# Cosmic Ray Muon Detector Experiment

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December 28, 2012

1 Muon
- Discovery
- Properties

2 What is this experiment about?
- Theory
- Procedure
- How it works

3 Analysis
- Graphs

# Outline

Muons were discovered by Carl D. Anderson and Seth Neddermeyer at Caltech in 1936, while studying cosmic radiation. Anderson had noticed particles that curved differently from electrons and other known particles when passed through a magnetic field. They were negatively charged but curved less sharply than electrons, but more sharply than protons, for particles of the same velocity. It was assumed that the magnitude of their negative electric charge was equal to that of the electron, and so to account for the difference in curvature, it was supposed that their mass was greater than an electron but smaller than a proton. Thus Anderson initially called the new particle a *mesotron*, adopting the prefix meso- from the Greek word for "mid-".

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Major sources of muons

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- High $P_t$ muons product of heavy objectsdecays: b,W/Z, etc.

# Outline

"Primary" cosmic rays, which are mainly protons (and a few heavier nuclei), interact with nucleons in the earth's upper atmosphere in much the same way that fixed target collisions occur at particle physics laboratories. Some primary cosmic rays can exceed human-made particle detector energies a million-fold. When these primary particles interact with nucleons in the atmosphere, they produce mainly pions and kaons.

In the collisions, if most of the incoming momentum is transferred to an atmospheric proton, the following reactions are common:

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The products of such interactions are called “Secondary” particles or “secondary” cosmic rays. Some of these products, however, are very short-lived and generally decay into daughter particles before reaching the earth’s surface. The charged pions, for instance, will decay into a muon and a neutrino:

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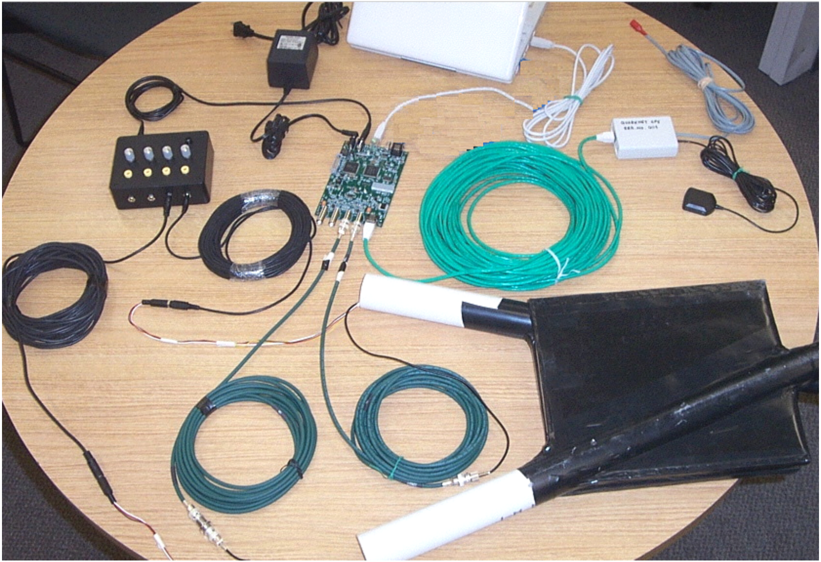
$$\pi^+ \longrightarrow \mu^+ + \nu_\mu$$

Although these reactions are not the only possibilities, they are examples of common reactions that produce secondary particles and their daughters. Counting all secondary particles detected at sea level, 70% are muons, 29% are electrons and positrons and 1% are heavier particles.



Hardware required for the experiment:

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- PDU power cable.
- Power distribution unit, PDU.
- Power extension cables for PMTs.
- USB cable.
- Personal Computer.

Plastic or glass scintillator is mated using optical glue and shaped fittings to PMTs. The scintillators are covered with reflective material (aluminum foil works) and then with black paper and tape to make them "light-tight." They are hooked up to the DAQ which feeds into the parallel port of a computer. When a cosmic ray muon passes through the scintillator, it causes a few photons to be emitted by impurities in the scintillator material. These are picked up by the PMTs, converted to an electrical pulse and amplified. Each PMT sends its signal to the DAQ.

## Muon Counting Experiment

When counting muons, the DAQ looks for "coincidences" - two signals (one from each PMT) which are received within a very short time. These are reported to the computer; all other signals are vetoed as likely noise from the PMTs. The computer can count the number of muons that come in over an interval to get a rate count.

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## Muon Lifetime Experiment

Some muons will be of low energy and will lose that energy in the scintillator. Such a muon will remain there for a short time until it decays into an electron and two neutrinos. We cannot detect the neutrinos, but we can detect the electron as it causes a few more photons to be emitted by impurities in the scintillator material. The DAQ measures the time between the "muon signal" and the "electron signal". These double hits and their time intervals are reported to the computer. The data can be fed into a spreadsheet and analyzed to calculate the lifetime of the muon.

# Outline

After running the program, we get a file which is then uploaded to the fermilab website to get a processed file which tells us about the Possible decay length.

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| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 6609.3 | 2456207 | 92.3425 | 0.205537 | 0.205537 | 17.5 | 21.25 | 1 | | | | |
| 5 | 6609.4 | 2456207 | 20.41875 | 0.207131 | 0.207131 | 13.75 | 23.75 | 1 | | | | |
| 6 | 6609.4 | 2456207 | 53.86 | 0.211838 | 0.211838 | 31.25 | 15 | 1 | | | | |
| 7 | 6609.4 | 2456207 | 92.68125 | 0.219891 | 0.219891 | 27.5 | 17.5 | 1 | | | | |
| 8 | 6609.3 | 2456207 | 43.8525 | 0.225285 | 0.225285 | 18.75 | 18.75 | 1 | | | | |
| 9 | 6609.2 | 2456207 | 5.21 | 0.234063 | 0.234063 | 25 | 20 | 1 | | | | |
| 10 | 6609.3 | 2456207 | 98.26249 | 0.235231 | 0.235231 | 11.25 | 21.25 | 1 | | | | |
| 11 | 6609.3 | 2456207 | 82.31375 | 0.237272 | 0.237272 | 17.5 | 17.5 | 1 | | | | |
| 12 | 6609.2 | 2456207 | 90.14 | 0.246628 | 0.246628 | 15 | 18.75 | 1 | | | | |
| 13 | 6609.1 | 2456207 | 99.1325 | 0.252243 | 0.252243 | 17.5 | 27.5 | 1 | | | | |
| 14 | 6609.3 | 2456207 | 0.63001 | 0.259001 | 0.259001 | 26.25 | 18.75 | 1 | | | | |
| 15 | 6609.3 | 2456207 | 96.33626 | 0.265459 | 0.265459 | 20 | 26.25 | 1 | | | | |
| 16 | 6609.2 | 2456207 | 95.56375 | 0.288445 | 0.288445 | 20 | 22.5 | 1 | | | | |
| 17 | 6609.2 | 2456207 | 67.47123 | 0.289414 | 0.289414 | 27.5 | 16.25 | 1 | | | | |
| 18 | 6609.4 | 2456207 | 38.46625 | 0.302191 | 0.302191 | 13.76 | 22.5 | 1 | | | | |
| 19 | 6609.2 | 2456207 | 65.08126 | 0.31137 | 0.31137 | 12.5 | 13.76 | 1 | | | | |
| 20 | 6609.4 | 2456207 | 40.92252 | 0.31871 | 0.31871 | 13.75 | 22.5 | 1 | | | | |
| 21 | 6609.4 | 2456207 | 0.68625 | 0.318902 | 0.318902 | 25 | 18.75 | 1 | | | | |
| 22 | 6609.4 | 2456207 | 88.03999 | 0.324866 | 0.324866 | 11.25 | 16.25 | 1 | | | | |
| 23 | 6609.4 | 2456207 | 70.19376 | 0.3324 | 0.3324 | 18.75 | 27.5 | 1 | | | | |
| 24 | 6609.3 | 2456207 | 70.575 | 0.344007 | 0.344007 | 15 | 26.25 | 1 | | | | |
| 25 | 6609.4 | 2456207 | 2.92 | 0.344428 | 0.344428 | 21.25 | 20 | 1 | | | | |
| 26 | 6609.4 | 2456207 | 0.65875 | 0.359193 | 0.359193 | 18.75 | 22.5 | 1 | | | | |
| 27 | 6609.4 | 2456207 | 53.38374 | 0.371835 | 0.371835 | 15 | 28.75 | 1 | | | | |
| 28 | 6609.3 | 2456207 | 0.485 | 0.373157 | 0.373157 | 26.25 | 11.25 | 1 | | | | |

| | A | B | C | D | E | F | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 65.67999 | 1 | 7 | | | | | | | | | | |
| 2 | 2.60124 | 2 | 3 | | | | | | | | | | |
| 3 | 92.3425 | 3 | 4 | | | | | | | | | | |
| 4 | 20.41875 | 4 | 3 | | | | | | | | | | |
| 5 | 53.86 | 5 | 3 | | | | | | | | | | |
| 6 | 92.68125 | 6 | 1 | | | | | | | | | | |
| 7 | 43.8525 | 7 | 0 | | | | | | | | | | |
| 8 | 5.21 | 8 | 0 | | | | | | | | | | |
| 9 | 98.26249 | 9 | 0 | | | | | | | | | | |
| 10 | 82.31375 | 10 | 1 | | | | | | | | | | |
| 11 | 90.14 | 11 | 0 | | | | | | | | | | |
| 12 | 99.1325 | 12 | 0 | | | | | | | | | | |
| 13 | 0.63001 | 13 | 0 | | | | | | | | | | |
| 14 | 96.33626 | 14 | 0 | | | | | | | | | | |
| 15 | 95.56375 | 15 | 0 | | | | | | | | | | |
| 16 | 67.47123 | 16 | 0 | | | | | | | | | | |
| 17 | 38.46625 | 17 | 0 | | | | | | | | | | |
| 18 | 65.08126 | 18 | 1 | | | | | | | | | | |
| 19 | 40.92252 | 19 | 1 | | | | | | | | | | |
| 20 | 0.68625 | 20 | 1 | | | | | | | | | | |
| 21 | 88.03999 | 21 | 1 | | | | | | | | | | |
| 22 | 70.19376 | 22 | 0 | | | | | | | | | | |
| 23 | 70.575 | 23 | 1 | | | | | | | | | | |
| 24 | 2.92 | 24 | 1 | | | | | | | | | | |
| 25 | 0.65875 | 25 | 1 | | | | | | | | | | |

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 65.67999 | 1 | 7 | 0.1 | | | | | | | | | | |
| 2 | 2.60124 | 2 | 3 | 0.042857 | | | | | | | | | | |
| 3 | 92.3425 | 3 | 4 | 0.057143 | | | | | | | | | | |
| 4 | 20.41875 | 4 | 3 | 0.042857 | | | | | | | | | | |
| 5 | 53.86 | 5 | 3 | 0.042857 | | | | | | | | | | |
| 6 | 92.68125 | 6 | 1 | 0.014286 | | | | | | | | | | |
| 7 | 43.8525 | 7 | 0 | 0 | | | | | | | | | | |
| 8 | 5.21 | 8 | 0 | 0 | | | | | | | | | | |
| 9 | 98.26249 | 9 | 0 | 0 | | | | | | | | | | |
| 10 | 82.31375 | 10 | 1 | 0.014286 | | | | | | | | | | |
| 11 | 90.14 | 11 | 0 | 0 | | | | | | | | | | |
| 12 | 99.1325 | 12 | 0 | 0 | | | | | | | | | | |
| 13 | 0.63001 | 13 | 0 | 0 | | | | | | | | | | |
| 14 | 96.33626 | 14 | 0 | 0 | | | | | | | | | | |
| 15 | 95.56375 | 15 | 0 | 0 | | | | | | | | | | |
| 16 | 67.47123 | 16 | 0 | 0 | | | | | | | | | | |
| 17 | 38.46625 | 17 | 0 | 0 | | | | | | | | | | |
| 18 | 65.08126 | 18 | 1 | 0.014286 | | | | | | | | | | |
| 19 | 40.92252 | 19 | 1 | 0.014286 | | | | | | | | | | |
| 20 | 0.68625 | 20 | 1 | 0.014286 | | | | | | | | | | |
| 21 | 88.03999 | 21 | 1 | 0.014286 | | | | | | | | | | |
| 22 | 70.19376 | 22 | 0 | 0 | | | | | | | | | | |
| 23 | 70.575 | 23 | 1 | 0.014286 | | | | | | | | | | |
| 24 | 2.92 | 24 | 1 | 0.014286 | | | | | | | | | | |

# Taking the average:

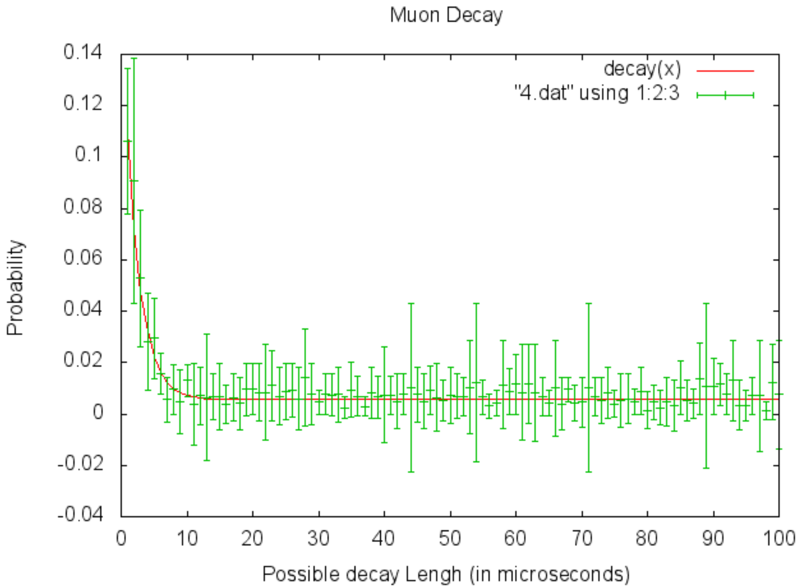
| | A | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0.1 | 0.13467 | 0.099099 | 0.111257 | | | | | | | | | |
| 2 | 2 | 0.042857 | 0.100287 | 0.135135 | 0.09276 | | | | | | | | | |
| 3 | 3 | 0.057143 | 0.060172 | 0.036036 | 0.051117 | | | | | | | | | |
| 4 | 4 | 0.042857 | 0.031519 | 0.009009 | 0.027795 | | | | | | | | | |
| 5 | 5 | 0.042857 | 0.025788 | 0.045045 | 0.037897 | | | | | | | | | |
| 6 | 6 | 0.014286 | 0.022923 | 0.009009 | 0.015406 | | | | | | | | | |
| 7 | 7 | 0 | 0.014327 | 0 | 0.004776 | | | | | | | | | |
| 8 | 8 | 0 | 0.011461 | 0.009009 | 0.006823 | | | | | | | | | |
| 9 | 9 | 0 | 0.017192 | 0 | 0.005731 | | | | | | | | | |
| 10 | 10 | 0.014286 | 0.008596 | 0.018018 | 0.013633 | | | | | | | | | |
| 11 | 11 | 0 | 0.002865 | 0 | 0.000955 | | | | | | | | | |
| 12 | 12 | 0 | 0.008596 | 0.018018 | 0.008871 | | | | | | | | | |
| 13 | 13 | 0 | 0.002865 | 0 | 0.000955 | | | | | | | | | |
| 14 | 14 | 0 | 0.005731 | 0 | 0.00191 | | | | | | | | | |
| 15 | 15 | 0 | 0 | 0 | 0.0016 | | | | | | | | | |
| 16 | 16 | 0 | 0.011461 | 0 | 0.00382 | | | | | | | | | |
| 17 | 17 | 0 | 0.011461 | 0 | 0.00382 | | | | | | | | | |
| 18 | 18 | 0.014286 | 0.005731 | 0 | 0.006672 | | | | | | | | | |
| 19 | 19 | 0.014286 | 0.005731 | 0 | 0.006672 | | | | | | | | | |
| 20 | 20 | 0.014286 | 0.008596 | 0.009009 | 0.01063 | | | | | | | | | |
| 21 | 21 | 0.014286 | 0.011461 | 0 | 0.008582 | | | | | | | | | |
| 22 | 22 | 0 | 0.005731 | 0.027027 | 0.010919 | | | | | | | | | |
| 23 | 23 | 0.014286 | 0.020057 | 0 | 0.011448 | | | | | | | | | |
| 24 | 24 | 0.014286 | 0.002865 | 0.018018 | 0.011723 | | | | | | | | | |

| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0.1 | 0.13467 | 0.099099 | 0.106318 | 0.028353 | | | | | | |
| 2 | 2 | 0.042857 | 0.100287 | 0.135135 | 0.090794 | 0.047937 | | | | | | |
| 3 | 3 | 0.057143 | 0.060172 | 0.036036 | 0.052765 | 0.02645 | | | | | | |
| 4 | 4 | 0.042857 | 0.031519 | 0.009009 | 0.027935 | 0.018926 | | | | | | |
| 5 | 5 | 0.042857 | 0.025788 | 0.045045 | 0.029414 | 0.015631 | | | | | | |
| 6 | 6 | 0.014286 | 0.022923 | 0.009009 | 0.015585 | 0.007833 | | | | | | |
| 7 | 7 | 0 | 0.014327 | 0 | 0.005601 | 0.008725 | | | | | | |
| 8 | 8 | 0 | 0.011461 | 0.009009 | 0.009567 | 0.009567 | | | | | | |
| 9 | 9 | 0 | 0.017192 | 0 | 0.004787 | 0.012405 | | | | | | |
| 10 | 10 | 0.014286 | 0.008596 | 0.018018 | 0.012972 | 0.006393 | | | | | | |
| 11 | 11 | 0 | 0.002865 | 0 | 0.003767 | 0.01597 | | | | | | |
| 12 | 12 | 0 | 0.008596 | 0.018018 | 0.00702 | 0.010998 | | | | | | |
| 13 | 13 | 0 | 0.002865 | 0 | 0.006471 | 0.024537 | | | | | | |
| 14 | 14 | 0 | 0.005731 | 0 | 0.006557 | 0.008947 | | | | | | |
| 15 | 15 | 0 | 0 | 0 | 0.006785 | 0.013017 | | | | | | |
| 16 | 16 | 0 | 0.011461 | 0 | 0.003832 | 0.00763 | | | | | | |
| 17 | 17 | 0 | 0.011461 | 0 | 0.006416 | 0.009088 | | | | | | |
| 18 | 18 | 0.014286 | 0.005731 | 0 | 0.004161 | 0.010125 | | | | | | |
| 19 | 19 | 0.014286 | 0.005731 | 0 | 0.009568 | 0.010169 | | | | | | |
| 20 | 20 | 0.014286 | 0.008596 | 0.009009 | 0.009897 | 0.009897 | | | | | | |
| 21 | 21 | 0.014286 | 0.011461 | 0 | 0.008406 | 0.011331 | | | | | | |
| 22 | 22 | 0 | 0.005731 | 0.027027 | 0.008478 | 0.018549 | | | | | | |
| 23 | 23 | 0.014286 | 0.020057 | 0 | 0.011141 | 0.013611 | | | | | | |
| 24 | 24 | 0.014286 | 0.002865 | 0.018018 | 0.006958 | 0.01106 | | | | | | |
| 25 | 25 | 0.014286 | 0.011461 | 0 | 0.008688 | 0.011114 | | | | | | |

1.plt - Notepad

File Edit Format View Help

```
reset
set title "Muon Decay"
set xlabel "Possible decay Lengh (in microseconds)"
set ylabel "Probability"
m=2; a=.5;c=.5;
decay(x) = c+a*exp(-(x/m))
fit decay(x) "4.dat" using 1:2:3 via m,a,c
plot decay(x),"4.dat" using 1:2:3 w yerrorbars
set terminal png
set output "output17.png"
```


Muon Decay
decay(x)
"4.dat" using 1:2:3
Probability
Possible decay Length (in microseconds)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
0
10
20
30
40
50
60
70
80
90
100

For fitting the curve we use the function :

$$decay(x) = C + Ae^{\frac{-x}{\tau}}$$

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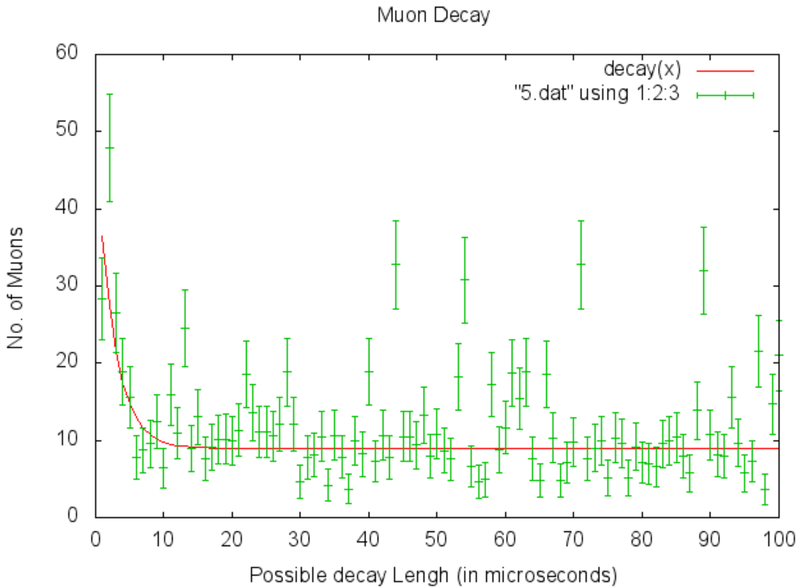
$$decay(x) = C + Ae^{\frac{-x}{\tau}}$$

After fitting the parameters we get:

$\tau$ = 2.16853 +/- 0.1771 (8.168%)

A = 0.166771 +/- 0.01875 (11.24%)

C = 0.00556742 +/- 0.0003015 (5.415%)


Muon Decay
decay(x)
"5.dat" using 1:2:3
No. of Muons
Possible decay Lengh (in microseconds)
0
10
20
30
40
50
60
70
80
90
100

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After fitting the parameters we get:

| | | |
|---|---|---|
| $\tau$ | = 2.55366 | +/- 0.8498 (33.28%) |
| A | = 40.7394 | +/- 14.38 (35.31%) |
| C | = 8.96301 | +/- 0.4858 (5.42%) |