Quarkonium Production at ATLAS

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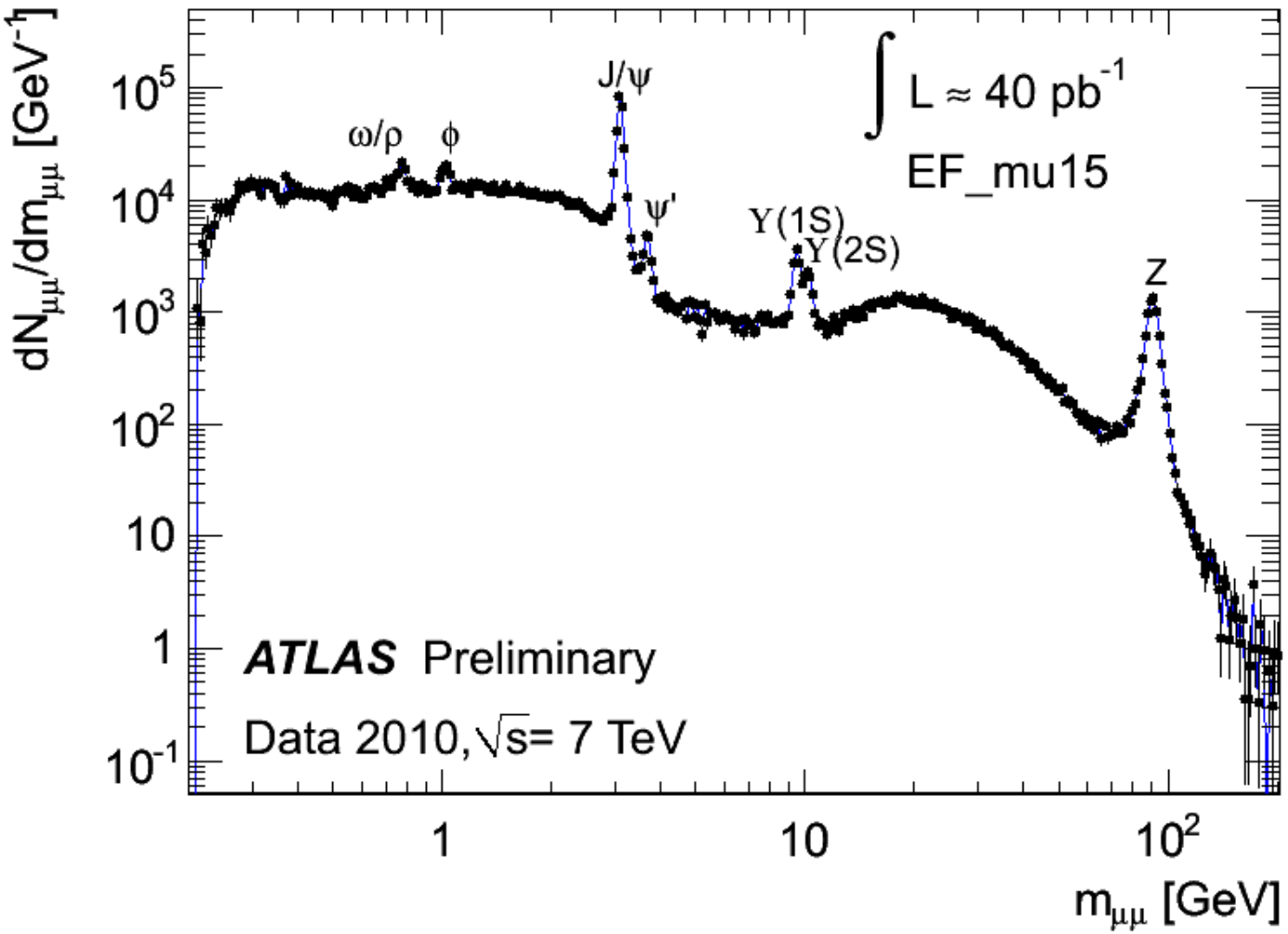
On behalf of the ATLAS Collaboration

Dimuon Invariant Mass Spectrum



Introduction

The measurements presented in this talk are:

- **Inclusive J/ψ production cross-section**
- **Fraction of J/ψ's coming from B-hadron decays**
- **Prompt J/ψ production cross-section**
- **Non-prompt (B decay) J/ψ production cross-section**

arXiv:1104.3038v1 [hep-ex]

These results were obtained using 2.2 pb^{-1} of data obtained using the ATLAS detector in 2010.

Measurements are presented both differentially as a function of J/ψ p_T and rapidity, and integrated over the maximum observed span to provide an integrated cross-section

Experimental uncertainties are at the 10—15% level across the range of measured cross-sections, and the results are limited by systematic uncertainties over the bulk of the distributions

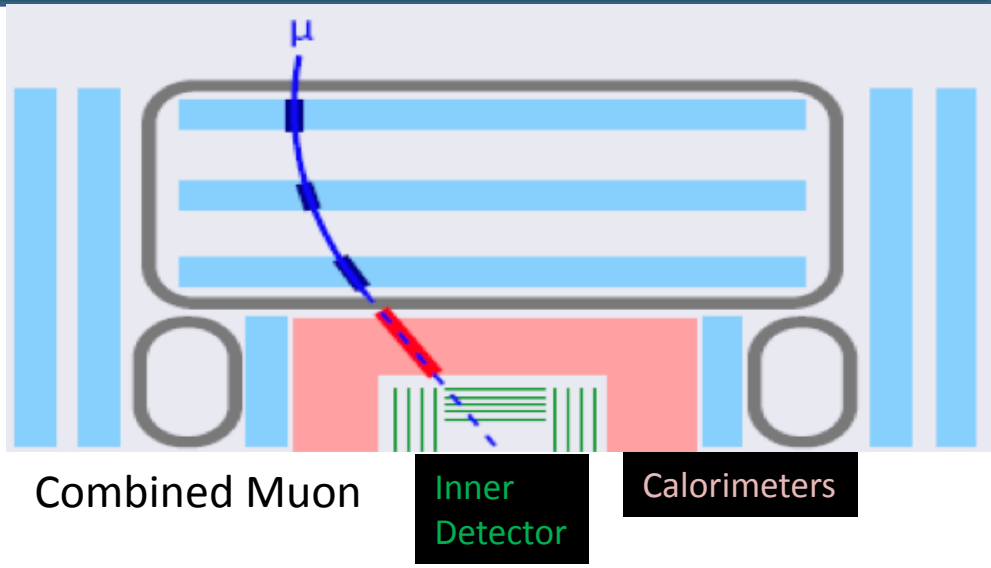
Where appropriate, results are compared to theoretical predictions from Color Evaporation Model, Color Singlet NNLO*, and FONLL.

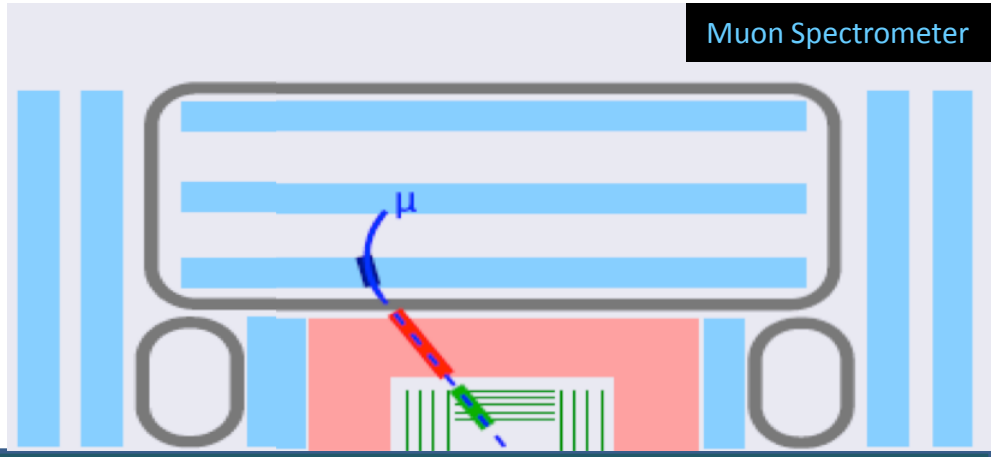
Data Selection and Trigger

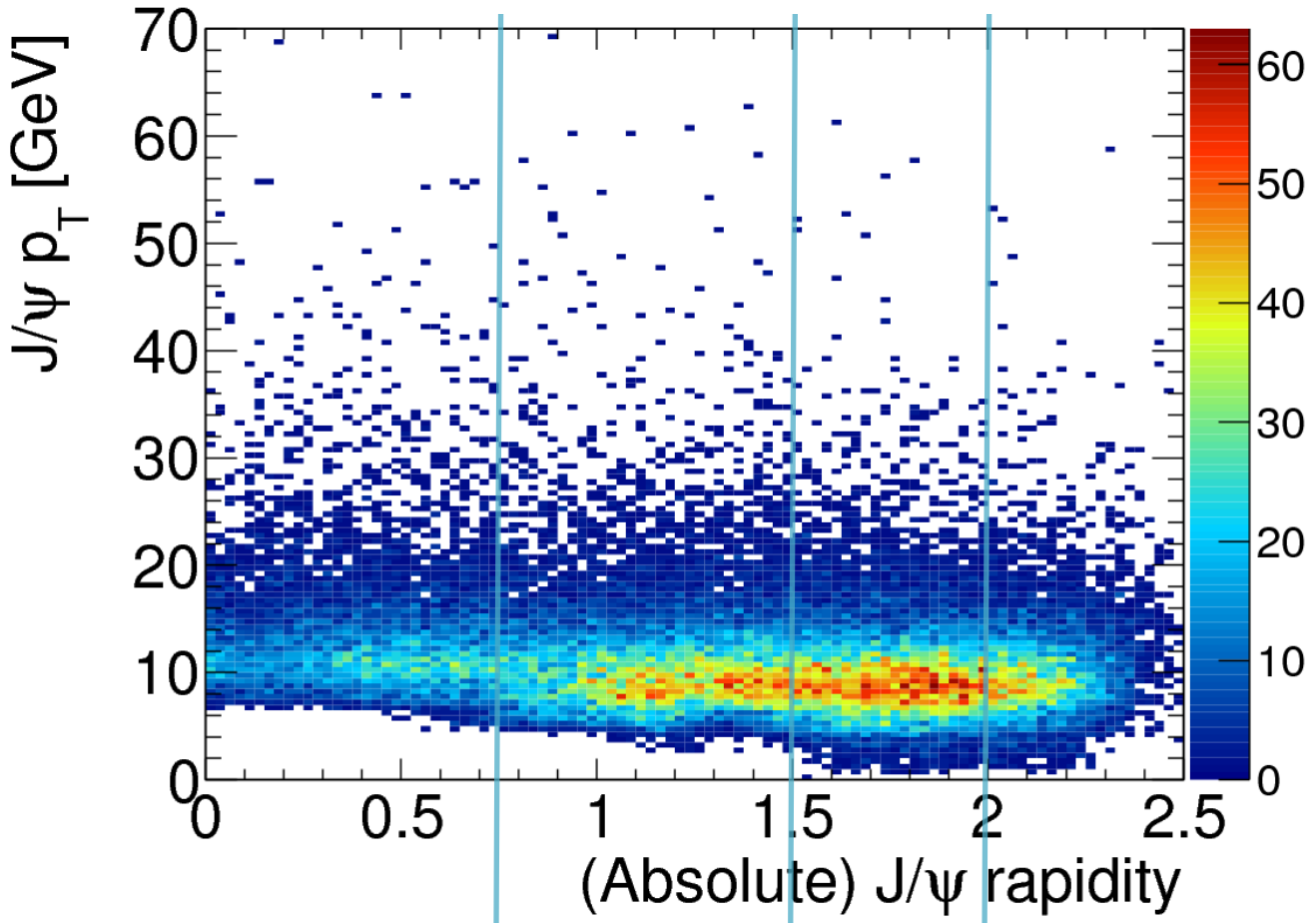
- Trigger Selection
  - Minimum Bias Scintillator trigger for earliest data taking
  - Single muon seeded trigger with thresholds of 0 GeV → 4 GeV → 6 GeV, with each step in threshold necessitated by increases in instantaneous luminosity
- Event Selection
  - Tracks (muons and primary vertex) must have
    - # Pixel Hits ≥ 1
    - # SCT Hits ≥ 6
  - 3 tracks associated to a primary vertex
  - 2 reconstructed muons with Inner Detector matched track

Candidate Selection

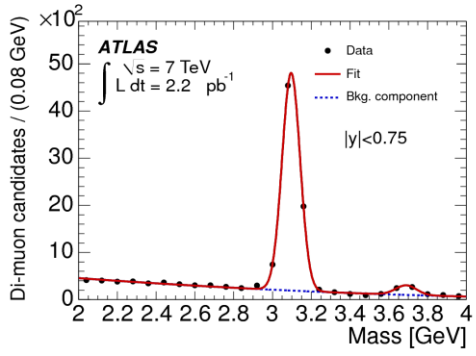
- 2 distinct classes of muon tracks associated to J/ψ candidates:
  - Combined: full track segments in both the muon spectrometer and the inner detector
  - Tagged: full track segment in the inner detector associated with at least 1 hit in the muon system
- Require at least one muon to be Combined
- Require at least one muon to have been a trigger object
- Require for both muons
  - $p > 3.0$ GeV
  - $p_T > 1.0$ GeV
  - $|\eta| < 2.5$
  - # Pixel Hits ≥ 1
  - # SCT Hits ≥ 6



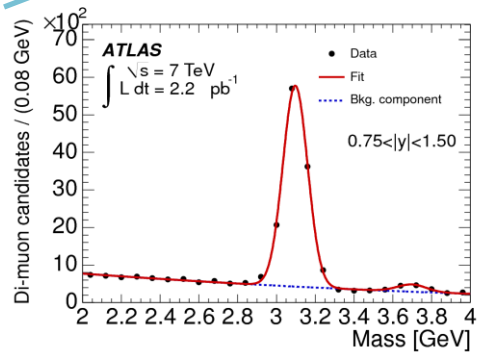




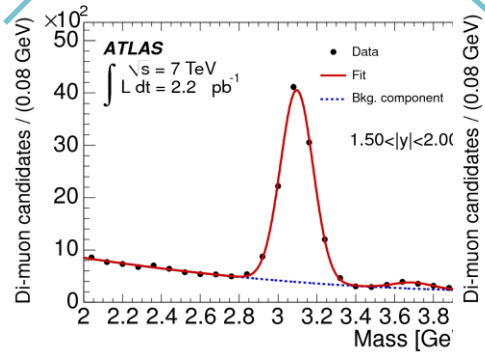
σ = 46 MeV



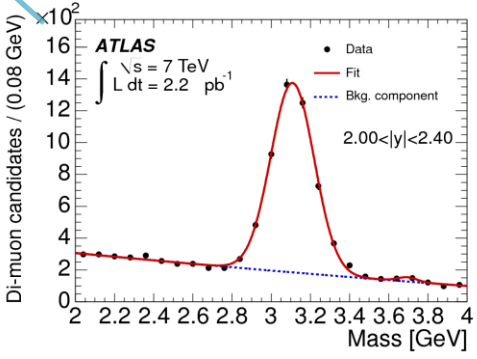
σ = 64 MeV



σ = 84 MeV



σ = 111 MeV



Inclusive Cross-Section Measurement

- Basic strategy
  - Reconstruct J/ψ candidates in bins of p_T and y
  - Correct on a candidate-by-candidate basis for efficiencies, bin migration, and acceptance
  - $N_{corr} = \Sigma\, w^{-1}\, N_{reco}$

Detector Acceptance

Inner Detector reconstruction efficiency per muon track

Trigger efficiency

$$w^{-1} = \mathcal{A} \cdot \mathcal{M} \cdot \mathcal{E}^2_{trk} \cdot \mathcal{E}^+_{\mu}(p_T^+, \eta^+) \cdot \mathcal{E}^-_{\mu}(p_T^-, \eta^-) \cdot \mathcal{E}_{trig}$$

Bin Migration

Charge dependent reconstruction efficiency per muon track

Fit the resultant weighted yields to derive the corrected value $N_{corr} \rightarrow N^{J/\psi}_{corr}$

Extract the resultant cross-section for a given analysis bin from $N^{J/\psi}_{corr}$

$$\frac{d^2\sigma(J/\psi)}{dp_T dy} \cdot Br(J/\psi \rightarrow \mu^+\mu^-) = \frac{N^{J/\psi}_{corr}}{\mathcal{L} \cdot \Delta p_T \Delta y}$$

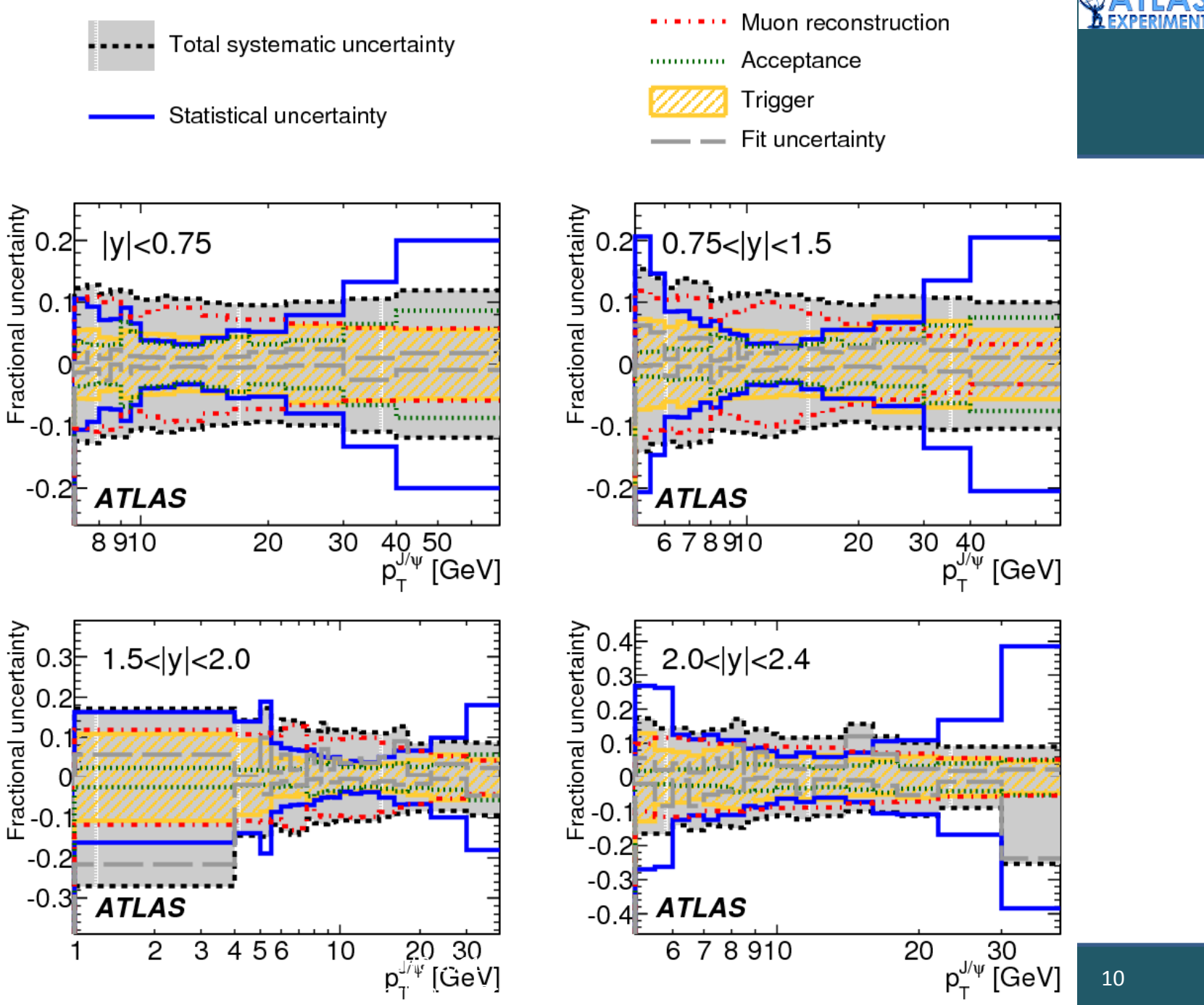
Acceptance, Bin Migration, and Efficiencies

- Acceptance maps
  - Offline reco. efficiency → Total inclusive distribution
  - Correct for differences, prompt vs. non-prompt
- Bin migration effects
  - Evaluated via smearing → change in yield/bin
- Vertex requirements
  - Negligible effect on signal
  - Background rejection
- Trigger efficiencies
  - Monte Carlo + Tag and Probe
    - Low p_T: J/ψ
    - High p_T: Z
  - Charge dependence of single-muon trigger

$$\mathcal{E}_{\text{trig}} = 1 - \left(1 - \mathcal{E}^{+}_{\text{trig}}(p_T^{+}, \eta^{+})\right) \cdot \left(1 - \mathcal{E}^{-}_{\text{trig}}(p_T^{-}, \eta^{-})\right)$$

Systematic Studies

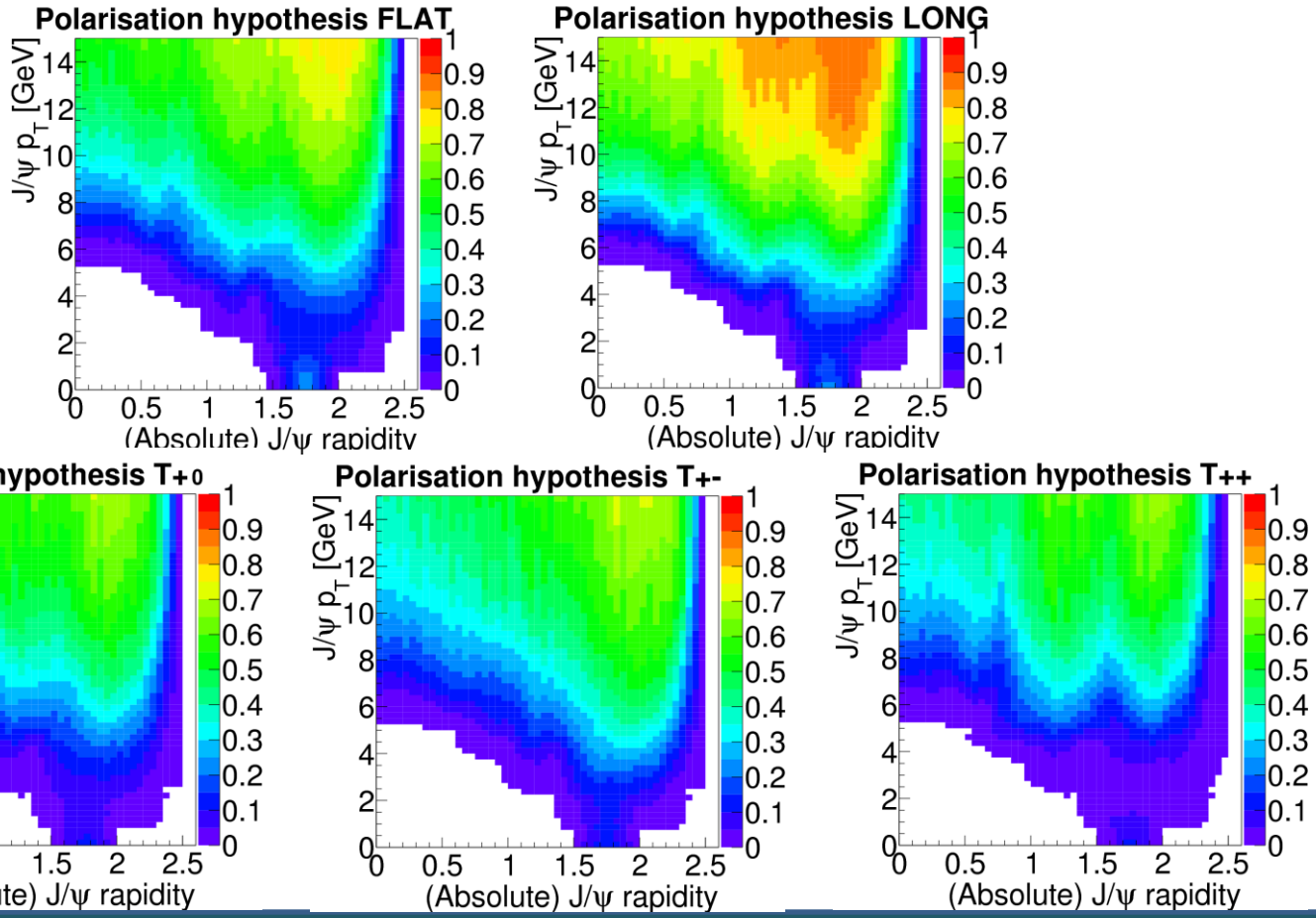
Source of Uncertainty	Value
Acceptance Maps from MC Simulation	~1 to 2 %
Bin Migration Effects	0.1 to 3 %
Inner Detector Reco Efficiency/muon	0.5%
Variation of MC Spectra, Prompt vs. Non-prompt	1.5%
Final State Radiation	< 0.1%
Luminosity (van der Meer Scans)	**3.4%**
Muon Reconstruction Efficiency	**5 to 10%**
Fit Uncertainty (pseudo experiments)	~1 to 3%
Trigger Efficiency	**~5%**
Vertex Reconstruction (primary and J/ψ)	< 0.1%

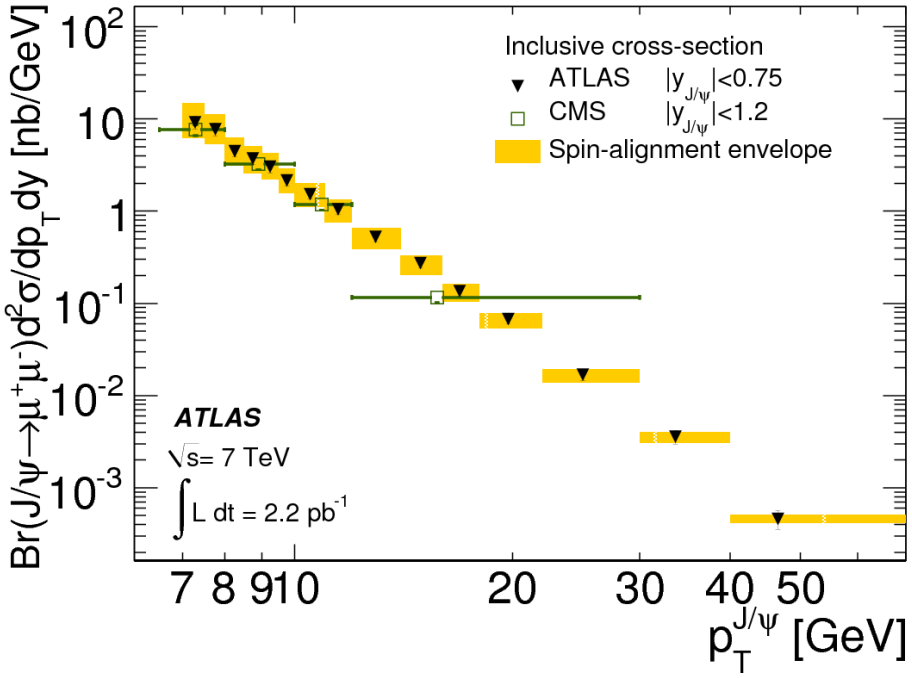

Total systematic uncertainty
Statistical uncertainty
Muon reconstruction
Acceptance
Trigger
Fit uncertainty
|y|<0.75
0.75<|y|<1.5
1.5<|y|<2.0
2.0<|y|<2.4
ATLAS
Fractional uncertainty
$p_T^{J/\psi}$ [GeV]

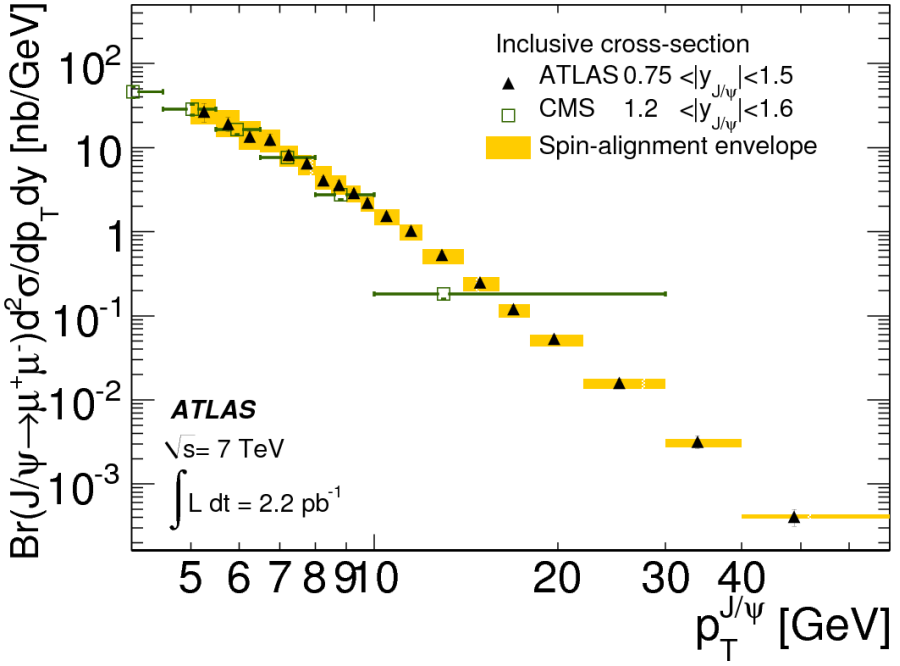
Spin Alignment

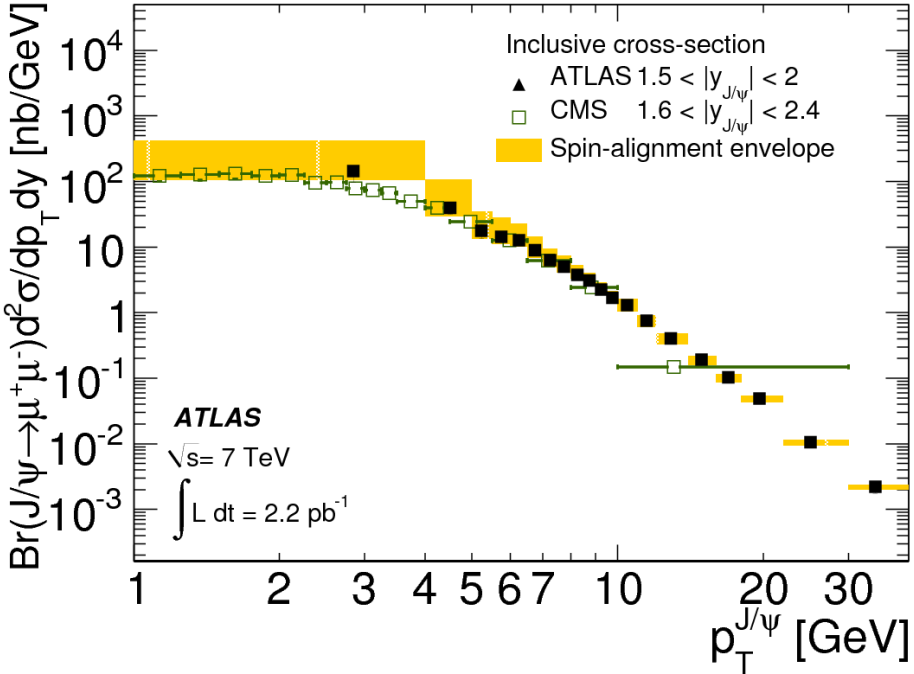
- Five extreme cases, different spin-alignment hypotheses → uncertainty envelope

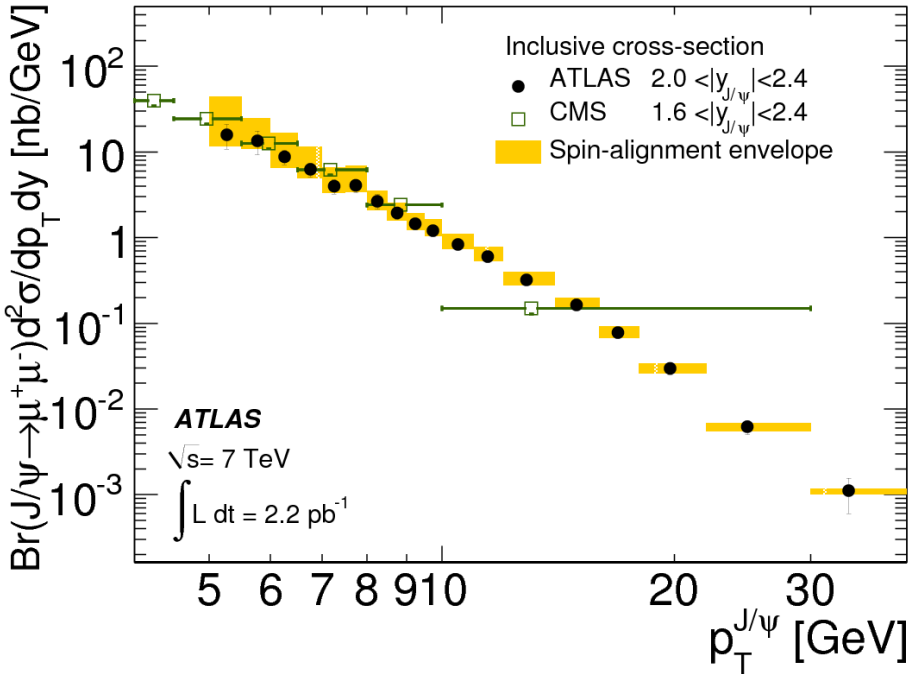
Monte Carlo




Inclusive cross-section
ATLAS |y_J/ψ|<0.75
CMS |y_J/ψ|<1.2
Spin-alignment envelope
ATLAS
√s= 7 TeV
∫L dt = 2.2 pb^-1
Br(J/ψ→μ+μ-)d²σ/dp_T dy [nb/GeV]
p_T^J/ψ [GeV]


Inclusive cross-section
ATLAS 0.75 <|y_J/ψ|<1.5
CMS 1.2 <|y_J/ψ|<1.6
Spin-alignment envelope
ATLAS
√s= 7 TeV
∫L dt = 2.2 pb^-1
Br(J/ψ→μ+μ-)d²σ/dp_T dy [nb/GeV]
p_T^J/ψ [GeV]


Inclusive cross-section
ATLAS 1.5 < |y_J/ψ| < 2
CMS 1.6 < |y_J/ψ| < 2.4
Spin-alignment envelope
ATLAS
√s= 7 TeV
∫L dt = 2.2 pb^-1
Br(J/ψ→μ+μ-)d²σ/dp_T dy [nb/GeV]
p_T^J/ψ [GeV]


Inclusive cross-section
ATLAS 2.0 <|y_J/ψ|<2.4
CMS 1.6 <|y_J/ψ|<2.4
Spin-alignment envelope
ATLAS
√s= 7 TeV
∫L dt = 2.2 pb^-1
Br(J/ψ→μ+μ-)d²σ/dp_T dy [nb/GeV]
p_T^J/ψ [GeV]

Inclusive Cross-Sections

- Summing up the differential inclusive cross-sections
  - Maximum range in rapidity

$$Br(J/\psi \to \mu^+\mu^-)\cdot\sigma(pp \to J/\psi X; |y^{J/\psi}| < 2.4, p_T^{J/\psi} > 7.0\ \text{GeV})$$
$$= 81 \pm 1\ (\text{stat.}) \pm 10(\text{syst.}) \pm^{25}_{20}\ (\text{spin}) \pm 3\ (\text{lumi.})\ \text{nb}$$

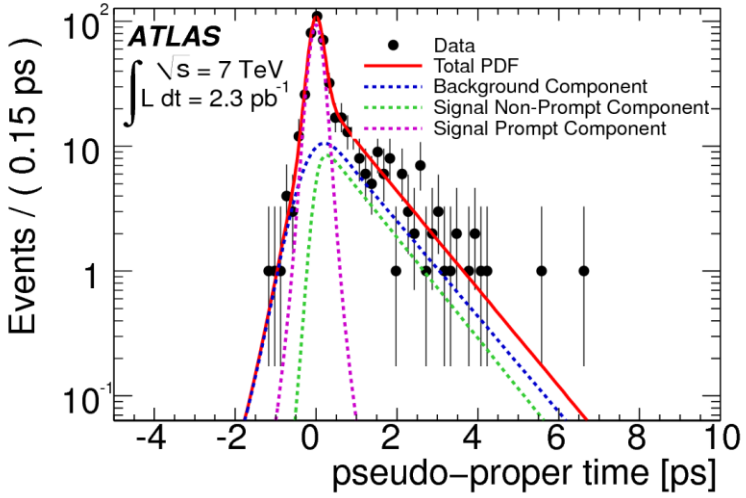
  - Maximum range in p_T

$$Br(J/\psi \to \mu^+\mu^-)\cdot\sigma(pp \to J/\psi X; 1.5 \le |y^{J/\psi}| < 2.0, p_T^{J/\psi} > 1.0\ \text{GeV})$$
$$= 510 \pm 70\ (\text{stat.}) \pm^{84}_{123}\ (\text{syst.}) \pm^{919}_{134}\ (\text{spin}) \pm 17\ (\text{lumi.})\ \text{nb}$$

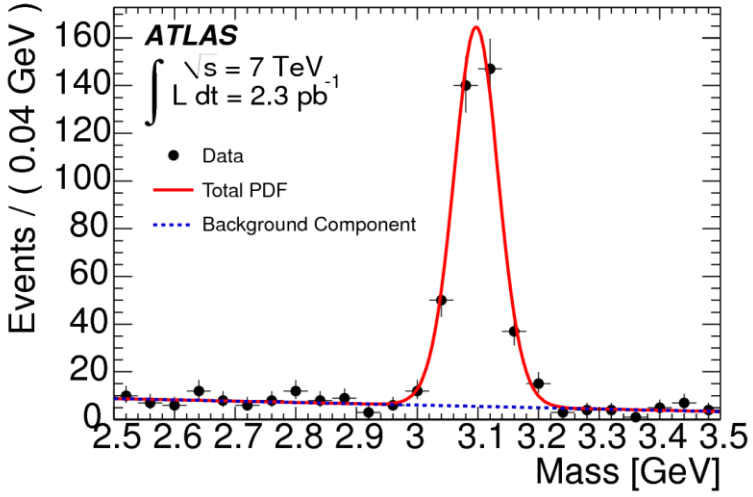
Non-Prompt (B-Decay) Component

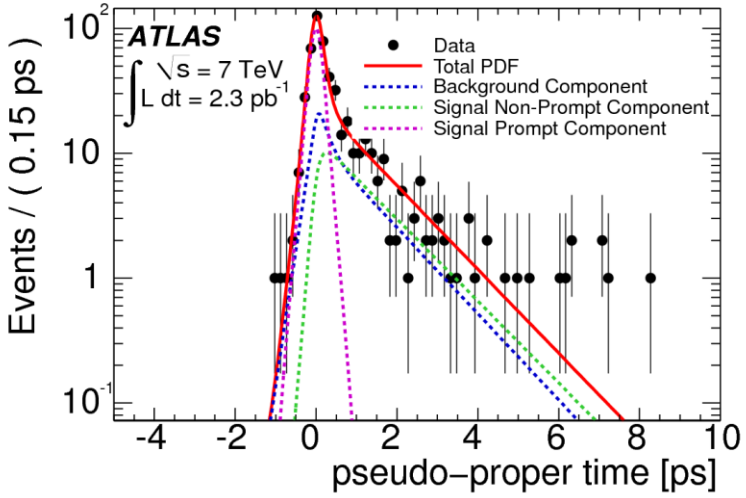
- Simultaneous unbinned maximum likelihood fit
  - Invariant mass
  - Pseudo-proper time distribution
    - discriminant for prompt/non-prompt J/ψ
  - Determine non-prompt fraction in bins of p_T, rapidity
- Mass Fit
  - Signal: Gaussian
  - Background: Chebyshev polynomial
- Lifetime Fit
  - Signal: Delta function plus exponential convoluted with a Gaussian
  - Background: Symmetric positive/negative exponentials plus positive exponential convoluted with a Gaussian
- Errors determined per candidate for signal and background

Mass and Lifetime Fit Projections

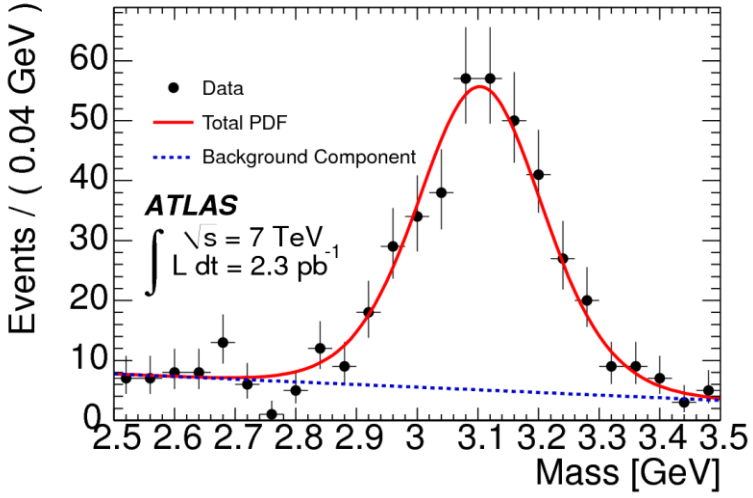


$|y_{J/\psi}| < 0.75$

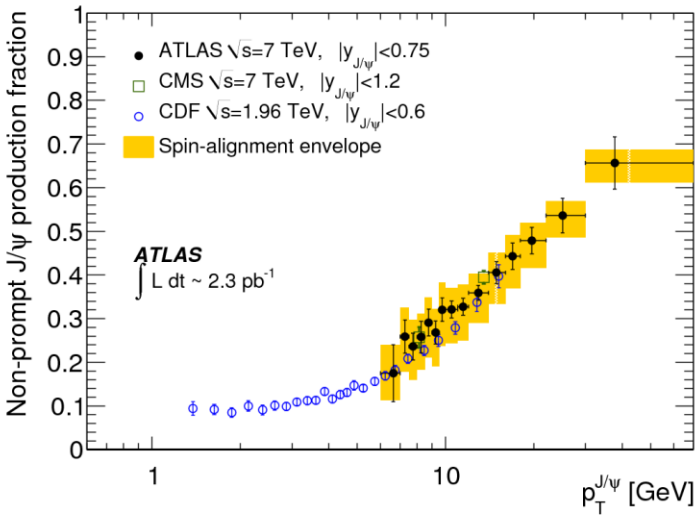


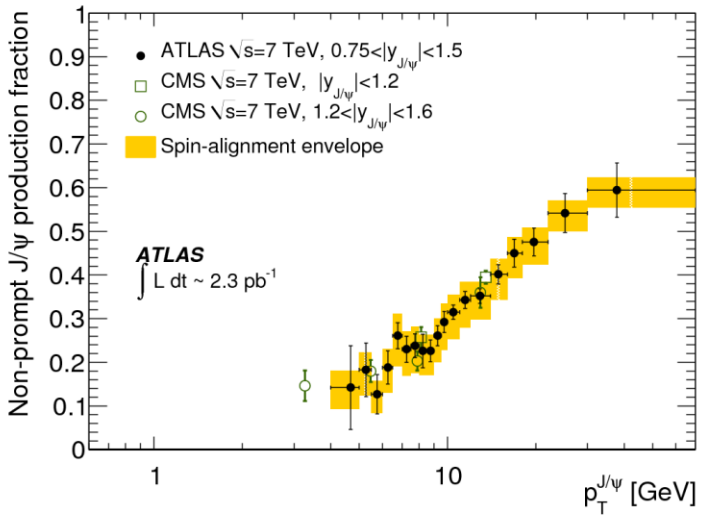


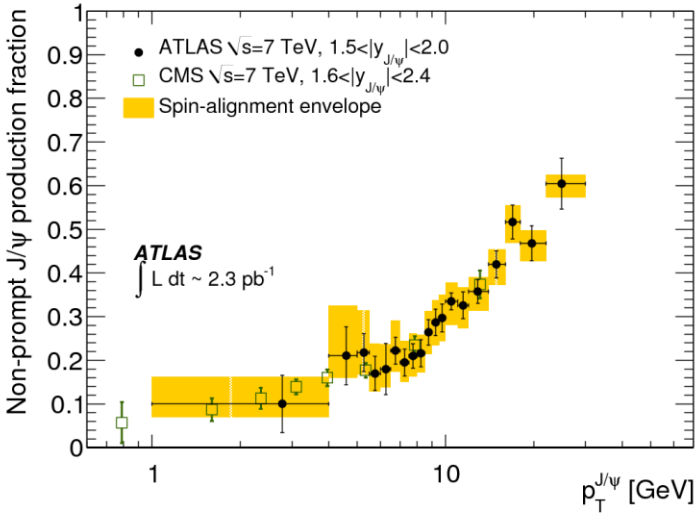
$2.0 < |y_{J/\psi}| < 2.4$

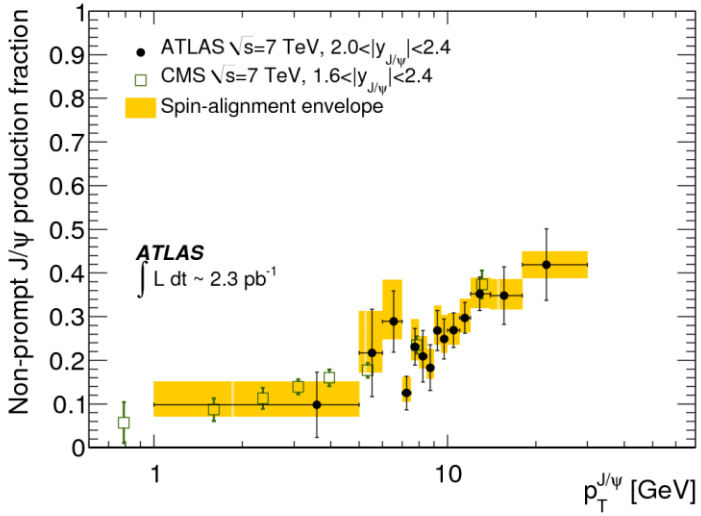


Non-Prompt Production Fractions









Non-Prompt Cross-Sections

- Full range rapidity:

$$Br(J/\psi \to \mu^+\mu^-)\cdot\sigma(pp \to B + X \to J/\psi X; |y^{J/\psi}| < 2.4, p_T^{J/\psi} > 7.0\ \text{GeV})$$
$$= 23.0 \pm 0.6\ (\text{stat.}) \pm 2.8(\text{syst.}) \pm 0.2\ (\text{spin}) \pm 0.8\ (\text{lumi.})\ \text{nb}$$

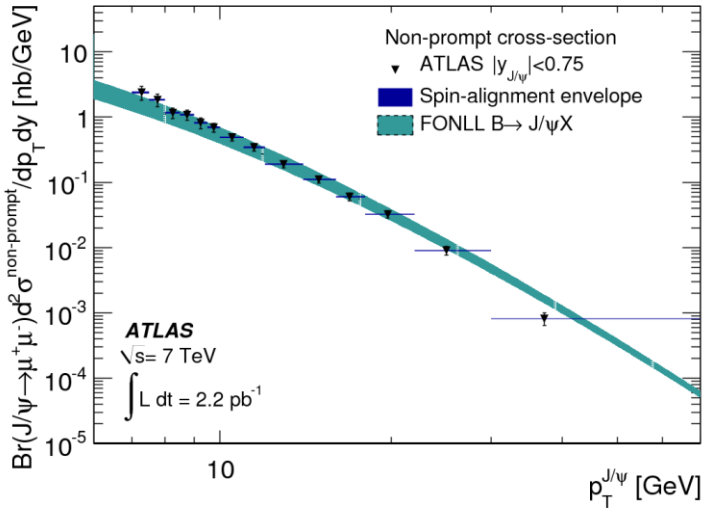
- Full range p_T:

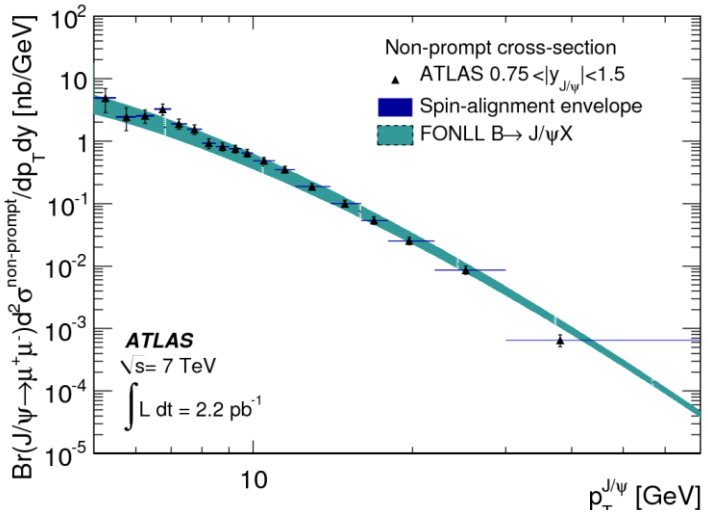
$$Br(J/\psi \to \mu^+\mu^-)\cdot\sigma(pp \to B + X \to J/\psi X; 1.5 \leq |y^{J/\psi}| < 2.0, p_T^{J/\psi} > 1.0\ \text{GeV})$$
$$= 61 \pm 24\ (\text{stat.}) \pm 19\ (\text{syst.}) \pm 1\ (\text{spin}) \pm 2\ (\text{lumi.})\ \text{nb.}$$

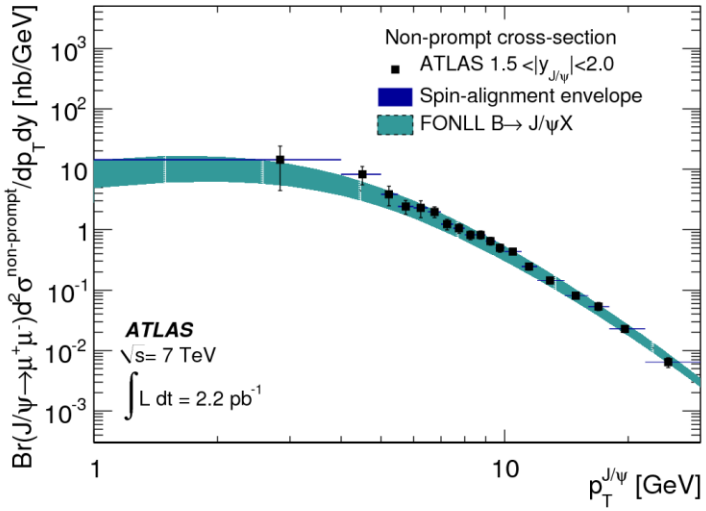
- Compare to predictions from
  - Fixed Order Next-to-Leading-Log (FONLL) [M. Cacciari]

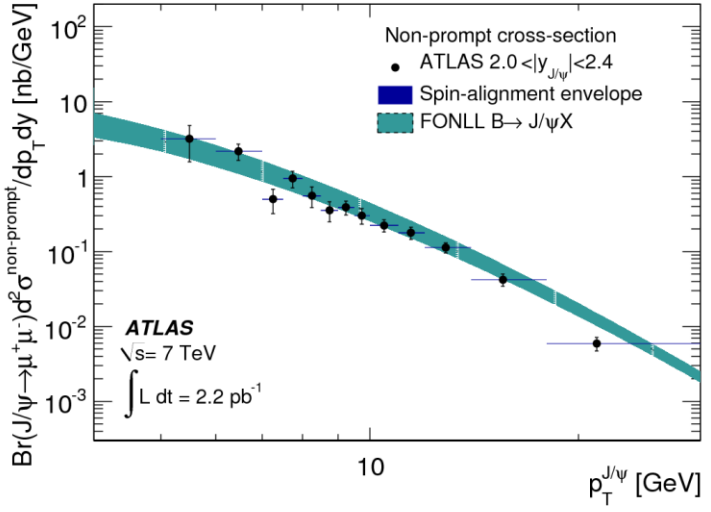
- Assumes isotropic distribution for spin-alignment central value. Spin-alignment envelope for non-prompt covers possible variation from isotropic λ_i=0 to λ_θ = ~±0.1, as measured by CDF and BaBar.

Non-Prompt Cross-Section, FONLL









Prompt Cross-Sections

- Integrated cross-section, full range rapidity

$$Br(J/\psi \to \mu^+\mu^-)\cdot\sigma(pp \to \text{prompt } J/\psi X; |y| < 2.4, p_T > 7.0 \text{ GeV})$$
$$= 59 \pm 1 \text{ (stat.)} \pm 8\text{(syst.)} \pm {}^{9}_{6} \text{ (spin)} \pm 2 \text{ (lumi.) nb}$$

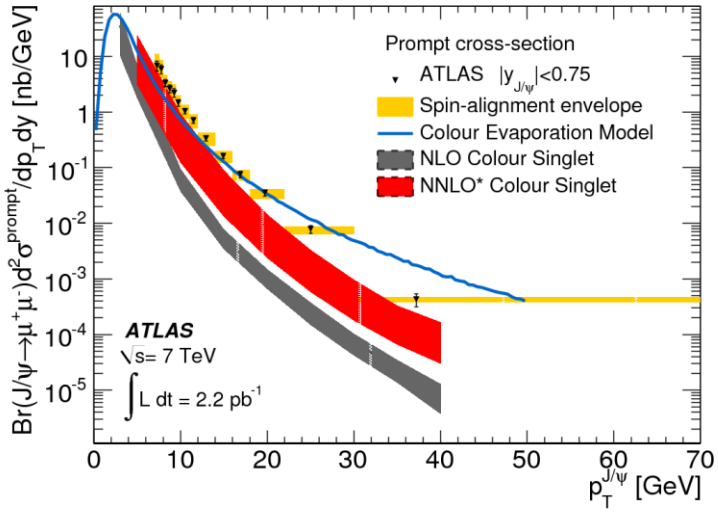
- Full range pT

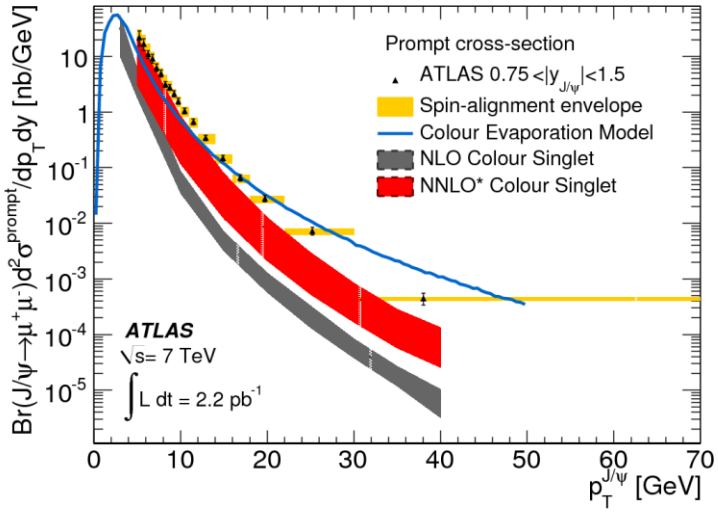
$$Br(J/\psi \to \mu^+\mu^-)\cdot\sigma(pp \to \text{prompt } J/\psi X; 1.5 \leq |y| < 2.0, p_T > 1.0 \text{ GeV})$$
$$= 450 \pm 67 \text{ (stat.)} \pm {}^{85}_{114} \text{ (syst.)} \pm {}^{741}_{105} \text{ (spin)} \pm 15 \text{ (lumi.) nb.}$$

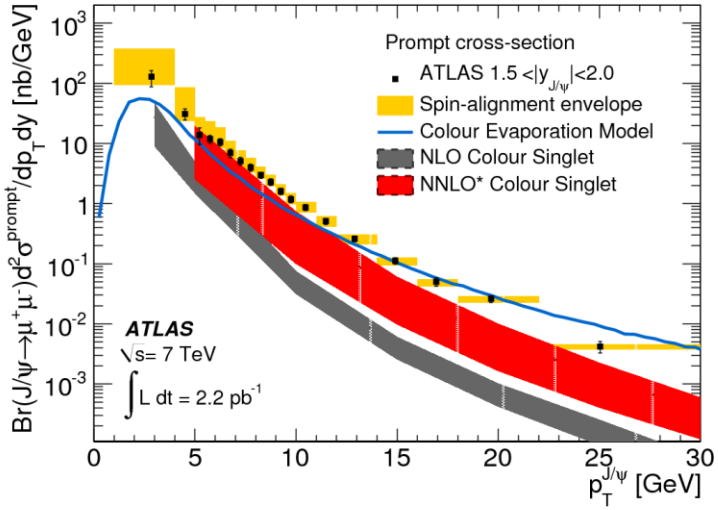
- Compare to predictions from
  - NLO/NNLO* pQCD (Color Singlet) [J. P. Lansberg]
  - Color Evaporation Model [R. Vogt]

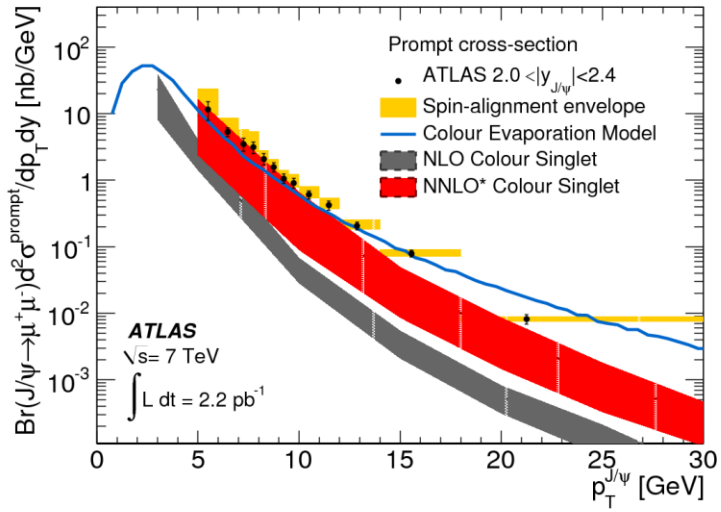
- Spin-alignment envelope covers the maximal possible variation due to spin alignment configurations for both θ^* and ϕ^*

Prompt Cross-Sections vs. Models









Summary

- Measurements:
  - Inclusive production cross-section of the J/ψ in 4 bins of rapidity, with a range of p_T from 1 to 70 GeV
  - Non-prompt production fraction, resultant prompt and non-prompt production cross-sections
- Highest reach in p_T
- Good agreement with CMS
- FONLL predictions, non-prompt component, agreement
- Description of prompt component appears to merit more study
- Analyses ongoing, more results soon…