Summary of Higgs mechanism (essence of 2nd QFT topic)

- Weak (nuclear) force modeled by gauge boson exchange based on Dirac structure of 4-fermion operator and size being "universal" ... and "hope" for being renormalizable (like QED) ... ... but gauge boson massive (short range)

- However, explicit mass term for gauge boson $\Rightarrow$ propagator $\sim 1/M_A^2$ in UV-limit, superficially **non**-renormalizable

- (Another) However, "annoying" piece of propagator does not contribute if fermion couples vectorially to gauge boson (current conserved) $\Rightarrow$ actually renormalizable

- Focus instead on chiral coupling of fermion to gauge boson (as in weak nuclear force empirically): current not conserved $\Rightarrow$ bad behavior of propagator relevant, (possibly) non-renormalizable

massive

— So, try gauged SSB: $\mathcal{L}$ symmetric (cf. explicit mass term), i.e., "gentle" breaking, so "hope" remnant of some features of unbroken theory, i.e., renormalizability

— indeed, in "warm-up" with global case, we get relations between couplings in broken phase, which subtly "realize" renormalizability in radial representation for complex scalar ...

— also, massless scalar (NGB), with derivative interactions (in linear representation for complex scalar, resulting from relations among non-derivative couplings)

— Unitarity gauge (based on radial representation of scalar): only physical d.o.f, i.e., NGB "eaten" by gauge boson, which becomes massive, acquiring longitudinal polarization (in addition to 2 transverse for massless case)

— However, renormalizability not manifest: indeed, gauge boson

propagator same as with explicit mass term, but presence of Higgs boson with SSB (absent for explicit mass term), which cannot be decoupled for chiral coupling indicates hope for renormalizability (jury still out!)

– In order to shed light on renormalizability, "switch" representation of scalar to linear, leading to general/R_ξ-gauge, where gauge boson propagator $\sim \frac{1}{k^2}$ in UV limit (for fixed ξ) $\Rightarrow$ clearly renormalizable ...

... but trade-off is inclusion of 2 unphysical d.o.f. ("would-be" NGB & time-like/scalar polarization of gauge boson) as (only) internal lines: "necessary" for manifest renormalizability (like adding longitudinal & time-like

or scalar polarization in QED to have manifest Lorentz covariance)

– Relatedly, would-be NGB contribution to amplitude ξ-dependent ... so is that of time-like/scalar polarization (again, the 2 unphysical d.o.f.) ... in such a manner that in total amplitude is ξ-independent

– So, we can perform loop calculations for fixed ξ with no ξ in end result (even though ξ appears in intermediate steps) ... of course, divergences under control (as indicated above); then take $\xi \to \infty$ limit, (again, without affecting physics) ... which is unitarity gauge, so unitarity gauge is also "secretly" renormalizable!

– As in any scientific process, "ultimate" test of a theory is verifying its predictions: in this case, Higgs boson (absent with explicit mass term) and precise loop calculations (again, not possible with explicit mass term: non-renormalizable) ...

... needless to say, both achieved successfully for weak force!

– As an aside, Higgs mechanism is a robust/natural possibility within QFT (whether or not realized in Nature): again, just QED with charged scalar having mass^2 (in potential) < 0 (~50% "chance"!)