Unitarity in $W_L^+ W_L^-$ scattering without a Higgs particle

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Presented at

Field Theory: Recent Trends and Applications, IISER-Kolkata

22-25 August, 2011

Based on arXiv:1107.1501, with Debmalya Mukhpadhyay

Current status of Higgs searches

Lepton-Photon 2011 announced on Aug 22

"ATLAS and CMS [crudely] taken together exclude all regions for the Standard Model Higgs particle except

- below 145 GeV,
- the range 288-296 GeV, and
- above 464 GeV."

– Matt Strassler, live blogging from Lepton-Photon 2011

What if the Higgs particle really does not exist?

Without a Higgs particle

Usual explanations do not work for

$\rightarrow$ vector boson mass

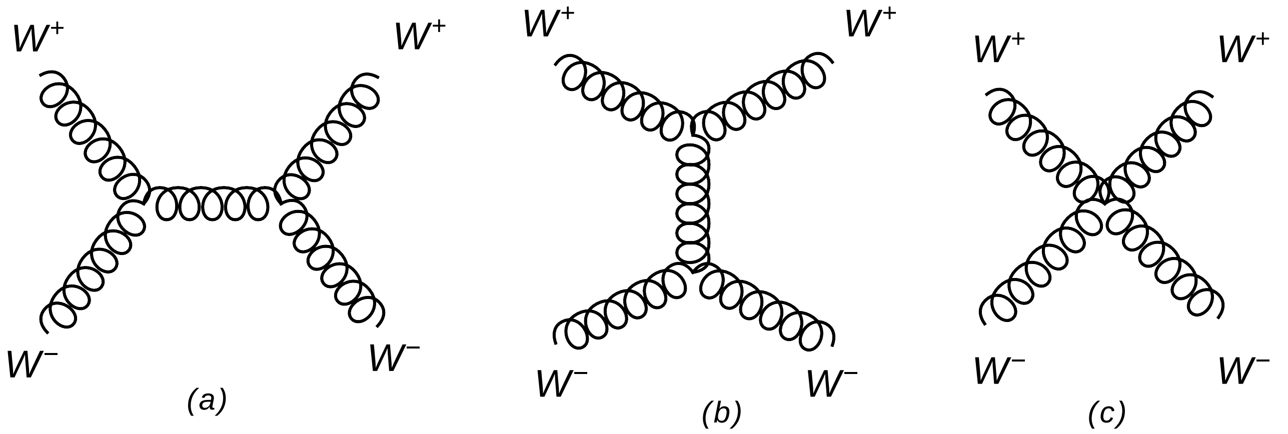
$\rightarrow$ SU(2)$\times$U(1) breaking
  $\rightsquigarrow$ $W - Z$ mass difference

$\rightarrow$ chiral symmetry breaking
  $\rightsquigarrow$ fermion masses

Fundamental inconsistencies in theory?

$W_L^+ W_L^- \to W_L^+ W_L^-$ at high energy

SU(2) vector bosons with massive propagators

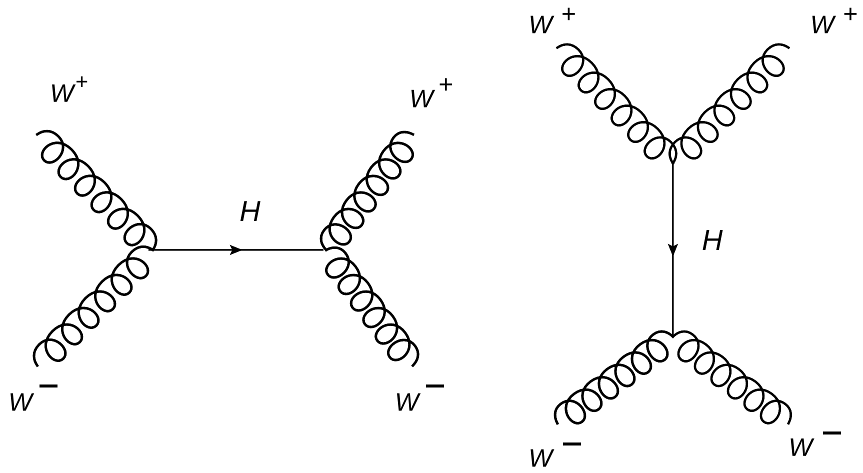


$$\mathcal{M}_W = \mathcal{M}_a + \mathcal{M}_b + \mathcal{M}_c \quad \sim \quad \frac{g^2 P^2}{2m^2}(1 + \cos\theta)$$

Unitarity requires Re $\mathcal{M} < \frac{1}{2} \Rightarrow$ conflict with QM!

Higgs to the rescue

Two more diagrams if there is a Higgs particle



$$\mathcal{M}_H = \mathcal{M}_s + \mathcal{M}_t \sim -\frac{g^2 P^2}{2m^2}(1+c)$$

Unitarity is salvaged!

Avoiding the Higgs field

Need two things from any alternative

- Vector boson mass generation

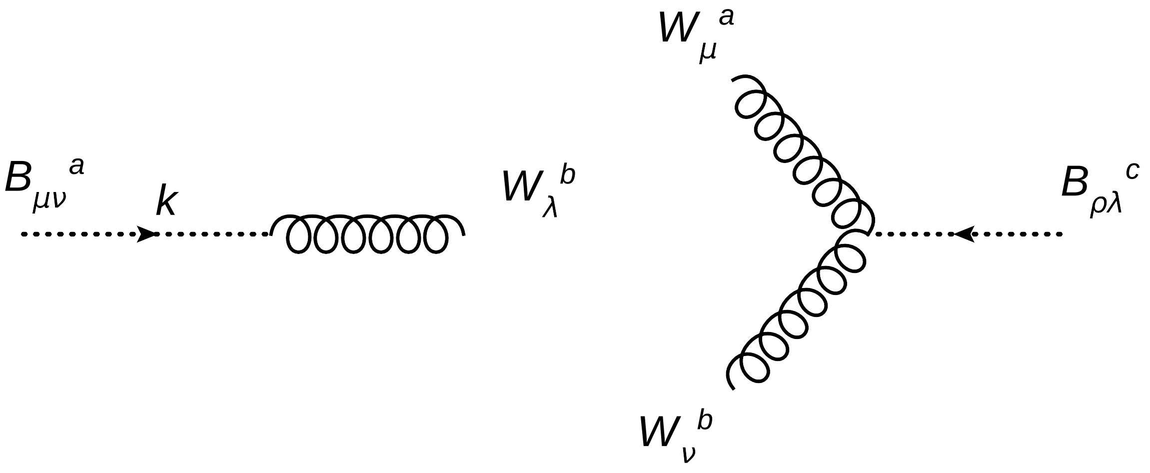
  $\rightarrow$ Must have propagator $\sim \dfrac{1}{k^2}$ as $k \to \infty$

- 3-point vertex with vectors
- (Also other things like renormalizability, absence of ghosts, SU(2)$\times$U(1) breaking $\ldots$)

The Alternative

Triplet of antisymmetric tensor fields $B^a_{\mu\nu}$

Coupled as $m\,\mathrm{Tr}\, B \wedge F = \frac{m}{4}\epsilon^{\mu\nu\lambda\rho} B^a_{\mu\nu} F^a_{\lambda\rho}$



$$
\begin{aligned}
iV^{ab}_{\mu\nu,\lambda} &= -m\delta^{ab}\epsilon_{\mu\nu\lambda\rho}k^\rho \\
iV^{abc}_{\mu,\nu,\lambda\rho} &= -igmf^{bca}\epsilon_{\mu\nu\lambda\rho}\,,
\end{aligned}
$$

Vector Boson Mass

Start with 'bare' propagators

$$i\Delta^{ab}_{\mu\mu'} = \frac{-ig_{\mu\mu'}}{k^2+i\varepsilon}\delta^{ab} \qquad i\Delta^{ab}_{\mu\nu,\mu'\nu'} = i\frac{g_{\mu[\mu'}g_{\nu']\nu}}{k^2+i\varepsilon}\delta^{ab}\,,$$

W propagator = sum over B insertions

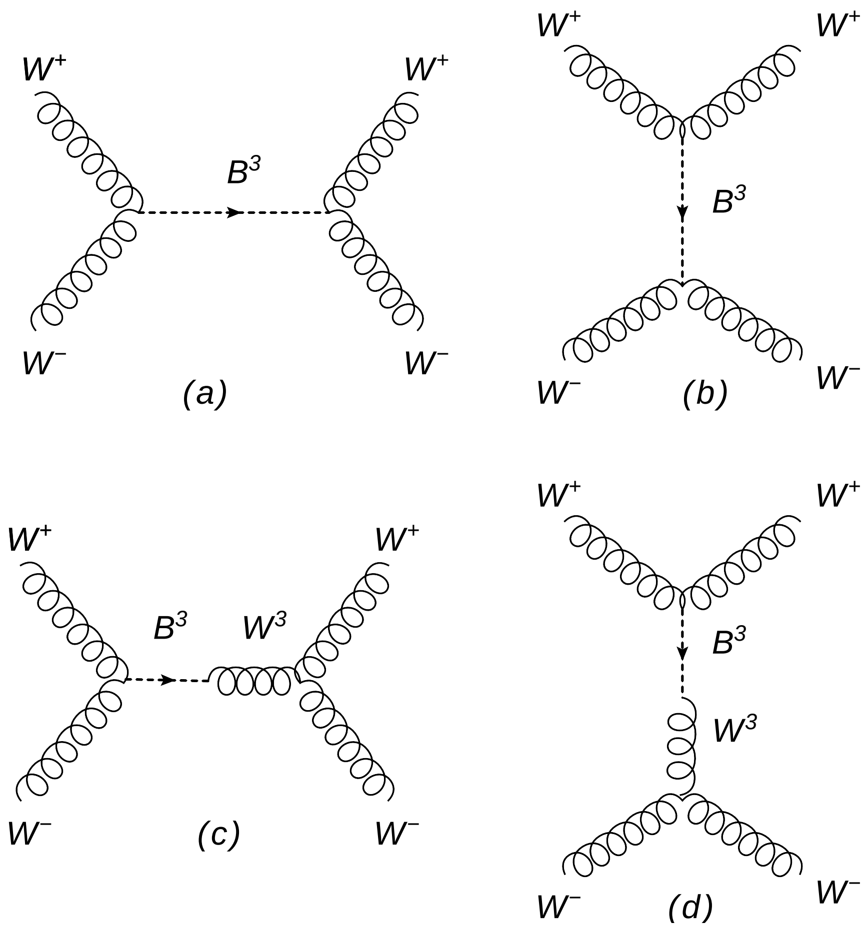
$$\begin{aligned} iD_{\mu\nu} &= i\Delta_{\mu\nu} + i\Delta_{\mu\mu'}iV_{\sigma\rho,\mu'}\frac{i}{4}\Delta_{\sigma\rho,\sigma'\rho'}\,iV_{\sigma'\rho',\nu'}i\Delta_{\nu'\nu} + \cdots \\ &= \frac{-ig_{\mu\nu}}{k^2+i\varepsilon}\left(1+\frac{m^2}{k^2}+\frac{m^4}{k^4}+\cdots\right) = \frac{-ig_{\mu\nu}}{k^2-m^2+i\varepsilon}\,, \end{aligned}$$

Mass Generation: Comments

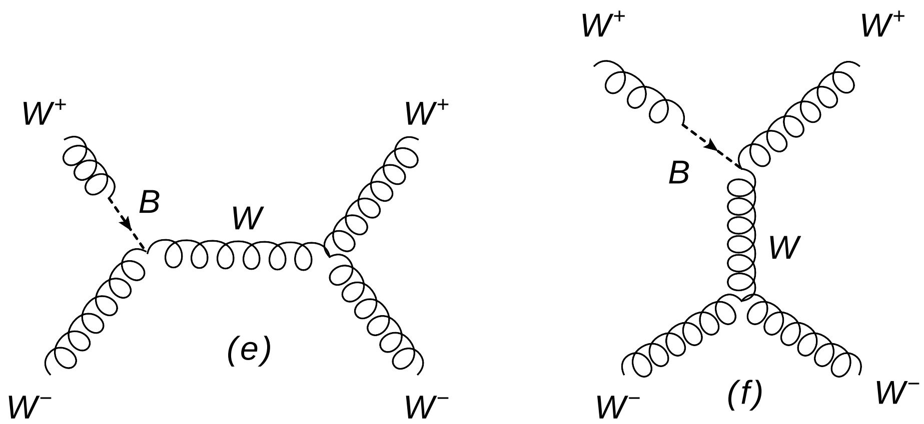
- $\rightarrow$ Massive vector propagator $\sim 1/k^2$ at large k
- $\rightarrow$ B acts like the Goldstone mode of the Higgs field
- $\rightarrow$ B does not take a vev
- $\rightarrow$ All three vectors have the same mass
- $\rightarrow$ $SU(2)$ is unbroken
- $\rightarrow$ No Higgs or Higgs-like particle

B-mediated diagrams

Using the vertices from the $B \wedge F$ term



B-mediated diagrams cont'd



$$\mathcal{M}_{a+b} + 2\mathcal{M}_{c+d} + 4\mathcal{M}_{e+f} \sim (-\frac{3}{2} + 3 - 2)\frac{g^2 P^2}{m^2}(1+c)$$
$$= -\frac{g^2 P^2}{2m^2}(1+c) = -\mathcal{M}_W$$

Unitarity is safe! Can we go home now?

Kinetic Term for B

B propagator came from

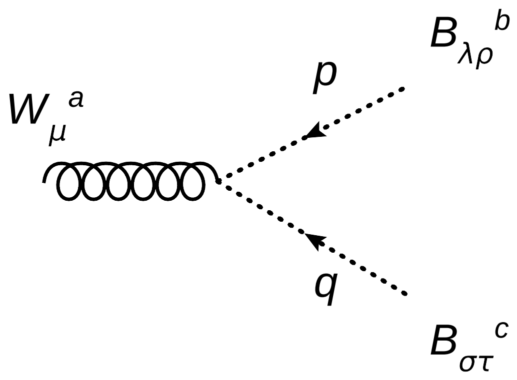
$$\frac{1}{12} H^a_{\mu\nu\lambda} H^{a\mu\nu\lambda}, \quad H_{\mu\nu\lambda} = D_\mu B_{\nu\lambda} + D_\nu B_{\lambda\mu} + D_\lambda B_{\mu\nu}$$

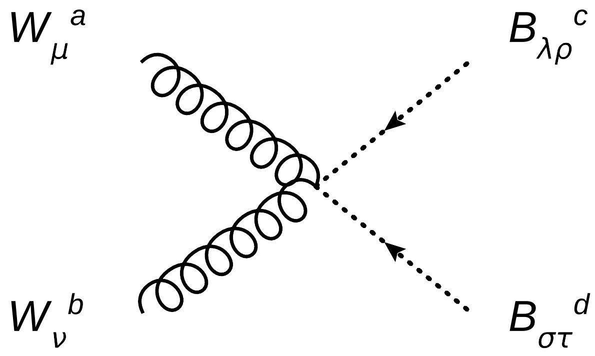
Leads to two more vertex rules

$\rightarrow$ from $dB \cdot [A, B]$

$\rightarrow$ from $[A, B] \cdot [A, B]$

More vertices

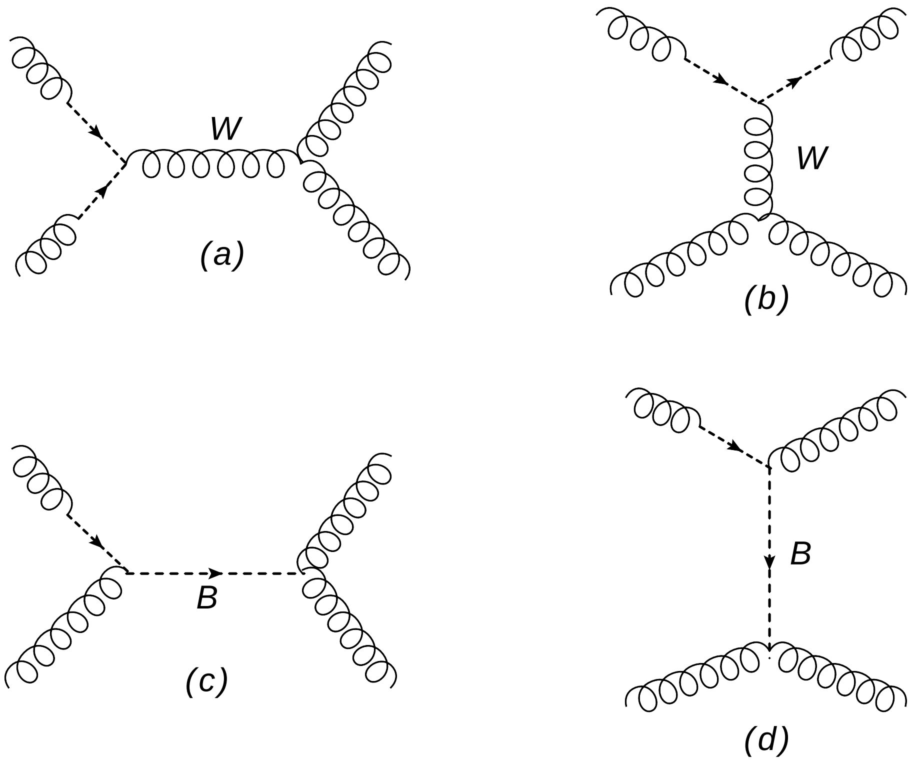




$$
\begin{aligned}
iV^{abc}_{\mu,\lambda\rho,\sigma\tau} &= gf^{abc}\left[(p-q)_\mu g_{\lambda[\sigma}g_{\tau]\rho} + p_{[\sigma}g_{\tau][\lambda}g_{\rho]\mu} - q_{[\lambda}g_{\rho][\sigma}g_{\tau]\mu}\right] \\
iV^{abcd}_{\mu,\nu,\lambda\rho,\sigma\tau} &= ig^2\left[f^{ace}f^{bde}\left(g_{\mu\nu}g_{\lambda[\sigma}g_{\tau]\rho} + g_{\mu[\sigma}g_{\tau][\lambda}g_{\rho]\nu}\right)\right. \\
&\qquad \left. + f^{ade}f^{bce}\left(g_{\mu\nu}g_{\lambda[\sigma}g_{\tau]\rho} + g_{\mu[\lambda}g_{\rho][\sigma}g_{\tau]\nu}\right)\right]
\end{aligned}
$$

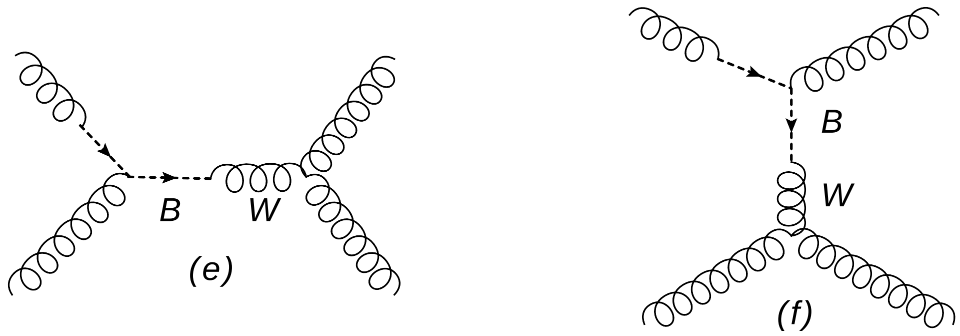
And more diagrams

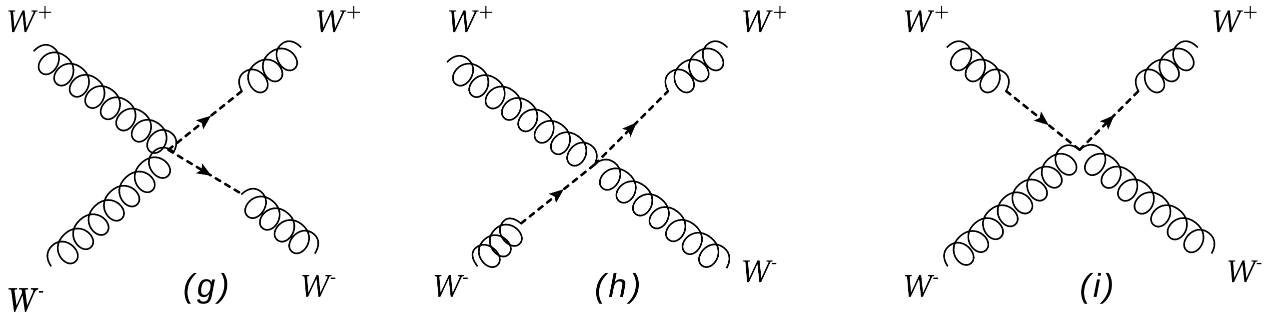
With two internal lines of B



And more ...

Still with two internal lines of B



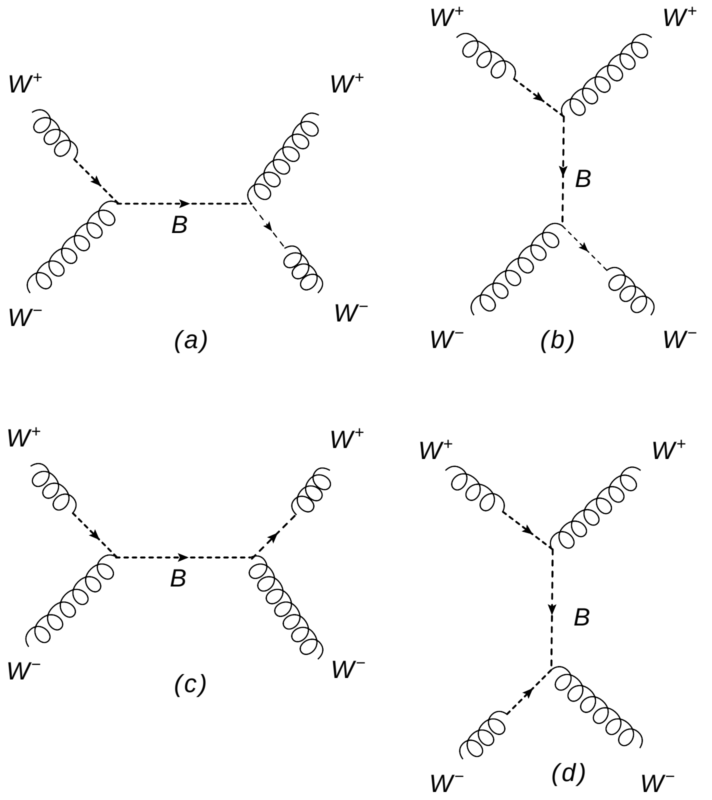


$$2\mathcal{M}_{a+b} + 4\mathcal{M}_{c+d} + 4\mathcal{M}_{e+f} + 2\mathcal{M}_{g+h+i} = \frac{4g^2P^2}{m^2}(1+2c+c^2)$$

Mistake in Eq (20) of the preprint!

And more ...

With three internal B lines



$$2\mathcal{M}_a + 2\mathcal{M}_b + 2\mathcal{M}_c + 2\mathcal{M}_d = -\frac{4g^2P^2}{m^2}(1 + 2c + c^2)$$

Now we are done!

$$\sum_{\text{no Higgs}} \mathcal{M} = \mathcal{O}(P^0)$$

Other issues

- → BRST invariance
  - ↪ Using a Stückelberg-type auxiliary field
- → Renormalizability
  - ↪ By solving Zinn-Justin Eq.
- → SU(2)$\times$U(1) symmetry breaking
  - ↪ by a soft term (effective term)
- → Chiral symmetry breaking
  - ↪ By quantum corrections (finite?)
- → Observable effects?
  - ↪ Any process currently involving the Higgs field
  - ↪ Branching ratios should be different

THANK YOU