J/ψ & ψ(2S) measurement with ATLAS 2012 @ 8TeV

J/ψ, ψ(2S) → mu mu
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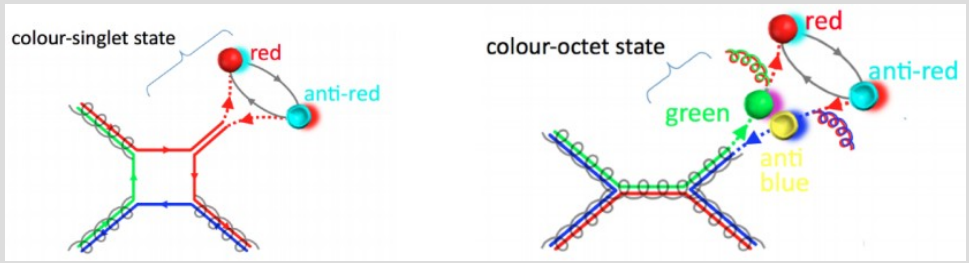
Overview

- ✔ Introduction
- ✔ ATLAS Detector
- ✔ J/ψ ψ(2S) analysis
  - ✔ Data & event selection
  - ✔ Event weight
  - ✔ Measured quantities
  - ✔ Fit model
  - ✔ Results
  - ✔ Comparison with theory
  - ✔ Systematics
- ✔ Summary

Introduction

- Ever since the discovery of J/ψ in 1974 study of quarkonium probes hadron configuration and the non pertubative behavior of QCD.
- Existing theoretical calculations have limited ability to model properly the production and decay of these states. The Color Singlet (CS) mechanism alone is insufficient to account for experimental measurements
  - In CS model only states with same quantum numbers as the resulting quarkonium contribute to the formation of bound state.

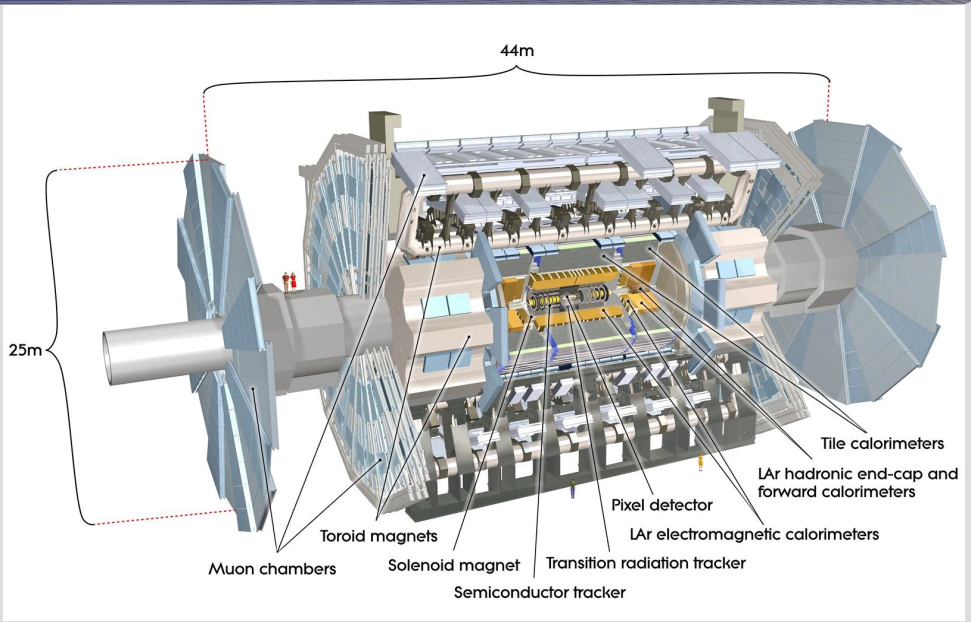


- Non-Relativistic QCD (Color Octet) in addition to CS provides the possibility of quarkonium formation in a colored state, which subsequently decays into a physical singlet quarkonium bound state through non-pertubative emission of gluons.
- LHC creates a test bench, highly populated with quarkonia, which will enable stringent tests of existing theoretical models across a large range of momentum.

J/ψ, ψ(2S) → μ⁺ μ⁻

ATLAS Detector

- General purpose detector at the LHC



Tracking

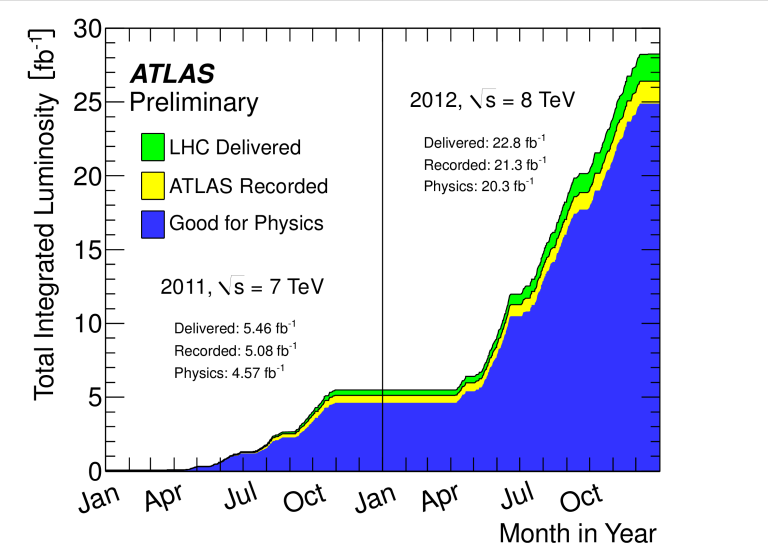
Silicon (Pixel + SemiConductor Tracker) and Transition Radiation Tracker

2 T solenoidal field

Muon identification

Dedicated tracking chambers

0.5-2 T toroidal field



- 10 μm Impact Parameter resolution
- σm (J/ψ-Y) ~ 60-120 MeV (ID dominated)

$J/\psi, \psi(2S) \rightarrow \mu^+ \mu^-$

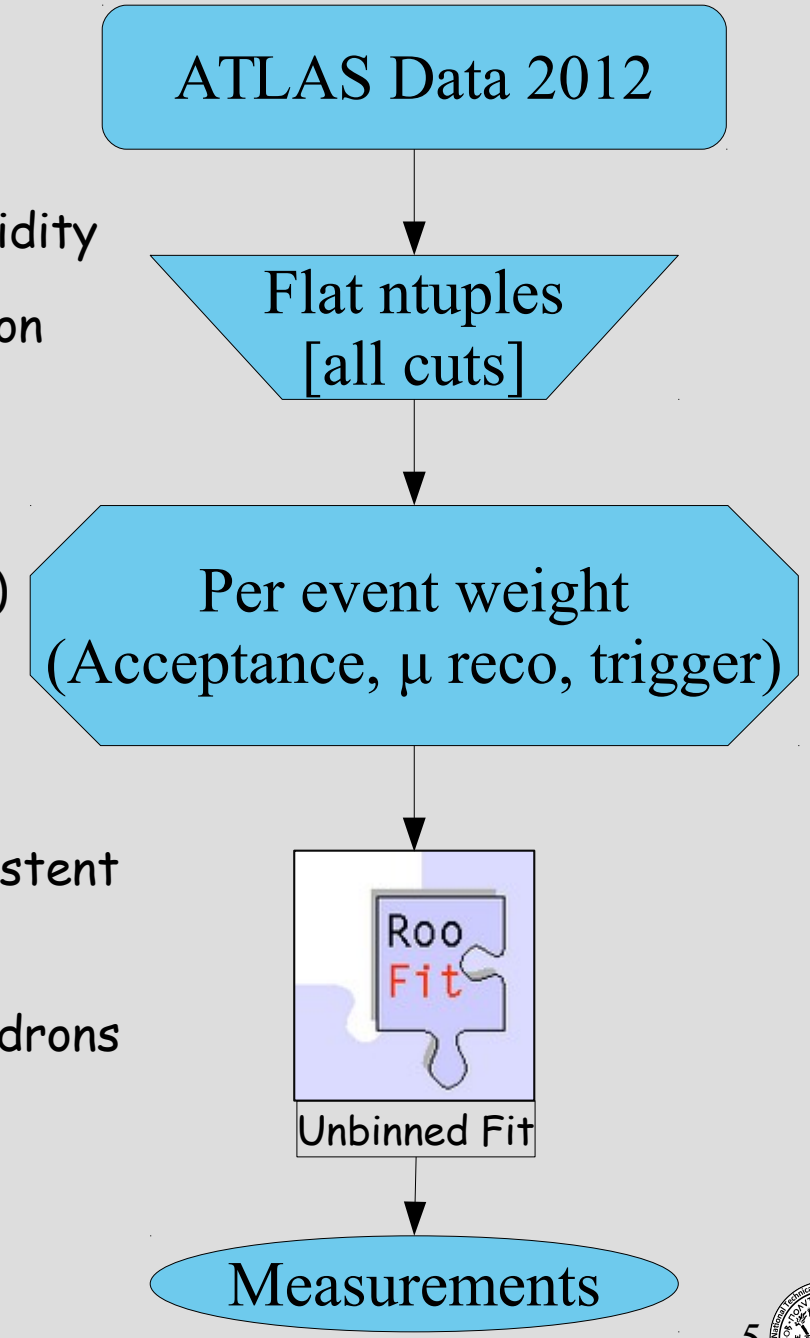
Analysis Overview

- Measurement of:
  - J/ψ and $\psi(2S)$ differential cross-sections:
    - Performed in slices of p_T and absolute rapidity
    - For both prompt and non-prompt production

- Measurement perform via unbinned maximum likelihood fit on mass and pseudo-proper time (2D)
- Through the fit prompt and non-prompt yields are extracted

  Prompt: from QCD sources with lifetime consistent with lifetime resolution

  Non-Prompt: from long-lived sources like b-hadrons decays



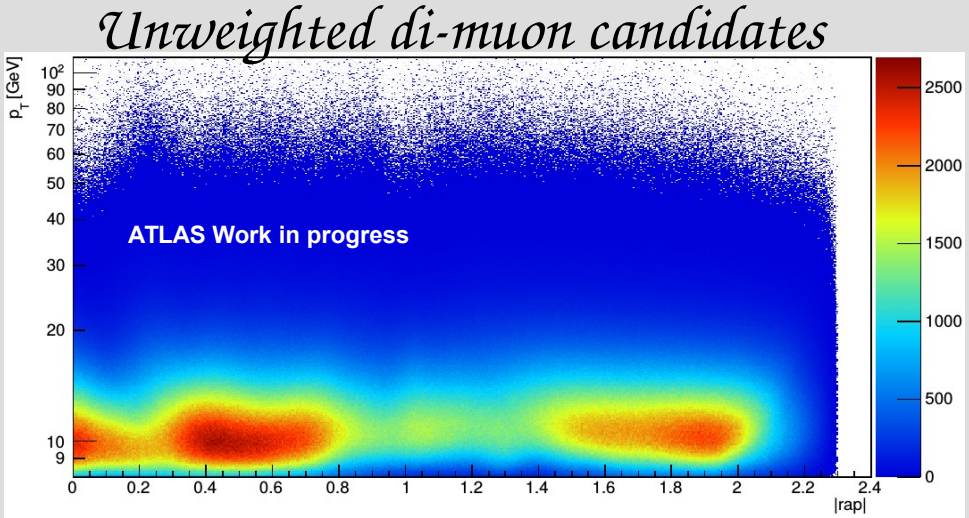
$J/\psi, \psi(2S) \rightarrow \mu^+ \mu^-$

Data & Event Selection

- 2012 Data at 8 TeV corresponding 11.4 fb^{-1}
- Quality approved data

  Muons:
  - Combined muons
  - $p_T > 4$ GeV, $|\eta| < 2.3$
  - MCP cuts

  Dimuon:
  - $p_T > 8$ GeV, $|y| < 2.0$
  - $m(\mu\mu)$: 2.6 – 4.0 GeV
  - $\chi 2/ndf < 250$



- Trigger matching used, dimuon trigger around J/ψ mass

  each muon with $p_T > 4$ GeV

- Results are determined after correcting for [$w^{-1} = A(p_T,y) \cdot \varepsilon_{\mu 1}(p_T,q^*\eta) \cdot \varepsilon_{\mu 2}(p_T,q^*\eta) \cdot \varepsilon_{trig}$] :

  Detector Acceptance

  Muon reconstruction efficiencies

  Trigger efficiency

- Weights are applied per event

J/ψ, ψ(2S) → μ⁺ μ⁻

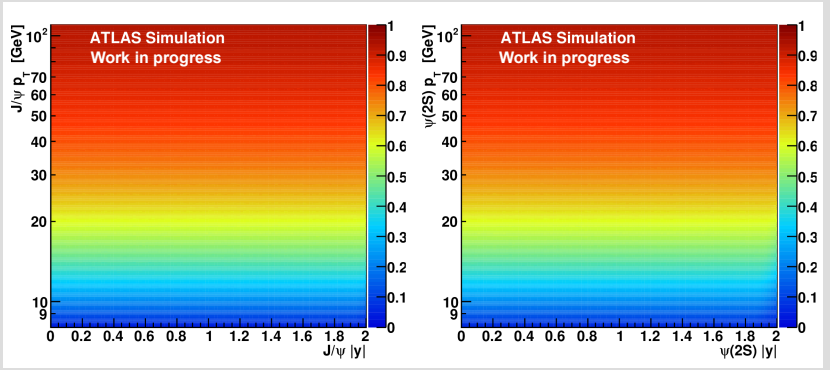
Event Weights

Detector Acceptance

arXiv:1407.5532

- Generate "FLAT" unpolarised acceptance(same technique widely used in onia analysis)
- Two mass points (J/ψ and ψ(2S))
- Weight applied using linear interpolation/extrapolation of the acceptance between the two points
- Ranges 8 < $p_T(\mu\mu)$ < 110 GeV, |y|<2.0

Variation of S-A hypotheses considered in systematics as a correction factor

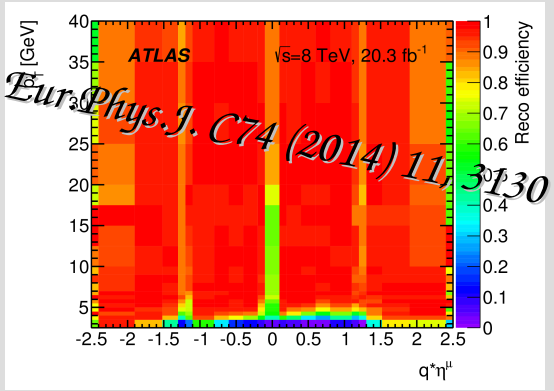


Muon reconstruction

- Officially produced maps
- Tag-and-Probe method used for calculations

100 pseudo experiments (with map bins varied according to their uncertainties)

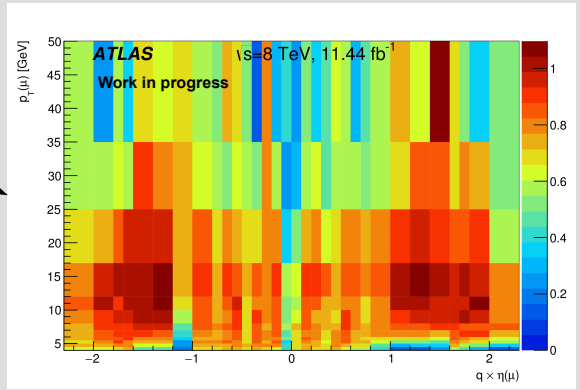
Variation on analysis bins population provides the uncertainty



Trigger efficiency

- Dimuon triggers require two muons Region of Interest
- $\varepsilon_{trig} = \varepsilon(p_T^{\mu 1}, \eta^{\mu 1}, q^{\mu 1}) \cdot \varepsilon(p_T^{\mu 2}, \eta^{\mu 2}, q^{\mu 2}) \cdot C_{\mu\mu}(\Delta R, y)$

Functional (for the extra quality cuts)



Systematics assessed as in Muon reconstruction

J/ψ, ψ(2S) → μ⁺ μ⁻

Analysis Measured Quantities

- The double differential cross-sections for each J/ψ and ψ(2S):

$$\frac{\mathrm{d}^2\sigma(pp \to \psi)}{\mathrm{d}p_\mathrm{T}\mathrm{d}y} \times \mathcal{B}(\psi \to \mu^+\mu^-) = \frac{N_\psi^\mathrm{p}}{\Delta p_\mathrm{T} \Delta y \times \int \mathcal{L} dt}$$

$$\frac{\mathrm{d}^2\sigma(b\bar{b} \to \psi)}{\mathrm{d}p_\mathrm{T}\mathrm{d}y} \times \mathcal{B}(\psi \to \mu^+\mu^-) = \frac{N_\psi^\mathrm{np}}{\Delta p_\mathrm{T} \Delta y \times \int \mathcal{L} dt}$$

  - Where N is the weighted-corrected signal yield acquired from the fit, Δp_T and Δy is the given bin interval

- The ratio analysis is determined for (non-)prompt by:

$$R^{\mathrm{p,np}} = \left\{ \frac{N_{\psi(2S)}}{N_{J/\psi}} \right\}^{\mathrm{p,np}}$$

- And the non-prompt J/ψ and ψ(2S) fractions using:

$$f_B^\psi \equiv \frac{pp \to B + X \to \psi X'}{pp \xrightarrow{\text{Inclusive}} \psi X''} = \frac{N_\psi^\mathrm{np}}{N_\psi^\mathrm{np} + N_\psi^\mathrm{p}}$$

- All quantities are extracted simultaneously from any single fit.

- Independent fits are performed to each of the analysis bins (of p_T and rapidity).

J/ψ, ψ(2S) → μ⁺ μ⁻

Fit model

- Weighted unbinned maximum log-likelihood fit is performed in 2D, mass and pseudo-proper time

$$PDF(m,\tau) = \sum_{i=1}^{7} \oplus f_i(m) \cdot h_i(\tau) \otimes g_i(\tau)$$

- Mass:
  - Crystal-ball + Gaussian for signals
  - Flat for prompt background
  - 1st order polynomial for non-prompt background
  - Exponential for double-sided background

i	Type	Source	$f_i(m)$	$h_i(\tau)$
1	J/ψ	P	$\omega_i B_1(m) + (1-\omega_i) G_1(m)$	$\delta(\tau)$
2	J/ψ	NP	$\omega_i B_1(m) + (1-\omega_i) G_1(m)$	$E_1(\tau)$
3	$\psi(2S)$	P	$\omega_i B_2(m) + (1-\omega_i) G_2(m)$	$\delta(\tau)$
4	$\psi(2S)$	NP	$\omega_i B_2(m) + (1-\omega_i) G_2(m)$	$E_2(\tau)$
5	Bkg	P	$F(m)$	$\delta(\tau)$
6	Bkg	NP	$C_1(m)$	$E_3(\tau)$
7	Bkg	NP	$E_4(m)$	$E_5(\|\tau\|)$

- Pseudo-proper time:
  - Lifetime resolution using double Gaussian (fixed mean=0)
  - Prompt signal and background using the resolution term
  - Non-prompt lifetimes from RooDecay as single exponentials
  - Also a Double-sided RooDecay for one background
- Possible variations of these models are considered within fit systematics

$J/\psi, \psi(2S) \rightarrow \mu^+ \mu^-$

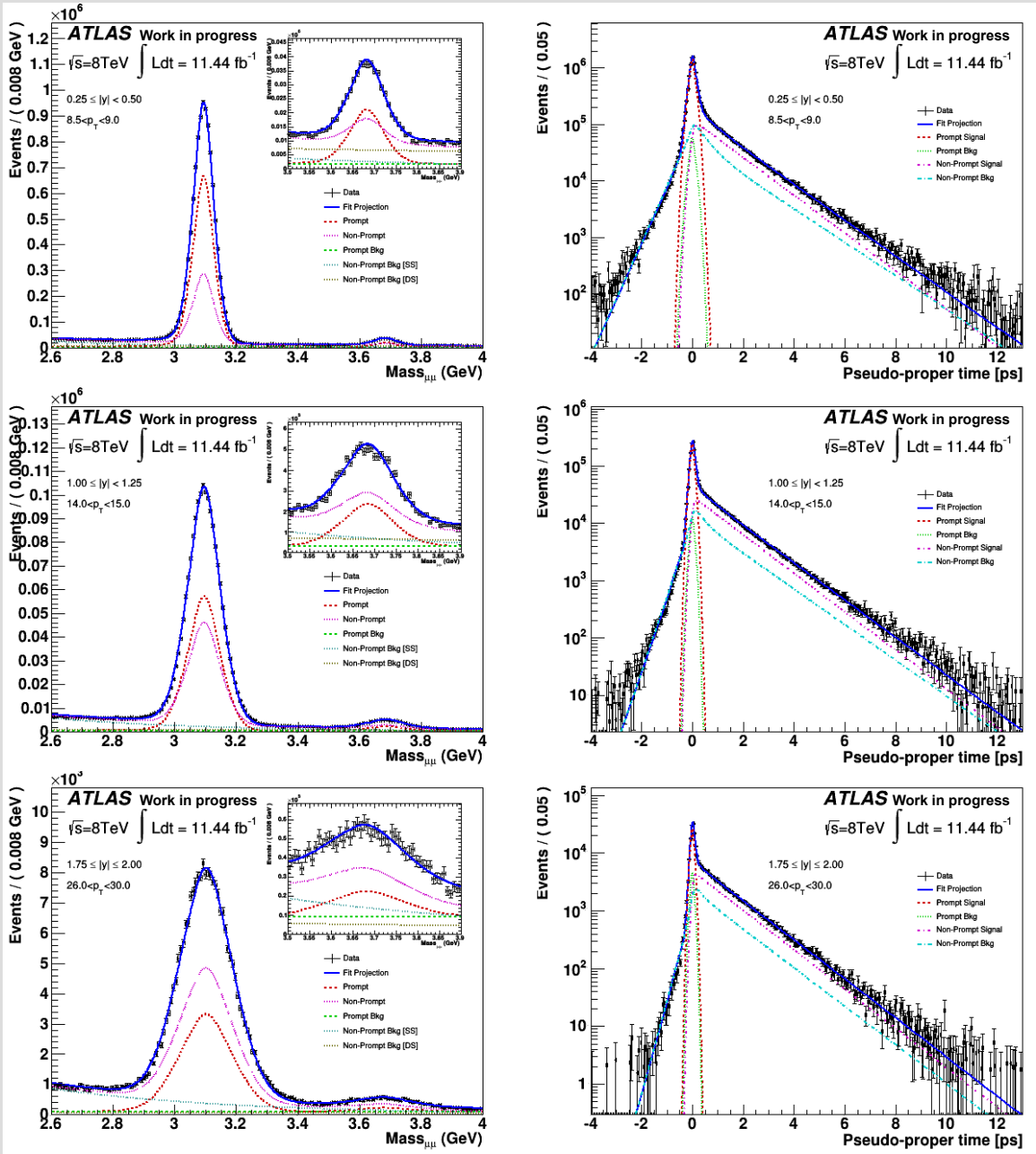
Fit Results

Randomly select 3 bins out of 172:

Low p_T – Low Rapidity

Mid p_T – Mid Rapidity

High p_T – High Rapidity



J/ψ, ψ(2S) → μ⁺ μ⁻

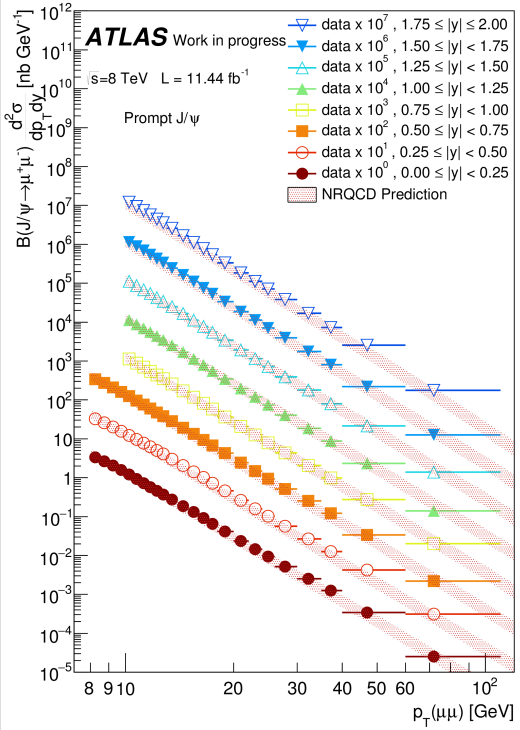
Cross-Section Results

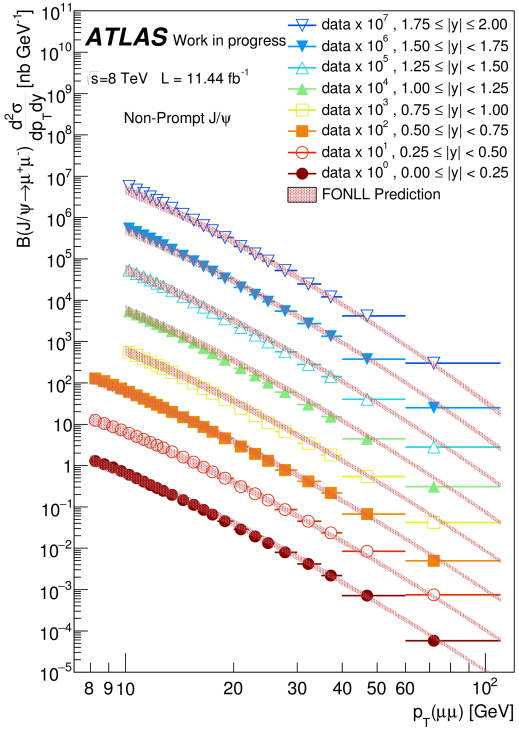
Prompt and Non-Prompt J/ψ and ψ(2s) – Errors are statistical + Systematics
Each increasing rapidity slice is scaled by x10

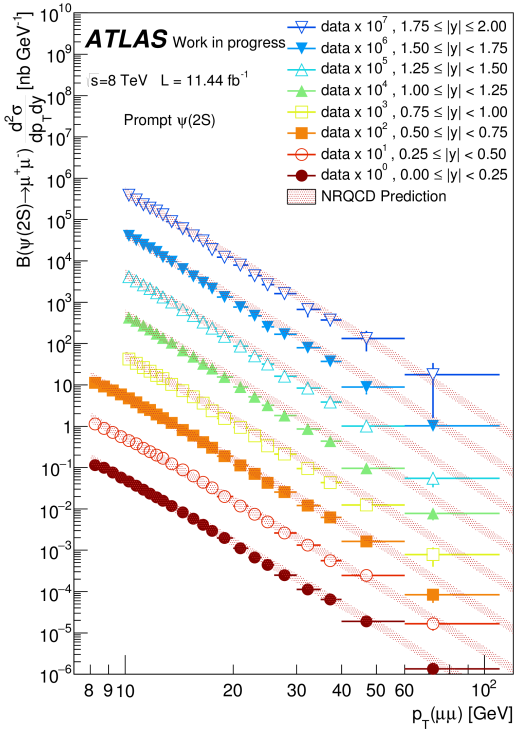
J/ψ

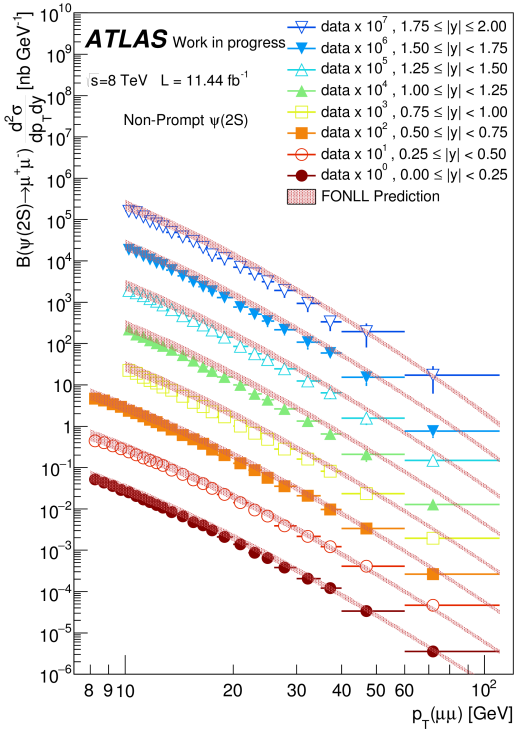
ψ(2S)

Prompt | Non-Prompt | Prompt | Non-Prompt









J/ψ, ψ(2S) → μ⁺ μ⁻

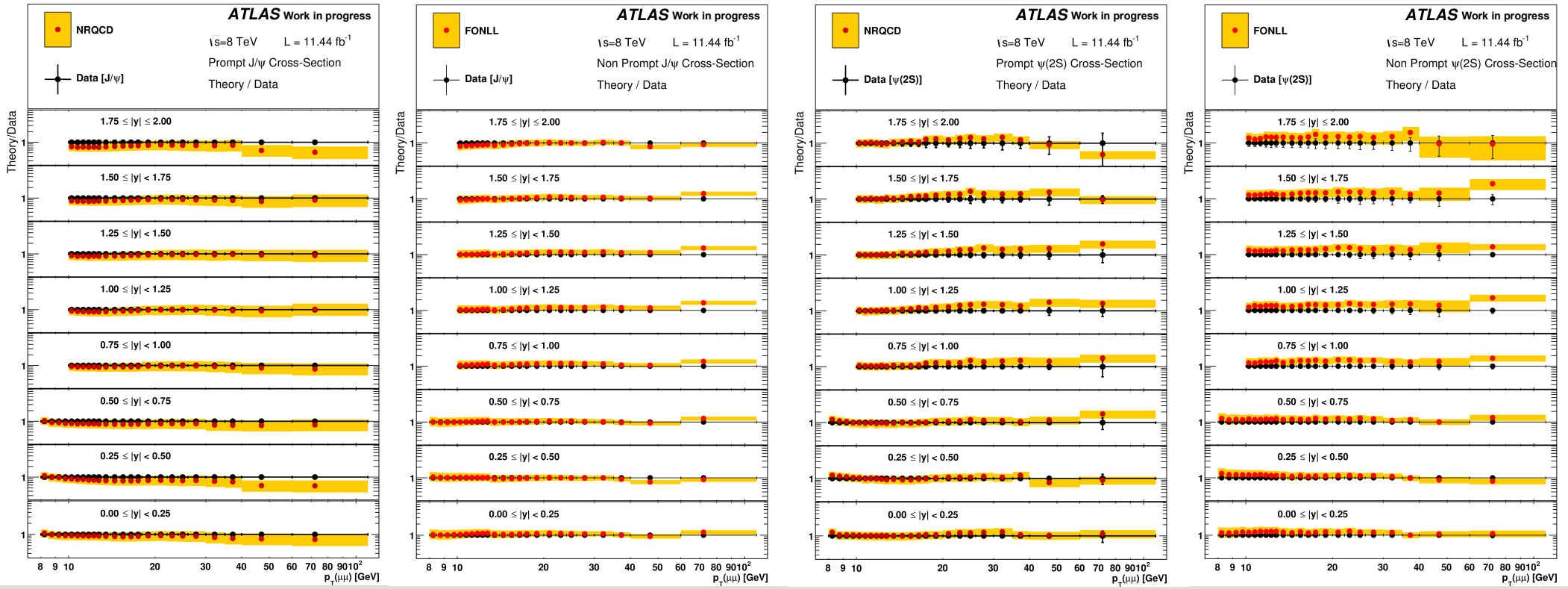
Cross-Section Theory Ratios

Prompt NLO NRQCD arXiv:1212.5293v3

Non-Prompt FONLL arXiv:1205.6344v1

J/ψ ψ(2S)

Prompt Non-Prompt Prompt Non-Prompt



Reasonable agreement over a large scale,
data overshoots theory at high p_T and high rapidity

J/ψ, ψ(2S) → μ⁺ μ⁻

Ratio and Fraction Results

Non-prompt fraction of J/ψ and ψ(2S)

Ratio of ψ(2S) to J/ψ production in prompt and non-prompt

Each increasing rapidity slice is scaled by x10

Non-Prompt Fraction

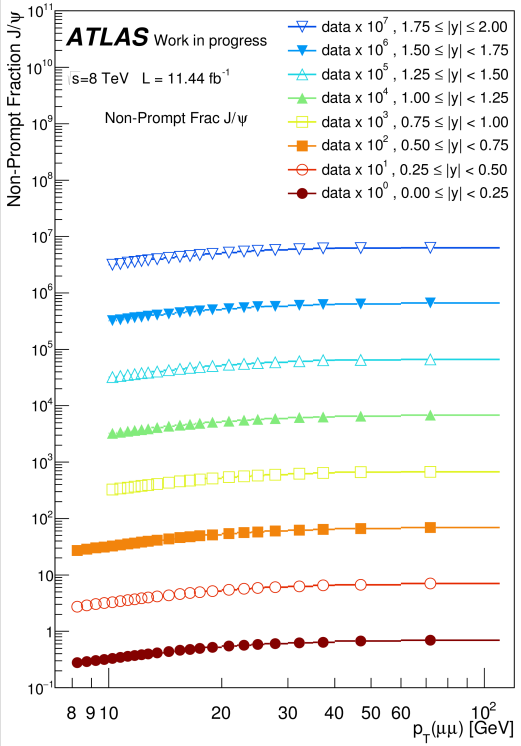
ψ(2S) / J/ψ Ratio

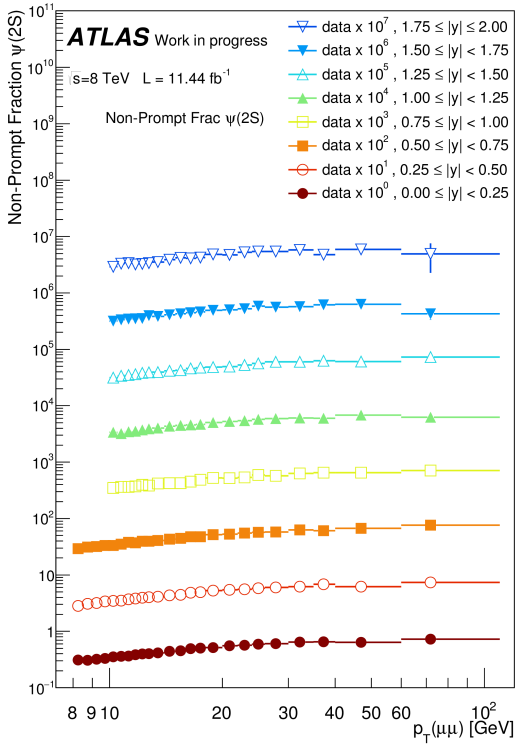
J/ψ

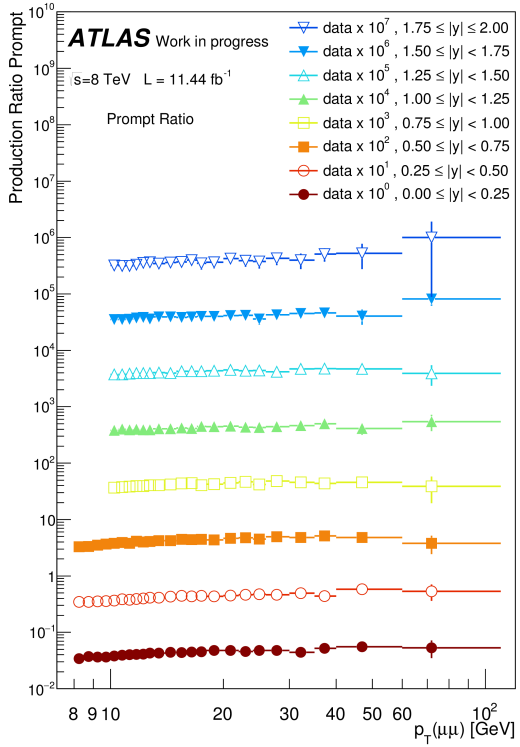
ψ(2S)

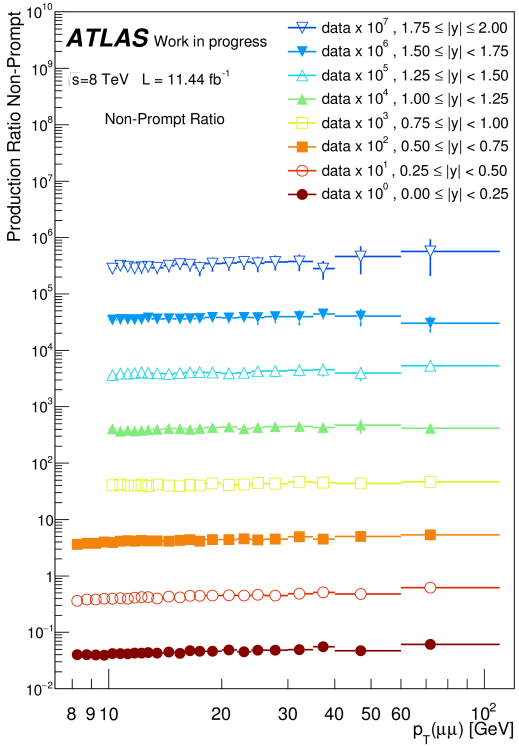
Prompt

Non-Prompt









$J/\psi, \psi(2S) \rightarrow \mu^+ \mu^-$

Systematics

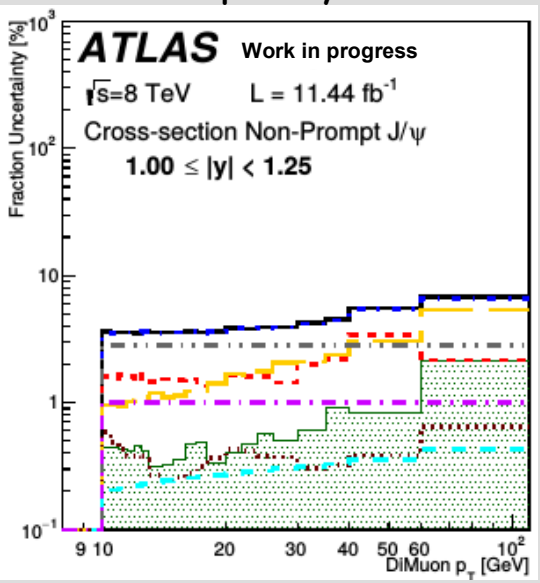
- Acceptance → S-A factors
  (correction tables for the central value provided for various S-A hypotheses)
- Muon reconstruction efficiency
  - 100 pseudo experiments (with map bins varied according to their uncertainties), variation on analysis bins population provides the uncertainty
- Trigger efficiency
  - Same procedure as in muon reconstruction case
- Inner detector tracking efficiency: 1% (0.5% applied coherently)
- Luminosity: 2.8%, (cancels in prompt - non-prompt ratio and in non-prompt fractions)
- Fit model
  - Various alterations of PDF for fit model components, re-fit with new models
  - Treat maximum deviations as fit model uncertainty
- Bin Migration effects

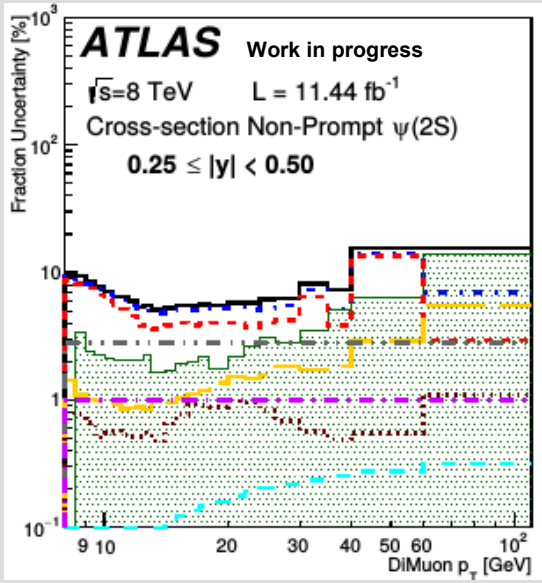
Total Systematic: Sum in quadrature

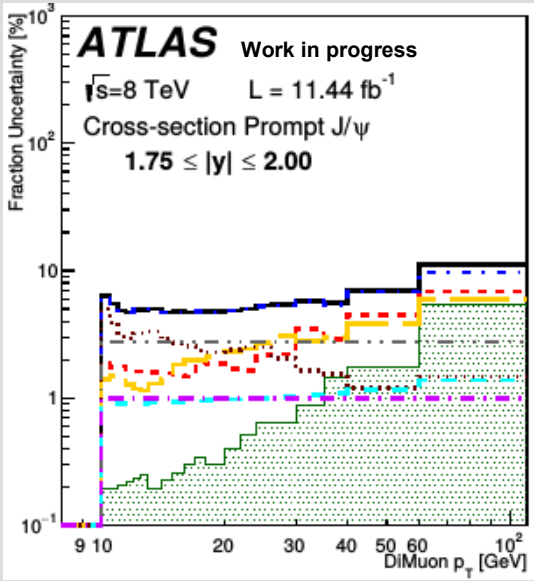
J/ψ, ψ(2S) → μ⁺ μ⁻

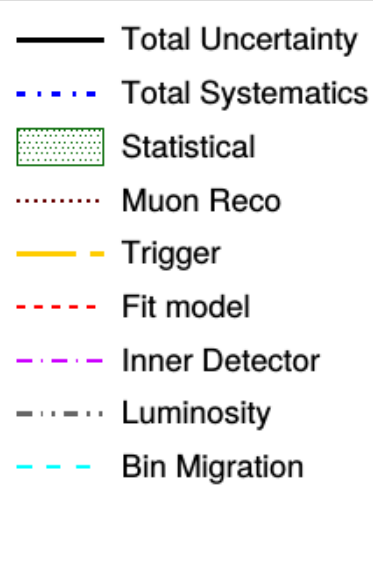
Systematics

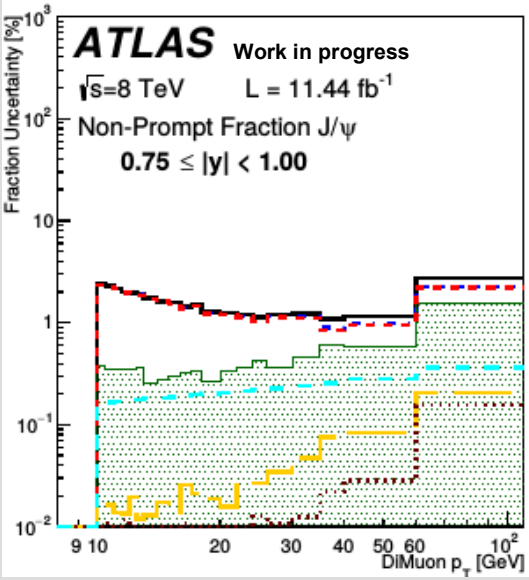
- For each measured quantity the relative statistical error and all (mentioned above) systematic uncertainties are calculated [(measurement types) x 8 (rap. Bins) → 64 plots]
- For simplicity few are shown here…

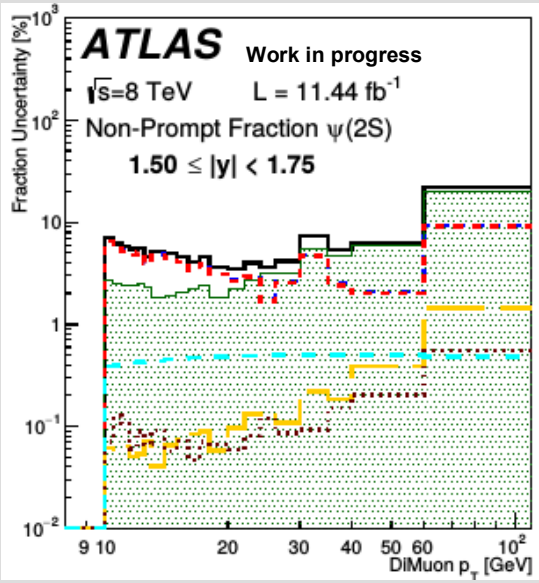


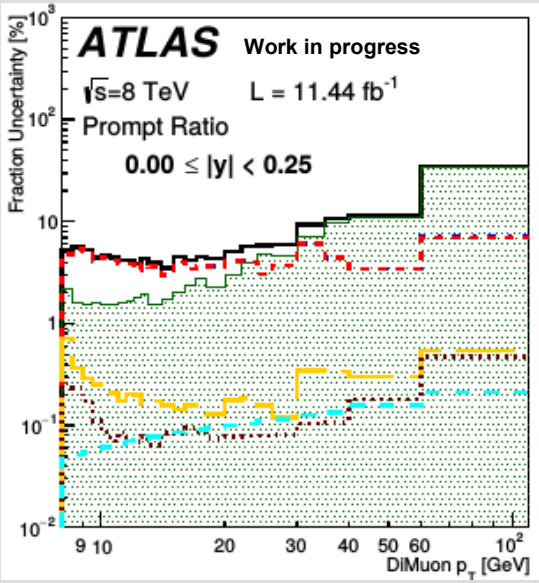












Summary

- Accurate measurement performed at 8TeV for:
  J/ψ and $\psi(2S)$ prompt and non-prompt differential cross-sections,
  non-prompt fractions and
  prompt and non-prompt $\psi(2S)$ to J/ψ ratios

- Very good agreement with dominant theoretical models over a large scale
  data overshoots theory at high p_T and high rapidity

~ Back Up~