PDFs and EW corrections

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N3PDF

Machine Learning • PDFs • QCD

Introduction

The PDF priorities

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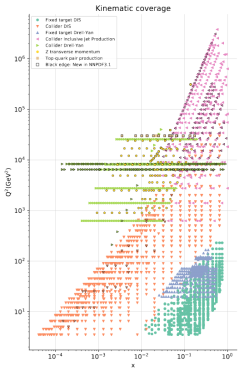
Collect and implement data from different processes.



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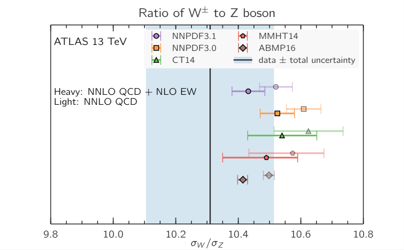

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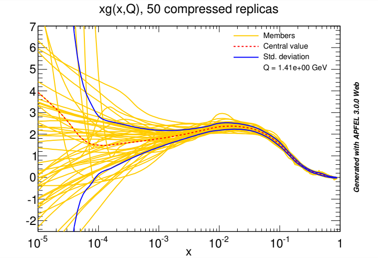
Compute theoretical predictions for multiple processes.

Methodology

Define an optimized regression models for the PDF fits.



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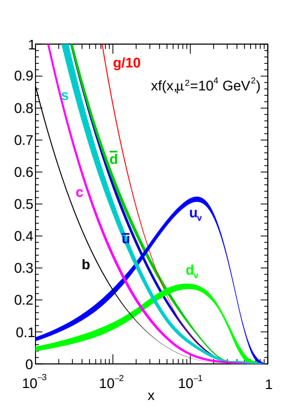
After several achievements, the PDF community then moved towards:



PDF uncertainties

Estimate PDF uncertainties from data.

Theory uncertainties

Estimate PDF uncertainties from theory. (see 1905.11313)

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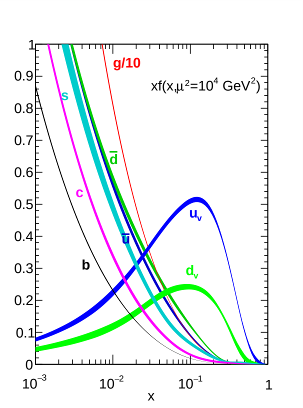

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Electroweak corrections

Photon PDF, QED and electroweak corrections

PDFs and EW corrections

Electroweak corrections to PDFs translates in:

- adding **QED corrections** to DGLAP, naively:

$$\frac{\mathcal{O}(\alpha_s^2)}{\mathcal{O}(\alpha)} \rightarrow \frac{\alpha_s^2(m_Z^2)}{\alpha(m_Z^2)} = \frac{0.118^2}{1/127} \sim 1.78;$$

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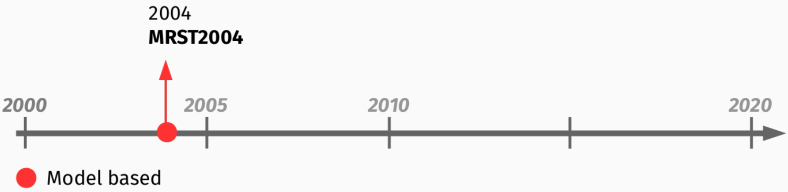
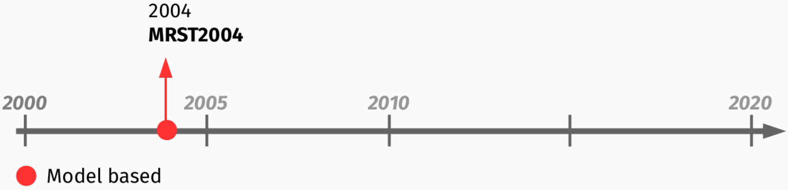
In the last years, the PDF community dedicated a large amount of effort in the reliable photon PDF determination.

Photon PDF timeline



Photon PDF timeline



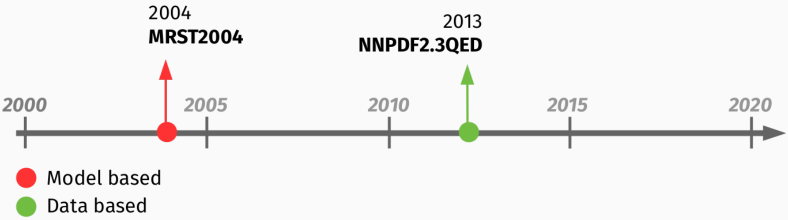
First determination of the photon PDF through a model:

$$
\begin{aligned}
\gamma^p(x, Q_0^2) &= \frac{\alpha}{2\pi}\left[\frac{4}{9}\log\left(\frac{Q_0^2}{m_u^2}\right)u_0(x) + \frac{1}{9}\log\left(\frac{Q_0^2}{m_d^2}\right)d_0(x)\right] \otimes \frac{1+(1-x)^2}{x} \\
\gamma^n(x, Q_0^2) &= \frac{\alpha}{2\pi}\left[\frac{4}{9}\log\left(\frac{Q_0^2}{m_u^2}\right)d_0(x) + \frac{1}{9}\log\left(\frac{Q_0^2}{m_d^2}\right)u_0(x)\right] \otimes \frac{1+(1-x)^2}{x}
\end{aligned}
$$

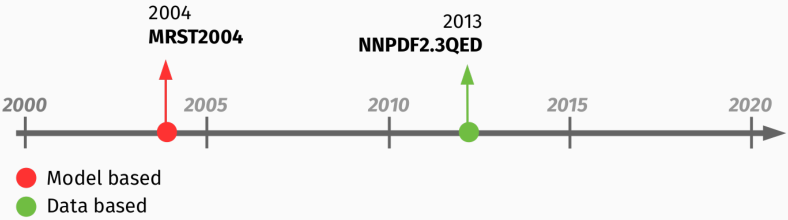
Limitations: no PDF uncertainties, limited model, no hadronic data.

[hep-ph/0411040: Martin, Roberts, Stirling, Thorne '04]

Photon PDF timeline



Photon PDF timeline



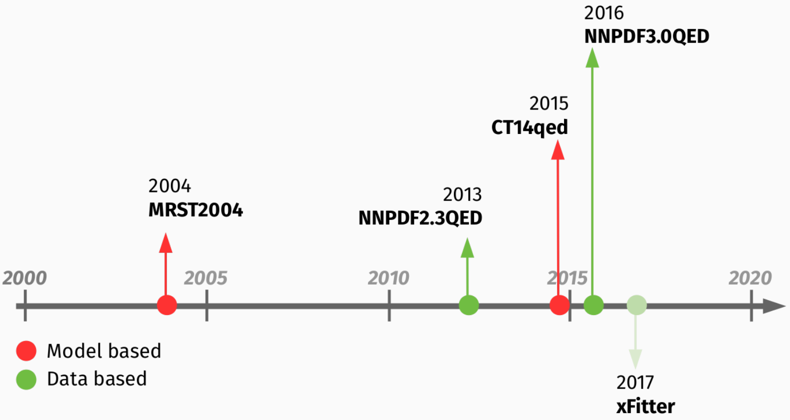
First data driven approach using the NNPDF framework:

- $\gamma(x, Q)$ generated from DIS data,
- reweighted with LHC data (high mass DY, W/Z rapidity).

Limitations: large uncertainties, lack of data constrains (*e.g.* LHC).

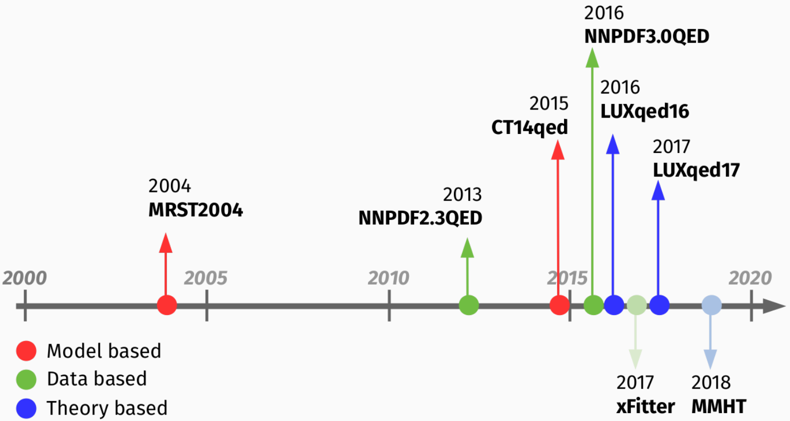
[1308.0598: NNPDF collaboration '13]

Photon PDF timeline



Further upgrades and studies based on both approaches however with limited final quality improvement for $\gamma(x, Q)$.

Photon PDF timeline



In 2016 a new analytic approach called LUXqed was discovered:

- analytic derivation, no experimental data required,
- high accuracy, small $\gamma(x, Q)$ uncertainties.

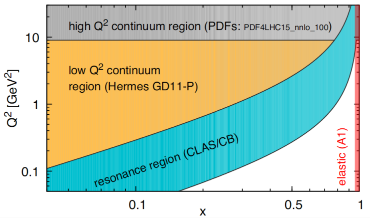
[1607.04266, 1708.01256, Manohar, Nason, Salam, Zanderighi '16, '17]

The LUXqed idea

In the LUXqed procedure, the photon PDF can be expressed in terms of the lepton-proton scattering inclusive structure functions F_2 and F_L by means of an exact QED calculation.

The photon PDF is obtained from analytic expressions:

$$x f_{\gamma/p}(x,\mu^2) = \frac{1}{2\pi\alpha(\mu^2)} \int_x^1 \frac{dz}{z} \left\{ \int_{\frac{x^2 m_p^2}{1-z}}^{\frac{\mu^2}{1-z}} \frac{dQ^2}{Q^2} \alpha^2(Q^2) \left[\left(z p_{\gamma q}(z) + \frac{2x^2 m_p^2}{Q^2} \right) F_2(x/z, Q^2) - z^2 F_L\left(\frac{x}{z}, Q^2\right) \right] - \alpha^2(\mu^2) z^2 F_2\left(\frac{x}{z}, \mu^2\right) \right\}, \quad (6)$$



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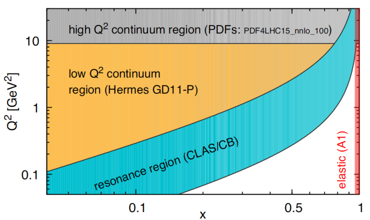


Where the structure functions are decomposed in 3 parts:

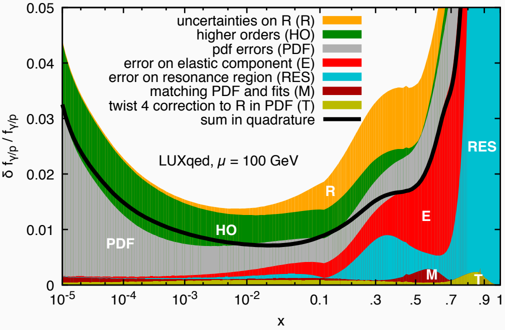
$$F_2(x,Q) = F_2^{\text{elastic}}(x,Q) + F_2^{\text{inelastic}}(x,Q) + F_2^{\overline{\text{MS}}}(x,Q)$$

- **Elastic:** from A1 world data spline model (and variations) below $Q < 10$ GeV^2, dipole model otherwise.
- **Inelastic:** HERMES+CLAS models for low-Q, PDFs for $Q^2 > 9$ GeV^2.
- $\overline{\textbf{MS}}$**:** same as inelastic.

[Manohar, Nason, Salam, Zanderighi '16, '17]

The LUXqed uncertainties

In the LUXqed procedure the final photon PDF uncertainty is obtained through 7 sources of uncertainties:



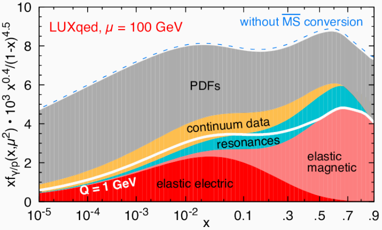
$\rightarrow$ Few-percent PDF uncertainties on $\gamma(x, Q)$.

[Manohar, Nason, Salam, Zanderighi '16, '17]

Photon PDF timeline

The LUXqed approach provides a theoretical framework which is considered the state of the art for the photon PDF determination.

The original papers do not implement a global PDF determination.



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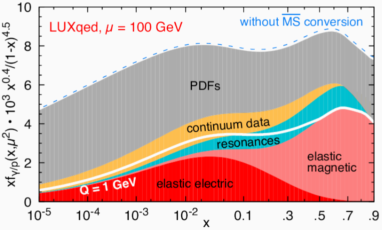
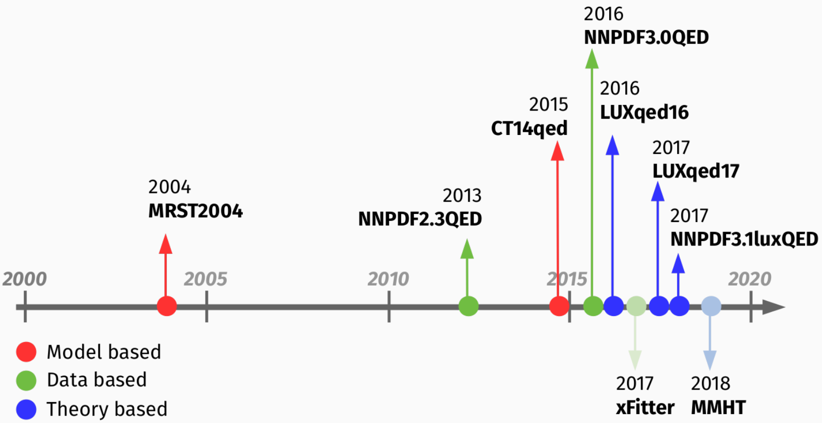


Further step:

NNPDF proposed a methodological approach to include the LUXqed photon in a global PDF determination.

Complete Photon PDF timeline (2004-2019)



Photon PDF in a global fit

Motivation

NNPDF3.1luxQED goals:

- impose the LUXqed photon PDF constraint in a NNPDF3.1 global fit
- use NLO QED theory and DGLAP evolution

NNPDF3.1luxQED strategy

In order to include the LUXqed constraint we have to:

- implement the LUXqed photon calculation [libfiatlux/APFEL]
- compute predictions with QED effects [APFEL/MG5_aMC]

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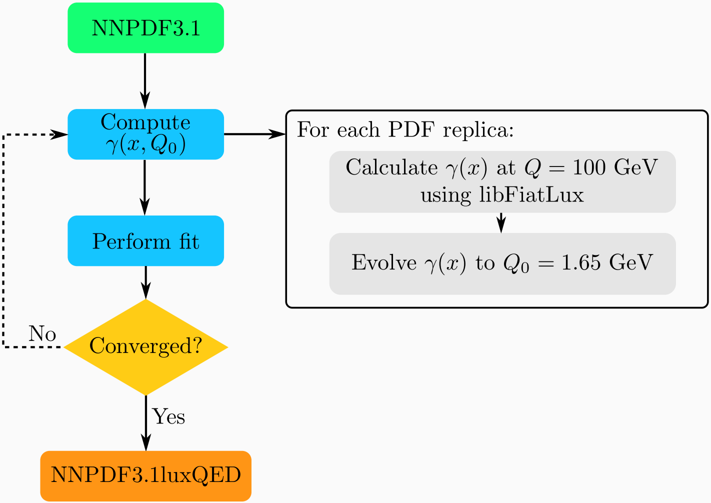
Modifications at the level of the fit strategy are also required:

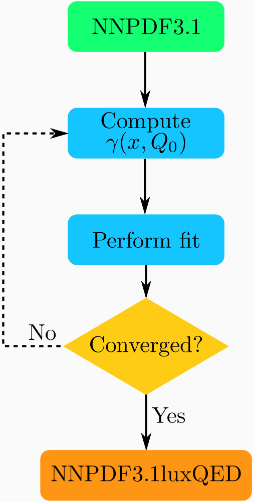
- establish an iterative procedure for the photon PDF determination
- include the photon PDF extra uncertainties from LUXqed17

Adapt the previous points to a Monte Carlo PDF approach.

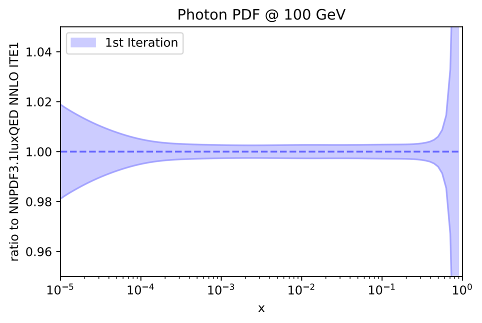
The iterative procedure



The iterative procedure

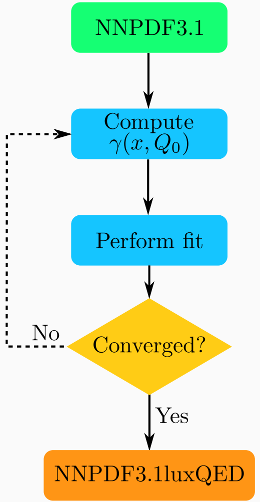


1st Iteration

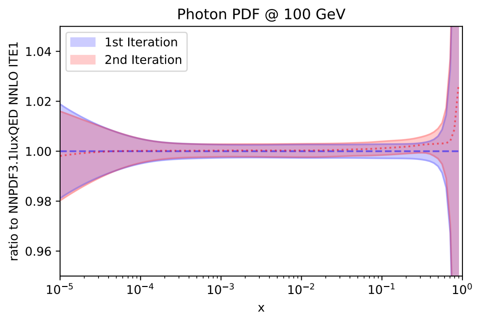


We perform the first iteration and obtain a photon PDF with PDF-only uncertainties.

The iterative procedure

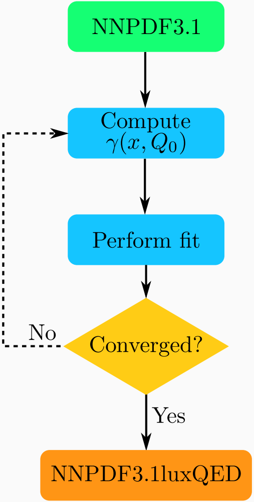


2nd Iteration

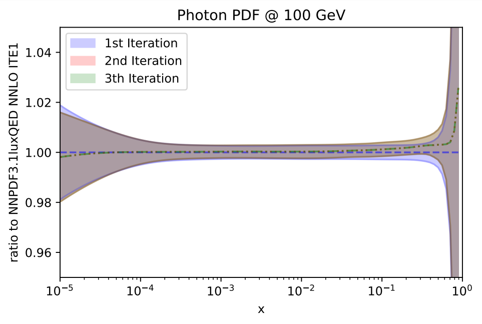


The 2nd iteration propagates NLO QED effects to the fit.

The iterative procedure

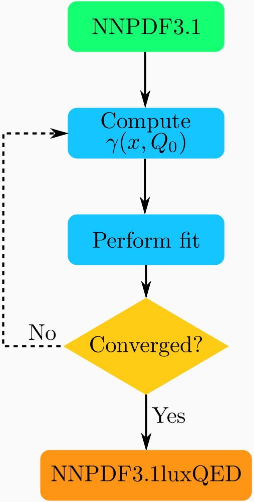


3th Iteration

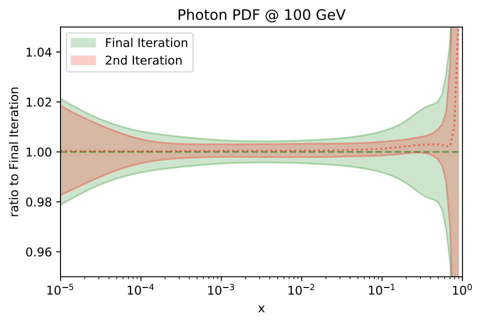


Fit converged, differences are numerically negligible.

The iterative procedure



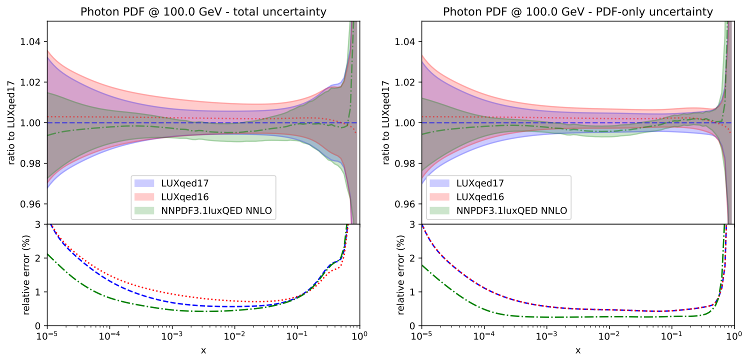
Final Iteration



In the final iteration we include the LUXqed17 extra uncertainties as statistical fluctuations with correlations in x.

Results

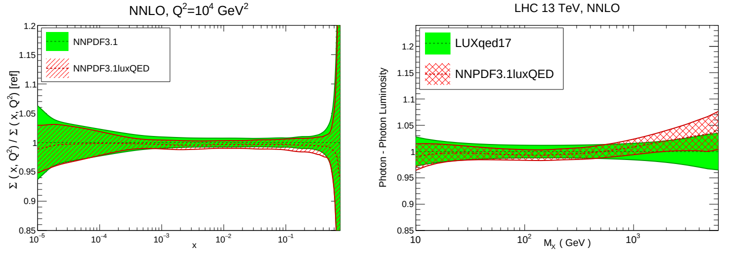
The photon PDF



- Good agreement between NNPDF3.1luxQED and the LUXqed photons.
- NNPDF3.1luxQED photon PDF has smaller uncertainties at small x.

Photon PDF properties

Differences between NNPDF3.1 QCD and QCD+QED fits are small.



The momentum fraction carried by photons in the proton.

	$\langle x\rangle_\gamma(Q = 1.65\,\mathrm{GeV})$	$\langle x\rangle_\gamma(Q = m_Z)$
NNPDF3.0QED	$(0.3 \pm 0.3)\%$	$(0.5 \pm 0.3)\%$
NNPDF3.1luxQED	$(0.229 \pm 0.003)\%$	$(0.420 \pm 0.003)\%$
LUXqed17	–	$(0.421 \pm 0.003)\,\%$

Phenomenology

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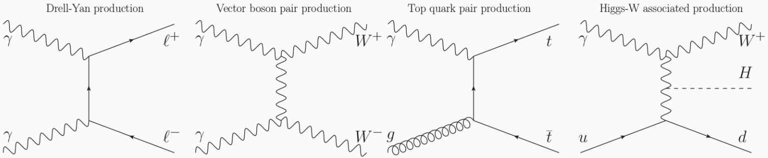
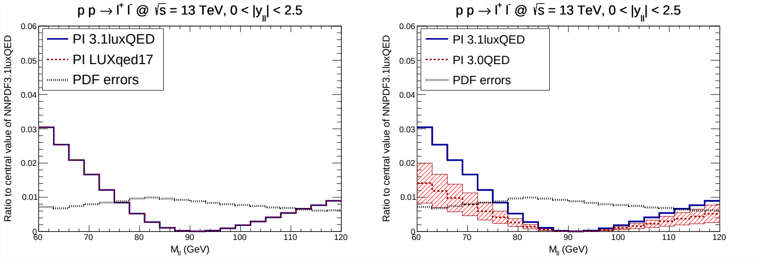
We consider the following processes with PI channel:

- Drell-Yan production
- Vector-boson pair production
- Top-quark pair production
- Higgs-production in association with a vector boson



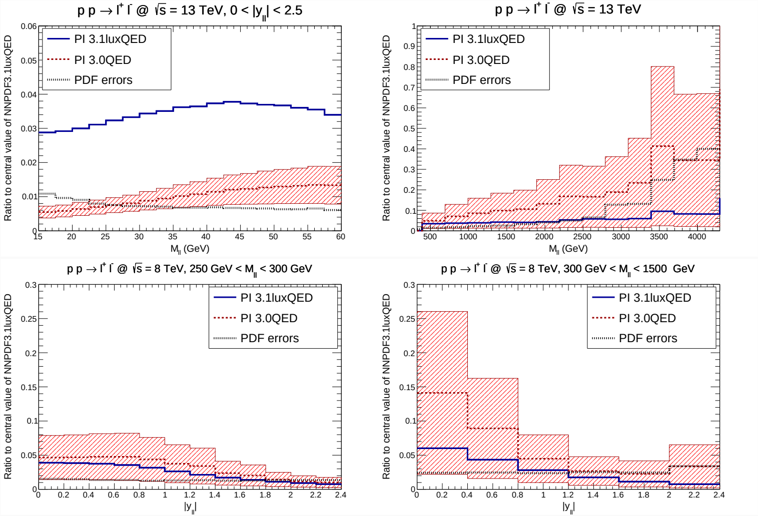
Tree-level simulations with default setup of MadGraph5_aMC@NLO 2.6.0.

Drell-Yan production

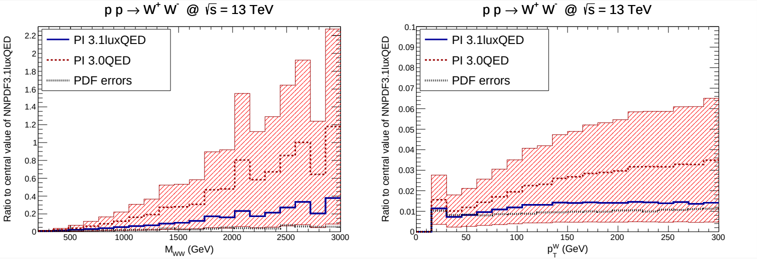


- LUXqed17 and 3.1luxQED in agreement (here and in all processes)
- 3.1luxQED lead to a larger PI contributions than 3.0QED
- 3.1luxQED PI effects:
  - Permille level at $M_{ll} \sim M_Z$
  - $\sim 3\%$ effects for $M_{ll} < 60$ GeV
  - up to 9% for $M_{ll} \sim 4$ TeV
- Moderate PI impact to the total cross-section ($\simeq 10\%$)

Drell-Yan production

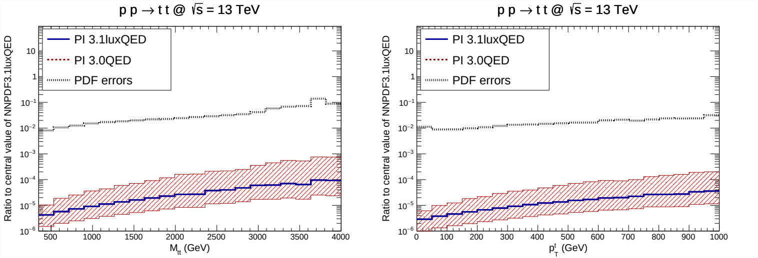


Vector-boson pair production



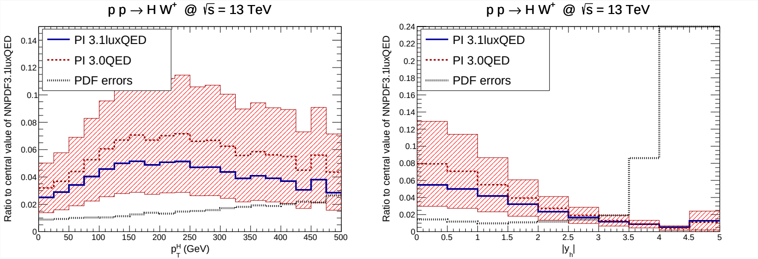
- 3.1luxQED PI effects:
  - up to 35% at $M_{WW} \simeq 3$ TeV
  - $\sim 1\%$ at $p_T^W \simeq 300$ GeV
- Minor PI impact to the total cross-section ($\simeq 1\%$)

Top-quark pair differential distributions



- PI effects below the PDF uncertainties
- Negligible PI contribution to the total cross-section ($\simeq 0.1\%$)

Higgs-production in association with a vector boson



- $pp \to hW^+$ and $pp \to hW^+ j$
- 3.1luxQED PI effects:
  - up to 5% at $p_T^h \simeq 200$ GeV
  - $\sim 6\%$ in central $|y_h|$ region
- Moderate PI impact in the total cross-section

Outlook

Outlook

PDF and EW corrections are quite interesting topic which has been improved a lot the last 10 years.

Future plans include:

- Future NNPDF releases will include the photon PDF by default.
- Looking towards new measurements sensible to PI contribution.
- Inclusion of full NLO EW corrections systematically in all hadronic observables.
- Develop of public tools for fast evaluation of theoretical predictions with EW corrections.

Thank you!