EP 328 Particle Physics

Cosmic Rays

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1. Origin of the Cosmic Rays

- Cosmic rays are energetic particles which do not originate from Earth.
- **Primary Cosmic Rays** originate from energetic processes on the Stars and travel interstellar medium.
- Apart from particles associated with solar flares, the cosmic radiation comes from outside the solar system (such as rotating neutron stars, supernovae)
- High energy primary cosmic rays collide with particles high in the atmosphere and cause jets of secondary particles known as **air shower**.

The cosmic radiation incident at the top of the terrestrial atmosphere includes all stable charged particles and nuclei with lifetimes of order $10^6$ years or longer.

Technically, **primary cosmic rays** are those particles accelerated at astrophysical sources.

**Secondaries** are those particles produced in interaction of the primaries with interstellar gas.

>> Electrons, protons and helium, as well as carbon, oxygen, iron, and other nuclei synthesized in stars, are primaries.

>> Nuclei such as lithium, beryllium, and boron are secondaries.

>> Antiprotons and positrons are also in large part secondary.
- Major components of the primary cosmic radiation.
  * Protons ~ 90%
  * He ~ 9%
  * e- s and other nuclei ~ 1%

- Note that some cosmic rays can have energies of over $10^6$ GeV = 1000 TeV = 1 PeV.

far higher than LHC protons (7 TeV)

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**Cosmic Rays in Atmosphere**

When primary cosmic rays hit Earth's atmosphere at around 30,000 m above the surface, the impacts cause nuclear reactions which produce pions, kaons and other unstable mesons called air shower.

\[ p + O^{16} \rightarrow n + \pi \]

\[ n + N^{14} \rightarrow p + C^{14} \]

*This is important for radio carbon dating*
Cosmic Muons

- The newly produced (many) charged pions, quickly decay into muons.
  \[ \pi^+ \rightarrow \mu^+ + \nu_\mu \]
  \[ \pi^- \rightarrow \mu^- + \bar{\nu}_\mu \]
  And neutral pions decay mostly to two photons
  \[ \pi^0 \rightarrow \gamma \gamma \]

- Because muons do not interact strongly with the atmosphere and because of the relativistic effect of time dilation many of these muons are able to reach the surface of the Earth.

- Muons are ionizing radiation, and may easily be detected by many types of particle detectors such as bubble chambers or scintillation detectors.
Spectrum of muons at $\theta = 0^\circ$ (●, ■, ▽, △, ×, +) and $\theta = 75^\circ$ ⊙

Muon charge ratio

$F_{\mu}\mu / F_{\mu\mu}$ vs $p_{\mu}$ [GeV/c]
Exercises

Consider you have cosmic muon detector (counter) of square shape whose one side is 30 cm. Assume that the detection efficiency is 90%.

1. Estimate number of muons that will be detected by your counter at the see level per steradian in 1 hour using the figure on page 8.

2. In problem 1, assuming the muon charge ratio is $F_+/F_- = 1.3$, calculate number of positive muons which will be detected.

3. Consider that you place your counter at a level of 5 km under the Earth surface. Using the figure on page 11, compute how many hours you should wait to count 20 muons per steradian.