Subatomic Physics II

Problem Set 6

Due on November 18, 2021, 11:59 PM

Problem 6.1: Helicity

The average helicity (polarisation, $\vec{\sigma} \cdot \vec{p}/E$) of spin-1/2 fermions and spin-1/2 antifermions participating in the charged weak interaction is $-\beta$ and $+\beta$, respectively, with $\beta = v/c$, i.e. for $\beta \to 1$, fermions must be fully left-handed and antifermions fully right- handed.

What is the preferred kinematic configuration (spin and momentum) of the three final-state particles in the decay $\tau^+ \to e^+ \nu_e \bar{\nu}_\tau$ (charged weak interaction)? Discuss the energy spectrum of the positrons. Justify your answer. Consider the decay in the rest system of the tau and assume neutrinos to be massless.
(4pt)

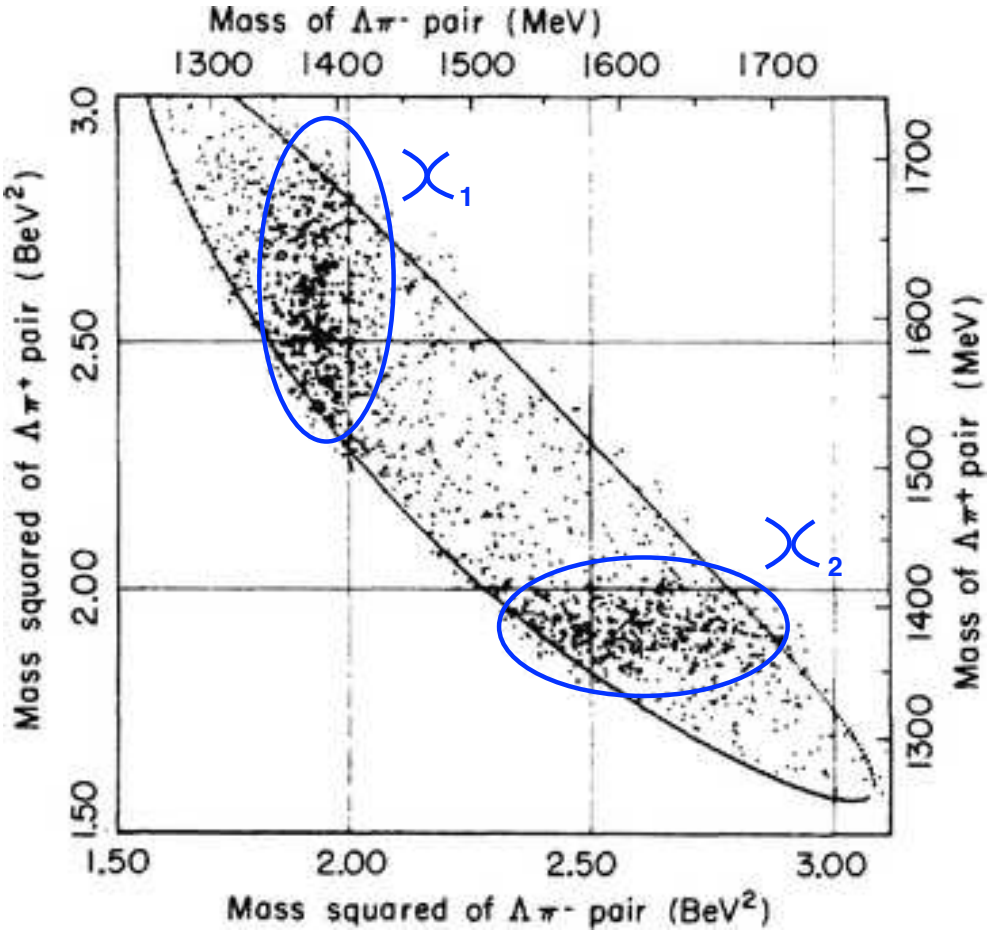
Problem 6.2: Particle hunting using the Dalitz plot

Particle decays or scattering reactions with three particles in the final state, for simplicity labelled $1 \to 3$ or $2 \to 3$ processes respectively, are described by two independent kinematic parameters in the overall CoM system. Possible kinematic quantities are the energies of two particles, or two invariant masses formed from two different pairs of final-state particles. Plotting events in the corresponding two-dimensional plane yields a so-called Dalitz plot.

Consider the $2 \to 3$ strong-interaction reaction $pK^- \to \pi^+\pi^-\Lambda$, whose Dalitz plot is shown on the next page. The solid curve encloses the region allowed by energy-momentum conservation. Each dot corresponds to an observed event; a few events fall outside the allowed region due to measurement uncertainties.

In answering the following questions, do not invoke the picture that hadrons are made of quarks!

1. What would we use today instead of the unit "BeV"? Can you think of a reason for its old name?
2. Consult the Particle Physics Book and write down the electric charge and $I(J^P)$ and strangeness quantum numbers of $p, K^-, \pi^+, \pi^-, \Lambda$.
3. Based on the Dalitz plot, how many intermediate resonances $X_i (i = 1, 2, ...)$ occur (resonance production in a $2 \to 2$ process, followed by resonance decay $1 \to 2$, yielding the $2 \to 3$ interpretation), and with which decay modes?
4. Are the X_i mesons, baryons or anti-baryons? Why?
5. Derive the electric charges and strangeness quantum numbers of the X_i.
6. Based on the Dalitz plot, estimate the masses of the X_i.
7. Derive the strong isospin I and third component I_z of the X_i.
8. Which possibilities exist for the spin/parity J^P quantum numbers of the X_i, restricting the quantum number of orbital angular momentum between the decay products of the X_i to either $l = 0$ or $l = 1$?
9. For $J = 3/2$ (measured in other experiments), identify the resonances X_i by looking them up in the Particle Physics Book; note down their names and decay modes.


Mass of Λπ⁻ pair (MeV)
1300
1400
1500
1600
1700
3.0
2.50
2.00
1.50
Mass squared of Λπ⁺ pair (BeV²)
1700
1600
1500
1400
1300
Mass of Λπ⁺ pair (MeV)
1.50
2.00
2.50
3.00
Mass squared of Λπ⁻ pair (BeV²)
X1
X2

(6pt)