Electroweak corrections at the LHC: the impact of and on the PDFs

Davide Pagani

Parton Distributions for the LHC

Benasque, Spain

18-02-2015

OUTLINE

EW corrections: the impact of the PDFs

Status of the art: LO QED evolution

Effects from QED evolution
Effects from photon-initiated processes: the photon PDF

EW corrections: the impact on the PDFs

What are the NLO EW+QCD event generators on the market?
(The market will change fast)

At which level will event generators be able to help in the fits of “EW PDF”?

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At which level will event generators be able to help in the fits of "EW PDF"?

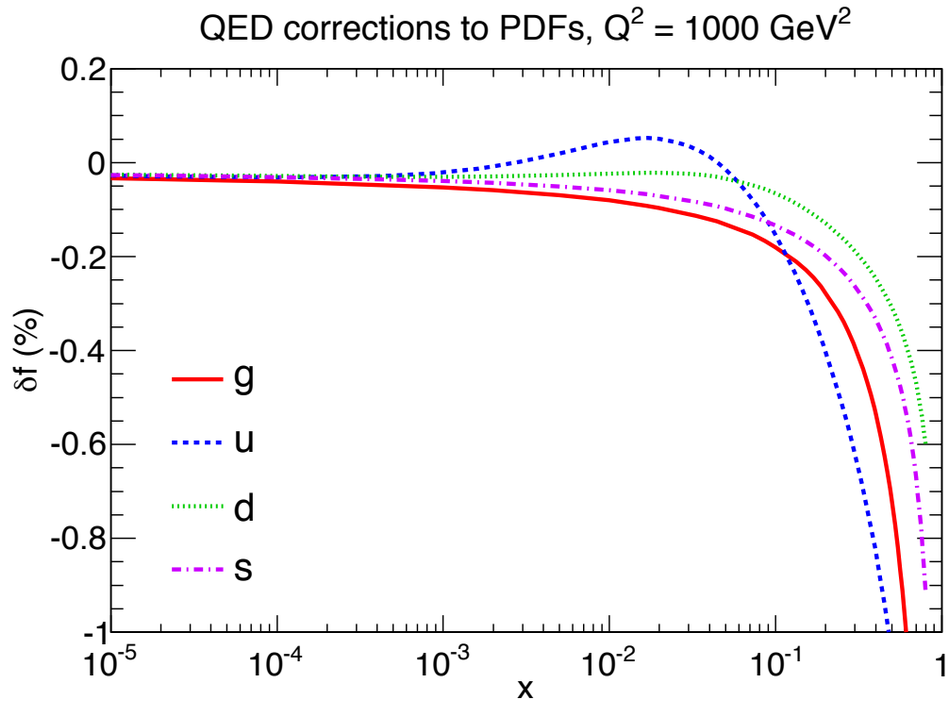
We need a more accurate photon PDF to reduce the error from photon-induced processes, which can affect predictions far beyond the percent level.

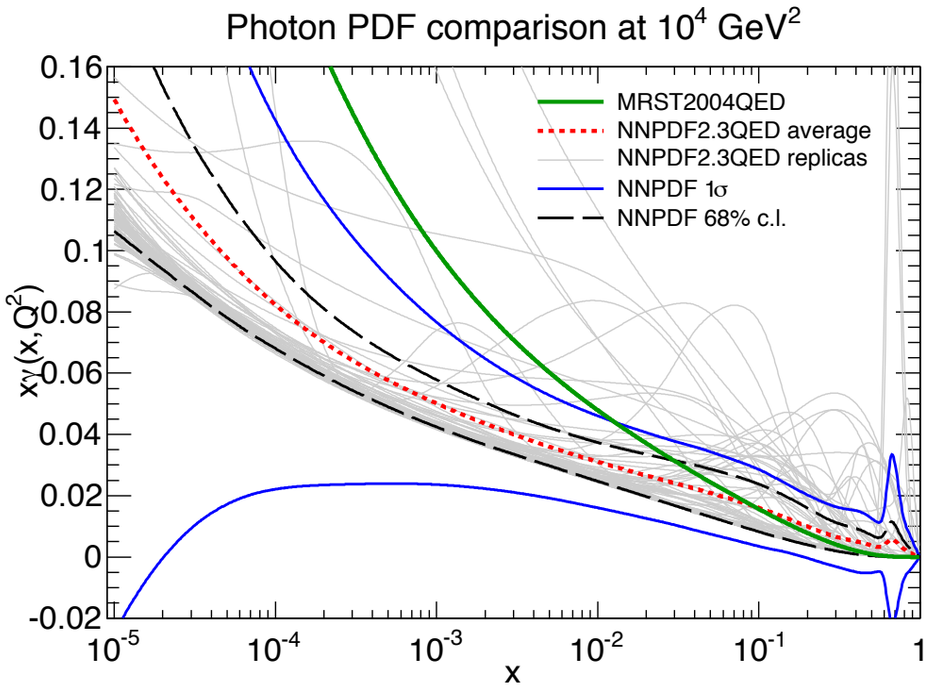
We need more accurate event generators (including both EW and QCD corrections) to be able to extract a photon PDF with a smaller uncertainty.

EW corrections: the impact of the PDFs

In NLO EW calculations, initial-state QED collinear singularities do not cancel at partonic level.

For theoretical consistency, one prefers to use PDFs with the corresponding evolution from QED splittings.





NNPDF2.3QED

The main numerical differences (QED vs. NO-QED) arise from the appearance of the photon PDF and new possible partonic channels.

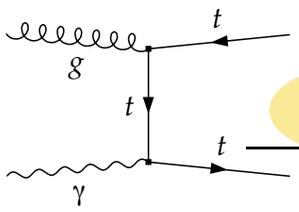
Why do we care about photons in the proton?

2 representative examples:

$t\bar{t}$

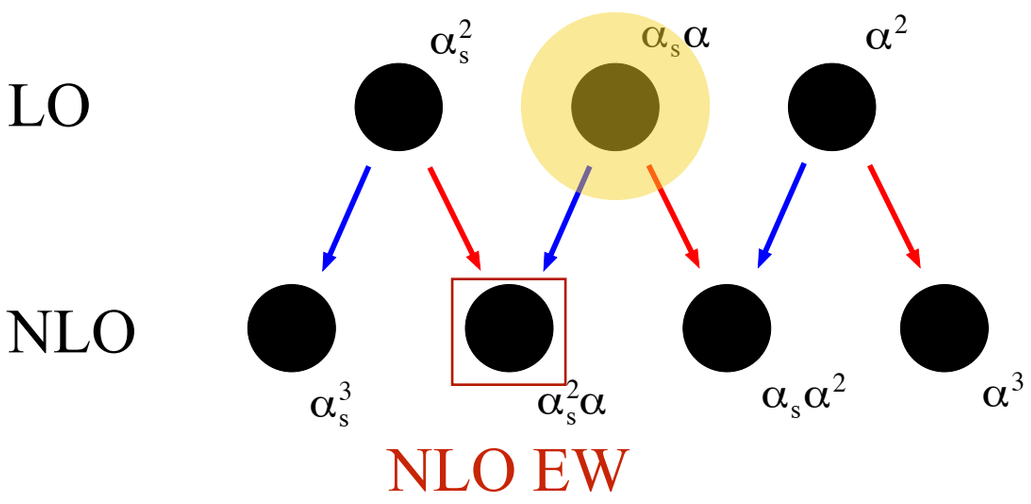
Process	σ_{tot} without cuts [pb]	
	Born	correction
$u\bar{u}$	34.25	-1.41
$d\bar{d}$	21.61	-0.228
$s\bar{s}$	4.682	-0.0410
$c\bar{c}$	2.075	-0.0762
gg	407.8	2.08
$g\gamma$		4.45
pp	470.4	4.78

NLO QED



Integrated hadronic cross section for $t\bar{t}$ production at the LHC, at NLO QED

Hollik, Kollar '07 MRST2004QED



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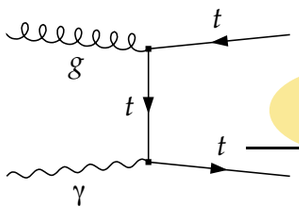

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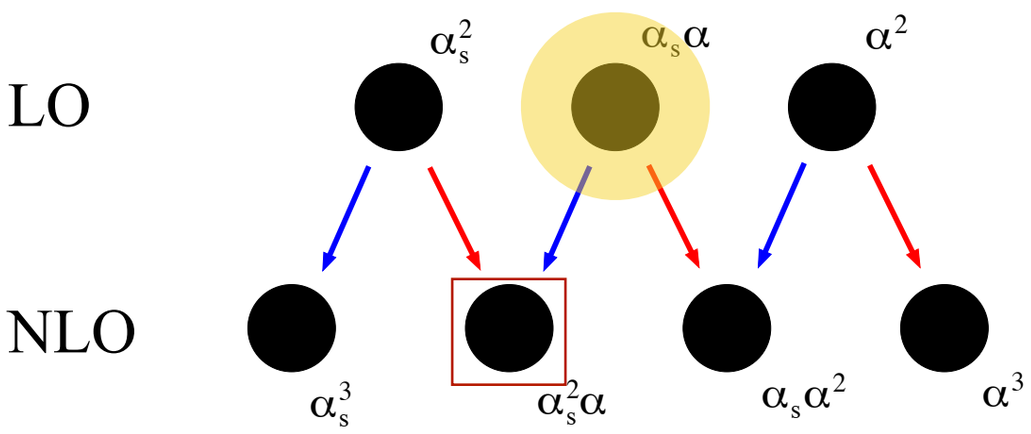
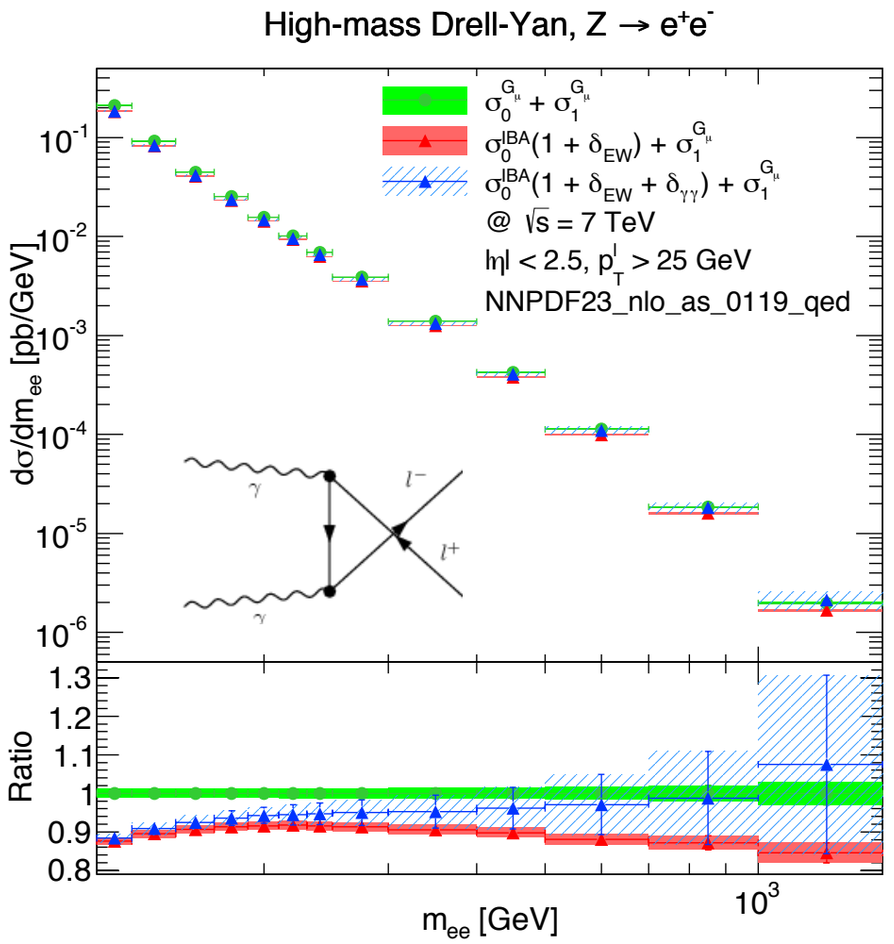
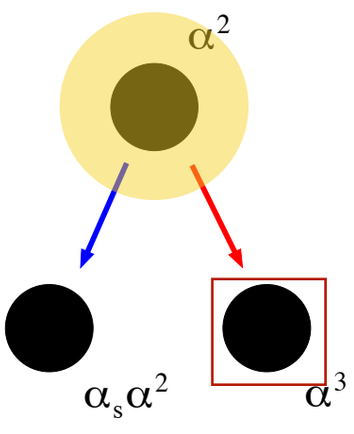


NLO EW



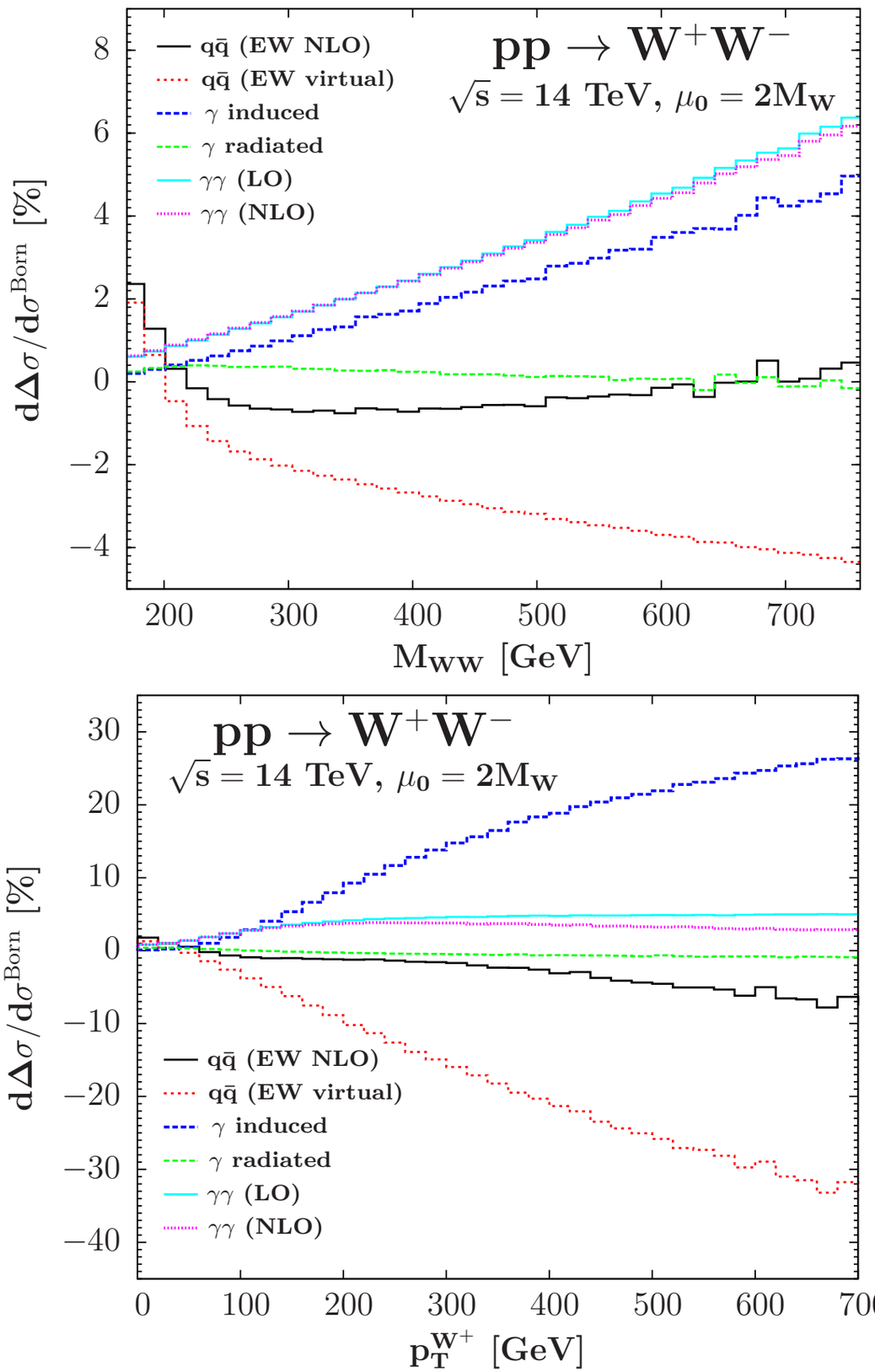
Carrazza '14 NNPDF2.3QED



NLO EW

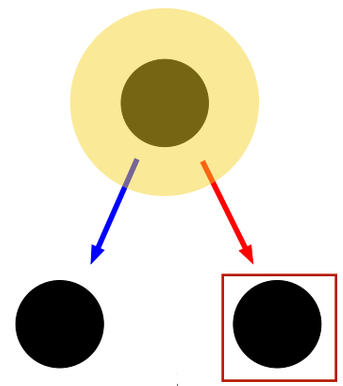
Initial-state photons at LO and NLO

Baglio, Ninh, Weber '13



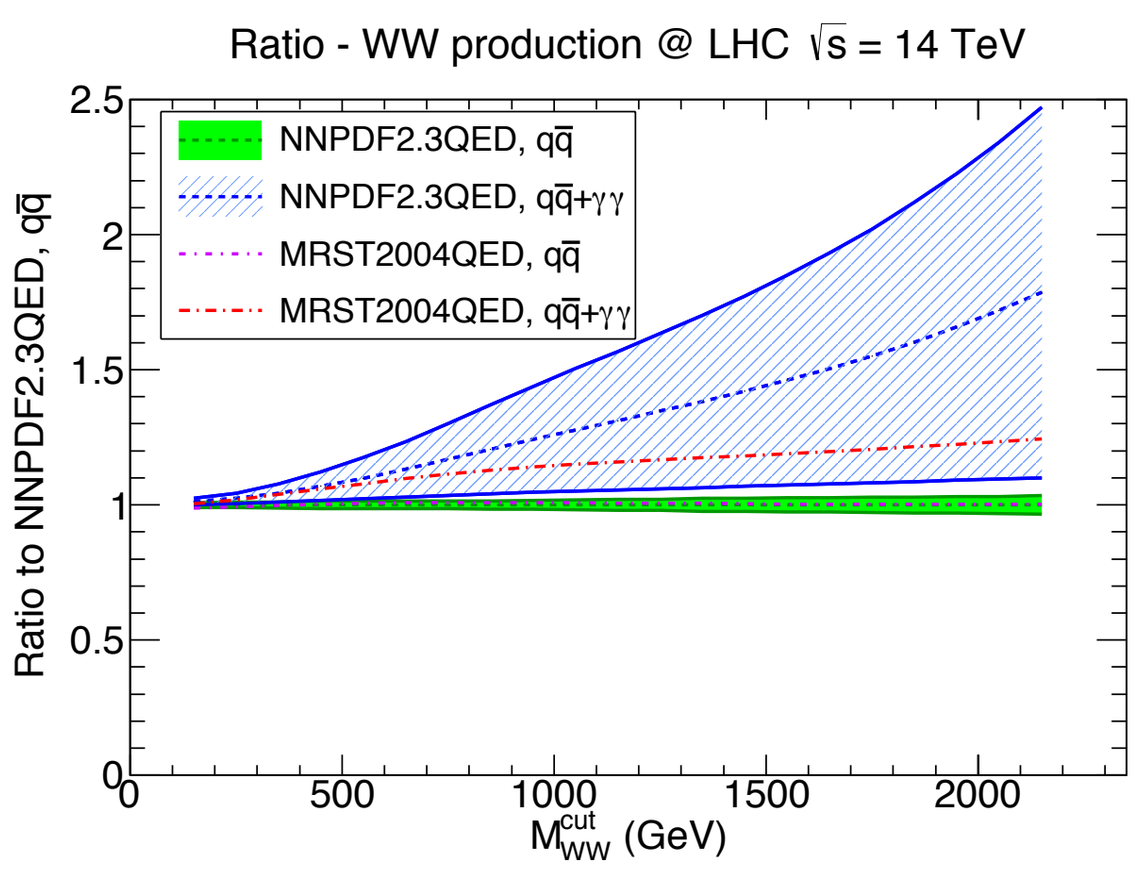
LO

NLO



NLO EW

Ball et al '13

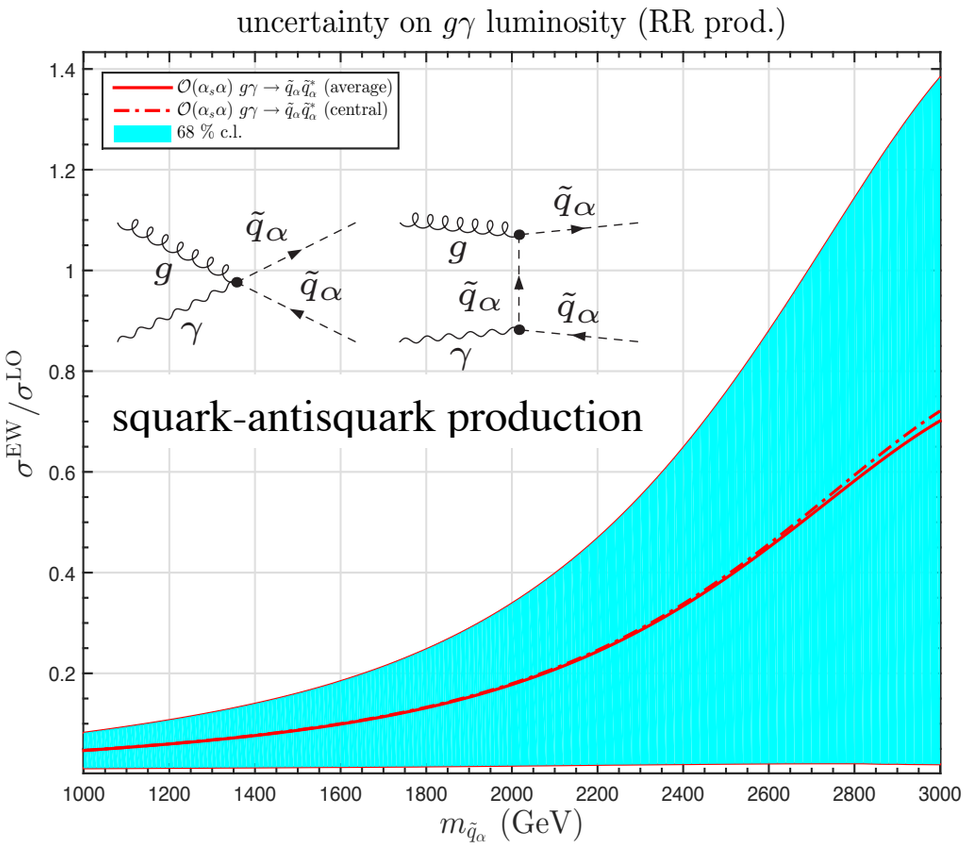


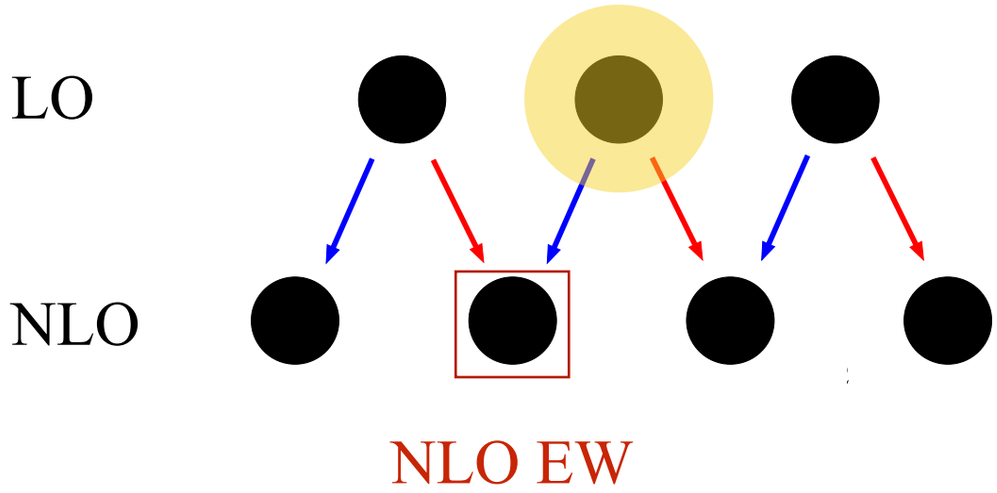
Initial-state photons in EW corrections

Many processes can include the photon-gluon initial state at the tree level: dijet (in association with vector bosons), top-quark pair production (in association with vector bosons or the Higgs) and etc.

NLO EW corrections in general open photon-(anti)quark initial states.

It is necessary to check PDFs uncertainties also for EW calculations.
Case by case, there can be surprises.





Hollik, Lindert, Mirabella, DP in preparation

EW corrections: the impact on the PDFs

PDF with LO QED evolution. What you need?

- Photon induced processes, at least at LO
- Other channels (at least) at NLO QCD accuracy
- In general EW corrections to take into account Sudakov logs effects

What is on the market? (Codes)

Drell-Yan	*POWHEG (+shower), FEWZ (NNLO)*
Higgs-strahlung and VBF	*HAWK, VBFNLO*
....	
Probably others.	A process-independent environment? Not yet

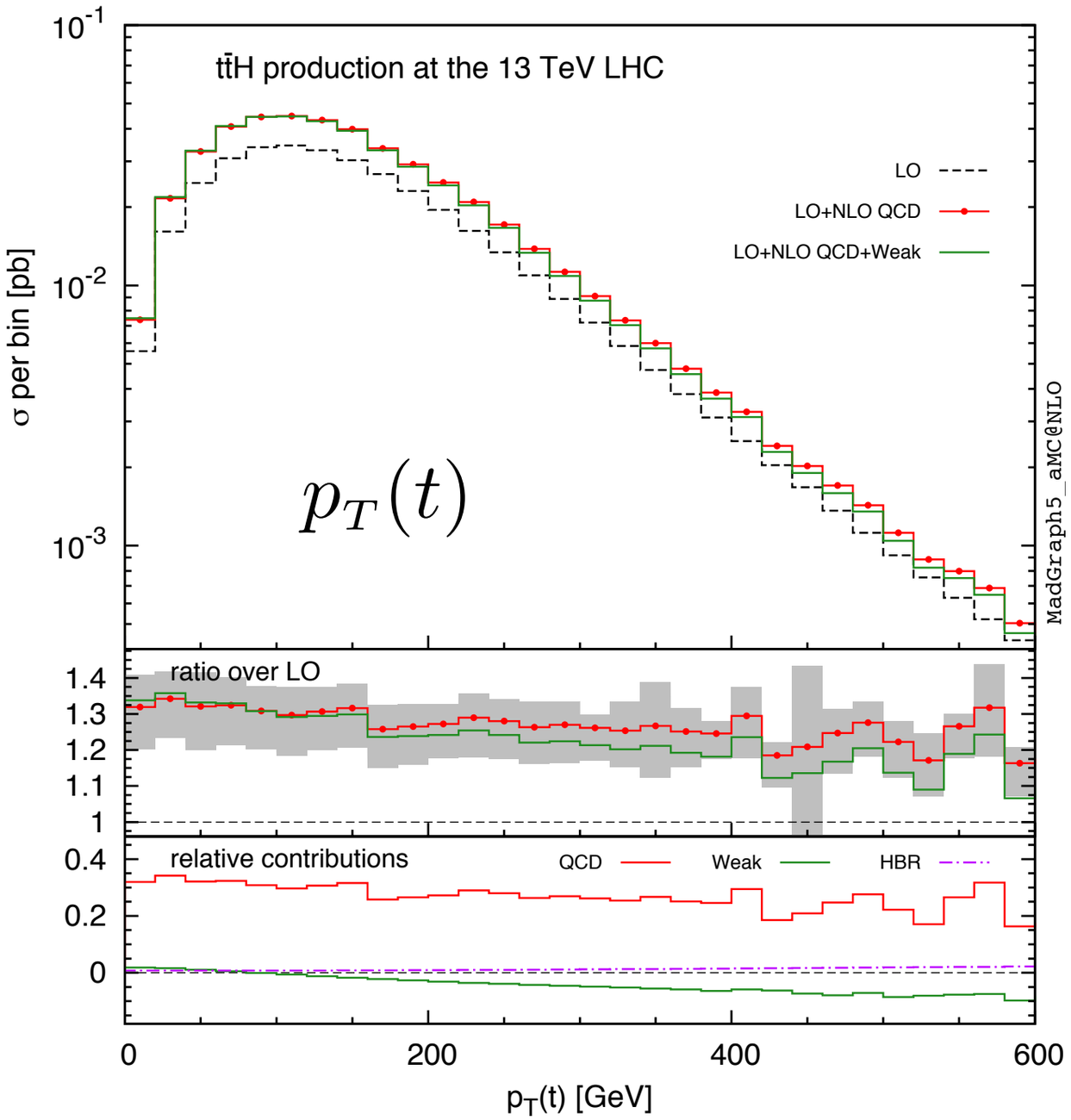
The market is changing. Full automation of QCD and EW corrections

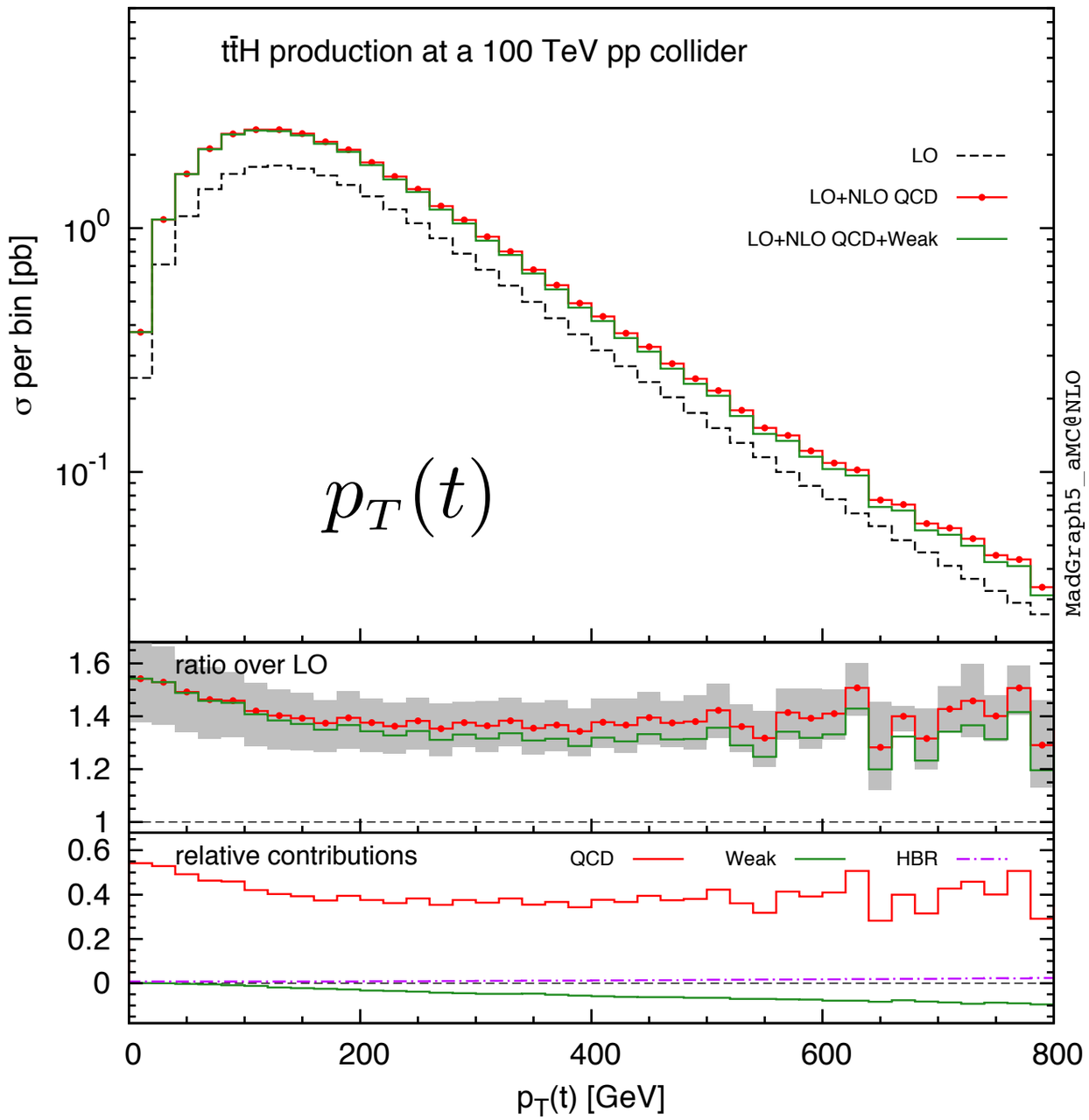
- aMC@NLO with EW corrections — Alwall et al '14 — Frixione, Hirschi, DP, Shao, Zaro '14

- OpenLoop+Sherpa/MUNICH — Kallweit, Lindert, Maierhöfer, Pozzorini, Schönherr '14

First pheno study in aMC@NLO: QCD vs QCD+Weak

$$t\bar{t}H$$





Frixione, Hirschi, DP, Shao, Zaro '14

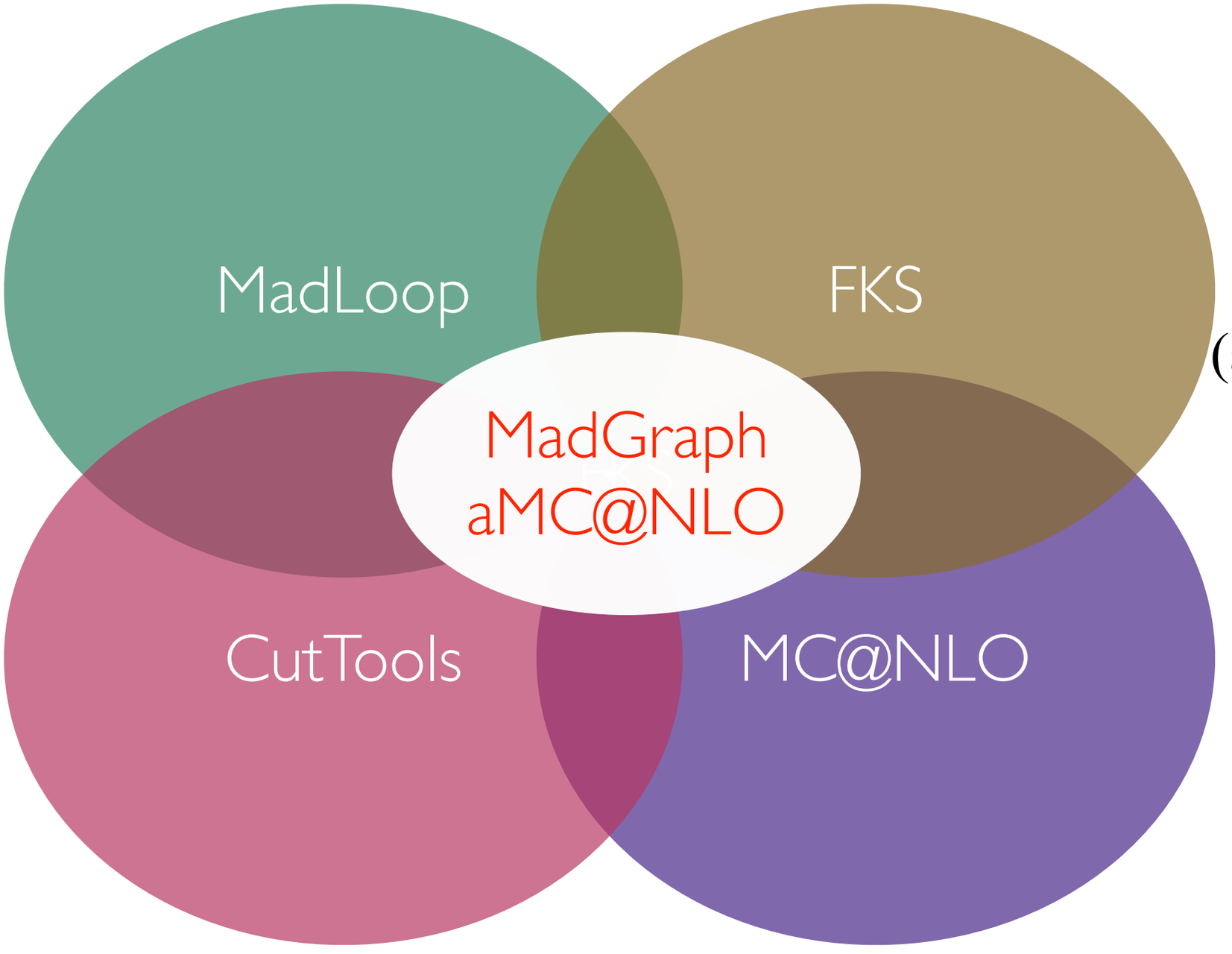
13 TeV

100 TeV

Automation of NLO corrections in Madgraph5_aMC@NLO

The **complete automation** for **QCD+EW** is in progress.

DONE!

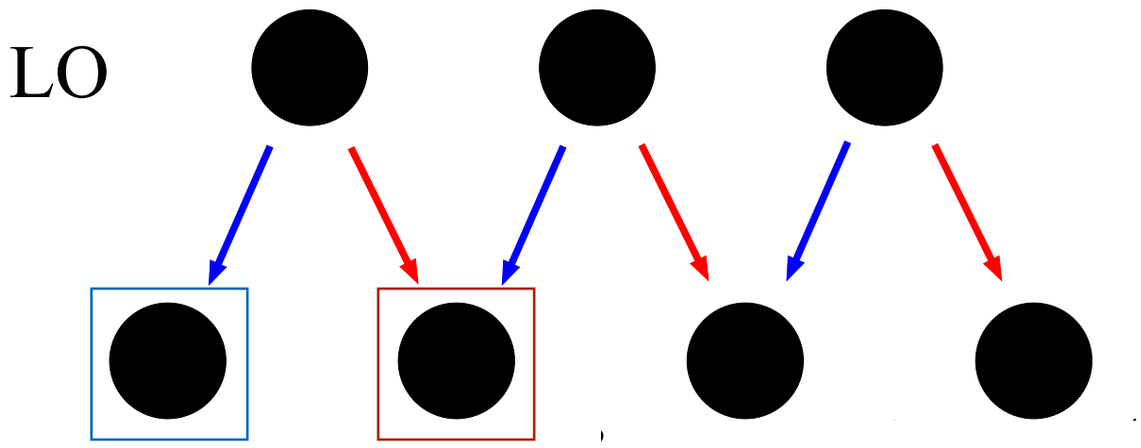


in progress
(almost DONE)

DONE!

in progress

What can you use for a PDF fit?



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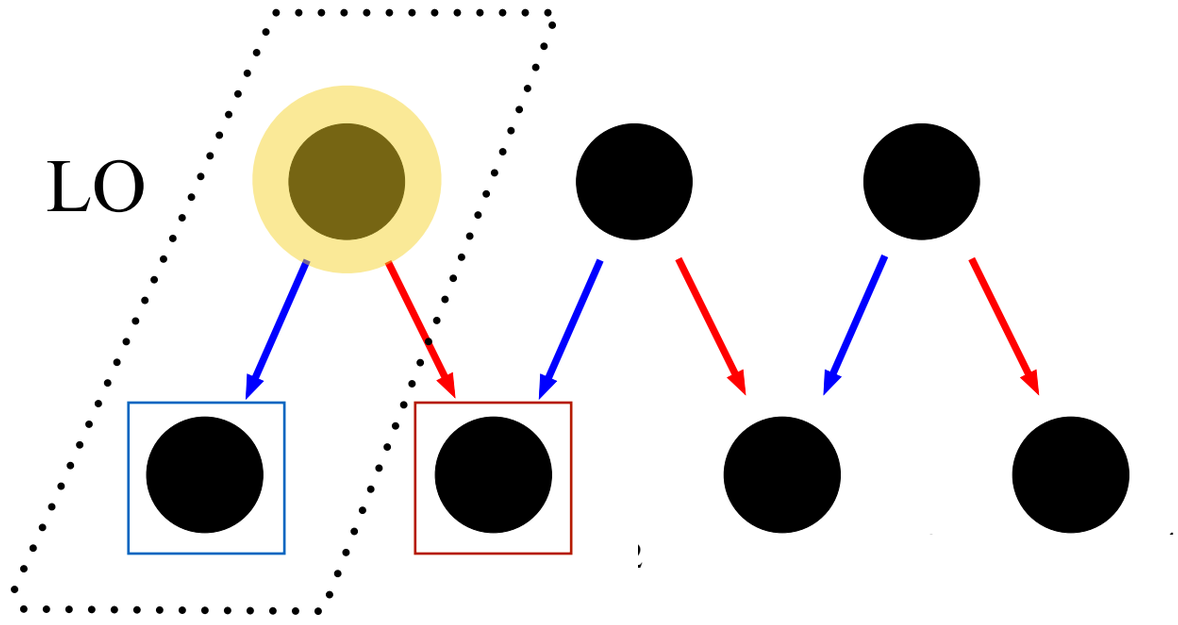
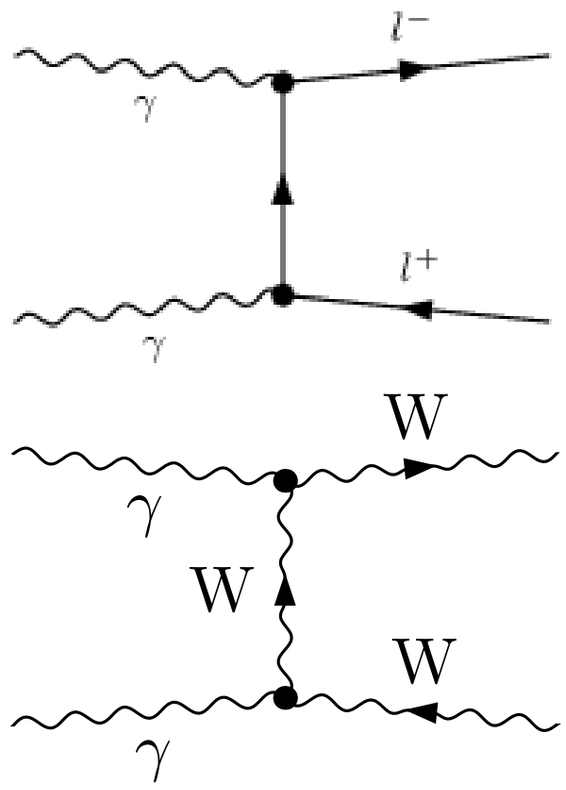


Standard recipe for NLO PDF.
The photon can already be there
(Drell-Yan, WW)



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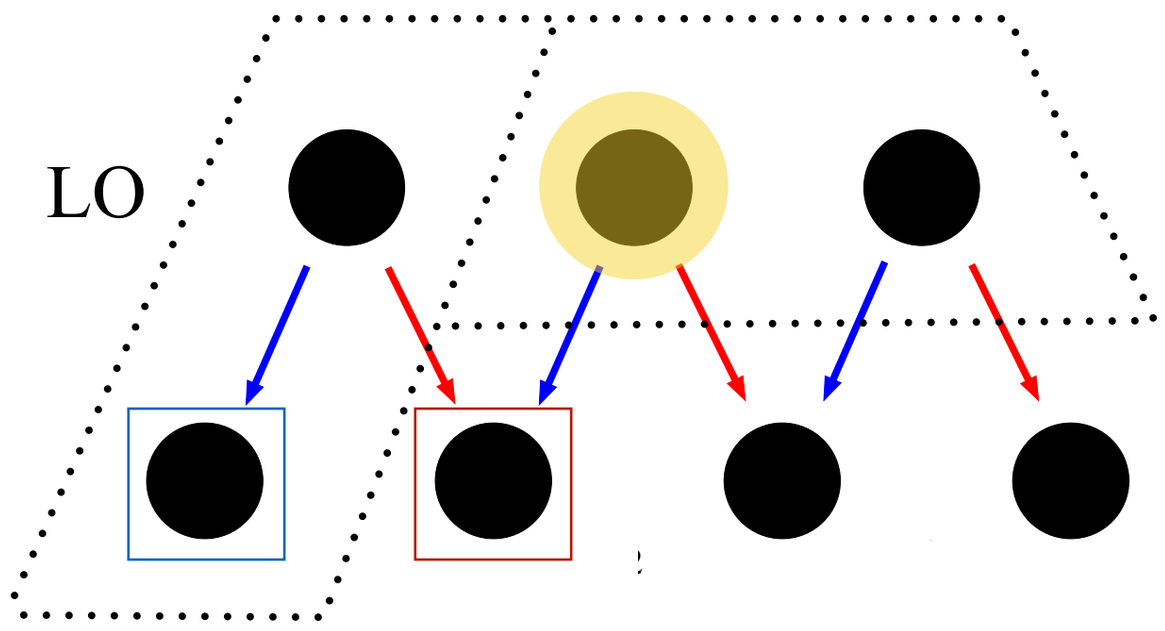
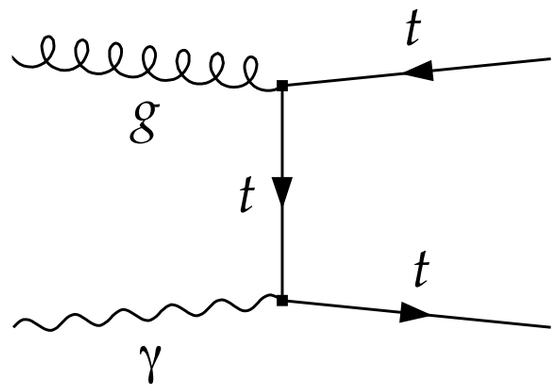
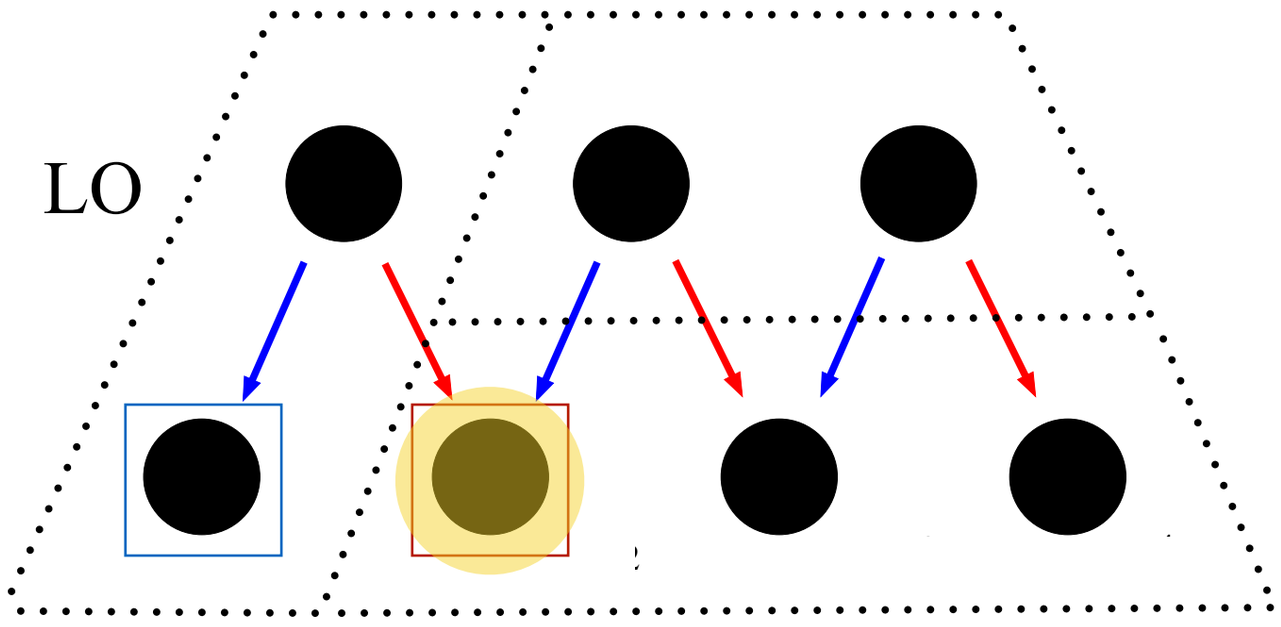


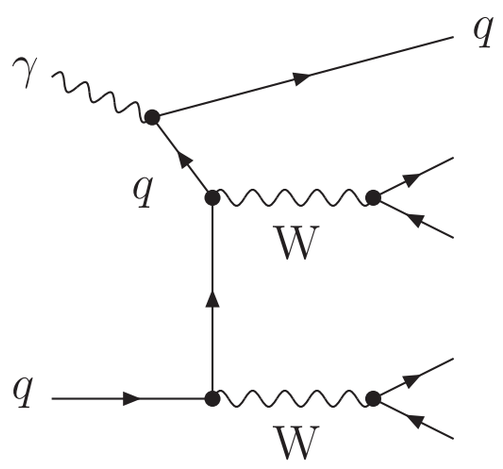
Standard recipe for NLO PDF
+ other tree-level orders,
they can be the first orders <u>including the photon</u>



This level can be easily automated in aMC@NLO,
Work in progress for aMCfast.

What can you use for a PDF fit?





Standard recipe for NLO PDF
+ other tree-level orders
+ NLO EW or even subleading NLOs

New photon-induced channels can appear at NLO.
Electroweak Sudakov Logs can compensate photon-induced contributions.
Do we need lepton PDFs? Can W, Z PDFs be fitted?

Conclusion

EW corrections: the impact of the PDFs

The impact of photon-initiated channels is important for precise predictions.

In some cases the photon PDF is fundamental for realistic descriptions and it induces large uncertainties.

EW corrections: the impact on the PDFs

The market of the EW Monte Carlo will change fast.

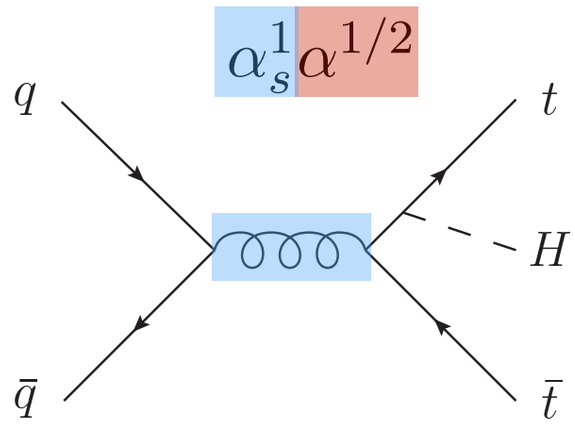
NLO QCD + tree-level photon-induced is automated, soon also the NLO EW.

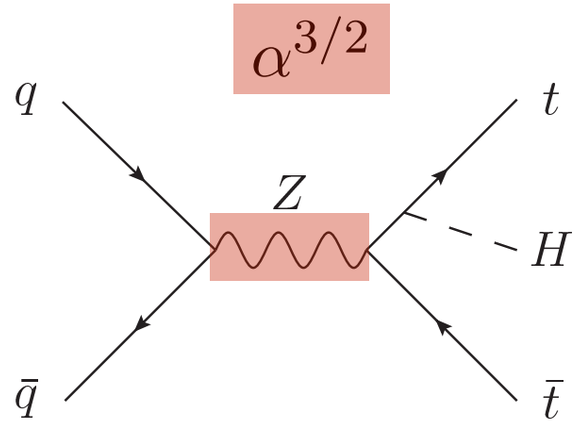
We need a more accurate photon PDF to reduce the error from photon-induced processes, which can affect predictions far beyond the percent level.

We need more accurate event generators (including both EW and QCD corrections) to be able to extract a photon PDF with a smaller uncertainty.

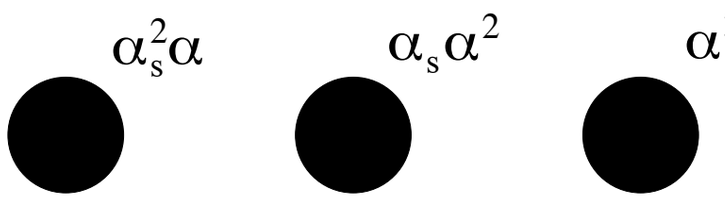
EXTRA SLIDES

Structure of NLO EW-QCD corrections



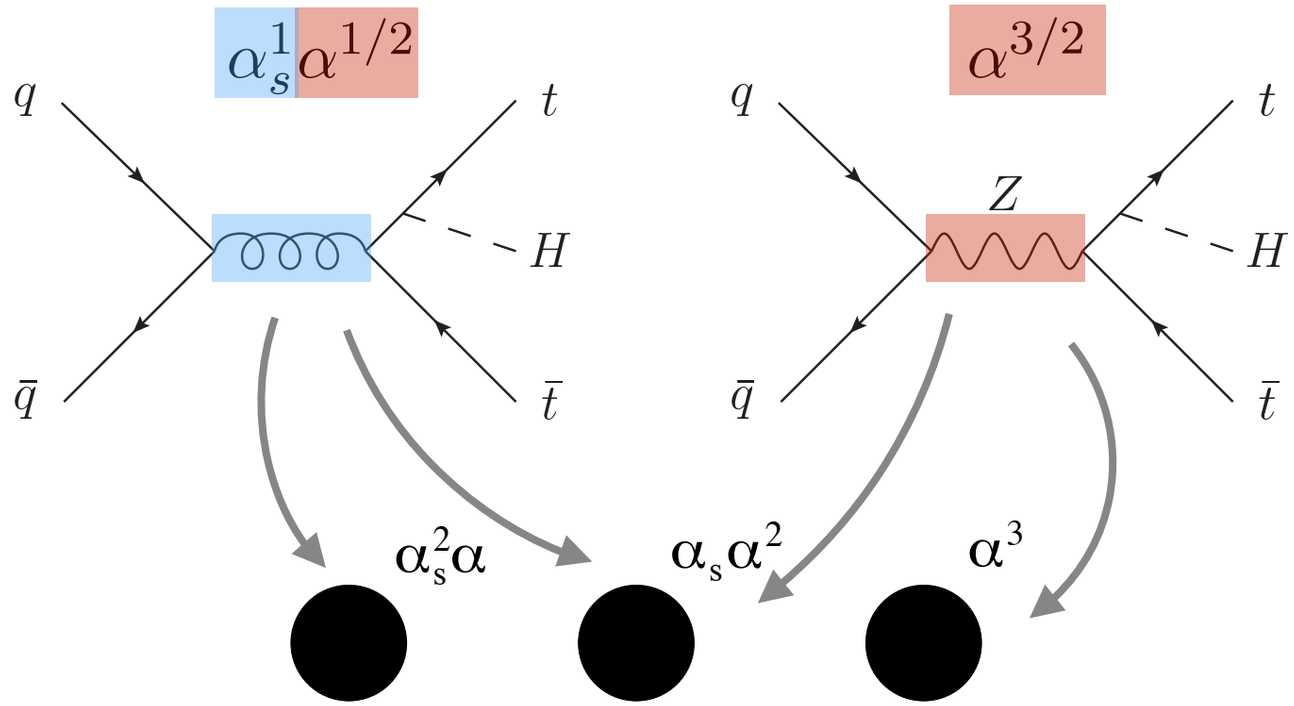


LO



Structure of NLO EW-QCD corrections

LO



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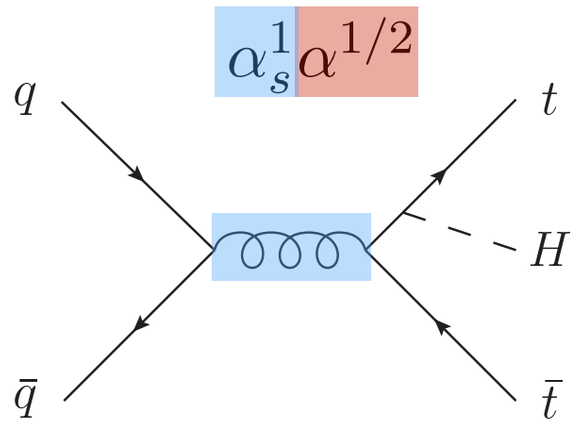

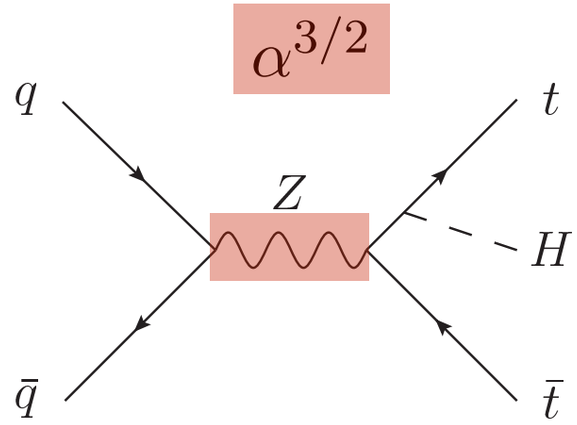

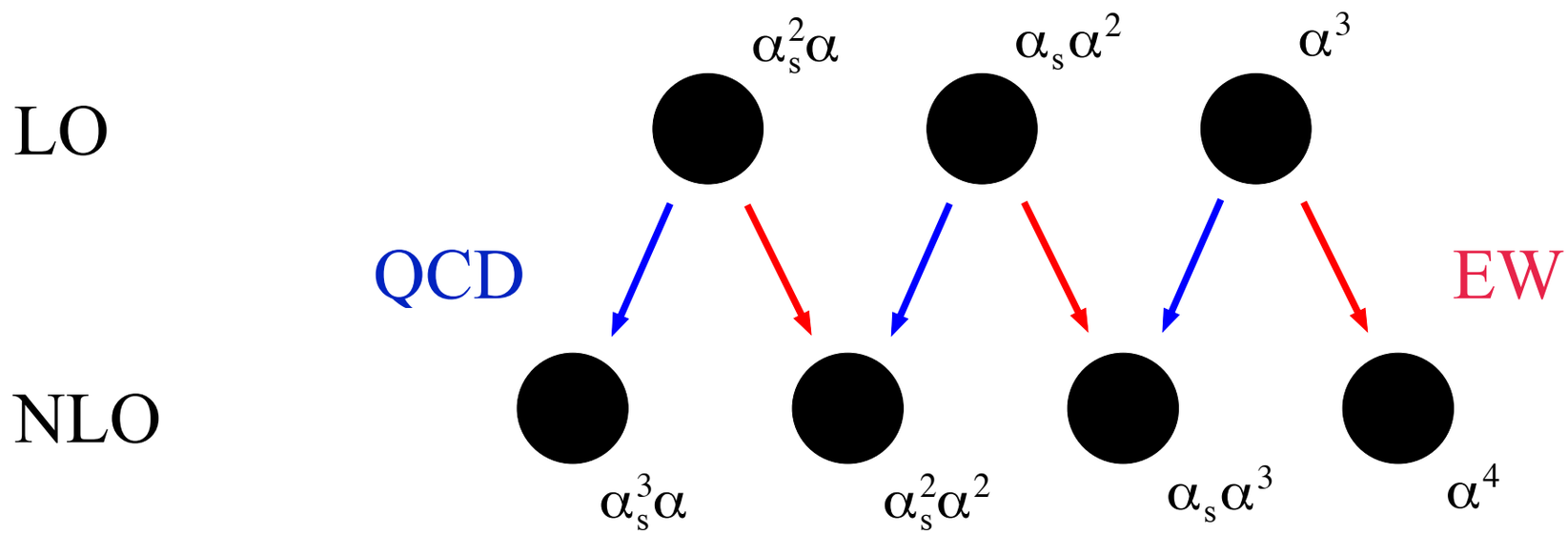

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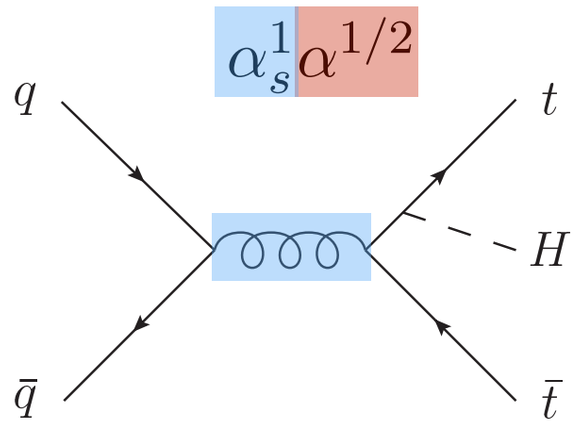
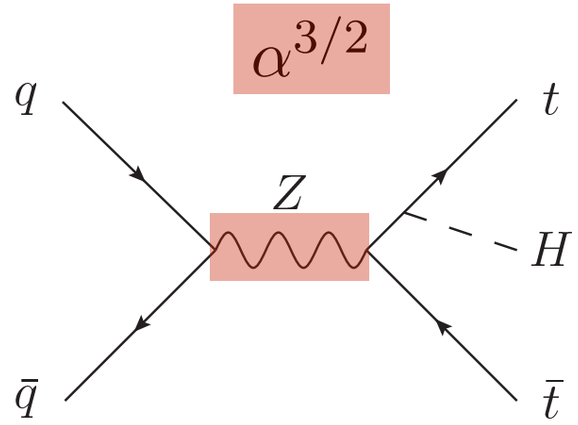
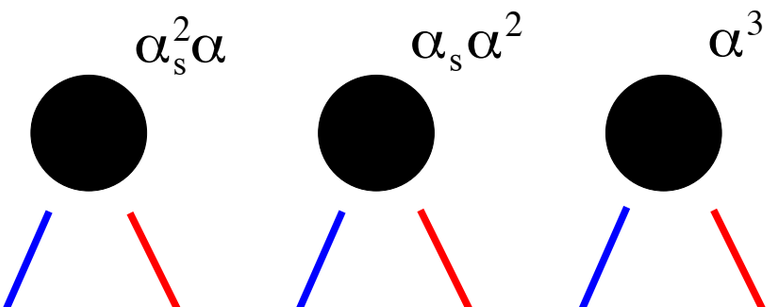
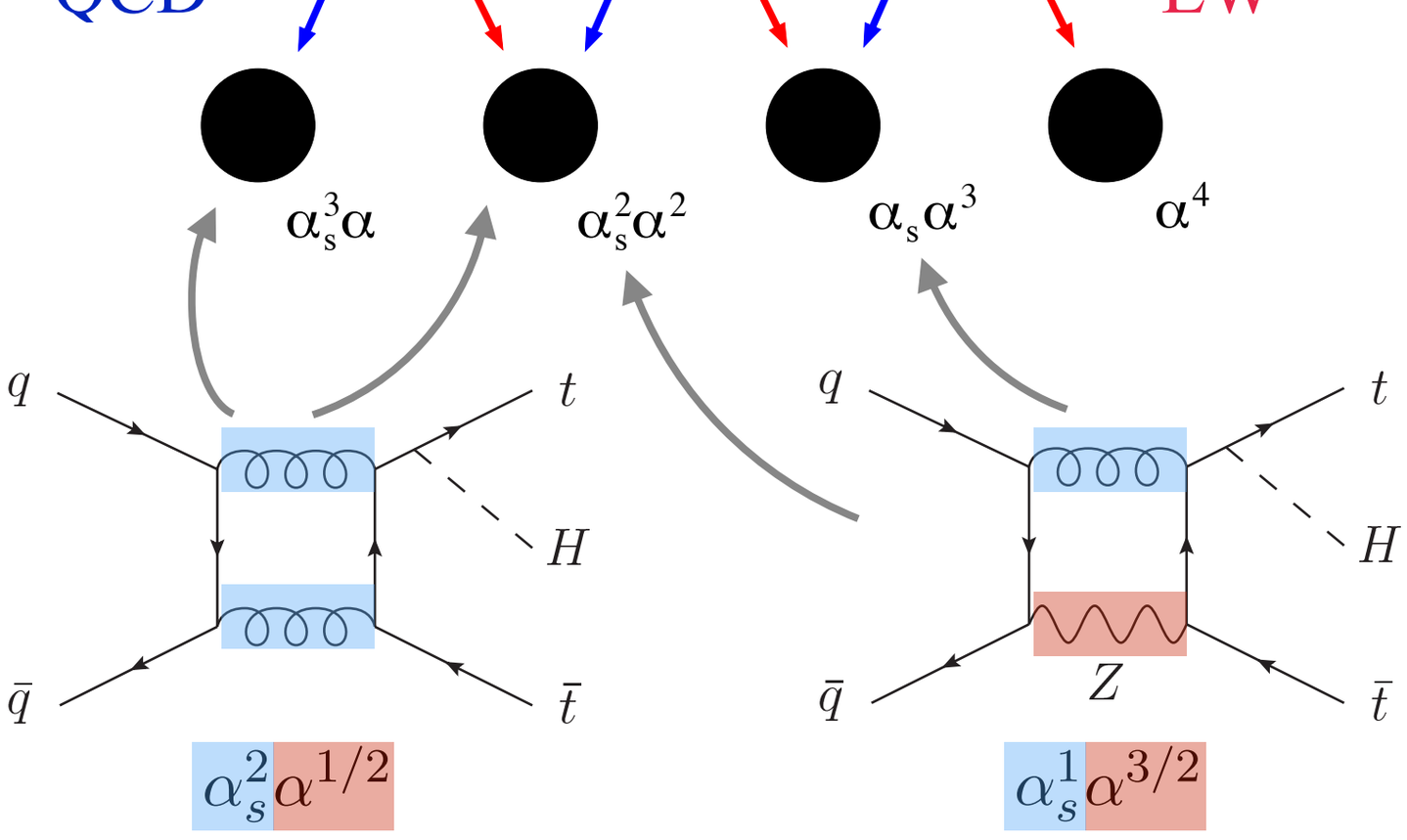




LO



NLO



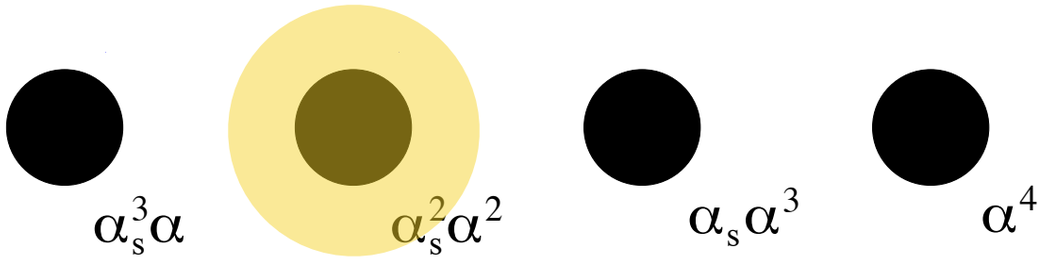
Amplitudes and matrix elements

NLO UFO models:	-SM-alpha(mZ)	(EW+QCD, Weak+QCD)
(UV CT, R2)	-SM-Gμ	(EW+QCD, Weak+QCD)

Weak = EW without photonics corrections (to be used when gauge invariant).

The matrix element calculation is completely automated.

NLO



Subprocesses

FKS assembled “by hand”, selecting IR regions.

$gg \to t\bar{t}H$ IR finite

$q\bar{q} \to t\bar{t}H$ Soft QCD divergencies, NO Coll.

$q\bar{q} \to t\bar{t}Hg$ Soft QCD divergencies, NO Coll.

$qg \to t\bar{t}Hq$ IR finite

Heavy Boson Radiation (HBR)

$pp \to t\bar{t}H + V$

$V = H, W, Z$

Formally of order $\alpha_S^2\alpha^2$

Numerical results

Inclusive rates

(Boosted regime in brackets)

Frixione, Hirschi, DP, Shao, Zaro '14

NLO corrections

$\delta_{\rm NLO}(\%)$	8 TeV	13 TeV	100 TeV
QCD	$+25.6^{+6.2}_{-11.8}$ $(+19.6^{+3.7}_{-11.0})$	$+29.3^{+7.4}_{-11.6}$ $(+23.9^{+5.4}_{-11.2})$	$+40.4^{+9.9}_{-11.6}$ $(+39.1^{+9.7}_{-10.4})$
weak	-1.2 (-8.3)	-1.8 (-8.2)	-3.0 (-7.8)

Heavy Boson Radiation

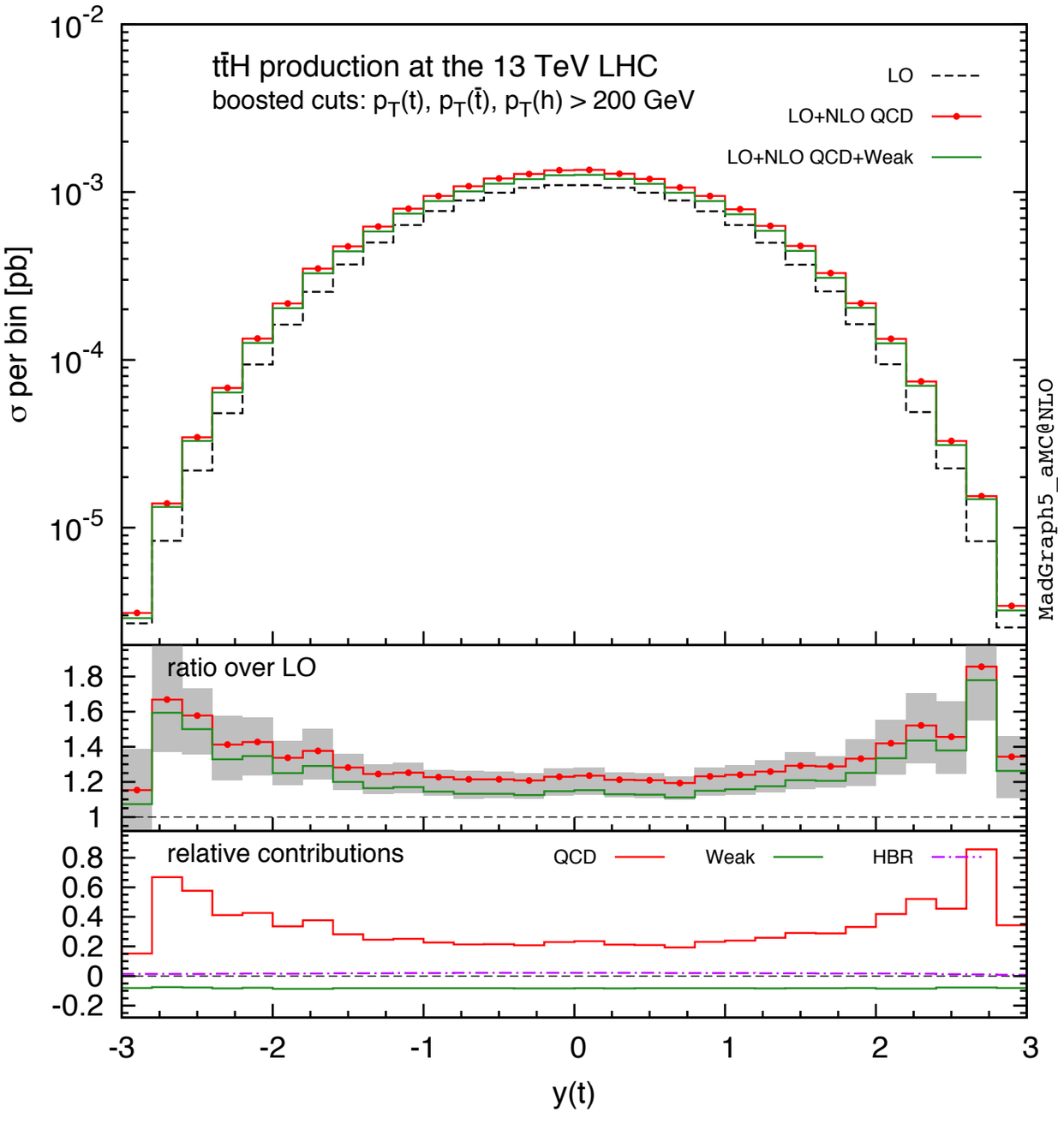
$\delta_{\rm HBR}(\%)$	8 TeV	13 TeV	100 TeV
W	$+0.42(+0.74)$	$+0.37(+0.70)$	$+0.14(+0.22)$
Z	$+0.29(+0.56)$	$+0.34(+0.68)$	$+0.51(+0.95)$
H	$+0.17(+0.43)$	$+0.19(+0.48)$	$+0.25(+0.53)$
sum	$+0.88(+1.73)$	$+0.90(+1.86)$	$+0.90(+1.70)$

Partial compensation of Sudakov logs

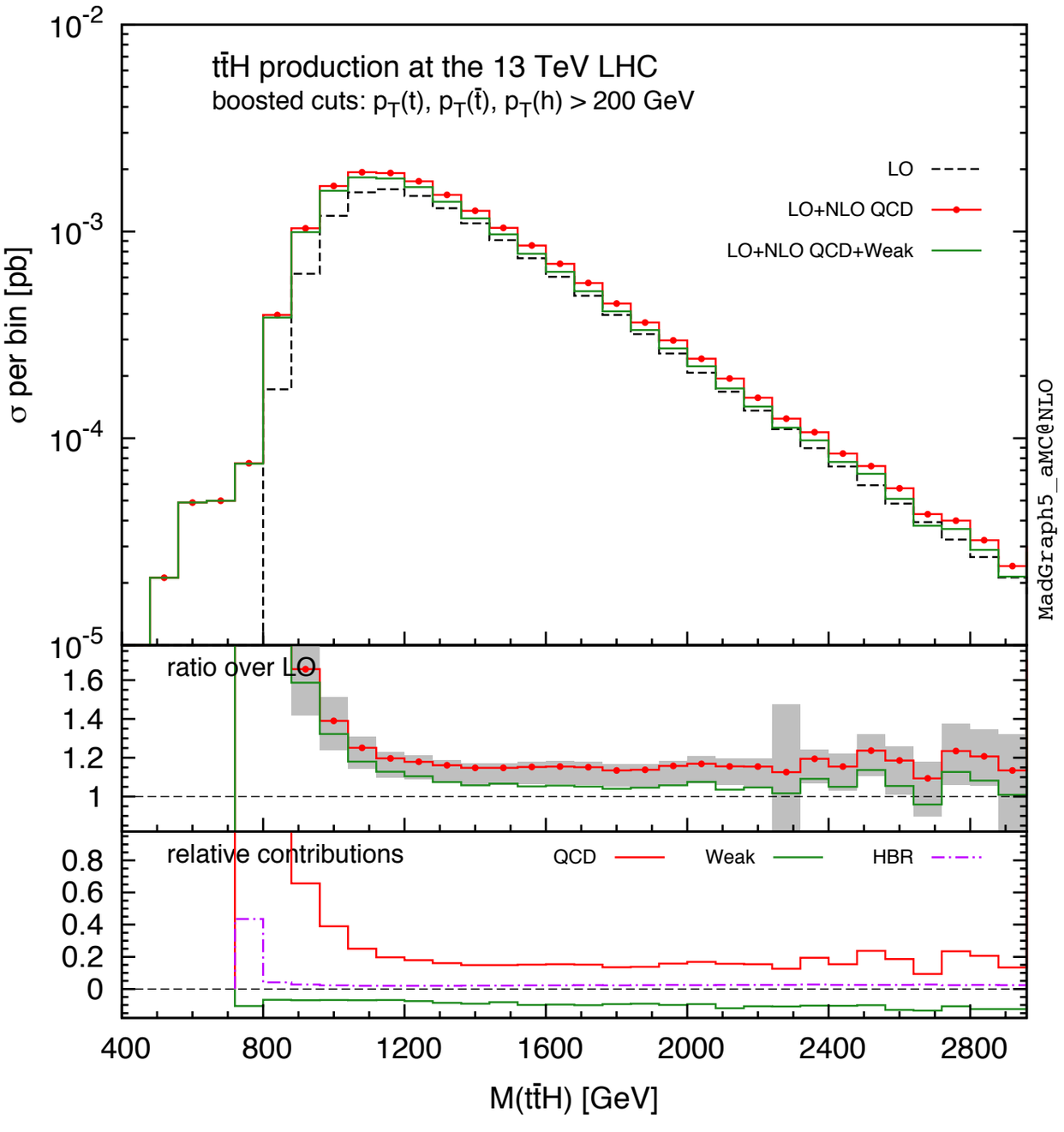
NLO weak subchannels

$\delta_{\rm NLO}(\%)$	8 TeV	13 TeV	100 TeV
gg	-0.67 (-2.9)	-1.12 (-4.0)	-2.64 (-6.8)
$u\bar{u}$	-0.01 (-3.2)	-0.15 (-2.3)	-0.10 (-0.5)
$d\bar{d}$	-0.55 (-2.2)	-0.52 (-1.9)	-0.23 (-0.5)

Distributions: boosted regime at 13 TeV

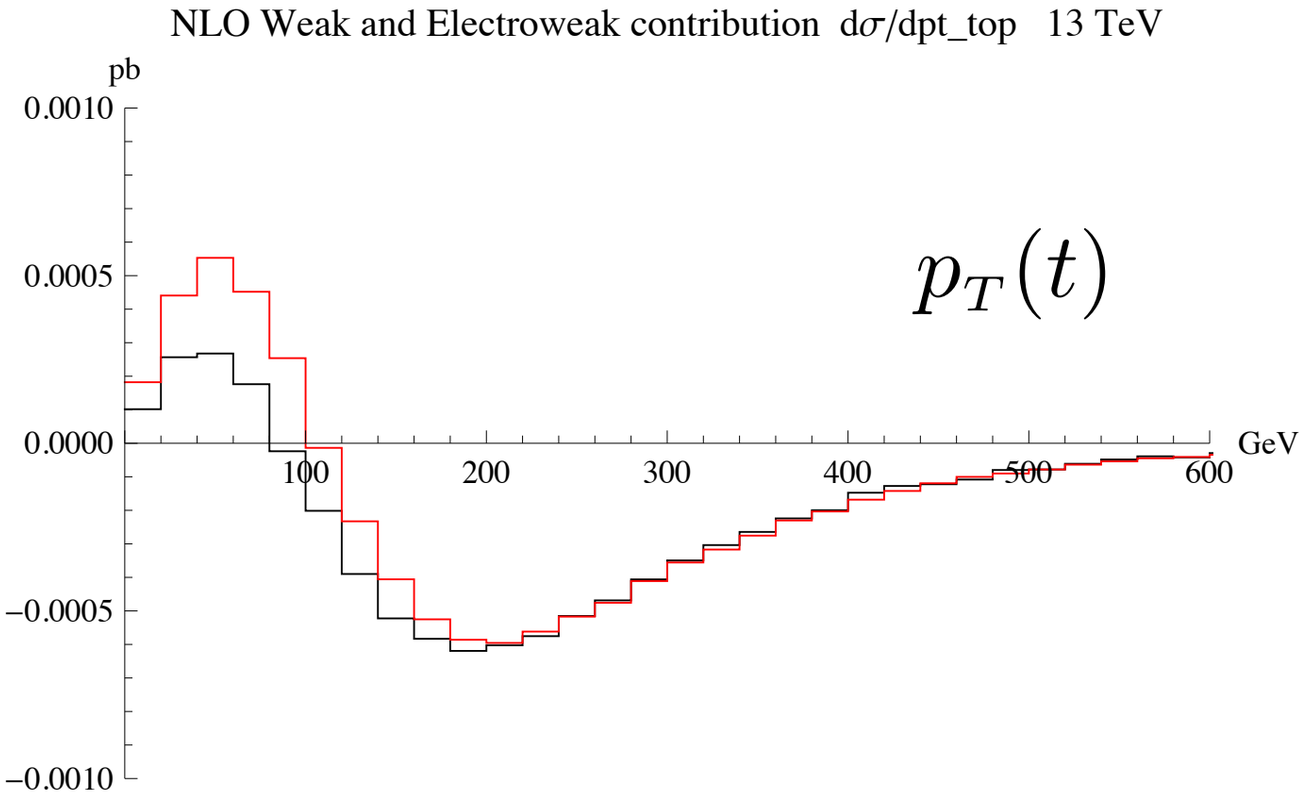


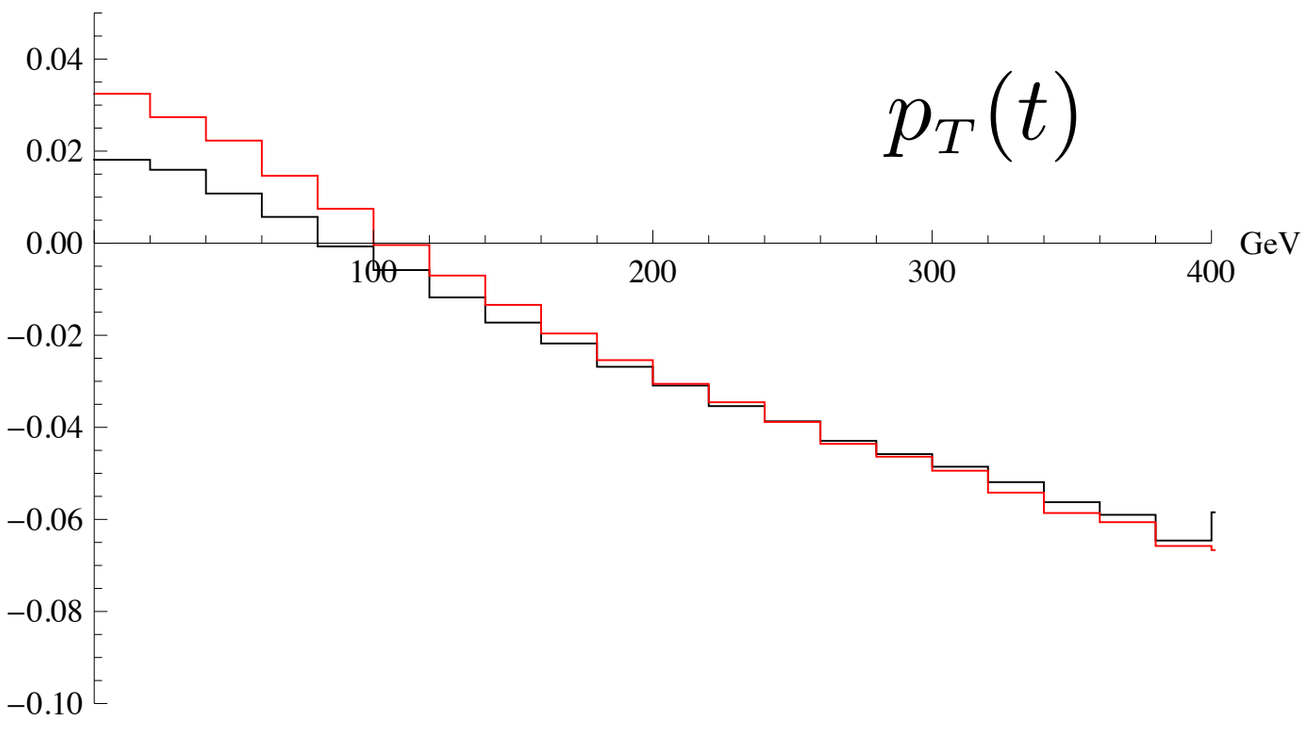
13 TeV



13 TeV

Electroweak vs. Weak corrections





Weak (-1.8 %)
(4/5 months of work)

ElectroWeak (-1.3 %)

```
import model loop_qcd_qed_SM
generate p p > t t~ h [QED]
output ttbarH_QED
```

Very preliminary results:
initial states with photons
are missing.