Subatomic Physics II: Problem set 8

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8.1 Higgs boson properties

8.1.1 Dominant Higgs boson production channels at LEP and LHC

Gluon-Gluon Fusion (LHC)

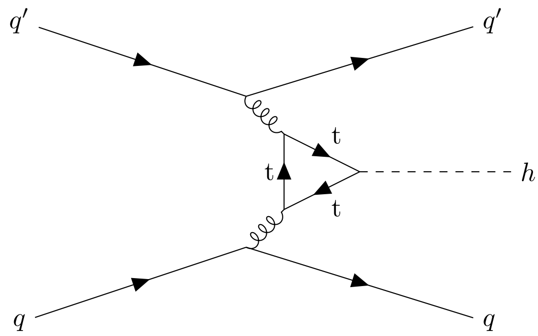


Figure 1: Gluon Gluon fusion

Vector Boson Fusion (LHC)

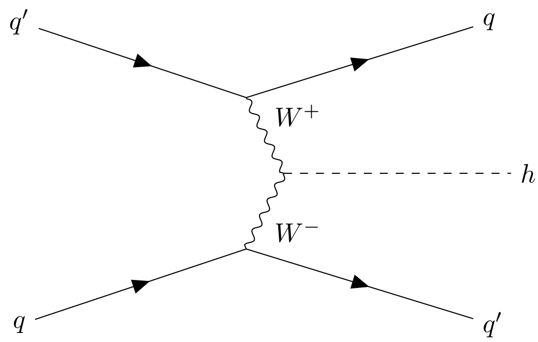


Figure 2: Vector Boson Fusion

Here one of the W bosons is off-shell.
Higgs stralung (LEP)

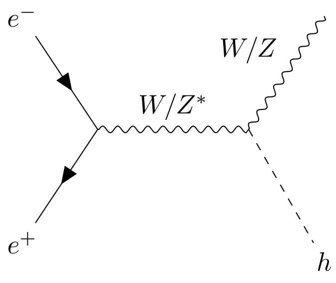
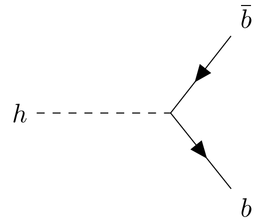


Figure 3: Vector Boson Fusion

Here the star denotes "off-shell".

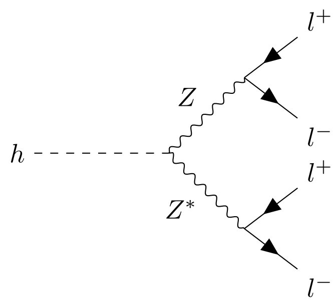
8.1.2 Dominant decay channel at $m_h = 125$ GeV

The dominant decay channel at $m_h = 125$ is $H \to b\bar{b}$:



8.1.3 Branching ratio in the "golden channel"

We can approximate the branching ratio of the feynman diagram under consideration:

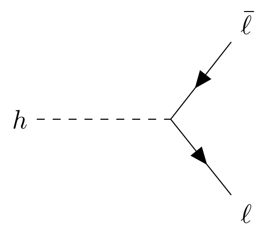


As the following product[1]:

$$\begin{aligned}
\mathcal{B}r(H \to l^+l^-l^+l^-) &\approx \mathcal{B}r(H \to ZZ^*) \times \mathcal{B}r(Z \to l^+l^-)^2 && (1)\\
&\approx 2.7\% \times [\mathcal{B}r(Z \to e^+e^-) + \mathcal{B}r(Z \to \mu^+\mu^-)]^2 && (2)\\
&\approx 0.014\% && (3)
\end{aligned}$$

8.1.4 Why dit it take longer to find $h \to \mu^+\mu^-$ than $h \to \tau^+\tau^-$?

This is because in a $h \to l^+l^-$ feynamnn diagram:



We have that in this vertex $\mathcal{M} \propto m_\ell \frac{g_w}{2m_w}$, so the decay into 2 τ leptons is $\frac{\Gamma_\tau}{\Gamma_\mu} \propto \frac{|\mathcal{M}_\tau|^2}{|\mathcal{M}_\mu|^2} \propto \left(\frac{m_\tau}{m_\mu}\right)^2 \approx 282.81$ times more likely then the decay into 2 muons. As such ≈ 283 times the measurements are needed to get the same σ which of course takes longer.

[1]individual branching ratio's from PDG [2]

8.2 Fighting misconceptions

8.2.1 Higgs bosons are responsible for masses of all other particles

Particles acquire masses through their interactions with the Higgs field, the boson is just the excitation of this field, a neutral scalar particle which couples to all fermions with a coupling strength proportional to the fermion mass.

8.2.2 Higgs mechanism gives mass to all massive objects in the Universe

Most of the mass in composite particles, like protons, nuclei, and atoms, does not come from the Higgs mechanism, but from the binding energy that holds these particles together.

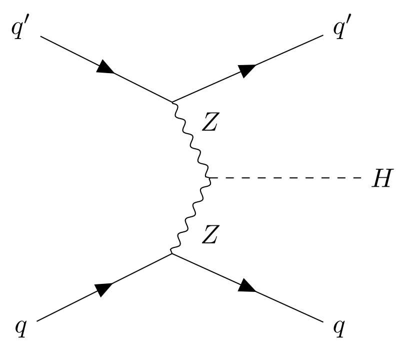
8.2.3 The Higgs mechanism produces mass, and masses gravitate, therefore the Higgs mechanism is the origin of gravity

By coupling with the Higgs field a massless particle acquires a certain amount of potential energy and, hence, according to the mass-energy relation, a certain mass. The stronger the coupling, the more massive the particle. In the Higgs mechanism mass is not "generated (/produced)" in the particle by a miraculous creatio ex nihilo, it is only transferred to the particle from the Higgs field [1]. Together with this I'd like to say, as already discussed, that the Higgs mechanism only accounts for a small percentage of the total mass present in the universe and thus in "gravity".
Aside from that, the conclusion on the right side of the sentence is also not completely right as it is not mass that gravitates, it's energy:
In Einsteins formulation of general relativity spacetime curves due to energy and momentum being present, we can see this in the field equation: $R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} + \Lambda g_{\mu\nu} = \kappa T_{\mu\nu}$ here $T_{\mu\nu}$ is the energy-momentum tensor, which contains the density and flux of all the energy and momentum being present (and thus the masses as $E^2 = m^2 + p^2$ but also light as $E^2 = p^2$). This equation then locks up the metric $g_{\mu\nu}$ which captures all the geometric and causal structure of spacetime, i.e the curvature $\equiv$ gravity.

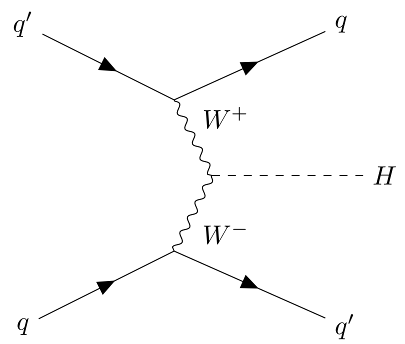
8.3 Non-standard Higgses

8.3.1 Tree-level production and decay Feynman diagrams of H and H$^{\pm}$ at the LHC

Production
The extra neutral higgs boson H can be produced by exactly the same processes as the higgs boson h but at higher energies:

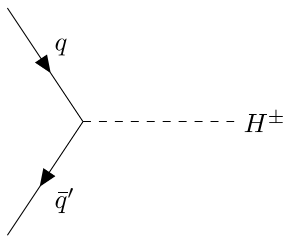


(a) Z boson fusion

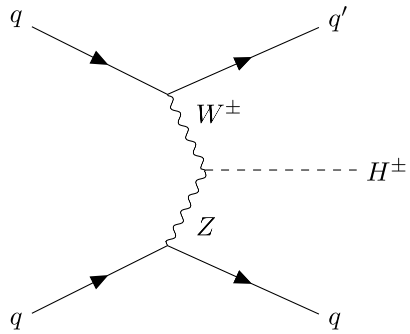


(b) Vector Boson Fusion

Now for the production of H$^{\pm}$ we can take a look at the processes necessary to produce $W^{\pm}$ and just increase the COM energy:

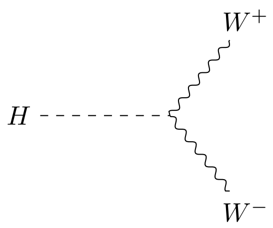


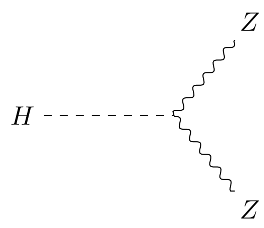
(a) Quark-Antiquark fusion



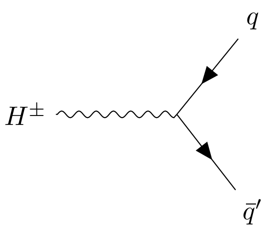
(b) ZW Boson Fusion

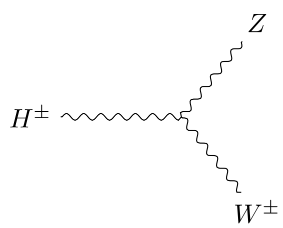
Decay
The extra neutral H boson will decay in the same way as the higgs boson (with more energy and no fermions):





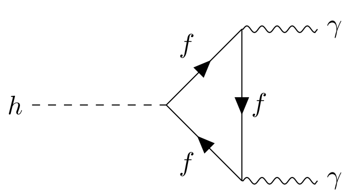
And the charged ones will decay as:

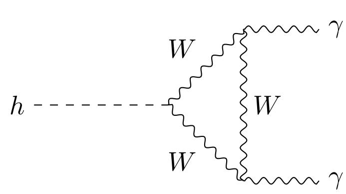




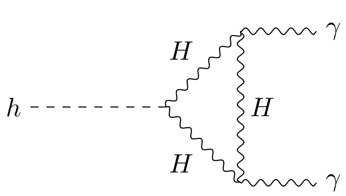
8.3.2 two-photon decay of the Standard-Model-like boson $h \to \gamma\gamma$

There'll be another contribution to the matrix element $\mathcal{M}$ of the decay mode, aside from the usual ones:





We'll now also have this possible Feynman diagram:



References

[1] M. Jammer. *Concepts of Mass in Contemporary Physics and Philosophy.* Princeton University Press, 2009.

[2] P.A. Zyla et al. Review of Particle Physics. *PTEP*, 2020(8):083C01, 2020.