APFEL
Improvements and Developments

arXiv:1310.1394

Valerio Bertone

CERN

HERAFitter External Meeting

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In collaboration with Stefano Carrazza and Juan Rojo

Recap on APFEL

Main Features

- APFEL is a **public** library with:
  - QCD+QED DGLAP evolution up to NNLO in QCD and LO in QED.
  - Module for the computation of DIS NC and CC observables up to NNLO in different mass schemes (ZM-VFNS, FFNS and FONLL).
  - Pole and $\overline{\text{MS}}$ heavy quark masses.
  - interfaces to FORTRAN, C/C++ and Python.
  - interfaced to LHAPDF 5 and 6 (both input and output).
  - Graphical User Interface (GUI).
  - publicly available from http://apfel.hepforge.org.
  - Amazing Web Interface: http://apfel.mi.infn.it

The Web Interface

apfel.mi.infn.it

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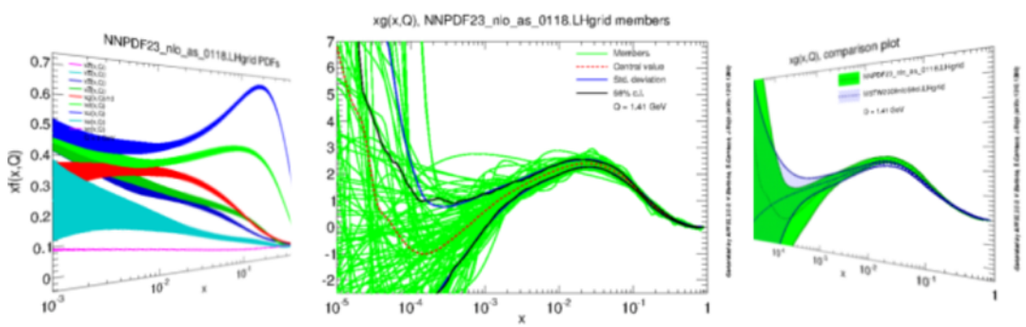
APFEL Web Contact Sign up Login

Welcome to APFEL online cluster!

This web-application is a tool designed for High Energy Physics by providing a simple and intuitive interface to plot and compute the most common observables with Parton Distribution Functions (PDFs).

To begin to produce on-line plots, please register and login!



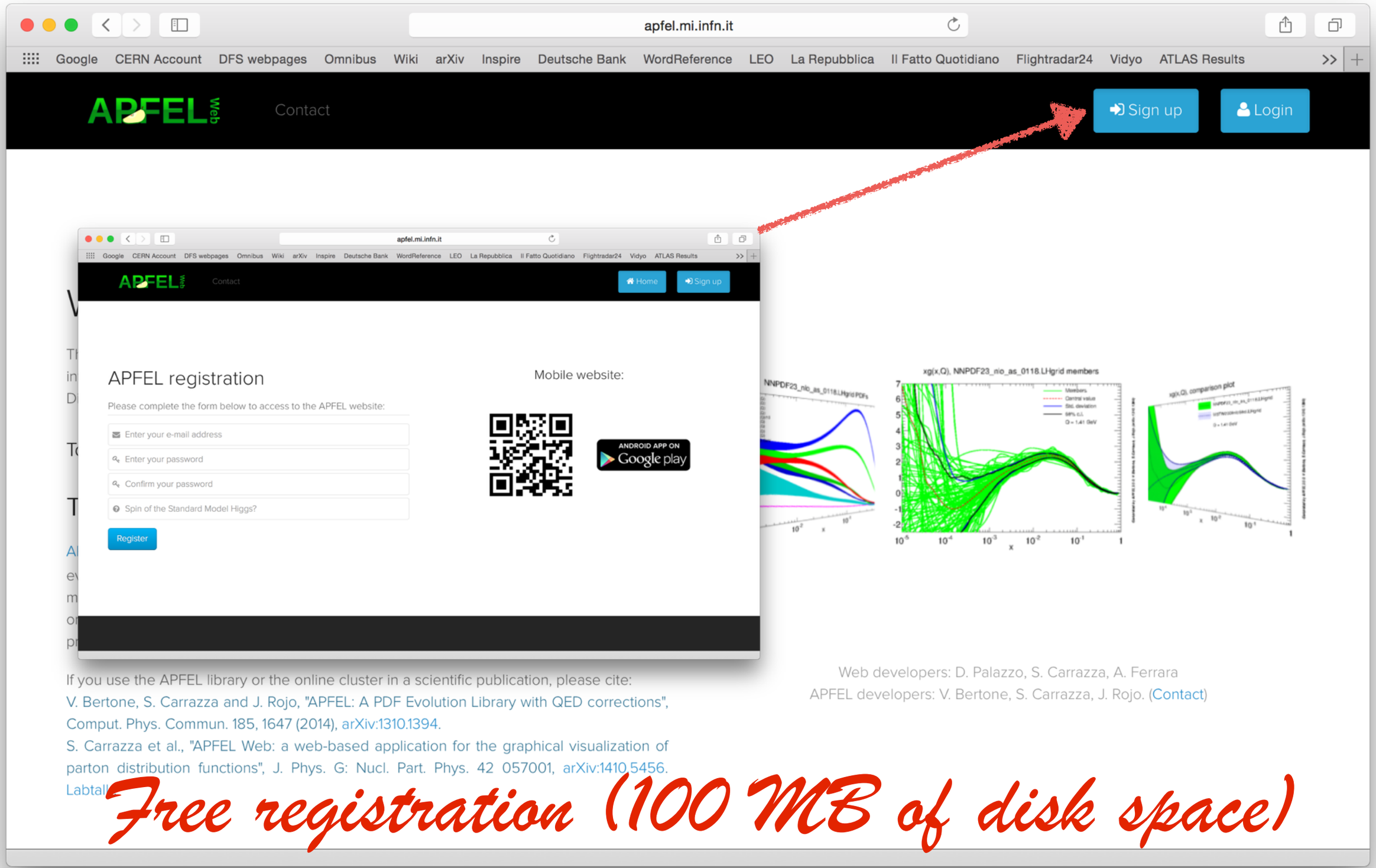
The APFEL library

APFEL, a PDF evolution library, is a computer library specialized in the solution of DGLAP evolution equations up to NNLO in QCD and to LO in QED, both with Pole and $\overline{\mathrm{MS}}$ masses. With APFEL you can replace the evolution of LHAPDF sets and check the impact on the choice of evolution parameters. APFEL also computes deep-inelastic scattering processes using multiple schemes.

If you use the APFEL library or the online cluster in a scientific publication, please cite:
V. Bertone, S. Carrazza and J. Rojo, "APFEL: A PDF Evolution Library with QED corrections", Comput. Phys. Commun. 185, 1647 (2014), arXiv:1310.1394.
S. Carrazza et al., "APFEL Web: a web-based application for the graphical visualization of parton distribution functions", J. Phys. G: Nucl. Part. Phys. 42 057001, arXiv:1410.5456. Labtalk.

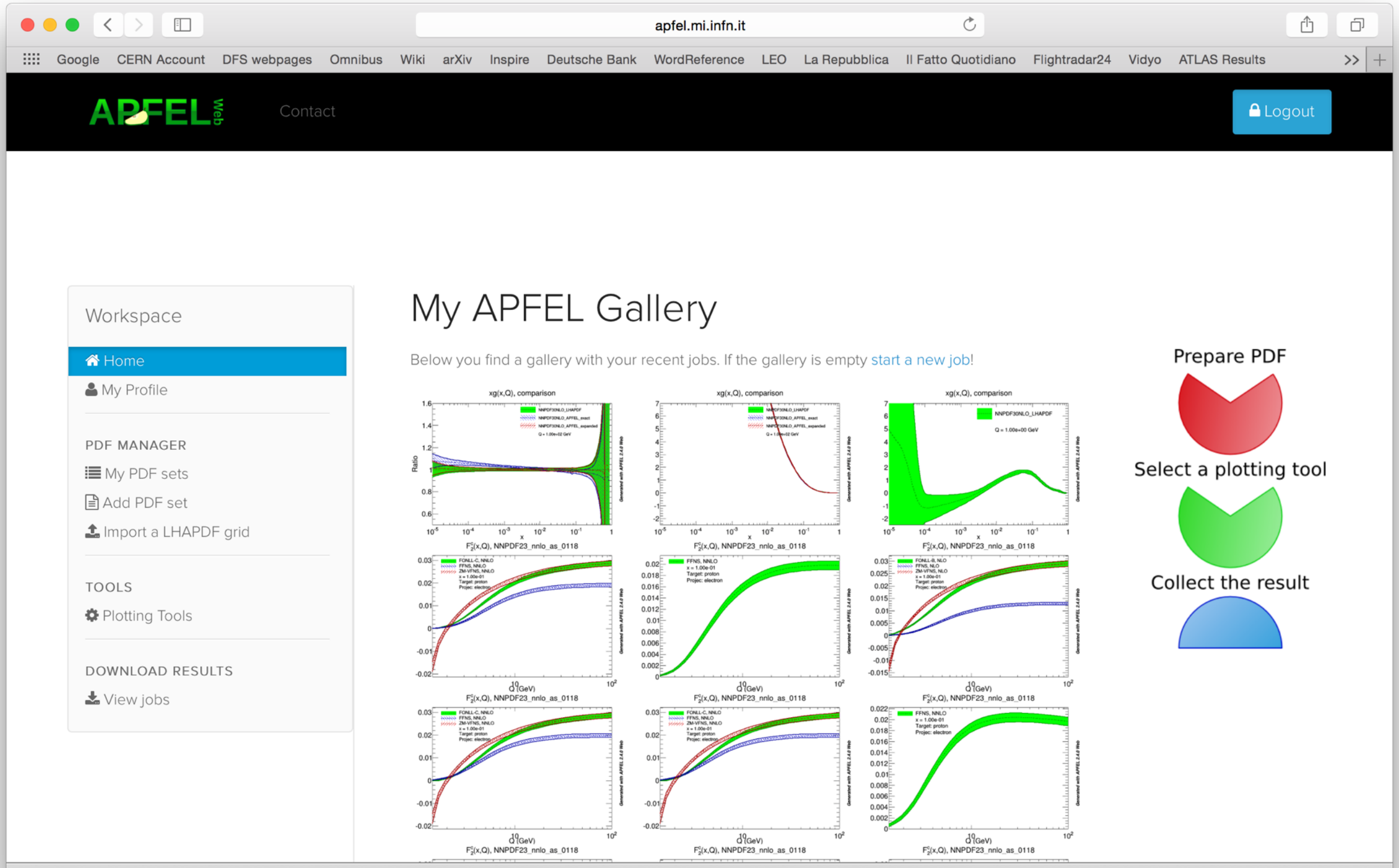
Web developers: D. Palazzo, S. Carrazza, A. Ferrara
APFEL developers: V. Bertone, S. Carrazza, J. Rojo. (Contact)

The Web Interface



Free registration (100 MB of disk space)

The Web Interface



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APFEL Web Contact Logout

Workspace

- Home
- My Profile

PDF MANAGER

- My PDF sets
- Add PDF set
- Import a LHAPDF grid

TOOLS

- Plotting Tools

DOWNLOAD RESULTS

- View jobs

Select your PDF and choose a plotting tool

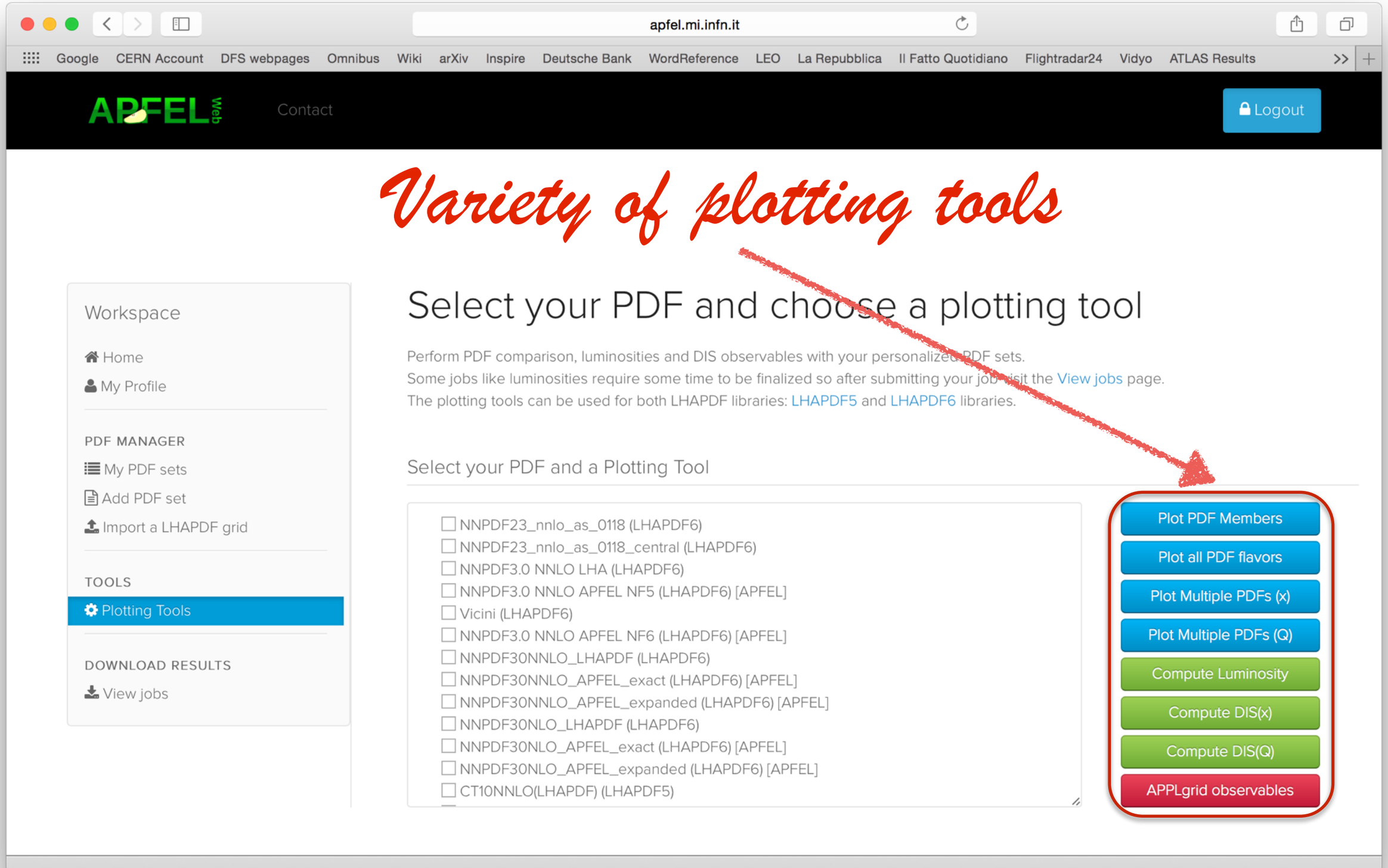
Perform PDF comparison, luminosities and DIS observables with your personalized PDF sets.
Some jobs like luminosities require some time to be finalized so after submitting your job visit the View jobs page.
The plotting tools can be used for both LHAPDF libraries: LHAPDF5 and LHAPDF6 libraries.

Select your PDF and a Plotting Tool

- NNPDF23_nnlo_as_0118 (LHAPDF6)
- NNPDF23_nnlo_as_0118_central (LHAPDF6)
- NNPDF3.0 NNLO LHA (LHAPDF6)
- NNPDF3.0 NNLO APFEL NF5 (LHAPDF6) [APFEL]
- Vicini (LHAPDF6)
- NNPDF3.0 NNLO APFEL NF6 (LHAPDF6) [APFEL]
- NNPDF30NNLO_LHAPDF (LHAPDF6)
- NNPDF30NNLO_APFEL_exact (LHAPDF6) [APFEL]
- NNPDF30NNLO_APFEL_expanded (LHAPDF6) [APFEL]
- NNPDF30NLO_LHAPDF (LHAPDF6)
- NNPDF30NLO_APFEL_exact (LHAPDF6) [APFEL]
- NNPDF30NLO_APFEL_expanded (LHAPDF6) [APFEL]
- CT10NNLO(LHAPDF) (LHAPDF5)

Plot PDF Members
Plot all PDF flavors
Plot Multiple PDFs (x)
Plot Multiple PDFs (Q)
Compute Luminosity
Compute DIS(x)
Compute DIS(Q)
APPLgrid observables

The Web Interface



Recent Developments

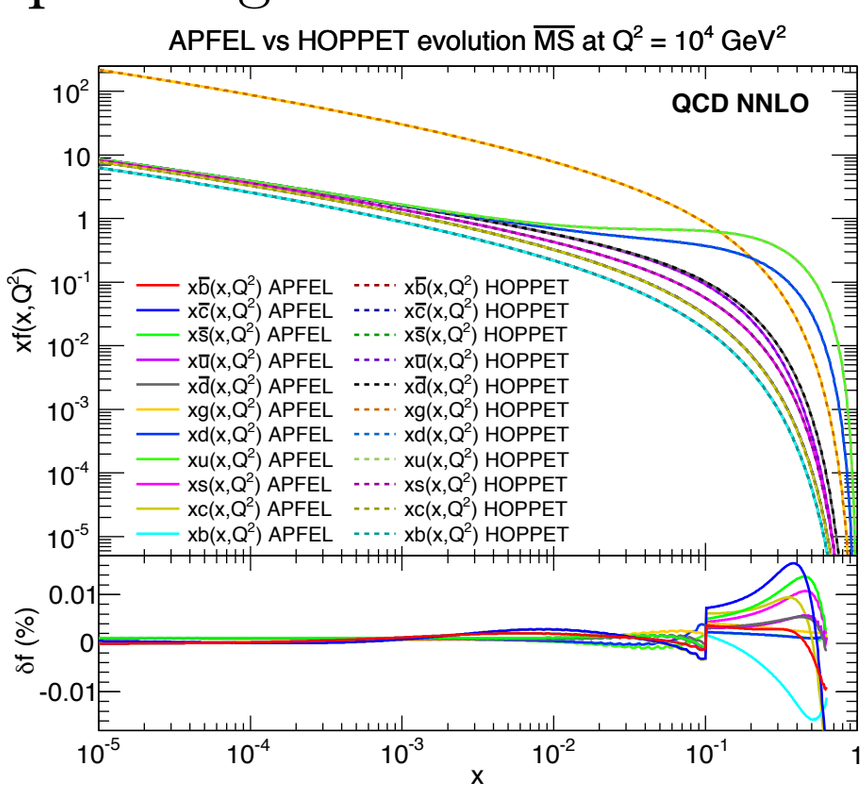
FONLL Structure Functions with MSbar Masses

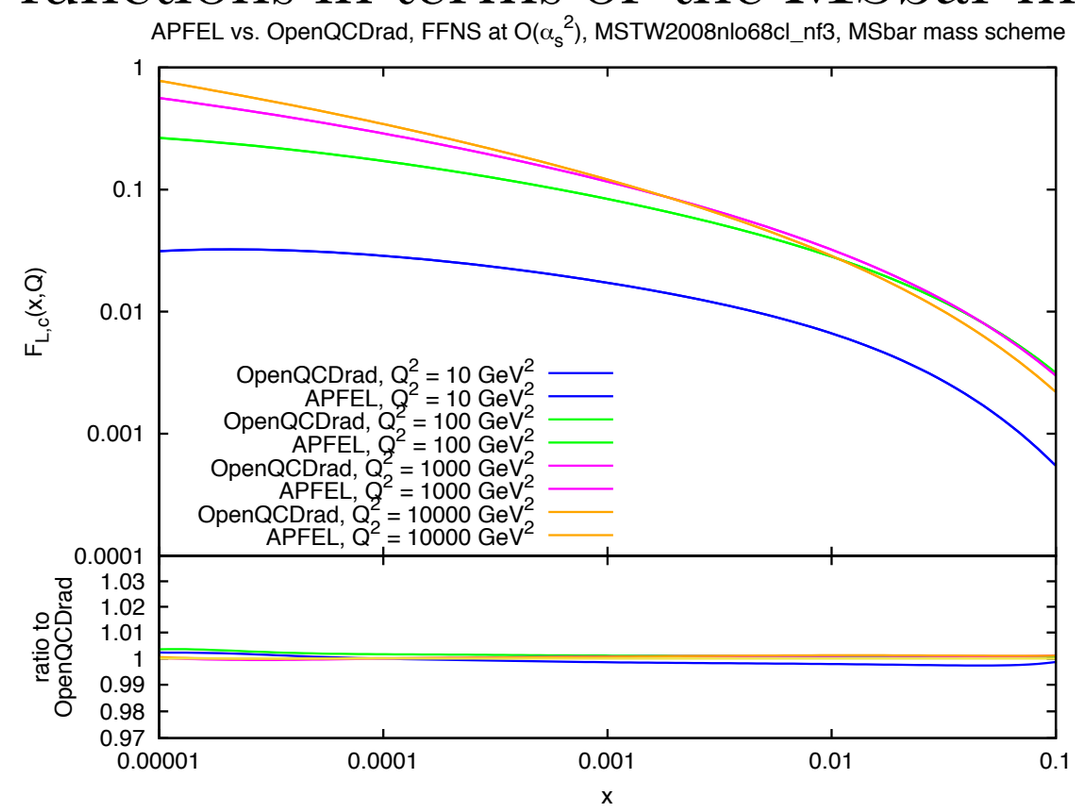
- APFEL implements also the MSbar scheme for the treatment of the heavy quark masses.

- When considering MSbar masses in a PDF fit, there are two aspects to be considered:

  1. different threshold matching conditions for the evolution of PDFs, α_s and (possibly) heavy quark masses themselves (relevant at NNLO in the VFNS),

  2. expressing the massive structure functions in terms of the MSbar masses.





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  2. expressing the massive structure functions in terms of the MSbar masses.

- Both these modifications are implemented in APFEL. Two possible approaches to the second aspect:

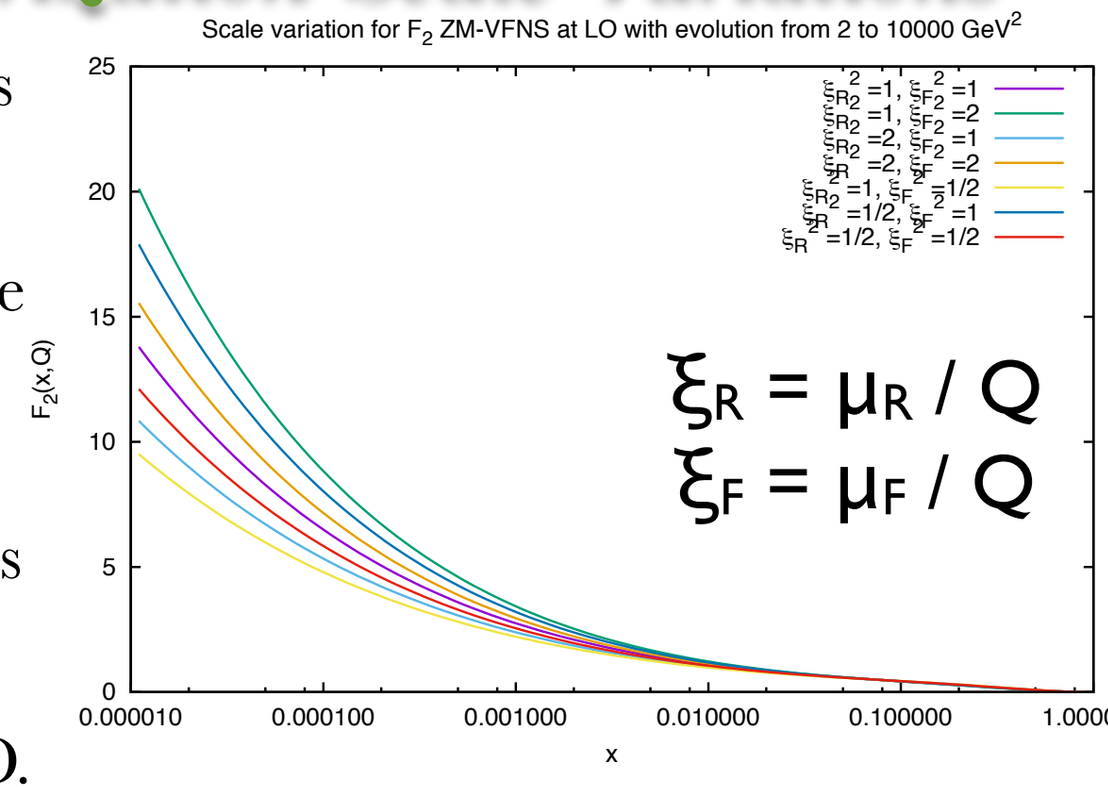
  - the conversion *pole* → *MSbar* masses is done at the heavy quark mass scale m and the dependence on the renormalization scale μ is restored by expressing $\alpha_s(m)$ in terms of $\alpha_s(\mu)$ (no running of the heavy quark masses).

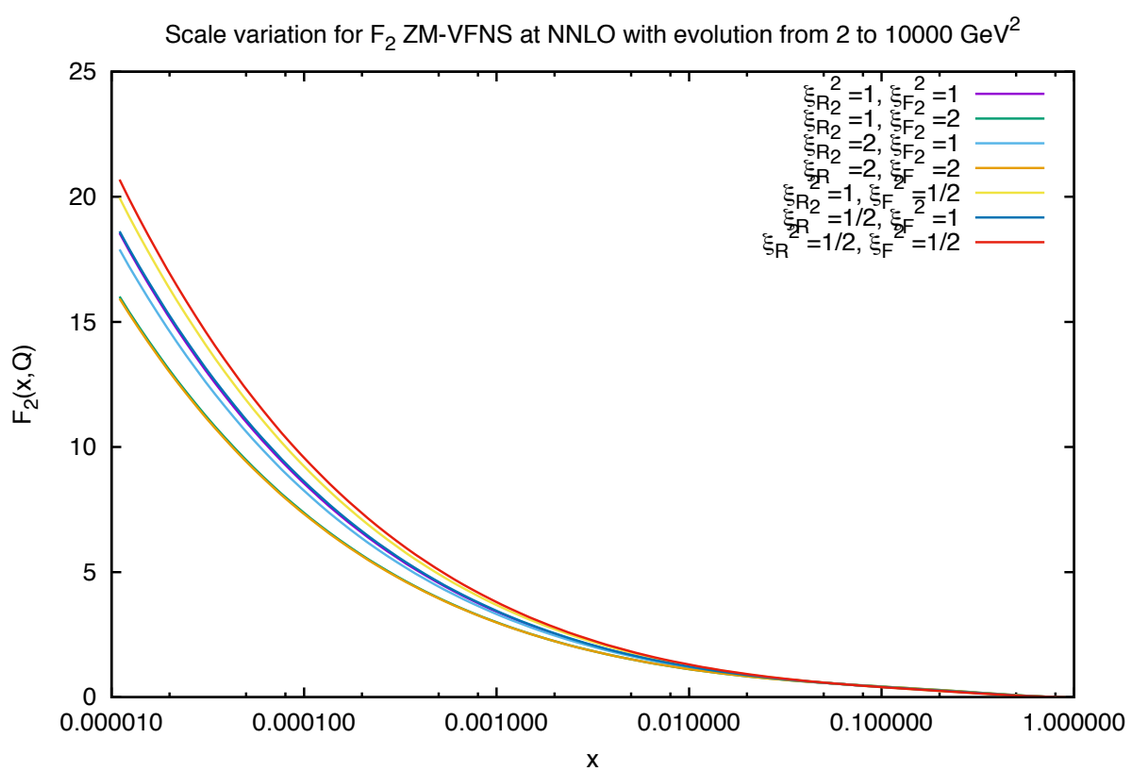
  - the conversion *pole* → *MSbar* masses is done at the arbitrary scale μ and the value of $m(\mu)$ is computed from the value $m(m)$ using the RG equation.

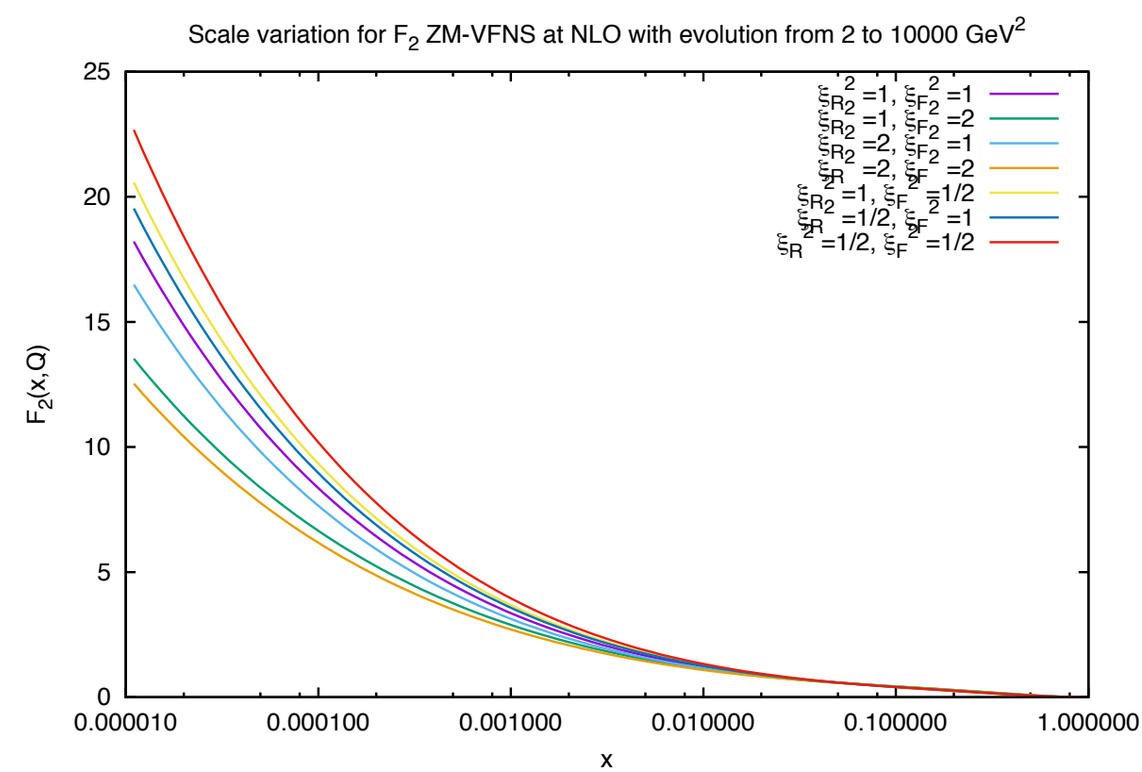
Recent Developments

Renormalization and Factorization Scale Variations

- Renormalization and factorization scale variations provide an estimate of the theoretical error.
- When considering scale variations in a PDF fit, the variations must be done both in the evolution and in the structure functions.
- In the VFNS evolution the threshold matching has to be done consistently.
- Reduction of the spread going from LO to NNLO.





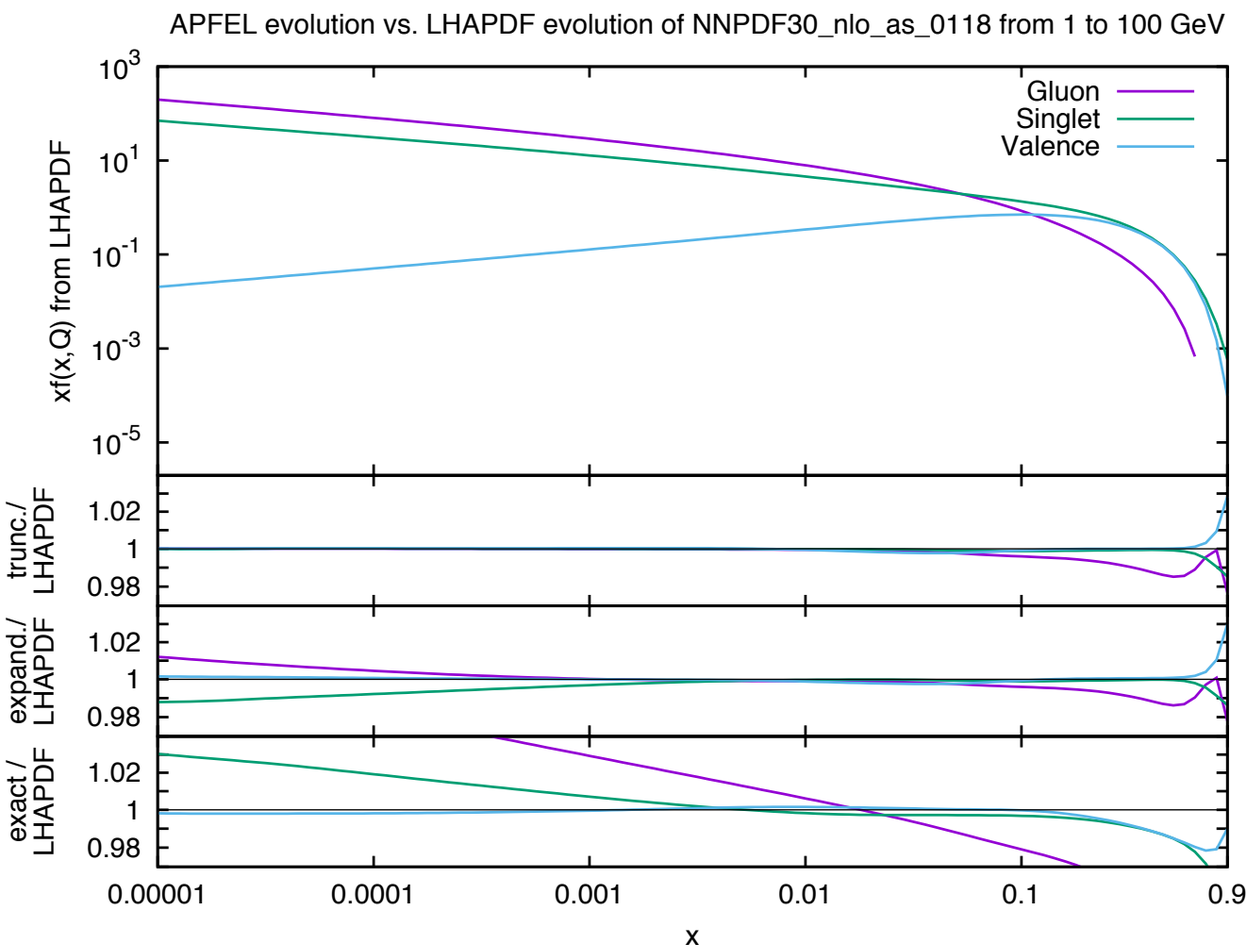


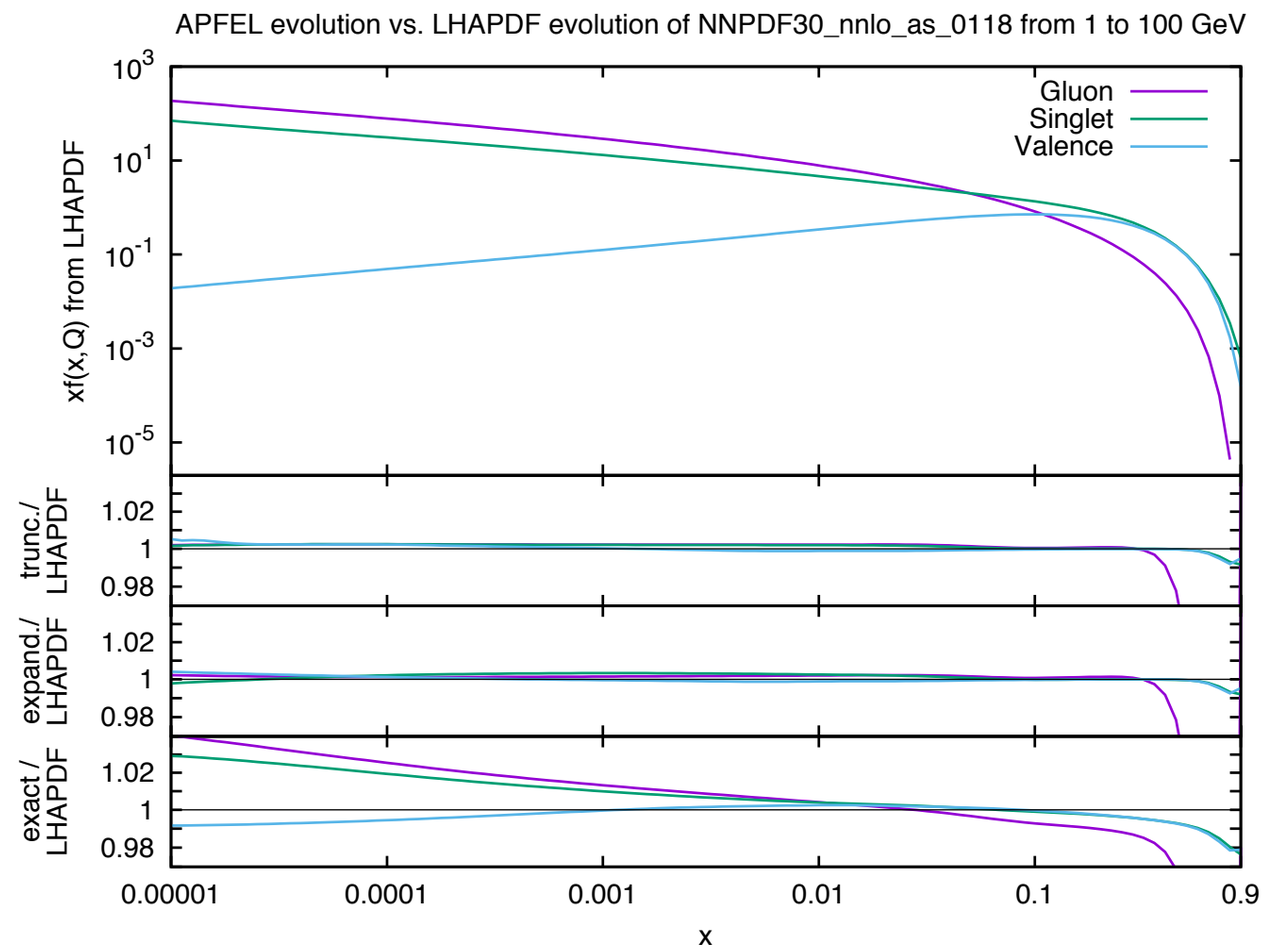
Recent Developments

Solutions of the DGLAP Equation

- A further way to estimate the theory error in the PDF evolution consists in considering different solutions of the DGLAP equation that do not spoil the logarithmic accuracy.

- APFEL implements three different solutions of the DGLAP equation:
  - "**exact**" solution: most common solution adopted in most of the PDF fits,
  - "**expanded**" solution,
  - "**truncated**" solution: used in the NNPDF fits.





Recent Developments

Tools for the Fitting of Fragmentation Function

- The framework used for PDF fits can also be used also for fitting Fragmentation Functions (FFs).
- The main modifications to be done are:

  1. space-like evolution ⇒ time-like evolution,
  2. DIS cross sections ⇒ Single-Inclusive e^+e^- Annihilation (SIA) cross section.

- APFEL implements the time-like evolution:
  - for the first time the time-like evolution is available in a public code up to NNLO accuracy.
  - See arXiv:1501.00494 for a detailed description and benchmark of the evolution.
- Since recently APFEL implements also the SIA cross-sections up to NNLO accuracy.

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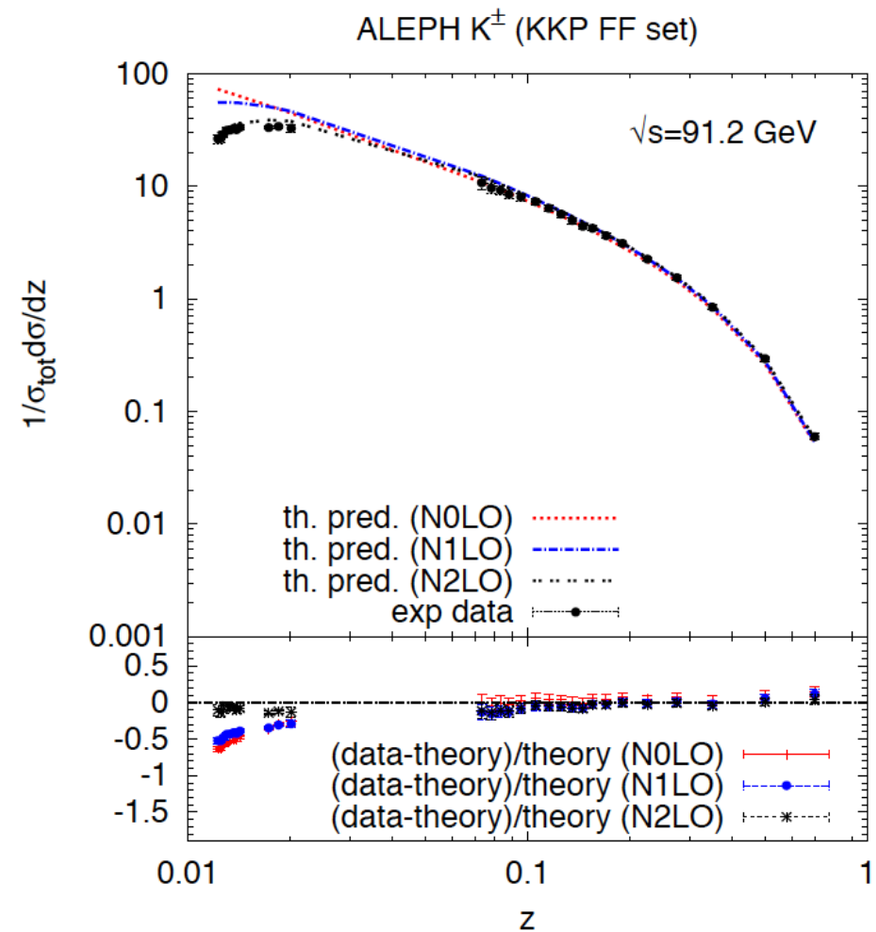


Recent Developments

Lepton PDFs

- The inclusion of QED corrections to a PDF fit immediately implies the appearance of a photon PDF.
- The photon PDF can be determined either by means of a fit (*e.g.* NNPDF2.3QED) or through a theory ansatz (*e.g.* MRST2004QED).
- However, the presence of photons in the proton also implies the presence of leptons $\Rightarrow$ lepton PDFs.
- Lepton PDFs are expected to be very small and thus a fit is not a viable option for the moment.
- Alternatively, assuming that leptons are produced only by photon splitting, at LL accuracy the respective PDFs at the initial scale can be inferred as:

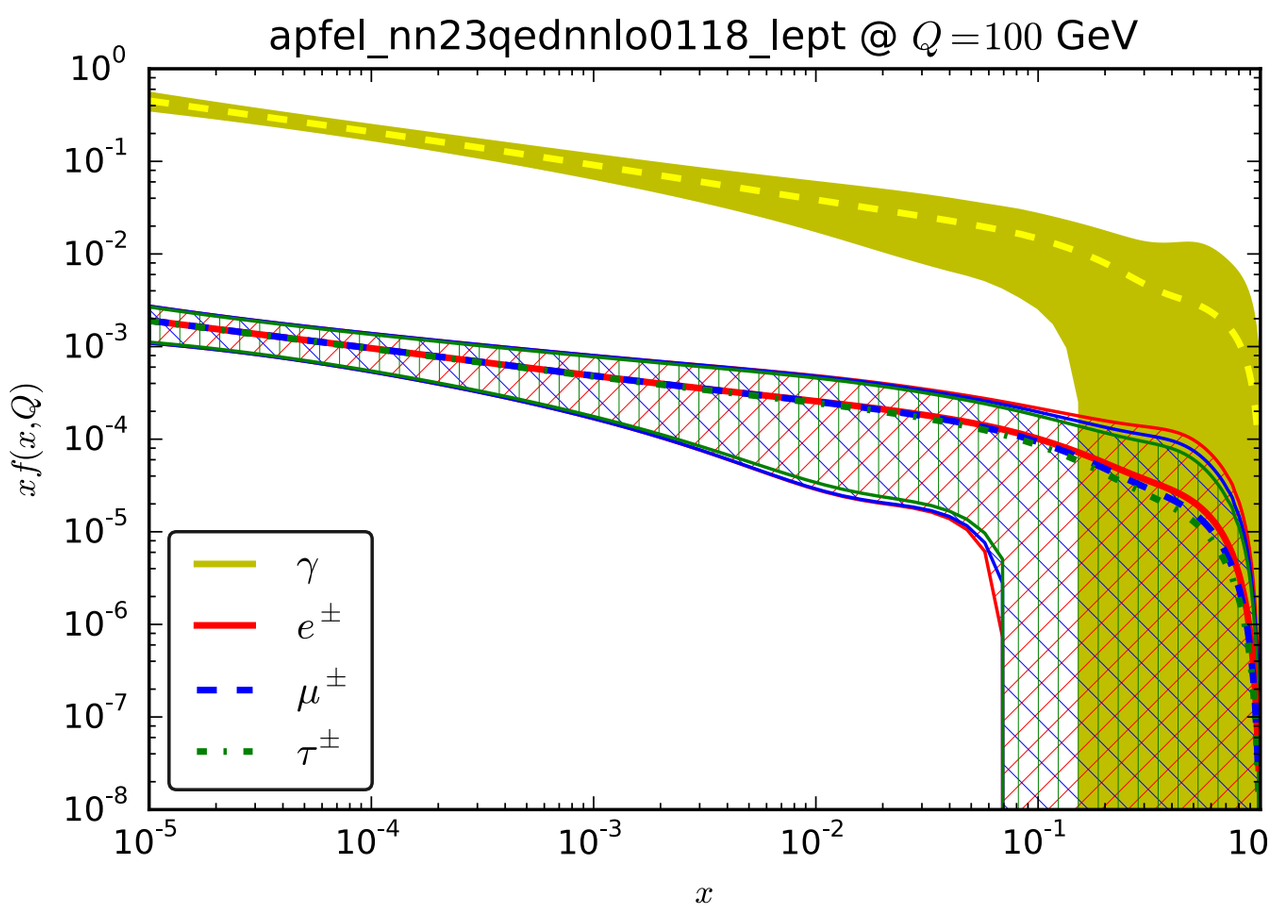
$$\ell_\beta(x, Q_0) = \bar{\ell}_\beta(x, Q_0) = \frac{\alpha(Q_0)}{4\pi} \ln\left(\frac{Q_0^2}{m_\beta^2}\right) \int_x^1 \frac{dy}{y} P_{\ell\gamma}^{(0)}\left(\frac{x}{y}\right) \gamma(y, Q_0)$$

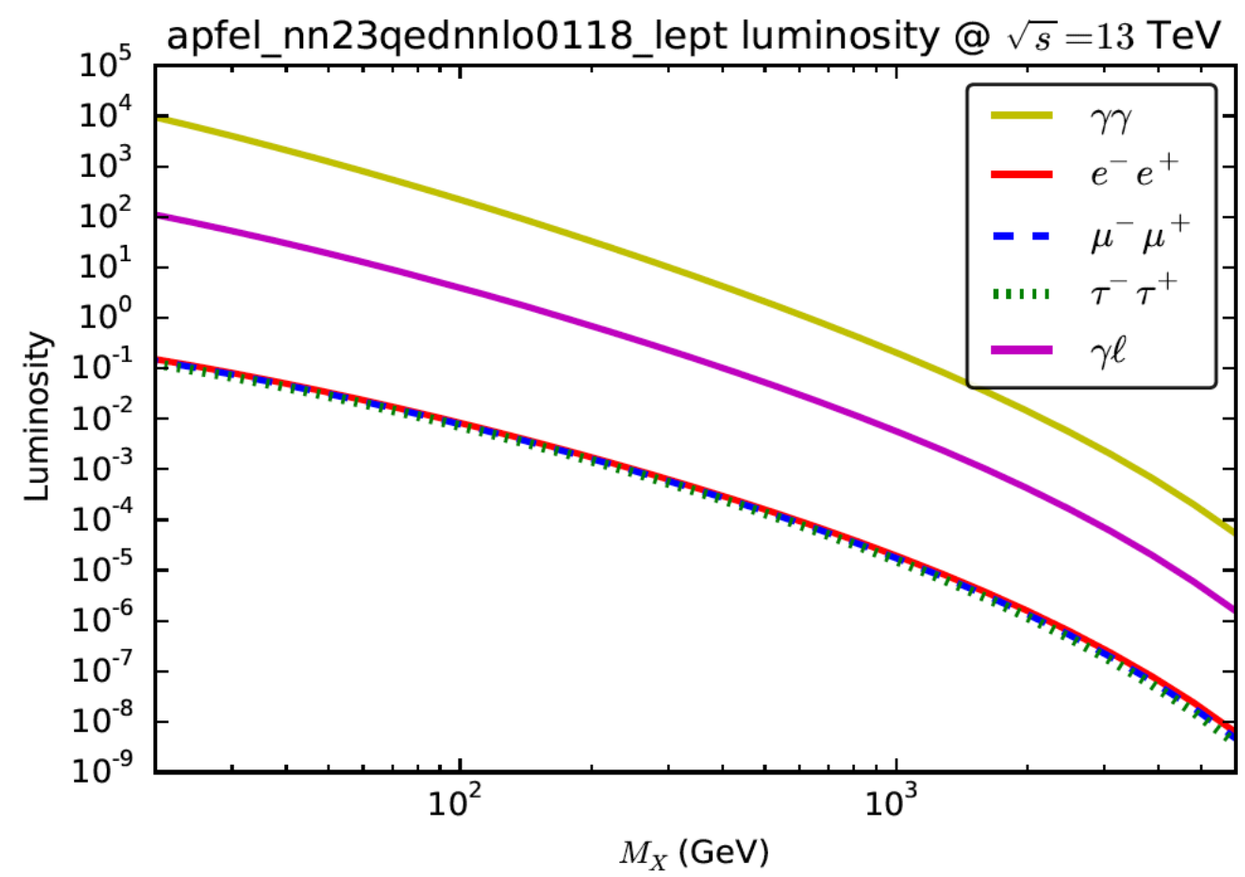
- and then evolved up using the proper **extended** DGLAP evolution implemented in APFEL.

Recent Developments

Lepton PDFs

- With APFEL we have produced and made public a bunch of PDF sets containing lepton PDFs produced starting from the NNPDF2.3QED and MRST2004QED sets.
- As expected, the lepton PDFs are very small.
- Same for the lepton-lepton and lepton-photon luminosities but the presence of leptons might be relevant for some hadron collider observables (?).

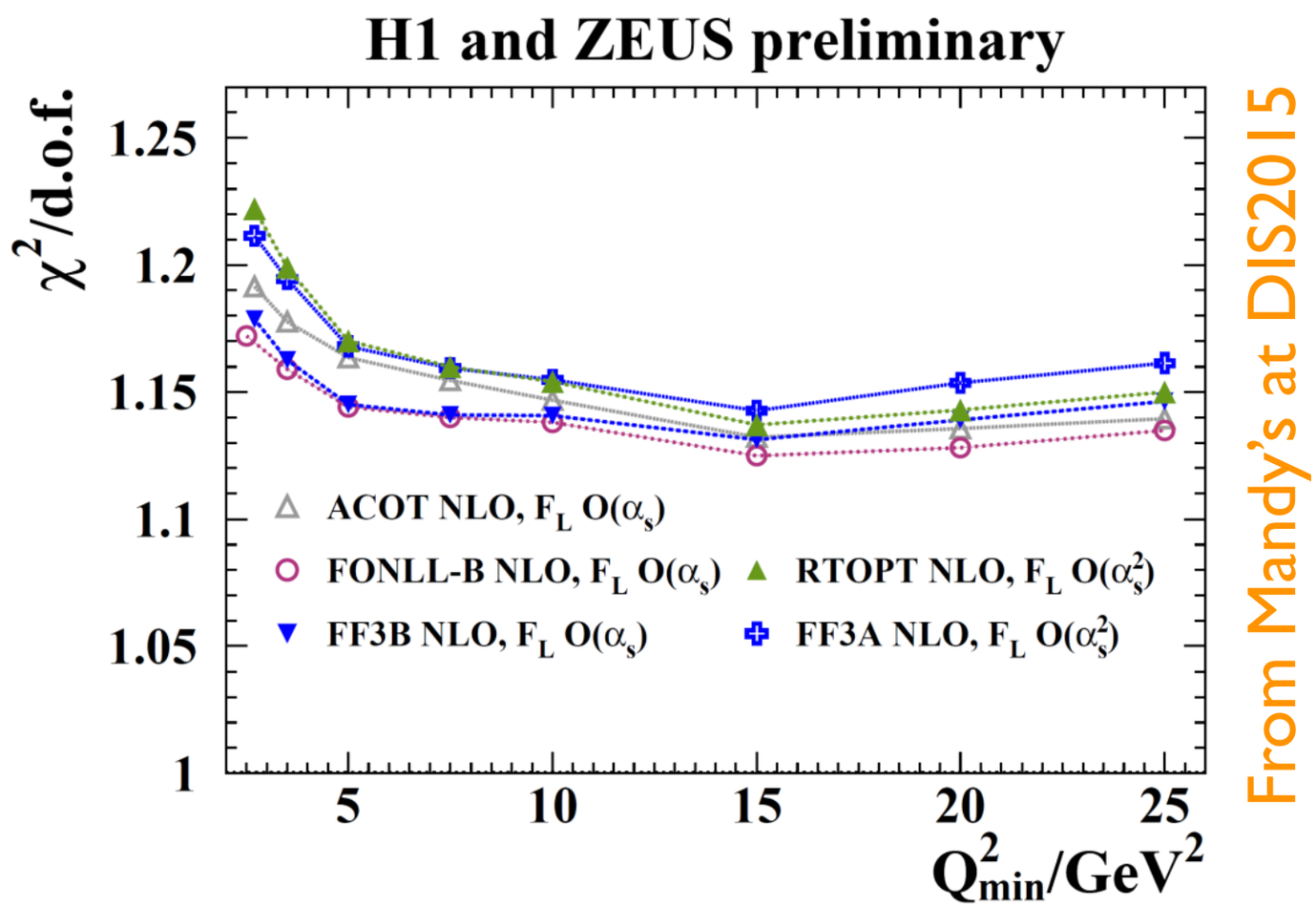




APFEL in HERAFitter

... a Fruitful Collaboration

- APFEL has recently been interfaced to HERAFitter.
- Presently, HERAFitter benefits of the APFEL DGLAP QCD evolution and of the FONLL structure functions up to NNLO.



From Mandy's at DIS2015

- The FONLL scheme provides a very good description of the HERA data.
- In addition, APFEL is very performing as compared to the other schemes.

APFEL in HERAFitter

... a Fruitful Collaboration

- As already mentioned, APFEL implements also the MSbar definition for the heavy quark masses.

- Since recently, this option is available also in HERAFitter:

  - FONLL-B scheme (NLO) with pole masses:

```
After minimisation     547.21   582     0.940
Dataset    1    107.95   145  NC cross section HERA-I H1-ZEUS combined e-p.
Dataset    2    388.85   379  NC cross section HERA-I H1-ZEUS combined e+p.
Dataset    3     20.25    34  CC cross section HERA-I H1-ZEUS combined e-p.
Dataset    4     30.17    34  CC cross section HERA-I H1-ZEUS combined e+p.
```

  - FONLL-B scheme (NLO) with MSbar masses

```
After minimisation     539.90   582     0.928
Dataset    1    108.39   145  NC cross section HERA-I H1-ZEUS combined e-p.
Dataset    2    381.68   379  NC cross section HERA-I H1-ZEUS combined e+p.
Dataset    3     20.13    34  CC cross section HERA-I H1-ZEUS combined e-p.
Dataset    4     29.70    34  CC cross section HERA-I H1-ZEUS combined e+p.
```

Improvement of the χ^2 in the MSbar scheme

- The MSbar mass seems to improve on the description of the HERA data (especially at the lowest scales).

- It would be interesting to use this framework to fit the heavy quark masses.

Conclusions

- APFEL has some features that can be of interest for HERAFitter:
  - QCD+QED DGLAP evolution ⇒ photon PDF,
  - FONLL structure functions,
  - different solutions of the DGLAP equation,
  - scale variations,
  - …
- APFEL is a solid code: it will be used for the next generation of the NNPDF fits (NNPDF3.1).
- Presently, HERAFitter benefits of the APFEL DGLAP QCD evolution and of the FONLL structure functions up to NNLO.
- The next step is the fit of the photon PDF with HERAFitter using APFEL.