Beyond the SM 5

Note Title 11/24/2009

EW $\longrightarrow$ BSM

$$EFT \sim \left(\frac{E^2}{\Lambda^2}\right)$$

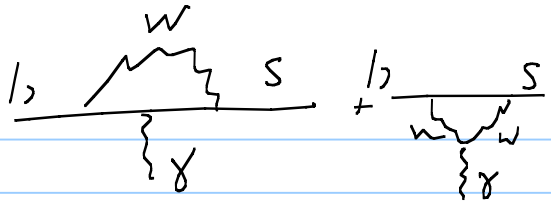
$\Lambda \gtrsim$ N.P

Tricks

1) Rare
2) Precision

} EW is good

Rare weak decay $b \to s\gamma$



Operators

$\bar{s} \not{A} b \to$ part of $\bar{s} \not{D} b$

diagonalizi Z

$$O_7 = \bar{s}\,\sigma^{\mu\nu} b\, F_{\mu\nu}$$

Problem? $\bar{s}_L \sigma^{\mu\nu} b_L = 0 \Rightarrow \bar{s}_R \sigma^{\mu\nu} b_L F_{\mu\nu}$ or $\bar{s}_L \sigma^{\mu\nu} b_R F_{\mu\nu}$

$$\not{p}\, b_L = \not{p}\, \tfrac{1}{2}(1+\gamma_5)\, b = \tfrac{1}{2}(1-\gamma_5)\, m_b\, b = m_B\, b_R$$

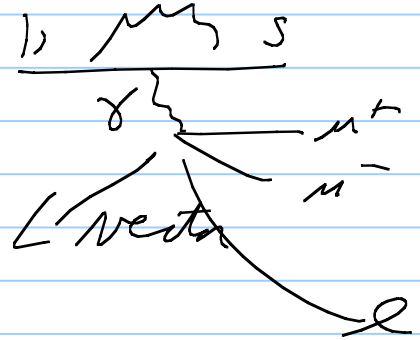
$$\mathcal{O}_7 = m_b \bar{s}_L \sigma_{\mu\nu} b_R F^{\mu\nu} + \cancel{m_s \bar{s}_R \sigma_{\mu\nu} b_L F^{\mu\nu}}$$

→ drop

↑ extra suppression

Contrast $b \to s \ell^+ \ell^-$

Same story?



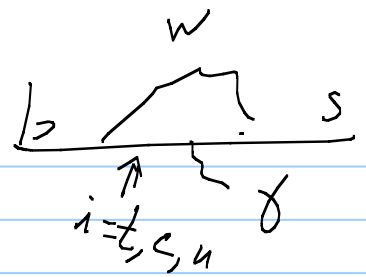
$$\mathcal{O}_{EWP} = \bar{s} \gamma^\mu (1+\gamma_5) b \; \bar{\ell} \gamma^\mu \ell$$

Generated $\bar{s}_L \gamma^\mu b_L (q^\mu q^\nu - g^{\mu\nu} q^2) A_\nu$ ⟸ upper vertex (charge radius)

+ propagator $\frac{1}{q^2}$

$\Longrightarrow$ $\cancel{(q^2/\ell^4)}$ $\bar{s} \gamma^\mu (1+\gamma_5) b \; \bar{\ell} \gamma^\mu \ell$

F.C.N. Processes



$$\mathcal{M} \sim \int d^4k \; \frac{1}{\not k - m} \; \frac{1}{\not k - m} \; \frac{1}{k^2 - M_W^2}$$

divergent not complexy for renorm.

CKM Unitarity (G.I.M. mechanism)

$$\mathcal{M} = \sum_{i = u,c,t} V_{is}^* \; V_{ib} \; * \; I(m_i)$$

Divergence is independent of masses $\sum_i V_{is}^* \; V_{ib} = 0$

$\Rightarrow$ cancels

Form of answer

$$V_{ts}^* V_{tb}\, I(m_t) + V_{cs}^* V_{cb}\, I(m_c) + V_{us}^* V_{ub}\, I(m_u)$$

$$-A\lambda^2 \cdot 1 \qquad 1 \cdot A\lambda^2 \qquad \lambda \cdot A\lambda^3(\rho+i\eta)$$

suppressed

$$V_{cs}^* V_{cb}\left[I(m_t) - I(m_c) \right]$$

all FCNP involve differences

If masses small $\quad \Delta I = \dfrac{m_t^2 - m_b^2}{m_W^2}$

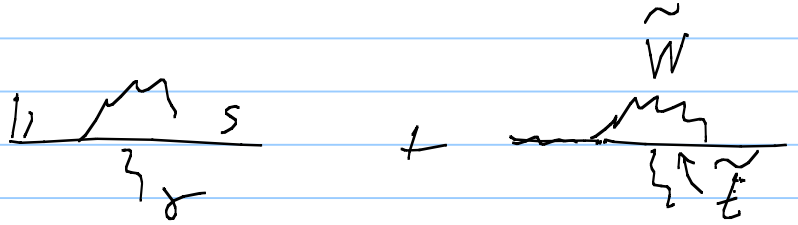
$$\Delta I = \ln m_t^2 / m_b^2$$

All functions are known – Inami Lim

Top dominance – M_t almost always main intermediate state
(except ΔM_K)

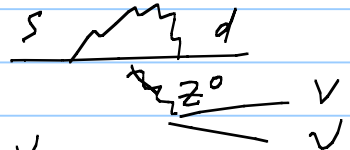
Rare + BSM

- loop sensitive to all physics



$$\frac{m_b}{M_W^2} \cdot V_{ts}^* V_{tb} \cdot \left[I(m_t) - I(m_c) \right] \quad \text{vs} \quad \frac{m_{\tilde{t}}^2}{M_{\tilde{W}}^2} \times 1 \times$$

Example $K_L \to \pi^0 \nu\bar{\nu}$



$$\mathcal{H}_{NP} = \frac{1}{\Lambda^2} \bar{s} \gamma_\mu (1+\gamma_5) d \, \bar{\nu} \gamma^\mu (1+\gamma_5) \nu$$

$$\frac{\Gamma_{NP}}{\Gamma(SM)} = \frac{(1/\Lambda^2)^2}{[SM]} = \begin{cases} 10^8 \\ 1 \end{cases}$$

if $\Lambda = 1$ TeV

if $\Lambda = 10^5$ GeV

Minimal Flavor Violation (MFV)

- problem – should have seen new physics

Flavor violation comes with universal V_{CKM}

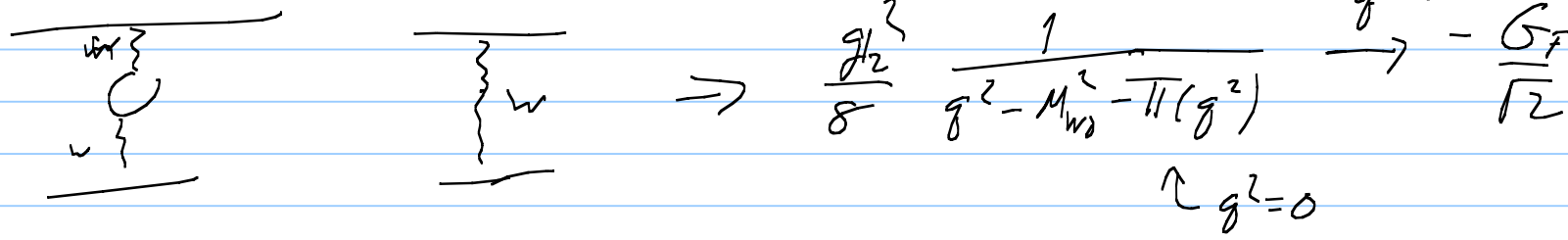
$$\mathcal{H}_{NP} = \frac{V_{ts} V_{td}^*}{\Lambda^2} \mathcal{O}$$

$\Rightarrow$ essentially no constraints

- ad hoc

Precision Test

Basic physics — Vac. pol.



But $M_W^2 = M_{W_0}^2 + \Pi(M_W^2)$

At tree level $M_W^2 = M_Z^2 \cos^2\theta_W$

→ Low E $\frac{g_2^2}{M_W^2}$ and $\frac{g_2^2}{M_Z^2 \cos^2\theta_W}$

→ High E pres

Vac. Pol.

$$\Pi^{ij}_{\mu\nu}(q^2) = \left[A_i + q^2 A_i' + \cdots \right] g_{\mu\nu} + \cdots$$

4 cases: WW, ZZ, $\gamma\gamma$, $Z\gamma$

3 parameters g_1 g_2, ν ←

— precisions α, G_μ, M_Z ←

Renorm constants

$$\frac{\delta\alpha}{\alpha} = -A_{\gamma\gamma}' \quad , \quad \frac{\delta G_F}{G_F} = A_{WW} \quad , \quad \frac{\delta M_Z^2}{M_Z^2} = -\frac{A_{33}}{M_Z^2} - A_{33}'$$

Current conservation $\Pi_{\gamma\gamma}(0) = 0 = \Pi_{\gamma 3}(0)$

$\Rightarrow$ 3 constr

S, T, U

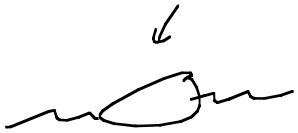
$$S = \frac{4 \sin\theta_W}{\alpha}\left[\frac{A'_{3\gamma}}{\sin\theta_W} - A'_{33}\right]$$

$$T = \frac{1}{\alpha}\left[A_{33} - A_{WW}\right]\frac{1}{M_W^2}$$

$$U = \frac{4 \sin^2\theta_W}{\alpha}\left[A'_{33} - A'_{WW}\right]$$

$\Rightarrow$ analyse precision data
- SM contributions - subtract off.
- M_t^2, $\ln M_H$ ← **

S, T, U sensitive to new physics



4 generations (quark)

$$S = \frac{1}{2\pi}\left[1 - \tfrac{1}{3}\ln m_u^2/m_d^2\right] = \frac{1}{2\pi}$$

$$T = \frac{3}{8\pi \sin^2\theta_w \cos^2\theta_w}\left[\frac{m_u^2+m_d^2}{2M_Z^2} - \frac{m_u^2 m_d^2}{(m_u^2-m_d^2)M_Z^2}\ln m_u^2/m_d^2\right] \to 0 \quad m_u \to m_d$$

S does not "decouple"

- violate Appelquist Carrazone?

$m_i = \Gamma^{\text{fixed}} N$, $\Gamma \to \infty$

T "SU(2) breaking"

Data say $|S| < 0.2$

$|T| < 0.1$

Nature of tests

1) Precision fits at Z pole (LEP)

2) High E vs low E comparisons

$$\rho = \frac{M_W^2}{\cos^2\theta_W M_Z^2} = 1 + \Delta\rho$$

M_Z: Z pole; $\Delta\rho$: measure at low E

$$\Delta\rho = \alpha T$$

$$S = \frac{4 s^2 c^2}{\alpha}\Delta\rho + \frac{4 s^2 (c^2 - s^2)}{\alpha}\Delta K$$

(ΔK: shift in $\sin^2\theta_W$)

$\Rightarrow$ little room for NP

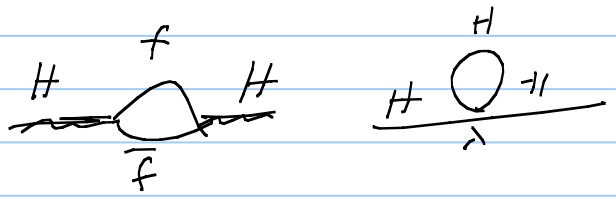
Expectations for BSM

1) Dark matter (or something)
   - TeV with < weak coupling

2) Inflation (or something)

3) Baryogenesis

4) Scale of EWSB
   - cutoff - quadratic in Λ



$$\Delta m_H^2 = -\frac{|y_f|^2}{8\pi^2}\left\{\Lambda^2 + \ln\Lambda\right\} + \frac{\lambda}{16\pi^2}\left[\Lambda^2 + \ln\Lambda\right]$$

$\Rightarrow$ Fine tuning to get M_H

$\Rightarrow$ Expect (?) New physics at Λ that makes Λ^2 disappear

3) Dreams of unification