SMEFT PRACTICALITIES

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April, 2021

SMEFT: SM EFFECTIVE FIELD THEORY

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

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

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

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

Assume no new light fields
Assume Higgs is in an SU(2) doublet

DISCLAIMER

- SMEFT has become the tool of choice for precision searches for new non-resonant physics effects
- Many beautiful theory talks in the *All Things EFT* series
- In this talk, I will discuss some of the issues that arise when attempting to tease out new physics effects from SMEFT studies
- *More questions than conclusions*
- Plan: begin with LEP/SLD studies, then touch on di-boson studies at the LHC
- Conclude: discussion of LHC EFT working group activities
- My personal view

ADVANTAGES OF SMEFT APPROACH

- Quantum field theory where calculations done order by order in $1/\Lambda$
  - Compute cross sections without knowing high scale (UV) physics
- Systematically improvable
- At this level, SMEFT calculations are model independent
- Measurements interpreted in terms of SMEFT coefficients
- Can compare very different classes of measurements

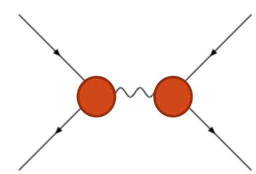
Sounds good, but how does this work in practice?

And even more important, how model independent is this?

COUNTING PARAMETERS

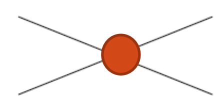
- Start with Warsaw basis and ignore flavor (A VERY BIG ASSUMPTION)
- Baby steps first: Consider interference of SM and dimension-6 operators
  - ie, new physics contributions are linear in Wilson coefficients
  - Example of neglected contribution:

$$O_{uW} = (\overline{u}\sigma^{\mu\nu}u)\tilde{\phi}W_{\mu\nu}$$



  - Dipole operator interference term is ~ m_f
  - SM resonant terms typically dominate over 4 fermion interactions by

True for LEP/Higgs pole data $$\left(\frac{\Gamma_R M_R}{v}\right)^a$$



  - Including quadratic $O(1/\Lambda^4)$ contributions increases number of parameters

MORE COUNTING

- Consider contributions to processes dominated by H/Z/W resonances, and interference with SM only (linear in EFT)
- At tree level:

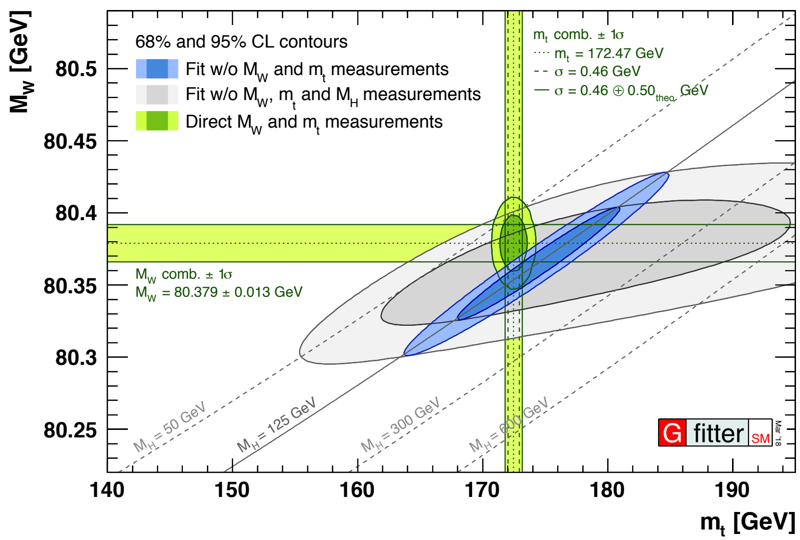
	Total	Not resonance suppressed
General	2499	46
MFV	108	30
$U(3)^5$	70	24

Brivio, Jiang, Trott, 1709.06492

But we know the top is different from the up quark

START WITH EWPO

- Tension with SM fit suggests that M_W should be observable in fit

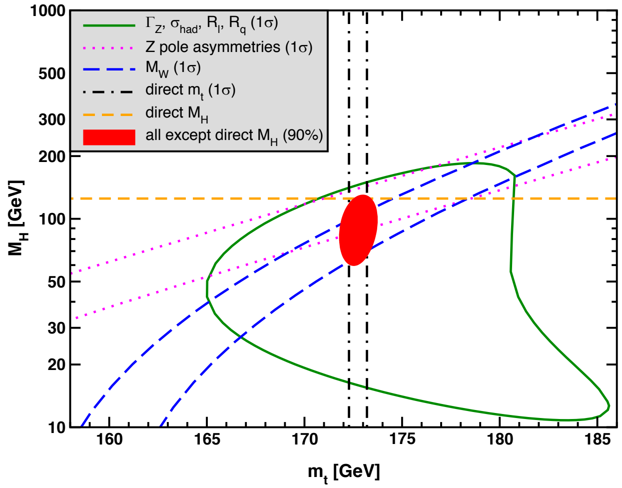


Fit without M_W, M_t, M_H

This assumes SM

Gfitter, [1803.01853]

M_H FROM INDIRECT MEASUREMENTS



Consistent picture, but room for new physics

1908.07327

INPUT PARAMETERS

- EW sector described by 3 input parameters (along with fermion masses)
- Typically take (G_μ, M_W, M_Z) , (G_μ, α, M_Z), (α, M_Z, M_W)
  - You can say it doesn't matter, but you have to be consistent
- SM relationships are altered in SMEFT (Lagrangian parameters, $\overline{g},\ \overline{g}'$)
- Well defined shifts:

G_μ, M_W, M_Z scheme

$$M_W^2 = \frac{\overline{g}v^2}{4}$$

$$M_Z^2 = \left(\frac{\overline{g}^2 + \overline{g}'^2}{4}\right) v^2 \left[1 + \frac{v^2}{2\Lambda^2} C_{HD}\right] + \frac{\overline{g}\overline{g}' v^4}{2\Lambda^2} C_{HWB}$$

$$G_F = \frac{1}{\sqrt{2}v^2}\left[1 - \frac{v^2}{\Lambda^2}\left(C_{ll} - 2C_{Hl}^{(3)}\right)\right]$$

Any scheme that uses $G\mu$ as an input is going to carry around C_{ll}, $C_{Hl}^{(3)}$

INPUT PARAMETERS

- New contributions when including v^4/Λ^4 terms involve small number of dimension-8 operators
- Well defined in terms of coefficients of unknown magnitude
- Also has mixed coefficient contributions

$$M_W^2 = \frac{\overline{g}v^2}{4}\left[1 + \frac{v^4}{4\Lambda^4}(C_{8,HD} - C_{8,HD2})\right]$$

$$M_Z^2 = \left(\frac{\overline{g}^2 + \overline{g}'^2}{4}\right)v^2\left[1 + \frac{v^2}{2\Lambda^2}C_{HD} + \frac{v^4}{4\Lambda^4}(C_{2,HD} + C_{8,HD2})\right] + \frac{\overline{g}\overline{g}'v^2}{2\Lambda^2}\left[C_{HWB} + \frac{v^4}{2\Lambda^2}\left(C_{8,HWB} + C_{HWB}(2C_{HB} + 2C_{HW} + C_{HD})\right)\right] + \frac{v^6}{4\Lambda^4}\overline{g}^2 C_{8,HW2}$$

Proliferation of unknown parameters

- +….contributions to G_μ-v relation, M_H relationship with Lagrangian parameters…

Hays, Martin, Sanz, Setford, 1808.00442

INPUT PARAMETERS: CONSIDERATIONS

- Want the extraction of input parameters to be well measured quantities that are insensitive to SMEFT effects
- On-shell masses from kinematic features have negligible sensitivity to new physics
- Most higher order EW calculations use (α, $G\mu$, M_Z)

$$\frac{G_\mu}{\sqrt{2}} = \frac{\pi\alpha}{2s_W^2 c_W^2 M_Z^2}\left(1 + \Delta r_{SM} + \Delta r_{EFT}\right) + \frac{\sqrt{2}}{\Lambda^2}\left(C_{Hl}^{(3)} - \frac{1}{2}C_{ll}\right)$$

$$c_W = \frac{M_W}{M_Z}$$

Dependence on M_W non-linear for LHC observables

- $G\mu$, M_Z, M_W typically used for LHC studies

W AND Z POLE OBSERVABLES

- Fit to 14 data points—inputs are G_μ, M_Z, α

$$M_W, \Gamma_W, \Gamma_Z, \sigma_h, A_{l,FB}, A_{b,FB}, A_{c,FB}, A_b, A_c, A_l, R_l, R_b, R_c$$

- Tree level expressions depend on (in Warsaw basis) assuming flavor independence

$$C_{ll}, C_{\phi WB}, C_{\phi u}, C_{\phi q}^{(3)}, C_{\phi q}^{(1)}, C_{\phi l}^{(3)}, C_{\phi l}^{(1)}, C_{\phi e}, C_{\phi D}, C_{\phi d}$$

- Tree level SMEFT expressions depend on 8 combinations of operators

$$M_W, \delta g_L^{Zu}, \delta g_L^{Zd}, \delta g_L^{Z\nu}, \delta g_L^{Ze}, \delta g_R^{Zu}, \delta g_R^{Zd}, \delta g_R^{Ze}$$

$\Rightarrow$ 2 blind directions (resolved by other measurements)

NON-SM COUPLINGS IN EFFECTIVE COUPLING LANGUAGE

- Effective Z/W-fermion couplings: still important despite LEP constraints
- (neglect RH W couplings and RH υ couplings since they don't interfere with the SM)

$$L = 2M_Z\sqrt{\sqrt{2}G_\mu}Z_\mu\Big\{\Big[g_L^{Zu}+\delta g_L^{Zu}\Big]\overline{u}_L\gamma_\mu u_L+\Big[g_L^{Zd}+\delta g_L^{Zd}\Big]\overline{d}_L\gamma_\mu d_L+\Big[g_R^{Zu}+\delta g_R^{Zu}\Big]\overline{u}_R\gamma_\mu u_R$$
$$+\Big[g_R^{Zd}+\delta g_R^{Zd}\Big]\overline{d}_R\gamma_\mu d_R+\Big[g_L^{Ze}+\delta g_L^{Ze}\Big]\overline{e}_L\gamma_\mu e_L+\Big[g_L^{Z\nu}+\delta g_L^{Z\nu}\Big]\overline{\nu}_L\gamma_\mu \nu_L$$
$$+\Big[g_R^{Ze}+\delta g_R^{Ze}\Big]\overline{e}_R\gamma_\mu e_R\Big\}+\frac{\overline{g}_2}{\sqrt{2}}\Big\{W_\mu\Big[(1+\delta g_L^{Wq})\overline{u}_L\gamma_\mu d_L\Big]+W_\mu\Big[(1+\delta g_L^{Wl})\overline{\nu}_L\gamma_\mu e_L\Big]+h.c.\Big\}$$

- SU(2) invariance requires

$$\delta g_L^{Wq} = \delta g_L^{Zu} - \delta g_L^{Zd}$$
$$\delta g_L^{Wl} = \delta g_L^{Z\nu} - \delta g_L^{Ze}$$

7 new parameters + M_W

RH W couplings do not interfere with SM

USE MOST PRECISE SM THEORY

Measurement	Experiment	"Best" theory
Γ_Z(GeV)	2.4952 ± 0.0023	2.4945 ± 0.0006
σ_h(nb)	41.540 ± 0.037	41.491 ± 0.008
R_l	20.767 ± 0.025	20.749 ± 0.009
R_b	0.21629 ± 0.00066	0.21586 ± 0.0001
R_c	0.1721 ± 0.0030	0.17221 ± 0.00005
A_l	0.1465 ± 0.0033	0.1472 ± 0.0004
A_c	0.670 ± 0.027	0.6679 ± 0.0002
A_b	0.923 ± 0.020	0.92699 ± 0.00006
$A_{l,FB}$	0.0171 ± 0.0010	0.0162 ± 0.0001
$A_{b,FB}$	0.0992 ± 0.0016	0.1023 ± 0.0003
$A_{c,FB}$	0.0707 ± 0.0035	0.0737 ± 0.0003
$A_l(SLD)$	0.1513 ± 0.0021	0.1472 ± 0.0004
$\sin^2\theta_{l,eff}$	0.23179 ± 0.00035	0.23150 ± 0.00006
M_W(GeV)	80.379 ± 0.012	80.359 ± 0.006
Γ_W(GeV)	2.085 ± 0.042	2.0904 ± 0.0003

PDG

- Theory uncertainties small
- Parametric uncertainties on M_H, M_t included

NLO CORRECTIONS IN SMEFT

- Compute NLO corrections to $O(v^2/\Lambda^2)$ (ie linear in EFT coefficients)
- SMEFT is a new theory; calculate consistently to one-loop QCD and EW
- One-loop SM electroweak/QCD corrections for free in SMEFT NLO calculations
  - Feynman rules in arxiv:1704.03888 or SMEFT sim, 1709.06492
  - QCD is automated in SMEFT@NLO, 2008.11743
- Coefficient functions renormalized in $\overline{MS}$
  - Solved problem at one-loop

$$C_i(\mu) = C_i^0 - \frac{1}{32\pi^2\hat{\epsilon}}\gamma_{ij}C_j$$

EW SMEFT corrections done on individual basis at present

Alonso, Jenkins, Manohar, Trott, arxiv:1312.2014;
Jenkins, Manohar, Trott, arxiv:1310.4838, 1309.0819

COMPLICATIONS FOR NLO EW SMEFT

- Δr with SMEFT contributions
  - Include poles of coefficients in definition, 1807.11504

$$G_\mu = \frac{1}{\sqrt{2}\Lambda^2}\left(2C_{\phi l}^{(3)} - C_{ll}\right) + \frac{1}{\sqrt{2}v_0^2}(1+\Delta r)$$

$$\Delta r = \Delta r_{SM} + \frac{v^2}{\Lambda^2}\Delta r_{EFT}$$

  - Logarithmic and finite contributions to Δr_{EFT} both numerically relevant

At 1-loop dependence on coefficients that don't occur at tree level

At NLO, 10 combinations of operators, involving 32 operators in EW fit

COMPUTE EACH OBSERVABLE TO NLO IN SMEFT

All SMEFT effects here

- Example $M_W = M_W^{SM} + \delta M_W$
- Dependence on many coefficients at NLO (QCD + EW)
- Always use "best" SM prediction for fits

This is not unique procedure

$$\delta M_W^{LO} = \frac{v^2}{\Lambda^2}\left\{-30C_{\phi l}^{(3)} + 15C_{ll} - 28C_{\phi D} - 57C_{\phi WB}\right\}$$

$$\delta M_W^{NLO} = \frac{v^2}{\Lambda^2}\left\{-36C_{\phi l}^{(3)} + 17C_{ll} - 30C_{\phi D} - 64C_{\phi WB} - 0.1C_{\phi d} - 0.1C_{\phi e} - 0.2C_{\phi l}^{(1)} - 2C_{\phi q}^{(1)} + C_{\phi q}^{(3)} + 3C_{\phi u} + 0.4C_{lq}^{(3)} - 0.03C_{\phi B} - 0.03C_{\phi \Box} - 0.04C_{\phi W} - 0.9C_{uB} - 0.2C_{uW} - 0.2C_W\right\}$$

α, G_μ, M_Z scheme

W AND Z OBSERVABLES TO NLO

- Compare χ^2 at LO and NLO
- Dependence on some coefficients changes by O(5-10%)
- NLO result depends on 32 coefficients

$$\Delta\chi^2_{LO} = \left(\frac{1\ TeV}{\Lambda}\right)^2 \Big\{ 32C_{\phi d} + 105C_{\phi e} - 445C^{(1)}_{\phi l} + 639C^{(3)}_{\phi l} - 49C^{(1)}_{\phi q} - 60C^{(3)}_{\phi q} - 11C_{\phi u} - 424C_{ll} + 491C_{\phi D} + 1114C_{\phi WB} \Big\} + \text{quadratic terms}$$

$$\Delta\chi^2_{NLO} = \left(\frac{1\ TeV}{\Lambda}\right)^2 \Big\{ 27C_{\phi d} + 176C_{\phi e} - 402C^{(1)}_{\phi l} + 667C^{(3)}_{\phi l} - 19C^{(1)}_{\phi q} - 93C^{(3)}_{\phi q} - 53C_{\phi u} - 403C_{ll} + 503C_{\phi D} + 1070C_{\phi WB} + \boxed{22 \text{ more terms}} \Big\} + \text{quadratic terms}$$

$\Rightarrow$ Not clear how to use NLO result without global fit

SD, Giardino; ArXiv:1909.02000

NLO SMEFT EFFECTS ON POLE OBSERVABLES

- Single parameter fits at 95% CL

Coefficient	LO	NLO
$\mathcal{C}_{ll}$	$[-0.0039, 0.021]$	$[-0.0044, 0.019]$
$\mathcal{C}_{\phi WB}$	$[-0.0088, 0.0013]$	$[-0.0079, 0.0016]$
$\mathcal{C}_{\phi u}$	$[-0.072, 0.091]$	$[-0.035, 0.084]$
$\mathcal{C}_{\phi q}^{(3)}$	$[-0.011, 0.014]$	$[-0.010, 0.014]$
$\mathcal{C}_{\phi q}^{(1)}$	$[-0.027, 0.043]$	$[-0.031, 0.036]$
$\mathcal{C}_{\phi l}^{(3)}$	$[-0.012, 0.0029]$	$[-0.010, 0.0028]$
$\mathcal{C}_{\phi l}^{(1)}$	$[-0.0043, 0.012]$	$[-0.0047, 0.012]$
$\mathcal{C}_{\phi e}$	$[-0.013, 0.0094]$	$[-0.013, 0.0080]$
$\mathcal{C}_{\phi D}$	$[-0.025, 0.0019]$	$[-0.023, 0.0023]$
$\mathcal{C}_{\phi d}$	$[-0.16, 0.060]$	$[-0.13, 0.063]$

Up to O(30%) effects from NLO

Single parameter fits to other coefficients not appearing at LO are not informative

*Λ= 1 TeV

NLO SMEFT EFFECTS ON POLE OBSERVABLES

- Fits marginalizing over other coefficients

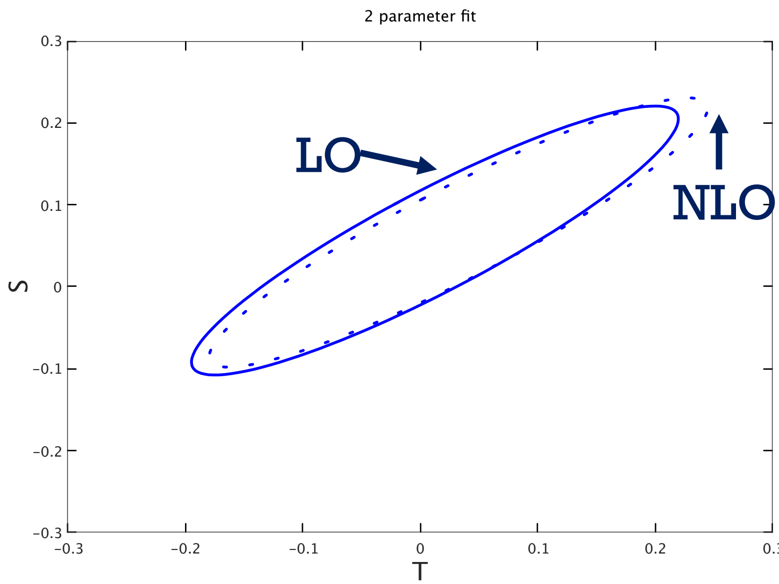
Coefficient	LO	NLO
$\mathcal{C}_{\phi D}$	$[-0.034, 0.041]$	[-0.039,0.051]
$\mathcal{C}_{\phi WB}$	$[-0.080, 0.0021]$	$[-0.098, 0.012]$
$\mathcal{C}_{\phi d}$	$[-0.81, -0.093]$	$[-1.07, -0.03]$
$\mathcal{C}_{\phi l}^{(3)}$	$[-0.025, 0.12]$	$[-0.039, 0.16]$
$\mathcal{C}_{\phi u}$	$[-0.12, 0.37]$	$[-0.21, 0.41]$
$\mathcal{C}_{\phi l}^{(1)}$	$[-0.0086, 0.036]$	$[-0.0072, 0.037]$
$\mathcal{C}_{ll}$	$[-0.085, 0.035]$	$[-0.087, 0.033]$
$\mathcal{C}_{\phi q}^{(1)}$	$[-0.060, 0.076]$	$[-0.095, 0.075]$

- Neglect flavor effects
- Contribution from top loops

NLO effects can be important

OBLIQUE PARAMETERS

- Arbitrarily set all parameters except $C_{\phi WB}$ and $C_{\phi D}$=0



$$\alpha\Delta S = 4c_W s_W \frac{v^2}{\Lambda^2} C_{\phi WB}$$

$$\alpha\Delta T = -\frac{v^2}{2\Lambda^2} C_{\phi D}$$

My bottom line: These are interesting calculations, but need to be part of a complete NLO global fit

LINEAR VS QUADRATIC

- Previous EWPO fit computes observables to $O(v^2/\Lambda^2)$.
- Would keeping $O(v^4/\Lambda^4)$ terms change fit results?
- Lepton observables, C_{llll}, $C_{\phi e}^{(3)}$, $C_{\phi 1}$, C_{BW} almost complete determined by EWPO

1812.01009	Quadratic Fit	Linear Fit
C_{lll}	(-.043, .013)	(-.045, .013)
$C_{\phi e}^{(3)}$	(-.077, .011)	(-.077, .055)
$C_{\phi l}$	(-.040, .15)	(-.034, .15)
C_{BW}	(-.32, 1.7)	(-.21, 1.8)

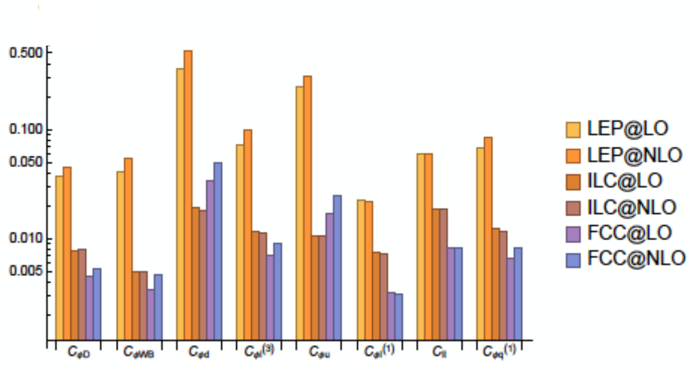
- EWPO expansion is E^2/Λ^2 with $E \sim M_Z$

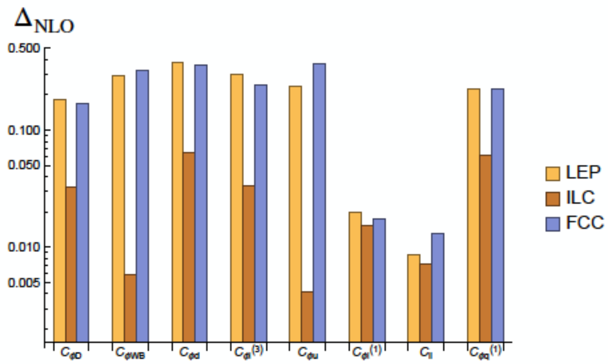
These are tree level. NLO $O(v^4/\Lambda^4)$ would have double insertions and would need dimension 8

Dimension-8 fits: 2102.02819

NLO PRECISION IN FUTURE COLLIDERS

$$\Delta_{NLO} = \frac{C_{NLO} - C_{LO}}{C_{LO}}$$



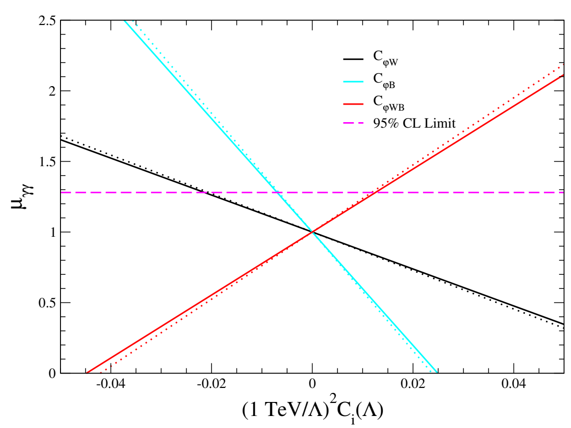


*Remember ILC polarization

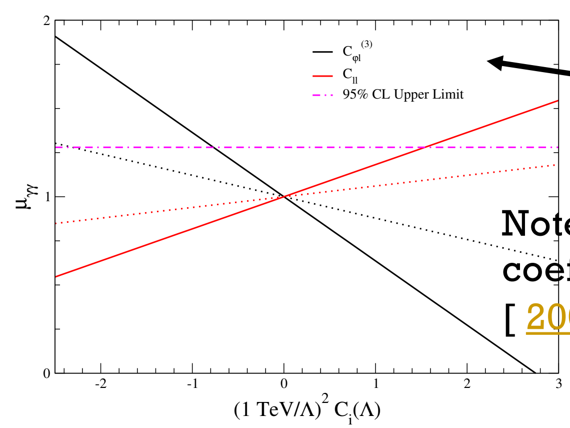
MORE EW NLO CONSIDERATIONS

- QCD NLO results can be generated from SMEFT@NLO
- EW NLO results done case by case: don't have complete set yet
- Test case, H→ $\gamma\gamma$: numerical effects of input scheme appear small

Solid: G_μ, M_W, M_Z Scheme; Dotted: α, G_μ, M_Z, M_W Scheme



Solid: G_μ, M_W, M_Z Scheme; Dotted: α, G_μ, M_Z, M_W Scheme



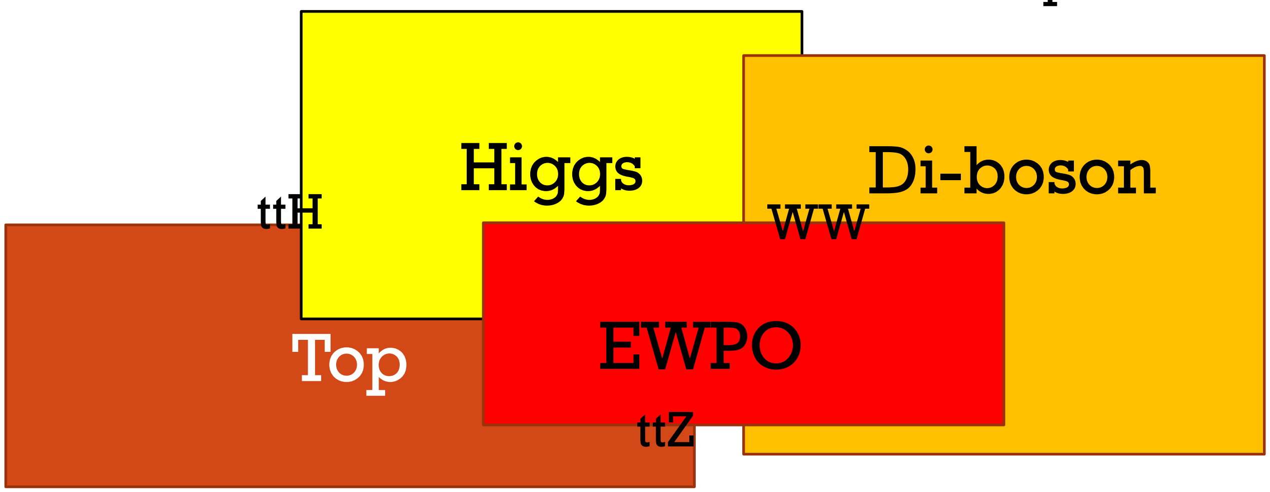
These operators involve leptons

Note large values of coefficients: recent fit [2007.04400]C_{llll} ~(-.22,-.5)

Dawson, Giardino 1807.11504

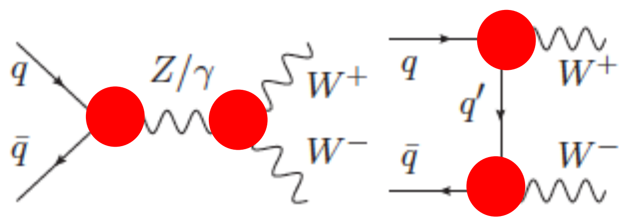
ISSUES ARE MORE COMPLICATED FOR pp

- Power of SMEFT is connection of data from different processes



DIBOSON PRODUCTION IS OLD STORY

- Sensitive to variations of Zff and Z(γ)WW couplings



No growth with energy in SM

- Old story: Individual contributions grow with energy
- Cancellations keep amplitudes from growing at high energy in SM

Changing gauge or fermion couplings spoils cancellation

Hagiwara, Peccei, Zeppenfeld, Hikasa, NPB482 (1987)

NON-SM WWZ AND WWγ

- Parameterize via anomalous couplings (can be written in terms of SMEFT coefficients)

$$L = -g_{WWV}\left(g_1^V(W^+_{\mu\nu}W^{-\mu}V^\nu - W^-_{\mu\nu}W^{+\mu}V^\nu) + \kappa^V W^+_\mu W^-_\nu V^{\mu\nu} + \frac{\lambda^V}{M_W^2}W^+_{\rho\mu}W^{-\mu\nu}V^{\nu\rho}\right)$$

$$g_1^Z = 1 + \delta g_1^Z,\ g_1^\gamma = 1,\ \kappa_Z = 1 + \delta\kappa^Z,\ \kappa^\gamma = 1 + \delta\kappa^\gamma$$

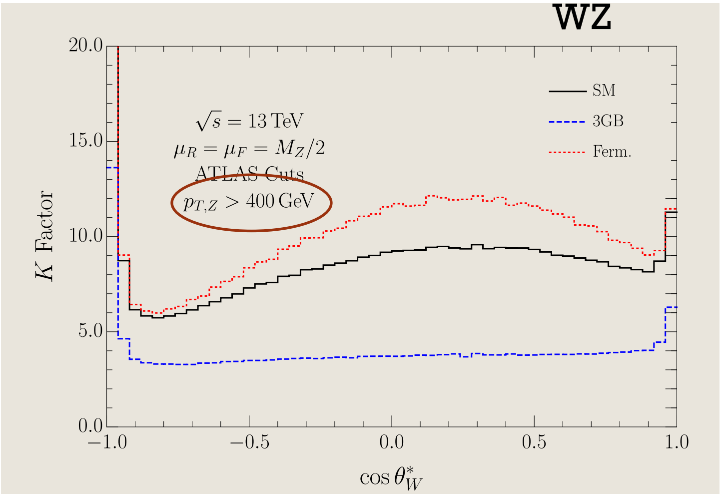
V=Z, γ

  - SU(2)$_L$ invariance implies $\lambda^Z = \lambda^\gamma,\ \delta\kappa^\gamma = \cot^2\theta_W(\delta g_1^Z - \delta\kappa^Z)$
  - 3 combinations of couplings here, plus 4 from fermion sector

Sensitivity to 7 combination of Wilson coefficients

QCD MATTERS

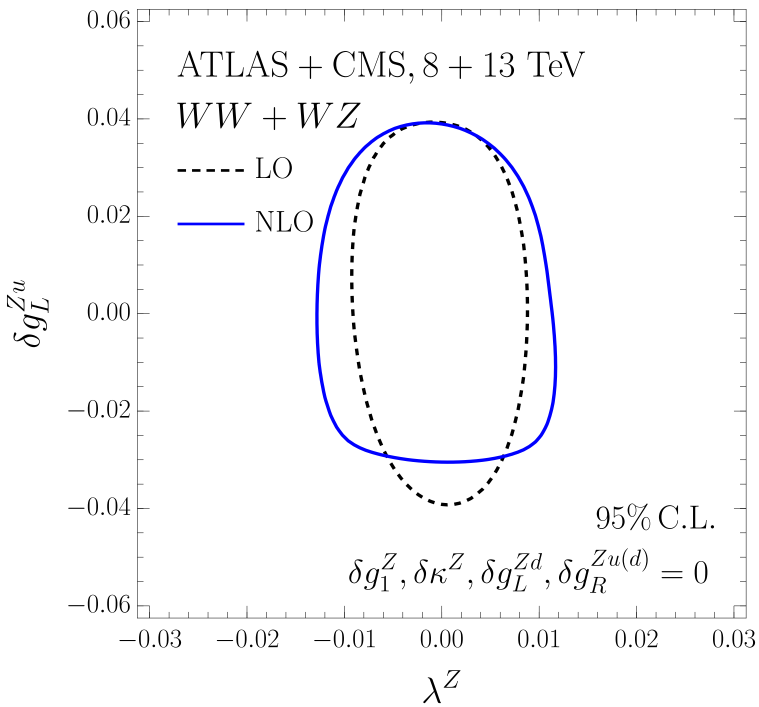
- K factors aren't the same as in SM
- Effect is enhanced for large momenta

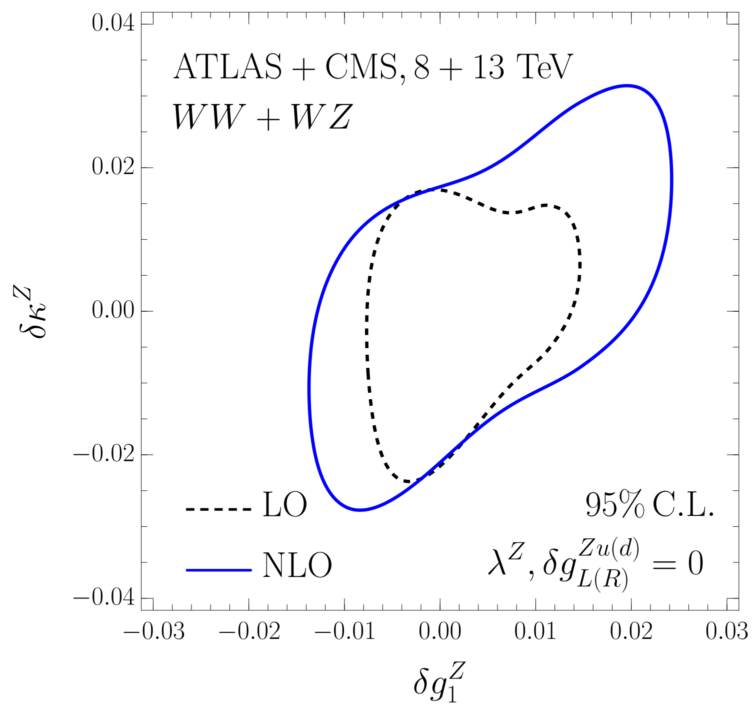


See talks by E. Vryonodou and K. Mimasu at KITP precision21 workshop on state of the art QCD NLO results

Baglio, Dawson, Homiller, 1909.11576

QCD IS RELEVANT





* Fits to $1/\Lambda^4$; Set all other coefficients to zero

Baglio, Dawson, Homiller, 1909.11576

WHEN IS EFT VALID?

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

- SMEFT

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

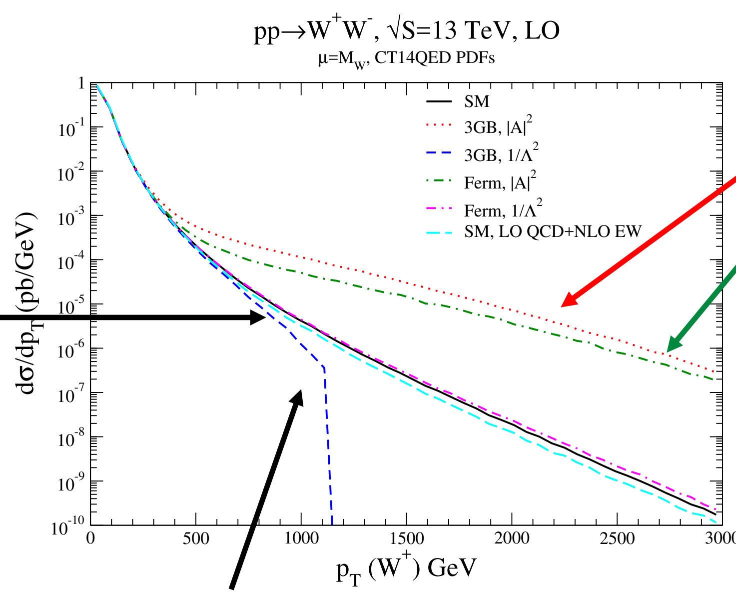
- Problem is that $(A_6)^2$ terms are the same order as A_8 terms that we have dropped when counting in $1/\Lambda$
- If we only keep A_6/Λ^2 terms and drop $(A_6/\Lambda^2)^2$, the cross section is not guaranteed to be finite
- Corrections are $O(s/\Lambda^2)$ or $O(v^2/\Lambda^2)$

OBVIOUS PROBLEM

- One proposal for dealing with this issue is to put a cut on the maximum energy where the SMEFT is assumed to be valid, 1604.06444

Linear expansion

Cannot ignore negative cross section region



…. Anomalous 3 gauge boson couplings

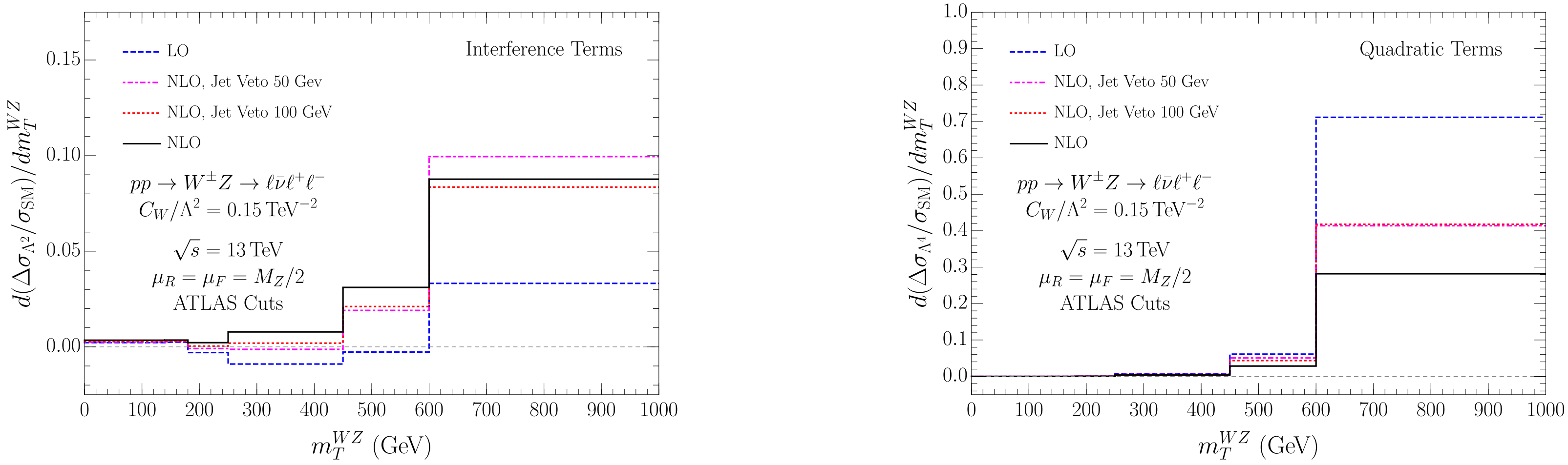
----Anomalous Z-fermion couplings allowed by LEP measurements

Baglio, Dawson, Lewis , arXiv:1708.03332

* σ goes negative, expansion not valid

LINEAR VS QUADRATIC?

- Can quantitatively study effects of linear and quadratic contributions

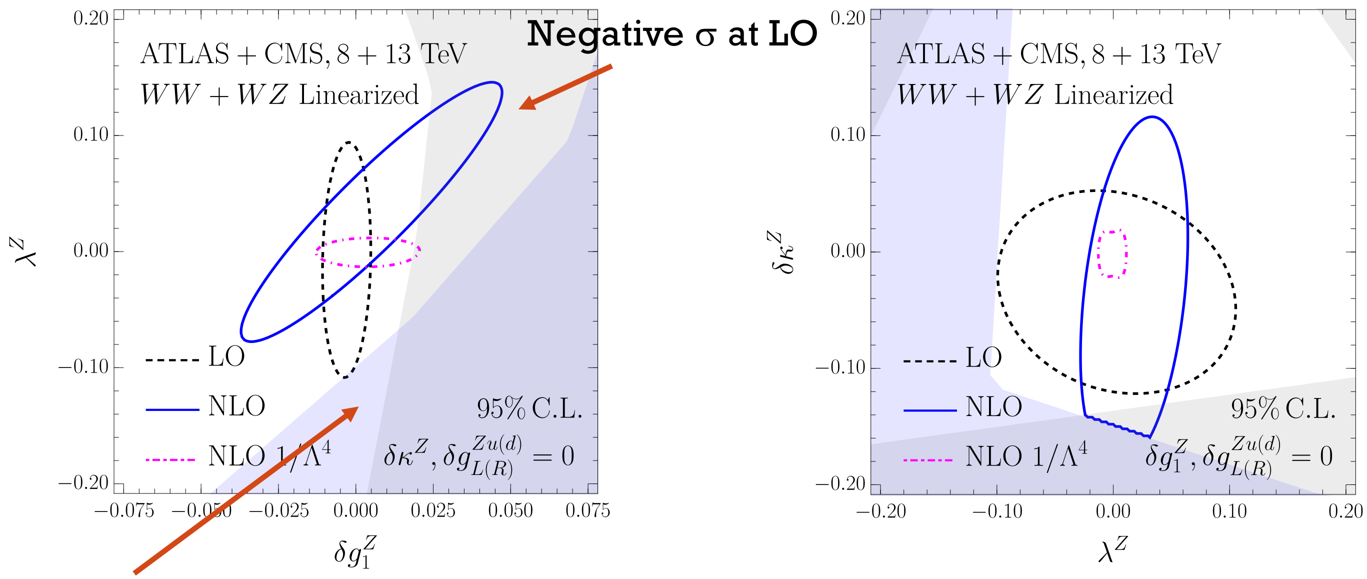


$$\sigma(C_i) \sim \sigma_{SM} + \Delta\sigma_{1/\Lambda^2}(C_i) + \Delta\sigma_{1/\Lambda^4}(C_i^2)$$

Try to use this to develop validity criteria

FIT TO LINEARIZED RATES

- Drop all coefficients where cross section is negative
- Linearized limits significantly weaker than $1/\Lambda^4$ limits (can cancel terms)

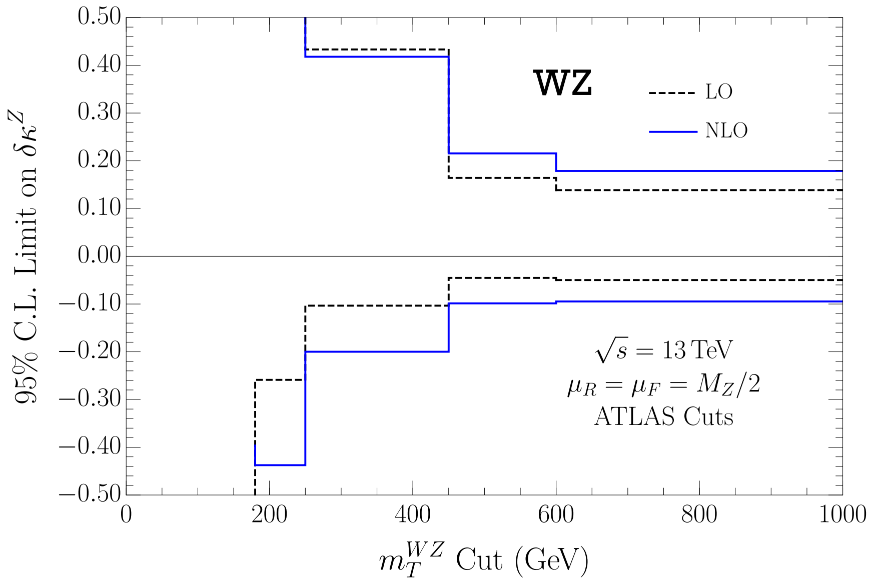


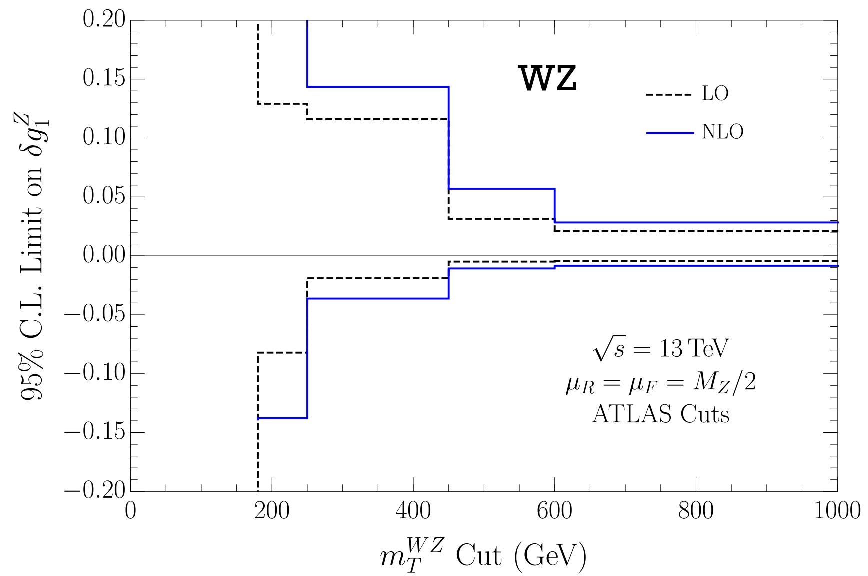
S. Dawson

1909.11576

IS IT ALL THE LAST BIN?

- Fit results depend on cut on maximum energy

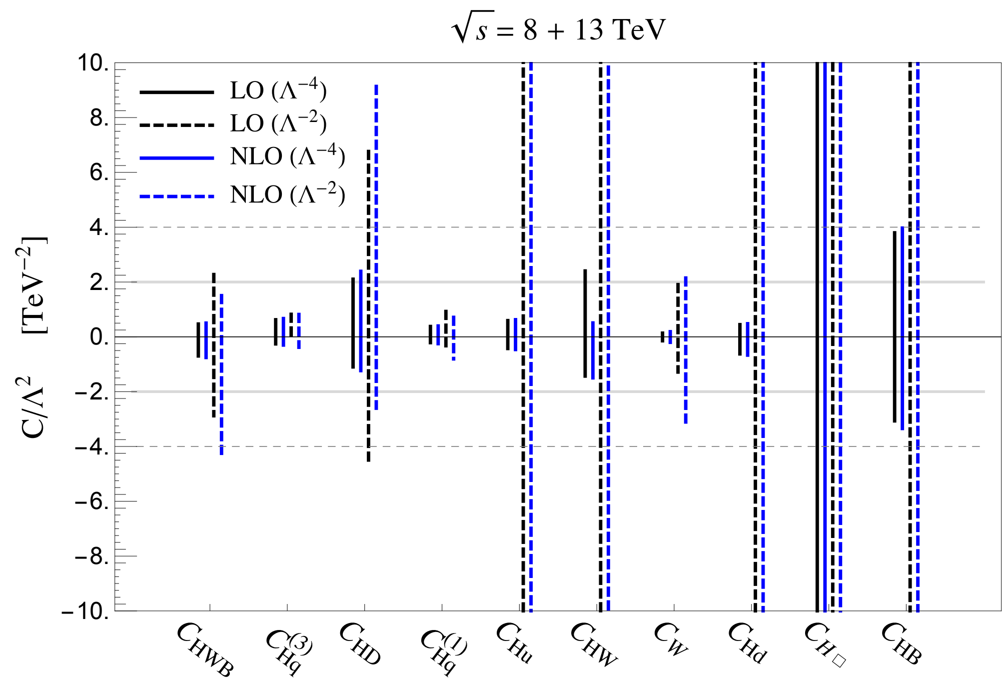




Plots successively remove high m_T bins

ASSUMPTIONS CREEPING IN

- Single parameter fit to WW/WZ/WH/ZH
- For linear fit, throw out points with negative cross section
- Fit assumes SM efficiencies in each bin (not necessarily true)
- Fit ignores flavor



See Madigan, HEFT2021 talk for more sophisticated fits

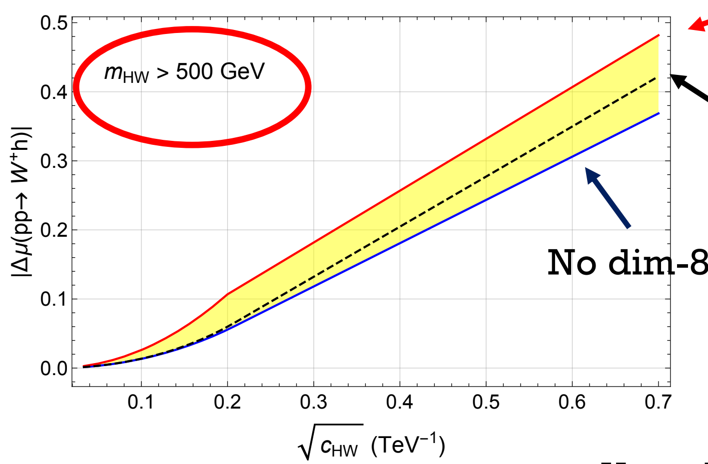
2003.07862

INVESTIGATE DIM-8 OPERATORS IN WH

- We have a catalogue of dim-8 operators
  - Combinations of dim-8 operators generate 16 form factors for WH process
  - In high energy limit, leading contribution from $(C_{HQ}{}^3)^2$ and combination of dim-8 operators
  - Neglecting $C_{HQ}{}^3$ (strongly limited by EWPO)

$$| A_6 |^2 \sim \frac{v^4}{\Lambda^4}$$

$$A^*_{SM} A_8 \sim \frac{sv^2}{\Lambda^4}$$



Maximum dim-8 effect allowed by validity of EFT expansion

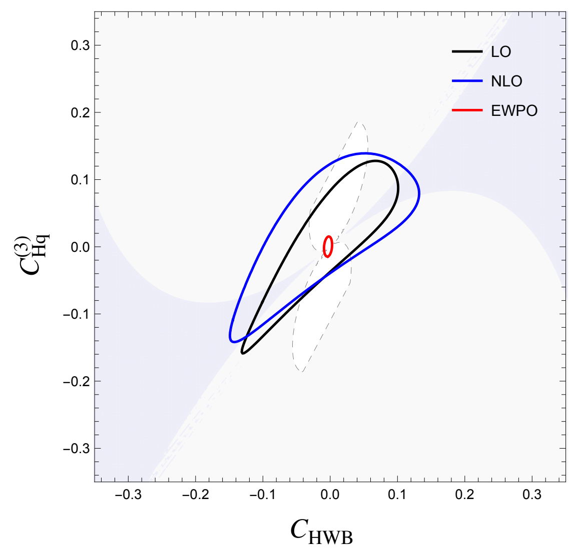
Dim-6 and dim-8 scales equal (A BIG ASSUMPTION!)

Hays, Martin, Sanz, Setford, 1808.00442

MY MESSAGE

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

ASSUMPTIONS



White=weakly coupled, grey/blue shading strongly coupled

- We have the tools to evaluate the numerical effects of these assumptions (my pragmatic approach)

LHC EFT WORKING GROUP

- https://lpcc.web.cern.ch/lhc-eft-wg
- The LHC effective field theory working group (LHC EFT WG) gathers members of the LHC experiments and the theory community to provide a framework for the interpretation of LHC data in the context of effective field theories (EFTs). The LHC EFT WG studies the physics requirements needed to facilitate an interpretation commensurate with the available measurements performed in a wide range of different processes, including Higgs bosons, top quarks, and electroweak bosons.

6 TOPICAL WORKSHOPS SO FAR

- EFT Formalism (which basis, which inputs?)
- Predictions and Tools
- Measurements and Observables
- Fits and Related Systematics
- Benchmark Scenarios from UV Models (what do fits tell us about UV?)
- Heavy flavor inputs to EFT fits

WHERE IS THIS GOING?

- General meeting of EFT-WG, May 3, 1-6 CERN time
- Hope for "proof of principle" combination exercise fit with CMS/ATLAS using selection of top/Higgs/di-boson data
- WG is writing drafts of short notes detailing issues in LHC EFT fits
- All are welcome!
- Many theory issues to be resolved for practical fits
  - Linear vs quadratic, cut-off for validity, inclusion of NLO theory, dimension-8 operators, effects of flavor, "best" observables….

BACKUP

$\mathcal{O}_{ll}$	$(\bar{l}\gamma_\mu l)(\bar{l}\gamma^\mu l)$	$\mathcal{O}_{\phi WB}$	$(\phi^\dagger \tau^a \phi)\, W^a_{\mu\nu} B^{\mu\nu}$	$\mathcal{O}_{\phi D}$	$(\phi^\dagger D^\mu \phi)^* \,(\phi^\dagger D_\mu \phi)$
$\mathcal{O}_{\phi e}$	$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\overline{e}_R \gamma^\mu e_R)$	$\mathcal{O}_{\phi u}$	$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\overline{u}_R \gamma^\mu u_R)$	$\mathcal{O}_{\phi d}$	$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\overline{d}_R \gamma^\mu d_R)$
$\mathcal{O}^{(3)}_{\phi q}$	$(\phi^\dagger i \overleftrightarrow{D}^a_\mu \phi)(\bar{q}\tau^a \gamma^\mu q)$	$\mathcal{O}^{(1)}_{\phi q}$	$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\bar{q}\tau^a \gamma^\mu q)$	$\mathcal{O}^{(3)}_{\phi l}$	$(\phi^\dagger i \overleftrightarrow{D}^a_\mu \phi)(\bar{l}\tau^a \gamma^\mu l)$
$\mathcal{O}^{(1)}_{\phi l}$	$(\phi^\dagger i \overleftrightarrow{D}_\mu \phi)(\bar{l}\tau^a \gamma^\mu l)$				