Weak corrections to Higgs hadroproduction in association with a top-quark pair

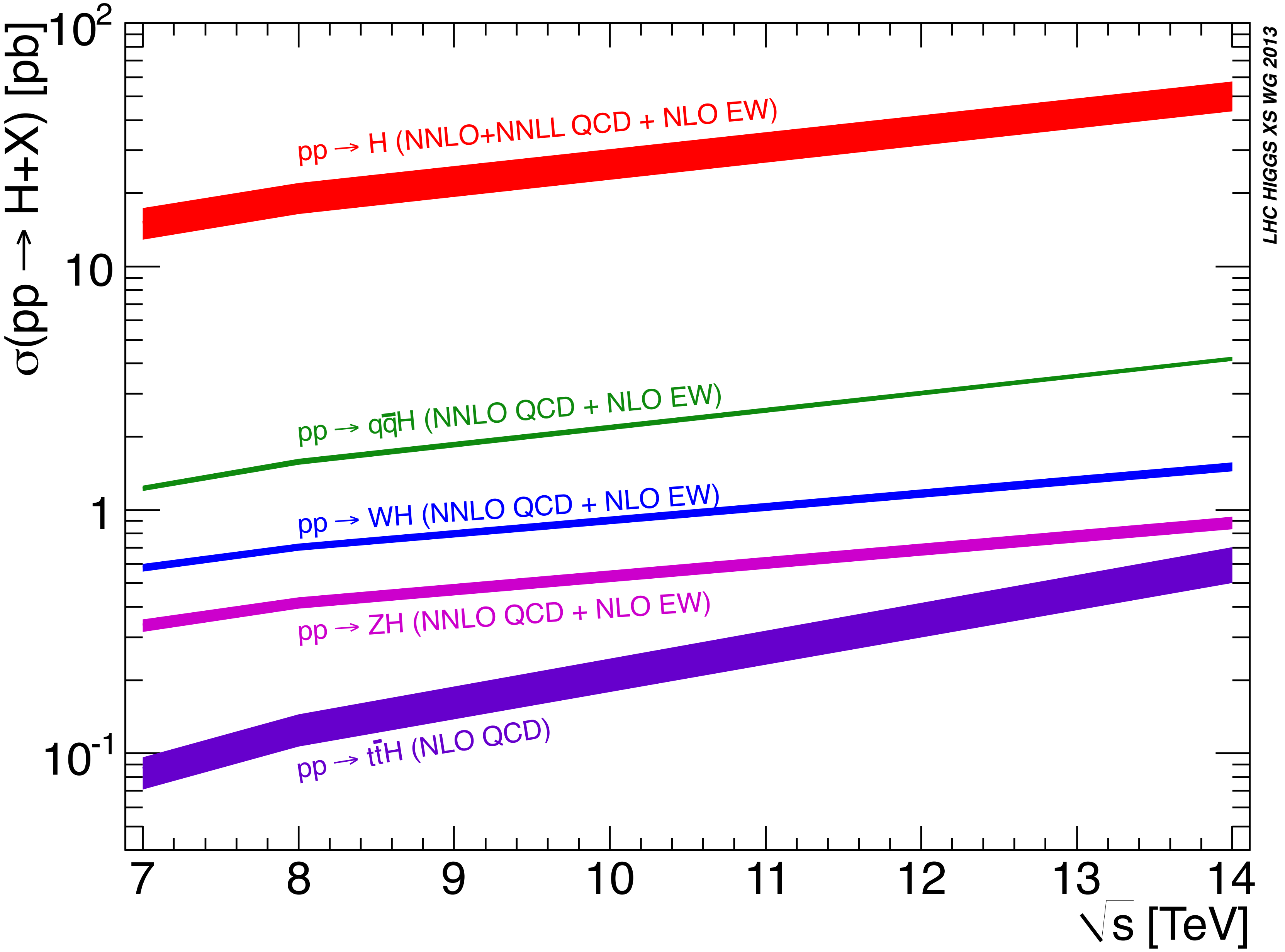
in collaboration with S. Frixione, V. Hirschi, H. -S. Shao and M. Zaro,
based on JHEP09(2014)065 (arXiv:1407.0823)

Davide Pagani

CP3, Université catholique de Louvain

Hamburg Workshop on Higgs Physics, DESY, 22-10-2014

Why $t\bar{t}H$ production?



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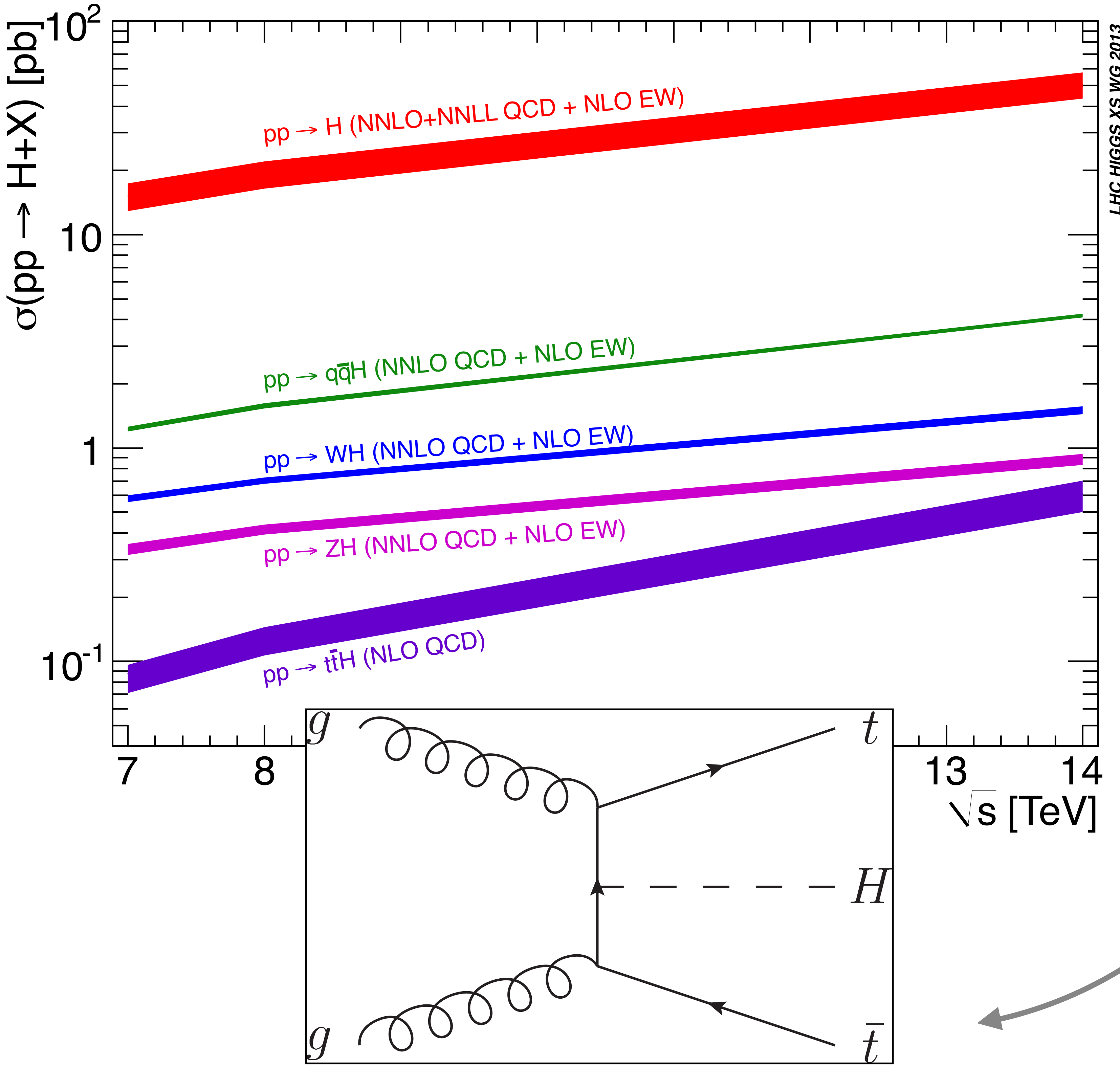
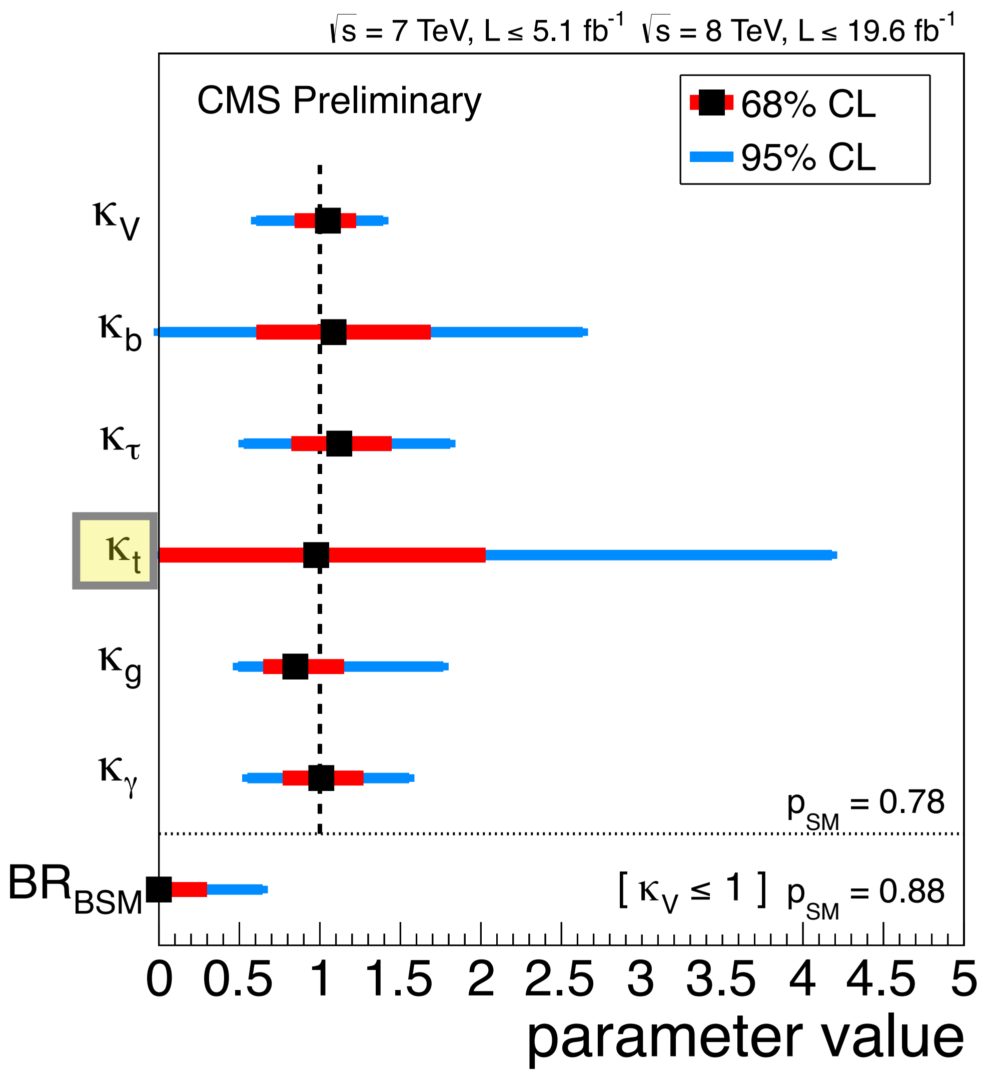
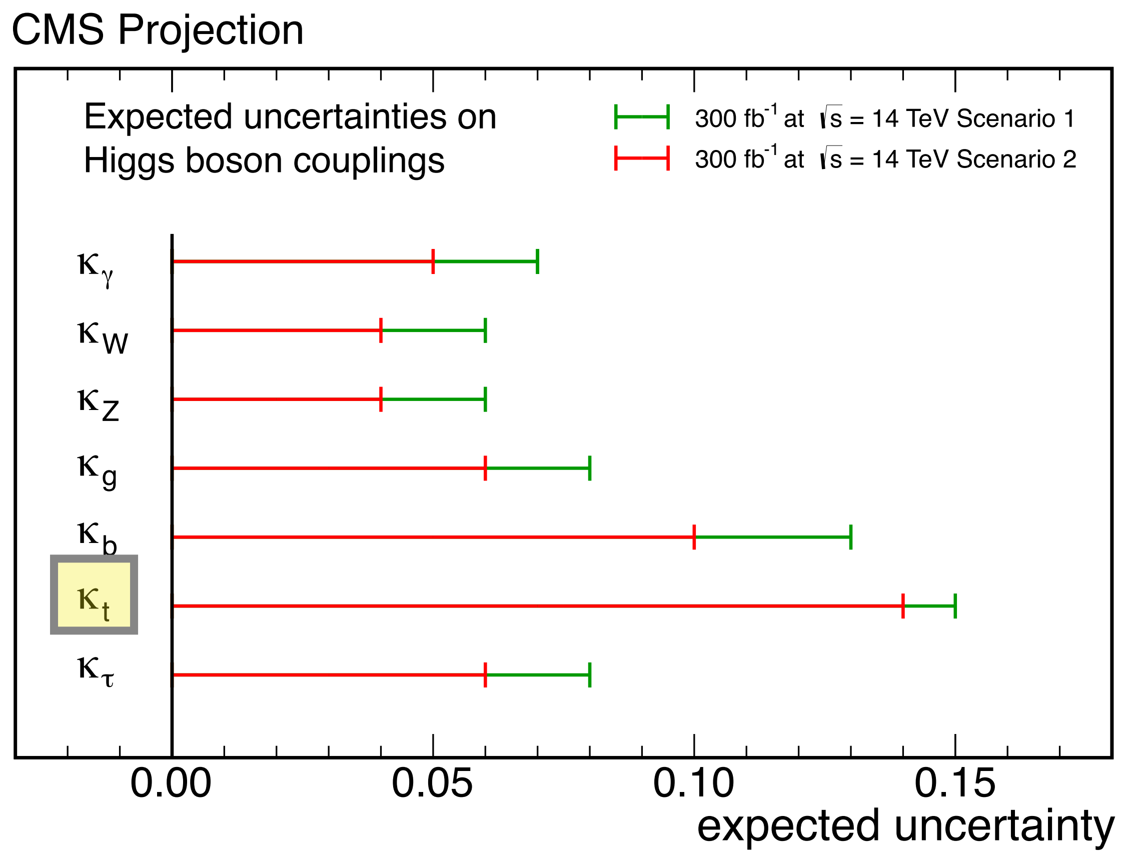
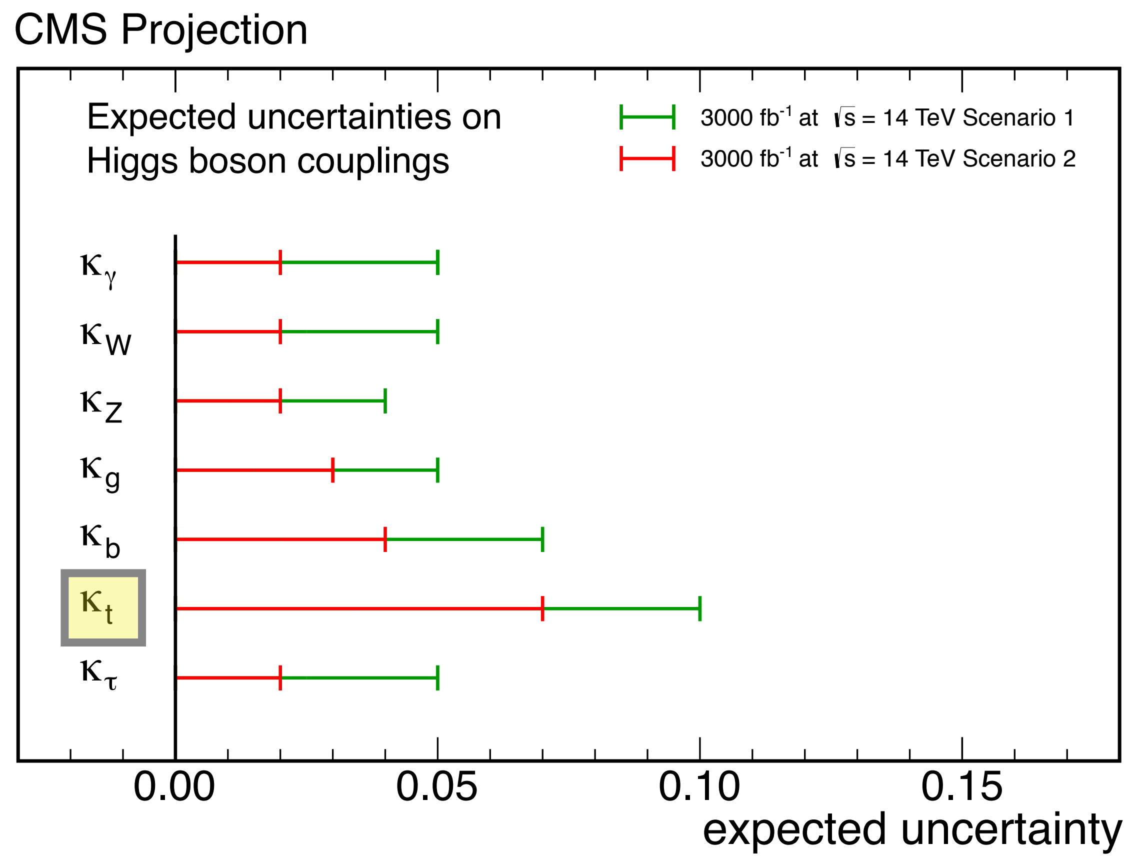


The $t\bar{t}H$ cross section is proportional to $\lambda_{t\bar{t}H}^2$.

$\lambda^2_{t\bar{t}H}$ today and tomorrow



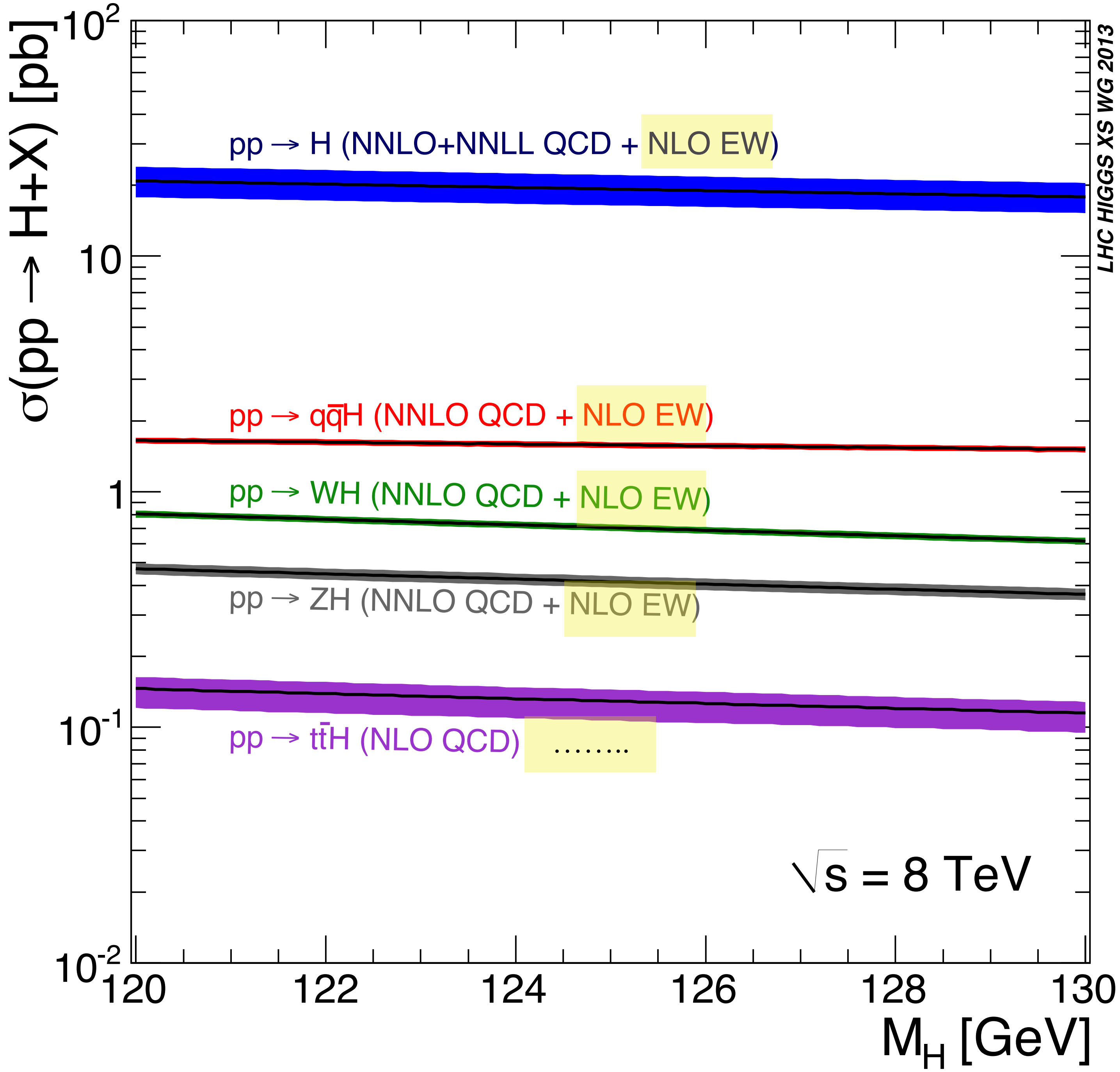




Projected Performance of an Upgraded CMS Detector at the LHC and HL-LHC: Contribution to the Snowmass Process. arXiv:1307.7135

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

EW corrections had been calculated for the main Higgs production channels at the LHC, with the exception of $t\bar{t}H$ production.



Djouadi, Gambino '94
Aglietti, Bonciani, Degrassi, Vicini '04
Degrassi, Maltoni '04
Actis, Passarino, Sturm, Uccirati '08

Ciccolini, Denner, Dittmaier '07, '08

Ciccolini, Denner, Dittmaier '03

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.

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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 $\lambda_{t\bar{t}H}^2$. At NLO, only Weak corrections introduce a dependence on other Higgs couplings.

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Automation of NLO corrections

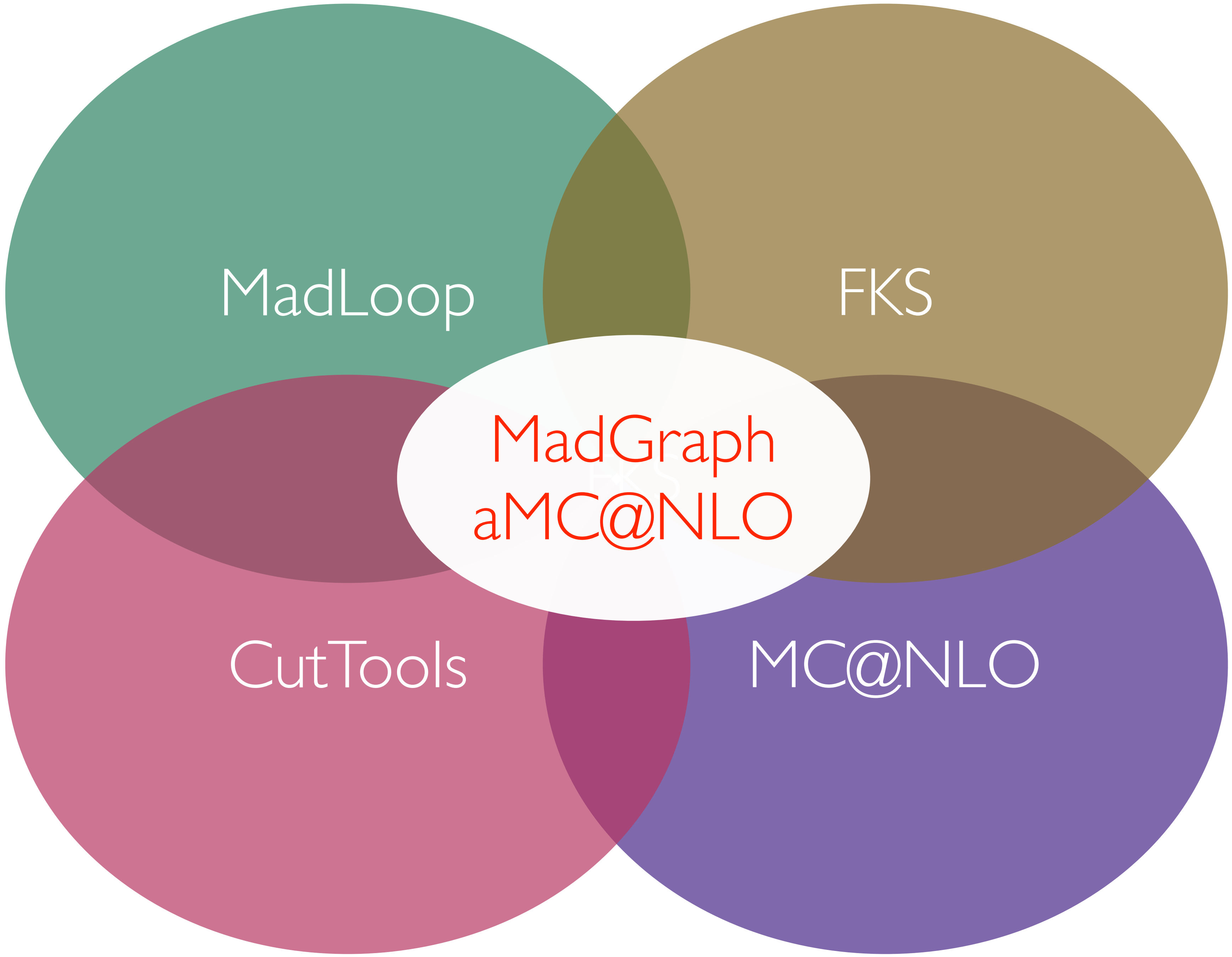
Without QED (photons), the structure of IR singularities is simpler
This is the first pheno study of EW corrections in the **MadGraph5_aMC@NLO** framework.

Automation of NLO corrections in Madgraph5_aMC@NLO

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

DONE!

in progress



DONE!

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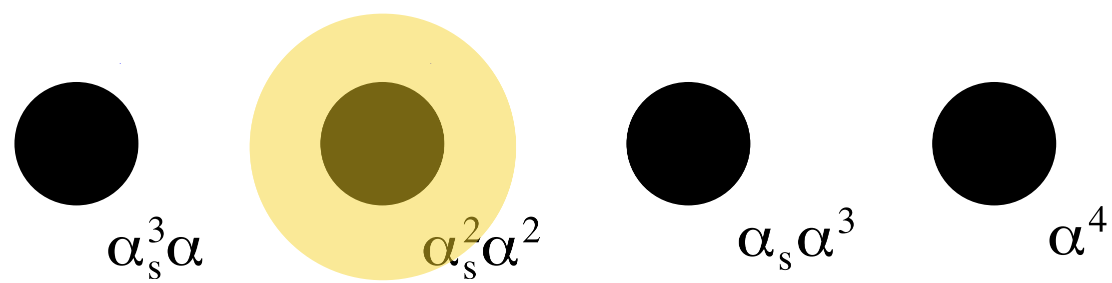
Amplitudes and matrix elements

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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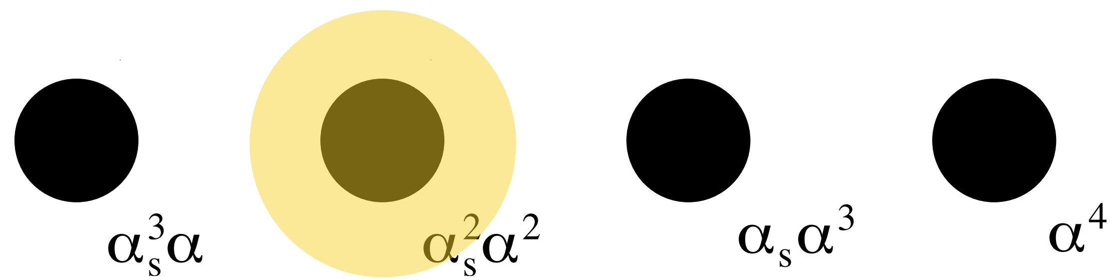

Subprocesses

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

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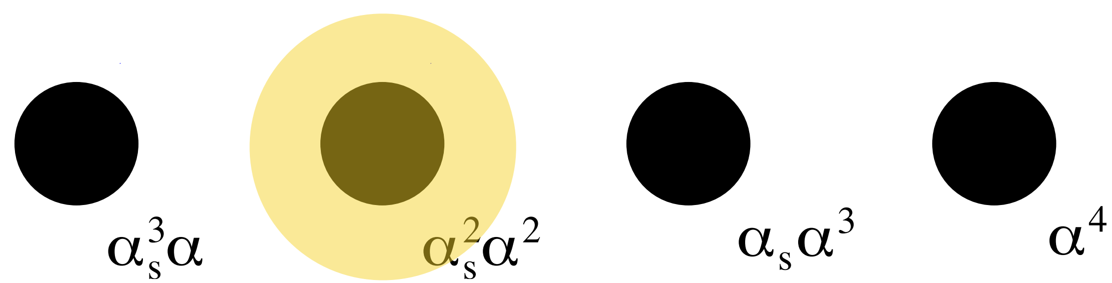

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$qg \rightarrow t\bar{t}Hq$ IR finite

Heavy Boson Radiation (HBR)

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

$V = H, W, Z$

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

Numerical results

Alpha(mZ)-scheme, MSTWNLO2008, $\mu = \frac{H_T}{2}, \quad \frac{1}{2}\mu \leq \mu_R, \mu_F \leq 2\mu$

Contributions

LO $\alpha_S^2\alpha$

NLO QCD $\alpha_S^3\alpha$

Beenakker, Dittmaier, Kramer, Plumper, Spira '01, '03

Dawson, Jackson, Orr, Reina, Wackeroth '02, '03

```
import model loop_sm-no_b_mass
generate p p > t t~ h [QCD]
output ttbarH_QCD
```

NLO Weak	$\alpha_S^2\alpha^2$	no QED, no $b\bar{b} \to t\bar{t}H + X$, no $pp \to t\bar{t}H + V$
HBR	$\alpha_S^2\alpha^2$	no QED, no $b\bar{b} \to t\bar{t}H + X$, only $pp \to t\bar{t}H + V$

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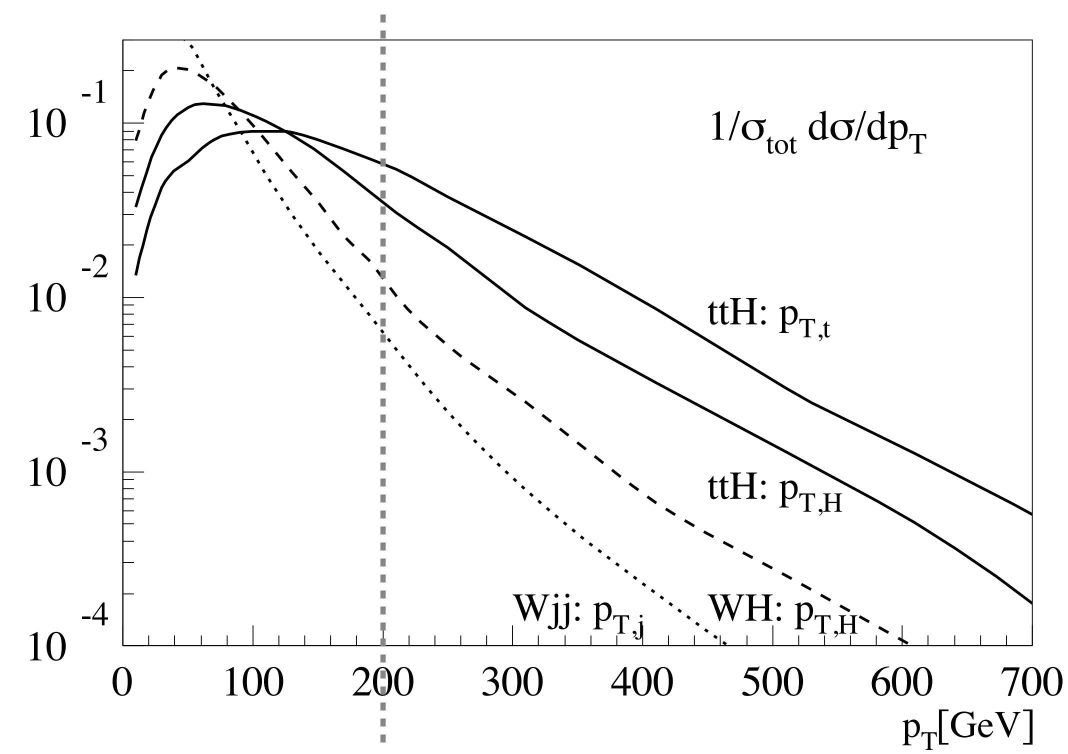
Boosted regime

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

S/B increases for boosted tops and Higgs.

Plehn, Salam, Spannowsky '10

Sudakov logs are relevant in these regions!



Numerical results

Inclusive rates

(Boosted regime in brackets)

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

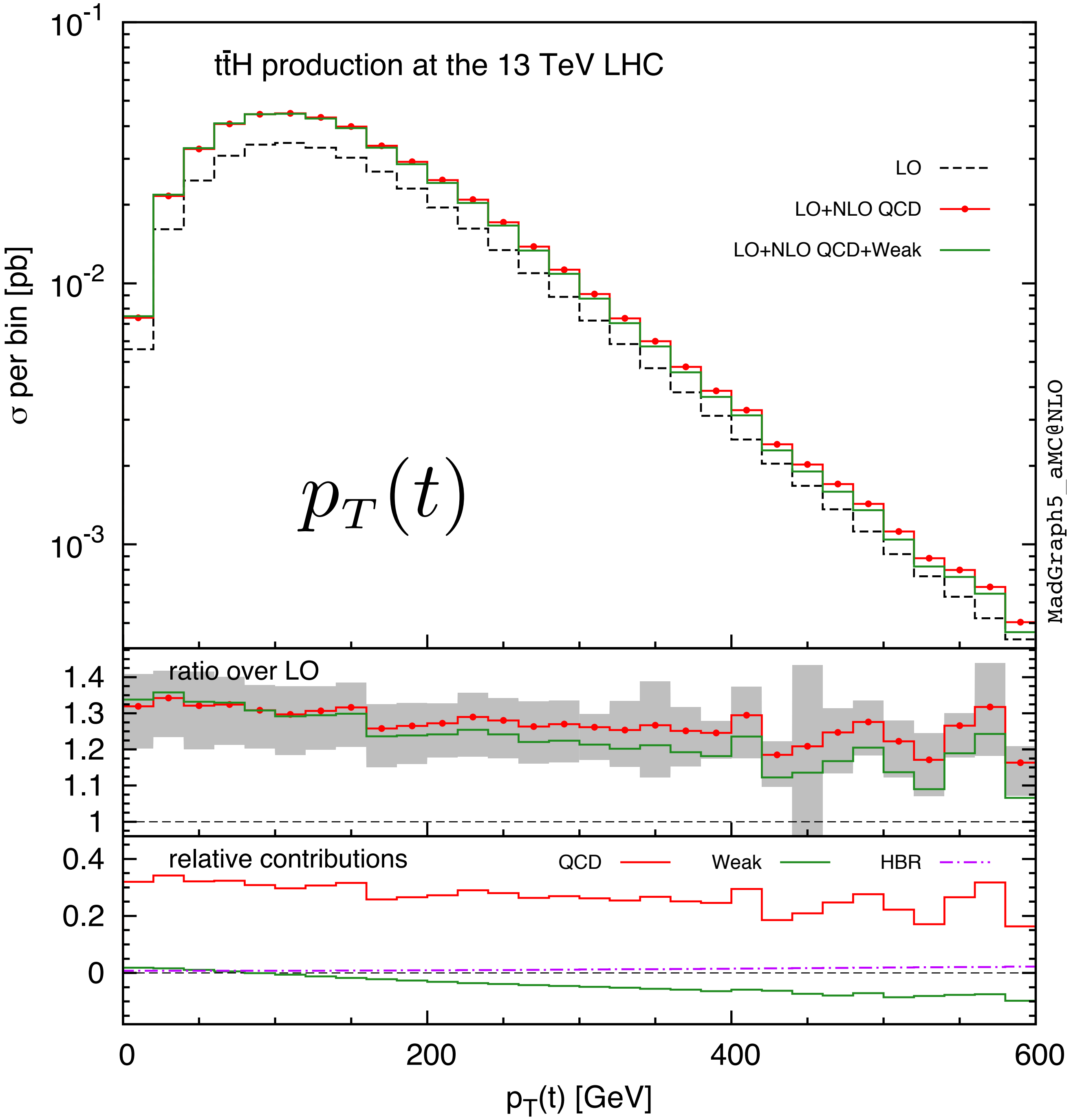
$\delta_{\rm HBR}(\%)$	8 TeV	13 TeV	100 TeV
W	$+0.42(+0.74)$	$+0.37(+0.70)$	$+0.14(+0.22)$
Z	$+0.29(+0.56)$	$+0.34(+0.68)$	$+0.51(+0.95)$
H	$+0.17(+0.43)$	$+0.19(+0.48)$	$+0.25(+0.53)$
sum	$+0.88(+1.73)$	$+0.90(+1.86)$	$+0.90(+1.70)$

Partial compensation of Sudakov logs

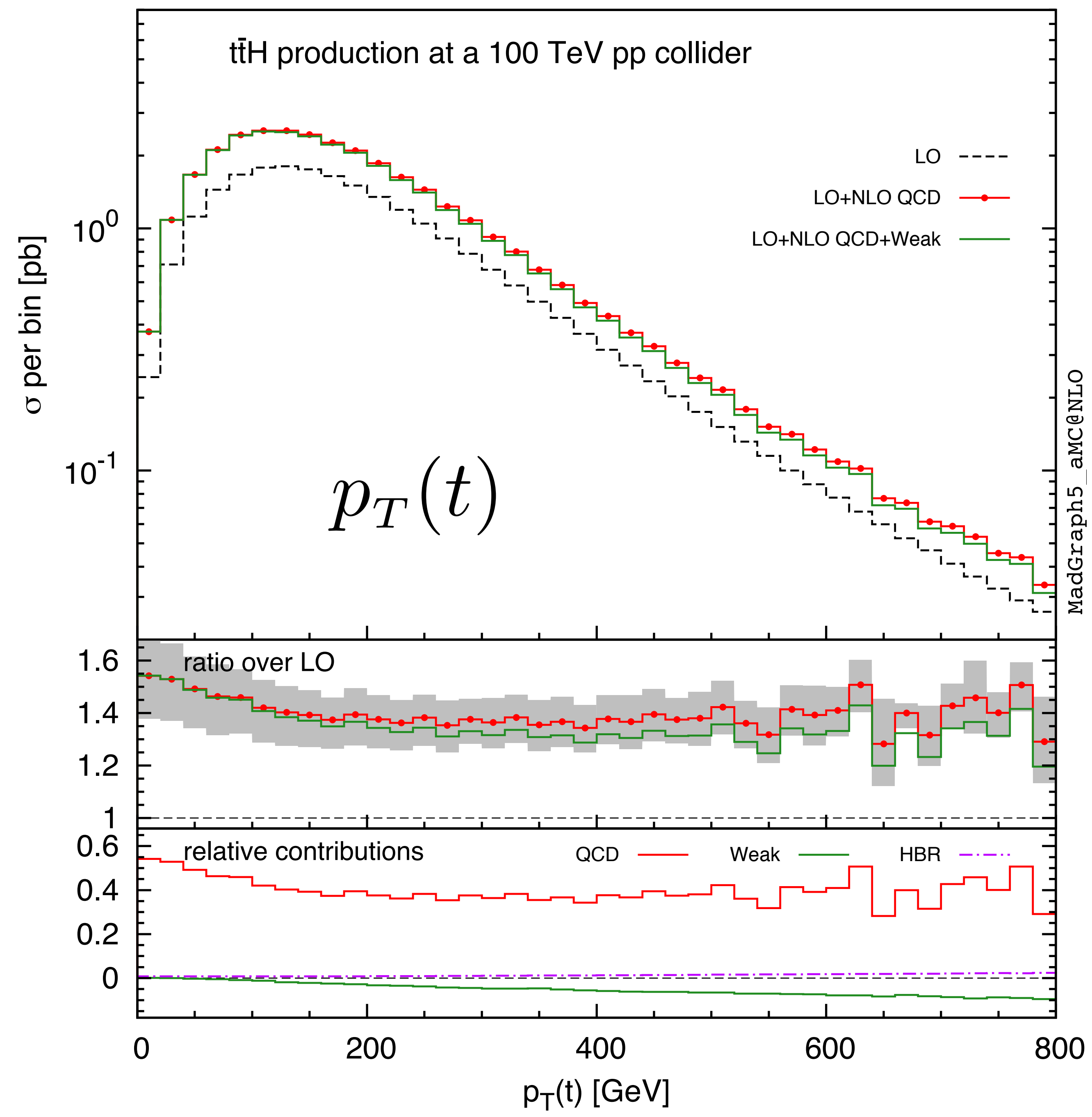
NLO weak subchannels

$\delta_{\rm NLO}(\%)$	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: QCD vs QCD+Weak

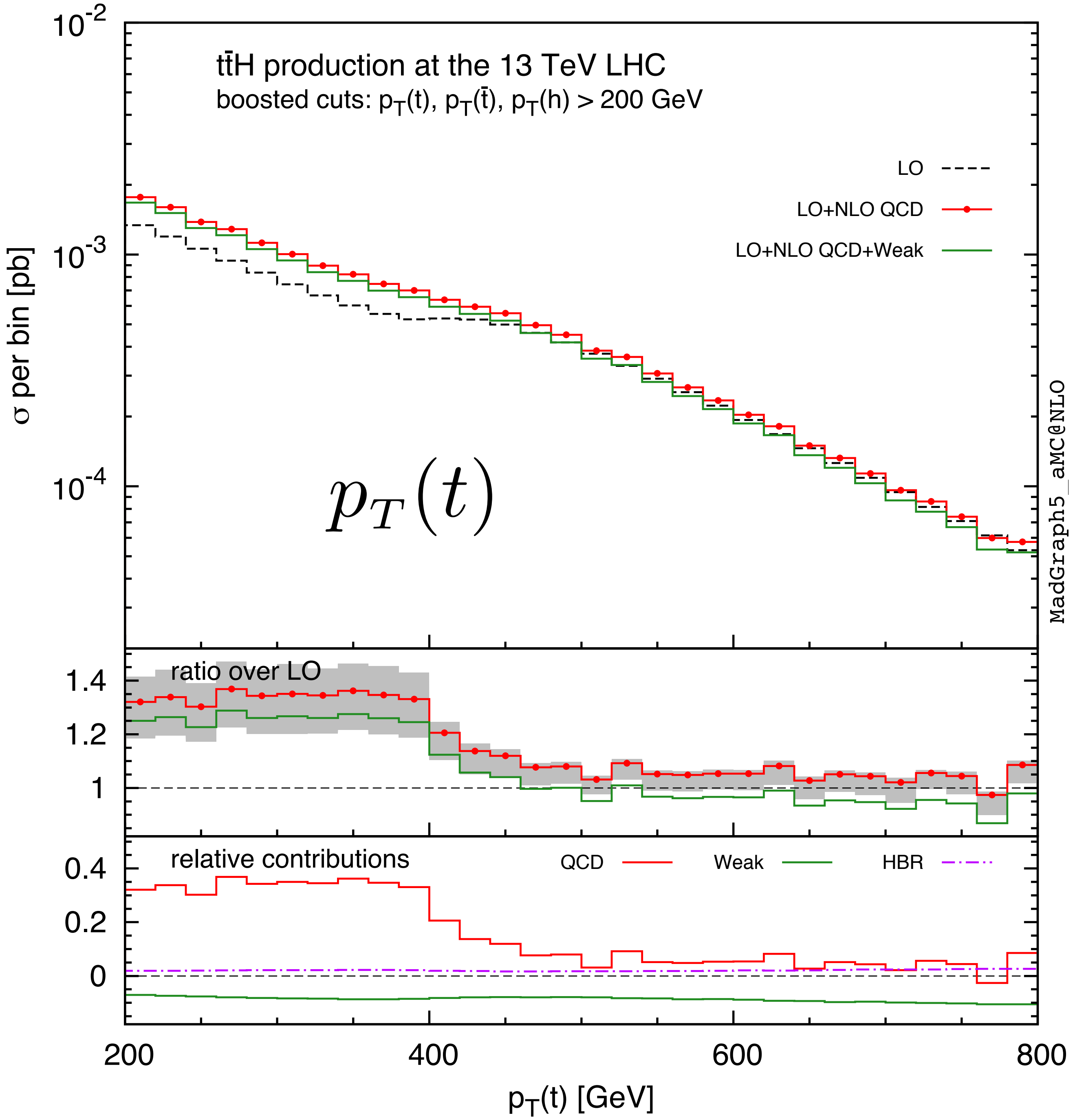


13 TeV

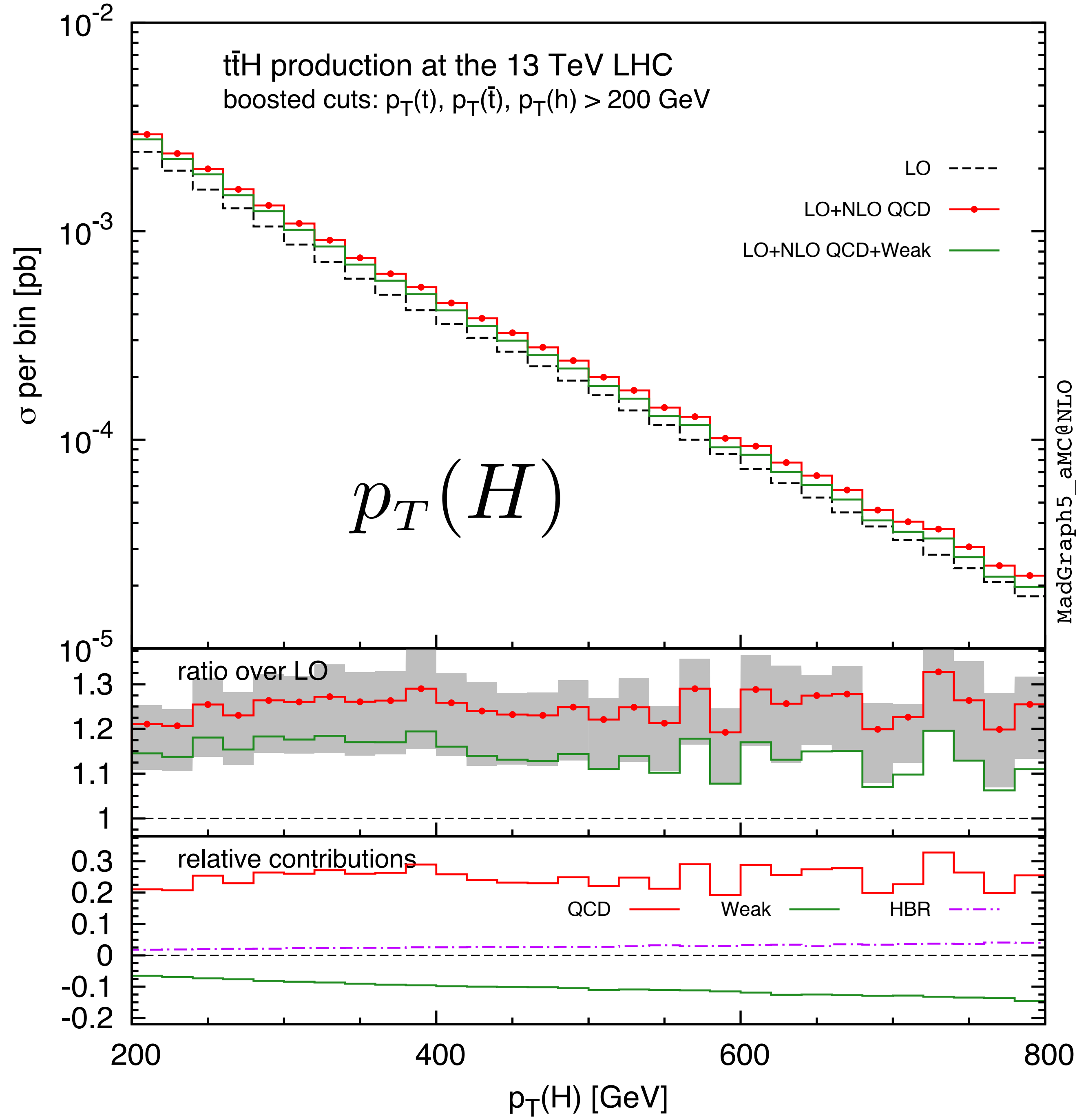


100 TeV

Distributions: boosted regime at 13 TeV

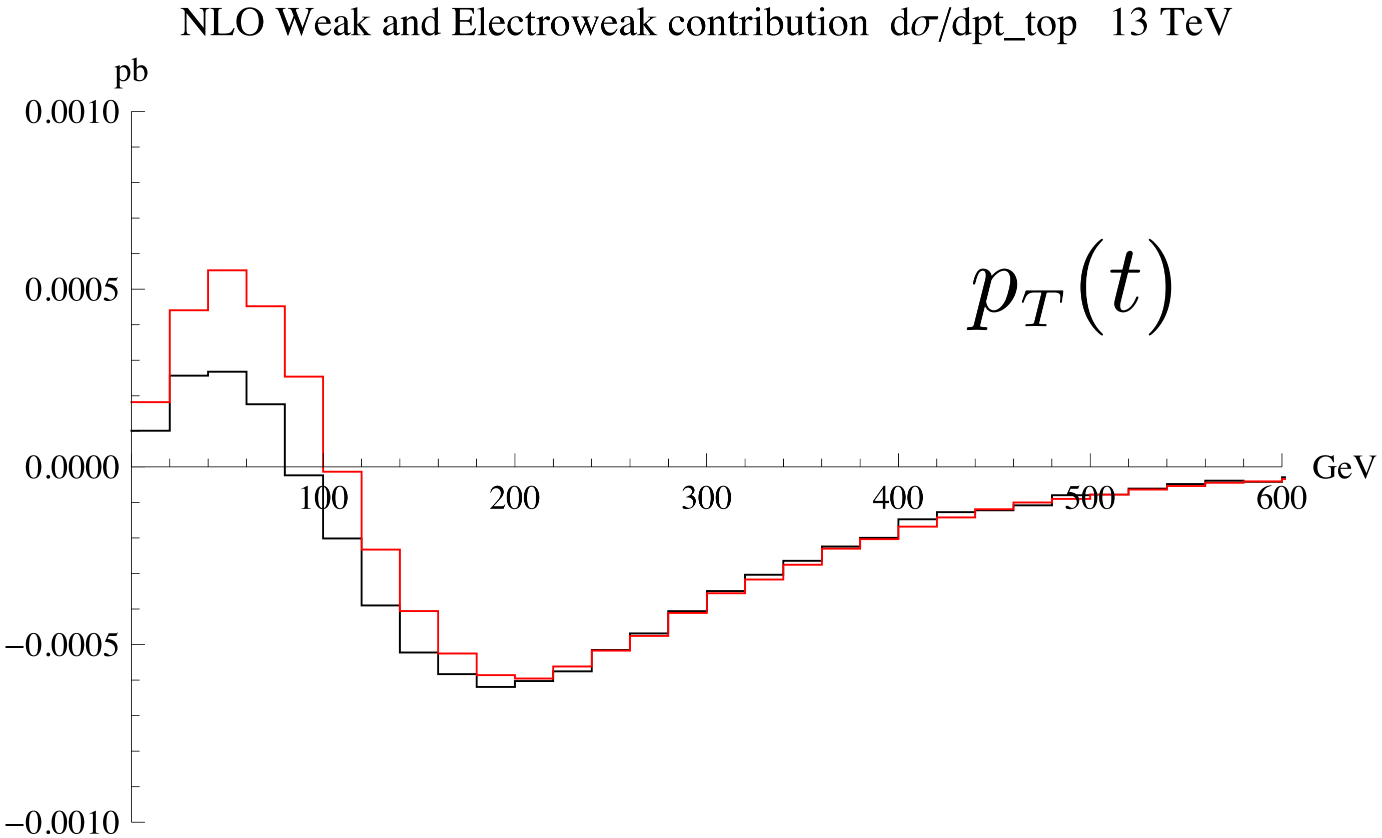


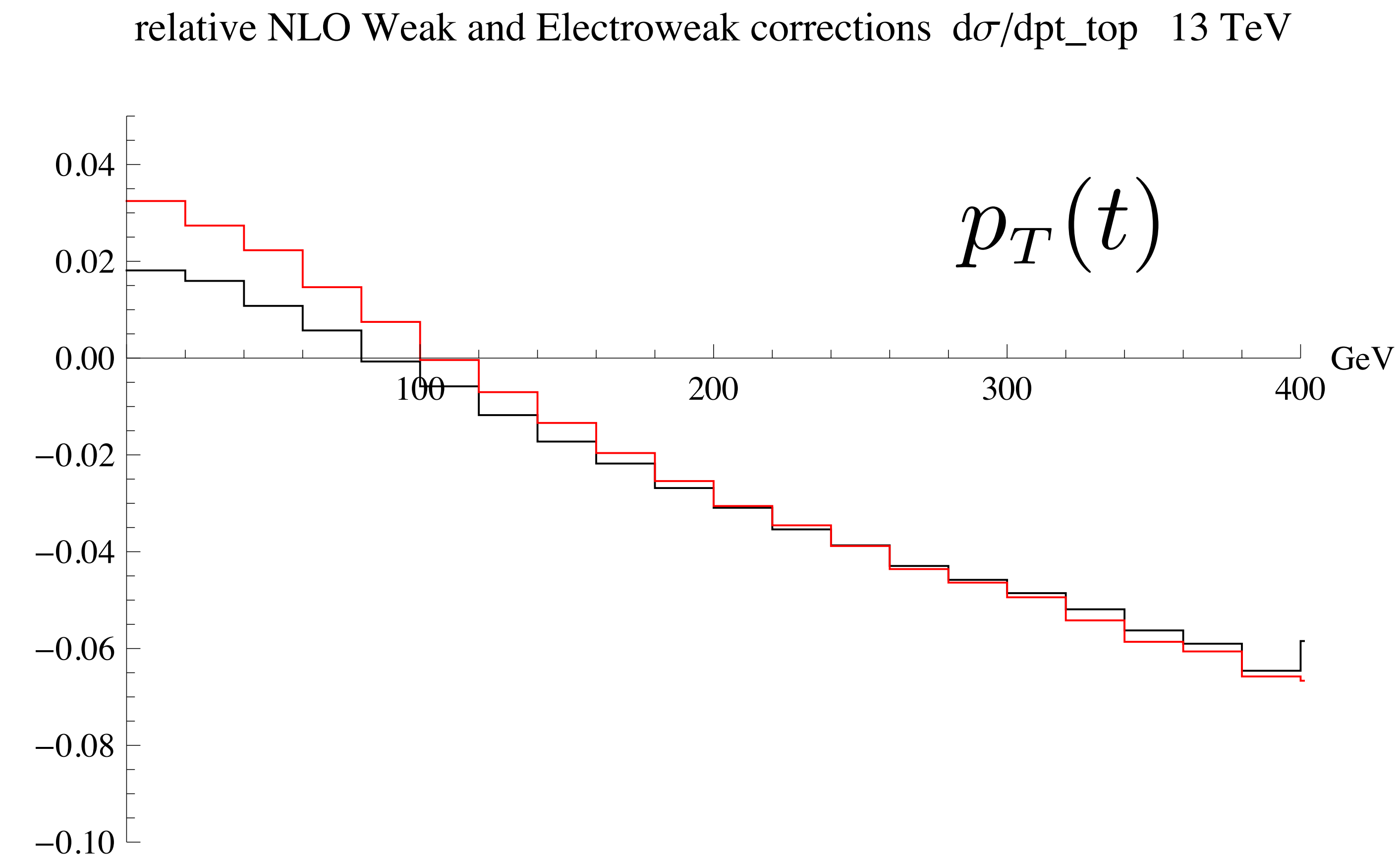
13 TeV



13 TeV

Electroweak vs. Weak corrections





Weak (-1.8 %)
(semi-automated)

ElectroWeak (-1.3 %)
(fully automated)

```
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

CONCLUSIONS

The automation of mixed EW+QCD corrections in **MadGraph5_aMC@NLO** is in progress. The first pheno study has been presented for $t\bar{t}H$ production.

NLO Weak corrections are not negligible, especially in the distributions for large pt and in the total cross sections for boosted top quarks and Higgs boson.

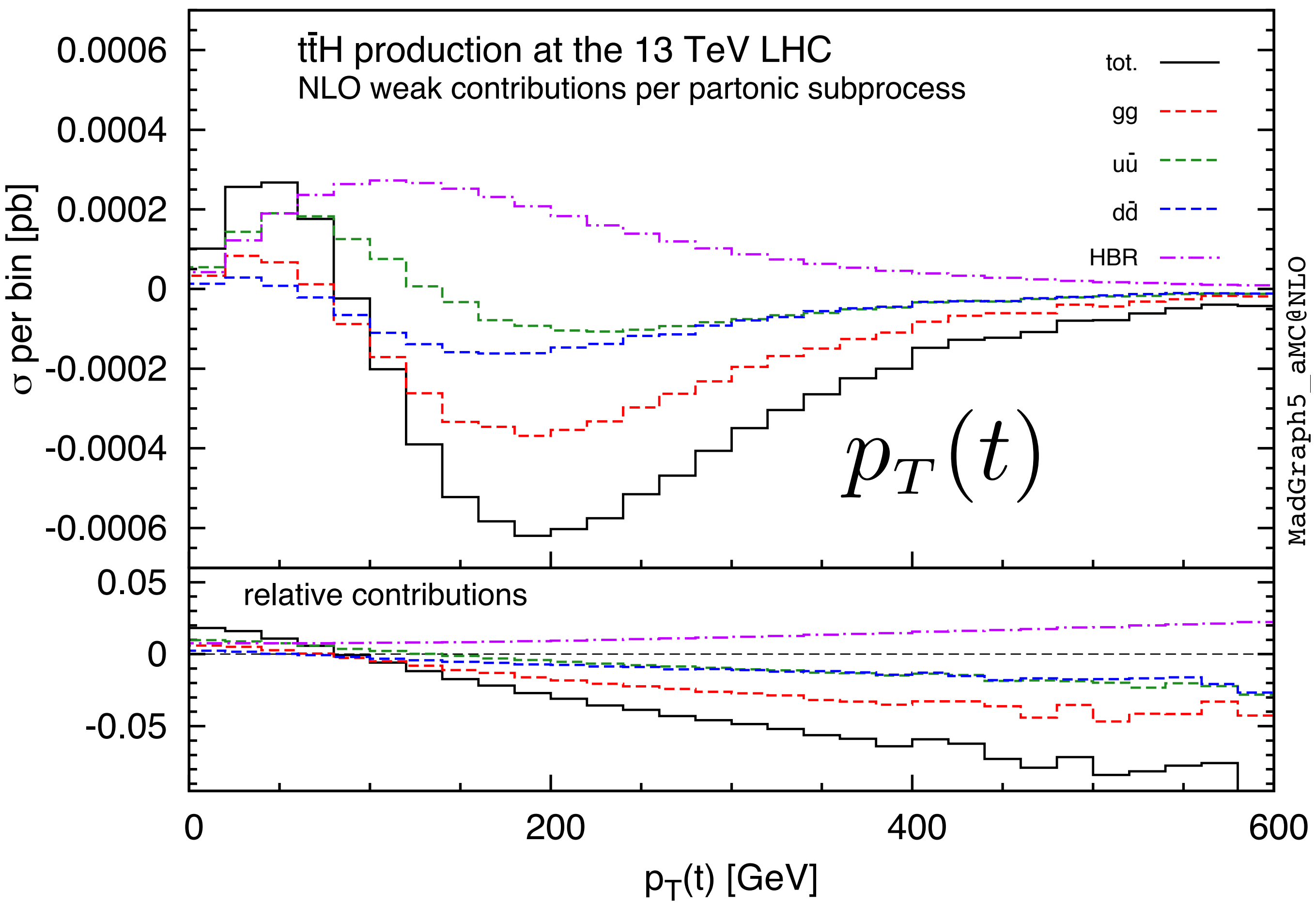
Negative contributions from Sudakov logs are partially compensated by the real radiation of heavy bosons (HBR).

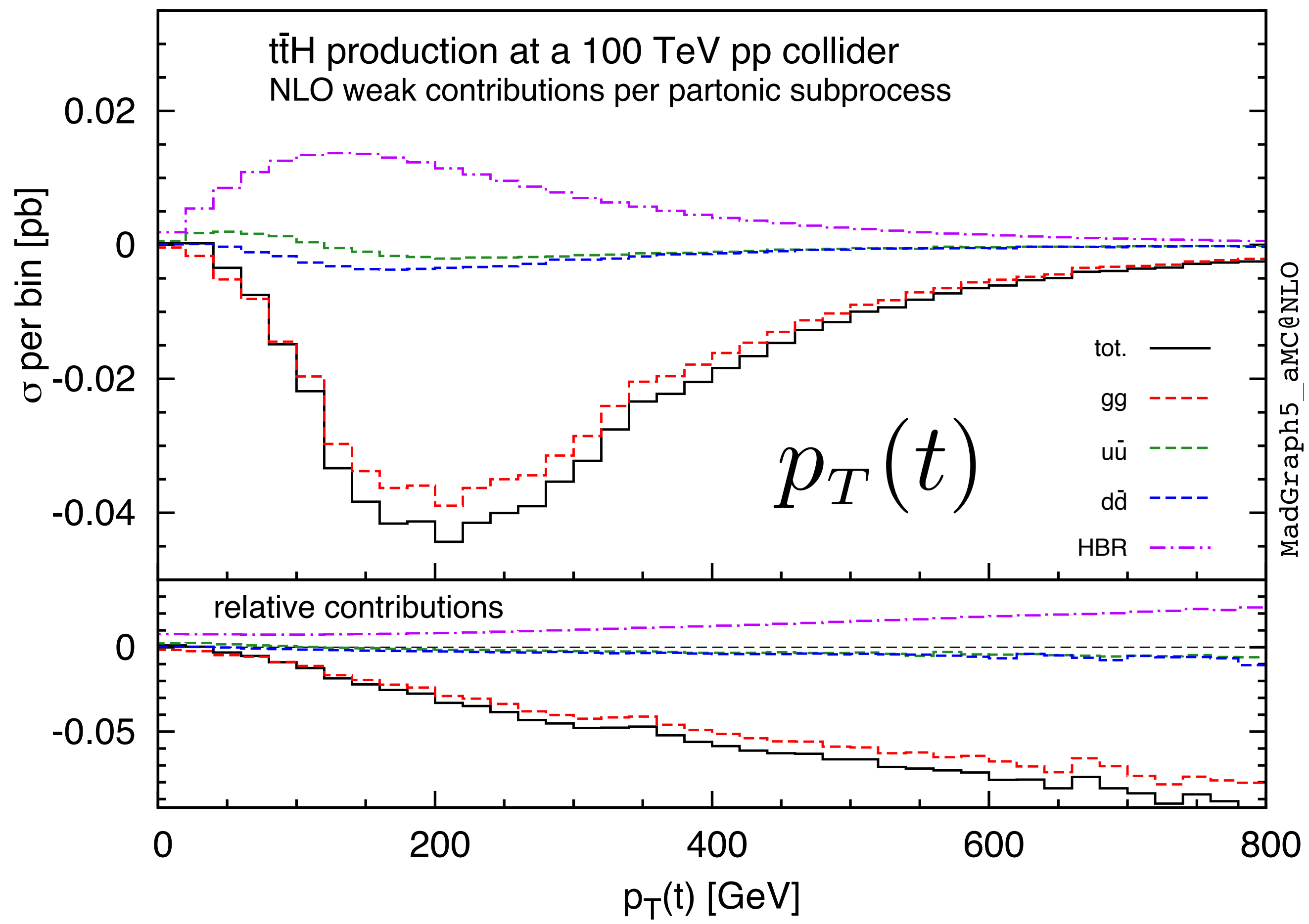
OUTLOOK

- Complete the automation of EW+QCD corrections.
- Calculate NLO QED corrections to $t\bar{t}H$ production.

EXTRA SLIDES

Distributions: NLO Weak Subprocesses, HBR



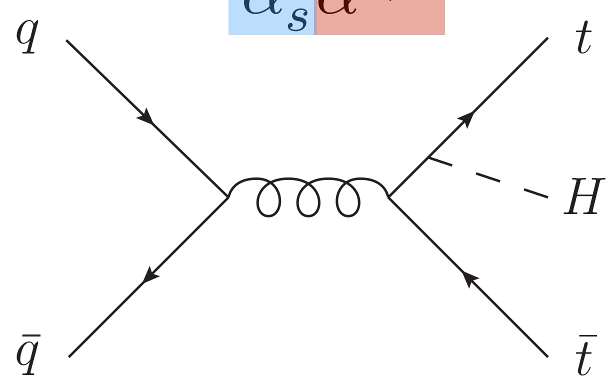


13 TeV

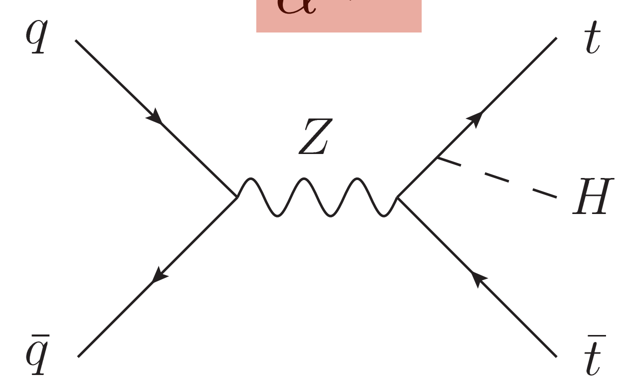
100 TeV

Structure of NLO EW-QCD corrections

$\alpha_s^1 \alpha^{1/2}$



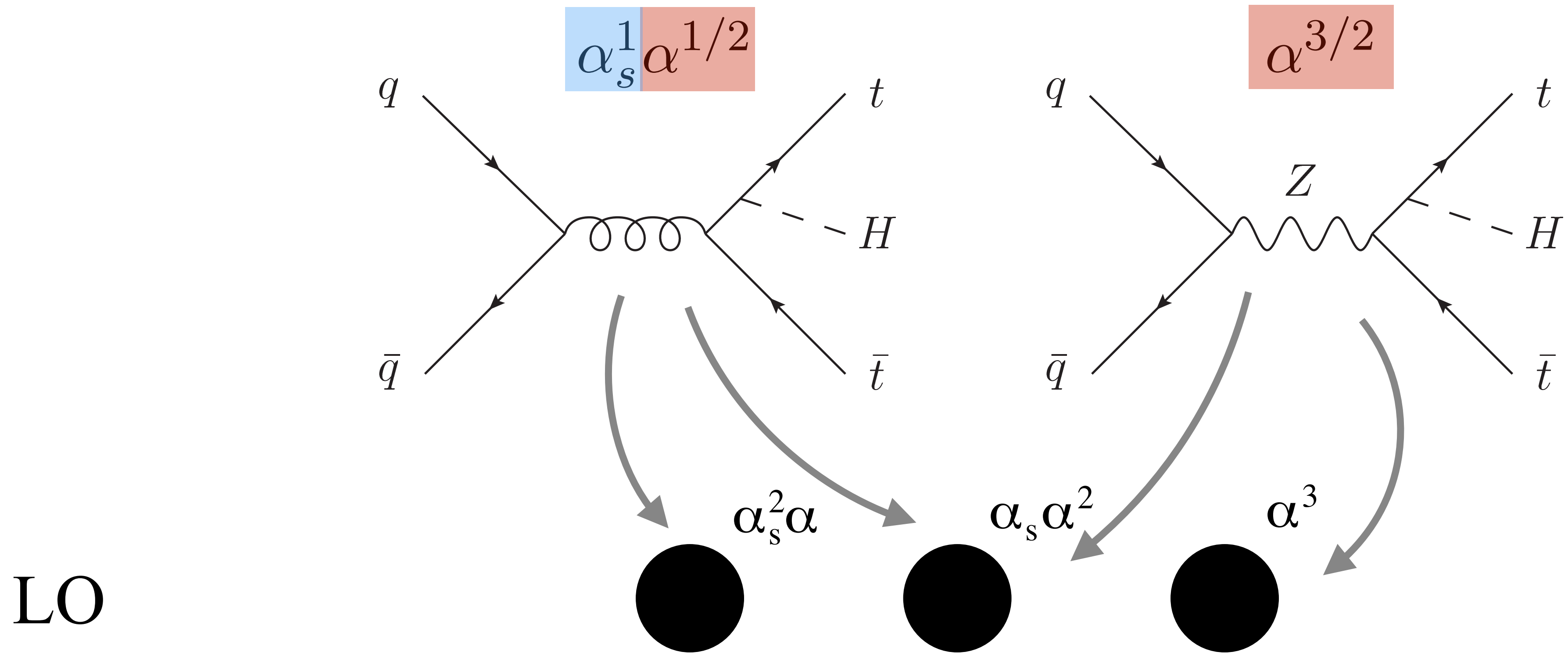
$\alpha^{3/2}$



$\alpha_s^2\alpha$ $\alpha_s\alpha^2$ α^3

LO

Structure of NLO EW-QCD corrections



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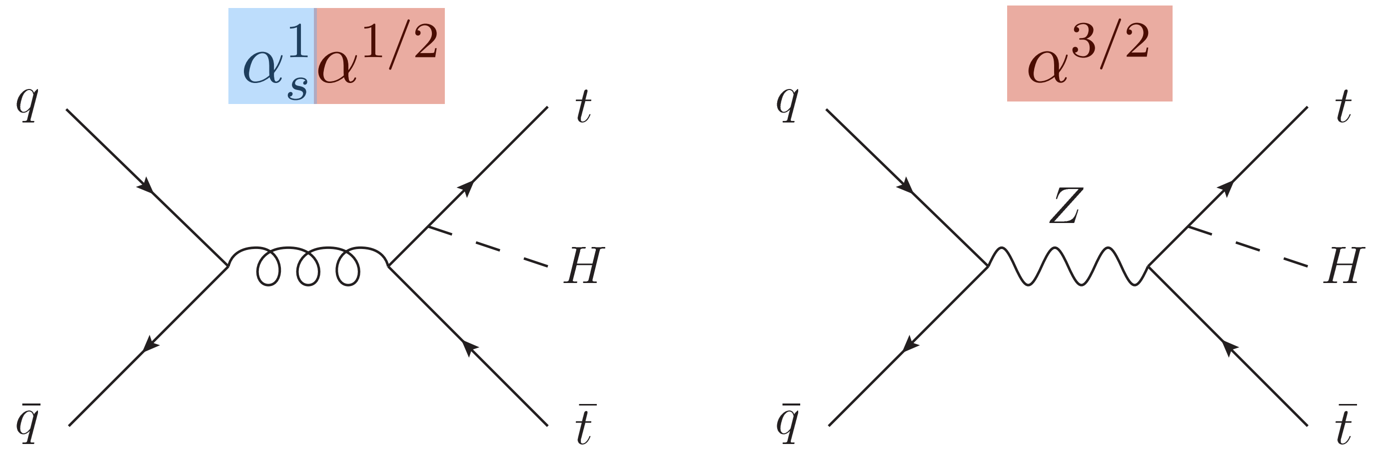

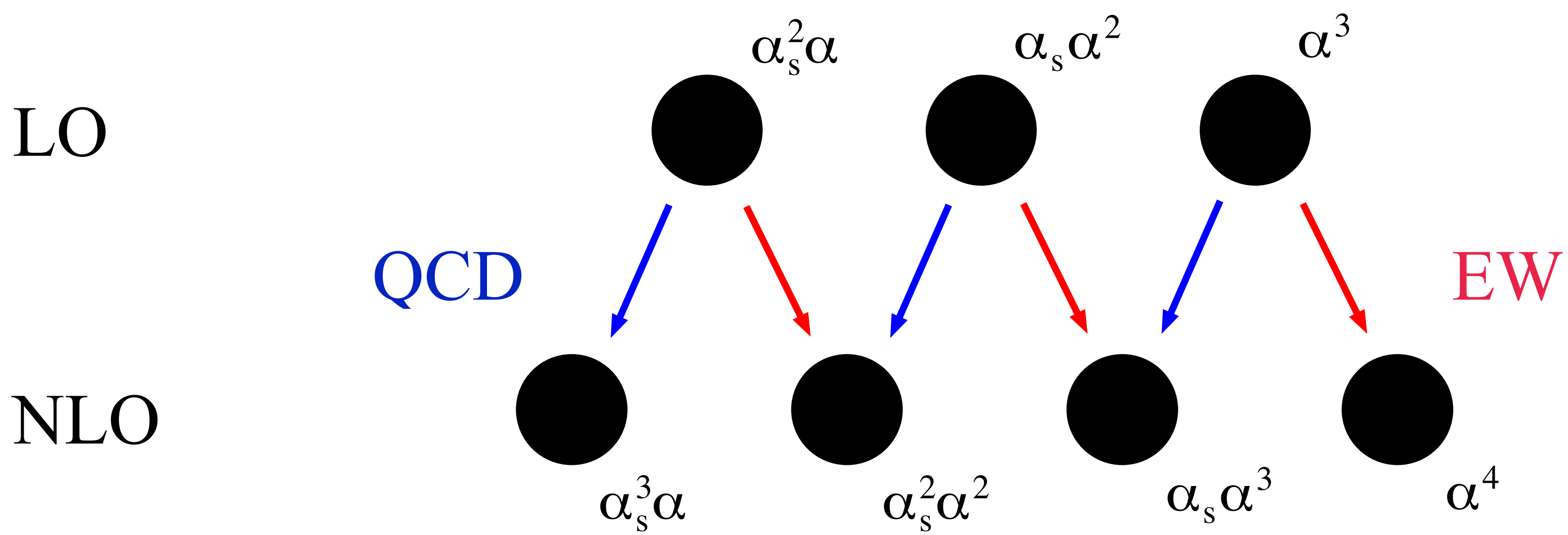

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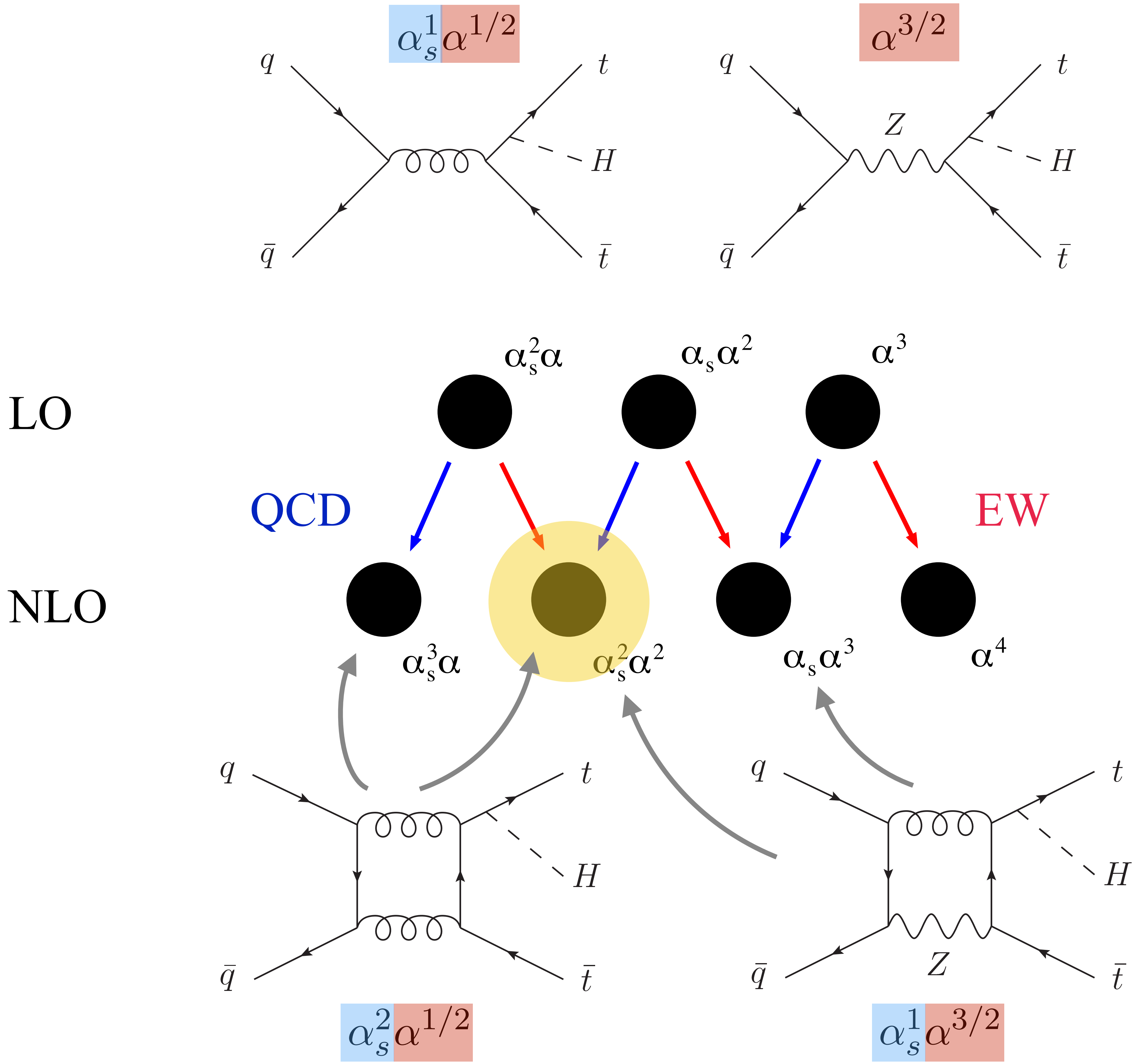

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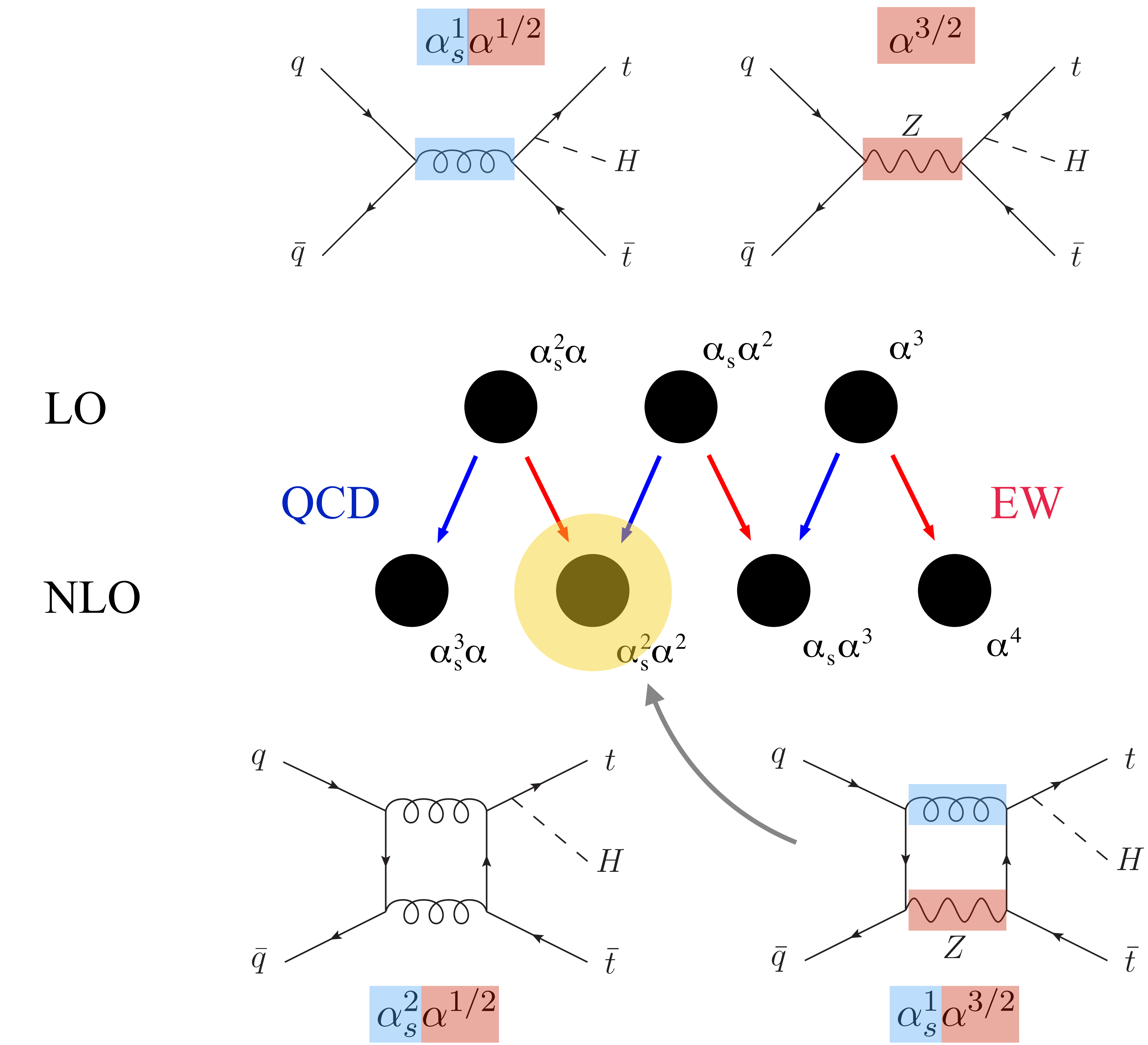
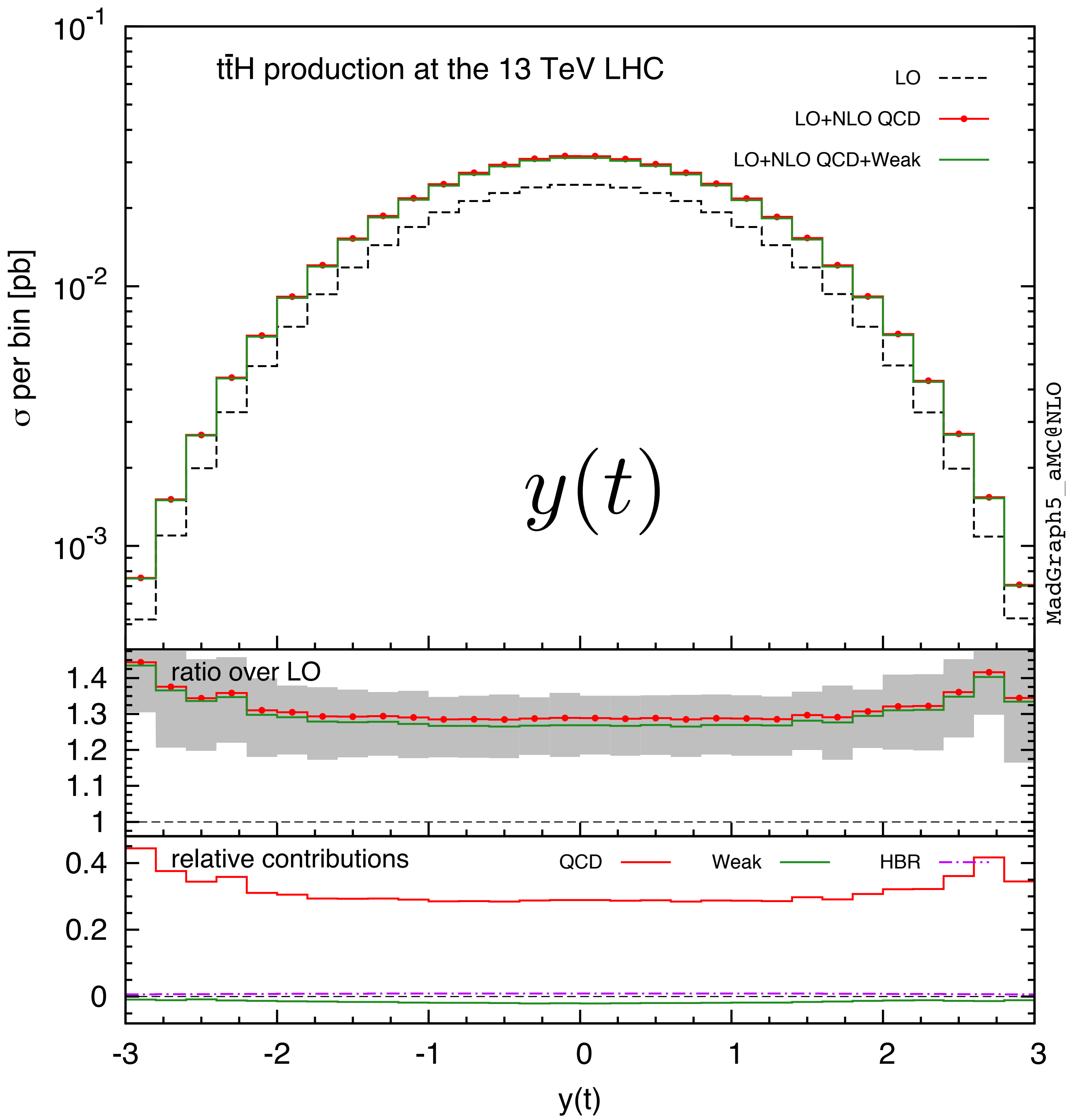
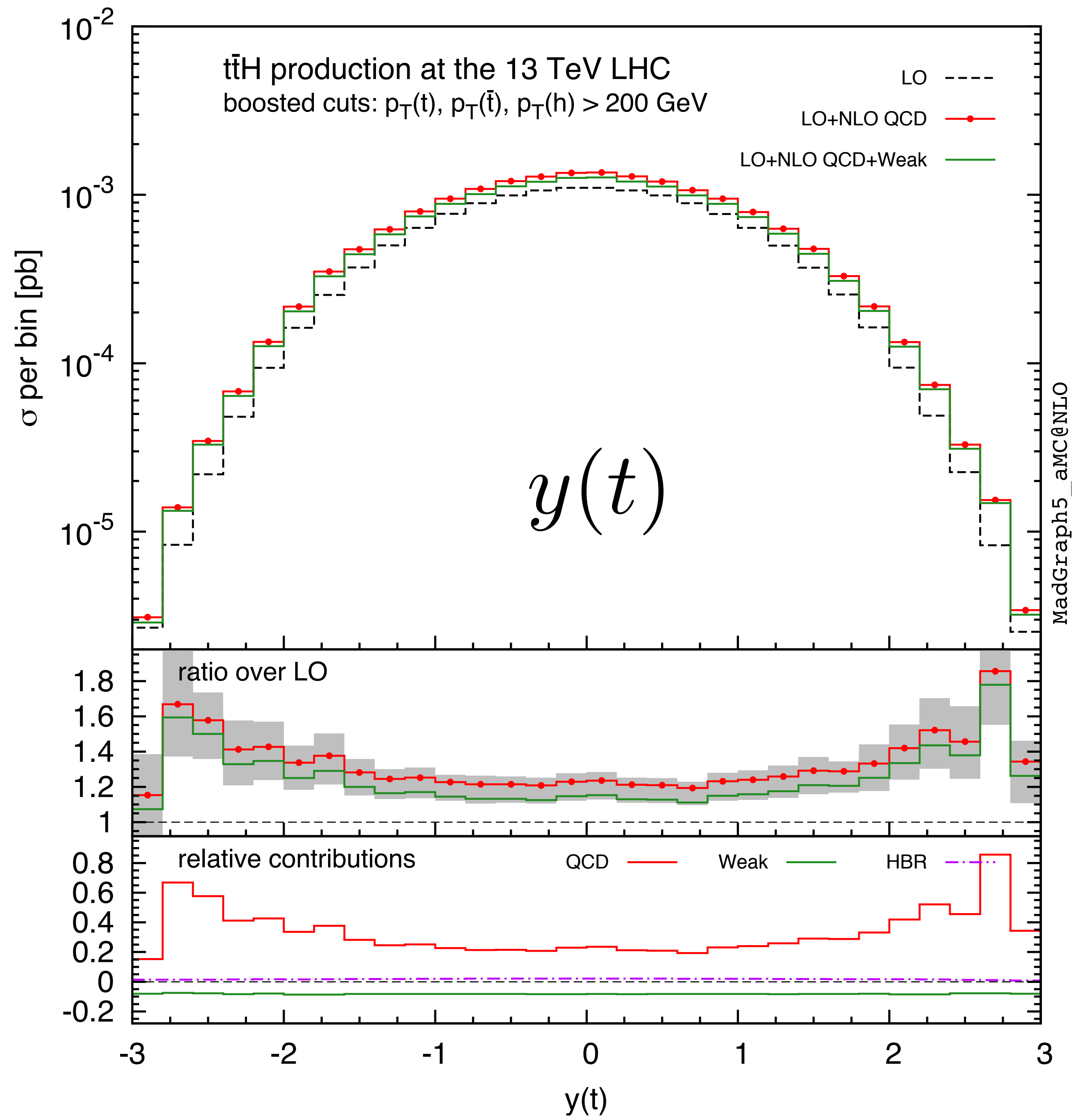


Rapidity distributions: unboosted vs. boosted

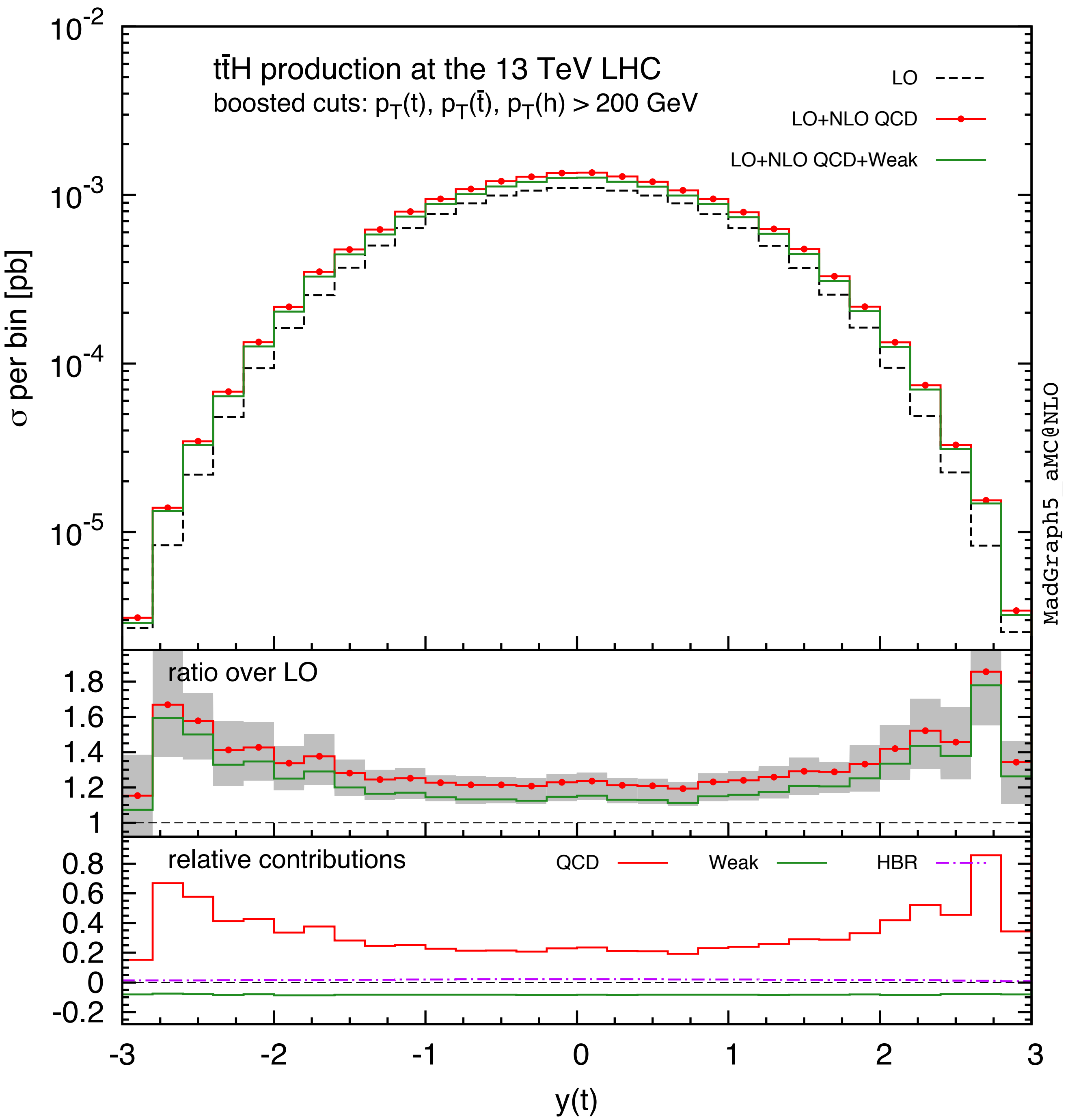


13 TeV



13 TeV

Distributions: boosted regime at 13 TeV



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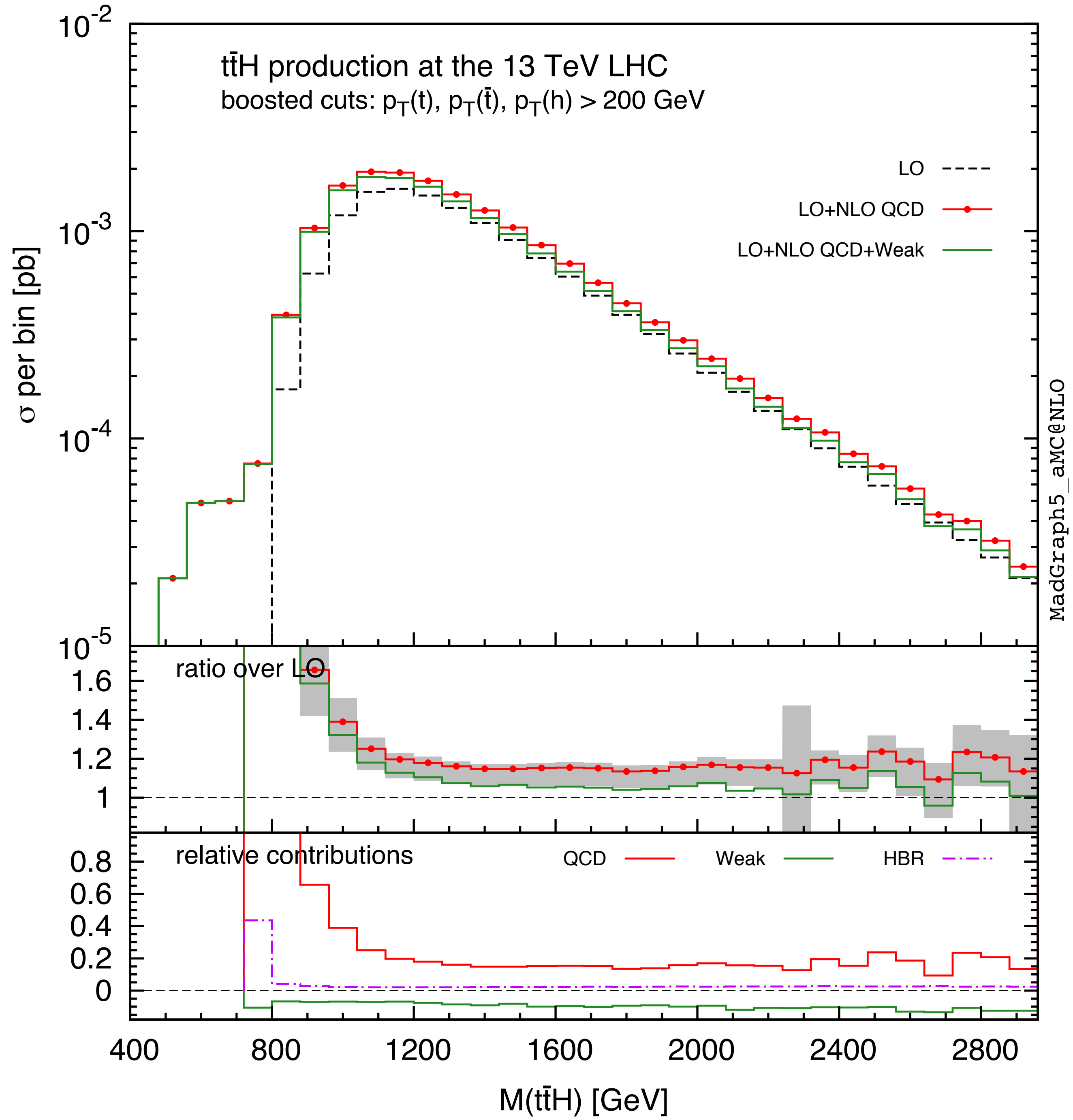

13 TeV

Alpha(mZ) vs Gmu schemes

σ(pb)	8 TeV	13 TeV	100 TeV
LO	$1.001 \cdot 10^{-1} (2.444 \cdot 10^{-3})$	$3.668 \cdot 10^{-1} (1.385 \cdot 10^{-2})$	$24.01 (2.307)$
NLO QCD	$2.56 \cdot 10^{-2} (4.80 \cdot 10^{-4})$	$1.076 \cdot 10^{-1} (3.31 \cdot 10^{-3})$	$9.69 (0.902)$
NLO weak	$-1.22 \cdot 10^{-3} (-2.04 \cdot 10^{-4})$	$-6.54 \cdot 10^{-3} (-1.14 \cdot 10^{-3})$	$-0.712 (-0.181)$

	8 TeV	13 TeV	100 TeV
LO^{G_μ}(pb)	$9.758 \cdot 10^{-2} (2.382 \cdot 10^{-3})$	$3.575 \cdot 10^{-1} (1.351 \cdot 10^{-2})$	$23.41 (2.249)$
$\Delta^{G_\mu}_{\mathrm{LO}}$(%)	$+2.5 (+2.5)$	$+2.5 (+2.5)$	$+2.5 (+2.5)$
$\delta^{G_\mu}_{\mathrm{weak}}$(%)	$+1.8 (-5.1)$	$+1.3 (-4.9)$	$+0.1 (-4.5)$
$\Delta^{G_\mu}_{\mathrm{LO+NLO}}$(%)	$-0.5 (-0.9)$	$-0.5 (-1.1)$	$-0.6 (-1.0)$

bb initial state at LO

$\sigma_{b\bar{b}\to t\bar{t}H}(\mathrm{pb})$	8 TeV	13 TeV	100 TeV
$\alpha_S^2\alpha\,\Sigma_{3,0}$	$1.8\cdot10^{-4}$	$9.1\cdot10^{-4}$	$8.6\cdot10^{-2}$
$\alpha_S\alpha^2\,\Sigma_{3,1}$	$-1.3\cdot10^{-4}$	$-1.5\cdot10^{-3}$	$-1.3\cdot10^{-1}$
$\alpha^3\,\Sigma_{3,2}$	$3.1\cdot10^{-4}$	$1.6\cdot10^{-3}$	$1.9\cdot10^{-1}$

$$\Sigma_{t\bar{t}H}^{(\mathrm{Born})}(\alpha_S,\alpha)=\alpha_S^2\alpha\,\Sigma_{3,0}+\alpha_S\alpha^2\,\Sigma_{3,1}+\alpha^3\,\Sigma_{3,2}$$