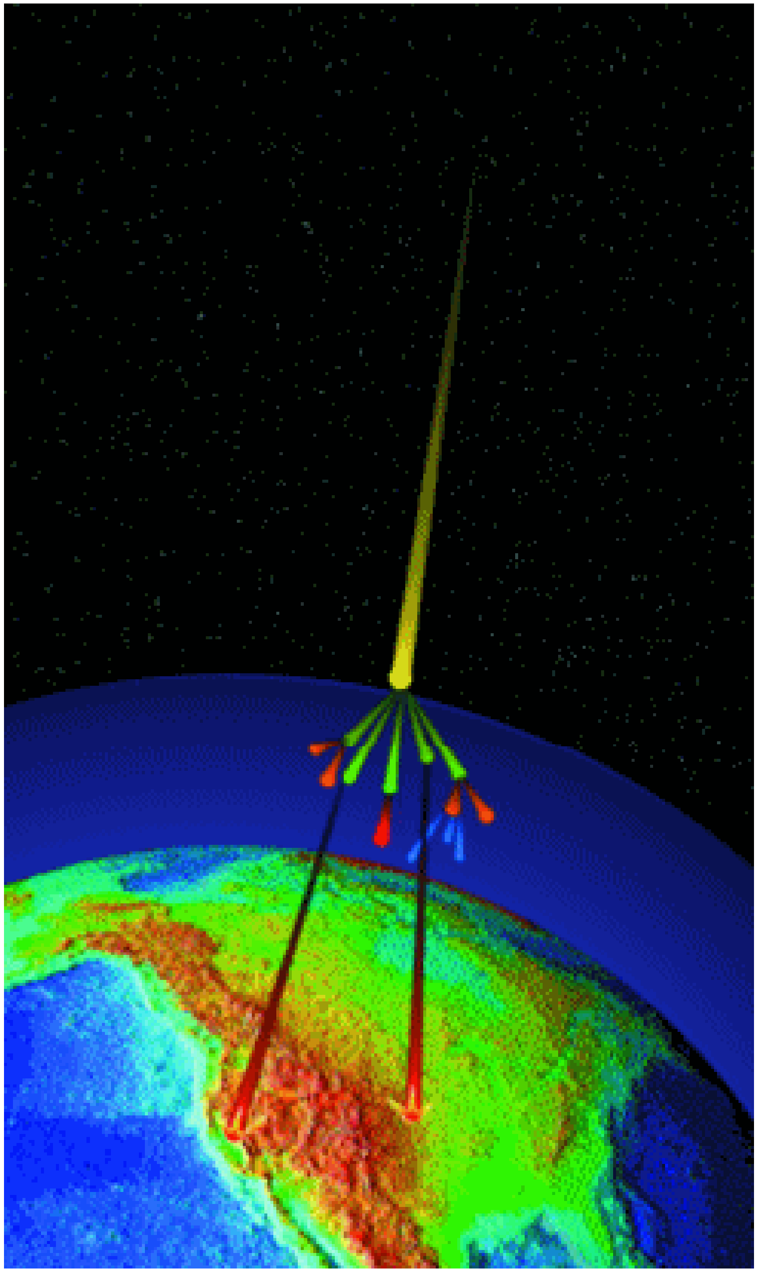
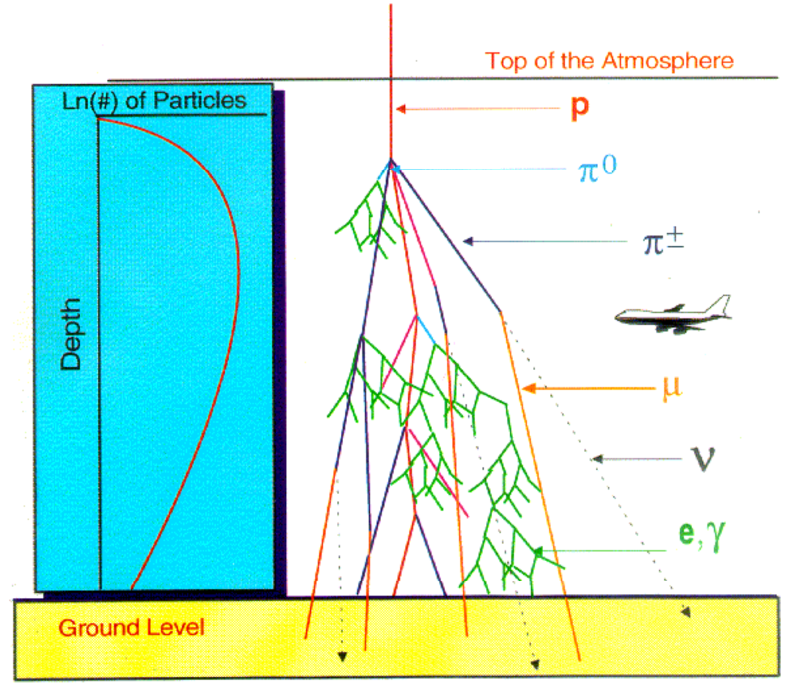
Time-dilation experiment

This experiment is an indirect verification of special theory of relativity using cosmic ray muons. The picture here shows how cosmic ray muons are created. They are created in the upper atmosphere when fast protons (having terra electron volts of energy) collide with nuclei of atoms such as oxygen or nitrogen. The yellow particle which comes from space is called the primary particle and the green, red, blue and brown which are created due to earth's atmosphere are called secondaries.



This is more detailed interaction of the proton from the cosmos with the proton present in earth's atmosphere.The collision of high energy proton from space with proton in atmosphere produces pions. The pions are short lived and they decay by the reactions:



Extensive Air Showers

$$\pi^0 \rightarrow \gamma + \gamma$$

$$\tau_{mean} = 8.4 \times 10^{-17} \text{sec.}$$

$$\pi^\pm \rightarrow \mu^\pm + \nu_\mu$$

$$\tau_{mean} = 2.6 \times 10^{-8} \text{secs}$$

The earth's atmosphere is about 8000 meters. Pions have a lifetime of 2.6×10^{-8} Secs.

If we assume that they are moving nearly with the speed of light = 0.998c, then from Newtonian Physics, they would travel

$.998 \times 3 \times 10^{8} \times 2.6 \times 10^{-8} = 7.784$ meters

In Special Relativity the pion lifetime would be dilated by a factor γ where,

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} = 15.87$$

Therefore, the Pions will travel $15.87 \times 7.784 = 123.53$ meters.

Either from relativity or from Newtonian Physics they will therefore not be able to reach the earths surface which is 8000 meters away.

We will now look at Muons. The decay mode and mean life time of muons is

$$\mu^{\pm} \rightarrow e^{\pm} + \nu_{\mu} + \nu_{e}$$

$$\tau_{mean} = 2.2 \times 10^{-6} \text{sec.}$$

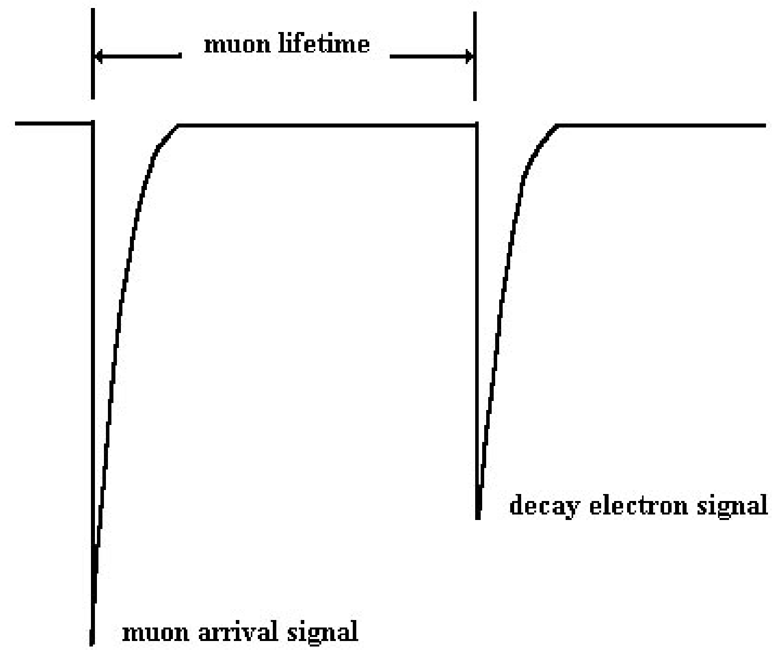
In Newtonian Physics, they would travel:

$$0.998 \times 3 \times 10^{8} \times 2.2 \times 10^{-6} = 659 \;\; meters$$

THUS, THEY WILL NOT BE ABLE TO REACH THE EARTH SURFACE.

We do see them because they are moving with speed of light, there will be time dilation. They travel 15.87 X 659 = 10458 meters and they are able to reach earth's surface.

- For cosmic ray muons, the lifetimes of individual particles can be measured by looking for pairs of pulses, from the detector, that are a few microseconds apart.
- We associate these pairs of pulses with muon decay events, the first pulse being due to the arrival and capture of the muon in the apparatus and the second associated with the emission of the decay electron.
- The first pulse starts a timer and the second one stops it. Whilst this is not a measurement of the true time between the creation and subsequent decay of the muon, the distribution of the measured time intervals has the same characteristics as the true lifetime curve. It is comparable to moving the origin of the graph to a new position; it doesn't matter where the origin is, the exponential has the same shape.



The data shown in the figure is then fitted with a curve of the form shown below. Here τ is the mean life time of the muons.

$$N(t) = N_0 e^{\frac{-t}{\tau}} + B$$