Dynamical mass generation and symmetry breaking

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Basic concepts

Continuum field theory

The (Euclidean) action defines the theory

$$S_E\,[\phi] \;=\; \int d^4x\; \mathscr{L}(\phi(x), \partial_\mu \phi(x))$$

with a classical field functions ϕ and $\mathscr{L}$ being the solution of the Euler-Langrange equation

$$\frac{\partial \mathscr{L}(x)}{\partial \phi(x)} - \partial_\mu \left(\frac{\partial \mathscr{L}(x)}{\partial\left(\partial_\mu \phi(x)\right)} \right) \;=\; 0$$

Quantisation of field function ϕ: Generating functional with source J

$$Z_E[J] \;=\; \int \mathcal{D}\phi \cdot \exp\left\{ -S_E[\phi] - \int d^4x\, \phi(x)\, J(x) \right\}$$

Calculation of Green's functions by

$$G_N(x_1, \ldots, x_N) \;=\; \langle 0 | T[\widehat{\phi}(x_1) \cdots \widehat{\phi}(x_N)] | 0 \rangle$$

$$= \; \frac{1}{Z_E[0]} \, \frac{\delta^N Z_E[J]}{\delta J(x_N) \cdots \delta J(x_1)} \bigg|_{J=0}$$

Performing the Legendre transformation

$$\Gamma_E[\phi_{\text{eff}}] \;=\; \ln Z_E[J] - \int d^4x\, \phi_{\text{eff}}(x)\, J(x)$$

leads to the generating functional of the proper Green's functions Γ_N

In Fourier space we have

$$(2\pi)^{4(1-N)}\delta^4(k_1+\cdots+k_N)\, g_0^{N-2}\, \Gamma_N(k_1,\ldots,k_N)$$

$$= \left.\frac{\delta^N \Gamma_E[\phi_{\text{eff}}]}{\delta\phi_{\text{eff}}(k_N)\cdots\delta\phi_{\text{eff}}(k_1)}\right|_{J=0}$$

With functional chain rules one can show

$$D(k)\,\Gamma_2(k) \;=\; -1$$

In a graphical notation the Γ_N are

- connected
- truncated
- 1-particle-irreducible

If you know the Γ_N you know all the physics!

Dyson-Schwinger equations

Invariance of $\Gamma_E[\phi]$ under variation of field functions $\phi \to \phi + \delta\phi$ yields Dyson-Schwinger equations

$$\begin{aligned}\Gamma_N &= \Gamma_N^{(0)\text{pert}} \\ &\quad + \left(\frac{g_0}{4\pi}\right)^2 \Phi_N\Big[\Gamma_2, \Gamma_3, \ldots, \Gamma_N, \Gamma_{N+1}, \Gamma_{N+2}\Big]\end{aligned}$$

- $\Gamma_N^{(0)\text{pert}}$ are perturbative Feynman rules
- Φ_N supply loop integrals

DS equations are exact relations between the vertex functions Γ_N

DS equations generate (semi-convergent) perturbation series

$$\Gamma_N^{\text{pert}} = \lim_{p\to\infty} \Gamma_N^{[p]\text{pert}}$$

$$\Gamma_N^{[p]\text{pert}} = \Gamma_N^{(0)\text{pert}} + \sum_{p'=1}^{p} \left(\frac{g_0}{4\pi}\right)^{2p'} \Gamma_N^{(p')\text{pert}}$$

for small coupling constant g_0

Not so basic concepts

Renormalisation

Loop integrals Φ_N produces divergencies

Regulation of the theory by setting $D = 4 - 2\varepsilon$, keeping $\varepsilon \to 0$ in mind

Lagrangian $\mathscr{L}$ no longer dimensionless, so substitute $g_0 \to g_0 \nu_0^\varepsilon$

We assume that our theory is strictly renormalisable!

Subtract divergencies depending on renormalisation scheme (MS, $\overline{MS}$); therefore defnine renormalised quantities

- running mass scale ν
- running coupling $g(\nu)$

The spontaneous mass scale Λ

Is there an intrinsic mass scale in the theory?

$$\nu \frac{d}{d\nu} \Lambda(g(\nu), \nu)\Big|_{g_0} \stackrel{!}{=} 0$$

After some algebra we obtain

$$\left(\nu \frac{\partial}{\partial \nu} + \beta\left(g(\nu), \epsilon\right) \frac{\partial}{\partial g}\right) \Lambda(g(\nu), \nu) = 0$$

$$\beta\left(g(\nu), \epsilon\right) := \nu \frac{d}{d\nu} g(\nu)$$

We know from perturbation theory

$$\beta\left(g(\nu), \epsilon\right) = -g(\nu)\left(\epsilon + \beta_0 \left(\frac{g(\nu)}{4\pi}\right)^2 + \mathcal{O}(g^4)\right)$$

After more algebra we find

$$\Lambda(g(\nu), \nu)^2 = \nu^2 \, e^{-\frac{1}{\beta_0}\left(\frac{4\pi}{g(\nu)}\right)^2} \left[\beta_0 \left(\frac{g(\nu)}{4\pi}\right)^2\right]^{-\frac{\beta_1}{\beta_0^2}}$$

$$\cdot \left\{1 - \frac{\beta_1^2 - \beta_0 \beta_2}{\beta_0^3} \left(\frac{g(\nu)}{4\pi}\right)^2 + \mathcal{O}(g^4)\right\}$$

Λ is nonanalytic in the coupling and exponentially supressed in perturbation theory!

Operator product expansion (OPE)

What do we learn from Wilson? Consider a two point function for small distance x:

$$\begin{aligned} D(x) &= \langle 0|\widehat{\phi}\,(x)\,\widehat{\phi}\,(-x)\,|0\rangle \\ &= \sum_{n=0}^{\infty}\sum_{i=1}^{l(n)} W_{n,i}(x)\langle 0|\widehat{\mathcal{O}}_{2n,i}(0)|0\rangle \end{aligned}$$

- $\widehat{\mathcal{O}}_{2n,i}(x)$ composite operators
- $W_{n,i}(x)$ Wilson coefficients

In Fourier space we have the function

$$-\Gamma_2(k) = k^2 \sum_{n=0}^{\infty}\sum_{i=1}^{l(n)}\sum_{q=0}^{\infty} V_{n,i}^{(q)}\left(\frac{g(\nu)}{4\pi}\right)^{2q} \cdot\frac{1}{(k^2)^n}\langle 0|\widehat{\mathcal{O}}_{2n,i}(0)|0\rangle$$

In massless theories condensates scale only with the Λ parameter!

Series expansion of the condensate

$$\langle 0|\widehat{\mathcal{O}}_{2n,i}(0)|0\rangle \;=\; (\Lambda^2)^n \sum_{t=0}^{\infty} c_{n,i}^{(t)} \left(\frac{g(\nu)}{4\pi}\right)^{2t}$$

leads to a double expansion of vertex functions in g and Λ

$$-\Gamma_2(k) \;=\; k^2 \sum_{n=0}^{\infty} \sum_{p=0}^{\infty} u_n^{(p)} \left(\frac{g(\nu)}{4\pi}\right)^{2p} \left(\frac{\Lambda^2}{k^2}\right)^n$$

$\Rightarrow$ Starting point for extended iterative scheme!

With above formula for the Λ scale we obtain

$$-\Gamma_2(k) \;=\; k^2 \sum_{n=0}^{\infty} \left(\frac{\nu^2}{k^2}\right)^n \left(e^{-\frac{1}{\beta_0}\left(\frac{4\pi}{g(\nu)}\right)^2}\right)^n$$

$$\cdot \left\{ \left(\beta_0 \left(\frac{g(\nu)}{4\pi}\right)^2\right)^{-n\frac{\beta_1}{\beta_0^2}} \sum_{p=0}^{\infty} \tilde{u}_n^{(p)} \left(\frac{g(\nu)}{4\pi}\right)^{2p} \right\}$$

in form of a resurgent double expansion

The extended iterative scheme

Definition of the scheme

$$\Gamma^{[r,p)}(\Lambda^2) \quad \text{approximates} \quad \sum_{n=0}^{\infty} b_n^{(p)} \left(\frac{\Lambda^2}{k^2}\right)^n$$

- p order of perturbative series
- r degree of approximation

The "real" vertex functions are now reconstructed by

$$\Gamma_N(\{k\},\Lambda) = \lim_{r\to\infty} \lim_{p_{\mathrm{max}}\to\infty} \Gamma_N^{[r,p_{\mathrm{max}}]}(\{k\},\Lambda)$$

with quasiperturbative series

$$\Gamma_N^{[r,p_{\mathrm{max}}]}(\{k\},\Lambda) = \Gamma_N^{[r,0]}(\{k\},\Lambda) + \sum_{p=1}^{p_{\mathrm{max}}} \left(\frac{g(\nu)}{4\pi}\right)^{2p} \Gamma_N^{[r,p)}(\{k\},\Lambda)$$

Boundary conditions

- perturbative limit

$$\Gamma_N^{[r,p)}(\{k\}, \Lambda \to 0) \;\longrightarrow\; c_\Gamma \, \Gamma_N^{(p)\mathrm{pert}}(\{k\})$$

- naive asymptotic freedom

$$\Gamma_N^{[r,0]}(\{\lambda k\}, \Lambda) \;\longrightarrow\; c_\Gamma \, \Gamma_N^{(0)\mathrm{pert}}(\{\lambda k\})$$

$$\text{for } \lambda \to \infty$$

  for an asymptotically free theory ($\beta_0 > 0$)

$c_\Gamma \neq 1$: infinite rearrangement of quasiperturbative series

Cannot use Wilson series for vertex functions!

Choice of rational approximants for $\Gamma_N^{[r,0]}(\{k\}, \Lambda)$ with factorising denominators

- spectral representations
- loop integrals are solvable as in perturbation theory

The self-consistency mechanism

Use equations of motion as input for

$$\left\{ \left(\frac{g_0}{4\pi}\right)^2 \Phi_N \left[\Gamma_N^{[r,0]}\right] \right\}_R = \Gamma_N^{[r,0]} - \Gamma_N^{(0)pert} + \mathcal{O}(g^2, e(r+1))$$

- Φ_N depend on renormalisation scheme R
- $\Gamma_N^{[r,p]}(\{k\}, \Lambda)$ for $p > 0$ are constructed automatically

$\Rightarrow$ $\Gamma_N^{[r,0]}(\{k\}, \Lambda)$ are the "new" Feynman rules

The Φ_N have to cancel coupling constant g_0^2, but we know from renormalisation analysis:

$$\Pi(\epsilon) = \left(\frac{g_0}{4\pi}\right)^2 \frac{1}{\epsilon} \left(\frac{\Lambda}{\nu_0}\right)^{-2\epsilon} \xrightarrow{\epsilon \to 0} \frac{1}{\beta_0}$$

$\Rightarrow$ Self-consistency mechanism is restricted to superficially divergent vertices of the theory

$\Rightarrow$ Self-consistency mechanism yields an algebraic (in general nonlinear) system of equations!

The SU(2) model

Action

$$S_E\,[\phi] \;=\; \int d^4x \left\{ \mathscr{L}_V(x) + \mathscr{L}_{FP}(x) + \mathscr{L}_F(x) \right\}$$

3 massless boson fields (2 charged, 1 uncharged)

$$\begin{aligned}
\mathscr{L}_V \;=\; & W^+_\mu \left[-\delta_{\mu\nu}\Box + \partial_\mu\partial_\nu \right] W^-_\nu \\
& + \frac{1}{2} W^0_\mu \left[-\delta_{\mu\nu}\Box + \partial_\mu\partial_\nu \right] W^0_\nu \\
& - i\, g_0 \, (\delta_{\mu\rho}\delta_{\nu\sigma} - \delta_{\mu\sigma}\delta_{\nu\rho}) \Big[\left(\partial_\mu W^+_\nu\right) W^-_\rho W^0_\sigma \\
& \quad + \left(\partial_\mu W^-_\nu\right) W^0_\rho W^+_\sigma + \left(\partial_\mu W^0_\nu\right) W^+_\rho W^-_\sigma \Big] \\
& - \frac{1}{2} g_0^2 \, (\delta_{\mu\nu}\delta_{\rho\sigma} - \delta_{\mu\rho}\delta_{\nu\sigma})\, W^+_\mu W^+_\nu W^-_\rho W^-_\sigma \\
& + g_0^2 \, (\delta_{\mu\nu}\delta_{\rho\sigma} - \delta_{\mu\rho}\delta_{\nu\sigma})\, W^+_\mu W^-_\nu W^0_\rho W^0_\sigma
\end{aligned}$$

No $U(1)$ gauge field!

$\mathscr{L}_{FP}(x)$ contains gauge fixing and Faddeev-Popov ghost fields

4 massless fermion (Dirac) fields

Lepton doublet

$$l(x) = \begin{pmatrix} \nu_e(x) \\ e(x) \end{pmatrix}, \quad \bar{l}(x) = \begin{pmatrix} \bar{\nu}_e(x) & \bar{e}(x) \end{pmatrix}$$

$$\frac{Q}{e} = (T_3)_f + Y_f \quad \text{where} \quad Y_f = -\frac{1}{2}$$

Quark doublet (color charged)

$$q(x) = \begin{pmatrix} u(x) \\ d(x) \end{pmatrix}, \quad \bar{q}(x) = \begin{pmatrix} \bar{u}(x) & \bar{d}(x) \end{pmatrix}$$

$$\frac{Q}{e} = (T_3)_f + Y_f \quad \text{where} \quad Y_f = \frac{1}{6}$$

Fermionic Lagrangian

$$\begin{aligned} \mathscr{L}_F = \; & i\,\bar{q}\,\partial\!\!\!/\, q + i\,\bar{l}\,\partial\!\!\!/\, l \\ & + g_0\,\bar{q}\,T_+\,\gamma_\mu\,q\,W_\mu^+ + g_0\,\bar{l}\,T_+\,\gamma_\mu\,l\,W_\mu^+ \\ & + g_0\,\bar{q}\,T_-\,\gamma_\mu\,q\,W_\mu^- + g_0\,\bar{l}\,T_-\,\gamma_\mu\,l\,W_\mu^- \\ & + g_0\,\bar{q}\,T_0\,\gamma_\mu\,q\,W_\mu^0 + g_0\,\bar{l}\,T_0\,\gamma_\mu\,l\,W_\mu^0 \end{aligned}$$

T_+, T_- and T_3 generators of the gauge group

Our theory is asymptotically free, because

$$\beta_0 = \frac{11}{3}N - \frac{2}{3}N_f = \frac{14}{3} > 0$$

What do we want to understand?

- Generation of boson and fermion masses (without Higgs fields)
- Description of photon γ and Z^0 boson by W^0 field simultaneously possible?
- Hypercharge Y_f as a nonperturbative effect
- Parity violating fermion vertices
- ($\mathcal{CP}$ violation)

Use the extended iterative scheme!

$\Rightarrow$ Construct approximants for vertex functions with above properties

$\Rightarrow$ Study equations of motion with these approximants!

Vertex approximants $r/r+1 = 0/1$

Choice of Landau gauge ($\xi = 0$)

Ghost propagators are perturbative up to a constant factor denoted by $\tilde{c}_\pm$ and $\tilde{c}_0$

$W^\pm$ propagator with 1 pole

$$D_{\mu\nu}^{\pm\,[0,0]}(k) \;=\; t_{\mu\nu}(k)\, D_T^{\pm\,[0,0]}(k^2)$$

$$D_T^{\pm\,[0,0]}(k^2) \;=\; \frac{1}{c_\pm}\frac{1}{k^2 + u^{(1)}_{\pm,1}\Lambda^2}$$

W^0 propagator with 2 poles

$$D_{\mu\nu}^{0\,[1,0]}(k) \;=\; t_{\mu\nu}(k)\, D_T^{0\,[1,0]}(k^2)$$

$$\begin{aligned} D_T^{0\,[1,0]}(k) \;&=\; \frac{1}{c_0}\frac{k^2 + u^{(2)}_{0,1}\Lambda^2}{k^2(k^2 + u^{(1)}_{0,1}\Lambda^2)} \\ &=\; \frac{1}{c_0}\left[\cos^2\phi\frac{1}{k^2} + \sin^2\phi\frac{1}{k^2 + u^{(1)}_{0,1}}\right] \end{aligned}$$

and "mixing angle" $\cos^2\phi \;=\; \frac{u^{(2)}_{0,1}}{u^{(1)}_{0,1}}$

The $\mathcal{C}$ and $\mathcal{CP}$ violating boson vertex

22 possible Lorentz tensors, but restrictions and transversal projections lead to

$$\begin{aligned}\Gamma_{3\ \mu_1\,\nu_1\,\rho_1}^{[0/1,0]\,+\ -\ 0}(k,p,q) &= t_{\mu_1\mu}(k)\,t_{\nu_1\nu}(p)\,t_{\rho_1\rho}(q)\\ &\cdot\Big\{\delta_{\mu\nu}(p-k)_\rho\ F_1^{[r/r+1,0]}(k^2,p^2,q^2)\\ &+\delta_{\nu\rho}(q-p)_\mu\ F_2^{[0/1,0]}(k^2,p^2,q^2)\\ &+\delta_{\rho\mu}(k-q)_\nu\ F_3^{[0/1,0]}(k^2,p^2,q^2)\\ &+\varepsilon_{\mu\nu\rho\sigma}(p-k)_\sigma\ F_4^{[0/1,0]}(k^2,p^2,q^2)\\ &+\varepsilon_{\mu\nu\rho\sigma}q_\sigma\ F_5^{[0/1,0]}(k^2,p^2,q^2)\Big\}\end{aligned}$$

Examples of invariant functions

$$F_1^{[0/1,0]}(k^2,p^2,q^2) = \frac{C_{001}^1 q^2 + C_{000}^0\Lambda^2}{q^2+u_{0,1}^{(2)}\Lambda^2}$$

$$F_4^{[0/1,0]}(k^2,p^2,q^2) = \frac{C_{000}^4\Lambda^2}{q^2+u_{0,1}^{(2)}\Lambda^2}$$

Symmetries: $C_{001}^2 = C_{001}^3$, $C_{000}^2 = C_{000}^3$

Assume the 4-point boson vertices to be perturbative.

Fermion propagators for $f = \nu_e, e, u, d$

$$S_f^{[0,0]}(p) \;=\; \frac{1}{\bar{c}_f} \frac{1}{\not{p} + \omega_{f,1}^{(1)} \Lambda}$$

Fermion 3-point vertices $(f, f') = (\nu_e, l), (u, d)$

$$\bar{\Gamma}_{3\;f'f\;\mu}^{[0,0]\;+}(-p_1, p_2, k) \;=\; -\frac{1}{\sqrt{2}}\, t_{\mu\nu}(k)\; V_{f'fW^+}^{[r]\,000}\, \gamma_\nu$$

$$\bar{\Gamma}_{3\;ff'\;\mu}^{[0,0]\;-}(-p_1, p_2, k) \;=\; -\frac{1}{\sqrt{2}}\, t_{\mu\nu}(k)\; V_{ff'W^-}^{[r]\,000}\, \gamma_\nu$$

$$\begin{aligned}
\bar{\Gamma}_{3\;\;\;ff\;\mu}^{[0/1,0]\;\;0}&(-p_1, p_2, k) \\
&= \; -(T_3)_f\; t_{\mu\nu}(k) \frac{N_{ff\;\nu}^{[0/1]\,0}(\not{p}_1, \not{p}_2, k^2)}{k^2 + u_{0,1}^{(2)} \Lambda^2} \\
&\qquad - \frac{1}{2}\,(\mathbf{1}_2)_f\; t_{\mu\nu}(k) \frac{M_{ff\;\nu}^{[0/1]\,0}(\not{p}_1, \not{p}_2, k^2)}{k^2 + u_{0,1}^{(2)} \Lambda^2}
\end{aligned}$$

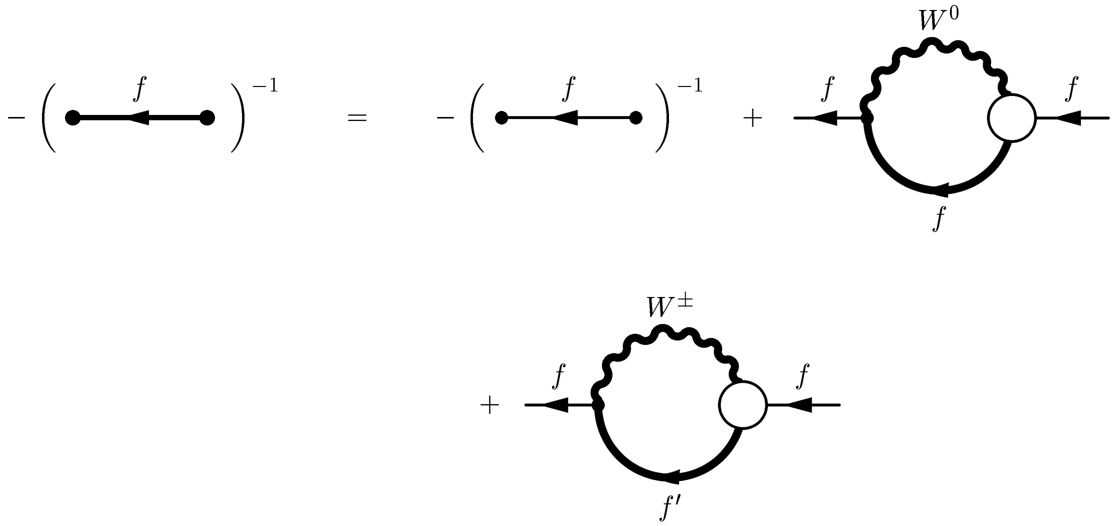
$$\begin{aligned}
N^{[0/1]\;0}_{\;\;ff\;\nu}(\not{p}_1, \not{p}_2, k^2) \;&=\; k^2\, V_{ff\,W^0}^{100}\, \gamma_\nu + \Lambda^2\, V_{ff\,W^0}^{000}\, \gamma_\nu \\
&\quad + \Lambda^2\, A_{ff\,W^0}^{000}\, \gamma_\nu \gamma_5
\end{aligned}$$

$$\begin{aligned}
M^{[0/1]\;0}_{\;\;ff\;\nu}(\not{p}_1, \not{p}_2, k^2) \;&=\; k^2\, W_{ff\,W^0}^{100}\, \gamma_\nu + \Lambda^2\, W_{ff\,W^0}^{000}\, \gamma_\nu \\
&\quad + \Lambda^2\, B_{ff\,W^0}^{000}\, \gamma_\nu \gamma_5
\end{aligned}$$

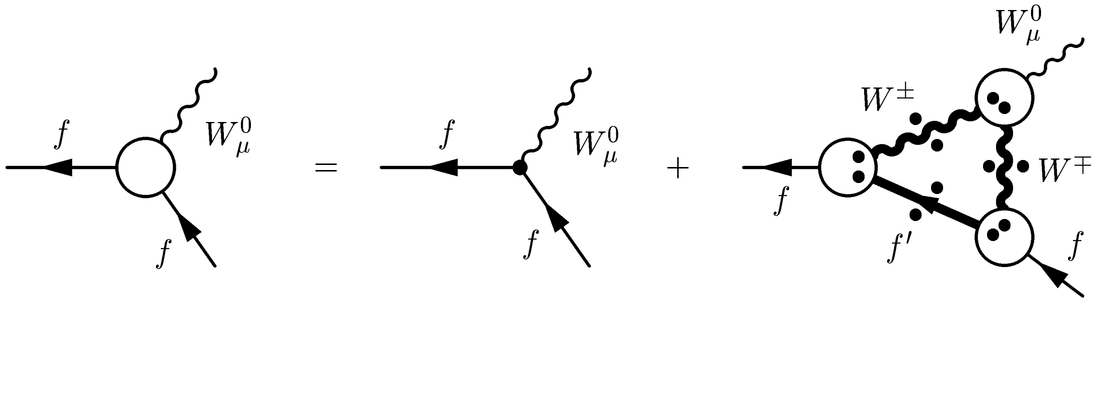
Effective equations of motion

Fermion sector

DS equation for fermion propagators



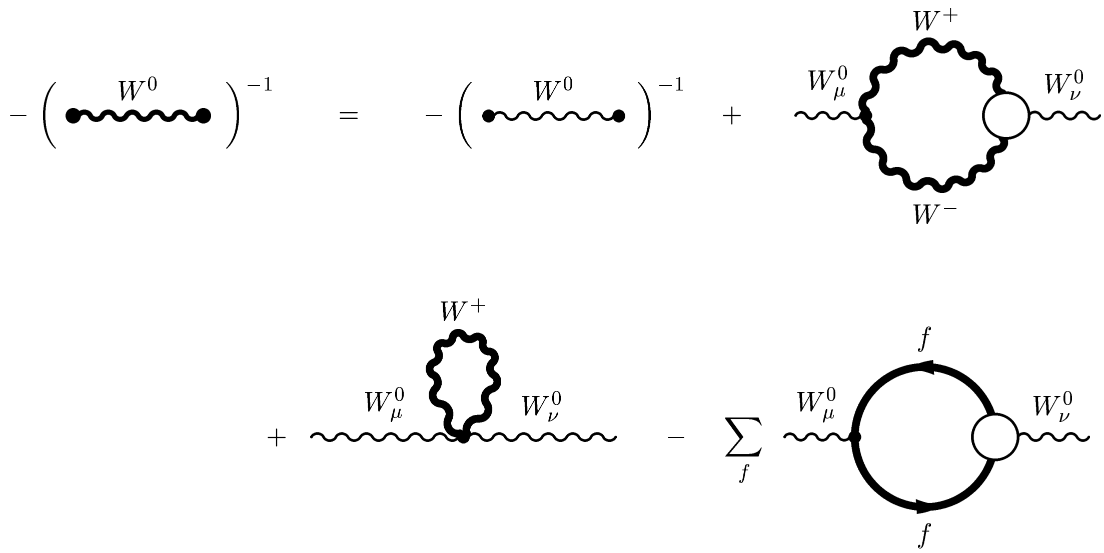
Rearranged (by Bethe-Salpeter equation) DS equations for 3-point vertices for symmetry reasons. For example



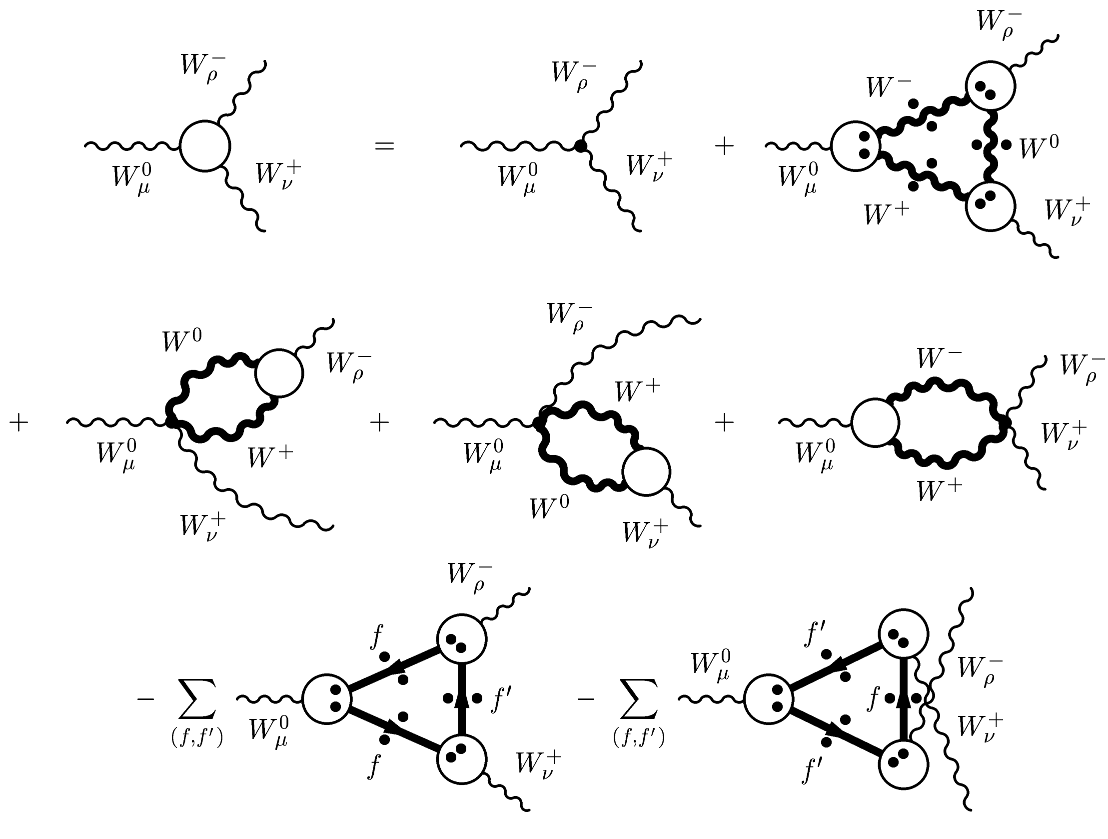
Dotted lines: compensating poles!

Boson sector

Example for a propagator equation (ghost diagrams omitted)



The 3-boson vertex equation (by use of Bethe-Salpeter equations, ghost diagrams omitted)



Numerical results

Solving the system with Hybrid algorithm using

- Newton‘s method (multi-dimensional)
- minimising algorithm to improve convergence

Randomly chosen initial values

Use perturbative limits of 3-point functions as test functions $\phi_{0,1}$ for "good" solutions

Equations scaled with $u^{(1)}_{\pm,1}$

1st step: Search for $\mathcal{CP}$ violation: Negative!
$\Rightarrow$ no γ_5's in the fermion vertices
$\Rightarrow$ Simplification of the system

2nd step: Check the rest for real roots
$\Rightarrow$ 49 physical solutions found

Best solution for the self consistency system:

$N_f = 4$	
$\omega_{l,1}^{(1)} = \omega_{\nu_l,1}^{(1)}$	$0.0000 \sqrt{u_{\pm,1}^{(1)}}$
$\omega_{d,1}^{(1)} = \omega_{u,1}^{(1)}$	$0.0000 \sqrt{u_{\pm,1}^{(1)}}$
$V_{\nu_l l W^+}^{000} = V_{l \nu_l W^-}^{000}$	0.6164
$V_{udW^+}^{000} = V_{duW^-}^{000}$	0.2139
$V_{llW^0}^{100} = V_{\nu_l \nu_l W^0}^{100}$	32.6960
$V_{llW^0}^{000} - W_{llW^0}^{000}$	$2.1774\ u_{\pm,1}^{(1)}$
$V_{\nu_l \nu_l W^0}^{000} + W_{\nu_l \nu_l W^0}^{000}$	$2.1774\ u_{\pm,1}^{(1)}$
$A_{llW^0}^{000} - B_{llW^0}^{000}$	0
$A_{\nu_l \nu_l W^0}^{000} + B_{\nu_l \nu_l W^0}^{000}$	0
$V_{uuW^0}^{100} = V_{ddW^0}^{100}$	5.4248
$V_{ddW^0}^{000} - W_{ddW^0}^{000}$	$2.0105\ u_{\pm,1}^{(1)}$
$V_{uuW^0}^{000} + W_{uuW^0}^{000}$	$2.0105\ u_{\pm,1}^{(1)}$
$A_{ddW^0}^{000} - B_{ddW^0}^{000}$	0
$A_{uuW^0}^{000} + B_{uuW^0}^{000}$	0
$\phi_{0/1}^{0}$	0.9829
$\phi_{0/1}^{1}$	0.0511

$N_f = 4$	
$c_\pm$	0.7900
c_0	6.5905
$u_{0,1}^{(1)}$	$2.8574\ u_{\pm,1}^{(1)}$
$u_{0,1}^{(2)}$	$3.0399\ u_{\pm,1}^{(1)}$
C_{100}^{1}	2.5769
C_{000}^{1}	$0.9006\ u_{\pm,1}^{(1)}$
$C_{100}^{2} = C_{100}^{3}$	1.5583
$C_{000}^{2} = C_{000}^{3}$	$-4.7369\ u_{\pm,1}^{(1)}$
C_{000}^{4}	0
C_{000}^{5}	$4.2748\ u_{\pm,1}^{(1)}$
$\tilde{c}_\pm$	0.3992
$\tilde{c}_0$	0.2486
$\phi_{0/1}^{2}$	0.0764
$\phi_{0/1}^{3}$	−0.7434

Ratio of $W^\pm$ and Z^0 masses $u_{0,1}^{(1)}/u_{\pm,1}^{(1)} = 2.8574$

No fermion masses

No hypercharge

Best solution for the "modified" self consistency system:

$N_f = 4$	
$\omega^{(1)}_{l,1} = \omega^{(1)}_{\nu_l,1}$	$0.0000\,\sqrt{u^{(1)}_{\pm,1}}$
$\omega^{(1)}_{d,1} = \omega^{(1)}_{u,1}$	$0.0000\,\sqrt{u^{(1)}_{\pm,1}}$
$V^{000}_{\nu_l l W^+} = V^{000}_{l \nu_l W^-}$	0.6251
$V^{000}_{udW^+} = V^{000}_{duW^-}$	1.7760
$V^{100}_{llW^0} = V^{100}_{\nu_l \nu_l W^0}$	24.9230
$V^{000}_{llW^0} - W^{000}_{llW^0}$	$1.7542\,u^{(1)}_{\pm,1}$
$V^{000}_{\nu_l \nu_l W^0} + W^{000}_{\nu_l \nu_l W^0}$	0
$A^{000}_{llW^0} - B^{000}_{llW^0}$	0
$A^{000}_{\nu_l \nu_l W^0} + B^{000}_{\nu_l \nu_l W^0}$	0
$V^{100}_{uuW^0} = V^{100}_{ddW^0}$	0.6985
$V^{000}_{ddW^0} - W^{000}_{ddW^0}$	$2.5842\,u^{(1)}_{\pm,1}$
$V^{000}_{uuW^0} + W^{000}_{uuW^0}$	$1.2921\,u^{(1)}_{\pm,1}$
$A^{000}_{ddW^0} - B^{000}_{ddW^0}$	0
$A^{000}_{uuW^0} + B^{000}_{uuW^0}$	0
$\phi^0_{0/1}$	-0.8944
$\phi^1_{0/1}$	0.1746

$N_f = 4$	
$c_\pm$	1.0819
c_0	3.8095
$u^{(1)}_{0,1}$	$2.3853\,u^{(1)}_{\pm,1}$
$u^{(2)}_{0,1}$	$2.5034\,u^{(1)}_{\pm,1}$
C^1_{100}	1.9709
C^1_{000}	$1.0157\,u^{(1)}_{\pm,1}$
$C^2_{100} = C^3_{100}$	1.5639
$C^2_{000} = C^3_{000}$	$-3.9150\,u^{(1)}_{\pm,1}$
C^4_{000}	0
C^5_{000}	$3.0842\,u^{(1)}_{\pm,1}$
$\tilde{c}_\pm$	0.2735
$\tilde{c}_0$	0.1765
$\phi^2_{0/1}$	0.0216
$\phi^3_{0/1}$	-0.9607

There is a hypercharge!

Conclusion and Outlook

Things done

"Built" Approximants for arbitrary r

Calculated Self consistency equations for 2- and 3-point function for arbitrary r

Numerical analysis for $r/r+1=0/1$

Things found

Vertices leave strict perturbative limit $c_\Gamma = 1$

Generation of different masses for $W^\pm$ and Z^0 bosons

W^0 propagator describes photon and Z^0

Creation of fermionic masses possible at $r=1$

Modelling of hypercharges possible

Things to be done (Somebody else)

Symmetry breaking in the fermion sector $\Rightarrow$ different r for fields of a doublet?

$\mathcal{CP}$ violation $\Rightarrow$ higher r or next order of quasiperturbative corrections

Examine equations for 4-point boson vertices

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