Phenomenology of Particle Physics II

Exercise Sheet 9

ETH
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In the following exercise sheet we will use all the techniques learnt during this course to study some of the most important decay channels for the Higgs boson, and discuss their phenomenological implications.

Exercise 16 [*Higgs boson decay widths - Computation*]

Consider the usual $SU(2) \times U(1)$ electro-weak theory, with a scalar Higgs boson H with mass m_H. Using the electro-weak Feynman rules compute the leading order decay widths for the following decay channels:

(i) Higgs into two fermions (leptons or quarks), $H \to f\,\bar{f}$:

$$\Gamma_{H\to f\,\bar{f}} = C\,\frac{G_F\,m_f^2\,m_H}{4\,\sqrt{2}\,\pi}\left(1-\frac{4\,m_f^2}{m_H^2}\right)^{\frac{3}{2}},$$

where m_f is the fermion mass, and $C = 3\,(1)$ for quarks (leptons).

(ii) Higgs into a W pair, $H \to W^+W^-$:

$$\Gamma_{H\to W\,W} = \frac{G_F\,m_H^3}{8\,\sqrt{2}\,\pi}\left(1-\frac{4\,m_W^2}{m_H^2}\right)^{\frac{1}{2}}\left(1-\frac{4\,m_W^2}{m_H^2}+\frac{12\,m_W^4}{m_H^4}\right),$$

where m_W is the W mass.

(iii) Higgs into a Z pair, $H \to Z\,Z$:

$$\Gamma_{H\to Z\,Z} = \frac{G_F\,m_H^3}{16\,\sqrt{2}\,\pi}\left(1-\frac{4\,m_Z^2}{m_H^2}\right)^{\frac{1}{2}}\left(1-\frac{4\,m_Z^2}{m_H^2}+\frac{12\,m_Z^4}{m_H^4}\right),$$

where m_Z is the Z mass.

Hints: Recall that in this case we never neglect the masses of the final states, so that you need to use the massive phase space integration discussed in ex. sheet 7, with the obvious modifications. Mind also the overall symmetry factor of 1/2 in the case of two identical vector bosons in the final state.

– please turn over –

Exercise 17 [*Higgs boson decay widths - Discussion*]

Consider the formulas found in ex. 16

(i) What are the allowed Higgs mass ranges for the different decay widths, if we suppose that the decays products are on-shell?

(ii) Plot in logarithmic scale the decay widths you computed for

$$H \to b\,\bar{b}, \qquad H \to t\,\bar{t}, \qquad H \to W^+W^-, \qquad H \to Z\,Z,$$

for a Higgs in the mass range $100\,\text{GeV} \leq m_H \leq 1\,\text{TeV}$.
What's the dominant decay channel?

(iii) What would you expect to change if we allow off-shell decay products, i.e. we consider for example a four-body decay

$$H \longrightarrow Z\,Z \longrightarrow l_1^+ l_1^-\, l_2^+\, l_2^-\,.$$

You don't need to perform any further computation!

(iv) Are you able to extract from your plots a possible explenation of why it is much easier to find a Higgs boson with $m_H > 160\,\text{GeV}$ at a hadron collider ?

Informations relative to the exercises

Testat condition : 60% of the exercise sheets worked out and solve one exercise at the blackboard.

Exercises may be solved in groups of up to 3 people.

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