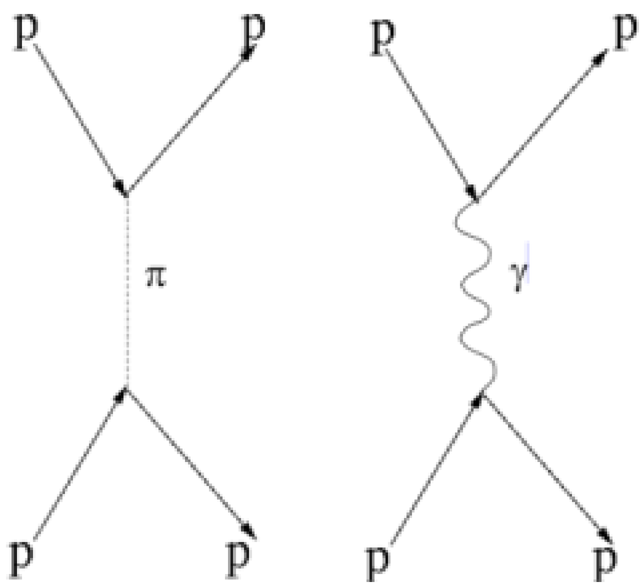
Assigment 1 - due Friday, May 14th

1. proton-proton scattering can occur via the strong force and E/M forces. A good first approximation to the strong force is given by π^0 exchange ($M_p = 938$ MeV/c^2, m_π=139.57 MeV/c^2)



   (a) Write down the amplitudes for these two diagrams in terms of the coupling constants and momentum transfer squared (q^2).

   (b) Assuming $g_\pi^2 = 0.079$ and $\alpha = \frac{1}{137}$, at what q are the amplitudes equal?

   (c) What is the final kinetic energy of a target proton if it receives this momentum transfer?

2. At the peak of the Z^0 resonance, the cross section for $e^+ + e^- \rightarrow Z^0$ is 28.5 nanobarns.

   (a) What Luminosity is required to create 10^7 Z^0 in one year of running?

   (b) Assuming the cross sectional area of the beams are 1 mm^2 at the interaction point and there are equal numbers of e^+ and e^-, what is the average circulating current (in μA) required to achieve this?

   (c) The circumference of LEP is 27 km, what is the total power lost to synchrotron radiation at this current?

3. The BELLE detector needs to able to distinguish π's from k's at a momentum of 3.0 GeV/c. This is acheived through the use of a "Threshold Cherenkov" detector. This

device gives off light when π's pass through it but does not emit light when kaon's pass through it.

(a) What is the maximum refractive index at which this is possible?

(b) At what angle Cherenkov to the beam direction is this Cherenkov light emitted?

(c) At what pion momentum will this material cease to give light?

(d) Explain how this detector distinguishes π/K and over what momentum range will it work?

(e) By consulting the Particle Data Group report, name a material that might have the properties required for this detector.

4. The ω meson is known to have spin less than 2 and to decay to the $\pi^+\pi^-$ frequently but never to the $\pi^0\pi^0$ state. The width of the ω meson is $\Gamma = 8.4$ MeV.

   (a) What is the spin of the ω meson?

   (b) What is the parity of the ω meson?

5. The f_0 meson has width $\Gamma = 33.6$ MeV. It is knwon to have spin less than 2 and always decays strongly to $\pi^+\pi^-$ and to $\pi^0\pi^0$.
   ie. Both $f_0 \rightarrow \pi^+\pi^-$ and $f_0 \rightarrow \pi^0\pi^0$ occur frenquently.

   (a) What is the spin of the f_0 meson?

   (b) What is the parity of the f_0 meson?

6. The Large Hadron Collider will collide counter rotating beams of 7,000 GeV protons to provide a CMS energy of 14,000 GeV. What laboratory incident energy would be required to acheive the same CMS energy if the proton beam collided with a stationary proton target?

7. One of the following three reactions cannot procede through the strong interaction.

   $$\pi^- p \rightarrow \Sigma^+ + K^-$$
   $$\pi^- p \rightarrow \Sigma^0 + K^0$$
   $$\pi^- p \rightarrow \Sigma^- + K^+$$

   Which is it? Why is it forbidden?

8. The Weak, Electromagnetic and the Strong force are each responsible for one of the following 3 decays. For each decay, state the force responsible and your reasons for naming that force.

   (a) $\Delta^{++} \rightarrow \pi^+ + \text{p}$

   (b) $\Sigma^0 \rightarrow \gamma + \Lambda$

   (c) $\Lambda \rightarrow \pi^- + \text{p}$

9. It is proposed to use the reaction:
   $\pi^- p \rightarrow K^0 + \Lambda$
   as a source of mono-energetic neutral kaons. The π^- particles are fired at a liquid Hydrogen target 40 cm thick. The density of liquid Hydrogen is 0.06 gm/cm^3.

   (a) The total cross section for the reaction is 8 millibarns. The pion beam intensity is 5×10^{10} particles per second. How many K^0 are created per second?

   (b) Find the expression for rate of decay as a function of time for:
   $$\text{K}^0 \rightarrow \pi^+\pi^-$$
   The branching ratio for $\text{K}_S \rightarrow \pi^+\pi^-$ is 0.66
   The branching ratio for $\text{K}_L \rightarrow \pi^+\pi^-$ is 0.002

   (c) For π^- particles of incident momentum 1.05 GeV, K^0 particles produced at 0 degrees to the incident beam have momentum of 636 MeV/c. Approximately how many $\text{K}^0 \rightarrow \pi^+\pi^-$ decays occur in the region between 1 and 2 meters downstream of the target?

10. (a) Describe the general features of hadronic and electromagnetic calorimeters.

    (b) What are the differences between electromagnetic and hadronic calorimeters?

    (c) How can a Hadronic Calorimeter be used to distinguish pions from muons?

11. Show that for $\text{E} \gg \text{m}$, $\text{E} \simeq \text{p} + \frac{m^2}{2p}$. Where E = total energy of the particle, p = momentum of the particle, m = particle mass and using units of speed of light=1, (c = 1)

12. The majority the energy release from a supernova is in the form of neutrinos as about 1 solar mass of protons undergo the reaction:

$$p + e^- \rightarrow \nu_e + n$$

The explosion of supernova 1987A in the Large Magellenic cloud was observed in neutrino detectors on Earth. These detectors consisted of about 1000 tonnes of water and events were detected via the Cherenkov light emitted by recoiling electrons from inverse beta decays.

(a) Estimate the number of neutrinos per square centimeter at the Earth from the explosion.

(b) The neutrino detectors were located about 1 km below ground. Why is this a good place for a neutrino detector?

(c) The refractive index of water is 1.3. What is the minimum energy electron that could be detected ?

(d) The Sudbury Neutrino Observatory (SNO) uses 1000 tonnes of D_2O (D, deuterium is an isotope of hydrogen that consists of a proton and a neutron) as the sensitive mass of it's detector. The binding energy the neutron in deuterium is 2 MeV, the binding energy a neutron in Oxygen is 16 MeV and the average neutrino energy from SN1987A was 10 MeV. If SNO had been operating when SN1987A was detected on Earth, it would have been particularly sensitive to it's neutrinos. What is the advantage of using D_2O to detect supernova neutrinos compared to ordinary light water?

(e) The cross section for the reaction that SNO can use to detect the presence of supernova neutrinos is about 1×10^{-40} cm^2. Estimate the number of neutrino events SNO would have observed, had it been operating when the neutrino pulse from SN1987A arrived.

(f) The relationship between the time of arrival of the neutrinos from SN1987A and their energy sets the present best upper limit on the mass of the electron neutrino. Assuming both neutrinos start from the exactly the same position at exactly the same time and have mass 10 eV/c^2, calculate the difference in time of flight for neutrinos of energies 10 MeV and 20 MeV from SN1987A.