

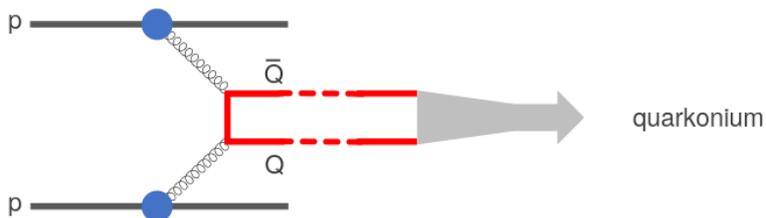
Prompt and non-prompt J/ψ in pp collisions with ALICE

Workshop on Advances, Innovations, and Prospects in High-Energy Nuclear Physics, Wuhan, China

Maurice Coquet, Subatech, CNRS, 22nd October 2024

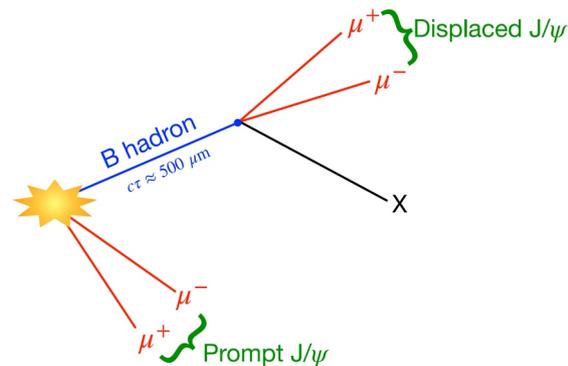
Quarkonium in small systems: testing QCD at its limits

- Quarkonium production involves different scales and processes:
 - hard-scales: heavy-quark production in initial hard scattering → test **perturbative QCD**
 - soft-scales: binding of pairs into a colorless final state → probe **non-perturbative physics**

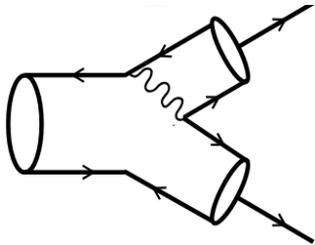
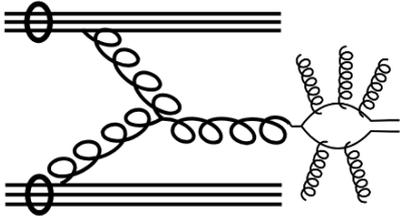
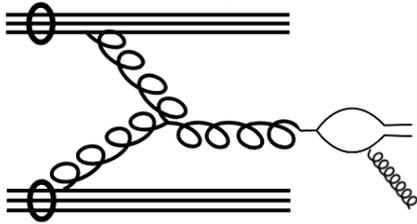


- Reference systems to study heavy-ion collisions and the quark-gluon plasma

- **Prompt charmonium:**
Direct production or feed-down from excited states.
- **Non-prompt charmonium:**
Produced via beauty hadrons decay through weak interactions

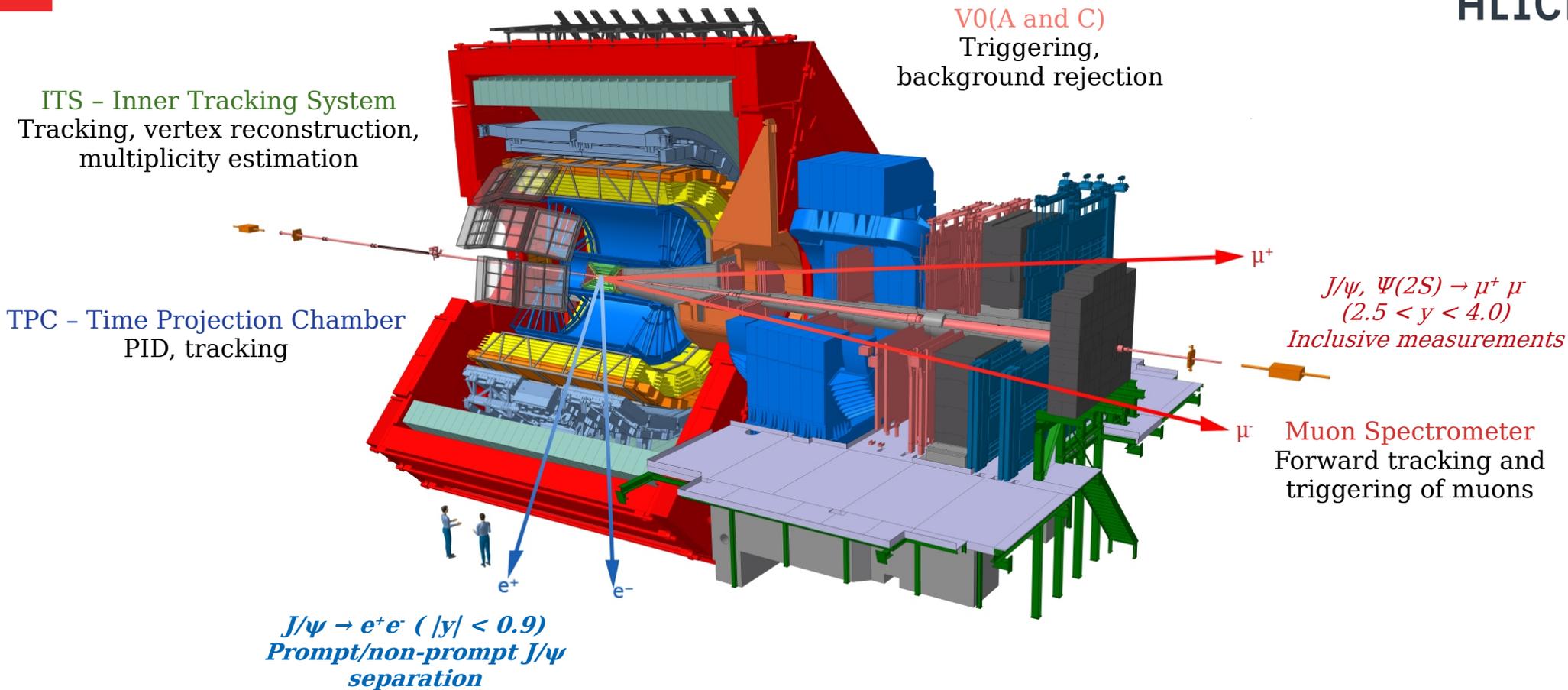


Quarkonium production in pp



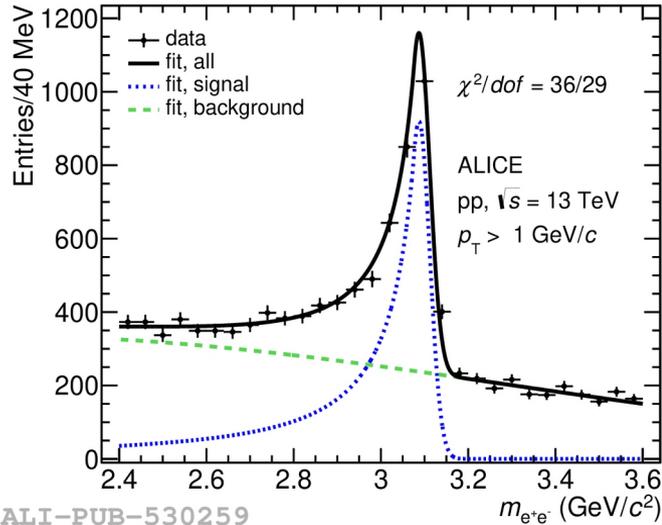
- **Non-Relativistic QCD** [PRD 51,1125-1171,1995]:
 - Non-relativistic expansion in terms of heavy quark relative velocity
 - Factorizes the short-distance hard scattering from long-distance evolution of the heavy quark pair into quarkonium
 - Includes CO and CS contributions
- **Color Evaporation Model** [PLB, 67,217-221, 1977]:
 - Assumes that all heavy quark pairs below open HF threshold hadronize into quarkonia
 - No distinction between CS or CO mechanisms, the color is « evaporated » by soft gluon emission
- **Fixed Order Next-to-Leading-Logarithm** [JHEP, 9805:007,1998]:
 - perturbative calculation for heavy quark production
 - Used for non-prompt charmonium production calculation

ALICE in Run 2

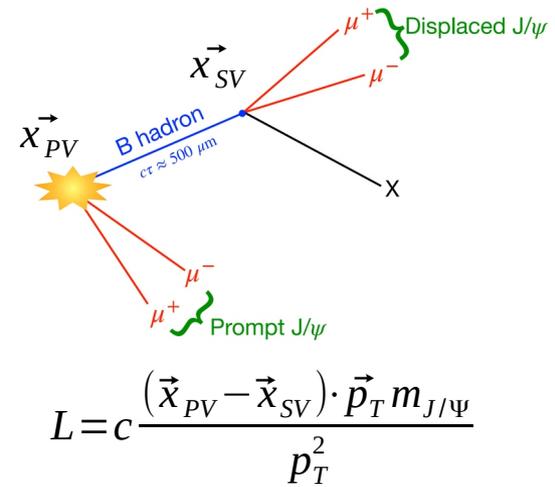
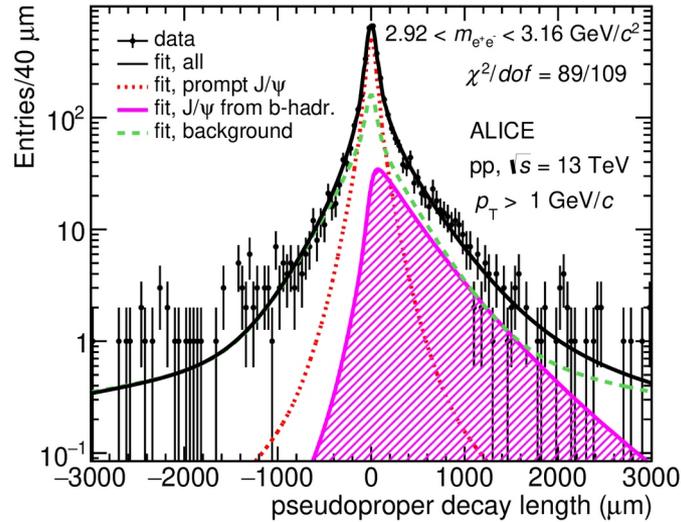


Non-prompt fraction extraction

[JHEP 03 (2022) 190]



ALI-PUB-530259



- Non-prompt J/ ψ fraction (f_B) measured by ALICE at midrapidity in **pp at $\sqrt{s}=13$ TeV**
- Analysis based on two-dimensional fit on invariant mass and **pseudoproper decay length L**

Prompt & non-prompt J/ψ in pp

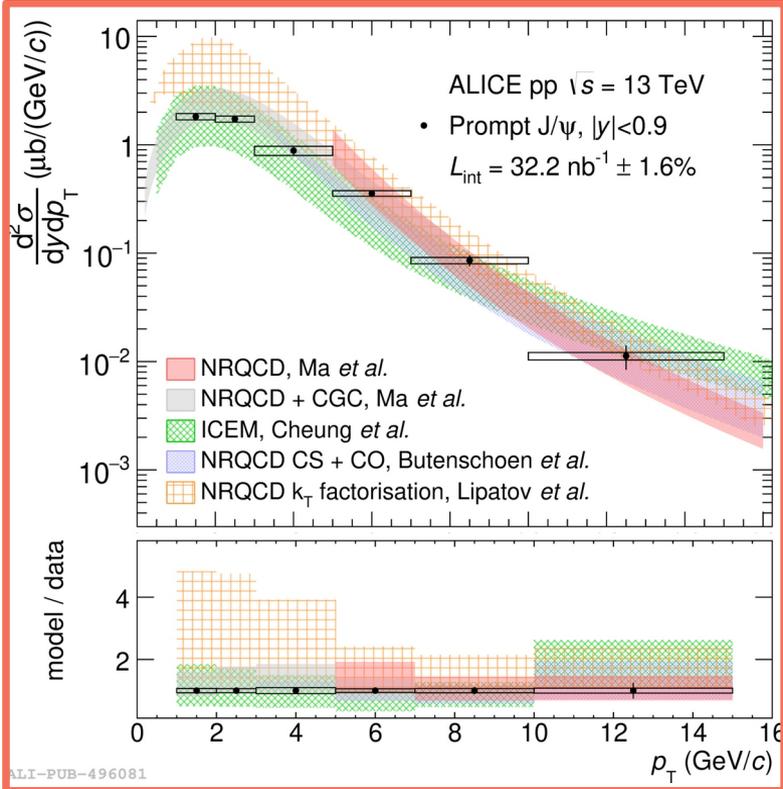


ALICE

prompt

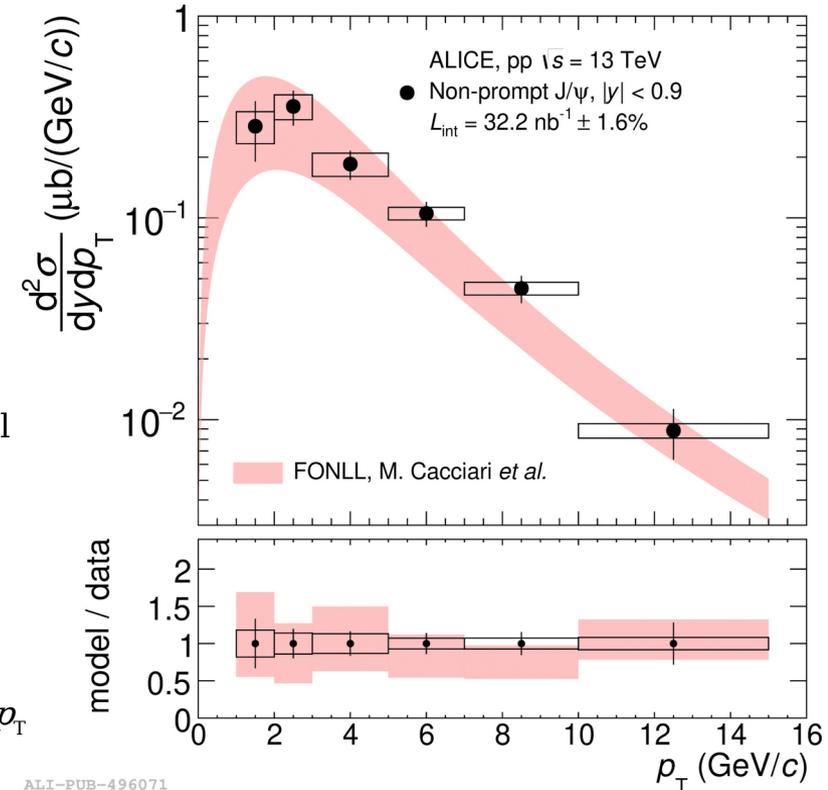
[JHEP 03 (2022) 190]

non-prompt



Models describe well the prompt differential cross sections at midrapidity, at $\sqrt{s} = 13$ TeV

- > **NRQCD+CGC:** Color Glass Condensate initial state + non-relativistic QCD hadronization → good agreement over full p_T range
- > **ICEM:** Improved Color Evaporation → slightly overshoots at high p_T
- > **NRQCD + k_T factorization:** overestimates data at low p_T



NRQCD CS+CO : Butenschoen, Phys. Rev. Lett. 106 (2011) 022003

NRQCD : Ma, Phys. Rev. Lett. 106 (2011) 042002

NRQCD+CGC : Ma, Phys. Rev. Lett. 113 no. 19 (2014) 192301

ICEM : Cheung, Phys. Rev. D 98 no. 11, (2018) 114029

NRQCD+ k_T fact. : Lipatov, Phys. Rev. D 100 no. 11, (2019) 114021

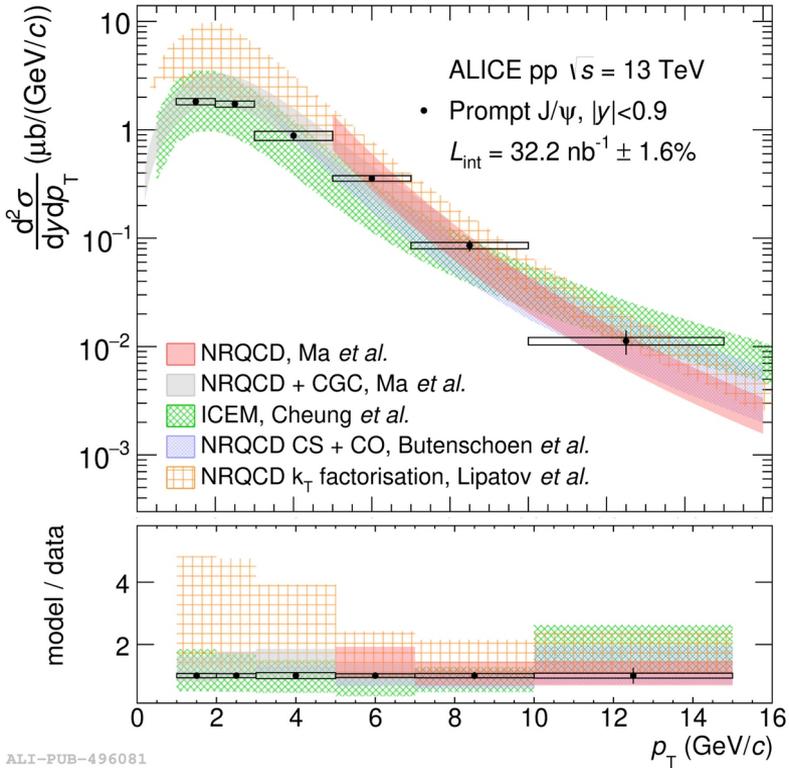
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ALICE

Prompt & non-prompt J/ψ in pp

prompt

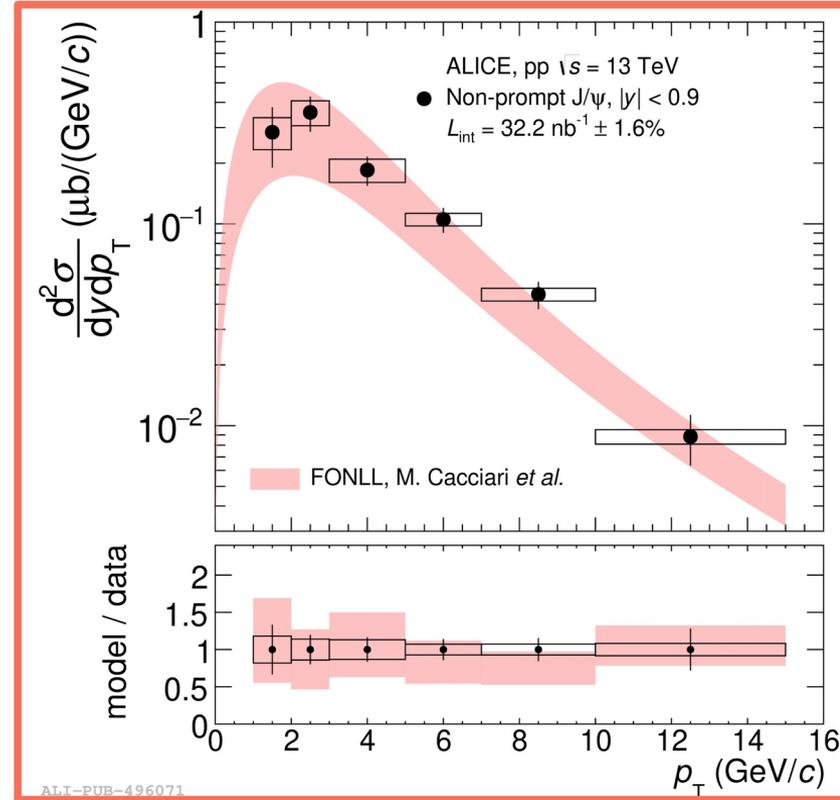


[JHEP 03 (2022) 190]

Models describe well the non-prompt J/ψ differential cross sections at midrapidity, at $\sqrt{s}=13$ TeV

> **FONLL**: Fixed-Order-Next-to-Leading-Log perturbative calculation

non-prompt

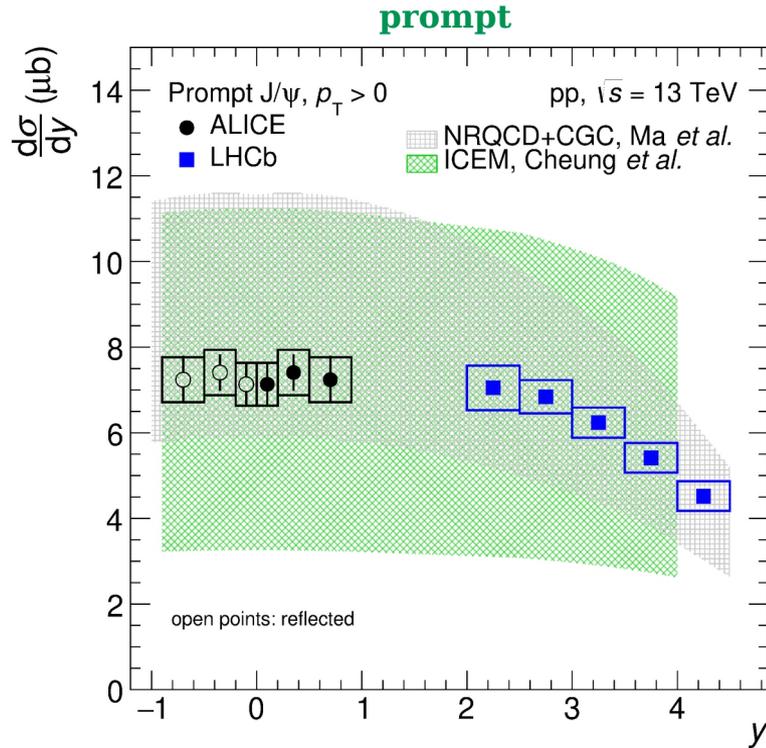


FONLL : Cacciari, JHEP 05 (1998) 007

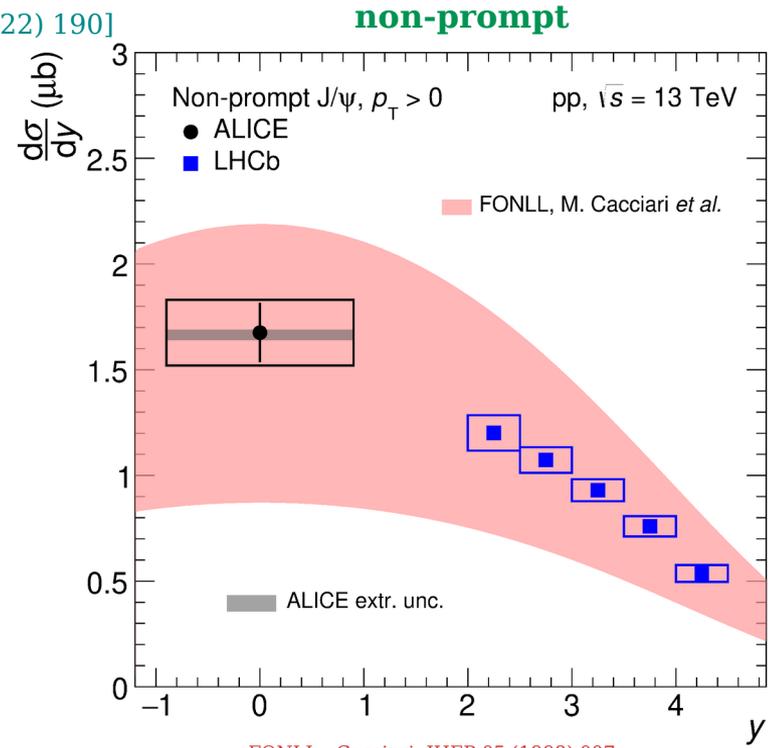


ALICE

Prompt & non-prompt J/ψ in pp



ALI-PUB-530295 NRQCD+CGC : Ma, Phys. Rev. Lett. 113 no. 19 (2014) 192301
ICEM : Cheung, Phys. Rev. D 98 no. 11, (2018) 114029



ALI-PUB-530291 FONLL : Cacciari, JHEP 05 (1998) 007

- Models also describe the **rapidity-differential** cross sections at midrapidity, at $\sqrt{s}=13$ TeV
- Large uncertainties on model predictions (main contribution from scale uncertainties)

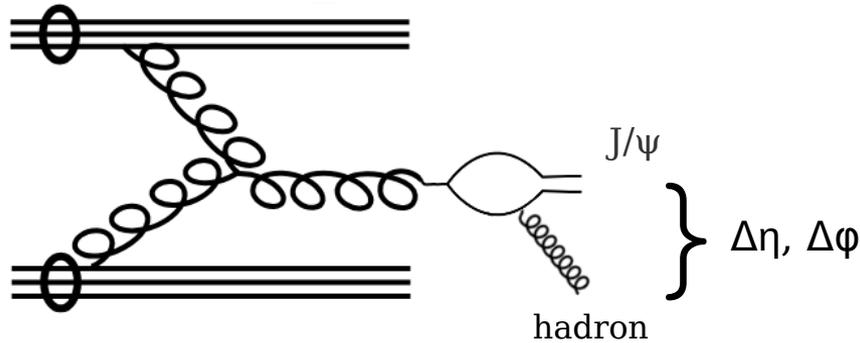
J/ψ-hadron correlation



ALICE

[arXiv:2409.04364]

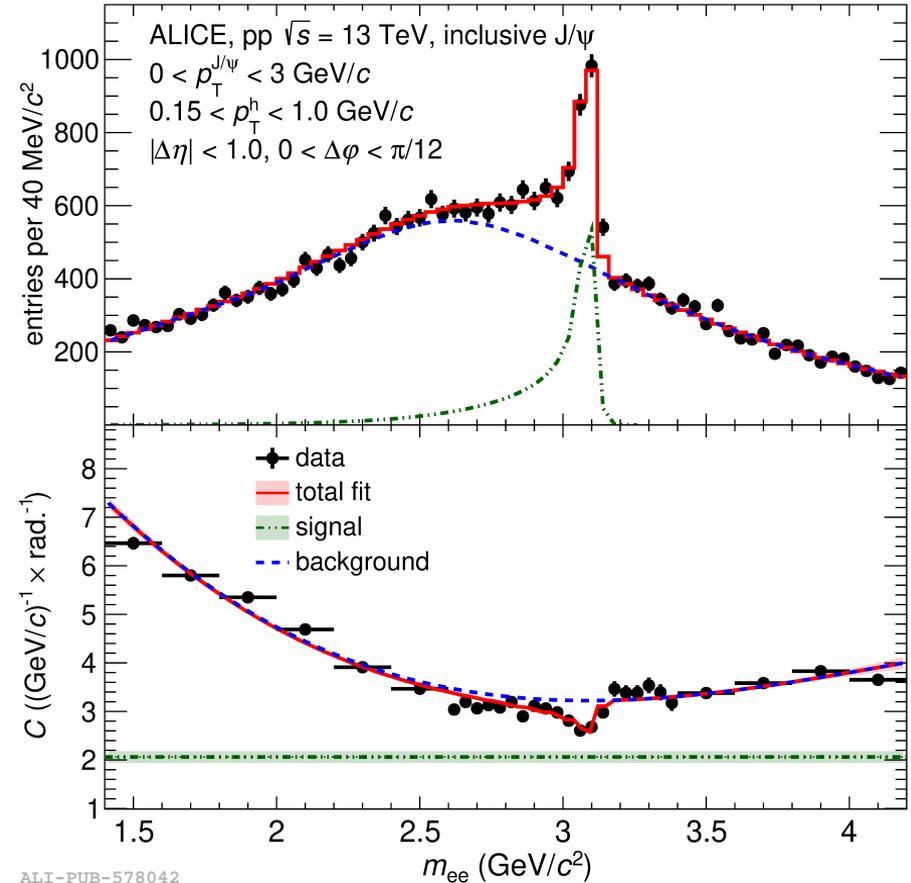
- Hadronization of heavy quark pair into quarkonium can be accompanied by gluon emission → **associated production**



- Correlation function** for associated J/ψ-hadron production at **midrapidity** in pp collisions at $\sqrt{s}=13$ TeV

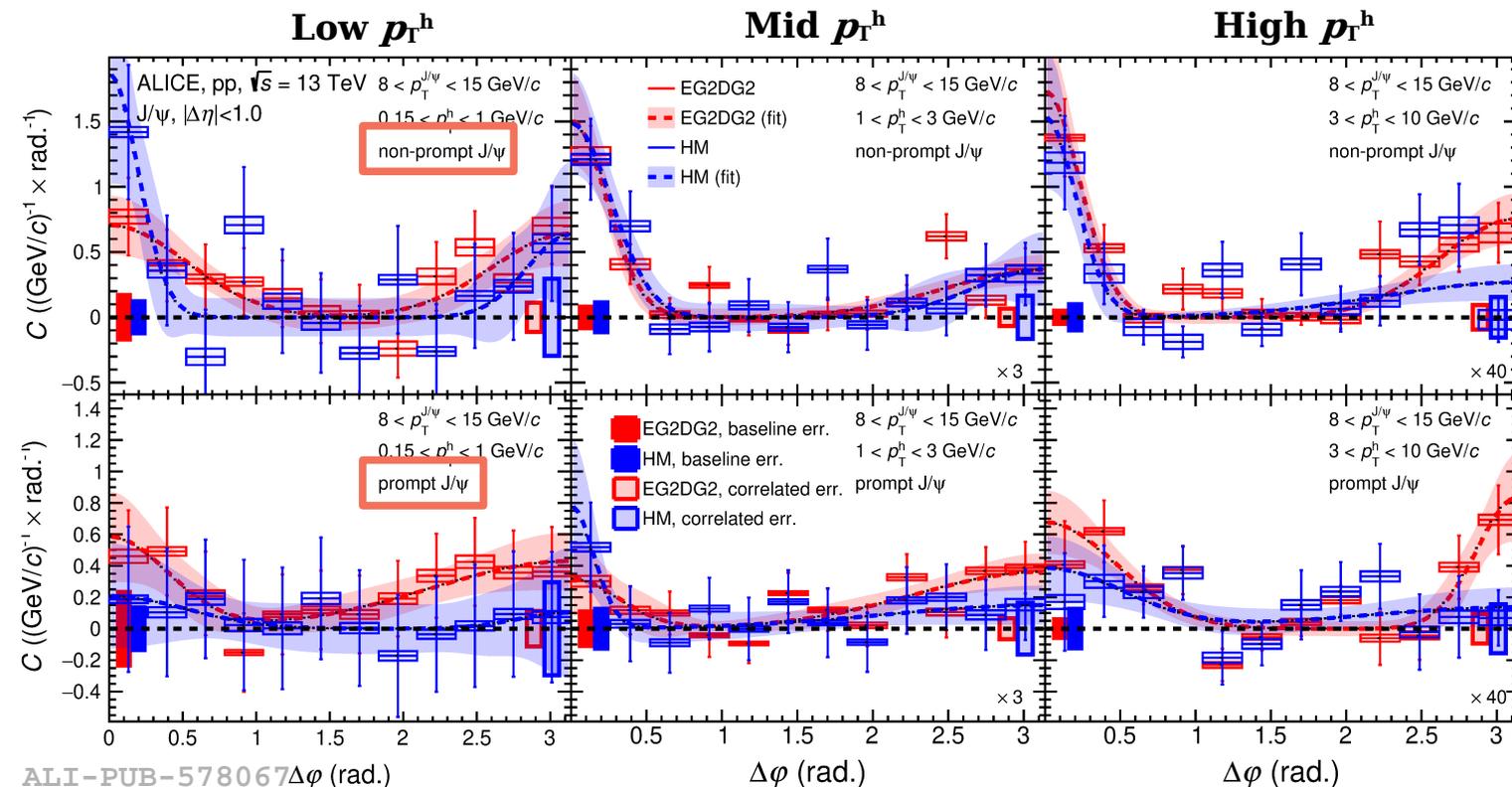
$$C(\Delta\eta, \Delta\phi; p_T^{J/\psi}, m_{e^+e^-}, p_T^h) = \frac{1}{N_{\text{trig}}} \cdot \frac{S(\Delta\eta, \Delta\phi)}{B(\Delta\eta, \Delta\phi)} \cdot B(0,0)$$

- S/B: same-event/mixed-event pairing



ALI-PUB-578042

J/ψ-hadron correlation



Different event triggers:

Minimum Bias:
Coincidence of signals in both V0 counters

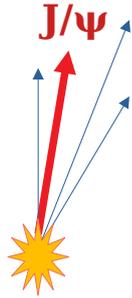
High Multiplicity: 0.1% events with the highest multiplicity in the V0 detector

EG2DG2: sum of energy in a sliding window in EMCAL above 4 GeV

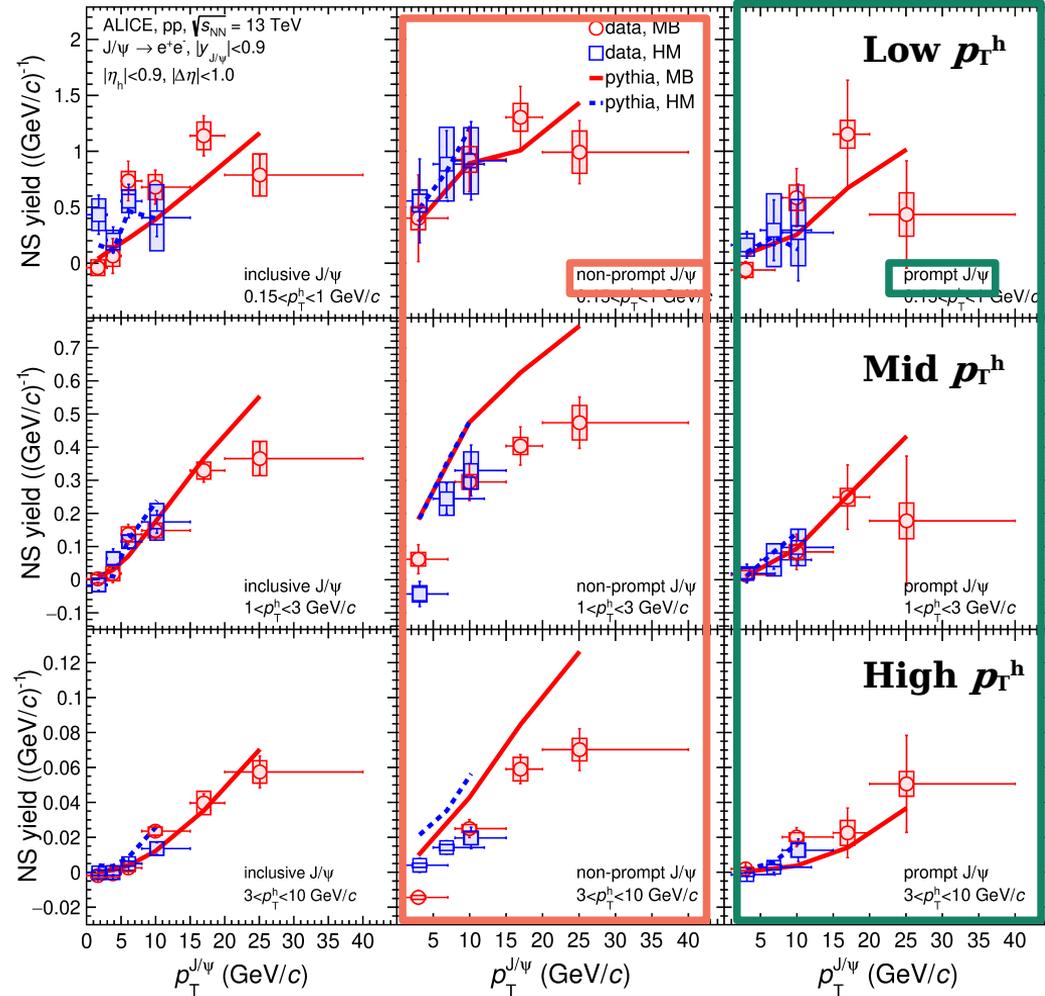
[arXiv:2409.04364]

Correlation patterns on both the **near ($\Delta\phi=0$)** and **away ($\Delta\phi=\pi$)** sides

Near Side yields



- Increasing trend as a function of J/ψ_T
- NS yields associated with **non-prompt J/ψ** larger than **prompt J/ψ**



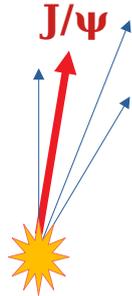
ALI-PUB-578072

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[arXiv:2409.04364]

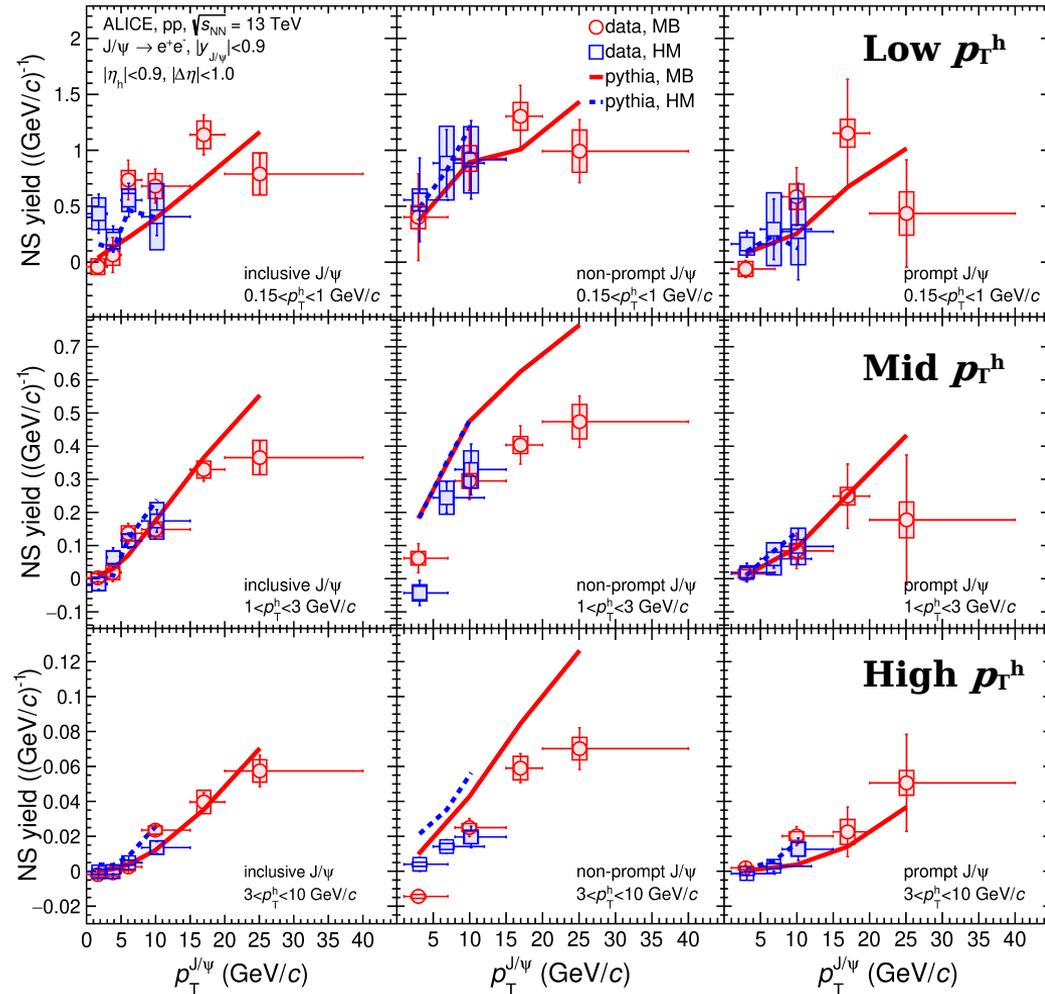


Near Side yields



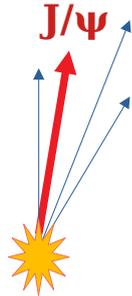
- Good agreement between the **High multiplicity** and **Minimum Bias** triggered events within uncertainties

→ **No strong event multiplicity dependence observed**

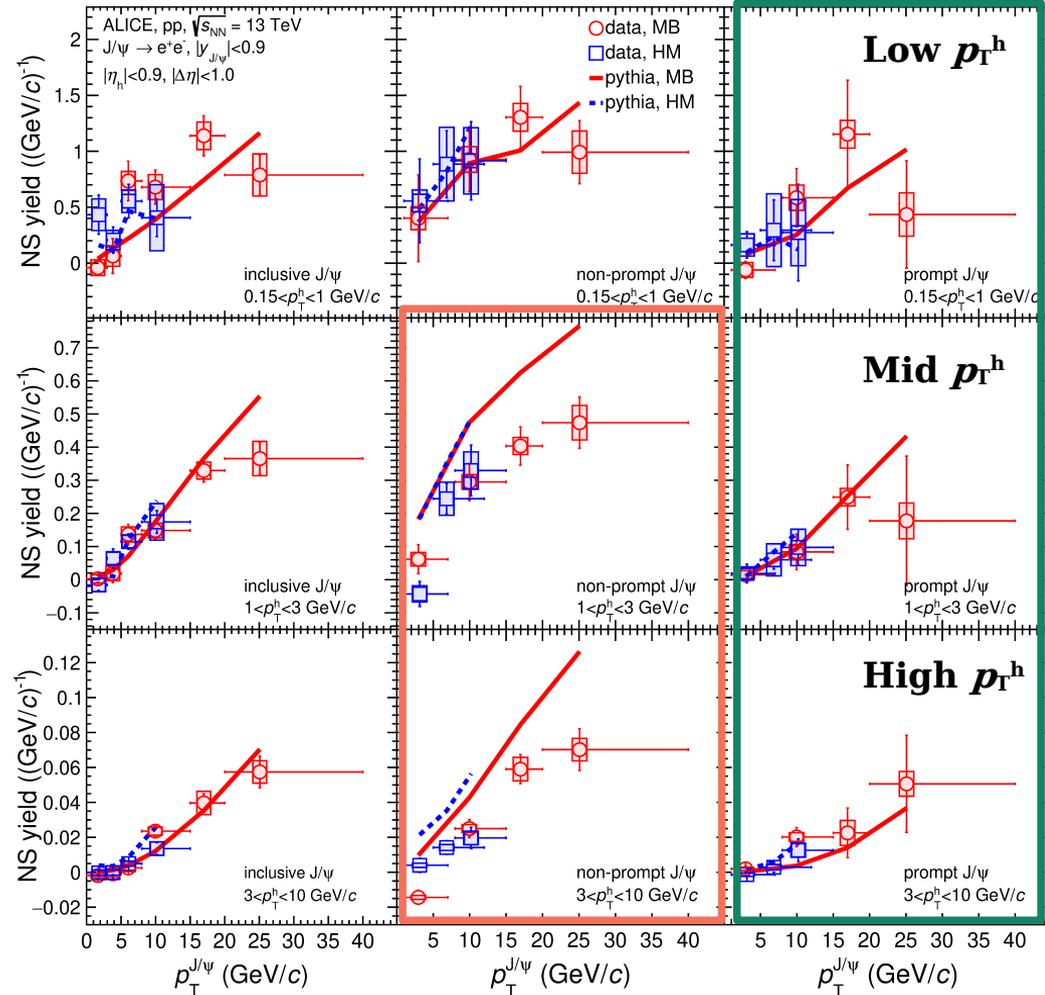


ALI-PUB-578072

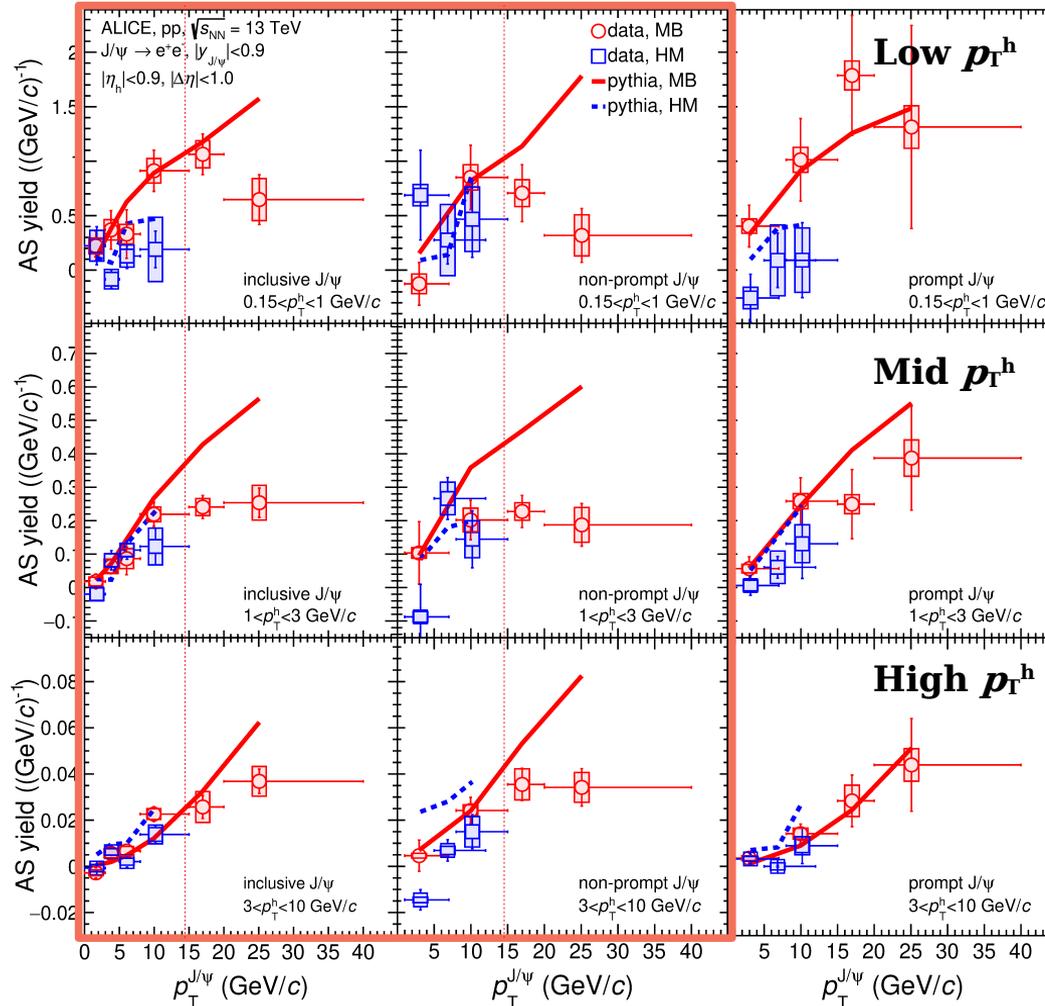
Near Side yields



- PYTHIA calculations are based on NRQCD (CO+CS) for **prompt J/ψ** production → good agreement with results
 - **Overestimate** yields for $p_{T^h} > 1 \text{ GeV}/c$ associated with **non-prompt J/ψ**
- **Hadronization or fragmentation not well reproduced in PYTHIA ?**



Away Side yields



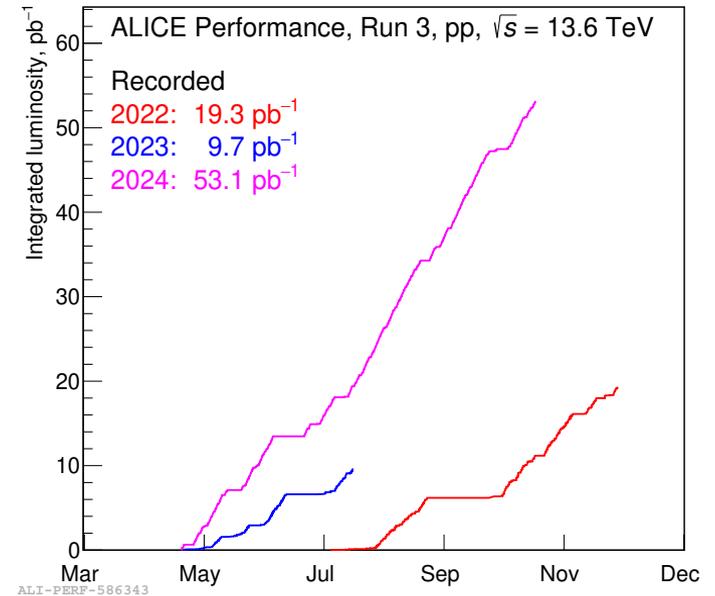
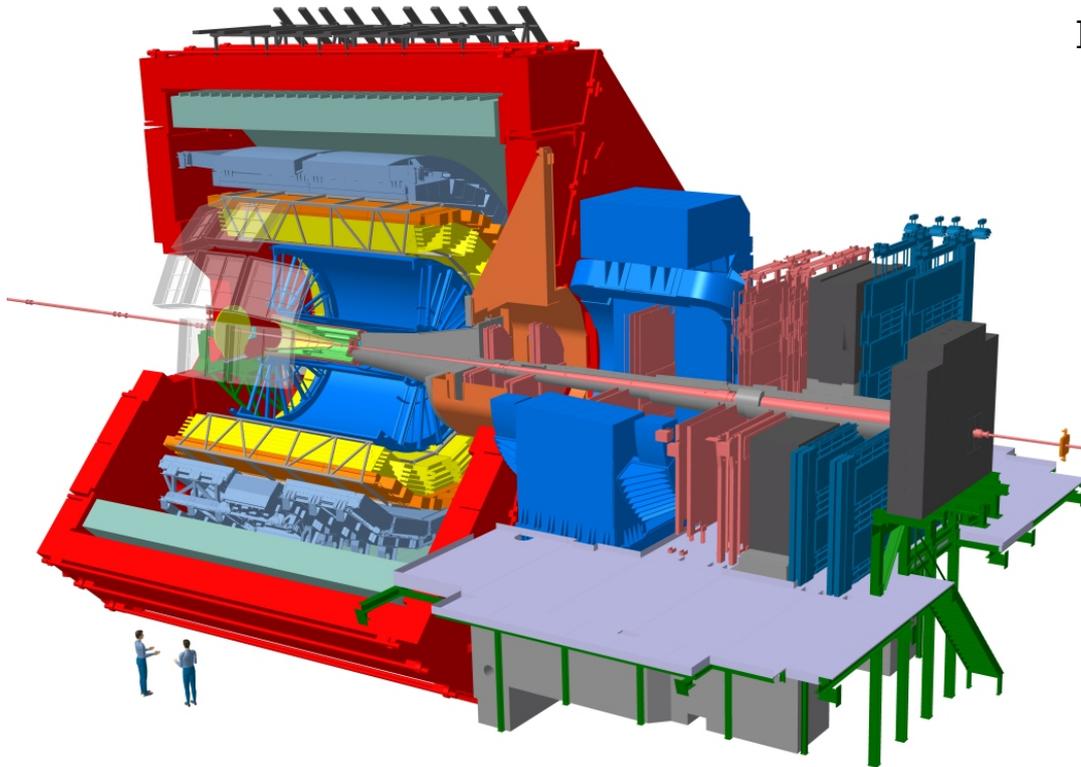
- PYTHIA calculations are in good agreement with results within uncertainties, but **overestimate** yields for **non-prompt J/ψ** with $p_T^{J/\psi} > 15 \text{ GeV}/c$

ALICE in Run 3



ALICE

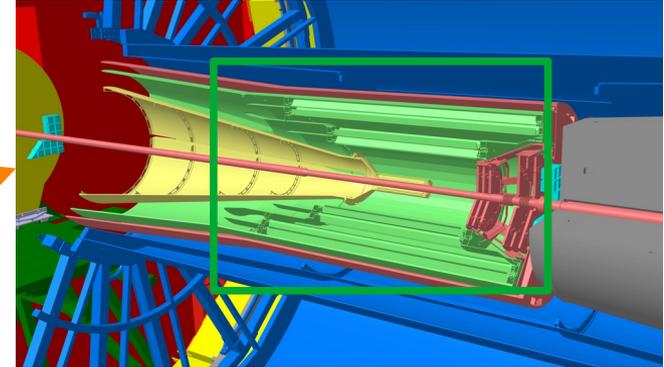
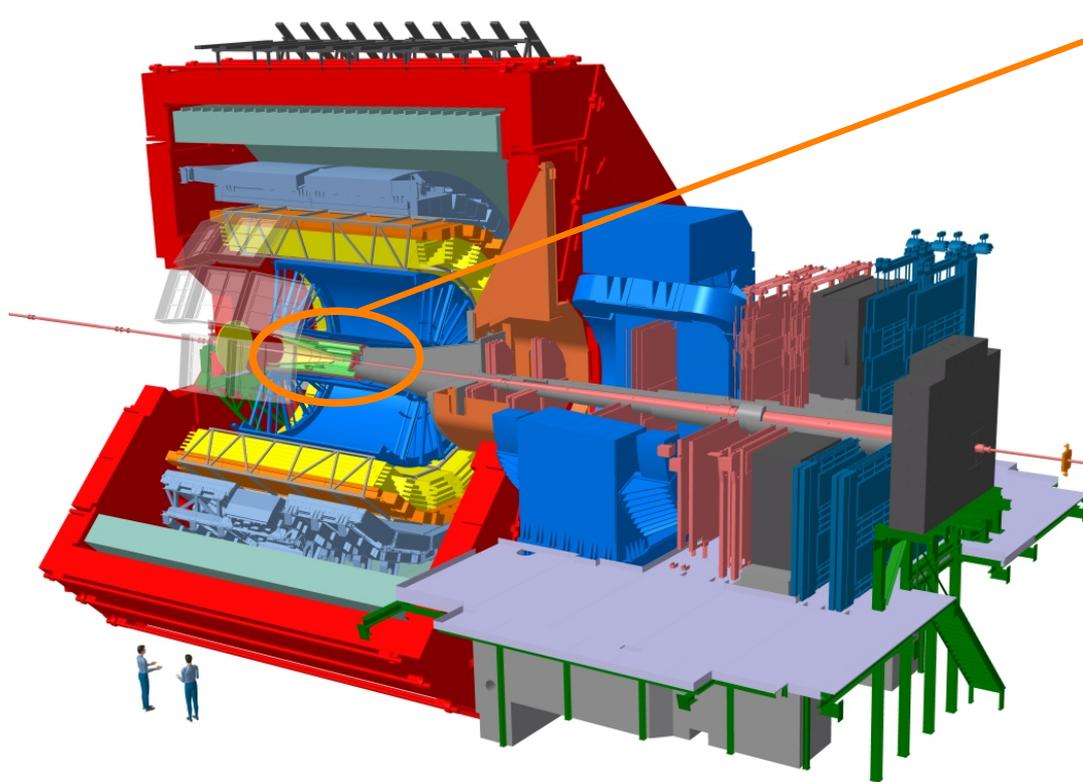
New global acquisition strategy, allowing operations in **continuous readout** mode
→ up to **500 kHz in pp** and **50 kHz in Pb-Pb**





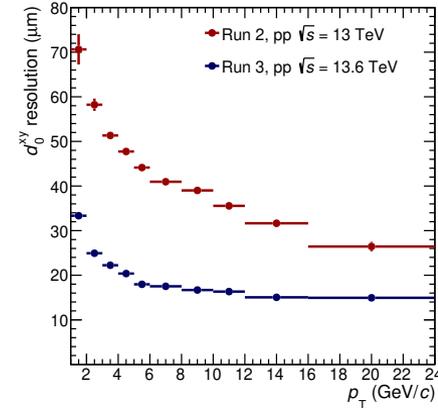
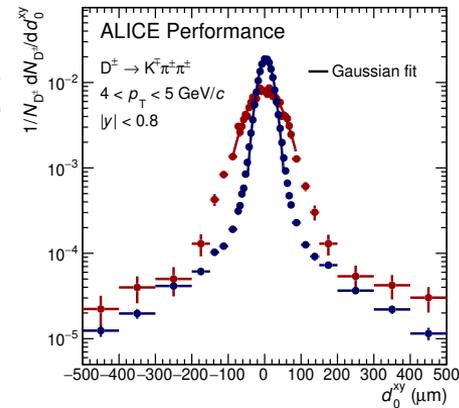
ALICE

ALICE in Run 3



ITS2 [CERN-LHCC-2013-024]

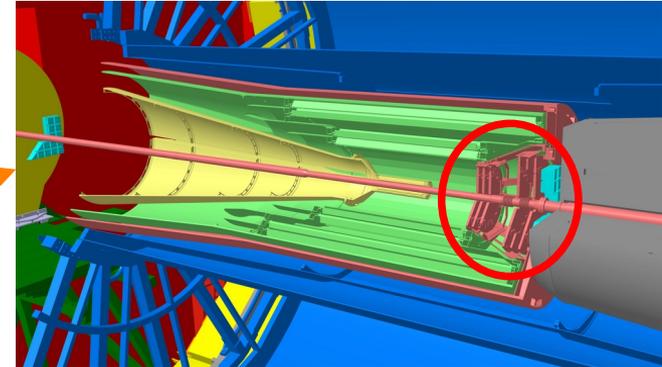
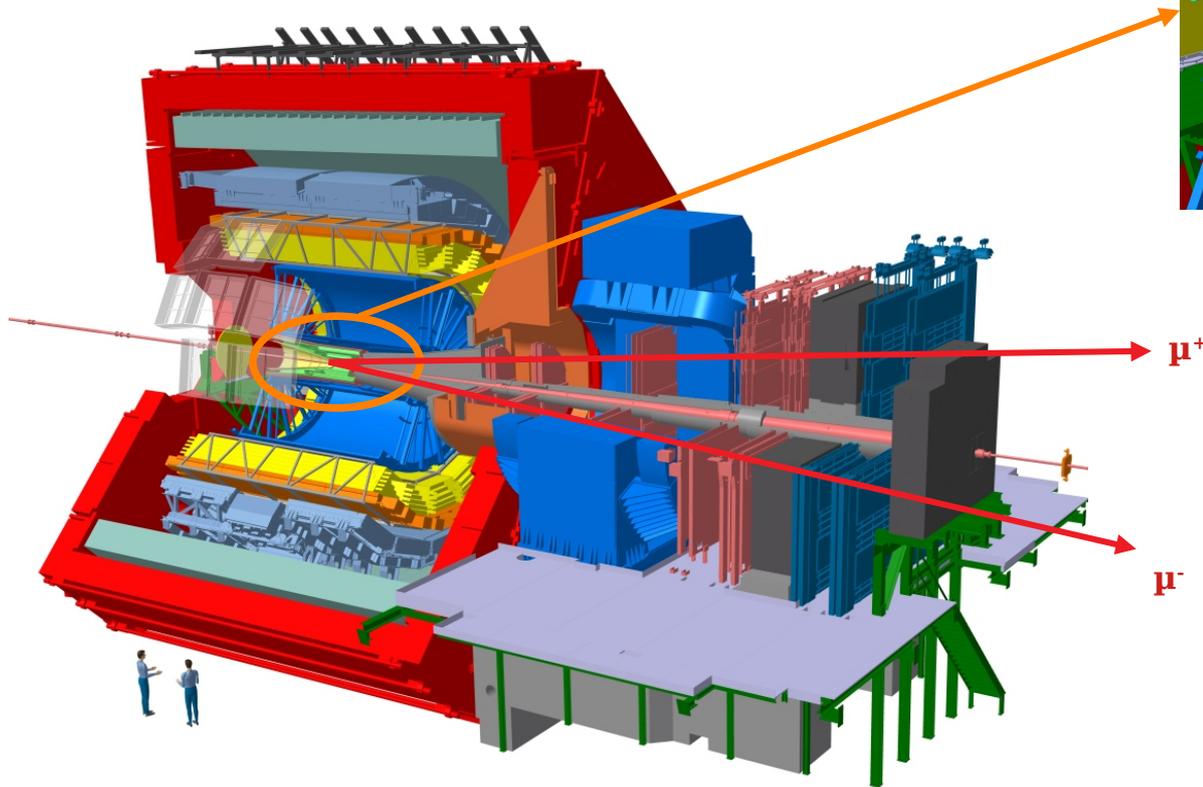
Upgraded detector, **improved pointing resolution** with respect to Run 2



ALICE in Run 3



ALICE

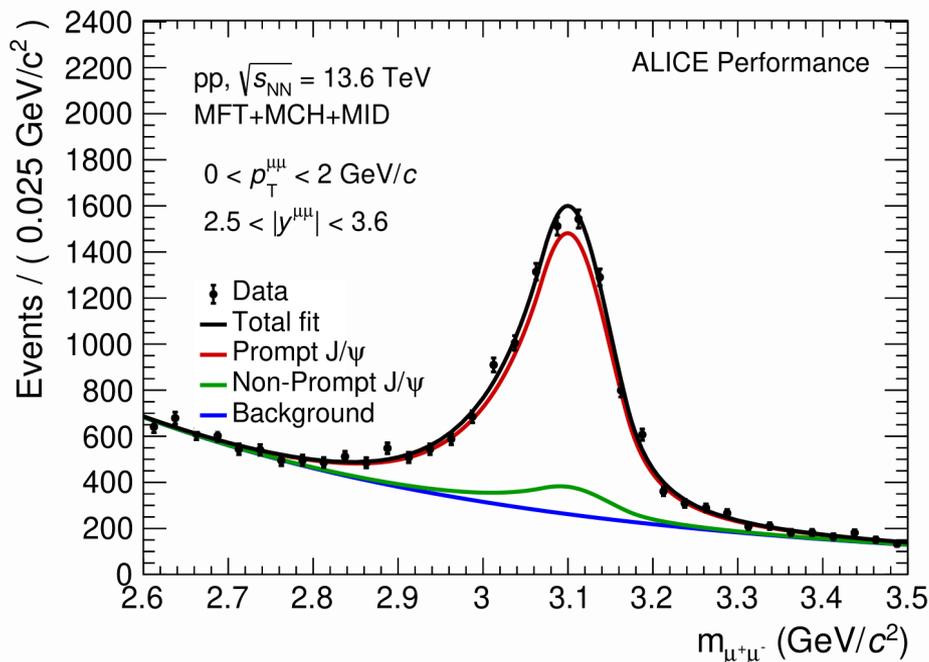


MFT - Muon Forward Tracker
[CERN-LHCC-2015-001]
Providing vertexing performance for muon spectrometer, **allowing prompt/non-prompt separation at forward rapidity** in ALICE

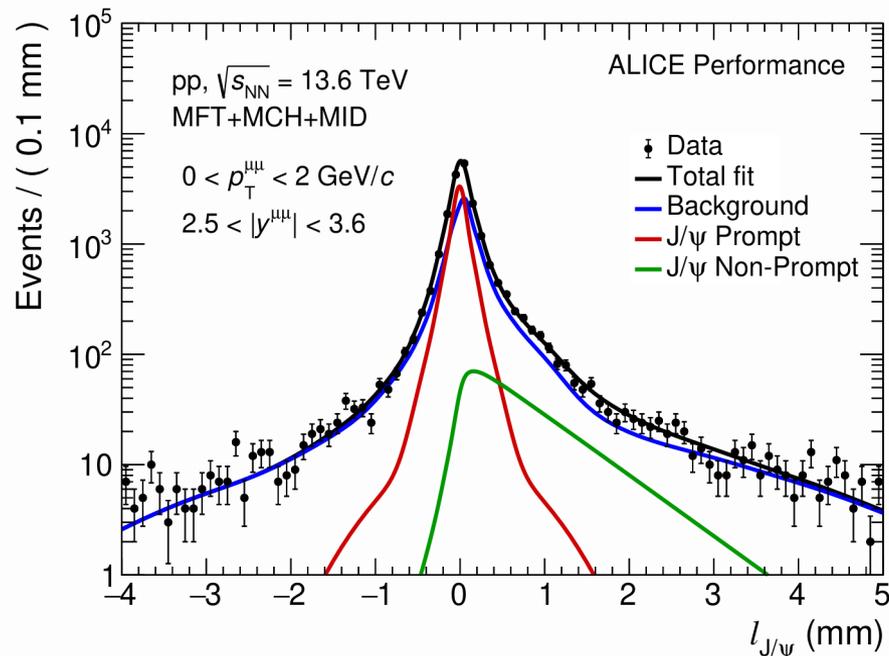
Run 3 performance at forward rapidity



- Performance in pp using muons tracks detected in all muon detectors: **MFT+MCH+MID**
- **First prompt/non-prompt J/ψ separation at forward rapidity in ALICE**
- Boost at forward rapidity allows non-prompt fraction measurement **down to $p_T = 0$**



ALI-PERF-571253



ALI-PERF-571258

$$l_{J/\psi} = c \frac{(z_{PV} - z_{SV}) m_{J/\psi}}{p_z}$$

Conclusion & outlook

- Prompt/non-prompt J/ψ separation at mid-rapidity in pp collisions achievable in ALICE down to $p_T = 1.5 \text{ GeV}/c$
 - Prompt J/ψ production captured by NRQCD and ICEM models
 - Non-prompt J/ψ production reproduced by perturbative FONLL calculation
- J/ψ -hadron correlations in pp collisions
 - Near-side yields associated with non-prompt J/ψ larger than prompt J/ψ
 - No strong event multiplicity dependence observed
- **In Run 3**, prompt/non-prompt charmonia measurement is possible at forward rapidity thanks to the installation of the **Muon Forward Tracker (MFT)**, down to $p_T = 0$

Thank you! 谢谢您!



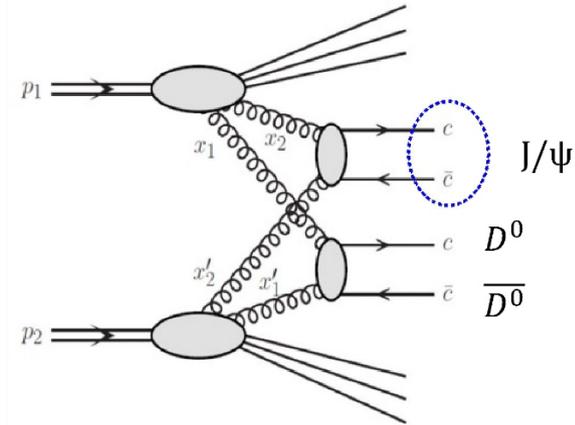
ALICE



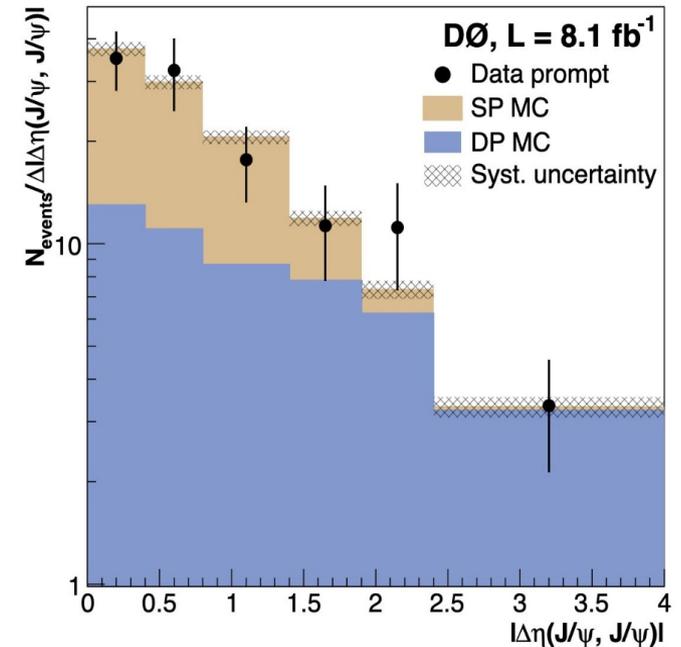
Backup

J/ ψ -D⁰ associated production

- The production of J/ ψ accompanied by open charm allows to constrain **Double Parton Scattering (DPS)**



- In Run 3, ALICE can conduct combined analysis of J/ ψ in muon spectrometer ($2.5 < y < 4.0$) and D⁰ in central barrel ($|y| < 0.8$)
- SPS-DPS separation sensitive to $\Delta y \rightarrow$ **Unique capabilities at the LHC to extend Δy coverage up to ~ 5**



[Phys. Rev. D 90, 111101(R) (2014)]



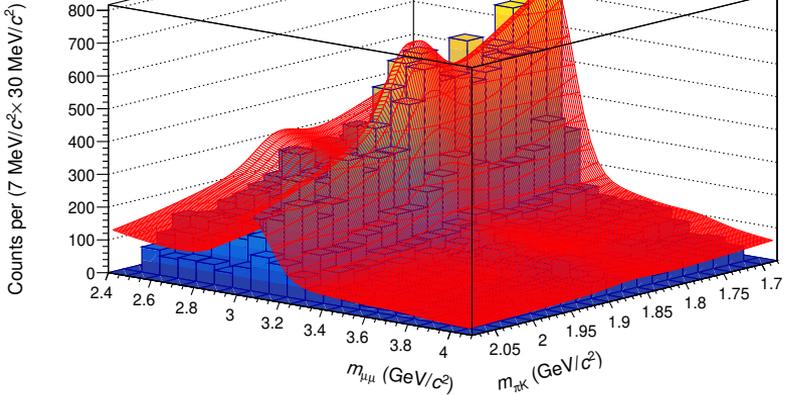
ALICE

J/ψ-D⁰ associated production

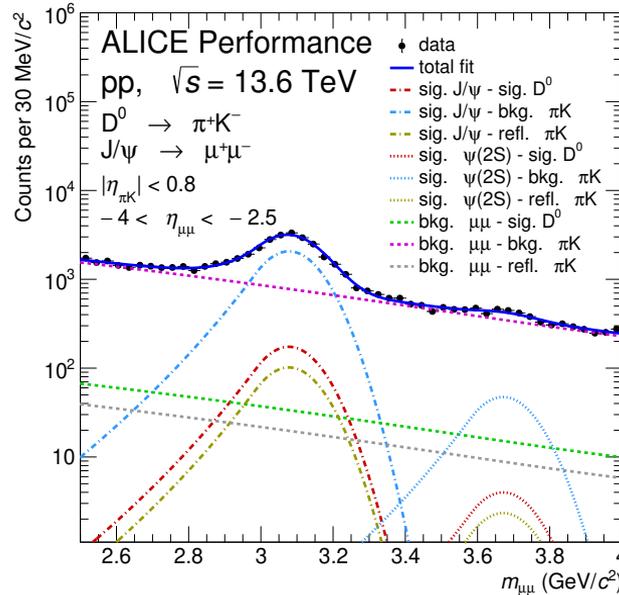
ALICE Performance
pp, $\sqrt{s} = 13.6$ TeV

D⁰ → π⁺K⁻
J/ψ → μ⁺μ⁻

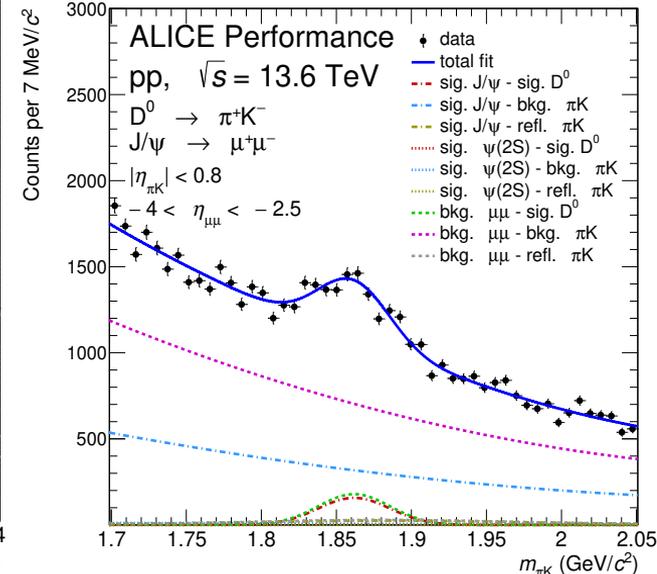
$|\eta_{\pi K}| < 0.8$
 $-4 < \eta_{\mu\mu} < -2.5$



ALI-PERF-580334



ALI-PERF-580356



ALI-PERF-580360

- Based on 2D unbinned maximum likelihood fit on $m_{\pi K}$ and $m_{\mu\mu}$
- First performance evaluation for associated production of D⁰ at midrapidity and inclusive J/ψ at forward rapidity → **towards prompt J/ψ-D⁰ associated production analysis ?**