Phys 772: Week 10 Thursday

* Higgs boson:

$$M_H^2 = 2\lambda v^2 \quad \text{with} \quad v = 246 \text{ GeV} = \langle \varphi^0 \rangle$$

$$\lambda = \frac{g^2 M_H^2}{8 M_W^2} = \frac{G_F}{\sqrt{2}} M_H^2 \quad \text{with } G_F = 1.2 \times 10^{-5} \text{ GeV}^{-2}$$

Couplings to fermions proportional to $\frac{m_f}{v}$

to W, Z boson $\frac{M_{Z,W}^2}{v}$ (H)

$\left(\frac{M_{Z,W}}{v}\right)^2$ (H^2)

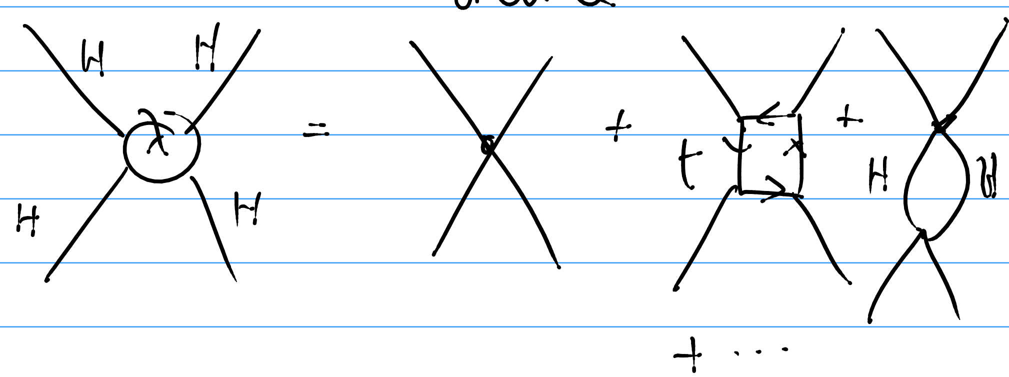
→ only couplings to t, b have high probability

$h_t = \frac{m_t}{v}$ = Yukawa coupling of top quark

Loop diagrams modify the couplings with energy scale:

$$\frac{d\lambda(Q^2)}{d\ln Q^2} \neq 0 \qquad \frac{dh_t(Q^2)}{d\ln Q^2} \neq 0$$

because of



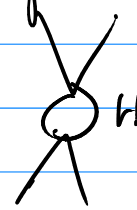
How heavy can the Higgs be?

If $M_H^2 \gg v^2 \rightarrow \lambda \gg 1$ but all other $\frac{m}{v}$ terms < 1

$\quad\;\; \overset{\|}{2\lambda v^2}$

$\downarrow$

leading λ terms define running of λ

dominated by  diagrams

$$\frac{d\lambda(Q^2)}{d\ln Q^2} = \frac{3}{4\pi^2}\lambda^2 \rightarrow \lambda(Q^2) = \frac{\lambda(v^2)}{1 - \frac{3\lambda(v^2)}{4\pi^2}\ln\frac{Q^2}{v^2}}$$

This diverges at $Q^2_{CP} = v^2 e^{4\pi^2/3\lambda(v^2)}$

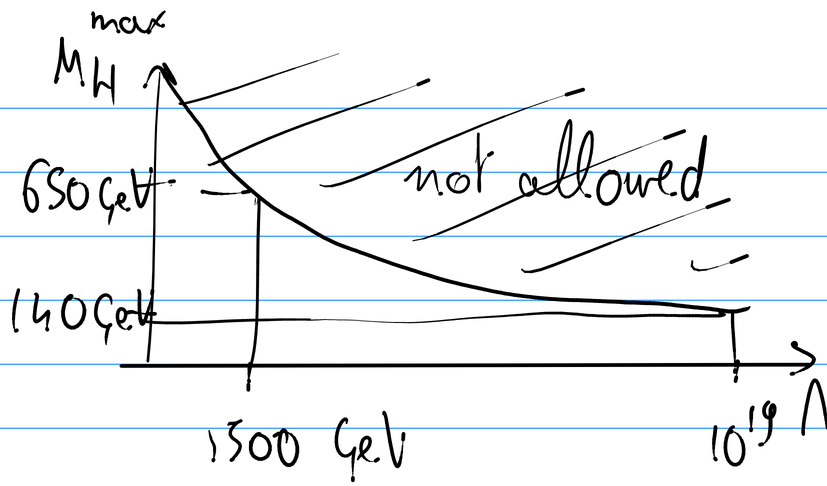
To avoid divergence within the range of validity, the Q_{LP} scale must be where new physics takes over:

$Q_{LP} > \Lambda = M_P$ for 10^{19} GeV Planck scale

$Q_{CP} > \Lambda = 1500$ GeV for SUSY scale

$$\rightarrow \lambda(v^2) < 4\pi^2 / 3\ln\frac{\Lambda^2}{v^2} = \frac{2\pi^2}{3\ln\frac{\Lambda}{v}}$$

$$\rightarrow M_H = \sqrt{2\lambda}\,\underset{\frac{1}{\sqrt{2G_F}}}{\overset{\|}{v}} = \sqrt{\frac{\lambda}{G_F}} < \left(\frac{2\pi^2}{3G_F\ln\frac{\Lambda}{v}}\right)^{1/2}$$



$$\Rightarrow \begin{cases} M_H < 140 \text{ GeV} & \text{if} \quad \Lambda = 10^{19} \text{ GeV} \\ M_H < 650 \text{ GeV} & \text{if} \quad \Lambda = 1500 \text{ GeV} \end{cases}$$

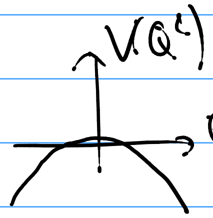
Discovery of M_H at $\gg 140$ GeV would have immediately given confidence that SM is violated below Planck scale.

$M_H = 125$ GeV

How light must the Higgs be?

If $\lambda \ll 1$ and only top quark decays are dominant.

$$\frac{d\lambda(Q^2)}{d\ln Q^2} = \frac{3}{4\pi^2} h_t^4 \rightarrow \lambda(Q^2) = \lambda(v^2) - \frac{3h_t^4}{4\pi^2} \ln\frac{Q^2}{v^2}$$

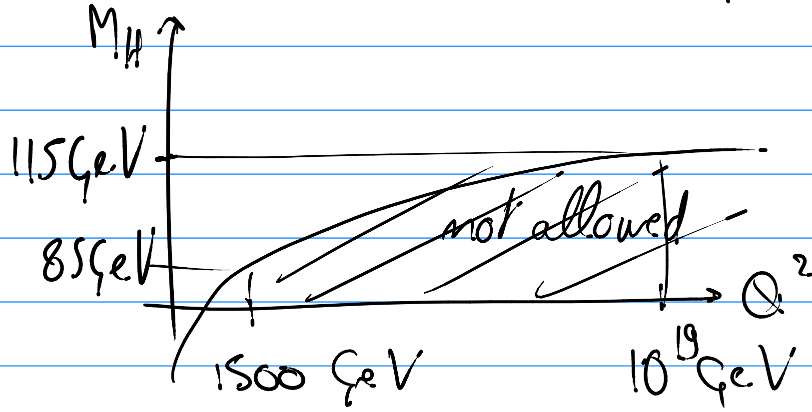
This is negative (

) when

$$\lambda(v^2) = \frac{3 h_t^4}{4\pi^2} \ln \frac{Q^2}{v^2} \qquad \left(v = \frac{1}{\sqrt{2 G_F}} \right)$$

$$\downarrow$$

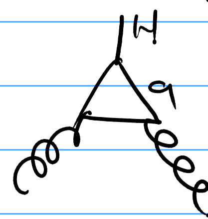
$$M_H^2 = 2\lambda v^2 = \frac{\lambda}{G_F} = \frac{3 h_t^4}{2 G_F \pi^2} \ln \frac{Q}{v}$$



* Higgs production:

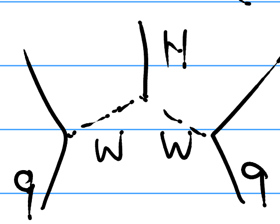
LHC: $p \times p \longrightarrow g, q, \bar{q} \times g, q, \bar{q}$

gluon fusion

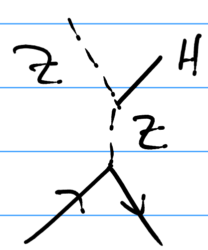


$q = t, b$ because of large h_t

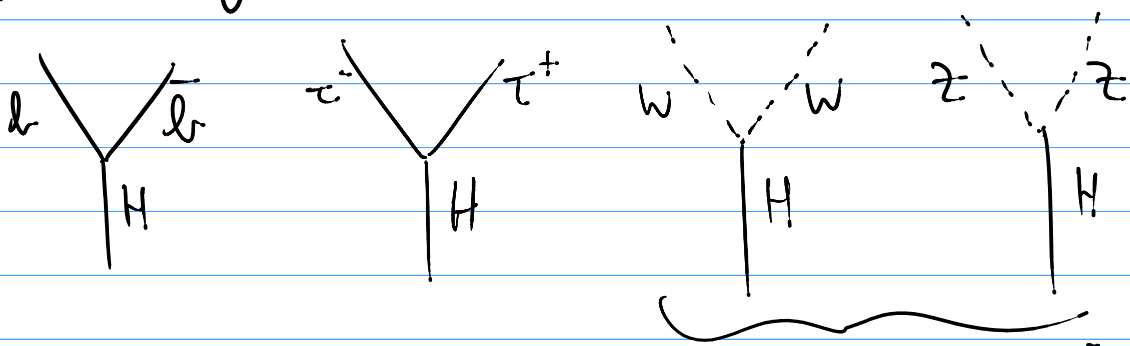
vector boson fusion



LEP: e^+e^-



* Higgs decay :



followed by $Z \to \ell\bar{\ell}, q\bar{q}$

golden channel : $H \to ZZ \to \ell\bar{\ell}\,\ell\bar{\ell}$
pure leptonic

more likely : $H \to ZZ \to \ell\bar{\ell}\, q\bar{q}$
semi-leptonic

large background : $H \to ZZ \to q\bar{q}\, q\bar{q}$
hadronic

two-photon channel $H \to \gamma\gamma$: clean, but low branching ratio

* LHC : testing the SM

- branching ratios and Higgs decay width
- Yukawa couplings
- spin-0 nature