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NEW PHYSICS AT THE TOP

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1. $\sin^2\theta_W$, m_H and the forward-backward b-asymmetry.
2. New Heavy Quarks: Beautiful Mirrors
3. Phenomenological Consequences: Higgs Physics
4. New Physics in the Tevatron top sample
5. Unification of Couplings and Proton Decay

Based on work done with D. Choudhury and T. Tait,
Phys. Rev. D65:053002,2002; and
with D. Morrissey, Phys.Rev.D69:053001,2004.

Introduction

- The Standard Model presents an excellent description of all the available high energy collider data.
- There is no clear indication for new physics at the weak scale.
- Neutrino masses, can be incorporated via small Yukawa couplings or by new, lepton number violating, physics at very large scales.
- Probable hints for new physics have been recently indicated in $g_\mu - 2$ and the and the CP-violation angle β coming from measurements of the CP-asymmetries in $B \rightarrow \Phi K_S$.
- In both cases, the discrepancy with the SM predictions is small and there are theoretical and experimental issues that need to be clarified before a definitive conclusion may be reached.

Precision Electroweak Data

- Very good agreement between the Standard Model predictions and the measured value of electroweak observables, for a Higgs mass below 200 GeV.
- Oblique corrections to precision observables are logarithmically dependent on the Higgs mass.
- Fit to the data is improved for a Higgs mass of order 90 GeV, what suggest a Higgs with mass somewhat above the present direct limit, $m_H > 114$ GeV.
- Before reaching this conclusion, however, a critical analysis of the relevant observables used for the Higgs mass fit should be performed.
- Due to the accuracy in their measurements, hadron and lepton forward backward asymmetries measured at LEP play a very relevant role in the Higgs mass determination.

Higgs Mass Fit

- Hadron forward-backward asymmetries are dominated by the b-quark asymmetry.
- The agreement between the SM prediction for A^b_{FB} and the measured value has been, for several years, very poor.
- Right now,

$$A^b_{FB} = 0.0995 \pm 0.0017; \quad A^b_{FB}(SM) = 0.1039,$$

A 2.6 σ discrepancy.

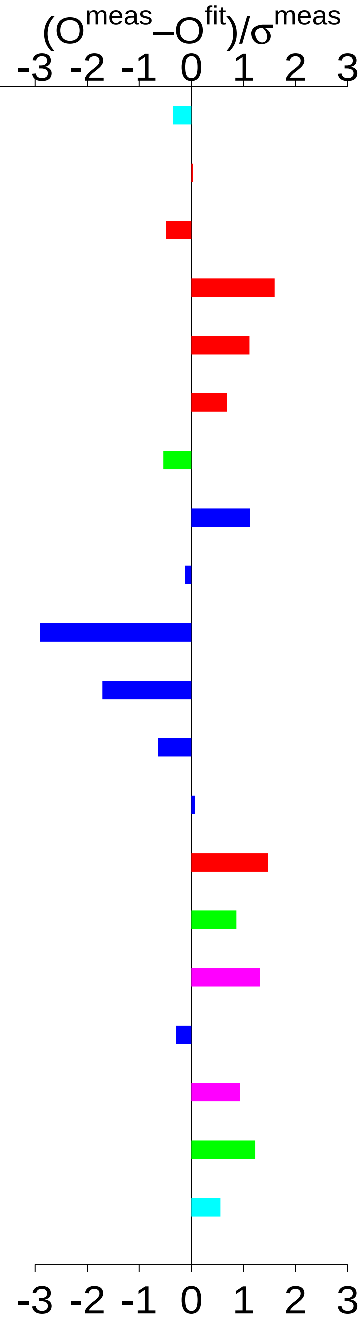
- On the other hand, a related quantity measured at SLC, A_b agrees within 1σ

$$A^b_{FB} = \frac{3}{4} A_b A_e$$

- Therefore, by itself, A^b_{FB} raises no significant concern, Systematics errors or statistical fluctuations may explain the difference. No clear indication of New Physics.

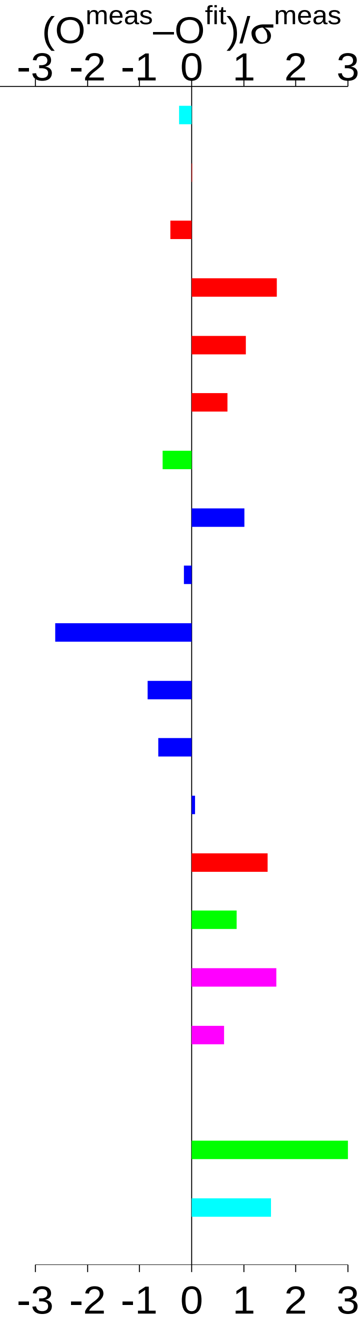
Summer 2001

	Measurement	Pull
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02761 ± 0.00036	-.35
m_Z [GeV]	91.1875 ± 0.0021	.03
Γ_Z [GeV]	2.4952 ± 0.0023	-.48
σ^0_{had} [nb]	41.540 ± 0.037	1.60
R_l	20.767 ± 0.025	1.11
$A^{0,l}_{fb}$	0.01714 ± 0.00095	.69
$A_l(P_\tau)$	0.1465 ± 0.0033	-.54
R_b	0.21646 ± 0.00065	1.12
R_c	0.1719 ± 0.0031	-.12
$A^{0,b}_{fb}$	0.0990 ± 0.0017	-2.90
$A^{0,c}_{fb}$	0.0685 ± 0.0034	-1.71
A_b	0.922 ± 0.020	-.64
A_c	0.670 ± 0.026	.06
A_l(SLD)	0.1513 ± 0.0021	1.47
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	.86
$m_W^{(LEP)}$ [GeV]	80.450 ± 0.039	1.32
m_t [GeV]	174.3 ± 5.1	-.30
$m_W^{(TEV)}$ [GeV]	80.454 ± 0.060	.93
$\sin^2\theta_W(\nu N)$	0.2255 ± 0.0021	1.22
$Q_W(Cs)$	-72.50 ± 0.70	.56



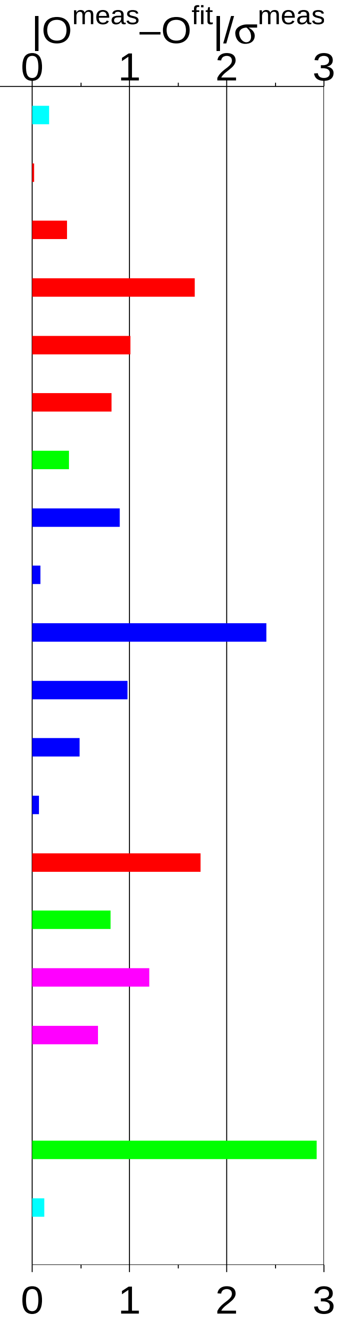
Summer 2002

	Measurement	Pull
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02761 ± 0.00036	-0.24
m_Z [GeV]	91.1875 ± 0.0021	0.00
Γ_Z [GeV]	2.4952 ± 0.0023	-0.41
σ^0_{had} [nb]	41.540 ± 0.037	1.63
R_l	20.767 ± 0.025	1.04
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.68
$A_l(P_\tau)$	0.1465 ± 0.0032	-0.55
R_b	0.21644 ± 0.00065	1.01
R_c	0.1718 ± 0.0031	-0.15
$A^{0,b}_{fb}$	0.0995 ± 0.0017	-2.62
$A^{0,c}_{fb}$	0.0713 ± 0.0036	-0.84
A_b	0.922 ± 0.020	-0.64
A_c	0.670 ± 0.026	0.06
A_l(SLD)	0.1513 ± 0.0021	1.46
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.87
m_W [GeV]	80.449 ± 0.034	1.62
Γ_W [GeV]	2.136 ± 0.069	0.62
m_t [GeV]	174.3 ± 5.1	0.00
$\sin^2\theta_W(\nu N)$	0.2277 ± 0.0016	3.00
$Q_W(Cs)$	-72.18 ± 0.46	1.52

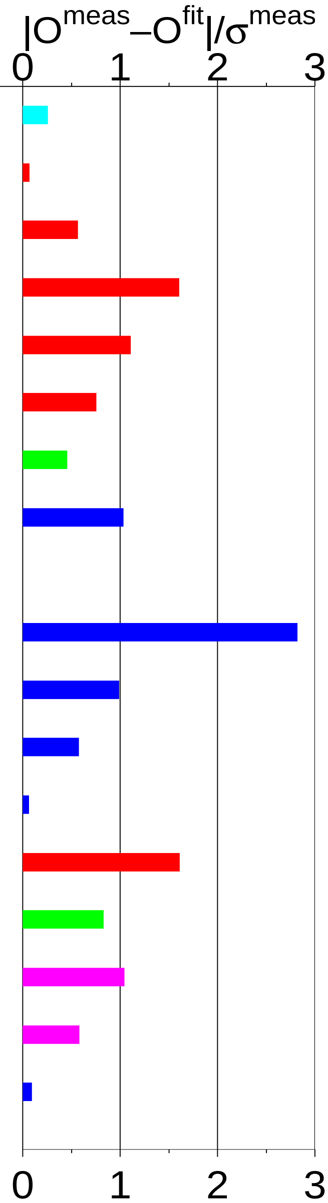


Summer 2003

	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02761 ± 0.00036	0.02767
m_Z [GeV]	91.1875 ± 0.0021	91.1875
Γ_Z [GeV]	2.4952 ± 0.0023	2.4960
σ^0_{had} [nb]	41.540 ± 0.037	41.478
R_l	20.767 ± 0.025	20.742
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01636
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1477
R_b	0.21638 ± 0.00066	0.21579
R_c	0.1720 ± 0.0030	0.1723
$A^{0,b}_{fb}$	0.0997 ± 0.0016	0.1036
$A^{0,c}_{fb}$	0.0706 ± 0.0035	0.0740
A_b	0.925 ± 0.020	0.935
A_c	0.670 ± 0.026	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1477
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.426 ± 0.034	80.385
Γ_W [GeV]	2.139 ± 0.069	2.093
m_t [GeV]	174.3 ± 5.1	174.3
$\sin^2\theta_W(\nu N)$	0.2277 ± 0.0016	0.2229
Q_W(Cs)	-72.84 ± 0.46	-72.90

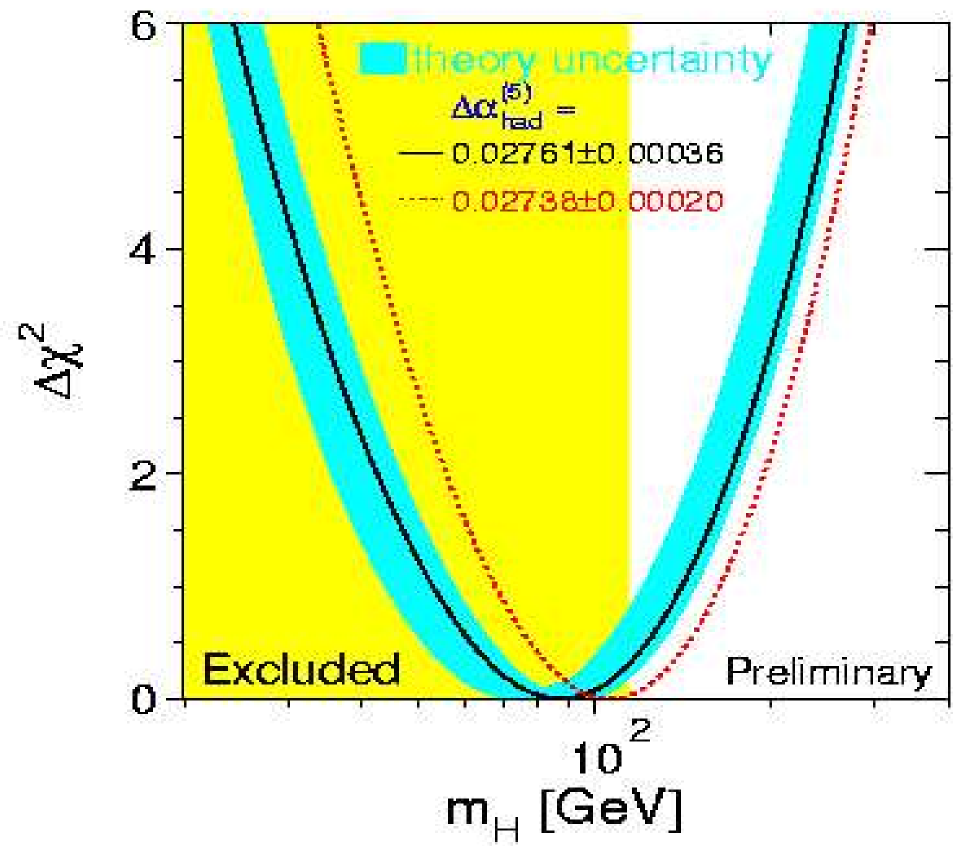


	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02761 ± 0.00036	0.02770
m_Z [GeV]	91.1875 ± 0.0021	91.1874
Γ_Z [GeV]	2.4952 ± 0.0023	2.4965
σ^0_{had} [nb]	41.540 ± 0.037	41.481
R_l	20.767 ± 0.025	20.739
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01642
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1480
R_b	0.21630 ± 0.00066	0.21562
R_c	0.1723 ± 0.0031	0.1723
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1037
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1480
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.425 ± 0.034	80.390
Γ_W [GeV]	2.133 ± 0.069	2.093
m_t [GeV]	178.0 ± 4.3	178.4



Precision EW Data: Fit to the Higgs Mass

From the LEPEWWG, www.cern.ch/LEPEWWG:



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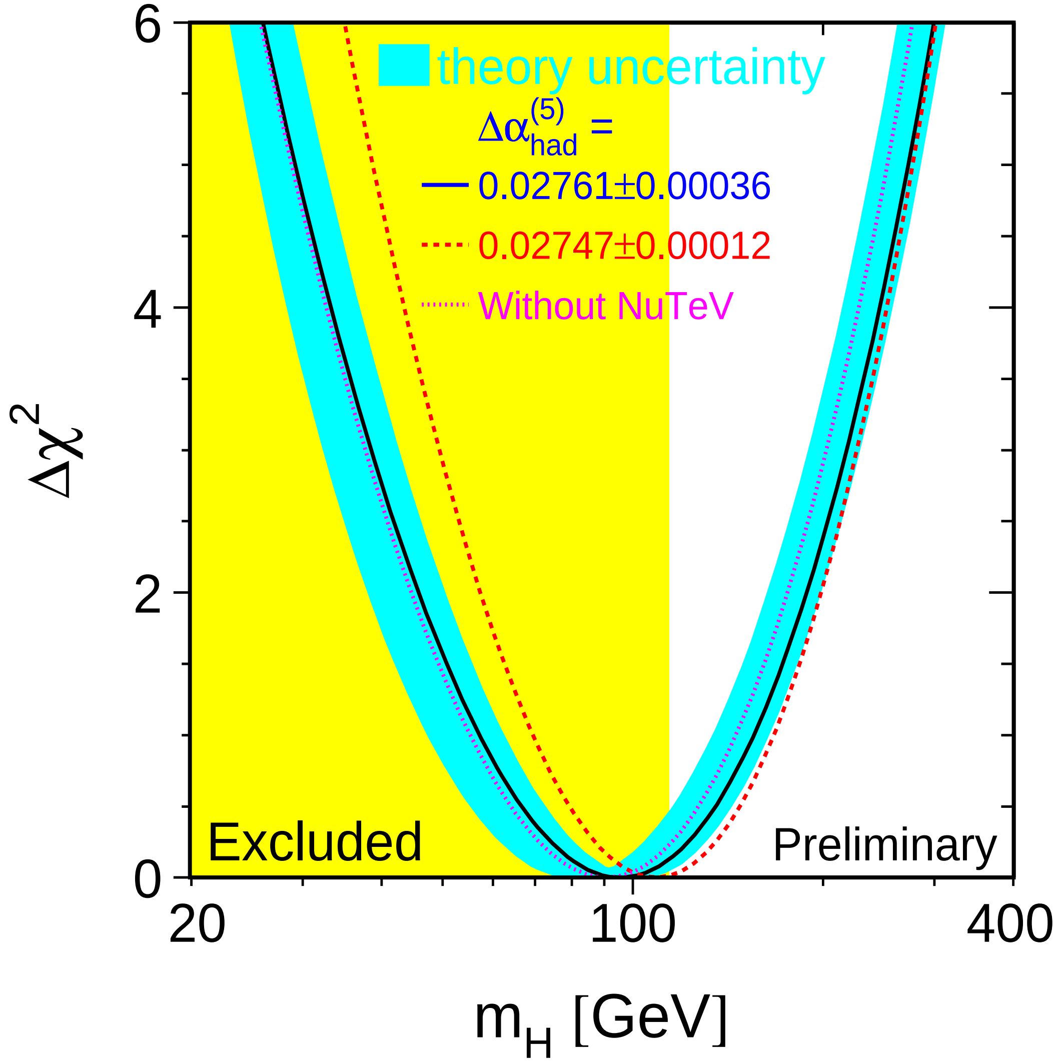


Higgs Mass Fit: The Problem

The effective weak mixing angle plays an important role in the Higgs mass determination. But hadronic and leptonic asymmetries disagree. What happens if we ignore the hadronic asymmetries,

$$\sin^2\theta_W^{\rm eff}\Big|_{\rm hadronic} = 0.23240 \pm 0.00029$$

and consider only

$$\sin^2\theta_W^{\rm eff}\Big|_{\rm leptonic} = 0.23114 \pm 0.00020\,?$$

- The EW-best fit value of m_H is close to the direct lower bound. Now it is pushed to lower values (approximately $m_H \simeq 50$ GeV).
- Most of the region allowed by direct searches would be excluded at the 90 $\%$ C.L. New physics ?
- Evidence for a light Higgs boson is weakened by this fact.
- M.S. Chanowitz, hep-ph/010402

New Physics impact on Zbb couplings.

A^b_{FB} deviation implies different values of the b-quark coupling to the Z gauge boson. The effective $Zb\bar{b}$ vertex :

$$\mathcal{L}_{Zb\bar{b}} = \frac{-e}{s_W c_W} Z_\mu \bar{b} \gamma^\mu \left[\bar{g}^b_L P_L + \bar{g}^b_R P_R \right] b$$

where $s_W \equiv \sin\theta_W$, $c_W \equiv \cos\theta_W$.

At LEP:

$$R_b \equiv \frac{\Gamma(Z \to b\bar{b})}{\Gamma(Z \to \text{hadrons})} \simeq \frac{(\bar{g}^b_L)^2 + (\bar{g}^b_R)^2}{\sum_q [(\bar{g}^q_L)^2 + (\bar{g}^q_R)^2]}$$

$$A_b \simeq \frac{(\bar{g}^b_L)^2 - (\bar{g}^b_R)^2}{(\bar{g}^b_L)^2 + (\bar{g}^b_R)^2}$$

$$A_\ell \simeq \frac{(g^\ell_L)^2 - (g^\ell_R)^2}{(g^\ell_L)^2 + (g^\ell_R)^2}.$$

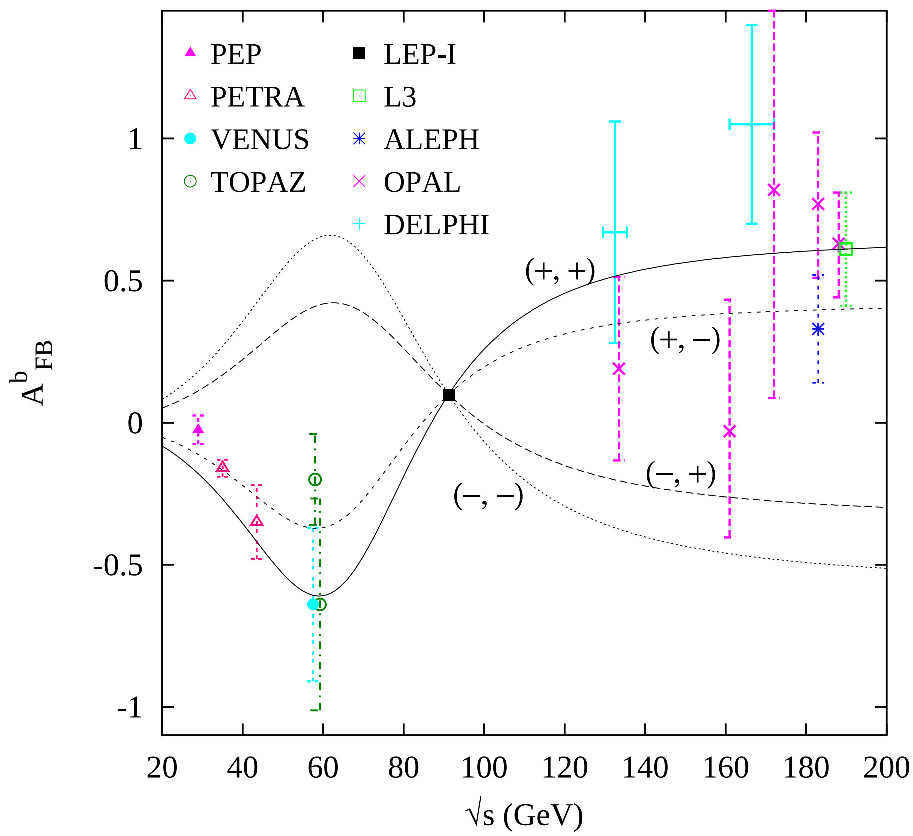
The solutions intersect at *four* points :

$$(\bar{g}^b_L, \bar{g}^b_R) \approx (\pm 0.992\, g^b_L(SM), \pm 1.26\, g^b_R(SM)) \,,$$

Langacker and Erler, Haber and Logan '99.

Information about the b-couplings

No experiment performed at the Z-peak can reduce the degeneracy any further. Off Z-peak : γ-mediated diagram becomes important.



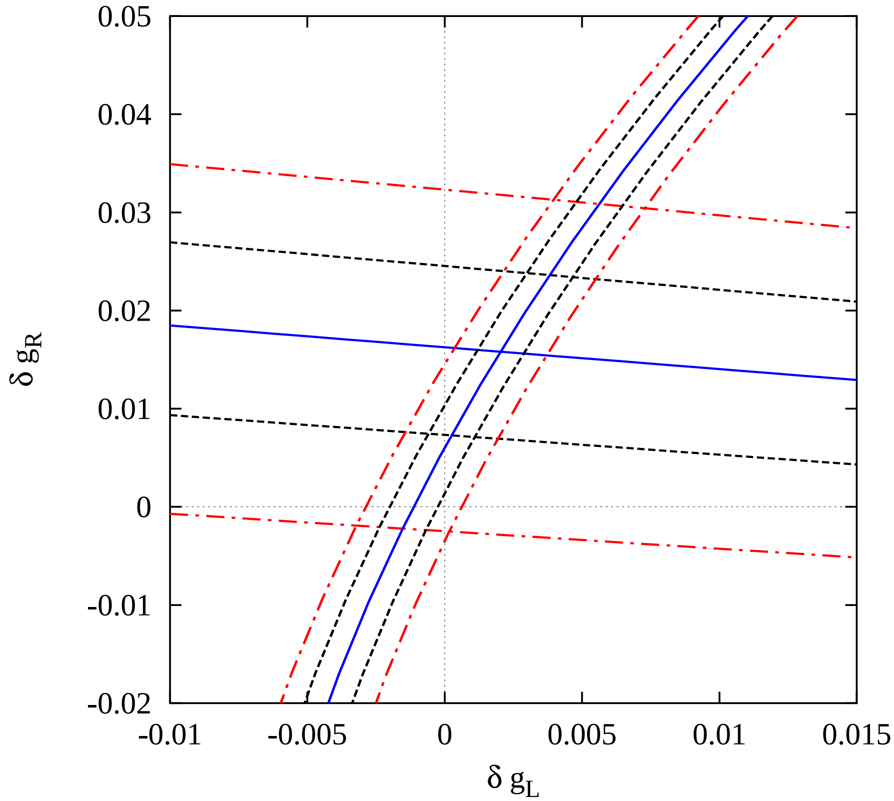
$\bar{g}_L^b \approx -g_L^b(SM)$: disallowed.

$\bar{g}_R^b \approx \pm 1.26\, g_R^b(SM)$: High-energy data inconclusive. However, measurements at LEP, 2 GeV away from Z-peak show preference towards equal sign (sign reversal is 2 σ away). Low-energy data, instead, prefers sign reversal!!

Resolution of the A_{FB}^{b} anomaly

$$g_f = T_3^f - Q \sin^2\theta_W,$$

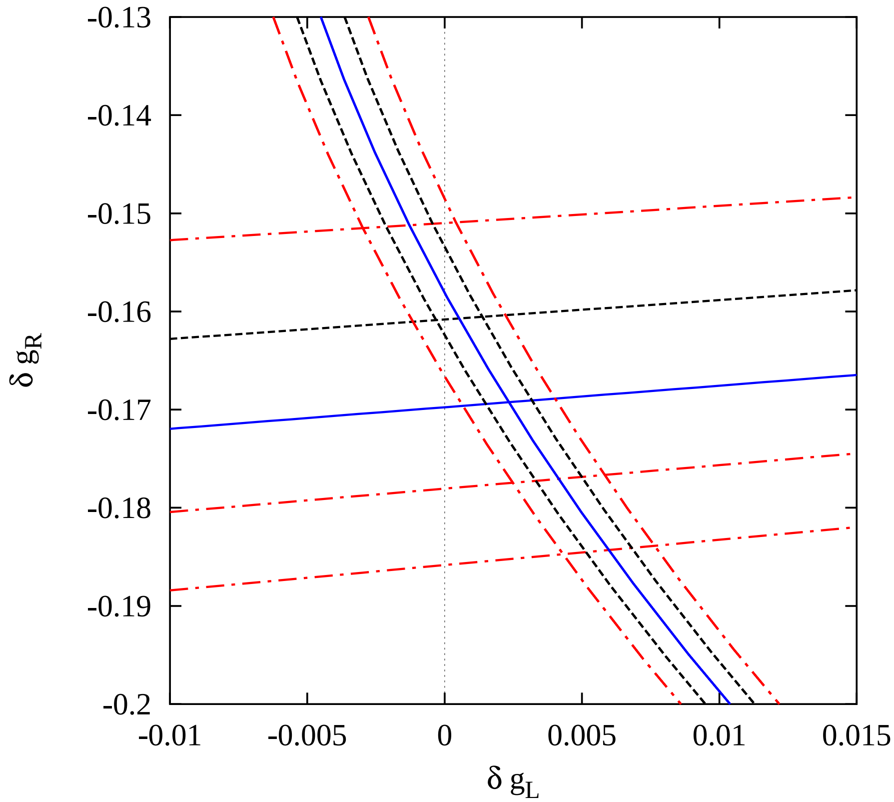
$$g_R \simeq 1/12, \qquad g_L \simeq -5/12$$



Where we have chosen

$$\frac{\delta g_R}{g_R} > 0$$

Resolution of the A_{FB}^b anomaly II.



where we have chosen

$$\frac{\delta g_R}{g_R} < 0$$

Since $g_R \simeq 0.077$ and $g_L \simeq 0.42$,

$$|\delta g_R / g_R| \gg |\delta g_L / g_L|$$

Beautiful Mirrors

Suppose there exists a charge $-1/3$ quark that mixes with b but not (significantly) with d, s.

Mass matrix :

$$\mathcal{L}_{m_b} = -\sum_{ij} \bar{b}'_{iL} M_{ij} b'_{jR} + \text{h.c.}, \quad M \equiv \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix}$$

b'_1 : ordinary b-quark.
b'_2 : exotic b-quark.

Mixing matrices for the left- and right-handed quarks : diagonalization matrices for $MM^\dagger$ and $M^\dagger M$ respectively.
$\Longrightarrow$ physical states $b_{1,2}$

Note : b'_2 need not have same $SU(2) \otimes U(1)_Y$ quantum numbers.
$\Longrightarrow$ non-trivial structure for gauge currents.

Bottom-quark weak neutral Current :

Third component of the isospin : $t_{3L(R)}$

$$J^3_\mu \quad (b) \quad = \frac{e}{s_W c_W} \sum_{ij} \bar{b}_i \gamma_\mu (L_{ij} P_L + R_{ij} P_R) b_j \ ,$$

$$L \quad \equiv \quad \begin{pmatrix} t_{3L} s_L^2 - \frac{1}{2} c_L^2 & -\left(t_{3L} + \frac{1}{2}\right) s_L c_L \\ -\left(t_{3L} + \frac{1}{2}\right) s_L c_L & t_{3L} c_L^2 - \frac{1}{2} s_L^2 \end{pmatrix}$$

$$R \quad \equiv \quad \begin{pmatrix} t_{3R} s_R^2 & -t_{3R} s_R c_R \\ -t_{3R} s_R c_R & t_{3R} c_R^2 \end{pmatrix}$$

- Flavour changing neutral currents
- $\delta g_L^b = \left(t_{3L} + \frac{1}{2}\right) s_L^2 \ , \qquad \delta g_R^b = t_{3R} s_R^2 \ ,$
- Right handed component of the exotic cannot be a $SU(2)_L$ singlet.

Possible Quark Represenations

In principle, b'_L and b'_R : any (and inequivalent) representation.

- Anomaly cancellation: vector-like assignment most economic choice.
- Also vector-like fermions $\Longrightarrow$ relatively small contribution to the oblique electroweak parameter S.
- Nonzero mass terms connecting ordinary b with exotic necessary.
- Demand: electroweak symmetry breaking only through $SU(2)$ doublet Higgs boson $\Longrightarrow$ Choice for the exotic limited to a $SU(2)$ singlet and two varieties each of $SU(2)$ doublets and triplets.
- $t_{3R} \neq 0$ eliminates the singlet and one of the triplets as source for δg_R^b.

Choices : $\Psi_{L,R} = (3, 2, 1/6)$, $(3, 2, -5/6)$ and $(3, 3, 2/3)$.

Standard Mirrors

$$\Psi^T_{L,R} = (\chi, \omega) \equiv (3, 2, 1/6)$$

Most general Yukawa and mass term :

$$\begin{aligned} \mathcal{L} \supset \quad & - \quad \left(y_1 \overline{Q'_L} + y_2 \overline{\Psi_L}\right) b'_R \phi - \left(x_1 \overline{Q'_L} + x_2 \overline{\Psi'_L}\right) t'_R \tilde{\phi} \\ & - \quad M_1 \overline{\Psi'_L} \Psi'_R + h.c., \end{aligned}$$

Ψ'_L and Q'_L have same quantum numbers : $\Longrightarrow \overline{Q'_L} \Psi_R$ can be trivially rotated away. In the basis (b', ω'), we then have a mass matrix of the form

$$M_b = \begin{pmatrix} Y_1 & 0 \\ Y_2 & M_1 \end{pmatrix}, \quad Y_i \equiv y_i \langle \phi \rangle$$

and an analogous one for the top.

Assume that the mass matrices are real.

$Y_1 \ll Y_2 < M_1$

$$\begin{aligned} m_b & \approx Y_1 / \sqrt{1 + \frac{Y_2^2}{M_1^2}}, & \tan \theta^b_R & \approx \frac{-Y_2}{M_1} \\ m_\omega & \approx \left(M_1^2 + Y_2^2\right)^{1/2}, & \tan \theta^b_L & \approx \frac{-Y_1 Y_2}{M_1^2 + Y_2^2}. \end{aligned}$$

- $\omega'_L \equiv b'_L$ and $\chi'_L \equiv t'_L$
  $\Longrightarrow$ gauge current in L-sector unmodified.

- FCNC's in both b_R and t_R sectors.

- $\delta g^b_R < 0$, (but $g^b_R(SM) > 0$)
  Large negative correction that takes us to the second allowed region in the parameter space. For example,

$$Y_2 \approx 0.7\, M_1 \quad \Longrightarrow \quad \delta g^b_R = \frac{-s^2_R}{2} \approx -0.165$$

  results in 1σ agreement for both A^b_{FB} A_b and R_b.

- Right-handed charged currents!
  $b \rightarrow s\gamma$ measurement requires $s^b_R s^t_R < 0.02$.
  Larios, Perez and Yuan ' 99

  Since the y's and x's are independent, could set $x_2 = 0$. $\Longrightarrow$ No mixing in top-sector and x_1 is the usual top Yukawa coupling.

- Tevatron limits on exotic quarks : $M_1 \gtrsim 200\ \mathrm{GeV}$.

Standard Mirrors

- Large mixing in the b-sector: Large corrections to parameters S, T and U. For $Y_2 \approx 0.7\, M_1$:
  $\Delta T(M_1 = 200 \text{ GeV}) = 0.35$,
  $\Delta T(M_1 = 250 \text{ GeV}) = 0.54$
  $\Delta S \simeq 0.1$ and increases slowly with M_1. ΔU small.

- Data $\Longrightarrow$ non-zero δg_L^b as well.
  Also large ΔT and g_R^b tend to increase Γ_{had} and Γ_{tot}.

- Solution: Introduce a $SU(2)$-singlet quark as well

$$\xi'_{R,L} \equiv (3, 1, -1/3)$$

Mass matrix modified. In the (b', ω', ξ') basis,

$$M_b = \begin{pmatrix} Y_1 & 0 & Y_3 \\ Y_2 & M_1 & 0 \\ 0 & 0 & M_2 \end{pmatrix}, \quad Y_i \equiv y_i \langle \phi \rangle$$

$(M_b)_{31}$: could be trivially rotated away. $(M_b)_{23}$ and $(M_b)_{32}$: minor effects if small.

- Left-handed mixing angle : $s_L \simeq \dfrac{Y_3}{\sqrt{Y_3^2 + M_2^2}}$,

$$\delta g_L^b = \frac{s_L^2}{2}$$

Hence, s_L (or Y_3) must be relatively small. Main effect of s_L : reduce Γ_b and thus $\Gamma_{\rm had} \Longrightarrow$ should improve fit.
Oblique corrections still dominated by b_R–ω_R mixing.
Precision observables have epsilon dependences:

$$\begin{aligned} \Gamma_Z &\simeq 2.489\,(1 + 1.35\,\epsilon_1 - 0.46\,\epsilon_3 + ...)\ \mathrm{GeV} \\ \sin^2\theta_l^{\rm eff} &\simeq 0.2310\,(1 + 1.88\,\epsilon_3 - 1.45\,\epsilon_1) \\ \frac{m_W^2}{m_Z^2} &\simeq 0.7689\,(1 + 1.43\,\epsilon_1 - \epsilon_2 - 0.86\,\epsilon_3)\,, \end{aligned}$$

$$\begin{aligned} \epsilon_1 &= \alpha T &&= 5.6 \times 10^{-3} \\ -\epsilon_2 &= \frac{\alpha U}{4 s_W^2} &&= 7.4 \times 10^{-3} \\ \epsilon_3 &= \frac{\alpha S}{4 s_W^2} &&= 5.4 \times 10^{-3} \end{aligned}$$

[Numbers for SM with $m_t = 174.3$ GeV and $m_H = 115$ GeV]

Additional dependence on $\alpha(M_Z)$ and $\alpha_s(M_Z)$, $\alpha(M_Z)$: $\Delta\alpha^{(5)}_{\rm had} = 0.02761$, $\alpha_s(M_Z)$: allowed to float around 0.118.

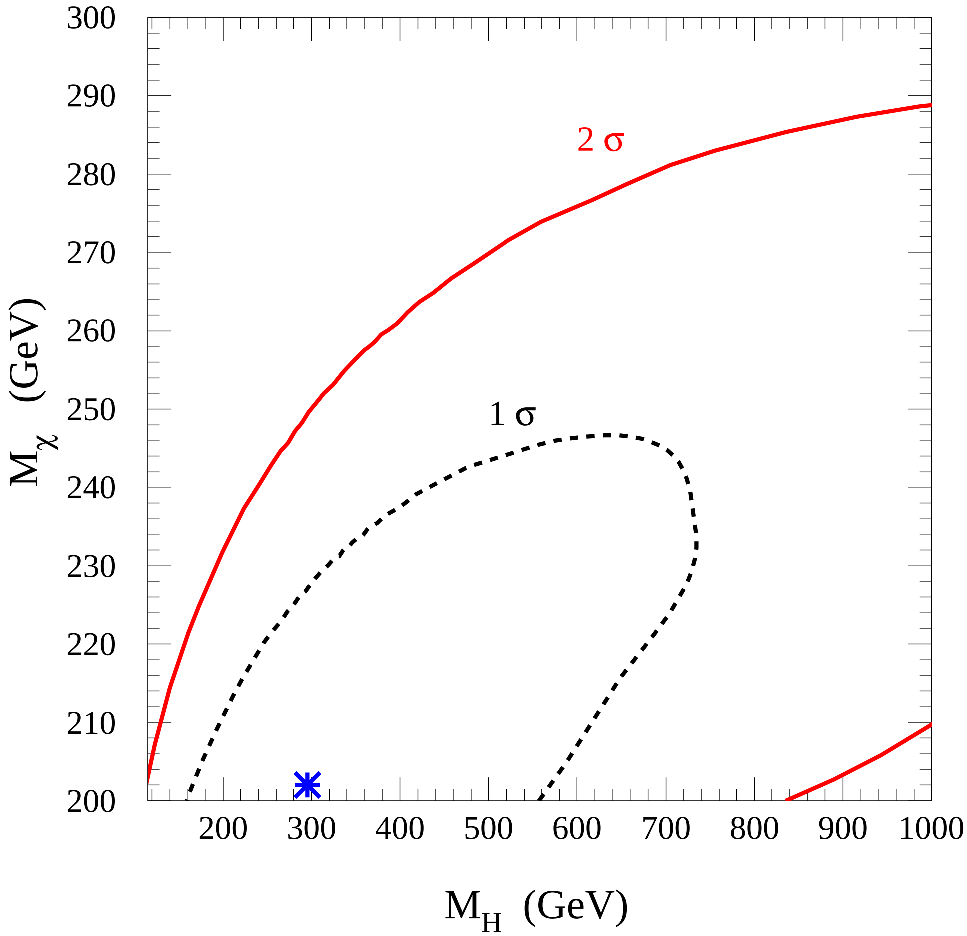
- Extra Quarks: Large positive corrections to $\epsilon_1 \equiv T$
- Heavy Higgs: Large negative corrections to ϵ_1. Positive ϵ_3 correction.
- Correlation between quark and Higgs masses.

Higgs and Quark Mass predictions : Standard Mirrors

$$M_1 = 200 \text{ GeV} \qquad Y_2 = 143 \text{ GeV}$$

$$m_H = 295.4 \text{ GeV} \qquad \sin^2\theta_L^b = 0.00811$$

$$\alpha_s(M_Z) = 0.118$$



Observable	Exp. Value	Best fit	Pull
Γ_Z	2.4952 ± 0.0023	2.49885	-1.59
R_ℓ	20.767 ± 0.025	20.7337	1.33
A_e	0.1465 ± 0.0033	0.14730	-0.24
A_ℓ^{FB}	0.01714 ± 0.00095	0.01627	0.91
σ_h	41.54 ± 0.037	41.482	1.56
R_b	0.21646 ± 0.00065	0.21597	0.76
R_c	0.1719 ± 0.0031	0.17225	-0.11
A_c^{FB}	0.0685 ± 0.0034	0.07375	-1.55
A_b	0.922 ± 0.02	0.9060	0.80
A_c	0.67 ± 0.026	0.6676	0.09
m_W/m_Z	0.778381 ± 0.00064	0.778397	-0.025
A_b^{FB}	0.099 ± 0.0017	0.100091	-0.64
$A_{LR}(SLD)$	0.1513 ± 0.0021	0.147297	1.91
M_t	174.3 ± 5.1	172.667	0.32
$CW(Ces)$	-72.5 ± 0.7	-73.2261	1.04

Top-less Mirror Quark Doublets

$$\Psi^T_{L,R} = (\omega, \chi) \equiv (3, 2, -5/6), \qquad \xi^T_{L,R} \equiv (3, 1, -1/3)$$

Mass matrix [basis (b', ω', ξ')] similar to the earlier one.

$$M_b = \begin{pmatrix} Y_1 & 0 & Y_L \\ Y_R & M_1 & 0 \\ 0 & 0 & M_2 \end{pmatrix}, \quad Y_i \equiv y_i \langle \phi \rangle$$

$(M_b)_{12}$: prevented by gauge inv, $(M_b)_{31}$: can be rotated away, $(M_b)_{23}$ and $(M_b)_{32}$: minor effects

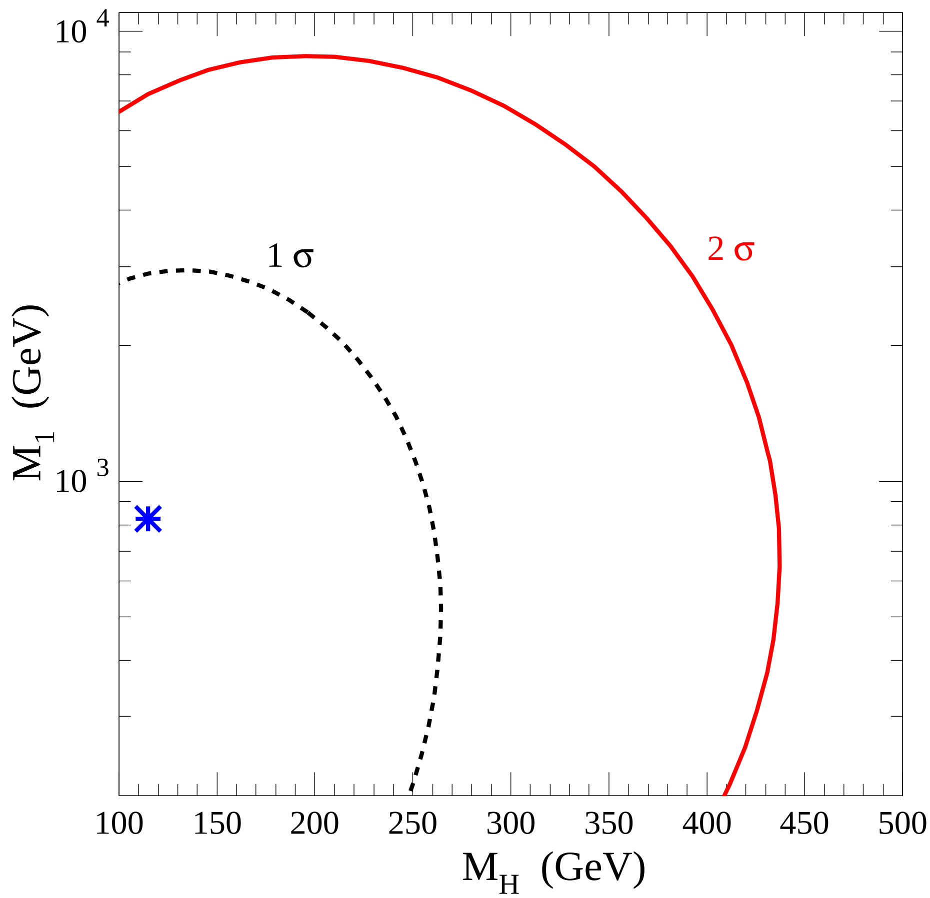
$$s_L \simeq \frac{Y_L}{\sqrt{Y_L^2 + M_2^2}} \qquad s_R \simeq \frac{Y_R}{\sqrt{Y_R^2 + M_1^2}}$$

$$\delta g_L^b = \frac{s_L^2}{2} \qquad \delta g_R^b = +\frac{s_R^2}{2}$$

- Positive $\delta g_R^b \Longrightarrow$ small s_R.
- EW symmetry breaking terms $\ll$ gauge inv masses.
  $\Longrightarrow$ Small corrections to S, T, U
- But, larger corrections needed for m_H to be in the experimentally allowed range: Heavy exotics (doublets) while light Higgs.

Best fi t : Top-less Mirrors

$$M_1 = 825 \text{ GeV} \qquad Y_R = 160 \text{ GeV}$$
$$m_H = 115 \text{ GeV} \qquad Y_L = 15 \text{ GeV}$$
$$\alpha_s(M_Z) = 0.116 \qquad M_t = 176.04 GeV$$



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σ_h	41.54 ± 0.037	41.482	1.56
R_b	0.21646 ± 0.00065	0.21613	0.50
R_c	0.1719 ± 0.0031	0.17225	-0.11
A_c^{FB}	0.0685 ± 0.0034	0.07451	-1.7
A_b	0.922 ± 0.02	0.9003	1.0
A_c	0.67 ± 0.026	0.6682	0.07
m_W/m_Z	0.778381 ± 0.00064	0.7778	0.92
A_b^{FB}	0.099 ± 0.0017	0.1004	-0.82
$A_{LR}(SLD)$	0.1513 ± 0.0021	0.148685	1.24
M_t	174.3 ± 5.1	176.046	-0.34
$CW(Ces)$	-72.5 ± 0.7	-73.1872	0.98

Higgs phenomenology

D. Morrisey, C. Wagner, hep-ph/0308001

- In the Standard Mirror case, if $m_H < m_\omega + m_b$, Higgs will preserve the Standard decay channels, but with a modified b-coupling:

$$\frac{g_{Hb\bar{b}}}{g_{Hb\bar{b}^{SM}}} = \cos^2\theta_R \tag{1}$$

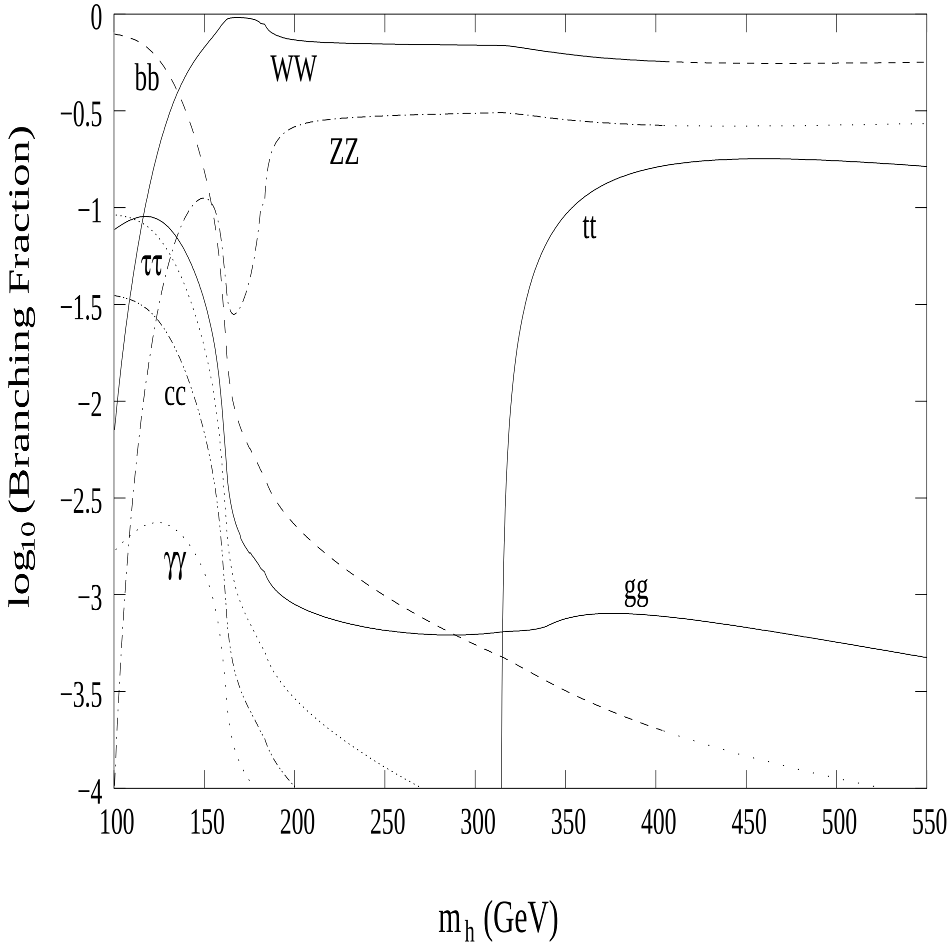
  Since $\tan\theta_R \simeq 0.7$, this leads to a reduction of order 2/3 with respect to the SM coupling. For a Higgs heavier than $2m_W$, this will have only a mild impact on phenomenology.

- Second important effect: The presence of new quarks with relevant coupling to the Higgs increase the effective $H \to g\ g$ coupling.

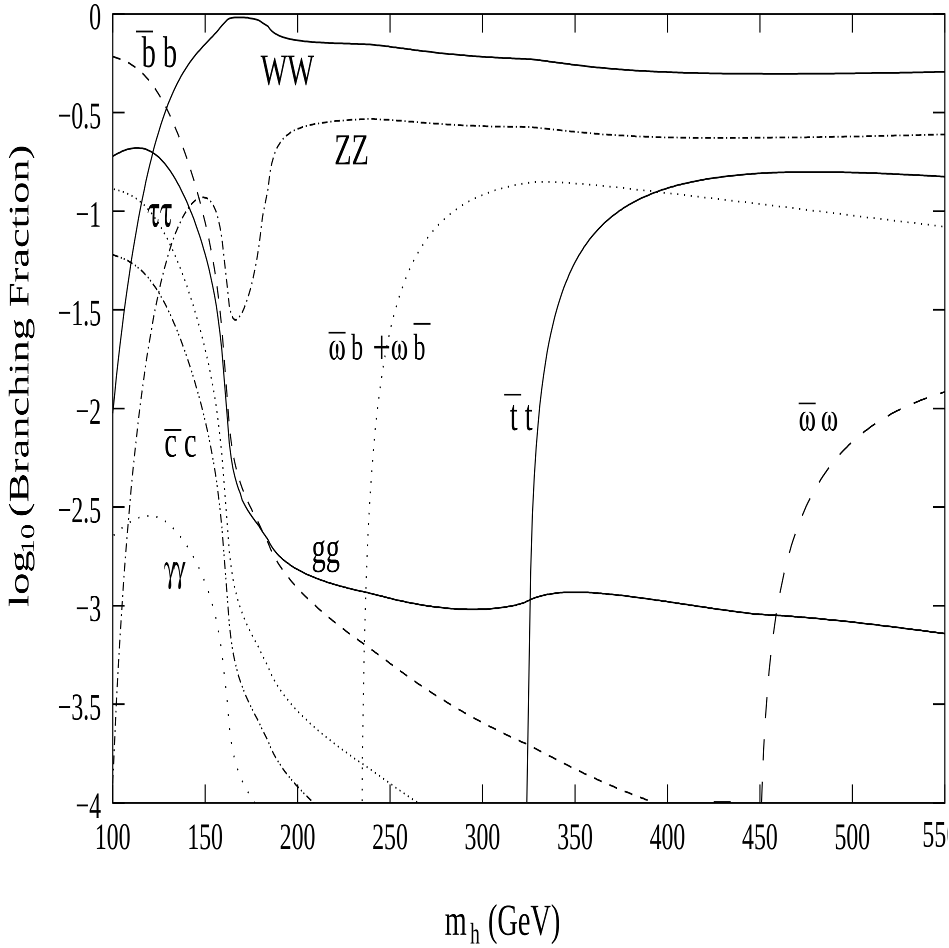
- $H \to \gamma\gamma$ coupling only slightly modified.

In the Top-less scenario, so far the quarks are heavy the Higgs boson carries standard phenomenology.

Higgs Branching Ratios in the Standard Model

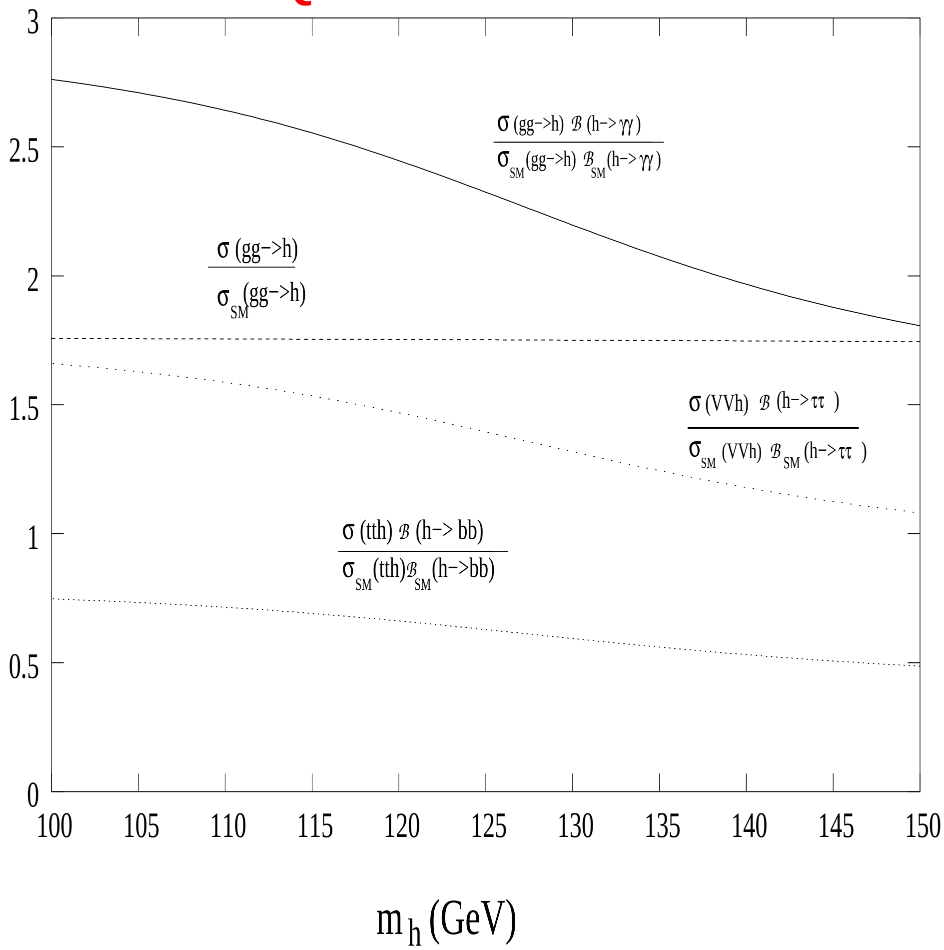


Higgs Branching Ratios in the Mirror Quark Model



- Relevant increase in $\tau\tau$ and $g\ g$ branching ratios.
- Suppression of the $b\bar{b}$ branching ratio.

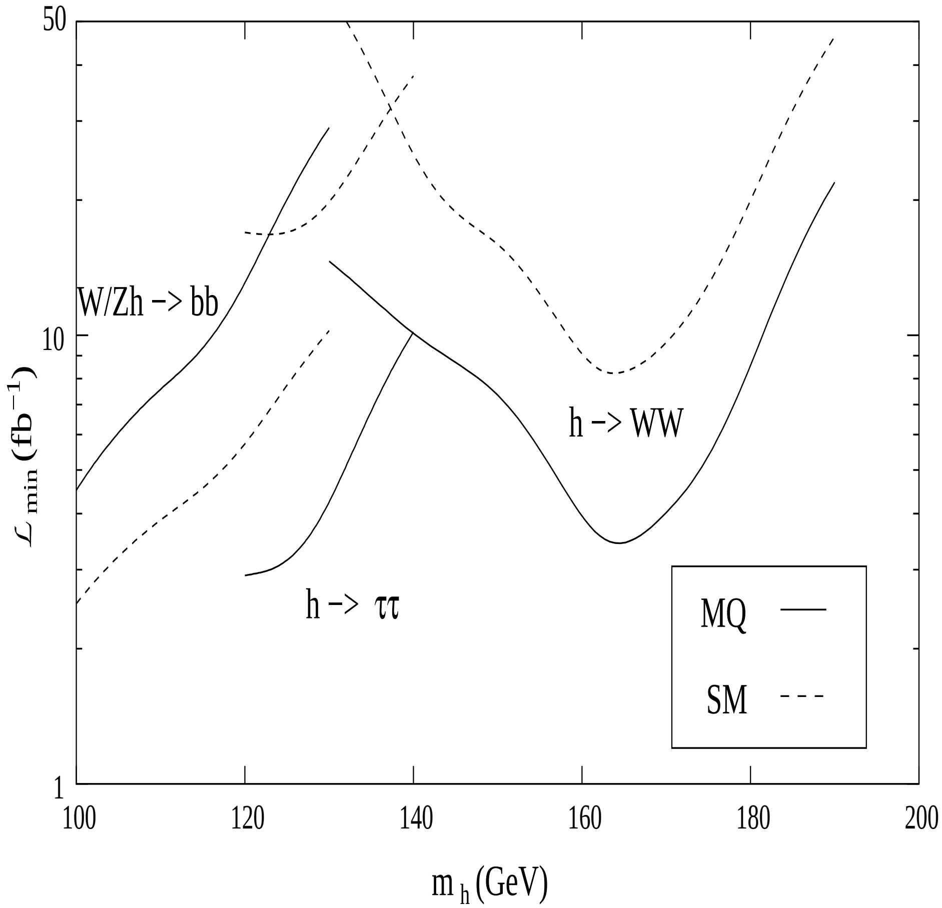
Relevant Higgs production rates: SM vs. Mirror Quark Model



Gluon fusion production, with $h \to \tau^+\tau^-$ may be inferred from above (VVh and $h\gamma\gamma$ couplings only slightly modified).

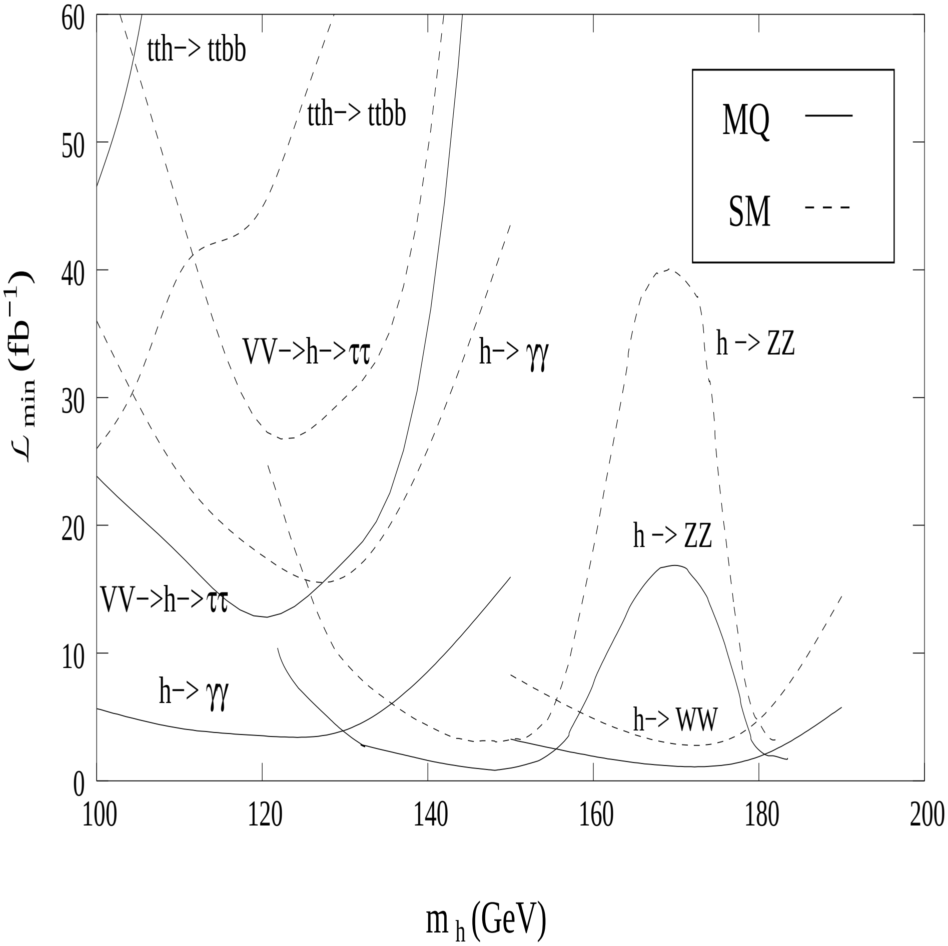
Higgs Searches at the Tevatron

Minimal luminosity for a 3-σ evidence of a Higgs.



- With 10 fb^{-1} of luminosity, a 3-sigma evidence is possible, up to Higgs masses of 180 GeV.
- The $\tau\tau$ channel is the most relevant one at low Higgs masses (Belyaev, Han and Rosenfeld, hep-ph/0204210)

Higgs Searches at the LHC



Significant improvement in all gluon fusion related channels.

Heavy Quark Collider Signatures:
New Physics at the Top

The lightest exotic quark in this model is the χ-quark. It decays overwhelmingly like a top quark:

$\chi \longrightarrow b + W^+$ (Usual t' search)

The χ should appear in the top sample, but with a reduce cross section and a higher reconstructed mass! Counting experiment: Present top quark cross section at the Tevatron is

$$\sigma_t = (6.1 \pm 1.1)\, pb \text{ (CDF and D0 average)}$$

comparable to the SM prediction $\sigma_t^{SM} = 5.8 \pm 0.4$ pb.

The Tevatron can rule out $m_\chi < 195$ GeV at the 2-σ level ($m_\omega \lesssim 245$ GeV).

At run II, 7% to 9% precision on σ_t expected, with a luminosity of a few fb^{-1}.

Tevatron run II is sensitive to χ-quarks with masses up to $m_\chi <$ 230 GeV.

More on χ-quark Decays

Contrary to the case of the top quark, the vertex

$$\chi \to bW$$

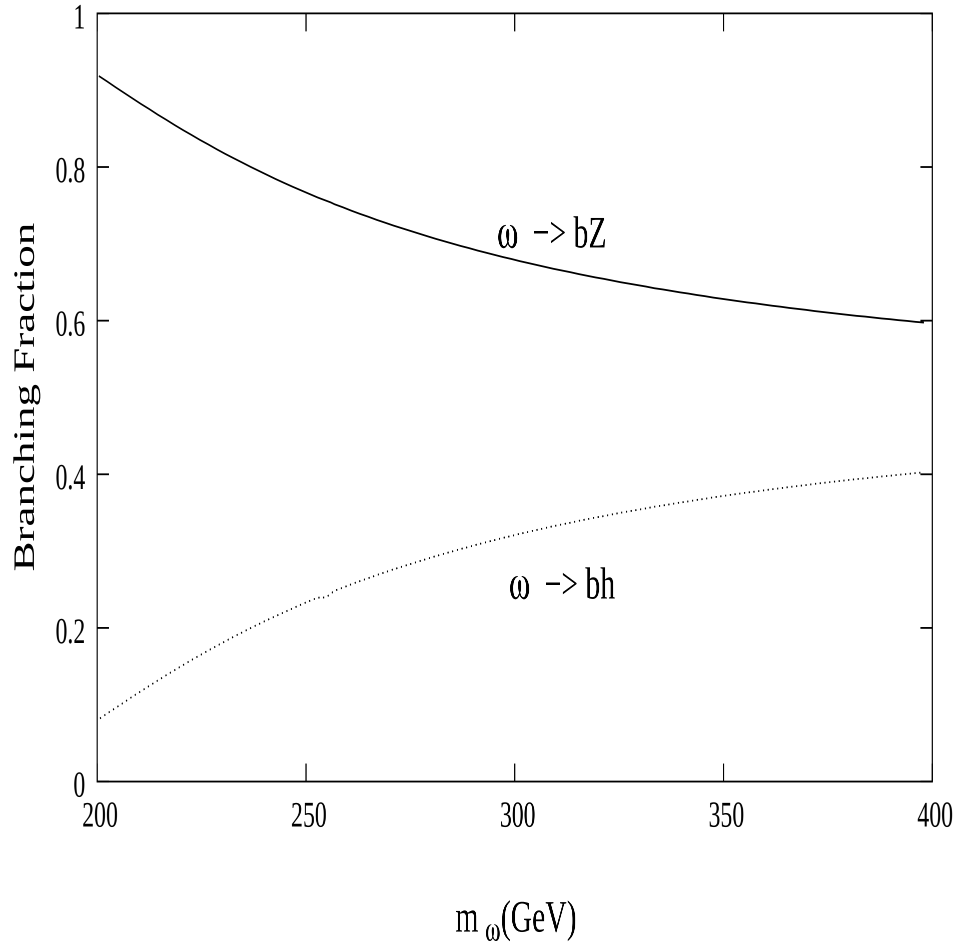
is (V+A). That makes the χ somewhat easier to find.

W^+ emitted from decaying χ's have positive or zero helicity, where those from top-quarks have negative or zero helicity. Most of the emitted W^+, however, are longitudinal.

The Tevatron experiments have looked for postivie helicity W's in top decays. An upper limit of the positive helicity fraction of order $\mathcal{F}_+ < 0.18$ at the 95% C.L. has been found by CDF.

The Standard Beautiful Mirror Model predicts a value $\mathcal{F} \simeq 0.08$–0.02 for a χ mass aboout 200–250 GeV.

Decays of the ω-quark



- If the Higgs mass is below 200 GeV, ω can decay into Higgs and bottom quarks.
- Decays into t-quark and W^- suppressed by kinematics and mixings
- Above example, for $m_H = 170$ GeV.

Searches for the quark ω

Run I : Exotic $b' \longrightarrow bZ$ must be heavier than 199 GeV.

If ω light enough (heavy Higgs), $\omega \longrightarrow b + Z$ dominant and the above bound is relevant.

For larger values of the ω mass, decays into a b-quark and a Higgs open up.

Considering the search for $\omega \longrightarrow Zb$, with one of the Z's decaying leptonically and the other hadronically, and similar efficiencies as in run I, and appropriate cuts, one obtains that run II may be able to test

$$m_\omega \lesssim 280 \text{ GeV}, \text{ for } \mathcal{L} = 2\text{fb}^{-1}$$

$$m_\omega \lesssim 300 \text{ GeV}, \text{ for } \mathcal{L} = 4\text{fb}^{-1}$$

More on Collider Signatures

In the Top-less model, the χ-quark signatures will be similar to that of the top quark, but decaying to a wrong sign W,

$$\chi \rightarrow \; b \; + \; W^-$$

The ω and χ signatures similar to the Standard Mirror case.

Although best fit prefers large masses, not accessible at the Tevatron, it does not exclude the presence of lighter masses of the order of the weak scale !

If quark masses of order of a few hundred GeV, only LHC is certain to find the new quarks.

FCNC: Although we have ignored it so far, the presence of non-trivial mixing with the first and second generations may lead to new physics effects. Under certain assumptions, may have an impact on $\sin 2\beta$ extracted from $B \rightarrow \Phi K_s$.

Unifi cation of Couplings: Standard Mirrors

In SM (for one Higgs doublet, $n_H = 1$), $\alpha_s(\mu)$ and $\alpha_2(\mu)$ meet at $\sim 10^{17}$ GeV.

But $\alpha_1(\mu)$ crosses them at a much lower scale.

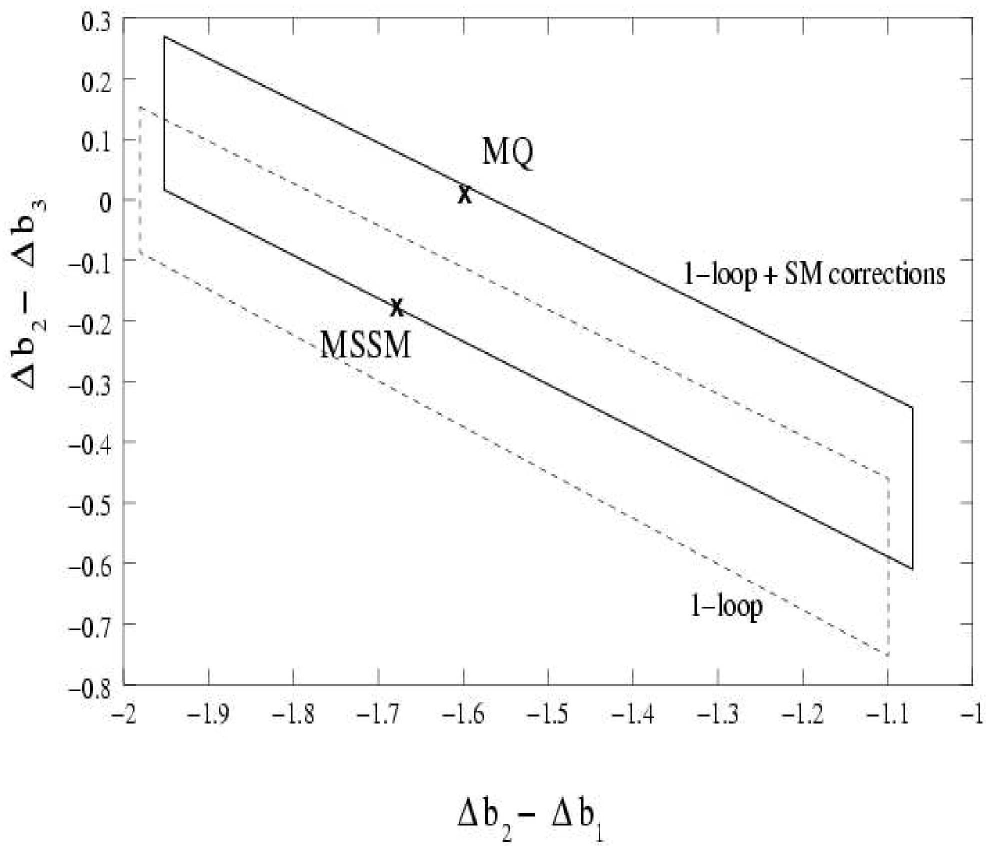
New physics may modify this situation. Notable example: Supersymmetry.

Standard Mirrors: We shall do a two-loop analysis. Will not take threshold effects into account. One-loop beta-function coefficients:

$$
\begin{aligned}
b_3 &= -11 + \frac{4}{3}n_g + 2 \\
b_2 &= \frac{-22}{3} + \frac{4}{3}n_g + \frac{n_H}{6} + 2 \\
b_1 &= \frac{4}{3}n_g + \frac{n_H}{10} + \frac{2}{5}
\end{aligned}
$$

where n_g is number of generations and n_H is number of Higgs doublets.

Necessary change of $\Delta b_i = b_i - b_i^{SM}$ to obtain Unification



These values should be compared with the contribution of a chiral fermion in the fundamental representation of $SU(N)$, $\Delta b_f = -1/3$.

Since $\delta b_1 < \delta b_2 = \delta b_3 \Longrightarrow \alpha_1$ crosses the others much later.

	Average M_{GUT}	Discrepancy
$n_H = 1$	5×10^{16} GeV	3%
$n_H = 2$	2×10^{16} GeV	1%

Small differences.

Two loop correctioins lead to improved unification for $n_H = 1$ model.

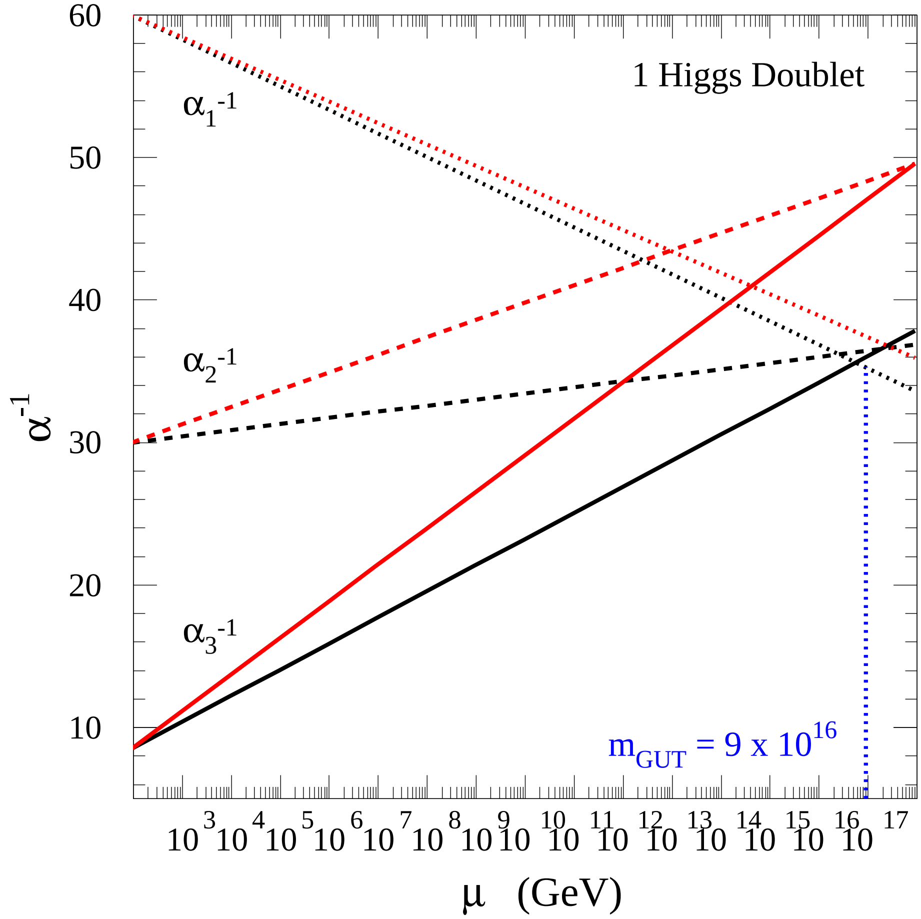
Predicted $\alpha_s(M_Z) = 0.118$.

D. Morrissey, C. Wagner, hep-ph/0308001

Proton decay:

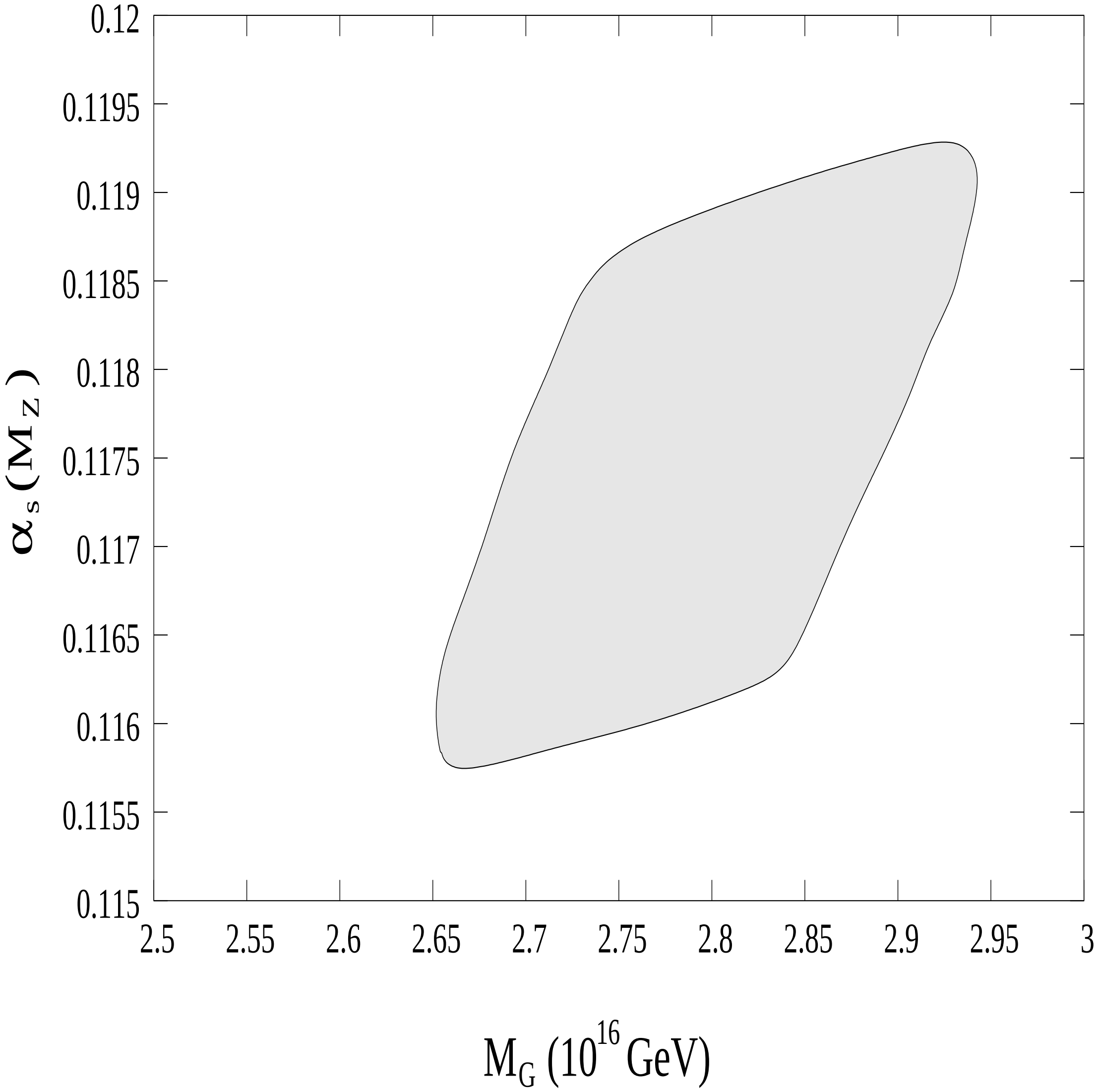
- No dimension five operators.
- Large M_{GUT} : dim-6 operators well suppressed.

Unifi cation in Standard Mirror Scenario with $n_H = 1$



Predicted values of $\alpha_s(M_Z)$ and M_G

Two loop predictions

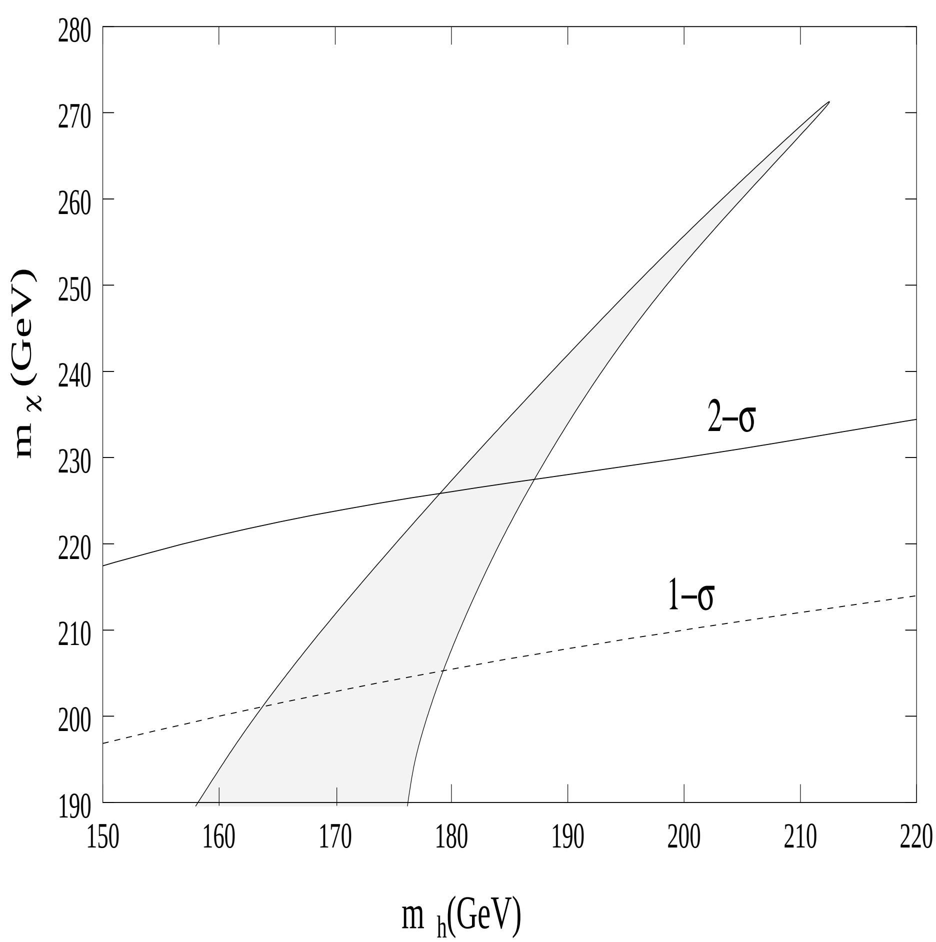


- Large values of the unification scale
- Perfect agreement with the measured value of $\alpha_s(M_Z)$.

Stability and Triviality Bounds

- Potential problem for Unification: Heavy Higgs $\Longrightarrow$ Landau pole well below M_{GUT}.

- As in the Standard Model, only limited region of Higgs mass values available.



- Small (large) overlap with region preferred by EW precision measurements at 1-σ (2-σ) level.

Proton Decay

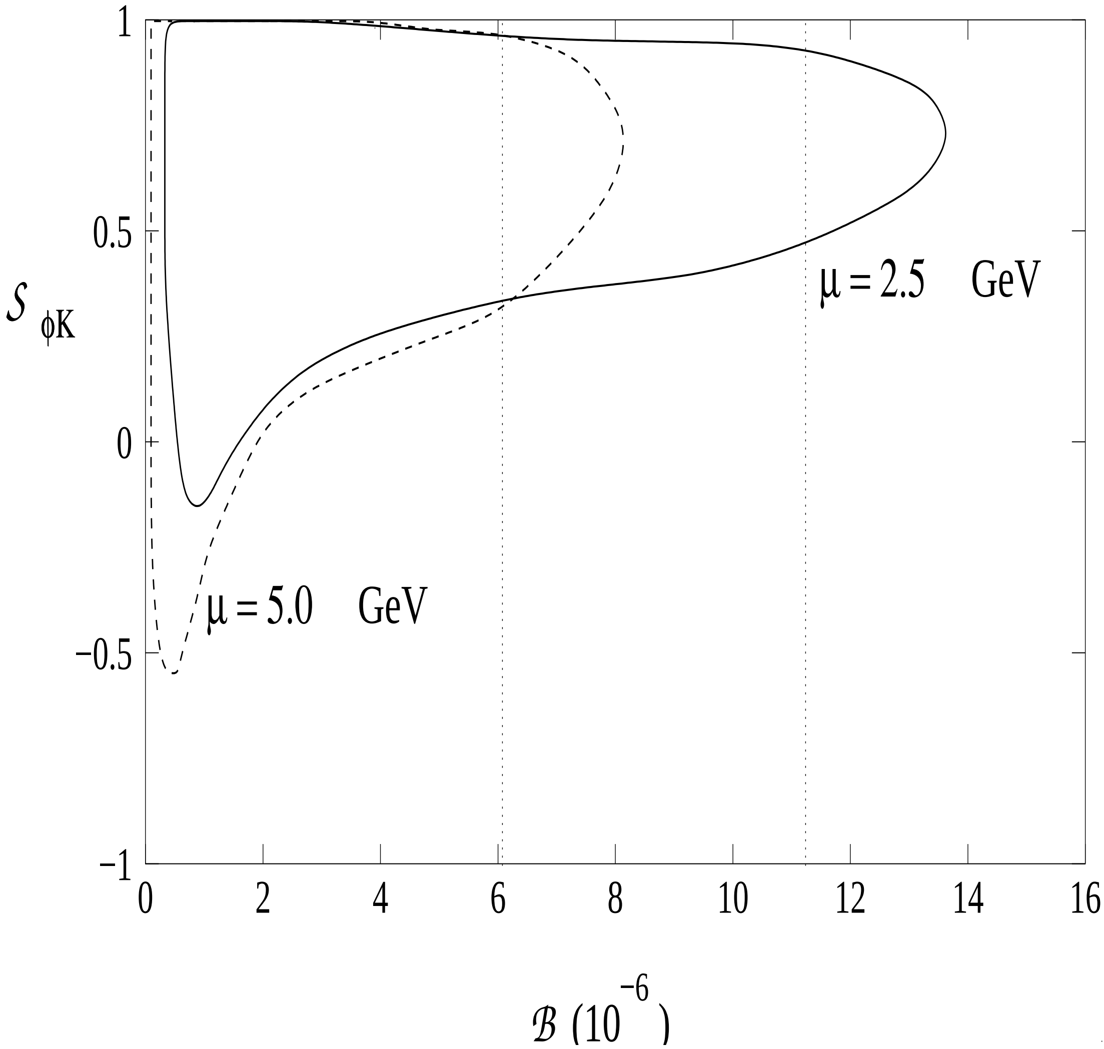
- Model provides consistency with unification of couplings at a large unification scale
- Contrary to the supersymmetric case, there are no dimension five operators induced
- Proton stability, then, improves dramatically in this model

$$\tau(p \to \pi^0 e^+) = 3 \times 10^{36 \pm 1} \text{ years}$$

well in excess of the Super-Kamiokande bound on $\tau(p \to \pi^0 e^+) = 5.3 \times 10^{33}$.
In the above, we have used $M_G = 2.8\ 10^{16}$ GeV and $\alpha_G^{-1} = 35.1$.

Predicted $\sin 2\beta$ for $B \to \Phi K_S$

Possible tree-level coupling of the Z to $\bar{s}_{L,R}\gamma^{\mu}b_{L,R}$.



Values restricted by semileptonic decays and by the $BR(B \to \Phi K_S)$.

Conclusions

- A^b_{FB} creates a problem in the SM fit to the precision electroweak data.
- New exotic quarks improve the fit, solving the $Zb_R\bar{b}_R$ coupling problem.
- Standard Beautiful Mirror Quarks: Imply light quarks and (may be) a relatively heavy Higgs.
- Top-less Mirror Quarks: Imply a light Higgs, with SM properties, and heavy quarks.
- Exciting New phenomenology at near future Colliders !
- Unification of Couplings at high scales with no proton decay achievable within the Beautiful Mirror Framework !

Unifi cation of Couplings : Top-less Model.

Higgs is light $\Longrightarrow$ No Landau-pole problem.

beta-function coefficients:

$$\begin{aligned} b_3 &= -11 + \frac{4}{3}n_g + 2 \\ b_2 &= \frac{-22}{3} + \frac{4}{3}n_g + \frac{n_H}{6} + 2 \\ b_1 &= \frac{4}{3}n_g + \frac{n_H}{10} + \frac{18}{5} \end{aligned}$$

$\delta b_1 > \delta b_2 = \delta b_3 \Longrightarrow \alpha_1$ crosses the others much earlier.

Unification problem worsened.

Note: doublets $\subset \mathbf{24}$, singlets $\subset \mathbf{5} + \bar{\mathbf{5}}$ of $SU(5)$.

(Everything in adjoint of $SU(6) \subset E_6$)

Complete the representations

(“ Gluino”, “ Wino”, “ Bino”) and “ Higgsino”

and we are back at the SM situation.

Unifi cation of Couplings: Hybrid Model

- Complete **24** of fermions at the weak scale, together with the standard mirror doublet and singlet quarks. (All these fields are contained in the adjoint of E_6.)
- b-quark mixes mainly with the top-less doublet (and singlet).
- Higgs tends to be light $\Longrightarrow$ No Landau-pole problem.
- Standard doublet: light but virtually no mixing with b.
- Unification of Couplings OK ! Not affected by complete representations.

  "Gaugino"-like fields: "Gluino": Unless new fields added, very long lived or even stable.

  "Wino", "Bino" : could mix with leptons $\Longrightarrow$ either a discrete symmetry (" R-Parity") or very small Yukawa's.
- Introduction of new Higgs doublet (slepton): correct coannihilation rate for "Bino" as a Dark Matter candidate.

Unifi cation in Hybrid Mirror Scenario with $n_H = 1$