Homework 1 *Due on Wednesday Sept 17, 3:00 pm*

13 + 3 (bonus) = 16 points

Problem 1 (1+4=5 points)

Whose names are associated with discoveries of electron, proton, photon, and neutron? (1 point)
What were the decisive measurements/observations for these discoveries? (4 points)

Problem 2 (2 points)

If muons were produced in the center of our galaxy, what should their typical energy be so that they could reach the Earth before decaying? (2 points)

Problem 3 (3 points)

Consider a photon of energy e_g incident on a stationary proton. For sufficiently large e_g, a neutral pion can be produced in a reaction $g + p \to p + p^0$. What is the threshold (minimal) photon energy for this reaction to occur? (3 points)

Problem 4 (3 points)

Consider the same process as in Problem 3, but for very different circumstances: a high energy proton interacting with a photon of the cosmic microwave background. Find the minimum energy the proton would need for this reaction to occur. (3 points)

Do you know why this example is very important? (no points)

Bonus Problem (3 points)

Consider an elastic scattering of two 0-spin particles A + B $\to$ C + D of known masses. There are four different 4-vectors that describe the kinematics of this process: two 4-vector momenta of the two particles before collision, p_1 and p_2, and two 4-vector momenta after the collision, p_3 and p_4. Naively, this adds up to 16 variables.

Show that only two independent variables are needed to describe **the physics** of this process. (2 points)
Hints: Does it matter for physics if we rotate the coordinate system? Does it matter for physics of the process if one would study it in the AB center of mass frame or in some other frame?

Two invariant variables are commonly used for these purposes: the center-of-mass energy squared $s=(p_1 + p_2)^2$ and the transferred momentum squared $t=(p_3 - p_1)^2$. Show that t is always negative. (1 point)