ElectroWeak corrections for processes involving top quarks

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HE-HL LHC workshop - WG1- Top Physics

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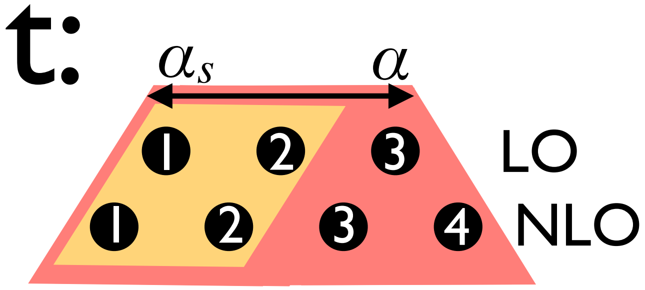
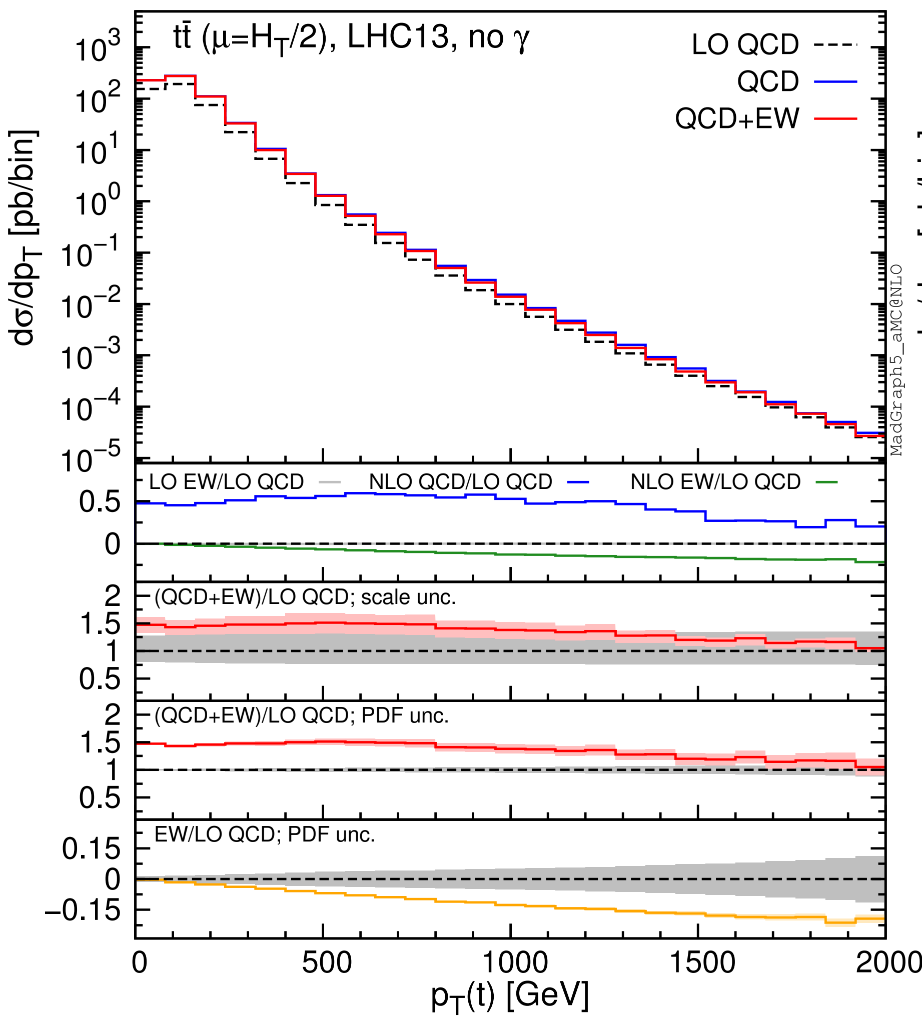
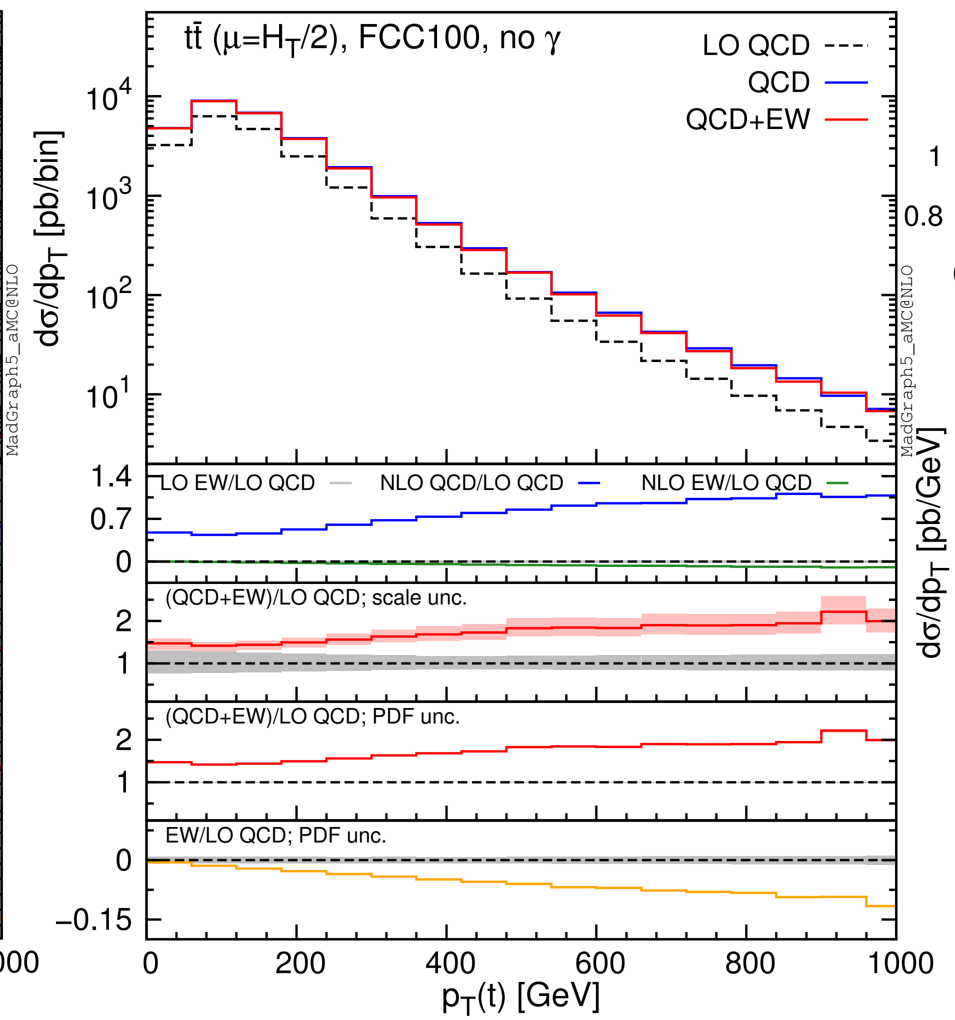
Outline and references:

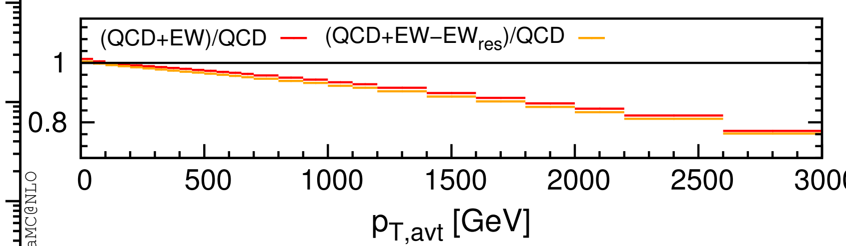
- $t\bar{t}$: EW (and complete-NLO) corrections (+NNLO QCD)
  Pagani, Tsinikos, MZ: arXiv:1606.01915, +Czakon, Mitov, Heymes: arXiv:1705.04105 & 1711.03945
- $t\bar{t}V$(V=W/Z/H): (EW corrections for $t\bar{t}V$ and) complete-NLO for $t\bar{t}W$
  Frixione, Hirschi, Pagani, Shao, MZ: arXiv:1504.03446, Frederix, Pagani, MZ:arXiv:1711.02116
- $t\bar{t}W$ charge asymmetry
  Maltoni, Mangano, Tsinikos, MZ, arXiv:1406.3262
- $t\bar{t}t\bar{t}$: complete-NLO corrections
  Frederix, Pagani, MZ:arXiv:1711.02116

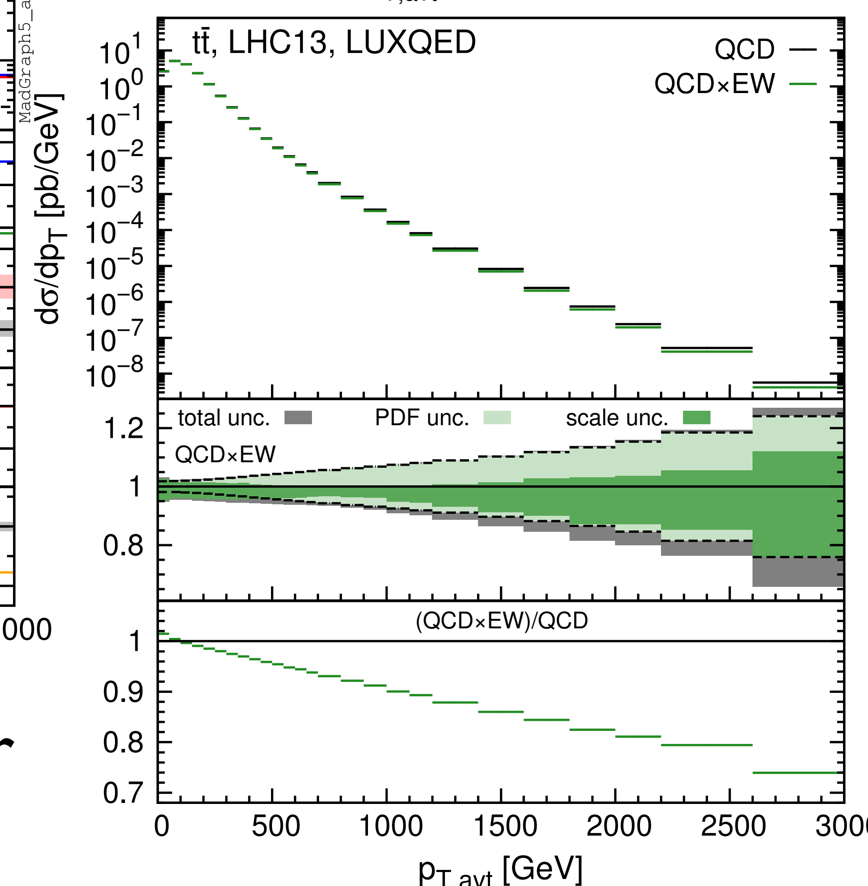
EW Corrections for $t\bar{t}$:





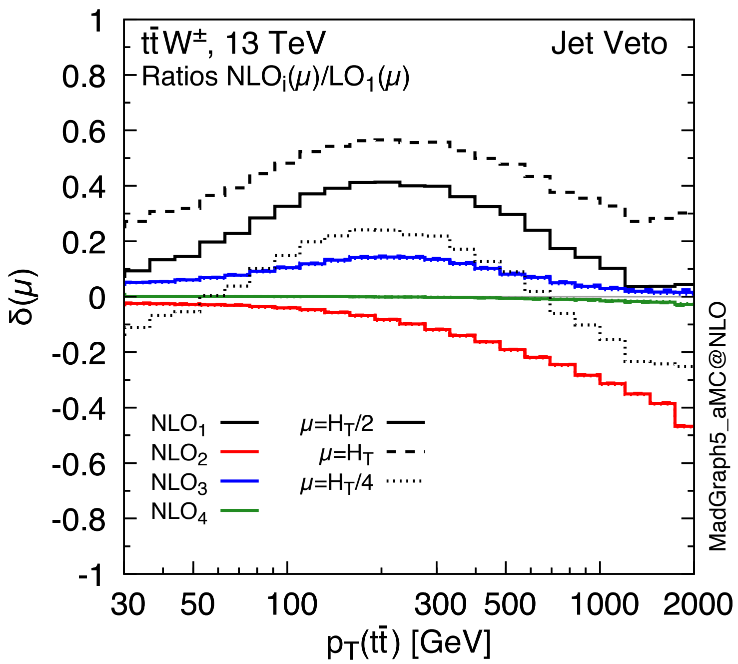


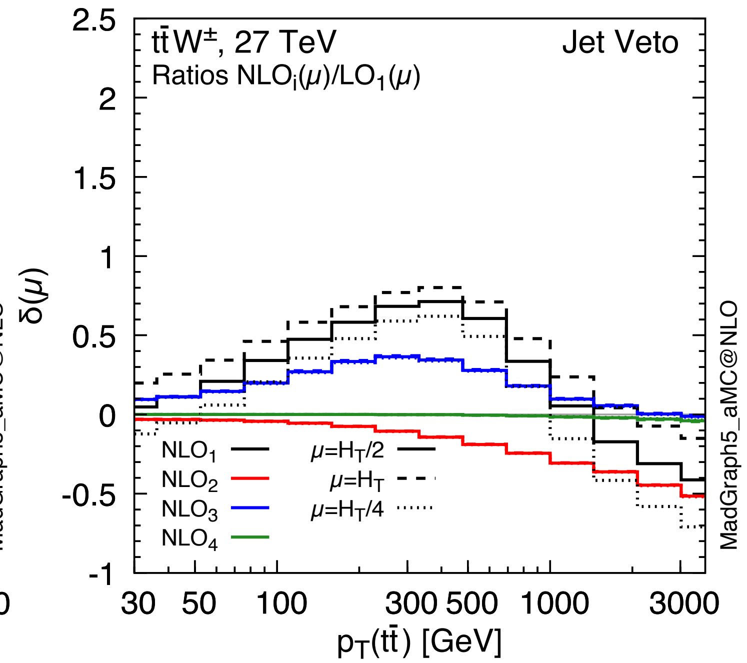


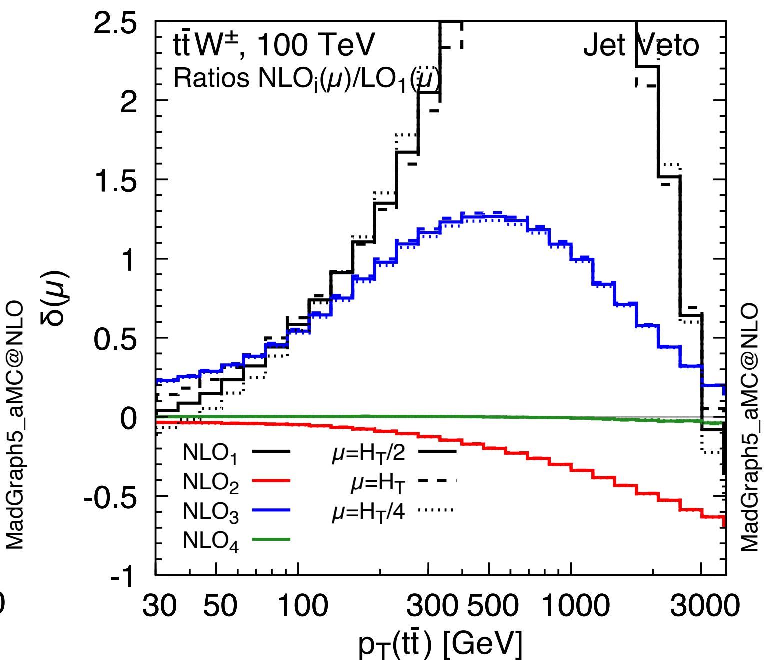


- Sudakov-like behaviour of EW corrections, very similar between 13 and 100 TeV
- Corrections are moderate (~-10% w.r.t LO at p_T=1 TeV), and comparable to NNLO QCD uncertainties (dominated by PDF at 13 TeV)
- Contributions of subleading coupling combinations at LO and NLO is negligible

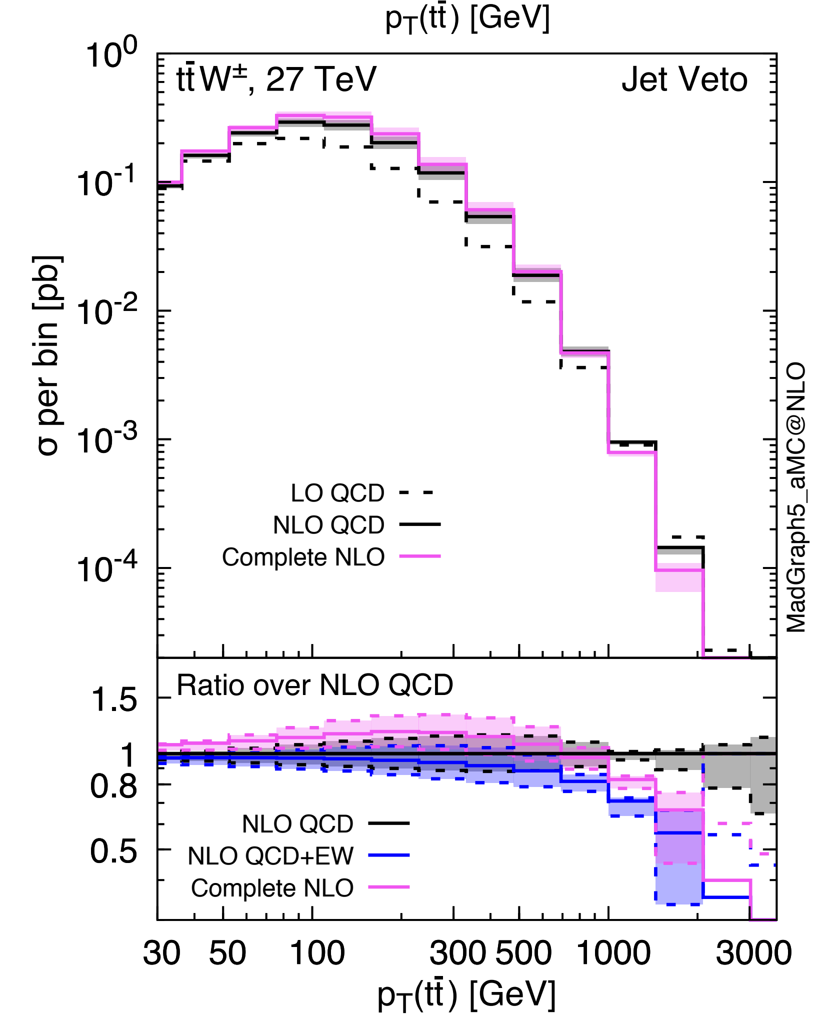
Complete-NLO corrections for $t\bar{t}W$







- QCD corrections to ttW are dominated by hard-jet and soft-W configurations (giant K-factors)
- A jet veto (p_T>100 GeV, |y|<2.5) disfavours these configurations, bringing more stable predictions
- NLO$_3$ ($\alpha_s\alpha^3$) includes t-W scattering, large and positive contribution which survives jet veto: 10/20/55% (vs NLO$_1$ 25/30/70%) w.r.t LO$_1$ at 13/27/100 TeV, while EW ($\alpha_s^2\alpha^2$) corrections are ~-5%
- Complete-NLO and NLO QCD+EW bands barely overlap in large part of the phase-space



Charge asymmetry in $t\bar{t}W$

	Order	$t\bar{t}W^{\pm}$	$t\bar{t}W^{+}$	$t\bar{t}W^{-}$
σ(fb)	NLO	$210^{+11\%}_{-11\%}$	$146^{+11\%}_{-11\%}$	$63.6^{+11\%}_{-11\%}$
A_C^t (%)	LO	0.01 ± 0.05	-0.02 ± 0.05	0.00 ± 0.05
	LO+PS	0.02 ± 0.03	0.05 ± 0.03	0.05 ± 0.03
	NLO	$2.5^{+0.7}_{-0.3}$	$2.7^{+0.8}_{-0.4}$	$2.0^{+0.8}_{-0.2}$
	NLO+PS	$2.3^{+0.6}_{-0.4}$	$2.4^{+0.6}_{-0.2}$	$1.9^{+0.4}_{-0.4}$

	Order	$t\bar{t}W^{\pm}$	$t\bar{t}W^{+}$	$t\bar{t}W^{-}$
A_C^b (%) *	LO+PS	$7.32^{+0.08}_{-0.28}$	$7.90^{+0.14}_{-0.16}$	$5.60^{+0.14}_{-0.08}$
	NLO+PS	$8.39^{+0.09}_{+0.04}$	$9.32^{+0.01}_{-0.20}$	$6.76^{+0.05}_{-0.11}$
A_C^e (%)	LO+PS	$-17.30^{-0.07}_{+0.27}$	$-18.65^{-0.18}_{+0.07}$	$-13.51^{-0.02}_{+0.05}$
	NLO+PS	$-15.1^{-1.2}_{+0.4}$	$-16.1^{-0.8}_{+0.8}$	$-12.1^{-0.9}_{+0.5}$

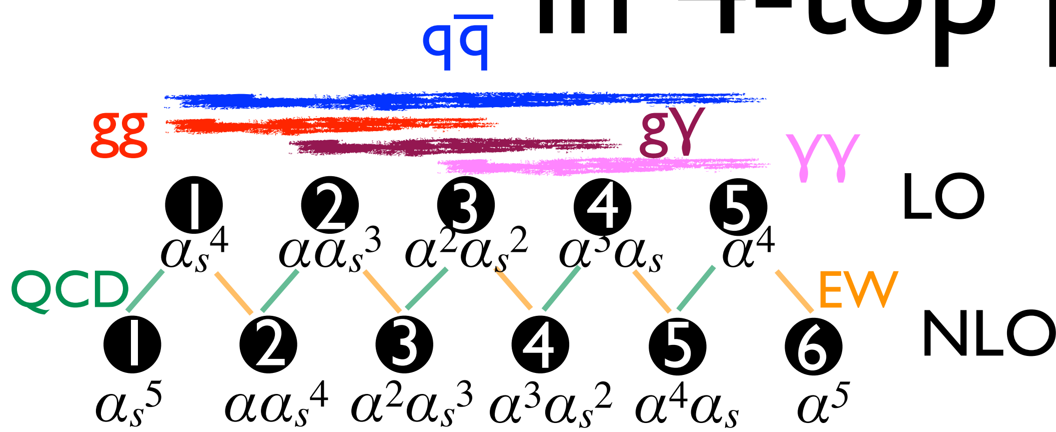
**b-jets, k_T-algo, R=0.5, p_T>20 GeV, |y|<4.5, MCTruth*

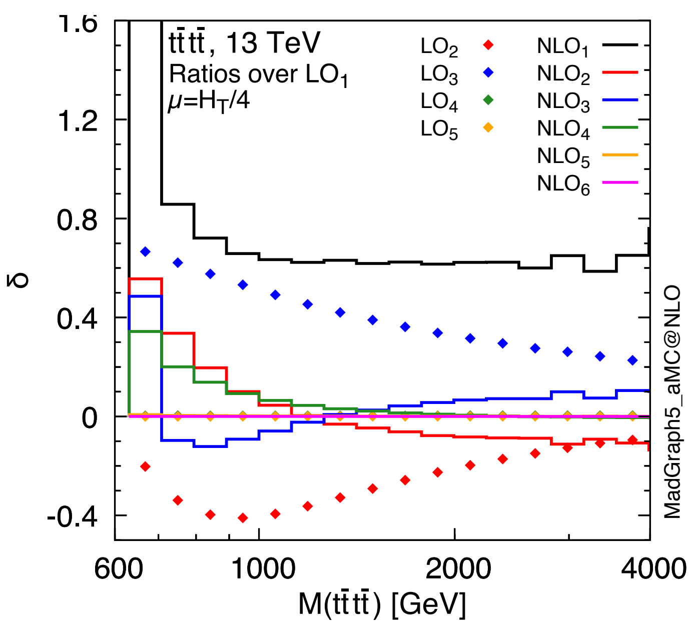
Uncertainties estimate
(di-leptonic top decay), 100% eff.

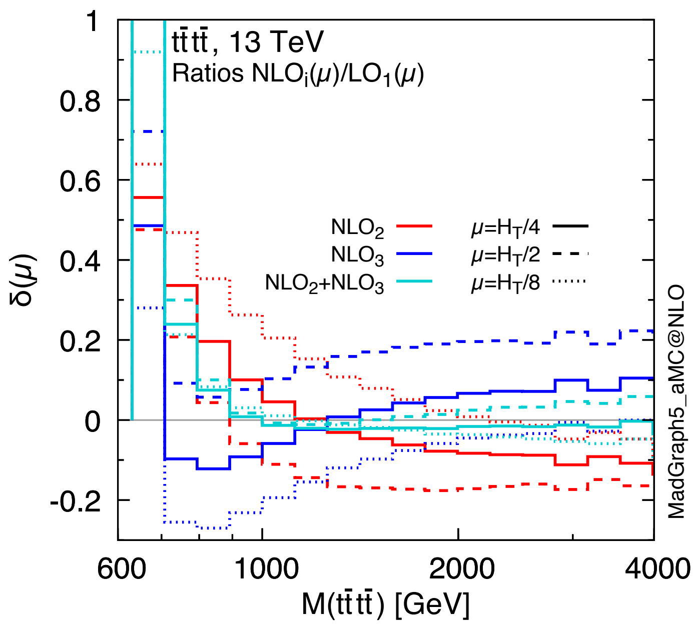
- 8 TeV ($\mathcal{L} = 40$ fb^{-1}):
  $\delta_{\rm rel} A_c^t = 209\%, \delta_{\rm rel} A_c^b = 58\%, \delta_{\rm rel} A_c^\ell = 33\%$
- 14 TeV ($\mathcal{L} = 300$ fb^{-1}):
  $\delta_{\rm rel} A_c^t = 45\%, \delta_{\rm rel} A_c^b = 13\%, \delta_{\rm rel} A_c^\ell = 8\%$
- 14 TeV ($\mathcal{L} = 3000$ fb^{-1}):
  $\delta_{\rm rel} A_c^t = 14\%, \delta_{\rm rel} A_c^b = 4\%, \delta_{\rm rel} A_c^\ell = 2\%$
- 100 TeV ($\mathcal{L} = 3000$ fb^{-1}):
  $\delta_{\rm rel} A_c^t = 3\%, \delta_{\rm rel} A_c^b = 2\%, \delta_{\rm rel} A_c^\ell = 1\%$

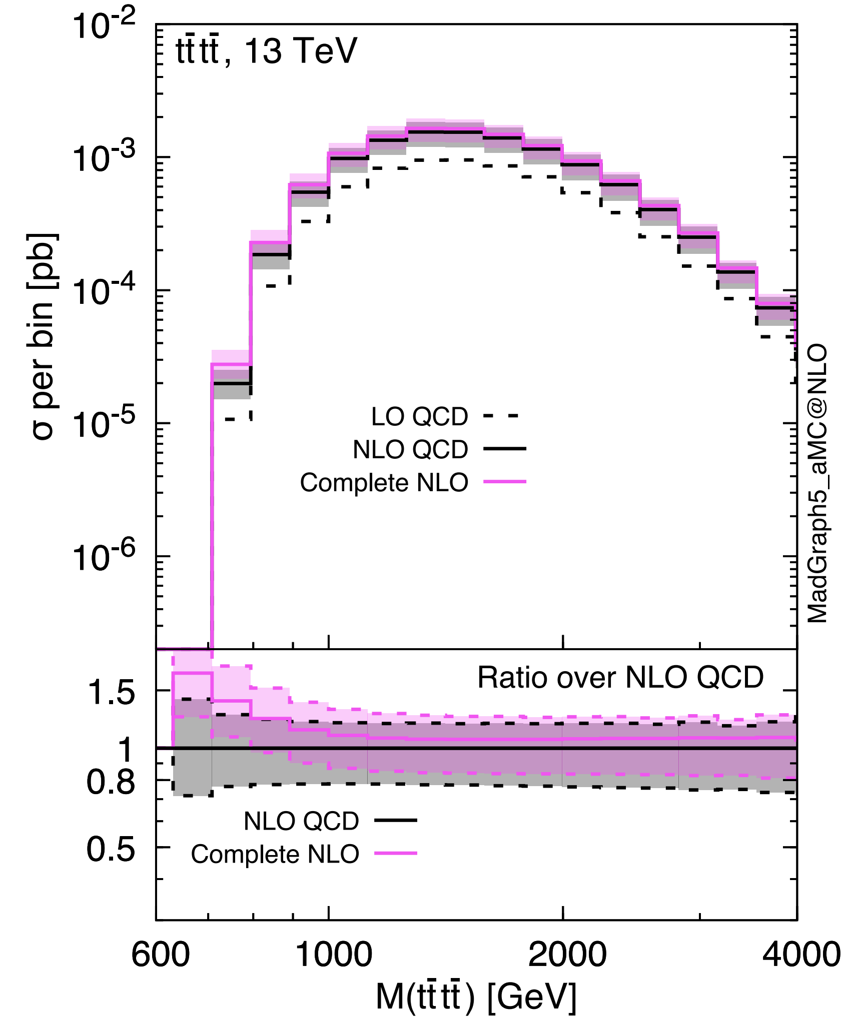
- $t\bar{t}W$ displays a rather large (2.5%) central-peripheral asymmetry
- W polarizes initial quarks→tops are highly polarised →very large asymmetries for the top decay products (if spin correlations are kept)
- Estimate of collider reach makes it interesting to try to measure asymmetries in $t\bar{t}W$ already at 13/14 TeV (more from Andrea and Pieter?)

Complete-NLO corrections in 4-top production









- Subleading corrections are numerically important, up to several 10%s of LO_1. Mostly originated by QCD corrections on LO_i, rather than EW corrections on LO_{i-1}
- Large (scale-independent) cancelations occur among terms at LO ($LO_{2,3}$) and NLO ($NLO_{2,3}$), in particular away from the 4-top threshold
- Away from threshold, complete-NLO and NLO QCD are remarkably closer
- Cancelations may be spoiled by BSM effects

Thank you!

Backup: $t\bar{t}H$ and $t\bar{t}Z$ rates (with boosted cuts)

$t\bar{t}H$: σ(pb)	13 TeV
LO QCD	$3.617 \cdot 10^{-1}$ $(1.338 \cdot 10^{-2})$
NLO QCD	$1.073 \cdot 10^{-1}$ $(3.230 \cdot 10^{-3})$
LO EW	$4.437 \cdot 10^{-3}$ $(3.758 \cdot 10^{-4})$
LO EW no γ	$-1.390 \cdot 10^{-3}$ $(-2.452 \cdot 10^{-5})$
NLO EW	$-4.408 \cdot 10^{-3}$ $(-1.097 \cdot 10^{-3})$
NLO EW no γ	$-4.919 \cdot 10^{-3}$ $(-1.131 \cdot 10^{-3})$
HBR	$3.216 \cdot 10^{-3}$ $(2.496 \cdot 10^{-4})$

$t\bar{t}Z$: σ(pb)	13 TeV
LO QCD	$5.282 \cdot 10^{-1}$ $(1.955 \cdot 10^{-2})$
NLO QCD	$2.426 \cdot 10^{-1}$ $(7.856 \cdot 10^{-3})$
LO EW	$-2.172 \cdot 10^{-4}$ $(4.039 \cdot 10^{-4})$
LO EW no γ	$-5.771 \cdot 10^{-3}$ $(-6.179 \cdot 10^{-5})$
NLO EW	$-2.017 \cdot 10^{-2}$ $(-2.172 \cdot 10^{-3})$
NLO EW no γ	$-2.158 \cdot 10^{-2}$ $(-2.252 \cdot 10^{-3})$
HBR	$5.056 \cdot 10^{-3}$ $(4.162 \cdot 10^{-4})$

$t\bar{t}H$: $\delta(\%)$	13 TeV
NLO QCD	$29.7^{+6.8}_{-11.1} \pm 2.8$ $(24.2^{+4.8}_{-10.6} \pm 4.5)$
LO EW	1.2 ± 0.9 (2.8 ± 2.0)
LO EW no γ	-0.4 ± 0.0 (-0.2 ± 0.0)
NLO EW	-1.2 ± 0.1 (-8.2 ± 0.3)
NLO EW no γ	-1.4 ± 0.0 (-8.5 ± 0.2)
HBR	0.89 (1.87)

$t\bar{t}Z$: $\delta(\%)$	13 TeV
NLO QCD	$45.9^{+13.2}_{-15.5} \pm 2.9$ $(40.2^{+11.1}_{-15.0} \pm 4.7)$
LO EW	0.0 ± 0.7 (2.1 ± 1.6)
LO EW no γ	-1.1 ± 0.0 (-0.3 ± 0.0)
NLO EW	-3.8 ± 0.2 (-11.1 ± 0.5)
NLO EW no γ	-4.1 ± 0.1 (-11.5 ± 0.3)
HBR	0.96 (2.13)

- NLO EW correction have modest impact on inclusive xsect, but can be important in the boosted regime (same order of QCD uncertainties)
- Boosted regime enhances photon contribution in LO-EW
- HBR contributions remain small

Backup: $t\bar{t}W$ $p_T(W)$