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PDF uncertainties in the determination of the W boson mass and of the effective lepton mixing angle at the LHC

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The precision measurement of the W boson mass allows to perform stringent consistency tests of the Standard Model by means of global electroweak fits. The accurate determination of the W boson mass is one of the legacy results of the Tevatron, where the experimental accuracy is such that M_W is now limited by theoretical uncertainties related to the parton distributions of the proton. In this contribution, we show how to quantify the impact of PDF uncertainties in the measurement of M_W at the Tevatron and the LHC by means of a template method, and study both the use of the W transverse mass and the lepton p_T kinematical distributions to generate these templates. We also present preliminary results on the quantification of the PDF uncertainties in the determination of the effective lepton mixing angle at the LHC, based on the same template method as for the W mass determination.

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PDF uncertainties in the determination of M_W at hadron colliders. The W boson mass has been accurately measured at the Tevatron [1], where the latest combination gives a total uncertainty of about 16 MeV. PDFs are the dominant theory uncertainty in this measurement. The precision measurement of the W mass allows to perform stringent consistency test of the Standard Model by means of global electroweak fits [2]. With the same motivation, it is of utmost importance to provide a precision determination of M_W also at the LHC, and to assess the feasibility of this goal one needs first to quantify the role of PDF uncertainties, and to provide new ideas to reduce their impact in the final M_W measurement.

In order to determine ΔM_W due to PDF uncertainties, a template method was followed in Ref. [3], an strategy similar to that used by the Tevatron collaborations. In a first step, we generate pseudo-data for the W transverse mass distribution, for various PDF sets and their corresponding error sets: CTEQ6.6 [4], MSTW08 [5] and NNPDF2.1 [6]. Then, with the central CTEQ6.6 as input, we generate a large number of templates varying M_W from the reference value in a suitable range. The shift in M_W corresponding to each PDF error set is determined by the template which leads to a better χ^2 agreement with the corresponding pseudo-data. An essential ingredient of our approach is to normalize the templates to the total integral of the distribution in the fit region, since this way PDF uncertainties are substantially reduced without losing sensitivity to the value of M_W.

Templates were generated with HORACE [7] at LO and with DYNNLO [8] at NLO. Our results are summarized in Fig. 1. A conservative estimate is that PDF uncertainties in M_W fits at the LHC will not be larger than 20 MeV. Note that these results where obtained with PDF sets without LHC data, and that PDF uncertainties are likely to be reduced in PDF sets which include the LHC W and Z production data such as NNPDF2.3 [9]. Our results do not support previous studies [10], which claimed that achieving a 10 MeV accuracy on M_W at the LHC was not feasible.

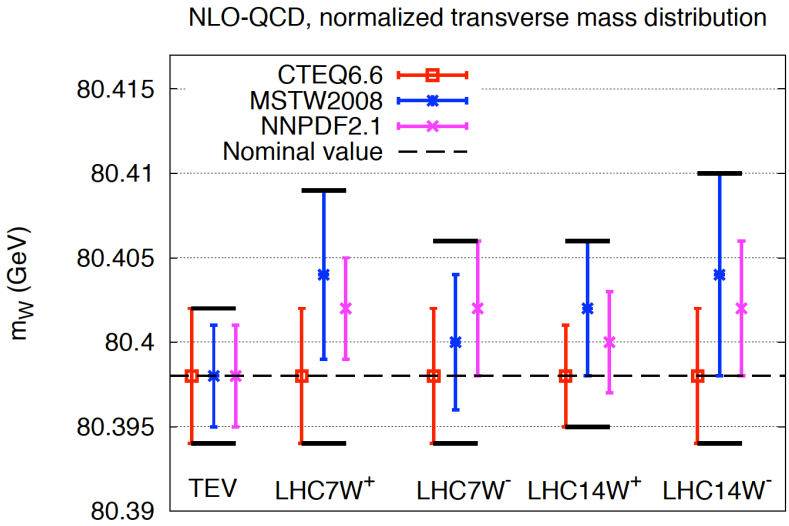

Figure 1: PDF uncertainties in the W boson determination from the transverse mass distribution at the Tevatron and the LHC. The templates for different M_W have been generated with the central CTEQ6.6 set.

In order to determine if a particular PDF combination is responsible for PDF uncertainties in M_W, it is useful to compute the correlations [11] between the $N_{\rm rep} = 100$ PDF replicas of NNPDF2.1

and the 100 determinations of M_w obtained from the template fits for each replica. The results are shown in Fig. 2. It is clear that there is not a particular range of Bjorken-x or a particular quark flavor that dominates the M_W measurement. The sensitivity to the gluon is smaller to that to quarks, consistent with the expectation that the W transverse mass distribution is stable against NLO and higher order corrections. This implies that to improve PDF uncertainties in the M_W measurement new data constraining quarks in a broad x range would be needed.

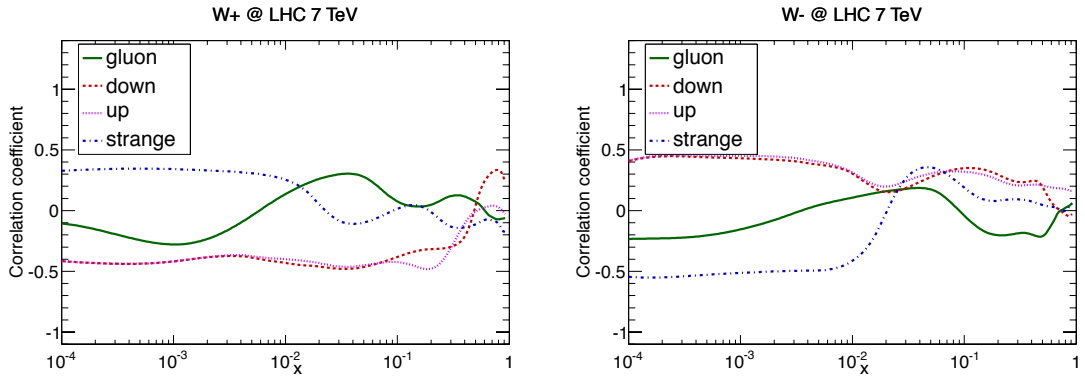

Figure 2: Correlations between different PDF flavours and the M_W determination at LHC 7 TeV, as a function of Bjorken-x. A large absolute value of the correlation coefficient indicates a strong sensitivity to a particular PDF combination.

M_W determination from the lepton p_T distribution. The previous results were based on the determination of M_W from the W transverse mass distribution. Another observable that has been used at the Tevatron is the lepton p_T distribution. Below we report preliminary work towards the extension of the results of [3] to template fits of the lepton transverse momentum [12].

As opposed to the transverse mass distribution, the lepton p_T is substantially modified by higher order corrections, given its strong correlation with the W p_T which vanishes at the Born level. For this distribution the use of resummed calculations for the W boson p_T is required, either using analytical p_T resummations or NLO calculations matched to parton showers.

The relevance of NLO corrections implies that the gluon PDF will be a more important contribution to the uncertainty in M_W than in the previous case. In order to confirm this, in Fig. 3 we show the contribution of quark-antiquark terms to the total PDF uncertainty in the transverse mass and lepton p_T distributions, computed at NLO with `DYNNLO`. Is clear that for the lepton p_T distribution the qg contributions are substantial, in particular near the Jacobian peak. Therefore, a dedicated analysis strategy should be pursued in order to limit as much as possible the contribution to ΔM_W due to the gluon PDF, such as taking ratios of W over Z distributions.

PDF uncertainties in the determination of $\sin^2\theta^l_{\rm eff}$ at the LHC. The same template methods can be used to study the role of PDF uncertainties in the determination of the effective lepton mixing angle, $\sin^2\theta^l_{\rm eff}$, at the LHC [13]. Currently, $\sin^2\theta^l_{\rm eff}$ is known accurately from global fits to LEP data. However, there is a some degree of tension between different inputs to the global electroweak fits. In particular, some of the most precise determinations of this quantity are inconsistent. Therefore, an additional independent determination of $\sin^2\theta^l_{\rm eff}$ at the LHC is potentially

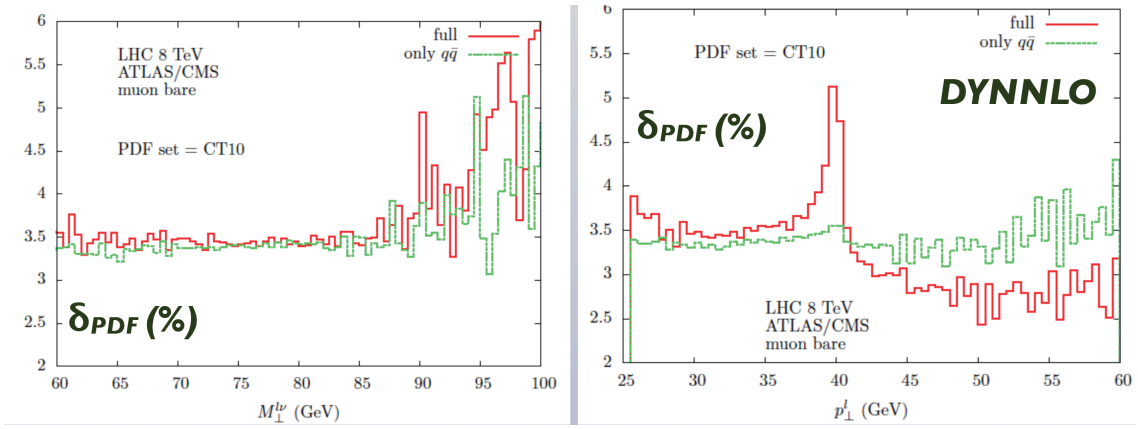

Figure 3: The total relative PDF uncertainty and the separate contribution of quark-antiquark diagrams for the transverse mass (left plot) and the lepton p_T (right plot) distributions, computed at NLO with DYNNLO.

relevant. However, the LHC determination will only be competitive with the LEP results if PDF uncertainties do not spoil the accuracy of the measurement.

Following the same approach as for M_W, we have generated pseudo-data and templates for the forward-backward asymmetry in γ^*/Z production at the LHC 7 TeV, using HORACE at LO. The templates have been generated varying the value of $\sin^2\theta^l_{\rm eff}$ from the nominal value. The binning of the templates have been optimized in order to have similar statistical uncertainties in the various bins, in the range $60 \leq M_{ll} \leq 120$ GeV. The kinematical cuts and acceptances have been selected to simulate both the typical selection cuts from ATLAS and CMS, and then for LHCb.

Preliminary results for the PDF uncertainties in $\sin^2\theta^l_{\rm eff}$ are shown in Fig. 4. The templates have been generated with the central NNPDF2.1 set. We show the results for CT10, MSTW and NNPDF2.1, as well as the current PDG uncertainty of this parameter. The central value of $\sin^2\theta^l_{\rm eff}$ in Fig. 4 is not relevant here. Our analysis seems to indicate that PDF uncertainties are quite substantial in the ATLAS/CMS acceptance, though they could be improved with the help of LHC data. On the other hand, for LHCb kinematics both the spread between different PDF sets and PDF uncertainties are small enough to suggest that the measurement of $\sin^2\theta^l_{\rm eff}$ would not be limited by PDF uncertainties. Of course, there are other sources of experimental and theory systematics that should be taken into account, but at least our exercise suggest a competitive measurement of $\sin^2\theta^l_{\rm eff}$ at the LHC could not be limited by PDF uncertainties.

While this preliminary study is certainly promising, a more reliable quantification of PDF uncertainties in $\sin^2\theta^l_{\rm eff}$ at the LHC requires to generate templates at NLO to include the contribution from gluon initiated diagrams. Work in this direction is ongoing.

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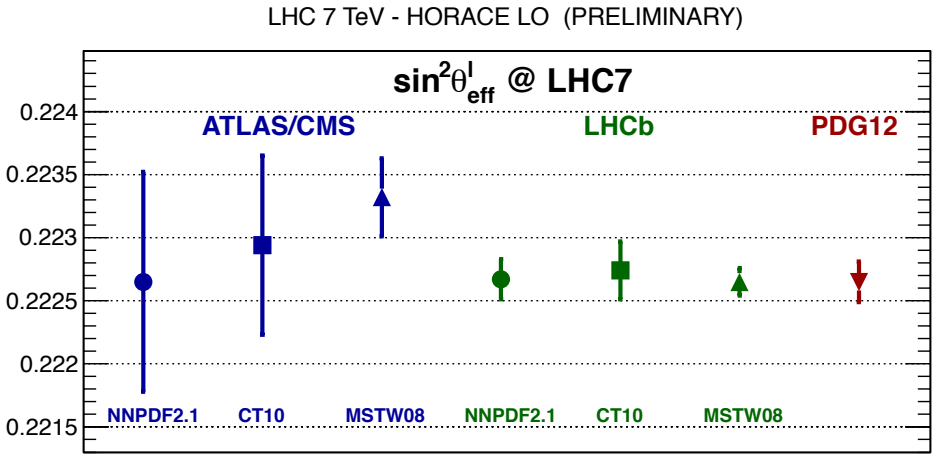

Figure 4: PDF uncertainties in the determination of $\sin^2\theta^l_{\rm eff}$ at the LHC 7 TeV, from [13]. The templates have been computed at LO with the HORACE program. We show the results for NNPDF, MSTW and CT, both for the ATLAS/CMS and the LHCb acceptances. We also show the uncertainty in the current PDF value, where the central value has been shifted to match the reference one used in the pseudo-data generation.

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