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)

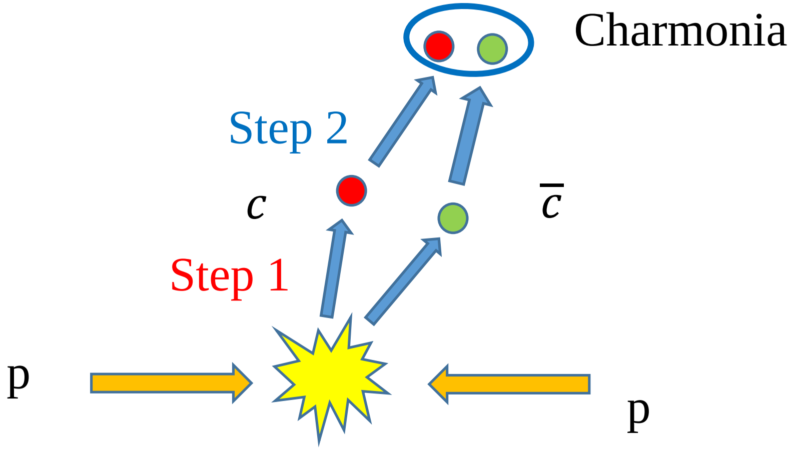
NRQCD:

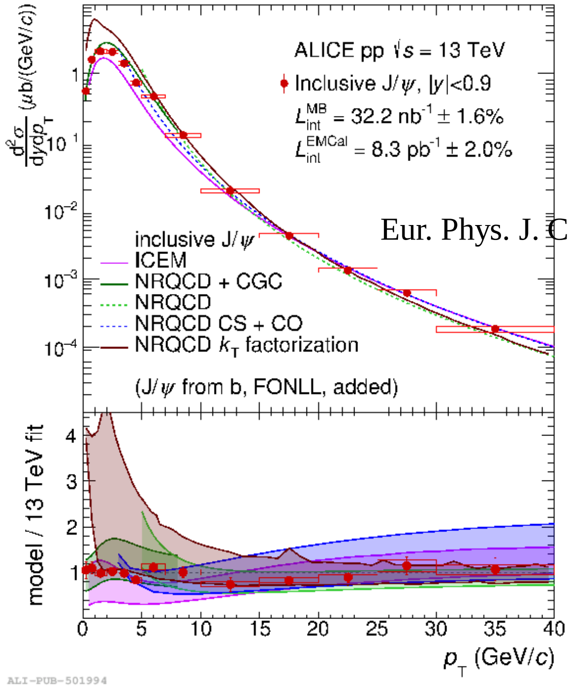
$$(2\pi)^3 2P_H^0 \frac{d\sigma_H}{d^3P_H} = \sum_n d\hat{\sigma}_n(P_H)\langle \mathcal{O}_n^H \rangle$$

Production of a heavy quark pair Expansion in: α_s	Hadronization (LDMEs) Expansion in: v

ICEM:

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





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Introduction

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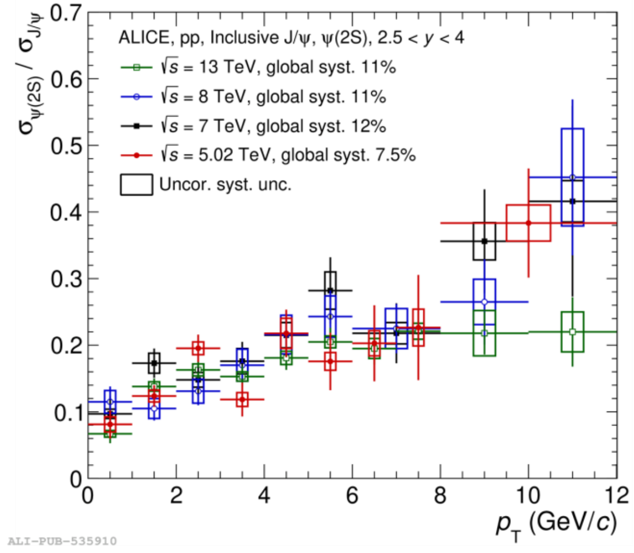
- **Crucial for studying charmonium production mechanisms and testing different QCD-based models.**
  - Heavy-quark production (perturbative QCD)
  - Formation of the charmonium states (non-perturbative QCD)
- **Study the rapidity and energy dependence of charmonium production by comparing to similar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



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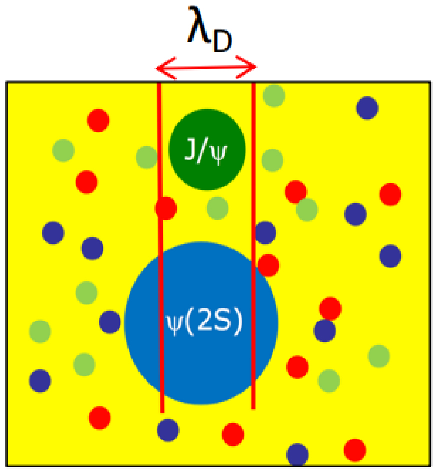
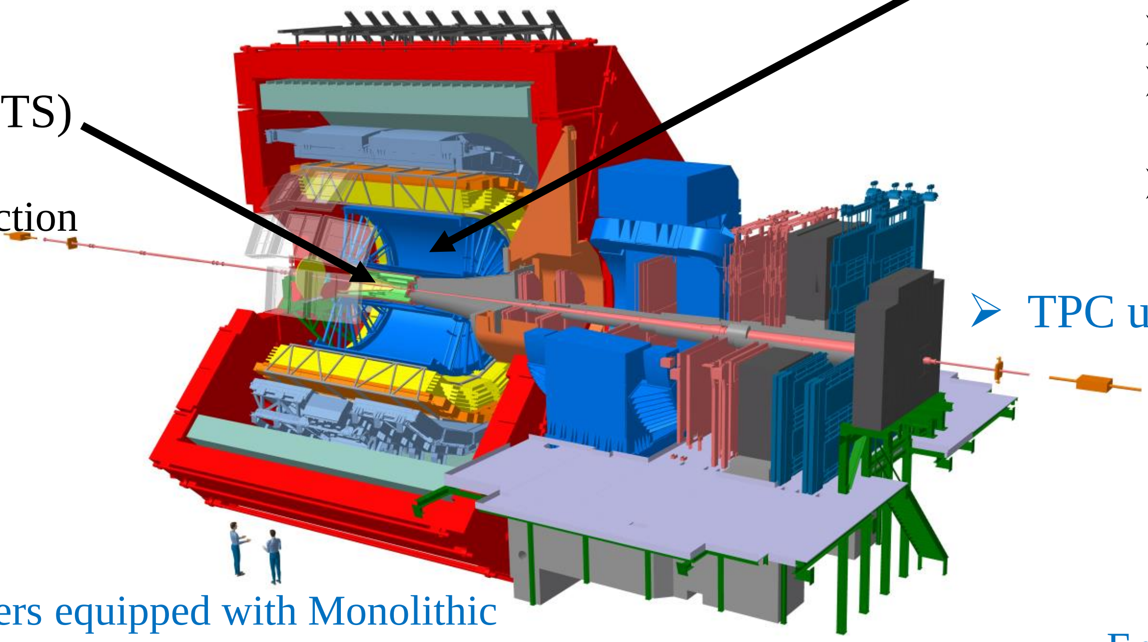


Illustration of colour screening affecting J/ψ and ψ(2S) differently

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 d*E*/d*x* measurement
  - Momentum measurement

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

- 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%.

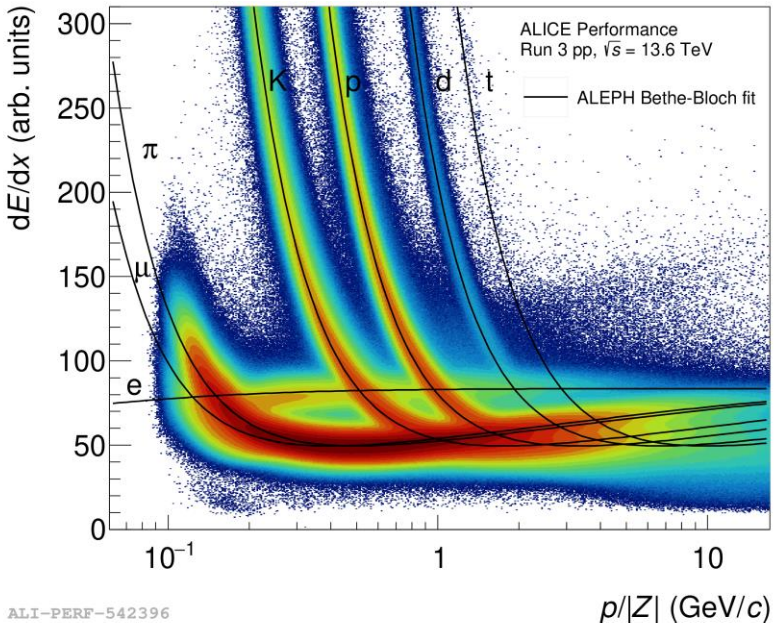
Enable continuous readout of Pb–Pb events at an interaction rate up to 50 kHz (~10^2 w.r.t. run 2).

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.

$$d^2\sigma/dp_T dy = \frac{N^{raw}_{J/\psi}}{(A \times \varepsilon) \cdot BR_{J/\psi \to e^+e^-} \cdot \Delta y \cdot \Delta p_T} \cdot \frac{1}{\mathscr{L}_{int}}$$

$$R = \frac{Y_{\psi(2S)}}{Y_{J/\psi}} = \frac{N_{\psi(2S)}}{N_{J/\psi}} \frac{A \times \varepsilon_{J/\psi}}{A \times \varepsilon_{\psi(2S)}} \frac{BR_{J/\psi \to e^+e^-}}{BR_{\psi(2S) \to e^+e^-}}$$



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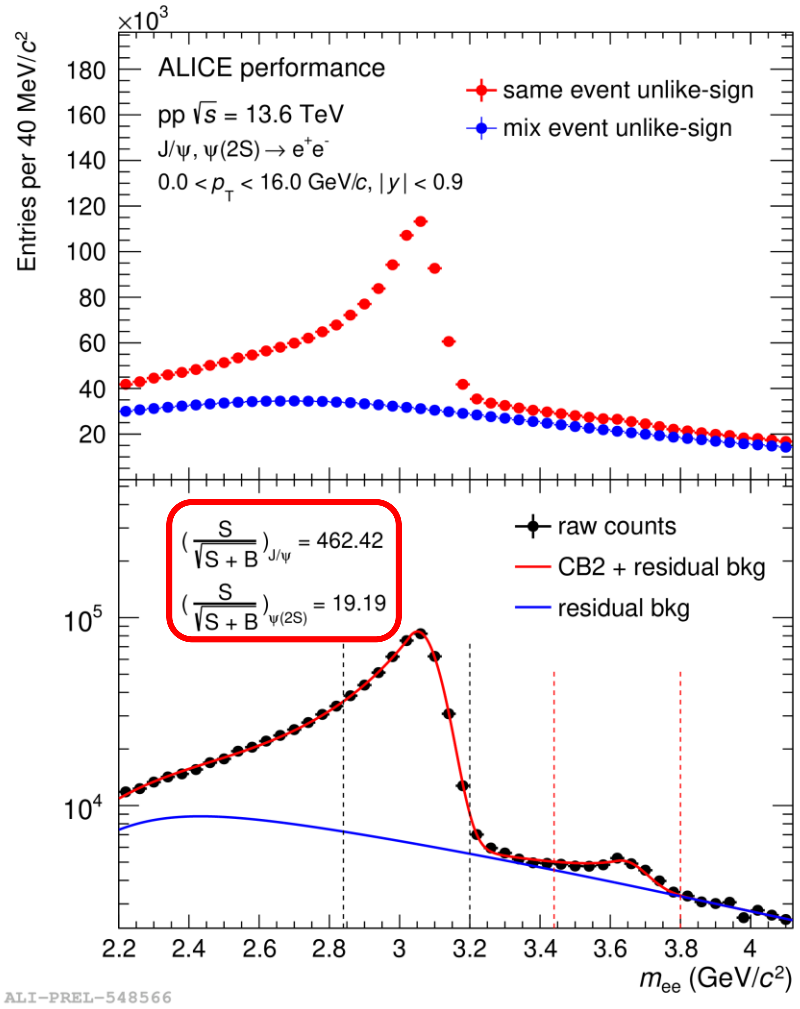
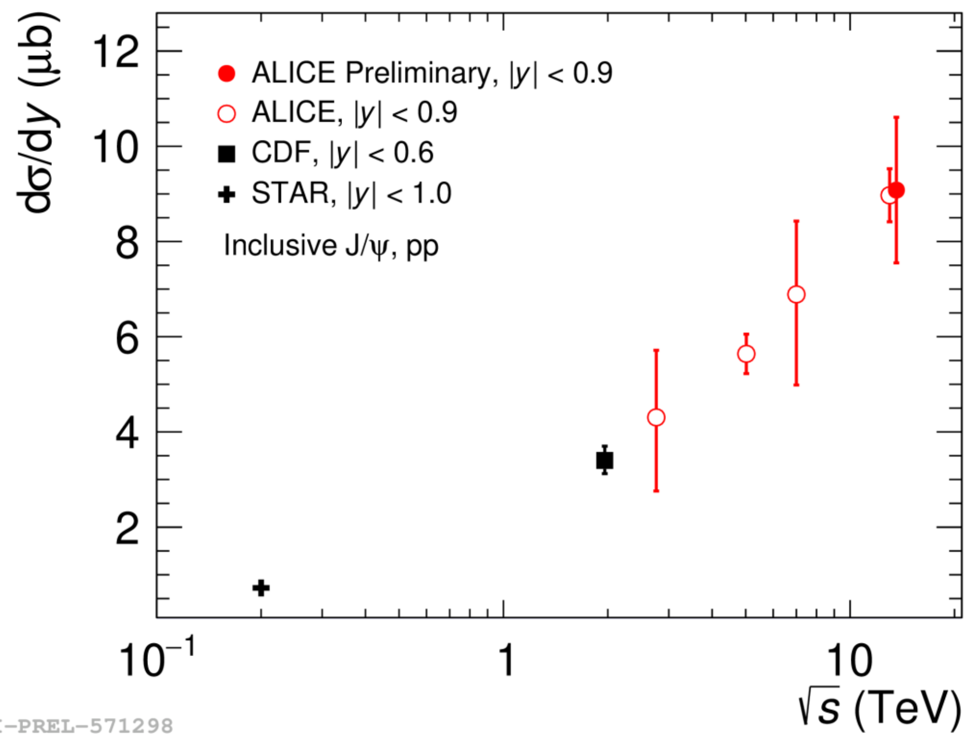
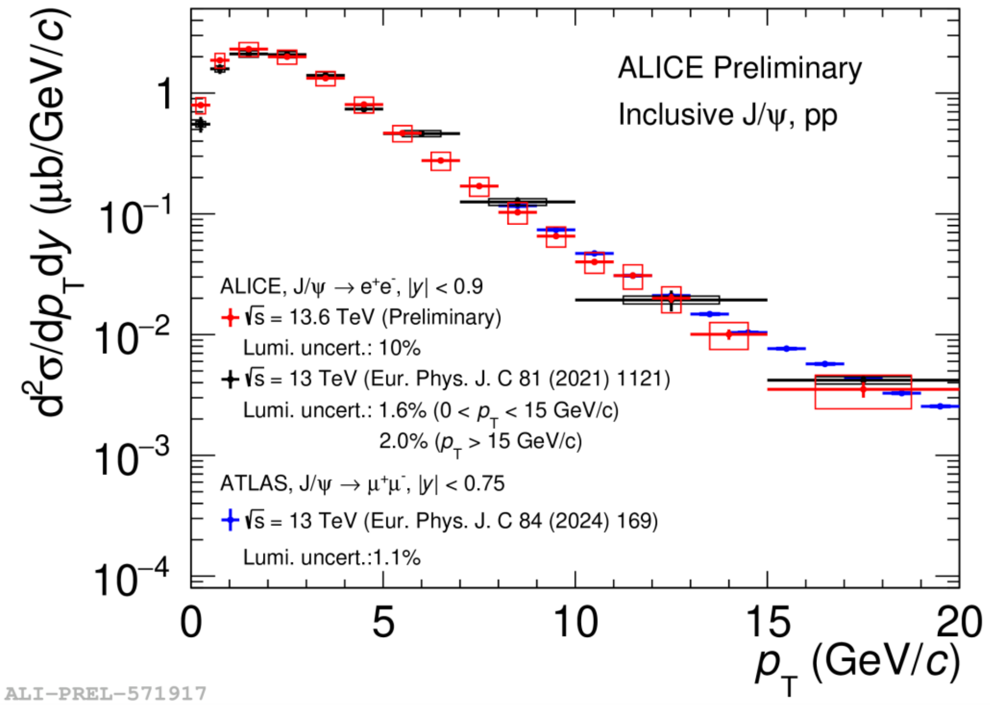


- Signal extraction:
  - Signal shapes are described by two Crystal Ball functions. Possible differences between the J/ψ and ψ(2S) shapes are assigned as systematic uncertainties.

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

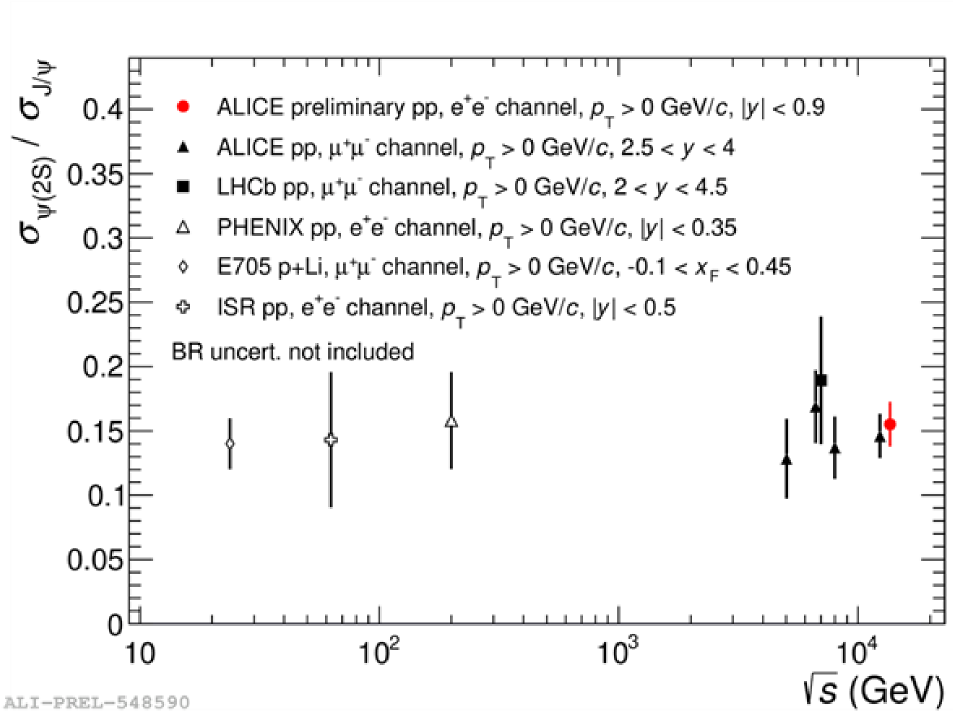
J/ψ cross section





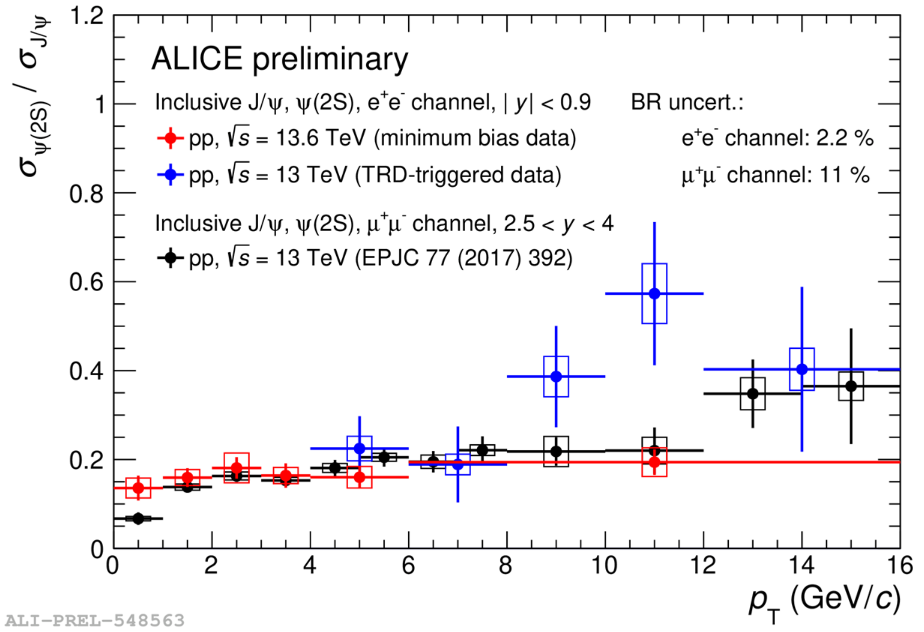
- The p_T integrated J/ψ cross section is 9.08 ± 0.046 (stat.) ± 1.23 (syst.) ± 0.91 (Lumi.) μb
- This results (red point) are shown together with existing results at different and similar collision energy from ALICE and other experiments.
  - The p_T integrated cross section increases with collision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

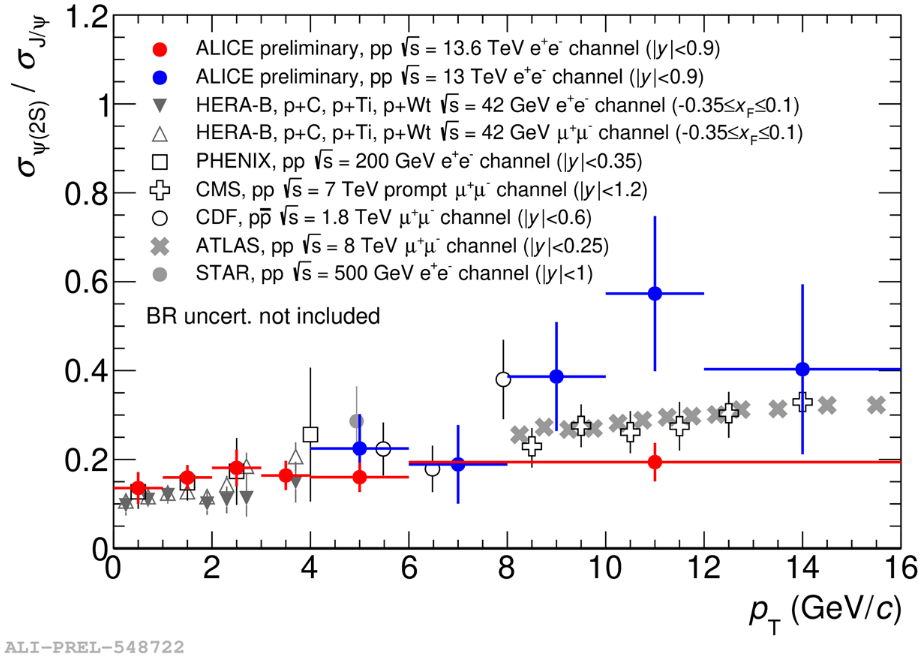
ψ(2S)-to-J/ψ ratio



- The measured p_T-integrated ratio without BR uncertainty is 0.155 ±0.010(stat.) ±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.

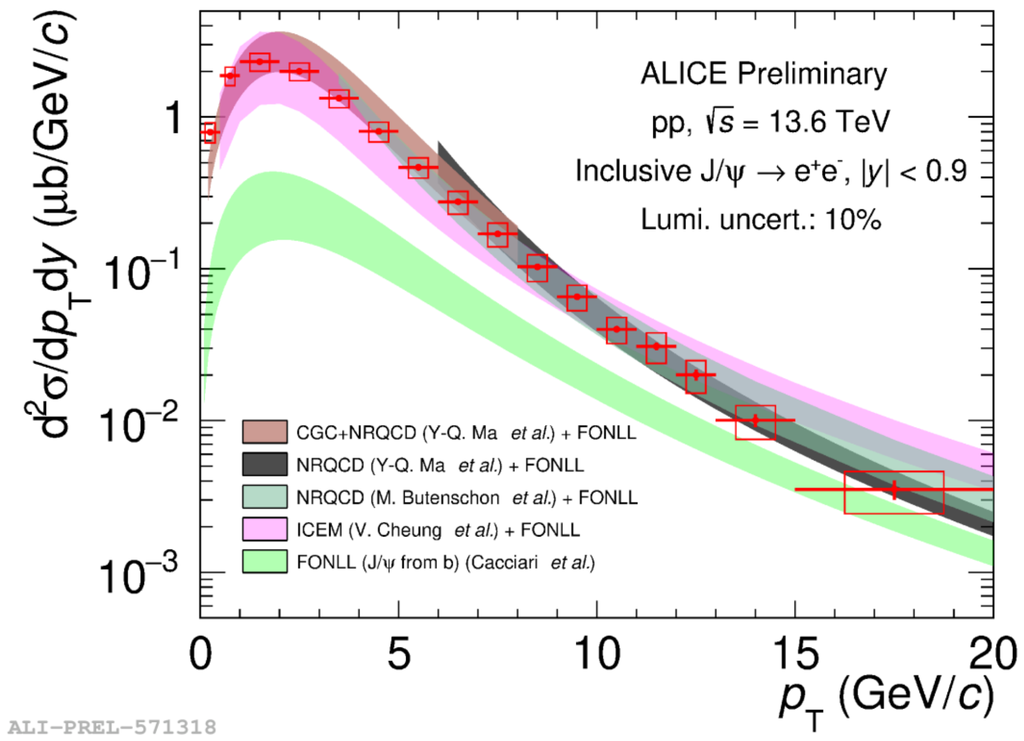
ψ(2S)-to-J/ψ ratio

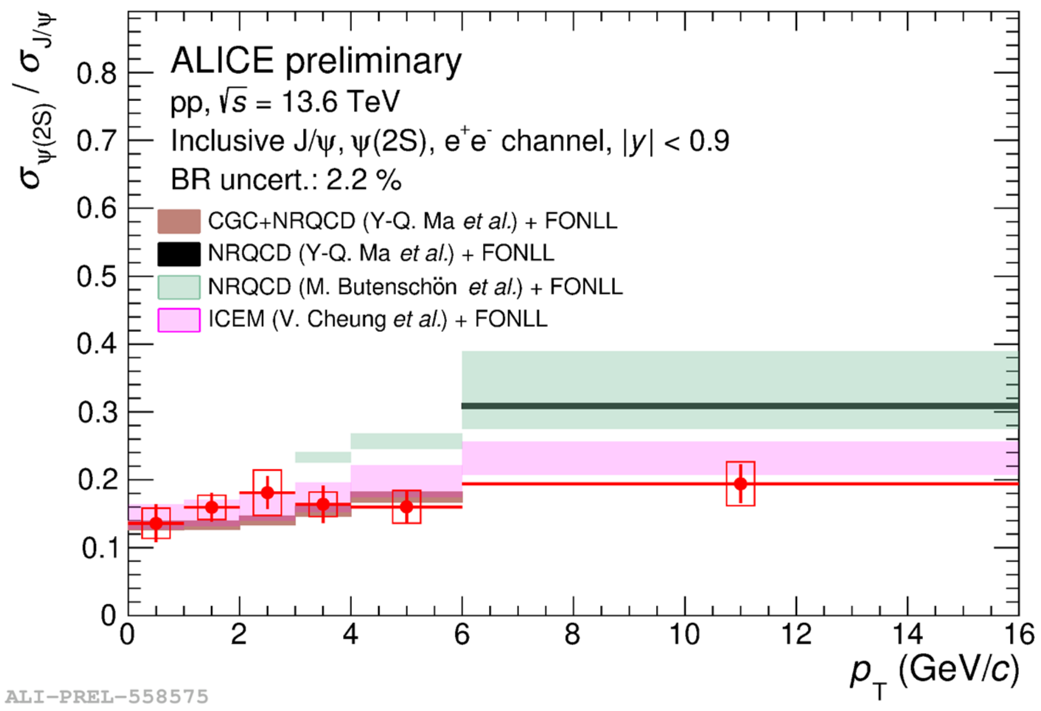




- The results (red points) are shown together with existing results from ALICE at forward rapidity and from other experiments.
  - In agreement with other results.
  - No significant rapidity dependence.
  - Slight p_T dependence (also expected from models).

Comparison with models

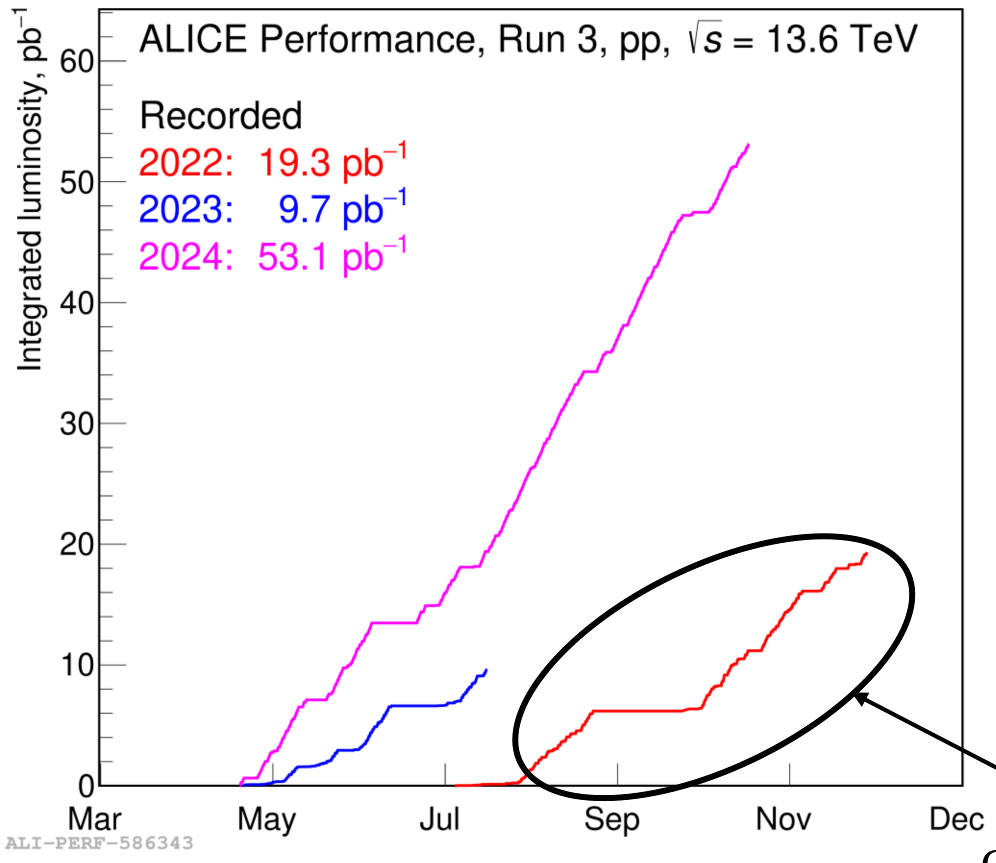




- Comparison with models (FONLL[5] is used to describe the non-prompt contribution):
  - Both of the NRQCD[1][2] and ICEM[3] can describe the cross section of J/ψ.
  - NRQCD overestimates the ratio.
  - CGC + NRQCD[4] describes the ratio at low p_T up to 6 GeV/c.
  - ICEM can reproduce the data.

[1] Y-Q. Ma et al., Phys.Rev.Lett. 106 (2011) 042002.
[2] M. Butenschoen et al., Phys.Rev.Lett. 106 (2011) 022003.
[3] Y-Q. Ma et al., Phys.Rev.D 94 (2016) 11, 114029.
[4] Y-Q. Ma et al., *JHEP* 12 (2018) 057
[5] M. Cacciari et al., JHEP 10 (2012) 137

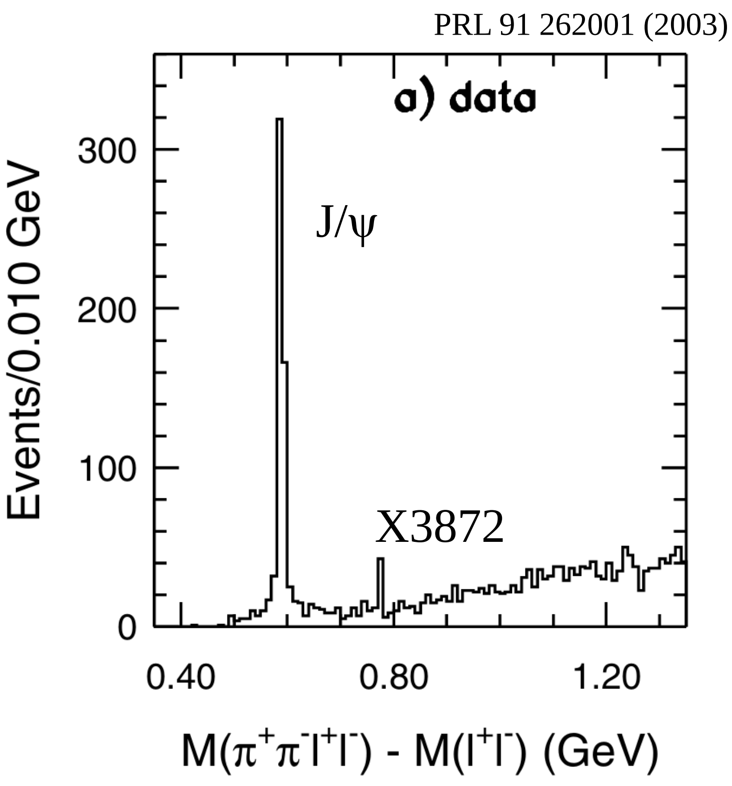
Outlook

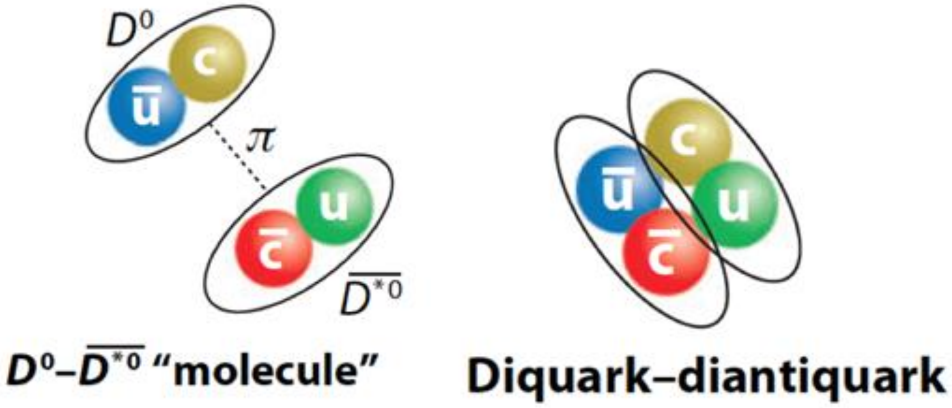


Only this part used for now.

- Only data collected in 2022 is used in this analysis.
- More datasets collected in this 3 years will be used.
  - Narrow p_T bins.
  - Smaller statistical and systematic uncertainty.

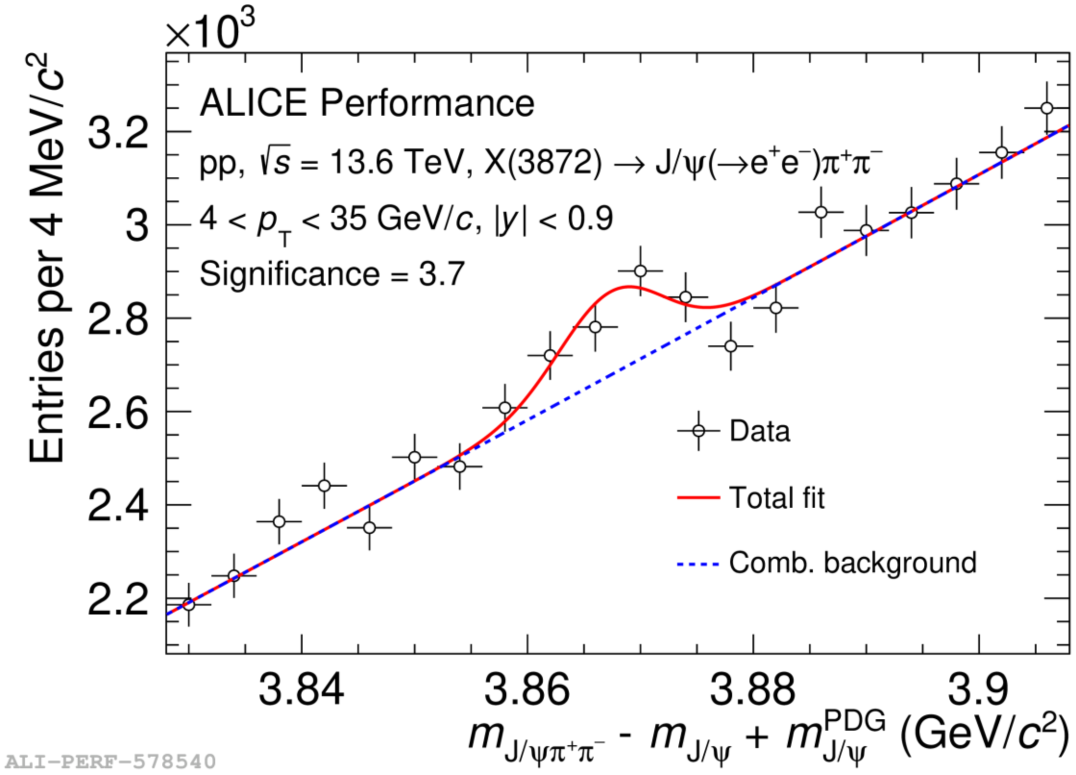
X(3872)





- X3872, now known as $\chi_{c1}(3872)$.
  - In 2003 first exotic hadron was identified in particle discovered in J/ψπ+π- by Belle.
  - Several possible explanations have been proposed to explain the properties of X(3872), including whether it may be a tetraquark or a hadronic molecule.

First look of X(3872)



Decay mode	Branching fraction
$X(3872) \to \pi^+\pi^- J/\psi$	$(4.1^{+1.9}_{-1.1})\%$

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

Conclusion

- The J/ψ cross section and ψ(2S)-to-J/ψ ratio is measured in pp collision at $\sqrt{s}$ = 13.6 TeV at midrapidity.
  - The cross section increases with p_{T}. Slight p_{T} dependence (also expected from models) for ratio.
  - The cross section increases with collision energy, but the ratio shows no significant energy and rapidity dependence.
  - Comparison with models[11-14].
    - Both of the NRQCD and ICEM can describe the cross section of J/ψ within uncertainties.
    - CGC + NRQCD describes the ratio at low and intermediate p_{T}.
    - ICEM can reproduce the ratio in measured p_{T} range.
- 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

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- 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.