Inside the Higgs

a perspective on Higgs compositeness

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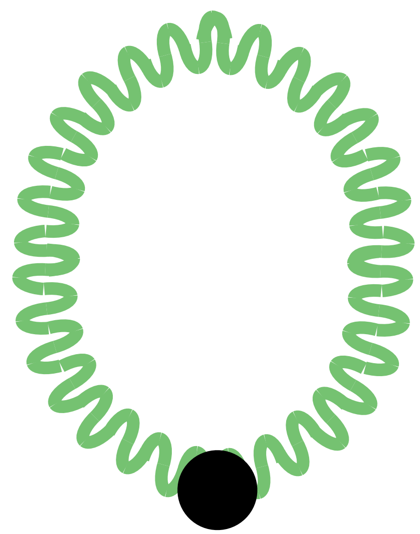

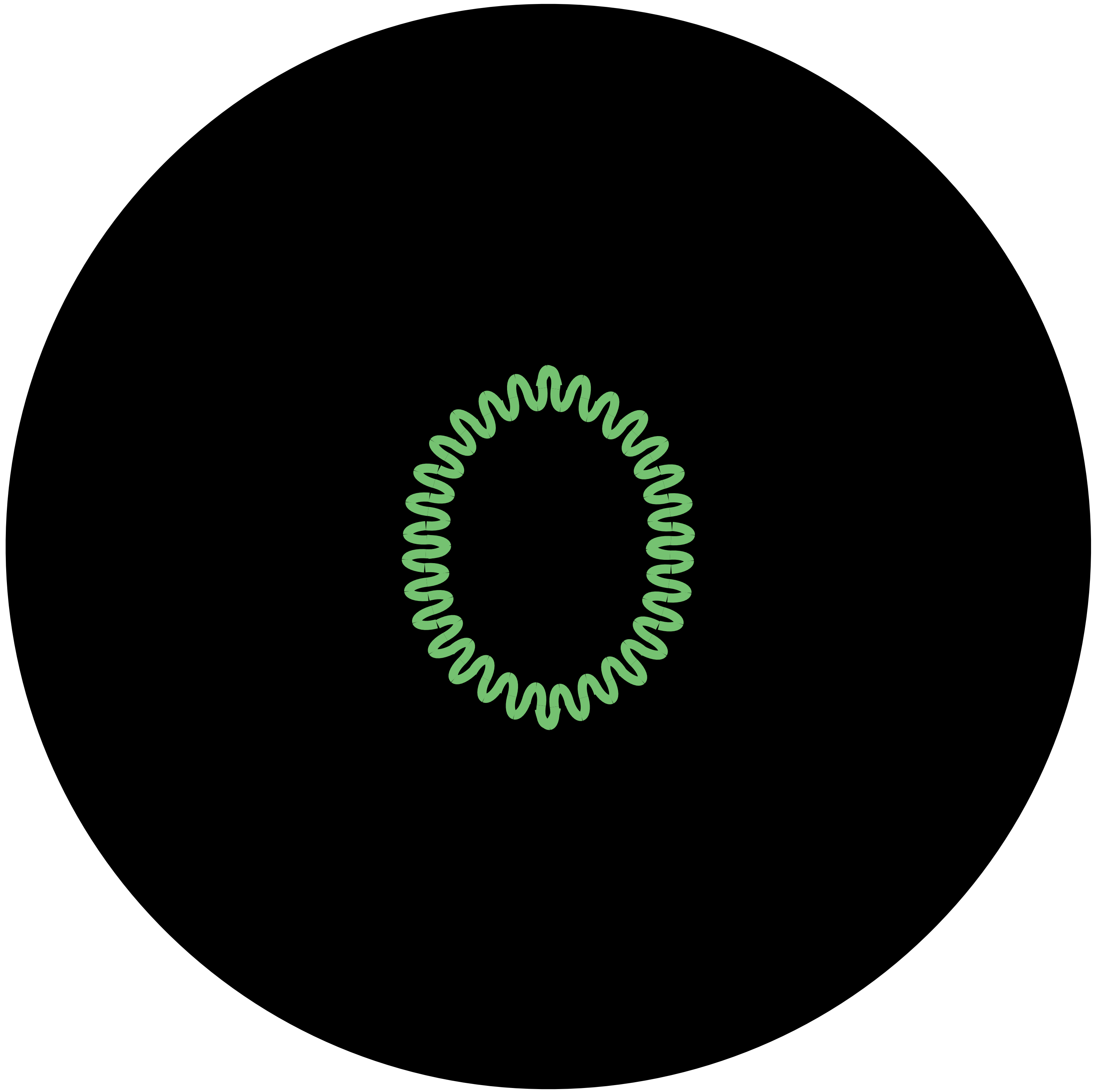

- Flavor

- Electroweak Precision Tests

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Standard Model ☺ $y_{ij}\, \underbrace{H \bar{F}_i \bar{F}_j}_{\text{dim }=4}$ $\Lambda_{UV} \to \infty$

- y_{ij} unaffected
- extra unwanted Flavor effects decouple

$$\frac{1}{\Lambda_{UV}^2}\,\bar{q}_i q_j \bar{q}_k q_\ell$$

☹ very relevant operator $\Lambda_{UV}^2 \, H^\dagger H$

makes $\Lambda_{UV} \to \infty$ problematic

Technicolor $H = \bar{\psi}\psi$ dimension ~ 3

Weinberg '79
Susskind '79

☺ no relevant singlet scalar

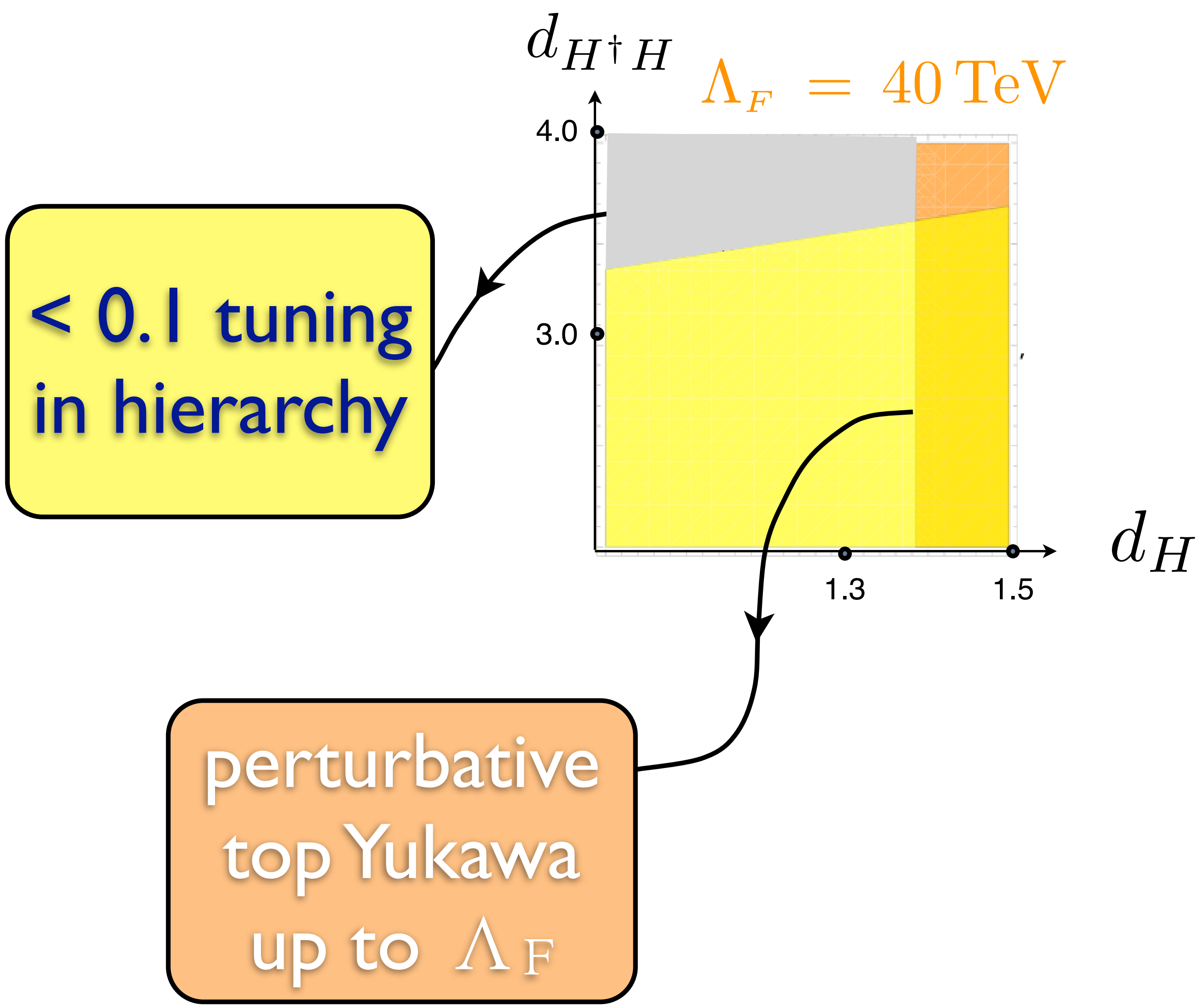
☹ Yukawas $\frac{y_{ij}}{\Lambda_{UV}^2} H \bar{F}_i F_j$ as relevant as $\frac{1}{\Lambda_{UV}^2}\,\bar{q}_i q_j \bar{q}_k q_\ell$

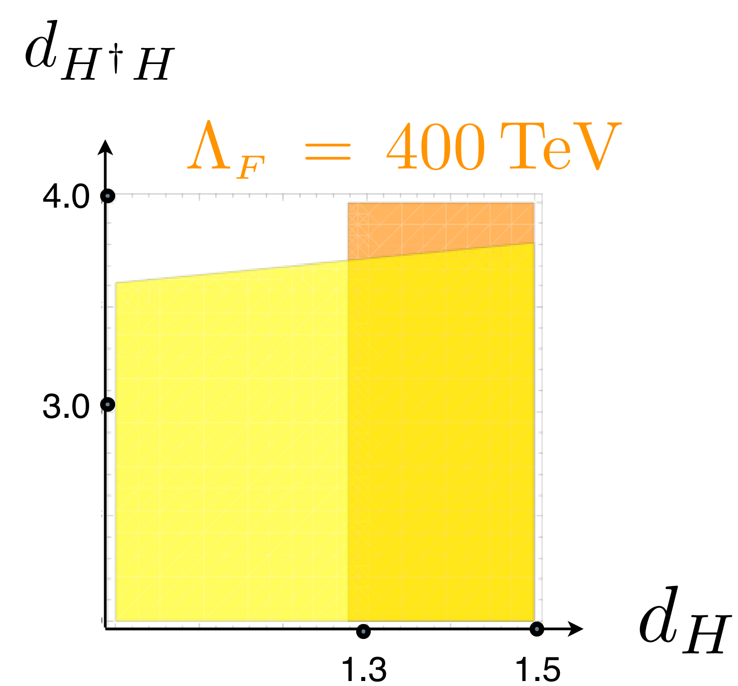
Ideal situation

- Flavor $\quad d_H \to 1$
- Hierarchy $\quad d_{H^\dagger H} \to 4$

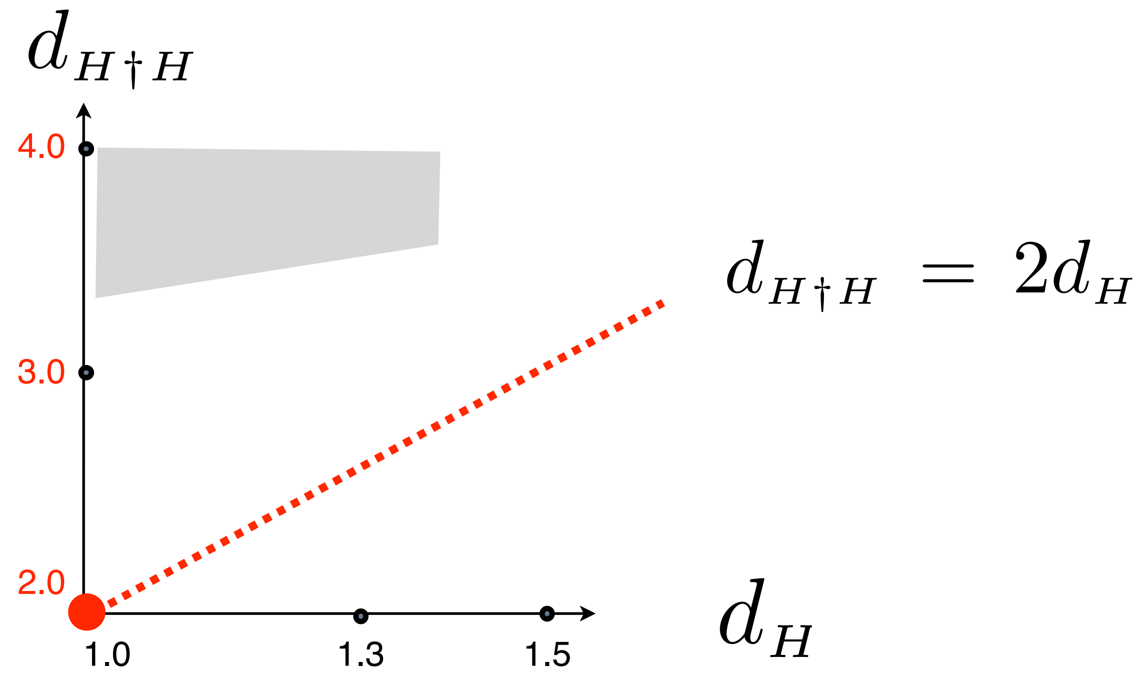
Conformal Technicolor: Higgs sector $\sim$ CFT above weak scale

Luty-Okui 04





RR, Rychkov, Tonni, Vichi 08



- Interesting region is not attainable at weak coupling or large N
- Is it at all compatible with prime principles?
- Unitarity + SO(4,2) : $d_H = 1 \Rightarrow d_{H^\dagger H} = 2$
- Can one derive a theoretical upper bound on $d_{H^\dagger H}$ as a function of d_H ?
- Standard proof for $d=1$ not extendable to $d = 1+\epsilon$

Basic CFT question

OPE $$\phi(x)\phi(0) = \frac{1}{x^{2d_\phi}}\left[\mathbb{I} + x^{d_{\phi^2}}\phi^2(0) + \quad \dots \quad \right]$$

lowest dimension
scalar in $\phi \times \phi$

higher dimension
higher spin

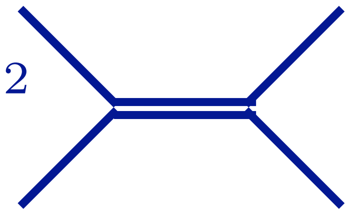
What can one say on d_{ϕ^2} as a function of d_ϕ ?

⭐ A prime principle upper bound $d_{\phi^2} < f(d_\phi)$ was found based on

RR, Rychkov, Tonni, Vichi 08

I. Conformal block decomposition

$$\langle \phi(x_1)\phi(x_2)\phi(x_3)\phi(x_4)\rangle = \sum_{\mathcal{O}} |\lambda_{\mathcal{O}}|^2$$

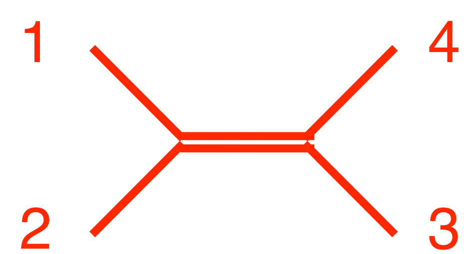


$$= \frac{1}{x_{12}^{2d} x_{34}^{2d}} \left(1 + \sum_{\mathcal{O}} |\lambda_{\mathcal{O}}|^2 g_{\mathcal{O}}(u,v)\right)$$

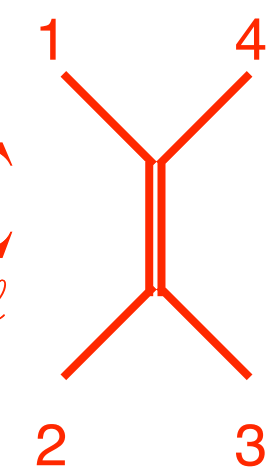
$\mathcal{O} \leftrightarrow (\Delta, \ell)$ = (dimension, spin)

II. Crossing symmetry

$$\sum_{\Delta,\ell}$$

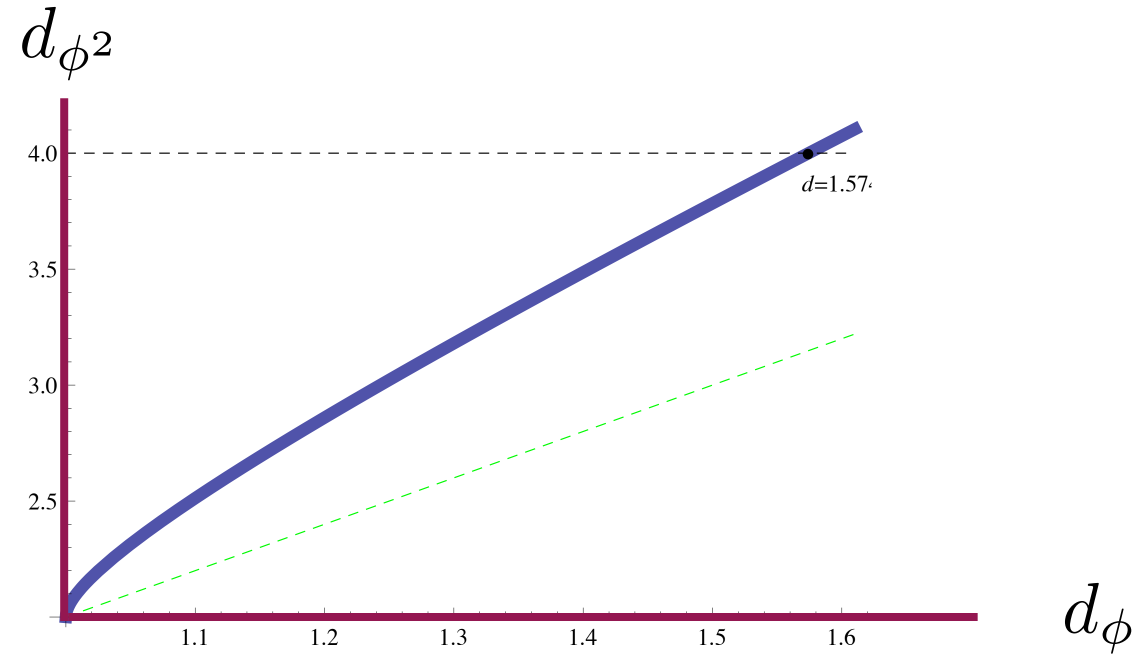


$$= \sum_{\Delta,\ell}$$



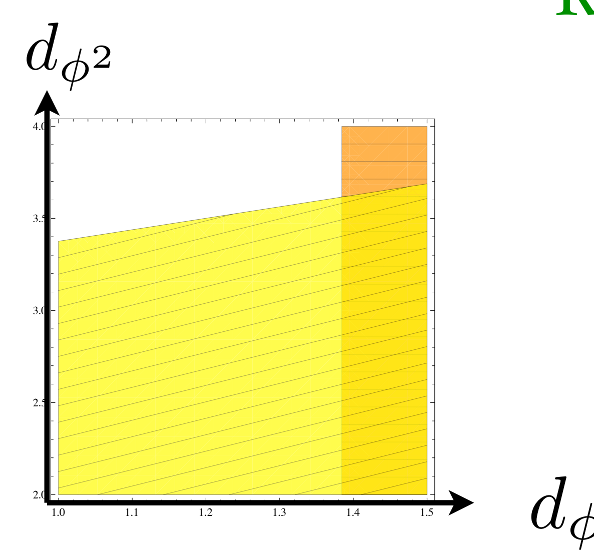
sum rule $$1 = \sum_{\Delta,\ell} |\lambda_{\Delta,\ell}|^2 F_{d,\Delta,\ell}(z,\bar{z})$$

Numerical bound



Rychkov, Vichi 09

If blindly applied it would rule out
Conformal Technicolor

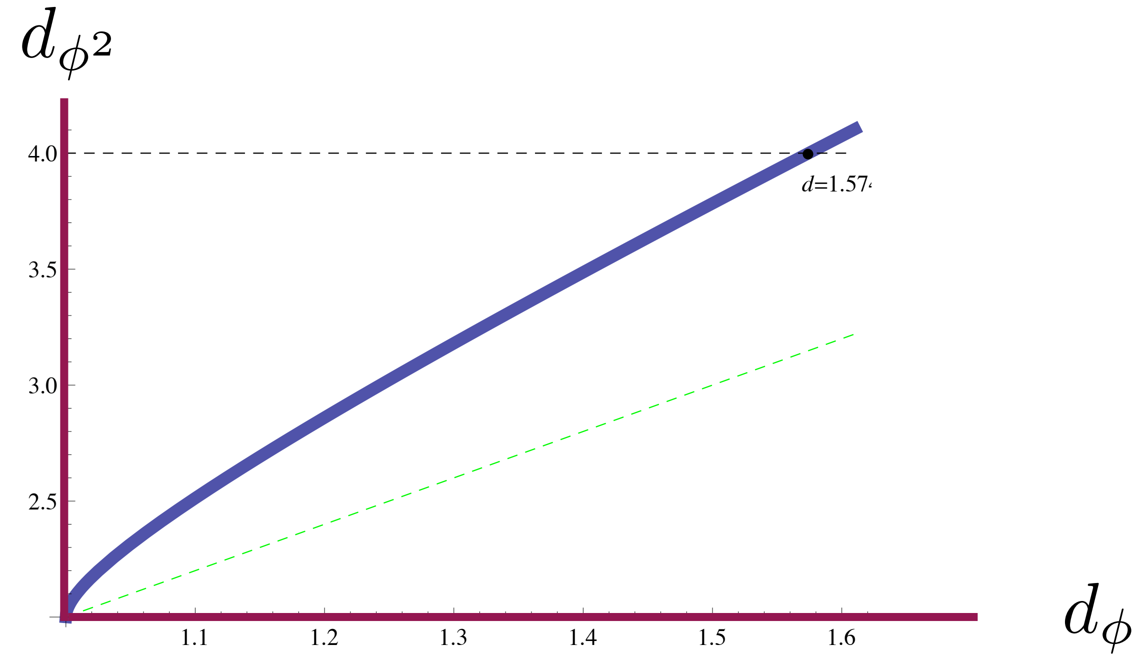


However

realistic case $$H_i^\dagger \times H_j = S\,\delta_{ij} + T_A\,\tau_{ij}^A \equiv (\text{singlet}) + (\text{triplet})$$

the obtained bound should be interpreted as one on $d_{\phi^2} = \min(d_S, d_T)$

Numerical bound



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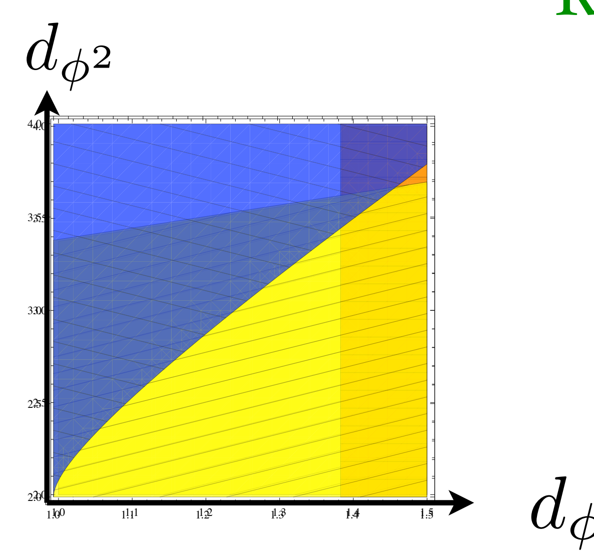

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Method can be extended to derive independent bounds in different isospin channels

Simplest case is CFT with O(N) global symmetry

RR, Rychkov, Vichi
in progress

$$\phi_i \times \phi_j \supset S_{ij} \oplus T_{ij} \oplus A_{ij}$$

even spin ℓ odd spin ℓ

✦ 3 sum rules involving 3 set of fields (S,T,A)

✦ slower convergence: must improve numerical method
until now relied on Linear Programming function in Mathematica

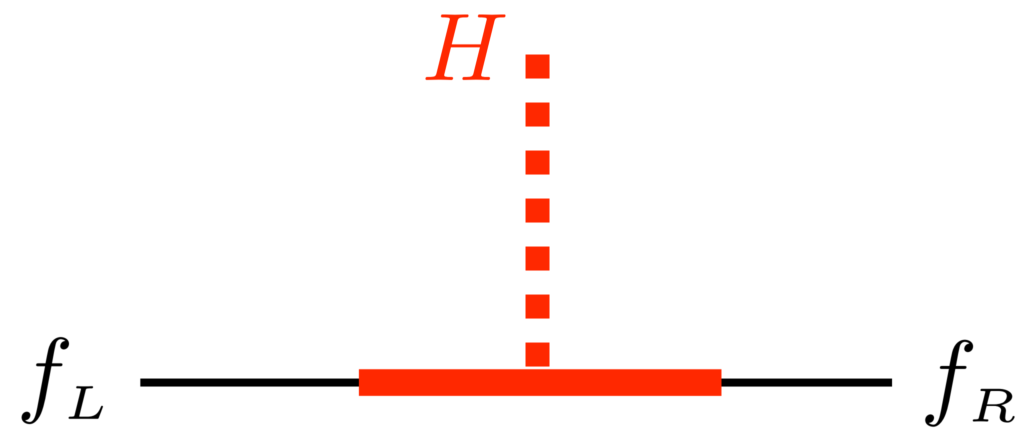
Probably more promising: Fermion masses by mixing to composites

D.B. Kaplan 80's
Agashe, Contino, Pomarol 04

$$d_f \sim \frac{3}{2}$$

$$\mathcal{L}_{\text{Flavor}} = \lambda_L^{ij} f_L^i \mathcal{O}_R^j + \lambda_R^{ij} f_R^i \mathcal{O}_L^j$$

$$d_{\mathcal{O}} \sim \frac{5}{2}$$



$d_\lambda \sim 0$: can decouple unwanted Flavor effets keeping λ fixed

- ✦ no obvious CFT obstacle to get $d_{\mathcal{O}} \sim 5/2$
- ✦ nicely implemented in Randall Sundrum scenario
- ✦ small differences in dimensions of λ^{ij} give plausible explanation of pattern of masses and mixings
- ✦ unwanted flavor violation at weak scale under control (some tension in ϵ_K) Csaki et al 08

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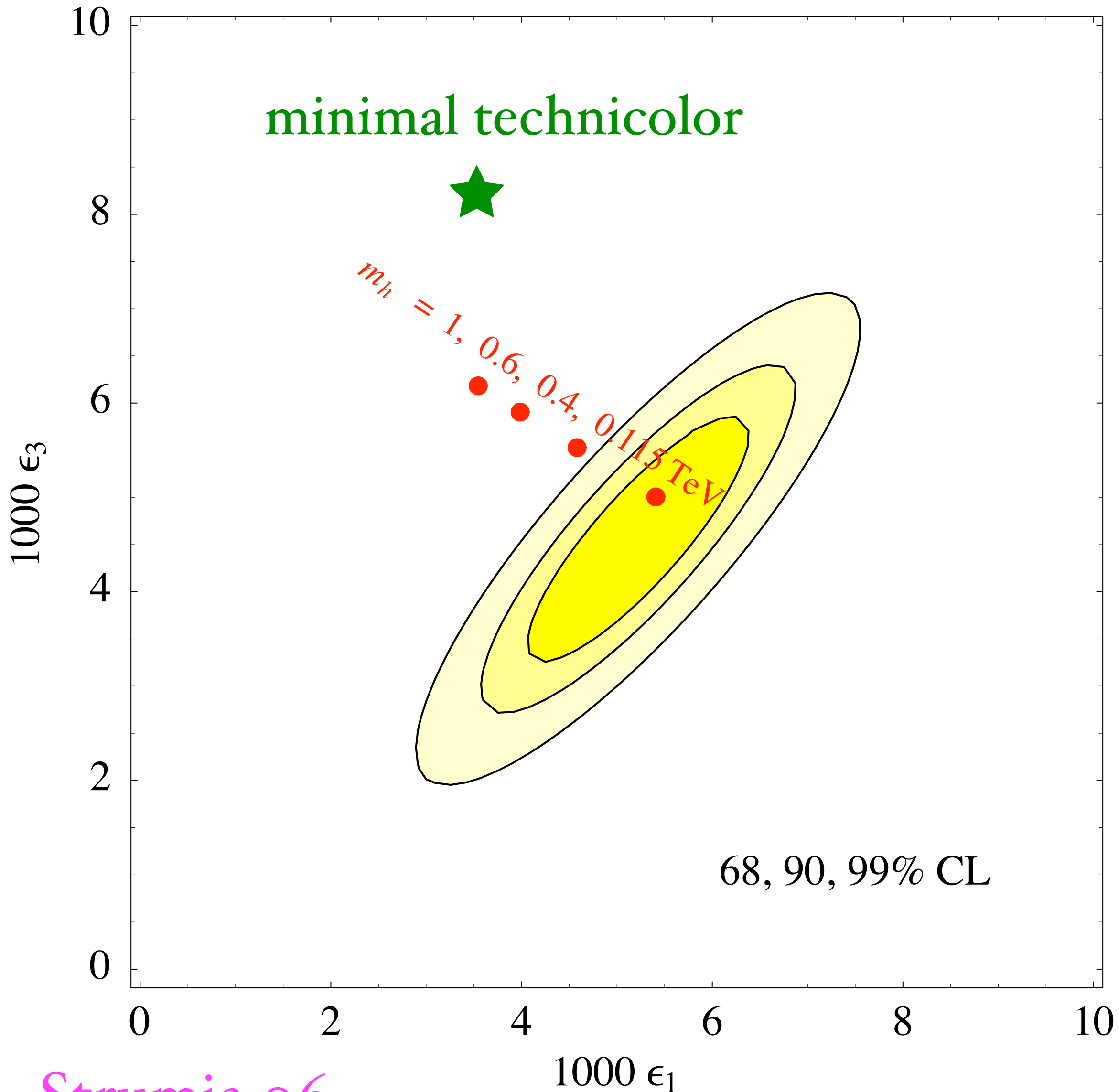

Strumia 06

$$\Delta\epsilon_3 \equiv \widehat{S} = \widehat{S}_{UV} + \frac{g^2}{96\pi^2}\ln(m_h/m_Z)$$

$$\widehat{S}_{UV} \sim \frac{g^2}{96\pi^2} N_{TF} N_{TC}$$

Peskin, Takeuchi '89

$$\Delta\epsilon_1 \equiv \widehat{T} = \widehat{T}_{UV} + \frac{3g^2\tan^2\theta_W}{32\pi^2}\ln(m_h/m_Z)$$

Minimal TC has no parameter to play with in order to reduce $\widehat{S}$

Positivity of S is also a difficulty of 5D Higgsless models

★ **Next to minimal TC**: light Higgs = 4th pseudo-Goldstone boson

Georgi, Kaplan '84
Banks '84
Arkani-Hamed, Cohen, Katz, Nelson '02
Agashe, Contino, Pomarol '04

Electroweak Precision tests are helped in two ways

✦ light Higgs screens IR contribution to $\widehat{S}$, $\widehat{T}$

✦ $\widehat{S}_{UV} \simeq \frac{g^2 N}{96\pi^2} \times \frac{v^2}{f^2}$

$$\begin{cases} \langle H \rangle \equiv v \\ f = \text{pseudo-Goldstone decay const.} \end{cases}$$

$\frac{v^2}{f^2}$ depends on extra parameters ➡ can in principle be tuned to be a little bit smaller than 1 say ~ 0.1

Compositeness scale $4\pi f$ could still be as low as a few TeV

Structure of the Models

Strong sector
H = Goldstone doublet
Ex. : $H = SO(5)/SO(4)$

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m_ρ mass of resonances

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$\Downarrow$

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Examples

- Technicolor type $\qquad g_\rho \sim \frac{4\pi}{\sqrt{N_{TC}}}$
- 5D models $\qquad m_\rho \sim m_{KK} \qquad g_\rho \sim g_{KK}$
- Little Higgs $\qquad (m_\rho, \; g_\rho) \qquad$ mass and coupling of 'regulators'

Simple Goldstone Higgs

$$V(H) \sim \frac{m_\rho^4}{g_\rho^2} \frac{g_{SM}^2}{16\pi^2} \hat{V}(H/f)$$

$$v \sim \frac{m_\rho}{g_\rho} = f$$

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Little Higgs

$$V(H) \sim \frac{m_\rho^4}{g_\rho^2}\frac{g_{SM}^2}{16\pi^2}\hat{V}(H/f) + g_{SM}^2 H^4$$

$$v \sim \frac{m_\rho}{4\pi} = \frac{g_\rho}{4\pi} f$$

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- ✦ g_ρ preferred large
- ✦ tune $\frac{v^2}{f^2}$ to ~ 0.2

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$$\boxed{\hat{S} \sim \frac{m_W^2}{m_\rho^2} = \frac{g_W^2}{g_\rho^2}\frac{v^2}{f^2}} \Rightarrow$$

not as good as it would seem

prefers $m_V \gg m_T$

$$g_V \gg g_T \sim g_{SM}$$

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$$\boxed{\hat{S} \sim \frac{m_W^2}{m_\rho^2} = \frac{g_W^2}{g_\rho^2}\frac{v^2}{f^2}}$$ $\rightarrow$ not as good as it would seem

prefers $m_V \gg m_T$

$g_V \gg g_T \sim g_{SM}$

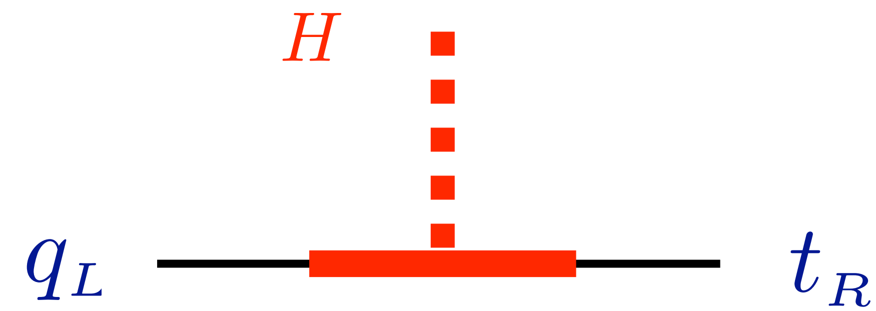
Vectors favored heavy and strongly coupled

LH reduces a bit the tuning at the price of cleverness ...

Agashe, Contino, Pomarol 04

The top complex

$$\mathcal{L}_{\rm top} = \lambda_L q_L \mathcal{O}_R + \lambda_R t_R \mathcal{O}_L$$



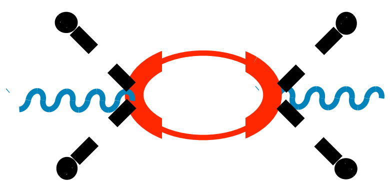
$$\boxed{\lambda_t \sim \frac{\lambda_L \lambda_R}{g_\rho}}$$

✦ If $\lambda_L \sim \lambda_R$ → $\lambda_L \sim \sqrt{g_\rho \lambda_t} \lesssim 3$ sizeable !

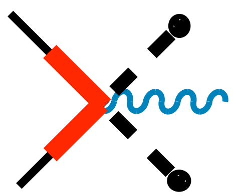
✦ $V(H) \propto \lambda_{L,R}^2 \hat{V}(H/f)$ in principle not so light a Higgs but no relief of fine tuning

$$\lambda_t \sim \frac{\lambda_L \lambda_R}{g_\rho}$$

Option I $\mathcal{O}_R = (2,1) \qquad \mathcal{O}_L = (1,2)$ under $SO(4) \sim SU(2)_L \times SU(2)_R$



$$\delta\rho \sim \frac{N_c \lambda_R^4}{16\pi^2 g_\rho^2} \frac{v^2}{f^2}$$

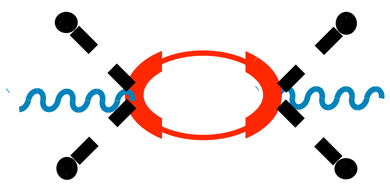


$$\frac{\delta g_b}{g_b} \sim \frac{\lambda_L^2}{g_\rho^2} \frac{v^2}{f^2} \sim \frac{\lambda_t^2}{\lambda_R^2} \frac{v^2}{f^2}$$

$$\Rightarrow \quad \frac{v^2}{f^2} \lesssim 0.03$$

$$\lambda_t \sim \frac{\lambda_L \lambda_R}{g_\rho}$$

Option I $\quad \mathcal{O}_R = (2,1) \qquad \mathcal{O}_L = (1,2) \qquad$ under $\quad SO(4) \sim SU(2)_L \times SU(2)_R$



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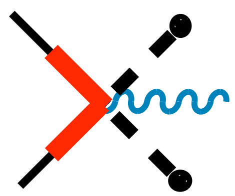

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$$\frac{v^2}{f^2} \lesssim 0.03$$

$$\delta\rho \sim \frac{N_c \lambda_L^4}{16\pi^2 g_\rho^2} \frac{v^2}{f^2}$$

Option II $\quad \mathcal{O}_R = (2,2) \qquad \mathcal{O}_L = (1,1)$

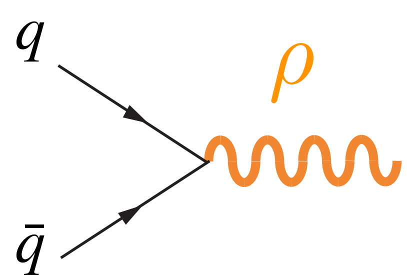
$$\frac{\delta g_b}{g_b} \sim \frac{\lambda_L^2}{g_\rho^2} \frac{v^2}{f^2}$$

- ✦ best choice $\quad \lambda_L \sim \lambda_t \qquad \lambda_R \sim g_\rho \quad \rightarrow \quad t_R \quad$ fully composite
- ✦ can further reduce $\delta g_b / g_b$ by extra symm in strong sector
- ✦ exotic top parters with charge $\frac{5}{3}$

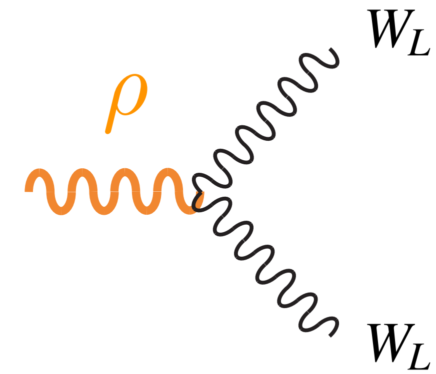
Agashe, Contino, Da Rold, Pomarol 06

★ vectors are preferably

- broad & heavy
- very weakly coupled to SM fermions



$$= \frac{g_W^2}{g_\rho} \ll g_W$$



$$= g_\rho$$

$$\sigma\left(pp \to \rho_H^{\pm} + X\right) = \left(\frac{4\pi}{g_\rho}\right)^2 \left(\frac{3\ \text{TeV}}{m_\rho}\right)^6 \ 0.5\ \text{fb}$$

increasingly harder to detect as $g_\rho \longrightarrow 4\pi$

★ 'top parners' can be below 1 TeV (preferably so in LH)

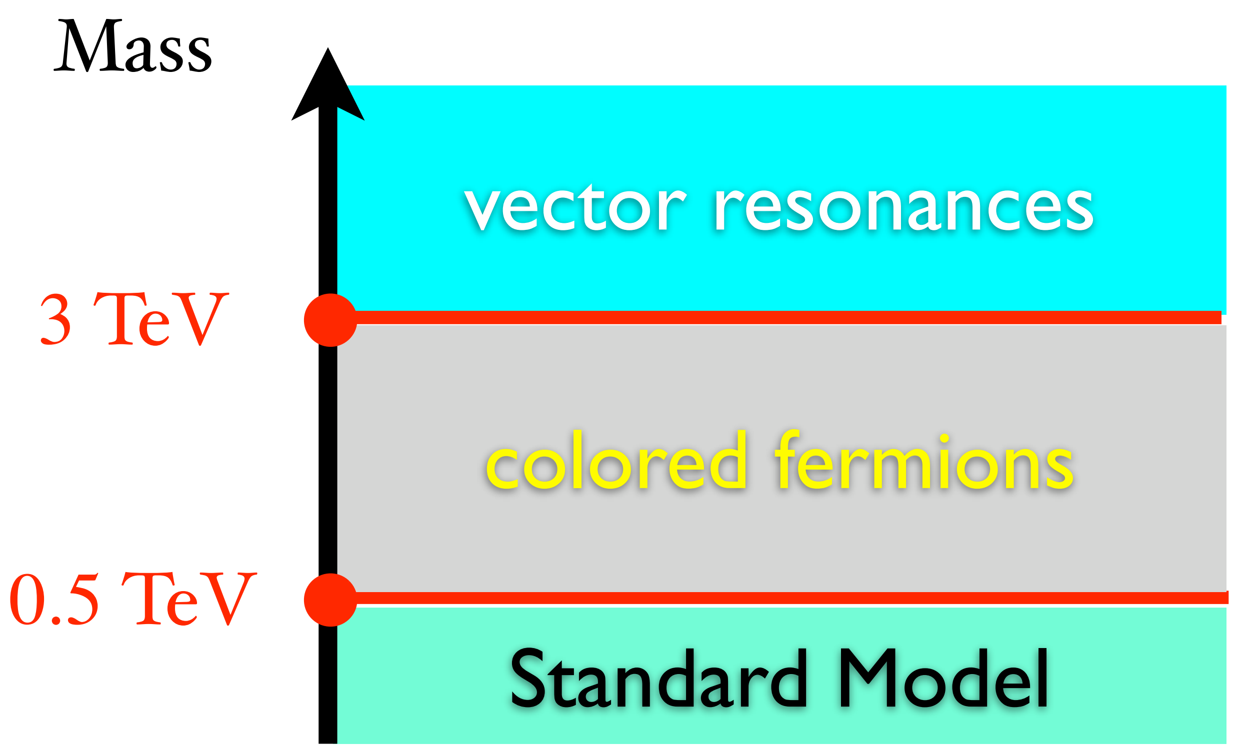
electric charges of heavy quarks $-\frac{1}{3}, \quad \frac{2}{3}, \quad \frac{5}{3}$

motivated by $Zb\bar{b}$

$\ell^-\ell^-$
$\ell^+\ell^+$ signature

Contino, Servant 08 - Mrazek, Wulzer 09

Conceivably



A ‘precision’ study of Higgs properties would in principle help understanding the origin of the weak scale

Effective Lagrangian for composite Higgs

$$\begin{aligned}
\mathcal{L}_{eff} = \quad & \frac{c_H}{2f^2}\partial^\mu\left(H^\dagger H\right)\partial_\mu\left(H^\dagger H\right) - \frac{c_6\lambda}{f^2}\left(H^\dagger H\right)^3 + \left(\frac{c_y y}{f^2}H^\dagger H\,\bar{\psi}_L H\psi_R + \text{h.c.}\right) \\
+ \quad & \frac{c_\gamma g^2}{16\pi^2 m_\rho^2}H^\dagger H B_{\mu\nu}B^{\mu\nu} + \frac{c_g y_t^2}{16\pi^2 m_\rho^2}H^\dagger H G^a_{\mu\nu}G^{a\mu\nu} \\
+ \quad & \frac{ic_W}{2m_\rho^2}\left(H^\dagger\sigma^i\overleftrightarrow{D^\mu}H\right)\left(D^\nu W_{\mu\nu}\right)^i + \frac{ic_B}{2m_\rho^2}\left(H^\dagger\overleftrightarrow{D^\mu}H\right)\left(\partial^\nu B_{\mu\nu}\right) \\
+ \quad & \frac{ic_{HW}}{16\pi^2 f^2}(D^\mu H)^\dagger\sigma^i(D^\nu H)W^i_{\mu\nu} + \frac{ic_{HB}}{16\pi^2 f^2}(D^\mu H)^\dagger(D^\nu H)B_{\mu\nu}
\end{aligned}$$

$$f = \frac{m_\rho}{g_\rho} \ll m_\rho$$

Giudice, Grojean, Pomarol, Rattazzi 07

$$\mathcal{L}_{eff} = \frac{c_H}{2f^2}\partial^\mu\left(H^\dagger H\right)\partial_\mu\left(H^\dagger H\right) - \frac{c_6\lambda}{f^2}\left(H^\dagger H\right)^3 + \left(\frac{c_y y}{f^2}H^\dagger H\,\bar{\psi}_L H\psi_R + \text{h.c.}\right)$$

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irrelevant

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Giudice, Grojean, Pomarol, Rattazzi 07

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Giudice, Grojean, Pomarol, Rattazzi 07

$$
\begin{aligned}
\mathcal{L}_{eff} = \; & \frac{c_H}{2f^2}\partial^\mu\left(H^\dagger H\right)\partial_\mu\left(H^\dagger H\right) - \frac{c_6\lambda}{f^2}\left(H^\dagger H\right)^3 + \left(\frac{c_y y}{f^2}H^\dagger H\,\bar{\psi}_L H\psi_R + \text{h.c.}\right) \\
& + \frac{c_\gamma g^2}{16\pi^2 m_\rho^2}H^\dagger H B_{\mu\nu}B^{\mu\nu} + \frac{c_g y_t^2}{16\pi^2 m_\rho^2}H^\dagger H G^a_{\mu\nu}G^{a\mu\nu} \\
& + \frac{ic_W}{2m_\rho^2}\left(H^\dagger\sigma^i\overleftrightarrow{D^\mu}H\right)\left(D^\nu W_{\mu\nu}\right)^i + \frac{ic_B}{2m_\rho^2}\left(H^\dagger\overleftrightarrow{D^\mu}H\right)\left(\partial^\nu B_{\mu\nu}\right) \\
& + \frac{ic_{HW}}{16\pi^2 f^2}(D^\mu H)^\dagger\sigma^i(D^\nu H)W^i_{\mu\nu} + \frac{ic_{HB}}{16\pi^2 f^2}(D^\mu H)^\dagger(D^\nu H)B_{\mu\nu}
\end{aligned}
$$

irrelevant

$$f = \frac{m_\rho}{g_\rho} \ll m_\rho$$

Giudice, Grojean, Pomarol, Rattazzi 07

★ Higgs compositeness described by very limited set of parameters !

- most relevant $\quad c_H, \quad c_y, \quad c_6$
- relevant when fermions are 'light' $\quad c_\gamma, \quad c_g,$

$$\frac{\delta\mathcal{A}}{\mathcal{A}_{SM}} \sim \frac{v^2}{f^2}$$

Analogues of S and T for precision Higgs physics

‘Theoretical’ constraints on c_H , c_y

Low, RR, Vichi 09

Simple Goldstone-Higgs

- ✦ c_H , c_y > 0 in all known models ➡ h couplings to SM reduced
- ✦ $c_H > 0$ follows from σ−model metric positivity
- ✦ $c_y > 0$ depends on quantum numbers of G-breaking parameters

Little-Higgs

- ✦ additional contributions $O(g^2_{SM}/g^2_\rho)$ by integrating out heavy scalars, vectors and fermions
- ☑ remarkably remains it true that

$$c_H > 0$$

$$c_H + 2c_y > 0$$

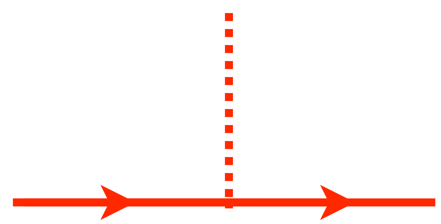
Effects in Higgs production & decay

all couplings rescaled by

$c_H \longrightarrow \quad \mathcal{L}_{kin} = \frac{1}{2}\left(1 + c_H \frac{v^2}{f^2}\right) \partial_\mu h \partial^\mu h$

$$\frac{1}{\sqrt{1 + c_H \frac{v^2}{f^2}}} \simeq 1 - c_H \frac{v^2}{2f^2}$$

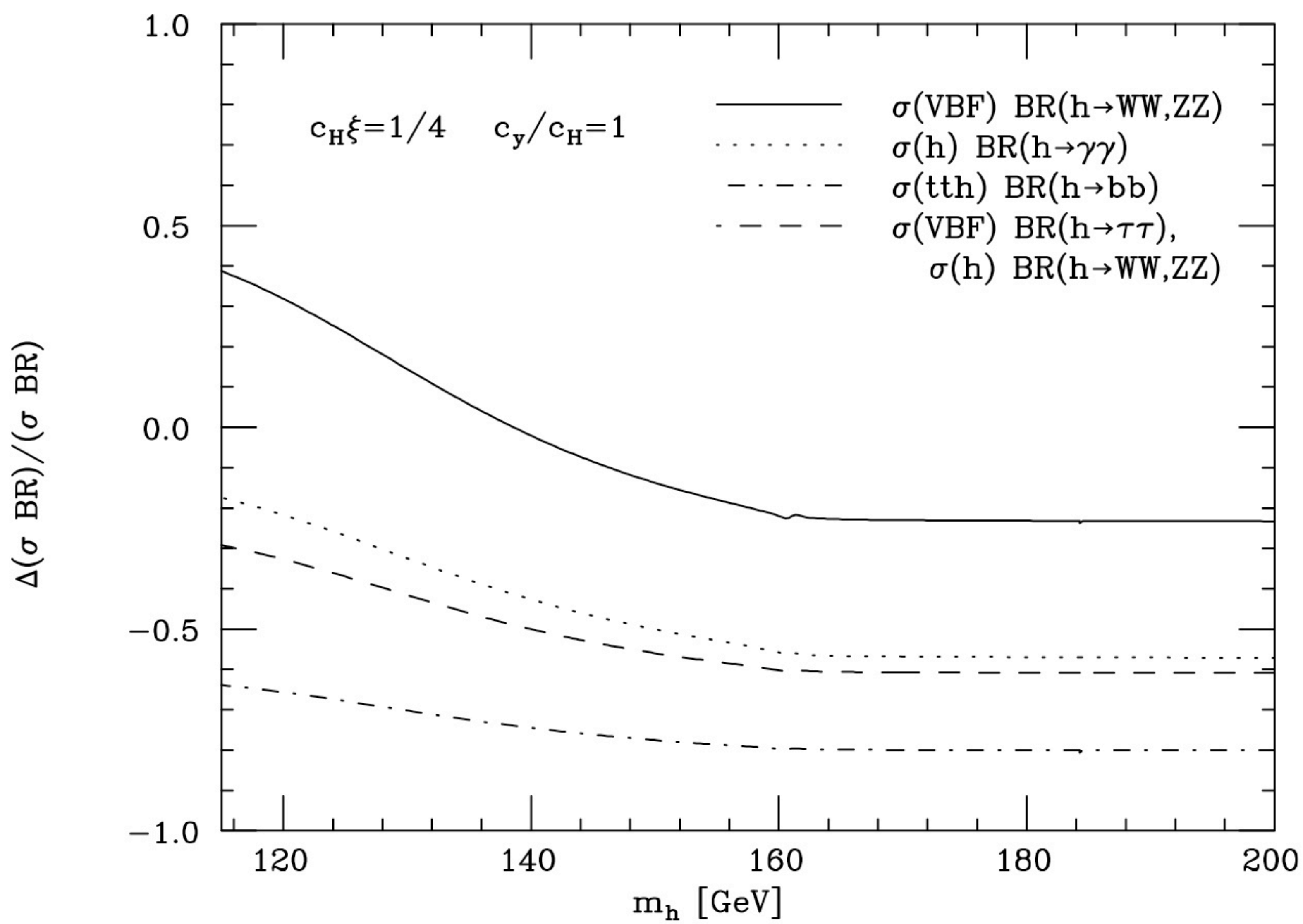
$c_y \longrightarrow$



$$\frac{m_\psi}{v}\left(1 - c_y \frac{v^2}{f^2}\right)$$

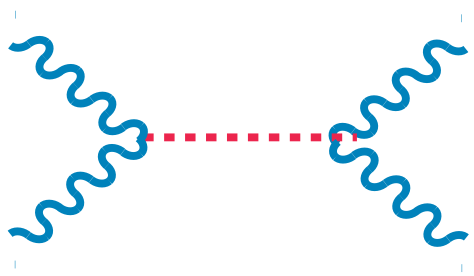
$$\frac{\Delta\left(\sigma(\mathrm{prod}) \times \mathrm{Br}\right)}{\left(\sigma(\mathrm{prod}) \times \mathrm{Br}\right)_{SM}}$$

$$= \# c_H \frac{v^2}{f^2} + \# c_y \frac{v^2}{f^2}$$

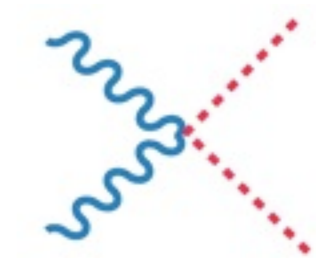


Direct signal of Higgs compositeness

$$\frac{c_H}{2f^2}\partial^\mu\left(H^\dagger H\right)\partial_\mu\left(H^\dagger H\right) \xrightarrow[\text{theorem}]{\text{equivalence}} \begin{array}{l} \mathcal{A}(W_L W_L \to W_L W_L) \sim \dfrac{s}{f^2} \\ \mathcal{A}(W_L W_L \to h\,h) \sim \dfrac{s}{f^2} \end{array}$$



$$\propto 1 - c_H \frac{v^2}{f^2}$$



$$\propto 1 - 2c_H \frac{v^2}{f^2}$$

fail to unitarize amplitudes

$$\sigma\left(pp \to V_L V_L' X\right)_{c_H} = \left(c_H \frac{v^2}{f^2}\right)^2 \sigma\left(pp \to V_L V_L' X\right)_{\not{H}}$$

sensitivity with 300 fb^{-1}

$$c_H \frac{v^2}{f^2} = 0.5 - 0.7$$

Bagger et al., '95

h = 4th goldstone: *VV* ➡ *VV* and *VV* ➡ *hh* related by linearly realized SO(4)

Higgs distinguished from a *random* light composite scalar in TC like model

General parametrization of *Higgslike* scalar

$$\mathcal{L} = \frac{1}{2}(\partial_\mu h)^2 + \frac{M_V^2}{2}\mathrm{Tr}\left(V_\mu V^\mu\right)\left[1 + 2a\frac{h}{v} + b\frac{h^2}{v^2} + \ldots\right] - m_i \bar{\psi}_{Li}\left(1 + c\frac{h}{v}\right)\psi_{Ri} + \mathrm{h.c.}$$

✦ Standard Model: $a = b = c = 1$

$$\mathcal{A}(VV \to VV) \simeq \frac{s}{v^2}(1 - a^2) \qquad \mathcal{A}(VV \to hh) \simeq \frac{s}{v^2}(b - a^2) \qquad \mathcal{A}(VV \to \psi\bar{\psi}) \simeq \frac{\sqrt{m_\psi s}}{v^2}(1 - ac$$

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✦ SILH $\quad a = 1 - \frac{c_H}{2}\frac{v^2}{f^2} \qquad b = 1 - 2c_H\frac{v^2}{f^2} \qquad c = 1 - \left(\frac{c_H}{2} + c_y\right)\frac{v^2}{f^2}$

$SO(5)/SO(4)$ $\quad a = \sqrt{1 - v^2/f^2} \qquad b = 1 - 2v^2/f^2 \qquad c = \sqrt{1 - v^2/f^2}$ fermions in **4**

$$c = \frac{1 - 2v^2/f^2}{\sqrt{1 - v^2/f^2}}$$ fermions in **5**

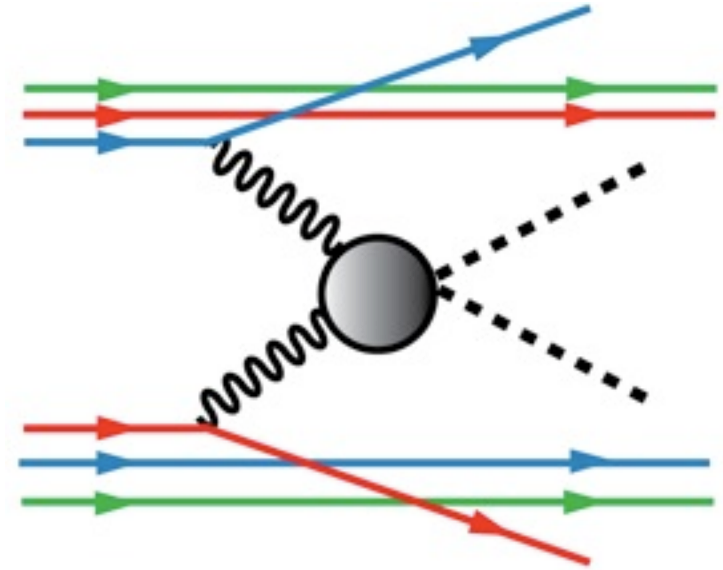
✦ Dilaton + TC $\quad a = \sqrt{b} = c = \frac{v}{f_D}$

Goldberger, Grinstein, Skiba 07

$$\mathcal{A}(VV \to hh) \sim \text{const}$$

$VV \Rightarrow hh$ at the LHC

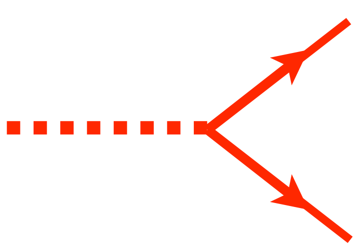
Contino, Grojean, Moretti, Piccinini, RR
in preparation



◆ $hh \to bbbb$ QCD background too big

◆ $hh \to 4W \to \text{leptons} + \text{jets} + \not{E}_T$ doable...

◆ Notice that $h \Rightarrow WW$ could also dominate for $m_h < 150\,\text{GeV}$



$\propto \dfrac{1-2v^2/f^2}{\sqrt{1-v^2/f^2}}$

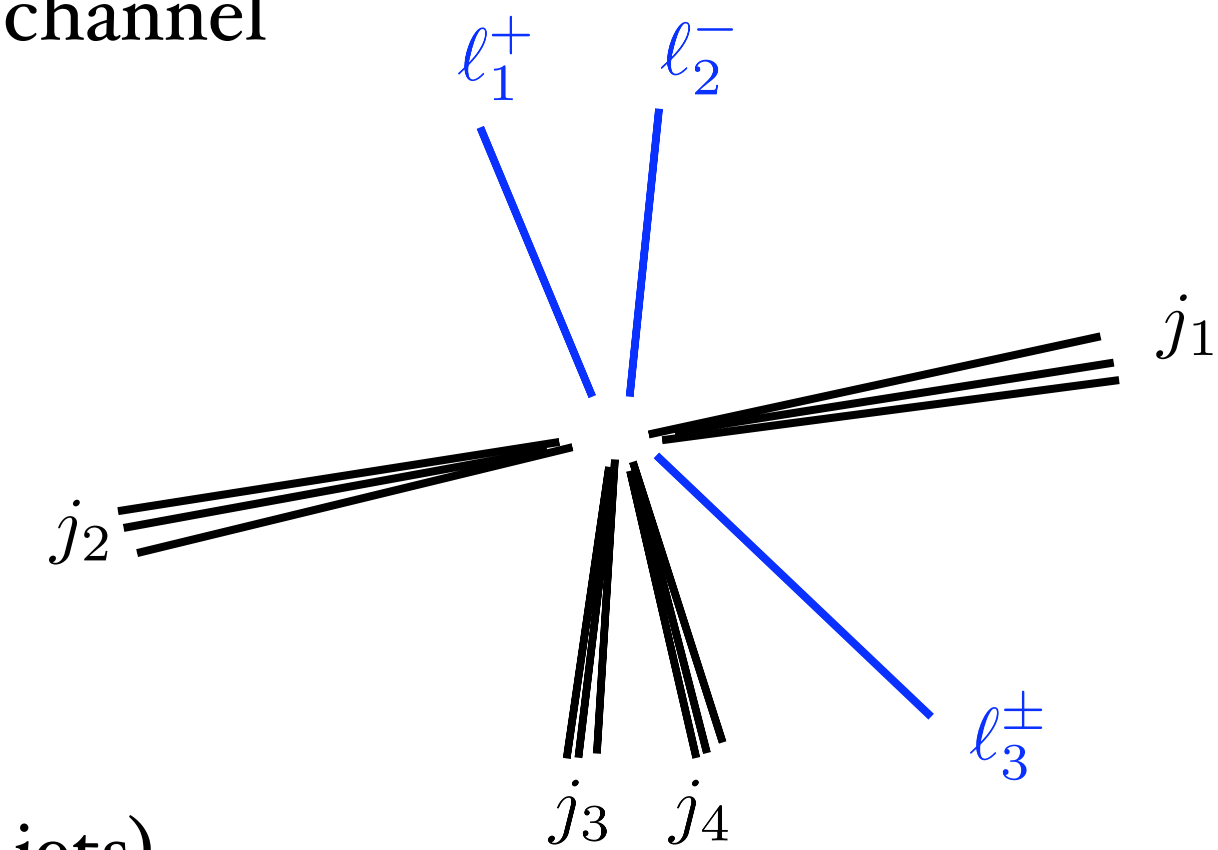
$h \Rightarrow bb$ suppressed around $\dfrac{v^2}{f^2} = \dfrac{1}{2}$

Trilepton channel

$$pp \rightarrow hh\, j_1 j_2$$

$$\quad hh \rightarrow WW \rightarrow \ell_1^+ \ell_2^- + \nu\nu$$

$$\quad hh \rightarrow WW \rightarrow \ell_3^\pm + \nu + j_3 j_4$$



- ✦ 2 energetic forward jets (reference jets)
- ✦ 4W in central region due to s-wave
- ✦ $\ell_1^+ \ell_2^-$ $\sim$ aligned because of boost and helicity conservation

Signal: $\ell^+ \ell^- \ell^\pm + (j \geq 4)$

In analysis we define

$|\eta_{j_1}|$ largest

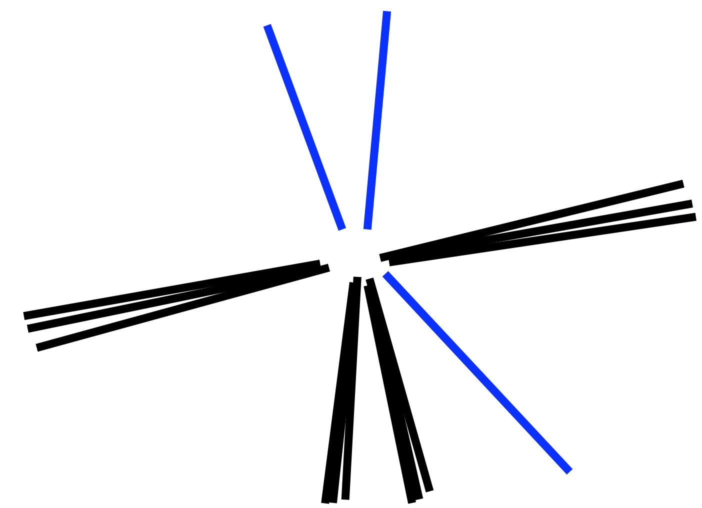
$m_{j_1 j_2}$ largest

$m_{\ell_1^+ \ell_2^-}$ smallest

$m_h = 180\,\mathrm{GeV}$ *ab*

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

Channel	σ_1	σ_2	σ_3	σ_4^{CMS}	σ_4^{ATLAS}
$\mathcal{S}_3$ ($\xi = 1$)	48.3	43.8	25.4	25.3	24.8
$\mathcal{S}_3$ ($\xi = 0.8$)	32.8	29.7	17.2	17.1	16.8
$\mathcal{S}_3$ ($\xi = 0.5$)	14.6	13.4	7.77	7.74	7.60
$\mathcal{S}_3$ ($\xi = 0$)	1.73	1.34	0.75	0.75	0.73
Wl^+l^-jjjj	12.0 $\times 10^3$	658	4.07	3.35	2.47
Wl^+l^-5j	3.83 $\times 10^3$	16.6	0.13	0.08	0.00
$hl^+l^-jj \to WWl^+l^-jj$	102	29.7	0.50	0.50	0.49
$WWWjjjj$	86.2	3.47	0.35	0.28	0.23
$t\bar{t}Wjj$	408	11.3	0.66	0.55	0.37
$t\bar{t}Wjjj$	287	2.40	0.15	0.12	0.09
$t\bar{t}WW$	315	4.48	0.02	0.02	0.02
$t\bar{t}WWj$	817	28.1	1.40	1.16	0.89
$t\bar{t}hjj \to t\bar{t}WWjj$	610	8.89	0.65	0.52	0.38
$t\bar{t}hjjj \to t\bar{t}WWjjj$	329	0.84	0.05	0.04	0.03
$W\tau^+\tau^-jjjj$	206	11.5	1.26	1.05	0.68
Total background	18.9 $\times 10^3$	775	9.23	7.66	5.65



acceptance

master

$|\eta_{j_1}| \geq 1.8$ $\quad m_{j_1 j_2} \geq 320$ GeV $\quad |\eta_{j_1} - \eta_{j_2}| \geq 2.9$

$|m_{j_3 j_4} - m_W| \leq 40$ GeV $\quad m^h_{l_1 l_2} \leq 110$ GeV $\quad m^h_{j_3 j_4 l_3} \leq 210$ GeV

optimization

$m_{SF-OS} \geq 20\,\mathrm{GeV}$ $\quad |m_{SF-OS} - M_Z| \geq 7\,\Gamma_Z$

$|\eta_{j_1} - \eta_{j_2}| \geq 4.5$ $\quad m_{j_1 j_2} \geq 700\,\mathrm{GeV}$ $\quad m^h_{j_3 j_4 l_3} \leq 160\,\mathrm{GeV}$

Significance

trilepton

cut on $\|m^W_{JJ} - M_W\|$	ξ	σ (300 fb^{-1})	σ (3000 fb^{-1})
$< 30\,\mathrm{GeV}$	1.0	3.6	12
	0.8	2.5	8.4
	0.5	1.2	4.2
$< 20\,\mathrm{GeV}$	1.0	3.9	13
	0.8	2.8	9.2
	0.5	1.3	4.7

same sign dilepton

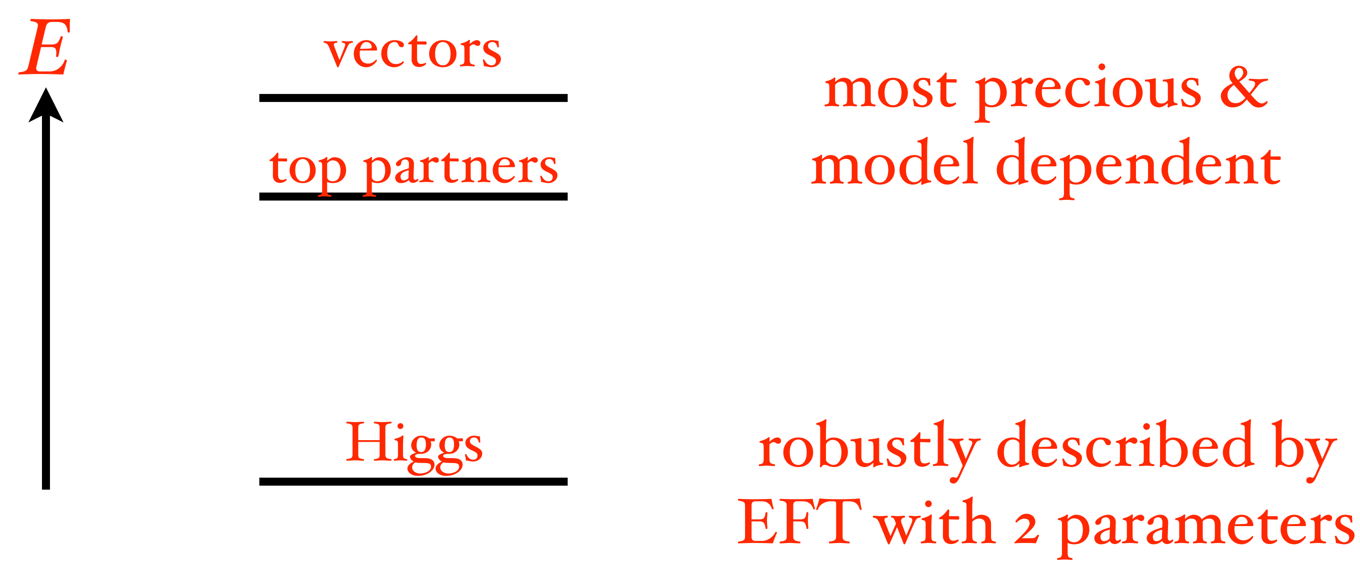
cut on $\|m^W_{J_1^{W_1} J_2^{W_1}} - M_W\|$	ξ	σ (300 fb^{-1})	σ (3000 fb^{-1})	σ (3000 fb^{-1}) w/o tau and b-jet veto
$< 30\,\mathrm{GeV}$	1.0	3.9	13	10
	0.8	2.7	8.8	7.0
	0.5	1.3	4.3	3.3
$< 20\,\mathrm{GeV}$	1.0	4.1	13	11
	0.8	2.9	9.2	7.3
	0.5	1.4	4.5	3.5

Summary

✦ Hierarchy problem still forcing us to explore QFT

✦ Refinement of ideas from the 80's
- pseudo-Goldstone Higgs
- fermion masses via fermion mixing

✦ What to expect:



- freedom to tune mass scale up, like in SUSY

Ex $m_T < 1.5\,\mathrm{TeV}$ discovery with 300 fb^{-1}

✦ Strong $VV \to VV$ and $VV \to hh$ genuine signal of Higgs compositeness

observable if $\dfrac{v^2}{f^2} > 0.3$ ...with luminosity upgrade

✦ Study of indirect signals of Higgs compositeness ideal at ILC ∼ Higgs factory

At ILC one would test $\frac{v^2}{f^2}$ at % level

Barger, Han,Langacker, McElrath,Zerwas 03

J.A. Aguilar Saavedra et al. [ECFA/DESY LC Physics WG]

Coupling	$M_H = 120$ GeV	140 GeV
g_{HWW}	$\pm$ 0.012	$\pm$ 0.020
g_{HZZ}	$\pm$ 0.012	$\pm$ 0.013
g_{Htt}	$\pm$ 0.030	$\pm$ 0.061
g_{Hbb}	$\pm$ 0.022	$\pm$ 0.022
g_{Hcc}	$\pm$ 0.037	$\pm$ 0.102
$g_{H\tau\tau}$	$\pm$ 0.033	$\pm$ 0.048
g_{HWW}/g_{HZZ}	$\pm$ 0.017	$\pm$ 0.024
g_{Htt}/g_{HWW}	$\pm$ 0.029	$\pm$ 0.052
g_{Hbb}/g_{HWW}	$\pm$ 0.012	$\pm$ 0.022
$g_{H\tau\tau}/g_{HWW}$	$\pm$ 0.033	$\pm$ 0.041
g_{Htt}/g_{Hbb}	$\pm$ 0.026	$\pm$ 0.057
g_{Hcc}/g_{Hbb}	$\pm$ 0.041	$\pm$ 0.100
$g_{H\tau\tau}/g_{Hbb}$	$\pm$ 0.027	$\pm$ 0.042

ILC can rule out Higgs compositeness scale $4\pi f$ below 30 TeV