Fenomenologia dei modelli di Higgs composto

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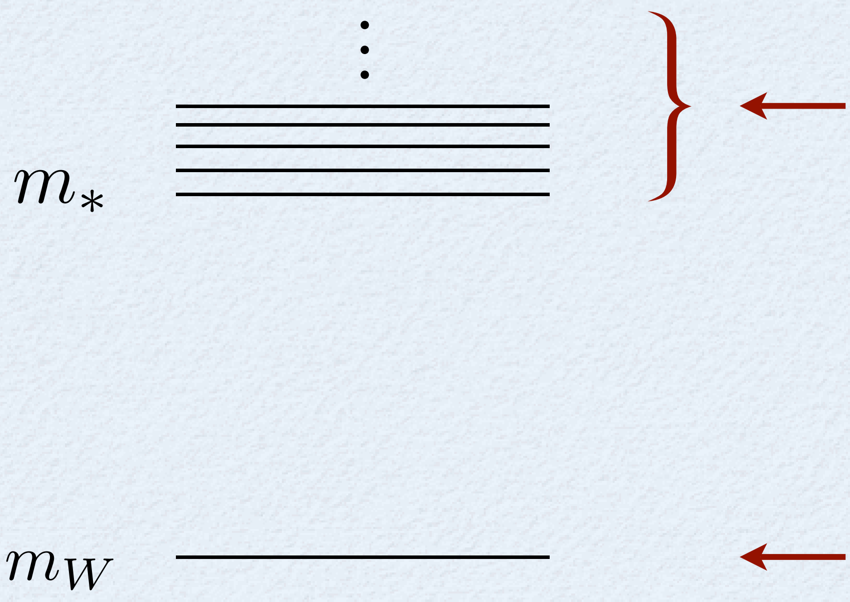
CERN - TH

hep-ph/0612180 R.C. , T. Kramer, M. Son, R. Sundrum

The case for a composite Higgs



a new strongly-interacting dynamics with heavy resonances is responsible for EWSB

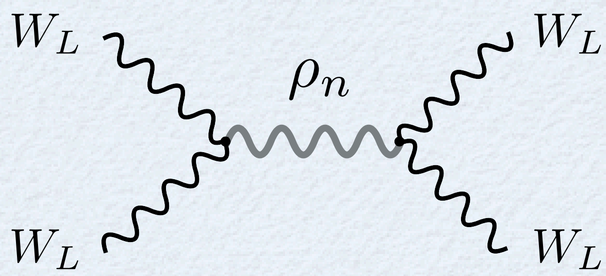
W_L , Z_L are Goldstone bosons of the new dynamics

TECHNICOLOR [WEINBERG,SUSSKIND]

How heavy are the new states ?

- The (vector) resonances that unitarize the WW scattering cannot be too heavy

$$\sum_n$$



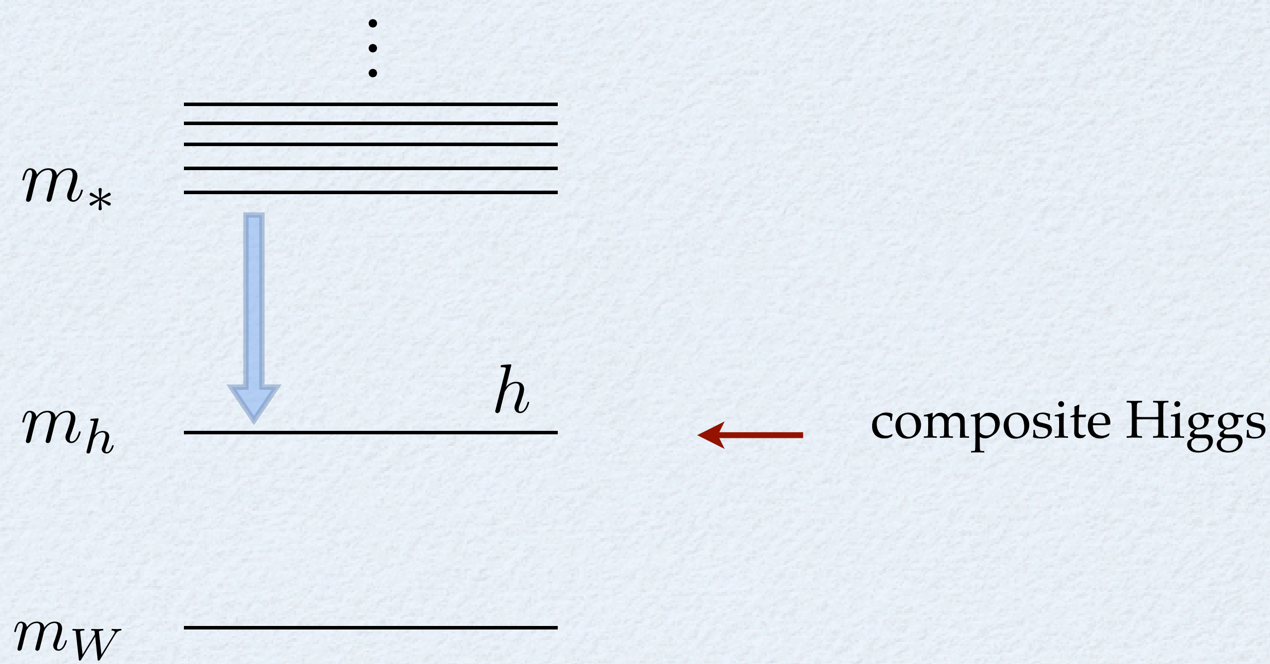
$$\Lambda \lesssim 1.3\,\text{TeV}$$

- The LEP precision tests show that the vector resonances cannot be too light

ex: $$\hat{S} \sim \left(\frac{m_W}{m_\rho}\right)^2$$

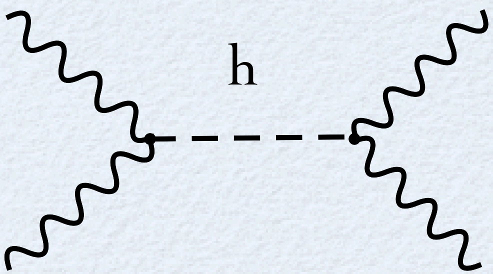
$$m_\rho \gtrsim 1.6\,\text{TeV}$$

☞ This tension is relaxed if the strong dynamics has a light scalar bound state playing the role of the Higgs boson



✔ The composite Higgs can partially unitarize the WW scattering

$$g_{hWW} = g_{hWW}^{SM} \sqrt{1-\epsilon^2}$$



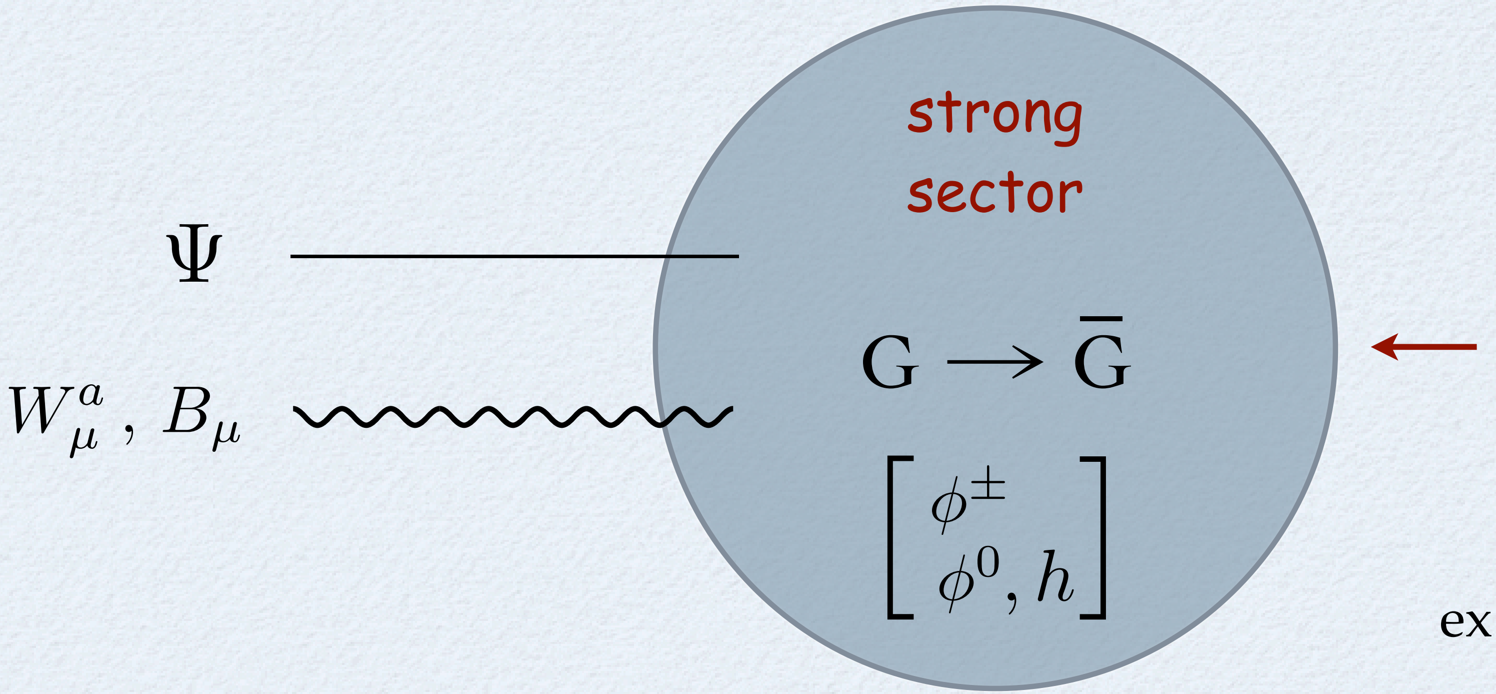
$$\Lambda' = \frac{\Lambda}{\epsilon}$$

this allows for → heavier vector resonances → smaller corrections to the EWPT

✔ Higgs compositeness solves the Hierarchy problem of the SM

Can the composite Higgs be naturally light ?

☞ yes, if it is a (pseudo) Goldstone boson **[Georgi & Kaplan, `80s]**



enlarge the global symmetry to have a full SU(2) doublet

ex: $\mathrm{SO(5)} \to \mathrm{SO(4)}$

the explicit breaking of the global symmetry by a weak interaction leads to a light Higgs

$$m_h^2 \sim \frac{\lambda^2}{16\pi^2} m_*^2$$

A new fundamental parameter:

being a Goldstone, the composite Higgs behaves like an "angle" :

$$V(h) = F_\pi^2 m_*^2 \frac{\lambda^2}{16\pi^2} g(h/F_\pi)$$

$F_\pi =$ scale at which $G \to \bar{G}$

$g(x) =$ periodic function

new parameter:

$$\epsilon = \frac{v}{F_\pi} \qquad 0 \leq \epsilon \leq 1$$

... ok, suppose we discover the Higgs: how can we tell it is composite ?

① Measuring its couplings

shifts expected at $\mathcal{O}(\epsilon^2)$

ex: for the SO(5)/SO(4) MCHM

$$g_{hVV} = g^{SM}_{hVV}\sqrt{1-\epsilon^2} \qquad V = W, Z$$

$$g_{hhVV} = g^{SM}_{hhVV}(1-2\epsilon^2)$$

$$g_{hf\bar{f}} = g^{SM}_{hf\bar{f}}\left(1-\frac{3}{2}\epsilon^2\right)$$

see ☞ Rattazzi's talk

and Giudice, Grojean, Pomarol, Rattazzi, hep-ph/0703164

② Probing its strong interaction in the WW scattering

Giudice, Grojean, Pomarol, Rattazzi
hep-ph/0703164

the composite Higgs fails to fully unitarize WW scattering at high energy

$$\mathcal{A}(s,t) = \frac{s}{v^2}\epsilon^2 - \frac{s\, m_h^2}{s - m_h^2}(1-\epsilon^2) + \left(s \leftrightarrow t\right)$$

smoking gun:

discovery of the Higgs
+
excess of events in WW scattering

see ☞ Rattazzi's talk

These signals would give direct evidence for the Higgs compositeness

- theoretically clean

- experimentally challenging

required: full control of the detector and of background

large integrated luminosity

Indirect evidence can come from the production of the new resonances of the strong sector

- experimentally easier

- more model dependent

① Discovering the vector resonances that ultimately unitarize the WW scattering

LEP precision tests → vectors are heavy and weakly coupled to light SM fermions

HARD to see at the LHC

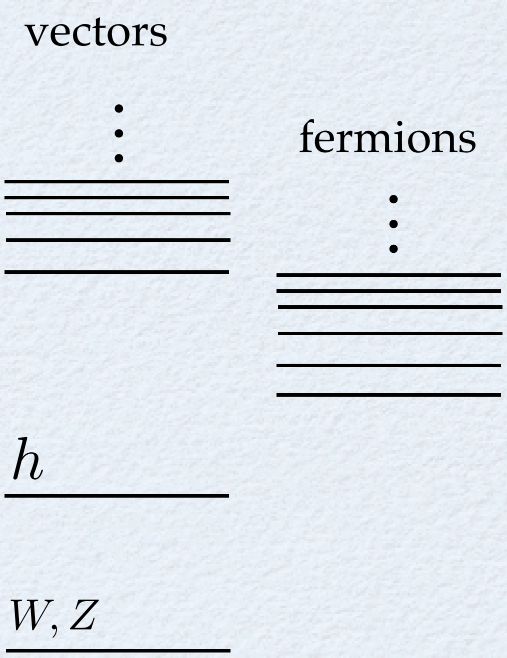
② Discovering the resonances that cut off the loop of the top

✔ Naturalness requires these new states to be light(er)

ex: $m_h = 200\,\mathrm{GeV}$ and NO tuning $\longrightarrow$ $m_* \sim 700\,\mathrm{GeV}$

✔ These states are colored fermions (no SUSY)

expected to be strongly coupled to t, b, W_L, Z_L



EASY to see at the LHC

Need a low-energy effective description

of the lowest-lying resonances

to study their phenomenology

we focus on the class of models with

- ✤ no T-parity

- ✤ linear couplings between composite and elementary sector

  ✔ Flavor ✔ Fermion masses

this includes extra-dimensional warped (Randall-Sundrum) theories

effective description of the lowest-lying resonances given by a

Two-site model

R.C., Kramer, Son, Sundrum hep-ph/0612180

RULES

•Elementary sector: {SM - Higgs}

inter-elementary coupling: $g_{el} \sim 1$

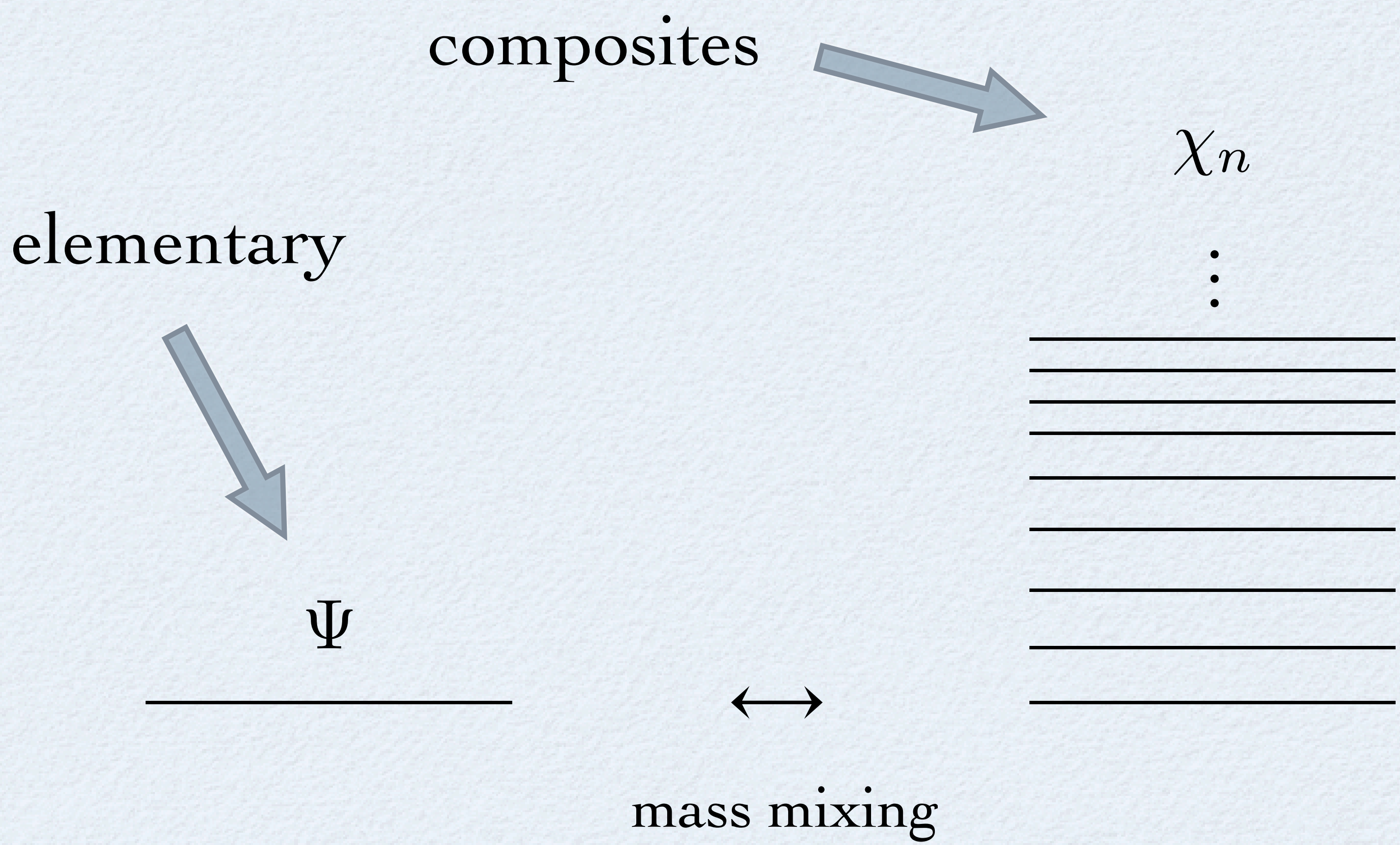
•Composite sector: {ρ, χ + Higgs}

[$\supset$ excited massive copy of the SM]

inter-composite coupling: $4\pi \gg g_* \gg 1$

•Mixing: only mass mixings allowed

•Higgs: H couples only to ρ and χ



$$\mathcal{L}_{mix} = \sum_n \Delta_n \, \bar{\Psi} \chi_n + h.c.$$

☞ Keep only the first resonance of each tower

Ψ $\longleftrightarrow$ χ

mass mixing

$$\mathcal{L}_{mix} = \Delta\,\bar{\Psi}\chi + h.c.$$

example:

A simple Two-Site SO(5)/SO(4) model

$$\mathrm{SO}(5)\times\mathrm{U}(1)_X \to \mathrm{SO}(4)\times\mathrm{U}(1)_X \qquad \mathrm{SO}(4)\sim\mathrm{SU}(2)_L\times\mathrm{SU}(2)_R$$

$$\Sigma_0 = (0,0,0,0,1) \qquad Y = T_{3R} + X$$

4 Goldstones

$$\Sigma = \Sigma_0\, e^{T^{\hat a} h^{\hat a}/F_\pi}$$

elementary sector: q_L, t_R

composite sector:

$$\begin{bmatrix} \begin{pmatrix} Q' \\ Q \end{pmatrix} \\ \tilde{T} \end{bmatrix} = \chi \longleftarrow \mathbf{5_{2/3}} \text{ of } \mathrm{SO}(5)\times\mathrm{U}(1)_X$$

$$[\mathbf{5} = (\mathbf{2},\mathbf{2})\oplus(\mathbf{1},\mathbf{1})]$$

$$Q = \begin{bmatrix} T \\ B \end{bmatrix} \qquad Q' = \begin{bmatrix} T_{5/3} \\ T_{2/3} \end{bmatrix}$$

$$Y[Q] = 1/6 \qquad Y[Q'] = 7/6$$

$$\mathcal{L} = \bar{\chi}\left(i\partial\!\!\!/ - m\right)\chi - m_\Sigma\, \bar{\chi}_i \Sigma_i \Sigma_j \chi_j$$

source of explicit SO(5) breaking →

$$+ \bar{q}_L i\partial\!\!\!/ q_L + \bar{t}_R i\partial\!\!\!/ t_R$$

$$+ \Delta_q\, \bar{q}_L Q_R + \Delta_{t_R}\, \bar{t}_R \tilde{T}_L + h.c.$$

$$\begin{aligned}
\mathcal{L} =& + \bar{Q}\left(i\partial\!\!\!/ - m - m_\Sigma \frac{s^2}{2}\, \hat{H}\hat{H}^\dagger\right) Q + \bar{Q}'\left(i\partial\!\!\!/ - m - m_\Sigma \frac{s^2}{2}\, \hat{H}^c\hat{H}^{c\,\dagger}\right) Q' \\
& + \bar{\tilde{T}}\left(i\partial\!\!\!/ - \tilde{m} + m_\Sigma\, s^2\right)\tilde{T} - m_\Sigma \frac{s^2}{2}\, \bar{Q}'\hat{H}\hat{H}^{c\,\dagger} Q + h.c. \\
& - m_\Sigma \frac{sc}{\sqrt{2}}\left(\bar{Q}\hat{H}^c\tilde{T} + \bar{Q}'\hat{H}\tilde{T} + h.c.\right) \\
& + \bar{q}_L i\partial\!\!\!/ q_L + \bar{t}_R i\partial\!\!\!/ t_R + \Delta_q\, \bar{q}_L Q_R + \Delta_{t_R}\, \bar{t}_R \tilde{T}_L + h.c.
\end{aligned}$$

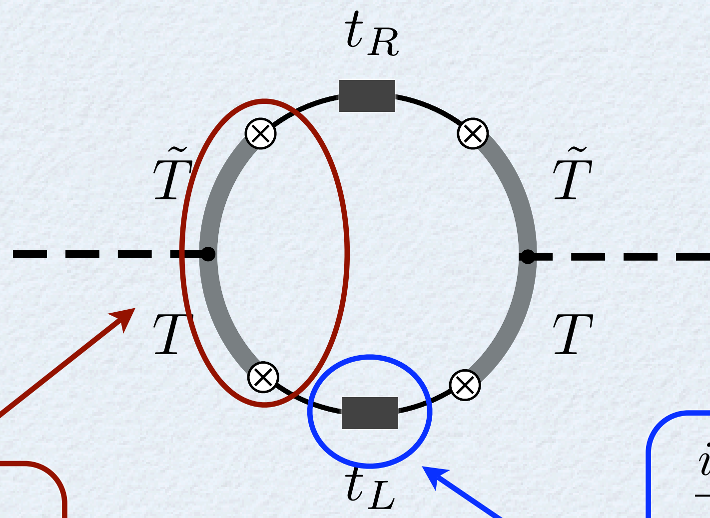
$$s \equiv \sin\frac{h}{F_\pi} \quad , \quad c \equiv \cos\frac{h}{F_\pi}$$

$$\hat{H} \equiv \frac{1}{h} H = \frac{1}{h}\begin{bmatrix} h^1 - ih^2 \\ h^3 - ih^4 \end{bmatrix} \qquad h = \sqrt{h^{\hat{a}} h^{\hat{a}}}$$

$$\tilde{m} = m + m_\Sigma$$

Higgs potential

$$\sin\frac{h}{F_\pi}\cos\frac{h}{F_\pi}$$



$$\sin\frac{h}{F_\pi}\cos\frac{h}{F_\pi}$$

$$F(p^2) = y_t\,\frac{m\tilde{m}\left(p^2 + m\tilde{m}\right)}{(p^2 - m^2)(p^2 - \tilde{m}^2)}$$

$$\frac{i}{\not p}\,\frac{1}{\Pi^q(p^2)}$$

$$\Pi^q(p^2) = \frac{1 + p^2\,(m^2 + \Delta_q^2)^{-1}}{1 + p^2\,m^{-2}}$$

$$\Delta V(h) = -\frac{2N_c}{8\pi^2}F_\pi^2\int_0^\infty dp\,p\,\frac{F^2(-p^2)}{\Pi^q(-p^2)\Pi^{t_R}(-p^2)}\;\sin^2\frac{h}{F_\pi}\cos^2\frac{h}{F_\pi}$$

$$\simeq -\frac{2N_c}{8\pi^2}y_t^2\frac{m^2}{6}F_\pi^2\;\sin^2\frac{h}{F_\pi}\cos^2\frac{h}{F_\pi}$$

DIAGONALIZATION:

elementary / composite → light / heavy

$$\begin{pmatrix} q_L \\ Q_L \end{pmatrix} \to \begin{pmatrix} \cos\varphi_L & -\sin\varphi_L \\ \sin\varphi_L & \cos\varphi_L \end{pmatrix} \begin{pmatrix} q_L \\ Q_L \end{pmatrix} \qquad \tan\varphi_L = \frac{\Delta_{q_L}}{m}$$

$$\begin{pmatrix} t_R \\ \tilde{T}_R \end{pmatrix} \to \begin{pmatrix} \cos\varphi_{t_R} & -\sin\varphi_{t_R} \\ \sin\varphi_{t_R} & \cos\varphi_{t_R} \end{pmatrix} \begin{pmatrix} t_R \\ \tilde{T}_R \end{pmatrix} \qquad \tan\varphi_{t_R} = \frac{\Delta_{t_R}}{\tilde{m}}$$

$$|\mathrm{SM}\rangle = \cos\varphi\,|\Psi\rangle + \sin\varphi\,|\chi\rangle$$

$$|\mathrm{heavy}\rangle = -\sin\varphi\,|\Psi\rangle + \cos\varphi\,|\chi\rangle$$

☞ φ parametrizes the degree of partial compositeness

$$
\begin{aligned}
\mathcal{L} =& \bar{q}_L i\not{\partial} q_L + \bar{t}_R i\not{\partial} t_R \\
& + \bar{Q}\left(i\not{\partial} - m_Q\right) Q + \bar{Q}'\left(i\not{\partial} - m\right) Q' + \bar{\tilde{T}}\left(i\not{\partial} - m_{\tilde{T}}\right)\tilde{T} \\
& - Y_* \Big[\left(\sin\varphi_L\, \bar{q}_L + \cos\varphi_L\, \bar{Q}\right) H^c \left(\sin\varphi_{t_R}\, t_R + \cos\varphi_{t_R}\, \tilde{T}\right) \\
& \qquad + \bar{Q}' H \left(\sin\varphi_{t_R}\, t_R + \cos\varphi_{t_R}\, \tilde{T}\right) + h.c. \Big] + \dots
\end{aligned}
$$

$$
m_{\tilde{T}} = \sqrt{\tilde{m}^2 + \Delta_{t_R}^2} \qquad m_Q = \sqrt{m^2 + \Delta_{q_L}^2}
$$

$$
\tilde{m} = m + m_\Sigma \qquad Y_* = \frac{m_\Sigma}{F_\pi \sqrt{2}}
$$

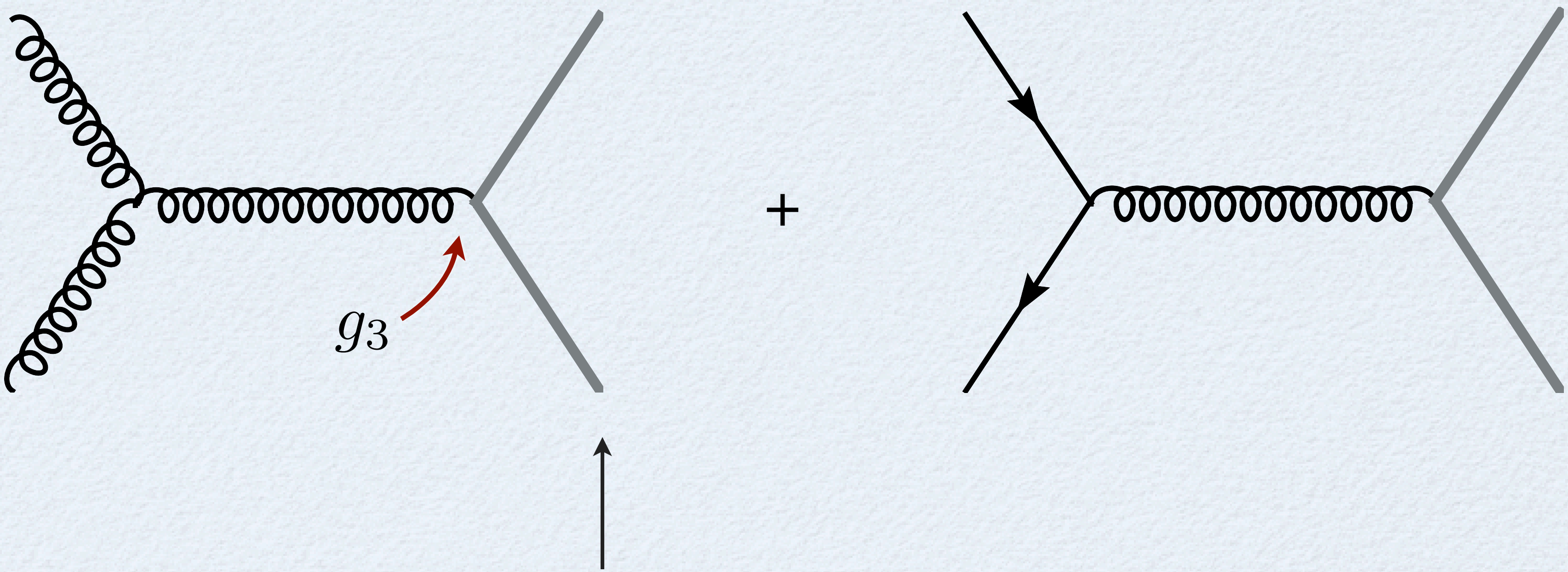
induced Yukawa coupling → $y_t = Y_* \sin\varphi_L \sin\varphi_{t_R}$

Heavy partners of the top

	charge	
$T_{5/3}$	$+\,5/3$	$\leftarrow$ $\mathrm{SU}(2)_R$ partners of q_L
$T_{2/3}$	$+\,2/3$	
T	$+\,2/3$	$\leftarrow$ partners of q_L
B	$-\,1/3$	
$\tilde{T}$	$+\,2/3$	$\leftarrow$ partner of t_R

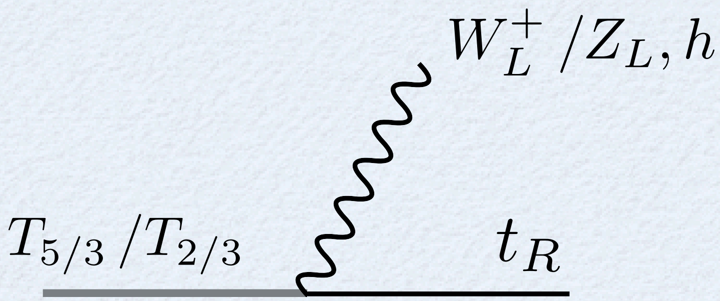
most studies focused on

PAIR PRODUCTION

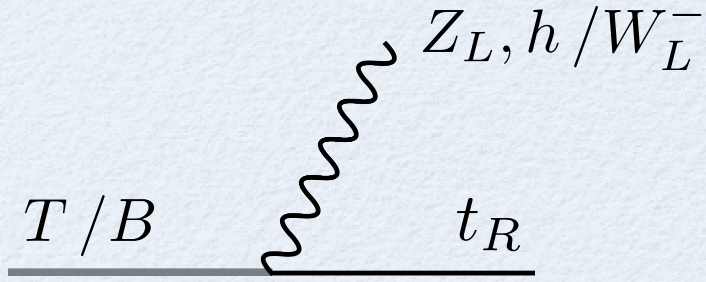


any of T, B, $T_{5/3}$, $T_{2/3}$, $\tilde{T}$

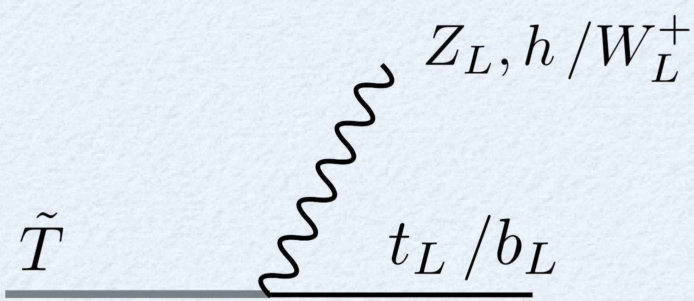
DECAYS



$$\lambda_{Q'} = Y_* \sin\varphi_{t_R}$$



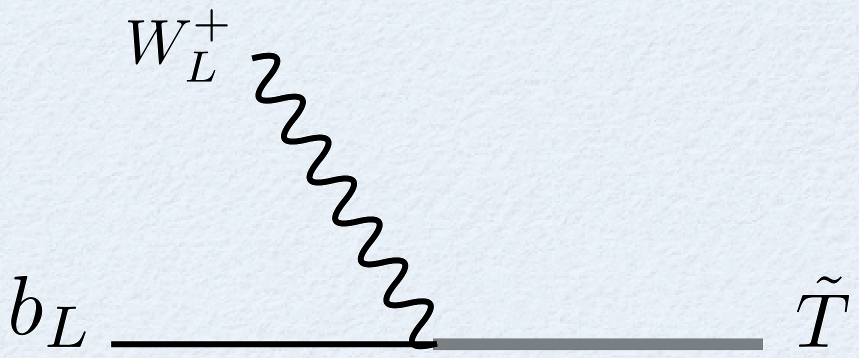
$$\lambda_Q = Y_* \sin\varphi_{t_R} \cos\varphi_L$$



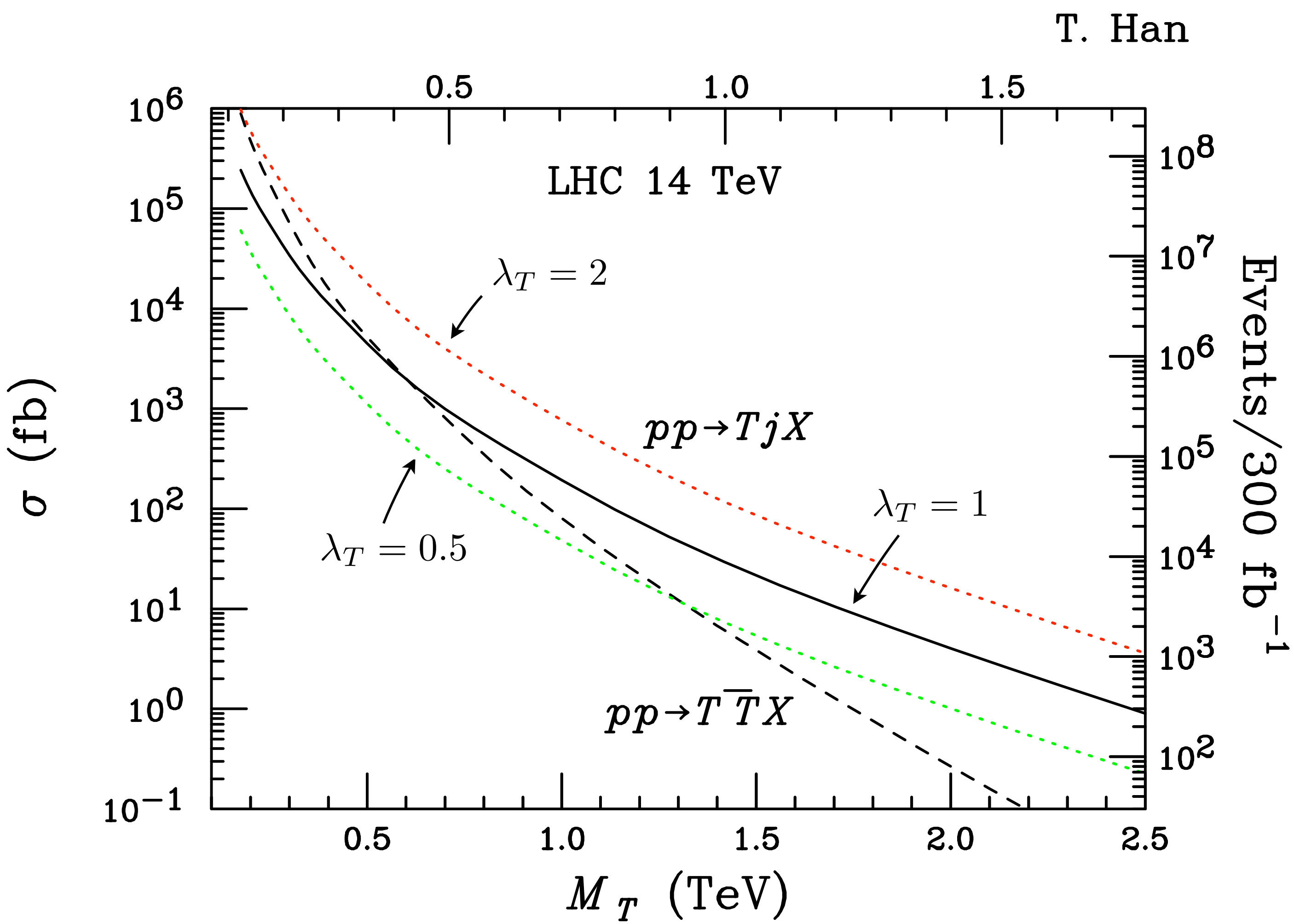
$$\lambda_{\tilde{T}} = Y_* \sin\varphi_L \cos\varphi_{t_R}$$

SINGLE PRODUCTION

ex:



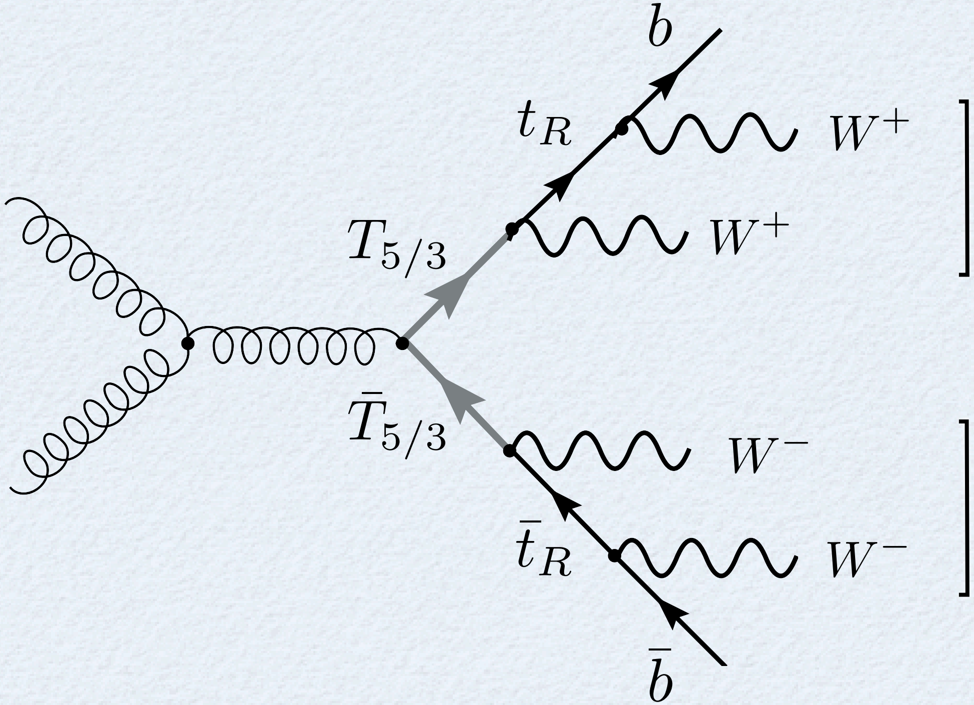
$\tilde{T}$ production cross section at the LCH



[From Azuelos et al. hep-ph/0402037]

Discovering the exotic $T_{5/3}$

work in progress
with G. Servant



$l^+ l^+ + \not{E}_T$ ← same-sign leptons

$j\, j\, j\, j$ ← invariant mass

Conclusions

- Discriminating between an elementary and a composite Higgs must be a goal of the LHC
- Direct evidence from shifts in the couplings of the Higgs and WW scattering $\longrightarrow$ challenging
- Indirect evidence might come much earlier by producing the partners of the top

more effort on the theoretical side is needed ... work in progress