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J/psi and Upsilon production cross-sections at the ATLAS experiment

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Quarkonium has been studied for over 40 years. Why are we still interested ?

Test multi-scale QCD calculations at the boundary of the perturbative and non-perturbative regimes
Challenges still remain in providing a coherent theoretical picture which can explain all measurements simultaneously

Inclusive production of heavy flavour represents a significant background for measurements in the electroweak and Higgs sectors.

Quarkonium: same-flavour quark and anti-quark in a bound state, e.g. $J/\psi(c\bar{c})$ and $\Upsilon(b\bar{b})$
Use di-muon decays
- Easy for reconstruction and triggering

Single-muon triggers supplemented by di-muon triggers:
- invariant mass window around J/ψ and Υ largely unprescaled

Prompt: Produced directly in the pp interaction or through feed-down decays from higher quarkonium states
Non-prompt: Produced in decay chain of B-hadrons (decay vertex can be displaced from primary pp vertex)

Separate prompt and non-prompt, signal and background, with simultaneous mass-decay time fits

J/psi and Upsilon production cross-sections at the ATLAS experiment

New measurements of prompt and non-prompt J/psi production at a centre-of mass energy of 13 TeV
Comparisons with theoretical predictions and precision measurements made at energies of 2.76, 7 and 8 TeV.

Inclusive production in pp collisions

- ATLAS-CONF-2015-030

Measurement of the differential non-prompt **J/ψ** production fraction √s = **13** TeV pp collisions at the ATLAS experiment

- arXiv:1512.03657 NEW!!!

Measurement of the differential cross-sections of prompt and non-prompt production of **J/ψ** and ψ(2S) in pp collisions at s√=**7** and **8** TeV with the ATLAS experiment

- arXiv:1211.7255 (2013)

Measurement of **Upsilon** production in **7** TeV pp collisions at ATLAS

Production in pPb collisions

- ATLAS-CONF-2015-050

Measurement of **Upsilon**(nS) production with p+Pb collisions at 5.02 TeV and pp collisions at **2.76** TeV

- ATLAS-CONF-2015-023

Study of **J/psi** and ψ(2S) production in √(s_NN) = 5.02 TeV p+Pb and √(s) = **2.76** TeV pp collisions with the ATLAS detector

Associated production with quarkonia

- arXiv:1412.6428 (2014)

Observation and measurements of the production of prompt and non-prompt **J/ψ** mesons in association with a Z boson in pp collisions at √s = **8** TeV with the ATLAS detector

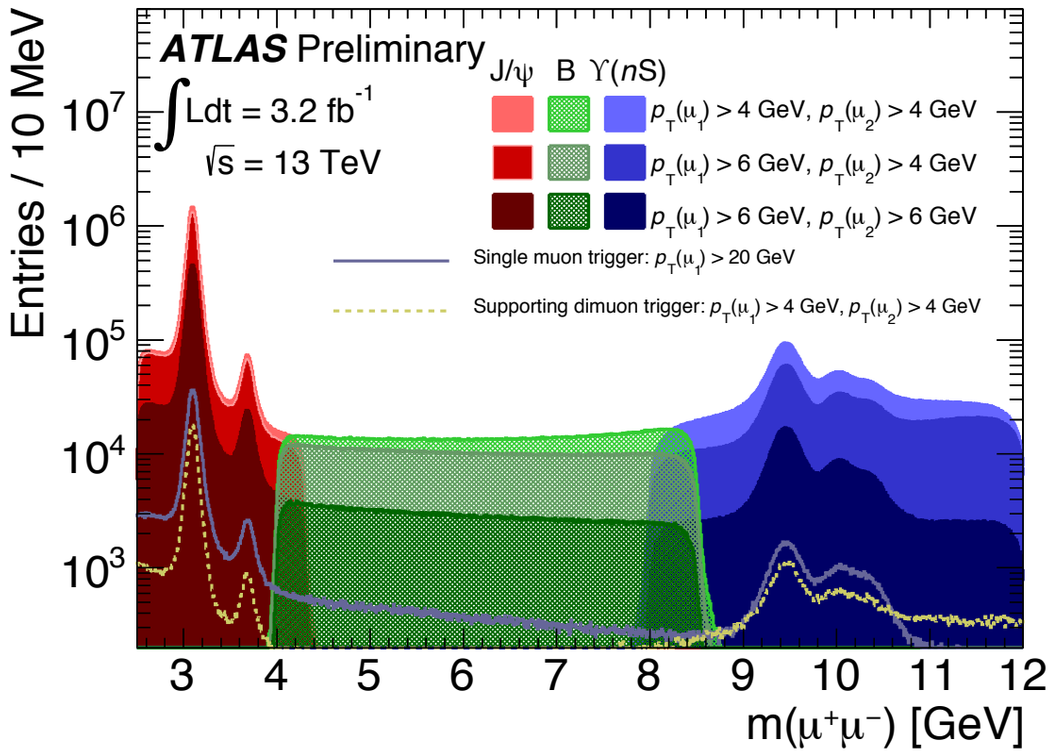
- arXiv:1401.2831 (2014)

Measurement of the production cross section of prompt **J/ψ** mesons in association with a W± boson in pp collisions at √s = **7** TeV

ATLAS-CONF-2015-023 2.76TeV
arXiv:1512.03657 7 & 8 TeV
ATLAS-CONF-2015-030 13 TeV

Event Selection

2.76 TeV	7 & 8 TeV	13 TeV
Muon Selection	**Muon Selection**	**Muon Selection**
pT > 4 GeV	pT >4 GeV	pT > 4 GeV && pT > 14 GeV
|η|< 2.3	|η|< 2.3	|η|< 2.3
Muon Pair	**Muon Pair**	**Muon Pair**
Oppositely charged	Oppositely charged	Oppositely charged
common vertex	common vertex chi2/ndf < 20	common vertex chi2/ndf < 20
8.5 GeV < pT < 30 GeV	pT> 8 GeV and |y|<2	pT >8 GeV and |y|<2
2.6 GeV < m <4.1 GeV	2.6 GeV < m < 4.0 GeV	



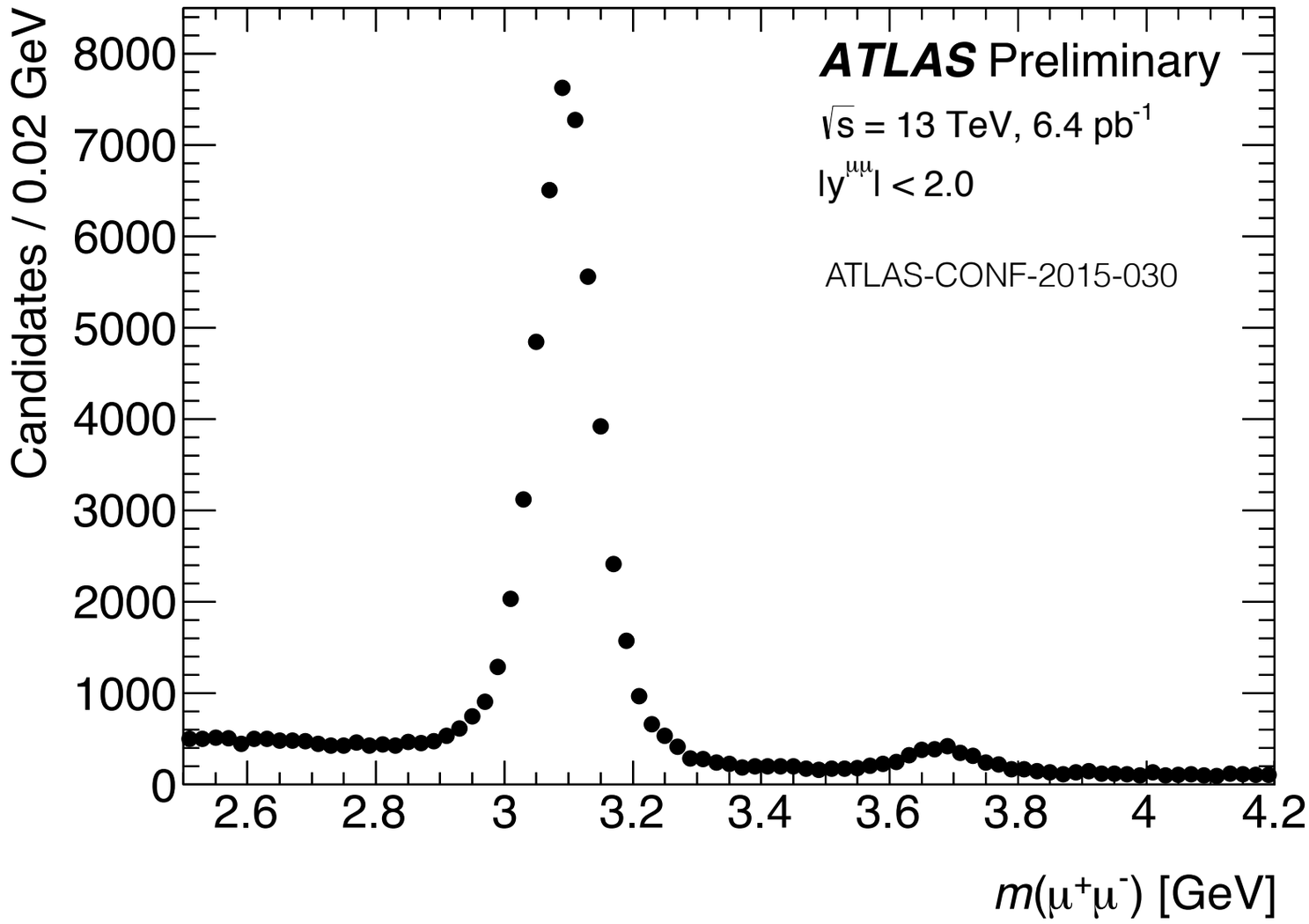
Requirement p_T>8 GeV and |y|<2 to ensure

- geometrical acceptance of the detector
- trigger and reconstruction efficiency corrections

- do not vary rapidly
- and consistent for prompt and non-prompt J/ψ

Invariant mass distributions for oppositely charged muon candidate pairs that pass various triggers.

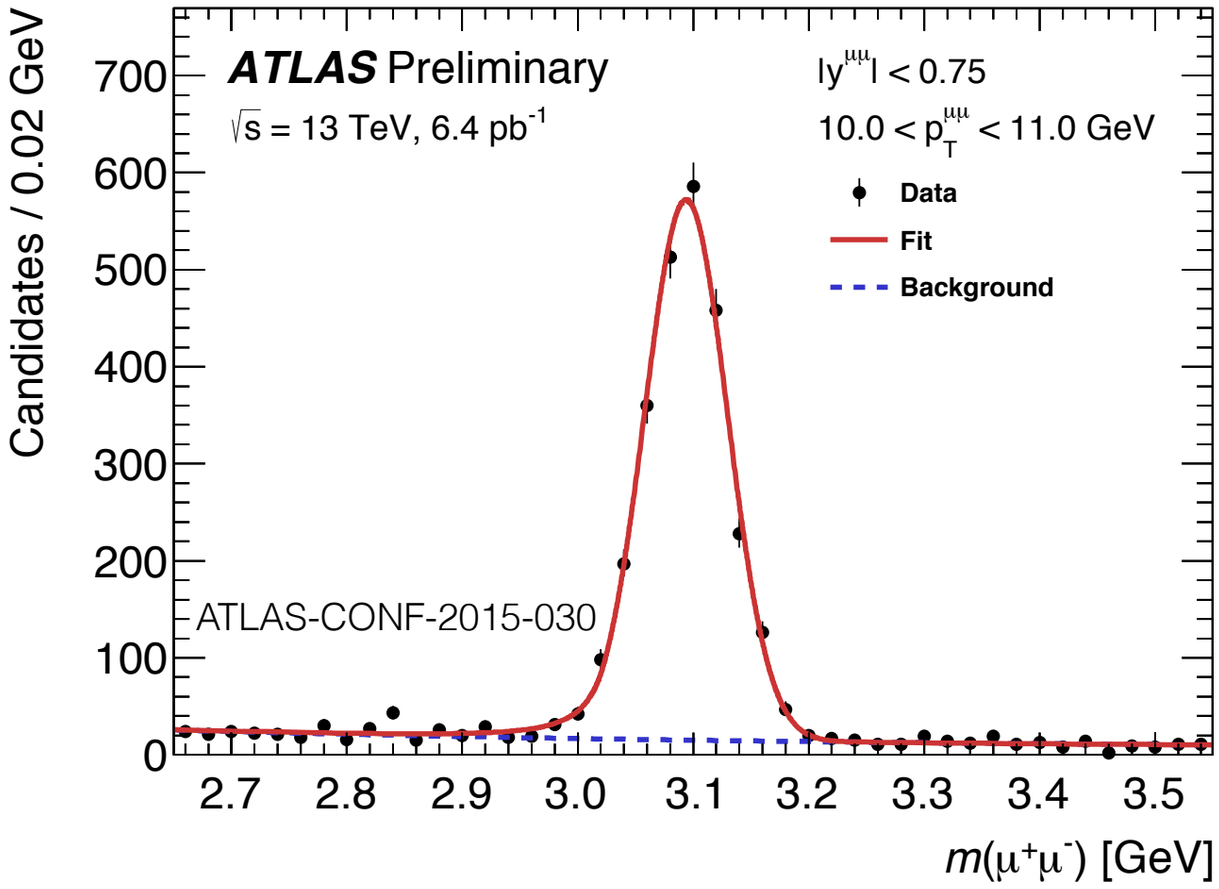
Non-prompt J/ψ production √s = 13 TeV

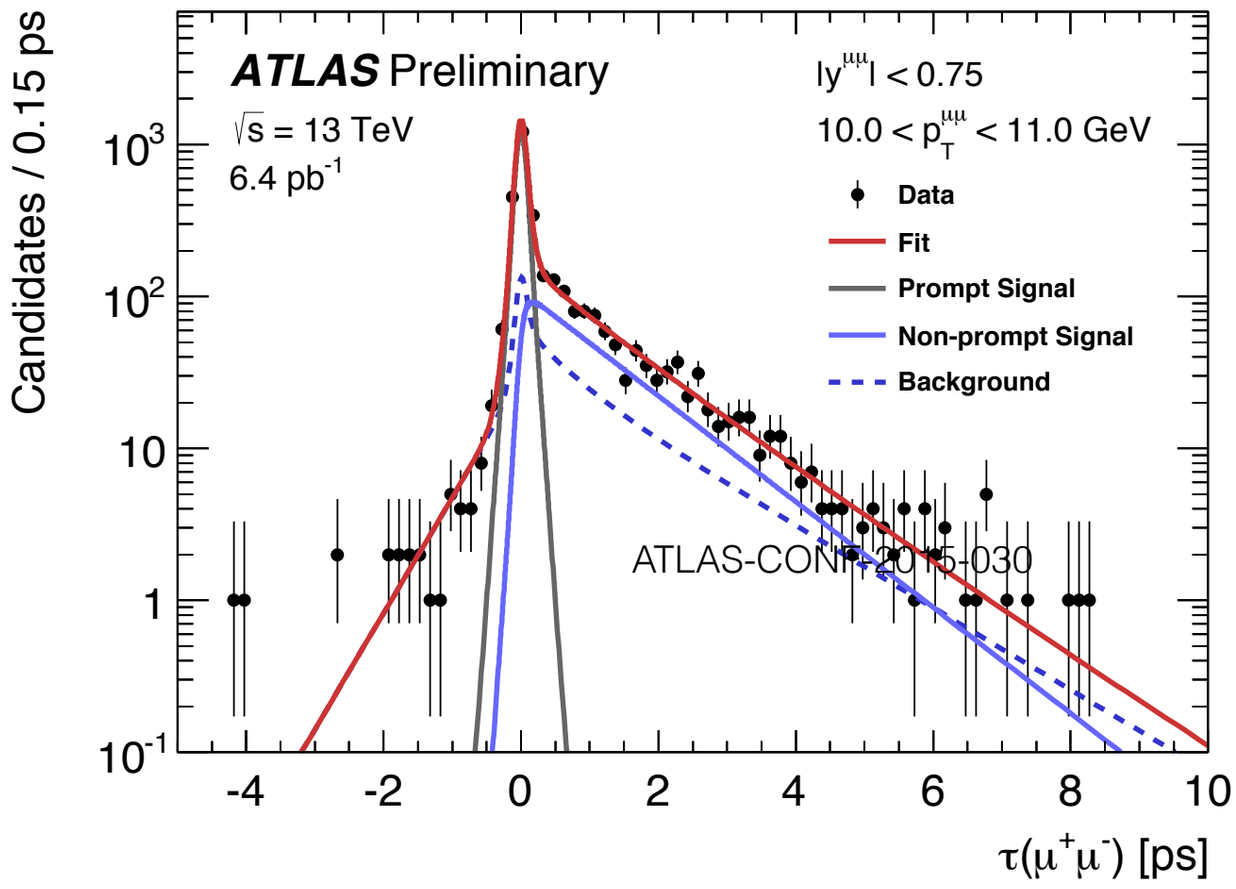


Invariant mass distribution of selected di-muon candidates.
Dataset recorded in June 2015
Mean number of individual pp interactions occurring within a single bunch crossing: reached up to 27.

6.4 pb^{-1} ~70,000 di-muon candidates
cf 2.1 fb^{-1} for 7 TeV data and 11.4 fb^{-1} for 8 TeV

Non-prompt J/ψ production √s = 13 TeV





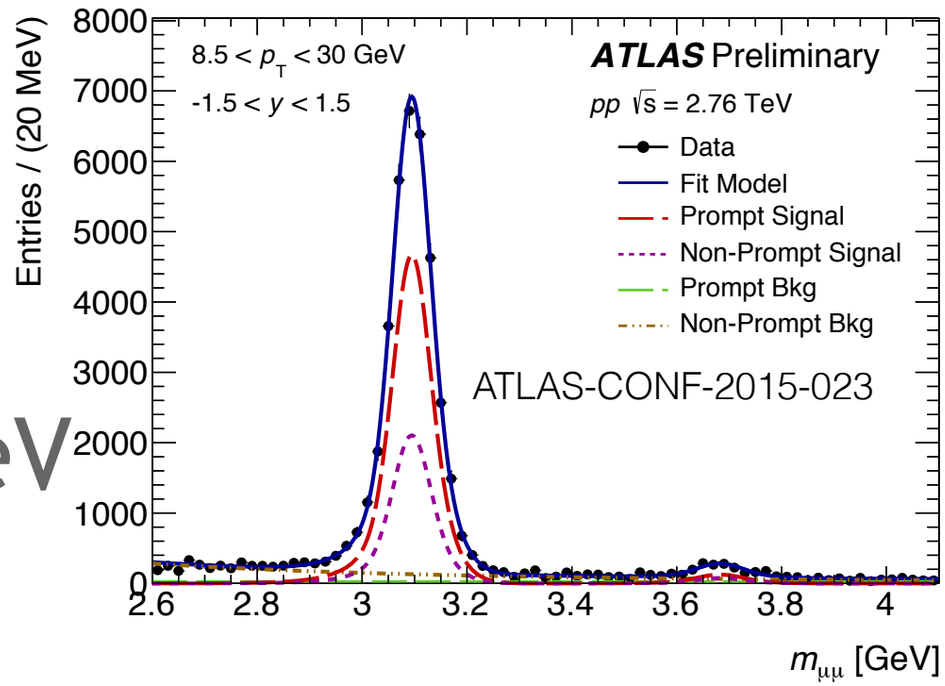
Unbinned maximum likelihood fit and data projections onto the invariant mass and pseudo-proper decay time of the di-muon candidates

An isotropic spin-alignment hypothesis assumed
- no geometric acceptance correction applied to the data
- no spin-alignment uncertainty considered

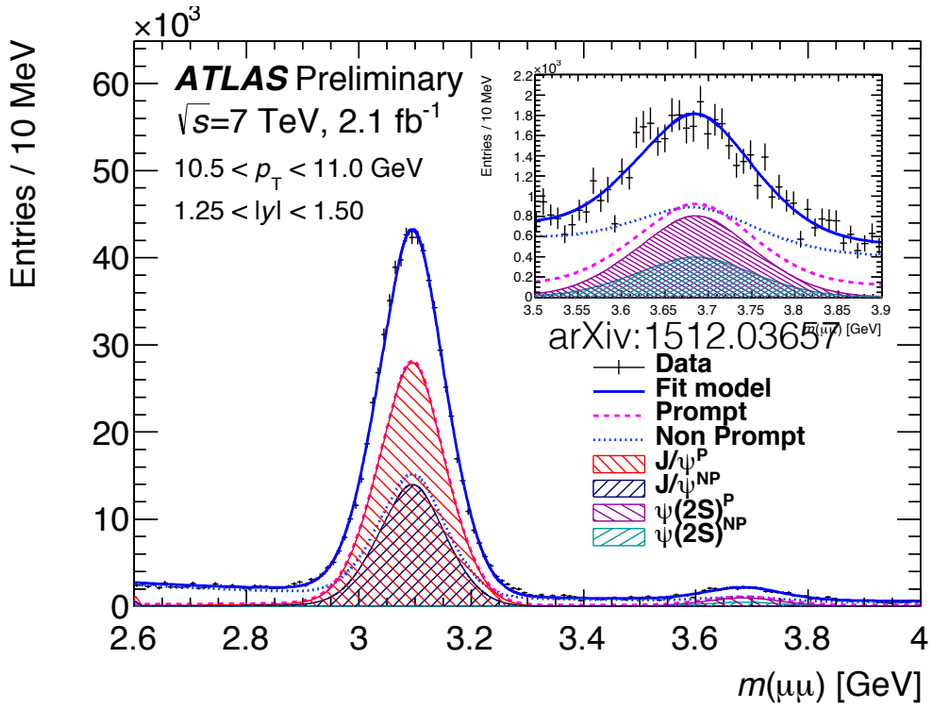
ATLAS-CONF-2015-023 2.76TeV
arXiv:1512.03657 7 & 8 TeV
ATLAS-CONF-2015-030 13 TeV

Prompt and non-prompt production of J/ψ

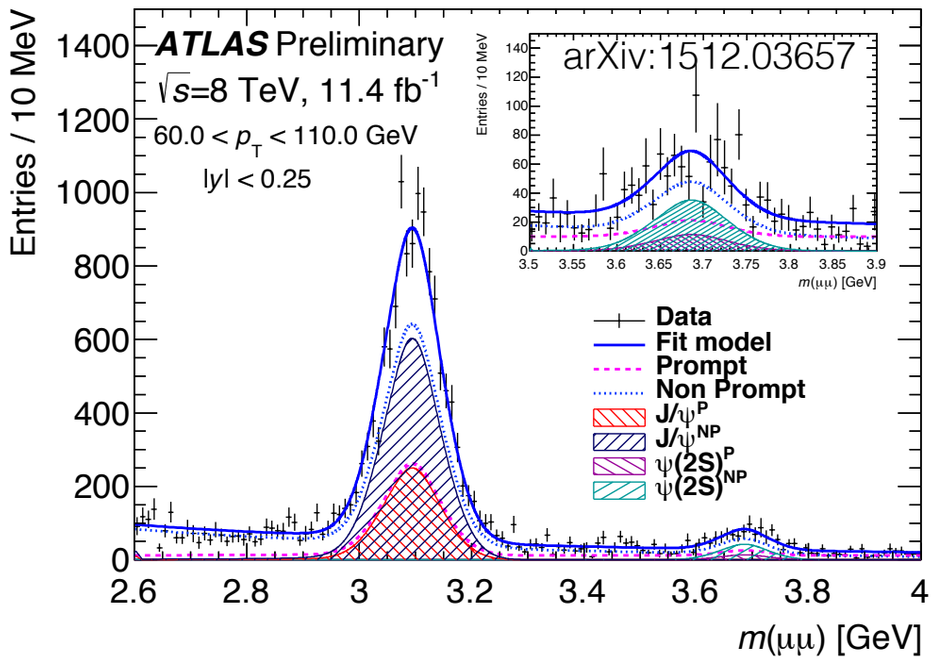
2.76 TeV



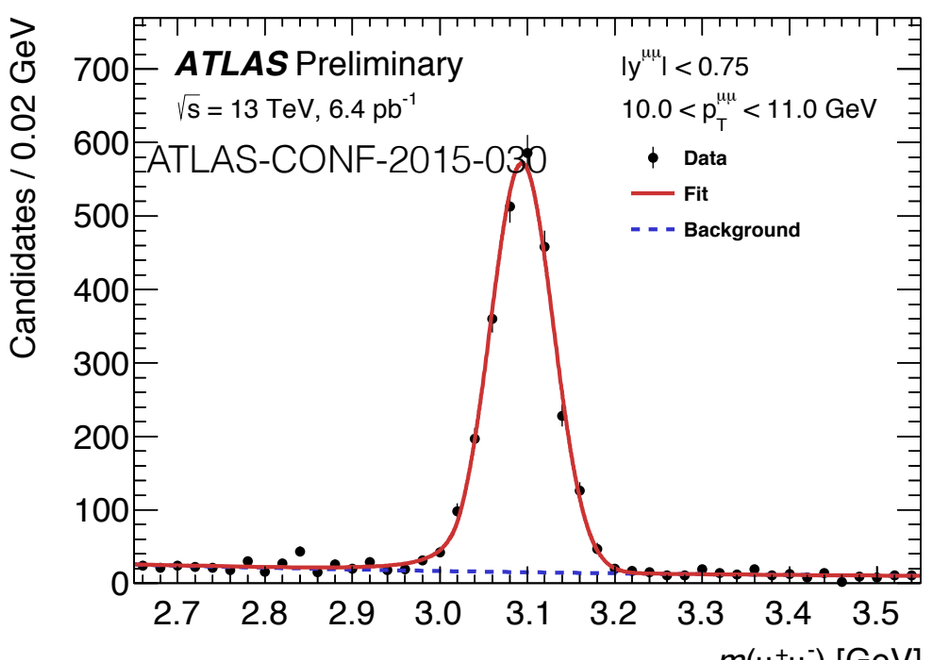
7 TeV



8 TeV



13 TeV



ATLAS-CONF-2015-023 2.76TeV
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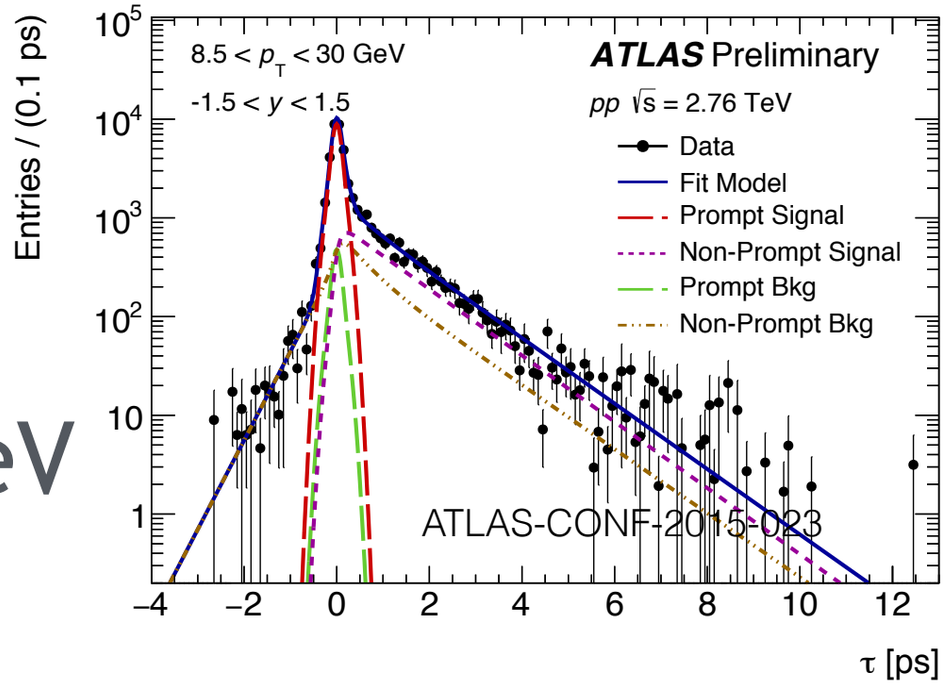
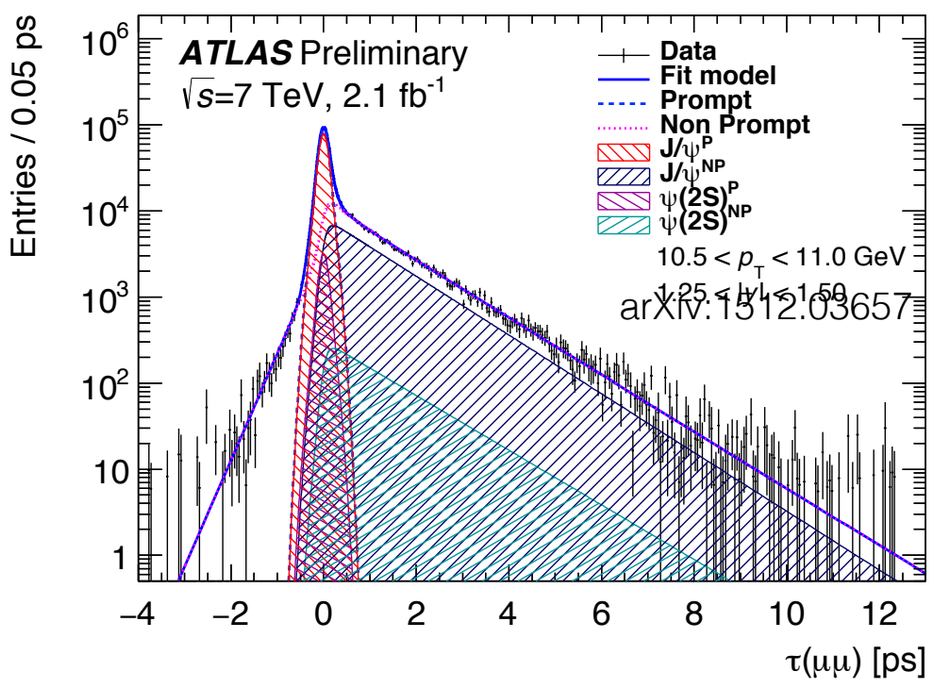
Prompt and non-prompt production of J/ψ

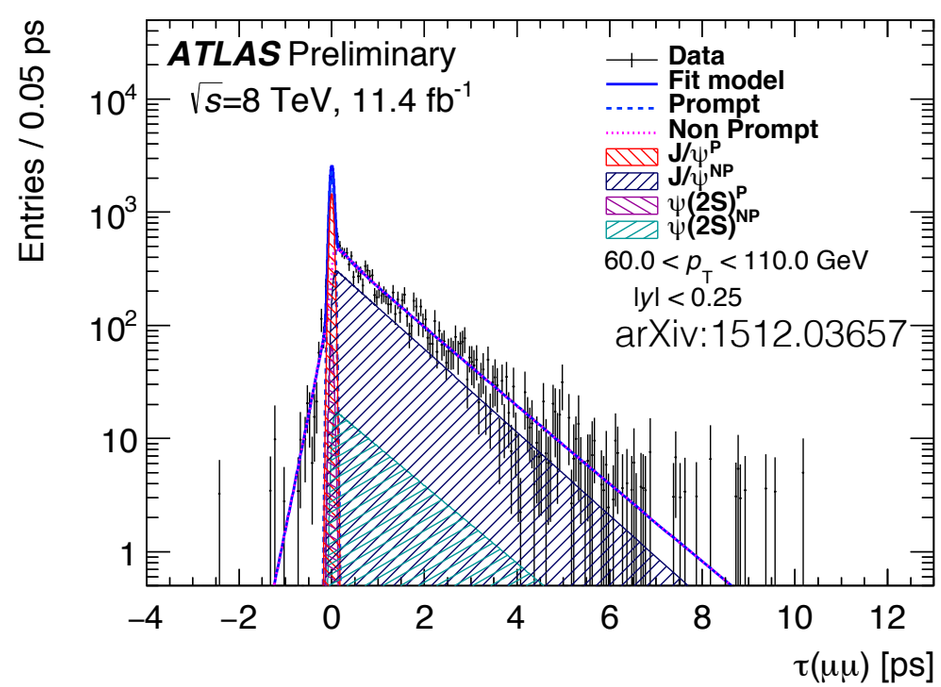
2.76 TeV



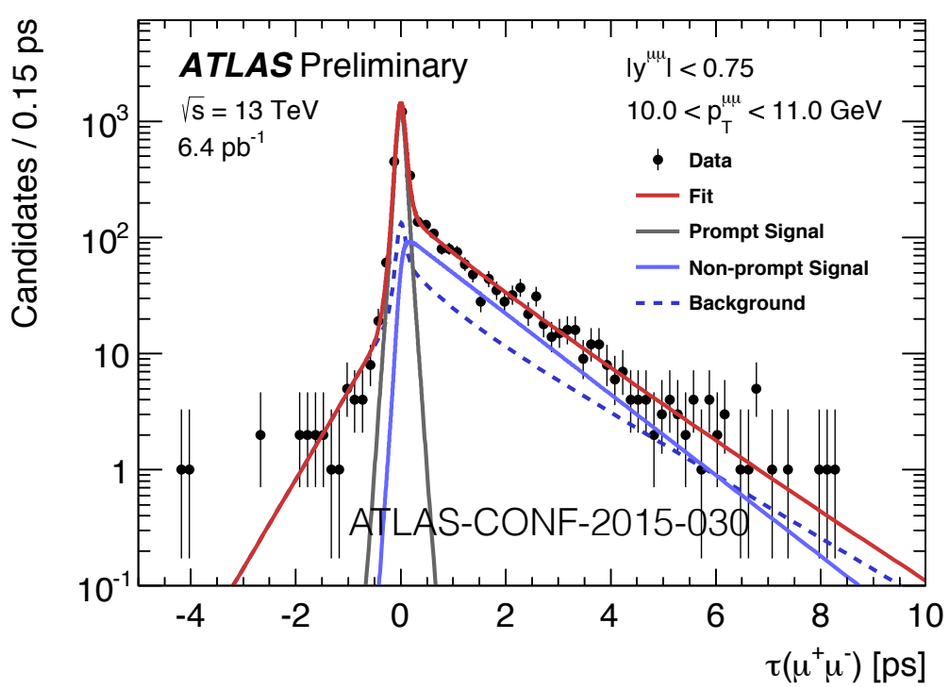
7 TeV



8 TeV



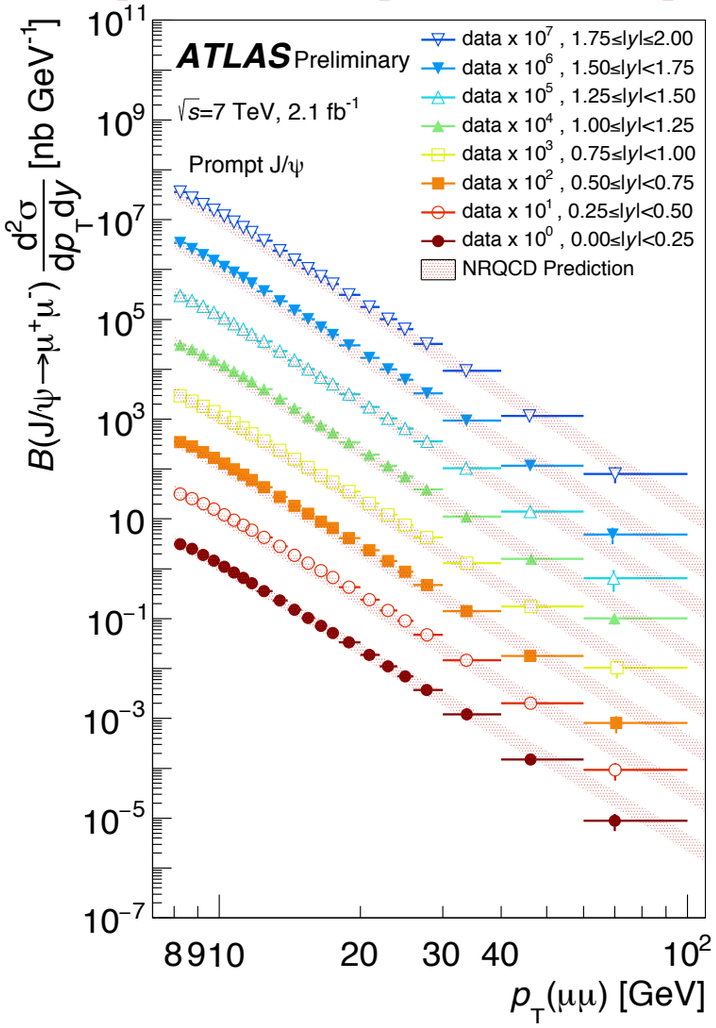
13 TeV



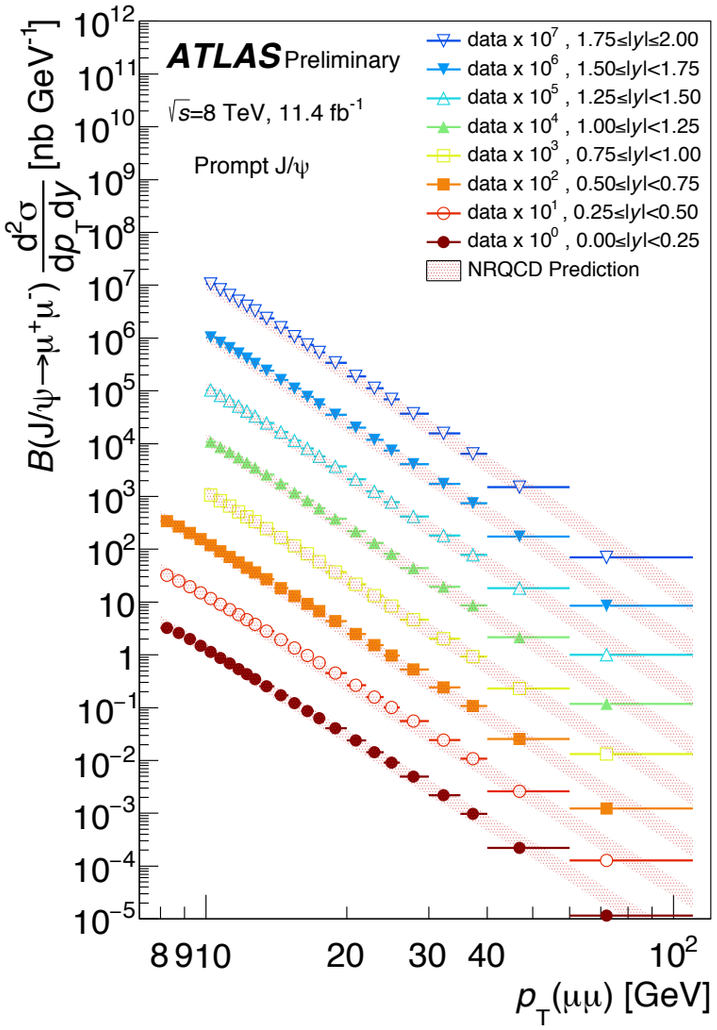
arXiv:1512.03657

Double-differential prompt J/ψ cross-sections

7 TeV



8 TeV



The differential prompt cross-sections times di-muon branching fraction of J/ψ as a function of di-muon p_T for 8 rapidity slices. Range $8 < p_T \leq 110$ GeV and $|y| < 2$
Measurements corrected for acceptance, trigger and reconstruction efficiencies

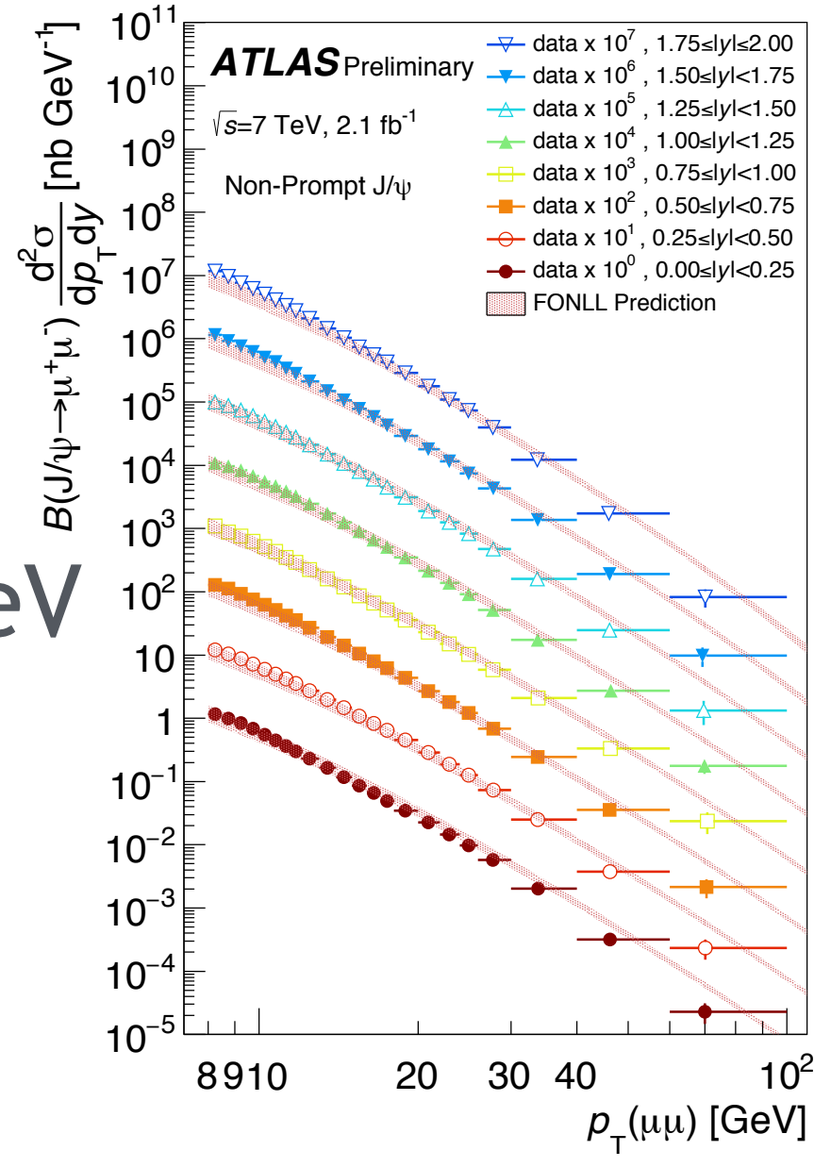
Prompt cross-sections compared to NLO Non-relativistic QCD (NRQCD) theory calculations
Theory uncertainties from scale, charm quark mass and long-distance matrix elements

Reasonable agreement between calculation and data

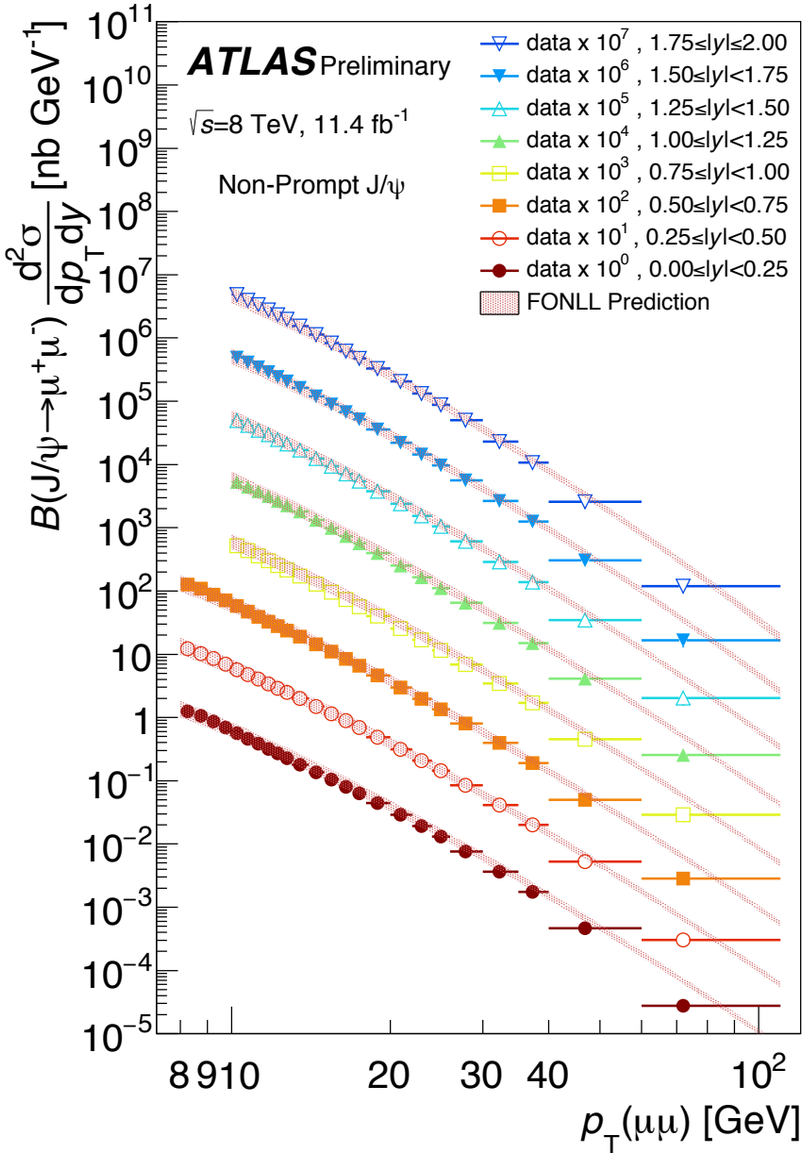
arXiv:1512.03657

Double-differential non-prompt J/ψ cross-sections

7 TeV



8 TeV



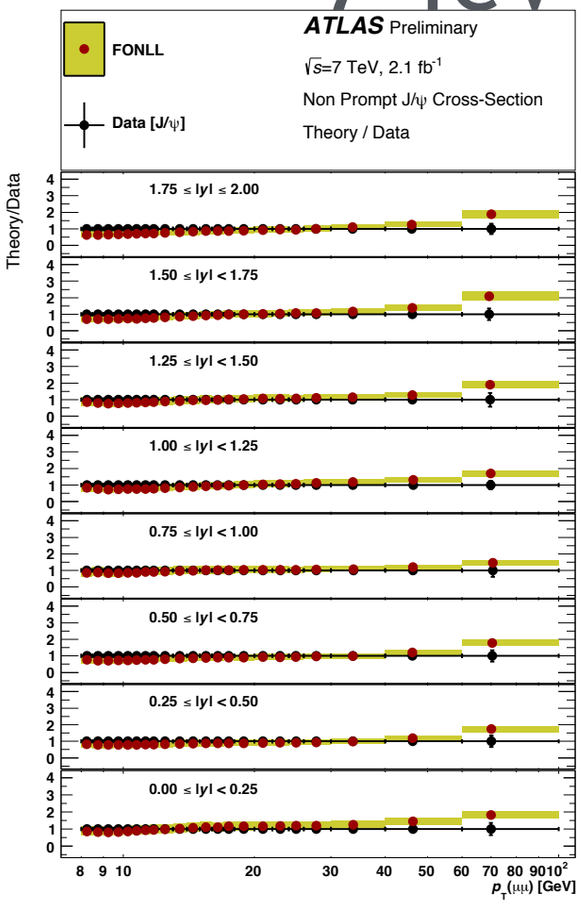
Non-prompt cross-sections compared to Fixed-Order with Next-to-Leading-Log (FONLL) theory calculations

Theory uncertainties from scale and quark masses

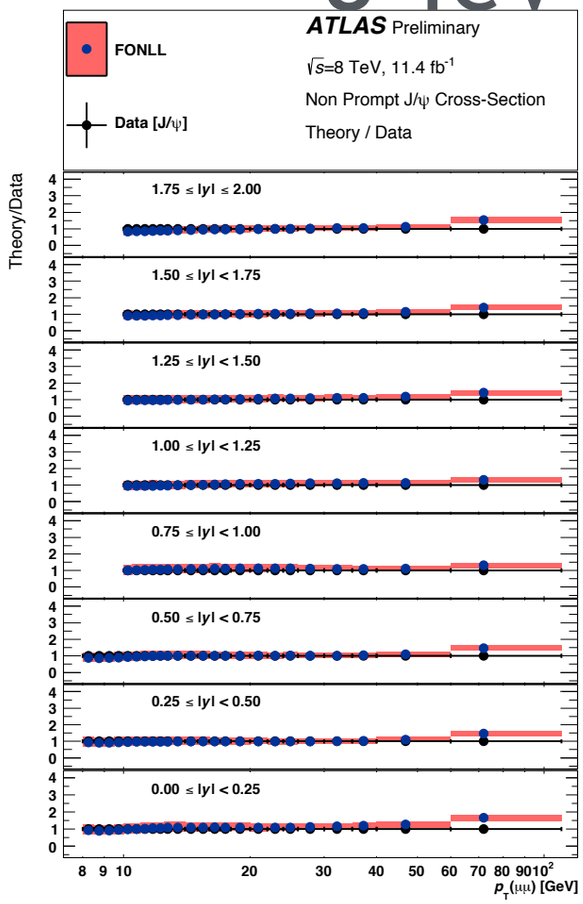
Theory predicts slightly harder p_T for J/ψ

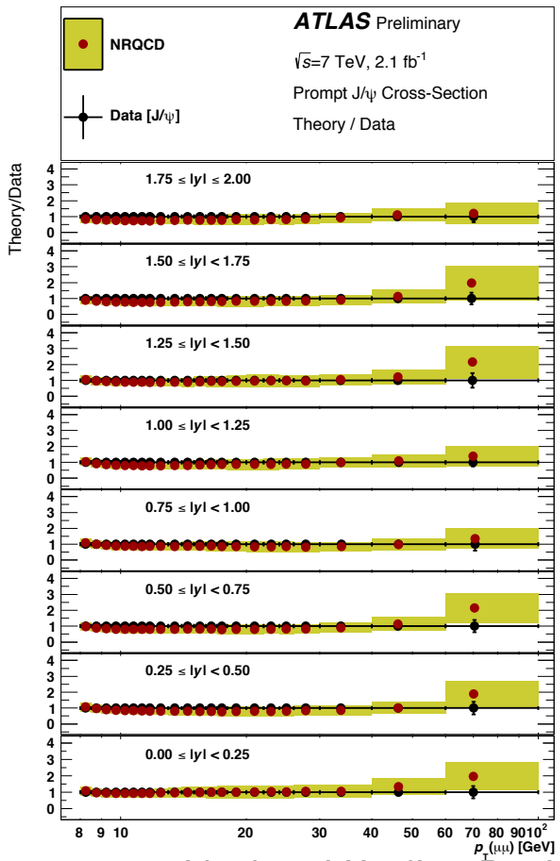
arXiv:1512.03657

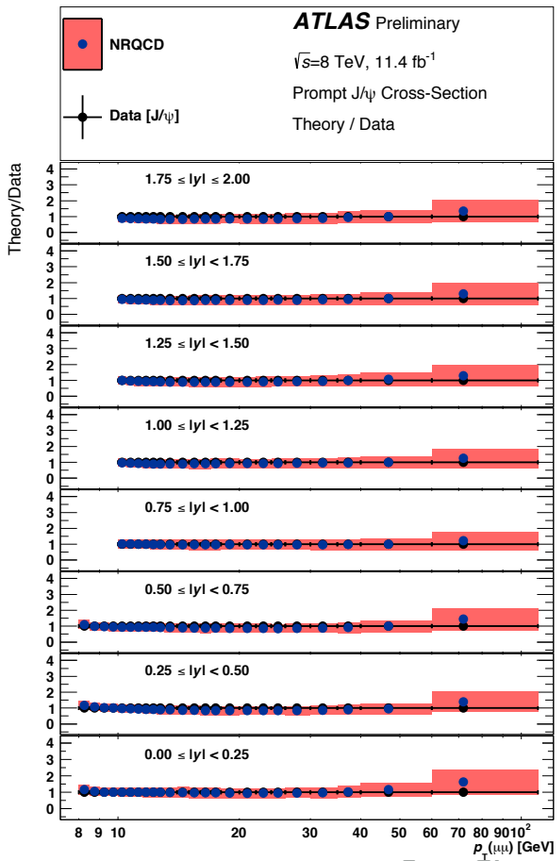
7 TeV



8 TeV







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Theory / Data

The ratios of the theoretical predictions to the data are presented for the differential prompt cross-sections of J/ψ as a function of $p_T(\mu\mu)$ for each rapidity slice

Non-prompt J/ψ

FONLL calculations made within the framework of perturbative QCD, are quite successful in describing non-prompt production of quarkonium states.

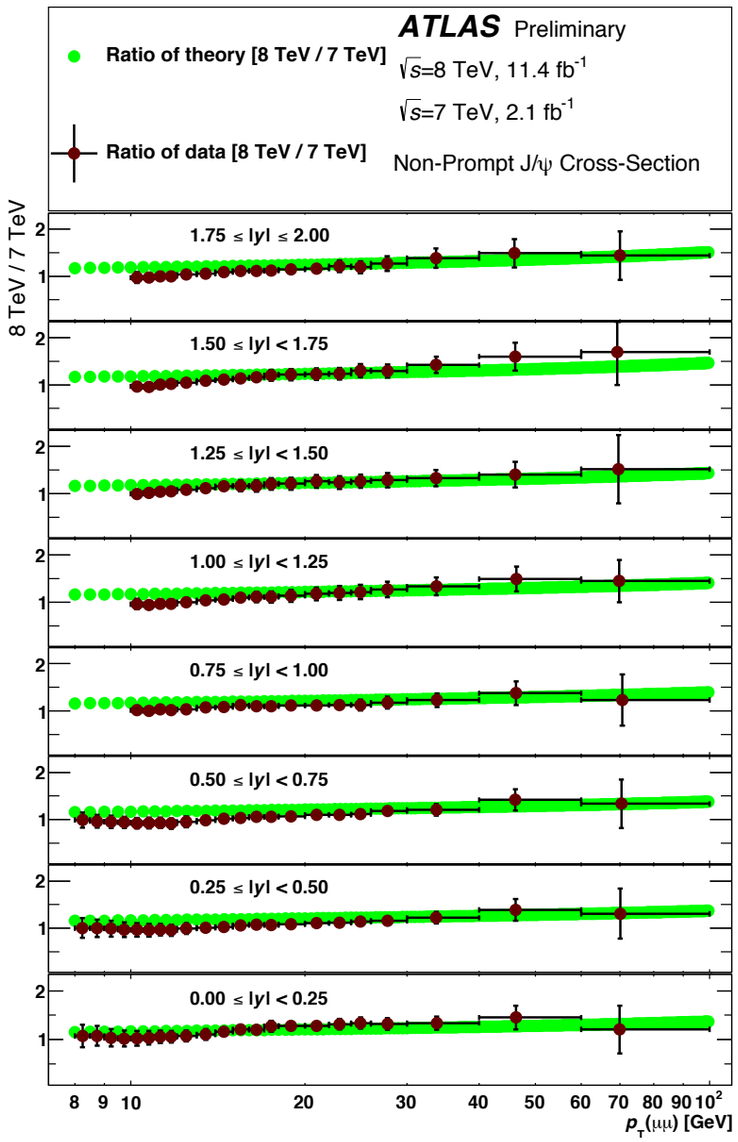
Prompt J/ψ

Prompt cross-sections are compared to NRQCD. A satisfactory understanding of the prompt production mechanisms is still to be achieved

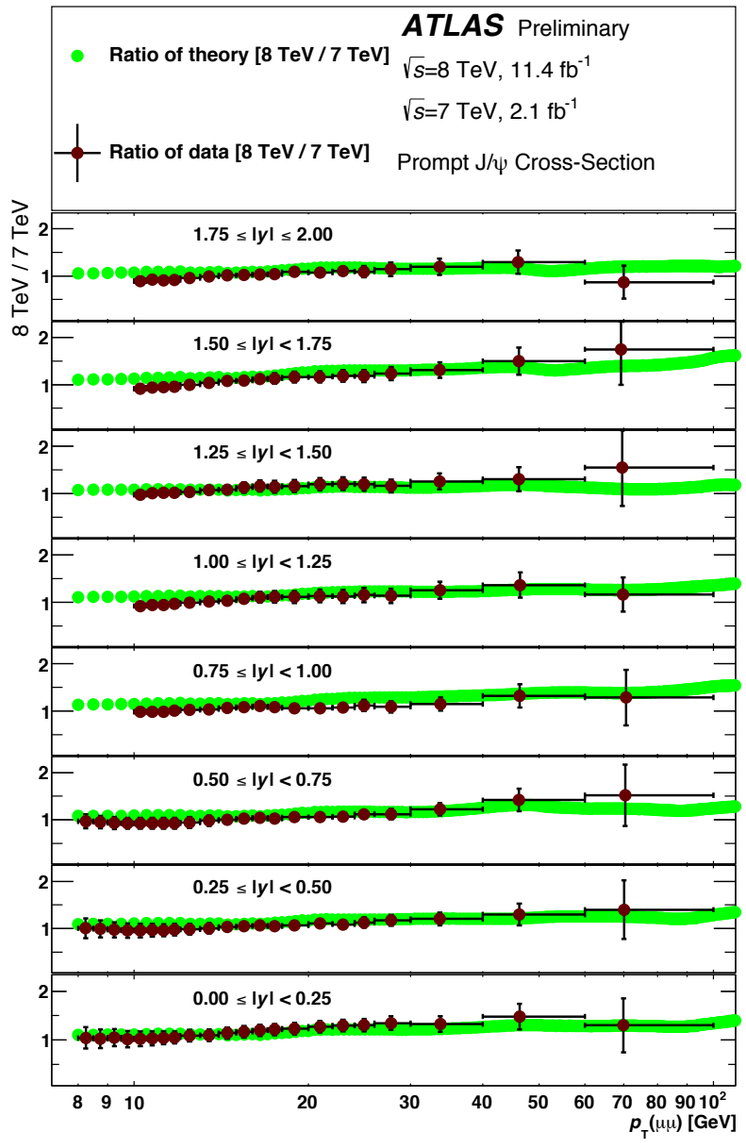
arXiv:1512.03657

Cross-section ratios [8 TeV/7 TeV]

Non-prompt J/ψ



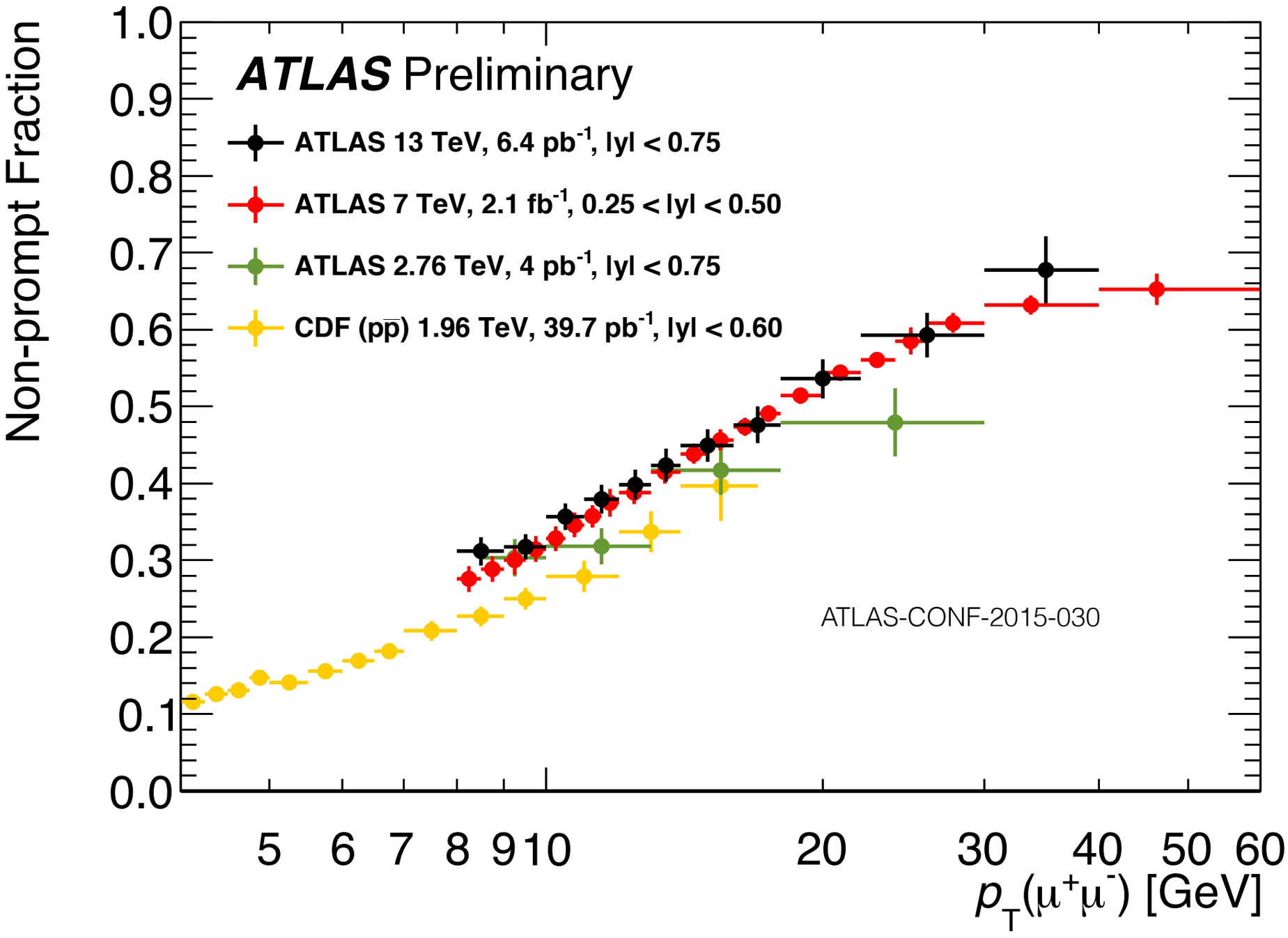
Prompt J/ψ



Ratios become larger with increasing p_T

Data<theory at low p_T for both prompt and non-prompt J/ψ production.

Non-prompt J/ψ production fraction

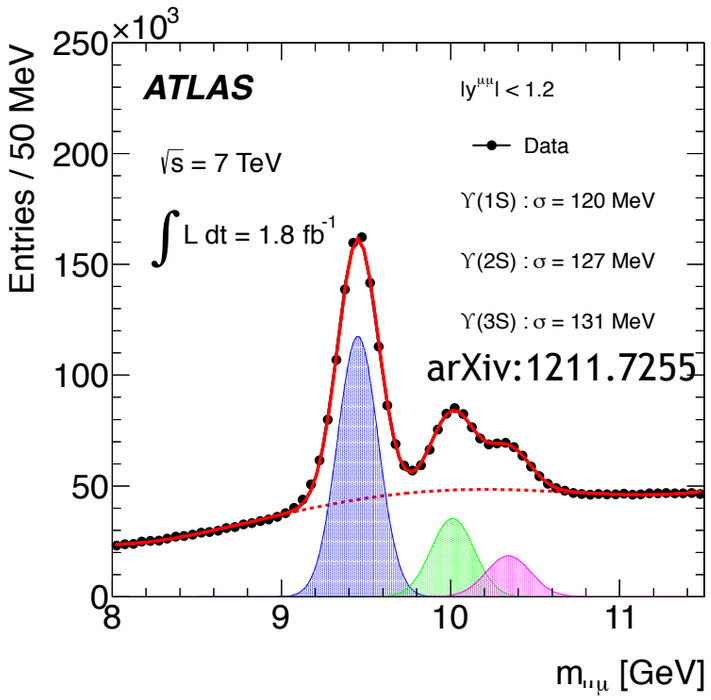


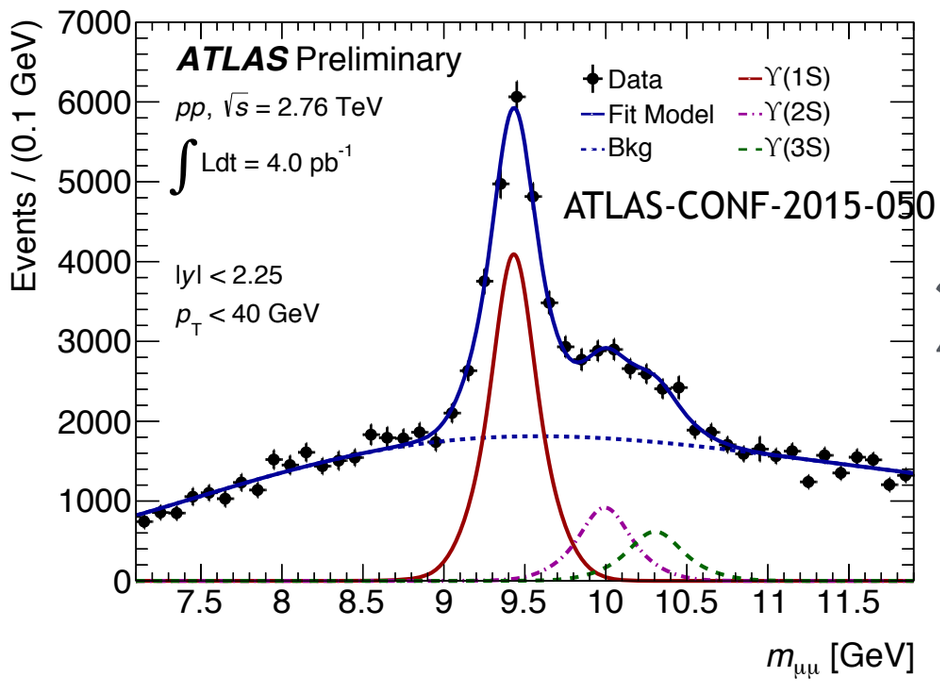
Some dependence on √s and initial state observed

arXiv:1211.7255 7 TeV
ATLAS-CONF-2015-050 2.76 TeV

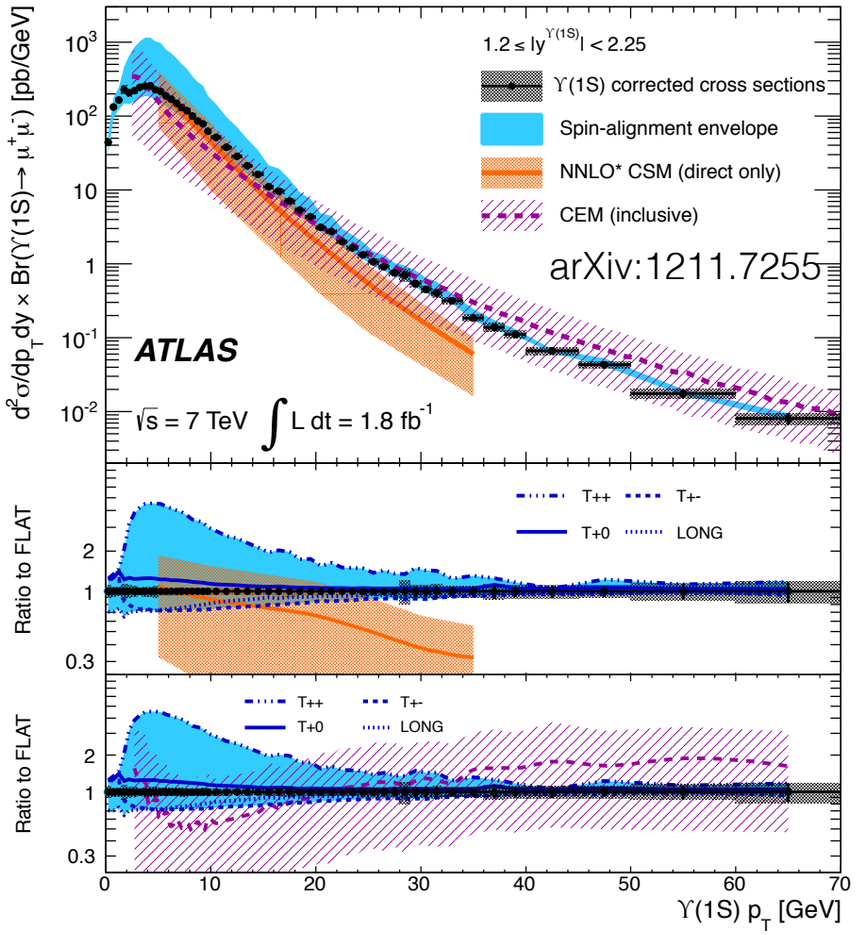
Upsilon Production

7 TeV





2.76 TeV



Both NNLO* Color Singlet Model (CSM) and the Color Evaporation Model (CEM) predictions have some problems in describing the normalisation and shape of the differential spectra.

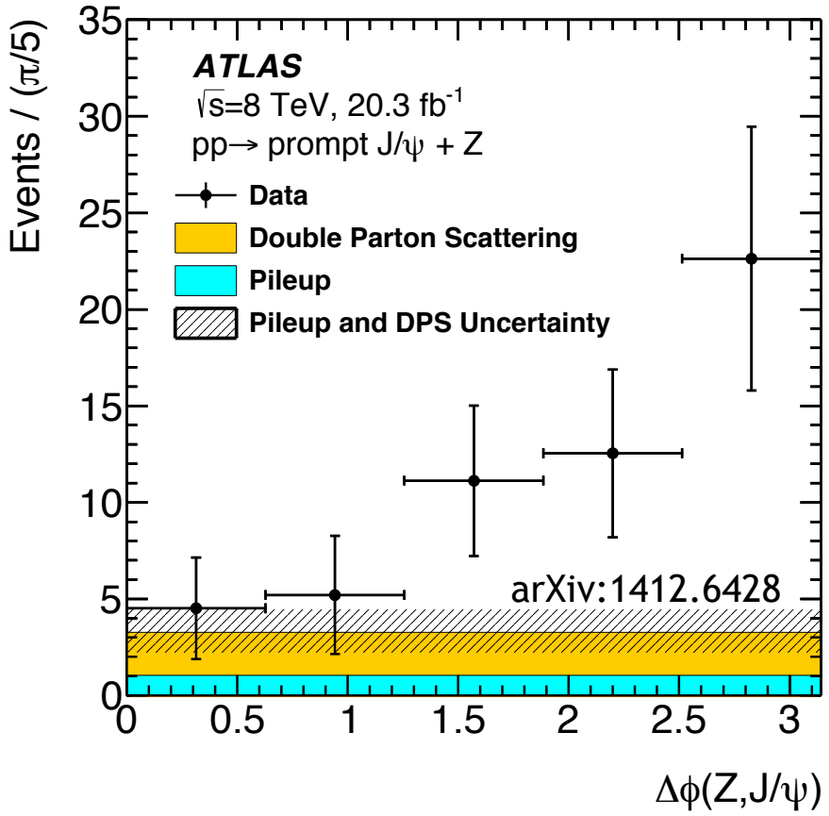
In particular, NNLO* CSM dramatically under-estimates the rate at high transverse momenta, where the data tend to agree better with the CEM.

Comparison of results to several theoretical models:
none provide an accurate description of the data over the full range of Y transverse momenta accessible with the 7 TeV dataset.

arXiv:1412.6428 J/ψ +Z
arXiv:1401.2831 J/ψ +W

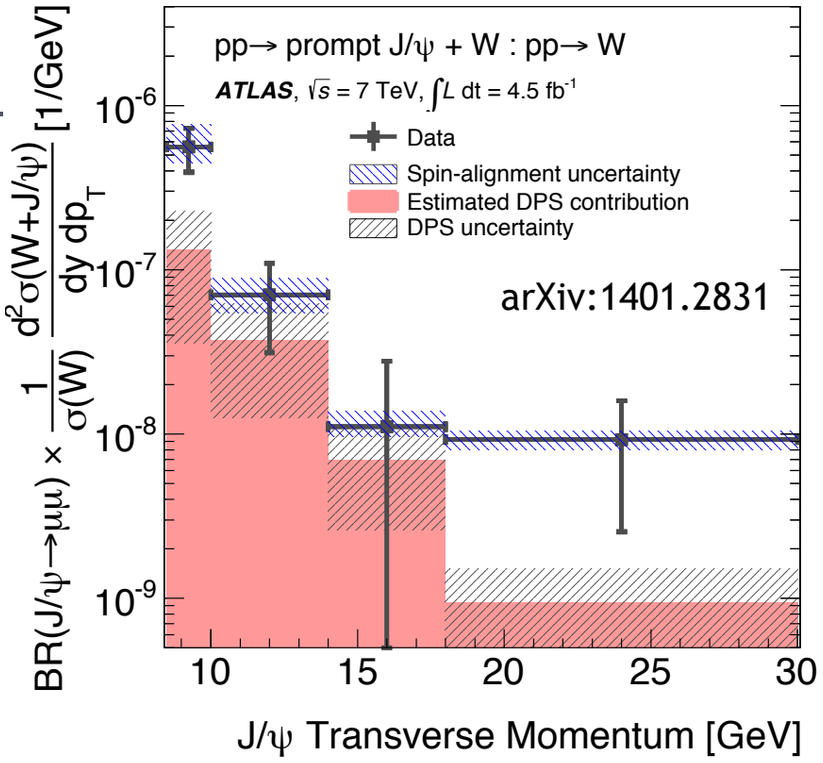
Associated Production

- Probes quarkonium production mechanism
- Sensitive to multiple parton interactions

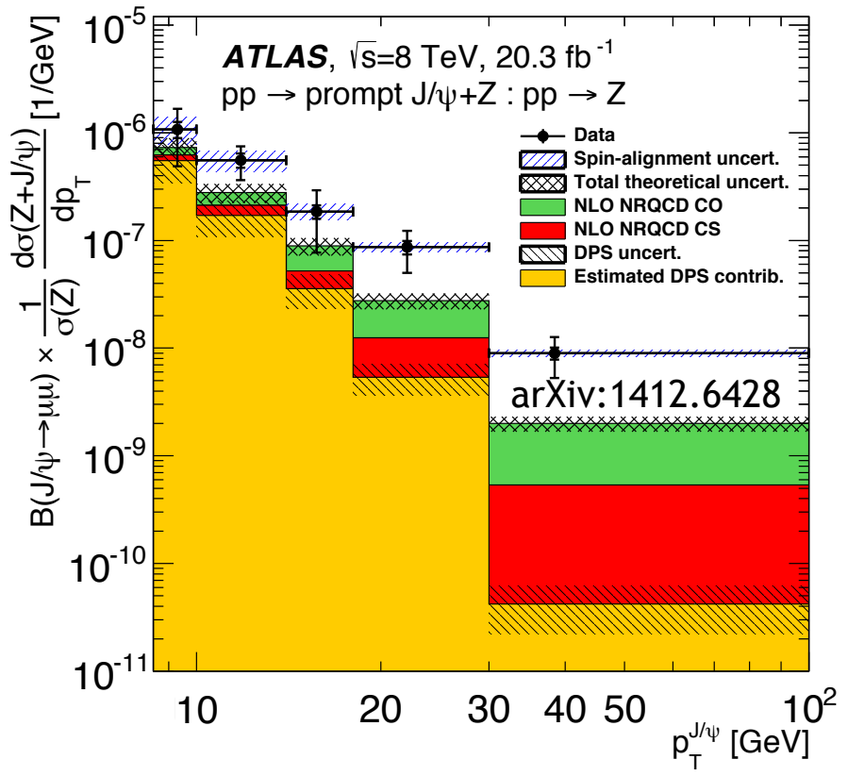


The final state of J/ψ + W/Z can arise from 2 distinct parton-parton interactions within the same pp collision.

Measurements of the azimuthal angle between the Z boson and J/ψ suggest that both single and double parton scattering (DPS) contributions may be present in the data.



Measurements of the W boson and J/ψ suggest that Single Parton Scattering is the dominant contribution



A higher production rate is predicted through colour-octet (CO) transitions than through colour-singlet (CS) processes, but the expected production rate from the sum of singlet and octet contributions is lower than the data by a factor of 2 to 5 in the p_T range studied.

Summary

Many publications and analyses in progress in 2016

The large quarkonium sample from Run 1 allows detailed tests of QCD:
- Standard quarkonium
- cross-sections and branching fractions
- Rare or exotic decays
- Associated production with vector bosons, photons or additional quarkonia
- Probe gluon splitting
- etc.

Run 2 measurements just starting

Full details of published results at:

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/BPhysPublicResults