Particle Astrophysics 959
Homework 2
Due September 28, 3pm
Email me if there are errors in the problems!

1. The LHC has a radius of about 4km and its magnets have a magnetic field of about 10 Tesla. From the Hillas criterion, estimate the maximum energy of the protons it can accelerate. Discuss whether this places the LHC at about the right place on the Hillas diagram. What B would be needed for an accelerator of this size to produce 1 ZeV? What would be the maximum energy of an accelerator circling the earth with a 10 T field?

2. Find the proton energy (in eV) at which collisions of protons with a typical CMB photon would be at the threshold for production of an e+ e- pair (Bethe-Heitler process).

3. If instead you collided photons of ~ TeV energy with typical IR photons of wavelength 1 μm and also produced e e pairs, what incident energy photon would produce them at threshold? Why is this calculation more uncertain than the p – CMB process?

4. A balloon payload is about 1m high. An incident particle's time of arrival is measured in plastic scintillator at the top and bottom of the detector. How accurately must the time be measured, in order to give a velocity measurement of a relativistic particle accurate to 5%? How accurate to tell an up-moving particle from a down-moving by 10 standard deviations? Which criterion is more demanding?

5. Suppose a satellite detector has a 5kG magnetic field over a 1m region, and the tracker goal is to measure the momentum of a 1 TeV charged particle to 1% accuracy. Let's approximate the trajectory measurement by 3 measurements: entering, in the middle, and leaving, so the sagitta of the path is the difference between the middle position on a circular arc and at the ends. How accurately must the position be measured? What technology might do this?

6. Tesla in 1901 proposed to capture the energy of cosmic rays as a source of power. Assuming a CR flux of 1 particle per square centimeter per second of particles averaging 3 GeV, calculate the energy flux density (Watts / square meter) of cosmic rays. Compare this with the energy flux density of sunlight on the surface of Earth.

7. At what particle energy (in eV) does a proton Larmor radius equal the scale height of the galactic disk (E2.5 pc) in the typical galactic field of E-5.3 G).

8. Consider a CR spectrum proportional to E^-2.7 . a) how many fewer CRs are there above 5 TeV than there are between 1 and 5 TeV? Than there are between .1 and 1 TeV? b) Suppose your measuring apparatus for CR energy is sensitive to only CR above 1 TeV, and measures energy in terms of x = Log_{10}(E) where E is in Ev. Further suppose the estimator of x has a Gaussian distribution of x for a given true energy, with resolution σ(x)= .2, that is the standard deviation is .2 decades of energy. Estimate the fraction of CR's measured as above 5 TeV, that are actually above 5 TeV, considering just the cosmic ray spectrum of 1 TeV and above. (may require numerical work).