PROCEEDINGS OF SCIENCE

Charmonium production in pp collisions at the LHC

T. Zakareishvili[a,*]

[a] *High Energy Physics Institute of Tbilisi State University, Tbilisi, Georgia*

E-mail: Tamar.Zakareishvili@cern.ch

An overview is given of the recent measurements of the differential cross-sections of charmonium production at the LHC. In particular, production of J/ψ and $\psi(2S)$ mesons in a high transverse momentum range by ATLAS is presented, together with the measurements of the non-prompt fractions of $\psi(2S)$ and J/ψ, and of prompt and non-prompt production ratios of $\psi(2S)$ to J/ψ. The results are compared to other recent measurements of charmonium production by other LHC experiments, ALICE and CMS, which are found to be in a good agreement and show useful synergy between the various experiments.

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1. Introduction

Studies involving heavy quarkonia provide a unique insight into the nature of Quantum Chromodynamics (QCD) near the boundary of perturbative and non-perturbative regimes. However, quarkonium production in hadronic collisions still presents significant challenges to both theory and experiment. In high energy hadronic collisions, charmonium states can be produced either from the short-lived QCD sources (referred to as 'prompt' production) or from long-lived sources such as decays of beauty hadrons (referred to as 'non-prompt' production). These can be separated experimentally by measuring the distance between the production and decay vertices of the quarkonium state. While the FONLL calculations [1, 2] within the framework of perturbative QCD have been reasonably successful in describing the non-prompt contributions, a satisfactory understanding of the prompt production mechanisms is still to be achieved. It is increasingly important to broaden the scope of comparison between theory and experiment by providing a broader variety of experimental information on quarkonium production in a wider kinematic range than it was done before. For this purpose the ATLAS experiment [3] at the Large Hadron Collider (LHC) investigated the above-mentioned points by studying the J/ψ and $\psi(2S)$ meson production in pp collisions at high transverse momentum (p_T).

2. Analysis strategy

Data for this analysis were taken during LHC proton-proton collision runs at $\sqrt{s} = 13$ TeV in years 2015 to 2018, with a total integrated luminosity of 139 fb^{-1}. The selected events are required to contain a pair of oppositely charged muons of high quality, triggered by a single muon with p_T threshold of 50 GeV.

Each muon is required to have $p_T > 4$ GeV and $|\eta| < 2.4$, with at least one of the muons having $p_T > 52.5$ GeV matched to the trigger object. The two inner-detector tracks are fitted to a common vertex, and dimuon masses within the range 2.6 GeV $< m_{\mu\mu} <$ 4.2 GeV are selected. The transverse distance L_{xy} between the primary vertex and the dimuon vertex is used to calculate the pseudo-proper decay time:

$$\tau = \frac{m_{\mu\mu}}{p_T} \cdot \frac{L_{xy}}{c}, \qquad (1)$$

where $m_{\mu\mu}$ and p_T are respectively the mass and the transverse momentum of the dimuon system, and c the speed of light. 2-dimensional unbinned maximum-likelihood fits are performed using mass and pseudo-proper time distributions to extract the yields $N_{\psi}^{P,NP}$ for prompt (P) and non-prompt (NP) ψ states, where $\psi = J/\psi$, $\psi(2S)$, see Figure 1. The respective double-differential cross-sections are then calculated:

$$B(\psi \to \mu^+\mu^-) \frac{d^2\sigma^{P,NP}(pp \to \psi)}{dp_T dy} = \frac{1}{\int L dt} \frac{1}{A(\psi)} C_{BM} \, C_{AP} \, \frac{N_{\psi}^{P,NP}}{\Delta p_T \Delta y}, \qquad (2)$$

where Δp_T and Δy are bin widths in dimuon transverse momentum and rapidity respectively, $\int L dt$ is the integrated luminosity, $A(\psi)$ is the kinematic acceptance for a given ψ mass, C_{BM} is a bin

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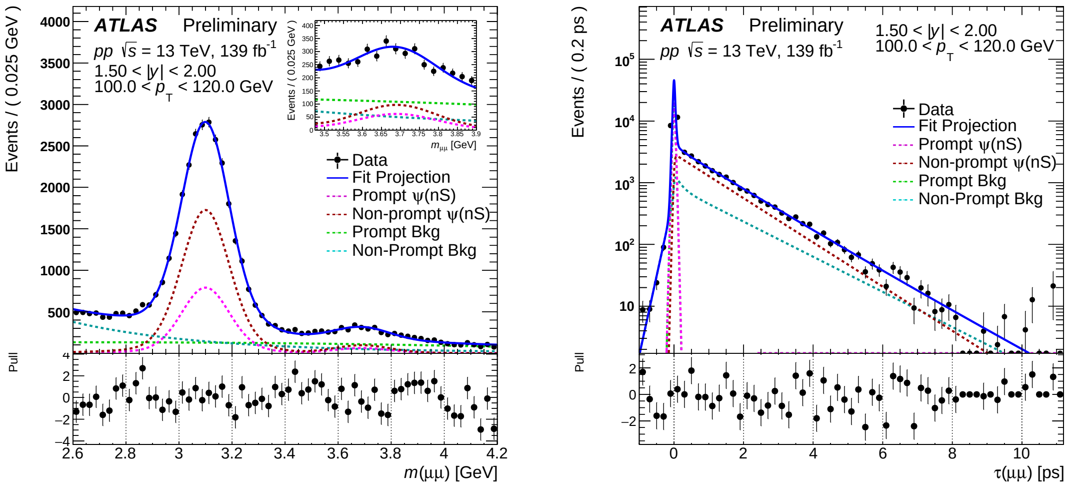
migration correction factor and C_{AP} factor is to correct for the dependence of the efficiencies on pileup conditions.

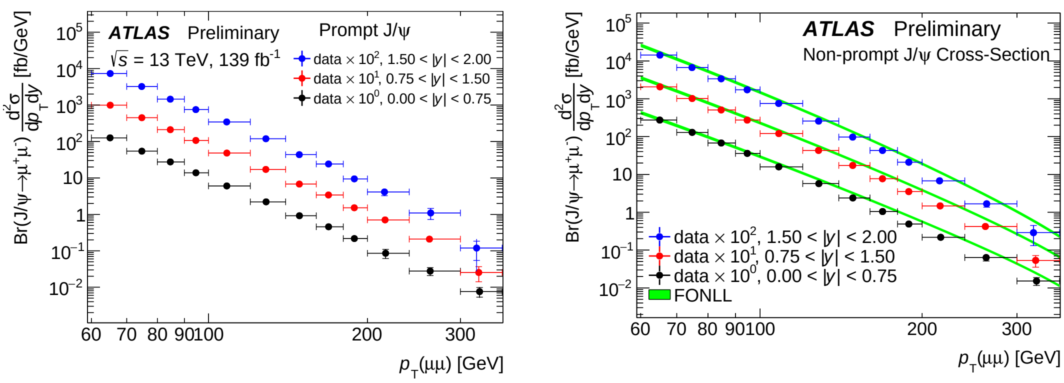


(a) (b)

Figure 1: Projections in (a) invariant mass and (b) pseudo-proper time of the two-dimensional mass–pseudo-proper time fit used to extract the yields of J/ψ and $\psi(2S)$ mesons, in a sample p_T bin [4].

3. Results

The measured double-differential cross-sections of prompt and non-prompt J/ψ production are presented in Figure 2(a) and (b), respectively. The non-prompt production fractions for J/ψ and $\psi(2S)$ are presented in Figure 3(a) and (b), respectively. Finally, the production ratios of $\psi(2S)$ relative to J/ψ are presented in Figure 3, separately for prompt (c) and non-prompt (d) production mechanisms.



(a) (b)

Figure 2: Differential cross-sections of (a) prompt and (b) non-prompt production of J/ψ mesons [4].

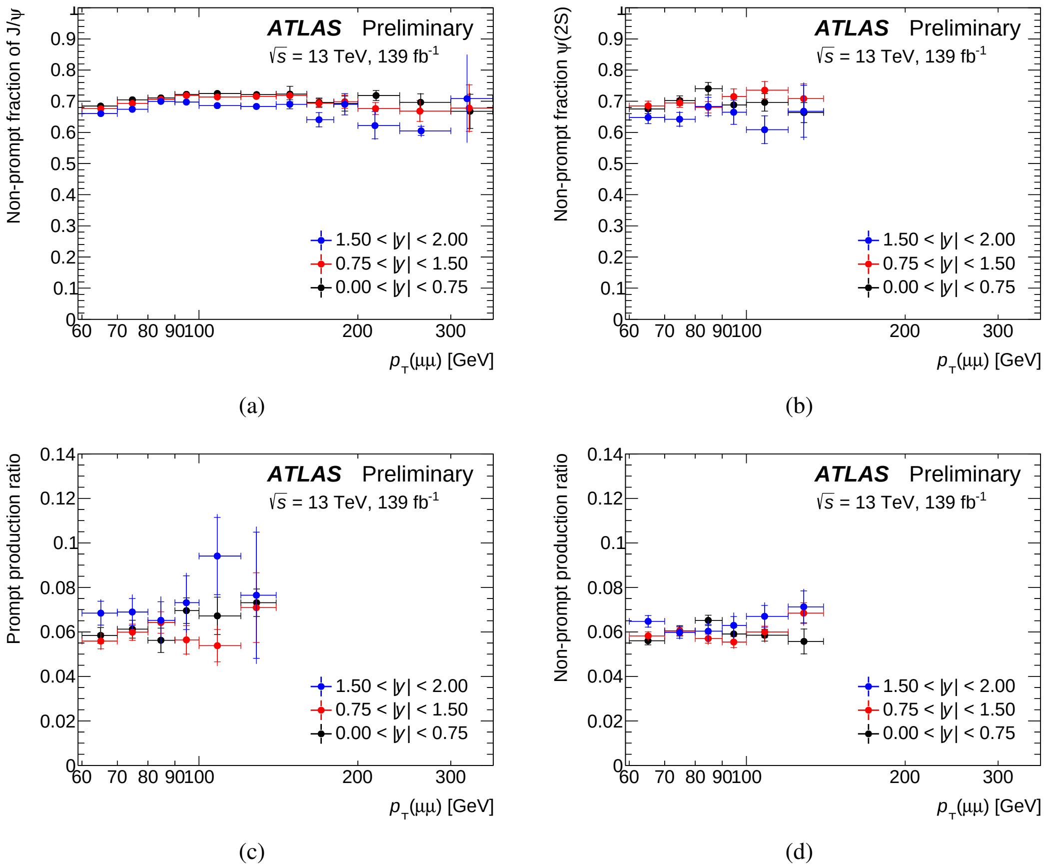


Figure 3: Non-prompt production fraction of J/ψ (a) and $\psi(2S)$ (b), and ratios of $\psi(2S)$ pro-duction with respect to J/ψ, for prompt (c) and non-prompt (d) production mechanisms [4].

4. Summary

The procedure and the results of a measurement of J/ψ and $\psi(2S)$ production at high transverse momenta are described, using the ATLAS detector and the full Run 2 data set collected with pp collisions at $\sqrt{s} = 13$ TeV. The measurement covers the range of transverse momenta between 60 and 360 GeV for J/ψ and 60 to 140 GeV for $\psi(2S)$, and the range of rapidities between -2 and $+2$. In both cases, the transverse momentum range goes well beyond the values reached so far, which should help discriminate between various theoretical models. Where they overlap, results are consistent with similar results obtained by the CMS experiment [5], and ALICE experiment [6], see Figure 4.

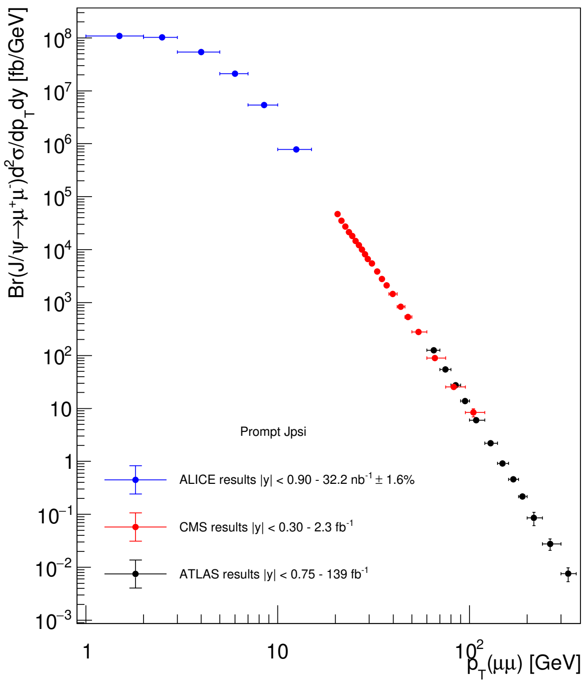


Figure 4: Comparison of the differential cross-section of prompt J/ψ production measured by ATLAS in the central rapidity range with the CMS [5] and ALICE [6] result in the closest-matching rapidity range [4].

The results for non-prompt production of J/ψ are compared with the predictions of the FONLL model with default set of parameters, see Figure 2(b). These predictions are consistent with this measurement at the low end of the p_T range, but overestimate data at high p_T.

5. Acknowledgments

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