Particle Physics 2 : Exercise 10

1) Gauge bosons

The longitudinally polarised W travelling in the z-direction has polarisation four-vector

$$\epsilon_L^\mu = \frac{1}{m_{\mathrm{W}}}(p_z, 0, 0, E).$$

Consequently, at high energy ($E \gg m_{\mathrm{W}}$) the matrix element for the t-channel process $e^+e^- \to W_L^+ W_L^-$ alone, will scale as

$$\mathcal{M}^2 \propto \left(\frac{E_{\mathrm{W}}}{m_{\mathrm{W}}}\right)^4,$$

and increases without limit. This is not the case for the transverse polarisation states

$$\epsilon_-^\mu = \frac{1}{\sqrt{2}}(0, 1, -i, 0) \quad \text{and} \quad \epsilon_+^\mu = \frac{1}{\sqrt{2}}(0, 1, i, 0).$$

2) Euler-Lagrange equation

The Lagrangian (density) for the Dirac equation is

$$\mathcal{L}_D = i\bar{\psi}\gamma_\mu \partial^\mu \psi - m\bar{\psi}\psi.$$

The partial derivatives with respect to each of the four components of the spinor ψ_i are

$$\frac{\partial \mathcal{L}_D}{\partial(\partial_\mu \psi_i)} = i\bar{\psi}\gamma^\mu \quad \text{and} \quad \frac{\partial \mathcal{L}_D}{\partial \psi_i} = -m\bar{\psi}$$

and the Euler-Lagrange equation gives :

$$\begin{aligned} \partial_\mu \left(\frac{\partial \mathcal{L}_D}{\partial(\partial_\mu \psi_i)}\right) - \frac{\partial \mathcal{L}_D}{\partial \psi_i} &= 0 \\ \partial_\mu i\bar{\psi}\gamma^\mu + m\bar{\psi} &= 0 \\ i(\partial_\mu \bar{\psi})\gamma^\mu + m\bar{\psi} &= 0. \end{aligned} \tag{1}$$

3) Higgs production cross section

The number of Higgs bosons produced in both the ATLAS and CMS experiments is :

$$N_{\mathrm{H}} = L \times \sigma(\mathrm{pp} \to \mathrm{H} + X),$$

where L is the integrated luminosity :

$$L = \int \mathcal{L} dt,$$

giving

$$N_{\mathrm{H}} = 20 \times 10^3 \text{ fb} \times 10 \text{ fb}^{-1} = 200000.$$

Updated: 12 mai 2025

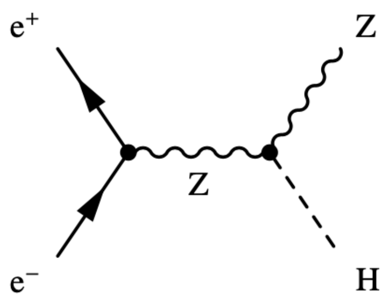
The relevant Standard Model branching fractions are $BR(\mathrm{H} \to \gamma\gamma) \approx 0.002$, $BR(\mathrm{H} \to \mathrm{ZZ}^*) \approx 0.027$ and $BR(\mathrm{Z} \to \mu^+\mu^-) \approx 0.035$ and thus

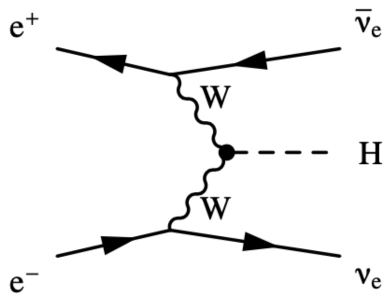
$$N(\mathrm{H} \to \gamma\gamma) = 2 \times 10^5 \times 0.002 = 400,$$

$$N(\mathrm{H} \to \mathrm{ZZ}^* \to \mu^+\mu^-\mu^+\mu^-) = 2 \times 10^5 \times 0.027 \times 0.0352^2 = 7.$$

Despite the fact that very few $\mathrm{H} \to \mathrm{ZZ}^* \to \mu^+\mu^-$ are produced, such events leave a very clear signature in the detectors and are relatively easily identified.

4) Higgs diagrams





Updated: 12 mai 2025