TÉCNICO LISBOA

1st test

November 8th 2016: 18h00

Duration of the test: 1h30

Mestrado em Eng. Física Tecnológica (MEFT)
Particle Physics
1st semester of 2017-18

Prof. Jorge Romão
Prof. Mário Pimenta
Prof. Ruben Conceição

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

The ZEUS experiment studied the internal structure of the proton through measurements of deep inelastic scattering (DIS) by colliding electrons with protons. The electrons and the protons were accelerated in the HERA particle accelerator.

1. **[6 val]** The first run that produced physics results was done accelerating electrons to an energy, in the LAB framework, 26.7 GeV and the protons to 820 GeV. An integrated luminosity of 2.1 nb^{-1} was reached.

a) Compute the centre-of-mass energy for the electron-proton collision.

b) Compute the electron energy in the reference frame were the proton is at rest.

c) To analyse the results, the experimental data is divided in bins of Q^2 and x. Knowing that the cross-section for the bin $Q^2 \sim 8.5\,\text{GeV}^2$ and $x \sim 4.1 \times 10^{-4}$, is $4.8 \times 10^{-32}\,\text{cm}^2$, how many events in that bin were detected if the detector has an efficiency of 80%?

d) Consider the kinematics of a deep inelastic scattering event. What should be the energy and the scattering angle, θ, with respect to the electron beam, of the out-coming electron so that $Q^2 = 8.5\,\text{GeV}^2$ and $x = 4.1 \times 10^{-4}$. Perform and present all calculations in the reference frame where the nucleon is at rest.

2. **[5 val]** Verify, from the point of view of quantum numbers, if the following reactions are possible and if not explain why.

a) $e^- \; p \to e^- \; p \; \overline{p}$

b) $e^- \; p \to e^- \; p \; K^- \pi^+$

c) $e^- \; p \to e^- \; p \; K^- \; K^+$

d) $e^- \; p \to \Delta^- \; e^+$

e) $e^- \; p \to \Delta^+ \; e^- \; \nu_e \; \overline{\nu_e}$

3. **[4.5 val]** In ZEUS the hadrons and electrons, produced in the DIS $e^- p \to e^- h$ were measured with a calorimeter. The calorimeter, which surrounds completely the interaction vertex, consists of alternating layers of 3.3 mm thick Uranium and 2.6 mm plastic scintillator.

a) How many radiation lengths has a single layer of Uranium?

b) Describe qualitatively the development of an electromagnetic shower initiated by a high-energy electron stating the purpose of each layer type.

c) Consider a charged kaon, K^+, of 20 GeV in the calorimeter. What is the average energy deposited through ionisation by the meson while traversing one Uranium layer?

4. **[4.5 val]** The baryon Δ^+ is one of the hadrons that can be produced in a DIS event. Consider that the Δ^+ was produced with a momentum of 4 GeV/c.

a) Compute the mean free path of the Δ^+ in the LAB framework.

b) The Δ^+ decays $\approx 99\%$ of the times in pure hadronic states. Prove that:

$$\frac{\Gamma(\Delta^+ \to p\pi^0)}{\Gamma(\Delta^+ \to n\pi^+)} = 2$$

c) As seen before, the Δ^+ decays approximately 2/3 of the times into a proton and a π^0. Moreover, the π^0 decays nearly promptly into two photons, such that $\Delta^+ \to p\pi^0 \to p\gamma\gamma$. Knowing that the number of produced Δ^+ is N_0, estimate the number of photons that could be observed by a detector, put 1 m away from the interaction vertex.