PARTON EVOLUTION WITH PHOTONS AND LEPTONS

Quantifying the impact of lepton PDFs

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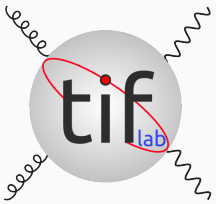

INTRODUCTION

Motivation:

- Are lepton PDFs relevant for the LHC and FCC measurements?

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Status of PDFs with EW corrections:

- Availability of sets with **QED corrections** up to $\mathcal{O}(\alpha)$ (LO QED).
- **MRST2004QED** and **NNPDF2.3QED** family:
  - **photon PDF** determined directly from DIS and LHC Drell-Yan data
  - **no lepton PDFs** $\rightarrow$ lepton-induced processes not quantified at that time

OUTLINE

GENERATING LEPTON PDFS

DGLAP EQUATIONS WITH PHOTONS AND LEPTONS

Procedure idea:

1. Implement the **lepton PDFs evolution** in **APFEL** [arXiv:1310.1394]
2. Use sets of PDFs with QED corrections as **initial condition**

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The implementation in **APFEL** consists in adding the equations

$$\mu^2 \frac{\partial \ell_i}{\partial \mu^2} = \frac{\alpha}{4\pi} \left[P^{(0)}_{\ell\gamma} \otimes \gamma + P^{(0)}_{\ell\ell} \otimes \ell_i \right],$$

where $\ell_i = (e^{\pm}, \mu^{\pm}, \tau^{\pm})$ with

$$\mu^2 \frac{\partial \gamma_i}{\partial \mu^2} = \frac{\alpha}{4\pi} \left[\sum_i N_c e_i^2 P^{(0)}_{\gamma\gamma} \otimes \gamma + \sum_i e_i^2 P^{(0)}_{\gamma q} \otimes (q_i + \bar{q}_i) + \sum_j P^{(0)}_{\gamma\ell} \otimes (\ell_j + \bar{\ell}_j) \right]$$

to the **combined QCD⊗QED** equations.

Lepton PDFs initial condition:

- Lepton PDFs from fit to experimental data are **hard to achieve**
- We try to **guess** the **functional form** of these PDFs

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We guess the functional form by assuming that:

Ansatz 1: Light leptons are generated by photon splitting

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

with $\beta = e^\pm, \mu^\pm$, at leading-logarithmic accuracy.

Ansatz 2: Lepton PDFs at the initial scale Q_0 are equal to zero

$$\ell_\beta(x, Q_0) = 0.$$

SETS WITH LEPTON PDFS

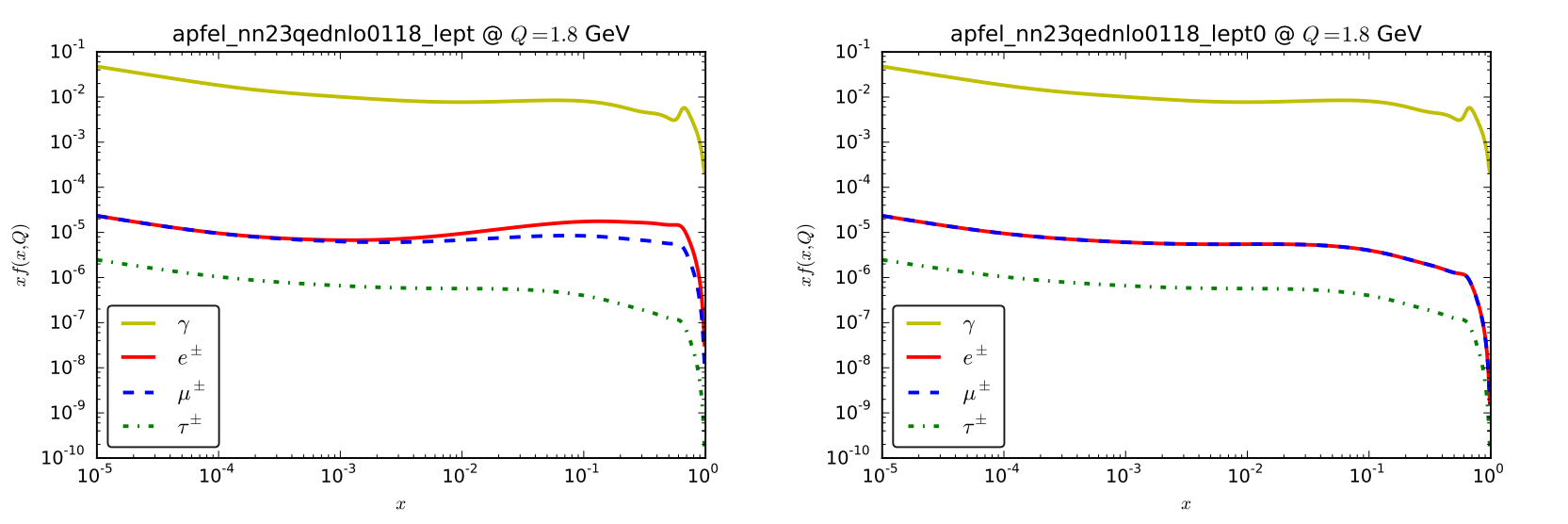
PDF Set	QCD	QED	Photon PDF	Lepton PDFs
apfel_nn23nlo0118_lept0	NLO	LO	$\gamma(x, Q_0) = 0$	Ansatz 2
apfel_nn23nnlo0118_lept0	NNLO	LO	$\gamma(x, Q_0) = 0$	Ansatz 2
apfel_nn23qedlo0118_lept0	LO	LO	Internal	Ansatz 2
apfel_nn23qednlo0118_lept0	NLO	LO	Internal	Ansatz 2
apfel_nn23qednnlo0118_lept0	NNLO	LO	Internal	Ansatz 2
apfel_mrst04qed_lept0	NLO	LO	Internal	Ansatz 2
apfel_nn23qedlo0118_lept	LO	LO	Internal	**Ansatz 1**
apfel_nn23qednlo0118_lept	NLO	LO	Internal	**Ansatz 1**
apfel_nn23qednnlo0118_lept	NNLO	LO	Internal	**Ansatz 1**
apfel_mrst04qed_lept	NLO	LO	Internal	**Ansatz 1**

Table 1: Summary of the PDF sets generated with APFEL.

PROPERTIES OF LEPTON PDFS

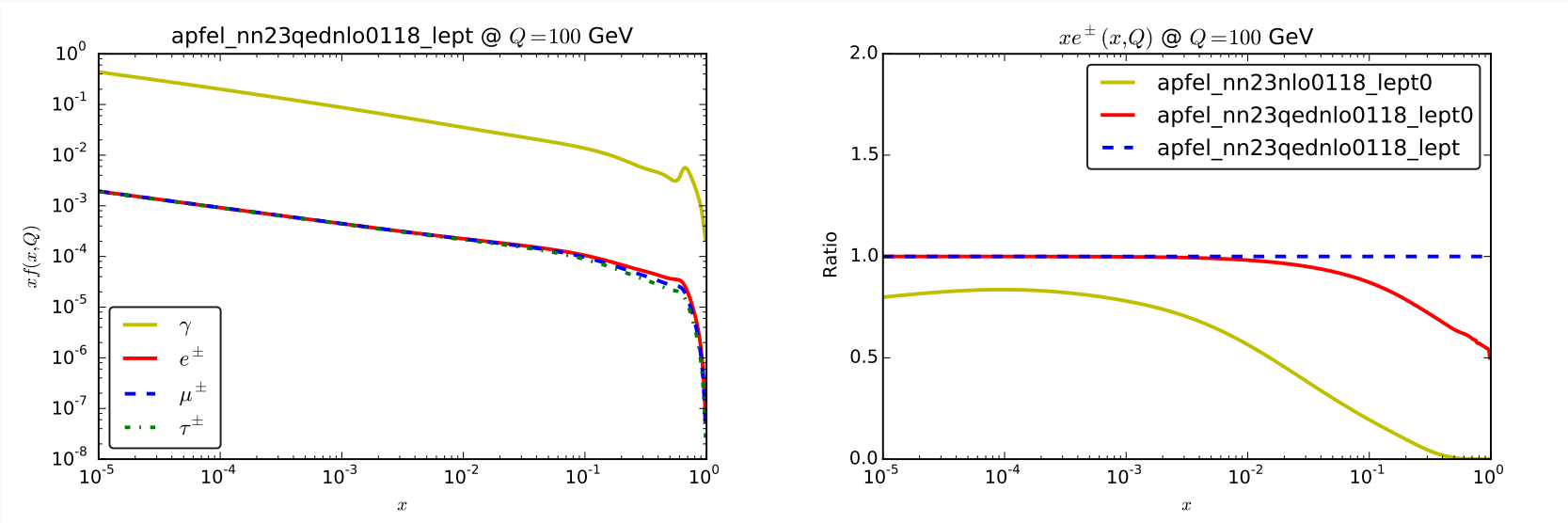
Lepton and photon PDFs **evolved** at $Q = 1.8$ GeV (central values)

- **Ansatz 1** and **2** for NNPDF2.3QED NLO



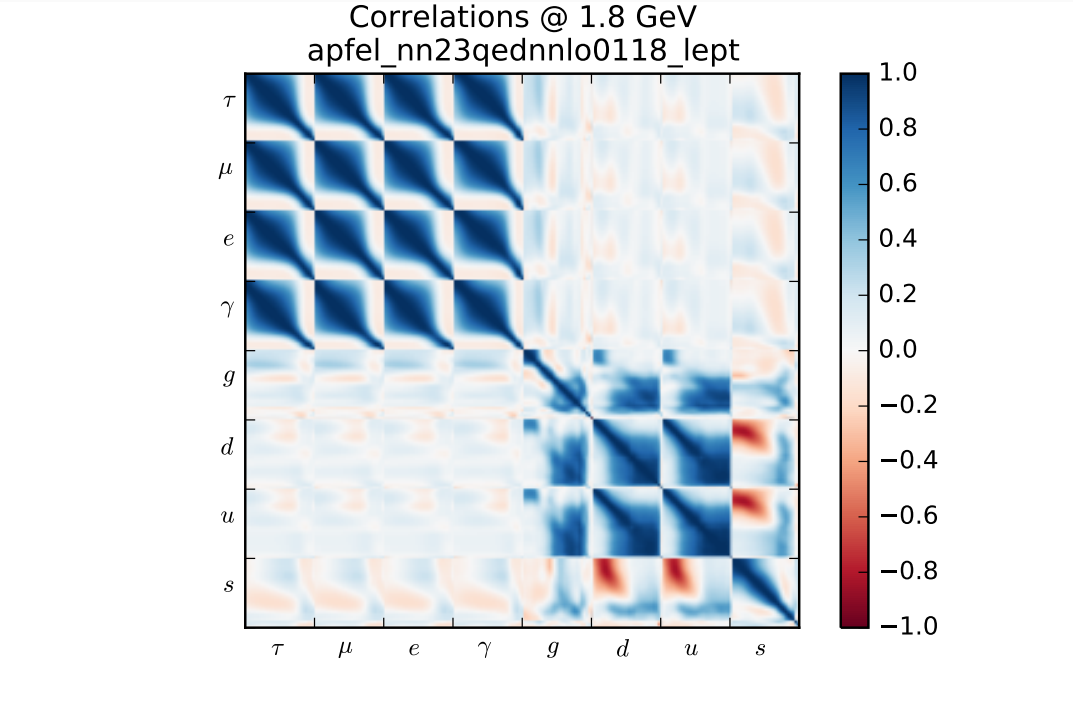
- Lepton mass dependence at **small energies** for the model (Ans. 1)
- **Remarkable** differences at **large x**.

Lepton and photon PDFs **evolved** at $Q = 100$ GeV:



- The ansatz show differences at large x, i.e. $x \geq 10^{-1}$
- The photon PDF controls the overall behavior of leptons

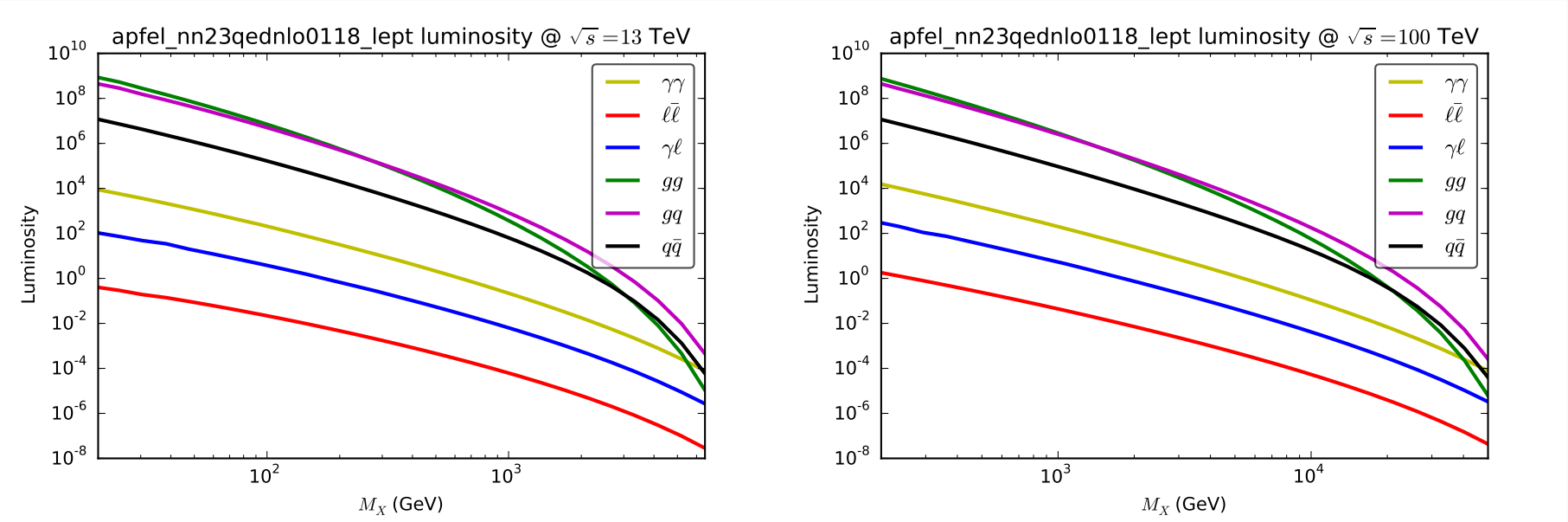
PDF correlations show the split between the QED and QCD sectors



Correlation in a grid of $N_x = 50$ points in $x_1, x_2 = \left[10^{-5}, 1\right]$ defined as

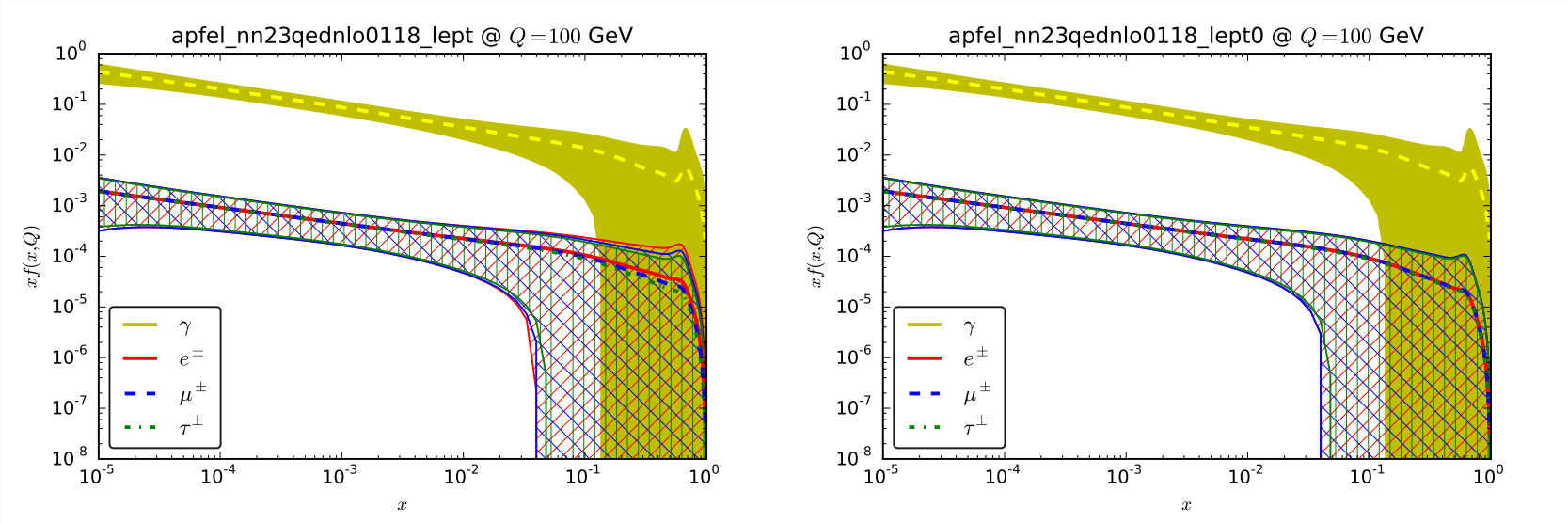
$$\rho_{\alpha\beta}(x_1, x_2, Q) = \frac{N_{\text{rep}}}{N_{\text{rep}} - 1} \left(\frac{\langle f_\alpha^{(k)}(x_1, Q) f_\beta^{(k)}(x_2, Q) \rangle_{\text{rep}} - \langle f_\alpha^{(k)}(x_1, Q) \rangle \langle f_\beta^{(k)}(x_2, Q) \rangle_{\text{rep}}}{\sigma_\alpha(x_1, Q) \cdot \sigma_\beta(x_2, Q)} \right)$$

Lepton and photon PDFs **luminosities** at the LHC and FCC:



- Differences tend to reduce at **large energies**
  - possible enhancement of **lepton-induced contributions at large** Q

Lepton and photon PDFs uncertainties for the NNPDF2.3QED sets:



- **Large uncertainties** at **large x**
- Similar **uncertainty magnitude** for both **ansatz**

PHENOMENOLOGY

Lepton-induced in MG5_aMC@NLO

1. **LHAPDF6** patch to output lepton PDFs in **LHAGlue**
2. Updated MG5_aMC@NLO PDF **driver** for these new sets
3. Implementation of the **lepton luminosities** in MG5_aMC@NLO

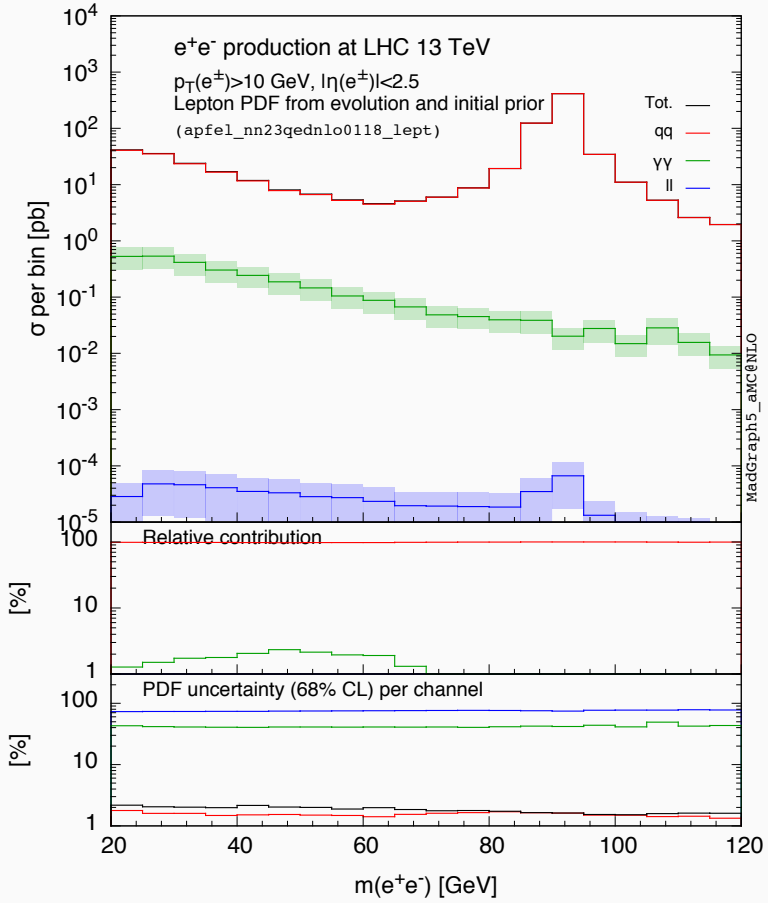
Phenomenology with MG5_aMC@NLO

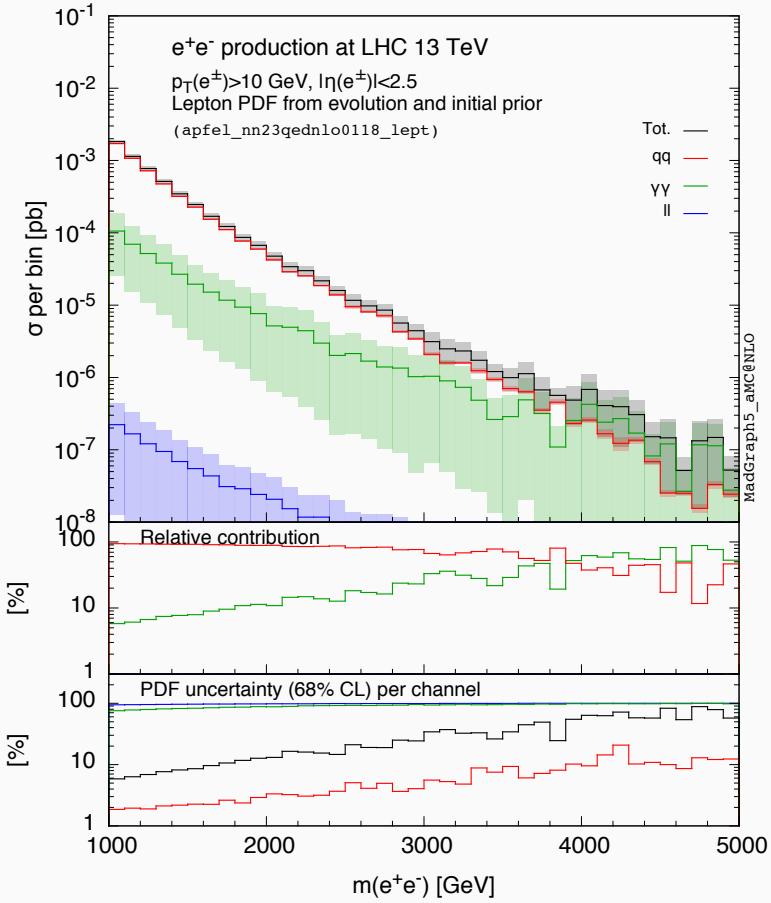
We consider processes at **13 TeV LHC** and **100 TeV FCC-hh**:

- lepton pair, dijet and vector boson pair production in the **SM**
- slepton pair production in the **MSSM**
- uncertainties refer to **PDF uncertainties** at the 68% c.l.
- all simulations are done at the **LO** and **parton level**

ELECTRON PAIR PRODUCTION @ LHC

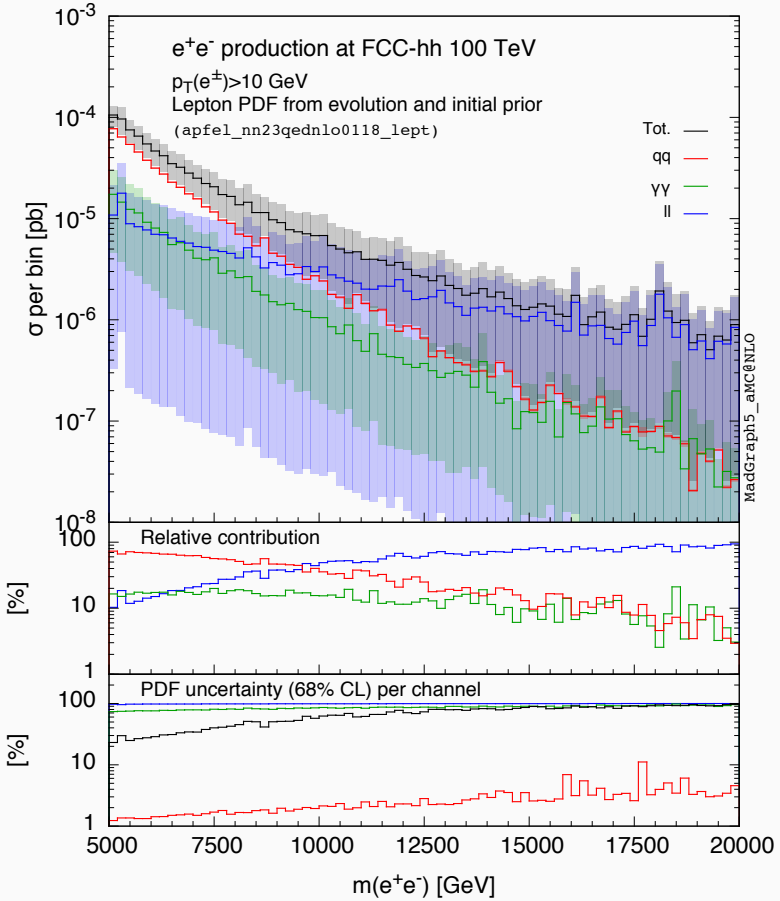
- e^+e^- production at the LHC 13 TeV:
  - low (left) and high invariant (right) mass of the lepton pair:

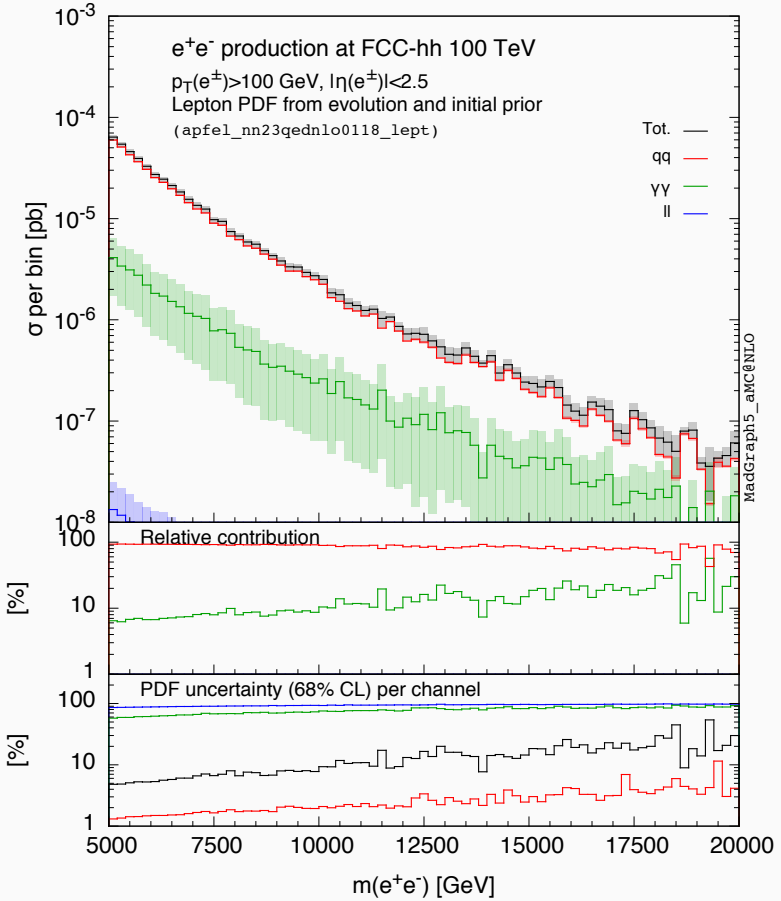




ELECTRON PAIR PRODUCTION @ FCC

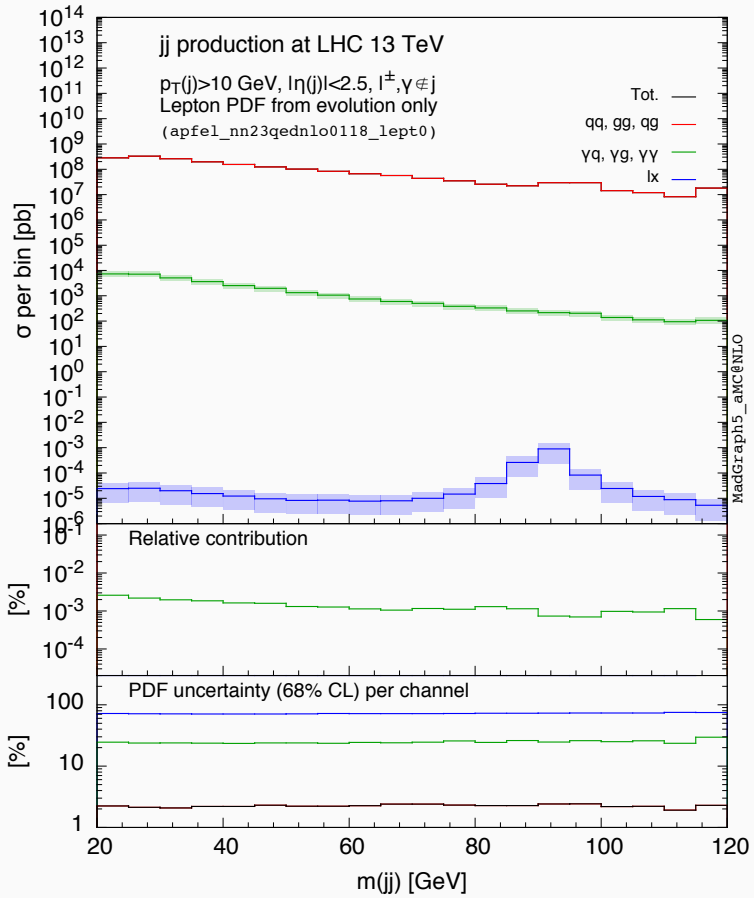
- e^+e^- production at the FCC-hh 100 TeV:
  - $p_T(e^\pm) > 10$ GeV (left), $p_T(e^\pm) > 100$ GeV and $|\eta| < 2.5$ (right)

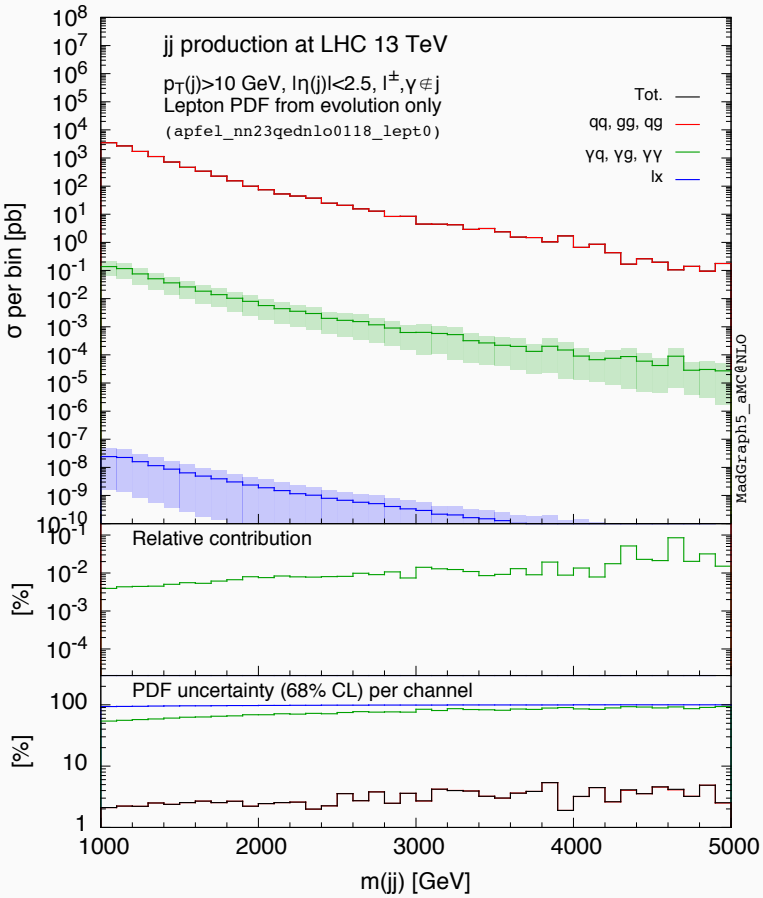




DIJET PRODUCTION @ LHC

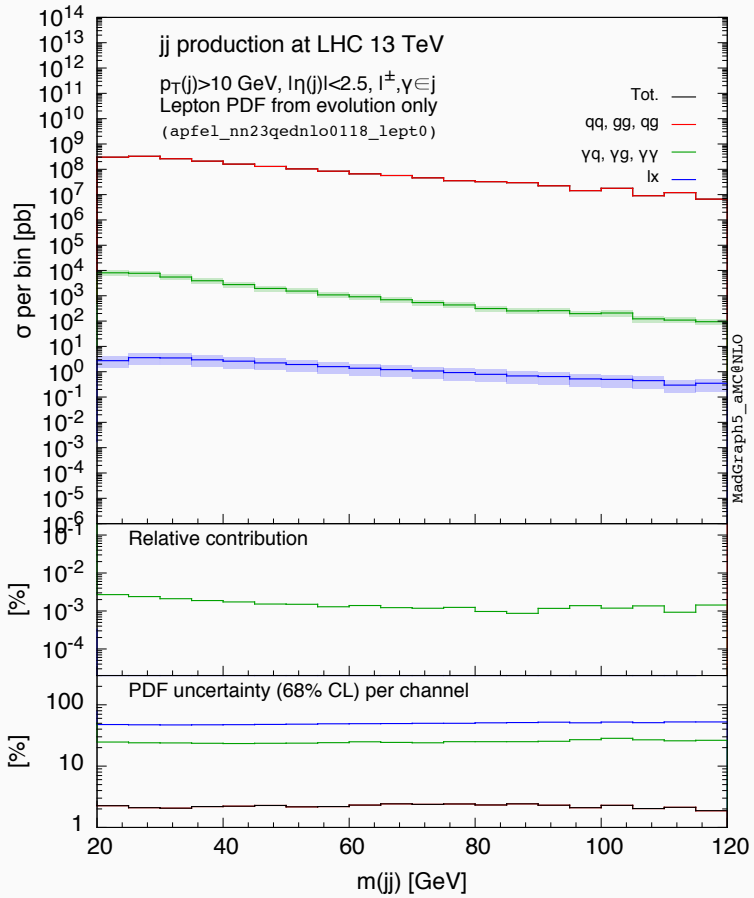
- Dijet production at the LHC 13 TeV (similar behavior for FCC-hh):
  - low invariant mass (left), high invariant mass (right),
  - zero probability of photons/leptons faking jets

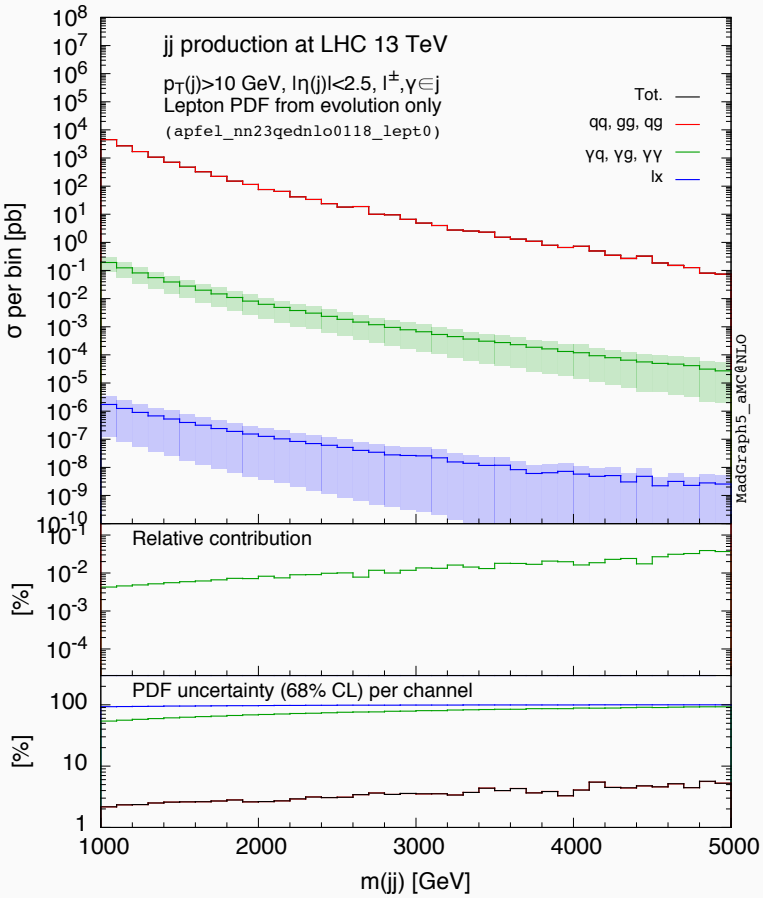




DIJET PRODUCTION @ LHC

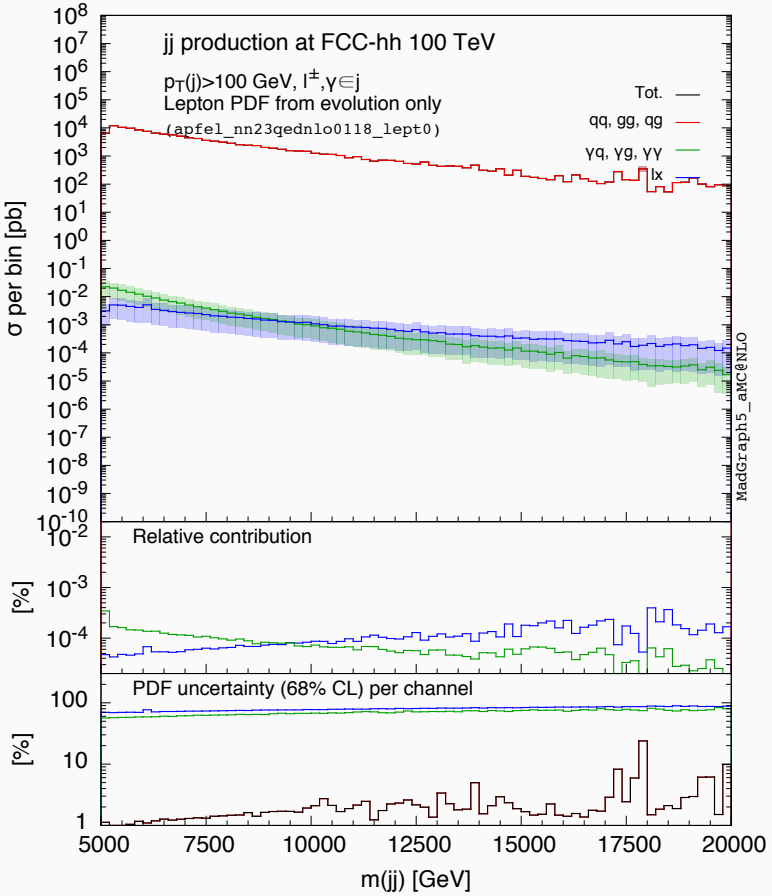
- Dijet production at the LHC 13 TeV:
  - low invariant mass (left), high invariant mass (right),
  - 100% probability of photons/leptons faking jets is assumed

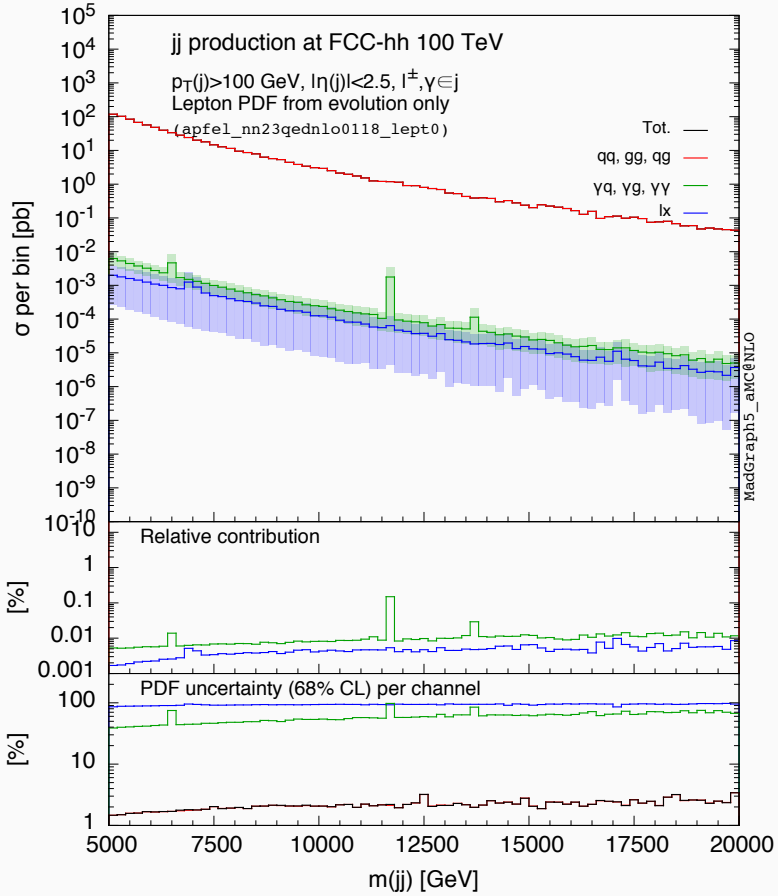




DIJET PRODUCTION @ FCC

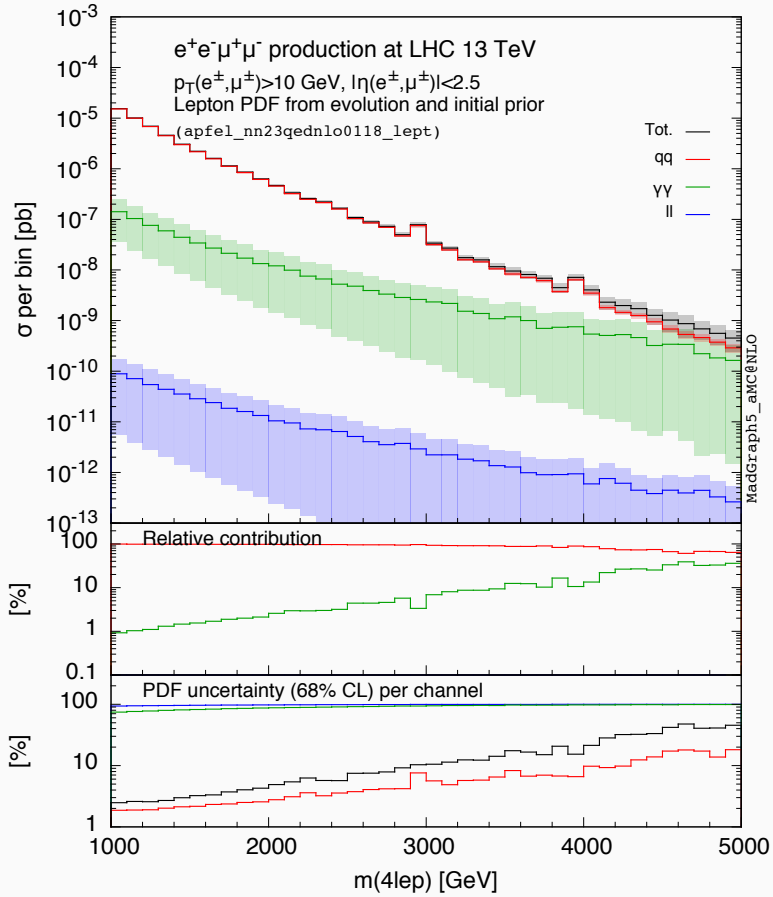
- Dijet production at the FCC-hh 100 TeV:
  - high invariant mass, with (right) and without (left) the $|\eta(j)|$ cut
  - 100% probability of photons/leptons faking jets is assumed

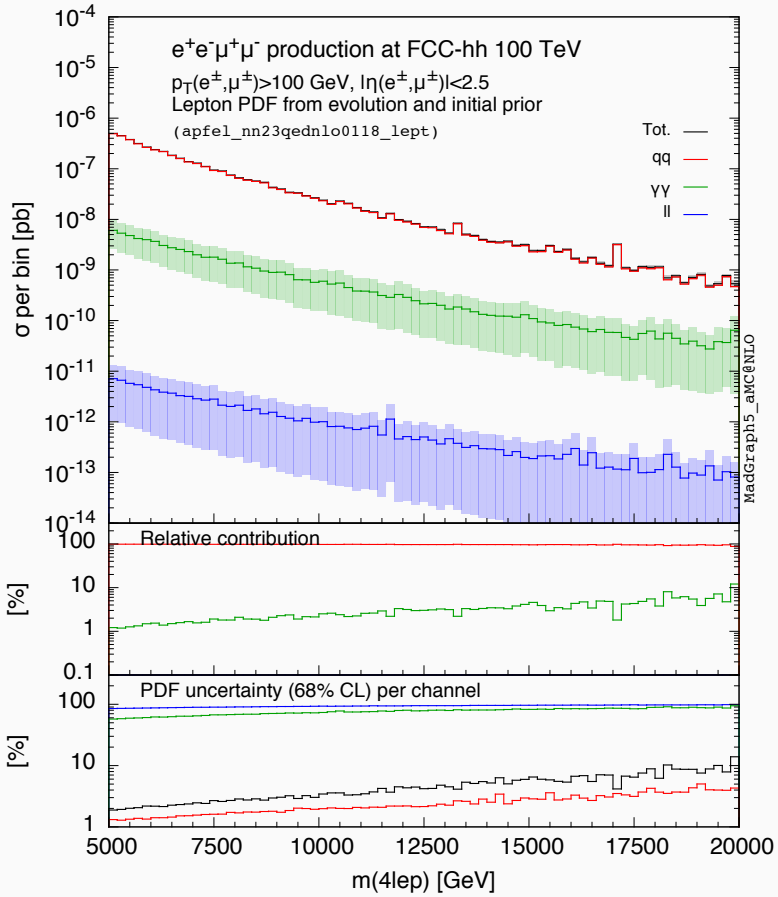




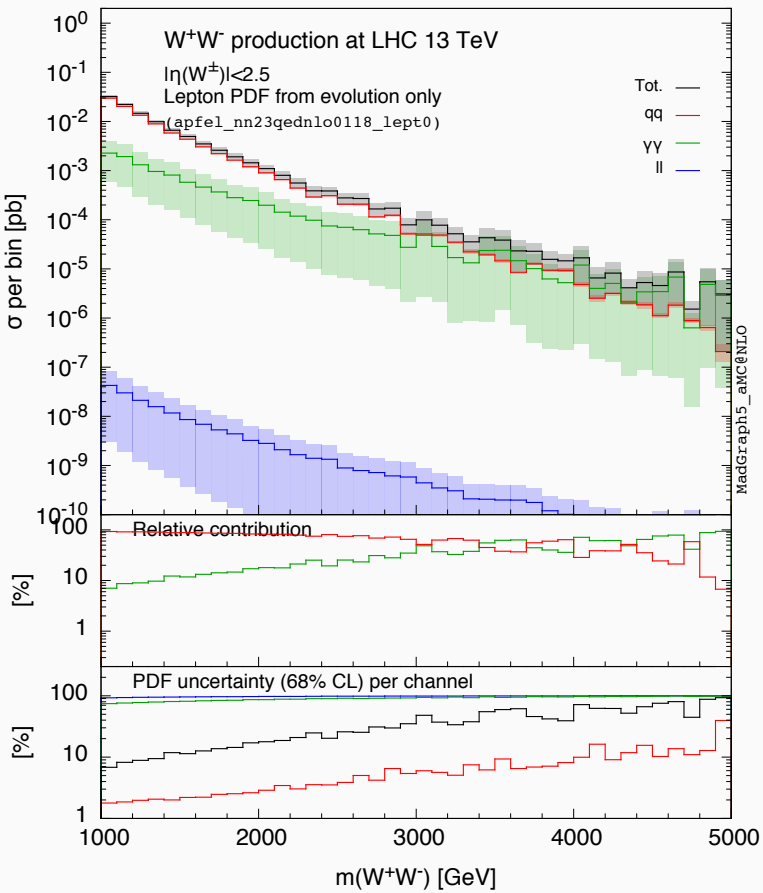
FOUR LEPTON PRODUCTION

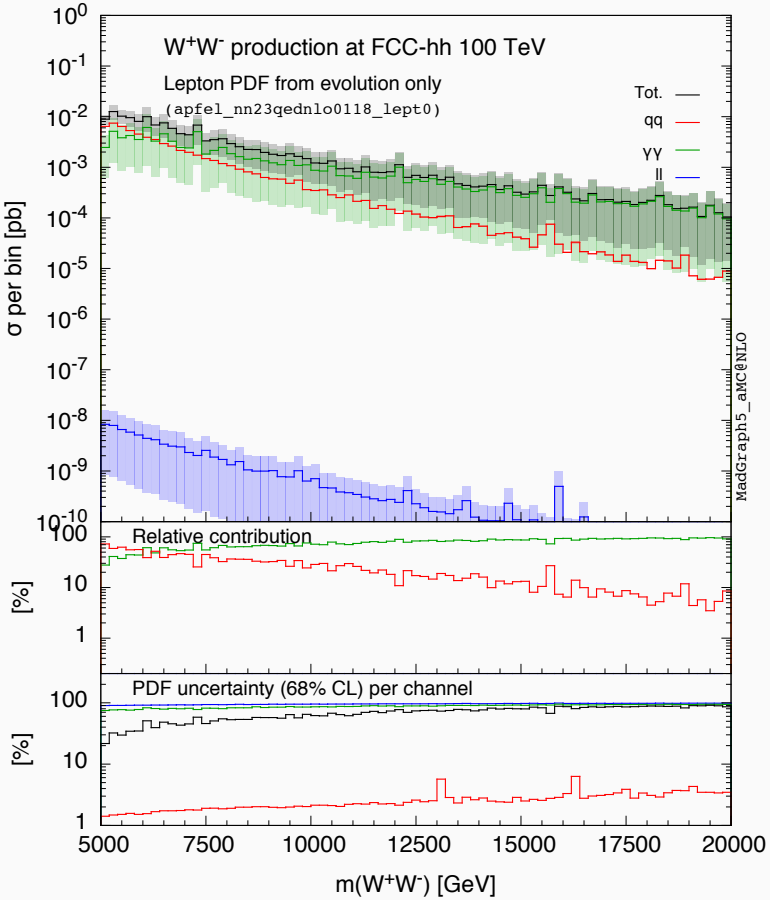
- 4-lepton production:
  - LHC 13 TeV (left), FCC-hh 100 TeV (right), similar results for $e^+e^-e^+e^-$





- *W* pair production at:
  - LHC 13 TeV with $|\eta(W^{\pm})| < 2.5$ (left)
  - FCC-hh 100 TeV without cuts (right)





- **Total rates** for slepton-pair production in the **MSSM**:
  - heavy slepton case at the **LHC 13 TeV**

LHC, $m_{\tilde{e},\tilde{\mu}} = 1203$ GeV, $m_{\tilde{\tau}} = 1134$ GeV

Initial state	σ[pb]
Total	$2.00 \cdot 10^{-5} \pm 40\%$
$q\bar{q}$	$1.22 \cdot 10^{-5} \pm 6\%$
$\gamma\gamma$	$7.83 \cdot 10^{-6} \pm 95\%$
ll	$4.01 \cdot 10^{-9} \pm 100\%$

  - light slepton case at the **FCC-hh 100 TeV**

FCC-hh, $m_{\tilde{e},\tilde{\mu}} = 203$ GeV, $m_{\tilde{\tau}} = 134$ GeV

Initial state	σ[pb]
Total	$3.08 \pm 2\%$
$q\bar{q}$	$2.99 \pm 2\%$
$\gamma\gamma$	$8.80 \cdot 10^{-2} \pm 45\%$
ll	$3.76 \cdot 10^{-5} \pm 72\%$

Discussion