Towards the inclusion of EW corrections in NNPDF

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with:
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EW/QED corrections and PDFs

EW corrections and PDFs:

- QED evolution kernels (DGLAP) [A. De Rujula, R. Petronzio, A. Savoy-Navarro], [J. Kripfganz, H. Perlt], [J. Blümlein], [M. Roth, S. Weinzierl], [V. Bertone, S. Carrazza, J. Rojo]
- photon PDF: calculate using structure functions: LUXQED [A. Manohar, P. Nason, G. P. Salam, G. Zanderighi], [A. V. Manohar, P. Nason, G. P. Salam, G. Zanderighi] and similar approach [L.A. Harland-Lang]
  → backup slides for an extreme observable

→ "EW corrections" for PDF fits: everything else than pure QCD

Battle plan:

Include every order we can calculate for LHC experiments!

→ **What's the effect of the (previously neglected) contributions?**

- Better or worse fit?
- Increased or decreased uncertainties?
- Shift of the central prediction?
- Can we be more inclusive (e.g. for DY $M_{\ell\bar{\ell}} > 200\,\text{GeV}$)?

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Where do EW corrections enter?

For hadron–hadron collider:

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

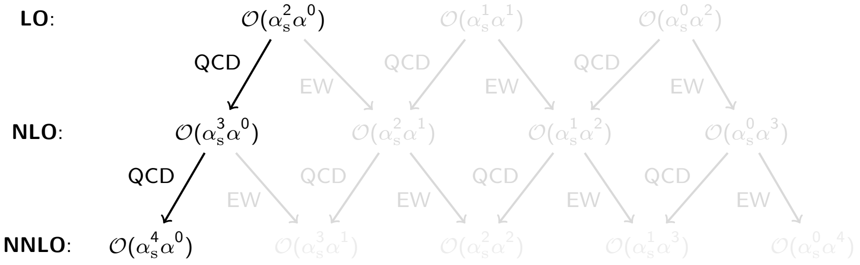
Notation:

- Data σ, measured in experiments: Drell–Yan, Jet production, Top-pairs, ...

→ **APPLgrid $\sigma_{ab}(x_1, x_2, Q^2)$**: Theory predictions; include also subleading orders in α_s!

- Ansatz for all $f_a(x)$
- Regression of data and theory to obtain $f_a(x, Q^2)$

Example: $\sigma_{ab}(x_1, x_2, Q^2)$ for (on-shell) top-pair production at NNLO



using the following (general) decomposition:

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

with

- ξ_{R}^2, ξ_{F}^2 scale factors for multiplying ren./fac. scale by ξ
- $\sigma_{ab}^{i,j,k,l}(x_1, x_2, Q^2)$: APPLgrid, contains the phase space integration and cuts
- a, b can denote photons, e.g. $\gamma g \to t\bar{t}$ @ $\mathcal{O}(\alpha_s\alpha)$ and $\gamma\gamma \to t\bar{t}$ @ $\mathcal{O}(\alpha^2)$

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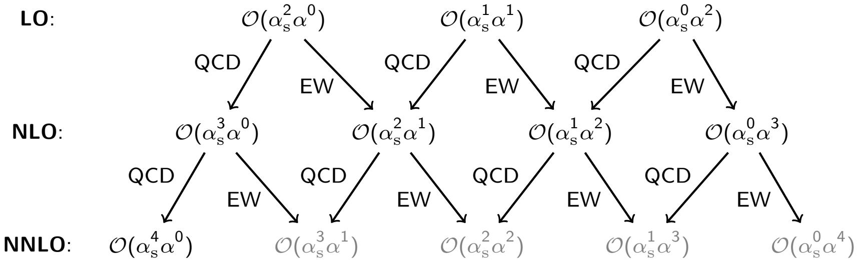

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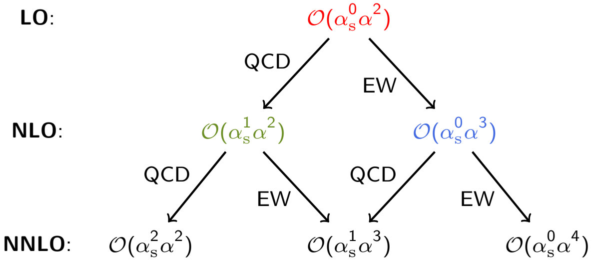
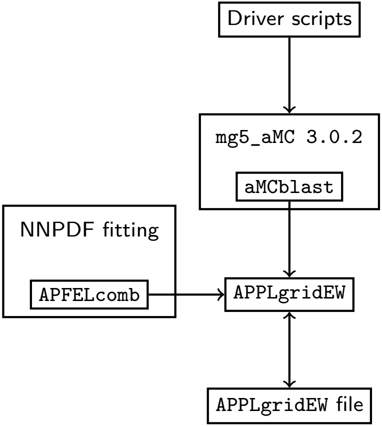
Example: $\sigma_{ab}(x_1, x_2, Q^2)$ for Drell–Yan



using the following decomposition ($\xi = 1$ is the central scale):

$$
\begin{aligned}
\sigma_{ab}(x_1, x_2, Q^2) = {} & \alpha_s^0 \log^0(\xi_R^2) \log^0(\xi_F^2) \left[\alpha^2 \sigma_{ab}^{0,0,0,2}(x_1, x_2, Q^2) \right] \\
& + \alpha_s^1 \log^0(\xi_R^2) \log^0(\xi_F^2) \left[\alpha^2 \sigma_{ab}^{1,0,0,2}(x_1, x_2, Q^2) \right] \\
& + \alpha_s^1 \log^1(\xi_R^2) \log^0(\xi_F^2) \left[\alpha^2 \sigma_{ab}^{1,1,0,2}(x_1, x_2, Q^2) \right] \quad (= 0) \\
& + \alpha_s^1 \log^0(\xi_R^2) \log^1(\xi_F^2) \left[\alpha^2 \sigma_{ab}^{1,0,1,2}(x_1, x_2, Q^2) \right] \\
& + \alpha_s^0 \log^0(\xi_R^2) \log^0(\xi_F^2) \left[\alpha^3 \sigma_{ab}^{0,0,0,3}(x_1, x_2, Q^2) \right] \\
& + \alpha_s^0 \log^1(\xi_R^2) \log^0(\xi_F^2) \left[\alpha^3 \sigma_{ab}^{0,1,0,3}(x_1, x_2, Q^2) \right] \quad (= 0) \\
& + \alpha_s^0 \log^0(\xi_R^2) \log^1(\xi_F^2) \left[\alpha^3 \sigma_{ab}^{0,0,1,3}(x_1, x_2, Q^2) \right] + \ldots
\end{aligned}
$$

Toolchain: How do we calculate the grids?



- Driver scripts set up mg5_aMC: parameters, cuts, scales, etc.
- mg5_aMC [J. Alwell et. al.] generates the MEs and simultaneously runs the LO/NLOs
- aMCblast (previously aMCfast [V. Bertone, R. Frederix, S. Frixione, J. Rojo, M. Sutton]) interfaces with mg5_aMC
- APPLgridEW based on APPLgrid [T. Carli et. al.]; can generate grids for *arbitrary* orders
- extended APFELcomb (interface to NNPDF fitting machinery)

Updated Analyses

Top-pair production analyses,

- the LOs $\mathcal{O}(\alpha_s^2)$ and $\mathcal{O}(\alpha_s \alpha)$,
- the NLOs $\mathcal{O}(\alpha_s^2)$ and $\mathcal{O}(\alpha_s^2 \alpha)$
- remaining orders can't be simultaneously generated with `mg5_aMC` (yet)

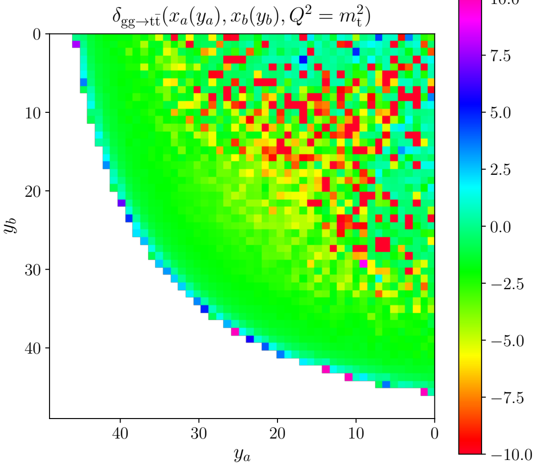
for

- ATLAS TTBAR TOT 7 TeV
- ATLAS TTBAR TOT 8 TeV ($\rightarrow$ see APPLgrid next slide)
- ATLAS TTBAR TOT 13 TeV
- CMS TTBAR TOT 13 TeV
- CMS TTBAR TOT 7 TeV
- CMS TTBAR TOT 8 TeV

and Drell–Yan, full NLO:

- ATLAS Z HIGHMASS 49FB ($\frac{\mathrm{d}\sigma}{\mathrm{d}M_{\ell\bar{\ell}}}$)
  - has a cut at $M_{\ell\bar{\ell}} < 200$ GeV
  - experiment goes up to 1.5 TeV $\rightarrow$ ideal candidate to test more inclusiveness

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



- correction for ixs roughly $-0.5\,\%$
- color: $\delta = \mathcal{O}(\alpha_s^2\alpha)/\mathcal{O}(\alpha_s^2)$
- $y_{a/b}(x) = -\ln x_{a/b} + 5(1 - x_{a/b})$, $y(1) = 0$
- no interpolation in y_a, y_b, or Q^2
- lower left corner $\to$ production threshold
- at threshold: Coulomb singularity
- $y_a \leftrightarrow y_b$ symmetry: initial-state symmetry of gg $\to$ t$\bar{\text{t}}$
- negative correction for larger x_a, x_b

Fitting: Preliminary Plan

To disentangle effects, try things roughly in the following order:

1. NLO QCD evolution, no photon, same cuts
2. Add all LHC analyses
3. Add more observables (e.g. relaxing $M_{\ell\bar{\ell}}$ cut for DY)
4. Add QED evolution
5. Add photon-PDF using NNPDF 3.1 LUXQED strategy ($\rightarrow$ backup slides)

Summary

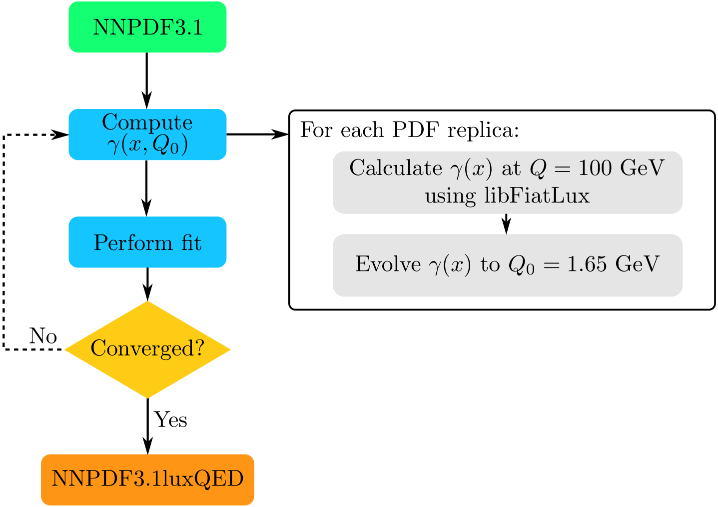
Summary:

- Setup toolchain, extended `APPLgrid` for arbitrary perturbative orders
- Showed differential cross section for $\mathtt{gg} \to \mathtt{t\bar{t}}$: APPLgrid
- Validation is ongoing

Outlook:

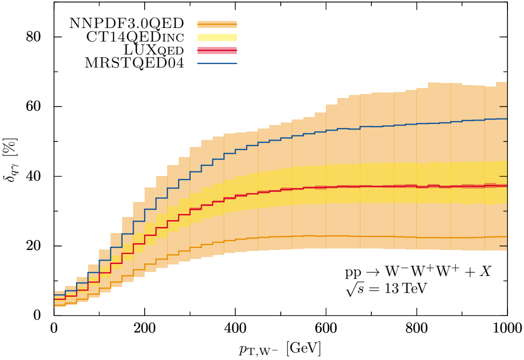
- We'll have a fit in the near future
- include more analyses: All LHC experiments
  (no DIS bc. of double-counting issues)
- include LUXQED-photon consistently

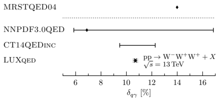
NNPDF 3.1 LUXQED Photon "Fitting" Strategy



plot from [NNPDF Collaboration]

Triple W-boson production [S. Dittmaier, A. Huss, G. Knippen]





- LO: 79 fb
- Large photon–quark contribution, $\delta_{\mathrm{q}\gamma} = 10.7\,\%$ (LUXQED)
- Partially cancelled by quark–quark contributions, $\delta_{\mathrm{qq}} = -4.1\,\%$
- At 100 TeV huge $\delta_{\mathrm{q}\gamma} = 41.3\,\%$ ($\delta_{\mathrm{qq}} = -5.4\,\%$)

$\rightarrow$ Jet veto to stabilize corrections