PROCEEDINGS OF SCIENCE

PDF Sensitivities using Electroweak Processes

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Measurements of the W, γ^* and Z cross-sections constitute important tests of the Standard Model at LHC energies. NNLO predictions for W and Z have uncertainties of between 3% and 10%, depending on rapidity, where the dominant uncertainty is due to knowledge of the parton distribution functions. Consequently, experimental measurements can test the Standard Model and constrain the PDFs. We show first signals from the LHCb experiment for the production of W and Z bosons, as well as the dimuon invariant mass spectrum down to 2.5 GeV. Estimates are presented for the improvement in the PDFs with 100 pb^{-1} of data. Of particular interest is Drell-Yan production at the lowest invariant masses, since these have sensitivity to very low-x values, down to about 10^{-6} where the PDFs are essentially unknown.

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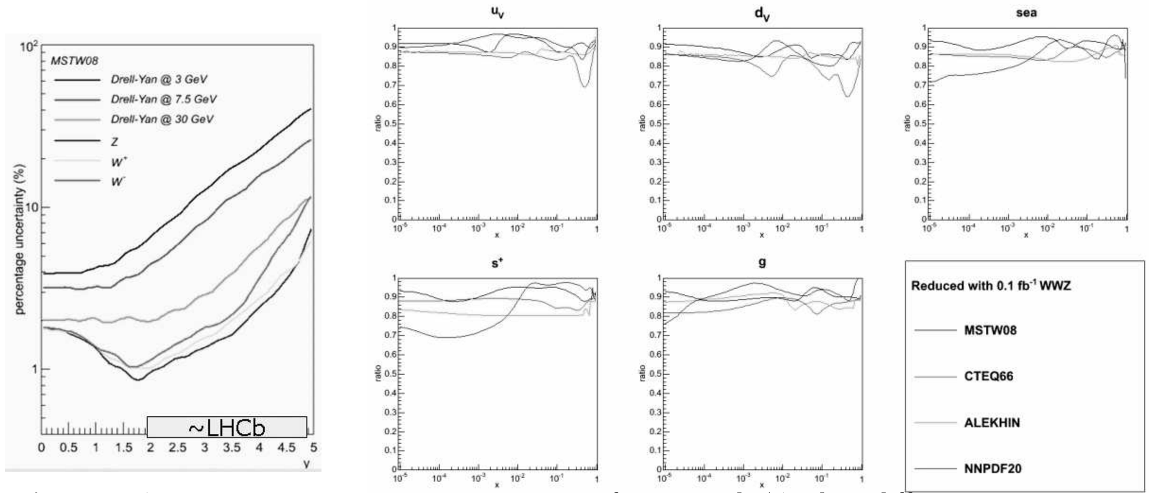

Figure 1: a) Percentage uncertainty on cross-sections for W,Z and γ^*(at three different invariant masses) as a function of rapidity (left). b) Estimated uncertainty on the PDFs after including 100 pb^{-1} of LHCb electroweak boson data, divided by the current uncertainty, for various models. (six plots on right).

1. Introduction

The cross-section, σ, for the production of a boson, X, at an energy scale, Q^2, can be written as $\sigma_X(Q^2) = \sum_{a,b} \int_0^1 dx_1 dx_2\, f_a(x_1,Q^2)\, f_b(x_2,Q^2)\, \hat{\sigma}_{ab\to X}(x_1,x_2,Q^2)$ where the sum extends over all partons a,b contributing a partonic cross-section, $\hat{\sigma}$, weighted by the probability, f, of finding a parton with fractional momentum x. The predictions for W and Z have uncertainties of between 3% and 10%, depending on rapidity, as shown in Figure 1a.

Two aspects of the LHCb experiment allow the PDFs to be probed in a unique region of x,Q^2 space. Firstly, the forward coverage of the detector extends from pseudorapidity values of 2.9 to 4.9. The rapidity, y, of an object of mass Q produced at a collider with centre-of-mass energy $\sqrt{s}$ is related via $x_{1,2} = Q/\sqrt{s}\exp\pm y$, so production of W and Z bosons probe one high-x parton and one low-x of about 10^{-4}. Secondly, LHCb can trigger on objects with low transverse momentum, p_T, down to 1 GeV, allowing low values of Q^2 and very low values of x to be reached, down to 10^{-6}.

2. Z boson selection

The selection for Z candidates requires two well reconstructed muons each with $p_T > 20$ GeV. The invariant mass distribution agrees with the expectations from simulation. Backgrounds under the Z peak are negligible and two Z candidates are observed in the 37nb^{-1} of data analysed for this conference. The event display for one of them is shown in Figure 2a. The back-to-back balance and high transverse momentum of the muons is characteristic of the decay of a Z boson to muon pairs. There is minimal other activity in the event.

3. W boson selection

The signature for W bosons is not dissimilar; a single high transverse momentum muon and minimal other activity in the event. However, the QCD backgrounds are higher, since a jet that balances the muon may fall outside LHCb's acceptance. Two isolation criteria are used requiring

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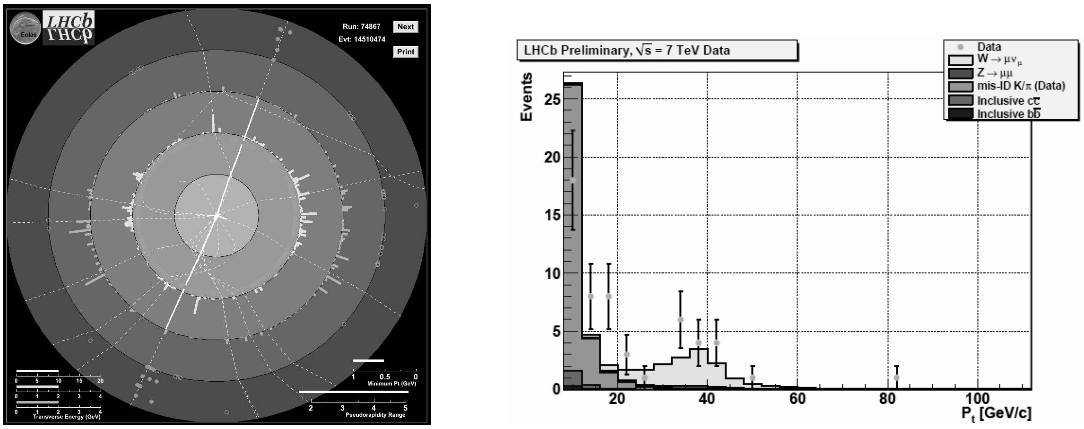

Figure 2: a) Z candidate shown in a transmogrified depiction of LHCb. In this (r,ϕ) polar co-ordinate frame, ϕ corresponds to the LHCb ϕ co-ordinate and r is related to the LHCb z co-ordinate (along the beam axis). The lengths of the bold lines are proportional to transverse momentum, transverse electromagnetic and hadronic energies. (left plot). b) Transverse momentum of muons in the W selection (right plot).

little activity in a cone around the muon and little activity in the rest of the event. Semileptonic B and D meson decays are supressed with a cut on the muon impact parameter. The transverse momentum spectrum for the muon in 14.6nb^{-1} of data analysed for this conference, is shown in Figure 2b, superimposed on the estimated sample composition. The largest background, coming from QCD events where a pion or kaon has been misidentified as a muon, has been derived from data. The other sources come from simulation. The muons with transverse momenta above 30 GeV are most likely due to W boson decay.

4. γ^* selection

To select events below the Z peak, the requirement on p_T of each muon is lowered to $p_T >$ 1GeV. To reduce backgrounds, both muons are required to be isolated and to be consistent with the primary vertex. The invariant mass spectrum with 37 nb^{-1} of data is shown in Figure 3. Above 30 GeV, there is little background to Drell-Yan produced events. However, going to lower masses, the background (particularly that due to muons coming from pions and kaons that decay in flight) quickly dominates, apart from the regions in which $J/\psi, \psi'$ resonances and the Υ family can be seen. More work is needed to suppress the backgrounds if x values of 10^{-6} are to be probed using this data.

5. Using electroweak data to constrain the PDFs

Current knowledge on the PDFs has been derived from global fits to HERA, Tevatron, and fixed target experiments and are expressed in terms of a number of orthogonal eigenvectors with a central value $\vec{e}_0$ and a set of vectors $\pm\vec{e}_i$ which describe 68% bounds on the i^{th} eigenvector. The central value for the differential cross-section, $\frac{d\sigma}{dy}$, is found by evaluating it at the central value of

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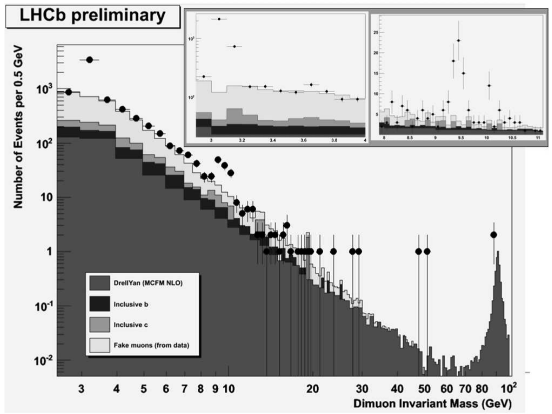

Figure 3: Dimuon invariant mass with estimated contributions from Drell-Yan production, inclusive b (without Υ) and inclusive c (without J/ψ), found using simulated events. Estimates of the number of pions and kaons that fake muons have been derived from minimum bias trigger data. The insets show close-ups of the regions around the J/ψ and Υ resonances.

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the PDFs and the probability density function for the observable can be mapped out through

$$f(\delta_1,\delta_2,...\delta_N) \equiv \frac{d\sigma}{dy}(\delta_1,\delta_2,...\delta_N) = \frac{d\sigma}{dy}(\vec{e}_0) + \sum_i \delta_i \{ \frac{d\sigma}{dy}(\vec{e}_i) - \frac{d\sigma}{dy}(\vec{e}_0) \}$$

where δ_i are sampled from a multinomial distribution.

We have performed pseudo-experiments with simulated LHCb data, counting the number of events, N, in bins of rapidity. Since the theory has been parametrised in terms of δ, the minimisation of $\chi^2(\delta_1,\delta_2,...\delta_N) = \sum_{bin} \left(N_{bin} - f(\delta_1,\delta_2,...\delta_N)\right)^2 / N_{bin} + \sum_i \delta_i^2$ improves δ and hence the PDFs.

We have calculated the improvement to the PDFs of MSTW [1], CTEQ [2], NNPDF [3] and Alekhin [4], that W and Z data would bring. The results are summarised in Figure 1b. With 100pb^{-1} of data an improvement of about 10% is obtained and there is some ability to distinguish between the models. With 1fb^{-1} of data, the improvement would be about 30%. A much greater impact on the PDFs is obtained with the low-mass Drell-Yan data, as might be expected from Figure 1a. With just 100pb^{-1} of data the uncertainty on the gluon at $x = 10^{-5}$ would reduce from 20% to 5% and at $x = 2 \times 10^{-6}$ where the gluon is currently essentially unconstrained, it would have an uncertainty of 12%. These results have been obtained assuming that the predictions are reliable at such low Q^2 values. However, the form for the PDFs at very low x varies widely depending on the order of the calculation, so more work is needed here, as it is experimentally in order to extract clean signals at such low Q^2. If these issues are resolved, it will allow interesting investigations of QCD in a previously unexplored region, which could be sensitive to saturation effects.

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