CMS measurements of EFT parameters with top quarks.

Nicolas TONON on behalf of the CMS Collaboration

TOP2020

17th September 2020

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

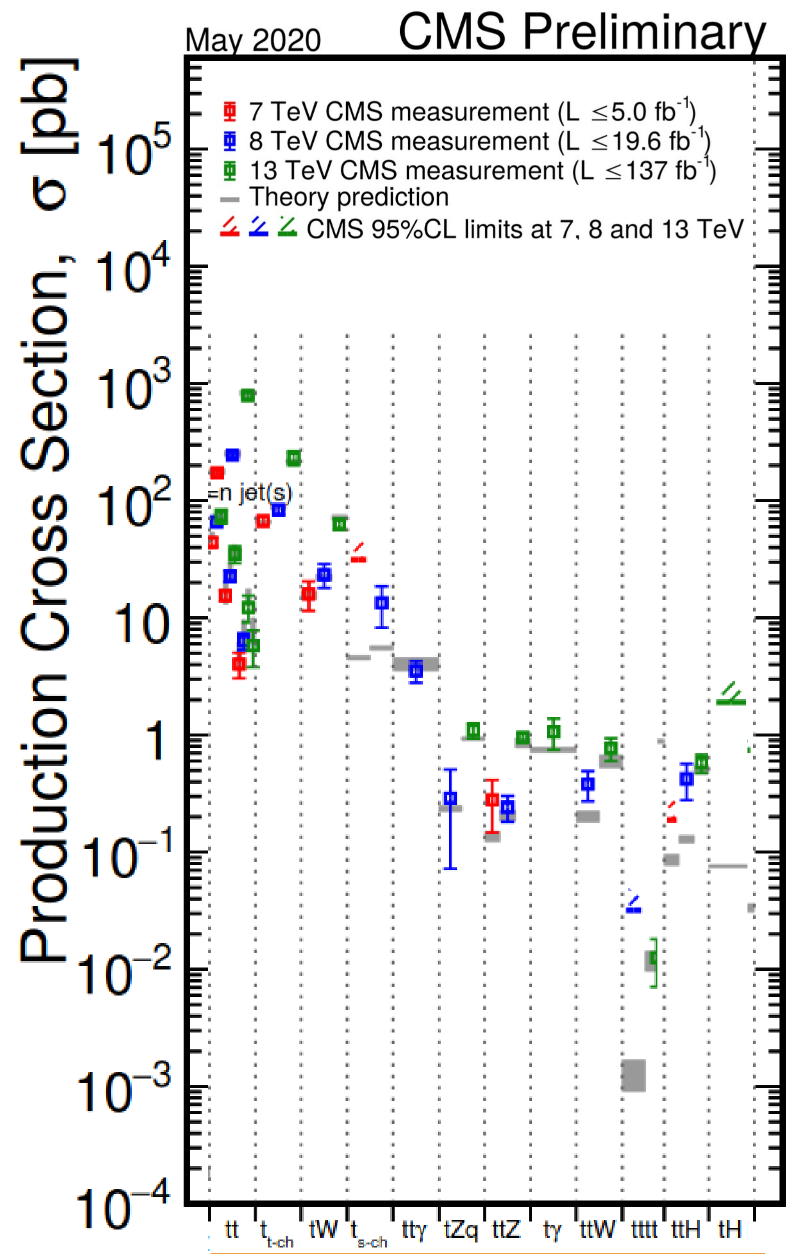
INTRODUCTION

- No clear sign of new physics (BSM) at LHC so far…
  - … and future accelerators in coming decades will increase $\int L$, not $\sqrt{s}$

- Many BSM theories predict sizeable deviations of top quark's couplings w.r.t. SM predictions

- Most of canonical top quark processes at LHC have reached precision era (systematics-limited)

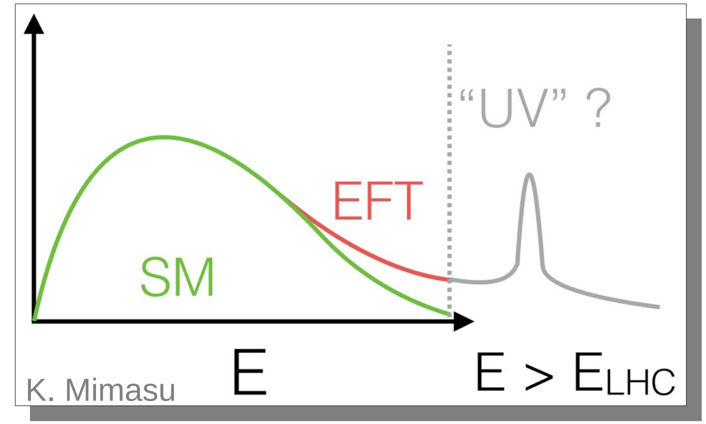
Motivates ambitious top physics programme to **reveal new physics** indirectly **through precision** measurements



Adapted from : http://cern.ch/go/pNj7

EFFECTIVE FIELD THEORY

- SM Effective Field Theory (SMEFT) framework allows for systematic & comprehensive interpretation of potential deviations in interactions between SM fields



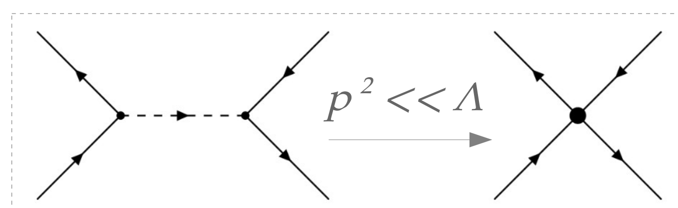
  - Assume new physics is characterized by (unknown) energy scale $\Lambda >> E_{LHC}$
  - Expand SM Lagrangian with higher-order operators
  - Model-independent → Can map experimental constraints to ~ any UV-complete model
  - Predicts well-defined deviation **patterns, correlated** in different observables/processes

Wilson coefficients (WC)
↔ coupling strengths

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_i \sum_{d>4} \frac{C_i^d}{\Lambda^{d-4}} \mathcal{O}_i^d$$

Higher-order operators

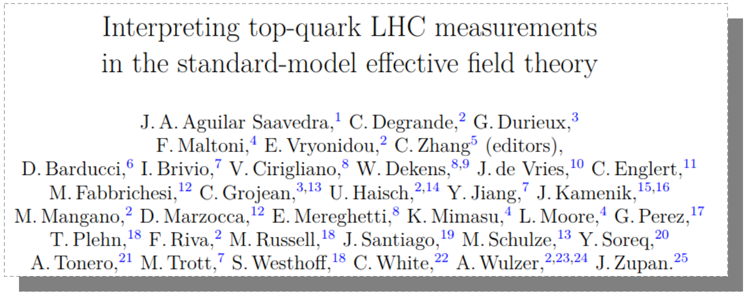
Famous EFT example : Fermi theory of beta decay (W boson → 4-fermions interaction)



→ Well-motivated, global approach to maximize discovery potential of massive BSM states at (HL)LHC

TOP EFT OPERATORS

[arXiv:1802.07237]


Interpreting top-quark LHC measurements
in the standard-model effective field theory

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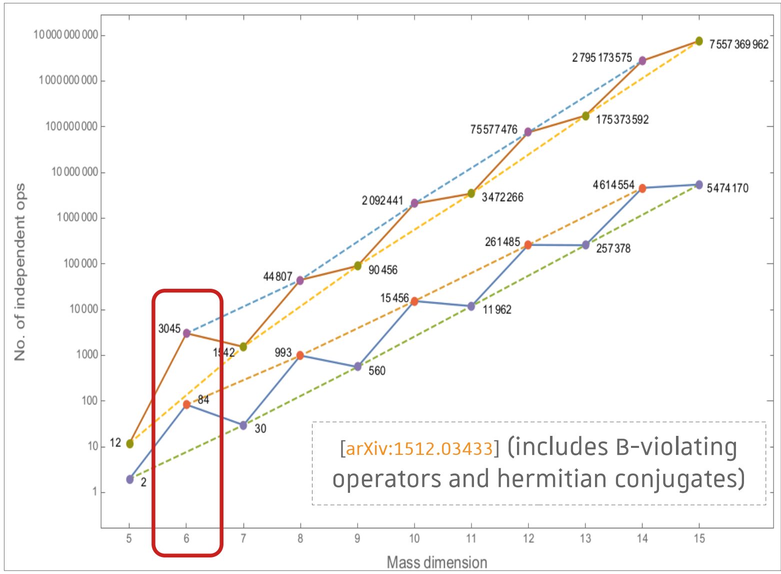
- Outcomes from fruitful EXP/TH collaboration within LHCTopWG summarized in EFT note
  - Provides extremely useful guiding principles, discusses assumptions, etc. → **Guideline for Top-EFT@LHC**
  - Use convenient **Warsaw basis** (complete, minimal set of operators)

- Restrict analysis to leading dimension-6
  - # operators grows exponentially with mass dimension
    → **$\mathcal{O}$(60) non-redundant operators involving top quark !**



- May further restrict huge param. space by making assumptions
  - *Ex* : Minimal Flavour Violation (MFV) hypothesis
    ↔ flavour/CP-violation only originates from SM-like Yukawa couplings

TOP EFT OPERATORS

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  - Provides extremely useful guiding principles, discusses assumptions, etc. → Guideline for Top-EFT@LHC
  - Use convenient Warsaw basis (complete, minimal set of operators)

- Restrict analysis to leading dimension-6
  - # operators grows exponentially with mass dimension
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- May further restrict huge param. space by making assumptions

- Top quark operators enter in numerous final states
  - Calls for global combinations of results

- Large ongoing effort by theorists to refine EFT predictions
  - Complete dim-8 operator basis [arXiv:2005.00008]
  - NLO simulation models
  - Study correlations/interferences, etc.

[arXiv:1901.05965]

Notation	Sensitivity at $\mathcal{O}(\Lambda^{-2})$ ($\mathcal{O}(\Lambda^{-4})$)								
	$t\bar{t}$	single-top	tW	tZ	$t\bar{t}W$	$t\bar{t}Z$	$t\bar{t}H$	$t\bar{t}t\bar{t}$	$t\bar{t}b\bar{b}$
OQQ1								✓	✓
OQQ8								✓	✓
OQt1								✓	✓
OQt8								✓	✓
OQb1									✓
OQb8									✓
Ott1								✓	
Otb1									✓
Otb8									✓
OQtQb1									(✓)
OQtQb8									(✓)
O81qq	✓				✓	✓	✓	✓	✓
O11qq	[✓]				[✓]	[✓]	[✓]	✓	✓
O83qq	✓	[✓]		[✓]	✓	✓	✓	✓	✓
O13qq	[✓]	✓		✓	[✓]	[✓]	[✓]	✓	✓
O8qt	✓				✓	✓	✓	✓	✓
O1qt	[✓]				[✓]	[✓]	[✓]	✓	✓
O8ut	✓					✓	✓	✓	✓
O1ut	[✓]					[✓]	[✓]	✓	✓
O8qu	✓					✓	✓	✓	✓
O1qu	[✓]					[✓]	[✓]	✓	✓
O8dt	✓					✓	✓	✓	✓
O1dt	[✓]					[✓]	[✓]	✓	✓
O8qd	✓					✓	✓	✓	✓
O1qd	[✓]					[✓]	[✓]	✓	✓
OtG	✓		✓		✓	✓	✓	✓	✓
OtW		✓	✓	✓					
ObW		(✓)	(✓)	(✓)					
OtZ				✓		✓			
Off		(✓)	(✓)	(✓)					
Ofq3		✓	✓	✓					
OpQM				✓		✓			
Opt				✓		✓			
Otp							✓		

- Quadratic EFT parameterization :

$$\mathcal{M} = \mathcal{M}_{SM} + \mathcal{M}_{EFT} = \mathcal{M}_{SM} + \sum_i c_i \cdot \mathcal{M}_i$$

$$\sigma \propto |\mathcal{M}^2| \propto \sum_{i,j=0}^{N} s_{ij} \cdot c_i \cdot c_j$$

WC

EFT APPROACHES IN CMS-TOP

- **Good scalability**
- **Easily combinable** in global fits beyond LHC
- Decouples experiment / theory
- ✗ **Treat all backgrounds SM-like**
- ✗ **Many assumptions**, overestimate uncertainties, missing all correlations, …

Post-measurement interpretation → Direct measurement at detector-level

- **Optimal sensitivity** to Wilson coefficients
- **Minimal assumptions**
- Can **probe EFT in all sensitive processes**
- In-situ constraint of systematics considering correlations
- Novel approach, less experience with combination

EFT APPROACHES IN CMS-TOP

Reinterpret inclusive measurement

- Wilson coeff. constrained using **straightforward EFT parameterization**
- Scalable & combinable
- **No MC EFT sample required**
- **Maximal assumptions**

Post-measurement interpretation

Direct measurement at detector-level

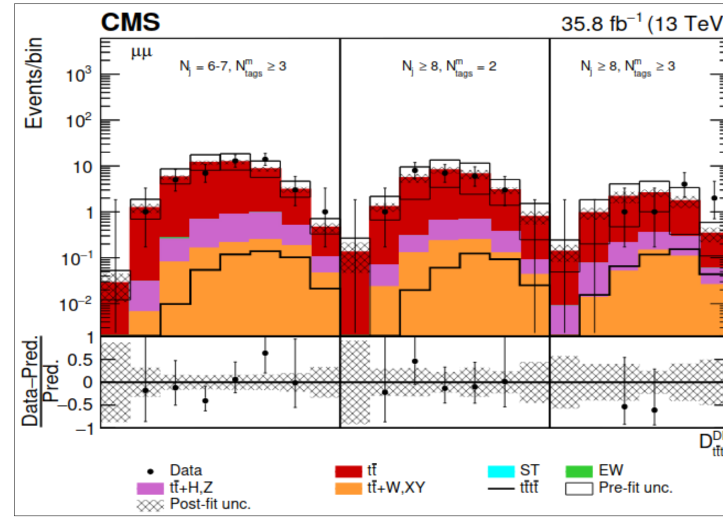
Inclusive

4 TOPS

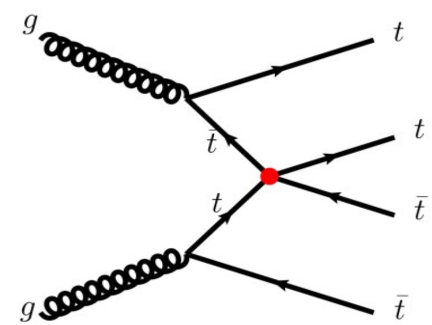
→ See talk by K. Schweiger

- Very rare process, not yet observed
  - σ(SM) = 9.2 fb, $\mathcal{O}(10^5)$ smaller than $t\bar{t}$ background
- Target 1ℓ and 2ℓ OS final states with jets (35.9 fb^{-1})
- BDTs to assign jets & isolate signal

Post-fit distributions of BDT-2l in eμ channel



- Results combined with same-sign 2ℓ + 3ℓ analysis
  - Observed limit = 3.6 σ(SM) / Observed significance = 1.4 s.d



- Highly sensitive to 4-heavy-quark operators
- Parameterization derived at gen-level :

$$\sigma_{t\bar{t}t\bar{t}} = \sigma^{\mathrm{SM}}_{t\bar{t}t\bar{t}} + \frac{1}{\Lambda^2}\sum_k C_k \sigma^{(1)}_k + \frac{1}{\Lambda^4}\sum_{j\leq k} C_j C_k \sigma^{(2)}_{j,k}$$

- 95 % CL upper limits derived on individual operators, marginalizing other operators

Operator	Expected C_k/Λ^2 (TeV^{-2})	Observed (TeV^{-2})
$\mathcal{O}^1_{tt}$	[−2.0, 1.9]	[−2.2, 2.1]
$\mathcal{O}^1_{QQ}$	[−2.0, 1.9]	[−2.2, 2.0]
$\mathcal{O}^1_{Qt}$	[−3.4, 3.3]	[−3.7, 3.5]
$\mathcal{O}^8_{Qt}$	[−7.4, 6.3]	[−8.0, 6.8]

10.1007/JHEP11(2019)082

EFT APPROACHES IN CMS-TOP

Reinterpret inclusive measurement

- Wilson coeff. constrained using straightforward EFT parameterization
- Scalable & combinable
- No MC EFT sample required
- Maximal assumptions

Post-measurement interpretation

Direct measurement at detector-level

Reinterpret unfolded differential measurement

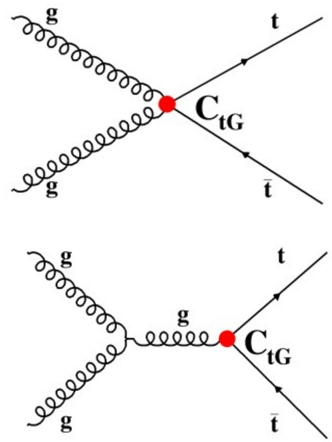
- Quantity(ies) sensitive to EFT are measured at particle/parton-level
- **Need differential MC EFT** at gen-level
- **Combinable** if bin correlations are provided
- Ignore EFT effects on acceptance/efficiency

TT → 2L DIFFERENTIAL

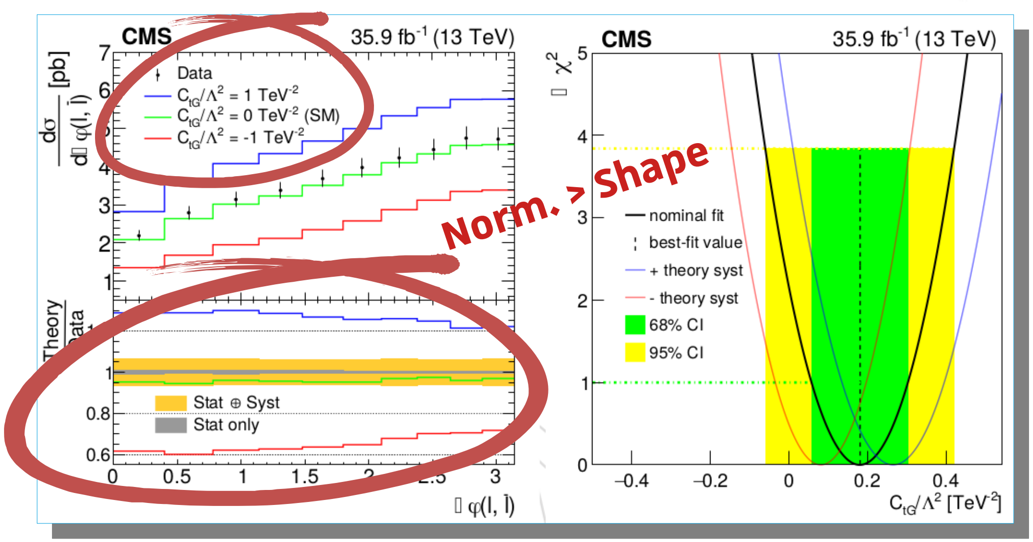
- 2ℓ OS + b-jets final states ($35.9\ fb^{-1}$)

- Differential $t\bar{t}$ cross section measurement as a function of kinematics of top quark, decay products, $t\bar{t}$, njets
  - Unfolded at parton- (full PS) & particle-level (fiducial PS)
  - Extract $t\bar{t}$ and leptonic charge asymmetries → EFT

- Small top chromomagnetic dipole moment (CMDM) predicted by SM, modified in 2HDM/SUSY/technicolor/…
  - Related to c_{tG} operator → Modifies yield, kinematics, spin structure



- EFT parameterized at gen-level at NLO QCD
  - Calculate $\Delta\Phi(\ell\ell) \leftrightarrow$ RIVET
  - LO → NLO : + ctG effect, – scale uncert.
  - Assume SM-like acceptance, k-factors (NLO → NNLO+NNLL), etc.

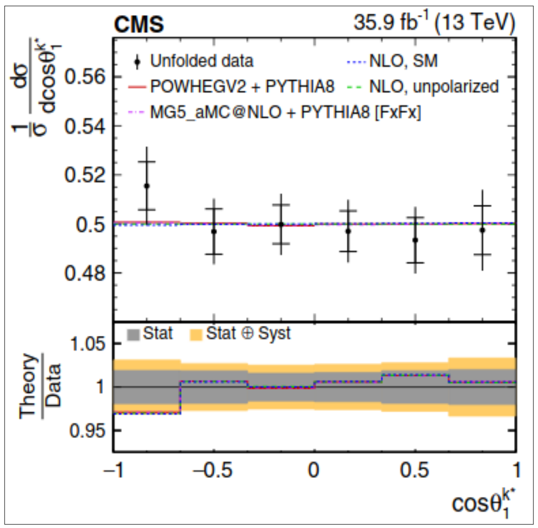


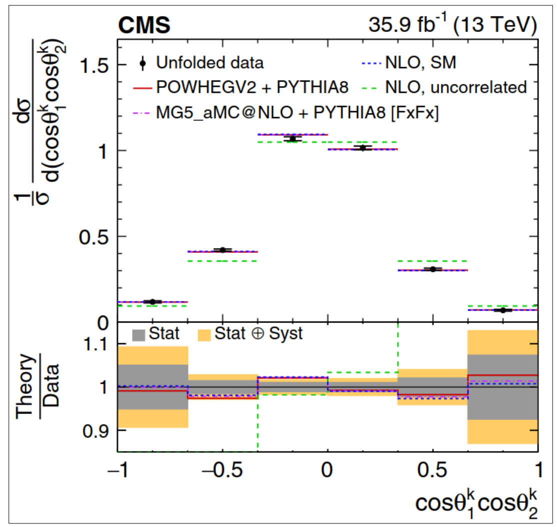
10.1007/JHEP02(2019)149

Unfolded diff. TT POLARIZATION & SPIN CORREL.

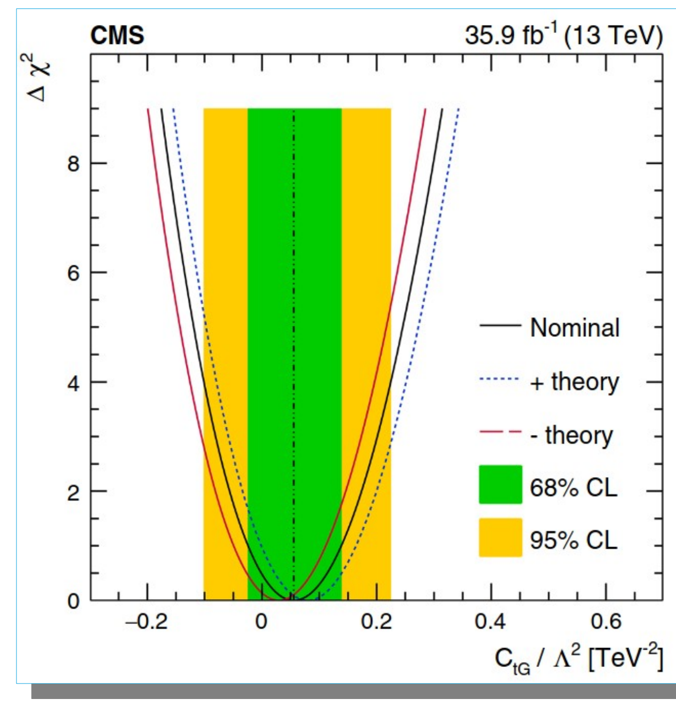
→ See talk by M. Kareem

- 2ℓ OS + b-jets final states ($35.9\ \mathrm{fb}^{-1}$)
- Differential $t\bar{t}$ cross section measurement as a function of polarization and spin correl. observables
  - Unfolded at parton-level, consistent with SM





- Similar parameterization & assumptions as previous analysis
- 95% CL limit on c_{tG} obtained from **simultaneous χ^2 fit to several differential spin distributions**
  - Stat./syst. correlation matrices determined for all bins
  - Sensitivity improved by ~ 30 % w.r.t. previous analysis



10.1103/PhysRevD.100.072002

EFT APPROACHES IN CMS-TOP

Reinterpret inclusive measurement

- Wilson coeff. constrained using straightforward EFT parameterization
- Scalable & combinable
- No MC EFT sample required
- Maximal assumptions

Hybrid measurement at detector-level

a) **Parameterize yields with SMEFT at gen-level,** translate to detector-level assuming SM shapes

Post-measurement interpretation

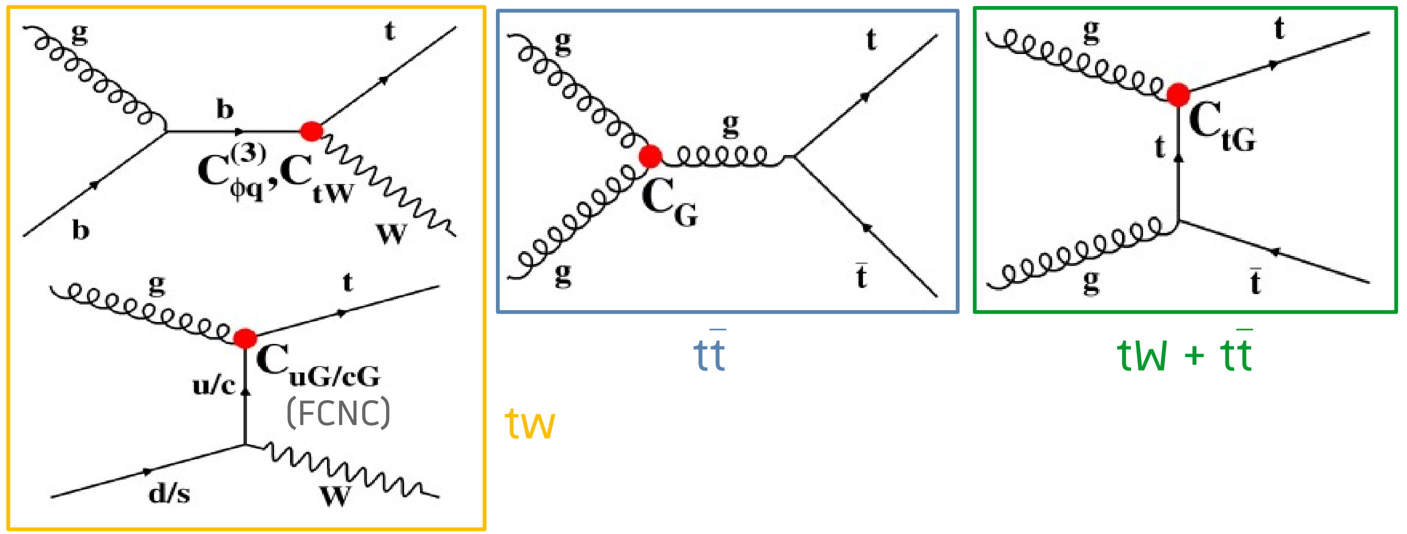
Direct measurement at detector-level

Reinterpret unfolded differential measurement

- Quantity(ies) sensitive to EFT are measured at particle/parton-level
- Need differential MC EFT at gen-level
- Combinable if bin correlations are provided
- Ignore EFT effects on acceptance/efficiency

BSM SEARCH IN TT/TW→2L

- 2ℓ channel (35.9 fb^{-1})
- Event categorized by :
  - lepton channel
  - jet/bjet multiplicities

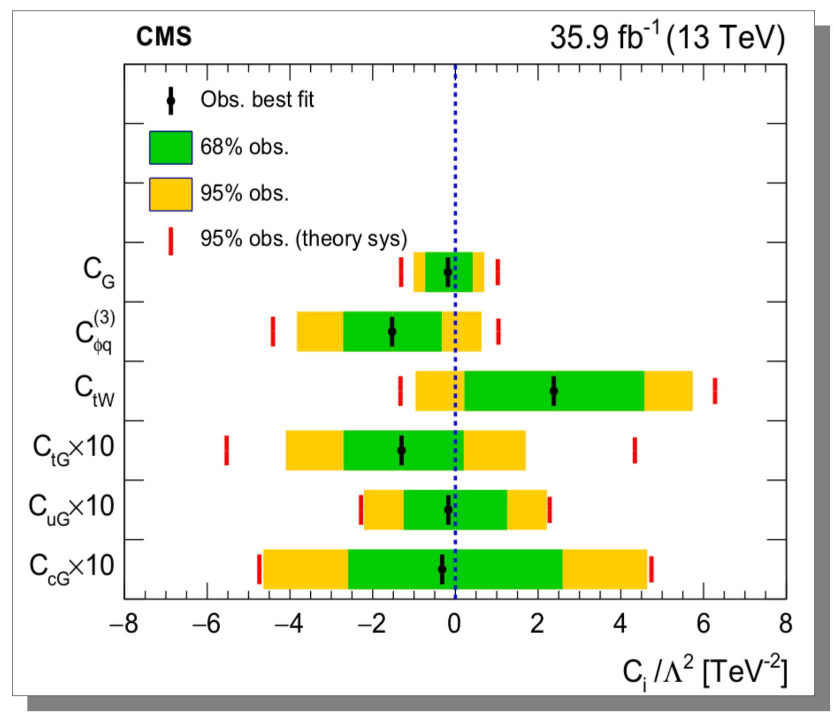


- Train dedicated neural networks to :
  - Isolate the tW process (+ sensitivity)
  - Distinguish FCNC signatures from SM

- EFT contributions estimated at gen-level, and extrapolated to detector-level

- Extract individual limits from simultaneous fit to yields or NN distributions in all categories

- First step towards more global fits



10.1140/epjc/s10052-019-7387-y

EFT APPROACHES IN CMS-TOP

Reinterpret inclusive measurement

- Wilson coeff. constrained using straightforward EFT parameterization
- Scalable & combinable
- No MC EFT sample required
- Maximal assumptions

Hybrid measurement at detector-level

a) **Parameterize yields with SMEFT at gen-level,** translate to detector-level assuming SM shapes

b) **Reweight distributions as SMEFT/SM at gen-level,** translate to detector-level under SM assumption

Post-measurement interpretation

Direct measurement at detector-level

Reinterpret unfolded differential measurement

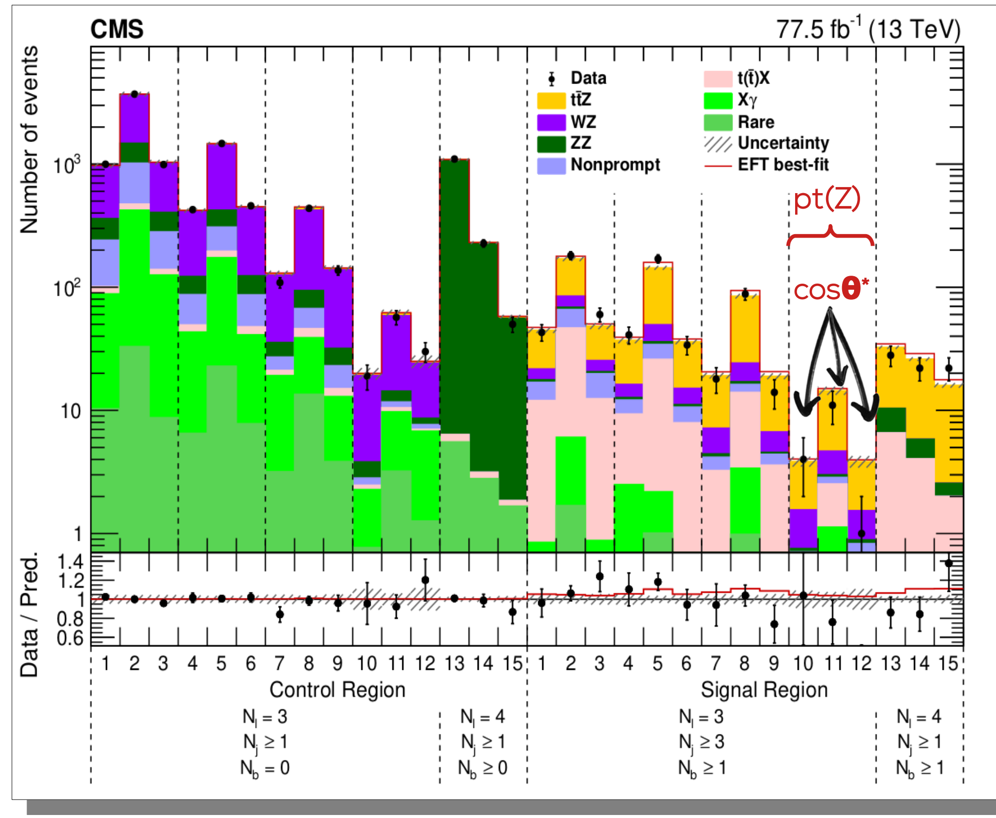
- Quantity(ies) sensitive to EFT are measured at particle/parton-level
- Need differential MC EFT at gen-level
- Combinable if bin correlations are provided
- Ignore EFT effects on acceptance/efficiency

TTZ DIFFERENTIAL

→ See talk by R. Ospanov

10.1007/JHEP03(2020)056

- $3\ell + 4\ell$ channels (77.5 fb^{-1})
- Event categorized by :
  - # of leptons
  - jet/bjet multiplicities



- Procedure :

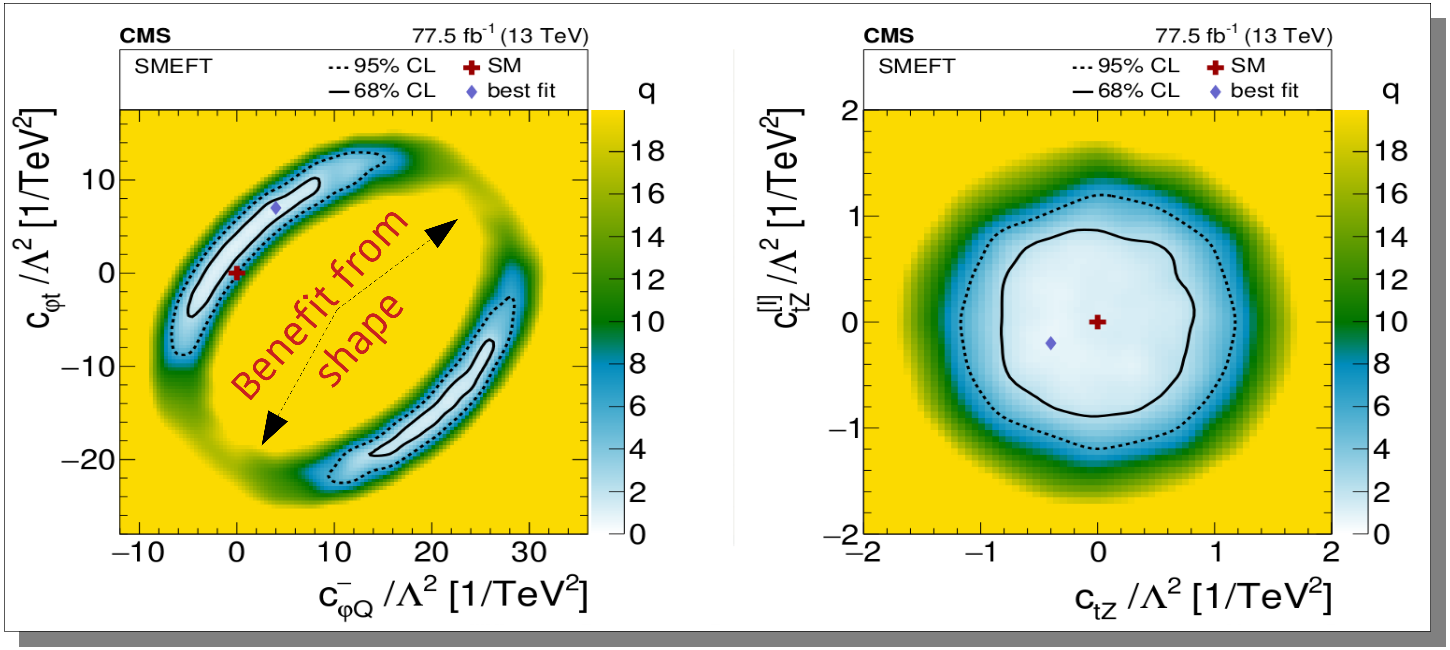
a) **Produce gen-level samples** for SM & SMEFT (LO), in fine grid of EFT parameter space

b) **Calculate weights SMEFT/SM** in bins of both observables, before event selection

c) **Apply weights to detector-level** (NLO) SM sample to emulate EFT contributions
+ verify closure

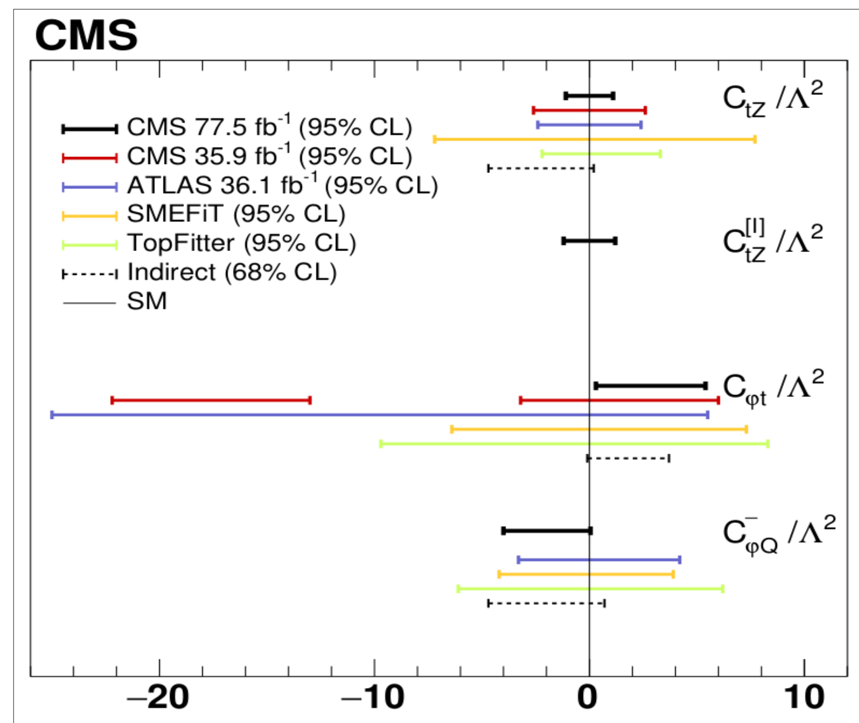
- Inclusive and differential measurements of σ(ttZ) found in good agreement with SM
- pt(Z) and cos(θ_Z*) are sensitive to BSM
  - Almost uncorrelated

Hybrid TTZ DIFFERENTIAL



10.1007/JHEP03(2020)056

- Extract 1D/2D limits on 4 independent top-Z operators
- Anomalous coupling interpretation :
  most stringent direct constraints on
  EWK dipole moment & top-Z vector couplings
- ~ 20 % improvement due to shape information



EFT APPROACHES IN CMS-TOP

Reinterpret inclusive measurement

- Wilson coeff. constrained using straightforward EFT parameterization
- Scalable & combinable
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Hybrid measurement at detector-level

a) Parameterize yields with SMEFT at gen-level, translate to detector-level assuming SM shapes

b) Reweight distributions as SMEFT/SM at gen-level, translate to detector-level under SM assumption

Post-measurement interpretation → Direct measurement at detector-level

Reinterpret unfolded differential measurement

- Quantity(ies) sensitive to EFT are measured at particle/parton-level
- Need differential MC EFT at gen-level
- Combinable if bin correlations are provided
- Ignore EFT effects on acceptance/efficiency

Direct EFT measurement

- **~ no SM assumption**
- Consider **EFT in all sensitive processes**
  → Need full SMEFT sample for each
- Simultaneous fit to multiple regions

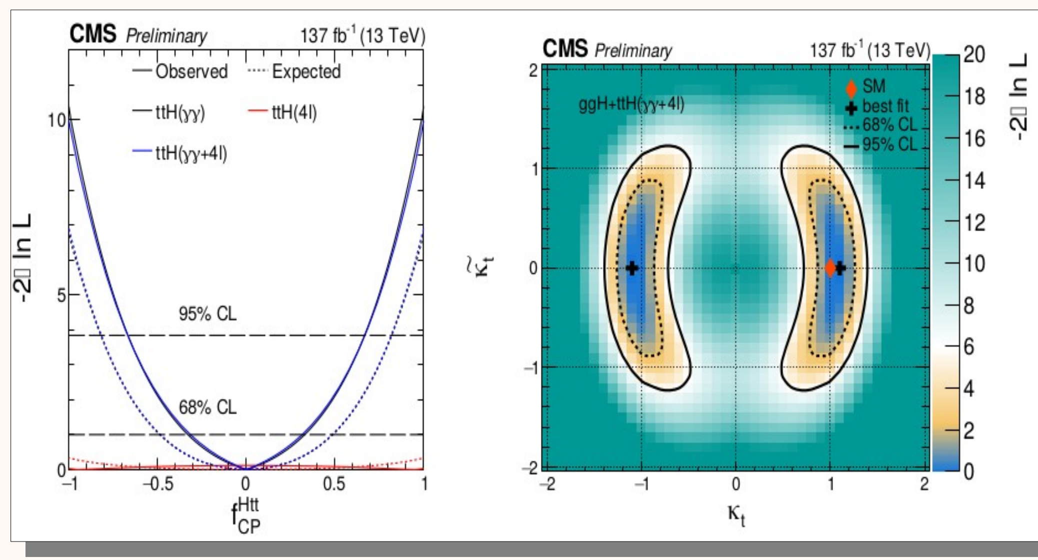
ANOMALOUS COUPLINGS IN H→4L

- Constraints on **anomalous Higgs couplings** to bosons & fermions in $H \rightarrow 4\ell$ events (137 fb^{-1})
  - Consider both production and decay
  - Simultaneous measurement of up to 9 couplings (5 HVV + 2 Hgg + 2 Htt)
    - → Requires arbitrary assumptions about their relationships
  - Results interpreted within EFT framework in terms of corresponding operators (Higgs basis)

[arXiv:1610.07922]

- Full detector simulation of all kinematic effects from BSM (event weights from JHUGen, LO & NLO)
- Enhance analysis sensitivity using discriminants from Matrix Element Method (MELA package)

- Constrain top-H coupling in ttH process
  - Combination with $H \rightarrow \gamma\gamma$, assuming no BSM particles enter the loop



CMS-PAS-HIG-19-009

FIT TO MULTIPLE T(T)X PROCESSES

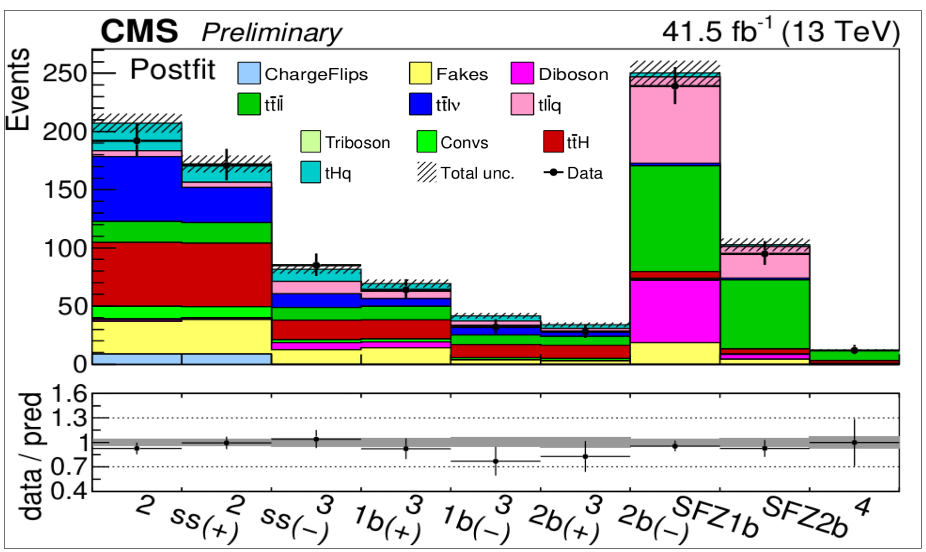
→ See talk by B. Yates

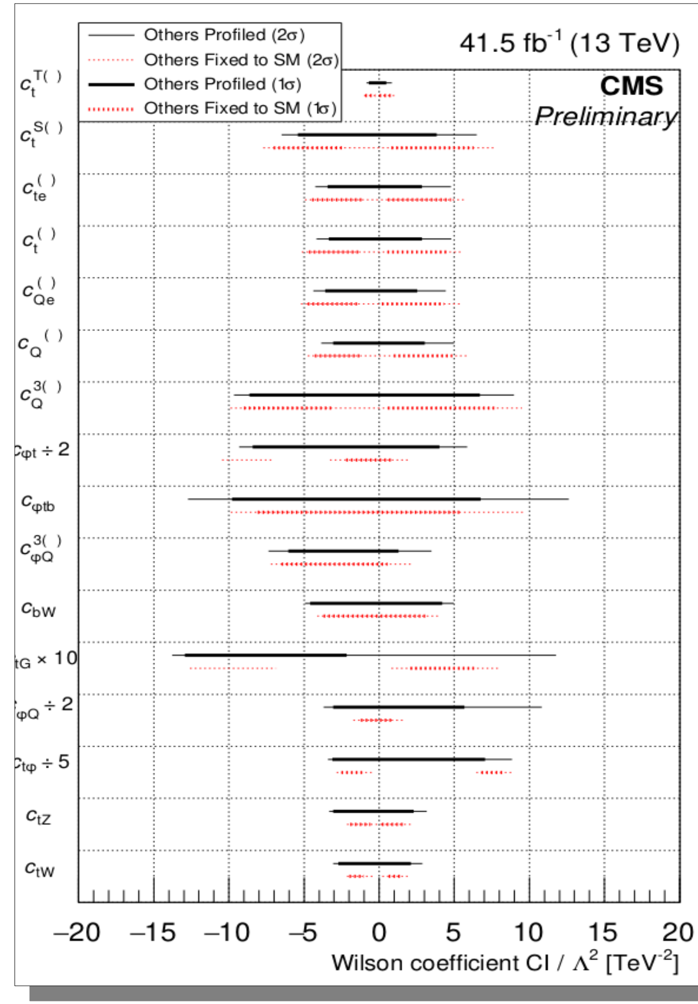
- Targets [ttll, ttlv, tllq, ttH, tHq] processes at once in the [2l SS, 3l, 4l + bjets] channels (41.5 fb^{-1})

- Full detector simulation of SMEFT samples
  - Per-event weights parameterized on *all* relevant WCs

- Categories based on lepton, jet and bjet multiplicities
  → Enhance sensitivity in different processes / operators

- Constrain 16 relevant EFT operators
  - For each WC, either profile the others or set them to 0





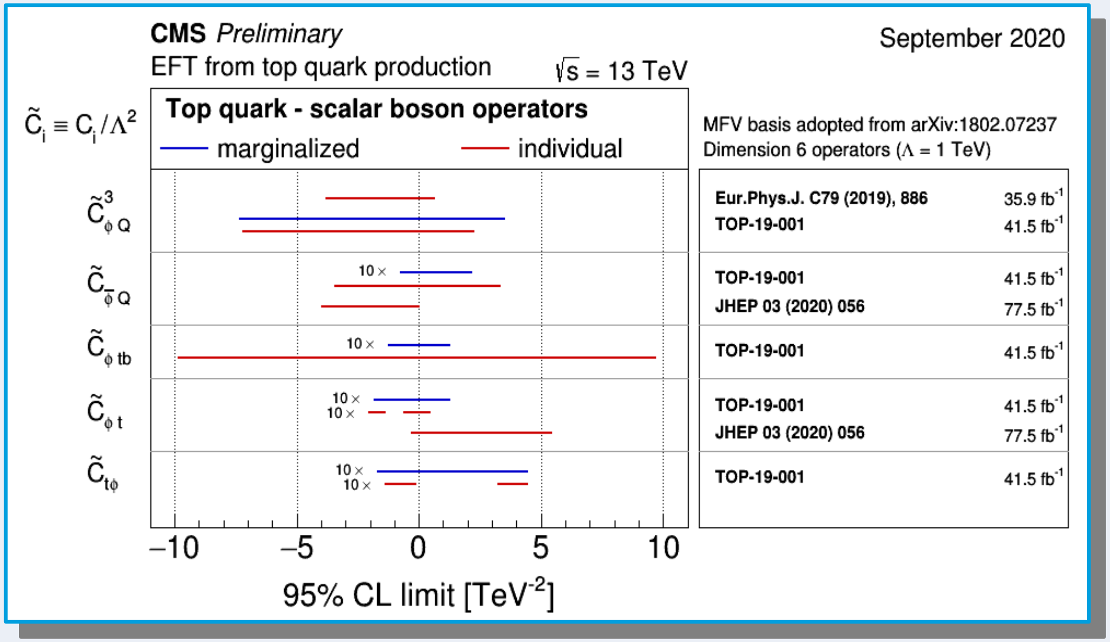
CMS-PAS-TOP-19-001

Important step towards direct measurements accounting for EFT in all sensitive processes

SUMMARY

- Top physics @ LHC has entered precision differential era for good
  - EFT measurements represent a key part of future physics programme & LHC legacy
- CMS Top-EFT group is building upon its expertise to continuously improve its strategies
  - Already numerous publications employing **different approaches** with pros/cons
- Discussion with community and theorists is key !
  - **Guidelines** from theorists within LHCTopWG **well received** by the collaborations
    - CMS has taken its first step towards global analysis
  - Floor is open for **further exchanges of ideas** in view of future developments

- Exciting developments and innovative analyses are forthcoming !

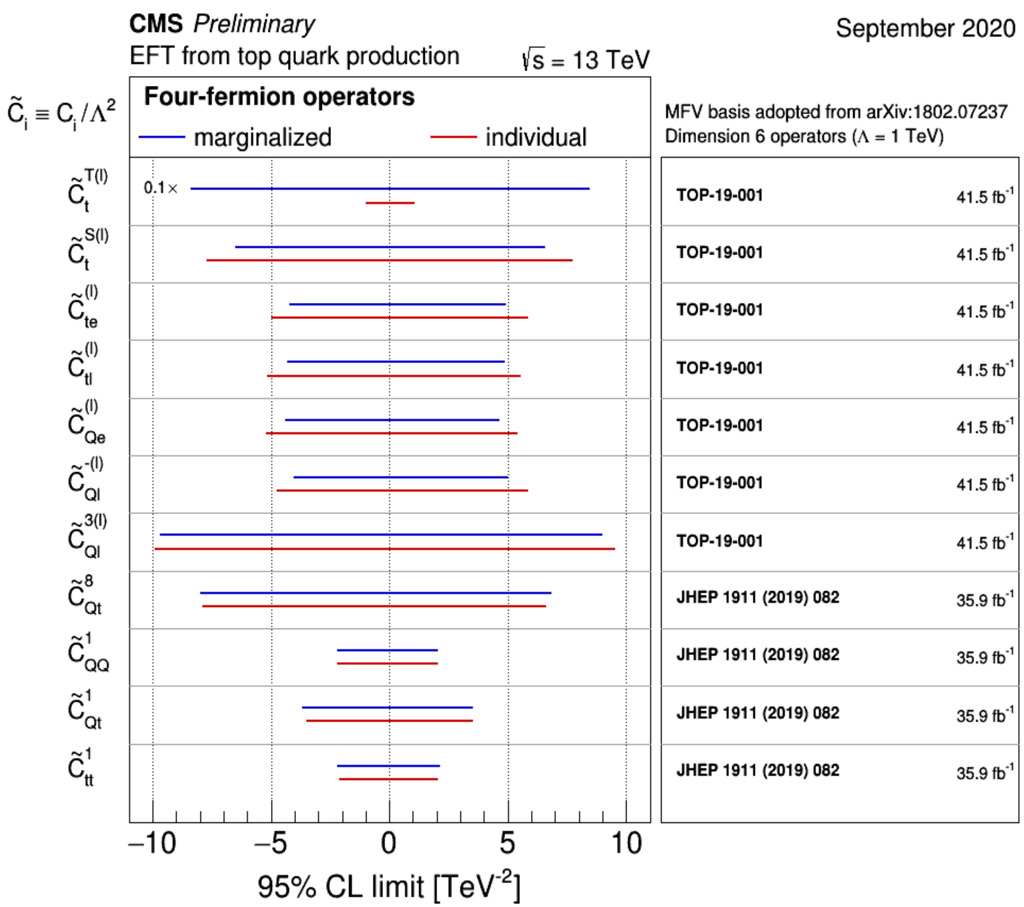


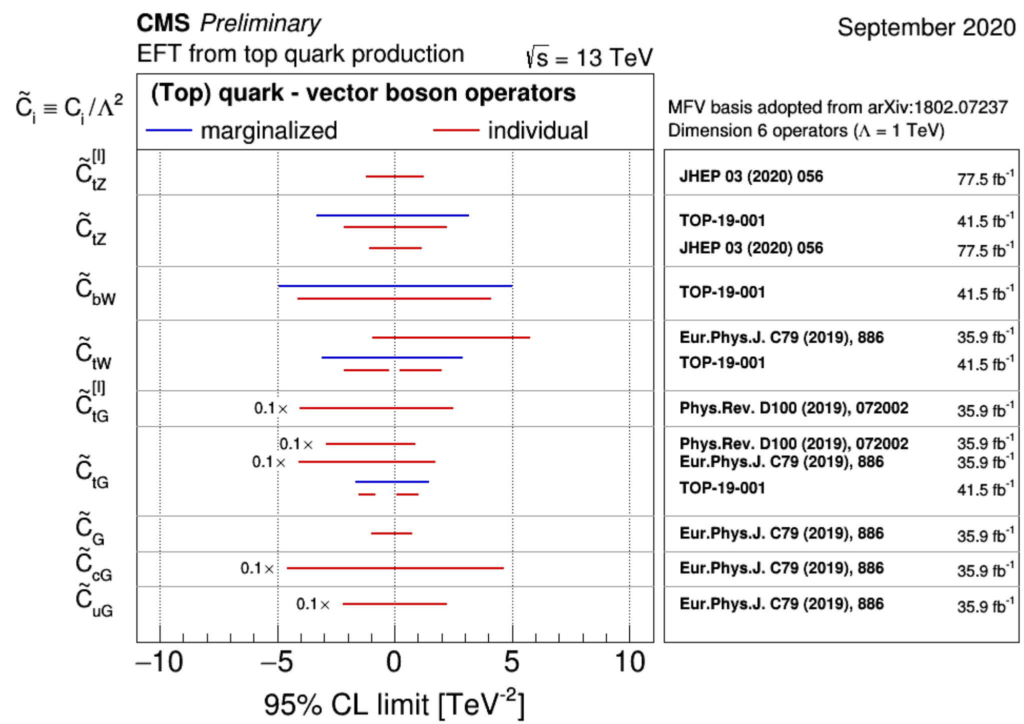
Other CMS EFT summary plots in backup

BACKUP

CMS TOP EFT SUMMARY PLOTS

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOPSummaryFigures

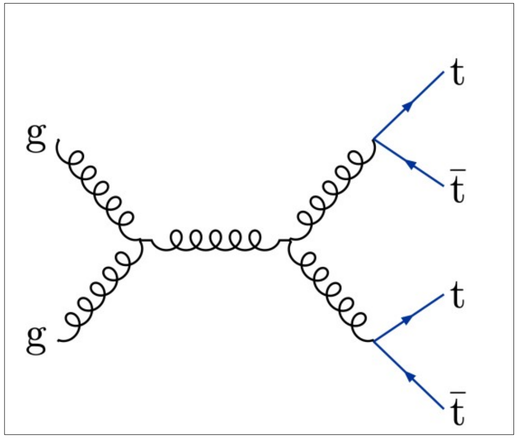




- Within restricted scenario (→ LHCTopWG note), assuming BSM physics couples predominantly to LH doublet and RH up-type quark singlet of 3rd generation , only 4 top operators are expected to contribute :

$$\mathcal{O}^1_{tt} = (\bar{t}_R\gamma^\mu t_R)\left(\bar{t}_R\gamma_\mu t_R\right),$$
$$\mathcal{O}^1_{QQ} = (\bar{Q}_L\gamma^\mu Q_L)\left(\bar{Q}_L\gamma_\mu Q_L\right),$$
$$\mathcal{O}^1_{Qt} = (\bar{Q}_L\gamma^\mu Q_L)\left(\bar{t}_R\gamma_\mu t_R\right),$$
$$\mathcal{O}^8_{Qt} = \left(\bar{Q}_L\gamma^\mu T^A Q_L\right)\left(\bar{t}_R\gamma_\mu T^A t_R\right),$$

Q_L ↔ left-handed 3rd generation quark doublet
t_R ↔ top quark singlet



- SM kinematics assumed, only rate information used to set constraints

Channel	Expected limit ($\times\sigma^{SM}_{t\bar{t}t\bar{t}}$)	Observed limit ($\times\sigma^{SM}_{t\bar{t}t\bar{t}}$)	Expected limit (fb)	Observed limit (fb)
Single lepton	$9.4^{+4.4}_{-2.9}$	10.6	86^{+40}_{-26}	97
Dilepton	$7.3^{+4.5}_{-2.5}$	6.9	67^{+41}_{-23}	64
Combined (this analysis)	$5.7^{+2.9}_{-1.8}$	5.2	52^{+26}_{-17}	48
Multilepton [25]	$2.5^{+1.4}_{-0.8}$	4.6	23^{+12}_{-8}	42
Combined (this analysis + multilepton)	$2.2^{+1.1}_{-0.7}$	3.6	20^{+10}_{-6}	33

- Parameterization coefficients :

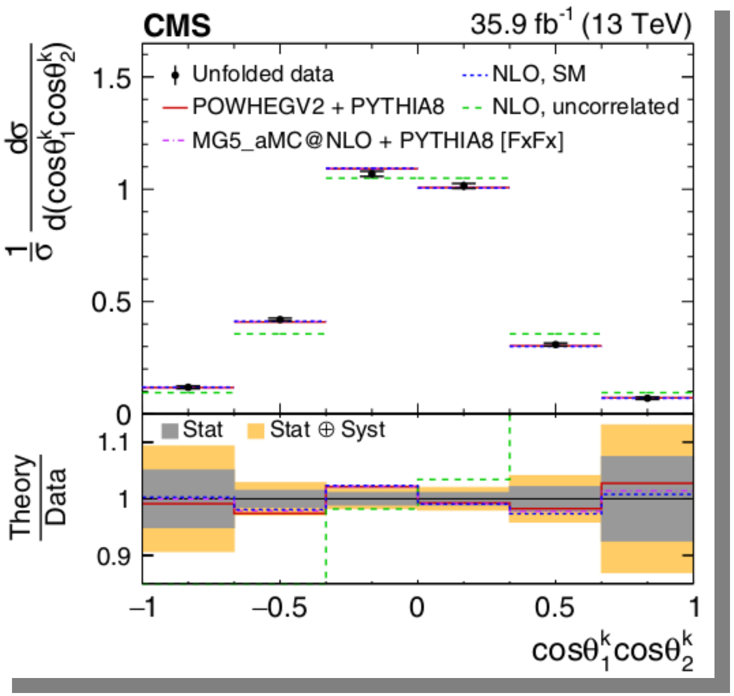
Operator	$\sigma^{(1)}_k$	$\sigma^{(2)}_{j,k}$ $\mathcal{O}^1_{tt}$	$\mathcal{O}^1_{QQ}$	$\mathcal{O}^1_{Qt}$	$\mathcal{O}^8_{Qt}$
$\mathcal{O}^1_{tt}$	0.39	5.59	0.36	−0.39	0.3
$\mathcal{O}^1_{QQ}$	0.47		5.49	−0.45	0.13
$\mathcal{O}^1_{Qt}$	0.03			1.9	−0.08
$\mathcal{O}^8_{Qt}$	0.28				0.45

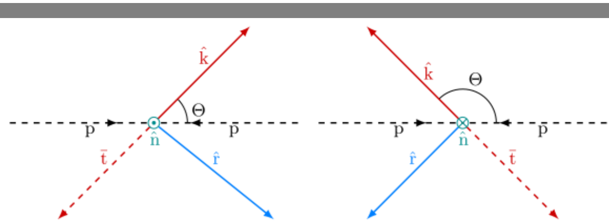
Table 4. Linear (left) and quadratic (right) parameterization coefficients, $\sigma^{(1)}_k$ and $\sigma^{(2)}_{j,k}$, of eq. (6.3). The coefficients $\sigma^{(1)}_k$ are in units (fb TeV^2), while the coefficients $\sigma^{(2)}_{j,k}$ are in units (fb TeV^4).

Unfolded diff. TT POLARIZATION & SPIN CORREL.

- 15 coefficients completely characterize the spin dependence of $t\bar{t}$ production
  - Probed by measuring 22 normalized angular distributions, unfolded at parton-level
- Imaginary part of ctG (top CEDM) assumed to be 0
- RIVET framework used to apply object definitions and calculate spin density matrix observables
- 4 independent observables chosen to constrain ctG

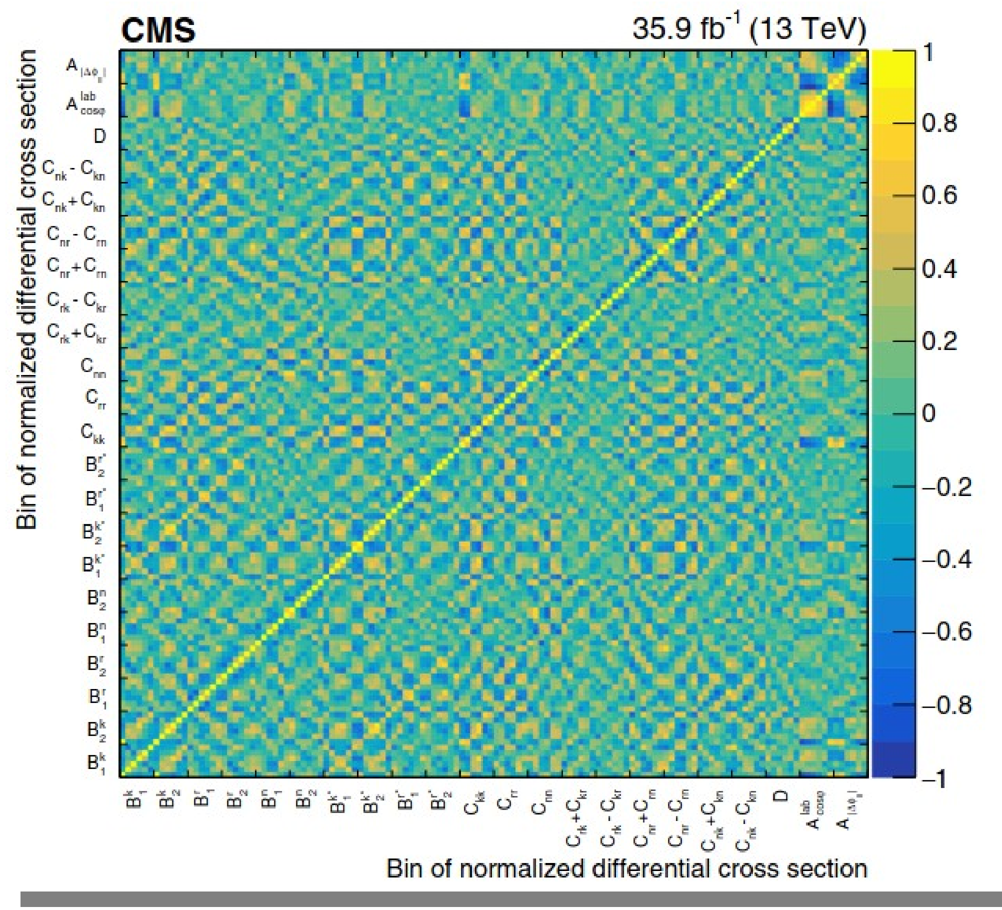
Data strongly favor spin-correlated (SM) scenario



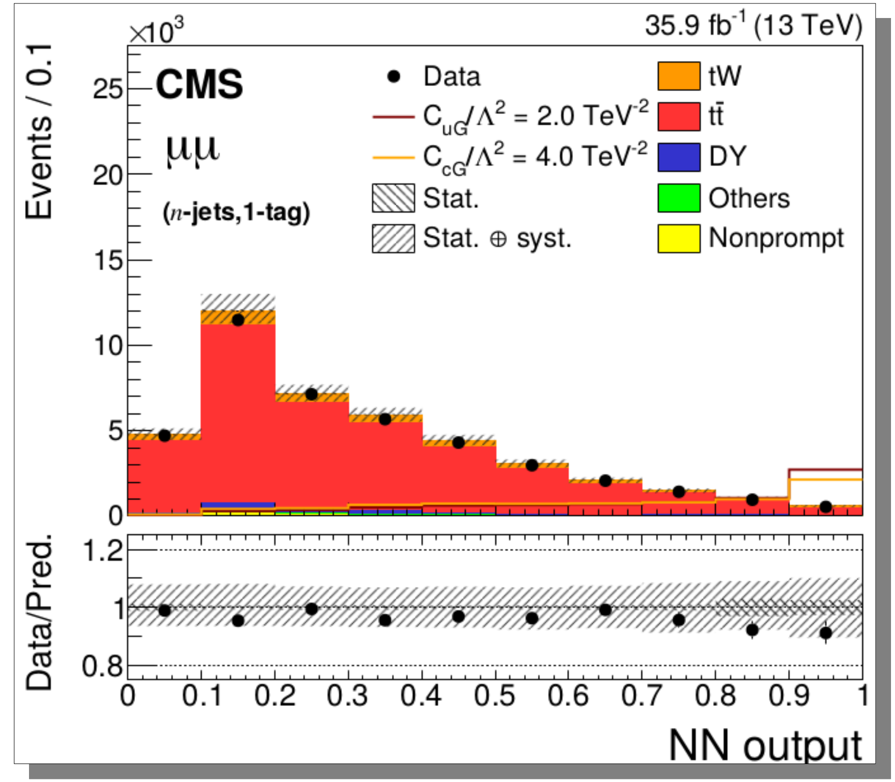


Coordinate system in $t\bar{t}$ CM frame

Systematic correlation matrix for all measured bins of the norm. differential xsecs.



- 6 WCs probed separately (in production, not decay)
- tW interferes with tt at NLO QCD
  - tW sample simulated with DR, difference with DS taken as systematic
- 4-fermion / CP-odd / … operators not considered
- NLO EFT parameterization (except for unavailable CtG)



$$O_{\phi q}^{(3)} = (\phi^+ \tau^i D_\mu \phi)(\bar{q}\gamma^\mu \tau^i q)$$

$$O_{tW} = (\bar{q}\sigma^{\mu\nu}\tau^i t)\tilde{\phi} W^i_{\mu\nu},$$

Modify Wtb

$$O_{tG} = (\bar{q}\sigma^{\mu\nu}\lambda^a t)\tilde{\phi} G^a_{\mu\nu},$$ → CMDM

$$O_G = f_{abc} G^{a\nu}_\mu G^{b\rho}_\nu G^{c\mu}_\rho$$ → Triple-gluon field strength

$$O_{u(c)G} = (\bar{q}\sigma^{\mu\nu}\lambda^a t)\tilde{\phi} G^a_{\mu\nu},$$ → FCNC

Eff. coupling	Channel	Categories 1-jet ,0-tag	1-jet ,1-tag	2-jets,1-tag	>2-jets ,1-tag	≥2-jets,2-tags
C_G	ee	—	Yield	Yield	—	Yield
	eμ	Yield	Yield	Yield	—	Yield
	μμ	—	Yield	Yield	—	Yield
$C^{(3)}_{\phi q}$, C_{tW}, C_{tG}	ee	—	NN_{11}	NN_{21}	—	Yield
	eμ	NN_{10}	NN_{11}	NN_{21}	—	Yield
	μμ	—	NN_{11}	NN_{21}	—	Yield
C_{uG}, C_{cG}	ee	—		NN_{FCNC}		—
	eμ	—		NN_{FCNC}		—
	μμ	—		NN_{FCNC}		—

TTZ DIFFERENTIAL

- Probe operators defined as linear combinations of Warsaw basis operators :

$$c_{\mathrm{tZ}} = \mathrm{Re}\left(-\sin\theta_{\mathrm{W}} C_{\mathrm{uB}}^{(33)} + \cos\theta_{\mathrm{W}} C_{\mathrm{uW}}^{(33)}\right)$$
$$c_{\mathrm{tZ}}^{[I]} = \mathrm{Im}\left(-\sin\theta_{\mathrm{W}} C_{\mathrm{uB}}^{(33)} + \cos\theta_{\mathrm{W}} C_{\mathrm{uW}}^{(33)}\right)$$
$$c_{\phi\mathrm{t}} = C_{\phi\mathrm{t}} = C_{\phi\mathrm{u}}^{(33)}$$
$$c_{\phi\mathrm{Q}}^{-} = C_{\phi\mathrm{Q}} = C_{\phi\mathrm{q}}^{1(33)} - C_{\phi\mathrm{q}}^{3(33)},$$

- Region definitions :

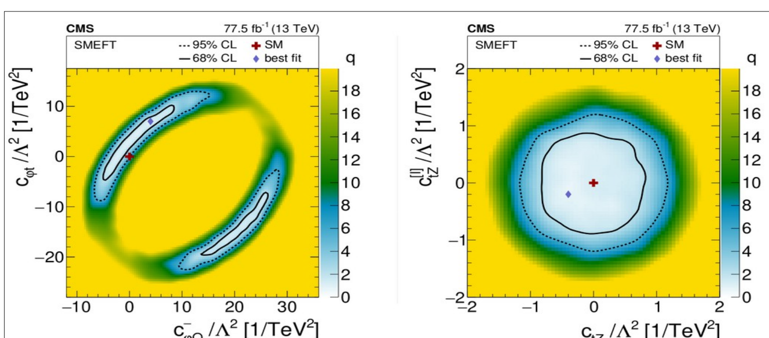
N_ℓ	N_b	N_j	N_Z	$p_\mathrm{T}(\mathrm{Z})$ (GeV)	$-1 \le \cos\theta_\mathrm{Z}^* < -0.6$	$-0.6 \le \cos\theta_\mathrm{Z}^* < 0.6$	$0.6 \le \cos\theta_\mathrm{Z}^*$
3	≥1	≥3	1	0–100	SR1	SR2	SR3
				100–200	SR4	SR5	SR6
				200–400	SR7	SR8	SR9
				≥400	SR10	SR11	SR12
4	≥1	≥1	1	0–100		SR13	
				100–200		SR14	
				≥200		SR15	
3	0	≥1	1	0–100	CR1	CR2	CR3
				100–200	CR4	CR5	CR6
				200–400	CR7	CR8	CR9
				≥400	CR10	CR11	CR12
4	≥0	≥1	2	0–100		CR13	
				100–200		CR14	
				≥200		CR15	

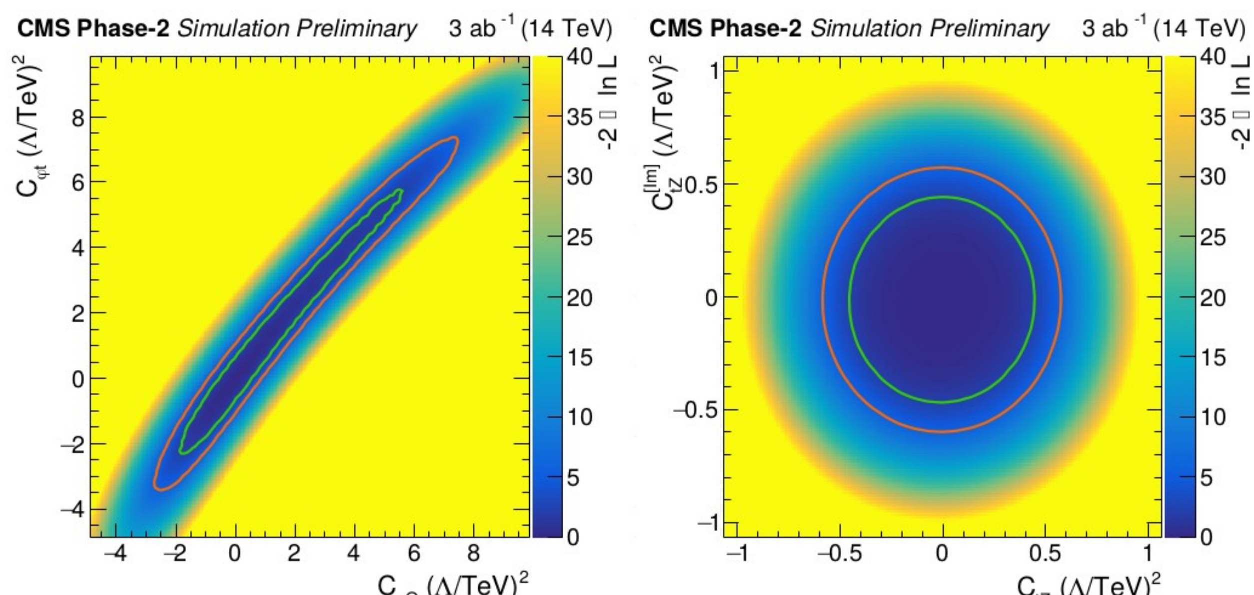
Table 5. Definition of the signal regions (SRs) and control regions (CRs). For signal regions SR13, SR14, and SR15 and control regions CR13, CR14, and CR15, there is no requirement on $\cos\theta_\mathrm{Z}^*$.

HL-LHC projection

CMS-PAS-FTR-18-036

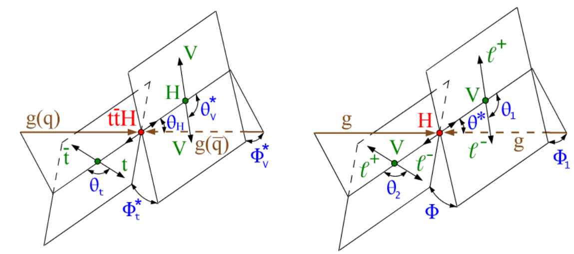
Measurement (2016+2017 data)





ANOMALOUS COUPLINGS IN H→4L

- Follow same formalism used in other Run-1 and Run-2 Higgs AC studies
- Results presented in model-independent way → Possible EFT or PO re-interpretation



- Observables designed with MEM (MELA FW)
  - Optimal sensitivity, exploiting both production and decay kinematics
  - Requires full set of observables describing LO kinematics for ggH, VBF, VH, ttH topologies

- Anomalous H-fermion couplings (e.g. in ttH or bbH) parameterized as : $A(\mathrm{Hff}) = -\frac{m_\mathrm{f}}{v}\bar{\psi}_\mathrm{f}\left(\kappa_\mathrm{f} + \mathrm{i}\,\tilde{\kappa}_\mathrm{f}\gamma_5\right)\psi_\mathrm{f}$
  - CP-even and CP-odd parts K_f and $\tilde{K}_f$ (1 and 0 in SM) can be treated as EFT parameters [arXiv:1610.07922]
  - Effective fractional xsec for Hff coupling : $f_{\mathrm{CP}}^{\mathrm{Hff}} = \frac{|\tilde{\kappa}_\mathrm{f}|^2}{|\kappa_\mathrm{f}|^2 + |\tilde{\kappa}_\mathrm{f}|^2}\,\mathrm{sign}\left(\frac{\tilde{\kappa}_\mathrm{f}}{\kappa_\mathrm{f}}\right)$

- Define 2 categorization schemes to enhance sensitivity to specific couplings
  - Target either Htt/Hgg or HVV couplings