Associated production of J/ψ pairs with the ATLAS detector

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A recent measurement of prompt J/ψ pair production is presented, using a sample of 11.4 fb^{-1} of proton-proton collision data collected at $\sqrt{s} = 8$ TeV in the ATLAS detector. The differential cross-section is measured as a function of kinematic distributions for the lower-p_{T} J/ψ meson and for the di-J/ψ system. A data-driven approach is used to extract the fraction of prompt J/ψ pair events due to double parton scattering and an effective cross-section of double parton scattering is measured to be $\sigma_{eff} = 6.3 \pm 1.6(\mathrm{stat}) \pm 1.0(\mathrm{syst}) \pm 0.1(\mathrm{BF}) \pm 0.1(\mathrm{lumi})$ mb.

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1. Introduction

The simultaneous production of quarkonium with vector bosons or with other quarkonium states allows the mechanism for quarkonium production to be probed in a new regime. These final states are sensitive to non-perturbative quantum chromodynamics (QCD) and to higher-order QCD corrections, and also allow the contribution from multiple parton interactions to be studied.

The ATLAS collaboration has published several measurements of the associated production of quarkonia, including $J/\psi+W$ production in the 7 TeV data [2] and $J/\psi+Z$ production in the 8 TeV data [3]. The current presentation will describe the recent measurement of J/ψ pair production in the 8 TeV dataset [4], using 11.4 fb^{-1} of proton-proton collision data recorded in the ATLAS detector [1] during the 2012 running period. Each J/ψ candidate is selected in the $J/\psi \rightarrow \mu^+\mu^-$ decay mode.

In the following, the J/ψ candidates are separated into *prompt* decays, where the J/ψ is produced directly in the p-p interaction or through feed-down decays from higher-mass charmonium states, or *non-prompt* decays, where the charmonium candidate is produced in the decay chain of a *b*-hadron and typically has a displaced decay vertex. Di-J/ψ candidates can be produced either from a single parton scattering (SPS) process, where the two mesons are produced from a single gluon-gluon collision, or from double parton scattering (DPS), where two independent pairs of partons scatter in a single p-p collision. The aim of this measurement is to extract the prompt-prompt di-J/ψ candidates, and to compare contributions arising from SPS and DPS processes.

2. Analysis

Events are selected using dimuon triggers and a set of kinematic selection cuts, including transverse momentum and rapidity requirements on each J/ψ candidate: $p_T > 8.5$ GeV and $|y| <$ 2.1. Corrections are applied for the trigger, reconstruction and event selection efficiencies, and the muon fiducial region is corrected with a kinematic acceptance factor.

The prompt di-J/ψ signal is separated from background processes using a sequence of fits: non-J/ψ background is removed using a two-dimensional fit to the J/ψ invariant masses; non-prompt background from *b*-hadron decays is removed in a two-dimensional fit to the J/ψ transverse decay lengths; and pile-up background is removed using a one-dimensional vertex separation fit. Figure 1 illustrates the one-dimensional projections of the 2D fit to the transverse decay length, L_{xy}, of each J/ψ candidate. Resolution functions are determined from an inclusive J/ψ sample and four fits are performed, depending on whether each J/ψ candidate lies in the central or forward rapidity region. Extracting the prompt-prompt di-J/ψ fraction in four coarse rapidity regions can lead to a possible bias in the prompt-prompt event weights when applied to differential kinematic distributions (e.g. as a function of J/ψ p_T). A bias correction is extracted from Monte Carlo samples generated with PYTHIA8 [5] and is shown in Figure 2 for all the kinematic variables considered in this analysis.

The double parton scattering (DPS) contribution is extracted using a data-driven procedure, in which pairs of J/ψ candidates are chosen randomly from two different events in the di-J/ψ sample. This procedure assumes that the J/ψ candidates in genuine DPS events are produced independently. A 2D template of the absolute difference in J/ψ rapidities, $|\Delta y|$, against the azimuthal
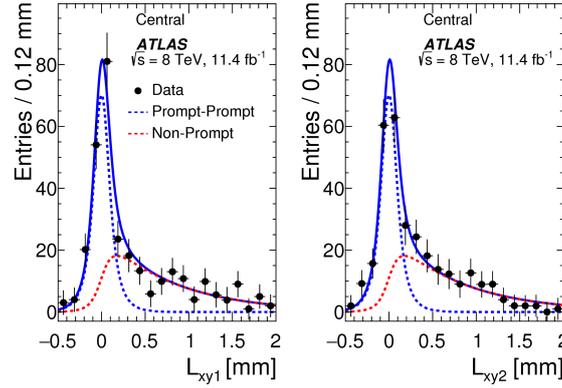
Figure 1: The transverse decay length spectra L_{xy} of the leading and sub-leading J/ψ mesons in the central-central rapidity region [4].
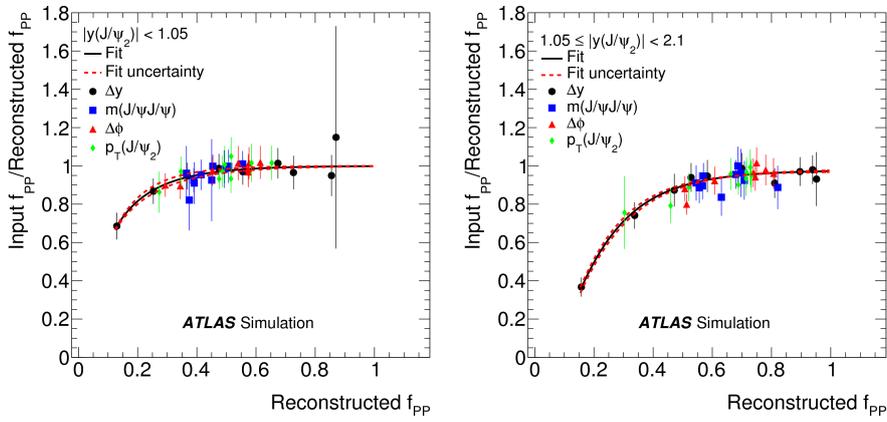
Figure 2: Bias correction for the prompt-prompt fraction f_{PP}: central (left) and forward (right) rapidity [4].

angle difference, $|\Delta\phi|$, is used to derive DPS event weights. The DPS-dominated region $|\Delta y| > 1.8$ and $|\Delta\phi| > \pi/2$ is normalised to the data, then the SPS template is obtained by subtracting the DPS contribution from the background-subtracted data. Figure 3 shows the data-driven DPS and SPS template distributions.

3. Results

Figure 4 shows two differential prompt-prompt di-J/ψ cross-section measurements in the J/ψ fiducial volume ($p_T > 8.5$ GeV and $|y| < 2.1$), as a function of the p_T of the sub-leading J/ψ and of the p_T of the di-J/ψ system. The central values assume unpolarised J/ψ mesons and the yellow bands indicate the maximal spin-alignment variation on the measurements. The DPS-weighted distributions are also shown. In the second plot, the peak at low $p_T(J/\psi\,J/\psi)$ corresponds to back-to-back J/ψ mesons (the "away" region), while the second peak at higher p_T is due to J/ψ mesons produced in the same direction, recoiling against a gluon, and hence is a next-to-leading order effect.
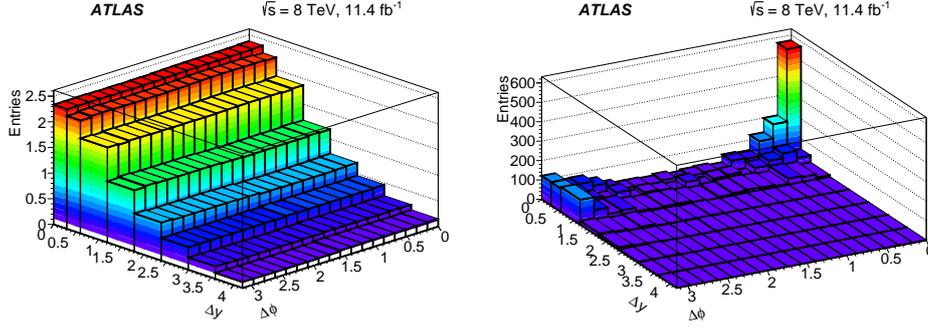
Figure 3: Data-driven templates of $|\Delta y|$ against $|\Delta\phi|$ for DPS (left) and SPS (right) [4].
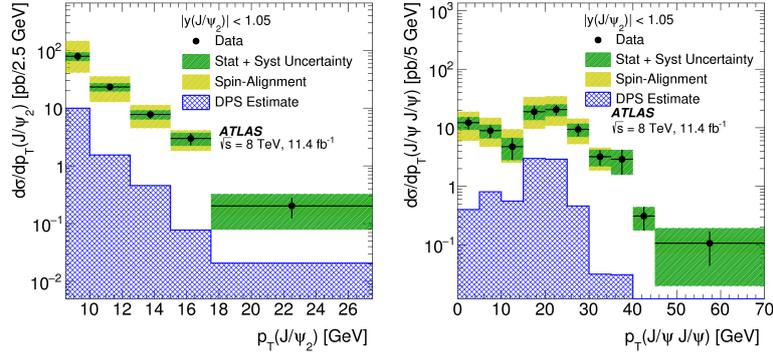
Figure 4: Differential cross-sections in the central rapidity region as a function of the p_T of the sub-leading J/ψ (left) and p_T of the di-J/ψ system (right) [4].

Further differential cross-section measurements are shown in Figure 5 within the muon fiducial volume, without acceptance corrections. The data are compared with a leading-order DPS prediction [6], normalised to the measured DPS fraction, and a partial next-to-leading order SPS calculation, denoted NLO* [7, 8]. The SPS prediction has been scaled by a constant feed-down correction factor of 1.85, to allow for feed-down from $\psi(2S)$. Although there is reasonable agreement between the data and predictions, it can be seen that the NLO* SPS + LO DPS cross-section shows some discrepancy with data at large di-J/ψ invariant mass, $m(J/\psi J/\psi)$, and at low $p_T(J/\psi J/\psi)$. These regions correspond to di-J/ψ production in an away topology, and may indicate that a non-constant feed-down correction or other effects need to be included in the predictions.

An inclusive prompt-prompt di-J/ψ cross-section can be measured in the J/ψ fiducial volume $p_T > 8.5$ GeV, $|y| < 2.1$ for two rapidity regions of the sub-leading J/ψ meson, assuming unpolarised J/ψ mesons:

$$\sigma(pp \to J/\psi J/\psi + X) = \begin{cases} 82.2 \pm 8.3\,(\text{stat}) \pm 6.3\,(\text{syst}) \pm 0.9\,(\text{BF}) \pm 1.6\,(\text{lumi})\,\text{pb}, & |y| < 1.05, \\ 78.3 \pm 9.2\,(\text{stat}) \pm 6.6\,(\text{syst}) \pm 0.9\,(\text{BF}) \pm 1.5\,(\text{lumi})\,\text{pb}, & 1.05 \leq |y| < 2.1, \end{cases}$$

where the contributions to the uncertainty are the statistical, systematic, branching fraction and luminosity uncertainties, respectively.

The effective DPS cross-section σ_{eff} can be derived using the formula

$$\sigma_{\text{eff}} = \frac{1}{2} \frac{\sigma_{J/\psi}^2}{\sigma_{\text{DPS}}^{J/\psi, J/\psi}} = \frac{1}{2} \frac{\sigma_{J/\psi}^2}{f_{\text{DPS}} \times \sigma_{J/\psi J/\psi}}, \tag{3.1}$$
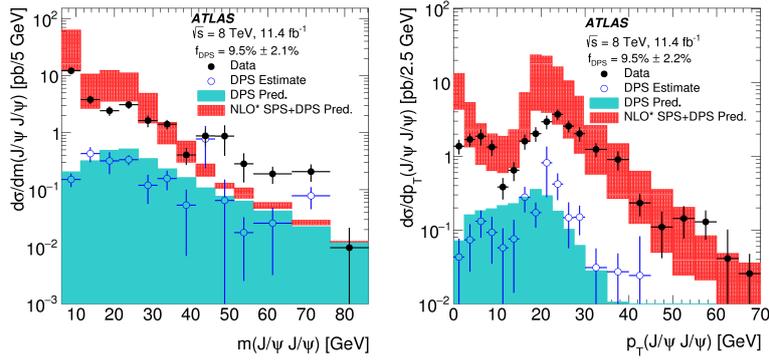
Figure 5: Total and DPS cross-sections as a function of the di-J/ψ invariant mass (left) and p_T (right) [4].

where $\sigma_{J/\psi J/\psi}$ is measured in the current analysis, $\sigma_{J/\psi}$ is taken from the ATLAS prompt J/ψ cross-section measurement at 8 TeV [9] and the DPS fraction $f_{DPS} = (9.2 \pm 2.1 \text{ (stat)} \pm 0.5 \text{ (syst)})\%$ is taken from the Δy distribution. This gives a value of

$$\sigma_{\text{eff}} = 6.3 \pm 1.6 (\text{stat}) \pm 1.0 (\text{syst}) \pm 0.1 (\text{BF}) \pm 0.1 (\text{lumi}) \text{ mb}, \tag{3.2}$$

where the uncertainties are as described above. A summary of σ_{eff} measurements from different centre-of-mass energies and different final states is presented in Figure 6. The current measurement lies somewhat lower than many of the previous values, and is close to the D0 di-quarkonia results [10, 11]. The di-J/ψ, J/ψ-Υ and 4-jet processes are dominated by gluon interactions and should therefore probe the gluon distribution in proton; however, other measurements of these processes give higher effective cross-sections. In addition, a recent LHCb measurement of the J/ψ pair production cross-section at 13 TeV [12] measures σ_{eff} in the range $9.2 - 14.4$ mb for $p_T(J/\psi) < 10$ GeV, $2.0 < y(J/\psi) < 4.5$. More detailed measurements of the DPS contribution will help to test the assumptions of process and energy dependence that are implicit in determining σ_{eff}.

4. Summary

A study of prompt di-J/ψ production has been presented, using 11.4 fb^{-1} of data recorded by the ATLAS detector at $\sqrt{s} = 8$ TeV. Differential cross-section measurements are shown for J/ψ and di-J/ψ observables, including a data-driven estimate of the double-parton scattering contribution. A substantial dataset has already been recorded at $\sqrt{s} = 13$ TeV, which will allow further measurements of the di-J/ψ final state at higher precision in the near future.

References

[1] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, JINST 3, 98 S08003 (2008).

[2] ATLAS Collaboration, *Measurement of the production cross section of prompt J/ψ mesons in association with a W boson in pp collisions at √s = 7 TeV with the ATLAS detector*, JHEP **04** (2014) 172, [arXiv:1401.2831].
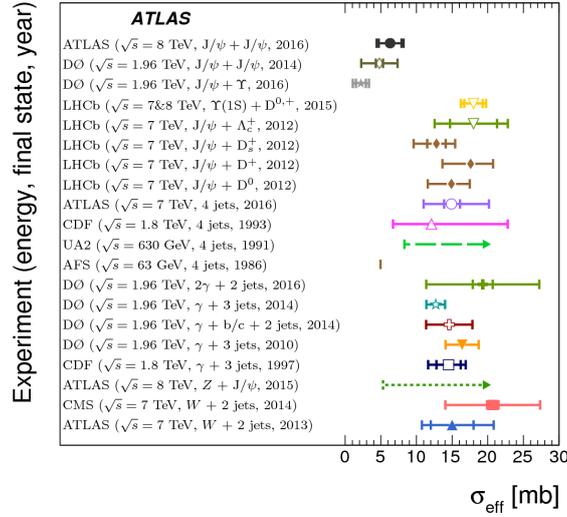
Figure 6: The effective cross-section of DPS from different energies and final states. The full list of journal references is cited in Ref. [4].

[3] 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 with the ATLAS detector*, Eur. Phys. J. C **75** (2015) 229, [arXiv:1412.6428].

[4] ATLAS Collaboration, *Measurement of the prompt J/ψ pair production cross-section in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector*, Eur. Phys. J. C **77** (2017) 76, [arXiv:1612.02950].

[5] T. Sjöstrand, S. Mrenna and P. Z. Skands, *A Brief Introduction to PYTHIA 8.1*, Comput. Phys. Commun. **178** (2008) 852, [arxiv:0710.3820].

[6] C. Borschensky and A. Kulesza, *Double parton scattering in pair-production of J/ψ mesons at the LHC revisited*, Phys. Rev. D **95** (2017) 034029, [arxiv:1610.00666].

[7] J. P. Lansberg and H. S. Shao, *J/ψ-pair production at large momenta: Indications for double parton scatterings and large α_s^5 contributions*, Phys. Lett. B **751** (2015) 479, [arxiv:1410.8822].

[8] J. P. Lansberg and H. S. Shao, *Production of $J/\psi + \eta_c$ versus $J/\psi + J/\psi$ at the LHC: Importance of Real α_s^5 Corrections*, Phys. Rev. Lett. **111** (2013) 122001, [arxiv:1308.0474].

[9] ATLAS Collaboration, *Measurement of the differential cross-sections of prompt and non-prompt production of J/ψ and ψ(2S) in pp collisions at $\sqrt{s} = 7$ and 8 TeV with the ATLAS detector*, Eur. Phys. J. C **76** (2016) 283, [arxiv:1512.03657].

[10] V. M. Abazov *et al.* [D0 Collaboration], *Observation and studies of double J/ψ production at the Tevatron*, Phys. Rev. D **90** (2014) 111101, [arxiv:1406.2380].

[11] V. M. Abazov *et al.* [D0 Collaboration], *Evidence for simultaneous production of J/ψ and Υ mesons*, Phys. Rev. Lett. **116** (2016) 082002, [arxiv:1511.02428].

[12] R. Aaij *et al.* [LHCb Collaboration], *Measurement of the J/ψ pair production cross-section in pp collisions at $\sqrt{s} = 13$ TeV*, JHEP **06** (2017) 047, [arxiv:1612.07451].