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Heavy flavours in ATLAS

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Summary. — The ATLAS experiment has an intensive flavour physics program. The signals for various charms state have been identified. The J/ψ prompt and non-prompt production cross-section has been determined allowing comparisons with various theoretical predictions in a kinematic regime not previously accessed. Exclusive B- and D-meson states have been reconstructed.

PACS 14.40.Pq – Heavy quarkonia.
PACS 14.20.Lb – Charmed baryons ($|C| > 0$, $B = 0$).

1. – Introduction

ATLAS [1] is a multipurpose detector operating at the LHC at CERN. During 2010 ATLAS has recorded $41\,\text{pb}^{-1}$ of data from proton-proton (pp) collisions with a centre of mass energy $\sqrt{s} = 7\,\text{TeV}$ and with a data-taking efficiency of about 95%. ATLAS excellent tracking and muon systems makes it well suited for heavy flavour analysis. Charmonia exclusive final states can be used as reference signals for commissioning and for studying the detector performance. In addition, heavy flavuor studies provide important insight into the production mechanism at these energies in order to test various theoretical predictions. Moreover they are also background to other rare and interesting processes and simulating them accurately is crucial for discovery.

2. – J/ψ observation and cross section measurement

The J/ψ can be produced via two mechanisms: prompt production in the pp collisions or in the feed-down of heavier charmonium states and J/ψ production from the decay of b-hadrons created in the collision. The selection is based on the requirement of 2 opposite sign muons with transverse momentum $p_T > 4\,\text{GeV}$ and $p_T > 2.5\,\text{GeV}$ coming from the same vertex. Figure 1 plot a) shows the di-muon spectrum in the mass ranges 2–4 GeV using $41\,\text{pb}^{-1}$ of data recorded in the 2010. The J/ψ peaks is clearly visible as

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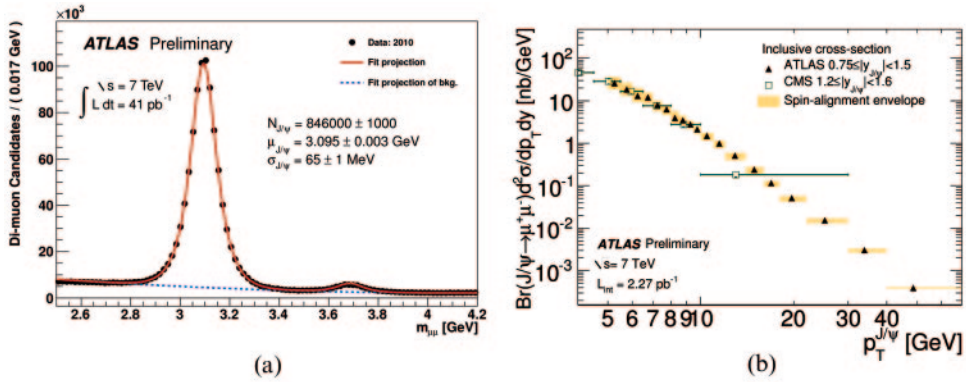

Fig. 1. – a) Invariant mass of opposite sign di-muon pairs in the range 2–4 GeV; b) Inclusive J/ψ production cross section as a function of J/ψ p_T in the $0.75 < |y| < 1.5$ rapidity bin.

well as the smaller ψ' peak. Using the J/ψ signal identified as described above, ATLAS has derived the doubly differential cross section in bins of rapidity $|y|$ and p_T [2]. This measurement require the determination of the true number of J/ψ decays, that imply a well understood and unbiased trigger selection. For this reason the selection has been applied on low luminosity data ($2.3\,\text{pb}^{-1}$) asking for single muon triggers. Corrections for detector efficiency and acceptance effects have also to be taken into account:

– the kinematic acceptance depends strongly on the spin alignment (polarisation) of J/ψ, this has not been yet measured at LHC. Full range of spin alignments have been studied, and 5 extreme cases were identified in determining the associated systematic uncertainties;

– the offline single muon reconstruction efficiencies are obtained from data using tag-and-probe method [3]. Trigger efficiencies are also obtained from data, the required fine binning, not available with the reduced statistics, has been obtained using MC predictions reweighted to the measured values with data.

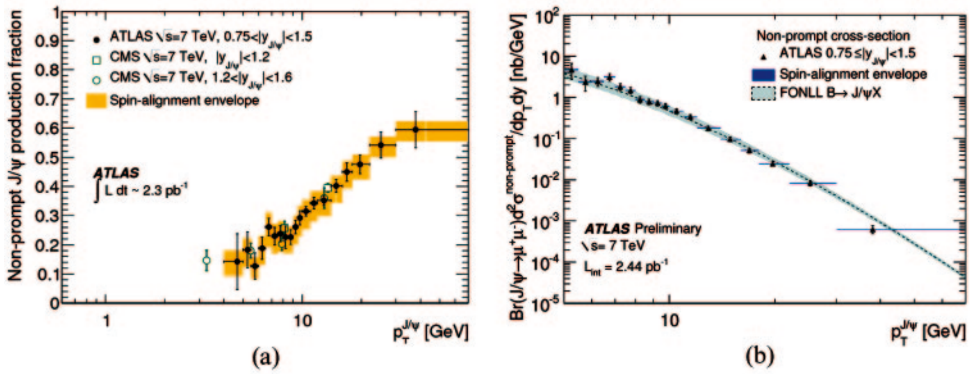

Fig. 2. – a) J/ψ non-prompt to inclusive fractions as a function of J/ψ p_T. The equivalent results from CMS and CDF are included; b) Non-prompt J/ψ production cross section as a function of J/ψ p_T, compared to theoretical predictions. In both plots the band represents the variation of the result under spin-alignment variation.

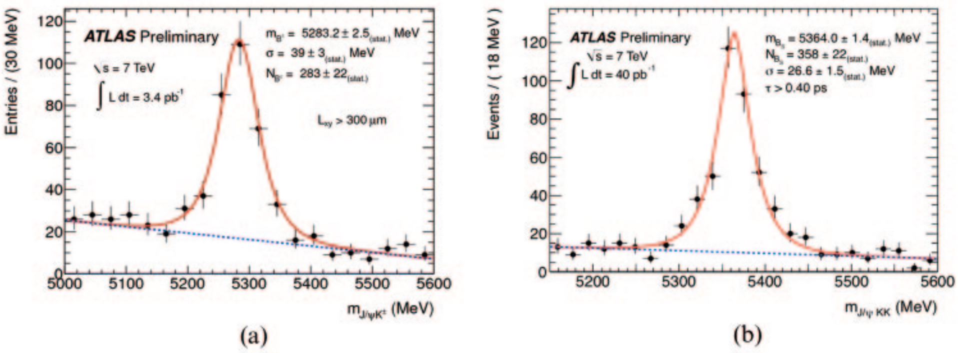

Fig. 3. – a) Invariant mass distribution of reconstructed $B^{\pm} \to J/\psi K^{\pm}$ candidates. The points are data, the solid line is the fit to all $J/\psi K^{\pm}$ candidates in the mass range 5000–5600 MeV and the dashed line is the background component of the same fit; b) Invariant mass distribution of $B_s^0 \to J/\psi\phi$ candidates. The points are data, the solid line is the fit to all $J/\psi(\mu^+\mu^-)\phi(KK)$ candidates and the dashed line is the background.

A second measurement involves the production fraction of non-prompt J/ψ, almost coming from B-hadron decays. The prompt decays occur very close to the interaction vertex so the non-prompt component may be distinguished by their pseudo decay length. This measurement has the advantage that many systematic effects cancel. For both measurements the J/ψ yields are extracted from data using an unbinned maximum likelihood fit to the mass spectra in bins of $|y|$ and p_T. The yields are translated into cross sections using a per-event weightening procedure that take into account the detector acceptance, reconstruction and trigger efficiencies. Flat spin-alignment hypothesis has been chosen and the maximum deviation to the other spin-alignment point taken as the systematic uncertainties. In fig. 1 plot b) the inclusive cross section for one of the rapidity bin is shown. The equivalent results for CMS are overloaded. They are in good agreement in the overlap region. The procedure for the non-prompt fraction uses both mass and pseudo-proper time to extract the ratio in p_T and $|y|$. In fig. 2 plot a) J/ψ non-prompt to

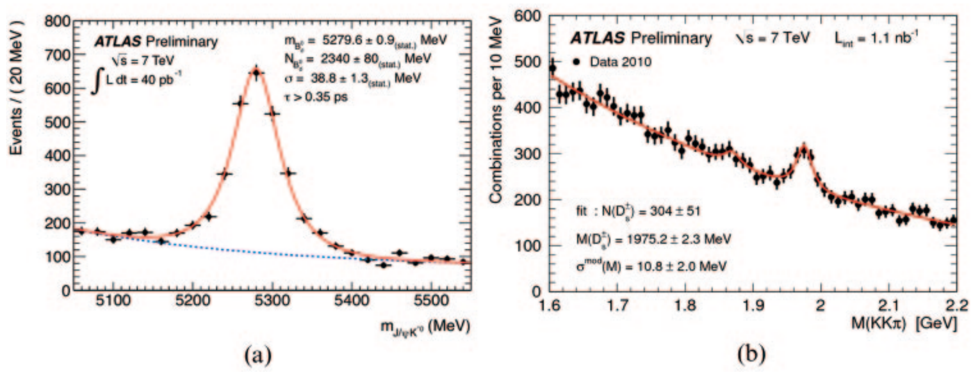

Fig. 4. – a) Invariant mass distribution of $B_d^0 \to J/\psi K^{*0}$ candidates; b) The $M(KK\pi)$ distribution for the $D_s^{\pm}$ candidates (points).

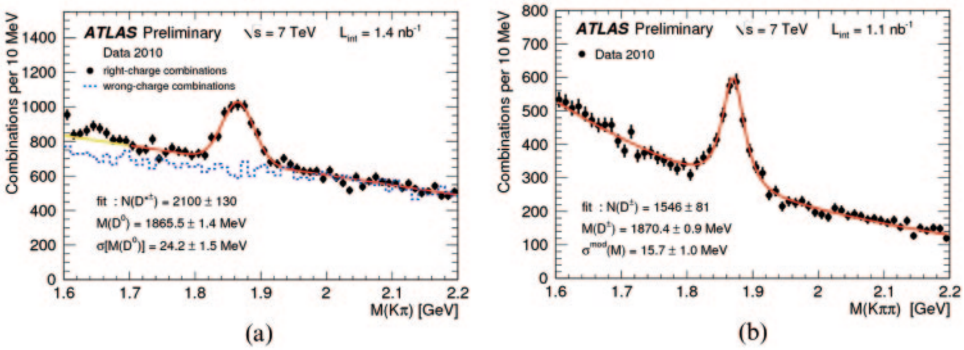

Fig. 5. – a) The distribution of the $M(K\pi)$ distribution for the $D^{*\pm}$ candidates (points); b) the $M(K\pi\pi)$ distribution for the $D^{\pm}$ candidates (points).

inclusive fractions with respect to J/ψ p_T is shown. Overlaid is a band representing the variation of the result under various spin-alignment scenarios representing a theoretical uncertainty on the prompt and non-prompt J/ψ components. The measurements made by ATLAS and CMS are in good agreement with each other and with CDF, thus suggesting independence of the ratio from the center of mass energy. Combining these two measurements the prompt and the non-prompt cross section can be derived as shown in fig. 2 plot b) where the non-prompt J/ψ production cross section as a function of J/ψ p_T, compared to theoretical predictions, is shown. The band represents the variation of the result under spin-alignment variation on the non-prompt J/ψ component.

3. – B meson decays with a J/ψ in the final state

$B^{\pm} \to J/\psi K^{\pm}$ production Charged B meson arising from $b\bar{b}$ pair can be reconstructed for both charged states in the $B^{\pm} \to J/\psi K^{\pm}$ decay, when the J/ψ dacays in a di-muon final state. This channel is a reference for a variety of high-precision B-physics measurements, such as the branching ratio of the rare B-decay $B_s \to \mu^+\mu^-$. The selection requires 2 opposite sign muons in the J/ψ mass range (2915–3275 MeV) and a third track which is assigned to the kaon mass [4]. A cut on the lifetime properties $L_{xy} > 300\,\mu$m has been applied to reduce the background contamination. A clear signal (fig. 3 plot a)) is observed with $3\,\text{pb}^{-1}$ of data. The $B^{\pm}$ mass measured is consistent with the PDG value.

B_s^0 and B_d^0

The B_s^0 and B_d^0 mesons arising from $b\bar{b}$ pairs produced in LHC pp collisions can be reconstructed from their exclusive decay modes $B_d^0 \to J/\psi K^{*0}$ and $B_s^0 \to J/\psi\phi$ using the J/ψ decay to a di-muon final state. These decays have been investigated in preparation for future studies involving CP violation. B_d^0 and B_s have been observed and the mass measured are consistent with PDG values [5]. In fig. 3 plot b) and 4 plot a) the invariant mass distributions of reconstructed $B_s^0 \to J/\psi\phi$ and $B_d^0 \to J/\psi K^{*0}$ are shown respectively.

4. – D-production studies

Due to the large cross section of $c\bar{c}$ and $b\bar{b}$ values and clean D^* meson signatures, reconstruction of charm mesons is already feasible with first LHC data. Clean $D^{*\pm}$, $D^{\pm}$ and D_s^+ signals have been reconstructed with the ATLAS detector with $1.4\,\text{nb}^{-1}$ of integrated luminosity. In all the cases the fitted mass values are found to be in agreement with their PDG world averages while the observed invariant mass resolution agrees with MC expectations [6].

Reconstruction of $D_s^{\pm}$ mesons
$D_s^{\pm}$ mesons are reconstructed from the decay $D_s^{\pm} \to \phi\pi^+$ with $\phi \to K^+K^-$. In each event, tracks with opposite charges are assigned the kaon mass and combined in pairs to form ϕ candidates. The ϕ candidate is kept if its invariant mass, $M(KK)$, is within $\pm 6\,\text{MeV}$ of the ϕ mass. Any additional track is assigned the pion mass and combined with the ϕ candidate to form a $D_s^{\pm}$ candidate with invariant mass $M(KK\pi)$. Figure 4 plot b) shows the $M(KK\pi)$ distribution for the $D_s^{\pm}$ candidates. A clear signal is seen at the nominal value of $M(D_s^+)$.

Reconstruction of $D^{*\pm}$
$D^{*\pm}$ mesons are identified using the decay channel $D^{*+} \to D^0\pi^+ \to (K^-\pi^+)\pi^+$. In each event, pairs of oppositely-charged tracks are assigned to $K\pi$ system and refitted to a common vertex. Any additional track, with $p_T > 0.25\,\text{GeV}$ and a charge opposite to that of the kaon track, is assigned the pion mass and combined with the D^0 candidate to form a D^{*+} candidate. Figure 5 plot a) shows the $M(K\pi)$ distribution for the $D^{*\pm}$ candidates. A clear signal is seen at the nominal value of $M(D^0)$.

Reconstruction of $D^{\pm}$ mesons
$D^{\pm}$ mesons are reconstructed from the decay $D^+ \to K^-\pi^+\pi^+$. In each event, two same-charge tracks are combined with a track of the opposite charge to form a $D^{\pm}$ candidate. A pion candidate is reconstructed from the two tracks with the same charge and the kaon mass is assigned to the third track, after which the candidate invariant mass, $M(K\pi\pi)$, is calculated. Figure 5 plot b) shows the $M(K\pi\pi)$ distribution for the $D^{\pm}$ candidates. A clear signal is seen at the nominal value of D^+ mass.

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