

Top quark EFT: recent theory progresses

Gauthier Durieux
(Technion)

personal selection of topics
from past year approximately
not already presented in WG meetings
apologies for omitted works and superficial coverage



Outline

More global EFT analyses

top/top+Higgs/top+bottom/...

More sensitive and detailed EFT analyses

Validation of MC EFT implementations

More global EFT analyses

Global SMEFT analyses

- ▶ New SMEFIT [1901.05965]
discussed by J. Rojo in last meeting [20 Nov 18 talk]
- ▶ Ongoing TOPFITTER run II update [ICHEP2018: 1901.03164]
particle level, extended parameter space, linearised EFT,...
- ▶ Ongoing SFITTER progresses [Moutafis Master's th.: 1905.03616]
[Biekötter Bruggisser Moutafis Westhoff et al.]
- ▶ Top loops in Higgs processes [Vryonidou Zhang 1804.09766]

Helping global analysis: *Recasting through reweighting*

[Cranmer Heinrich, J. Brief Ideas, Oct '17]

True full parton-level distr. $p_0(z)$

Reconstructed distributions $p_0(x)$

Abstract *folding operator* $W(x|z)$

$$p_0(x) = \int dz \ p_0(z) \ W(x|z) \quad \text{through MC sampling}$$

Reweighting from theory hypothesis 0 to 1

given a set of pre-folded events (x_k, z_k) distributed following $p_0(z)$

$$p_1(x) = \int dz \ p_0(z) \ \frac{p_1(z)}{p_0(z)} \ W(x|z)$$

Recipe:

1. take events $\{(x_k, z_k, p_0(z_k))\}$ (published?!)
2. reweight by $p_1(z_k)/p_0(z_k)$ (no new sample generation)
3. get arbitrarily fine-grained and multidimensional reco. $p_1(x)$
4. change observable too, if x is rich enough (?)

Helping global analysis: *Recasting through reweighting*

[Cranmer Heinrich, J. Brief Ideas, Oct '17]

True full parton-level distr. $p_0(z)$

Reconstructed distributions $p_0(x)$

Abstract *folding operator* $W(x|z)$

$$p_0(x) = \int dz p_0(z) W(x|z)$$

- CPU-affordable multidimensional coverage
given a set of MC samples $p_0(z)$ through MC sampling
- clean and easy reinterpretation outside collab.
(still need a recipe for systematics)

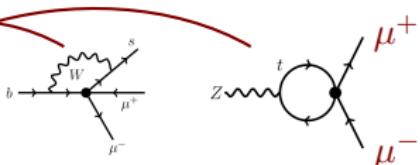
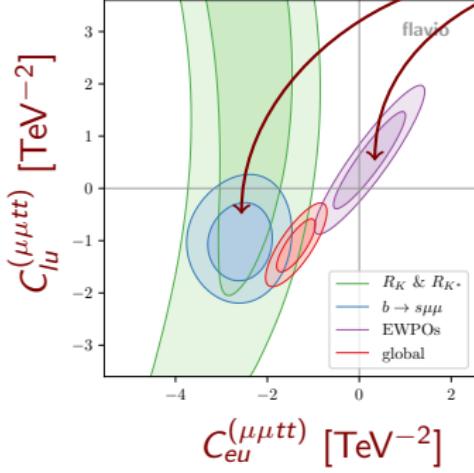
- works for $x = \text{MVA}$

Recipe:

1. take events $\{(x_k, z_k, p_0(z_k))\}$ (published?!)
2. reweight by $p_1(z_k)/p_0(z_k)$ (no new sample generation)
3. get arbitrarily fine-grained and multidimensional reco. $p_1(x)$
4. change observable too, if x is rich enough (?)

Top-bottom interplay

B anomalies from NP in top (right-handed)



- ▶ $[C_{eu}]_{2233}$, i.e. RH $t\bar{t}\mu\mu$ operator, suggested as solution to $b \rightarrow s\ell\ell$ anomalies in Celis et al., arXiv:1704.05672

- ▶ see Z' model in Kamenik et al., arXiv:1704.06005

- ▶ Later realized that there are strong constraints from $Z \rightarrow \mu\mu$

Camargo-Molina, Celis, Faroughy, arXiv:1805.04917

- ▶ Plot: SMEFT at 1 TeV (RG mixing)

No direct LHC constraint on $\mu\mu tt$ operators!

More top-bottom interplay

- tcV operators in B decays and meson oscillations

[Fox Ligeti Papucci Perez Schwartz 0704.1482]

- Wtb operators in B decays

[Drobnak Fajfer Kamenik 1109.2357]

- ttZ operators in meson decays

[Brod Greljo Stamou Uttayanat 1408.0792]

- $tcl\ell$ operators in $B_s \rightarrow \ell\ell$, $B \rightarrow K^{(*)}\bar{\nu}\nu$, $b \rightarrow cl\nu$ [Fajfer Kosnik 1511.06024]

- $ttqq'$ operators in $b \rightarrow s$ and $b \rightarrow c$ transitions

[Aebischer Crivellin Fael Greub 1512.02830]

- $tt\tau\tau$ operators on $b \rightarrow c\tau\nu$, $(g-2)_\tau$ and $h \rightarrow \tau\tau$

[Feruglio Paradisi Sumensari 1806.10155]

- $t \rightarrow b\tau\nu$ vs. $b \rightarrow c\tau\nu$

[Kamenik Katz Stolarski 1808.00964]

- $ttqq'$ operators effects on meson oscillations

[Endo Kitahara Ueda 1811.04961]

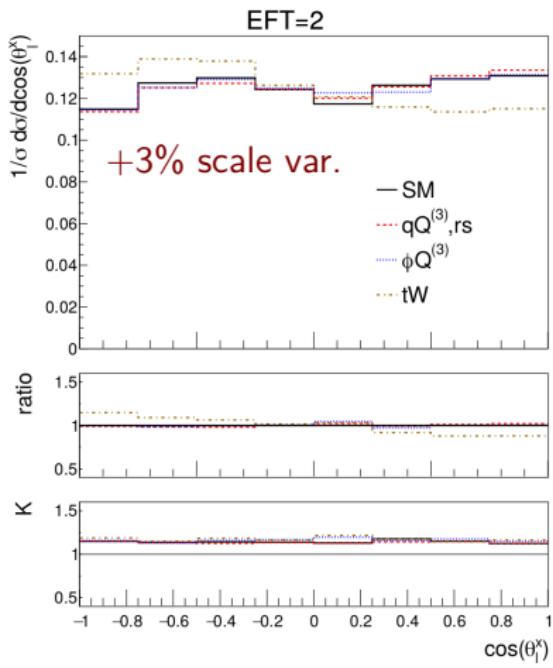
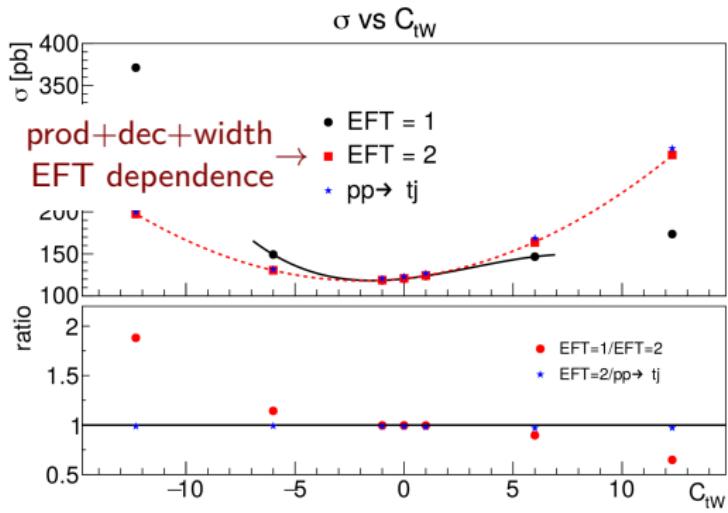
- ...

More sensitive and detailed
EFT analyses

Single top

[de Beurs Laenen Vreeswijk Vryonidou 1807.03576]

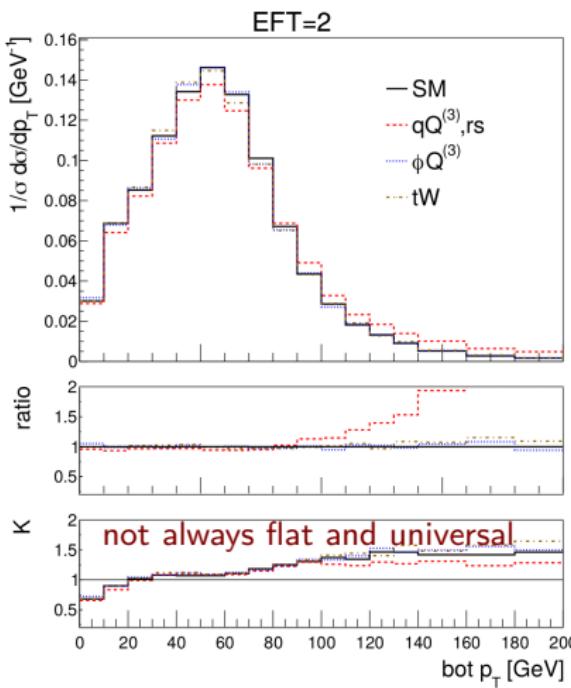
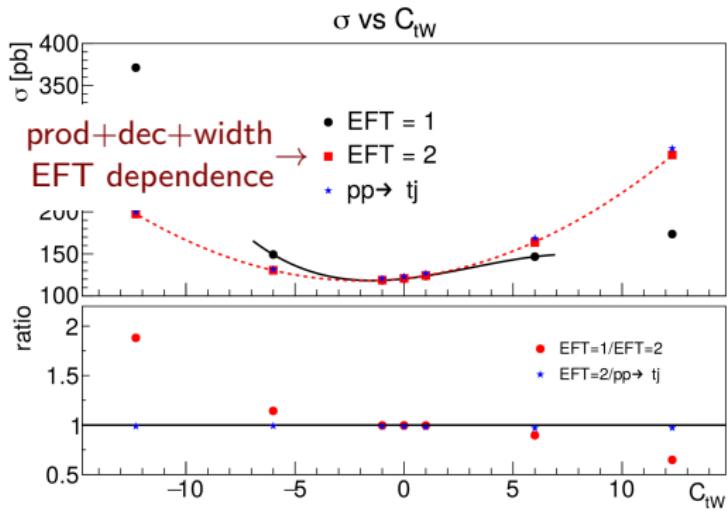
- ▶ differential distributions (sensitive to production and/or decay)
- ▶ EFT at NLO-QCD
- ▶ beyond NWA (quite good for total rate)
 - EFT in prod., dec., and total width
 - resonance-aware matching to PS



Single top

[de Beurs Laenen Vreeswijk Vryonidou 1807.03576]

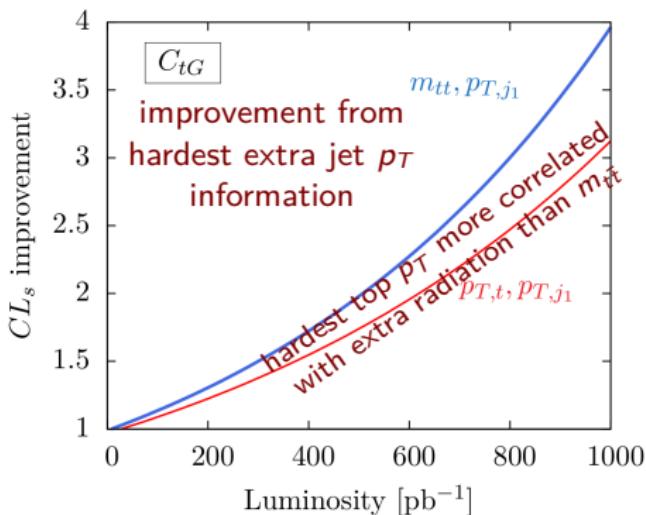
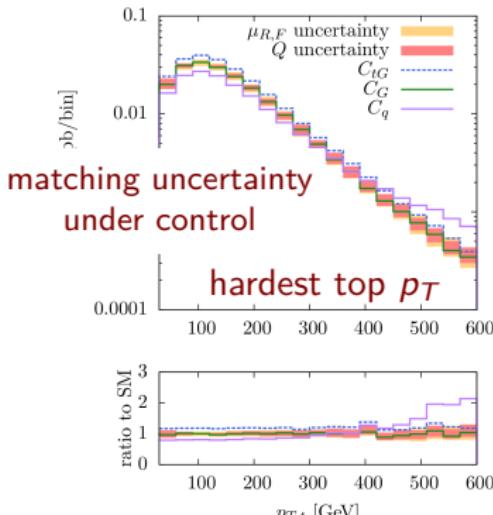
- ▶ differential distributions (sensitive to production and/or decay)
- ▶ EFT at NLO-QCD
- ▶ beyond NWA (quite good for total rate)
 - EFT in prod., dec., and total width
 - resonance-aware matching to PS



Top pair + jets

[Englert Russell White 1809.09744]

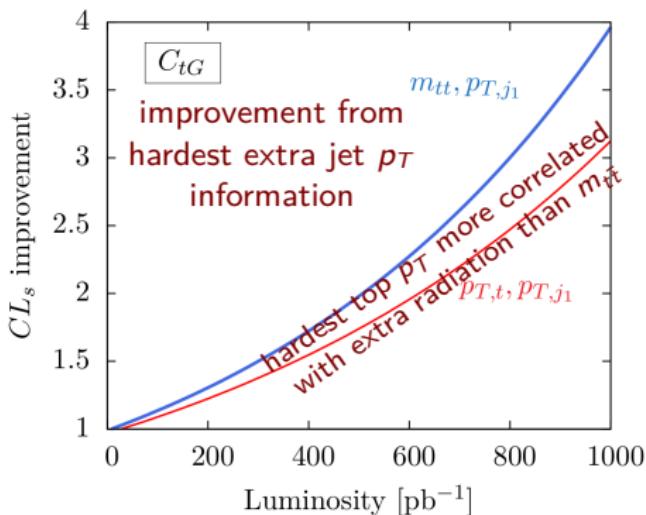
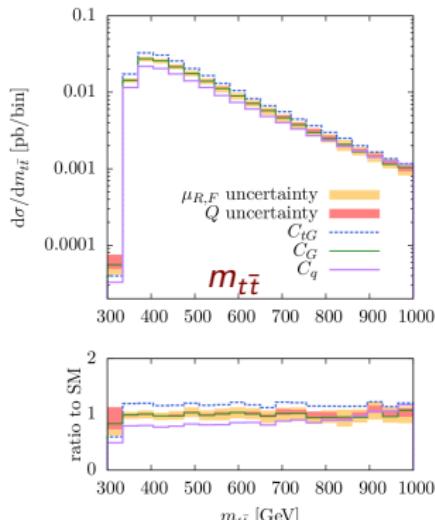
- TOPFITTER goes to particle level
- No EFT corrections in shower!
 - theory discontinuity in matching
 - OK: no soft or collinear EFT divergence
 - since, dimensionally, massless partons splitting Q^2/Λ^2 -suppressed
- There is more about EFT in $t\bar{t} + \text{jets}$ than in $t\bar{t}$



Top pair + jets

[Englert Russell White 1809.09744]

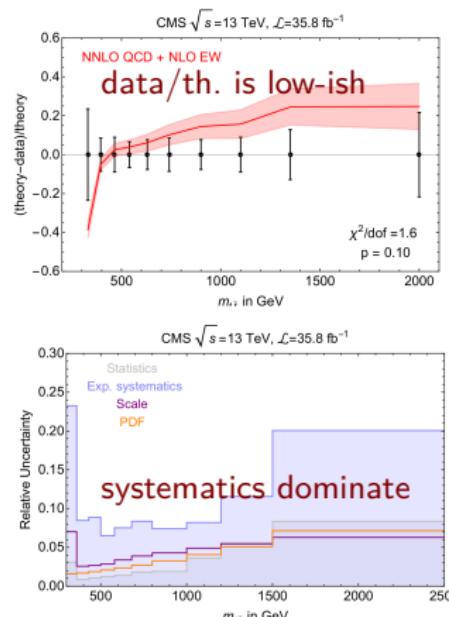
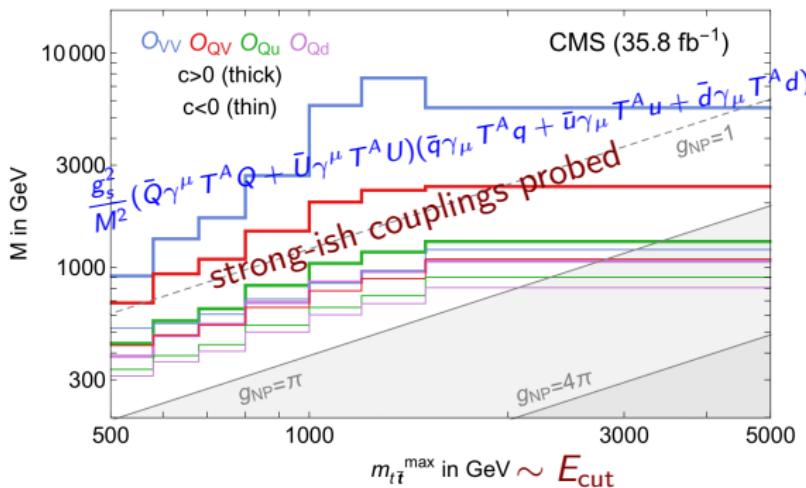
- TOPFITTER goes to particle level
- No EFT corrections in shower!
 - theory discontinuity in matching
 - OK: no soft or collinear EFT divergence
 - since, dimensionally, massless partons splitting Q^2/Λ^2 -suppressed
- There is more about EFT in $t\bar{t} + \text{jets}$ than in $t\bar{t}$



High-energy $m_{t\bar{t}}$

[Farina Mondino Pappadopulo Ruderman 1811.04084]

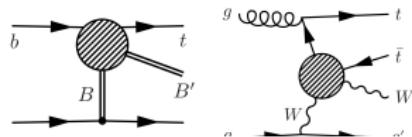
- $m_{t\bar{t}}$ tail is a powerful probe of top (hence Higgs) compositeness
- considering $qqt\bar{t}$ operators that interfere with massless SM amplitudes
- using NNLO-QCD + NLO-EW SM; LO quadratic EFT
- unfolded CMS 13 TeV-36/fb semileptonic distribution
- correlated exp. systematics; th. scale and PDF uncertainties
- $pp \rightarrow b\bar{b}$ analysis (with b -tag) could be beneficial
- $pp \rightarrow t\bar{t}t\bar{t}$ is not (yet?) competitive



Top electroweak sensitivity at high energies

[Matoni Mantani Mimasu 1904.05637]
 [Mantani talk at HEFT 2019]

- EFT causes energy growing effects in top-EW 2-to-2 amp.
- embed them in 2-to-3 and 2-to-4 processes
- MC study + analytical in effective W approx.
- study sensitivity systematically (70p!)

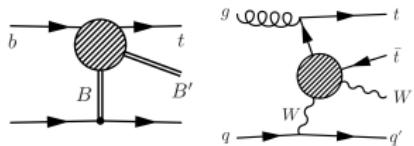


$\lambda_b, \lambda_W, \lambda_t, \lambda_Z$	SM	$\mathcal{O}_{\varphi D}$	$\mathcal{O}_{\varphi WB}$	\mathcal{O}_W	\mathcal{O}_{tB}	\mathcal{O}_{tW}	$\mathcal{O}_{\varphi Q}^{(1)}$	$\mathcal{O}_{\varphi Q}^{(3)}$	$\mathcal{O}_{\varphi t}$	$\mathcal{O}_{\varphi tb}$
$-,-,0,-,0$	s^0	s^0	s^0	s^0	—	s^0	—	$\sqrt{s(s+t)}$	—	—
$-,-,+,-,0$	$\frac{1}{\sqrt{s}}$	$\sqrt{-t}m_t$	—	—	$\sqrt{-t}m_W$	$\frac{m_W(s+t)}{\sqrt{-t}}$	$\sqrt{-t}m_t$	$\sqrt{-t}m_t$	$\sqrt{-t}m_t$	—
$+,-,-,0,-,0$	—	—	—	—	—	—	—	—	—	—
$+,-,+,-,0$	—	—	—	—	$bW^+ \rightarrow tZ$		—	—	—	$\sqrt{s(s+t)}$
$-,-,-,-,-$	$\frac{1}{\sqrt{s}}$	—	$\frac{sm_W}{\sqrt{-t}}$	$\frac{m_W^2(s+t)}{\sqrt{-tv}}$	$\sqrt{-t}m_t$	$\sqrt{-t}m_t$	—	$\sqrt{-t}m_W$	—	—
$-,-,-,-,0$	$\frac{1}{\sqrt{s}}$	—	—	$\frac{m_W^2(s+t)}{\sqrt{-tv}}$	—	—	—	$\sqrt{-t}m_W$	—	—
$-,-,+,-,-$	s^0	s^0	s^0	s^0	—	s^0	s^0	s^0	—	—
$-,-,+,-,0$	$\frac{1}{s}$	s^0	s^0	s^0	s^0	$\sqrt{s(s+t)}$	s^0	s^0	s^0	—
$-,-,-,+,-$	$\frac{1}{\sqrt{s}}$	—	$\frac{m_W(s+t)}{\sqrt{-t}}$	$\frac{m_W^2(s+t)}{\sqrt{-tv}}$	—	—	—	—	—	—
$-,-,+,-,0$	$\frac{1}{\sqrt{s}}$	—	—	$\frac{m_W^2(s+t)}{\sqrt{-tv}}$	—	—	—	—	—	—
$-,-,+,-,+$	$\frac{1}{s}$	s^0	—	—	$\sqrt{s(s+t)}$	$\sqrt{s(s+t)}$	s^0	s^0	s^0	—
$-,-,+,-,0$	s^0	s^0	s^0	—	—	s^0	—	s^0	—	—

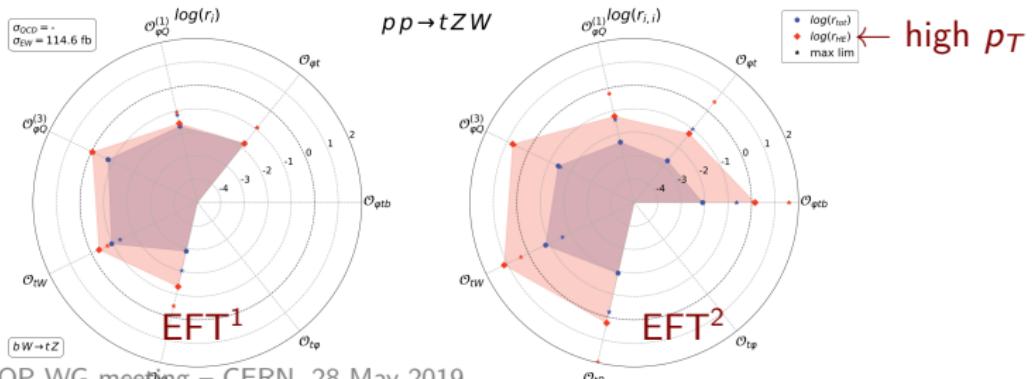
Top electroweak sensitivity at high energies

[Matoni Mantani Mimasu 1904.05637]
[Mantani talk at HEFT 2019]

- EFT causes energy growing effects in top-EW 2-to-2 amp.
- embed them in 2-to-3 and 2-to-4 processes
- MC study + analytical in effective W approx.
- study sensitivity systematically (70p!)



	tWj	tZj	$t\gamma j$	tWZ	$tW\gamma$	thj	thW
$bW \rightarrow tZ$	✓	✓			✓		
$bW \rightarrow t\gamma$	✓		✓		✓		
$bW \rightarrow th$						✓	✓

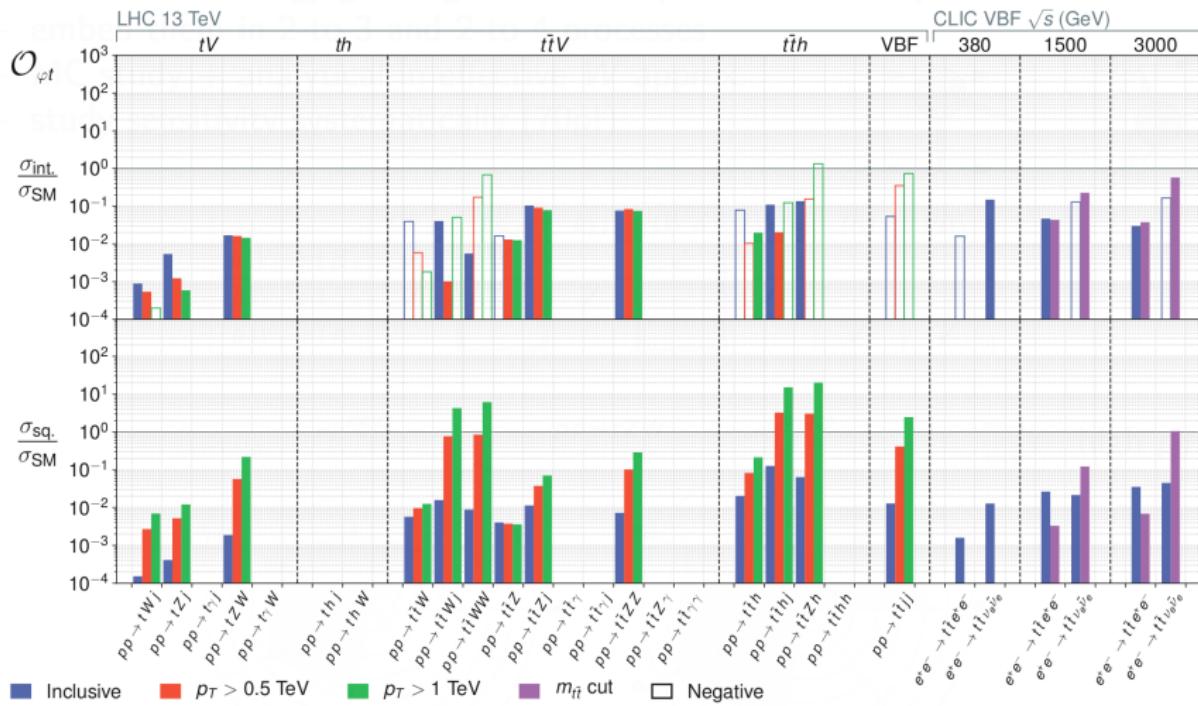


Top electroweak sensitivity at high energies

[Matoni Mantani Mimasu 1904.05637]

[Matoni: talk at LHCET 2019]

Which process for each operator:



Validation of EFT MC implementations

Validating SMEFT implementations

[arxiv ref. to appear here in $\mathcal{O}(\text{days})$]

[see also Michelangelo's talk, LHCXSWG 12 Dec 18]

- ▶ Mandate from Higgs+EW+Top WGs
- ▶ Note on principles being finalized (40⁺ theorists)
 - compute 1-to-2 and 2-to- n square amplitudes
 - at various phase-space points (fast, without MC uncertainty)
 - at equivalent parameter points in pairs of implementations
 - with EFT fully linearised, and squared
 - so far: widths=0, spin+colour averaged, CKM=1 by default
 - input scheme including all masses (m_Z , m_W , ...)
 - gather all numerics in LHE+SLHA format (mostly standard)
 - extendable to 1-loop following BLHA
- ▶ Decentralized pair-wise comparisons to cope with large diversity
- ▶ Dictionaries between implementations needed [Rosetta, wcxr-python]
- ▶ MG5 comparison plugin developed for UFO models [Mattelaer, GD]
- ▶ First comparisons already ongoing

Validating SMEFT implementations

[arxiv ref. to appear here in \mathcal{O} (days)]

[see also Michelangelo's talk, LHCXSWG 12 Dec 18]

```
</header>
...
<event>
    4      2 +5.7925728e-01 9.11180000e+01 0.00000000e+00 1.18400000e-01
          21 -1     0     0     0     0 +0.00e+00 +0.00e+00 +5.00e+02 5.00e+02 0.00e+00 0.00e+00 9.00e+00
          22 -1     0     0     0     0 +0.00e+00 +0.00e+00 -5.00e+02 5.00e+02 0.00e+00 0.00e+00 9.00e+00
          -6  1     1     2     0     0 +1.66e+02 -3.90e+02 +2.01e+02 5.00e+02 1.72e+02 0.00e+00 9.00e+00
          6   1     1     2     0     0 -1.66e+02 +3.90e+02 -2.01e+02 5.00e+02 1.72e+02 0.00e+00 9.00e+00
<rwgt>
<wgt id='mod1-sm-sq'> +2.1166989e-01 </wgt>
<wgt id='mod1-ctW-int'> +3.6769585e-01 </wgt>
<wgt id='mod1-ctZ-int'> -3.2187585e-01 </wgt>
<wgt id='mod1-ctG-int'> +3.0451935e-02 </wgt>
<wgt id='mod1-ctW-sq'> +1.5438777e+00 </wgt>
<wgt id='mod1-ctZ-sq'> +1.1830749e+00 </wgt>
<wgt id='mod1-ctG-sq'> +1.0589251e-02 </wgt>
<wgt id='mod2-sm-sq'> +2.1166988e-01 </wgt>
<wgt id='mod2-ctW-int'> +3.6769591e-01 </wgt>
<wgt id='mod2-ctZ-int'> -3.2187587e-01 </wgt>
<wgt id='mod2-ctG-int'> +3.0451934e-02 </wgt>
<wgt id='mod2-ctW-sq'> +1.5438783e+00 </wgt>
<wgt id='mod2-ctZ-sq'> +1.1830750e+00 </wgt>
<wgt id='mod2-ctG-sq'> +1.0589251e-02 </wgt>
...
</rwgt>
</event>
...
</LesHouchesEvents>
```

▶ First comparisons already ongoing

Top-quark EFT: recent theory progresses

- make analyses more detailed, more precise, and more global,
- explore the power and complementarities
of observables and processes,
- examine BSM implications,
- develop and validate the necessary methods and tools.