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Studies of W and Z production with the LHCb experiment

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We report on studies of W and Z production with the LHCb experiment. Due to its acceptance, LHCb can probe a regime of low Bjorken x electroweak boson production, where parton distribution functions are not well constrained. In this review strategies for triggering, selection and background rejection are discussed, and studies of the sensitivity of differential cross-section measurements to the underlying parton density functions presented.

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1. Introduction

Studies of W and Z boson production, here isolated by selecting muon final states, at the Large Hadron Collider are of importance for a number of reasons. The clean experimental signature allows samples to be isolated in early data, providing events that can be used to calibrate detector performance and potentially provide a luminosity measurement. Theoretical predictions for electroweak boson production are known to next-to-next-to-leading order, and are limited in precision by the uncertainty in parton density functions. Measurements of W and Z production can therefore also provide precise Standard Model tests, in regions where parton density functions are well known, and data to constrain the parton density functions themselves where they are not.

In this review we present studies by the LHCb experiment [1], one of the four main experiments sited at the Large Hadron Collider. Unlike the ATLAS and CMS experiments LHCb is instrumented only on one side of the interaction point, and covers the pseudorapidity region $1.9 \leq \eta \leq 4.9$. Inside this acceptance LHCb possesses the full range of tracking, particle identification, calorimetry and muon detection, and can trigger on objects with low thresholds. For example, muons can be triggered with transverse momentum (p_T) above 0.8 GeV, and dimuon invariant masses above 2.5 GeV. Measurements made within $1.9 \leq \eta \leq 2.5$ are therefore complementary to ATLAS and CMS, and beyond are unique to LHCb with this full detector complement.

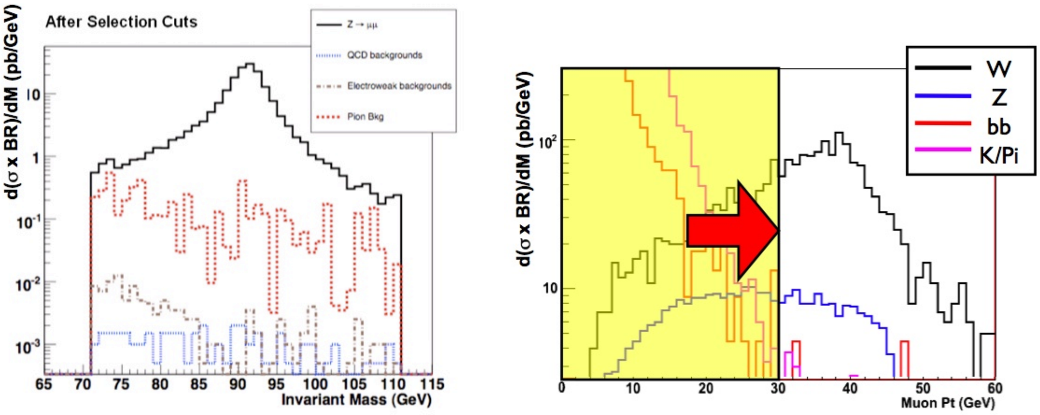
This particular combination of trigger thresholds and angular acceptance ensures that LHCb can probe W and Z production for partons of low [2] and high x. Production typically involves a valence and a sea quark. It is the low x sea quark that is less well known. The uncertainty on parton density functions are the dominant uncertainty in the predicted differential cross-sections. For Z production inside the LHCb acceptance the uncertainty varies between 2% and 10%. We discuss the potential sensitivity Z and W differential cross-section measurements have to the underlying parton density functions.

2. Z and W boson selection

2.1 Z selection

LHCb employs a two level trigger system. The first, L0, takes place in hardware. Events containing Z bosons are triggered by requiring two muon objects, of summed p_T above 1.5 GeV. The second, HLT, takes place in software. Here Z bosons are triggered by confirming the existence of two muons with p_T above 10 GeV, having a dimuon invariant mass above 50 GeV. This trigger is just over 90% efficient for Z events containing two muons inside the LHCb acceptance.

Backgrounds from top, bottom and charm decays ("QCD"), Z, W and WW decay ("electroweak") and pions and kaons misidentified as muons ("Pion bkg"), have been studied. To suppress these, candidate Z bosons must satisfy additional criteria in the offline event selection. The highest (second highest) transverse momentum muons must exceed a p_T of 20 (15) GeV, be coincident with having originated at the primary vertex, and possess less than 50 GeV of associated hadronic energy. The dimuon invariant mass $m_{\mu\mu}$ must lie within $71 < m_{\mu\mu} < 111$ GeV. Figure 1(a) shows the invariant mass of selected candidates after this selection has been applied. The selection is pure (about 97%), and efficient (91% of events passing the trigger are selected).



(a) Differential cross-section as a function of dimuon invariant mass for Z candidates.

(b) Differential cross-section as a function of muon p_T for W candidates. The arrow shows where the requirement is placed.

2.2 W selection

W bosons are triggered by requiring a single muon of p_T above 1.1 GeV at L0, and a confirmed muon at HLT with p_T above 20 GeV. This criterion results in a trigger efficiency of about 74%.

Here backgrounds from semi-leptonic decays of bottom quarks ("bb"), Z bosons where one muon is located outside the LHCb acceptance ("Z"), and misidentified pions and kaons ("K/pi"), have been studied. To suppress these, candidate W bosons must possess a muon of p_T exceeding 30 GeV. The muon must also be isolated. Figure 1(b) shows the muon transverse momentum of selected candidates. This selection has a lower efficiency (35% of triggered events pass), owing to the more restrictive transverse momentum criteria, and a purity of about 90%.

2.3 Measurement uncertainties

Estimated measurement uncertainties for W and Z production, inside the LHCb acceptance and using a dataset of 100 pb^{-1} are shown in table 1. Note that statistical errors are below 1% on the total cross-section in both cases. Systematic errors have been estimated for the background estimation, reconstruction efficiency and acceptance, trigger efficiency and luminosity following [3]. Although these are still under study, it seems likely that the total cross-section will be dominated by knowledge of the integrated luminosity.

Error source	$\sigma(W \to \mu\nu; 1.9 < \eta_\mu < 4.9)$	$\sigma(Z \to \mu\mu; 1.9 < \eta_{\mu\mu} < 4.9)$
Statistical	0.5	0.8
Background	0.3	0.2
Reconstruction efficiency	0.2	0.3
Trigger efficiency	0.1	0.1
Luminosity	1-5	1-5

Table 1: Error estimates, as percentages of the W and Z measured cross-sections with 100 pb^{-1} of data.

3. PDF sensitivity studies

The integrated luminosity limits the precision of experimental measurements of both the total, and differential, cross-sections (where it enters as a correlated error). It has been suggested that ratios of Z and W production can be studied instead. Besides cancelling luminosity dependance, ratios can be chosen that either minimise sensitivity to parton density functions (such as Z/W), or maximise sensitivity (eg. the W^+/W^- ratio, which is sensitive to the u/d quark ratio, or the W^+ W^- production asymmetry which is sensitive to the difference between u valence and d valence distributions). However, it is also possible to fit W^+, W^- and Z differential cross-sections in data to theoretical prediction [4], allowing the shape and normalisation of the prediction to vary. The fitted normalisation corresponds to the integrated luminosity of the dataset, thus removing the need for an external measure. The fitted shape constrains the uncertainty in parton density functions, whose uncertainty allows the shape to vary.

Studies show that even in datasets as small as 100 pb^{-1}, luminosity can be extracted with a precision of about 2%. The precision depends on the parton density model adopted. As parton density shapes are not known a priori the choice of a particular model can lead to a bias - no more than 3.5% in this case. Parton density functions are constrained in the low and higher x regions which LHCb data probes. In 1 fb^{-1} of combined W and Z data for example, the u valence, d valence and gluon distribution uncertainties could be reduced by up to a third at an x of 10^{-4}. Measurements of Z and W production at LHCb can therefore help to constrain knowledge of the parton density functions even in the absence of a good luminosity measure.

4. Conclusions

Studies of Z and W production with the LHCb experiment have been presented. LHCb can trigger and reconstruct samples of both bosons with reasonable efficiency and purity, and provide data which can probe partons of x at 10^{-4}. Measurements of the total cross-section will quickly be dominated by the uncertainty on integrated luminosity. Measurements of the differential cross-section can help constrain the parton density functions even if the luminosity is not well known.

References

[1] A. Augusto Alves *et al.* JINST **3:S08005** 2008.

[2] For a fuller description of the LHCb low x reach see S. Ochesanu, these proceedings.

[3] J. Anderson, "Testing the electroweak sector and determining the absolute luminosity at LHCb using dimuon final states", CERN-THESIS-2009-020.

[4] See F. de Lorenzi, "Indirect precise luminosity measurement with LHCb", proceedings of Deep Inelastic Scattering conference 2009.