



Measurement of charmonium production at midrapidity in pp collisions at 13.6 TeV with ALICE

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Introduction

➤ Charmonia:

➤ Bound states of charm and anti-charm quark pairs.

➤ Crucial for studying charmonium production mechanisms and testing different QCD-based models.

➤ Heavy-quark production (perturbative QCD)

➤ Formation of the charmonium states (non-perturbative QCD)

NRQCD:

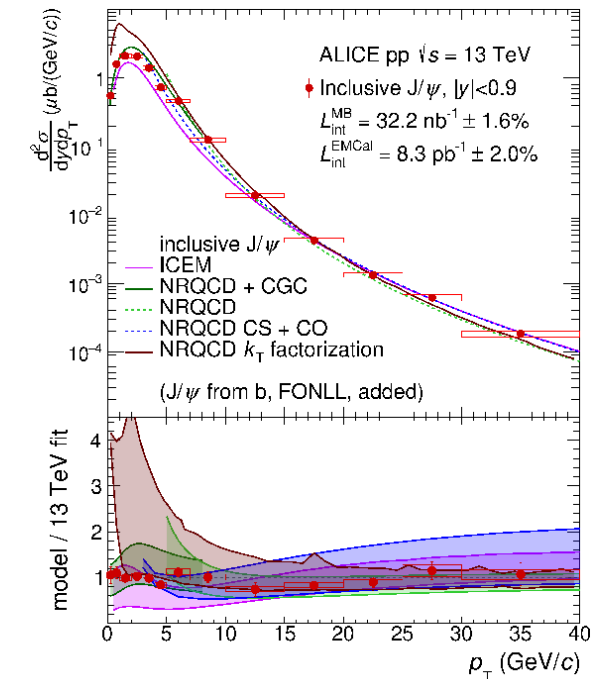
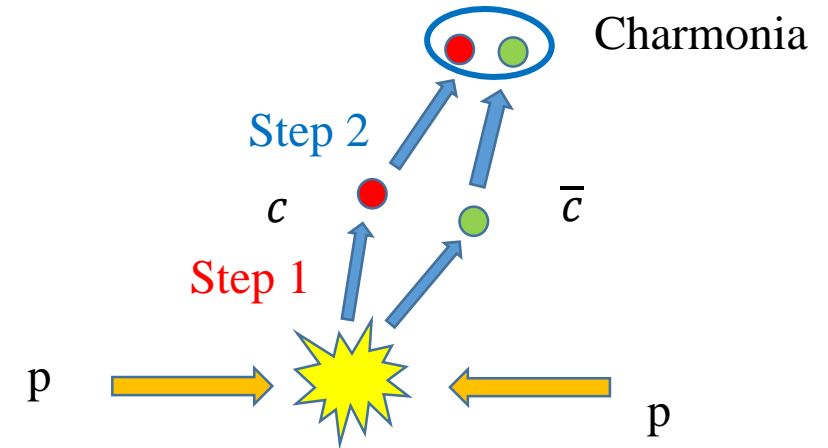
$$(2\pi)^3 2P_H^0 \frac{d\sigma_H}{d^3P_H} = \sum_n d\hat{\sigma}_n(P_H) \langle \mathcal{O}_n^H \rangle$$

Production of a heavy quark pair
Expansion in: α_s

Hadronization (LDMEs)
Expansion in: v

ICEM:

$$\frac{d\sigma_\psi(P)}{d^3P} = F_\psi \int_{M_\psi}^{2M_D} d^3P' dM \frac{d\sigma_{c\bar{c}}(M, P')}{dM d^3P'} \delta^3\left(P - \frac{M_\psi}{M} P'\right)$$

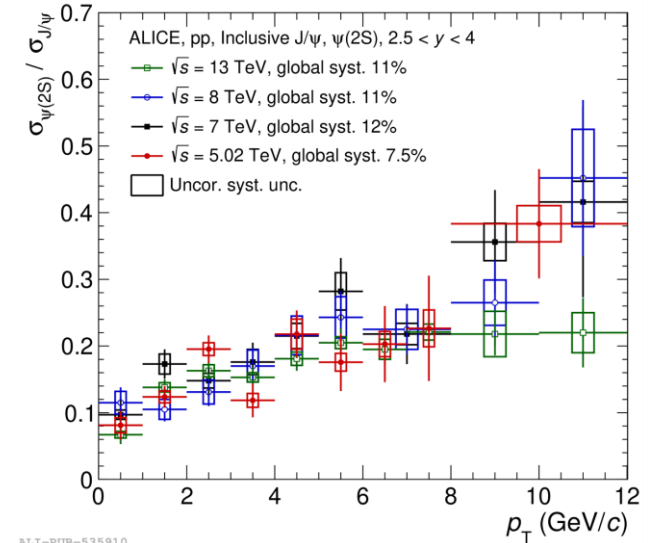


ALI-PUB-501994

Introduction

➤ Charmonia:

- Bound states of charm and anti-charm quark pairs.
- **Crucial for studying charmonium production mechanisms and testing different QCD-based models.**
 - Heavy-quark production (perturbative QCD)
 - Formation of the charmonium states (non-perturbative QCD)
- **Study the rapidity and energy dependence of charmonium production by comparing to similar measurements.**
- **Used as reference for studying AA collisions.**
 - The $\psi(2S)$ -to- J/ψ ratio has not been measured at midrapidity in ALICE



ALICE Collaboration, S. Acharya et al., Eur. Phys. J. C 83 (2023) 61

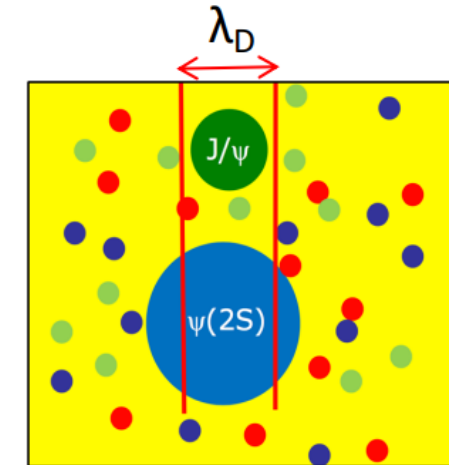


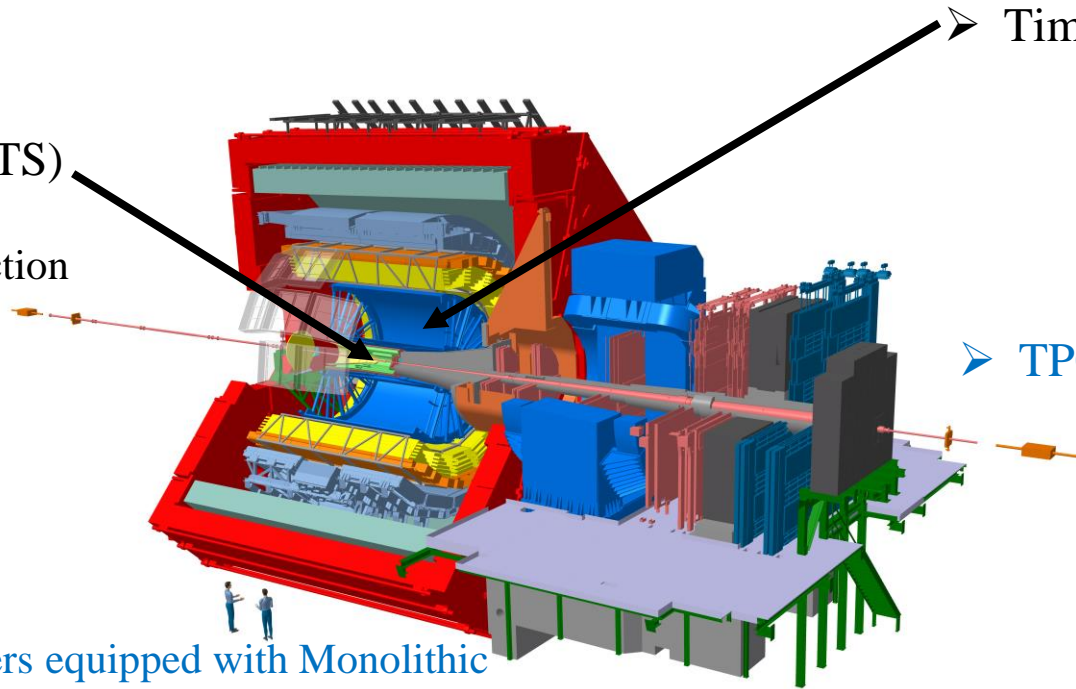
Illustration of colour screening affecting J/ψ and $\psi(2S)$ differently

ALICE detector Run 3 upgrade

- Uniform acceptance at midrapidity ($|y| < 0.9$) and good PID for electrons.

- Inner Tracking System (ITS)

- Tracking
- Vertex reconstruction



- Time Projection Chamber (TPC)

- Tracking
- Particle identification via dE/dx measurement
- Momentum measurement

- TPC upgrade:

- Readout chambers replaced with Gas Electron Multiplier (GEM) chambers.

- ITS upgrade:

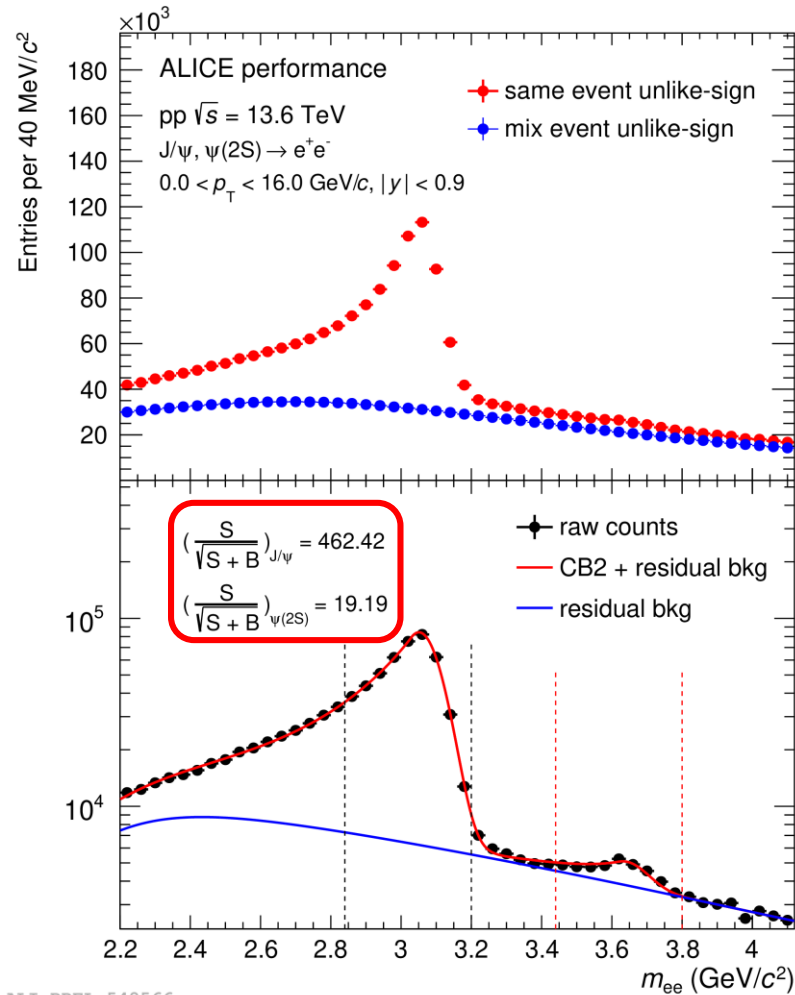
- 6 layers \Rightarrow 7 layers equipped with Monolithic Active Pixel Sensors (MAPS).
- Radius of innermost layer: 39 mm \Rightarrow 23mm.
- Material budget for each of the 3 innermost layers: 1.15% \Rightarrow 0.35%.



Enable continuous readout of Pb–Pb events at an interaction rate up to 50 kHz ($\sim 10^2$ w.r.t. run 2).

Data analysis procedure

- Inclusive quarkonia are reconstructed in e^+e^- channel at midrapidity ($|y| < 0.9$) down to $p_T = 0$.



- Dataset:

- pp collisions at $\sqrt{s} = 13.6$ TeV collected in 2022 with the ALICE upgraded detector.
- 524×10^9 minimum-bias (MB) events used in this analysis thanks to the continuous readout.

- Electron identification via TPC dE/dx .

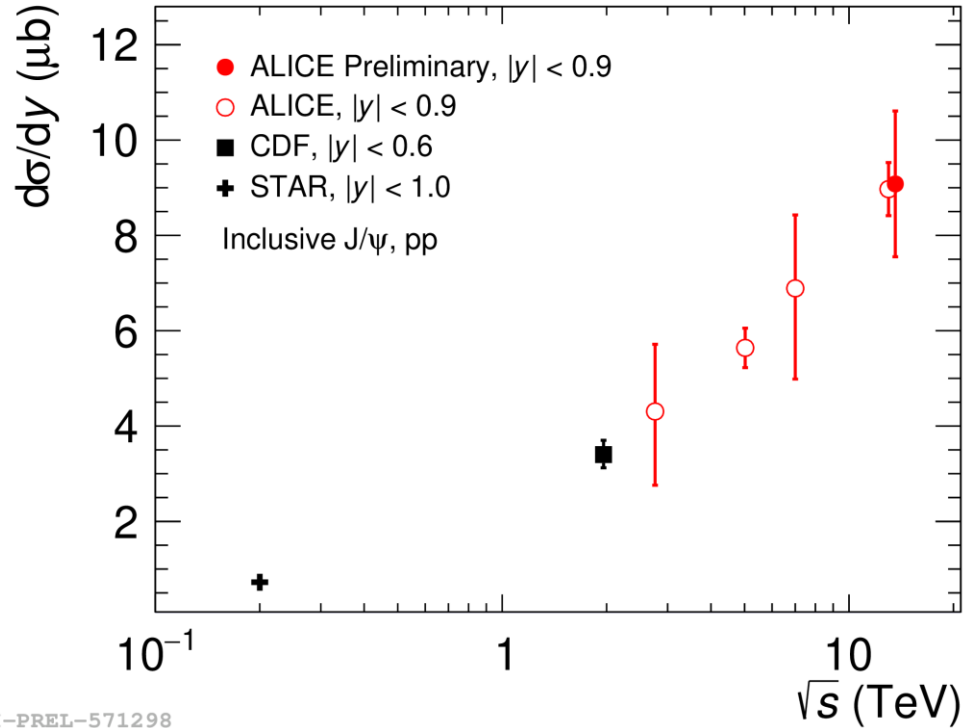
- Signal extraction:

- Signal shapes are described by two **Crystal Ball functions**. Possible differences between the J/ψ and ψ(2S) shapes are assigned as systematic uncertainties.

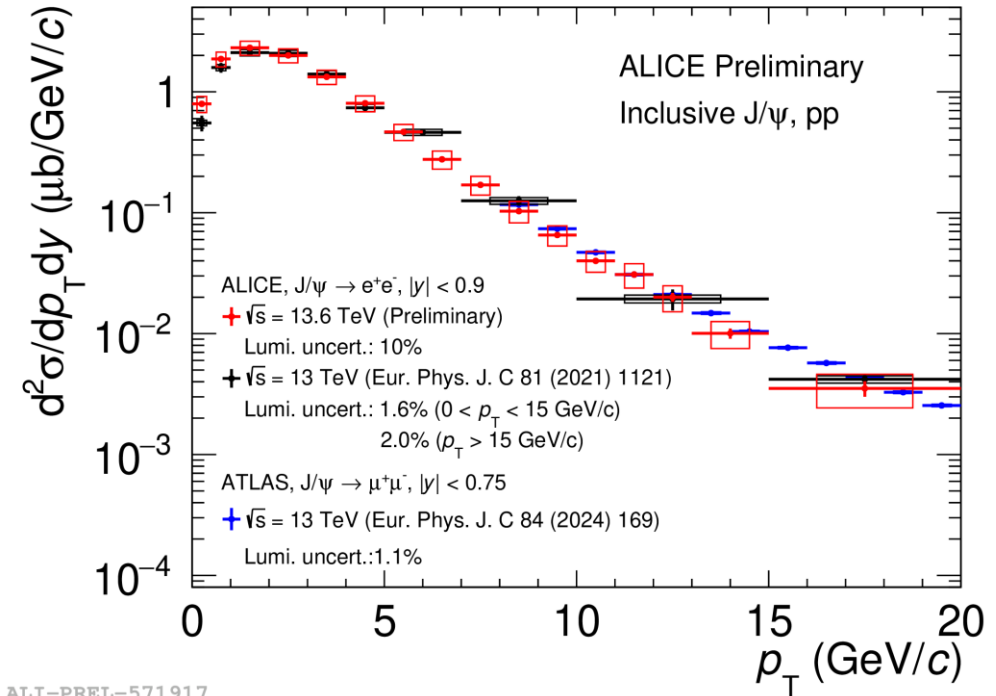
- The significance of J/ψ is about 462 and the significance of ψ(2S) reach to nearly 20.

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J/ψ cross section



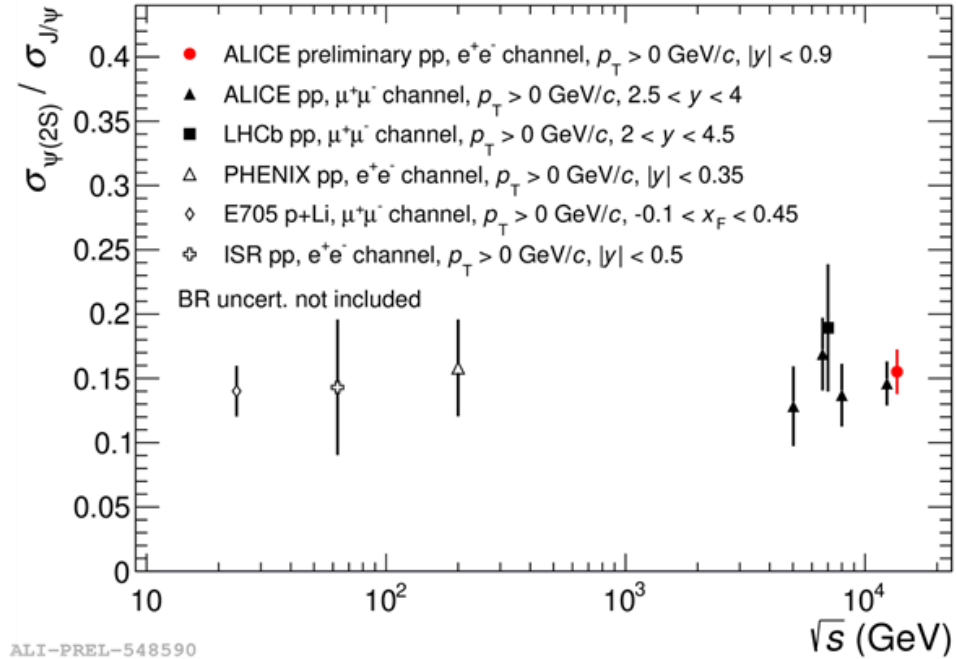
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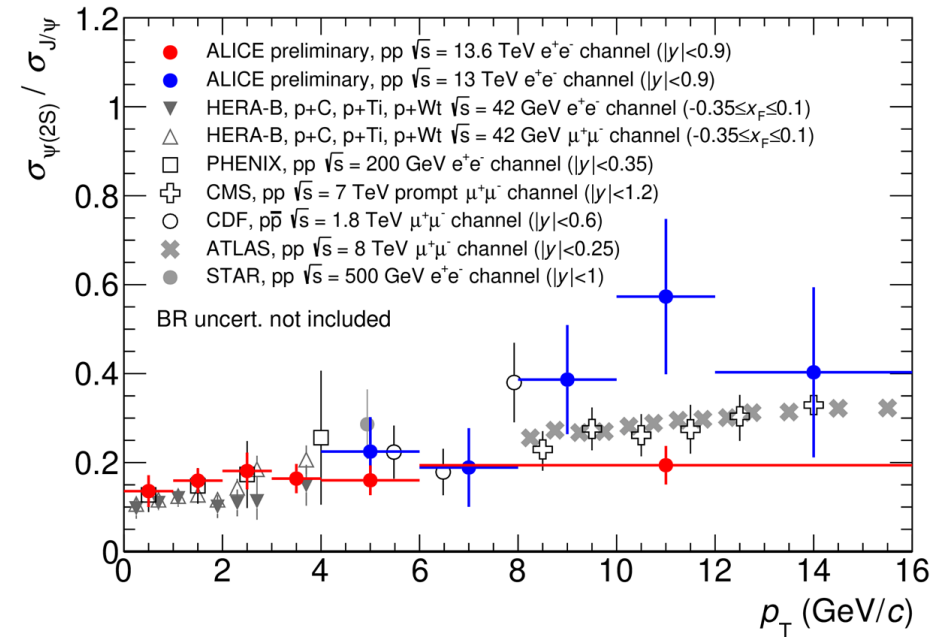
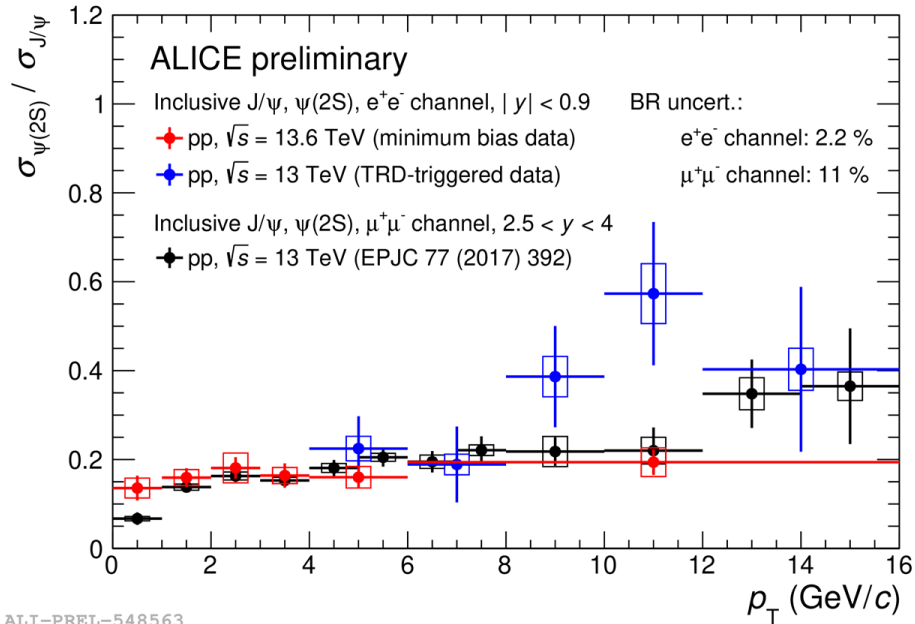
- The p_T integrated J/ψ cross section is 9.08 ± 0.046 (stat.) ± 1.23 (syst.) ± 0.91 (Lumi.)
- This results (red point) are shown together with existing results at different and similar collision energy from ALICE and other experiments.
 - The p_T integrated cross section increases with collision energy.
 - p_T differential cross section are in consistent with results at similar collision energy.

$\psi(2S)$ -to- J/ψ ratio



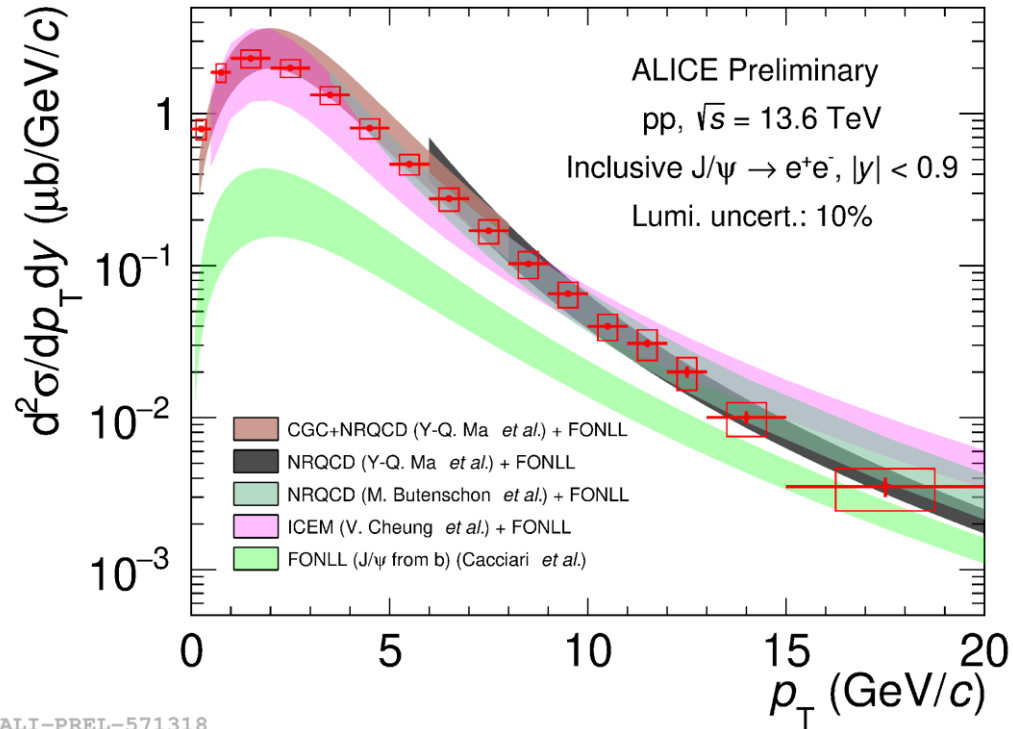
- The measured p_T -integrated ratio without BR uncertainty is $0.155 \pm 0.010(\text{stat.}) \pm 0.014(\text{syst.})$
 - Large fraction of systematic uncertainty are **canceled out** by taking ratio.
- The result (**red point**) is shown together with existing results from ALICE at forward rapidity and from other experiments.
 - The **uncertainty is reduced** because of the improvement of statistics.
 - No significant energy and rapidity dependence.

$\psi(2S)$ -to- J/ψ ratio

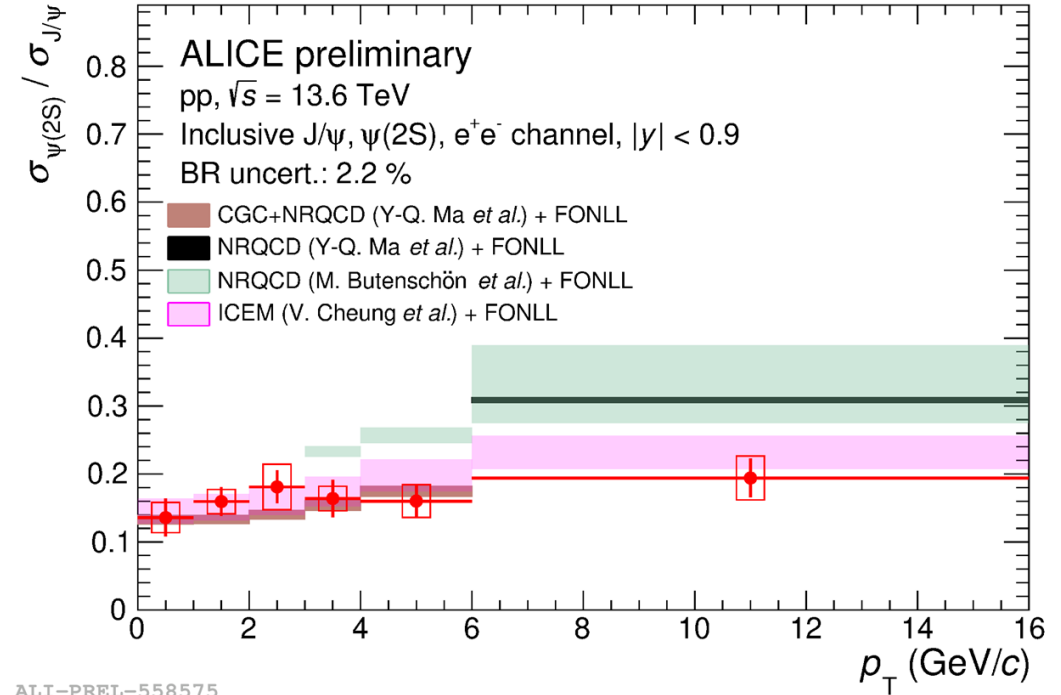


- The results (**red points**) are shown together with existing results from ALICE at forward rapidity and from other experiments.
 - In agreement with other results.
 - No significant rapidity dependence.
 - Slight p_T dependence (also expected from models).

Comparison with models



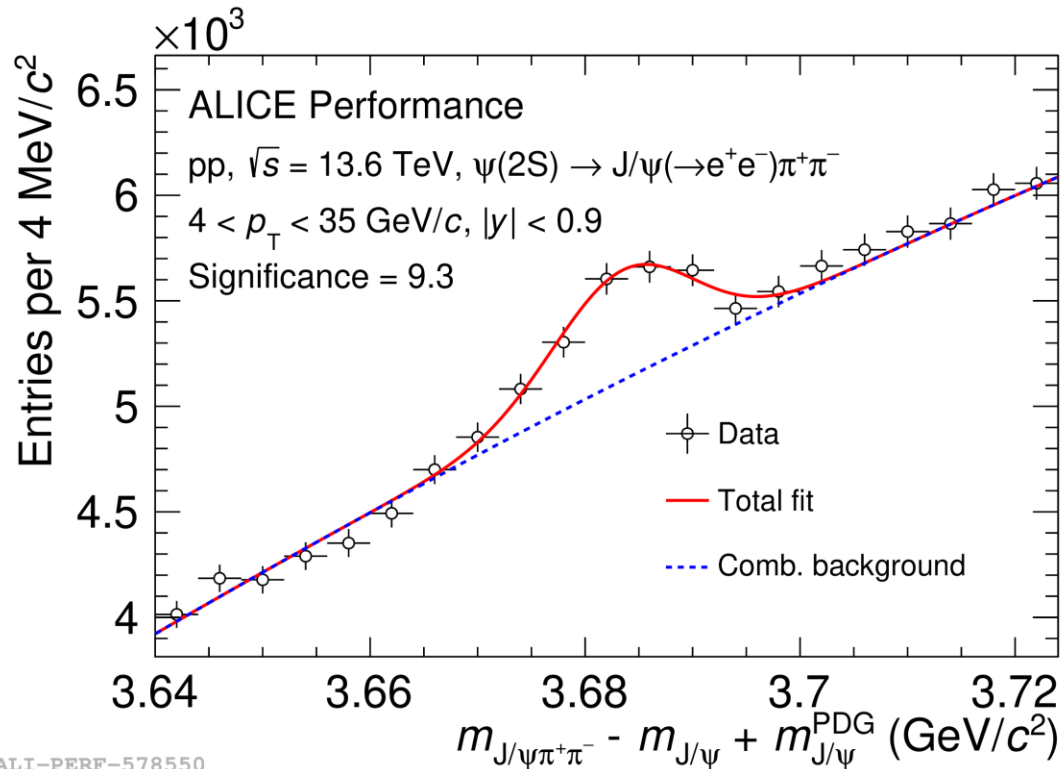
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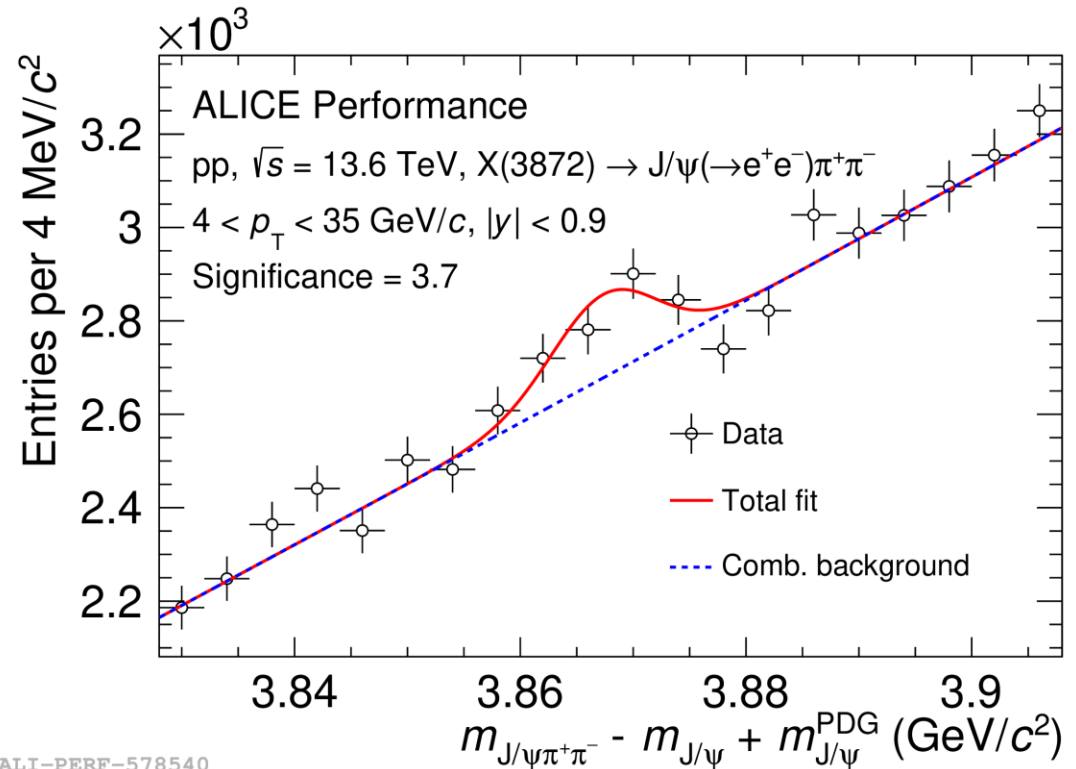
ALI-PREL-558575

- Comparison with models (FONLL is used to describe the non-prompt contribution):
 - Both of the NRQCD and ICEM can describe the cross section of J/ψ .
 - NRQCD overestimates the ratio.
 - CGC + NRQCD describes the ratio at low p_T up to 6 GeV/c.
 - ICEM can reproduce the data.

First look of X(3872)

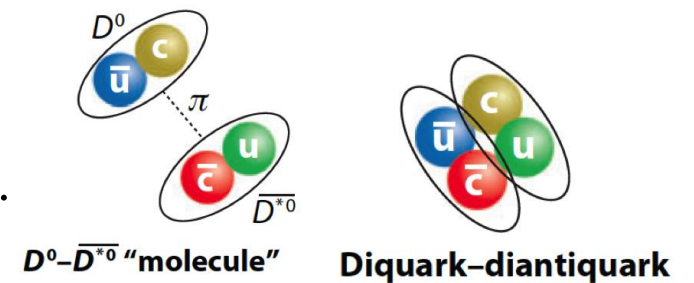


ALI-PERF-578550



ALI-PERF-578540

- First look of X(3872) in **low** p_T at midrapidity.
- $\psi(2S)$ and X(3872) using $J/\psi\pi^+\pi^-$ channel at pp 13.6 TeV in ALICE Run 3.



Conclusion

- **J/ψ cross section is measured in pp collision at $\sqrt{s} = 13.6$ TeV at midrapidity.**
 - p_T integrated result shows a **dependence on the collision energy**.
 - Comparison with models.
 - **Both ICEM and NRQCD** can describe the p_T distribution within uncertainties.
- **First measurement of the $\psi(2S)$ -to-J/ψ ratio in pp collision at $\sqrt{s} = 13.6$ TeV at midrapidity.**
 - **Precision is improved** thanks to the improved statistic of Run 3.
 - **No significant energy and rapidity dependence**, a slight p_T **dependence** is observed.
 - Comparison with models.
 - NRQCD overestimates the ratio.
 - CGC + NRQCD describes the ratio at low and intermediate p_T .
 - ICEM can reproduce the data.
- Provides a reference for investigating the quark-gluon plasma in nucleus-nucleus collisions and the cold nuclear matter effects in proton-nucleus collisions.
- First look of X(3872) in **low p_T** at midrapidity using $J/\psi\pi^+\pi^-$ channel with ALICE.

Thank you

Back up

Back up

- The two NLO NRQCD calculations from Butenschon and from Ma differ in the parametrization of the Long Distance Matrix Elements(LDME) used to calculate the color-octet contributions to the charmonium production cross section.

$$\frac{\sigma_{\psi(2S)}}{\sigma_{J/\psi}} = \frac{N_{\psi(2S)}}{N_{J/\psi}} \frac{(A \times \varepsilon)_{J/\psi}}{(A \times \varepsilon)_{\psi(2S)}} \frac{BR_{J/\psi \rightarrow ee}}{BR_{\psi(2S) \rightarrow ee}}$$