Modern Experimental Particle Physics (FYST17) - Problems

Chapters 1-4; return by February 5

1. 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 $m_H = 114.3\ GeV/c^2$

2. 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)

3. A secondary particle beam can consist of several types of different particles. Separators are used to select the type of particle required. The separator consists of two parallel plates with a high potential between them. The beam passes between the plates and then through a deflecting magnet and slit system. Show that the difference in angular deflection, $\Delta\theta$, of two relativistic particles with momentum p and masses m_1 and m_2, after traversing an electric field of strength E and length L, is $\Delta\theta = eEL(m_1^2 - m_2^2)/2p^3$.

4. The 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 $E_0 = 100\ MeV$.

5. 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) deduce the parity of η, knowing that it has spin 0;
b) deduce intrinsic parity of the pion, knowing that decays of η to three pions are readily observed.

Modern Experimental Particle Physics (FYST17) - Problems

Chapters 5-7; return by February 17

1) In a fixed target experiment, a π^- beam is used on a proton target and the process
$\pi^- + p \rightarrow \Delta^0 \rightarrow \pi^0 + n$ can occur.
a) Draw a quark diagram for this process and estimate the mean distance travelled by the Δ^0 before it decays, assuming it was produced with $\gamma = E/m \approx 10$.
b) Using four-vectors, compute the π^- beam energy required to produce the above process at the Δ^0 resonance, $m(\Delta^0)$=1230 MeV.
c) Show that, if the π^0 and n are produced with an angle $\theta=\pi/2$ between them, they can only obtain the energies $E(n)E(\pi^0)=E(\pi^-)$ and $E(\pi^0)E(n)=m(p)$, assuming that $m(\pi^-)=m(\pi^0)$ and $m(n)=m(p)$.

2) 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. Could a baryon with three down quarks exist?

3) The Coulomb potential represents a point charge. When an electrostatic potential is instead represented by a spherically symmetric charge density $\rho(r)$, the differential scattering cross section differs from the Rutherford cross section by a form factor squared, $G^2_E(q^2)$:

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_R G_E^2(q^2)$$

where

$$G_E(q^2) = \int \rho(r) e^{i\vec{q}\cdot\vec{x}} d^3\vec{x}$$

Perform the angular integration of the form factor and show that:
- $G^2_E(q^2)$ is a function of q^2 only
- the mean squared radius of $\rho(r)$ equals

$$\overline{r^2} = \int r^2 \rho(r) d^3\vec{x} = -6 \left.\frac{dG_E(q^2)}{dq^2}\right|_{q^2 = 0}$$

Bonus problem (not mandatory, but you can get an extra point):

Explain the effect on the differential cross section (w.r.t. the scattering angle θ) when a point charge (infinitely narrow distribution) is replaced by a charge density $\rho(r)$, represented by a Gaussian (normal) distribution.
Note that the Fourier transform of a "narrow" Gaussian becomes a "wide" Gaussian distribution (and vice versa). Both charge distributions are normalized to 1.

Modern Experimental Particle Physics (FYST17) - Problems

Chapters 8-12; return by March 4

1) In the lowest order weak interactions, decays proceed via single W-boson exchange. Explain why the decay $\Sigma^- \rightarrow n + e^- + \bar{\nu}_e$ 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.

2) Which of the following processes are allowed in electromagnetic, and which - in weak interactions? Consider only single boson exchange processes.

1. $\Sigma^- \rightarrow \pi^- + n$
2. $\Sigma^0 \rightarrow \Lambda + \gamma$
3. $B^+ \rightarrow K^+ + e^+ + e^-$
4. $K^+ \rightarrow \pi^0 + \mu^+ + \nu_\mu$

3) Using Feynman diagrams, show that the neutral meson mixing can occur not only in the case of neutral kaons, but also for neutral D mesons (D^0 ($\bar{u}c$) and $\bar{D}^0$ ($u\bar{c}$)) and neutral B mesons (B^0 ($d\bar{b}$) and $\bar{B}^0$ ($\bar{d}b$), as well as B_s^0 ($s\bar{b}$) and $\bar{B}_s^0$ ($\bar{s}b$)).

4) In February 1987, bursts of neutrino interactions associated with $\bar{\nu}_e$ were observed at both the *Kamioka* and the *IMB* detectors, which were built to detect proton decay. A few hours later, astronomers reported visual observation of the supernova SN1987A, approximately 1.5×10^5 light years away. Assuming that this event was the source of registered neutrino bursts, estimate an upper limit of the electron antineutrino mass, knowing that the incident neutrino energies covered the range 10-40 MeV and the interactions were observed to occur over a ~ 10 second period.