MINOS Problems

Muons have relatives

Muons are cousins to the electron, and have a mass about 207 times as large as an electron. They are, however, unstable and decay in a time of 2.2 µs (τ) in their own reference frame. Muons can be produced in high-energy particle decay of pions, such as from collisions of protons with carbon in the Main Injector, or by cosmic ray interacts in the upper atmosphere. The Far Detector can detect these cosmic muons that can penetrate to 2341 feet underground in Soudan.

![Diagram of particle interactions](http://www.lanl.gov/milagro/images/cosmic_interactions.gif)

Consider a muon generated in the atmosphere traveling downward toward the Far Detector above the Soudan mine at 0.95 c.

1. Using the reference frame of the muon, how far would it travel in the atmosphere before it decayed?

2. Experiments have proved that muons can make it to the surface (and under the surface) of the ground and be detected. Prove this is possible considering relativistic effects of the muon if its distance of travel is measured from an Earth-frame observer. Recall that the distance traveled would be \( d = \gamma \nu \tau \) where \( \gamma = \left(1 - \frac{v^2}{c^2}\right)^{-1/2} \).