**Marco**: EWPO

5 NOV 2012

**Refs**: 0706.0684 CH. 4 (BARBIERI)
CERN-TH 6659/92 (KEK)

**SM**: EW SECTOR – gauge & higgs
w/o HIGGS MASS, 3 PARAM: $\boxed{g, g', v}$

$$\mathcal{L}_{SM-EW} = \mathcal{L}_h + \frac{1}{2}\frac{v^2}{2}\left[ g^2 (W^{1,2}_\mu)^2 + (-g W^3_\mu + g' B_\mu)^2 \right]$$

WANT TO DESCRIBE OBSERVABLES FROM THIS (NEGLECT FERMION COUPL.)

$$\boxed{g, g', v} \xrightarrow[\text{observables}]{\text{trade for}} \boxed{\alpha, G_F, M_Z} \quad (\text{+ fermion mass...})$$

$$\alpha \to (g-2), \qquad G_F \to \tau_\mu, \qquad M_Z \to M_Z \text{ peak}$$

FROM THIS WE CAN COMPUTE:
$$\begin{cases} M_W \\ \gamma \to f\bar{f} \\ Z \to f\bar{f} \\ W \to f\bar{f}' \\ A_{LR,\,FB}, \ldots \end{cases}$$

WANT PREDICTIVE POWER OVER RADIATIVE CORRECTIONS, PROBE HIGGS SECTOR, & EVEN NP SECTOR?

THE KING EW PARAMETER

$$\boxed{\rho = \frac{m_W^2}{m_Z^2 c_W^2}} = 1 \quad @ \text{ tree level}$$

from CUSTODIAL symmetry

SM GAUGE: $SU(2)_L \times U(1)_Y$

BUT AS $g' \to 0$, $\exists$ LARGER SYM: $SU(2)_L \times SU(2)_R$

HIGGS POTENTIAL : $H = \underbrace{(i\sigma_2 \phi^*, \phi)}_{(2,2)}$

is inv't under these

$\phi$ usual $\begin{pmatrix} \phi^+ \\ v+h \end{pmatrix}$

then: $H \to e^{i w_L^i \frac{\sigma_i}{2}} H e^{-i w_R^i \frac{\sigma_i}{2}}$

b/c $V \sim \mu^2 \mathrm{Tr}(H^\dagger H) + \lambda [\mathrm{Tr}(H^\dagger H)]^2$ ✓

WHAT ABOUT KINETIC?

$$D_\mu H = \left(\partial_\mu H + \frac{ig}{2} W_\mu \cdot \sigma - \underbrace{\frac{ig'}{2} B_\mu \sigma_3 H}_{\text{NOT INVARIANT.}}\right)$$

$\langle h \rangle = v$: $SU(2)_L \otimes SU(2)_R \longrightarrow SU(2)_V \quad (W_L^i = W_R^i)$

$W^i$ is A TRIPLET UNDER $SU(2)_V \iff \rho = 1$

$$m_Z^2 Z^2 = c_W^2 m_W^2 W_3^2 + \cdots$$

$$\Rightarrow m_W/m_{W_3} = 1 \rightarrow m_W^2/m_Z^2 c_W^2 = 1$$

NOW TURN ON $g'$

GIVE CORRECTIONS TO $\rho = m_W^2/m_Z^2$

$\hookrightarrow$ BUT CAN RESTORE $\rho = 1$ @ TREE LEVEL BY DEFINING $\rho = m_W^2/m_Z^2 c_W^2$

EXERCISE : $Z_\mu = c_W W^3 - s_W B_\mu \Leftrightarrow \rho = 1$

EXERCISE : WHAT IF YOU USE AN $n^{\text{PLET}}$ FOR EWSB?

ADDITIONAL CUSTODIAL BREAKING: $(y_t - y_b)$

MEASURE $\rho$ @ PER MILLE LEVEL

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$\rho$ IN GAUGELESS LIMIT

$$\mathcal{L} = i\bar{\Psi}\not{D}\Psi + |D\phi|^2 - V(\phi) - \left(y_t \phi Q_3 t^c + h.c.\right)$$

WHAT HAPPENS TO GOLDSTONE BOSONS? $(\pi_i)$

$$\mathcal{L}_{\text{KIN}}(\pi) = \underbrace{\left|\partial_\mu \pi^+ - g\frac{v}{\sqrt{2}} W^+\right|^2}_{Z_2^{(+)}} + \underbrace{\frac{1}{2}\left(\partial_\mu \pi^0 - \frac{gv}{2c_W} Z_\mu\right)^2}_{Z_2^{(0)}}$$

WF REN.

then: $$\boxed{\rho = \frac{Z_2^{(+)}}{Z_2^{(0)}}}$$ @ ALL ORDERS

ratio of wf REN of EACH GOLDSTONES.

$\xi = 0$

SO IN LANDAU GAUGE (CORRECT GAUGE FOR THIS CALC)

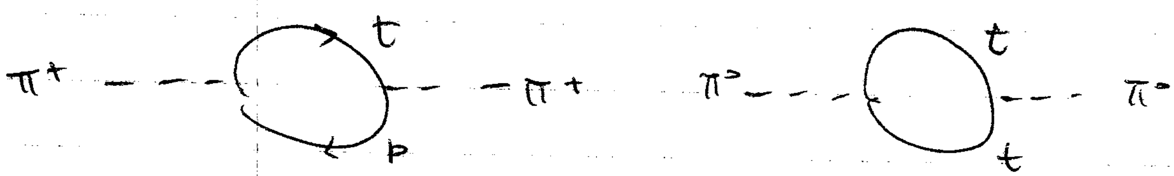
$$\rho = \delta Z_2^{(+)}\Big|_{\text{LANDAU}} - \delta Z_2^{(0)}\Big|_{\text{LANDAU}} + 1$$

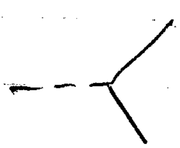
So @ 1-LOOP LEVEL: RENORMALIZE

OBSERVABLES $(g-2)$, $\tau_H$, $M_Z$

note: finiteness since written in terms of obs.

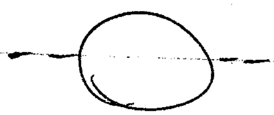
WHAT IS EFFECT OF t ON $\rho$?





$$= \frac{-g M_t}{2 M_W} \gamma^5$$

THEN:  $= \Pi(q^2) = q^2 A - \cdots$

s.t. $\delta Z_L \propto A$

 $= \overset{\text{color}}{3}\, \frac{g^2 m_t^2}{4 M_W^2} \underbrace{\int d^4k \; \gamma_5 \frac{\not k + \not q + m_t}{(k+q)^2 - m_t^2} \gamma_5 \frac{\not k + m_t}{k^2 - m_t^2}}_{\sim k^2}$

TO ISOLATE A $q^2$ COEFFICIENT

$$\rho = 1 + \underbrace{\frac{3 g^2 m_t^2}{4 M_W^2}}_{\frac{2 G_F}{\sqrt{2}} m_t^2} \times \underbrace{\frac{1}{8\pi^2}}_{\text{loop}} = 1 + \frac{3 \times G_F m_t^2}{4\pi \sqrt{2}}$$

$x = 1/2$

Exercise:

DEPENDENCE ON $m_t$: 30% est. for $m_t$ BEFORE THE LHC.

Q: in principle also bottom loops to give $(m_t - m_b)^2$ DEPENDENCE.

NEXT CORRECTIONS: from B $(g' \neq 0)$


ALSO, IN GEN: LOOPS w/ HIGGS INSIDE.
WHAT WOULD THESE GO LIKE?

$\Delta\rho \sim M_h^2$ (cf $\rho \sim m_t^2$)

$\Downarrow$

$\Rightarrow \Delta\rho \sim \lambda$

BUT THIS IS CUSTODIALLY INVARIANT.

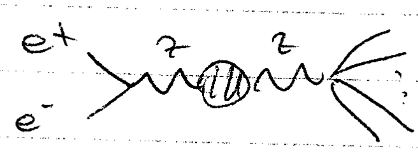
So: $\Delta\rho \sim \ln M_h/\Lambda$ @ MOST.

(ONE CAN SHOW THAT) IN GENERAL NP CONTRIBUTIONS SHOW UP IN:

- VACUUM POLARIZATION 
- TRIANGLES
- BOXES

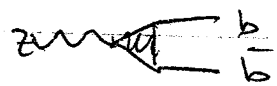
<u>claim</u>: these are most interesting.

↳ eg. LEP:




↑

BOXES DON'T AT.




CAN BE IMPORTANT

ALL OTHERS NOT IMPORTANT.

$$\mathcal{L} = -\frac{1}{2} W^3 \Pi^{33}(q^2) + \frac{1}{2} B \Pi^{00} B - W^3 \Pi^{30} B$$
$$- W^+_\mu \Pi^{WW}(q^2) W^-_\mu$$

IF YOU ONLY CARE UP TO $\log M_H$,
THEN ALL YOU NEED IS

$$\Pi(q^2) = \underbrace{\Pi(0) + \Pi'(0)\, q^2}$$

SO NOW $\boxed{8}$ OPERATORS

FIX $\boxed{3}$ w/ $g, g', v$

$\gamma$ MASS $\rightarrow$ THEN $\boxed{2}$ COND. FROM WARD IDENTITIES.

LEFT w/ $\boxed{3 \text{ PARAMS.}}$

Peskin-Takeuchi UP TO PREFACTOR.

ALTARELLI-BARBIERI

$$\hat{S} = (g/g')\, \Pi'_{30}(0) \qquad = \varepsilon_3 - \varepsilon_3^{SM}$$

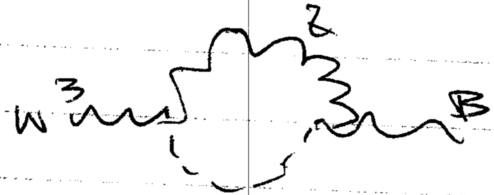
$$\hat{U} = \Pi'_{33}(0) - \Pi'_{WW}(0) \qquad = \varepsilon_1 - \varepsilon_1^{SM}$$

$$\hat{T} = \frac{\Pi_{33}(0) - \Pi_{WW}(0)}{M_W^2}$$

DIRECT MEAS of CUSTODIAL BREAKING

NOTE: $\boxed{\rho - 1 = \hat{T}}$ nice. ✓

then consider, eg.




$$\rightarrow \hat{S} \approx \frac{G_F M_W^2}{12\sqrt{2}\,\pi^2} \log M_h$$

AS WE SHOWED.
BIGGEST DEP. IS
$M_t^2$, $\log M_h$

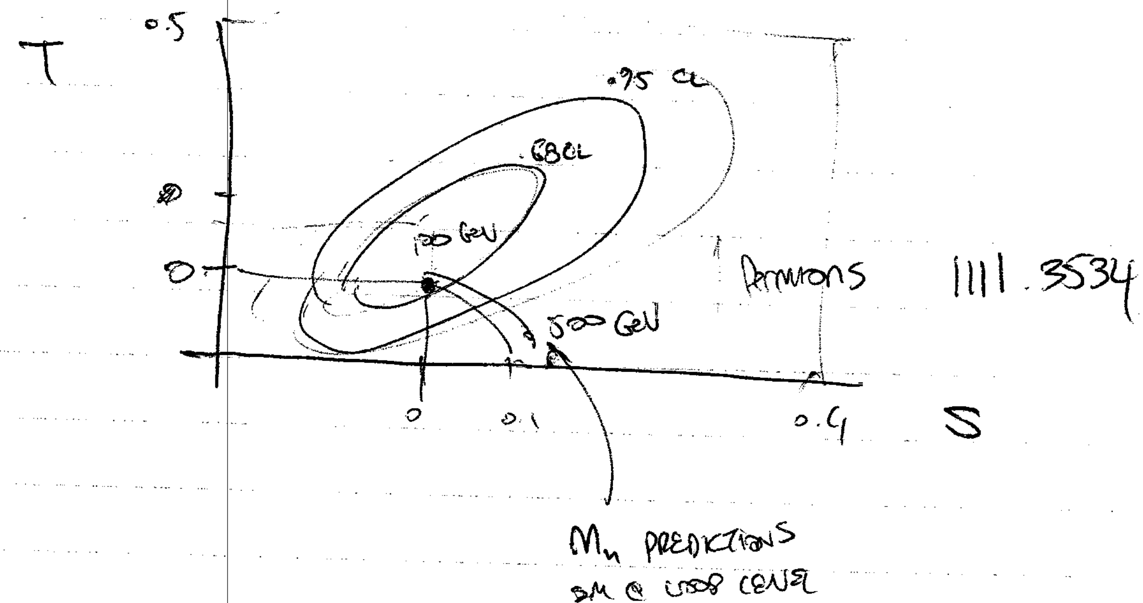
this is why after LEP,
we knew $M_t^2$ w/in 20%.
but not $M_h^2$. (log)

WHAT'S LEFT? SLD @ SLAC  $\mathcal{O}(10)$ OBSERVABLES.

<u>INPUT</u> : $(g-2)$, $\tau_\mu$, $M_Z$ $\longrightarrow$ CAN COMPARE SM
IF ALSO $M_h$ $\longrightarrow$ CAN CALC TO HIGHER $\mathcal{O}$

IF NP IN BLOBS
THEN LET $\hat{S}, \hat{T}, U$ BE FREE PARAMS.
↳ S } see WHAT VALUE YOU GET.
eg. ESTIMATING $M_t$

FAMOUS RESULT:




INCLUDING HIGGS: $\exists$ A PAPER

PROBLEMATIC: $Z \to b\bar{b}$ $(\epsilon_b)$

($g_L$ & $g_R$ DON'T AGREE, $3\sigma$: ONE IS SM-LIKE, ONE IS DIFF)