



# First measurement of associated vector boson plus prompt charmonium production at the ATLAS experiment

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## Abstract

The associated production of vector boson + prompt  $J/\psi$  is a key observable for understanding of quarkonium production mechanisms. Here we present the first evidence of such process and the measurement of its production rate. Relative contributions to the signal from single and double parton scattering are estimated and possible implications of this novel final state for studying multiple parton interactions are discussed. Finally, we compare Single parton scattering cross-sections to cutting-edge theoretical calculations in the colour singlet and colour octet formalisms.

*Keywords:* Hadron-hadron scattering, vector boson, charmonium, associated production

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## 1. Introduction

Contributions of colour singlet (CS) and colour octet (CO) processes to the inclusive  $J/\psi$  production is still unclear [1, 2]. The associated production of the  $W^\pm$  boson with a  $J/\psi$  filters out different initial states compared to those participated in the inclusive  $J/\psi$  production. This makes the associated production of  $W^\pm + J/\psi$  ideal for studying the CS and CO models. Two processes contribute to the associated production of  $W^\pm + J/\psi$ . The first one is the single parton scattering (SPS) and the second is the double parton scattering (DPS). In SPS, the  $W^\pm$  and the  $J/\psi$  are produced from the same pair of partons and, in DPS, two different pairs of partons interact and produce the  $W^\pm$  and  $J/\psi$  particles.

The first measurement of the associated production of  $W^\pm(\rightarrow \mu^\pm \nu_\mu)$  + prompt  $J/\psi(\rightarrow \mu^+ \mu^-)$  [3] is presented, using data collected with the ATLAS experiment

[4] during the 2011  $pp$  run of the Large Hadron Collider (LHC) [5] at centre of mass energy of 7 TeV.

## 2. The ATLAS detector

ATLAS detector is a multi-purpose detector at the LHC. During 2011 ATLAS recorded  $4.5 \text{ fb}^{-1}$  of physics data from  $pp$  collisions at  $\sqrt{s} = 7 \text{ TeV}$ . The inner detector (ID) of ATLAS performs tracking of charged particles for  $|\eta| < 2.5$  and is inside a solenoidal magnet that provides an axial field of 2 T. Muon system (MS) covers a range of  $|\eta| < 2.7$ . A system of air coil toroidal magnets provide a bending integral of 2.5 Tm in the barrel and 6 Tm in the endcaps. The combination of the ID and MS can reconstruct muons with  $p_T \geq 2.5 \text{ GeV}$  with resolution  $\sigma(p_T)/p_T$  better than 3% (in the momentum range used in this analysis). Muon detectors are also used to trigger on high transverse momentum muons.

## 3. Event selection

The  $J/\psi$  is reconstructed requiring muons to have  $p_T > 3.5 (2.5) \text{ GeV}$  for  $|\eta| < 1.3 (> 1.3)$ , both to have

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\*on behalf of the ATLAS collaboration

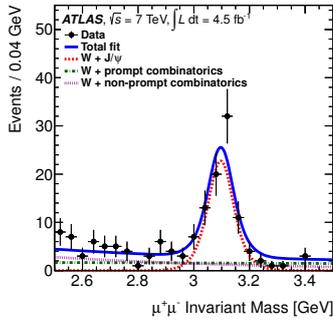
Email address: [Stefanos.Leontsinis@cern.ch](mailto:Stefanos.Leontsinis@cern.ch)  
(S. Leontsinis)



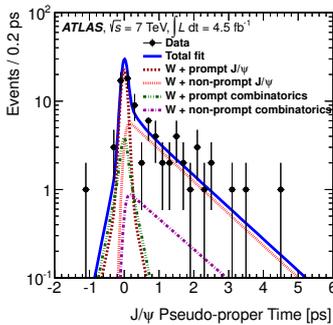
$|\eta| < 2.5$ , to originate at a common point and at least one of them to have  $p_T > 4 \text{ GeV}$ . The invariant mass of the dimuon system must be within  $2.5 < m_{\mu^+\mu^-} < 3.5 \text{ GeV}$ . To establish high acceptance and efficiency, the rapidity of the  $J/\psi$  is required to be  $|y^{J/\psi}| < 2.1$  and its transverse momentum to be  $8.5 < p_T^{J/\psi} < 30 \text{ GeV}$ , to improve the signal to background ratio.

The  $W^\pm$  muon is required to match the muon fired the high  $p_T$  single muon trigger, have  $p_T > 25 \text{ GeV}$  and  $|\eta| < 2.4$ . The transverse energy-momentum imbalance measured in the detector must satisfy  $E_T^{\text{miss}} > 20 \text{ GeV}$  and the transverse mass of the  $W^\pm$  needs to be  $m_T^W > 40 \text{ GeV}$ .

Events with two oppositely charged muons and invariant mass within  $10 \text{ GeV}$  of the  $Z$  boson mass are rejected. Applying the selections described above, 149 events are left.



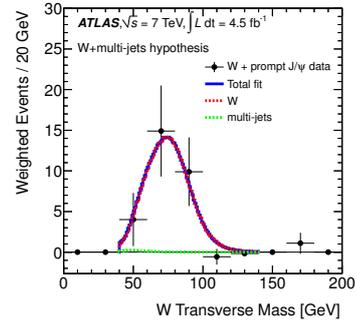
(a)



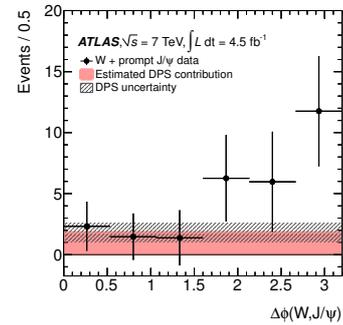
(b)

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 prompt  $J/\psi$  candidates in the full rapidity region ( $|y_{J/\psi}| < 2.1$ ). The pseudo-proper time distribution is shown for the  $J/\psi$  mass peak region ( $3.0 < m(\mu^+\mu^-) < 3.2 \text{ GeV}$ ).

Signal  $J/\psi$  events are separated from combinatorial background events and non prompt  $J/\psi$  by a 2D max-



(a)



(b)

Figure 2: (a) The sPlot-weighted  $W^\pm$  boson transverse mass distribution and (b) The sPlot-weighted azimuthal angle between the  $W^\pm$  and the  $J/\psi$ , shown for  $W^\pm +$  prompt  $J/\psi$  candidates.

imum likelihood fit in mass and pseudo-proper time (Figure 1).  $29.2^{+7.5}_{-6.5}$   $W^\pm +$  prompt  $J/\psi$  events are found. Events that may have been produced in different proton-proton collisions but in the same bunch crossing (pileup) are estimated to be  $1.8 \pm 0.2$ . Using the extracted prompt  $J/\psi$  yield, per event weights are produced [6]. Applying these weights to the dataset, the  $m_T^W$  distribution for events that are associated with the prompt  $J/\psi$  is obtained. The weighted  $m_T^W$  distribution (Figure 2a) is fitted with a multijet plus signal  $W^\pm$  templates. The  $W^\pm$  signal hypothesis is strongly supported and an estimation of  $0.1 \pm 4.6$  of multijet events is calculated.

#### 4. Double parton scattering

$W^\pm$  and  $J/\psi$  can be produced from the scattering of two different pairs of partons in the same proton-proton collision. The probability that an extra  $J/\psi$  is produced additionally to the production of the  $W^\pm$  is parameterised as  $P_{J/\psi|W^\pm} = \sigma_{J/\psi} / \sigma_{\text{eff}}$ , with  $\sigma_{\text{eff}}$  be-

ing the effective cross section parameter and is measured by ATLAS using  $W^\pm \rightarrow l\nu + 2$  jet events to be  $\sigma_{\text{eff}} = 15 \pm 3(\text{stat.})_{-3}^{+5}$  mb [7]. ATLAS measurement [8] is used for computing the  $\sigma_{J/\psi}$ , corrected for the fiducial phase space of this analysis. The estimation of the total number of DPS events is  $10.8 \pm 4.2$ . These events are distributed uniformly along the azimuthal angle between the  $W^\pm$  and the  $J/\psi$ , assuming that the two interactions are independent. Figure 2b shows the  $\Delta\phi(W, J/\psi)$  distribution weighted by the prompt  $J/\psi$  yield. The peaking structure at  $\pi$ , on top of the flat DPS component, reveals an indication of SPS.

## 5. Results

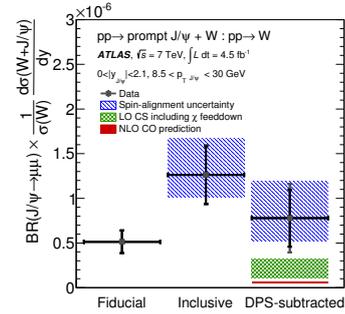
ATLAS collaboration observed for the first time the associated production of  $W^\pm +$  prompt  $J/\psi$  with a  $5.1\sigma$  significance and measured the cross-section ratio of  $W^\pm + J/\psi$  to inclusive  $W^\pm$  (Figure 3a). The fiducial cross-section ratio of  $W^\pm +$  prompt  $J/\psi$  relative to inclusive  $W^\pm$  is measured to be  $R_{J/\psi}^{\text{fid}} = (51 \pm 13(\text{stat.}) \pm 4(\text{syst.})) \times 10^{-8}$ . The acceptance-corrected observed ratio is  $R_{J/\psi}^{\text{incl}} = (126 \pm 32(\text{stat.}) \pm 9(\text{syst.})_{-25}^{+41}) \times 10^{-8}$  with the last uncertainty representing possible variation due to the unknown spin-alignment. Subtracting the DPS contribution, the SPS rate  $R_{J/\psi}^{\text{DPS sub}} = (78 \pm 32(\text{stat.}) \pm 22(\text{syst.})_{-25}^{+41}) \times 10^{-8}$  is extracted. The last bin also presents LO CS and NLO CO calculations for SPS production [9, 10].

Figure 3b shows the differential cross section ratio  $dR_{J/\psi}^{\text{incl}}/dp_T$  as a function of the  $J/\psi$  transverse momentum. The DPS contribution is overlaid and the measurement indicates a large SPS contribution in the low  $p_T^{J/\psi}$  bin.

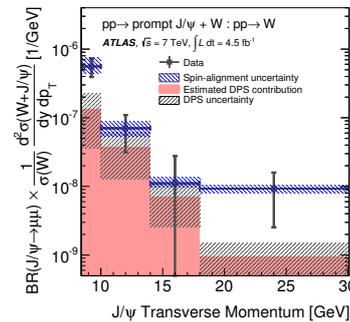
Analysis of the data collected during 2012 could allow us to measure the relative fraction of SPS and DPS production. In addition, the  $W^\pm + J/\psi$  process can be used to study Higgs decays to charmonia and physics beyond the standard model[11].

### Acknowledgements

I would like to thank Stamatis Leontsinis for his continuous support and encouragement. This research has been co-financed by the European Union (European Social Fund - ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: **THALES**. Investing in knowledge society through the European Social Fund.



(a)



(b)

Figure 3: (a) The  $W^\pm +$  prompt  $J/\psi$  :  $W^\pm$  production cross-section ratio in the  $J/\psi$  fiducial region, after correction for  $J/\psi$  acceptance, and after subtraction of the double parton scattering component. (b) The inclusive (SPS+DPS) cross-section ratio  $dR_{J/\psi}^{\text{incl}}/dp_T$  as a function of  $p_T^{J/\psi}$ .

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