Ian Low's research highlights:

Trying to understand the identity of the Higgs at the LHC :

- gluon-fusion production channel -- compositeness and naturalness

  0901.0266, Low and Shalgar; 0907.5413, Rattazzi, Low, and Vichi; 1010.2753, Low and Vichi
- decay into ZZ final states -- spin, CP, and origin of electroweak symmetry breaking

  0806.2864, Keung, Low, and Shu
  0911.3398, Cao, Jackson, Keung, Low, and Shu
- decay branching fractions V_1V_2: electroweak quantum numbers

  1005.0872, Low and Lykken; 1105.4587, Low, Lykken, and Shaughnessy

Trying to understand the identity of the dark matter:

- relating direct detections to indirect detections -- CDMS and CoGeNT v.s. PAMELA anti-proton

  0912.4510, Cao, Low, and Shaughnessy; 1010.1774, Keung, Low, and Shaughnessy
- reconcile different indirect detection anomalies -- Fermi v.s. PAMELA positron

  1012.5300, Cheng, Huang, Low and Menon

what is the identity of the higgs?

UV identity:

- is the higgs fundamental or composite?
- is the higgs mass fine-tuned?
- is the new physics at the TeV scale, if any, follows from naturalness principle?

IR identity:

- if we observe a scalar resonance, how do we know it has a VEV that breaks the electroweak symmetry?
- what are its quantum numbers and electroweak properties?

i will try to provide some partial answers to the above questions, by looking into :

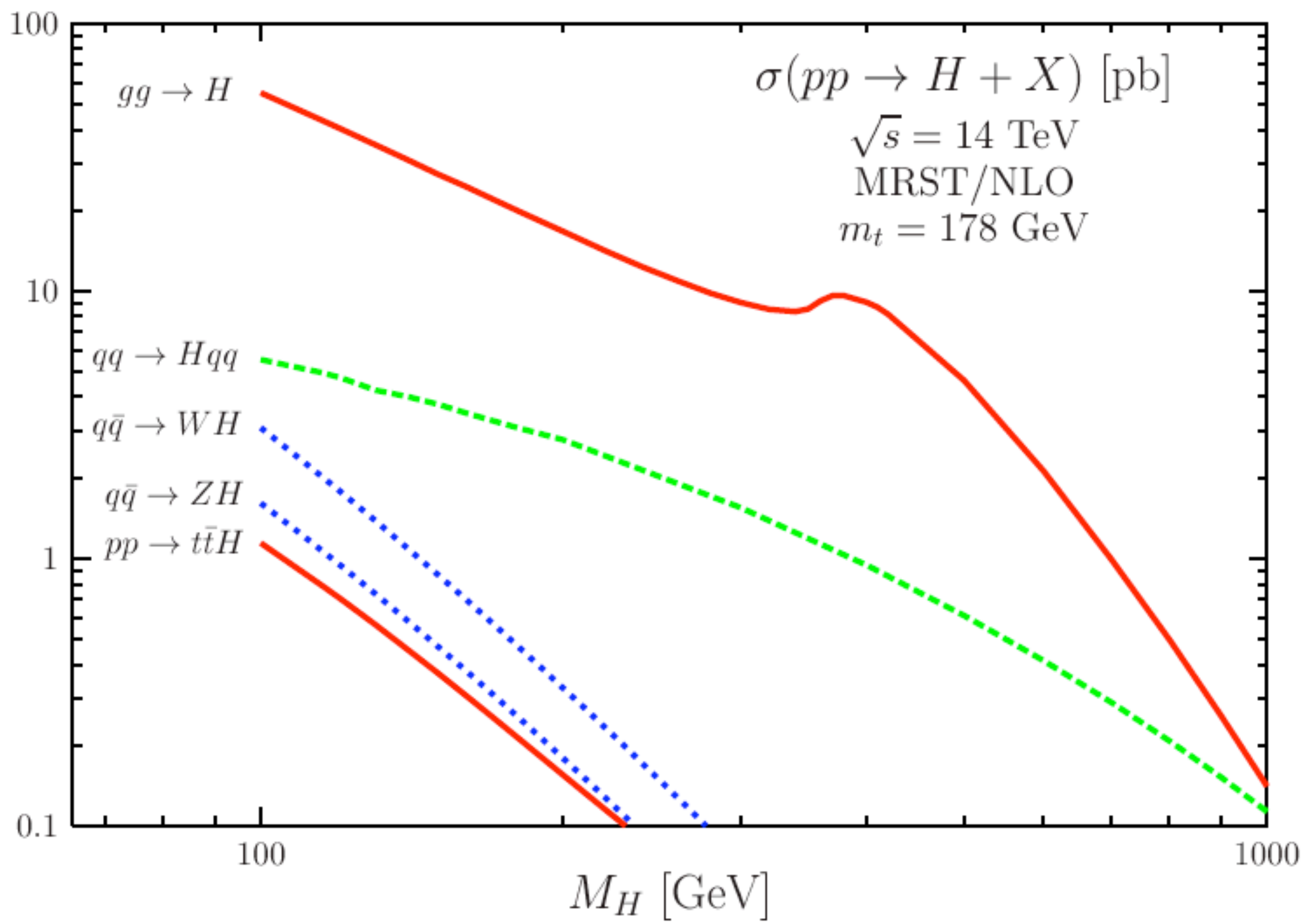
- gluon-fusion production channel:
  compositeness and naturalness

- decay into ZZ final states:
  spin, CP, and origin of electroweak symmetry breaking

- decay branching fractions into pairs of electroweak vector bosons:
  electroweak quantum numbers

compositeness and naturalness

at the LHC gluon fusion is the dominant production channel:

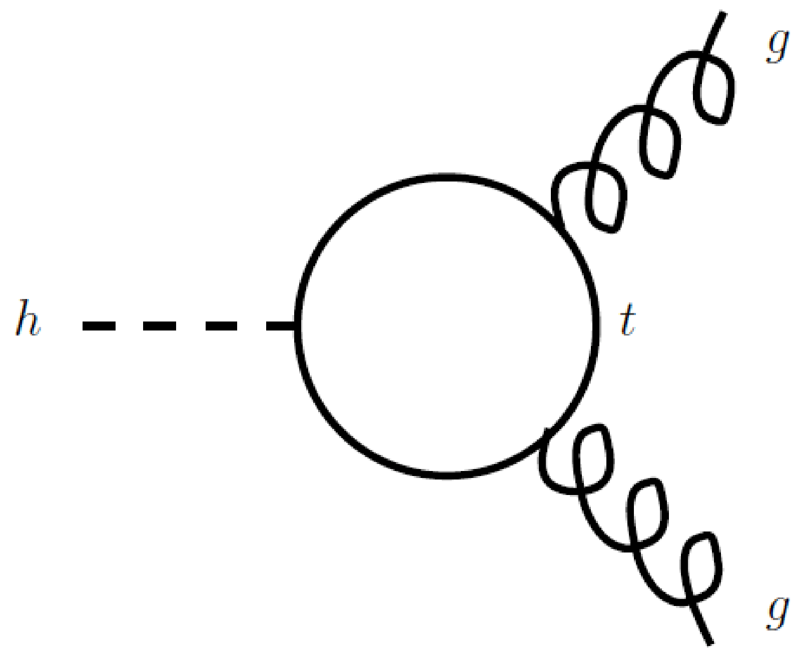


gluon fusion is a loop-induced process!

in the SM the dominant contribution comes from the top loop.

since the top is "heavy", the loop can be shrunk to a point and approximated by a dim-5 operator:

$$\frac{\alpha_s}{6\pi}\frac{y_t}{m_t}hG^a_{\mu\nu}G^{a\,\mu\nu} \qquad m_t = \frac{1}{\sqrt{2}}y_t v$$



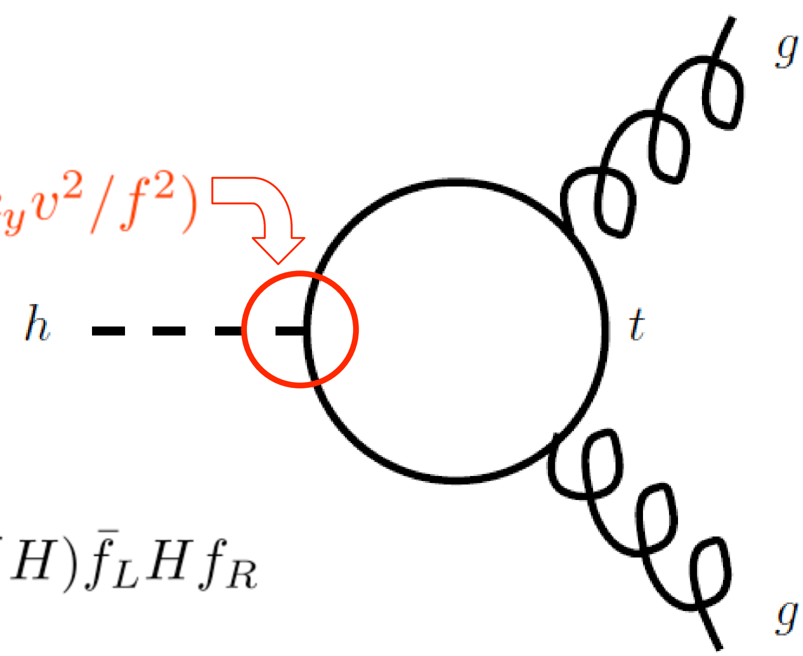
there are three ways new physics could modify the SM cross-section:

1. the higgs-fermion-fermion coupling could be modified:

$$g_{hff} = g_{hff}^{(SM)} \times \left(1 - c_y \frac{v^2}{f^2}\right)$$

$f =$ (roughly) scale of new physics

$g_{hff}^{(SM)}(1 - c_y v^2/f^2)$



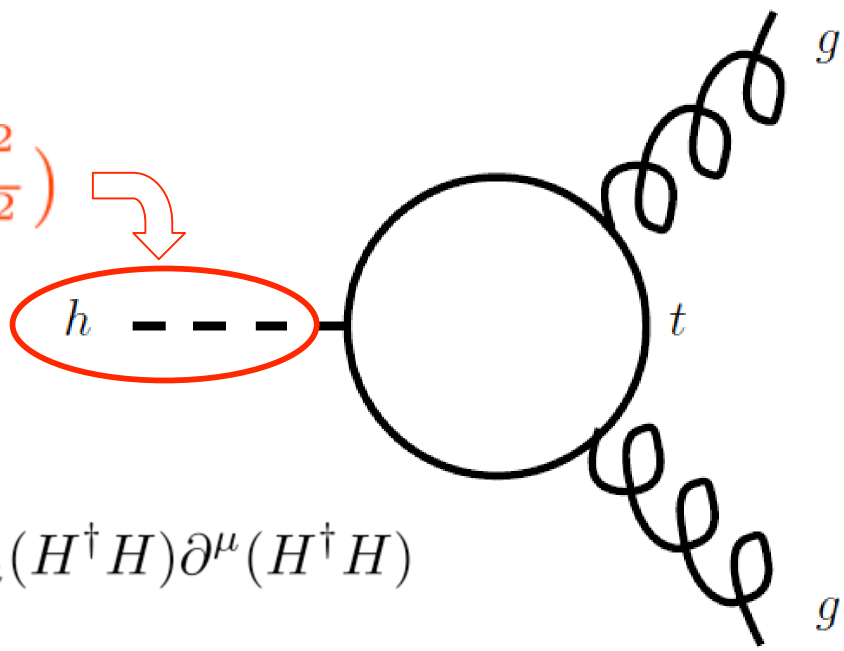
$$c_y \mathcal{O}_y \equiv \frac{c_y\, y_t}{f^2}(H^\dagger H)\bar{f}_L H f_R$$

there are three ways new physics could modify the SM cross-section:

2. the definition of the higgs field may be modified:

$$h \to \frac{h}{\sqrt{1 + c_H v^2/f^2}} \approx h\left(1 - \frac{c_H}{2}\frac{v^2}{f^2}\right)$$

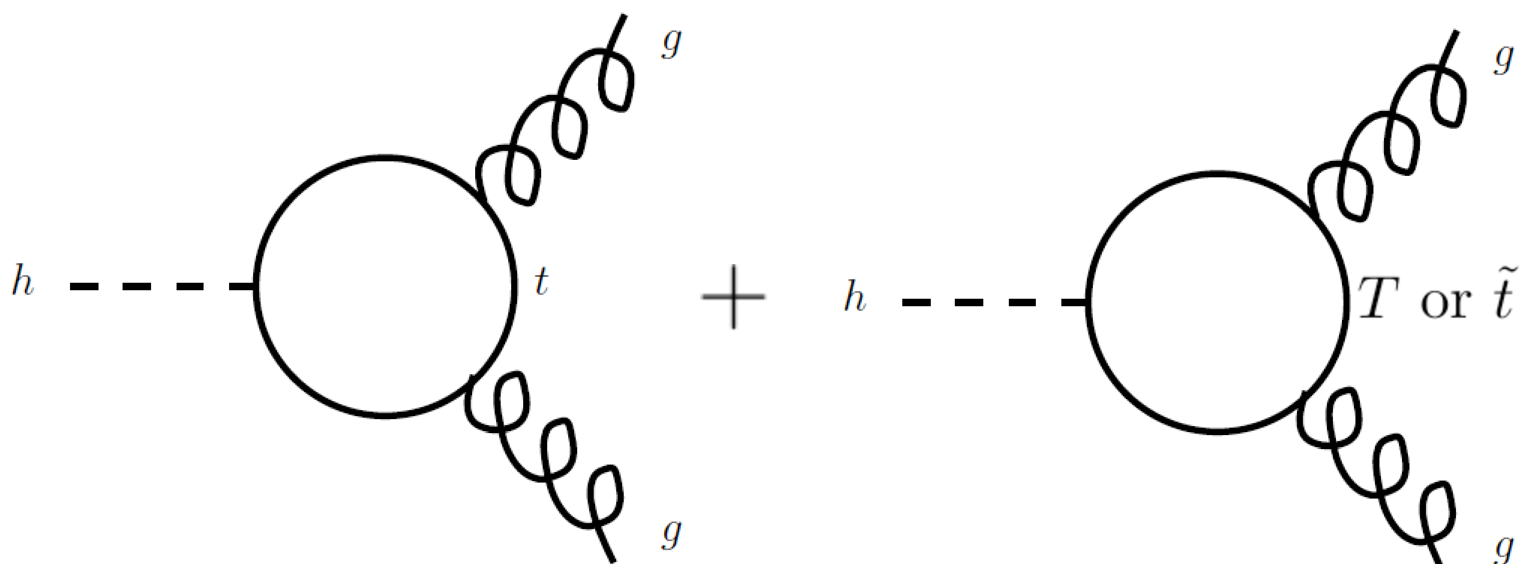
$$h\left(1 - \frac{c_H}{2}\frac{v^2}{f^2}\right)$$



$$c_H \mathcal{O}_H = \frac{c_H}{2f^2}\partial_\mu (H^\dagger H)\partial^\mu (H^\dagger H)$$

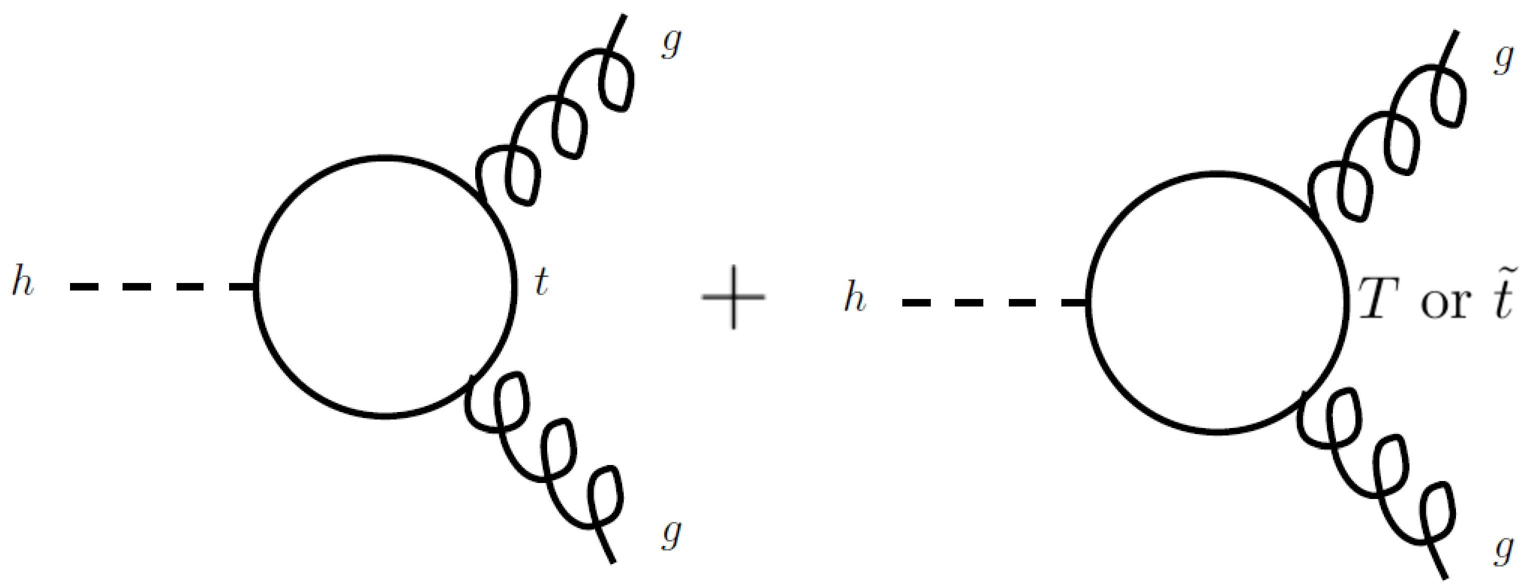
finally, there could a new loop diagram in addition to the SM top loop:

1. for non-supersymmetric theories, it could be a new top-like fermion, the top partner.
2. for supersymmetric theories, it could be a new top-like scalar, the stop.



when the new particle in the loop is heavy, the new contribution is encoded in the parameter c_g:

$$c_g \frac{\alpha_s}{2\pi} \frac{y_t v}{m_\rho^2} h G^a_{\mu\nu} G^{a\,\mu\nu} \qquad m_\rho = m_T \text{ or } m_{\tilde{t}}$$



summarizing these three effects, we have

$$\xi \equiv \frac{v^2}{f^2}$$

$$\Gamma(h \to gg) \; = \; \Gamma(h \to gg)_{SM} \left[1 - \xi \, \mathrm{Re} \left(c_H + 2c_y + \frac{4 y_t^2 c_g}{g_\rho^2 I_g} \right) \right]$$

if interactions of the higgs are described by a non-linear sigma model, ggh rate is reduced! 0907.5413, Rattazzi, Low, and Vichi

in addition, the interference between SM top and a heavy top-like fermion is *destructive* if the higgs quadratic divergence is *cancelled*, and *constructive* if it is *not cancelled*.

(in SUSY the trend is reversed, unless the stop mixing is large.)

ggh in UED:

the higgs scalar is fundamental and its mass unnatural (fine-tuned).
the rate is enhanced over the SM!

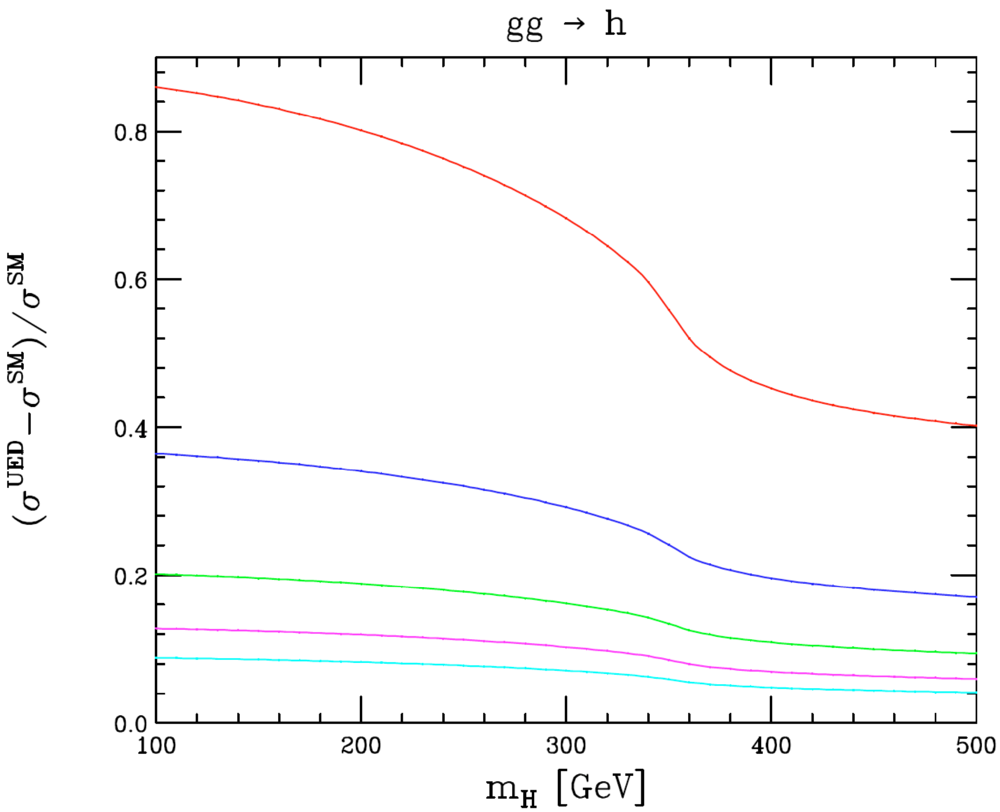
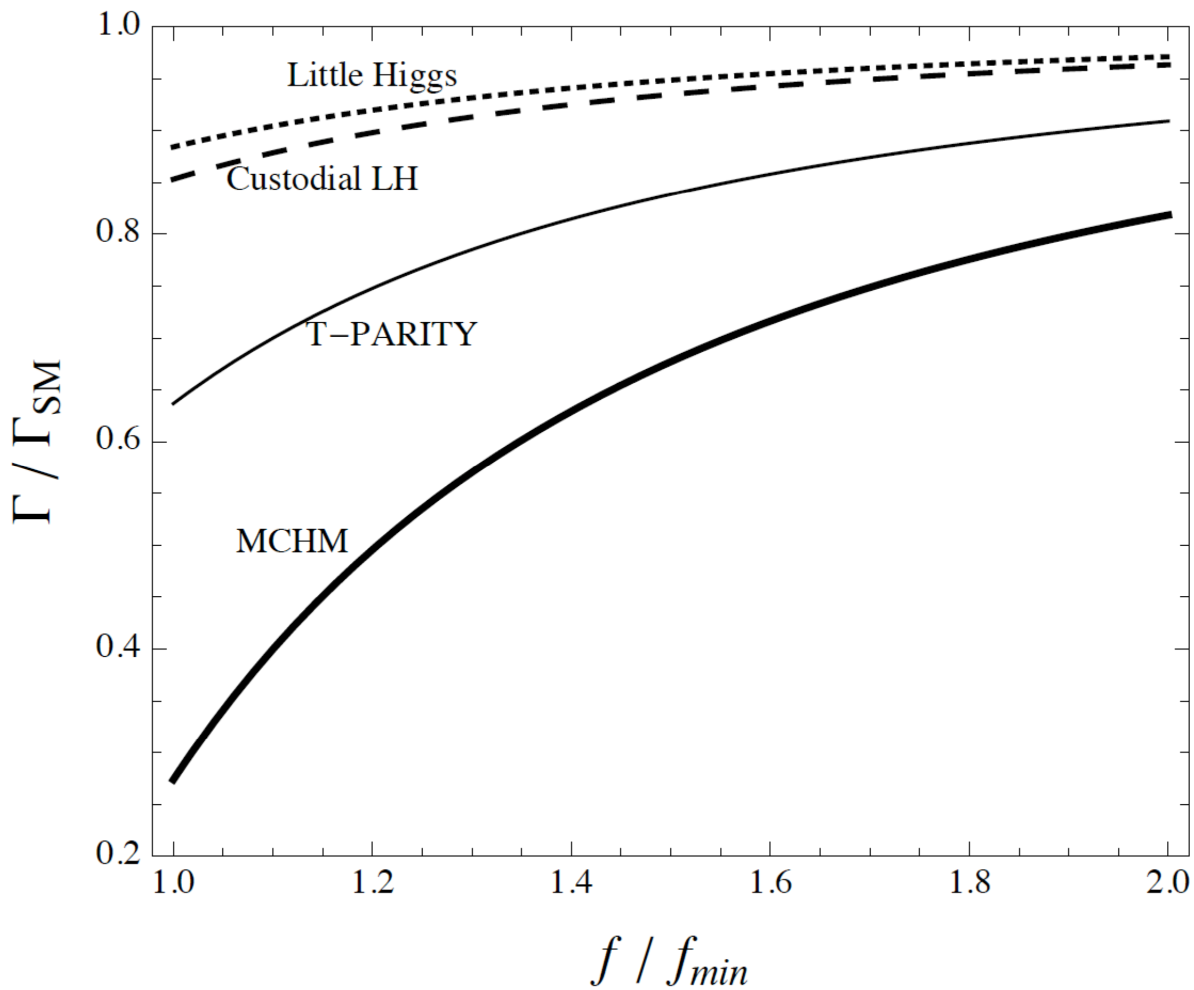


Figure 1: The fractional deviation of the $gg \to h$ production rate in the UED model as a function of m_H; from top to bottom, the results are for $m_1 = 500, 750, 1000, 1250, 1500$ GeV.

F. Petriello, hep-ph/0204067

we made the arguments using a completely general nlsm lagrangian. Here is a survey of explicit models confirming the results. (in fact, most of the literature didn't include all three effects properly.) 1010.2753, Low and Vichi



spin, CP, and higgs mechanism

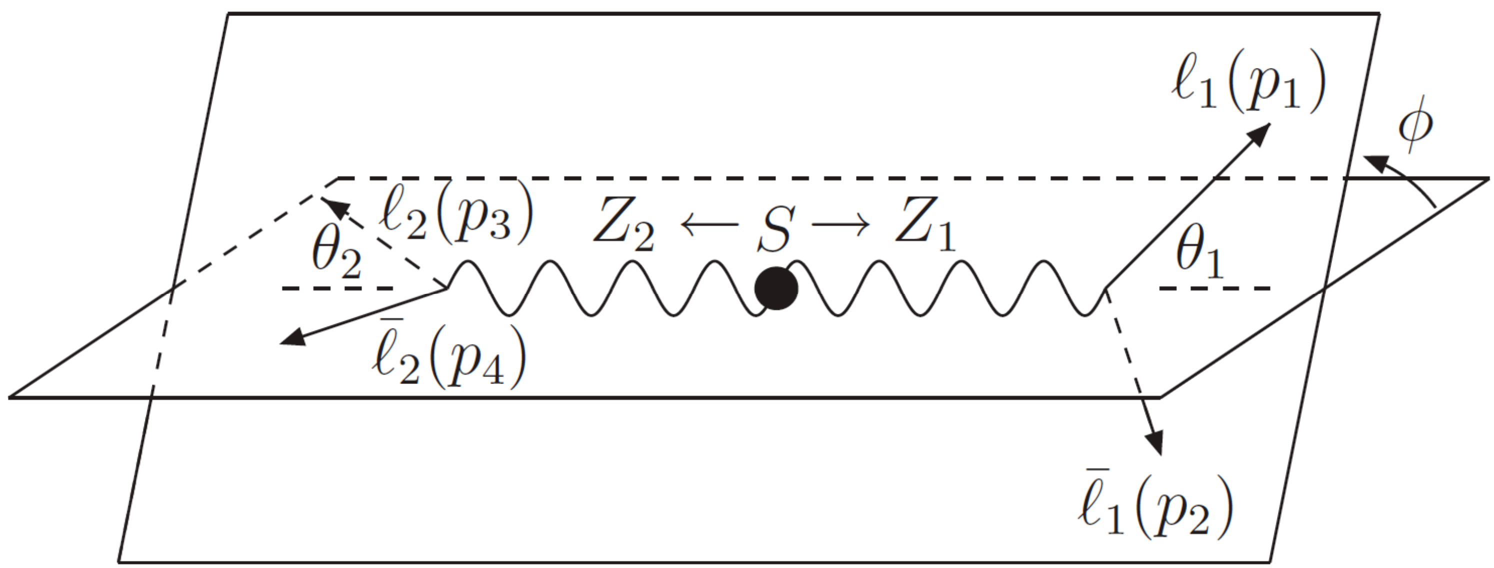
higgs -> ZZ ->4l is the gold-plated mode for higgs mass above 130 GeV ---- the kinetmatics could be fully reconstructed!!

- there have been studies using the angular correlations to determine the spin and CP property of the resonance (eg, see the CMS TDR.)

I wish to emphasize the usefulness of a particular observable:

ϕ, the azimuthal angle between the two decay planes of the Z.

(see also Gao, et al: 1001.3396 and De Rujula, et al:1001.5300 !)


$\ell_1(p_1)$
ϕ
$\ell_2(p_3)$
θ_2
$Z_2 \leftarrow S \rightarrow Z_1$
θ_1
$\bar{\ell}_2(p_4)$
$\bar{\ell}_1(p_2)$

a general analysis of a scalar decaying into ZZ:

- the higgs mechanism predicts

$$\Rightarrow \left(1+\frac{h}{v}\right)^2 m_V^2 V_\mu V^\mu \qquad g_{hVV} = -2i\frac{m_V^2}{v} g_{\mu\nu}$$

- but there are still two other possible couplings of a scalar with two Z bosons:

the other two terms are higgs imposters!!

$$\mathcal{L}_{eff} = \frac{1}{2} m_S\, S\left(c_1 Z^\nu Z_\nu + \frac{1}{2}\frac{c_2}{m_S^2} Z^{\mu\nu} Z_{\mu\nu} + \frac{1}{4}\frac{c_3}{m_S^2}\epsilon_{\mu\nu\rho\sigma} Z^{\mu\nu} Z^{\rho\sigma}\right)$$

higgs mechanism predicts only this term!

- we computed the azimuthal angular distribution, assuming new physics could be integrated out:

$$\frac{d\Gamma}{\Gamma d\phi} = \frac{1}{N}\left\{\frac{8}{9}\cos(2\phi+2\delta) + \frac{\pi^2}{2}\frac{M_L}{M_T}\left(\frac{g_R^2-g_L^2}{g_R^2+g_L^2}\right)^2\cos(\phi+\delta) + \frac{16}{9}\left(\frac{M_L^2}{M_T^2}+2\right)\right\}.$$

Negligible (~0.06) in the SM!

$$\delta = 0 \text{ for vanishing } c_3. \text{ (CP-even scalar!)}$$

$$\delta = \pi/2 \text{ for vanishing } c_1 \text{ and } c_2. \text{ (CP-odd scalar!)}$$

- previous studies (eg, CMS TDR) only focus on c_1 and c_3 without including c_2!

we see the cos(2ϕ) dependence, signaling a spin-0 resonance.
notice the cos(ϕ) component is tiny!
(for spin-1 resonance it would be cos(ϕ).)

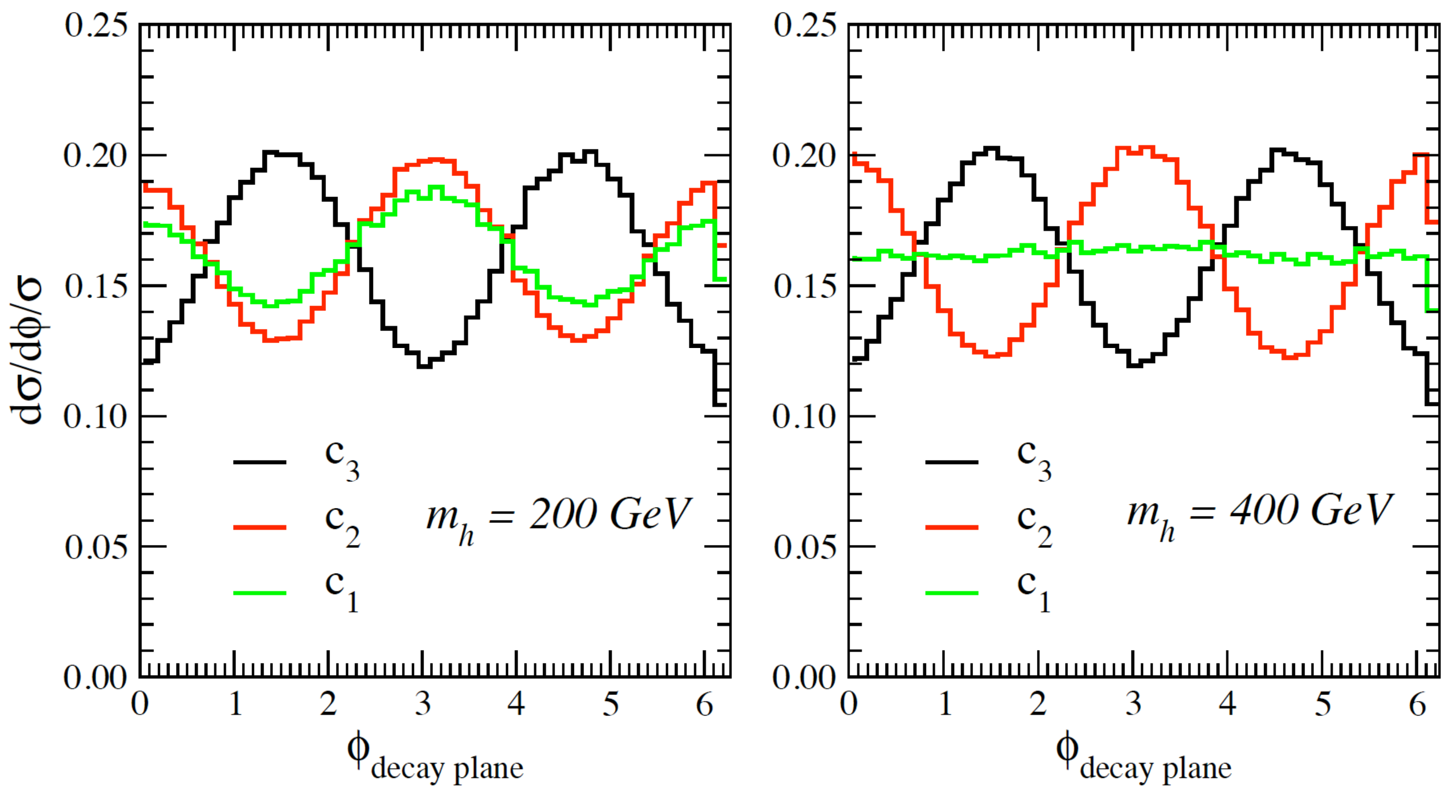


FIG. 4: *The normalized azimuthal angular distributions for 200 and 400 GeV scalar masses, turning on one operator at a time.*

0911.3398, Cao, Jackson, Keung, Low, and Shu notice c_1 and c_2 will be difficult to tell unless the higgs is heavy!

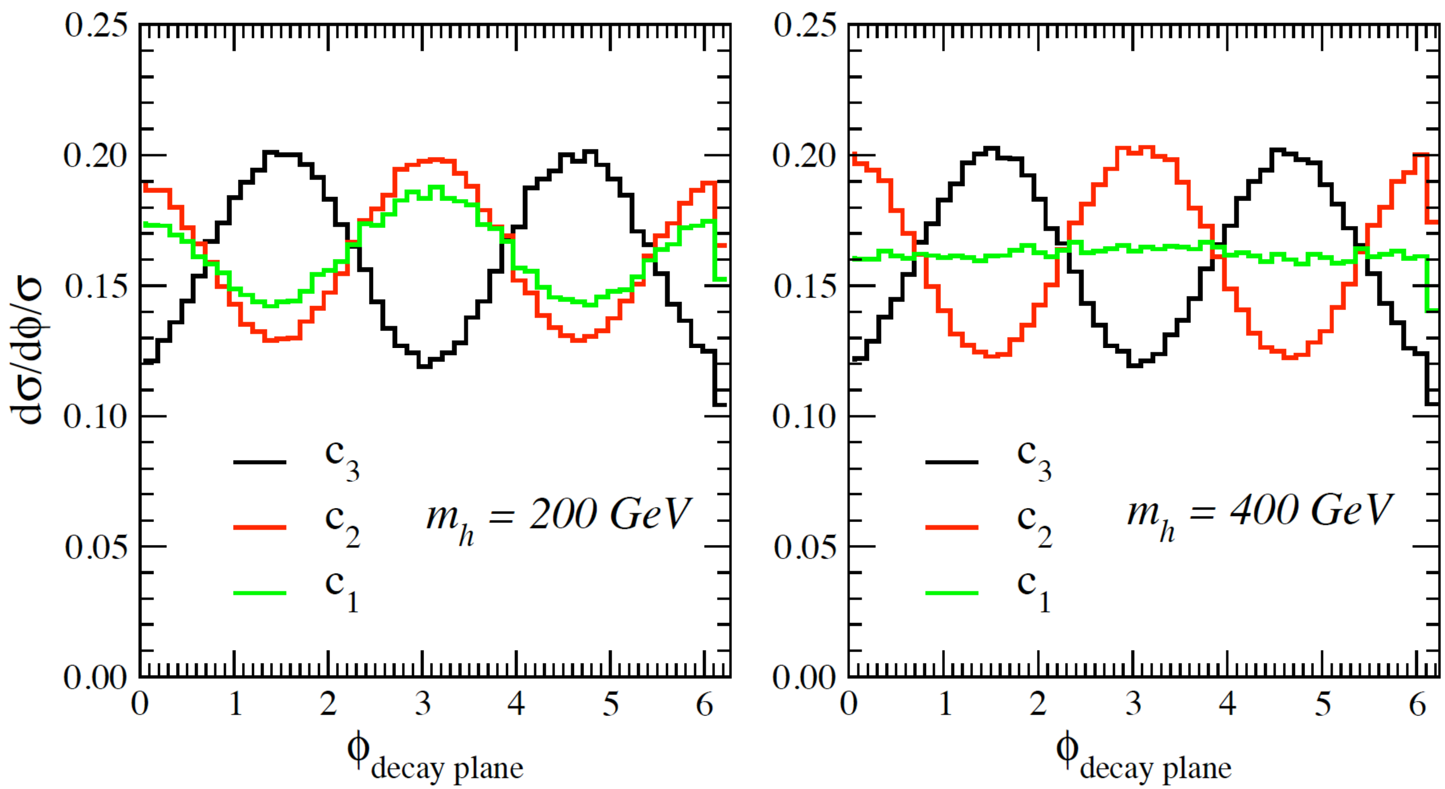


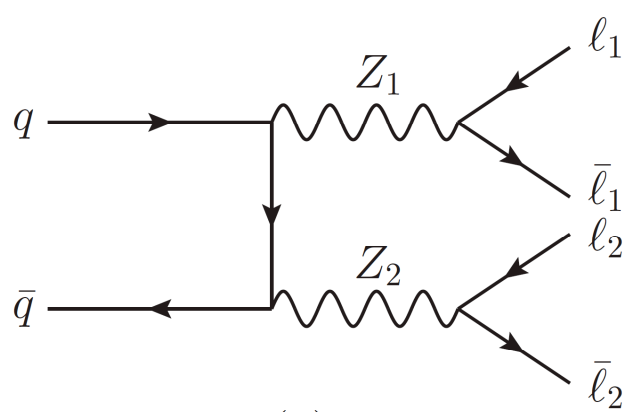
FIG. 4: *The normalized azimuthal angular distributions for 200 and 400 GeV scalar masses, turning on one operator at a time.*

0911.3398, Cao, Jackson, Keung, Low, and Shu it turns out that one could (and should!) use the full angular distributions to extract a putative Higgs signal from the background!

given the low CM energy and luminosity of the LHC in the early running, we need all the handles we can get!

we are performing a study on implementing the matrix element method with full angular correlations to discover the Higgs boson at 7 TeV in the golden channel.

(ongoing work with J. Gainer, K. Kumar, and R. Vega-Morale.)



(a)

We computed the full decay angular distributions without assuming both Z bosons are on-shell:

The production helicity amplitude for $q\bar{q} \to Z_1 Z_2$ in the CM frame reads [10]

$$\mathcal{M}^{ZZ}_{\sigma\bar{\sigma};\lambda_1\lambda_2} = 4\sqrt{2}\, e^2 \left(g^{Zq\bar{q}}_{\Delta\sigma}\right)^2 \epsilon\, \delta_{|\Delta\sigma|,\,\pm 1} \frac{\mathcal{A}^{\Delta\sigma}_{\lambda_1\lambda_2}(\Theta)\; d^{J_0}_{\Delta\sigma,\Delta\lambda}(\Theta)}{4\beta_1\beta_2 \sin^2\Theta + (1-\beta_1\beta_2)^2 - x^2(1+\beta_1\beta_2)^2}$$

$$\begin{aligned}
\Delta\lambda = \pm 2 &: \quad \mathcal{A}^{\Delta\sigma}_{\pm\mp} = -\sqrt{2}(1+\beta_1\beta_2)\ , \\
\Delta\lambda = \pm 1 &: \quad \mathcal{A}^{\Delta\sigma}_{\pm 0} = \mathcal{A}^{\Delta\sigma}_{0,\pm} = \frac{-\Delta\sigma}{2\gamma_2(1+x)} \big[2 + \beta_1^2 + \beta_2^2 - 4\Delta\sigma\Delta\lambda\cos\Theta \\
&\qquad -2(\beta_2^2 - \beta_1^2 + 2\Delta\sigma\Delta\lambda\cos\Theta)x - (2-\beta_1^2-\beta_2^2)x^2\big] \\
\Delta\lambda = 0 &: \quad \mathcal{A}^{\Delta\sigma}_{\pm\pm} = (1-\beta_1\beta_2)\cos\Theta + \lambda_1\Delta\sigma(1+\beta_1\beta_2)x\ , \\
\Delta\lambda = 0 &: \quad \mathcal{A}^{\Delta\sigma}_{00} = 2\gamma_1\gamma_2\cos\Theta\left[((1-x)\beta_1 + (1+x)\beta_2)\sqrt{\frac{\beta_1\beta_2}{1-x^2}} - (1+\beta_1^2\beta_2^2)\right]
\end{aligned}$$

the final expression is quite long, and I will spare you the details….

the analysis is close to being completed. so stay tuned.

electroweak quantum number

- electroweak quantum numbers determine its couplings to pairs of electroweak vector bosons:

  WW, ZZ, Zγ, and $\gamma\,\gamma$.

for a Higgs doublet:

Br(WW) > Br(ZZ) >>> Br($\gamma\,\gamma$) >~ Br(Zγ)

tree level couplings (Br(WW) > Br(ZZ))

loop-induced couplings (Br($\gamma\,\gamma$) >~ Br(Zγ))

the pattern does not hold for an electroweak singlet scalar!

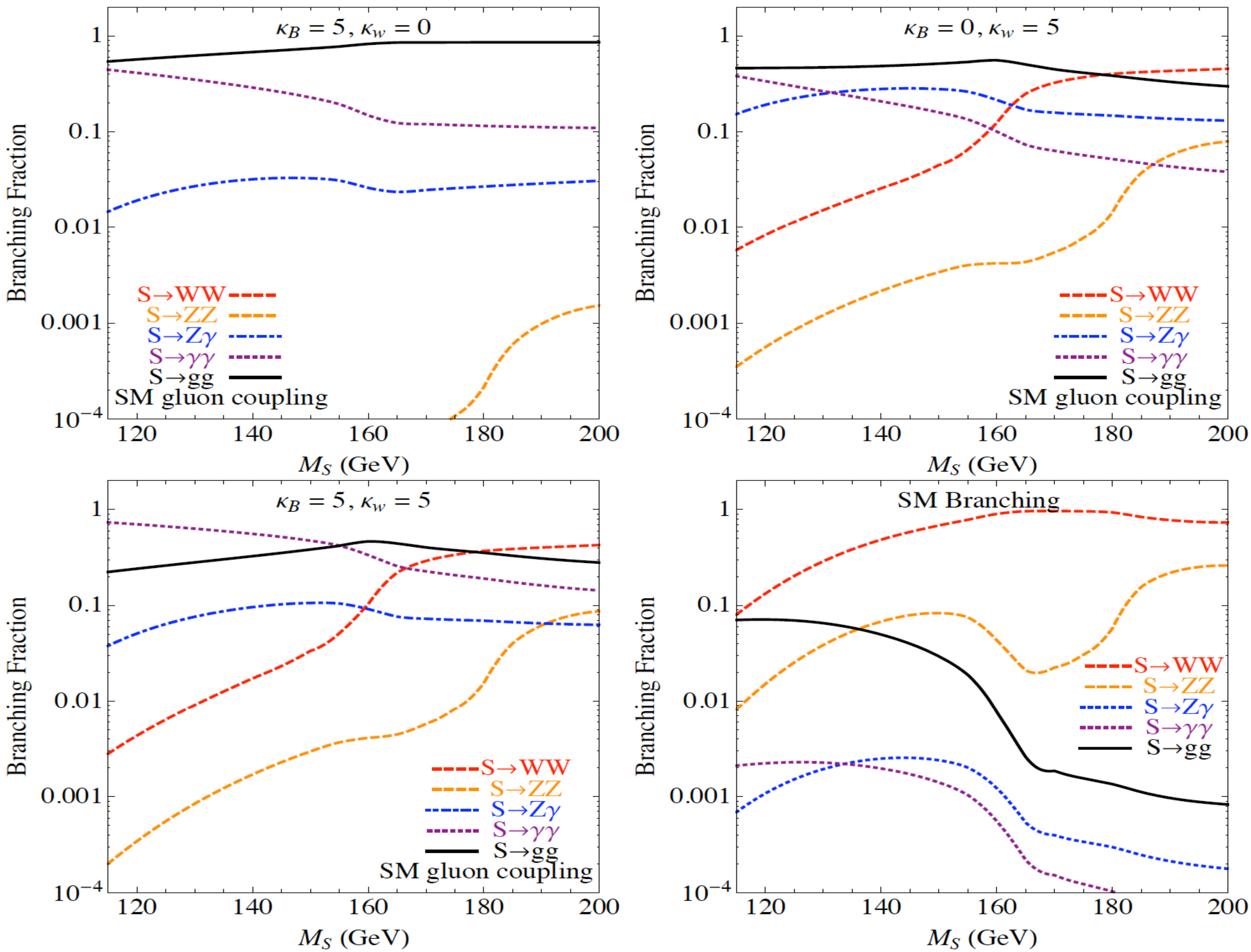
1005.0872, Low and Lykken

- for a singlet scalars, three unknowns control couplings to all five pairs of vector bosons

$$\mathcal{L}_{eff} = \kappa_g \frac{\alpha_s}{4\pi} \frac{S}{4m_S} G^a_{\mu\nu} G^{a\,\mu\nu} + \kappa_W \frac{\alpha_{em}}{4\pi s_w^2} \frac{S}{4m_S} W^a_{\mu\nu} W^{a\,\mu\nu} + \kappa_B \frac{\alpha_{em}}{4\pi c_w^2} \frac{S}{4m_S} B_{\mu\nu} B^{\mu\nu}$$

as a result, patterns of decay branching fractions are very different from that of a SM Higgs. 1105.4587, Low, Lykken, and Shaughnessy

- In fact, there may be surprises in unexpected places….



a higgs imposter (eg a singlet scalar) is likely to show up first in the $\gamma\gamma$ and $Z\gamma$ channels,

while the search in the WW and ZZ channels might turn up empty!

this is the case even if the mass is above WW threshold!