Heavy-flavour hadron production in ATLAS

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J/ψ and $\psi(2S)$ Cross-section Measurements

- Paper published in February:
  Eur. Phys. J. C 84 (2024) 169
- Summarised in an ATLAS **briefing**.
- Previous measurements:
  - 7 TeV: **JHEP 2014, 79 (2014)**
  - 8 TeV: **Eur. Phys. J. C 76(5), 1-47, (2016)**
- New in this result: higher energy, broader p_{T} range.

Overview

Motivation

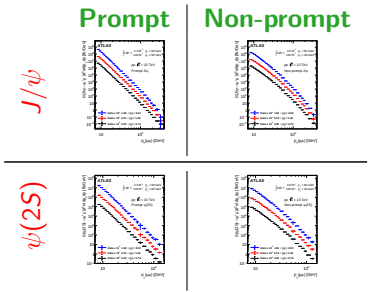
- Charmonium can be produced promptly (from QCD sources) or non-promptly (from b-hadron decays).
- Prompt production is poorly modeled.
- The measurements presented here join a library of measurements, including those by **CMS**, **ALICE**, and **LHCb**, that can help guide theoretical models.

Four production modes:

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

Measurement categories:

- Double differential cross section in $p_T(\mu\mu)$ and $|y|$.
- Non-prompt fraction.
- J/ψ vs $\psi(2S)$ fraction.



Event selection

Data samples

- 2.6 fb^{-1} sample for $p_T(\mu\mu) \in [8, 60]$ GeV $\rightarrow$ using **low-p_T dimuon** trigger.
  - **Dimuon trigger looses efficiency at high-p_T.**
- 140 fb^{-1} sample for $p_T(\mu\mu) \in [60, 360]$ GeV $\rightarrow$ using **50 GeV single muon** trigger.
- Multiple candidates allowed per event.

Measurement bins

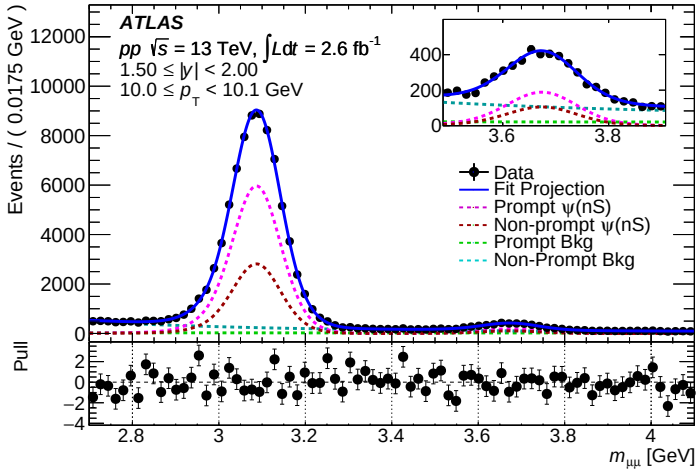
- 34 $p_T(\mu\mu)$ bins from 8 to 360 GeV
- 3 bins in rapidity, $|y|$, from 0 to 2.0.

Key observables

- Dimuon mass (distinguishes J/ψ and $\psi(2S)$).
- Pseudo-proper lifetime (distinguishes prompt and non-prompt).

Observables 1) $m_{\mu\mu}$

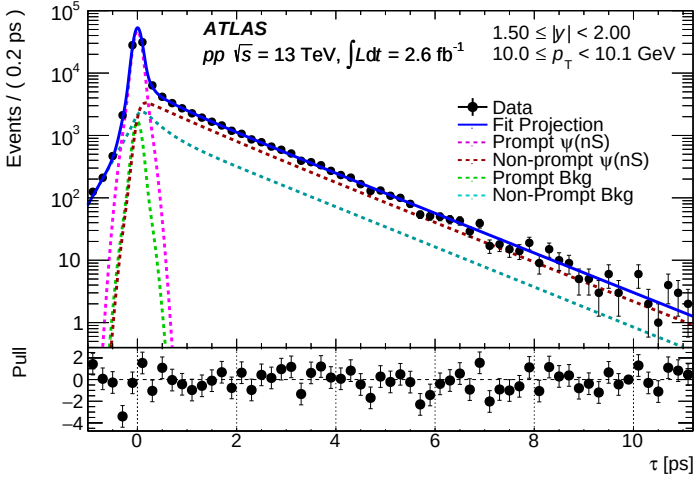
- **Dimuon mass** distribution distinguishes J/ψ and $\psi(2S)$.
- **Signal** modeled by combination of Gaussians and Crystal Ball functions.
- **Background** modeled by exponentials and polynomials.



Observables 2) τ

- **Pseudo-proper lifetime** $\tau = \frac{m_{\mu\mu}}{p_T}\frac{L_{xy}}{c}$, where L_{xy} is the distance between the primary and secondary vertex.
- Distinguishes prompt and non-prompt production.
- Prompt production modeled by delta functions.
- Non-prompt production modeled by exponentials.

All are convolved with detector resolution.



Cross-section measurement

The $m_{\mu\mu}, \tau$ fit is performed in bins of (p_T,y):

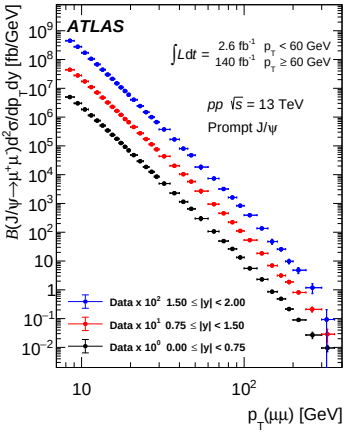
- For prompt (P) and non-prompt (NP), and $\psi = J/\psi, \psi(2S)$:

$$\frac{d^2\sigma^{\mathrm{P,NP}}(pp \to \psi)}{dp_T dy} \times \mathcal{B} = \frac{1}{\mathcal{A}(\psi)\epsilon_{\mathrm{trig}}\epsilon_{\mathrm{trigSF}}\epsilon_{\mathrm{reco}}\epsilon_{\mathrm{recoSF}}} \times \frac{N_\psi^{\mathrm{P,NP}}}{\Delta p_T \Delta y \mathcal{L}}$$

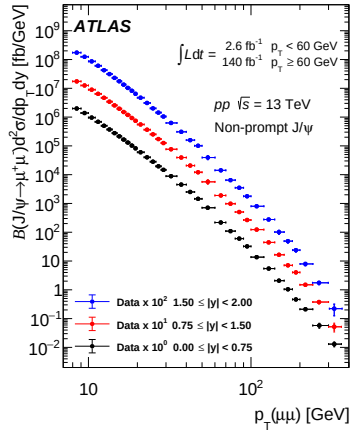
- $N^{\mathrm{P,NP}}$: yield extracted 2D fit in $m_{\mu\mu}$ and pseudo-lifetime (τ)
- $\mathbf{A}(\psi)$: Acceptance, determined by truth variable distributions.
- **Efficiencies**: determined from simulation, including reconstruction and trigger efficiencies.
- Δp_T, Δy, $\mathcal{L}$: bin widths and integrated luminosity.

Results: Differential XS for J/ψ

Prompt J/ψ



Non-prompt J/ψ

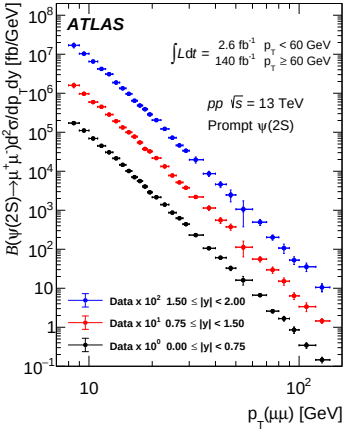


- **Measurements in y bins scaled for visual clarity**

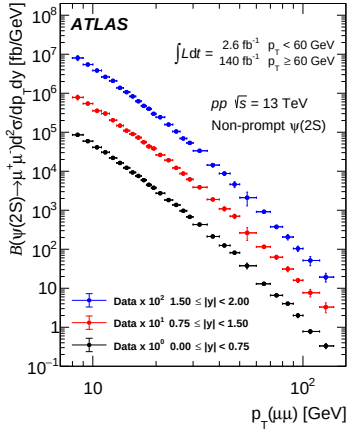
Results: Differential XS for $\psi(2S)$

- Differential J/ψ
- Differential $\psi(2S)$
- Non-prompt fraction
- $\psi(2S)/J/\psi$ fraction

Prompt $\psi(2S)$

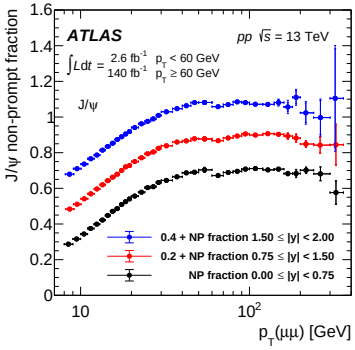


Non-prompt $\psi(2S)$

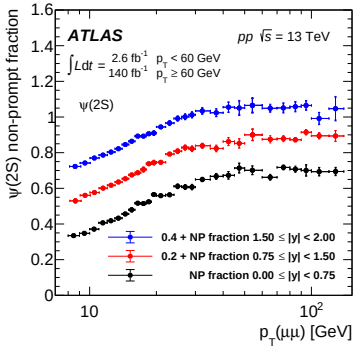


Results: Non-prompt fractions

J/ψ fraction



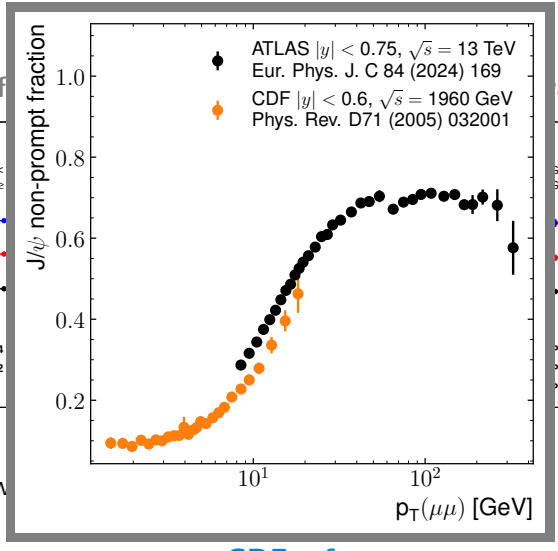
$\psi(2S)$ fraction

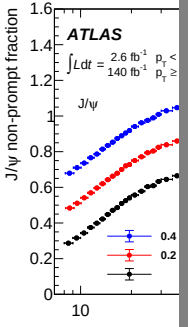


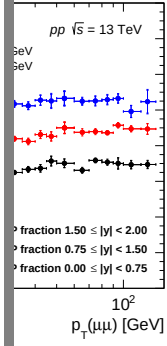
- Increasing in low-p_T region, flat above p_T ≈100 GeV.

Results: Non-prompt fractions

- Differential J/ψ
- Differential $\psi(2S)$
- Non-prompt fraction
- $\psi(2S)/J/\psi$ fraction







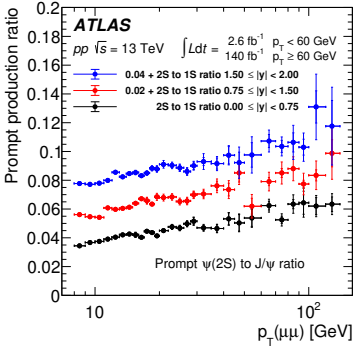
- Increasing in low

CDF ref

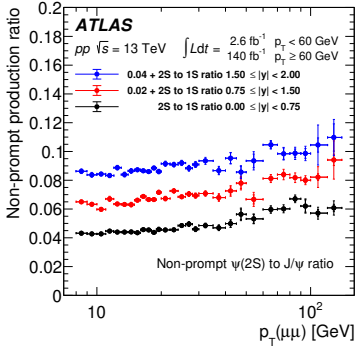
Results: $\psi(2S)$-vs-J/ψ fractions

- Differential J/ψ
- Differential $\psi(2S)$
- Non-prompt fraction
- $\psi(2S)/J/\psi$ fraction

Prompt ratio



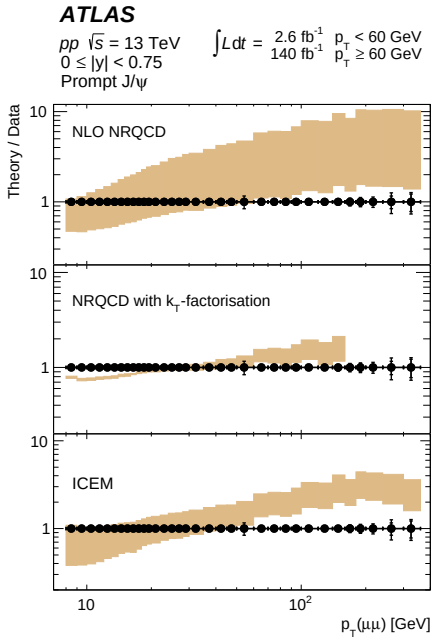
Non-prompt ratio



Theory comparison: prompt production

Prompt J/ψ →

- **NLO NRQCD**: non-relativistic QCD, with corrections. **Overestimate** at high-$p_T(\mu\mu)$.
- **NRQCD with k_T**: takes into account transverse degrees of freedom of initial gluons. **Underestimates** at low-$p_T(\mu\mu)$.
- **ICEM**: improved colour evaporation model. Model that fixes individual charmonium production cross-sections. **Overestimation** at high-$p_T(\mu\mu)$.



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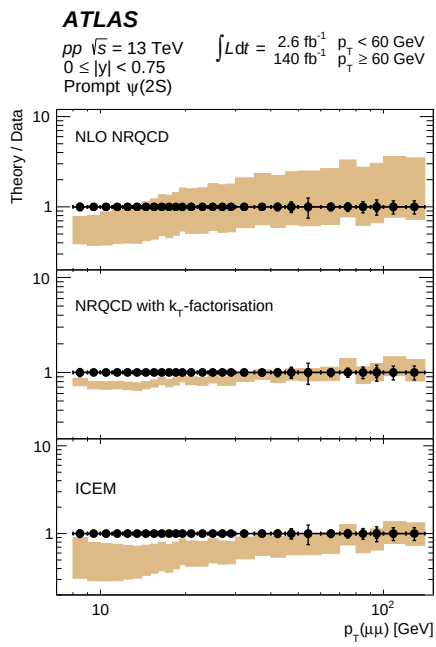
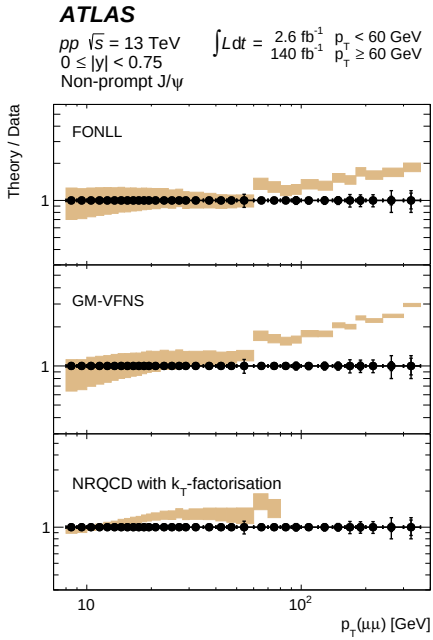


Theory comparison: non-prompt

Non-prompt J/ψ →

- **FONLL**: matches NLO QCD to NLL. **Overestimates** for high $p_T(\mu\mu)$.
- **GM-VFNS**: non-purturbative fragmentation function for b. **Overestimates** for high $p_T(\mu\mu)$.
- **k_T factorization**: takes into account transverse degrees of freedom of initial gluons.



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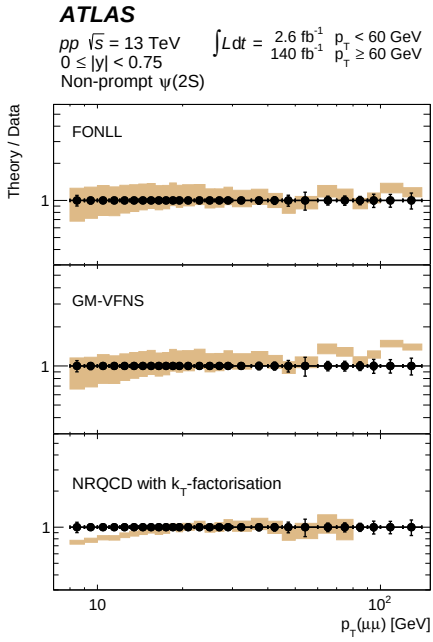
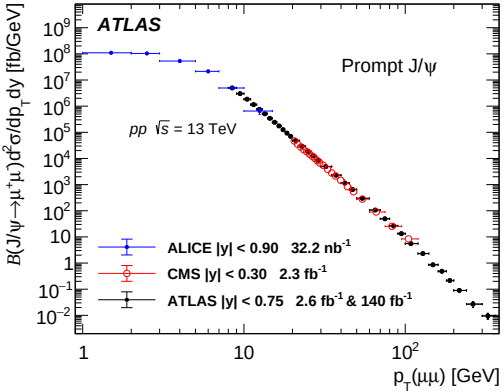


Summary

- Differential cross-section measurements are presented for **prompt and non-prompt J/ψ and $\psi(2S)$**.
- These complement previous ATLAS results at higher $\sqrt{s}$ and cover a broader p_{T} range.
- Measurement in the widest kinematic region to date.
- The **non-prompt ratio** and $\psi(2S)$-vs-J/ψ ratio are provided.
- Comparisons are made with theoretical predictions, with general **over-prediction of the cross-section at high-p_{T}**.



- **Excellent agreement with CMS and ALICE**
- Complementarity areas of coverage.
- CMS measurement: 1710.11002
- ALICE measurement: 2108.02523
- **Note the different y ranges.**