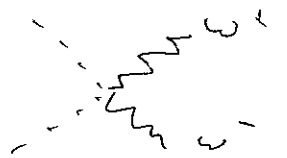
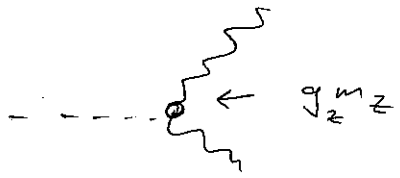
The Higgs Boson

After Symmetry Breaking

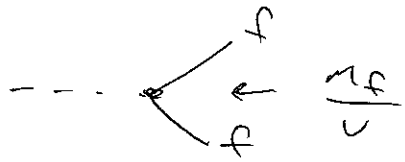
$$\mathcal{L} \supset \frac{1}{4} g^2 W^-_\mu W^{+\mu} (v+h)^2 = \underbrace{\frac{1}{4} g^2 v^2 W^+_\mu W^{-\mu}}_{\text{mass term } W\text{'s}} + \frac{1}{2} g^2 v W^+_\mu W^{-\mu} h + \frac{1}{4} g^2 W^+_\mu W^{-\mu} h h$$



Same for the Z



Saw last time Yukawa coupling leads to interacts w/ Higgs



Higgs Boson in SM is neutral $\underline{\text{Spin} = 0}$ → Scalar

Mass is free parameter ($m_H = 2\lambda v^2$)

H decays $H \to ff$ $\forall f$ w/ $m_H > 2m_f$

$H \to WW, ZZ$ if massive enough

H wants to decay to the most massive thing it can for 125

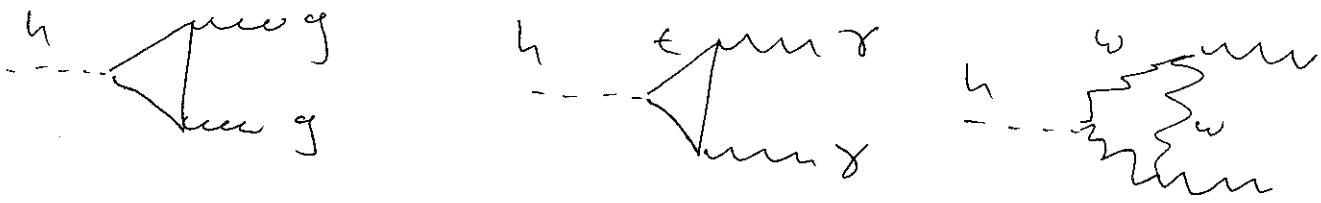
$B.R.(h \to bb) \simeq 60\%$ $\quad ZZ \simeq 3\%$

$h \to WW^* \simeq 20\%$ $\quad \gamma\gamma \simeq 0.2\%$

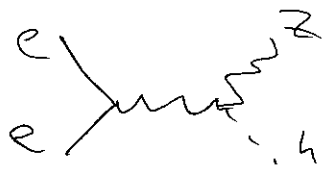
$ZZ \simeq 6\%$

$gg \simeq 10\%$

Decays to massless particles

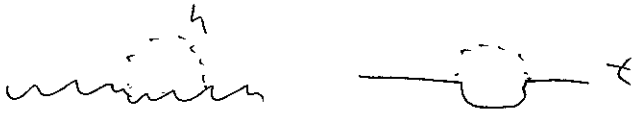


Prior to LHC ~~Searched~~ directly for the Higgs @ LEP



$m_H > 115$ GeV

Also Studied m_{top} & m_W which put a limit on size of m_H



$m_H < 150$ GeV

Major goal of LHC was to discover higgs

How to make Higgs Bosons.

Collide proton (quarks / gluons) The stuff in in proton is light

$\Rightarrow$ Small coupling to higgs

$\Rightarrow$ Small σ_H

top, W, Z are the heaviest things in the theory

$\Rightarrow$ largest coupling to the higgs

Would really want to use processes like

Problem is we dont have top / W/Z colliders

So

First have to make e's W's + Zs from protons then make higgs Boson

This is one reason the higgs was so hard to find ("god particle" from "god-dumned particle" So god damned hard to find)

leading production diagrams from higher order processes.

How much data is needed? Estimate how often we make a Higgs

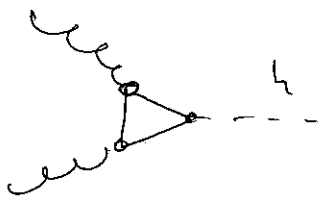
Warm-up How often do we make a W/Z?

$$\sigma_{W/Z} \sim \frac{\alpha_W}{(m_{W/Z})^2} \sim \frac{1}{50}\,\frac{1}{(100)^2}\,GeV^{-2}$$

$$\sim 2\,10^{-6}\,GeV^{-2}$$

$\sigma_{pp} \sim GeV^{-2}$ $\Rightarrow$ 1 W/Z for every 1 Million pp collisions

Same thing for Higgs



$$\sigma_H \sim \frac{1}{16\pi^2}\,\frac{\alpha_s^2\,\alpha_W}{m_H^2}$$

$$\sim \frac{1}{160}\left(\frac{1}{10}\right)^2\left(\frac{1}{50}\right)\left(\frac{1}{100}\right)^2 GeV \sim 1\cdot 10^{-10}\,GeV^{-2}$$

1 higgs for every billion proton collisions

How to look for it

~~$h \to bb$ 60%~~

$h \to WW$ 20%

~~$h \to gg$ 10%~~

~~$h \to \tau\tau$ 8%~~

$h \to ZZ$ 3%

$h \to \gamma\gamma$ 0.2%

good target $\sim 100\,\frac{h\to\gamma\gamma}{gen.}$

$\Rightarrow 10^5\,\frac{higgs}{gen} \sim 1\,\frac{h}{s}$

$\Rightarrow$ Need a billion p collisions/s

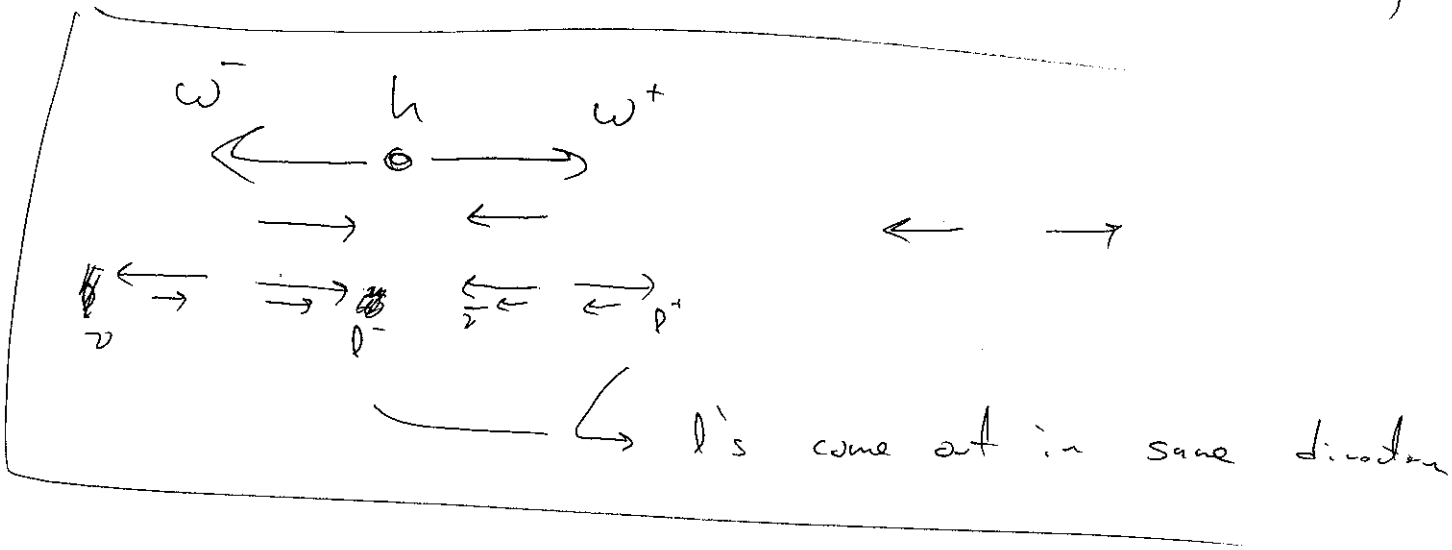
Only have beams that ~~cost~~ cross @ 40 million times/s ⇒ need ~25 proton collision per crossing

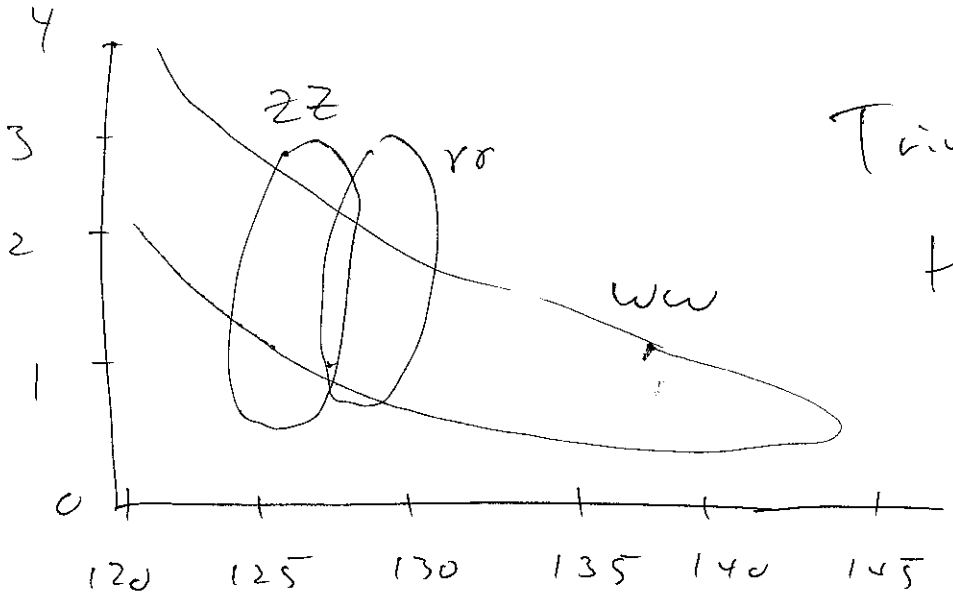
thats why we have to live w/ pile-up

Higgs discovered $h \to WW^* \to l^+\bar{\nu} l\nu$ (hard)

$h \to ZZ \to ll\,ll$ (easy)

$h \to \gamma\gamma$ (straight forward)





Triumph of Humanity

So far looks like SM higgs in every way
(Stupidest version)

What we don't know

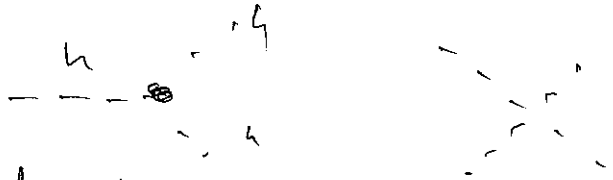
- if established couplings are modified @ 20% level

$\begin{pmatrix} \nu \\ e \end{pmatrix}\begin{pmatrix} \nu \\ \mu \end{pmatrix}\begin{pmatrix} \nu \\ \tau \end{pmatrix}$ $\begin{pmatrix} u \\ d \end{pmatrix}\begin{pmatrix} c \\ s \end{pmatrix}\begin{pmatrix} t \\ b \end{pmatrix}$

γ W Z g

- if higgs decays in unexpected way ~30% of the time.

- Very important unobserved interaction



Higgs self interaction

Di-Higgs Production Next frontier