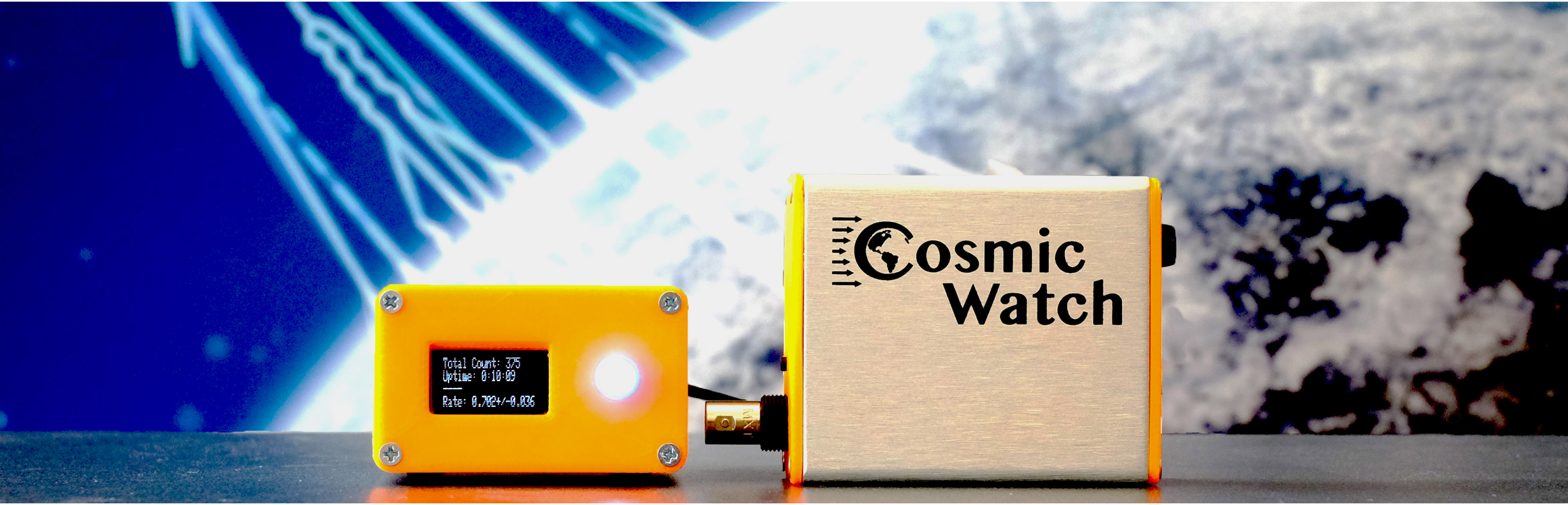
CosmicWatch

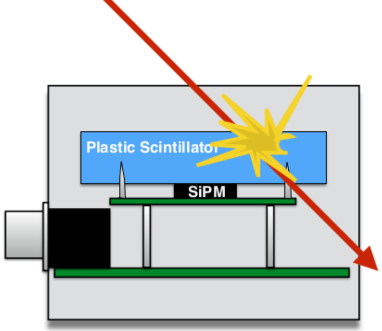
- a particle detector you can build yourself



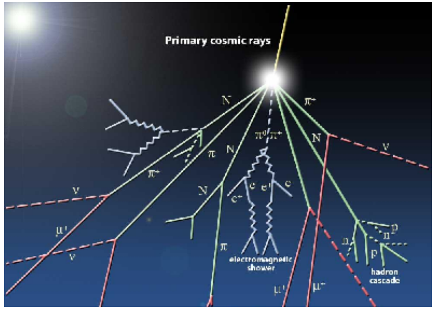
Katarzyna Frankiewicz, Spencer N. Axani

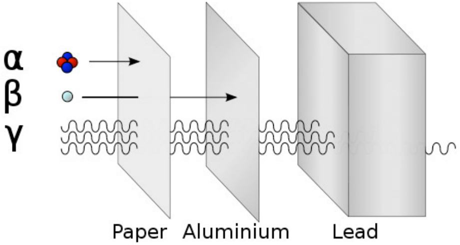
NCBJ | MIT | WIPAC Wisconsin IceCube Particle Astrophysics Center | NSF | sensL sense light

Detector – how it works?

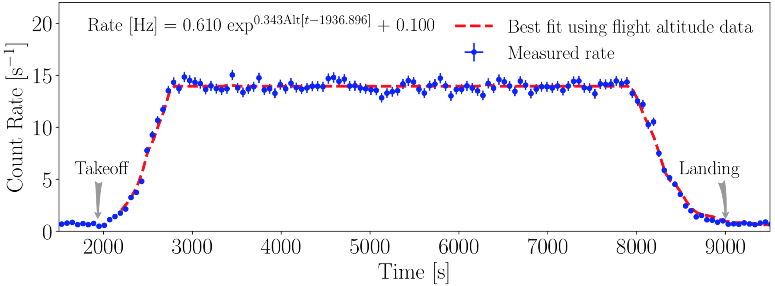


What we can measure?



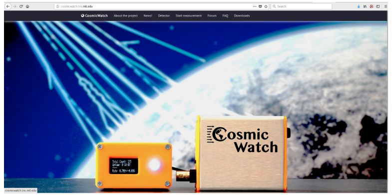


Examples and ideas



Outreach program

Where to find more information?



About the project

Massachusetts Institute of Technology:

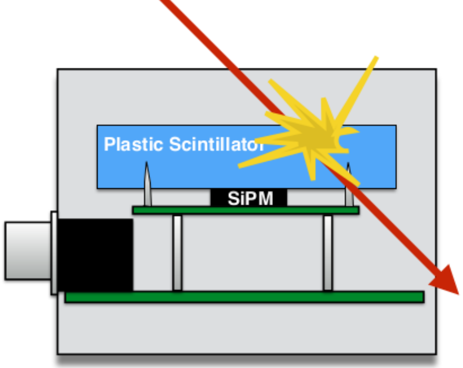
Spencer Axani
– PhD student

Prof. Janet Conrad
– project supervisor

National Centre for Nuclear Research:

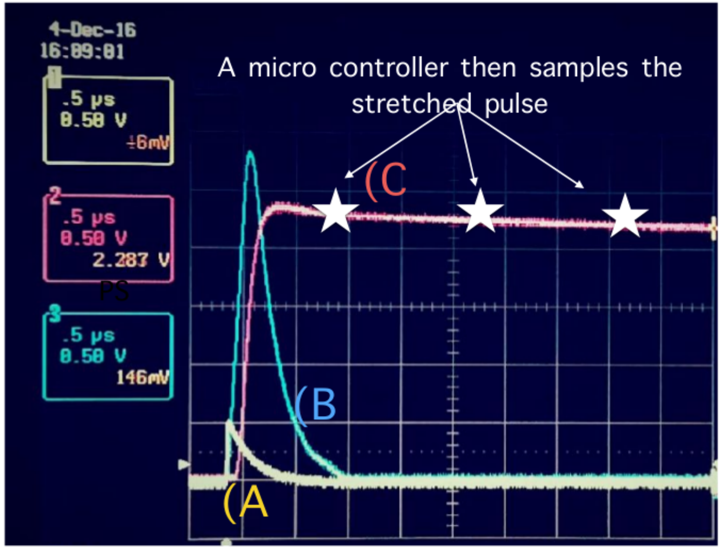
Katarzyna Frankiewicz
– PhD student

How the detector works?

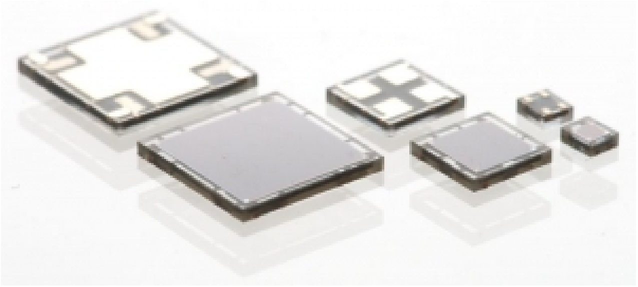


1. Charged particles emit light when they pass through the scintillator.

3. Signal (A) is amplified (B) and shaped (C), and measured by a micro-controller: Arduino Nano.



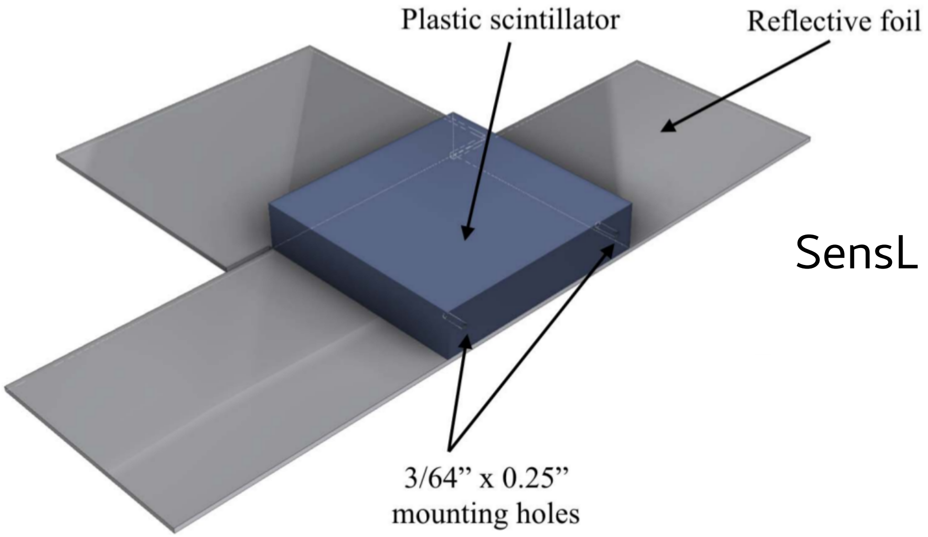
2. Light is collected by a silicon photomultiplier (SiPM) and creates a measurable current.

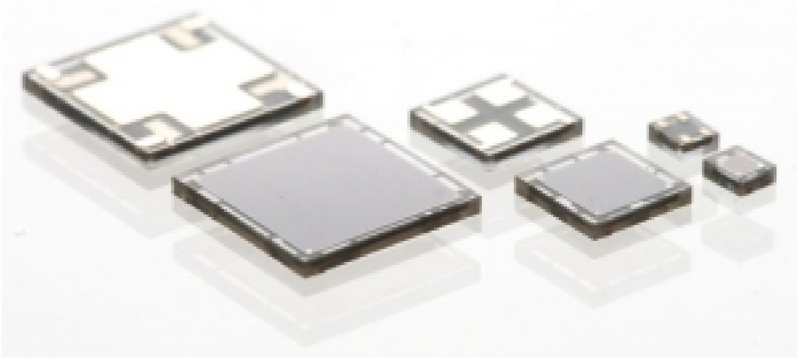


4. Measurements are displayed on the OLED screen or read-out to a microSD card.

A bit more details...

5 cm × 5 cm × 1 cm slab of plastic scintillator
as a detection medium





SensL C-series 6 mm × 6 mm Micro-FC 60035 SiPM
for light collection

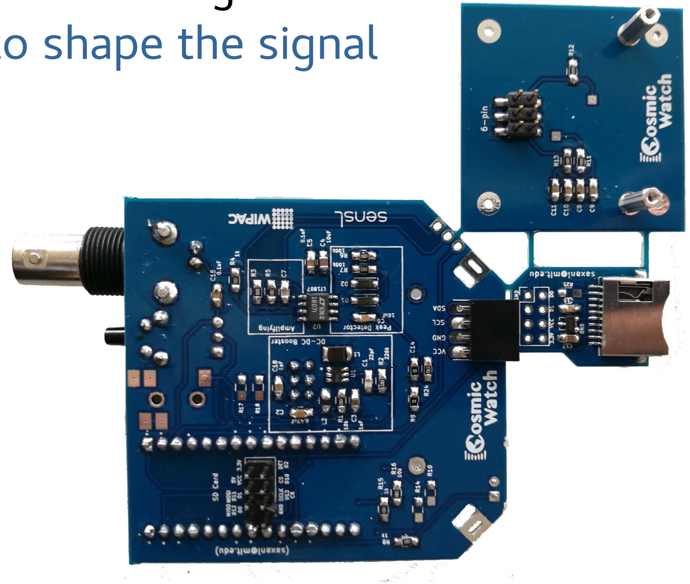
- high gain (~10^6) → single photon capabilities
- high quantum efficiency (30% at 400 nm)
- fast response time (ns)
- not affected by magnetic fields

More details about the scintillator:
ieeexplore.ieee.org/abstract/document/1596558/

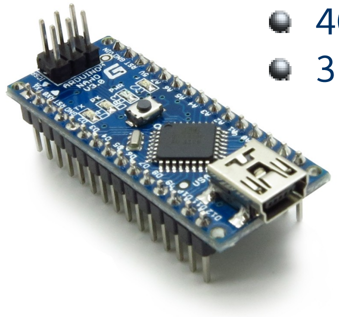
Introduction to SiPMs (by SensL):
www.sensl.com/downloads/ds/TN%20-%20Intro%20to%20SPM%20Tech.pdf

A bit more details…

Custom designed PCB
to shape the signal



16 MHz Arduino Nano ATmega328
to perform the measurement

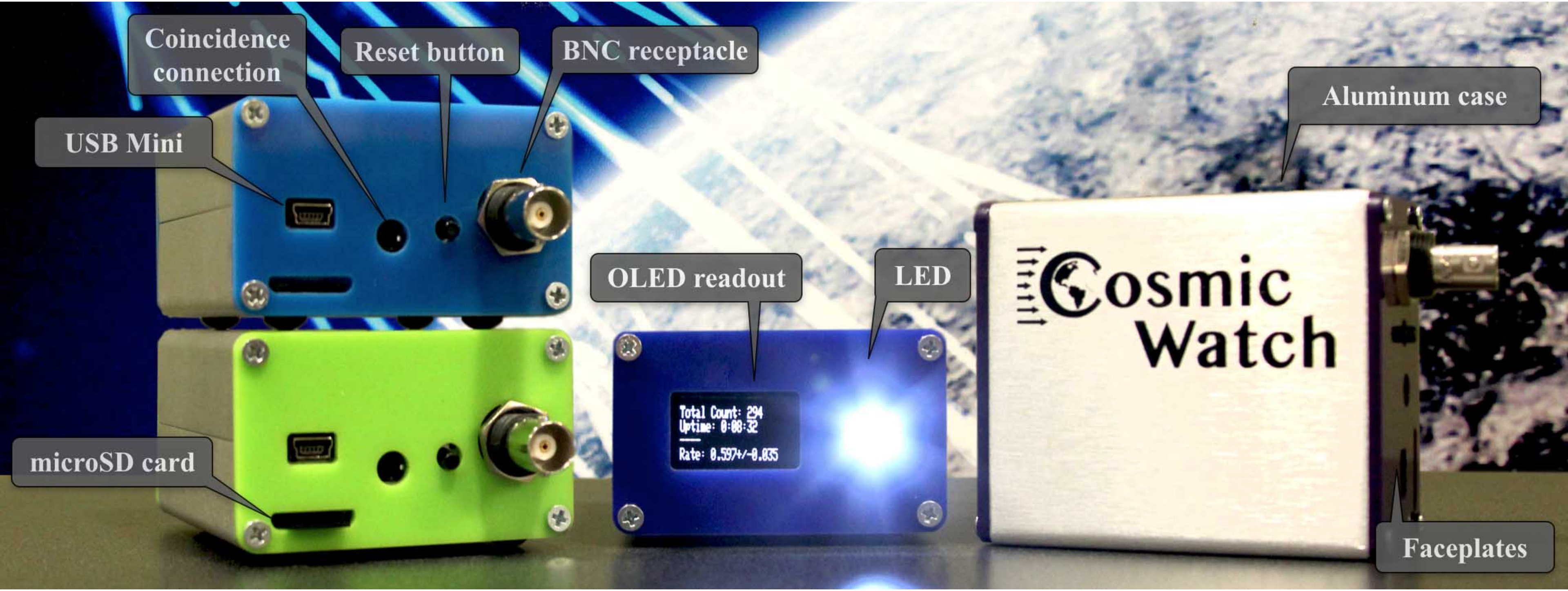


- simple open-source micro-controller
- 16 MHz crystal oscillator
- 14 digital I/O
- 8 analog inputs
- 40 mA current output per pin
- 32 kb flash memory

We record the count number, time of the event, pulse ADC amplitude, temperature, and the detector deadtime.

The threshold for a signal from the SiPM to trigger the data acquisition can be tuned in the provided Arduino software.

Detector design

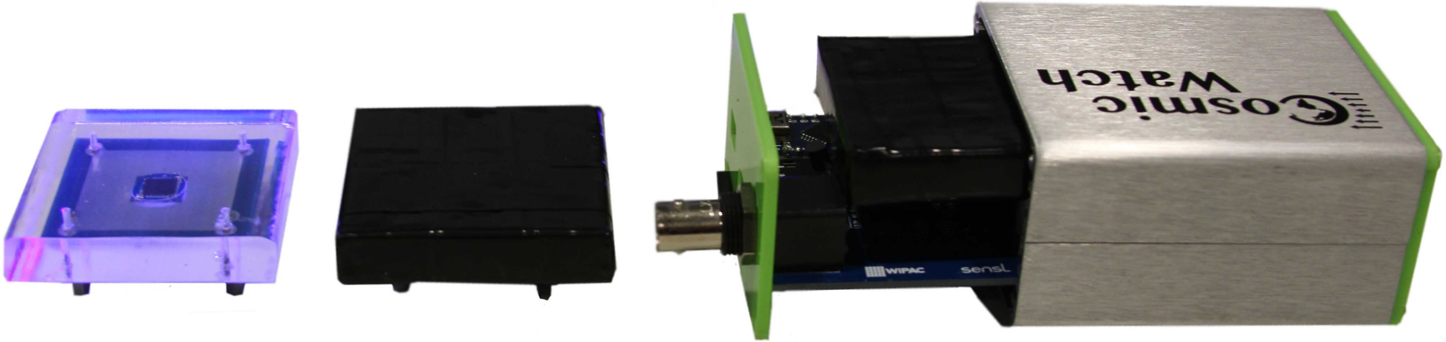


CosmicWatch is a simple, physics-motivated electronics project for everyone!

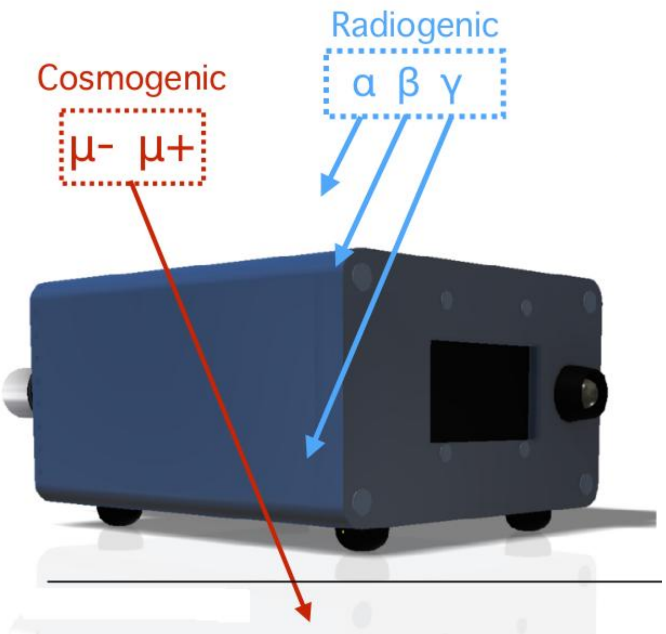
It’s easy to build and inexpensive: total cost ~100 USD.

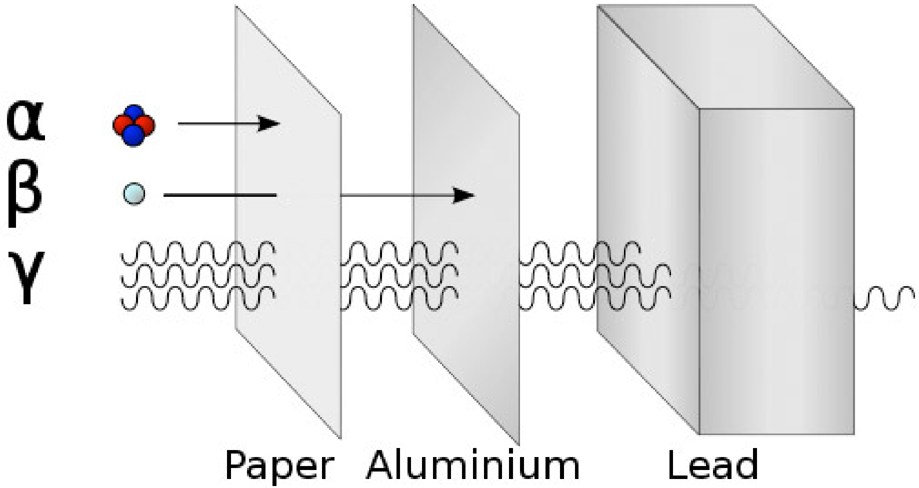
Detector design

- The detector can be powered either by a mini-USB, or by the coincidence connection (3.5mm audio jack). It can also be battery powered.
- The detector can also be connected to an oscilloscope through the BNC header on the back of the detector to view the raw SiPM pulse.
- Two detectors can be connected together to work in coincidence.
- Data from the detector can be recorded to a microSD card or directly to a computer.
- OLED screen displays the information in real-time (updated every second).
- LED light flashes every time the detector measures an event.
- Actual detector weights only 68g with an active area of ~50 cm^2.



What we can measure?





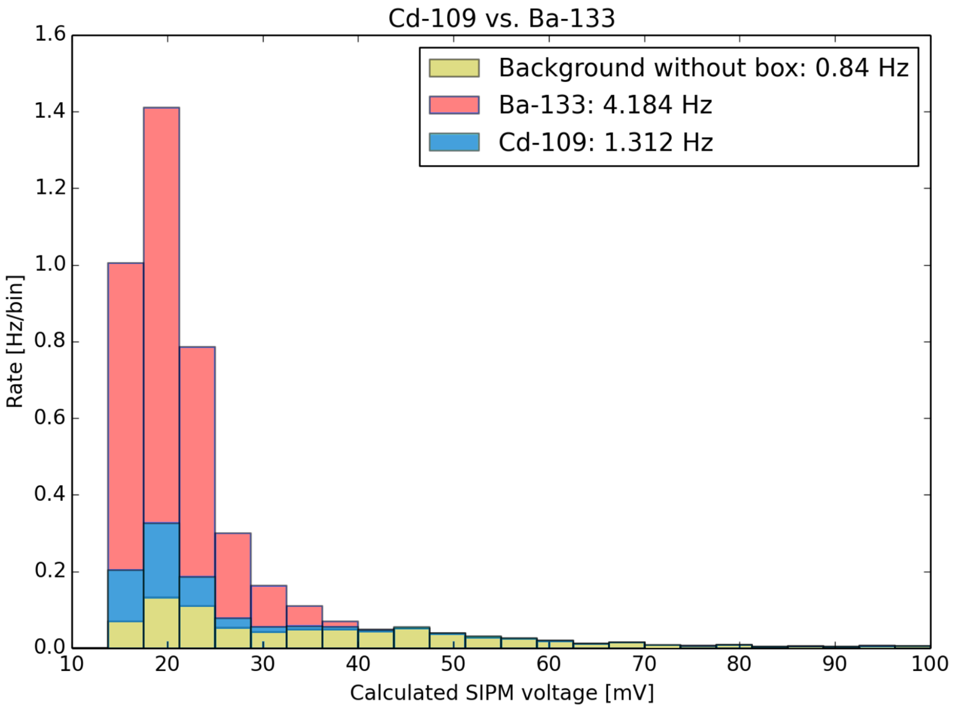
α, β and γ radiation is caused by unstable atoms, which have either an excess of energy or mass (or both).

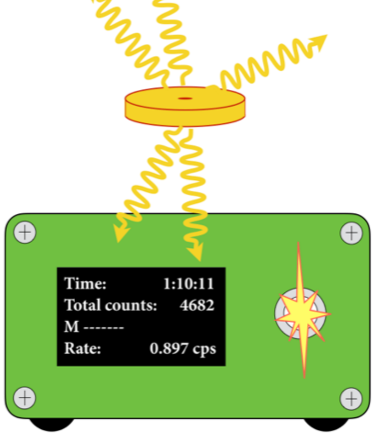
Muons μ are coming from the sky.

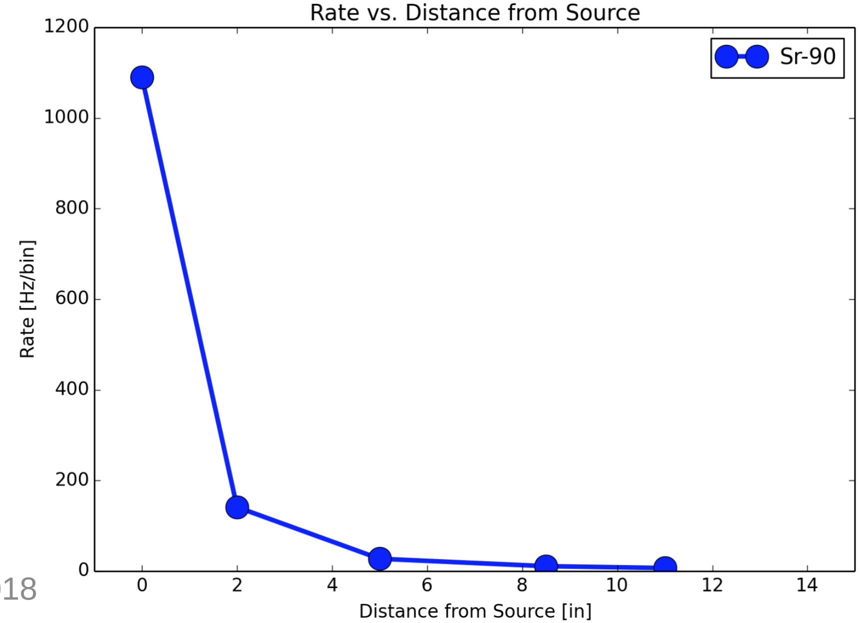
α radiation is very easy to stop, it can't reach the detector. Most of the **β radiation** is stopped by aluminium case, but without the case, it can be measured. **γ radiation** will easily penetrate through detector, it is very hard to stop.

Radioactive sources

Detector is sensitive to **β** and **γ radiation**
→ many interesting measurements are possible

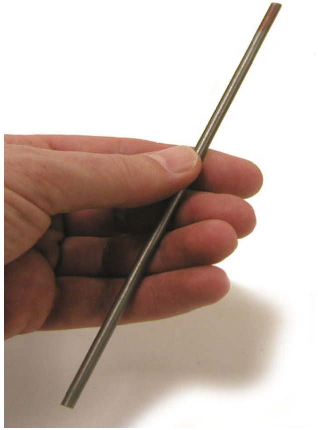






Radioactive substances around us

Thorium welding rod



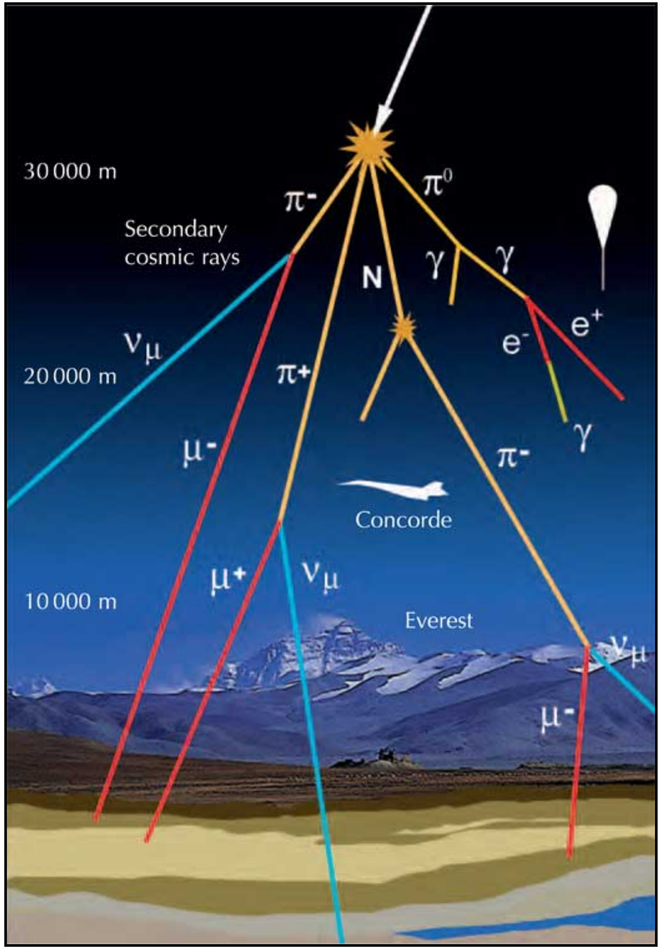
Uranium glass

Building materials

Old wrist watch

Potassium salts

Granite



Cosmic rays

There is a constant shower of charged particles raining down on Earth.

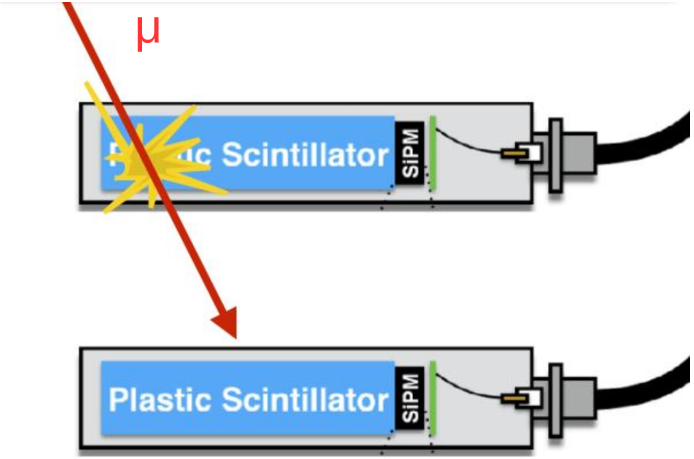
- **Discovery:** in 1912 by Victor Hess during a balloon flight.
- **Origin:** High-energy particles (mainly protons) arriving from outer space, collide with the nuclei of atoms in the Earth's atmosphere and create mesons, mainly pions (π) and kaons (K). These charged mesons can swiftly decay, emitting particles called muons (μ) which can reach the ground.
- **Muons:** are very similar to electrons, but 200x heavier. They live only 10^{-6} seconds. Muons are very hard to stop, they can easily penetrate through a matter.
- Due to **relativistic effects** muons can reach the Earth's surface.

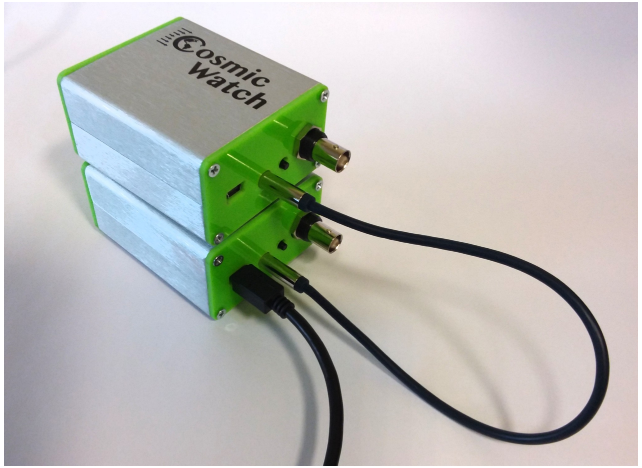
If we want to focus on the cosmic ray muons

Possible ways to reduce the radiogenic background:

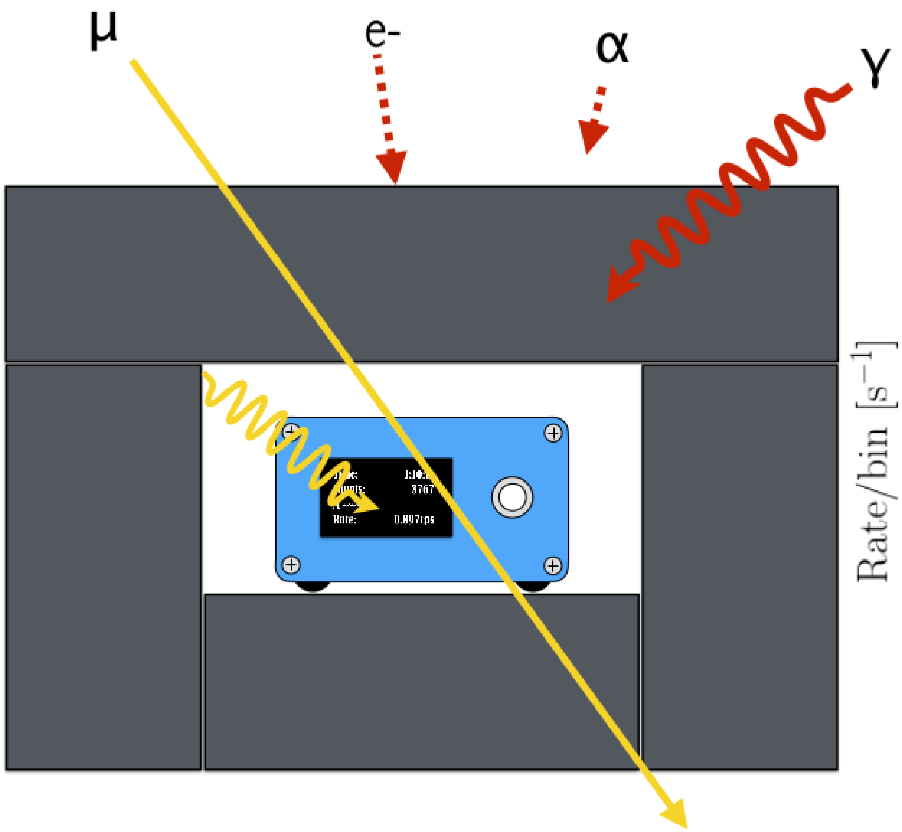
- Shielding the detector
  → lead bricks

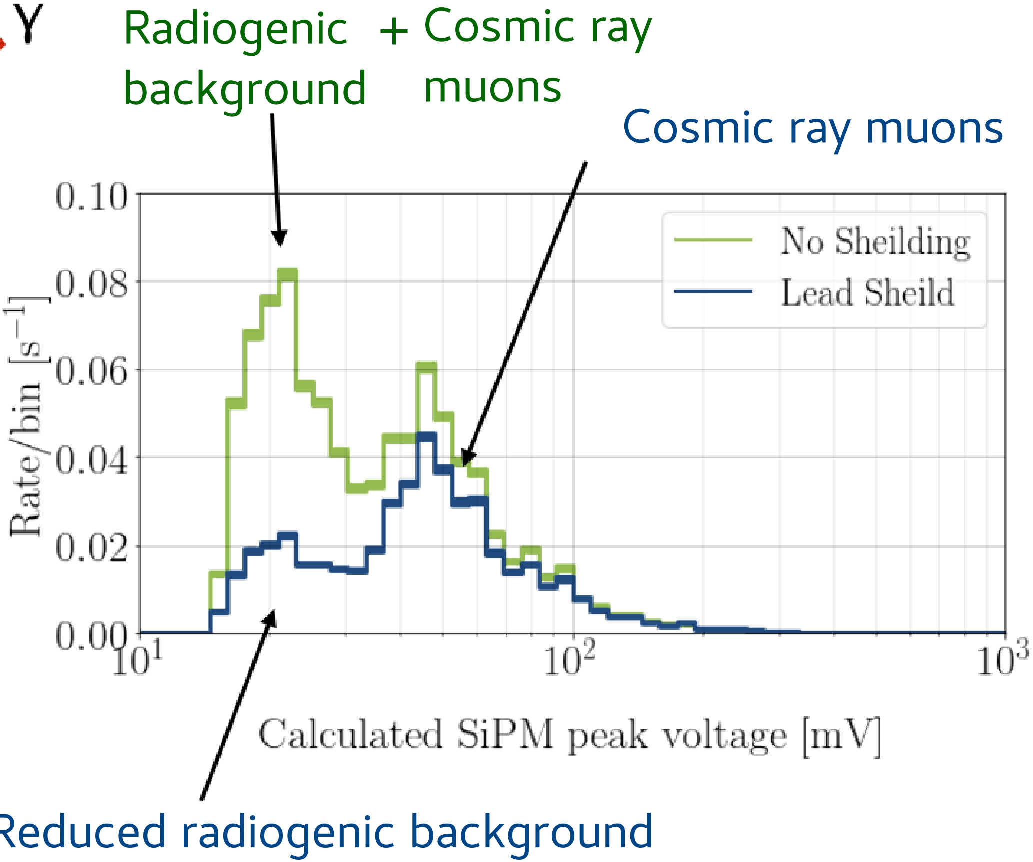
- Making a coincidence measurement
  → signal present in two or more detectors
  + we can also get directional information this way.





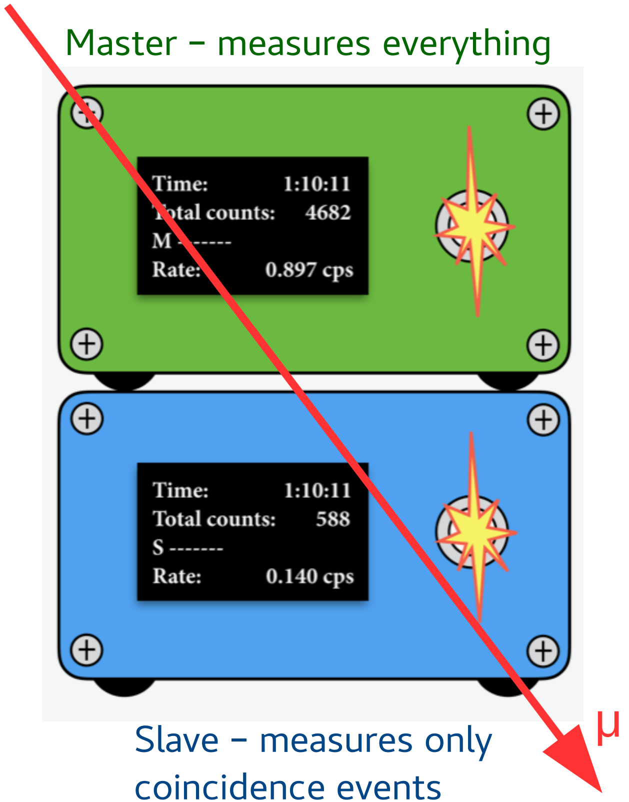
Shielding against radiogenic background





Coincidence measurement
Master vs Slave

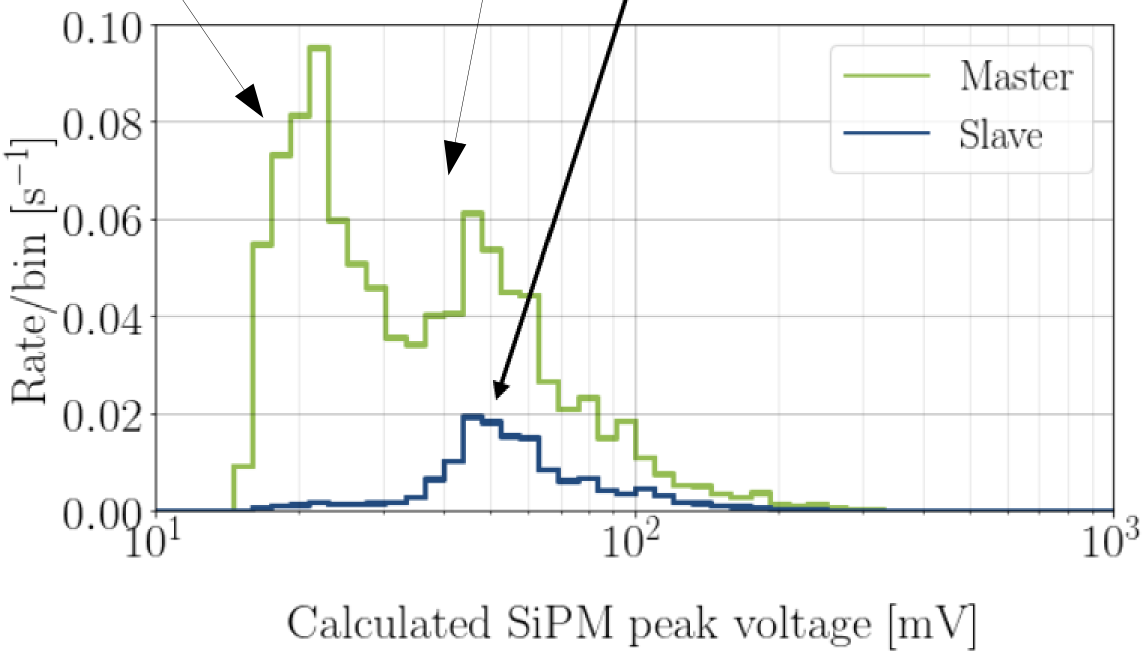
Master – measures everything



Slave – measures only coincidence events

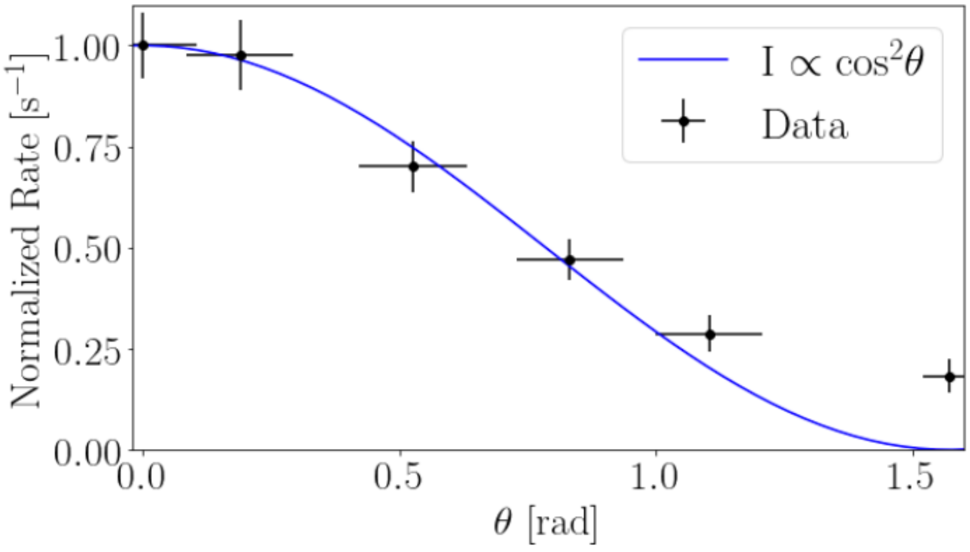
Radiogenic background + Cosmic ray muons

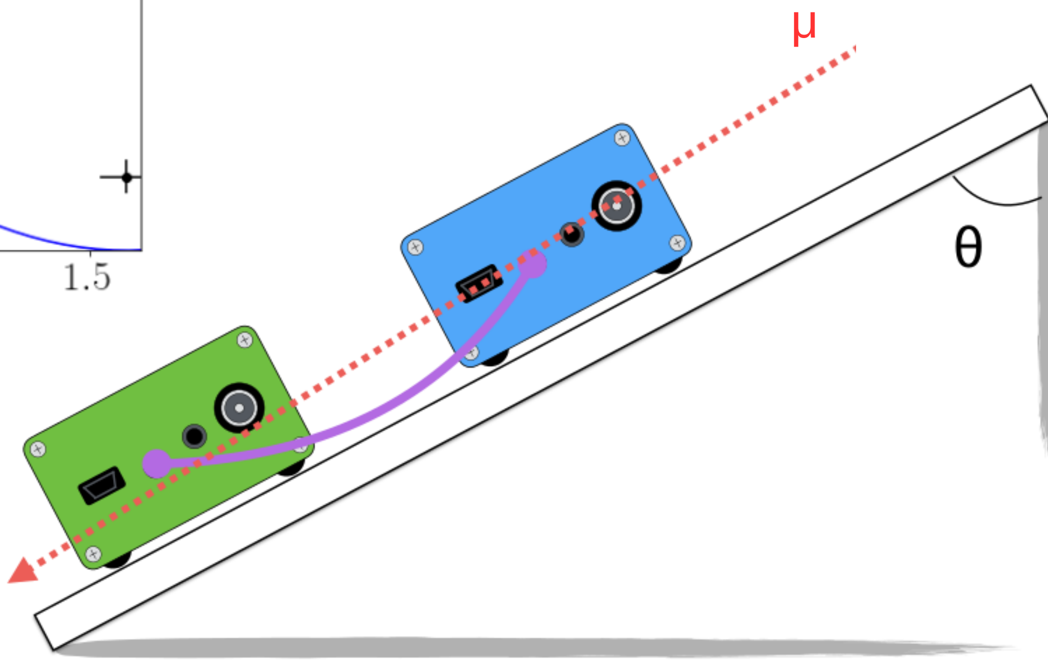
Cosmic ray muons



→ high purity sample of cosmic ray muons

Muon rate as a function of the zenith angle

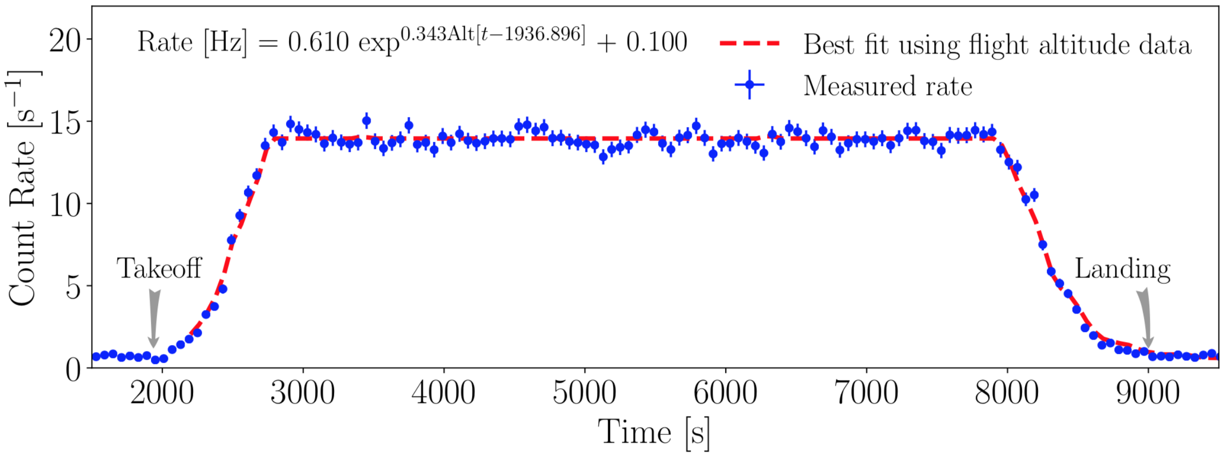


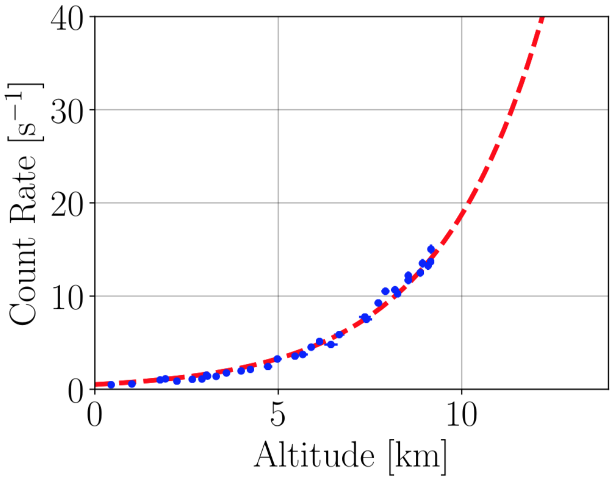


→ Two connected CosmicWatch detectors can work as muon telescope and be sensitive to the direction of the cosmic ray muons.

Airplane measurement

Does the flux of cosmic ray muons change at different altitudes?



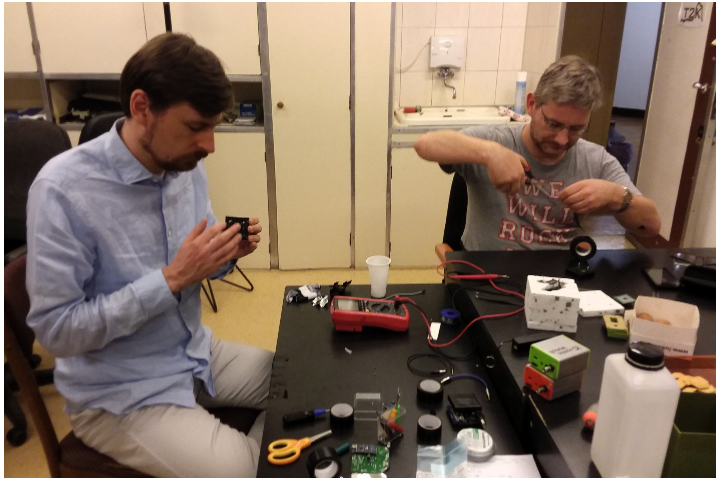


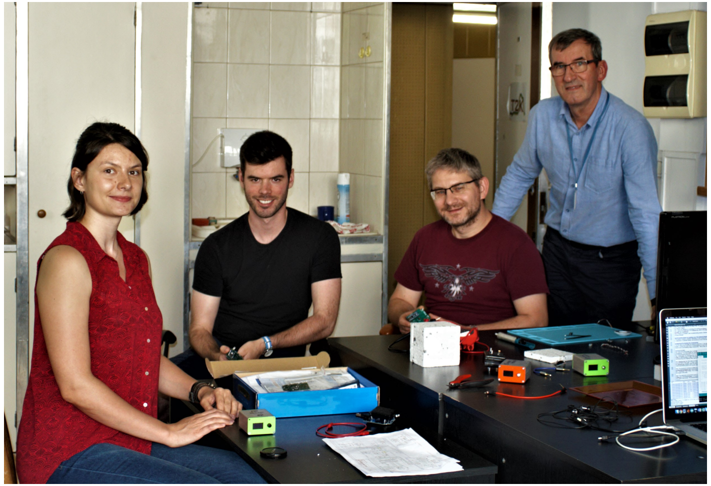
→ Yes! Muon flux is increasing very fast with altitude.

What if we will get even higher? High altitude balloons can take us up to ~30 km!

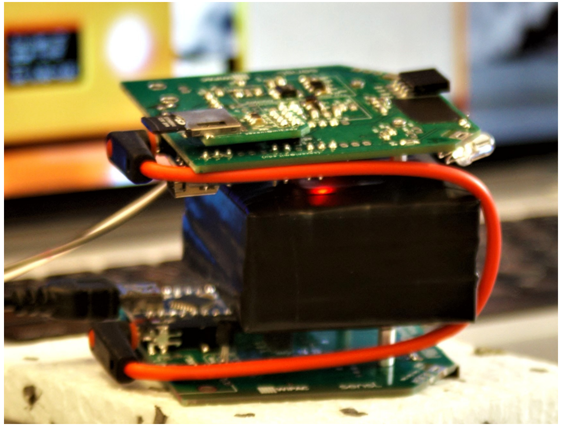
Preparations to reach near space...

Our team:
Armand Budzianowski
Kasia Frankiewicz
Andrzej Bigos
Bartek Maksiak
and
Spencer Axani (MIT)





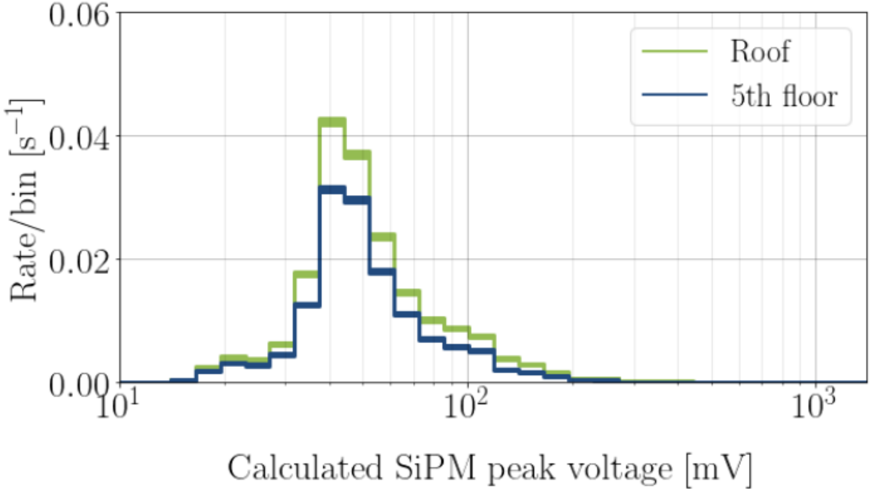
During **Near Space Conference 2018** (September 22), two CosmicWatch detectors will be sent for high altitude balloon flight → **Stay tuned!**



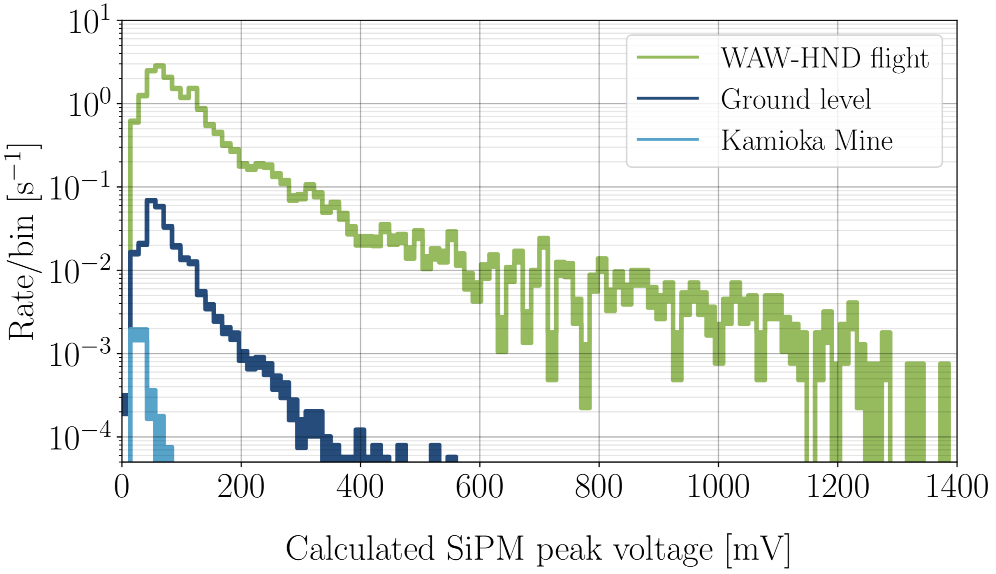
More measurements

Different floors of the building

Roof	**0.1886**	**+/-**	**0.0011**
5th floor	**0.1389**	**+/-**	**0.0009**



Airplane flight, ground level, and mine



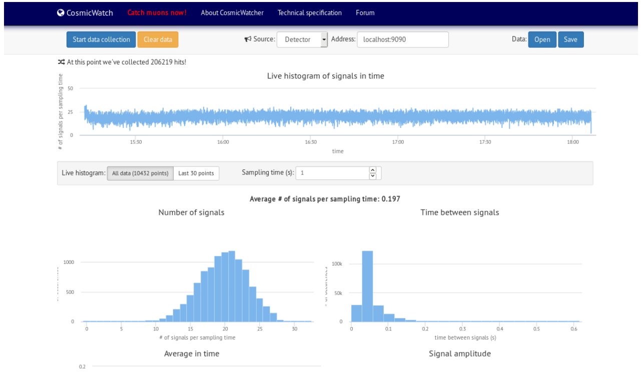
→ we can observe a small difference in muon rate between the **roof** and **5th** floor of the building.

→ the difference in measured muon rate between **ground level**, **plane (9 km),** and the **mine (1 km underground)** is very significant.

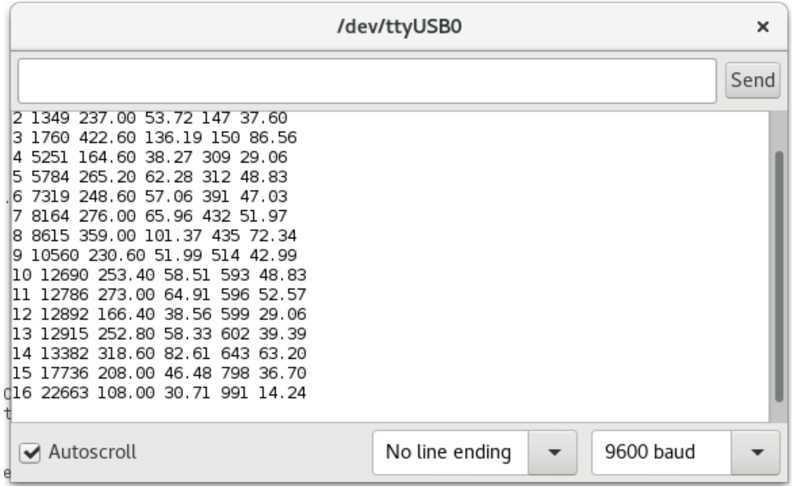
Data taking methods

a) Application on our website:

www.cosmicwatch.lns.mit.edu



b) Serial port monitor from **Arduino IDE**



c) Save data to your computer:

import_data.py

```
########################################################################
### Desktop Muon Detector
### Questions? saxani@mit.edu
### Comp_time Counts Ardn_time[ms] Amplitude[mV] SiPM[mV] Deadtime[ms]
### Device ID: 1
########################################################################
2017-07-14 14:01:16.657004 1 112 35.00 31.25 19
2017-07-14 14:01:23.202956 2 6653 96.67 47.14 45
2017-07-14 14:01:31.789663 3 15233 79.00 44.28 145
2017-07-14 14:01:32.171374 4 15613 103.00 48.06 90
2017-07-14 14:01:46.866385 5 30300 353.33 153.88 81
2017-07-14 14:01:56.141732 6 39572 167.00 59.77 11
2017-07-14 14:01:57.930102 7 41358 137.33 53.38 248
2017-07-14 14:02:17.210412 8 60630 255.00 94.21 10
2017-07-14 14:02:27.674790 9 71089 56.00 39.03 216
2017-07-14 14:02:29.776414 10 73188 159.00 57.82 10
```

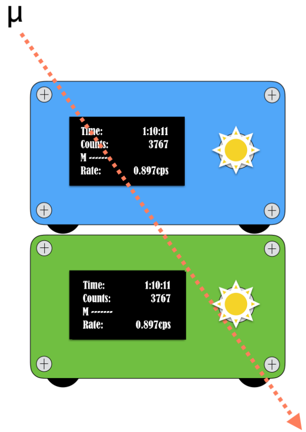
d) Write data to a **microSD card**

e) Read data directly from **OELD screen**

Education and outreach

National Centre for Nuclear Research
Education and Training Division
Poland

Workshops for teachers



30 Detectors

Program: **"Detectors for schools"**

→ Schools can borrow particle detectors for one month to perform various measurements and discuss the results. We provide some ideas, instructions and software.

Education and outreach

Wisconsin IceCube Particle Astrophysics Center

Madison, USA

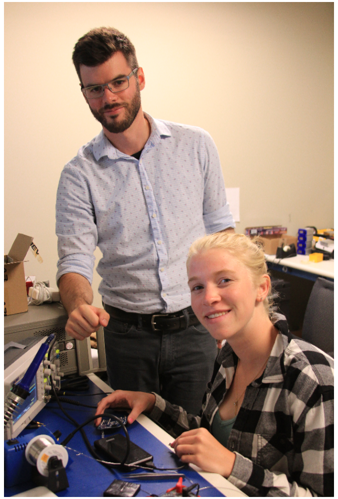
Learn a new advanced laboratory experiment well enough to teach it - with confidence!

3 day intensive program

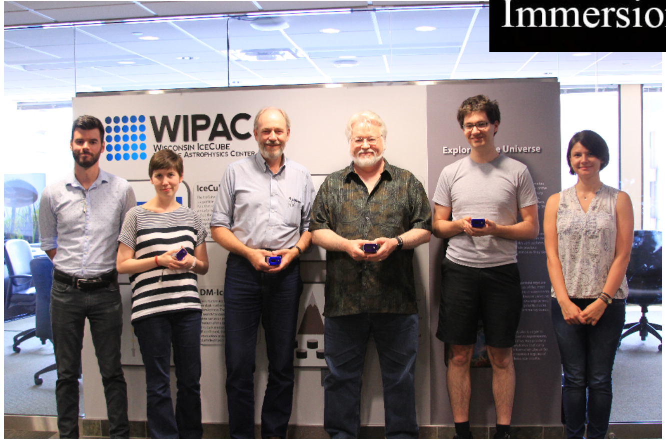
ALPhA's Laboratory Immersions

Program for high school and undergraduate students

WIPAC
WISCONSIN ICECUBE PARTICLE ASTROPHYSICS CENTER



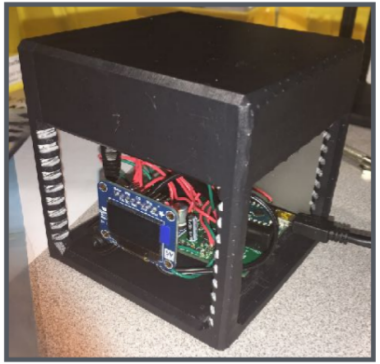
50 Detectors



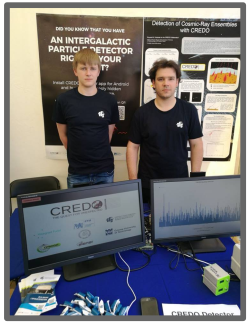
GEANT4 simulation and Calibration measurements

F. Delgado, D. Hernandez, J. Masias, B. Rodríguez, D. Sánchez, M. Yui, J. Bazo, A.Gago

Dr. Alberto Gago
Pontificia Universidad Catolica del Peru
Peru



Barry Holland et al
Missouri University of Science and Technology
Aerospace Engineering | Physics Minor
2019



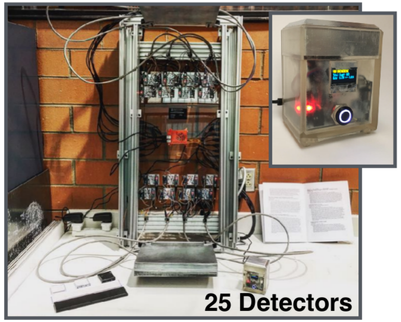
13 Detectors

Dr. S.Stephen Rajkumar Inbanathan
Head, Department of Applied Science
Department of Physics
The American College
Madurai - 625002
India

Konrad Kopański, Wojciech Noga
CREDO project https://credo.science/

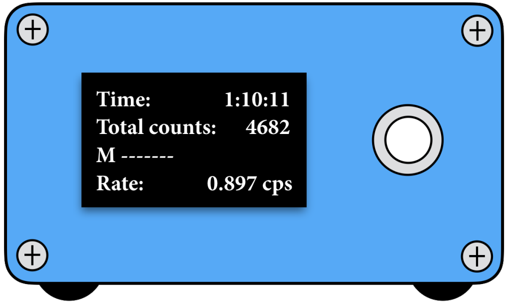
BURPG
Boston University
Sub-orbital rocket

MWSU Muon Group
20 SiPM coincidence detector
High-altitude balloon measurement



Dr. Paul Verge
Air force officer
High Altitude Balloons.
NearSys.com
near space exploration,
microcontrollers,
robotics,
space, and astronomy.

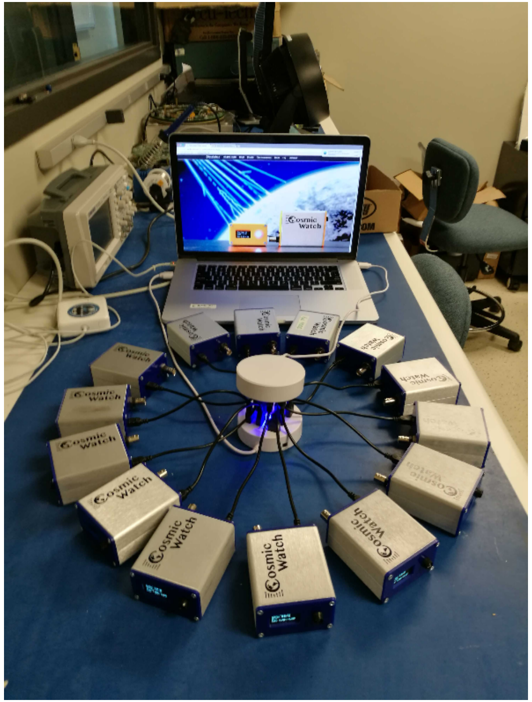
CosmicWatch - a particle detector you can build yourself



- You don't need a high-voltage power supply.
- It is efficient, less than 1 watt per detector, USB powered.
- It is light-weight. The current detector weighs 68 grams.
- It is inexpensive. Our students build the detectors for ~100$/unit.
- Simple open-source software is available.
- It is expandable. The Arduino allows students to implement their own hardware. We've had students add on bluetooth connectivity, SDcard readers, and temperature sensors.
- It is an attractive alternative to the current cosmic ray programs.
- **It's a lot of fun!**

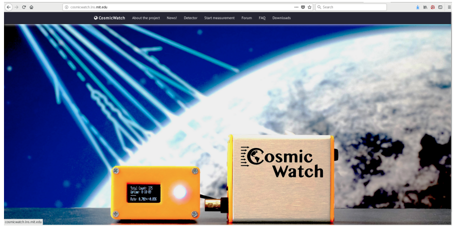
CosmicWatch – teaching ideas

- Introduction to cosmic rays, measuring properties associated with cosmic muons
- Introduction to radioactivity, measuring beta/gamma radiation
- Introduction to building/designing the detectors (plastic scintillator, silicon photomultipliers, simulations in Geant4)
- Experience in the electronics and machine shop
  - → using oscilloscope, multimeters, waveform generators
  - → soldering surface mount components (SMT)
  - → designing PCBs
  - → introduction to basic electronics
- Introduction to data analysis techniques, statistics
- Introduction to programming, data visualization
  - → Python, matplotlib
  - → ROOT
  - → Arduino, programming micro-controllers
  - → Web/mobile applications



More about the project:

Web page:



cosmicwatch.lns.mit.edu

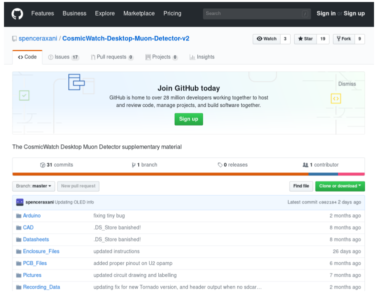
Facebook:

www.facebook.com/cosmicwatch.mit

Want to build your own detector?

GitHub repository:

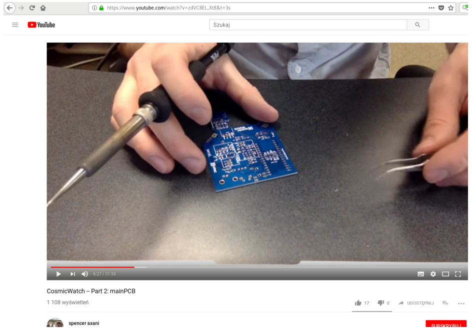
→ all necessary information



github.com/spenceraxani/
CosmicWatch-Desktop-Muon-Detector-v2

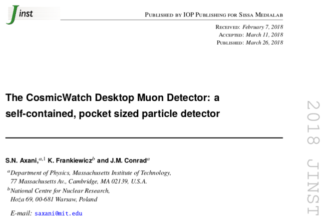
YouTube:

→ step-by-step instructions



www.youtube.com/watch?v=e4IXzNiNxgU&

Recent Paper: S. N. Axani, K. Frankiewicz, J. M. Conrad, "*The CosmicWatch Desktop Muon Detector: a self-contained, pocket sized particle detector*", JINST 13 (2018) no.03, P03019


Jinst

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Published: March 26, 2018

The CosmicWatch Desktop Muon Detector: a self-contained, pocket sized particle detector

S.N. Axani,[a,1] K. Frankiewicz[b] and J.M. Conrad[a]

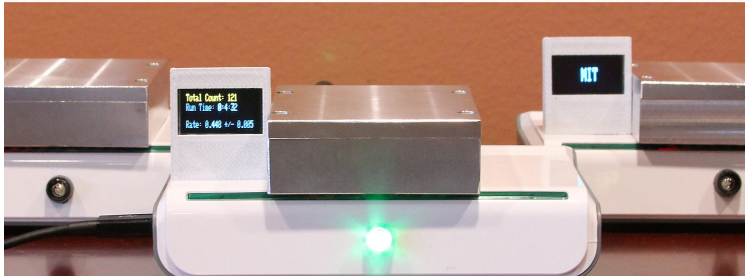
[a] Department of Physics, Massachusetts Institute of Technology, 77 Massachusetts Av., Cambridge, MA 02139, U.S.A.
[b] National Centre for Nuclear Research, Hoża 69, 00-681 Warsaw, Poland

E-mail: saxani@mit.edu

2018 JINST

Symmetry magazine: The $100 muon detector

symmetry topics follow
A joint Fermilab/SLAC publication



https://www.symmetrymagazine.org/article/the-100-muon-detector

HACKADAY: Dirt Cheap Muon Detector Puts Particle Physics Within DIY Reach

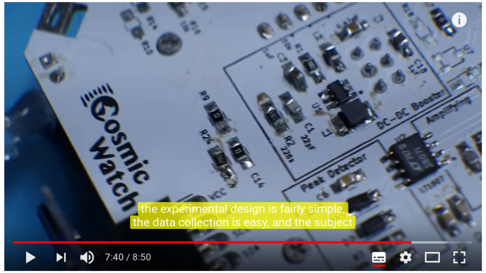
American Journal of Physics: publication

The Desktop Muon Detector: A simple, physics-motivated machine- and electronics-shop project for university students

PRACTICAL ENGINEERING

https://www.youtube.com/watch?v=86zZuqqi5gU

YouTube Szukaj



What are Cosmic Rays?

MIT DEPARTMENT OF PHYSICS

PHYSICS SPOTLIGHT

Photo courtesy of Katarzyna Frankiewicz

An easy-to-build desktop muon detector

MIT News
ON CAMPUS AND AROUND THE WORLD

Sprint LTE 12:08 PM 99%
reddit.com

reddit

r/science • 5h • u/mvea • Physics
Physicists from MIT designed a pocket-sized cosmic ray muon detector that costs just $100 to make using common electrical parts, and when turned on, lights up and counts each time a muon passes through. The design is published in the American Journal of Physics.
news.mit.edu

342 Comments ... 7953

r/AbandonedPorn • c1.staticflickr • 6h • u/ethan
Norway, the country of fairy tales. [OS] [1600×1084].

WIPAC
WISCONSIN ICECUBE PARTICLE ASTROPHYSICS CENTER

NEWS

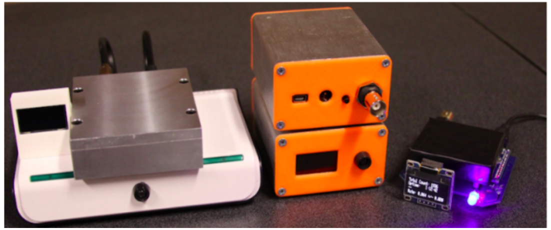
https://wipac.wisc.edu/news/article/2017-wipac-quarknet

PHYSICS TODAY

The design of a simple, inexpensive cosmic-ray-muon detector has led to an international outreach program.

Spencer N. Axani

8 COMMENTS 4.2K SHARES

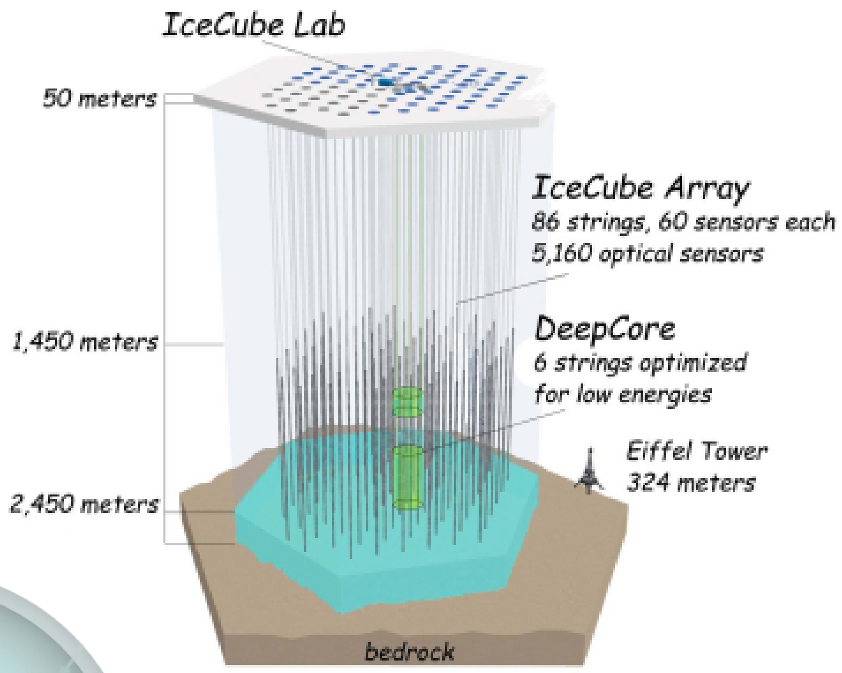


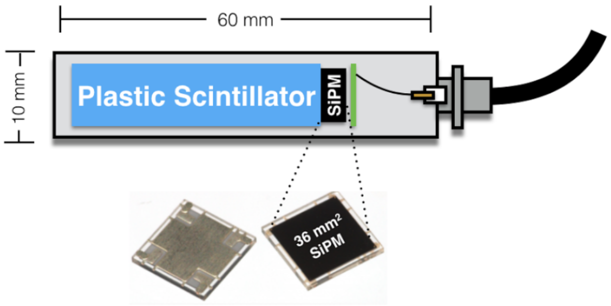
https://physicstoday.scitation.org/do/10.1063/PT.6.1.20170614a/full/

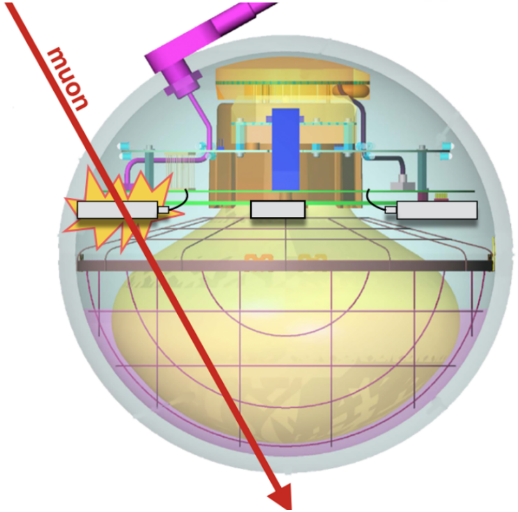
Motivation

Muon Tagging Optical Modules (mTOMs) for PINGU, the proposed low energy upgrade for IceCube experiment

Optically isolated muon detectors designed to be mounted inside the DOMs (IceCube optical modules) in order to tag the position of muons with high precision (within a few cm).

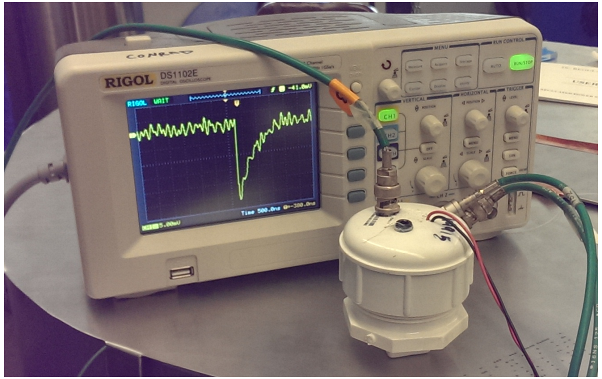






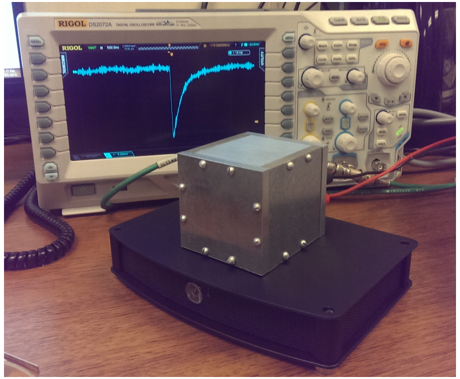
→ This can help us understand the angular reconstruction of IceCube detector.

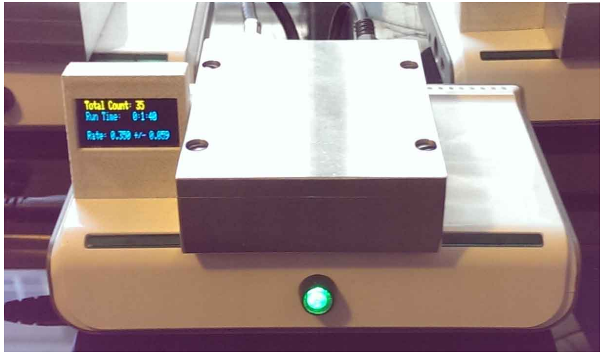
Project evolution



Version 1
- cheap
- leaked
- looked like a bomb..

Version 2
- too slow
- too large
- too expensive
- still looked too much like a bomb..



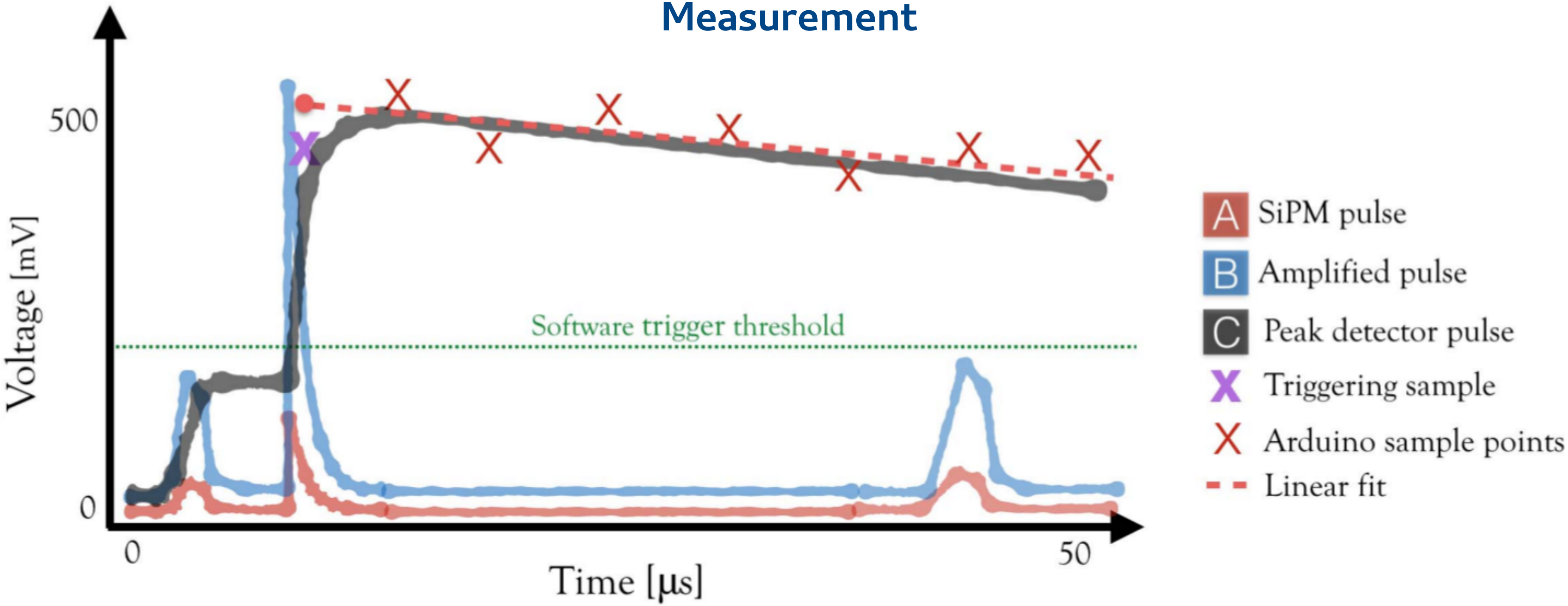


Version 3
- cheap
- fast electronics
- much smaller

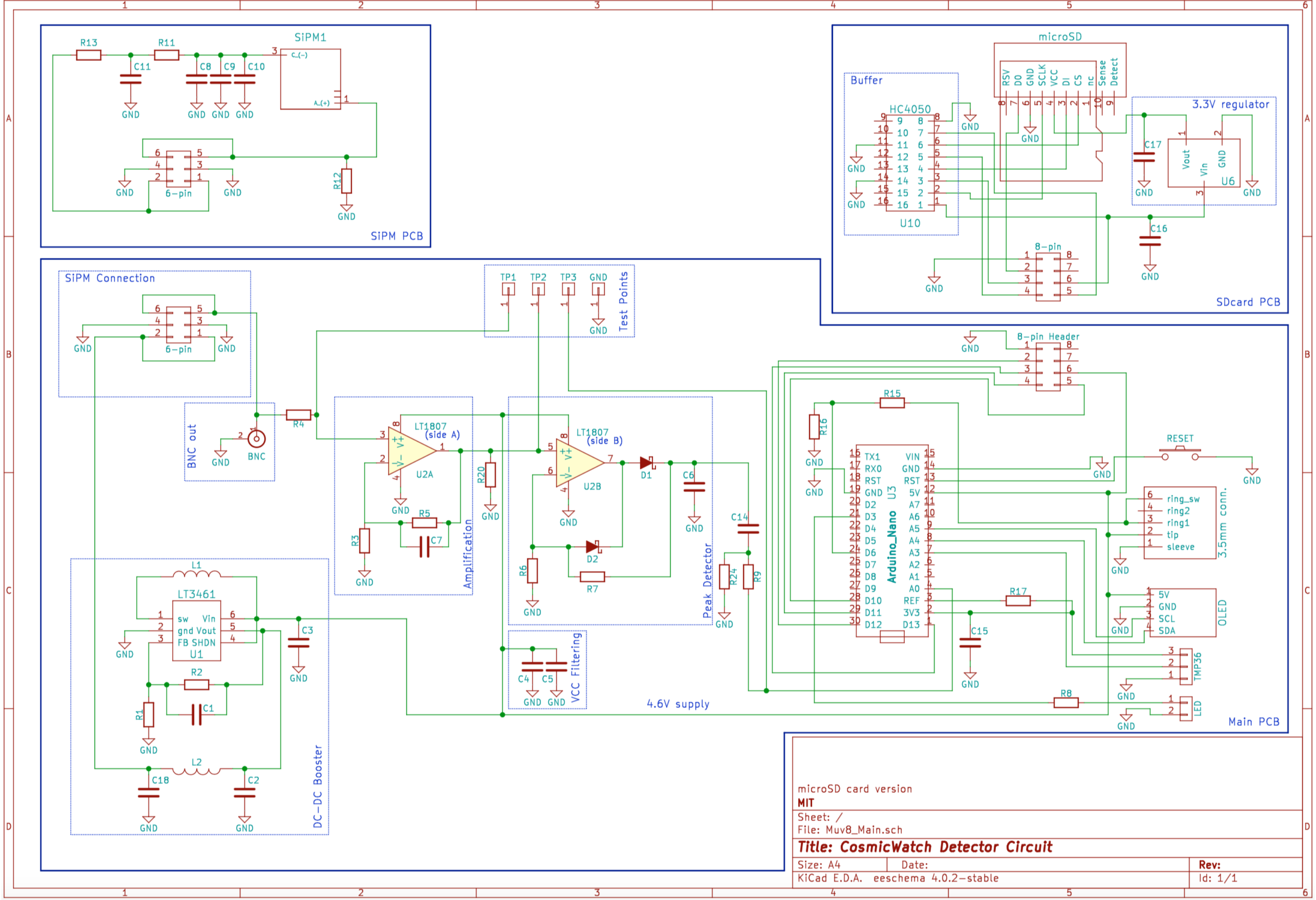
Current version
- software threshold trigger
- less than 100$ total cost
- sub 1W power consumption
- battery or USB powered,
- expandable hardware (SDcard, bluetooth...)
- build time for new student ~4 hours

In progress: GPS timing, single piece of code. Faster processing, better ADC. CosmicWatch mobile app.

Measurement



- A muon induced photo-avalanche in the SiPM will create a positive pulse, width ~0.5 µs, height ~10-100 mV → A
- SiPM pulse is amplified by a factor ~20 → B
- Peak-detector stretch the pulse over a period of roughly 200-500 µs → C
- Arduino samples the decaying pulse and uses this information to calculate the initial pulse amplitude → X



SiPM1
R13
R11
C11
C8
C9
C10
R12
6-pin
SiPM PCB
microSD
RSV
DO
GND
SCLK
VCC
DI
CS
nc
Sense
Detect
Buffer
HC4050
U10
3.3V regulator
C17
Vout
Vin
GND
U6
C16
8-pin
SDcard PCB
SiPM Connection
Test Points
TP1
TP2
TP3
BNC out
BNC
R4
LT1807 (side A)
U2A
R20
R3
R5
C7
Amplification
LT1807 (side B)
U2B
D1
D2
R6
R7
C6
C14
R24
R9
Peak Detector
8-pin Header
R15
R16
U3
Arduino_Nano
TX1
RX0
RST
GND
D2
D3
D4
D5
D6
D7
D8
D9
D10
D11
D12
VIN
5V
A7
A6
A5
A4
A3
A2
A1
A0
REF
3V3
D13
RESET
ring_sw
ring2
ring1
tip
sleeve
3.5mm conn.
R17
C15
OLED
5V
GND
SCL
SDA
TMP36
R8
LED
LT3461
sw
Vin
gnd
Vout
FB
SHDN
U1
L1
L2
R1
R2
C1
C2
C3
C18
DC-DC Booster
C4
C5
VCC Filtering
4.6V supply
Main PCB
microSD card version
MIT
Sheet: /
File: Muv8_Main.sch
Title: CosmicWatch Detector Circuit
Size: A4
Date:
Rev:
KiCad E.D.A. eeschema 4.0.2-stable
Id: 1/1