Measurements with electroweak bosons at LHCb

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The LHCb measurements of electroweak boson production, either inclusive, or in association with a jet or a D meson at a centre-of-mass energy $\sqrt{s}$=7 TeV as well as Z boson production in proton-lead collisions are reported. The LHCb forward acceptance allows measurements complementary to the other LHC experiments.

1 Introduction

The LHCb detector [1] is a single-arm forward spectrometer instrumented in the pseudorapidity region $2 < \eta < 5$ and is optimised for the study of B and D mesons. Its unique kinematic coverage allows it perform measurements that are sensitive to both low and high values of Bjorken x and hence are complementary to those performed at the general purpose detectors, ATLAS and CMS. At energy scales typical for electroweak boson production, LHCb measurements are sensitive to values of x as low as 1.7 $\times 10^4$, where they can provide a fundamental input to parton distribution functions (PDFs) kinematic parametrisations of the partons within the colliding protons. The results presented here, except for Z production in proton-lead, are based on data collected at a centre-of-mass energy of 7 TeV with an integrated luminosity of about 1 fb^{-1}.

2 W boson production

A measurement of inclusive W boson production is performed at LHCb using the muonic decay mode of the W boson [2]. Events are selected which contain a muon with a transverse momentum, p_T, above 20 GeV/c and $2 < \eta^\mu < 4.5$. In addition, the muon is required to be isolated and consistent with production from the primary vertex. Furthermore it is required that there is no other muon in the event with $p_T > 2$ GeV/c. The signal purity is obtained by fitting the p_T distribution of the data sample in eight bins of muon pseudorapidity for both charges, simultaneously, to the expected shapes for signal and background. Background contributions are decay-in-flight of pions and kaons, semi-leptonic decays of heavy-flavour mesons, $Z \to \mu\mu$ events with one muon outside the LHCb acceptance and $Z \to \tau\tau$ events with a single muon in the final state. The templates are obtained from simulation for the signal and the electroweak backgrounds and from data for the other backgrounds. A total of about 8×10^6 W candidates are selected, with signal purities of about 77% for both charges of the muon. The signal yield is corrected for losses due to reconstruction and selection efficiency, acceptance and final-state radiation (FSR). The reconstruction and selection efficiencies are primarily estimated from data, while the acceptance and FSR corrections are determined with simulation. The total cross-sections for W^+ and W^- production in the fiducial range defined as $p_T^\mu > 20$ GeV/c and $2 < \eta^\mu < 4.5$ are measured to be $\sigma(W^+ \to \mu\nu) = 861.0 \pm 2.0 \pm 11.2 \pm 14.7$ pb and $\sigma(W^- \to \mu\nu) = 675.8 \pm 1.9 \pm 8.8 \pm 11.6$ pb, where the first uncertainty is statistical, the second is systematic and the third is due to the luminosity. The W^+ and W^- cross-sections and the lepton charge asymmetry as a function of muon pseudorapidity are shown in Fig. 1, where many experimental and theoretical uncertainties cancel for the latter. The measurements are compared to theoretical predictions calculated at next-to-next-to-leading order (NNLO) in QCD [3] using different parameterisations of the PDFs. In general, the results are in good agreement with the predictions.

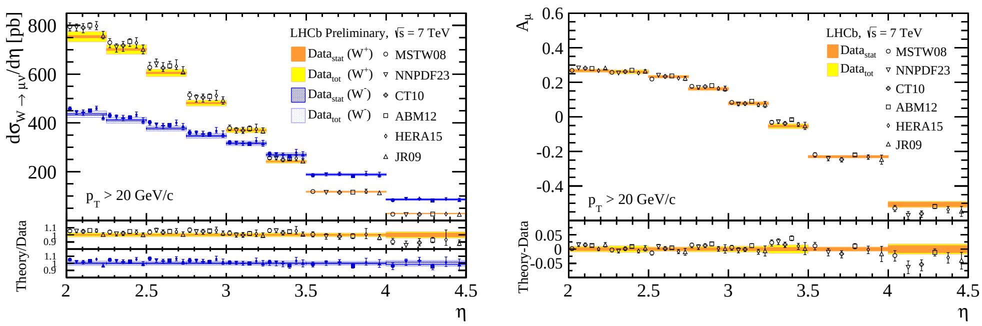

Figure 1: W^+ and W^- cross-sections (left) and lepton charge asymmetry (right) as a function of muon pseudorapidity [2]. The measurements, shown as coloured bands, are compared to NNLO predictions with different PDF sets. They are displaced horizontally for better visibility.

3 Z plus jet production

The production of a Z boson in association with a hadronic jet is studied with the Z decaying into two muons [4] with the same kinematic requirements for the muons as in the W analysis. In addition, the di-muon invariant mass is restricted to $60 < M_{\mu\mu} < 20$ GeV/c^2 and the event is required to contain a high-p$_T$ jet with $2 < \eta^{jet} < 4.5$ and $p_T^{jet} > 10$ or 20 GeV/c. The jets are reconstructed using an anti-k_T algorithm [5] with radius parameter of R=0.5. Reconstructed tracks and neutral clusters serve as charged and neutral inputs to the jet reconstruction algorithm and are selected using a particle flow algorithm. The jet energy scale is determined using simulation and cross-checked in data, with the jet energy resolution varying between 10 and 15% for the p_T^{jet} between 10 and 100 GeV/c. The fraction of $Z \to \mu\mu$ events containing a jet are determined to be $\sigma(Z + jet)/\sigma(Z) = 0.209 \pm 0.002 \pm 0.015$ for jet $p_T^{jet} > 10$ GeV/c and $\sigma(Z + jet)/\sigma(Z) = 0.083 \pm 0.001 \pm 0.007$ for jet $p_T^{jet} > 20$ GeV/c. The first uncertainty is statistical and the second systematic. The differential cross-section normalised to the inclusive Z cross-section for $p_T^{jet} > 20$ GeV/c is shown as a function of the azimuthal separation of the Z boson and the jet, $\Delta\phi$, in Fig. 2. The measurement is compared to theoretical predictions at up to $\mathcal{O}(\alpha_s^2)$ with parton showering and hadronisation effects included. As expected, the calculations performed at $\mathcal{O}(\alpha_s)$ fail to describe the distribution.

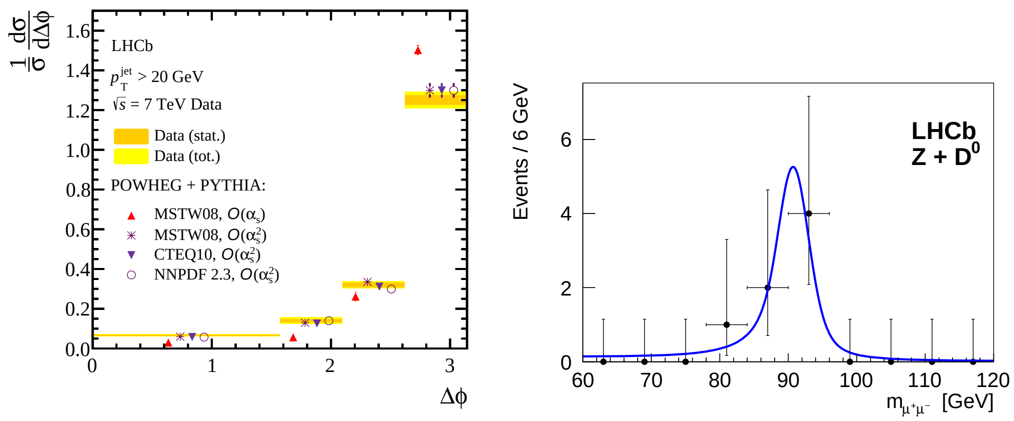

Figure 2: Z plus jet cross-section as a function of $\Delta\phi$ [4] (left). Invariant di-muon mass for the selected $Z + D^0$ candidates [6] (right).

4 Z plus D production

The $Z \to \mu\mu$ selection is also applied to search for the production of Z bosons in association with D mesons [6]. The D candidates are reconstructed using the $D^0 \to K\pi^+$ and $D^+ \to K\pi^+\pi^+$ decay modes and are restricted to the kinematic range of $2 < \eta^D < 4$ and $2 < p_T^D < 12$ GeV; together with the kinematic range of the muons of the Z decay, this also defines the fiducial volume of the measurement. The Z and the D are furthermore required to come from the same primary vertex. Backgrounds are taken into account from feed-down from beauty meson decays, which is the dominant contribution, combinatorics, and pile-up where the Z boson and the D meson are produced in different proton-proton interactions. The signal purity is determined to be about 95%. A total of 7(4) candidates are found for the $Z + D^0(Z + D^+)$ decay channel, corresponding to a combined significance of 5.1σ. The reconstructed mass of the Z boson for events in the $Z + D^0$ sample is shown in Fig. 2 (right). The production cross-sections are measured to be $\sigma(Z \to \mu\mu, D^0) = 2.50 \pm 1.12 \pm 0.22$ pb and $\sigma(Z \to \mu\mu, D^+) = 0.44 \pm 0.23 \pm 0.03$ pb, where the first uncertainty is statistical and the second systematic. The cross-sections receive contributions from single parton (SPS) and double parton scattering processes (DPS). The latter dominates in the kinematic range of the measurement. The measured cross sections are found to be in agreement with theoretical predictions[1] for the $Z + D^0$ but lower for $Z + D^{\pm}$. However, the large statistical uncertainties do not allow a firm conclusion.

5 Inclusive Z boson production in proton-lead collisions

Measurements in proton-lead collisions can serve as reference for future lead-lead collisions but can also provide significant constraining power for nuclear PDFs in unprobed regions of the phase space, at both low and high x_A, where x_A is the longitudinal momentum fraction of the parton in the nucleon. A search for Z boson production is performed based on two data samples corresponding to 1.6 nb^{-1} of proton-lead collisions at a centre-of-mass energy per

[1] The SPS contribution is calculated with MCFM [7], DPS as $\sigma = (\sigma_{Z\to\mu\mu}\sigma_D)/\sigma_{eff}$ with σ_{eff} from [8].

proton-nucleon pair of $\sqrt{s_{NN}}$ =5 TeV [9]. The two data samples correspond to two different beam configurations, with the proton (lead) beam into the direction of LHCb, referred to as forward (backward). The Z candidates are reconstructed in the di-muon final state. Background contributions from muon mis-identification and the decay of heavy flavour mesons are determined from data. A total of 15 candidates are selected with a purity of above 99%, corresponding to a significance of 10.4σ (6.8σ) for the Z signal in the forward (backward) direction. Figure 3 (left) shows the di-muon invariant mass of the Z candidates in the forward direction. The inclusive Z boson production cross-section is measured to be $\sigma(Z \to \mu\mu) = 13.5^{+5.4}_{-4.0} \pm 1.2$ nb in the forward and $\sigma(Z \to \mu\mu) = 10.7^{+8.4}_{-5.1} \pm 1.0$ nb in the backward configuration. Here, the first uncertainty is statistical and the second systematic. The measurements are compared to theoretical predictions calculated at NNLO using the FEWZ generator [3] and computed with and without considering nuclear effects based on the EPS09 nuclear PDF set [10] in Fig. 3 (right).

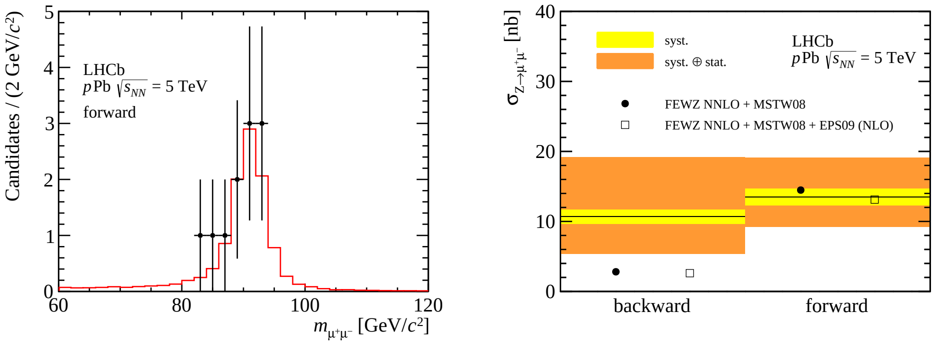

Figure 3: Left: Invariant di-muon mass of the Z candidates in proton-lead collisions. Right: Experimental results and theoretical predictions for the Z production cross-section in proton-lead collisions [9].

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