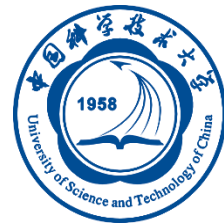




ALICE



Prompt / non-prompt charmonia measurement at midrapidity and forward rapidity in pp collision at 13.6 TeV

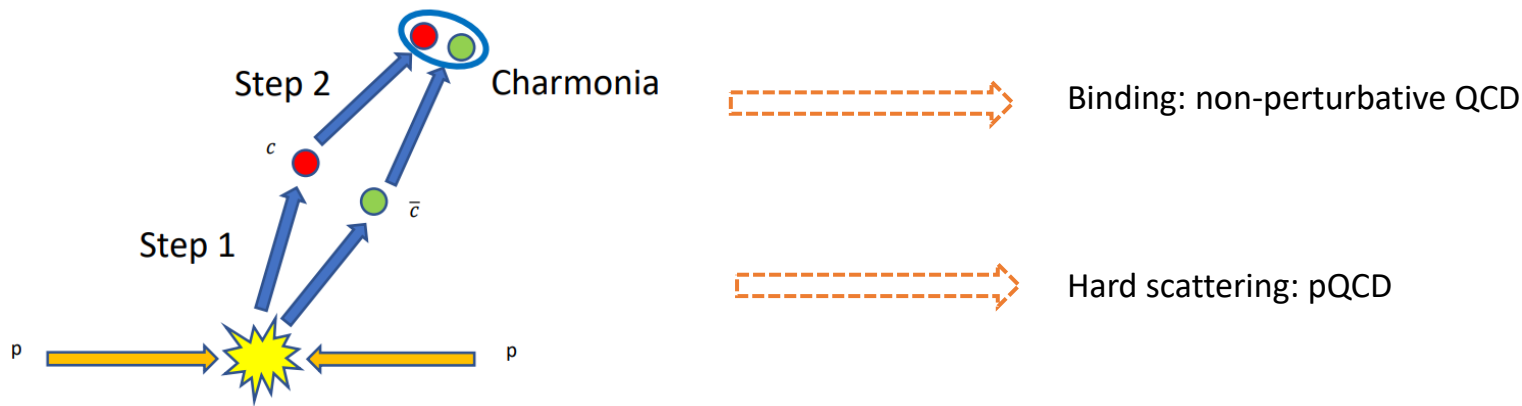
Yiping Wang

University of Science and Technology of China

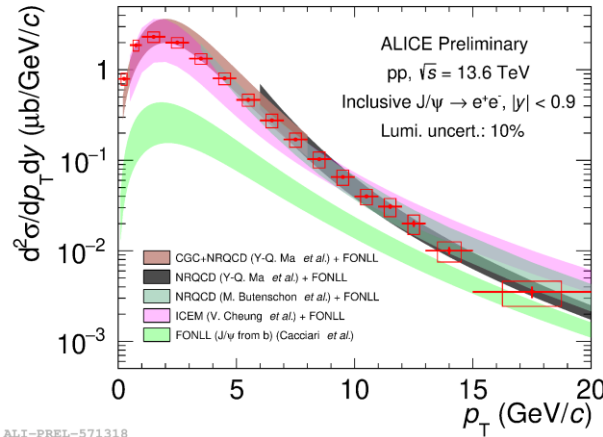
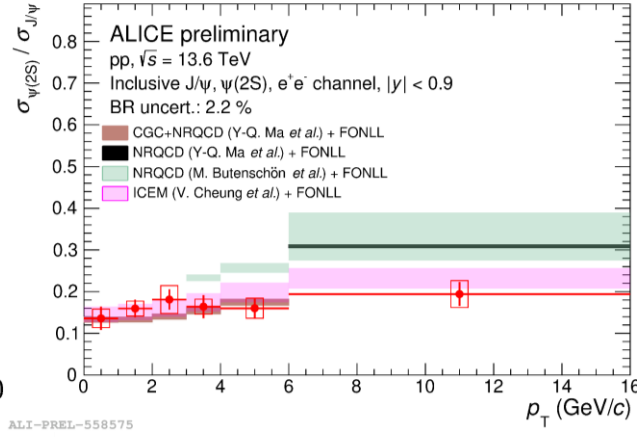
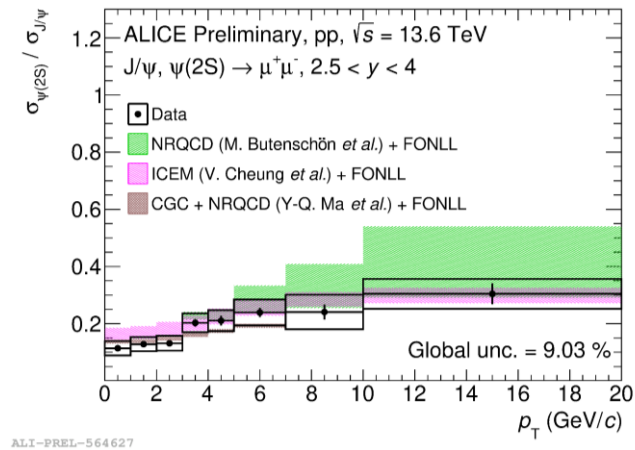
The 12th China LHC Physics Conference

Study quarkonium in pp

- Quarkonium: heavy quark pairs ($b\bar{b}/c\bar{c}$).
- Quarkonium production: perturbative QCD + non-perturbative QCD.
- Quarkonium productions in pp act as a baseline for heavy-ion collisions.

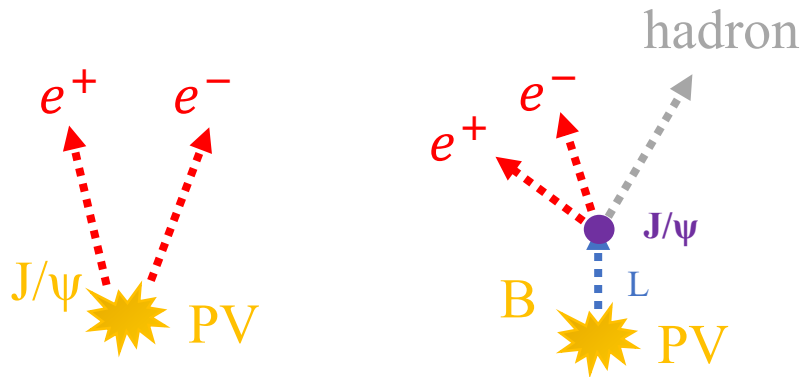
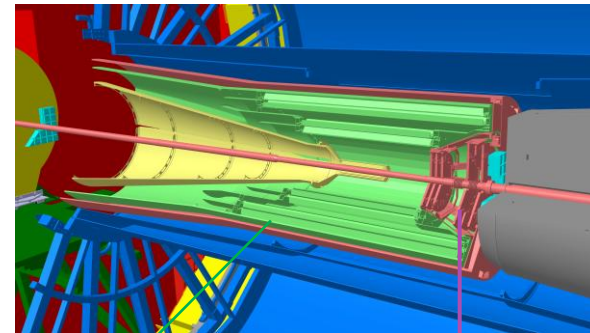


Inclusive charmonia in pp collisions at $\sqrt{s} = 13.6$ TeV



- Inclusive J/ψ and $\psi(2S)$ have been measured at both midrapidity and forward rapidity.
- Contains information from both charm and beauty.
- FONLL is used to calculate beauty contribution.

Prompt and non-prompt J/ψ production



7 layers ITS

Muon Forward Tracker

Separate prompt and non-prompt J/ψ:

$$\text{Pseudoproper decay time } (x) = c \cdot \vec{L} \cdot \frac{M_{J/\psi}}{\vec{p}}$$

Quarkonium measurements with ALICE detector

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

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

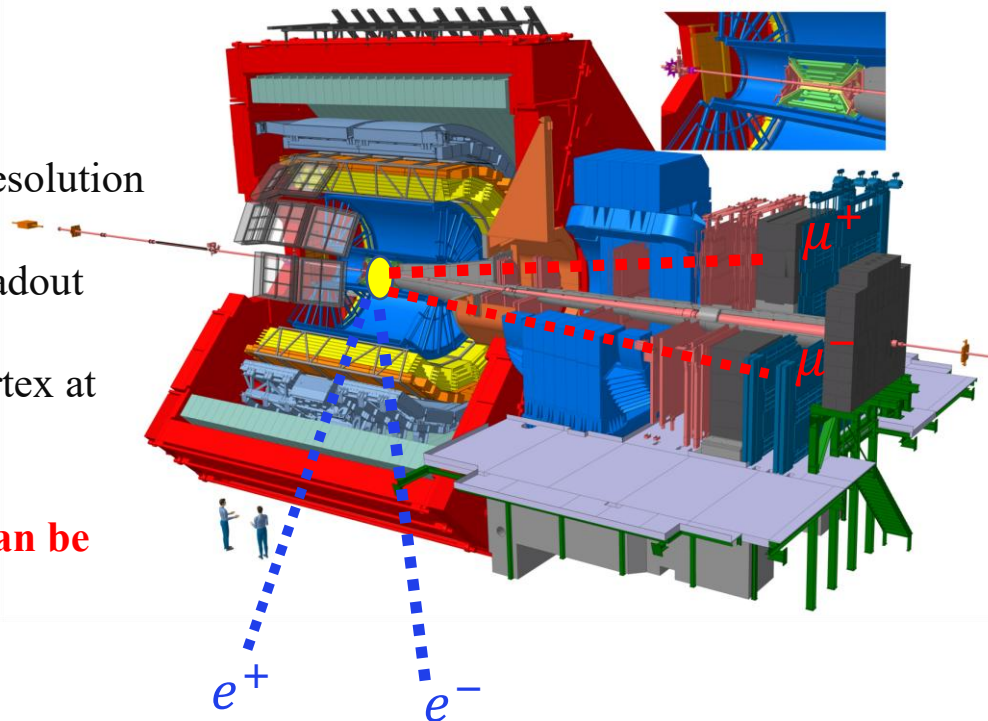
Run 3 upgrade:

ITS: Better vertex resolution

TPC: continuous readout

MFT: secondary vertex at forward rapidity

Measured pair p_T can be down to 0



Time Projection Chamber
Tracking, particle identification

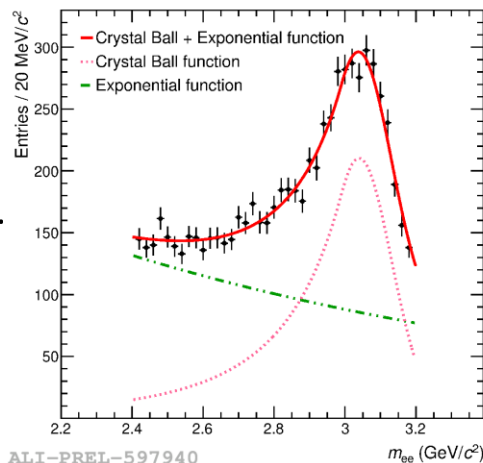
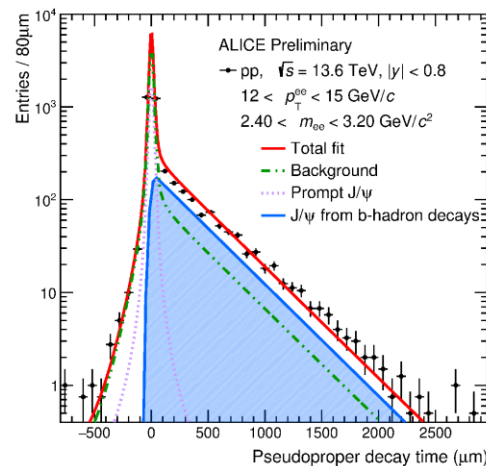
Inner Tracking System
Tracking, vertex reconstruction

FT0 Detector
Centrality determination
triggering, and reaction plane measurement

Muon spectrometer
Trigger and tracking for muons

Prompt and non-prompt J/ψ production

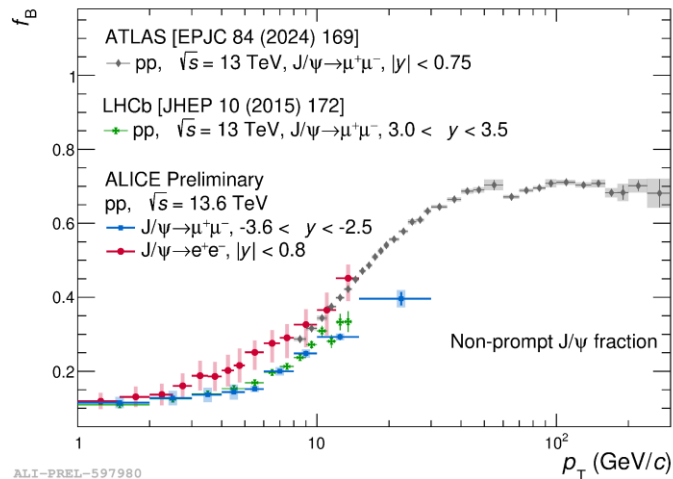
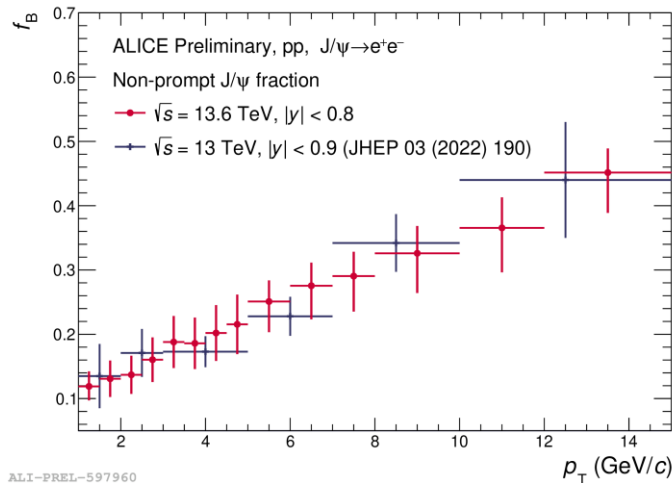
- Non-prompt J/ψ fraction (f_B) extracted by maximum **2D-unbinned likelihood fit** on invariant mass and pseudoproper decay time (x).
- Pseudoproper decay time distribution for prompt and non-prompt J/ψ are obtained from MC simulations.



$$2D \text{ Fit: } \mathcal{F}(m_{ee/\mu\mu}, x)_{tot} = f_{sig} \cdot \mathcal{F}(m_{ee/\mu\mu}, x)_{sig} + (1 - f_{sig}) \cdot \mathcal{F}(m_{ee/\mu\mu}, x)_{bkg}$$

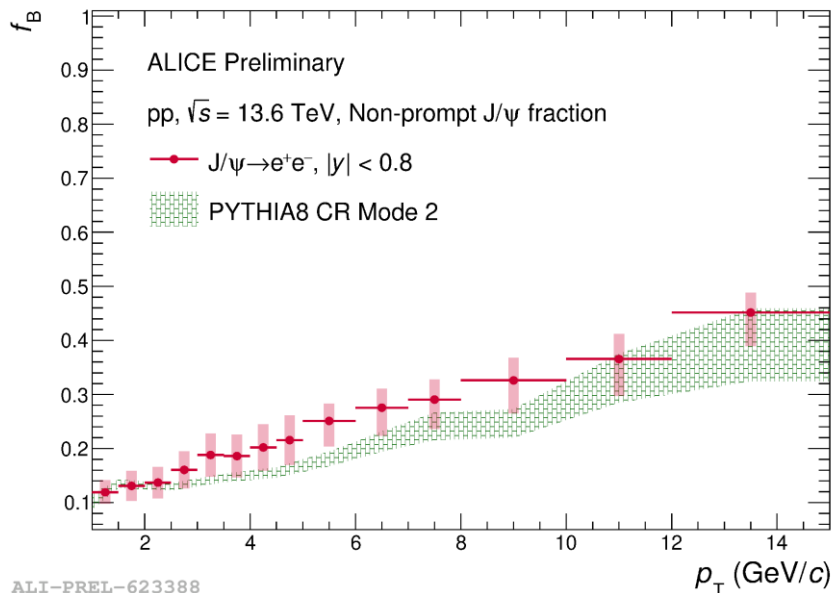
$$\begin{aligned} \mathcal{F}(m_{ee/\mu\mu}, x) &= M(m_{ee/\mu\mu}) \times F(x) \\ F(x)_{sig} &= f_B \times F(x)_B + (1 - f_B) \times F(x)_p \end{aligned}$$

Prompt and non-prompt J/ψ production



- **First measurement** of non-prompt fraction J/ψ is measured at **forward rapidity** with ALICE thanks to the new MFT.
- f_B is higher at midrapidity especially at high p_T compared to forward rapidity.
- Run 3 measurements at 13.6 TeV with ALICE agree with 13 TeV results with LHCb at forward rapidity and ATLAS at midrapidity in overlapping p_T ranges.
- Run 3 results is compatible with Run 2 results in ALICE but with better precision.

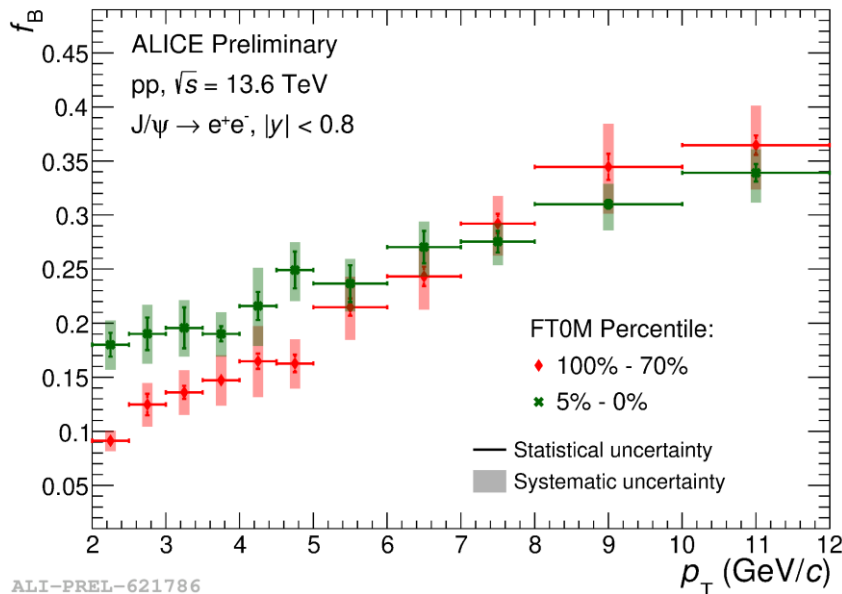
Prompt and non-prompt J/ψ production



- PYTHIA model can describe data well until $p_T \sim 11$ GeV/c.
- No significant difference in f_B in the PYTHIA versions within uncertainty is observed.
- PYTHIA8.311: Production of quarkonia via NRQCD in a timelike parton shower.

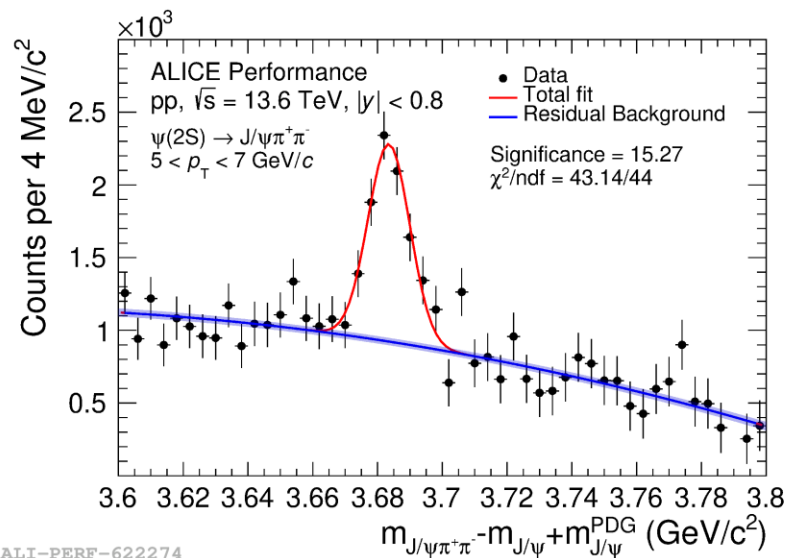
EPJC (2024) 84, 432

Prompt and non-prompt J/ψ production



- Non-prompt J/ψ f_B in low multiplicity and high multiplicity at midrapidity
- Higher f_B at high multiplicity events
- Indicating higher beauty cross section at higher multiplicity events

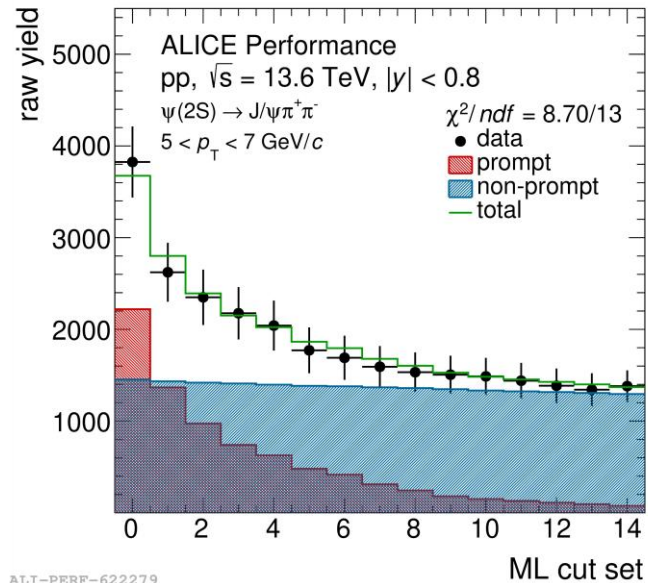
Prompt and non-prompt $\psi(2S)$ production



ALI-PERF-622274

- $\psi(2S)$ has fewer feed-down contribution compared to J/ψ
- A cleaner probe to study beauty contribution
- $\psi(2S)$ is reconstructed at midrapidity using $\psi(2S) \rightarrow J/\psi \pi \pi$ channel

Prompt and non-prompt $\psi(2S)$ production



- BDT is used to get the non-prompt $\psi(2S)$ fraction

$$\begin{pmatrix} \epsilon_1^p & \epsilon_1^{np} \\ \vdots & \vdots \\ \epsilon_n^p & \epsilon_n^{np} \end{pmatrix} \times \begin{pmatrix} N_p \\ N_{np} \end{pmatrix} - \begin{pmatrix} Y_1 \\ \vdots \\ Y_n \end{pmatrix} = \begin{pmatrix} \delta_1 \\ \vdots \\ \delta_n \end{pmatrix}.$$

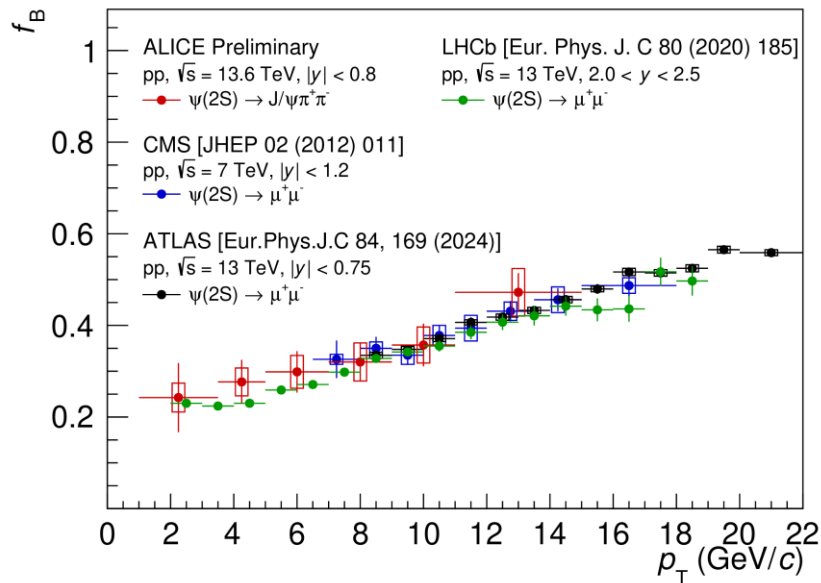
$$\chi^2 = \delta^T \mathbf{C}^{-1} \delta,$$

$$\mathbf{C} = \begin{pmatrix} \sigma_1^2 & \sigma_{1,2} & \cdots & \vdots \\ \sigma_{2,1} & \sigma_2^2 & \cdots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ \vdots & \vdots & \vdots & \sigma_{n-1,n}^2 \\ \cdots & \sigma_{n,n-1} & \cdots & \sigma_n^2 \end{pmatrix}$$

$$\sigma_i^2 = \sigma_{Y_i}^2 + N_p \cdot \sigma_{\epsilon_i^p}^2 + N_{np} \cdot \sigma_{\epsilon_i^{np}}^2$$

- Chi2 is defined based on the estimated raw yield and extracted raw yield after applying a set of cut on BDT output
- Corrected yield of prompt and non-prompt $\psi(2S)$ is estimated based on the minimisation of the Chi2

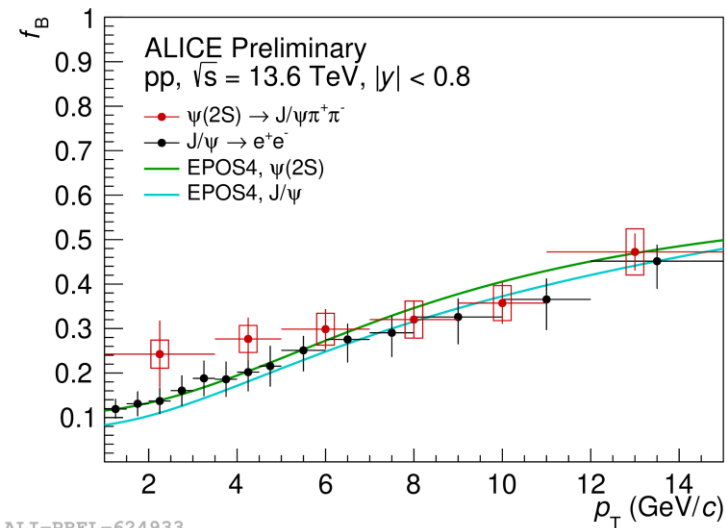
Prompt and non-prompt $\psi(2S)$ production



ALI-PREL-622346

- First measurement of non-prompt $\psi(2S)$ fraction at midrapidity in the low p_T region
- The results are consistent with forward rapidity measurement with LHCb within uncertainty
- The results are consistent with ATLAS and CMS measurements at midrapidity in the overlapping p_T range

Prompt and non-prompt $\psi(2S)$ production



ALI-PREL-624933

- Non-prompt $\psi(2S)$ and J/ψ f_B compared with EPOS4 model at midrapidity
- Hint of larger f_B for $\psi(2S)$ than J/ψ at low p_T , due to different feed-down contribution to prompt J/ψ
- EPOS4 provides a reasonable description of the trend f_B for both J/ψ and $\psi(2S)$

Summary

- **Non-prompt J/ψ in pp collisions at $\sqrt{s} = 13.6$ TeV**
 - The f_B measurements consistent with ATLAS and LHCb in the overlapping p_T range corresponding rapidity regions.
 - Midrapidity results agree with 13 TeV data within uncertainties with smaller uncertainty.
 - High-multiplicity events show a larger non-prompt fraction at midrapidity.
- **Non-prompt $\psi(2S)$ at midrapidity**
 - First measurement of the non-prompt fraction at low p_T
 - Results consistent with LHCb, ATLAS and CMS within uncertainties in the overlapping p_T ranges.
 - A hint of a larger $\psi(2S)$ non-prompt fraction at low p_T .
 - EPOS4 reasonably describes the p_T trends for both states.

Thank you

Backup

Study quarkonium in pp

➤ NRQCD

Non-Relativistic QCD approach, long-distance matrix elements (LDME) fitted to experimental data.

Quarkonium produced in a singlet or octet state, with soft gluon emission to reach final state.

➤ NRQCD + CGC

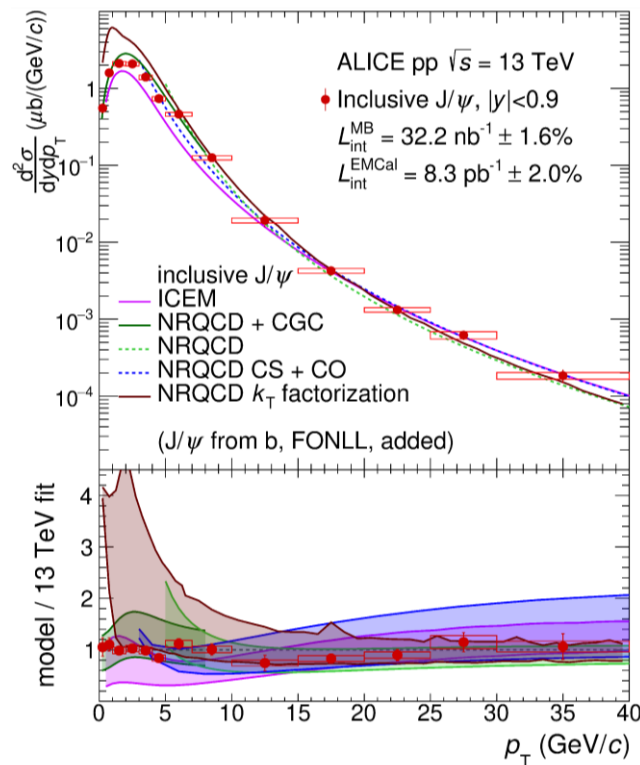
Color Glass Condensate effective theory coupled to leading order NRQCD calculations.

Taking gluon saturation into account.

➤ ICEM

using the k_T -factorization approach to improve Color Evaporation Model (CEM) with gluons transverse momentum.

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

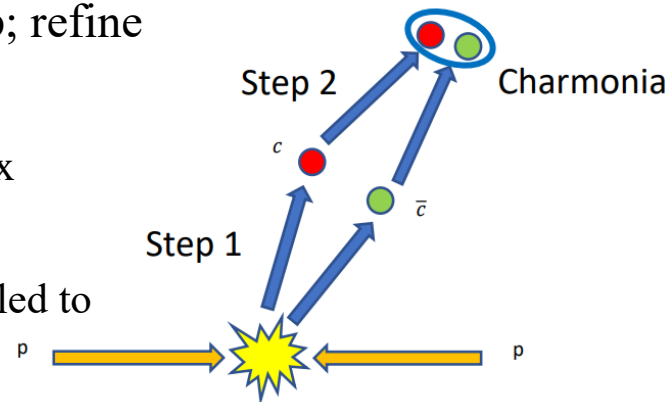


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Eur. Phys. J. C 81 (2021) 1121

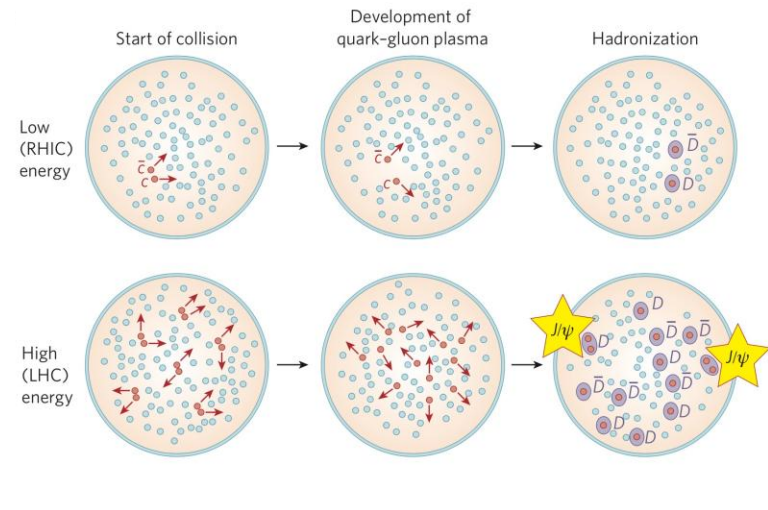
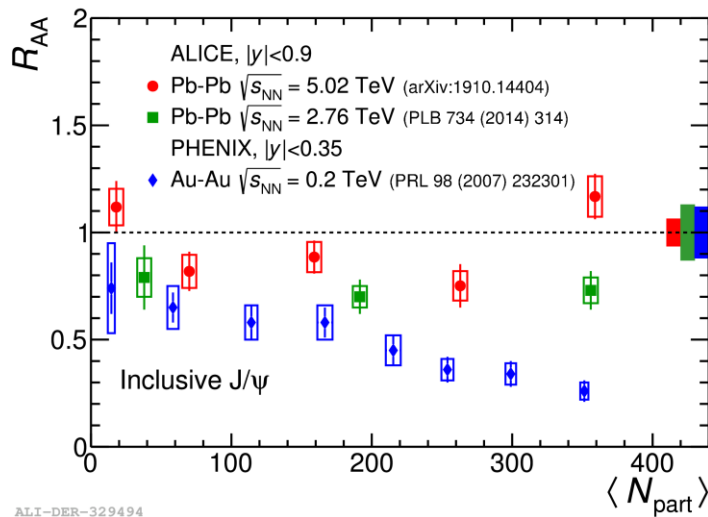
Study quarkonium in pp

- 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.



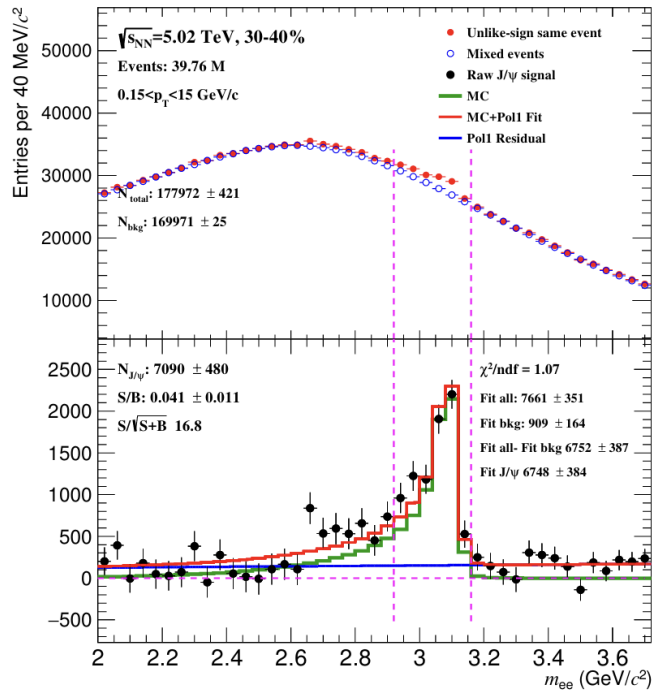
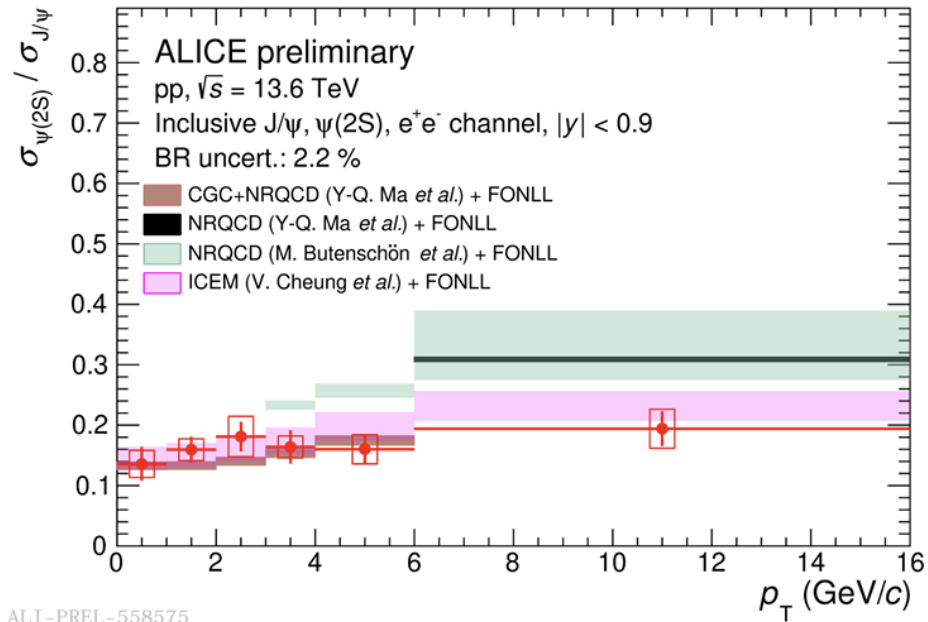
NRQCD: Phys. Rev. D51 (1995) 1125–1171
 NRQCD+CGC: JHEP 01 (2014) 056
 ICEM: Phys. Rev. D 94 no. 11, (2016) 114029

Quarkonium as a probe of QGP in Pb–Pb



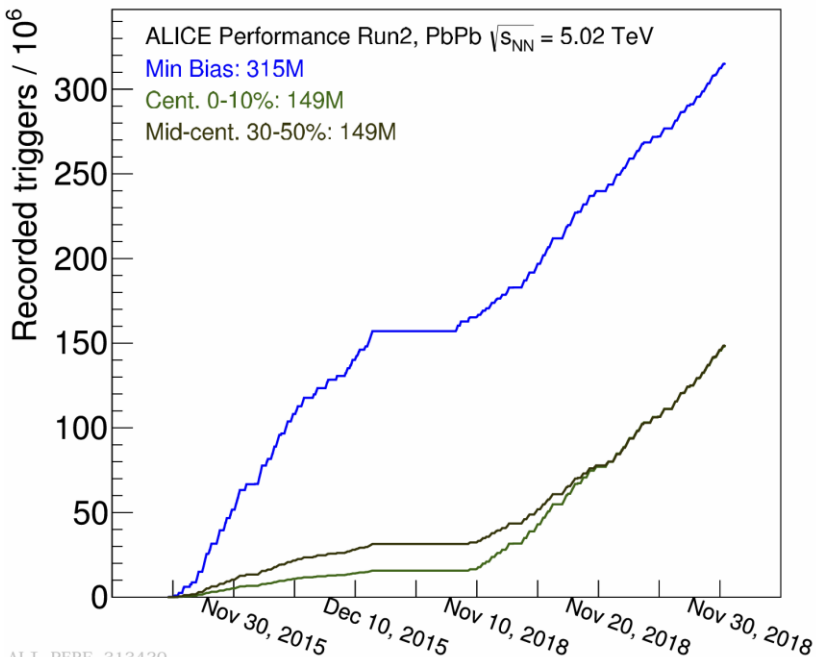
Phys. Lett.B 178 (1986) 416–422
 Phys. Rev. Lett. 92 (2004) 212301
 Phys. Lett. B 490 (2000) 196–202
 Phys. Rev. D 64 (2001) 094015
 Nucl. Phys. A 943 (2015) 147–158

- Heavy quarks are produced at initial hard scattering stage and experience whole evolution of QGP.
- **Suppression** of the direct charmonium due to color screening and dissociation.
- **Recombination** enhances the charmonium production close to the transition at LHC energies.

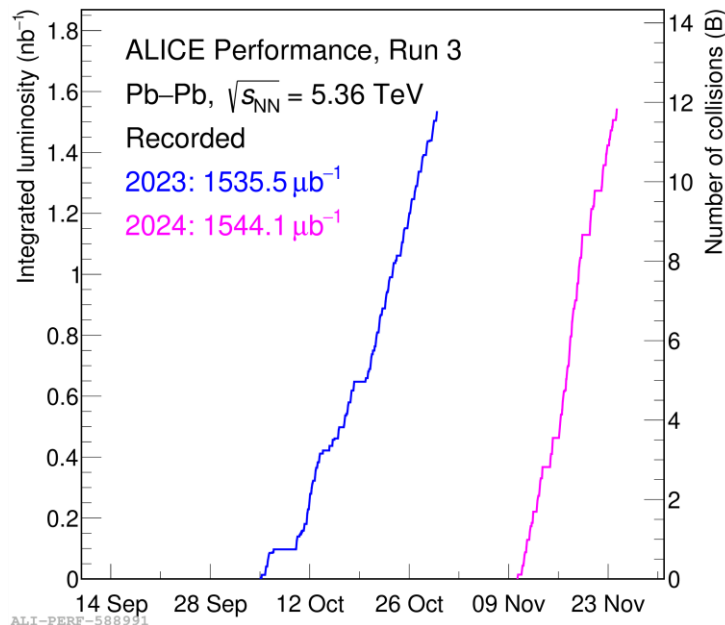


ALI-PREL-558575

Luminosity



ALI-PERF-313420



ALI-PERF-588991

Quarkonium: Production Mechanism

Collinear factorization + on-shell pair + hadronization

$$d\sigma_\psi = \sum_{i,j,n} \int dx_1 dx_2 \underbrace{G_{i/A} G_{j/B}}_{\Lambda_{QCD}} \times \underbrace{\hat{\sigma}[ij \rightarrow c\bar{c}[n] + X]}_{m_c} \times \underbrace{\langle O_n^\psi \rangle}_{m_c v}$$

Parton distribution function

Production of heavy quark pair

Hadronization (LDMEs)