

# Recent Developments in **APFEL**

[V. Bertone, *et al.*, Comput. Phys. Commun. 185, 1647 (2014)]

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**DIS 2017**

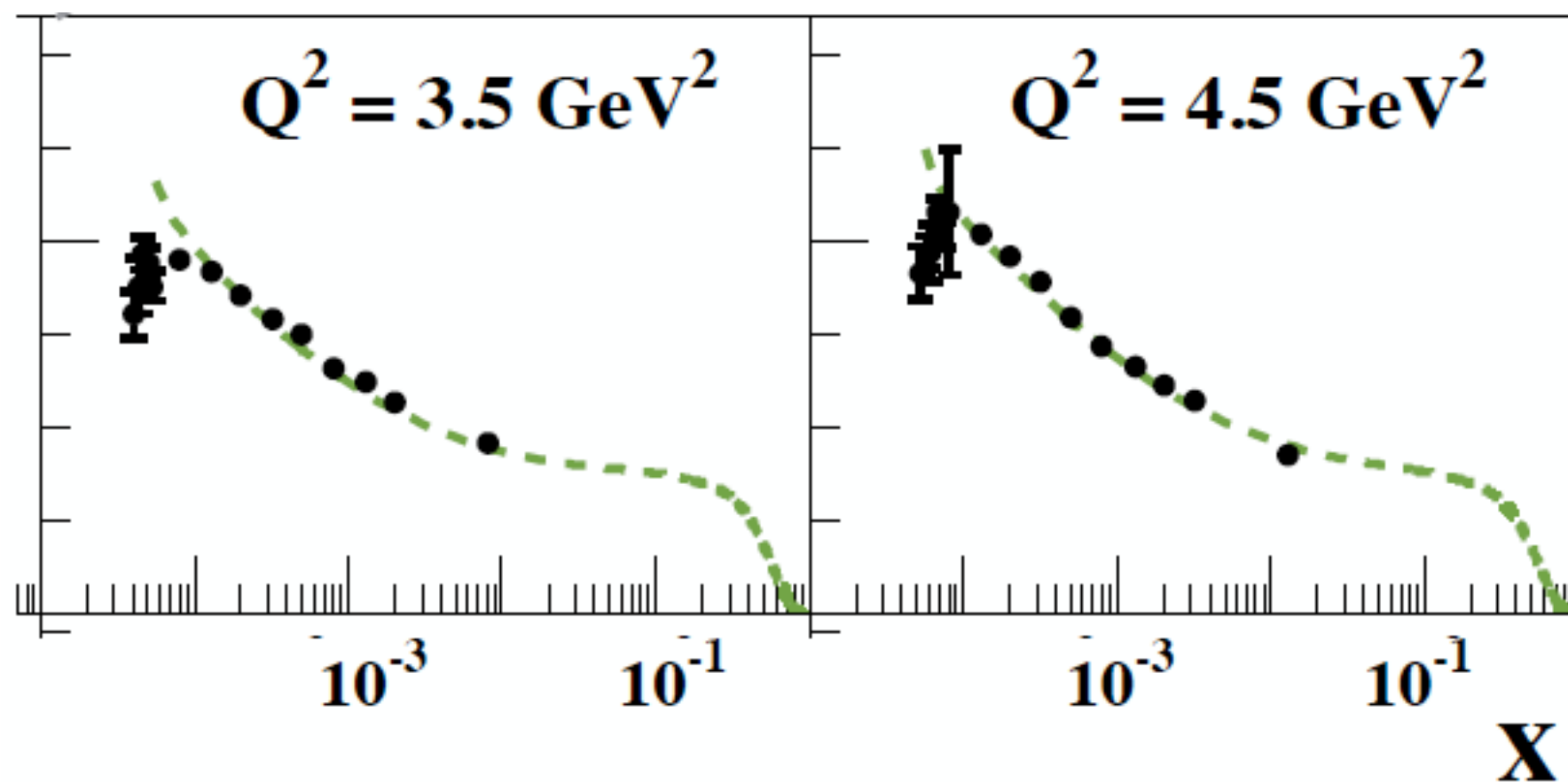
April 4, 2017, Birmingham

# APFEL in a Nutshell

- 🍏 APFEL is a **public** library for the computation of collinear PDF evolution and DIS structure functions:
  - 🍏 up to NNLO in QCD combined to QED corrections up to NLO.
  - 🍏 FFN and VFN schemes.
  - 🍏 Pole and  $\overline{\text{MS}}$  heavy-quark masses.
  - 🍏 fast computation of DIS NC and CC observables in different mass schemes (ZM-VFNS, FFNS and FONLL).
  - 🍏 Interfaces to FORTRAN, C/C++ and Python.
  - 🍏 Web interface available on <http://apfel.mi.infn.it>.
  - 🍏 available from <http://apfel.hepforge.org/>.
- 🍏 Currently interfaced to **xFitter** and **Alpos**.
- 🍏 Used for the next generation of the **NNPDF** fits (including FFs).

# Small- $x$ Resummation

🍏 **Tension** between fixed-order predictions and data in the small- $x$  region reached by HERA:



From Eram Rizvi talk  
at QCD@LHC14

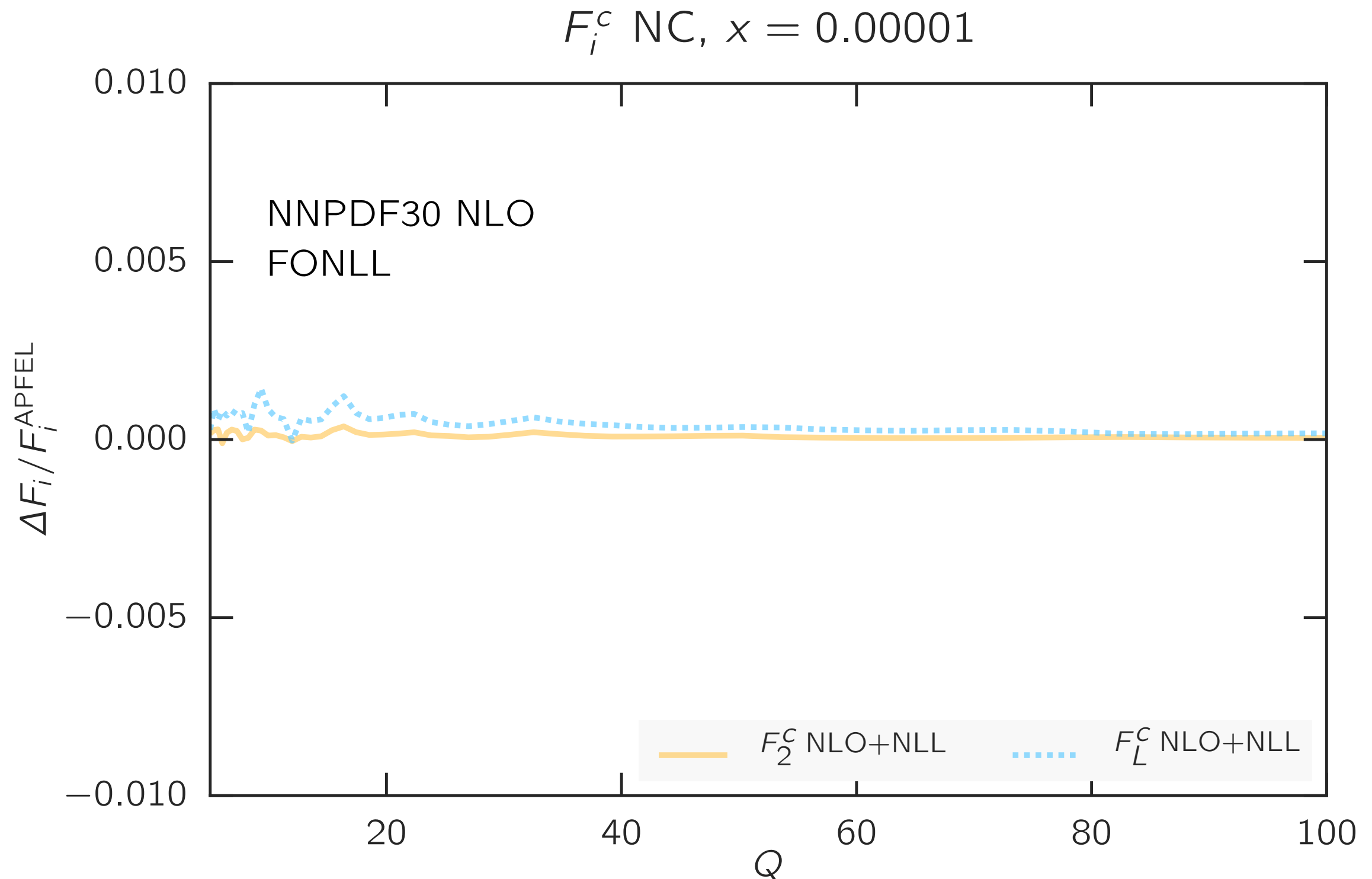
🍏 A similar effect was observed some time ago in the NNPDF framework by F. Caola *et al.* [[arXiv:1007.5405](https://arxiv.org/abs/1007.5405)].

🍏 Suggestion of the need for **small- $x$  resummation**.

# Small- $x$ Resummation

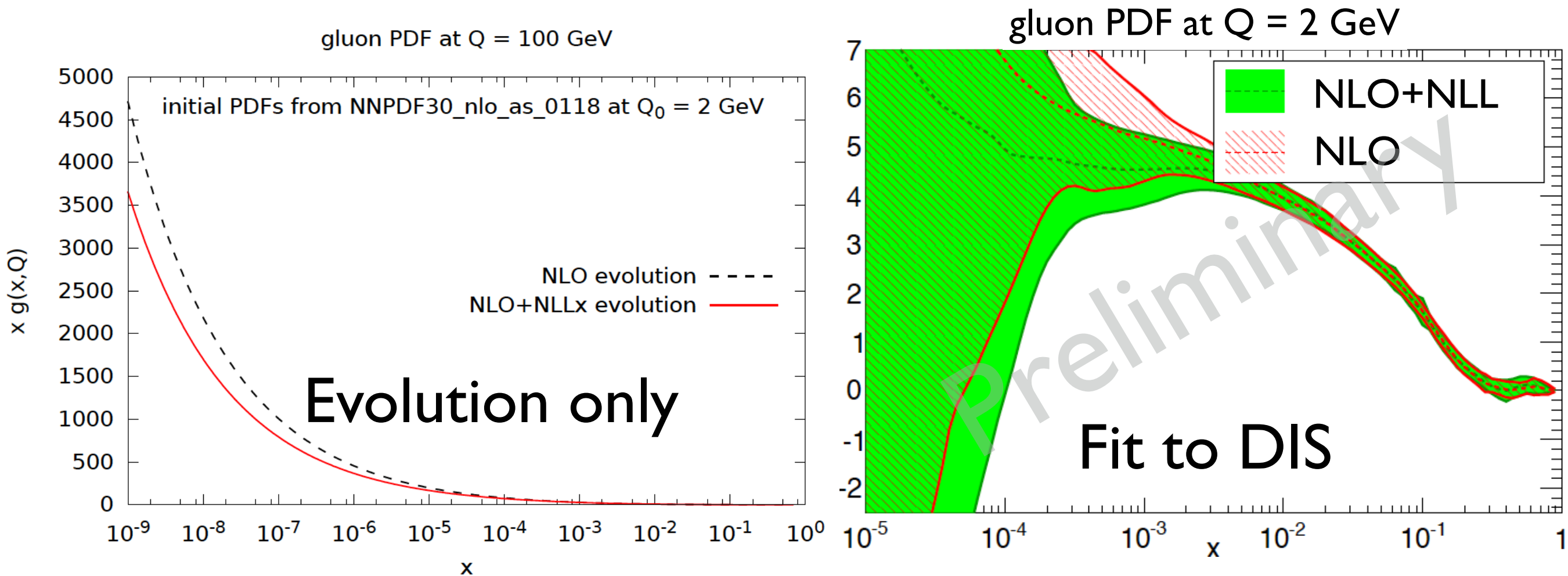
- 🍏 The **HELL** code [\[arXiv:1607.02153\]](#) has been interfaced to APFEL:
  - 🍏 based on the ABF formalism (e.g. see [\[hep-ph/9501231\]](#)).
  - 🍏 Small- $x$  **resummed splitting functions** up to **NLL** accuracy,
  - 🍏 Small- $x$  **resummed DIS coefficient functions** up to **NLL**:
    - 🍏 massless,
    - 🍏 massive.
  - 🍏 **Resummed matching conditions.**
- 🍏 It is now possible to compute structure functions in the FONLL GM-VFNS scheme including small- $x$  resummation up to NLL.
- 🍏 Forthcoming PDF fits in NNPDF.

# Small- $x$ Resummation



🍏 Excellent agreement with MassiveDIS [Thanks to L. Rottoli]

# Small- $x$ Resummation



- 🍏 Resummed evolution leads to a **suppression** of the **gluon PDF** at small values of  $x$  as compared to fixed order.
- 🍏 **Compensation** when also resummed **coefficient functions** are introduced  $\Rightarrow$  effect on the small- $x$  gluon PDF at the level of  $1-\sigma$ .
- 🍏 Other PDFs mostly unchanged.

# NLO QCD+QED Corrections

## *Evolution*

In order to implement the full NLO QCD+QED corrections in the DGLAP evolution two main steps are required:

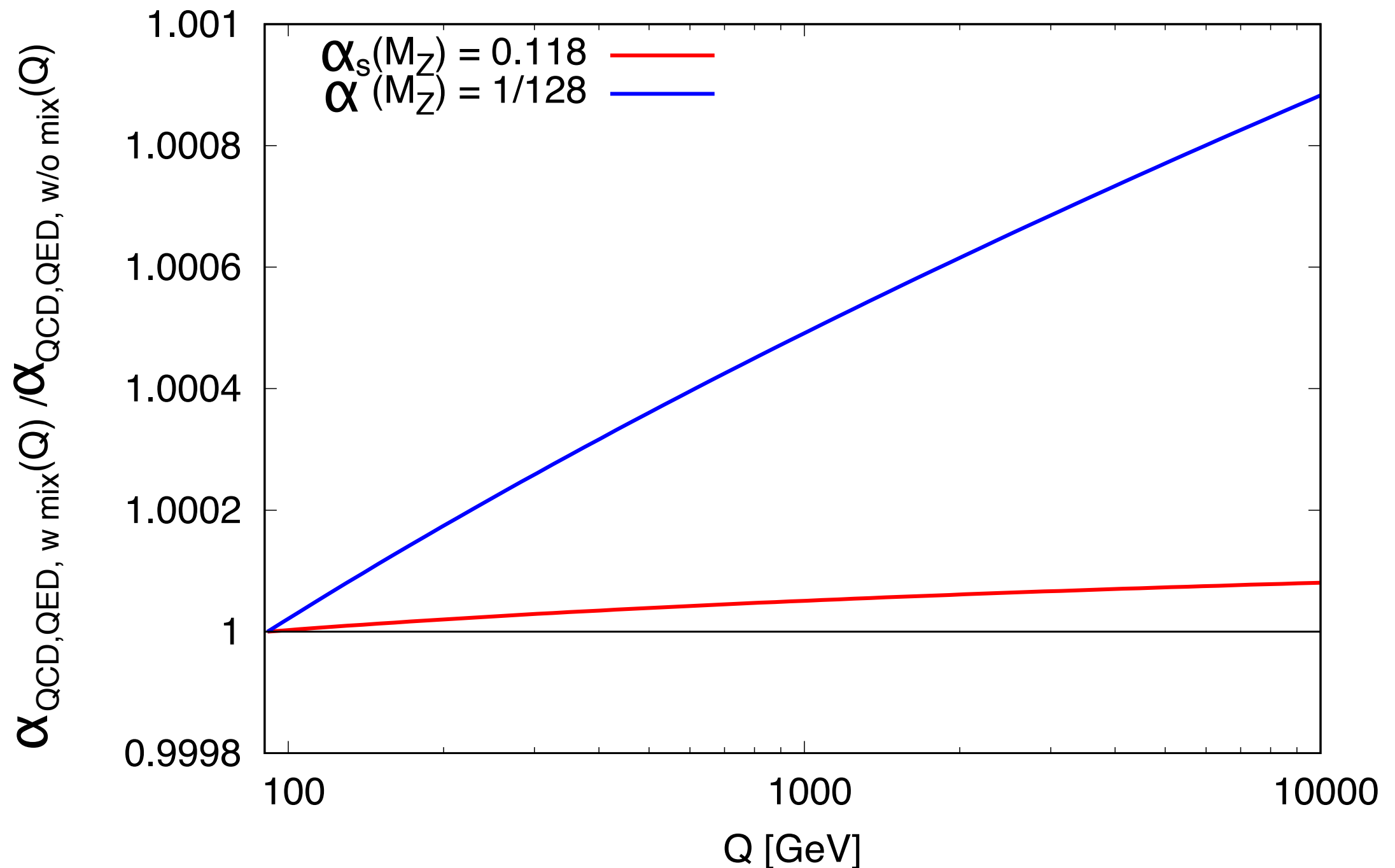
1. Implementing the  $O(\alpha_s^2\alpha)$ ,  $O(\alpha^3)$ ,  $O(\alpha^2\alpha_s)$  corrections to the  **$\beta$ -functions**:
  - running of  $\alpha_s$  and  $\alpha$  is coupled  $\Rightarrow$  solve of a coupled ODE,
  - Numerical tests have shown that such terms lead to differences of  $O(10^{-4})$  for  $\alpha_s$  and  $O(10^{-3})$  for  $\alpha \Rightarrow$  **unneeded complication**.



# NLO QCD+QED Corrections

## *Coupling Evolution*

running of the couplings,  $N_F = 5$



🍏 Mixed terms in the  $\beta$ -functions lead to negligible effects.



# NLO QCD+QED Corrections

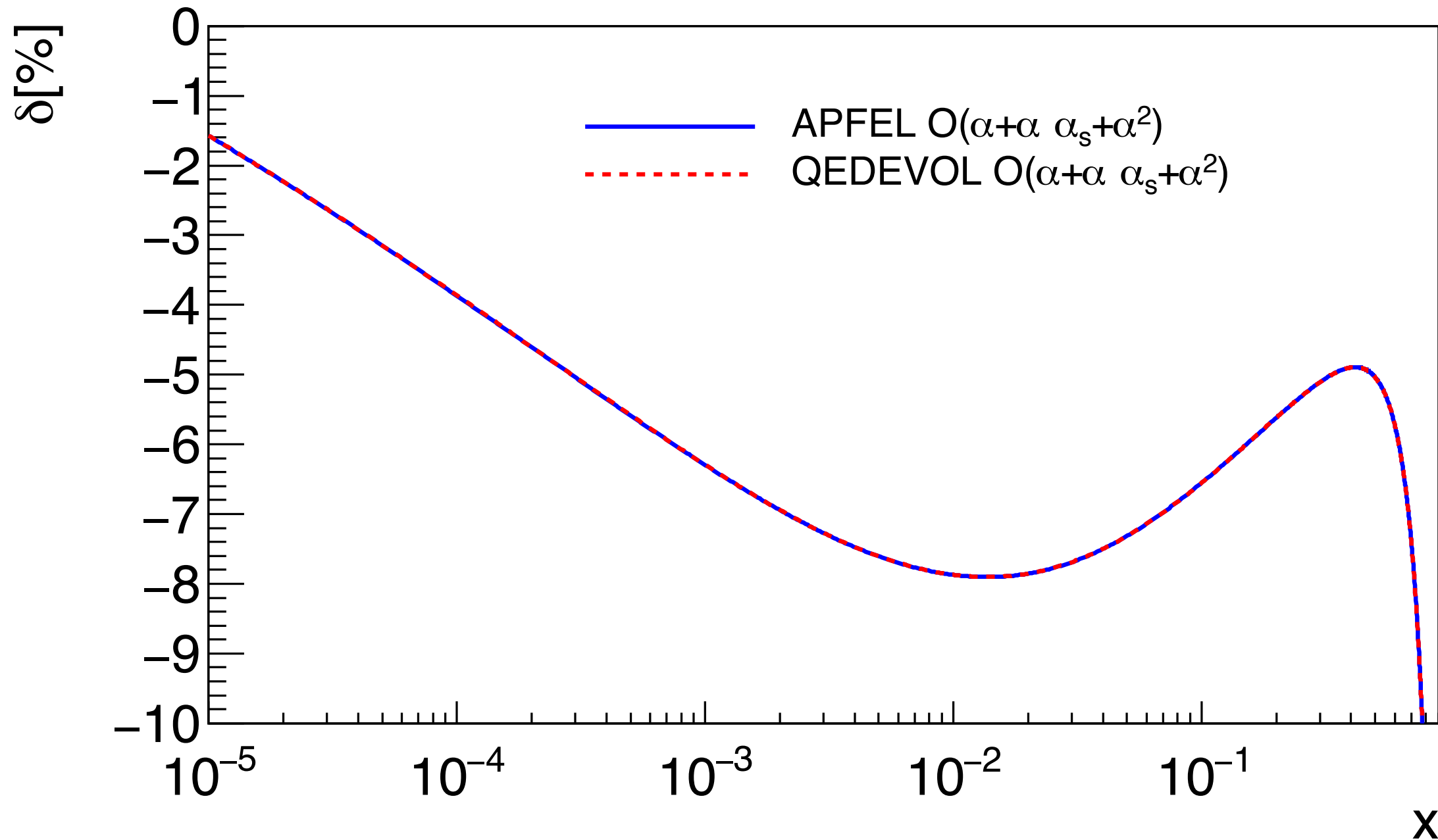
## *Evolution*

In order to implement the full NLO QCD+QED corrections in the DGLAP evolution two main steps are required:

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  - running of  $\alpha_s$  and  $\alpha$  is coupled  $\Rightarrow$  solve of a coupled ODE,
  - Numerical tests have shown that such terms lead to differences of  $O(10^{-4})$  for  $\alpha_s$  and  $O(10^{-3})$  for  $\alpha \Rightarrow$  **unneeded complication**.
2. Implementing the  $O(\alpha_s\alpha)$  and the  $O(\alpha^2)$  corrections to the DGLAP **splitting functions** on top of the  $O(\alpha)$  ones:
  - complication of the flavour structure due to the presence of terms promotional to  $e_q^2$  and  $e_q^4$  that break the isospin symmetry,
  - need for a more optimal evolution basis as compared to pure QCD.

# NLO QCD+QED Corrections

## *Benchmark against QEDDEVOL*



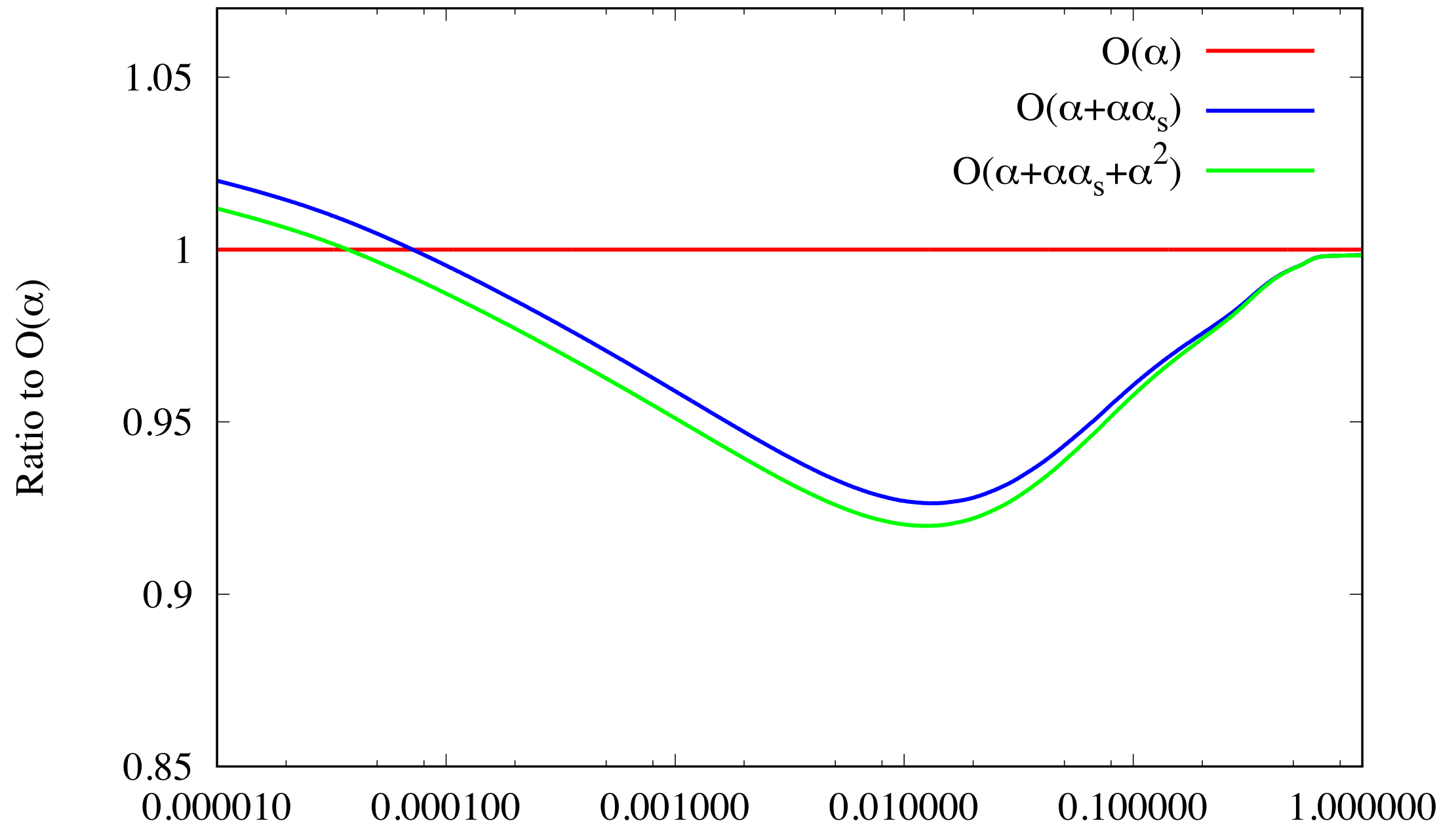
[Thanks to Renat Sadykov]

🍏 Perfect agreement between APFEL and QEDDEVOL.

# NLO QCD+QED Corrections

## *Photon PDF*

$\gamma$  PDF at  $Q = 100$  GeV

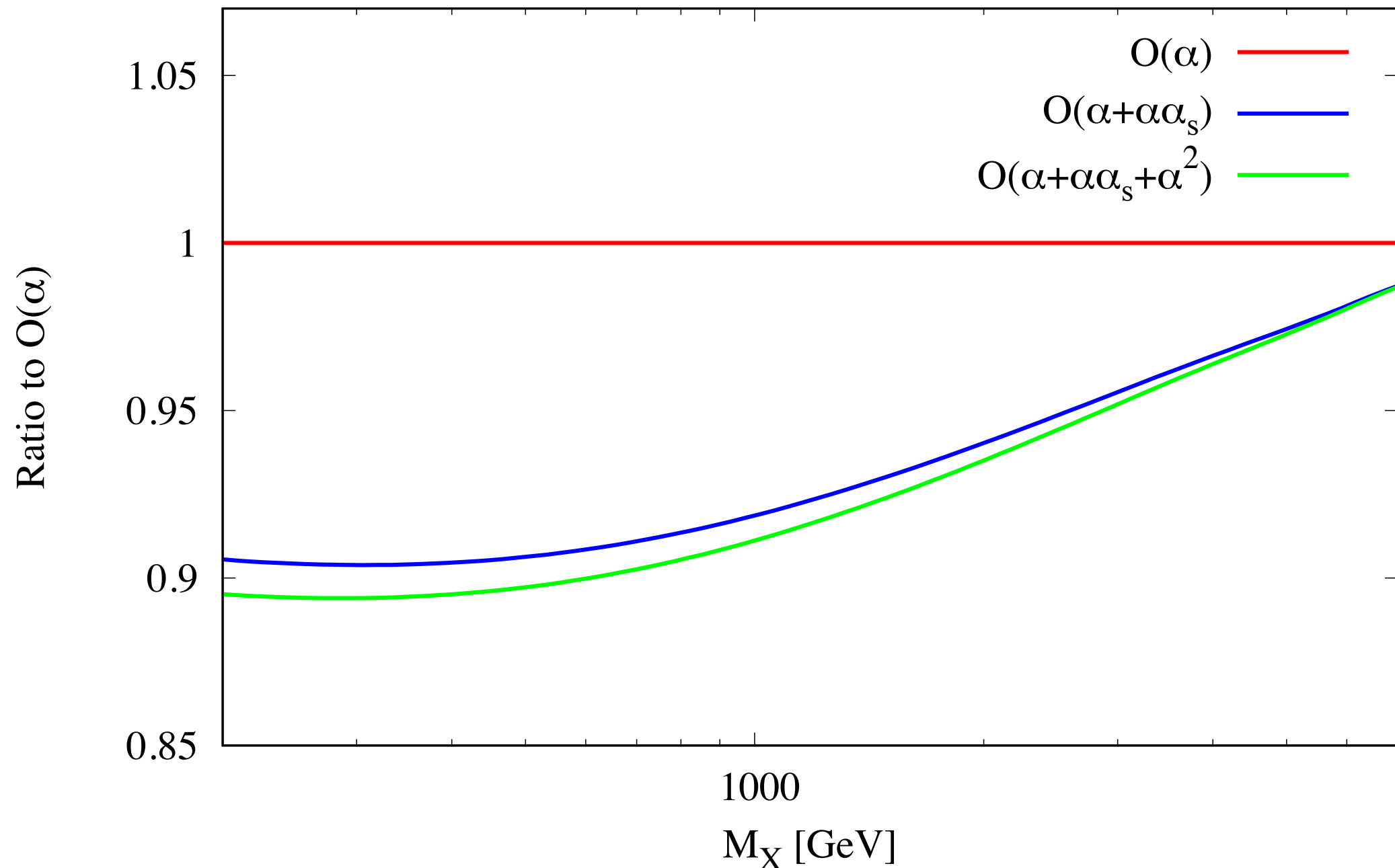


🍏 Effect on the photon PDF of the NLO<sup>x</sup> corrns. at the level of 5%.

# NLO QCD+QED Corrections

## *Photon Luminosity*

$\gamma\gamma$  Luminosity at  $\sqrt{s} = 13$  TeV



🍏 More sizeable effect on the  $\gamma\gamma$  luminosity.

# NLO QCD+QED Corrections

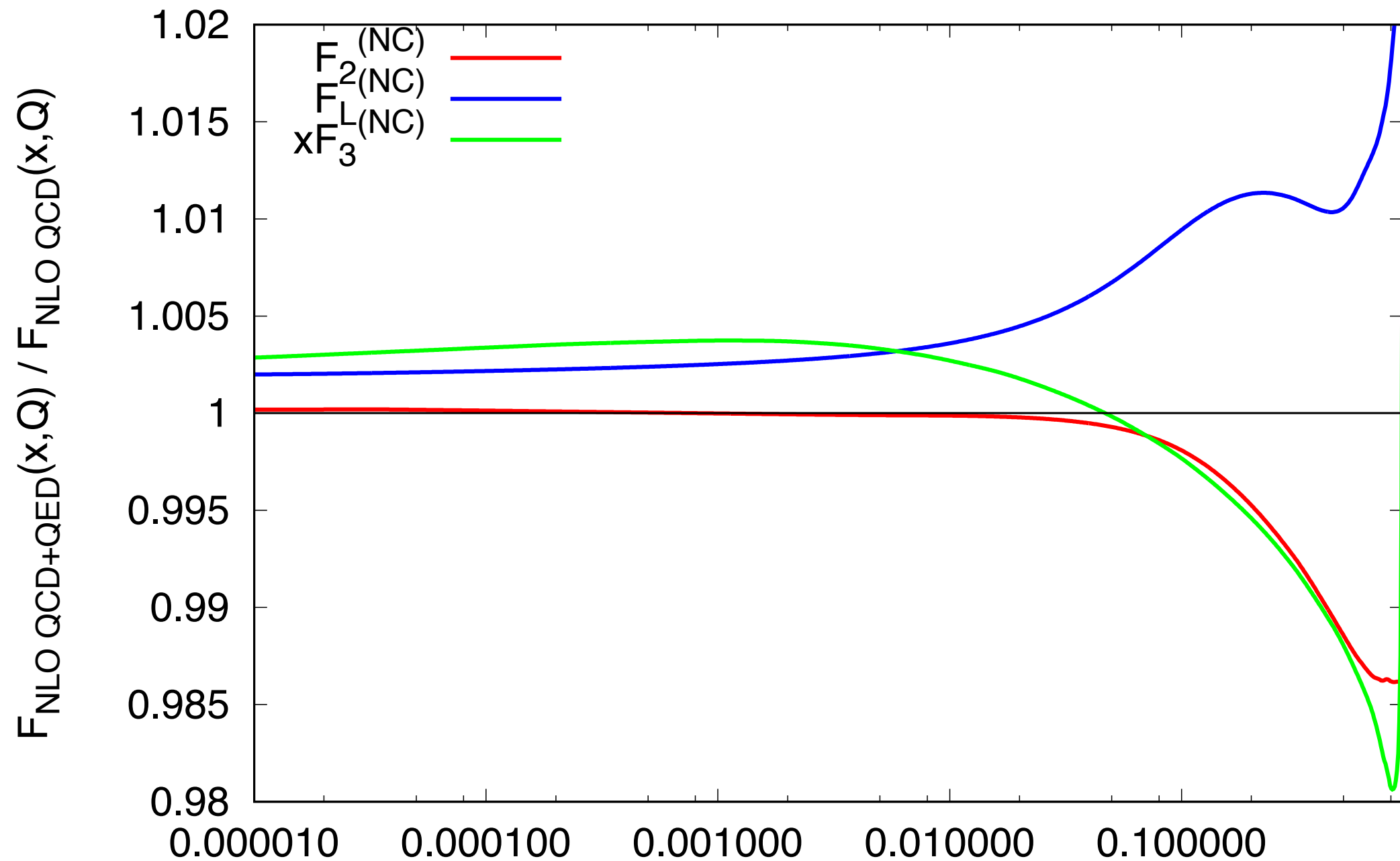
## *DIS Structure Functions*

- While at LO in QED no corrections to the DIS structure functions are required ( $\gamma^* q \rightarrow q$  itself is the LO), at NLO in QED  $O(\alpha)$  corrections need to be taken into account:
  - **new diagrams:**  $\gamma^* \gamma \rightarrow q\bar{q}$  and  $\gamma^* q \rightarrow q\gamma$ ,
  - easily derivable from the corresponding QCD diagrams.
- The additional diagrams offer a **direct handle** on the photon PDF in DIS observables:
  - at LO in QED the photon PDF was entirely driven by the evolution.
- Small contribution proportional to  $\alpha\gamma \sim O(\alpha^2)$  but can be relevant in some kinematic regions:
  - typically at large  $x$  and large  $Q^2$ .

# NLO QCD+QED Corrections

## *DIS Structure Functions (NC)*

NC structure functions in the FONLL-B scheme

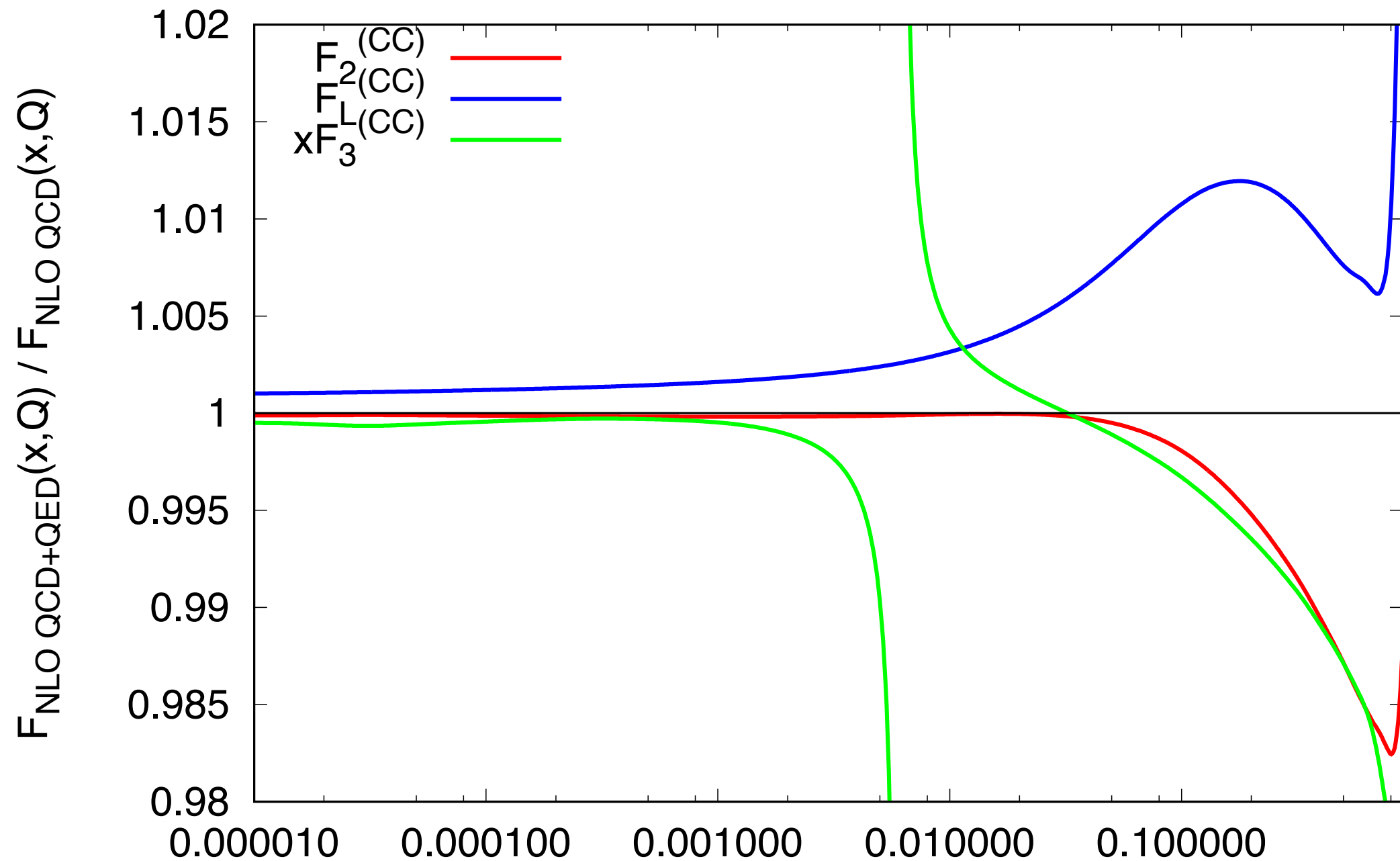


🍏 Generally small effect which becomes large at large  $x$ .

# NLO QCD+QED Corrections

## *DIS Structure Functions (CC)*

CC structure functions in the FONLL-B scheme



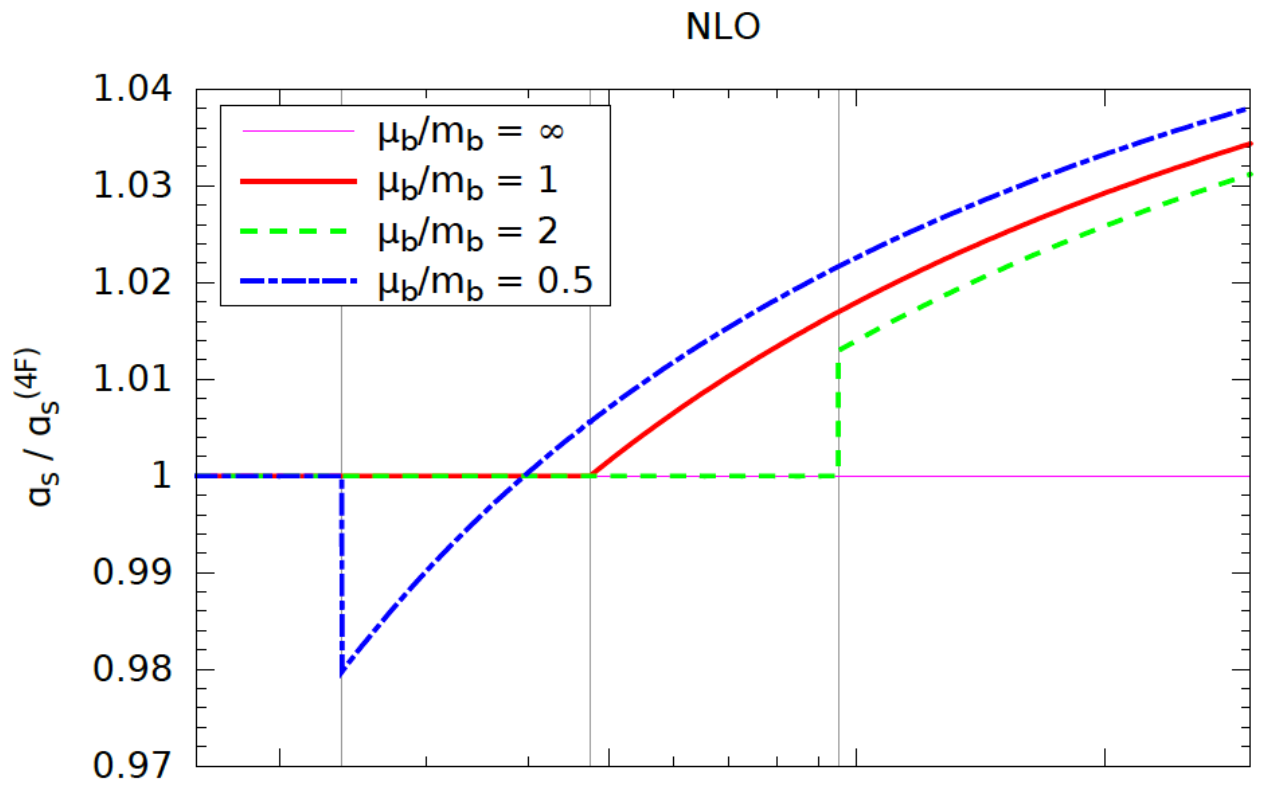
🍏 Generally small effect which becomes large at large  $x$ .



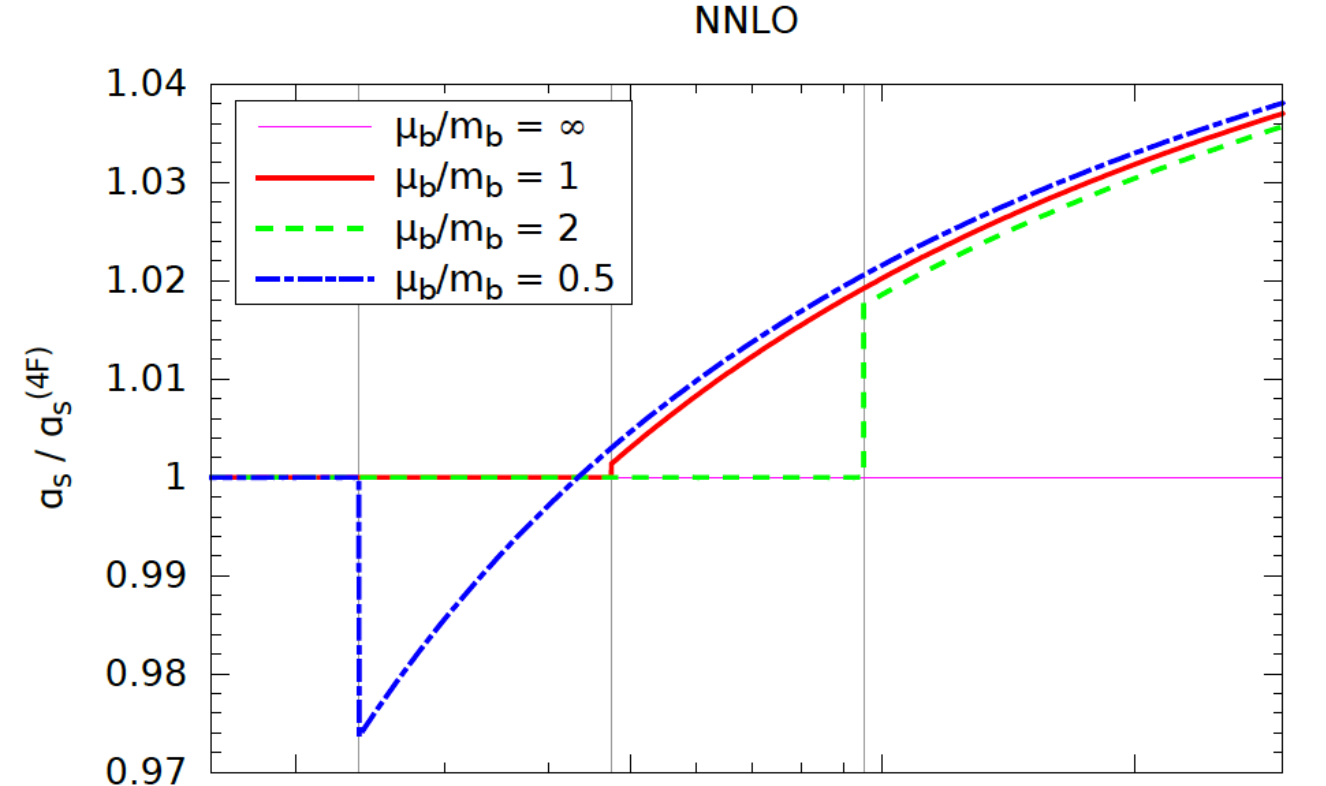
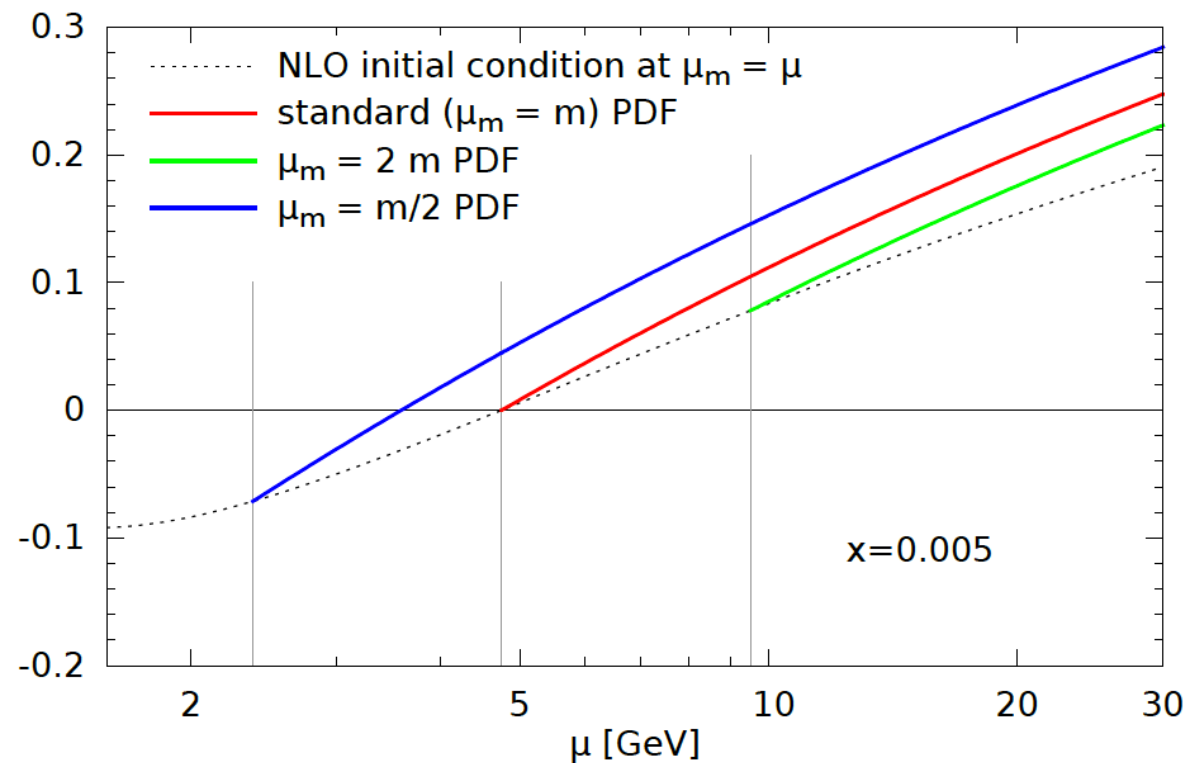
# Displaced Heavy-Quark Thresholds

- 🍏 The implementation of the VFNS evolution both for PDFs and  $\alpha_s$  requires **matching** factorisation schemes differing in the number of active flavours:
  - 🍏 the scale at which two consecutive factorisation schemes are matched are usually referred to as **heavy-quark thresholds**.
  - 🍏 Heavy-quark thresholds are usually (and for convenience) identified with the heavy quark masses by means of the so-called **matching conditions** presently known up to  $\mathcal{O}(\alpha_s^2)$  [[hep-ph/9612398](#)].
  - 🍏 However, heavy-quark thresholds are actually free parameters and can be chosen **arbitrarily**.
  - 🍏 If masses and thresholds are taken to be different, the matching conditions need to be “generalised” including **logarithmic terms**.
- 🍏 APFEL now implements the possibility to set masses and thresholds to different values in a consistent way both in the pole mass and in the  $\overline{\text{MS}}$  renormalisation schemes.

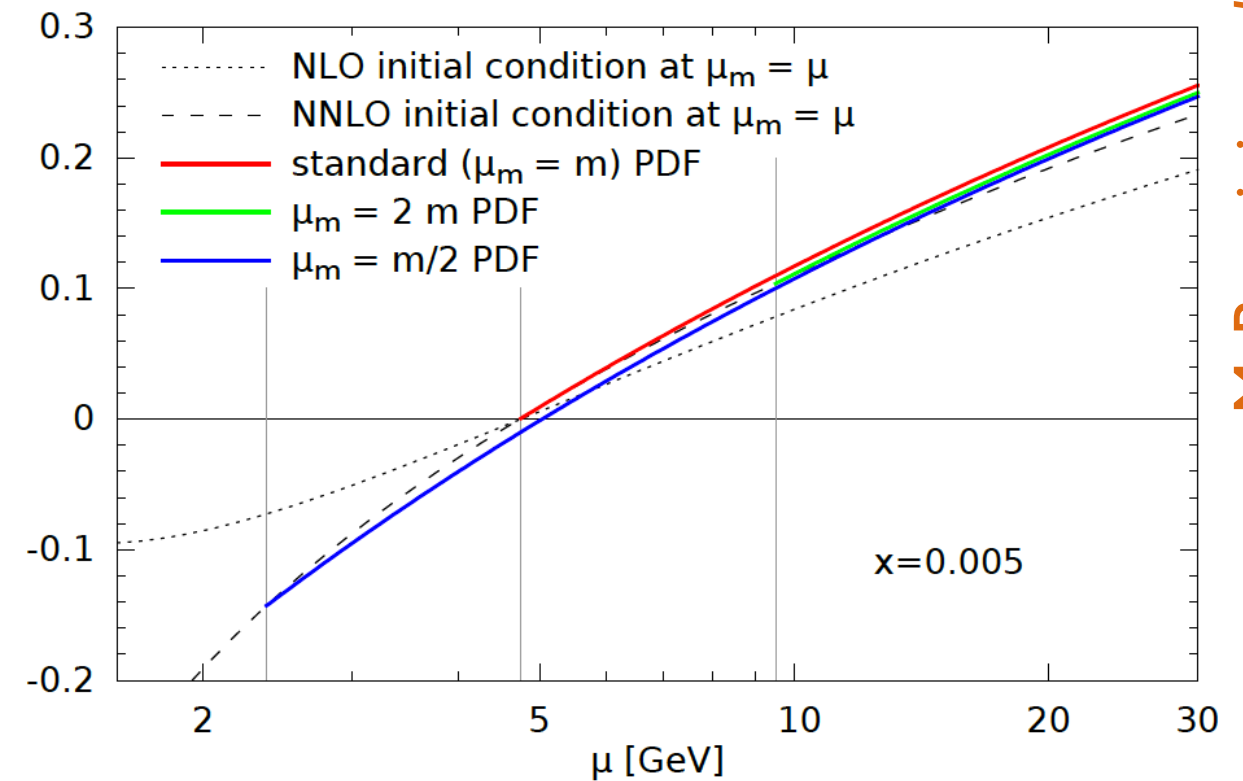
# Displaced Heavy-Quark Thresholds



bottom PDF at NLO



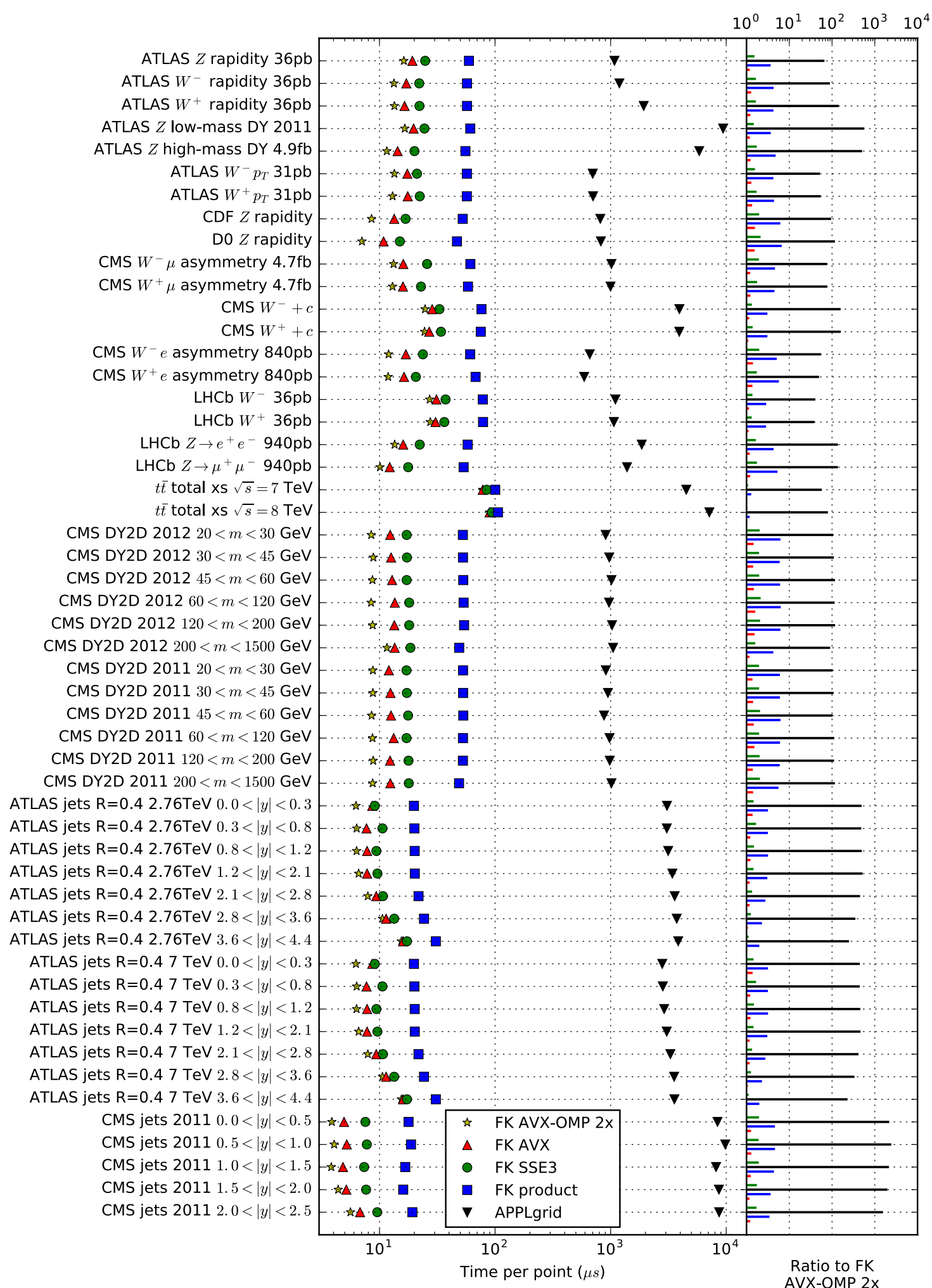
bottom PDF at NNLO



# APFELgrid

*A fast(er) interface for PDF fits*

- While being extremely useful tools, **APPLgrid** and **FastNLO** might not be appropriate to be directly employed in a global PDF fit where usually **thousands of iterations** are needed:
  - need to calculate PDF and  $\alpha_s$  **evolution in real time**.
  - not particularly fast** convolution.
  - many tables need to be loaded with the concrete risk of **exceeding the memory limit** (pretty common on clusters).
- We developed **APFELgrid** which, starting from an APPLgrid, combines the PDF evolution from APFEL to the hard cross sections producing *derived* tables (FK tables) to be directly convoluted with the initial scale PDFs.
- APFELgrid relies on the precomputation of the evolution of  $\alpha_s$  and PDFs:
  - less flexible than APPLgrid as the evolution parameters (perturbative order, reference value of  $\alpha_s$ , heavy-quark thresholds, etc.) cannot be changed.



[V. Bertone, S. Carrazza, N.P. Hartland,  
 Comput.Phys.Commun. 212 (2017) 205-209]

# APFEL<sup>++</sup>

*An object oriented rewriting of APFEL*

- 🍏 APFEL core is currently based on **FORTRAN77**.
- 🍏 It thus provides “**singleton objects**”, *i.e.* it is not possible to instantiate different evolutions and/or structure functions with different parameters.
- 🍏 It includes a **large number of features**:
  - 🍏 limited modularity  $\Rightarrow$  **hard to maintain and extend**,
  - 🍏 static memory management  $\Rightarrow$  **large memory footprint** to ensure appropriate accuracy for all foreseeable applications.
- 🍏 **C++** provides a natural solution to these issues:
  - 🍏 possibility to instantiate any number of evolutions and structure functions,
  - 🍏 **modularity** ensured by the possibility to define objects,
  - 🍏 optimal memory management,
  - 🍏 based on C++11 standard (Lambda funcs., auto declaration, smart pointers, etc.)



# APFEL++

*An object oriented rewriting of APFEL*

🍏 A good excuse to do better:

🍏 improve integration procedure (faster and more accurate):

```
Initialization... elapsed time: 0.209144 seconds  
Tabulation... elapsed time: 0.111195 seconds
```

🍏 improve interpolation procedure:

```
Interpolating 100000 times PDFs on the (x,Q) grid... elapsed time: 0.604006 seconds
```

🍏 overload operators to make convolutions in an easy way:

```
//-----  
Set<Distribution> Dglap::Derivative(int const& nf, double const& t, Set<Distribution> const& f) const  
{  
    return _SplittingFunctions(nf, exp(t/2)) * f;  
}
```

🍏 use the same technology for specific hadronic observables (*e.g.* double differential DY).

🍏 Exploit CPU acceleration techniques (AVX, SSE).

# APFEL++

*An object oriented rewriting of APFEL*

```
vbertone@MacBook-Pro-di-Valerio.local: ~/Codes/apfelxx/tests — -b...
vbert...cern.ch  × vberto...-bash  vberto...-bash ...  vbe...bash ... >> +
Initialization... elapsed time: 0.212053 seconds
Evolution (4th order Runge-Kutta with 10 steps) from Q0 = 1.414214e+00 G
eV to Q = 1.000000e+02 GeV... elapsed time: 0.039274 seconds

AlphaQCD(Q) = 1.156047e-01

  x      u-ubar      d-dbar      2(ubr+dbr)      c+cbar      gluon
1.0e-05  3.1907e-03  1.9532e-03  3.4732e+01  1.5875e+01  2.2012e+02
1.0e-04  1.4023e-02  8.2749e-03  1.5617e+01  6.7244e+00  8.8804e+01
1.0e-03  6.0019e-02  3.4519e-02  6.4173e+00  2.4494e+00  3.0404e+01
1.0e-02  2.3244e-01  1.3000e-01  2.2778e+00  6.6748e-01  7.7913e+00
1.0e-01  5.4993e-01  2.7036e-01  3.8526e-01  6.4464e-02  8.5267e-01
3.0e-01  3.4622e-01  1.2833e-01  3.4600e-02  4.0132e-03  7.8898e-02
5.0e-01  1.1868e-01  3.0811e-02  2.3200e-03  2.3753e-04  7.6403e-03
7.0e-01  1.9486e-02  2.9901e-03  5.2355e-05  5.6022e-06  3.7082e-04
9.0e-01  3.3523e-04  1.6935e-05  2.5757e-08  4.3401e-09  1.1724e-06

vbertone@MacBook-Pro-di-Valerio:~/Codes/apfelxx/tests$
```

APFEL

```
vbertone@lxplus037.cern.ch: ~/hoppet-qcd/example_f90 — ssh vberton...
vbert...cern.ch  vberto...-bash  vberto...-bash ...  vbe...bash ... >> +
WARNING in InitMTMNNLO: using parametrisation (less accurate) for A2PS
hg
Streamlined initialization completed!
Evolution done!

      Evaluating PDFs at Q = 100.000 GeV
  x      u-ubar      d-dbar      2(ubr+dbr)      c+cbar      gluon
1.0E-05  3.1907E-03  1.9532E-03  3.4732E+01  1.5875E+01  2.2012E+02
1.0E-04  1.4023E-02  8.2749E-03  1.5617E+01  6.7244E+00  8.8804E+01
1.0E-03  6.0019E-02  3.4519E-02  6.4173E+00  2.4494E+00  3.0404E+01
1.0E-02  2.3244E-01  1.3000E-01  2.2778E+00  6.6746E-01  7.7912E+00
1.0E-01  5.4993E-01  2.7035E-01  3.8526E-01  6.4466E-02  8.5266E-01
3.0E-01  3.4622E-01  1.2833E-01  3.4600E-02  4.0134E-03  7.8898E-02
5.0E-01  1.1868E-01  3.0811E-02  2.3198E-03  2.3752E-04  7.6398E-03
7.0E-01  1.9486E-02  2.9901E-03  5.2352E-05  5.6038E-06  3.7080E-04
9.0E-01  3.3522E-04  1.6933E-05  2.5735E-08  4.3368E-09  1.1721E-06
vbertone@lxplus037:~/hoppet-qcd/example_f90$
vbertone@lxplus037:~/hoppet-qcd/example_f90$
```

HOPPET

🍏 Perfect agreement between APFEL and HOPPET.



# Other Recent Developments

- 🍏 **Intrinsic-charm** in DIS *a la* FONLL.
- 🍏 **Polarised DGLAP evolution** up to NNLO.
- 🍏 Independent factorisation and renormalisation **scale variations** both in the DIS structure functions and in the evolution,
- 🍏 framework for the **determination of FFs**.

## In the Pipeline

- 🍏 Implementation of **TMD evolution** and **SIDIS cross sections**,
- 🍏 Implementation of the **polarised structure functions**,
- 🍏 **mass corrections** to SIA structure functions.

# TMD Evolution (PDFs)

$$\begin{aligned} F_{f/P}(x, \mathbf{b}_T; \mu, \zeta) &= \sum_j C_{f/j}(x, b_*; \mu_b, \zeta_F) \otimes f_{j/P}(x, \mu_b) && : A \\ &\times \exp \left\{ K(b_*; \mu_b) \ln \frac{\sqrt{\zeta_F}}{\mu_b} + \int_{\mu_b}^{\mu} \frac{d\mu'}{\mu'} \left[ \gamma_F - \gamma_K \ln \frac{\sqrt{\zeta_F}}{\mu'} \right] \right\} && : B \\ &\times \exp \left\{ g_{j/P}(x, b_T) + g_K(b_T) \ln \frac{\sqrt{\zeta_F}}{\sqrt{\zeta_{F,0}}} \right\} && : C \end{aligned}$$

# TMD Evolution (PDFs)

$$F_{f/P}(x, \mathbf{b}_T; \mu, \zeta) = \underbrace{\sum_j C_{f/j}(x, b_*; \mu_b, \zeta_F) \otimes f_{j/P}(x, \mu_b)}_{: A} \times \underbrace{\exp \left\{ K(b_*; \mu_b) \ln \frac{\sqrt{\zeta_F}}{\mu_b} + \int_{\mu_b}^{\mu} \frac{d\mu'}{\mu'} \left[ \gamma_F - \gamma_K \ln \frac{\sqrt{\zeta_F}}{\mu'} \right] \right\}}_{: B} \times \underbrace{\exp \left\{ g_{j/P}(x, b_T) + g_K(b_T) \ln \frac{\sqrt{\zeta_F}}{\sqrt{\zeta_{F,0}}} \right\}}_{: C}$$

- $b_T \ll 1/\Lambda_{\text{QCD}}$
- matching to the collinear region
- factorises as hard and non-perturbative
- numerically cumbersome
- precompute using the APFEL technology

- CS evolution
- perturbative

- matching between the small and large  $b_T$
- non perturbative
- parametrised and fitted to data

# TMDs in SIDIS

🍏 In SIDIS, what enters the computation of the cross sections is:

$$\mathcal{L}_{\text{SIDIS}} = \int \frac{d^2 \mathbf{b}_T}{(2\pi)^2} e^{-i \mathbf{q}_T \cdot \mathbf{b}_T} F_{f/P}(x, \mathbf{b}_T; \mu, \zeta_F) D_{H/f}(x, \mathbf{b}_T; \mu, \zeta_D)$$

Fourier transform

PDFs

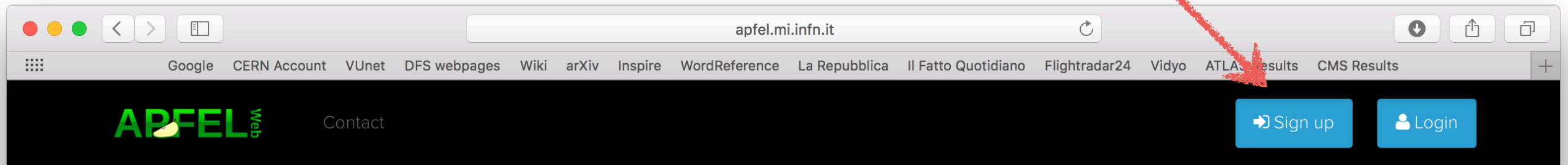
FFs

🍏 The ingredients are:

- 🍏 a set of evolved TMD-PDFs,
- 🍏 a set of evolved TMD-FFs,
- 🍏 the Fourier transform of its product.
- 🍏 Complex set of tasks that have to be performed optimally
- 🍏 APFEL provides the ideal environment for this computation:
  - 🍏 fast and accurate interpolation techniques,
  - 🍏 precomputation of the time consuming bits.

# APFEL Web

Go to <http://apfel.mi.infn.it> and sign up



Welcome to APFEL online cluster!

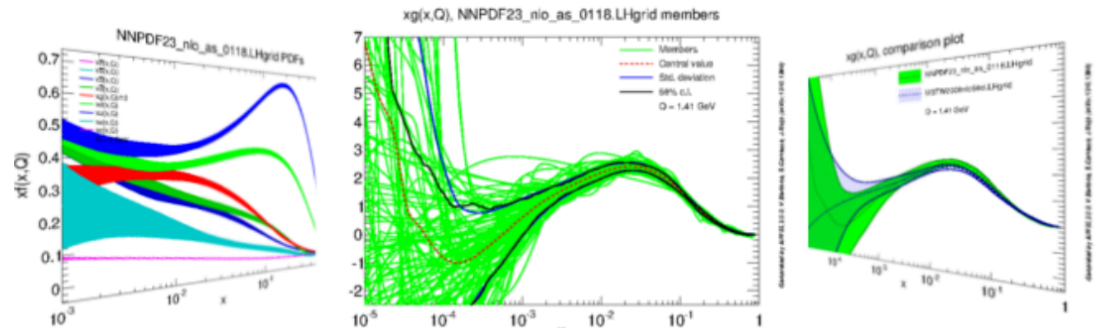
This web-application is a tool designed for High Energy Physics by providing a simple and intuitive interface to plot and compute the most common observables with Parton Distribution Functions (PDFs).

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  $\overline{\text{MS}}$  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](#))

# APFEL Web

Go to <http://apfel.mi.infn.it> and sign up

The screenshot shows a desktop browser window with the URL [apfel.mi.infn.it](http://apfel.mi.infn.it). The browser's address bar and tabs are visible. The website's header features the APFEL logo, a 'Contact' link, and 'Sign up' and 'Login' buttons. A red arrow points from the text 'sign up' in the instruction above to the 'Sign up' button on the website. The main content area is titled 'APFEL registration' and includes the instruction 'Please complete the form below to access to the APFEL website:'. The registration form consists of four input fields: 'Enter your e-mail address', 'Enter your password', 'Confirm your password', and 'Spin of the Standard Model Higgs?'. A blue 'Register' button is located below the form. To the right of the form, there is a section titled 'Mobile website:' which contains a QR code and an 'ANDROID APP ON Google play' badge. On the far right, a partial view of another browser window shows a plot titled 'xgix.QI comparison plot'.

APFEL Web

Contact

Sign up

Login

APFEL Web

Contact

Home

Sign up

## APFEL registration

Please complete the form below to access to the APFEL website:

Enter your e-mail address

Enter your password

Confirm your password

Spin of the Standard Model Higgs?

Register

Mobile website:

QR code

ANDROID APP ON Google play

xgix.QI comparison plot

# APFEL Web

## Workspace

Workspace

Home

My Profile

PDF MANAGER

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

TOOLS

- Plotting Tools

DOWNLOAD RESULTS

- View jobs

### Welcome to APFEL Web

APFEL Web News & Documentation

#### Tweets by @apfelwebteam

01 Jun

**APFEL Web** @apfelwebteam  
Check out the updated graphics interface in

Embed View on Twitter

#### APFEL Web Status

Component	Status
Cores	100%
APFEL library	2.4.0
LHAPDF6	61.5
LHAPDF5	5.91
ROOT	5.34/21
APPLgrid	1.4.56
Overall	running

APFEL Web Workflow



# APFEL Web Workspace

The screenshot displays the APFEL Web Workspace interface. At the top, a browser window shows the URL `apfel.mi.infn.it`. Below the browser window, a navigation bar includes links to Google, CERN Account, VUnet, DFS webpages, Wiki, arXiv, Inspire, WordReference, La Repubblica, Il Fatto Quotidiano, Flightradar24, Vidyo, ATLAS Results, and CMS Results. The main header features the APFEL Web logo and a Contact link. A red arrow points from the 'Workspace' title to the 'Workspace' section on the left sidebar.

The left sidebar contains the following sections:

- Workspace**
  - Home
  - My Profile
- PDF MANAGER**
  - My PDF sets
  - Add PDF set
  - Import a LHAPO
- TOOLS**
  - Plotting Tools
- DOWNLOAD RESULTS**
  - View jobs

The main content area is titled 'My APFEL Web Gallery' and contains the text: 'Below you find a gallery with your recent jobs. If the gallery is empty [start a new job!](#)'. The gallery displays a grid of 20 plots, arranged in 5 rows and 4 columns. Each plot shows a comparison of theoretical predictions (green shaded regions) with experimental data (blue lines). The plots are labeled with various parameters and scales, including  $x$ ,  $Q$ , and  $Q^2$ . The plots are titled with the following labels:  $xy(x,Q)$ ,  $xg(x,Q)$ ,  $xu(x,Q)$ ,  $xv(x,Q)$ ,  $x\bar{u}(x,Q)$ ,  $x\bar{d}(x,Q)$ ,  $x\bar{s}(x,Q)$ ,  $x\bar{c}(x,Q)$ ,  $x\bar{b}(x,Q)$ ,  $x\bar{t}(x,Q)$ ,  $x\bar{g}(x,Q)$ ,  $x\bar{u}(x,Q)$ ,  $x\bar{d}(x,Q)$ ,  $x\bar{s}(x,Q)$ ,  $x\bar{c}(x,Q)$ ,  $x\bar{b}(x,Q)$ ,  $x\bar{t}(x,Q)$ ,  $x\bar{g}(x,Q)$ ,  $x\bar{u}(x,Q)$ ,  $x\bar{d}(x,Q)$ ,  $x\bar{s}(x,Q)$ ,  $x\bar{c}(x,Q)$ ,  $x\bar{b}(x,Q)$ ,  $x\bar{t}(x,Q)$ .

At the bottom right, there is a logo for 'APFEL Web Workflow'.

# APFEL Web

## Add a new PDF set

The screenshot shows the APFEL Web interface. The left sidebar contains a 'Workspace' section with links to 'Home' and 'My Profile'. Below this is the 'PDF MANAGER' section, which includes 'My PDF sets' and 'Add PDF set' (highlighted with a red arrow). Further down are 'TOOLS' (Plotting Tools) and 'DOWNLOAD RESULTS' (View jobs). The main content area is titled 'Set parameters for PDF' and contains the 'LHAPDF grid setup' form. The form has four fields: 'PDF Set:' (a dropdown menu showing 'NNPDF30\_nlo\_as\_0118' with a note 'a LHAPDF6 grid'), 'PDF Error:' (a dropdown menu showing 'Montecarlo - Standard Deviation'), 'Select member:' (a dropdown menu showing '0'), and 'Library for evolution:' (a dropdown menu showing 'LHAPDF', which is pointed to by a red arrow). Below the form is a 'Confirm' button. At the bottom of the page, the text 'Use tabulated LHAPDF evolution...' is displayed.

Workspace

- Home
- My Profile

PDF MANAGER

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

TOOLS

- Plotting Tools

DOWNLOAD RESULTS

- View jobs

### Set parameters for PDF

LHAPDF grid setup:

PDF Set: NNPDF30\_nlo\_as\_0118 a LHAPDF6 grid

PDF Error: Montecarlo - Standard Deviation

Select member: 0

Library for evolution: LHAPDF

[APFEL advanced evolution options](#)

Confirm

Use tabulated LHAPDF evolution...

# APFEL Web

## Add a new PDF set

The screenshot shows the APFEL Web interface in a browser window. The browser's address bar displays 'apfel.mi.infn.it'. The page has a sidebar on the left with links to 'Import a LHAPDF grid', 'TOOLS' (including 'Plotting Tools'), and 'DOWNLOAD RESULTS' (including 'View jobs'). The main content area is titled 'Library for evolution:' and features a dropdown menu set to 'APFEL'. A red arrow points to this dropdown. Below this, there is a link for 'APFEL advanced evolution options'. The 'APFEL evolution setup:' section contains various configuration options, each with a dropdown or input field:

Parameter	Value
Theory:	QCD
Solution:	Exact
Perturbative order:	LO (LO QED)
Scheme:	VFNS
HQ Scheme:	POLE
$m_c$ , charm mass in (GeV):	1,275
$m_b$ , bottom mass in (GeV):	4,18
$m_t$ , top mass in (GeV):	173,07
$\alpha_S(Q_{\text{ref}})$ :	0,118
$Q_{\text{ref}}$ (GeV):	91,2
$\alpha(Q_{\text{ref}})$ :	0,007496252
$Q_{\text{ref}}$ (GeV):	1,777
$\mu_R/\mu_F$ :	1,00
Maximum flavor PDFs:	6
Maximum flavor $\alpha$ :	6

At the bottom of the configuration area is a blue 'Confirm' button.

...or customised APFEL evolution

## Plotting tools

Workspace

Home

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TOOLS

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View jobs

Choose a plotting tool and select your PDF set

Some jobs, like PDF luminosities, require some time to be finalized. Check the job status at [View jobs](#) page.

The plotting tools can be used for both the LHAPDF libraries: [LHAPDF5](#) and [LHAPDF6](#).

Tools for PDF basic plotting

Plot PDF Members

Plot Multiple PDF Flavors

Tools for PDF analysis & comparisons

Compare PDFs in  $x$

Compare PDFs in  $Q$

Compare PDF Luminosity

All PDF Luminosities

Compare PDF Correlations

PDF Correlation Matrix

Tools for theoretical predictions from PDFs

DIS in  $x$

DIS in  $Q$

APPLgrid Observables

## View your jobs

Workspace

- Home
- My Profile

PDF MANAGER

Choose a plotting tool and select your PDF set

Some jobs, like PDF luminosities, require some time to be finalized. Check the job status at [View jobs](#) page.

apfel.mi.infn.it

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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

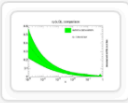
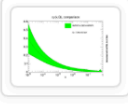
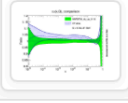
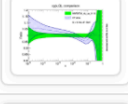
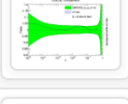
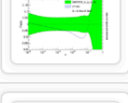
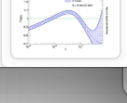
- Plotting Tools

DOWNLOAD RESULTS

[View jobs](#)

## View and download your jobs

View, modify and delete your jobs.

Image	Label	Status	Date	Actions
	LH6_30	Done	Oct. 22, 2016, 11:16 p.m.	<a href="#">Details</a> <a href="#">Clone</a> <a href="#">Erase</a>
	LH5_30	Done	Oct. 22, 2016, 11:16 p.m.	<a href="#">Details</a> <a href="#">Clone</a> <a href="#">Erase</a>
	NN_vs_CT_NLO_up	Done	Aug. 10, 2016, 5:13 p.m.	<a href="#">Details</a> <a href="#">Clone</a> <a href="#">Erase</a>
	NN_vs_CT_NLO_gluon	Done	Aug. 10, 2016, 5:13 p.m.	<a href="#">Details</a> <a href="#">Clone</a> <a href="#">Erase</a>
	NN_vs_CT_LO_up	Done	Aug. 10, 2016, 5:12 p.m.	<a href="#">Details</a> <a href="#">Clone</a> <a href="#">Erase</a>
	NN_vs_CT_LO_gluon	Done	Aug. 10, 2016, 5:11 p.m.	<a href="#">Details</a> <a href="#">Clone</a> <a href="#">Erase</a>
	gluon_CT14_LO_vs_NLO_ext	Done	Aug. 1, 2016, 11:33 a.m.	<a href="#">Details</a> <a href="#">Clone</a> <a href="#">Erase</a>

