Four top quarks in SMEFT

Aoude, HF, Maltoni, Vryonidou, arXiv: 2208.04962

Hesham El Faham
University of Manchester

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Status

- Top quark plays a special role in SM and beyond
- So far, no direct signs of beyond the SM physics → effective theories?
- Keep measuring rare processes
Into effective field theories and SMEFT
SMEFT in a nutshell

UV physics projected onto the low-energy dynamics

Assume new physics is larger than all other scales...

\[ \mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{c_i}{\Lambda^2} Q_i^{\text{dim}-6} + \ldots \]
Top quark operators in SMEFT

**Currents**
\[ i(\varphi^* D^\mu \varphi)(\bar{Q} \gamma^\mu Q) \]
- Shift SM $f\bar{f}V$ couplings
- $f\bar{f}Vh$ contact interactions

**Yukawa**
\[ (\bar{q} t \bar{\varphi})(\varphi^* \varphi) \]
- Decouple $m_t$ & $y_t$
- $t\bar{t}hh(h)$ contact interactions

**Dipole**
\[ (\bar{q} \sigma_{\mu\nu} t \bar{\varphi})V^{\mu\nu} \]
- Chirality flipping $f\bar{f}V$ couplings
- $f\bar{f}V(V)h$ contact interactions
- $W, B & G$ fields

**4 Fermion**
\[ (\bar{q}\gamma_\mu t)(\bar{Q} \gamma^\mu Q)(\bar{Q} \gamma^\mu Q) (\bar{e} \gamma_\mu \ell) \]
- Contact interactions
- 2-heavy-2-light or 4-heavy
- Numerous ($\sim O(20)$ w/ top)

By Ken Mimasu
Pragmatic SMEFT

To constraint SMEFT, we need fits.

\[ \Delta \text{Obs}_n = \text{Obs}_n^{\text{EXP}} - \text{Obs}_n^{\text{SM}} = \frac{1}{\Lambda^2} \sum_i c_i^6(\mu) a_{n,i}^6(\mu) + \mathcal{O}\left(\frac{1}{\Lambda^4}\right) \]

- Precise EFT predictions
- Precise SM predictions
- Precise experimental measurements

Adapted from a slide by Eleni Vryonidou
Global fits

Theory predictions

Experimental data

Bounds

Uncertainty estimate
Global fits: results

The SMEFiT Collaboration, arXiv: 2105.00006
Global fits: results

Can we do something about four-fermions?
Four tops in SMEFT

\[ \text{tttt in SM } \sim 0.02 \text{ pb} \]
Be careful when doing four tops

- Cao, Chen, Liu, arXiv: 1602.01934
  “.. be careful at LO SM”

- Frederix, Pagani, Zaro, arXiv: 1711.02116
  “.. be careful at NLO SM”

  “.. be careful at SMEFT for some operators”

- Aoude, HF, Maltoni, Vryonidou, arXiv: 2208.04962
  “..we are being careful at SMEFT for all operators”

.. and a lot of other work considering four-fermion operators/ four tops in SMEFT [arXiv:1010.6304, 1708.05928, 1903.07725, 2010.05915, 2104.09512, ..]
Four tops in SMEFT: interference

Interference
Four tops in SMEFT: interference

\[ \text{Interference} \]

\[ \bar{t} \bar{t} \text{ production, noted above. Table II also provides the} \]
\[ \text{LO interferences with subleading SM amplitudes of order } \alpha_s \alpha_{\text{EW}} \text{ and } \alpha_s y_t^2 \text{ which are actually larger than} \]
\[ \text{with the leading QCD ones. Note they also have opposite signs. At the quadratic level, the NLO enhance-} \]
Four tops in SMEFT

Electroweak contributions are important

Aoude, HF, Maltoni, Vryonidou, arXiv: 2208.04962
Four tops in SMEFT

Electroweak contributions are important
Four tops in SMEFT

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<th>2L2H</th>
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<td>$c_{t\varphi}, c_{tZ}, c_{tW}$</td>
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<td>$\sigma_2$</td>
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<td>$c_{31}^{Qq}$</td>
<td>$c_{\varphi t}, c_{\varphi Q}$</td>
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Electroweak contributions are important
Four tops in SMEFT

- Differential information is important

Aoude, HF, Maltoni, Vryonidou, arXiv: 2208.04962
Four tops in SMEFT

- Differential information is important
- FCC-hh provides a good handle

Aoude, HF, Maltoni, Vryonidou, arXiv: 2208.04962
Four tops finally observed!

ATLAS and CMS observe simultaneous production of four top quarks

The ATLAS and CMS collaborations have both observed the simultaneous production of four top quarks, a rare phenomenon that could hold the key to physics beyond the Standard Model.

24 MARCH, 2023  |  By Naomi Dinmore
Summary

- SMEFT is a tool to **parametrise and constrain** potential new physics systematically
- Four top quark production is a rare process with **exciting features for new physics scenarios**
- Four tops with SMEFT insertions requires **considering predictions with sub-leading orders in the strong coupling**
- Differential information can provide a **firm handle on SMEFT bounds** for four-fermion operators, also FCC-hh energies
- Four tops has been finally **observed**