GRAN SASSO hands-on

NUSES & HERD

with Adriano di Giovanni

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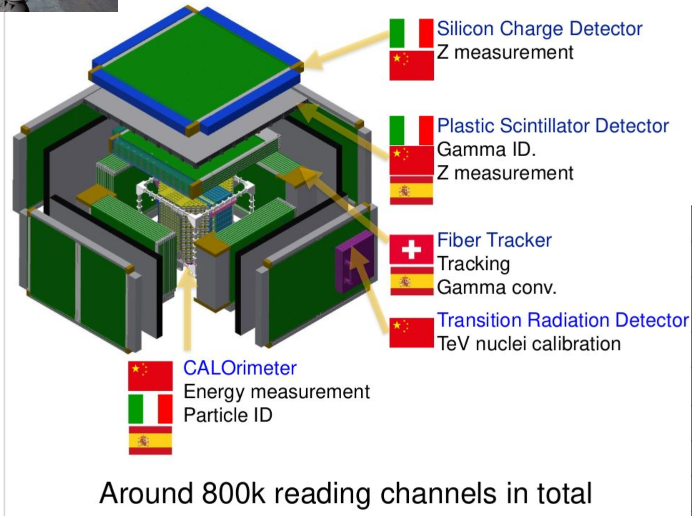
GSSI Hands-On School, LNGS, l'Aquila, Italy 05.10.2023

Aim of the Experiment

- Characterization of Photo-Multiplier Tubes (PMTs)
- Characterization of Silicon Photo Multiplers (SiPMs)
- Plastic Scintillators (PScis) attenuation length
- MIP response of Bismuth Germanium Oxide (BGO) using SiPMs

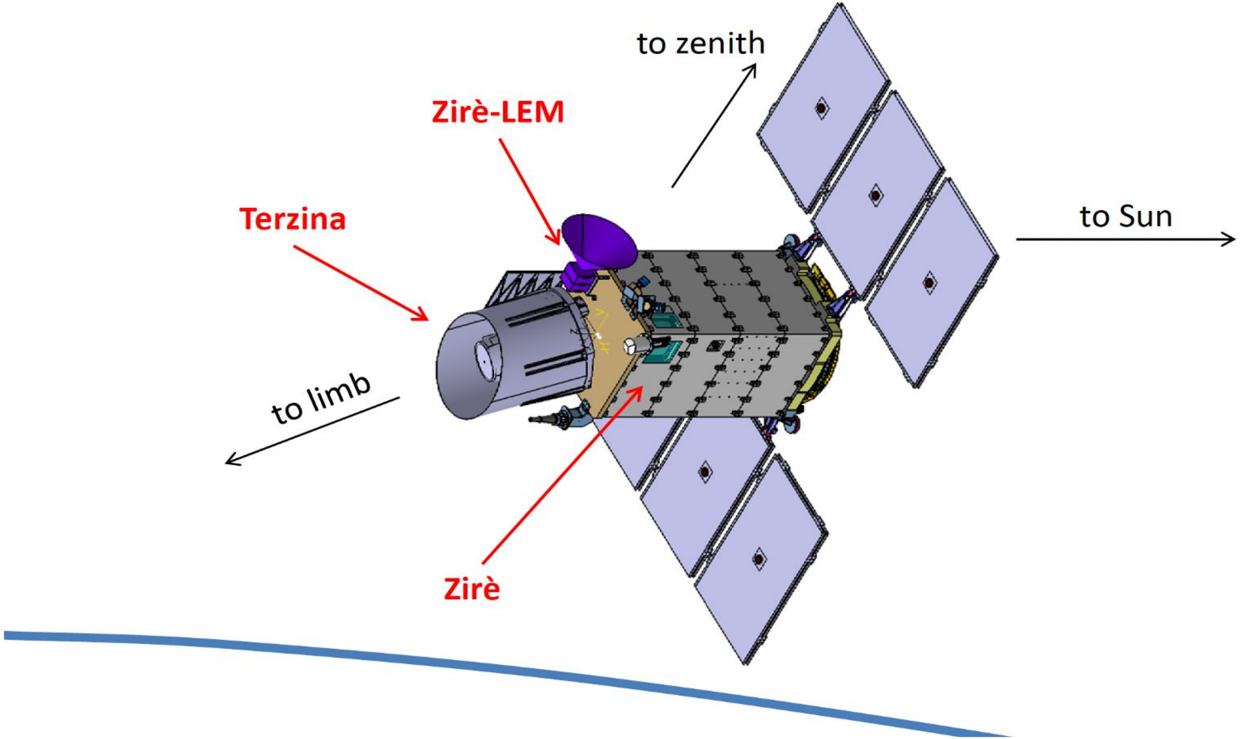
HERD: HIGH ENERGY COSMIC RAY DETECTION FACILITY



HERD Payload-[DONG Yong-Wei-ASAPP Conference 2023]]

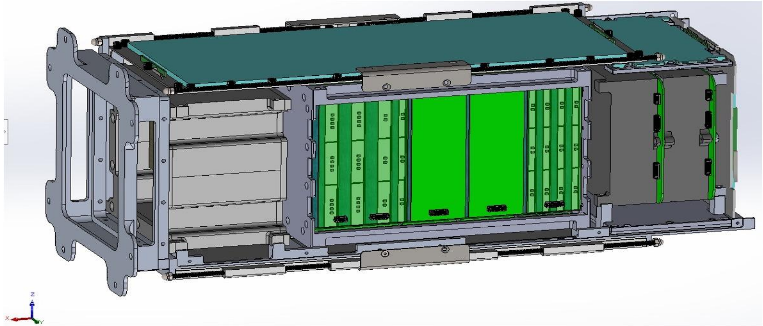
- **Dedicated to the study of cosmic rays, gamma-ray astronomy, electron spectra and dark matter searches**
- **Larger acceptance** [geometry factor + the Top and Side instrumentation]
- **Extension in Energy** [deep calorimeter, $55X_0$]
- **Precise measurement of charge** [Silicon detector + Plastic Scintillator Detector]
- **Plastic Scintillator Detector :** γ identification and nuclei identification (energy loss ∝ Z^2)

NUSES

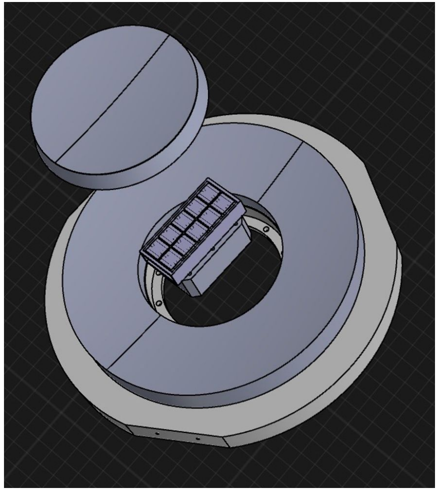


Source: I. De Mitri et al 2023 J. Phys.: Conf. Ser. 2429 012007

NUSES



ZIRÉ payload
- Cosmic Rays (~MeV)
  (Van Allen Belt, solar activity)
- Gamma Rays (0.1 – 10MeV)



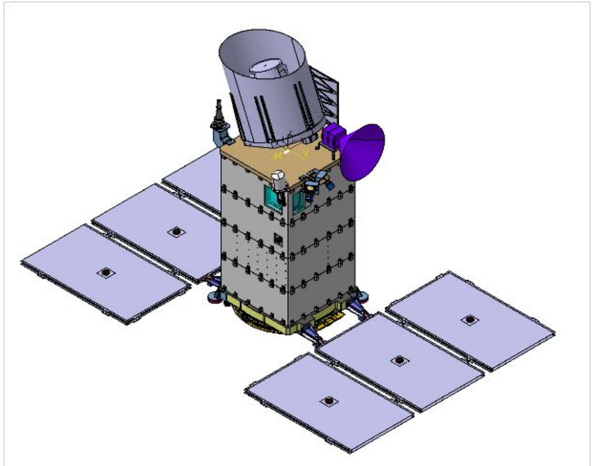
TERZINA payload
Cherenkov light detector for upward-going particle air showers

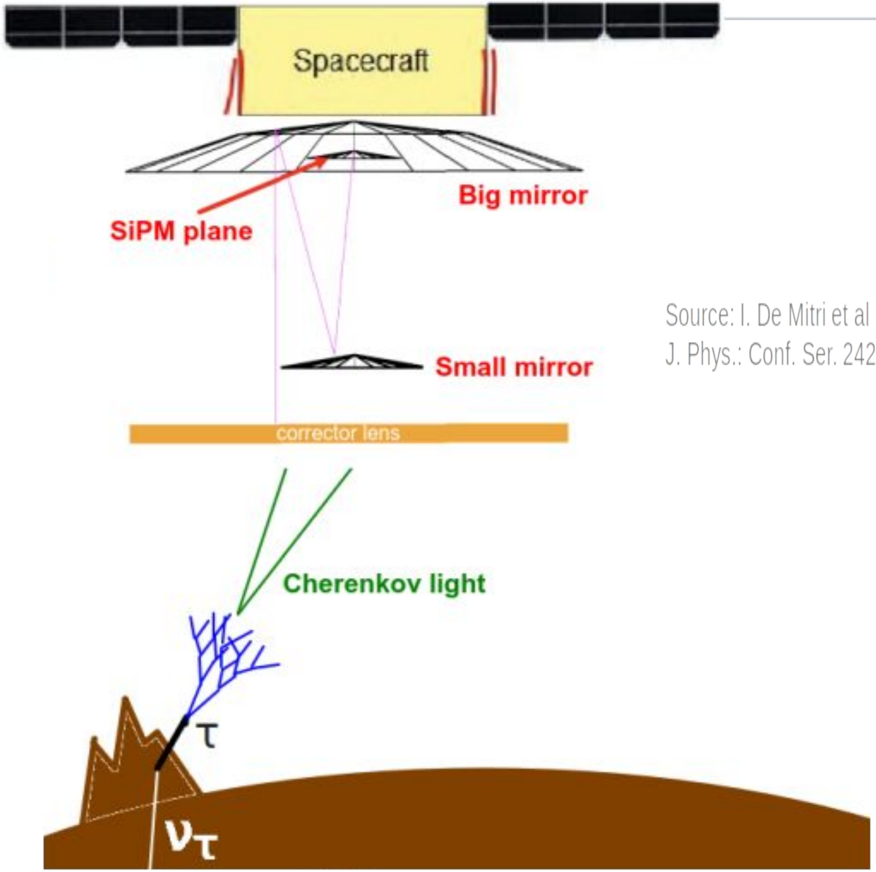
Source: I. De Mitri et al 2023 J. Phys.: Conf. Ser. 2429 012007

NUSES: TERZINA payload module

- Pathfinder for future missions

  - Earth skimming Neutrino

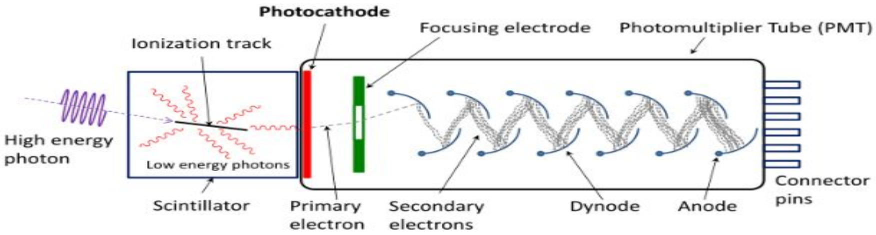




Source: I. De Mitri et al 2023
J. Phys.: Conf. Ser. 2429 012007

Photo Multiplier Tubes (PMTs)

- PMT is a vacuum tube consist of:
  - ✔ an input window,
  - ✔ a photocathode,
  - ✔ focusing electrodes,
  - ✔ electron multiplier (dynodes),
  - ✔ sealed in evacuated glass tube.
- Photomultiplier tubes (PMTs) are extremely sensitive photo-detectors in
  - ✔ the ultraviolet,
  - ✔ visible,
  - ✔ near-infrared ranges
- PMTs are able to:
  - ✔ reach a gain of 10^8

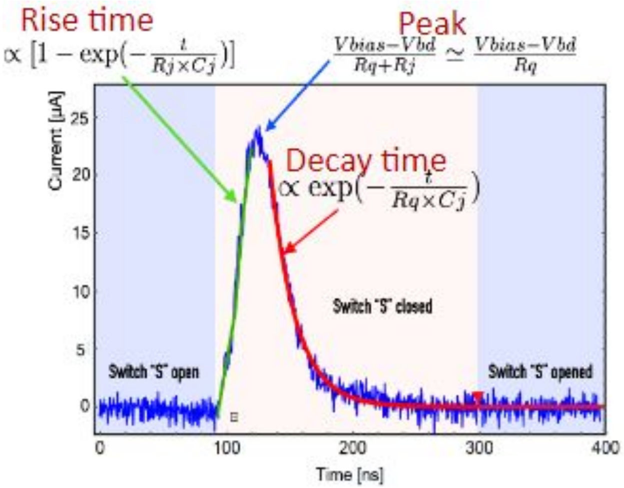


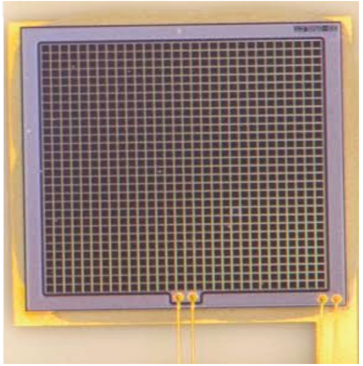
Schematic diagram of PMT

Photo Multiplier Tube
Courtesy: Wikipedia

Silicon Photo Multipliers (SiPMs)

- SiPMs are detectors that gives output current pulse upon absorption of photon.
- Collection of Single-Photon Avalanche Diode (SPAD) or Avalanche Photo Diode (APD).
- Operated on reverse bias voltage
- An avalanche of electrons is caused.
- Gain in the order of 10^6,
- Short dead time and fast time response.





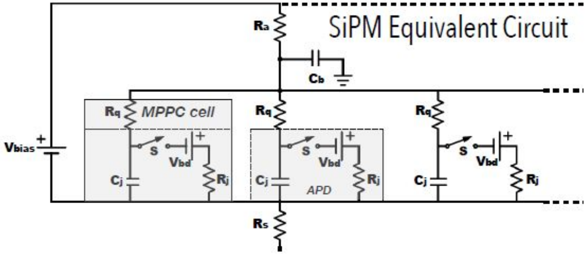
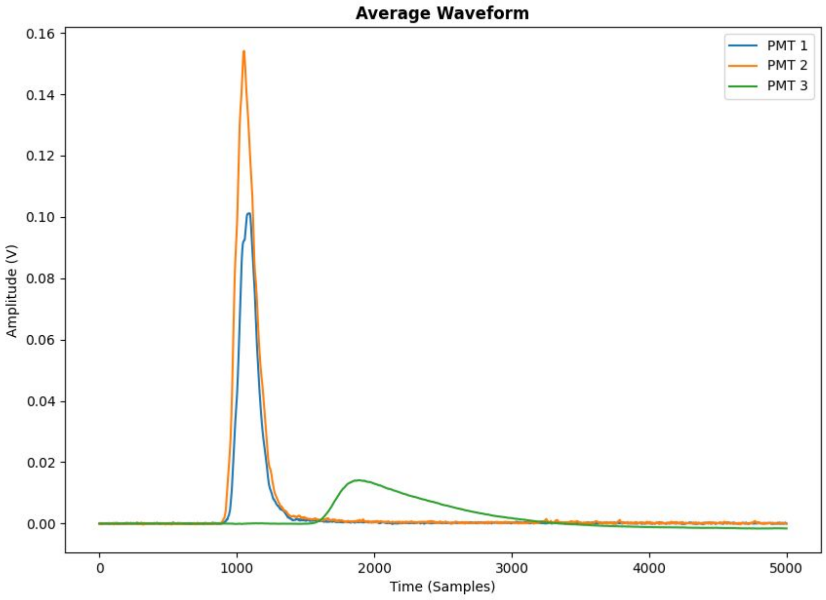
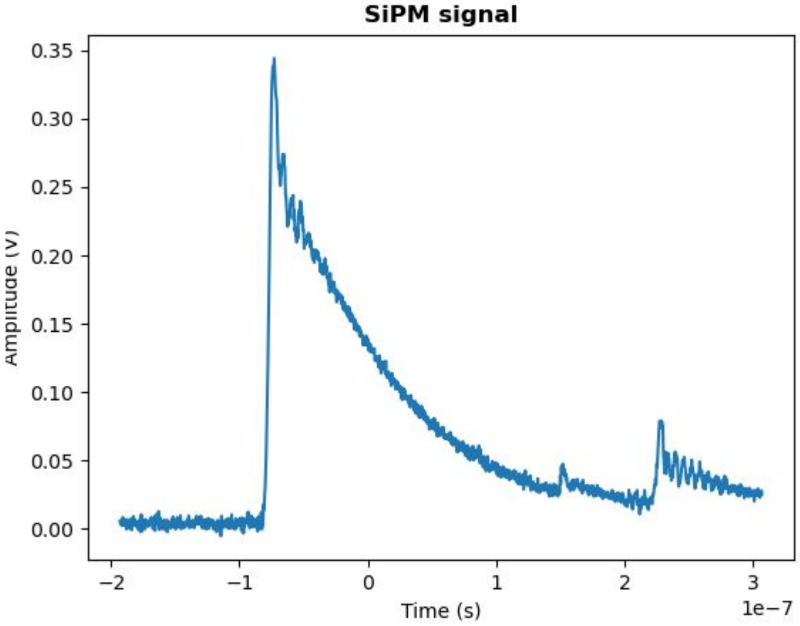


Photo Multiplier Tubes Vs Silicon Photo Multiplier

PMT
Output Signal



(Pre-Amplified) SiPM Output Signal



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PMT vs. SiPMs

SiPMs pros:

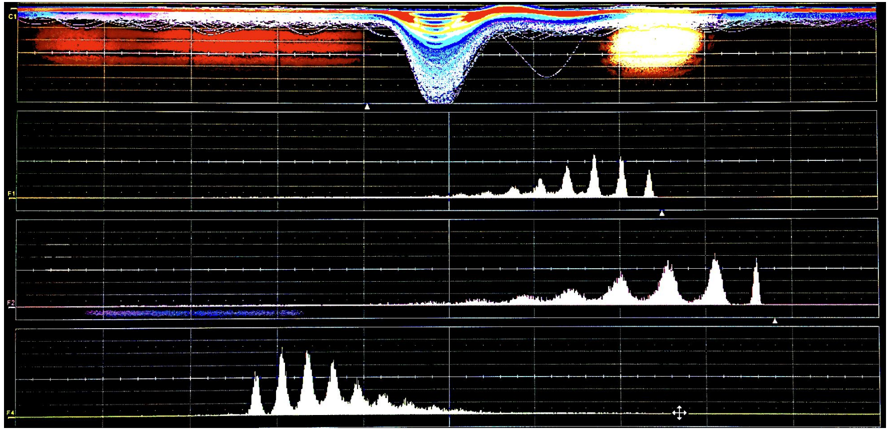
- ✔ Good timing resolution
- ✔ Insensitivity to magnetic field
- ✔ Low power
- ✔ More radio pure

SiPMs cons:

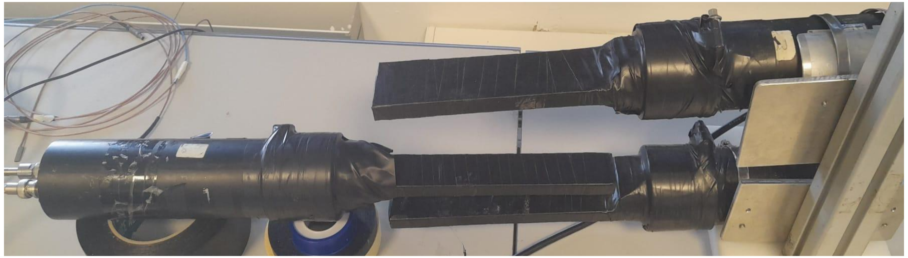
- ✘ Low gain
- ✘ High dark counting rate
- ✘ Cross-talk
- ✘ Very sensitive to temperature variation

Characterisation of PMTs

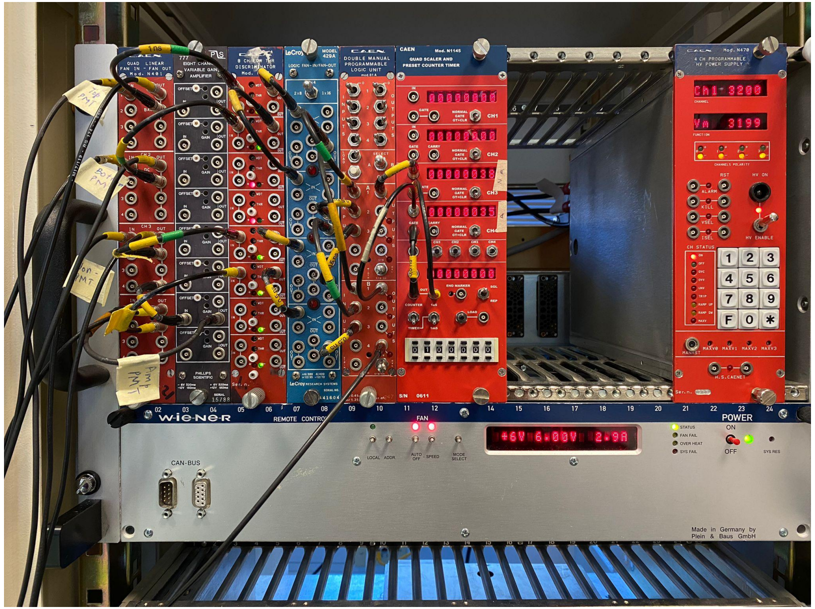
Lecroy HDO 6104, 1 GHz, 4+16 Ch, 12 bits, 10 GS/s



N. 3 Photomultiplier Tubes coupled to as many plastic scintillator bars

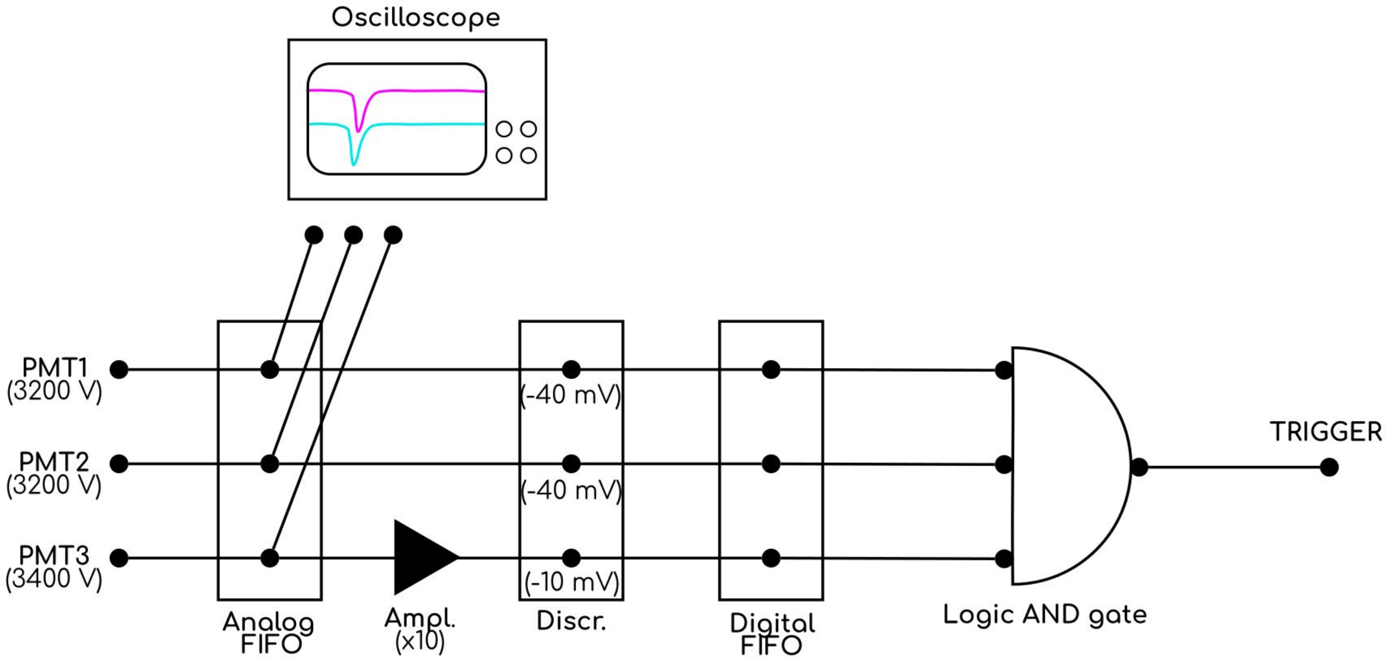


NIM Crate

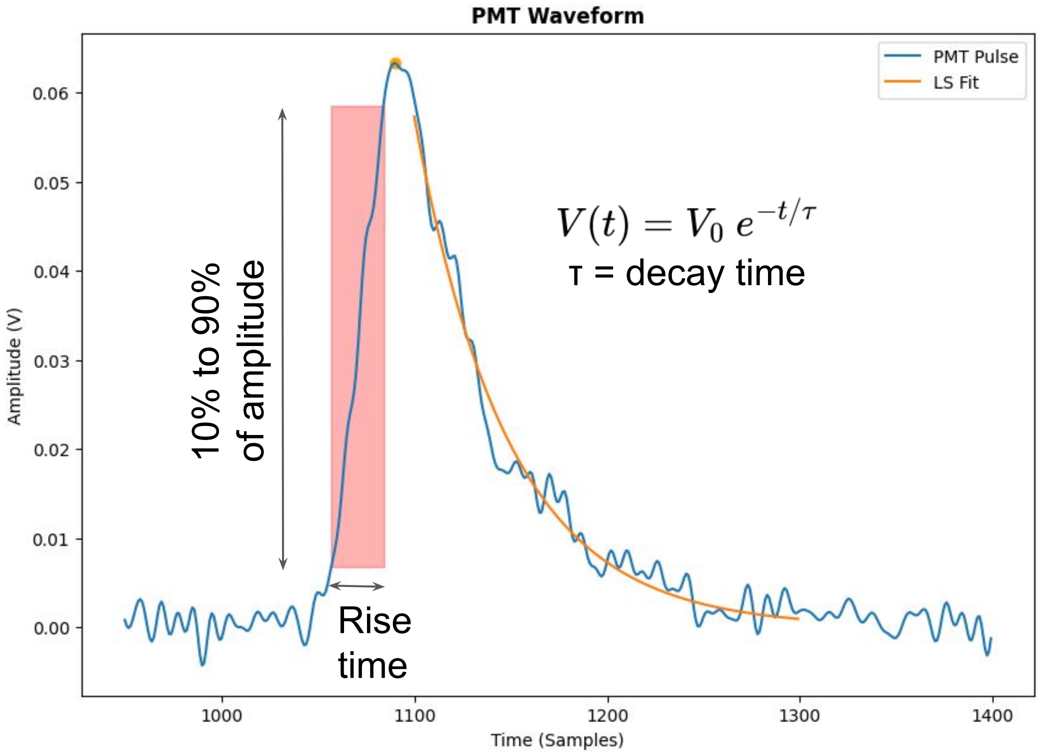


- **Signal conditioning and processing**
- **Trigger generation**

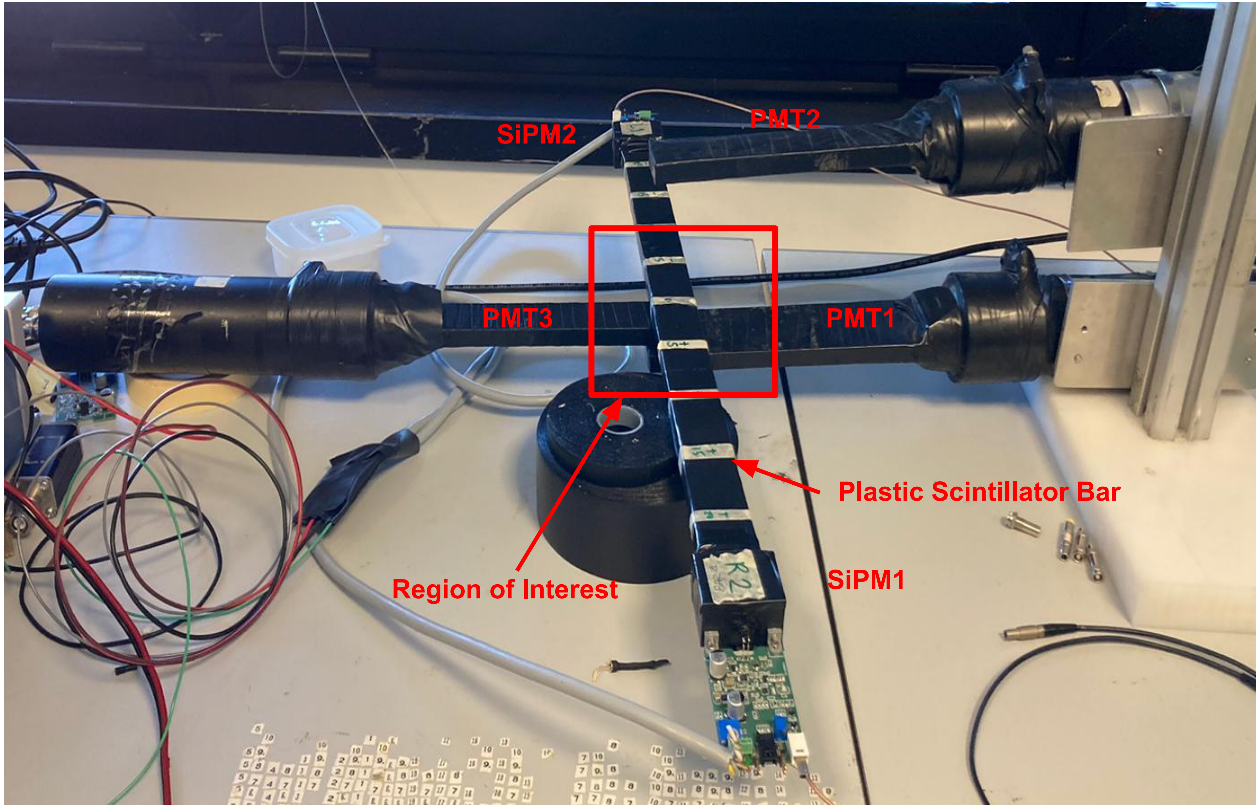
Trigger Schematics



Characterisation of PMTs



Measurement of scintillating light attenuation: experiment configuration



Collected charge ratio depends on the impinging particle position

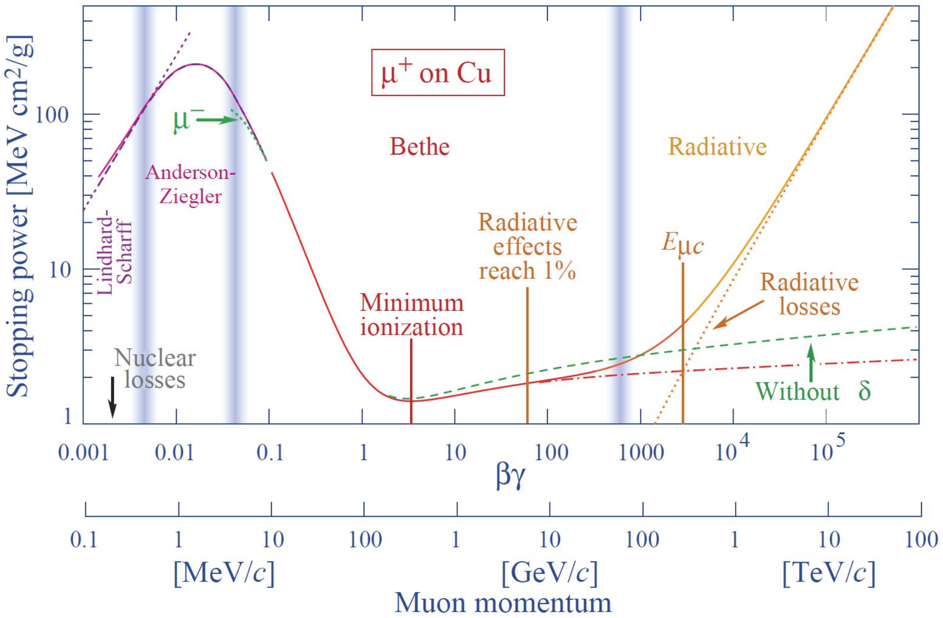
↓

Calibratig the response let us extimate the impinging position

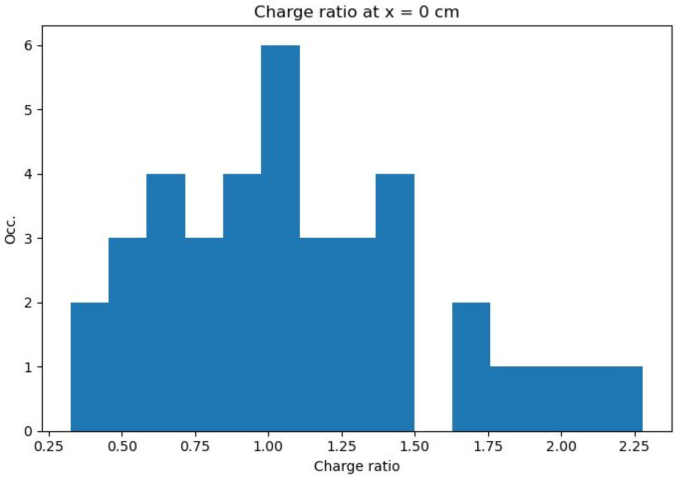
Radiation source

Naturally occurring cosmic muons are mostly in MIP (*Minimum Ionization Particle*) regime

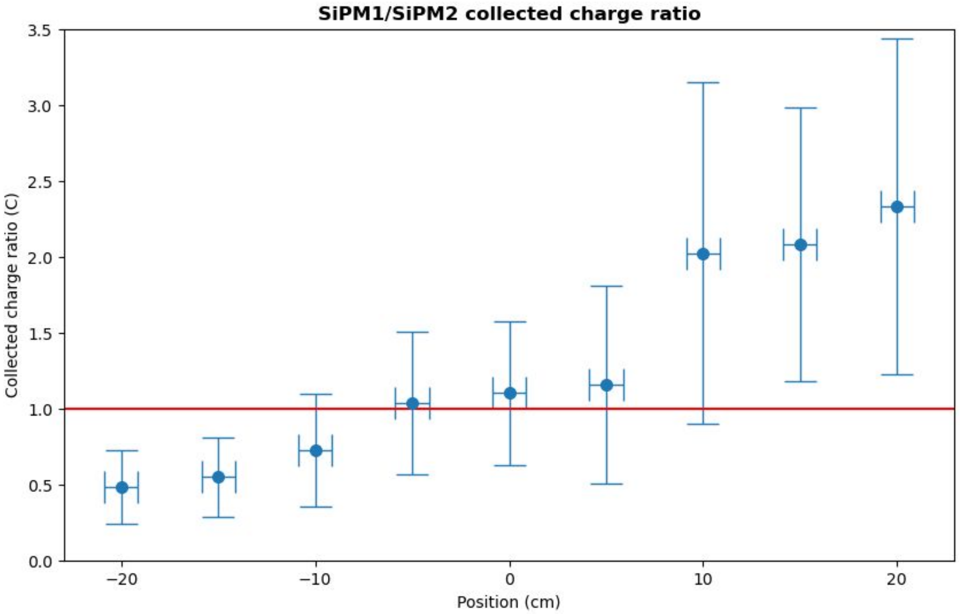
All particles deposit about
2 MeV/(g*cm^2)
-> in our scintillator ~2 MeV



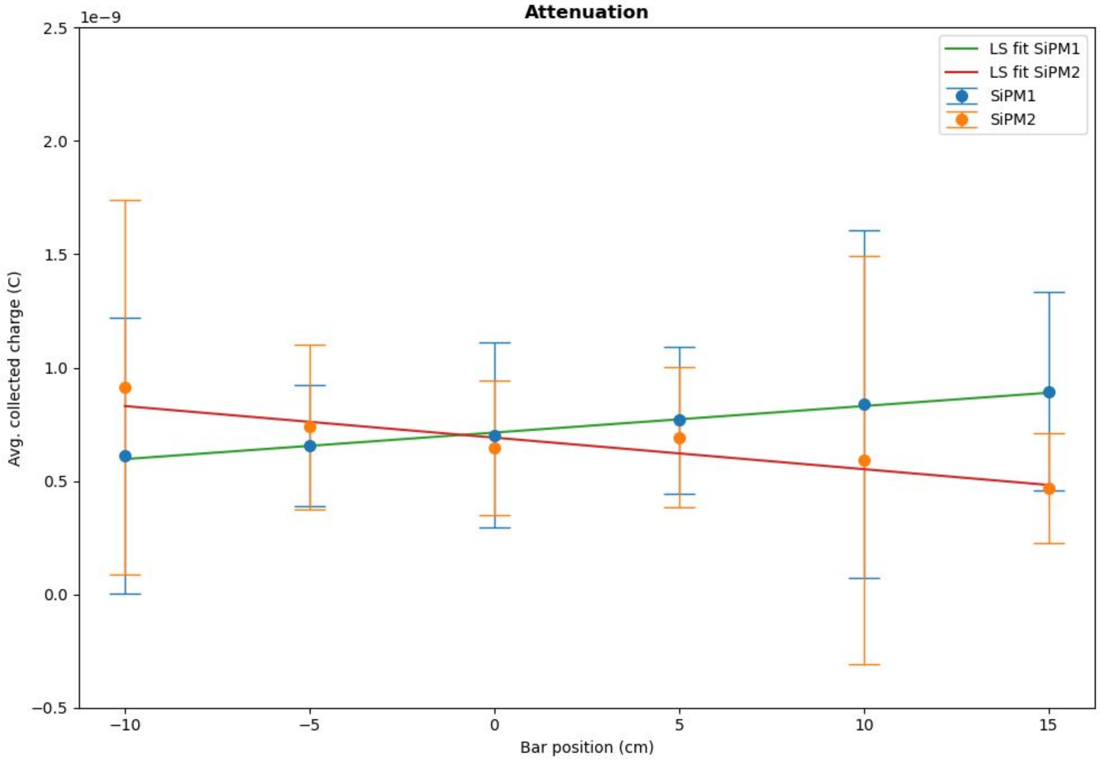
SiPM Calibration



When selecting central events signal is on average the same in both SiPM



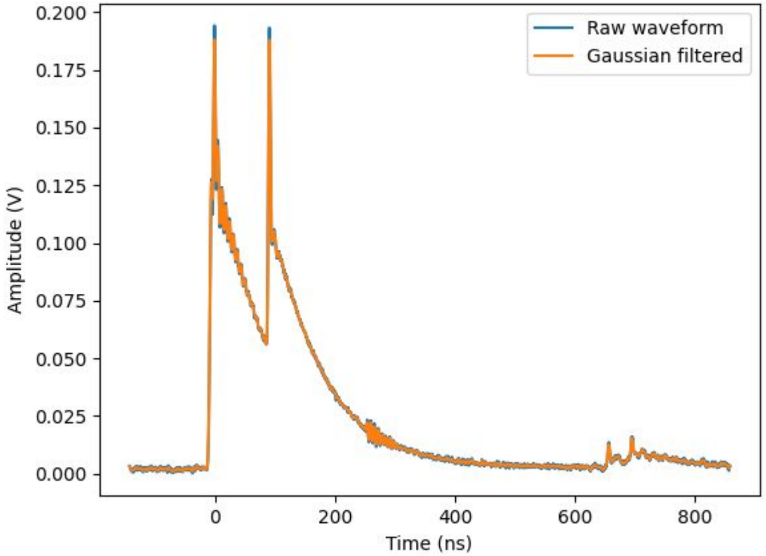
Light attenuation in plastic scintillator bar

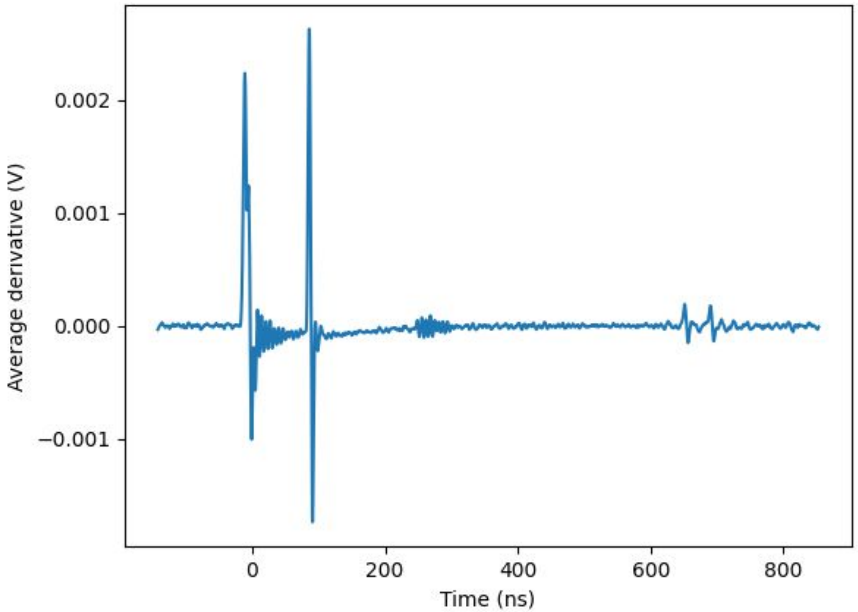


$$Q(x) = Q_0 \, e^{-x/\lambda}$$

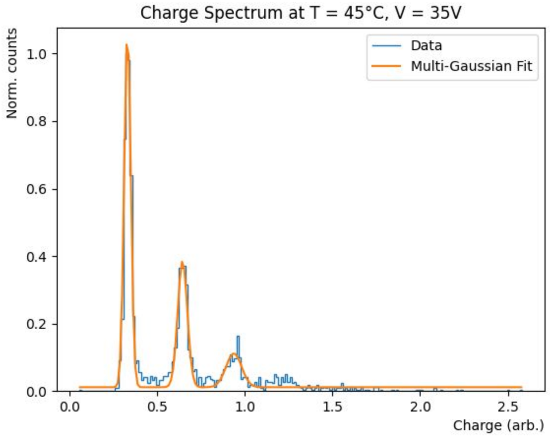
Fitted values for attenuation length:
$\lambda 1$=55 cm
$\lambda 2$=51 cm

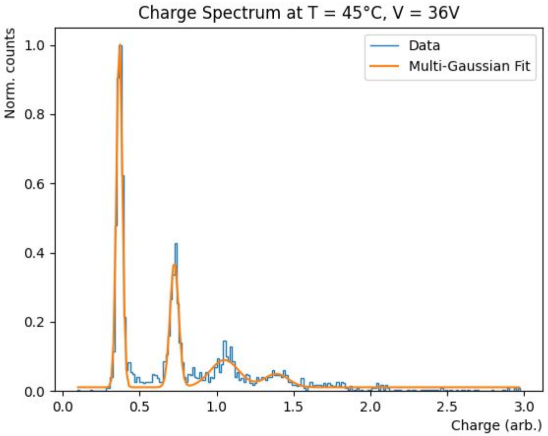
SiPM Gain - Charge Reconstruction

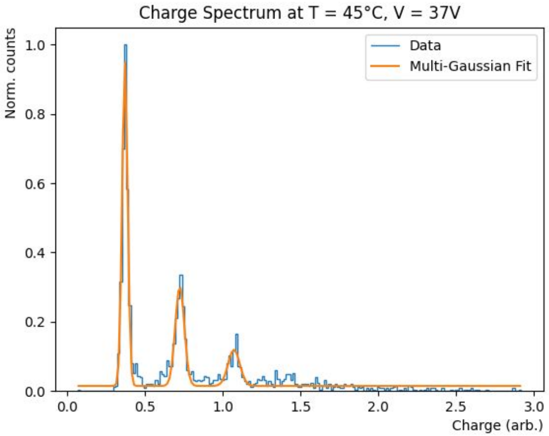


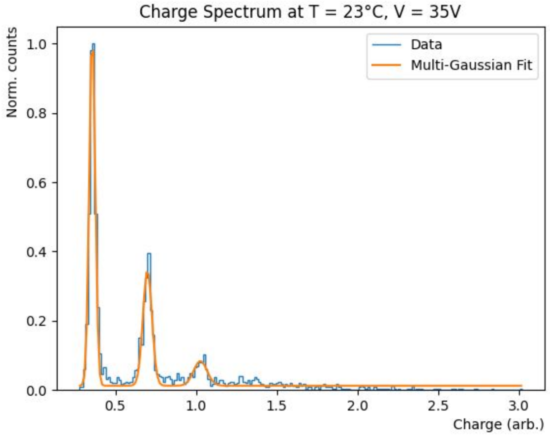


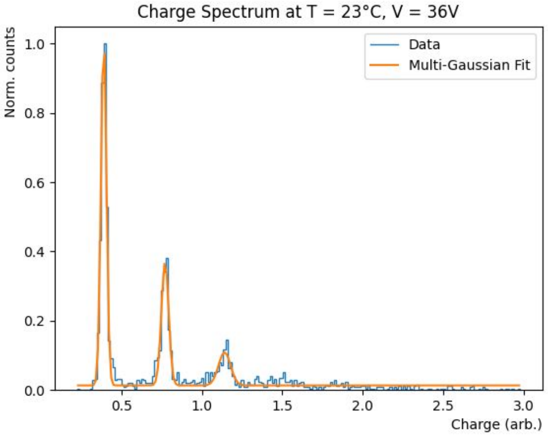
SiPM Gain - Charge Spectra

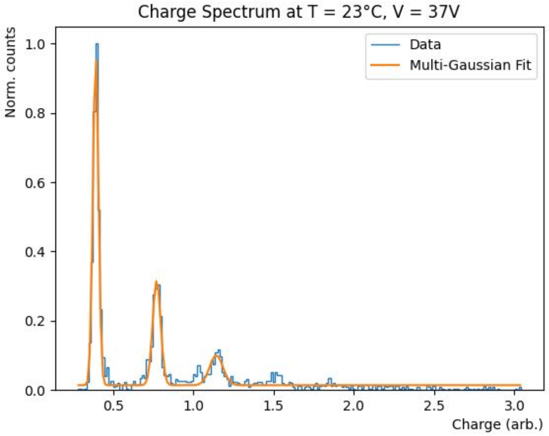




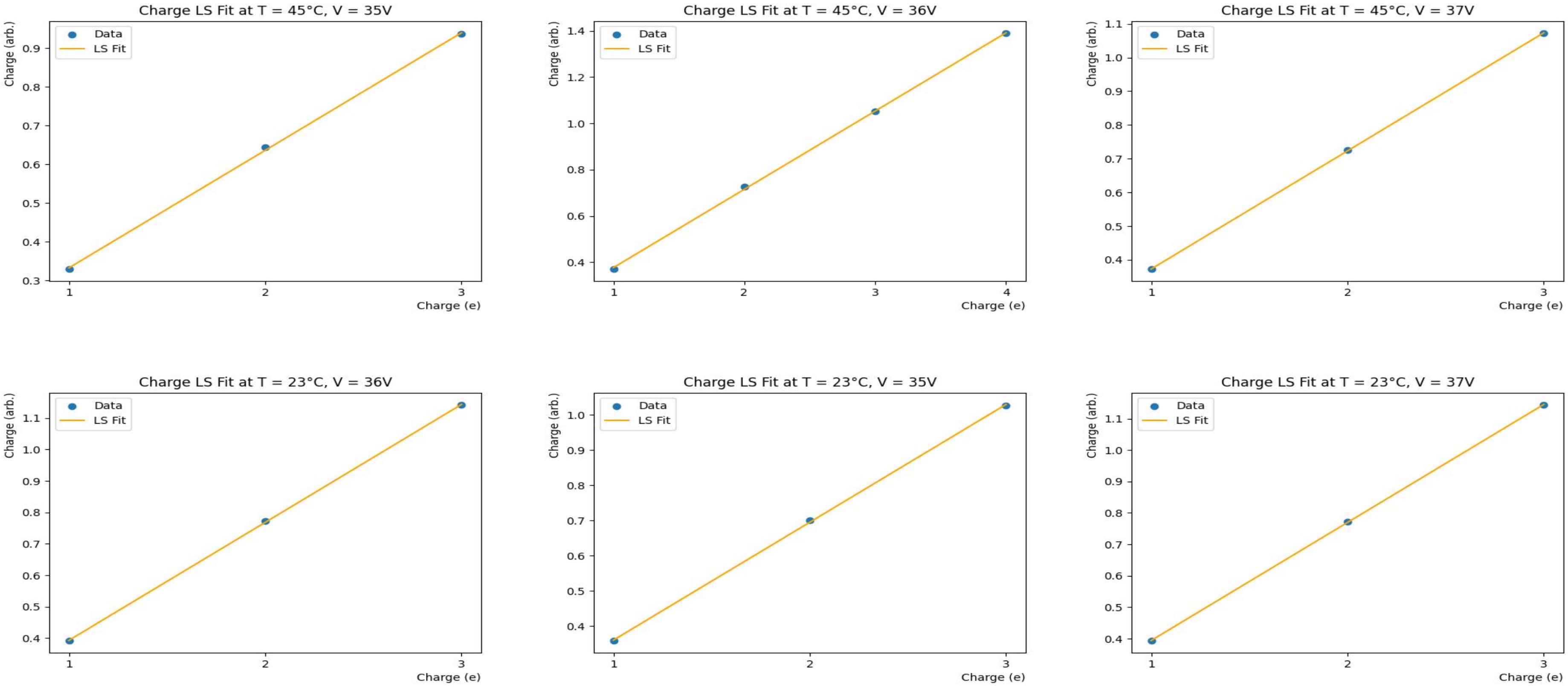




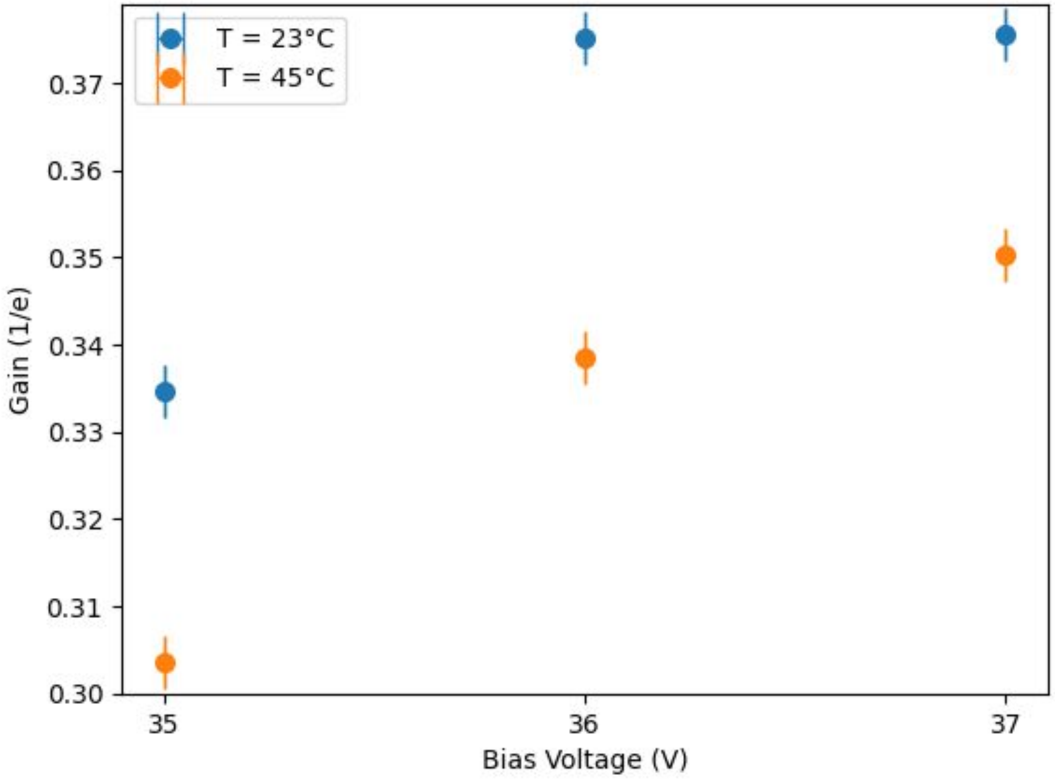




SiPM Gain - Linear Fit



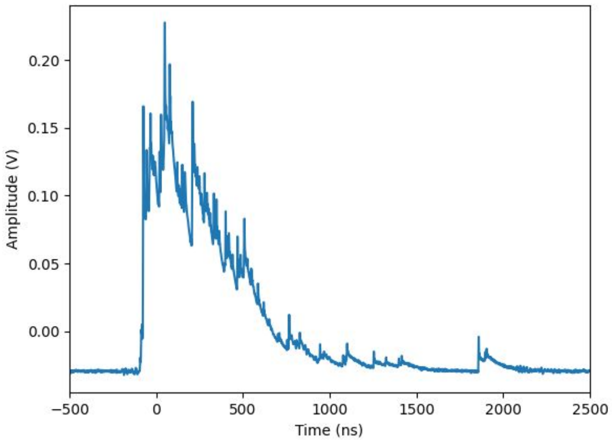
SiPM Gain



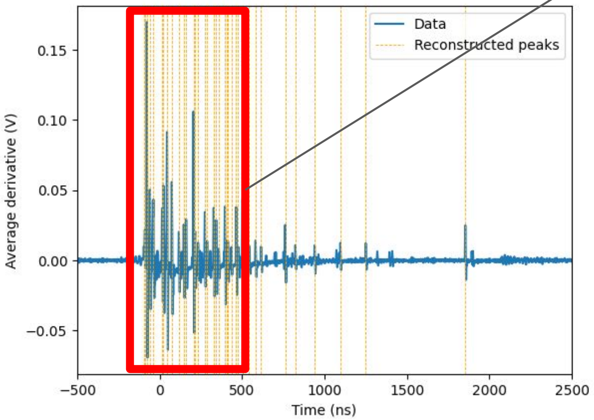
T = 23°C
T = 45°C
0.37
0.36
0.35
0.34
0.33
0.32
0.31
0.30
Gain (1/e)
35
36
37
Bias Voltage (V)

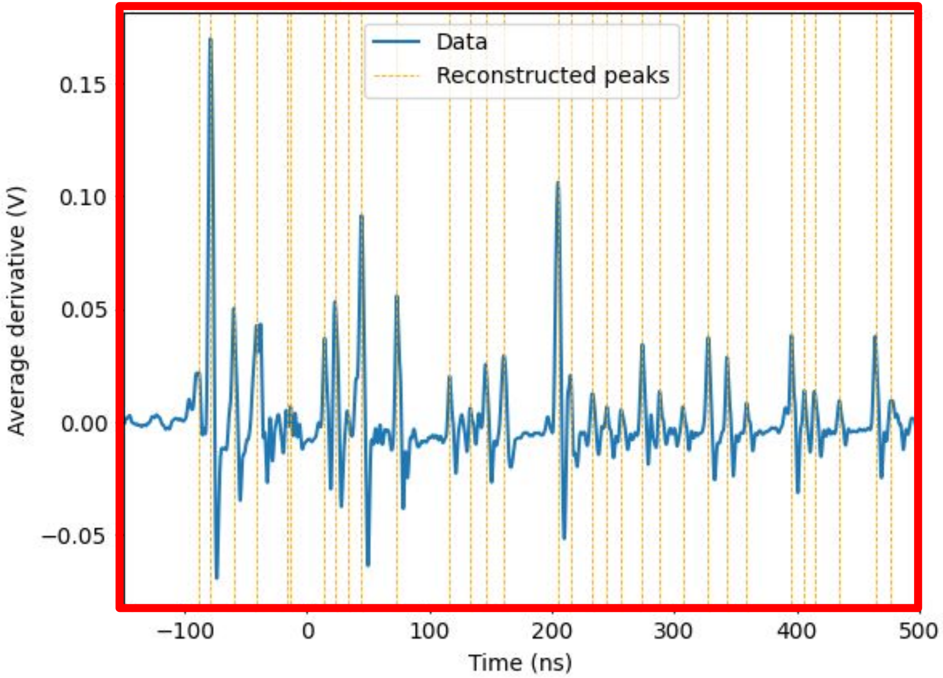
MIP response of BGO Crystal

Scintillation Signal

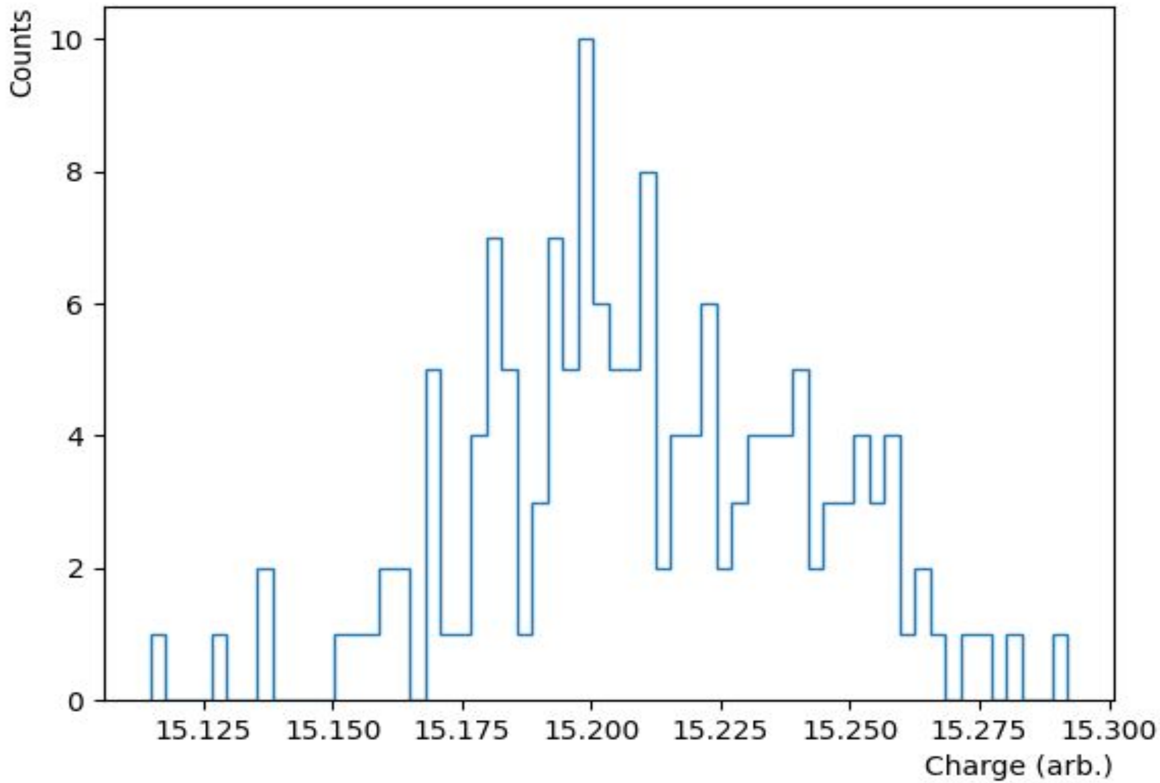


Charge Reconstruction

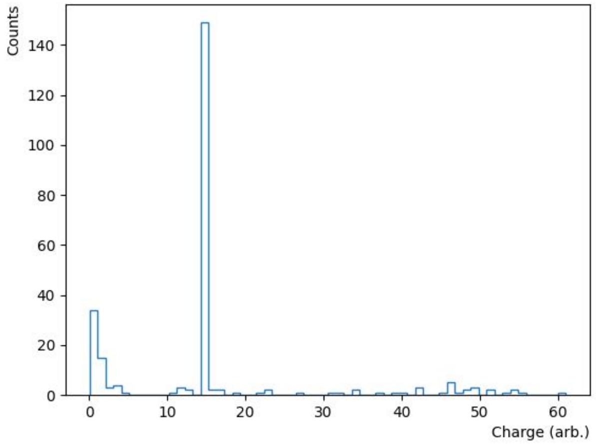




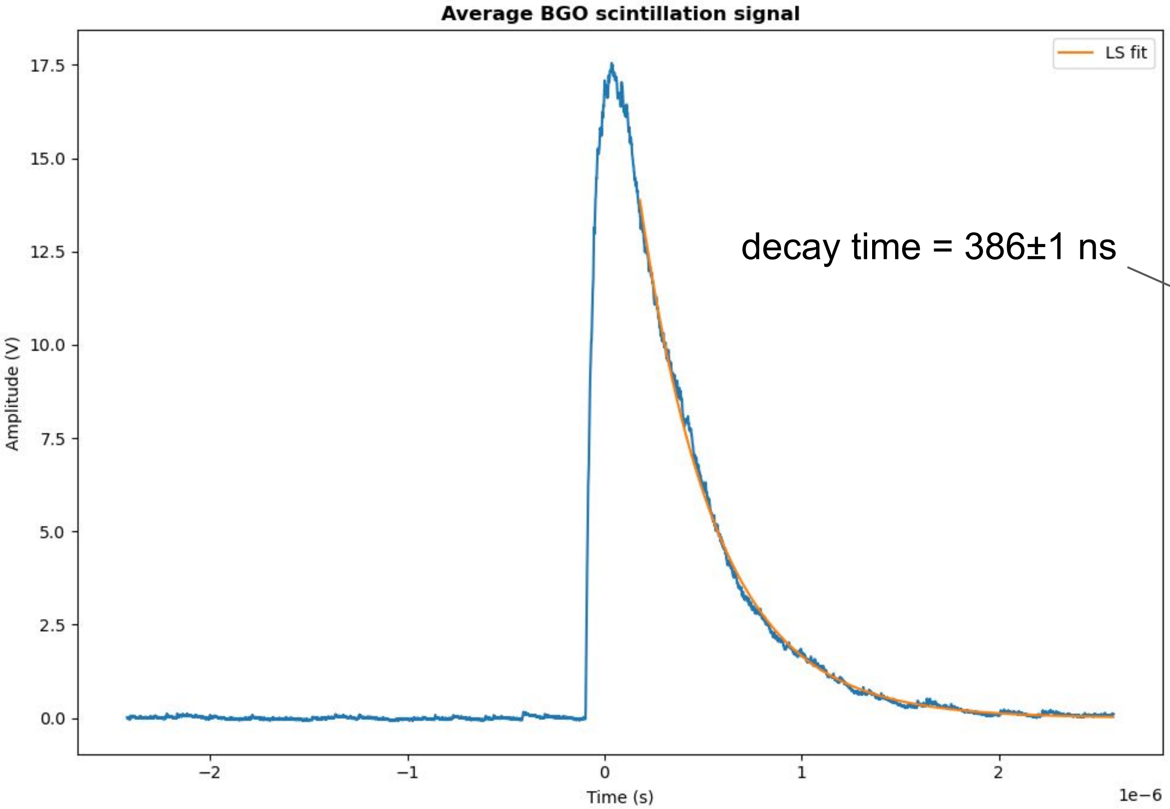
MIP response of BGO Crystal: Scintillation Spectrum



Scintillating Crystals will be used in NUSES (also in HERD) to instrument the detector calorimeter



MIP response of BGO Crystal: Decay Time



decay time = 386±1 ns

Consistent with nominal value

Stay Tuned...

WINE So Serious?!