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TEACHSPIN

Instruments Designed For Teaching

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Muon Physics

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Newsletter 1 – Muons on Parade
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Mean Muon Lifetime

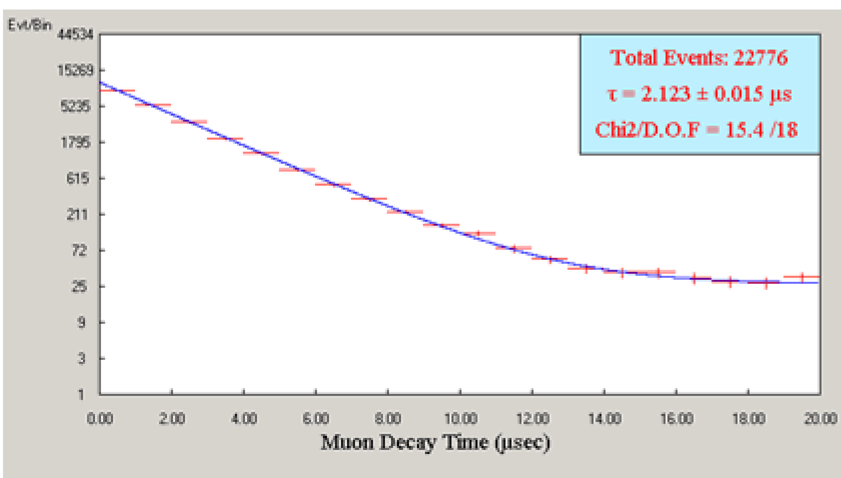
Straightforward determinations of average muon lifetime can be made using the curve fitting software provided. More advanced students can be asked to create their own curve fitting algorithms.

FINDING THE MUON LIFETIME

The form for the decay time distribution for muons stopped in the scintillator is characteristic of the decay of radioactive substances with some background counts.

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

Additional background counts can be easily induced by bringing a 1 micro-Curie Cs-137 source close to the detector. After measuring and plotting the distribution of times between successive scintillator flashes, students can fit the exponential-like distribution and extract the mean muon lifetime (t) in matter, using either our curve fitting algorithm or their own. (The data can be exported to third-party software.) The figure below is a screen capture from the included software and shows a fit to actual student data. Note that the central value for the muon's lifetime is less than the free space value t = 2.197 ± 0.001 µsec. This correctly indicates the effect of nuclear interactions between protons and negative muons.



Once the muon lifetime is measured, a value of the Fermi coupling constant G_F, characterizing the strength of the weak interactions, is easily determined from the relation:

$$\tau = \frac{192\pi^3}{G_F^{\,2} m_\mu^{\,5}}$$

Accounting only for statistical error, the student data shown in this brochure yields

$G_F = (1.18 \pm 0.01) \times 10^{-5}$ GeV^{-2}, which is consistent with more precise measurements.

Sea-level Charge Ratio
With this instrument, the muon lifetime measured in matter (i.e., plastic scintillator) is an average over negatively and positively charged muons. Negatively charged muons have nuclear interactions that slightly lessen their mean lifetime in matter. Therefore, using the lifetime of negative muons in carbon taken from the literature (tau = 2.043 ± 0.003 μsec), the sea-level charge ratio of positive to negative muons at low energy , E_μ = 200 MeV, can be easily determined. The student data included in this brochure yields a sea-level charge ratio f+/f– = 1.08 ± 0.01 (32.5° latitude), which is consistent with published values.

TIME DILATION EFFECT OF SPECIAL RELATIVITY

Once the muon lifetime is measured, the stopping rate as a function of elevation above sea level can be used to distinguish between the predictions of classical mechanics and special relativity, providing evidence for the time dilation effect of special relativity. Although the instrument is not optimized for this measurement, the simplicity of the measurement is appealing since it requires no lead shielding. For example, after measuring the muon stopping rate to a statistical precision of 2% at two locations vertically separated by 1985 meters, the ratio of these stopping rates (0.55 ± 0.02) agrees well with a straightforward calculation (0.56 ± 0.05) that accounts for time dilation, muon energy loss in the atmosphere and the differential muon momentum spectrum at sea level.

PREDICTIONS OF PROBABILITY THEORY

The decay times of individual muons are an excellent source of genuinely random numbers. Once the exponential form of the probability distribution for these times is measured, students can make predictions about the outcomes of corresponding binomial experiments. Taking a new data set then allows a direct comparison between actual data and the predictions of probability theory.

COSMIC RAY BACKGROUND RADIATION

Included rate monitors measure both the stopping rate of muons and the combined total charged particle flux (which includes both muons and electrons) that pass through the scintillator. This data can be used to monitor variations in cosmic radiation at the geographic location of the observer.

EXPLORE PROCESSING OF PHOTOMULTIPLIER SIGNAL

Probe points are provided along the entire electronic signal chain so that students can examine the waveforms of the photomultiplier signal, either real or simulated, at various stages of processing. The photomultiplier high voltage, the amplifier gain, the threshold setting and the FPGA timing characteristics are easily measured with an oscilloscope or voltmeter.

Detailed technical information and a copy of the user's manual for Muon Physics can be found at www.matphys.com. The website is maintained by Professors Thomas Coan and Jingbo Ye of Southern Methodist University, with whom TeachSpin collaborated in developing this exciting apparatus.

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