Measurement of the production cross-section of J/ψ and ψ(2S) mesons at high transverse momentum in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

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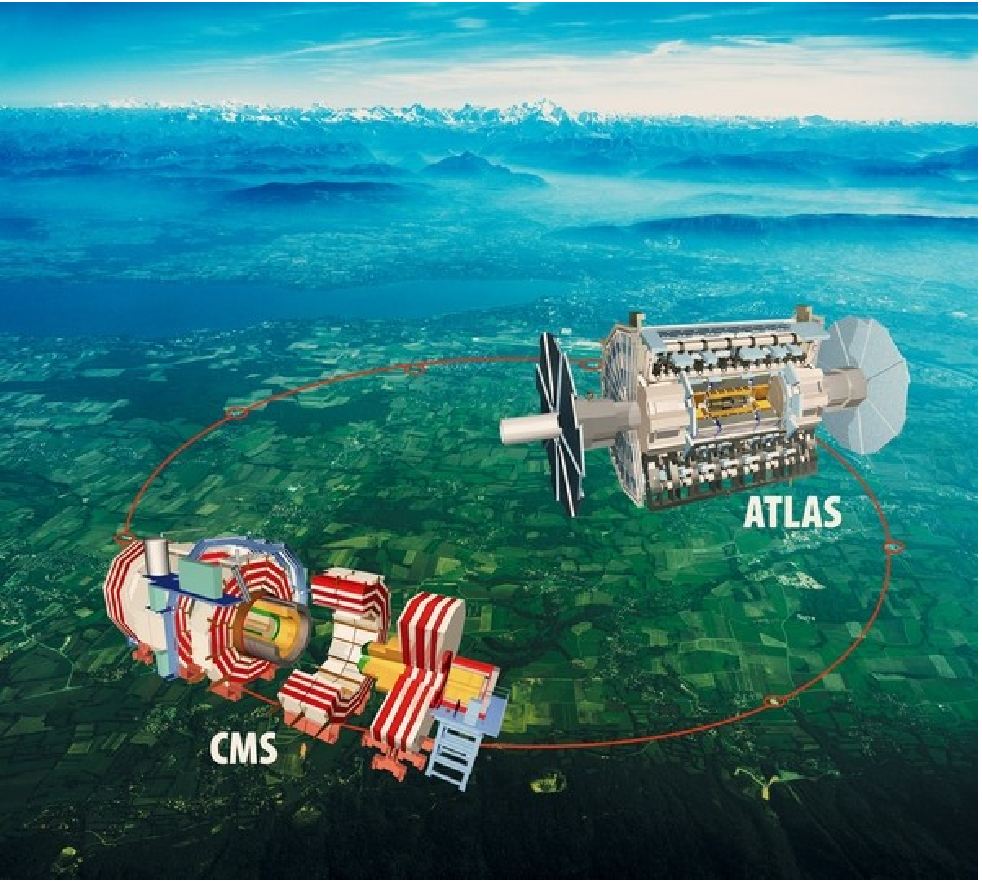

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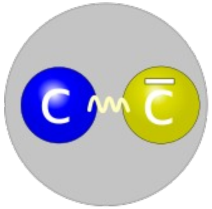
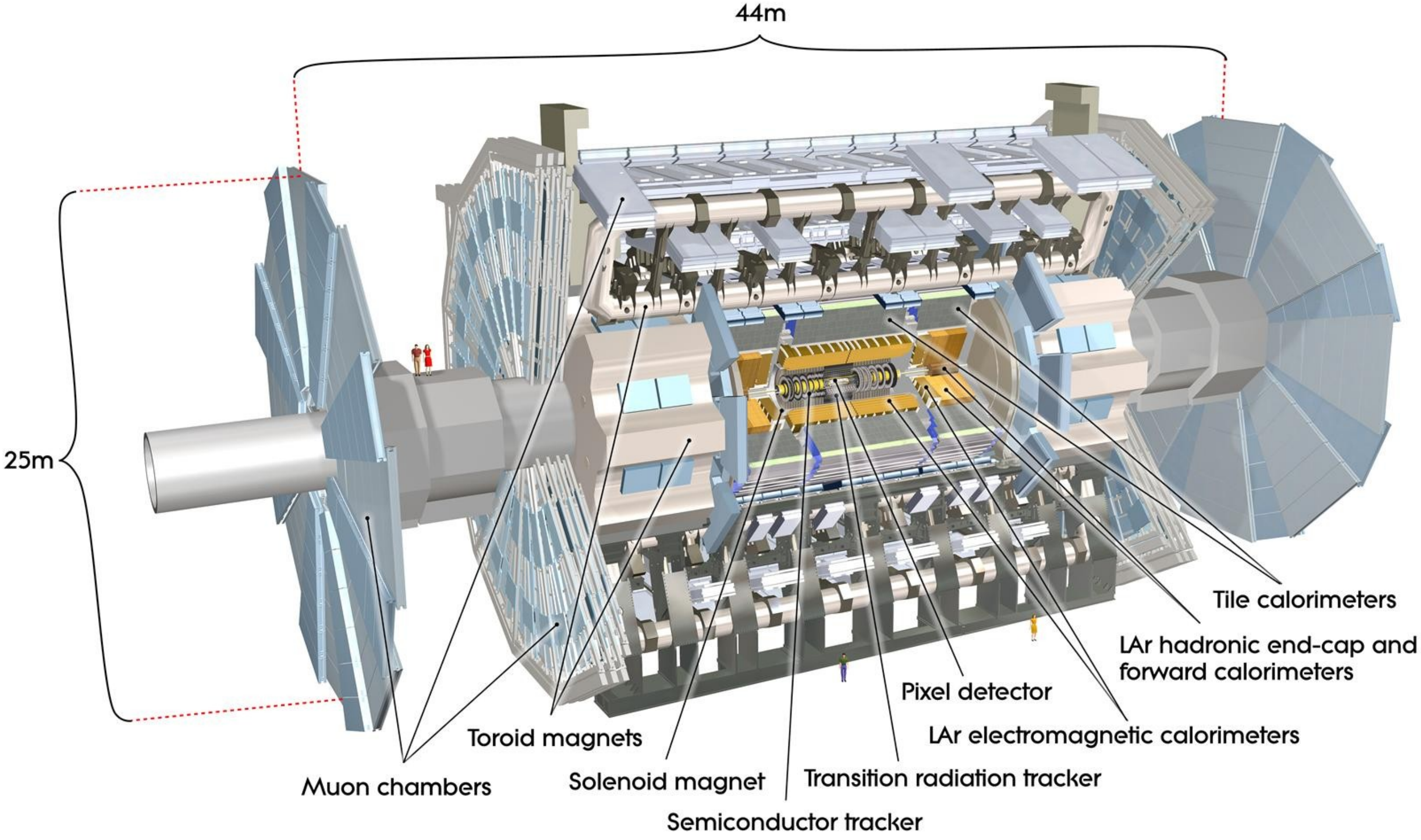
Introduction



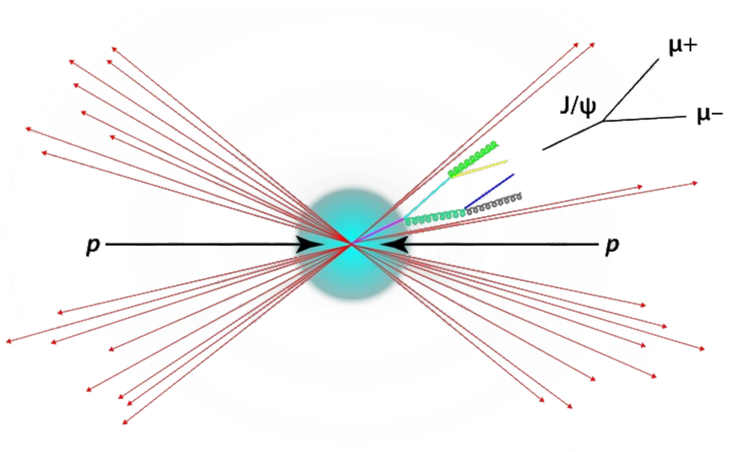
- Quarkonia (J/ψ and ψ(2S)) are formed from a quark pair of the same flavor and should represent one of the simplest systems described by QCD theory.
- However the mechanisms responsible for the production of quarkonia, are not fully understood in hadron collisions.
- Analysis goals are to:
  - Perform the measurement of J/ψ and ψ(2S) production cross-sections;
  - Separately for prompt and non-prompt contributions;
  - Measure ψ(2S) to J/ψ production ratios;
  - Achieve the widest possible range of transverse momenta, to help distinguish better different theoretical contributions;
  - This preliminary measurement covers only the high p_T part of measurement.
  - 12 bins in pT between 60 GeV up to 360 GeV, 3 bins in rapidity;
  - Broaden the scope of comparison between theory and experiment.

ATLAS detector at LHC



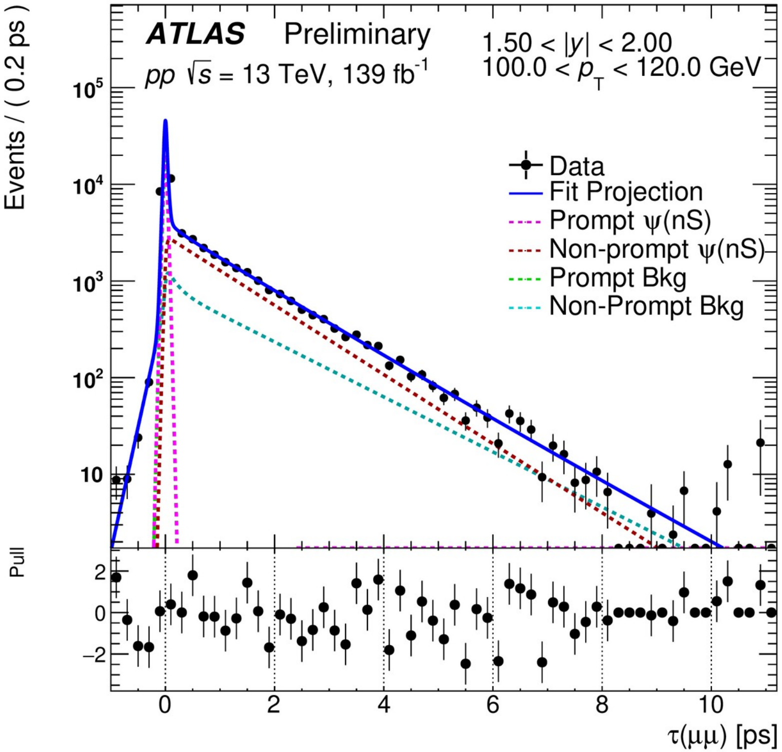
Strategy

- Full Run 2 statistics of LHC pp collisions at $\sqrt{s}$=13 TeV with ATLAS detector;
- Integrated luminosity L = 139 fb^{-1};
- Select charmonium candidates, J/ψ and $\psi(2S)$, as pairs of oppositely charged muons: $J/\psi\ (\rightarrow \mu^{+}\mu^{-})$.



- Used a single-muon trigger, with p_T > 50 GeV;
- Perform 2-dimensional unbinned maximum-likelihood fits to mass and pseudo-proper time to extract yields.
- Apply corrections for acceptance, efficiency and bin migration.

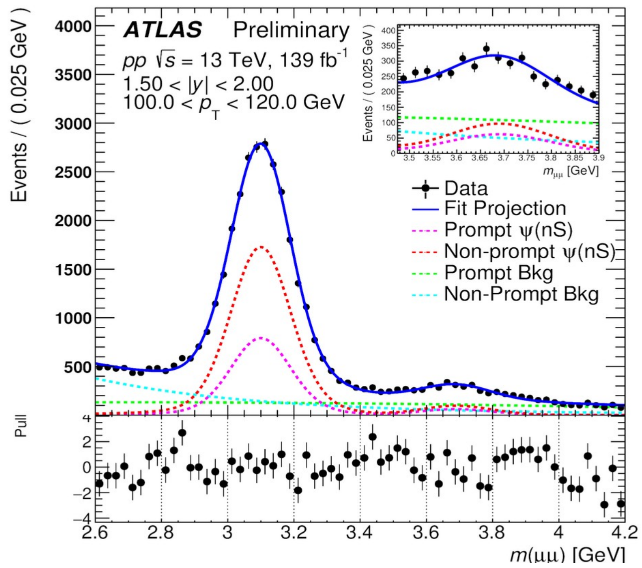
Prompt and Non-prompt production

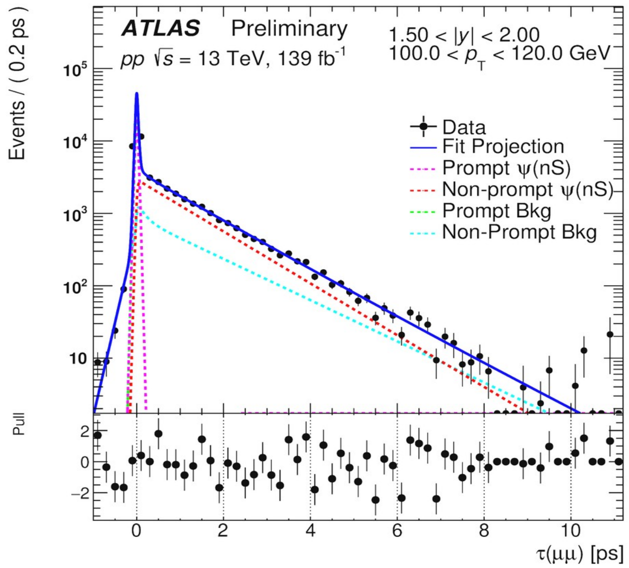


Prompt production: J/ψ and ψ(2S) produced in the hard scattering process. They have a pseudo-proper time consistent with zero within resolution.

Non-prompt production: J/ψ and ψ(2S) produced in the decay of a B hadron, decay vertex separated from the primary vertex. Their decay vertices are displaced from the primary vertex and have positive pseudo-proper time on average.

$$\tau = \frac{m}{p_T}\frac{L_{xy}}{c}$$





Fit model

The 2D fit model is described by a sum of the following terms:

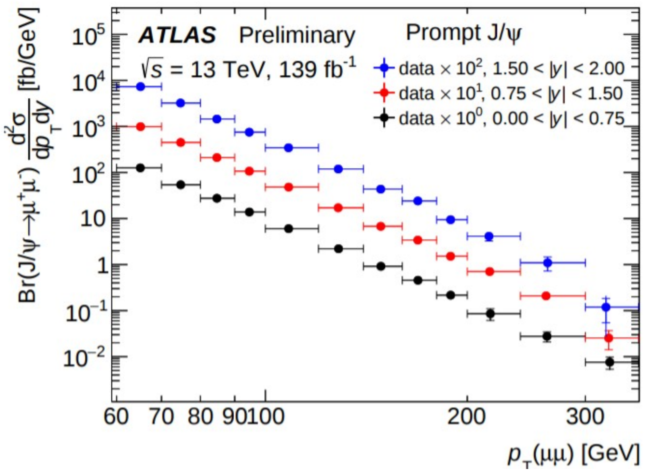
$$PDF(m,\tau) = \sum_{i=1}^{7} \kappa_i f_i(m) \cdot (h_i(\tau) \otimes R(\tau)) \cdot C_i(m,\tau).$$

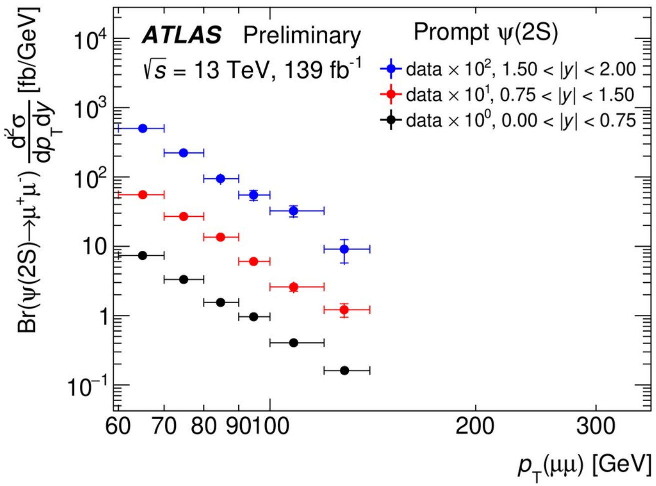
Where m is the dimuon invariant mass, while τ is the pseudo-proper lifetime of the dimuon. R(τ) in the equation is the function describing the experimental resolution in pseudo-proper lifetime. It is parameterised as a weighted sum of three Gaussians, with $\sigma_2 = 2\,\sigma_1$ and $\sigma_3 = 3\,\sigma_1$, where the relative weights and σ_1 are free parameters.

i	Type	P/NP	$f_i(m)$	$h_i(\tau)$	$C_i(m,\tau)$
1	J/ψ	P	$\omega G_1(m) + (1-\omega)CB_1(m)$	$\delta(\tau)$	$BV(m,\tau,\rho)$
2	J/ψ	NP	$\omega G_1(m) + (1-\omega)CB_1(m)$	$E_1(\tau)$	1
3	$\psi(2S)$	P	$\omega G_2(m) + (1-\omega)CB_2(m)$	$\delta(\tau)$	1
4	$\psi(2S)$	NP	$\omega G_2(m) + (1-\omega)CB_2(m)$	$E_2(\tau)$	1
5	Bkg	P	B	$\delta(\tau)$	1
6	Bkg	NP	$E_4(m)$	$E_5(\tau)$	1
7	Bkg	NP	$E_6(m)$	$E_7(\|\tau\|)$	1

Notations: G – Gaussian; CB – Crystal Ball; E – Exponential; B – Bernstein polynomials; BV – Correlation term of the bivariate Gaussian distr.

Differential cross sections: prompt production





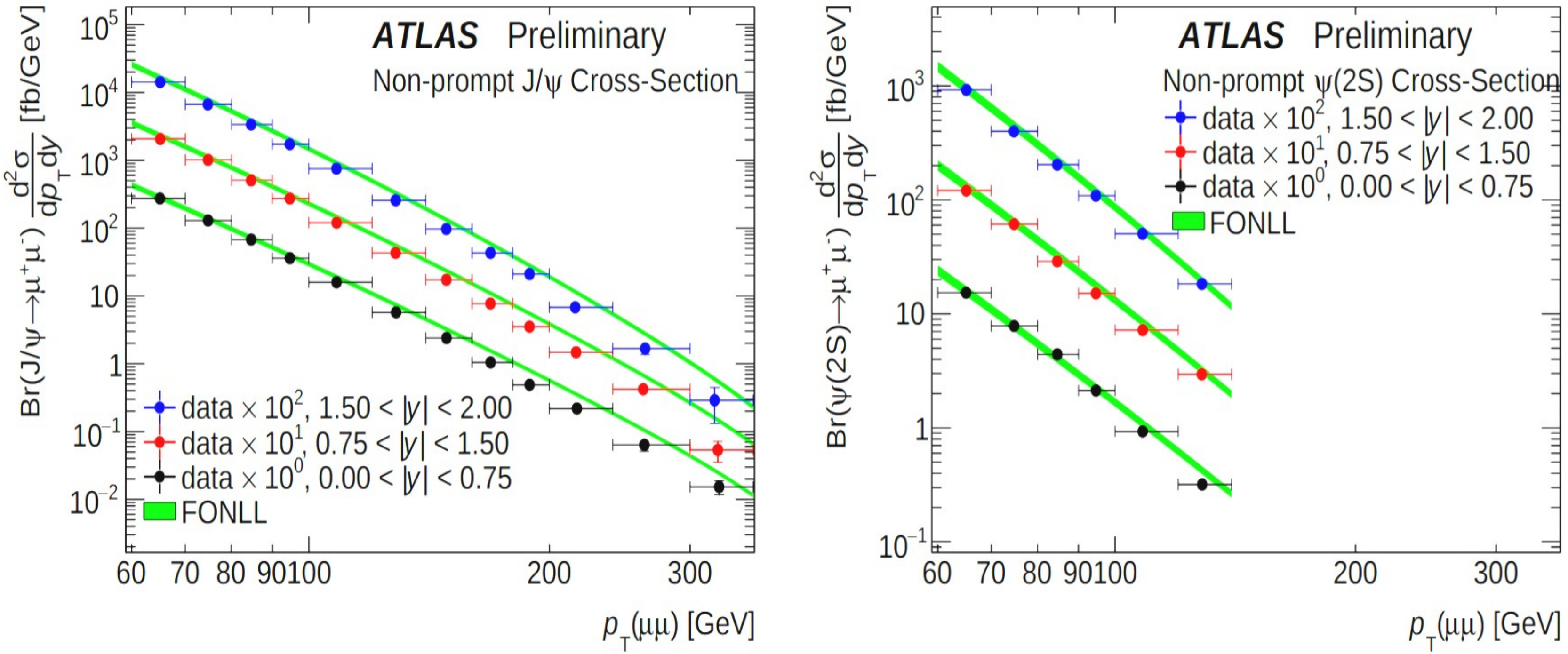
- The 2D fits produce corrected yields $N_\psi^{P,NP}$ for prompt (P) and non-prompt (NP) ψ states, where ψ = J/ψ, ψ(2S).
- The respective double-differential cross sections are then calculated using the formula:

$$\frac{d^2\sigma^{\mathrm{P,NP}}(pp\to\psi)}{dp_T\,dy}\times\mathcal{B}(\psi\to\mu^+\mu^-)=\frac{1}{\mathcal{A}(\psi)}\,C_{\mathrm{BM}}\,C_{\mathrm{AP}}\,\frac{N_\psi^{\mathrm{P,NP}}}{\Delta p_T\,\Delta y\,\int\mathcal{L}dt},$$

where Δp_T and Δy are bin widths in dimuon transverse momentum and rapidity respectively, $\int Ldt$ is the integrated luminosity, A(ψ) is the kinematic acceptance for a given ψ mass, C_{BM} is a migration correction factor and C_{AP} factor is to correct for the dependence of the efficiencies on pileup conditions.

Differential cross sections: non-prompt production

Non-prompt production results are compared with FONLL* and gives good agreement at the lower p_T, but with FONLL predicting somewhat higher cross-sections at high-p_T.

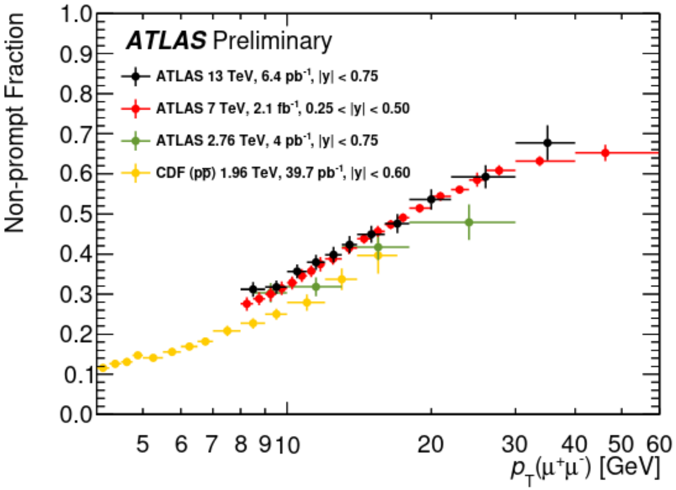


* FONLL Heavy Quark Production, M. Cacciari, http://www.lpthe.jussieu.fr/~cacciari/fonll/fonllform.html.

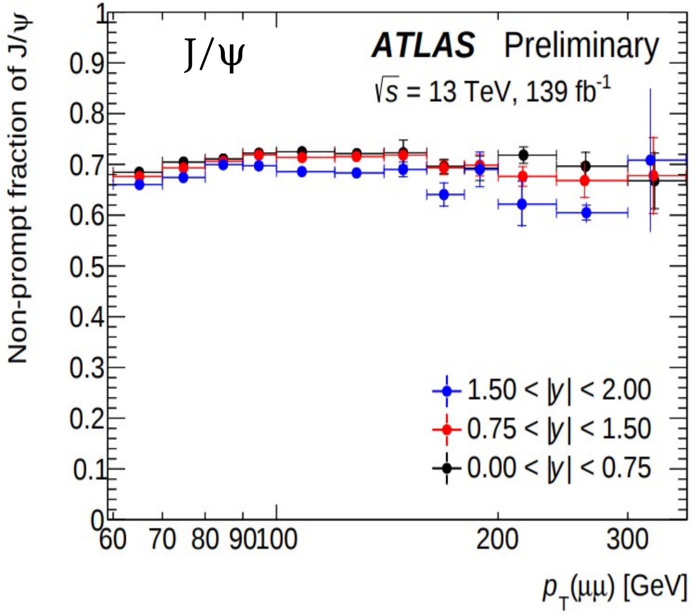
Production fractions

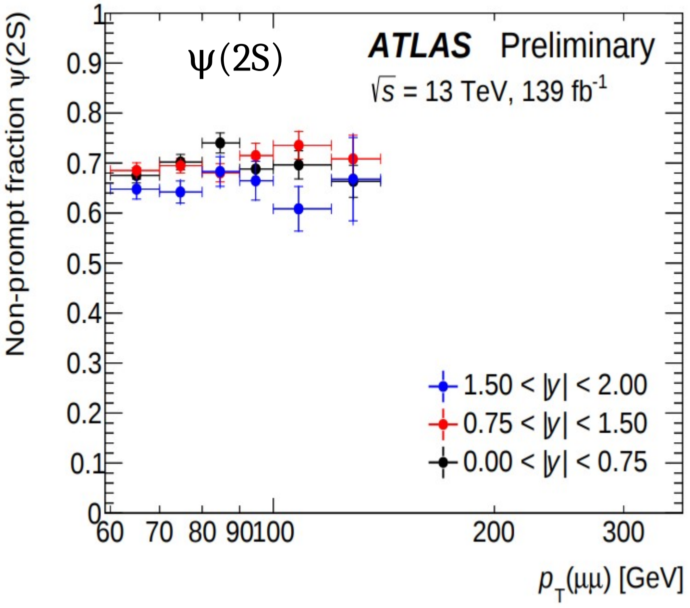
Non-prompt production fraction of J/ψ and ψ(2S) is presented:

- The p_T dependence of prompt and non-prompt contributions in the p_T range covered by this measurement is similar, resulting in the non-prompt fractions being close to constant, for both J/ψ and ψ(2S).



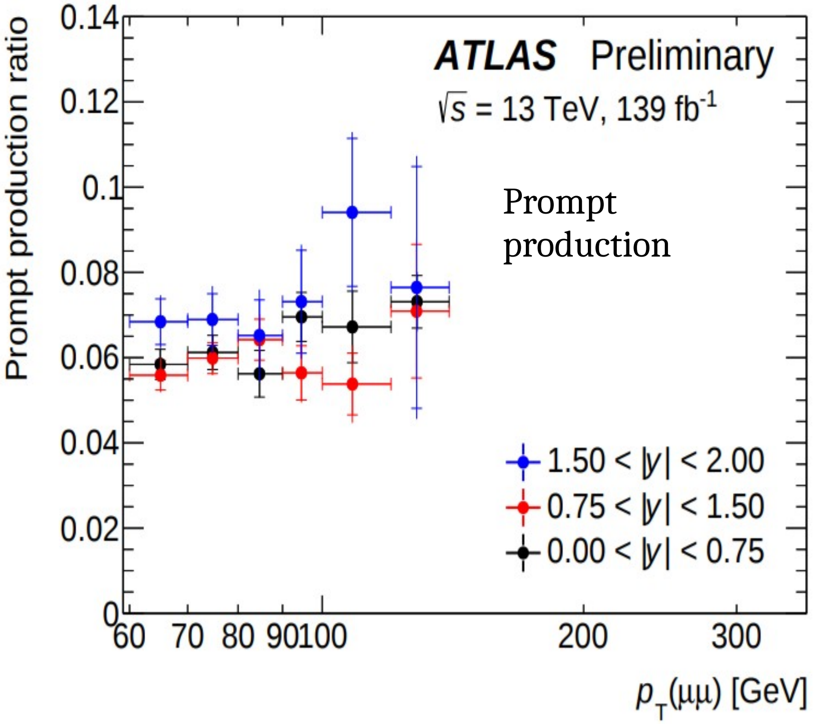
The non-prompt fraction of J/ψ production as a function of p_T and its evolution with collision energy

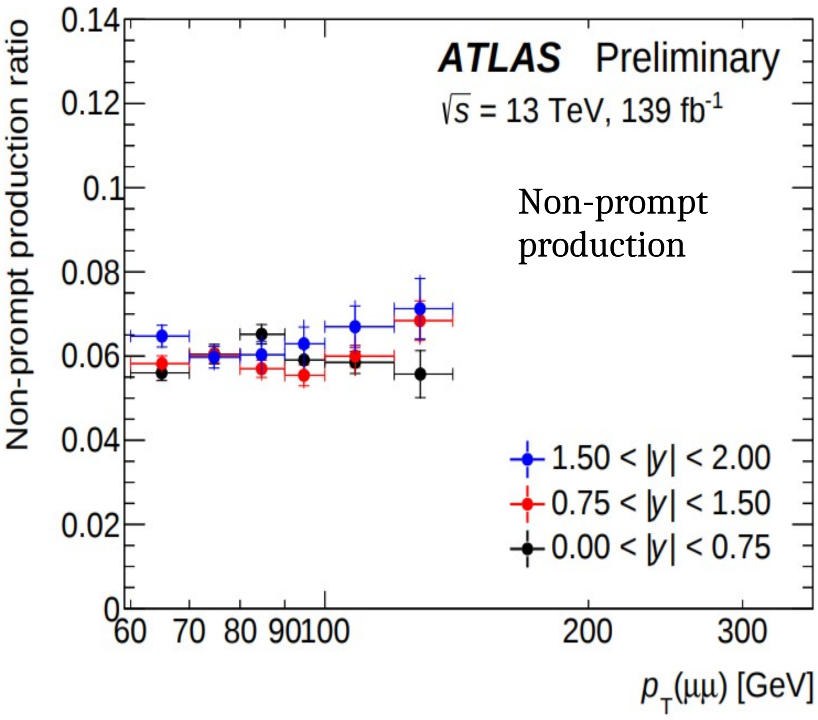




Production fractions

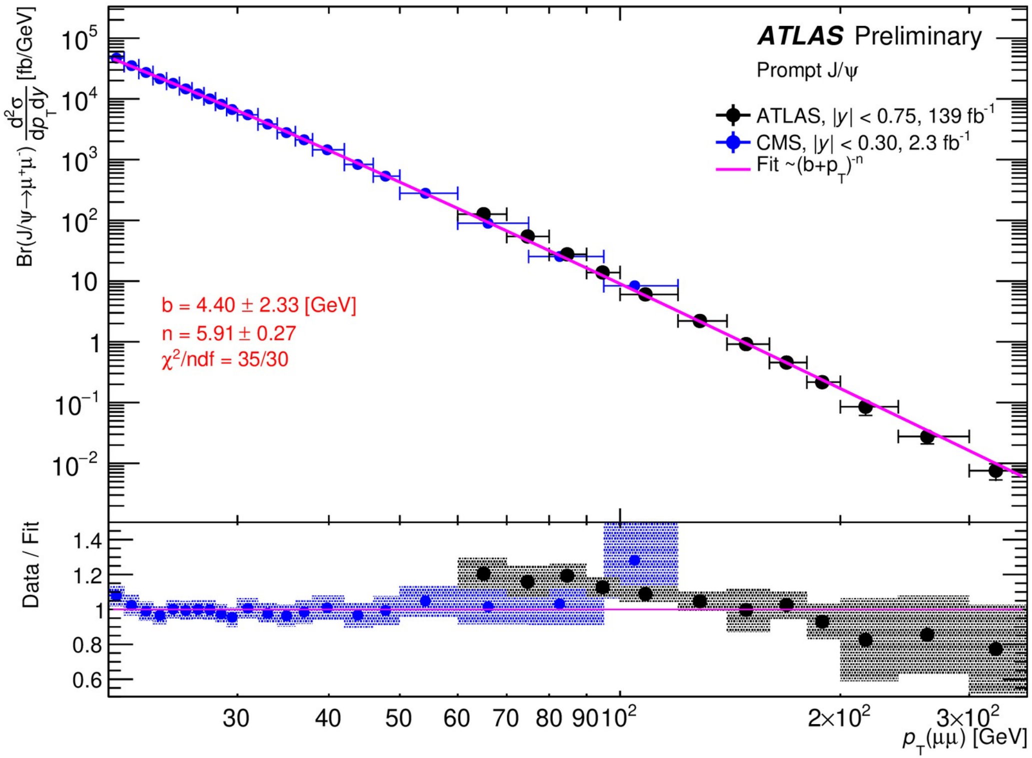
Ratio of ψ(2S) production with respect to J/ψ, for prompt and non-prompt production is presented:





Summary

- For J/ψ and $\psi(2S)$ charmonium states, the cross-sections are measured separately for prompt and non-prompt production mechanisms.
- The results show similar p_T-dependence for prompt and non-prompt differential cross sections, with non-prompt fractions close to constant for both J/ψ and $\psi(2S)$ in this range of transverse momenta.
- Where they overlap, results for prompt production are consistent with similar results obtained by the CMS collaboration [4].



- The results for non-prompt production are compared with the predictions of the FONLL model with default set of parameters.
- These predictions are consistent with the present measurement at the low end of the p_T range, but exceed the experimental values at large transverse momenta.
- The measurements of the full accessible range of p_T starting from about 8 GeV are in progress.

Thank you!

References

[1] ATLAS Collaboration, Measurement of the production cross-section of J/ ψ and ψ (2S) mesons at high transverse momentum in pp collisions at √s = 13 TeV with the ATLAS detector, ATLAS-CONF-2019-047.

[2] ATLAS collaboration, The ATLAS Experiment at the CERN Large Hadron Collider, 2008 JINST 3 S08003.

[3] FONLL Heavy Quark Production, M. Cacciari, http://www.lpthe.jussieu.fr/~cacciari/fonll/fonllform.html.

[4] CMS Collaboration, Measurement of quarkonium production cross sections in pp collisions at √s=13TeV, Phys. Lett. B780(2018) 251.

Backup

Colour-Singlet (CS) and Colour-Octet (CO) states

Perturbative calculations of heavy quarkonium production in hadronic collisions distinguish between terms that produce a heavy quark system ($Q\bar{Q}$) in a colour-singlet (CS) or a colour-octet (CO) state.