1 Introduction

The ATLAS detector [1] is a multipurpose particle physics apparatus built at the Large Hadron Collider (LHC). In addition to a wide range of measurements of high mass particles produced at high transverse momenta ($p_T$), both within or beyond the Standard Model, ATLAS has a rich quarkonium physics programme concentrating on low-$p_T$ di-muon final states. Quarkonia are formed from a quark-antiquark pair of the same flavour. Despite being among the most studied of the bound-quark systems, there is still no clear understanding of the production mechanisms that can consistently explain both the cross-section and spin-alignment measurements [2]. The LHC provides the opportunity to test existing models at a higher energy regime, a higher $p_T$ and a wider rapidity ranges than previously.

2 Quarkonia production and observation of $\chi_b(3P)$

In order to allow efficient collection of low-$p_T$ di-muon samples, dedicated $b$-physics triggers had been developed. Two low-$p_T$ muons identified by hardware-based first level trigger are subsequently analysed by higher level software trigger algorithms. Once the muons are confirmed, a fit is performed to the combined vertex and mass constraints are applied. Figure 1 shows the di-muon mass spectrum for events recorded in the first half of 2011 data taking period. The coloured histograms show the significant data samples collected by the dedicated $b$-physics triggers. In 2010 and 2011, ATLAS has recorded 48 pb$^{-1}$ and 5.6 fb$^{-1}$ of data, respectively, from $pp$ collisions at a centre of mass energy of 7 TeV.

ATLAS has measured the differential cross-sections of inclusive, prompt and non-prompt $J/\psi$ production using 2.2 pb$^{-1}$ of 2010 data [4]. Trigger and reconstruction efficiencies were measured in data and validated with Monte Carlo simulations. Weights incorporating acceptance and efficiency corrections were applied to quarkonia candidates on an event-by-event basis before fits were used to extract cross-section. $J/\psi$ can be produced either promptly from the hard interaction or non-promptly via decay of a $b$-hadron. $J/\psi$ from $B$-decays have positive displaced di-muon vertices and can be distinguished from the prompt production via the pseudo-proper time discriminant,
Figure 1: Invariant mass of oppositely charged muon candidate pairs selected by a variety of ATLAS triggers. The coloured histograms show events selected by the dedicated $b$-physics triggers compared to those triggered by the single muon trigger (grey). The different colours correspond to triggers with different mass ranges [3].

$$\tau = L_{xy} \cdot \frac{m_{J/\psi}^2}{p_T^{J/\psi}}$$

where $L_{xy}$ is the transverse decay length of the $J/\psi$ vertex. Figure 2 shows the inclusive $J/\psi$ cross-section as a function of the $p_T^{J/\psi}$ for one rapidity bin (left) and the $\tau$ distribution (right). By combining these two measurements, the prompt and non-prompt $J/\psi$ cross-sections were derived. The largest source of systematic uncertainty of the cross-section measurement is due to the unknown spin alignment of the $J/\psi$. Five spin alignment scenarios were identified that induce the largest envelope of variation on visible cross-sections. Figure 3 shows the non-prompt (left) and prompt (right) $J/\psi$ production cross-sections as a function of $p_T^{J/\psi}$ compared to theoretical predictions. The measured non-prompt cross-section is in good agreement with Fixed-Order Next-to-Leading-Log theoretical predictions. The prompt cross-section is compared to colour-singlet model (CSM) NLO and NNLO* pQCD predictions and to the phenomenological Colour Evaporation Model (CEM). The CEM predictions describe the shape better and the NNLO* prediction shows a significant improvement in the normalisation over the NLO prediction.

Production cross-sections of $\Upsilon(1S)$ have been derived in bins of rapidity and $p_T^{\Upsilon(1S)}$ with 1.1 pb$^{-1}$ of 2010 data [5]. The measurement was restricted to the fiducial region, $p_T^{\Upsilon} > 4$ GeV and $|y^{\Upsilon}| < 2.5$, to remove the uncertainty due to the spin alignment. Unfolded differential cross-sections are compared to CSM NLO prediction in figure 4 left and significant disagreement is observed. However, the prediction does not include feed-down from higher mass states estimated to contribute a factor of two at the Tevatron [6].

ATLAS observed a new $\chi_b(3P)$ state through its radiative decays to $\Upsilon(1S)$ and $\Upsilon(2S)$ with 4.4 fb$^{-1}$ of data collected in 2011 [7]. Radiative decays of $\chi_b(3P)$ have been reconstructed from the photon emitted during the transition, and the subsequent decay of the $\Upsilon$ into two muons. Figure 4 right shows the mass distribution.
for candidates with converted photons. The mass for $\chi_b(3P)$ is determined as $10.539\pm 0.005$ (stat.) $\pm 0.009$ (syst.) GeV, which is consistent with the expectation from theoretical models averaging the mass over the three $\chi_b(3P)$ hyperfine triplet states.

3 Summary

The ATLAS quarkonia programme has produced many important measurements of production cross-sections which are already providing valuable input for theoretical models. A new bottomonium state, $\chi_b(3P)$, has been observed for the first time.

References

Figure 3: Non-prompt (left) and prompt (right) $J/\psi$ production cross-sections as a function of $p_T^{J/\psi}$. The non-prompt (prompt) cross-section is compared to predictions from FONLL (NLO, NNLO* and the CEM). Coloured bands show the changes of the results under spin-alignment scenarios representing a theoretical uncertainty [4].

Figure 4: Left figure shows $\Upsilon(1S)$ cross-section for $|y^{\Upsilon(1S)}| < 1.2$ as a function of $p_T^{\Upsilon(1S)}$. Also shown is the CSM and the NRQCD predictions. Right figure shows the mass distribution of $\chi_b \rightarrow \Upsilon(kS)\gamma$ ($k = 1, 2$) candidates for converted photons. $\chi_b \rightarrow \Upsilon(1S)\gamma$ and $\chi_b \rightarrow \Upsilon(2S)\gamma$ decays are plotted using circles and triangles, respectively. Solid (dashed) lines show the total (background) fit result for each mass window [5, 7].