BSM implications for top (and Higgs) physics

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Outline

- heavy top + naturalness → BSM near the TeV scale
- top partner searches
- top AFB implications from TeV scale BSM
- top/Higgs connexion

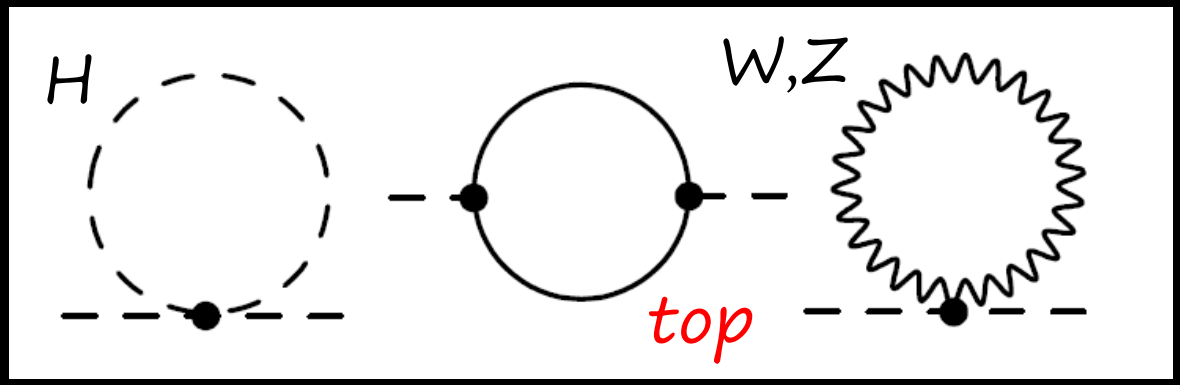
Q: why top quark is so special?

A: because it's heavy!

- *experimentally:* heavy top does not hadronize $\Gamma_{top} \gg \Lambda_{QCD}$
  - measure top spin → spin-spin correlation in t-tbar events
  - measure top chirality if boosted from BSM decay
- *theoretically:* heavy top destabilizes the weak scale

both features have common origin:
top couples with $o(1)$ strength
to electroweak symmetry breaking sector

Q: what makes the observed SM-like Higgs so light?

$\delta m^2 =$ 

$\sim \frac{g^2 \Lambda^2}{16\pi^2}$

What's Λ? natural theory if $\delta m^2 \sim m^2 \rightarrow \Lambda \sim$ TeV

If nothing but gravity $\rightarrow \Lambda = M_{Pl} \sim 10^{19}$ GeV = *hierarchy problem*

2 ***new physics*** paths:

- $\Lambda \sim M_{Pl}$ but there's a new symmetry above the TeV scale
  e.g. supersymmetry
- SM fields couple to a new strong dynamics with $\Lambda \sim$ TeV
  e.g. composite Higgs models

be it weakly or strongly coupled,
natural BSM theories have
top partners < 1 TeV
to soften the UV sensitivity of the Higgs mass

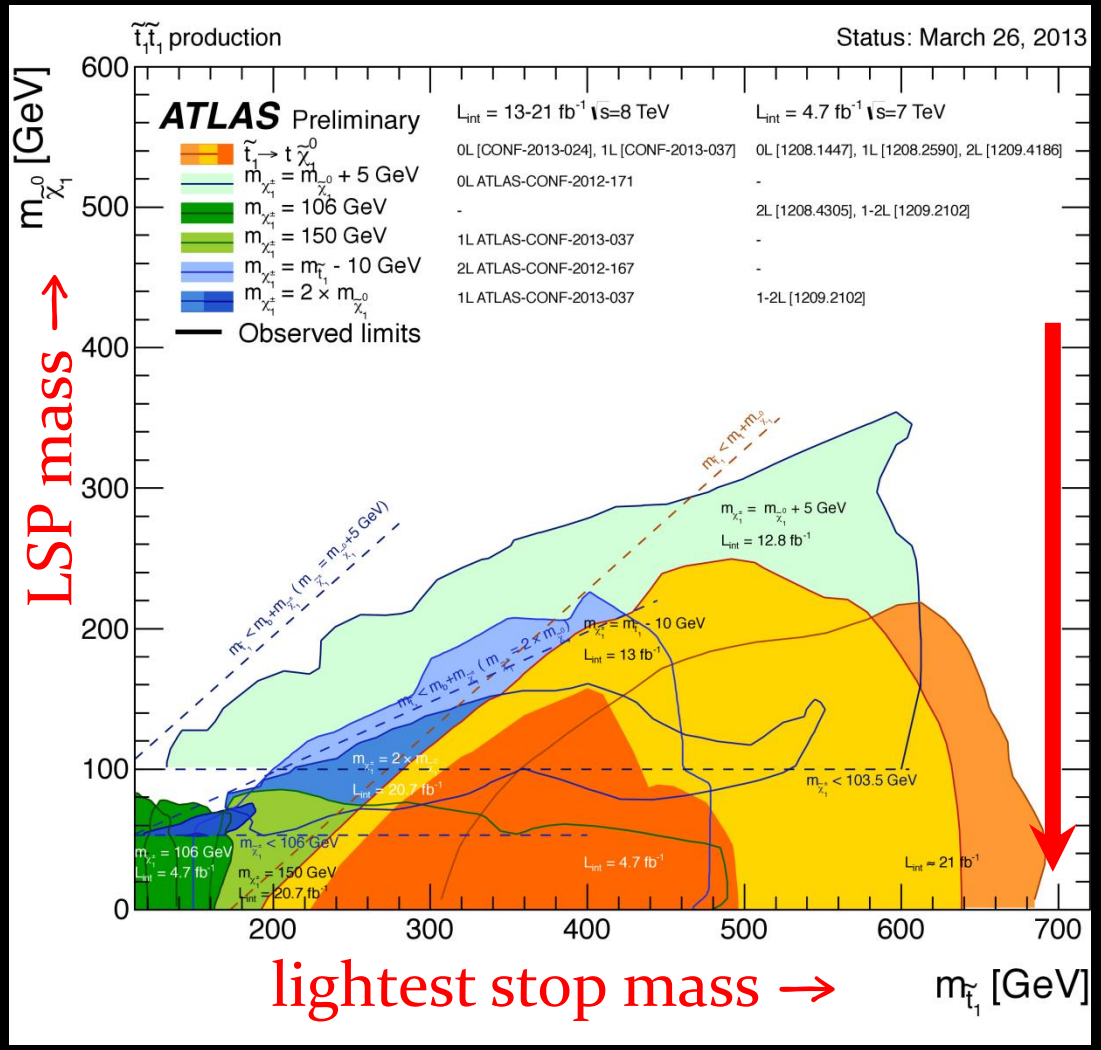
SUSY → light stops

Barbieri-Giudice '88,..., Papucci-Ruderman-Weiler '11

current limits are rather strong:

$m_{stop} > \sim 700 GeV$

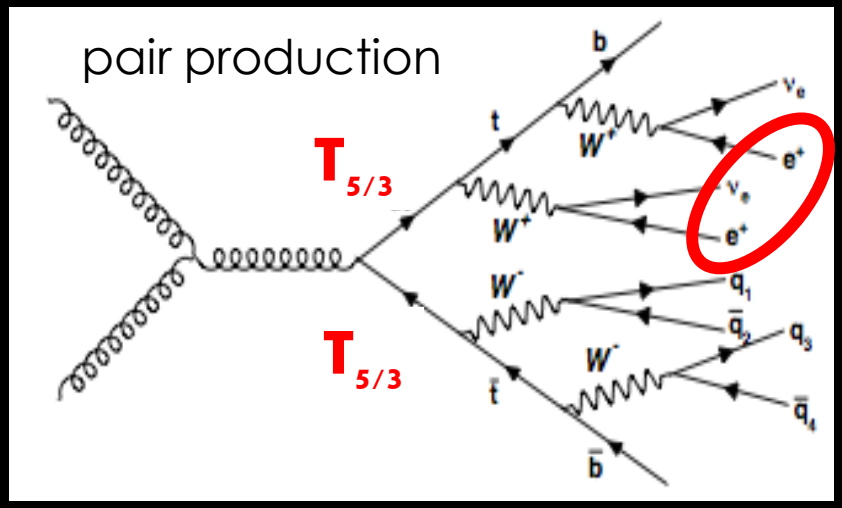
unless spectrum is compressed $m_{stop} \sim m_{top}$

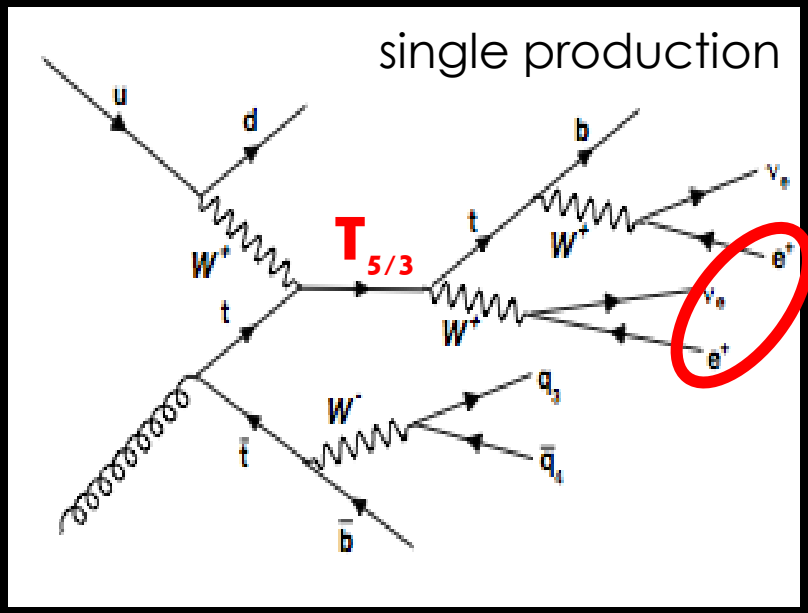


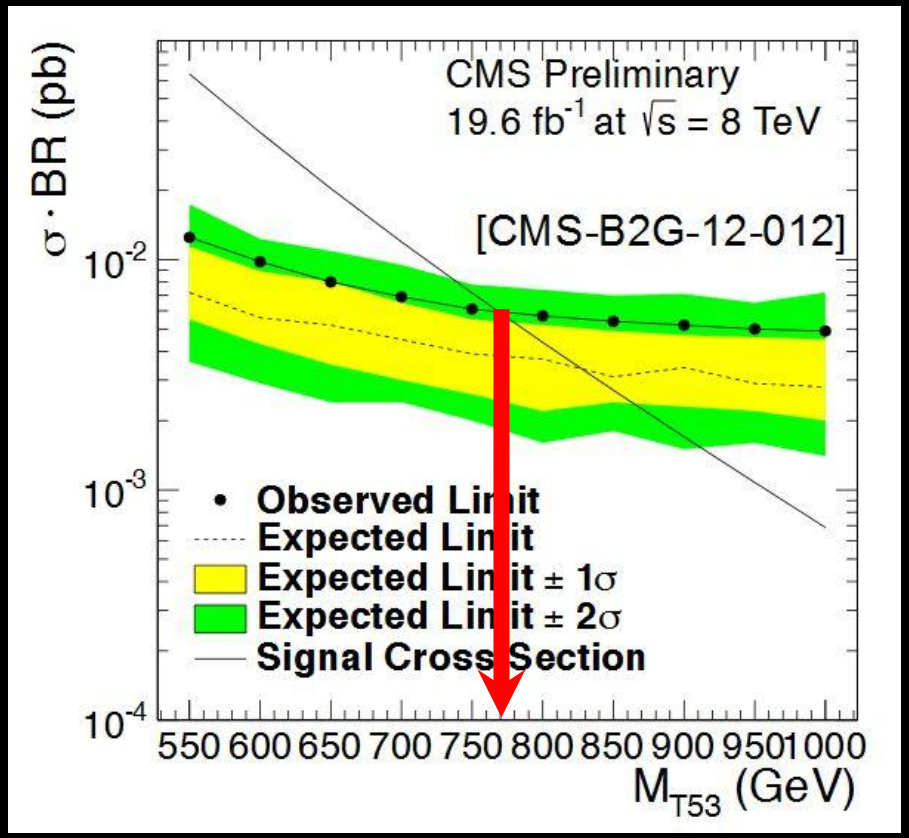
composite pGB Higgs models → cleanest signal = $T_{5/3}$

Contino-Servant '08, Mrazek-Wulzer '09, Rattazzi et al. '12

vector-like quark (Q=5/3)
« custodial » partner of top







$m_{T5/3} > \sim 770$ GeV

taken from Stelzer @HCP'12

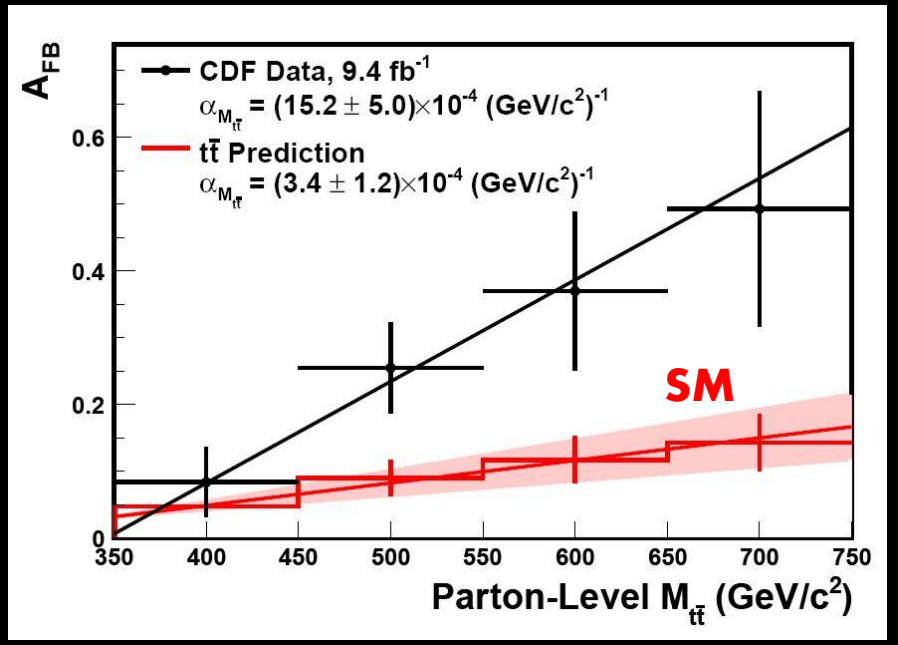
direct searches of top partners at the LHC7+8
have started to pressure naturalness

are there other indirect hint for BSM in top physics?

CDF 1211.1003

A_{FB} at the Tevatron:

"tops fly forward, even more at higher energies"



CDF+DO combined results: post-Moriond 2012

$A_{FB}^{\text{inclusive}} \approx (18\pm4)\%$ *in ttbar rest frame*

$A_{FB}^{>450\text{GeV}} \approx (28\pm6)\%$ *in ttbar rest frame*

QCD+EW state of the art: $A_{FB}^{[\text{incl}|>450]} \approx [6.6|10]\% \pm ??$

→ $o(3\sigma)$ tension with QCD

Q: ***is it new physics?***

A_{FB} from hard top physics:

CD-Gedalia-Hochberg -Perez-Soreq '11
(see also Degrande et al. '10)

Λ_{NP}>TeV : $\mathcal{L}_{top} = \mathcal{L}_{SM} + \mathcal{L}_{d=6}$

operators relevant to $q\bar{q} \to t\bar{t}$ transition @high m_{tt}

above 450GeV $q \simeq u$ since luminosity ratio $d\bar{d}/u\bar{u} \lesssim 20\%$

$\mathcal{L}_{d=6} \supset$

$$\mathcal{O}_A^8 = (\bar{u}\gamma_\mu\gamma^5 T^a u)(\bar{t}\gamma^\mu\gamma^5 T^a t)\,,$$
$$\mathcal{O}_V^8 = (\bar{u}\gamma_\mu T^a u)(\bar{t}\gamma^\mu T^a t)\,.$$

interfere w/QCD prodution

$$\mathcal{O}_{AV}^8 = (\bar{u}\gamma_\mu\gamma^5 T^a u)\,(\bar{t}\gamma^\mu T^a t)\,, \qquad \mathcal{O}_{VA}^8 = (\bar{u}\gamma_\mu T^a u)\,(\bar{t}\gamma^\mu\gamma^5 T^a t)$$

$$\mathcal{O}_V^1 = (\bar{u}\gamma_\mu u)\,(\bar{t}\gamma^\mu t)\,, \qquad \mathcal{O}_A^1 = (\bar{u}\gamma_\mu\gamma^5 u)\,(\bar{t}\gamma^\mu\gamma^5 t)\,,$$
$$\mathcal{O}_{AV}^1 = (\bar{u}\gamma_\mu\gamma^5 u)\,(\bar{t}\gamma^\mu t)\,, \qquad \mathcal{O}_{VA}^1 = (\bar{u}\gamma_\mu u)\,(\bar{t}\gamma^\mu\gamma^5 t)\,.$$

don't interfere w/QCD

$$\mathcal{O}_S^{1,8} = (\bar{u}\,T_{1,8}u)\,(\bar{t}\,T_{1,8}t)\,, \qquad \mathcal{O}_P^{1,8} = (\bar{u}\,T_{1,8}\gamma^5 u)\,(\bar{t}\,T_{1,8}\gamma^5 t)\,,$$
$$\mathcal{O}_{SP}^{1,8} = i\,(\bar{u}\,T_{1,8}u)\,(\bar{t}\,T_{1,8}\gamma^5 t)\,, \qquad \mathcal{O}_{PS}^{1,8} = i\,(\bar{u}\,T_{1,8}\gamma^5 u)\,(\bar{t}\,T_{1,8}t)\,,$$
$$\mathcal{O}_T^{1,8} = (\bar{u}\,T_{1,8}\sigma^{\mu\nu}u)\,(\bar{t}\,T_{1,8}\sigma_{\mu\nu}t)\,,$$

Fitting the EFT to Tevatron data:

CD-Gedalia-Hochberg-Soreq '12

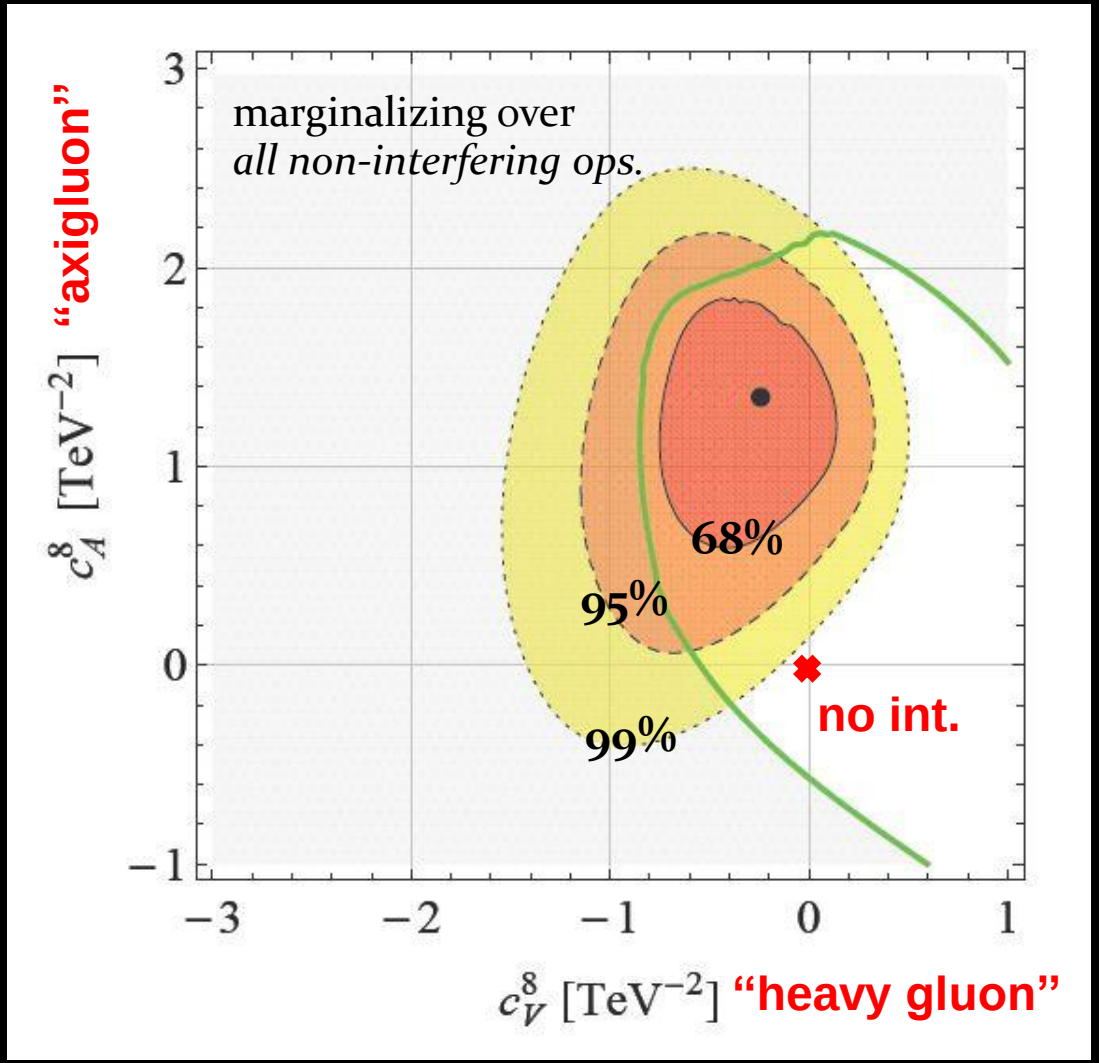
- fitted data:
  - inc. XS@DO
  - diff. XS@CDF
  - inc. A_{FB}@DO l+j *&* CDF dil
  - diff. A_{FB}@CDF l+j

- main lesson:

heavy BSM for AFB is most likely an *axigluon*

→ *looks like ad-hoc BSM...*

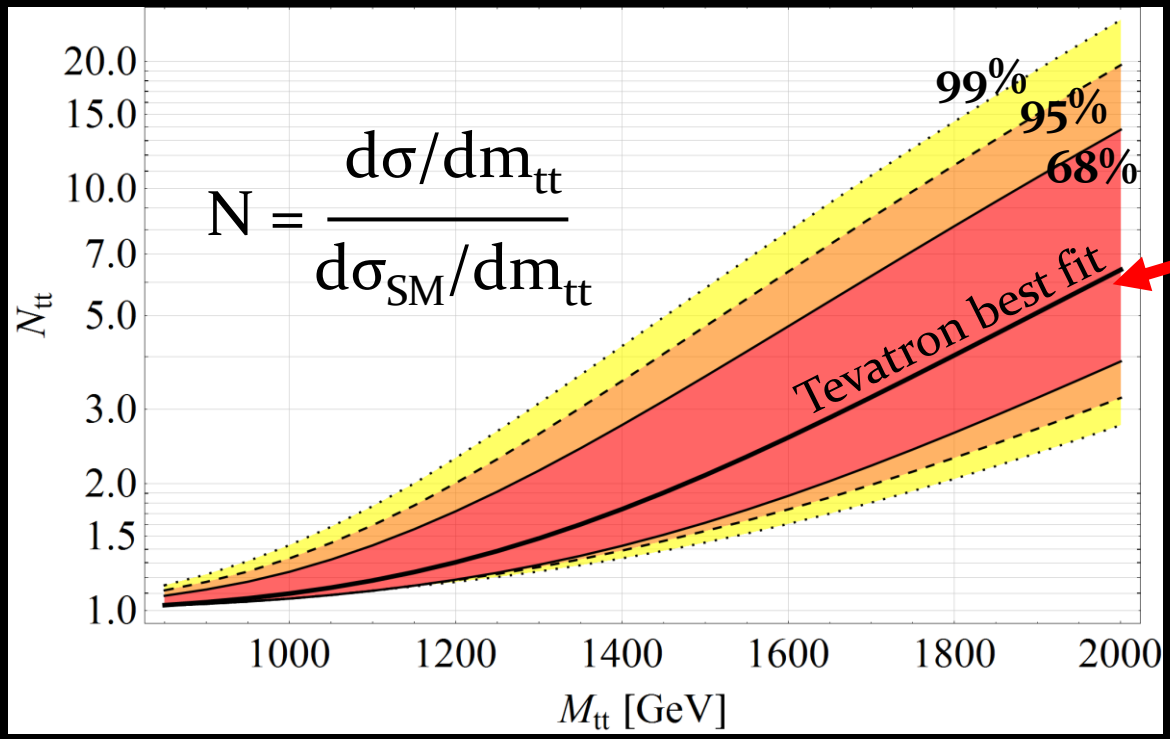
$\Lambda_{NP} \sim< 10\text{TeV}$



EFT generic predictions for the LHC

LHC higher $E_{c.m.}$ could unveil the hard scale driving A_{FB}
by directly producing heavy (wide) t-tbar resonances

If NP state are still too heavy, EFT applies again
and predicts a visible imprint in ttbar spectrum tail



contours consistent
with Tevatron fit's CLs

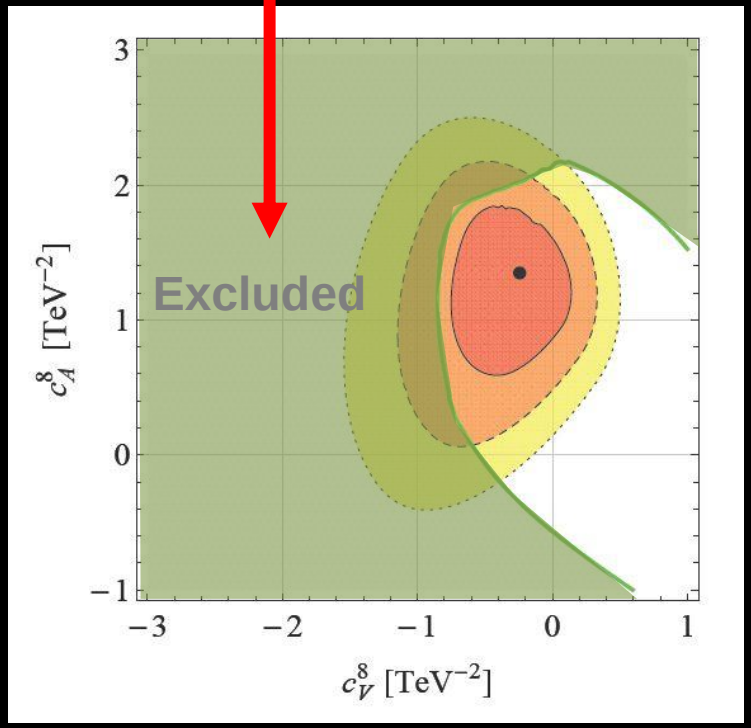
CD-Gedalia
-Hochberg-Soreq '12

hard to see a wide resonance decaying to boosted tops

CMS bounded the integrated t-tbar tail above 1TeV
@LHC7 *(boosted all hadronic sample)* arxiv:1204.2488

$$\mathcal{S} = \frac{\int_{m_{t\bar{t}}>1\,\mathrm{TeV}/c^2} \frac{d\sigma_{SM+NP}}{dm_{t\bar{t}}} dm_{t\bar{t}}}{\int_{m_{t\bar{t}}>1\,\mathrm{TeV}/c^2} \frac{d\sigma_{SM}}{dm_{t\bar{t}}} dm_{t\bar{t}}}$$

< 2.6 @95%CL

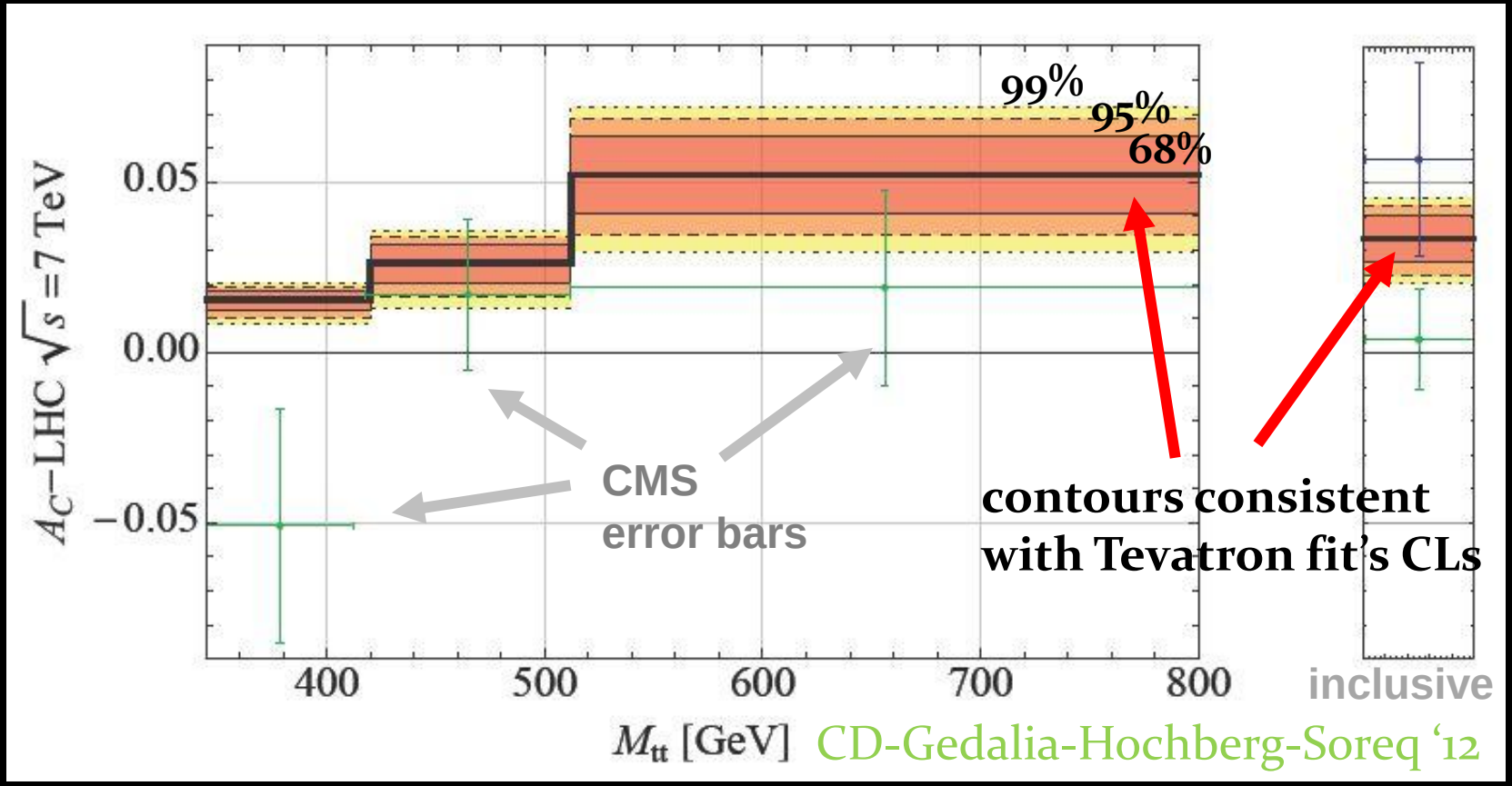


LHC8 has a good chance to
test the bulk of the EFT prediction

EFT also predicts a positive charge asymmetry @LHC

$A_C^{\text{inclusive}} \approx (0.4 \pm 1.0[\text{stat}] \pm 1.1[\text{syst}])\%$ CMS (5/fb)
$A_C^{\text{inclusive}} \approx (-1.8 \pm 2.8[\text{stat}] \pm 2.3[\text{syst}])\%$ ATLAS (1.04/fb)

QCD $A_C^{\text{inclusive}} \approx 0.6\%$ → consistent with QCD but could be consistent w/many things...hard to interpret



top has $o(1)$ coupling to EW symmetry breaking

naturalness $\rightarrow$ top+higgs dynamics is modified

Higgs EFT:

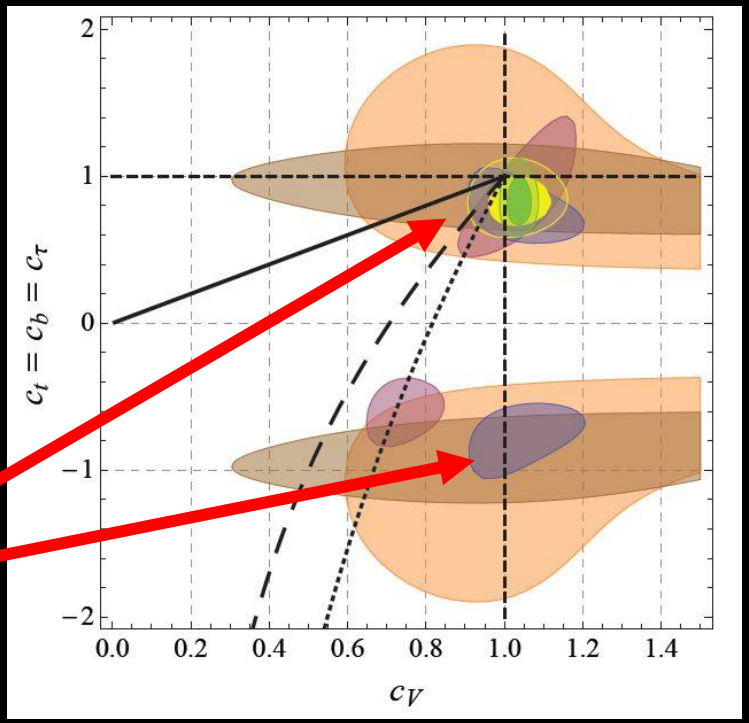
$$\mathcal{L} = \frac{1}{2}\partial_\mu h\,\partial^\mu h - \frac{1}{2}m_h^2 h^2 - c_3\,\frac{1}{6}\left(\frac{3m_h^2}{v}\right)h^3 + \dots$$
$$+ m_W^2\,W_\mu^+ W^{-\mu}\left(1 + 2c_W\,\frac{h}{v} + \dots\right) + \frac{1}{2}m_Z^2\,Z_\mu Z^\mu\left(1 + 2c_Z\,\frac{h}{v} + \dots\right)$$
$$- \sum_{\psi=u,d,l} m_{\psi^{(i)}}\,\bar{\psi}^{(i)}\psi^{(i)}\left(1 + c_\psi\frac{h}{v} + \dots\right) + \dots$$

h = $SU(2)_{L+R}$ (custodial) singlet
custodial symmetry → $c_Z = c_W = c_V$

SM limit → all $c_i = 1$

sign($c_t c_V$) not fixed *a priori*

hard to resolve from the rates
only $h\gamma\gamma$ is sensitive



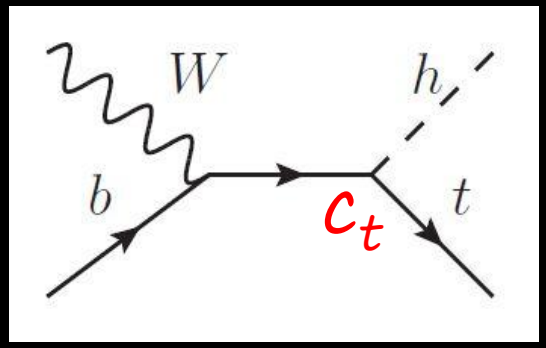
Falkowski-Riva-Urbano '12

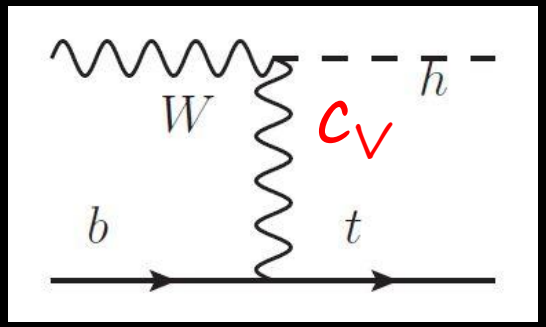
Ideally, one could look at t-tbar+h, but not for now...

it might be better to first look at single top + h production

Farina-Grojean-Maltoni-Salvioni-Thamm '12

because top and W SM amplitudes cancel almost perfectly:



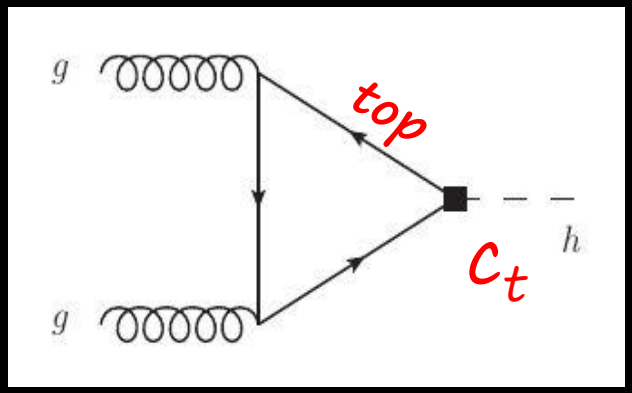


$$\frac{|A_W - A_t|^2}{|A_W + A_t|^2} \approx 13$$

large enhancement expected for $c_t<0$

Higgs production as a probe of the top sector:

$\mathcal{M}_{gg\to h}$ =



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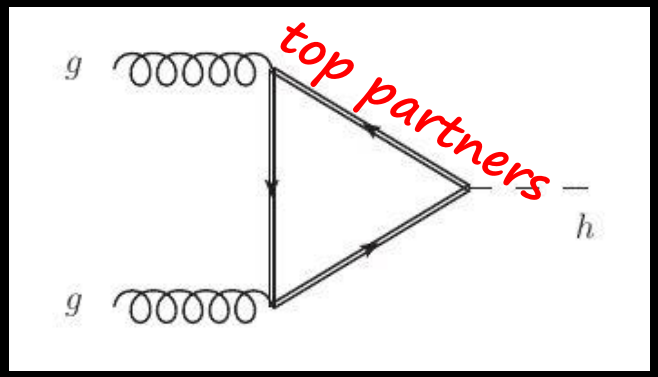


in composite pGB Higgs:

fermionic top partners mix with SM top → $c_t = 1+\delta c_t$

yet in minimal constructions *e.g.* MCHM5,10

δc_t + partner's loop = 0 → no sensitivity to the partners!

Falkowski '08

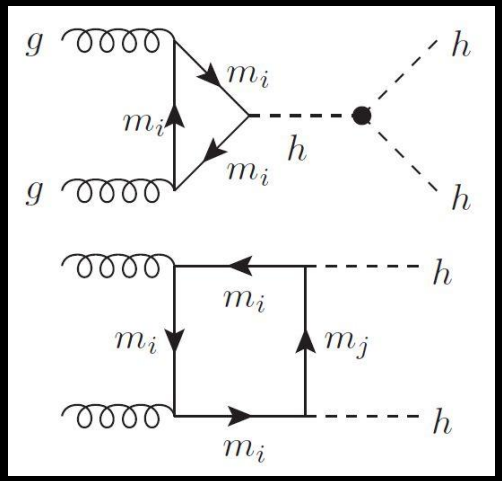
from Higgs low-E Theorem: Shifman et al. '78

$$\mathcal{M}_{gg\to h} \propto \left(\frac{\partial}{\partial \log H} \log\det \mathcal{M}^2(H) \right)_{H=v}$$

typically in CHM:

$\det \mathcal{M} \propto H$

some handle on top parners in double Higgs production:



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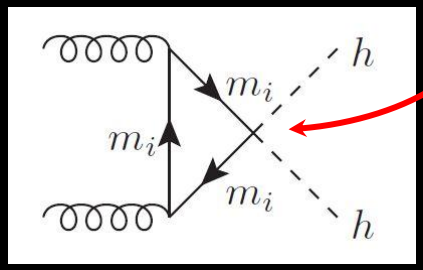
pGB Higgs non-linearity

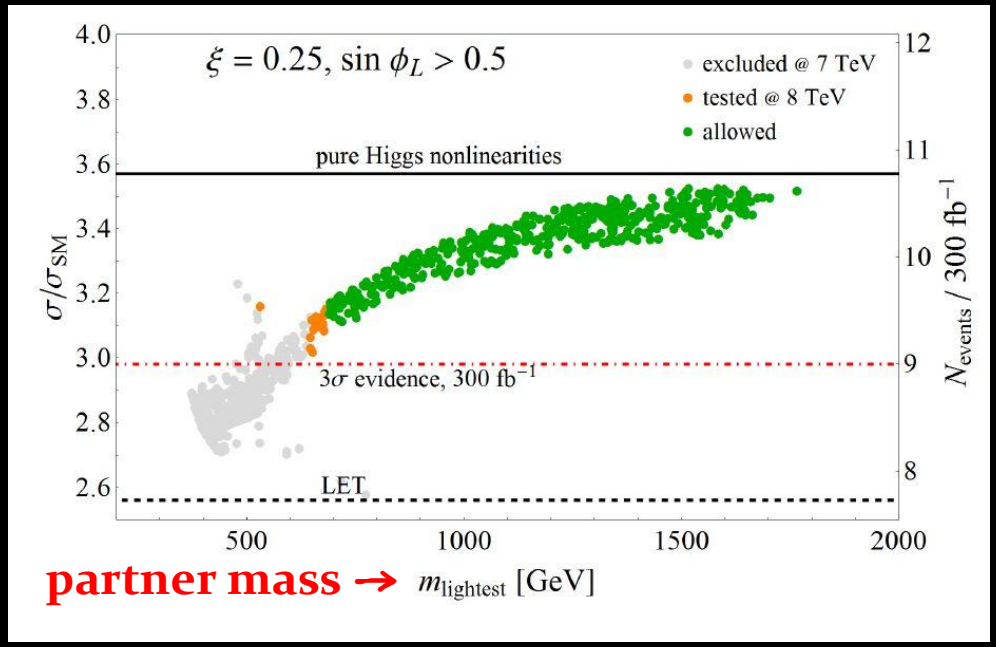


yields large enhancement w/out partners

Contino-Grojean-Moretti-Piccinini-Rattazzi '10

adding top partners →

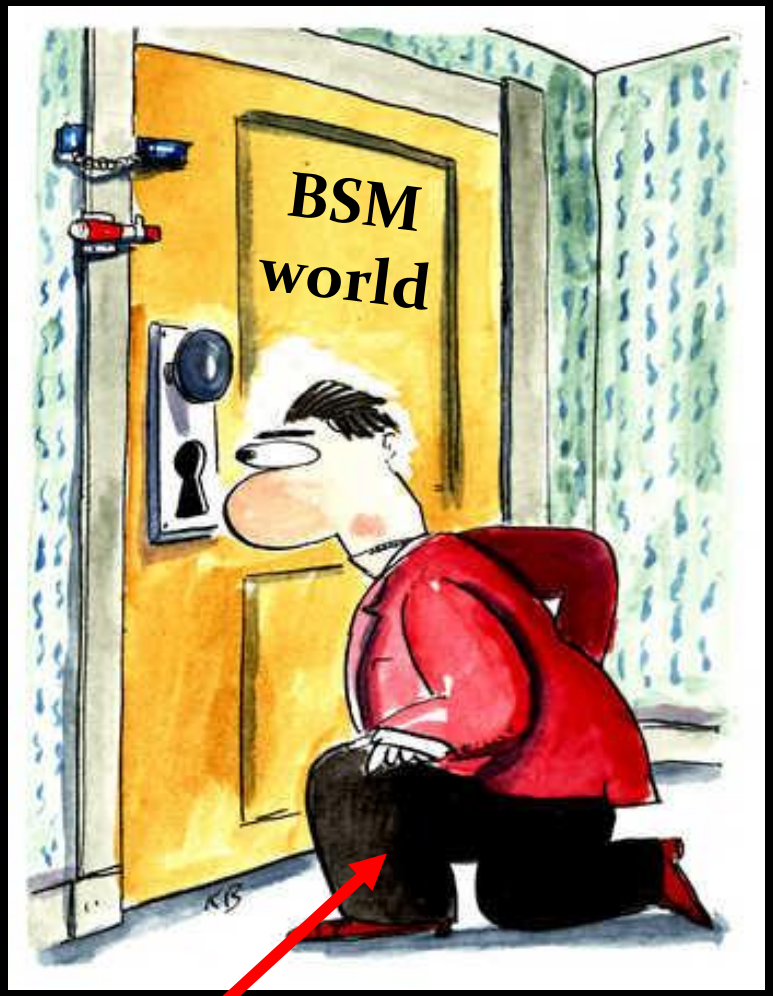
Gillioz-Grober-Grojean -Muhlleitner-Salvioni '12



to conclude:

Before the LHC, we've tried
to grossly picture the BSM world
from looking through the
naturalness key-hole (+EWPTs)

Now it's to time to step in
and explore the TeV scale



HEP physicist stuck in the SM waiting room