Some Thoughts on Top

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UNIVERSITÀ DEGLI STUDI DI PADOVA

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Why Studying the Top Quark ?

0) **It is there!**
   and we have the opportunity to study its properties

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We need to know top properties precisely!*
even to answer questions that are **unrelated** with the top quark itself

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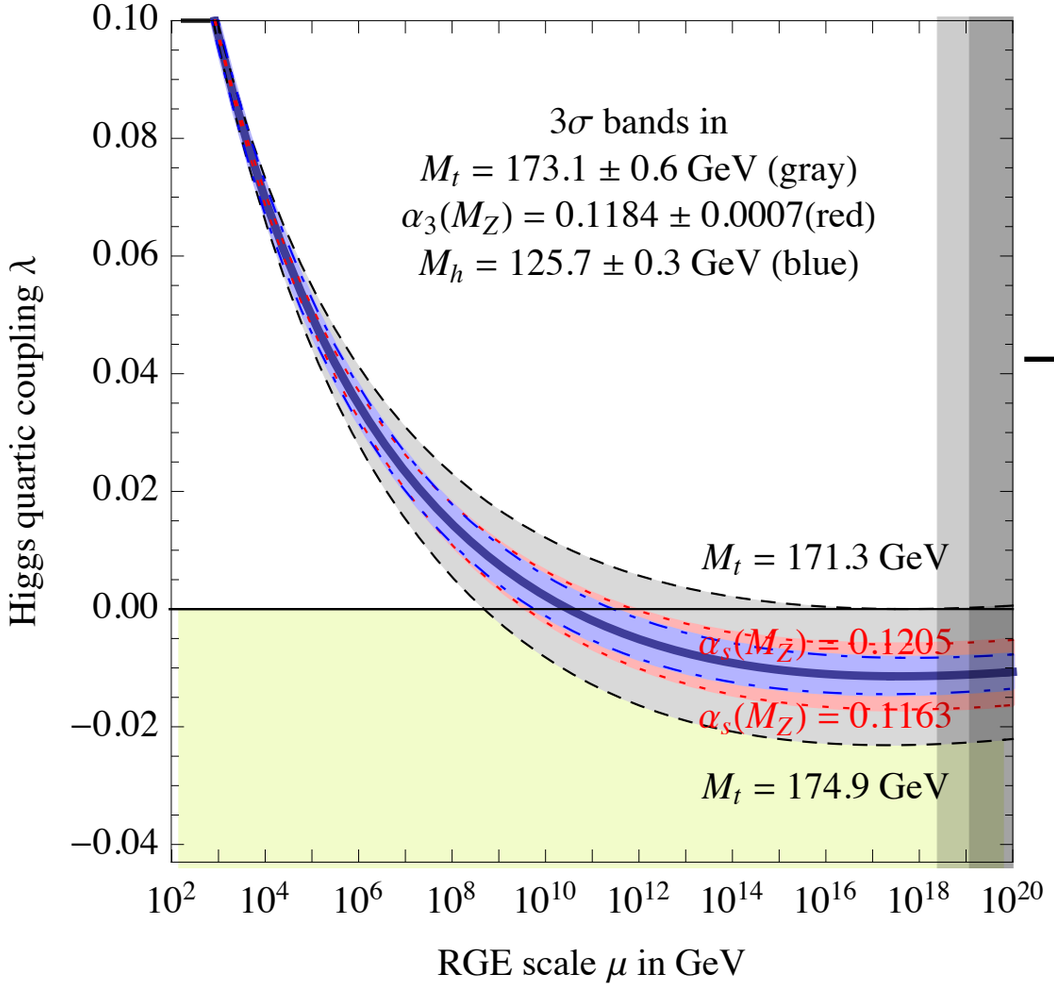
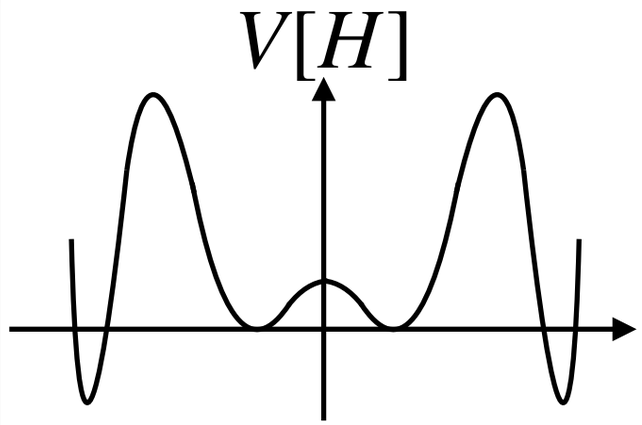
*See Sebastian’s talk

Vacuum (Meta-)Stability





…
[Bezrukov et al., 1205.2893]
[Degrassi et al., 1205.6497]
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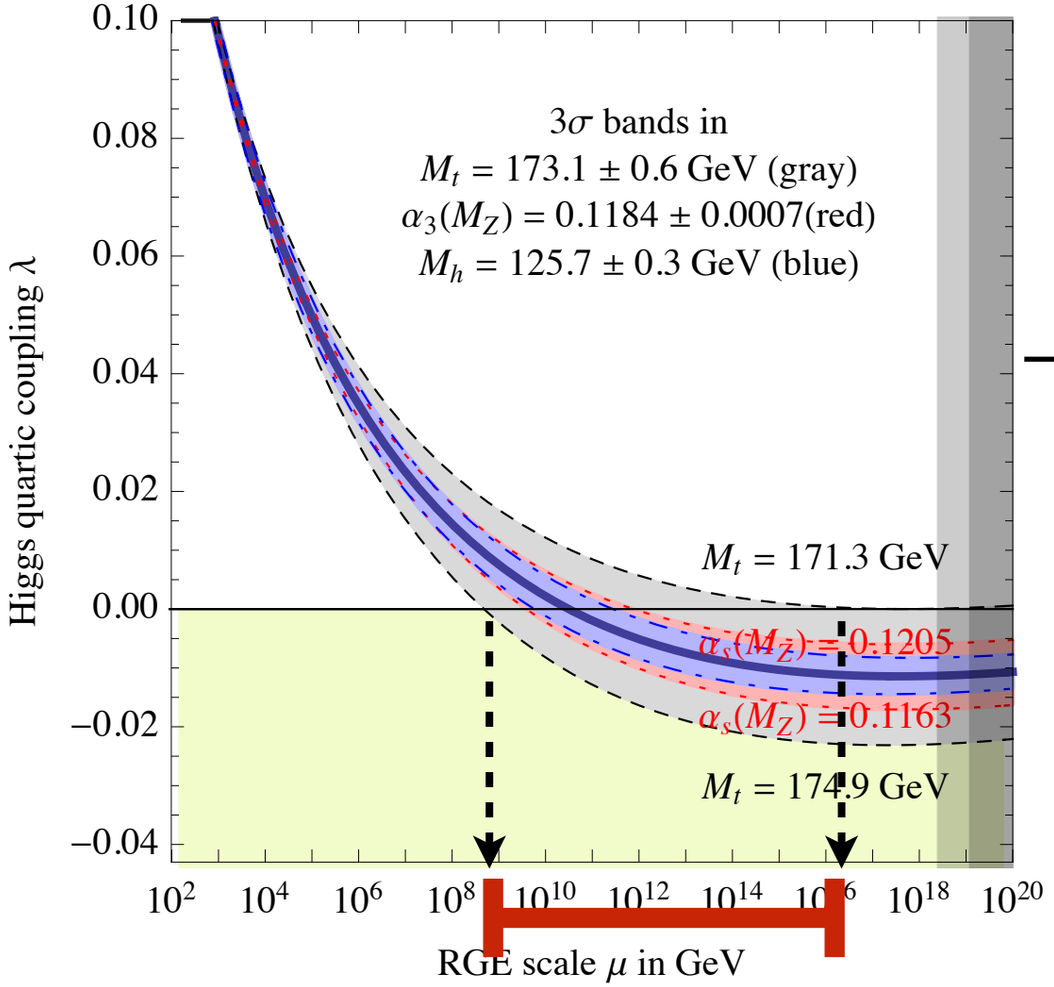

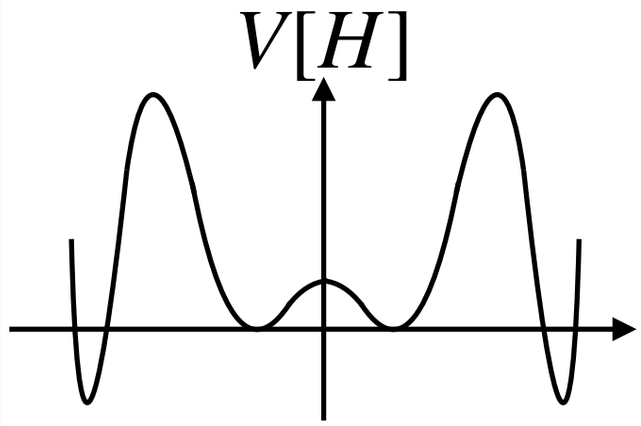

Uncertainty on Top mass (actually, y_t*) dominates instability scale uncertainty

Target for Future Colliders, see Andre's talk

*See Javier's talk

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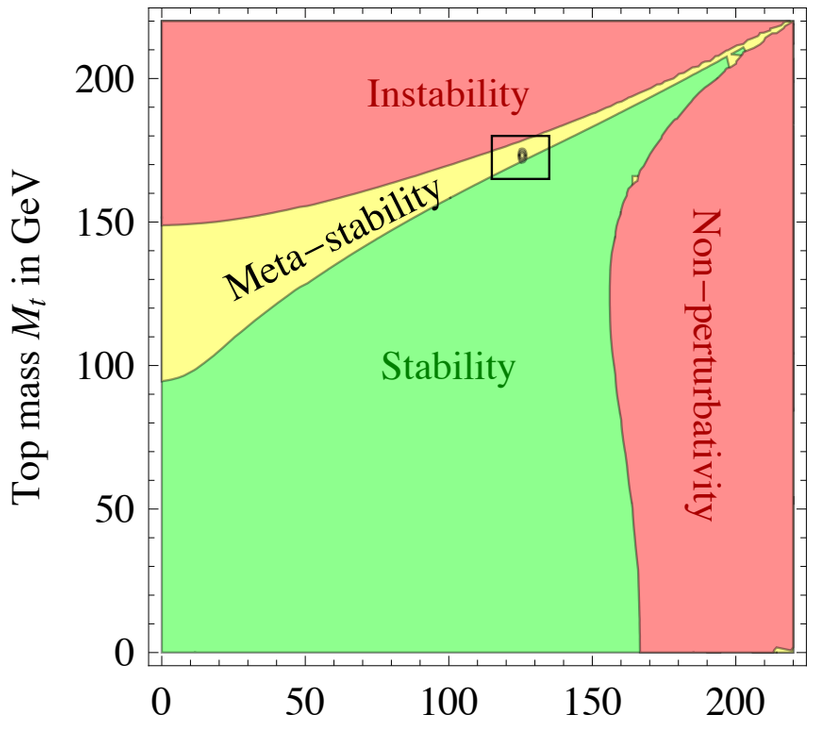

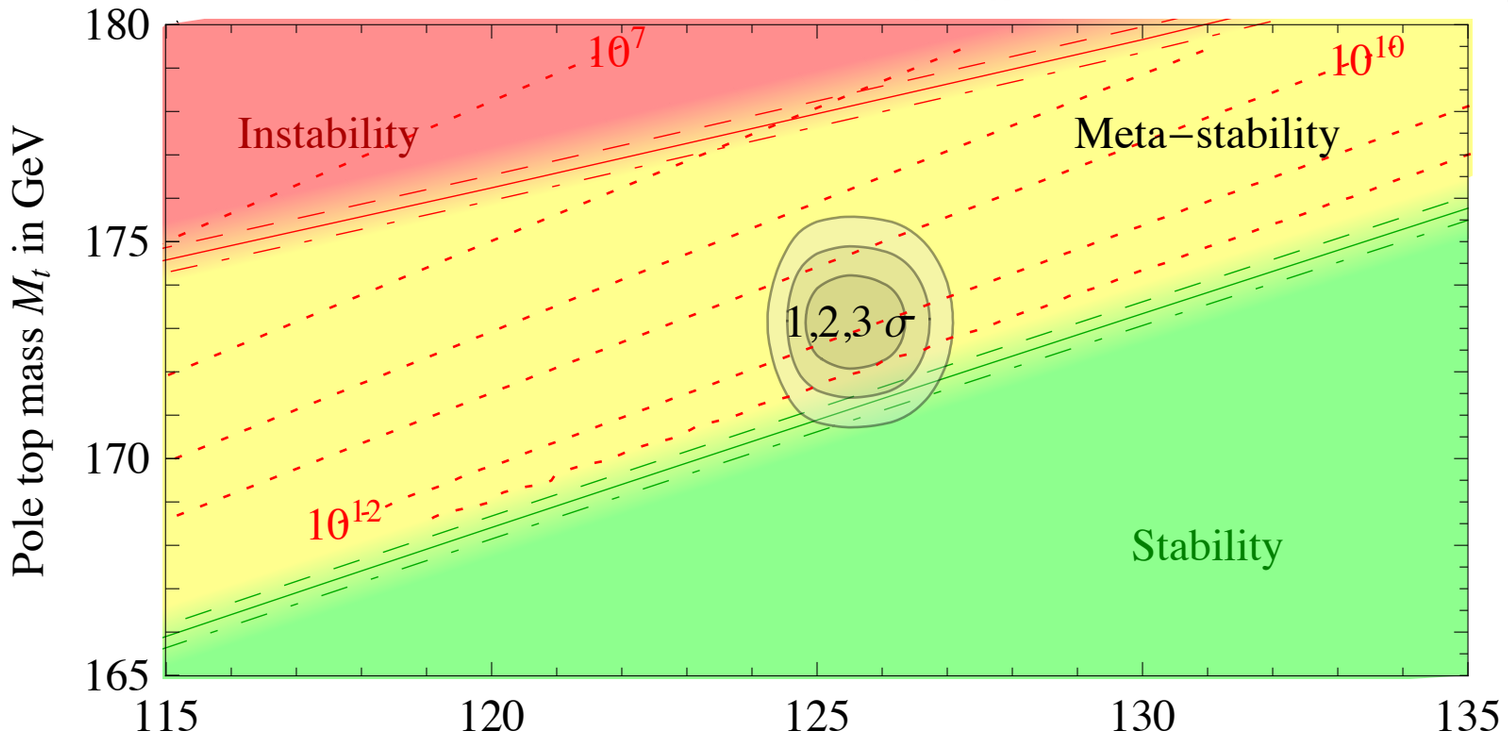

Knowing where the SM sits on this plane, precisely, will offer solid grounds to non-solid speculations like Asymptotic Safety and Higgs Inflation

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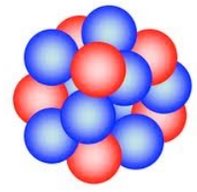
let’s discuss this concretely, for a **Composite Higgs**

Composite Higgs

Higgs is bound state of a new strong force:  $\left[l_H = \frac{1}{m_*} \right.$

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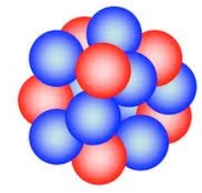
Higgs is bound state of a new strong force:  $l_H = \frac{1}{m_*}$

A sharp **putative** answer to the question of EWSB origin

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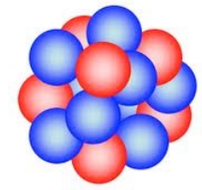

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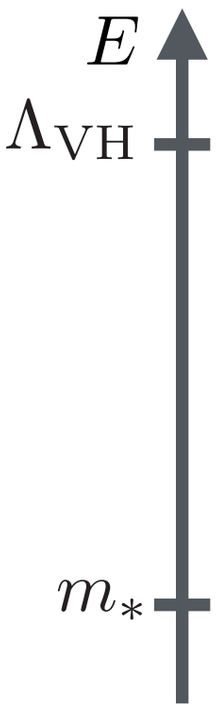

Two sectors exist at some Very High (>>TeV) scale $\Lambda_{\rm VH}$:

Composite Sector
QCD-like confining theory.
No Higgs field.

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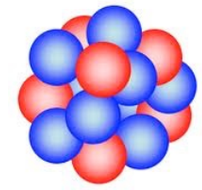
Higgs is bound state of a new strong force:  $l_H = \frac{1}{m_*}$

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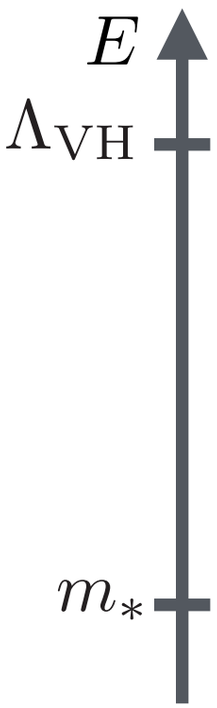

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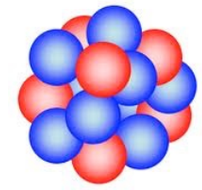
Higgs is bound state of a new strong force:  $l_H = \frac{1}{m_*}$

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SM **minus** Higgs
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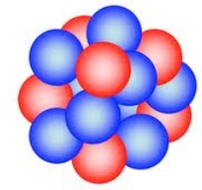
Higgs is bound state of a new strong force:  $l_H = \frac{1}{m_*}$

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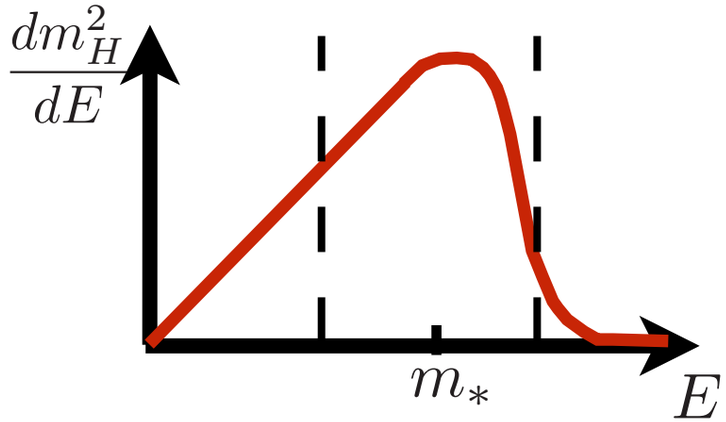
Higgs is SM-like if it is a **Nambu-Goldstone boson**

Higgs is **Naturally light** if $m_* \sim \mathrm{TeV}$
Composite Higgs is **transparent** to HE modes



Composite Higgs, Composite Top

The Top must couple a lot to CS, to get large Yukawa

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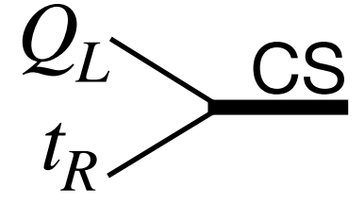
The “SM-like” bilinear coupling structure …



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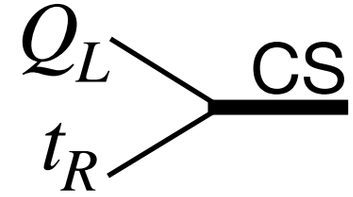

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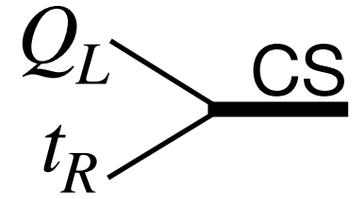

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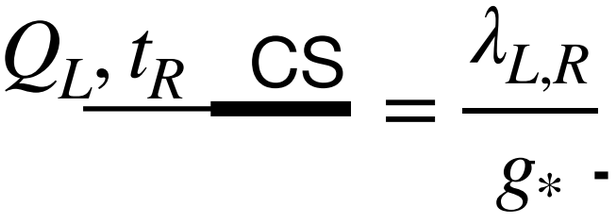

g_* is the typical coupling between CS "hadrons".

$$g_{\rm SM} \leq g_* < 4\pi$$

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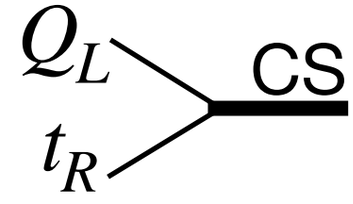

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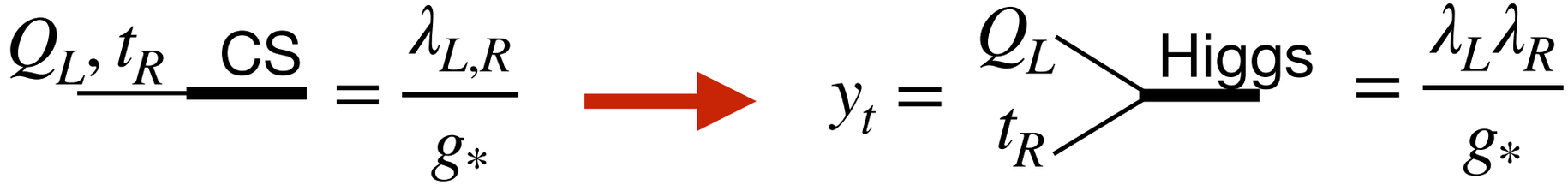

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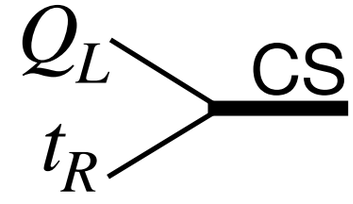

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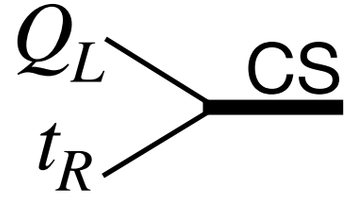

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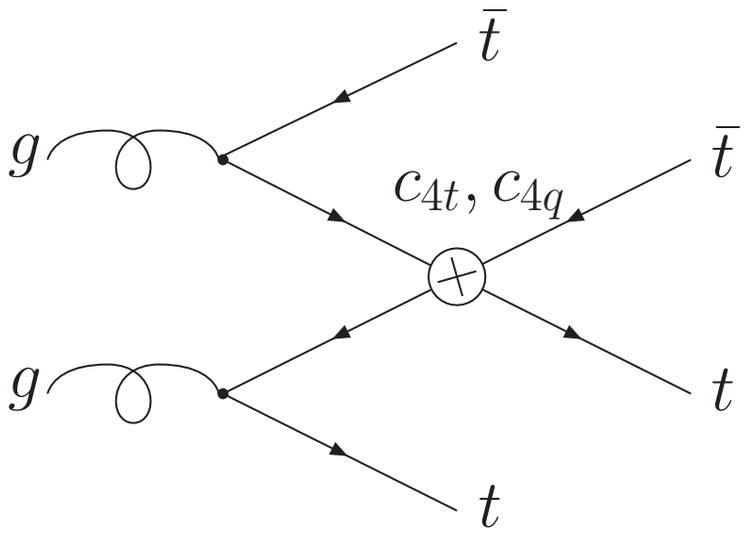
Totally Composite Top Right

Four Tops



$$\frac{g_*^2}{m_*^2}\bar{t}_R\gamma^\mu t_R\,\bar{t}_R\gamma_\mu t_R$$

[Pomarol et al., 0806.3247]
[Banelli et al., 2010.05915]
[ATLAS, 2007.14858]
[CMS, 1908.06463]
[CMS-PAS-FTR-18-031]
...
See Javi's talk

Coupling as large as it can be in CH —> best m_* reach

Grows $\propto E^2 = M_{tt}^2$ —> exploit both **energy** and **luminosity**

Its effect **CAN overcome** the SM tt>tt amplitude *

*what matters for EFT validity is $E < m_*$

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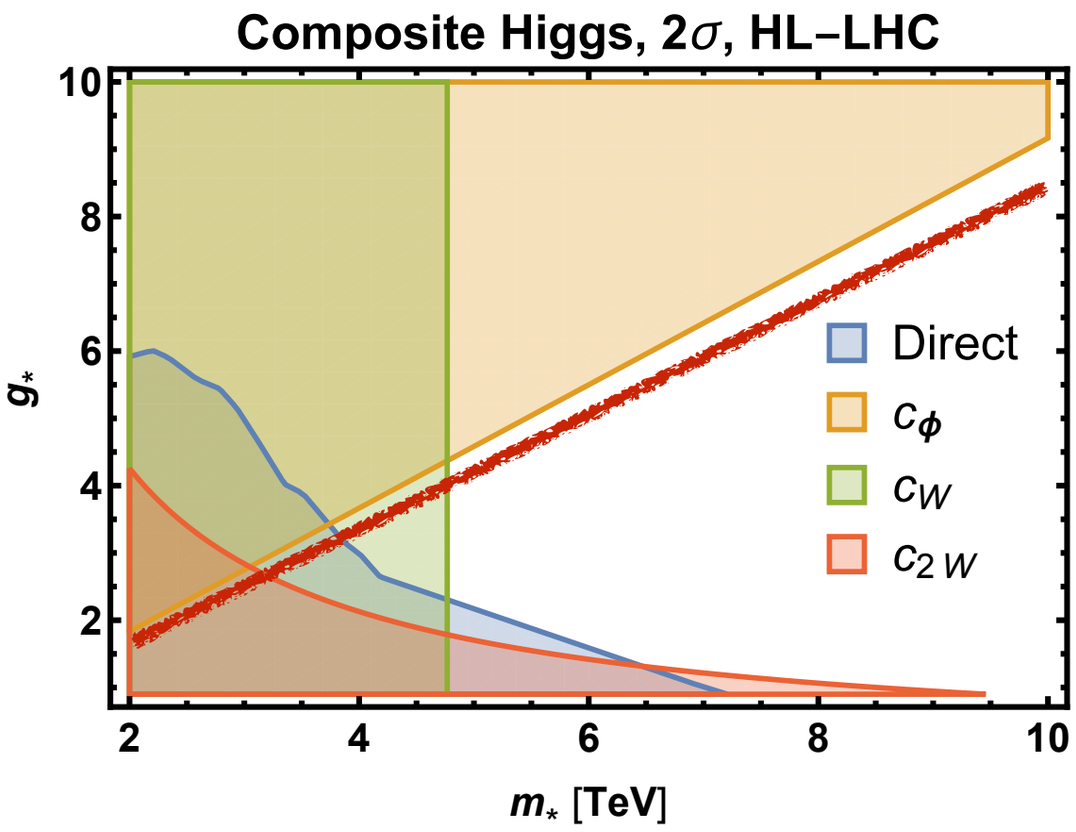
Best single-measurement CH probe at HL-LHC!
Today's data also competitive



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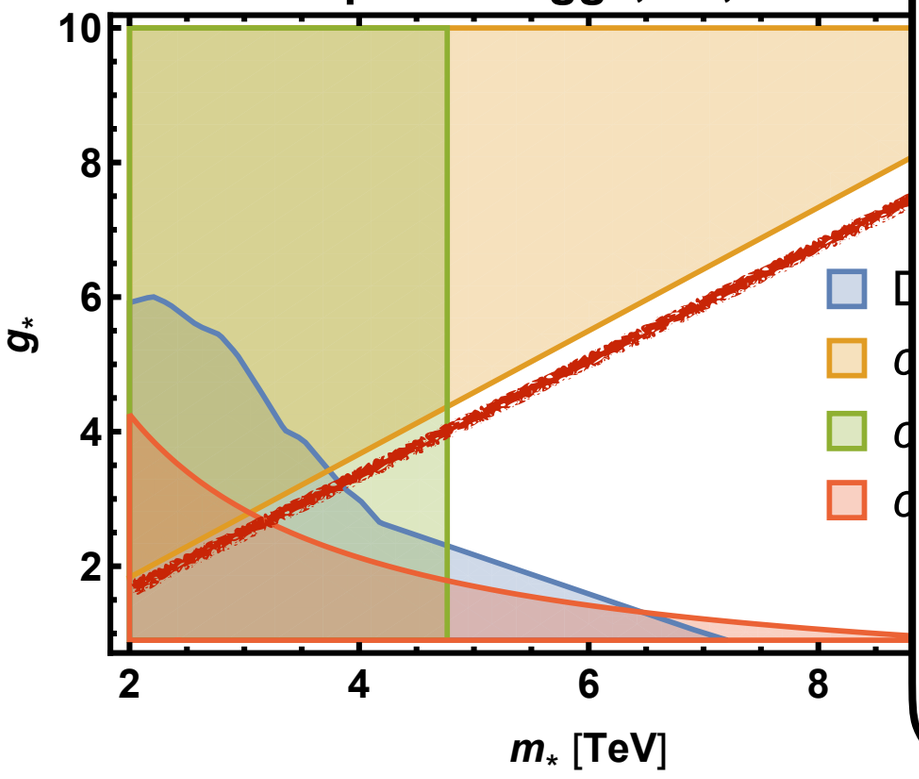
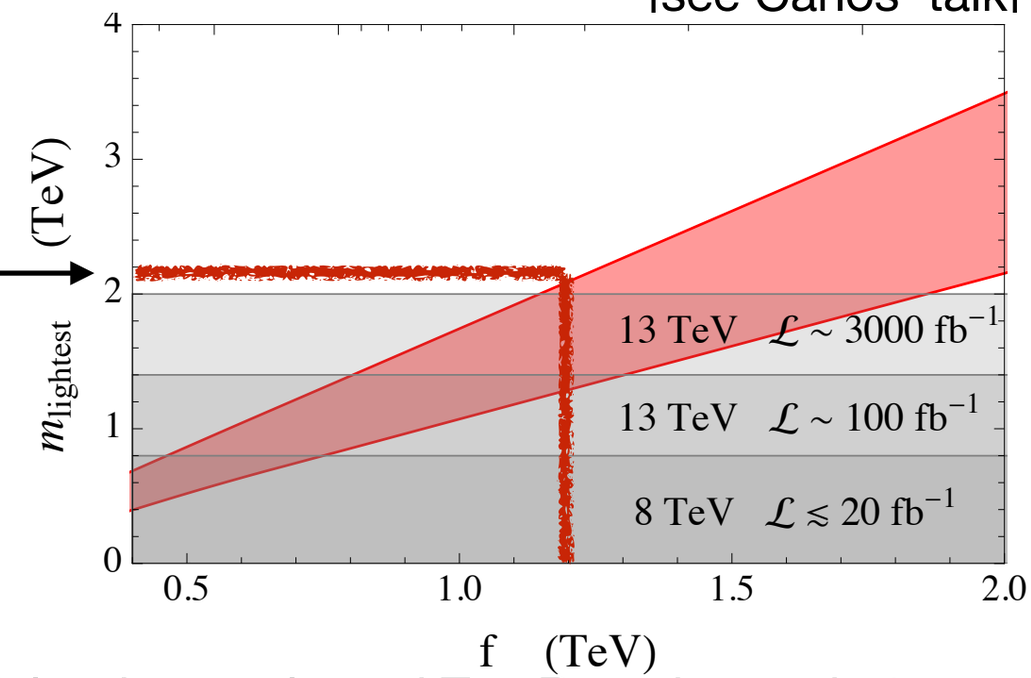


Don't forget **direct** Top Partners searches!*

[see Carlos' talk]

"equivalent" Top P. reach



*We have models where coloured Top P. are heavy, but we do not necessarily like those models!

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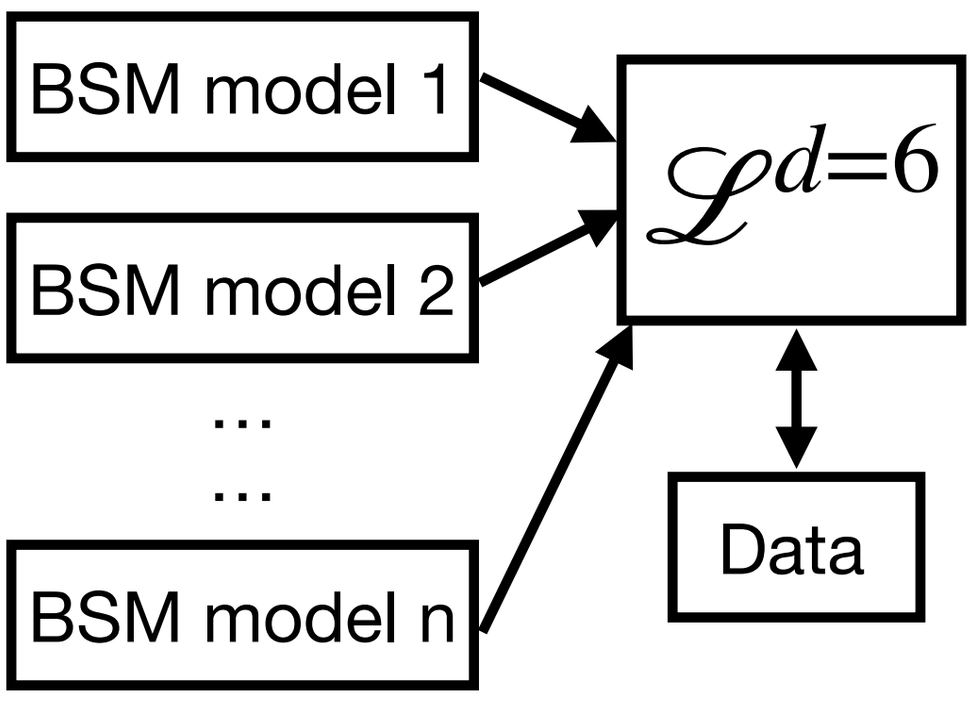

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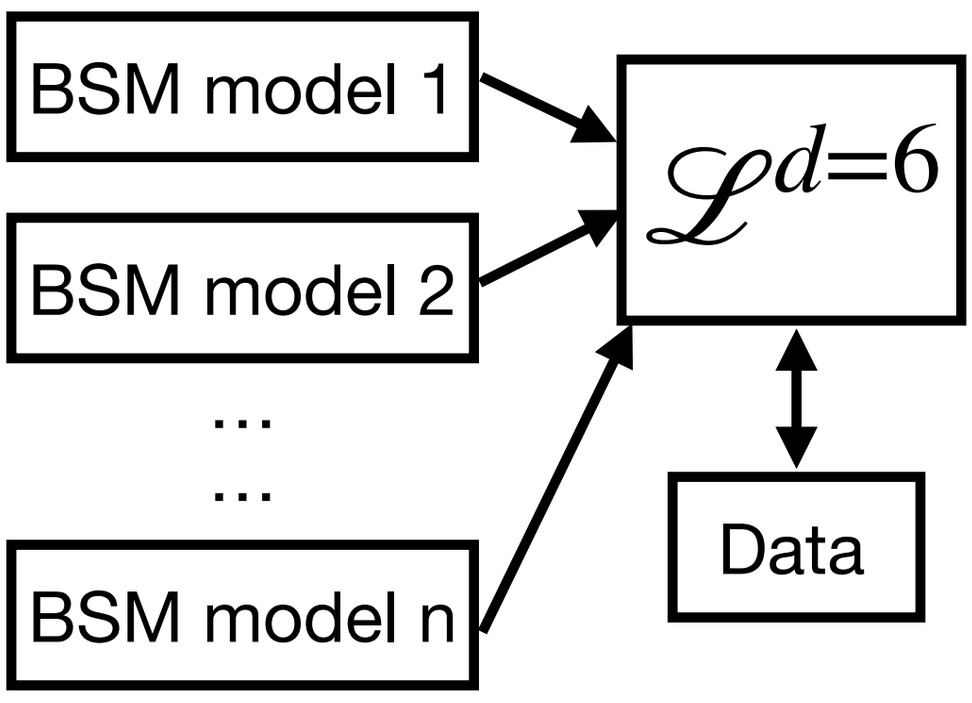

The EFT is a **container of models,** not a self-standing BSM scenario

Probes **several models** at once, including **not-yet formulated ones**

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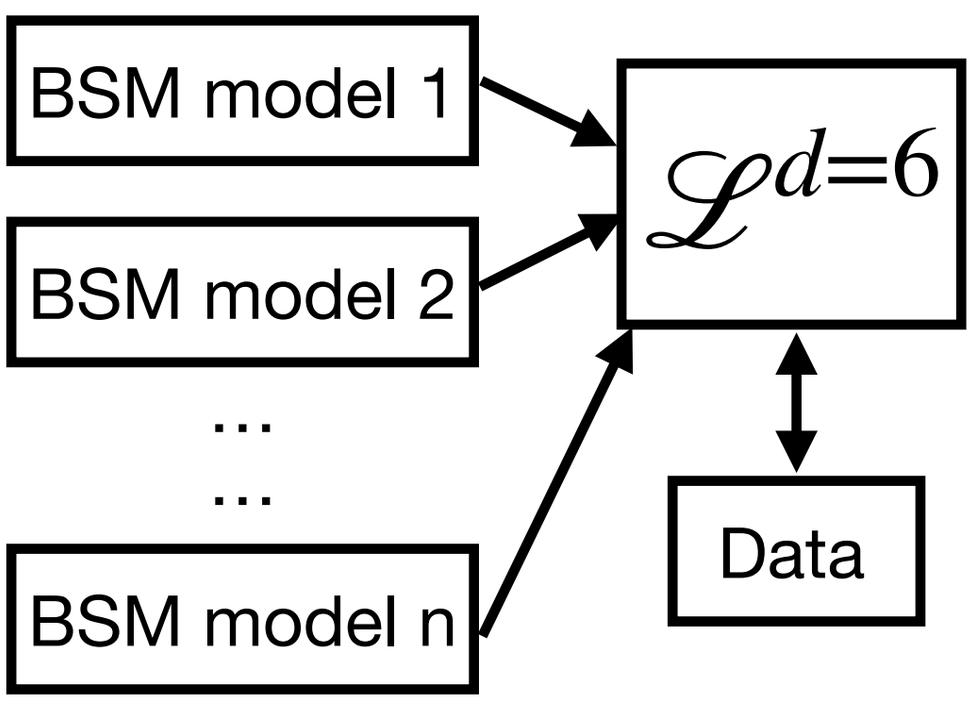

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Synergetic with one-model searches

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The EFT ToDo list, **unordered:**

- ✦ Define target interaction operators: [1802.07237]
  the **initial** target must be simple enough. E.g., **top-philic EFT** [1807.02441]

$$O_{tt} = (\bar{t}_R \gamma_\mu t_R)^2$$
$$O_{tq} = (\bar{t}_R \gamma_\mu t_R)(\bar{q}_L \gamma^\mu q_L)$$
$$O_{tq}^{(8)} = \left(\bar{t}_R \gamma_\mu t^A t_R\right)\left(\bar{q}_L \gamma^\mu t^A q_L\right)$$
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$$O_{Ht} = i(H^\dagger \overset{\leftrightarrow}{D}_\mu H)(\bar{t}_R \gamma^\mu t_R)$$
$$O_{Hq} = i(H^\dagger \overset{\leftrightarrow}{D}_\mu H)(\bar{q}_L \gamma^\mu q_L)$$
$$O_{Hq}^{(3)} = i(H^\dagger \sigma^a \overset{\leftrightarrow}{D}_\mu H)(\bar{q}_L \gamma^\mu \sigma^a q_L)$$
$$O_{y_t} = y_t H^\dagger H \bar{q}_L \tilde{H} t_R$$

$$O_{tW} = \left(\bar{q}_L \sigma^{\mu\nu} \tau^I t_R\right) \tilde{H} W^I_{\mu\nu}$$
$$O_{tB} = \left(\bar{q}_L \sigma^{\mu\nu} t_R\right) \tilde{H} B_{\mu\nu}$$
$$O_{tG} = \left(\bar{q}_L \sigma^{\mu\nu} T^A t_R\right) \tilde{H} G^A_{\mu\nu}$$

$$O_{tD} = (\partial^\mu B_{\mu\nu})(\bar{t}_R \gamma^\nu t_R)$$
$$O_{tD}^{(8)} = (D^\mu G^A_{\mu\nu})(\bar{t}_R \gamma^\nu t^A t_R)$$
$$O_{qD} = (\partial^\mu B_{\mu\nu})(\bar{q}_L \gamma^\nu q_L)$$
$$O_{qD}^{(8)} = (D^\mu G^A_{\mu\nu})(\bar{q}_L \gamma^\nu t^A q_L)$$
$$O_{qD}^{(3)} = (D^\mu W^a_{\mu\nu})(\bar{q}_L \gamma^\nu \sigma^a q_L)$$

= 4 Fermions

see Gauthier's and Javi's talks

The (Top) EFT Opportunity

The EFT ToDo list, **unordered:**

- ✦ Define target interaction operators: [1802.07237]
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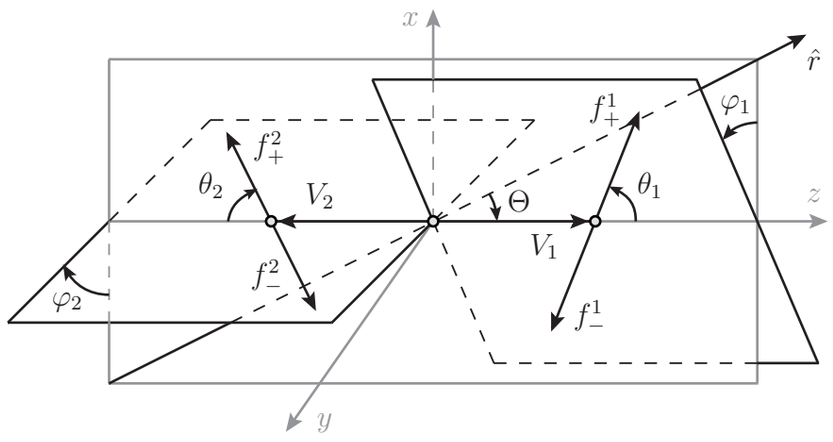
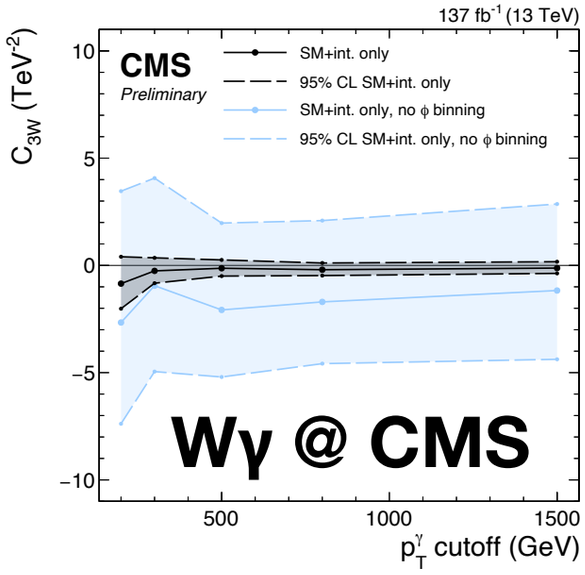
Interference Resurrection:

[1708.07823, CMS-PAS-SMP-20-005]





Gain factor 10 at int. level

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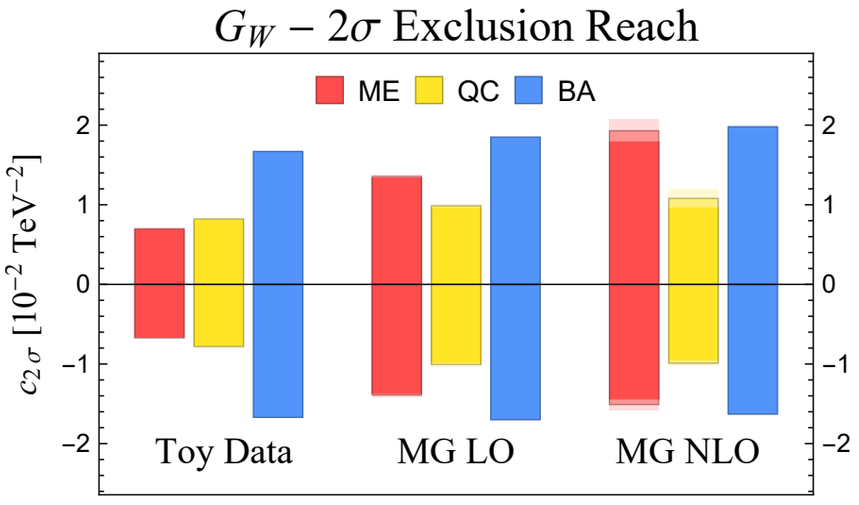

2007.10356

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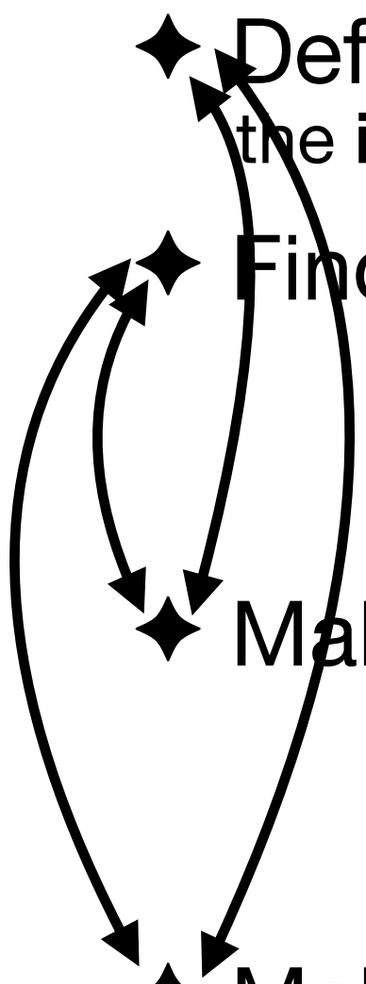

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The (Top) EFT Opportunity

For instance …

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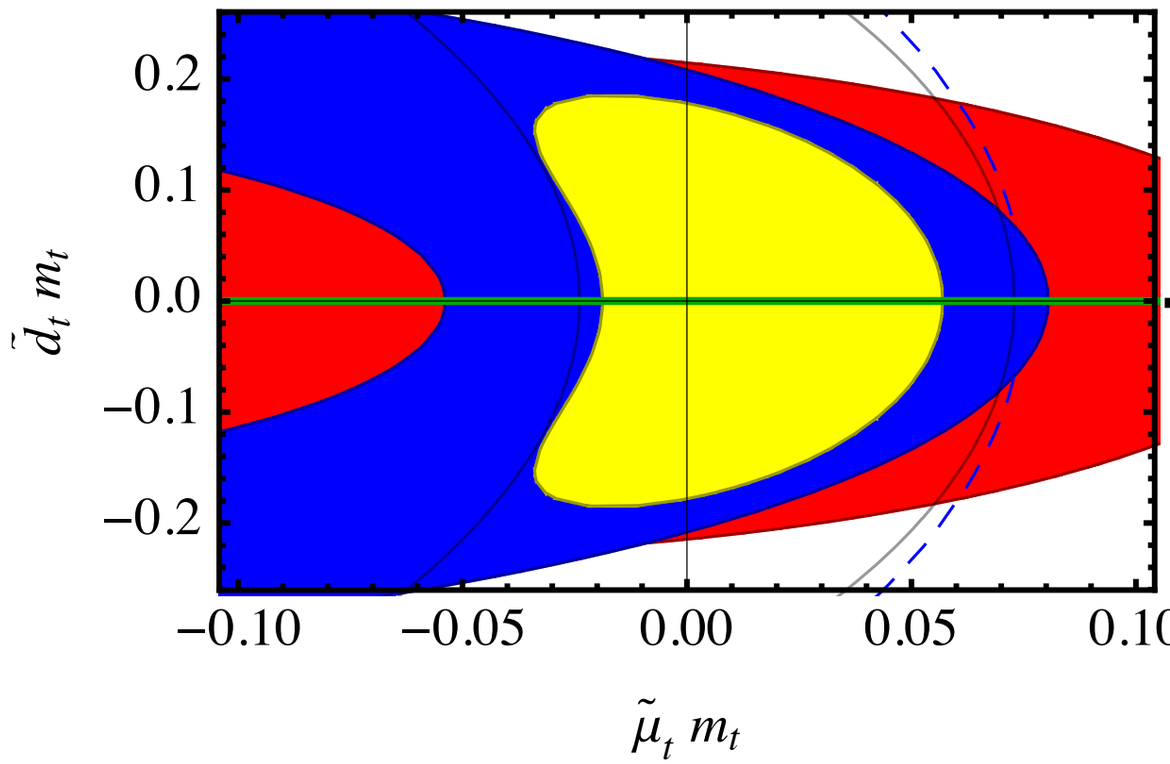

→ Top CEDM from neutron EDM

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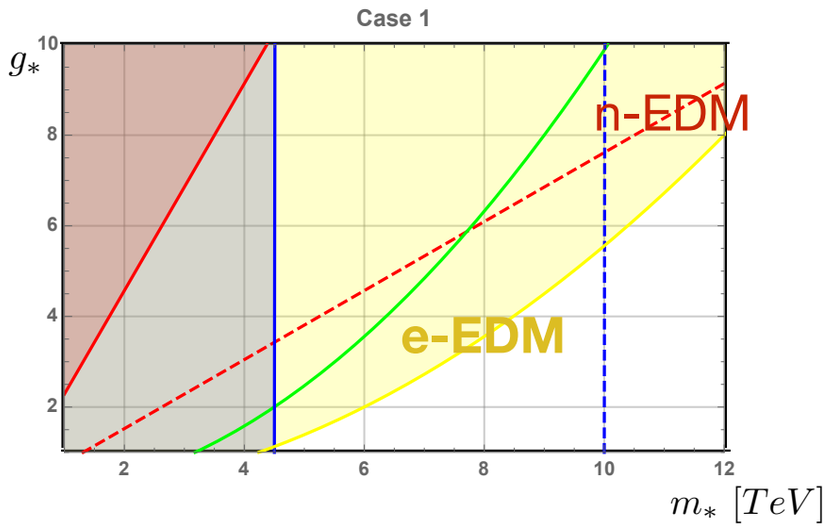
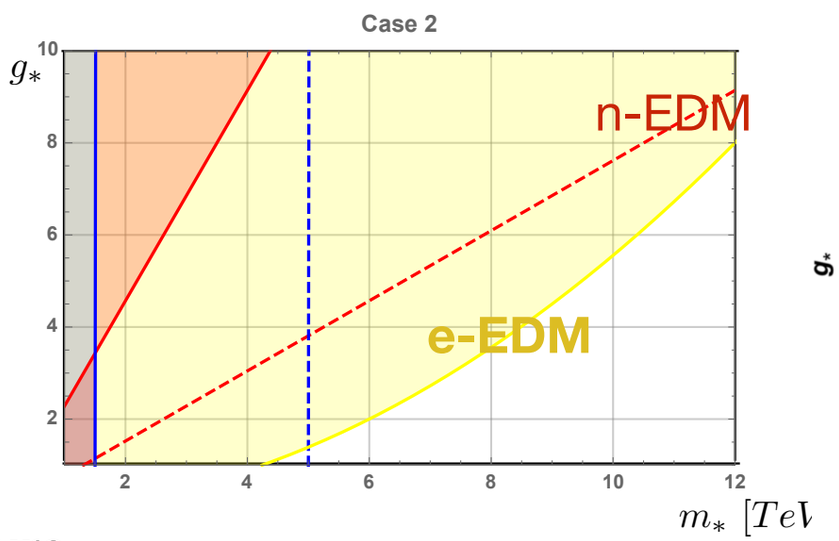
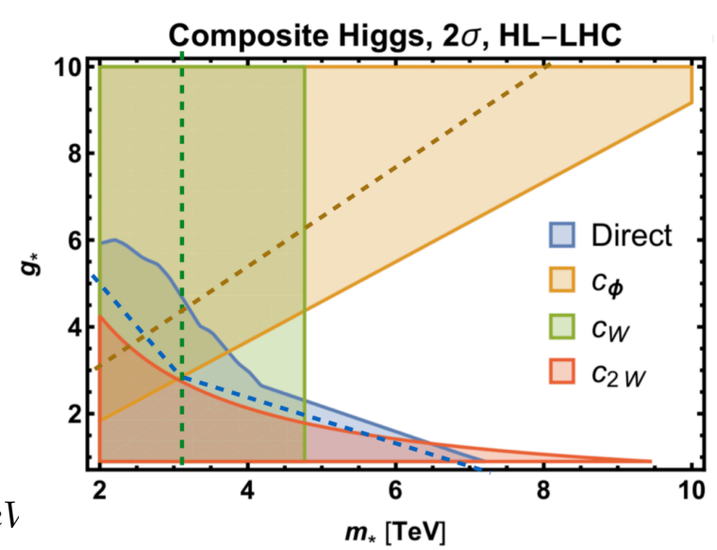
Simple Top-philic Flavour Patterns: [Barbieri, 1910.00371]







——— = now - - - - - - = future

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  Clear ≠ **Easy !** Needs EXP/QCD/PDF/BSM work

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Thank You