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Single top + Higgs

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in collaboration with Farina, Grojean, Maltoni, Salvioni
based on arXiv:1211.3736

Introduction

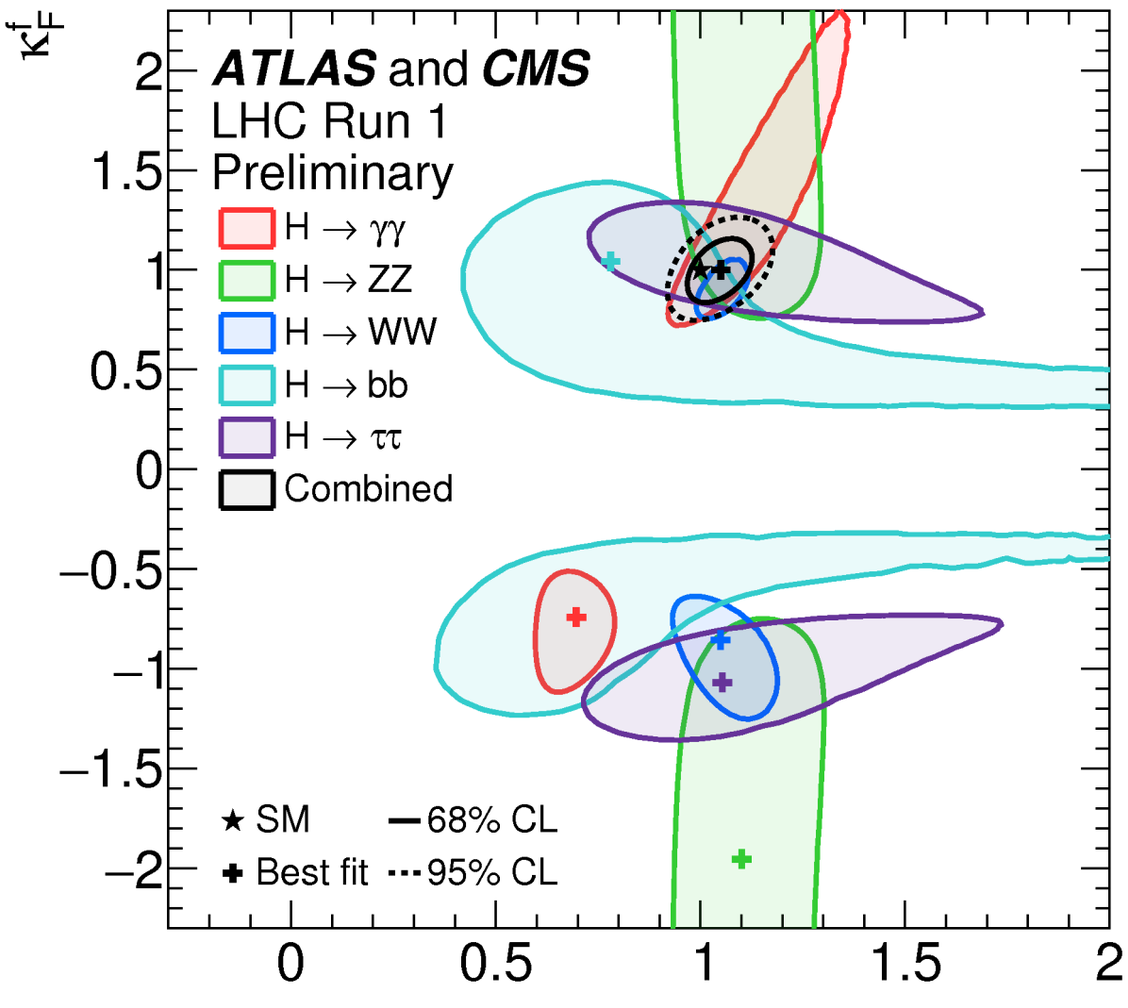
- many LHC searches looking for new physics
  - many direct searches for new particles
  - measure new and old couplings with greater precision
- any deviation would hint to new physics

- one coupling of great interest: $\bar{t}th$
- resolve sign ambiguity of $\bar{t}th$ coupling
  (still present in current data)
- need channels which can resolve sign ambiguity
  - channels where coupling interferes with another coupling
- here: single top + Higgs

Sign ambiguity

- ambiguity in sign in $\bar{t}th$ coupling
- best fit point at 8 TeV $g_{hf\bar{f}} > 0$

[ATLAS-CONF-2015-044]



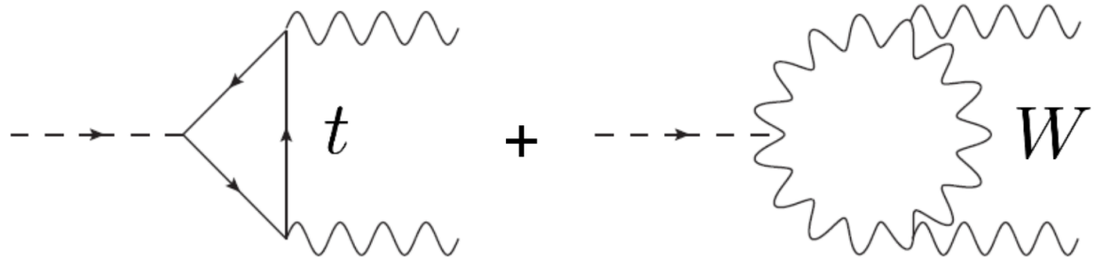
$$\kappa_V = c_V \equiv g_{hWW}/g_{hWW}^{\mathrm{SM}}$$
$$\kappa_F = c_F \equiv g_{hf\bar{f}}/g_{hf\bar{f}}^{\mathrm{SM}}$$

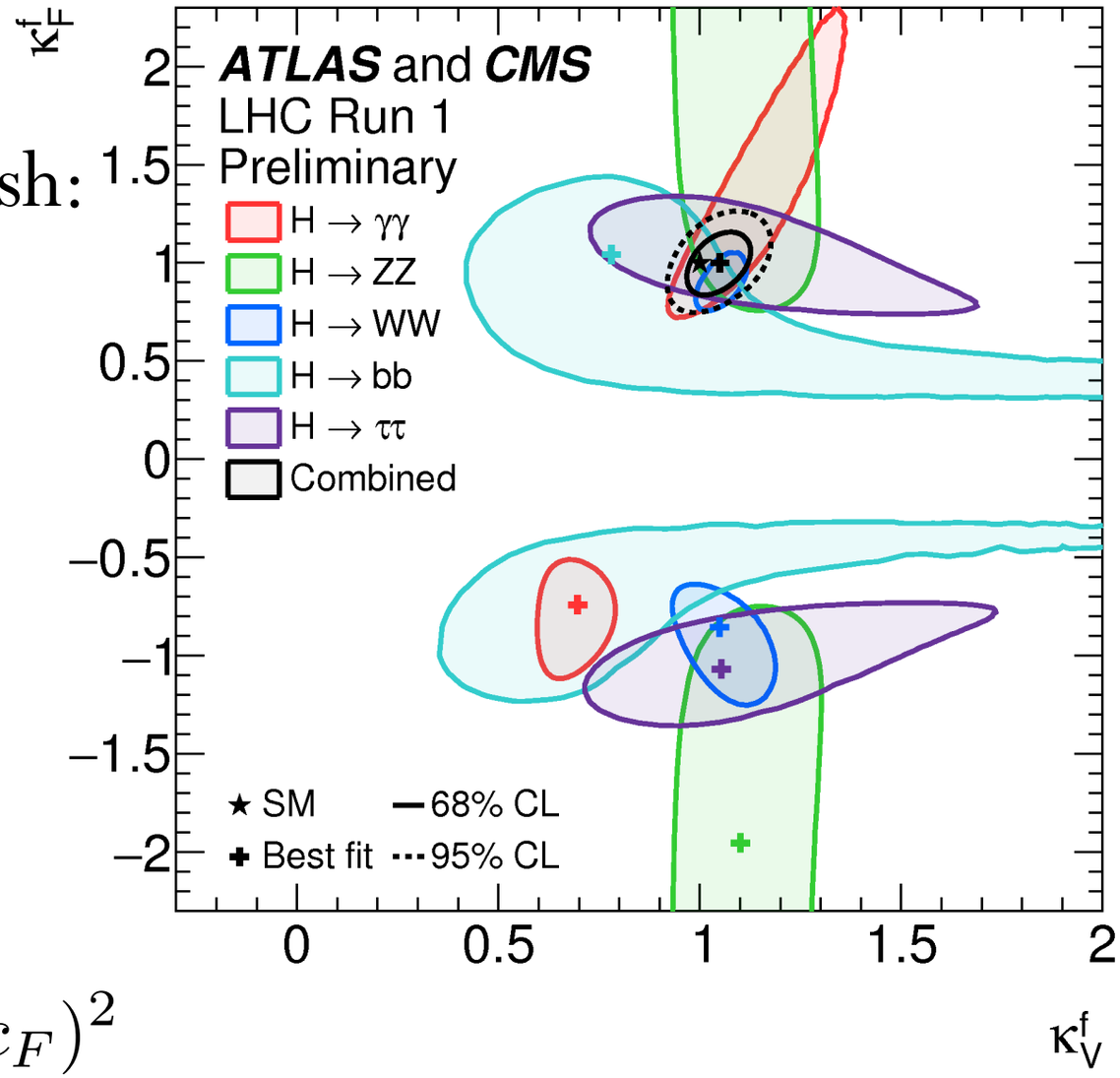
- sign ambiguity in most channels:
  quadratic dependence of all Higgs partial widths on c_V, c_F

Sign ambiguity

[ATLAS-CONF-2015-044]

- degeneracy: $c_F \to -c_F$
- only interference term to distinguish: $\Gamma(h \to \gamma\gamma)$ where W and top loops interfere





- can write

$$\frac{\Gamma(h \to \gamma\gamma)}{\Gamma(h \to \gamma\gamma)_{\rm SM}} = (1.26c_V - 0.26c_F)^2$$

- assume true signal: $(c_V, c_F) = (c_V^t, c_F^t)$ but also

$$c_V = c_V^t \left| \frac{1.26c_V^t - 0.26c_F^t}{1.26c_V^t + 0.26c_F^t} \right| \qquad c_F = -c_F^t \left| \frac{1.26c_V^t - 0.26c_F^t}{1.26c_V^t + 0.26c_F^t} \right|$$

Sign ambiguity

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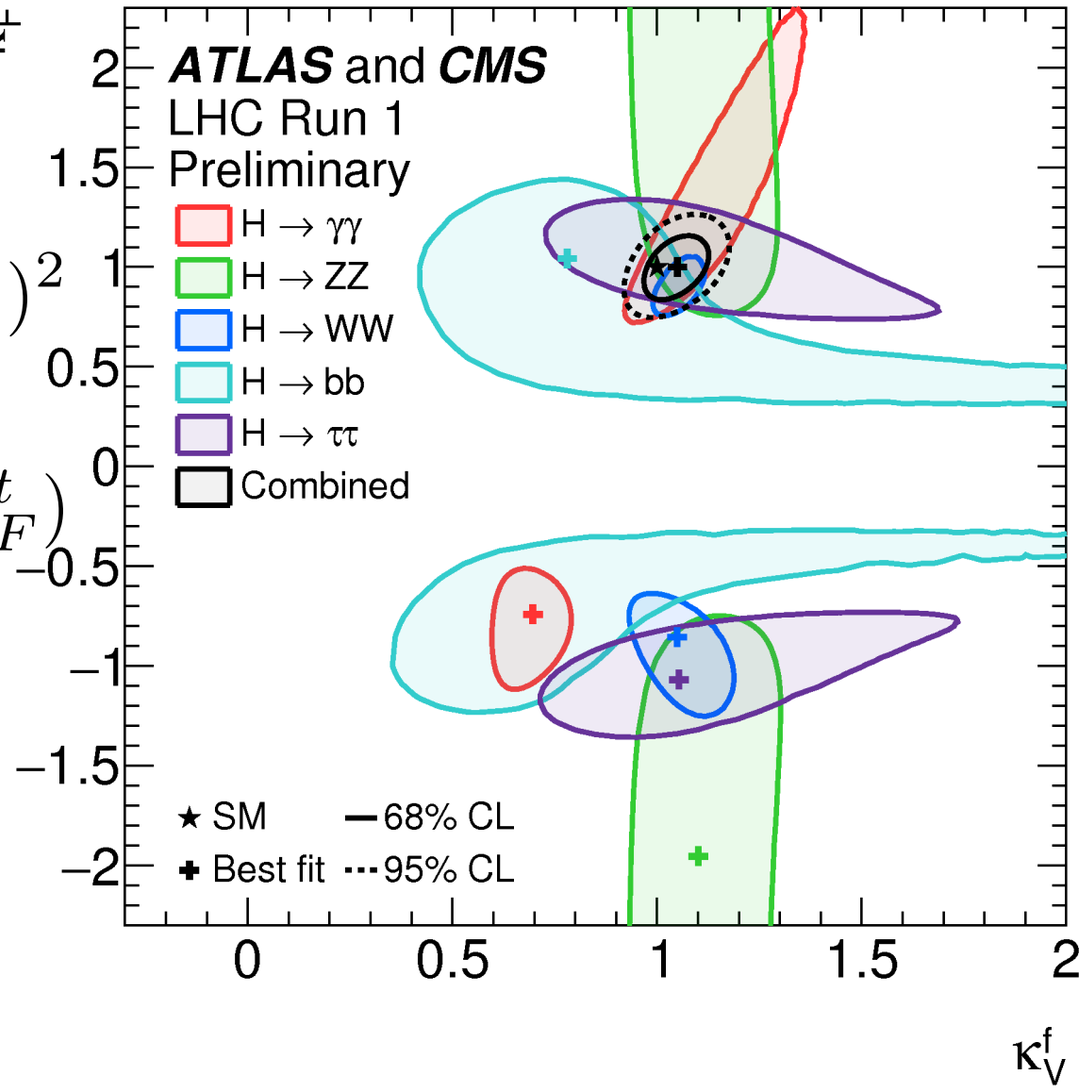
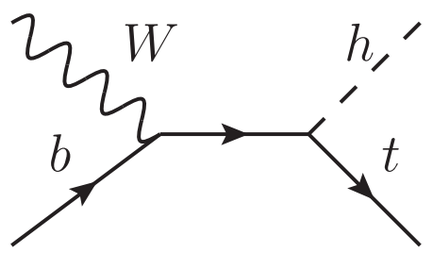
[ATLAS-CONF-2015-044]

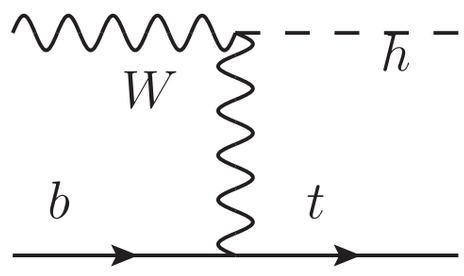


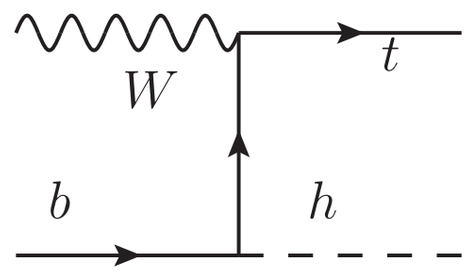
- assume SM: $(c_V, c_F) = (0.66, -0.66)$
- what we see in the plot, impossible to eliminate negative solution
- need a direct and robust way to confirm $g_{hf\bar{f}} > 0$

Single top + Higgs

- to lift degeneracy consider partonic process $Wb \to th$







suppressed by bottom Yukawa

- in the high energy regime $s, -t, -u \gg m_t^2, m_W^2, m_h^2$

$$\mathcal{A} = \frac{g}{\sqrt{2}}(c_F - c_V)\frac{m_t\sqrt{s}}{m_W v} A\left(\frac{t}{s}, \varphi; \xi_t, \xi_b\right) + \text{const}$$

$c_V \equiv g_{hWW}/g_{hWW}^{SM}$

$c_F \equiv g_{ht\bar{t}}/g_{ht\bar{t}}^{SM}$

- in the SM: $c_V = c_F$ cancellation

deviations: $c_V \neq c_F$ enhancement

amplitude growing with energy

Single top + Higgs

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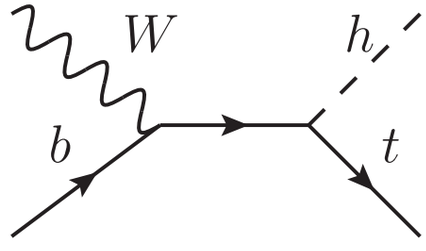

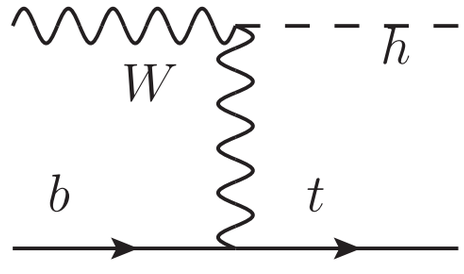

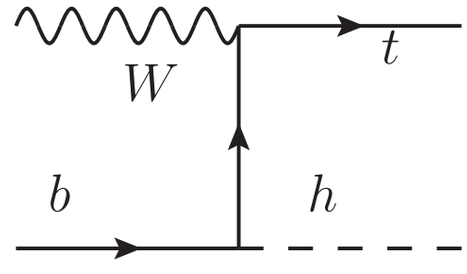

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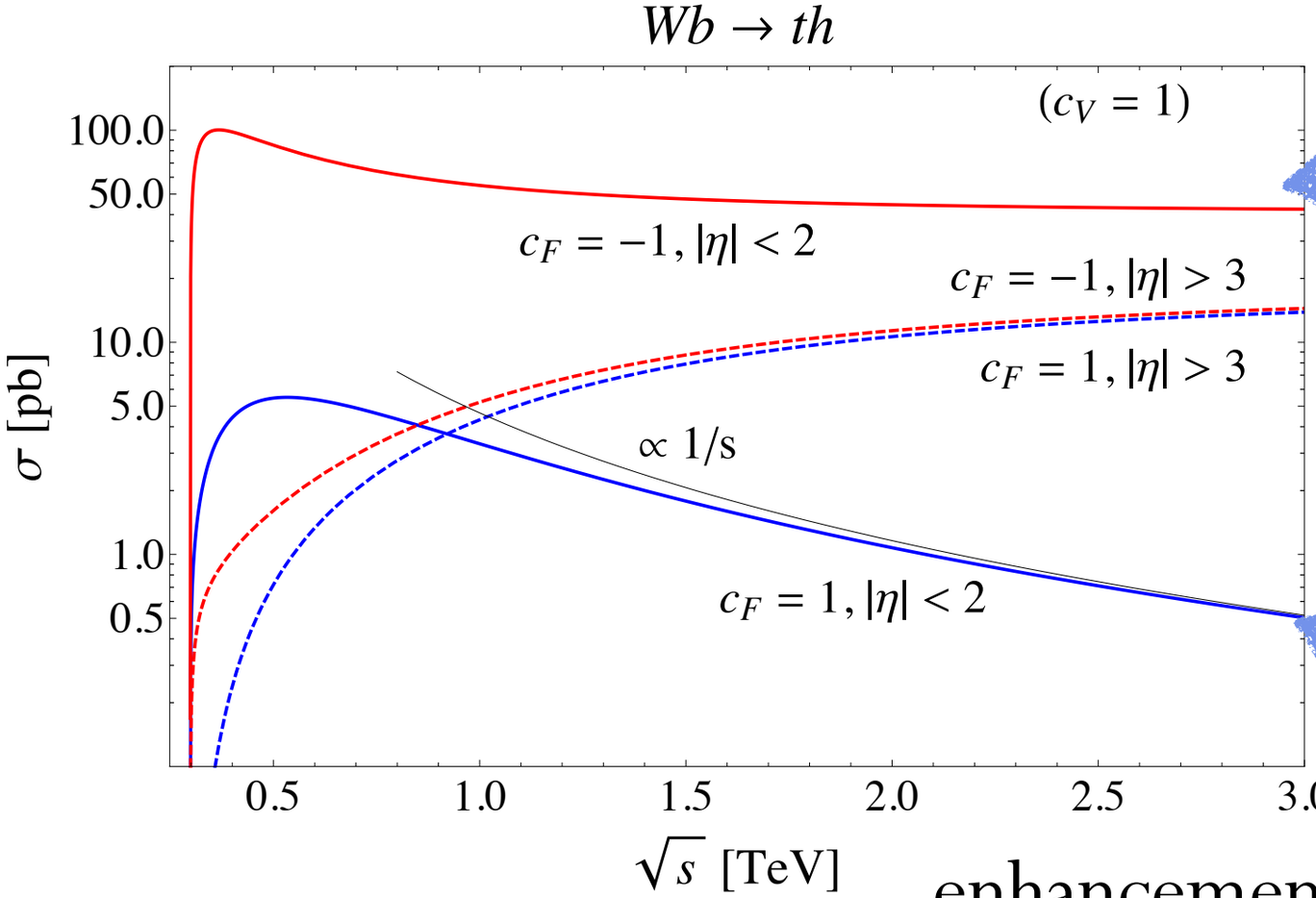


for $c_V = -c_F$: amplitude grows as $\sqrt{s}$, cross-section ~constant

for $c_V = c_F$: constant amplitude at large s, cross-section goes as $1/s$

enhancement more than order of magnitude!

Breakdown of perturbative unitarity

- amplitude growing with the energy

  → perturbative unitarity lost at some scale

- we can estimate this scale by finding the s-wave amplitude:

$$a_0 = -\frac{1}{24\sqrt{2}\pi}(c_F - c_V)\frac{g m_t \sqrt{s}}{m_W v} e^{i\varphi}$$

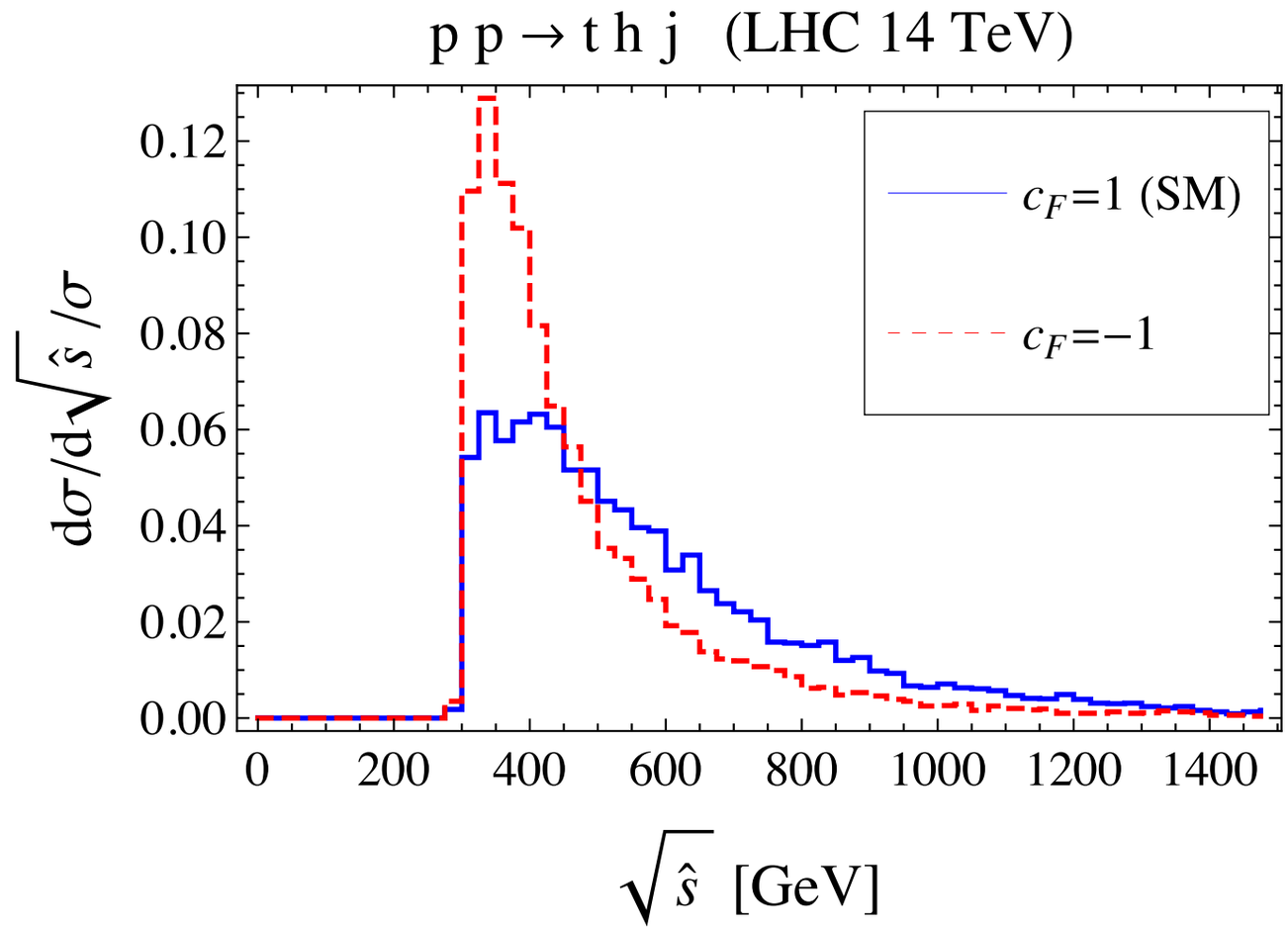
- considering $|a_0| < 1$ perturbative unitarity violated at scale

$$\Lambda = 12\sqrt{2}\pi \frac{v^2}{m_t\,|c_F - c_V|}$$

- for $c_V = -c_F = 1$ the cutoff is $\Lambda \simeq 9.3\,\mathrm{TeV}$
- no need to worry about UV physics
- other process: $W_L^+ W_L^- \to \bar{t}t$, cutoff scale at $8.8\,\mathrm{TeV}$

Breakdown of perturbative unitarity

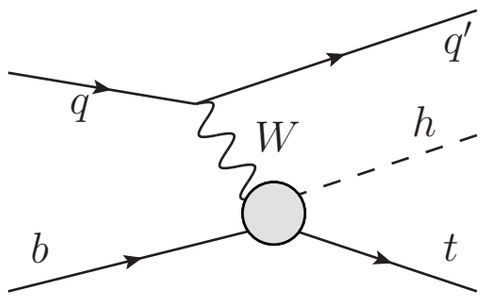
- confirm this by looking at differential cross-section (from simulations)

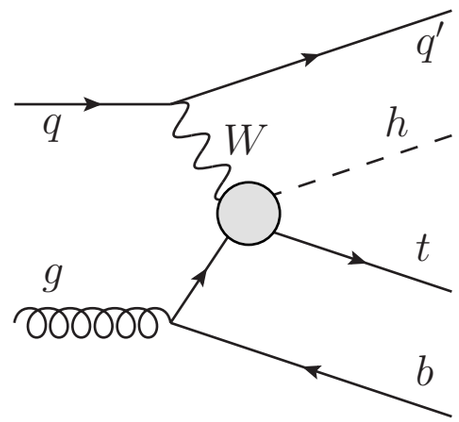


- negligible contribution from $\sqrt{\hat{s}} > 1\,\text{TeV}$
- so perturbative unitarity can be trusted

Single top + Higgs at the LHC

- processes at the LHC
  b from initial gluon splitting

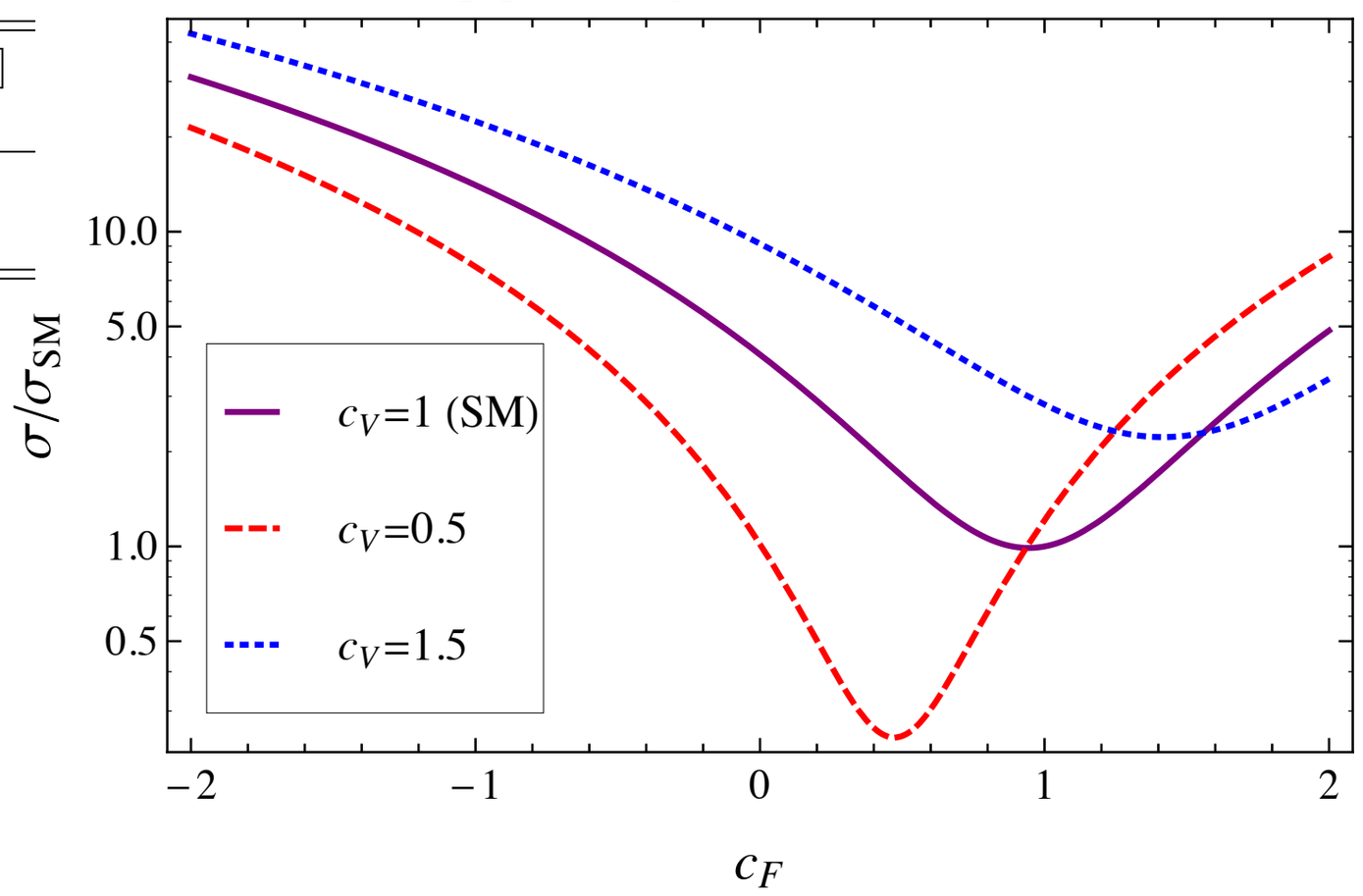




- cross sections:

	$\sigma^{\rm LO}(pp \to thj)$ [fb]		$\sigma^{\rm LO}(pp \to thjb)$ [fb]	
	$c_F = 1$	$c_F = -1$	$c_F = 1$	$c_F = -1$
8 TeV	17.4	252.7	5.4	79.2
14 TeV	80.4	1042	26.9	363.5

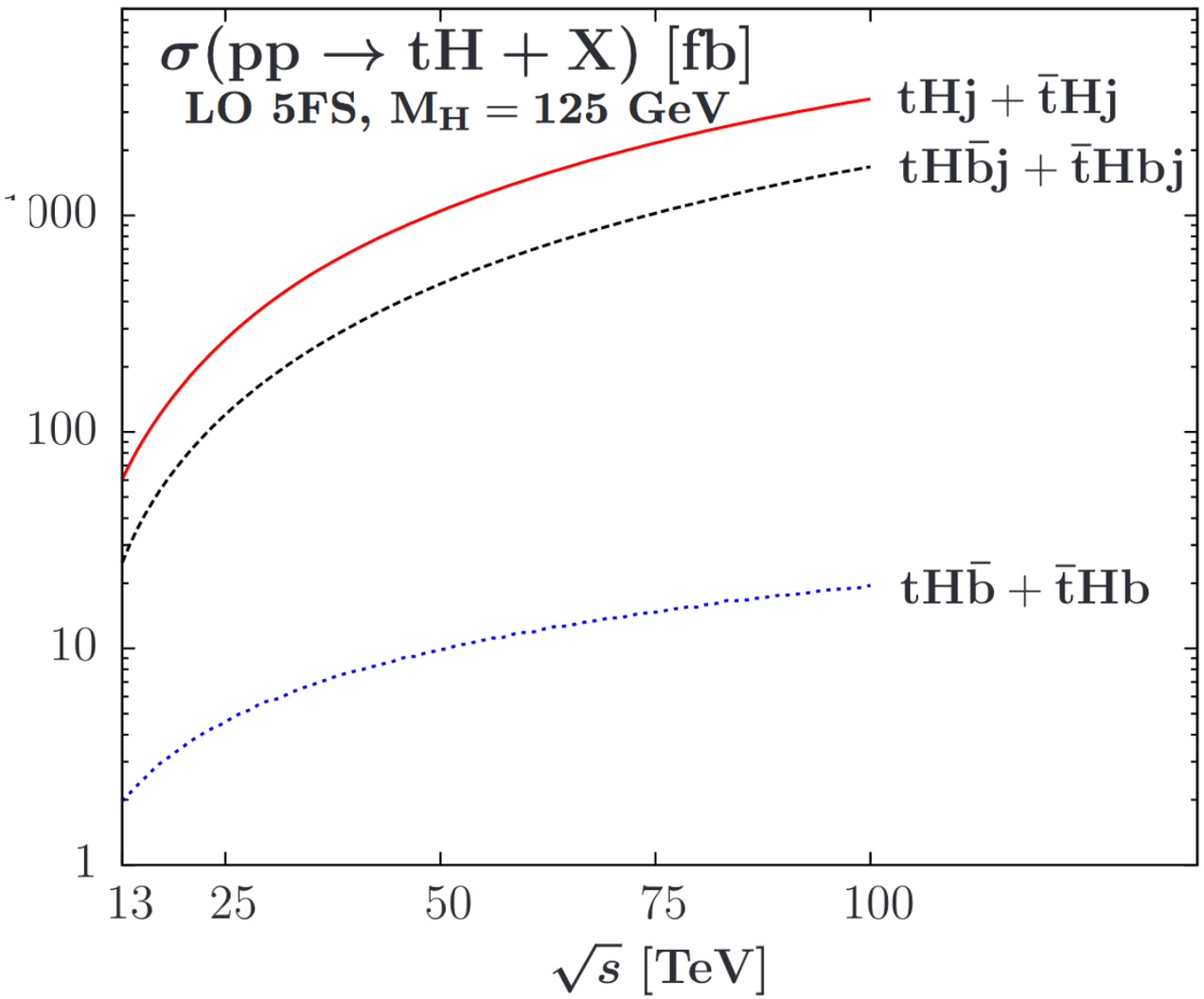
- enhancement of a factor of 10



Single top + Higgs at future colliders

- cross sections:

$\sqrt{s}$ [TeV]	$\sigma^{\rm LO}_{q\bar{q}'\to tH\bar{b}}$ [fb]	$\sigma^{\rm LO}_{qb\to tHq'}$ [fb]	$\sigma^{\rm LO}_{qg\to tH\bar{b}q'}$ [fb]
13	1.97	60.54	24.90
14	2.17	72.68	30.90
33	6.34	475.8	216.0
100	19.61	3453	1676



[Baglio, Djouadi, Quevillion, arXiv:1511.07853]

Higgs and top decays

- decay channels for $pp \to htj$

$h \to \bar{b}b$ semileptonic top	$3\,b + 1\,\text{forward jet} + \ell^{\pm} + E_T^{miss}$
consider $pp \to thjb$	$4\,b + 1\,\text{forward jet} + \ell^{\pm} + E_T^{miss}$

[Farina, Grojean, Maltoni, Salvioni, Thamm, arXiv:1211.3736]

$h \to \gamma\gamma, WW^*, \bar{\tau}\tau$	
hadronic top	$2\gamma + b + 3\ \text{jets}$
semileptonic top	$2\gamma + l + b + jet + E_T^{miss}$
	$> 2l + b + jets + E_T^{miss}$

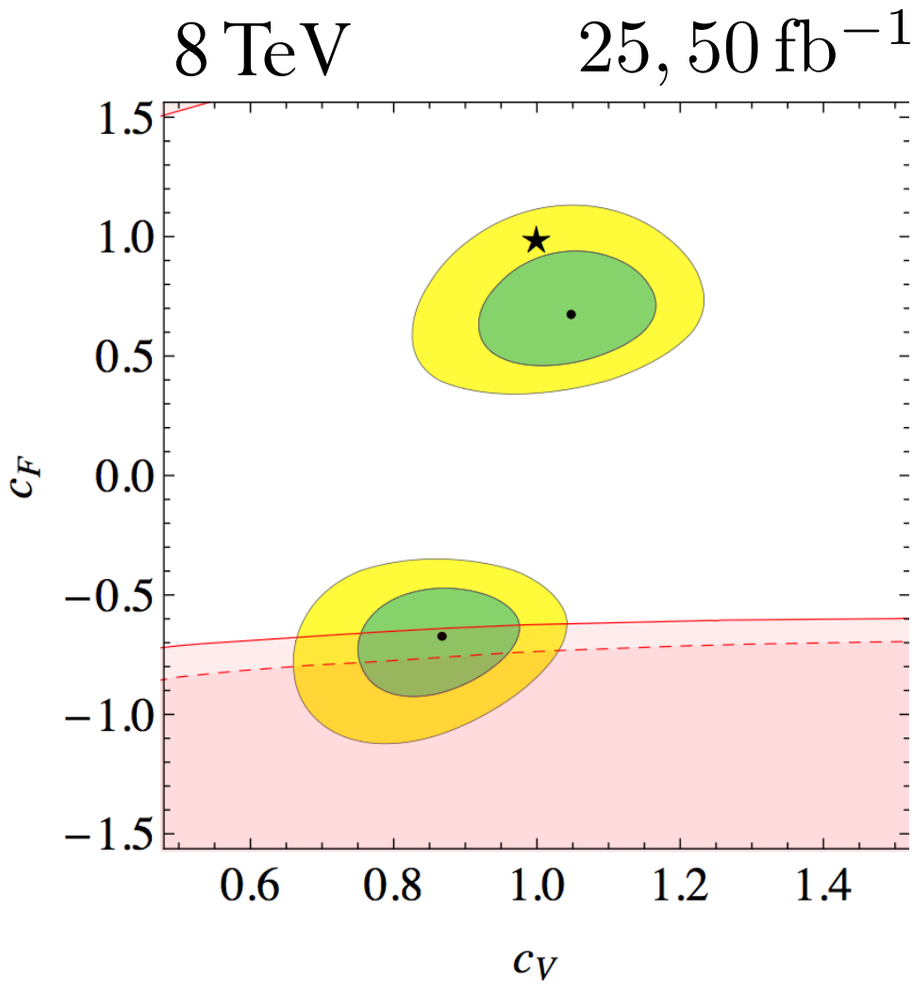
[Biswas, Gabrielli, Mele, arXiv:1211.0499]
[Biswas, Gabrielli, Margaroli, Mele, arXiv:1304.1822]

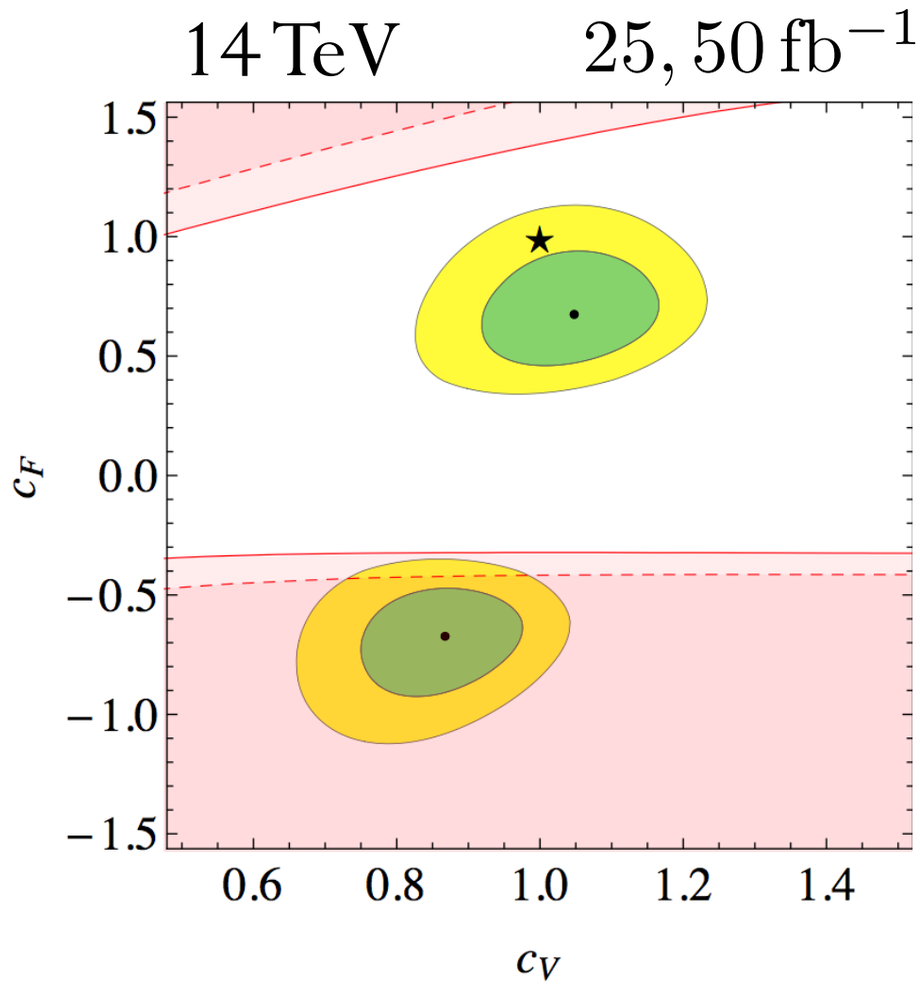
- already many experimental searches in these channels
- 95% CL upper limits on 2x expected cross-section for $c_F = -1$
- more in the next talk!

[CMS Combination, arXiv:1509.08159]

Higgs and top decays

- expectations, only to give an idea





[Farina, Grojean, Maltoni, Salvioni, Thamm, arXiv:1211.3736]

- 8 TeV not conclusive, 14 TeV can distinguish
- results a bit too optimistic?

How can $c_F = -1$ be realised in a model?

Models for negative Yukawa

- negative Yukawa coupling would point to new physics
- hard to explain, models are tightly constrained/have problems
- example: dim-6 operator

$$\mathcal{L}_{\text{eff}}^{(1)} = \frac{Y^3}{\Lambda^2}\left(H^\dagger H - \frac{v^2}{2}\right)(H\bar{q}_3 u_3^c + h.c.)$$

- does not change top mass
- gives a contribution to the top Yukawa coupling

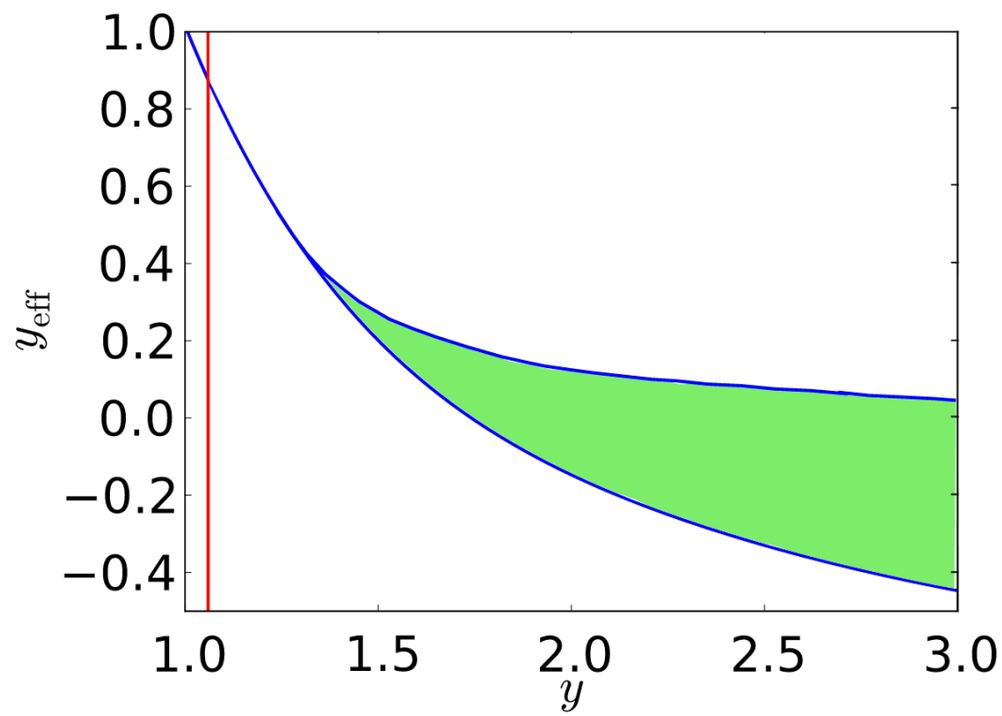
$$y_t^{\text{eff}} = \frac{\sqrt{2}m_t}{v} + \frac{Y^3}{\sqrt{2}}\frac{v^2}{\Lambda^2}$$

[El Hedri, Fox, Wacker, arXiv:1311.6488]

- for $y_t^{\text{eff}} < 0$, the cutoff scale Λ must be close to electroweak scale
- need new sub-TeV particles to generate operator
- tightly constrained
- possibilities are vector-like fermions, charged scalars

Models for negative Yukawa

- examples: top partners, additional Higgses
- light new particles with large couplings to the Higgs and the top
- serious trouble with 13 TeV data?
- too large couplings lead to low Landau problems
- models barely reach -1



[El Hedri, Fox, Wacker, arXiv:1311.6488]

Conclusions

- sign ambiguity in current Higgs coupling fits in $\bar{t}th$
- degeneracy can be lifted by single top + H production
- due to enhancement of $pp \to htj$ for $c_F = -1$
- already many experimental searches for leptonic and bosonic decays of the Higgs, hadronic and semileptonic top
- current searches not conclusive
- but expect 95% CL exclusion at 13 TeV
- need more data!

Backup

NLO Cross-sections

	$\sigma^{\mathrm{NLO}}(pp \to thj)$ [fb]	
	$c_F = 1$	$c_F = -1$
8 TeV	$18.28^{+0.42}_{-0.38}$	$233.8^{+4.6}_{-0.}$
14 TeV	$88.2^{+1.7}_{-0.}$	982^{+28}_{-0}