第九届中国LHC物理年会

Non-prompt J/ψ production in pp collisions

Wenda Guo
Central China Normal University & University of Bergen

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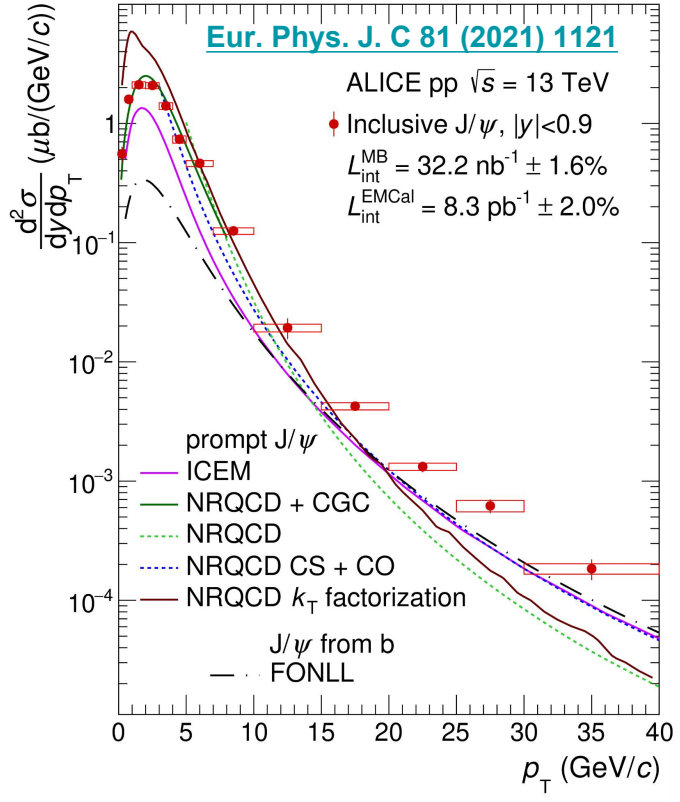
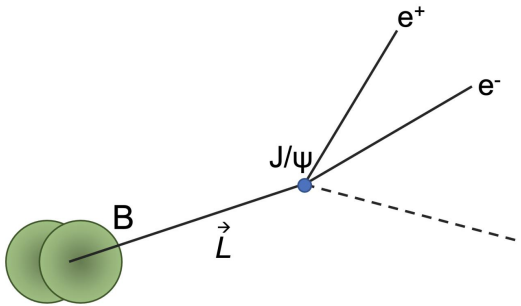
Prompt and non-prompt J/ψ



- The inclusive J/ψ yield can be separated between prompt and non-prompt charmonium.



- Prompt :
  - produced in the collision
- Non-prompt :
  - decayed from B hadron
    - large lived length
    - large rest mass

- Non-prompt J/ψ production allows:
  - Separation of prompt/non-prompt charmonium production
  - Access beauty hadron production.

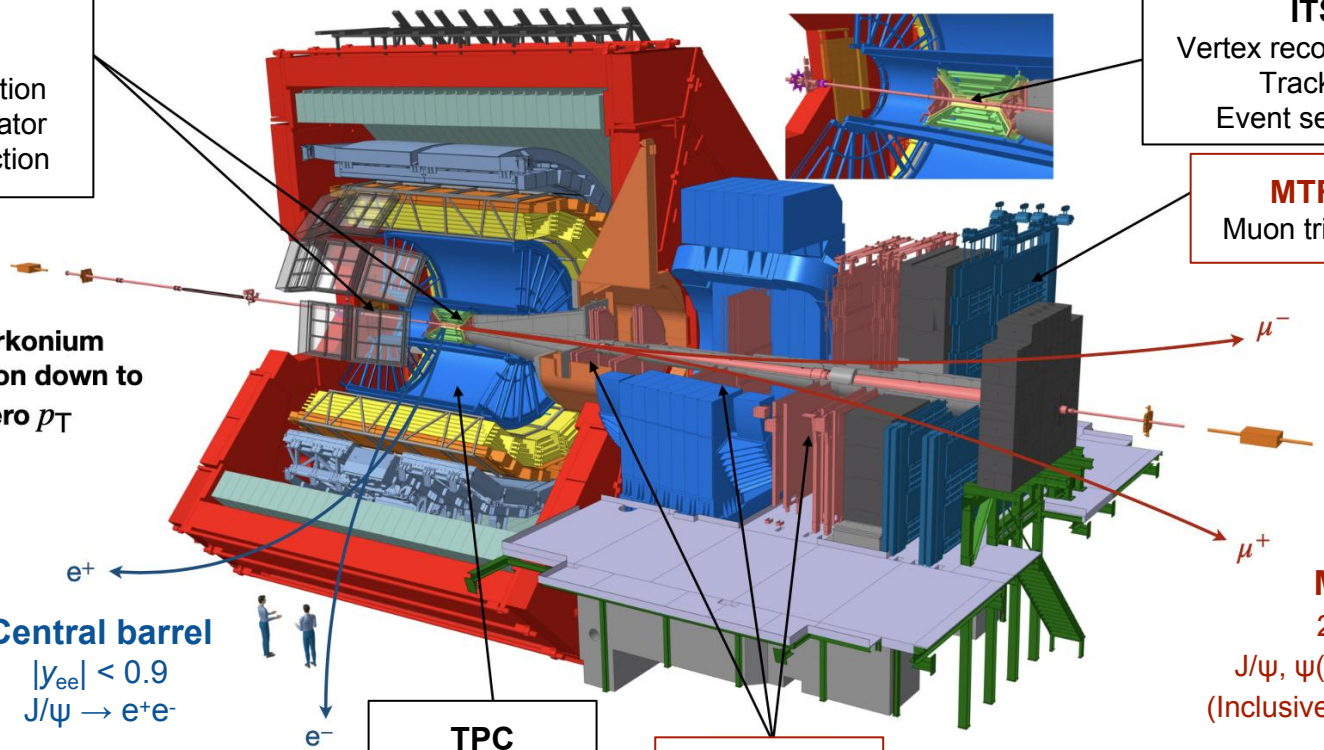
ICEM: V. Cheung et al, Phys. Rev. D 98 (2018) 114029
NRQCD: Ma et al, Phys. Rev. Lett. 106 (2011) 042002
NRQCD+CGC: Ma et al, Phys. Rev. Lett. 113(19) (2014) 192301
NRQCD CS+CO: Butenschoen et al, Phys. Rev. Lett. 106 (2011) 022003
NRQCD kT factorisation: Lipatov et al, Eur. Phys. J. C 80(4) (2020) 330
FONLL: M. Cacciari et al, JHEP 10 (2012) 137

ALICE detector (Run 1 and Run 2)

V0
Trigger
Beam-gas rejection
Centrality estimator
Multiplicity selection

ITS
Vertex reconstruction
Tracking
Event selection

MTR
Muon trigger



Quarkonium detection down to zero p_T

Central barrel
$|y_{ee}| < 0.9$
$J/\psi \rightarrow e^+e^-$

Prompt and non-prompt J/ψ can be separated at midrapidity

TPC
Tracking
PID via d*E*/d*x*

MCH
Muon tracking

Muon arm
$2.5 < y_{\mu\mu} < 4$
J/ψ, $\psi(2S)$, $\Upsilon(nS) \rightarrow \mu^+\mu^-$
(Inclusive quarkonium states)

Separation of prompt and non-prompt J/ψ

- Analysis technique: based on maximization of 2D likelihood function, on invariant mass and pseudoproper decay length (x) fitted simultaneously

Signal Background

$$F(x, m_{ee}) = f_{Sig} \times F_{Sig}(x) \times M_{Sig}(m_{ee}) + (1 - f_{Sig}) \times F_{Bkg}(x) \times M_{Bkg}(m_{ee})$$

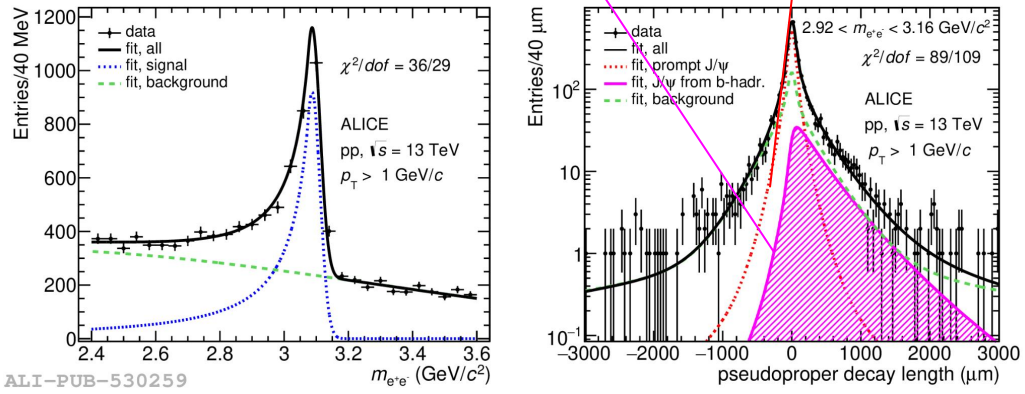
$$F_{Sig}(x) = f_B' \times T(x) + (1 - f_B') \times R(x)$$

non-prompt prompt

Likelihood function:

$$\ln\{L\} = \sum \ln\{F(x, m_{ee})\}$$

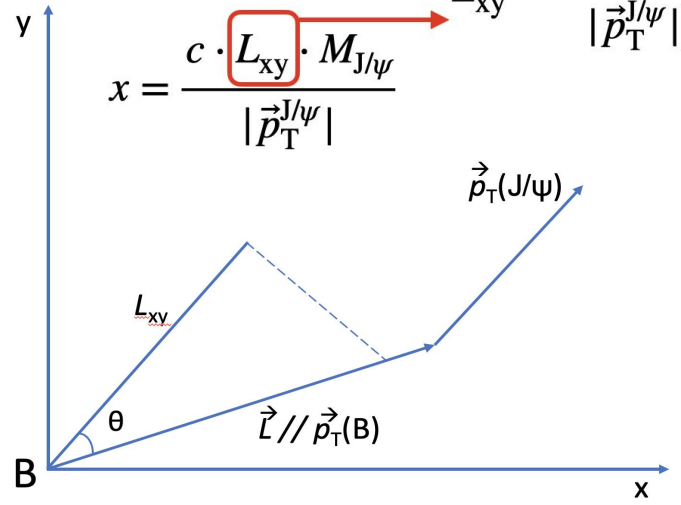
Likelihood fit performance



x is defined as

$$x = \frac{c \cdot L_{xy} \cdot M_{J/\psi}}{|\vec{p}_T^{J/\psi}|}$$

$$L_{xy} = \frac{\vec{L} \times \vec{p}_T^{J/\psi}}{|\vec{p}_T^{J/\psi}|}$$



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Separation of prompt and non-prompt J/ψ

- Analysis technique: based on maximization of 2D likelihood function, on invariant mass and pseudoproper decay length (x) fitted simultaneously

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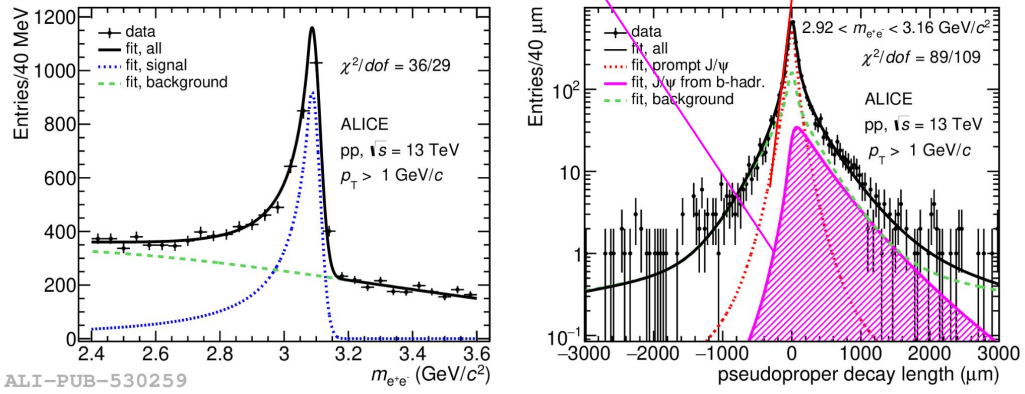
non-prompt prompt

Likelihood fit performance



- f_B' is the raw fraction of non-prompt J/ψ, which is extracted from the likelihood fit, needs to be corrected by acceptance times efficiency which could be slightly different for prompt and non-prompt J/ψ

- Efficiency and acceptance correction formula:

$$f_B = \left(1 + \frac{1 - f_B'}{f_B'} \cdot \frac{\langle A \times \varepsilon \rangle_B}{\langle A \times \varepsilon \rangle_{Prompt}}\right)^{-1}$$

  - f_B is the fraction of non-prompt J/ψ after efficiency and acceptance correction

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f_B fraction vs p_T in pp at $\sqrt{s}$ = 13 TeV

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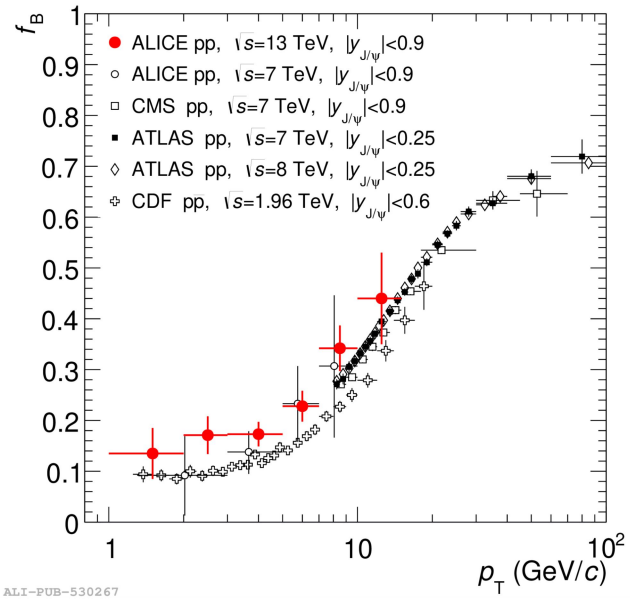

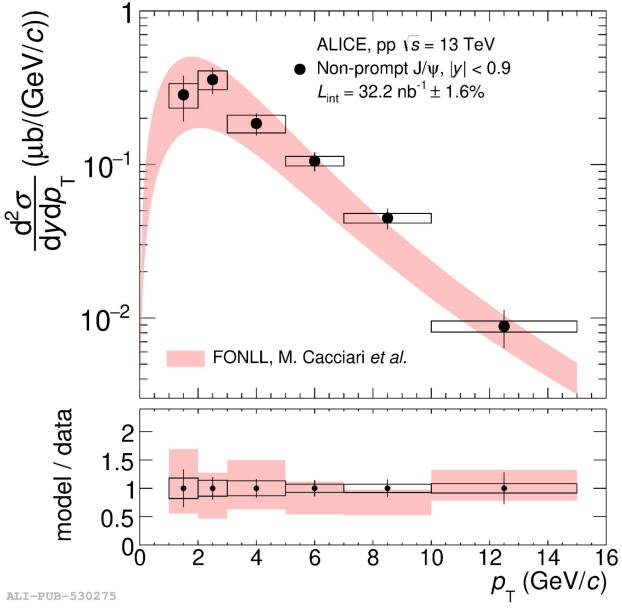

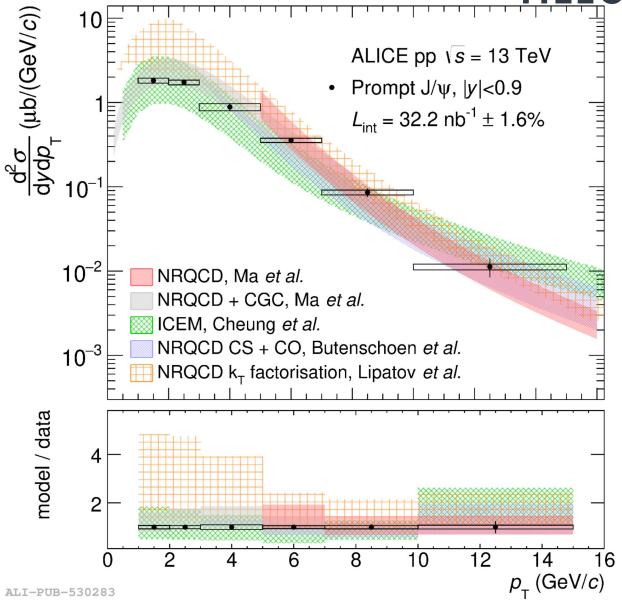

- Fraction of non-prompt J/ψ vs p_T at $\sqrt{s}$ = 13 TeV is measured.
- Non-prompt and prompt J/ψ cross sections are computed by combining non-prompt J/ψ fractions and inclusive J/ψ measurements
- The cross sections are consistent with different model calculations.
- Beauty-quark production cross sections can be inferred from non-prompt J/ψ measurements

Inclusive J/ψ production: Eur. Phys. J. C 81 (2021) 1121
FONLL: M. Cacciari et al, JHEP 10 (2012) 137
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f_B fraction vs p_T in pp at $\sqrt{s}$ = 5 TeV

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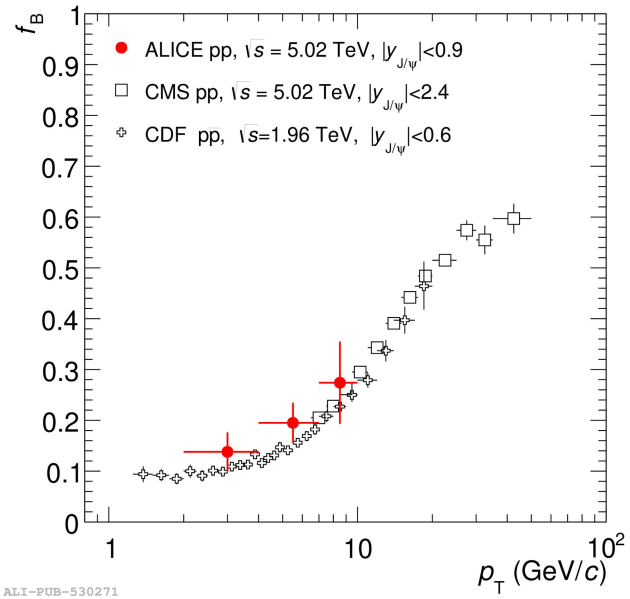

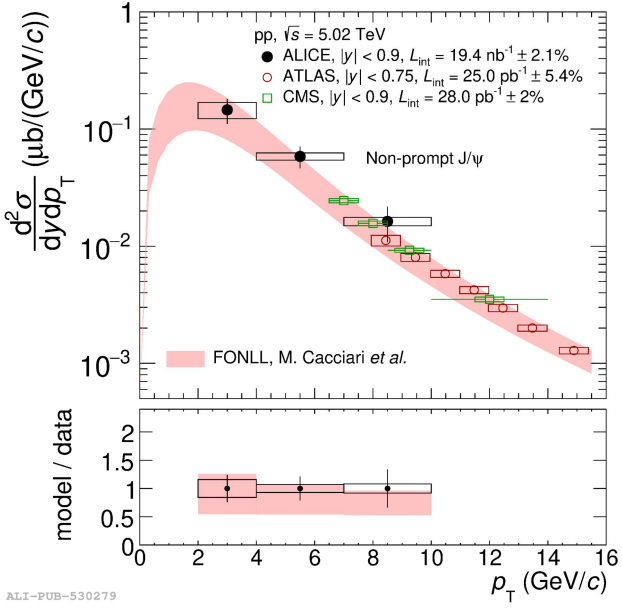

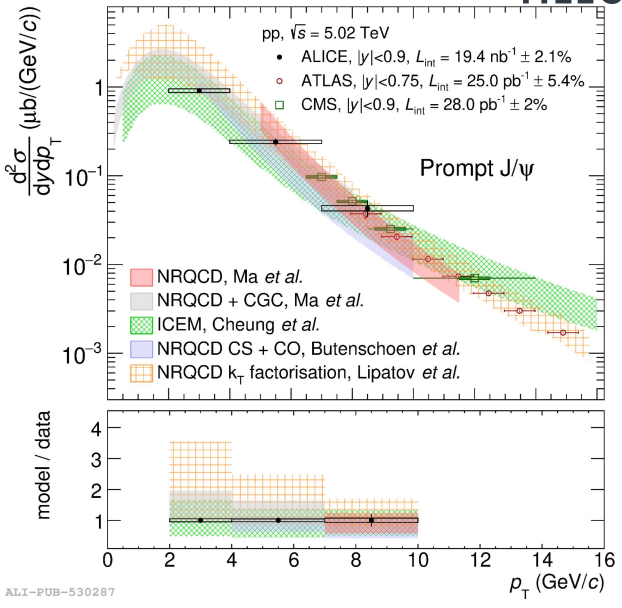

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Cross section of beauty

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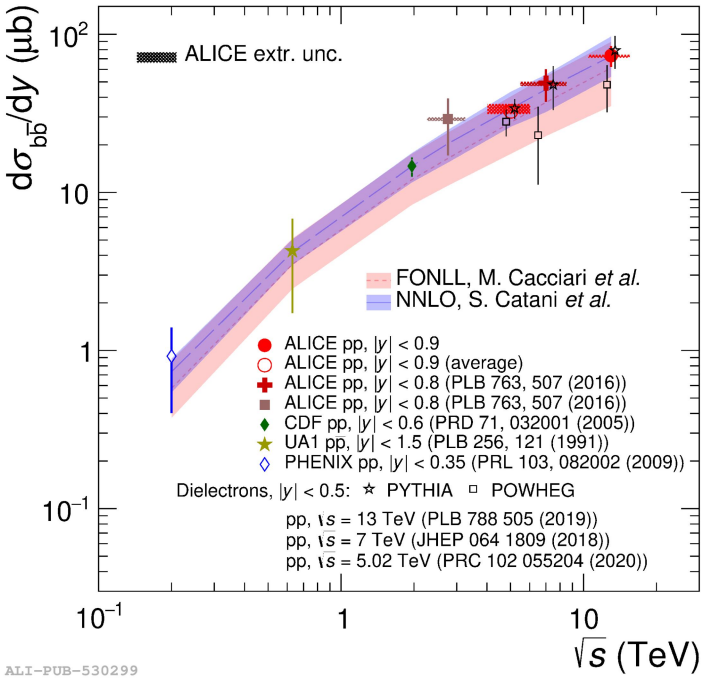
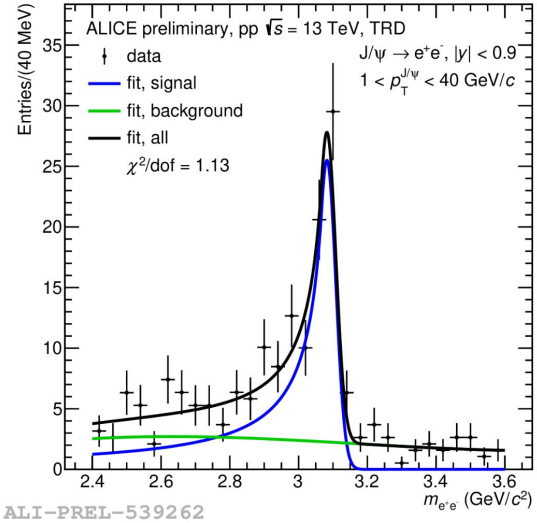


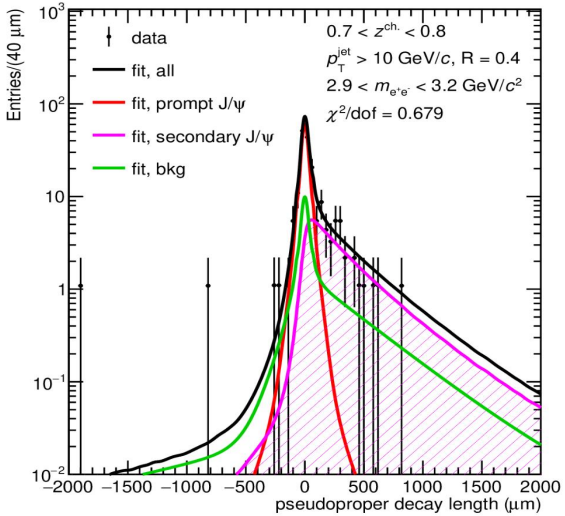
- The beauty cross sections are derived by non-prompt J/ψ production.
  - Calculation is by:

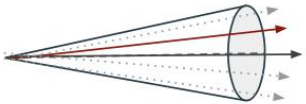
$$\sigma(\mathrm{pp} \to \mathrm{b\bar{b}} + \mathrm{X}) = \frac{\alpha_{4\pi}}{2 \times BR(\mathrm{h_B} \to \mathrm{J}/\psi + \mathrm{X})} \times \sigma_{\mathrm{J}/\psi}^{\mathrm{non-prompt}}$$

    - $\alpha_{4\pi}$: full phase correction
    - *BR* : branch ratio from beauty hadrons to J/ψ

prompt and non-prompt J/ψ in jets at $\sqrt{s}$ = 13 TeV







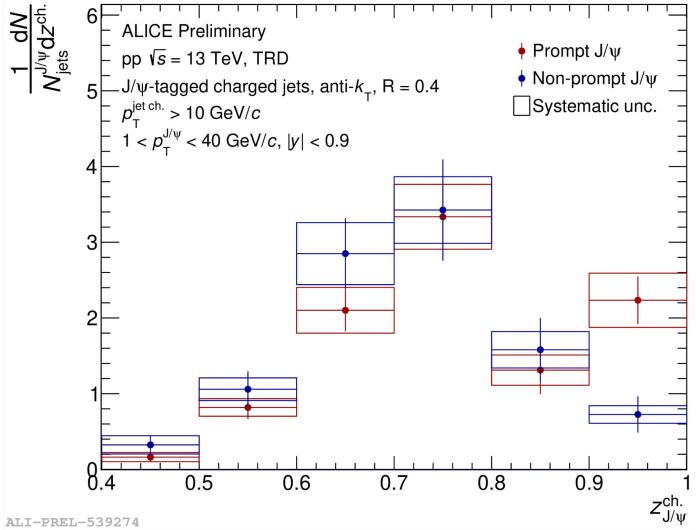
$$z^{ch} = \frac{p_T^{J/\psi}}{p_T^{jet,ch}}$$

Fragmentation function

- Prompt and non-prompt J/ψ fragmentation functions are found to be similar within uncertainties
- Insight on J/ψ production/fragmentation interplay with underlying event

Jets tagged with presence of a reconstructed J/ψ in the e^+e^- channel at midrapidity

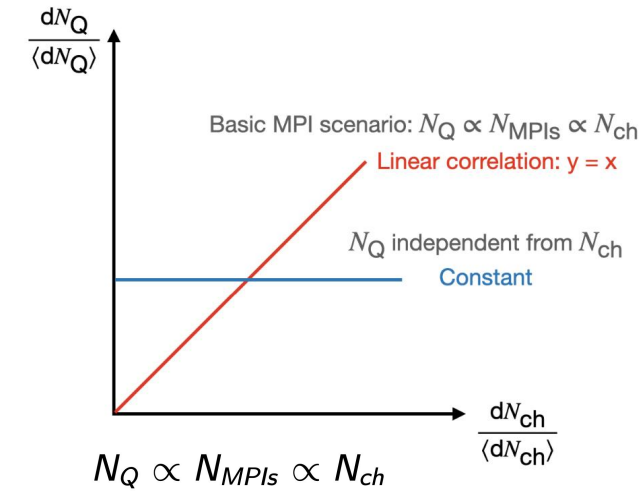
Separate prompt and non-prompt J/ψ signal with maximum likelihood fit

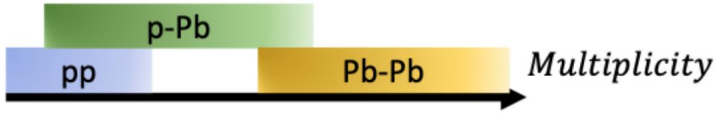


Multiplicity dependence of J/ψ production

- Multiplicity dependent analysis can give insights into
  - Multiparton Interactions (MPI)
  - Interplay of hard components (NQ) and underlying event (Nch)
  - Key observable to disentangle initial and final state effects

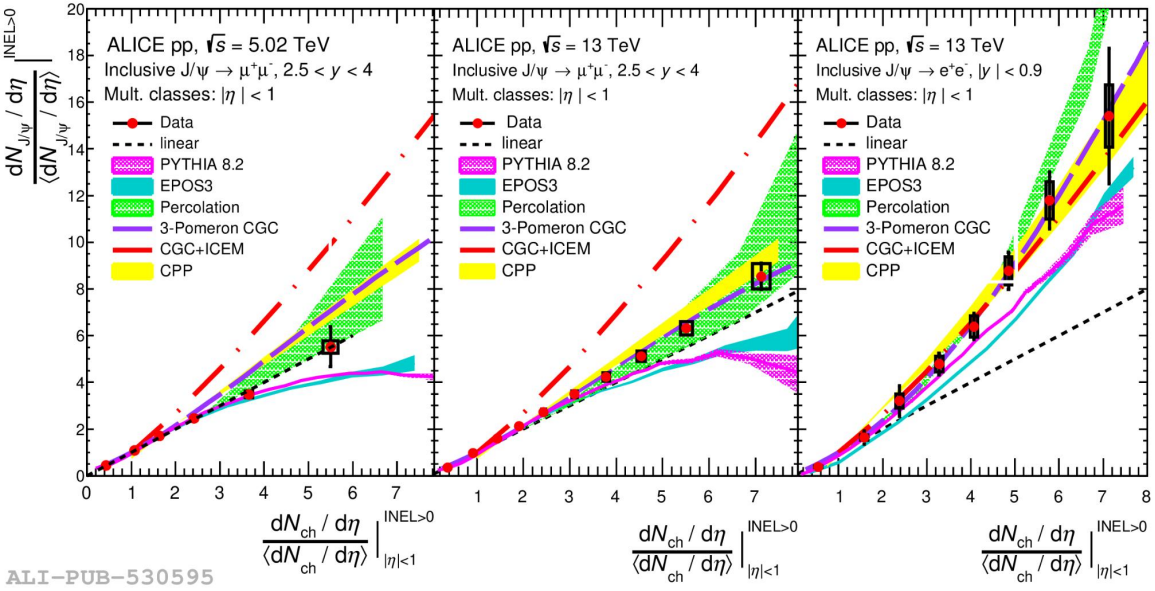
- Prompt and non-prompt J/ψ vs multiplicity measurements
  - possible estimation of B-hadron production vs multiplicity
  - more accurate calculation on prompt J/ψ





Inclusive J/ψ production vs multiplicity

JHEP 06 (2022) 015



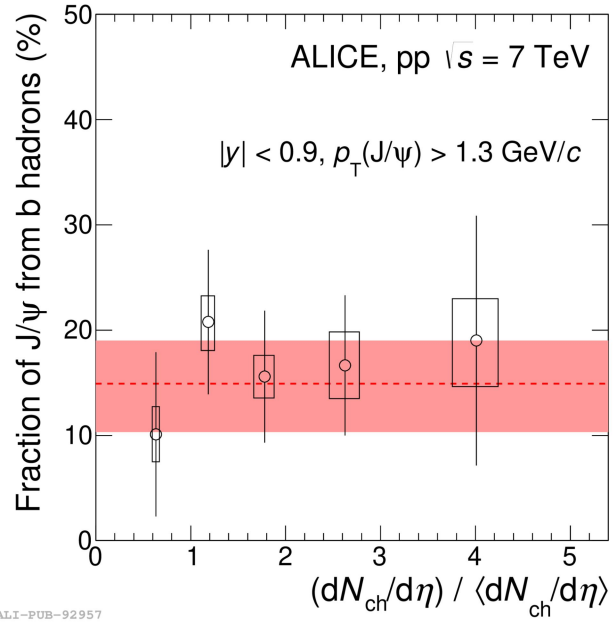
- J/ψ at forward rapidity (left & middle panels)
  - Approximately increases linearly independently of the collision energy
- J/ψ at midrapidity (right panel)
  - Faster than linear increase

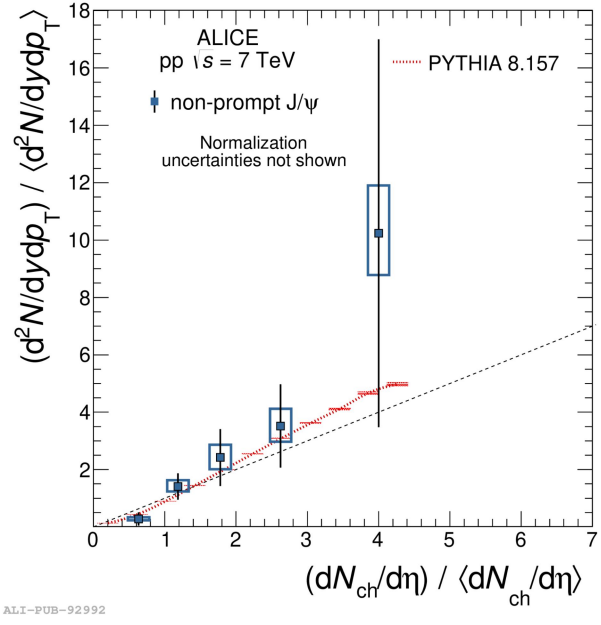
- Good agreement at $\sqrt{s}$ = 13 TeV provided by the Coherent Particle Production (CPP), the 3-Pomeron CGC and Percolation models in both rapidity intervals
- Stronger than linear correlation at midrapidity well reproduced by the models although the exact origin of this behaviour is still not well understood

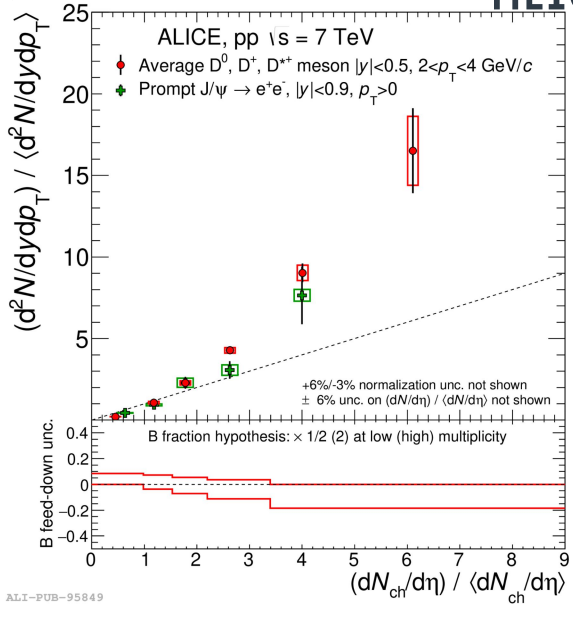
f_B fraction vs multiplicity in pp at $\sqrt{s}$ = 7 TeV

JHEP 09 (2015) 148

D meson production: JHEP 09 (2015) 148
PYTHIA 8.157: T. Sjoestrand et al, Comput. Phys. Commun. 178 (2008) 852

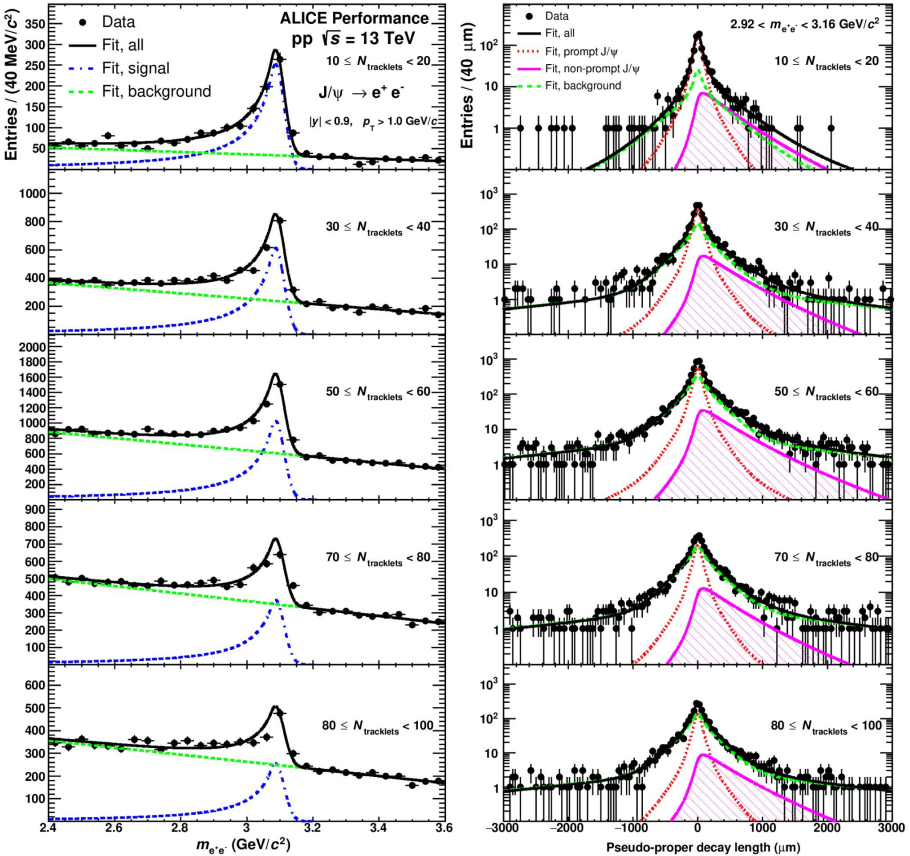






- Fraction of non-prompt J/ψ in pp collisions at $\sqrt{s}$ = 7 TeV shows no multiplicity dependence
- The results at $\sqrt{s}$ = 7 TeV can reach 4 times the average multiplicity (higher multiplicity reach expected at $\sqrt{s}$ = 13 TeV thanks to high-multiplicity triggered data)
- Prompt J/ψ production vs multiplicity shows an increase with charged-particle multiplicity, which is faster than linear
- Hint for similar faster than linear increase of the yields with the multiplicity for non-prompt J/ψ, however uncertainties are large to conclude

Towards f_B fraction measurement vs multiplicity in pp at $\sqrt{s}$ = 13 TeV

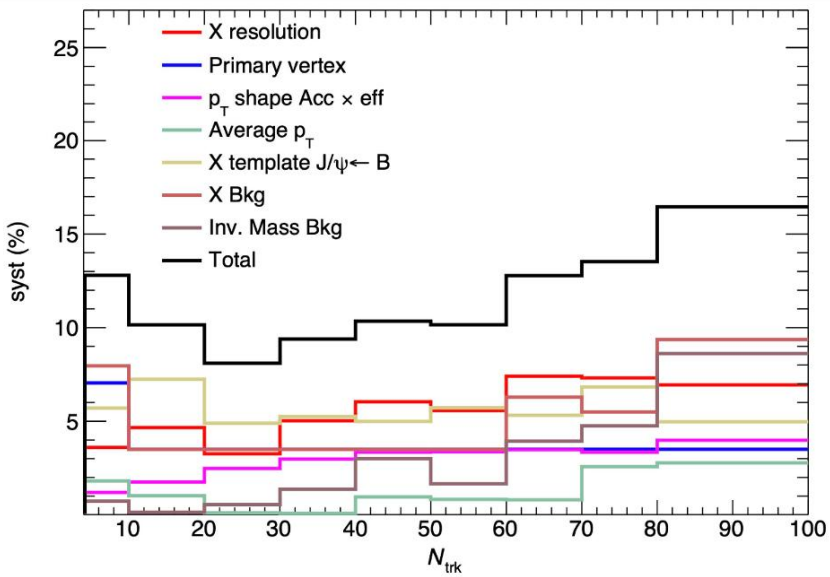


ALI-PERF-539349

- Fraction of non-prompt J/ψ vs multiplicity in pp collisions at $\sqrt{s}$ = 13 TeV is measured with ALICE, via 2D maximum likelihood fit method.
- Significantly higher multiplicity region reach compared to $\sqrt{s}$ = 7 TeV thanks to high-multiplicity triggered events, reaching ***7 times*** the average multiplicity (4 times at $\sqrt{s}$ = 7 TeV).

Systematic uncertainties

- syst. on resolution function
  - residual mismatch data / MC for single leg impact parameter
  - dependence on multiplicity due to a change of <pT>
- syst. on x-background PDF
- syst. on x-template PDF of non-prompt J/ψ
- syst. on pT shape variation vs multiplicity
- syst. on invariant mass signal shape
- syst. on invariant mass background fit



Summary and outlook

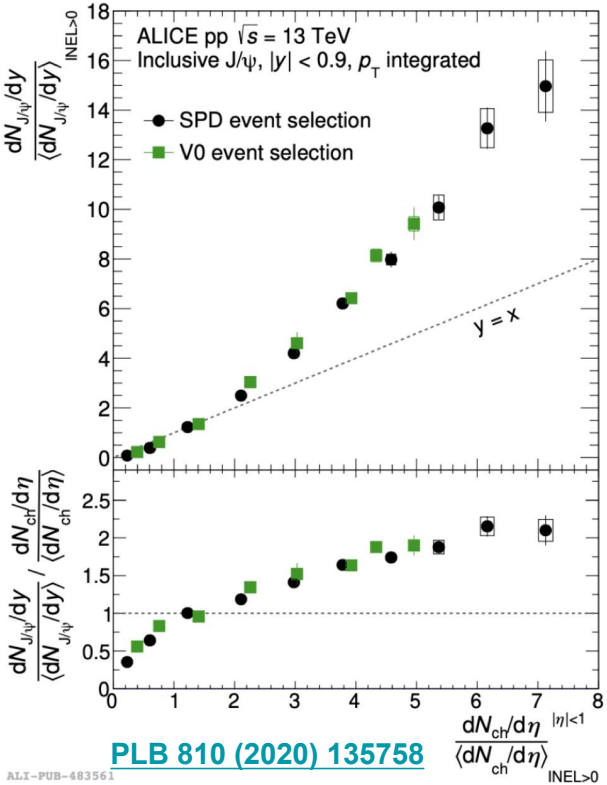
Summary

- The prompt and non-prompt J/ψ cross sections are measured and have a good agreement with other experimental results and theoretical models.
- The study of non-prompt J/ψ vs multiplicity is ongoing.
- The framentation function of prompt and non-prompt J/ψ show no difference.

Outlook

- Prompt and non-prompt J/ψ yields vs multiplicity will be evaluated by combining with existing inclusive J/ψ measurements

Thanks for your attention!



PLB 810 (2020) 135758