TÉCNICO LISBOA

1^{st} test
October 29^{th} 2016: 10h00
Duration of the test: 1h30

Mestrado em Eng. Física Tecnológica (MEFT)
Particle Physics
1^{st} semester of 2016-17

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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 5 questions (2 pages).

Kaon mesons can be produced in proton-proton collisions. The following questions are based on realistic experimental measurements conducted at ANKE facility (Germany) and Argonne National Laboratory (USA).

1. [2 val] *Possible final states.* Verify, from the point of view of quantum numbers, if the following reactions are possible and if not explain why.

a) $p\,p \to p\,p\,p\,\overline{p}$

b) $p\,p \to p\,p\,K^-\pi^+$

c) $p\,p \to p\,p\,K^-\,K^+$

d) $p\,p \to p\,\pi^+\pi^+\pi^0$

e) $p\,p \to p\,p\,\phi$

where ϕ is a $s\bar{s}$ meson with a mass of 1020 MeV.

2. [4 val] *Luminosity.* In the USA experiment, bunches of 1.5×10^{11} protons hit a liquid hydrogen (H_2) target every 2.5 seconds. The target had a depth of 5 cm and a density of 0.071 g cm^{-3}. The total cross-section for the production of positive kaons in p-p collisions is around 400 μb for centre-of-mass energies of around 5 GeV.

a) Compute the total number of K^+ produced in one hour of run, at these energies

b) In fact, the liquid hydrogen was contained in an aluminium vessel with Mylar windows. Explain briefly how you could experimentally infer the interactions induced in these windows.

3. [4 val] *Kaon decay.*

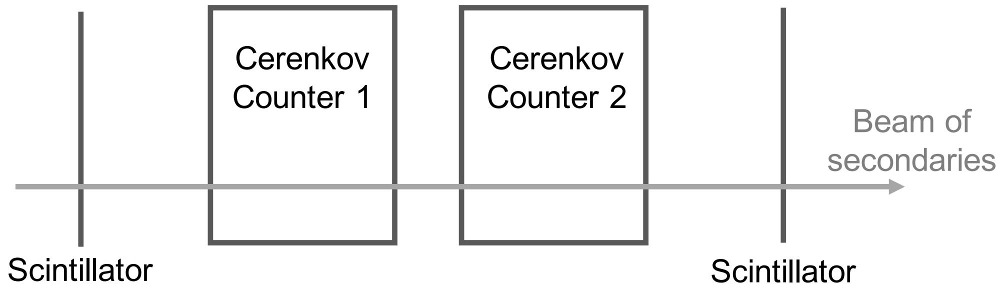
a) Consider the decay of one K^+. Indicate the probability of finding at least one π^0 in the final state, justifying the calculation. Neglect decay modes below 1%.

b) Supposing that the K^+ was produced with a momentum of 1 GeV/c, determine the mean distance that the kaon travels before decaying into $\mu^+\nu_\mu$. What would be the distance if the decay mode is now $K^+ \to \pi^+\pi^0$.

4. **[4 val]** *Cerenkov radiation.* The secondary kaons were separated from the pions using two Threshold Cerenkov Counters.

a) What should be the refractive index of the Cerenkov counter so that the detection threshold for a kaon is 1 GeV/c.

b) Discuss how one should set the thresholds of the two Cerenkov counters in order to unambiguously separate the pions the kaons and the protons that can be present in the 1 GeV/c secondary beam. The beam was defined using external scintillator counters, as shown in the figure below.



5. **[6 val]** *Kinematics.* In a fixed target experiment in ANKE, the kaon pair production was studied ($p\,p \to p\,p\,K^+\,K^-$). The proton beam had a kinetic energy of 2.7 GeV.

a) Compute the center-of-mass energy of the reaction and verify if it is enough to produce the kaon pair.

b) i. The production of the pair of kaons is enhanced whenever its invariant mass is equal to the mass of the ϕ meson and therefore, there is an intermediate virtual state (ϕ) that decays into K^+K^-. Compute in the reference frame of the ϕ the momentum of the kaons.

ii. Compute the momentum of the kaons in the laboratory frame, assuming that they were produced in the ϕ reference frame at 90° with the line of flight of the ϕ. Assume that the ϕ was produced along the beam line with a momentum of 1 GeV/c.

iii. Suppose now that you measure the quadrivectors of the two kaon mesons and one of the final protons. Explain how could one be sure that the above reaction ($p\,p \to p\,p\,K^+\,K^-$) had indeed occurred. Describe all the necessary calculations.