Introduction to High Energy Physics
HomeWork #2, Due Oct 23, 2007

Chapter 3 problems: 16, 22, 23

An ultimate energy

Magnetic fields in the universe accelerate charged particles in intergalactic space up to enormous energies. These energetic particles rain down on the Earth as "cosmic rays". Particle physicists conjecture that there is an ultimate limit to the energy of cosmic rays due to their collisions with the "cosmic background radiation" (CBR) that suffuses the Universe. Suppose the cosmic rays are protons (with rest mass $m_p = 1.67 \times 10^{-27}$ kg.). Suppose the CBR consists of photons of energy 2.1×10^{-4} eV. [This is the energy corresponding to the temperature ($E = kT$) of $2.3^{\circ}K$ that characterizes the background radiation.] The reaction that degrades the energy of the cosmic rays is "pion production"

$$\gamma + p \rightarrow \pi^0 + p,$$

where γ is a CBR photon and the π^0 is a "meson" with rest mass $m_{\pi^0} = 0.240 \times 10^{-27}$kg.

(a) What is the threshold energy of the proton, *ie.* what is the minimum proton energy necessary for this reaction to go in the frame where the photons have energy 2.1×10^{-4} eV?

Hint 1: As always, the use of invariants will make this problem much simpler.

Hint 2: Consider the threshold condition in the center of mass of the final proton and pion. What is their configuration at threshold?

(b) Suppose the proton has just enough energy to make the reaction possible. What is its energy after the collision?