Multi-PMT for SWGO

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On behalf of the SWGO Naples group

The multi-PMT

Strong experience at INFN Napoli in developing and building multi-PMTs for astroparticle experiments

KM3Net DoM

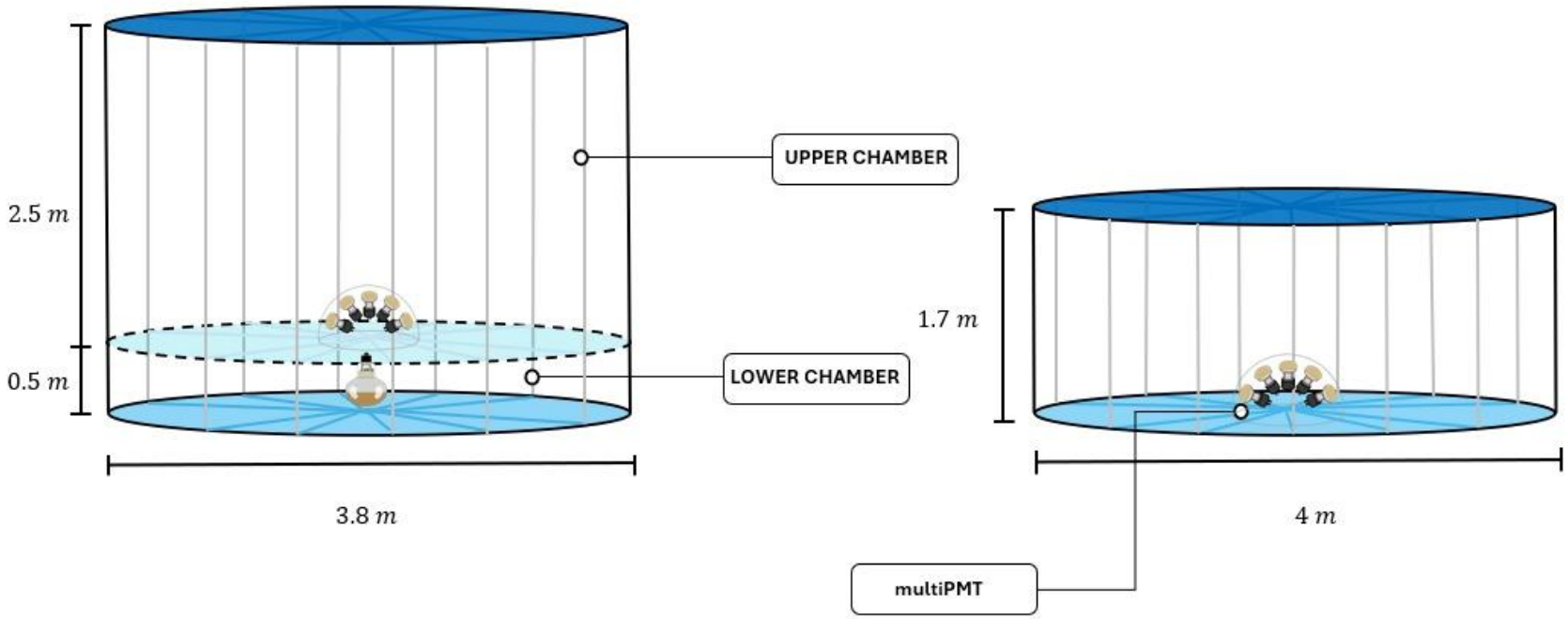
Hyper-K mPMT

SWGO multi-PMT

Why a multi-PMT?

- Intrinsic directional sensitivity
- Increased timing resolution
- More uniformity among the detectors
- More reliable in the long term
- Cost optimization
- Possibility to adapt the system to different environments

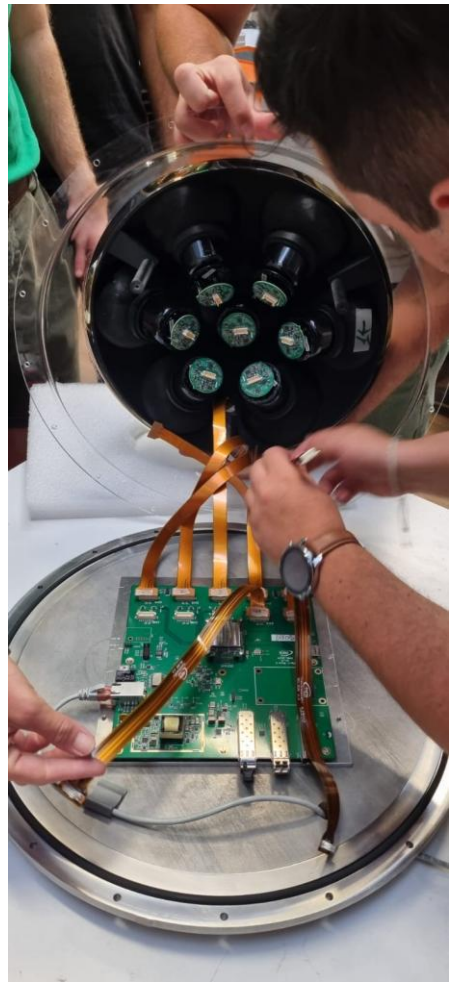
The multi-PMT: flexibility



Design is flexible, possibility to adapt the multi-PMT in any possible tank design

The recipe of the design

- A watertight vessel
- A trasparent optical windows
- Optical coupling
- Low power electronics
- Photosensors



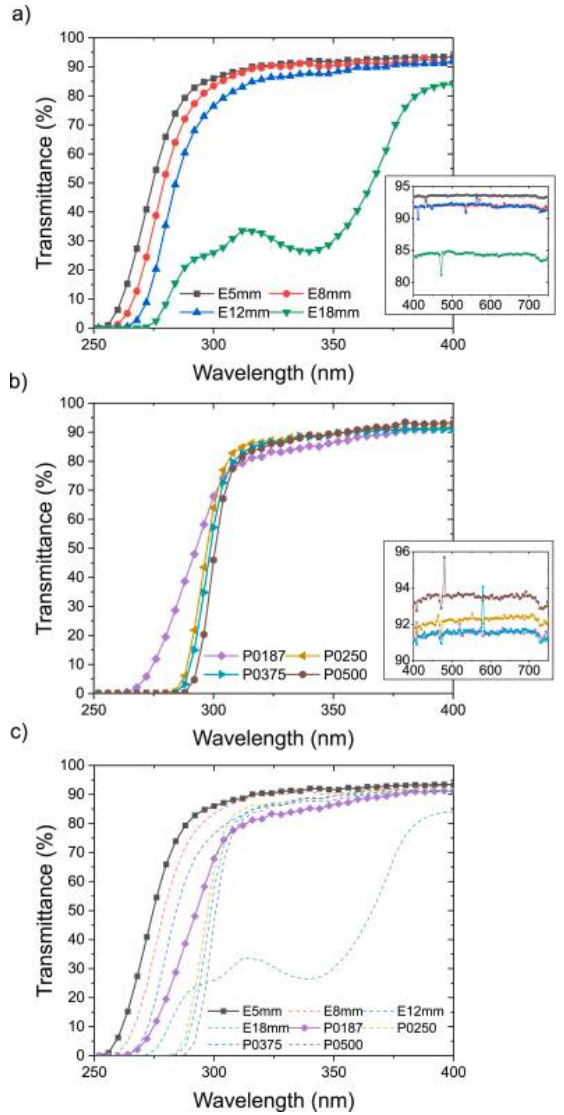
The optical window

- Years of studies finally published
  - https://doi.org/10.1016/j.nima.2025.170488

  - The best material is a UVT acrylic from Evonik in Germany, optimized for the Hyper-K specification.
  - This material is easily obatainable in big foils (6 sqm)

  - Around 90% transmittance in the region of interest for the PMTs.

- The material is easy to shape with specialized companies.



The watertight vessel

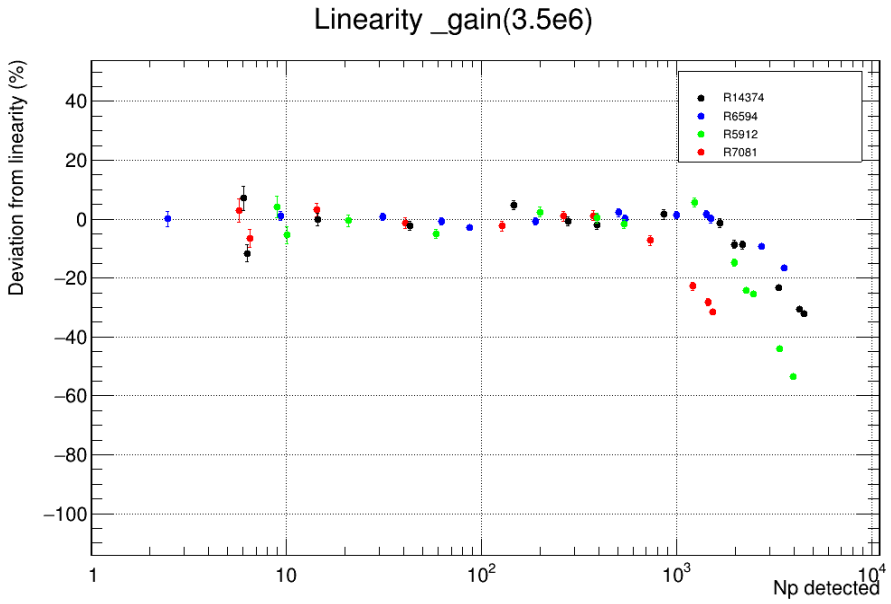
- Stainless steel backplate to prevent corrosion and to help in thermal management
- Vacuum penetrator to guide copper or fiber cable inside the volume.

- Weight and dimension customized based on the tank geometry.

The photosensor

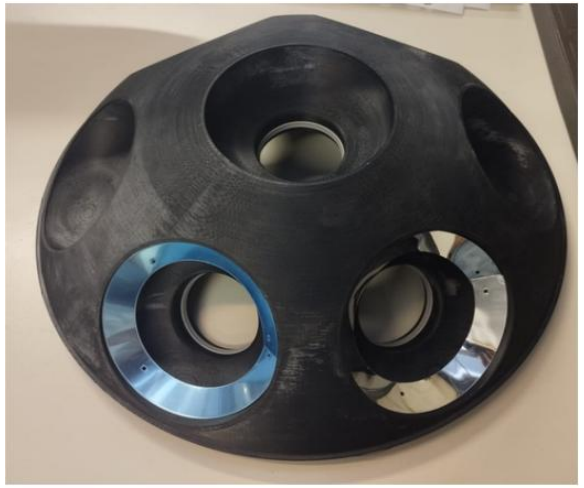
- INFN choose the Hamamatsu R14374
  - The best for cost to photocatode area.
  - Km3Net experience showed great uniformity among different batches, no need to perform extensive calibration runs.

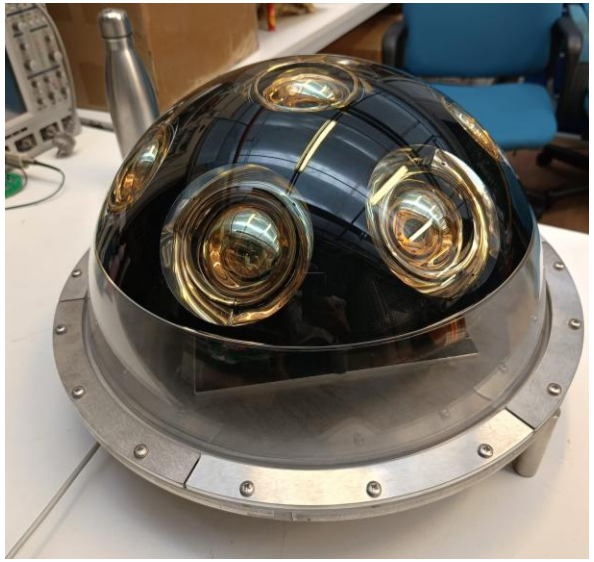
  - 1.5 ns FWHM TTS
  - Good linearity with standard voltage divider
  - Increase in linearity with a tapered divider



Optical coupling and efficiency

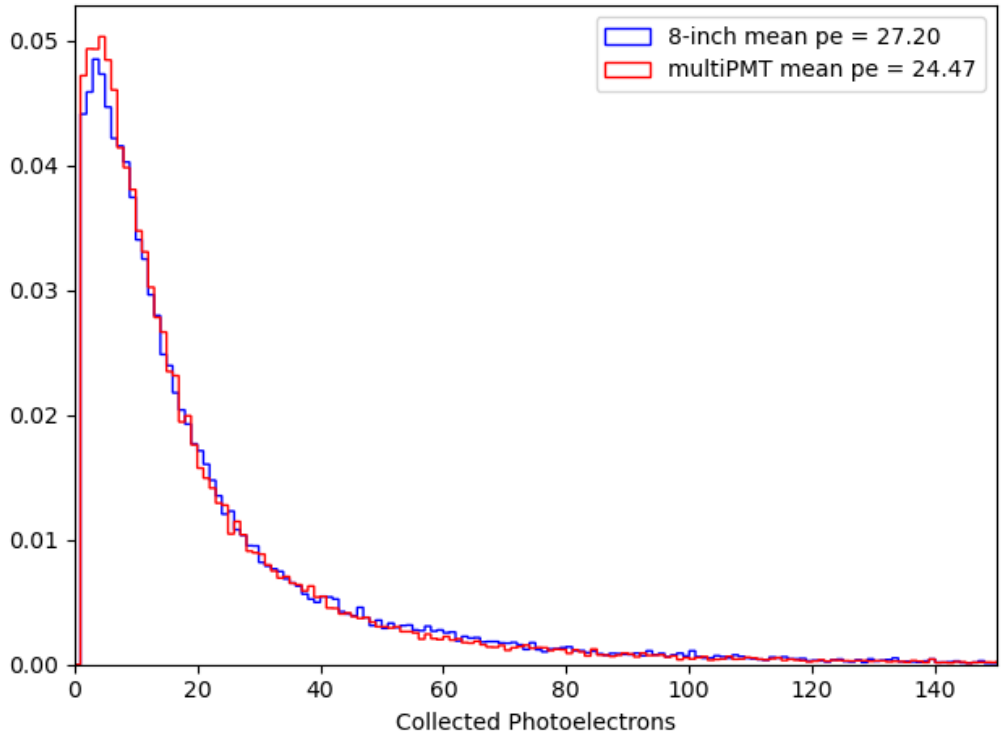
- Optical gel between the acrylic and the PMT to keep refractive index similar
- Reflector ring to increase the total collection efficiency without adding PMTs.
- For big mass production also pads of optical gel can be produced to make the assembly even faster.





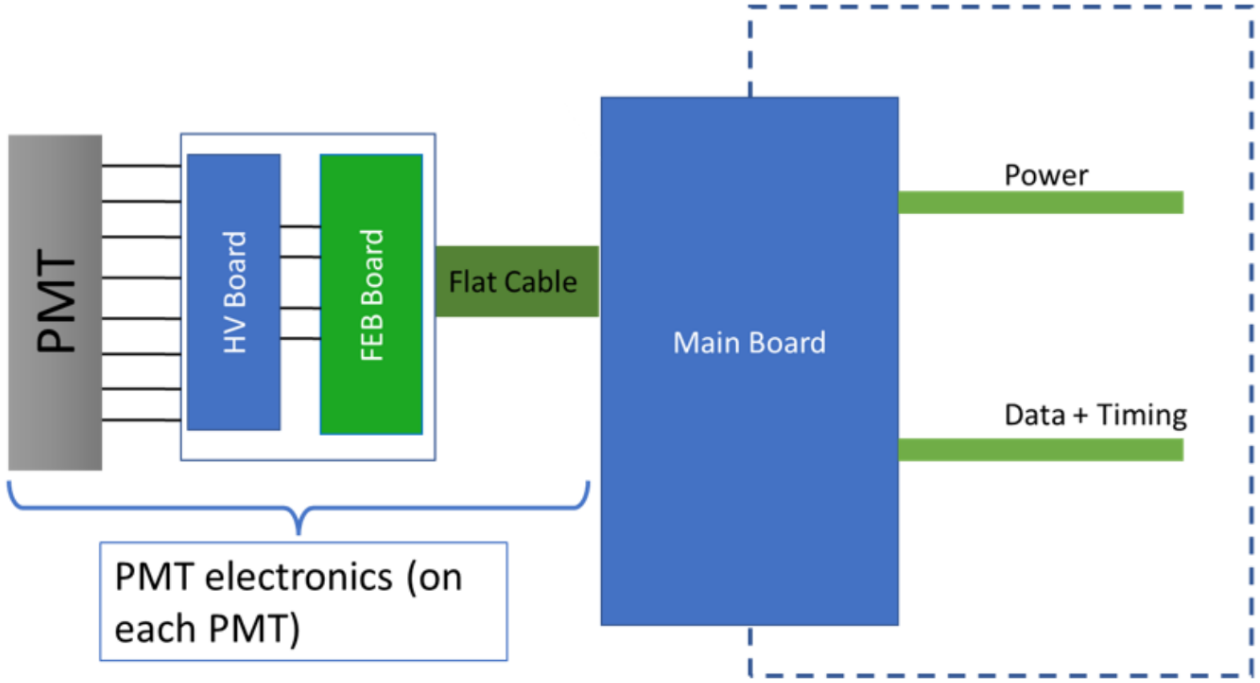
Optical coupling and efficiency

- This system shows the same efficiency of a 8 inch PMT but with the possibility to exploit much more information from the data



The electronics

- Low power and low noise electronics
  - Around 5 W per module
  - Possibility to trigger each PMT at 0.25 PE
- All the electronics inside the module
  - Only power and data link going out of the module.
- Based on a single Main Board comon to all the channels and dedicated HV/FE boards on each channel.
- Many customization possible thanks to the huge experience of the INFN electronics workshop.

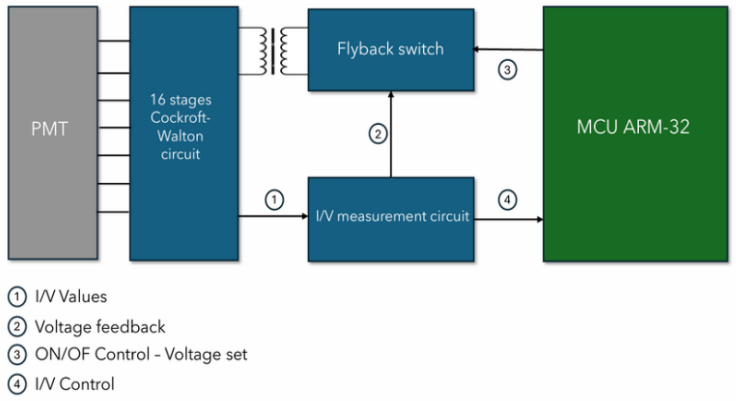


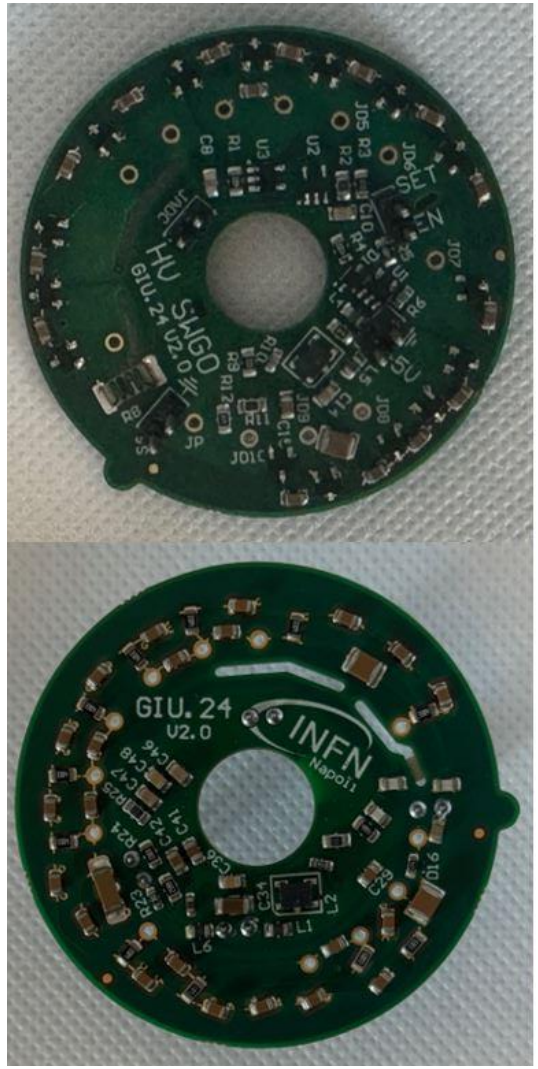
The HV board

- Based on a CW voltage multiplier.
  - Base voltage multiplier
  - Tapered voltage multiplier

- Only 3.2 mW of power consumption @ 1.5 kV
- Designed to work even at 200 mBar without additional potting
- Able to work in vacuum after potting.

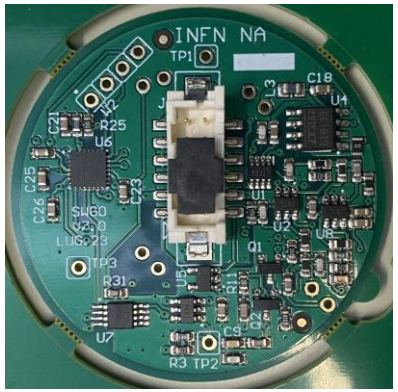
- Custom HV board automatic tester can be used in mass production to validate each individual board (2 minutes test)

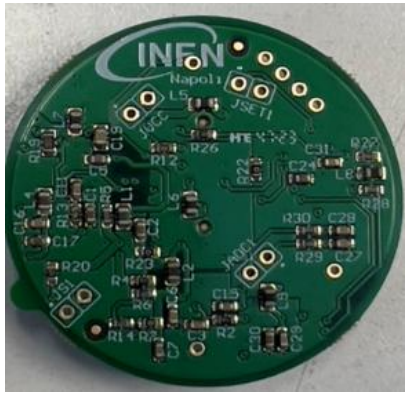


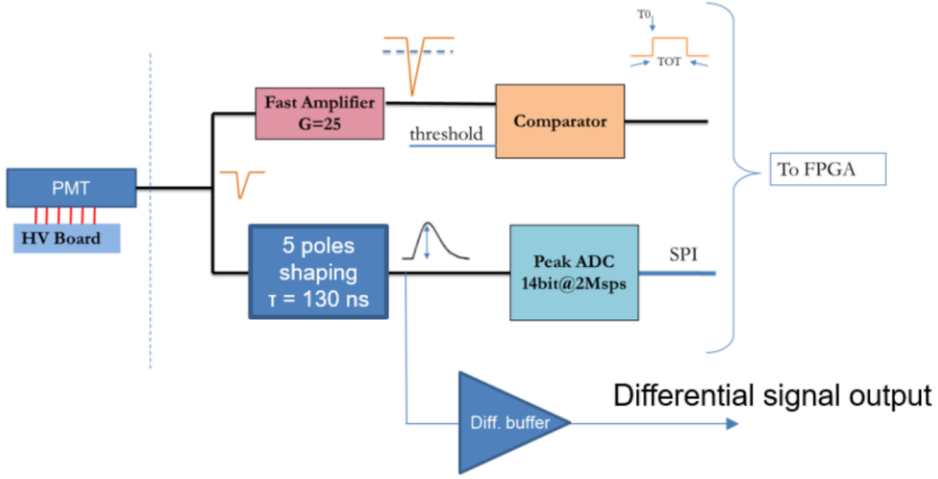


The FE board

- Controls the HV and FE parameter thanks to a low power MCU (STM32L0 family)
- Generate a fast and precide LVDS trigger for timing acquisition
  - ToA and ToT (270 ps LSB, 100 ps resolution)
- Slow shaper to get the charge information with a peak ADC
- Differential output of the PMT analog signal for a possible FADC in the Main Board







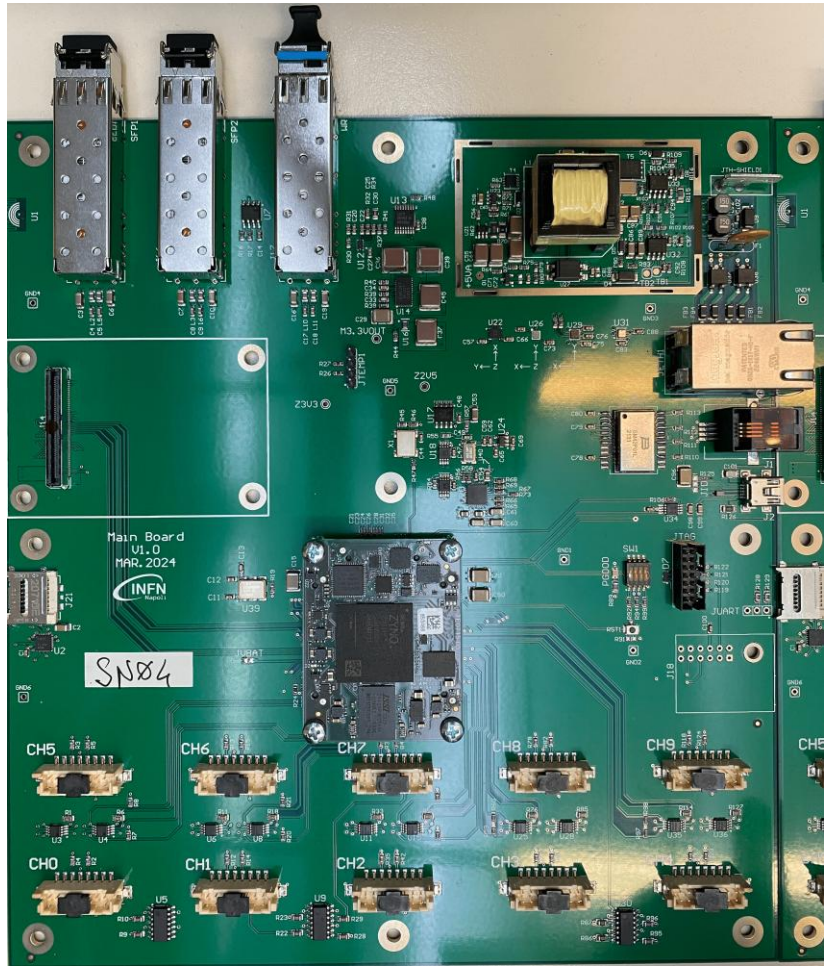
The Main Board

- Based on a ADM Xilinx ZYNQ SoC
  - FPGA and CPU in one chip.
  - Fully fledged Linux distribution on board

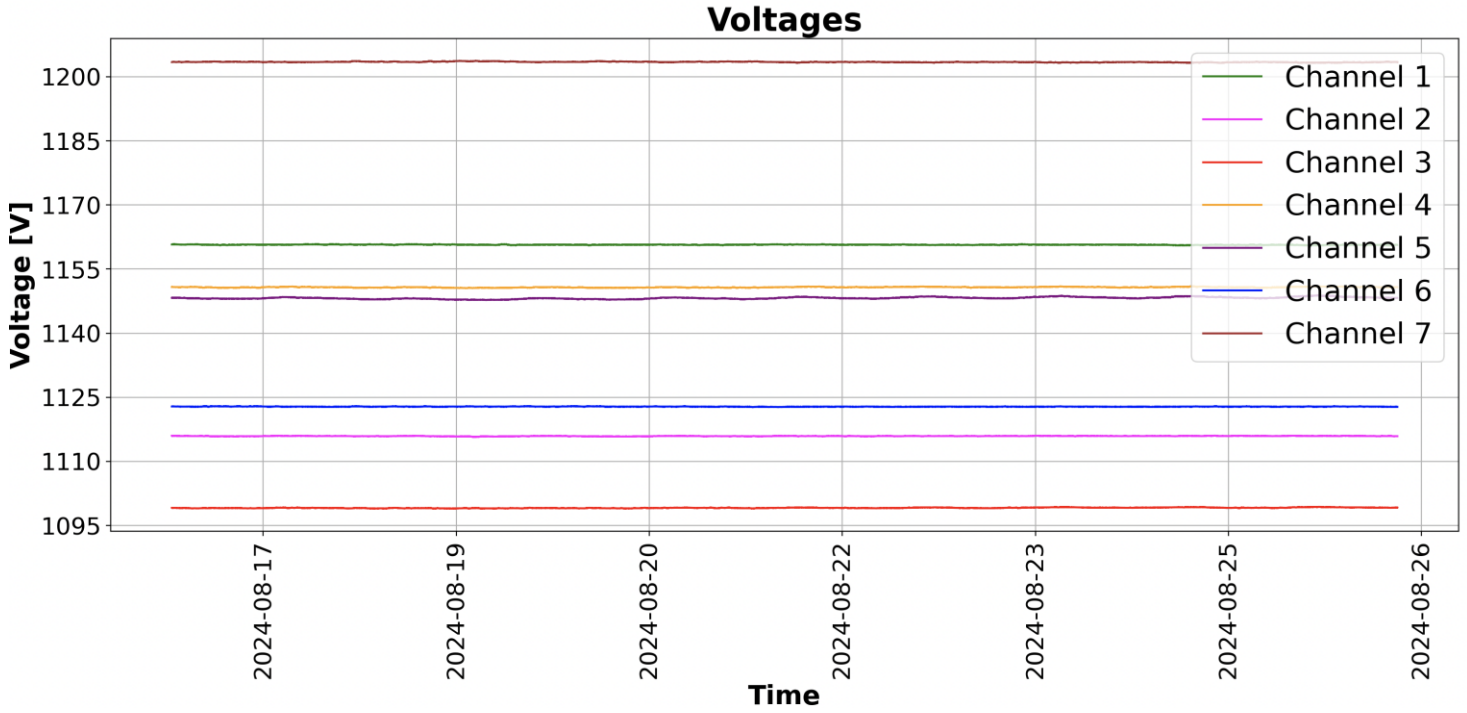
- Possibility to change power supply and comunication link
  - Ethernet on copper or fiber
  - Power over Ethernet
  - DC power (even from solar arrays)

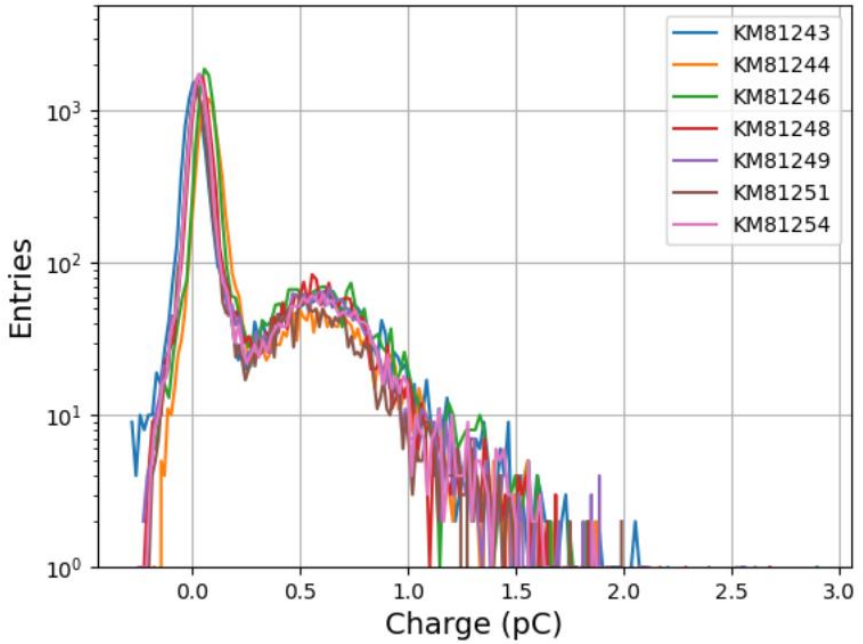
- Integration of timing link for the experiment
  - Custom protocols on copper or fiber
  - White Rabbit on fiber

- Possibility to host calibration sources, like LEDs inside the module.



Example of acquisition





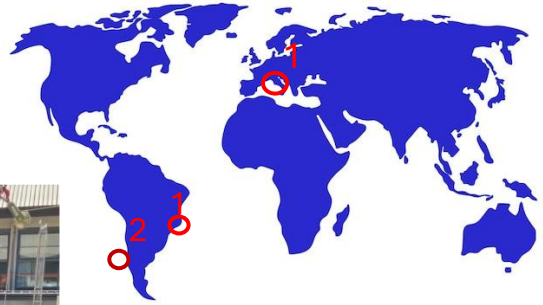
PMTs are gain equalized and we can control all the parameters in real time from a DAQ PC

The full prototypes

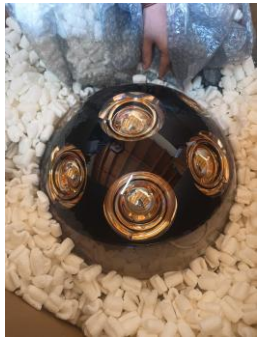
- Currently, **four** multiPMT units have been **assembled**;
  - One is in **Rio** taking data;
  - One is in **Milan** taking data;







  - Two are at the **Radiosky facility** in Chile ready for the **Pathfinder**




- Monitoring of the modules in **realistic environments**;
- First-generation multi-PMT: these tests provide **valuable input** for **future improvements**

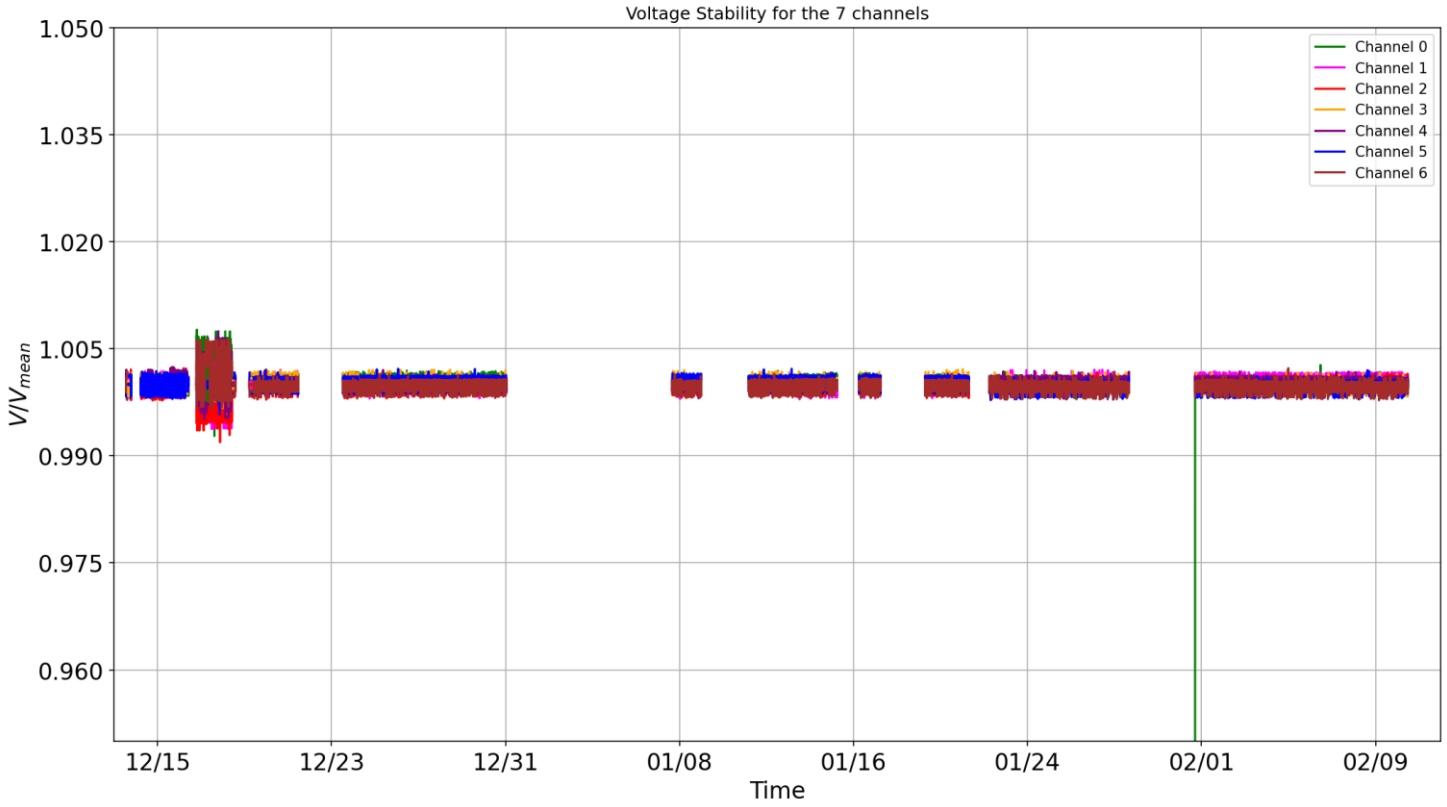
The full prototypes

- One more should be sent to Auger to be assembled in the SWGO plastic tank already there
- Idea is to test the multiPMT in a real working array where we can benefit from trigger information from Auger.
- We can think to install the tank close to the double layer of PEPS?

The prototype in Rio at CBPF

First multiPMT installed in a proposed tank and taking data since 6 months

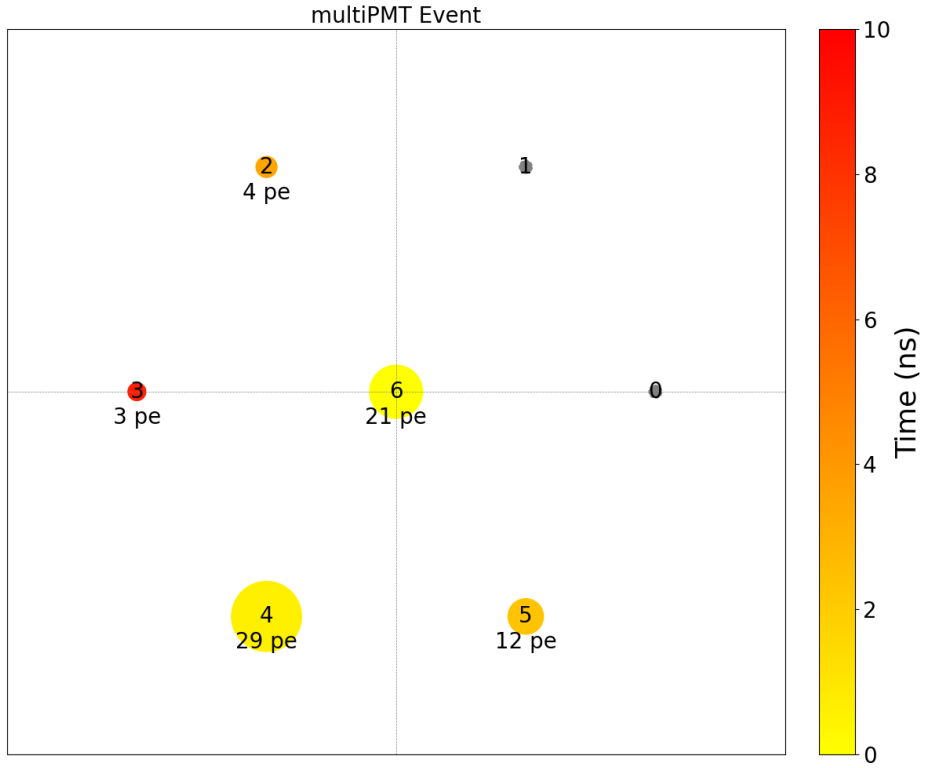
The prototype in Rio at CBPF



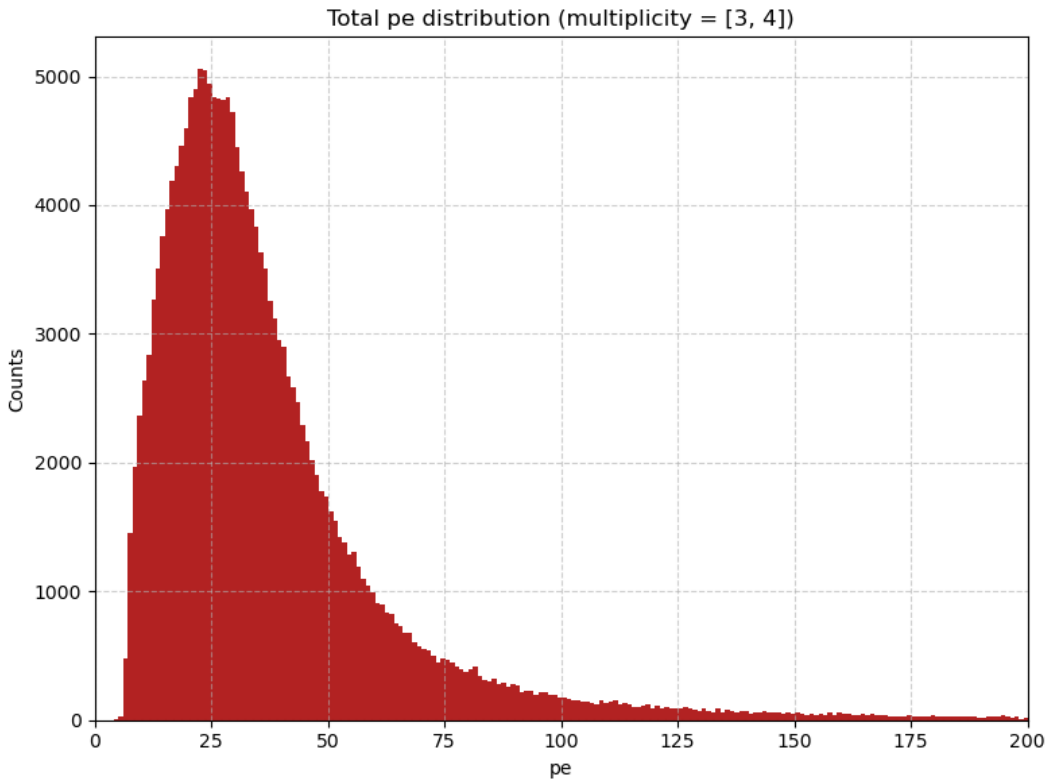
Less than 0.5 % variation

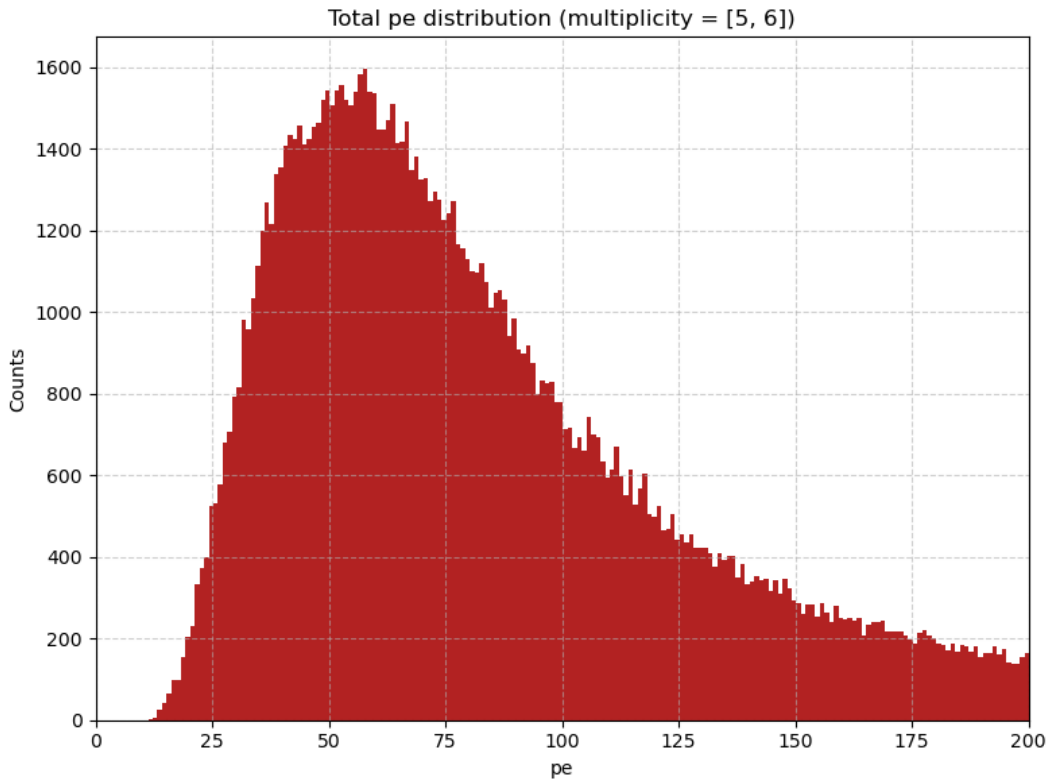
The prototype in Rio at CBPF

- PMTs are individually self triggered at 0.3 PE level
- Software trigger looking for 10 ns window coincidence
- Possibility to select different multiplicity

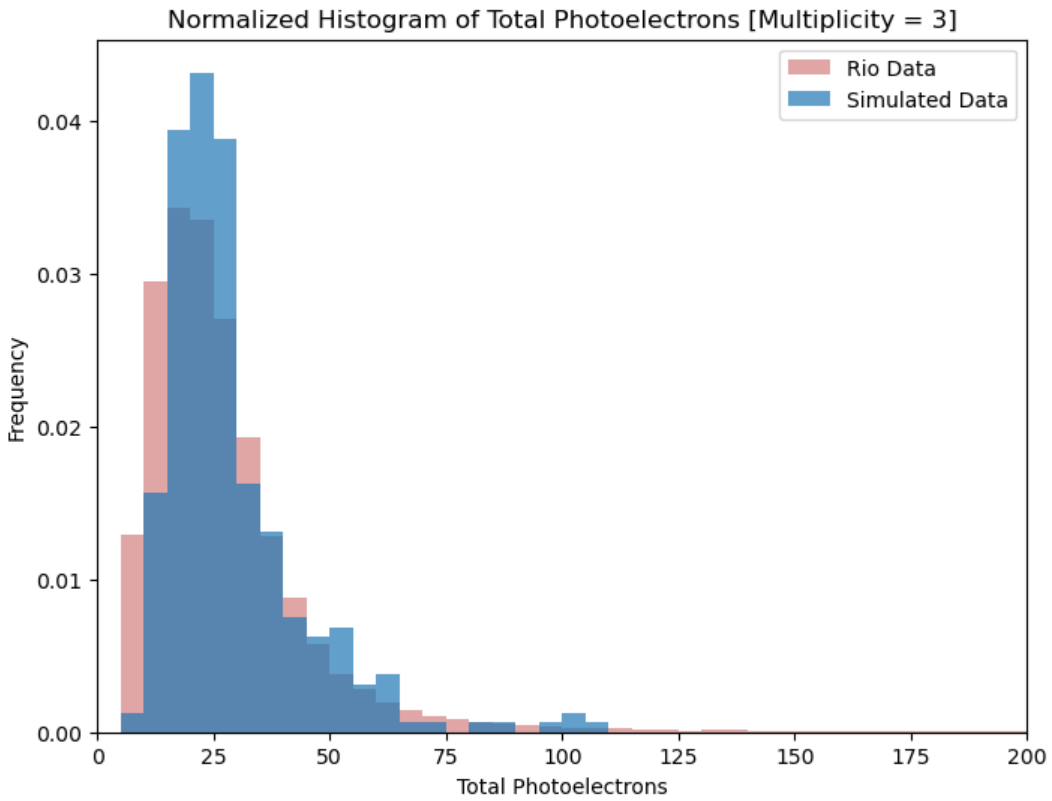


The prototype in Rio at CBPF



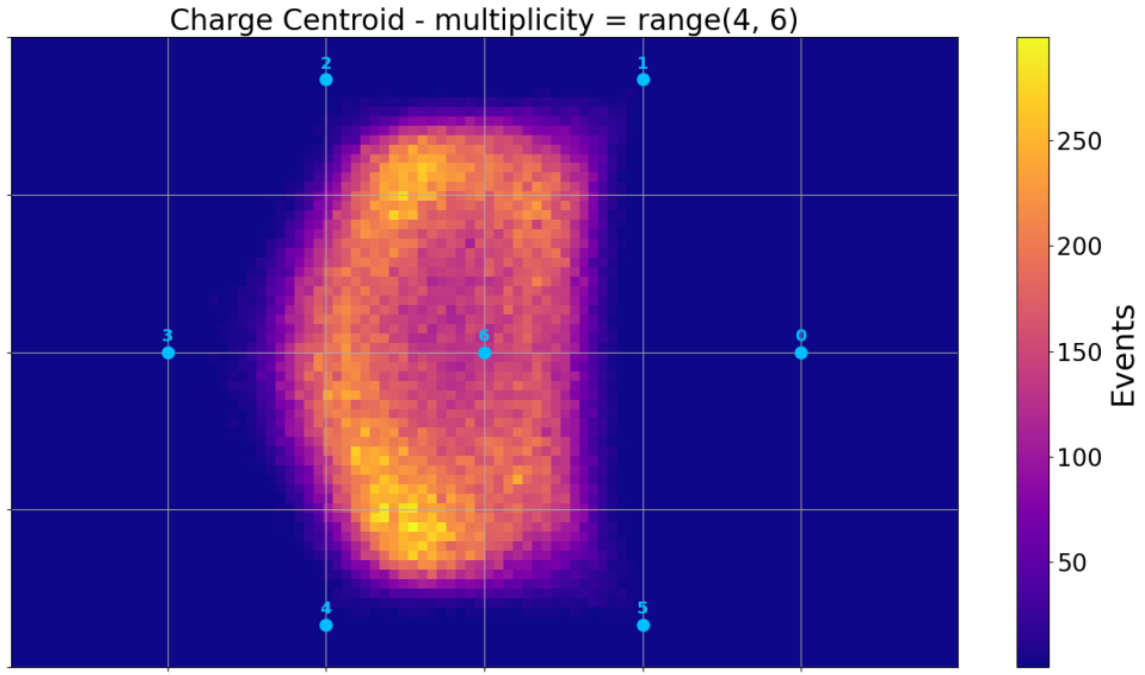


The prototype in Rio at CBPF



Simulations are in agreement with real data, promising results

The prototype in Rio at CBPF



One broken channels, but uniformity everywhere else

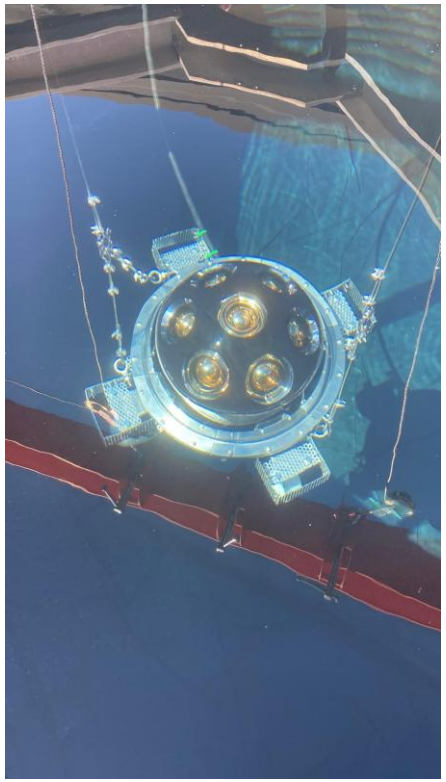
The prototype in Milan

Open top with removable 2-layer cover

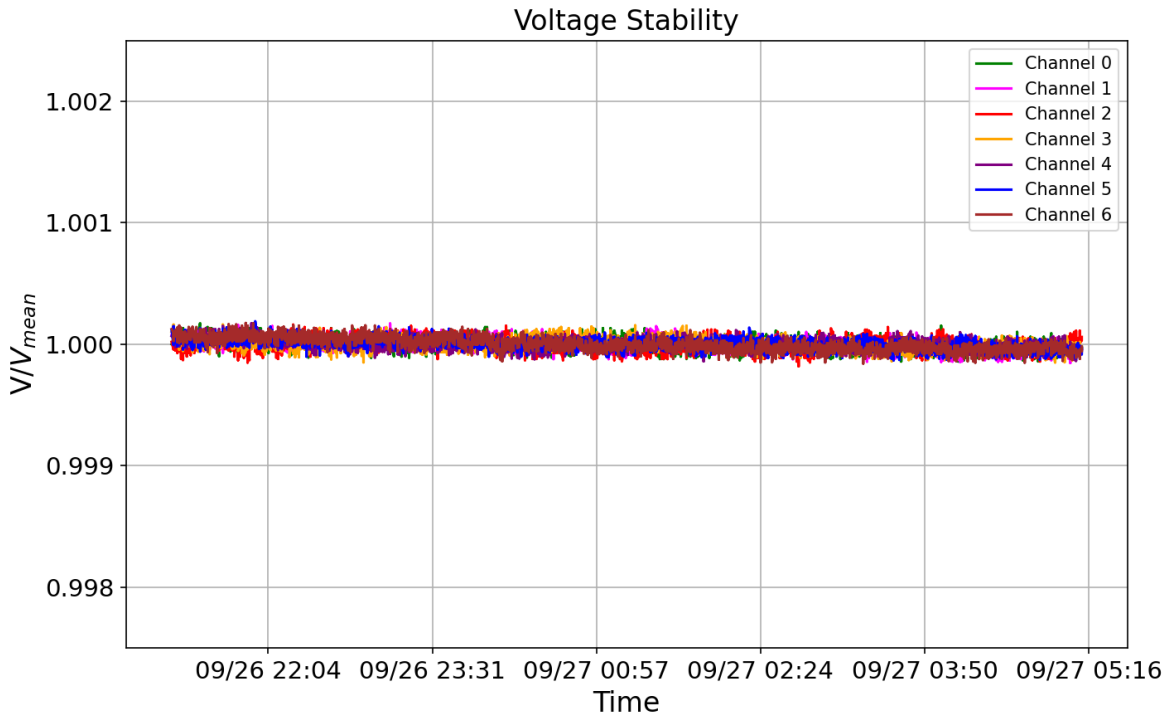
PP non-reflective water-tight bladder

The prototype in Milan

- A **custom lifting system** was designed by **INFN Torino** for the **multiPMT deployment**;
- Process was **fast, efficient and safe**;

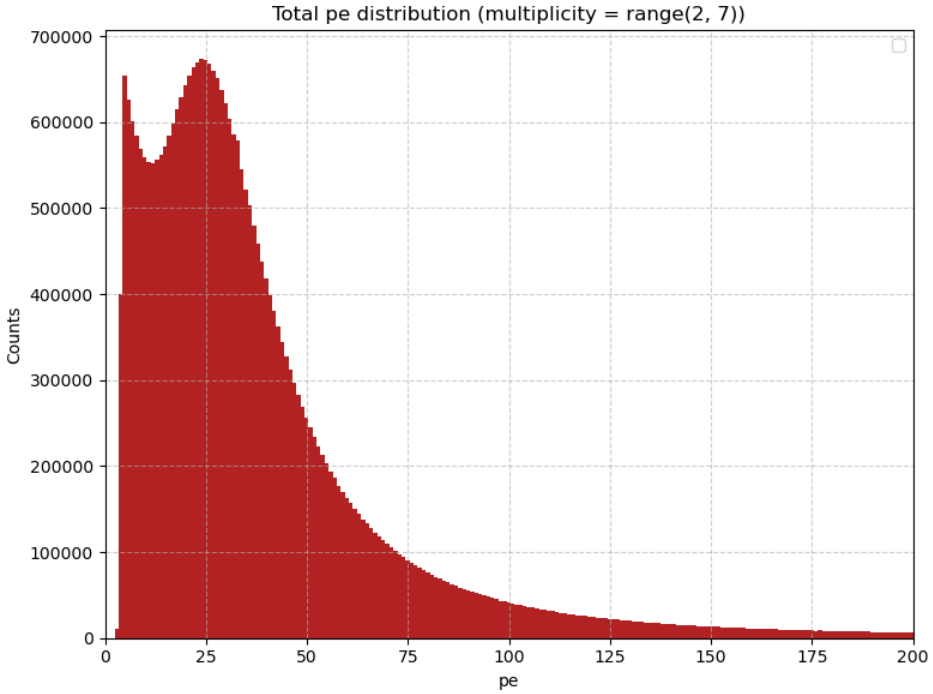


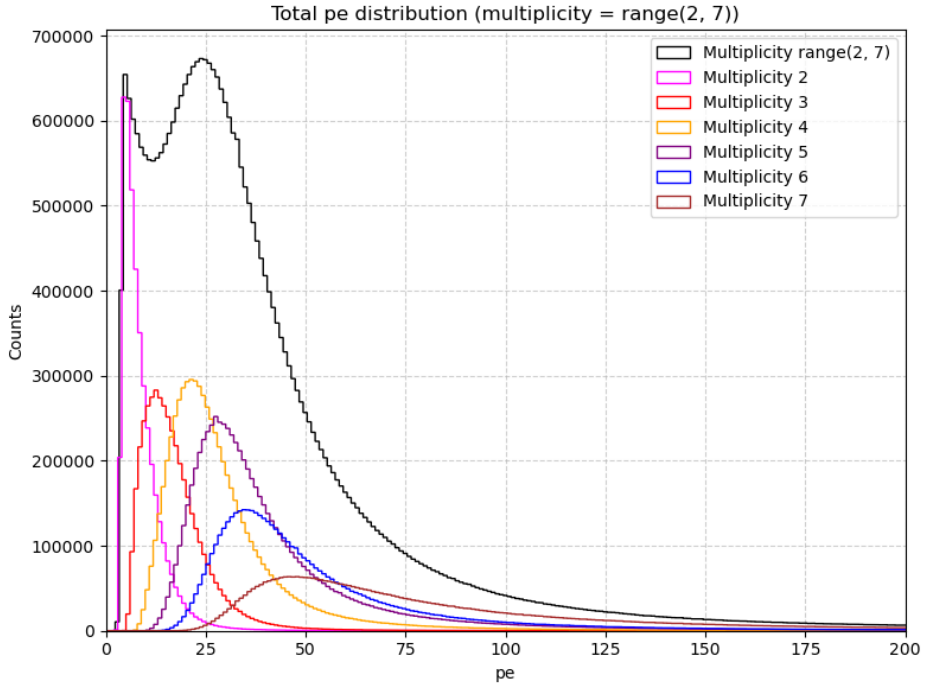
The prototype in Milan



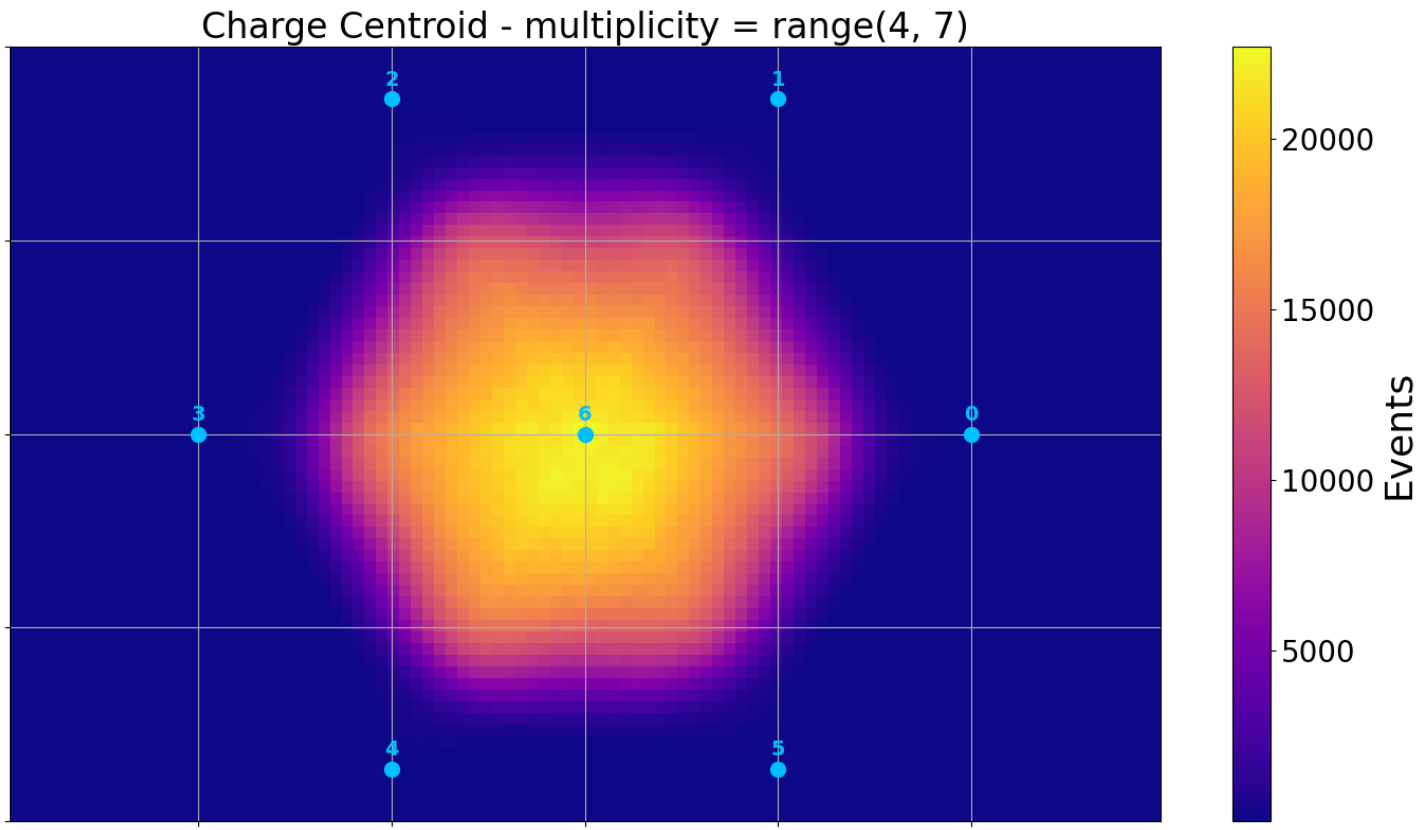
Much more stable system with a new generation of HV boards

The prototype in Milan



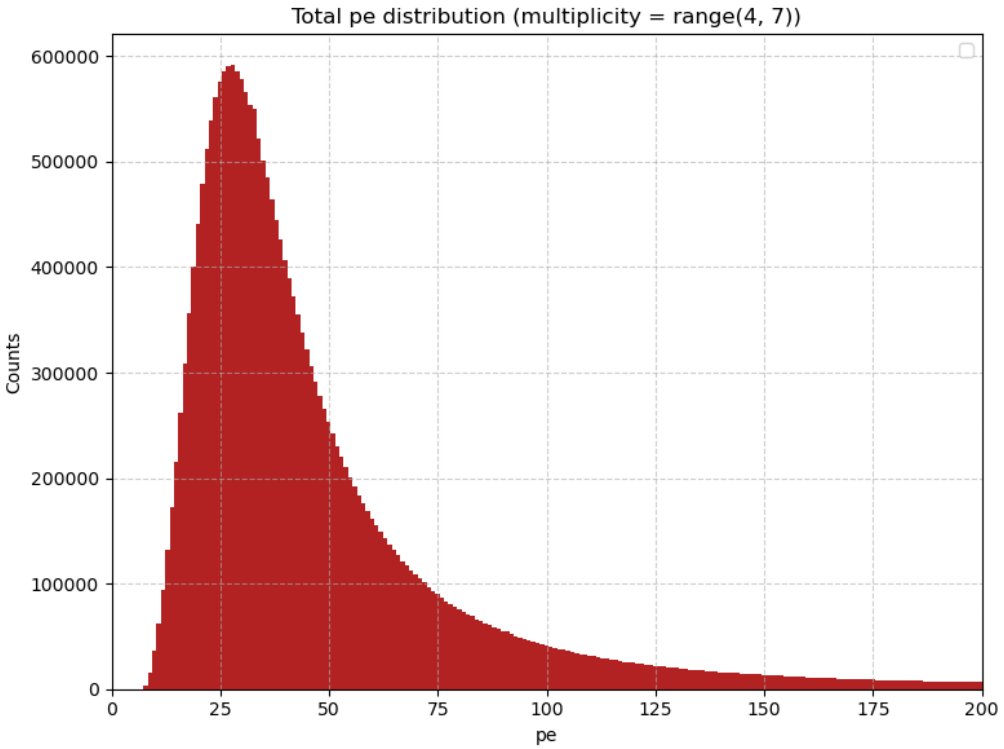


The prototype in Milan

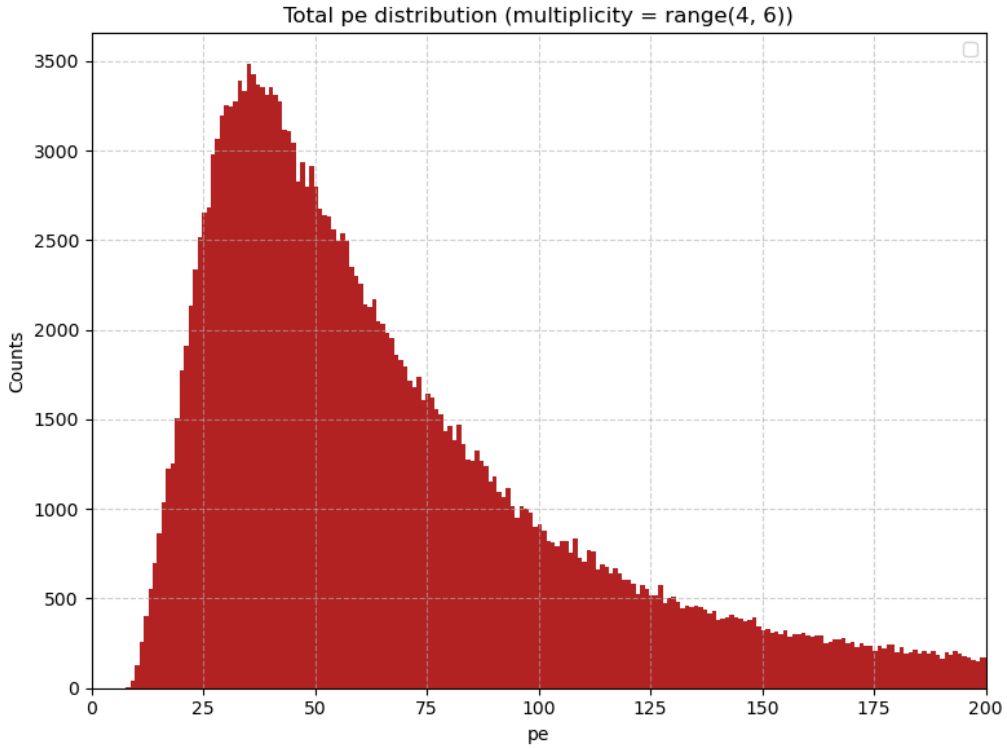


Very uniform distribution in all direction

The possible muon peak



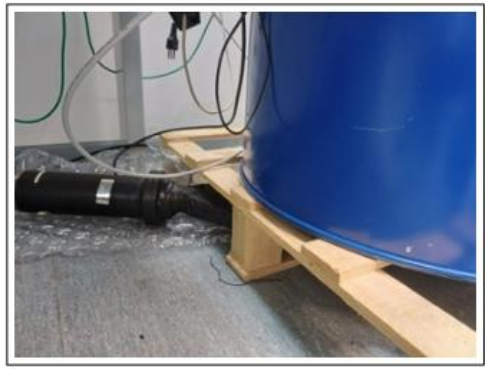
Milan

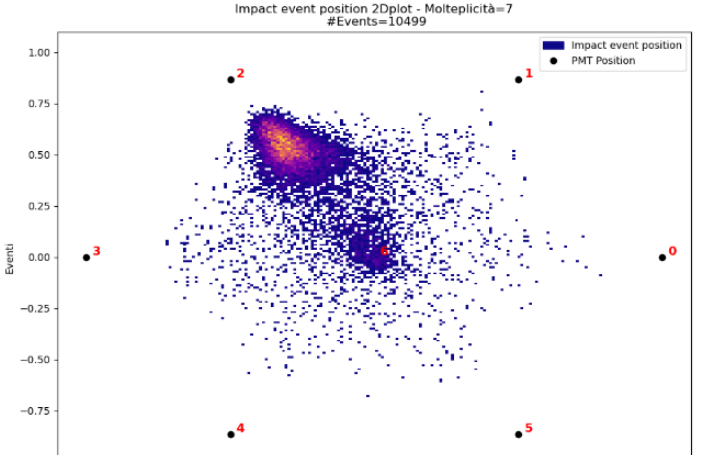


Rio

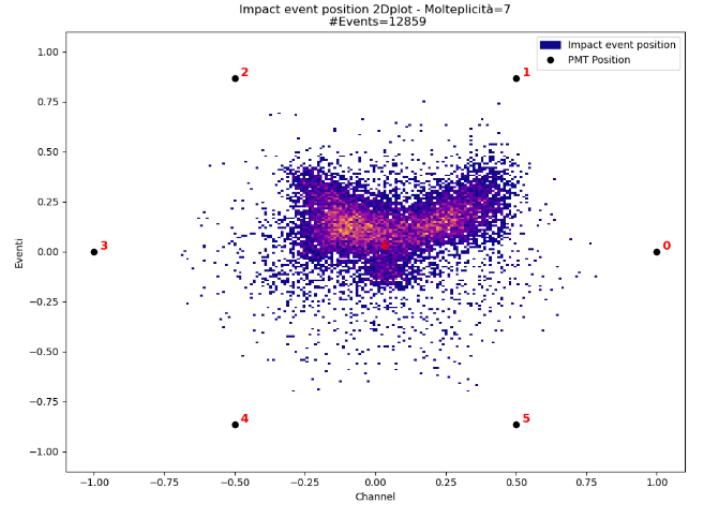
Only Milan water is filtered, in Rio we used tap water

multiPMT test with scintillators



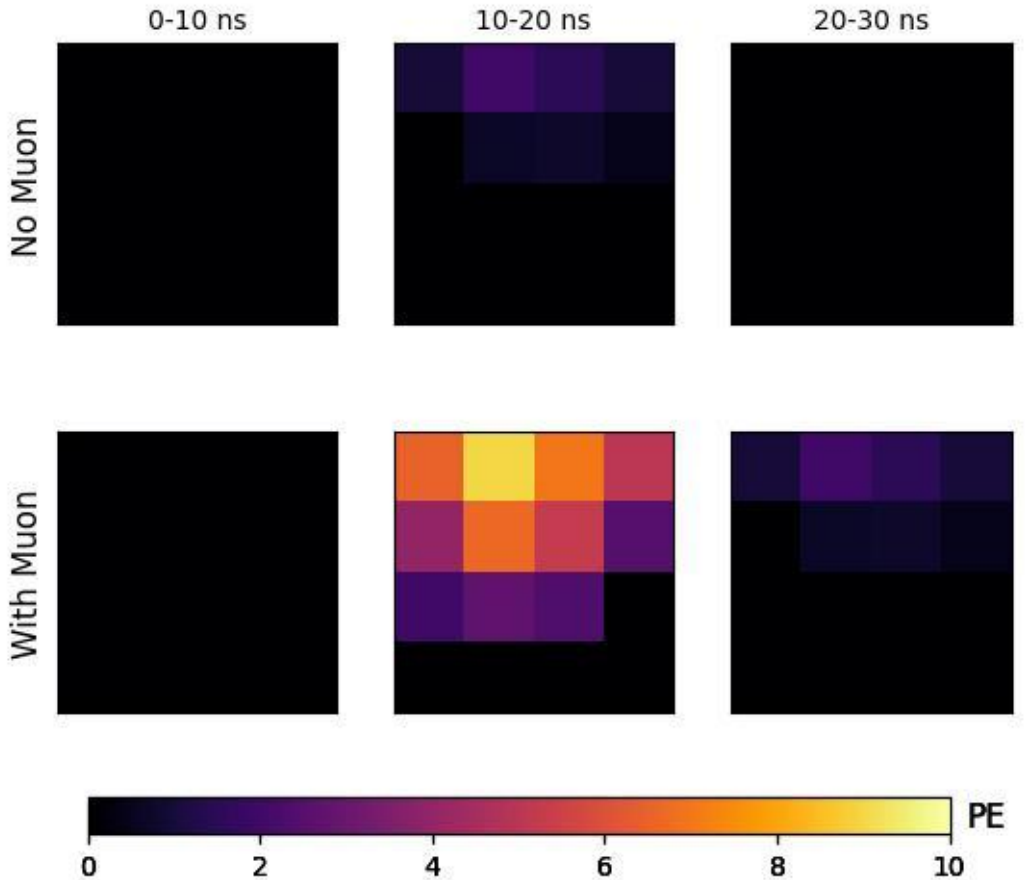


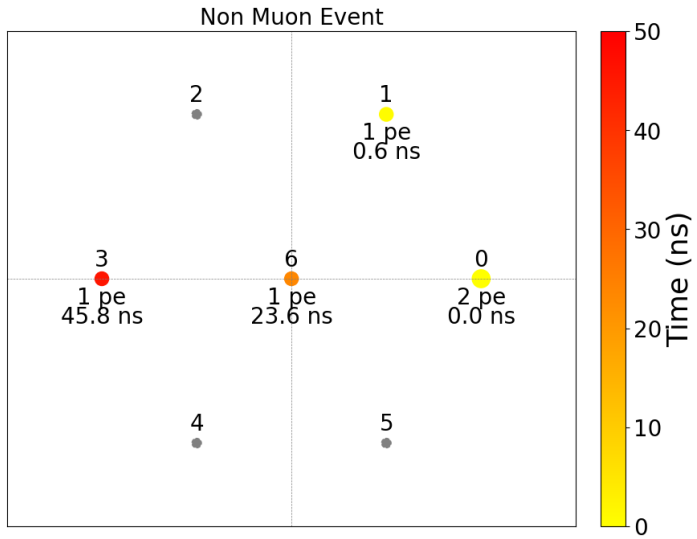
Diagonal configuration

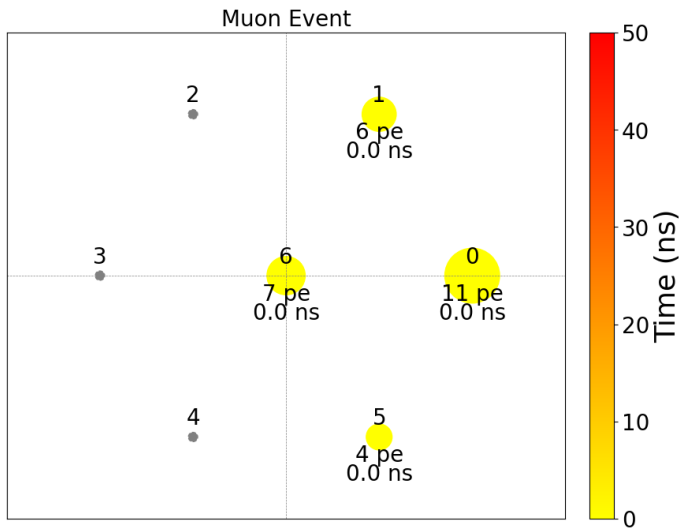


Lateral configuration

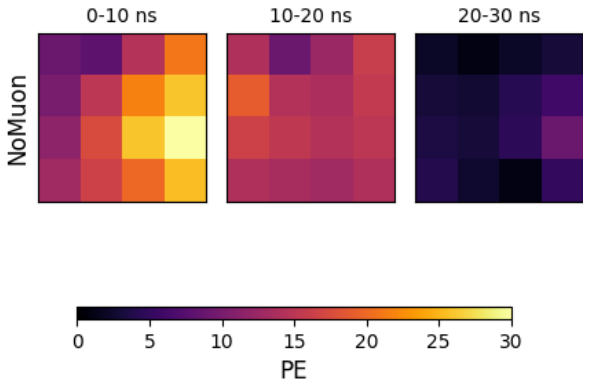
Simulation of tanks with multiPMT at 100 m from shower core

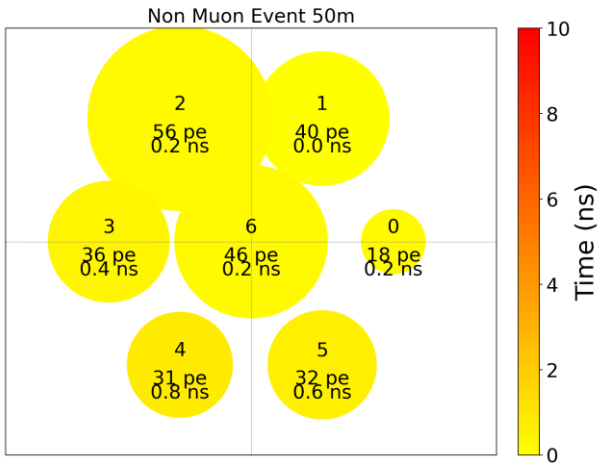


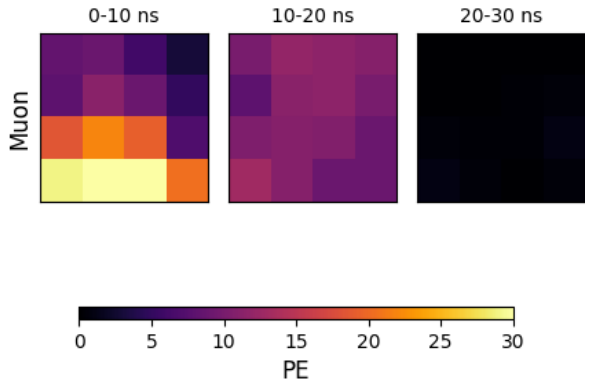


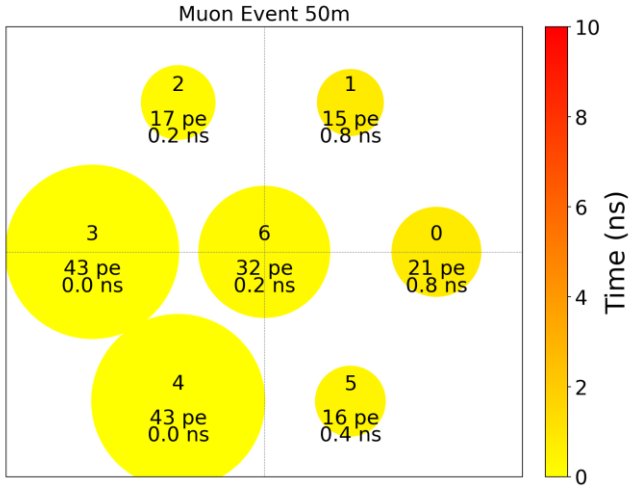


Simulation of tanks with multiPMT at 50 m from shower core



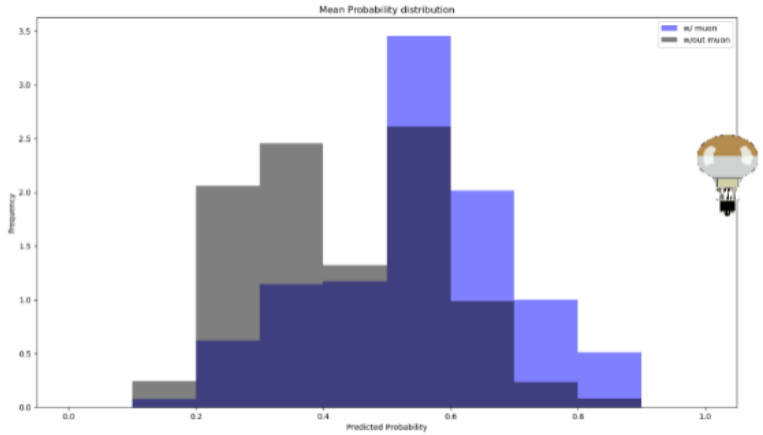


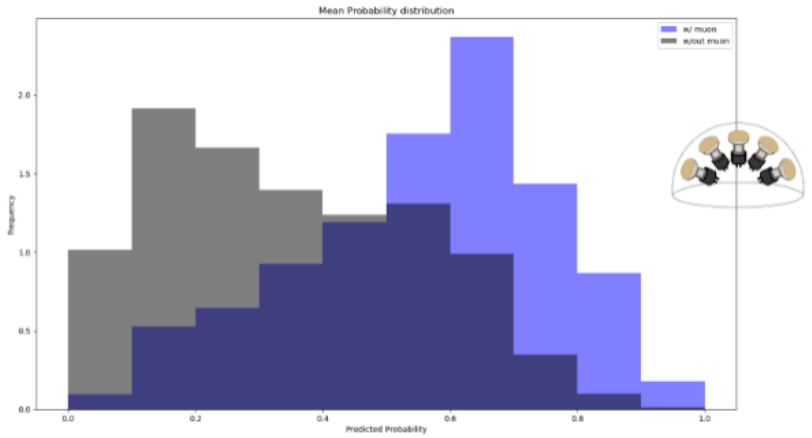




Muon Tagging with the multiPMT?

- The output of the model is a **Probability Distribution that expresses the «muonicity»** of each event





- the mPMT gives more confident predictions (more extreme values for the probabilities) and more separated disitributions profile

- Bhattacharyya distance measures the dissimilarity of the distributions : $D_B = -\ln(\sum_i \sqrt{p_i^1 p_i^2})$

$$D_B^{8inches} = 0.08 \qquad D_B^{mpmt} = 0.13 \text{ (65\% increase)}$$

Conclusion

- The multiPMT can help in improving performances of WCD
- Prototypes for SWGO have been assembled and are now taking data
- Simulations are on going to understand better the data
- Hints of possible major improvements in gamma hadron discrimination just adding a multiPMT in the tank.