# Towards EW Corrections for the Next Generation of PDF Sets

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with:
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# How are PDFs determined?

For hadron–hadron collider:

$$\sigma = \sum_{a,b} \int \mathrm{d}x_1 \int \mathrm{d}x_2 \int \mathrm{d}Q^2 f_a(x_1, Q^2) f_b(x_2, Q^2) \sigma_{ab}(x_1, x_2, Q^2)$$

Basic recipe:

- Data $\sigma$, measured in experiments: Drell–Yan, Jets, Top-pairs, ...
- Theory for partonic cross sections $\rightarrow \sigma_{ab}$: Up to NNLO QCD
- Ansatz for all $f_a(x)$: Analytic form with parameters/numerical representation

$\rightarrow$ Do a regression of data and theory to obtain $f_a(x, Q^2)$

- To solve the dependence on $Q^2$ use DGLAP,

$$Q^2 \frac{\partial}{\partial Q^2} f_a(x, Q^2) = \frac{\alpha_s(Q^2)}{2\pi} \sum_b \int_x^1 \frac{\mathrm{d}\xi}{\xi} P_{ab}\left(\frac{x}{\xi}, Q^2\right) f_b(\xi, Q^2),$$

to evolve all $f_a(x, Q^2)$ down to $f_a(x, Q_0^2)$, with the same starting scale $Q_0^2$

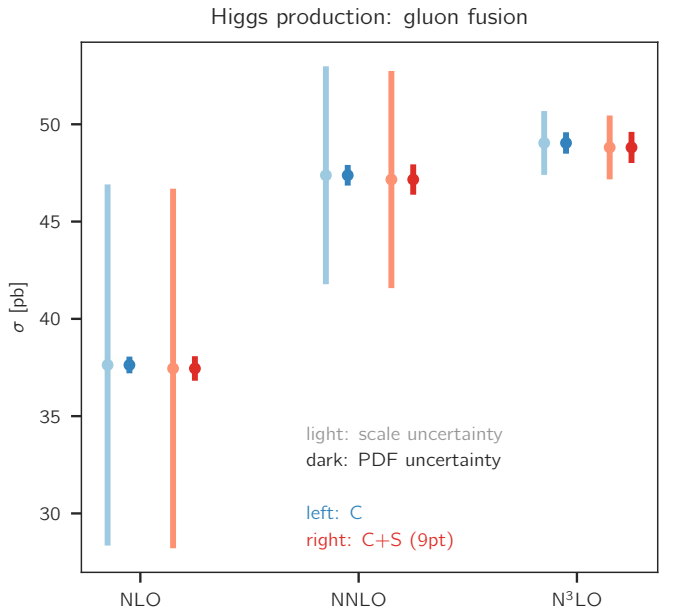
# How do we improve the accuracy/precision of our PDFs?

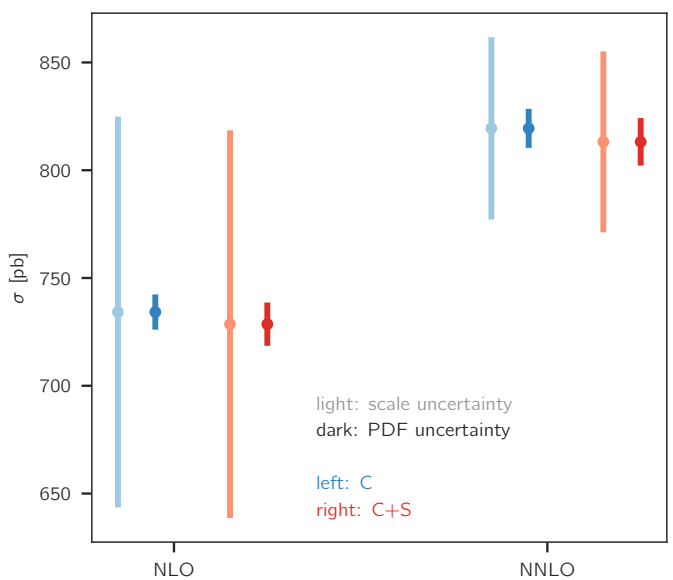
PDF uncertainties will be/is bottleneck for certain observables

→ Use more information:

1. Add more experiments + predictions
2. Take into account MHOU (talk by Z. Kassabov, [NNPDF Collaboration])
3. Improve fitting procedure itself
   - for example using machine learning (talk by J. Cruz, [Carrazza, Cruz-Martinez])
4. Go beyond peturbative methods: Resummation (e.g. NNPDF3.0resum, NNPDF3.1sx)
5. Use more perturbative results: Electroweak/mixed corrections (?!)

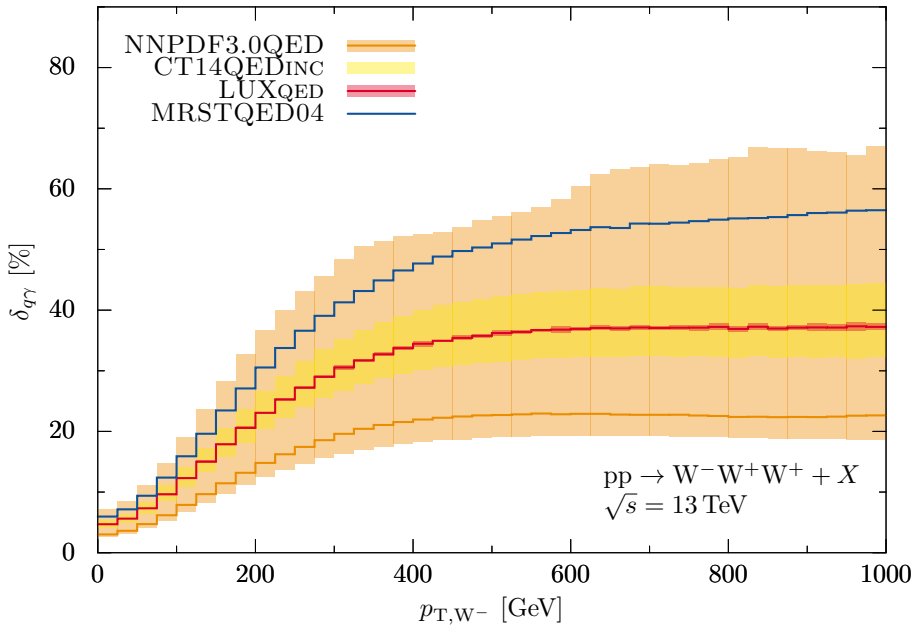
RHS plots from [NNPDF Collaboration]



# What is needed for EW corrections?

- ✓ Photon as a parton (can be very important, see e.g. RHS [Dittmaier, Huss, Knippen])
- ✓ LUXQED method [Manoha, Nason, Salam, Zanderighi] leads to precise $\gamma$-PDF
- ✓ QED evolution in the DGLAP equations




## To be done

→ Electroweak/mixed corrections for all PDF processes binned in $a$, $b$, $x_1$, $x_2$, and $Q^2$
→ "APPLgrid/fastNLO"

- Include them in a global fit

# What do we expect from EW corrections?

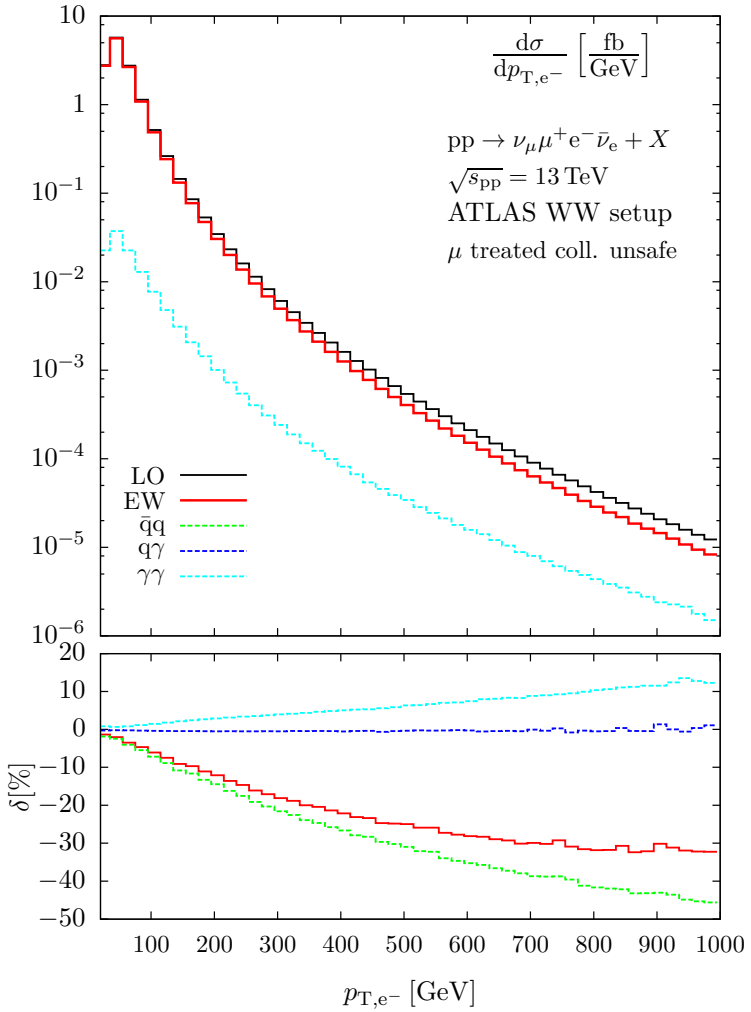
Typical features of EW corrections:

- dominated by virtual corrections
- small corrections for the integrated cross section
- negative and larger in certain phase space regions (large $p_{\mathrm{T}}$, large masses, ...)
- caused by "mismatch" of real-/virtual: no $\mathrm{Z}/\mathrm{W}^{\pm}$ radiation

→ often shape-changing distributions

- example on the RHS: diboson production [Biedermann, Billoni, Denner, Dittmaier, Hofer, Jäger, Salfelder]

→ how do they affect a PDF fit?

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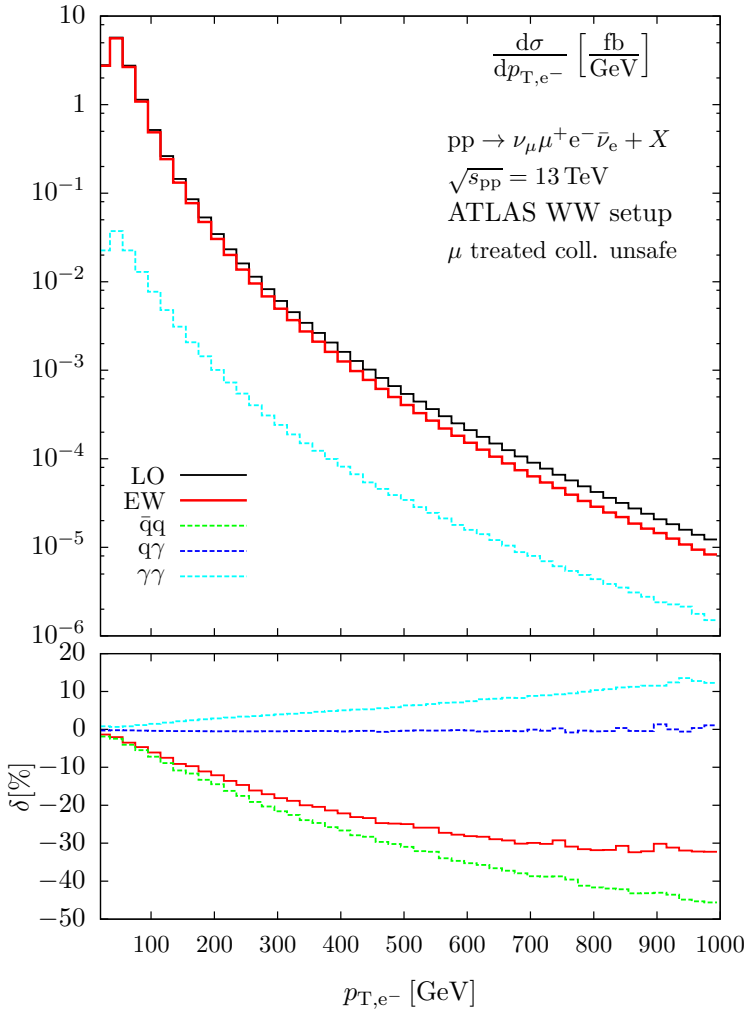


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# EW/mixed contributions in general

→ Extended `APPLgrid` 1.4.70 [Carli et al.] for arbitrary (LO, NLO, NNLO, ...) predictions/corrections and photon:

$$\sigma_{ab}(x_1, x_2, Q^2) = \sum_{i,j,k,l} \alpha_s^i \log^j(\xi_R^2) \log^k(\xi_F^2) \left[\alpha^l \sigma_{ab}^{i,j,k,l}(x_1, x_2, Q^2)\right]$$

- Bin $\alpha^l$ together with $\sigma^{i,j,k,l}$

→ Toolchain: `mg5_aMC` 3.0.2 [Alwall et al.] $\xrightarrow{*}$ custom APPLgrid $\sigma_{ab}^{i,j,k,l}$

∗ replaced `aMCfast` [Bertone, Frederix, Frixione, Rojo, Sutton] interface

## NLO Tower for $\sigma_{ab}(x_1, x_2, Q^2)$ processes with one quark line at LO

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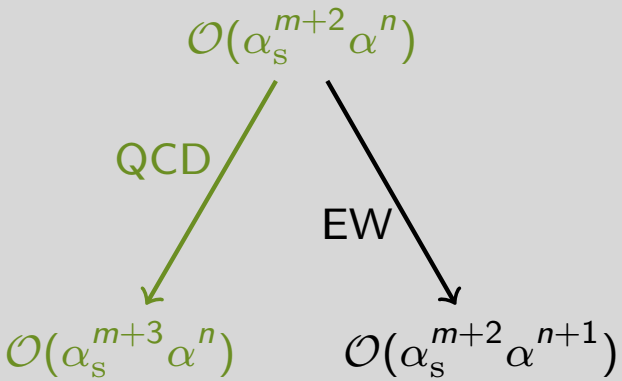

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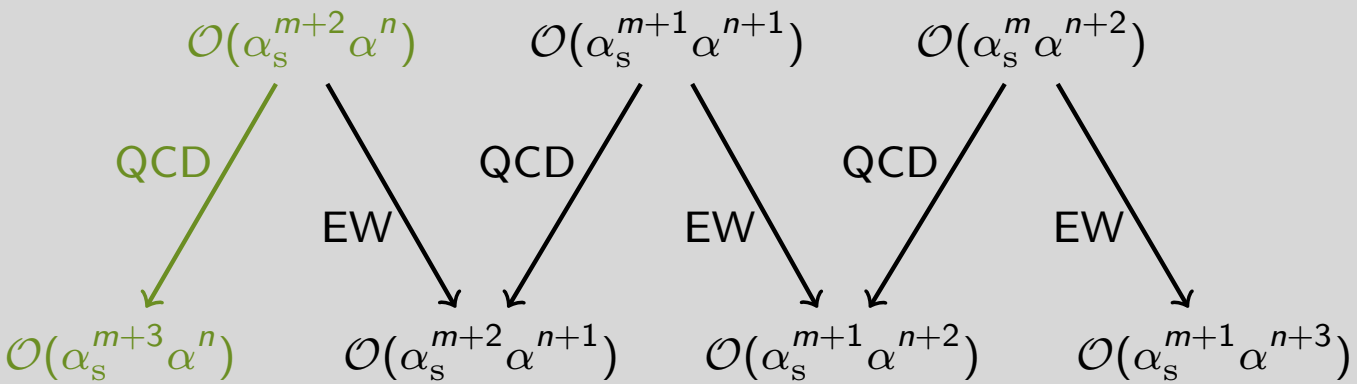
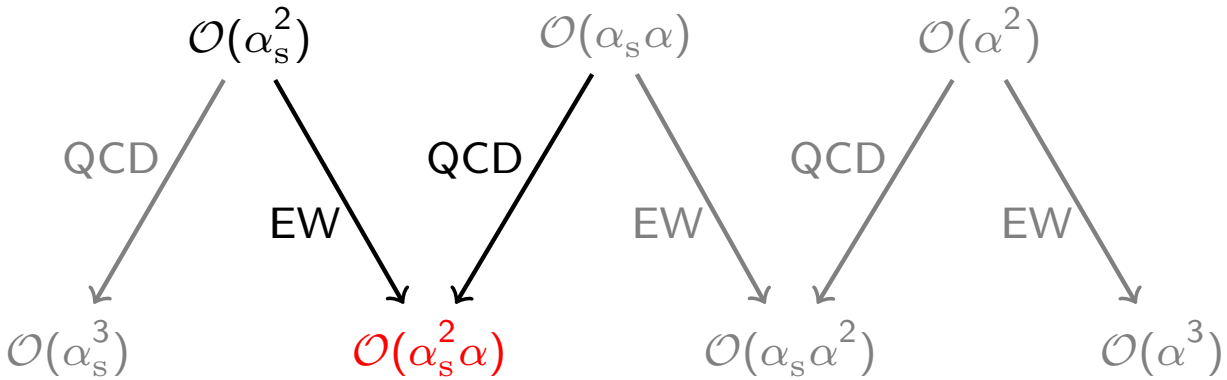


# Setup

- $pp \to t\bar{t}$
- 8 TeV
- Shown is the grid $\sigma_{ab}(x_1, x_2, Q^2)$,

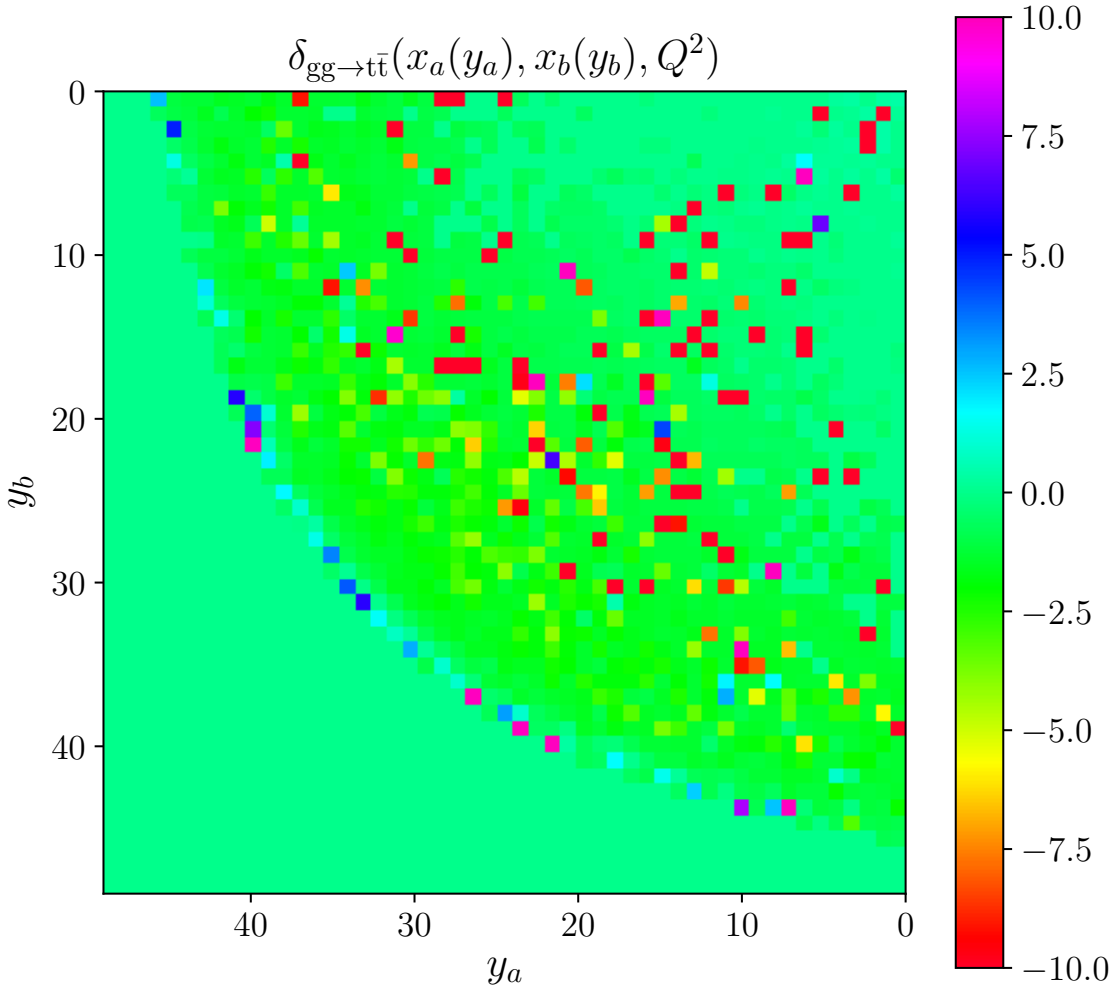
$$\sigma = \sum_{a,b} \int dx_1 \int dx_2 \int dQ^2 f_a(x_1, Q^2) f_b(x_2, Q^2) \sigma_{ab}(x_1, x_2, Q^2)$$

- $Q = 172.5$ (fixed ren./fac. scale)
- for $gg \to t\bar{t}$
- for $\mathcal{O}(\alpha_s^2\alpha)$ relative to $\mathcal{O}(\alpha_s^2)$




- all results are preliminary!

# EW Gluon–Gluon-Grid: $\mathcal{O}(\alpha_s^2\alpha)$ for $gg \to t\bar{t}$ @ 8 TeV




- $y_{a/b}(x) = -\ln x_{a/b} + 5(1 - x_{a/b})$, $y(1) = 0$
- color: $\delta = \mathcal{O}(\alpha_s^2\alpha)/\mathcal{O}(\alpha_s^2)$
- no interpolation

- lower left corner $\to$ production threshold
- $x \leftrightarrow y$ symmetry: initial-state symmetry of $pp \to t\bar{t}$
- at threshold: coulomb singularity
- negative correction for larger $x_a$, $x_b$

# Summary

- EW/Mixed corrections for PDF determinations
- Showed $\mathcal{O}(\alpha_s^2\alpha)$ grid for 8 TeV $t\bar{t}$-prod. at the LHC

$\rightarrow$ Validation

$\rightarrow$ Include into PDF fit (WIP)

$\rightarrow$ Study impact of EW/mixed contributions of all processes