1990 Schedule.

Feb 90

(Interrupted by Kyoto visit Nov 89 – Jan 90)

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1. Weisskopf decomposition of self-energy

2. Bootstrap w. Higgs only

3. Inclusion of Gauge fields

4. Structure of Higgs
   Decays, etc.

5. QSusy models.
   GUT "

Weisskopf decomposition. + tadpole cancellation.

1. Tadpole condition → $G : f$ or $m_\sigma : m_f$ fixed.

2. Fermion loops & boson loops separately Λ^2-free for certain models: $U(1) \times U(1) \to U(1)$, $SU(2) \times SU(2) \to SU(2)$
see p. 32–34.

3 Does not work if color is included.

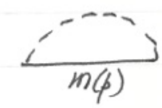
4. Meaning of 2. not clear. But would this lead to $m_u : m_d$ for $SU(2) \times U(1)$ model?

5 Can m_f be generated without a tadpole?

Question: Higgs bootstrap.

With scalar boson only. with $\langle\sigma\rangle = m_0 \neq 0$.
Can $m(p)$ be soft?
DS equation is

$$m(p) = m_0 + \Sigma(p) \qquad \Sigma(p) =$$



$$\Sigma(p) \to -m_0, \quad p \to \Lambda.$$

Structure of $\Sigma(p) \sim g \dfrac{m(k)}{k^2 - m^2(k)} \dfrac{1}{(p-k)^2 - \mu^2(p-k)}$

$$\sim \frac{m(k)}{k^2} \frac{1}{(p-k)^2}$$

so $\dfrac{m(k)}{k^2} \equiv \psi \qquad m(k) = k^2 \psi = -\Box \psi(x)$

$$\frac{1}{p^2} \to \frac{1}{x^2}$$

$$-\Box \psi(x) = m_0 \delta^4(x) + g \frac{1}{x^2} \psi(x)$$

indicial eq. for $\psi(x)$:

$$n(n+2) + g = 0 \qquad n = -1 \pm \sqrt{1-g}$$

If $\psi \sim \frac{1}{x}$, $\Rightarrow \Box\psi, \ \frac{1}{x^2}\psi \sim m(x) \sim \frac{1}{x^3}$

This does not produce $\delta^4(x)$

If $\psi \sim \frac{1}{x^2} \to$ produces $\delta^4(x)$ but $m(k) \not\to 0$.

$n = -2$ only if $g = 0$.

N.B. $g > 0$ for vector
< 0 scalar
> 0 pscalar

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Solving S-D eq. numerically.

4-dim polar coordinates.

$$\frac{1}{(p-k)^2+\mu^2} \to \frac{1}{p^2-2pk\cos\Omega+k^2+\mu^2}$$

$$d^4k = C k^3 dk\, d\Omega \sin^2\Omega\ , \quad C = 2\pi^2$$

$$\int \frac{2\pi^2 \sin^2\Omega\, d\Omega}{p^2-2pk\cos\Omega+k^2+\mu^2}\, k^3 dk$$

$$= \int_0^\pi \frac{2\pi^2}{2pk}\cdot k^3 \frac{\sin^2\Omega\, d\Omega\, dk}{\lambda-\cos\Omega} \qquad \lambda = \frac{p^2+k^2+\mu^2}{2pk}$$

$$\int d\Omega \equiv \frac{1}{2pk} F\left(\frac{p^2+k^2+\mu^2}{2pk}\right) \qquad \text{sym. between } p \,\&\, k$$

$$\int \frac{\sin^2\Omega\, d\Omega}{\lambda-\cos\Omega} = \int_{-1}^{1} \frac{\sqrt{1-z^2}\, dz}{\lambda-z} = \pi\left(\lambda-\sqrt{\lambda^2-1}\right)$$

$$\lambda^2-1 = \frac{(p-k)^2+\mu^2}{2pk}\ \frac{(p+k)^2+\mu^2}{2pk} \equiv \alpha\beta$$

$$\lambda = \frac{1}{2}(\alpha+\beta)$$

$$\lambda-\sqrt{\lambda^2-1} = \frac{1}{2}(\alpha+\beta)-\sqrt{\alpha\beta} = \frac{1}{2}(\sqrt{\alpha}-\sqrt{\beta})^2$$

$$\begin{matrix}\alpha\\ \beta\end{matrix} = \frac{1}{2}\left[\left(\sqrt{\frac{p}{k}} \pm \sqrt{\frac{k}{p}}\right)^2 + \frac{\mu^2}{pk}\right]$$

self-en. integral.

$$m(p) = \frac{\pm g^2}{(2\pi)^4}\int_0^\infty \frac{2\pi^2}{2pk}\cdot k^3 dk \cdot \pi \cdot \frac{1}{2}(\sqrt{\alpha}-\sqrt{\beta})^2 \frac{m(k)}{k^2+m^2(k)}$$

$$\lambda - \sqrt{\lambda^2-1} = \cancel{2}1 \Big/ (\lambda + \sqrt{\lambda^2-1}) = \frac{1}{\lambda}\ \frac{1}{1+\sqrt{1-1/\lambda^2}}$$

$$\lambda > 1$$

$$\int = g^2 \frac{2\pi^{\cancel{2}3}}{(2\pi)^4}\int \frac{k^3 dk}{2pk}\ \frac{1}{\lambda}\ \frac{1}{1+\sqrt{1-1/\lambda^2}}\cdot\frac{m}{k^2+m^2}$$

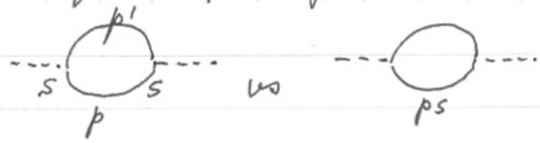
$$= g^2\frac{2\pi^{\cancel{2}3}}{(2\pi)^4}\int \frac{k^3 dk}{p^2+k^2+\mu^2}\ \frac{1}{1+\sqrt{1-\frac{1}{\lambda^2}}}\ \frac{m}{k^2+m^2}$$

$$\sim \frac{g^2}{8\pi}\int \frac{k^3 dk}{p^2+k^2+\mu^2}\ \frac{m}{k^2+m^2}$$

This form looks simple enough.

~~N. B.~~

scalar field pole from



$$I_s : \quad \frac{4(p\cdot p' + m_p m_{p'})}{(p^2-m^2)(p'^2-m^2)} \qquad I_p : \quad \frac{4(p\cdot p' - m_p m_{p'})}{(p^2-m^2)(p'^2-m'^2)}$$

$$I_s - I_p(0) = \cancel{\frac{8 m_p m_{p'}}{(p^2-m^2)(p'^2-m^2)}} \qquad I_p(0) = \frac{4(p^2-m_p^2)}{(p^2-m_p^2)^2} = \frac{4}{p^2-m_p^2}$$

or Euclidean metric:

$$8 m_p m_{p'} / (p^2+m^2)(p'^2+m'^2)$$

$$\psi_p \equiv m / p^2+m^2$$

$$\rightarrow \quad I \sim \iint \psi_p \, \psi_{p'} \, \delta^4(p-p'-k)$$

N.B. Inconsistency: $U(1)\times U(1)$ case, the S-D equation cannot produce log terms for mass.

Variational principle for m:

$$L = \int \left[-\frac{1}{2} \ln (p^2 + m_p^2) + \frac{m_p^2}{p^2 + m_p^2} \right] d^4p$$

$$\oplus \; \frac{1}{2} \iint \frac{m_p}{p^2 + m_p^2} \, \frac{1}{(p-k)^2 + \mu^2} \, \frac{m_k}{k^2 + m_k^2}$$

The problem is that the $\int$'s are $\sim \Lambda^2$

The $\iint$ term $\sim \iint \psi_p \frac{1}{(p-p')^2 + \mu^2} \psi_{p'}$

Expansion of  in k^2

$$I_s =: \frac{4(p\cdot p' + mm')}{(p^2-m^2)(p'^2-m'^2)} \qquad I_p(0) = \frac{4(p^2-m^2)}{(p^2-m^2)(p^2-m^2)}$$

$$p \to p - k/2 \,, \quad p' \to p + k/2$$

$$\frac{1}{p^2-m^2} \to \frac{1}{p^2 - p\cdot k + \frac{k^2}{4} - m^2} \to \frac{1}{(p^2-m^2)} + \frac{1}{(p^2-m^2)^2}\left(p\cdot k - \frac{k^2}{4}\right) + \frac{(p\cdot k)^2}{(p^2-m^2)^3}$$

$$\frac{1}{p'^2-m^2} \to \frac{1}{p^2-m^2} + \frac{1}{(p^2-m^2)^2}\left(-p\cdot k - \frac{k^2}{4}\right) + \frac{(p\cdot k)^2}{(p^2-m^2)^3}$$

$$p\cdot p' + mm' \to p^2 - \frac{k^2}{4} + mm'$$

$$\left\{\begin{matrix} I_s \\ -\,I_p \end{matrix}\right. \Rightarrow 4\left[\frac{p^2}{(p^2-m^2)^2} + \frac{p^2}{(p^2-m^2)^3}\left(-\frac{k^2}{2}\right) + \frac{-(p\cdot k)^2 p^2}{(p^2-m^2)^4} + \frac{2p^2(p\cdot k)^2}{(p^2-m^2)^4} + \frac{2m^2 - k^2/4}{(p^2-m^2)^2}\right]$$

$$(p\cdot k)^2 \to \frac{1}{4}p^2k^2$$

$$\Rightarrow 4 \frac{p^2}{(p^2-m^2)^3}\left(-\frac{k^2}{2} + 2m^2\right)$$

so the mass $\doteq 4\int \frac{p^2 m^2}{(p^2-m^2)^3} \Big/ \int \frac{p^2}{(p^2-m^2)^3}$

Euclidean metric $\doteq 4\langle m^2 \rangle$

$$\langle m^2 \rangle = \int \frac{p^2 d^4p}{(p^2+m^2)^3}\, m^2 \Big/ \int \frac{p^2}{(p^2+m^2)^3}\, d^4p$$

$$p^2 \equiv x \qquad \int \frac{x m^2}{(x+m^2)^3}\cdot x\, dx \Big/ \frac{x^2\, dx}{(x+m^2)^3}$$

or $\sim \int_m^\Lambda \frac{dp}{p}\, m^2 \Big/ \int_m^\Lambda \frac{dp}{p}$

$$m \sim p^{-\gamma} \rightarrow \langle m^2 \rangle = \frac{1}{2\gamma}\left(m^{-2\gamma} - \Lambda^{-2\gamma}\right) / \ln\frac{\Lambda}{m}$$

$$= \frac{1}{2\gamma} m^{-2\gamma}\left(1 - \left(\frac{\Lambda}{m}\right)^{-2\gamma}\right) / \ln\frac{\Lambda}{m}$$

↳ should be normalized to m.

Next the gap eq :

$$\frac{g^2}{(2\pi)^4} \cdot 2\pi^2 \int \frac{dp}{p} m_p = m$$

For constant m, $\frac{g^2}{8\pi^2} \ln\frac{\Lambda}{m} = 1 \rightarrow \frac{\Lambda}{m} = e^{\frac{8\pi^2}{g^2}}$

Anomalous dim γ :

$$m(p) = \frac{g^2}{(2\pi)^4} \int \frac{m\, d^4k}{k^2 - m^2} \frac{1}{(p-k)^2 - \mu^2}$$

If $\mu = 0$: $(-\Box + m^2)\psi = \frac{g^2}{4\pi^2} \frac{1}{x^2} \psi$

$$\rightarrow n(n+2) + \frac{g^2}{4\pi^2} = 0 \qquad n = -1 + \sqrt{1 - \frac{g^2}{4\pi^2}}$$

$$\gamma = -n = 1 - \sqrt{1 - \frac{g^2}{4\pi^2}}$$

$$\langle m^2 \rangle = \frac{1}{2\gamma} \cdot \left(1 - e^{-2\gamma \frac{8\pi^2}{g^2}}\right) / 8\pi^2/g^2$$

$$= \frac{1}{y}\left(1 - e^{-y}\right), \qquad y = 2\gamma \Big/ \frac{g^2}{8\pi^2} = 2\, \frac{1 - \sqrt{1-x}}{\frac{1}{2}x}$$

$$= 4\, \frac{1 - \sqrt{1-x}}{x} \qquad x = \frac{g^2}{4\pi^2}$$

$$= 4 \big/ \left(1 + \sqrt{1-x}\right)$$

For $x = 0$: $y = 2$

$$\langle m^2 \rangle = \frac{1}{2}\left(1 - e^{-2}\right)$$

Interruption: SU(5) Quasi-SUSY

1. matching OK for 3 gen. + SU(5) gauge field
   + 2 adjoint Higgs.

2. No Yukawa O.K.

3. How to break $SU(5) \to 1 \times 2 \times 3$:

$W(\phi, \phi^{+})$: $\phi = 5 \times \bar{5}$

$\exists$ four ways to construct bilinears

$\phi \times \phi \to$ adjoint: $\phi^{\times}_{\circ} \phi^{\times}_{\circ} \to 5 \cdot \bar{5}$ or $\bar{5} \cdot 5$

$\underbrace{\overbrace{\phi^{\times}_{\circ} \cdot \phi^{\times}_{\circ}}^{\bar{10}}}_{10} \times \psi_{\circ\circ}$: $\downarrow \bar{10}$

$\underbrace{\overbrace{\phi^{\times}_{\circ} \phi^{\times}_{\circ}}^{\bar{10}}}_{10}$ $\psi^{\times\times}$

ϕ: $5 \times \bar{5} = 1 \oplus$ $\times 5 =$ $\oplus$ $\oplus$

$\times \bar{10} =$ $\oplus$ $\oplus$

$\times 1 = 0 +$

$\exists$ four one-column reps. , $\times 2$, 0

In momentum space, The DS eq.

$$m(p) = \frac{g^2}{(2\pi)^4} \int \frac{d^4k}{(p-k)^2} \frac{m(k)}{k^2+m^2(k)}$$

$$\Box_p^2 m = -\frac{g^2}{4\pi^2} \frac{m(p)}{p^2+m^2(p)}$$

$$m_p \sim p^\gamma \qquad \gamma(\gamma+2) + \frac{g^2}{4\pi^2} = 0$$

$$\gamma = -1 \pm \sqrt{1-\frac{g^2}{4\pi^2}}$$

If $g^2 \to g^2(k) \sim k^{-\alpha}$: $\alpha > 0$

Then no singularity from the potential,

so $\qquad \gamma = 0, -2$

$\hookrightarrow$ bare mass $\qquad$ $\longrightarrow$ soft mass

Higgs bootstrap

The DS eq has PS - S contributions

$$\frac{1}{(p-k)^2} - \frac{1}{(p-k)^2+m_\sigma^2} = \frac{1}{(p-k)^2((p-k)^2+m_\sigma^2)} \cancel{m_\sigma^2}$$

$$m(p) = \frac{g^2}{(2\pi)^4} \int \frac{m(k)}{k^2+m^2} \cancel{\frac{1}{m_\sigma^2}} \frac{m_\sigma^2}{(p-k)^2[(p-k)^2+m_\sigma^2]}$$

If m is soft, $m \sim 1/p^4$

If "hard" ~~$m \sim 1/p^2$~~ ? $m \sim$ const.

In x-space $\frac{1}{k^2} \to \frac{1}{x^2}$, $\frac{1}{k^2+m^2} \to \frac{1}{x^2} + m^2 \ln x$

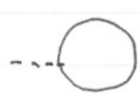
so the kernel $\sim m^2 \ln x$

$\to \quad \psi \equiv \frac{m}{k^2+m^2} \quad \psi(x) \sim x^\gamma \quad \gamma = 0, -2$

$\to \quad m^{(x)} = (-\Box^2 + m^2)\, \psi(x) \sim x^0, x^{-4}$

$\to \quad \cancel{m(k) \sim} \quad \psi(k) \sim k^{-4-\gamma}$

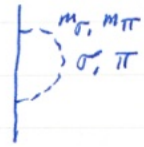
$m(k) \sim k^{-2-\gamma} \to k^0$ or k^{-2}

If tadpole exists,  $< \infty$ for soft m.

If $m \to$ const, then $\int \sim \frac{1}{p^2} \ln p \to 0$

Consistency requires tadpole $= 0$ if m soft.

Fermion mass gap eq:

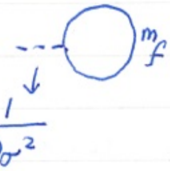
$m_f =$  $+$ 

Boson mass

$m_\sigma^2 =$  $+$ 

$m_\pi^2 =$  $+$ 

Can a tadpole be generated $\langle \sigma \rangle \neq 0$?

Then $v = v_0 +$  $+$ 

The Λ^2 terms are

$$v = v_0 + \frac{1}{4G^2 v_0^2}\left[C_f f^2 v_0^2 + C_\sigma G_0 v_0^2\right]\Lambda^2$$

or
$$v = v_0 + \frac{1}{4G^2 v_0}\left[C_f f^2 + C_\sigma G_\sigma^2\right]\Lambda^2$$

$$\rightarrow \quad v - v_0 = \frac{1}{4G^2 v}\left[\ \cdots\ \right]\Lambda^2$$

Then let $v_0 \rightarrow 0$

$$v^2 = \frac{1}{4G^2}\left[\sum c_i f_i^2\right]\Lambda^2$$

For v^2 to be small : $\sum c_i f_i^2 = 0$

Then

$$v^2 = \frac{1}{4G^2}\left[-\sum c_i f_i^2 m_i^2\right] C \ln \frac{\Lambda^2}{v^2}$$

or $$1 = \frac{1}{4G^2}\left[-\sum c_i' f_i^4\right] C \ln \frac{\Lambda^2}{v^2} \quad \text{gap eq.}$$

If $\Sigma \neq 0$, $\quad \frac{1}{\cancel{G}} \ln \frac{\Lambda}{v} = O(f^2)$

and $\quad \sum c_i' f_i^4 < 0$

If $\Sigma = 0 \rightarrow$ "$\ln \frac{\Lambda}{v}$" $= O(1)$

$$C \sim \frac{1}{16\pi^2}$$

$$c_1 = 4N_f, \quad c_2 = 12$$
$$c_2' = 6$$

But if Λ-dependence goes away, the scale v cannot be fixed.

~~A~~ Can ~~σ~~ m_f be generated without v?

$$\frac{1}{k^2} - \frac{1}{k^2+m_\sigma^2} = \frac{m_\sigma^2}{k^2(k^2+m_\sigma^2)}$$

leads to $m(p) \to m_0$ (p.48)
Is there a solution?

In x-space, the D-S equation is

$$(-\Box^2 + m^2)\,\psi = \frac{g^2}{\cancel{(2\pi)^4}} \left(\Delta_0(x^2) - \Delta_m(x^2)\right)\psi$$

$$\psi(k) = \frac{m(k)}{k^2+m^2}, \qquad \Delta_0 = \frac{1}{4\pi^2}\frac{1}{x^2}$$

$$\Delta_1 = \frac{1}{4\pi^2} K_1(mx)/x$$

$$K_1(\cancel{z}x) = \frac{1}{x} + \frac{x}{2}\ln\frac{x}{2} + \cdots$$

$$\frac{1}{x}K_1 = \frac{1}{x^2} + \frac{1}{2}\ln\frac{x}{2}$$

$$-V \sim \Delta_0 - \Delta_1 \to \frac{1}{4\pi^2}\left(-\frac{1}{2}\ln\frac{x}{2} + \cdots\right)$$

The potential is always attractive.

$$V \sim -\ln\frac{1}{x} \qquad \text{small } x$$

$$\sim -\frac{1}{x^2} \qquad \text{large } x \gg \frac{1}{m_\sigma}$$

$$m(x) \approx V\psi \sim \frac{1}{x^2}\psi$$

$\psi(x)$ must be regular near $x \sim 0$

Else $\Box\psi$ would have a δ-fn

Bubble integrals

1. $\displaystyle\int \frac{d^4k}{(k^2+m^2)^n} = \pi^2 \frac{\Gamma(n-2)}{(m^2)^{n-2}}$

$n=2: \quad \rightarrow \pi^2\left(\Lambda^2 - m^2 \ln \frac{\Lambda^2}{m^2}\right)$

2. I_S  $\dfrac{4}{16\pi^2}\left\{\Lambda^2 + \left(\frac{p^2}{2} - 3m^2\right)\ln \Lambda^2\right\}$

$= (a) + (b)$

3. I_P " $\left\{\Lambda^2 + \left(\frac{p^2}{2} - m^2\right)\ln\Lambda^2\right\}$

$= (a) - (b)$

4. I_V $\dfrac{4\cancel{8}}{16\pi^2}\left\{\frac{\Lambda^2}{2} + \frac{p^2}{\cancel{2}\,4}\ln\Lambda^2 - (m-m')^2\ln\Lambda^2\right\} \times(-g_{\mu\nu})$

$= \left[\frac{1}{2}(a) - \cancel{1}(b)\right](-g_{\mu\nu})$

(c) $\dfrac{p^2}{(p^2+m^2)(p'^2+m^2)} = \pi^2\left(\Lambda^2 + 2\left(\frac{1}{6}k^2 - m^2\right)\ln\frac{\Lambda^2}{m^2}\right)$

k
~~$p = p'' + \alpha k$~~
$p = p'' + \alpha k$
$p' = p'' - \beta k$

(a) $\dfrac{p\cdot p'}{(p^2+m^2)(p'^2+m^2)} = \pi^2\left[\Lambda^2 + \left(\frac{k^2}{2} - 2m^2\right)\ln\frac{\Lambda^2}{m^2}\right]$

$2m^2 \downarrow m^2+m'^2$

(b) $\dfrac{m^2}{(\quad)(\quad)} = -\pi^2 m^2 \ln\frac{\Lambda^2}{m^2}$

$m^2 \downarrow mm'$

Fierz $\quad S + P \rightarrow \frac{1}{2}(-V + A)$

$\boxed{\text{Fierz formulas}}$

$$(\sigma\cdot\sigma)^2 = 3 - 2\sigma\cdot\sigma \qquad P_{\sigma\cdot\sigma} = \frac{3-\sigma\cdot\sigma}{2}$$

$U(1)\times U(1)$: $(S+P) \rightarrow (-V+A)/2$ (metric + ~~[illegible]~~)

$$SU(2)\times SU(2): (S+\tau P) \rightarrow \tfrac{1}{4}(S+\tau P) - \tfrac{1}{4}(P+\tau S)$$

$$- \tfrac{1}{2}(V-A)$$

$$+ \tfrac{1}{4}\, T\,(1-\tau\cdot\tau) \qquad T = (\rho_3\rho_3 - \rho_2\rho_2)\,\sigma\cdot\sigma$$

Gap eq.

$$1 = \frac{1}{m_H^2} \sum c_i g_i^2 \left(\Lambda^2 - m_i^2 \ln \frac{\Lambda^2}{m_i^2}\right)$$

(1) Λ^2 condition

$$y = \frac{1}{4}x + \frac{1}{4}(2+r) \qquad r = \frac{m_Z^2}{m_W^2} = 1.299$$

for $\sin^2\theta = .23$

$$y = \left(\frac{m_t}{m_W}\right)^2$$

$$x = \left(\frac{m_H}{m_W}\right)^2$$

(2) ln condition

$$* \quad \left(\tfrac{1}{2}\right) m_H^2 v^2 = \left[-12 m_f^4 + \frac{3}{2} m_H^4 + 3(2m_W^4 + m_Z^4)\right] C$$

$$C = \frac{1}{16\pi^2} \ln \frac{\Lambda^2}{m^2}$$

$v \sim 3 m_W$

$$\rightarrow \frac{1}{2}\frac{9x}{C} = -12 y^2 + \frac{3}{2}x^2 + 3(2+r^2)$$

$$y^2 = \frac{1}{8}x^2 - \frac{3}{2 \cdot 48 C}x + \frac{1}{4}(2+r^2)$$

From (1) $$y^2 = \frac{x^2}{16} + \frac{1}{8}(2+r)x + \frac{1}{16}(2+r)^2$$

$$\rightarrow x^2 - 2\left(2+r+\frac{6}{2C}\right)x + 4\left(1-r+\frac{3}{4}r^2\right) = 0$$

$$t \equiv 6/2C = \frac{96}{2}\pi^2/\ln\Lambda^2 = \frac{48}{2}\pi^2/\ln\Lambda$$

GUT $\Lambda/m \sim 10^{13}$ $\quad \ln \Lambda/m \sim 30$ $\quad t \sim 16/2 = 8$

Planck $\quad 10^{17}$ $\quad \sim 40$ $\quad \sim 12/2 = 6$

$\Lambda/m \sim 10^4$ $\quad \ln \sim 10$ $\quad \sim 50/2 = 25$

Mixing of ϕ and A_{long} without the 't Hooft gauge.

$$L = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + m^2 A_\mu A^\mu - \alpha (\partial \cdot A)^2 + \cdots$$

In the (ϕ, A_ℓ) space, $A_\ell = q \cdot A / q$

$$L = \begin{pmatrix} q^2 & imq \\ -imq & -\alpha q^2 + m^2 \end{pmatrix} \qquad L^{-1} = \frac{1}{-\alpha q^4} \begin{pmatrix} -\alpha q^2 + m^2 & -imq \\ imq & q^2 \end{pmatrix}$$

$$= -\frac{1}{\alpha q^4} \underset{(1)}{\begin{pmatrix} m^2 & -imq \\ imq & q^2 \end{pmatrix}} + \frac{1}{q^2} \underset{(2)}{\begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}}$$

(1) is related to the Ward identity when coupled to the source: $L(p')\gamma_5 + \gamma_5 L(p) = \gamma_5 \gamma \cdot \underset{\substack{\parallel \\ q}}{(p - p')} + 2m\gamma_5$

(2): massless ps.

$\alpha \to \infty$ means the Landau gauge.

Quantum no assignments

$$Q = I_3 + Y/2$$

	I_3	Y
u_L	$1/2$	$1/3$
u_R	0	$4/3$
D_L	$-1/2$	$1/3$
D_R	0	$-2/3$
e_L	$-1/2$	-1
e_R	0	-2
H^0	$1/2$	-1
H^-	$-1/2$	-1