Quarkonium Production in ATLAS

Sue Cheatham on behalf of the ATLAS Collaboration
McGill University, Montreal, Canada.

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The production of Quarkonium is an important testing ground for QCD calculations. The J/ψ and Υ(1S) production cross-sections are measured in proton-proton collisions at the ATLAS detector at the LHC. Differential cross sections as a function of transverse momentum and rapidity have been measured. Charmonium states χ_{c1}(1P) and χ_{c2}(1P) have been observed through radiative decays, as well as a new χ_b state. Results are compared to perturbative QCD predictions.

1 Introduction

Despite being among the most studied of the bound quark systems, there is still no clear understanding of the production mechanisms for quarkonium states like the J/ψ and the Υ that can consistently explain both the production cross-section and spin alignment measurements in e^+e^-, hadron and heavy ion collisions. Data from the LHC allow tests of theoretical models of quarkonium production in a new energy regime. Details of the ATLAS detector may be found in [1]. The sub-detectors of greatest importance to the analyses presented here are the Inner Detector (ID) and Muon Spectrometer systems.

2 Measurement of the differential cross-sections of inclusive, prompt and non-prompt J/ψ production

The inclusive J/ψ production cross-section is measured at ATLAS in the di-muon decay channel using 2.3 pb^{-1} of 2010 data [2]. The number of J/ψ candidates are extracted from the observed di-muon pairs, applying event weights to unfold the response of the detector, reconstruction and trigger efficiency. The J/ψ yields are then determined in regions of the di-muon $\mathrm{p_T}$ and rapidity. The spin alignment of the J/ψ is unknown, as yet, at the LHC. An envelope of all possible spin alignment assumptions is taken as an additional theoretical uncertainty.

Prompt J/ψ are produced directly from the hard-scatter of the p-p collision, as well as through decays from higher charmonium states. Non-prompt J/ψ are produced via the decay of a B-hadron and can be distinguished experimentally due to the associated displacement of the J/ψ vertex in the transverse plane, due to the long lifetime of the B hadron.

Figure 1 shows the inclusive J/ψ production cross-section as a function of $\mathrm{p_T}$, in two regions of J/ψ rapidity. The prompt and non-prompt J/ψ production cross-sections, as a function of $\mathrm{p_T}$, are also shown in Figure 1. The non-prompt component is seen to be in good agreement

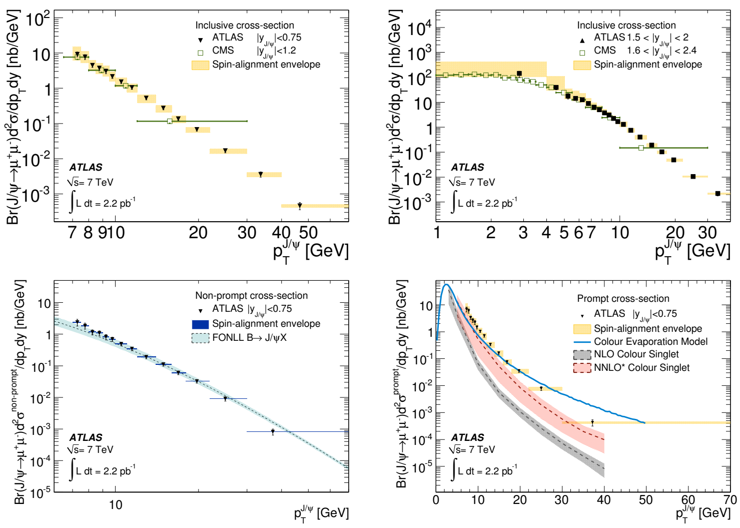

Figure 1: The inclusive J/ψ production cross-section as a function of J/ψ transverse momentum, for low J/ψ rapidity (top left) and higher J/ψ rapidity (top right). The equivalent results from CMS are overlaid. The non-prompt J/ψ production cross-section is shown (bottom left) and the prompt J/ψ production cross-section (bottom right), as a function of J/ψ $\mathrm{p_T}$.

with the FONLL predictions. For the prompt component, the data are reasonably consistent with NNLO* Colour Singlet calculations at low $\mathrm{p_T}$, but does less well at high $\mathrm{p_T}$.

3 Observation of the χ_{c1}(1P) and χ_{c2}(1P) charmonium states

The χ_{c1}(1P) and χ_{c2}(1P) charmonium states in $\chi_c \to J/\psi\gamma$ decays are observed using an integrated luminosity of 39 pb^{-1} [3]. J/ψ candidates are reconstructed via the decay J/$\psi \to \mu^+\mu^-$ while photons are reconstructed with a calorimetric measurements. χ_c candidates are observed in the kinematic range $p_T^{\chi_c} > 10$ GeV and rapidity $\mid y_{\chi c} \mid < 2.4$. An extended unbinned maximum likelihood fit is performed to the invariant mass difference of the $\mu^+\mu^-$ and $\mu^+\mu^-\gamma$ systems to yield 2960 $\pm$ 120 (stat.) $\pm$ 90 (syst.) χ_{c1} and χ_{c2} candidates. The result of a simultaneous fit to the signal sample and background sample is shown in Figure 2. The small mass difference between the two χ_c states is comparable to the achievable mass resolution, which is dominated by the photon energy resolution.

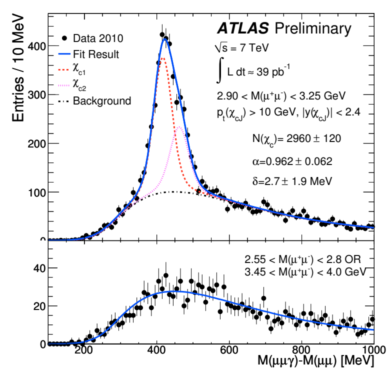

Figure 2: $\chi_c \to J/\psi\gamma$ decays. The result of a simultaneous fit to the signal selection (top) and background (J/ψ sideband) selection (bottom). The individual signal components are shown (dashed lines).

4 Measurement of the centrality dependence of J/ψ yields and observation of Z production in lead-lead collisions

A centrality-dependent suppression has been observed in the yield of J/ψ mesons produced in the collisions of lead ions in ATLAS [4]. In a sample of lead-lead collisions at a nucleon-nucleon centre of mass energy $\sqrt{s_{NN}} = 2.76$ TeV, corresponding to an integrated luminosity of about 6.7 μb^{-1}, J/ψ mesons are reconstructed via their decays to $\mu^+\mu^-$ pairs. The measured J/ψ yield, normalized to the number of binary nucleon-nucleon collisions, is found to significantly decrease from peripheral (glancing) to central (head-on) collisions, as shown in Figure 3. The centrality dependence is found to be qualitatively similar to the trends observed at previous, lower energy experiments. The same sample is used to reconstruct Z bosons in the $\mu^+\mu^-$ final state, and a total of 38 candidates are selected in the mass window of 66 to 116 GeV. No centrality-dependent supression is seen in the Z boson yield, as expected. This analysis provides the first results on J/ψ and Z production in lead-lead collisions at the LHC.

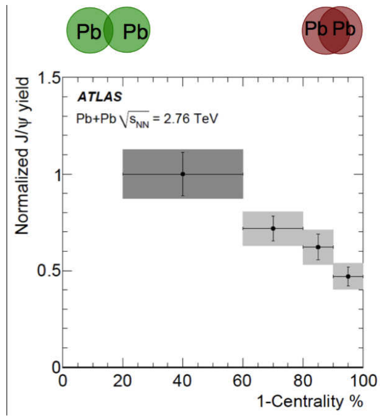

Figure 3: The measured J/ψ yield, normalized to the number of binary nucleon-nucleon collisions, is found to significantly decrease from peripheral to central collisions.

5 Measurement of the Υ(1S) Production Cross-Section

A measurement of the cross-section for $\Upsilon(1S) \to \mu^+\mu^-$ production is made as a function of the $\Upsilon(1S)$ transverse momentum, where both muons have $p_T > 4$ GeV and $|\eta| < 2.5$. The results, as shown in Figure 4, are based on an integrated luminosity of 1.13 pb^{-1} [5]. When the cross-section measurement is compared to theoretical predictions, it agrees to within a factor of two with a prediction based on the NRQCD model including colour-singlet and colour-octet matrix elements as implemented in PYTHIA while it disagrees by up to a factor of ten with the NLO prediction based on the Colour Singlet Model. This measurement is independant of the unknown Υ spin-alignment and as such offers a precise test of theoretical descriptions of quarkonium production.

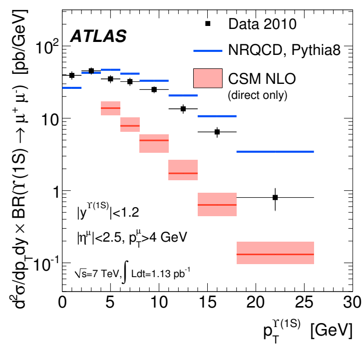

Figure 4: Υ(1S) cross-section as function of Υ transverse momentum for $|y_{\Upsilon(1S)}| < 1.2$

6 Observation of a New $\chi(b)$ State in Radiative Transitions to Υ(1S) and Υ(2S)

The $\chi_b(nP)$ quarkonium states are studied using a data sample corresponding to an integrated luminosity of 4.4 fb^{-1}. These states are reconstructed through their radiative decays to Υ(1S,2S) with $\Upsilon \rightarrow \mu^+\mu^-$ [6]. Photons are reconstructed with both calorimetric measurements (unconverted) and ID tracking (converted photons). In addition to the mass peaks corresponding to the decay modes χ_b(1P,2P)$\rightarrow$ Υ(1S)γ, a new structure centered at a mass of 10.530 ± 0.005 (stat.) $\pm\, 0.009$ (syst.) GeV is also observed, in both the Υ(1S)γ and Υ(2S)γ decay modes. This is interpreted as the χ_b(3P) system. The mass difference $m(\mu^+\mu^-\gamma) - m(\mu^+\mu^-)$ distributions are shown in Figure 5.

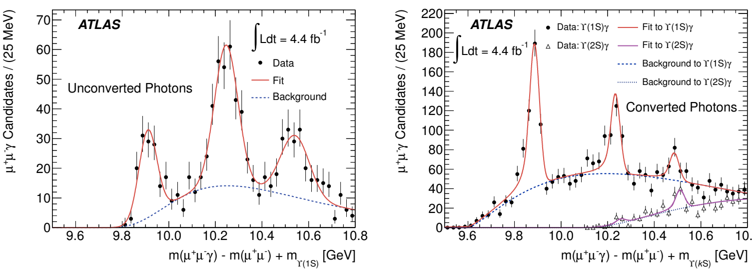

Figure 5: The mass distribution of $\chi(b)(nP) \rightarrow \Upsilon(1S)\gamma$ candidates for unconverted photons reconstructed using the electromagnetic calorimeter (left). The mass distributions of $\chi(b)(nP) \rightarrow \Upsilon(kS)\gamma$ (k = 1, 2) candidates formed using converted photons and been reconstructed in the ID (right).

7 Conclusions

In the first year of 7 TeV data-taking ATLAS has observed and measured charmonium and bottomonium states, including a new χ_b state. The production of heavy quarkonium provides particular insight into QCD theory as its mechanisms of production operate at the boundary of the perturbative and non-perturbative regimes. These measurements provide input towards an improved understanding and theoretical description of QCD.

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