Heavy Hadron Production and Spectroscopy at ATLAS

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ATLAS has studied heavy flavor production and measured the production cross sections of heavy quarkonium, open bottom and charm in $\sqrt{s}$=7 TeV proton-proton collisions at the Large Hadron Collider. Differential cross sections as a function of transverse momentum and pseudo-rapidity are hereby discussed. ATLAS capabilities to reconstruct heavy quarkonium states, D-mesons and B-hadrons in exclusive decay modes are demonstrated.

1 Introduction

ATLAS (A Toroidal LHC ApparatuS) is a general purpose experiment operating at the Large Hadron Collider at CERN. Its research program is mainly focused on the investigation of processes beyond the Standard Model, but includes also a wide set of flavor physics studies with early data. Heavy flavor processes provide valuable samples to measure detector performance, based on the reconstruction of known particles with c and b quark content. Once this is established, measurements of production cross sections for open beauty and charm and heavy quarkonium states allow to test QCD predictions for proton-proton collisions at $\sqrt{s}$ = 7 TeV.
After a brief description of the relevant ATLAS detector and reconstruction components, results on inclusive $J/\psi \to \mu^+\mu^-$ production and on the study of exclusive B and D hadron decays are reported.

2 ATLAS tracking and trigger systems

The main ingredients for flavor physics studies are the reconstruction of charged particles and the identification of muons produced in the pp collisions. For this purpose, the ATLAS detector [1] is equipped with two main tracking systems.
The Inner Detector (ID), placed in the immediate proximity of the beam line and surrounded by a solenoidal magnet providing a 2 T field, measures charged particle tracks in a pseudo-rapidity range of $|\eta| < 2.5$. Adopting three different detector technologies (pixel sensors, silicon strips and straw tubes) it reaches an overall design momentum precision of $\sigma_{p_T}/p_T = 3.4\times10^{-4} \cdot p_T/\text{GeV} \oplus 0.015$.

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The Muon Spectrometer (MS), the outermost ATLAS detector, covers a range of $|\eta| < 2.7$, adopting four detector technologies suitable for both triggering and tracking purposes (monitored drift tubes, cathode strip chambers, thin-gap chambers and resistive plate chambers). Exploiting the field generated by an air-core toroidal magnet, it is designed to measure transverse momenta with $\sim$3% precision over most of the p_T range and below 10% up to 1 TeV.
The muon reconstruction is performed matching tracks or track segments in the MS and ID, combining them to form a full muon track and refitting its track parameters.
Another crucial ingredient for any physics study is the trigger system, selecting a few relevant events out of a vast majority of uninteresting pp collisions. The ATLAS trigger consists of a first hardware level, mainly based on MS and calorimeters, and two subsequent software levels, accessing data from the entire detector to refine the first level selection.
The results presented in the following use two different trigger selections. Studies based on the reconstruction of $J/\psi \rightarrow \mu^+\mu^-$ decays rely on single muon triggers, with different p_T thresholds for different luminosities. The D meson studies are instead performed on events selected by minimum bias triggers, based on scintillators mounted at each end of the ID or on the measurement of tracking activity in randomly triggered events.

3 Inclusive J/ψ cross section measurement

Charmonium states decaying into muon pairs have been studied both to evaluate the ATLAS detector performance and to measure their production properties.
The analysis of $J/\psi \rightarrow \mu^+\mu^-$ decays [2], based on an integrated luminosity of 2.3 pb^{-1}, measures the inclusive J/ψ production cross section and the fractions of prompt and non-prompt components. Pairs of reconstructed muons passing standard quality and kinematical cuts are used to identify J/ψ candidates with p_T between 1 and 70 GeV. These are grouped in four rapidity bins, covering $|y| < 2.4$, and their number is extracted fitting the $\mu^+\mu^-$ invariant mass spectrum. In order to estimate the true number of J/ψ decays in each bin, corrections for detector and reconstruction efficiency, bin migration and acceptance are applied with the corresponding uncertainties. For the kinematic acceptance, which strongly depends on the J/ψ polarization, not yet measured at LHC, different spin alignment scenarios are studied. Five extreme cases, including isotropic, fully longitudinal and transverse polarization, are identified; acceptance factors are evaluated for each case and the envelope of the resulting values is taken as an additional uncertainty. Figure 1 shows the resulting inclusive J/ψ production cross section, as a function of J/ψ transverse momentum, in the four rapidity bins analyzed. A comparison with CMS results [3] is performed for those rapidity bins close enough to permit it, showing good agreement within experimental uncertainties.

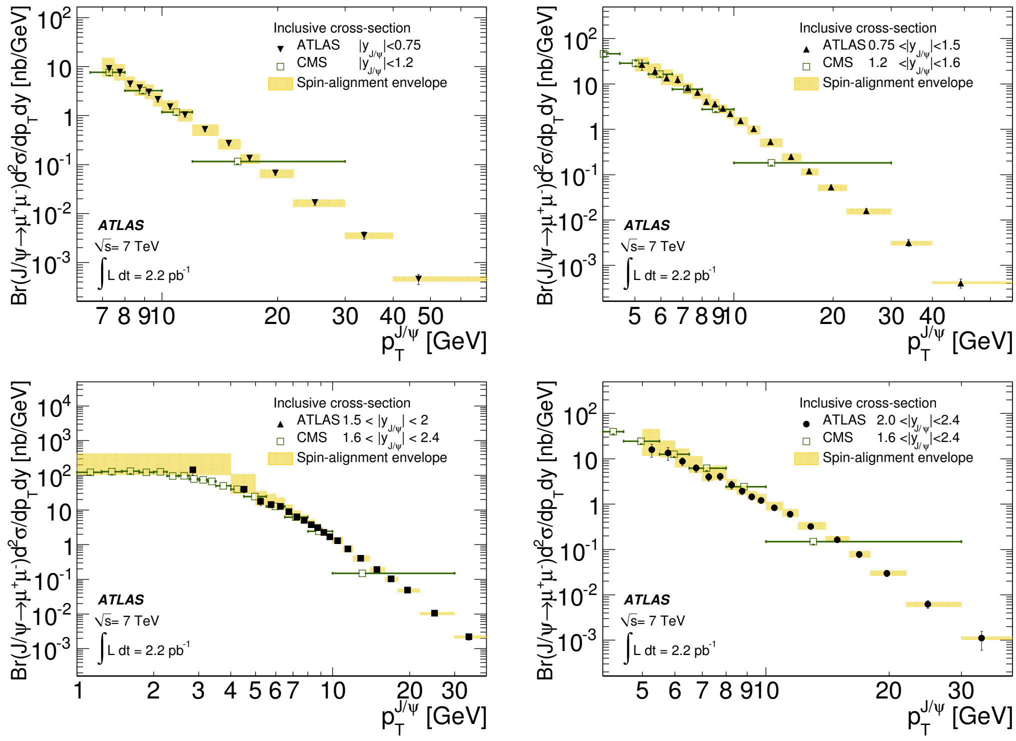

Figure 1: Inclusive J/ψ production cross section as a function of J/ψ transverse momentum in the four rapidity bins studied. Overlaid are a band representing the variation of the result under various spin-alignment scenarios and the equivalent results from CMS. The luminosity uncertainty (3.4%) is not shown.

4 Exclusive B and D hadron reconstruction

The reconstruction and identification of open beauty is a necessary prerequisite for the investigation of CP violation processes and rare decays. As a first step, the reconstruction of various exclusive B hadron decay modes, in which a J/ψ is produced and decays to opposite sign muons, is studied. Event selection and reconstruction proceed very similarly to what described for the inclusive J/ψ case, with additional constraints specific to each exclusive decay chain. In particular, the capability to identify $B^{\pm} \to J/\psi K^{\pm}$, $B_d^0 \to J/\psi K^0$ and $B_s^0 \to J/\psi \phi$ decays [4] [5] is demonstrated. Figure 2 shows the invariant mass distributions of B_d^0 and B_s^0 candidates reconstructed in an integrated luminosity of 40 pb^{-1}.

In the open charm sector, several exclusive D meson decay modes are observed and the corresponding production cross sections are measured [6], with an integrated luminosity of 1.1 nb^{-1}. The limitation on the data sample size comes from the use of minimum bias triggers, which were active only in the earliest data-taking phase, due to their high rate, incompatible with running at higher luminosities. The D meson candidates are

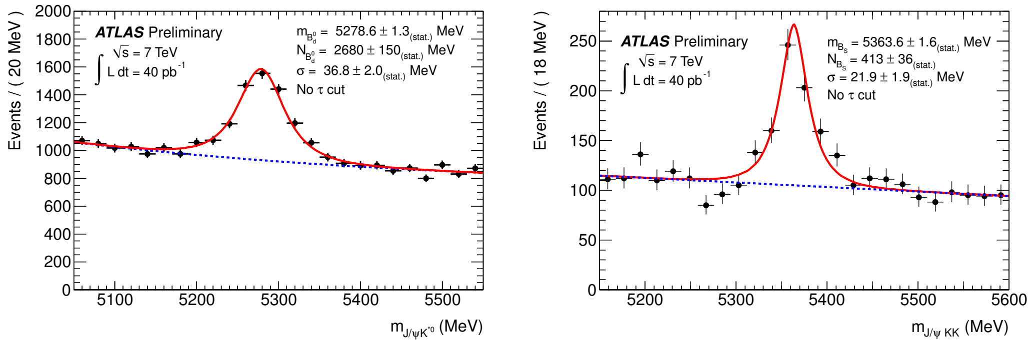

Figure 2: Invariant mass distributions of reconstructed candidates of $B_d^0 \to J/\psi\, K^0$ (left) and $B_s^0 \to J/\psi\, \phi$ (right). The points with error bars are data. The solid line is the projection of the result of the unbinned maximum likelihood fit. The dashed line is the projection for the background component of the same fit.

identified starting from charged tracks reconstructed in the ID and applying different tracking, vertexing, lifetime and invariant mass cuts, depending on the exclusive decay chain under study. Similarly to what done for the $J/\psi \to \mu^+\mu^-$ case, the true number of D mesons is estimated applying efficiency, bin migration and acceptance corrections. For $D^{\star\pm}$ studies, the decay chain $D^{\star+} \to D^0\pi^+$ with $D^0 \to K^-\pi^+$ is analyzed; the resulting $D^{\star\pm}$ production cross section, as a function of $D^{\star\pm}$ transverse momentum and absolute pseudo-rapidity, are shown in Figure 3, where a comparison with different theoretical predictions is overlaid, showing good agreement within experimental and theoretical uncertainties.

5 Conclusions

During its first year of data taking, the ATLAS experiment produced many heavy flavor measurements at an unprecedented proton-proton collision energy. As part of the rich ATLAS physics programme, the inclusive J/ψ and exclusive D meson production cross sections were measured. In the open bottom sector, the capability of reconstructing and identifying exclusive decay modes was demonstrated, paving the way for precise measurements of B meson properties and searches for the new physics phenomena in rare decays.

References

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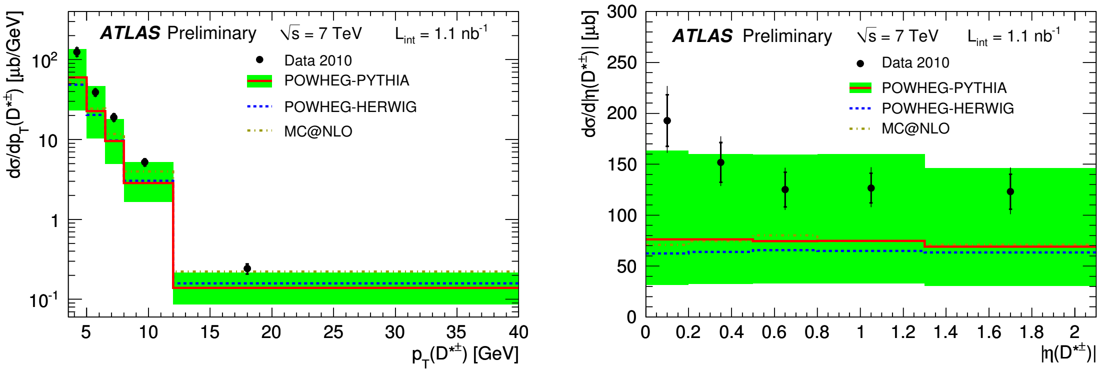

Figure 3: Differential cross section for $D^{\star\pm}$ mesons as a function of p_T (left) and $|\eta|$ (right) for data (points) compared to the NLO QCD calculations of POWHEG-PYTHIA, POWHEG-HERWIG and MC@NLO (histograms). The inner error bars show the statistical uncertainties and the outer error bars show the statistical and systematic uncertainties added in quadrature. The band shows the estimated theoretical uncertainty of the POWHEG-PYTHIA calculation.

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