



MUONpi

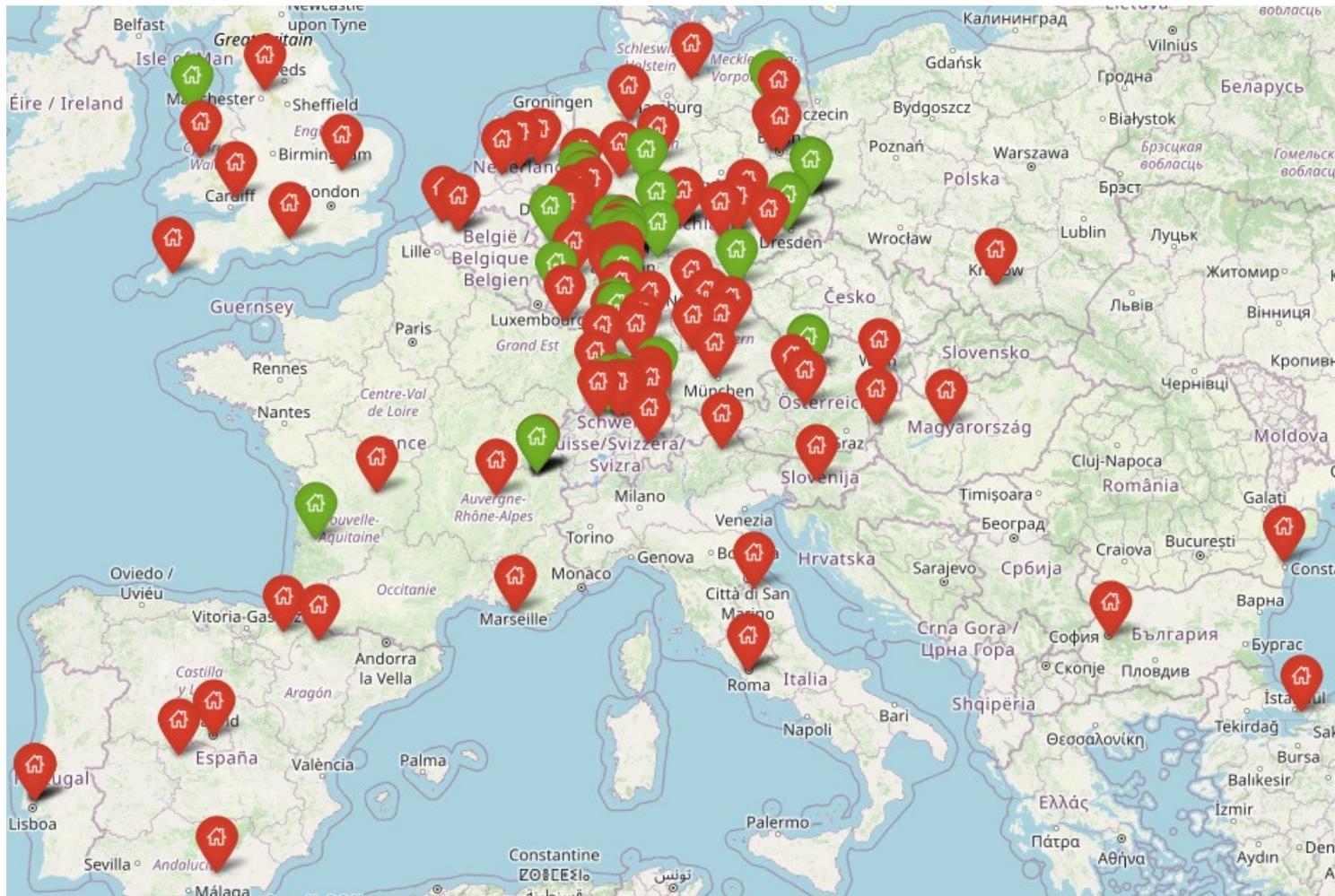
Ein Teilchendetektor Netzwerk

Hans-Georg Zaunick
Für das MuonPi-Projekt

Overview

- Synergy between high-energy physics and hardware/ software hacking
- Group of researchers, university & school students, teachers, hackers, programmers, HAM-amateurs, **interested layman**
- Objective:
 - low-cost, (mostly) DIY, easy to use
 - Build up distributed detector network for cosmic radiation

Overview



The Network (April 2023):

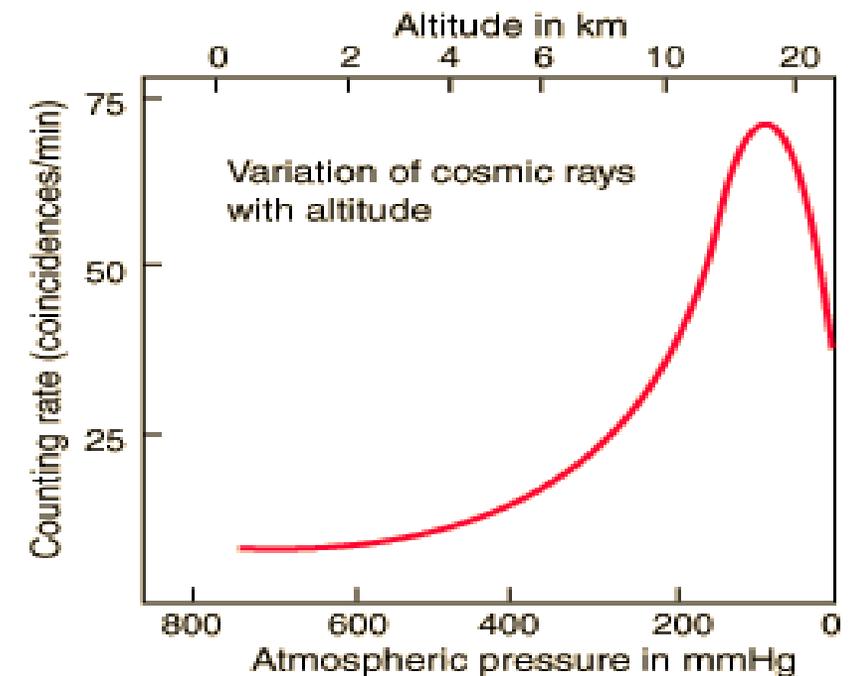
- 28 active users
- 35 live stations
- 151 upcoming stations
- 4 countries
- 26 GB of collected data so far

Cosmic Radiation

Victor Hess before his 1912 balloon flight in Austria, during which he discovered cosmic rays



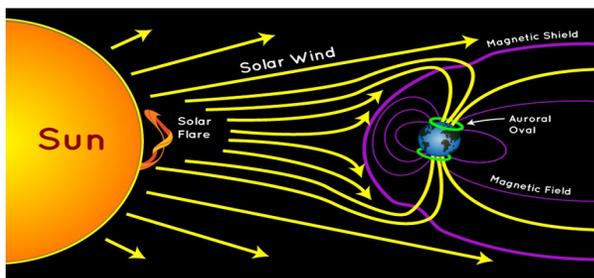
- Victor Hess 1912: Increase of ionizing radiation in balloon-borne experiments up to 5 km
- Contemporary assumption: Radiation originates from Earth
- Strong dependance on height: doubling of radiation level in 5 km altitude
- Hess & Milikan (1925): “Cosmic Radiation”
- Hess & Anderson: Nobel Prize 1936



Cosmic Radiation

“Soft” Component: Sun

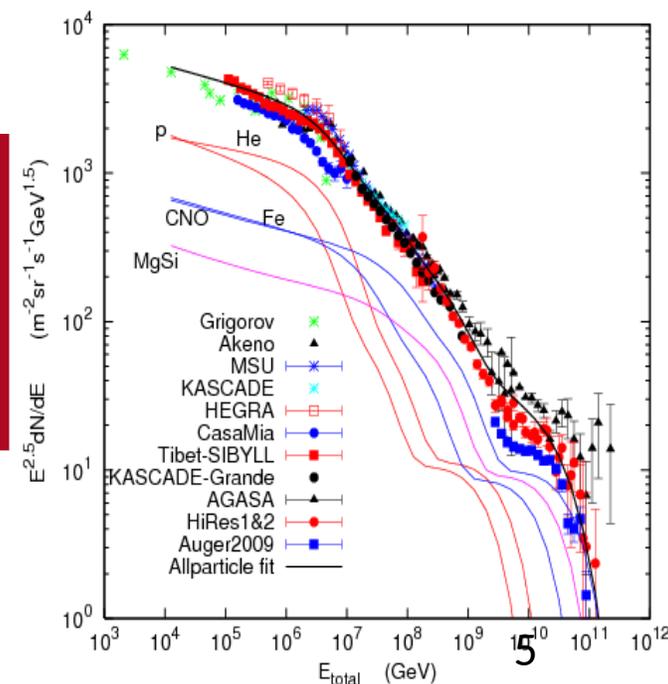
- Protons up to hundreds MeV kinetic energy
- Deflection in Earth’s magnetic field towards the poles
- Ionization of upper atmosphere (Aurorae)



“Hard” Component: (Extra)Galactic Sources

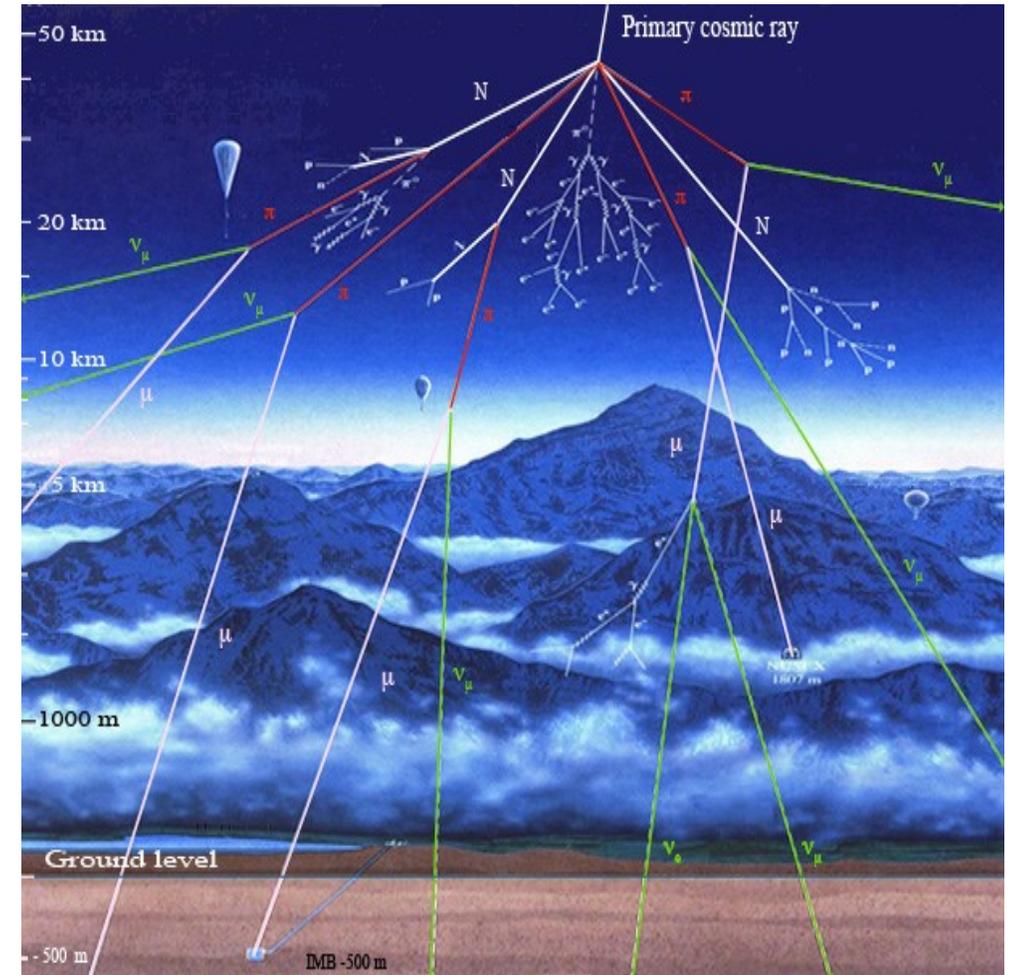
- Protons & Nuclei up to 10^{20} eV
- No deflection by magnetic fields
- Origin: supernovae & yet unknown

Trivia:
 10^{20} eV \approx 50 J
 Kinetic energy of a hard pitched baseball



Cosmic Radiation

- Primary super-high energetic particles collide with the atmosphere (>10 km height)
- High energetic shower cascade emerges
 - **Secondary cosmic radiation**
- Many different particles, many decay into **muons**
- Muons can reach the surface



Cosmic Radiation

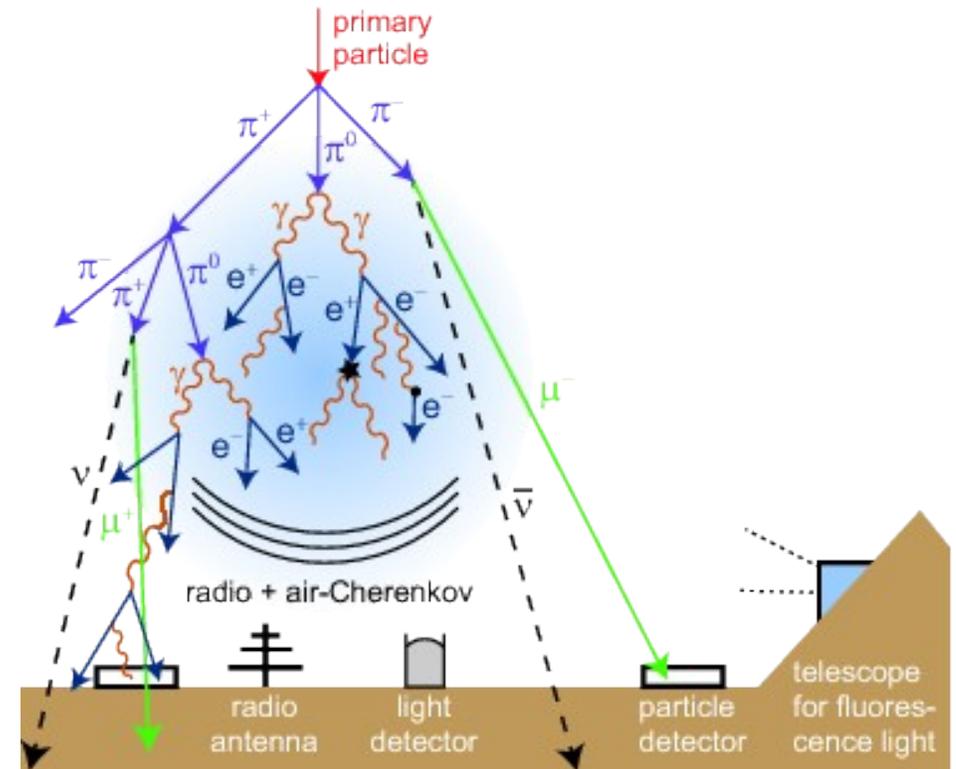
Why is this interesting?

- Origin of the highest energies in the universe?
- Multi-Messenger Astronomy: Build an earth sized particle detector
- Link to lightning discharges?
- Link to climate models?

How to measure?

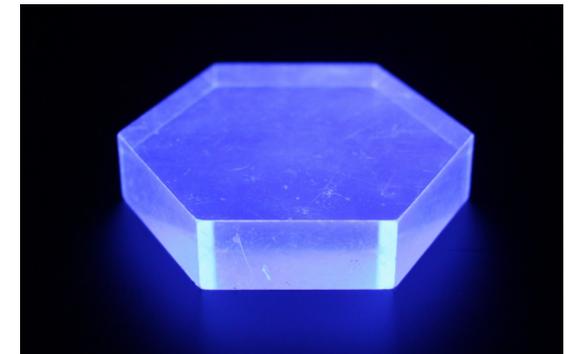
- Detect charged particles
- Detect coincident (=simultaneous) hits
- Measure Time-of-Flight (ToF) differences

Determine **time**, **direction**, maybe **energy** of the primary particle



Low-Cost Detector

- Organic (plastic) scintillator
- Silicon Photo Multiplier (SiPM): Ketek PM3350/3325
- Wrapped in reflective foil (VM2000, also possible: Teflon & alu foil)
- Pond liner & 3M tape for light tightness



Trivia:

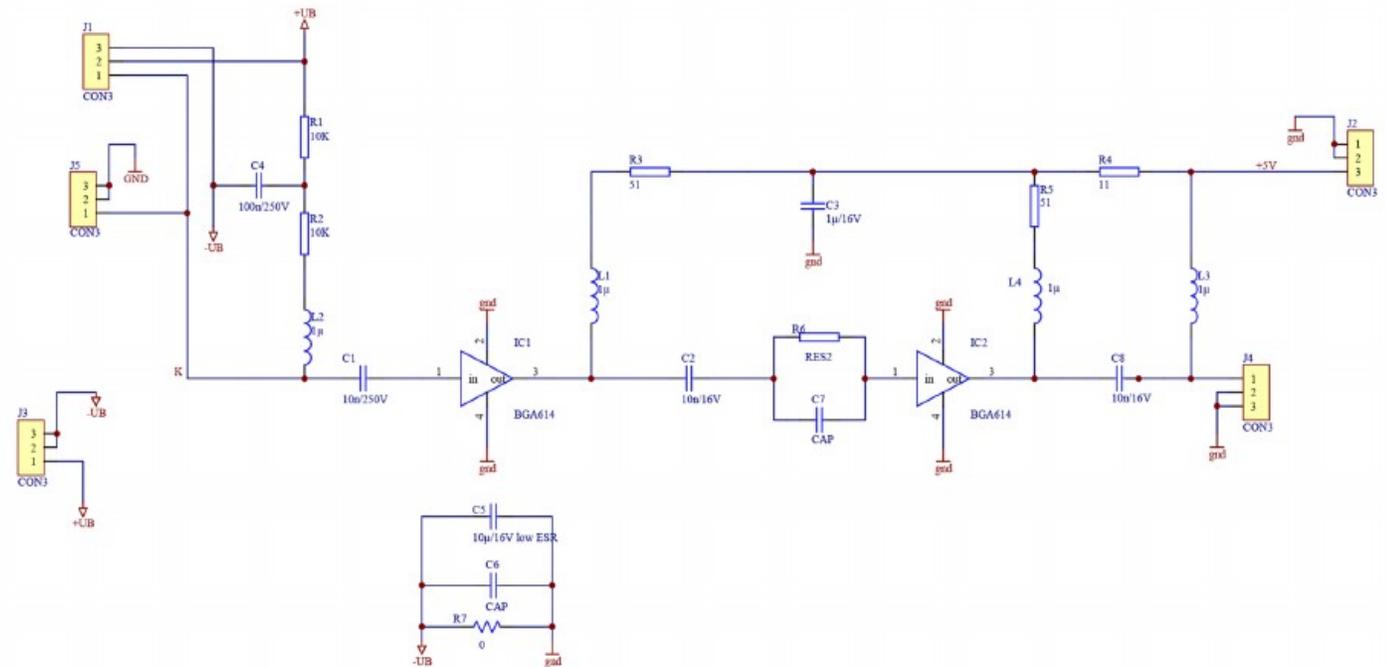
The scintillator starts to "glow" on exposure with ionizing radiation.

Low-Cost Detector

- Modular preamplifier plug-on for SiPM-PCB
- Super low-cost wide-band MMIC (BGA614)
- Options:
 - Single/ dual stage
 - Remote powered
- Ultra low cost (~5€)

Why?

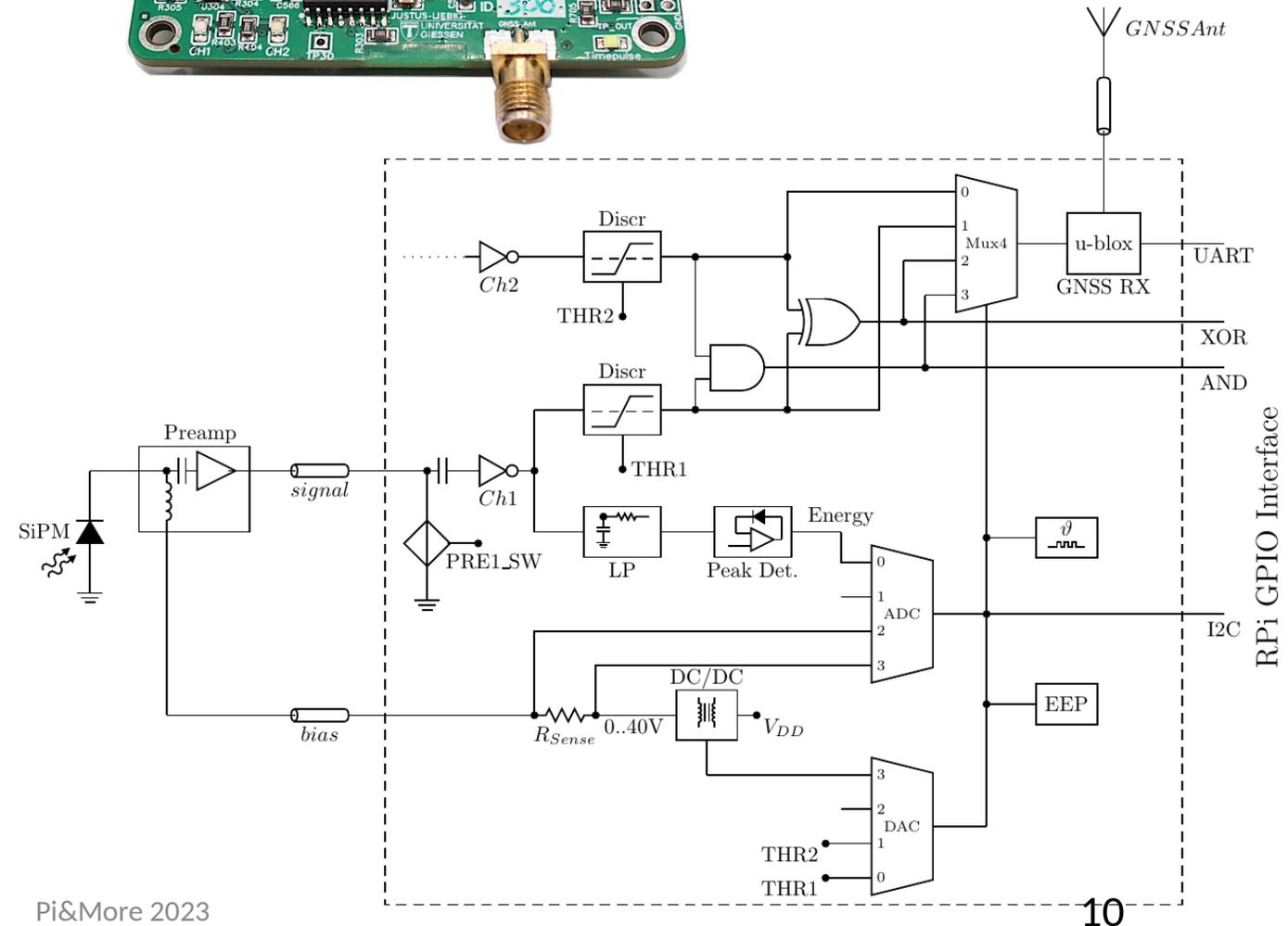
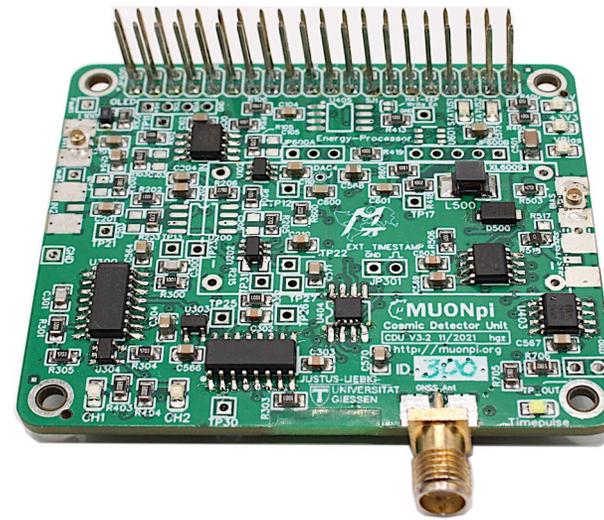
- Wide availability -> more detectors
-> better shower reconstruction
- Expensive is easy...



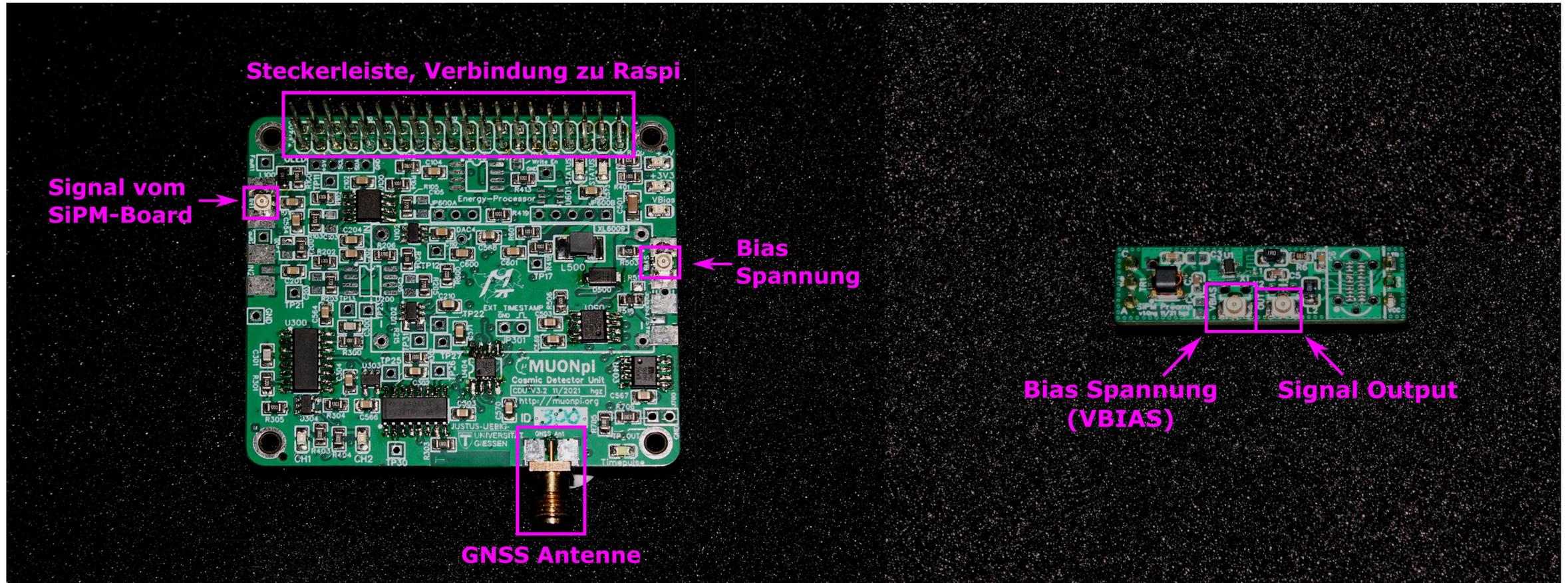
Trivia:
 Detector pulses are only a few nanoseconds short and tiny, so we need a $\approx 1\text{GHz}$ RF amplifier

The RPi HAT board

- Readout and control of the detector
- On-board: voltage supplies and surveillance of the SiPM (0-40 V)
- Discriminators and coincidence logic (AND/XOR)
- Amplitude measurement with plug-on detector
- GNSS - Navigation receiver for nanosecond timestamping of detector events
- EEPROM for calibration, DACs for thresholds, switches for signal selection (Ch1, Ch2, XOR, AND, etc.)



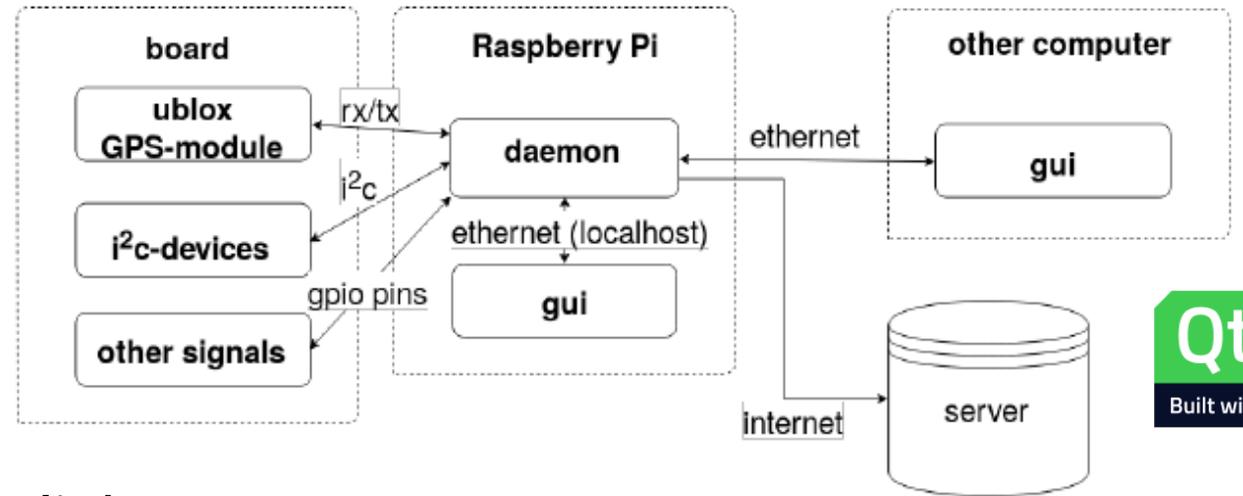
Plug and Play



Software

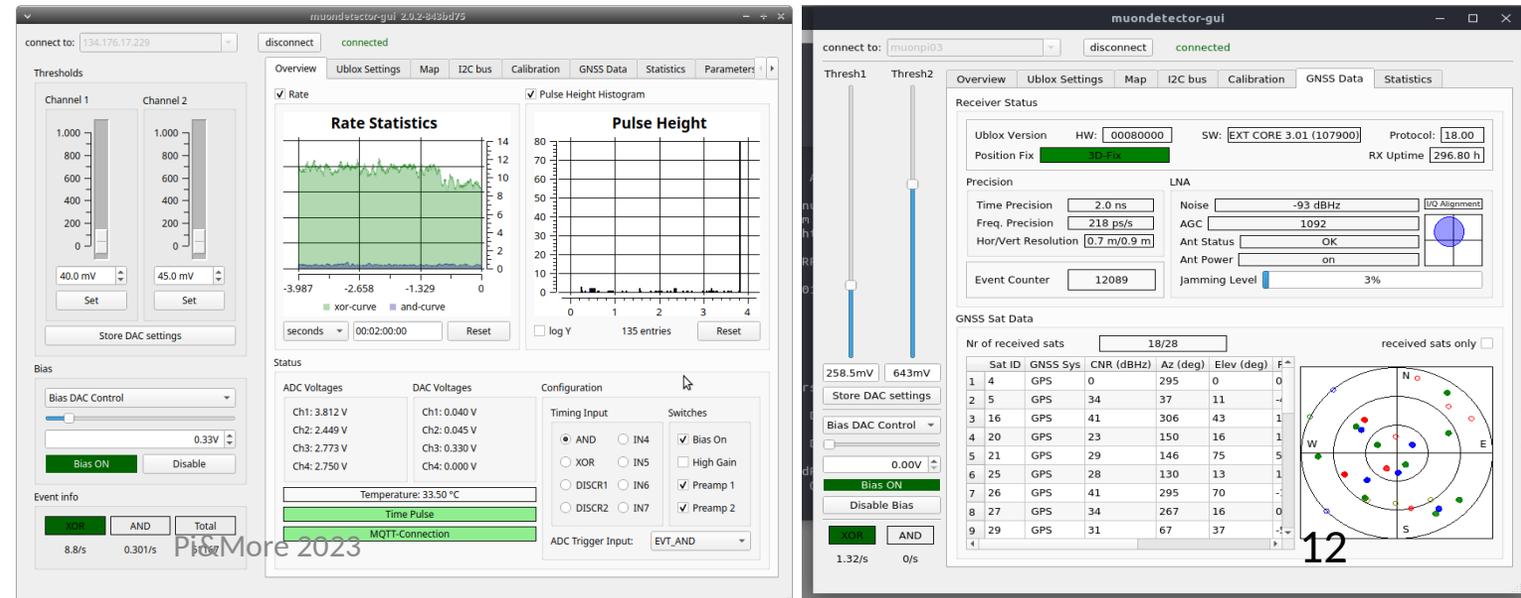
RPi daemon program

- Systemd process
- Interface to HAT board
- Interface to outside world via TCP-Socket
- Automatic data delivery to server via MQTT-link



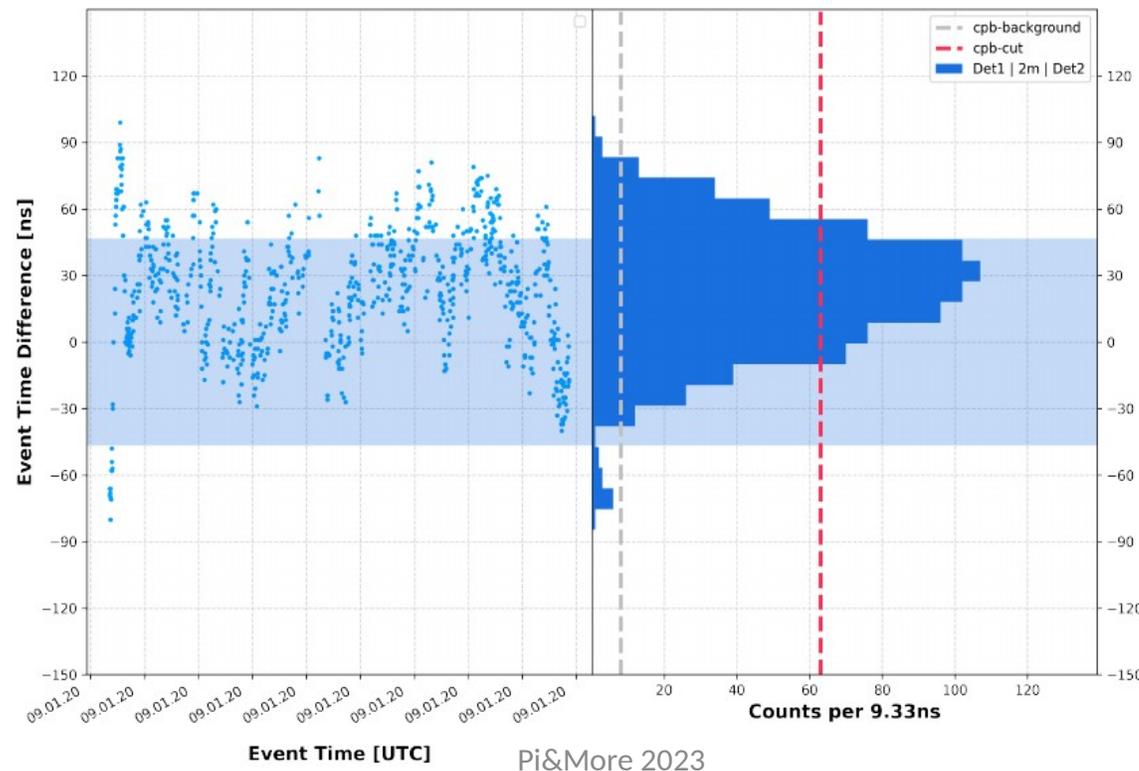
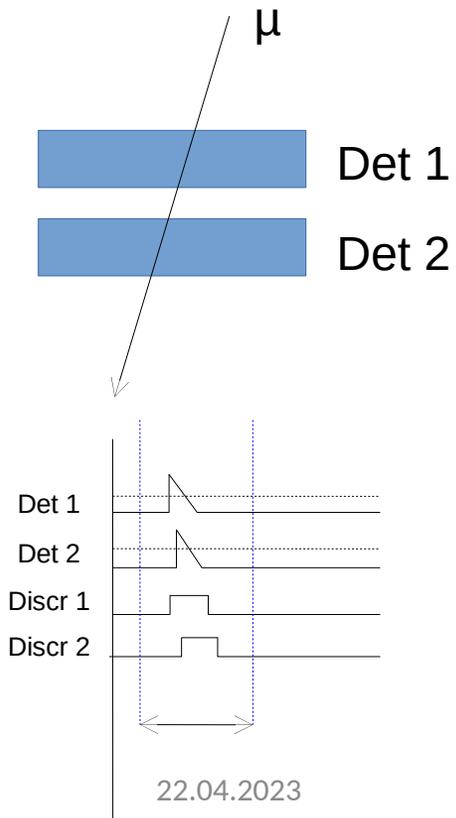
Graphical User Interface (GUI)

- Optional
- Insight in details of operation & access to all system parameters
- Locally on same RPi or remotely in the same LAN



Test and Results

- Detecting the coincidence (=simultaneous appearance) in two overlapping detectors
- Accumulation = physical evidence of one and the same particle

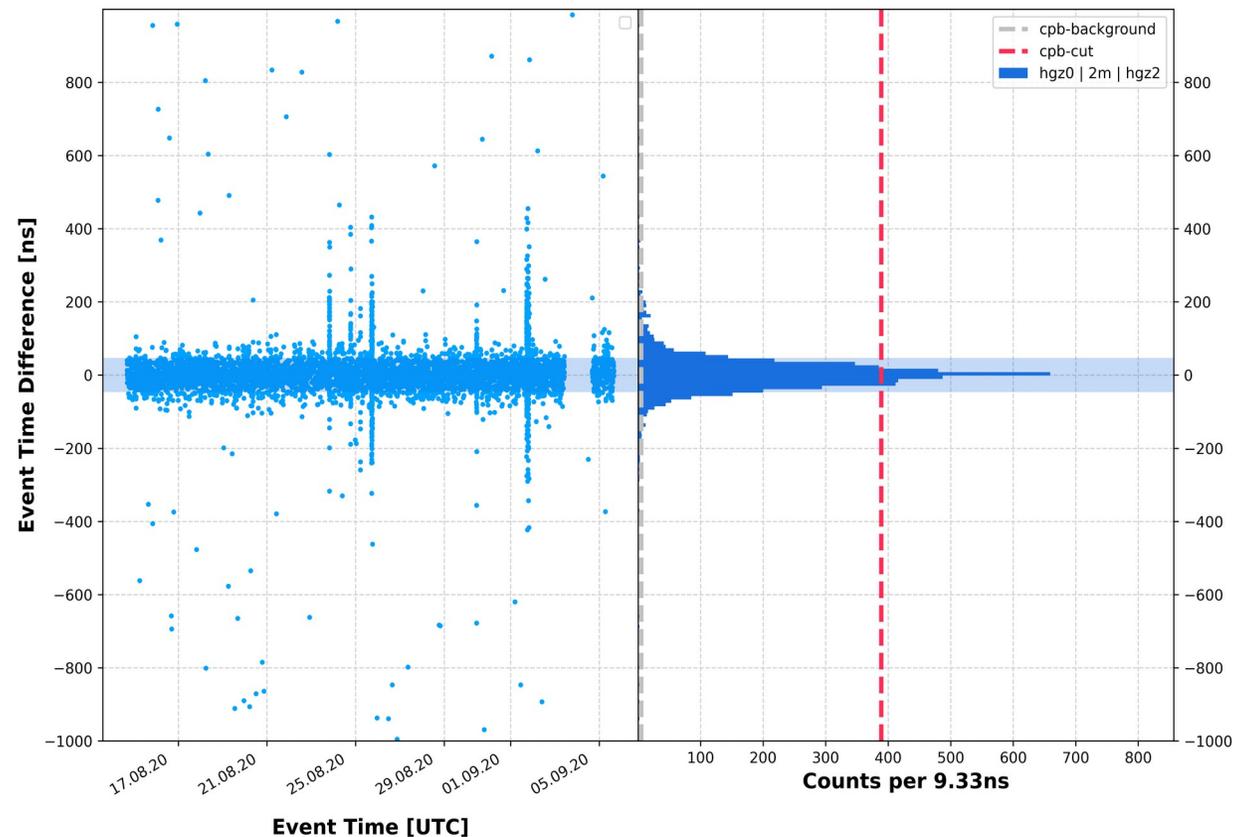
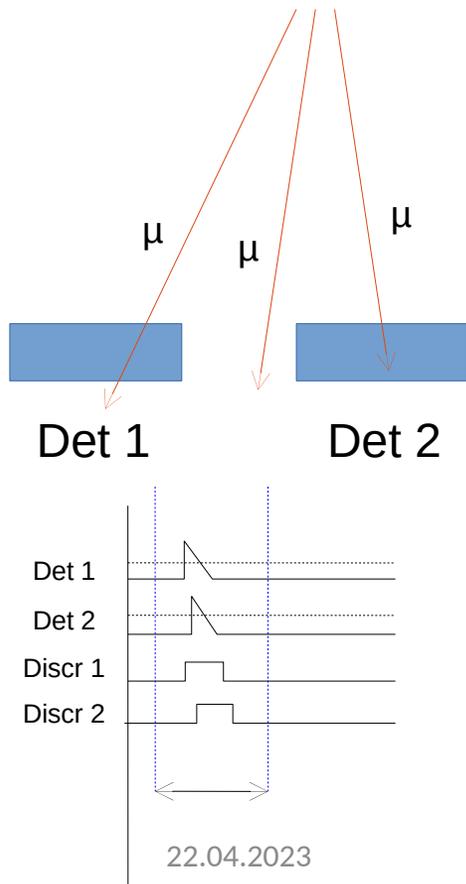


Trivia

The coincidence method looks for simultaneous pulses in a tight time window (~100 ns) and is an extremely powerful suppressor of noise and background events. It was invented by W. Bothe (Giessen) and rewarded with the Nobel prize in physics in 1954.

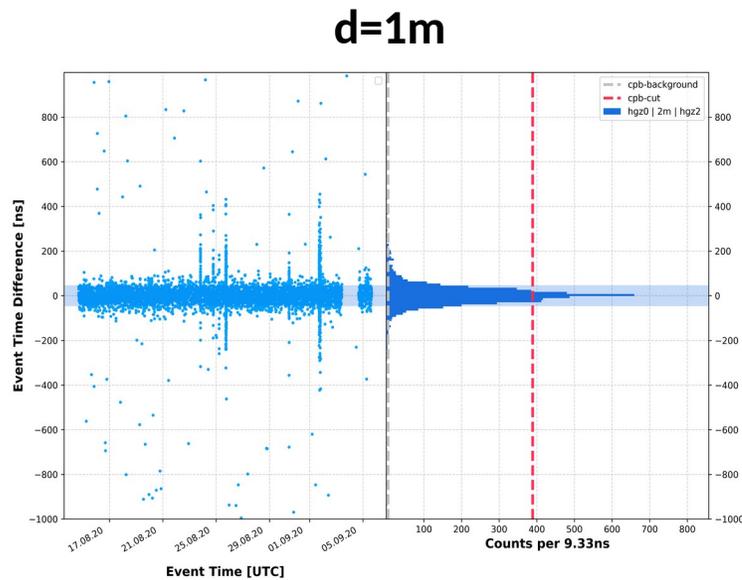
Test and Results

- Coincidence in two separated (non-overlapping) detectors
- Accumulation = physical link between different muons due to same origin

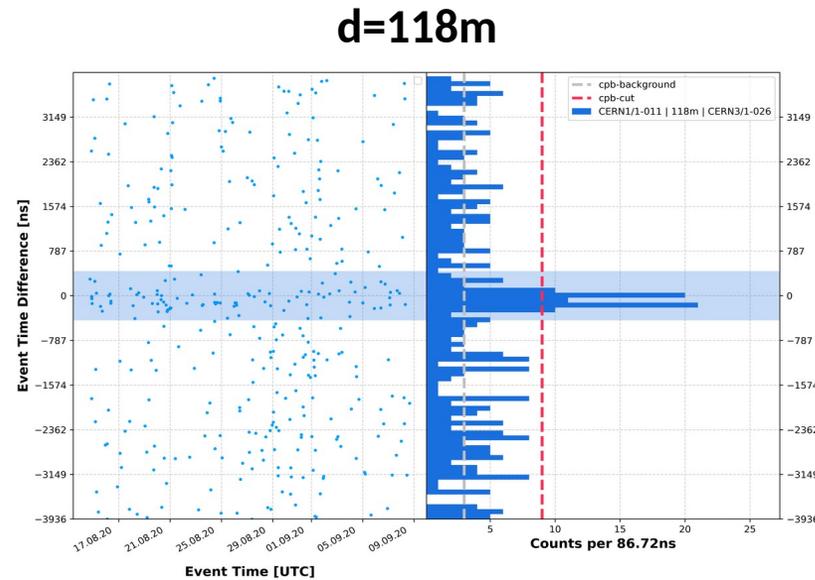


Test and Results

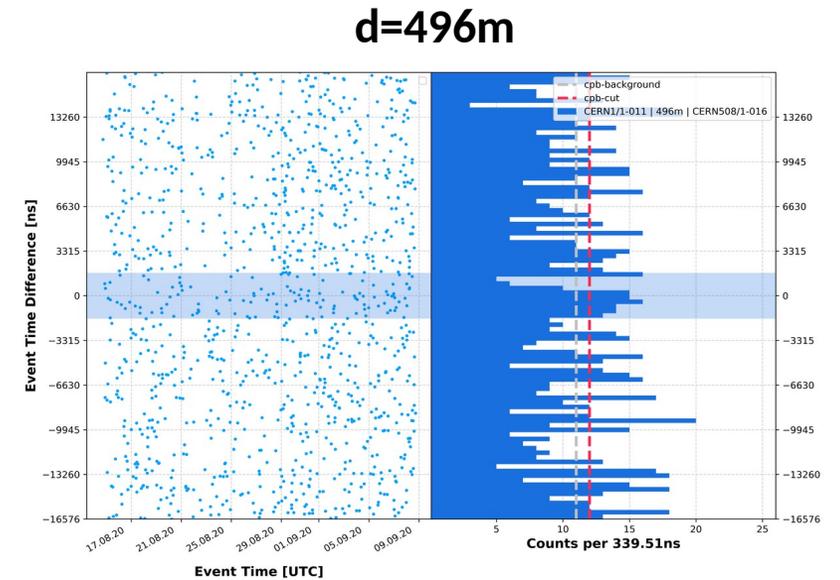
- Shower energy proportional to shower radius
- Coincidence rate drops with distance
- Need more statistics and observers for large (=high energy) showers



22.04.2023



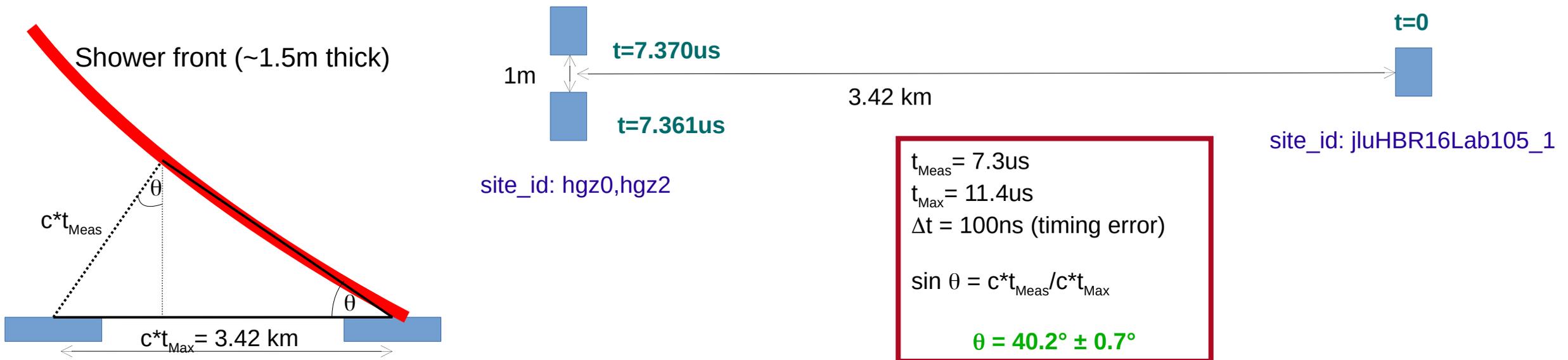
Pi&More 2023



First Results

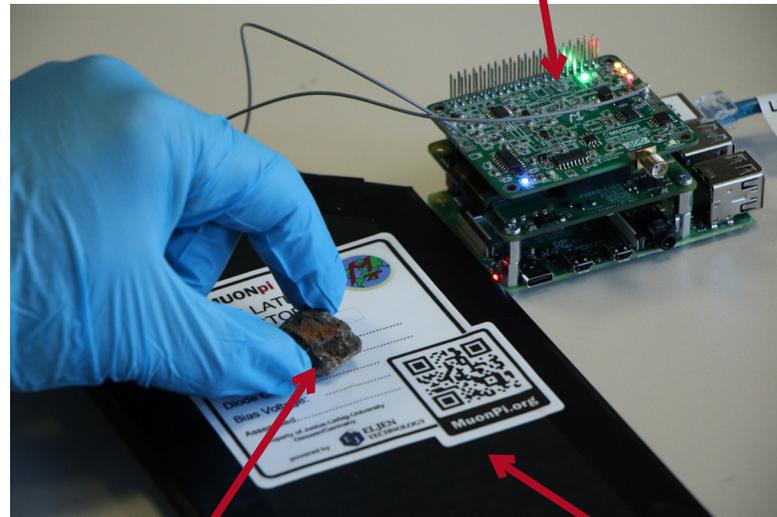
Event 06/20/2020 @ 7:20pm (UTC)
(ID:de5cbef8696ad3cb9da05bc291a71611)

```
> select * from "L1Event" where "coinc_level">2 and "cluster_coinc_time"<10000 and time>now()-3d group by "uuid"
name: L1Event
tags: uuid=de5cbef8696ad3cb9da05bc291a71611
time          accuracy cluster_coinc_time coinc_level coinc_time counter detector length site_id time_ref user valid_fix
-----
1592680847914449929 28      7370           3        -7370    56422  HBR16Lab105_1 104  jluHBR16Lab105_1 2      jlu  1
1592680847914457290 26      7370           3         -9      47439   2             125  hg2             2      hg2  1
1592680847914457299 24      7370           3          0      45867   0             125  hg0             2      hg2  1
>
```



First Results

Use as a dosimeter: measure gamma and beta activity of environment or samples

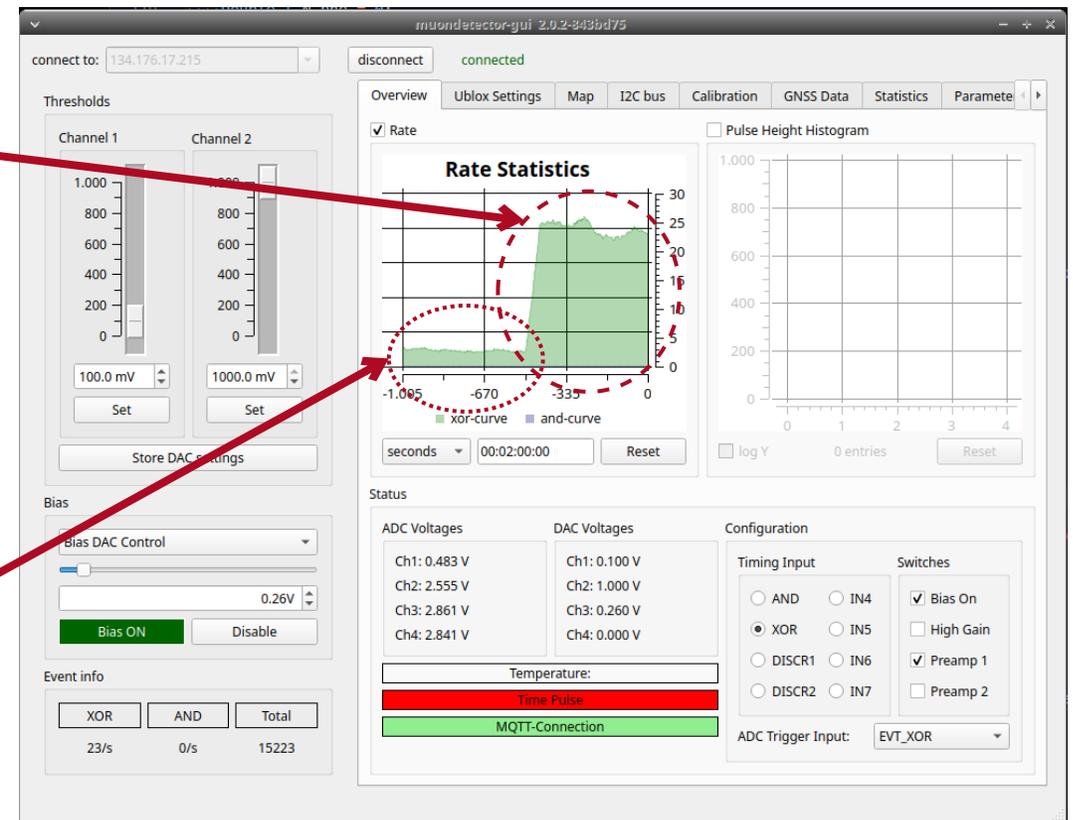


Rpi + PoE-HAT +
MuonPi HAT v3.2

Pitchblende
stone

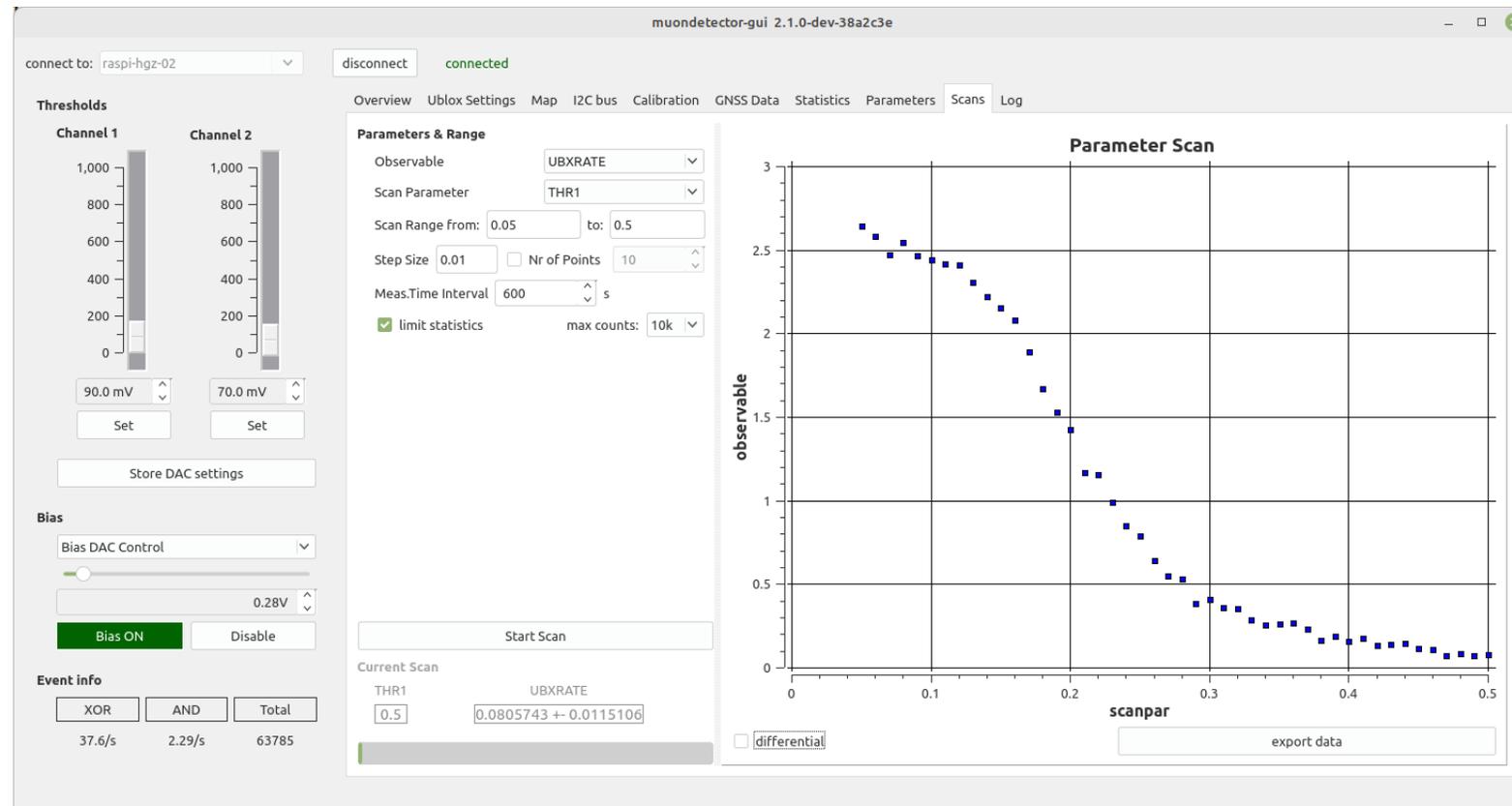
Pitchblende stone

MuonPi standard
detector (large)



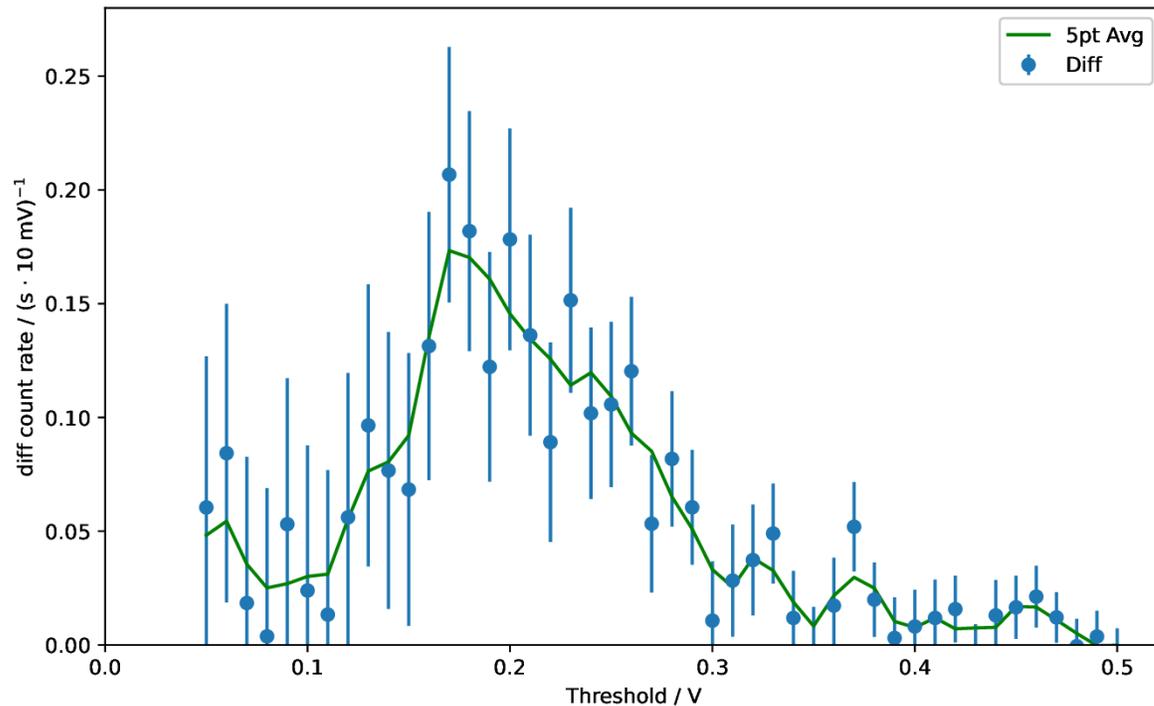
Test and Results

- Threshold scan: record mean rate vs. amplitude cutoff threshold
- Automated in Muondetector-GUI

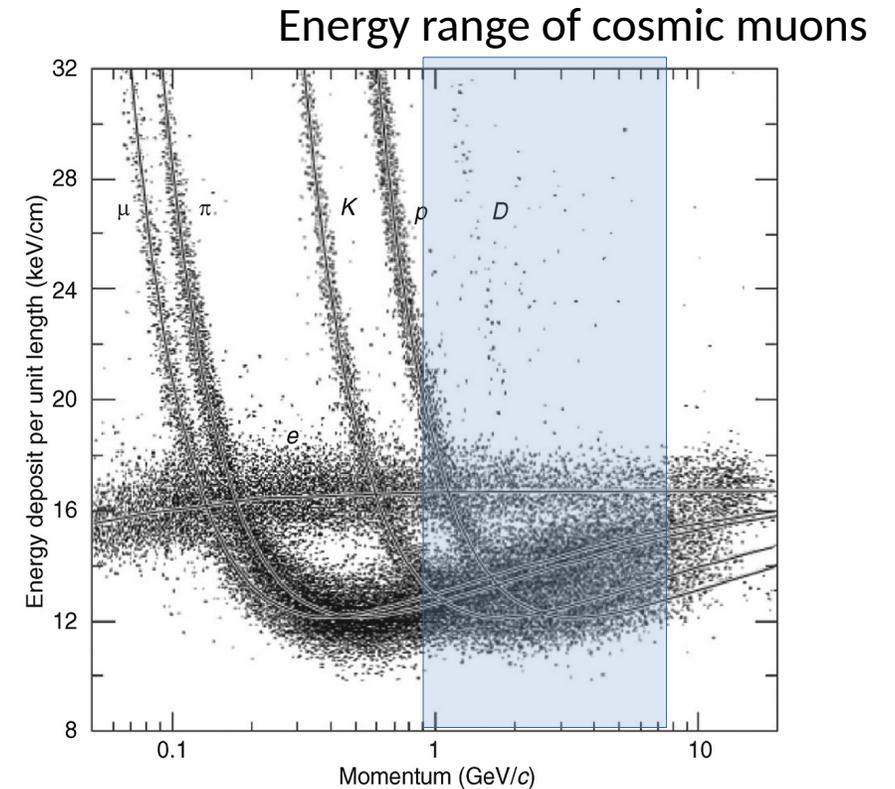


Test and Results

Reconstruct energy spectrum of muons by numerical differentiation



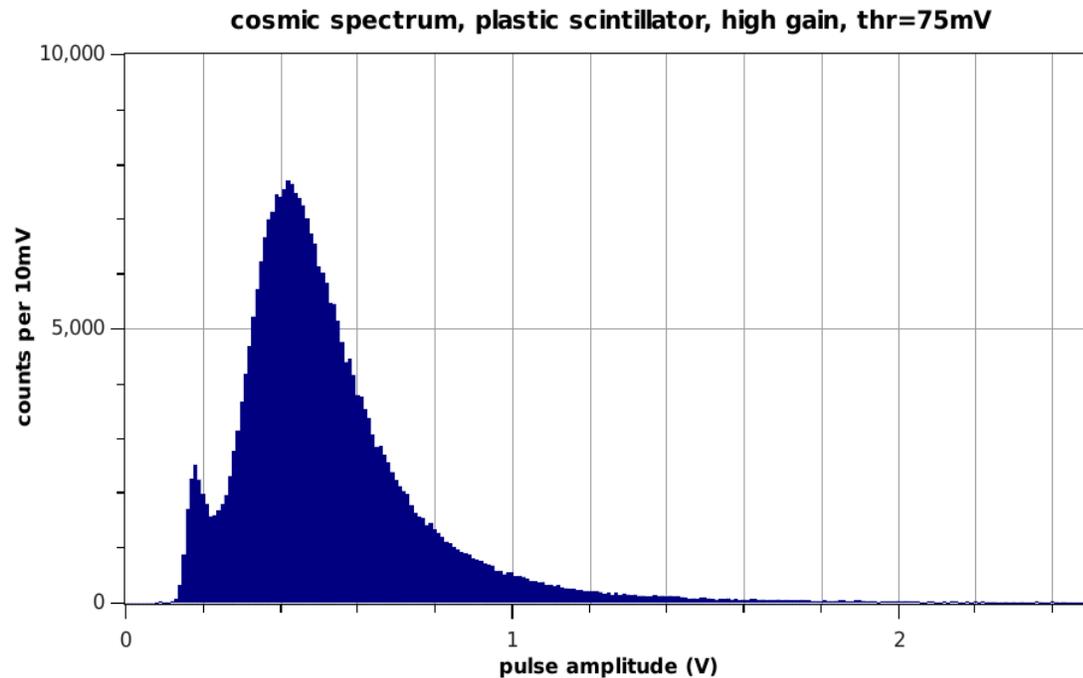
Energy deposit of different particles in material vs. kin. energy: Bethe-Bloch formalism



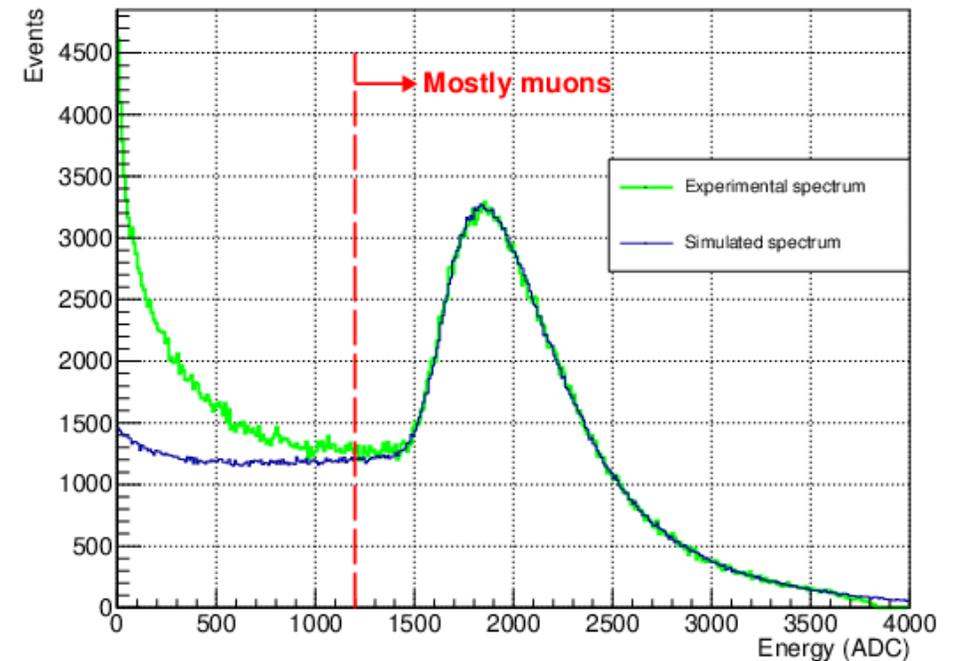
Data:
ALICE TPC detector, LHC/CERN

Test and Results

Same spectrum measured with plug-on peak-detector and ADC



Comparison btw. Simulation and data obtained with high-energy physics detectors

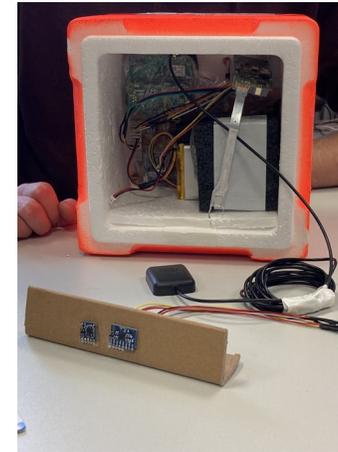


MuonPi@Stratosphere

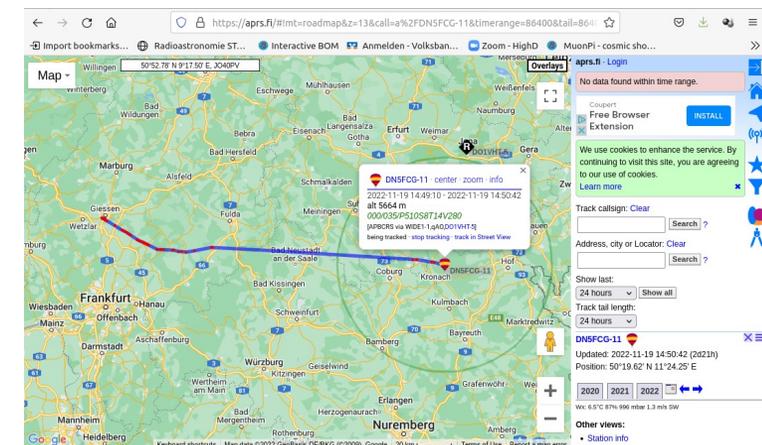
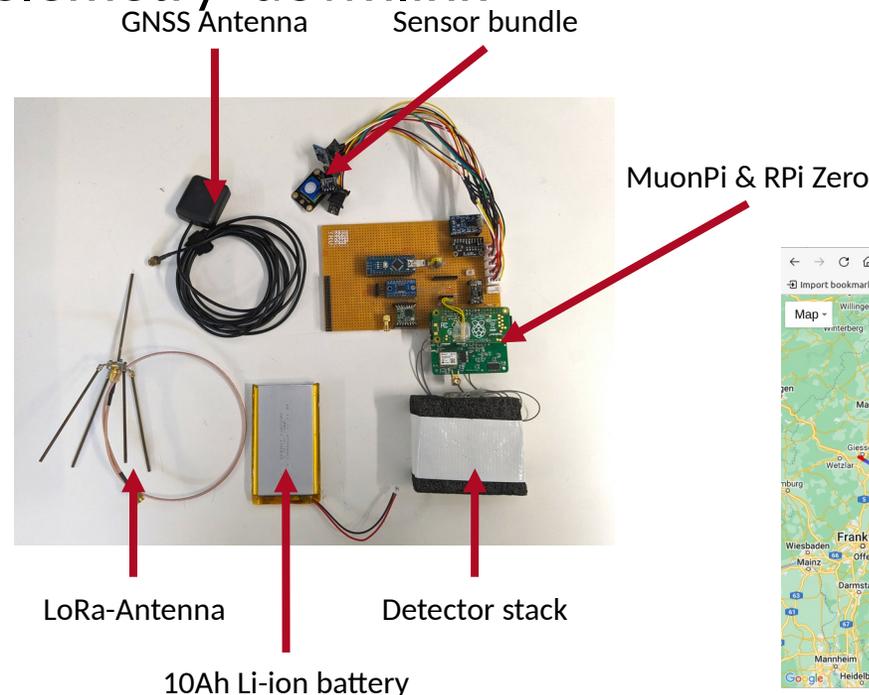
Stratospheric balloon flight as student experiment

Apparative tests:

- Environmental sensors (p, T, RH, UVI, gyro, magn. field, O₃)
- MuonPi unit with 2 coincidence detectors
- LoRa Transmitter with constant telemetry downlink

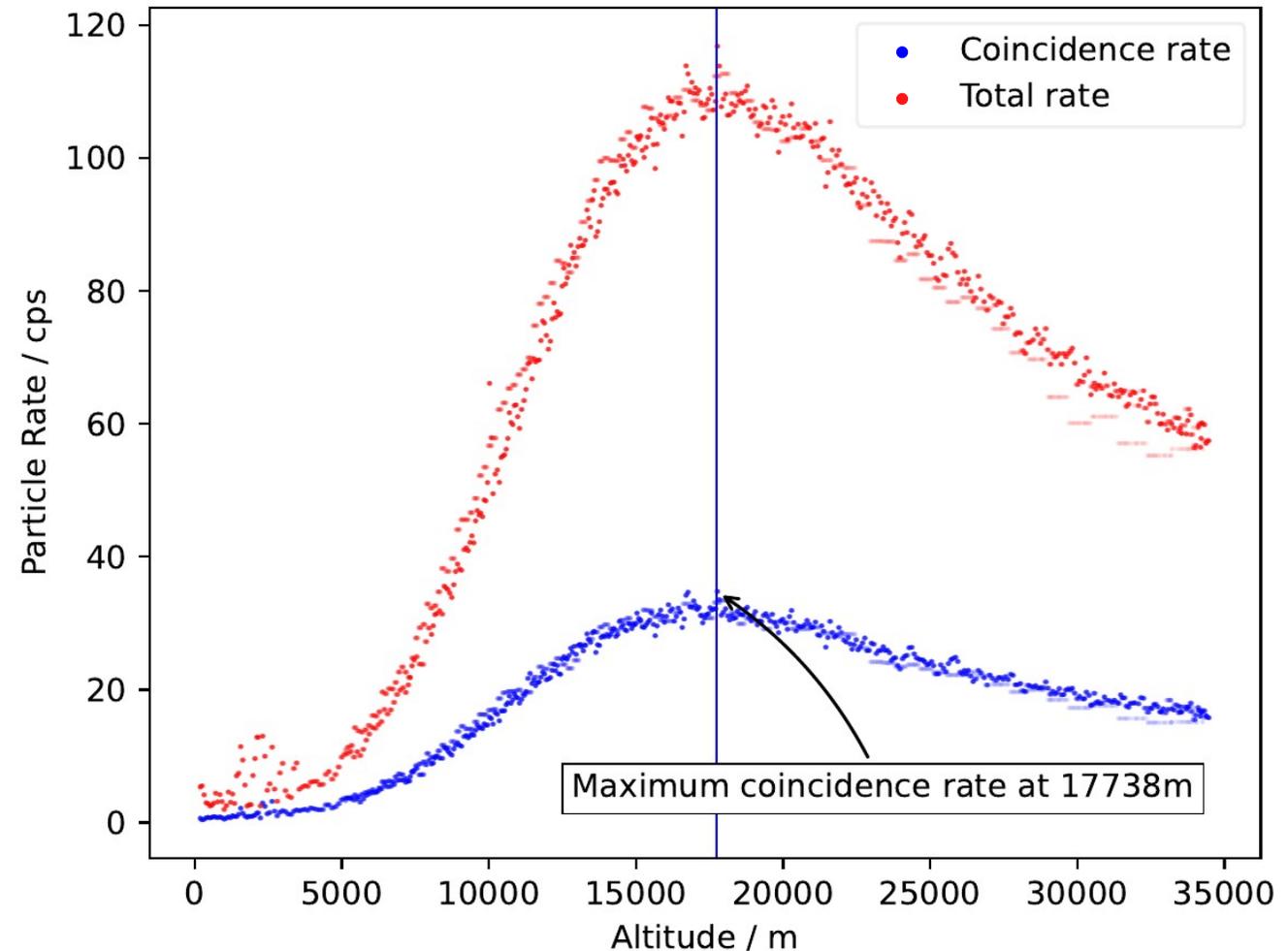


At the edge of space at highest altitude of 34,800 m



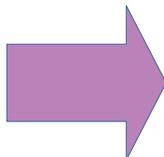
MuonPi@Stratosphere

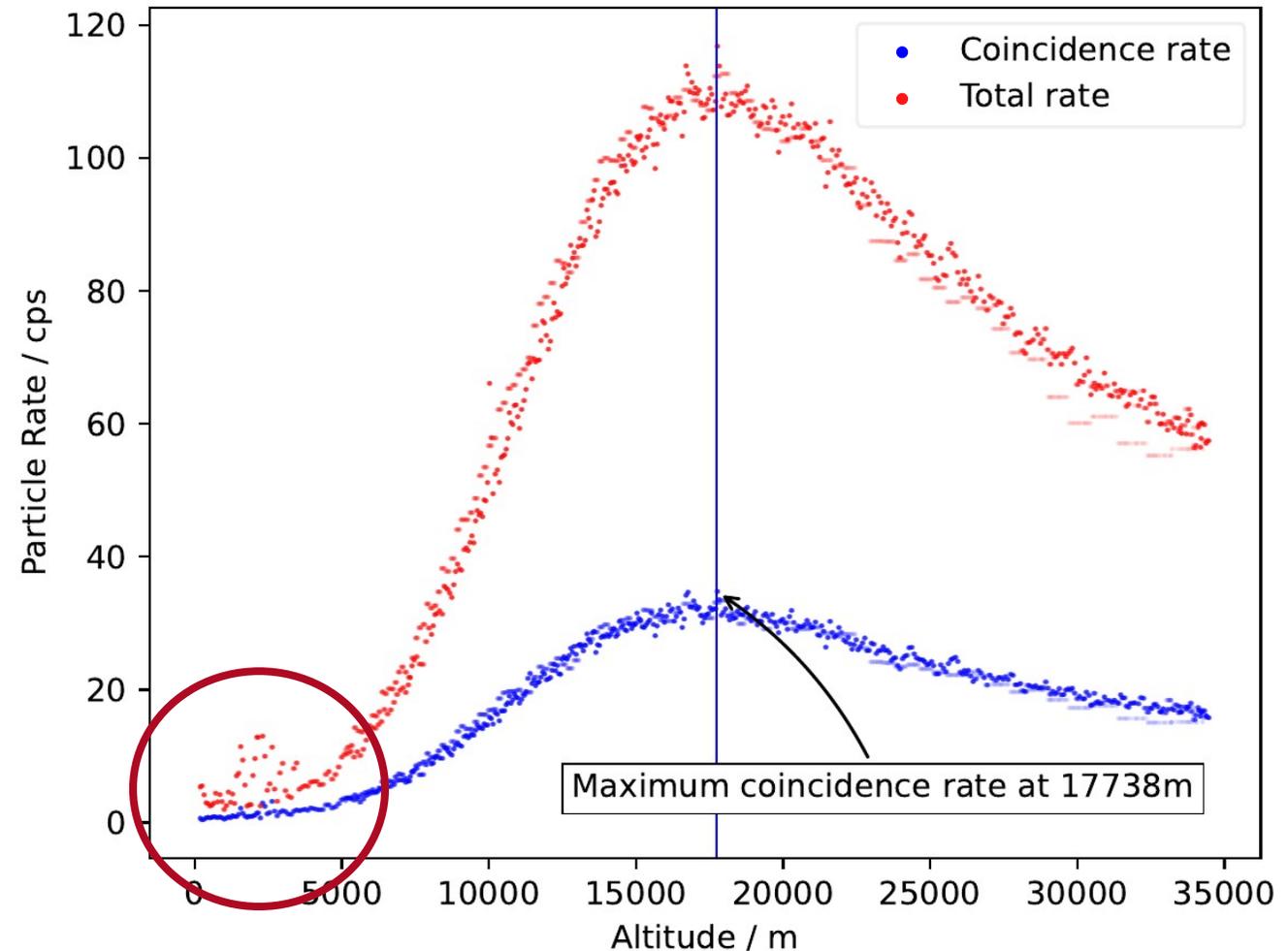
- Measurement of coincidence and total particle rates
 - Distinction between gammas and muons
- Direct determination of Regener-Pfotzer maximum (mean intrusion depth of GCRs into atmosphere)



MuonPi@Stratosphere

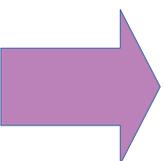
- Measurement of coincidence and total particle rates
 - Distinction between gammas and muons
- Direct determination of Regener-Pfotzer maximum (mean intrusion depth of GCRs into atmosphere)
- Strong excursions of total rate after start
- Coincidence rate not affected

 Increased Gamma rate from ground



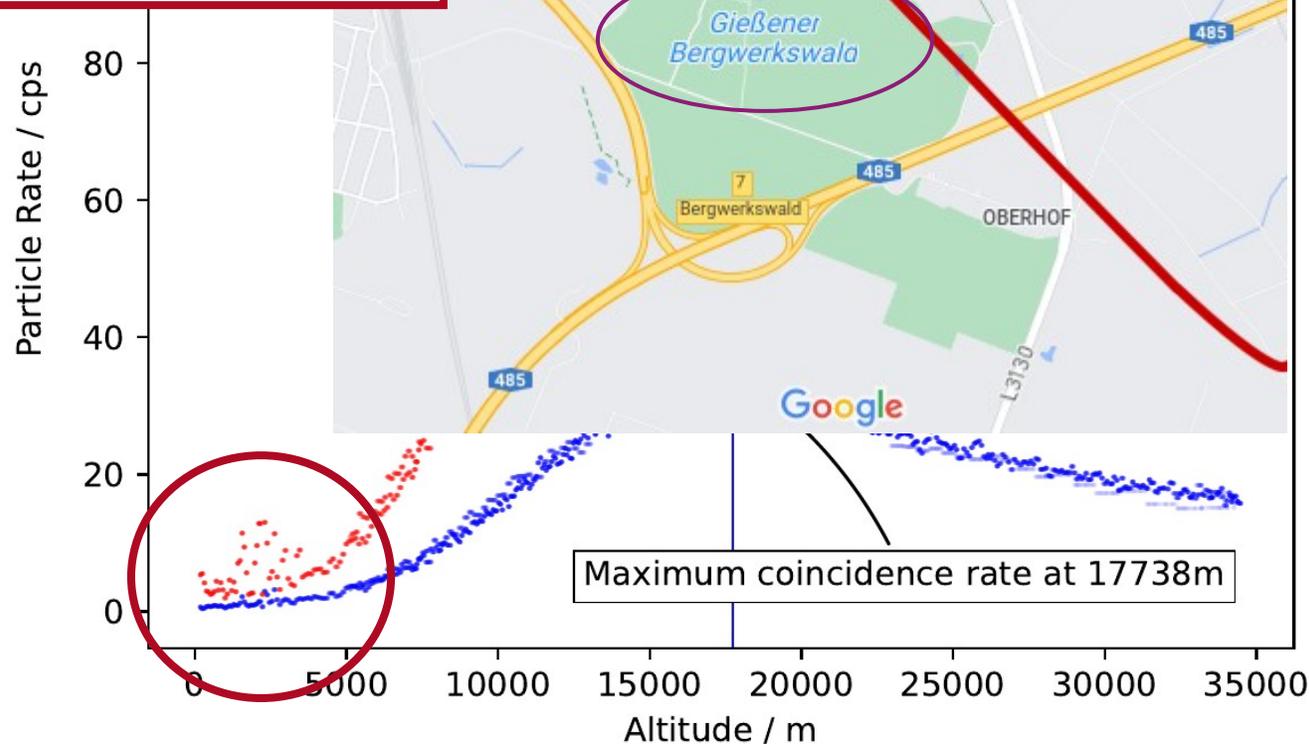
MuonPi@Stratosphere

- Measurement of coincident total particle rates
 - Distinction between background and muons
- Direct determination of Regener-Pfotzer maximum (mean intrusion depth of GCRs into atmosphere)
- Strong excursions of total rate after start
- Coincidence rate not affected



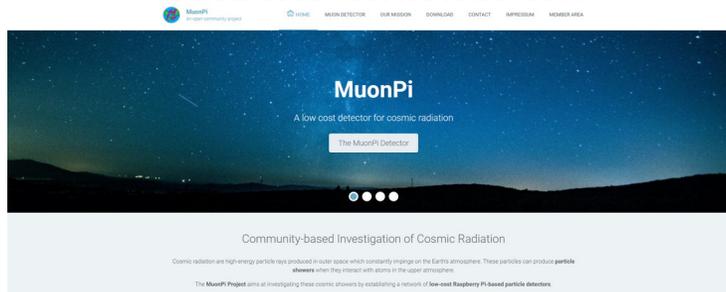
Increased Gamma rate from ground

Trivia:
Mining sites usually show stronger radioactive background due to disturbed geological layers



About the Project

Website: muonpi.org



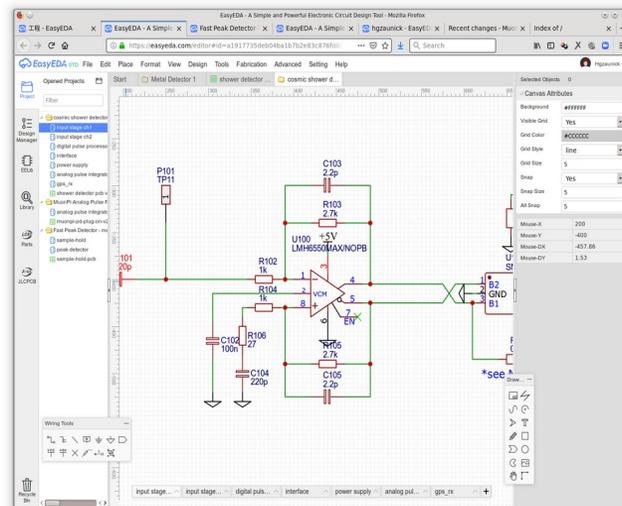
Documentation: wiki.muonpi.org



Live Data: grafana.muonpi.org



EasyEDA: easyeda.com/MuonPi
Schematics, PCB-Layouts, BOMs



Contact Us!

support@muonpi.com

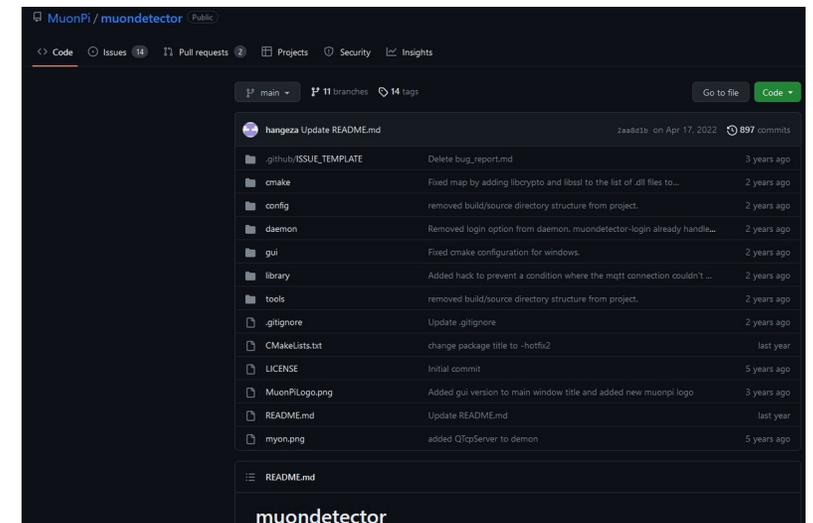
Twitter: @PiMuon

Instagram: @MuonPi

Youtube: @muonpi778

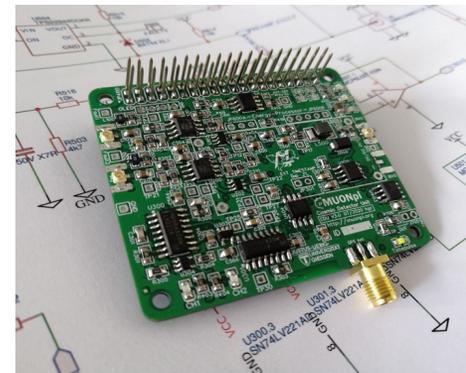
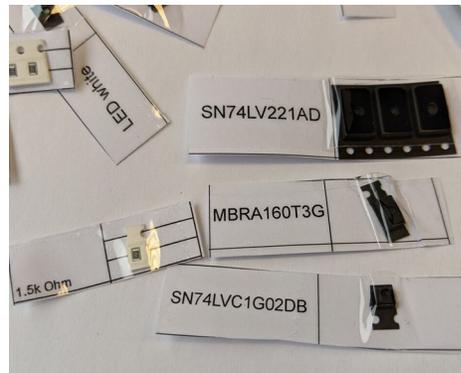
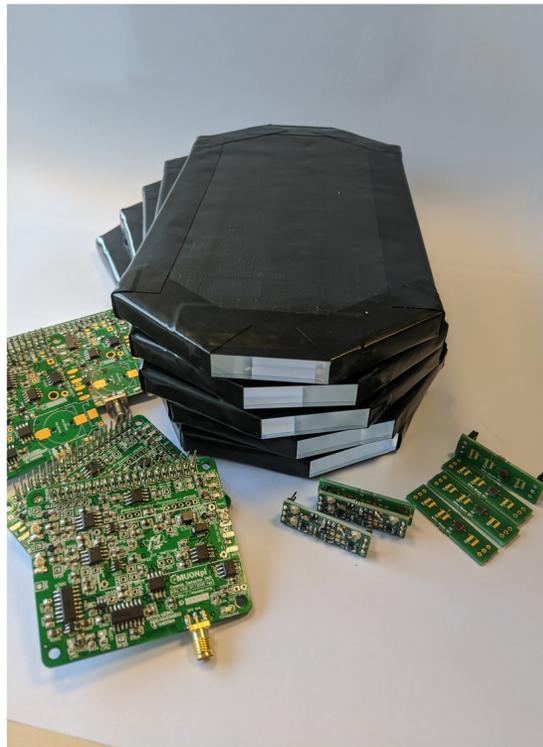
GitHub: github.com/MuonPi/muondetector

GIT-Repository of software collection



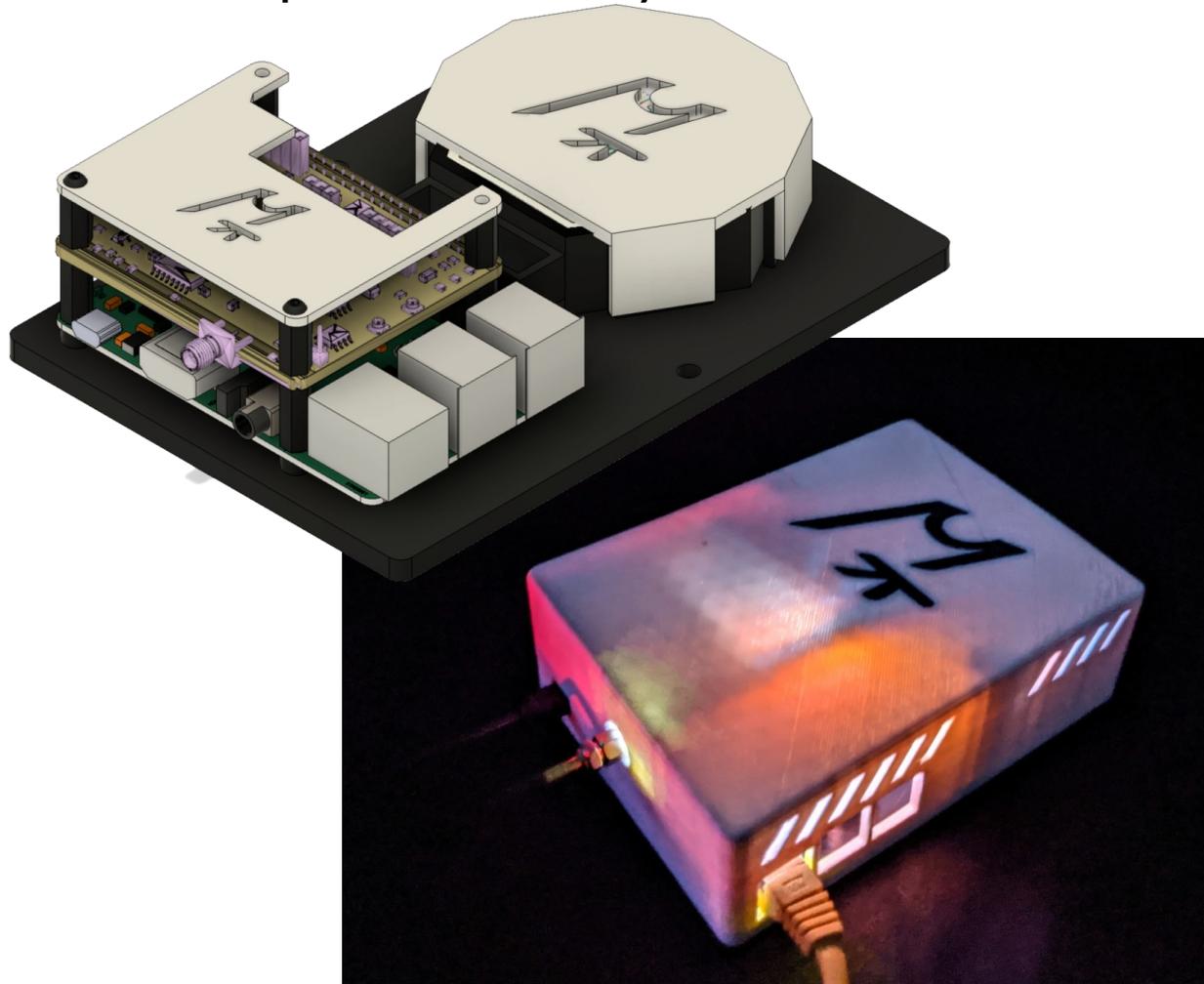
Participate

Sign up for assembly kits or fully assembled stations: <https://muonpi.org/member.php>



User Contributions

3D-printed case by user Slu



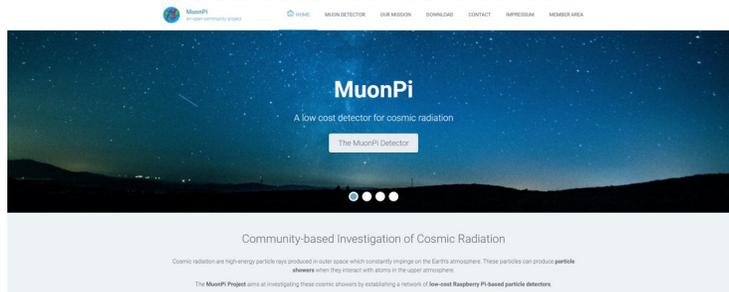
MuonPi Board Lite
by user oe5hcl

Detector assembly
of Makerspace
Giessen (MaGie)



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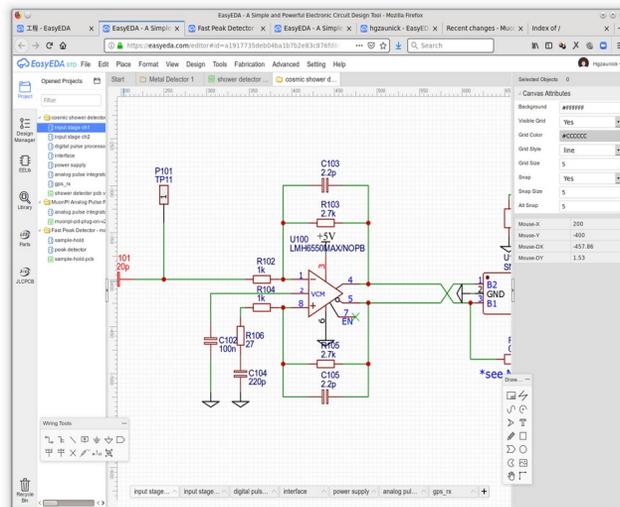
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