Experiments in Modern Physics:
Cosmic Rays
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Goals
Understand the workings of high energy physics detectors and electronics. Use these to measure the rate of cosmic rays and the lifetime of the muon.

Introduction
Fast atomic particles are moving through interstellar space. The earth is thus under a constant bombardment by protons, and, to a lesser degree, by light nuclei (see ref. [1], fig.20.1). The average energy of these particles of in the order of 1 GeV, but can range to energies higher than those that can be produced by accelerators. When the particles make contact with the upper atmosphere, they start to undergo nuclear reactions with the air. Almost none of them reach the surface of the earth. However, the products of these reactions can survive.

In high-energy collisions in the atmosphere, pions are produced in abundance. Pions have a mean life of only 26 ns (at the speed of light, they travel only about 8m). When they decay, they produce a muon (µ) and a neutrino (ν). The charged muons lose energy in the atmosphere, but an initial energy of about 1 GeV is enough to reach the surface of the earth.

The muon is also unstable, decaying into an electron and two neutrinos with a mean life of about 2 µs. Thus, it seems that the muons should decay before they reach the surface. However, according to special relativity, seen from an earth-bound observer, the muon clock runs slow by a factor of $\gamma = \left(1 - \beta^2\right)^{-1/2}$, where $\beta = v/c$ is the velocity of the muon (in units of c). For a 2 GeV muon, for instance, $\gamma = 20$, and in 40µs such a muon travels about 12 km, plenty far enough to reach the surface.

Thus, what remains of the interstellar cosmic rays at the earth's surface are mainly muons. Their energy distribution ranges from zero to many tens of GeV [1]. Their flux depends on the angle of incidence. Because of the deflection of charged particles in the earth's magnetic field, there is a slight east-west dependence, too. The muon flux is hardly affected by the walls of a building, and we have these particles at our disposition to carry out experiments with them in our laboratory. As a rule of thumb, the flux in the vertical direction for a given accepted angular range (solid angle in sr) is about $10^{-2}$ cm$^{-2}$ s$^{-1}$sr$^{-1}$. 
Equipment
- Several scintillators attached to photomultiplier tubes (PMTs). There are two paddles for cosmic ray rate measurements and one cylindrical scintillator for the muon lifetime measurement. Be careful with the paddles - they break from the PMTs easily!
- HV (high-voltage) power supplies for the PMTs.
- Various NIM electronics: amplifiers, discriminators, coincidence units, time-amplitude converter, scaler.
- Multichannel analyzer (MCA), oscilloscope.

Preparation
- Read the chapter in Ref [1] on cosmic rays.
- Read Ref [5] to learn more about scintillators, PMTs, and electronics. Section 9.7.3 describes how to "plateau" a PMT.

Experiment
In this experiment you will first setup and understand the electronics. Then you will measure the cosmic ray flux and the lifetime of the muon.

1. **Setup and adjust the scintillators.**
   - Setup the 3 detectors with HV at ~1700 V.
   - Measure the rate of discriminator "fires" as a function of discriminator threshold for each detector. The discriminator setting may be measured with a voltmeter (the output is x10 the setting!). This may be also viewed on the scope. Plot the rate vs disc. setting and determine the optimum setting.
   - Two at a time - place the detectors close to one another so that a cosmic ray that goes through one is likely to go through the other. Set the discriminator thresholds to a low value. Setup a coincidence circuit for the two detectors. Measure (and plot) the coincidence rate as a function of discriminator threshold for both detectors. From this data determine the optimum discriminator settings. Discuss with your instructor, set, and proceed to next steps.

2. **Measure the cosmic ray flux.**
   - Setup the two paddles and measure the cosmic ray flux for two different distances between the two detectors.
   - Compare to the value in the literature.

3. **Measure the muon lifetime.**
   - Form the coincidence of one of the paddles (lower one) with the cylindrical cylinder.
   - Setup the electronics with the time-to-amplitude converter and the MCA to measure the time between a muon stopping in the cylindrical detector and subsequent decay.
   - Calibrate the time-to-channel conversion.
   - Take a long run (several days) to collect sufficient statistical precision. From this data, determine the muon lifetime.
Misc. Hints:
- To get the data from the MCA:
  - During the long run to collect stopping muons, save the time distribution daily in case of a power glitch, etc. Save the files as type "Integer CHN". You can read these back into the MCA program if needed.
  - Convert the (binary) "Integer CHN" file into a text file that we can read with PAW using the AttenCHN program located in C:\MPLMCA (a detailed writeup is available).
  - Use the macro: mulife.kumac to read this data, histogram, rebin, and fit the data. This macro is on the "links" page of our www site. PAW is available on the MCA computer.

Ideas for advanced measurements:
- Adjust the relative positions of the paddles to maximize the stopping muon rate.
- Stop muons in the large lead-glass detector and measure the muon lifetime and decay energy distribution.

References