PDFs at large x for 100 TeV

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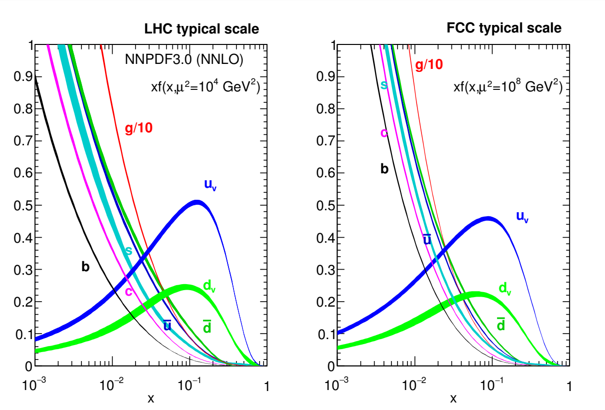
QCD, EW and tools at 100 TeV, October 9, 2015, CERN

INTRODUCTION

- **Describe** the **differences** between **LHC** and **FCC** in terms of PDFs for luminosities and phenomenology.
- **Identify** the **required improvements** for a **precise determination** of **PDFs** at **large** *x*.



Disclaimer: results based on the current state of the art PDFs, great improvements expected before FCC: next 5-20 years.

- Introduction
- Known issues at large x
- PDFs and luminosities at FCC-hh 100 TeV
- Large-x phenomenology at FCC-hh 100 TeV
- Summary

KNOWN ISSUES AT LARGE x

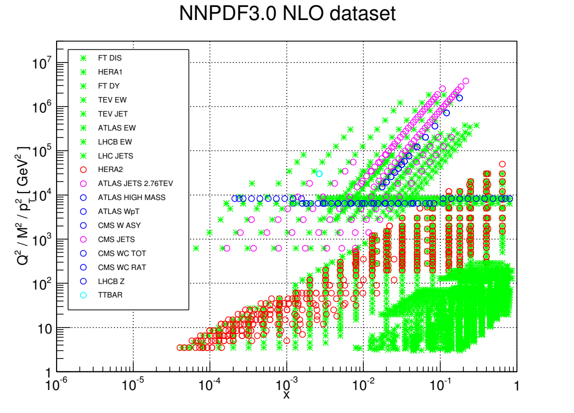
There are 3 categories of issues when dealing with PDFs at large x:

1. Lack of experimental data$*$
2. PDF parametrization bias$*$
3. Theory :
    - EW corrections$*$
    - Threshold resummation$*$
    - Nuclear corrections and low Q related issues: TMCs, higher-twists, etc.

We will discuss $*$.

Lack of experimental data:

Current data has $x \lesssim 0.75 \Rightarrow$ almost **Tevatron** and **LHC data** points.
$\Rightarrow$ data with **large uncertainties** at **large** x



PDF parametrization bias:

Fixed parametrization, i.e. polynomials, underestimates PDF uncertainties. Possibly also NNPDF underestimates uncertainties.

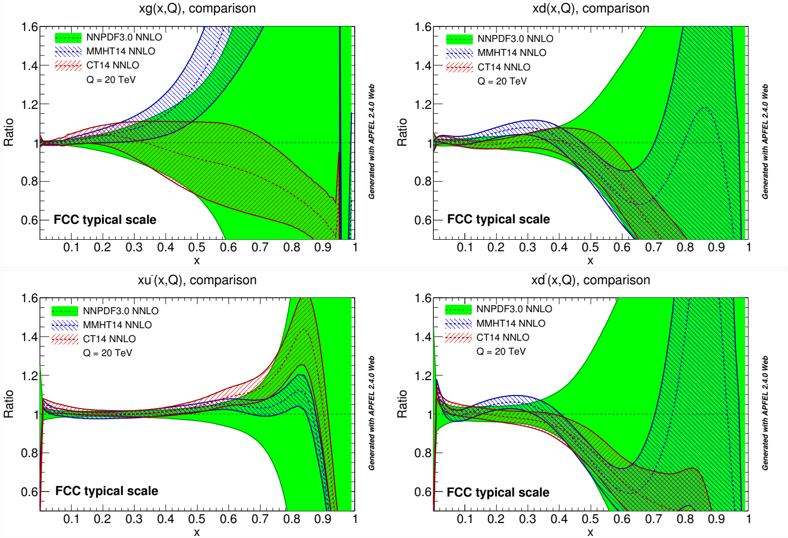
Theory:

- **EW corrections** $\Rightarrow$ photon- (and lepton-) induced contributions:
  - dominated by large uncertainties [arXiv:1508.07002]
- **Threshold resummation**
  - resummation up to NLL and NNLL [arXiv:1507.01006]

PDFS AT FCC

PDFS AT FCC-HH 100 TEV

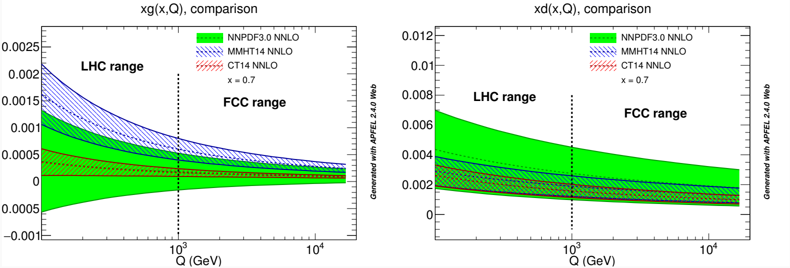
- **FCC-hh 100 TeV PDF comparison** for NNPDF3.0, CT14 and MMHT2014:



- Uncertainties **blow up at large** *x*.

PDFS AT FCC-HH 100 TEV

- For a given value of x, uncertainties **are smaller at FCC-hh 100 TeV** in comparison to **LHC 13 TeV.**



- **LHC $\Rightarrow$ FCC-hh:** PDF **uncertainties are rescaled**
  - **Example:** a 2 TeV state at LHC has much larger uncertainties than FCC-hh. FCC-hh is **"translated" to smaller** x **values**.

LUMINOSITIES FOR GLOBAL PDF FITS

- PDF **luminosities** are **doubly differential** quantities defined as:

$$\frac{d^2\mathcal{L}_{ij}}{dyd\tau} = f_i(x_1, Q) f_j(x_2, Q), \quad x_1 \equiv \sqrt{\tau} e^{y}, \quad x_2 \equiv \sqrt{\tau} e^{-y}, \quad \tau \equiv M_X^2/s.$$

- We define the M_X-differential luminosities as:

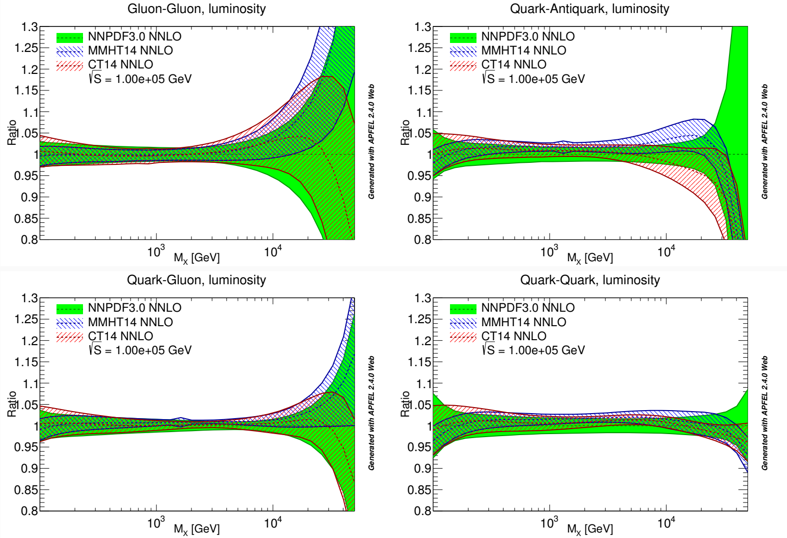
$$\frac{d\mathcal{L}_{ij}}{dM_X^2} = \frac{1}{s}\int_{\tau}^{1} \frac{dx}{x} f_i(x, M_X) f_j(\tau/x, M_X), \quad \tau \equiv M_X^2/s$$

- The y-differential luminosities are given by

$$\frac{d\mathcal{L}_{ij}}{dy} = 2e^{-2y}\int_{\sqrt{\tau_{\mathrm{cut}}}e^{y}}^{e^{-y}} dx\, x\, f_i(x, \sqrt{s}xe^{-y}) f_j(xe^{-2y}, \sqrt{s}xe^{-y})$$

with $\tau_{\mathrm{cut}} \equiv M_{X,\mathrm{cut}}^2/s$, which implies $M_X \geq M_{X,\mathrm{cut}}$, necessary to ensure the IR and collinear finiteness of the cross section.

- **FCC-hh 100 TeV luminosity comparison** for NNPDF3.0, CT14 and MMHT2014:



- Large uncertainties for $M_X > 20$ TeV.

LUMINOSITIES FOR PDFS WITH QED CORRECTION

PDF LUMINOSITY WITH QED CORRECTIONS AT FCC-HH 100 TEV

Luminosities based on PDF sets with **QED corrections**:

- We use **NNPDF2.3QED NLO** where:
  - **DGLAP** is NLO QCD and LO QED
  - **quarks** and **gluons** from the NNPDF2.3 global fit
  - **photon PDF** extracted from DIS and LHC data (2013)
  - **lepton PDFs** model based on photon splitting a leading-log accuracy:

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

with $\ell = e, \mu$. More details in [arXiv:1508.07002].

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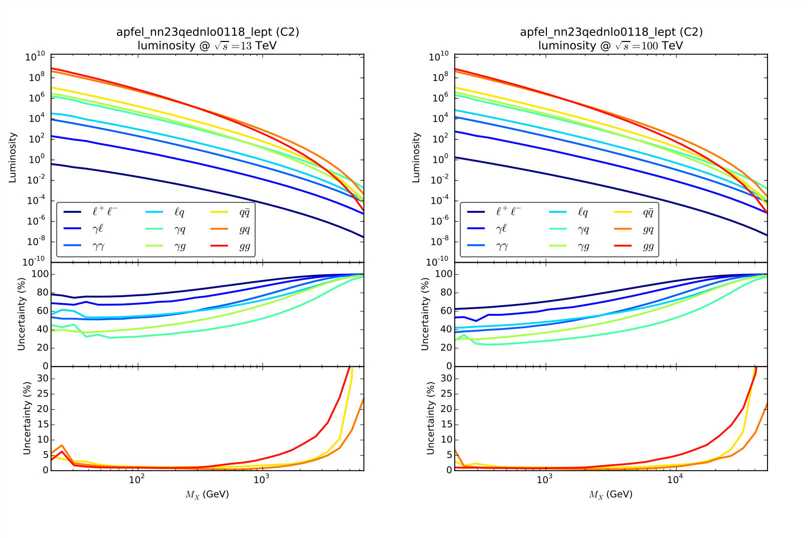
Motivation:

Quantify the impact of photon- and lepton-induced processes at LHC 13 TeV and FCC-hh 100 TeV.

PDF LUMINOSITY WITH QED CORRECTIONS AT FCC-HH 100 TEV

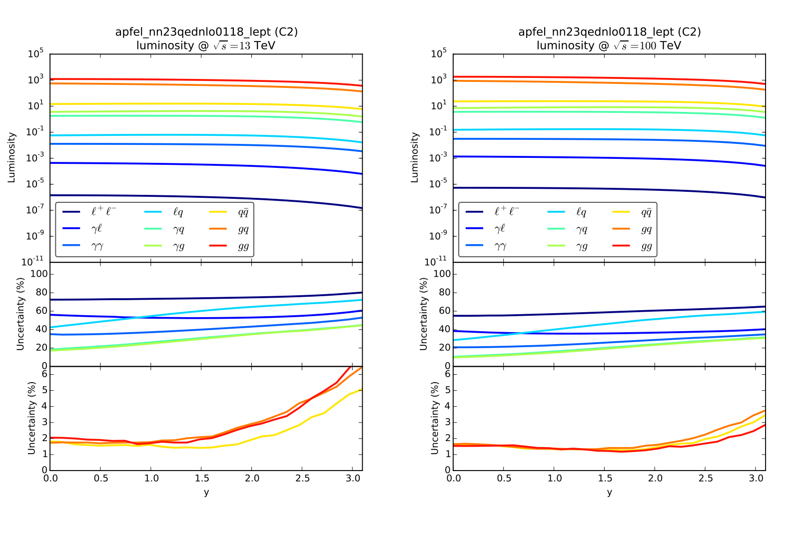
M_X—**luminosities** at the **LHC (13 TeV)** and **FCC-hh (100 TeV)**:



- Large invariant masses dominated by QED channels uncertainty.

PDF LUMINOSITY WITH QED CORRECTIONS AT FCC-HH 100 TEV

$y-$**luminosities** at the **LHC (13 TeV)** and **FCC-hh (100 TeV)**:

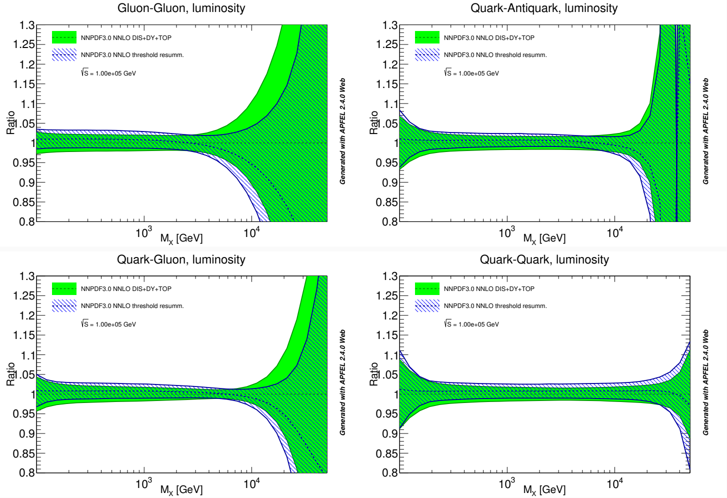


- Large y dominated by QED channels uncertainty.

THRESHOLD RES. LUMINOSITIES

PDF LUMINOSITY WITH THRESHOLD RES. AT FCC-HH 100 TEV

- **FCC-hh 100 TeV luminosity comparison** for **standard fit** vs **threshold resummed** fits:



- **Similar** uncertainties, **different** central values.

LARGE-X PHENOMENOLOGY AT FCC

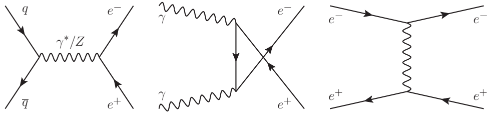
Phenomenology with MadGraph5_aMC@NLO

We consider processes at **13 TeV LHC** and **100 TeV FCC-hh**:

- Drell-Yan, dijet, 4 leptons production, lepton-pair production in **SM**
- uncertainties refer to **PDF uncertainties** at the 68% c.l.
- all simulations are done at the **LO** and **parton level**

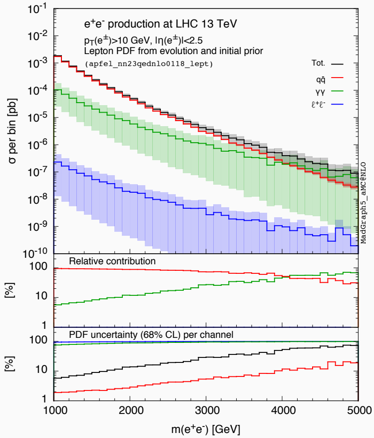
Photon- and Lepton-induced in MadGraph5_aMC@NLO

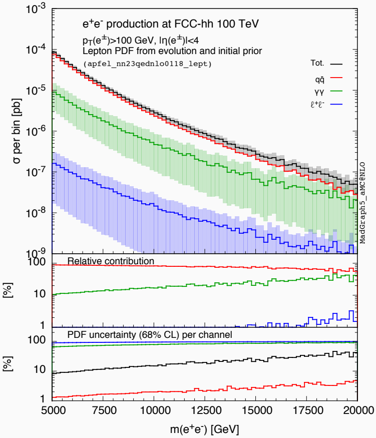
- Implementation of the **lepton luminosities** in MG5_aMC@NLO
- Using **NNPDF2.3QED** as prior set with lepton PDF ansatz.



NEUTRAL DRELL-YAN

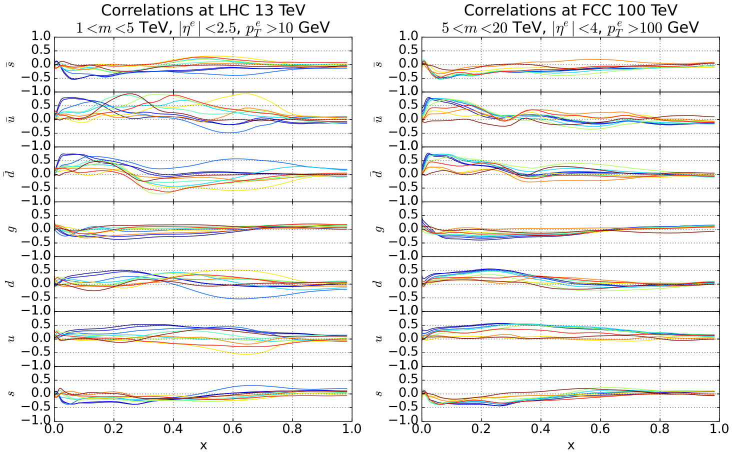
- e^+e^- production:
  - **left:** LHC 13 TeV, $p_T(e^\pm) > 10$ GeV, $|\eta(e^\pm)| < 2.5$
  - **right:** FCC 100 TeV, $p_T(e^\pm) > 100$ GeV and $|\eta(e^\pm)| < 4$



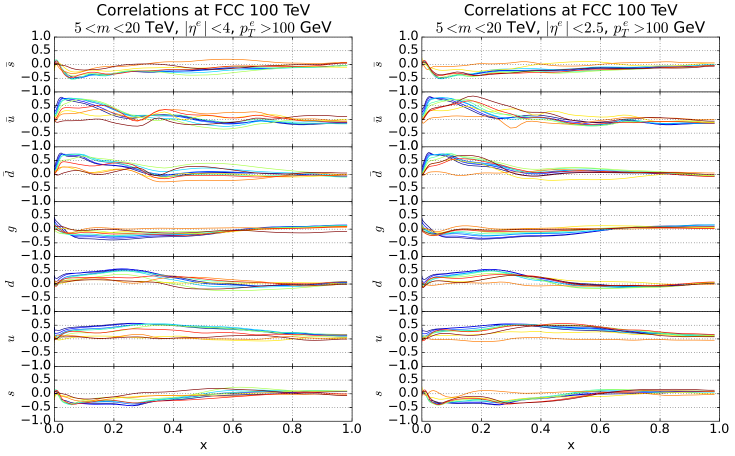


- LHC ⇒ FCC: **PDF uncertainty scaling** and γ-induced not negligible.

- PDF-observable correlations: **LHC vs FCC**
  - same setup as before, 10 bins of invariant mass.
  - LHC with $m \gtrsim 4$ TeV, $|\eta| < 2.5$, $p_T > 10$ GeV touches values in x larger FCC up to 20 TeV with $|\eta| < 4$ and $p_T > 100$ GeV.

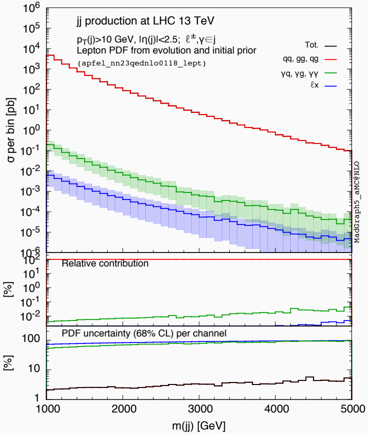


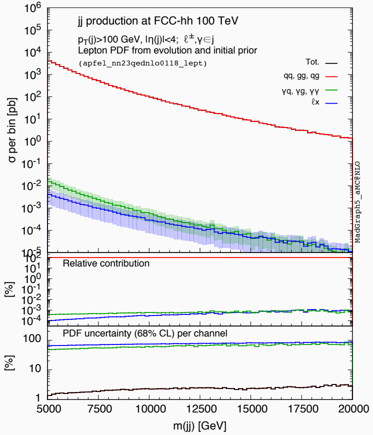
- Increase effective x by reducing the rapidity cut from $|\eta| < 4$ (left) to $|\eta| < 2.5$ (right).



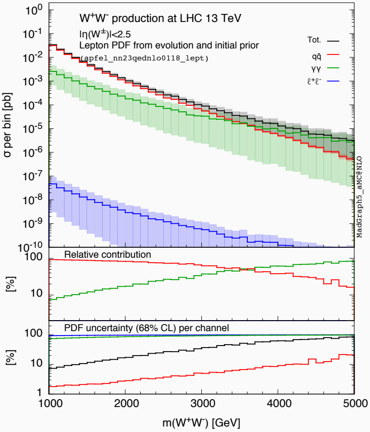
- Larger domain in x from $m \gtrsim 30 - 40$ TeV with $|\eta| < 2.5 - 4$.

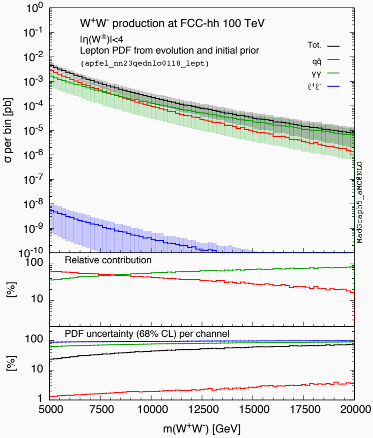
- Dijet production:
  - high invariant mass, LHC (left) and FCC-hh (right)
  - 100% probability of photons/leptons faking jets is assumed



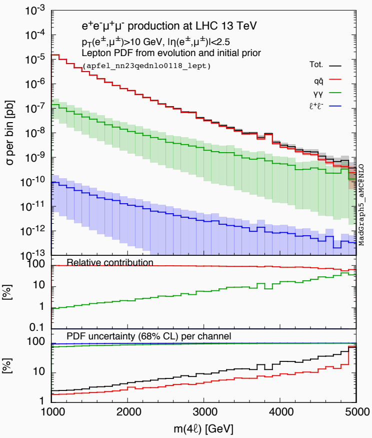


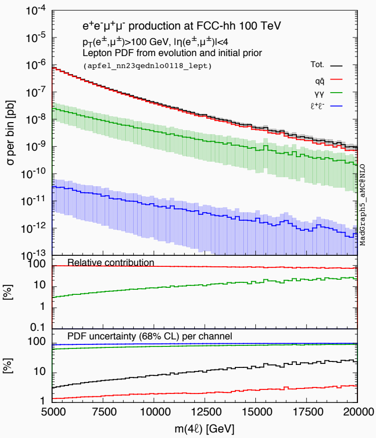
- W pair production at:
  - LHC 13 TeV (left) and FCC-hh 100 TeV (right)
  - photon-induced effects are not negligible





- 4-lepton production:
  - LHC 13 TeV (left), FCC-hh 100 TeV (right), similar results for $e^+e^-e^+e^-$
  - Included all diagrams with/without intermediate Z bosons.





SUMMARY

SUMMARY

Conclusions:

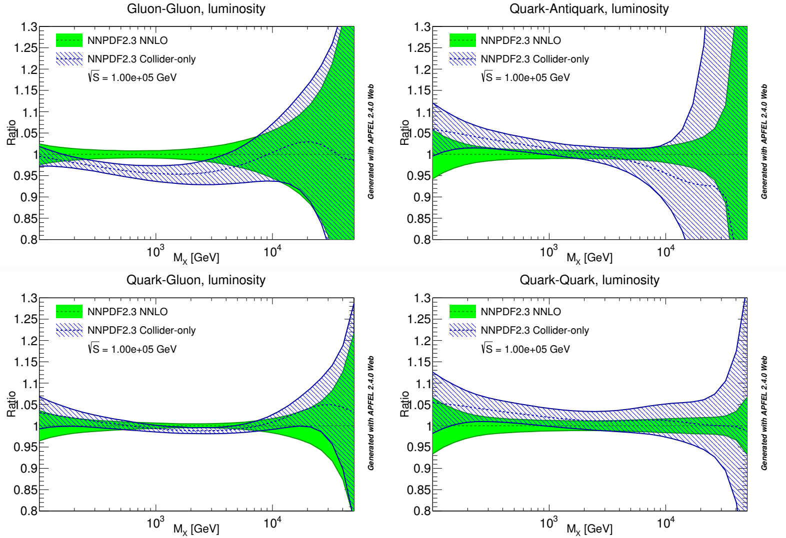
1. From LHC to FCC we observe the PDF scaling in x.
   - for a fixed Q, FCC uses values of x smaller than LHC
2. At FCC we expect a coverage in x larger than LHC, however thanks to the scaling precise measurements at LHC improve the PDF uncertainty control at FCC.
   - extension of the domain in x possible at very high-masses in the FCC
3. Always consider EW corrections to PDFs with uncertainties
   - better determinations are required, to be released in the next years

New LHC data will improve the overall framework in the next years.

- e.g. high-mass Drell-Yan, high$-p_T$ jets, etc.

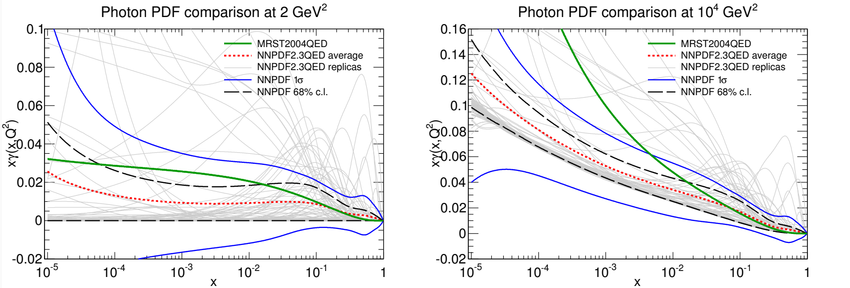
Thank you!

- **FCC-hh 100 TeV luminosity comparison** for **collider-only** vs **global fit**:



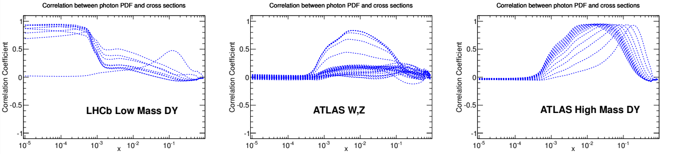
- Future data will improve this situation.

- Photon PDF comparison with MRST2004QED @ $Q = 2$ and 10^4 GeV^2



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

Dataset	Observable	$N_{\rm dat}$	$[\eta_{\rm min}, \eta_{\rm max}]$	$[M_{\rm ll}^{\rm min}, M_{\rm ll}^{\rm max}]$
LHCb γ^*/Z Low Mass	$d\sigma(Z)/dM_{ll}$	9	[2,4.5]	[5,120] GeV
ATLAS W, Z	$d\sigma(W^{\pm}, Z)/d\eta$	30	[-2.5,2.5]	[60,120] GeV
ATLAS γ^*/Z High Mass	$d\sigma(Z)/dM_{ll}$	13	[-2.5,2.5]	[116,1500] GeV



For each replica k compute predictions with:

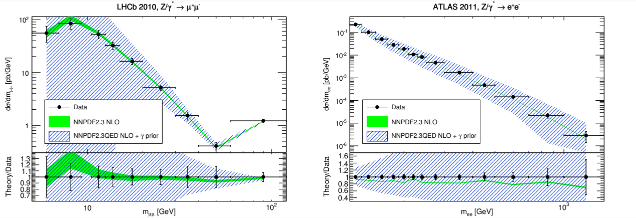
- **DYNNLO** for QCD NLO/NNLO channels
- **HORACE** for **photon-induced** contributions

Determine the weight of replica $k \Rightarrow w_k \propto \chi_k^{n-1} e^{-\frac{1}{2}\chi_k^2}$ (arXiv:1108.1758)

PHOTON PDF FROM W AND Z PRODUCTION AT LHC

LHC electroweak vector boson data reduces the **photon PDF uncertainties.**

- Example: LHC predictions **before including LHC data** (DIS-only):



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