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# PHYS 229: Experiment 3 — Measurement of the Cosmic Ray Flux

Summary of the cosmic ray interactions:

$$pp \rightarrow \; pn\pi^{+} \quad \text{or} \quad pp\pi^{0}$$
$$pn \rightarrow \; pp\pi^{-} \quad \text{or} \quad pn\pi^{0} \; \text{or} \; nn\pi^{+}$$
$$\pi^{+} \rightarrow \; \mu^{+} \; \nu \quad \text{and} \quad \pi^{-} \rightarrow \; \mu^{-} \; \nu \quad (26\, ns)$$
$$\pi^{0} \rightarrow \; \gamma\gamma \quad (10^{-16}\, s)$$

We will detect the muons with a pair of scintillators connected to a photomultiplier tube, forming a sort telescope. The instrument setup is illustrated below. Note that we actually measured the distance between the scintillators, h, to be 36cm.

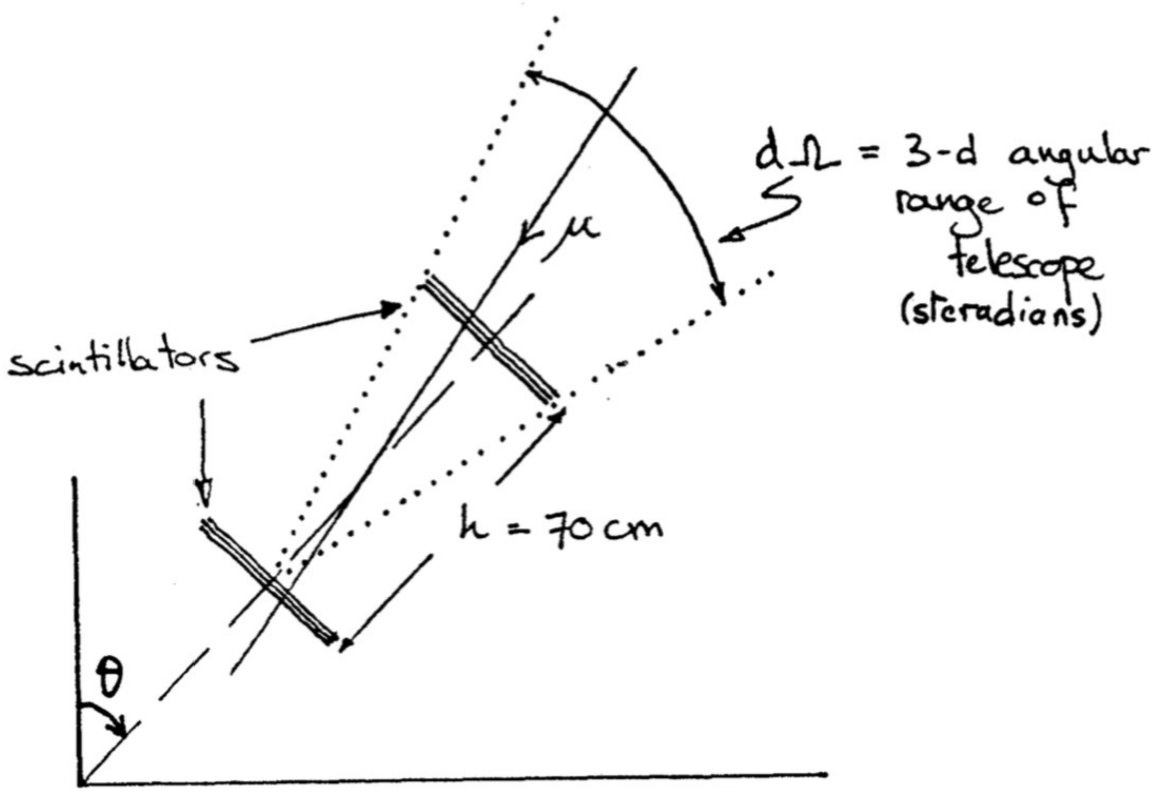


Figure 1: The muon telescope. H is actually 36cm.

Figure 2. Photograph of the muon telescope.

An event is a coincidence of hits in the scintillators. In order to detect these coincidences, we set up a delay between the detectors. This is done through a delay unit. The setup is illustrated below.

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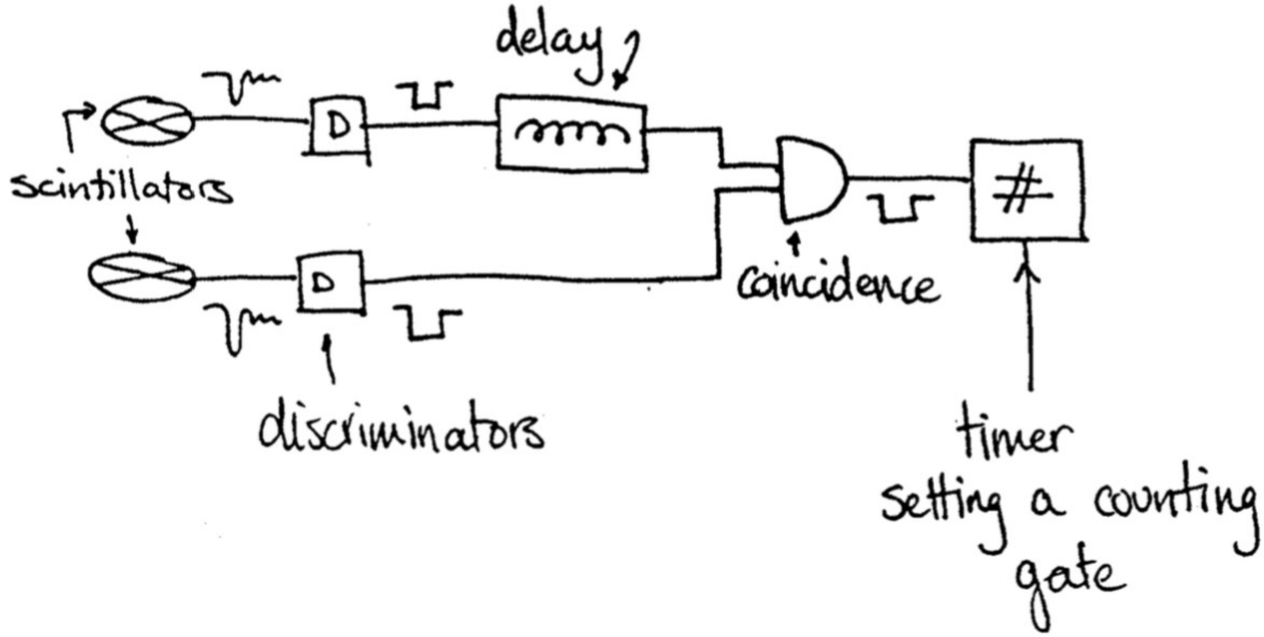


Figure 3. The delay unit is used to detect coincidences.

To set up the muon telescope, we first set the high voltages on the PMT bases to 2kV. The telescope is pointing straight up by putting the bolts into the highest position. We connected the output of the top scintillator into the oscilloscope and observed the signal from the random noise and the external photons getting into the scintillators.

We then fed the PMT signal into the top pair of discriminators to convert it into a logic signal. We then took the output from the fourth OUT terminal to the oscilloscope. With the screwdriver, we turned the width setting a couple of times to the left (making the width smaller) until the width was approximately 20ns. (We set the scale to 20ns and tried to match the edges of the signal to the width of a box on the screen).

Then, we disconnected the signals from the oscilloscope and plugged it into the counter input labeled 2. We set DISPLAY SELECT to 2. TIME BASE to EXT. Using the screwdriver again, we adjusted the THR (threshold setting) until the pulse rate is about 100Hz. To do this, we looked at hundred place of the count and adjusted the THR until the hundred place changes at the same pace as the seconds digit of the stopwatch on my phone.

Next, we connected the output of the coincidence unit to the counter and constructed a delay curve.

| delay (ns) | count | time (min) | rate |
|---|---|---|---|
| 0 | 152 | 3 | 50.67 |
| 1 | 106 | 2 | 53 |
| 2 | 117 | 2 | 58.5 |
| 3 | 93 | 2 | 46.5 |
| 4 | 120 | 2 | 60 |
| 5 | 127 | 2 | 63.5 |
| 6 | 125 | 2 | 62.5 |
| 7 | 97 | 2 | 48.5 |
| 8 | 87 | 2 | 43.5 |
| 9 | 95 | 2 | 47.5 |
| 10 | 50 | 2 | 25 |
| 11 | 35 | 2 | 17.5 |
| 12 | 11 | 2 | 5.5 |
| 13 | 23 | 2 | 11.5 |
| 14 | 4 | 2 | 2 |
| 15 | 7 | 2 | 3.5 |

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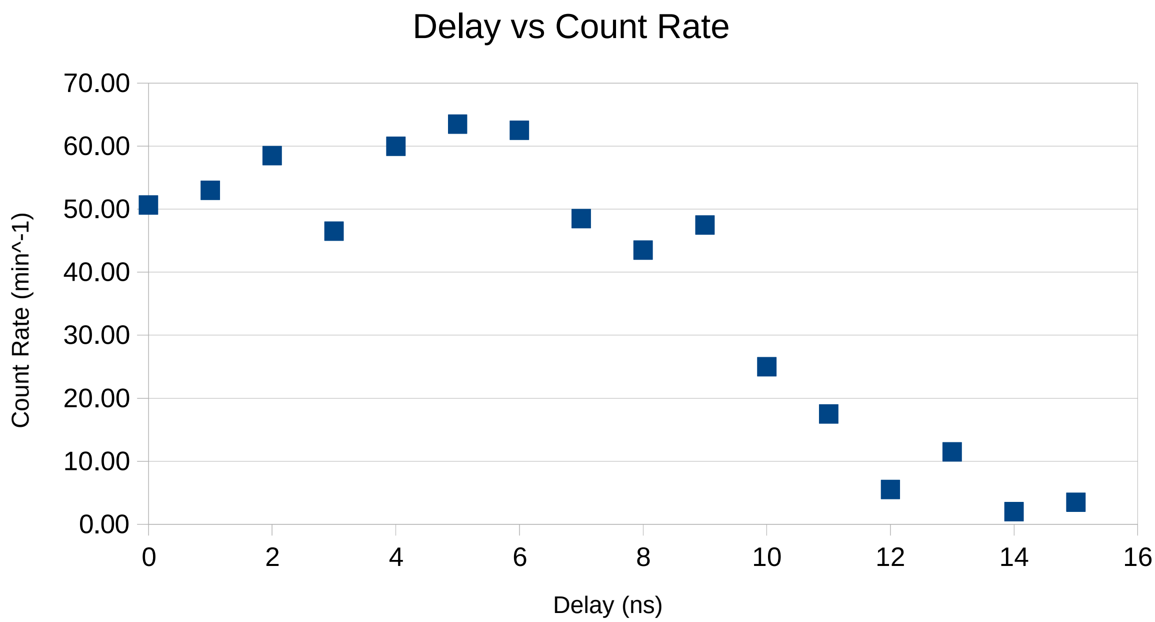


The curve increases slowly as delay time increases because the delay time is getting closer to the actual time difference between when the muon hits the top detector and the bottom detector. It reaches a max at t=5ns, then decreases quickly after t=6ns. This is because the delay is too long and we are now detecting the coincidence of hits from two different muons hitting the detectors at the same time (since one muon would be too fast). From the delay curve, we selected 5ns as our delay time because it gave us the highest count rate, and should be close the actual time between the two detectors.

By sliding the plank along the supporting two rails, we changed the angle and measured the count rate at different angles. We measured the angle from the vertical position

(i.e. 0° = vertical; 90° = horizontal) with a standard, plastic protractor. This time we measured for 10-20 minutes because the count rates were low and we wanted an accurate measurement. Uncertainties in counts are sqrt(count). Uncertainties in rates are just relative uncertainties in count divided by the time. We did not take into account the uncertainty in time because the time measured with the built-in timer is much more precise than the count, therefore insignificant.

| Angle (degrees) | dAngle | count | d count | time | rate | drate |
|---|---|---|---|---|---|---|
| 87 | 2 | 147 | 12.12436 | 20 | 7.35 | 0.606218 |
| 75 | 2 | 109 | 10.44031 | 10 | 10.9 | 1.044031 |
| 61 | 2 | 209 | 14.45683 | 10 | 20.9 | 1.445683 |
| 45 | 2 | 310 | 17.60682 | 10 | 31 | 1.760682 |
| 25 | 2 | 481 | 21.93171 | 10 | 48.1 | 2.193171 |

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To calculate the random pulse rate, we have from appendix I:

$NR = N1*N2(t2+t2)$

Estimate N1 = N2 = 100 <-- this is what we calibrated the machine to in the previous steps.

t2 = 1ns <-- this is an estimate of the time it takes for a muon to be detected.

$NR = 10^4 * 10^{-9} = 10^{-5}$

This random count rate is the value the count rate decays to in the Delay vs Count Rate plot.

9. Convert the muon count rates to muon flux. $S^{-1} * sr^{-1} * m^{-2}$.

Separation between paddles = 0.30m

diameter of detector = 0.20m --> area = $0.1^2 * \pi = 3.14 * 10^{-2}$ m^2

From appendix II, we have that $Nc = (N* A1 * A2)/(d^2) = N * 0.010955$

| Angle (degree | uncertainty | count | time | rate | drate | muon flux | d flux |
|---|---|---|---|---|---|---|---|
| 87 | 2 | 147 | 20 | 7.35 | 0.6062177826 | 0.08051925 | 0.0066411158 |
| 75 | 2 | 109 | 10 | 10.9 | 1.0440306509 | 0.1194095 | 0.0114373558 |
| 61 | 2 | 209 | 10 | 20.9 | 1.4456832295 | 0.22895995 | 0.0158374598 |
| 45 | 2 | 310 | 10 | 31 | 1.7606816862 | 0.339605 | 0.0192882679 |
| 25 | 2 | 481 | 10 | 48.1 | 2.1931712199 | 0.52693555 | 0.0240261907 |
| 0 | 2 | 127 | 2 | 63.5 | 5.6347138348 | 0.69564225 | 0.0617282901 |

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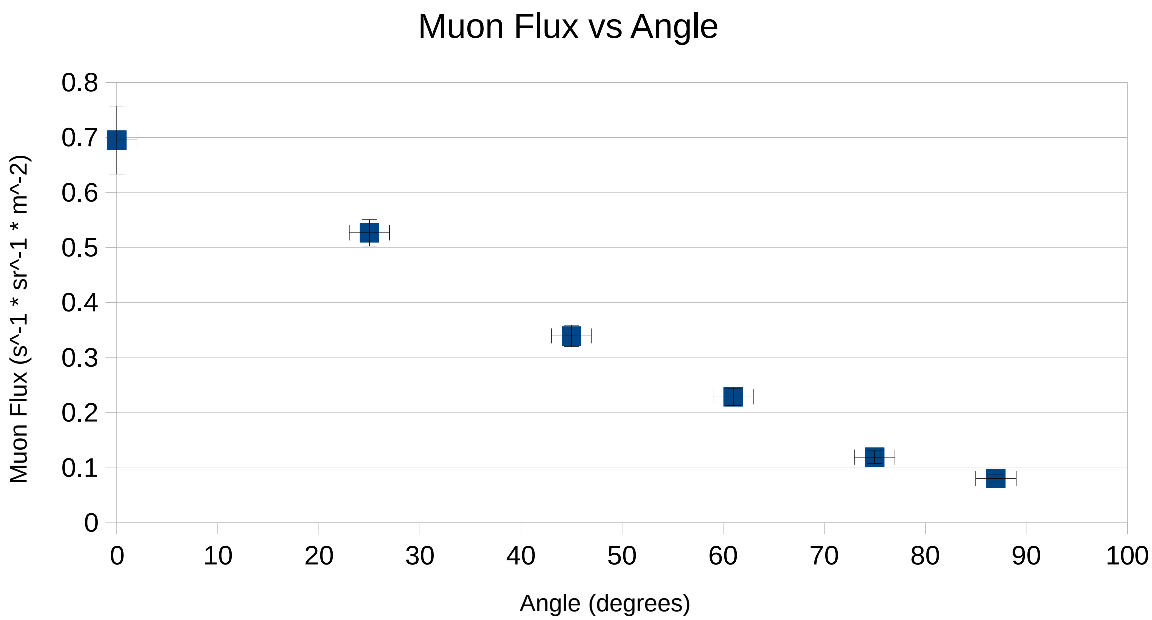


Although there are too few data points to be sure, it appears that the muon flux depends on the cos(angle). This makes sense if we make the assumption that the muons come from high up in the atmosphere so that it essentially comes in perpendicular to the detector. The muon flux at each angle, is then just the perpendicular part of the flux, which is cos(angle). The graph, does seem to resemble a graph of cos(x) from 0 to 90 degrees.