Exp. N - 5  Cosmic ray telescope and muon lifetime measurement

References:

1. Melissinos, Experiments in Modern Physics, 2nd ed., Sec. 9.4
3. H. Frauenfelder and E.M. Henley, Subatomic Physics, 2nd ed.

Objectives:

1. To observe coinciding fast signals of cosmic muons as they traverse 2 plastic scintillator counters and to measure coincidence rates as function of geometric configuration.
2. To measure the dependence of the cosmic ray muon flux on certain variables, such as zenith angle, stereo angle, horizontal direction (North-South vs. East-West) orientation, …
3. To measure the lifetime of an unstable elementary particle, the muon.

Theory:

High-energy cosmic rays (mainly protons, but also nuclei) of galactic or even extra-galactic origin hit Earth's atmosphere and interact with oxygen and nitrogen nuclei of air molecules. In these interactions, charged pions are produced among other particles. The pions decay into charged muons and muon (anti-) neutrinos. Due to their relative long lifetime and relativistic time dilation, a sizable fraction of the charged muons reaches the surface of the earth and can be detected by appropriate particle detectors. For more, see above references.

Apparatus:

- 2 plastic scintillator paddles
- 2 Photomultiplier tubes (PMTs)
- 2 Cockcroft-Walton high voltage bases for PMTs
- 5V power supply with cables
- QuarkNet Coincidence Logic Board with counter (v.1)
- LEMO signal cables, RS232 interface cable
- small screwdriver for adjusting threshold values on Logic Board
- digital oscilloscope, BNC T’s and BNC 50Ω terminators, PC

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CAUTION:

We have only one set of most of the equipment used in this lab and some of it, especially the scintillator paddles and the QuarkNet Coincidence Logic Board, are fragile. Please handle them with care and, if in doubt, check with your lab instructor first. Future generations of students will be grateful to you!

In particular,

- Be gentle when plugging in connectors, especially the small LEMO signal cables. Do not force them in or out. If you have trouble, ask your instructor for help.
- Before turning on the HV on the photomultiplier tubes (PMTs) with the small switch, make sure that the HV is set to zero on the dial (all the way counter-clockwise). Then slowly dial up the HV.
- Before turning off the HV on the photomultiplier tubes (PMTs) with the small switch, make sure that the HV is dialed down all the way to zero on the dial (all the way counter-clockwise). Do not switch the HV from 100% to off.
- Do not touch the QuarkNet readout printed-circuit board with your hand.

Experimental Procedure:

1. Connect 5V power to scintillator paddles by daisy-chaining power cables.
2. Connect LEMO signal cable to scope input using BNC ‘T’ and 50 Ω terminator.
3. On one paddle, set high voltage (HV) dial to ~8.0 units (out of 10) and observe signal on scope. Determine approximate noise level in mV. Any ideas where the noise might be coming from? Measuring its frequency offers a clue…
4. Set scope trigger threshold such that noise gets suppressed. Look for pulses from muons.
5. Characterize pulse shape (amplitude, polarity, duration).
6. Repeat 3-5 for other paddle.
7. Change HV setting on dials and observe effect on noise and signal on scope.
8. Display both PMT signals simultaneously on scope. Put boxes with scintillator paddles on top of each other and look for coinciding signals on scope.
9. Connect 5V also to QuarkNet Logic Board (daisy-chained from paddles).
10. Connect one paddle with LEMO cable to an input channel of the Logic Board.
11. With a scope probe, check (= display on scope) the signal after \( \times 10 \) amplification on the board. Test points on the board are labeled TPV1 (= Test Point Voltage 1) through TPV4.
12. Check which of the four channels are working (we have some dead channels).
13. Find a good HV setting for the paddle so that the amplified signal on the board is significantly larger than the observed noise level.
14. Check voltage of discrimination threshold on board (test points are TPVTH1,...,TPVTH4). If necessary, adjust threshold by turning appropriate 50 kΩ potentiometer on the board so that noise gets suppressed. Threshold should be large enough to suppress all noise reliably, yet low enough for smaller, but real signals from the paddles to pass so that the detection is as efficient as possible.
15. Connect other paddle to board and repeat 10, 13.
16. Display both amplified signals simultaneously on scope. Look for coinciding signals on scope.
17. With scintillator paddle boxes on top of each other (hopefully) start counting coincidences due to muons traversing both paddles.
18. Put boxes next to each other to convince yourselves that you are really observing muons.
19. Connect the Logic Card to PC, fire up hyperterminal (see icon on desktop) and spend some time understanding the data that the Logic Card sends to the PC and how to control the data acquisition. Ignore descriptions of the GPS receiver and barometer as those are not used for this experiment. Follow the relevant sections in the Quarknet manual. Review how hexadecimal numbers work.
20. To get started, type “HE” in the hyperterminal window for HELP to get a listing of available commands for the Logic Card (see also Fig. 15 in the manual).
21. Specifically, figure out how to select data from specific input channels (ch.0-3) on the board. Figure out how to select single pulse date and coincidence data. Refer to Tab.3 in Ch.6 in the Quarknet manual. (Note: The example in that table for selecting all channels but ch.2 is wrong. The least significant (rightmost) bit in control register 00 that acts as a bit mask for enabling and disabling each of the four input channels corresponds to ch.0 on the card, not ch. 3. So, to disable ch.2 and enable the other three channel, you want a bit mask of “1011 = B”, not “1101 = D”.)
22. Learn how to capture the displayed data to a file for later analysis.
23. First measurement: With boxes on top of each other measure the cosmic ray flux using the coincidences. See reference 2 for converting from count rate to flux. With boxes next to each other, measure the background rate due to noise and accidental coincidences. Compare measured rate with accepted value and estimate the efficiency of your setup for catching muons.
24. Second measurement: Change the area of overlap for the paddles and observe the count rate.
25. Third measurement: Increase the distance between the paddles and observe the count rate.
26. Fourth measurement: Create a muon “telescope” by carefully mounting the closed boxes in the zenith angle mount; orient mount in direction of your choice and measure count rate and muon flux as a function of polar angle.
27. Fifth measurement: Dismount boxes from zenith angle mount, place directly on top of each other. `Suppress singles’ on Logic Board. In this mode, only coincidence followed by an extra hit (“doubles”) in either counter will be displayed. You will also see some additional information, especially the time (in 20 ns units) between the coincidence and the extra hit. Understand where the extra hit comes from and measure the lifetime of the muon. You might want to leave the setup running overnight to accumulate a good data set as the “doubles” rate is quite low. Think about how this data can be translated into a radioactive decay curve so that you can determine the muon life time.

Final Note:
Use the provided USB flash drive to save the data and to transfer them to your laptop for analysis. Do not take the USB drive with you! Note that the PC can only handle up to 2 GB flash drives. If you try to copy the data to a bigger USB flash drive, it will most likely not work. Use the provided drive instead.

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