The automation of the electroweak corrections in Madgraph5_aMC@NLO

in collaboration with S. Frixione, V. Hirschi, H. -S. Shao and M. Zaro,
based on JHEP09(2014)065 (arXiv:1407.0823) and forthcoming works

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Madgraph5_aMC@NLO Femto Workshop
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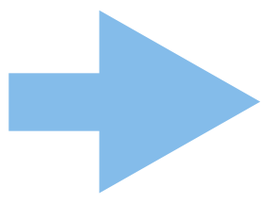
Automation of NLO corrections in Madgraph5_aMC@NLO

What do we mean with automation of EW corrections?

The possibility of calculating QCD and EW corrections for SM processes (matched to shower effects) with a process-independent approach.

```
generate process [QCD]
output process_QCD
```



```
generate process [QCD EW]
output process_QCD_EW
```

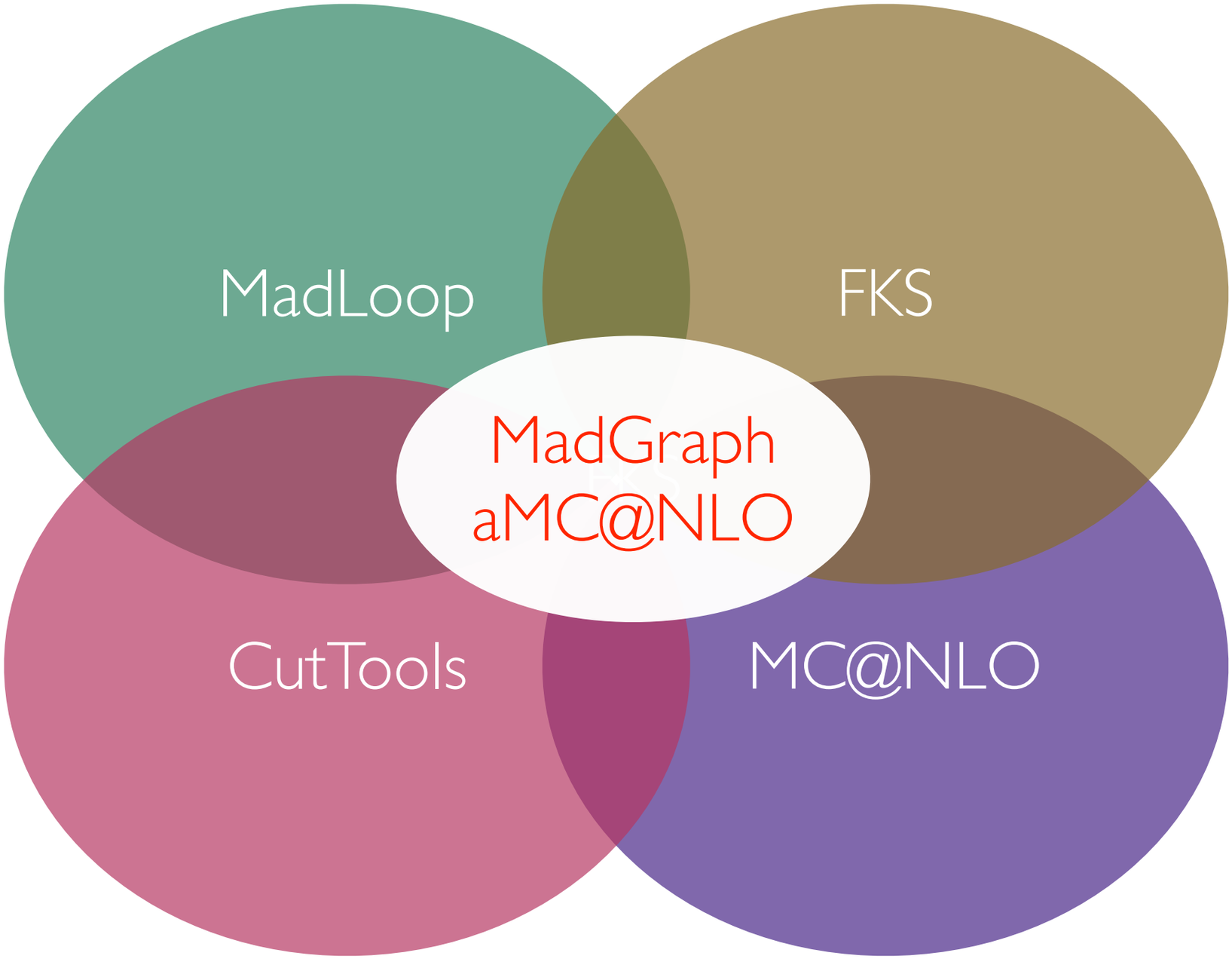
The automation of NLO QCD is a solved problem, but we need higher precision to match the experimental accuracy at the LHC and future colliders.

- NNLO QCD automation is out of our theoretical capabilities at the moment.
- NLO EW corrections are of the same order ($\alpha_s^2 \sim \alpha$), the Sudakov logarithms can enhance their size. NLO QCD and EW corrections **can be automated.**

In this talk I will discuss the structure of NLO QCD and EW corrections.
I will present the first *completely automated* NLO QCD and EW calculations.

Automation of NLO corrections in Madgraph5_aMC@NLO

The **complete automation** has already been achieved for **QCD**.

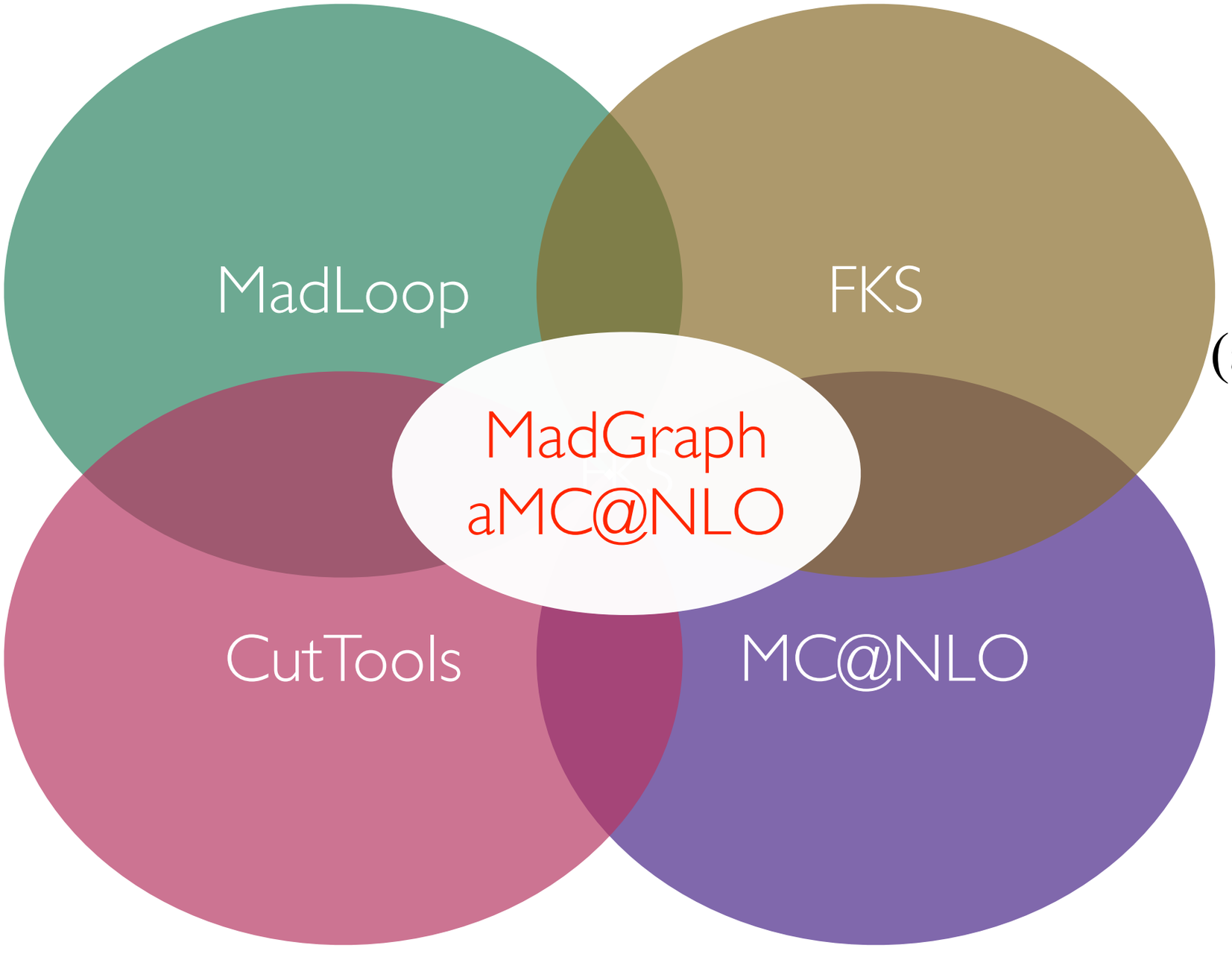


Alwall, Frederix, Frixione, Hirschi, Maltoni, Mattelaer, Shao, Stelzer, Torrielli, Zaro ‘14

Automation of NLO corrections in Madgraph5_aMC@NLO

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

DONE!



in progress
(almost DONE)

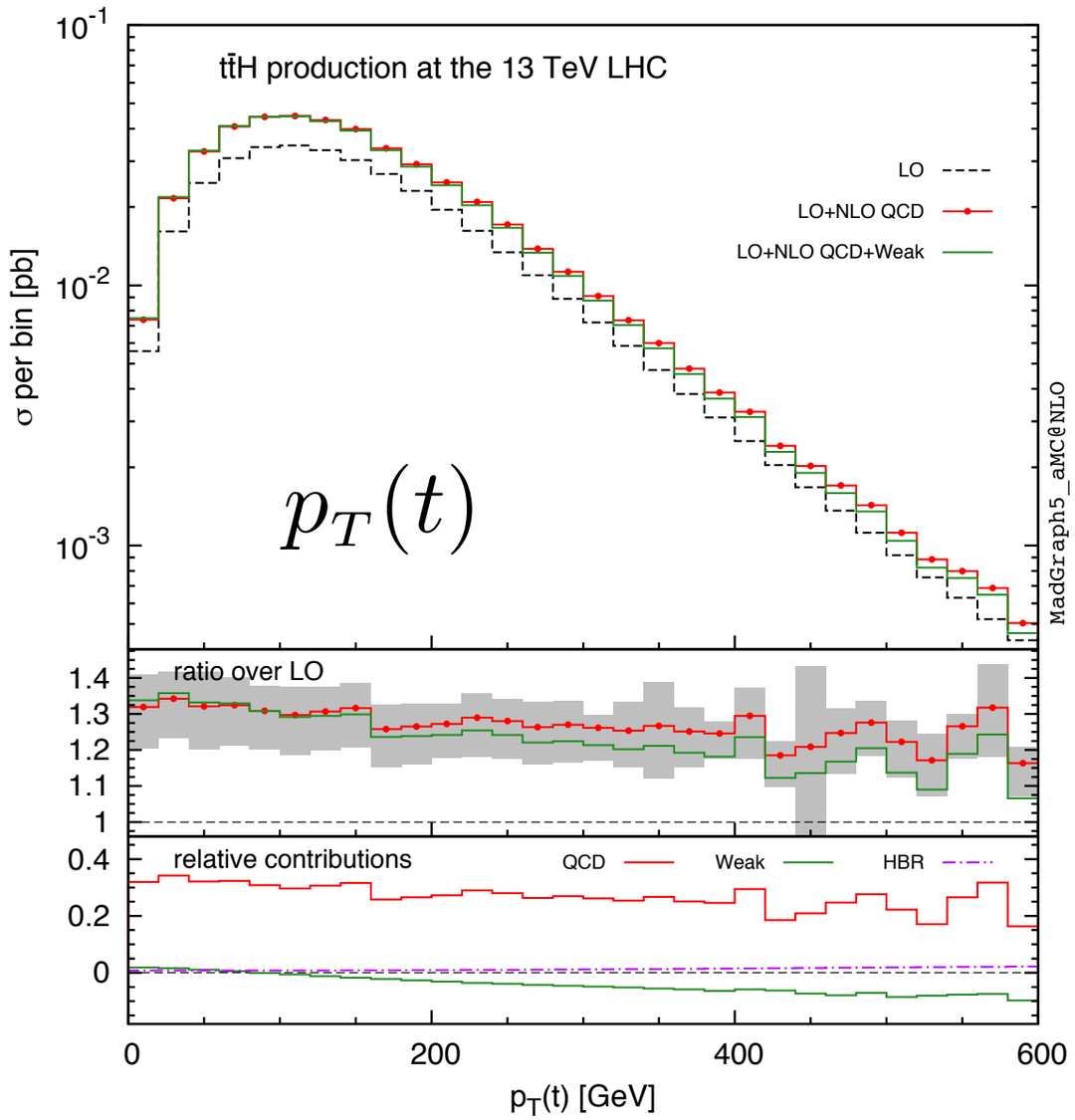
DONE!

in progress

Pheno studies

NLO purely Weak and QCD corrections to $t\bar{t}H$ production have been produced "assembling by hand" the FKS counterterms.

Frixione, Hirschi, DP, Shao, Zaro '14



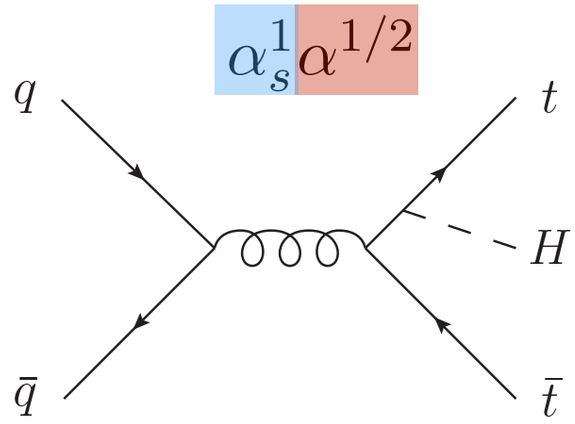
Now, for the complete NLO QCD and EW corrections, with photon in the initial state, we need to type:

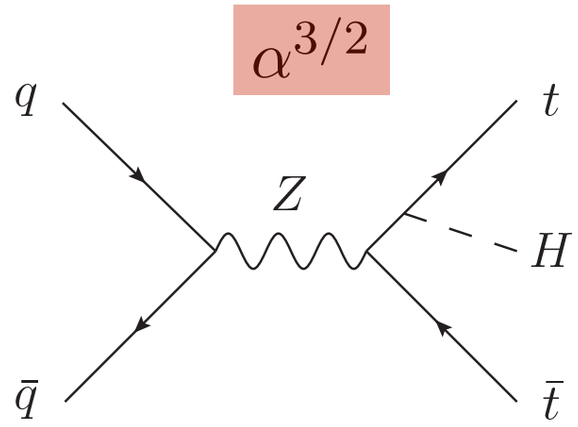
```
define p = p b b~ a
generate p p > t t~ h [QCD QED]
output ttbarh_QCD_QED
```

In this talk I will present results for NLO QCD and EW corrections to

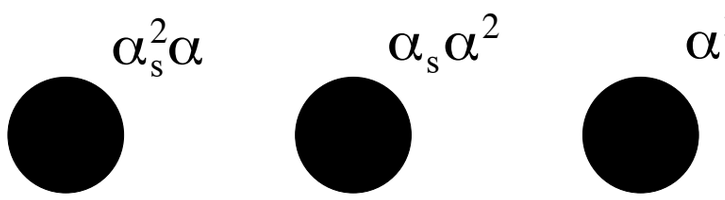
$t\bar{t}V \qquad V = H, W, Z$

Structure of NLO EW-QCD corrections



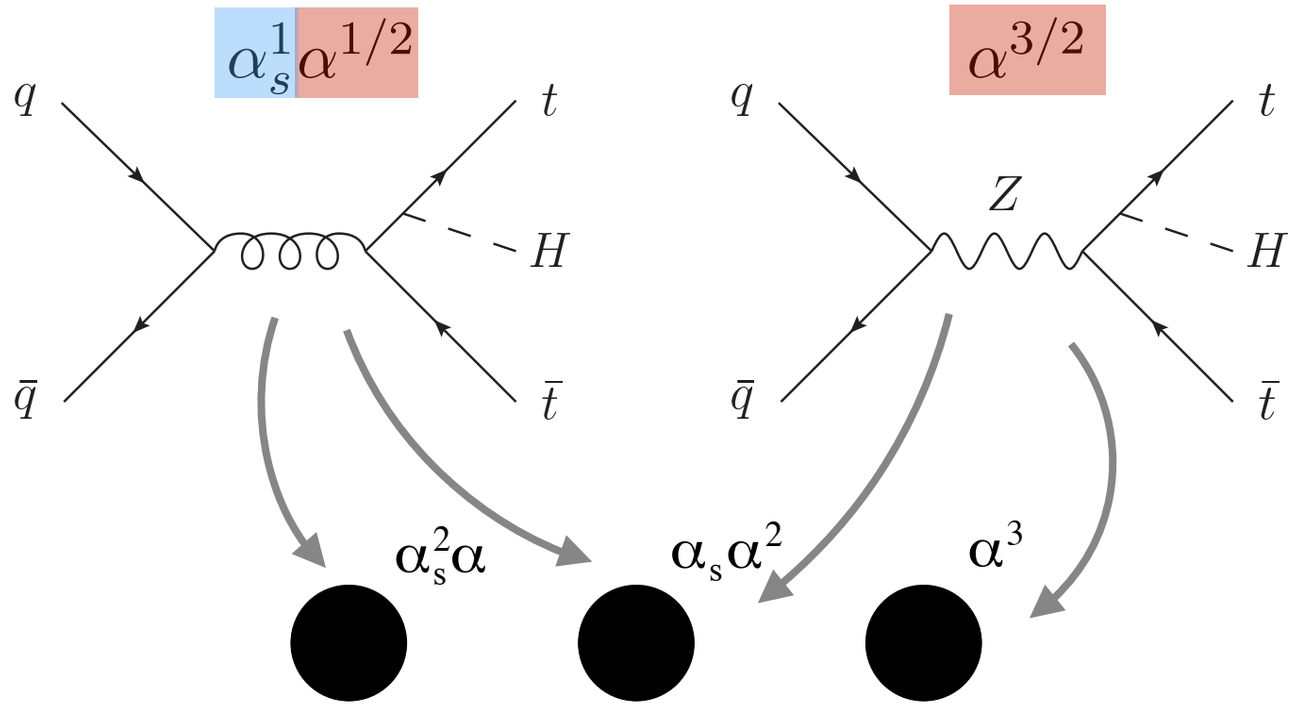


LO



Structure of NLO EW-QCD corrections

LO



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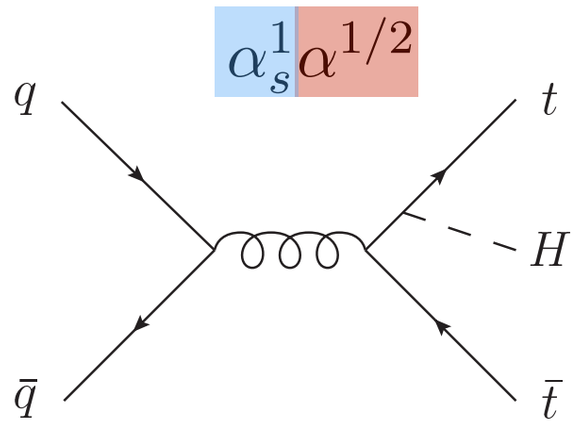
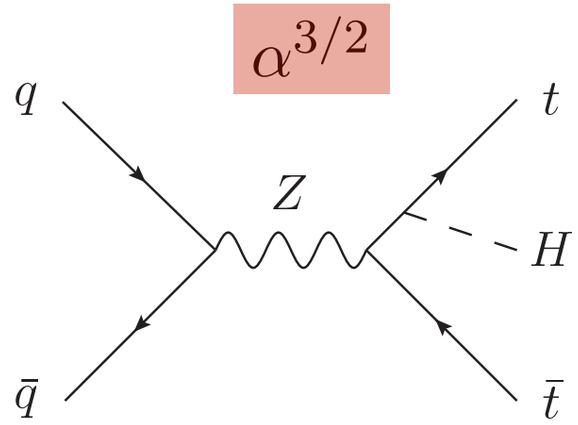
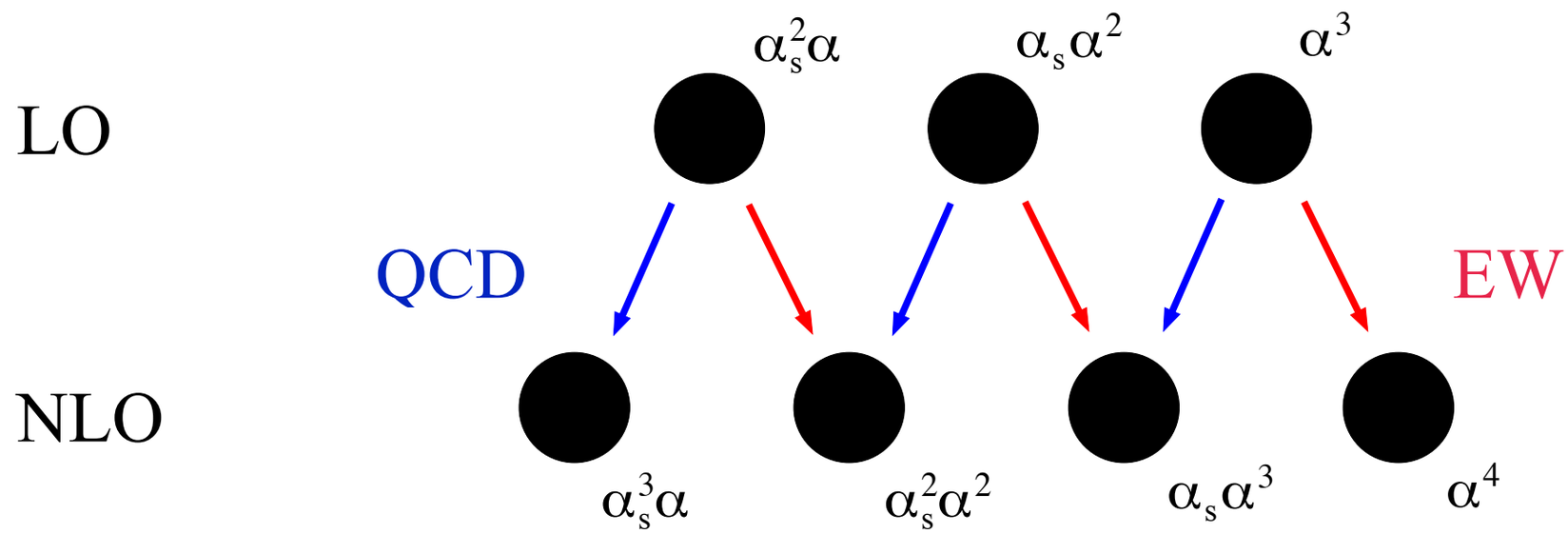
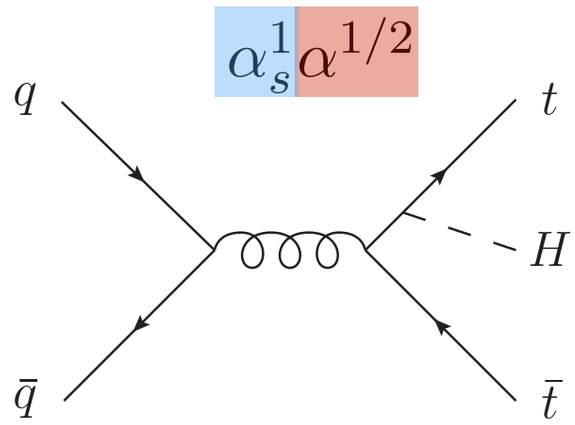
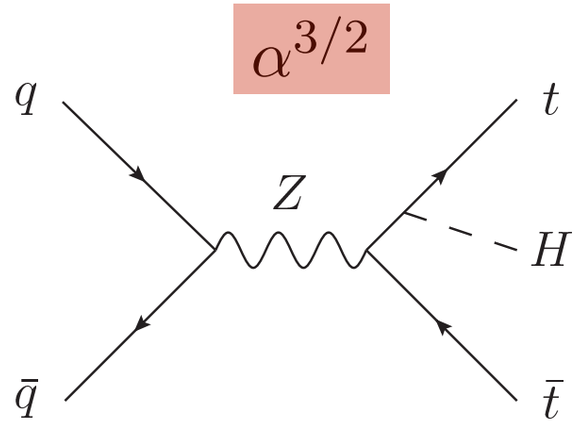




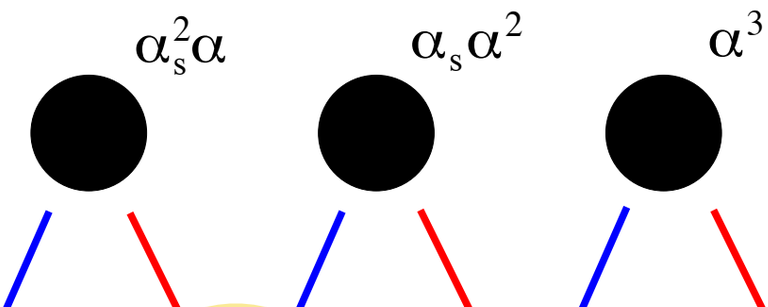


Structure of NLO EW-QCD corrections





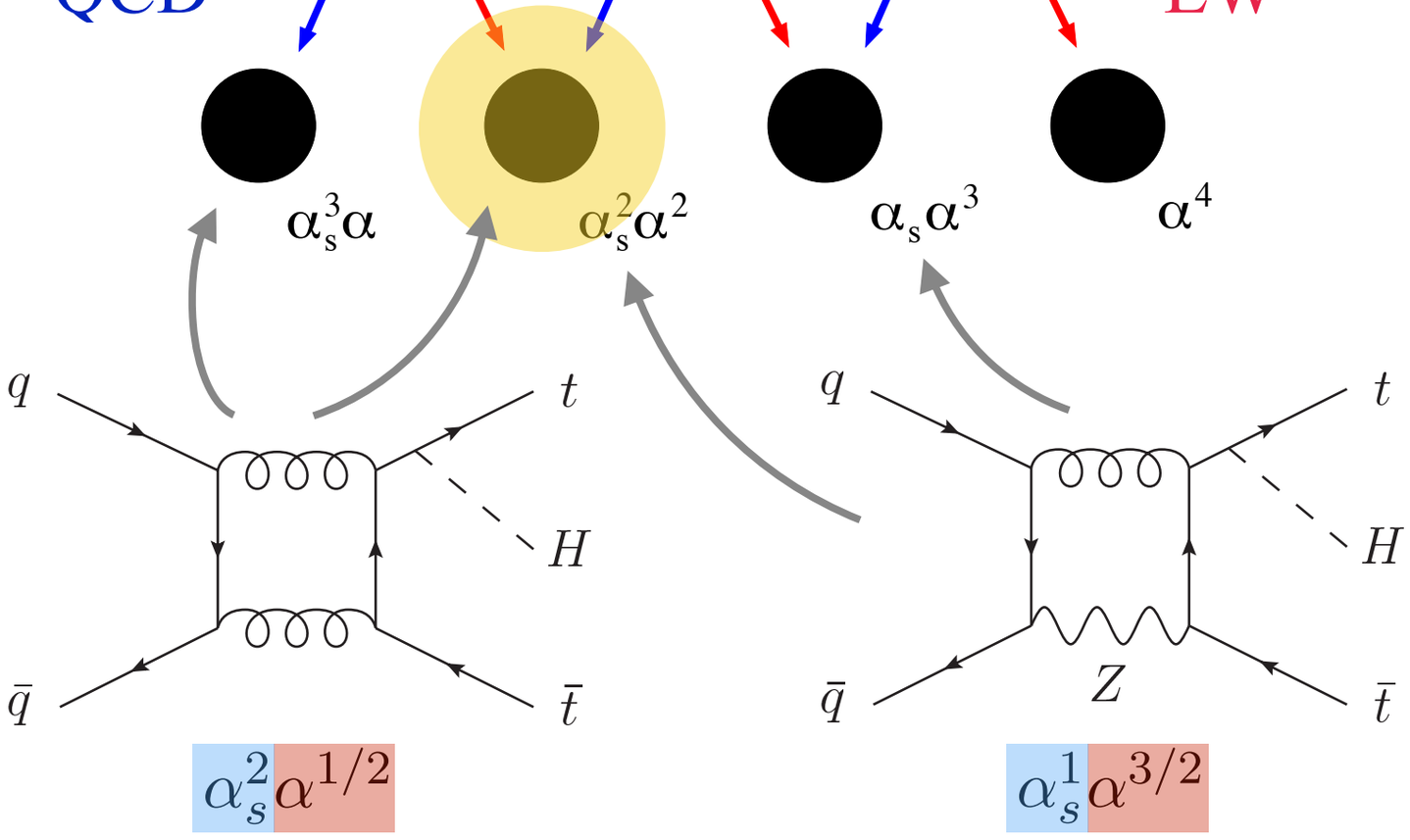
LO



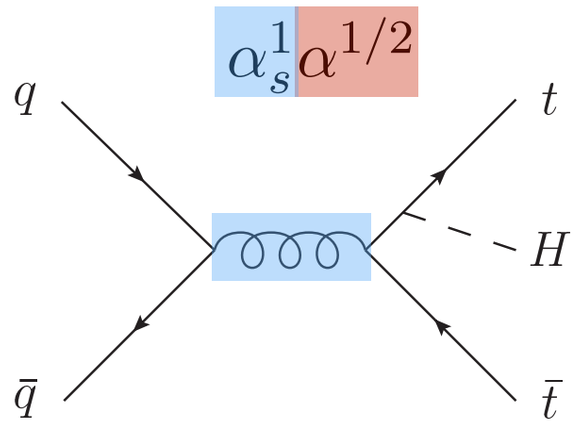
QCD

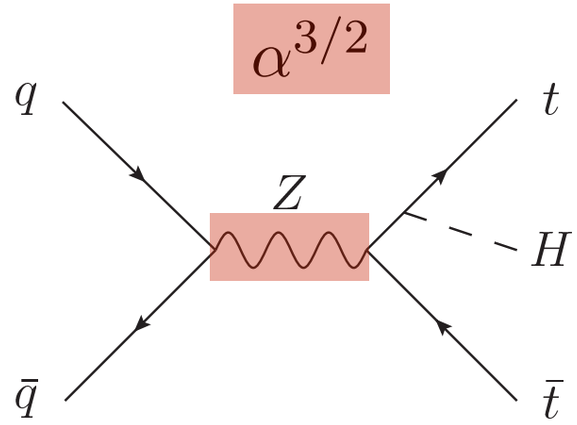
EW

NLO

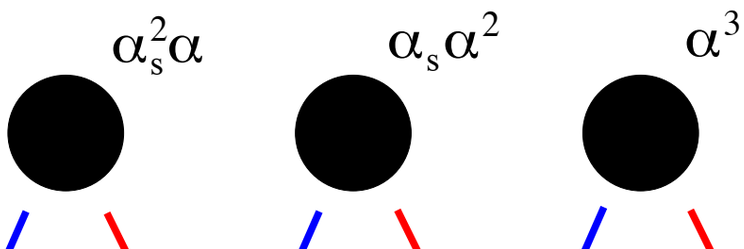


Structure of NLO EW-QCD corrections





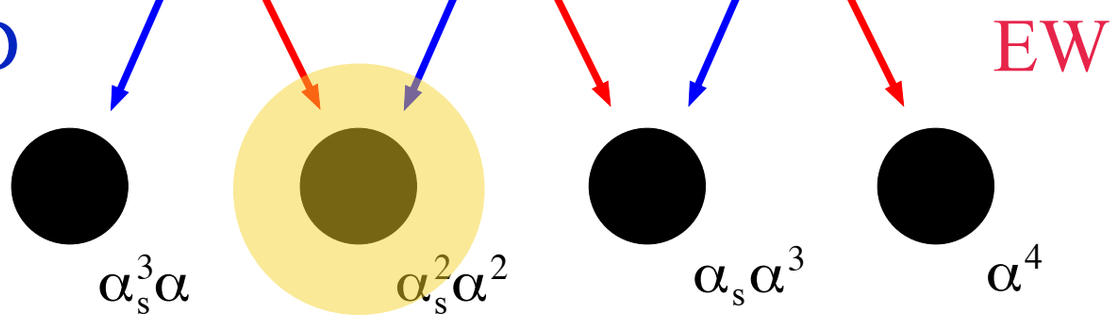
LO

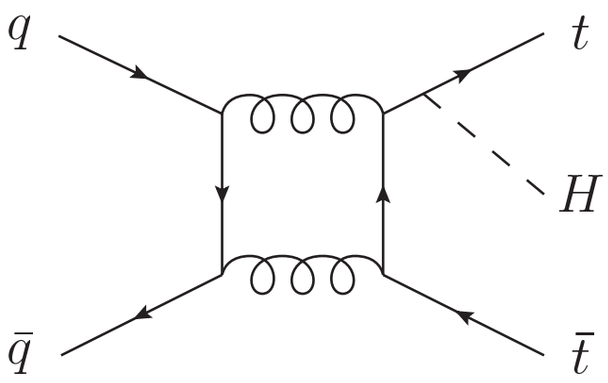


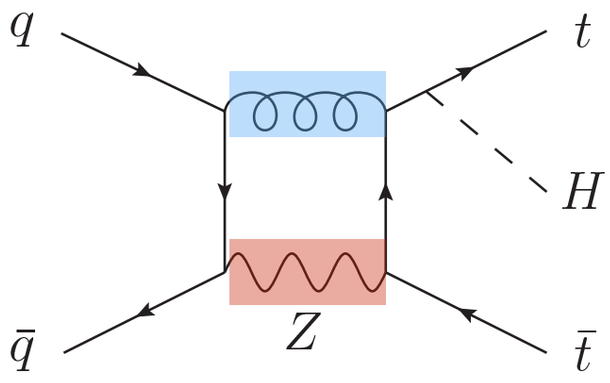
QCD

EW

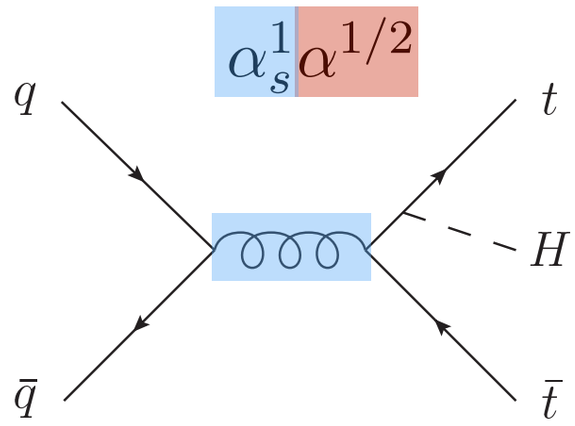
NLO

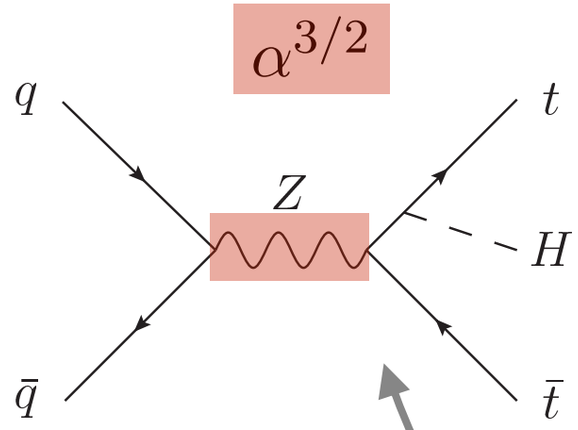






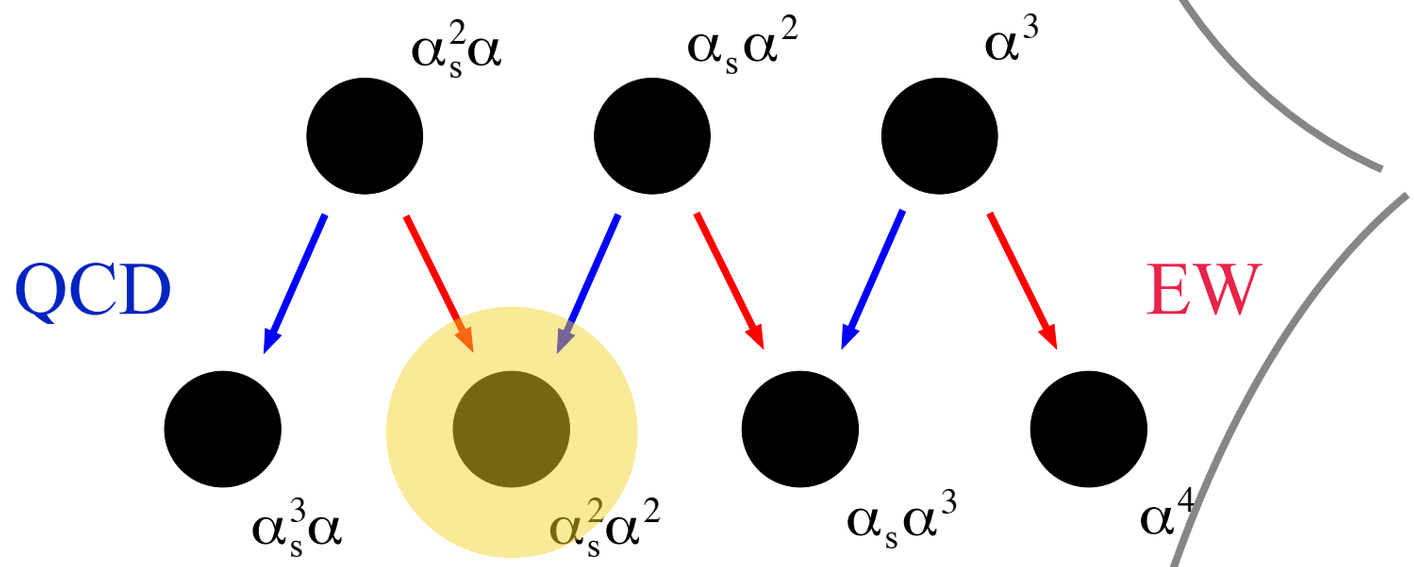
Structure of NLO EW-QCD corrections



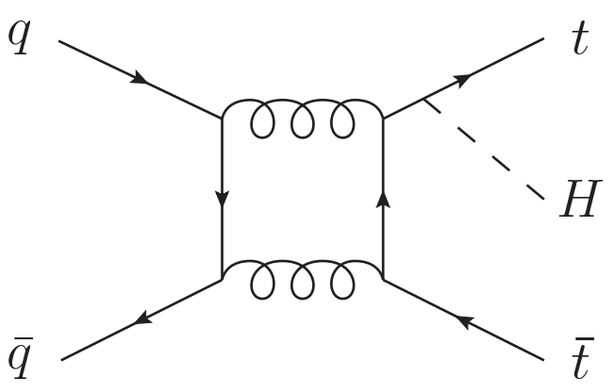


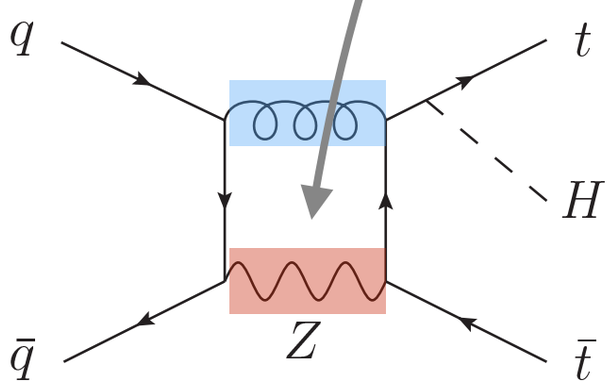
LO

NLO



If it is a photon there are new IR singularities





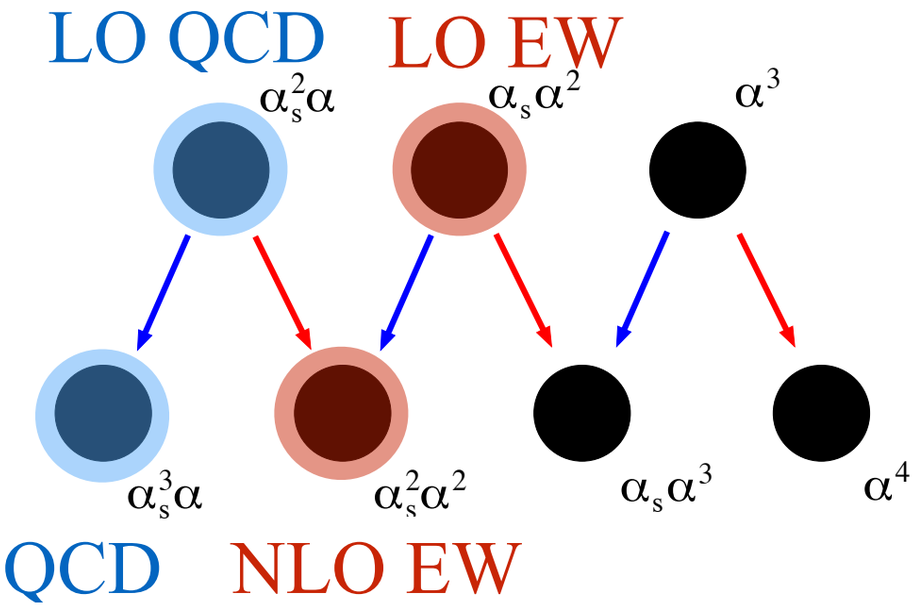
$t\bar{t}V$ production: numerical results

Alpha(mZ)-scheme, NNPDF2.3_QED, $\mu = \dfrac{H_T}{2}, \qquad \dfrac{1}{2}\mu \leq \mu_R, \mu_F \leq 2\mu$

Contributions

HBR ($pp \to t\bar{t}V + V'$) is of the same order of NLO EW.

Photon PDF (with large uncertainties) enters in LO EW and NLO EW.



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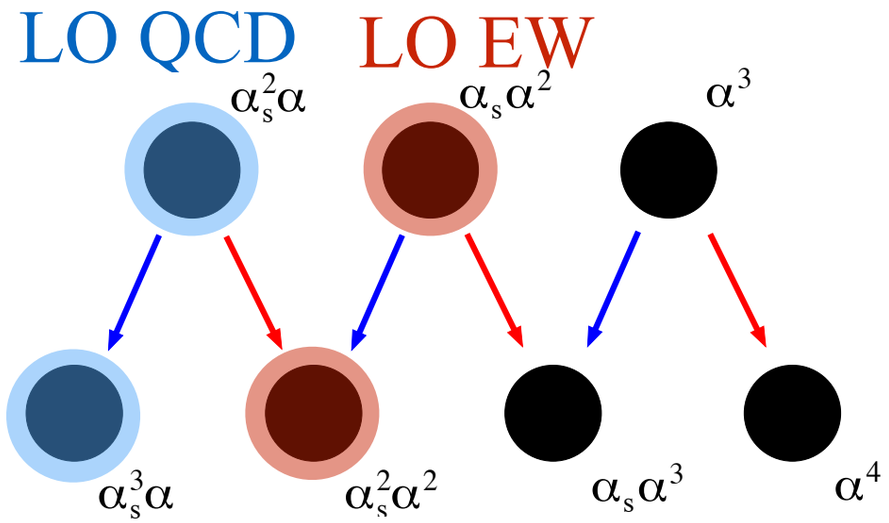


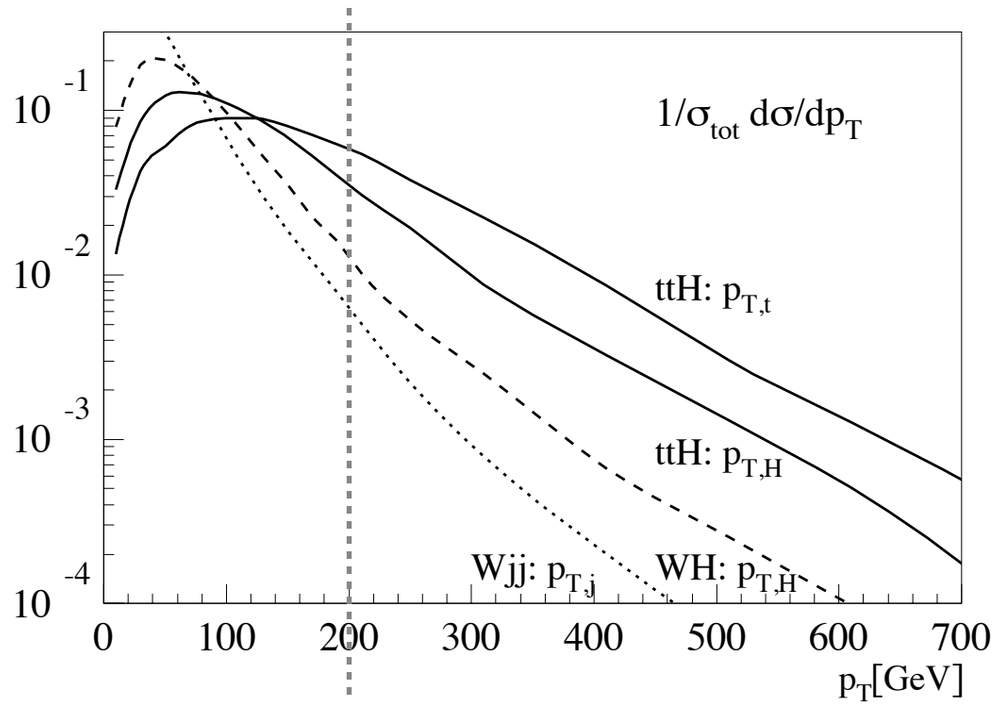
Boosted regime

$p_T(t) \geq 200\ \text{GeV}, \qquad p_T(\bar{t}) \geq 200\ \text{GeV}, \qquad p_T(H) \geq 200\ \text{GeV}$

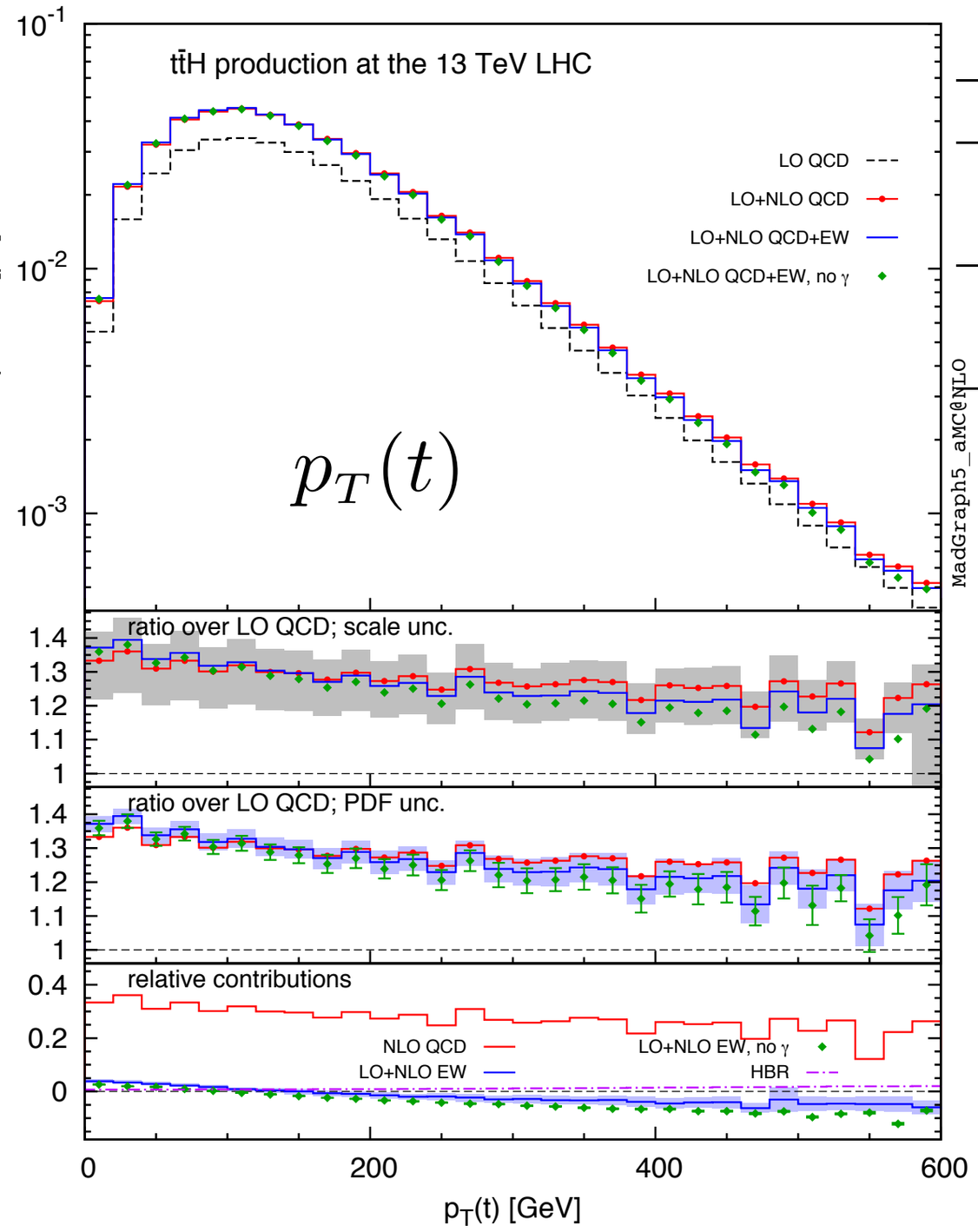
S/B increases for boosted tops and Higgs.

Plehn, Salam, Spannowsky '10

Sudakov logs are relevant in these regions!



Numerical results



$t\bar{t}H$: $\delta(\%)$	8 TeV	13 TeV	100 TeV
NLO QCD	$25.9^{+5.4}_{-11.1}$	$29.7^{+6.8}_{-11.1}$ $(24.2^{+4.8}_{-10.6})$	$40.8^{+9.3}_{-9.1}$
LO EW	1.8 ± 1.3	1.2 ± 0.9 (2.8 ± 2.0)	0.0 ± 0.2
LO EW no γ	-0.3 ± 0.0	-0.4 ± 0.0 (-0.2 ± 0.0)	-0.6 ± 0.0
NLO EW	-0.6 ± 0.1	-1.2 ± 0.1 (-8.2 ± 0.3)	-2.7 ± 0.0
NLO EW no γ	-0.7 ± 0.0	-1.4 ± 0.0 (-8.5 ± 0.2)	-2.7 ± 0.0
HBR	0.88	0.89 (1.87)	0.91

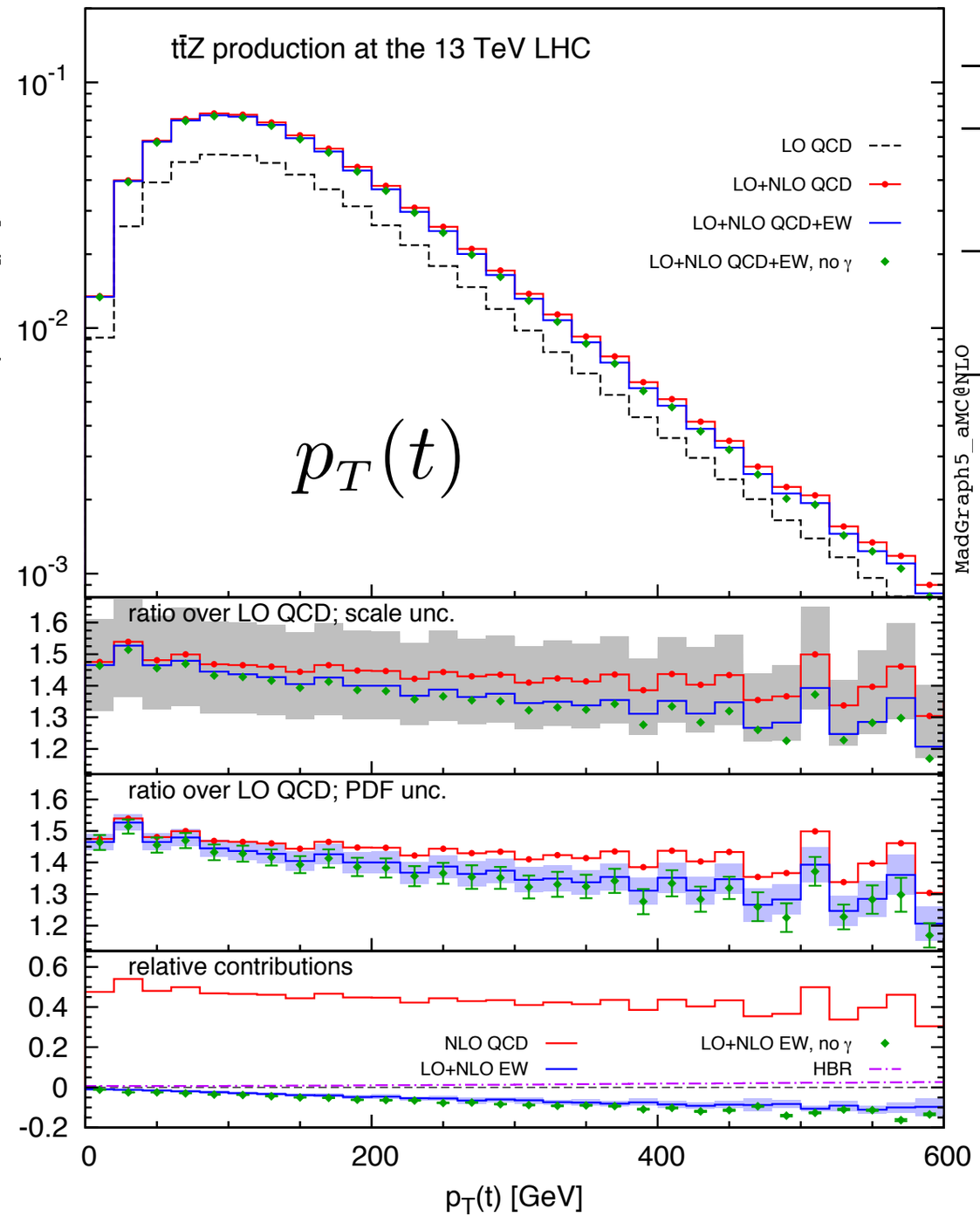
(Boosted regime in brackets)

Scale variation

(NLO QCD+EW) PDF var.

$t\bar{t}H$

Numerical results



$t\bar{t}Z$: $\delta(\%)$	8 TeV	13 TeV	100 TeV
NLO QCD	$43.2^{+12.8}_{-15.9}$	$45.9^{+13.2}_{-15.5}$ $(40.2^{+11.1}_{-15.0})$	$50.4^{+11.4}_{-10.9}$
LO EW	0.5 ± 0.9	0.0 ± 0.7 (2.1 ± 1.6)	-1.1 ± 0.2
LO EW no γ	-0.8 ± 0.1	-1.1 ± 0.0 (-0.3 ± 0.0)	-1.6 ± 0.0
NLO EW	-3.3 ± 0.3	-3.8 ± 0.2 (-11.1 ± 0.5)	-5.2 ± 0.1
NLO EW no γ	-3.7 ± 0.1	-4.1 ± 0.1 (-11.5 ± 0.3)	-5.4 ± 0.0
HBR	0.95	0.96 (2.13)	0.85

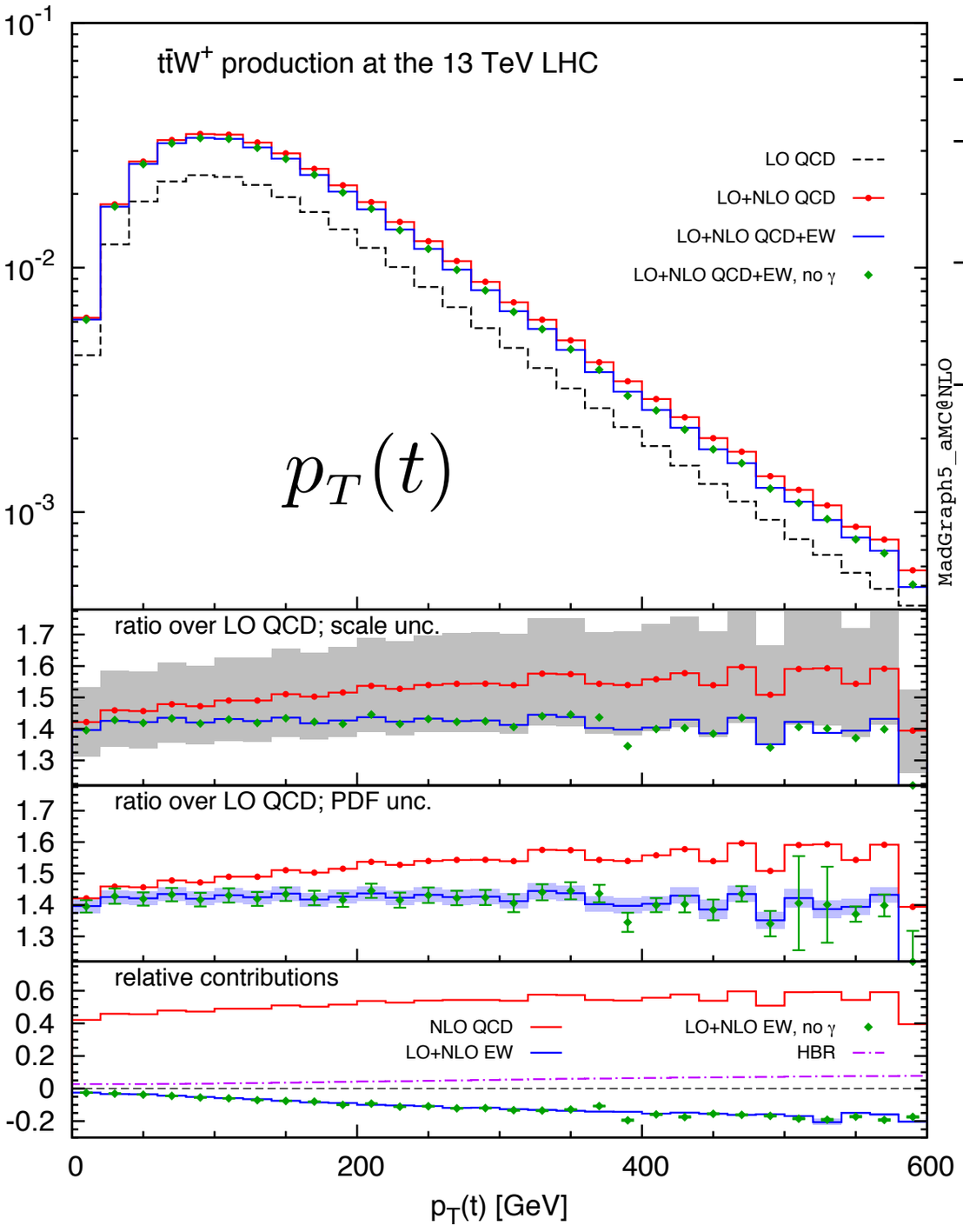
(Boosted regime in brackets)

Scale variation

(NLO QCD+EW) PDF var.

$t\bar{t}Z$

Numerical results



$t\bar{t}W^+$: $\delta(\%)$	8 TeV	13 TeV	100 TeV
NLO QCD	$40.8^{+11.2}_{-12.3}$	$50.1^{+14.2}_{-13.5}$ $(59.7^{+18.9}_{-17.7})$	$156.4^{+38.3}_{-35.0}$
LO EW	0	0	0
LO EW no γ	0	0	0
NLO EW	-6.9 ± 0.2	-7.7 ± 0.2 (-19.2 ± 0.7)	-9.3 ± 0.2
NLO EW no γ	-7.1 ± 0.2	-8.0 ± 0.2 (-20.0 ± 0.5)	-9.6 ± 0.1
HBR	2.41	3.88 (7.41)	21.52

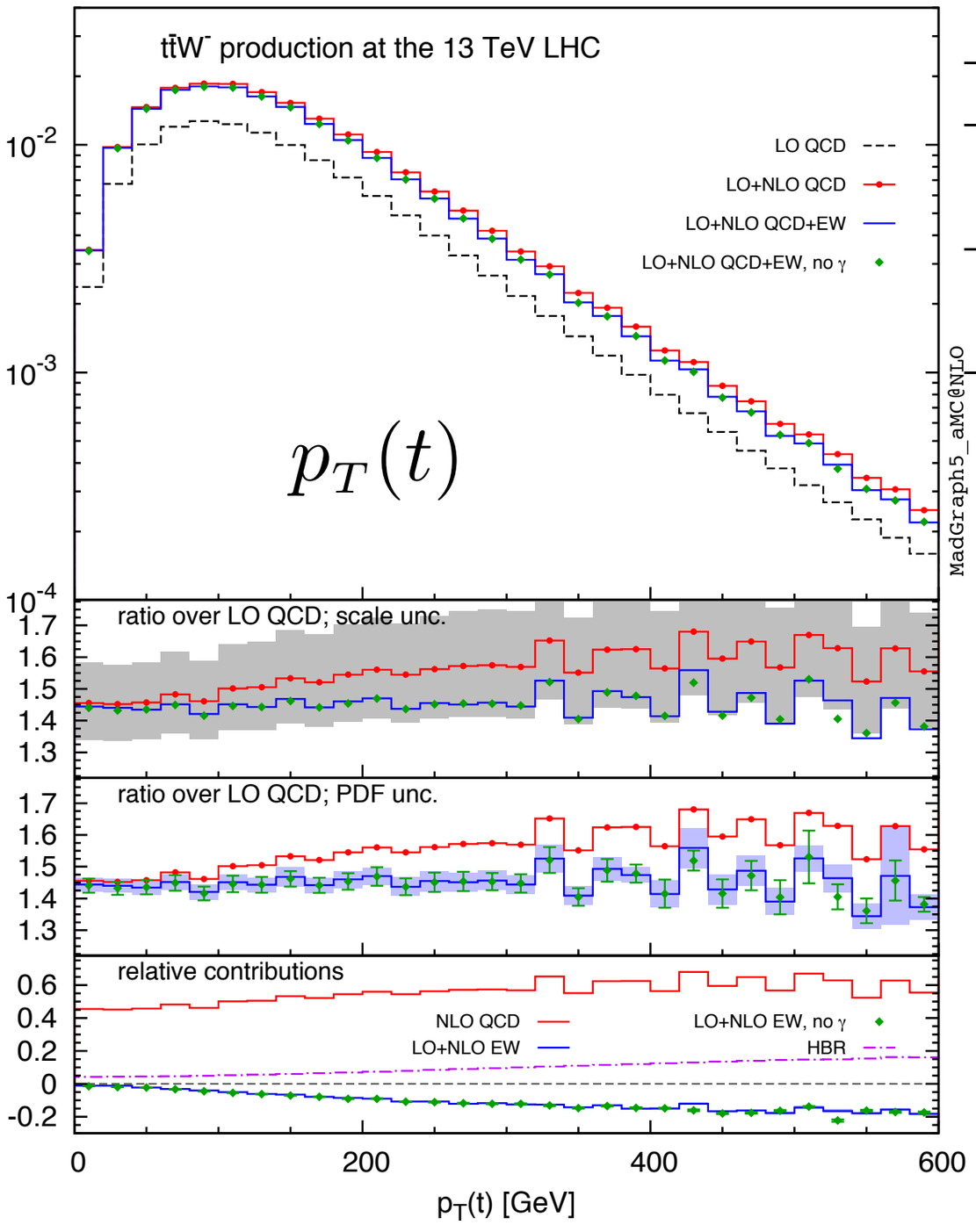
(Boosted regime in brackets)

Scale variation

(NLO QCD+EW) PDF var.

$t\bar{t}W^+$

Numerical results



$t\bar{t}W^-$: $\delta(\%)$	8 TeV	13 TeV	100 TeV
NLO QCD	$42.2^{+11.9}_{-12.7}$	$51.5^{+14.8}_{-13.8}$ $(66.3^{+21.7}_{-19.6})$	$153.6^{+37.7}_{-34.9}$
LO EW	0	0	0
LO EW no γ	0	0	0
NLO EW	-6.0 ± 0.3	-6.7 ± 0.2 (-18.3 ± 0.8)	-8.5 ± 0.2
NLO EW no γ	-6.2 ± 0.2	-7.0 ± 0.2 (-19.1 ± 0.6)	-8.8 ± 0.1
HBR	4.35	6.50 (15.01)	28.91

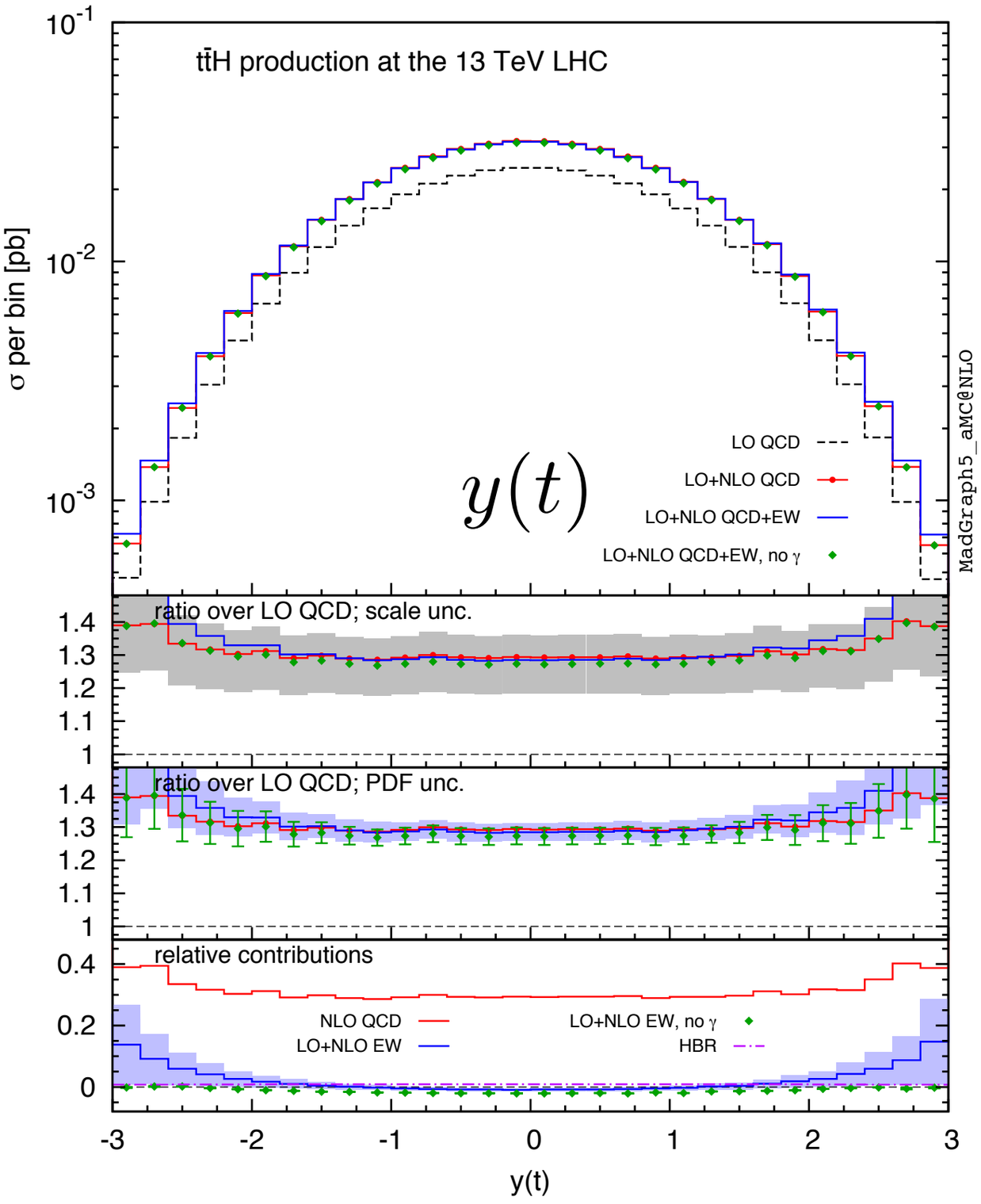
(Boosted regime in brackets)

Scale variation

(NLO QCD+EW) PDF var.

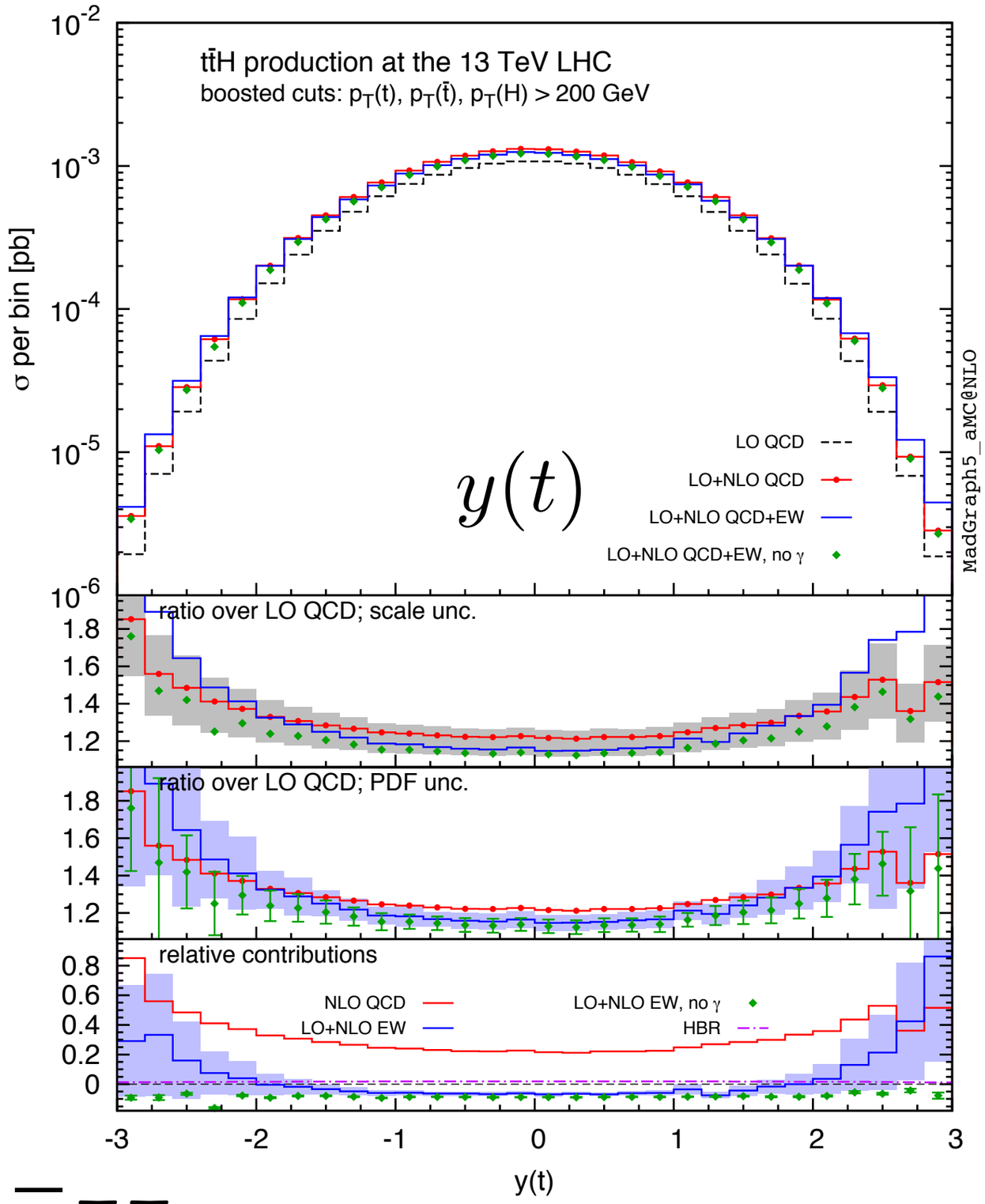
$t\bar{t}W^-$

Rapidity distributions: unboosted vs. boosted



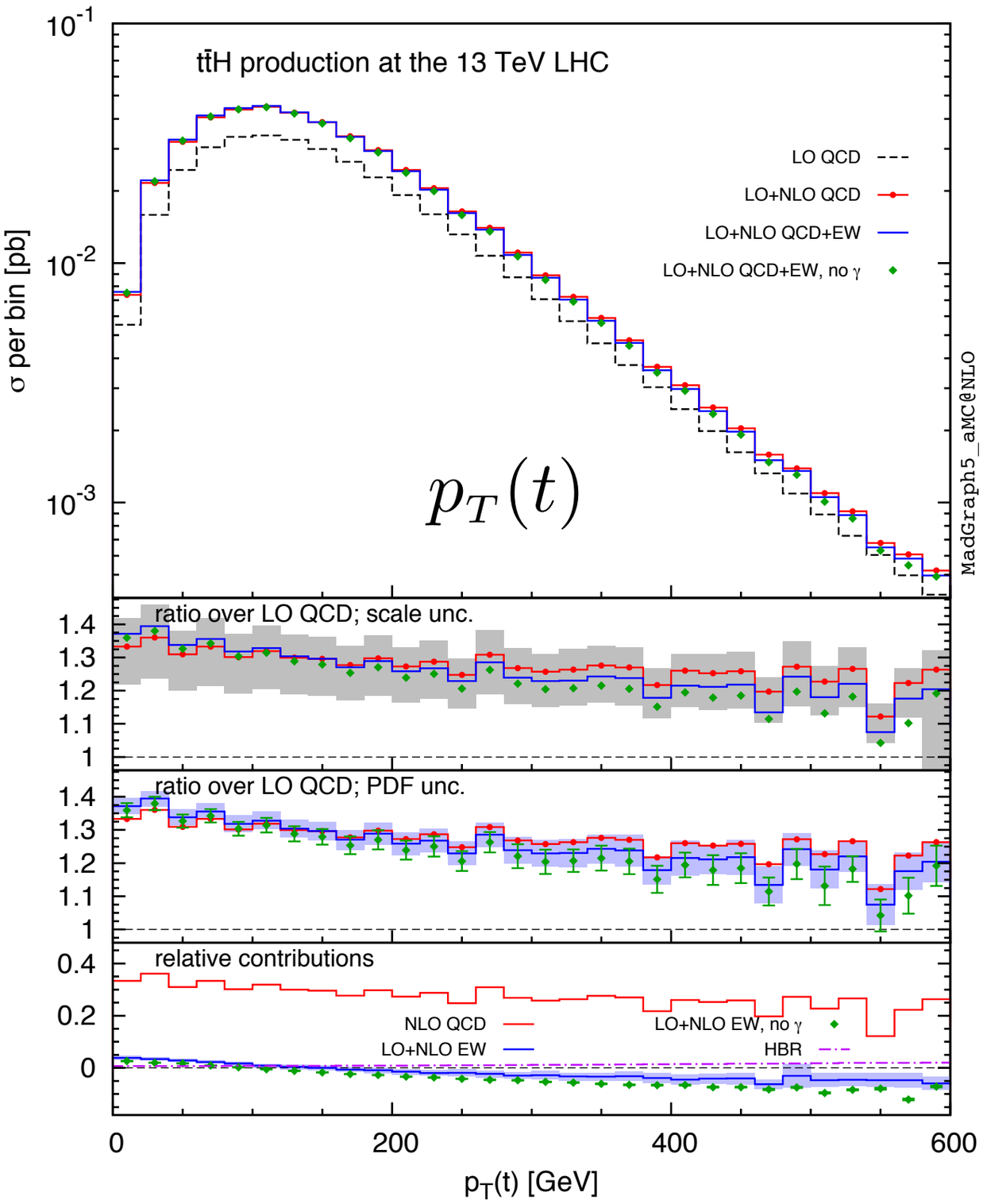
13 TeV

$t\bar{t}H$



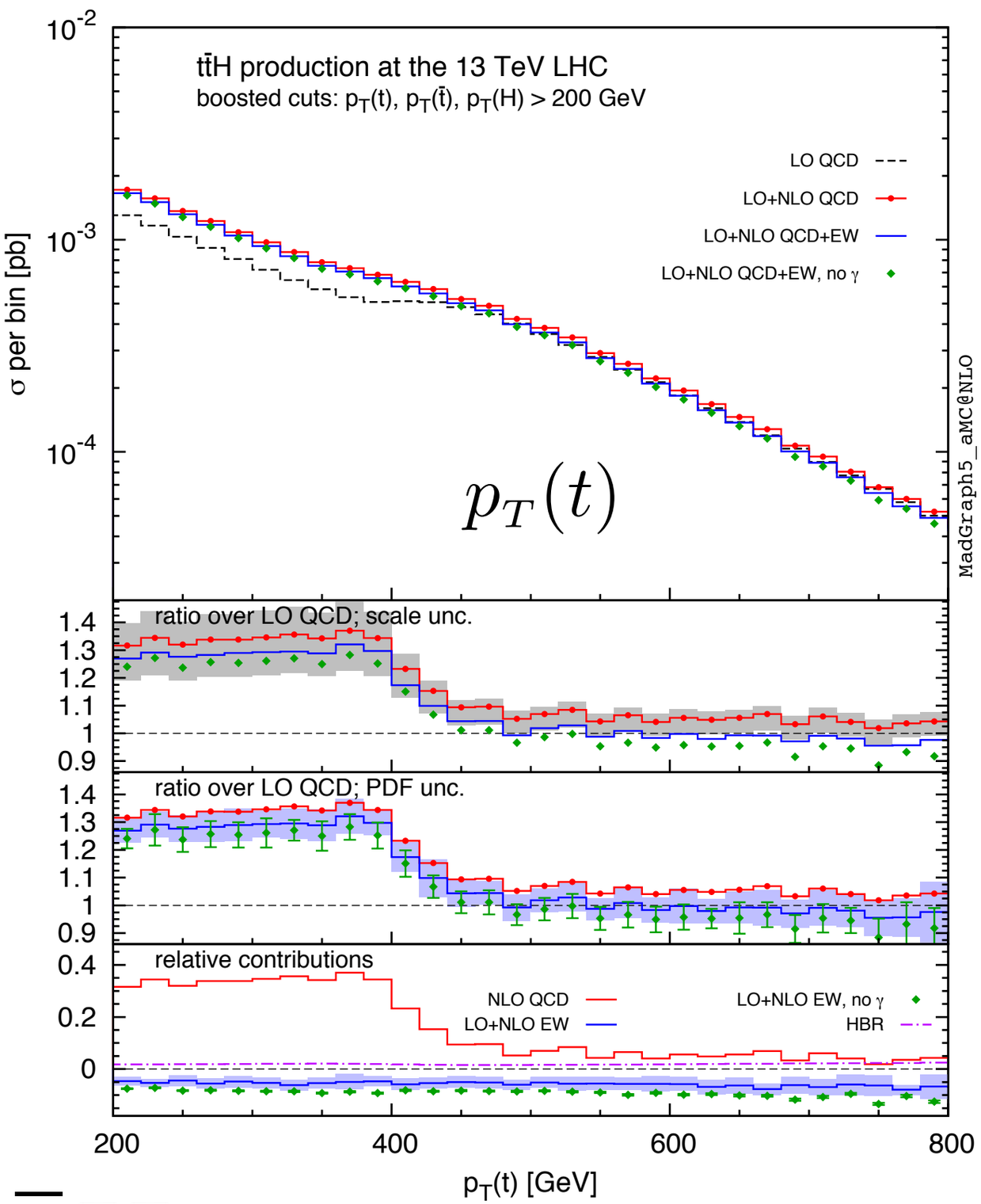
13 TeV

transverse momentum distributions: unboosted vs. boosted



13 TeV

$t\bar{t}H$



13 TeV

CONCLUSIONS

The automation of NLO EW and QCD corrections in **MadGraph5_aMC@NLO** is in progress. NLO QCD and EW corrections to $t\bar{t}V$ have been calculated in a completely automated approach.

NLO EW corrections are not negligible, especially in the tails of pt distributions and in the total cross sections with boosted cuts.

Negative contributions from Sudakov logs are partially compensated by the real radiation of heavy bosons (HBR).

OUTLOOK

- Complete the automation of EW+QCD corrections for all processes
- Match NLO EW corrections to shower effects

EXTRA SLIDES

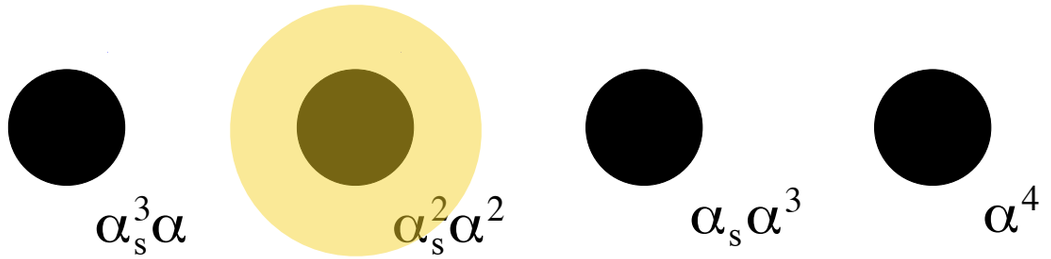
Amplitudes and matrix elements

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



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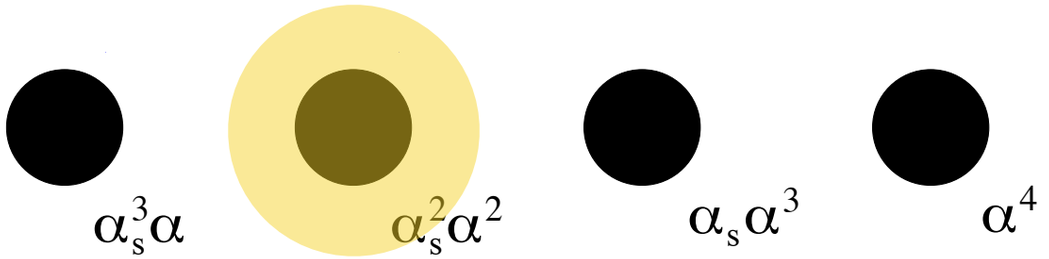
NLO



Subprocesses

The generation of EW-QCD loops, real emission of gluons, quarks and photons is completely automated.

FKS IR counterterms completely automated.
Also for photons in the initial state.

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 weak corrections

Inclusive rates

(Boosted regime in brackets)

NLO corrections

$\delta_{\mathrm{NLO}}(\%)$	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

$\delta_{\mathrm{HBR}}(\%)$	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

$\delta_{\mathrm{NLO}}(\%)$	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)

Why Weak corrections to $t\bar{t}H$ production?

We calculated NLO corrections of mixed QCD-Weak origin, ignoring QED effects. We compared them to NLO QCD corrections.

Phenomenology motivations

Electroweak corrections are in general small. However, the Sudakov logarithms $\alpha_W \ln^2 s/M_W^2$ can enhance their size. They originate only from Weak corrections

The cross section of $t\bar{t}H$ depends directly on $\lambda^2_{t\bar{t}H}$. At NLO, only Weak corrections introduce a dependence on other Higgs couplings.

Automation of NLO corrections

Without QED (photons), the structure of IR singularities is simpler

$t\bar{t}H$ was the first pheno study of EW corrections in the **MG5_aMC@NLO** framework.