

PDFs with QED corrections

NNPDF2.3QED: Parton distributions with QED corrections

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on behalf of the NNPDF and the APFEL collaborations
arXiv:1308.0598 and arXiv:1310.1394



Introduction to NNPDF2.3QED

- NNPDF2.3QED set is our latest release: [\[arXiv:1308.0598\]](https://arxiv.org/abs/1308.0598)
 - ▶ it includes the **photon PDF** $\gamma(x, Q)$, where
 - ▶ PDFs are **LO/NLO/NNLO** in QCD + **LO** in QED
- **QED corrections** to PDFs are unavoidable for the LHC phenomenology.
- The presence of the photon PDF $\gamma(x, Q)$ allows for the inclusion of **photon-induced processes** in the computation of predictions.
- The photon PDF $\gamma(x, Q)$ in NNPDF2.3QED is:
 - ▶ parametrized by a 2-5-3-1 Neural Network and **fitted to data**
 - ★ no model assumption
 - ▶ determined from **DIS and LHC data**
 - ★ DIS: 2767 data points, e.g. $F_2^{\gamma,p}$, $F_2^{\gamma,d}$, dimuon CC cross-section
 - ★ LHC: 52 data points, W, Z rapidity and γ^*/Z high and low mass DV



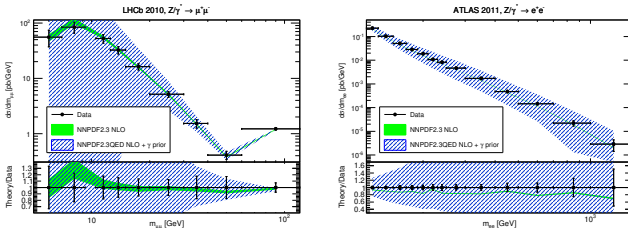
Technical aspects NNPDF2.3QED determination

- In order to achieve our goal we had to implement the following steps:
 - ① Modify PDF evolution (DGLAP)
 - ★ **QCD (LO/NLO/NNLO) + QED (LO)**
 - ② Rewrite observables by including the photon contribution
 - ③ Perform a fit to DIS data with QED corrections
 - ★ **NNPDF2.3QED DIS-only, $N_{rep} = 500$**
 - ④ Combine the photon PDF from DIS-only with quark and gluons from the global NNPDF2.3 set, replace DGLAP
 - ★ **Construction of the NNPDF2.3QED prior**
 - ⑤ Compute predictions for LHC $W, Z/\gamma^*$ production
 - ★ **Reweight the NNPDF2.3QED prior**
 - ⑥ Unweight the reweighted PDF set:
 - ★ **Final NNPDF2.3QED set with $N_{rep} = 100$**

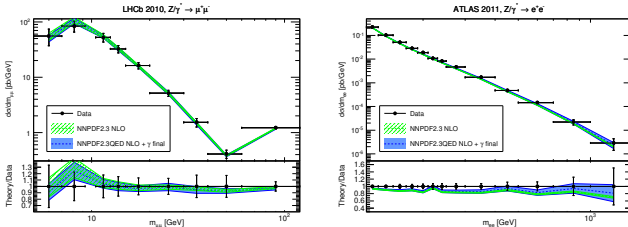


Importance of LHC data

- **LHC electroweak vector boson data** is absolutely needed
 - ▶ reduces drastically the **photon PDF uncertainties**.
- Example: LHC predictions **before including LHC data** (DIS-only):

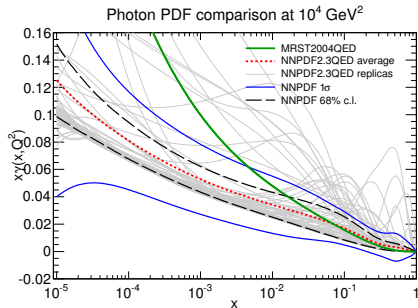
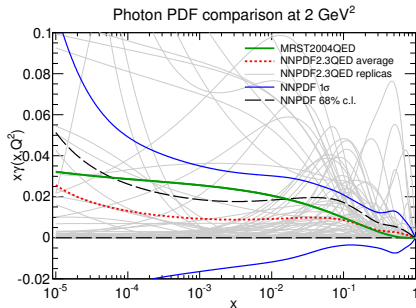


- Example: LHC predictions **after including LHC data**:



NNPDF2.3QED: the photon PDF

- Photon PDF comparison with MRST2004QED at 2 and 10^4 GeV²:

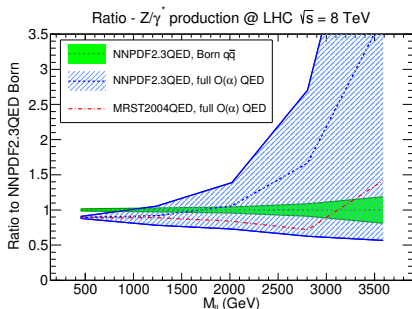
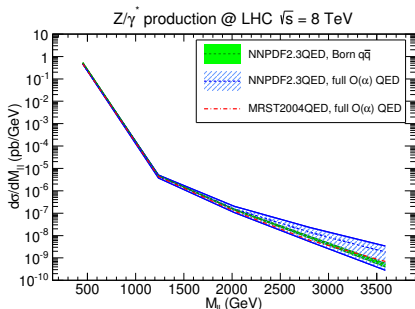


- First determination of the photon PDF uncertainty.
- Good agreement with MRST2004QED model at large- x .
- The photon PDF momentum fraction is less than 1%.



NNPDF2.3QED phenomenology

- Potential large impact on the LHC High-mass Drell-Yan production due to lack of constrains on the photon PDF at large- x .

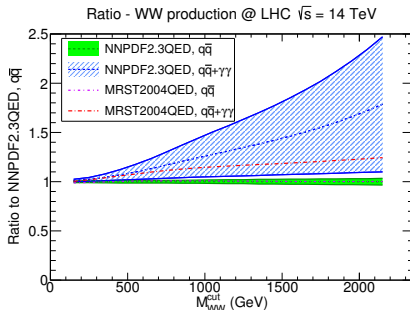
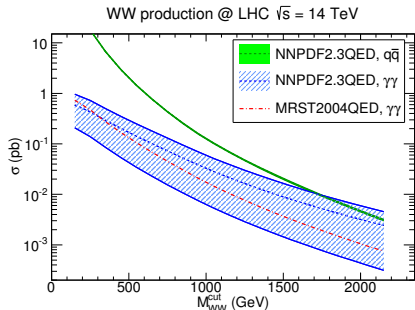


- Results obtained with HORACE [[arXiv:0710.1722](https://arxiv.org/abs/0710.1722)], show that the photon PDF can improve/change limits for BSM models, e.g. Z' .



NNPDF2.3QED phenomenology for precision physics

- Photon-induced processes have large impact on high-mass WW production. (results from T. Kasprzik [arXiv:1208.3147])



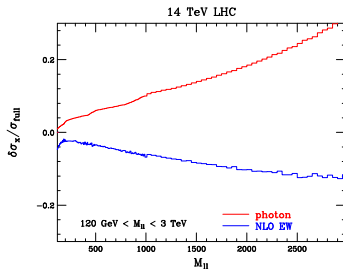
Conclusion The photon PDF opens new scenarios for phenomenology, but in parallel suggests new measurements in order to constrain and reduce its uncertainties.



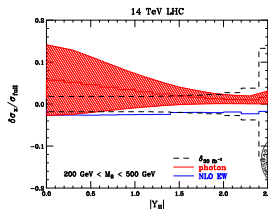
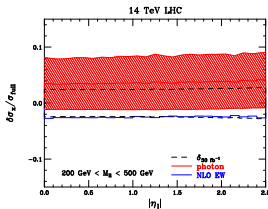
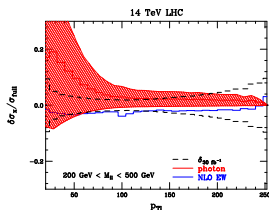
NNPDF2.3QED: more LHC phenomenology

- Recent work about radiative corrections using high-mass Drell-Yan at the LHC shows more details about the impact of NNPDF2.3QED photon PDF at LHC [Boughezal, Li, Petriello, arXiv:1312.3972]

- Photon-induced processes introduce differences up to +30% at $M_{ll} \sim 3$ TeV.



- Isolating observables and regions where the photon PDF enhances the predictions: p_T , $|\eta|$, $|Y|$ distributions.

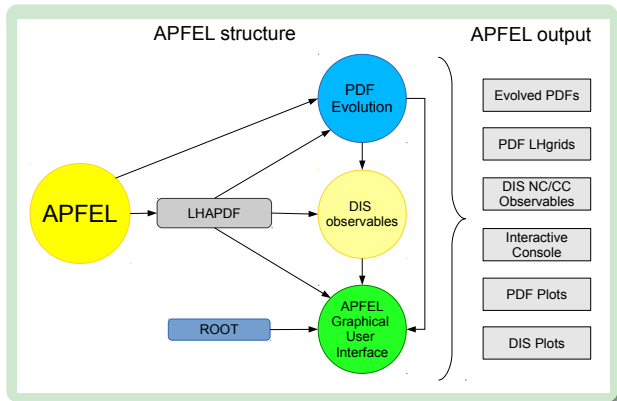


Introduction to APFEL

- **APFEL** is a **public** PDF evolution library with **QED corrections** developed by product of the NNPDF2.3QED sets. [V. Bertone, S.C., Juan Rojo, arXiv:1310.1394]

<http://apfel.hepforge.org/>

- **APFEL** is composed by **three modules**: DGLAP, DIS, GUI:



APFEL evolution features

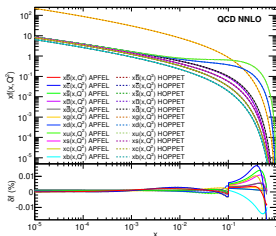
- APFEL evolution features:

- ▶ up to **NNLO** in **QCD** and **LO** in **QED**,
- ▶ **FFNS** and **VFNS** solution in x-space,
- ▶ Pole and $\overline{\text{MS}}$ heavy quark masses

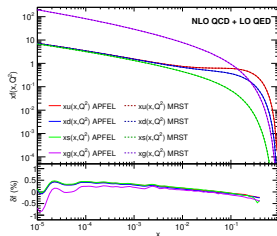
- Technical features:

- ▶ interface to **LHAPDF5** (input/output)
- ▶ interfaces in **Fortran**, **C/C++** and **Python**, interactive console.

- Benchmark against HOPPET, partonevolution, MRST2004QED [[arXiv:1310.1394](https://arxiv.org/abs/1310.1394)]



(a) HOPPET vs APFEL (QCD)



(b) MSTW04 vs APFEL



APFEL DIS module

- The **DIS module**:

- ▶ Computation of **DIS observables**:

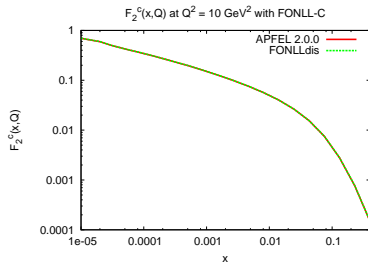
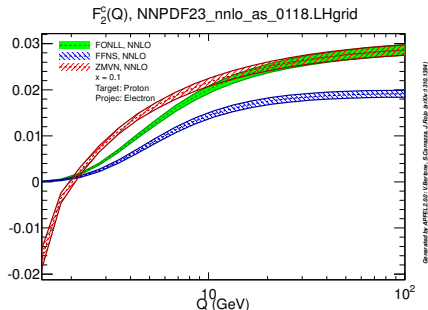
- ★ all the **NC** and **CC** observables: F_2, F_1, F_3 and reduced cross sections

- ▶ Up to order α_s^2 (when possible)

- ▶ Schemes: **FONLL**, **FFNS** and **ZM-VFNS**,

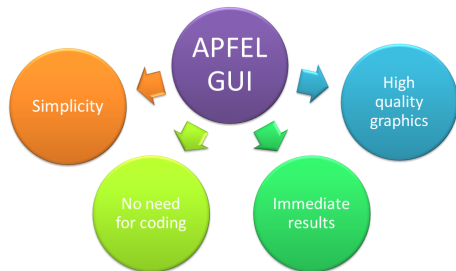
- ▶ Interface to **APFEL evolution** and/or **LHAPDF**

- Benchmark of NC F_2 against FONLLdis [arXiv:1001.2312]



APFEL Graphical User Interface

- Why a **Graphical User Interface (GUI)**?



APFEL GUI

- ▶ PDF plots: **all LHAPDF grids**
 - ★ PDF error treatment
- ▶ Evolution performed by
 - ★ APFEL and/or LHAPDF
- ▶ Computation of Luminosities
- ▶ Computation of DIS observables

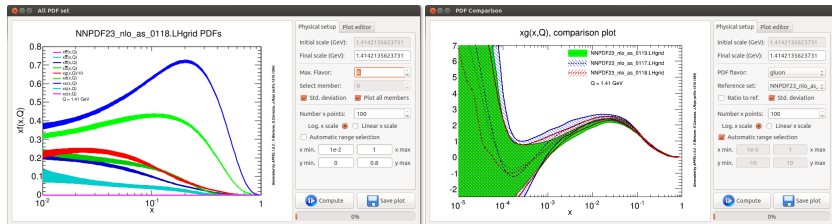
- APFEL GUI:

- ▶ System requirements: ROOT, LHAPDF5, Qt4
- ▶ <http://apfel.hepforge.org/download.html>

- Plots cross-checked against “PDF benchmarking 2012” [[arXiv:1211.5142](https://arxiv.org/abs/1211.5142)]



- Possibility to select and tune the evolution of every single PDF set.
 - ▶ takes as input **PDFs from LHAPDF** and/or the **internal APFEL toy**.
 - ▶ simple and intuitive **customization** of the PDF evolution.
- Functionalities:
 - ▶ compares multiple **PDF sets**
 - ▶ compares **luminosities**: gg , $q\bar{q}$, qg , $c\bar{c}$, $b\bar{b}$, cg , bg , qq , $\gamma\gamma$, γg .
 - ▶ compares **DIS observables** with different schemes.



- Planning to release a **online web application** based on APFEL GUI.



Summary and Outlook

● Summary:

- ▶ NNPDF2.3QED is a modern PDF set with
 - ★ **QED corrections**
 - ★ the **photon PDF** extracted from data with **uncertainties**
- ▶ APFEL is a
 - ★ **PDF evolution library** with QCD+QED combination
 - ★ **DIS observables code** based on FONLL
 - ★ GUI: a complete **PDF analysis tool**

● Outlook (*coming soon*):

- ▶ **NNPDF3.0 release before summer**
 - ★ inclusion of more LHC data, e.g. jets, double differential Drell-Yan
 - ★ updated methodology based on closure tests
- ▶ **APFEL**
 - ★ possibility to modify/generate **APPLgrid** tables
 - ★ web application interface to APFEL GUI
 - ★ small-x corrections



NNPDF2.3QED sets

- NNPDF2.3QED are available directly from LHAPDF5 and LHAPDF6.
- Sets are also available from our website: <http://nnpdf.hepforge.org/>

NNPDF2.3QED grids

Proton NLO grids	Neutron NLO grids
NNPDF23_nlo_as_0117_qed	NNPDF23_nlo_as_0117_qed_neutron
NNPDF23_nlo_as_0118_qed	NNPDF23_nlo_as_0118_qed_neutron
NNPDF23_nlo_as_0119_qed	NNPDF23_nlo_as_0119_qed_neutron

Proton NNLO grids	Neutron NNLO grids
NNPDF23_nnlo_as_0117_qed	NNPDF23_nnlo_as_0117_qed_neutron
NNPDF23_nnlo_as_0118_qed	NNPDF23_nnlo_as_0118_qed_neutron
NNPDF23_nnlo_as_0119_qed	NNPDF23_nnlo_as_0119_qed_neutron

- We provide special sets for Monte Carlo event generators, including Pythia8 and aMC@NLO through a stand-alone driver in Fortran and C++.

Special NNPDF2.3QED grids for MCs (positive defined):

Proton LO grids	Proton LO grids (only replica 0)
NNPDF23_lo_as_0119_qed	NNPDF23_lo_as_0119_qed_mem0
NNPDF23_lo_as_0130_qed	NNPDF23_lo_as_0130_qed_mem0

Proton NLO grids	Proton NLO grids (only replica 0)
NNPDF23_nlo_as_0119_qed_mc	NNPDF23_nlo_as_0119_qed_mc_mem0

Proton NNLO grids	Proton NNLO grids (only replica 0)
NNPDF23_nnlo_as_0119_qed_mc	NNPDF23_nnlo_as_0119_qed_mc_mem0

