TÉCNICO LISBOA

1^{st} test
November 7^{th} 2018: 18h30
Duration of the test: 1h30

Mestrado em Eng. Física Tecnológica (MEFT)
Particle Physics
1^{st} semester of 2018-19

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- 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 3 questions (2 pages).

Carl D. Anderson received the 1936 Nobel Prize in physics for the discovery of the positron, the antiparticle of the electron. In 1932, during an experiment designed to observe cosmic rays, he observed a track of a positive particle with a mass about equal to that of the electron in a cloud chamber.

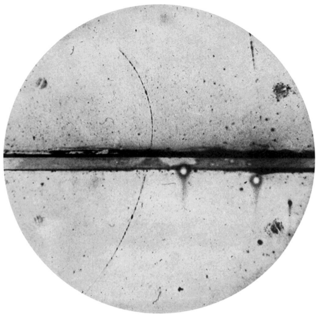

Figura 1: Anderson's photograph of the positron track.

1. **[10 val]** Charged particles were deflected in the chamber due to a strong magnetic field of 1.7 T and had to traverse a lead plate. Assume that the particle that caused the track is a positron.

a) What would be the radius of curvature if the positron has an energy of 63 MeV?

b) In the positron discovery paper, Anderson discusses and refutes the possibility of the track in fig. 1 to be produced by a proton or an electron with a reverse trajectory. Discuss, succinctly, how one can reach this conclusion with the data above.

c) Knowing that the positron has an energy of 63 MeV before it reached the lead plate and 23 MeV after emerging it, estimate the lead plate thickness in centimeters?

d) One striking feature in fig.. 1 is that although produced by cosmic rays, the positron seems to be coming from below. Show that a vertical muon, going down, cannot produce a positron with an energy of 63 MeV in the opposite direction? Why? (Remember that: $\mu^+ \to \overline{\nu}_\mu e^+ \nu_e$)

e) Imagine that the thin lead plate is now substituted by a small slab of water, where light can be collected by a photomultiplier (PMT). Could this setup be able to distinguish between a positron and a proton of 63 MeV? Justify.

2. **[8 val]** Atmospheric positrons may arise from muons which are essentially produced in the decay of charged pions, for instance $\pi^+ \to \mu^+ \nu_\mu$. Assume that the π^+ has an energy of 10 GeV.

a) Compute the mean distance travelled by the pion before decaying.

b) The pion can have also hadronic interactions with the atmosphere atoms. Supposing that the pion was created at 2 km from the ground were the density is relatively constant ($\rho \sim 1.1\,\mathrm{kg\,m^{-3}}$) and knowing that the pion-Air cross-section is roughly $\sigma_{\pi-Air} \sim 200\,\mathrm{mb}$, compute the interaction length of the pion. With this information indicate justifying if the pion is expected to interact or to decay? Note that the pion interacts with the atoms in the atmosphere and remember that the Earth's atmosphere composition is roughly 80% Nitrogen and 20% Oxygen.

c) Determine the minimum and maximum energy that the muon can get in the pion reference frame.

d) Determine the minimum and maximum energy that the muon can get in the LAB framework.

3. **[2 val]** Cosmic rays interact with the atmosphere's atoms producing cascades of particles that can give origin to positrons at some stage. Verify, from the point of view of quantum numbers, if the following reactions are possible and if not explain why.

a) $pp \to pne^+$

b) $pp \to p\pi^+$

c) $\pi^+ p \to \pi^+ \pi^- \Delta^{++}$

d) $pp \to pnK^+ \pi^0$