The impact of the photon PDF and of EW corrections on $t\bar{t}$ differential distributions

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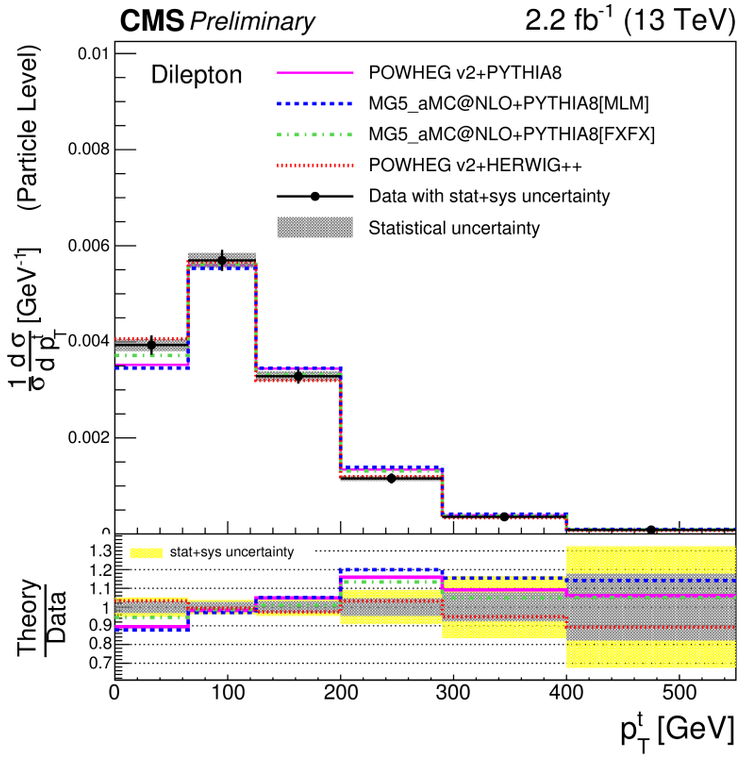
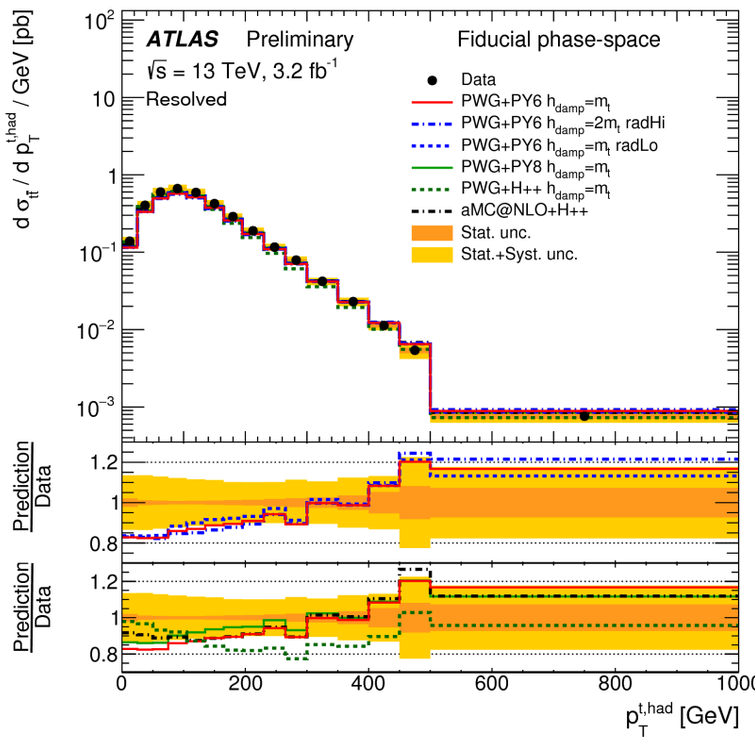
based on D. Pagani, I. Tsinikos, MZ, arXiv:1606.01915

PDF4LHC Meeting, September 13th 2016, CERN

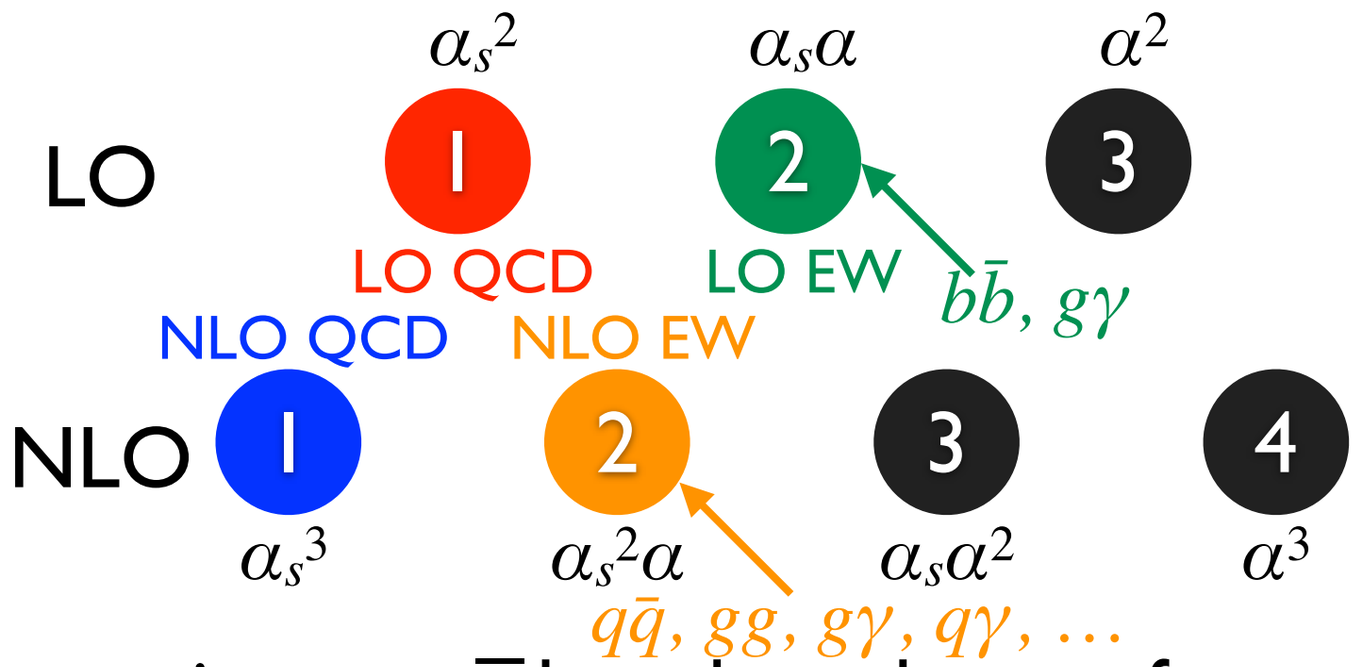
Motivation

- Top pair production enters almost all LHC analyses, either as a signal, as a background or via PDF fits and MC-tunes
- NLO-accurate MCs do a decent job, still there is some tension with data
- The decreasing exp. uncertainties call for better predictions: NNLO and/or NLO EW mandatory
- Unlike QCD corrections, the EW ones bring two new features:
  - Sudakov suppression (negative) and photon-initiated contributions (positive).
  - How large is their effect? Can $t\bar{t}$ production be used to constrain the photon PDF?





EW corrections to $t\bar{t}$ production



- NLO EW corrections to $t\bar{t}$ have been known for years, but they remain a hot topic

  Weak: Beenakker et al., Nu.Ph.B.411(1994), Kuhn et al., hep-ph/0610335 & arXiv:1305.5773, Bernreuther et al., hep-ph/0508091, Campbell et al., arXiv:1608.03356; QED+$g\gamma$ LO: Hollik et al., arXiv:0708.1697; FB asymmetry: Hollik et al., arXiv:1107.2606, Kuhn et al., arXiv:1109.6830, Manohar et al., arXiv:1201.3926, Bernreuther et al., arXiv:1205.6580; NLO+EW+decay (NWA): Bernreuther et al., arXiv:1003.3926; EW to $e^+\mu^-\nu\nu b\bar{b}$: Denner et al., arXiv:1607.05571

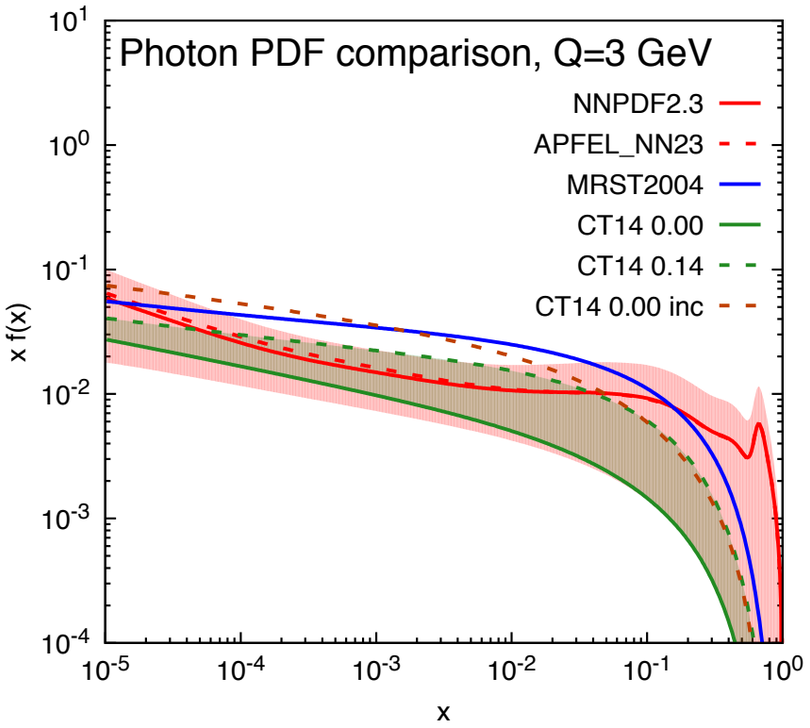
- The γ-initiated contribution was known only at LO and with the old PDF set MSTW2004…

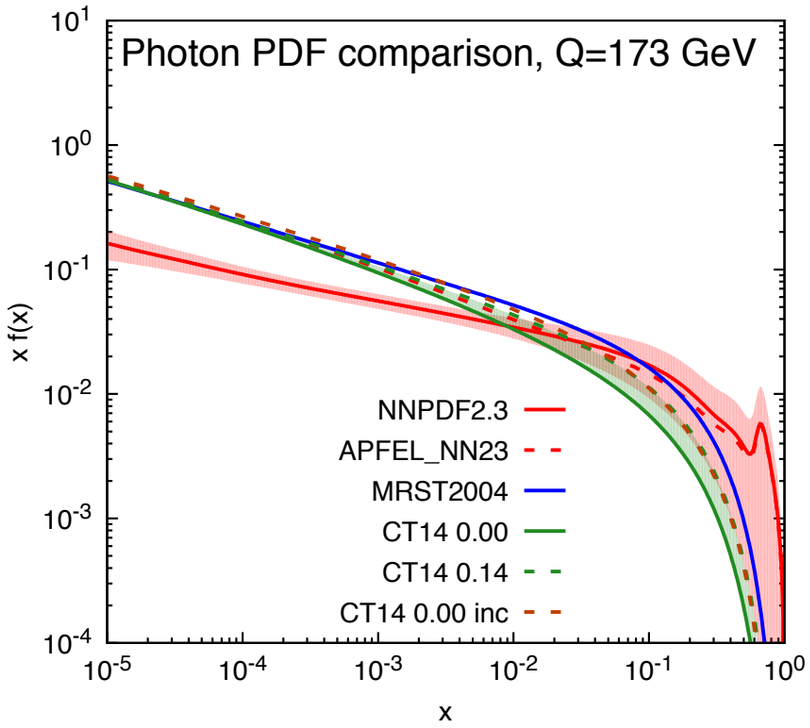
  Things have changed (and are changing) since then!

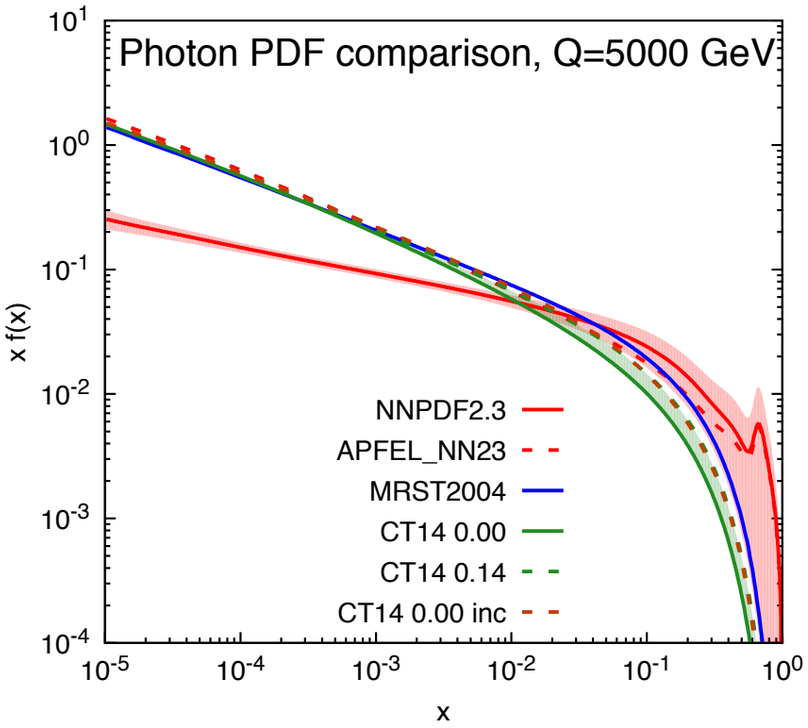
The photon PDF, circa June 2016

- Two modern PDF sets with the photon exist, NNPDF2.3/3.0 QED and CT14-QED
  NNPDF coll., arXiv:1308.0598 & Bertone, Carrazza arXiv:1606.07130;
  Schmidt, Pumplin, Stump, Yuan, arXiv:1509.02905
- Very different assumptions and strategies:
  - NNPDF uses no assumption for the $\gamma(x,Q^0)$ functional form, and uses DIS and 7-TeV DY data data to constrain it
  - CT14QED uses an ansatz *à la* MRST2004, with one free parameter (momentum fraction at the initial scale constrained to be <0.14% at 90% CL). A set which includes the elastic photon contribution is also provided
  - Unlike all other sets, NNPDF2.3 uses different scales for QCD/QED evolution. The simultaneous evolution has been implemented in APFEL and is used in NNPDF3.0. This has no impact on $t\bar{t}$ phenomenology

The photon PDF, circa June 2016





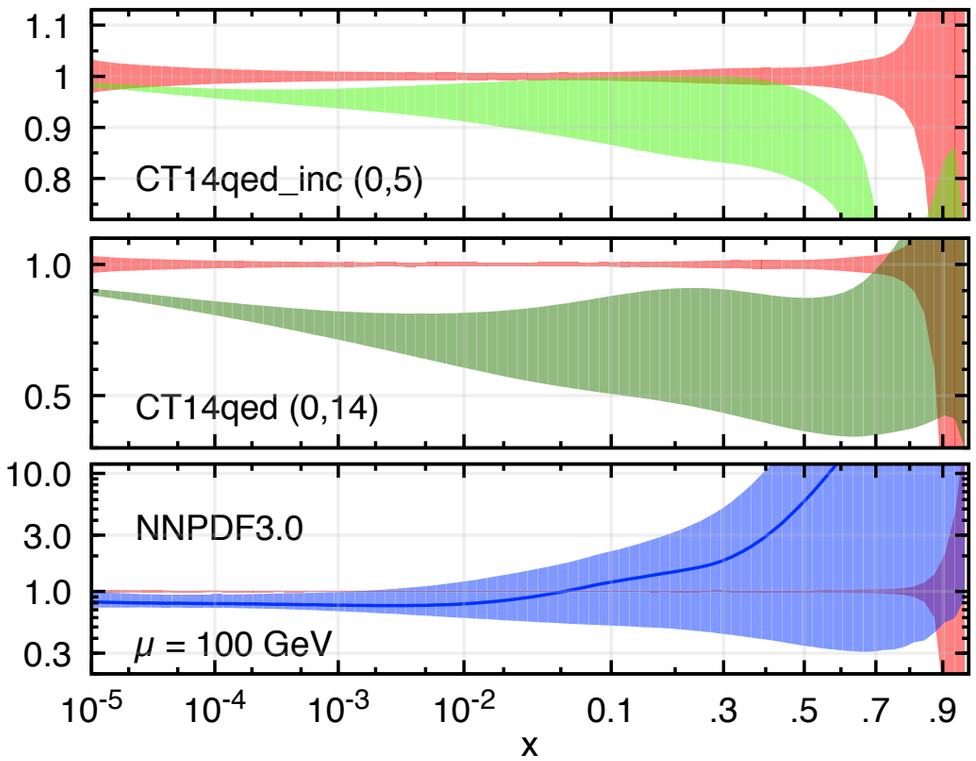


- The NNPDF photon PDF is large at large x, with O(100%) error bands
- CT14 (and MRST) have a much smaller photon at large x
- APFEL_NN23 has the same photon PDF at the initial scale as NNPDF2.3, but with the simultaneous QED+QCD evolution

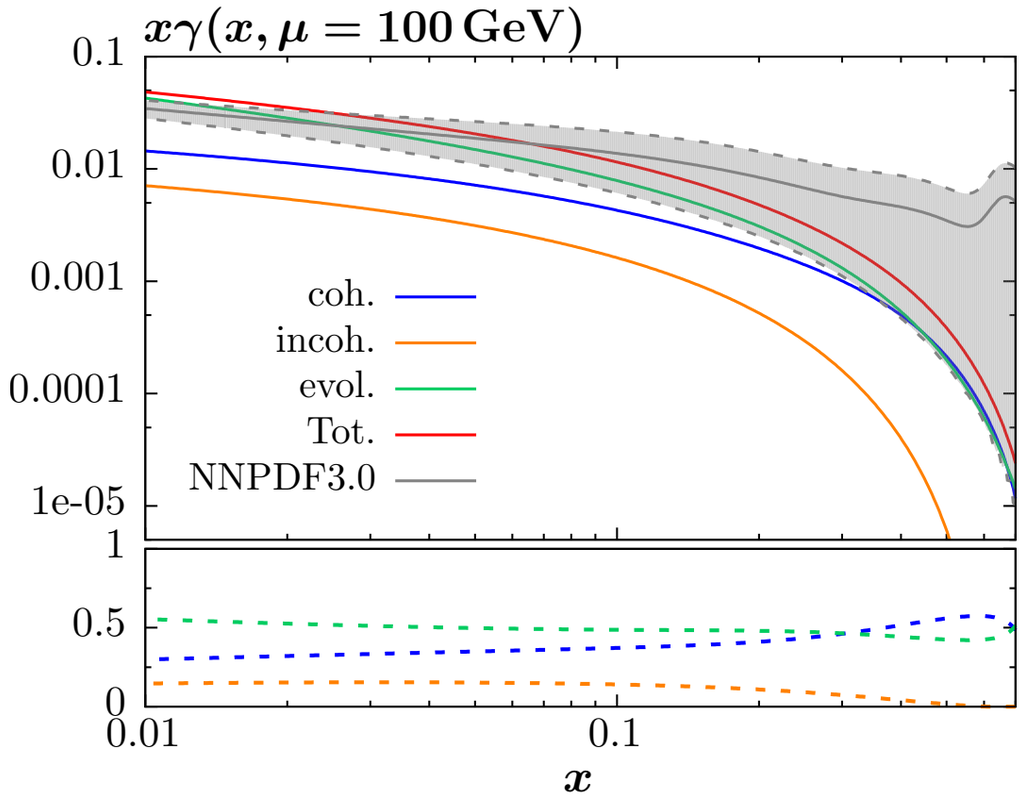
Bertone, Carrazza, Pagani, MZ, arXiv:1508.07002

The photon PDF, circa July 2016

- Two new studies appeared with new predictions for the photon PDF
- Both support the case of a small photon PDF (at large x) with small errors

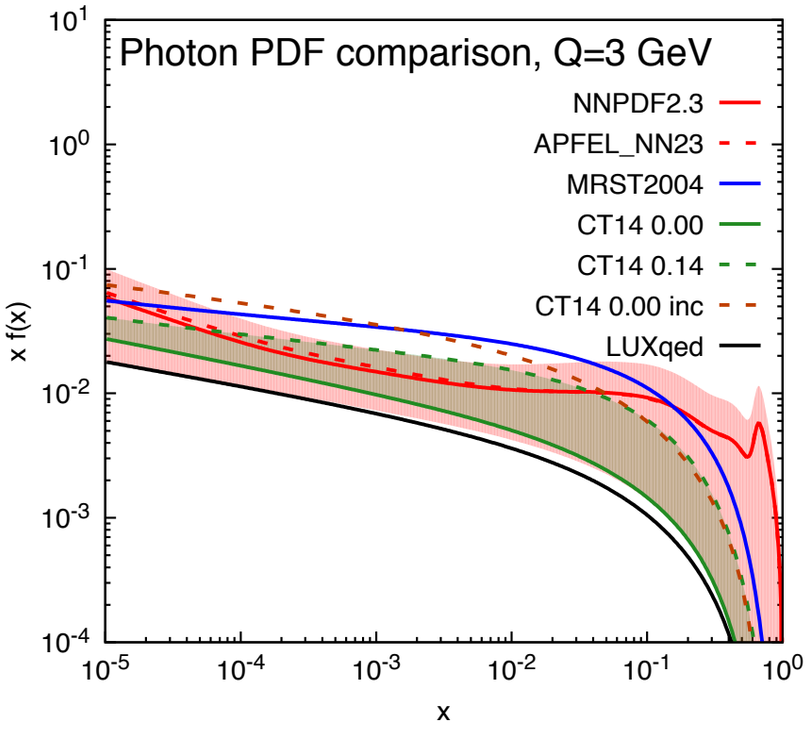


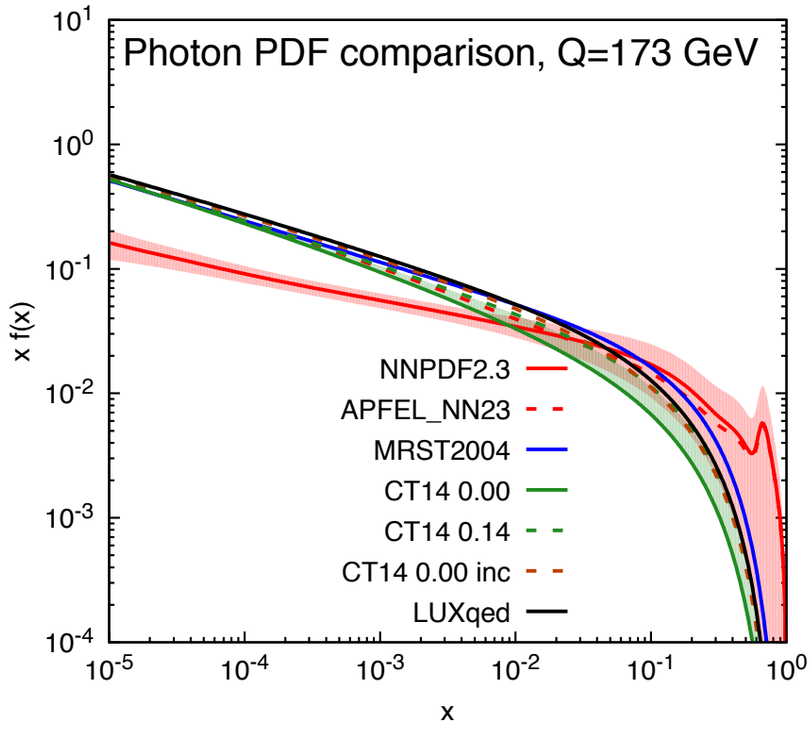
LUXqed: Manohar, Nason, Salam, Zanderighi, arXiv:1607.04266

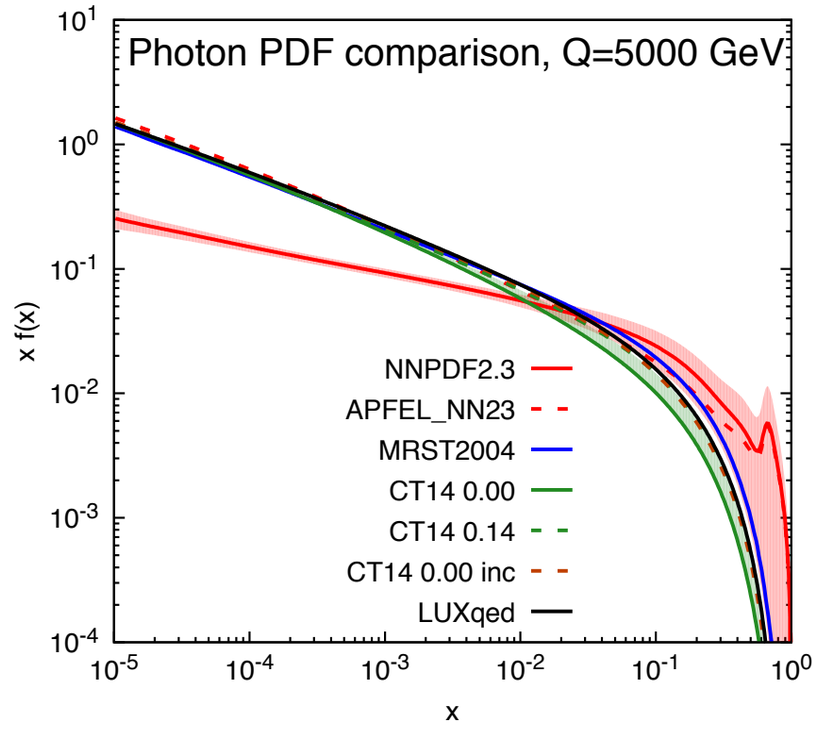


Harland-Lang, Khoze, Ryskin, arXiv:1607.04635

The photon PDF, circa July 2016

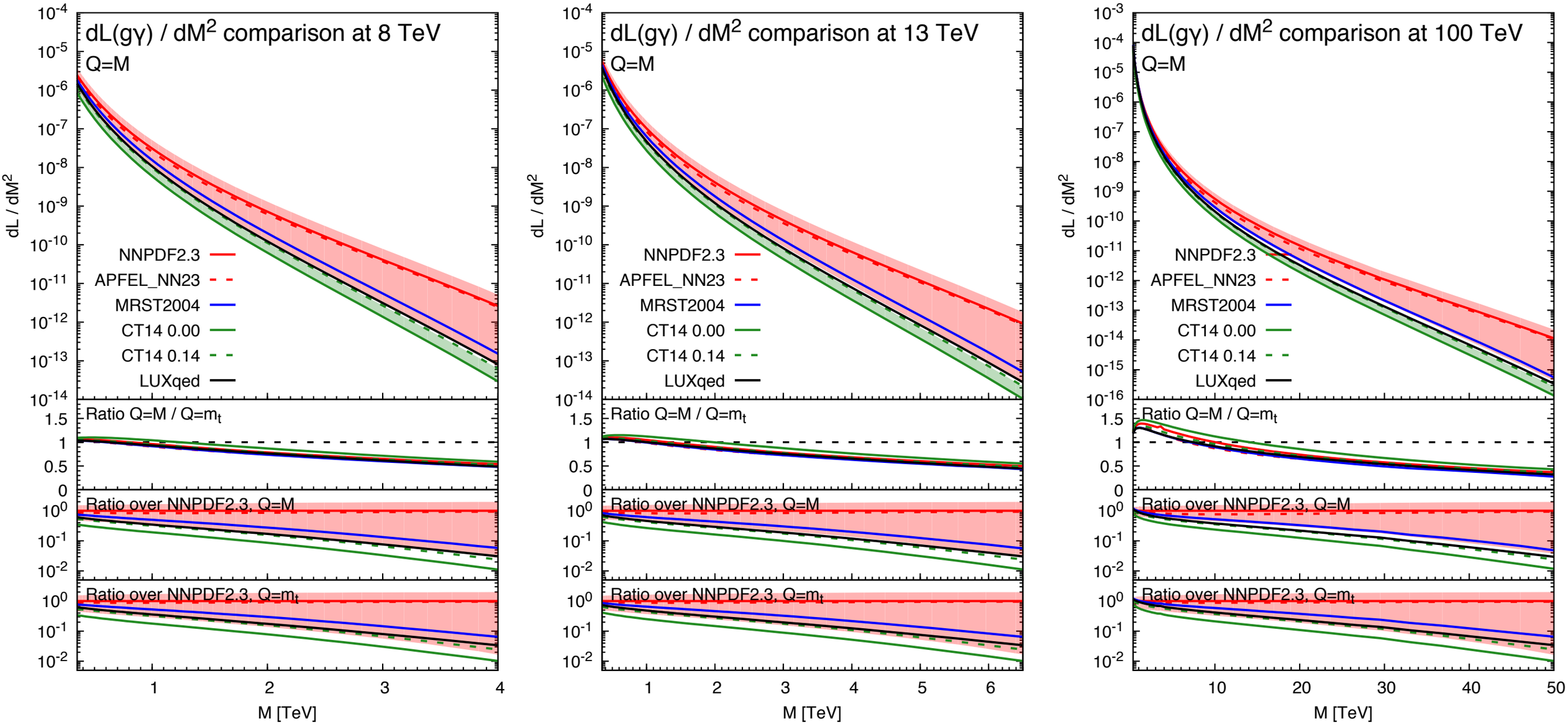






- LUXqed lies very close to CT14 0.14% and to CT14_inc 0.00

The photon PDF, circa July 2016



- LUXqed lies very close to CT14 0.14% and to CT14_inc 0.00
- Effects due to the different evolution in NNPDF2.3 are not visible

Calculation setup:

- Calculation of QCD and EW corrections carried out with MadGraph5_aMC@NLO
- Input parameters:

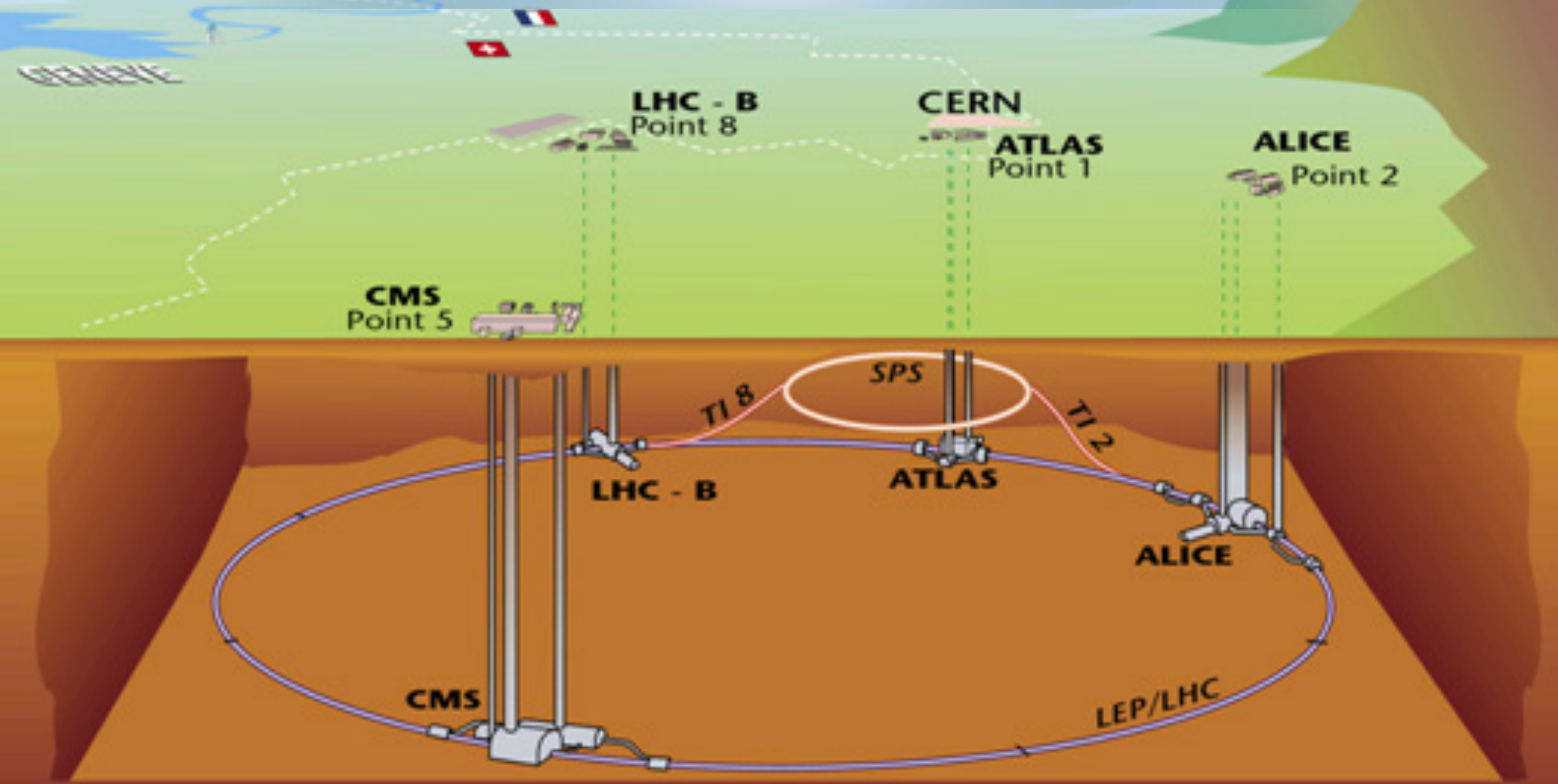
$$m_t = 173.3\ \text{GeV}\,, \quad m_H = 125.09\ \text{GeV}$$
$$m_W = 80.385\ \text{GeV}\,, \quad m_Z = 91.1876\ \text{GeV}$$
$$G_\mu = 1.1663787 \cdot 10^{-5}\ \text{GeV}^{-2}$$

- Scale choice:

$$\mu = \frac{H_T}{2} = \frac{1}{2}\sum_i m_{T,i}$$

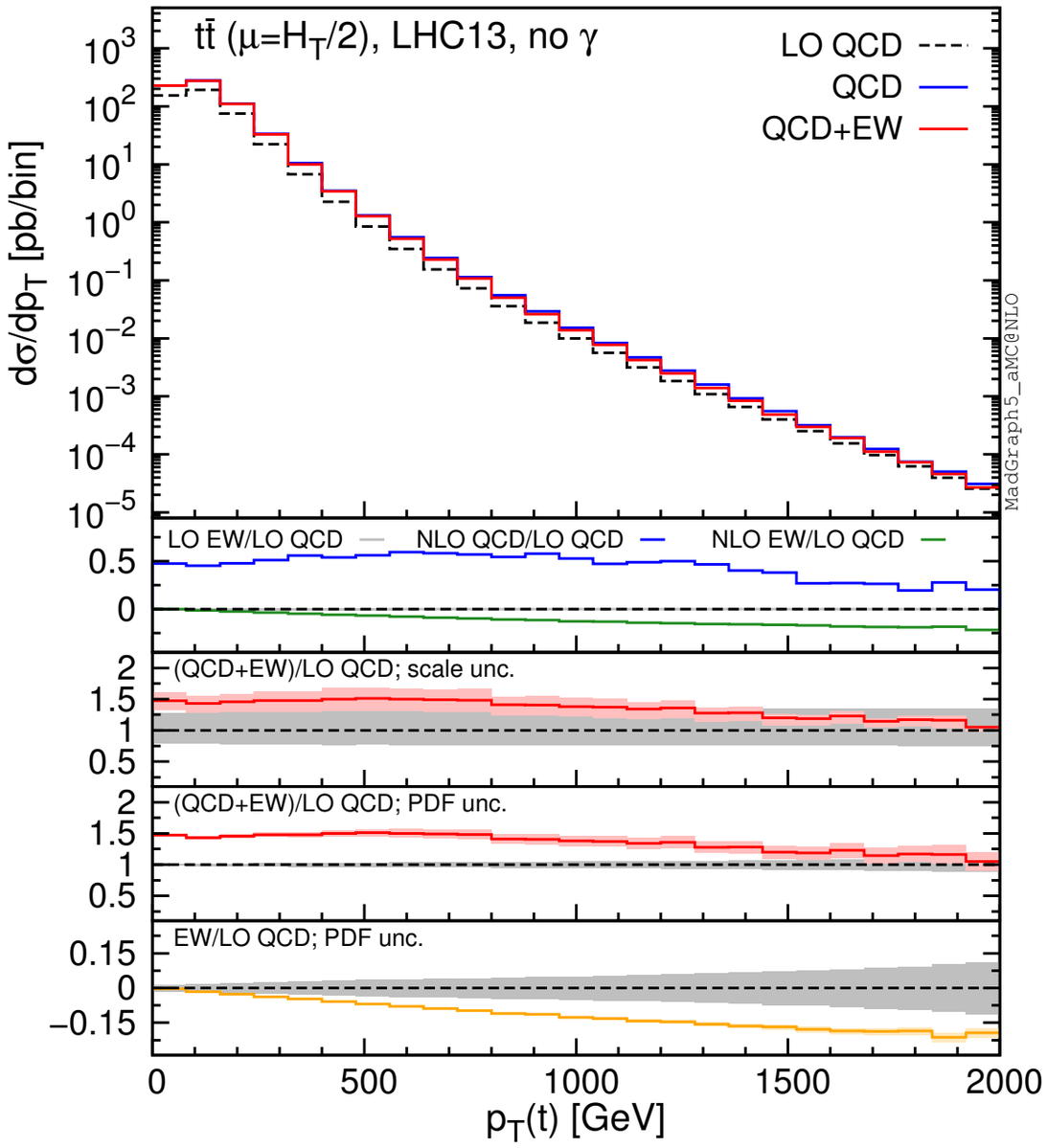
- We will show results with the NNPDF2.3 QED and CT14 QED PDF sets.
- To gauge the impact of the photon PDF in NNPDF2.3 QED, we will also show results with this set and the photon artificially set to 0

Results at the LHC, $\sqrt{s}$=13 TeV

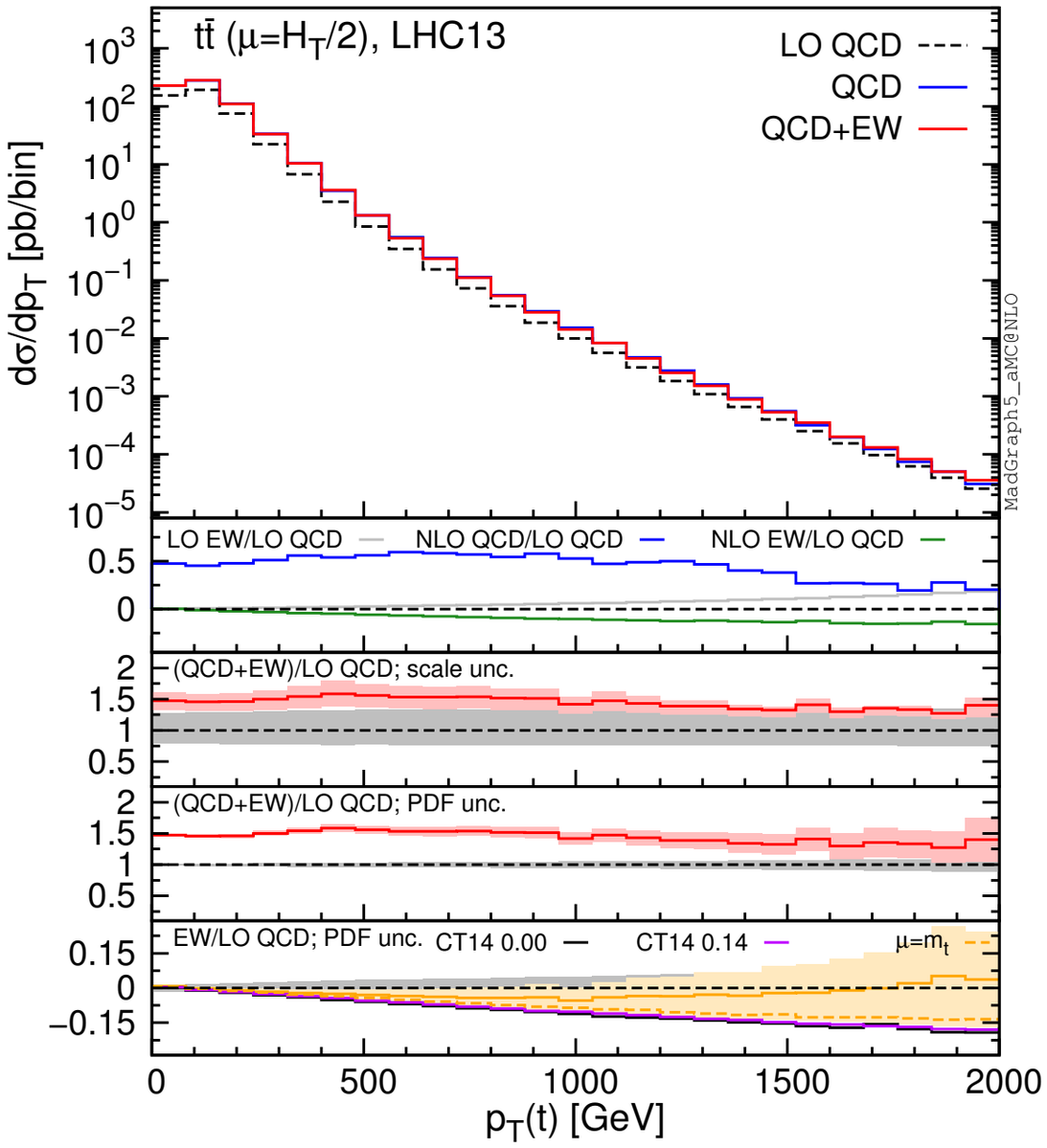


$t\bar{t}$ distributions at 13 TeV: $p_T(t)$

w/o photon

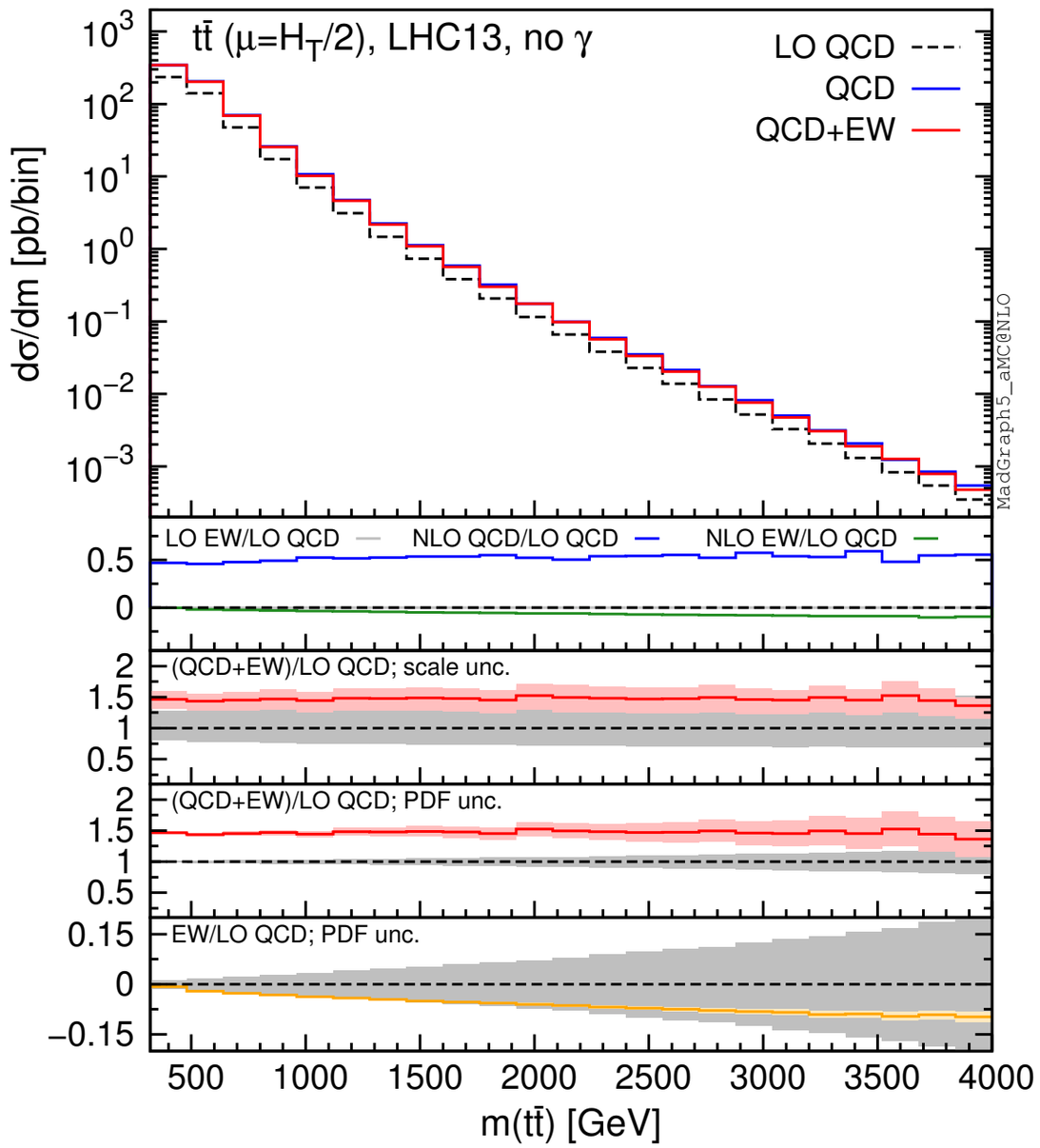


with photon

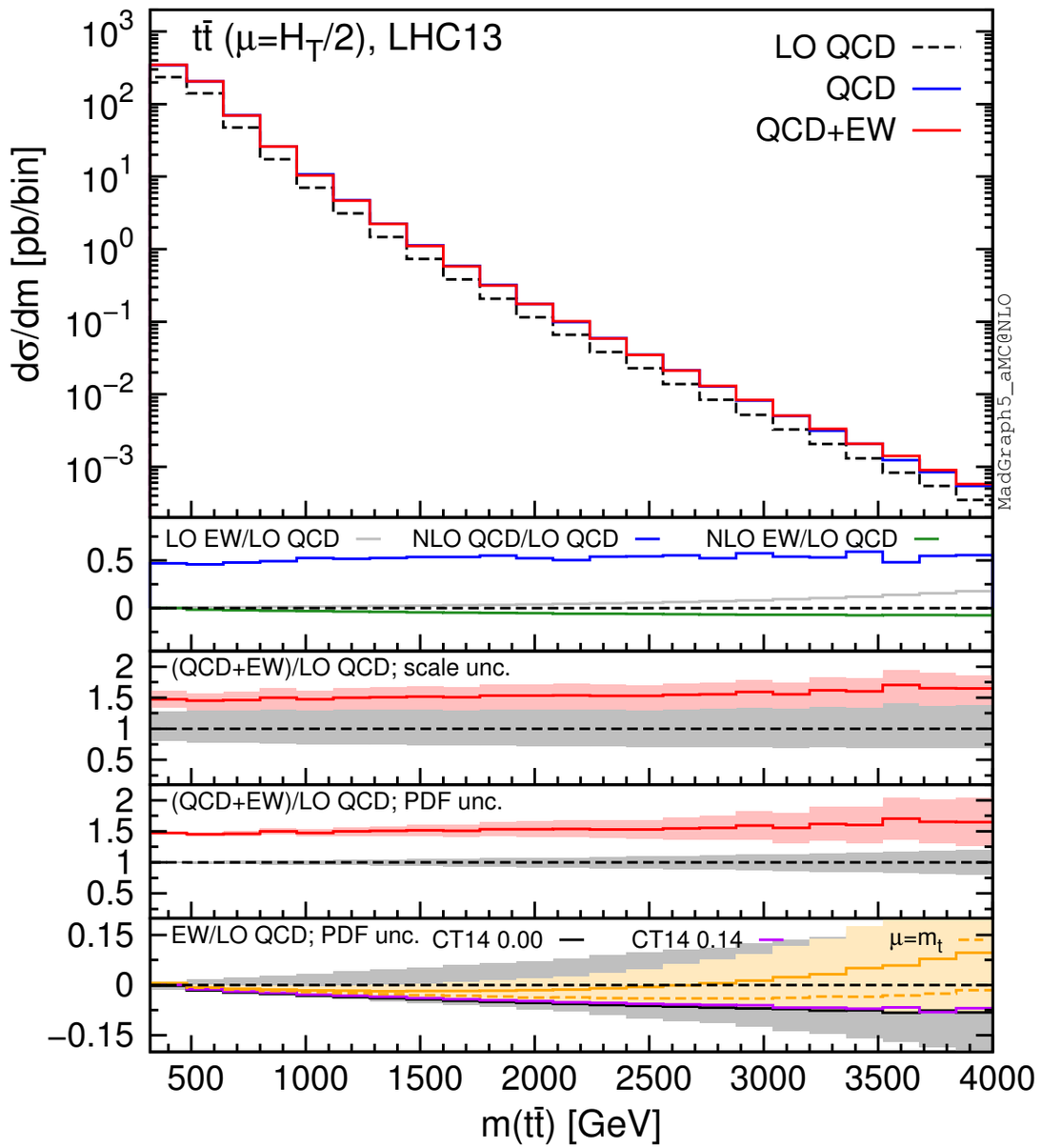


$t\bar{t}$ distributions at 13 TeV: m(tt)

w/o photon

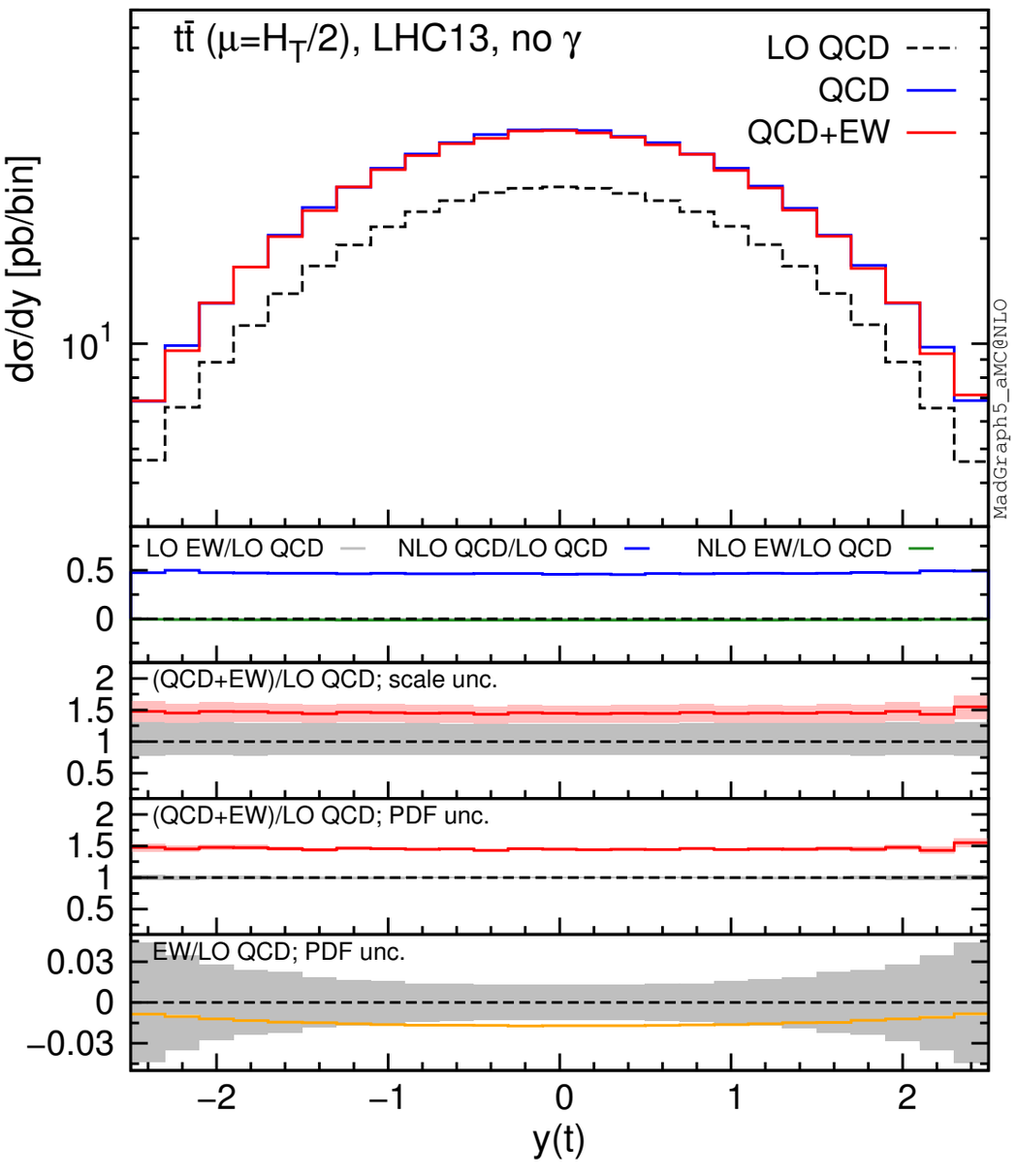


with photon

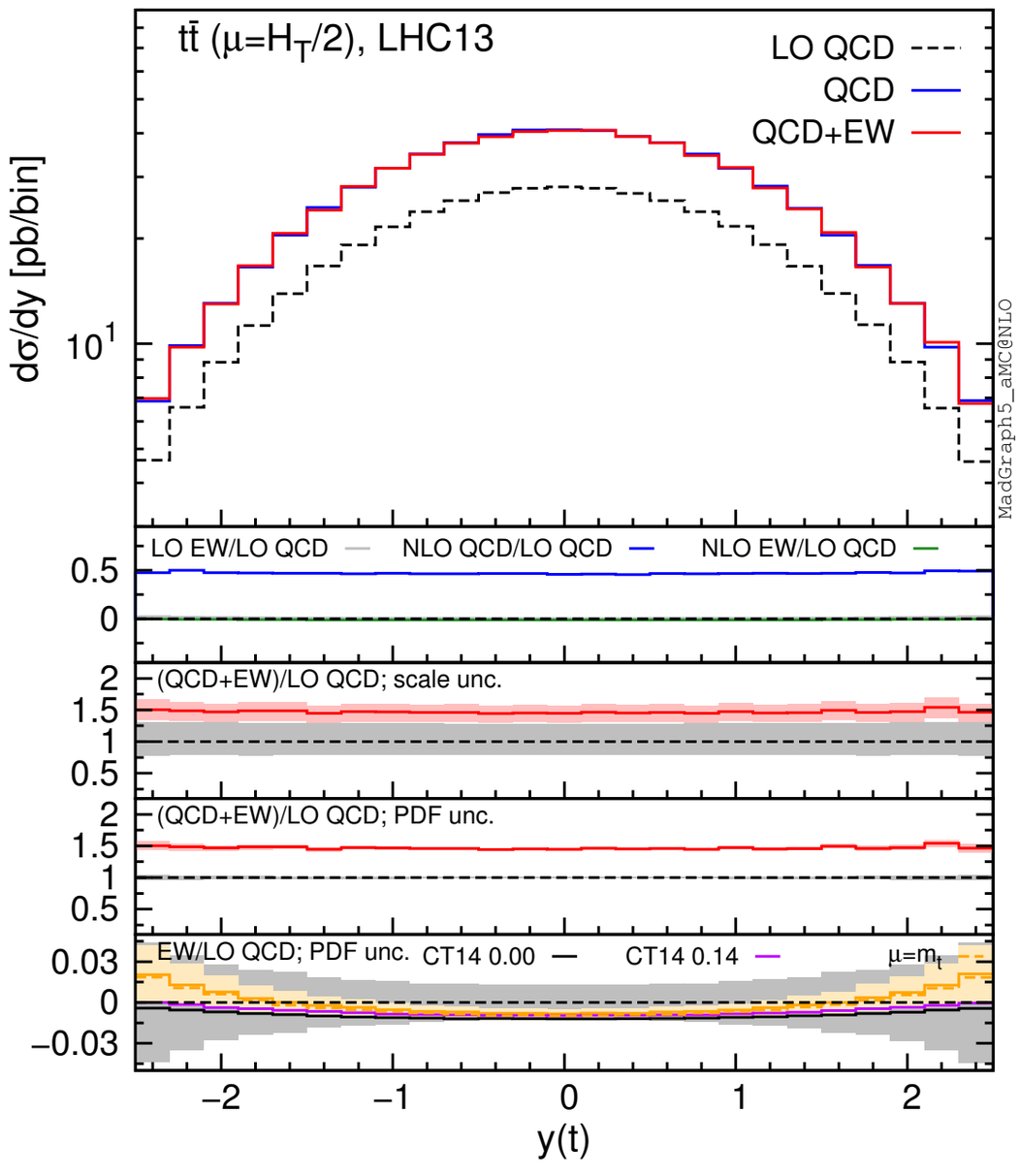


$t\bar{t}$ distributions at 13 TeV: y(t)

w/o photon

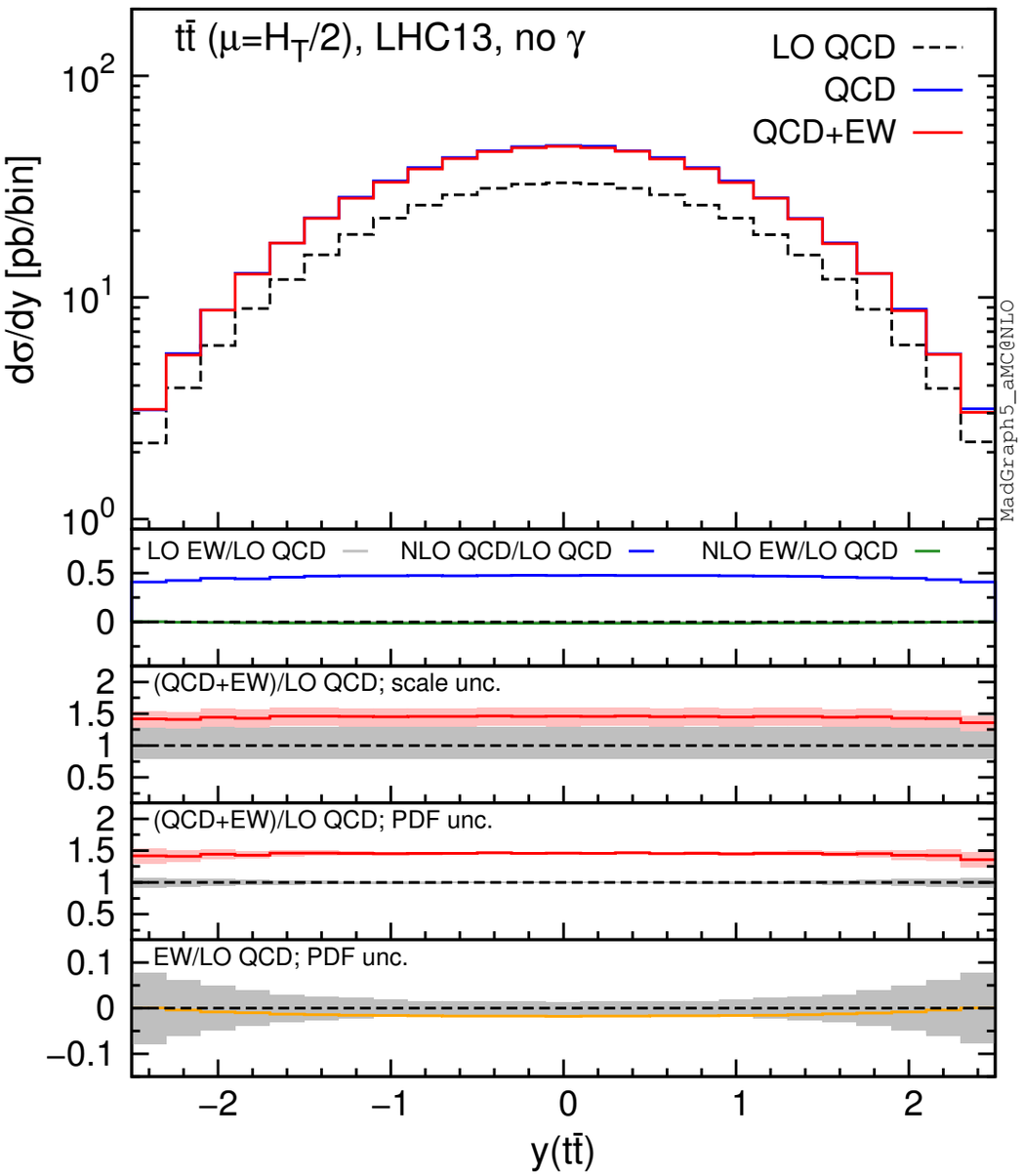


with photon

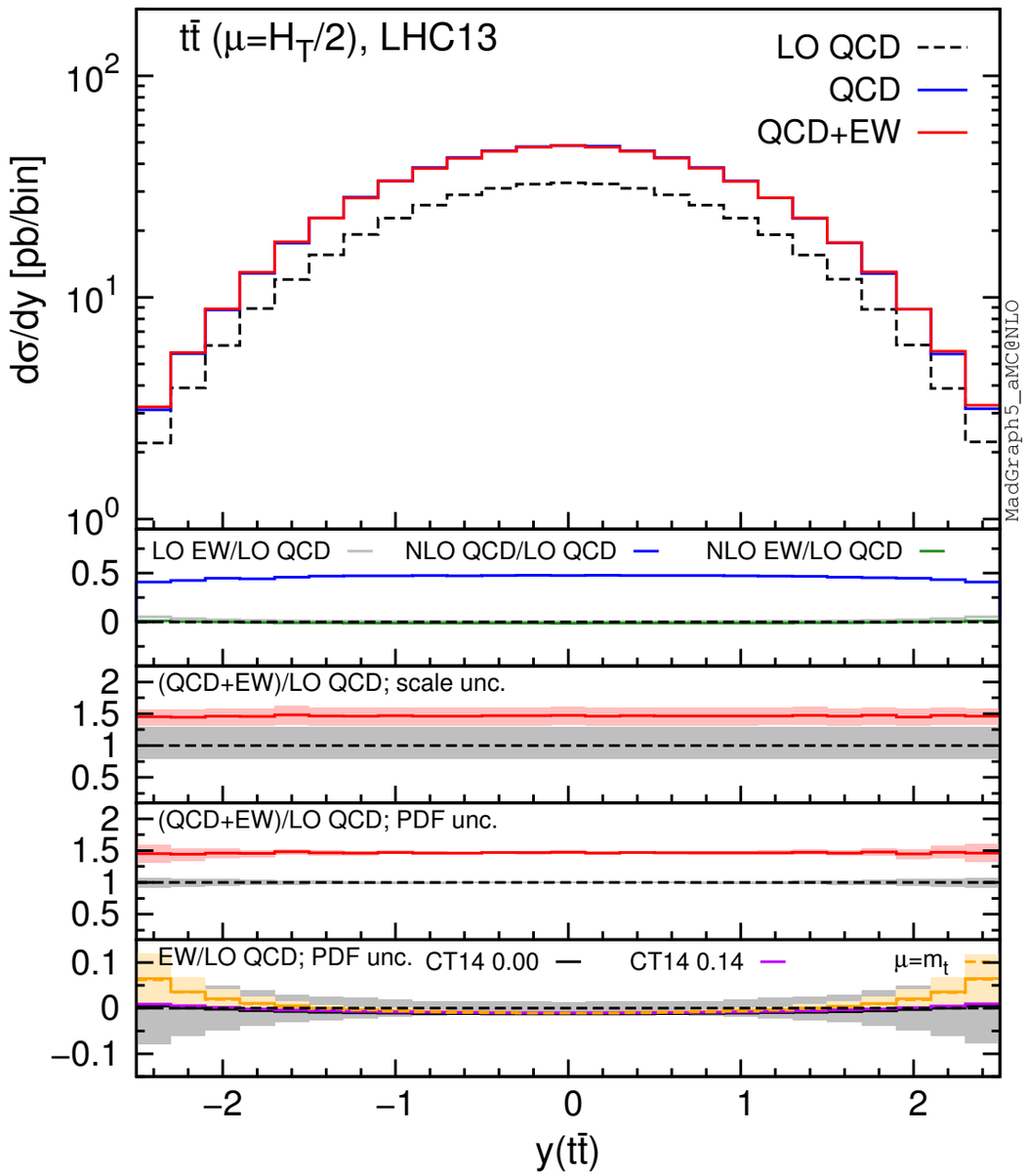


$t\bar{t}$ distributions at 13 TeV: y(tt)

w/o photon



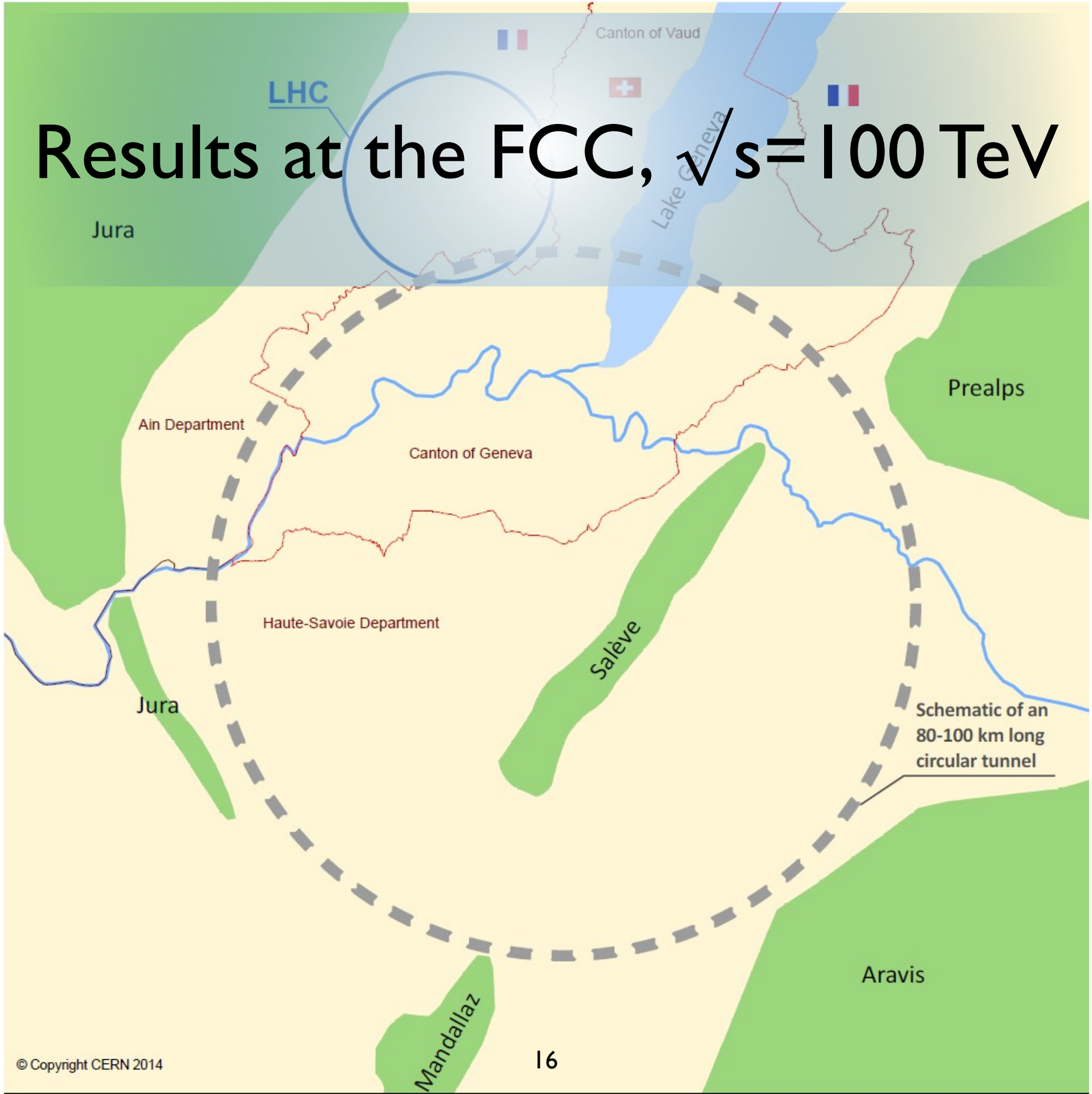
with photon



$t\bar{t}$ distributions at 13 TeV: Comments

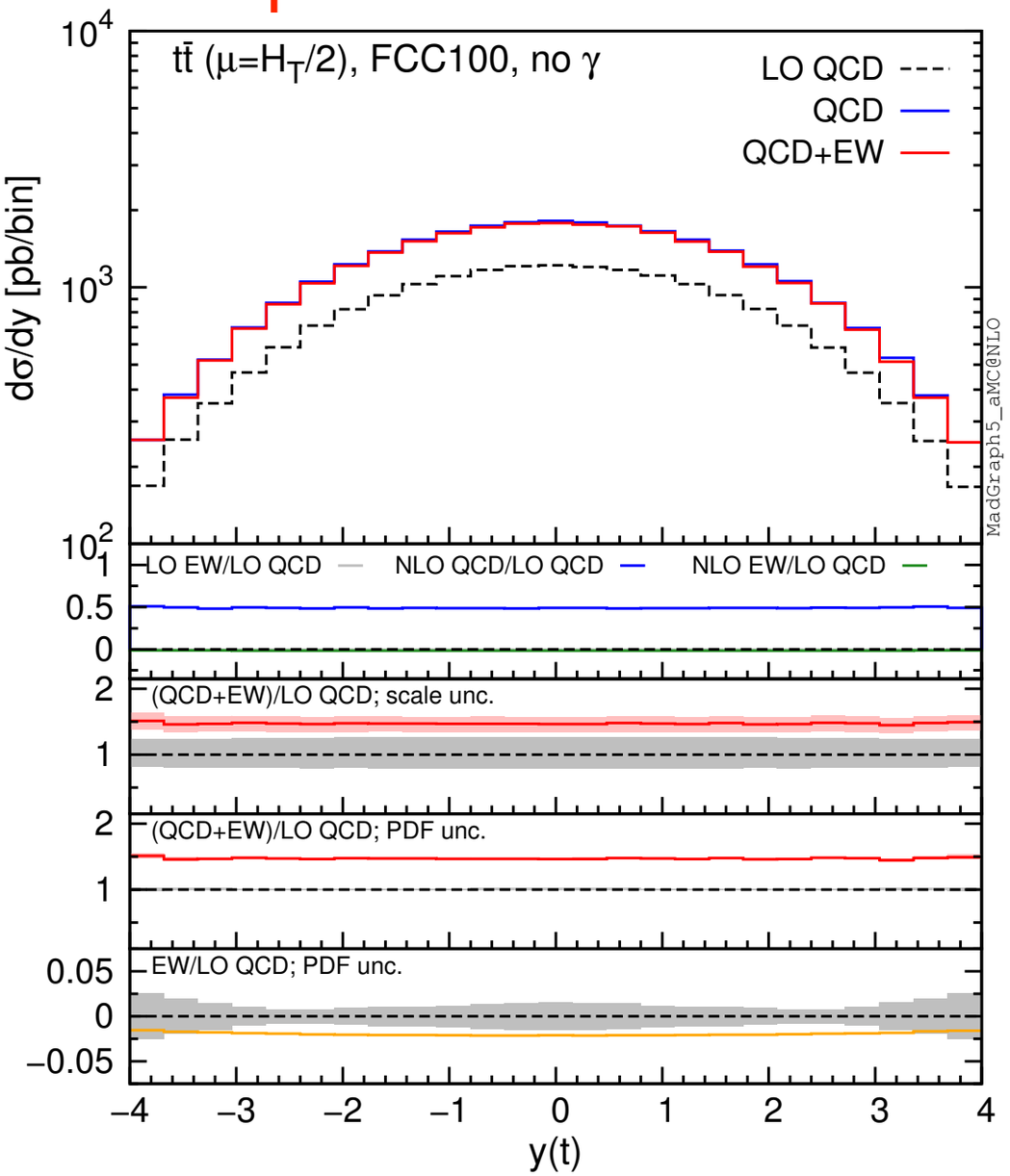
- Relative impact of EW corrections computed with CT14QED or setting $\gamma(x,Q)=0$ in NNPDF2.3QED are equivalent; the photon PDF of CT14QED gives a negligible effect to $t\bar{t}$ distributions
- With NNPDF2.3QED, there are important cancelations at large $p_T(t)$ or m(tt) between Sudakov logs and photon-induced effects
- At large rapidities of the top quark or $t\bar{t}$ system, photon-induced effects are not negligible
- In all cases, photon-induced effects dominantly come from the LO QED term. Genuine NLO effects are negligible

Results at the FCC, $\sqrt{s}$=100 TeV

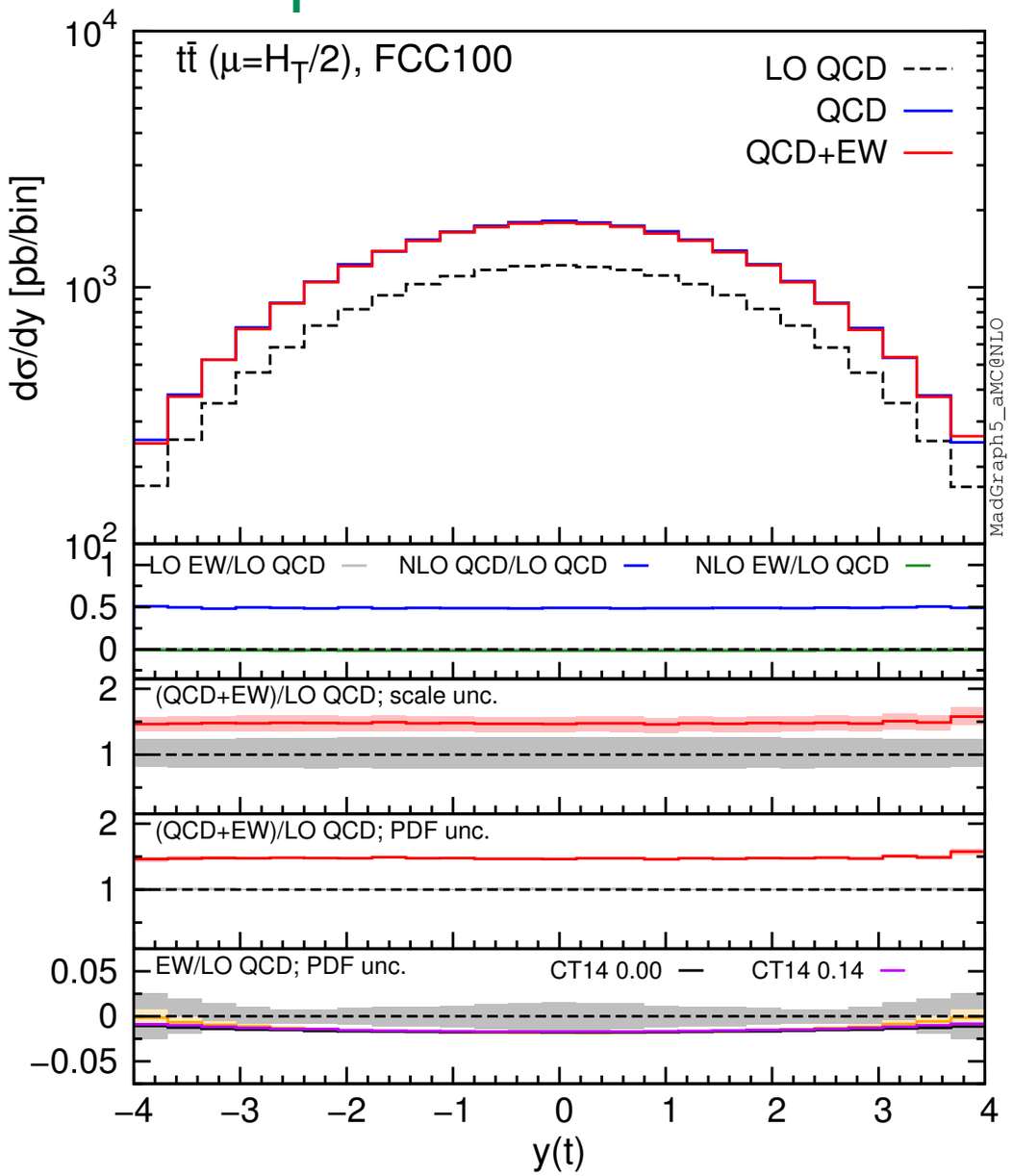


$t\bar{t}$ distributions at 100 TeV: y(t)

w/o photon

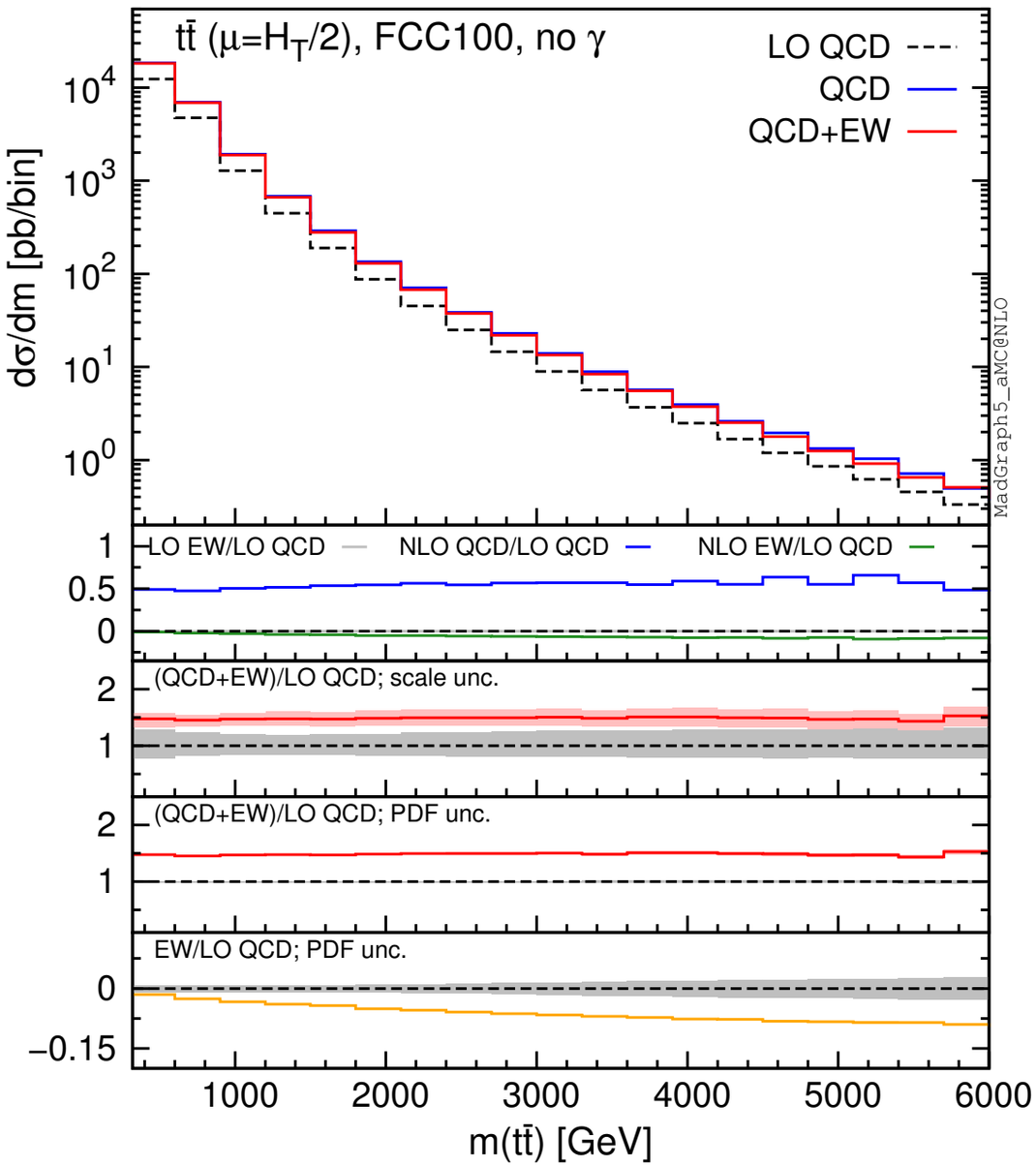


with photon

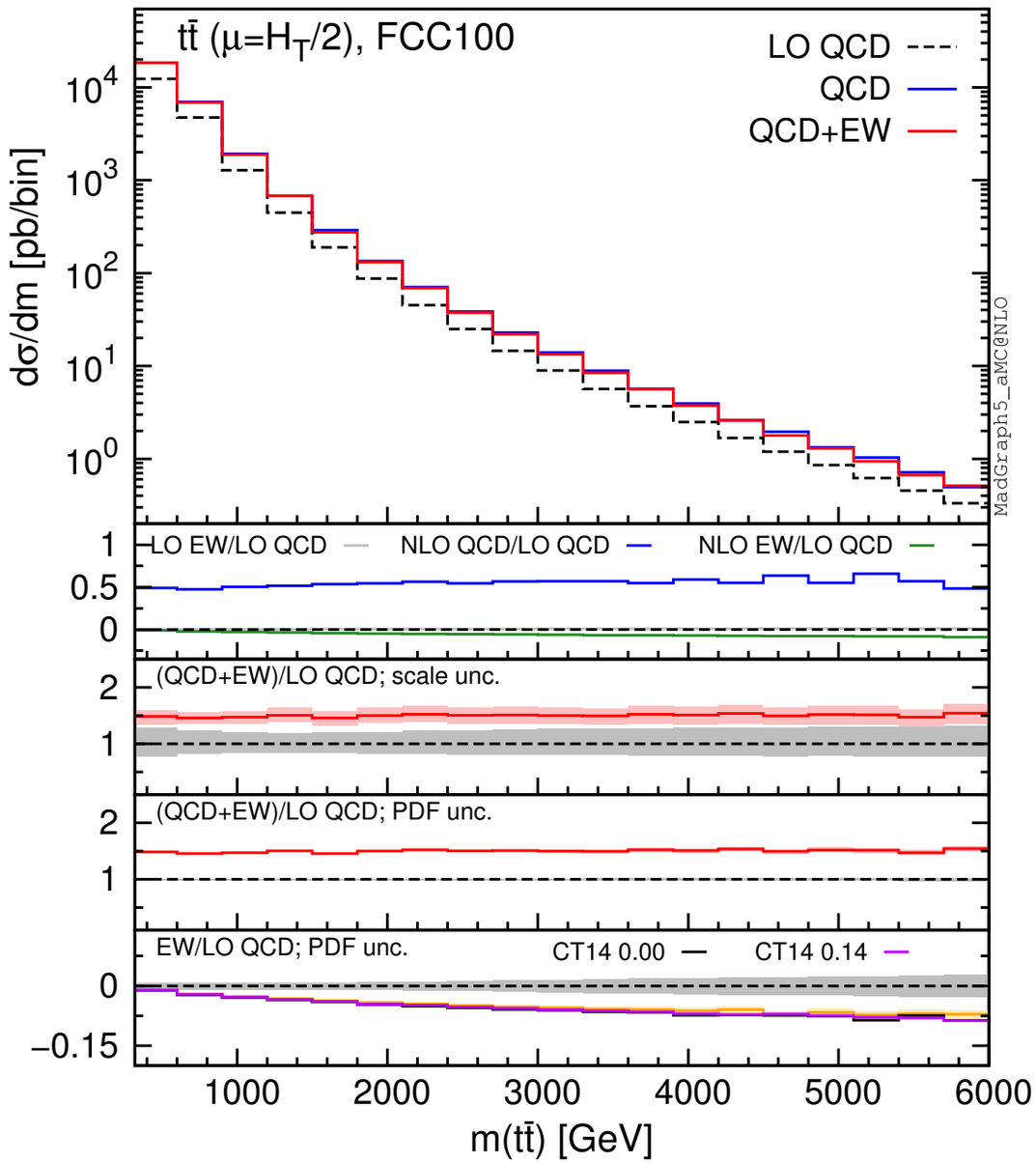


$t\bar{t}$ distributions at 100 TeV: m(tt)

w/o photon

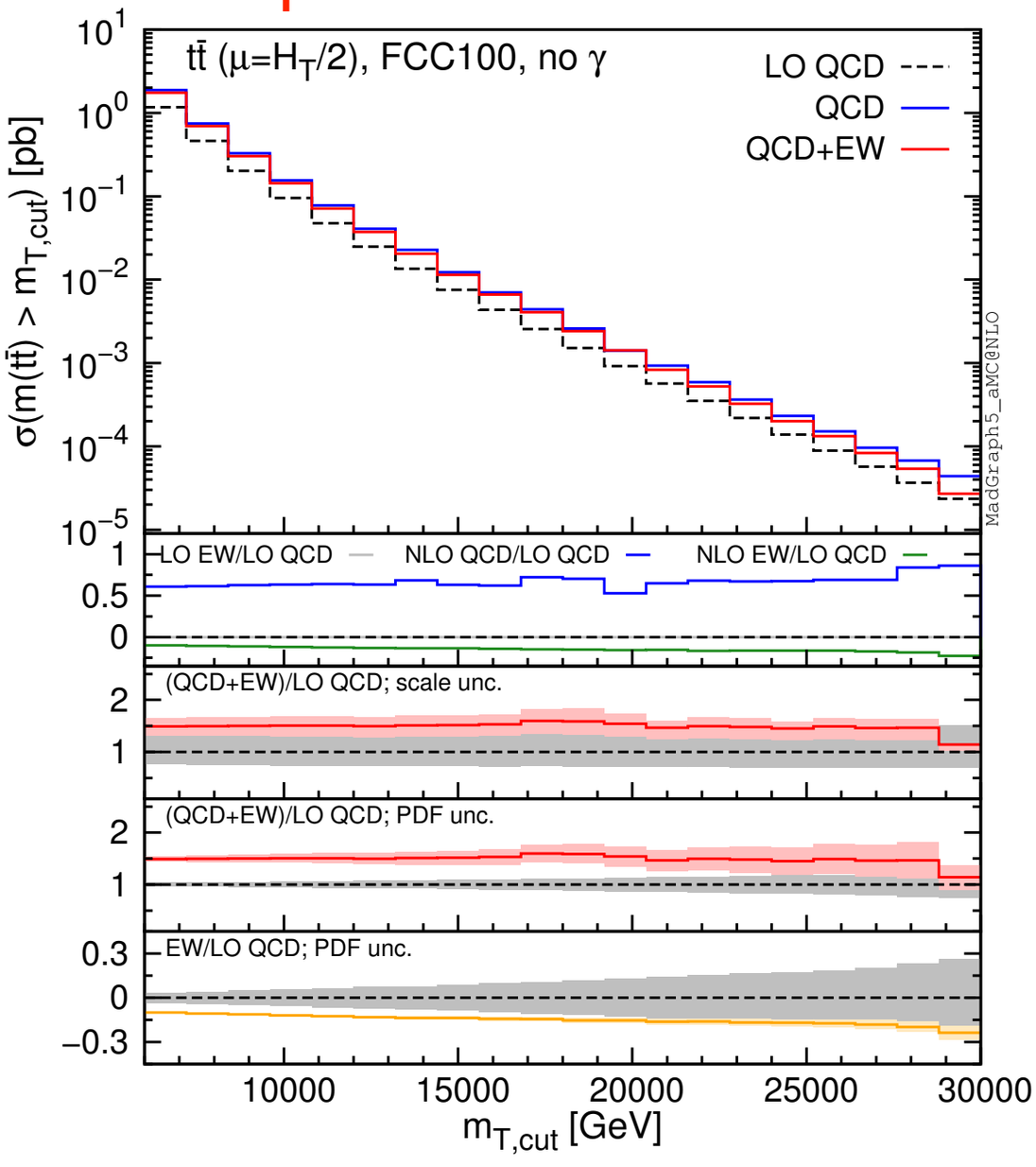


with photon

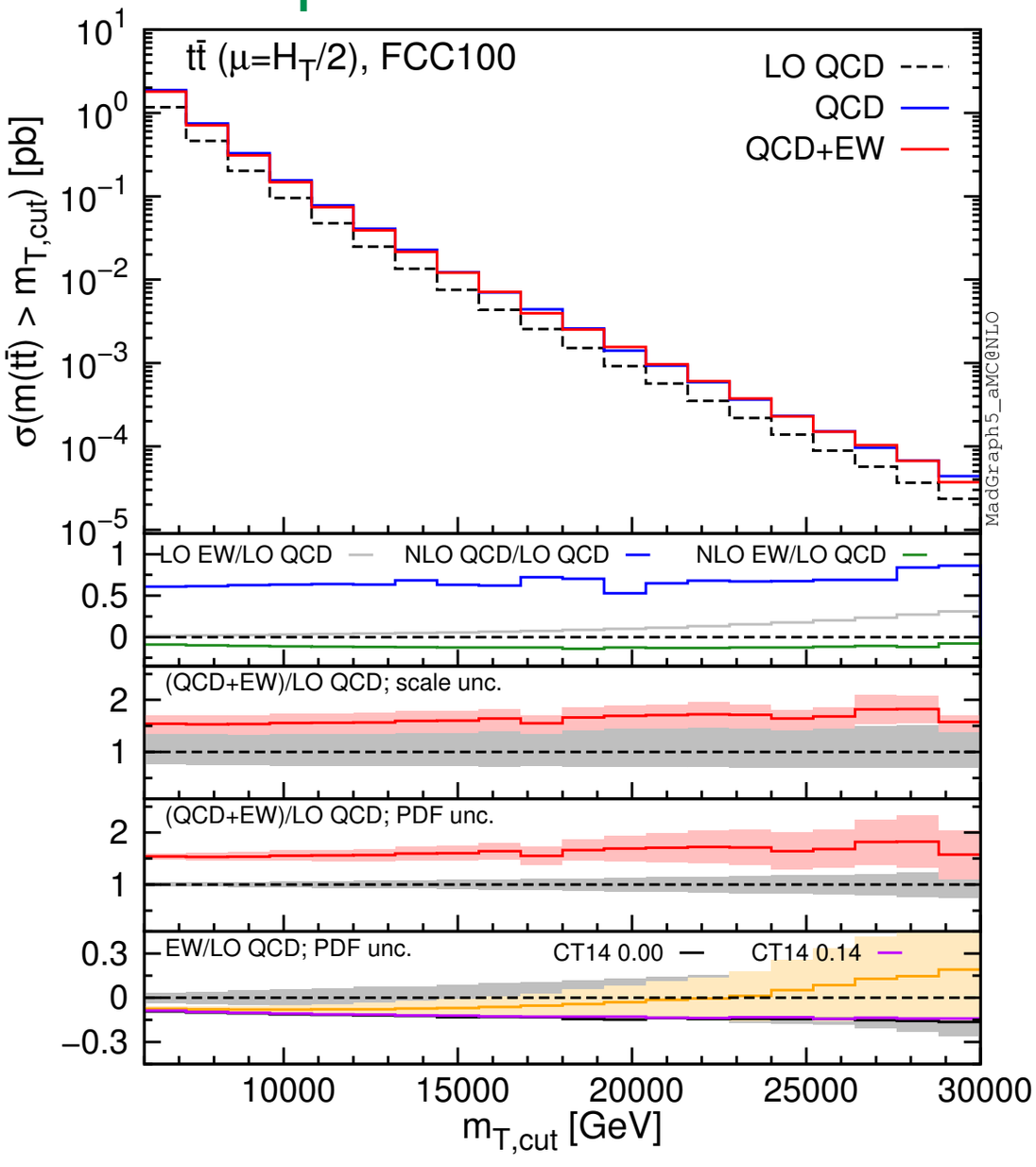


$t\bar{t}$ distributions at 100 TeV: m(tt)

w/o photon



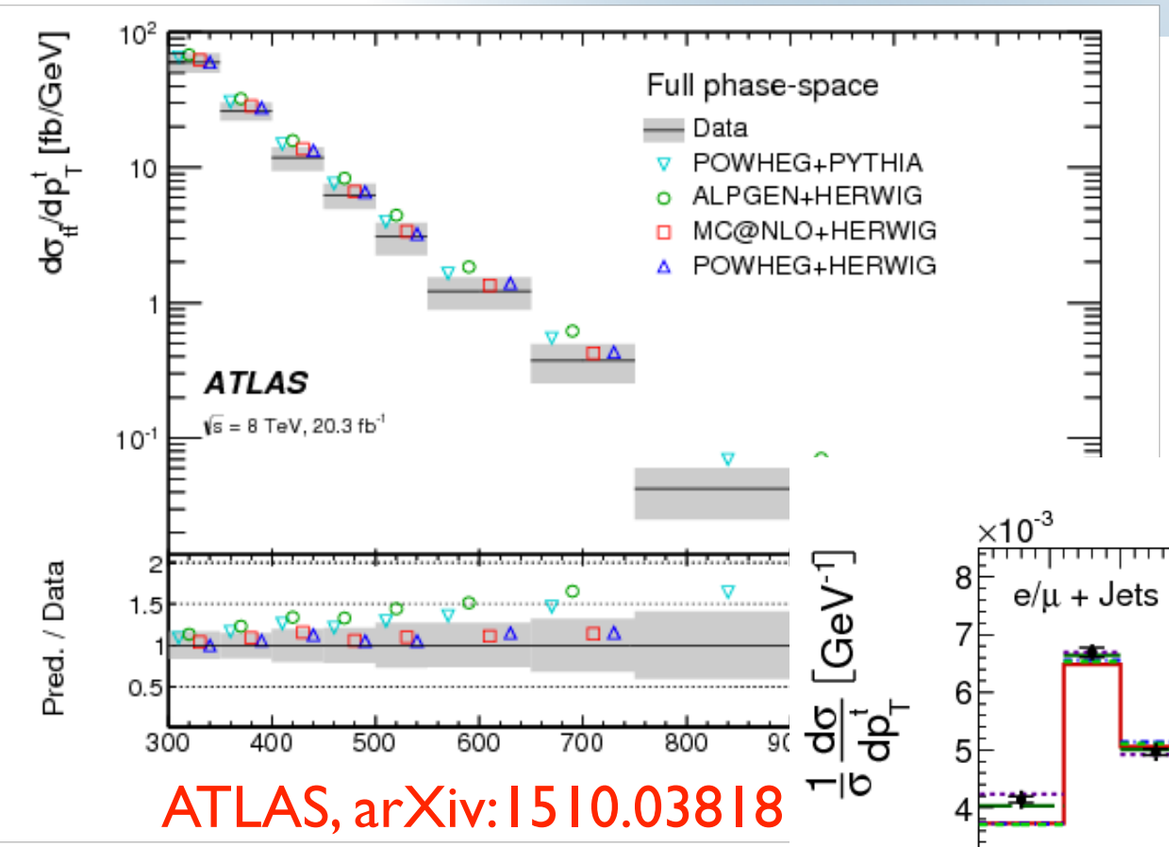
with photon



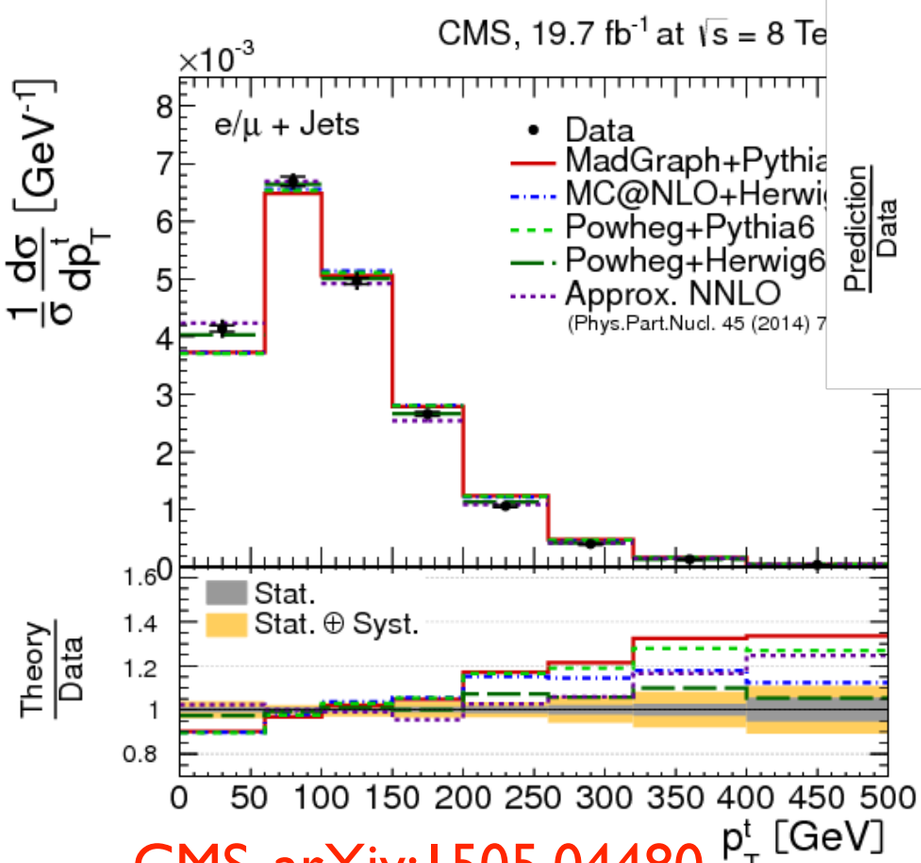
$t\bar{t}$ distributions at 100 TeV: Comments

- At 100 TeV, $t\bar{t}$ differential distributions are almost insensitive to photon-induced effects, because of the smaller Bjorken x's
- Photon-induced effects can be seen only when very hard cuts are imposed
- Larger effects (even larger than at 13 TeV) are expected at 8 TeV: we have data to compare with!

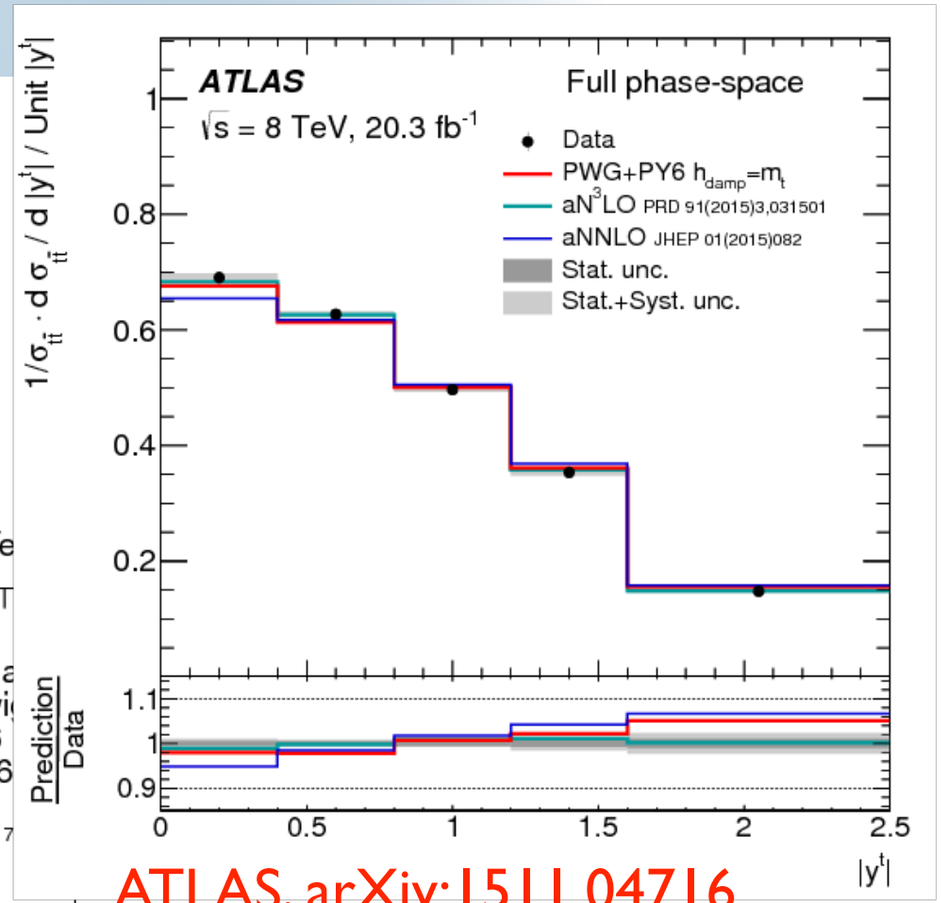
Results at the LHC, $\sqrt{s}$=8 TeV and comparison with data



ATLAS, arXiv:1510.03818



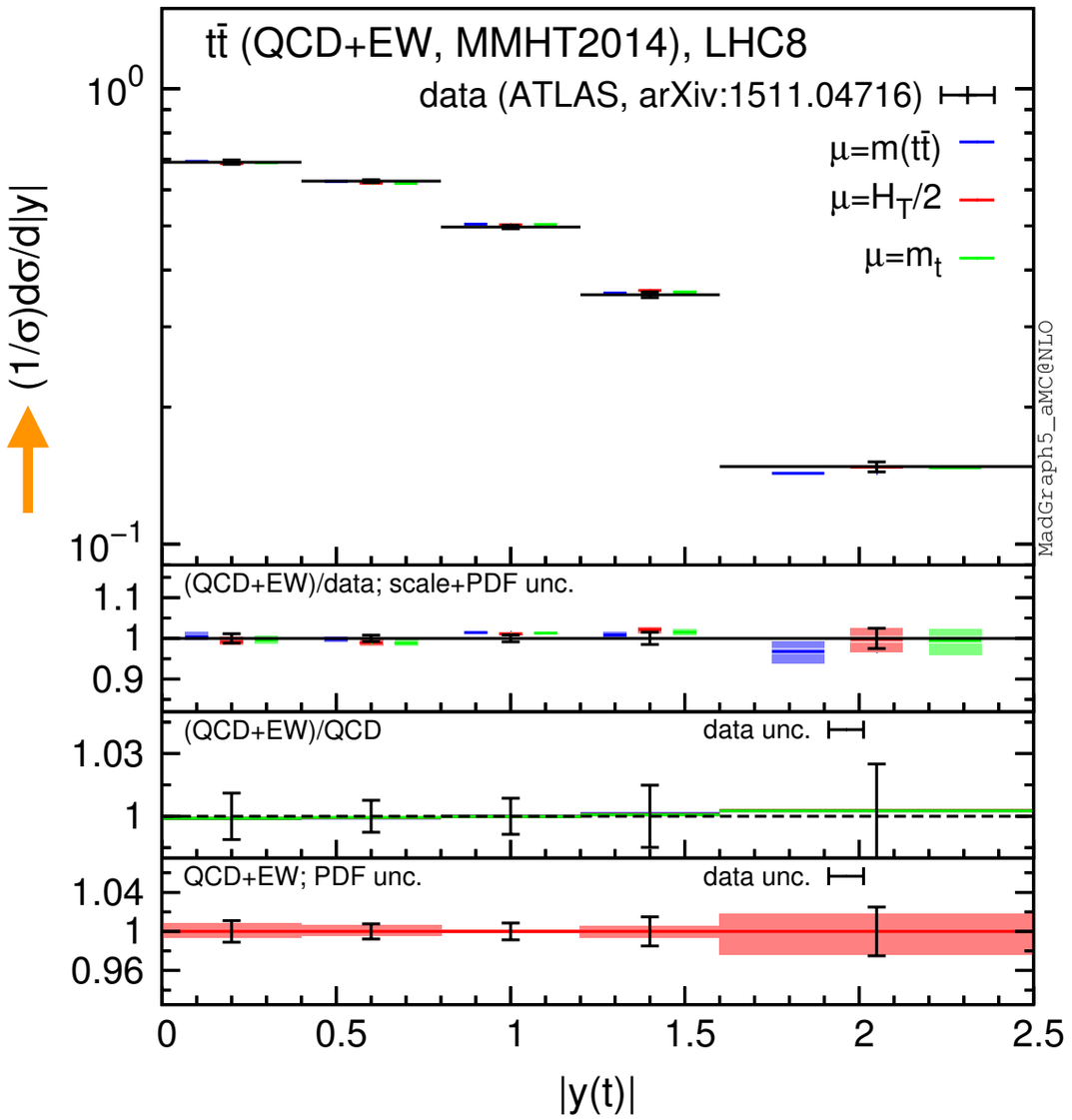
CMS, arXiv:1505.04480



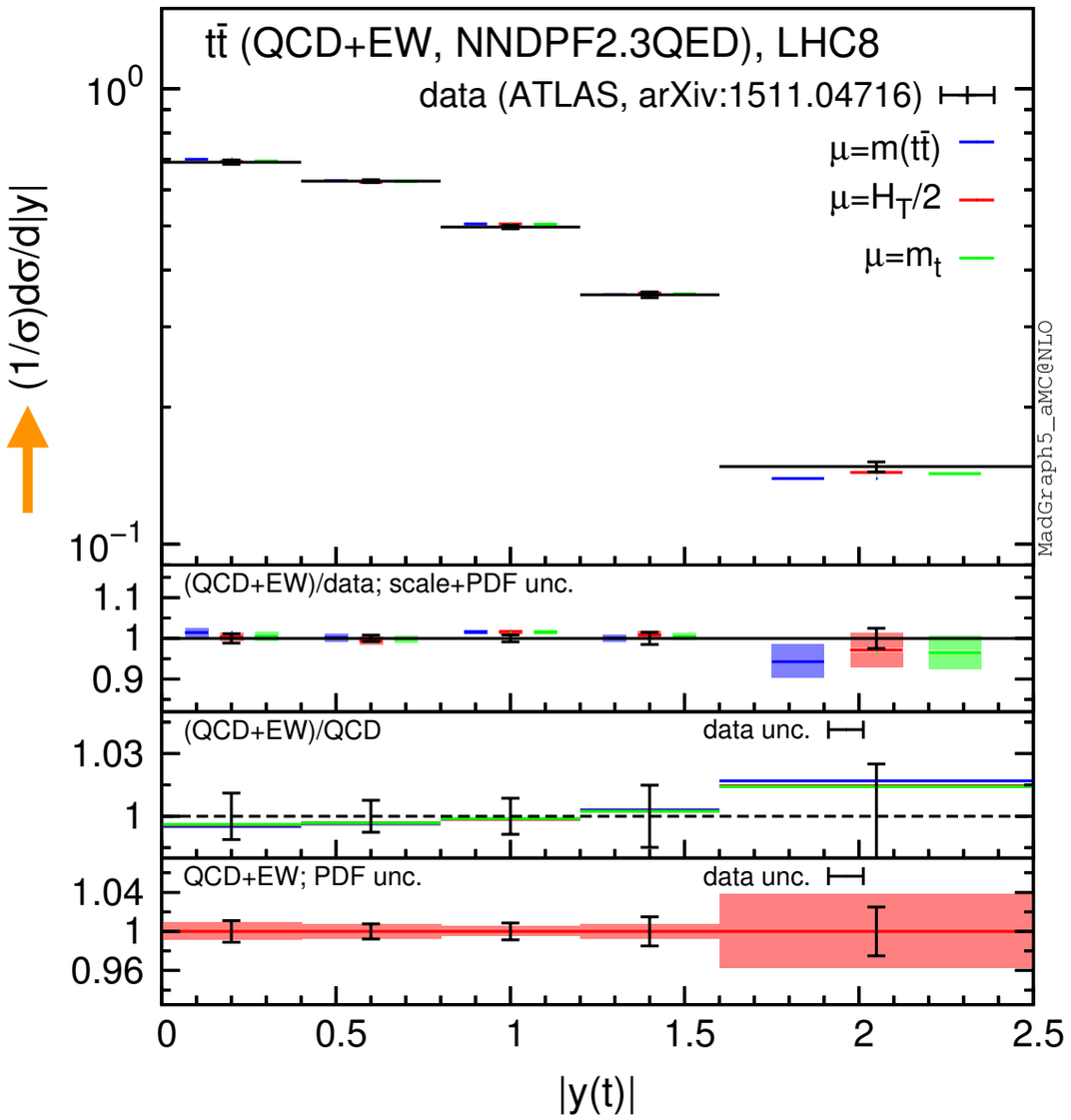
ATLAS, arXiv:1511.04716

Results at the LHC, $\sqrt{s}$=8 TeV and comparison with data

MMHT14

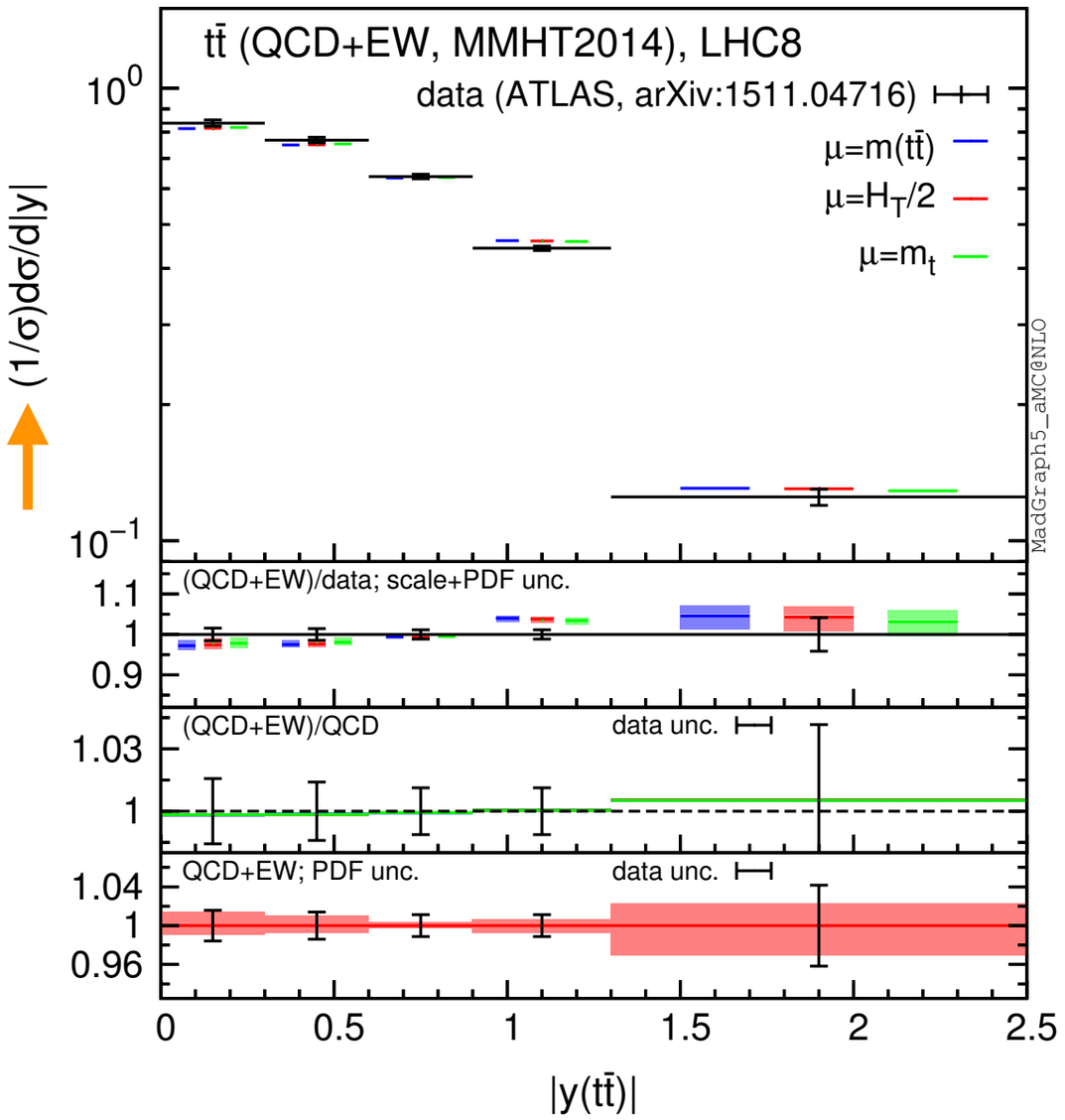


NNPDF2.3QED



Results at the LHC, $\sqrt{s}$=8 TeV and comparison with data

MMHT14



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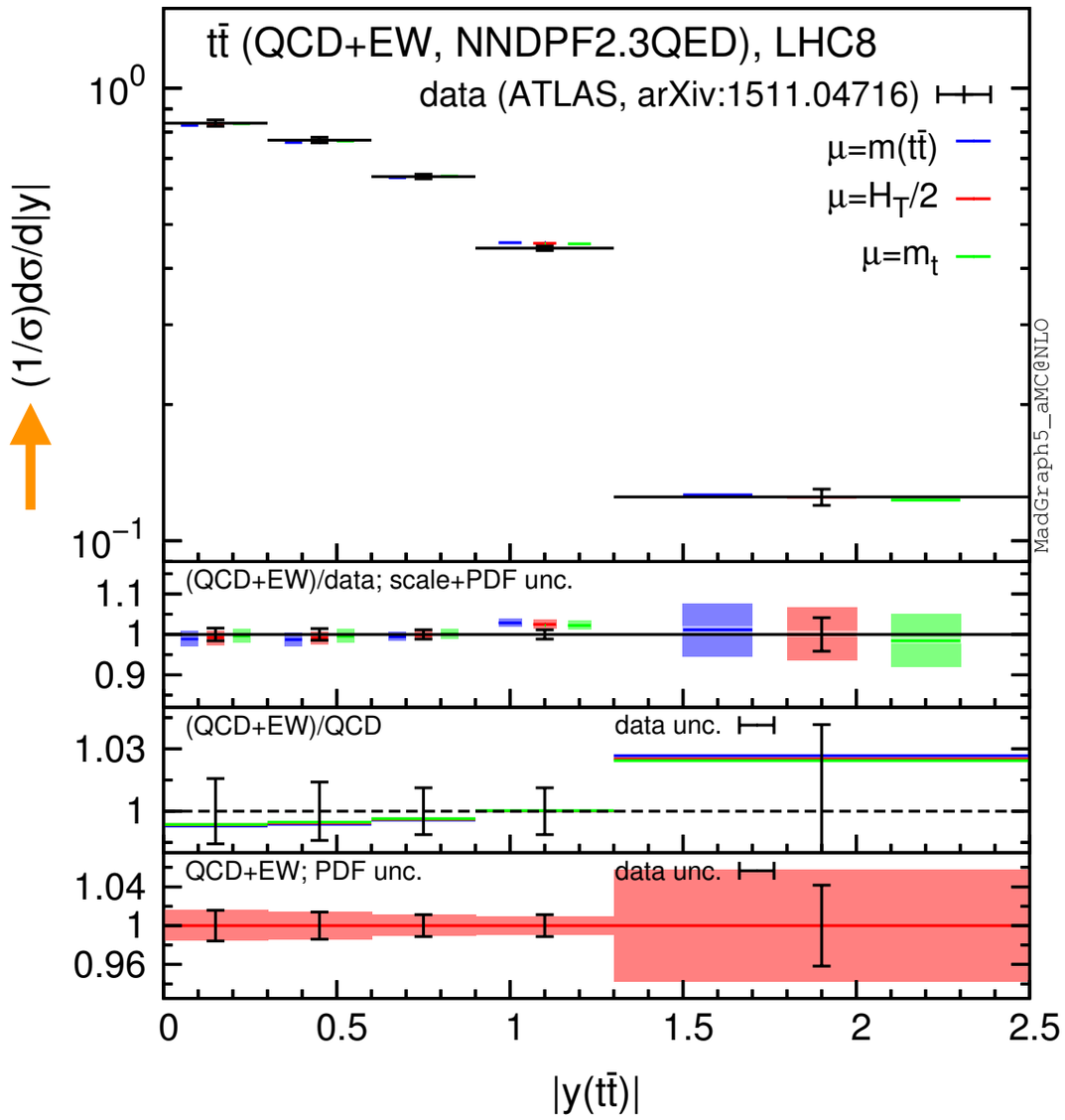
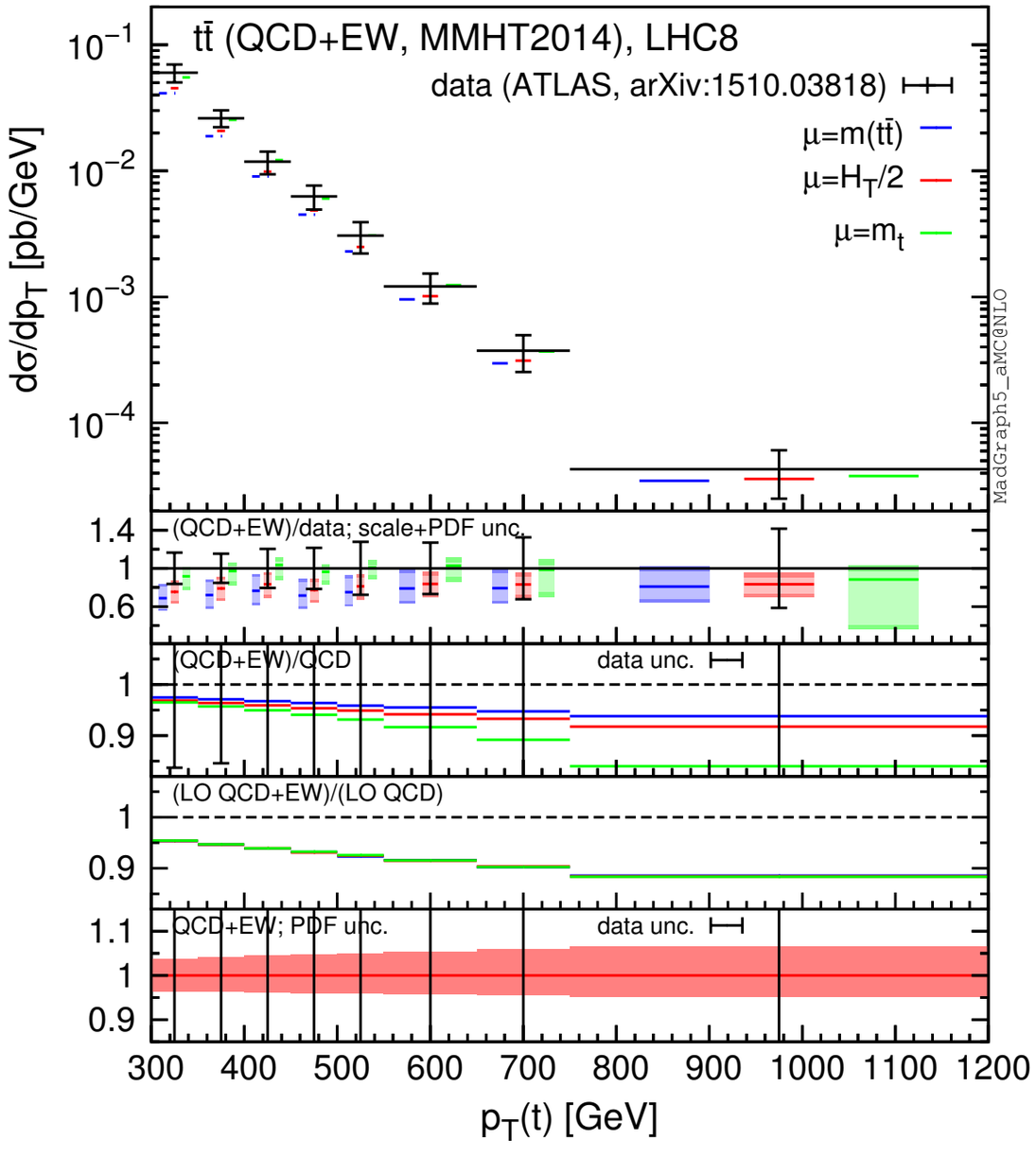


Results at the LHC, $\sqrt{s}$=8 TeV and comparison with data

MMHT14



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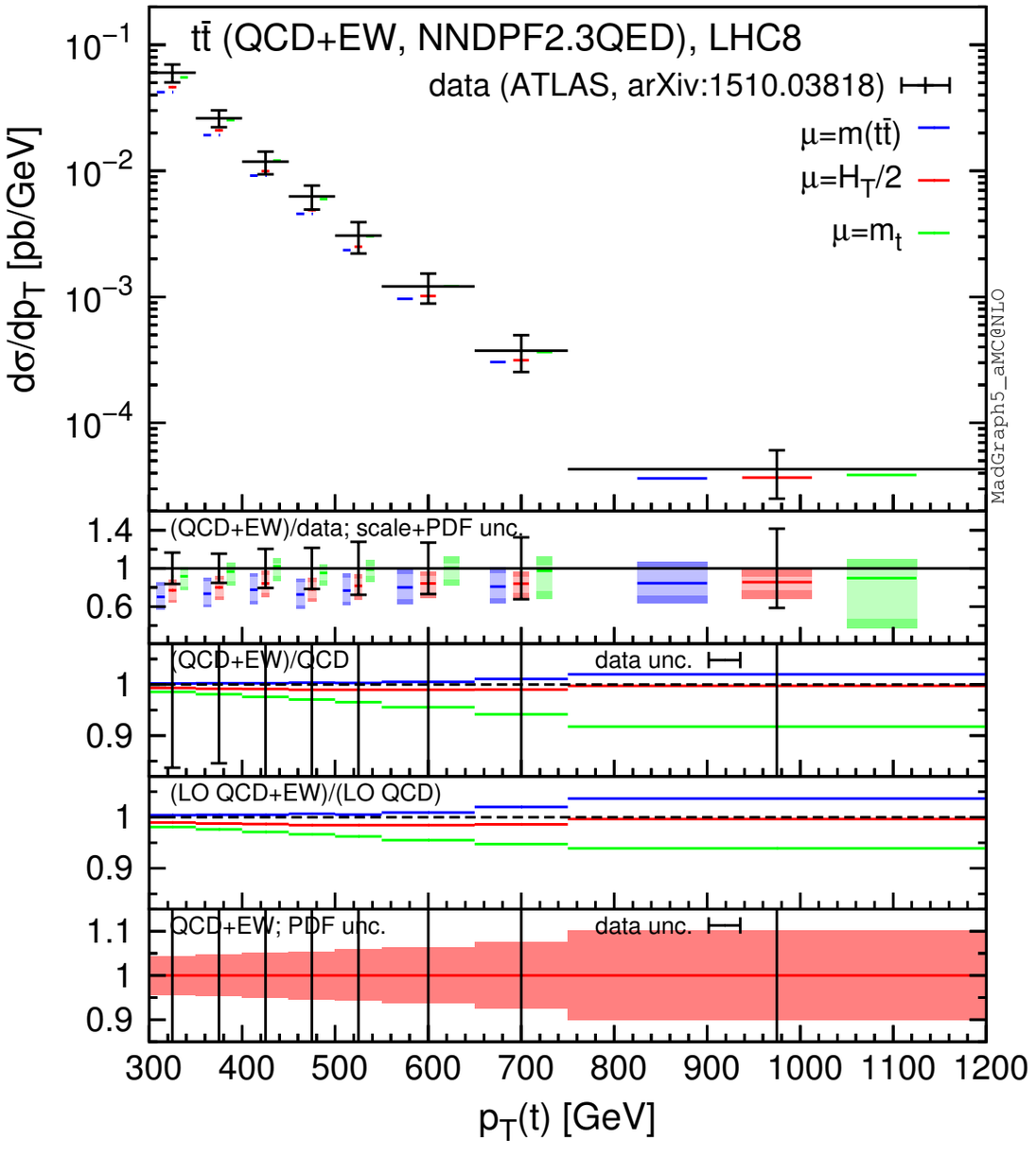
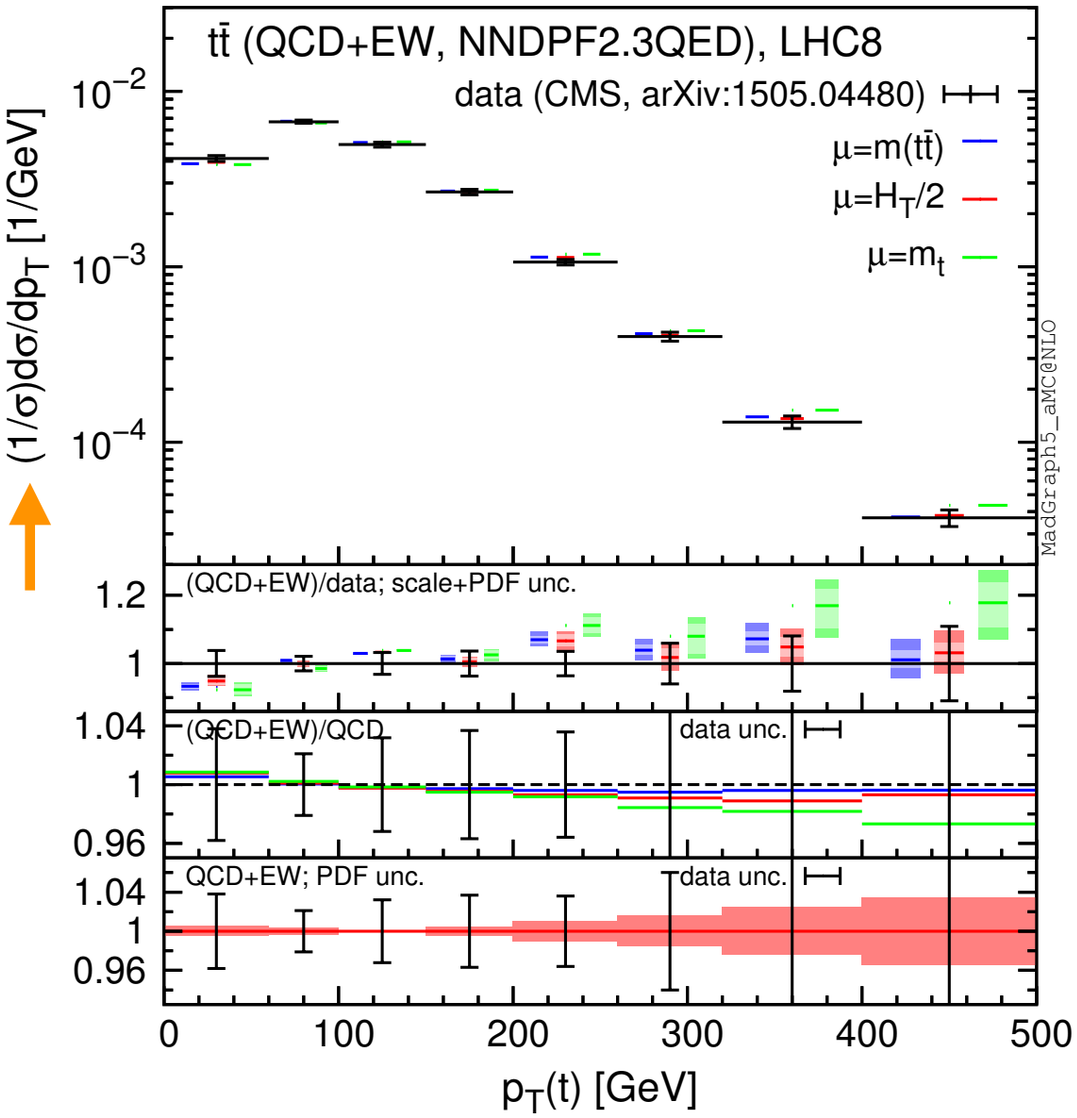
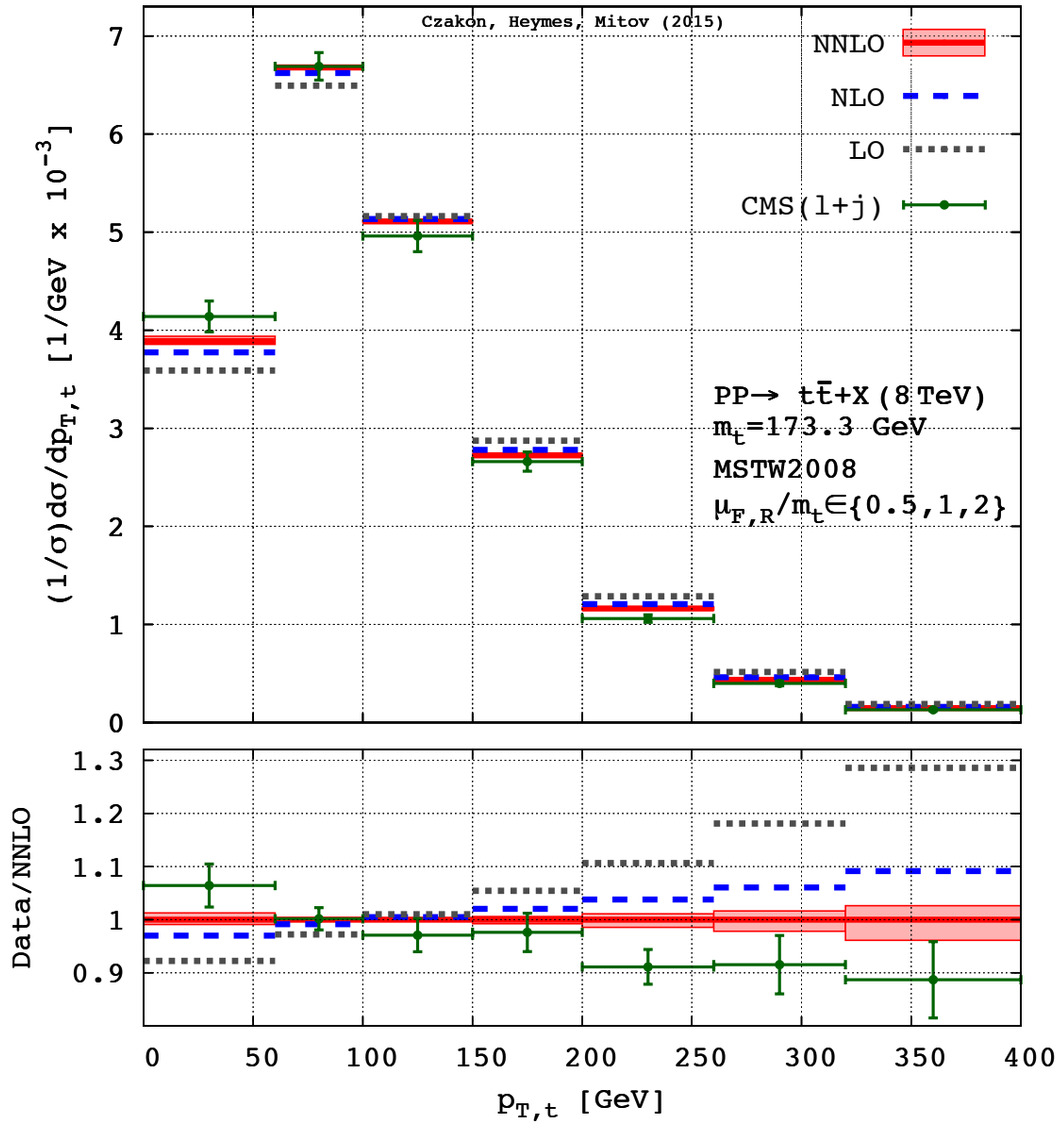


Results at the LHC, $\sqrt{s}$=8 TeV and comparison with data

NNPDF2.3QED



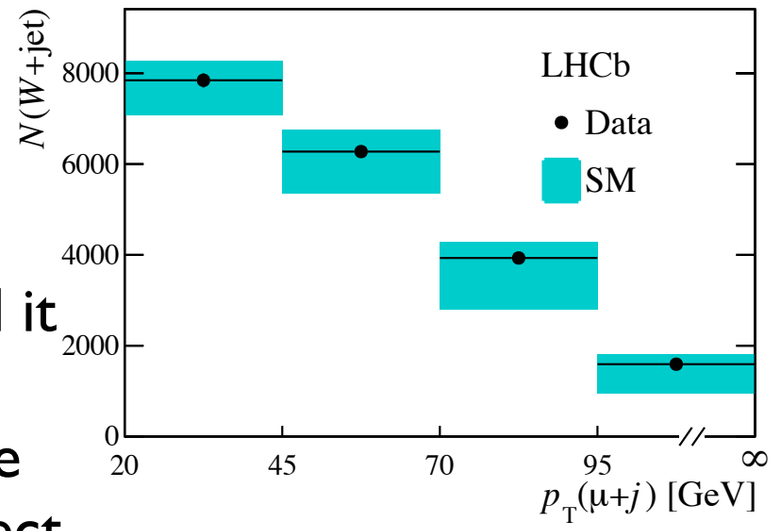
Czakon, Heymes, Mitov, arXiv:1511.00549



Results at the LHC, $\sqrt{s}$=8 TeV: Comments

- Normalised rapidity distributions show very small (1%) experimental uncertainties and even smaller scale uncertainties already at NLO QCD. PDF uncertainties are larger and the impact of the photon PDF is visible at large rapidities
  Constraints to a large photon PDF (*à la* NNPDF) can be set
  Can LHCb future data help?
- The impact of the photon PDF is larger in the large-p_T tail, and it compensates the Sudakov logs. The compensation strongly depends on the scale choice. However, experimental errors are larger than these effects, and also larger scale uncertainties affect the results
- In view of the quality of the 13 TeV data, EW corrections and photon-initiated contributions need to be taken into account
- For a reliable TH vs EXP comparison, NNLO QCD is mandatory. Combination of NNLO QCD and NLO EW is in progress
  Czakon, Heymes, Mitov, Pagani, Tsinikos, MZ, in progress

LHCb, arXiv:1506.00903

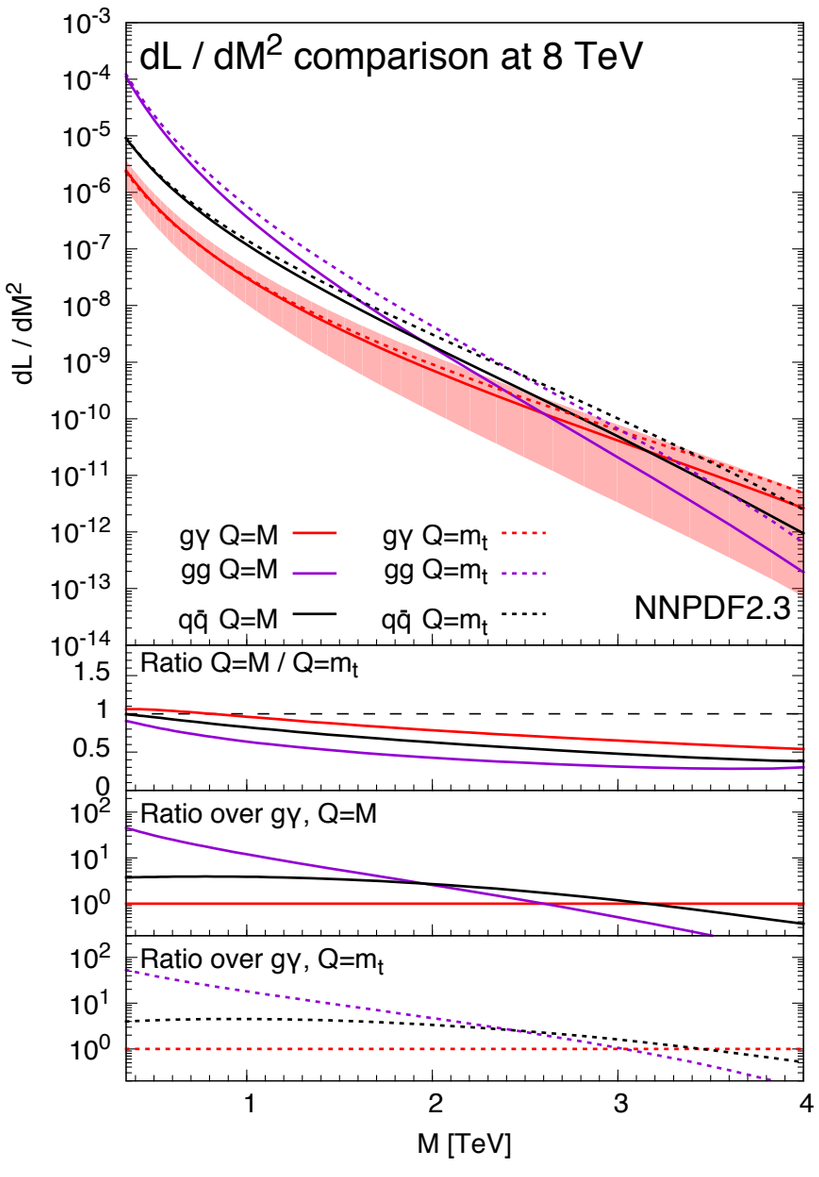


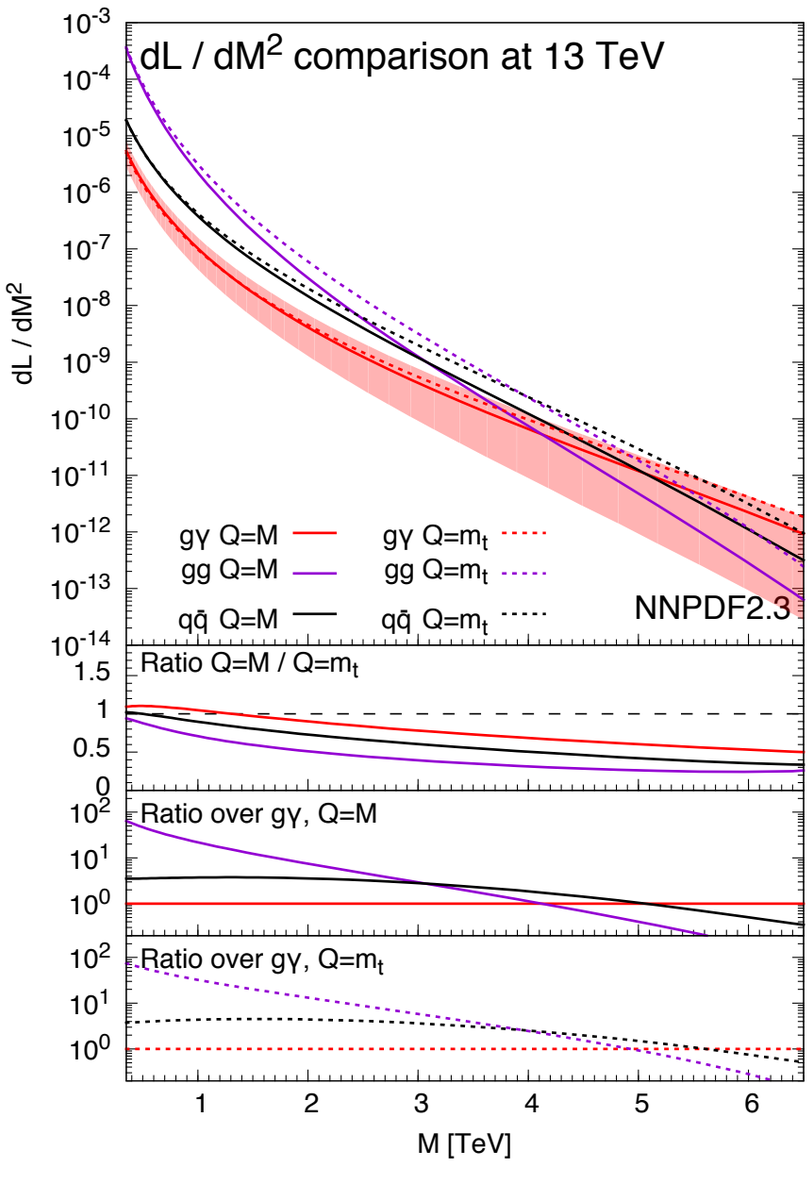
Conclusions

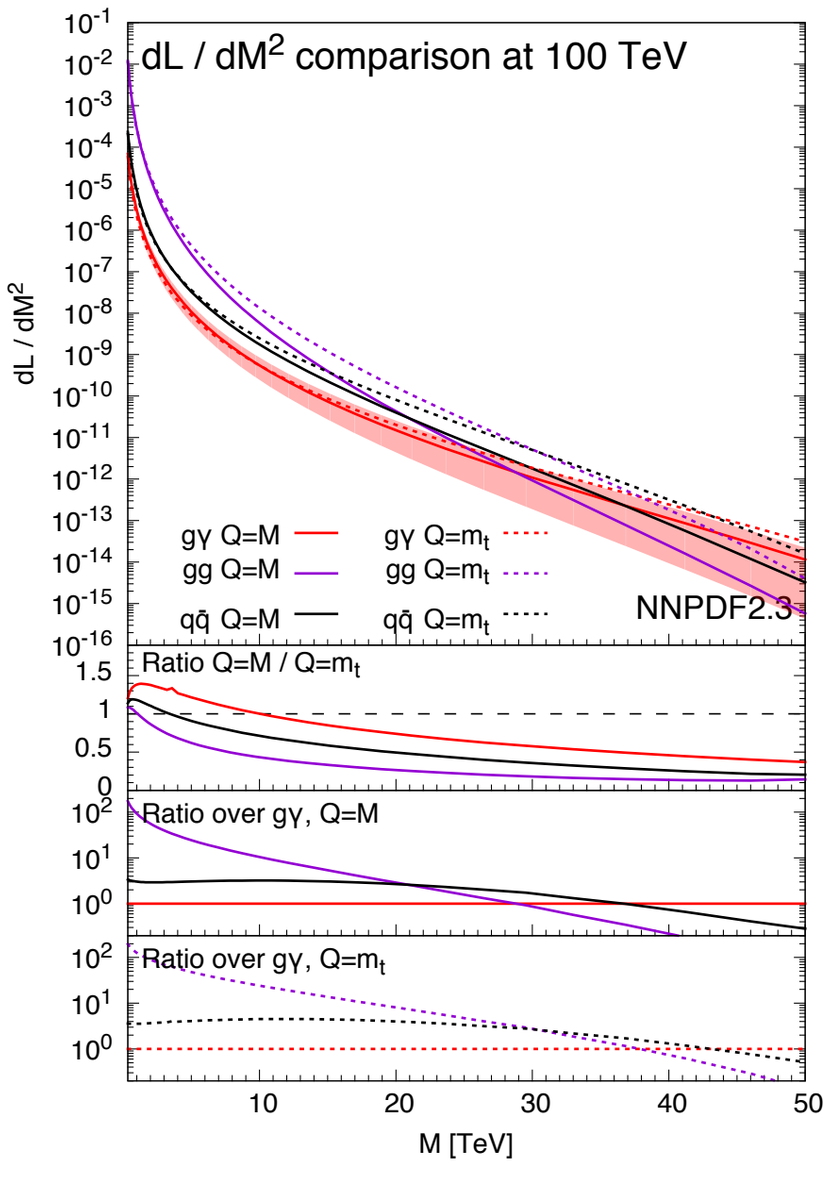
- Can the study of tt production at differential level provide informations on the photon PDF?
- With NNPDF, photon-initiated effects are large with large uncertainties. On the contrary, with CT14QED (and LUXqed) these effects are almost invisible
- 8 TeV data, in particular normalised rapidity distributions, show a possible sensitivity to a photon *à la* NNPDF
- For 13 TeV data and un-normalised distributions, NNLO QCD corrections are mandatory to reduce the scale dependence. Photon-initiated contributions are smaller than at 8 TeV, but may be still visible in p_T distributions
- The sensitivity to the photon PDF is strongly reduced at 100 TeV, unless very hard cuts are imposed

Backup slides

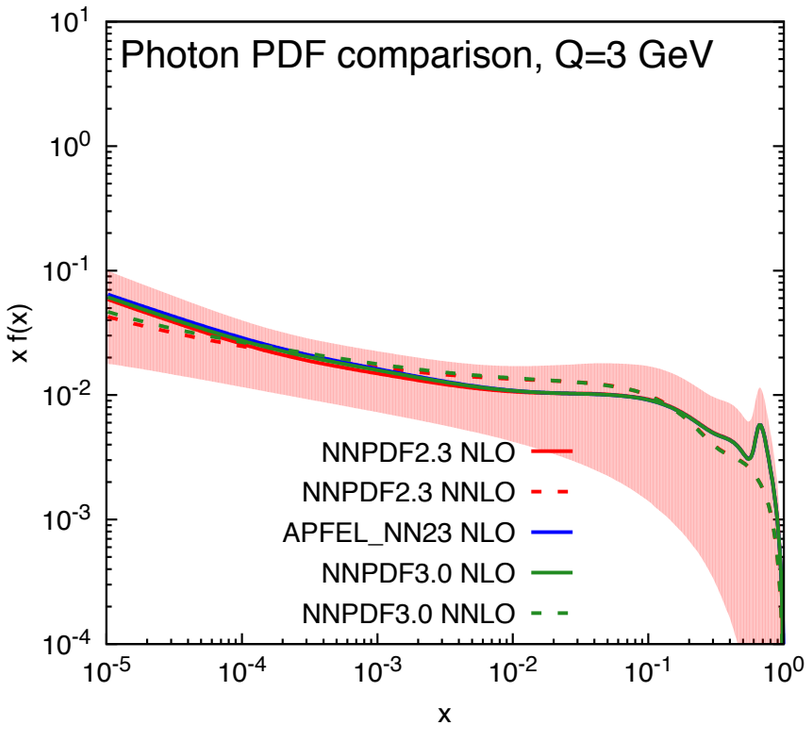
Parton luminosities and the scale choice

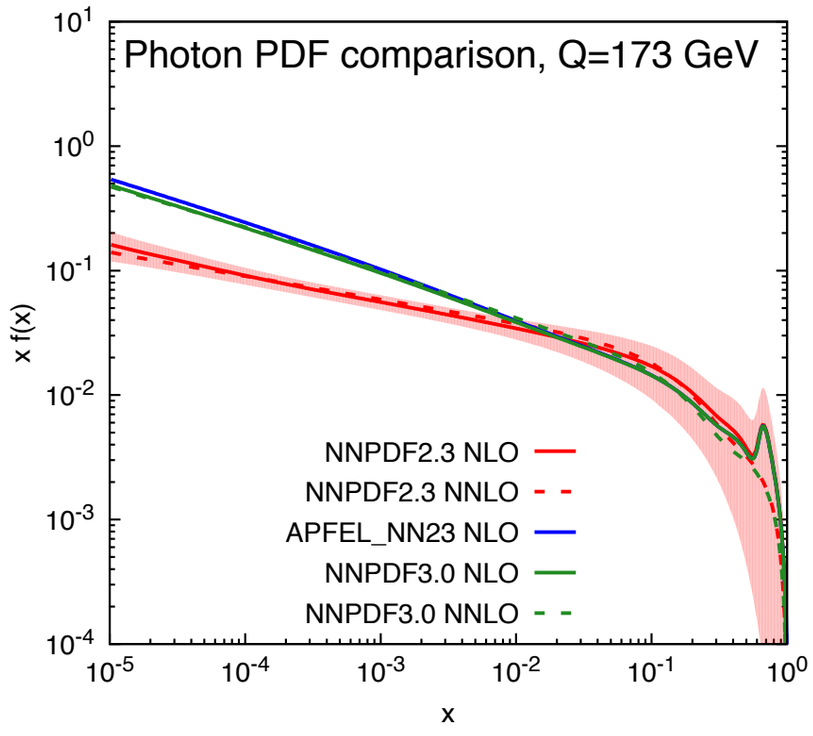


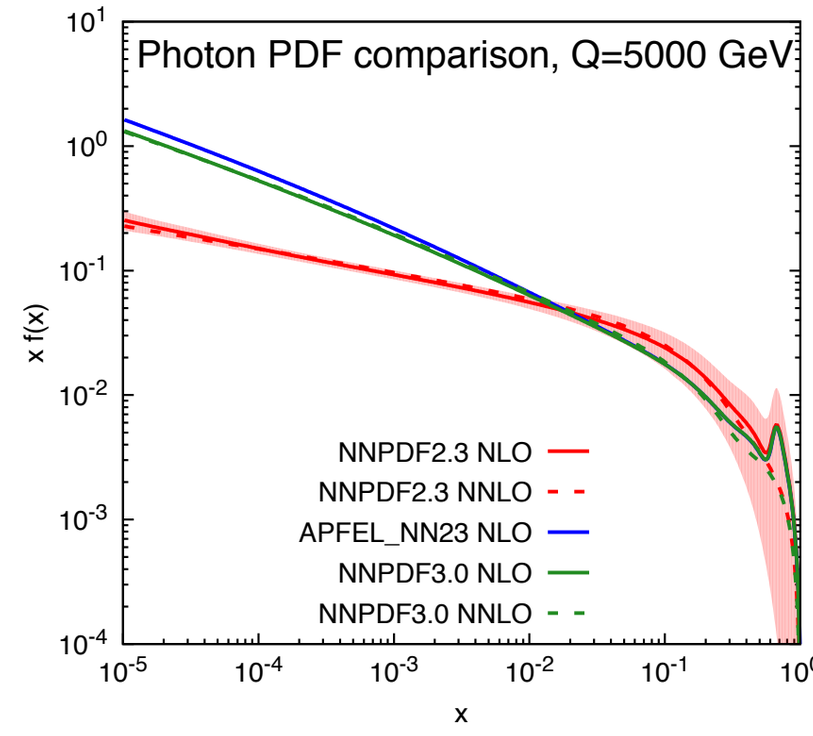




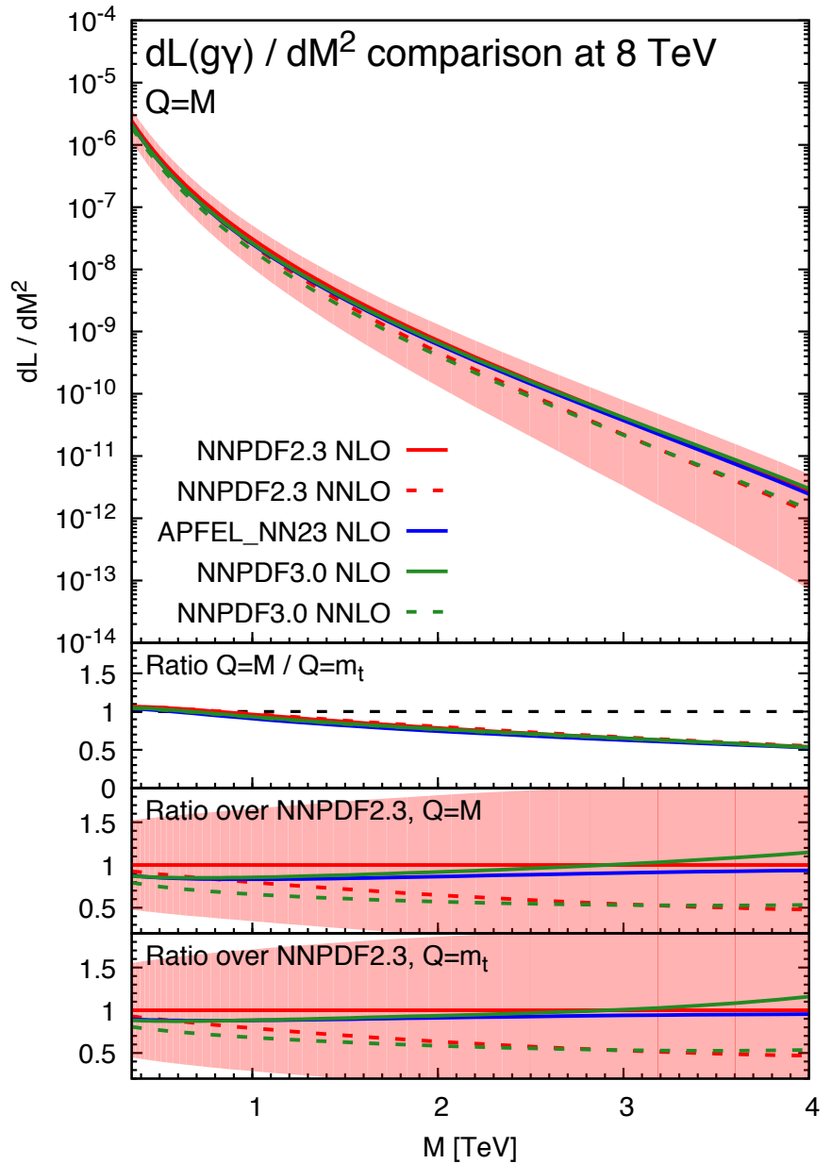
Photon PDFs with the NNPDF sets

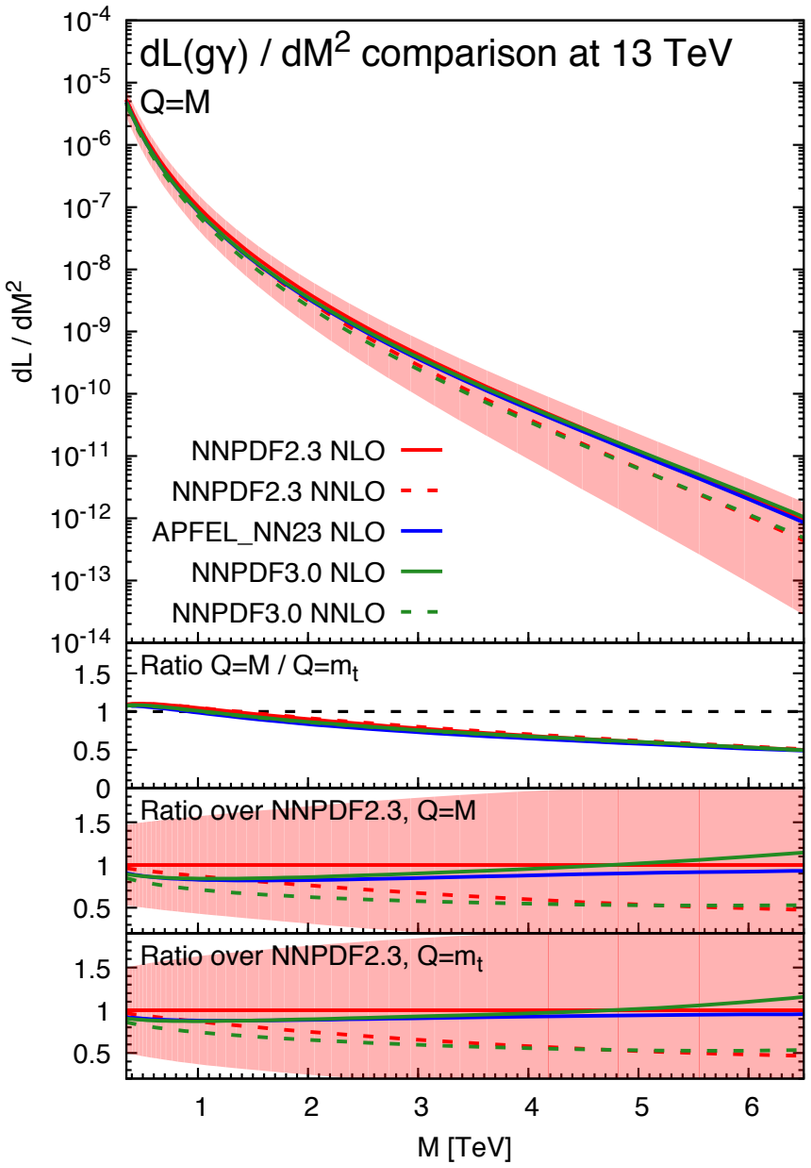


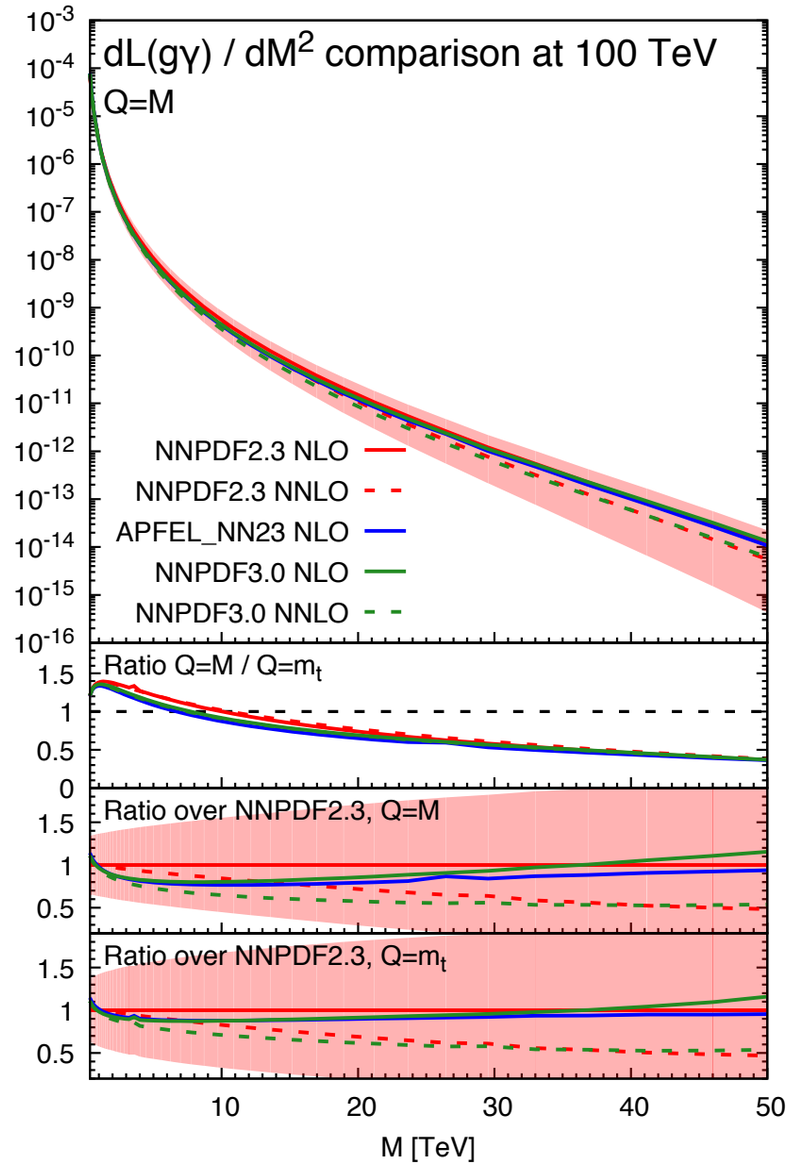




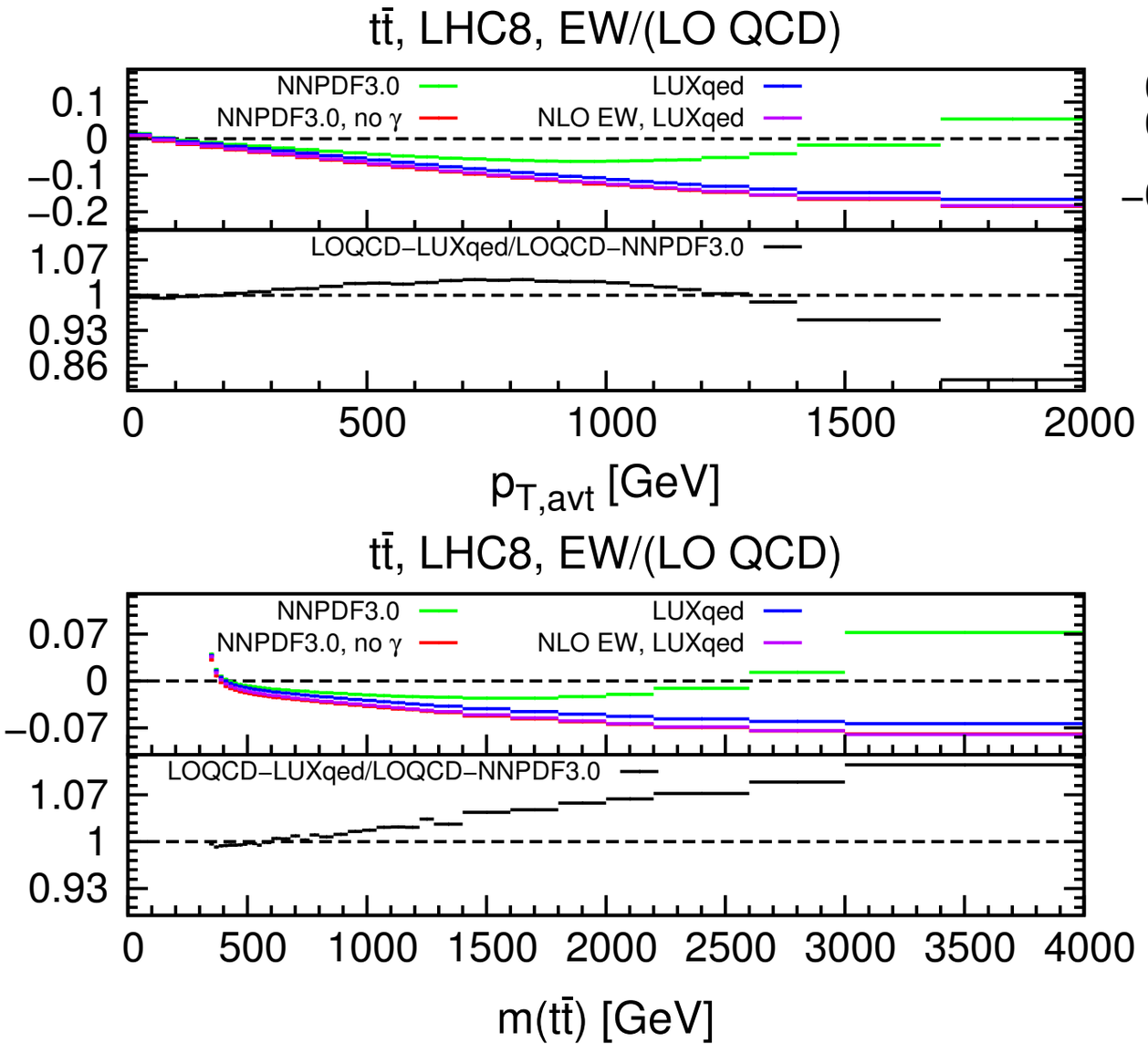
Luminosities with the NNPDF sets

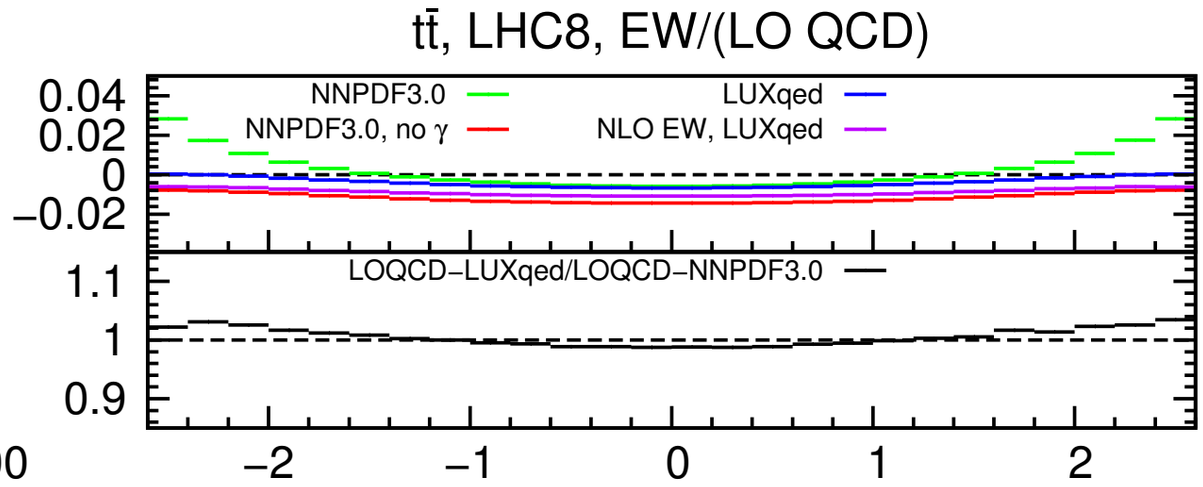


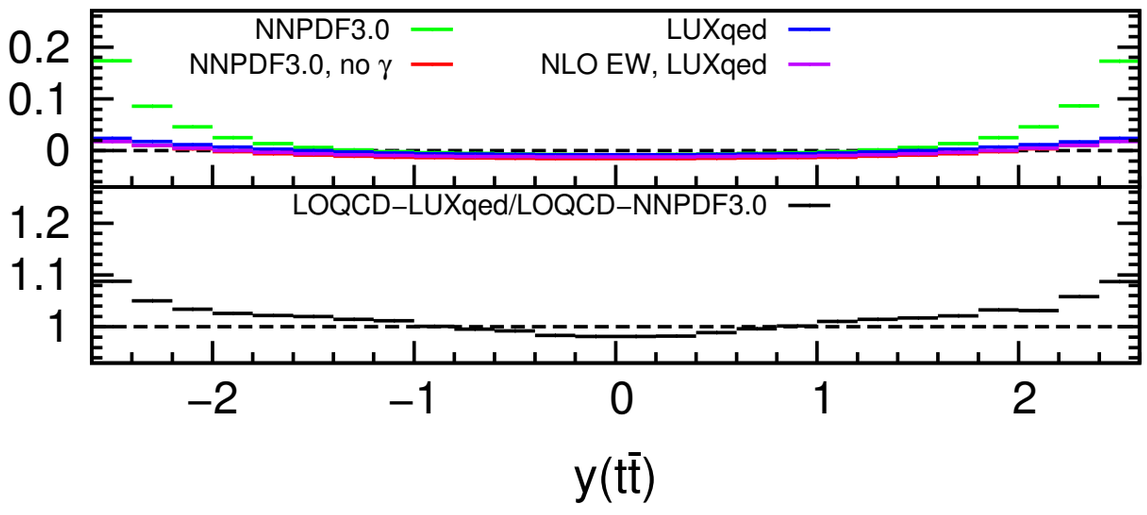




Results with LUXqed
8 TeV







Results with LUXqed
13 TeV