HEAVY FLAVOUR PRODUCTION AT ATLAS AND CMS

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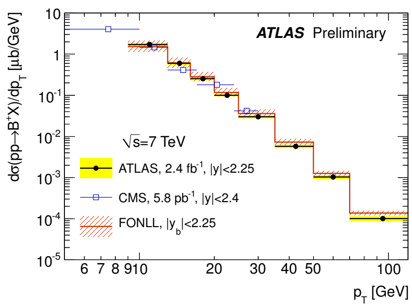
Recent measurements of open beauty and heavy quarkonium production, made by ATLAS and CMS at the Large Hadron Collider, are presented and compared to theoretical predictions.

1 Introduction

Large amounts of data have been collected by the experiments at the LHC, allowing detailed studies of heavy flavour production to be performed and setting new challenges to theory. This note presents an overview of recent results on open beauty and quarkonium production from the ATLAS and CMS collaborations, obtained using data collected at $\sqrt{s} = 7$ TeV.

2 Open Beauty Production

ATLAS have measured the B^+ production cross section [1] using 2.4 fb^{-1} of 2011 data, extending the p_T reach up to 120 GeV. Figure 1 (left) shows the B^+ cross section as a function of p_T. Superimposed are the CMS measurement for $p_T < 30$ GeV and the FONLL [2] prediction, both in good agreement with the ATLAS results.



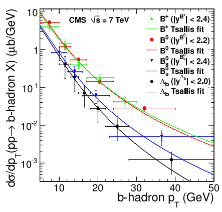


Figure 1: differential cross section of B^+ production as a function of p_T measured by the ATLAS[1] collaboration (left), transverse momentum distribution of various B hadrons measured by the CMS collaboration (right)

An updated summary of the CMS measurements of the differential cross sections for beauty hadrons as a function of the transverse momentum of the hadrons is shown in Figure 1 (right), indicating steeper p_T distributions for heavier B hadrons.

The B hadron production cross section from partially reconstructed final states, $D^*\mu$, measured by ATLAS [3] is shown in Figure 2 (left) with a comparison to NLO predictions. The shape of the distribution is reproduced reasonably well, but the cross section is underestimated.

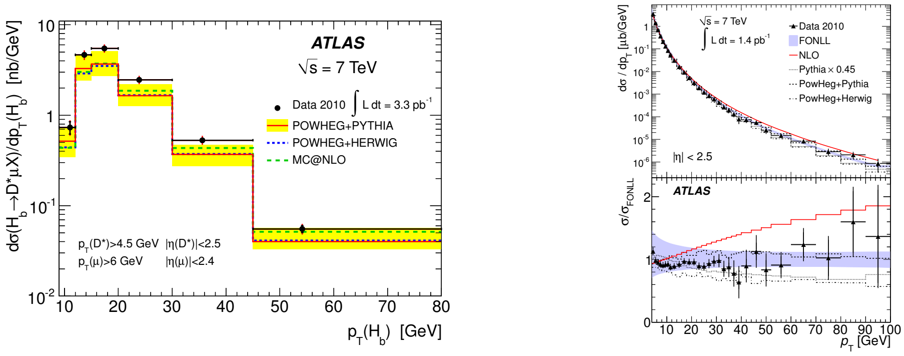


Figure 2: transverse momentum distributions of: partially reconstructed B hadrons[3] (left), and muons from heavy flavour decays[4] (right), measured by the ATLAS collaboration

Similar conclusions can be drawn from the studies of inclusive muons originating from heavy flavour decays, performed by ATLAS [4] and CMS [5]. While at lower p_T both NLO and FONLL perturbative QCD calculations show reasonable agreement with data, at high p_T, up to 100 GeV reached by ATLAS, FONLL represents the experimental data more accurately (Figure 2, right).

3 Charmonium Production

ATLAS and CMS have accumulated huge statistics of J/ψ and $\psi(2S)$ candidates decaying to two muons, allowing them to perform a multitude of measurements. Both particles can be produced either from prompt short-lived QCD sources, or from non-prompt, long-lived B hadron decays. Both cases include direct production as well as feed-down from excited states. The measured transverse decay length of the di-muon pair is used to separate prompt from non-prompt decays.

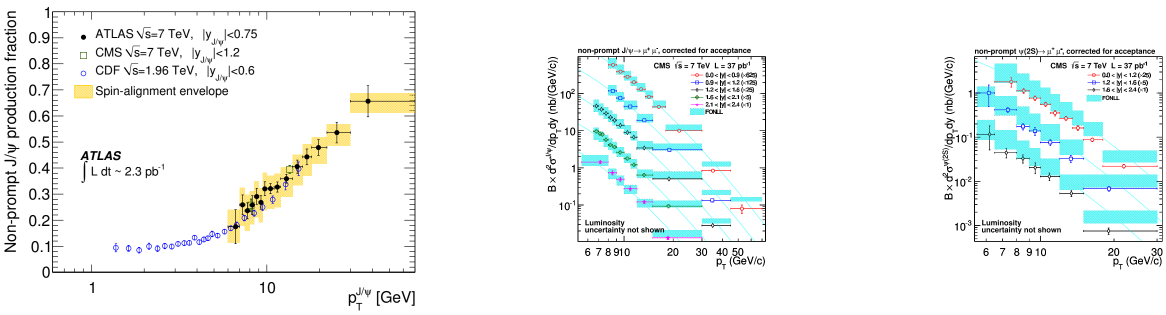


Figure 3: non-prompt J/ψ production fraction[6] at central rapidities (left) and transverse momentum distributions for non-prompt J/ψ (center) and $\psi(2S)$ (right) production[7]

The non-prompt fraction has been measured for J/ψ by ATLAS[6] and CMS[7] and for $\psi(2S)$ by CMS as a function of p_T and rapidity. The results (Figure 3, left), including CDF [8] measurements at low p_T, are in good agreement with each other. The non-prompt fraction of J/ψ starts at $\sim 10\%$ at low p_T and central rapidity and slowly increases to a plateau at high p_T, with the height of the plateau decreasing with increasing rapidity [6].

Figure 3 shows the double differential cross sections for non-prompt J/ψ (center) and $\psi(2S)$ (right), assuming unpolarised production. It is in agreement, within the uncertainties, with the FONLL calculations. There is an overall scale discrepancy observed for $\psi(2S)$.

The theoretical models seem to have more difficulty describing prompt charmonium decays. NLO calculations in Colour Singlet Models underestimate the data by a large factor as illustrated in Figure 4 (left). Inclusion of NNLO contributions[9] (without feed-down from χ_c states) improves things significantly, but the p_T dependence is still steeper than in data. The opposite is true for the Colour Evaporation Model [10]. Neither of these models has free parameters. Colour Octet

Models, such as NRQCD [11] use data to constrain a multitude of model parameters and as a consequence can describe the measured distributions reasonably well (Figure 4).

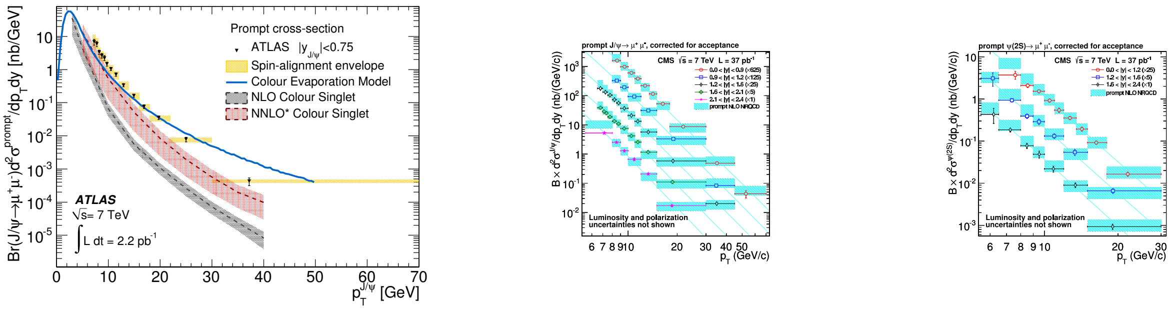


Figure 4: transverse momentum distributions for prompt J/ψ production measured by the ATLAS[6] (left) and CMS (center) collaborations and prompt $\psi(2S)$ (right) production measured by the CMS[7] collaboration

The production dynamics of $\psi(2S)$ are similar to J/ψ but do not include a significant feed-down from excited states. CMS [7] have measured the p_T dependence of the cross section ratio of $\psi(2S)$ to J/ψ. The non-prompt case (Figure 5, left) is described well by FONLL, while the NRQCD prediction for the prompt ratio (Figure 5, center), although consistent within the large theoretical uncertainties, seems to deviate at higher p_T.

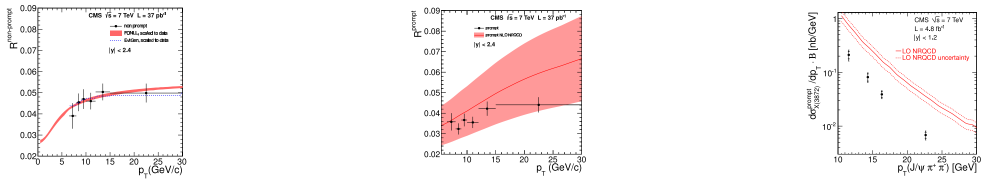


Figure 5: ratio of $\psi(2S)$ to J/ψ production cross sections as a function of p_T for non-prompt (left) and prompt (center) contributions, measured by CMS[7]; prompt $X(3872)$ production cross section (right), measured by CMS[12]

CMS [12] have studied the production of X(3872) via decays to $J/\psi\pi^+\pi^-$. The ratio of the inclusive cross section to the $\psi(2S)$ one as a function of p_T and the fraction originating from B decays show no significant dependence on p_T. The prompt $X(3872)$ production cross section as a function of p_T is shown in Figure 5 (right). The NRQCD prediction significantly exceeds the measured value, while the p_T dependence is well described.

Figure 6: ratio of χ_{c2} to χ_{c1} production cross sections as a function of the J/ψ transverse momentum, measured by the CMS[13] collaboration in $\chi_c \to J/\psi\gamma$ decays

The ratio of prompt χ_{c2} to χ_{c1} cross sections measured by CMS [13] is shown in Figure 6. The k_T factorisation prediction shape is in good agreement but a factor of 2 higher than the measurement (Figure 6, left), while NRQCD (with no specific prediction for the χ_c polarisations) is in reasonable agreement (Figure 6, right).

4 Bottomonium Production

ATLAS [14] have published results on the p_T and rapidity dependence of the production cross sections of $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$, which are in agreement with the previously published CMS results [15] but extend the p_T range up to 70 GeV (Figure 7). The measured cross section rates of $\Upsilon(2S)$ and $\Upsilon(3S)$ to $\Upsilon(1S)$ show a non-trivial p_T dependence, confirming the existence of multiple production mechanisms. The production of a new orbitally excited χ_b state, first announced by ATLAS [16], means that all three Υ states are subject to feed-down from χ_b states. The comparison with theoretical models leads to conclusions similar to the charmonium case: the Colour Singlet, Colour Evaporation [10] and Colour Octet Models [11] show reasonable agreement with data but none can reproduce the full range.

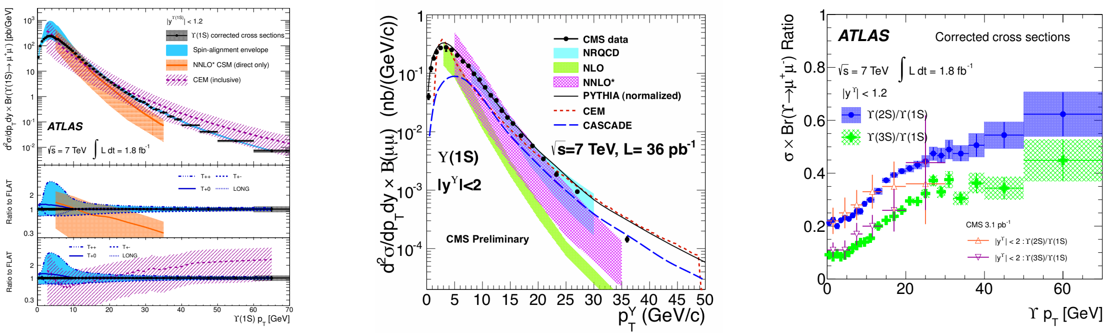


Figure 7: transverse momentum distributions for $\Upsilon(1S)$ production measured by ATLAS (left) and CMS (center); ratios of the production cross sections of $\Upsilon(2S)$ to $\Upsilon(1S)$ and $\Upsilon(3S)$ to $\Upsilon(1S)$, measured by ATLAS [14] (right)

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