Treatment of EW effects in PDF fits and in experimental data

arXiv:2008.12789

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QCD-only PDF fits

- all global PDF fits use mainly QCD corrections as input for their PDF fits and
- EW corrections are neglected,
- except for FSR corrections which are subtracted from data (where needed)

but...

- Data/PDFs are becoming more precise, and theory has to become more precise as well!
- Look at the effects of NLO EW corrections in PDF fits

→ EW corrections become large in large-mass regions of phase space, not described by FSR

What exactly is neglected?

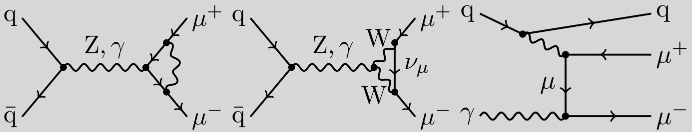
Steps in this direction; inclusion of the photon PDF:

- [NNPDF Collaboration] NNPDF 3.1 + LUXQED [A. Manohar, P. Nason, G. P. Salam, G. Zanderighi], [A. Manohar, et al.]
- [MMHT Collaboration] MMHT2015qed

But fully EW corrections in the processes are missing:

- Drell–Yan: $\mathcal{O}(\alpha^3)$ at NLO, mixed QCD–EW $\mathcal{O}(\alpha_s\alpha^3)$
- Transverse momentum of the Z: $\mathcal{O}(\alpha_s\alpha^3)$ at NLO
- Top-pair production: $\mathcal{O}(\alpha_s^2\alpha)$ and two more LO/two more NLO

Drell–Yan @ NLO $\mathcal{O}(\alpha^3)$



Towards a global QCD–EW PDF fit: Problems to be solved

Issues

1. PDF-independent QCD–EW predictions (done, see next slides)
2. Understand double-counting problems; use the right data (WIP, this talk: DY)
3. Perform a (consistent[1]) fit!

[1] Consistent fit: All processes with NLO EW + NNLO QCD treated equally

Issue #1: PDF-independent predictions with PineAPPL

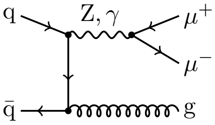
$$\frac{\mathrm{d}\sigma}{\mathrm{d}\mathcal{O}} = \sum_{a,b} \int_0^1 \mathrm{d}x_1 \int_0^1 \mathrm{d}x_2 \, f_a(x_1) f_b(x_2) \boxed{\frac{\mathrm{d}\sigma_{ab}}{\mathrm{d}\mathcal{O}}(x_1, x_2, \mathcal{O})}$$

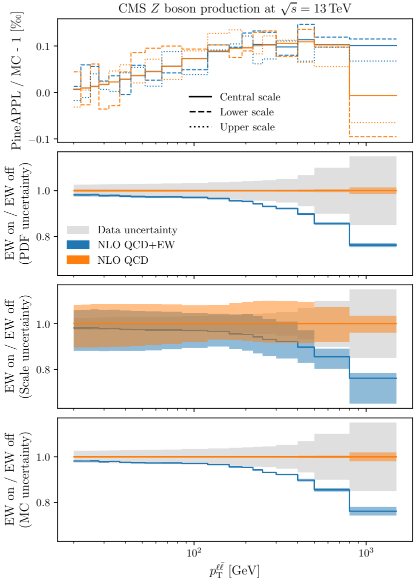
- PDF-independent predictions $\boxed{\sigma_{ab}(x_1, x_2, \mathcal{O})}$ are needed for PDF fits
- typically used for QCD corrections: APPLgrid [T. Carli et al.], fastNLO [T. Kluge, K. Rabbertz, M. Wobisch]
- both do not support EW corrections, therefore: PineAPPL
- much faster than APPLgrid, integrated with mg5_aMC@NLO v3 [R. Frederix et al.]
- possible: integration with SHERPA [E. Bothmann et al.]/MCgrid, resummation, photon-shower, ...
- all grids that we will generate will be published shortly: `https://n3pdf.github.io/pineappl`

PineAPPL example: transverse momentum of the Z boson

Significantly large EW corrections:

- second plot: large EW corrections, larger than data uncertainty
- coloured bands are PDF uncertainty
- first plot: grid interpolation error
- third plot: 9-point scale uncertainty
- fourth plot: MC integration uncertainty





Issue #2: Experimental data and double-counting problems

- We consider the Drell–Yan datasets for NNPDF 4.0[2] for this exercise
- 23 datasets from CDF (1), D0 (3), ATLAS (7), CMS (5), and LHCb (7)
- 9 out of the 23 (39 %) seem unusable:

Experiment	$\sqrt{s}$	Description	Reference
CDF	1.96 TeV	Z rapidity distribution	arXiv:0908.3914
D0	1.96 TeV	Z rapidity distribution	hep-ex/0702025
D0	1.96 TeV	W electron asymmetry	arXiv:1412.2862
D0	1.96 TeV	W muon asymmetry	arXiv:1309.2591
ATLAS	7 TeV	2010 rapidity distribution	arXiv:1109.5141
ATLAS	7 TeV	high-mass DY	arXiv:1305.4192
ATLAS	7 TeV	low-mass DY	arXiv:1404.1212
ATLAS	8 TeV	W,Z 2011 rapidity distribution central region	arXiv:1612.03016
ATLAS	8 TeV	W,Z 2011 rapidity distribution forward region	arXiv:1612.03016
ATLAS	8 TeV	high-mass DY 2D differential distributions	arXiv:1606.01736
ATLAS	8 TeV	DY 3D differential cross sections	arXiv:1710.05167
CMS	7 TeV	W electron asymmetry	arXiv:1206.2598
CMS	7 TeV	W muon asymmetry	arXiv:1312.6283
CMS	7 TeV	double-differential NC DY cross sections	arXiv:1310.7291
CMS	8 TeV	double-differential NC DY cross sections	arXiv:1412.1115
CMS	8 TeV	differential distributions W muon distribution and asymmetry	arXiv:1603.01803
LHCb	7 TeV	muon W and Z rapidity distribution	arXiv:1505.07024
LHCb	7 TeV	dielectron Z rapidity distribution	arXiv:1212.4620
LHCb	8 TeV	dielectron Z rapidity distribution	arXiv:1503.00963
LHCb	8 TeV	muon W and Z rapidity distribution	arXiv:1511.08039
LHCb	8 TeV	electron W rapidity distribution	arXiv:1608.01484
LHCb	13 TeV	dimuon Z rapidity distribution	arXiv:1607.06495
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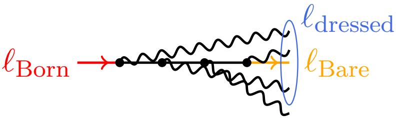
[2] See also `http://nnpdf.mi.infn.it/wp-content/uploads/2020/03/SForte_CERN_022020.pdf`

Problem 1: No post-FSR/dressed-lepton data



- pre-FSR data/Born leptons: observables of leptons “before they radiate”, calculated using photon-shower inversion (PHOTOS), from
- post-FSR data/dressed leptons: observables using leptons with photon recombined around $\Delta R_{f\gamma}$, typically $\Delta R_{f\gamma} = 0.1$
- pre-FSR data for comparisons with QCD-only theory predictions
- post-FSR data for comparisons with EW corrections

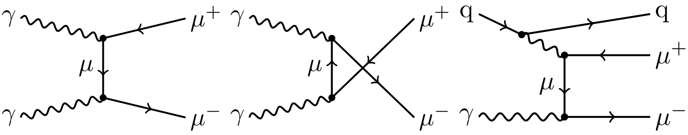
$\rightarrow$ absence of post-FSR data big problem for our exercise: otherwise significant double-counting problem

- all datasets previously marked with 'red' suffer from this: no post-FSR dataset or dressing factors:

$$C_{\mathrm{dress}} = \frac{\mathrm{d}\sigma_{\text{post-FSR}}/\mathrm{d}\mathcal{O}}{\mathrm{d}\sigma_{\text{pre-FSR}}/\mathrm{d}\mathcal{O}}$$

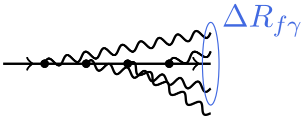
$\rightarrow$ can we get them somewhere nevertheless?

Problem 2: Subtraction of photon–photon contribution



- For ATLAS and CMS (LHCb?) it seems to be standard procedure to subtract double-photon induced contributions
- Why?
- How can this be undone?
- This is a problem: proton contains photons, should be counted towards signal!
- Size of the LO contribution can become significant in large-invariant-mass bins (3 %) depending on the used PDF—up to twice as large for pre-LUXQED photon PDFs

Problem 3: Miscellaneous



- Photon recombination radius $\Delta R_{f\gamma}$ unknown (LHCb)
- No error for dressing factors C_{dress}
- not covered/unknown: DIS and fixed target datasets, jets, single-tops, ...

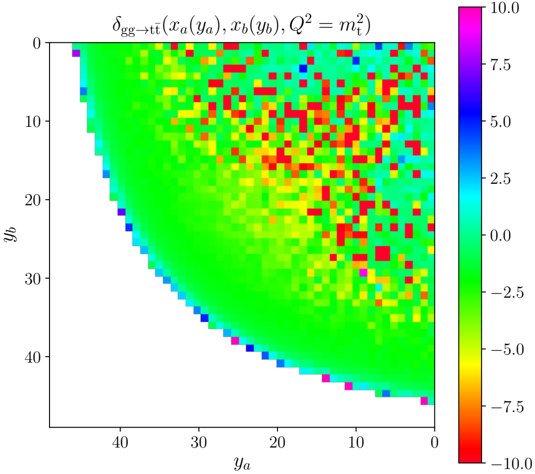
Conclusion and wish list for data

- New tool for storage of PDF-independent arbitrary FO calculations: PineAPPL, `https://github.com/N3PDF/pineappl`, arXiv:2008.12789
- Useful for very quick calculations of PDF-uncertainties

Please ...

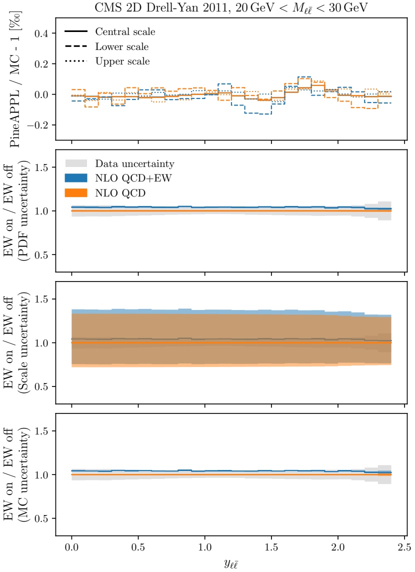
- publish your data with post-FSR data/dressed leptons (and pre-FSR data/Born leptons)
- do not subtract photon–photon initial states (or publish procedure to undo it)
- state explicitly the photon recombination procedure

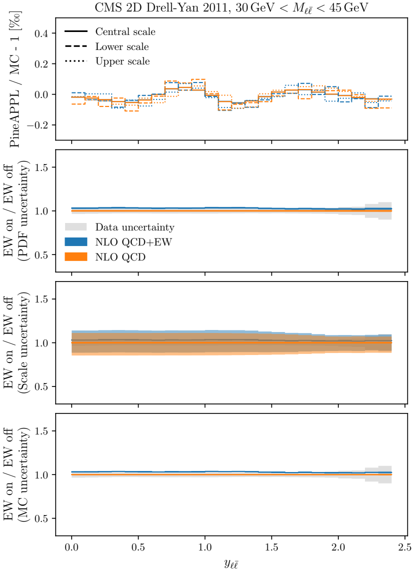
Gluon–Gluon-Grid: $\mathcal{O}(\alpha_s^2\alpha)$ for $\mathrm{gg} \to \mathrm{t\bar{t}}$ @ 8 TeV



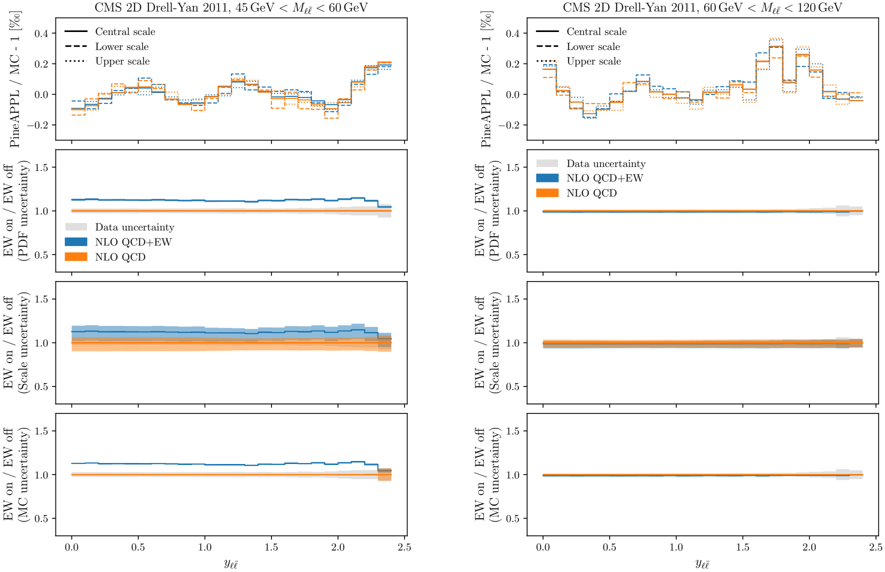
- correction for ixs roughly $-0.5\,\%$
- color: $\delta = \mathcal{O}(\alpha_s^2\alpha)/\mathcal{O}(\alpha_s^2)$
- $y_{a/b}(x) = -\ln x_{a/b} + 5(1 - x_{a/b})$, $y(1) = 0$
- no interpolation in y_a, y_b, or Q^2
- lower left corner $\to$ production threshold
- at threshold: Coulomb singularity
- $y_a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

CMS DY 2D (I)

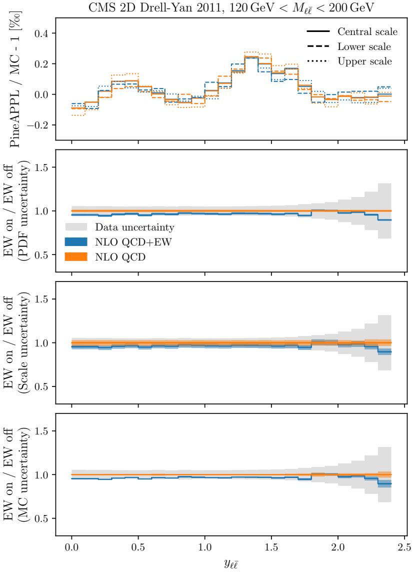

CMS 2D Drell-Yan 2011, 20 GeV < $M_{\ell\bar{\ell}}$ < 30 GeV
Central scale
Lower scale
Upper scale
PineAPPL / MC - 1 [‰]
Data uncertainty
NLO QCD+EW
NLO QCD
EW on / EW off (PDF uncertainty)
EW on / EW off (Scale uncertainty)
EW on / EW off (MC uncertainty)
$y_{\ell\bar{\ell}}$

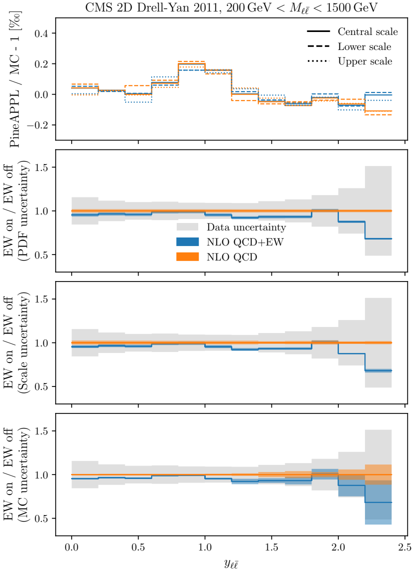

CMS 2D Drell-Yan 2011, 30 GeV < $M_{\ell\bar{\ell}}$ < 45 GeV
Central scale
Lower scale
Upper scale
PineAPPL / MC - 1 [‰]
Data uncertainty
NLO QCD+EW
NLO QCD
EW on / EW off (PDF uncertainty)
EW on / EW off (Scale uncertainty)
EW on / EW off (MC uncertainty)
$y_{\ell\bar{\ell}}$

CMS DY 2D (II)


CMS 2D Drell-Yan 2011, 45 GeV < $M_{\ell\bar{\ell}}$ < 60 GeV
CMS 2D Drell-Yan 2011, 60 GeV < $M_{\ell\bar{\ell}}$ < 120 GeV
PineAPPL / MC - 1 [‰]
Central scale
Lower scale
Upper scale
EW on / EW off (PDF uncertainty)
EW on / EW off (Scale uncertainty)
EW on / EW off (MC uncertainty)
Data uncertainty
NLO QCD+EW
NLO QCD
$y_{\ell\bar{\ell}}$

CMS DY 2D (III)


CMS 2D Drell-Yan 2011, 120 GeV < $M_{\ell\bar{\ell}}$ < 200 GeV
Central scale
Lower scale
Upper scale
PineAPPL / MC - 1 [‰]
EW on / EW off (PDF uncertainty)
Data uncertainty
NLO QCD+EW
NLO QCD
EW on / EW off (Scale uncertainty)
EW on / EW off (MC uncertainty)
$y_{\ell\bar{\ell}}$


CMS 2D Drell-Yan 2011, 200 GeV < $M_{\ell\bar{\ell}}$ < 1500 GeV
Central scale
Lower scale
Upper scale
PineAPPL / MC - 1 [‰]
EW on / EW off (PDF uncertainty)
Data uncertainty
NLO QCD+EW
NLO QCD
EW on / EW off (Scale uncertainty)
EW on / EW off (MC uncertainty)
$y_{\ell\bar{\ell}}$