Introduction to astroparticle physics

Part 2, Exercises 2

May 2, 2025

1 Cherenkov radiation

A muon with momentum $p = 555$ MeV/c travels through a high-pressure gas. The refractive index of the gas can be adjusted by changing its pressure.

1. Determine the minimum refractive index (n_{min}) the gas must have to allow the muon to induce Cherenkov radiation.

2. Calculate the emission angle (θ_0) of the Cherenkov radiation when the refractive index of the gas is $n_0 = 1.61$.

2 Particle energy loss by Cherenkov effect

The Surface Detector (SD) of the Pierre Auger Observatory (PAO) covers an area of 3000 km^2 and includes more than 1600 water Cherenkov detectors. Each detector consists of a cylindrical tank containing 12 tons of water, with a height of 1.2m. Consider a vertical muon entering one of the tanks with an energy $E_0 = 5$ GeV. The refractive index of water is $n = 1.33$, assumed constant across the relevant range of photon wavelengths. Estimate the energy lost by the muon due to ionization as it traverses the water. Compare this with the energy lost via the Cherenkov effect, assuming the ionization energy loss in water is approximately the same as in carbon.

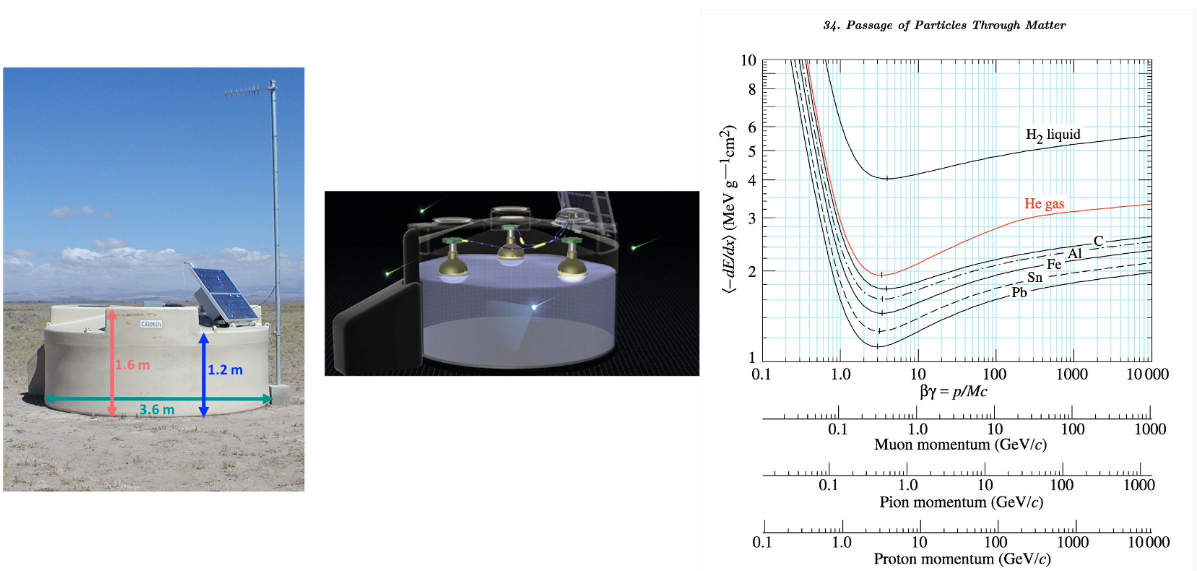

Figure 1: A water Cherenkov detector of the Pierre Auger Observatory (left). Drawing of the inner part of a PAO water Cherenkov detector (center). Mean energy loss per unit length by ionization (right, from https://pdg.lbl.gov/2023/reviews/rpp2023-rev-passage-particles-matter.pdf).

3 Multiple Coulomb scattering

What is the root mean square scattering angle of atmospheric muons of 100 GeV after a path of 320 meter water equivalent (mwe) in rock?
For the radiation length of rock, please see https://pdg.lbl.gov/2023/AtomicNuclearProperties/index.html.