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Heavy flavour production in ATLAS

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The associated production of vector boson with quarkonia is a key observable for understanding the quarkonium production mechanisms, including the separation of single and double parton scattering components. Using data collected by the ATLAS experiment, located at the LHC, measurements of prompt and non-prompt J/ψ and $\psi(2S)$ mesons with p_{T} between 60–360 GeV is reported at $\sqrt{s}$= 13 TeV in pp collisions. A measurement of the production of a prompt J/ψ in association with a $W^{\pm}$ boson is presented at $\sqrt{s}$=8 TeV in pp collisions.

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1. Charmonium high p_T production cross sections at 13 TeV

Charmonium production can provide important insight into QCD near the perturbative and non-perturbative boundary. Increasing the p_T [1] range for the production of quarkonium states is important since high p_T behavior may help discriminate between different theoretical models. Previous ATLAS measurements primarily required dimuon triggers which limited the p_T range to be less than 100 GeV. By using single muon triggers and the full Run 2 dataset, measurements at high p_T (60–360 GeV) are possible.

The dataset consists of 139 fb^{-1} of data collected at ATLAS [1], located at the LHC, at $\sqrt{s}$=13 TeV [2]. All measurements are made in the dimuon decay channel and all events are weighted to take into account the acceptance, reconstruction efficiencies and trigger efficiencies. Using a two-dimensional unbinned maximum-likelihood fit to the dimuon invariant mass and pseudo-proper time, the yield of prompt and non-prompt charmonium components are extracted.

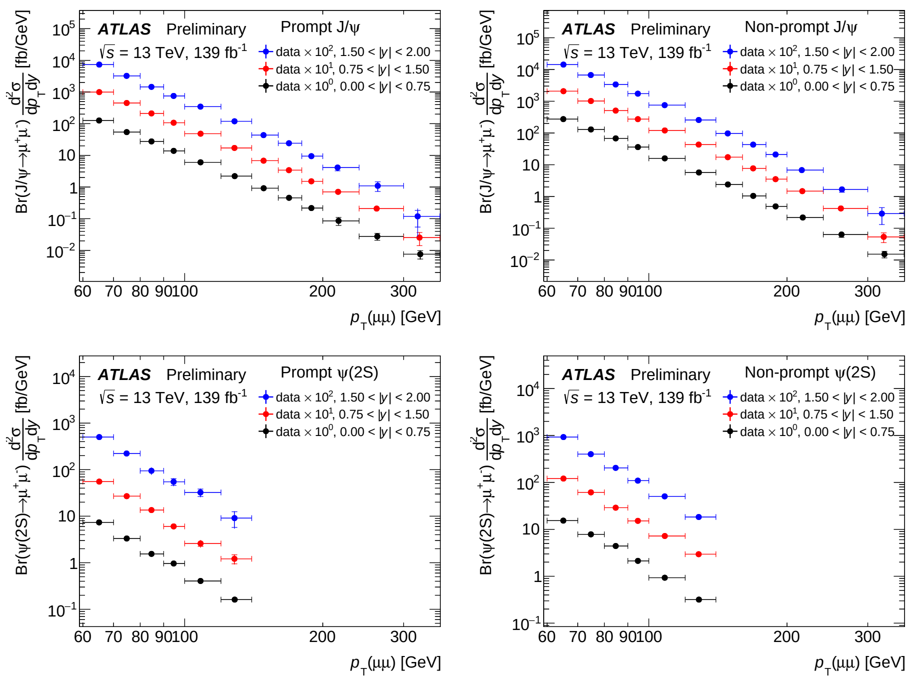

Figure 1: Differential cross sections of prompt and non-prompt production of J/ψ mesons (top) and $\psi(2S)$ mesons (bottom) [2].

The results shown in Figures 1-4 indicate that the p_T dependence for both prompt and non-prompt differential distributions are similar. The non-prompt fractions are approximately constant as a function of p_T for both J/ψ and $\psi(2S)$ mesons. The FONLL [3, 4] predictions are consistent with the data in the lower p_T range for non-prompt production but exceed the experimental results at larger p_T. For further details about these results see Ref. [2].

[1] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the z-axis along the beam pipe. The x-axis points from the IP to the centre of the LHC ring, and the y-axis points upward. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the z-axis. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln\tan(\theta/2)$.

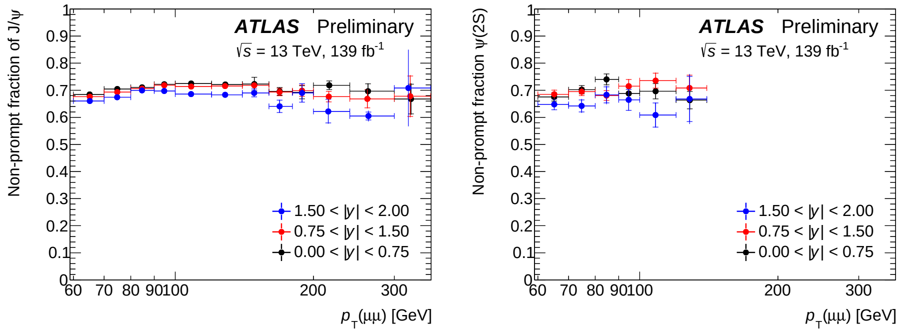

Figure 2: Non-prompt production fraction for J/ψ (left) and $\psi(2S)$ (right) [2].

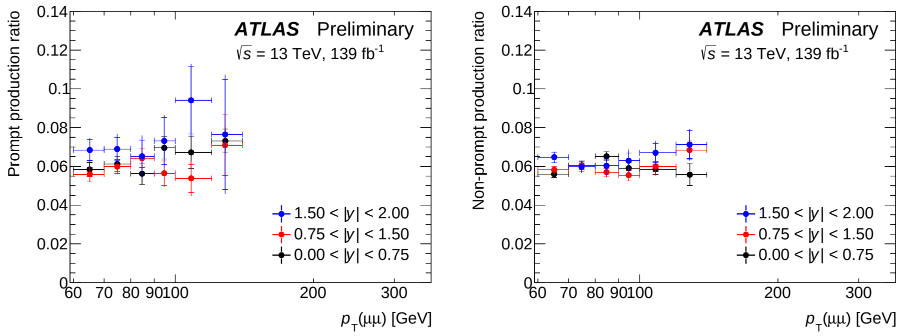

Figure 3: Ratio of $\psi(2S)$ production with respect to J/ψ for prompt (left) and non-prompt (right) production mechanisms [2].

2. J/ψ production in association with a $W^{\pm}$ boson at 8 TeV

Charmonium production mechanisms in hadronic collisions are not completely understood since the relative contribution of color singlet to color octet production is unknown. By requiring an associated object, such as a $W^{\pm}$ boson, it is possible to filter the various color singlet/color octet diagrams. Additionally, the contribution of double parton scattering (DPS) versus single parton scattering (SPS) is unknown and measuring $\Delta\phi$ between the J/ψ and $W^{\pm}$ can probe the relative contributions.

The dataset consists of 20.3 fb^{-1} of data collected at $\sqrt{s}$=8 TeV [5]. All events were selected using a non-prescaled single muon trigger. An inclusive $W^{\pm}$ sample is collected by requiring a prompt, isolated muon with $p_{\mathrm{T}} > 25$ GeV, missing transverse momentum > 25 GeV and the $W^{\pm}$ boson transverse mass > 40 GeV.

In addition, if an event has two muons which satisfy a J/ψ muon criterion, this event is defined as the associated $J/\psi + W^{\pm}$ sample. All events in the associated sample are weighted to take into account the acceptance and reconstruction efficiencies of the two muons from the J/ψ. A two-dimensional unbinned maximum-likelihood fit to the dimuon invariant mass and pseudo-proper time is used to extract the prompt charmonium components. After the fit is performed, the sPlot tool [6] is used to extract per-event weights which allow the azimuthal opening angle $\Delta\phi(J/\psi, W^{\pm})$ to

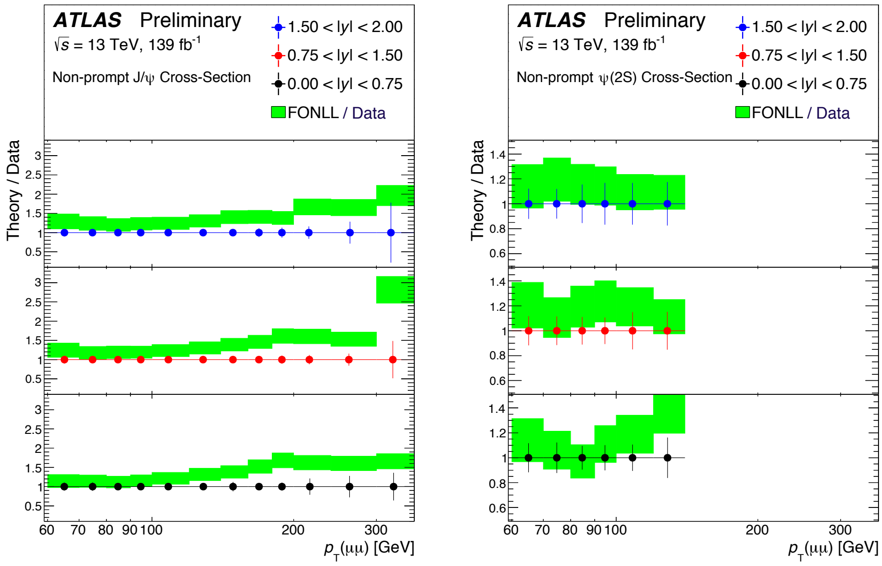

Figure 4: Ratio of the FONLL prediction to the measured differential cross sections for non-prompt J/ψ (left) and $\psi(2S)$ (right) mesons [2].

be measured. Figure 5 shows the sPlot-weighted opening angle $\Delta\phi(J/\psi, W^{\pm})$ for prompt $J/\psi + W^{\pm}$ candidates.

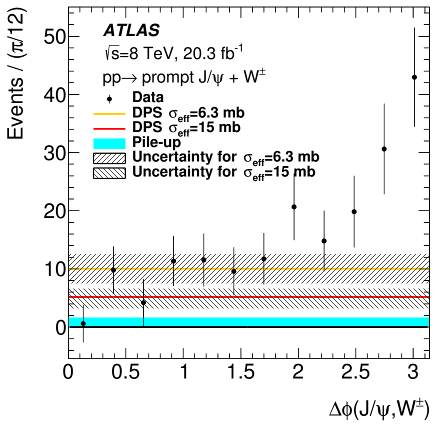

Figure 5: The sPlot-weighted opening angle $\Delta\phi(J/\psi, W^{\pm})$ for prompt $J/\psi + W^{\pm}$ candidates [5].

Based on the assumption that the two hard scatters are uncorrelated, the probability that a J/ψ is produced by a second hard process in an event containing a $W^{\pm}$ boson can be written as

$$P^{ij}_{J/\psi|W} = \frac{\sigma^{ij}_{J/\psi}}{\sigma_{\text{eff}}},$$

where $\sigma^{ij}_{J/\psi}$ is the cross-section for J/ψ production in the appropriate p_{T} (i) and rapidity (j) interval and σ_{eff} is the effective transverse overlap area of the interacting partons. Since σ_{eff} may not be process-independent, two different choices of σ_{eff} are considered. The data show that both choices of σ_{eff} is consistent with the data at low $\Delta\phi$. The data is also consistent with both SPS and DPS contributions.

A fully corrected inclusive production cross-section ratio, in which the J/ψ acceptance and the unknown J/ψ spin-alignment are taken into account, is given by

$$R^{\mathrm{incl}}_{J/\psi} = \frac{\sigma_{\mathrm{incl}}(pp \to J/\psi + W)}{\sigma(pp \to W)} \cdot \mathcal{B}(J/\psi \to \mu\mu) = \frac{1}{N(W)} \sum_{p_{\mathrm{T}}\ \mathrm{bins}} [N^{\mathrm{eff+acc}}(J/\psi + W) - N_{\text{pile-up}}],$$

where $N^{\mathrm{eff+acc}}(J/\psi + W)$ is the background subtracted yield of prompt $J/\psi + W$ events after J/ψ acceptance corrections and efficiency corrections for the J/ψ decay muons, and $N_{\text{pile-up}}$ is the expected number of pile-up events in the full range of J/ψ decay phase space. The result is

$$R^{\mathrm{incl}}_{J/\psi} = (5.3 \pm 0.7 \pm 0.8^{+1.5}_{-0.7}) \times 10^{-6},$$

where the first uncertainty is statistical, the second systematic and the third uncertainty is due to the choice of spin-alignment scenario.

Additional measurements are found by subtracting the estimated DPS contribution in each p_{T} and rapidity interval from the inclusive cross-section ratio,

$$R^{\mathrm{DPSsub}}_{J/\psi} = (3.6 \pm 0.7^{+1.1}_{-1.0}{}^{+1.5}_{-0.7}) \times 10^{-6}, \quad [\sigma_{\mathrm{eff}} = 15^{+5.8}_{-4.2}\ \mathrm{mb}]$$

and

$$R^{\mathrm{DPSsub}}_{J/\psi} = (1.3 \pm 0.7 \pm 1.5^{+1.5}_{-0.7}) \times 10^{-6}, \quad [\sigma_{\mathrm{eff}} = 6.3 \pm 1.9\ \mathrm{mb}]$$

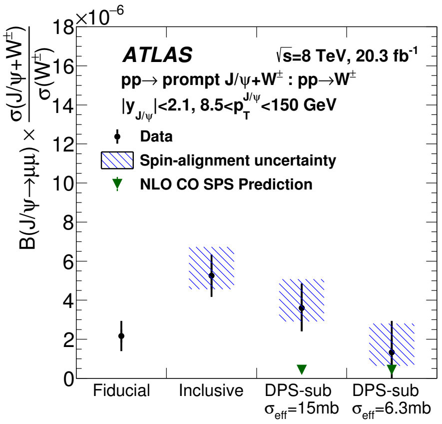

Figure 6: Production cross section ratios for the measurement in the fiducial volume (bin 1), the ratio corrected for acceptance effects (bin 2) and the ratio corrected for double parton scattering for two different choices of σ_{eff}. (bins 3,4). The data in bins 3 and 4 are compared to an NLO CO SPS prediction [5].

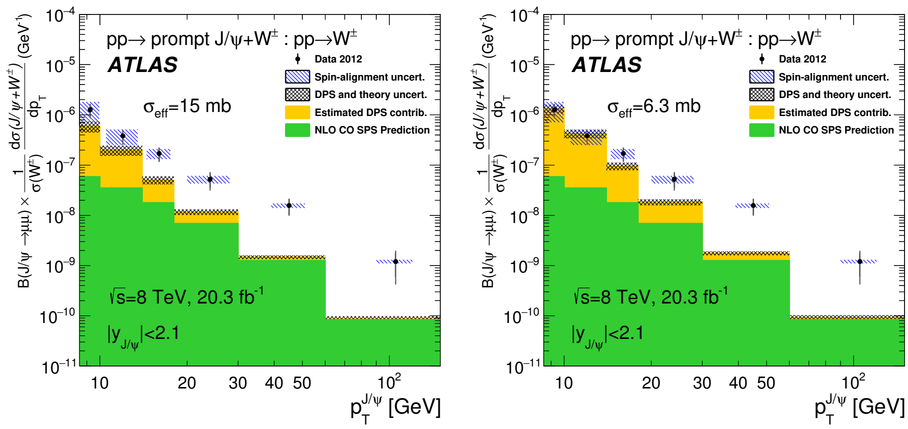

Figure 7: The inclusive differential cross-section ratio compared to theory in six different $p_{\mathrm{T}}^{J/\psi}$ regions for σ_{eff} = 15 mb (left) and σ_{eff} = 6.3 mb (right) [5].

Figures 6 and 7 show the production cross section ratio and differential cross section ratio for two different choices of σ_{eff} compared to a NLO CO SPS prediction [7, 8]. A smaller value of σ_{eff} is preferred however neither value of σ_{eff} can describe the $p_{\mathrm{T}}^{J/\psi}$ dependence. For further details about these results see Ref. [5].

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