



Measurement of inclusive J/ψ and $\psi(2S)$ production at midrapidity in pp collisions at 13.6 TeV with ALICE

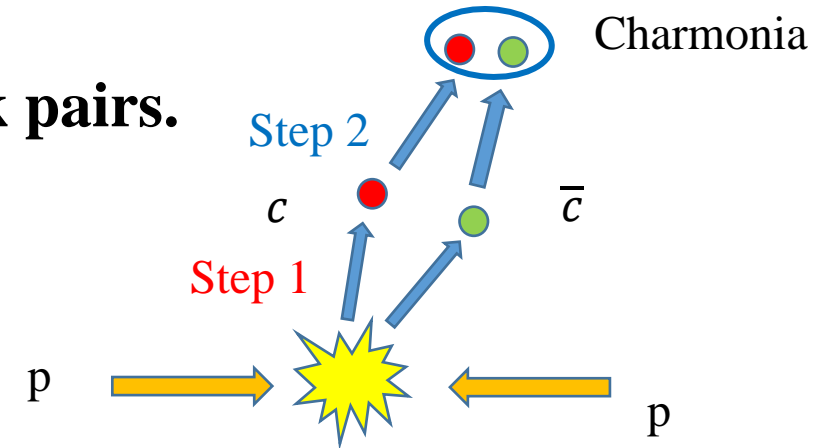
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The 9th China LHC Physics Workshop (CLHCP2023), Shanghai

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:

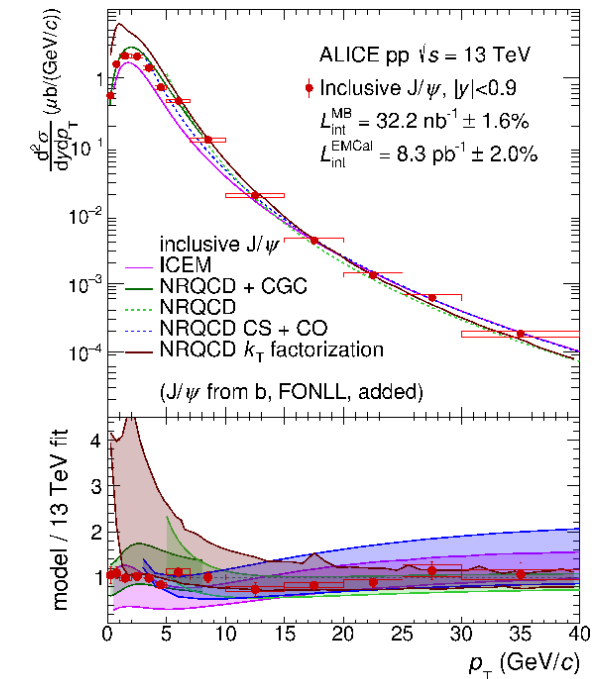
$$(2\pi)^3 2P_H^0 \frac{d\sigma_H}{d^3P_H} = \sum_n d\hat{\sigma}_n(P_H) \langle \mathcal{O}_n^H \rangle$$

Production of a heavy quark pair
Expansion in: α_s

Hadronization (LDMEs)
Expansion in: v

ICEM:

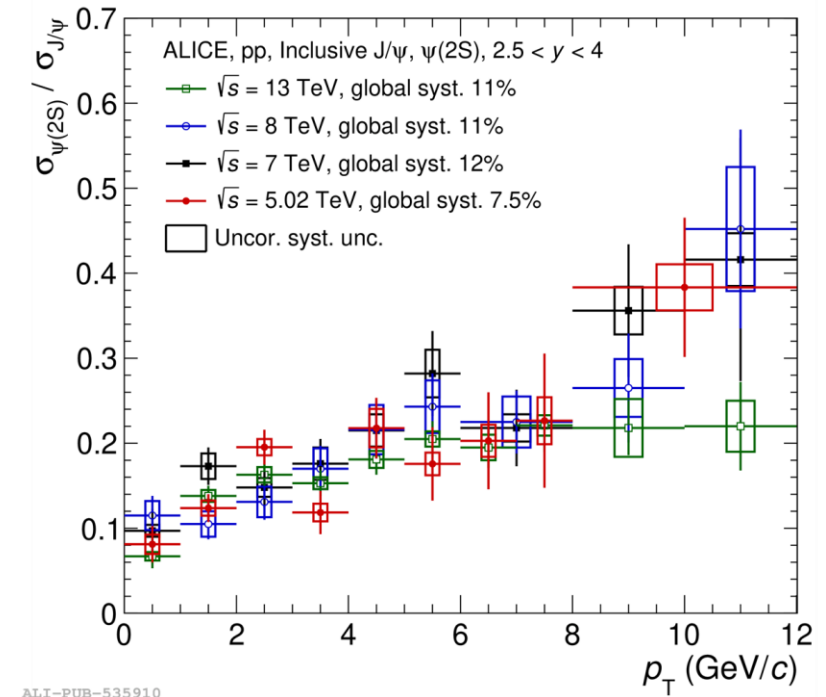
$$\frac{d\sigma_\psi(P)}{d^3P} = F_\psi \int_{M_\psi}^{2M_D} d^3P' dM \frac{d\sigma_{c\bar{c}}(M, P')}{dM d^3P'} \delta^3\left(P - \frac{M_\psi}{M} P'\right)$$



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Introduction

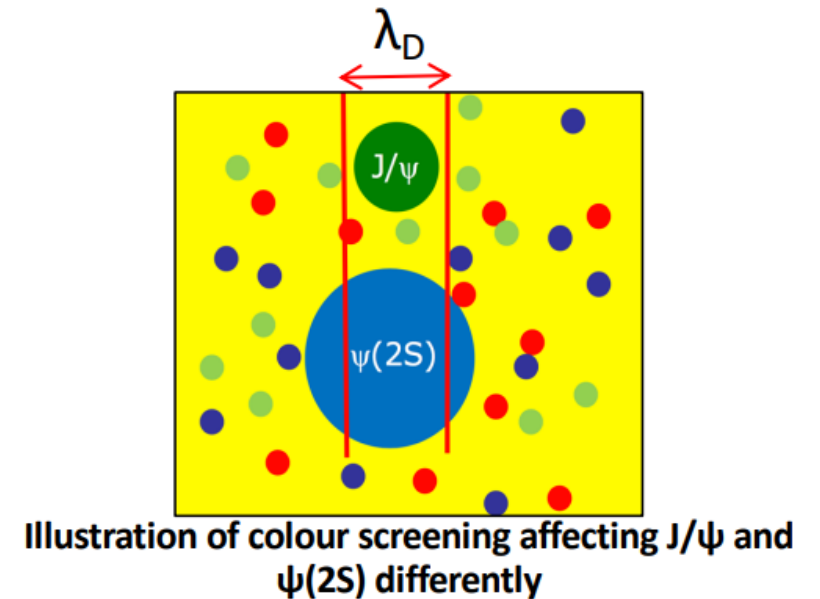
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 - Heavy-quark production (perturbative QCD)
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- **Study the rapidity and energy dependence of charmonium production by comparing to similar measurements.**



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

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

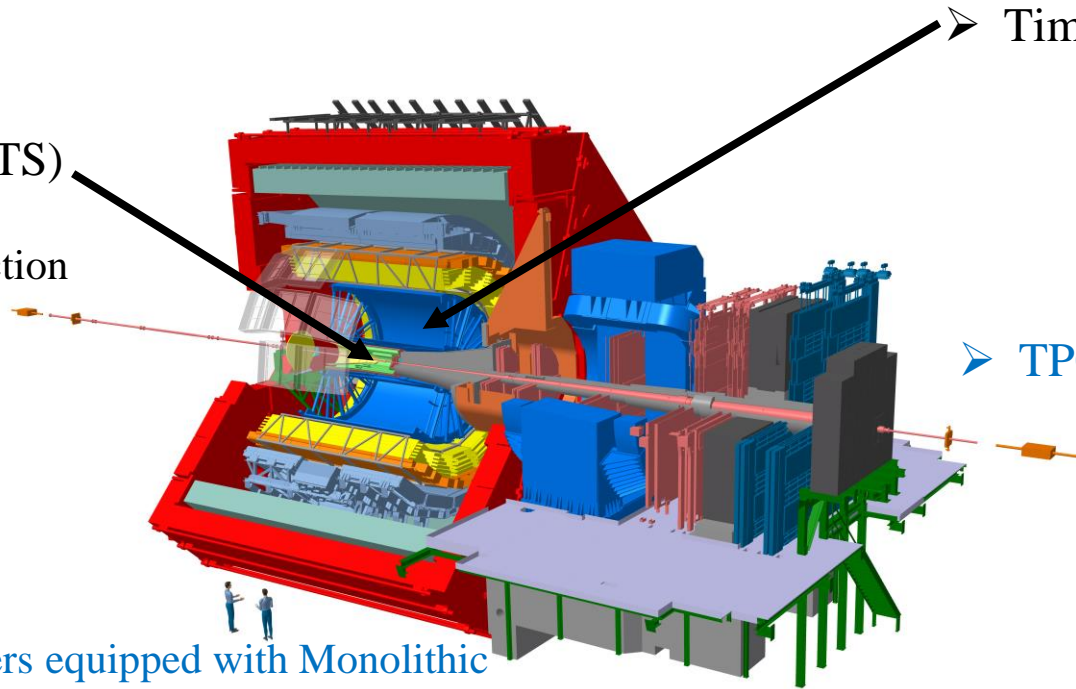


ALICE detector Run 3 upgrade

- 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 22mm.
- Material budget for each of the 3 innermost layers: 1.15% \Rightarrow 0.35%.

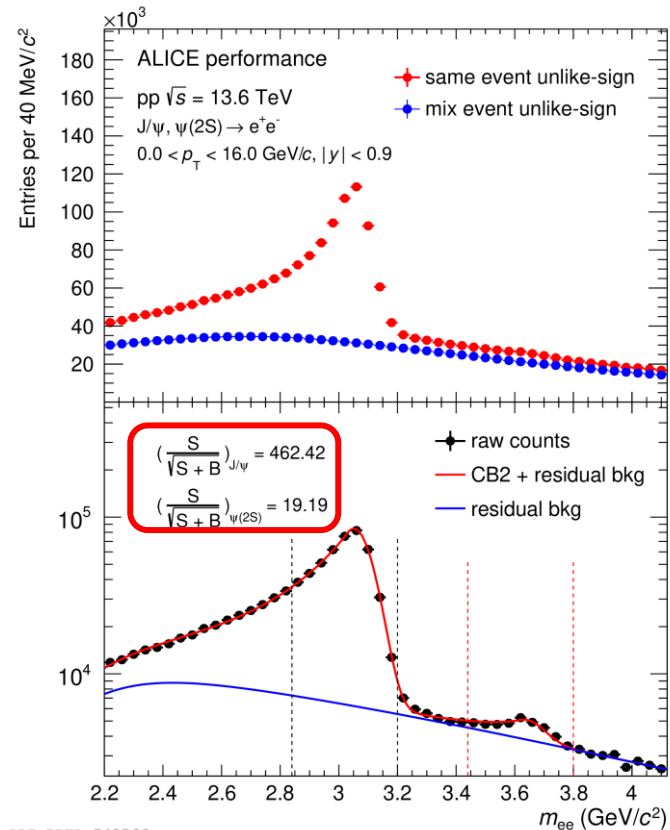


Enable continuous readout of Pb–Pb events at an interaction rate up to 50 kHz ($\sim 10^2$ w.r.t. run 2).

Data analysis procedure

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

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



- 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.

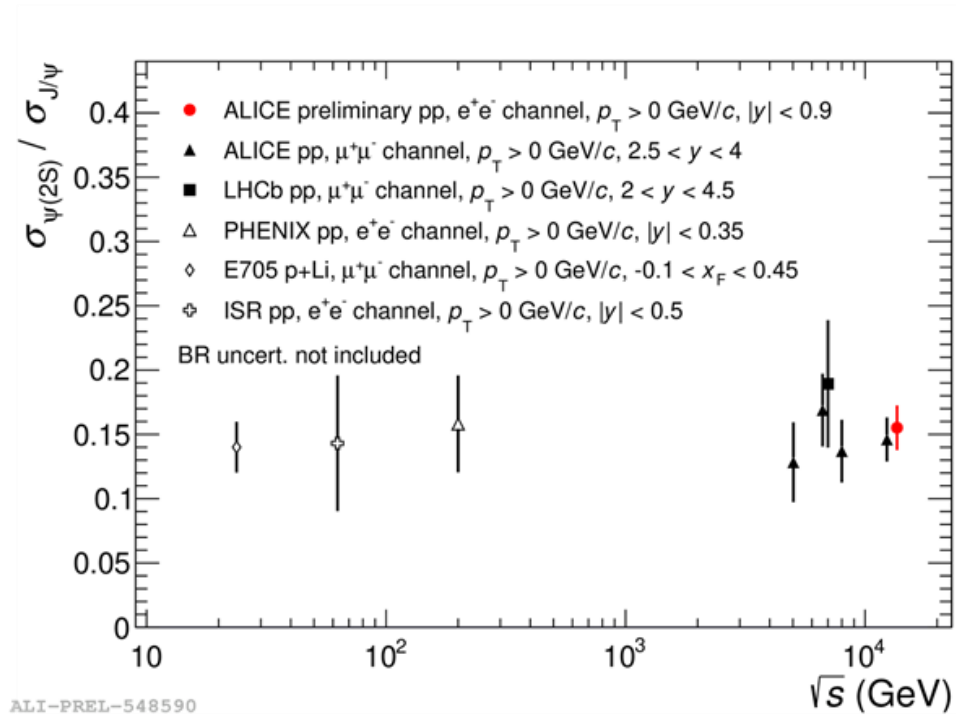
- Electron identification via TPC dE/dx .

- Signal extraction:

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

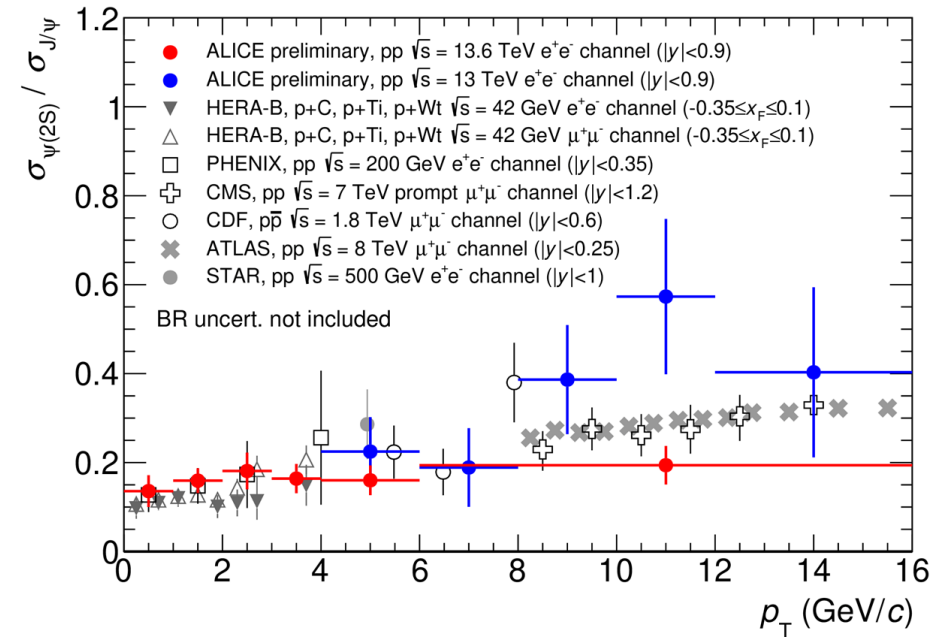
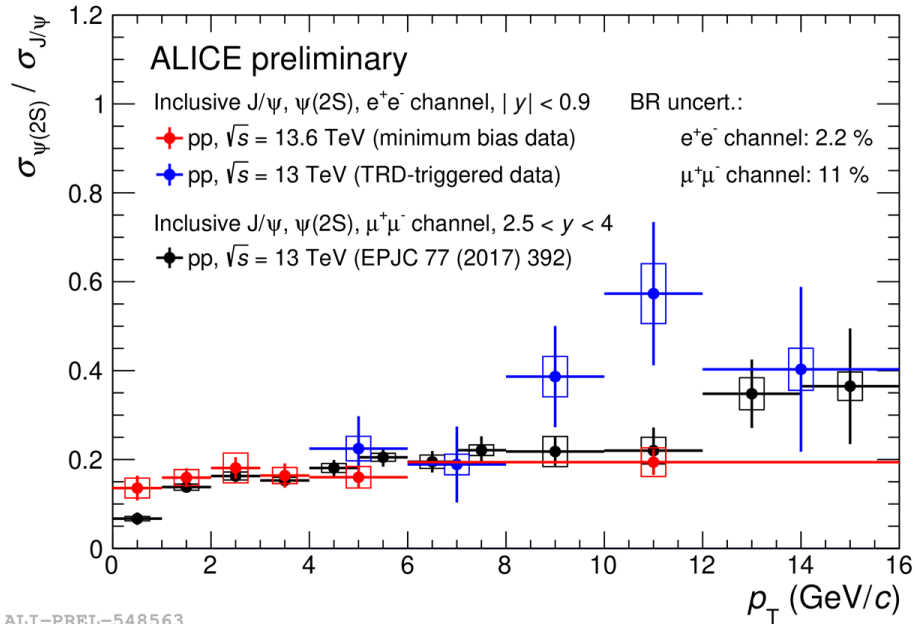
- The significance of J/ψ is about 462 and the significance of $\psi(2S)$ reach to nearly 20.

Results



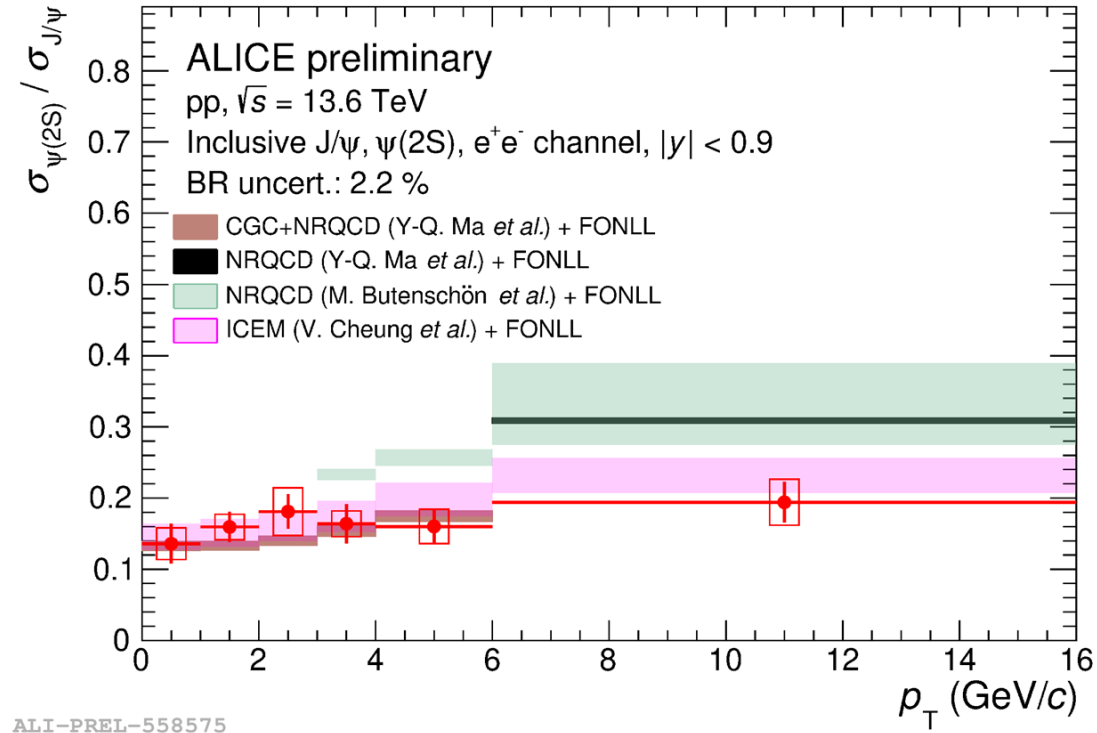
- The measured p_T -integrated ratio without BR uncertainty is $0.155 \pm 0.010(\text{stat.}) \pm 0.014(\text{syst.})$
- The result (**red point**) is shown together with existing results from ALICE at forward rapidity and from other experiments.
 - The uncertainty is reduced because of the improvement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

Results



- 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 energy and rapidity dependence.
 - Slight p_T dependence (also expected from models).

Comparison with models



➤ Comparison with models:

- NRQCD overestimates the ratio.
- CGC + NRQCD describes the ratio at low p_T up to 6 GeV/c.
- ICEM can reproduce the data.

➤ Color Glass Condensate:

- Resum small-x $\log \ln(x)$, higher twist contributions

Conclusion

- **First measurement of the $\psi(2S)$ -to- J/ψ ratio in pp collisions at $\sqrt{s} = 13.6$ TeV at midrapidity.**
 - Precision is improved thanks to the high statistic of Run 3 data.
 - 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.
- Outlook:
 - The prompt and non-prompt $\psi(2S)$ -to- J/ψ ratio as well as the cross section of prompt/non-prompt charmonia will be measured in Run 3.

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.