NNPDF3.1 luxQED

Based on [VB, S. Carrazza, N.P. Hartland, J. Rojo *et al.*, arXiv:1712.07053]

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Extraction of the photon PDF

The "standard" approaches

1) **Model-based** determinations:

- the `MRST2004QED` set:
  A. Martin *et. al* [hep-ph/0411040]
  - only *inelastic* component determined as collinear emission off valence quarks,
  - no experimental uncertainty propagation.
- the `CT14QED` set(s):
  C. Schmidt *et. al* [arXiv:1509.02905]
  - similar approach as MRST2004QED but with an estimate of the uncertainty based on a comparison to HERA isolated photon production.
  - includes an *elastic* component derived from equivalent photon approximation.

2) **Data-driven** determinations:

- `NNPDF2.3QED/NNPDF3.0QED` and `xFitter_epHMDY` sets:
  [arXiv:1308.0598, arXiv:1606.07130] F. Giuli *et al.* [arXiv:1701.08553]
  - the photon PDF is fitted to data using DIS and LHC Drell-Yan data.
  - Large uncertainties due to limited sensitivity of the dataset to the photon PDF.

Extraction of the photon PDF

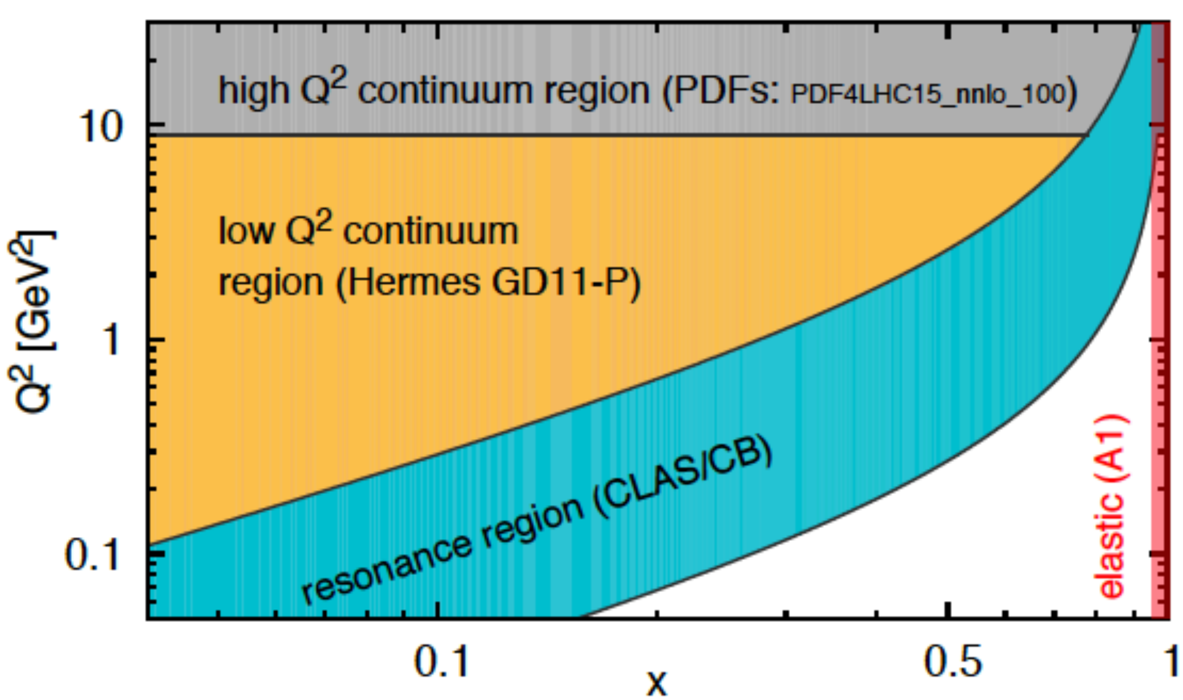
The LUXqed approach

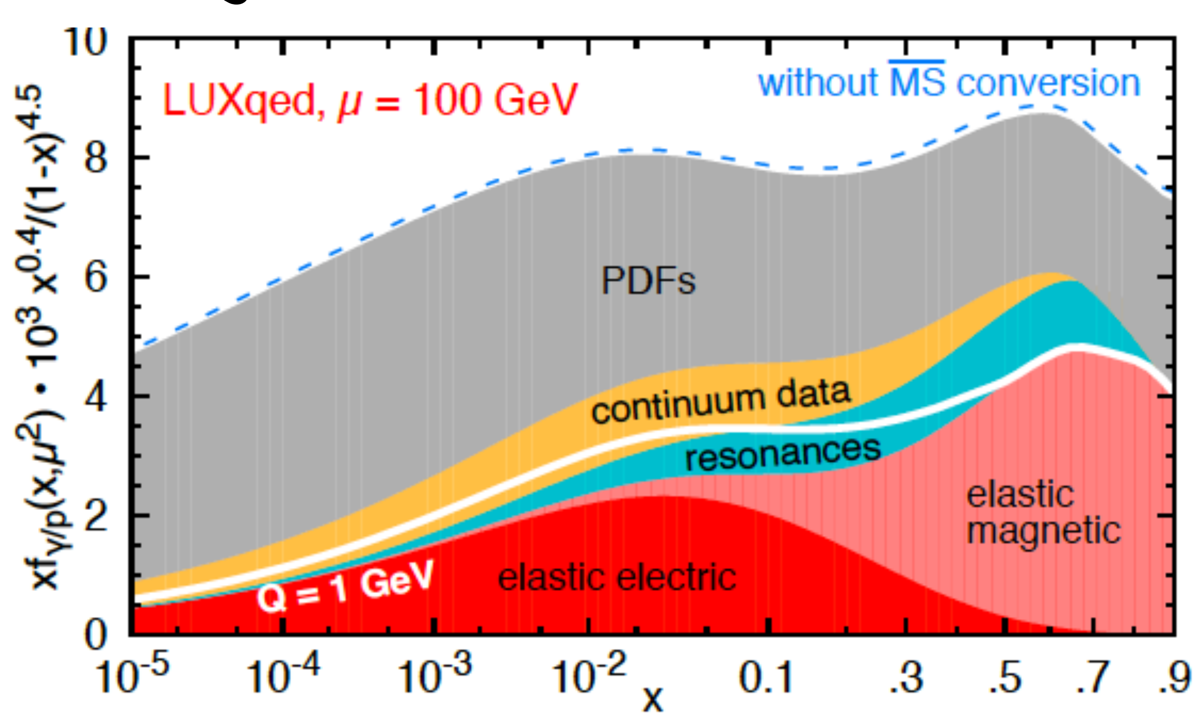
$$Q^2_{\rm min} = (m_p^2 x^2)/(1-z)$$

$$x\gamma(x,\mu) = \frac{1}{2\pi\alpha(\mu)}\int_x^1 \frac{dz}{z}\left\{\int_{Q^2_{\rm min}}^{\mu^2/(1-z)} \frac{dQ^2}{Q^2}\alpha^2(Q^2)\left[-z^2 F_L(x/z,Q^2) + \left(zP_{\gamma q}(z) + \frac{2x^2m_p^2}{Q^2}\right)F_2(x/z,Q^2)\right] - \alpha^2(\mu)z^2F_2(x/z,\mu^2)\right\} + \mathcal{O}(\alpha\alpha_s,\alpha^2)$$

$\overline{\rm MS}$ conversion

- Photon PDF written in terms of inclusive **DIS structure functions**:
  - *elastic* component given by magnetic/electric form factors from A1 + dipole,
  - *inelastic* component:
    - *resonance* region $(m_p + m_\pi)^2 < W^2 < 3.5$ GeV^2: CLAS fit/CB parameterisation,
    - *low-Q^2 continuous* region $W^2 > 3.5$ GeV^2 and $Q^2 < 9$ GeV^2: Hermes GD11-P fit,
    - *high-Q^2 continuous* region $W^2 > 3.5$ GeV^2 and $Q^2 > 9$ GeV^2: PDFs.





A. Manohar *et al.* [arXiv:1607.04266]

Extraction of the photon PDF

The LUXqed approach

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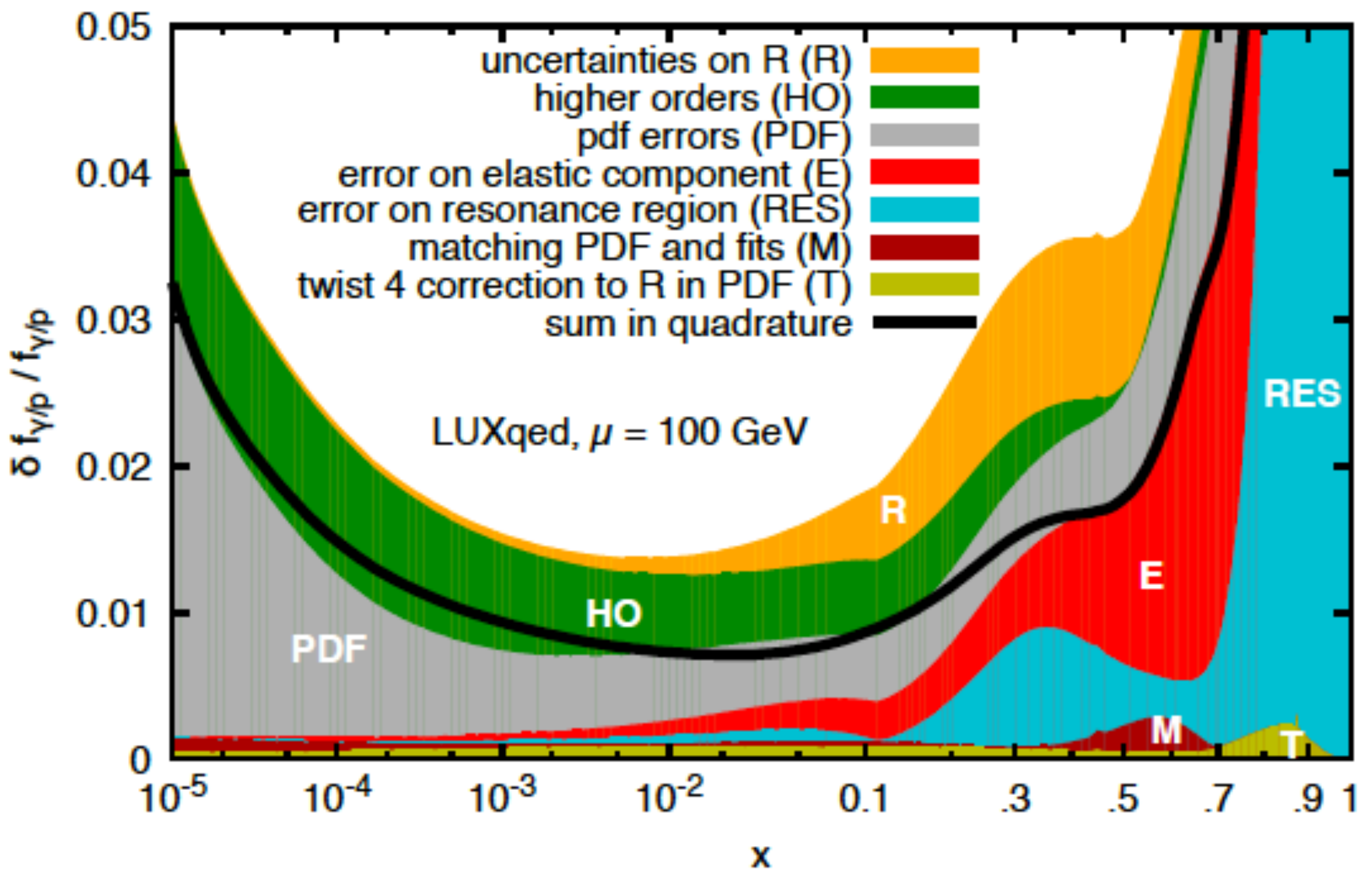
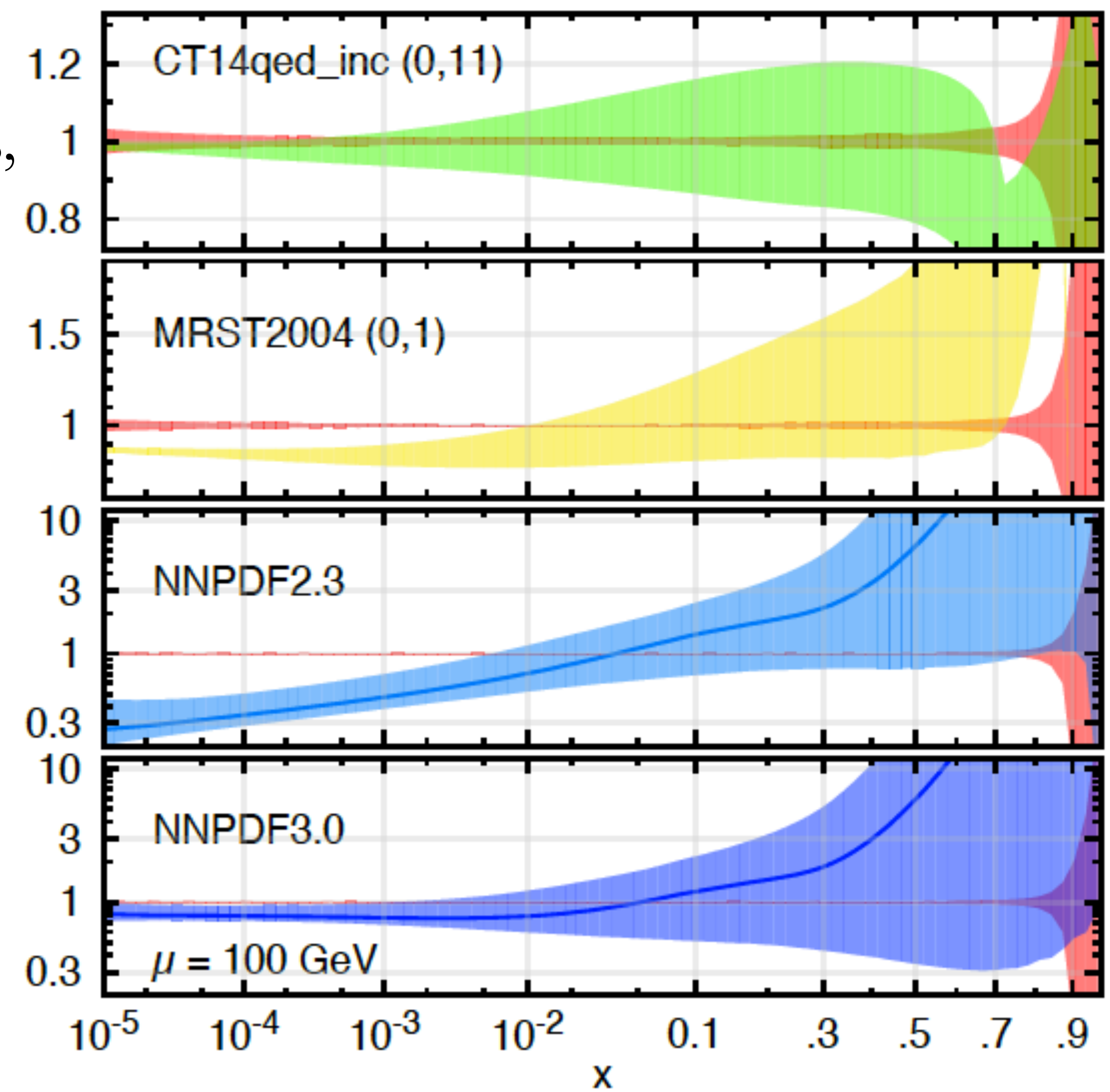
$$x\gamma(x,\mu) = \frac{1}{2\pi\alpha(\mu)} \int_x^1 \frac{dz}{z} \left\{ \int_{Q^2_{\rm min}}^{\mu^2/(1-z)} \frac{dQ^2}{Q^2} \alpha^2(Q^2) \left[-z^2 F_L(x/z, Q^2) \right.\right.$$

$$\left.\left. + \left(z P_{\gamma q}(z) + \frac{2x^2 m_p^2}{Q^2} \right) F_2(x/z, Q^2) \right] - \alpha^2(\mu) z^2 F_2(x/z, \mu^2) \right\} + \mathcal{O}\left(\alpha\alpha_s, \alpha^2\right)$$

- Estimate of the uncertainty:
  - variations of parameters/parameterisations,
  - PDF uncertainties.





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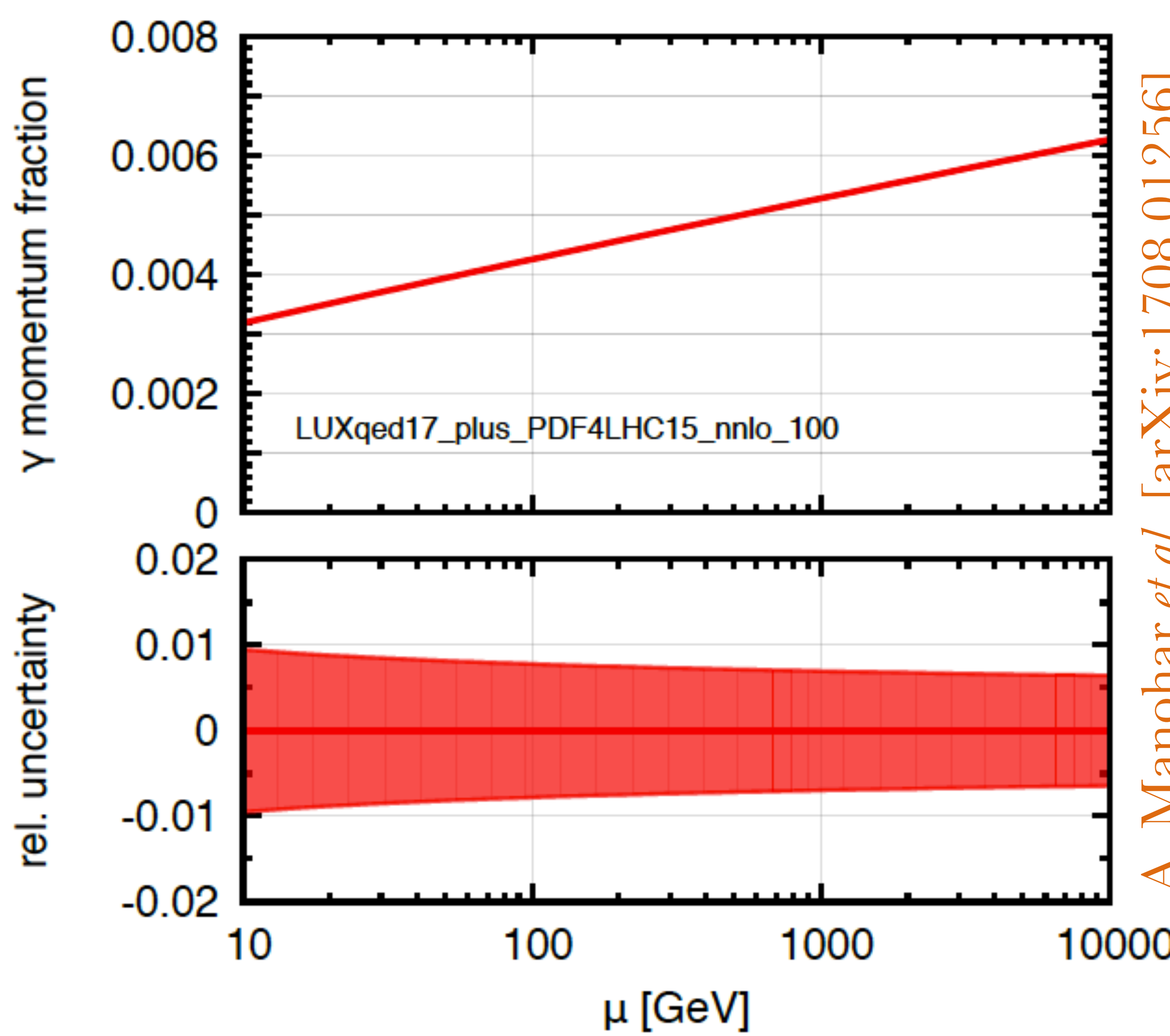
The photon PDF in a global fit

- How does the photon PDF modify the result of a global PDF fit?

1. **Momentum sum rule**:

$$\int_0^1 dx\, x\,[\Sigma(x,\mu) + g(x,\mu) + \gamma(x,\mu)] = 1$$



A. Manohar *et al.* [arXiv:1708.01256]

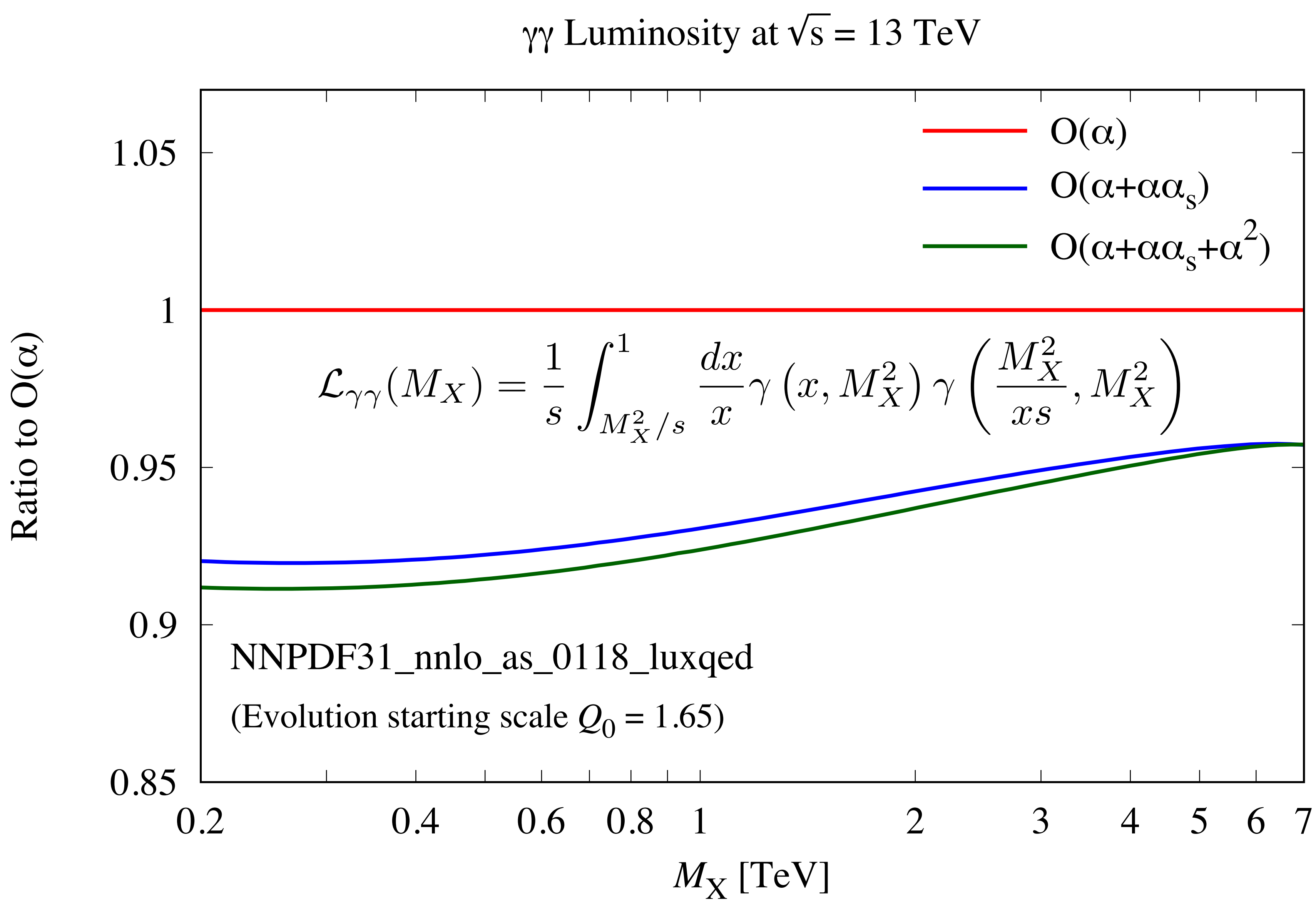
The photon PDF in a global fit

- How does the photon PDF modify the result of a global PDF fit?

  2. **QED corrections** to the DGLAP equations up to (full) NLO:

$$P_{ij} = \alpha_s P_{ij}^{(1,0)} + \alpha_s^2 P_{ij}^{(2,0)} + \alpha_s^3 P_{ij}^{(3,0)} + \alpha P_{ij}^{(0,1)}(x) + \alpha\alpha_s P_{ij}^{(1,1)} + \alpha^2 P_{ij}^{(0,2)}$$

[arXiv:1512.00612]
[arXiv:1606.02887]

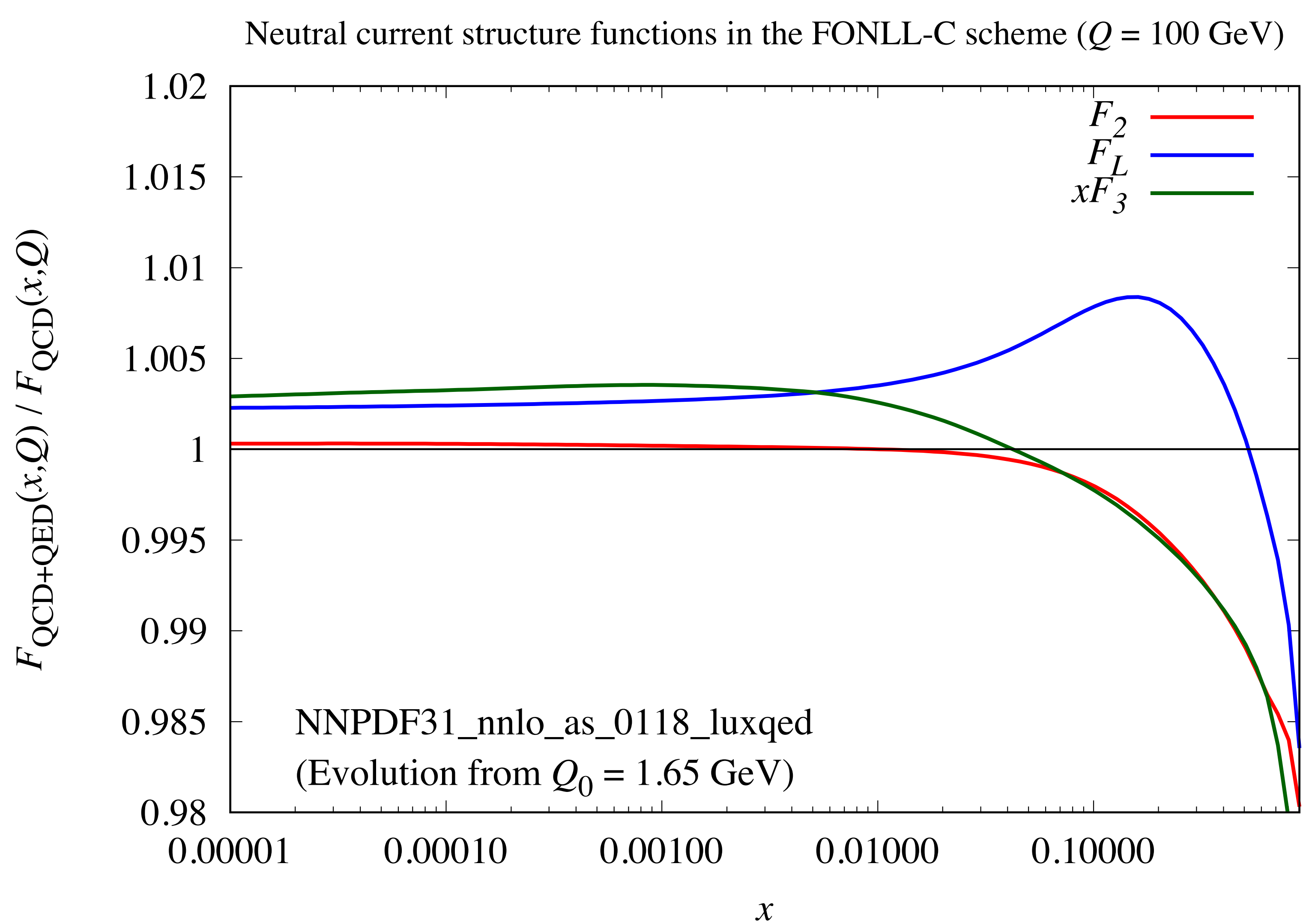


The photon PDF in a global fit

- How does the photon PDF modify the result of a global PDF fit?

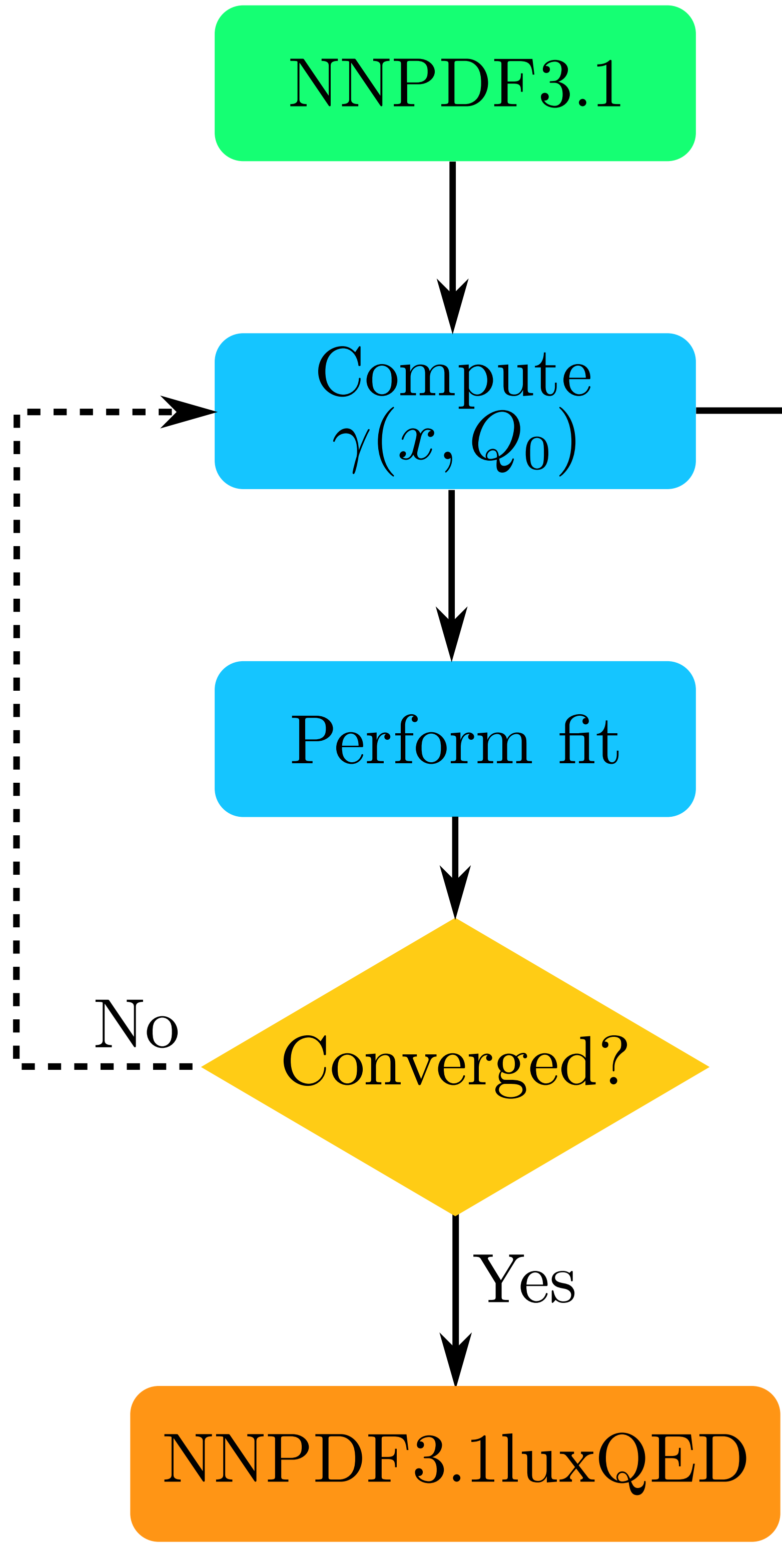
3. **QED corrections** to the hard cross sections including photon-initiated (PI) diagrams:

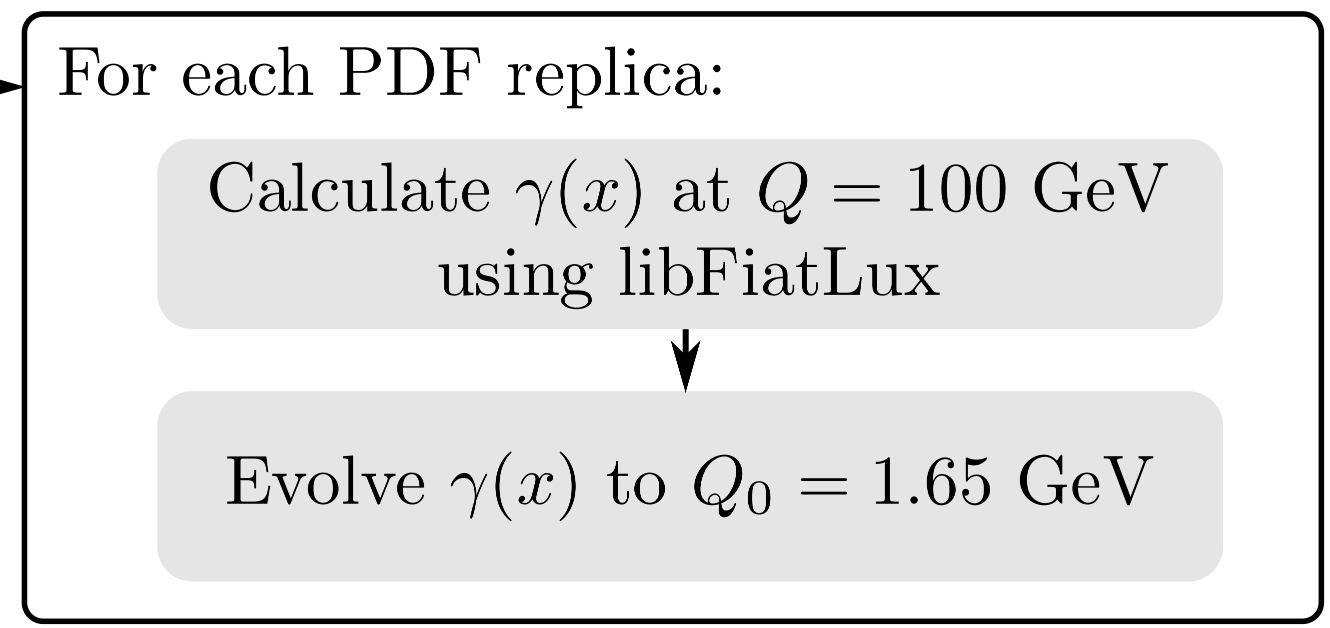
   - included in **DIS** to $O(\alpha)$,
   - no QED corrections to the **hadronic processes** (*ad hoc* cuts to the NNPDF3.1 dataset to minimise their impact).



The photon PDF in a global fit

The NNPDF iterative strategy

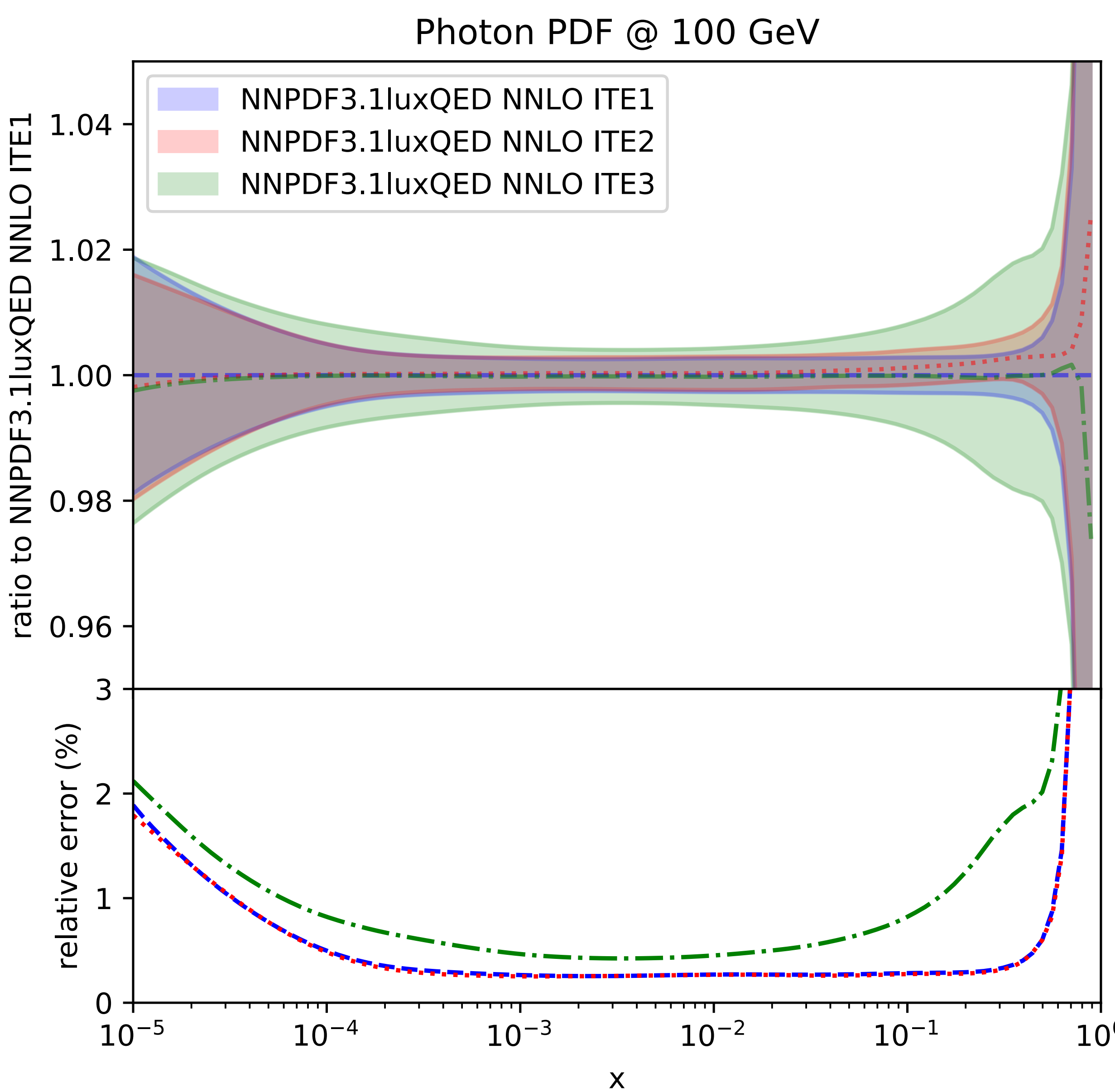


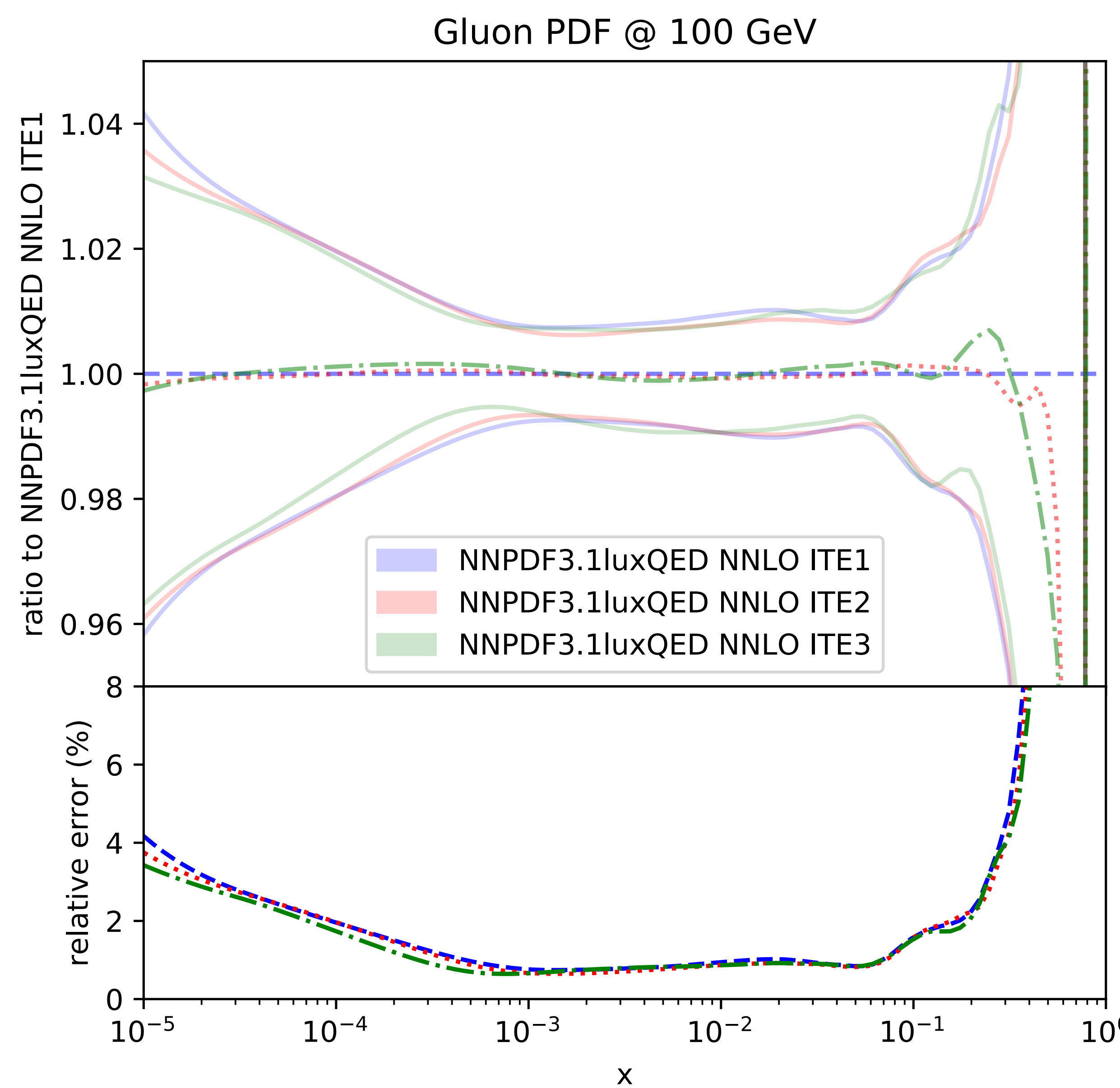


- Same dataset as NNPDF3.1 (including cuts),
- Convergence when differences on the photon PDF are less than 5%,
- LUXqed systematic uncertainties added at the last iteration as statistical fluctuations.

Convergence of the procedure

- The iterative procedure converges **quickly**:
  - **two iterations** are enough to get stable results for the photon PDF,
  - a third iteration is performed to include the LUXqed **systematic uncs**.,
  - **quark** and **gluon** PDF almost unaffected.

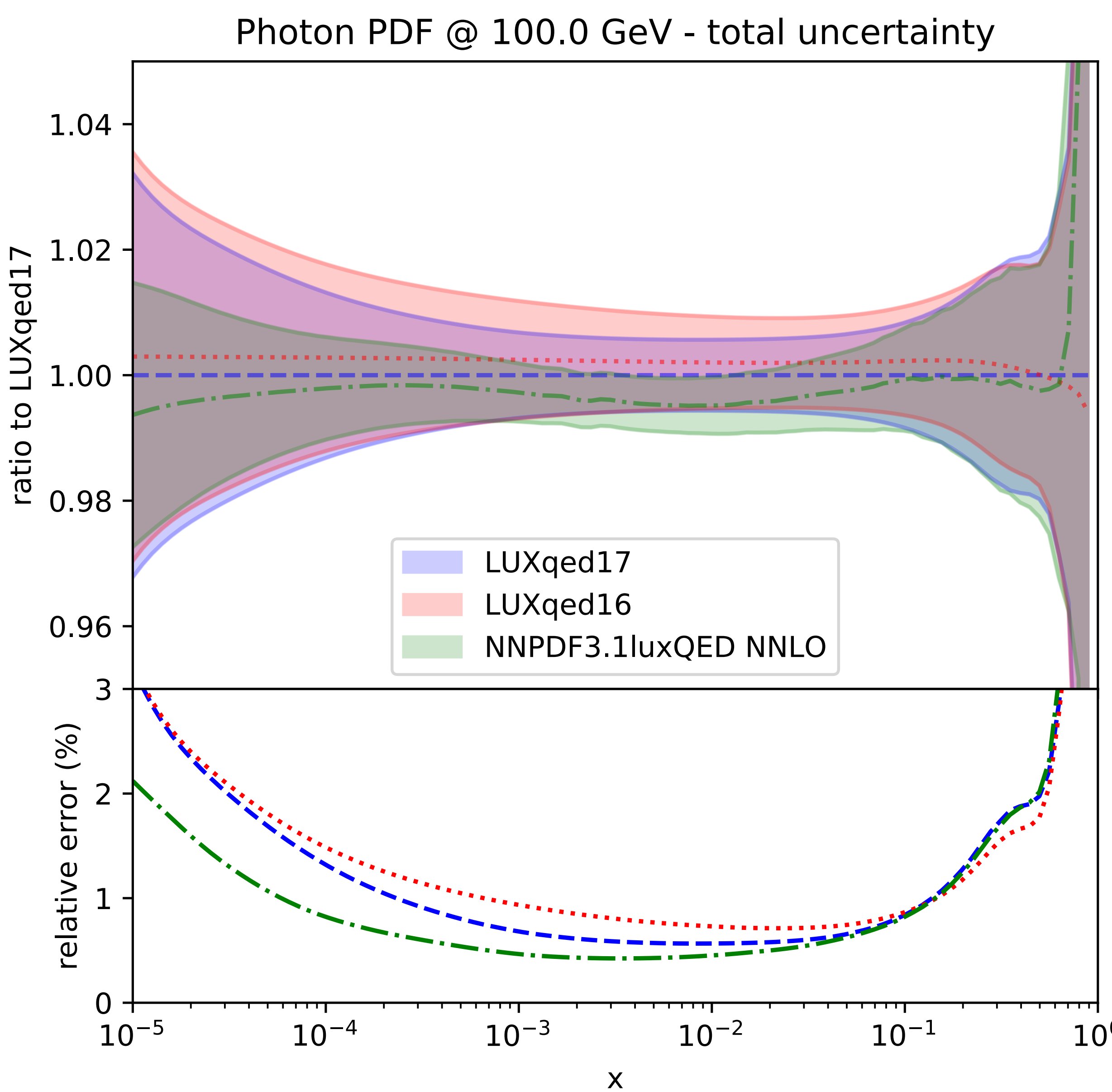


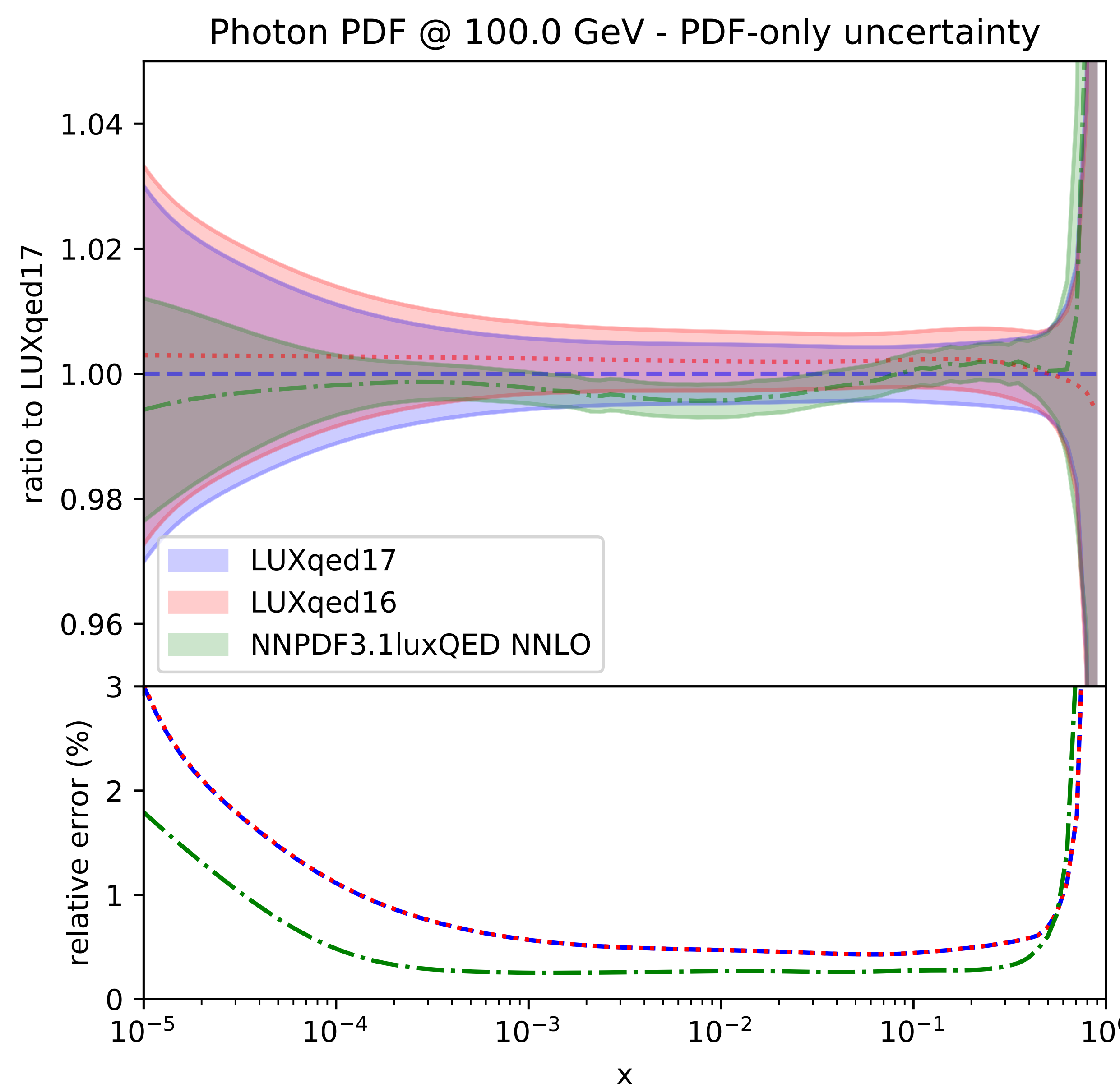


The NNPDF3.1luxQED set

NNPDF3.1luxQED versus LUXqed16/17

- Good agreement with the LUXqed results:
  - **central values** well within uncertainties,
  - **Reduction** of the error at small *x* where PDF uncertainties dominate:
    - difference in the **starting PDF set** (NNPDF3.1 vs. PDF4LHC15).

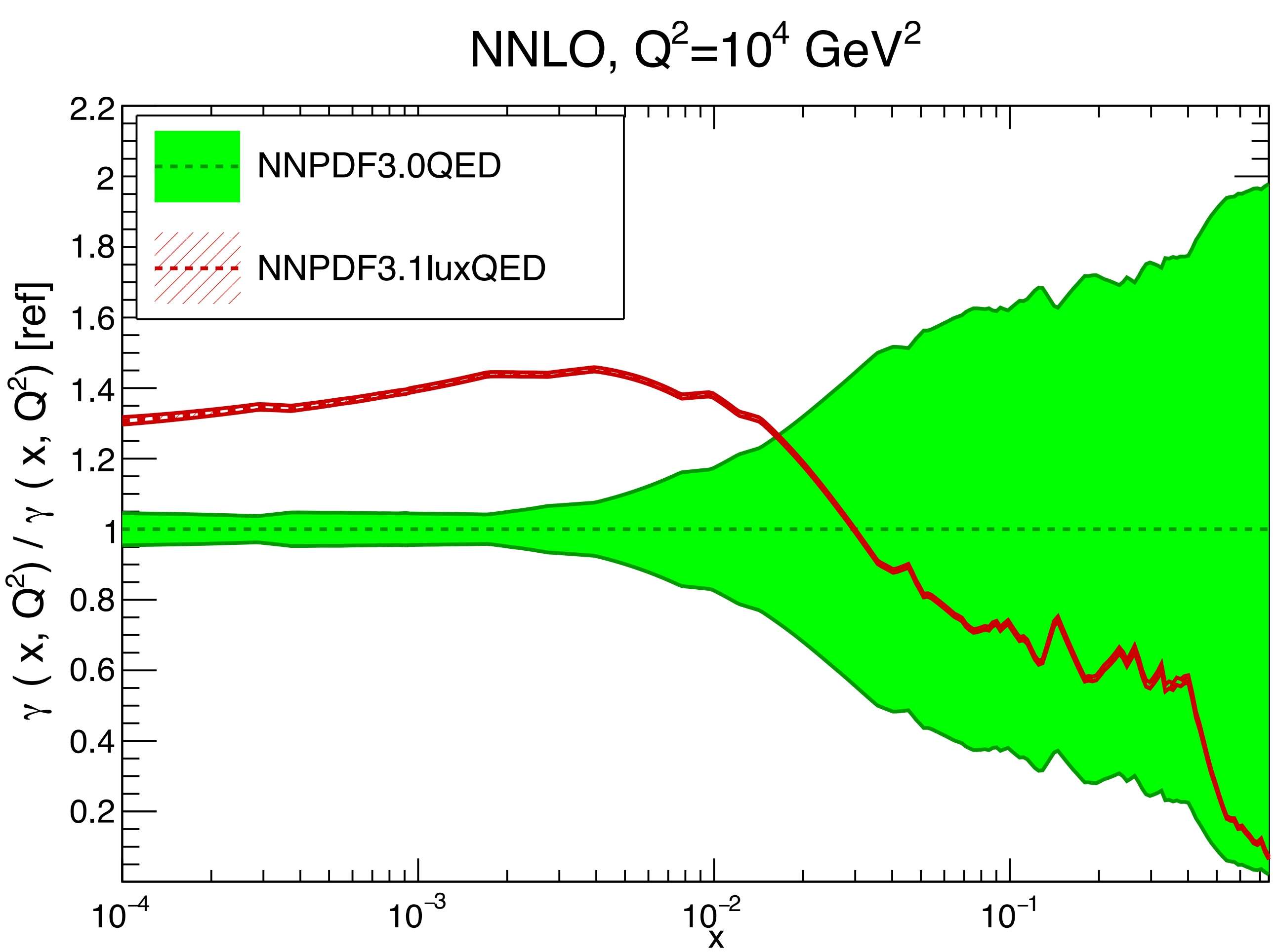


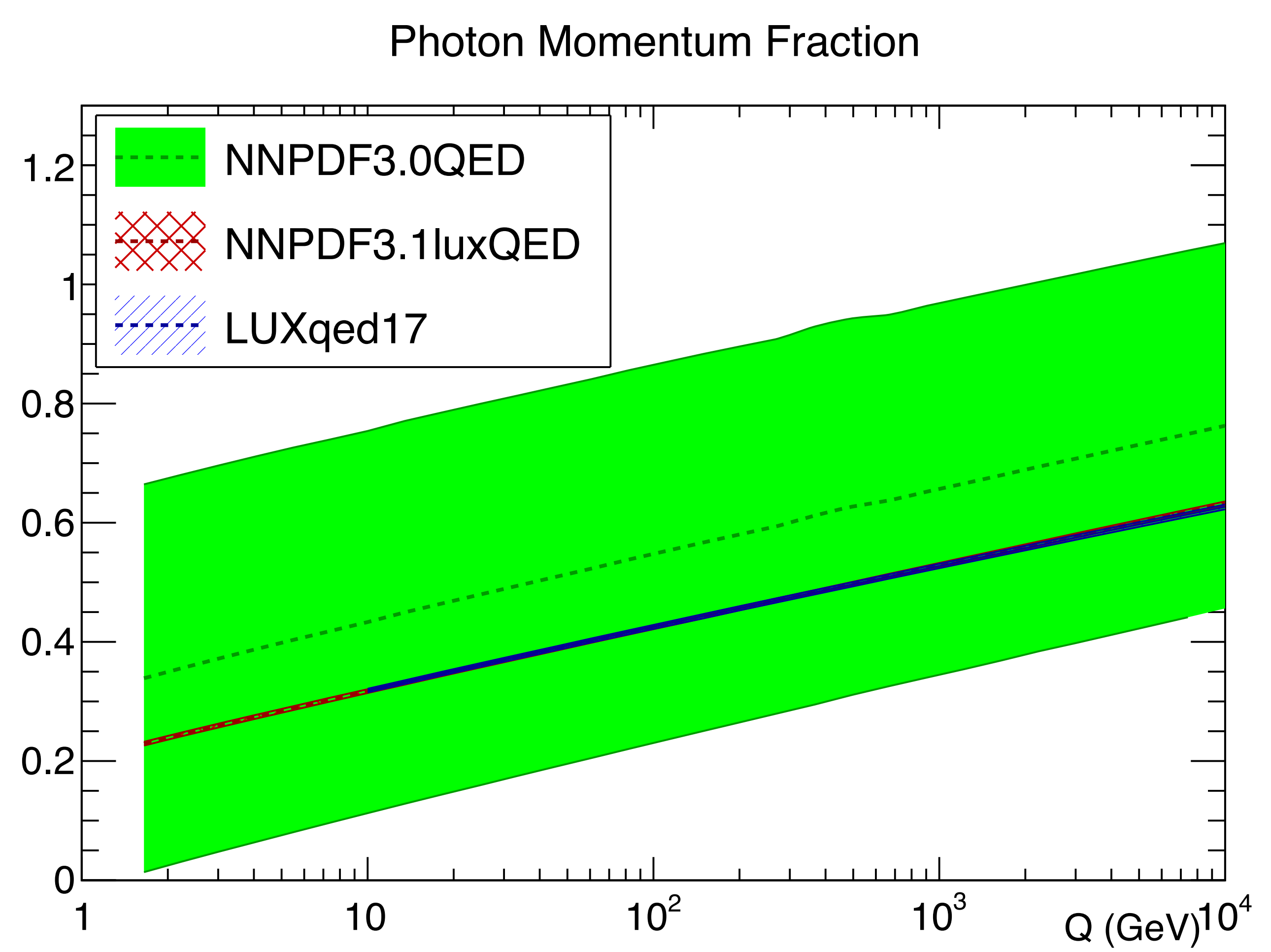


The NNPDF3.1luxQED set

NNPDF3.1luxQED versus NNPDF3.0QED

- Consistency within the large uncertainties of NNPDF3.1 at **large *x***,
- More substantial difference al **small *x***:
  - different **evolutions** (NNPDF3.0QED is based on NNPDF2.3QED),
- Agreement within (large) uncertainties for the momentum sum rule.

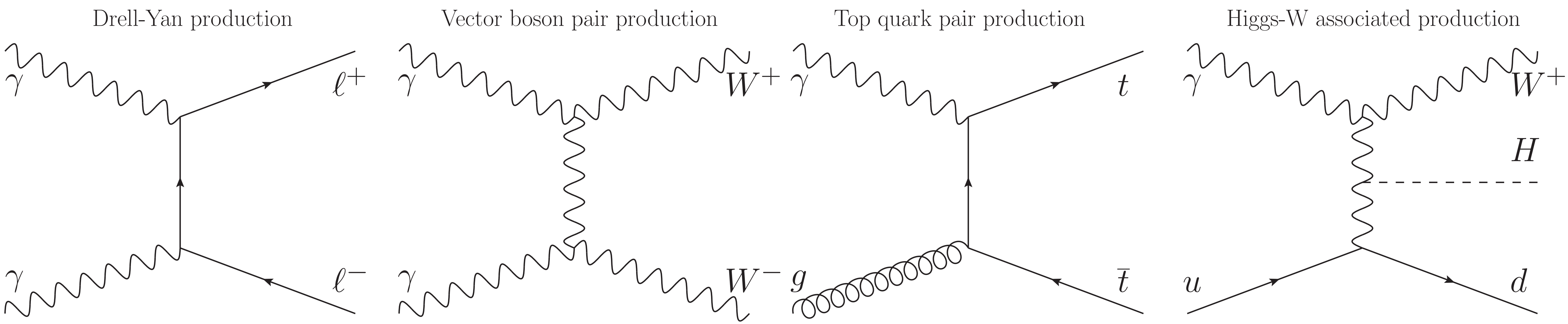




The NNPDF3.1luxQED set

Phenomenology

- Consider processes **sensitive to PI** diagrams at LO:

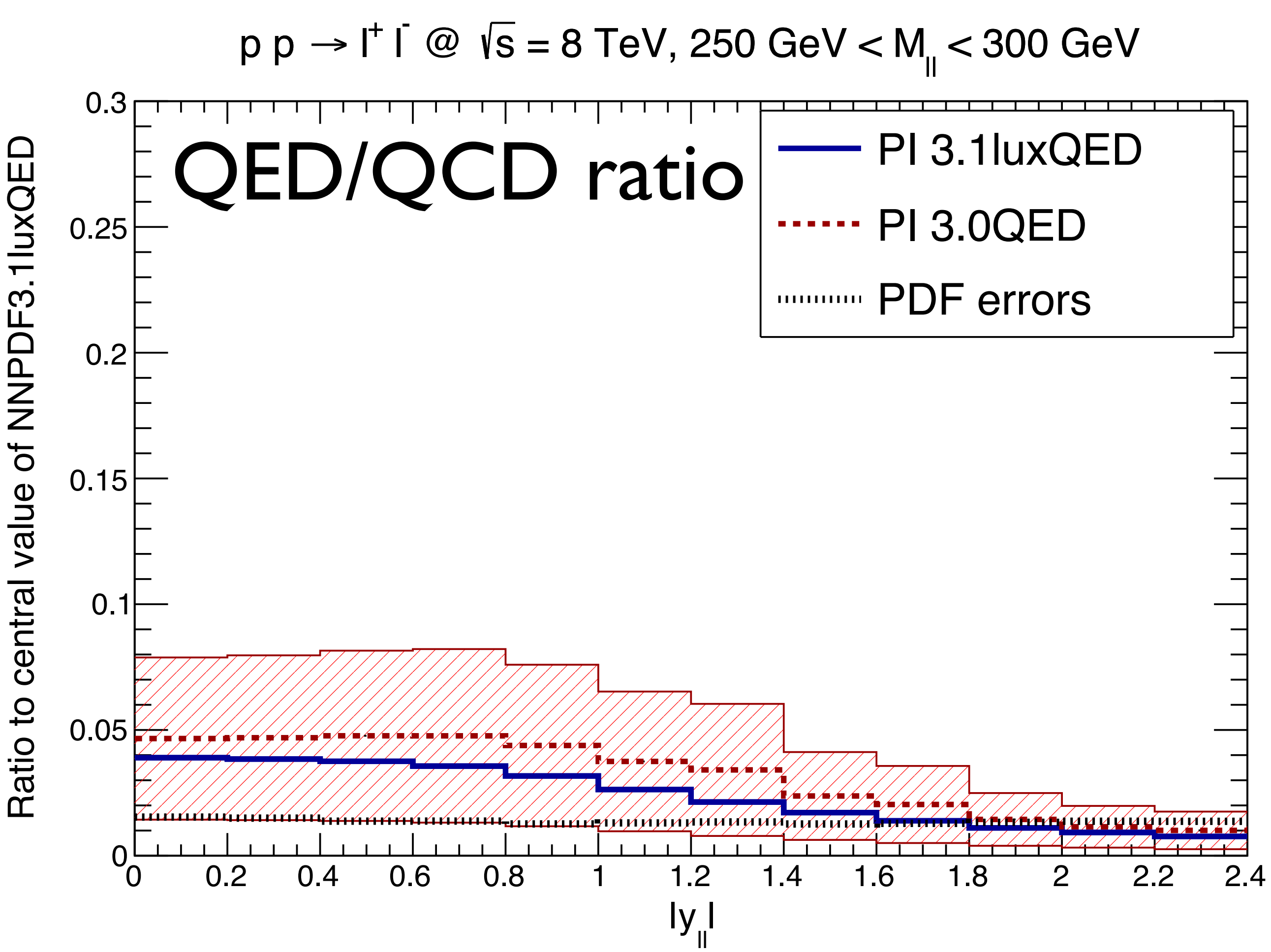


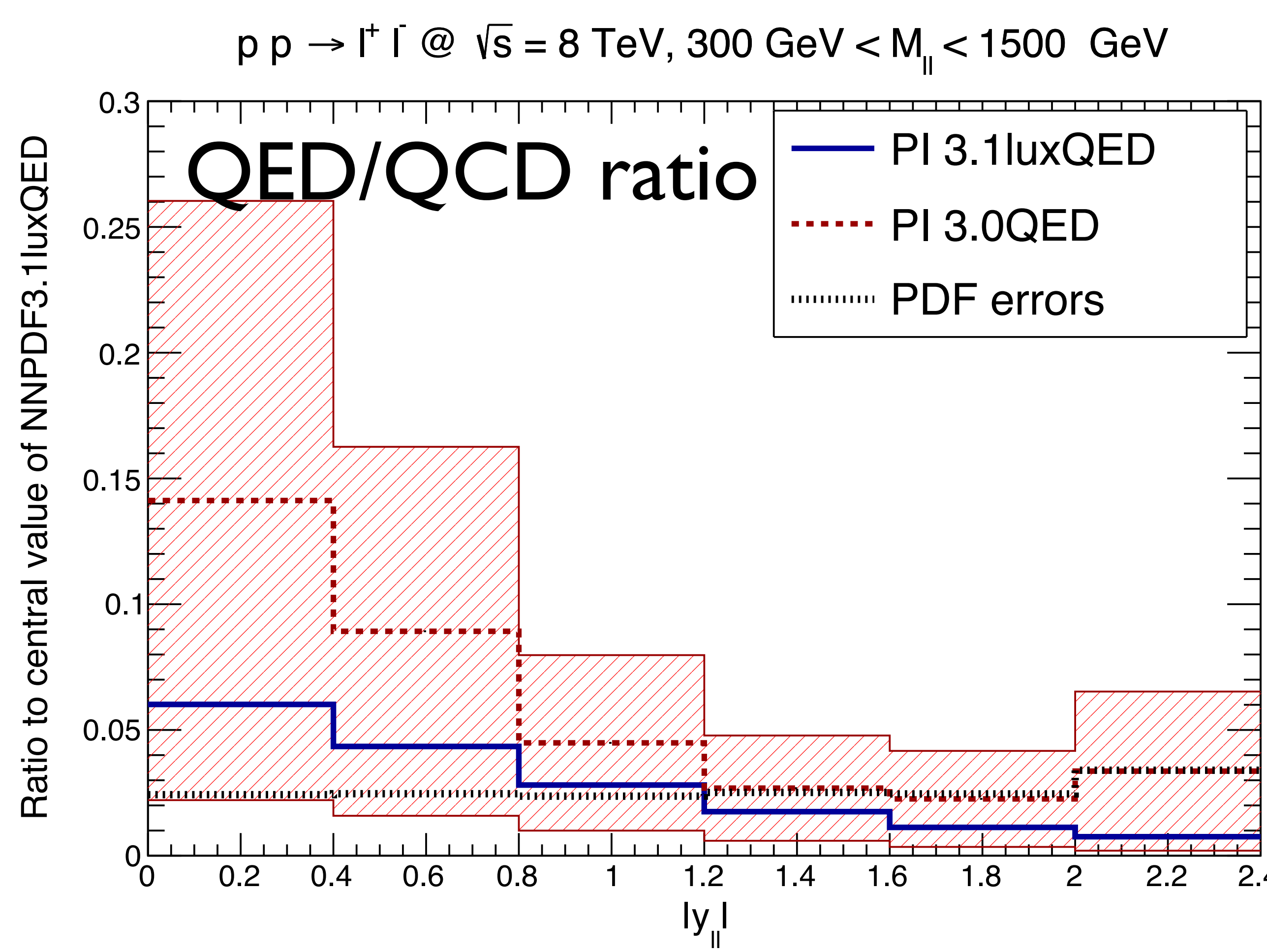
- Processes are computed:
  - at **LO** in QCD and QED (in the following plots the QED/QCD ratio is shown),
  - using **MadGraph5_aMC@NLO**,
  - producing interpolation grids in the **APPLgrid** format with **aMCfast**,
  - use **NNPDF3.1luxQED** and **NNPDF3.0QED**.

The NNPDF3.1luxQED set

Phenomenology: high-mass Drell-Yan (HMDY)

- The **8 TeV ATLAS** HMDY data is particularly sensitive to PI:
  - sensitive to the **large-x** photon PDF where 3.0 is particularly uncertain,
  - with 3.1luxQED the effect of PI can be as large as **5 - 6%**,
  - important to include this data accounting for PI in **future fits**.

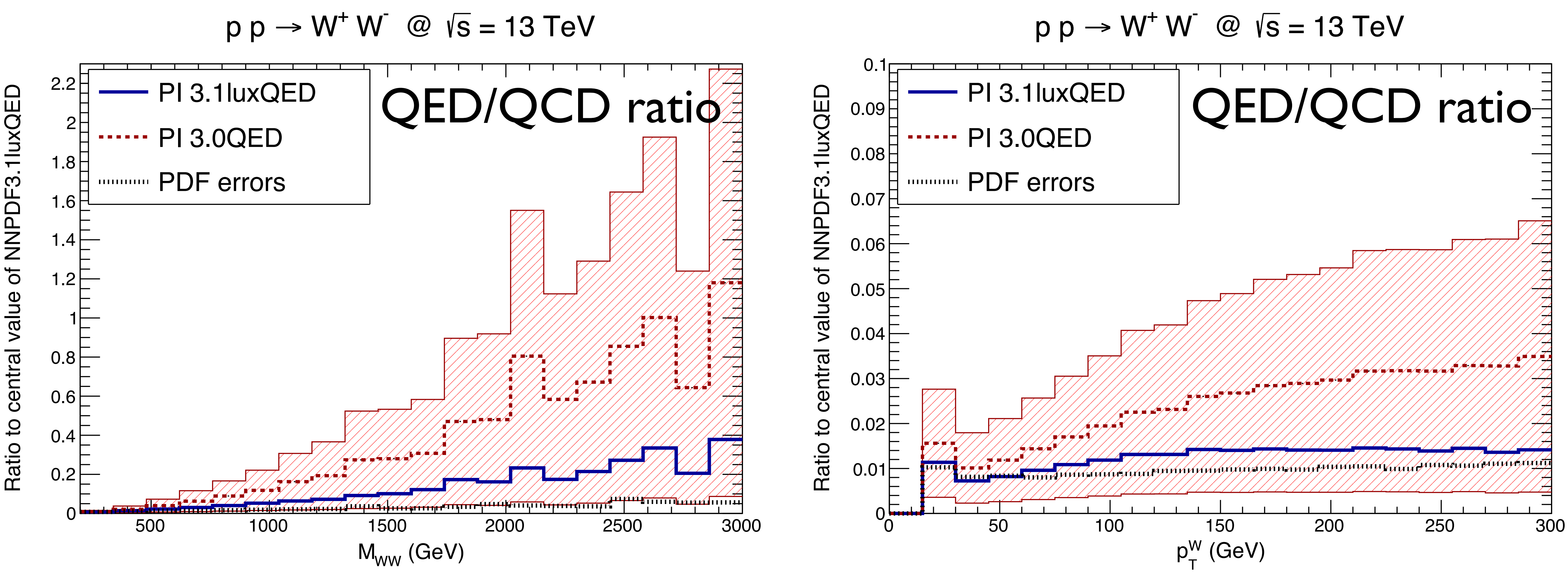




The NNPDF3.1luxQED set

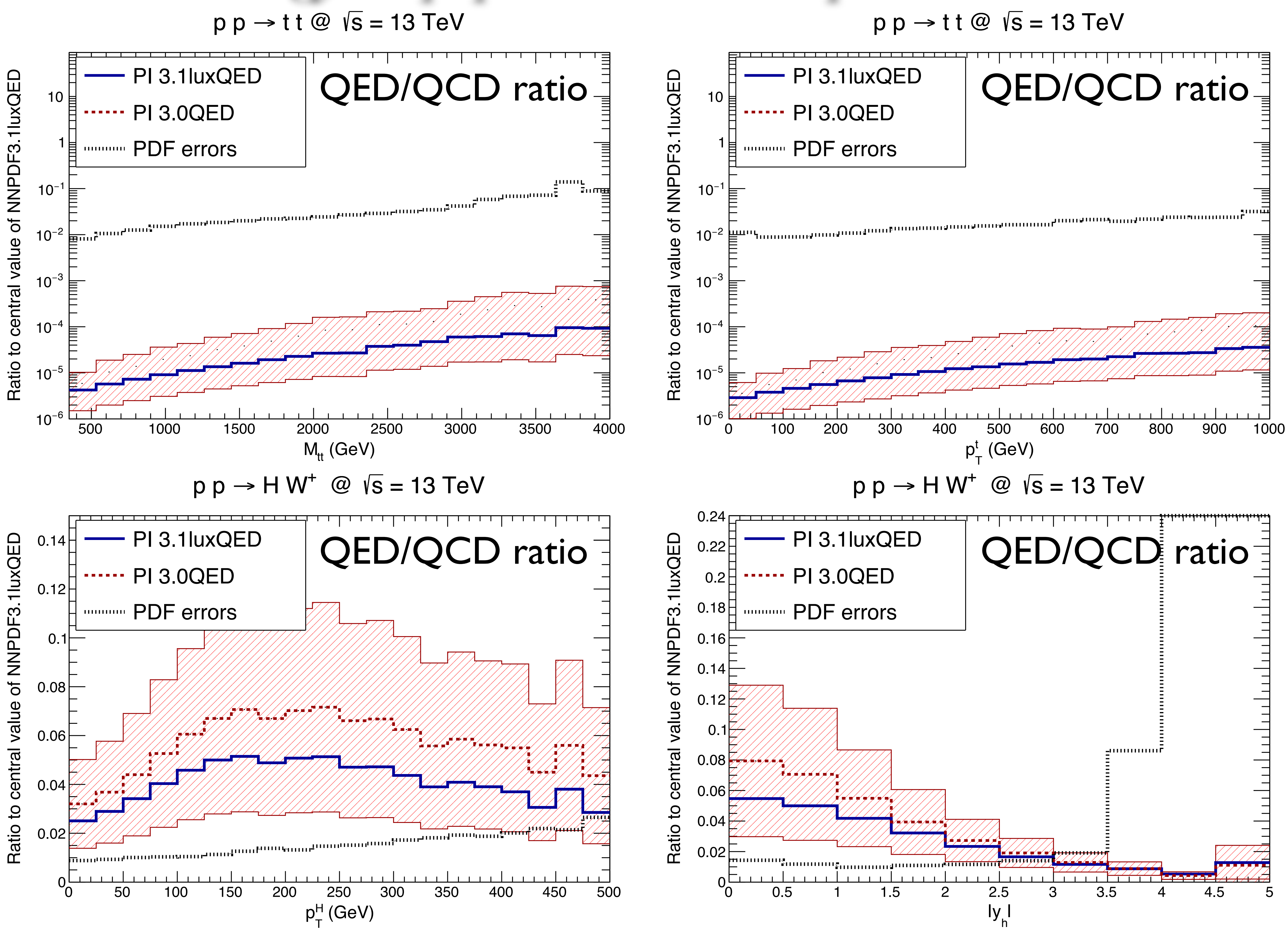
Phenomenology: WW production

- Vector-boson pair production at the LHC provides a direct probe of the **EW sector** and thus is important to BSM searches:
    - WW inv. mass distribution at large M_{WW} heavily affected by PI (~35%),
    - different picture for the W p_T constantly at the 1 - 2% level.



The NNPDF3.1luxQED set

Phenomenology: top-pair and HW production



Summary

- I presented the **NNPDF3.1luxQED** PDF set:
  - **consistent** inclusion of the LUXqed formalism in the NNPDF framework:
    - **momentum sum rule** including the photon PDF,
    - **DGLAP equation** including QED correction up to $O(\alpha_s\alpha)$ and $O(\alpha^2)$,
    - QED corrections to the **DIS structure functions** to $O(\alpha)$.
  - first exploration of the impact of this PDF set on some processes sensitive to the photon PDF and relevant to the **LHC phenomenology**.
- NNPDF3.1luxQED is available through the **LHAPDF** interface.
- An **open-source implementation** of the LUXqed formalism is available from here:

https://github.com/scarrazza/fiatlux