TÉCNICO LISBOA

1° teste

8 de Novembro de 2014:
13H00

Duration of the test: 1H30

Mestrado em Eng. Física Tecnológica (MEFT)
Particle Physics
1° semester of 2014-15

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- The allowed elements for consult during the test are:
  - the PDG (Particle Data Book)
  - one single A4 page with formulas.
- Clearly identify all pages of the test.
- The test has 4 questions (2 pages).

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1. **[6 val]** In the Pierre Auger Observatory the surface detectors are composed by Water Cherenkov tanks with 12 tons of water and 1.2 m of height. These detectors are able to measure the light produced by charged particles crossing them. Consider one tank crossed by a single vertical muon. The refraction index of the Water is $n \approx 1.33$ and can be in good approximation considered constant for all the relevant photons wavelengths. ($\rho_{water} \approx 1\,\mathrm{gcm}^{-3}$)

a) Determine the minimum energy of a muon in order that Cherenkov light will be emitted inside the tank.

b) If such muon has an energy of 5 GeV determine:

i. The number of Cherenkov photons emitted along the muon trajectory inside the tank as well as the emission angle of the photons, for photons produced within energies $E \in [3;4]$ eV ($\lambda \in [309;412]$ nm).

ii. The energy lost by ionization and compare it with the energy lost by Cherenkov emission. Consider that the mean energy loss rate for water is somewhere between the helium gas and carbon.

c) Evaluate the probability of a muon to decay inside of the tank as a function of its velocity, β. Determine the probability for the limits when $\beta \to 0$ and $\beta \to 1$.

d) Discuss the experimental signature which may indicate that the muon had decayed.

2. **[4 val]** Verify if the following reactions/decays are or not possible and if not say why:

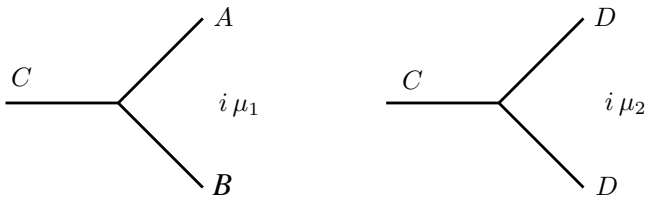
a) $pp \to ppp\overline{p}$ b) $\overline{p}p \to \gamma$ c) $e^- \to \nu_e\gamma$ d) $p \to ne^+\nu_e$

3. **[4 val]** In the beginning of the fifties the total cross-sections, σ_T, for the reactions $\pi^- p$ and $\pi^+ p$ were measured. Considering an energy in the centre-of-mass of **1232** MeV:

a) Indicate what are the possible final states coming from these collisions.

b) Discuss the ratio between these cross-sections, i.e., $\sigma_T(\pi^+ p)/\sigma_T(\pi^- p)$.

4. **[6 val]** Consider a model with four neutral scalars A, B, C, D, that interact through the following vertices,



where the constants μ_1 e μ_2 have dimension of a mass in our natural system of units ($\hbar = c = 1$). It is known that $m_C > m_A + m_B$.

a) Determine the total decay width $\Gamma(C \to A + B)$ as a function of the particle masses.

b) For the scattering $D + D \to A + B$ draws the diagram(s) that contribute in lowest order in perturbation theory and write down the corresponding amplitude(s).

c) Evaluate the differential cross section $d\sigma/d\Omega$ in the CM frame as a function of the square of the energy in the CM frame, $s = (p_1 + p_2)^2$ and the masses of the particles.

d) In the limit that $\sqrt{s} \gg m_A, m_B, m_C, m_D$ neglect the masses and evaluate the total cross section in the CM frame. Show that it has the correct dimensions for a cross section.