Traces of composite light quarks at the LHC

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CERN-TH

based on *arxiv:1303.!!!!* w/ Grojean-Perez
1306.asap w/ Flacke-Lee-Panico-Perez
1306.asap w/ Blanke-Martin-Perez

Outline

- Naturalness → there's a top sector ~< TeV
  but no hint for (a scale for) flavor physics

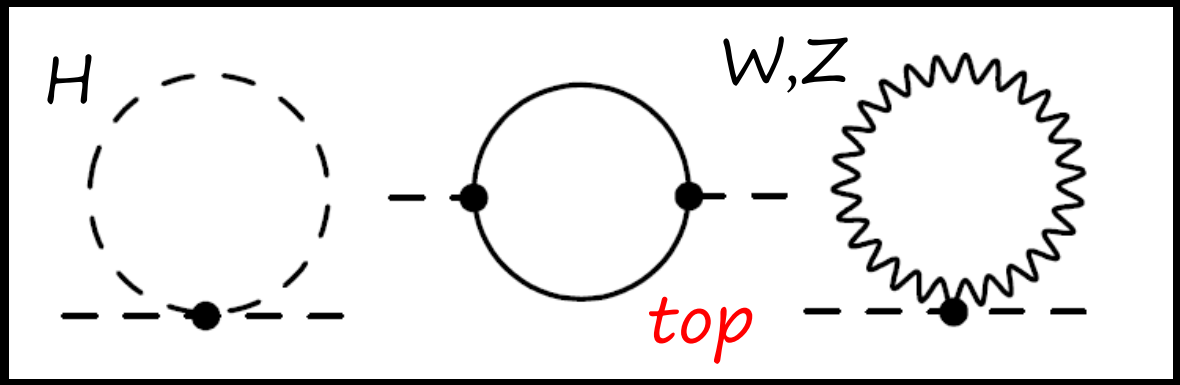
- Composite PNGB Higgs & partial compositeness

$$|SM\rangle = \cos\theta\,|elementary\rangle + \sin\theta\,|composite\rangle$$
$$|partner\rangle = -\sin\theta\,|elementary\rangle + \cos\theta\,|composite\rangle$$

- Constraining light quark compositeness w/
  - dijet searches
  - direct searches of partners
  - Higgs couplings to gluons and photons

- Hidding top partners with top/charm mixing

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

$\delta m^2 =$ 

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

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

Q: where are they?

SUSY → light stops

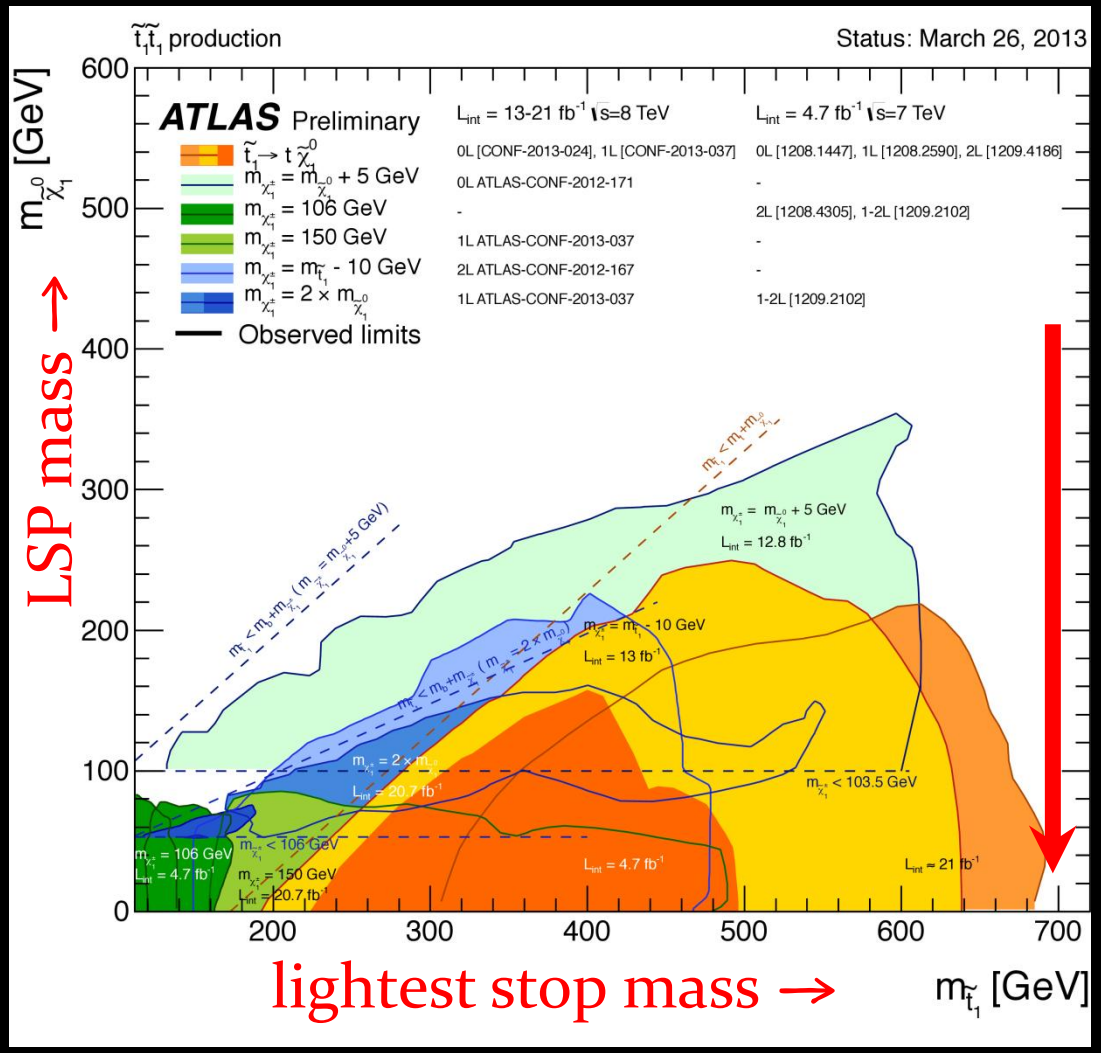
Barbieri-Giudice '88,..., Papucci-Ruderman-Weiler '11

current limits are rather strong:

$m_{stop} > \sim 700\,GeV$

unless
compressed spectrum?

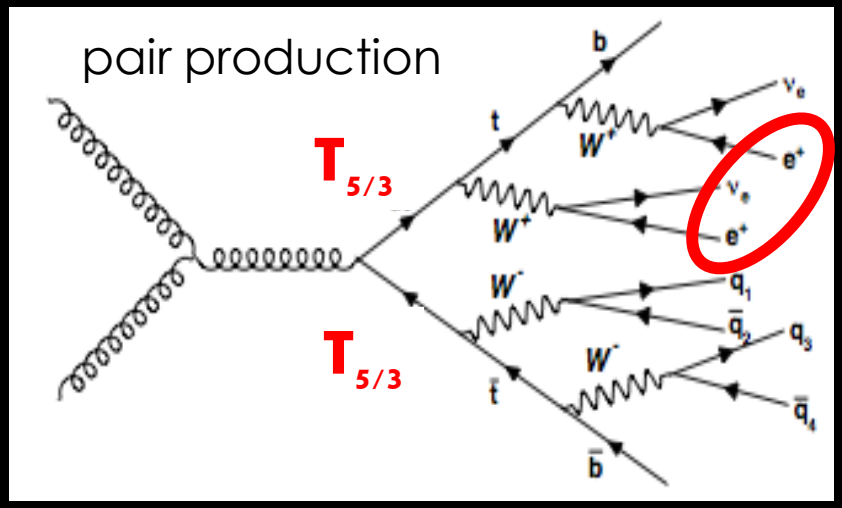
$m_{stop} \sim m_{top}$

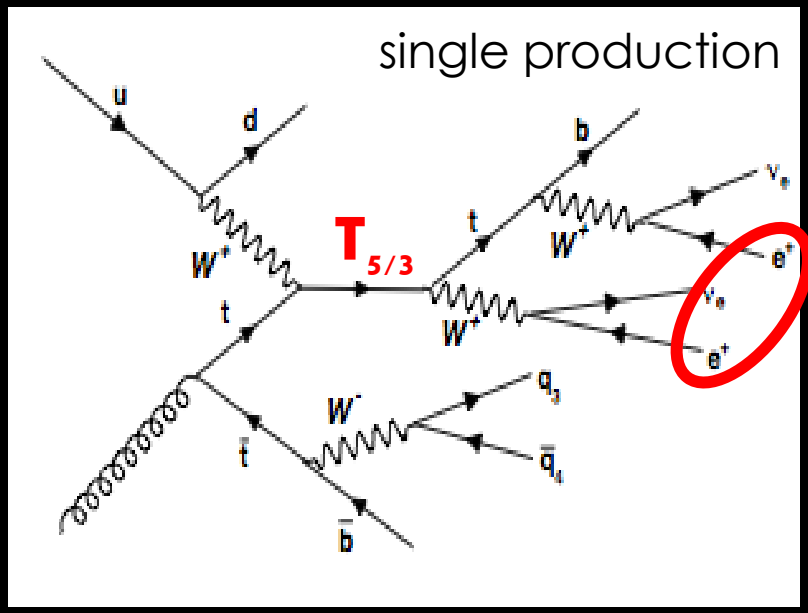


composite pGB Higgs models → cleanest signal = $T_{5/3}$

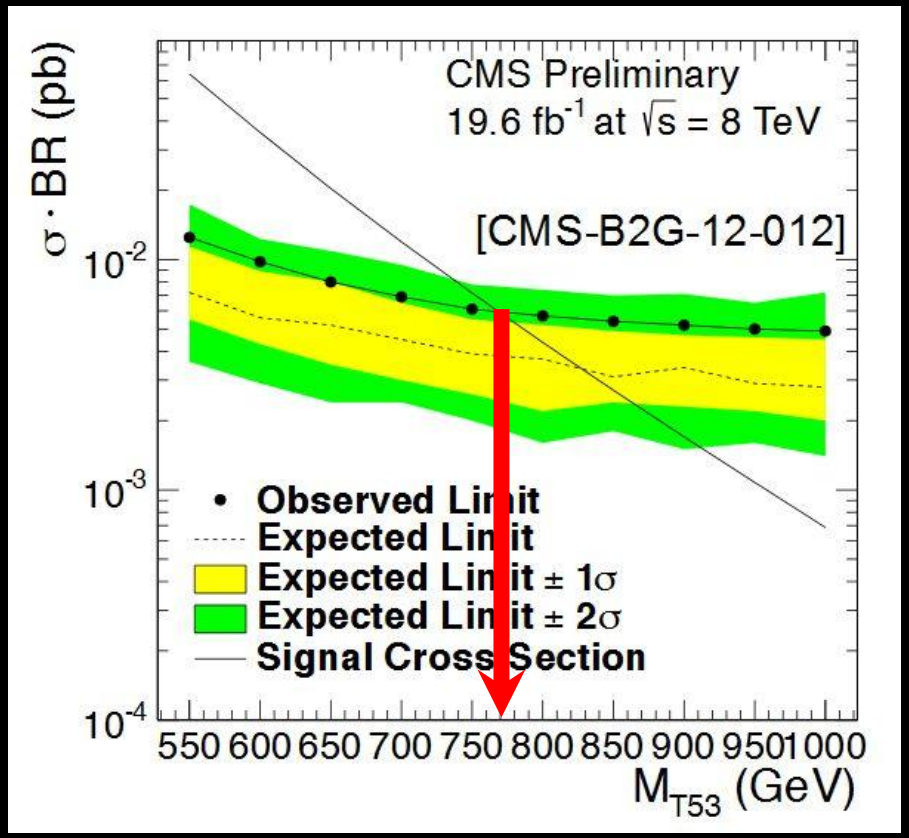
Contino-Servant '08, Mrazek-Wulzer '09, Rattazzi et al. '12

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





taken from Stelzer @HCP'12



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

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

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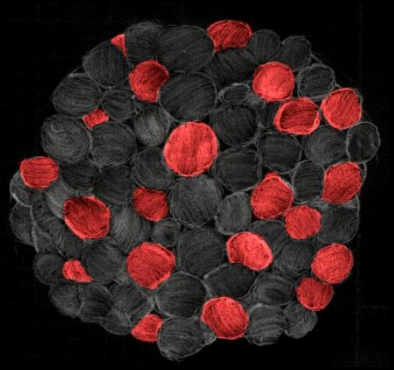
have started to pressure naturalness

light quarks are (almost exactly) blind to EWSB,
no hint for flavor physics from naturalness

Q1: do they have partners too? within LHC reach?

Q2: are light quark composite objects?

Assume a new QCD-like force confining at $\Lambda \sim$ few TeV

$H \sim$  $l_H \sim \Lambda^{-1}$

EW symmetry breaking through a composite Higgs has no (big) hierarchy problem!

Georgi-Kaplan '84

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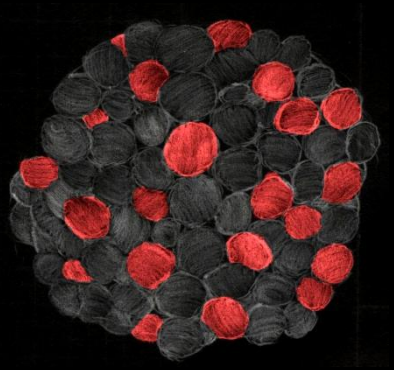
$H \sim$  $l_H \sim \Lambda^{-1}$

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to solve little hierarchy problem *and* naturally get $m_H \ll$ TeV:

make H a "pion" *i.e.* a PNGB : $H \subset \mathcal{G}/\mathcal{H}$

(QCD pions $\subset SU(2)_L \times SU(2)_R/SU(2)_V$)

Contino-Nomura-Pomarol '03
Agashe-Contino-Pomarol '04

CHM 2-site description

Contino-Kramer-Son-Sundrum '06
Redi-Tesi '11

elementary sector
$\Lambda \sim M_{Pl}$

$q_L \; u_R \; d_R$
$W_\mu \; B_\mu \; G_\mu$

← mass mixing →

$g_i \, \psi_i \, O_i$

$\epsilon_i = g_i / g_\rho$

strong sector $\Lambda = 4\pi f$ ~few TeV

$H \in G/\mathcal{H}$

+ resonances $m_\rho = g_\rho f$

f = Higgs "decay constant" , $g_\rho < 4\pi$

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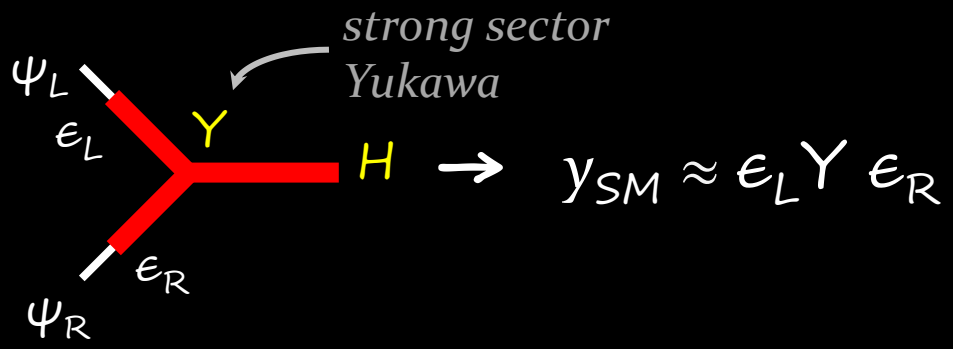
smallest coset w/ unbroken custodial symmetry: $SO(5)/SO(4)$
fermion masses induced by ϵ_i



$y_{SM} \approx \epsilon_L Y \epsilon_R$

partial compositeness:

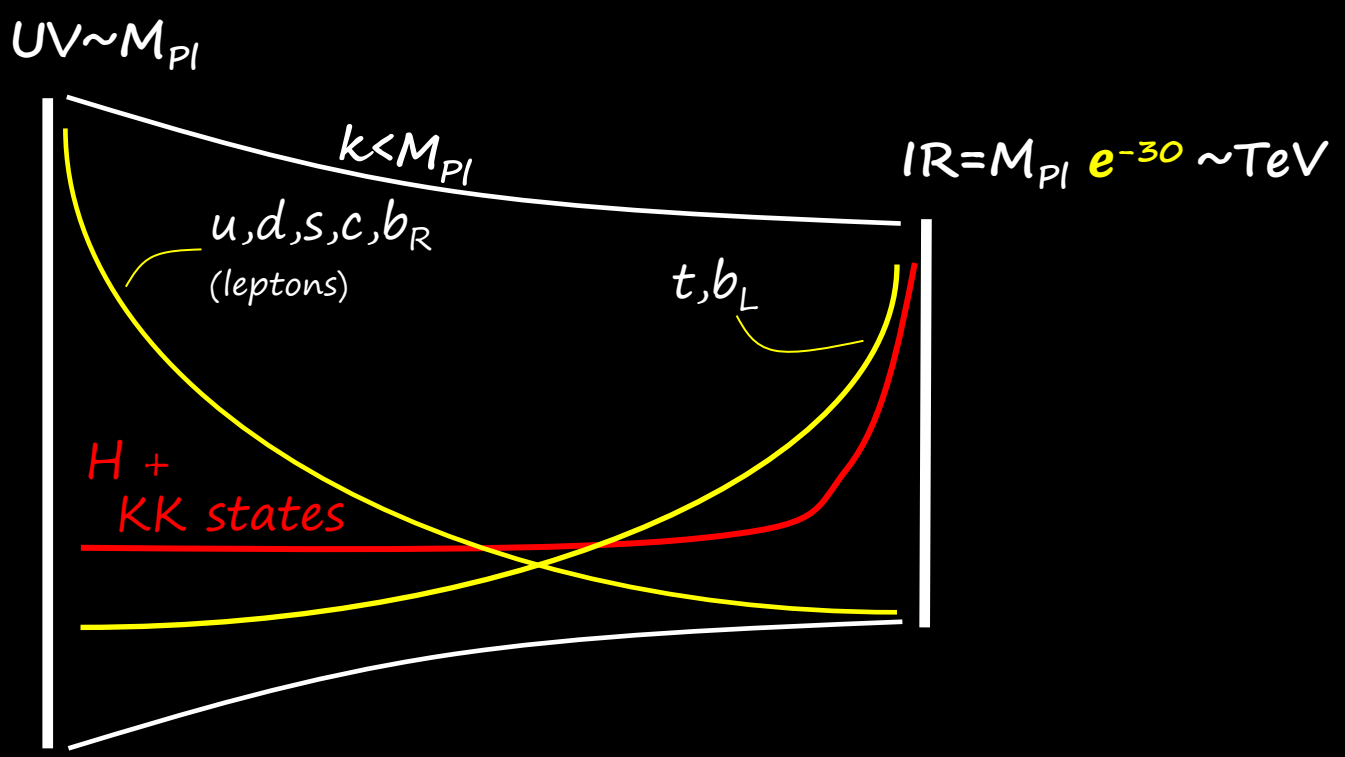
$|SM\rangle = \cos |elem\rangle + \sin |comp\rangle$
$\approx |elem\rangle + \epsilon\, |comp\rangle$

Higgs=NGB → no tree-level potential
EWSB $SO(4) \to SO(3)$ radiatively induced by top mixings ϵ_{tL}, ϵ_{tR}

CHM 5D warped duals

Maldacena'97: « strong 4D SYM theories are dual to gravity in AdS5xS5 »

RS'99: « Hierarchy problem is solved in AdS5 bckg: $ds^2 = e^{-2ky} dx^2 - dy^2$ »



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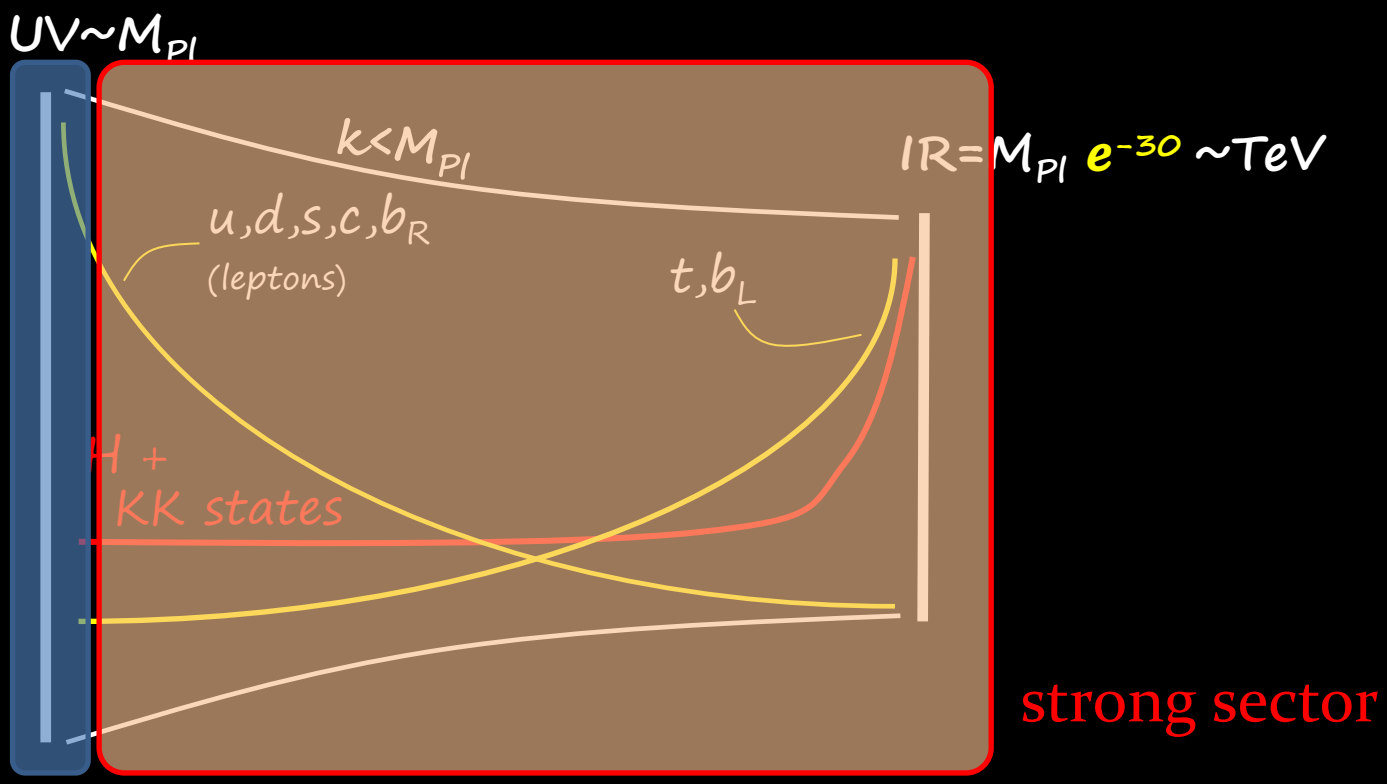


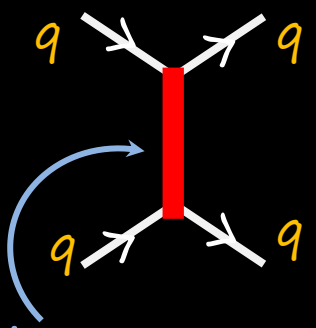
$\epsilon \sim$ IR zeromode-wavefunction $f(c)$,

c = 5D fermion mass ~ anomalous dim' of chiral operators

Arkani-Hamed-Porrati-Randall 'oo

Q: are light quarks also composite?

1) dijets searches:

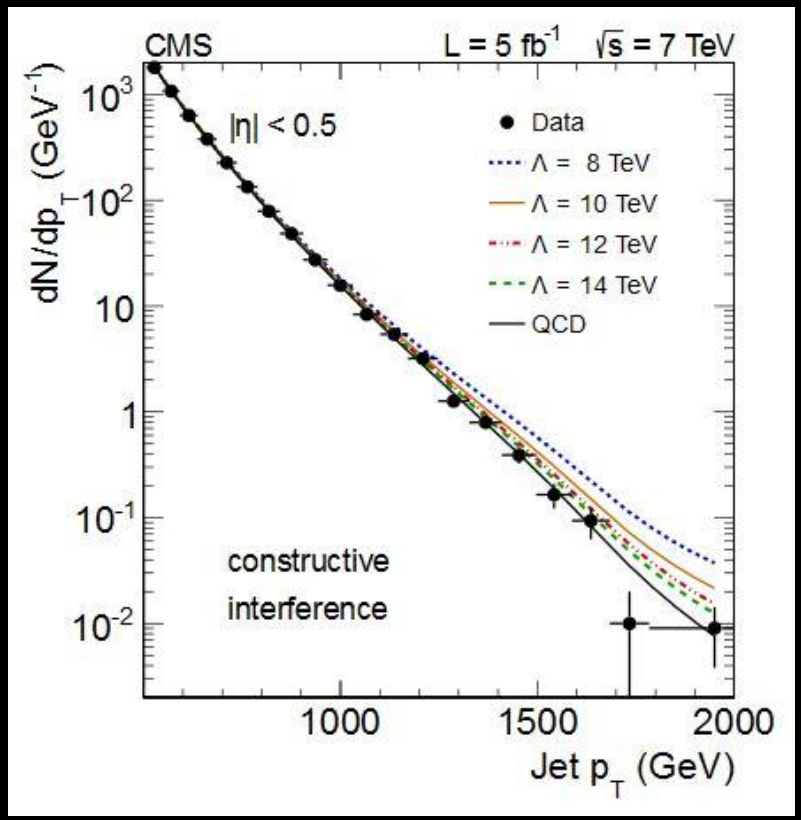


spin 1 resonance
~few TeV

→ low E $\frac{qqqq}{\Lambda^2}$

« *compositeness scale* »

$\Lambda \sim f/\epsilon_q$



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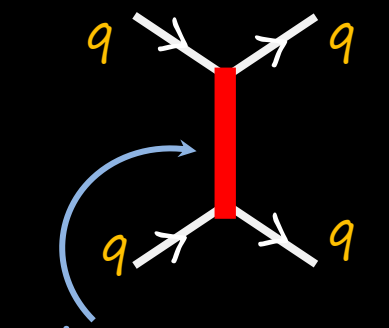

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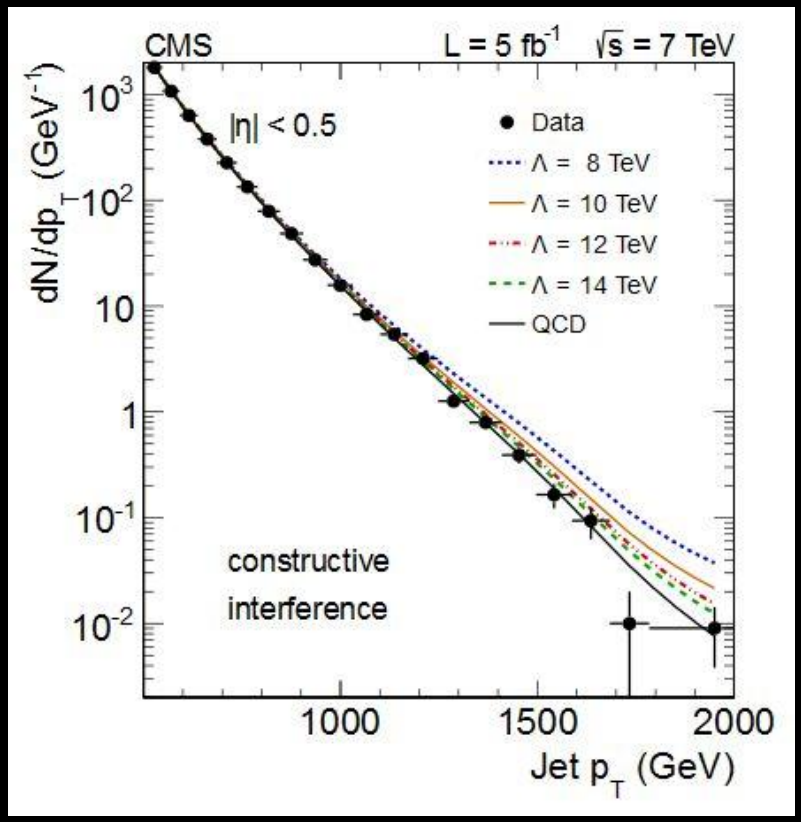


$q=u,d$: $\Lambda > 4\text{-}6$TeV *e.g.* CMS-EXO-11-010 '13

$q=s,c$: $\Lambda > o(300)$GeV DaRold-CD-Grojean-Perez '12

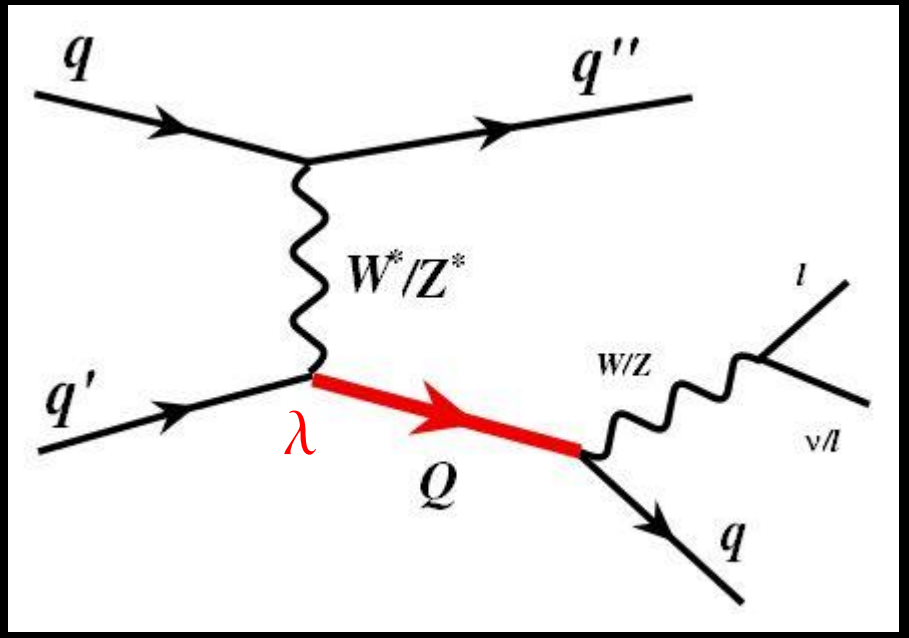
→ 2nd generation's not constrained thanks to small pdf

Q: are light quarks also composite?

2) direct searches of partners = vector-like Q

Carena-Han-Santiago et al. '11

$\lambda \sim v/f \times \epsilon_q$



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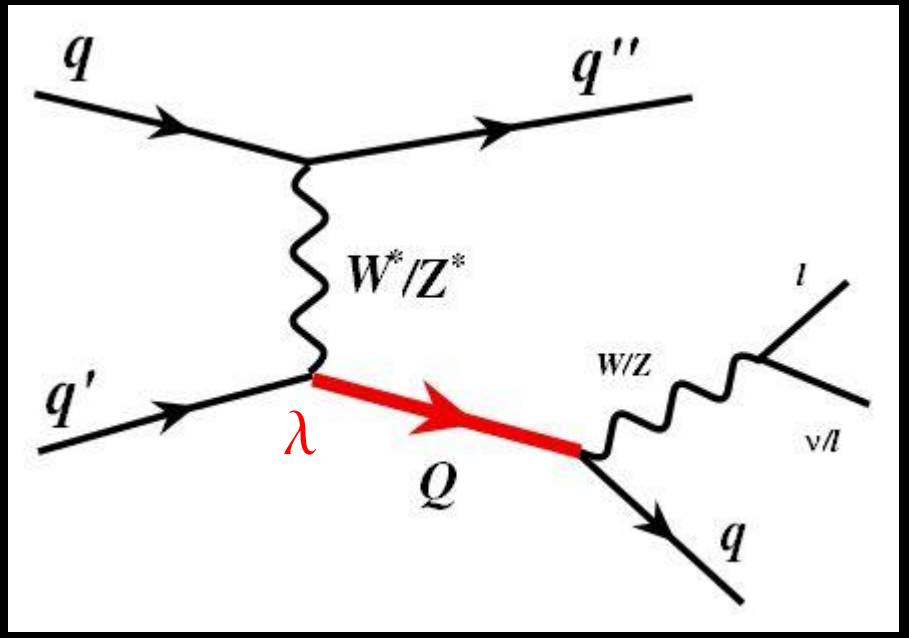


Q=u,d partners: $m_Q > 1.0\text{–}1.4\,\text{TeV}$ ATLAS-CONF-2012-137

driven by valence quark PDFs + t-channel (*assumed* $\lambda \sim v/m_Q$)

Q=c,s partners: $m_Q >\sim$ few 100GeV

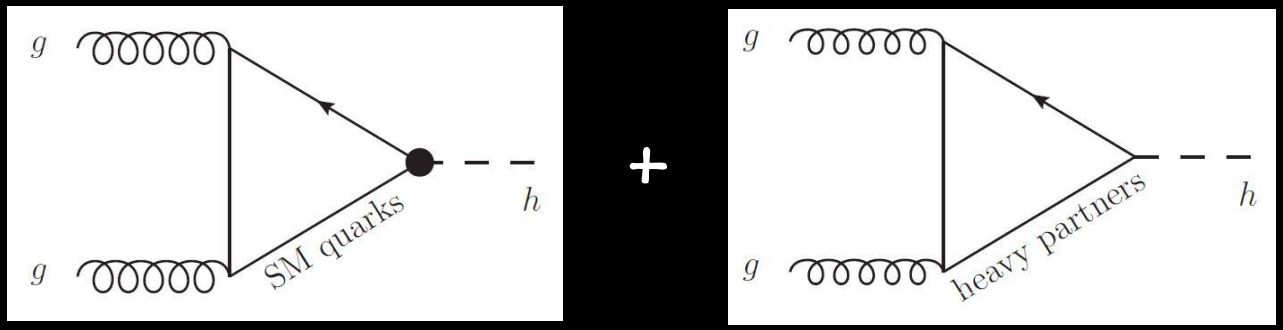
CD-Flacke-Gonzalez-Lee-Panico-Perez, to appear

Q: are light quarks also composite?

CD-Grojean-Perez '13

3) Higgs (radiative) couplings:

$M_{gg\to h}$ =



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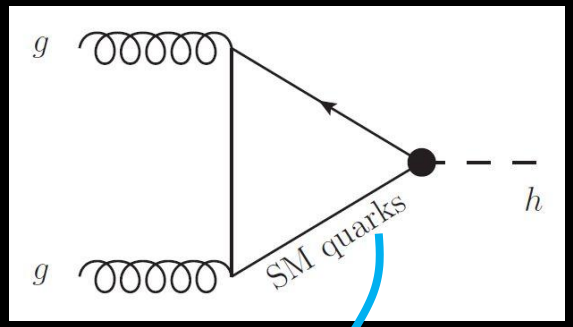

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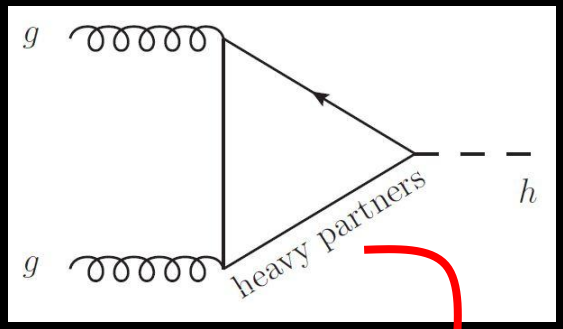

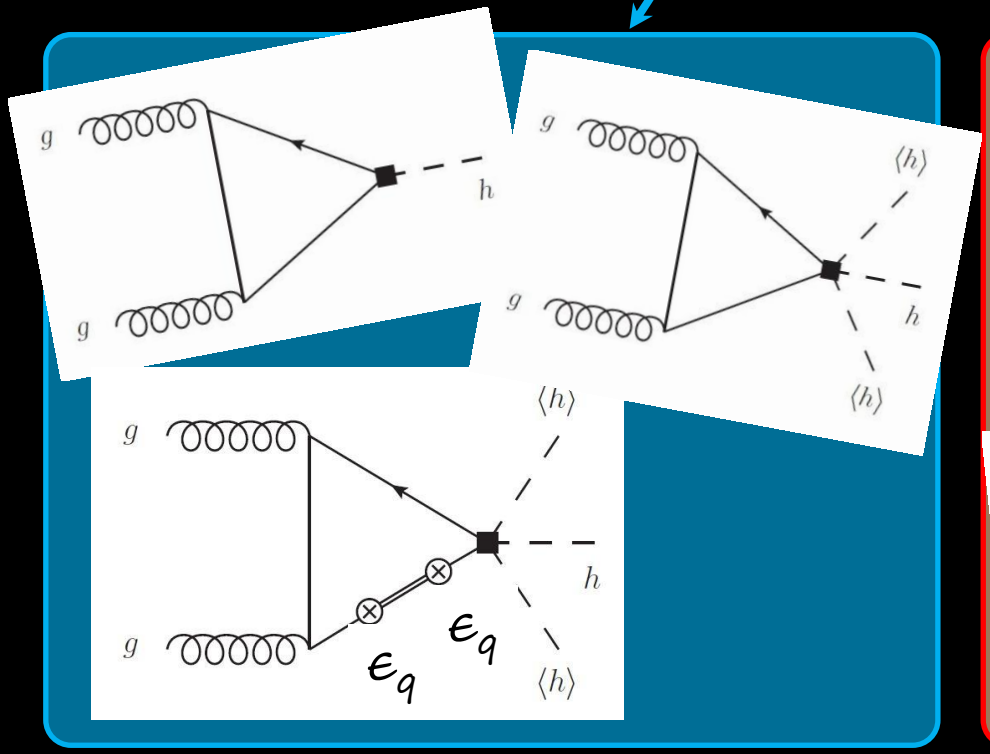

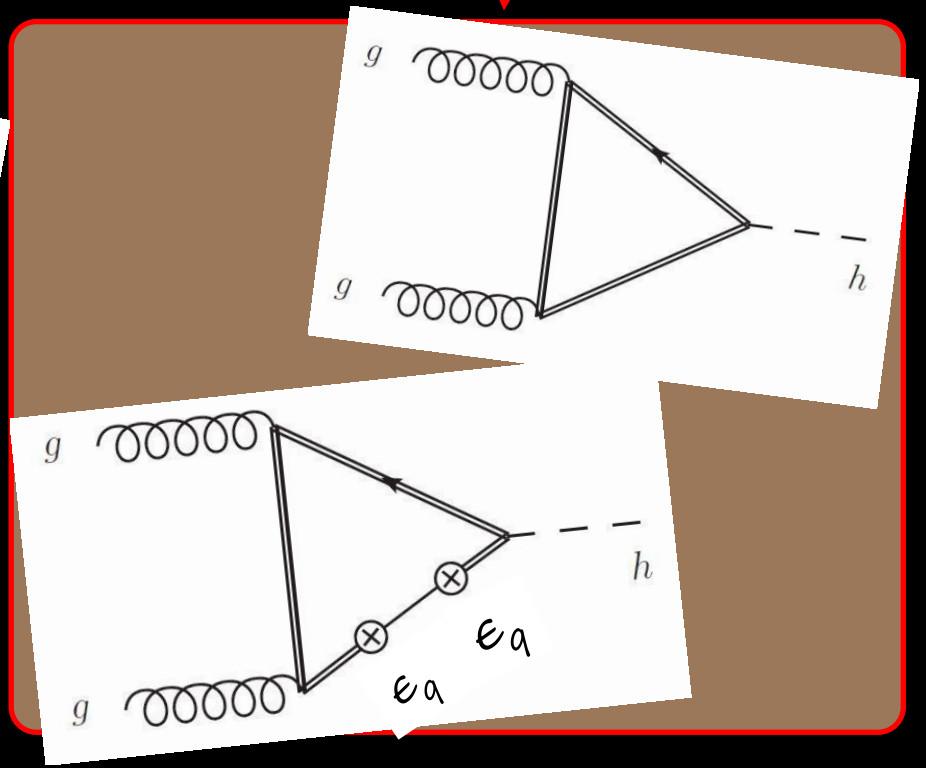

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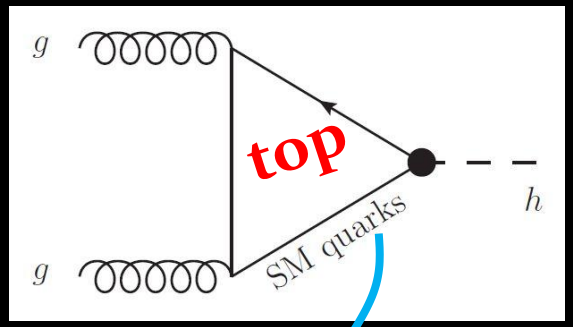

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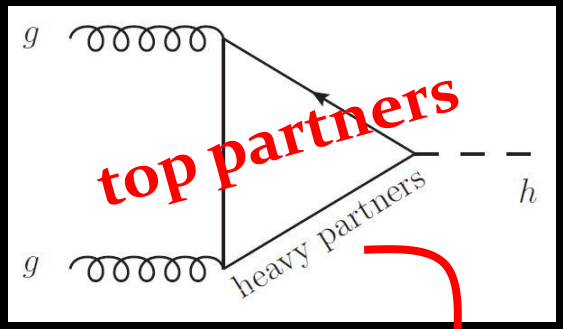

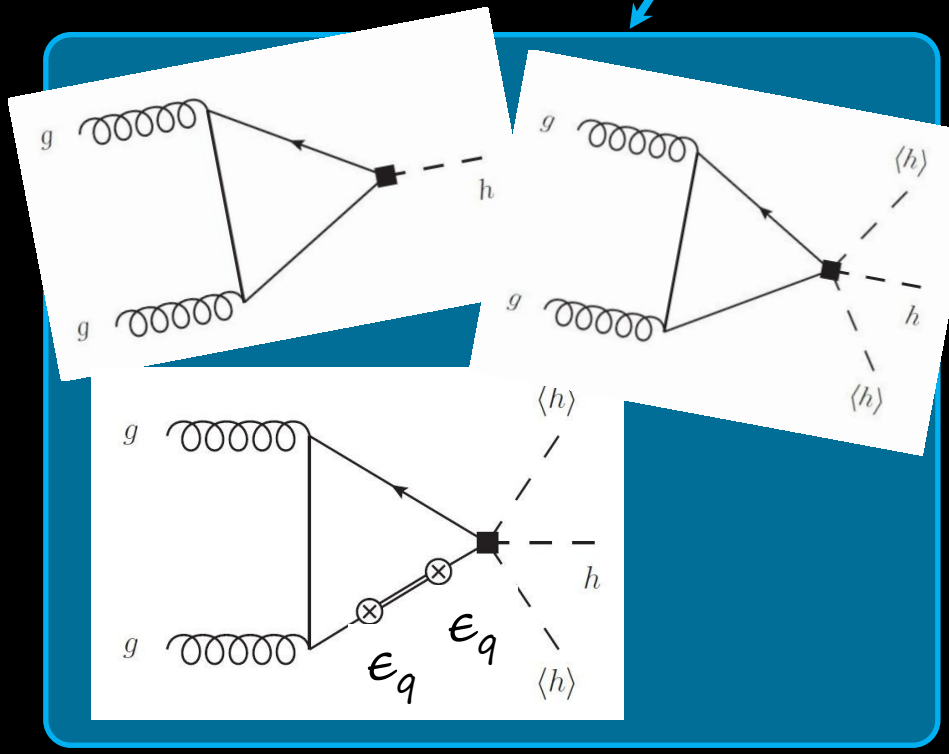

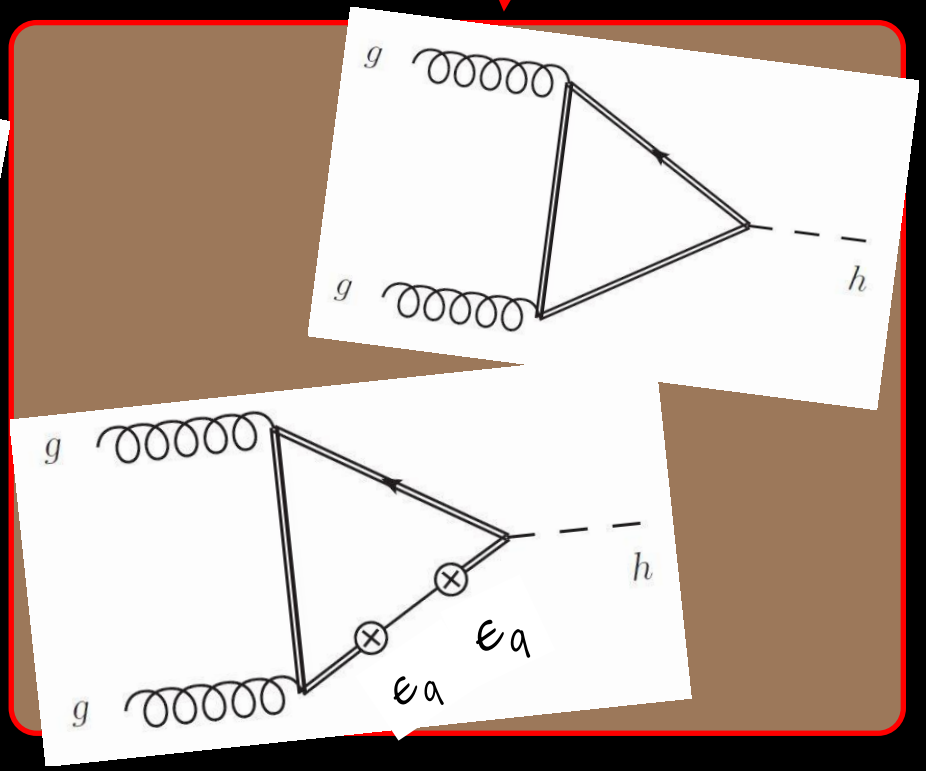

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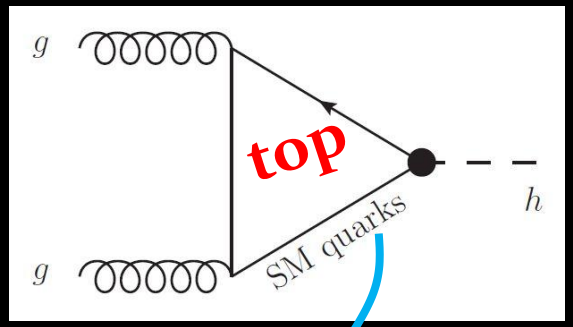

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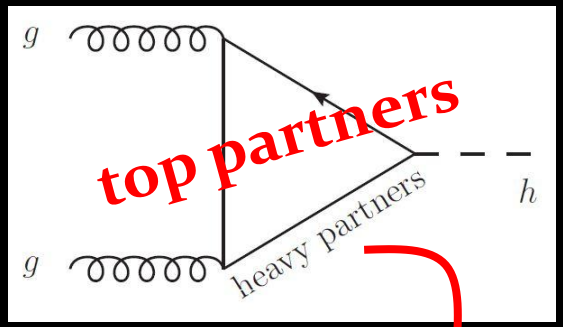

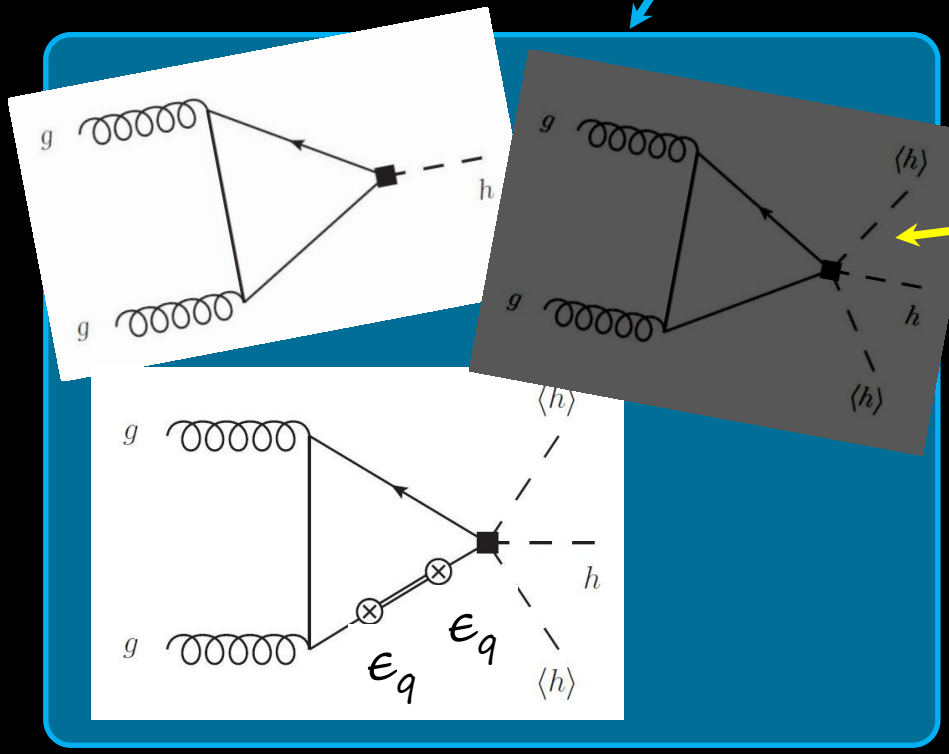

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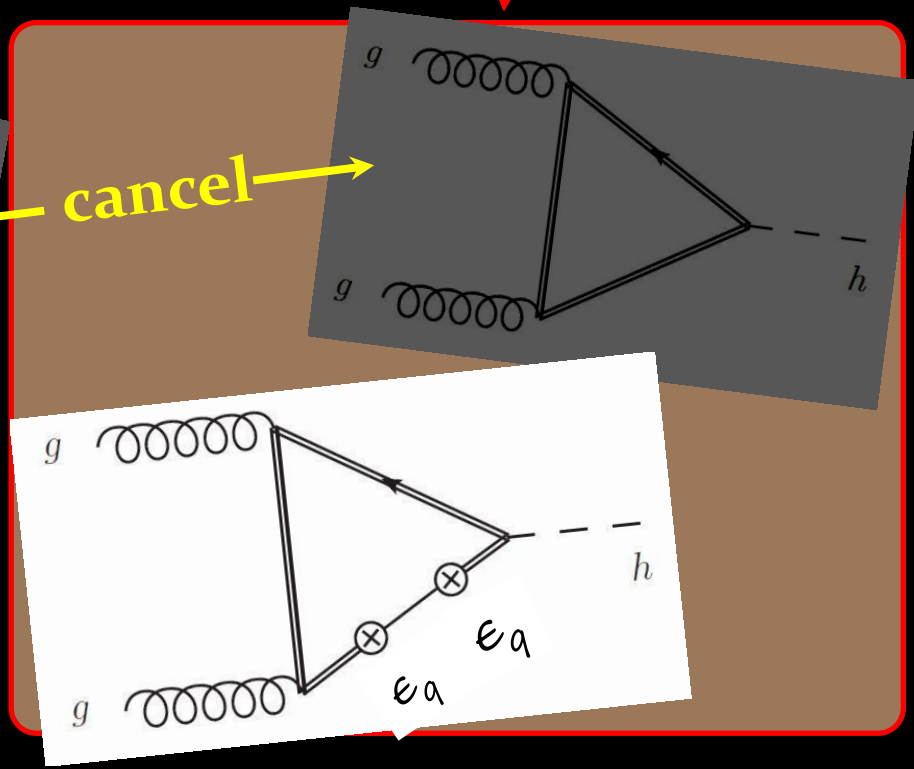

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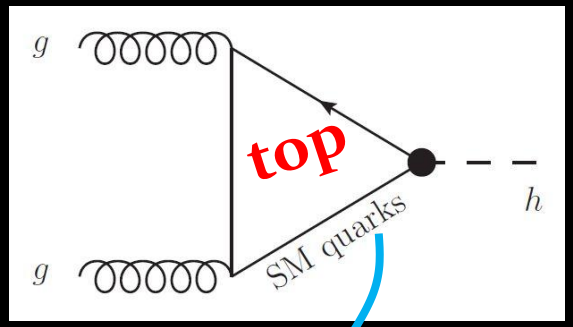

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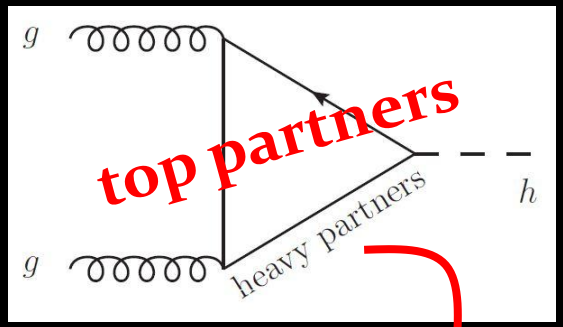

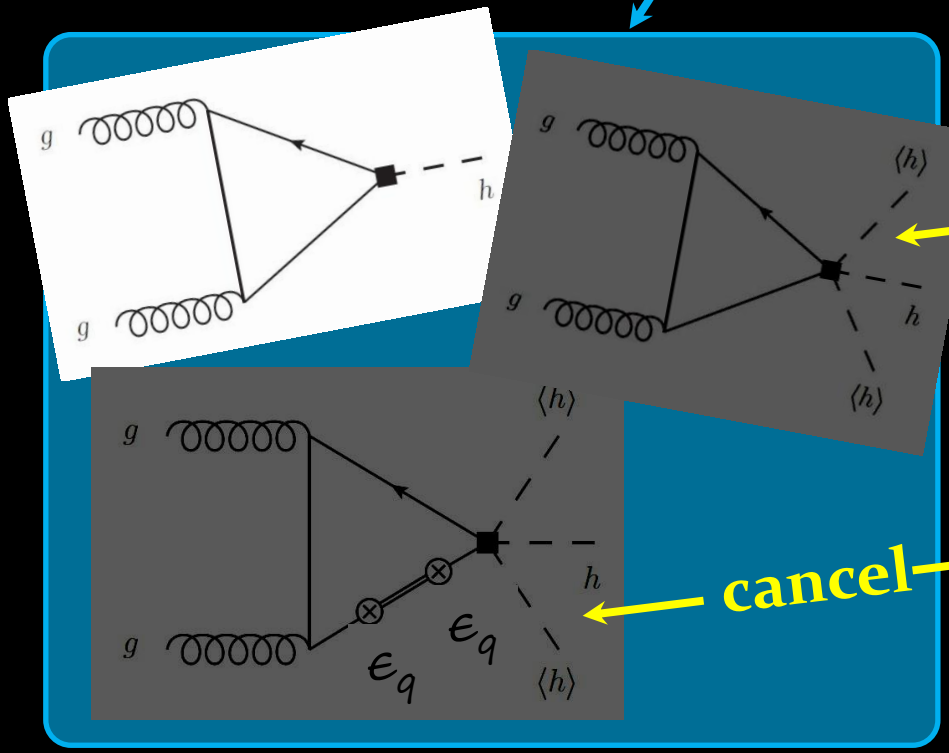

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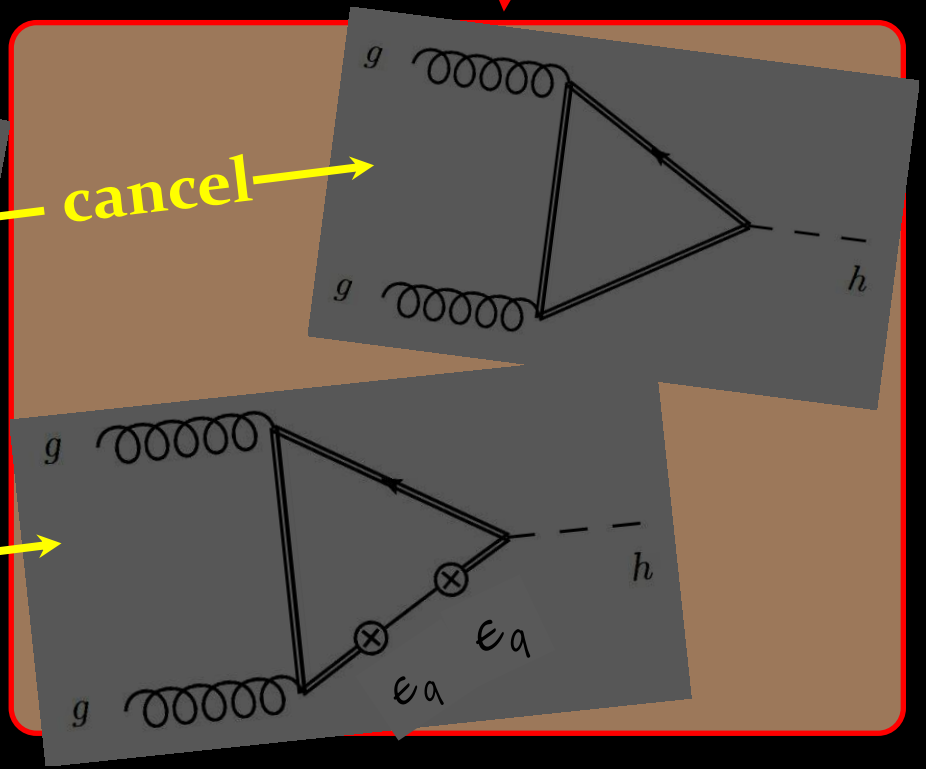

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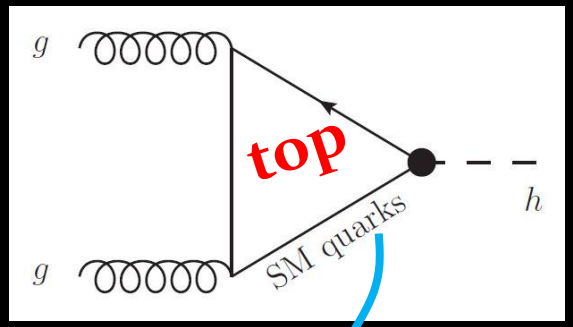

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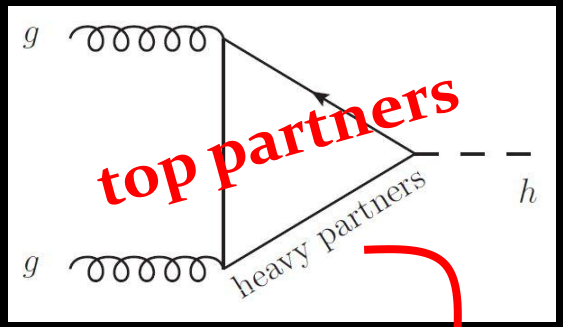

Low-energy Higgs theorem:
Vainshtein-Voloshin-Zakharov-Shifman '79

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

$\propto 1$

typical structure in CHM:

$$\mathcal{M} = \begin{pmatrix} 0 & \lambda_q & 0 \\ 0 & M_Q & Y\tilde{H} \\ \lambda_u & \tilde{Y}\tilde{H}^\dagger & M_U \end{pmatrix}$$

$\det M \propto H$

→ *no sensitivity to top compositeness and top partners spectrum*

Falkowski '08, Azatov-Galloway '10

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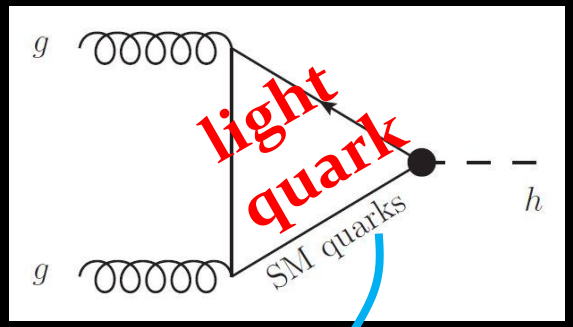

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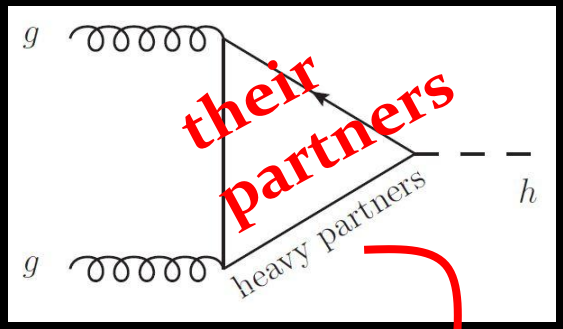

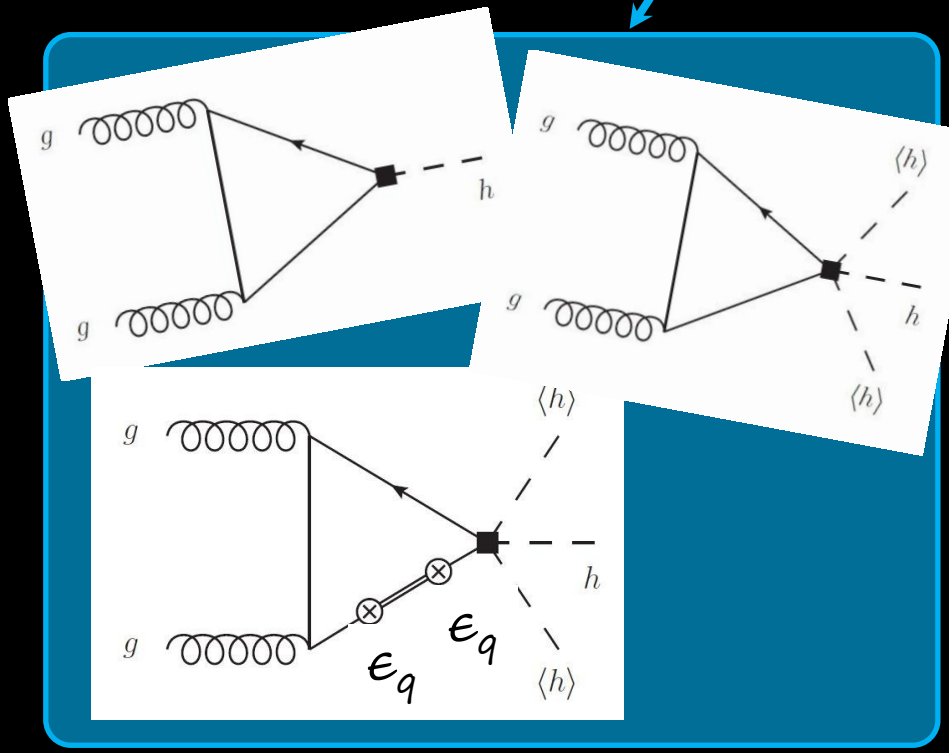

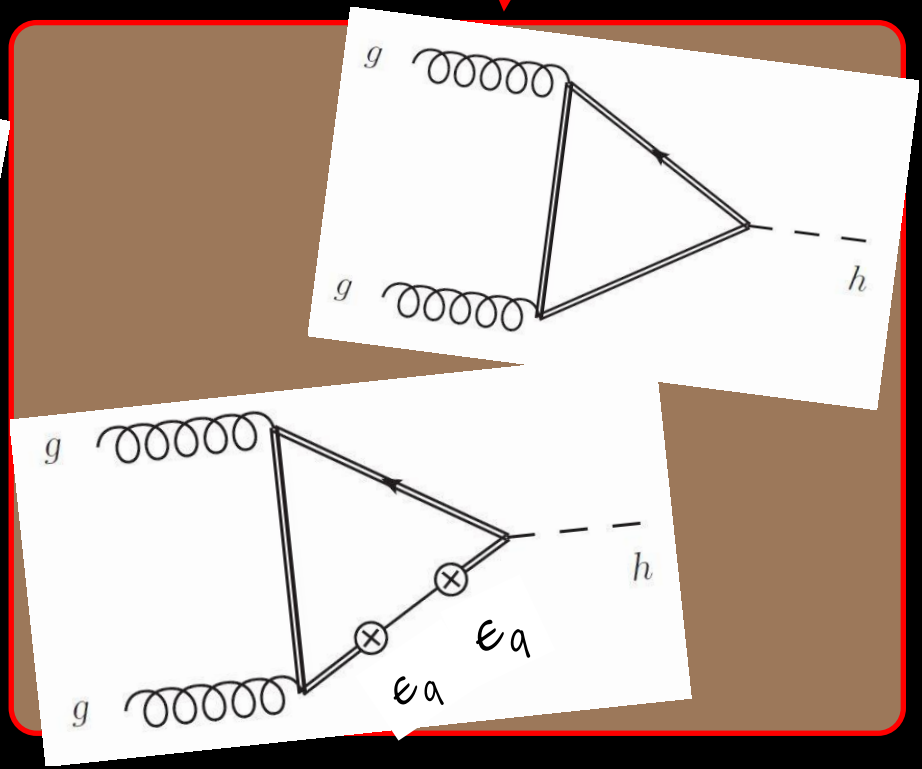

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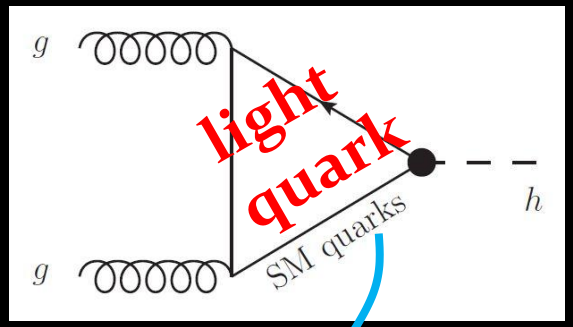

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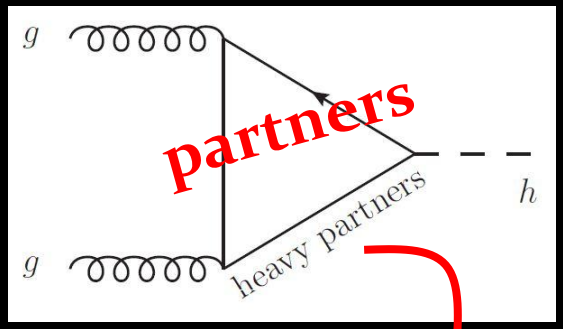
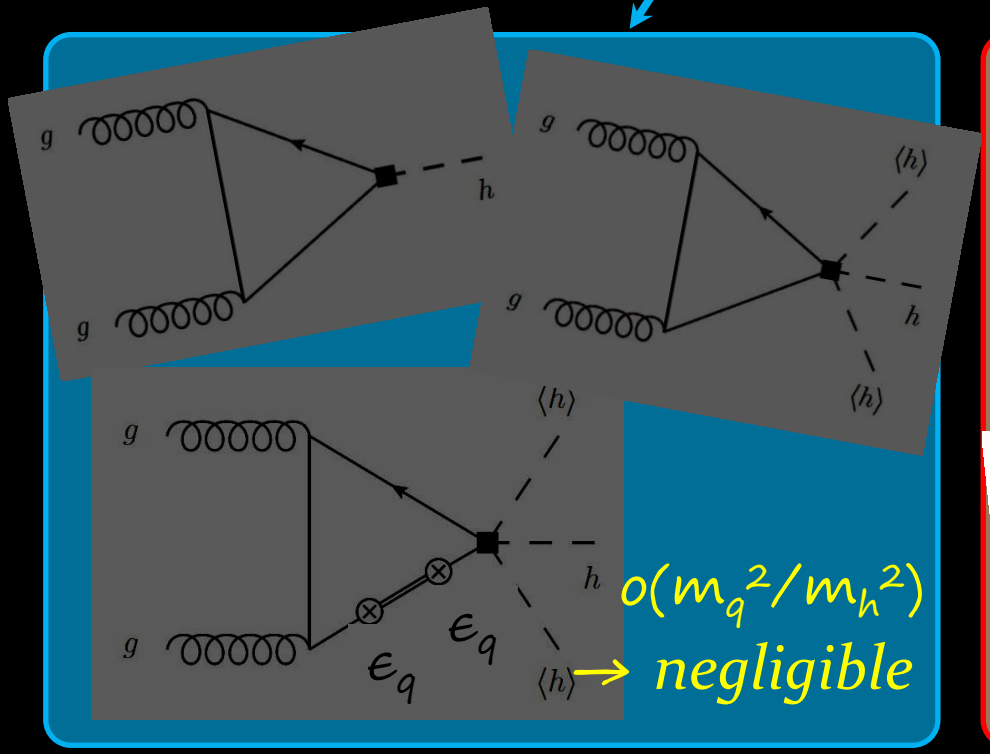
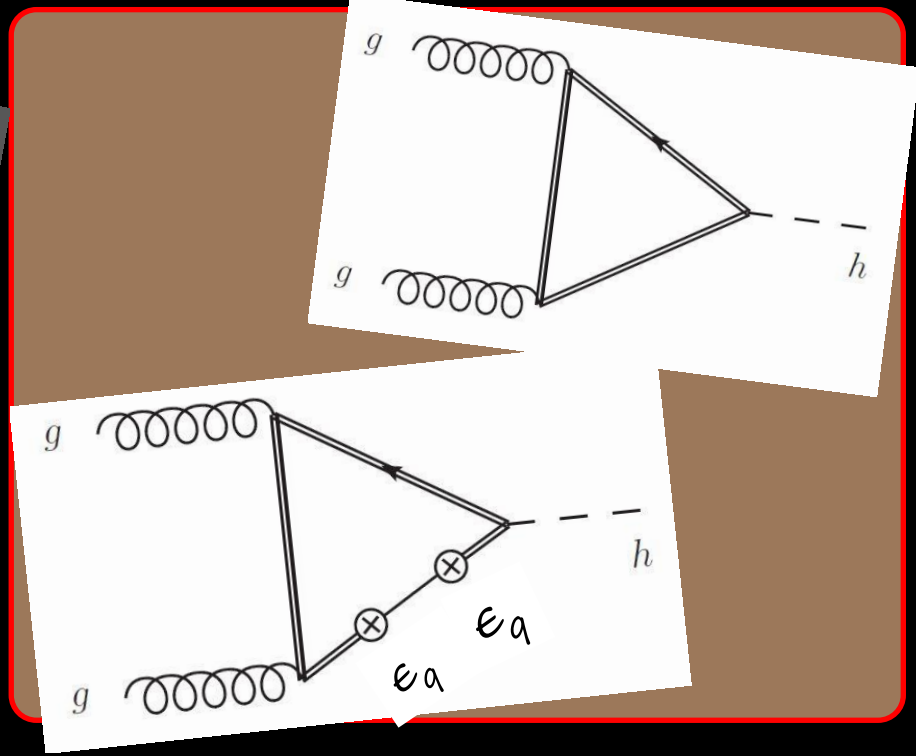




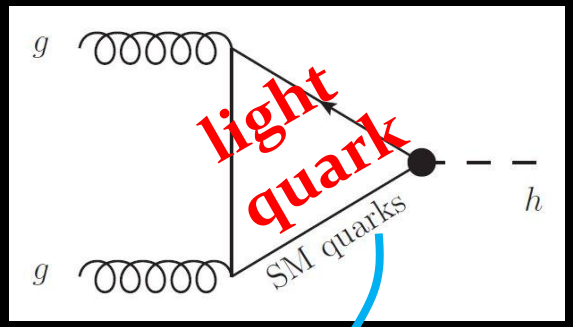


Q: are light quarks also composite?

CD-Grojean-Perez '13

3) Higgs (radiative) couplings:

$M_{gg\to h}$ =



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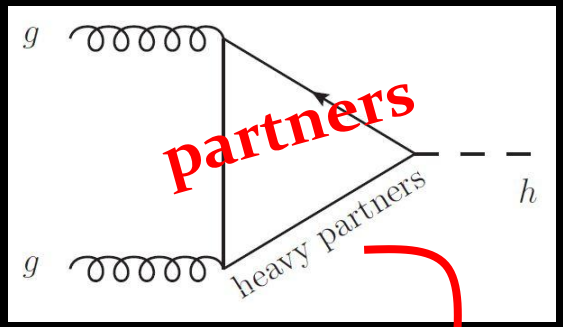

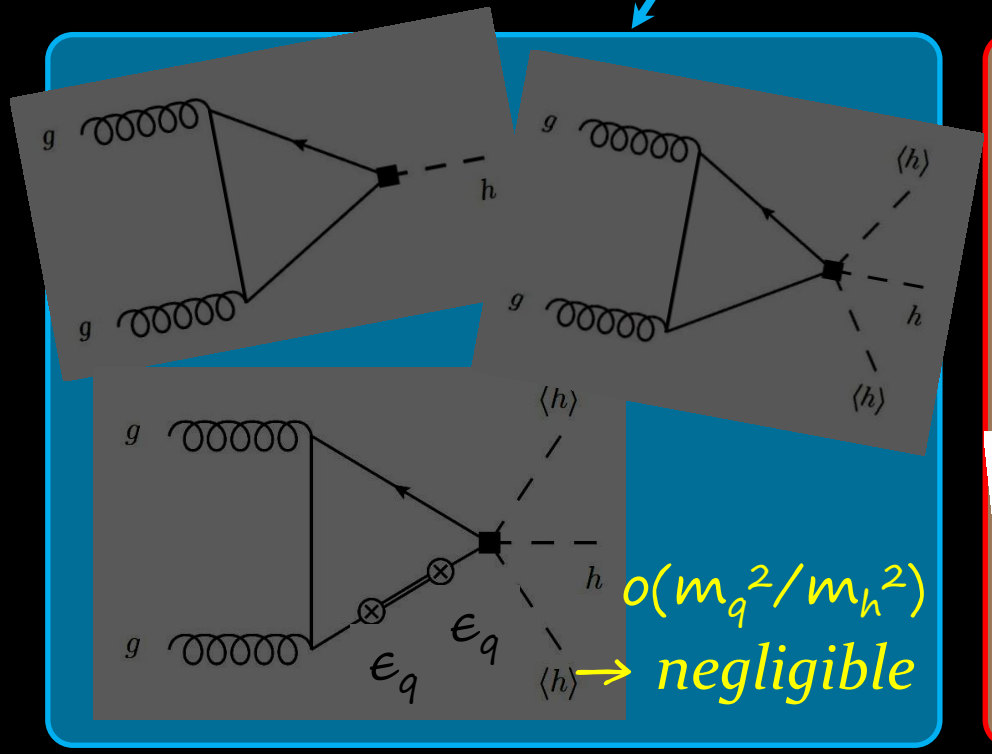

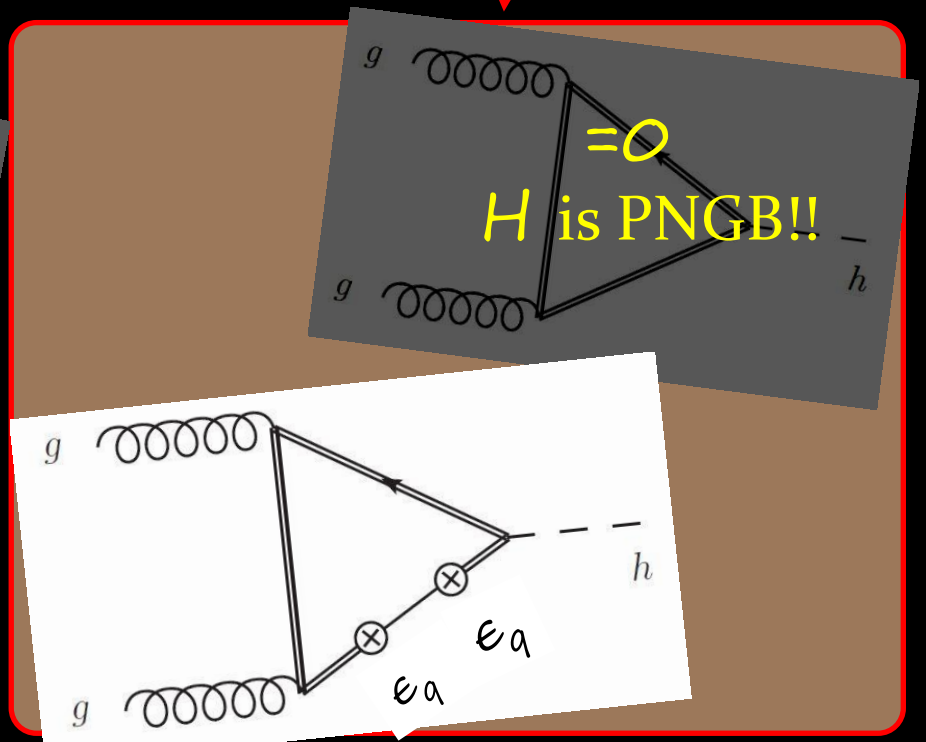

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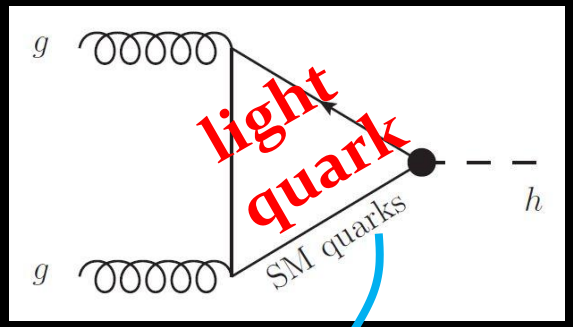

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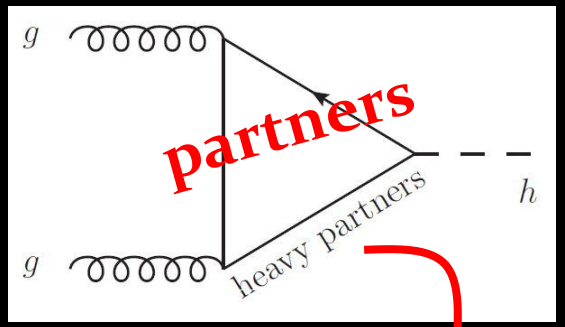
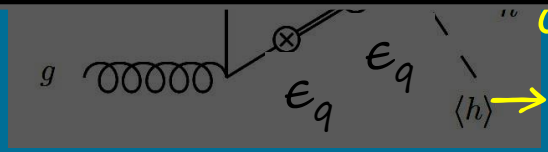


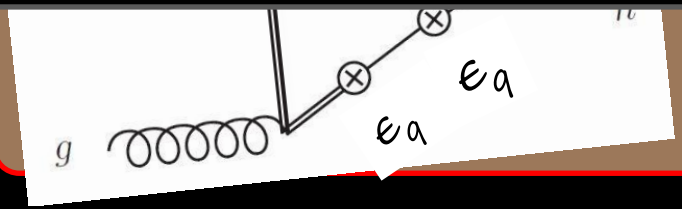
→ composite higgs couplings to gluon and photon probe light quark compositeness !!

net effect scales like ϵ_L^2 or ϵ_R^2 but not $\epsilon_L\epsilon_R$ *(hgg is flavor singlet)*

→ one chirality composite is enough, *say RH to pass EWPTs*



$O(m_q^2/m_h^2)$ → *negligible*



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3) Higgs (radiative) couplings:

$$\frac{\sigma_{gg\to h}}{\sigma_{gg\to h|SM}} = X_{gg}^{\rm MCHM} \simeq 1 - 3\xi + 2\sum_{i=u,d} N_i x_i \sin^2\theta_i\,(1+2r_i) + \dots$$

top sector

$\xi=(v/f)^2$ → suppresses ggh

Rattazzi-Low '09

light q_R sector

N = # composite flavors

$x = (Y\,v/M)^2$

$\sin\theta_R \approx \epsilon_R$

$r = M/Yf \sim o(1)$

→ enhances ggh

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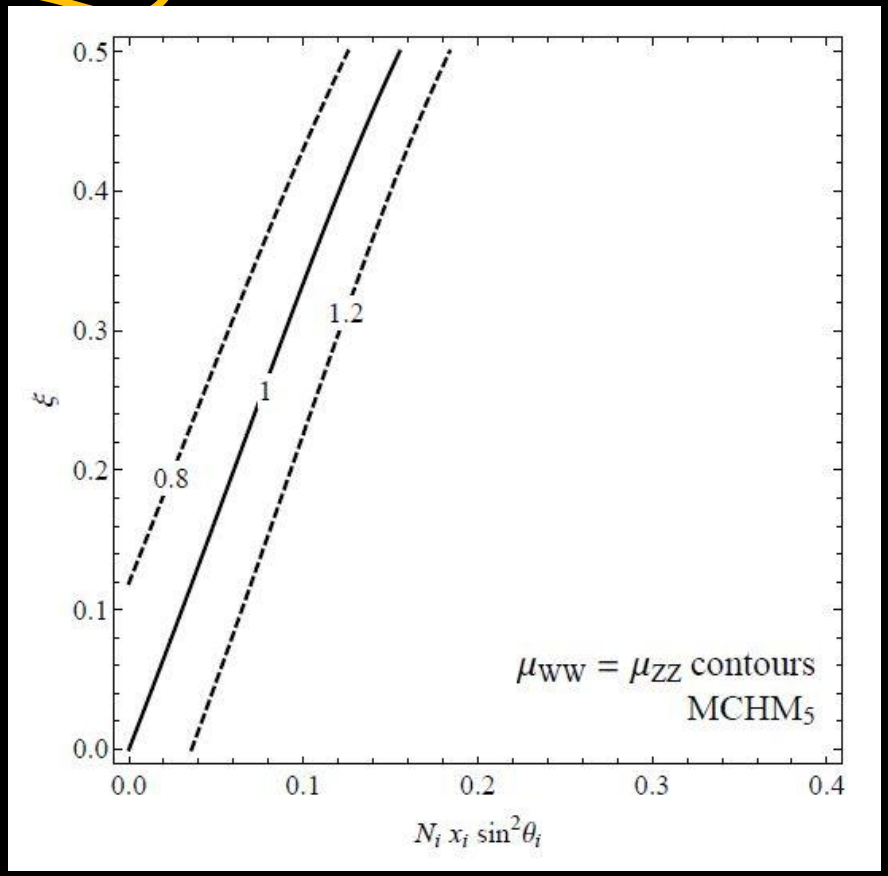

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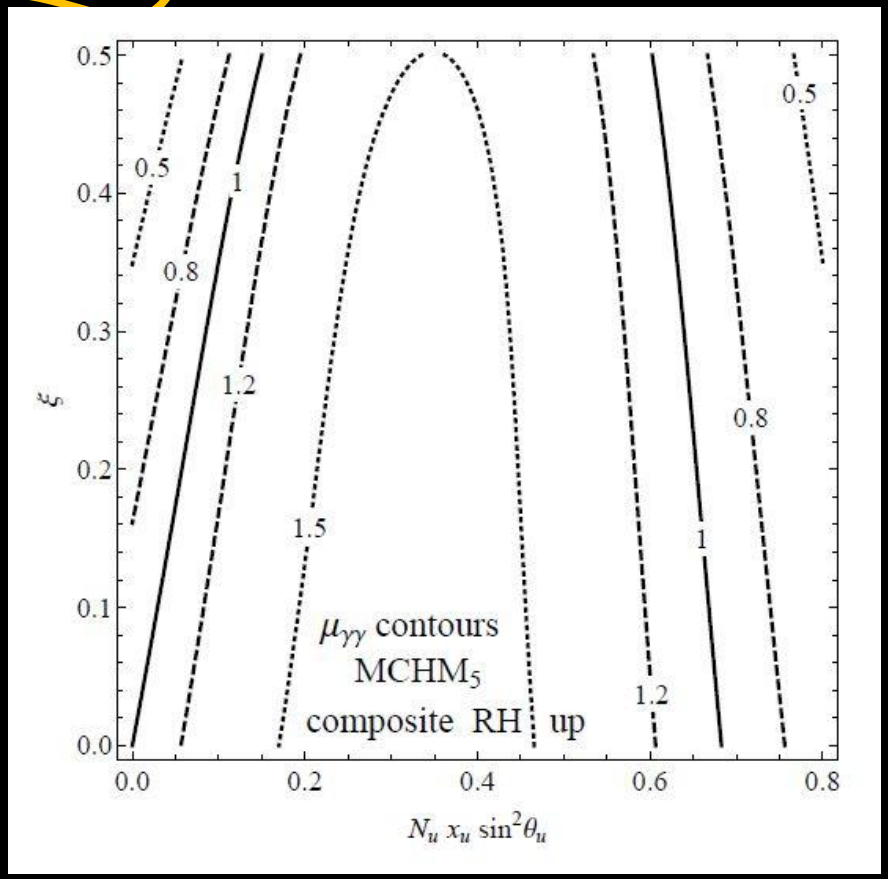

Q: can one bury composite top partners @LHC?

Yes! *by mixing (RH) top with composite charm*

Blancke-CD-Martin-Perez
to appear

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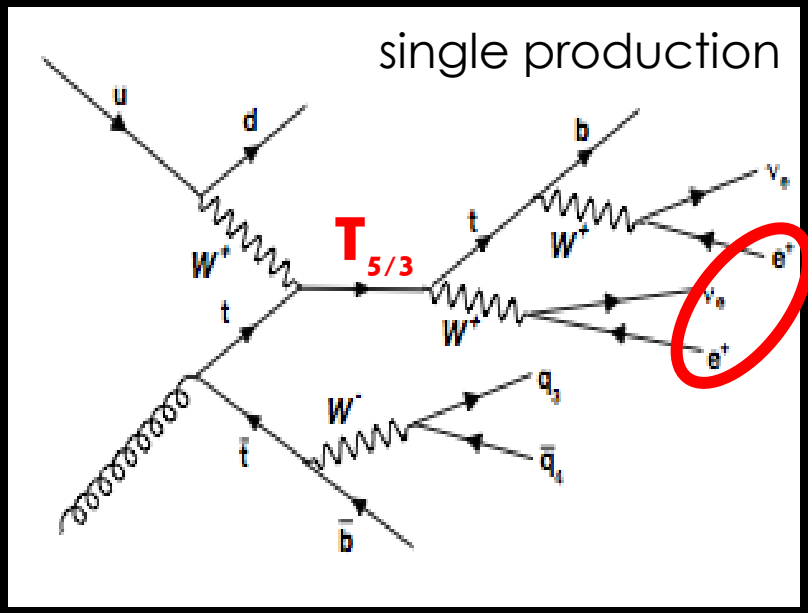

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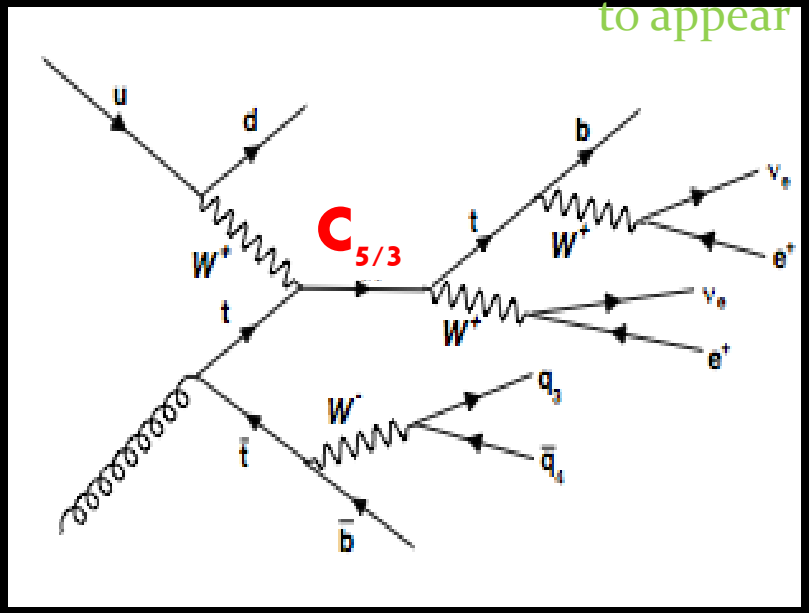

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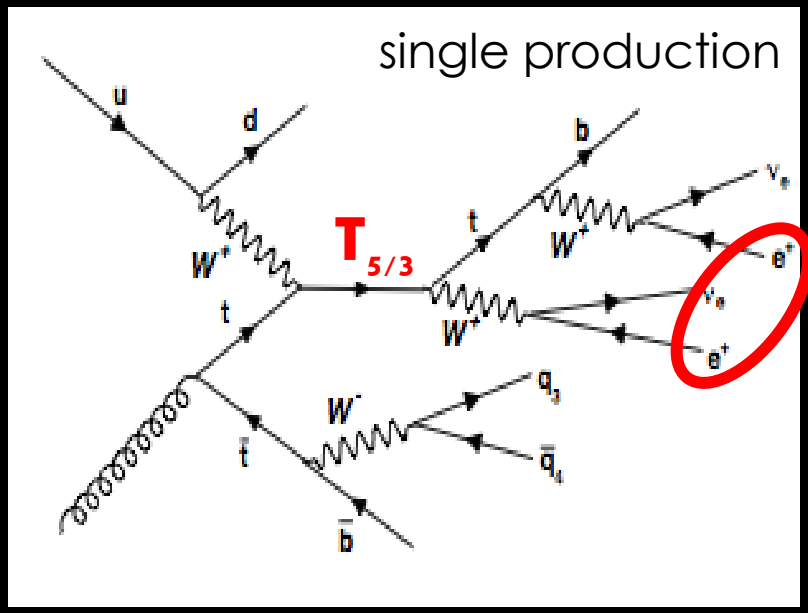

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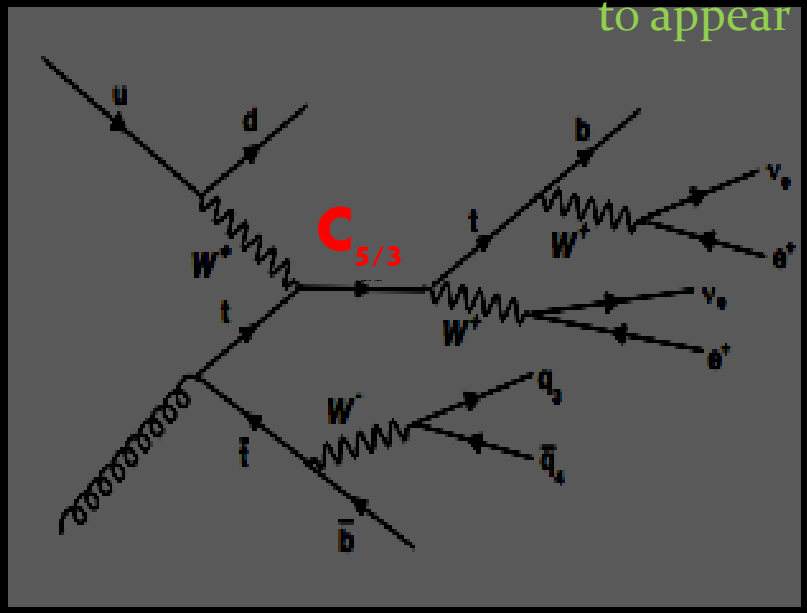

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PNGB Higgs potential is controlled by ϵ^2

→ one can slightly decouple C5/3 without introducing fine-tuning since the c/t mixing is in the RH sector!

→ limit on top partners much weaker, T2/3 dominated