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Lecture II

SUMMER SCHOOL IN HIGH ENERGY PHYSICS AND COSMOLOGY

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# AN INTRODUCTION TO THE STANDARD MODEL

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Please note: These are preliminary notes intended for internal distribution only.

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From the previous discussion: 4

a possibly promising approach *might* be that of introducing a gauge symmetry and of breaking it spontaneously to generate masses for the needed massive gauge bosons.

First problem: choice of a proper *electroweak* Gauge group (for SI: $SU_3(C)$ o.k.) (not to be discussed here)

Consider the oversimplified case of *one* family of fermions ($e, \nu_e, u, d$)

The charged *lepton* current to be coupled to $W$ is then:

$$J_{\lambda,e} \equiv \bar{\psi}_{\nu_e} \gamma_\lambda (1-\gamma_5) \psi_e$$

and the component of the candidate Lagrangian contains *both* $J_\lambda$ *and* $J_\lambda^+$.

If one wants to introduce a gauge symmetry group $G$, this will have to contain <u>at least</u> two charges (generators) associated to these currents (<u>and</u> to the charged bosons $W^+, W^-$):

$$T_+ \equiv \frac{1}{2}\int d\vec{x}\; J_0(x)$$

$$T_- \equiv T_+^{\dagger} \equiv \frac{1}{2}\int d\vec{x}\; J_0^{\dagger}(x).$$

No meaningful groups are known with two generators. The "smallest" one that is available has the <u>mathematical</u> structure of $SU(2)$

$$G \doteq SU(2)$$

and it has <u>three</u> generators, with an algebra

$$[T_+, T_-] = 2\, T_3 .$$

$\Rightarrow$ <u>at least</u> one more (neutral!) gauge boson $\Rightarrow T_3$ !

Could this third "minimal" gauge boson be the photon?
$(L = L_W + L^{e.m.}, L^{e.m.} = e J_\lambda^{e.m.} A^\lambda,$
$e \simeq g)$

<u>NO</u>. Because $[T_+^{\ell}, T_-^{\ell}] = 2 T_3^{e} =$

$=$ (from canonical a.m. rules)

$$2 \cdot \frac{1}{4} \int d\vec{x} \left[ \bar{\psi}_\nu (1-\gamma_5) \psi_\nu - \psi_e^{+} (1-\gamma_5) \psi_e \right]$$

$$\neq 2 Q^{\ell} \,!$$

$\Rightarrow$ one solution: (initially, not the only one – extra charged lepton $E^+$ also ...)

Introduce another gauge boson $W_3$ <u>different</u> from the photon but (coupled to $T_3 \Rightarrow \tau_3 \ldots$) <u>electrically neutral</u>.

In this case, a Lagrangian describing both weak and electromagnetic interactions ("electroweak" interactions) should contain at least four different gauge bosons $\Longrightarrow$ a minimal gauge group $G$ should have four generators.

A simple group $G$ with four generators is not available.

But one can consider the minimal non simple group

$$G \doteq SU(2) \times U(1)$$

(mathematical structure)

where the condition ($U(1) \Rightarrow Y$)

$$[Y, T_i] = 0 \quad (i = +,-,3)$$

implies that also the $U(1)$ g. boson $= B$ cannot be the photon !

The prescription to ensure that the fermionic Lagrangian has $G$ as a (simmetry) gauge group is to replace systematically (generalizing QED)

$$\partial_\mu \psi_i \Longrightarrow D_\mu \psi_i$$

where $\psi_i$ is the $i$-th independent "structure", having certain transformation properties under $SU(2)$ and $U(1)$, and

$$D_\mu \psi_i \equiv \left[ \partial_\mu - i g \vec{t}^{(i)} \cdot \vec{W}_\mu - i g' \frac{Y^{(i)}}{2} B_\mu \right] \psi_i$$

with $\vec{t}^{(i)} \equiv$ matrices representing the 3 $SU(2)$ generators $\vec{T}$ in the irrid. repr. provided by $\psi_i$, whose $Y$ value is $Y^{(i)}$.

In practice, either $SU(2)$ doublets e.g. $\psi_1 \equiv \begin{vmatrix} \nu \\ e \end{vmatrix} \dots \Longrightarrow \vec{t} = \frac{\vec{\tau}}{2}$, or singlets $e, \nu$ ($\vec{t}=0$) (same for $u, d$).

A number of purely phenomenological considerations now appears, that will influence

DRASTICALLY

the construction of the fermionic/g.boson sector of the candidate Lagrangian.

I) To reproduce correctly the known low-energy features of weak interactions, the charged part of the interaction $\Rightarrow T_{\pm}$ ($\Rightarrow W^{+,-}$) must only involve left-handed fermions ($e_L, \nu_L, u_L^w, d_L^w$) ($q^w \neq q^{SU(3)} \ldots$).

$\Rightarrow$ the covariant derivative "belonging" to $SU(2)$, that only acts on the $SU(2)$ doublets, must find in these doublets left-handed fermions

$$\Rightarrow \psi_1 \equiv \begin{vmatrix} \nu_L \\ e_L \end{vmatrix}, \quad \psi_2^{(c)} \equiv \begin{vmatrix} u_L^{w,c} \\ d_L^{w,c} \end{vmatrix} \quad (c \Rightarrow \text{color}) \; (= 1, 2, 3)$$

For this reason, the "electroweak" $SU(2)$ was called $SU(2)_L$.

I) If one wants to incorporate e.m. interactions in the game, the Lagrangian must contain right-handed fermions as well (photons interact equally with $f_L$ and $f_R$ ...). But these must not be affected by the $SU(2)_L$ covariant derivative $\Longrightarrow$ must be $SU(2)_L$ singlets.

$$\underbrace{\cancel{\psi_3 \equiv \nu_R}}_{}^{\text{NO!}}, \quad \psi_4 \equiv e_R, \quad \psi_5^{(c)} \equiv u_R^{w(c)}, \quad \psi_6^{(c)} \equiv d_R^{w(c)}$$

(quarks have $SU(3)$ color, $q^{(c)} \equiv q^{(1),(2),(3)}$)

($\nu_R$ "not wanted" ....)

II) One still has to fix the values of $Y^{(i)}$ for the $i$-th "structure".

Request: $Y$ must commute with $\vec{T}$.

Discovery: $(Q^{e.m.} - T_3)$ commutes with $\vec{T}$

$\Rightarrow$ natural proposal

$$U(1) \Longrightarrow \frac{Y}{2} \equiv [Q - T_3] \Rightarrow U(1)_Y$$

In this way, the relation

$$Q = T_3^{\text{strong}} + \frac{1}{2} Y^{\text{strong}}$$

is retained at the e.w. level:

$$Q = T_3^{\text{e.w.}} + \frac{1}{2} Y^{\text{e.w.}}$$

with $\quad G^{\text{e.w.}} \equiv SU(2)_L + U(1)_Y.$

This fixes $Y^{(i)}$ for the i-th structure.

E.g. $\quad \psi_1 \equiv \begin{vmatrix} \nu_L \, (T_3 = +1/2) \\ e_L \, (T_3 = -1/2) \end{vmatrix} \Rightarrow Y^{(1)} = -1$

$$\psi_2^{(c)} = \begin{vmatrix} u_L^{(c)} \, (T_3 = +1/2) \\ d_L^{(c)} \, (T_3 = -1/2) \end{vmatrix} \Longrightarrow Y^{(2)} = 1/3$$

and so on.

So the fermion content is fixed: 15 two-components fields ($\nu_L, e_L, e_R, u_L^{(c)}, d_L^{(c)}, u_R^{(c)}, d_R^{(c)}$) with known transformation properties.

$\underline{\mathrm{V}}$) No $\nu_R$ in the original ("Minimal") Standard Model: only "phenomenological".

Once the group has been fixed, what follows?

From the request of "Wigner-symmetry" one derives that:

$$M_{\vec{W},B} = 0 \quad (\text{like in QED})$$

$$M_{fi} = 0$$

since $\bar{\psi}\psi = \bar{\psi}_L \psi_R + \bar{\psi}_R \psi_L$

(no SU(2) invariance).

Back to page 21", 1st Lecture:
"spontaneous breaking" of the G
(N = 4) symmetry can generate
as many masses as one wishes
for gauge bosons.

And also, as one will see, for
fermions!

⇒ one only must decide
how many gauge bosons **must**
acquire a mass.

(remember that $SU(3)_c$ is also involved

## Generalization to the MSM:

no need of the trick in the $SU(3)_c$ sector (gluons remain massless).

In fact, $SU(3)_c$ can be separated away and treated "canonically" ($SU(3)_c$ commutes with $SU(2)_L \times U(1)_Y$)

(only quark masses "borrowed" from $SU(2)_L \times U(1)_Y$ Sp. Sy. Br.)

From now on: concentrate on the E.W. component $SU(2)_L \times U(1)_Y$.

Of the four g. bosons, only one (the photon) <u>must</u> remain massless. Three must acquire a mass ....

$\Longrightarrow$ four real Higgs fields (two complex fields) <u>will do the job.</u>

("bonus": fermions too will become massive)

# The $SU(2)_L \times U(1)_Y$ Lagrangian

This is made of four pieces:

$$L = L_1 + L_2 + L_3 + L_4$$

$$L_2 = -\frac{1}{4} F^i_{\mu\nu} F^{i\mu\nu} - \frac{1}{4} G_{\mu\nu} G^{\mu\nu}$$

$$F^i_{\mu\nu} = \partial_\mu A^i_\nu - \partial_\nu A^i_\mu + g_0 \varepsilon^{ijk} A^j_\mu A^k_\nu \Rightarrow SU(2)_L$$

$$G_{\mu\nu} = \partial_\mu B_\nu - \partial_\nu B_\mu \Rightarrow U(1)_Y$$

$$L_1 = \sum_j \overline{\psi_j}\, i \gamma^\mu D_\mu \psi_j$$

$$j \Rightarrow (L)_{L,R} \;,\; Q_L^{1,2,3} \;,\; (u,d)_R^{1,2,3}$$

$$D_\mu \psi_j = \left(\partial_\mu - i g_0 \vec{T}^j \cdot \vec{A}_\mu - i g_0' \frac{Y^j}{2} B_\mu\right) \psi_j$$

$$(D_\mu L)_L = \left(\partial_\mu - i g_0 \frac{\vec{\tau}}{2} \cdot \vec{A}_\mu + i g_0' \frac{1}{2} B_\mu\right) L_L$$

$$L_4 = \sum_i \Big[ \bar{L}^i_L \Phi e^i_R h^i_e + \bar{Q}^i_L \Phi d^i_R h^i_d + \bar{Q}^i_L \tilde{\Phi} u^i_R h^i_u + \text{h.c.} \Big]$$

$$\Phi \equiv \begin{vmatrix} \phi^+ \\ \phi^0 \end{vmatrix} \;,\quad \tilde{\Phi} \equiv i \tau_2 \Phi^* \Rightarrow Y_{\tilde{\Phi}} = -1 .$$

$$L_3 = (D_\mu \Phi)^\dagger (D_\mu \Phi) - V(\Phi)$$

$$D_\mu \Phi = \Big(\partial_\mu - \frac{i}{2}\, \underset{\substack{\downarrow \\ SU(2)_L}}{g}\, \vec{\tau}\cdot\vec{A}_\mu - \frac{i}{2}\, \underset{\substack{\downarrow \\ U(1)_Y}}{g'}\, B_\mu\Big)\Phi$$

$$V(\Phi) = \mu^2 \Phi^\dagger \Phi + \lambda (\Phi^\dagger \Phi)^2$$

$$\mu^2 < 0 \Rightarrow \text{Sp. Sy. Br. (SSB)}$$

$$\text{SSB}: \ \langle 0|\Phi|0\rangle = \begin{vmatrix} 0 \\ v/\sqrt{2} \end{vmatrix} \neq 0, \quad v = \sqrt{\frac{-\mu^2}{\lambda}}$$

Then: $$\Phi(x) \equiv e^{-i\left[\vec{\xi}(x)\cdot \frac{\vec{T}}{v}\right]} \cdot \begin{vmatrix} 0 \\ \frac{v+\eta(x)}{\sqrt{2}} \end{vmatrix}$$

$$t_b \Rightarrow T_b : \ T_b |0\rangle \neq 0$$

$\xi_{1,2,3} \sim$ are the "would-be" Golds. bosons that <u>can</u> be washed away (Unitary gauge).

The <u>physical</u> spectrum is then made by the following particles:

i) One physical massive scalar (the Higgs) $\Rightarrow \eta(x)$:

$$m_{0\eta}^2 = -2\mu^2$$

I) 3 families of fermions with a massless neutrino and massive electron and quarks:

$$m_{0e} = h_e\, v/\sqrt{2}$$
$$m_{0u,d} = h_{u,d}\, v/\sqrt{2}$$

II) 3 massive and one massless ($\equiv$ photon) gauge bosons.

The derivation of the g.b. masses is a "key-point" of the MSM. It contains predictions and features that will affect both the tree-and the

In the unitary gauge

$$\Phi(x) \Longrightarrow \frac{(v+\eta(x))}{\sqrt{2}}\,\chi\ ; \quad \chi \equiv \begin{vmatrix} 0 \\ 1 \end{vmatrix}$$

The derivative-term in $L_3$ produces:

$$L_{3,M} = \frac{v^2}{2}\chi^+\left(\frac{g_0}{2}\vec{\tau}.\vec{A}'_\mu + \frac{g'_0}{2}B'_\mu\right)^2\chi =$$

$$= \frac{v^2}{8}\left\{ g_0^2\left[(A'^1_\mu)^2 + (A'^2_\mu)^2\right] + \left[g_0 A'^3_\mu - g'_0 B'_\mu\right]^2\right\}$$

$$W^\pm \equiv \frac{1}{\sqrt{2}}\left[A^1 \mp i A^2\right]$$

$$L_{3,M} \equiv M^2_{0W}\left[W^+_\mu W^{-\mu}\right] + \frac{1}{2}M^2_{0Z}\, Z_\mu Z^\mu$$

where $M^2_{0W} = g_0^2 v^2/4$

and $\frac{1}{2}M^2_{0Z}\, Z_\mu Z^\mu \equiv \frac{v^2}{8}\left[g_0 A'^3_\mu - g'_0 B'_\mu\right]^2 =$

$$= \frac{v^2}{8}\begin{vmatrix} A'^3_\mu & B'_\mu \end{vmatrix} \begin{vmatrix} g_0^2 & -g g'_0 \\ -g g'_0 & g'^2_0 \end{vmatrix} \begin{vmatrix} A'^\mu \\ B'^\mu \end{vmatrix} \equiv$$

$$\equiv \frac{1}{2}\begin{vmatrix} Z_\mu & A^\gamma_\mu \end{vmatrix} \begin{vmatrix} M^2_{0Z} & 0 \\ 0 & 0 \end{vmatrix} \begin{vmatrix} Z^\mu \\ A^{\mu\gamma} \end{vmatrix}$$

The physical states are obtained diagonalizing the "mathematical" states mass matrix via the $\theta_0$-rotation:

$$\operatorname{tg}\theta_0 \equiv g_0'/g_0$$

$$\sin\theta_0 \equiv s_0 = \frac{g_0'}{\sqrt{g_0^2+g_0'^2}}$$

$$\cos\theta_0 \equiv c_0 = \frac{g_0}{\sqrt{g_0^2+g_0'^2}}$$

Thus, by construction:

$$Z_\mu = c_0 A'^3_\mu - s_0 B'_\mu$$
$$A^\gamma_\mu = s_0 A'^3_\mu + c_0 B'_\mu$$

and $$M_{0Z}^2 = \frac{v^2}{4}\left(g_0^2 + g_0'^2\right)$$

$$\left(M_\gamma^2 = 0\right)$$

$$\boxed{\theta_0 \equiv \text{Weinberg-Salam angle}}$$
$(\Rightarrow \theta_W \ldots)$

In terms of the physical states $Z_\mu$, $A_\mu^\gamma$, the part of $L_1$ that describes the neutral interactions of fermions can be written as:

$$L_{1,NC} \equiv e_0 \, J_\mu^{e.m.} A^{\mu\gamma} + \frac{e_0}{s_0 c_0} J_\mu^{Z} Z^\mu$$

$$\left\{ \text{with} \qquad \underline{e_0} \equiv \underline{g_0 s_0} \equiv \underline{g_0' c_0} \right\}$$

and $$J_\mu^{Z} \equiv J_\mu^{(I_{3L})} - s_0^2 \, J_\mu^{e.m.}$$

Thus, the Z couplings to fermions will be:

$$g_{L,R}^{f} = (I_{3L})_{L,R} - s_0^2 \, (Q_f)$$

$$(Q_f \equiv e/|e|)$$

with $$J_\mu^{Z} \equiv \sum_f \left[ g_{0L}^{f} \, \bar{f}_L \gamma_\mu f_L + g_{0R}^{f} \, \bar{f}_R \gamma_\mu f_R \right]$$

(equivalently $$\equiv \sum_f \bar{f} \left[ g_{0V}^{f} \gamma_\mu - g_{0A}^{f} \gamma_\mu \gamma_5 \right] f;$$

$$g_{0V} \equiv \frac{1}{2} (g_{0L} + g_{0R}); \qquad g_{0A} \equiv \frac{1}{2} (g_{0L} - g_{0R}))$$

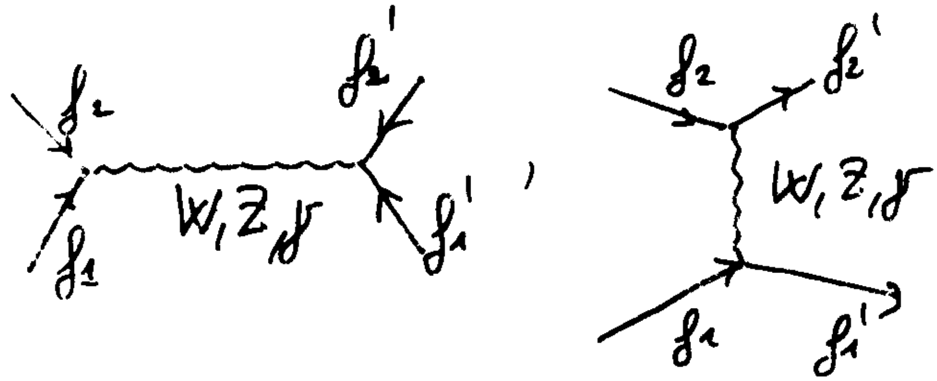
Analogously, one can write for the charged component:

$$L_{1,cc} = \frac{g_0}{\sqrt{2}} \left( J_\mu^+ W^{+\mu} + J_\mu^- W^{-\mu} \right)$$

where $J_\mu^+ = J_\mu^1 + i J_\mu^2 =$

$$= \sum_f \left[ \frac{1}{2} \bar{\nu}' \gamma_\mu (1-\gamma_5) e' + \frac{1}{2} \bar{u}' \gamma_\mu (1-\gamma_5) d' \right]^f$$

The fermion - g.bosons interactions to lowest order, corresponding to four fermion processes of the kind




will depend at this order on $e_0$, $s_0$, $M_{0Z}$, $M_{0W}$

( we assume that in the unitary gauge "naive" Feynman rules are valid, But: from the expressions of the g.b. masses one has

$$\frac{M_{0W}^2}{M_{0Z}^2} = \frac{g_0^2}{g_0^2+g_0'^2} \equiv c_0^2$$

that is more conveniently written

$$\frac{M_{0W}^2}{c_0^2 M_{0Z}^2} = 1 .$$

Therefore one can eliminate one of the 3 parameters e.g. $c_0 \Rightarrow s_0$ and retain, to describe 4-fermion processes at tree level, the set (e.g.) $e_0$, $M_{0W}$, $M_{0Z}$ (~at the time 70)

The elimination of one parameter is due to the formal identity

$$\rho_0 = \frac{M_{0W}^2}{c_0^2 M_{0Z}^2} = 1$$

that is peculiar of the MSM. In fact, it is not completely accidental.

A better way of understanding it is to consider the "mathematical" (1,1) element of the non-diagonal 2x2 mass matrix in the $(A^{3}_{\mu}, B_{\mu})$ basis $\equiv M^2_{03} \equiv \frac{v^2}{4} g_0^2 \equiv c_0^2 M^2_{0Z}$.

Then one can alternatively define

$$\rho_0 \equiv \frac{M^2_{0W}}{M^2_{03}} = 1$$

and this is a consequence of a residual SU(2) <u>global</u> "custodial" symmetry of the scalar potential after SSB (in this case, reflected into the fact that $(A^1_\mu)^2, (A^2_\mu)^2, (A^3_\mu)^2$ appear symmetrically in $L_{3,M}$).

(a more general proof exists).

# SM predictions: tree level

From the previously defined SM Lagrangian one can already make a number of "tree level" predictions, e.g. for $M_W, M_Z$!

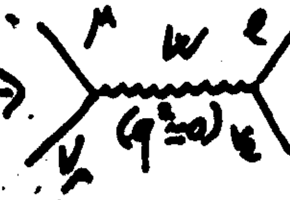
Since several unknown parameters are involved, one has to choose a specific "optimal" strategy.

The latter in turn is, almost unavoidably, related to the available experimental facilities.

~ 20 years ago, the approach was the following:

I) Consider the "fundamental" equality ("tree level" SM quantities)

$$\frac{G_\mu}{\sqrt{2}} = \left[\frac{g^2}{8 M_W^2}\right]^{tree} \quad \left(\equiv G_\mu \rightarrow \right.$$




"lowest order" SM parameters implied)

as a "prediction" for $M_W$:

$$M_W^{(tree)} = \sqrt{\frac{\sqrt{2}\, g^{2\,(tree)}}{8\, G_\mu}} = \quad (e \equiv g\, s_W) \quad (s_W \equiv \sin\theta_W)$$

$$= \sqrt{\frac{\sqrt{2}\, e^{2\,(tree)}}{8\, G_\mu}} \quad \frac{1}{s_W^{(tree)}}$$

At this "lowest order" calculation $e^{(tree)} \equiv e = \sqrt{4\pi\alpha_{QED}}$, and one gets:

$$\boxed{M_W^{(tree)} = \frac{37.2804\ldots\ \text{GeV}}{s_W^{(tree)}}}$$

(error from $G_\mu$ negligible.....).

As a byproduct of the previous derivation:

$$\frac{G_\mu}{\sqrt{2}} \equiv \frac{g^2}{8 M_W^2} \equiv \frac{1}{2v^2}$$

$$\Rightarrow \quad v = \frac{1}{2^{1/4}} \frac{1}{\sqrt{G_F}} \simeq 250\,\mathrm{GeV}$$

($\sim$ "scale" of $SU(2)_L \times U(1)_Y$ BREAKING).

II) Consider the tree level identity:

$$\left[\frac{M_W}{M_Z}\right]^{(tree)} = \cos\theta_W^{(tree)} \equiv c_W^{(tree)} \equiv \left|\sqrt{\frac{g^2}{g^2+g'^2}}\right|^{(tree)}$$

as a "prediction" for $M_Z^{(tree)}$:

$$\boxed{M_Z^{(tree)} = \frac{M_W^{(tree)}}{c_W^{(tree)}} = \frac{37.2804\ldots \text{ GeV}}{(s_W c_W)^{(tree)}}}$$

III) Measure $s_W$ ($c_W$) from a suitable experiment.

IV) Give numbers for $M_W, M_Z \Longrightarrow$

$\Rightarrow$ then .....

# Find W, Z ~ at the predicted masses.

("spectacular" ≡ *** prediction)

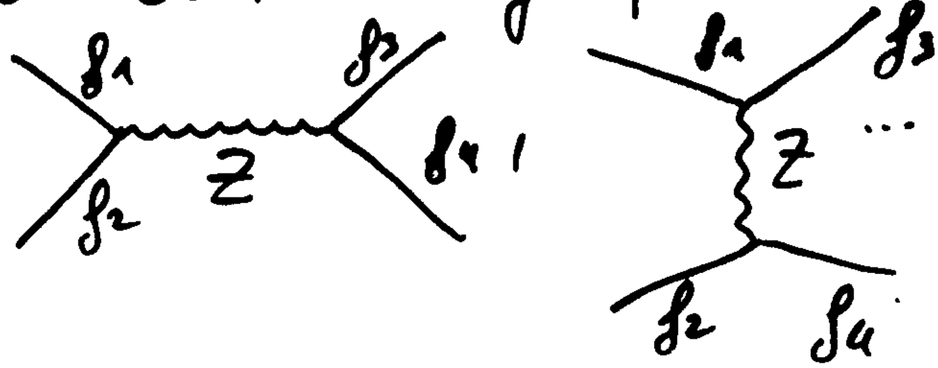
Fundamental for this original approach: choose a <u>suitable</u> process to "measure" $s_W$.

Which process was <u>suitable</u> ~ 20 years ago?

<u>I</u>ntuitively, a process that was <u>differently</u> described by <u>Fermi th. and SM</u>

At tree level, the relevant difference comes from **virtual Z exchange** e.g. in a four fermion process $f_1 + f_2 \Rightarrow f_3 + f_4$.

("neutral" current graphs

~ 

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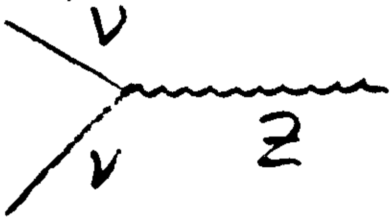
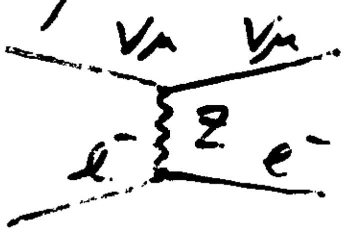
In particular: the vertex




is not appearing in Fermi + QED.

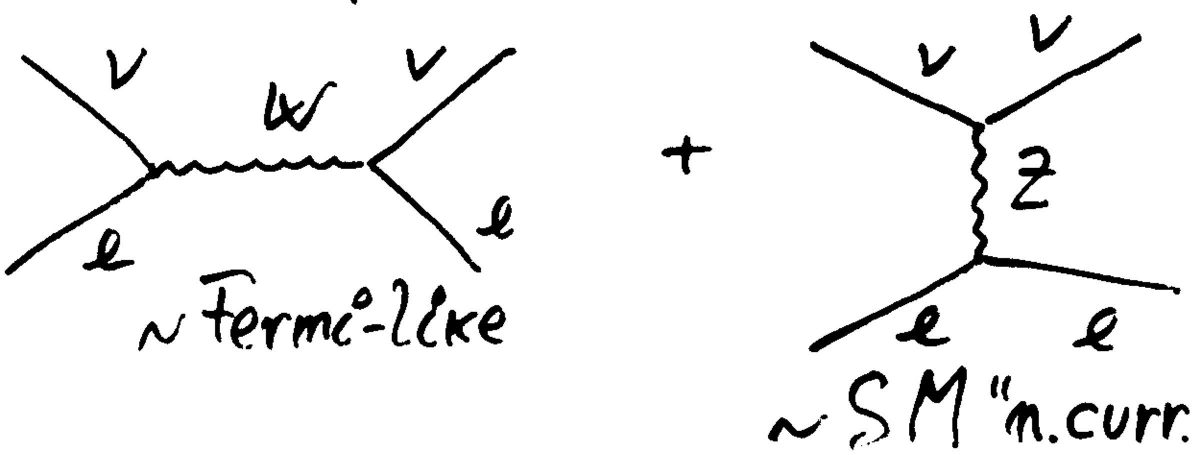
$\Rightarrow$ typically: the process $\nu_\mu e^- \Rightarrow \nu_\mu e^-$ is allowed by SM, but NOT by Fermi+QED



Also, a process like

$$\nu_e e^- \longrightarrow \nu_e e^-$$

is differently parametrized in a Fermi-like (charged current) picture and in the SM:




In fact, the first historycal (memorable) indirect evidence for a "SM-like" picture came from the observation of neutral current events in ν-hadrons at CERN by Gargamelle (Hasert et al 1973)

Then, five years of confusion

(negative result in search of neutral current effects in atoms – Atomic Parity Violation, APV – at Clarendon lab., Oxford)

until <u>1978</u> when

C. Prescott et. al. (SLAC, Stanford)

N.B.

by scattering of <u>LONGITUDINALLY POLARIZED</u> electrons on deuterons identified neutral current effects beyond any doubt (Clarendone agreed.)

N.B.

Longitudinal $e^-$ ($e^+$) polarization is a key-point in the SM since $e_{L,R}$ couple differently to the Z (and equally to the $\gamma$)

$\Longrightarrow$ in the SM there will be non zero long. polar. asymmetries

$$\left( \sim \frac{\sigma_{e_L} - \sigma_{e_R}}{\sigma_{e_L} + \sigma_{e_R}} \right)$$

From 1978 to 1983:
several n. curr. experiments leading to an average value:

$$s_W^2\,(1983) \simeq 0.22 \pm 0.02$$

Thus, at the beginning of 1983, one had the predictions:

$$\boxed{M_W^{(\text{true})} \simeq (79 \pm 3)\ \text{GeV}}$$
(approximate .....)

$$\boxed{M_Z^{(\text{true})} \simeq (90 \pm 3)\ \text{GeV}}$$
(approximate .....)

In 1983, at the end of a memorable search, the UA1 collaboration led by C. Rubbia at CERN found experimental evidence for the existence of W, Z with a mass (first values):

$$\frac{M_W}{\text{GeV}} = (81.0 \pm 5.0)$$ (Phys. Lett. B 122, 103)

$$\frac{M_Z}{\text{GeV}} = (95.2 \pm 2.5)$$ (Phys. Lett. B 126, 398)

$\Longrightarrow$ SM at "tree" level

undeniably impressive.

To make more enthusiastic claims:

calculation (<u>and</u> verification)

of next order perturbative

"electroweak" effects

(analogy with $(g-2)_\mu$ ...)

<u>compulsory.</u>