

Probing the flavor structure of the composite Higgs with $gg \rightarrow h$ and $h \rightarrow \gamma\gamma$

Cédric Delaunay
CERN-TH

based on *arxiv:1303.5701* w/ Grojean-Perez

CHM 2-site description

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

elementary sector

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

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

← mass mixing →

$$g_i f \psi_i O_i$$

$$\epsilon_i = g_i / g_\rho$$

strong sector $\Lambda = 4\pi f$
 $\sim \text{few TeV}$

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

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

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

CHM 2-site description

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

elementary sector

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

$$\begin{matrix} q_L & u_R & d_R \\ W_\mu & B_\mu & G_\mu \end{matrix}$$

← mass mixing →

$$g_i f \psi_i O_i$$

$$\epsilon_i = g_i / g_\rho$$

strong sector $\Lambda = 4\pi f$
 $\sim \text{few TeV}$

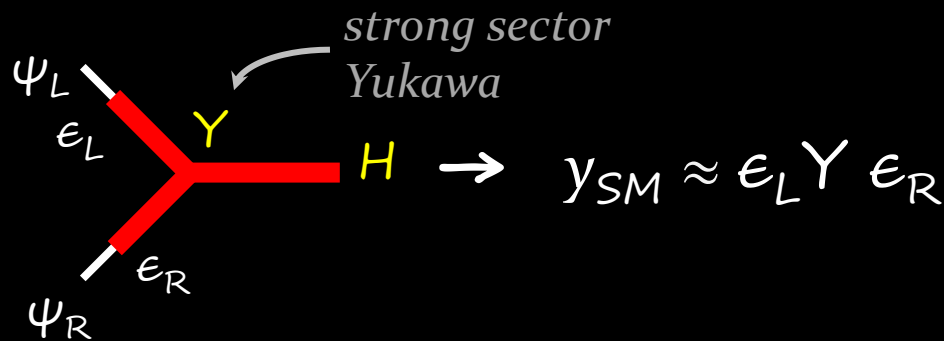
$$H \in \mathcal{G}/\mathcal{H}$$

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

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

smallest coset w/ custodial symmetry: $SO(5)/SO(4)$

fermion masses induced by ϵ_i



partial compositeness:

$$\begin{aligned} |SM\rangle &= \cos |elem\rangle + \sin |comp\rangle \\ &\approx |elem\rangle + \epsilon |comp\rangle \end{aligned}$$

Higgs=NGB → no tree-level potential

EWSB $SO(4) \rightarrow SO(3)$ radiatively induced by top mixings ϵ_{tL} , ϵ_{tR}

much of the 3rd generation inferred from naturalness:
top+bL are mostly composite,
top VLQ partner $< 1\text{TeV}$

on the other hand:

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

Q1: are light quark composite objects?

Q2: do they have partners too?

Flavor structures of CHMs

Agashe-Perez-Soni '04

$$G_{\text{flavor}} = U(3)_{q,u,d}^3 \times U(3)^3$$

elementary \swarrow \searrow *composite*

flavor anarchy

m_ρ, Y fully break $U(3)^3$
 ϵ_i are hierarchical $\propto \sqrt{y_{SM}}$

flavor agnosia

m_ρ, Y, ϵ_R preserve $U(3)^3$
 $\epsilon_L \propto y_{SM}$ and $U(3)^3 \rightarrow \approx U(2)^3$
 \rightarrow MFV rules

Flavor structures of CHMs

Agashe-Perez-Soni '04

$$G_{\text{flavor}} = U(3)_{q,u,d}^3 \times U(3)_{\text{composite}}^3$$

elementary \swarrow \nwarrow *composite*

flavor anarchy

m_ρ, Y fully break $U(3)^3$
 ϵ_i are hierarchical $\propto \sqrt{y_{SM}}$

$\rightarrow t (+b_L)$ composite

\rightarrow light $q (+b_R)$ elementary

FCNCs suppressed by ϵ_i

RS-GIM at work Agashe-Perez-Soni '04

yet K -mixing/decay too large

$m_\rho > \sim 10 \text{ TeV}$ Csaki-Falkowski-Weiler '08
KerenDur-Rattazzi et al. '12

flavor agnosia

m_ρ, Y, ϵ_R preserve $U(3)^3$

$\epsilon_L \propto y_{SM}$ and $U(3)^3 \rightarrow \approx U(2)^3$

\rightarrow **MFV rules** CD-Gedalia-
Lee-Perez-
Ponton '10
Redi-Weiler '11

$\rightarrow t (+b_L) +$ light q_R composite

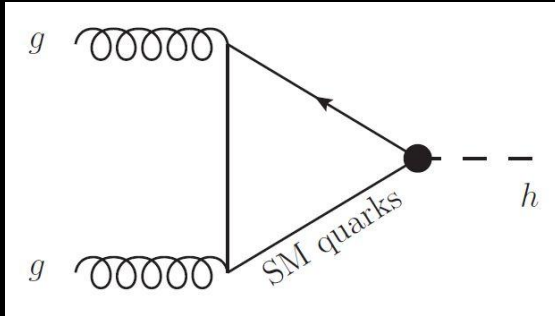
\rightarrow light q_L elementary

No K problem, $m_\rho > \sim 2-3 \text{ TeV}$

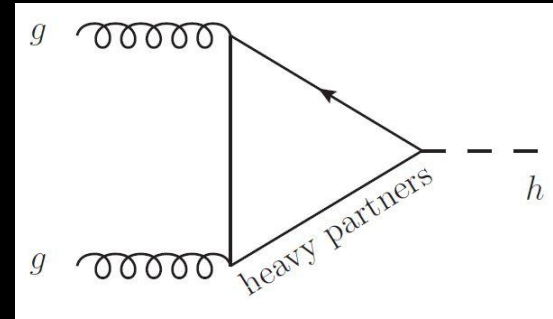
from S parameter@LEP \nearrow

Composite Higgs radiative couplings

$$M_{gg \rightarrow h} =$$

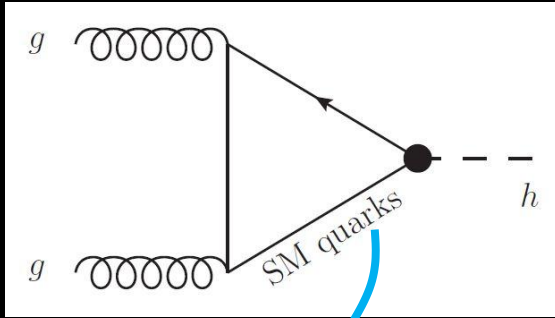


+

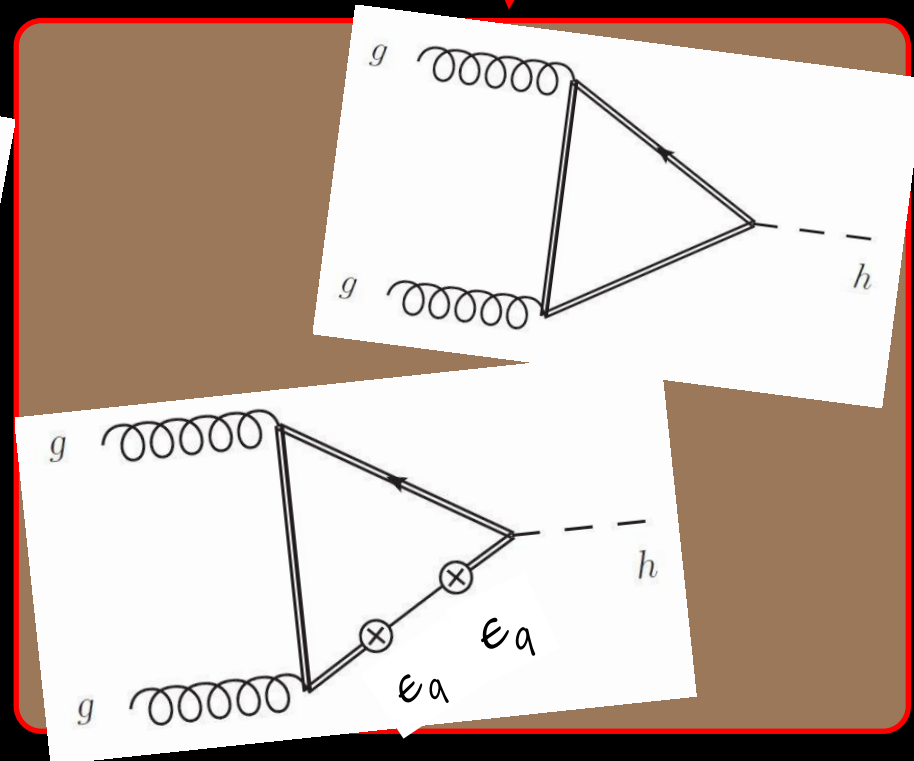
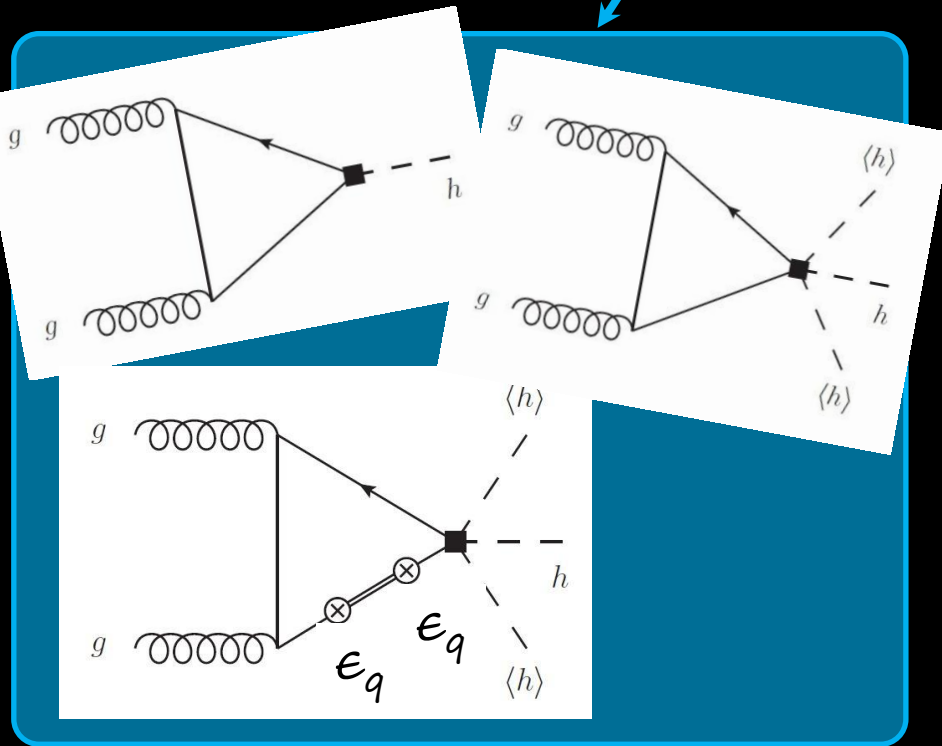
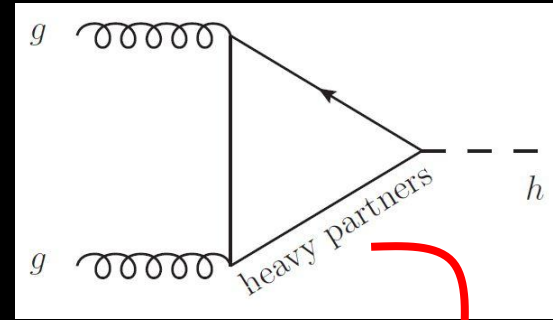


Composite Higgs radiative couplings

$$M_{gg \rightarrow h} =$$

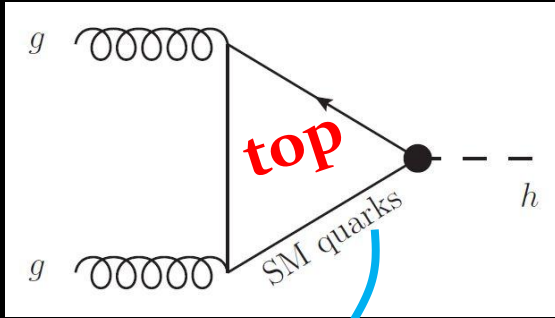


+

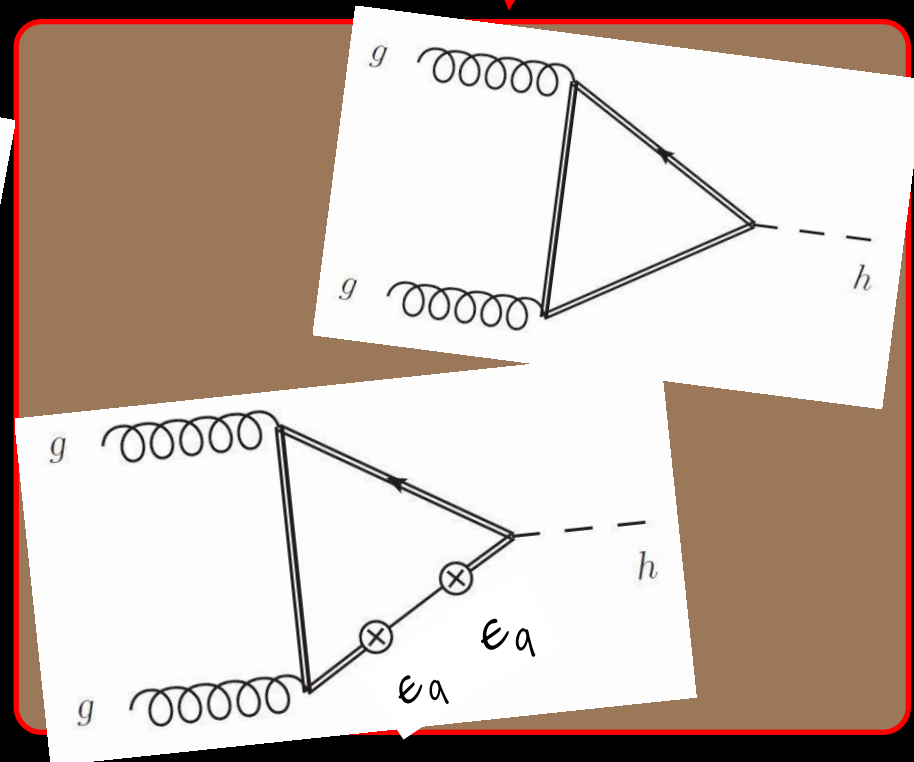
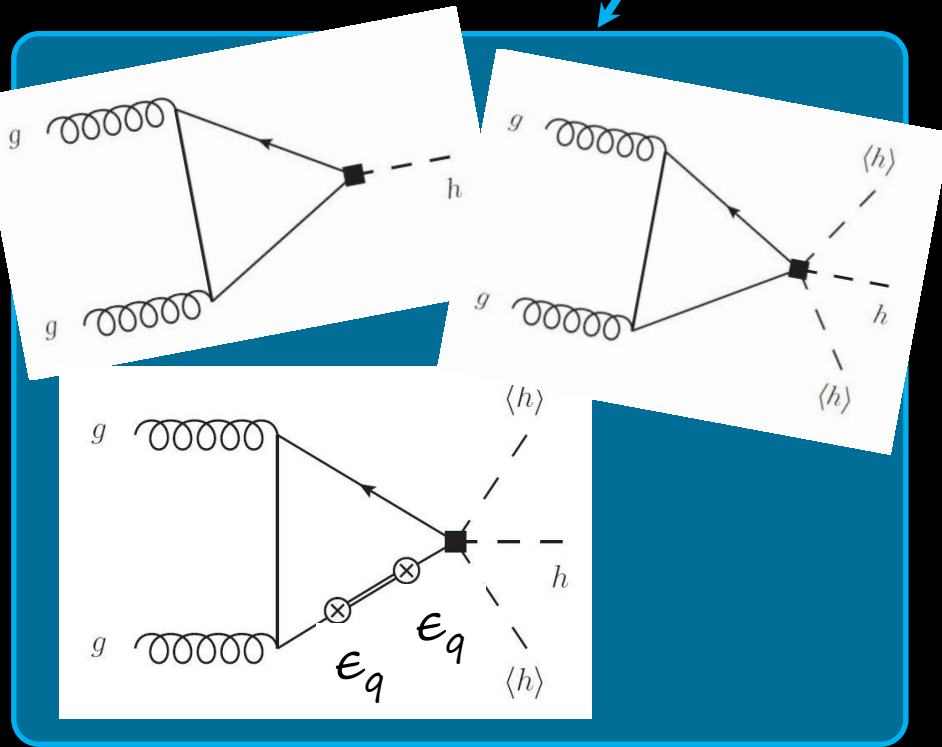
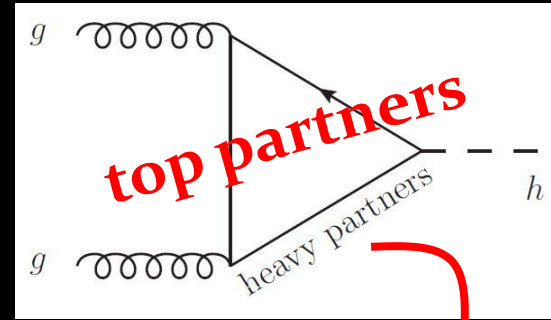


Composite Higgs radiative couplings

$$M_{gg \rightarrow h} =$$

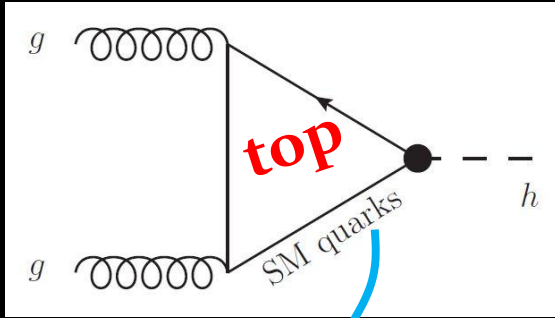


+

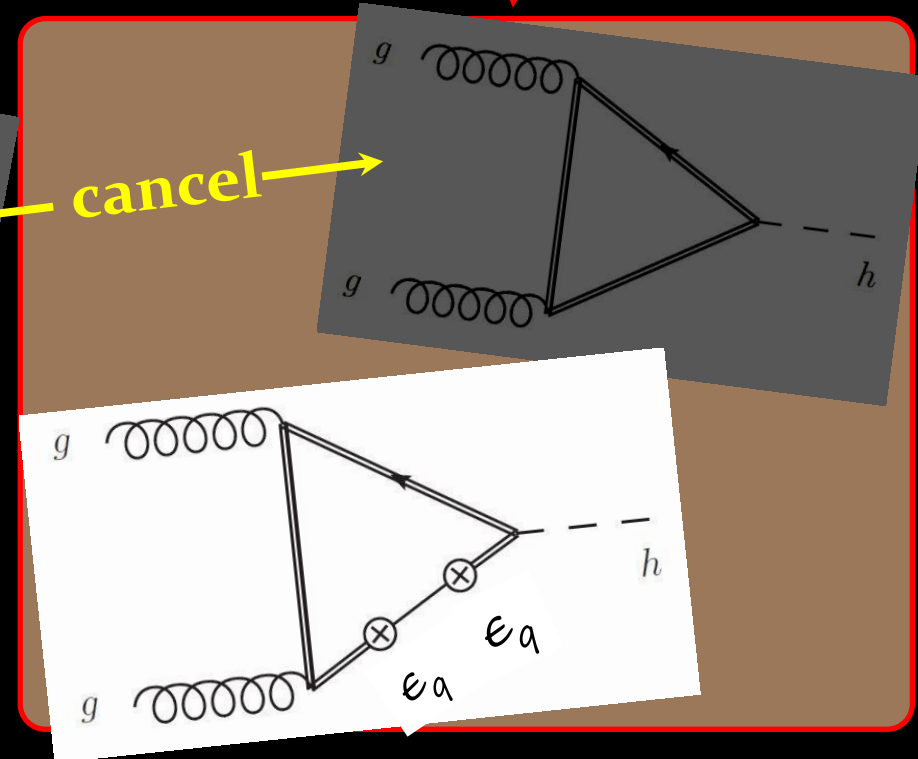
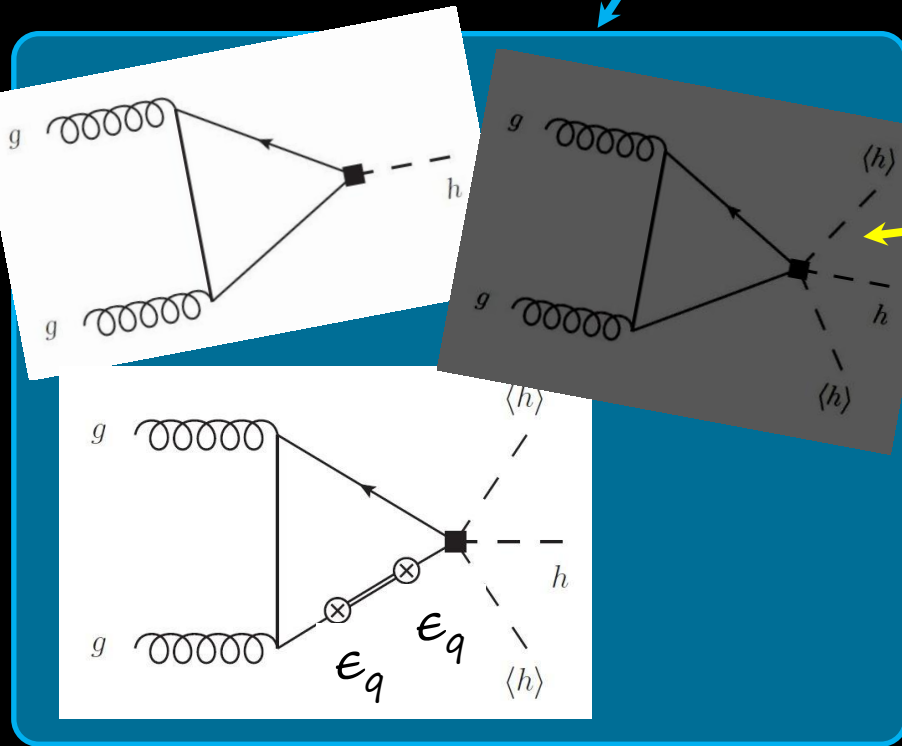
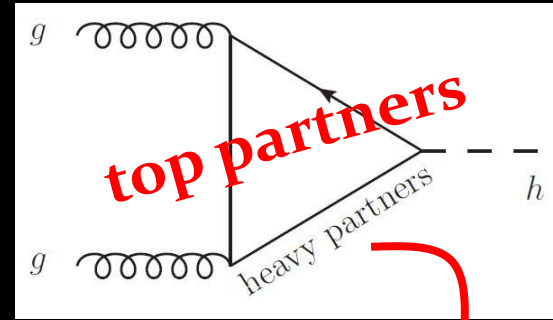


Composite Higgs radiative couplings

$$M_{gg \rightarrow h} =$$

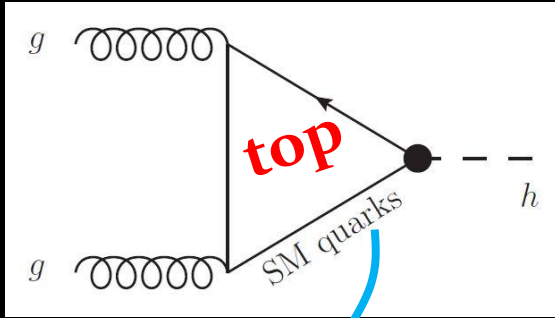


+

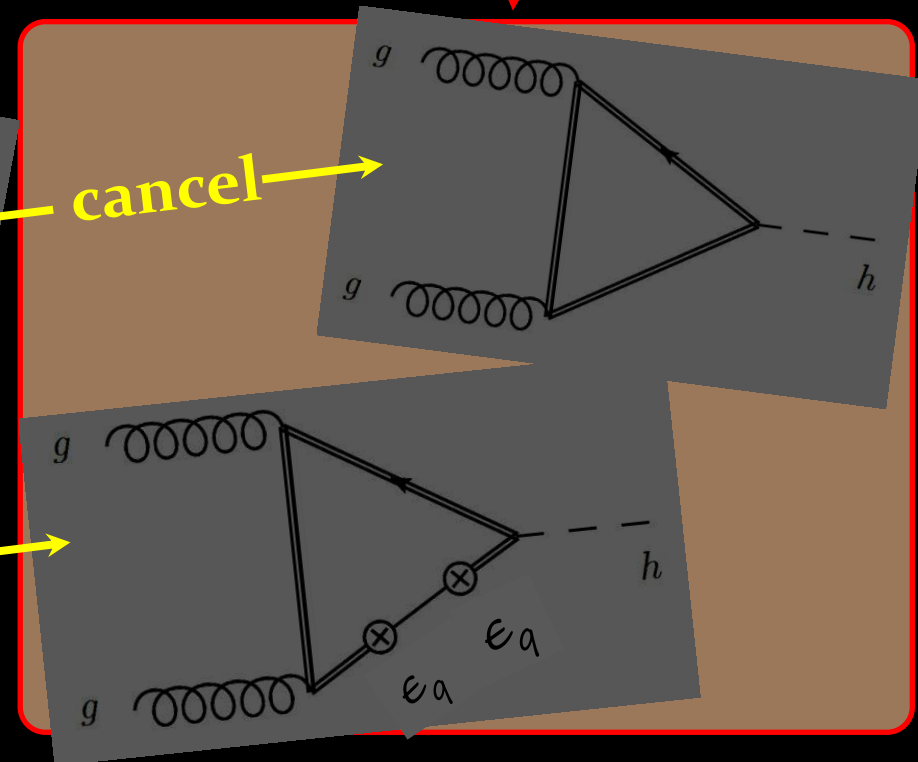
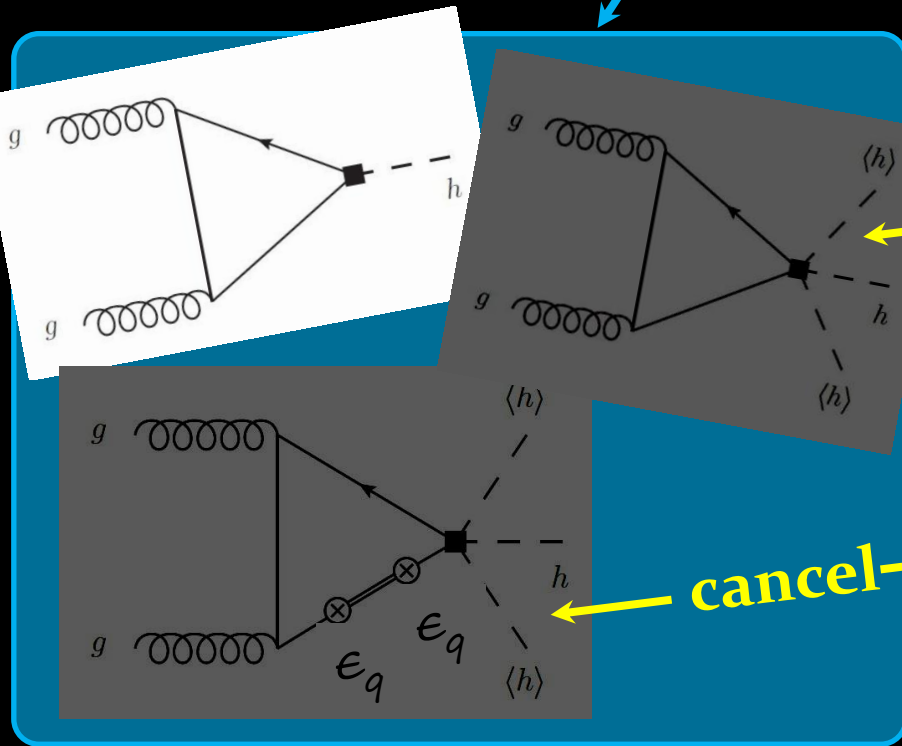
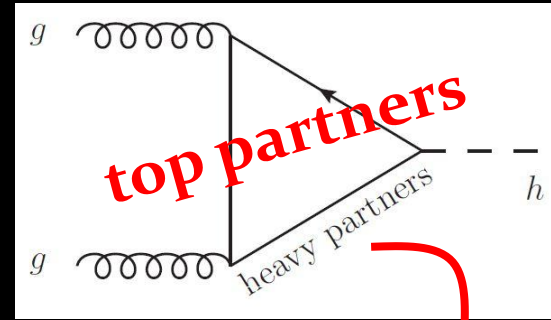


Composite Higgs radiative couplings

$$M_{gg \rightarrow h} =$$

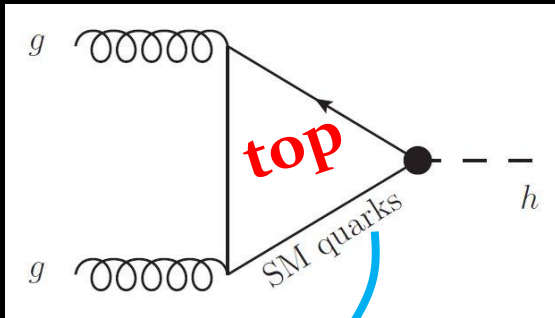


+

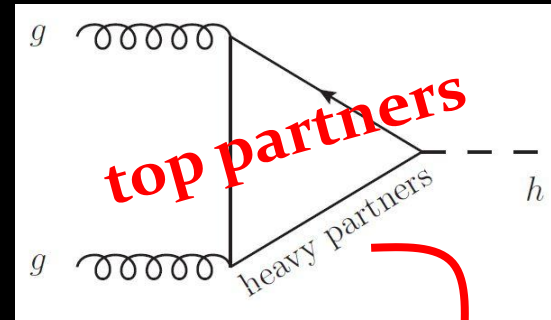


Composite Higgs radiative couplings

$$M_{gg \rightarrow h} =$$



+



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

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

$\propto 1$

\rightarrow no sensitivity to top compositeness and top partners spectrum

typical structure in CHM:

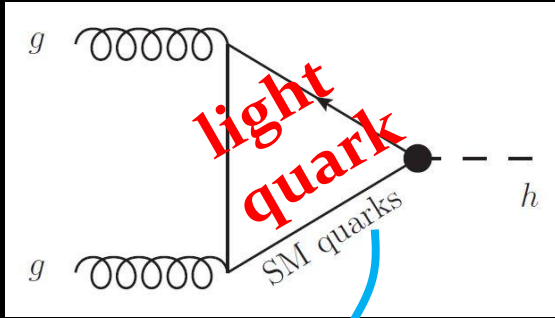
$$\mathcal{M} = \begin{pmatrix} 0 & \lambda_q & 0 \\ 0 & M_Q & Y \tilde{H} \\ \lambda_u & \tilde{Y} \tilde{H}^\dagger & M_U \end{pmatrix}$$

$$\det M \propto H$$

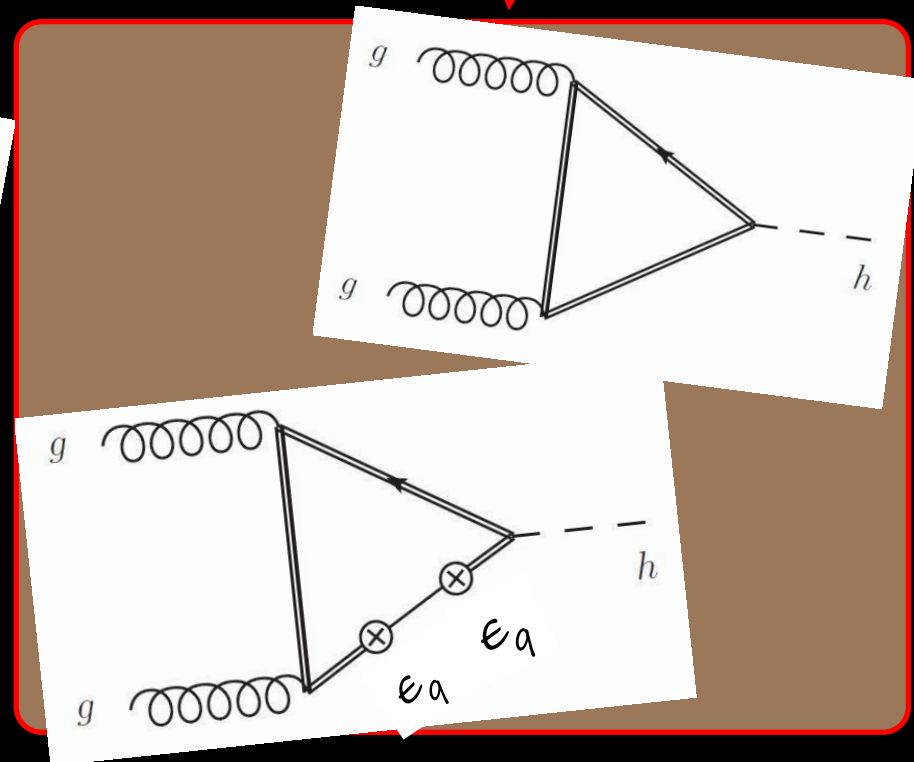
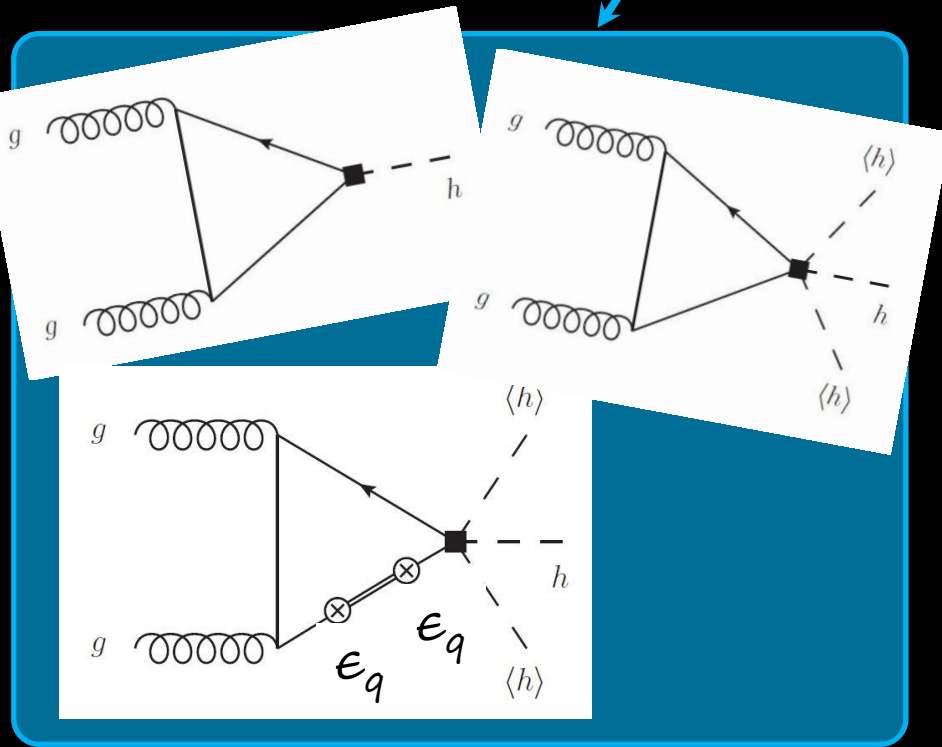
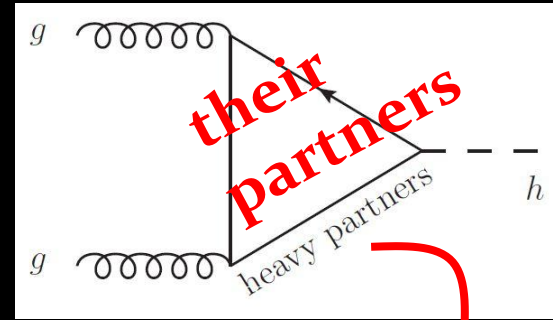
Falkowski '08, Azatov-Galloway '10

Composite Higgs radiative couplings

$$M_{gg \rightarrow h} =$$

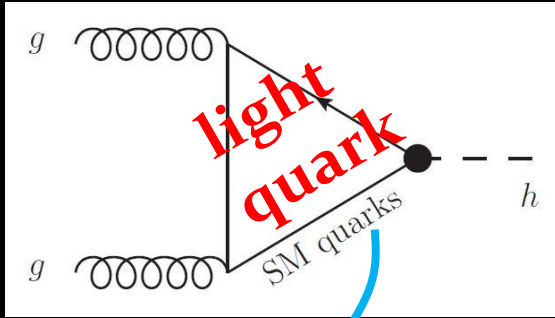


+

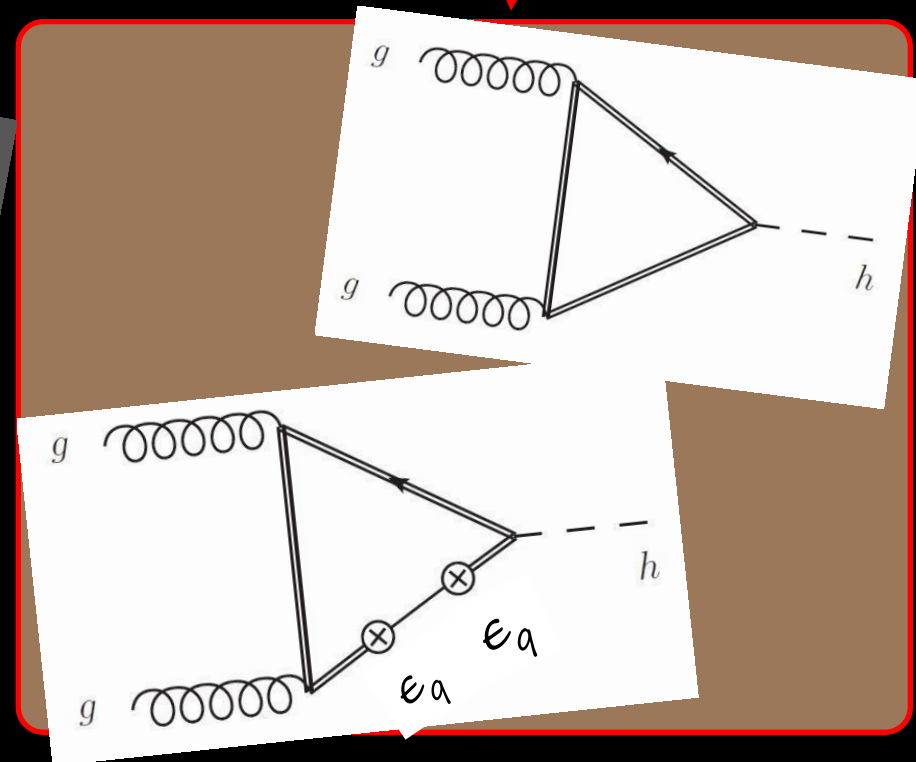
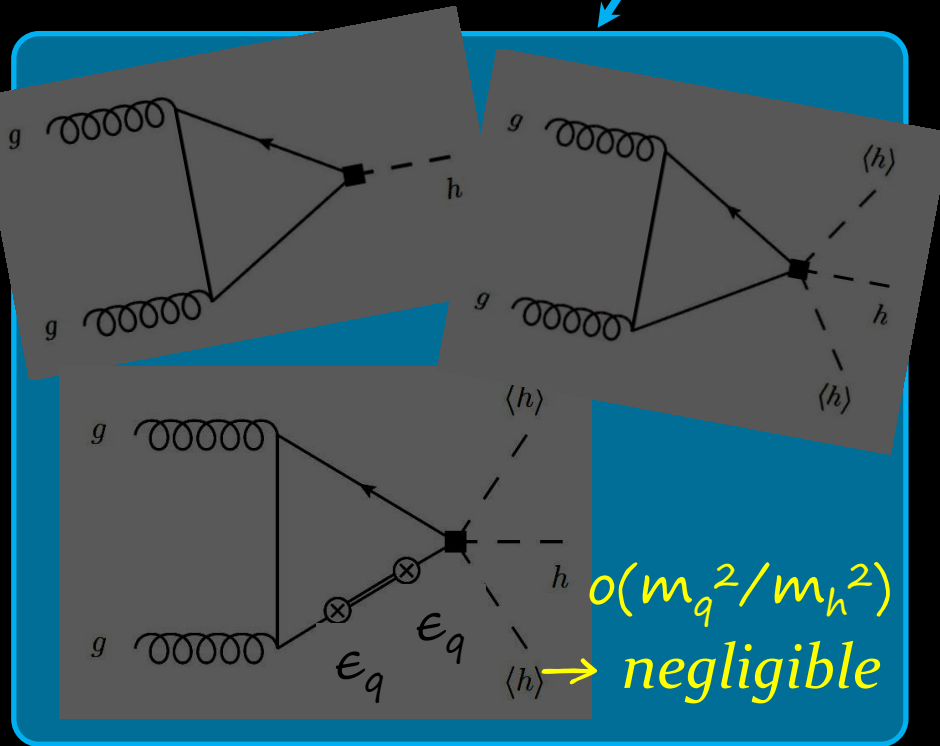
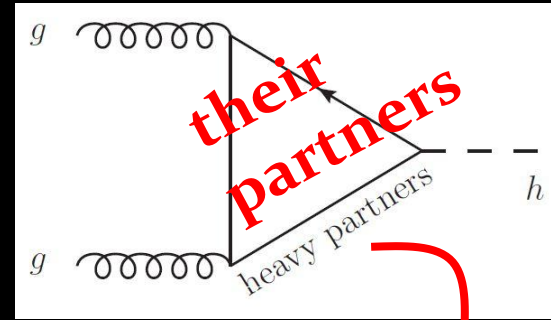


Composite Higgs radiative couplings

$$M_{gg \rightarrow h} =$$

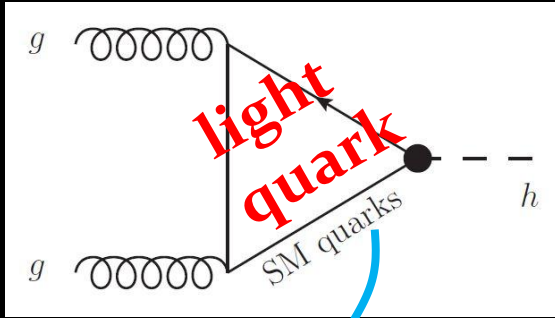


+

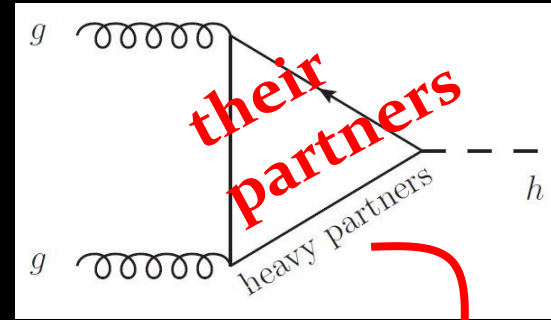


Composite Higgs radiative couplings

$$M_{gg \rightarrow h} =$$



+



A collage of four Feynman diagrams on a blue background, illustrating corrections to the SM quark loop. The diagrams show various loop topologies involving quarks and Higgs bosons. One diagram includes a vertex correction with a cross symbol and the label ϵ_a . A yellow arrow points to the diagrams with the text $o(m_q^2/m_h^2) \rightarrow$ negligible.

A collage of two Feynman diagrams on a brown background. The top diagram shows a triangle loop of heavy partners with a yellow $=0$ written next to it, and the text "H is PNGB!!" below it. The bottom diagram shows a more complex loop structure with a cross symbol and the label ϵ_a .

Composite Higgs radiative couplings

$$M_{gg \rightarrow h} =$$

The image shows two Feynman diagrams representing the radiative coupling $gg \rightarrow h$. The left diagram features a loop of Standard Model (SM) quarks, with a red arrow pointing to the loop and the text "light quark" written in red. The right diagram features a loop of heavy partners, with a red arrow pointing to the loop and the text "their partners" written in red. Both diagrams have two incoming gluon lines (g) and one outgoing Higgs line (h).

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

no need to resum higher resonances, thanks to PGB symmetry
→ qualitatively different from RS

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**, mostly RH to pass EWPTs

Higgs rates as probe of light quark compositeness

CD-Grojean-Perez '13

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

top sector

$\xi = (v/f)^2 \rightarrow$ suppresses $gg \rightarrow h$
Rattazzi-Low '09

light q_R sector

$N = \#$ composite flavors

$x = (Yv/m_\rho)^2$

$\sin \theta_R \approx \epsilon_R$

$r = g_\rho/Y \sim o(1)$

\rightarrow enhances $gg \rightarrow h$

Higgs rates as probe of light quark compositeness

CD-Grojean-Perez '13

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

top sector

$\xi = (v/f)^2 \rightarrow$ suppresses $gg \rightarrow h$
Rattazzi-Low '09

light q_R sector

$N = \#$ composite flavors

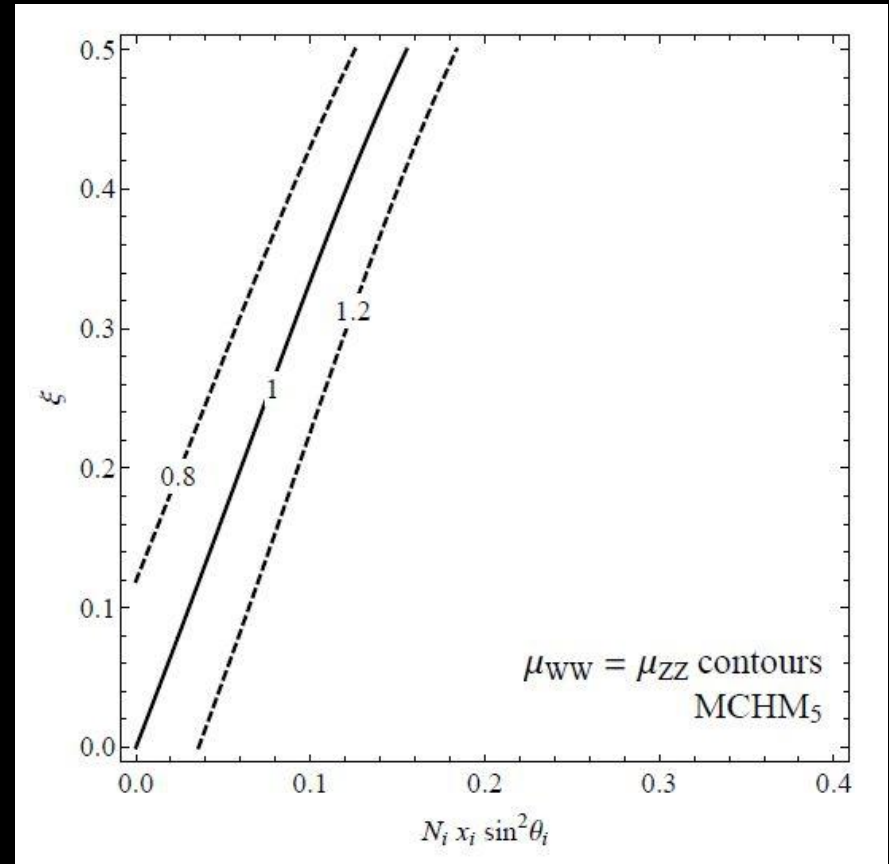
$x = (Yv/m_\rho)^2$

$\sin \theta_R \approx \epsilon_R$

$r = g_\rho/Y \sim o(1)$

\rightarrow enhances $gg \rightarrow h$

Higgs compositeness \rightarrow



light quark compositeness \rightarrow

Higgs rates as probe of light quark compositeness

CD-Grojean-Perez '13

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

top sector

$\xi = (v/f)^2 \rightarrow$ suppresses $gg \rightarrow h$
Rattazzi-Low '09

light q_R sector

$N = \#$ composite flavors

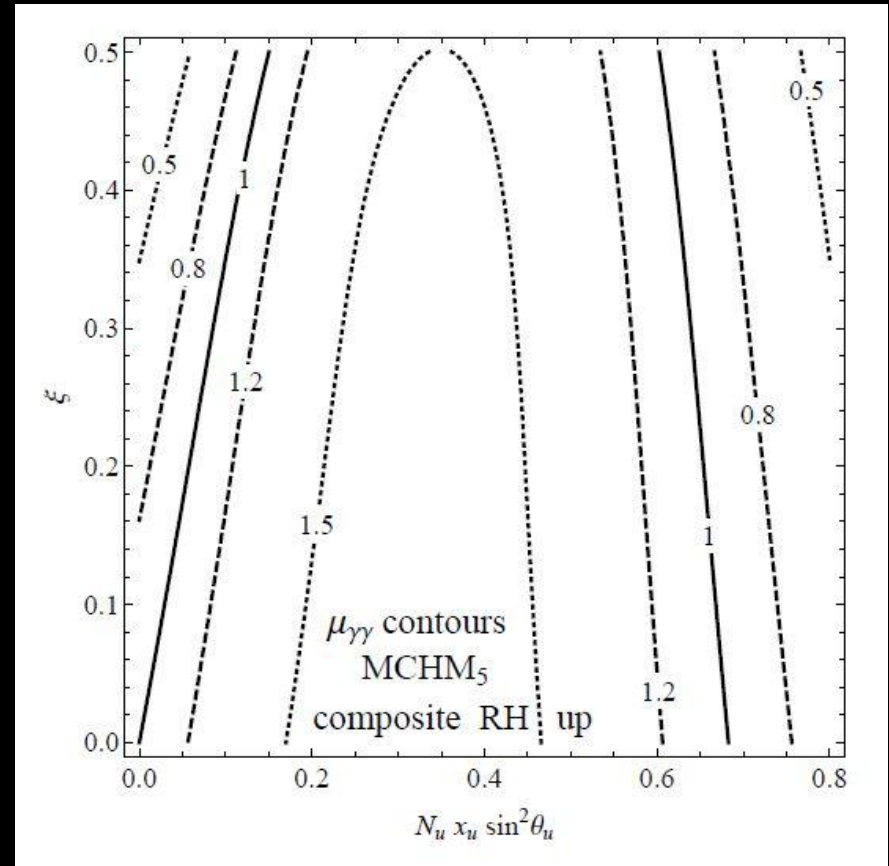
$x = (Yv/m_\rho)^2$

$\sin \theta_R \approx \epsilon_R$

$r = g_\rho/Y \sim o(1)$

\rightarrow enhances $gg \rightarrow h$

Higgs compositeness \rightarrow



light quark compositeness \rightarrow

Outro

- *Naturalness (+ m_h) dictates the top sector of CHMs*
- *but there's no guide line for flavor physics:*
 - *anarchy: ~~flavor~~ from strong dynamics*
 - *agnosia: ~~flavor~~ external to strong sector (like in QCD)*
- *being sensitive to light flavor compositeness*
Higgs couplings to gluons and photons
are interesting handles on this question
- *relax Higgs couplings tension w/ CHM at $f \sim 500\text{GeV}$*
→ could help with naturalness?

backups

Minimal Composite Higgs Model

Consider $G/H=SO(5)/SO(4)$ (+ extra $U(1)_X$ to get hypercharges)

$$\Sigma \sim 5_0 = (0,0,0,0,1) \exp[-i h \hat{a} T \hat{a} / f], \hat{a}=1\dots 4, \Sigma \Sigma^\dagger = 1$$

$SO(5)$ is non-linearly realized.

4 PGBs $\sim 4_0$ of $SO(4)$

Fermion resonances are also embedded in $SO(5) \times U(1)_X$ irreps, for definiteness consider $\psi_u \sim 5_{2/3}, \psi_d \sim 5_{-1/3}$

$5 = 1+4$ under $SO(4) \sim SU(2)_L \times SU(2)_R$

contains 2 $SU(2)_L$ doublets of hycharge $y = \pm 1/2 + X$

$$\text{e.g. } 5_{2/3} = \frac{1}{\sqrt{2}} \left(D_{\frac{1}{6}}^- - D_{\frac{7}{6}}^+, -i \left(D_{\frac{1}{6}}^- + D_{\frac{7}{6}}^+ \right), D_{\frac{1}{6}}^+ + D_{\frac{7}{6}}^-, i \left(D_{\frac{1}{6}}^+ - D_{\frac{7}{6}}^- \right), \sqrt{2} S_{\frac{2}{3}} \right)^T$$

Minimal Composite Higgs Model

$$\mathcal{L} = \mathcal{L}_{\text{elem}} + \mathcal{L}_{\text{strong}} + \mathcal{L}_{\text{mix}}$$

$$\mathcal{L}_{\text{elem}} = i\bar{q}_L \not{D} q_L + i\bar{u}_R \not{D} u_R + i\bar{d}_R \not{D} d_R,$$

$$\mathcal{L}_{\text{strong}} = \sum_{i=u,d} \bar{\Psi}^i (i\not{D} - M_i) \Psi^i - Y_i f (\bar{\Psi}_L \Sigma^T) (\Sigma \Psi_R^i) + \text{h.c.},$$

$$-\mathcal{L}_{\text{mix}} = \lambda_{q^u} \bar{q}_L D_{\frac{1}{6}R}^u + \lambda_{q^d} \bar{q}_L D_{\frac{1}{6}R}^d + \lambda_u \bar{u}_R S_{\frac{2}{3}L} + \lambda_d \bar{d}_R S_{-\frac{1}{3}L} + \text{h.c.},$$