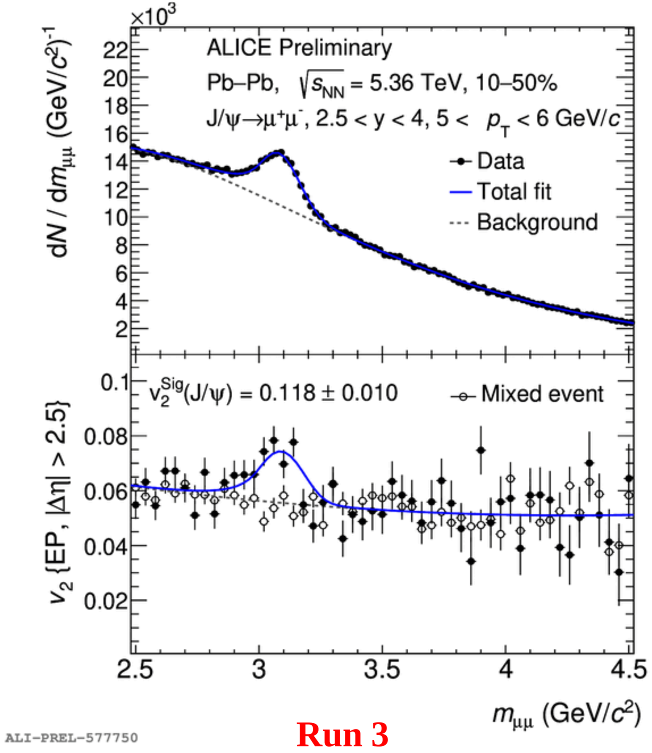
Upgraded TPC
Time Projection Chamber

New MFT
Muon Forward Tracker

- **ITS**: 6 layers → 7 layers
- **TPC**: continuous read out

New FIT
Fast Interaction Trigger
FDD, FV0, FT0

J/ψ v_2 in Pb−Pb collisions at $\sqrt{s_{NN}}$ = 5.36 TeV



Run 3

- Ongoing analysis of inclusive J/ψ v_2 vs. p_T at forward rapidity in ALICE Run 3.

See poster by C. Zhang