1. Plot the photon density integrated over 400 to 700 nm of a vertical muon ($\beta = 1$) versus the distance of the impact on ground level (assume mountain altitude of 2400 m; $p = 750$ hPa, $T = -10^\circ$ C). You may use the numerical results shown in Fig. 1. Assume there is no absorption or scattering.

You can use $P(h) = P_0 \exp(-mg h / kT)$ everywhere for this problem, although an isothermal atmosphere is really only a good approximation above 10 km (stratosphere). Below this, the atmosphere is much more nearly adiabatic (temperature drops about $10^\circ$ C/km).

Recommendation: don’t write a program. You’ll get a better feeling for the problem (although a less accurate result) if you decide on about five altitude zones. Use the average properties for each, and add their contributions per unit area as a function of off-axis distance.

Fig. 1 — Number of Cherenkov photons for $\beta=1$ particles as function of the refractive index, or more precisely of $(n-1)$. Integrated from $\approx 400$ to 700 nm. Note that $(n-1)$ is proportional to air density, and is equal to 0.00030 at 1000 hPa and $0^\circ$ C.
2. Make a crude plot (4 or 5 points are enough if you choose them well) of the mean free path in kpc for gamma rays in intergalactic space for photon-photon pair production on the 3 K microwave background. You can approximate the blackbody spectrum by a delta function at $<h\nu> = 2.7\ k_B T$ for $T = 2.7\ K$, but use the correct total energy density. What would be the most important correction from using the real distribution instead?

3. What is the minimum temperature of an intergalactic infrared photons background that can produce significant absorption at $1 \times 10^{13} \ eV$? You can again approximate the blackbody with a delta function at $2.7\ kT$. What energy density is required to produce 50% absorption in a path length of 50 Mpc? What fraction of blackbody density is this?