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Towards the determination of the photon parton distribution function constrained by LHC data

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We provide a discussion of the impact of a subset of Drell-Yan data from LHC on the determination of the photon parton distribution function (PDF), using the NNPDF methodology. In previous work we have shown that the photon PDF determined from deep-inelastic scattering (DIS) data only has large uncertainties, suggesting the need for more data from other processes such as Drell-Yan, which unlike DIS, includes photon-induced contributions at leading order in QED. We describe the inclusion of ATLAS Drell-Yan W, Z/γ^* data, which is a subset of the LHC data used in a final photon PDF determination, by means of a reweighting procedure. We show the impact of such data by comparing the reweighted photon PDF with the photon PDF from DIS, highlighting the reduction of uncertainties at medium/small-x. We conclude that the Drell-Yan data from LHC allows a reasonably accurate determination of the photon PDF.

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1. Introduction

In Ref. [1] we have shown, using the latest NNPDF technology [2], that the photon parton distribution function (PDF) obtained from deep inelastic scattering (DIS) data has large uncertainties. Furthermore, by computing with HORACE [3] the $Z \to \mu^+\mu^-$ production in proton-proton collision, we have confirmed that the photon PDF from DIS is not sufficiently precise for the level of accuracy required by the LHC physics.

The large uncertainties of the photon PDF from DIS are due to the lack of photon-induced contributions to DIS processes, when including QED corrections up to leading order (LO) in α (i.e. $O(\alpha)$) to PDFs. A possible cure for this issue is the inclusion of Drell-Yan data where there are photon-induced contributions at $O(\alpha)$: for example in Z/γ^* production the $\gamma\gamma \to l^+l^-$ process.

Here we present the determination of the photon PDF, for a PDF set which is determined at NLO in QCD and LO in QED, by including a subset of Drell-Yan data from LHC. Currently, fast interface codes for QCD computations do not include contributions from photon PDFs, so we decided to include these data through a reweighting procedure. In short, the reweighting assigns weights to PDF replicas which satisfies the new data by computing the χ^2 between the new experimental data and theoretical predictions obtained from each replica. Technical details about the reweighting and unweighting procedure are presented in Ref. [4, 5] and will not be discussed here.

2. Reweighting with ATLAS data

We start the reweighting procedure by creating a prior PDF set with 500 replicas, combining the photon PDF from DIS with five copies of the NNPDF2.3 NLO set [2] at the initial scale $Q_0^2 = 2$ GeV^2 and then evolving with the combined QCD+QED DGLAP evolution equations. The prior PDF set thus defined preserves the prediction accuracy of a global set for pure QCD computations: indeed we have explicitly verified that PDF sets with and without QED corrections are statistically equivalent which means that the corrections to the quark and gluon due to their mixing with the photon are indistinguishable from statistical fluctuations. Also, the violation of the momentum sum rule due to the inclusion of the photon PDF is less than 1%.

We perform reweighting with two LHC data sets: ATLAS W, Z/γ^* rapidity distributions [6] and ATLAS Drell-Yan high mass differential cross-section [7]. These data sets provide constraints to the photon PDF at medium and large-x thanks to the presence of photon-induced contributions in the Z/γ^* and W production. The QCD computation is performed with APPLGRID [8] for ATLAS $W, Z/\gamma^*$ rapidity distributions data and DYNNLO [9] for ATLAS Drell-Yan high mass data, while, in both cases we have computed the Born and NLO photon-induced contributions with HORACE [3], knowing that NLO contributions have a very small effect.

Figure 1 shows the weights and $P(\alpha)$ distributions, defined in [4], for the present reweighting. Recall that α is the rescaling of the covariance matrix: $\alpha = 1$ means that uncertainties are correctly estimated. From these distributions we conclude that the procedure is consistent and that the data is compatible with the reweighted PDF set. After performing the reweighting we obtain a total number of effective replicas of $N_{\text{eff}} = 266$ and the χ^2 to the ATLAS data is reduced from 1.98 to 1.14. In Table 1 we collect the χ^2 and $P(\alpha)$ values for the individual reweighting procedure, looking at the χ^2 values before and after reweighting we confirm that data far from the W, Z/γ^*

NLO	ATLAS all	ATLAS W, Z/γ^*	ATLAS DY high mass
χ^2_{in}	1.98	1.20	3.78
χ^2_{rw}	1.14	1.15	1.01
N_{eff}	266	364	326
$\langle\alpha\rangle$	1.48	1.24	1.53

Table 1: Reweighting properties: χ^2_{in} and χ^2_{rw} are before and after reweighting, respectively; N_{eff} is the number of effective replicas; $\langle\alpha\rangle$ is the average rescaling of the covariance matrix.

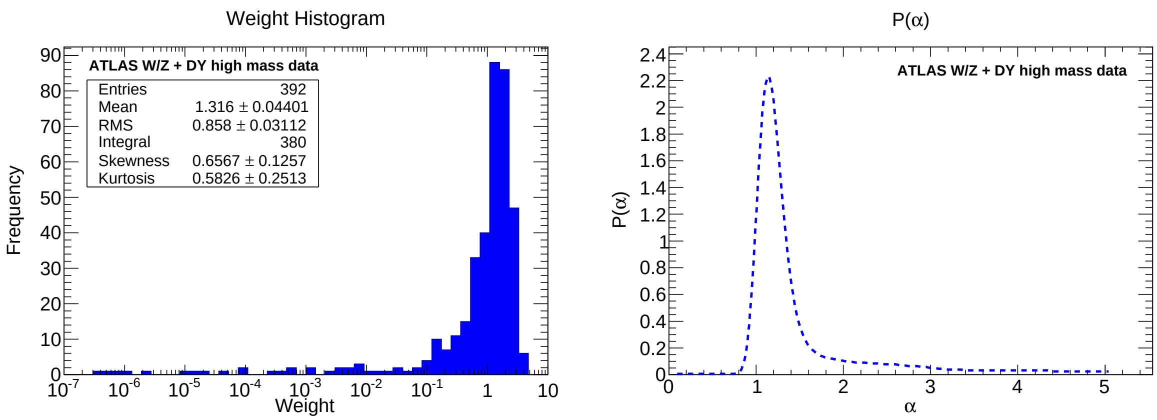

Figure 1: On the left, the distribution of weights after performing the reweighting with ATLAS W, Z/γ^* rapidity data and ATLAS Drell-Yan high mass data. The prior set of $N_{\mathrm{rep}} = 500$ replicas after the reweighting procedure is reduced to $N_{\mathrm{eff}} = 266$ effective replicas. On the right, the associated $P(\alpha)$ distribution.

peaks, where the photon contribution is substantial, contributes strongly to constrain the photon PDF.

Figure 2 shows a comparison between ATLAS data and theoretical predictions computed with NNPDF2.3 NLO, with and without photon-induced contributions using the photon PDF obtained after the reweighting procedure. Again, the comparison shows that the Z/γ^* high mass production provides the most relevant information to constrain the photon PDF.

3. Unweighting the photon PDF

Following the procedure presented in Ref. [5] we construct an unweighted photon PDF set. Figure 3 shows the comparison between the photon PDF before and after performing the reweighting with ATLAS data, in logarithmic scale (left) and linear scale (right). We observe a significant reduction of the uncertainties which essentially overlaps with the coverage in x of the ATLAS data used in the reweighting. It is interesting to observe that the central value is also substantially reduced. This means that the central value from the DIS fit is mostly determined by statistical fluctuations.

Figure 4 shows the details of the unweighted photon PDF set with $N_{\mathrm{rep}} = 100$ replicas. Also in this example, the current reweighted photon PDF in comparison to the photon PDF from DIS has small central values and smaller uncertainties at medium/small-x, improving the quality of

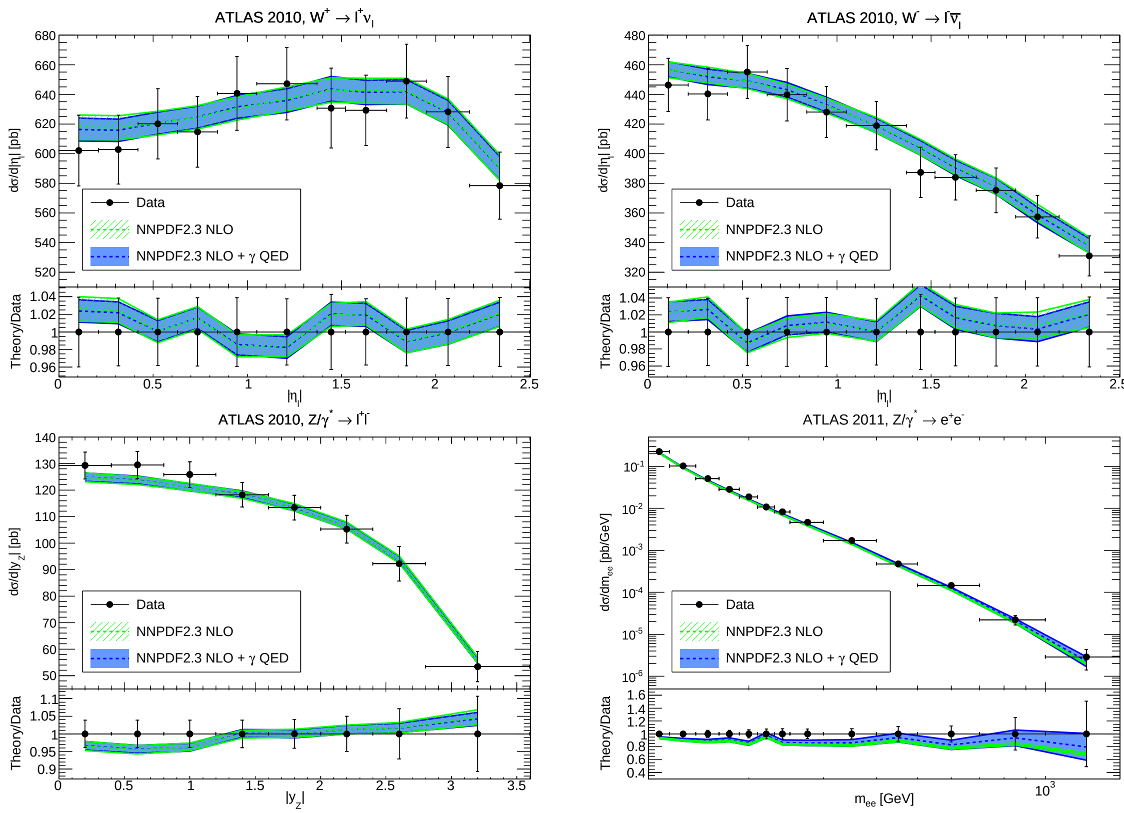

Figure 2: Comparison between experimental data and theoretical predictions computed with NNPDF2.3 NLO for each data set, with (blue lines) and without (green lines) photon-induced contributions.

theoretical predictions. On the other hand, we observe that at very small-x the photon PDF has large uncertainties, because the ATLAS data does not cover this region.

4. Outlook

In conclusion, the Drell-Yan LHC data from ATLAS reduces the photon PDF uncertainties at medium/small-x, providing a much more constrained and reliable photon PDF in comparison to the results obtained by fitting DIS-only data.

Here we have shown only the impact of ATLAS data to the photon PDF. In a the final photon PDF set [10] we will also include the LHCb low mass data, which reduces uncertainties at very small-x. This will provide the first extraction of a modern photon PDF with uncertainties and constrained by LHC data. Further improvements of the photon PDF uncertainties will be possible when more LHC data will be available, specifically, measurements of *WW* production which at high energy scales constrains the photon PDF at large-x.

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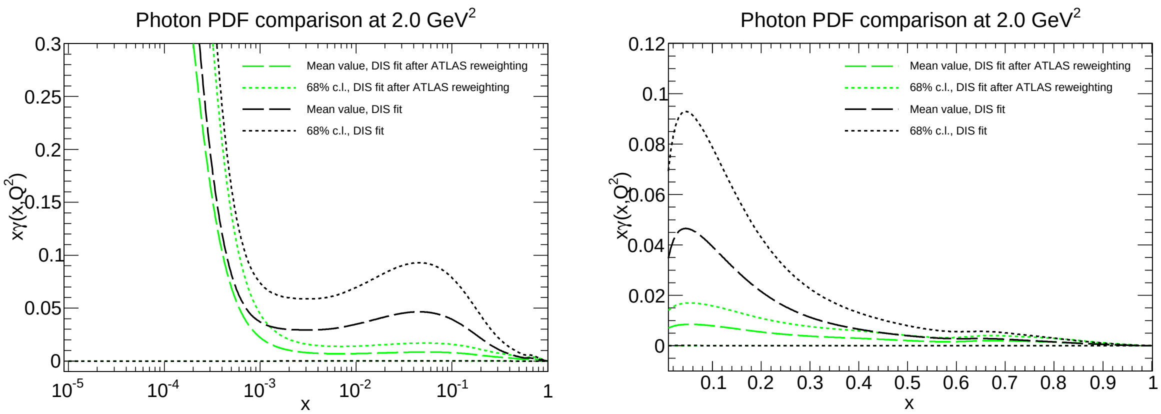

Figure 3: Direct comparison between the photon PDF before (black lines) and after (green lines) the reweighting procedure. The reweighted photon PDF uncertainties are reduced at medium/small-x. The 68% c.l. band is defined from the PDF mean value.

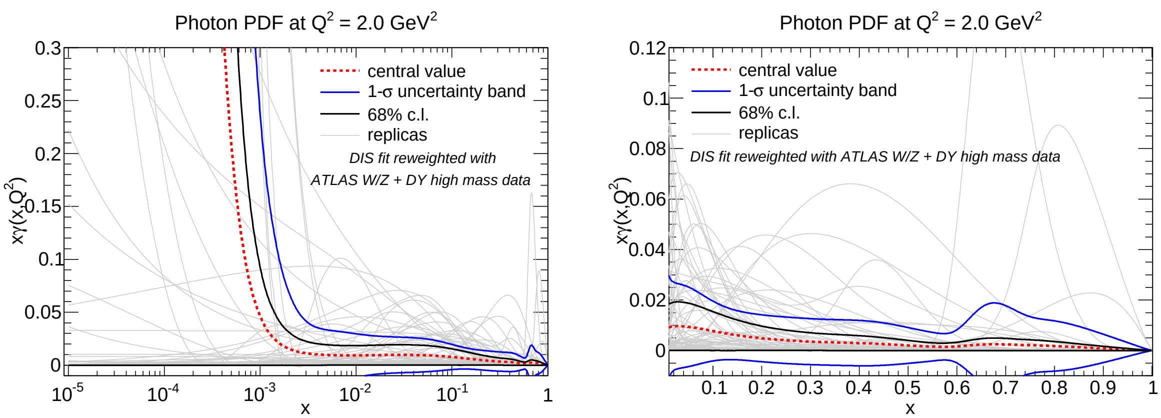

Figure 4: The unweighted photon PDF at $Q_0^2 = 2$ GeV^2 obtained after the reweighting procedure with ATLAS W, Z/γ^* rapidity data and ATLAS Drell-Yan high mass data. The PDF set includes 100 replicas.

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