SOLDERING GROUP

Muon hunter kit group

The best group 😇
• Intro to Muons – Eva
• Muon hunting by location – Ilia
• Statistical Analysis – Salah
• Shielding Experiments – Matthew
• Detectors Compared – Darwin
• 4-tube Detector - Eero
About us...
ILIA
And the Boss, ÉVA
About the muon...
The image displays a diagram of fermions and gauge bosons categorizing particles based on quarks, leptons, and strong and electromagnetic forces. The diagram includes:

- **Quarks** (up, charm, bottom, down, strange, top)
- **Leptons** (electron, muon, tau, electron neutrino, muon neutrino, tau neutrino)
- **Fermions**
- **Gauge Bosons** (Higgs, gluon, photon, W boson, Z boson)

Each particle is listed with its mass in GeV/c^2, charge, and spin, providing a comprehensive overview of fundamental particles in particle physics.
- Fermion (s=1/2)
- Lepton (L=+1)
- The "Big Brother" of electron
- Weak interaction
- Unstabil

Hello there! I'm a muon, a "heavy electron". My life lasts for only 2.2 microseconds, but that's fine by me.
Our Muon tracks from auto-triggered camera
Muons by Location

Ilia
Graphical Analysis

Salah
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>98</td>
</tr>
<tr>
<td>Q2</td>
<td>105</td>
</tr>
<tr>
<td>Q3</td>
<td>116</td>
</tr>
<tr>
<td>Median</td>
<td>105</td>
</tr>
<tr>
<td>IQR</td>
<td>18</td>
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**Cumulative Frequency: Building 156 Data**

![Cumulative Frequency Graph](image-url)
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Q1</td>
<td>72.25</td>
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<tr>
<td>Q2</td>
<td>83.5</td>
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<tr>
<td>Q3</td>
<td>93.75</td>
</tr>
<tr>
<td>Median</td>
<td>83.5</td>
</tr>
<tr>
<td>IQR</td>
<td>21.5</td>
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</table>

Cumulative Frequency: S'Cool Lab data
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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<tbody>
<tr>
<td>Q1</td>
<td>26</td>
</tr>
<tr>
<td>Q2</td>
<td>37</td>
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<tr>
<td>Q3</td>
<td>63.5</td>
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<tr>
<td>Median</td>
<td>37</td>
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<tr>
<td>IQR</td>
<td>37.5</td>
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**Cumulative Frequency: Building 193 data**
Cumulative Frequency: Chamonix Data

<table>
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<tr>
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<th>91</th>
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<tbody>
<tr>
<td>Q2</td>
<td>116</td>
</tr>
<tr>
<td>Q3</td>
<td>151.5</td>
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<tr>
<td>Median</td>
<td>116</td>
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<tr>
<td>IQR</td>
<td>60.5</td>
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Cumulative Frequency vs. Muon Count Rate (μ/hour)
Shielding

Matthew
**Vertical** tube arrangement: Cosmic Muons

### Table

<table>
<thead>
<tr>
<th>muon</th>
<th>1</th>
<th>2</th>
</tr>
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<tbody>
<tr>
<td>No</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>No</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>No</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Yes</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
**Horizontal** tube arrangement: Secondary particle cascades
Bruno Rossi,

Fig. 1.

Rossi, 1933
Fig. 8.

Rossi, 1933
Shielding with Water

$H_2O$

Horizontal Arrangement
Effect of Water Shielding on Coincidences

Coincidences Detected vs. Water Thickness (mm)

Water 15 minutes

The graph shows the effect of water shielding on coincidences, where the number of coincidences detected decreases with increasing water thickness, reaching a minimum at approximately 15-20 mm, and then increases again before decreasing again with further increases in water thickness.
• Muons lose energy faster in lead than in air – **NOT** just ionization energy loss

• Therefore, muons **decay**

• Lifetime at rest = $2.4 \times 10^{-6}$ sec

• Muons experience **relativistic time dilation.**

Rossi, 1940
Out of a million particles at 10 km, how many will reach the Earth?

**μ**: mass 207 m\(_e\)
- Charge: + or -
- Rest halflife: \(T_0 = 1.56 \times 10^{-6}\) sec

Measure muon flux at 10 km height.

\[\mu \quad 1,000,000\]

\[v = 0.98c\]

\[L_0 = 10 \text{ km}\]

Simultaneously monitor flux at ground level.

**Distance:** \(L_0 = 10^4\) meters

**Time:** \[T = \frac{10^4\ \text{m}}{(0.98)(3 \times 10^8\ \text{m/s})}\]

\[T = 34 \times 10^{-6}\ \text{s} = 21.8\ \text{halflives}\]

**Survival rate:**

\[\frac{1}{I_0} = 2^{\frac{-21.8}{0.27 \times 10^{-6}}}\]

Or only about 0.3 out of a million.
Classroom Detectors

Darwin
Muon detection & collaboration

What is available for our students?
Student detectors in use or development

♦ Muon hunter detector
♦ Quarknet detector
♦ Cosmix detector
♦ Netzwerk Teilchenwelt
♦ Cosmic Pi
Muon hunter
Quarknet CRMD, 6000 series
Cosmix detector
Netzwerk Teilchenwelt detectors

- CosMO
- muon
- detector
CosMO scintillator
(b) Water Cherenkov detector with a coffee thermos as detector volume.
Which detector...?

► Availability
  ► muon scintillators
  ► price
  ► data analysis
  ► collaboration ability
  ► user-friendly
<table>
<thead>
<tr>
<th>Muon hunter detector</th>
<th>Quarknet detector</th>
<th>Cosmix detector</th>
<th>CosMO (Netzwerk Teilchenwelt)</th>
<th>Cosmic Pi</th>
</tr>
</thead>
<tbody>
<tr>
<td>availability</td>
<td>October (?), anywhere</td>
<td>US†</td>
<td>France</td>
<td>Germany</td>
</tr>
<tr>
<td>muon scintillators (size affects count rate)</td>
<td>2 G-M (or 4 if you’re Eero); small area, ~5cm²</td>
<td>4 scintillator (plastic) Large area (&gt;700 cm²)</td>
<td>2 scintillator (PbWO₄); ~30 cm²</td>
<td>3 scintillator (plastic) 400 cm²</td>
</tr>
<tr>
<td>price</td>
<td>€120</td>
<td>Free, with strings</td>
<td>~€1000</td>
<td>Available through Teil. Netzwerk</td>
</tr>
<tr>
<td>data analysis</td>
<td>DIY, mostly with Python</td>
<td>elab</td>
<td>Excel, etc</td>
<td>e-lab</td>
</tr>
</tbody>
</table>

† Some are also found in Brazil, Canada, China, France, Republic of Georgia, Great Britain, India, Mexico, Japan, Poland, Puerto Rico, Russia, Singapore, and Thailand.
<table>
<thead>
<tr>
<th></th>
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<th>Cosmix detector</th>
<th>Netzwerk Teilchenwelt</th>
<th>Cosmic Pi</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Collaboration ability</strong></td>
<td>Not at this time</td>
<td>high</td>
<td>Unknown, seems to be low</td>
<td>high</td>
<td>?? Seems to be a goal; still far off</td>
</tr>
<tr>
<td><strong>User-friendly</strong></td>
<td>Reasonably easy if already constructed</td>
<td>50+ page user manual</td>
<td>high</td>
<td>?? probably similar to QN</td>
<td>Low unless you can solder and program. Also see below*</td>
</tr>
<tr>
<td><strong>Research options</strong></td>
<td>several</td>
<td>Almost unlimited</td>
<td>&gt;μh, but limited</td>
<td>Almost unlimited</td>
<td>Seem to be mostly individual at this time</td>
</tr>
</tbody>
</table>
Known bugs with Prototype 1 of Cosmic Pi

Lots: Hard limit of 1 Hz for event rate due to timer implementation, Murata PSU isn't suitable for SiPMT as it's too noisy. The ADC's are not pipelined and we have issues getting the Raspberry Pi to respond fast enough via the interrupt using standard Raspian. Version 2 is going to have a different hardware architecture to avoid these flaws!

Conclusions (mostly personal)

- Muon hunter will be useful as an introduction to muon detection and data analysis. It may become useful for collaboration someday.
- QN CRMD and CosMO are very well-suited for collaboration. Limited availability
- Cosmix is also useful as an introduction if you are in France. Collaboration unlikely.
- Cosmic Pi is still early in its development. Good for technologically oriented
data taken from Cosmic ray e-lab
4-coincidence Detector

Eero
AC + BD: 742
AB + CD: 1026
AD: 835
BD: 16
BC: 5238
A + B + C + D: 0
day: 0:13:43