The charmonium and beauty physics programme in ATLAS

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The first $J/\psi \rightarrow \mu^+\mu^-$ signal in the ATLAS detector, from 7 TeV proton-proton collisions in the LHC, with integrated luminosity of 6.4 nb^{-1} was extracted and analysed. The reconstructed invariant mass agrees with the PDG value within statistical uncertainties, whilst the peak width is compatible with Monte Carlo expectations. The kinematic properties of the J/ψ candidates are presented. Two examples of future B-physics measurements are given. First, lifetime determinations are shown, in preparation for future high precision CPV measurements, second, the expected ATLAS sensitivity for rare decay $B_s \rightarrow \mu^+\mu^-$ is reported.

1. INTRODUCTION

The ATLAS B-physics programme covers multiple aspects of beauty flavour physics. Measuring production cross sections of the heavy flavour quarkonia, J/ψ and Υ and of beauty and charm hadrons will test QCD in central proton - proton collisions at the Large Hadron Collider (LHC) [1] . Furthermore, ATLAS will study the properties of the entire family of B-mesons B^0, B^+, B_s, B_c and B-baryons, and thereby broaden our knowledge of the spectroscopic and dynamical aspects of B-physics. The main emphasis will be on precision measurements of weak B-hadron decays where, thanks to the large beauty production cross section and the high luminosity of the machine, the sensitivity of measurements is expected to improve the existing values. Analysing properties of reconstructed J/ψ resonance in ATLAS with early LHC data is a crucial step both for understanding the detector performance and for performing further measurements of various B-physics channels at LHC.

In this paper we present the first studies on the J/ψ resonance in the di-muon decay channel with the ATLAS detector using data collected in $\sqrt{s} =$ 7 TeV proton-proton collisions between the end of March and early May 2010, corresponding to an integrated luminosity of approximately 6.4 nb^{-1}. Section 2 gives a brief overview of the ATLAS detector and trigger and section 3 presents results on the J/ψ signal. Finally we present two Monte Carlo based studies representing typical examples of the B-physics progamme.

2. THE ATLAS DETECTOR, TRIGGER AND MUON RECONSTRUCTION

The ATLAS detector [2] covers almost the full solid angle around the collision point with layers of tracking detectors, calorimeters and muon chambers. For the measurements presented in this paper the trigger system, the Inner Detector tracking devices (ID) and the Muon Spectrometer (MS) were of particular importance. The ATLAS ID covers the pseudorapidities $|\eta| < 2.5$. It consists of a silicon Pixel detector (Pixel), a silicon strip detector (SCT) and a Transition Radiation Tracker (TRT) immersed in a 2 Tesla solenoid magnetic field. The ATLAS Muon Spectrometer [3] detects tracks over a region of $|\eta| <2.7$. It consists of a large toroidal magnet (with an average magnetic field of 0.5 Tesla) and comprises four detector technologies. It has one Barrel Region (B) and two End-cap Regions (E). Monitored Drift Tube chambers (MDT) in both the B and E sections and Cathode Strip Chambers (CSC) in the forward region of E ($|\eta| < 2$) are used as precision chambers, whereas Resistive Plate Chambers (RPC) in the B and Thin Gap Chambers (TGC) in the E are used as trigger chambers. For the J/ψ measurements presented in this paper, the trigger relies on the Minimum Bias Trigger Scintillators (MBTS), mounted at each end of the detector in front of the Liquid Argon Endcap-Calorimeter cryostats. The MBTS trigger required two hits on either sides of the detector. A dedicated muon software trigger commissioning chain was required to confirm the candidate events by finding at least one muon track in the entire Muon Spectrometer.

Two categories of reconstructed muons were selected for the current study. Muons from combined reconstruction relying on a statistical combination of track parameters of both MS track and an ID track. Second, tagged muons, formed by MS segments which are matched to ID tracks extrapolated to the MS. For the evaluation of the mass, the parameters of the ID tracks associated with the muons were used.

3. RECONSTRUCTION AND PROPERTIES OF THE FIRST $J/\psi \to \mu^+\mu^-$ SIGNAL

3.1. Event and candidate selection

To ensure that collision events were selected, events passing the trigger selection were required to have at least three tracks associated with the same reconstructed primary vertex. In each surviving event, pairs of reconstructed muons were sought. Only muons associated with ID tracks that had at least one hit in the pixels and six in the SCT were admitted. The two ID tracks from each pair of muons were fitted to a common vertex using the ATLAS offline vertexing tools based on the Kalman filtering method [4]. A very loose requirement on the quality of the vertex fit was imposed ($\chi^2 < 200$). Cuts in this analysis were not optimized to reject backgrounds, since the aim of this study is to understand the shape of the low p_{T} combinatorial background. Monte Carlo (MC) comparisons were made using samples generated with PYTHIA 6 [5], tuned using the ATLAS MC09 tune [6] and MRST LO* [7] parton distribution functions. The NRQCD Colour Octet Mechanism framework, tuned to describe Tevatron results [8] was used for the prompt J/ψ. Zero polarisation was assumed in J/ψ dimuon decays.

3.2. J/ψ Mass signal

Once the vertex fit was applied, the refitted track parameters and error matrices were used to calculate the invariant mass and per-candidate mass error. An unbinned maximum-likelihood fit was used to extract the J/ψ mass and the number of J/ψ signal candidates from the data. The likelihood function is defined by:

$$L = \prod_{i=1}^{N} f_{signal}(m^i_{\mu\mu}) + f_{bkg}(m^i_{\mu\mu}) \quad (1)$$

where N is the total number of pairs of oppositely charged muons in the invariant mass range $2 < m_{\mu\mu} < 4$ GeV$/c^2$. The f_{signal} and f_{bkg} are probability density functions that model the J/ψ signal and background mass shapes in this range and a_0 is the fraction of pairs originating from J/ψ decay. For the signal, the mass was modelled with a Gaussian distribution:

$$f_{signal}(m_{\mu\mu}) \equiv a_0 \frac{1}{\sqrt{2\pi}\ S\delta m_{\mu\mu}} e^{\frac{-(m_{\mu\mu}-m_{J/\psi})^2}{2(S\delta m_{\mu\mu})^2}} \quad (2)$$

whose mean value $m_{J/\psi}$ is the J/ψ mass and its width is a product $S\delta m_{\mu\mu}$, where a scale factor S is a parameter of the fit and $\delta m_{\mu\mu}$ is the measured mass error. For the background, the mass distribution is assumed to follow a flat function:

$$f_{bkg}(m_{\mu\mu}) \equiv (1 - a_0) \quad (3)$$

The fit returns values of the free parameters a_0, $m_{J/\psi}$ and S and a covariance matrix of the fit. They are used to calculate the number of J/ψ signal decays N_{sig}, the mass resolution σ_m and the number of background events N_{bck} in the mass interval $m_{J/\psi} \pm 3\sigma_m$. The same fit procedure was applied to the prompt J/ψ MC events, in this case $f_{bkg}(m_{\mu\mu}) \equiv 0$.

In Figure 1 the invariant mass is shown and the results of the fit are summarised in Table 1. No systematic errors are considered in the current study. The J/ψ mass returned by the fit is 3.095 GeV$/c^2$with the error of 4 MeV$/c^2$. The number of J/ψ signal decays is $N_{sig} = 612 \pm 34$, the mass resolution of J/ψ signal is $\sigma_m = 82 \pm 7$ MeV$/c^2$ and the number of background pairs in the mass range corresponding to $m_{J/\psi} \pm 3\sigma_m$ is $N_{bck} = 332 \pm 9$. The invariant mass resolution depends on the pseudorapidities of the two muon tracks. To illustrate this effect all accepted J/ψ candidates are divided into the three classes: both muons in the barrel detector (BB), that is, in $|\eta| < 1.05$; both muons in the endcap (EE), that is, in $1.05 < |\eta| < 2.5$ and one muon in the barrel and one in the endcap (EB). The results of fits are summarised in Table 1. As expected, due to material effects, the mass width when both muons are in the endcap region is $\sim$2.5 times greater than when both muons are in the barrel. This behaviour is also well reproduced in the MC. The J/ψ mass determined from data agrees with the PDG mass within the statistical precision. No statistically significant mass shifts from the PDG value are observed in any of the pseudorapidity regions.

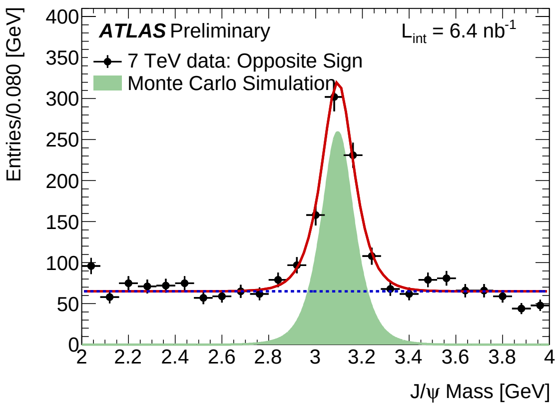

Figure 1. Invariant mass of $J/\psi \to \mu^+\mu^-$ candidates. The solid line illustrates the result of the maximum likelihood fit to all dimuon pairs in the mass window 2–4 GeV/c^2, the dashed lines is the result for background only in the same fit. The solid area represents the MC prediction, from prompt J/ψ.

3.3. Kinematic distributions of the J/ψ candidates

The kinematic properties of the candidates in the J/ψ mass region 2.86 GeV/c^2- 3.34 GeV/$c^2$are shown in Figure 2. A comparison with MC (for both prompt J/ψ and minimum bias simulation) is also shown in the same figure. As can be seen we have access at the lowest possible J/ψ p_{T} which in turn is a result of the muon acceptance of the ATLAS detector without any threshold requirement on the muon trigger. The observed J/ψ distributions are fairly well described by MC.

4. ATLAS B-PHYSICS PROGRAM

Two studies, based on MC at 14 TeV, are selected in this paper as examples of the future B-physics programme. Details on both can be found in [9]. When luminosity of few tens to hundreds of pb^{-1} will be accumulated, series of B hadron lifetime measurements will be performed. In particular, using the decay $B_d \to J/\psi K^{0*}$ the B^0 lifetime can be determined with a relative statistical error of 10%, with an integrated luminosity of 10 pb^{-1}. The same precision is expected for

Table 1
Summary of fit results to mass distributions of $J/\psi \to \mu^+\mu^-$ candidates.

	m MeV/c^2	σ_m MeV/c^2	N_{sig}	N_{bck}
all				
data	3095 ± 4	82 ± 7	612 ± 34	332 ± 9
MC	3098 ± 1	63 ± 0.3		
BB				
data	3097 ± 5	36 ± 6	69 ± 9	8 ± 1
MC	3098 ± 1	36 ± 0.6		
EB				
data	3089 ± 8	66 ± 12	88 ± 11	34 ± 3
MC	3097 ± 1	51 ± 0.7		
EE				
data	3095 ± 6	88 ± 9	437 ± 31	324 ± 10
MC	3098 ± 1	75 ± 0.4		

the B_s lifetime in $B_s \to J/\psi\phi$ with 150 pb^{-1}. The method is based on a simultaneous fit to masses and proper decay times of signal and background events. The expected distributions for $B_s \to J/\psi\phi$ case are shown in Figure 3. Precise lifetime measurements provide, at first, the means to test Inner Detector performance and alignment and lead the way for precision measurements on CP violation in the $B_s \to J/\psi\phi$ decay, which is potentially sensitive to New Physics.

Thanks to the large beauty production cross section and the high luminosity of the LHC machine, ATLAS will contribute to measurements of a rare decay $B_s \to \mu^+\mu^-$. It is important that with the first real data the performance analyses made with J/ψ signal has shown that the dimuon performance of ATLAS detector is consistent with MC expectations. The MC based study of $B_s \to \mu^+\mu^-$ measurement was performed at conditions and trigger menu corresponding to instantaneous luminosity 10^{33} cm^{-2} s^{-1}. With 10 fb^{-1} ATLAS will be able to select 5.7 signal events, assuming the Standard Model value for the $B_s \to \mu^+\mu^-$ decay probability. Number of 14^{+13}_{-10} background events is expected, consisting predominantly of beauty decays, where the dimuon candidates originate either from semileptonic decays of b and $\bar{b}$ quarks or from cascade decays of one of the b, $\bar{b}$ quarks. The errors

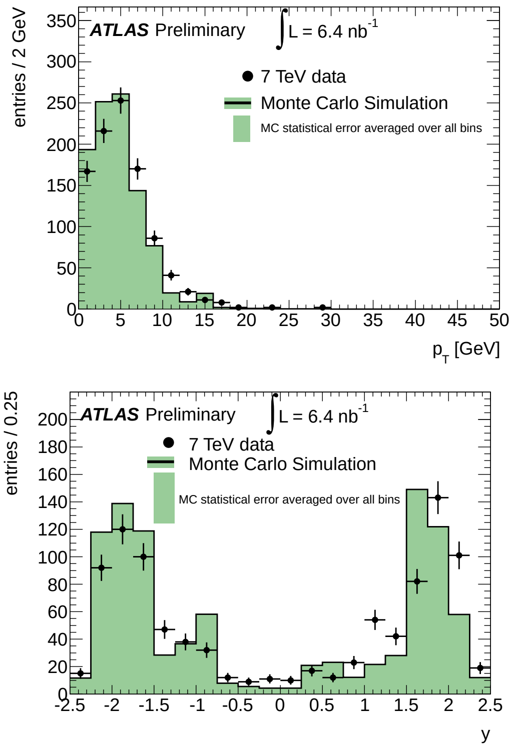

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Figure 2. Transverse momentum *(up)* and rapidity *(down)* distributions of the J/ψ candidates in the mass range $m_{J/\psi} \pm 3\sigma_m$. MC distributions from both prompt J/ψ and minimum bias simulation are superimposed for comparison.

were dominated by limited statistics of simulated events. Contributions from other backgrounds: $B_s \to K^-\mu^+\nu$, $B_d \to K^-\pi^+$ and $B_d \to \pi^-\pi^+$ are expected to be negligible.

5. SUMMARY AND CONCLUSIONS

With an integrated luminosity of $6.4 \pm 1.3\text{nb}^{-1}$ ATLAS reconstructed 234 ± 22 $J/\psi \to \mu\mu$ decays over a background of 128 ± 7 candidates. The extracted mass of 3.099 ± 0.007 GeV/c^2, is consistent with the PDG value within statistical uncertainty. The signal mass resolution varies with the pseudorapidity of the muons in correspondence with Monte Carlo simulations. This validation of the detector performance in di-muon events is an important step on a way towards future measurements, in particular of the rare decay $B_s \to \mu^+\mu^-$, in ATLAS.

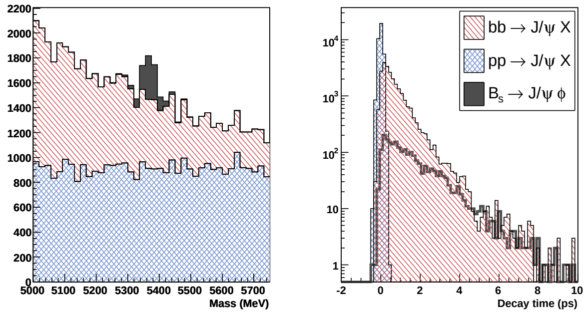

Figure 3. MC based study, signal channel $B_s \to J/\psi\phi$: the distributions of the reconstructed B_s mass (left) and decay time (right) expected with 150 pb^{-1}.

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