

Exploring particle/nuclear/astro physics with CosmicWatch: The Desktop Muon Detectors v3X



AAPT, CS regional meeting
100 SHL
10:30AM – 10:45PM, 2026-04-17

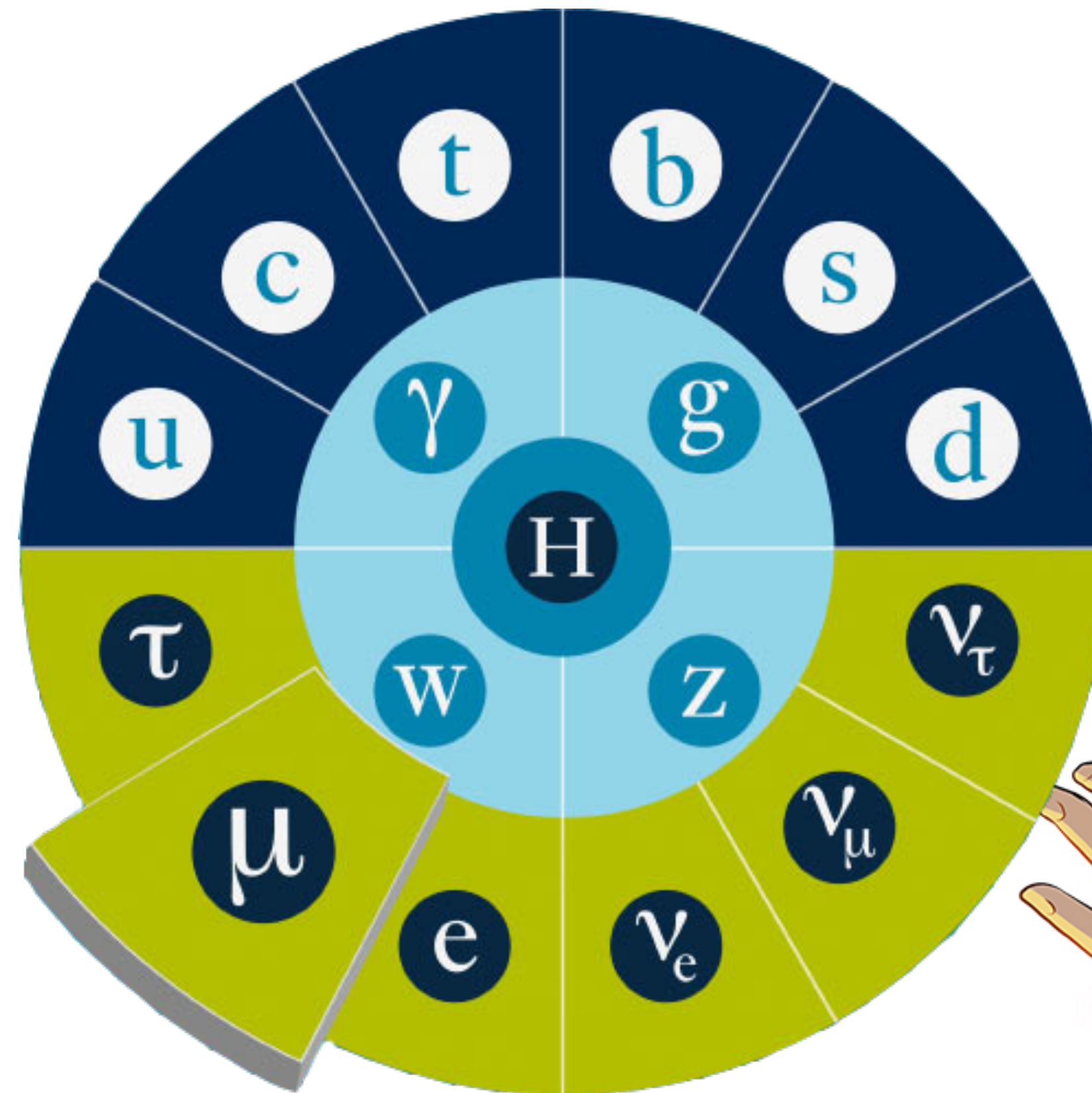
Big Thanks to:
Masooma Sarfraz, Miles Garcia, Collin Owens,
& Katarzyna Frankiewicz, Janet Conrad

Dr. Spencer N. Axani

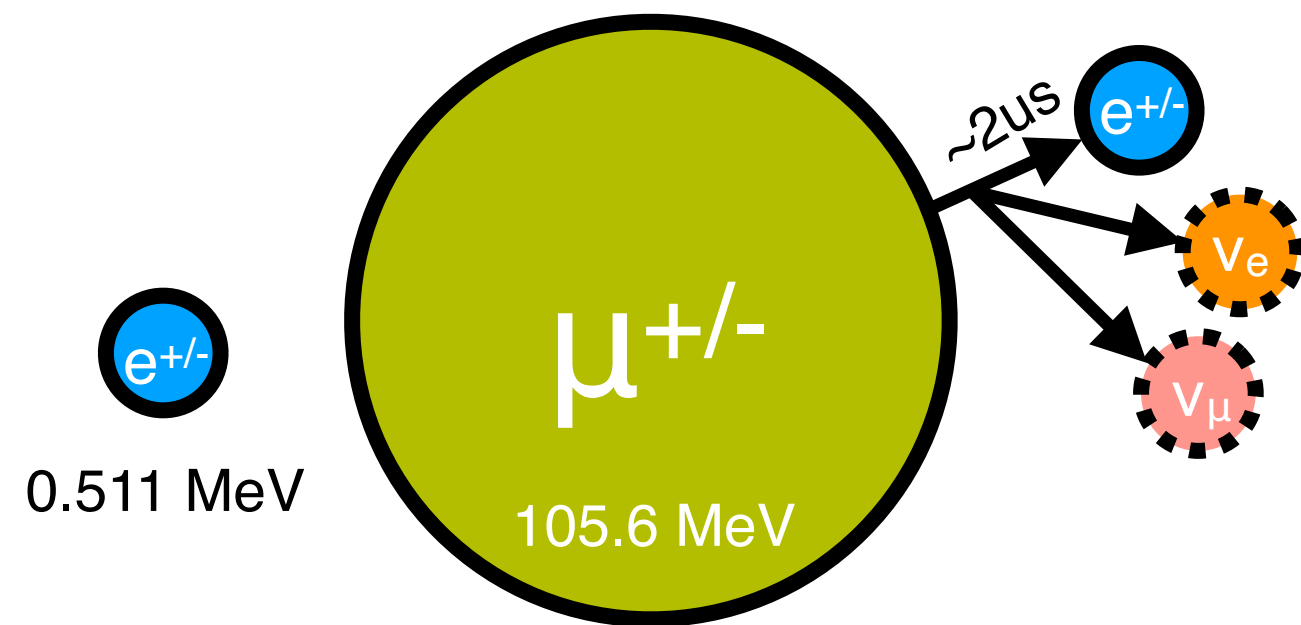
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What is a muon?

1. Muons are fundamental particles of the Standard Model.



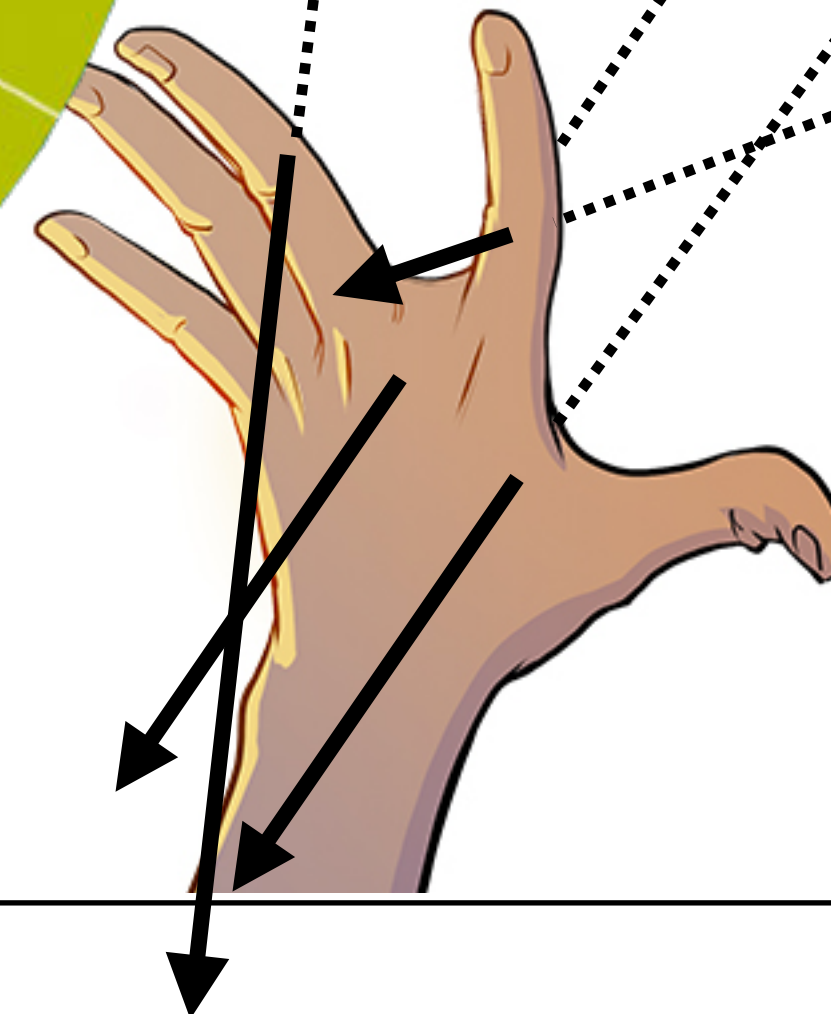
2. They are 207 times the mass of the electron.



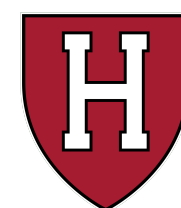
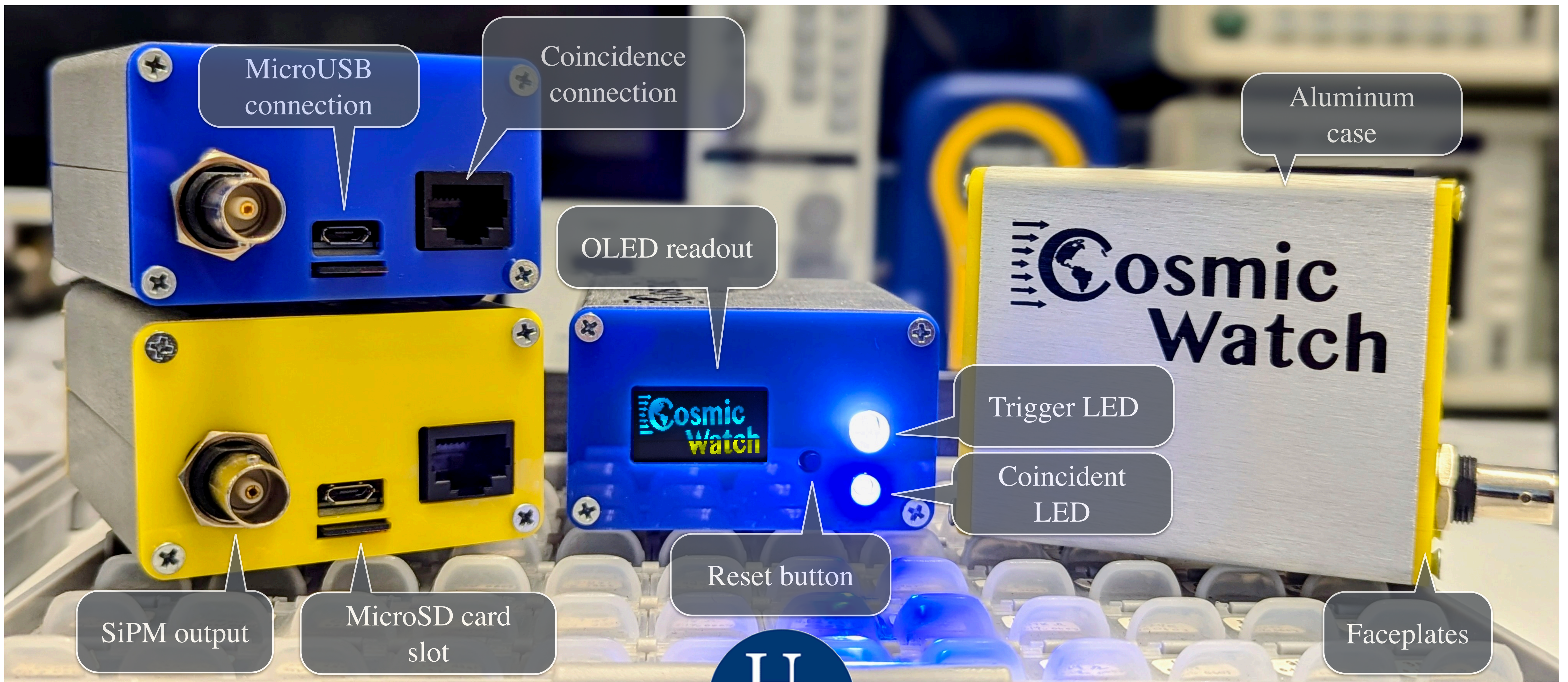
3. They can decay!
(1.56 μs half life)

$$\mu^\pm \rightarrow e^\pm + \nu_e(\bar{\nu}_e) + \bar{\nu}_\mu(\nu_\mu) \dots (100.0\%),$$

4. Muon rain down on us. Mean energy of 4 GeV.
→ Relativistic ($v \approx c$)!



CosmicWatch: The Desktop Muon Detector (v3X)

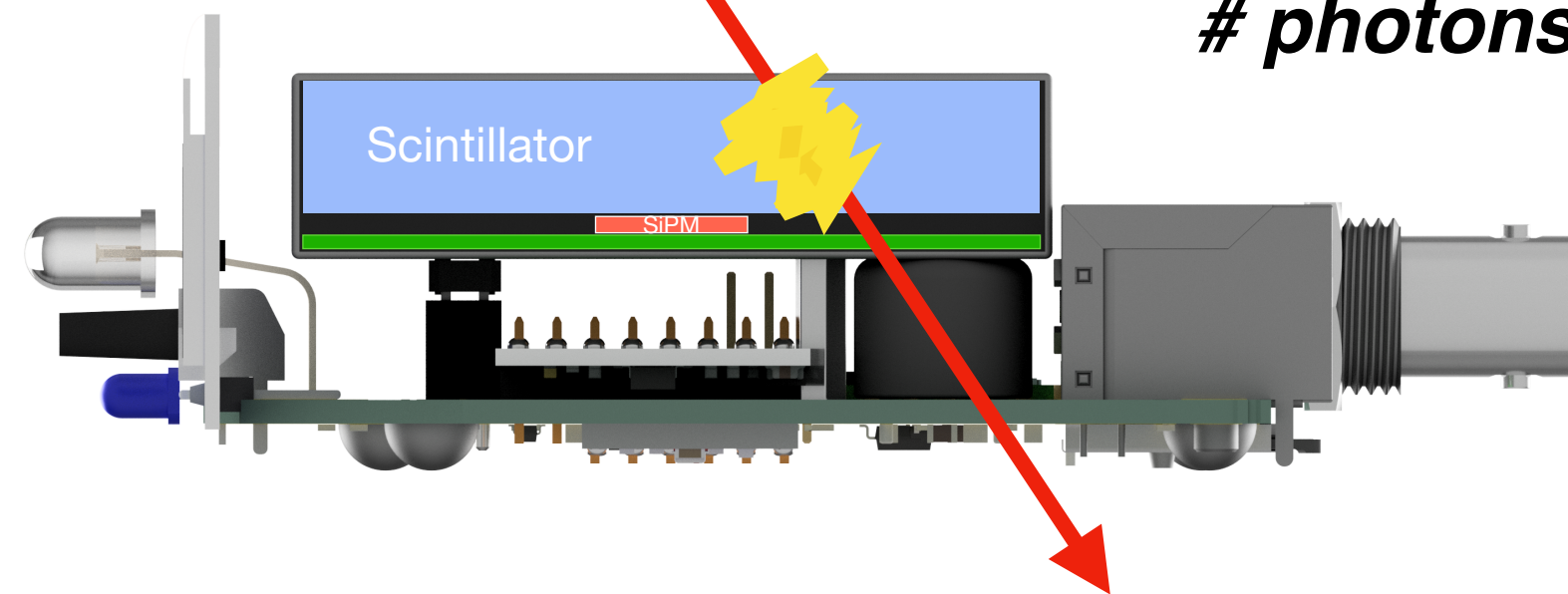


How does the detector work?

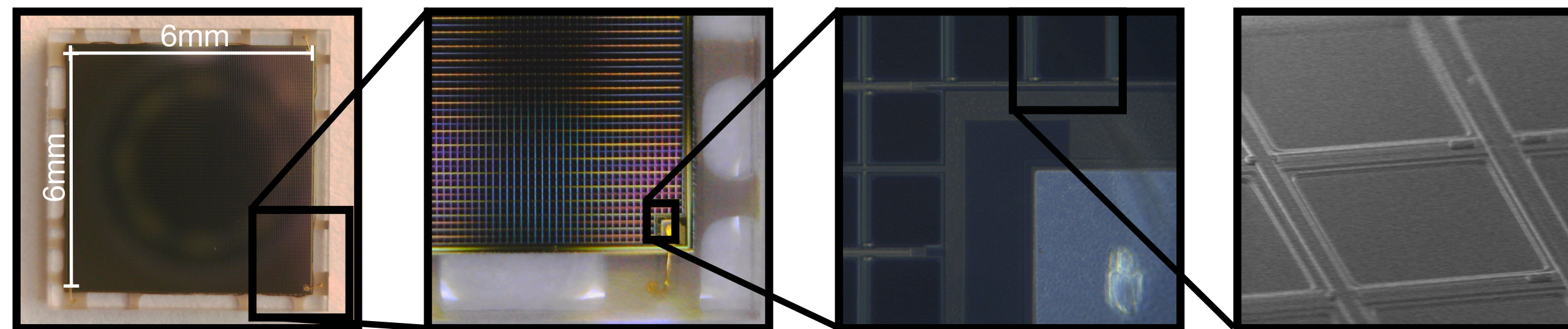
$\mu^{+/-}$

1. A charge particle interacts with scintillator, excites scintillator, and emits light.

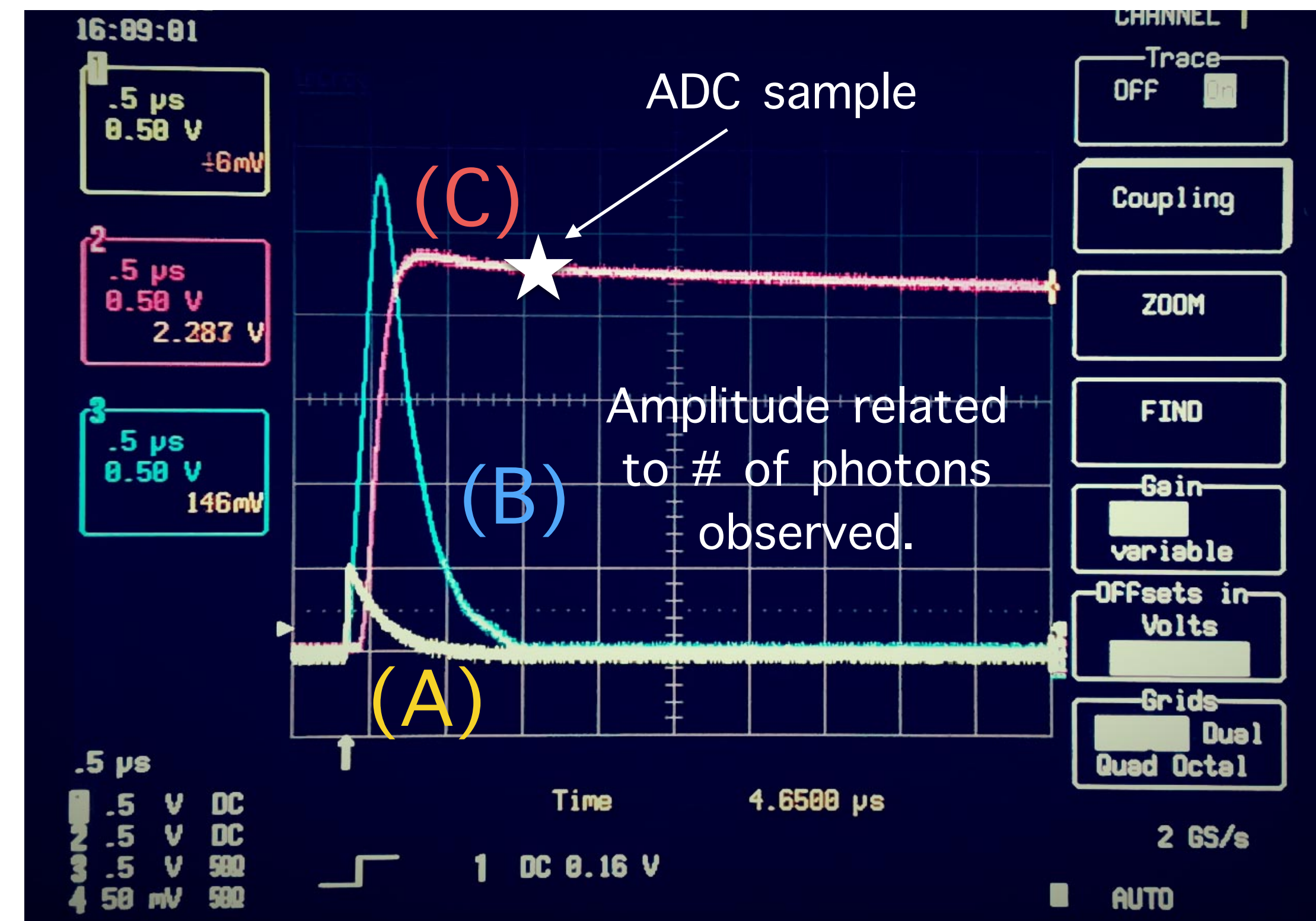
photons \propto energy deposited



2. Light is collected by a silicon photomultiplier (**SiPM**) and creates a measurable current.

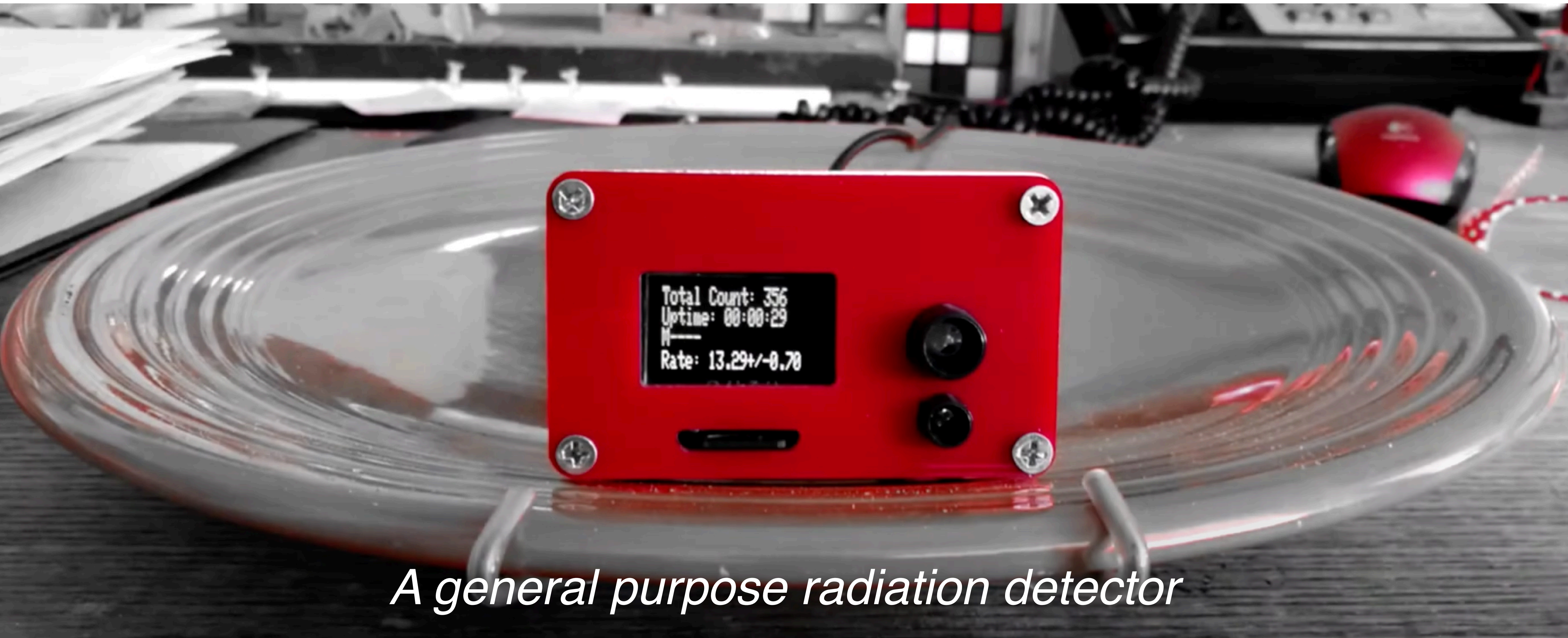


3. The signal **(A)** is amplified **(B)** and shaped **(C)**, such that we can measure it with an inexpensive micro-controller.



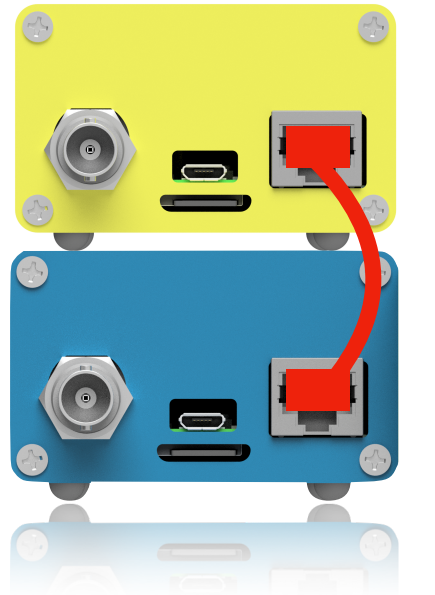
4. The measurements can be readout using the OLED, microSD, or a computer.

Demo: Radioactive Fiesta Ware from the late 30s



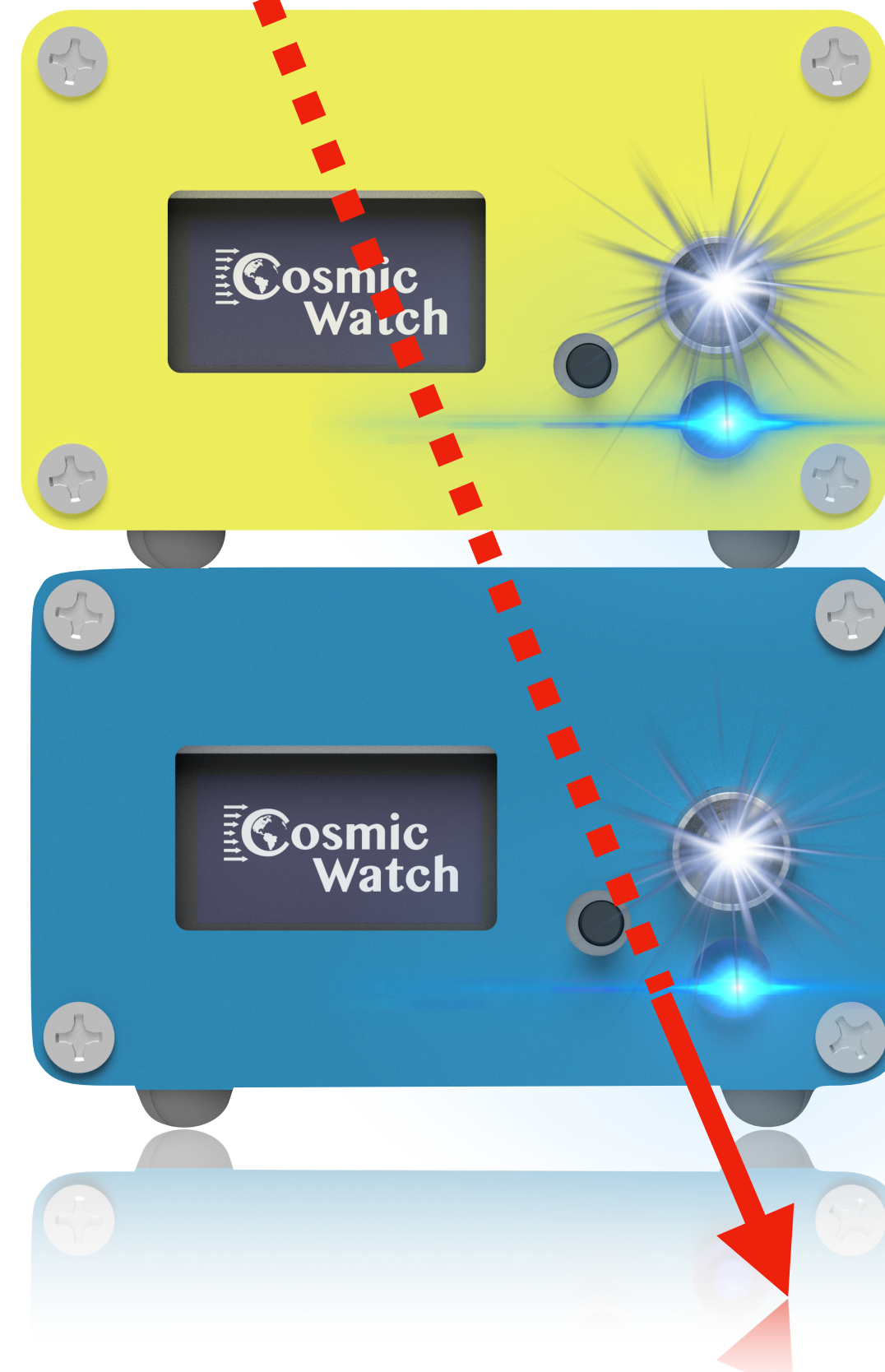
Coincidence mode to extract muons

Connect **coincidence cable** to enable "**coincidence mode.**"
The set of detectors will now identify **muons.**



When both detectors register an event at the same time, we call that a **coincident event.**

$\mu^{+/-}$



AxLab_C_003.txt

```
#####  
# CosmicWatch: The Desktop Muon Detector v3X  
# Questions? saxani@udel.edu  
# Detector Name: AxLab  
# Event Timestamp[s] Flag ADC[12b] SiPM[mV] Deadtime[s] Temp[C] Press[Pa] Accel(X:Y:Z)[g] Gyro(X:Y:Z)[deg/sec]  
#####
```

1	0.352988	0	70	3.0	0.000062	24.7	100939	-0.009:-0.005:0.997	1.4:-1.2:0.1
2	1.128271	1	610	30.5	0.000538	24.7	100939	-0.002:-0.007:0.987	1.3:-1.7:0.9
3	1.287253	0	186	9.2	0.000955	24.7	100939	-0.012:-0.004:0.987	1.4:-1.3:0.6
4	1.853932	0	85	3.6	0.001351	24.7	100938	-0.007:0.000:0.994	1.7:-1.5:0.6
5	1.918029	0	136	6.3	0.001745	24.7	100938	-0.003:-0.006:0.999	1.2:-1.5:0.2
6	1.952504	0	66	2.8	0.002138	24.7	100938	-0.007:-0.007:0.993	1.3:-1.5:0.4
7	2.071804	1	332	16.4	0.002567	24.7	100938	-0.002:-0.005:0.993	1.4:-1.6:0.5
8	2.078546	0	67	2.9	0.002951	24.7	100938	-0.002:-0.005:0.993	1.4:-1.6:0.5
9	3.225000	0	77	3.3	0.003315	24.7	100937	-0.009:-0.005:0.991	1.2:-1.5:0.1
10	3.559229	0	66	2.8	0.003716	24.7	100937	-0.005:-0.006:0.987	1.5:-1.2:0.2
11	3.853281	0	78	3.3	0.004109	24.7	100937	-0.006:-0.004:0.994	1.5:-1.6:0.4
12	4.124590	0	83	3.6	0.004510	24.7	100936	-0.008:-0.010:0.993	1.4:-1.4:0.4
13	4.521386	0	90	3.9	0.004898	24.7	100938	-0.009:-0.007:0.995	1.3:-1.4:0.4
14	4.633145	0	1309	68.0	0.005308	24.7	100938	-0.006:-0.006:0.993	1.3:-1.4:0.4
15	5.139348	0	184	9.1	0.005758	24.7	100938	-0.007:-0.008:0.995	1.3:-1.4:0.2

Data is saved to a microSD card, in an easy to parse .txt file.

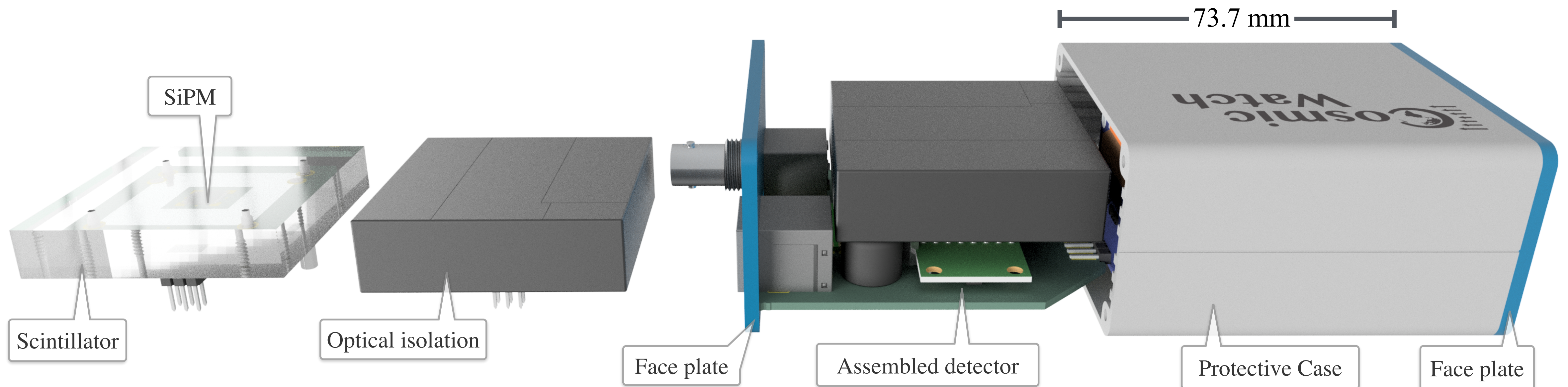
CosmicWatch @ UD

PHYS646: Experimental Techniques for Quantum Systems & Experimental Methods of Physics

1. Students build their own muon detectors from scratch, following an exercise document.
 - ▶ Soldering SMT components, electronics troubleshooting, and general knowledge about particle detection
2. In pairs, they design an experiment, and spend one-month taking data.
3. Present their results in an conference-style (15m+5m) presentation at the end of the semester.

PHYS645: Electronics for Scientists

1. Students learn how to design high speed analog electronics and program microcontrollers
2. We print the students circuit boards, and each student builds a compact gamma-ray spectrometers



"I am fascinated by your muon detector project."
M. McClure (CEO)

"Thank you so much for this creation."
J. Diodato (Lab Director)

"It was such a cool and memorable experience."
E. Forberger (CS Student)

"The CosmicWatch project is very impressive."
J. Dorfan (Professor)

"I will be attending Yale this fall to study Physics and Philosophy, and I would never have had this opportunity without CosmicWatch."
A. Schwarz (Student)

"I never would have thought this compact, was possible if I hadn't stumbled across your site. Thank you so much for going out of your way to do this"
R. Sorba (Student)

"You've done SO MUCH for me, informally."
M. Szydagis (Professor)

"CosmicWatch has been a fantastic platform to learn from"
A. Ajmera (High School Student)

"I'm grateful that you made an effort to make the project accessible and encourage more people to learn about particle physics."
S. Muller (Student)

"Let me congratulate for the CosmicWatch project, very nice."
N. V. Maira (Student)

"Clever piece of electronic!"
L. Ferrian (Enthusiast)

"...congrats on your very nice project."
G. Barouch (Student)

"Your work on detecting muons has been a huge inspiration for us."
R. Bhintade (Director of SSRP)

"The design is beautiful — I mean that both technically and as someone who builds art / music instruments."
K.Hassim (Artist)
South Africa

"The CosmicWatch detector is indeed a marvelous invention."
V. Sankar (Student)

"They are totally fantastic... thanks for maintaining such a great educational tool.."
T. Melia (Prof U Tokyo)

"We were truly amazed by it."
I. Mozumder (Independent Student Author)
Bangladesh

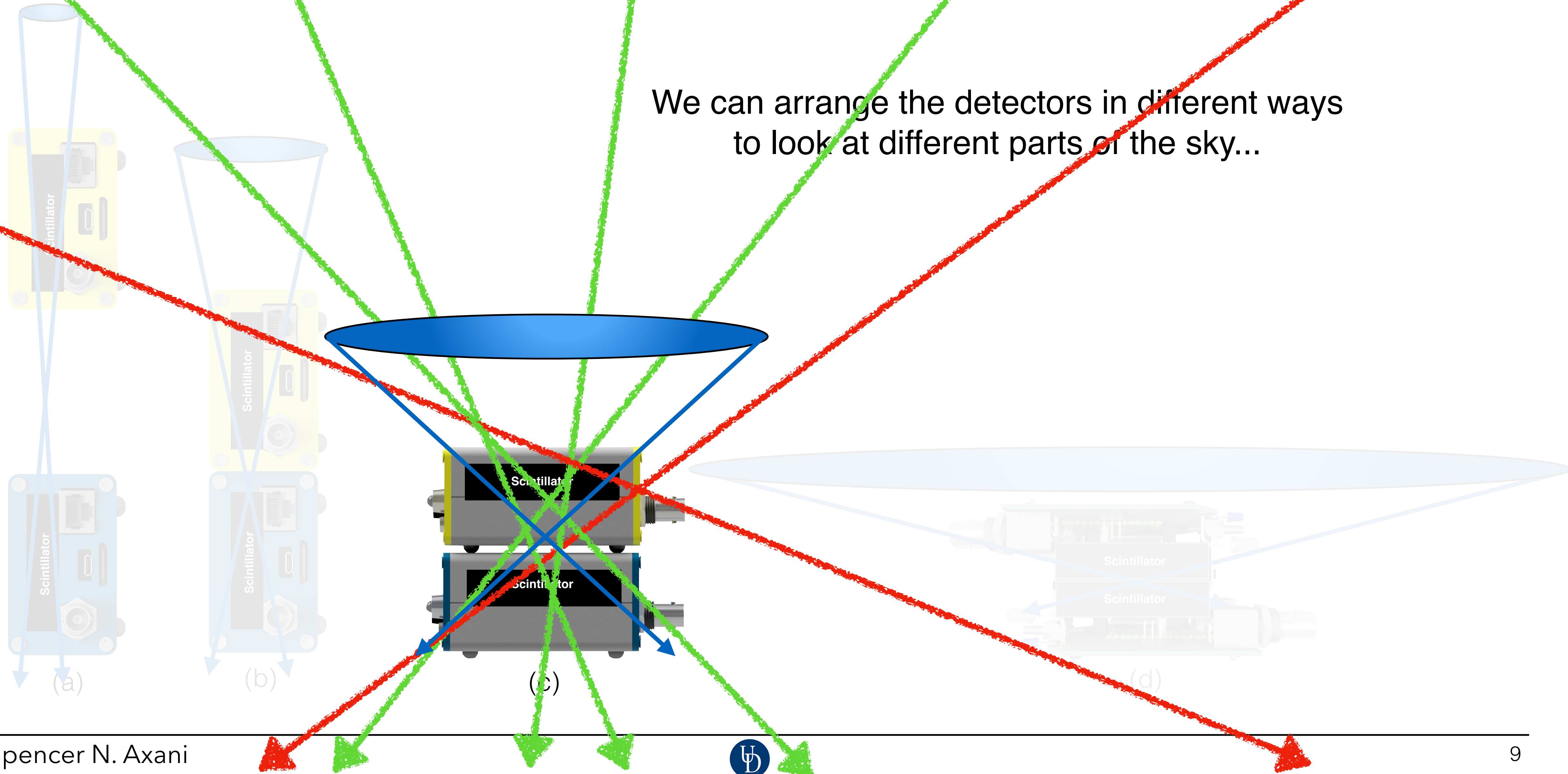
"I would like to say a big thank you for the CosmicWatch muon detector."
S. Inbanathan (Head, Dept)

"I take this opportunity to thank you with all my heart and I hereby extend a heartfelt appreciation on behalf of all the students who will benefit from this detector. "
D. Senadheera (Student)
Sri Lanka



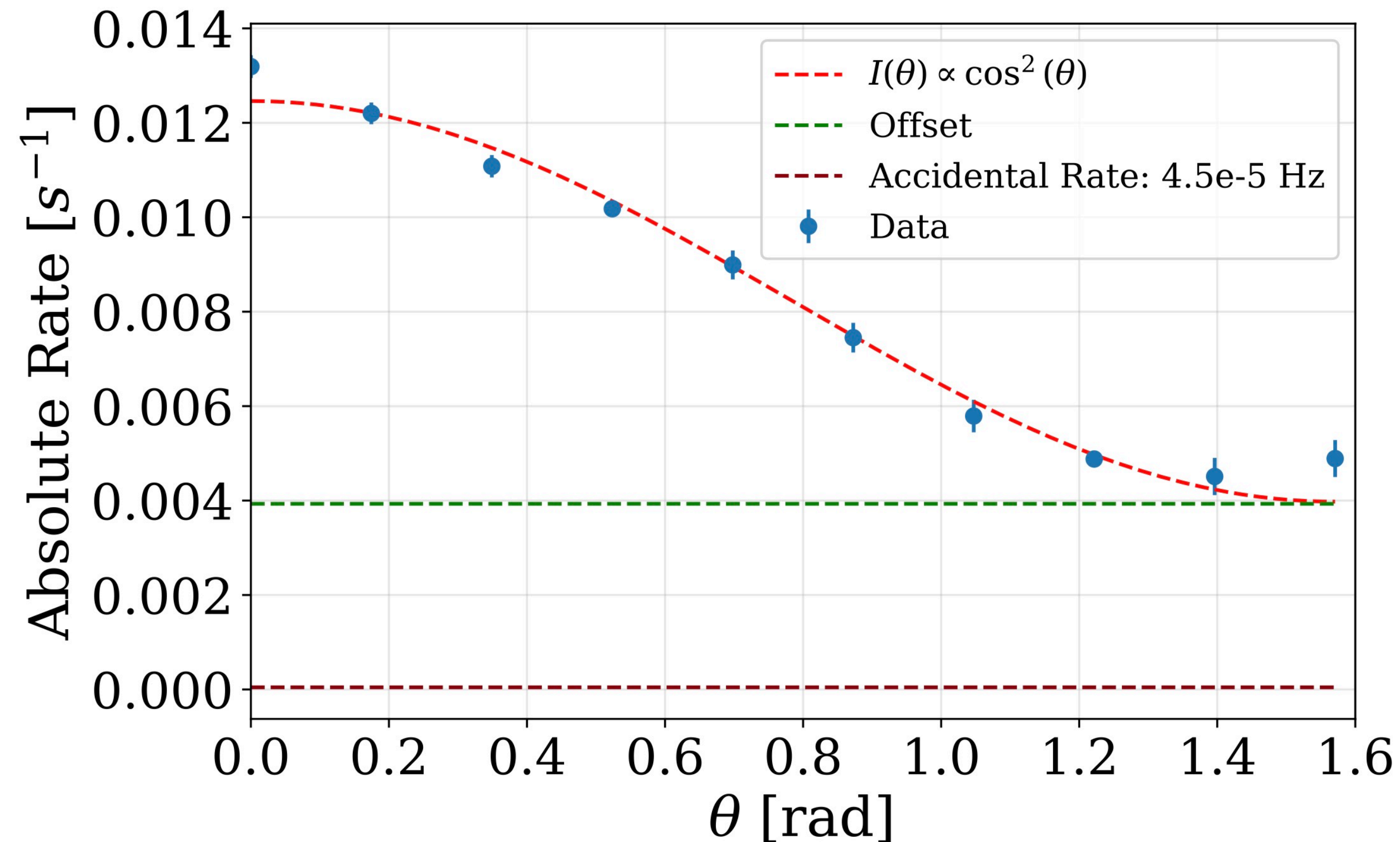
Setting up a cosmic-ray muon telescope

We can arrange the detectors in different ways to look at different parts of the sky...

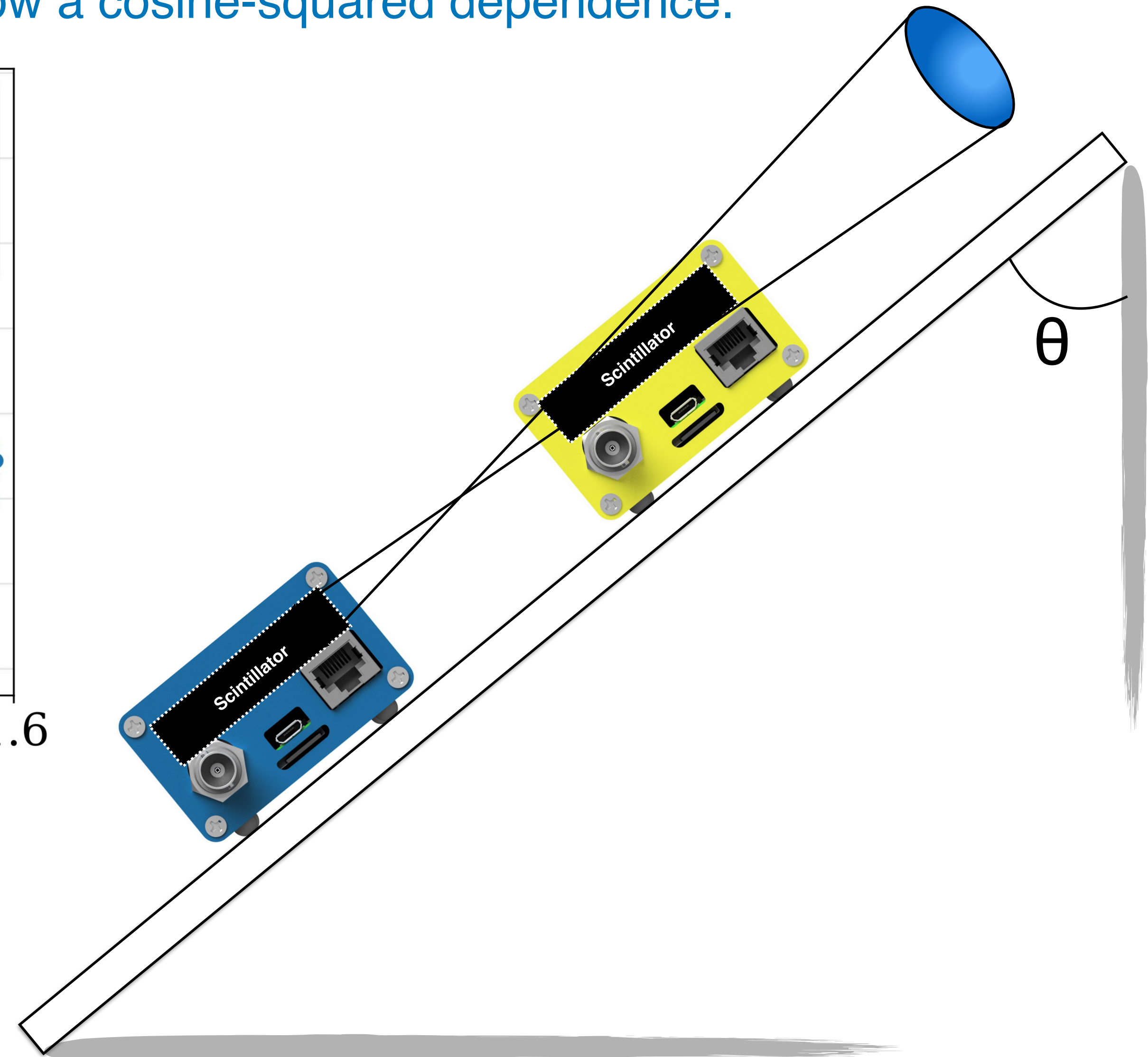


Example 1: The angular distribution of cosmic ray muons

The angular distribution should follow a cosine-squared dependence.

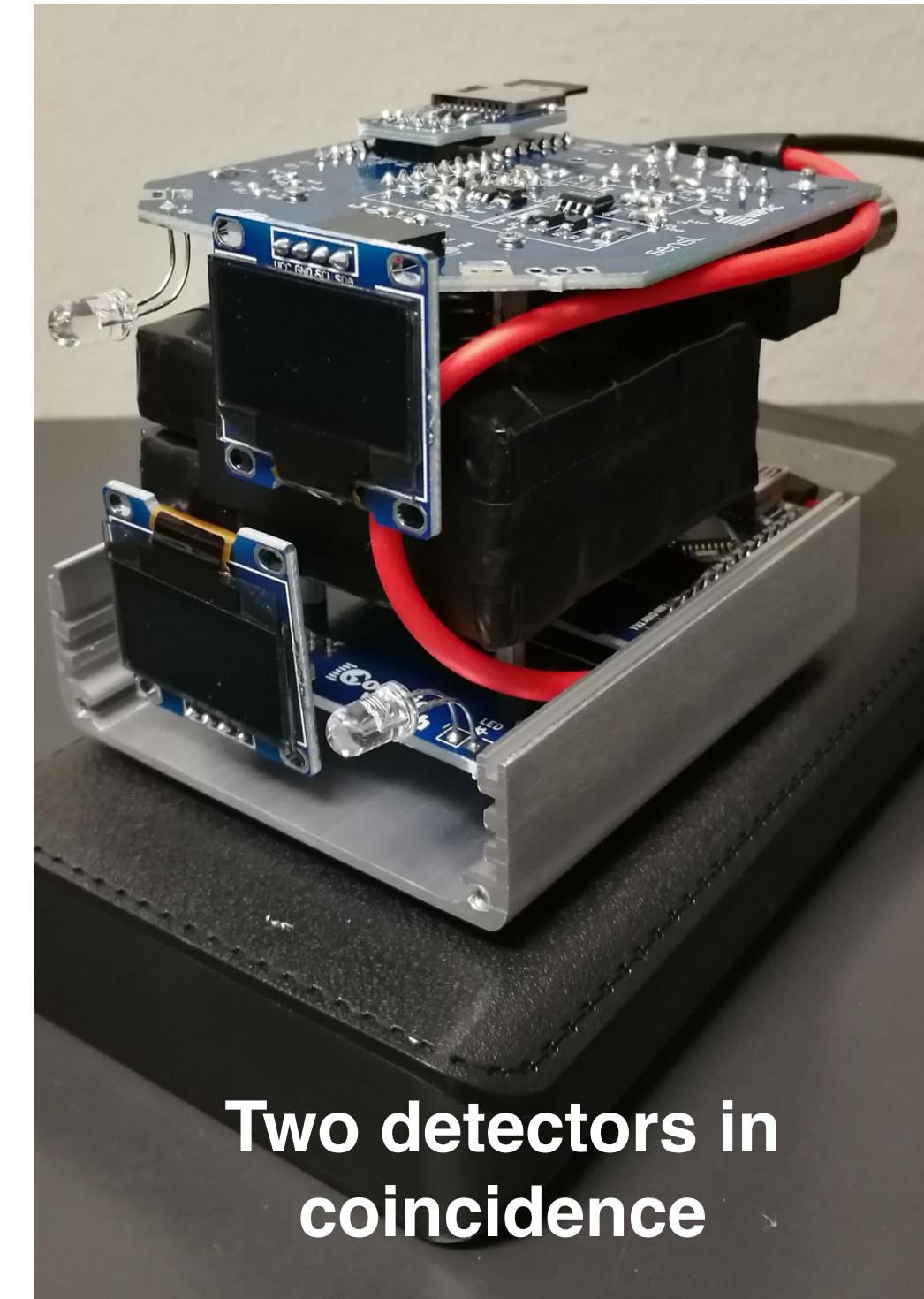
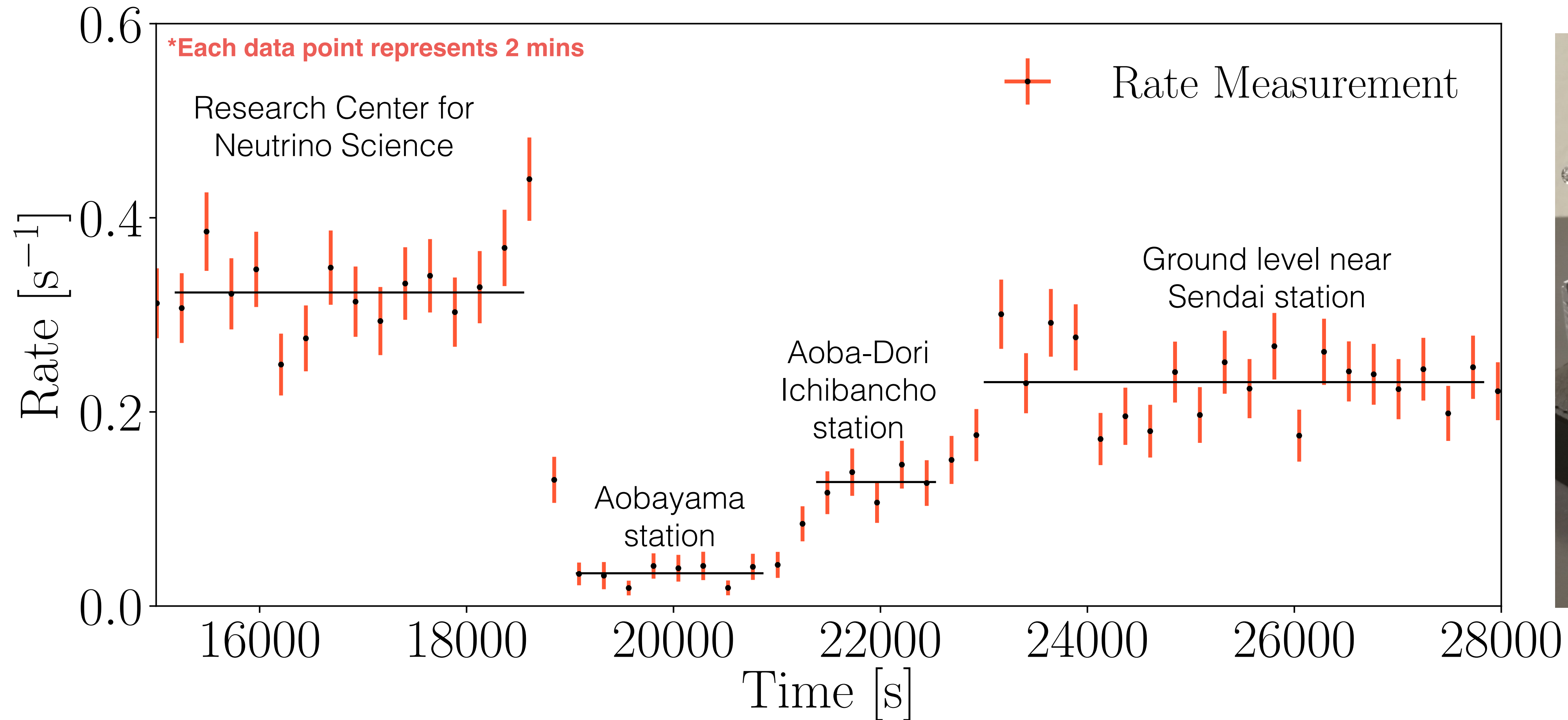


Two CosmicWatch detectors can work as muon telescope and be **sensitive to the direction** of the cosmic ray muons.



Example 2: Going deep underground

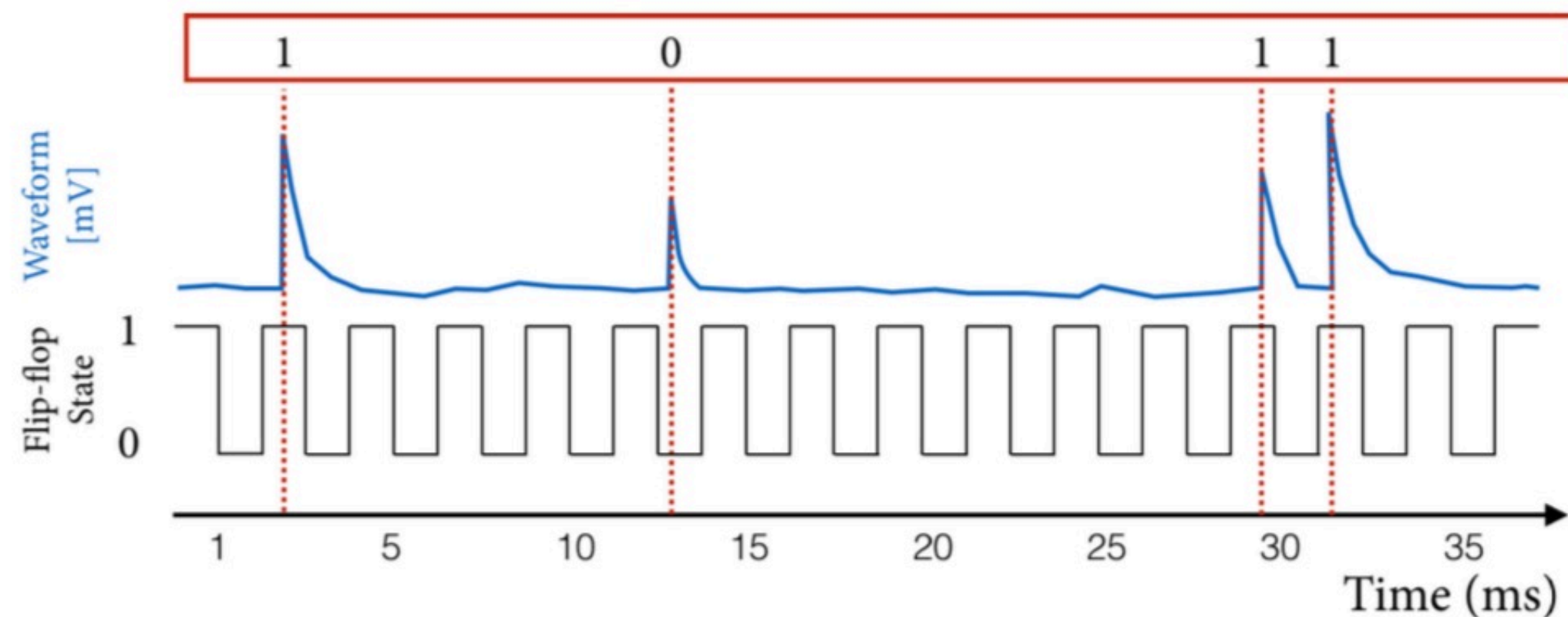
Cosmic-ray muons are highly penetrating — it takes about 10m of concrete to stop the average muon.



You can measure the depths of subway stations!

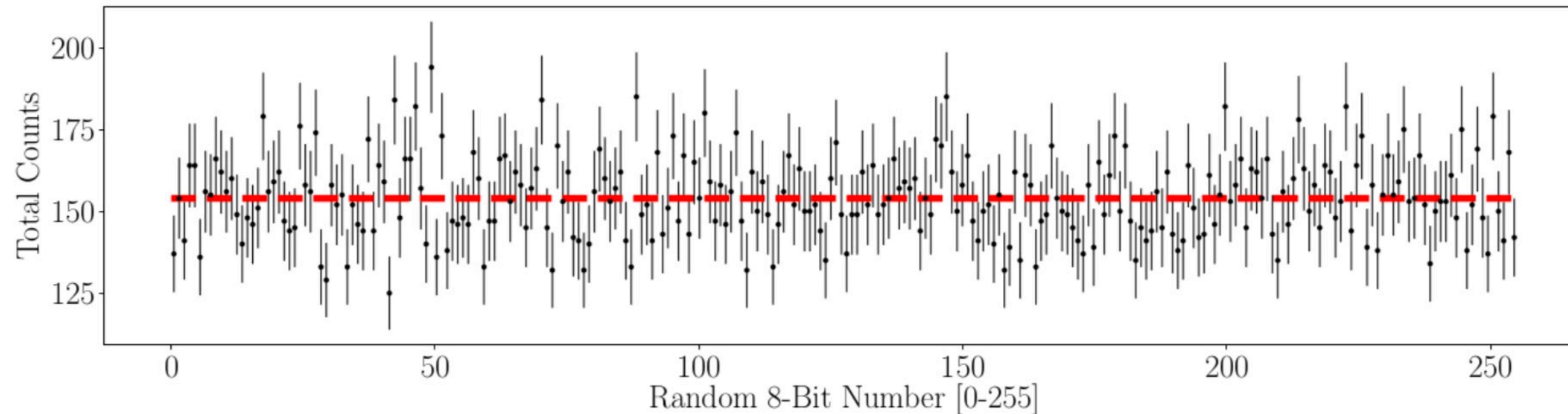
Example 3: A true random number generator

Cosmic rays muons are random in time.



- A random number generator would ideally be generated from a **random process**, such as the **arrival times of cosmic ray muons** or radioactive decay
- We can convert the time stamp of a trigger into a '1' or a '0' using a **toggle flip-flop** (here, 1kHz)
- After N triggers, we can build an **N-bit random number**

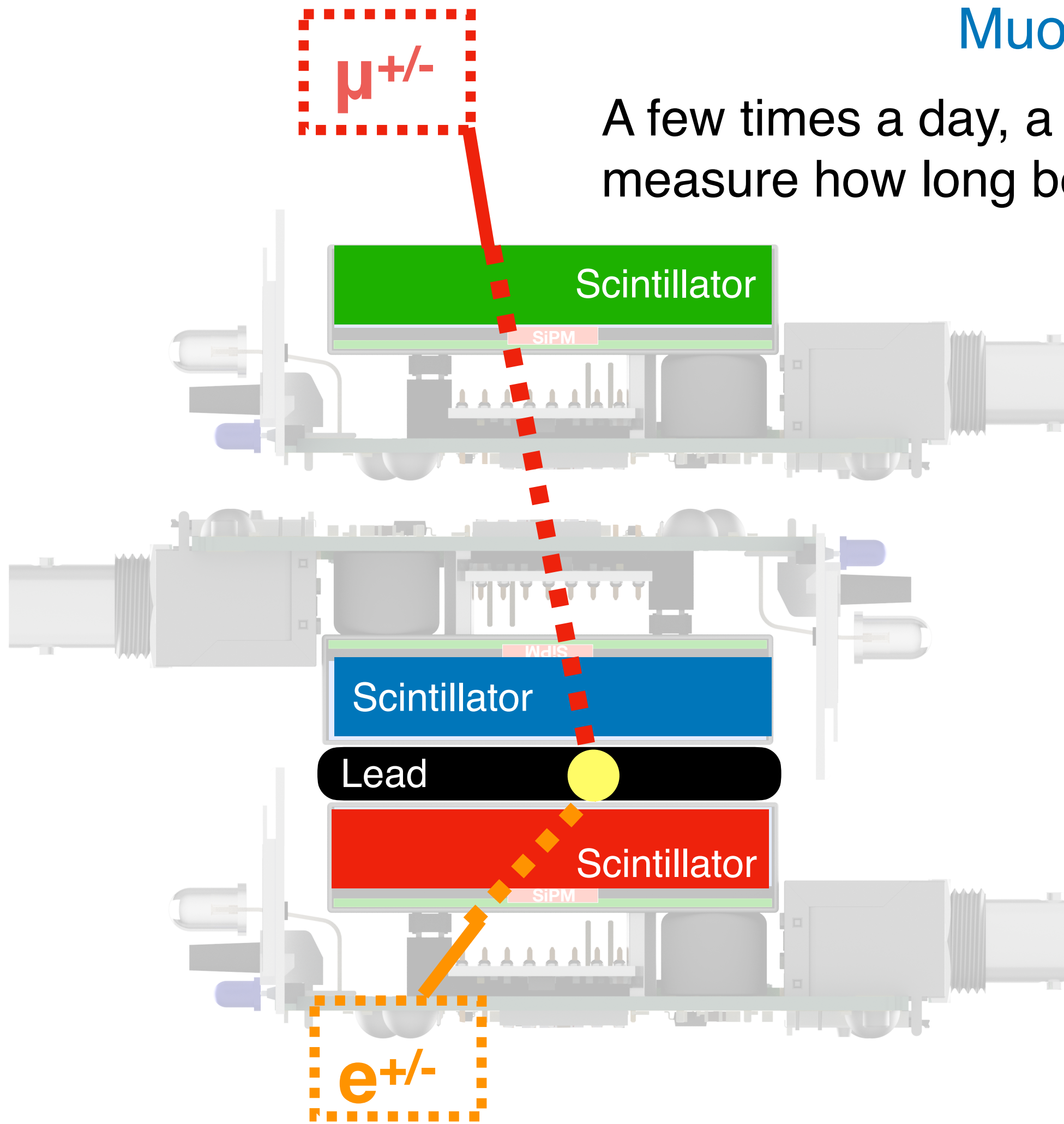
The number of occurrences of the generated numbers from 0-255



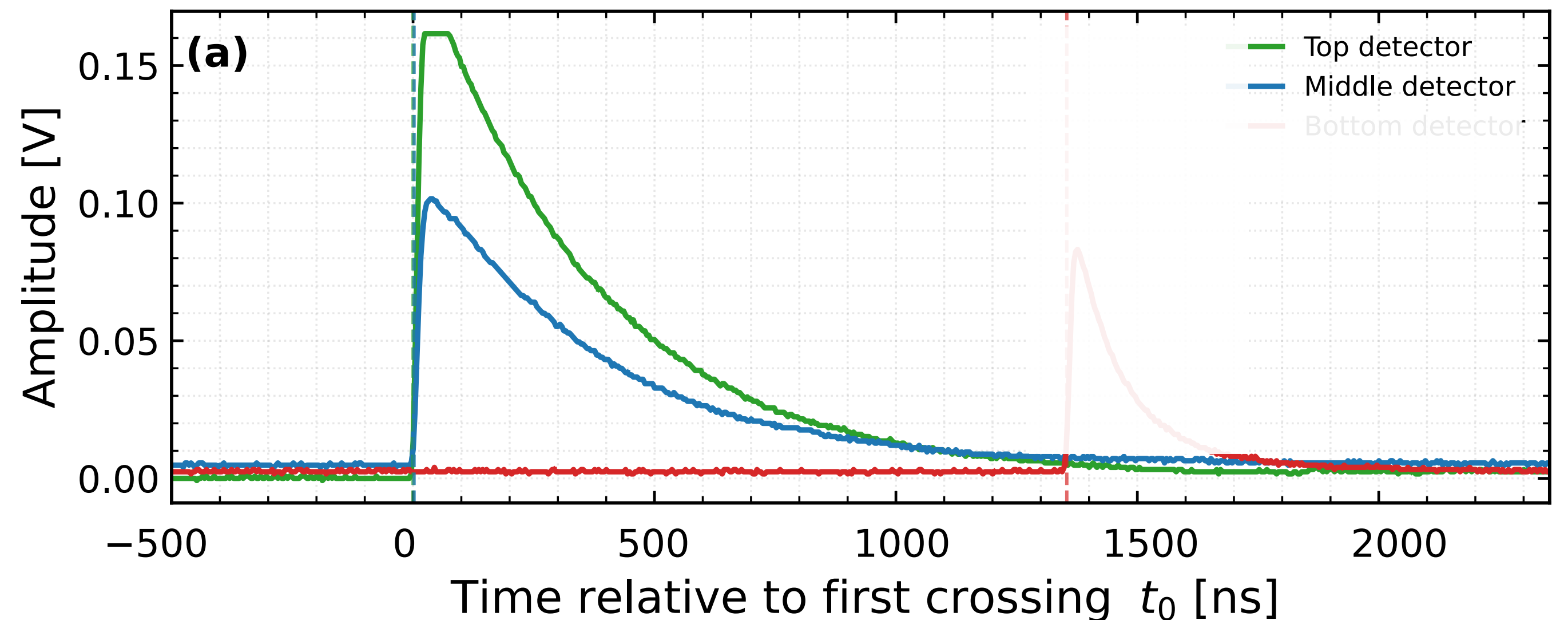
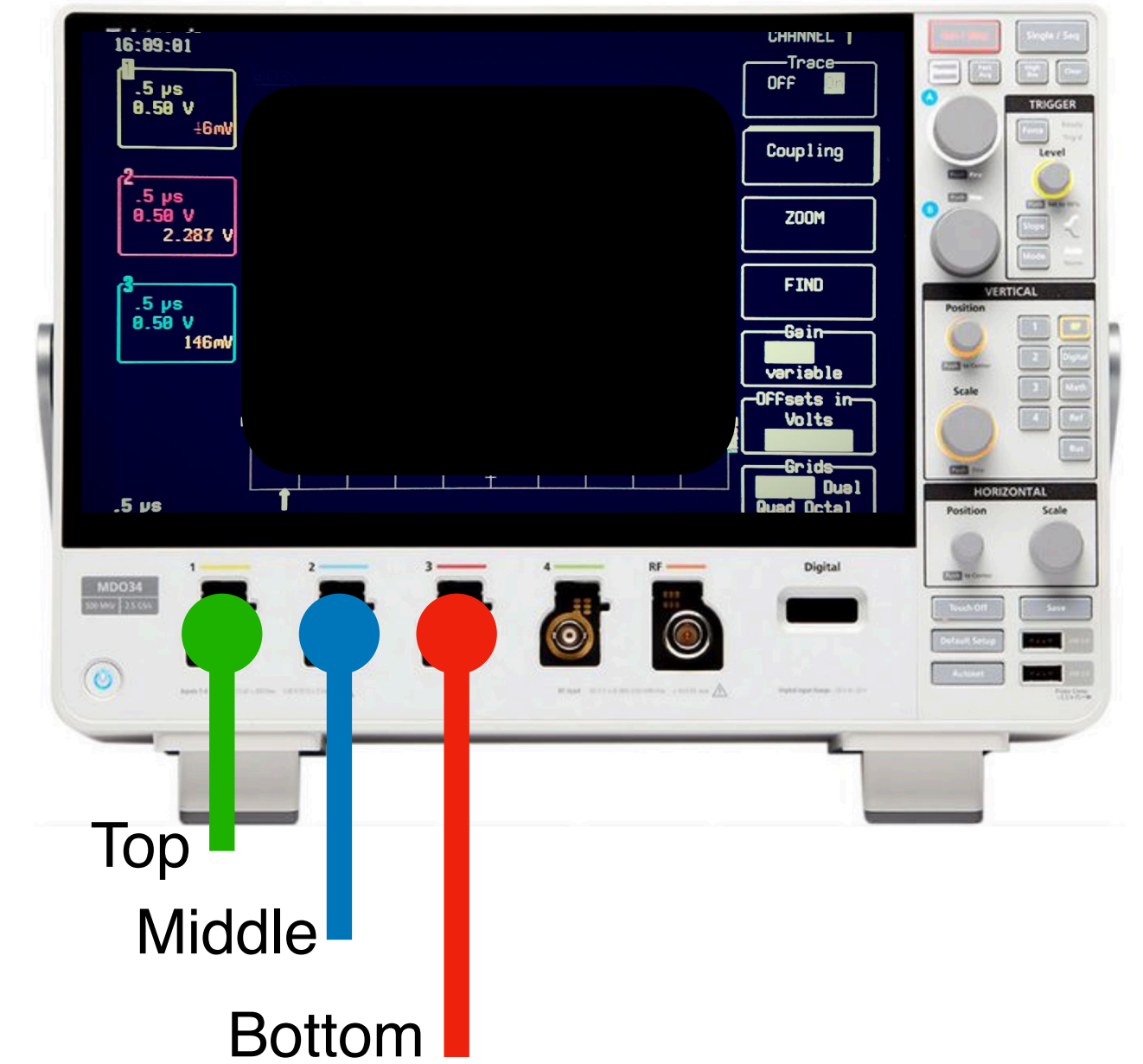
Example 4: Measuring the muon lifetime

Muons have a half-life of $1.56\mu s$.

A few times a day, a muon will stop in a detector and we can measure how long before it decays.

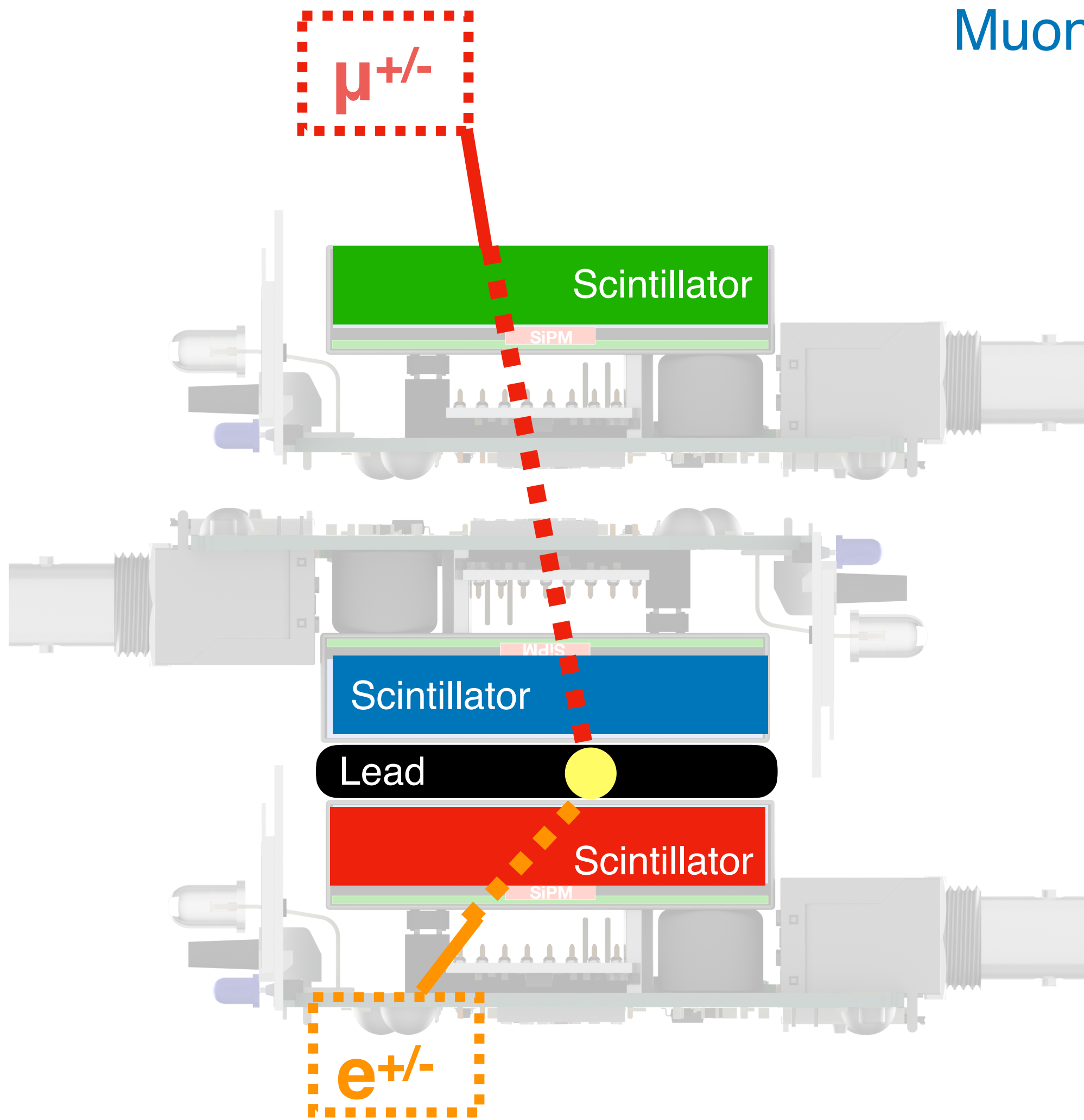


1. Muon trigger **Top** and **Middle**.
2. Not the **bottom**, indicating it stopped.
3. Search for delayed pulse, in **Middle** or **Bottom** resulting from muon decaying to an electron.

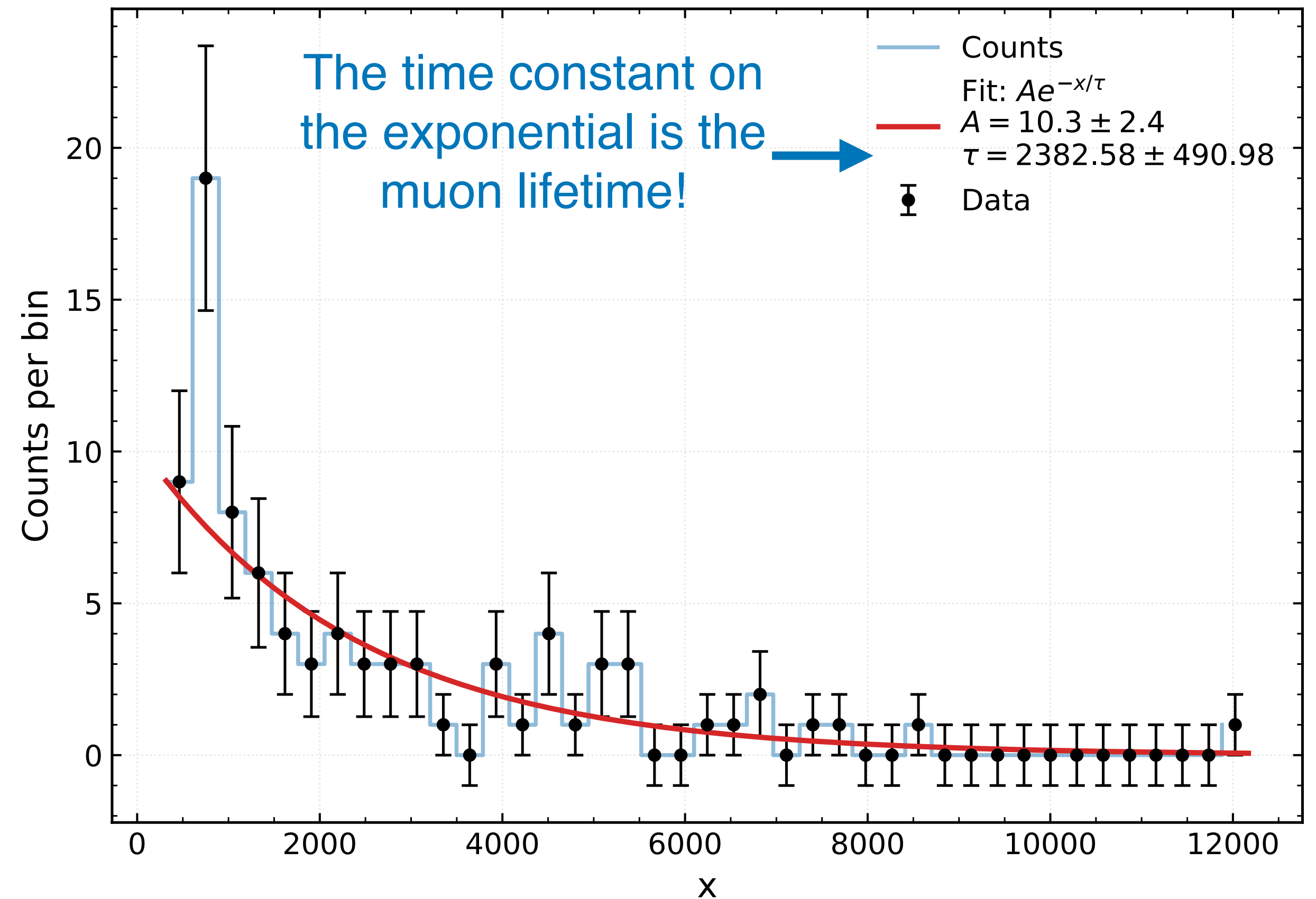


Example 4: Measuring the muon lifetime

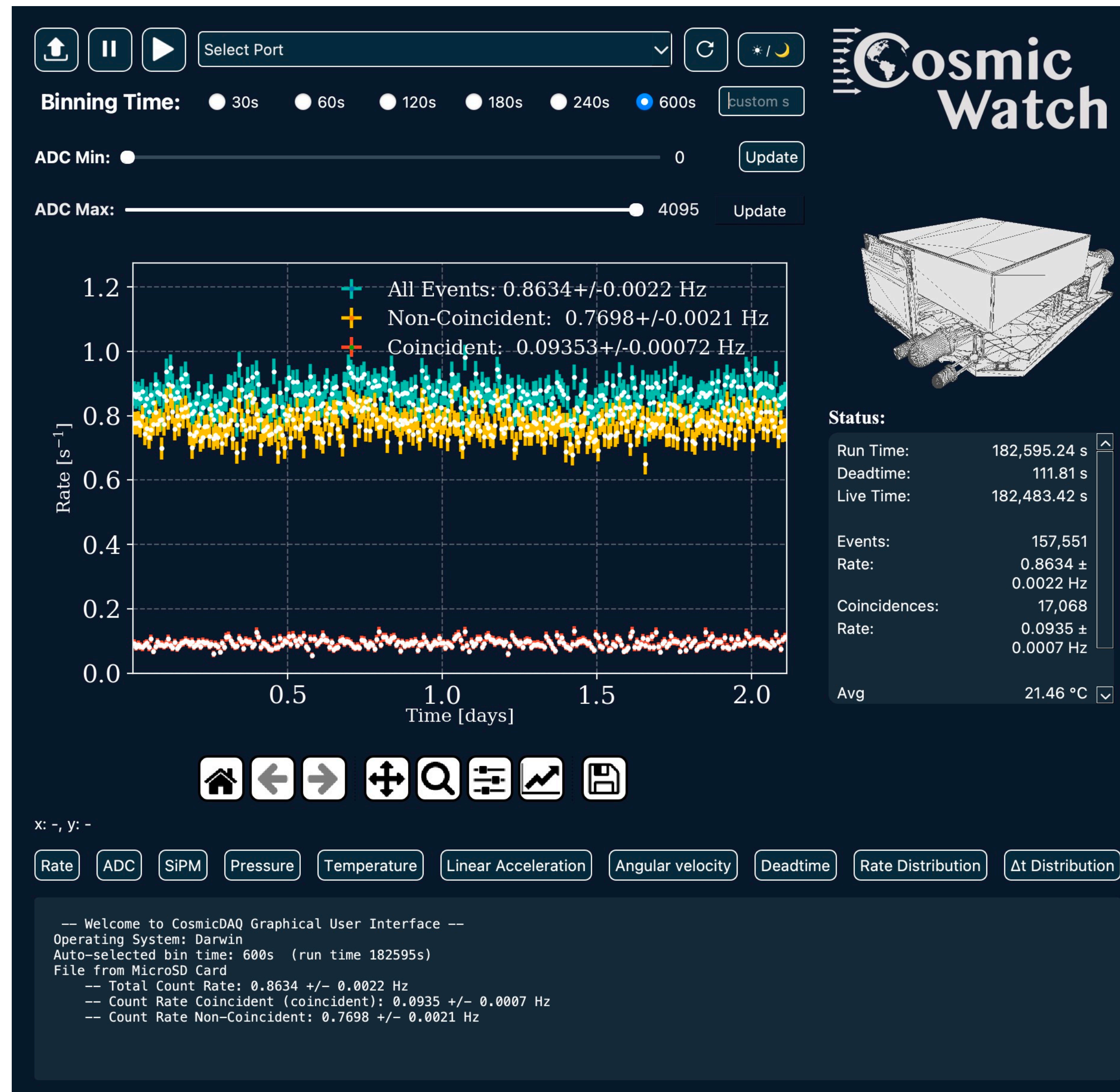
Muons have a half-life of $1.56\mu s$.



Histogram the difference in time between the pulses.



Demo: Plotting data with the CosmicWatch GUI



General information

Want to build one? All information is available in the GitHub repository:

<https://github.com/spenceraxani/CosmicWatch-Desktop-Muon-Detector-v3X>

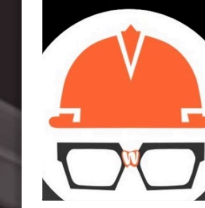
What's there?

- InstructionManual.pdf : All material for constructing a detector.
- PhysicsPaper.pdf : Describes the physics.
- ExampleMeasurements.pdf : explore dozens of potential experiments.
- Gerber files for manufacturing PCBs, CAD drawings and 3D renderings.
- CosmicWatch GUI for plotting data
- The most up-to-date firmware

Have a question/suggestion?

- Feel free to email me: saxani@udel.edu

THANKS FOR YOUR TIME!

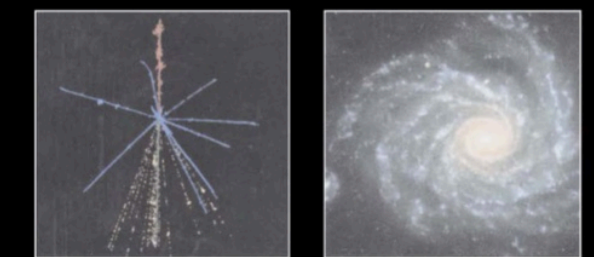


MUON DETECTOR



COSMIC RAYS AT EARTH

Researcher's Reference Manual
and Data Book



Peter K.F. Grieder

2001 -- Peter Grieder

CORSIKA
ELSEVIER

COSMIC RAYS

COSMIC RAYS
BRUNO ROSSI

Professor of Physics
Massachusetts Institute of Technology

ROSSI

1964 -- Bruno Rossi

"Understandable to any
educated layman"

539.7
RD

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