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SiPM and Cherenkov radiation detectors in water

Anderson Fauth

State University of Campinas – UNICAMP, Brazil
fauth@unicamp.br

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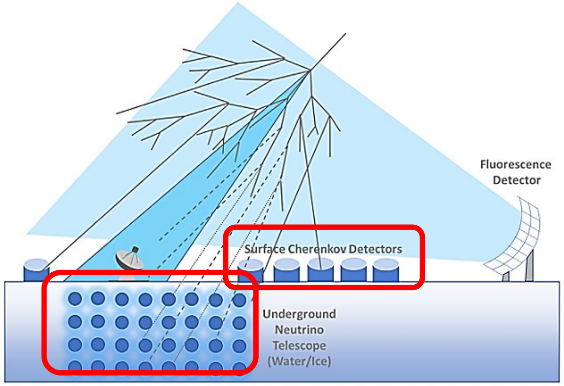
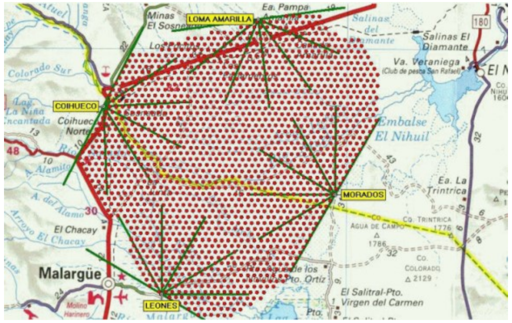
Esc Física Unìversidad Industrial de Santander, Bucaramanga, Colombia

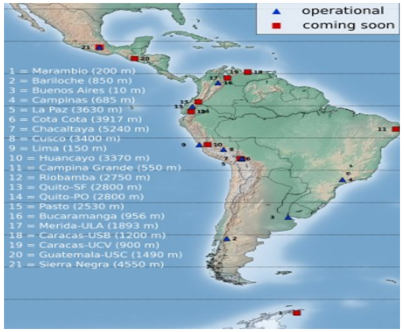
Water-Cherenkov Detectors

High Energy Cosmic Rays and Neutrinos Physics



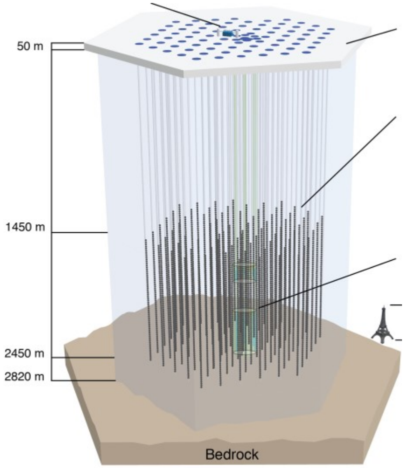


Observatory Pierre Auger



Latin American Giant Observatory

LAGO



IceCube

High Altitude Water Cherenkov Observatory

HAWC

The Large High Altitude Air Shower Observatory

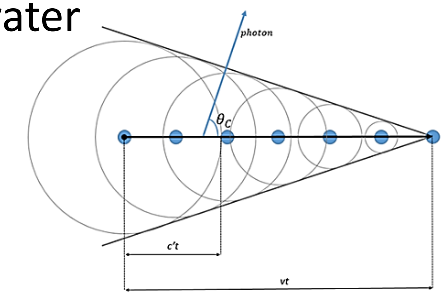
LHAASO

Water-Cherenkov Detector

Cherenkov radiation in water

$n_{water} = 1{,}33$

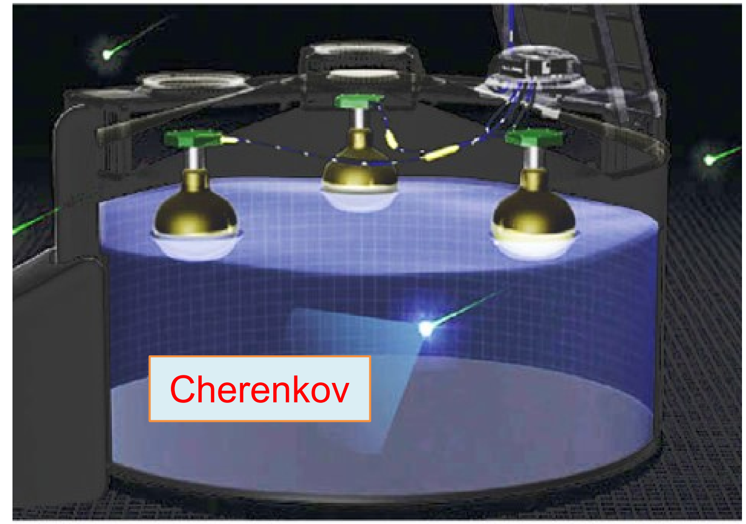
$\theta_{max} = arccos\left(\frac{1}{n}\right) = 41{,}3^o$



minimum values to produce Cherenkov radiation

	P (MeV/c)	E (MeV/c²)
Muon	121	160
Electron	0.58	0.77

- 3 PMTs **9”** Photonis XP1805
- 2000 Volts DC power supply
- 1140 liters of ultrapure water
- Tyvek liner



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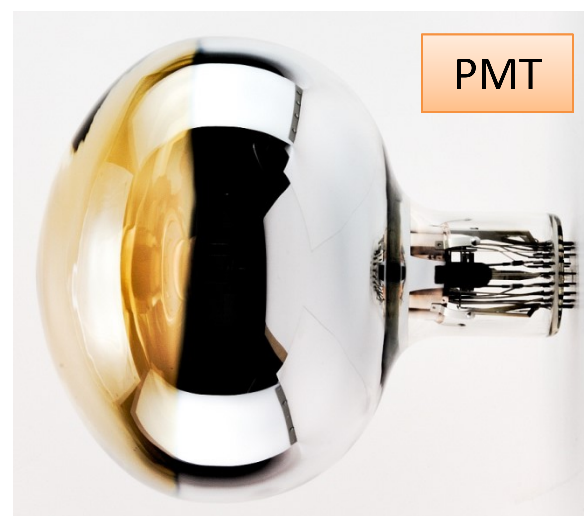
SiPM

- **Low bias voltage** (< 60 V)
- High Gain: 10^6 order
- **High Quantum Efficiency** (~ 50%)
- Geiger mode operation provides **sub-nanosecond timing**
- Excellent SNR, high single photon resolution
- Low radioactivity
- **Not damaged when exposed to light**
- **No aging**

- **But SMALL!**

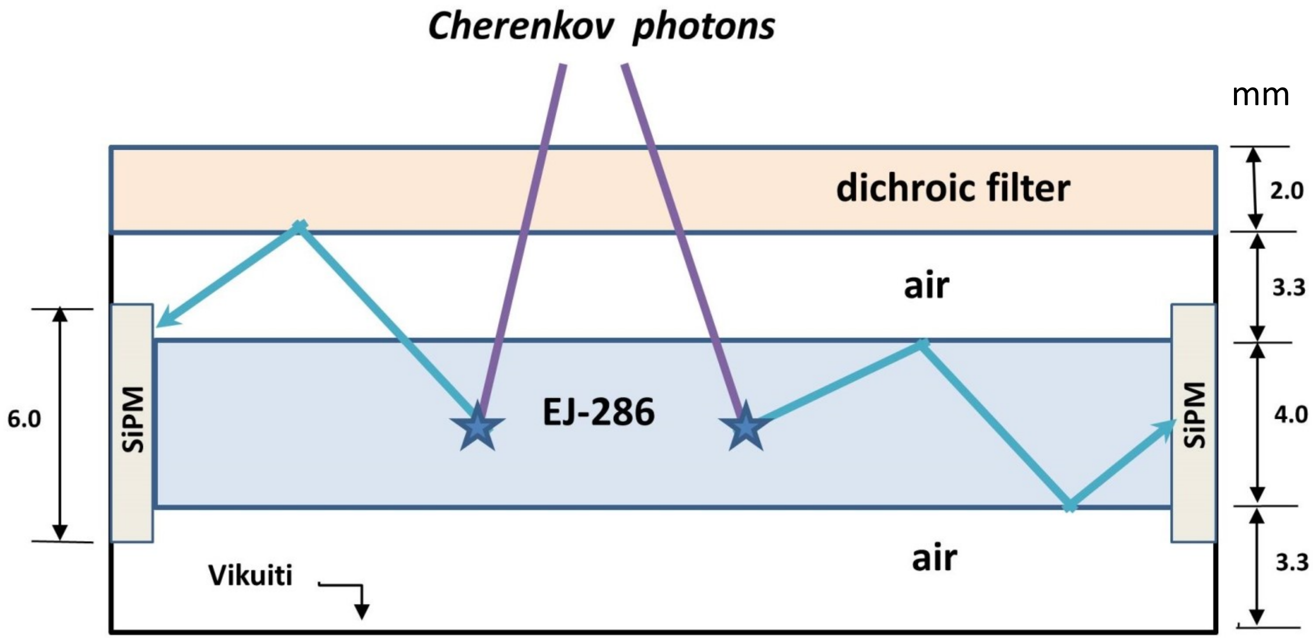
SiPM



C-Arapuca

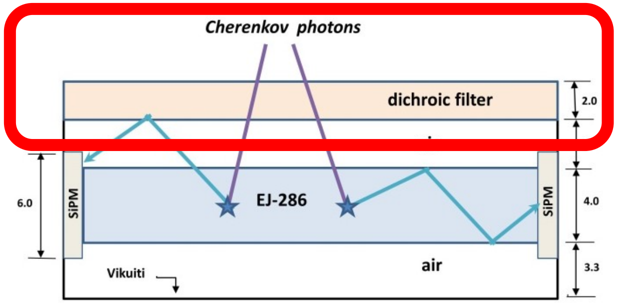
C = Cherenkov

Arapuca is a word from the Tupi-Guarani language of the native peoples of Brazil, meaning a device used to trap wild animals

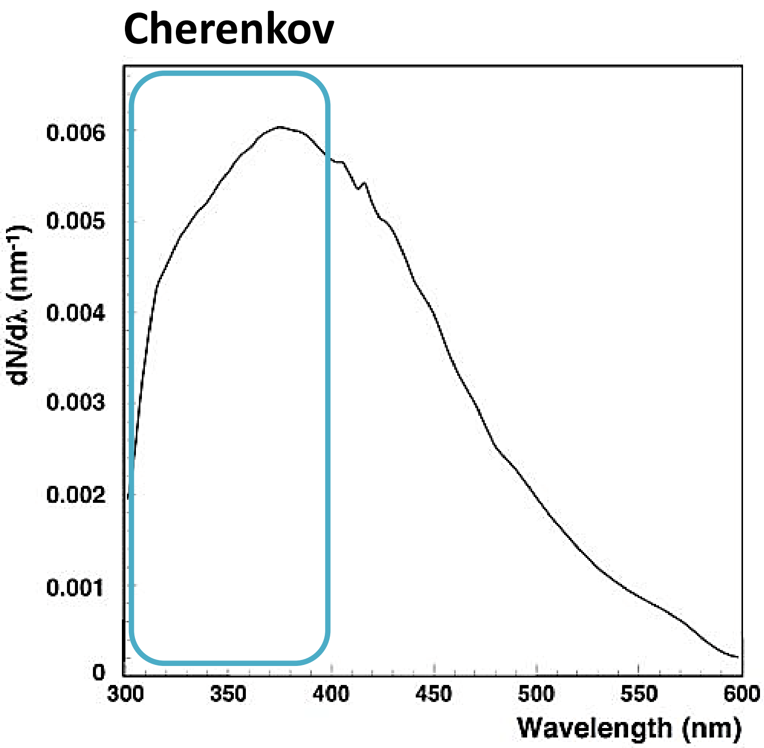


- dichroic shortpass 400 nm Omega filter
- wavelength shifter Eljen EJ-286
- eight SiPMs Hamamatsu S13360-6050VE (6x6mm)
- Vikuit 3M

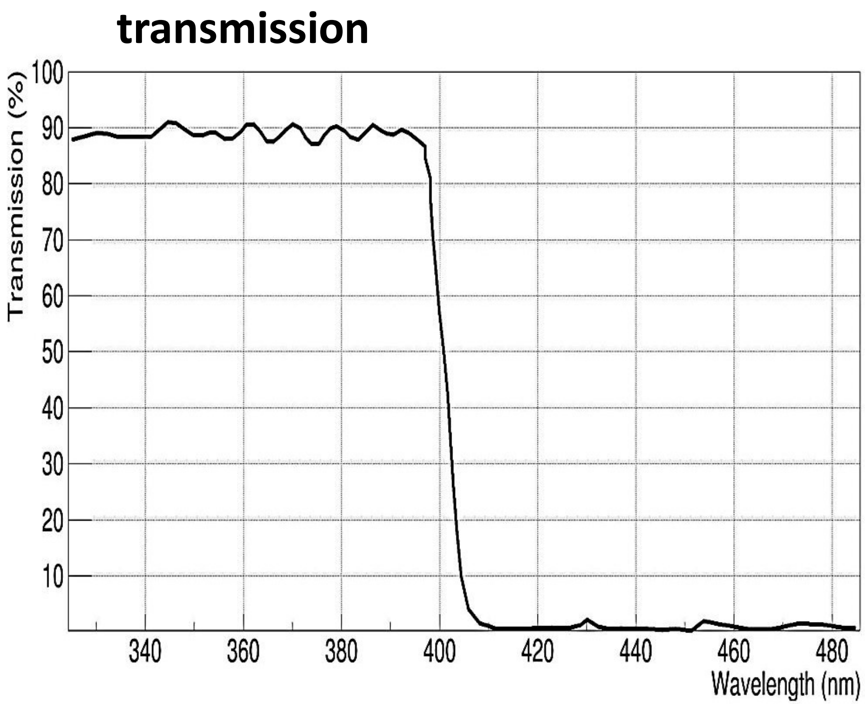
C-Arapuca window



Cherenkov photons with wavelengths up to 400 nm enter the box.

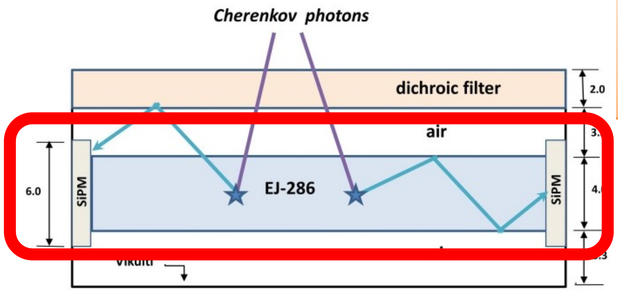


Cherenkov radiation spectrum in water



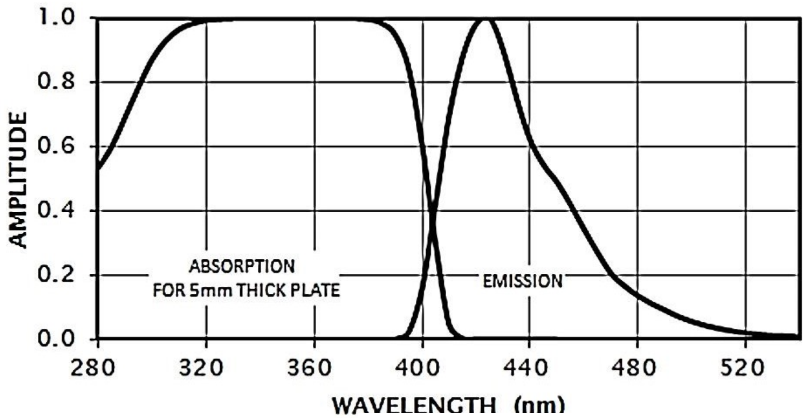
Dichroic filter **transmission**

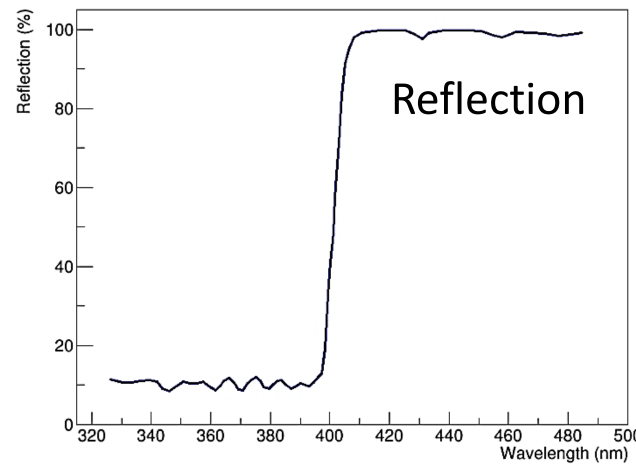
C-Arapuca wavelength shifter



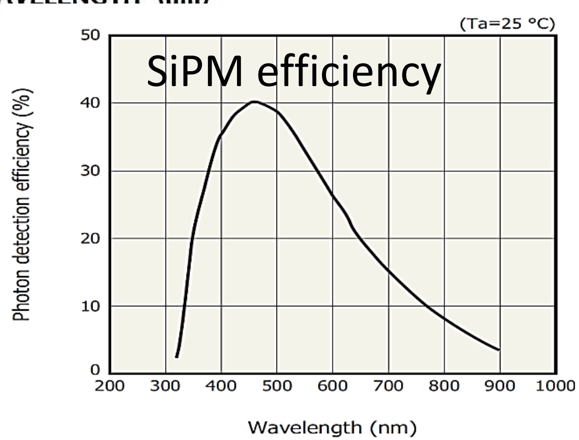
- The EJ-286 absorbs photons and emits others with wavelengths above 400 nm;
- The EJ-286 is also a light guide that directs the photons to the SiPMs;
- The photons that do not reach the SiPMs directly are reflected by the dichroic filter and the Vikuit and have additional chances to reach the SiPMs.

EJ-286 Absorption Emission



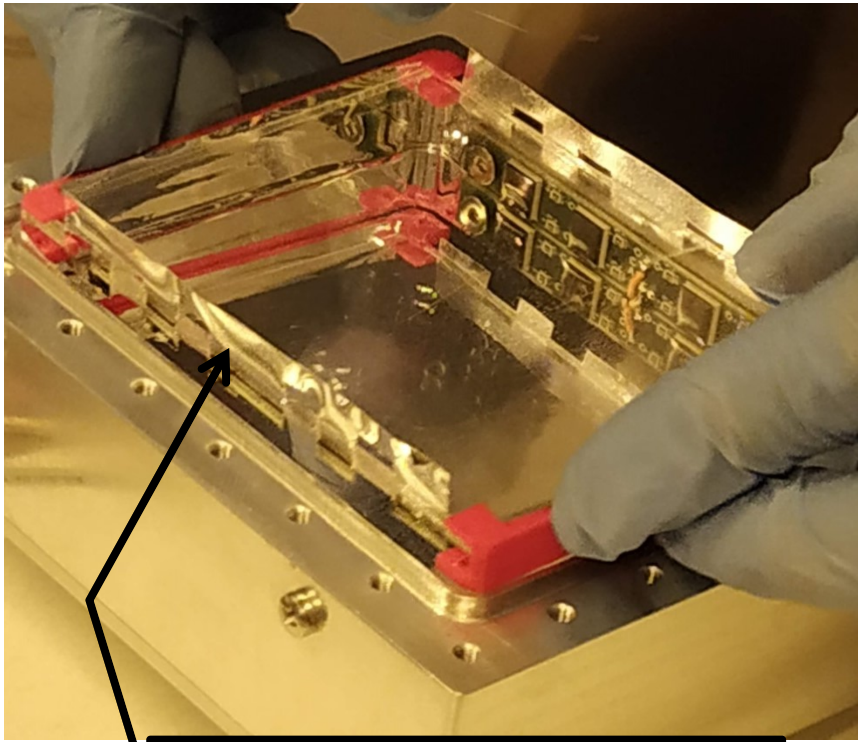


Dichroic Reflection

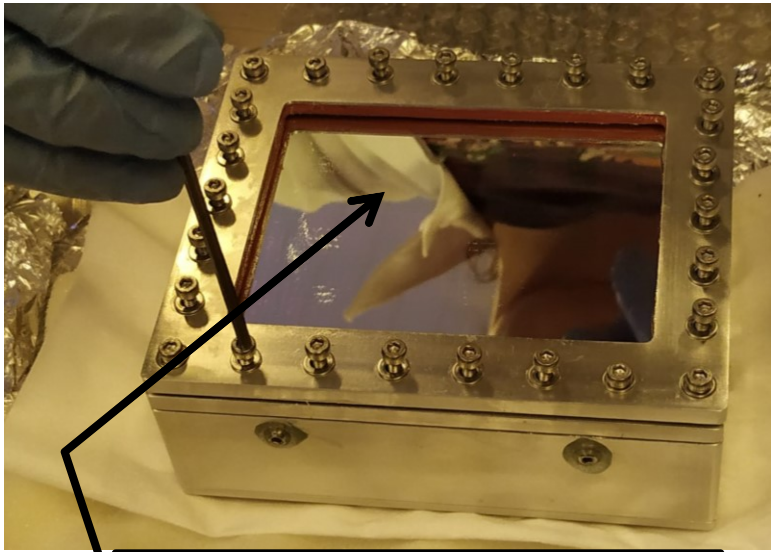


- The EJ-286 emits in the region of maximum efficiency of the SiPM.

C-Arapuca assembling

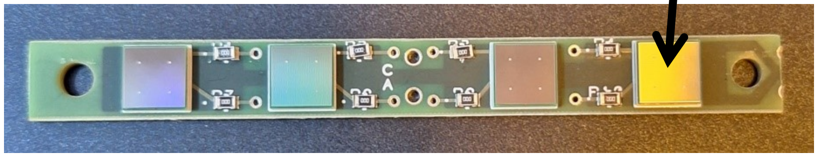


Wavelength shifter EJ-286



Omega dichroic filter

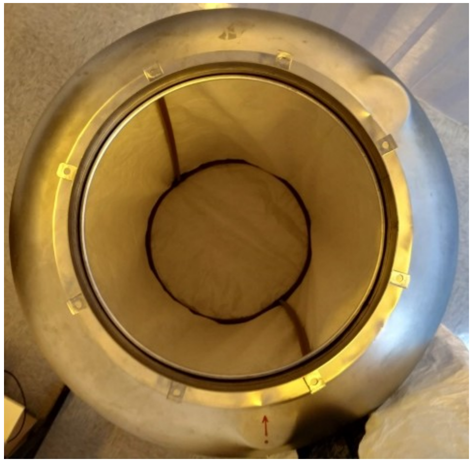
Hamamatsu S13360-6050VE

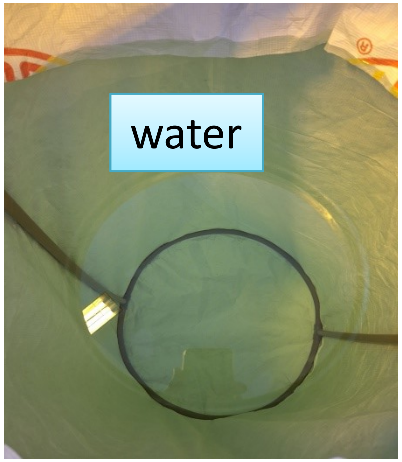


The metal box is made of aluminum with dimensions of (100.0×130.0×30.0) mm and a window of (70.0×93.0) mm.

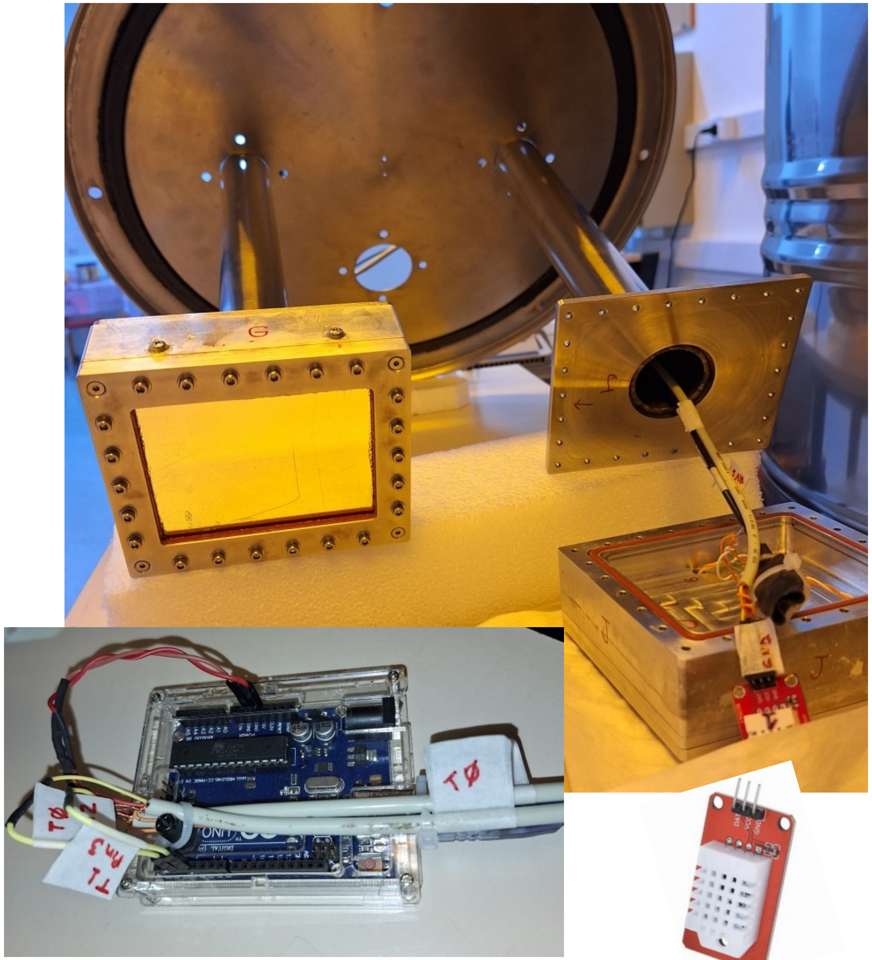
The Tank

- Two C-Arapuca prototypes were installed inside a stainless-steel tank filled with **550 liters** of ultrapure deionized water with an impedance of **18.25 MΩ**.
- A bag made of **Tyvek™**, an excellent material for diffuse photon reflection, was placed at the bottom and along the side walls of the tank to reflect Cherenkov photons generated in the downward direction.

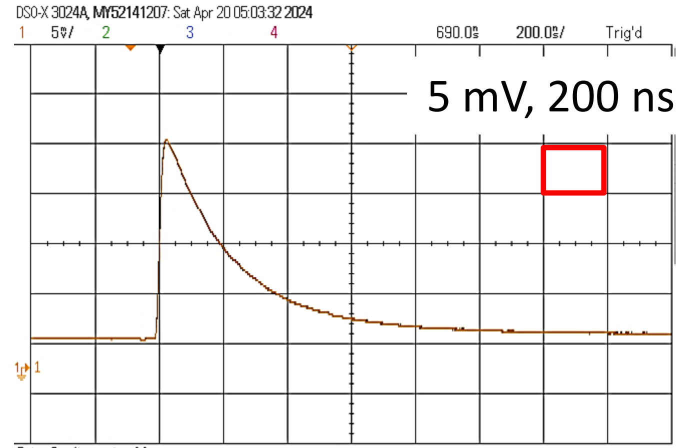




Before installation in the tank



We used an Arduino UNO with an AM2302 DHT22
temperature and humidity sensor installed inside the C-Arapuca.



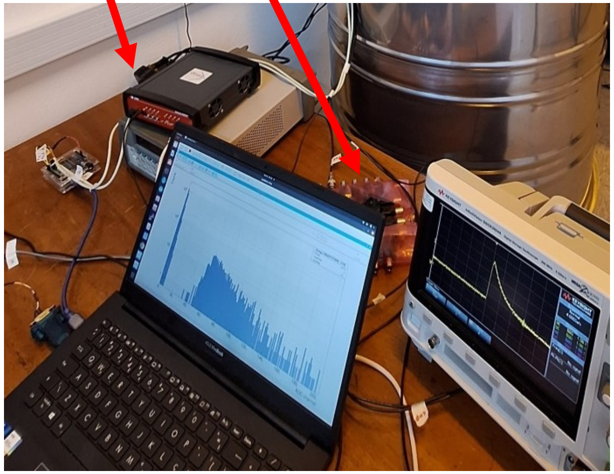
C-Arapuca's pulse
with a 395 nm UV **LED** in the dark box.

Data acquisition

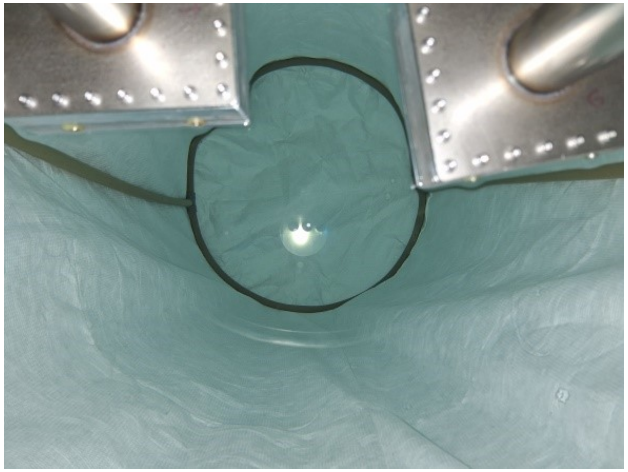
- A **plastic scintillator** (39x39 cm²) above the tank and another below
- pulse coincidence within 80 ns defines the data acquisition **trigger**
- trigger (**vertical muons**) rate = 0.4 Hz

CAEN SpA digitizer, model DT5730S, **14-bit, 500 MS/s**

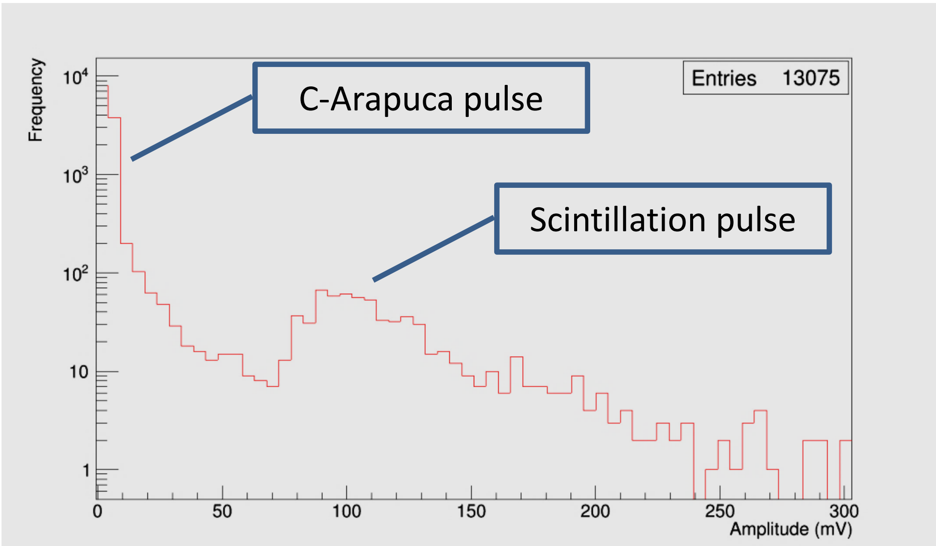
APSAIA module produced by AGE Scientific srl (**amplifier 20x or 40x** and **power supply 30-60 VDC**)

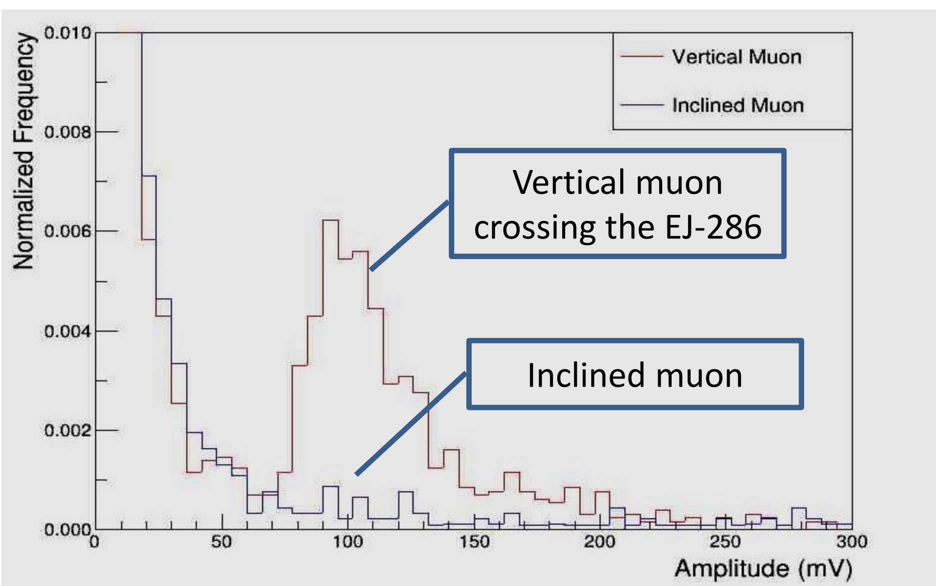


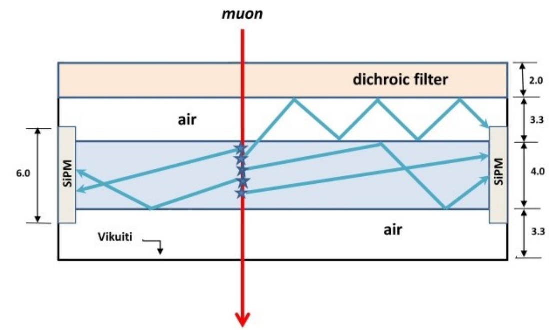
Jaci and Guaraci prototypes



WLS scintillation pulse





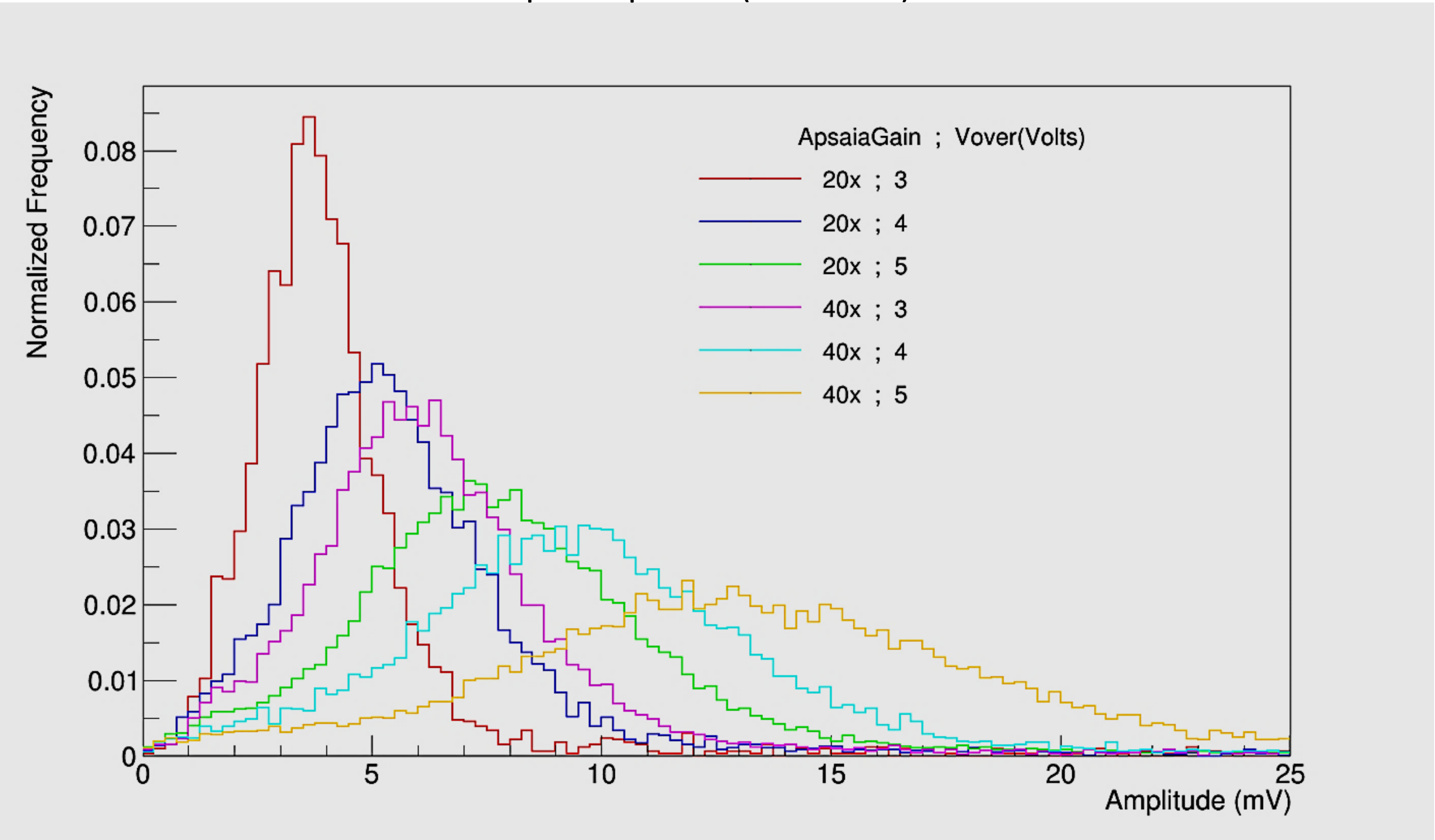


Vertical muon

Inclined muon

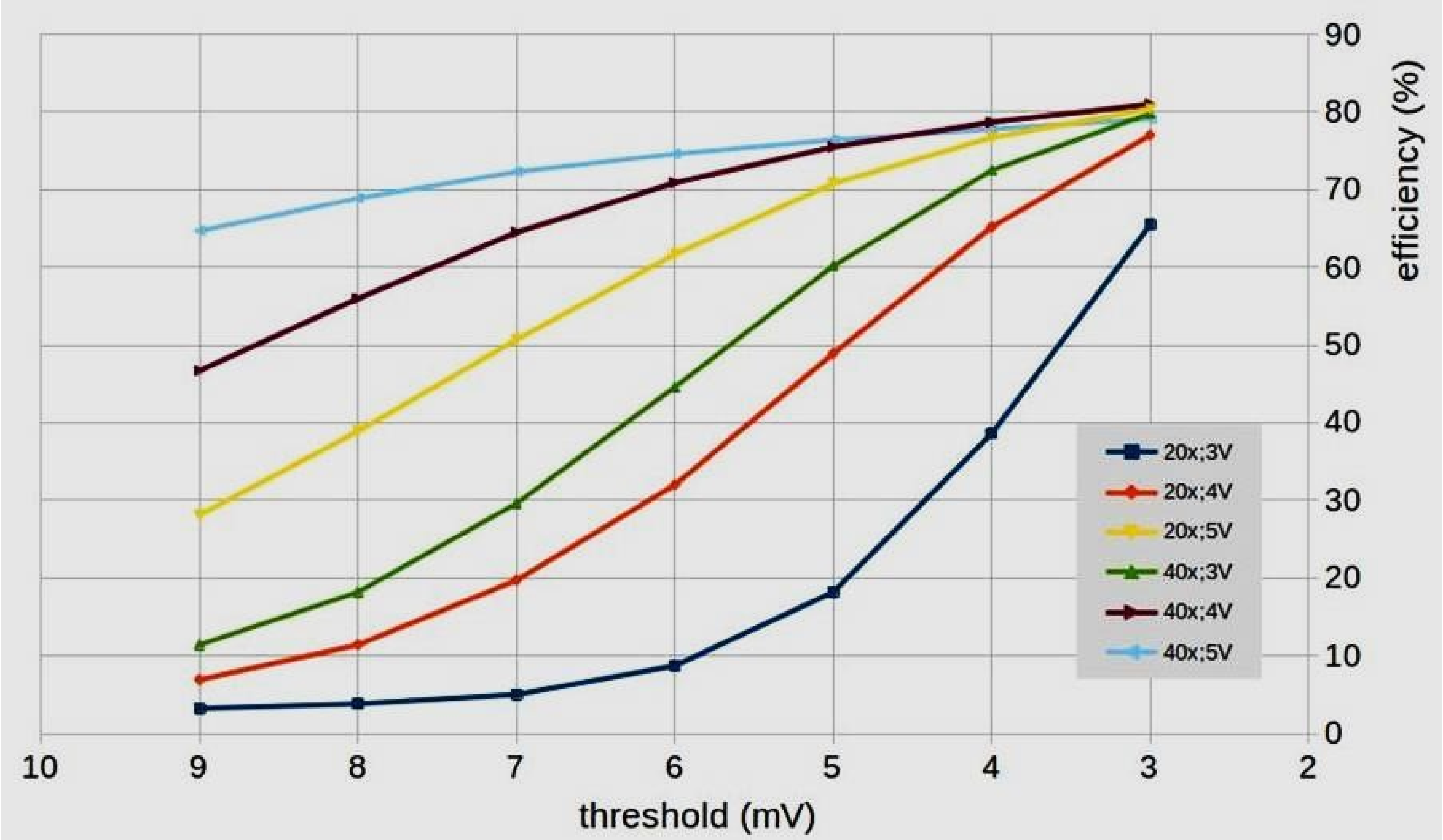
C-Arapuca amplitude spectra

- Two Apsaia amplifier gains and three voltages over the breakdown
- Sum of the two C-Arapucas pulses (~ 5” PMT)

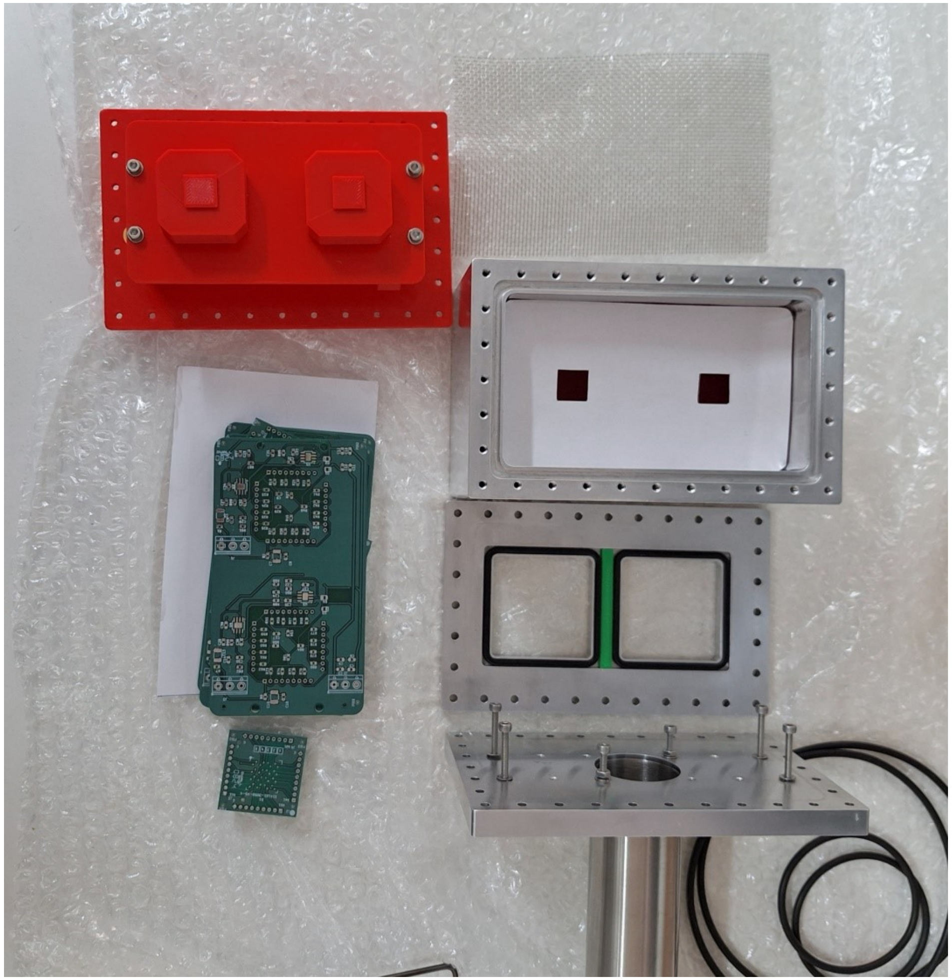


Efficiency ε

$$\varepsilon_{threshod} = \frac{N_{>threshod}}{N_{trigger} - N_{accidental}}$$

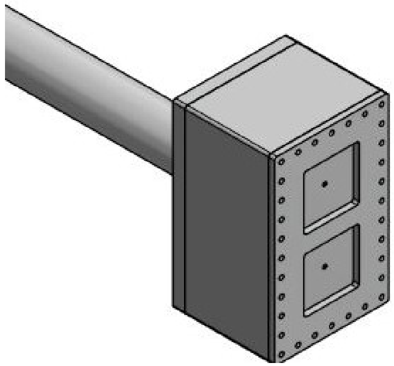


C-Arapuca version2



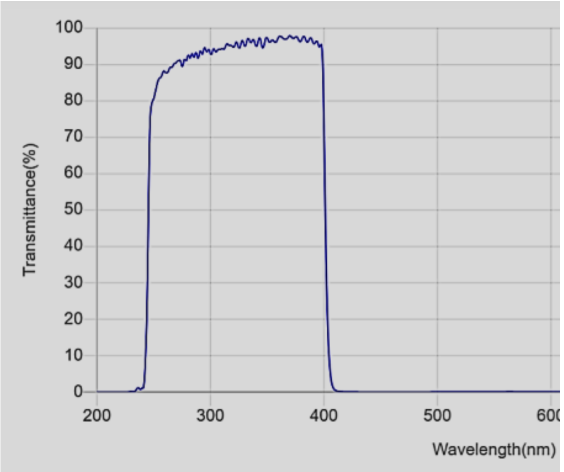
- two **dichroic filters** by Ashai **400 nm**, **50 x 50** x 1 mm^3
- **quartz window 127 x 72** x 2 **mm^3**
- wavelength shifter with **paint** WLS Eljen EJ-298
- Two SiPM **arrays** Hamamatsu , (4x4) **13 x 13** mm^2 S14161-3050HS-04
- Electronics, amplifier inside the C-Arapuca (motherboard and daughterboard)

C-Arapuca version 2

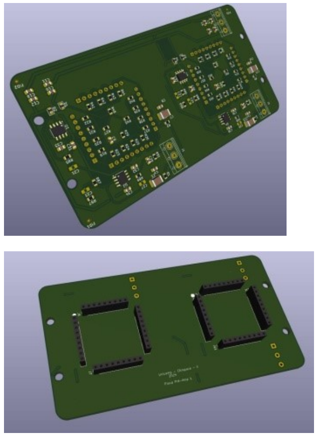


Drawing of version 2

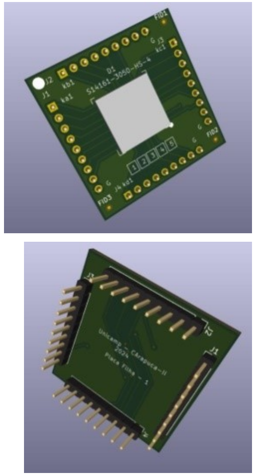
SiPM array
Hamamatsu
S14161-3050HS-04



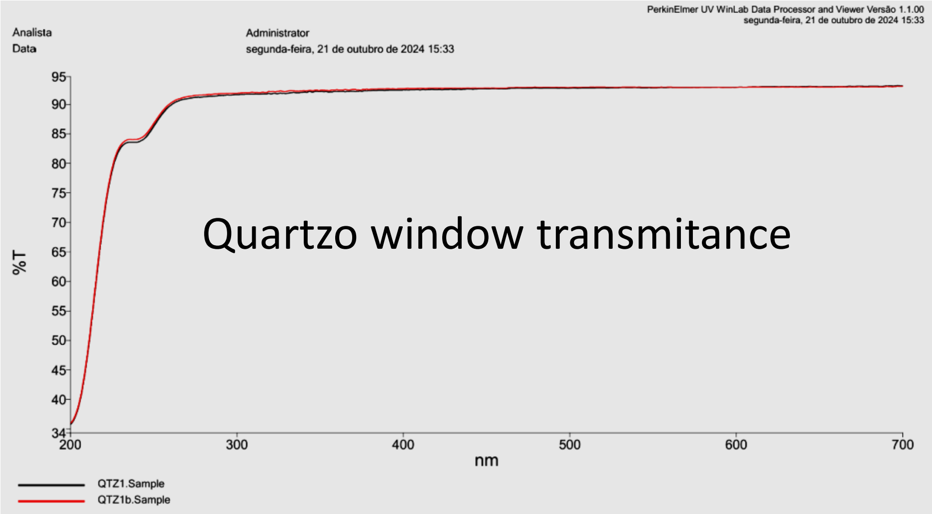
transmission spectrum
of the Asahi filter



Preamplifier board
(motherboard)



SiPM board
(daughterboard)

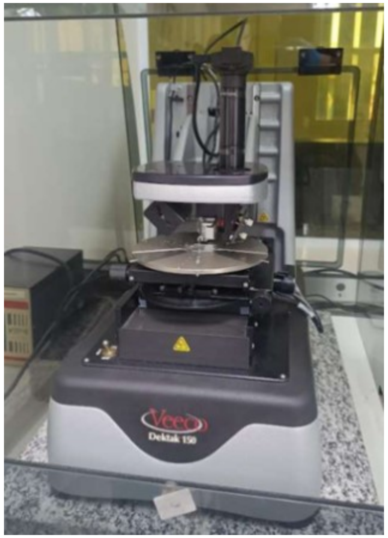


PerkinElmer UV
Multiuser Lab – IFGW UNICAMP

Painting the wavelenght shifter

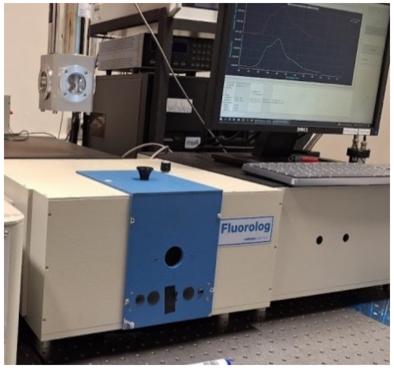
Wavelength shifting paint EJ-298, ~ 50 μm

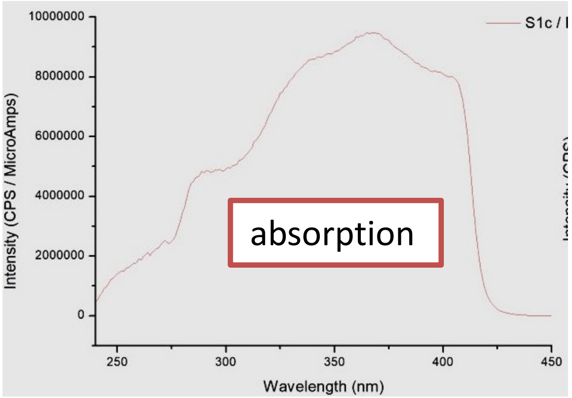
Blade-Coating Equipment
https://www.autocoat.com.br/en
Startup at UNICAMP

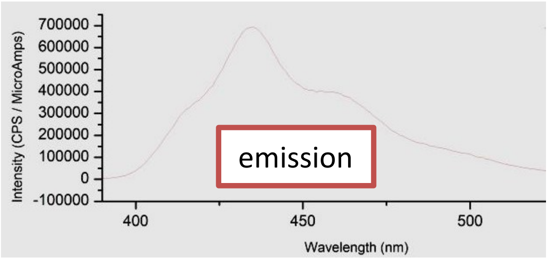


DeKTaK 150 Profilometer
https://sites.ifi.unicamp.br/lamult/
Multiuser Lab – IFGW UNICAMP

Fluorimetro Horiba
Chemistry Institute
UNICAMP







Ana Paula Mendonça –pos-doc Lab. Leptons

Conclusion

- We demonstrate that the C-Arapuca photon detection concept is effective, achieving a counting efficiency of approximately 80% for muon detection with the studied tank and prototype.
- The C-Arapuca design compensates for the reduced area of SiPMs by increasing the effective area of the photodetector.
- The C-Arapuca presents a new approach to detecting Cherenkov photons in water, offering advantages such as low-voltage operation, compact size and design flexibility.
- Future WCDs could use this new concept in cosmic ray and astrophysics experiments.
- We are planning to build the next prototype of the C-Arapuca with a WLS coating instead of the bar and a new front-end pre-amplifier board.

Tank you for your attention

I would like to thank **Universidad Industrial de Santander** for their wonderful hospitality and the organization of the Encuentro CyTED LAGO INDICA, especially **Prof. Luis Nunes**.

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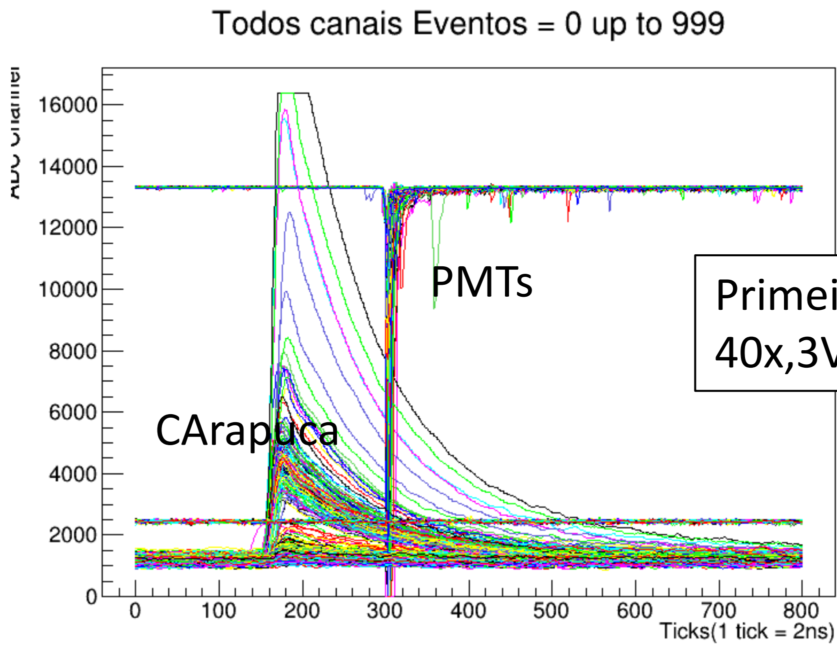
Backup slides



Primeiros 1000 pulsos
40x,3V

$$\varepsilon_{threshod} = \frac{N_{threshod}}{N_{trigger} - N_{accidental}},$$

$$N_{accidental} = 2\ C_1 C_2\ T = 0.000144\ Hz$$

$$C_1 = C_2 = 30\ Hz, T = 80ns$$

$$N_{trigger} = 0.4 \text{ Hz}$$

Jaci’s breakdown voltage is 52.1 V DC and Guaraci’s is 52.2 V DC for the room temperature of 25°C.