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Indirect luminosity measurements with LHCb

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We report on two studies of indirect luminosity measurements, using events containing muon final states, in LHCb. The first method exploits elastic two photon dimuon production in LHCb. The process has a theoretical uncertainty of less than 1%, making it an ideal choice for use in performing an indirect luminosity measurement in hadron colliders. Strategies for triggering, selection and background rejection are discussed. Our studies indicate that a measurement precision of 1% can be obtained with 1 fb^{-1} of data. The second method uses measurements of electroweak boson production where a similar precision can be obtained. It should be possible to measure the luminosity to better than 1% precision by combining both approaches.

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1. Introduction

It is essential to have a precise measurement of integrated luminosity to measure absolute cross-sections and to estimate background contributions to new physics. The number of events, N, seen for a given process is related to the cross-section, σ, and the beam luminosity L by $N = L/\sigma$.

Traditional luminosity measurements involve the direct measurement of the beam current and shape. However this technique has associated uncertainties of about 10%. Indirect measurements of the luminosity can be obtained from applying $L = N/\sigma$ if one can find a process which is both theoretically well known and which produces a sufficient number of events that can be detected with a well-determined efficiency and purity.

In this short review two indirect luminosity measurements are discussed; the quantum electro-dynamic (QED) process $pp \to p + \mu + \mu + p$; and W and Z boson production.

2. Exclusive production of dimuons

The QED process $p + p \to p + \mu + \mu + p$ is known to better than 1% theoretically, and has an effective cross-section of about 70 pb inside the LHCb acceptance. It has a distinctive experimental signature of two back-to-back muons (in the transverse plane), in an otherwise empty event.

LHCb has a fast hardware trigger (L0) with an output rate of 1MHz and a software trigger (HLT), running on a computing cluster, with an output rate of 2kHz. To select our signal, the trigger must record two types of event: single events, which contain a single collision of type $pp \to p + \mu + \mu + p$; and pile-up events, which contain more than 1 collision, one of which is $pp \to p + \mu + \mu + p$ and another which can be any type.

The L0 trigger requires at least one muon with transverse momenta > 1GeV, in coincidence with a low number of hits in the SPD (Silicon Pad Detector). At HLT two muon candidates are required with an invariant mass exceeding 1 GeV. The trigger has an efficiency of 77% (64%) for single (pile-up) events which contain two muons inside the LHCb acceptance.

Candidate events are selected offline [1] by requiring that no other tracks are consistent with the dimuon vertex, and that the dimuon transverse momentum is below 50 MeV. This selection has an efficiency of 17%, and a purity of 96%, where the dominant background arises from double pomeron exchange. With 100 pb^{-1} of data the statistical precision of a luminosity measurement should be 3%, reaching 1% with a dataset of 1 fb^{-1}.

3. Vector boson production of muons

Electroweak boson production is theoretically known to $2-3\%$. Most of the uncertainty is due to knowledge of the parton distribution functions (PDFs), which have been calculated by several groups using global fits to experimental data.

LHCb has a high efficiency (> 90%) for triggering and reconstructing muons from W and Z bosons [2] inside the LHCb acceptance. In 100 pb^{-1} of data about 20,000 Z, 40,000 W$^-$ and 75000 W$^+$ will be selected. The luminosity extracted from these production measurements will thereore quickly become limited by the PDF uncertainties.

To avoid this, an alternative analysis method has been devised [3]. The W^+, W^- and Z differential cross-sections in data, measured as a function of pseudorapidity, are fitted to theoretical prediction. A χ^2 is formed between the number of observed and expected events in each pseudorapidity bin. The fit minimises the χ^2 by 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 the parton density functions (the MSTW, CTEQ, Alekhin, NNPDF [4] models have been tested), whose uncertainty allows the shape to vary. These PDFs are constrained to vary within their current bounds. Only those theoretical predictions whose corresponding χ^2 probability is greater than 1% are considered.

With 100 pb^{-1} of data the luminosity is expected to be known up to 1.7% [1], decreasing to 1.3% with 1 fb^{-1} and 0.8% with 10 fb^{-1} of data. It should be noted that the goodness of fit implicit in the method will allow these different models to be distinguished in the data. Expected statistical errors for 10 fb^{-1} of data, and different PDF models, are given in table 1.

	MSTW08	CTEQ6.6	Alekhin02	NNPDF1.0
W^+	1.3	2.0	1.5	2.1
W^-	1.2	1.9	1.6	2.1
Z	1.4	1.9	1.9	1.8
W^+,W^-,Z	0.8	1.7	1.0	1.3

Table 1: Expected statistical precision on the luminosity with 10 fb^{-1} of data, for fits to W and Z bosons separately and together, assuming four different parton density function models.

4. Conclusions

Two indirect luminosity measurement strategies are presented. The first, using a QED process, can reach a measurement precision of 1% with 1 fb^{-1} of data. The second, using W and Z data, can reach a similar precision. Together, it should be possible to measure the luminosity to better than 1% precision.

References

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

[2] For a discussion of W and Z selections see T. Shears, these proceedings.

[3] F. de Lorenzi, "Indirect precise luminosity measurement with LHCb", Deep Inelastic Scattering 2009.

[4] A. D. Martin *et al.*, arXiv:hep-ex/0901.0002v2; P. Nadolsky *et al.* Phys. Rev. **D78** 013004 2008; S. Alekhin, Phys. Rev. **D63** 094022 2001; R. D. Ball *et al.* Nucl. Phys. **B809** 2009.

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[1]depending on the PDF model employed