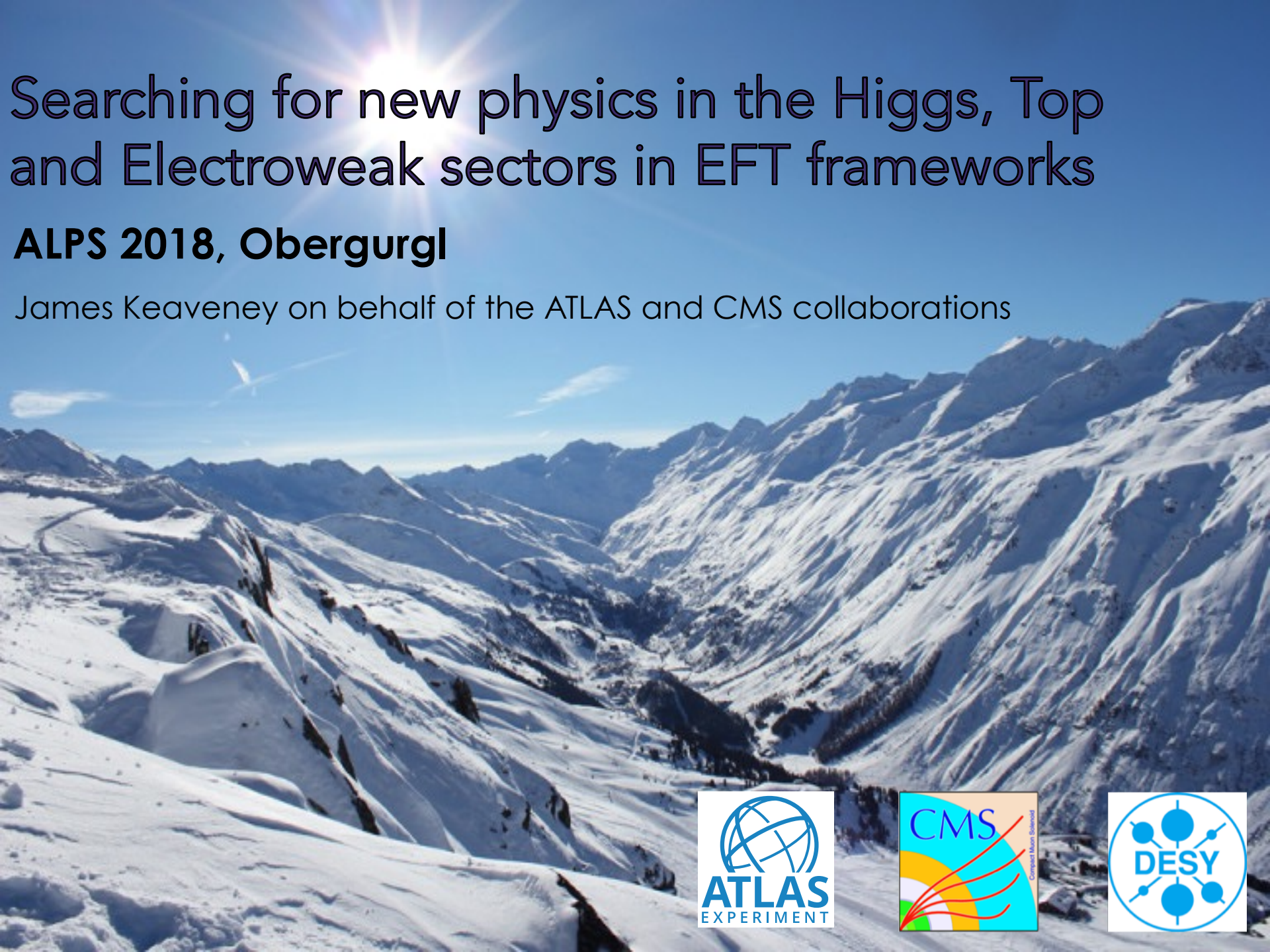
Searching for new physics in the Higgs, Top and Electroweak sectors in EFT frameworks

ALPS 2018, Obergurgl

James Keaveney on behalf of the ATLAS and CMS collaborations



this talk

- **why EFT?**
  - the basic idea
  - general theoretical and experimental considerations

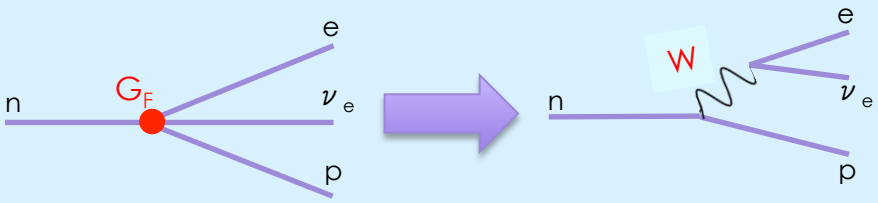
- **the status of efforts to constrain new physics in EFT**
  - a selection of **Higgs, Top and Electroweak** experimental results
    - focusing on 13 TeV measurements including EFT interpretation
    - also highlight some results that could be reinterpreted

- **outlook**

the search for new physics

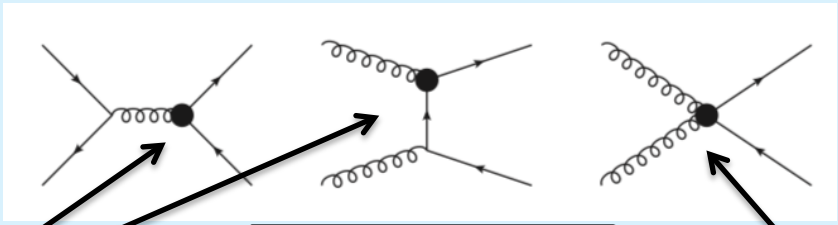
- no new BSM light particles observed at the LHC sofar...
- **why?** is the NP scale (Λ_{NP}) far larger than the LHC scale?
- extend the SM Lagrangian with higher-order operators to model NP @ Λ_{NP}

famous example of Fermi theory of Beta decay



$$\mathcal{L}_{SM}^{(6)} = \mathcal{L}_{SM}^{(4)} + \sum_i \frac{c_i}{\Lambda^2}\mathcal{O}_i + \dots$$

LHC example – O_{tG} affecting **rate and kinematics** of tt production



modified **gtt** vertices

arXiv:1505.08841

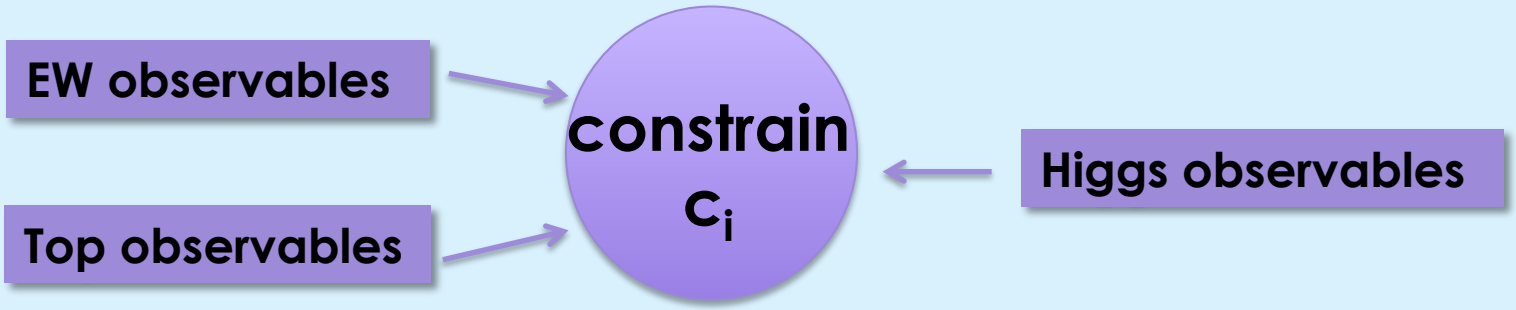
new **ggtt** vertex

searching for new particles → searching for new interactions

bump-hunting →determining c_i

why EFT?

- well-defined parameterisation of array of new physics
- model-independent
- but for EFT to make sense, *all* operators must be considered together
- **long term goal**: (semi) global analyses to simultaneously constrain many c_i using multiple measurements



- **theory considerations**
  - NLO vs LO
  - what operators to consider?
  - how to estimate theory uncertainties

thoroughly discussed in arXiv:1610.07922

sensitivity
detector level fit

Vs.

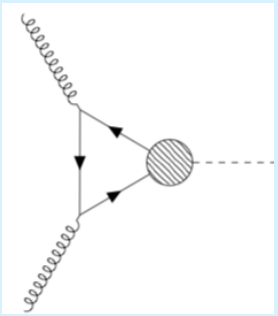
scalability
unfold to particle-level

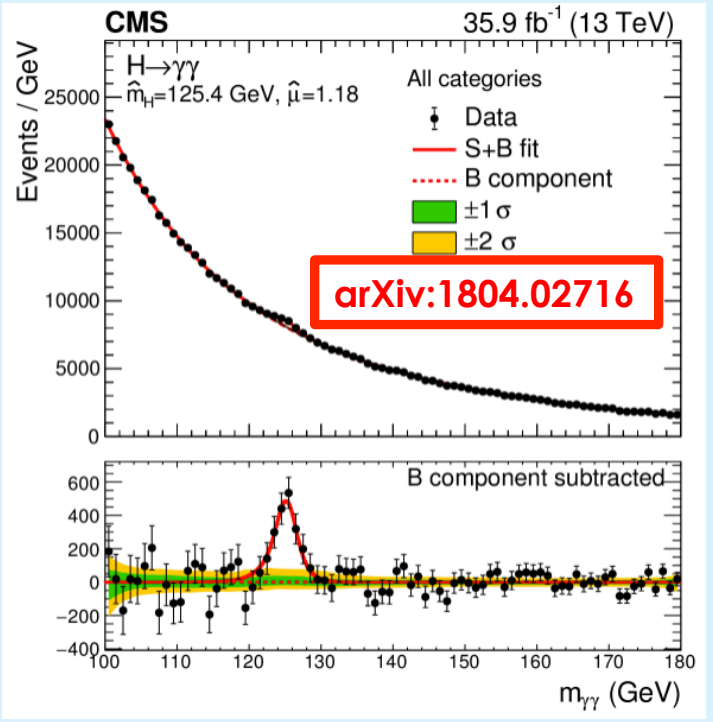
experiment-theory collaboration is crucial

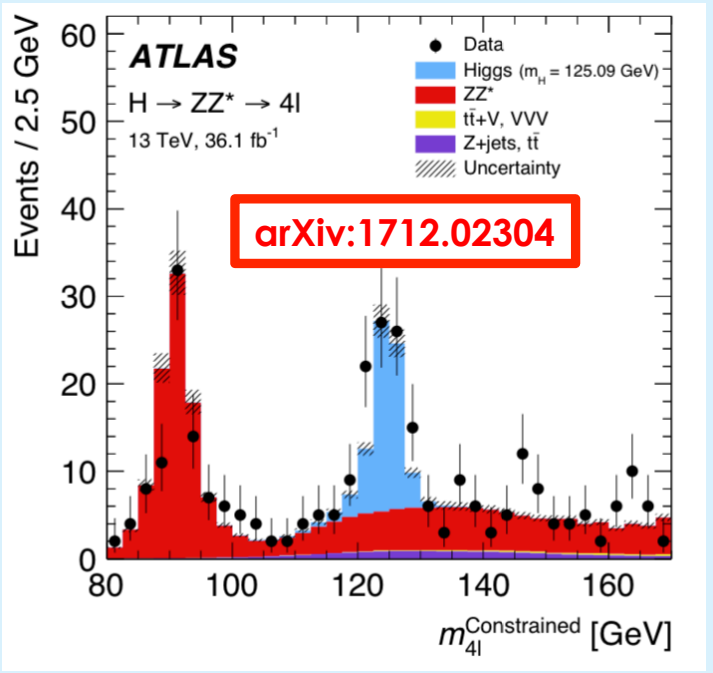
EFT in the Higgs sector

- **rich Higgs phenomenology at the LHC**
  - multiple production and decay modes
  - diverse experimental signatures
- **many observables to measure**
  - inclusive cross sections, fiducial rates,
  - rates by production mode, decay mode
- **large statistics ➔ detailed studies**
  - (double) differential cross sections
  - jet activity in higgs production
  - rare production modes accessible – ttH
- **observables affected by EFT operators**
  - rescaling of rates
  - deformations of distribution shapes

example
– operator modifies the top loop in gg Higgs production mode





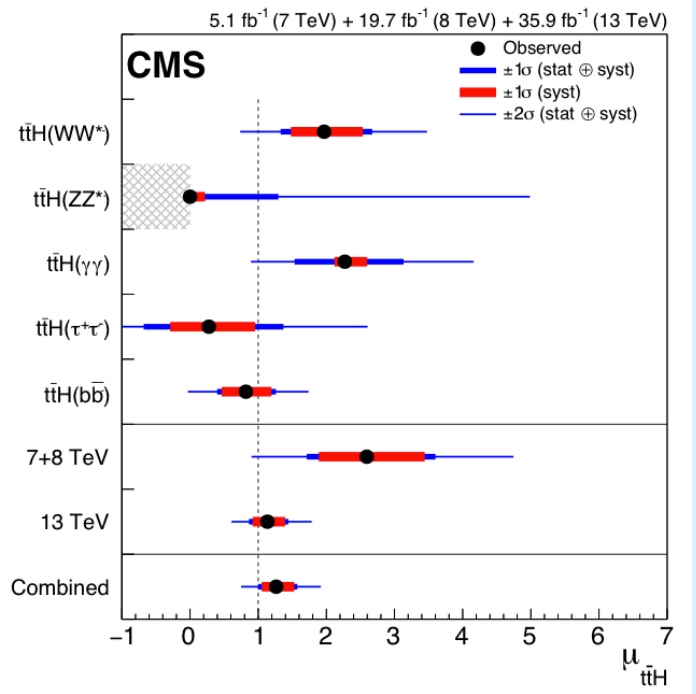


J. Phys.: Conf. Ser. **878** 012020

ttH observation

NEW arXiv:1804.02610

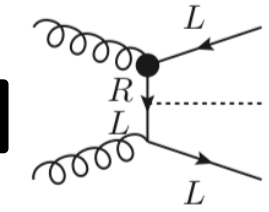
- **observation of ttH @ 7 + 8 + 13 TeV**
- significance across H decay channels and COM energies:
  - **5.2 σ (obs.) , 4.2 σ (exp.)**
- signal strength (relative to SM) $\mu = 1.26^{+0.31}_{-0.26}$
- signal strength in all decay channels consistent with SM
- important milestone – paves the way for more detailed measurements

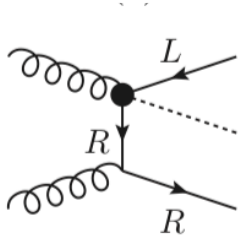


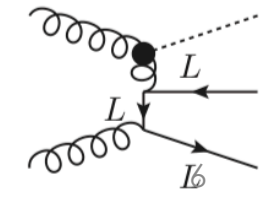
consequences for EFT

- dim-6 operators O_{hg}, O_{HG}, $O_{H,}$ O_{Hy} contribute to ttH production at tree-level
- $O_{H,}$ O_{Hy} affect ttH rate,
  - can already be constrained
- O_{hg}, O_{HG} alter distribution shapes
  - can be constrained with more detailed future measurements

arXiv:1205.1065



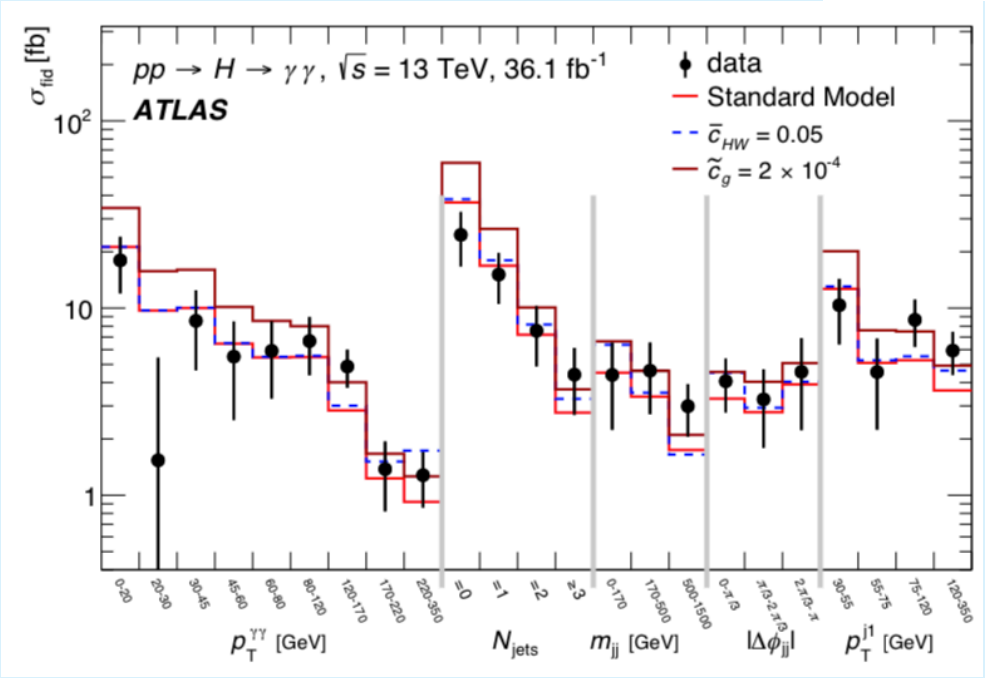




H -> $\gamma\gamma$

NEW arXiv:1802.04146

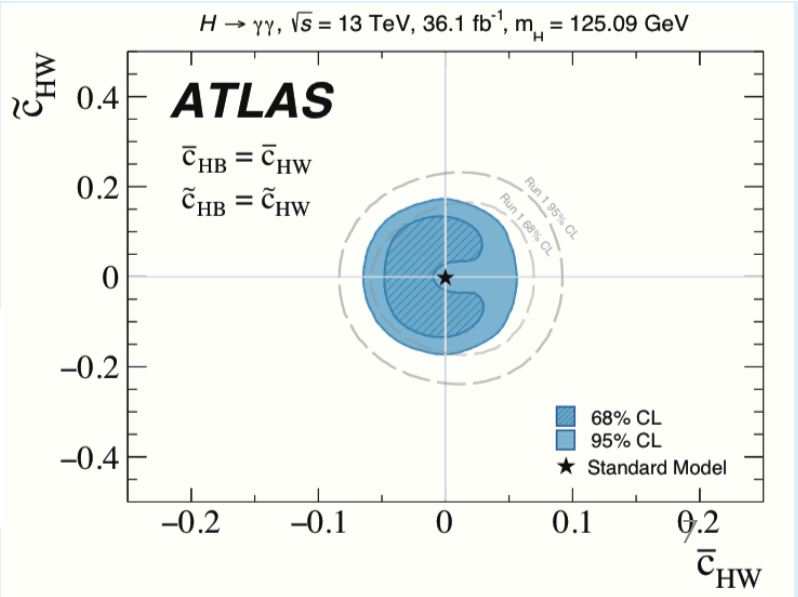
- **H-> $\gamma\gamma$ @ 13 TeV with 36.1fb^{-1}**
- large stats allow detailed measurements
- **signal strength** $\mu = 0.99^{+0.15}_{-0.14}$
- diff. results agree with SM



EFT reinterpretation

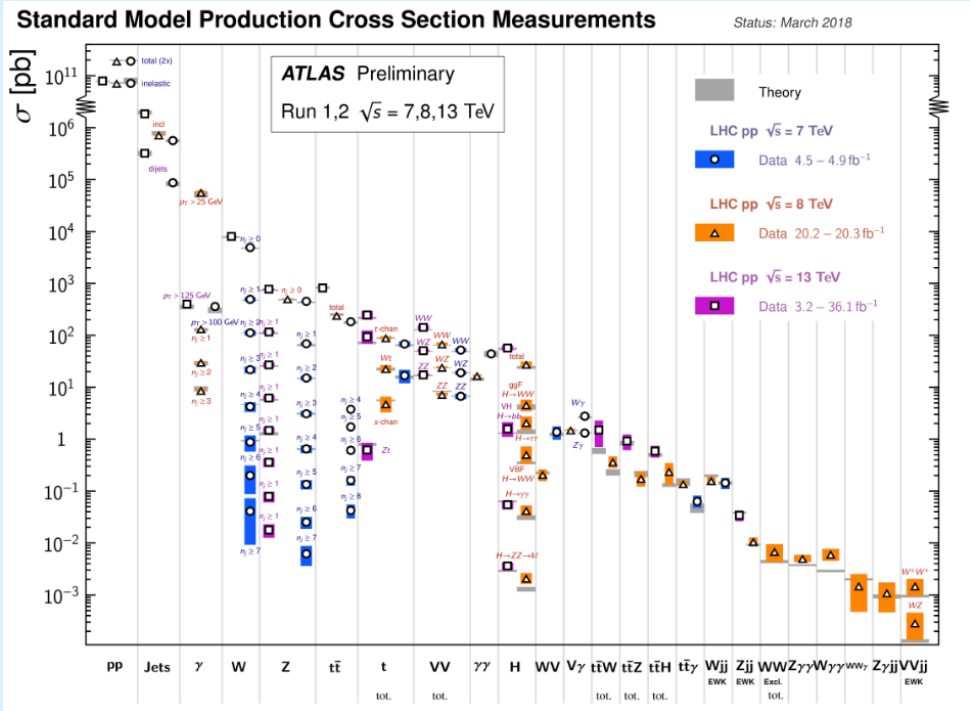
- dim-6 operators
  - O_g, $\tilde{O}_g$ ➔ ggH interactions
  - O_{HW}, $\tilde{O}_{HW}$ ➔ HWW, HZZ, HZγ interactions
    - shape + rate changes
  - O_{HB}, $\tilde{O}_{HB}$ ➔ HZZ, HZγ interactions
- diff. distributions constrain associated c_i

Coefficient	Observed 95% CL limit	Expected 95% CL limit
$\bar{c}_g$	$[-0.8, 0.1] \times 10^{-4} \cup [-4.6, -3.8] \times 10^{-4}$	$[-0.4, 0.5] \times 10^{-4} \cup [-4.9, -4.1] \times 10^{-4}$
$\tilde{c}_g$	$[-1.0, 0.9] \times 10^{-4}$	$[-1.4, 1.3] \times 10^{-4}$
$\bar{c}_{HW}$	$[-5.7, 5.1] \times 10^{-2}$	$[-5.0, 5.0] \times 10^{-2}$
$\tilde{c}_{HW}$	$[-0.16, 0.16]$	$[-0.14, 0.14]$



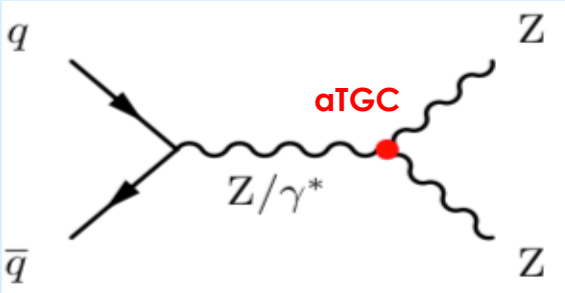
EFT in the electroweak sector

- **large stats. @ LHC allow EW studies in great detail**
- rare EW processes measured
  e.g. EW V+jets, EW ZZ, same sign WW
- sufficient stats for differential measurements in some cases
- subtle effects of NP in multiboson events



Triple-Gauge-Couplings (TGC)

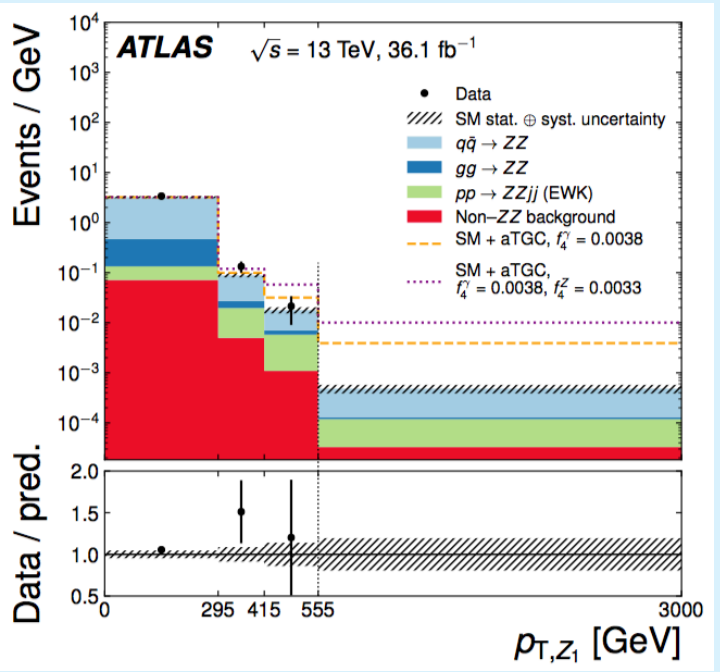
- fixed in SM
- aTGC in EFT increases cross section especially at large energy scales
- diboson and Higgs production are related in EFT



ZZ production

arXiv:1709.07703

- **inclusive and differential ZZ cross sections at 13 Tev with 36.1fb^{-1}**
- 4l final state
- differential cross sections for a range of observables

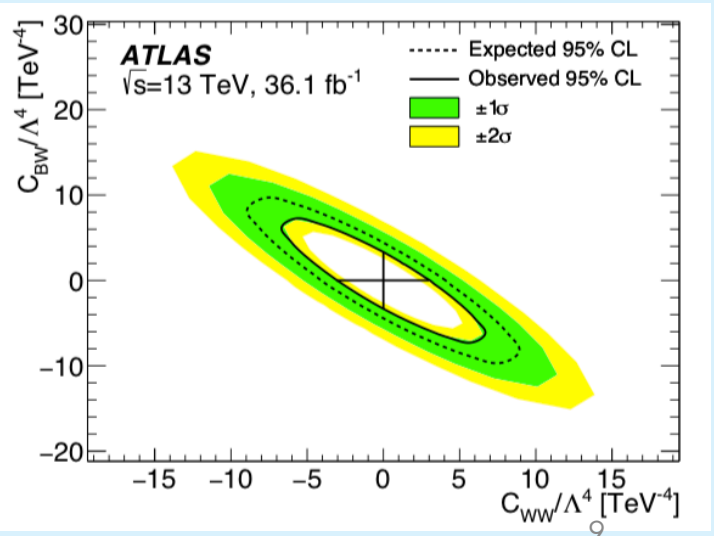


EFT reinterpretation

- aTGC vertex forbidden in SM
  - enhanced in BSM @ large energy scales
- **leading Z P_T** distribution constrains aTGC
- data consistent with no aTGC

EFT parameter	Expected 95% CL [TeV^{-4}]	Observed 95% CL [TeV^{-4}]
$C_{\tilde{B}W}/\Lambda^4$	−8.1, 8.1	−5.9 , 5.9
C_{WW}/Λ^4	−4.0, 4.0	−3.0 , 3.0
C_{BW}/Λ^4	−4.4, 4.4	−3.3 , 3.3
C_{BB}/Λ^4	−3.7, 3.7	−2.7 , 2.8

EFT coefficients constrained individually

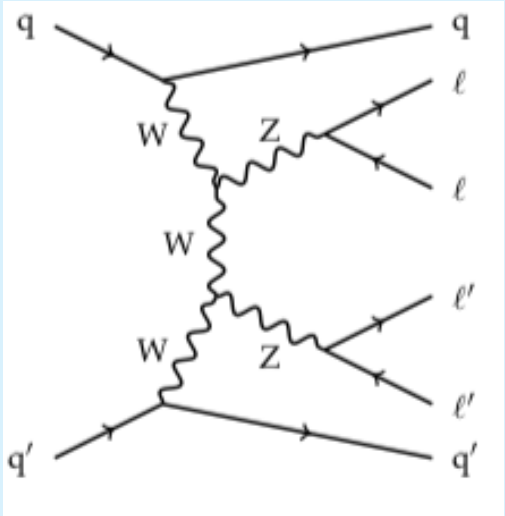


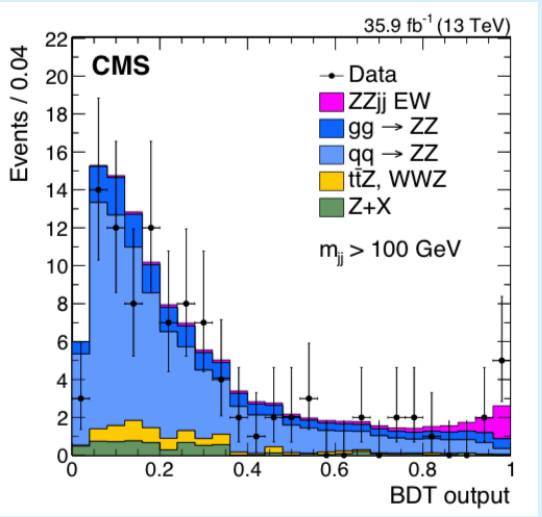
EFT coefficients constrained in pairs

EW ZZ production

arXiv:1708.02812

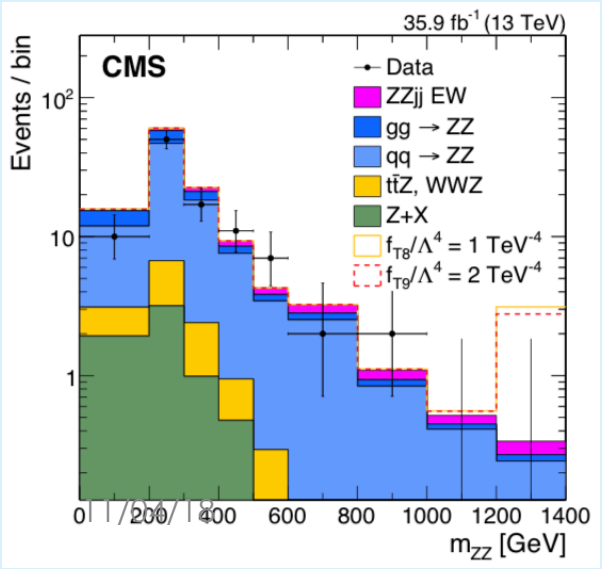
- **measurement of EW production of ZZ+2jets @ 13 TeV with 35.9fb^{-1}**
  - four lepton + 2jet final state
  - BDT discriminant distinguishes QCD and EW processes
  - signal extracted with 2.7 σ significance
  - fiducial cross section result consistent with SM





EFT reinterpretation

- m_{ZZ} distribution used to constrain EFT parameters f_{Ti}/Λ^4 describing aQGC



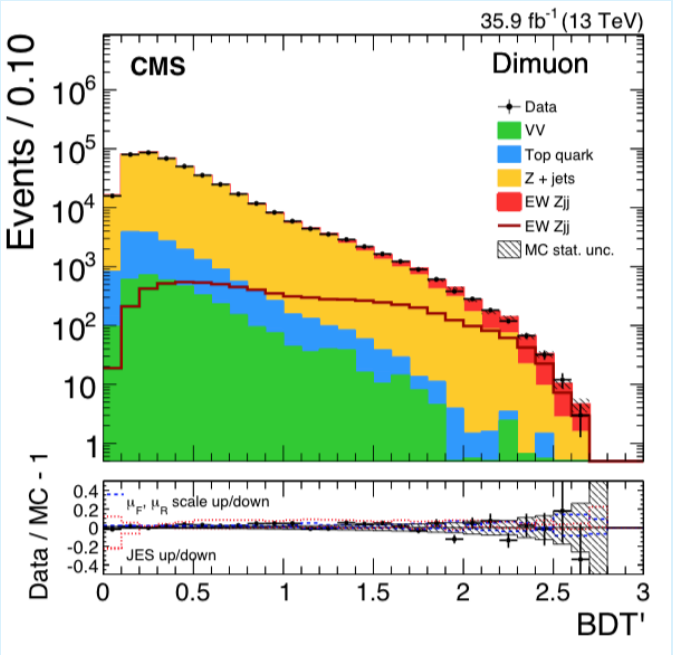
Coupling	Exp. lower	Exp. upper	Obs. lower	Obs. upper	Unitarity bound
f_{T0}/Λ^4	−0.53	0.51	−0.46	0.44	2.5
f_{T1}/Λ^4	−0.72	0.71	−0.61	0.61	2.3
f_{T2}/Λ^4	−1.4	1.4	−1.2	1.2	2.4
f_{T8}/Λ^4	−0.99	0.99	−0.84	0.84	2.8
f_{T9}/Λ^4	−2.1	2.1	−1.8	1.8	2.9

- coefficients constrained individually
  - most precise constraints to date
- first results on EW ZZ production

EW Z+2jet

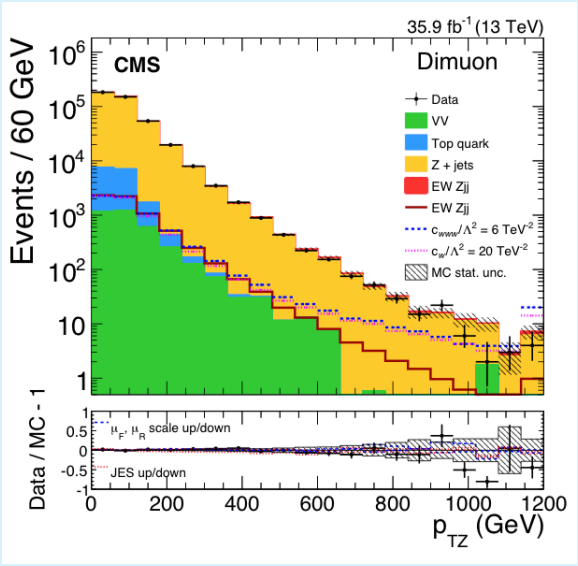
arXiv:1712.09814

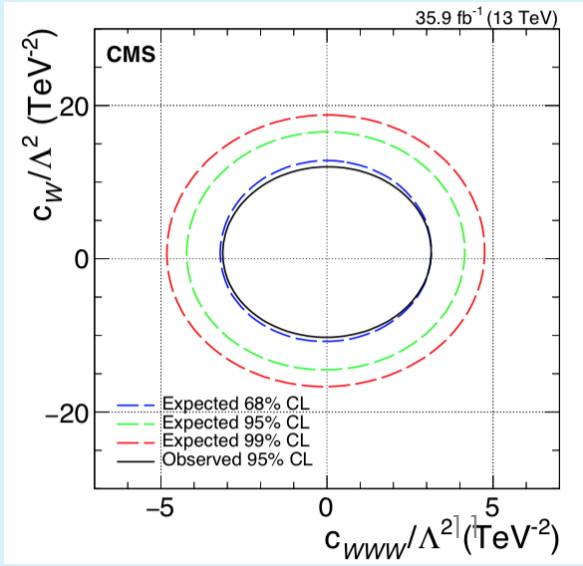
- **EW Z+2jet @ 13 TeV with 35.9fb^{-1}**
  - 2 lepton + 2 jet final state
  - BDT discriminant distinguishes Drell-Yan and signal
  - cross section extracted from fit to BDT
  - **result consistent with SM**



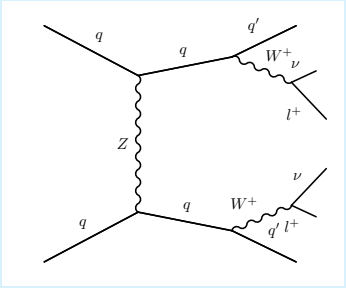
EFT reinterpretation

- P_{TZ} distribution used to constrain EFT parameters c_{WWW}/Λ^2, c_W/Λ^2
- results consistent with SM
- parameters constrained individually and in pair



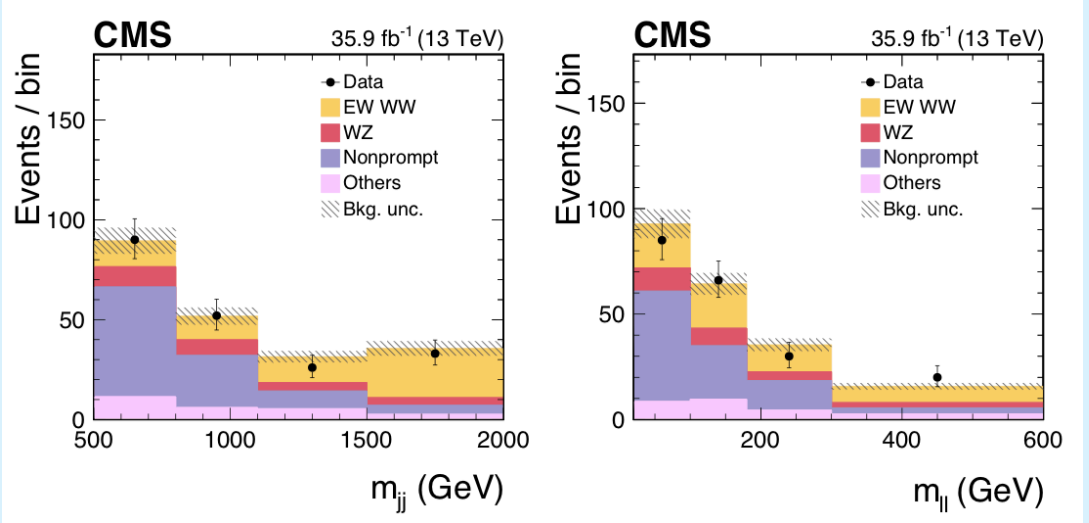


same sign WW



arXiv:1709.05822

- **measurement of same-sign WW @ 13 TeV with 35.9fb^{-1}**
  - 2 SS lepton + 2 jet + MET
  - signal extracted with 5.5 σ
  - **result consistent with SM**
  - **first observation of SS WW**

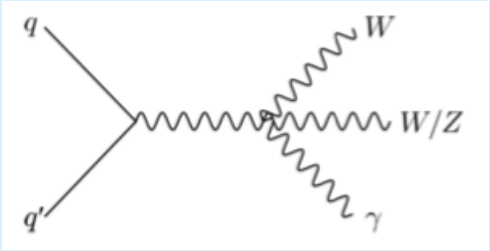


EFT reinterpretation

- m_{ll} distribution used to constrain dim-8 EFT operators
- independently constrain 9 c_i
- bounds improved by up to factor of 6 on previous results

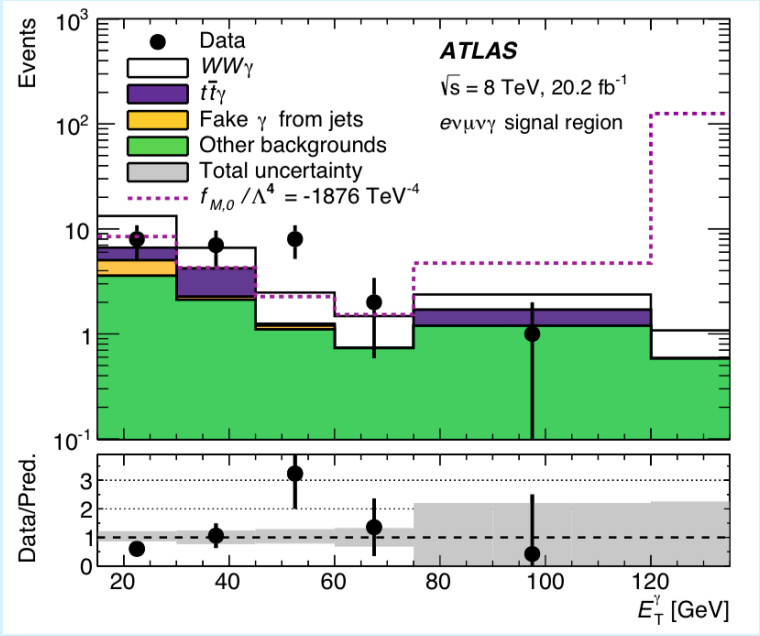
	Observed limits (TeV $^{-4}$)	Expected limits (TeV $^{-4}$)	Previously observed limits (TeV $^{-4}$)
f_{S0}/Λ^4	$[-7.7, 7.7]$	$[-7.0, 7.2]$	$[-38, 40]$, [11]
f_{S1}/Λ^4	$[-21.6, 21.8]$	$[-19.9, 20.2]$	$[-118, 120]$, [11]
f_{M0}/Λ^4	$[-6.0, 5.9]$	$[-5.6, 5.5]$	$[-4.6, 4.6]$, [36]
f_{M1}/Λ^4	$[-8.7, 9.1]$	$[-7.9, 8.5]$	$[-17, 17]$, [36]
f_{M6}/Λ^4	$[-11.9, 11.8]$	$[-11.1, 11.0]$	$[-65, 63]$, [11]
f_{M7}/Λ^4	$[-13.3, 12.9]$	$[-12.4, 11.8]$	$[-70, 66]$, [11]
f_{T0}/Λ^4	$[-0.62, 0.65]$	$[-0.58, 0.61]$	$[-0.46, 0.44]$, [37]
f_{T1}/Λ^4	$[-0.28, 0.31]$	$[-0.26, 0.29]$	$[-0.61, 0.61]$, [37]
f_{T2}/Λ^4	$[-0.89, 1.02]$	$[-0.80, 0.95]$	$[-1.2, 1.2]$, [37]

WWγ, WZγ



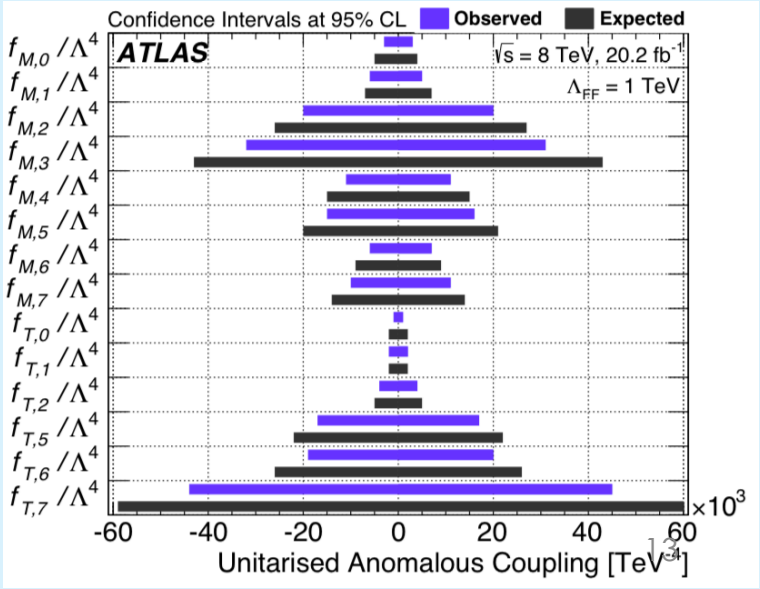
arXiv:1707.05597

- **search for WWγ WZγ production @ 8TeV with 20.2fb^{-1}**
  - e, mu, γ, 2 jet, MET
  - fiducial region defined to be optimal wrt aQGC effects
  - backgrounds determined from control regions
  - upper limit placed on cross sections in optimal fiducial region for BSM



EFT reinterpretation

- upper limit used to constrain dim-8 EFT
- aQGC affect fiducial rates
- independently constrain 14 c_i describing anomalous WWZγ and WWγγ
- results consistent with SM

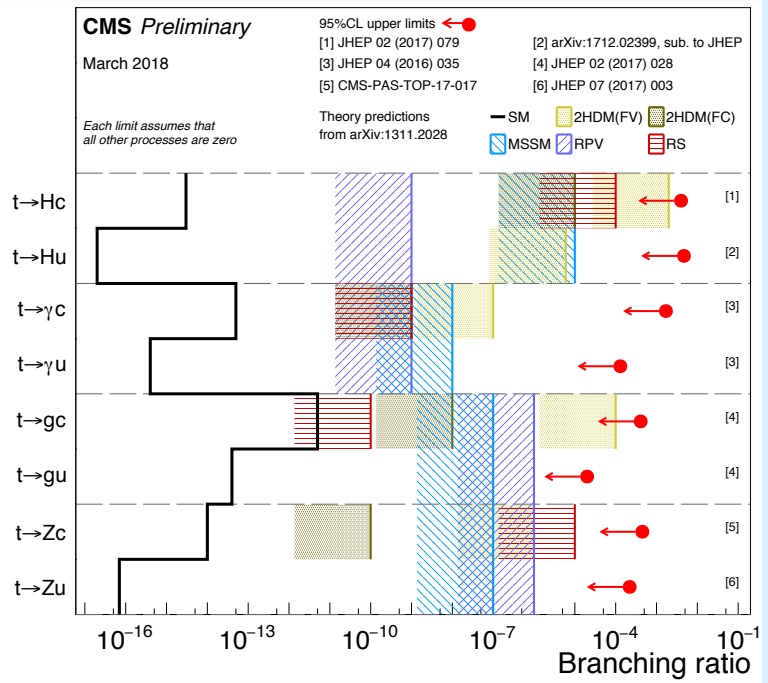


EFT in the top sector

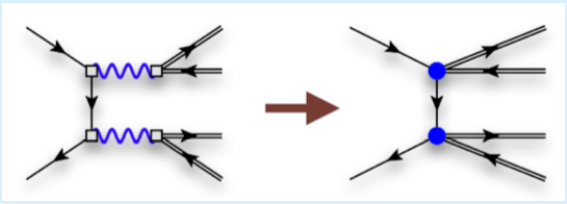
- **top observables at the LHC**
  - **tt** - > precision regime: percent level incl. cross section, multi-differential, jet spectra, charge asymmetries, spin correlations
  - **single-top** - > detailed diff measurements: t-channel, tW, tZq channels,
  - **ttV** -> observed, first inclusive measurements
  - **tttt** -> approaching observation
  - **FCNC decays** -> upper limits at the 10^{-5} level

- **EFT in top**
  - many top observables modified in EFT
  - both rate increase and shape deformations
  - interplay with Higgs sector in ttH, tttt and FCNC
  - NLO QCD EFT predictions for many observables already available
  - suggested "common standards" from theory experts

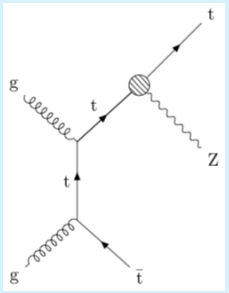
arXiv:1802.07237



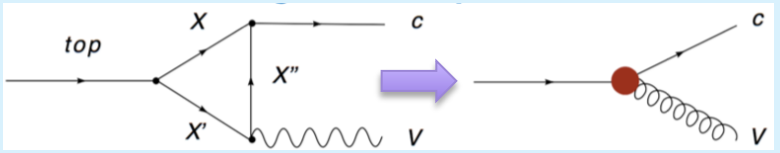
limits on FCNC branching rations @ 8TeV



BSM alters tttt rate in EFT

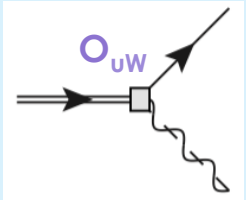


dim-6 operator in ttZ production



BSM loop modifying Br(FCNC) in EFT

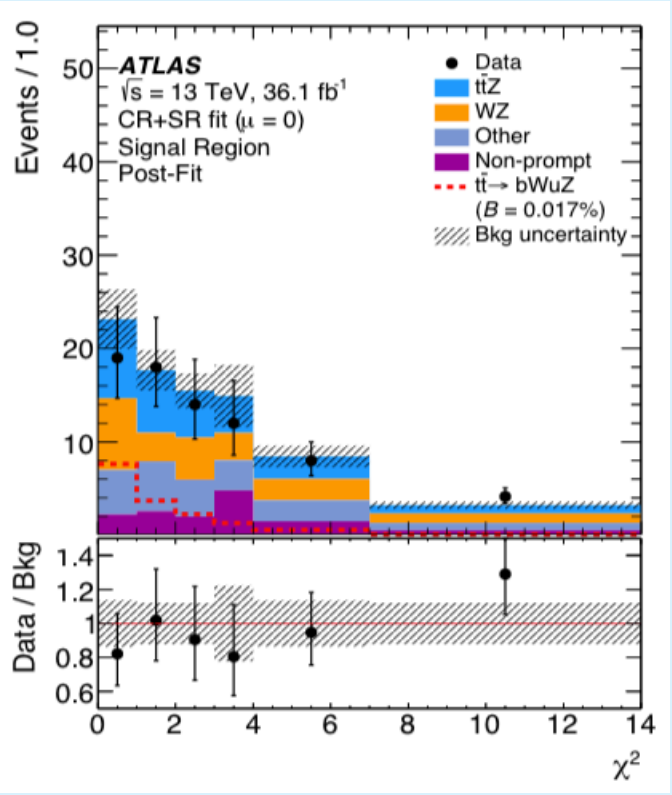
top FCNC decays



NEW arXiv:1803.09923

- **t->uZ, t->cZ decays @ 13 TeV with 36.1 fb^{-1}**
- anomalous t->uZ, t->cZ branching ratios is a feature of BSM scenarios

- **strategy**
  - tt events where one top decays to uZ, or cZ
  - require 3 leptons, 2 jets, 1 b-tag and MET
  - kin. reco. to find t->uZ or t->cZ decays
  - binned likelihood fit to kinematic distributions



result- no evidence of t->uZ, t->cZ decays

- **upper limits on branching ratios @ 95% CL**

  Br(t->uZ) < 1.7 x 10^{-4}

  Br(t->cZ) < 2.4 x 10^{-4}

Operator	Observed	Expected
$\lvert C_{uB}^{(31)}\rvert$	0.25	0.30
$\lvert C_{uW}^{(31)}\rvert$	0.25	0.30
$\lvert C_{uB}^{(32)}\rvert$	0.30	0.34
$\lvert C_{uW}^{(32)}\rvert$	0.30	0.34

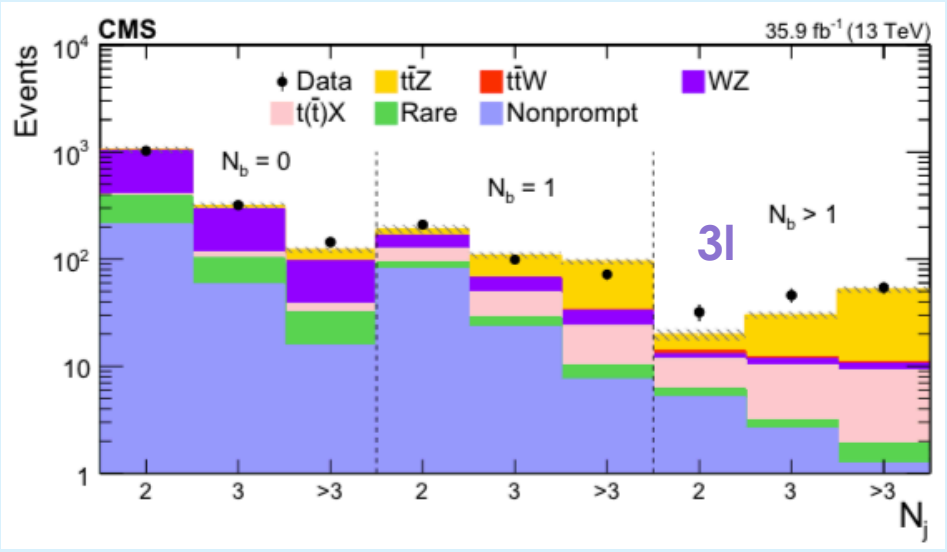
interpretation in TopFCNC EFT model arXiv:1412.5594

- assume only one operator has non-zero value

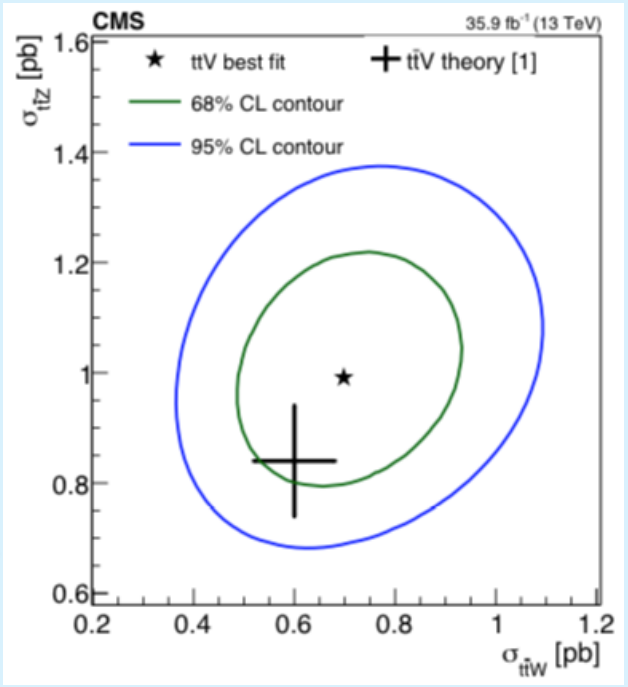
tt + V

arXiv:1711.02547

- **measurement of tt+Z and tt+W cross sections at 13 TeV with 35.9 fb^{-1}**
- tt + V rates increased in NP scenarios
  - same-sign dileptons -> optimal for tt+W
  - 3, 4 leptons -> optimal for tt+Z
  - BDT discriminator in same-sign dilepton



fit across categories to extract σ_{ttW} and σ_{ttZ}



- 8 c_i independently constrained
- results consistent with SM

Wilson coefficient	68% CL [TeV^{-2}]	95% CL [TeV^{-2}]
$\bar{c}_{uW}/\Lambda^2$	$[-1.6, 1.5]$	$[-2.2, 2.2]$
$\lvert\bar{c}_H/\Lambda^2 - 16.8\,\text{TeV}^{-2}\rvert$	$[3.7, 23.4]$	$[0, 28.7]$
$\tilde{c}_{3G}/\Lambda^2$	$[-0.5, 0.5]$	$[-0.7, 0.7]$
$\bar{c}_{3G}/\Lambda^2$	$[-0.3, 0.7]$	$[-0.5, 0.9]$
$\bar{c}_{uG}/\Lambda^2$	$[-0.9, -0.8]$ and $[-0.3, 0.2]$	$[-1.1, 0.3]$
$\lvert\bar{c}_{uB}/\Lambda^2\rvert$	$[0, 1.5]$	$[0, 2.1]$
$\bar{c}_{Hu}/\Lambda^2$	$[-9.2, -6.5]$ and $[-1.6, 1.1]$	$[-10.1, 2.0]$
$\bar{c}_{2G}/\Lambda^2$	$[-0.7, 0.4]$	$[-0.9, 0.6]$

summary and outlook

- EFT provides a model-independent framework in which to search for subtle hints of new physics at the LHC
- facilitates the simultaneous usage of Top, Higgs and EW data in *global* analysis
- global analysis becoming more feasible with wealth of Higgs, EW and Top measurements
- many analyses from ATLAS and CMS appearing with *stand-alone* EFT reinterpretations
  - **so far no hints of new physics**
- **particle-level, fiducial measurements crucial to move towards desired *global* analysis**