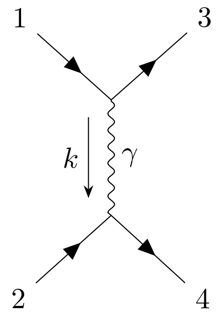
Particle physics

27 January 2017

1 Theoretical part (Van Riet)

1.1 Electron-muon scattering

The electron-muon scattering is represented by the following Feynman-diagram:



The particles 1 and 3 are the incoming and outgoing electrons and the particles 2 and 4 are the incoming and outgoing muons.

- **[7pts]** Starting from the averaged absolute square scattering amplitude

$$\langle|\mathcal{M}|^2\rangle = \left(\frac{e^2}{q^2}\right)^2 \frac{1}{4} \sum_{s_1,s_2,s_3,s_4} |\bar{u}^{s_3}(3)\gamma^\mu u^{s_1}(1)\eta_{\mu\lambda}\bar{u}^{s_4}(4)\gamma^\lambda u^{s_2}(2)|^2.$$

  Use the correct identities and tricks to simply this to the following expression

$$\langle|\mathcal{M}|^2\rangle = \frac{e^4}{4(p_1-p_3)^4} Tr\left[\gamma^\mu(\not{p}_1+m)\gamma^\nu(\not{p}_3+m)\right] \times Tr\left[\gamma_\mu(\not{p}_2+M)\gamma_\nu(\not{p}_4+M)\right]$$

  with $q=(p_1-p_3)$ and m and M respectively the electron mass and the muon mass.

- **[6pts]** Work out these traces and prove every property of traces of gamma-matrices used in this calculation. The final result is then:

$$\langle|\mathcal{M}|^2\rangle = \frac{8e^4}{(p_1-p_3)^4}\left\{(p_1\cdot p_2)(p_3\cdot p_4)+(p_1\cdot p_4)(p_2\cdot p_3)-(p_1\cdot p_3)M^2-(p_2\cdot p_4)m^2+2m^2M^2\right\}$$

- **[7pts]** The differential cross section in the CM frame equals

$$D = \frac{d\sigma}{d\Omega} = \frac{1}{64\pi^2\hbar^2}\frac{|\vec{p}_f|}{|\vec{p}_i|(E_1+E_2)^2}|\mathcal{M}_{fi}|^2.$$

  From here, ignore relativistic effects by making the correct approximations in order to obtain the Rutherford's equation

$$D = \left(\frac{e^2 m}{8\pi|\vec{p}|^2\sin^2(\theta/2)}\right)^2.$$

  (Note that Rutherford's equation is valid in the lab frame such that a correct approxiamtion has to be made in order to switch from the CM frame to the lab frame.)
  The way to do this is by neglecting the recoil of the muon.

2 Phenomenological part (Severijns)

1. Explain why reactions are possible where the charm is raised or lowered by one unit (e.g. $D^0 \to K^- + e^+ + \nu_e$ with $D^0 = \bar{u}c$, $K^- = \bar{u}s$). Link this with the Cabbibo-Kobayashi-Maskawa-matrix.

2. Answer the following questions using only up to half a page.

  a) What is the helicity of a particle? Is it Lorentz invariant?
  b) What effect does the CP-operator have on a righ-handed antiparticle? Give an example.
  c) What are radiative (perturbative) corrections? Draw a Feynman-diagram of such a correction.
  d) What are neutral currents and in which interactions (strong, electromagnetic, weak) do they occur? Draw a Feynman-diagram of a neutral current for every interaction.

What are atmospheric neutrino's?

- How are they formed and observed?
- How are they used in the explanation of neutrino oscillations?
- Which generations (e^-, μ, τ) are the most important for this explanation?

4. Draw a Feynamn-diagram for each of the following processes. Is the process hadronic, leptonic or semi-leptonic? Is the process a neutral current or a charged current?

- $K^+ \to \pi^0 + e^+ + \nu_e$ ($K^+ = u\bar{s}$, $\pi^0 = u\bar{u}$)
- $\pi^- \to \pi^0 + e^- + \bar{\nu}_e$ ($\pi^- = \bar{u}d$, $\pi^0 = u\bar{u}$)
- $D^+ \to K^- + \pi^+ + e^+ + \nu_e$ ($D^+ = c\bar{d}$, $K^- = \bar{u}s$, $\pi^+ = u\bar{d}$)
- $\pi^+ \to e^+ + \nu_e + e^+ + e^-$ ($\pi^+ = u\bar{d}$)
- $\tau^+ + \bar{\nu}_e \to e^+ + \bar{\nu}_\tau$