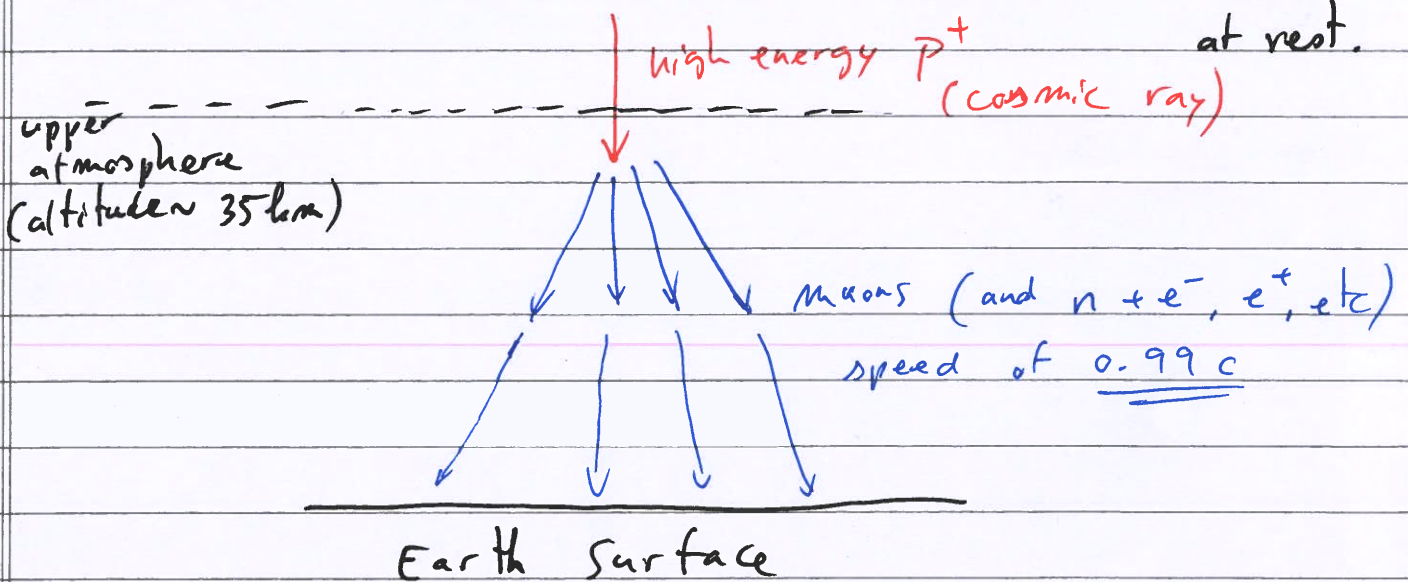


Example: Muons from Cosmic Rays

A muon (μ) is a "heavy electron" with the same charge as an electron but with 207 times the mass of an electron.

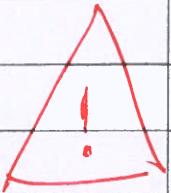
Muons are unstable and have a lifetime of $2.2 \mu\text{s}$ at rest.



Galilean "naive" travel distance

$$\Delta z = \Delta t \times v = (2.2 \times 10^{-6} \text{ s}) \left(\underbrace{0.99 \times 3 \times 10^8 \text{ m/s}}_{2.97 \times 10^8 \text{ m/s}} \right)$$

$$= 653 \text{ m}$$



Wrong

Experimental fact: Cosmic ray muons are observed in large numbers on Earth's surface.

Special Relativity calculation of travel distance

Muons "live" for $2.2 \mu\text{s} = \Delta t'$ in their rest frame.

In our frame (Earth's frame), the muon lifetime experiences time dilation.

$$\Delta t = \gamma \Delta t' \quad \text{with } \gamma = \frac{1}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} \quad \text{with } v = 0.99c$$

↑
↑
↑

Earth's frame
muon's rest frame
muon's rest frame

In Earth's frame, the

muon's lifetime, i.e. travel

time, is

$$\Delta t = 50.3 \times 2.2 \mu\text{s}$$

$$= 110.5 \mu\text{s}$$

$$= 110.5 \times 10^{-6} \text{ s}$$

$$\Delta t \approx 110 \times 10^{-6} \text{ s}$$

Vertical travel distance of muons: $\Delta z = v \times \Delta t$

$$= (2.97 \times 10^8 \frac{\text{m}}{\text{s}}) (110 \times 10^{-6} \text{ s})$$

$$= 32834 \text{ m} = 32.8 \text{ km}$$

\Rightarrow

$$\Delta z \approx 33 \text{ km}$$

\Rightarrow many moons should make it to the Earth's surface.