Universidade do Minho
Departamento de Física

Experimental Particle and Astroparticle Physics
Master Course
(Univ.Minho, Univ.Aveiro e Univ.Porto)

Examination (duration: 3h00)

Justify all your answers!

7 December 2021, 14h00-17h00

(1) Consider the scattering process $e^- + \mu^- \rightarrow e^- + \mu^-$ (figure 1) in the center-of-mass system, where particles 1 and 2 are moving along the z-direction (in opposite directions) with energy E (consider the masses of all particles are negligeable, given E). Evaluate the madelstam variables *s*, *t* and *u* for the scattering.

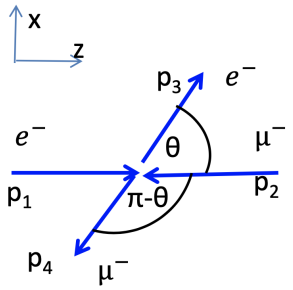

Figure 1

(2) Consider a three-body decay M→ 1+2+3 (having particles 1, 2 and 3 four-momentum p_1, p_2 and p_3, and masses m_1, m_2 and m_3, respectively)

a) show how to construct a Dalitz plot using the invariant masses squared, m^2_{12} and m^2_{23} , and check if the phase space is uniform across the distribution. What are the minimum and maximum values of m^2_{12} and m^2_{23}?

b) In figure 2, an unknown particle X is observed to decay according to X→p+K+π. (p=proton, K=kaon and π=pion). What can you tell, from the figure, about the different particles present in the decay?

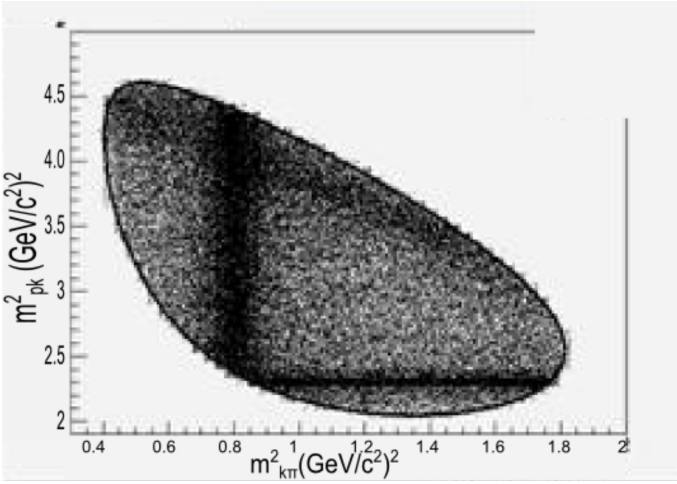

Figure 2.

(3) Check the commutation relation of momentum and position $[p^\mu, x^\nu] = i\hbar g^{\mu\nu}$.

(4) Consider the Klein-Gordon (KG) equation $p_\mu p^\mu \psi = m_0^2 c^2 \psi$ for a free particle with mass m_0. Discuss the free particle solutions of the KG equation and construct the four current density. Show how introducing the current density *of charge* affects the solutions of the KG equation.