Measurement of inclusive J/ψ and ψ(2S) 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:

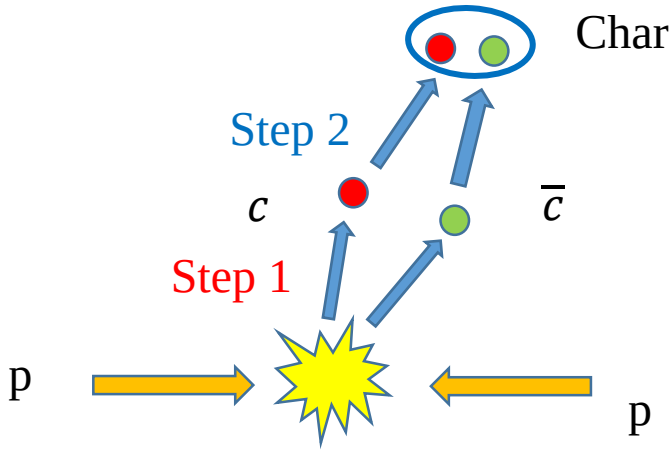
$$(2\pi)^3 2P_H^0 \frac{d\sigma_H}{d^3P_H} = \sum_n d\hat{\sigma}_n(P_H)\langle \mathcal{O}_n^H \rangle$$

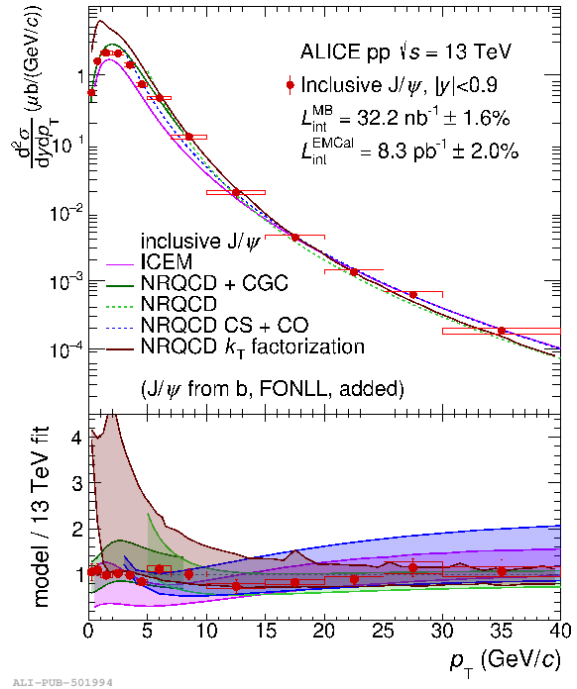
Production of a heavy quark pair
Expansion in: α_s

Hadronization (LDMEs)
Expansion in: v

ICEM:

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





Introduction

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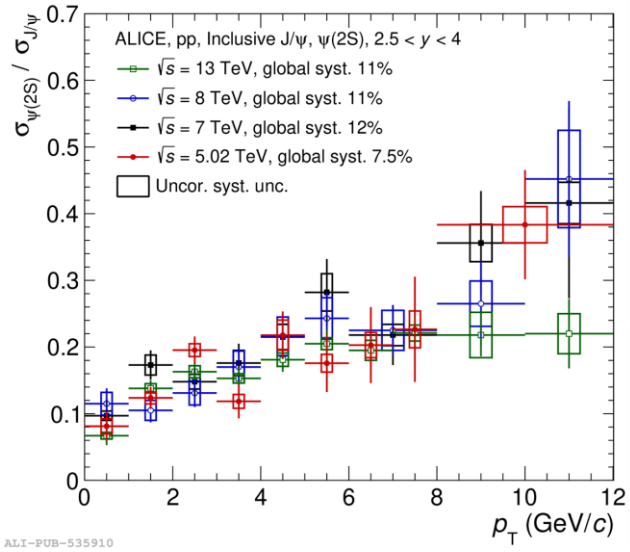
  - Heavy-quark production (perturbative QCD)
  - Formation of the charmonium states (non-perturbative QCD)
- **Study the rapidity and energy dependence of charmonium production by comparing to similar measurements.**
- **Used as reference for studying AA collisions.**
  - The ψ(2S)-to-J/ψ ratio has not been measured at midrapidity in ALICE



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

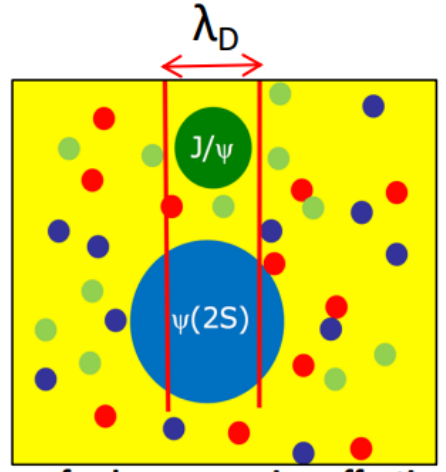


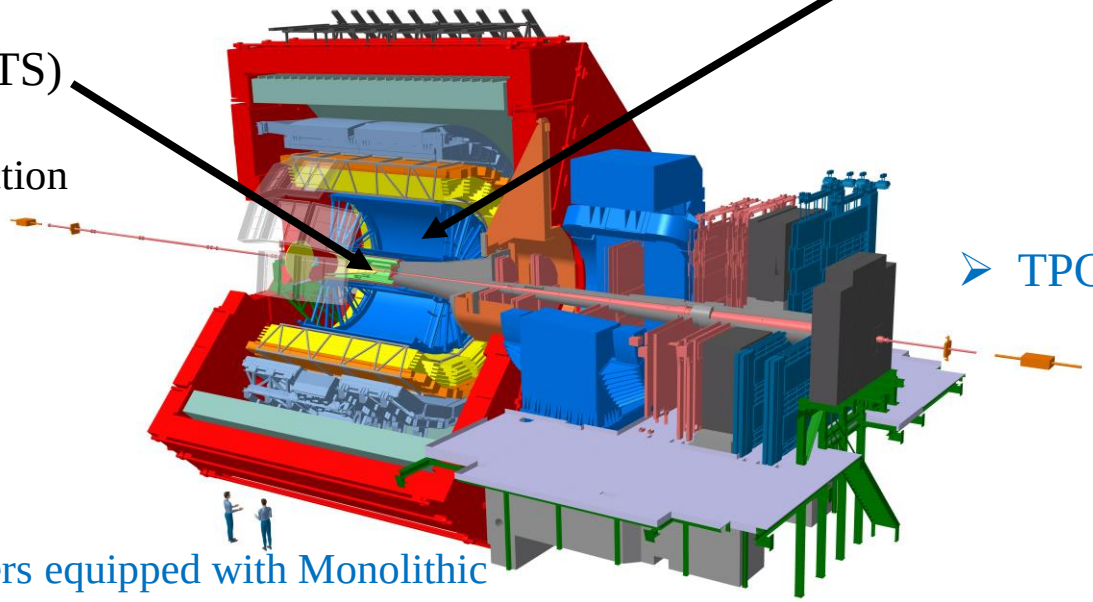
Illustration of colour screening affecting J/ψ and ψ(2S) differently

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



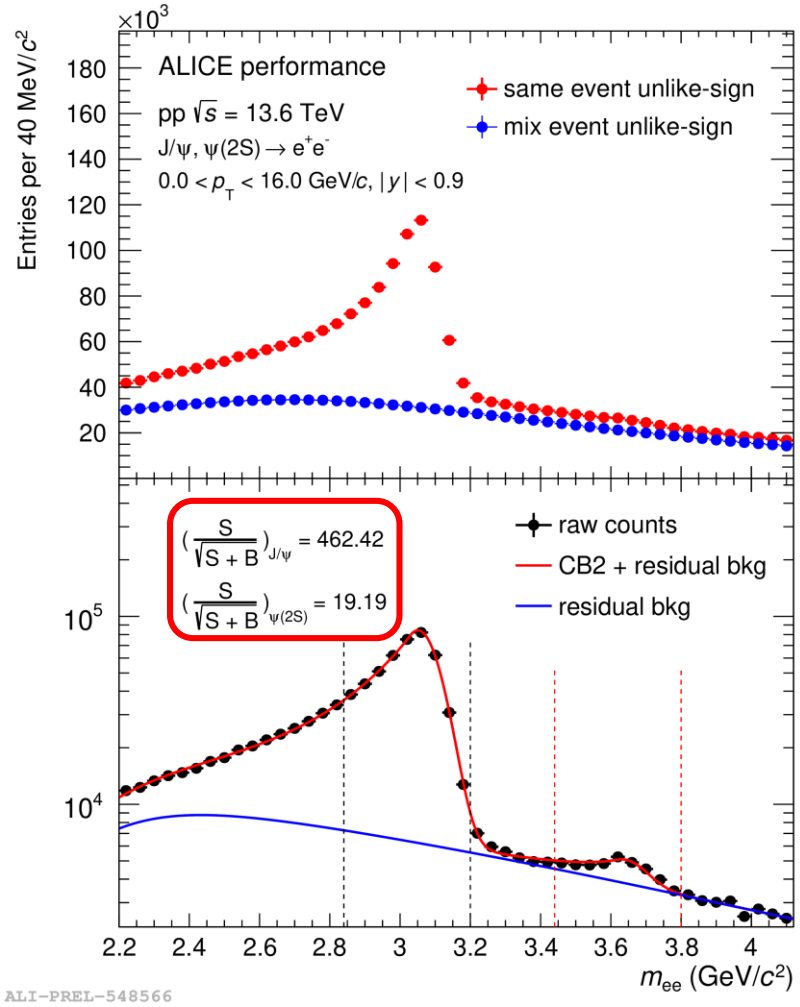
- ITS upgrade:
  - 6 layers ⟹ 7 layers equipped with Monolithic Active Pixel Sensors (MAPS).
  - Radius of innermost layer: 39 mm ⟹ 23mm.
  - Material budget for each of the 3 innermost layers: 1.15% ⟹ 0.35%.

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

Enable continuous readout of Pb–Pb events at an interaction rate up to 50 kHz (~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 $p_T = 0$.

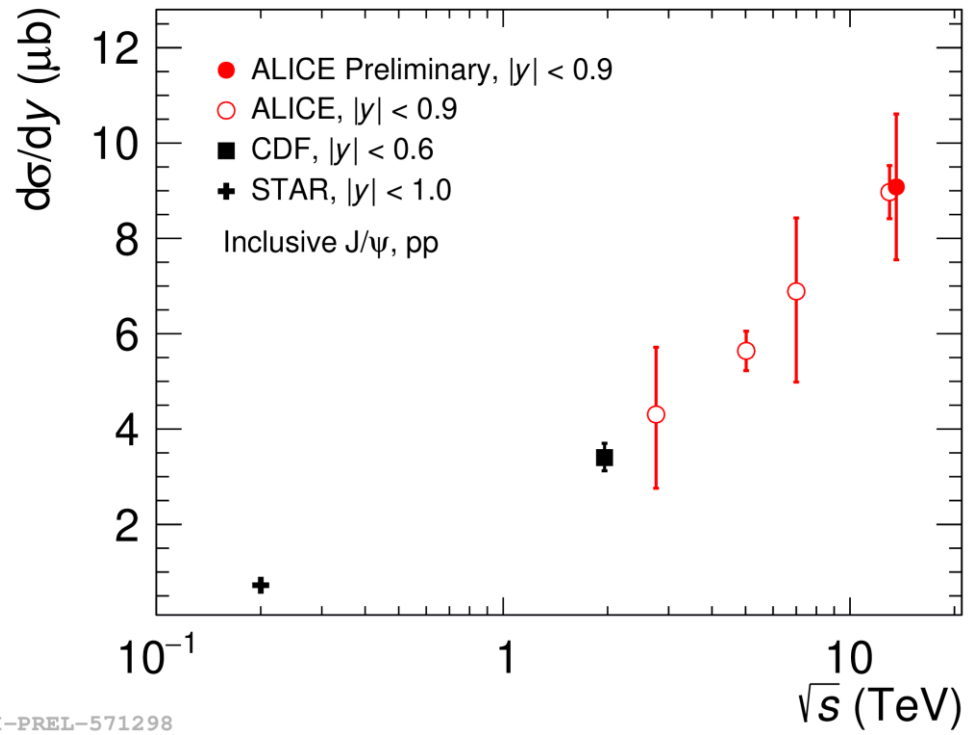


- Dataset:
  - pp collisions at $\sqrt{s}$ = 13.6 TeV collected in 2022 with the ALICE upgraded detector.
  - 524×10^9 minimum-bias (MB) events used in this analysis thanks to the continuous readout.
- Electron identification via TPC dE/dx.

- 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.

J/ψ cross section



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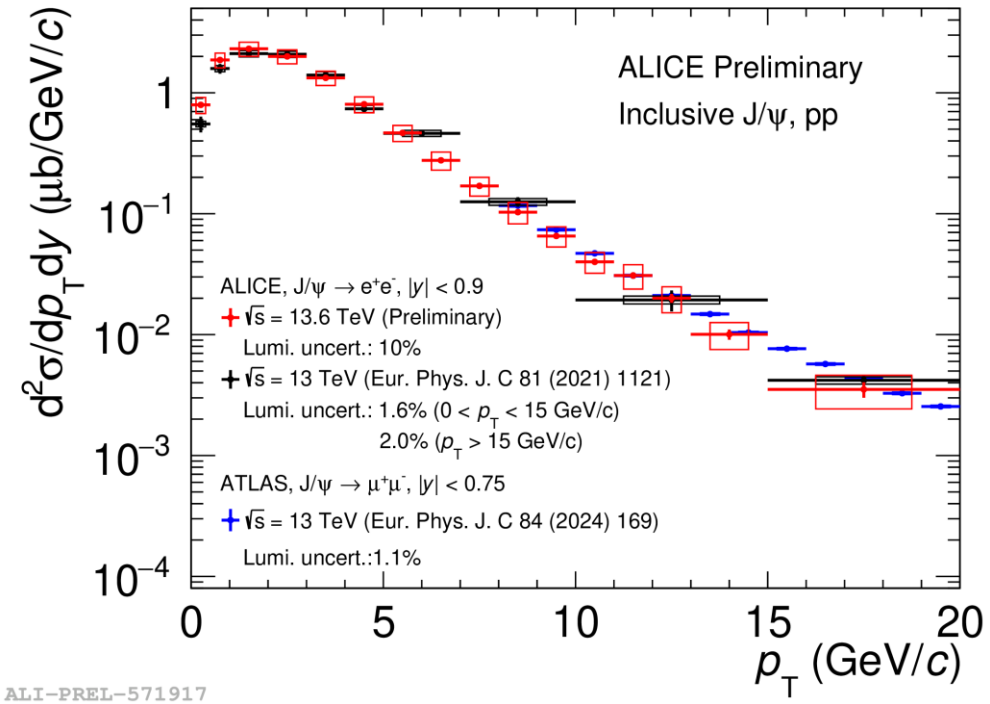
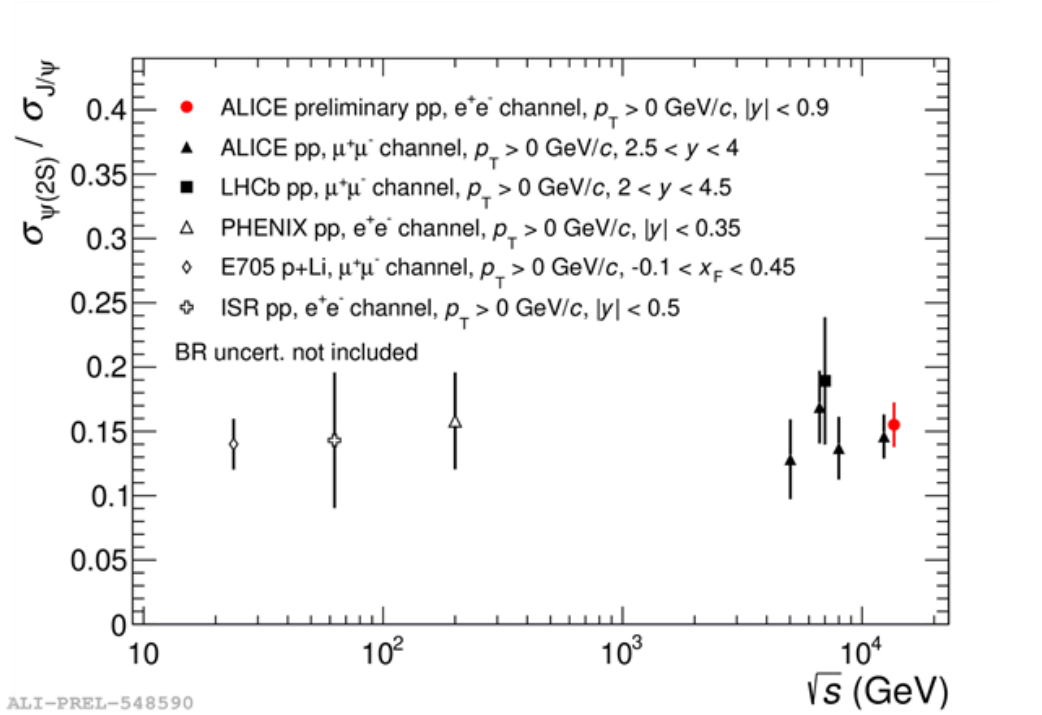


ALI-PREL-571917

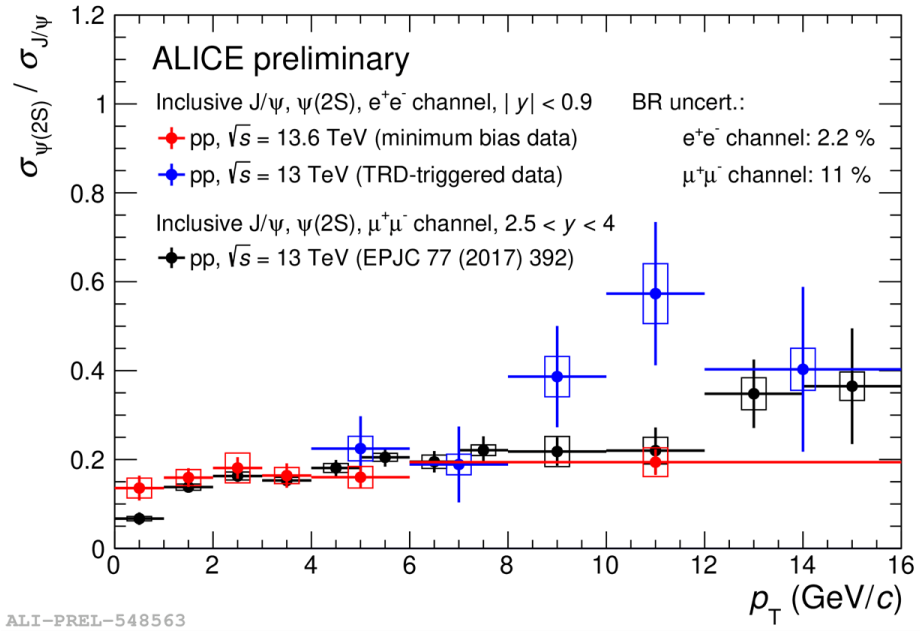
- The p_T integrated J/ψ cross section is 9.08 $\pm$ 0.046 (stat.) $\pm$ 1.23 (syst.) $\pm$ 0.91 (Lumi.)
- This results (red point) are shown together with existing results at different and similar collision energy from ALICE and other experiments.
  - The p_T integrated cross section increases with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

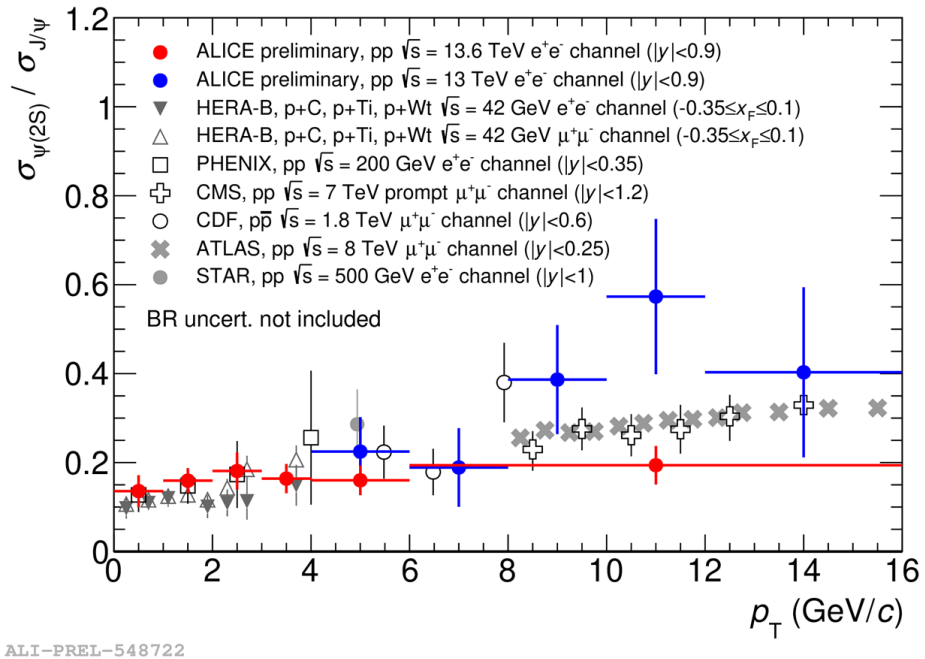
ψ(2S)-to-J/ψ ratio



- The measured p_T-integrated ratio without BR uncertainty is 0.155 $\pm$0.010(stat.) $\pm$0.014(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.

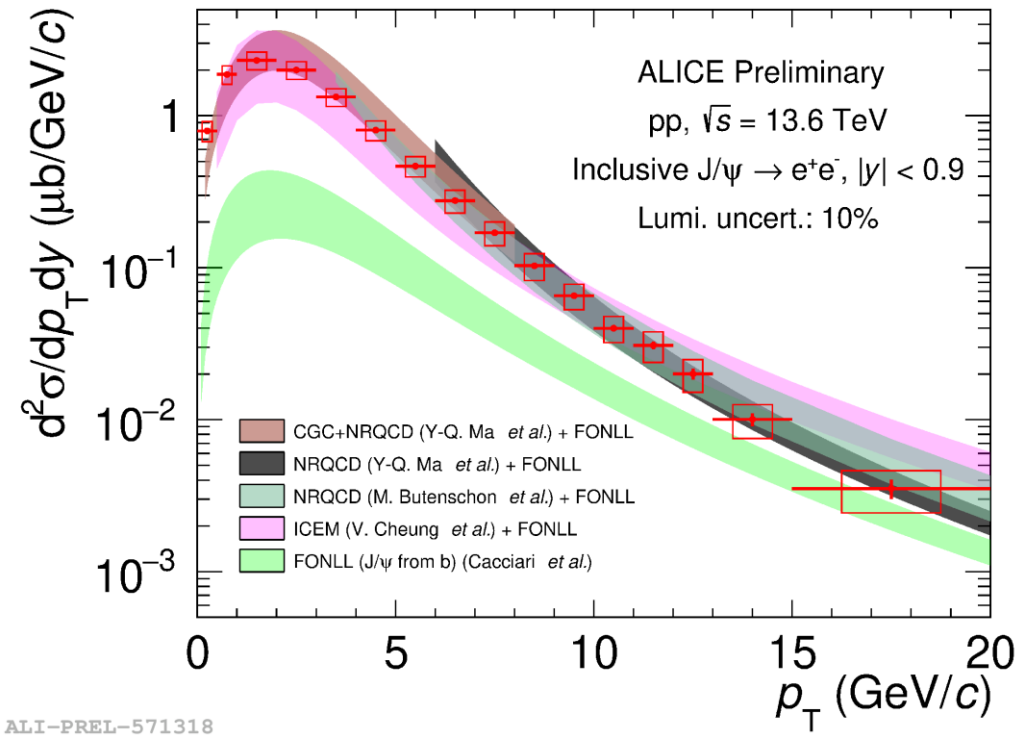
ψ(2S)-to-J/ψ ratio

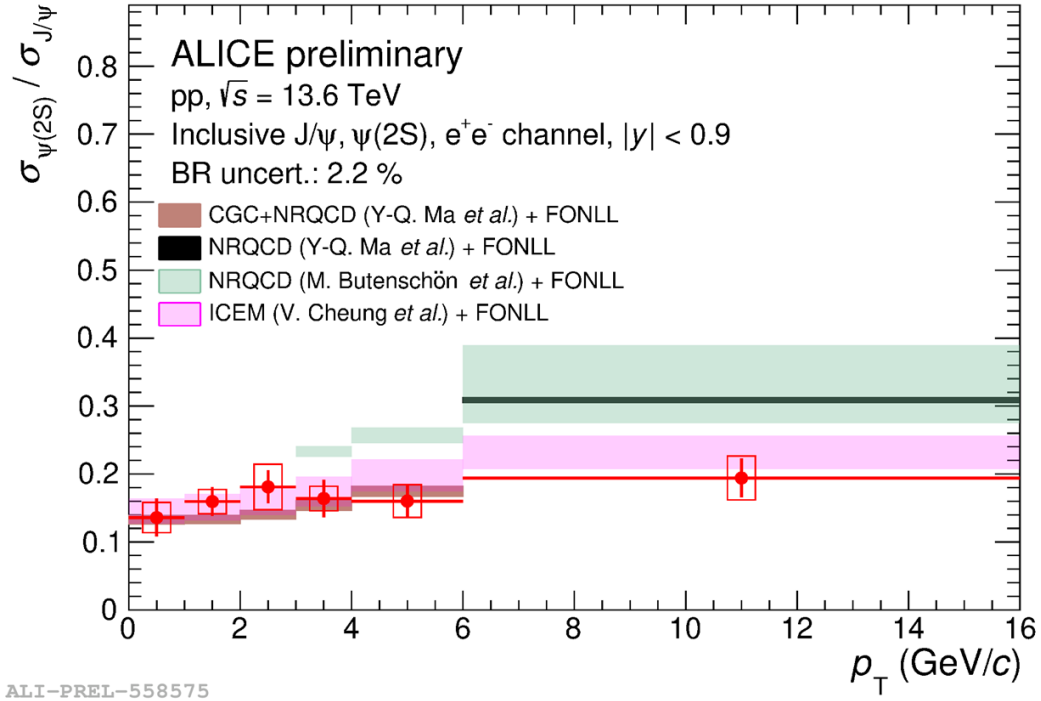




- The results (red points) are shown together with existing results from ALICE at forward rapidity and from other experiments.
  - In agreement with other results.
  - No significant rapidity dependence.
  - Slight p_T dependence (also expected from models).

Comparison with models





- 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.

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.
  - p_T differential distribution are similar with results at similar collision energy.
  - Comparison with models.
    - Both ICEM and NRQCD can describe the p_T distribution within uncertainties.
- **First measurement of the ψ(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.

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.

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