Chapter 1: Basic concepts

Elastic scattering of elementary particles preserves their identities, and proceeds via exchange of neutral gauge bosons . Estimate the maximal range over which such exchange can take place, if the exchanged boson is:

a) photon, $m_\gamma = 0\ GeV/c^2$

b) Z boson, $m_Z = 91.19\ GeV/c^2$

c) hypothetical Higgs boson, estimated minimal mass $m_H > 114.3\ GeV/c^2$

Hint: $\hbar \equiv h/2\pi = 6.582 \times 10^{-22}\ MeV\,s$ and $c = 2.998 \times 10^8\ m/s$

Chapter 2: Leptons, quarks and hadrons

Define which hadron quantum number combinations $(Q,B,S,C,\tilde{B})$ are allowed by the quark model, and suggest their quark constituents:

a) (0,0,1,0,0)
b) (2,1,0,1,0)
c) (0,0,0,0,1)
d) (-1,1,-2,0,-1)

Chapter 3: Experimental methods

1. Two beams of accelerated protons, each with energy $E_{beam} >> m_p$, collide at a crossing angle θ. Using the four-vector formalism, prove that maximal E_{CM} is achieved when the beams collide head-to-head.

2. Critical energy of the electromagnetic shower development in iron is $E_C=24\ MeV$, and one radiation length is $X_0=1.76\ cm$. Estimate the necessary thickness of a calorimeter that uses iron as an absorber, if initial electrons have energies not exceeding $E_0=100\ MeV$.

Chapter 4: Space-time symmetries

Electromagnetic decays of η meson to two pions have never been observed, which is explained by the parity conservation requirement. Use this knowledge to:

a) knowing that η has spin 0, deduce its parity
b) knowing that decays of η to three pions are readily observed, deduce intrinsic parity of a pion

Chapter 5: Hadron quantum numbers

Draw a quark diagram for the process $\pi^- + p \rightarrow \Delta^0 \rightarrow \pi^0 + n$ and estimate the mean distance travelled by Δ^0 before it decays, assuming it was produced with $\gamma = E/m \approx 10$.

Chapter 6: Quark states and colours

Resonance Δ^{++} has a barion number B=1, electric charge Q=2, and $S = C = \tilde{B} = T = 0$. Explain why such particle can not exist unless color charge is introduced.

Chapter 7: QCD, jets and gluons

In a deep-inelastic scattering of a lepton off a proton target (mass M_p), energy-momentum transfer is denoted by the four-vector Q, and the final hadron state has the invariant mass W. In the proton rest frame, Lorentz-invariant energy transfer is $\nu = E - E'$ (E and E' are lepton energies before and after scattering). Prove it using the definition of ν : $2M_p\nu \equiv W^2 + Q^2 - M_p^2$

Chapter 8: Weak interactions: W and Z bosons

In the lowest order weak interactions, decays proceed via single W-boson exchange. Explain why the decay $\Sigma^- \rightarrow n + e^- + \overline{\nu}_e$ have been observed, while $\Sigma^+ \rightarrow n + e^+ + \nu_e$ - never. Σ^- has quark contents of (dds), and Σ^+ - (uus). Plot the quark diagram for the Σ^- decay.