PROCEEDINGS OF SCIENCE

Measurements of the $\mathrm{W}^{\pm}$ and Z^{0} boson production by LHCb

David Hutchcroft*
University of Liverpool, UK
E-mail: David.Hutchcroft@cern.ch

Measurements of the $\mathrm{W}^{\pm}$ and Z^{0} boson production cross-sections and angular distributions in the forward region are presented, based on $16.5\mathrm{pb}^{-1}$ of $\sqrt{s} = 7\,\mathrm{TeV}$ proton-proton collision data collected by the LHCb experiment.

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*Speaker.

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1. Introduction

The LHCb detector is a purpose designed *b* physics experiment at the Large Hadron Collider [1]. The detector is designed with an acceptance in the forward region of the proton-proton collisions. First measurements of W and Z production, using muonic final states, have been made and are presented here.

2. LHCb

The LHCb detector is described in Ref. [2]. LHCb comprises of several subsystems covering a nominal angular acceptance of 250 mrad (vertical) and 300 mrad (vertical). There is a vertex detector, a four station tracking detector containing a 4 Tm dipole magnetic field between the first and second stations, two ring imaging Čerenkov detectors, a calorimeter system with four subsystems and five walls of muon detectors. The dipole magnetic field is reversed in polarity regularly to minimise the systematic effects of asymmetries in the detector.

The data used in this analysis were the first $16.5 \pm 1.7\,\mathrm{pb}^{-1}$ of $\sqrt{s} = 7\,\mathrm{TeV}$ data collected by LHCb in which all of the detector systems were operating normally. The luminosity is estimated from measurements of the volume of the interaction region of the two proton beams at LHCb, regular Van de Meer scans and the instantaneous beam currents.

The LHCb trigger takes the 40 MHz nominal LHC interaction rate, and reduces this to a 1kHz output rate. The first trigger level (level-0), is based in hardware and selects electrons, photons and hadrons from the calorimeter and muons from the muon system. This cuts the rate to at most 1 MHz and then a farm of computers run a set of a set of algorithms, called the high level trigger, using all of the detector information to confirm the information from the L0 and do a partial reconstruction of the event. At most 30kHz is passed from HLT1 to a second level, called HLT2, where a full offline style reconstruction is performed to select specific physics events.

3. Electro-weak Physics at high η at the LHC

The unique pseudo-rapidity range of LHCb, covering $2 < \eta < 5$, means that the production of $W^{\pm}$ and Z^{0} bosons is dominated by taking a high-x quark out of one proton and a very low-x out of the other. Combined with the high beam energy means we simultaneously probe both the region covered by the HERA experiments [3, 4] in x and Q^2 and the much lower x for the same Q^2 which is unexplored by other experiments, see figure 1.

The cross-section for the production of a Z or $W^{\pm}$ boson from two quarks is known to next to next to leading order (NNLO) e.g. [5]. By measuring the boson pseudo-rapidity distributions the parton density functions for the protons can be probed in the very low x high Q^2 regime [6].

4. Event selection

To minimise biases the trigger and event selections were kept as simple as possible. The trigger applied was an L0 candidate muon which was confirmed in HLT1 and HLT2 to be associated to a track starting at the proton-proton interaction region with a transverse momentum (p_T) greater

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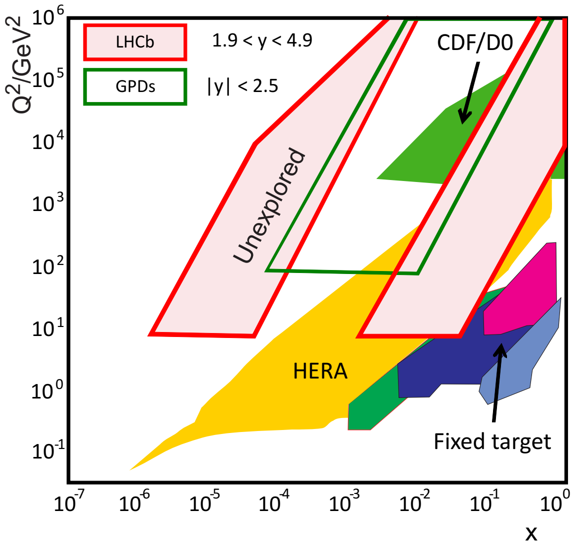

Figure 1: The $x-Q^2$ region explored by the LHC general purpose detectors and LHCb, compared to that probed by earlier experiments.

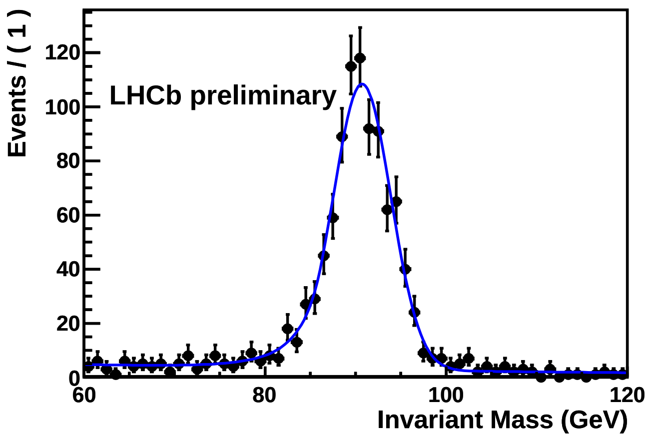

Figure 2: The invariant mass distribution of $\mu^+\mu^-$, the curve is a Gaussian peak and a polynomial fit to the data.

than $10\,\mathrm{GeV}/c$. This was tightened in the pre-selection for the analysis to be one well reconstructed track that was identified as a muon with $p_T > 20\,\mathrm{GeV}/c$.

For the $\mathrm{Z}^0 \to \mu^+\mu^-$ reconstruction two muons with $p_T > 20\,\mathrm{GeV}/c$ are required. The invariant mass distribution is shown in fig. 2 showing both the peaking component around the Z^0 mass and the continuum of the $q\overline{q} \to (\mathrm{Z}^0/\gamma)^* \to \mu^+\mu^-$ contribution and that there is very little background passing this selection. The cross-section is evaluated for events where $81 < M(\mu\mu)/\mathrm{GeV}/c^2 < 101$.

The selection for $\mathrm{W}^\pm \to \mu^\pm$ places requirements on the p_T of the muon ($p_T > 20\mathrm{GeV}/c$), the impact parameter significance of the muon to the primary vertex ($IP_{\mathrm{sig}} < 2$), the $\sum p_T$ in a cone of radius 0.5 in $\eta - \phi$ around the muon ($\sum p_T^{\text{cone}} < 2\text{GeV}/c$), the $\sum(p_T)$ of the rest of the event ($\sum p_T^{\text{rest}} < 10\text{GeV}/c$) and the invariant mass of the rest of the event ($m_{\text{rest}} < 20\text{GeV}/c^2$).

5. Efficiencies

The efficiency for the reconstruction of $Z \to \mu^+\mu-$ can be factorised as

$$\varepsilon_Z = A_Z \varepsilon_Z^{\text{trig}} \varepsilon_Z^{\text{track}} \varepsilon_Z^{\text{muon}} \varepsilon_Z^{\text{sel}} \tag{5.1}$$

where A_Z is the acceptance of LHCb, $\varepsilon_Z^{\text{trig}}$ is the trigger efficiency, $\varepsilon_Z^{\text{track}}$ is the track finding efficiency, $\varepsilon_Z^{\text{muon}}$ is the muon identification efficiency and $\varepsilon_Z^{\text{sel}}$ is the selection efficiency. The $W^\pm \to \mu^\pm$ reconstruction is factorised in the same way.

To minimise the dependence on the Monte Carlo where possible these are estimated using data. By quoting the W and Z cross-sections where the muon (or both muons) are within the LHCb acceptance the value of A_W and A_Z are set to 1 by construction.

The trigger efficiency for a single muon is estimated by comparing the fraction of Z^0 events where only a single muon caused a trigger verse both muons independently triggering the event. This was measured as $86 \pm 1\%$ for $\varepsilon_Z^{\text{trig}}$ and $79.1 \pm 1.9\%$ for W^+ and $81.9 \pm 1.9\%$ for W^-. The higher efficiency for W^- is due to the different η distribution of the muons.

The efficiency to identify a track as a muon is measured by a tag-and-probe method. In events with an identified μ^+ (or μ^-) the muon is combined with each negative (or positive) track in the event to make an invariant mass distribution. As the Z^0 resonance is nearly background free the track combinations with reconstructed masses around the Z^0 mass are both muon tracks. So the fraction of these tracks with correct muon identification can be used to measure the muon ID efficiency per track, which is $98.2 \pm 0.5\%$ for both muon charges.

The tracking efficiency is checked in the same way by taking only the hits in the muon chambers and the first tracking station, neither of which are used in the track finding, with a well reconstructed muon an invariant mass distribution is made. The resolution is worse without the hits in the vertex detector and tracking stations after the magnet, however there is still sufficient information to resolve the Z^0 resonance. Using the events peaking around the Z^0 mass the single track finding efficiency is estimated as a function of p_T, η and ϕ. Integrating for the observed distributions the efficiencies were found to be $\varepsilon_{W^+} = 73 \pm 3\%$, $\varepsilon_{W^-} = 78 \pm 3\%$ and $\varepsilon_{Z^0} = 83 \pm 3\%$, where again the different η distribution of the W for each charge gives the efficiency asymmetry.

6. Backgrounds

For the Z^0 data sample the background was estimated by enhancing the heavy flavour QCD jet backgrounds by adding a requirement to the selection to have tracks with $p_T > 5\text{GeV}/c$ in a cone of 0.5 in $\eta - \phi$ around each muon and the muons both have an impact parameter significance of 5. The invariant mass distribution was plotted with no events in the window $81 < M(\mu^+\mu^-)/(\text{GeV}/c^2) < 101$, so the lower mass event distribution was extrapolated into the signal region as an estimate. The background from QCD events with misidentified tracks was measured by taking 8.1nb^{-1} of data with a minimum bias trigger, then reconstructing events with two tracks without applying a particle identification. The rate of muon misidentification was applied to the events to estimate the

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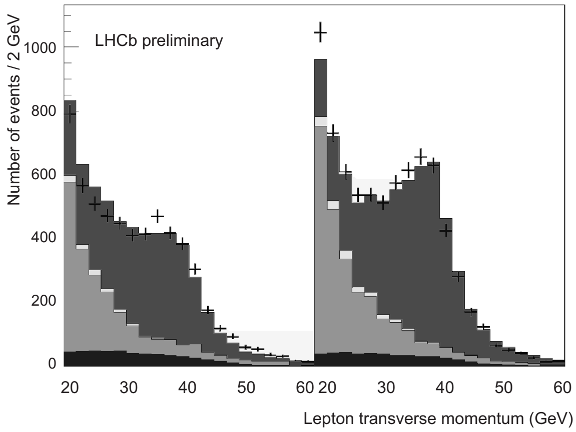

Figure 3: Single muon p_T fit to LHCb data for negative (left) and positive (right) leptons. From the bottom the bands are the $Z^0 \to \mu\mu$, QCD and $W \to \tau$ background and the signal templates scaled to their fitted amounts, the points are the data.

rate of QCD events with misidentified muon pairs. The $Z^0 \to \tau^+\tau^-$ rate was estimated from MC. Overall the background to the Z^0 measurement is estimated to be 1.2 ± 1.2 events, with the largest fraction from heavy flavour decays.

For the W decays the backgrounds are larger. We consider $Z^0 \to \mu^+\mu^-$ with a muon outside the acceptance, $Z^0 \to \tau^+\tau^-$ with a single $\tau \to \mu$ decay, $W \to \tau\nu$, heavy flavour decays with a muon and QCD events where pions decay in flight or there is punch through of the track to fake a muon signal. The Z^0 analysis provides an estimate of rate of Z^0 bosons faking Ws, with corrections for the different momentum distributions expected. The fraction of $W \to \tau$ decays faking $W \to \mu$ is taken from MC.

The heavy flavour and QCD backgrounds are estimated from data. The $Z^0 \to \mu\mu$ events with one muon masked are used as a template and the backgrounds determined in a fit to the W p_T spectrum with templates for the other background categories. To validate this the muons from Z^0 decays are compared to $W^\pm$ MC events, also background enriched samples are created by adding the IP and anti-isolation cuts as was done for the Z^0 background to provide templates of the QCD backgrounds. The fit to the W data is shown in fig. 3.

7. Cross-sections

For the Z^0 cross-section the two muons are required to be in the range $2 < \eta < 4.5$, which is $\sigma(Z^0) = 68 \pm 4 \pm 7\,\text{pb}$ where the first error is statistical and systematic and the second comes from the luminosity uncertainty. For the $W^\pm$ cross-sections the single muon is in the range $2 < \eta < 4.5$ with $\sigma(W^+) = 1007 \pm 48 \pm 101\,\text{pb}$ and $\sigma(W^-) = 680 \pm 40 \pm 68\,\text{pb}$ again the first errors are statistical plus systematic the second is the luminosity uncertainty. The results are consistent with the NLO QCD predictions.

The ratios are determined more accurately as the luminosity uncertainty cancels, the background uncertainties are assumed correlated but the tracking and trigger efficiencies anti-correlated to account for asymmetries in the detector. The combined result is then $\sigma(W^+)/\sigma(W^-) = 1.48 \pm$

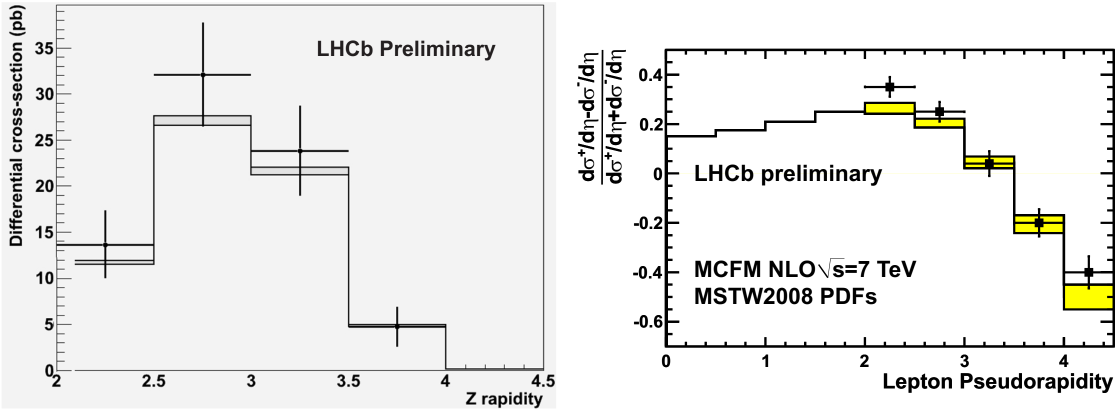

Figure 4: Left: Z rapidity distribution, points are data and the histogram is the NLO FEWZ prediction. Right: Lepton asymmetry in bins of lepton pseudo-rapidity, points are data and the histogram is the MCFM prediction. In both plots the shaded band is the uncertainty from the MSTW08NLO PDF set [8].

0.11 where the error is statistical plus systematic. The ratio between Z^0 and W cross-sections is defined as $(\sigma(W^+)+\sigma(W^-))/\sigma(Z^0) = 23.1 \pm 1.5$ (stat.+syst. error) with the same acceptances as the measurements in the paragraph above.

The rapidity distributions for Z^0 and asymmetry in lepton pseudo-rapidity distribution for $W^\pm$ decays are shown in fig. 4 compared to NLO FEWZ [7] and MCFM [6] predictions.

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