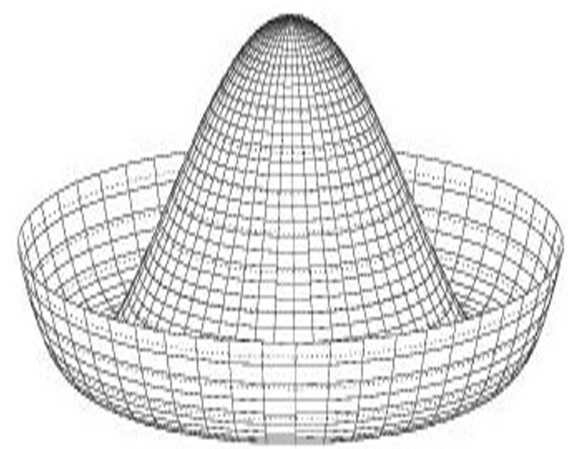
THE SEARCH FOR NEW PHYSICS AND SMEFT

S. Dawson, BNL

IFT Christmas Workshop

December 13, 2023

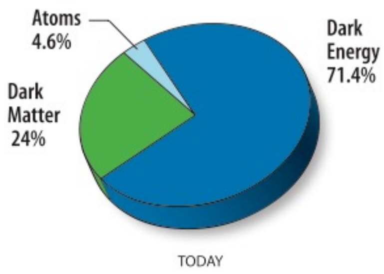


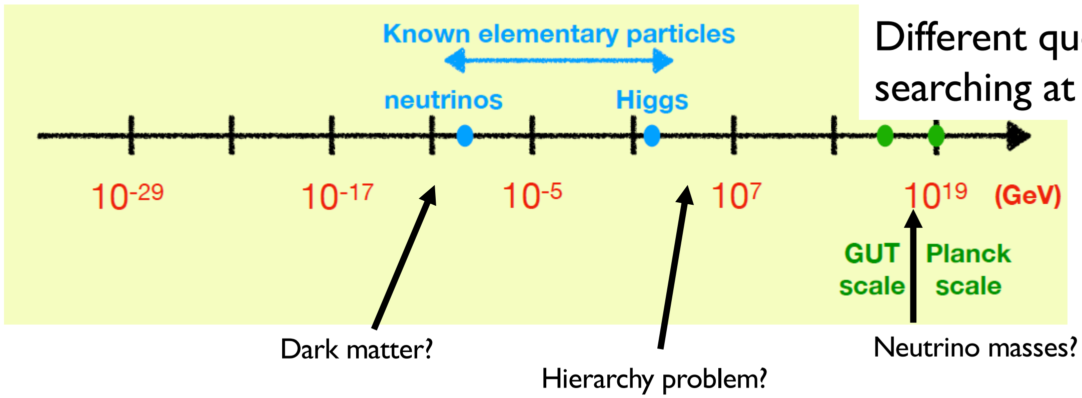
Complaints, suggestions to dawson@bnl.gov

WE KNOW THERE MUST BE NEW PHYSICS

- What is dark matter?
- Why is there a matter-antimatter asymmetry?
- What sets the pattern of fermion masses?
  - Why is the top so heavy and why are neutrinos so light?
- Why are the W and Higgs so much lighter than the Planck scale?
- Why is the Standard Model so simple with only one Higgs doublet?

Many possibilities for new physics that attempts to answer these questions





Different questions suggest searching at different scales

I will focus on scenario where new physics is heavy

WHERE TO LOOK FOR NEW PHYSICS?

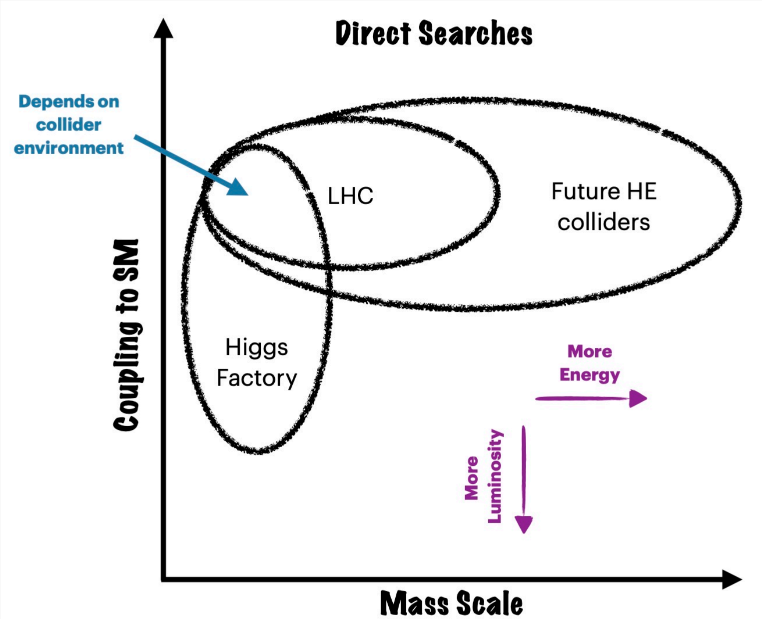
NEW PHYSICS

- Hard to know what we expect
- Can we determine source of new physics?

Precision measurements

No resonance or light resonance or new signatures

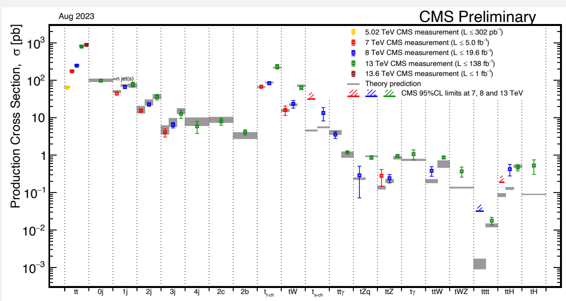
Find resonance!



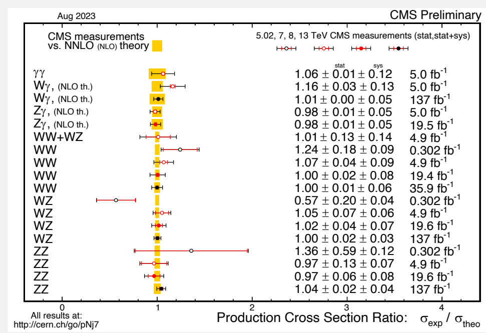
Current knowledge will be strengthened at HL-LHC

EVERYTHING LOOKS LIKE THE SM AT THE WEAK SCALE

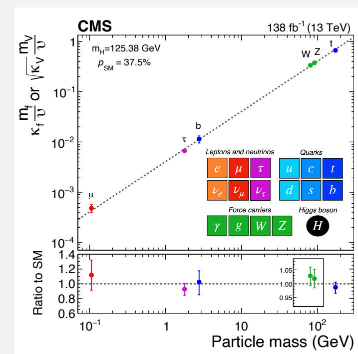
Top quark physics



Di-boson physics

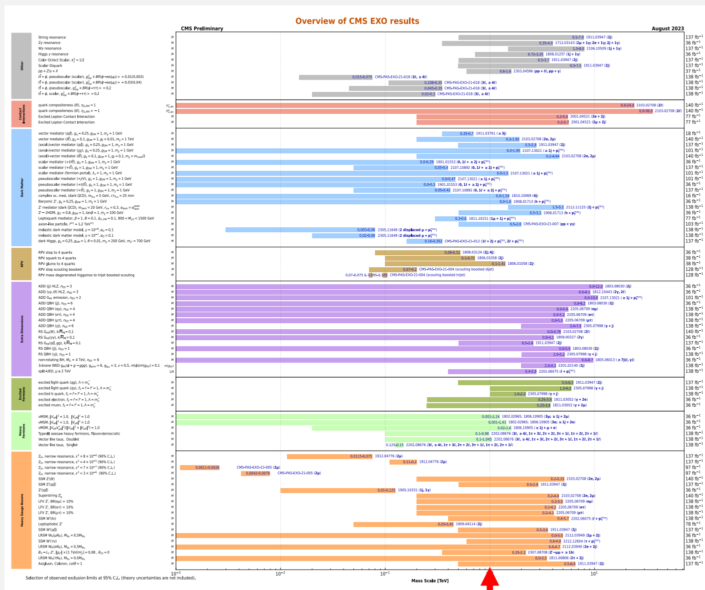


Higgs physics



- Suggests that the SM is a good approximation to physics at the weak scale and in many different sectors

IT APPEARS THAT NEW PHYSICS IS HEAVY (> 1 TEV) *[OR VERY LIGHT AND WEAKLY COUPLED]*

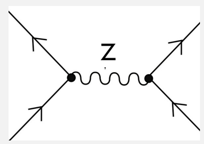


1 TeV

Searching for new physics as an expansion around the SM assuming no new light particles is reasonable

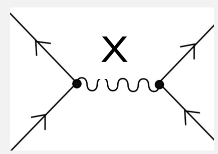
START FROM THE IDEA OF HIGH SCALE DECOUPLING

- Suppose there is a new particle X, with mass $M_X >> M_W$
- SM scattering:



$$A_{SM} \sim \frac{g^2}{M_Z^2}$$

- Contribution from X:



$$A_X \sim \frac{g_X^2}{M_X^2}$$

- Scattering rate:

$$\sigma \sim \sigma_{SM} + \frac{g^2 g_X^2}{M_X^2} \rightarrow \sigma_{SM}$$

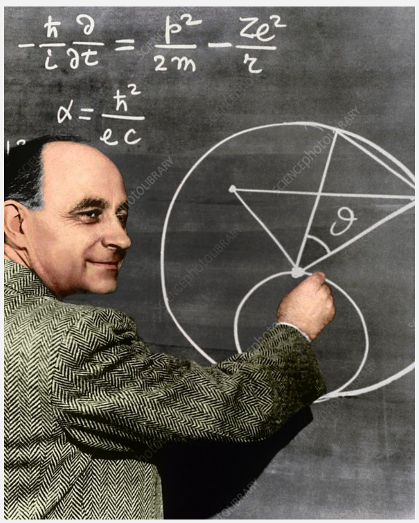
If UV theory is non-decoupling, then expansion in powers of $1/M_X^2$ will fail at some point

Effects of X vanish as $1/M_X^2$ for ***weak coupling***

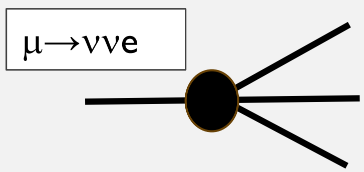
This is implicit assumption as we construct SMEFT

*Note: Higgs is example of non-decoupling particle

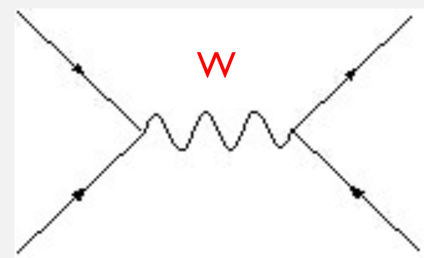
INDIRECTLY DISCOVER NEW PHYSICS



- Fermi theory ($\mu \rightarrow \nu\nu e$) becomes non-perturbative at E ~ 600 GeV
- W boson saves the day



$G_F E^2 \rightarrow G_F M_W^2$



Indirectly discover new physics

Goal is to apply this lesson to TeV scale physics

ASSUME A HIERARCHY OF SCALES

$\Lambda >> M_W$ where complete theory exists

- Any new particles or symmetries are at this scale
- Expect effects of heavy particles at low scales to be suppressed

This is sad scenario where there is no intermediate scale physics

Only SM particles in theory at low scales

M_W

Learn about high scale physics by measuring deviations from SM predictions

SMEFT: SM EFFECTIVE FIELD THEORY

- Assumptions: New physics decouples at Λ >> v, E
- At the weak scale: SM SU(3) x SU(2) x U(1) symmetry and SM particles only
- New physics described by

$$L_{SMEFT} = L_{SM} + \frac{L_5}{\Lambda} + \frac{L_6}{\Lambda^2} + \frac{L_7}{\Lambda^3} + \frac{L_8}{\Lambda^4}$$

$$L_n = \Sigma_i C_i^n O_i^n$$

Assume Higgs is in an SU(2) doublet

- New physics contributions contained in coefficients C (can calculate in specific models)
- Operators form a complete basis (not unique)
- L_5 and L_7 are lepton number violating

Learn about high scale physics by measuring coefficients of effective operators with global fits

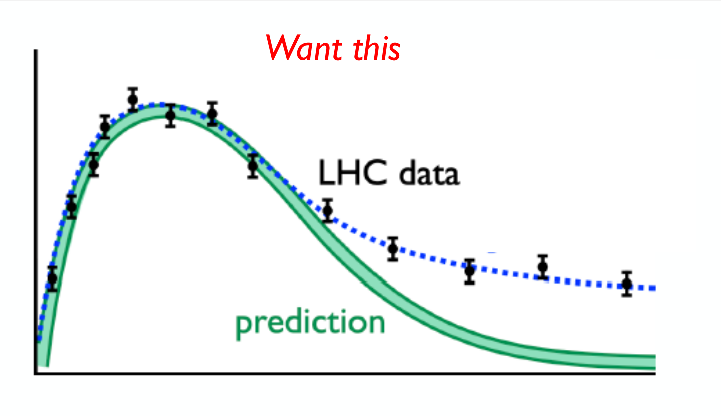
LEARNING FROM SMEFT

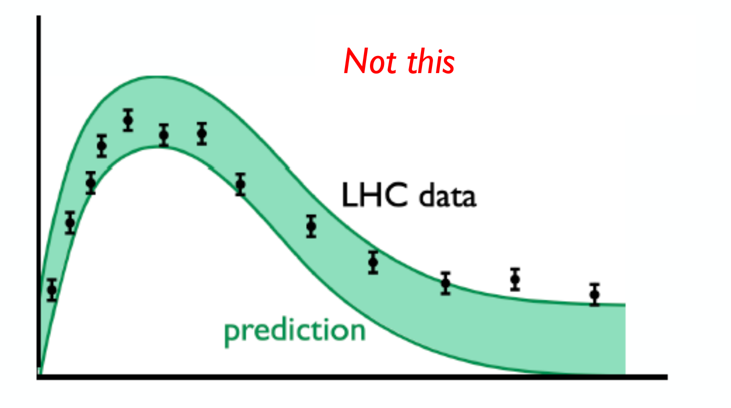
$$\text{Experiment} = \text{Theory}_{SM} + \sum \frac{x_i C_i^6}{\Lambda^2} + \ldots$$

Precise experimental measurements

Precise SM calculations

Precise SMEFT calculations



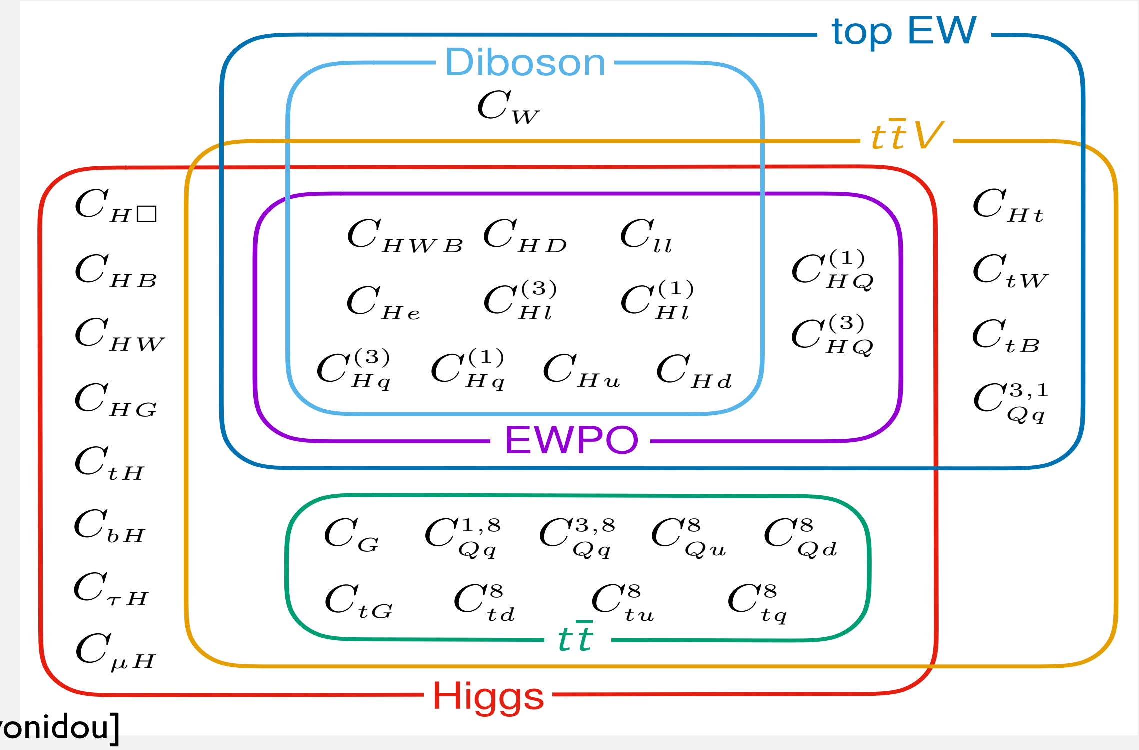


MY GOAL TODAY:

- Examine assumptions that go into SMEFT studies
- To what extent does SMEFT give "model independent" predictions?
- What needs doing from a theoretical perspective in order to draw firm conclusions about UV physics from SMEFT?

SMEFT IS COMPLICATED

- Power of SMEFT is connection of data from different processes



[Vryonidou]

CHOOSING OPERATORS FOR A FIT

- We now know complete dimension-6 and dimension-8 basis
- Too many operators to be useful for global fits
  - At dimension-8, 895 (36,971) baryon number preserving for 1 (3) generation
  - At dimension-6, 59 (2499) baryon number preserving for 1 (3) generation
- Study impact of cherry picked operators
  - Assumptions worm their way in here
- Try to limit number of operators by assuming specific structures for UV scenarios

DIMENSION-6 VS DIMENSION-8?

$$L \to L_{SM} + \Sigma_i \frac{C_{6i}}{\Lambda^2} O_{6i} + \Sigma_i \frac{C_{8i}}{\Lambda^4} O_{8i} + ...$$

- SMEFT

$$A^2 \sim | A_{SM} + \frac{A_6}{\Lambda^2} + ... |^2 \sim A_{SM}^2 + \frac{A_{SM} A_6}{\Lambda^2} + \frac{A_6^2}{\Lambda^4} + ...$$

- Problem is that $(A_6)^2$ terms are the same order as A_8 terms that we have dropped when counting in $1/\Lambda$
- If we only keep A_6/Λ^2 terms and drop $(A_6/\Lambda^2)^2$, the cross section is not guaranteed to be positive-definite
- Corrections are $O(s/\Lambda^2)$ or $O(v^2/\Lambda^2)$

WHICH TERMS TO INCLUDE?

$$A \sim A_{SM} + a_i \frac{C_{6i}}{\Lambda^2} + a_{ij} \frac{C_{6i} C_{6j}}{\Lambda^4} + b_i \frac{C_{8i}}{\Lambda^4} + \frac{1}{16\pi^2} \left[c_i \frac{C_{6i}}{\Lambda^2} + d_i C_{6i} \log\left(\frac{\mu^2}{\Lambda^2}\right) \right]$$

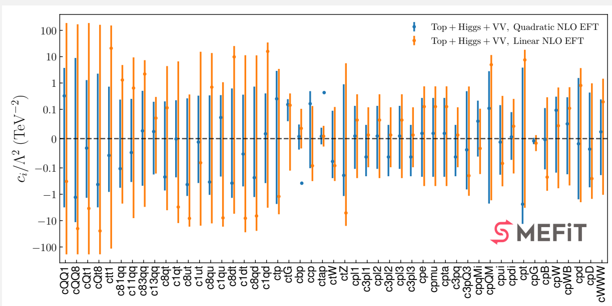
Dim-6 Double insertions Dim-8 Loops

- Loops generate dependence on new operators
- Are logarithms good approximation to loop effects?

MANY FITS WITH SINGLE DIM-6 INSERTIONS

$$A \sim A_{SM} + a_i \frac{C_{6i}}{\Lambda^2} + a_{ij} \frac{C_{6i} C_{6j}}{\Lambda^4} + b_i \frac{C_{8i}}{\Lambda^4} + \frac{1}{16\pi^2} \left[c_i \frac{C_{6i}}{\Lambda^2} + d_i \log\left(\frac{\mu^2}{\Lambda^2} \right) \right]$$

Log scale



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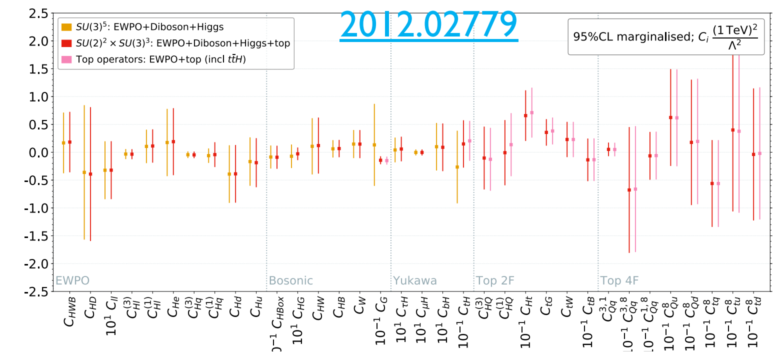
Blue: Observables calculated to $1/\Lambda^2$ at dimension-6
Red: Obserables calculated to $1/\Lambda^4$ at dimension-6

2012.02779

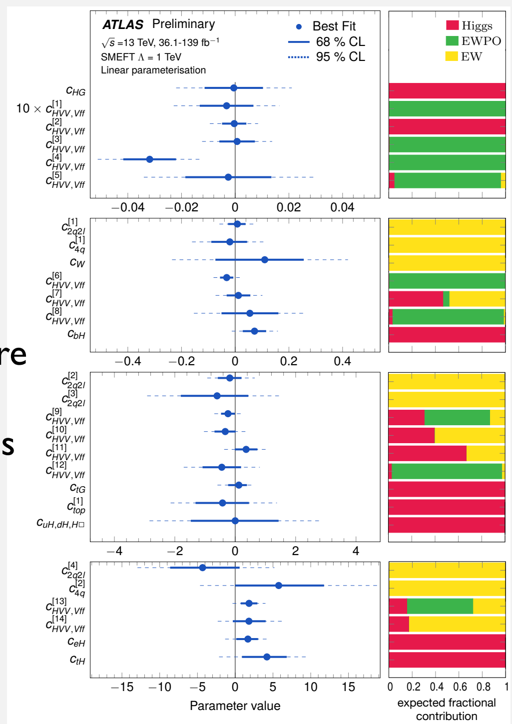


Red:/pink top included
Orange: No top

IT'S NOT JUST THE HIGGS ANYMORE

- Higgs data, top quark data, gauge boson pair production, and EW precision observables all contribute to SMEFT predictions

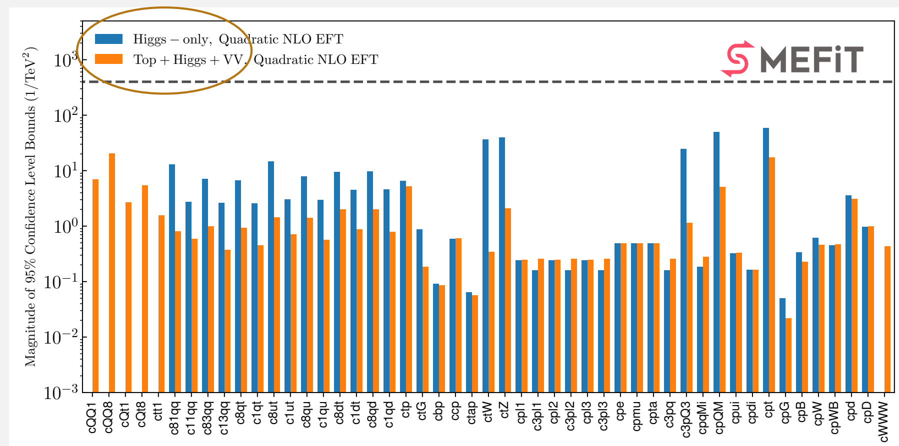
ATLAS fit to Higgs, VV, EWPO data



In the future, more differential information needs to be included!

*Outlier is LEP A_l (bb)

Top data important for some operators



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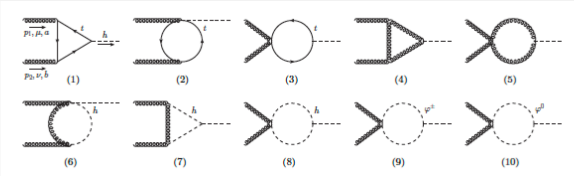
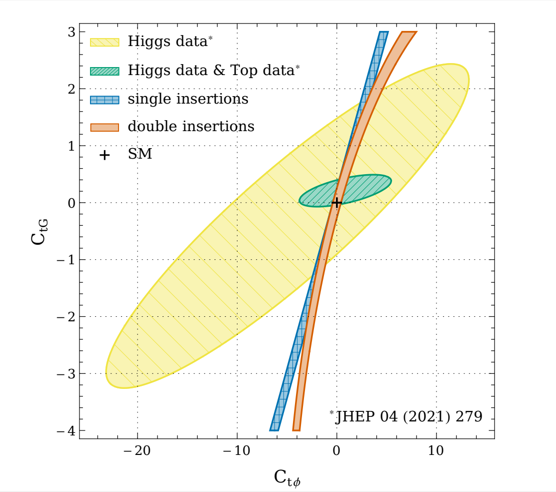
DOUBLE INSERTIONS OF DIM-6 OPERATORS

$$A \sim A_{SM} + a_i \frac{C_{6i}}{\Lambda^2} + a_{ij} \frac{C_{6i} C_{6j}}{\Lambda^4} + b_i \frac{C_{8i}}{\Lambda^4} + \frac{1}{16\pi^2} \left[c_i \frac{C_{6i}}{\Lambda^2} + d_i \log\left(\frac{\mu^2}{\Lambda^2} \right) \right]$$

- Consider double insertions in gluon fusion
- Consider models where $C_{\phi G}=0$ ($O_{\phi G} = (\phi^\dagger \phi)\, G^{\mu\nu} G_{\mu\nu}$ contributes at tree level and complicates counting)





When top data is included, double insertions irrelevant for $gg \to H$ in $C_{\phi G}=0$ limit

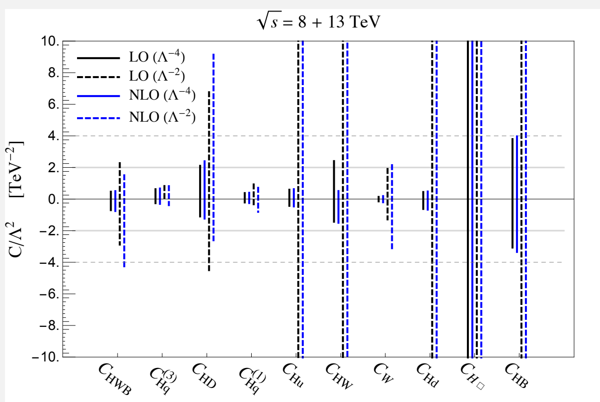
* Double insertions for tree level processes straightforward

2212.03258

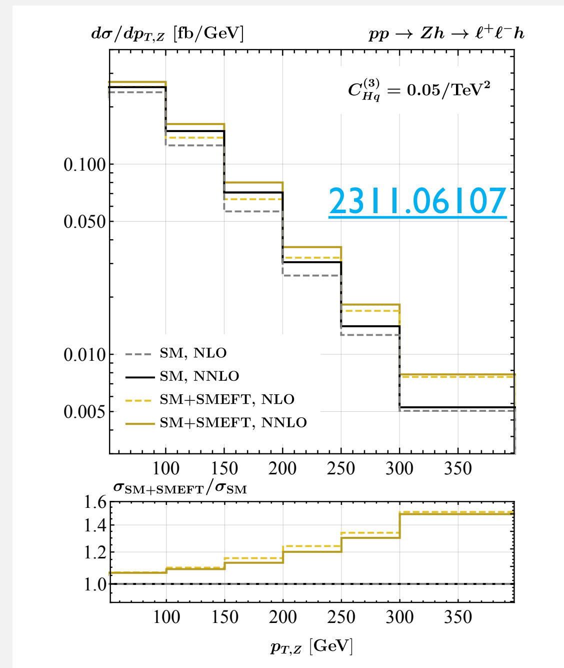
HIGHER ORDER CORRECTIONS

- Progress in computing SMEFT processes to NLO
- NLO SMEFT QCD at dimension-6 is automated: [2008.11743](2008.11743)
- QCD effects matter!

WW/WZ/WH/ZH



[2003.07862](2003.07862)



[2311.06107](2311.06107)

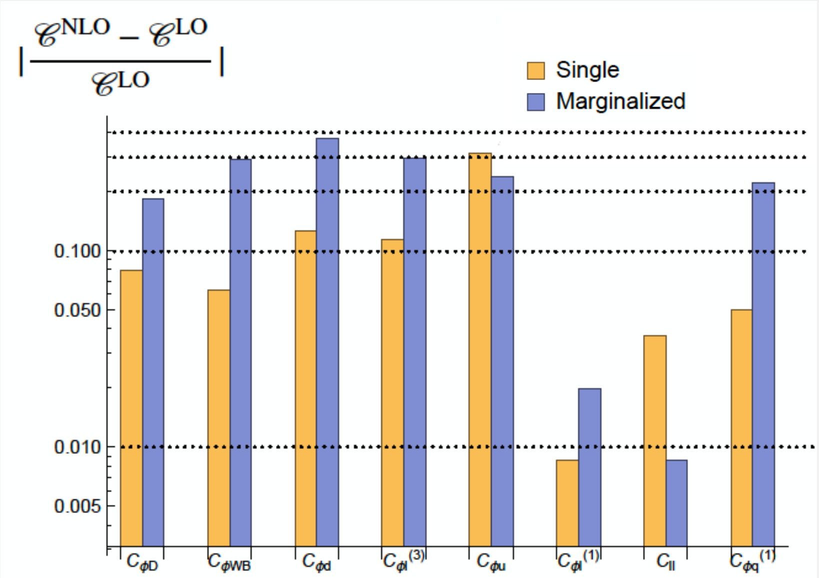
DIMENSION-6 EW CORRECTIONS

- These are not automated:
  - One-loop EW SMEFT calculations done on a case by case basis
- Not all observables that are relevant for LHC data are known at NLO EW SMEFT
- NLO EW introduces dependence on operators that don't contribute at LO
  - Does this affect global fits?

Still work to do…..

HOW BIG ARE NLO EW EFFECTS?

Fit to precision EW data:
LEP / SLC / M_W / Γ_W

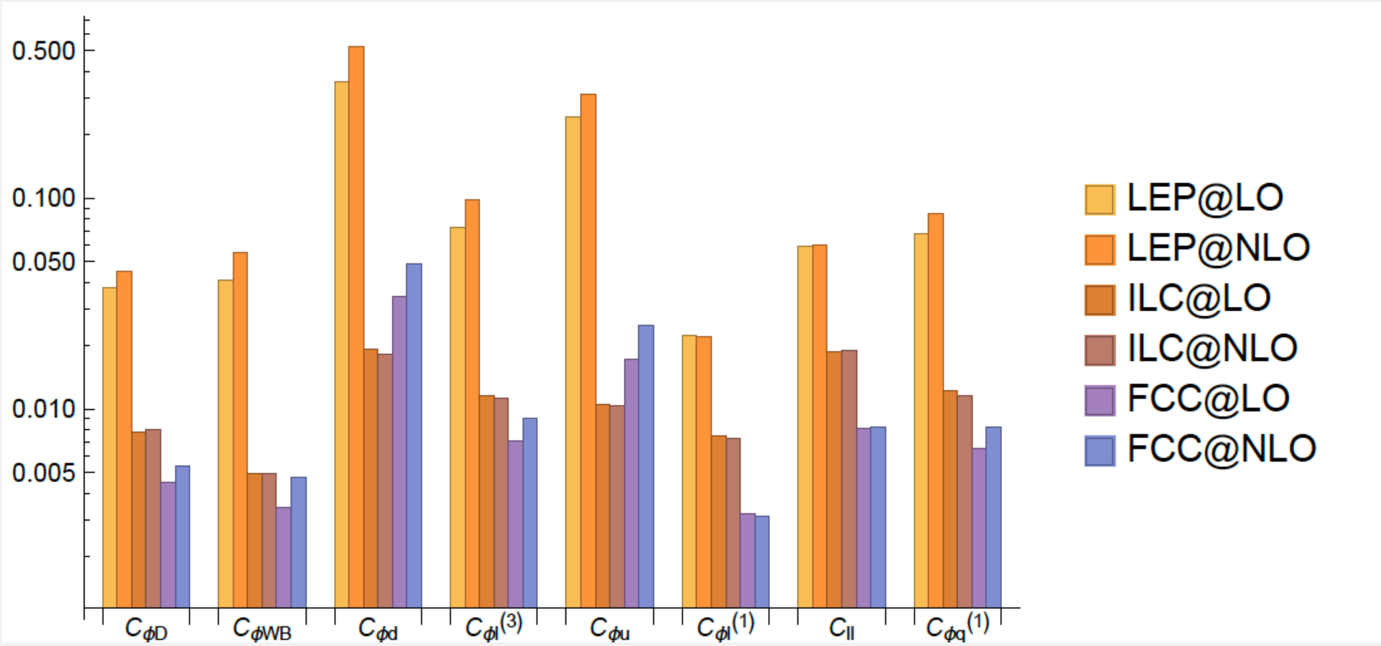


8 coefficients that contribute at tree level

EW corrections can be up to 30%

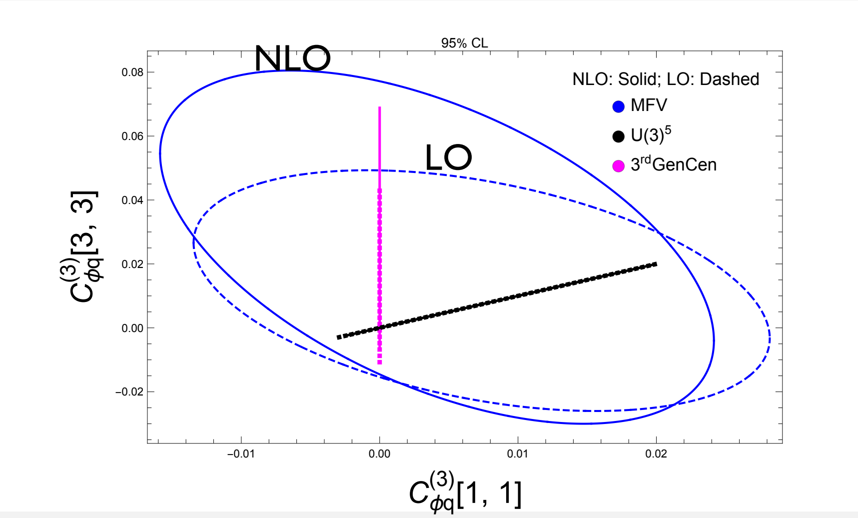
[Giardino, HEFT2020]

FUTURE LIMITS NEED NLO EW SMEFT



EW EFFECTS CAN AFFECT SMEFT FITS

Fit to precision EW data:
LEP / SLC / M_W / Γ_W



NLO can change shape

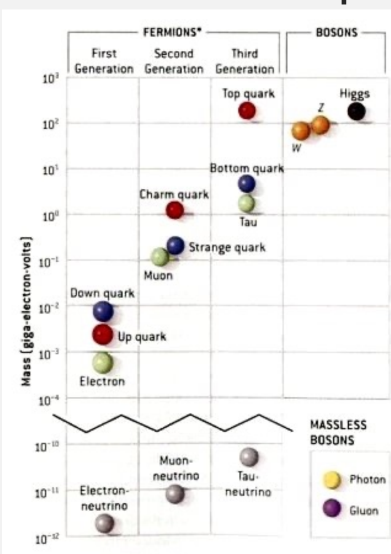
Note that including NLO EW changes the fits in a significant way

2304.00029

FLAVOR AND THE SMEFT

$$L_{YUK} = -\bar{q}_L V^\dagger Y_u \tilde{H} u_R - \bar{q}_L Y_d H d_R - \bar{l}_L Y_e H e_R + h.c$$

- Flavor is poorly understood in the SM



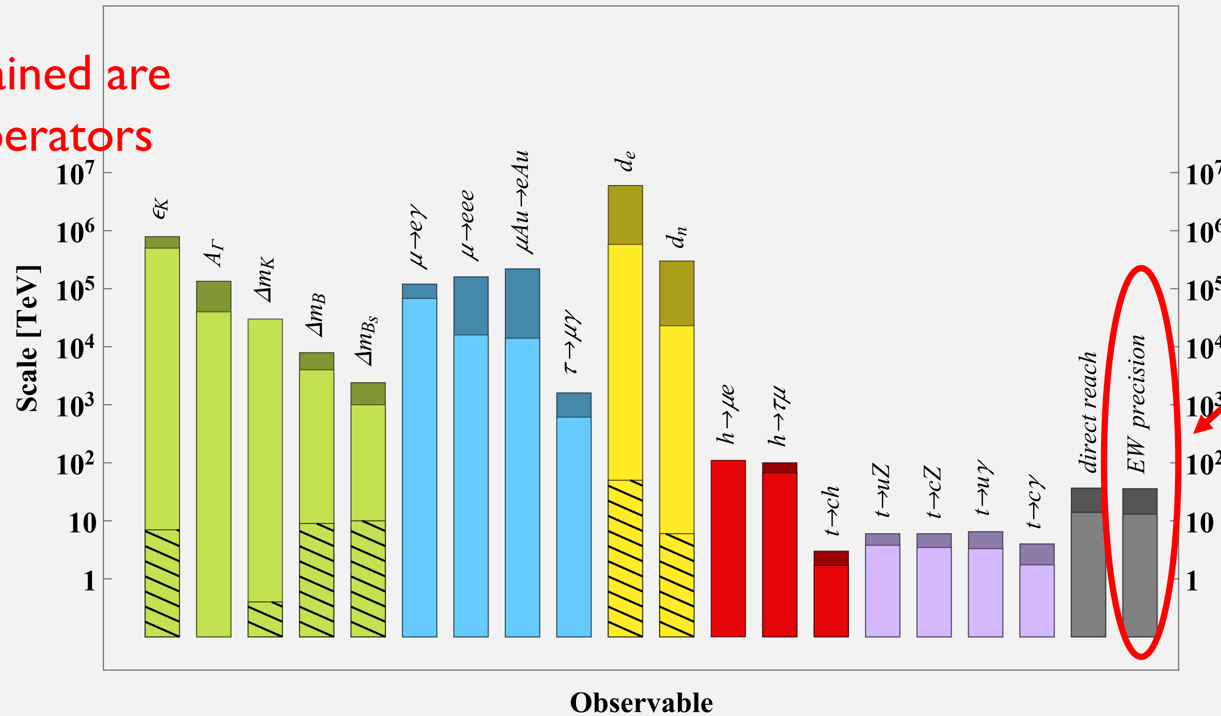
- Large hierarchy of masses: Y_u, Y_d, Y_e
- Approximate alignment of CKM matrix:

$$V_{CKM} \sim \begin{pmatrix} 1 & .2 & (.2)^3 \\ .2 & 1 & (.2)^2 \\ (.2)^3 & (.2)^2 & 1 \end{pmatrix}$$

- Do SMEFT operators follow a similar flavor pattern?
- Imposing global flavor symmetries reduces number of operators

STRONG CONSTRAINTS ON FLAVOR VIOLATION IN SMEFT FROM LOW ENERGY MEASUREMENTS

Most constrained are 4-fermion operators



What are assumptions?

Interpreting measurements in terms of scale implies assuming SMEFT coefficients C=1

European Strategy, 1910.11775

INCLUDE FLAVOR STRUCTURE IN EWPO STUDY

- Consider CKM diagonal, which implies specific flavor structures
- In Warsaw basis:
  - 4-fermion operators

$$(\overline{f}_i \gamma^\mu f_j)(\overline{f}_k \gamma_\mu f_l)$$

  - 2-fermion operators

$$(H^\dagger i\overleftrightarrow{D}_\mu H)(\overline{q}_i \gamma^\mu q_j) \rightarrow C_X[ij] = E_X \delta_{ij}$$

  - Bosonic operators

Not all combinations of flavor indices arise in EWPOs

- Most general case: NLO EWPO calculation involves 178 independent coefficients (6 from bosonic, 23 from 2-fermion, 149 from 4-fermion)

WHAT ABOUT FLAVOR ASSUMPTIONS?

- Global fits often done assuming flavor universality
- SM has U(3)^5 global symmetry that is broken only by Yukawas

$$(q_L)^T = (u_L, d_L),\ (l_L)^T = (\nu_L, e_L),\ u_R,\ d_R,\ e_R$$

- 3rd generation is different
  - Do fits with U(2)^5 global symmetry
- MFV assumption assumes top Yukawa is only source breaking U(3)^5 symmetry (since we assume all other fermions are massless)

Do flavor assumptions make significant differences to SMEFT fits?

FLAVOR ASSUMPTIONS REDUCE POSSIBILITIES

Operators that contribute to EWPO at NLO

2-fermion

4-fermion with identical representations

Remaining 4-fermion

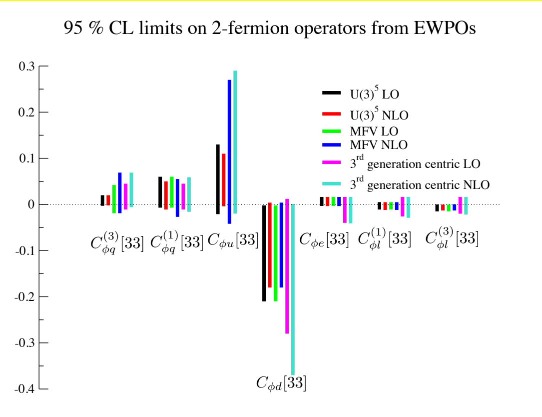
Operator	$U(3)^5$	MFV	$U(2)^5$	3^{rd} gen specific	3^{rd} gen phobic	3^{rd} gen phobic $+ U(2)^5$	Flavorless
Class A	7	12	16	9	14	7	9
Class B	11	17	27	5	23	11	6
Class C	11	21	44	11	44	11	11
Total	29	50	87	25	81	29	26

- NLO SMEFT EW fits done with coefficients evaluated at M_Z
- Input parameter dependence? Results use G_F, M_Z, α
- After separating out dominant scheme independent contributions, residual scheme dependent contributions similar in commonly used schemes [Biekotter, Pecjak, Scott, Smith, 2305.03763]

FLAVOR MATTERS!

- Take-away: Neglecting flavor gives overly aggressive limits
- Strong correlations in flavor space
- NLO can have large effects

2-fermion operators



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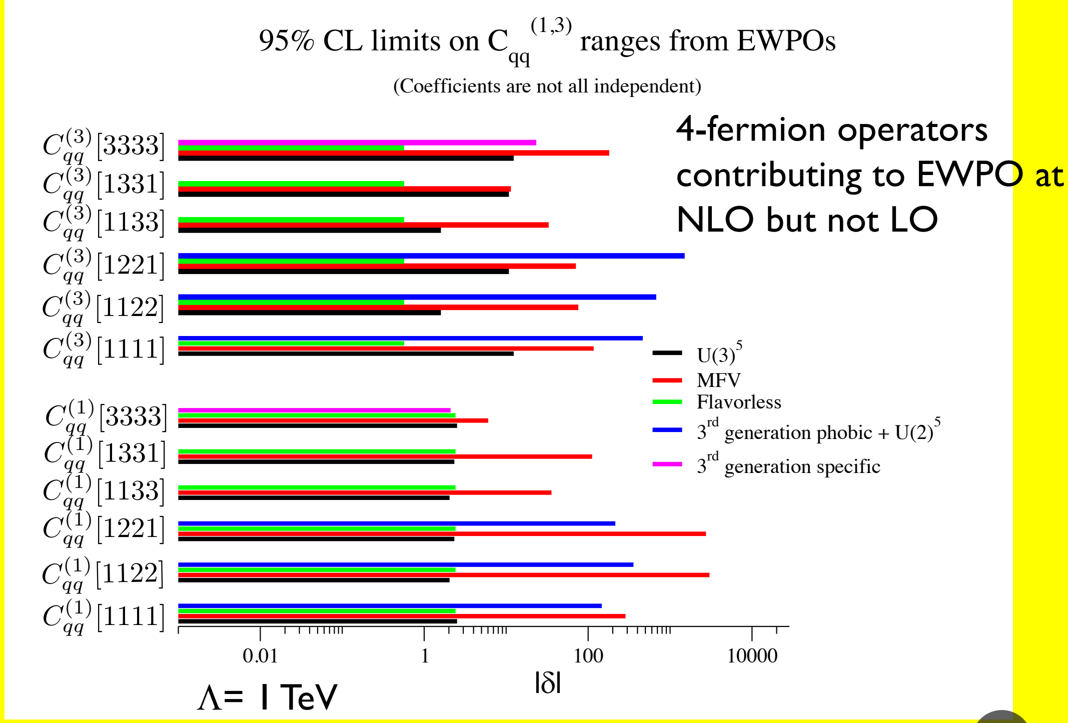
* Coefficients are related by flavor assumptions

FLAVOR MATTERS

Flavorless assumption yields more stringent bounds than flavor scenarios

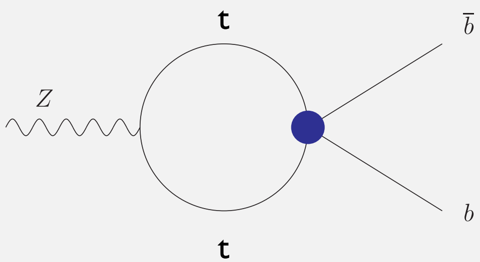
Can also limit these coefficients with fits to LHC dijets. More stringent limits for gens 1 and 2 from dijets (tree level process) [Bruggisser, Westhoff: 2212.02532]

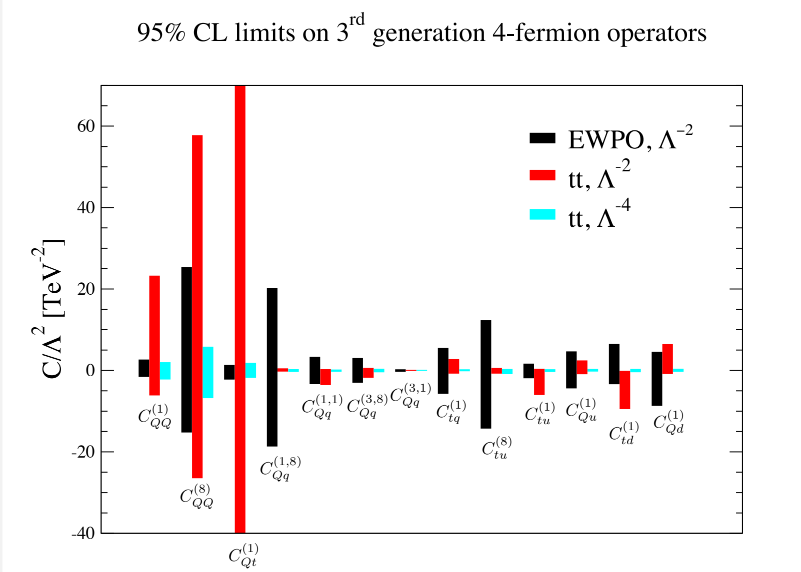


U(3)⁵ results more constrained than MFV

FLAVOR IN EWPO AND TOP PHYSICS

- Some operators contribute both to top pair production at the LHC and to EWPO at 1-loop
- For some operators, similar sensitivity





SMEFT message: CONNECTIONS between data sets

2201.09887 1802.07237

SO….WHO CARES?

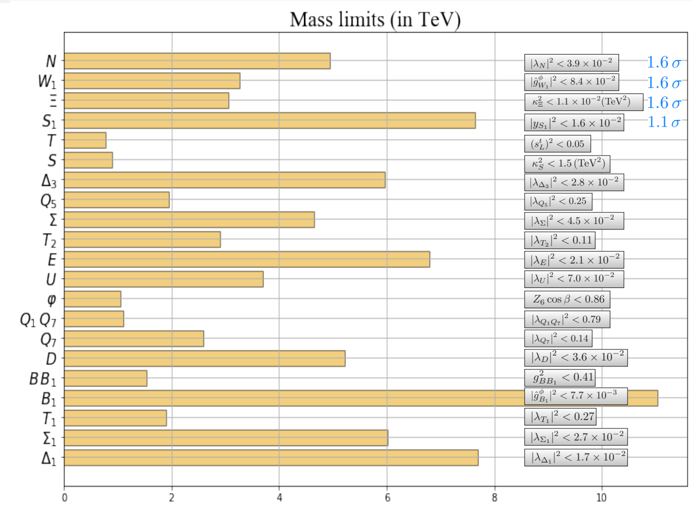
- SMEFT fits provide a comparison point to quantify deviations from the SM

I have highlighted the many assumptions that go into SMEFT fits and shown the importance of NLO corrections and flavor assumptions

- Interest in SMEFT is the hope that it will provide insight into high scale physics that cannot be directly probed.

GOAL IS TO INFER BSM PHYSICS FROM PATTERNS OF COEFFICIENTS

- Compare models with one new heavy particle
- Do global fits to just the sets of operators generated in these models
- Fits can restrict high scale models
- Need to study complete models



Scale of new physics

* Mass limits assume C=1

[2012.02779](https://arxiv.org/abs/2012.02779)

2HDM IS A GOOD TESTING GROUND

- Consider model with 2 Higgs doublets, Φ_1 and Φ_2 with a softly broken Z_2 symmetry: $\Phi_1 \rightarrow \Phi_1$ and $\Phi_2 \rightarrow -\Phi_2$
- 5 physical Higgs bosons, h_{125}, H_0, A, $H^\pm$
- Rotate to the Higgs basis
- In this basis $\langle H_2\rangle=0$, $\langle H_1\rangle=v/\sqrt{2}$

$$\left(\begin{array}{c} H_1 \\ H_2 \end{array}\right) = \left(\begin{array}{cc} \cos\beta & \sin\beta \\ -\sin\beta & \cos\beta \end{array}\right)\left(\begin{array}{c} \Phi_1 \\ \Phi_2 \end{array}\right),$$

- Very convenient for SMEFT studies

$$\boxed{\begin{aligned} V =& Y_1 H_1^\dagger H_1 + Y_2 H_2^\dagger H_2 + \left(Y_3 H_1^\dagger H_2 + \text{h.c.}\right) + \frac{Z_1}{2}\left(H_1^\dagger H_1\right)^2 \\ &+ \frac{Z_2}{2}\left(H_2^\dagger H_2\right)^2 + Z_3\left(H_1^\dagger H_1\right)\left(H_2^\dagger H_2\right) + Z_4\left(H_1^\dagger H_2\right)\left(H_2^\dagger H_1\right) \\ &+ \left\{\frac{Z_5}{2}\left(H_1^\dagger H_2\right)^2 + Z_6\left(H_1^\dagger H_1\right)\left(H_1^\dagger H_2\right) + Z_7\left(H_2^\dagger H_2\right)\left(H_1^\dagger H_2\right) + \text{h.c.}\right\} \end{aligned}}$$

- Z's can be written in terms of physical parameters $\boxed{v,\ \beta-\alpha,\ m_{h_{125}},\ Y_2,\ m_{H_0},\ m_A,\ m_{H^\pm}}$

2HDM CONTINUED

- 4 choices for fermion Yukawas (avoid tree level FCNC)

$$\mathcal{L}_Y \sim -\lambda_u^{(1)}\bar{u}_R\tilde{H}_1^\dagger q_L - \lambda_u^{(2)}\bar{u}_R\tilde{H}_2^\dagger q_L - \lambda_d^{(1)}\bar{d}_R H_1^\dagger q_L - \lambda_d^{(2)}\bar{d}_R H_2^\dagger q_L + h.c.$$

$$\lambda_f^{(1)} = \frac{\sqrt{2}}{v} m_f \qquad \lambda_f^{(2)} = \frac{\eta_f}{\tan\beta}\lambda_f^{(1)}$$

	Type-I	Type-II	Type-L	Type-F
η_u	1	1	1	1
η_d	1	$-\tan^2\beta$	1	$-\tan^2\beta$
η_l	1	$-\tan^2\beta$	$-\tan^2\beta$	1

- Type II is MSSM-like
- Type I has enhanced (suppressed) couplings to b quarks at small (large) tan β

MATCH TO SMEFT AT DIMENSION-6

- At dimension-6, observables depend on C/Λ^2 (ie you can't determine a scale independently of assumptions about coefficients, C)
- Decoupling limit: $(Y_3/Y_2) << 1$
- At tree level dimension-6, 2HDM SMEFT matching generates:

$$\frac{v^2 C_H}{\Lambda^2} = \frac{\cos^2(\beta-\alpha) M^2}{v^2} \qquad \frac{v^2 C_{tH}}{\Lambda^2} = -\frac{\eta_t \sqrt{2} m_t \cos(\beta-\alpha)}{v \tan\beta}$$

$$\frac{v^2 C_{bH}}{\Lambda^2} = -\frac{\eta_b \sqrt{2} m_b \cos(\beta-\alpha)}{v \tan\beta} \qquad \frac{v^2 C_{\tau H}}{\Lambda^2} = -\frac{\eta_\tau \sqrt{2} m_\tau \cos(\beta-\alpha)}{v \tan\beta}$$

- Dimension-6 matching does NOT generate 2HDM VVh_{125} couplings!

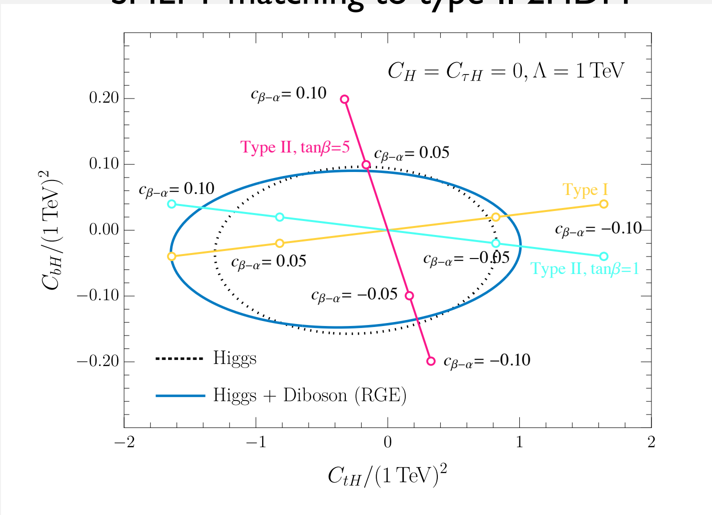
$$O_{fH} = (H^\dagger H)(\overline{q}_L \tilde{H} f_R) \qquad O_H = (H^\dagger H)^3 \qquad \frac{C_H}{\Lambda^2} \sim (...)\delta\lambda_3$$

* M is common mass of heavy scalars

2HDM SMEFT AND RGE

- Operators generated from 2HDM matching don't contribute to EWPOs at tree level
- Limits from Higgs data
- Matching done at high scale, then coefficients evolved to M_Z using renormalization group running
- This generates new operators which contribute to di-boson production
- Effect of RGE running small for O_{fH} operators

SMEFT matching to type-II 2HDM



Model predictions are straight lines

MATCH 2HDM TO DIMENSION-8

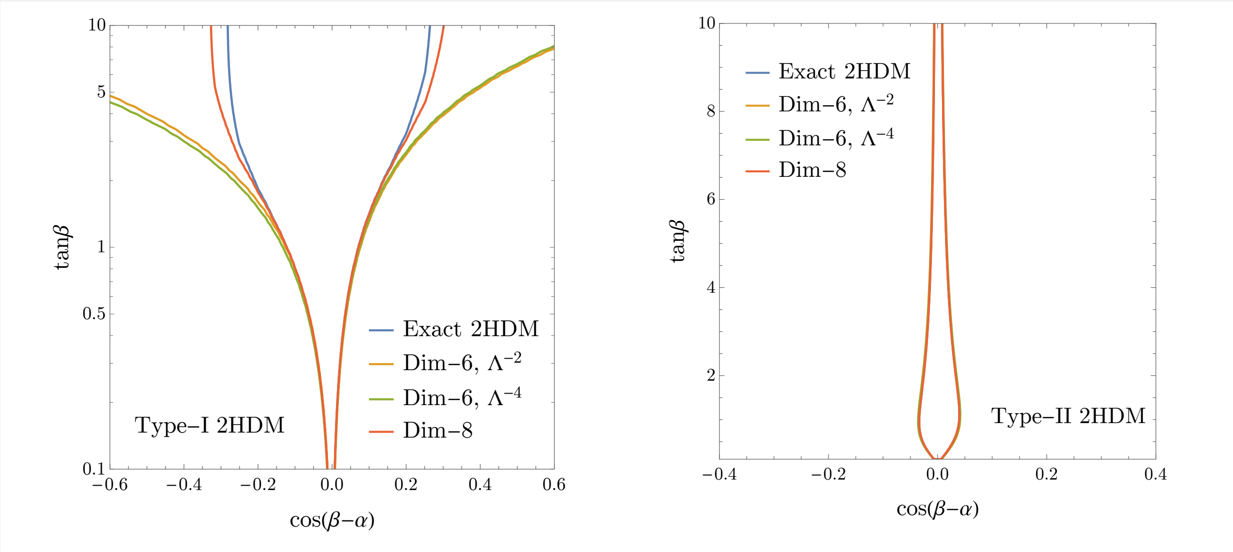
- Matching generates new operators, some with new kinematic structures
- Dimension-8 coefficients can all be written in terms of parameters of 2HDM
- Also need relations between gauge couplings and input parameters (G_F, M_W, M_Z) to dimension-8

$$
\begin{aligned}
L_8 \sim \frac{1}{\Lambda^4}\Big\{ & C_{H^8}(H^\dagger H)^4 + C^{(1)}_{H^6}(H^\dagger H)^2 (D_\mu H)^\dagger (D^\mu H) + \Big\{ C_{quH^5}(H^\dagger H)^2 \bar{q}_L u_R \tilde{H} \\
& + C^{(1)}_{quH^3D^2}(D_\mu H)^\dagger (D^\mu H)\bar{q}_L u_R \tilde{H} + C^{(2)}_{quH^3D^2}\Big[(D_\mu H)^\dagger \tau^a (D^\mu H)\Big]\Big[\bar{q}_L u_R \tau^a \tilde{H}\Big] \\
& + C^{(5)}_{quH^3D^2}\Big[(D_\mu H)^\dagger H\Big]\Big[\bar{q}_L u_R \widetilde{D^\mu H}\Big] + C_{qdH^5}(H^\dagger H)^2 \bar{q}_L d_R H \\
& + C^{(1)}_{qdH^3D^2}(D_\mu H)^\dagger (D^\mu H)\bar{q}_L d_R H + C^{(2)}_{qdH^3D^2}\Big[(D_\mu H)^\dagger \tau^a (D^\mu H)\Big]\Big[\bar{q}_L d_R \tau^a H\Big] \\
& + C^{(5)}_{qdH^3D^2}(H^\dagger D_\mu H)(\bar{q}_L d_R D^\mu H) + h.c.\Big\} + 4\ Fermion\Big\}
\end{aligned}
$$

Note: $O_{H6}^{(1)}$ gives VVh_{125} coupling

DIMENSION-8 MATTERS IN 2HDM

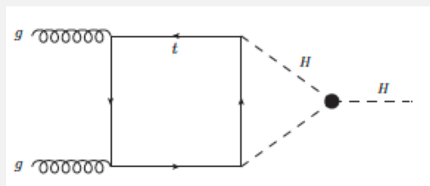
We understand why dim-8 matters: it gives VVh coupling absent at dim-6

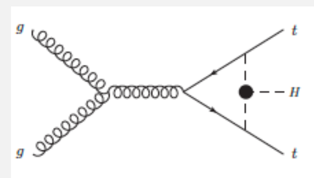


SD, D. Fontes, S. Homiller, and M. Sullivan, 2205.01561

SCALE DEPENDENCE FOR C_H

- C_H modifies Higgs tri-linear
- Affects Higgs coupling limits through loop contributions





- C_H scaling different than Yukawa like terms

$$\frac{v^2 C_{tH}}{M^2} \sim \frac{\cos(\beta-\alpha)\eta_t m_t}{v\tan\beta}$$

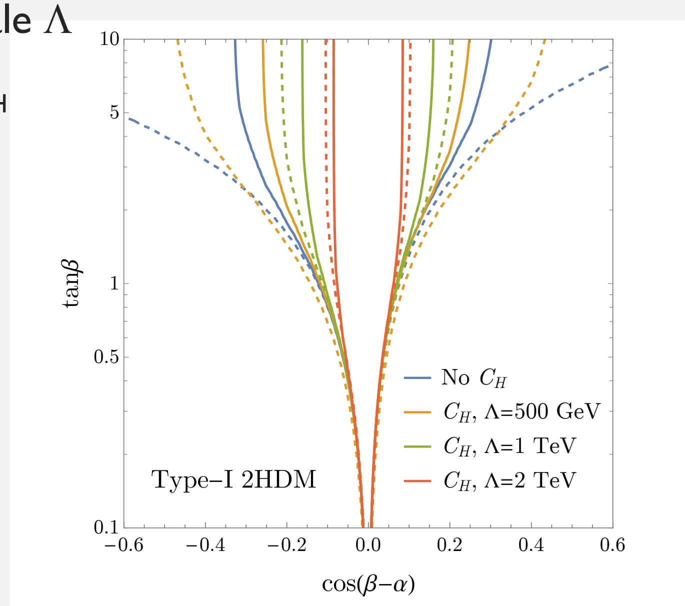
$$\frac{v^2 C_H}{M^2} \sim \frac{\cos^2(\beta-\alpha) M^2}{v^2}$$

Decoupling requires $\cos^2(\beta-\alpha) << \frac{v^2}{M^2}$

Degrassi, Giardino, Maltoni, Pagani, 1607.04251

HIGGS TRI-LINEAR AT DIMENSION-8

- C_H fits have dependence on scale Λ
- Fits sensitive to inclusion of C_H



Dashed: $1/\Lambda^2$
Solid: $1/\Lambda^4$

BOTTOM LINE ON DIMENSION-8 AND 2HDM

- Dimension-8 terms are important in matching SMEFT to type-I 2H2M
- This is for a well-understood physics reason (VVh_{125} first arises at dimension-8)
- Studies of matching to other models (Gauge triplet, 2102.02819 ,Vector like top quark, 2110.06929) show that the importance of dim-8 terms appears to be model dependent

FINALLY, WHAT IF IT'S NOT SMEFT?

- What if Higgs is not part of an SU(2) doublet? $\rightarrow$ HEFT (Higgs Effective Field Theory)
- Expansion is different from SMEFT (LO Lagrangian here)

$$L_{HEFT} \sim \frac{v^2}{4}\left[1 + 2a\frac{h}{v} + b\frac{h^2}{v^2} + ...\right] Tr\left\{D_\mu U^\dagger D_\mu U\right\} + \frac{1}{2}(\partial_\mu h)^2 - V(h)$$

$$V(h) = \frac{1}{2}m_h^2 h^2 \left(1 + \kappa_3 \frac{h}{v} + \frac{\kappa_4}{4}\frac{h^2}{v^2} + ...\right)$$

h is physical Higgs

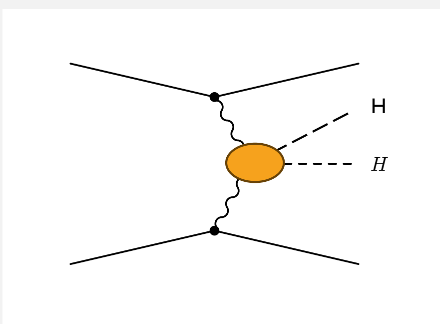
$$D_\mu U = \partial_\mu U + igW_\mu^a \frac{\sigma^a}{2} U - ig' U \frac{\sigma^3}{2} B_\mu$$

- Unitary gauge, U→1; SM: $a=b=\kappa_3=\kappa_4=1$ SMEFT: $b - a = \frac{3C_{H\Box}v^2}{\Lambda^2}$
- Suggests that hh→hh, WW→hh can distinguish between SMEFT and HEFT
- (Do same matching to 2HDM as in SMEFT……)

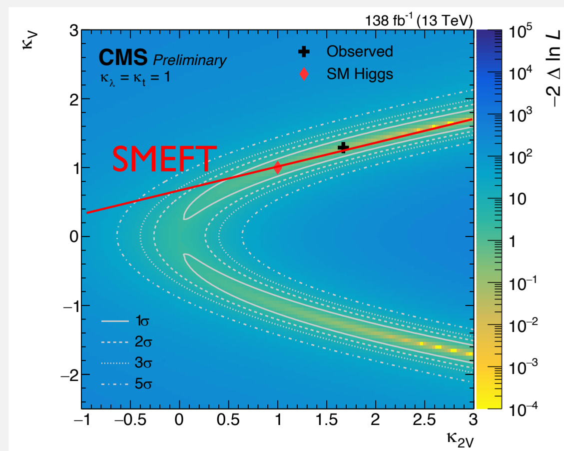
2204.01763 , 2307.15693, 2305.07689 , 2311.16897 , 2312.03877, 2211.09605

HH PRODUCTION

HH production via VBS can potentially distinguish SMEFT from HEFT

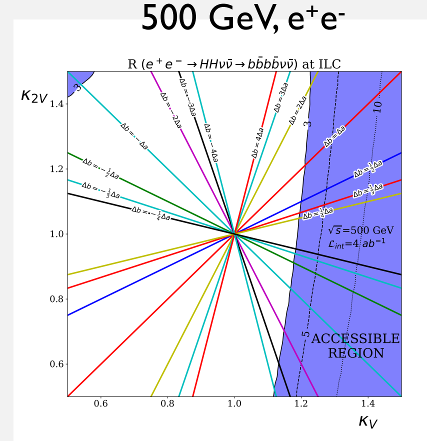


LHC



[2211.09605](https://arxiv.org/abs/2211.09605)

500 GeV, e^+e^-



[2312.03877](https://arxiv.org/abs/2312.03877)

$a=\kappa_V$, $b=\kappa_{2V}$

CONCLUSIONS

- SMEFT offers the promise of probing UV scale physics that is not accessible directly
- There are many effects which can affect predictions…order of the $1/\Lambda^2$ expansion, flavor, higher dimension operators, loop effects….
- Double Higgs production offers the possibility to distinguish SMEFT from HEFT

Sill a lot of work to do!