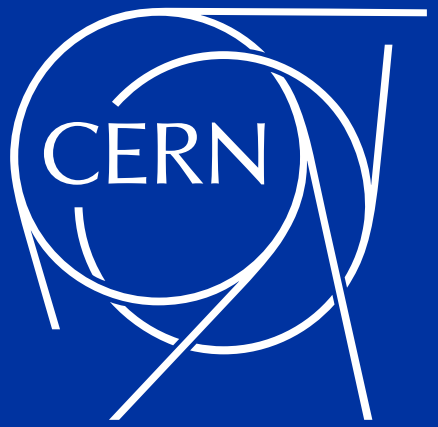


Recent Results on Charmonium Production From ATLAS (inclusive and associated)

C. D. Burton, on behalf of the ATLAS Collaboration

26 September 2022

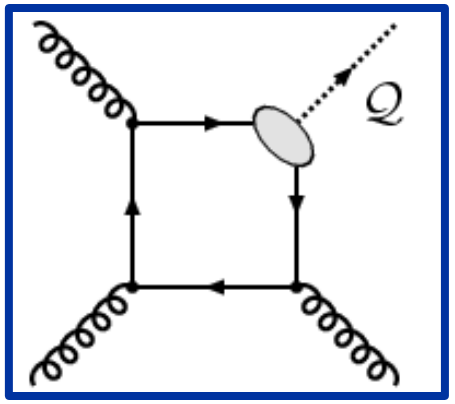
Outline

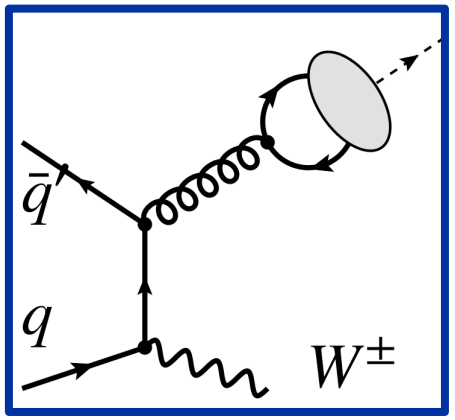
In recent years, the ATLAS Collaboration has continued to develop and extend its quarkonium measurement physics program.

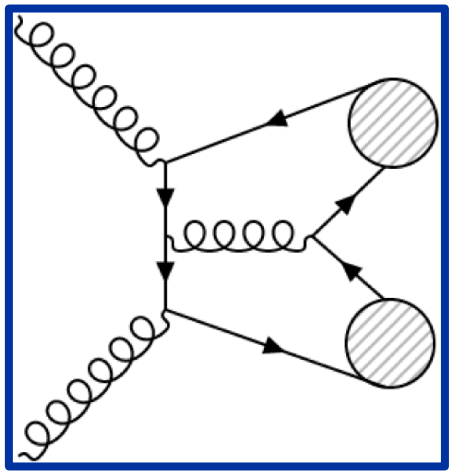
Inclusive and associated quarkonium cross-section measurements have been performed in several channels, both in pp and $p\mathrm{Pb}$ collisions.

In this talk, I will focus on the following ATLAS measurements:

- Inclusive J/ψ and $\psi(2S)$ cross-sections.
- J/ψ and $\psi(2S)$ production in $p\mathrm{Pb}$ collisions.
- Associated $J/\psi + W^{\pm}$ cross-section.
- Inclusive di-J/ψ cross-sections.







Experimental Motivation

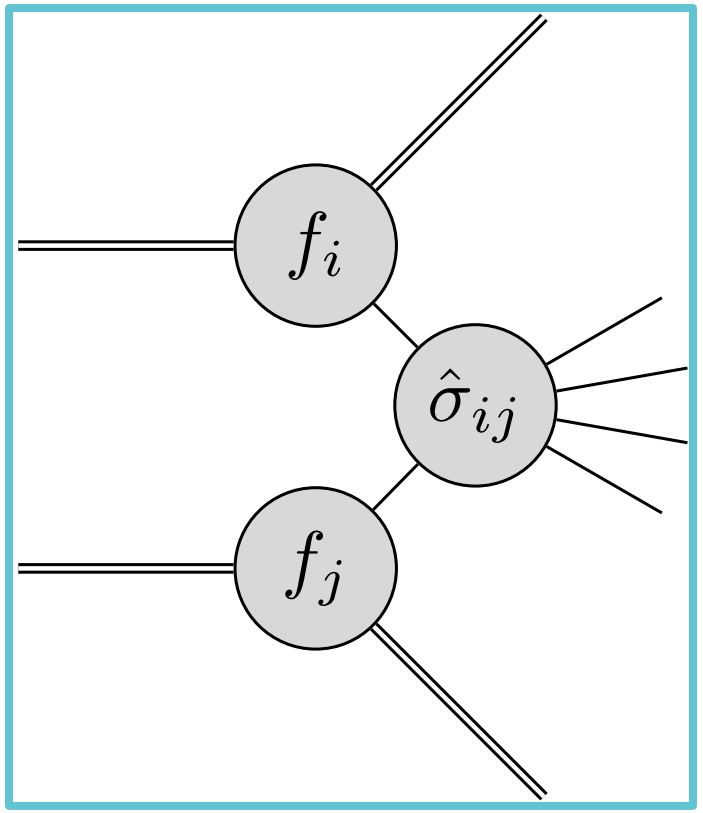
$$\sigma = \sum_{ijn} \int dx_1 dx_2 f_i(x_1) f_j(x_2) \cdot \hat{\sigma}(ij \to Q\bar{Q}[n]) \cdot \langle \mathcal{O}_n^Q \rangle$$

Non-relativistic QCD (NRQCD) provides a framework for making theoretical predictions by factorizing the quarkonia cross-sections into:

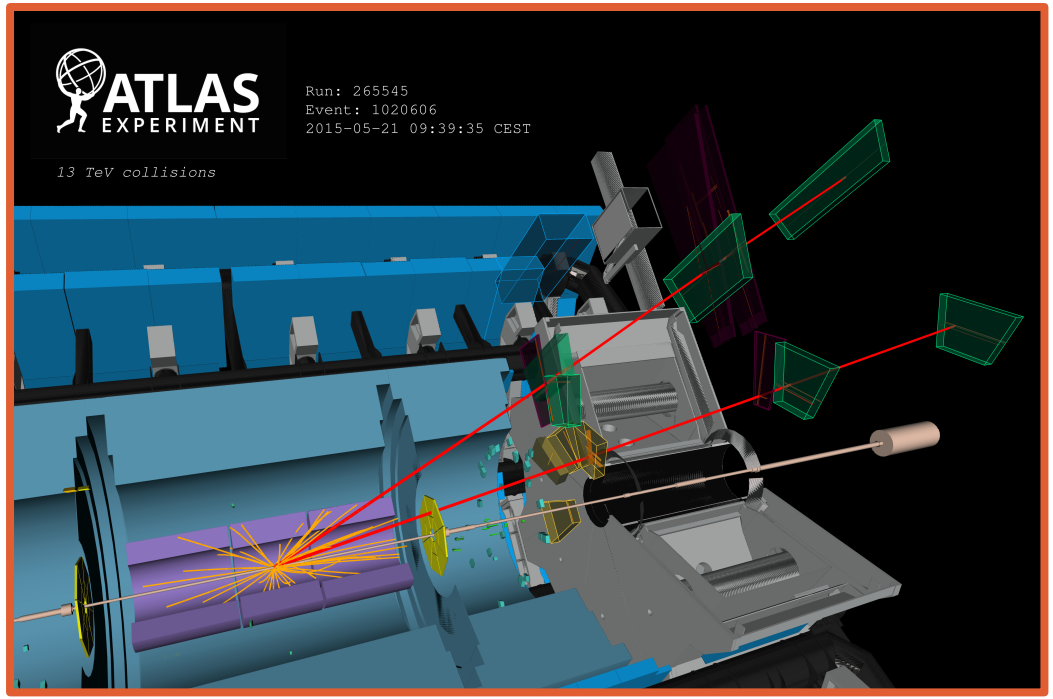
- Short distance, perturbative QCD quark-level interactions.
- Long distance evolution of a compatible quark pair into a physical meson.

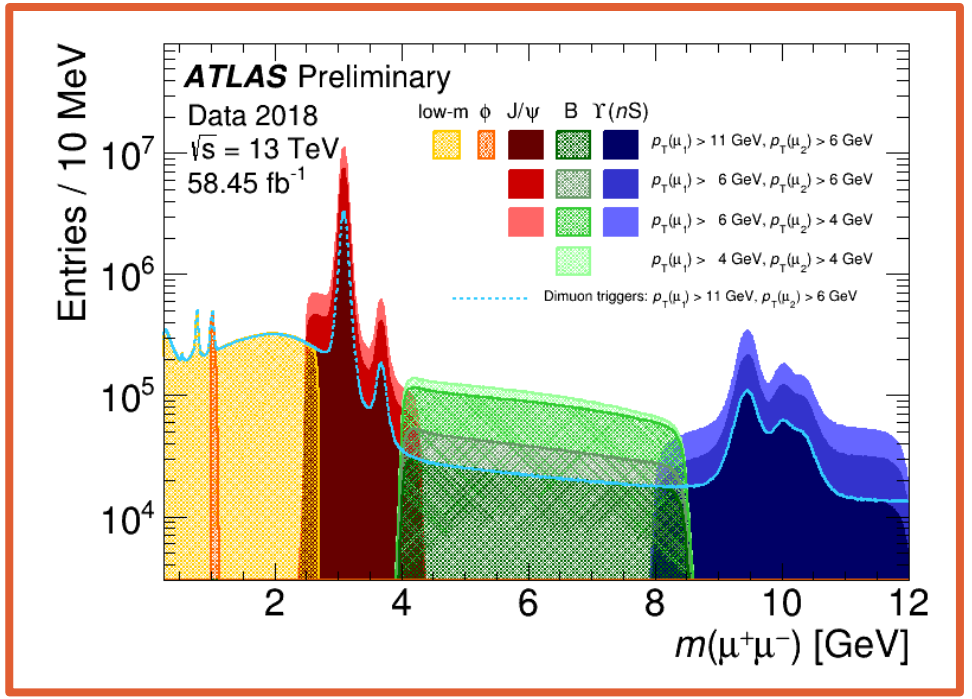
Each measurement offers an important test of non-perturbative QCD production modes in hadron collisions and double-parton scattering (DPS) production.

Attempts to model quarkonia production for numerous bound states—including polarization—have had mixed results. A universal set of LDME parameters is challenging to produce.



Quarkonia Reconstruction in ATLAS





In ATLAS, quarkonia are typically experimentally identified in the di-muon channel.

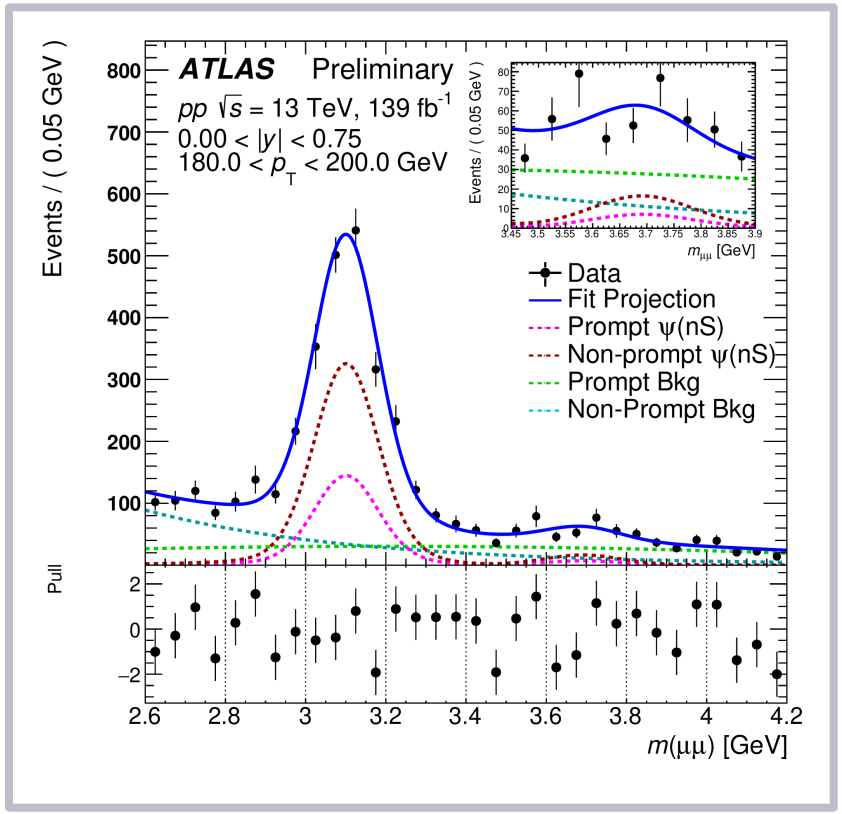
A set of dedicated "B-physics" triggers and high muon reconstruction efficiency provide a large, clean dataset.

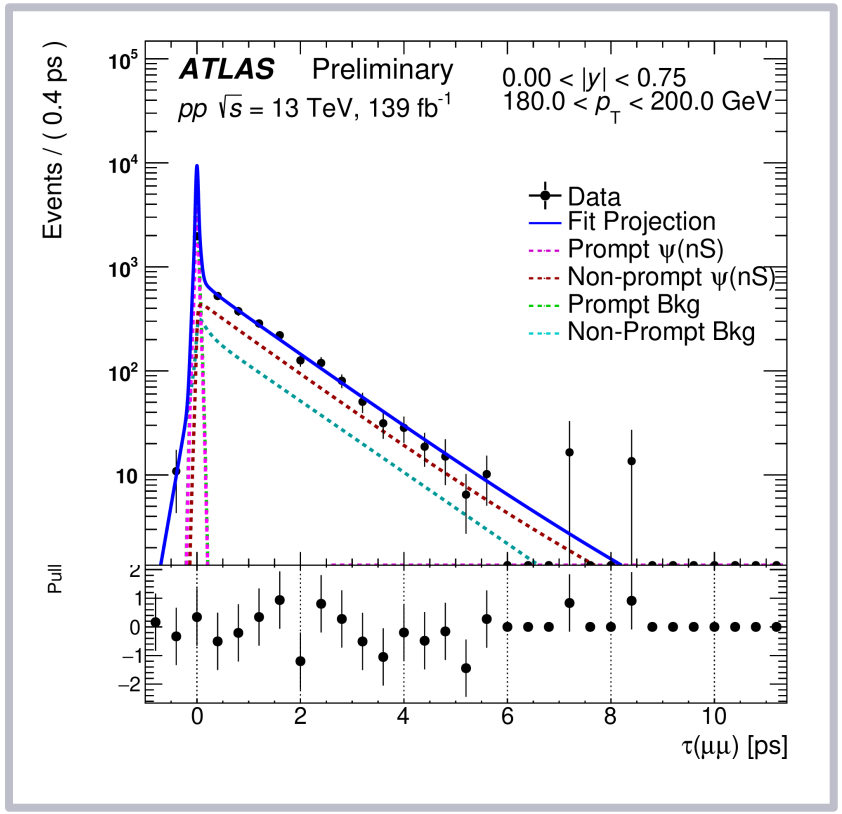
Inclusive J/ψ and $\psi(2S)$ Cross-sections

Double-differential measurement of prompt and non-prompt J/ψ and $\psi(2S)$ cross-sections using the full $13\ \text{TeV}\ pp$, $139\ \text{fb}^{-1}$ Run II dataset.

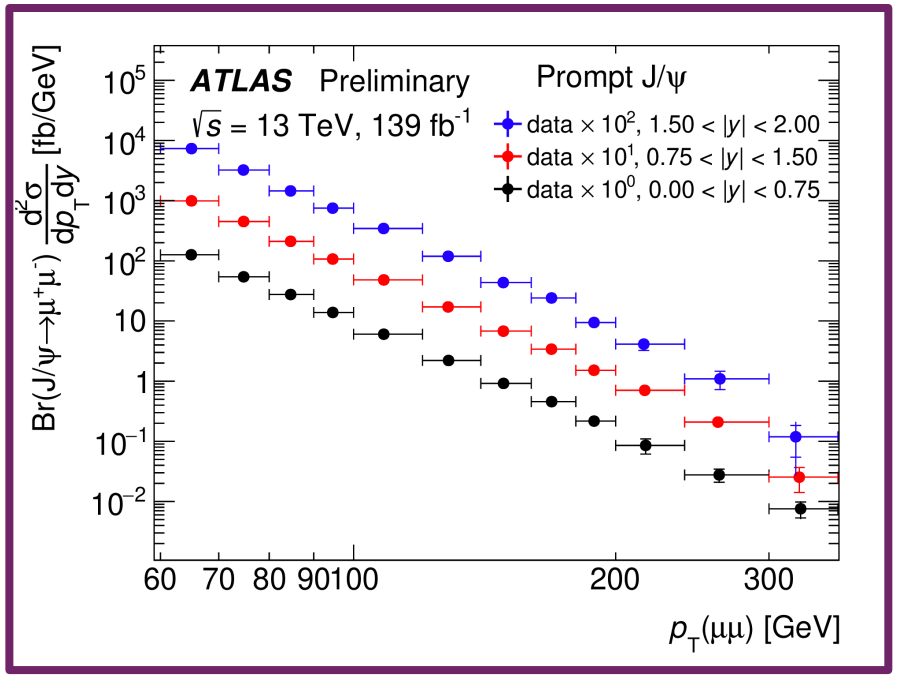
In one analysis bin, the signal extraction using the di-muon invariant mass and pseudo-proper time is shown.

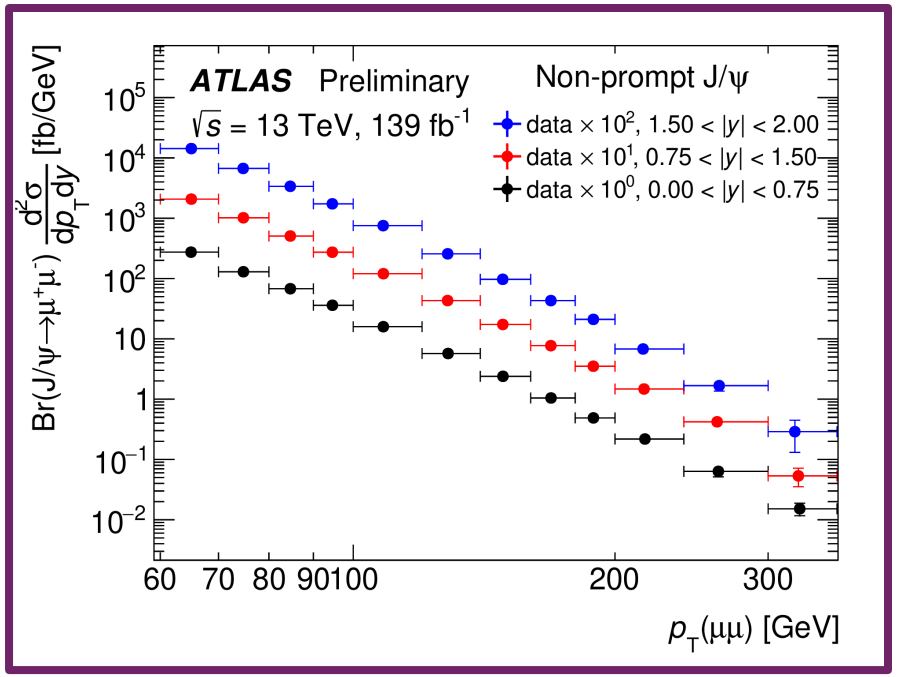
Signal events are weighted by acceptance, trigger efficiency, and detector efficiency.





Inclusive J/ψ and $\psi(2S)$ Cross-sections



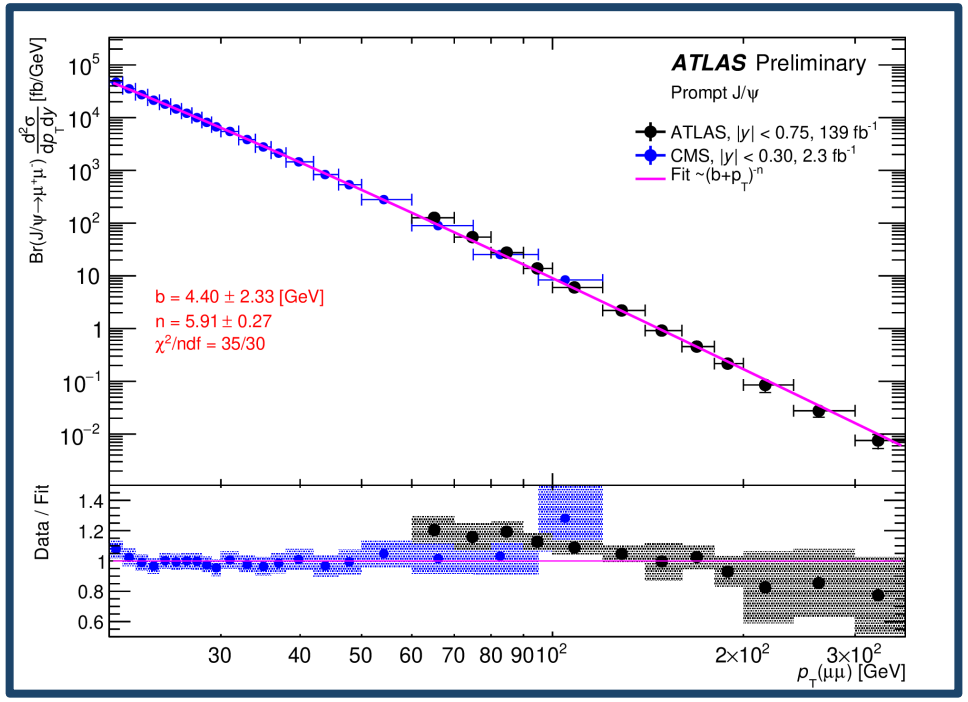


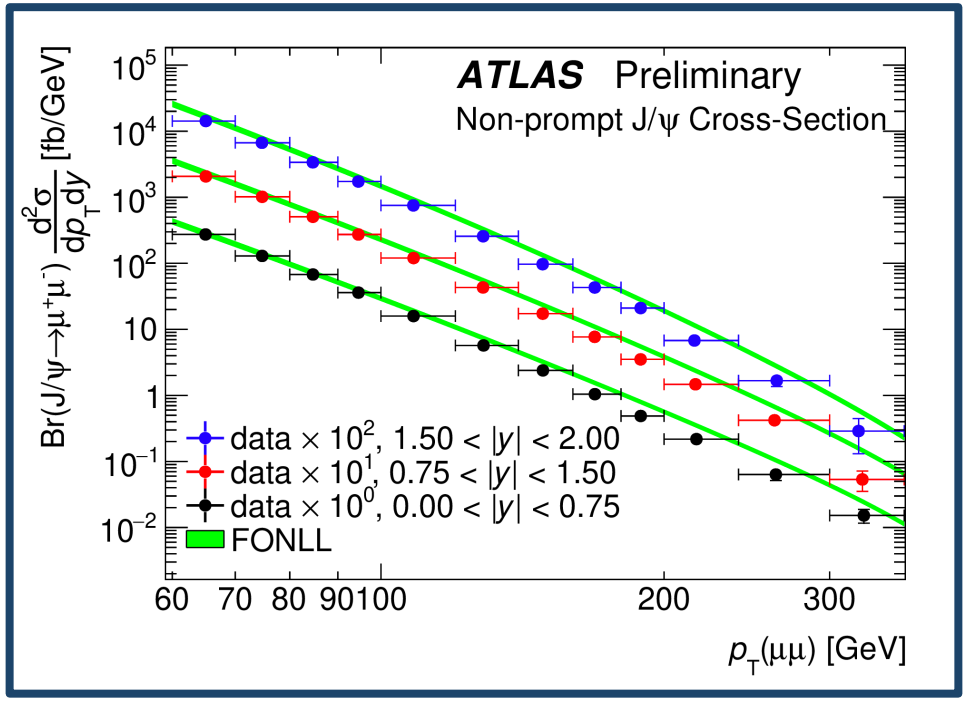
Cross-sections in $p_T^{J/\psi} \in (60, 360)$ GeV and $|y^{J/\psi}| < 2$ are presented.

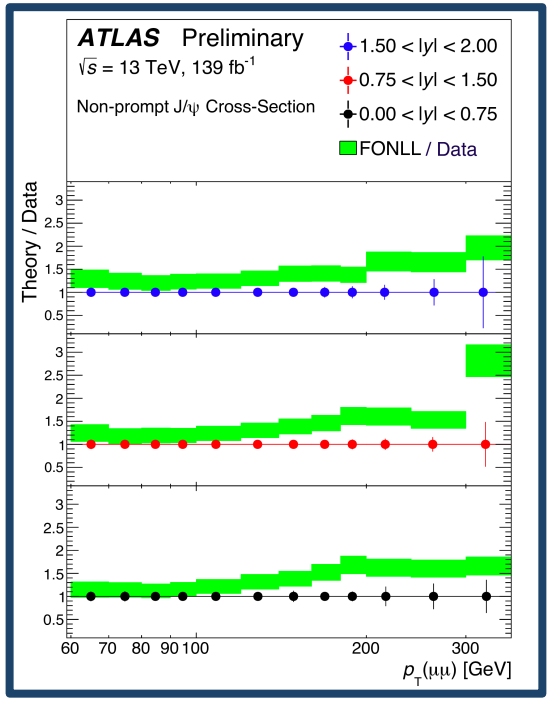
This differential measurement can be used to test NRQCD models of quarkonium production and determine a set of LDMEs.

Inclusive J/ψ and $\psi(2S)$ Cross-sections

Prompt measurements have been compared to low-$p_T^{J/\psi}$ CMS results and non-prompt measurements to NLL predictions.





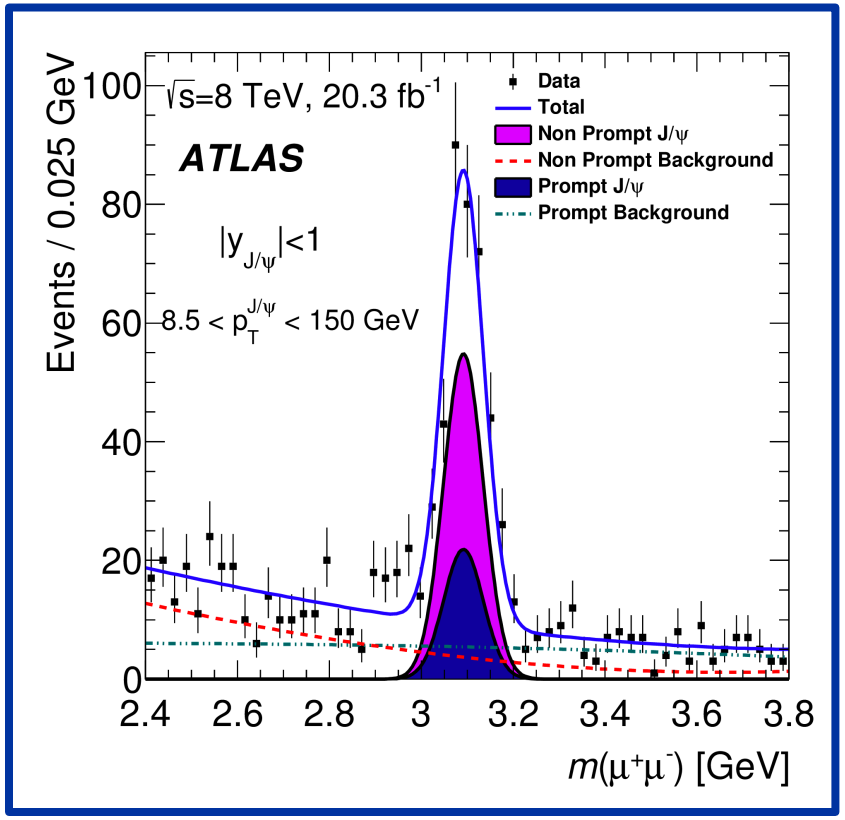


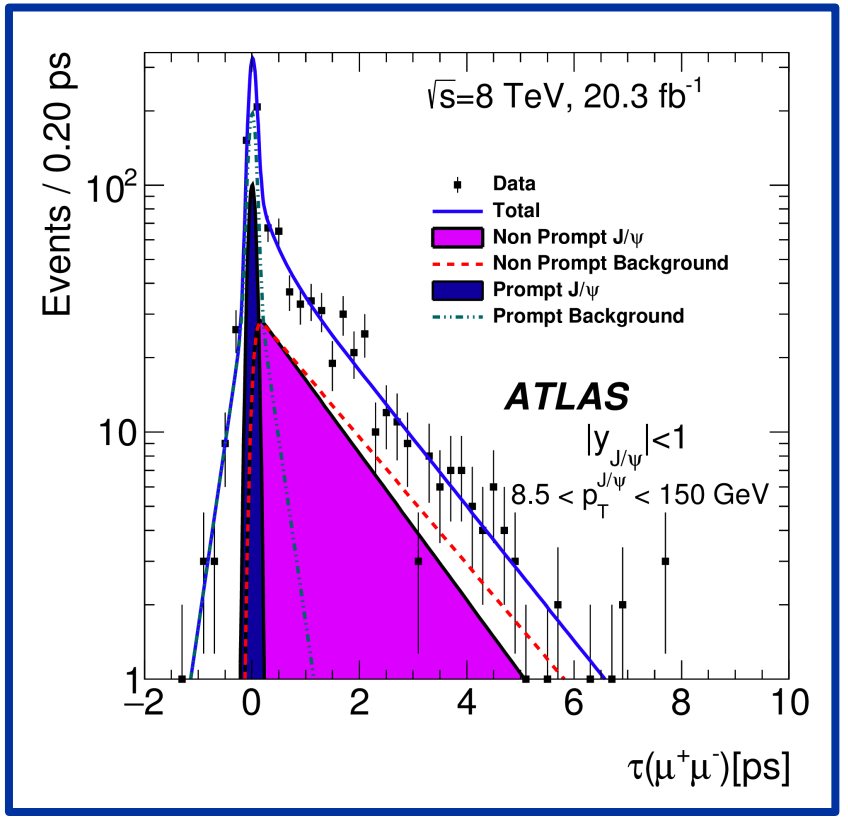
Associated $J/\psi + W^{\pm}$ Cross-sections

NRQCD models distinguish between color singlet (CS) and color octet (CO) production modes.

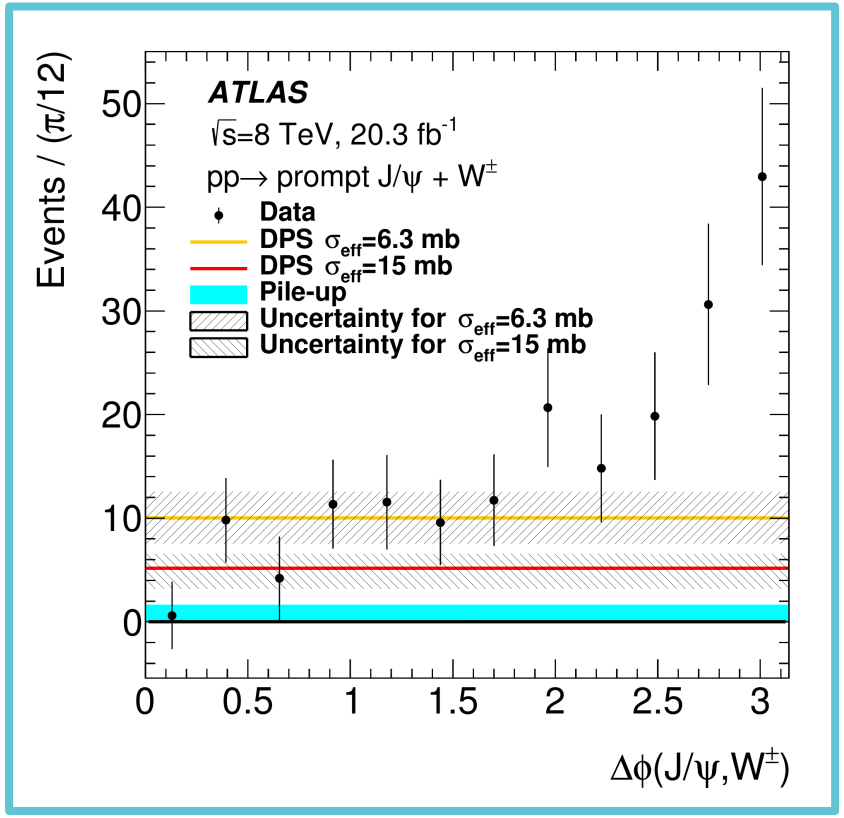
To better understand CO production, seek a process dominant in that mode.

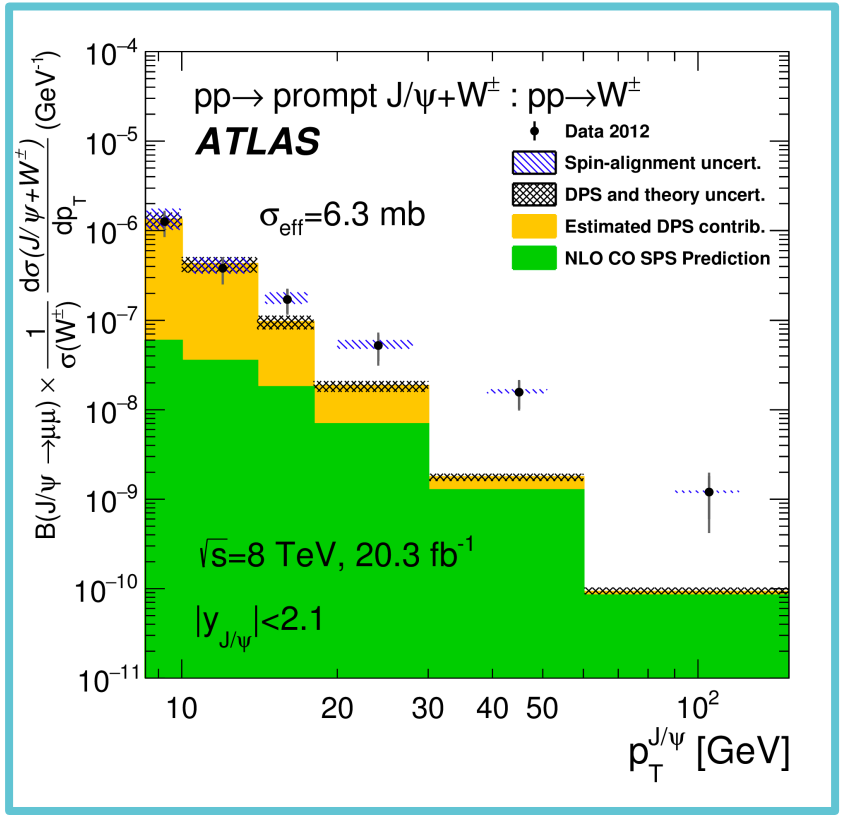
Selected events with $J/\psi \to \mu^{-}\mu^{+}$ and $W^{\pm} \to \mu^{\pm}\nu_{\mu}$.





Associated $J/\psi + W^{\pm}$ Cross-sections





Angular separation variables can be used to distinguish SPS and DPS production modes.

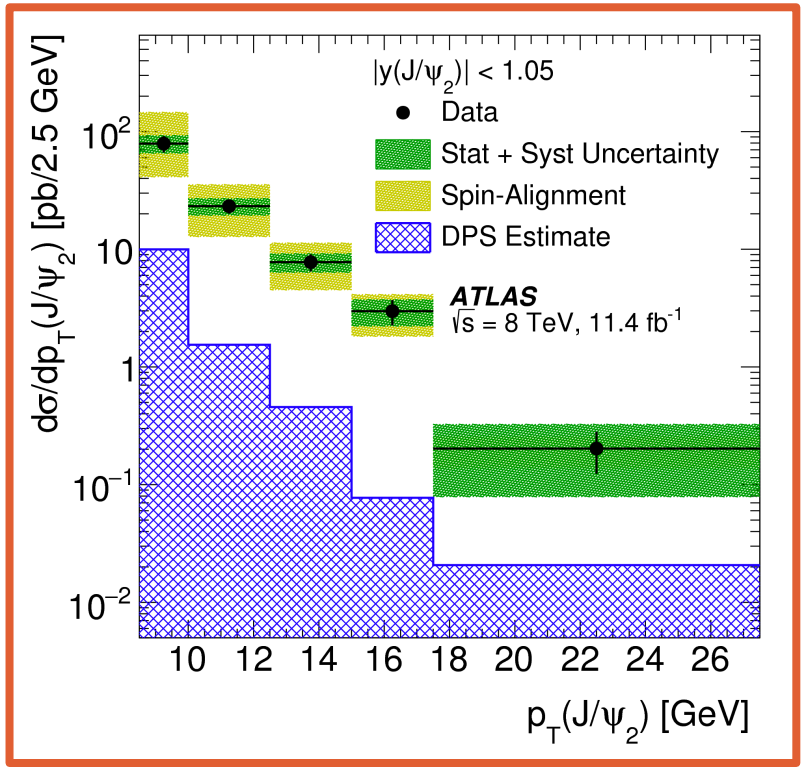
The differential $p_T^{J/\psi}$ spectrum is compared to models of SPS and DPS.

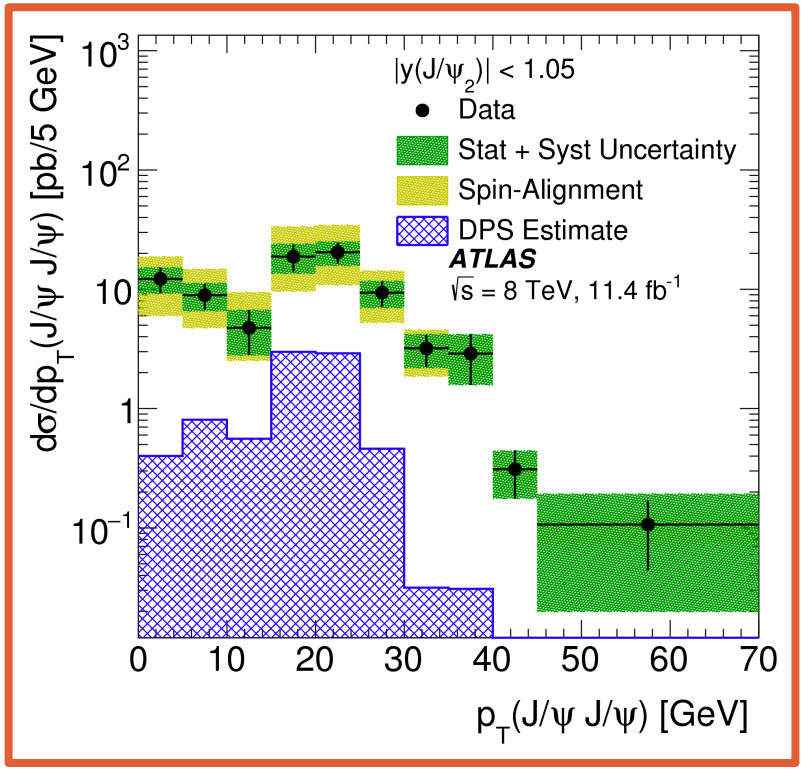
7 TeV / 4.5 fb^{-1} and 8 TeV / 20.3 fb^{-1} measurements have been performed. 13 TeV / 139 fb^{-1} in progress.

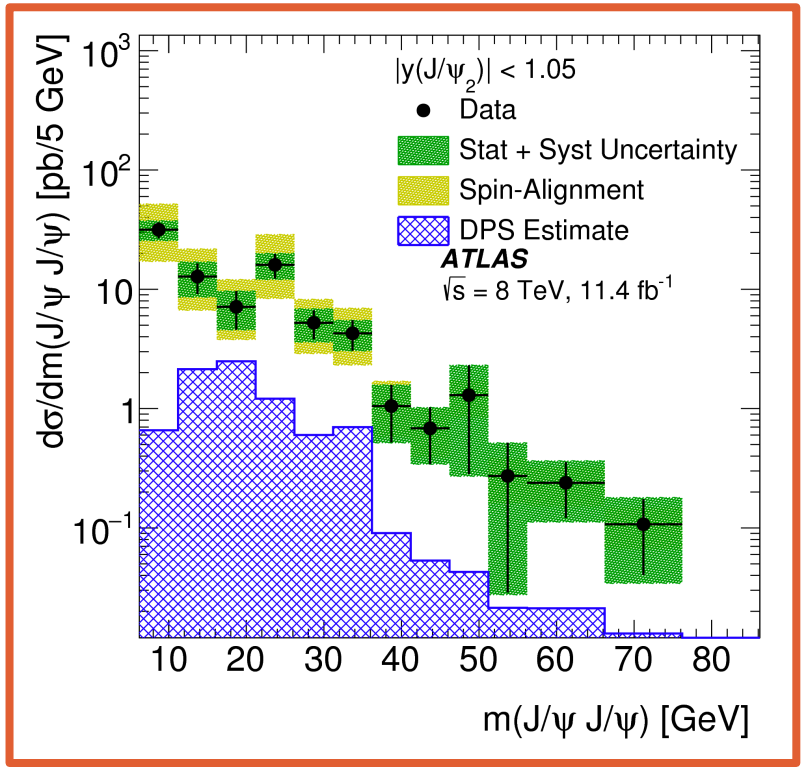
Di-J/ψ Cross-section

Similarly, J/ψ meson pairs can be produced via SPS or DPS. ATLAS has published an $8\ \text{TeV}$ / $11.4\ \text{fb}^{-1}$ measurement of di-J/ψ production, differential in p_T^{J/ψ_2}, $p_T^{\text{di-}J/\psi}$, and $m^{\text{di-}J/\psi}$.

Data points assume an unpolarized spin-alignment.







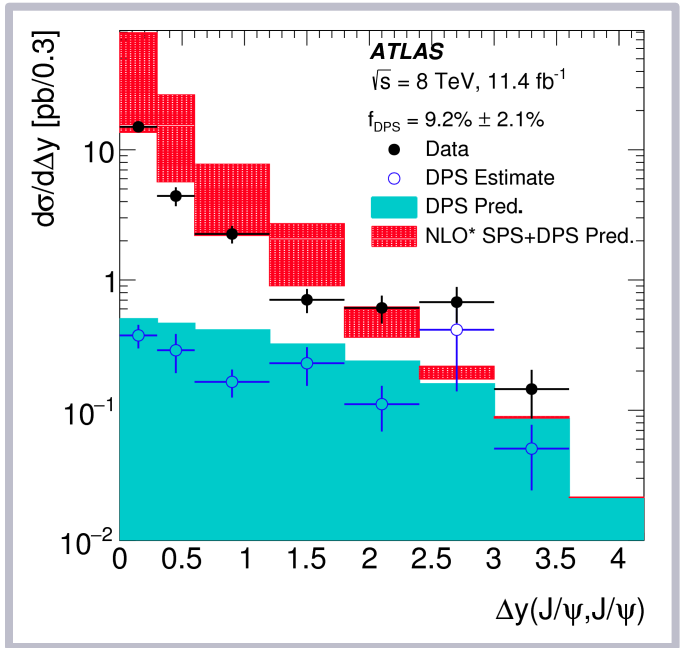
Di-J/ψ Cross-section

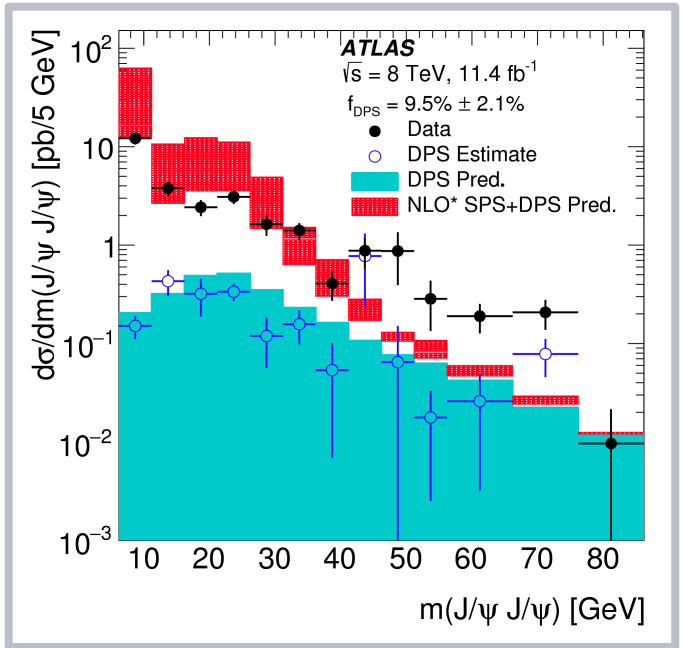
The di-J/ψ distributions in data are compared to MC models.

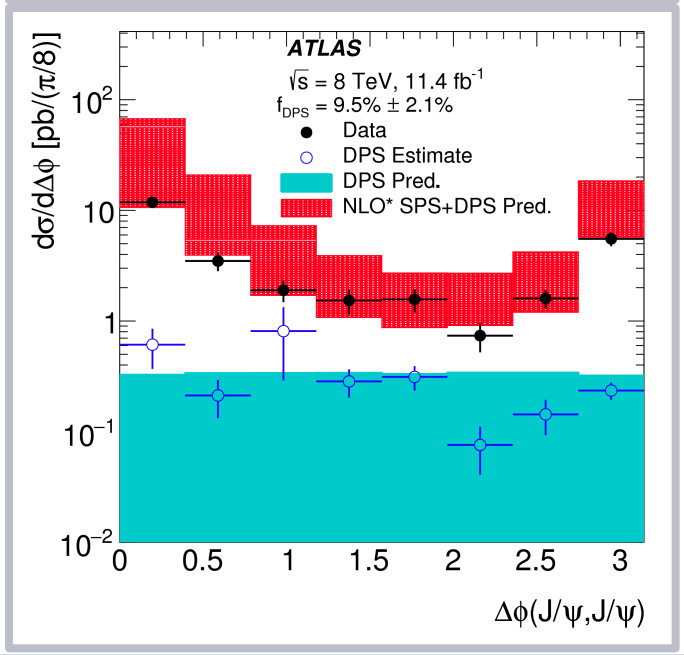
Angular separation variables may be used to distinguish SPS and DPS production.

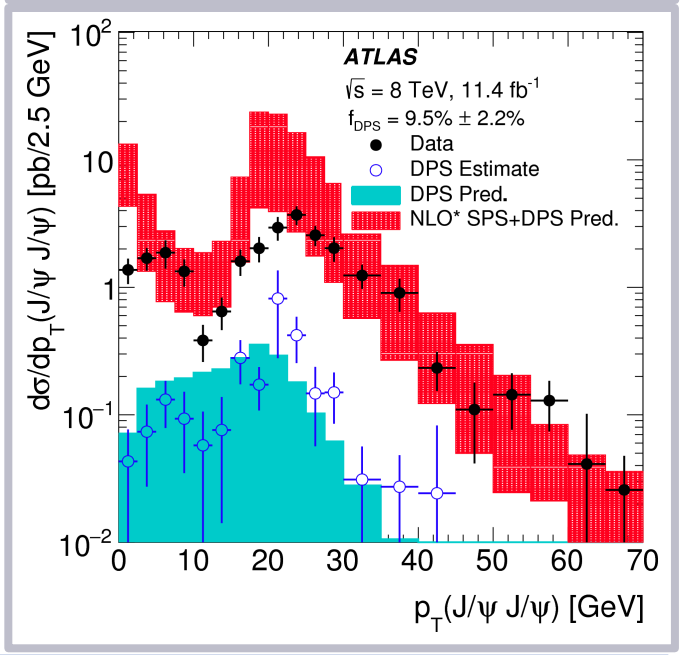
- $\Delta\varphi(J/\psi, J/\psi)$
- $\Delta y(J/\psi, J/\psi)$

Additionally, di-J/ψ invariant mass and p_T distributions are compared to the MC models.







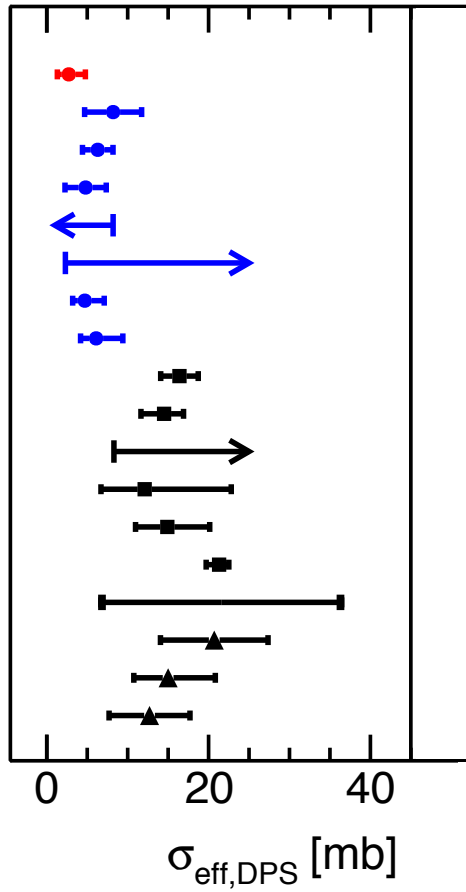


DPS Production Measurements

DPS production has been studied across many different channels.

The simplest model of DPS is parameterized with an "effective cross section," σ_{eff}.

The measurements of σ_{eff} are compared across many processes and pp collision energies.

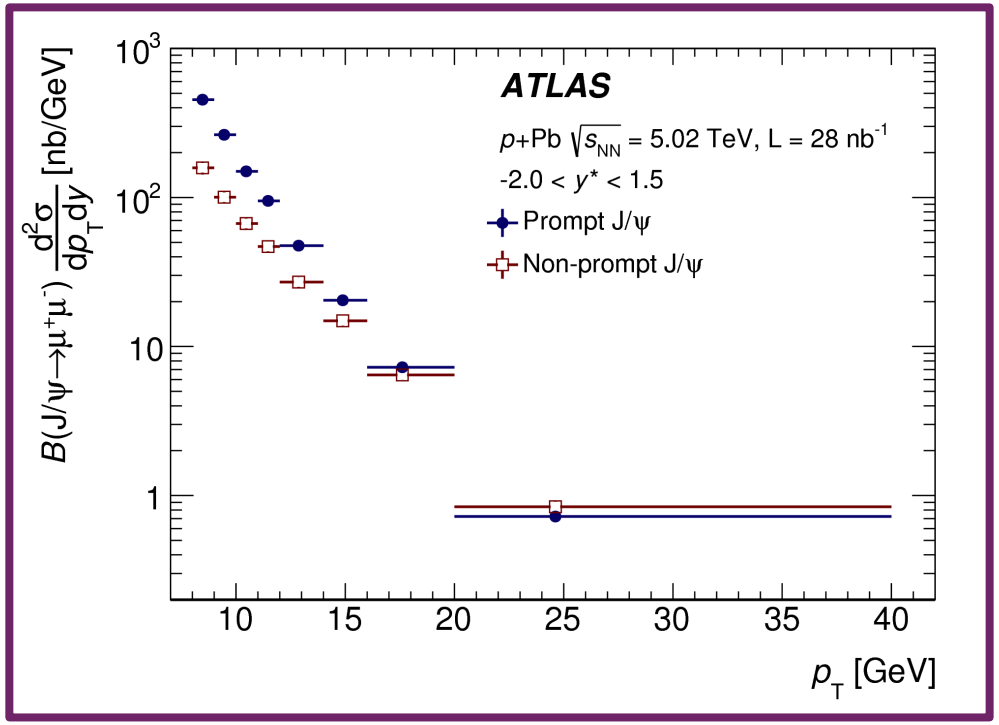


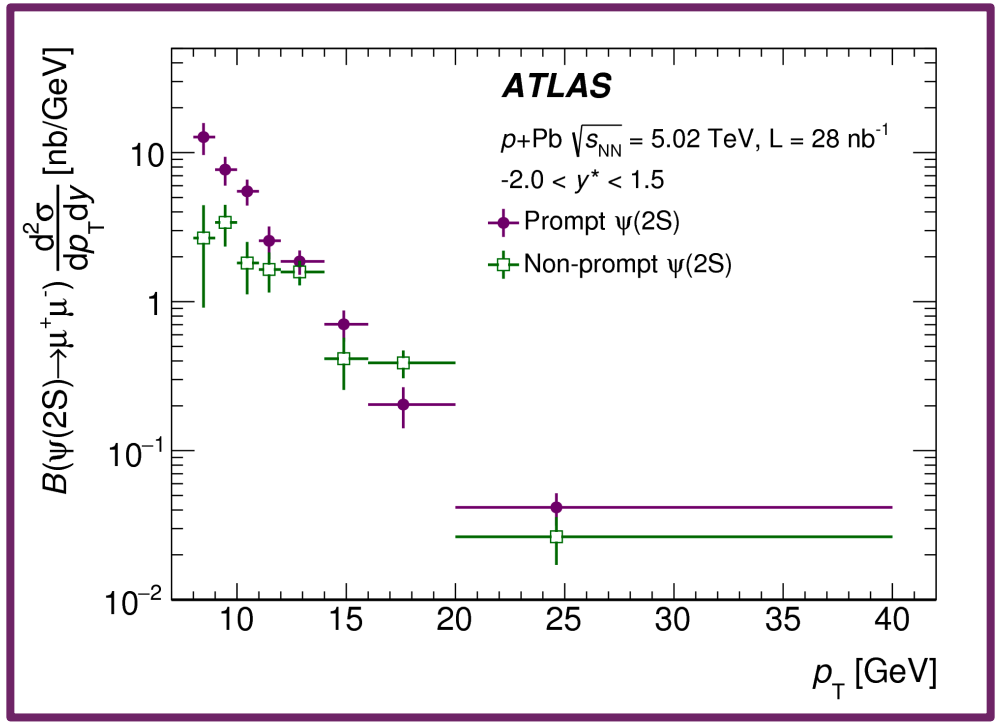
CMS, $\sqrt{s}$=13 TeV, J/ψ+J/ψ+J/ψ	
CMS, $\sqrt{s}$=8 TeV, J/ψ+J/ψ	Phys. Rept. 889 (2020) 1
ATLAS, $\sqrt{s}$=8 TeV, J/ψ+J/ψ	Eur. Phys. J. C 77 (2017) 76
D0, $\sqrt{s}$=1.96 TeV, J/ψ+J/ψ	Phys. Rev. D 90 (2014) 111101
D0, $\sqrt{s}$=1.96 TeV, J/ψ+Y	Phys. Rev. Lett. 117 (2016) 062001
ATLAS, $\sqrt{s}$=8 TeV, Z+b→J/ψ	Nucl. Phys. B 916 (2017) 1312
ATLAS, $\sqrt{s}$=8 TeV, Z+J/ψ	Phys. Rept. 889 (2020) 1
ATLAS, $\sqrt{s}$=8 TeV, W+J/ψ	Phys. Lett. B 781 (2018) 485
D0, $\sqrt{s}$=1.8 TeV, γ+3-jet	Phys. Rev. D 81 (2010) 052012
CDF, $\sqrt{s}$=1.8 TeV, γ+3-jet	Phys. Rev. D 56 (1997) 3811
UA2, $\sqrt{s}$=640 GeV, 4-jet	Phys. Lett. B 268 (1991) 145
CDF, $\sqrt{s}$=1.8 TeV, 4-jet	Phys. Rev. D4 7 (1993) 4857
ATLAS, $\sqrt{s}$=7 TeV, 4-jet	JHEP 11 (2016) 110
CMS, $\sqrt{s}$=7 TeV, 4-jet	Eur. Phys. J. C 76 (2016) 155
CMS, $\sqrt{s}$=13 TeV, 4-jet	arXiv:2109.13822
CMS, $\sqrt{s}$=7 TeV, W+2-jet	JHEP 03 (2014) 032
ATLAS, $\sqrt{s}$=7 TeV, W+2-jet	New J. Phys. 15 (2013) 033038
CMS, $\sqrt{s}$=13 TeV, WW	Eur. Phys. J. C 80 (2020) 41

Quarkonia Production in Heavy Ion Collisions

ATLAS has studied charmonia production in HI collisions as a probe of quark-gluon plasma (QGP) and cold nuclear matter (CNM) effects.

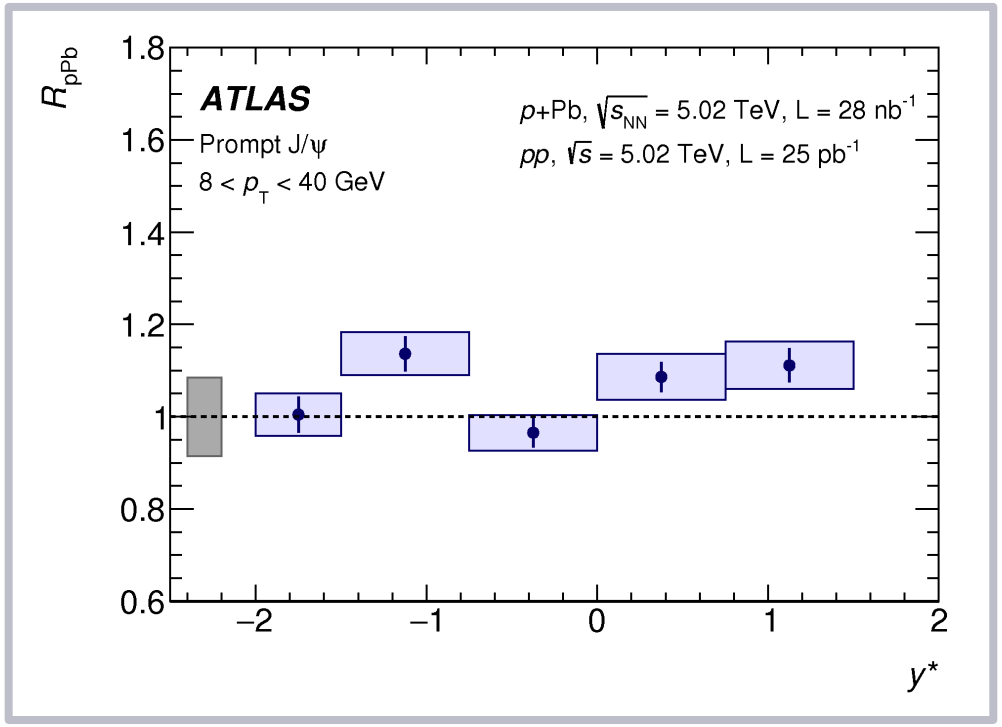
The yields are compared to those from pp collisions to measure the nuclear modification factor as a function of p_T, rapidity, and quarkonium excitation state.

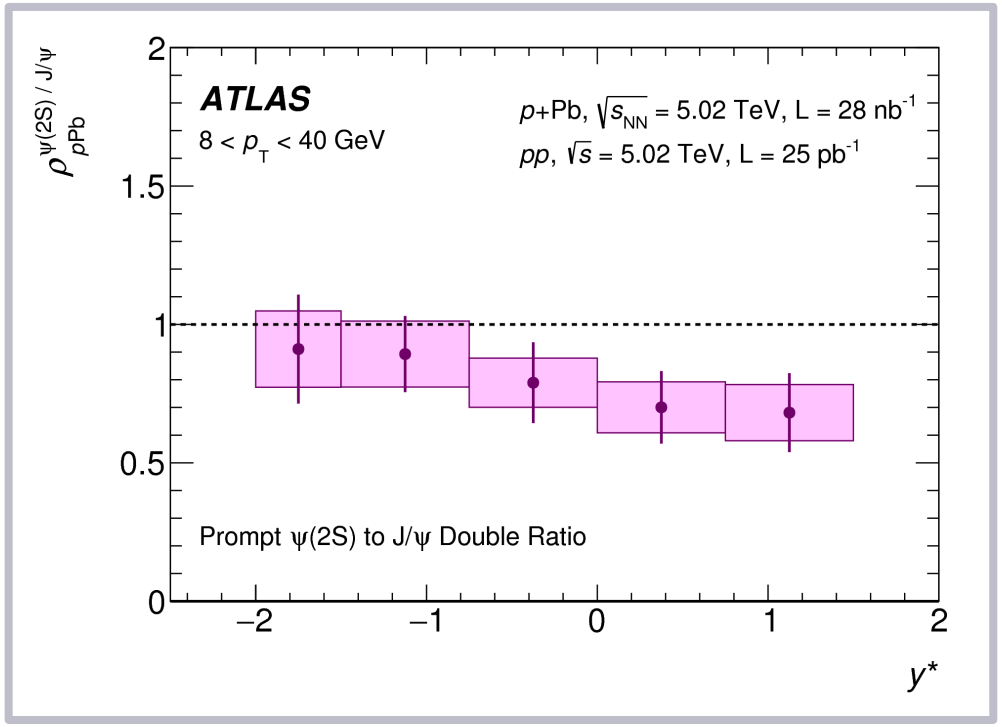




Quarkonia Production in Heavy Ion Collisions

The nuclear modification factor shows that prompt J/ψ production is not suppressed in pPb collisions. The double ratio of $\frac{\psi(2S)}{J/\psi}$ shows that excited charmonium states are more suppressed.





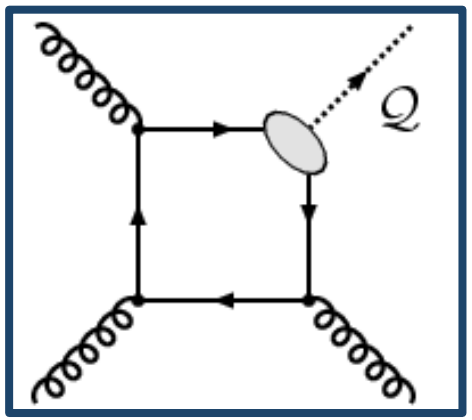
Summary

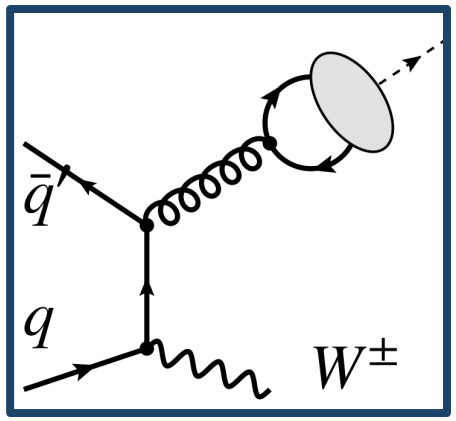
Inclusive J/ψ and $\psi(2S)$ production has been studied in pp collisions. Prompt and non-prompt cross-sections have been measured and compared to NRQCD predictions.

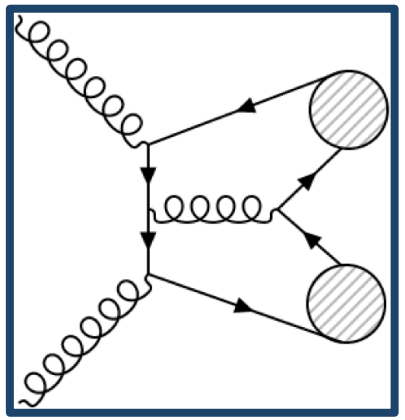
Associated $J/\psi + W^{\pm}$ and $J/\psi + J/\psi$ cross-sections have been measured at $\sqrt{8}\,\mathrm{TeV}$. SPS and DPS production modes have been investigated.

J/ψ and $\psi(2S)$ production has been measured in $p\mathrm{Pb}$ and PbPb collisions.

Upcoming $13\,\mathrm{TeV}$ measurements offer large datasets to analyze quarkonia production.







Efficiency and Acceptance

Corrections are calculated for J/ψ acceptance as a function of $p_T^{J/\psi}$ and $y^{J/\psi}$. (Assuming one J/ψ polarization profile.)

Efficiency corrections are based on the muon trigger and reconstruction efficiency measurements, which are provided by the Muon Combined Performance Group as a function of p_T^{μ}, η^{μ}, and run period.