Four Generations and Precision Constraints

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Beyond 3 Generations, Taipei, 2010

Outline

Chiral 4th Generation

Electroweak precision data

Higgs physics

Chiral 4th Generation

Some questions

– simply phenomenological: why three generations? [review: Framton, Hung, Sher]

– anomaly cancellation?
light neutrinos and LEP?
Majorana neutrinos in neutrinoless double beta decay?
electroweak precision data?
flavor constraints?

⇒ none of the constraints convincing ['Why there should not be a fourth generation'; Feyerabend]

– strongly interacting theory? [Holdom; Burdman & De Rold]
electroweak baryogenesis? [Fok & Kribs]
dark matter?

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The model [old story]

– complete additional generation [Q_4, U_4, D_4, L_4, e_4, ν_4]

– masses from Yukawas

– representations as Standard Model: no FCNC

– charged currents: (4×4) fermion–mixing matrices [single-top (D0) $V_{bt} \gtrsim 0.68$]

– neutrino mass: $\mathcal{L} \sim y_4 \; \tilde{H} \bar{L}_4 \nu_{4R} + M \; \bar{\nu}^c_{4R} \nu_{4R}/2$

Electroweak precision data

Oblique parameters

- weak sector overconstrained
- universal terms contributing to $sin^2\theta_w$ or m_W with given M_Z and G_F.
- states contributing to M_Z

$$\alpha S = \frac{4 s_w^2 c_w^2}{M_Z^2} \left[\Pi_{ZZ}(M_Z^2) - \Pi_{ZZ}(0) - \frac{c_{2w}}{c_w s_w} \Pi_{Z\gamma}(M_Z^2) - \Pi_{\gamma\gamma}(M_Z^2) \right]$$

- one generation of fermions [$Y_\ell = -1/2$; $Y_q = 1/6$]

$$\Delta S = \frac{N_f}{6\pi} \left(1 - 2Y \log \frac{m_u^2}{m_d^2} \right)$$

$\Rightarrow$ counting mass degenerate new states [old problem for ETC]

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- $SU(2)$ symmetry of W and Z [$m_Z \to \sqrt{\rho} m_Z$]

$$\alpha T = 4 m_Z^2 (\rho - 1) = \frac{\Pi_{WW}(0)}{M_w^2} - \frac{\Pi_{ZZ}(0)}{M_Z^2}$$

- two Standard Model contributions [$m_t^2 = m_b^2 + \delta$]

$$\Delta^{(f)} \rho = \frac{3 G_F}{8\sqrt{2}\pi^2} \left(m_t^2 + m_b^2 - 2 \frac{m_t^2 m_b^2}{m_t^2 - m_b^2} \log \frac{m_t^2}{m_b^2} \right) \propto \frac{\delta^2}{m_W^4}$$

$$\Delta^{(H)} \rho = - \frac{11 G_F m_Z^2 s_w^2}{24\sqrt{2}\pi^2} \log \frac{m_H^2}{m_Z^2}$$

$\Rightarrow$ limit on m_H for known m_t [blue band plot]

On a fourth generation

Electroweak precision data [LEPEWWG]

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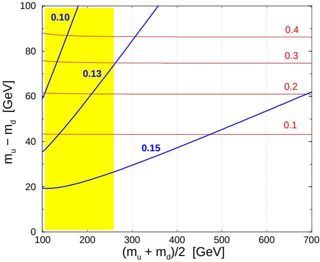
  Just as the 3rd generation... [Holdom; Vysotsky,...; Kribs, TP, Spannowsky, Tait]
- okay, got is, some people prefer a boring Z'
  but let's be honest for a change...
- for our purpose: leading S and T [$\Delta U \sim 0$ as in SM]
- neutrino with Dirac mass
- remember doublet: $\Delta S = N_f/(6\pi)(1 - 2Y \log m_u^2/m_d^2)$

(1) keep ΔS and ΔT small

[ΔS_q blue; ΔT_q red]



Heavy quark masses

Electroweak precision data [LEPEWWG]

(2) old trick: compensate $\Delta S \sim \Delta T > 0$ [Hill...]
small m_H: $\Delta T \sim \Delta S \sim 0.2$
large m_H: $\Delta T \sim \Delta S + 0.2 \sim 0.3$

– allowed parameter points [$m_{\nu_4} = 100$ GeV, $m_{\ell_4} = 155$ GeV]

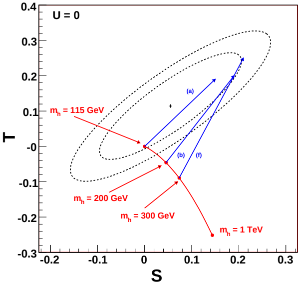
m_{u_4}	m_{d_4}	m_H	ΔS_{tot}	ΔT_{tot}
310	260	115	0.15	0.19
310	260	200	0.19	0.20
330	260	300	0.21	0.22
400	350	115	0.15	0.19
400	340	200	0.19	0.20
400	325	300	0.21	0.25

– within 68% CL of electroweak ellipse

– generic feature $m_{u_4} > m_{d_4}$ allows for $u_4 \to d_4 W$

– $\Delta S < 0$ but dangerous U for Majorana neutrino

[Kniehl, Kohrs]



Higgs physics

Dimension-5 Higgs couplings [e.g. SFitter-Higgs; got a hacked HDecay]

– loop effects of new particles [Arik, Arik, Cetin, Conca, Mailov, Sultansoy; Kribs, TP, Spannowsky, Tait]
– chiral fermions without Appelquist-Carazone decoupling

$$\Gamma_{H\to\gamma\gamma} = \frac{G_\mu \alpha^2 m_H^3}{128\sqrt{2}\pi^3} \left| \sum_f N_c Q_f^2 A_f(\tau_f) + A_W(\tau_W) \right|^2$$

$$\Gamma_{H\to gg} = \frac{G_\mu \alpha_s^2 m_H^3}{36\sqrt{2}\pi^3} \left| \frac{3}{4} \sum_f A_f(\tau_f) \right|^2 \qquad \text{with} \quad \tau_i = \frac{m_H^2}{4m_i^2}$$

$$A_f(\tau) = \frac{2}{\tau^2} \left[\tau + (\tau - 1) f(\tau)\right]$$

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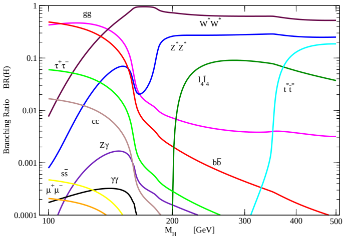
(1) increase $g_{ggH} \to 3 \times g_{ggH}$
decrease $g_{\gamma\gamma H} \to 1/3 \times g_{\gamma\gamma H}$
light–Higgs BRs suppressed by $H \to$ jets



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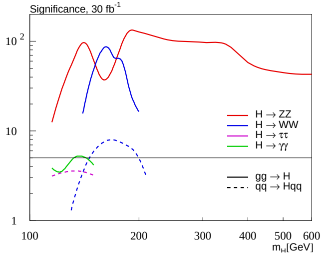
(2) factor 9 enhancement of $gg \to H$ [Tevatron!?]
$\sigma_{gg}\, \text{BR}_{\gamma\gamma} \to \sigma_{gg}\, \text{BR}_{\gamma\gamma}$
$\sigma_{gg}\, \text{BR}_{ZZ} \to (5 \cdots 8)\, \sigma_{gg}\, \text{BR}_{ZZ}$



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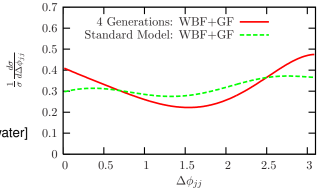
(3) misleading WBF correlations

(4) Higgs pair production the winner [Baur, TP, Rainwater]

$\Rightarrow$ if nothing else — what a great straw man!



Higgs couplings

Coupling extraction at the LHC [Zeppenfeld, Kinnunen, Nikitenko, Richter-Was; Dührssen et al.]

– light Higgs around 120 GeV: 10 main channels ($\sigma \times BR$) [bb channel new]

– measurements: $GF : H \to ZZ, WW, \gamma\gamma$
$WBF : H \to ZZ, WW, \gamma\gamma, \tau\tau$
$VH : H \to b\bar{b}$ [Butterworth, Davison, Rubin, Salam]
$t\bar{t}H : H \to \gamma\gamma, WW, (b\bar{b})$... [TP, Salam, Spannowsky]

– parameters: couplings $W, Z, t, b, \tau, g, \gamma$ [plus masses]

– hope: cancel uncertainties

$(WBF : H \to WW)/(WBF : H \to \tau\tau)$
$(WBF : H \to WW)/(GF : H \to WW)$...

Alternative best-fit points and error bars [Dührssen, Lafaye, TP, Rauch, Zerwas]

– all couplings varied around SM values $g_{HXX} = g_{HXX}^{SM} \, (1 + \delta_{HXX})$

– $\delta_{HXX} \sim -2$ means sign flip [$g_{HWW} > 0$ fixed, only broken by loops]

– error bars for Standard Model hypothesis [smeared data point, 30fb^{-1}]

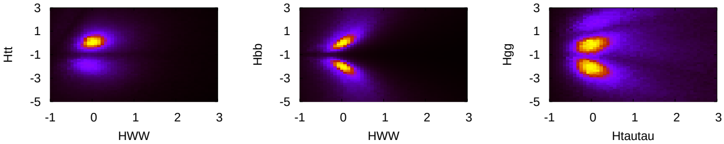
	σ_{symm}	σ_{neg}	σ_{pos}	σ_{symm}	σ_{neg}	σ_{pos}
δ_{WWH}	± 0.23	-0.21	$+0.26$	± 0.24	-0.21	$+0.27$
δ_{ZZH}	± 0.50	-0.74	$+0.30$	± 0.44	-0.65	$+0.24$
$\delta_{t\bar{t}H}$	± 0.41	-0.37	$+0.45$	± 0.53	-0.65	$+0.43$
$\delta_{b\bar{b}H}$	± 0.45	-0.33	$+0.56$	± 0.44	-0.30	$+0.59$
$\delta_{\tau\bar{\tau}H}$	± 0.33	-0.21	$+0.46$	± 0.31	-0.19	$+0.46$
$\delta_{\gamma\gamma H}$	—	—	—	± 0.31	-0.30	$+0.33$
δ_{ggH}	—	—	—	± 0.61	-0.59	$+0.62$

SFitter — Higgs couplings at LHC

Two-dimensional correlations and effective coupings

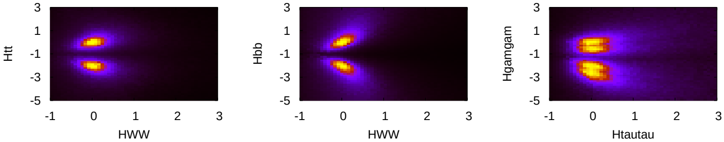
(1) including effective g_{Hgg}

- sign of g_{Htt} fixed, correlated to g_{HWW} on other branch
- correlation of g_{Hbb} and g_{HWW} [loops and width]
- effective coupling g_{Hgg} accessible



(2) including effective $g_{H\gamma\gamma}$

- correlation of g_{Htt} and g_{HWW} on both branches
- still correlation of g_{Hbb} and g_{HWW} [width]
- effective coupling $g_{H\gamma\gamma}$ more complex



A fourth generation at the LHC

– it's fun
– it's not ruled out
– it has many interesting faces