Different G_F and $\sin^2\theta_W$ for Different Processes

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* Natural extension of Standard Model

$\Rightarrow$

$$(G_F)^{NC}_{\ell q} \lesssim (G_F)^{CC}_{\ell q} \lesssim (G_F)^{CC}_{\ell\ell} \lesssim (G_F)^{NC}_{\ell\ell}$$

and $(\sin^2\theta_W)_{\ell q} \neq (\sin^2\theta_W)_{\ell\ell}$

* Z pole data are also affected

Ref. X. Li & E. Ma, hep-ph/0212029.

Standard Model

2 electroweak gauge couplings : g, g'

2 weak gauge bosons : $W^\pm, Z^0$

1 vac. exp. value : v

$$\frac{4G_F^{CC}}{\sqrt{2}} = \frac{\frac{1}{2}g^2}{\frac{1}{2}g^2v^2} = \frac{1}{v^2},$$

$$\frac{4G_F^{NC}}{\sqrt{2}} = \frac{\frac{1}{2}(g^2+g'^2)}{\frac{1}{2}(g^2+g'^2)v^2} = \frac{1}{v^2},$$

$$\sin^2\theta_W = \frac{g'^2}{g^2+g'^2}, \quad s_0^2(1-s_0^2) = \frac{\pi\alpha(M_Z)}{\sqrt{2}G_F M_Z^2},$$

$$\Gamma_{Z\to\ell\bar{\ell}} = \frac{G_F M_Z^3}{24\sqrt{2}\pi}\left(1+\frac{3\alpha}{4\pi}\right)\rho_\ell\left[1+(1-4\sin^2\theta_\ell)^2\right]$$

This Model

4 electroweak gauge couplings : $g_{1,2,3,4}$

5 weak gauge bosons : $W^{\pm}_{1,2}$, $Z^0_{1,2,3}$

4 vev's : $v_{1,2}$, u, w

$$\left.\frac{4G_F^{CC}}{\sqrt{2}}\right|_{\ell\ell} = \frac{u^2+v_1^2}{(v_1^2+v_2^2)u^2+v_1^2v_2^2}, \quad [\mu \to e\nu\bar{\nu}]$$

$$\left.\frac{4G_F^{CC}}{\sqrt{2}}\right|_{\ell q} = \frac{u^2}{(v_1^2+v_2^2)u^2+v_1^2v_2^2}, \quad [n \to pe\bar{\nu}]$$

$$\left.\frac{4G_F^{NC}}{\sqrt{2}}\right|_{\ell\ell} = \frac{u^2w^2+v_1^2(u^2+w^2)}{(v_1^2+v_2^2)u^2w^2+v_1^2v_2^2(u^2+w^2)}, \quad [\nu_\mu e \to \nu_\mu e]$$

$$\left.\frac{4G_F^{NC}}{\sqrt{2}}\right|_{\ell q} = \frac{u^2w^2}{(v_1^2+v_2^2)u^2w^2+v_1^2v_2^2(u^2+w^2)}, \quad [\nu_\mu q \to \nu_\mu q]$$

* All G_F's are independent of $g_{1,2,3,4}$.

* All G_F's are equal in the limit $v_{1,2}^2 \ll u^2, w^2$, but otherwise

$$(G_F)^{NC}_{\ell q} < (G_F)^{CC}_{\ell q} < (G_F)^{CC}_{\ell\ell} < (G_F)^{NC}_{\ell\ell}$$

$$\underbrace{1 - \frac{v_1^2}{u^2} - \frac{v_1^2 v_2^2}{(v_1^2+v_2^2)w^2}} < \underbrace{1 - \frac{v_1^2}{u^2}} < 1 < \underbrace{1 + \frac{v_1^4}{(v_1^2+v_2^2)w^2}}$$

NuTeV measures $1 - \frac{v_1^2 v_2^2}{(v_1^2+v_2^2)w^2}$ and $(\sin^2\theta_W)_{\ell q}$

β decay measures $1 - \frac{v_1^2}{u^2}$

$\Downarrow$

apparent CKM nonunitarity

SLAC E158 measures $G_F(1-4\sin^2\theta_W)^{NC}_{\ell\ell}$

Gauge Group :

$$SU(3)_c \times SU(2)_q \times SU(2)_\ell \times U(1)_q \times U(1)_\ell$$

$$g_s \qquad g_1 \qquad g_2 \qquad g_3 \qquad g_4$$

$$\begin{pmatrix} u \\ d \end{pmatrix}_L \sim \left(3,2,1,\tfrac{1}{6},0\right), \quad \begin{pmatrix} \nu \\ e \end{pmatrix}_L \sim \left(1,1,2,0,-\tfrac{1}{2}\right),$$

$$u_R \sim \left(3,1,1,\tfrac{2}{3},0\right), \quad e_R \sim \left(1,1,1,0,-1\right),$$

$$d_R \sim \left(3,1,1,-\tfrac{1}{3},0\right),$$

Higgs sector

$$\begin{pmatrix} \phi_1^+ \\ \phi_1^0 \end{pmatrix} \sim \left(1,2,1,\tfrac{1}{2},0\right), \quad \begin{pmatrix} \phi_2^+ \\ \phi_2^0 \end{pmatrix} \sim \left(1,1,2,0,\tfrac{1}{2}\right),$$

$$\chi^0 \sim \left(1,1,\tfrac{1}{2},-\tfrac{1}{2}\right),$$

$$\eta = \frac{1}{\sqrt{2}}\begin{pmatrix} \eta^0 & -\eta^+ \\ \eta^- & \bar{\eta}^0 \end{pmatrix} \sim \left(1,2,2,0,0\right),$$

$$\eta = \tau_2 \eta^* \tau_2 \quad (\text{self-dual})$$

* Prototype of this model was proposed over 20 years ago [X. Li & E. Ma, PRL **47**, 1788 (1981)] to distinguish generations and predicted a longer τ lifetime.

* Now we may have a longer neutron lifetime:

Abele et al., PRL **88**, 211801 (2002)

$$\Rightarrow |V_{ud}| = 0.9713(13)$$

$$\Rightarrow |V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9917(28)$$

$$\Rightarrow \boxed{\frac{v_1^2}{u^2} = 0.0042(14)}$$ in this model.

Charged Currents

$$m_W^2 = \frac{1}{2}\begin{bmatrix} g_1^2(v_1^2+u^2) & -g_1 g_2 u^2 \\ -g_1 g_2 u^2 & g_2^2(v_2^2+u^2) \end{bmatrix}$$

$$\frac{4(G_F)^{cc}_{\ell\ell}}{\sqrt{2}} = \frac{1}{2} g_2^2 \left(m_W^{-2}\right)_{22} = \frac{u^2+v_1^2}{(v_1^2+v_2^2)u^2+v_1^2 v_2^2},$$

$$\frac{4(G_F)^{cc}_{\ell q}}{\sqrt{2}} = \frac{1}{2} g_1 g_2 \left(m_W^{-2}\right)_{12} = \frac{u^2}{(v_1^2+v_2^2)u^2+v_1^2 v_2^2}.$$

Neutral Currents

$$e^{-2} = g_1^{-2}+g_2^{-2}+g_3^{-2}+g_4^{-2}, \quad g_{ij}^{-2} \equiv g_i^{-2}+g_j^{-2}$$

$$Z_1 = e\left(\frac{g_{12}}{g_{34} g_1}, \frac{g_{12}}{g_{34} g_2}, \frac{-g_{34}}{g_{12} g_3}, \frac{-g_{34}}{g_{12} g_4}\right),$$

$$Z_2 = g_{12}\left(\frac{1}{g_2}, \frac{-1}{g_1}, 0, 0\right),$$

$$Z_3 = g_{34}\left(0, 0, \frac{1}{g_4}, \frac{-1}{g_3}\right).$$

$$m_Z^2 = \frac{1}{2}\begin{bmatrix} \frac{g_{12}^2 g_{34}^2}{e^2}(v_1^2+v_2^2) & (\text{sym}) & (\text{sym}) \\ \frac{g_{12}^2 g_{34}}{e\, g_1 g_2}(g_1^2 v_1^2 - g_2^2 v_2^2) & \frac{g_1^2 g_2^2}{g_{12}^2}u^2 + O(v^2) & (\text{sym}) \\ \frac{g_{12} g_{34}^2}{e\, g_3 g_4}(g_4^2 v_2^2 - g_3^2 v_1^2) & O(v^2) & \frac{g_3^2 g_4^2}{g_{34}^2} w^2 + O(v^2) \end{bmatrix}$$

Z_1 couples universally to quarks + leptons,

$Z_{2,3}$ do not,

* Observed Z is $Z_1 - \epsilon_2 Z_2 - \epsilon_3 Z_3$.

Define $r \equiv \frac{v_2^2}{v_1^2}$, $y \equiv \frac{g_2^2}{g_1^2+g_2^2}$, $x \equiv \frac{g_4^2}{g_3^2+g_4^2}$,

then

$$\Delta\rho_\ell = -y^2(1+r)\frac{v_1^2}{u^2} + \frac{[1-x^2(1+r)^2]}{1+r}\frac{v_1^2}{w^2},$$

$$\Delta\rho_q - \Delta\rho_\ell = -2\left[1-y(1+r)\right]\frac{v_1^2}{u^2} - 2\left[1-x(1+r)\right]\frac{v_1^2}{w^2},$$

$$\Delta \sin^2\theta_\ell = \frac{s^2 y[1-s^2 y(1+r)]}{c^2-s^2}\frac{v_1^2}{u^2} + \frac{c^2[1-x(1+r)]}{(c^2-s^2)(1+r)}\left[-s^2+c^2x(1+r)\right]\frac{v_1^2}{w^2},$$

$$\Delta \sin^2\theta_q - \Delta \sin^2\theta_\ell = s^2[1-y(1+r)]\frac{v_1^2}{u^2} - c^2[1-x(1+r)]\frac{v_1^2}{w^2},$$

Low-energy data:

$$(\Delta \sin^2\theta_W)_{\ell q} = \left[\frac{s^2c^2}{(c^2-s^2)}\left[2y-y^2(1+r)\right]+s^2(1-y)\right]\frac{v_1^2}{u^2} - \left[\frac{s^2c^2}{(c^2-s^2)}\frac{[1-x(1+r)]^2}{1+r}+c^2(1-x)\right]\frac{v_1^2}{w^2}$$

$$\Rightarrow \Delta(g_L^{eff})^2 = -\left(\frac{2r}{1+r}\right)\frac{v_1^2}{w^2}(g_L^{eff})^2_{SM} - \left(1-\frac{10s^2}{9}\right)(\Delta \sin^2\theta_W)_{\ell q}$$

$$\Delta(g_R^{eff})^2 = -\left(\frac{2r}{1+r}\right)\frac{v_1^2}{w^2}(g_R^{eff})^2_{SM} + \frac{10s^2}{9}(\Delta \sin^2\theta_W)_{\ell q}$$

Winter 2002

	Measurement	Pull
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02761 ± 0.00036	-.27
m_Z [GeV]	91.1875 ± 0.0021	.01
Γ_Z [GeV]	2.4952 ± 0.0023	-.42
σ^0_{had} [nb]	41.540 ± 0.037	1.63
R_l	20.767 ± 0.025	1.05
$A^{0,l}_{fb}$	0.01714 ± 0.00095	.70
$A_l(P_\tau)$	0.1465 ± 0.0033	-.53
R_b	0.21646 ± 0.00065	1.06
R_c	0.1719 ± 0.0031	-.11
$A^{0,b}_{fb}$	0.0994 ± 0.0017	-2.64
$A^{0,c}_{fb}$	0.0707 ± 0.0034	-1.05
A_b	0.922 ± 0.020	-.64
A_c	0.670 ± 0.026	.06
A_l(SLD)	0.1513 ± 0.0021	1.50
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	.86
m_W [GeV]	80.451 ± 0.033	1.73
Γ_W [GeV]	2.134 ± 0.069	.59
m_t [GeV]	174.3 ± 5.1	-.08
$\sin^2\theta_W(\nu N)$	0.2277 ± 0.0016	3.00
Q_W(Cs)	-72.39 ± 0.59	.84

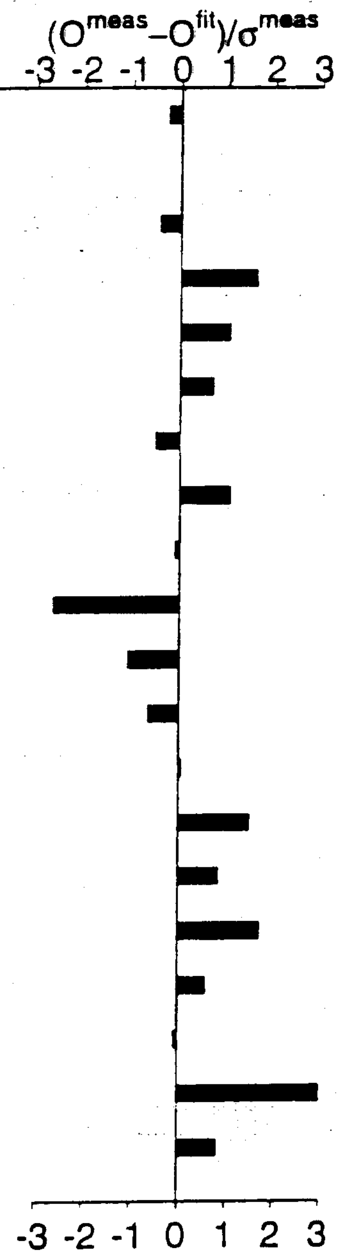

Table 1: Fit Values of 22 Observables

Observable	Measurement	Standard Model	Pull	This Model	Pull
Γ_l [MeV]	83.985 ± 0.086	84.015	−0.3	83.950	+0.4
Γ_{inv} [MeV]	499.0 ± 1.5	501.6	−1.7	501.2	−1.5
Γ_{had} [GeV]	1.7444 ± 0.0020	1.7425	+1.0	1.7444	−0.0
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.01649	+0.7	0.01648	+0.7
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1483	−0.6	0.1482	−0.5
R_b	0.21644 ± 0.00065	0.21578	+1.0	0.21582	+1.0
R_c	0.1718 ± 0.0031	0.1723	−0.2	0.1722	−0.1
$A_{fb}^{0,b}$	0.0995 ± 0.0017	0.1040	−2.6	0.1039	−2.6
$A_{fb}^{0,c}$	0.0713 ± 0.0036	0.0743	−0.8	0.0740	−0.8
A_b	0.922 ± 0.020	0.935	−0.7	0.934	−0.6
A_c	0.670 ± 0.026	0.668	+0.1	0.665	+0.2
A_l(SLD)	0.1513 ± 0.0021	0.1483	+1.4	0.1482	+1.5
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314	+0.8	0.2322	+0.2
m_W [GeV]	80.449 ± 0.034	80.394	+1.6	80.390	+1.7
Γ_W [GeV]	2.139 ± 0.069	2.093	+0.7	2.093	+0.7
$g_V^{\nu e}$	-0.040 ± 0.015	−0.040	−0.0	−0.039	−0.1
$g_A^{\nu e}$	-0.507 ± 0.014	−0.507	−0.0	−0.507	−0.0
$(g_L^{eff})^2$	0.3001 ± 0.0014	0.3042	−2.9	0.3032	−2.2
$(g_R^{eff})^2$	0.0308 ± 0.0011	0.0301	+0.6	0.0299	+0.8
Q_W(Cs)	-72.18 ± 0.46	−72.88	+1.5	−72.26	+0.2
Q_W(Tl)	-114.8 ± 3.6	−116.7	+0.5	−115.7	+0.3
$\sum_{i=d,s,b} \|V_{ui}\|^2$	0.9917 ± 0.0028	1.0000	−3.0	0.9902	+0.5

Best fit parameter values:

$\frac{v_1^2}{u^2} = 0.00489$, $\frac{v_1^2}{w^2} = 0.00238$,

$r = 10.2$, $y = 0.0955$, $x = 0.135$

$$\Delta A_{fb}^{0,b} = \frac{3}{4}\left(A_e \Delta A_b + A_b \Delta A_e\right)$$

$$= -0.07\, \Delta \sin^2\theta_q - 5.57\, \Delta \sin^2\theta_\ell$$

essentially measures $\Delta \sin^2\theta_\ell$, not $\Delta \sin^2\theta_q$

SLAC E158 : $e^- e^- \to e^- e^-$

$$\frac{\Delta\, G_F(1-4\sin^2\theta_W)}{G_F(1-4\sin^2\theta_W)} \simeq -0.022$$

Qweak at TJNAF : $ep \to ep$

$$\frac{\Delta Q_W^p}{Q_W^p} \simeq +0.03$$

$M_{W_2} \simeq M_{Z_2} \simeq 1.2$ TeV

$M_{Z_3} \simeq 0.8$ TeV