Precise SMEFT predictions

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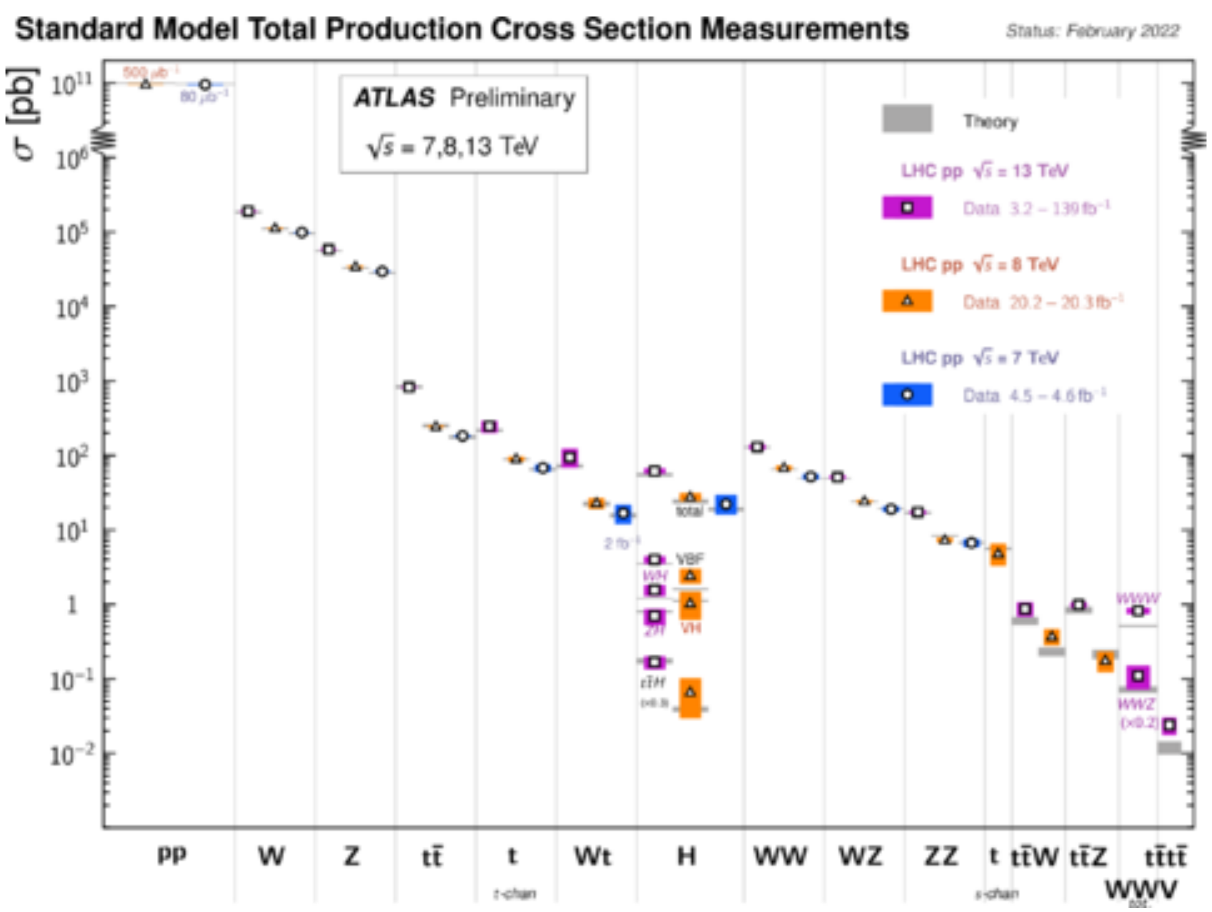
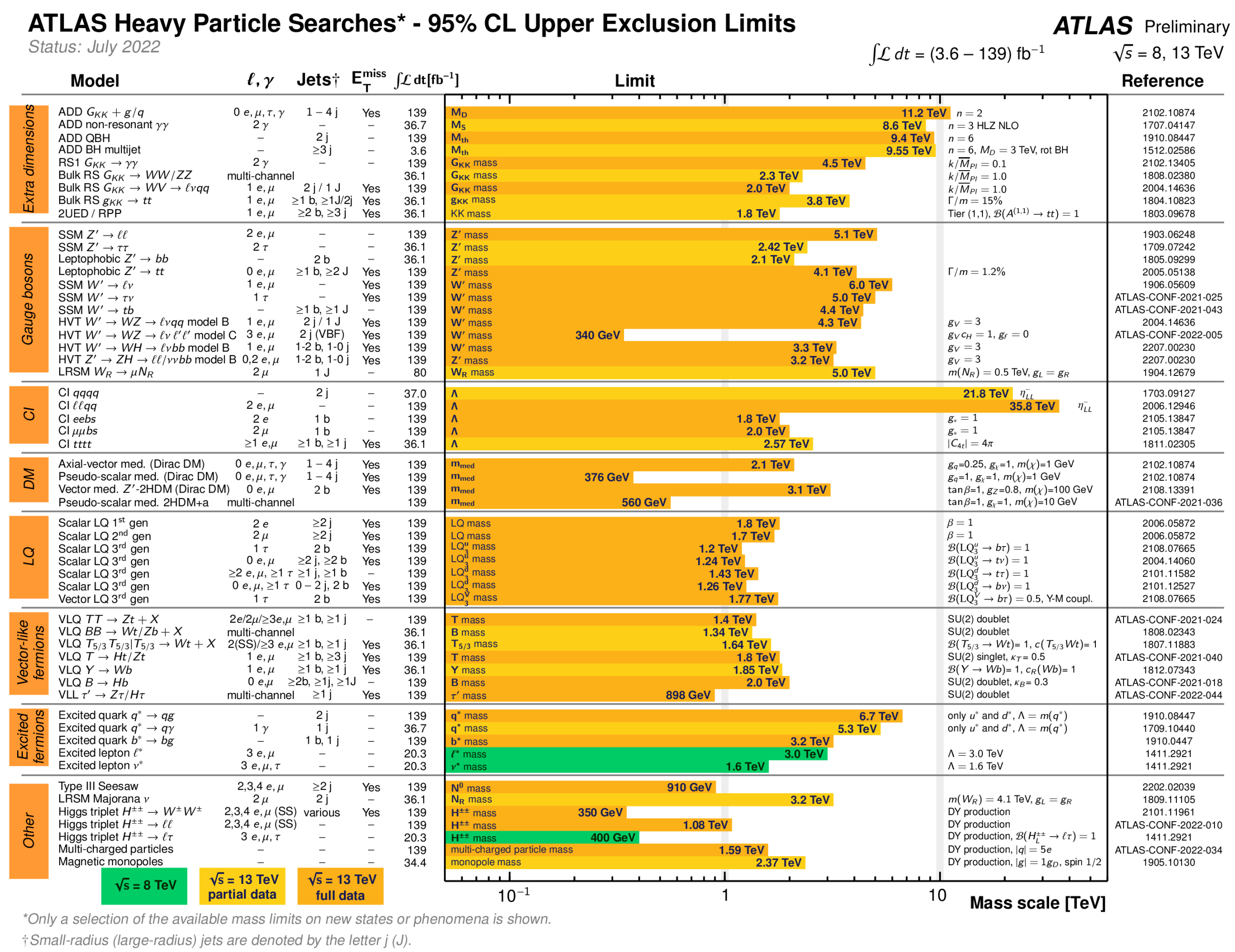
LHC: the story so far

Rediscovering the SM



Searching for the unknown



Good agreement with the SM predictions
No evidence of new light particles

Where is New Physics?

There is a good chance that New Physics is Heavy

→ Not enough energy to produce it

Indirect searches are needed → **SMEFT opens new directions**

Effective Field Theory

Energy

UV physics (heavy particles) $\mathcal{L}_{NP}(\phi, \underbrace{\boldsymbol{Z', X, Q, S}}_{\textbf{new}} \dots)$

Λ

Effective Field Theory $\mathcal{L}_{SM}(\phi) \boxed{+ \mathcal{L}_{dim6}(\phi)} + \dots$

Standard Model $\mathcal{L}_{SM}(\phi)$

Effective Field Theory reveals high energy physics through precise measurements at low energy.

EFT pathway to New Physics

$$\Delta \mathrm{Obs}_n = \mathrm{Obs}_n^{\mathrm{EXP}} - \mathrm{Obs}_n^{\mathrm{SM}} = \frac{1}{\Lambda^2}\sum_i c_i^6(\mu)\, a_{n,i}^6(\mu) + \mathcal{O}\left(\frac{1}{\Lambda^4}\right)$$

Precise EFT predictions

Precise SM predictions

Precise experimental measurements

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Constraints $\frac{1}{\Lambda^2} c_i^6(\mu)$

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→ Precise EFT predictions

→ Precise SM predictions

→ Precise experimental measurements

Constraints $\frac{1}{\Lambda^2} c_i^6(\mu)$ ⟶ UV

EFT pathway to New Physics

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Precise EFT predictions

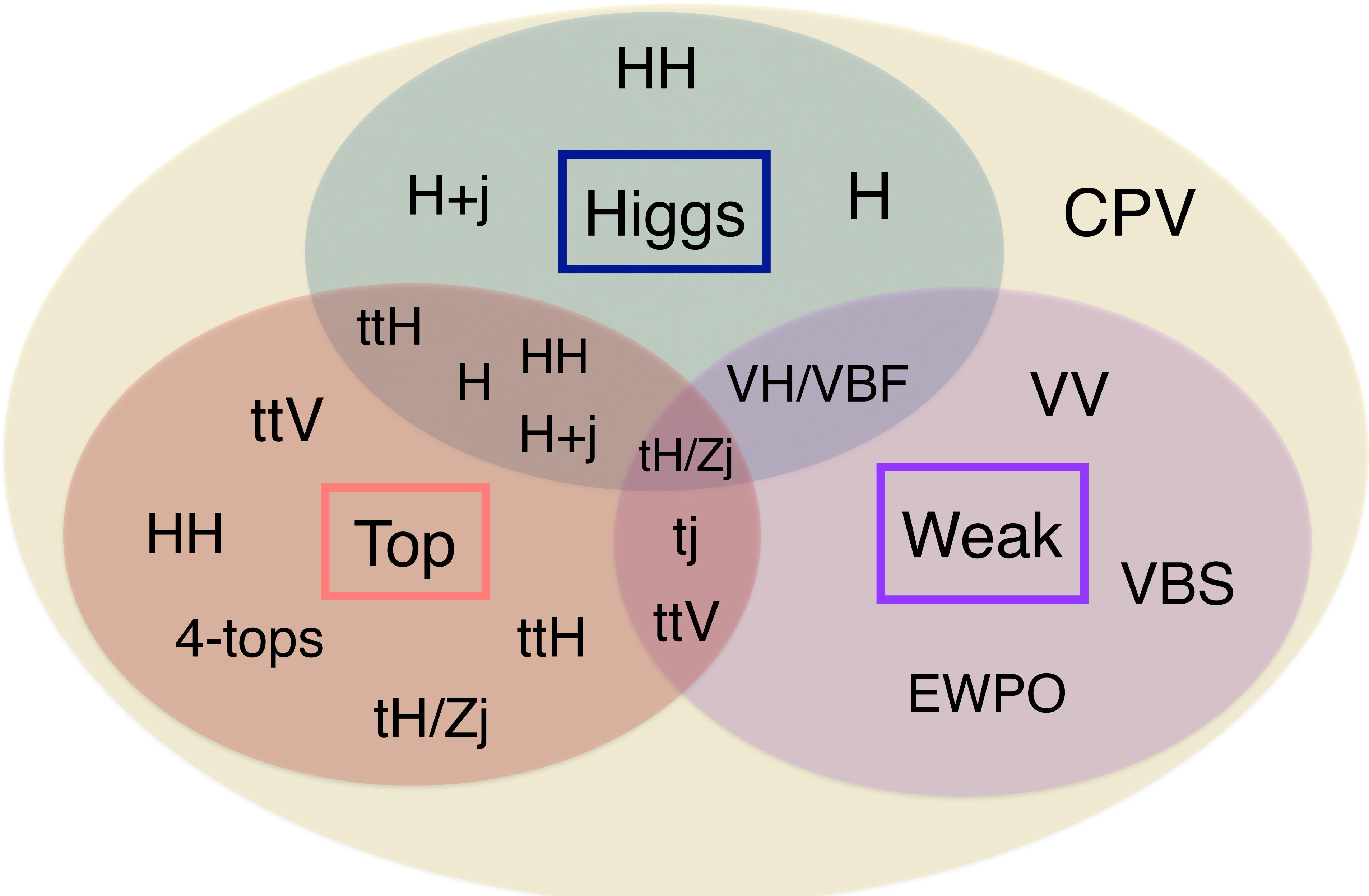
Precise SM predictions

Precise experimental measurements

Constraints $\frac{1}{\Lambda^2} c_i^6(\mu)$ → UV

Huge effort to improve each one of these steps!

Global nature of EFT



SMEFT correlates different sectors → Global fits

Global fit Setup

Theory

Accurate predictions for the SM and the EFT

Data

Top data, Higgs data, EW data, EWPO
Inclusive and differential

Global SMEFT fit

Methodology

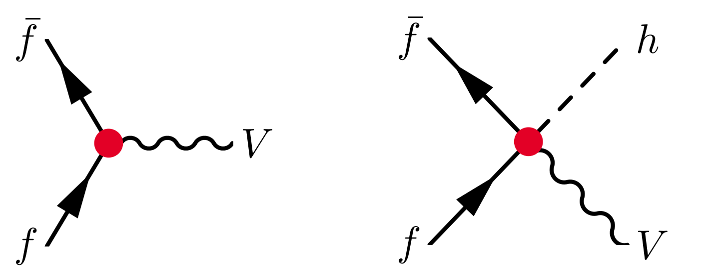
Faithful uncertainty estimate
Avoid under- and over-fitting
Validated on pseudo-data (closure test)

Output

Constraints on New Physics scale
Fit results can be used to bound specific UV complete models

Operator examples

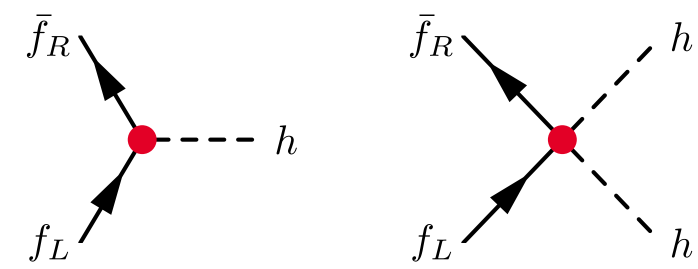
currents $i(\varphi^\dagger \overleftrightarrow{D}^\mu \varphi)(\bar{Q}\gamma^\mu Q)$



$C_{\phi f}$

- Shift SM $f\bar{f}V$ couplings
- $f\bar{f}Vh$ contact interactions

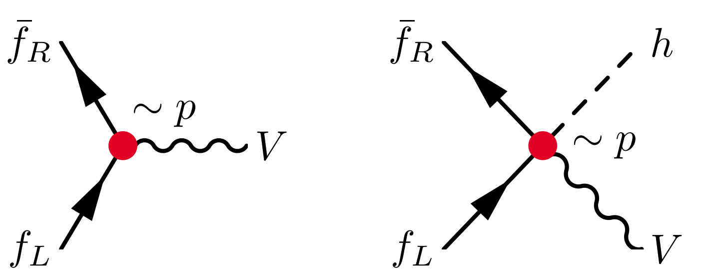
Yukawa $(\bar{q}\, t\, \tilde{\varphi})(\varphi^\dagger \varphi)$



$C_{t\phi}$

- Decouple m_t & y_t
- $t\bar{t}hh(h)$ contact interactions

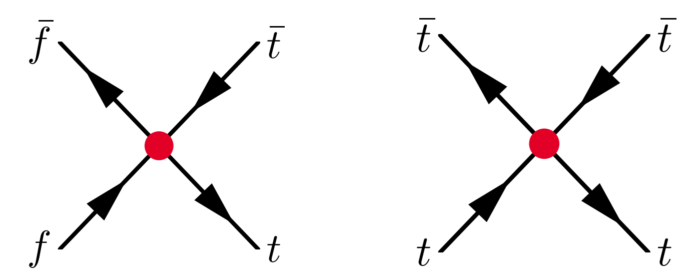
dipole $(\bar{q}\, \sigma_{\mu\nu}\, t\, \tilde{\varphi})V^{\mu\nu}$



C_{tV}

- Chirality flipping $f\bar{f}V$ couplings
- $f\bar{f}V(V)h$ contact interactions
- W, B & G fields

4 fermion $(\bar{q}\gamma_\mu q)(\bar{Q}\gamma^\mu Q)$



C_{ft}

- Contact interactions
- 2-heavy-2-light or 4-heavy
- Numerous (~O(20) w/ top)

+Purely bosonic operators

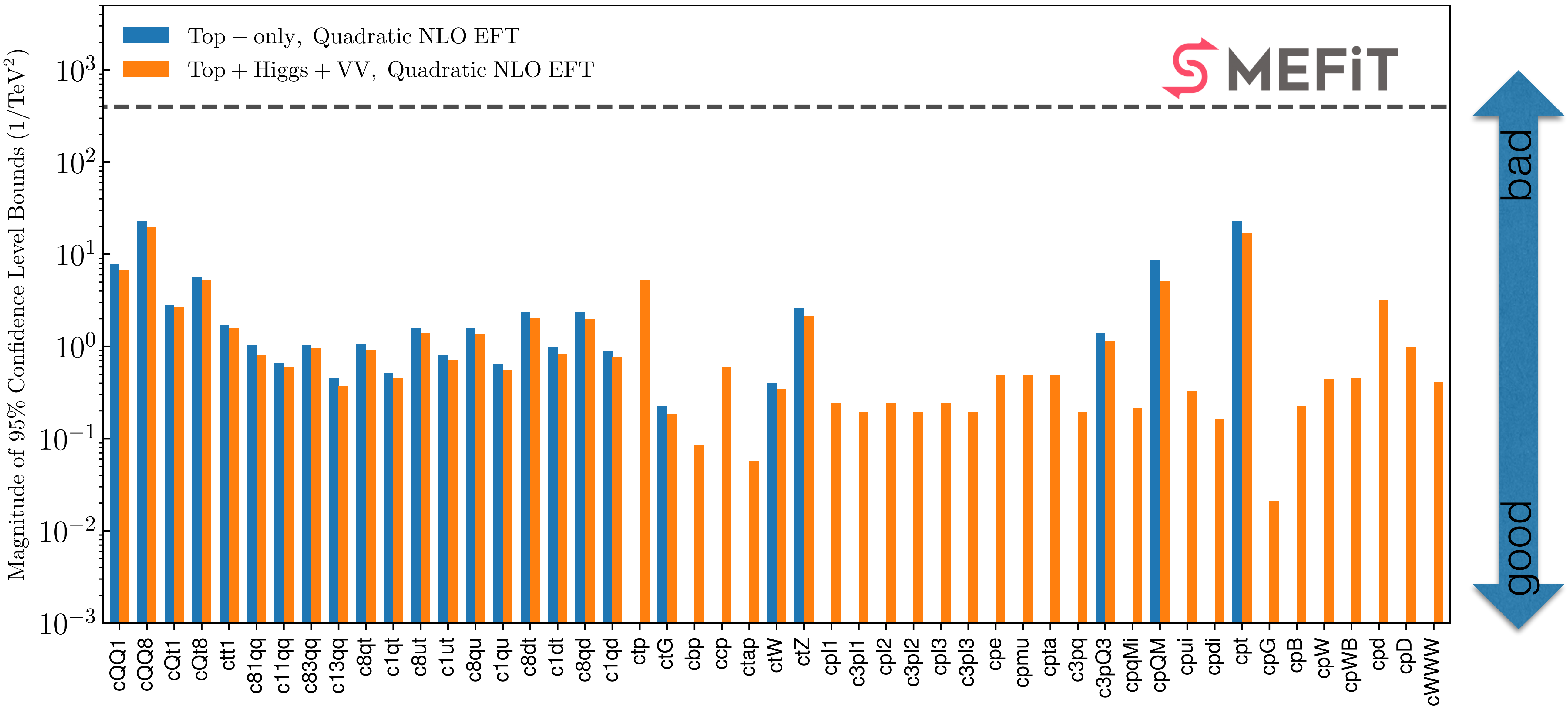
From K. Mimasu

Global fit observables

	Category	Processes	n_{dat}
Top	Top quark production	$t\bar{t}$ (inclusive)	94
		$t\bar{t}Z$, $t\bar{t}W$	14
		single top (inclusive)	27
		tZ, tW	9
		$t\bar{t}t\bar{t}$, $t\bar{t}b\bar{b}$	6
		Total	**150**
Higgs	Higgs production and decay	Run I signal strengths	22
		Run II signal strengths	40
		Run II, differential distributions & STXS	35
		Total	**97**
EW	Diboson production	LEP-2	40
		LHC	30
		Total	**70**
	Baseline dataset	**Total**	**317**

Ethier, Maltoni, Mantani, Nocera, Rojo, Slade, EV and Zhang arXiv:2105.00006

Global fit results



Bounds vary from operator to operator! Lots of information

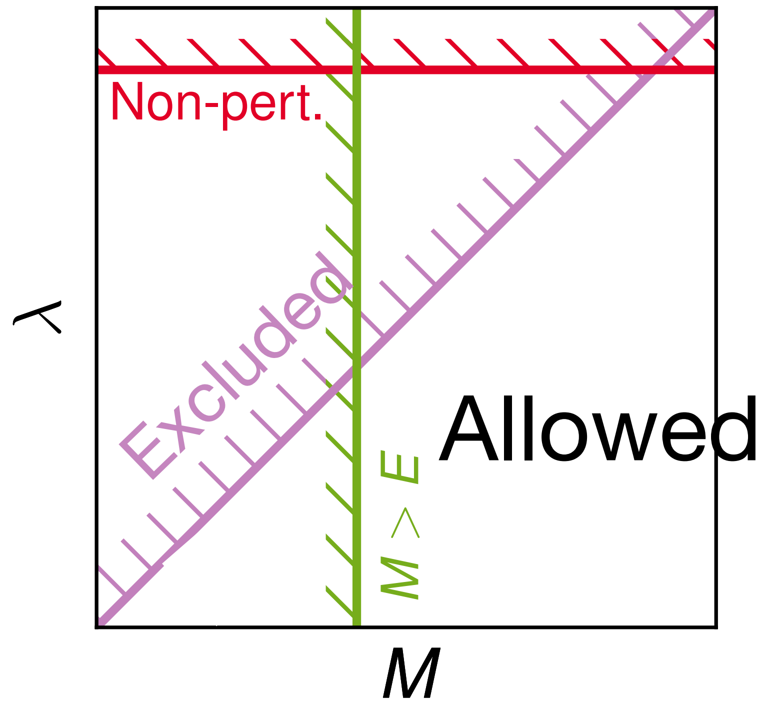
Ethier, Maltoni, Mantani, Nocera, Rojo, Slade, EV and Zhang arXiv:2105.00006

What do we learn from global fits?

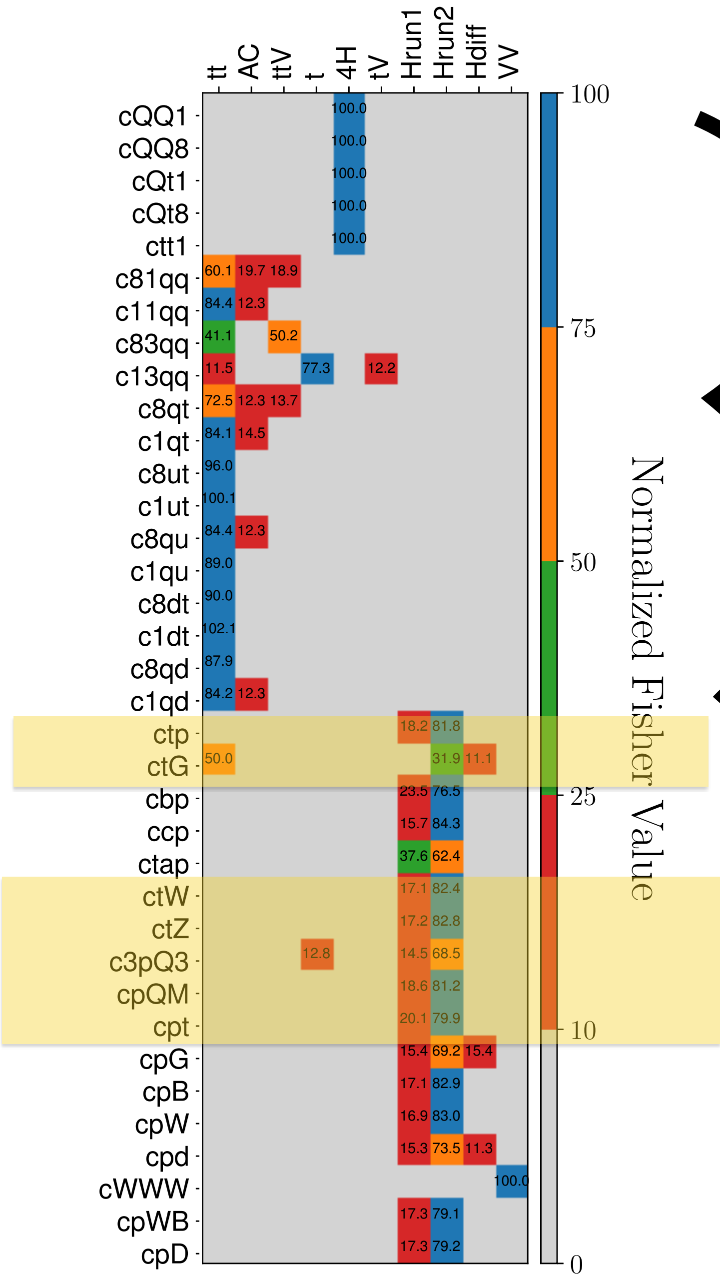
Bounds on new physics scale vary from 0.1 TeV (unconstrained) to 10s of TeV.
Bounds depend on:

- the operator
- assumption of a strongly or weakly coupled theory
- individual or marginalised bounds (reality is somewhere in-between)
- linear or quadratic bounds

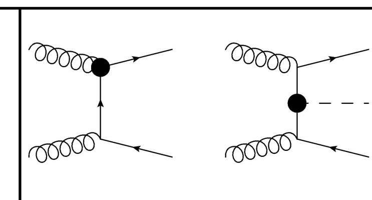
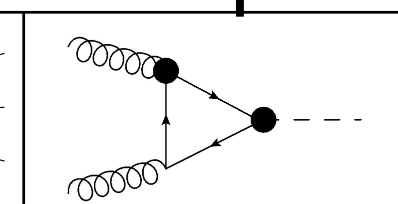
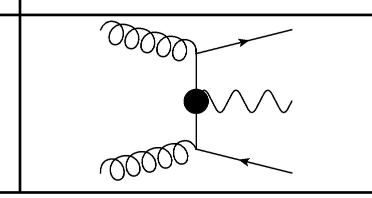
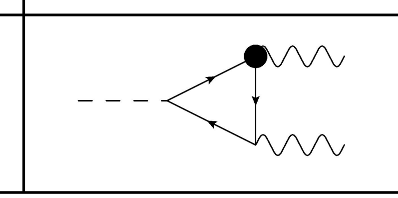
$$\frac{c_i^6(\mu)}{\Lambda^2} = \frac{\lambda^2}{M^2} < X$$



Where is most information from?



4-fermion operators: mostly top

	Tree	Loop
Top Yukawa Top Chromomagnetic		
ttV couplings		

Higgs-Top interface

Fisher information table

Ethier, Maltoni, Mantani, Nocera, Rojo, Slade, EV and Zhang arXiv:2105.00006

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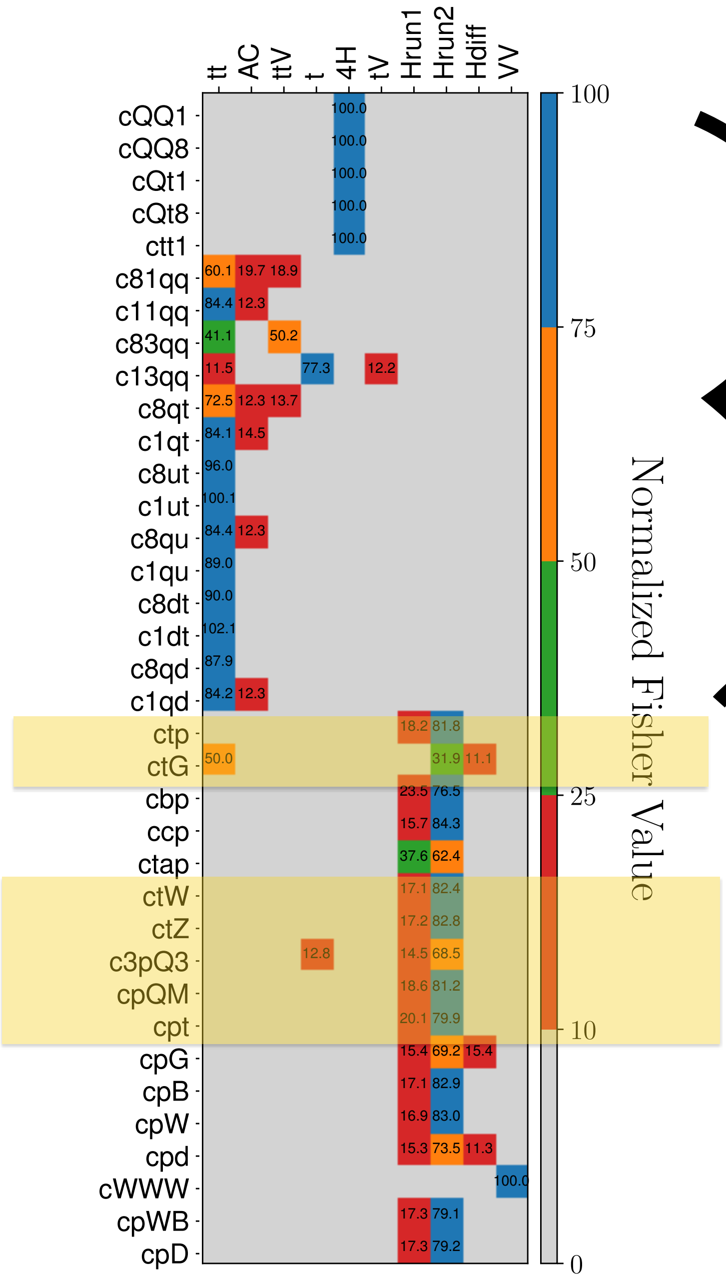
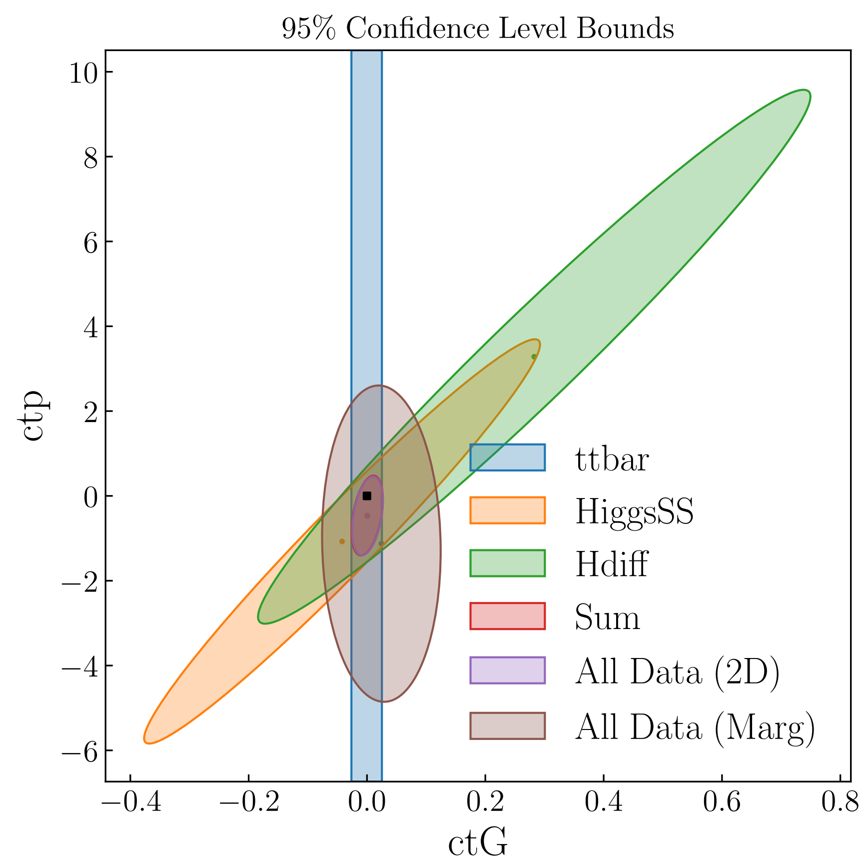


4-fermion operators: mostly top

$$\left(\varphi^{\dagger}\varphi\right)\bar{Q}\,t\,\tilde{\varphi}$$



$$(\bar{Q}\tau^{\mu\nu}\,T_A\,t)\,\tilde{\varphi}\,G^{A}_{\mu\nu}$$

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Future of global fits

More observables:

- particle level observables
- spin correlations
- new final states

More/different operators:

- different flavour assumptions
- dimension-8 operators

Better EFT predictions

Higher Orders in $1/\Lambda^4$

- squared dim-6 contributions
- double insertions of dim-6
- dim-8 contributions

Higher Orders in QCD and EW

EFT is a QFT, renormalisable order-by order in $1/\Lambda^2$

$$\mathcal{O}(\alpha_s, \alpha_{ew}) + \mathcal{O}\left(\frac{1}{\Lambda^2}\right) + \mathcal{O}\left(\frac{\alpha_s}{\Lambda^2}\right) + \mathcal{O}\left(\frac{\alpha_{ew}}{\Lambda^2}\right)$$

SMEFT of computations at dimension-6

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Tree level: Done (SMEFTsim)

https://smeftsim.github.io/ Brivio, arXiv: 2012.11343

NLO QCD: ~Done (SMEFT@NLO)

http://feynrules.irmp.ucl.ac.be/wiki/SMEFTatNLO

Degrande, Durieux, Maltoni, Mimasu, EV, Zhang arXiv:2008.11743

NLO EW: Some examples available, needed to probe unconstrained operators.

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How about this μ?

Running and mixing in SMEFT

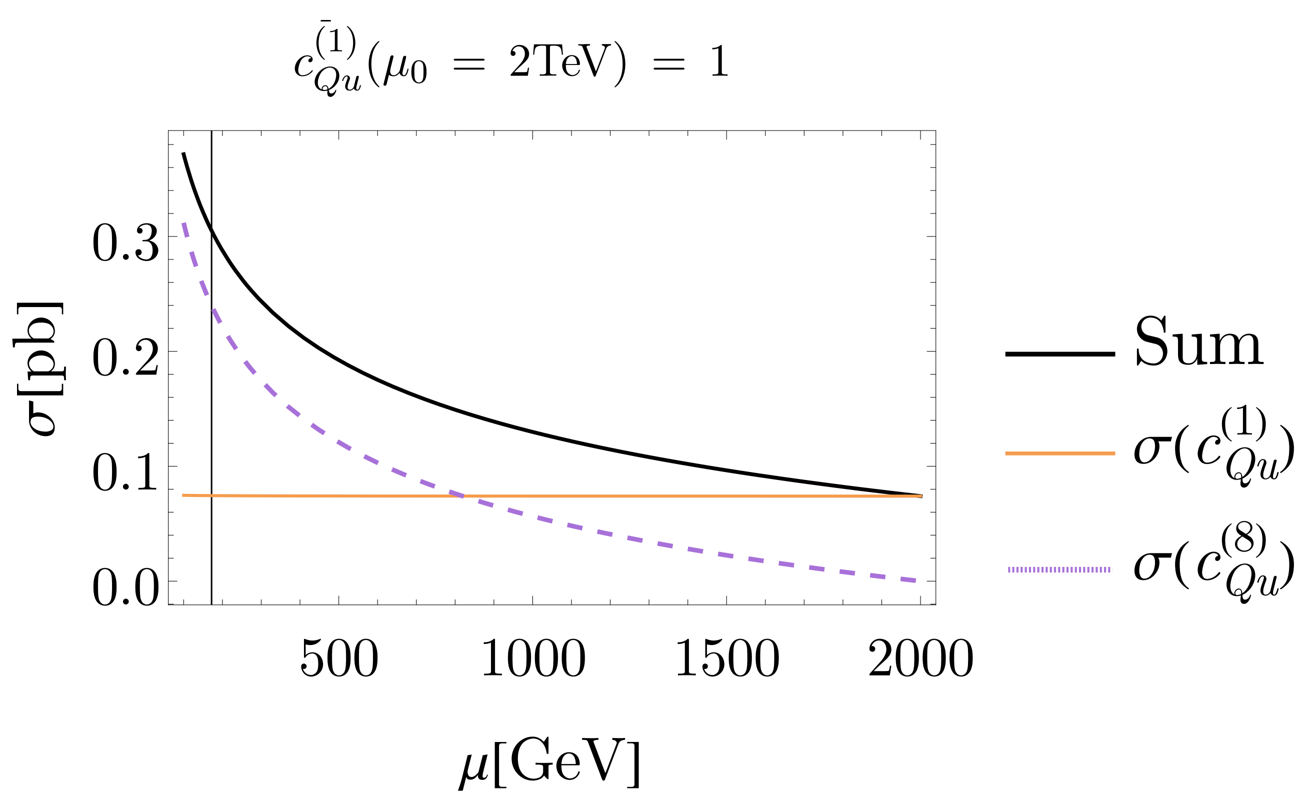
$$\frac{dc_i(\mu)}{d\log\mu} = \gamma_{ij}\, c_j(\mu)$$

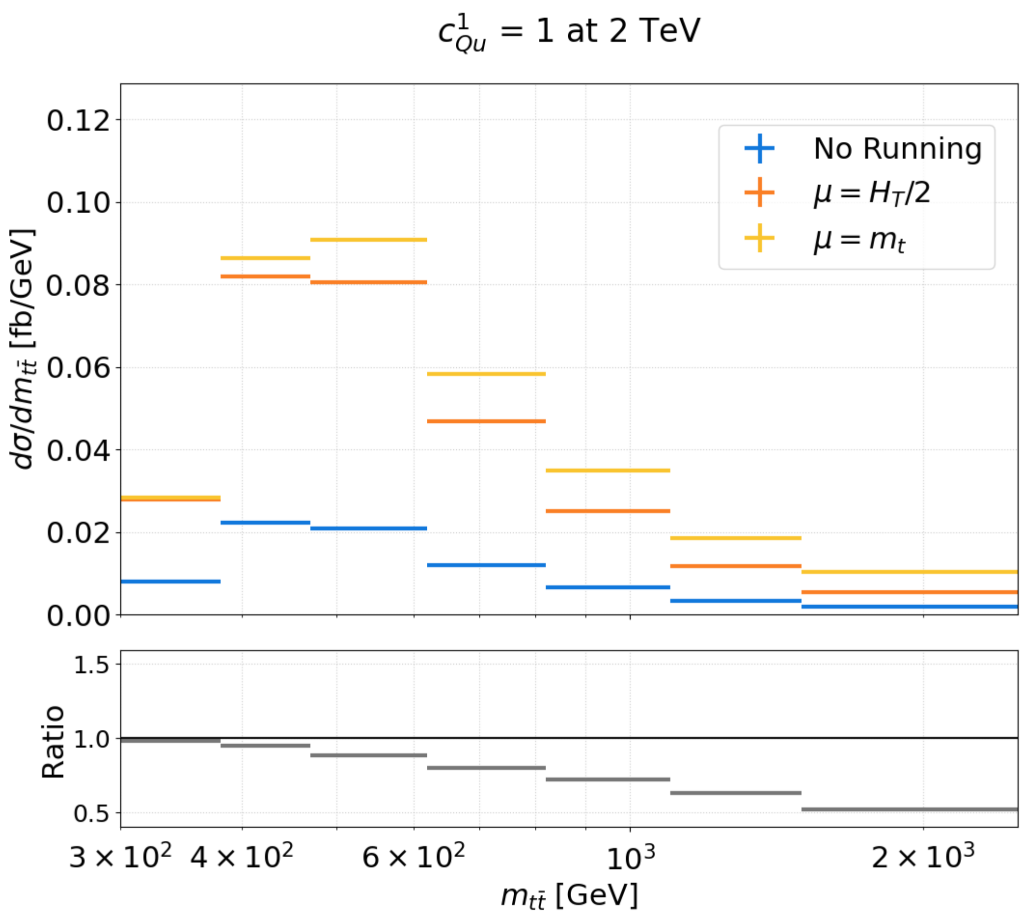
One loop anomalous dimension known:

(Alonso) Jenkins et al arXiv:1308.2627, 1310.4838, 1312.2014

Example: Turn one 1 operator at high-scale

Compute effect on top pair cross-section



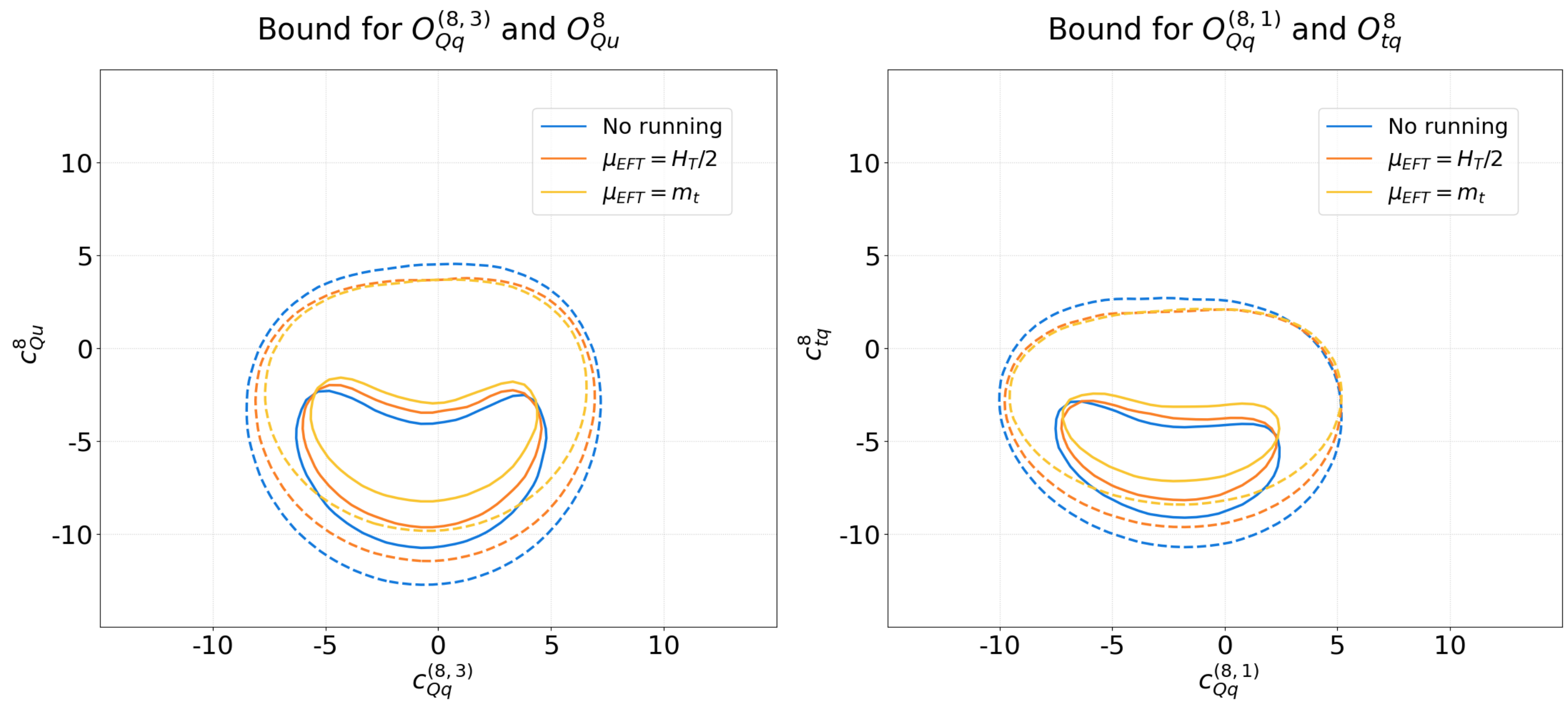


Aoude, Maltoni, Mattelaer, Severi, EV arXiv:2212.05067

Impact of RGE on constraints

How does running and mixing impacts the constraints?

Top sector fit:



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Effect becomes more important for differential distributions & measurements with very different scales

Conclusions

- SMEFT is a consistent way to look for new interactions
- The LHC gives a lot of opportunities to explore SMEFT through a lot of new measurements

- First global fits results already available: important to combine as many processes as possible
- Strong link between Higgs and top sectors
- Precise EFT predictions (NLO, RGE-improved) maximise the potential of EFT probes
- Eventually global fit results give us a clear indication of the scale of potential new physics


Thank you for your attention