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

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Olomouc, 20 Sep 2016

Top 2016

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Motivation

- EW corrections

  - Tension between theory and data at high $p_T(t)$ region at 8 TeV

  - Theory uncertainties decrease $\rightarrow$ Relevance of EW corrections increase

  - Experimental uncertainties will further decrease at LHC13

  - $t\bar{t}$ process enters many LHC analyses as signal or background $\rightarrow$ NNLO QCD and NLO EW predictions are necessary for $t\bar{t}$ production

  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

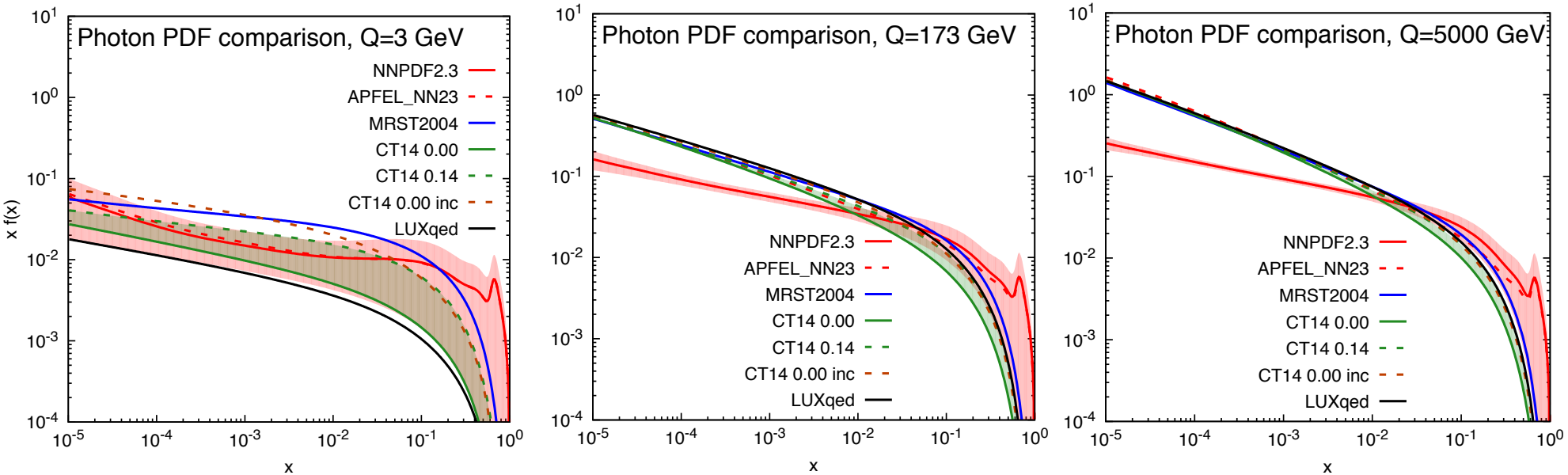
- Photon-induced contributions

  - The (negative) Sudakov suppression is compensated by the (positive) photon-induced contributions

  PDF sets including $\gamma(x, Q)$: MRST2004QED: *Martin et al. '04*, NNPDF2.3QED: *Ball et al. '13*, CT14QED(inc): *Schmidt et al. '16*, NNPDF3.0QED: *Bertone, Carrazza '16*, LUXqed: *Manohar et al. '16*, MMHTQED (in progress), additional Studies: *Harland-Lang, Khoze, Ryskin '16*

Different PDF sets

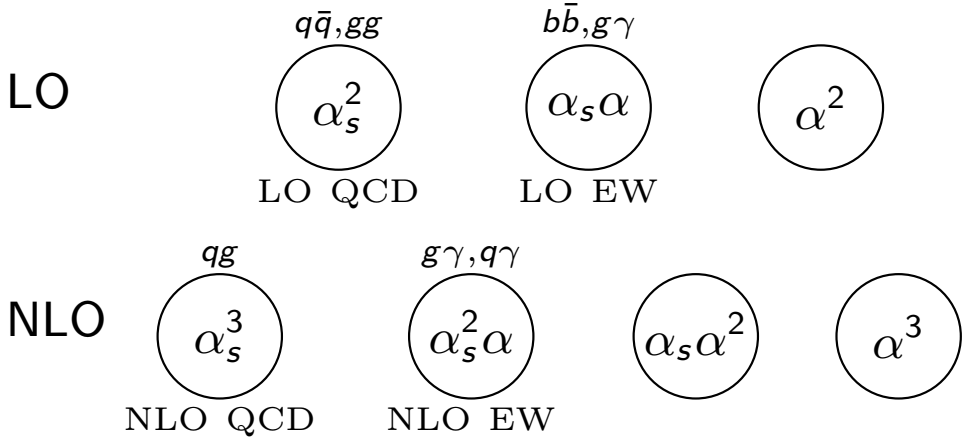
LO QED evolution but different assumptions for all PDF sets



- At low $Q = 3$ GeV there is a similar behaviour
- At high Q values and low x, the NNPDF2.3QED is different due to different DGLAP QCD and QED running (not relevant for $t\bar{t}$)
- At large $x \rightarrow$ $\begin{cases} \text{NNPDF2.3QED, large } \gamma(x, Q) \\ \text{CT14QED, LUXqed, small } \gamma(x, Q) \end{cases}$

Calculation framework

NLO QCD+EW corrections to $t\bar{t}$ production (MadGraph5_aMC@NLO)

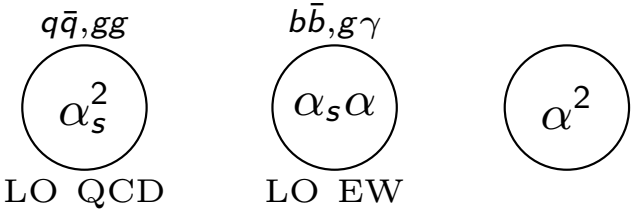


$$\Sigma_{\text{QCD}} \equiv \Sigma_{\text{LO QCD}} + \Sigma_{\text{NLO QCD}}$$
$$\Sigma_{\text{EW}} \equiv \Sigma_{\text{LO EW}} + \Sigma_{\text{NLO EW}}$$
$$\Sigma_{\text{QCD+EW}} \equiv \Sigma_{\text{QCD}} + \Sigma_{\text{EW}}$$

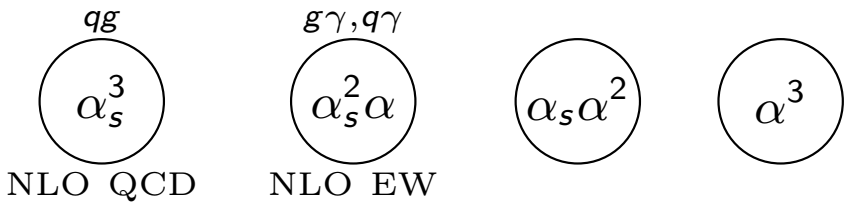
Calculation framework

NLO QCD+EW corrections to $t\bar{t}$ production (MadGraph5_aMC@NLO)

LO



NLO



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- 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

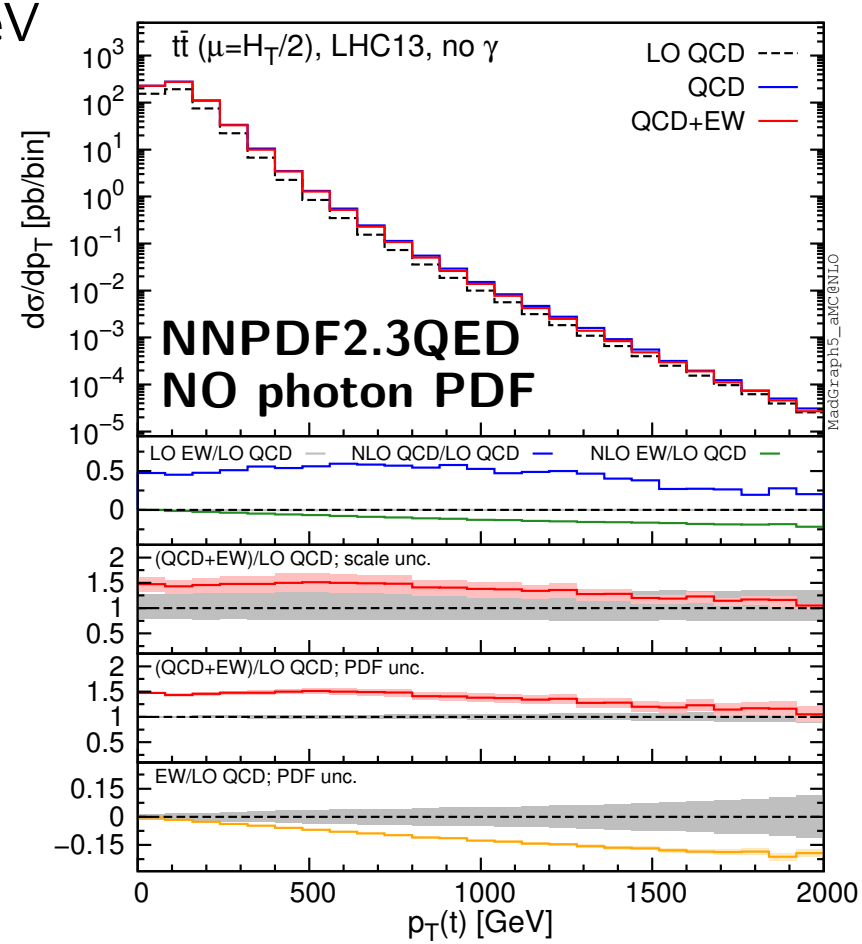
$$\mu = \frac{H_T}{2} = \frac{1}{2}\sum_i m_{T,i}$$

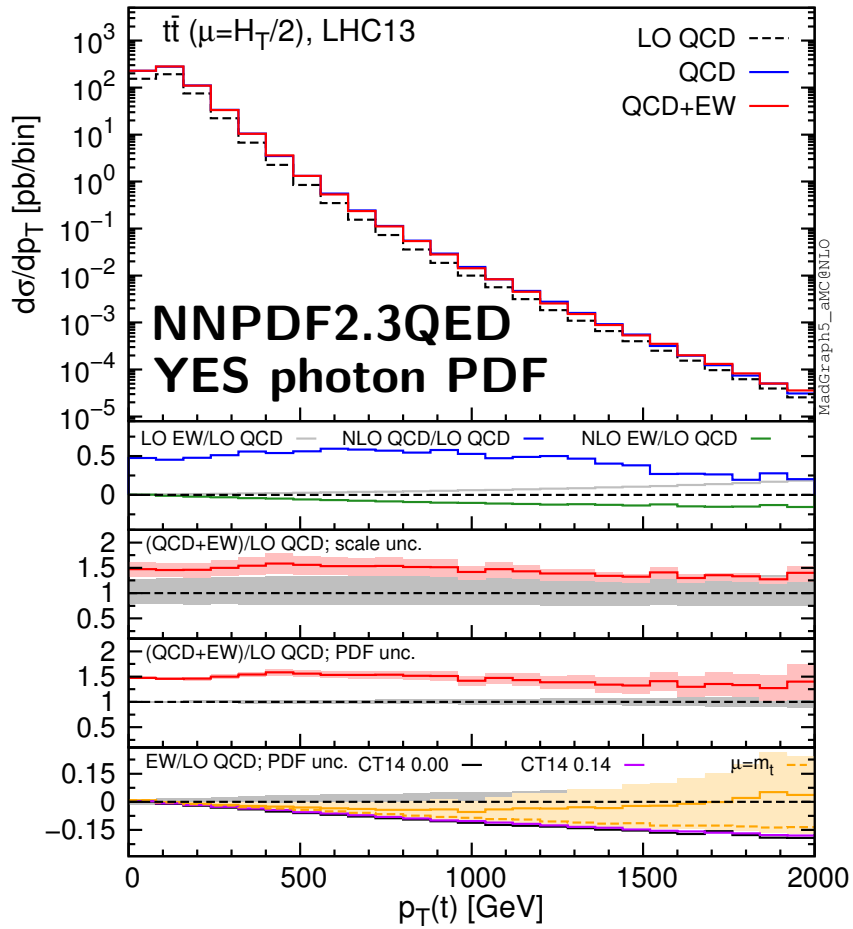
- PDF sets considered

  - Main results → NNPDF2.3QED, NNPDF2.3QED (no $\gamma(x, Q)$)
  - Comparison with CT14QED at 13 TeV

Results at 13 TeV

13 TeV

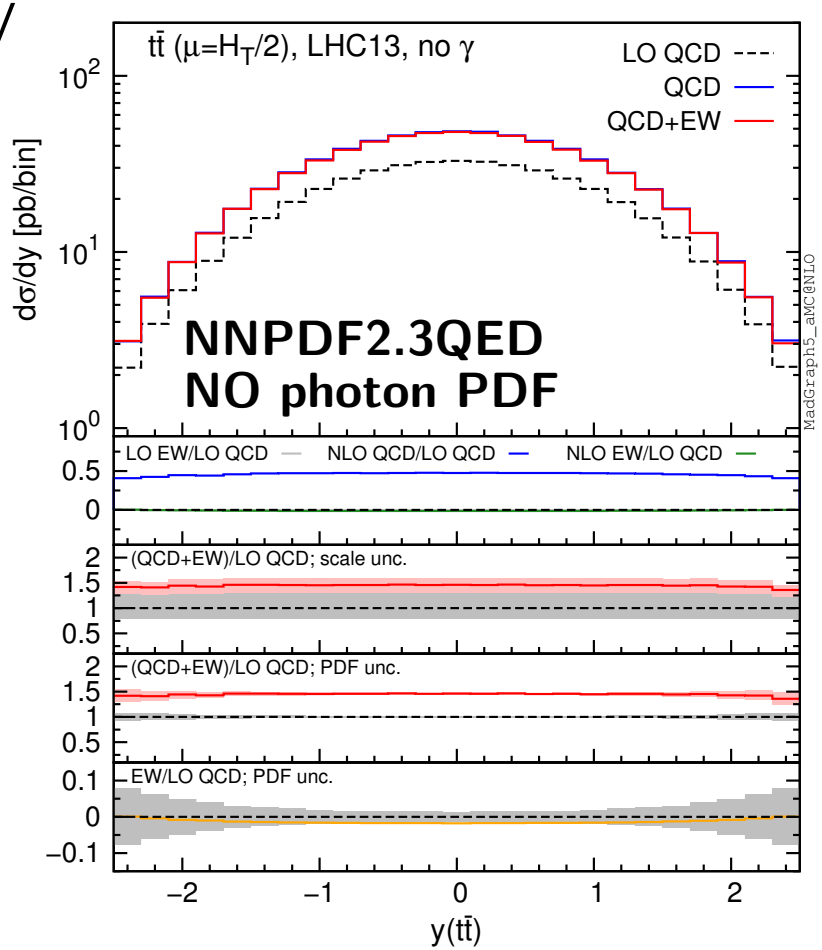


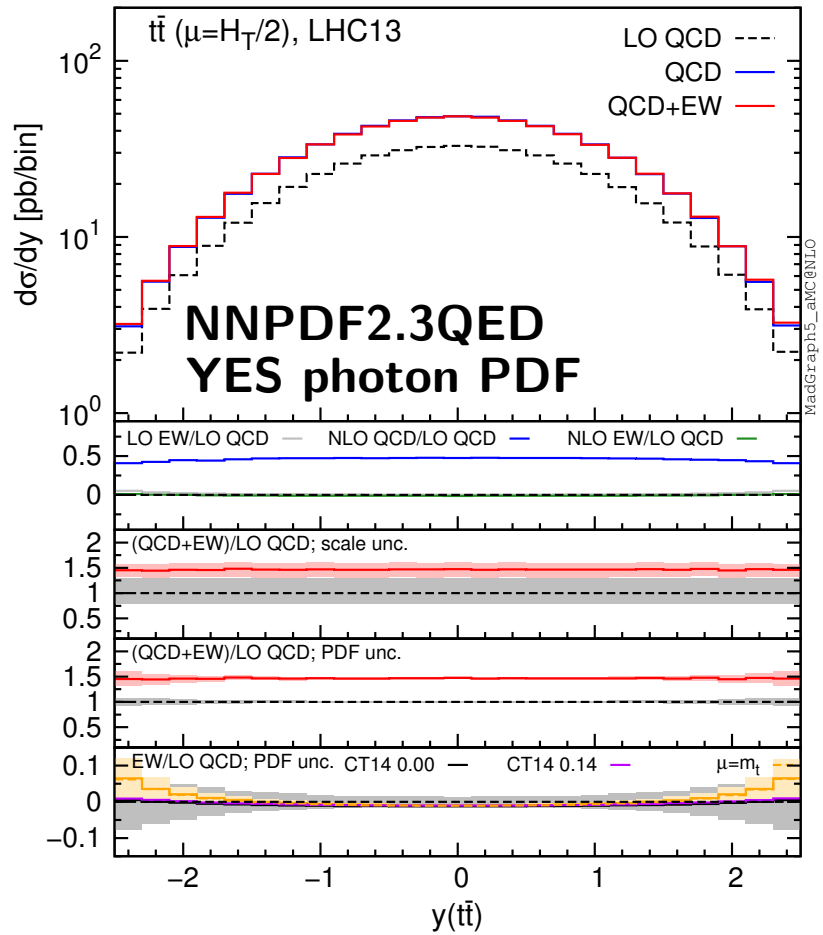


- NNPDF2.3QED: Photon PDF effect is mostly due to LO EW contribution
- NNPDF2.3QED: Large cancellations between Sudakov logs and photon-induced contributions
- photon PDF impact $\longrightarrow$ large in NNPDF2.3QED, negligible in CT14QED

Results at 13 TeV

13 TeV





- NNPDF2.3QED: $\sim 5\%$ effect of photon PDF at large rapidity regions, which are reachable experimentally
- CT14QED $\longleftrightarrow$ NNPDF2.3QED (no $\gamma(x, Q)$)
- CT14QED and NNPDF2.3QED in agreement within uncertainties

Calculation framework

$t\bar{t}$ distributions at NNLO QCD+NLO EW accuracy **(PRELIMINARY)**

in collaboration with
Michal Czakon, David Heymes, Alex Mitov, Davide Pagani, Marco Zaro

- Scale choice based on $\mathrm{arXiv:1606.03350}$ (*Czakon, Heymes, Mitov*)

$$\mu = \begin{cases} m_T/2 \text{ for } p_{T,avt} \\ H_T/4 \text{ for } m(t\bar{t}), y_{avt}, y(t\bar{t}) \end{cases}$$

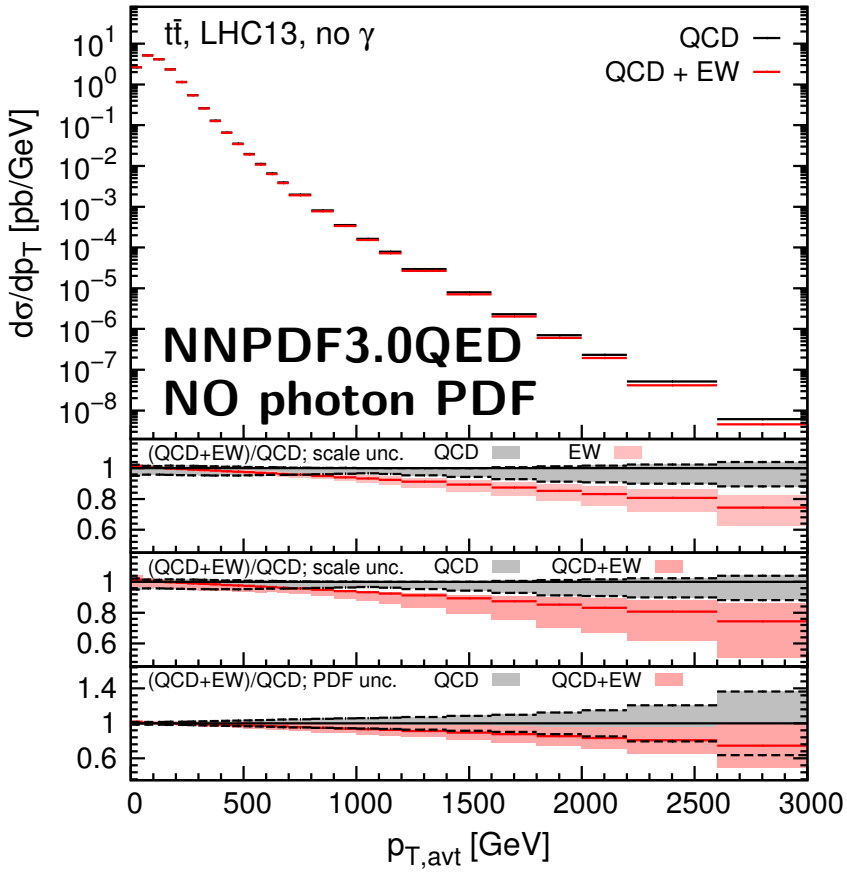
- PDF sets considered

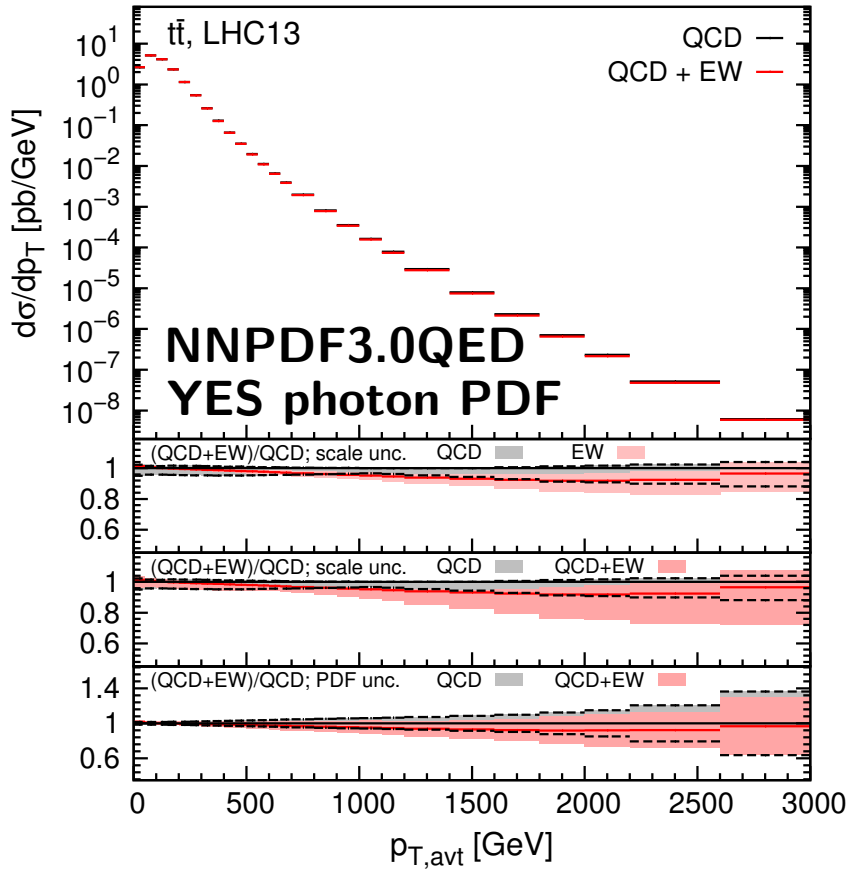
  - Main results $\rightarrow$ NNPDF3.0QED, NNPDF3.0QED (no $\gamma(x, Q)$)

  - Comparison with LUXqed

Preliminary Results at 13 TeV

13 TeV

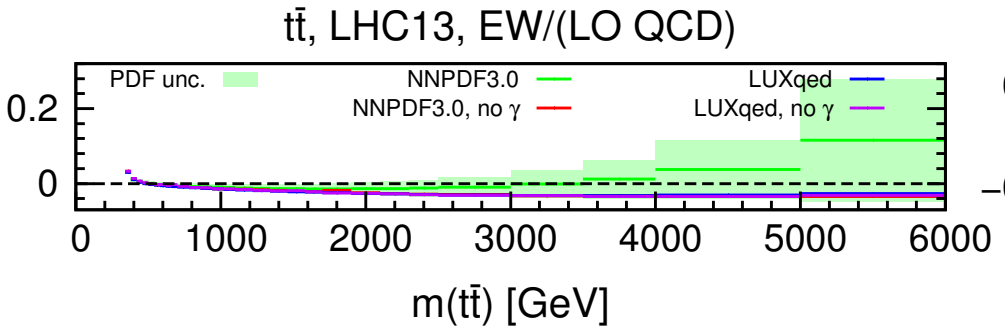


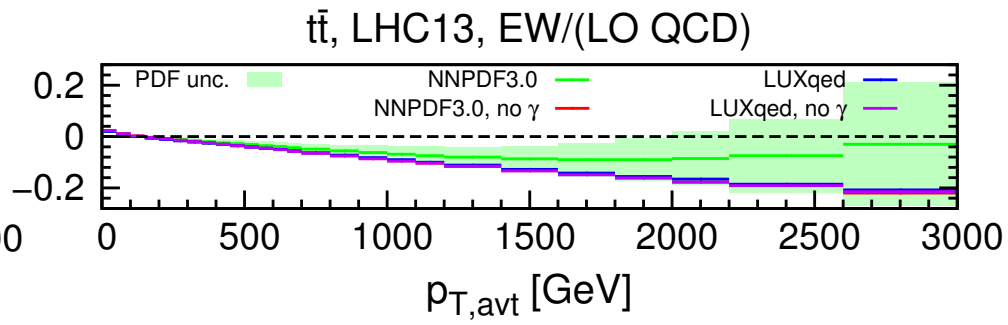


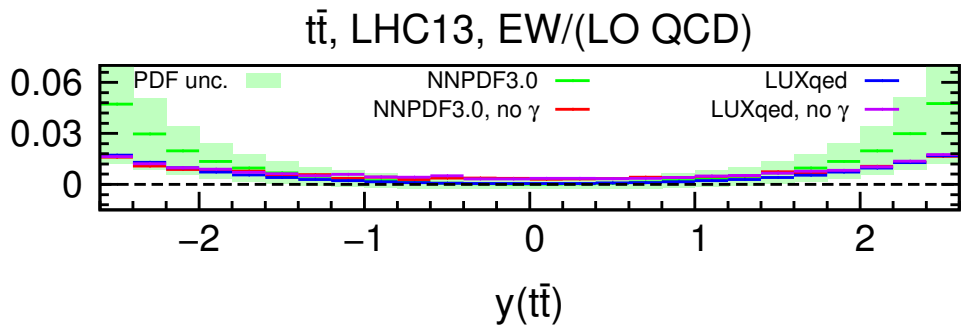
- NNLO QCD corrections reduce the scale dependence significantly
- PDF uncertainties become large at high p_T region
- For this distribution the photon PDF uncertainty does not increase the total PDF uncertainty

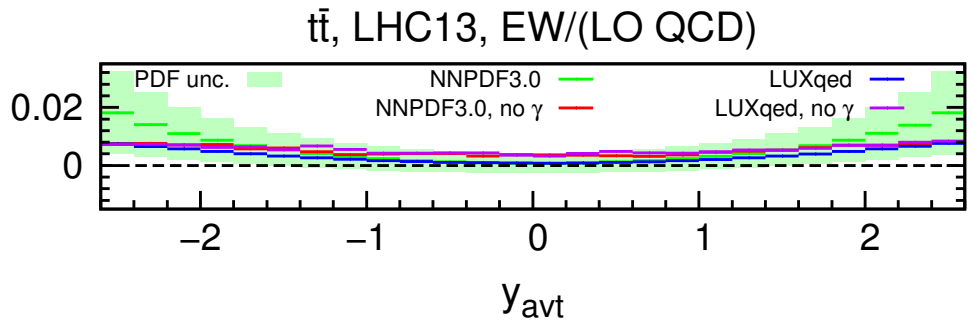
Preliminary Results at 13 TeV

NNPDF3.0QED vs LUXqed









- photon PDF impact $\longrightarrow$ large in NNPDF3.0QED, negligible in LUXqed
- LUXqed $\longleftrightarrow$ NNPDF3.0QED (no $\gamma(x, Q)$)
- LUXqed and NNPDF3.0QED in agreement within uncertainties

Conclusions

- PDF sets

  - NNPDFQED $\rightarrow$ Large impact of photon-induced contributions accompanied with large uncertainties

  - CT14QED, LUXqed $\rightarrow$ Negligible impact of photon-induced contributions in $t\bar{t}$ distributions

- 13 TeV

  - Photon-induced contributions may be visible in rapidity but also in p_T distributions

  - NNLO QCD are necessary in order to reduce the scale dependence

  - NNLO QCD + NLO EW in progress

Conclusions

- PDF sets

  - NNPDFQED $\rightarrow$ Large impact of photon-induced contributions accompanied with large uncertainties

  - CT14QED, LUXqed $\rightarrow$ Negligible impact of photon-induced contributions in $t\bar{t}$ distributions

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...Thank you

The photon PDF

- NNPDF2.3QED

  - No assumption for the $\gamma(x, Q^0)$ functional form

  - Different scales for QCD/QED evolutions

- CT14QED

  - Uses an ansatz like MRST2004 with one free parameter

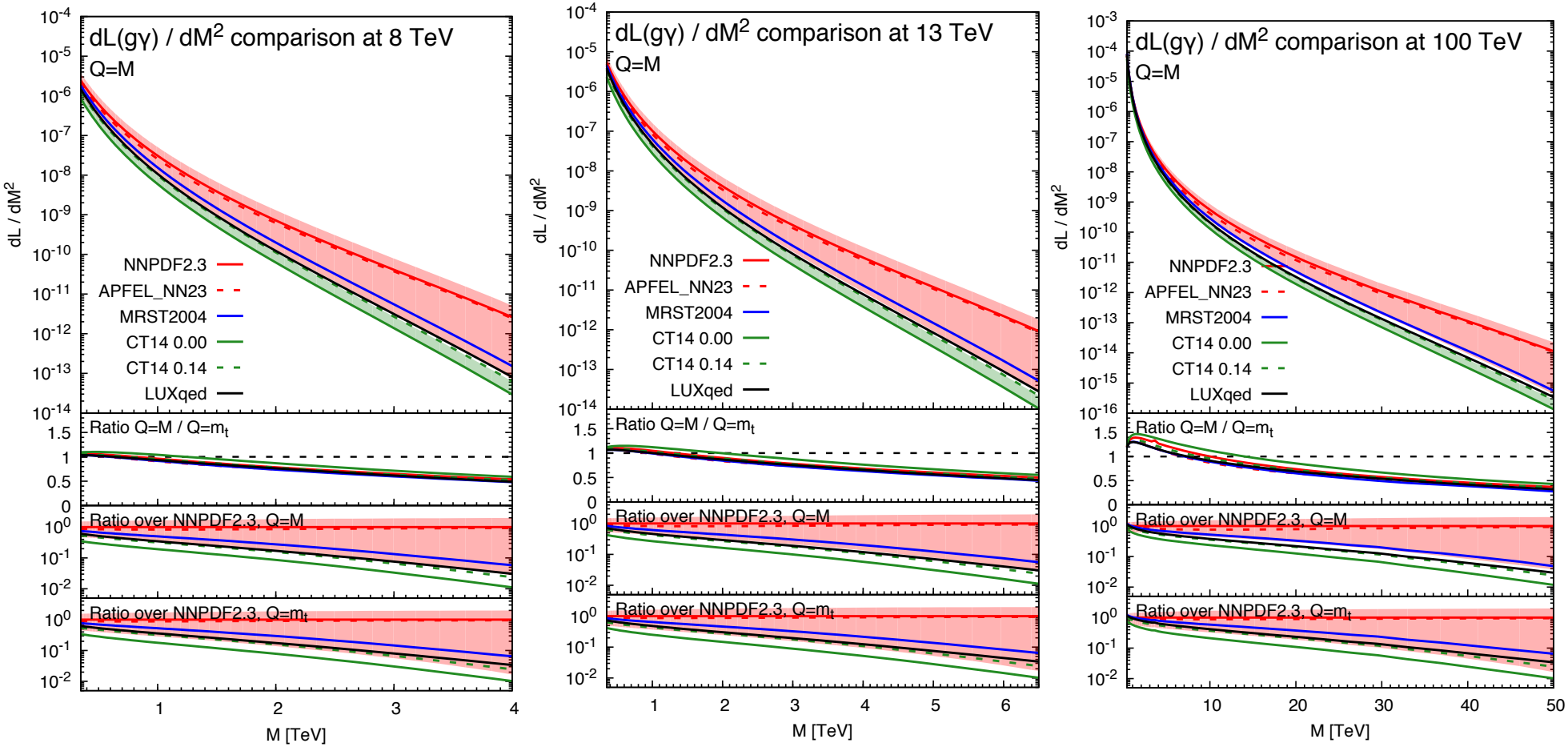
  - The momentum fraction carried by the photon is constrained to be $\leq 0.14\%$ at 90% CL

  - A set including the elastic photon contribution is also provided (CT14QEDinc)

- NNPDF3.0QED

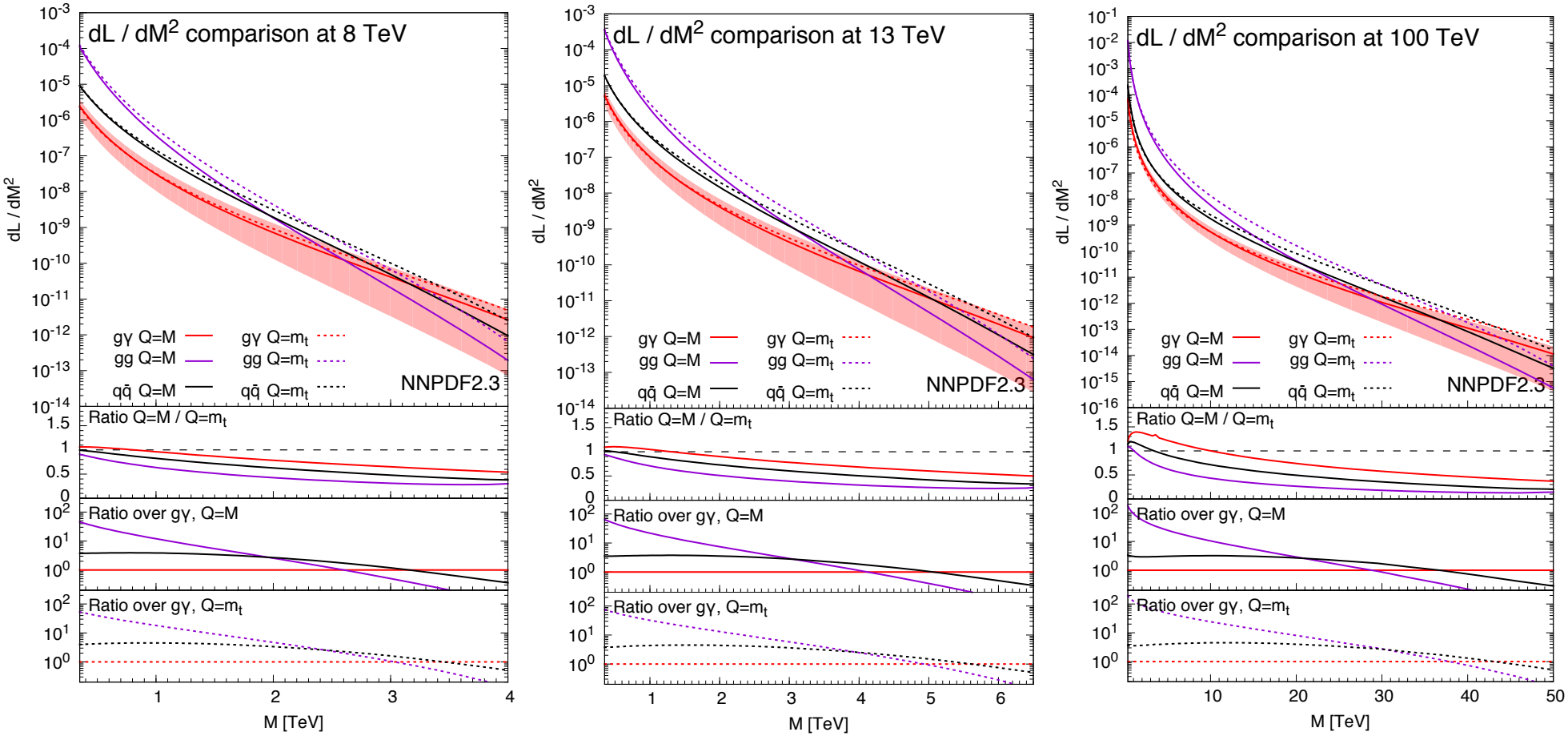
  - Simultaneous evolution of QCD/QED is implemented (also in APFEL_NN23), which changes the low x behaviour, but with no effect in $t\bar{t}$ phenomenology

The $g\gamma$ Luminosity



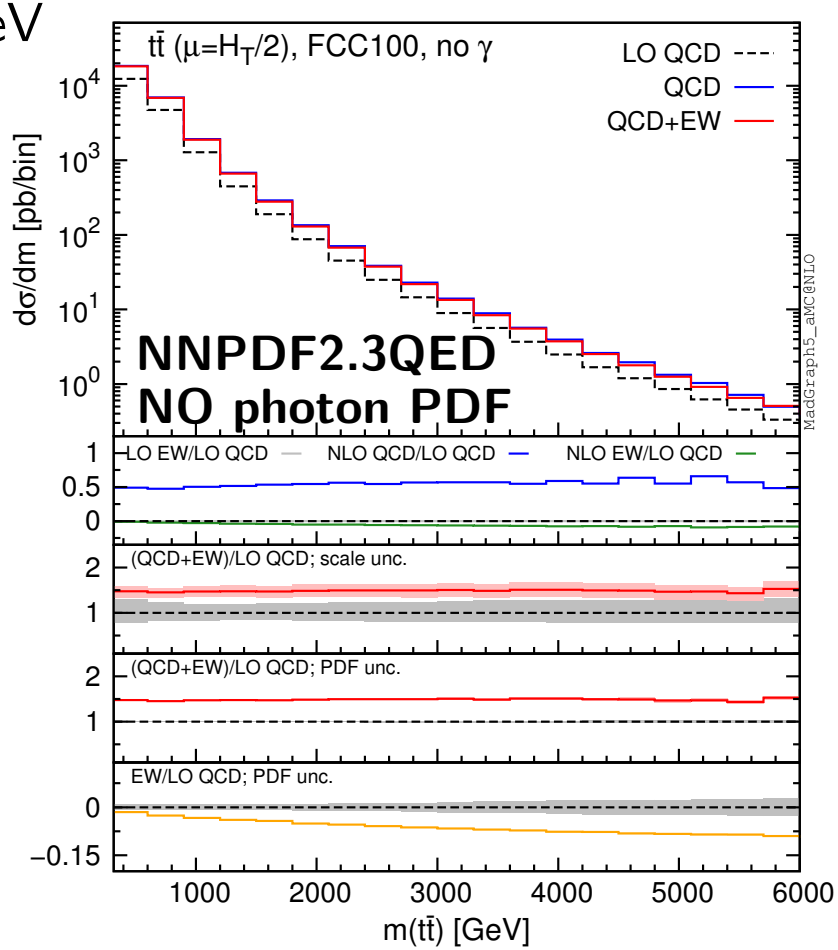
- LUXqed lies very close to CT14QED
- Effects due to the different evolution in NNPDF2.3QED are not visible

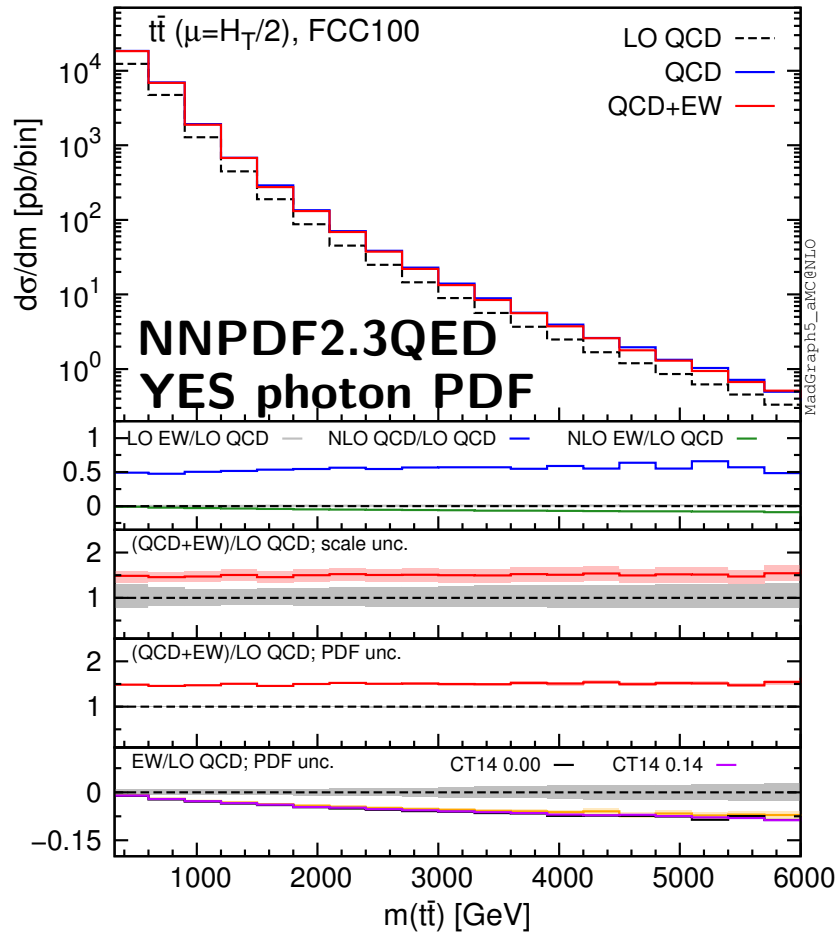
Parton Luminosities and scale choice



- In both dynamical and fixed scales the $g\gamma$ luminosity is suppressed with respect to the gg one at the low M region

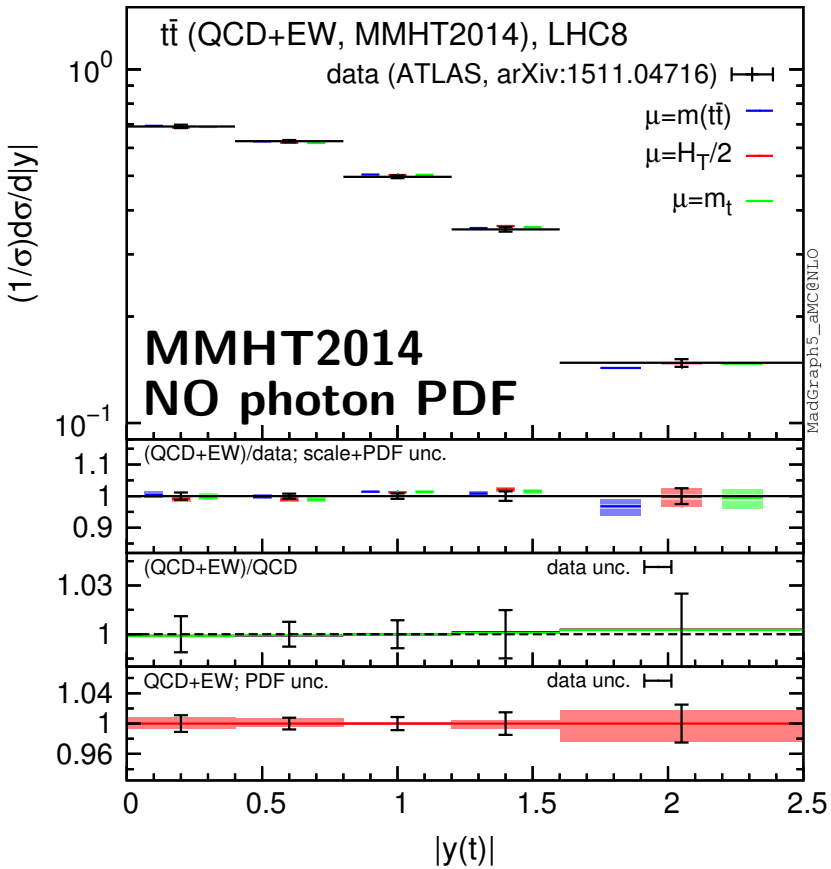
100 TeV

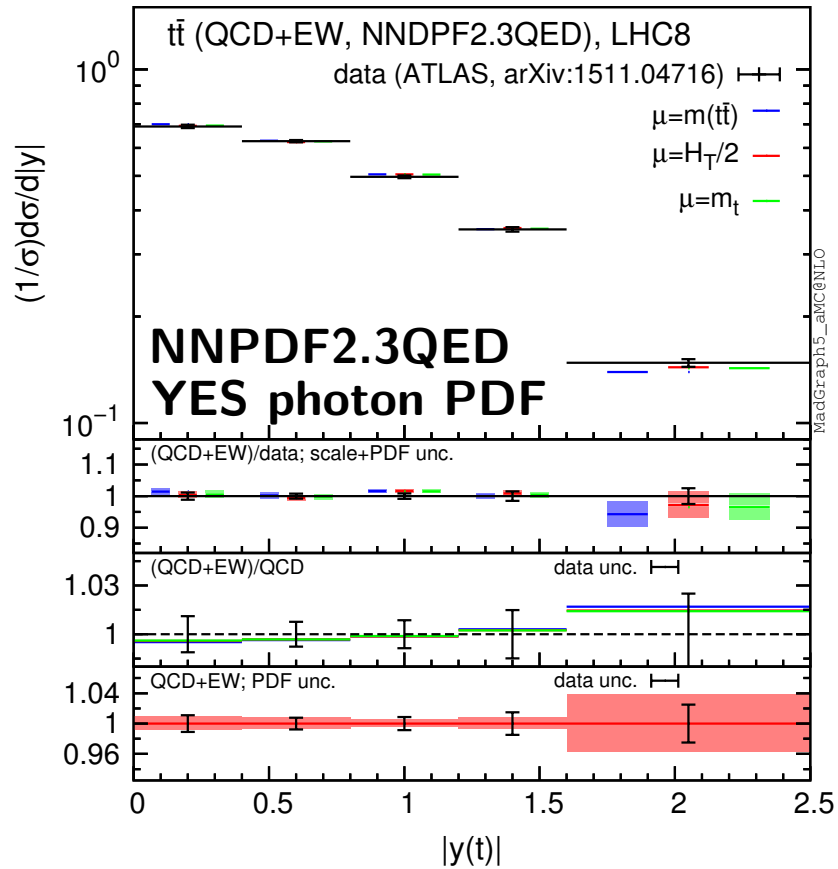




- At 100 TeV $t\bar{t}$ differential distributions are not sensitive to photon-induced contributions
- $\sqrt{s} \uparrow \Longrightarrow$ Bjorken x's $\downarrow$
- Larger effects are expected at 8 TeV, where already we have data

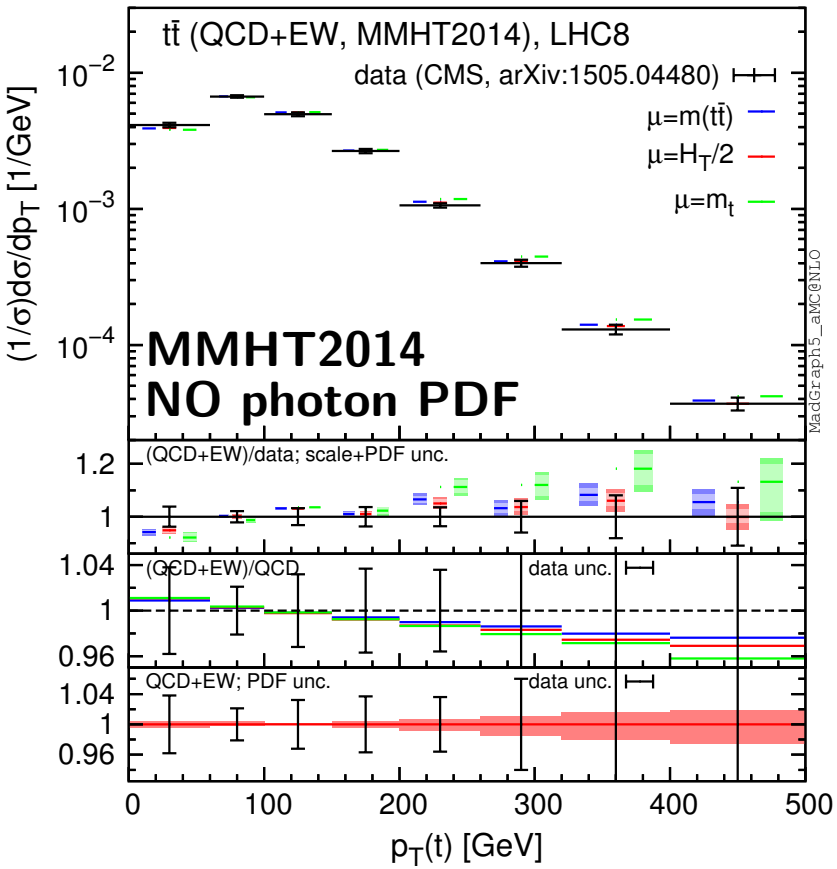
8 TeV

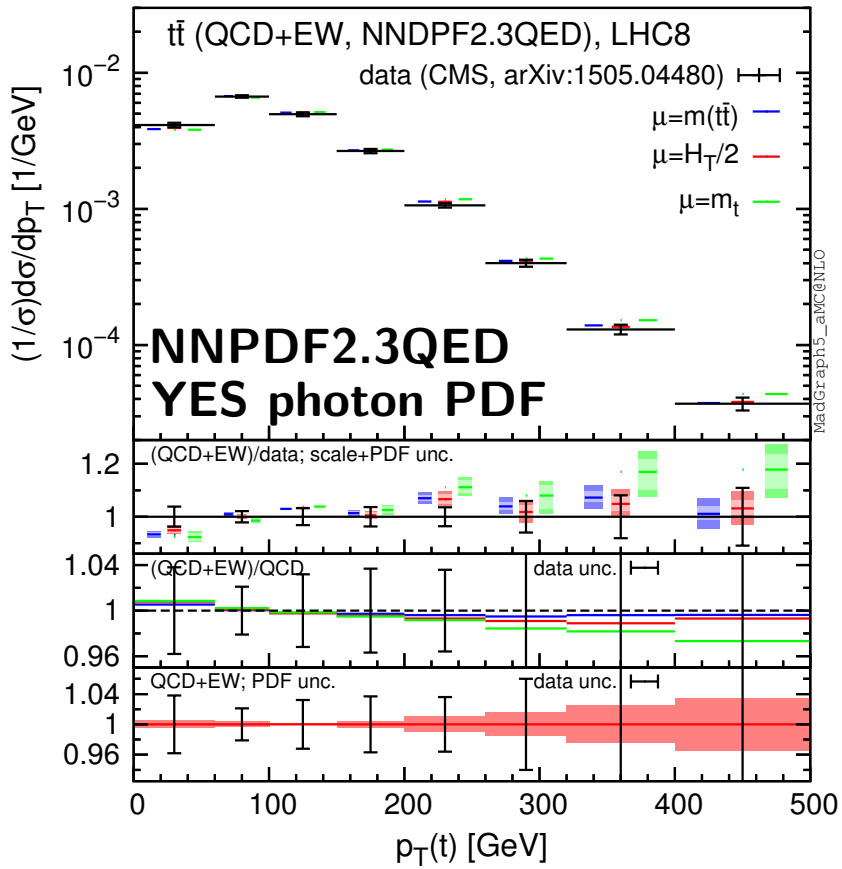




- Normalised $(1/\sigma)$ rapidity distributions $\rightarrow$ Exp. errors reduce at few % level.
- Large PDF uncertainties and visible impact of photon PDF (NNPDF2.3QED)
- Can be used for constraining the photon PDF (NNPDF2.3QED)

8 TeV





- In p_T distributions the impact of the photon PDF is larger at the tail
- Sudakov logs vs $\gamma(x, Q)$ cancellation depends on the scale definition
- Scale uncertainty still large at NLO QCD $\rightarrow$ NNLO QCD needed
- For 13 TeV comparisons between theory and experiment EW corrections and photon-induced contributions need to be taken into account