Cosmic ray telescope

Purpose: How energetic are the cosmic ray muons? Are they coming from everywhere, evenly in all directions? These are two of the questions that we address in this laboratory.

We will address this question by using the computer to find and record co-incidences between stacked arrays of geiger tubes. There will be a significant background rate of counts from other decays and cosmic rays that do not go through the axis of the cosmic ray telescope. The rate of false co-incidences is related to mean duration of a geiger tube firing.

Once we determine the false co-incidence rate (Part A), we can remove that rate from the co-incidence rate that we measure with the counters stacked. This gives a rate proportional to the cosmic ray (mostly energetic muons) count, and we can (part B) stack lead bricks to various heights above the paired detectors and see how the coincidence rate decreases with depth of the lead. Fitting those data with a line, we get a rough idea of the mean kinetic energy of the muons (the density of lead is 11.35 d/cm^3) and thus how far they could actually travel before decaying (their lifetime is about 2 microseconds) using relativity.

In Part C, keeping the detectors in fixed locations relative to one another, remove the lead and determine the cosmic ray rate versus angle from zenith. Do so for just two other angles (other than normal incidence which you did in the first part). Compare the rate graph you find with a rate being proportional to the $\cos^2(\theta)$ curve mentioned in literature.

Proceedure:

Preliminaries: turn on the box supply to 5 volts, then the tube supply to about 890 volts or so. DO NOT PUT MORE THAN 1000 VOLTS ACROSS THE HIGH VOLTAGE INPUT OF THE BOX feeding the tubes. Oh, yeah, high voltage in the lab...please be careful; listen to your instructor/TA on basic safety with this laboratory. Allow 5 minutes or so for warmup.

Use a source to excite various geiger tubes and verify on the scope that all tubes are working. Record the mean temporal width of the spikes = ___________________ s.

Part A: The tubes are arranged in a stack of three sets of tubes...set 1 and (cojoined) set 2 and 3. Remove them from the frame and seperate them from some distance from one another. Collect data for about 1/2 hour or so to get a mean, uncorrelated background event rate for each counter.

counts/sec tubeset 1: ___________________ counts/s
counts/sec tubeset 2: ___________________ counts/s
counts/sec tubeset 3: ___________________ counts/s

Use these data and the average width of a pulse to estimate a mean **random** co-incidence event rate between the various counter combinations.

tubeset 1 with tubeset 2: ___________________ counts/s
tubeset 1 with tubeset 3: ___________________ counts/s
tubeset2 with tubeset 3: ___________________ counts/s

Note that since the counts are distributed randomly, the percentage error in your count rate is essentailly $1/\sqrt{N}$ where N is the total number of events. Since the number of events scales with the total run time, t, this means that the accuracy of your ability to determine the count rate is proportional to $1/\sqrt{t}$.

Part B: Penetrating depth: Read over the first page of the attached lab (written for high school students and teachers). Carefully replace the tubes sets into their holder and place them in a vertical orientation underneath the desk. Now let the computer collect events for several hours. Your instructor will familiarize you with the software and you will need and then you need to estimate how long you will need to run in this configuration to determine the mean count rate to within about 10 percent.

Collect your counts. Return to the setup at the end of the run to stop the program and re-run the program after stacking some lead bricks on the desk over the counters in such a way that the cosmic rays threading both counters must be going through the bricks. Ideally do four different depths, including depths up to 60 cm if possible. For each depth it is simplest to run for the same amount of time you did in the first run...if not, you can correct for the difference later as long as you record the total time you ran (recall...you want to compare the *rates* of counts and coincidences, not just the total counts and coincidences). You will end up with a single file for each run, and have thus four files.

Please be careful to handle the lead bricks only with gloves on and to wash your hands after moving bricks around.

Part C: Angular Dependence Remove all lead bricks. Tilt the entire tubeset holder assembly to an angle wrt the vertical. Record the angle and rerun the program, again for about the same amount of time. Do so for two angles different than vertical.

Analysis:

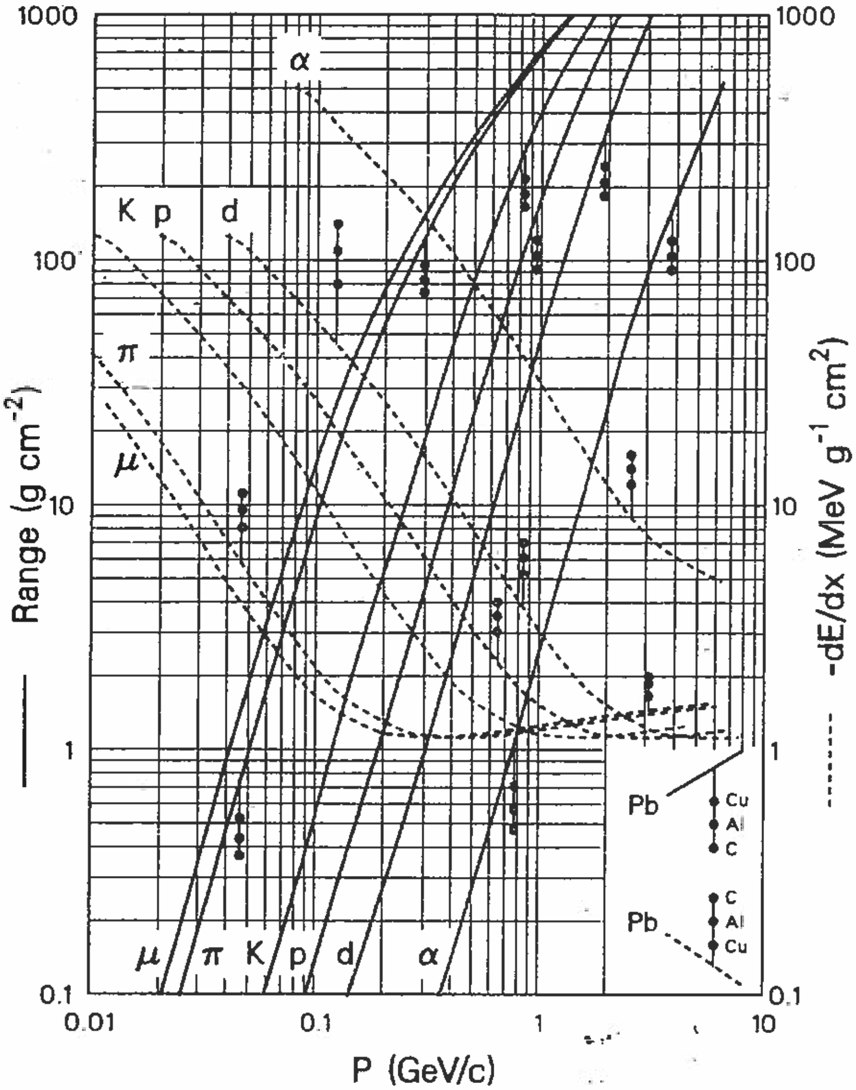
1) For part B, study the files for co-incidences between various tubeseet combinations flashing in unison. Find the various co-incindence rates and remove the background 'accidental' coincident rates that you computed in Part A.

2) Part B (con't) now plot the cosmic ray event rate as a function of the lead depth. Fit these data with a straight line to get the mean maximum range (the depth at which the straightline fit crosses the x-axis) Use your mean maximum range in the graph on the next page to *estimate* the $\gamma = \frac{1}{\sqrt{1-\beta^2}}$ of the average cosmic ray muon.

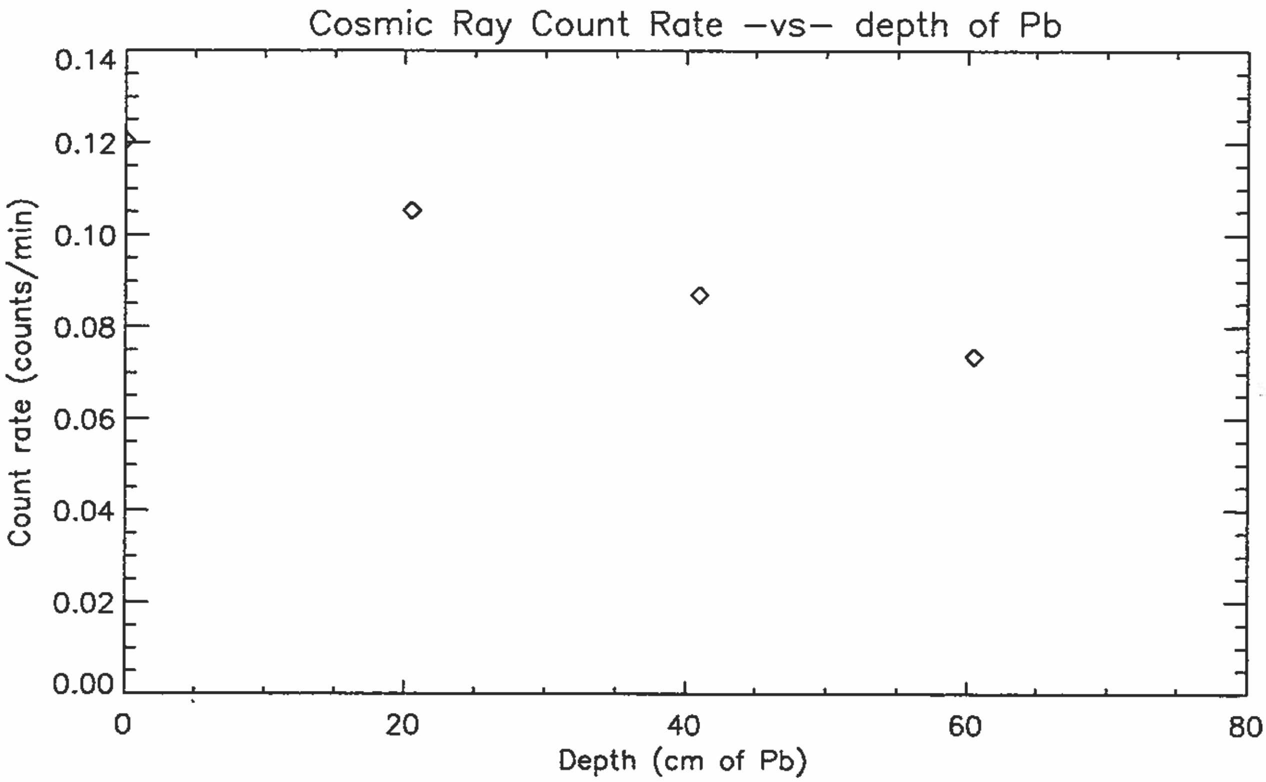
Finally, using that estimateed gamma, how far could the muon's go before decaying? They are made in the upper atmosphere, about 10 Km or so up. Does your gamma explain how they can make it to the ground?

3) For Part C, plot your background-subtracted coincidence rate to determine the dependence of the cosmic ray flux with angle. In various early literature they record this as a $\cos^2\theta$ distribution, where θ is the angle from the vertical. Does your data support that functional form or not?

S
in Lead, Copper, Aluminum, and Carbon



Mean range and energy loss due to ionization for the indicated particles in Pb, with scaling to Cu, Al, and C indicated, using Bethe-Bloch equation [See Sec. (1) of Passage of Particles Through Matter] with corrections. Calculated by M.J. Berger, using ionization potentials and density effect corrections as discussed in M.J. Berger and S.M. Seltzer, "Stopping Powers and Ranges of Electrons and Positrons," (2nd ed.), U.S. National Bureau of Standards Report NBSIR 82-2550-A (1982). The average ionization potentials (I) assumed were: Pb (823 eV), Cu (322 eV), Al (166 eV), and C (78.0 eV). Figure indicates total path length; observed range may be smaller (by ~ 1 % - 2% in heavy elements) due to multiple scattering, primarily from small energy-loss collisions with nuclei. The functional forms have not been experimentally verified to better than roughly ±1%. For higher energies refer to discussion by Cobb ["A Study of Some Electromagnetic Interactions of High Velocity Particles with Matter," University of Oxford Report HEP/T/55 (1973)] and by Turner ["Penetration of Charged Particles in Matter: A Symposium," National Academy of Sciences, Washington D.C. (1970), p. 48]. For lower energies both data and theory are not well understood. Scaling to other beam particles is, to a good approximation, described by the formula on the next page.



<u>ANS:</u> ATTENUATION DEPTH IS INVERSE OF THE SLOPE OF THIS "LINE." FOR COINCIDENCE COUNTING OF THIS TYPE THERE IS ESSENTIALLY NO BACKGROUND TO SUBTRACT. THE ATTENUATION DEPTH IS THUS ABOUT 160CM, WHERE THE "LINE" WOULD CROSS THE X AXIS ($y = 0 \Rightarrow$ ZERO COUNTS).

OF COURSE, THE COUNTS DON'T ACTUALLY GO TO ZERO ABOVE 160CM OF LEAD....

$$\rho l = (11.35)(160) \cong 1800$$

$\Rightarrow \sim 2$ TO 3 GEV/C SO $\gamma = 30 - 100$