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

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

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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 →

$g_i f \psi_i O_i$

$\epsilon_i = g_i / g_\rho$

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

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

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

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

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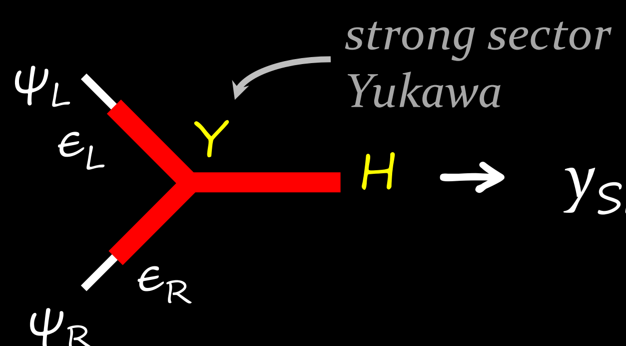
smallest coset w/ custodial symmetry: $SO(5)/SO(4)$
fermion masses induced by ϵ_i



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

partial compositeness:

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

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

much of the 3rd generation infered from naturalness:
top+bL are mostly composite,
top VLQ partner <1TeV

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

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

elementary → $U(3)^3_{q,u,d}$ *composite* → $U(3)^3$

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 $U(3)^3 \to \approx U(2)^3$

→ MFV rules

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→ t $(+b_L)$ composite

→ 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_ρ >~10TeV *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 $U(3)^3 \to \approx U(2)^3$

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

→ t $(+b_L)$ + light q_R composite

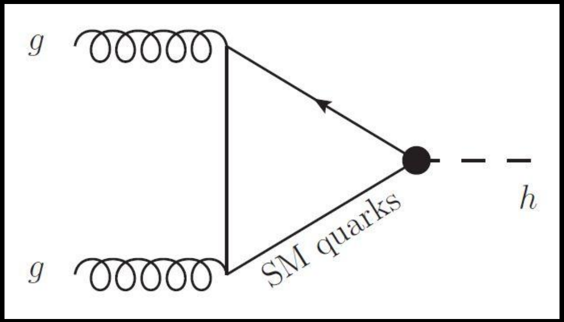
→ light q_L elementary

No K problem, m_ρ>~2-3TeV

from S parameter@LEP

Composite Higgs radiative couplings

$M_{gg \to h}$ =



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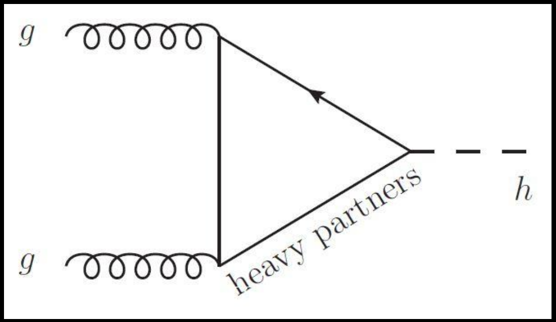

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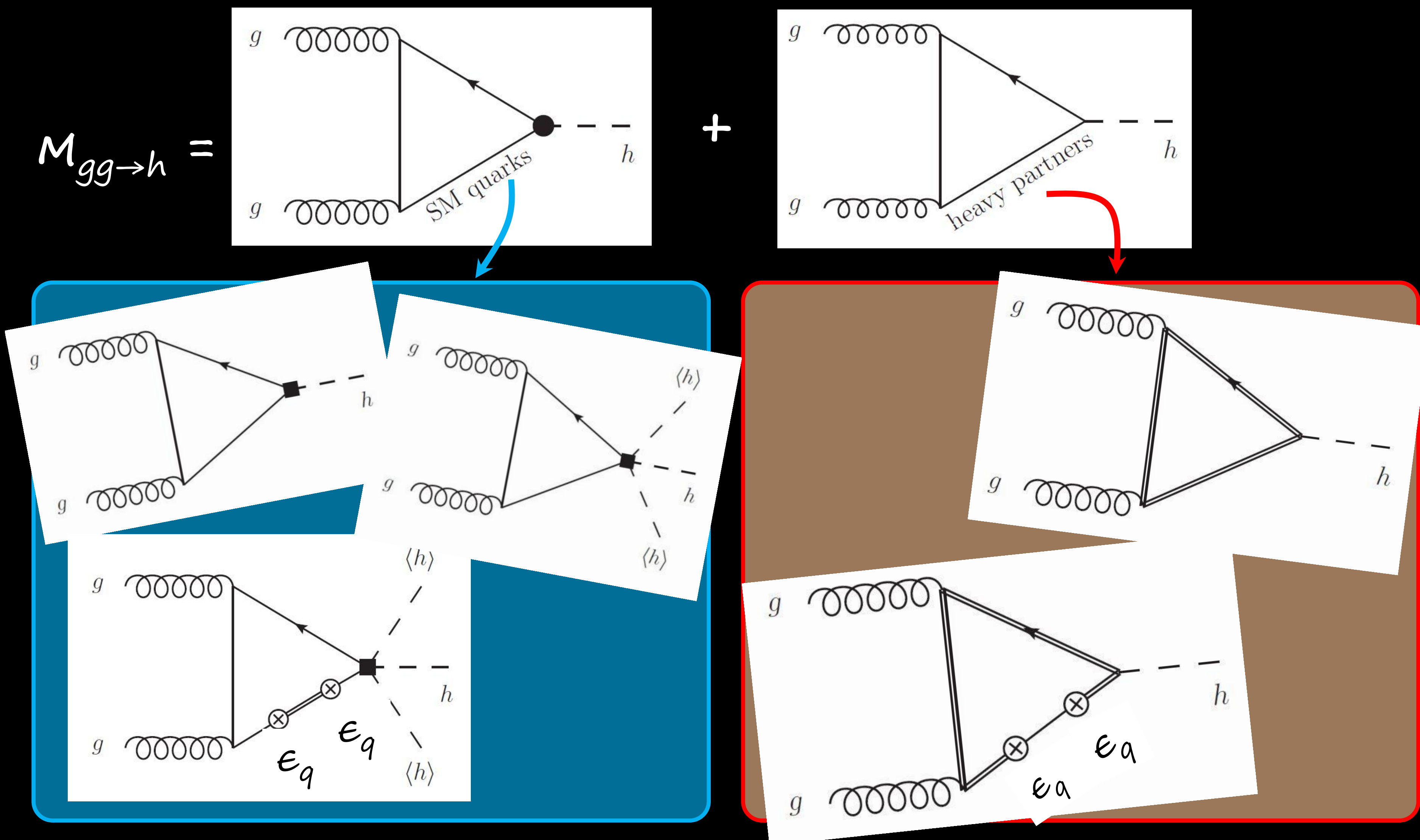

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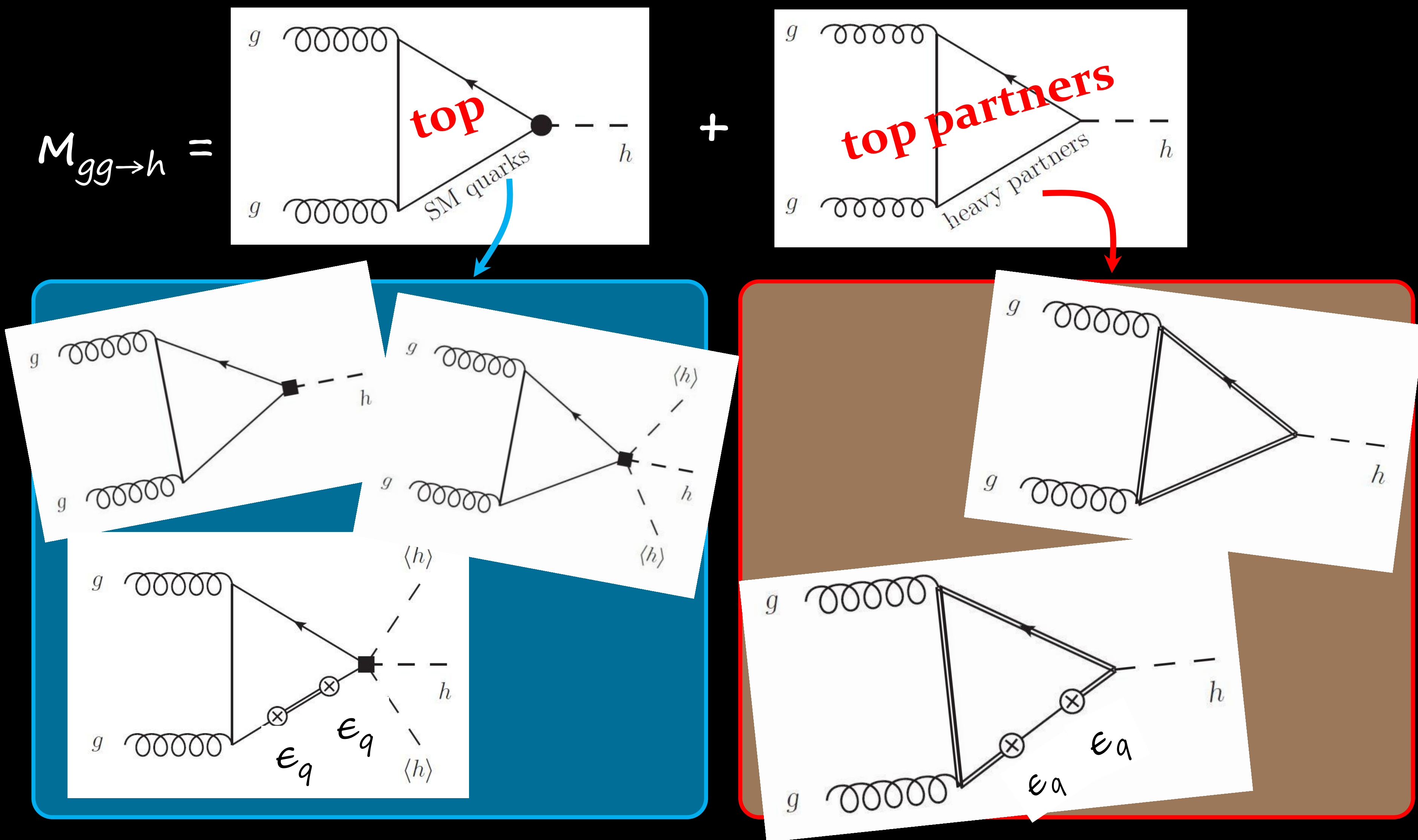

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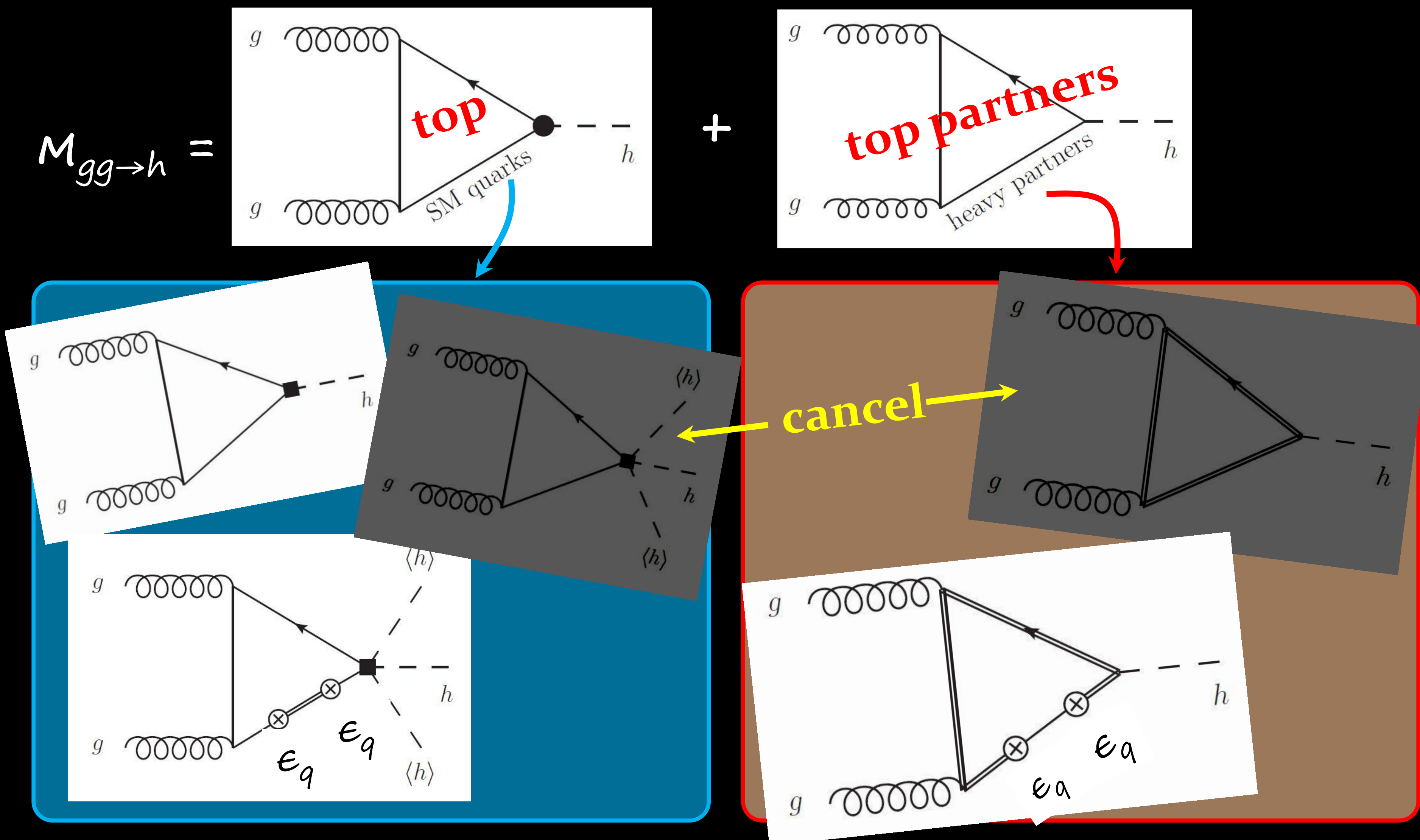

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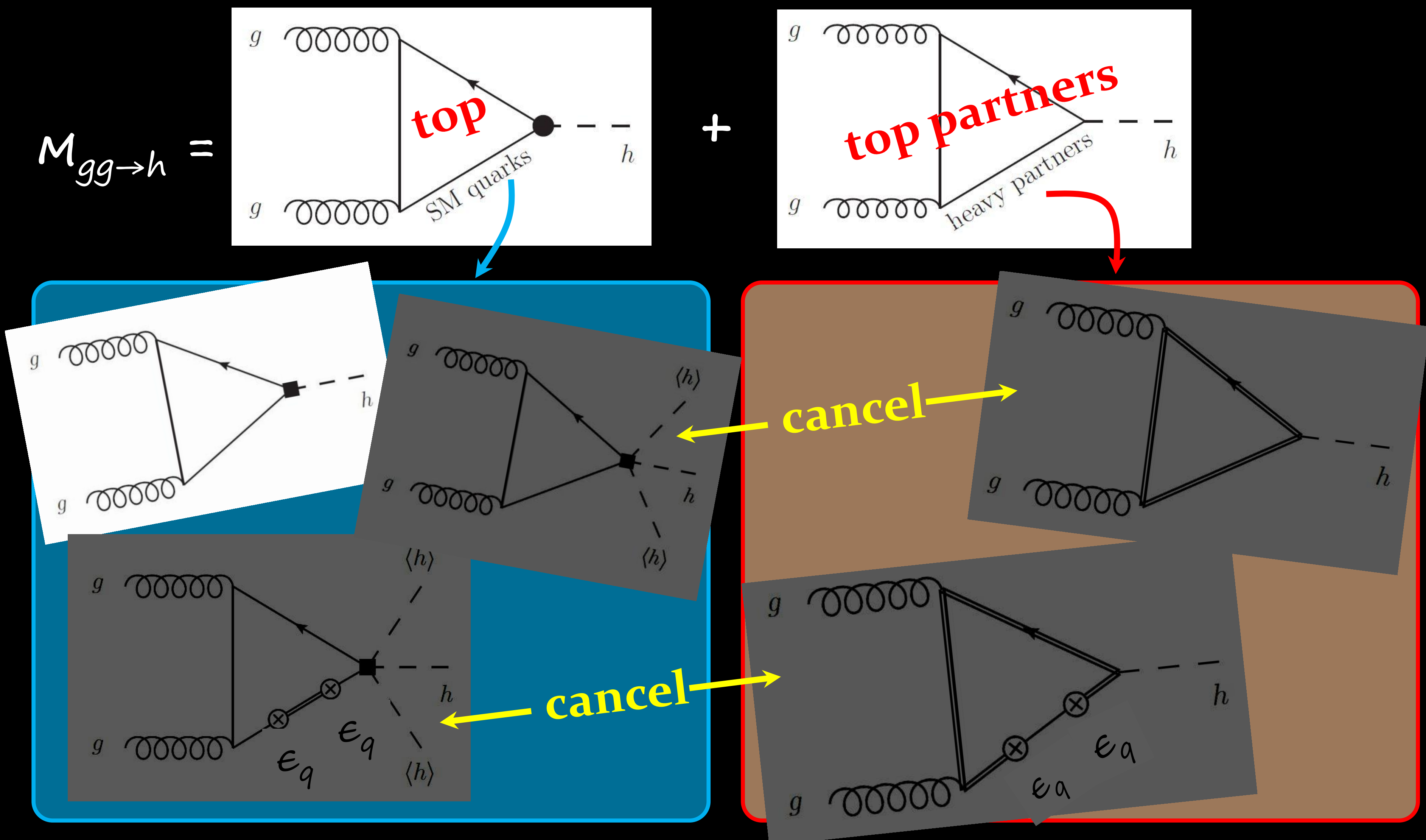
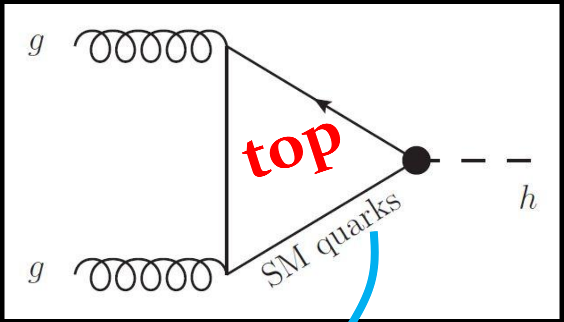


Composite Higgs radiative couplings

$M_{gg\to h} =$



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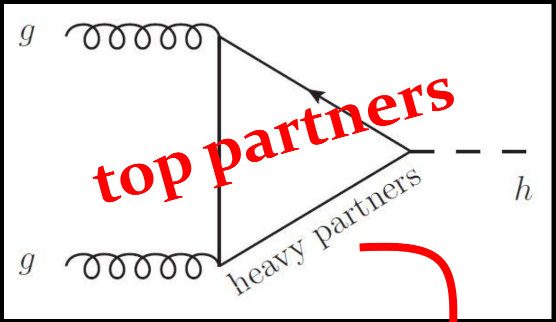


Low-energy Higgs theorem:

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:

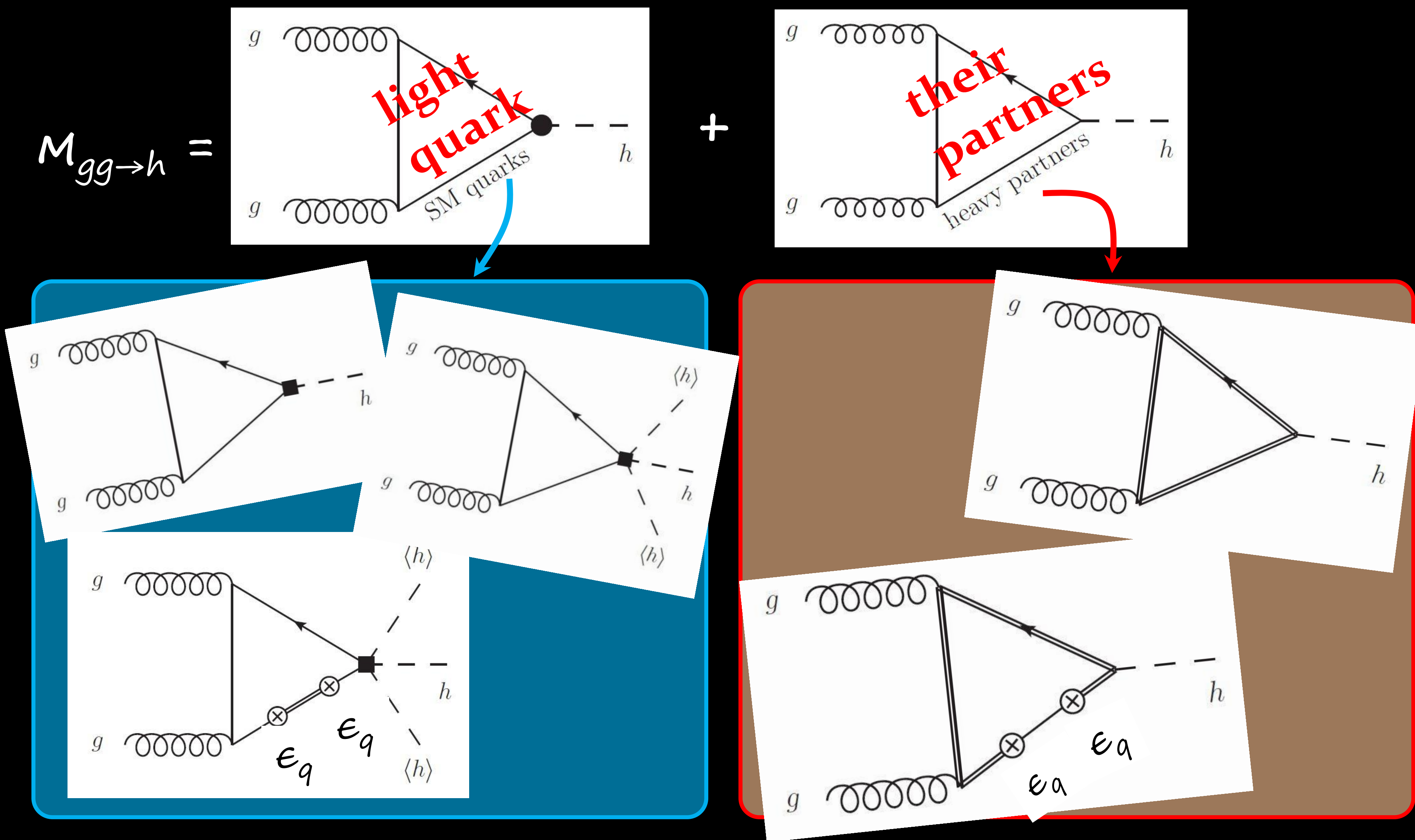
$$\mathcal{M} = \begin{pmatrix} 0 & \lambda_q & 0 \\ 0 & M_Q & Y\tilde{H} \\ \lambda_u & \tilde{Y}\tilde{H}^\dagger & M_U \end{pmatrix}$$

$\det M \propto H$

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

Falkowski '08, Azatov-Galloway '10

Composite Higgs radiative couplings



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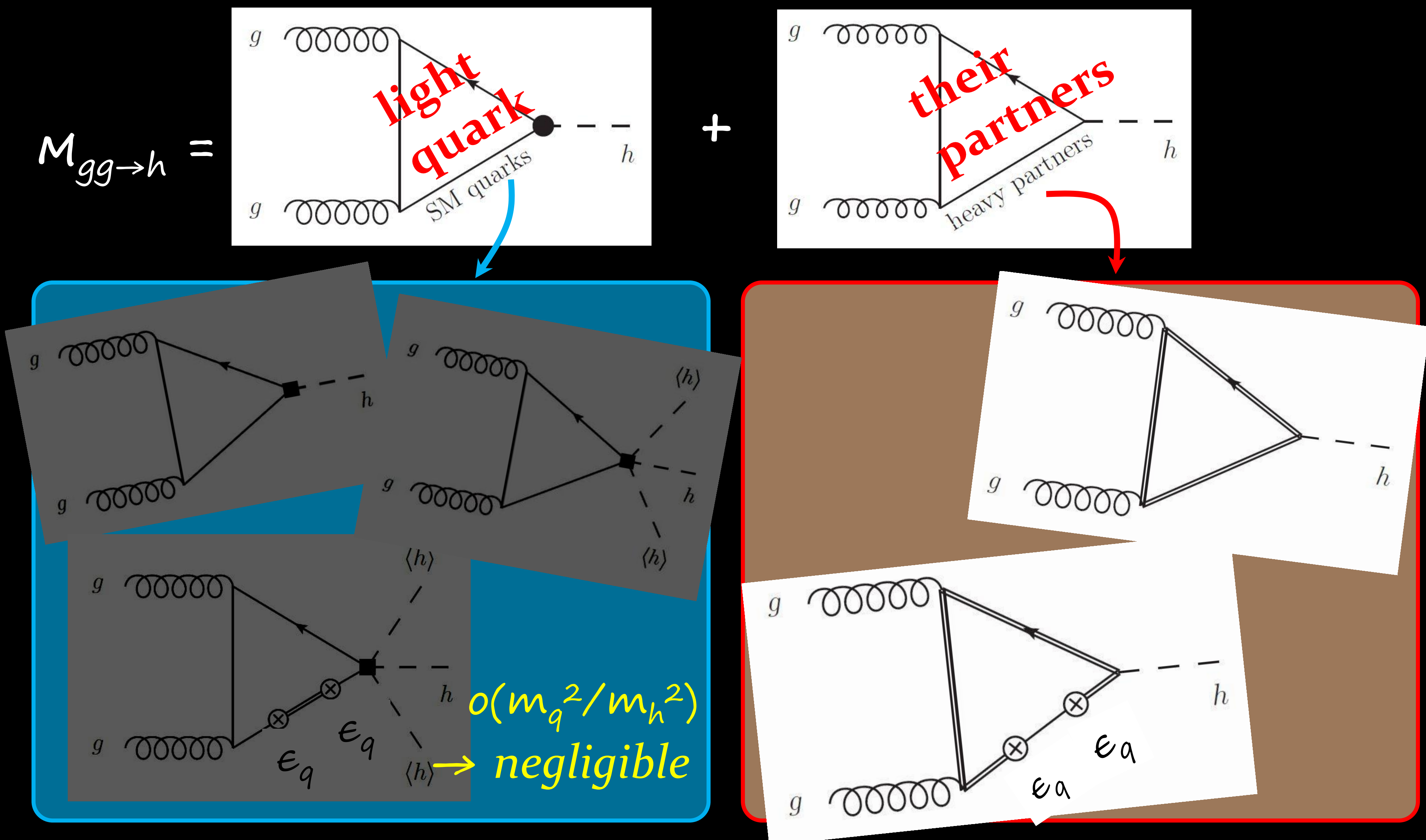

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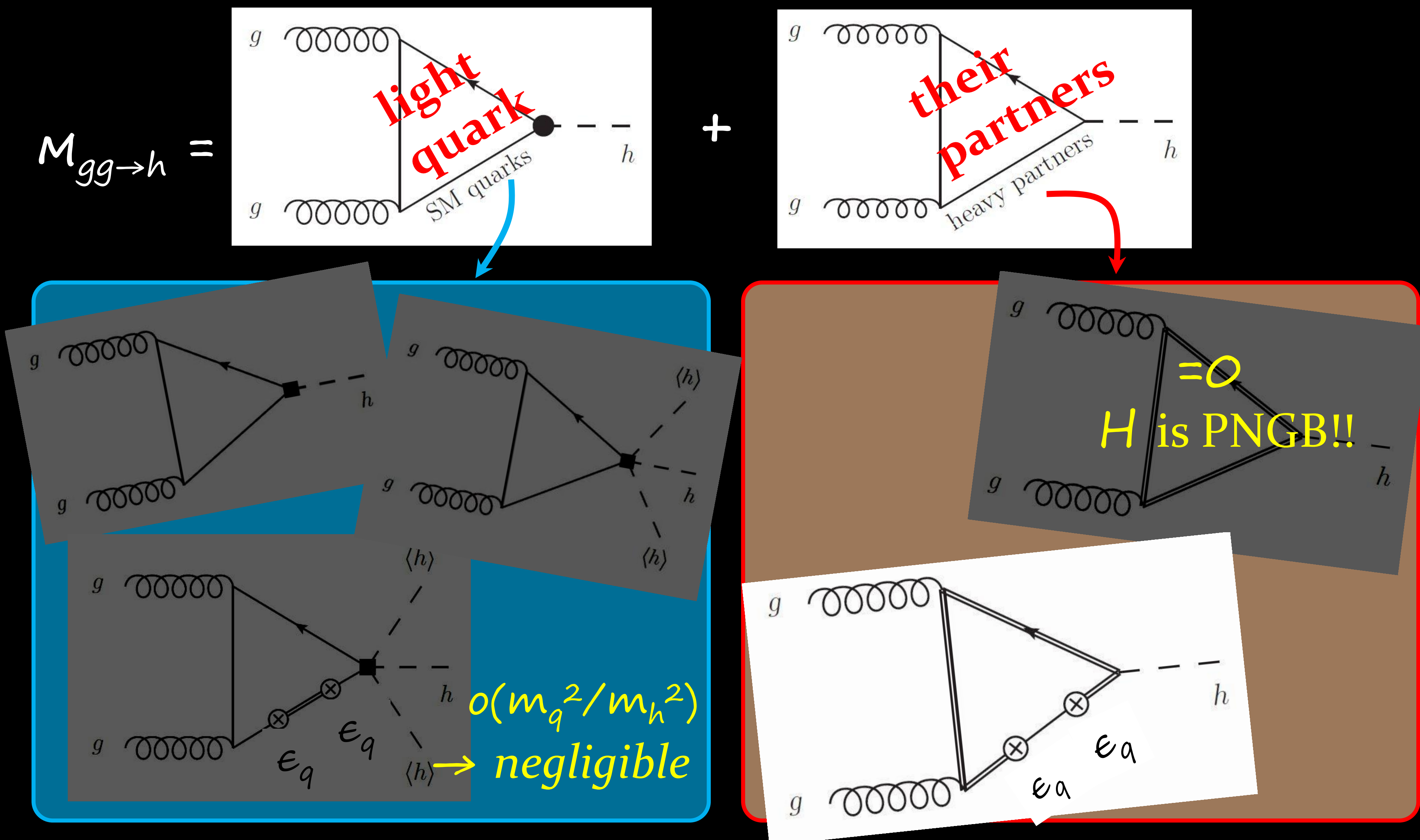

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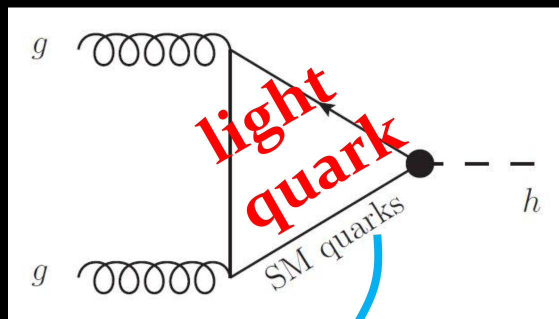
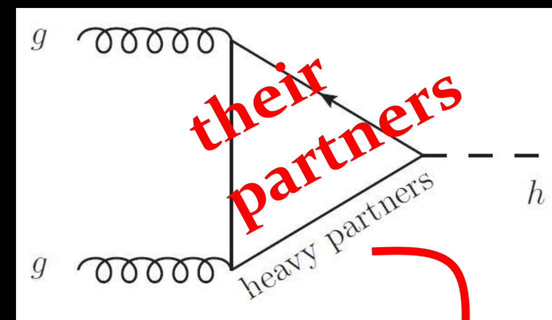
$M_{gg\to h}$ =  + 

→ 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 $\epsilon_L{}^2$ or $\epsilon_R{}^2$ 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

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

top sector

$\xi=(v/f)^2$ → suppresses $gg\to h$

Rattazzi-Low '09

light q_R sector

N = # composite flavors

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

$\sin\theta_R \approx \epsilon_R$

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

→ enhances $gg\to h$

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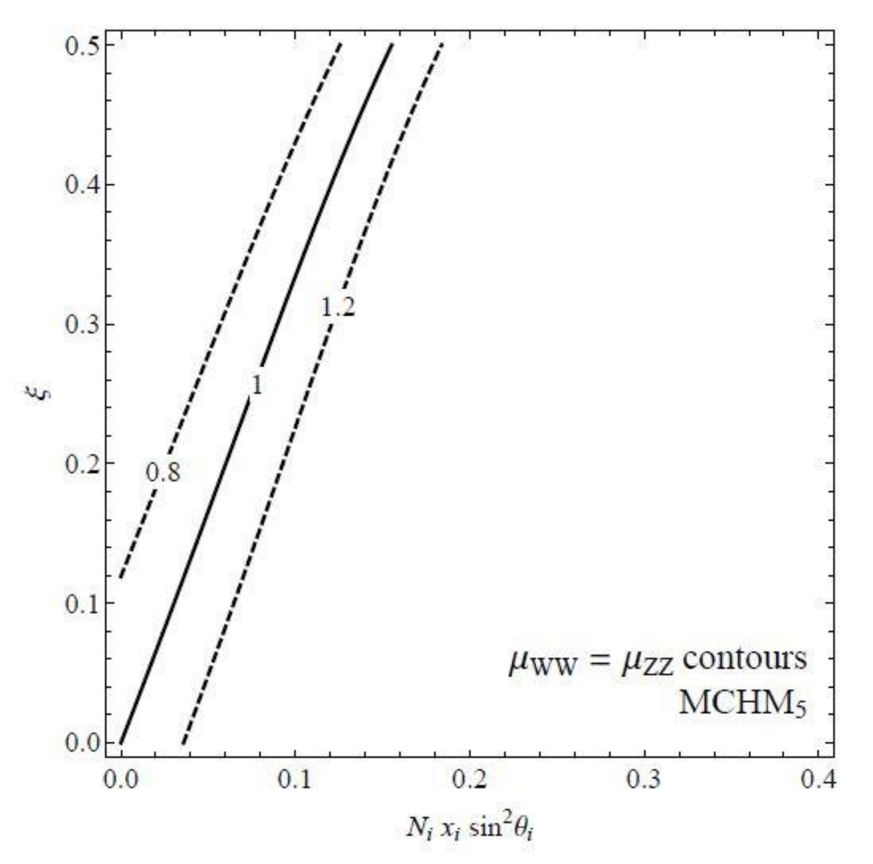

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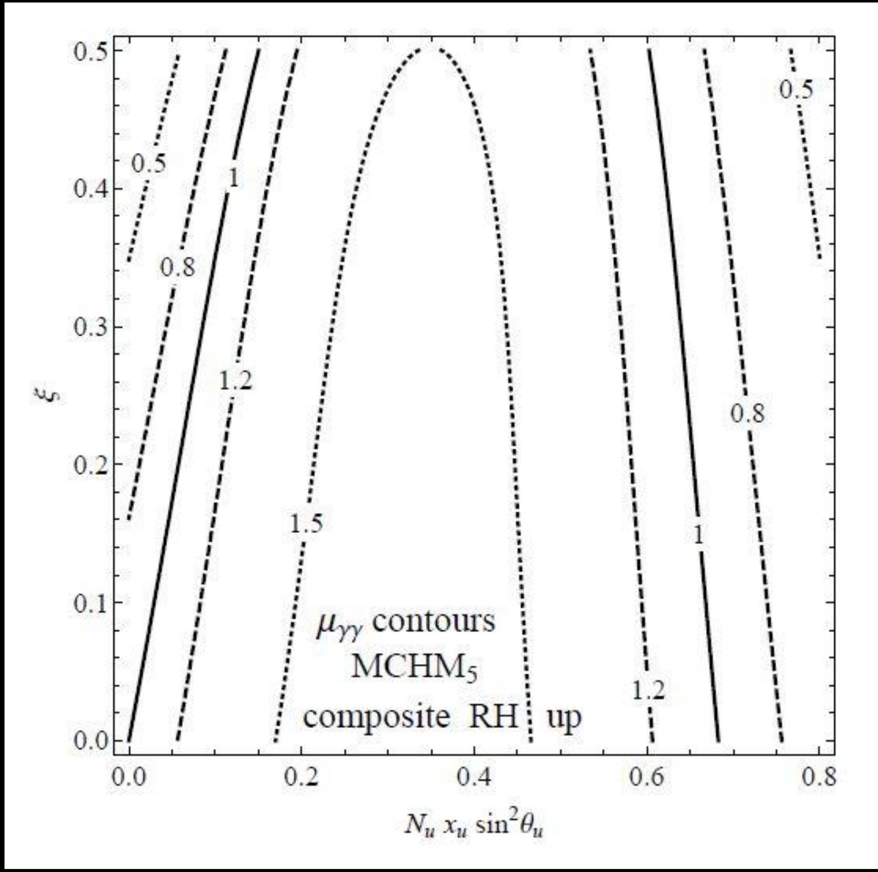

light quark compositeness →

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 $f \sim 500 GeV$*
  $\rightarrow$ *could help with naturalness?*

backups

Minimal Composite Higgs Model

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

$$\Sigma \sim 5_0 = (0,0,0,0,1)\exp[-ih^{\hat{a}}T^{\hat{a}}/f], \ \hat{a}=1\ldots4, \ \Sigma\Sigma^{\dagger}=1$$

$SO(5)$ 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 $y = \pm 1/2 + X$

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

Agashe-Contino-Pomarol '04

Minimal Composite Higgs Model

$$L = L_{elem} + L_{strong} + L_{mix}$$

$$\begin{aligned}
\mathcal{L}_{\rm elem} &= i\bar{q}_L \not{D} q_L + i\bar{u}_R \not{D} u_R + i\bar{d}_R \not{D} d_R \,, \\
\mathcal{L}_{\rm strong} &= \sum_{i=u,d} \bar{\Psi}^i \left(i\not{D} - M_i \right) \Psi^i - Y_i f \left(\bar{\Psi}^i_L \Sigma^T \right) \left(\Sigma \Psi^i_R \right) + \text{h.c.} \,, \\
-\mathcal{L}_{\rm mix} &= \lambda_{q^u} \bar{q}_L D^u_{\frac{1}{6}R} + \lambda_{q^d} \bar{q}_L D^d_{\frac{1}{6}R} + \lambda_u \bar{u}_R S_{\frac{2}{3}L} + \lambda_d \bar{d}_R S_{-\frac{1}{3}L} + \text{h.c.} \,,
\end{aligned}$$