PROCEEDINGS OF SCIENCE

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

Sue Cheatham*
Lancaster University, UK
E-mail: susan.cheatham@cern.ch

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

XXIV International Workshop on Deep-Inelastic Scattering and Related Subjects
11-15 April, 2016
DESY Hamburg, Germany

*Speaker.

PoS(DIS2016)161

1. Introduction

Measurements of quarkonium production test multi-scale Quantum Chromo Dynamics (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. These studies are also interesting since inclusive production of heavy flavour represents a significant background for measurements in the electroweak and Higgs sectors.

Quarkonium studies consider the dimuon decays of same-flavour quark and anti-quark bound states such as J/ψ(c$\bar{c}$) and Υ(b$\bar{b}$). Single-muon triggers are used, supplemented by dimuon triggers, which leave the invariant mass window around the signal largely unprescaled. Prompt quarkonia are produced directly in the proton-proton (pp) interaction or through feed-down decays from higher quarkonium states. Non-prompt quarkonia are produced in the decay chain of B-hadrons, where the decay vertex can be displaced from the primary pp vertex. Prompt and non-prompt production, as well as signal and background, are separated using simultaneous mass-decay time fits.

The large cross-section for quarkonium production and extensive data samples available at the Large Hadron Collider (LHC) will enable detailed study of theoretical models across a large range of momentum transfer. Details of the ATLAS detector may be found in [1].

2. J/ψ production

Figure 1 shows the mass distributions and Figure 2 shows the pseudo-proper decay time distributions for data collected at 2.76, 7, 8 and 13 TeV. Projections of the unbinned maximum likelihood fit result are shown for a representative p_T interval.

The muon selection is equivalent in all four energy regimes, requiring muon $p_T > 4$ GeV and $|y| < 2.3$. In addition the muon pair are selected to be oppositely charged with a common vertex. A requirement of muon pair $p_T > 8$ GeV and $|y| < 2$ ensures the geometrical acceptance of the detector and the trigger and reconstruction efficiency corrections do not vary rapidly and are consistent for prompt and non-prompt J/ψ.

In the 13 TeV study an isotropic spin-alignment hypothesis was assumed, with no geometric acceptance correction applied to the data and no spin-alignment uncertainty considered. The measurements at 2.76, 7 and 8 TeV are corrected for acceptance, trigger and reconstruction efficiencies.

Double-differential prompt and non-prompt J/ψ cross-sections are shown in Figure 3 for data collected at 7 and 8 TeV. Measurements are corrected for acceptance, trigger and reconstruction efficiencies. The prompt cross-sections are compared to NLO Non-relativistic QCD (NRQCD) theory calculations. [2, 3, 4] Theory uncertainties arise from scale, charm quark mass and long-distance matrix elements. Reasonable agreement is seen between theory and data.

The non-prompt cross-sections are compared to Fixed-Order with Next-to-Leading-Log (FONLL) theory calculations. In this case theory uncertainties arise from scale and quark masses. Theory predicts slightly harder p_T for J/ψ than is seen in the data.

The ratios of the theoretical predictions to the data are presented in Figure 4 for the differential prompt cross-sections of J/ψ as a function of $p_T(\mu\mu)$ for each of the eight rapidity slices. FONLL

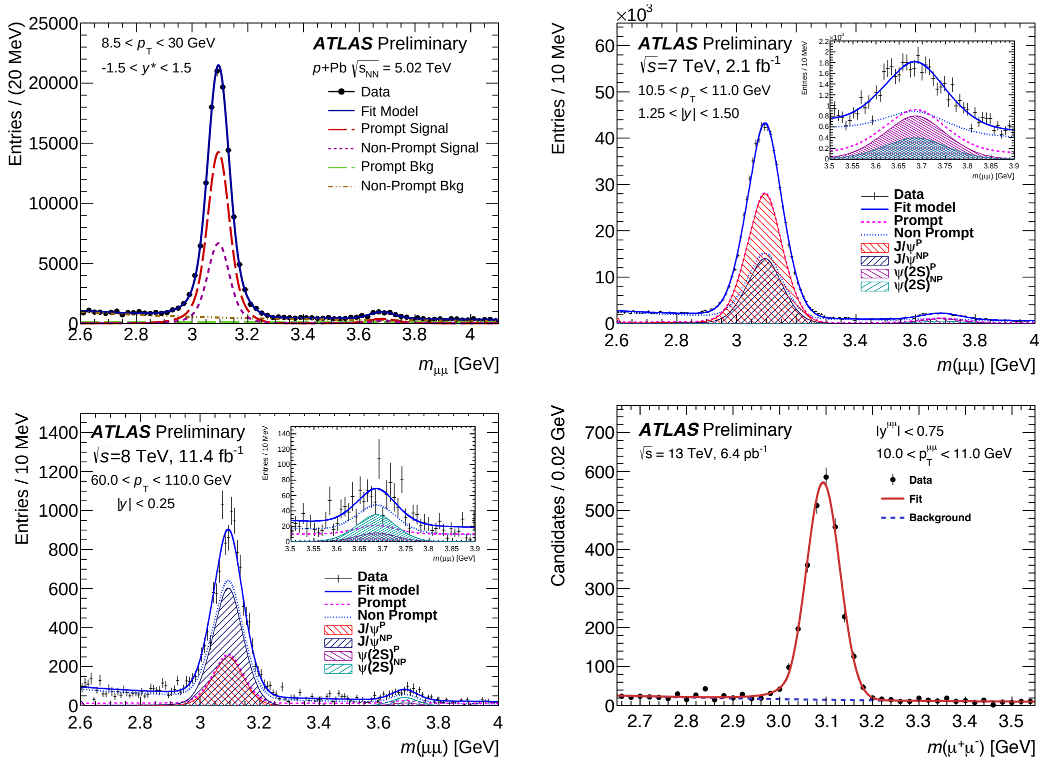

Figure 1: Projections of the fit result over the mass distributions for data collected at 2.76, 7, 8 and 13 TeV for one representative p_T interval. The data are shown with error bars in black, superimposed with the individual components of the fit result projections, where the total prompt and non-prompt components are represented by the dashed and dotted lines, respectively, and the shaded areas show the signal prompt and non-prompt contributions. [9, 10, 8]

calculations made within the framework of perturbative QCD are quite successful in describing non-prompt production of quarkonium states. The prompt cross-sections are compared to NRQCD. There is greater uncertainty seen in the theory indicating a satisfactory understanding of the prompt production mechanisms is still to be achieved

Figure 5 shows the non-prompt differential J/ψ production fraction at 13 TeV measured in the most central rapidity region ($|y| < 0.75$) compared to previous measurements from ATLAS in pp collisions at 2.76 and 7 TeV, and from the Collider Detector at Fermilab (CDF) in $p\bar{p}$ collisions at $\sqrt{s}$ = 1.96 TeV. Some dependence is seen on the centre-of-mass energy and initial state.

3. Upsilon production

Both NNLO* Color Singlet Model (CSM) [5] and the Color Evaporation Model (CEM) [6, 7] 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.

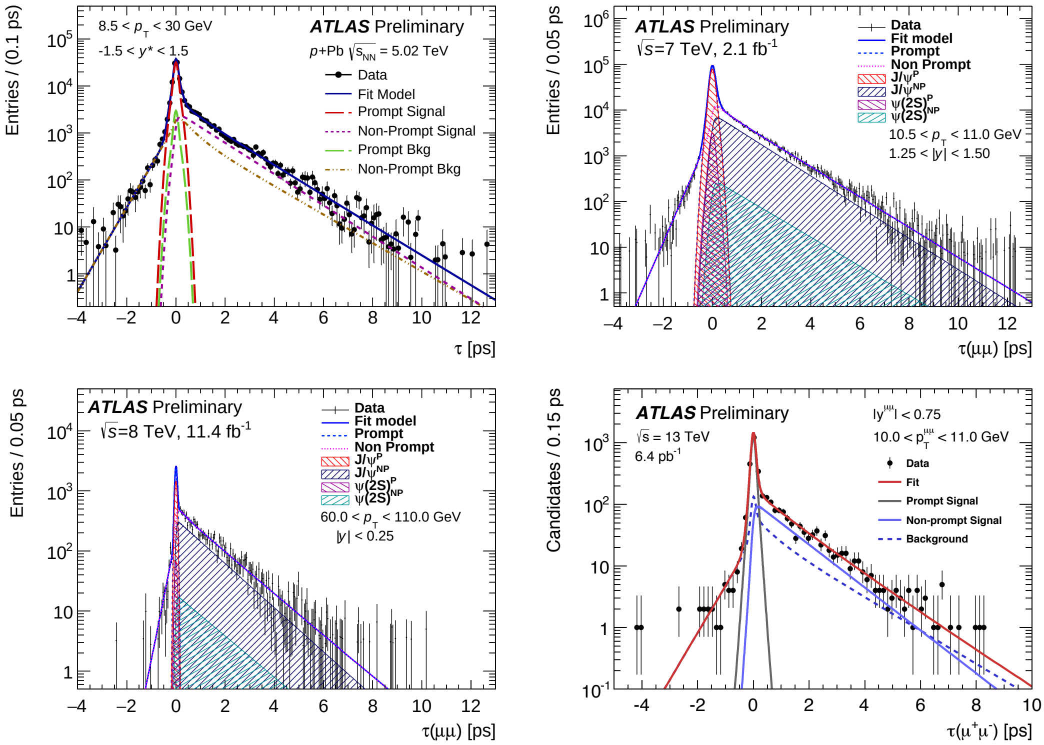

Figure 2: Projections of the fit result over the pseudo-proper decay time distributions for data collected at 2.76, 7, 8 and 13 TeV for one representative p_T interval. The data are shown with error bars in black, superimposed with the individual components of the fit result projections, where the total prompt and non-prompt components are represented by the dashed and dotted lines, respectively, and the shaded areas show the signal prompt and non-prompt contributions. [9, 10, 8]

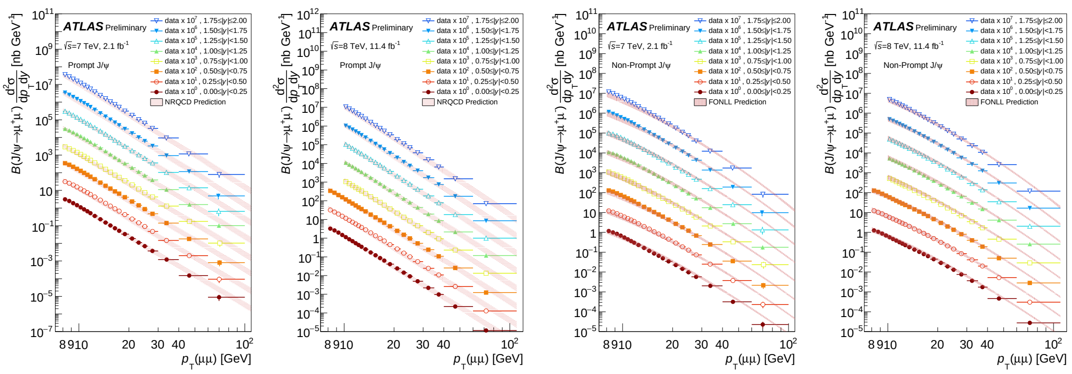

Figure 3: The differential prompt cross-section times dimuon branching fraction of J/ψ as a function of $p_T(\mu\mu)$ for each slice of rapidity. Prompt production (top), non-promt (bottom), 7 TeV (left) and 8 TeV (right). For each increasing rapidity slice, an additional scaling factor of 10 is applied to the plotted points for visual clarity. The theoretical predictions used are NRQCD for prompt and FONLL for non-prompt production. [10]

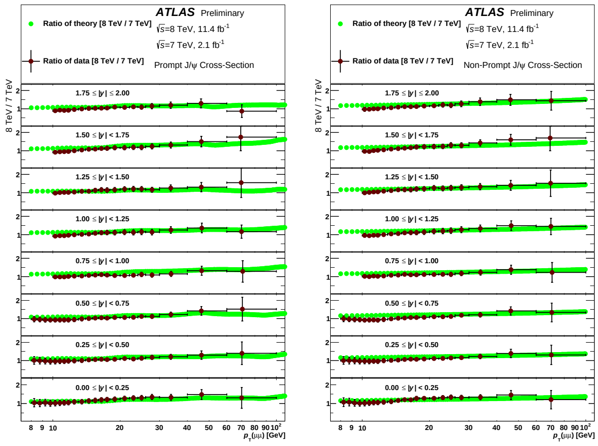

Figure 4: The ratio of the 8 TeV and 7 TeV differential cross-sections are presented for prompt (left) and non-prompt (right) J/ψ for both data and theoretical predictions. The theoretical predictions used are NRQCD for prompt and FONLL for non-prompt production. The uncertainty on the data ratio does not account for possible correlations between 7 and 8 TeV data, and no uncertainty is shown for the ratio of theory predictions. [10]

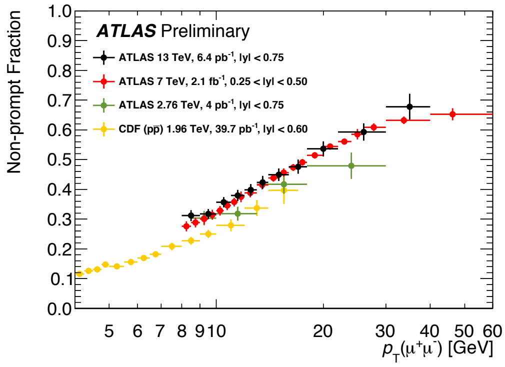

Figure 5: Non-prompt differential J/ψ production fraction measured in the most central rapidity region ($|y| < 0.75$) compared to previous measurements from ATLAS in pp collisions at 2.76 and 7 TeV, and from CDF in p$\bar{p}$ collisions at $\sqrt{s}$ = 1.96 TeV. The error bars represent the total uncertainty on the measurements (statistical and systematic). [8]

Comparison of results have been made to several theoretical models, but none provide an accurate description of the data over the full range of Υ transverse momenta accessible with the 7 TeV dataset.

4. Associated production

The final state of J/ψ associated with a W or Z boson can arise from a single parton-parton interaction or two distinct parton-parton interactions within the same pp collision. Associated production probes the quarkonium production mechanism and is sensitive to multiple parton interactions.

Measurements of the azimuthal angle between the Z boson and J/ψ suggest that both single and double parton scattering 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 transitions than through colour-singlet 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.

5. Conclusion

Many publications and analyses are in progress in 2016. The large quarkonium sample from Run 1 has allowed detailed tests of QCD including cross-sections and branching fractions of standard quarkonium, associated production with vector bosons, photons and additional quarkonia. Run 2 measurements are just starting and the results are eagerly awaited.

References

[1] The ATLAS Collaboration *"The ATLAS Experiment at the CERN Large Hadron Collider",* [JINST 3 (2008) S08003]

[2] Y.-Q. Ma, K. Wang, and K.-T. Chao, [arXiv:1002.3987]

[3] H.-S. Shao, [arXiv:1212.5293]

[4] Ma, Yan-Qing and Wang, Kai and Chao, Kuang-Ta, [arXiv:1009.3655]

[5] L.Harland-Lang and W.A. Stirling, http://superchic.hepforge.org/chigen.html.

[6] Frawley, Anthony D. and Ullrich, T. and Vogt, R. [arXiv:0806.1013]

[7] Barger, Vernon D. and Keung, Wai-Yee and Phillips, R. J. N., [ZEPYA,C6,169]

[8] The ATLAS Collaboration *"Measurement of the differential non-prompt J/ψ production fraction in $\sqrt{s}$ = 13 TeV pp collisions at the ATLAS experiment",* [ATLAS-CONF-2015-030]

[9] The ATLAS Collaboration *"Study of J/ψ and $\psi(2S)$ production in $\sqrt{s_{NN}} = 5.02$ TeV p+Pb and $\sqrt{s} = 2.76$ TeV pp collisions with the ATLAS detector*", [ATLAS-CONF-2015-023]

[10] The ATLAS Collaboration *"Measurement of the differential cross-sections of prompt and non-prompt production of J/ψ and $\psi(2S)$ in pp collisions at $\sqrt{s} = 7$ and 8 TeV with the ATLAS detector",* [ARXIV:1512.03657]

[11] The ATLAS Collaboration *"Measurement of Upsilon production in 7 TeV pp collisions at ATLAS",* [arXiv:1211.7255]

[12] The ATLAS Collaboration *"Measurement of $\Upsilon(nS)$ production with p+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV and pp collisions at $\sqrt{s} = 2.76$ TeV",* [ATLAS-CONF-2015-050]

[13] The ATLAS Collaboration *"Observation and measurements of the production of prompt and non-prompt J/ψ mesons in association with a Z boson in pp collisions at $\sqrt{s}$ = 8 TeV",* [arXiv:1412.6428]

[14] The ATLAS Collaboration *"Measurement of the production cross section of prompt J/ψ mesons in association with a $W^{\pm}$ boson in pp collisions at $\sqrt{s} = 7$ TeV",* [arXiv:1401.2831]