SM EW Precision Measurements and EFT Fits

Pushing the Boundaries
The Standard Model and Beyond at the LHC

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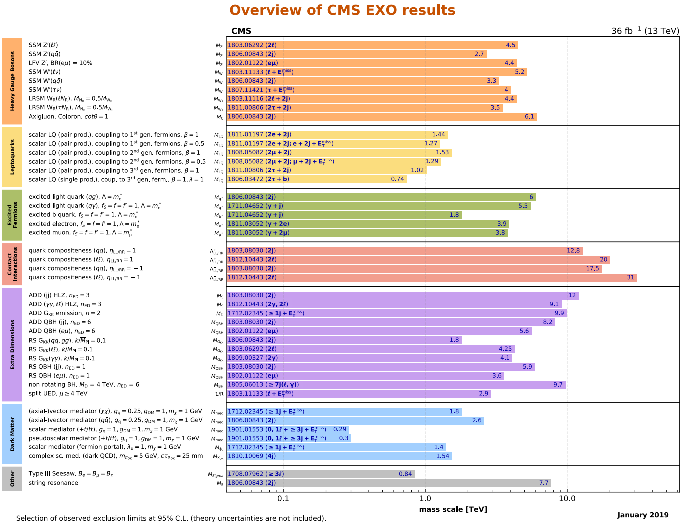
Outline

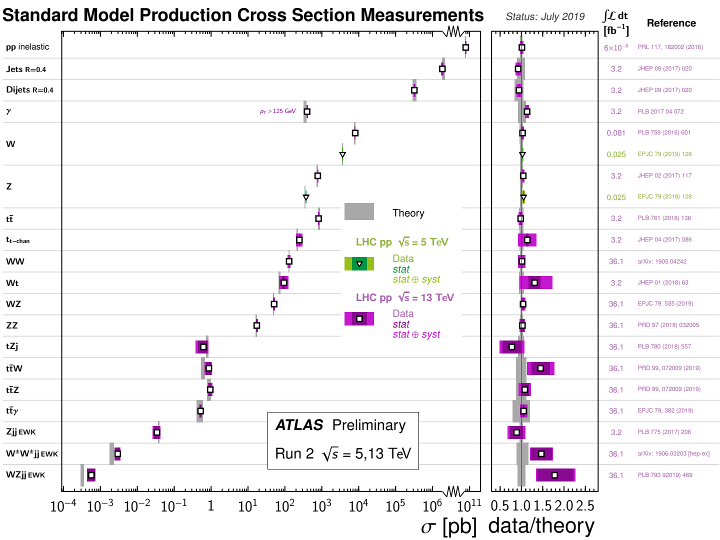
1. Short introduction to EFT (for EW measurements)
2. Presentation of selected LHC Run 2 measurements
3. Discussion of possible improvements

BSM Searches



- So far, no direct hints for new physics found at the LHC...

SM Precision Measurements



- ...but wide range of SM precision measurements available

The Standard Model Effective Field Theory

- Make best use of SM precision measurements to constrain new physics
- One possibility: constrain the SM Effective Field Theory
- SM EFT: expansion of new physics in inverse of energy scale $1/\Lambda$
  - Introduces operators Q_i of energy dimension $n > 4$, suppressed by increasing powers of $\Lambda \gg v$
  - Lagrangian (without L and B violating operators):

$$\mathcal{L}_{\text{SM EFT}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{c_i^{\text{dim6}}}{\Lambda^2} Q_i^{\text{dim6}} + \sum_i \frac{c_i^{\text{dim8}}}{\Lambda^4} Q_i^{\text{dim8}} + \ldots$$

  - SMEFT respects SM symmetries and assumes linear realisation of SU(2)
  - Captures low-energy effect of UV theory beyond Λ for $\sqrt{\hat{s}} \ll \Lambda$
  - Can only measure c_i/Λ^n, not c_i or Λ separately
  - Operator basis not unique, different conventions in use
- Constrain EFT coefficients $\Rightarrow$ constrain large classes of UV theories

Important Concepts

- Comparison of size of terms linear ($\propto c/\Lambda^n$) and quadratic ($\propto c^2/\Lambda^{2n}$) in EFT coefficients can be test of convergence of EFT expansion

Dimension six example

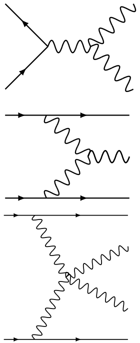
$$\sigma = \sigma_{\text{SM}} + \sum_i \frac{c_i}{\Lambda^2}\sigma_i^{\text{dim-6-interf}} + \sum_{ij} \frac{c_i c_j}{\Lambda^4}\sigma_{ij}^{(\text{dim-6})^2} + \sum_k \frac{c_k}{\Lambda^4}\sigma_k^{\text{dim-8-interf}} + \ldots$$

Naive expectation: SM $<$ dim-6-interf $<$ (dim-6)^2 $\approx$ dim-8-interf

- Energy scale probed by measurement relevant: Λ has to be larger than directly probed energy scale (given e.g. by $\sqrt{\hat{s}}$)
- Effect of operators typically growing with $(E/\Lambda)^n \Rightarrow$ measure in tails
- Growth of amplitude with $\hat{s}$ can violate unitarity, different unitarisation schemes in use

Anomalous Gauge Coupling Measurements

- In SM precision measurements at the LHC: EFT constraints almost exclusively from anomalous gauge coupling measurements
- *Anomalous triple gauge couplings (aTGCs)*: Dibosons (WW, WZ, Wγ) and VBF production (Zjj, Wjj)
- *Neutral triple gauge couplings (nTGCs)*: ZZ and Zγ
- *Anomalous quartic gauge couplings (aQGCs)*: Triboson, VBS production of boson pairs, exclusive WW



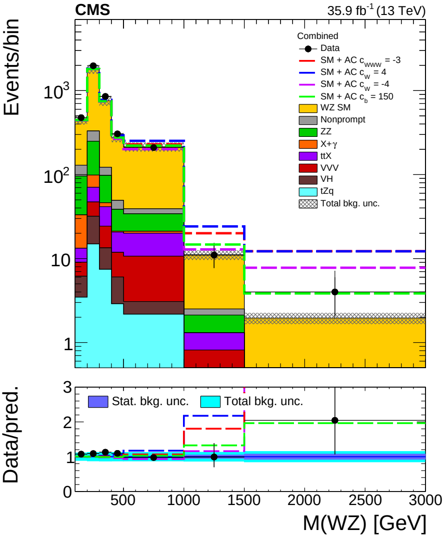
aTGCs and EFT

- aTGC operators at dimension six in EFT expansion, usual basis:

$$\begin{aligned} O_B &= (D_\mu H)^\dagger B^{\mu\nu} D_\nu H, \\ O_W &= (D_\mu H)^\dagger W^{\mu\nu} D_\nu H, \\ O_{WWW} &= \mathrm{Tr}[W_{\mu\nu} W^\nu_\rho W^{\rho\mu}] \end{aligned}$$

$$\begin{aligned} O_{\tilde{W}} &= (D_\mu H)^\dagger \tilde{W}^{\mu\nu} D_\nu H, \\ O_{\tilde{W}WW} &= \mathrm{Tr}[W_{\mu\nu} W^\nu_\rho \tilde{W}^{\rho\mu}] \end{aligned}$$

WZ (CMS) 1/2



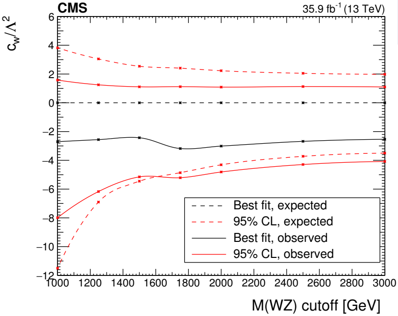
CMS SMP-18-002: $WZ \to \ell\nu\ell'\ell'$

- Measurements in relatively clean three-lepton channel
  - Low background
  - Can deduce neutrino momentum
- Limits from tails of m_{WZ} distribution, where impact of aTGC largest
- Order 2/TeV^2 constraints on c_{WWW}/Λ^2 and c_W/Λ^2, hardly sensitive to c_B

Parameter	95% CI (expected) $[\mathrm{TeV}^{-2}]$	95% CI (observed) $[\mathrm{TeV}^{-2}]$
c_W/Λ^2	$[-3.3, 2.0]$	$[-4.1, 1.1]$
c_{WWW}/Λ^2	$[-1.8, 1.9]$	$[-2.0, 2.1]$
c_b/Λ^2	$[-130, 170]$	$[-100, 160]$

WZ (CMS) 2/2

- Importance of quadratic term studied
  - Small effect for limit on c_W
  - Quadratic term dominant for c_{WWW} and c_B



Linear vs Quadratic Terms

Limits using linear+quadratic terms

Parameter	95% CI (expected) [TeV^{-2}]	95% CI (observed) [TeV^{-2}]
c_W/Λ^2	$[-3.3, 2.0]$	$[-4.1, 1.1]$
c_{WWW}/Λ^2	$[-1.8, 1.9]$	$[-2.0, 2.1]$
c_b/Λ^2	$[-130, 170]$	$[-100, 160]$

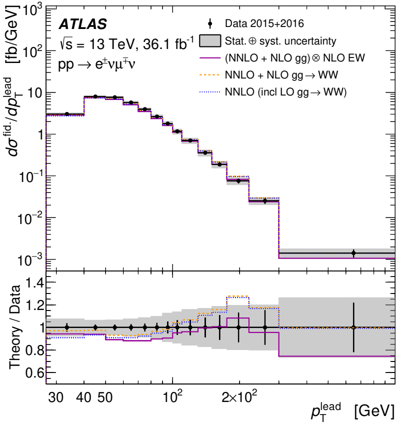
Linear terms only

Parameter	95% CI (expected) [TeV^{-2}]	95% CI (observed) [TeV^{-2}]
c_W/Λ^2	$[-2.3, 3.4]$	$[-2.2, 2.7]$
c_{WWW}/Λ^2	$[-33.2, 28.6]$	$[-13.8, 41.2]$
c_b/Λ^2	$[-360, 300]$	$[-230, 390]$

- "Clipping" study performed as well (ad-hoc unitarisation with sliding cut-off)
- Restrict effect of aTGC up to a cut-off value of M(WZ) (SM prediction and data not affected)

WW (ATLAS)

ATLAS STDM-2017-24: $WW \to e\nu\mu\nu$



- More background than WZ, need to suppress $t\bar{t}$ with jet-veto
- Two neutrinos in final state
- Limits from unfolded leading p_T^ℓ fiducial cross section - validated BSM terms behave as SM in unfolding
- Large EW correction to tail of p_T^ℓ
- Less sensitive to O_W, O_{WWW} than WZ
- Results given with and without quadratic term as well

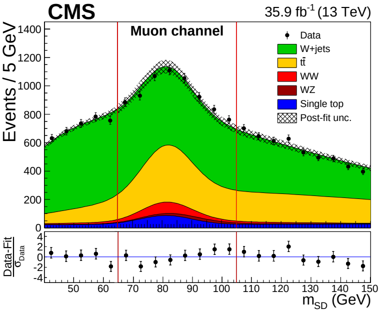
Parameter	Observed 95% CL [TeV^{-2}]	Expected 95% CL [TeV^{-2}]
c_{WWW}/Λ^2	[−3.4 , 3.3]	[−3.0 , 3.0]
c_W/Λ^2	[−7.4 , 4.1]	[−6.4 , 5.1]
c_B/Λ^2	[−21 , 18]	[−18 , 17]
$c_{\tilde{W}WW}/\Lambda^2$	[−1.6 , 1.6]	[−1.5 , 1.5]
$c_{\tilde{W}}/\Lambda^2$	[−76 , 76]	[−91 , 91]

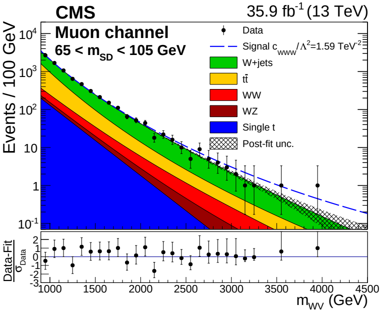
Operator	95% CL (linear and quadratic terms)	95% CL (linear terms only)
c_{WWW}/Λ^2	[−3.4 TeV^{-2} , 3.3 TeV^{-2}]	[−179 TeV^{-2} , −17 TeV^{-2}]
c_W/Λ^2	[−7.4 TeV^{-2} , 4.1 TeV^{-2}]	[−13.1 TeV^{-2} , 7.1 TeV^{-2}]
c_B/Λ^2	[−21 TeV^{-2} , 18 TeV^{-2}]	[−104 TeV^{-2} , 101 TeV^{-2}]

WV (CMS)

CMS SMP-18-008: $WV \to \ell\nu J$ ($J =$ fat jet)

- Least clean channel – SM signal buried beneath $t\bar{t}$ and W+jets
- Higher statistics / energy reach for aTGCs
- Simultaneous unbinned fit of jet and diboson mass





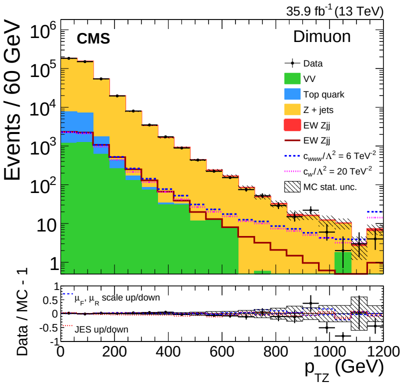
- Best sensitivity to all three tested operators

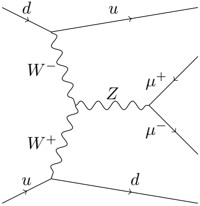
Parametrization	aTGC	Expected limit	Observed limit
EFT	c_{WWW}/Λ^2 (TeV^{-2})	[-1.44, 1.47]	[-1.58, 1.59]
	c_W/Λ^2 (TeV^{-2})	[-2.45, 2.08]	[-2.00, 2.65]
	c_B/Λ^2 (TeV^{-2})	[-8.38, 8.06]	[-8.78, 8.54]

- No study on unitarity, energy scale probed, or quadratic terms

VBF Z (CMS)

SMP-16-018: Z(ℓℓ)jj

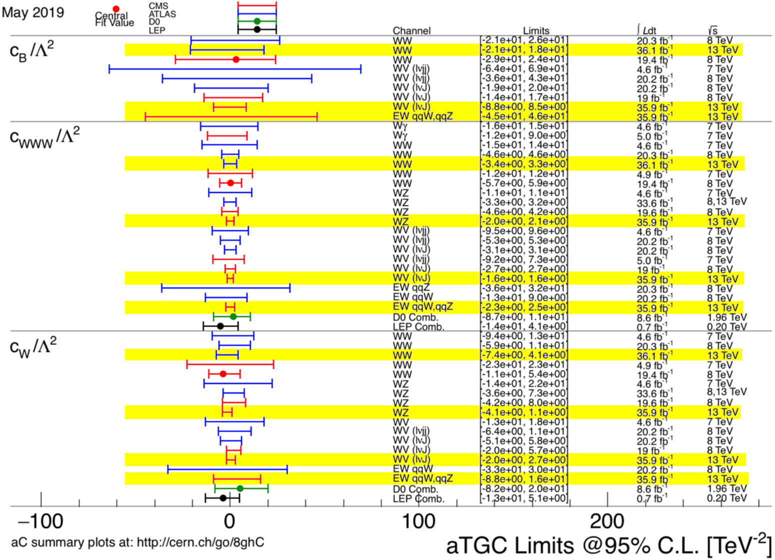




- Targeting VBF production of Zjj
- Characterised by two tagging jets with rapidity gap
- Large irreducible Z+jets background ("QCD production")
- Limits from tail of p_{TZ}, competitive limit on c_{WWW}

Coupling constant	Expected 95% CL interval (TeV^{-2})	Observed 95% CL interval (TeV^{-2})
c_{WWW}/Λ^2	$[-3.7, 3.6]$	$[-2.6, 2.6]$
c_W/Λ^2	$[-12.6, 14.7]$	$[-8.4, 10.1]$

Summary of EFT constraints from aTGC measurements



Presented results (highlighted) most sensitive ones, far surpassing LEP

Beyond dimension six: nTGCs and aQGCs

Neutral Triple Gauge Couplings

- Reminder: no neutral triple gauge couplings in SM
- nTGC operators only at dim-8 in EFT expansion

$$\mathcal{O}_{\widetilde{B}W} = i H^\dagger \widetilde{B}_{\mu\nu} W^{\mu\rho} \left\{D_\rho, D^\nu\right\} H, \qquad \mathcal{O}_{WW} = i H^\dagger W_{\mu\nu} W^{\mu\rho} \left\{D_\rho, D^\nu\right\} H,$$
$$\mathcal{O}_{BW} = i H^\dagger B_{\mu\nu} W^{\mu\rho} \left\{D_\rho, D^\nu\right\} H, \qquad \mathcal{O}_{BB} = i H^\dagger B_{\mu\nu} B^{\mu\rho} \left\{D_\rho, D^\nu\right\} H.$$

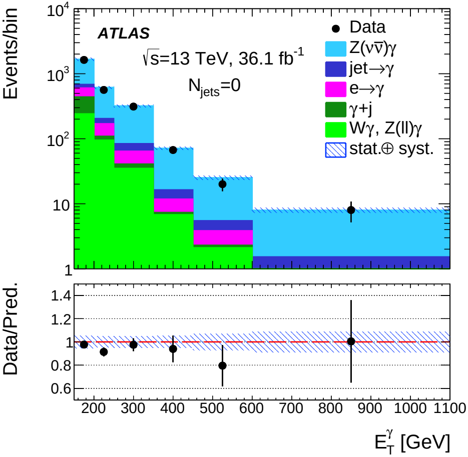
Anomalous Quartic Gauge Couplings

- Only at dim-8 (or higher) operators with quartic vertices but no two or three-boson couplings
- Assumption: aQGC due to dim-6 already constrained elsewhere
- Operators affect all quartic boson couplings

$$\mathcal{L}_{S,0-1} \propto (D_\mu \Phi)^4, \qquad \mathcal{L}_{M,0-7} \propto (F^{\mu\nu})^2 (D_\mu \Phi)^2, \qquad \mathcal{L}_{T,0-9} \propto (F^{\mu\nu})^4$$

$Z\gamma$ (ATLAS)

ATLAS STDM-2017-18: $Z(\nu\nu)\gamma$



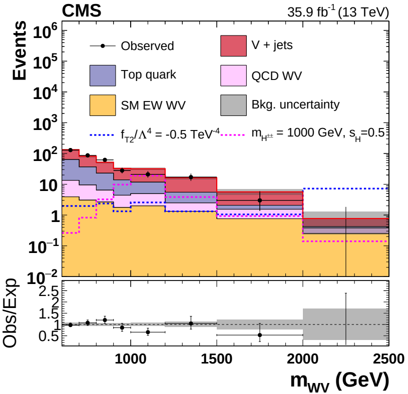
- nTGCs constrained in ZZ and $Z\gamma$
- EFT constraints from $Z\gamma$ tighter
- Best channel: $Z \to \nu\nu$ (large branching ratio, no FSR)
- Limits extracted from $E_T^\gamma > 600$ GeV events, in 0-jet category
- Constraints of order 1/TeV^4

Parameter	Limit 95% CL	
	Measured [TeV^{-4}]	Expected [TeV^{-4}]
$C_{\widetilde{B}W}/\Lambda^4$	$(-1.1, 1.1)$	$(-1.3, 1.3)$
C_{BW}/Λ^4	$(-0.65, 0.64)$	$(-0.74, 0.74)$
C_{WW}/Λ^4	$(-2.3, 2.3)$	$(-2.7, 2.7)$
C_{BB}/Λ^4	$(-0.24, 0.24)$	$(-0.28, 0.27)$

VBS WV/ZV (CMS)

CMS SMP-18-006: $WV \to \ell\nu J$ and $ZV \to \ell\ell J$

- Lepton(s) + fat jet + VBS jets final state
- As in semi-leptonic aTGC analysis: no attempt to discover SM process, only constraints of new physics
- Fit of m_{WV} distribution, binning as aggressive as MC statistics permits
- World-best limits for all operators tested (no unitarisation)



	Observed (WV) (TeV^{-4})	Expected (WV) (TeV^{-4})	Observed (ZV) (TeV^{-4})	Expected (ZV) (TeV^{-4})	Observed (TeV^{-4})	Expected (TeV^{-4})
f_{S0}/Λ^4	$[-2.7, 2.7]$	$[-4.2, 4.2]$	$[-40, 40]$	$[-31, 31]$	$[-2.7, 2.7]$	$[-4.2, 4.2]$
f_{S1}/Λ^4	$[-3.3, 3.4]$	$[-5.2, 5.2]$	$[-32, 32]$	$[-24, 24]$	$[-3.4, 3.4]$	$[-5.2, 5.2]$
f_{M0}/Λ^4	$[-0.69, 0.69]$	$[-1.0, 1.0]$	$[-7.5, 7.5]$	$[-5.3, 5.3]$	$[-0.69, 0.70]$	$[-1.0, 1.0]$
f_{M1}/Λ^4	$[-2.0, 2.0]$	$[-3.0, 3.0]$	$[-22, 23]$	$[-16, 16]$	$[-2, 0, 2.1]$	$[-3.0, 3.0]$
f_{M6}/Λ^4	$[-1.4, 1.4]$	$[-2.0, 2.0]$	$[-15, 15]$	$[-11, 11]$	$[-1.3, 1.3]$	$[-1.4, 1.4]$
f_{M7}/Λ^4	$[-3.4, 3.4]$	$[-5.1, 5.1]$	$[-35, 36]$	$[-25, 26]$	$[-3.4, 3.4]$	$[-5.1, 5.1]$
f_{T0}/Λ^4	$[-0.12, 0.11]$	$[-0.17, 0.16]$	$[-1.4, 1.4]$	$[-1.0, 1.0]$	$[-0.12, 0.11]$	$[-0.17, 0.16]$
f_{T1}/Λ^4	$[-0.12, 0.13]$	$[-0.18, 0.18]$	$[-1.5, 1.5]$	$[-1.0, 1.0]$	$[-0.12, 0.13]$	$[-0.18, 0.18]$
f_{T2}/Λ^4	$[-0.28, 0.28]$	$[-0.41, 0.41]$	$[-3.4, 3.4]$	$[-2.4, 2.4]$	$[-0.28, 0.28]$	$[-0.41, 0.41]$

Summary, Comments

- All presented measurements constrain new physics in tails of kinematic distributions (m_{VV}, $p_{\mathrm{T}V}$ or proxies)
- No excesses observed
- Across the board: limits greatly improved compared to Run 1
- Tightest limits from semi-leptonic measurements
- Usually limited by statistics – sensitivity will improve
- Many full Run 2 measurements ongoing: good time to think about improvements

Possible Improvements (1/2)

Allow Reinterpretation of Analyses

- Perform model independent measurements, publish HEPdata + Rivet

Restrict Energy Scale Probed

- Barely done so far (difficult in WW, otherwise $\approx \sqrt{\hat{s}}$ in principle accessible)

Perform Linearised Fit

- Linear vs quadratic difference not always checked $\rightarrow$ trivial to do!

Study Unitarisation

- Unitarisation applied only sporadically
- Clipping scans nowadays most popular method – useful?

Possible Improvements (2/2)

Measure Better Observables

- Improve sensitivity, in particular to interference effect
- CP-odd observables for CP-odd operators?

Improve Statistical Interpretation

- Combine measurements
- Perform multi-parameter fits

Use Additional Models

- Should we also use the Warsaw basis in aTGC studies?
- NLO models available for limited set of operators (SMEFT@NLO)

Higher Order Corrections

- Precise SM predictions clearly of utmost importance
- Some aspect of particular importance for EFT studies

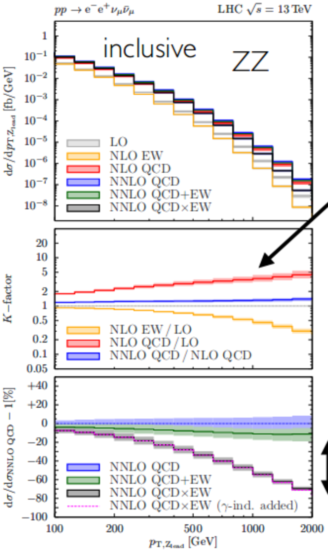
EW Corrections and EFT

- EW correction typically growing with $\sqrt{\hat{s}}$ – like EFT operators
- In tails, corrections of similar size as measurement uncertainties – inclusion of correction (and associated uncertainty) affects limits
- Uncertainty scheme less clear compared to QCD

QCD Corrections and EFT

- SM QCD corrections sometimes applied to BSM terms
  - Can be OK, in some cases
  - Not always, for example: beware of giant k-factors when correcting LO EFT predictions for diboson

Giant k-factors



Slide by Jonas Lindert

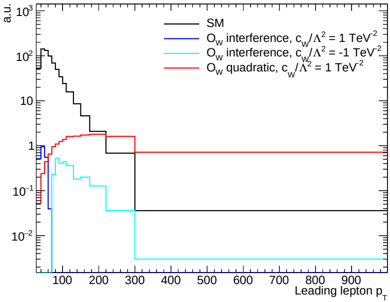
- NLO QCD/LO=2-5! ("giant K-factor")
  - at large pTV1: VV is dominated by V+jets (w/ soft V radiation)
- NNLO QCD uncertainty: 5-10%
- NLO EW/LO=-40-50%
- O(1) difference in

$d\sigma^{(N)NLO}_{QCD+EW}$ vs. $d\sigma^{(N)NLO}_{QCD\times EW}$

pTV1

Importance of Quadratic Terms

- Interference of SM and dim6 amplitudes helicity suppressed in diboson (in particular for $Q_W = \epsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$) [1609.06312]
- Furthermore: quadratic term grows more strongly with energy than naively expected



$\mathcal{O}_i$	$\sigma_{SM\times dim_6}/(g_{SM}^4/E^2)$	$\sigma_{dim_6^2}/(g_{SM}^4/E^2)$
F^3	$\frac{c_1}{g_{SM}} \frac{m_W^2}{\Lambda^2}$	$\frac{c_1^2}{g_{SM}^2} \frac{E^4}{\Lambda^4}$
$\phi^2 F^2$	$\frac{c_2}{g_{SM}^2} \frac{m_W^2}{\Lambda^2}$	$\frac{c_2^2}{g_{SM}^4} \frac{m_W^2 E^2}{\Lambda^4}$
$(\phi D \phi)^2$	$\frac{c_3}{g_{SM}^2} \frac{m_W^2}{\Lambda^2}$	$\frac{c_3^2}{g_{SM}^4} \frac{m_W^4}{\Lambda^4}$
$\bar\psi\gamma\psi\,\phi D\phi$	$\frac{c_4}{g_{SM}^2} \frac{E^2}{\Lambda^2}$	$\frac{c_4^2}{g_{SM}^4} \frac{E^4}{\Lambda^4}$

- In tails, essentially no sensitivity to interference
- Improvements possible:
  - Less suppression for VV+jets
  - Different observables?
- Similar situation in VBS: limits driven by quadratic terms

In the future: (more) global fits?

- UV theories introduce large number of non-zero EFT coefficients, affecting many processes $\Rightarrow$ should constrain SM EFT in global fit
- Initial scope of global fit not entirely clear for SM measurements
  - Measurements to be included: going beyond aTGCs?
  - What is a good set of operators to constrain?
  - Where do we gain when combining with top or Higgs measurements?
  - How to include EW precision data? Where can we improve on it?
- Models and tools exists to start endeavour
  - Warsaw basis includes all dimension six operators
  - Implemented in SMEFTsim, partially also in SMEFT@NLO
  - Useful MC generator features make simulation feasible: e.g. MadGraph reweighting and interference integration

Possible Global Fit Strategy (for SM measurements)

- Use SMEFTsim LO model (LO)
  - Focus on dimension six, Warsaw basis
  - LO: Keep things simple
- Rely on unfolded measurements where possible
  - Standard way to present SM physics results anyway
  - Reduces need for CPU expensive detector simulation
- Fit both linear and linear+quadratic terms
  - Both seems to be of interest, effect of quadratic at least as uncertainty
  - Quadratic terms increase simulation effort significantly

Case for Fit by Experimental Collaborations

If published unfolded measurements used, why EFT fits in experimental collaborations? (all information available outside)

- We know our measurements best
- Can guide measurements strategy
- Resources available
- Makes sure all relevant information is published

Potentially Relevant Operators

- Warsaw basis operators (omitting most four-fermion operators)

$1 : X^3$	
Q_G	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$
$Q_{\widetilde{G}}$	$f^{ABC} \widetilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$
Q_W	$\epsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$
$Q_{\widetilde{W}}$	$\epsilon^{IJK} \widetilde{W}_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$

$2 : H^6$	
Q_H	$(H^\dagger H)^3$

$3 : H^4 D^2$	
$Q_{H\Box}$	$(H^\dagger H)\Box(H^\dagger H)$
Q_{HD}	$\left(H^\dagger D_\mu H\right)^* \left(H^\dagger D_\mu H\right)$

$5 : \psi^2 H^3 + \text{h.c.}$	
Q_{eH}	$(H^\dagger H)(\bar{l}_p e_r H)$
Q_{uH}	$(H^\dagger H)(\bar{q}_p u_r \widetilde{H})$
Q_{dH}	$(H^\dagger H)(\bar{q}_p d_r H)$

Affect aTGC

Affect Vff

$4 : X^2 H^2$	
Q_{HG}	$H^\dagger H\, G_{\mu\nu}^A G^{A\mu\nu}$
$Q_{H\widetilde{G}}$	$H^\dagger H\, \widetilde{G}_{\mu\nu}^A G^{A\mu\nu}$
Q_{HW}	$H^\dagger H\, W_{\mu\nu}^I W^{I\mu\nu}$
$Q_{H\widetilde{W}}$	$H^\dagger H\, \widetilde{W}_{\mu\nu}^I W^{I\mu\nu}$
Q_{HB}	$H^\dagger H\, B_{\mu\nu} B^{\mu\nu}$
$Q_{H\widetilde{B}}$	$H^\dagger H\, \widetilde{B}_{\mu\nu} B^{\mu\nu}$
Q_{HWB}	$H^\dagger \tau^I H\, W_{\mu\nu}^I B^{\mu\nu}$
$Q_{H\widetilde{W}B}$	$H^\dagger \tau^I H\, \widetilde{W}_{\mu\nu}^I B^{\mu\nu}$

$6 : \psi^2 X H + \text{h.c.}$	
Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r)\tau^I H W_{\mu\nu}^I$
Q_{eB}	$(\bar{l}_p \sigma^{\mu\nu} e_r) H B_{\mu\nu}$
Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r)\widetilde{H}\, G_{\mu\nu}^A$
Q_{uW}	$(\bar{q}_p \sigma^{\mu\nu} u_r)\tau^I \widetilde{H}\, W_{\mu\nu}^I$
Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r)\widetilde{H}\, B_{\mu\nu}$
Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) H\, G_{\mu\nu}^A$
Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r)\tau^I H\, W_{\mu\nu}^I$
Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r) H\, B_{\mu\nu}$

$7 : \psi^2 H^2 D$	
$Q_{Hl}^{(1)}$	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{l}_p \gamma^\mu l_r)$
$Q_{Hl}^{(3)}$	$(H^\dagger i \overleftrightarrow{D}^I_\mu H)(\bar{l}_p \tau^I \gamma^\mu l_r)$
Q_{He}	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{e}_p \gamma^\mu e_r)$
$Q_{Hq}^{(1)}$	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{q}_p \gamma^\mu q_r)$
$Q_{Hq}^{(3)}$	$(H^\dagger i \overleftrightarrow{D}^I_\mu H)(\bar{q}_p \tau^I \gamma^\mu q_r)$
Q_{Hu}	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{u}_p \gamma^\mu u_r)$
Q_{Hd}	$(H^\dagger i \overleftrightarrow{D}_\mu H)(\bar{d}_p \gamma^\mu d_r)$
Q_{Hud} + h.c.	$i(\widetilde{H}^\dagger D_\mu H)(\bar{u}_p \gamma^\mu d_r)$

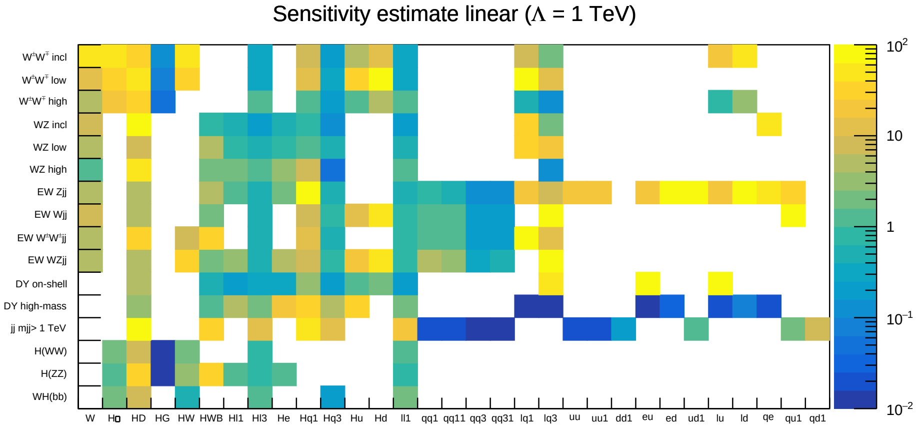
$8 : (\bar{L}L)(\bar{L}L)$	
Q_{ll}	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$
$Q_{qq}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$
$Q_{qq}^{(3)}$	$(\bar{q}_p \gamma_\mu \tau^I q_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$
$Q_{lq}^{(1)}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_t)$
$Q_{lq}^{(3)}$	$(\bar{l}_p \gamma_\mu \tau^I l_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$

Affects qqll

- Not directly clear which operators (beyond Q_W) relevant for electroweak measurements

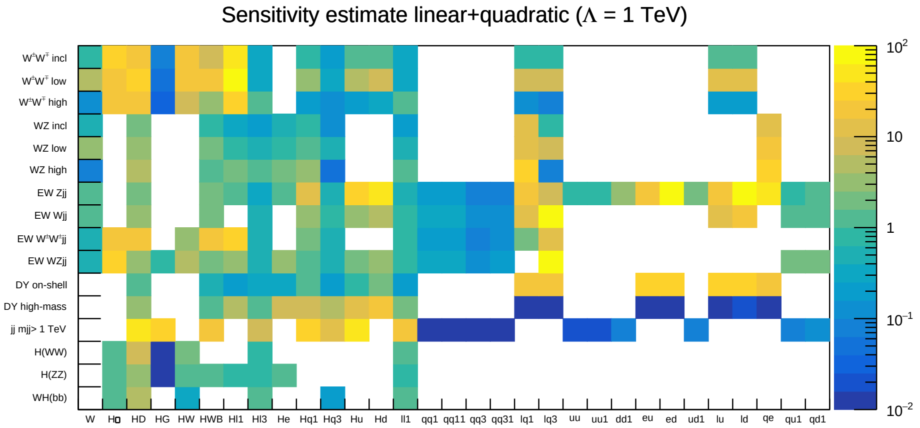
Sensitivity study

- Quick sensitivity study: calculated linear effects for different processes and fiducial regions with MadGraph
- Estimate sensitivity by comparing relative change in cross section with measurement uncertainty



Sensitivity study, including quadratic terms

- Adding also quadratic terms
  - Channels with good sensitivity to linear term not changed too much
  - Channels with previously bad sensitivity → slightly better sensitivity
  - Notable exception: Measurement of Q_W relies on quadratic term



Conclusion

- At the LHC: EFT fits in EW precision measurements (so far) synonymous with anomalous gauge coupling measurements
- Many measurements with 2015+16 data published, much improved sensitivity to anomalous couplings w.r.t. LHC Run 1 (and LEP)
- Analysis of full Run 2 dataset in progress
- Some obvious points where measurements and their interpretations can be improved
- Longer term: should move towards combinations and perform more global EFT fits