Development of 2.5m cubic hodoscope, proof of concept

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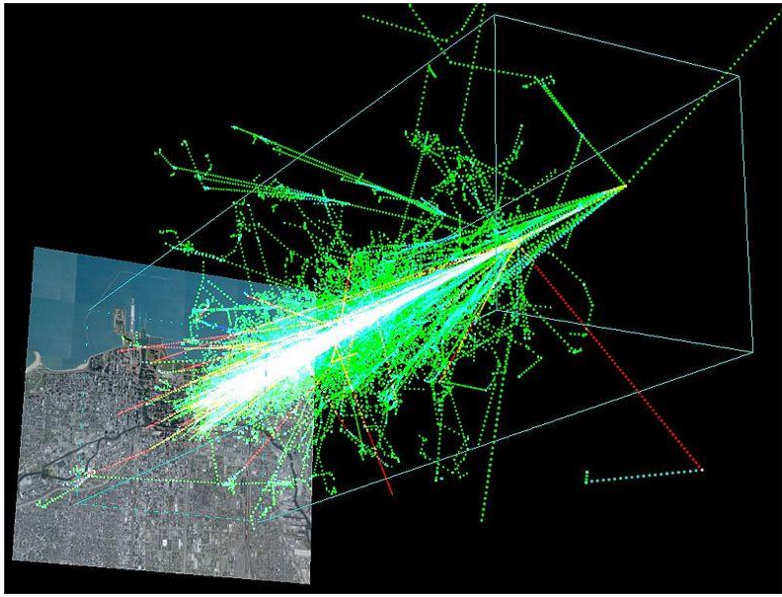
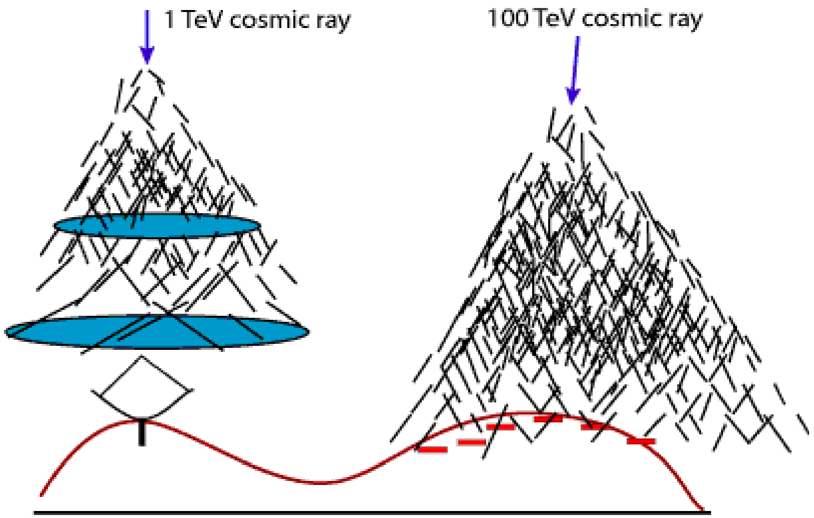
Cosmic Ray

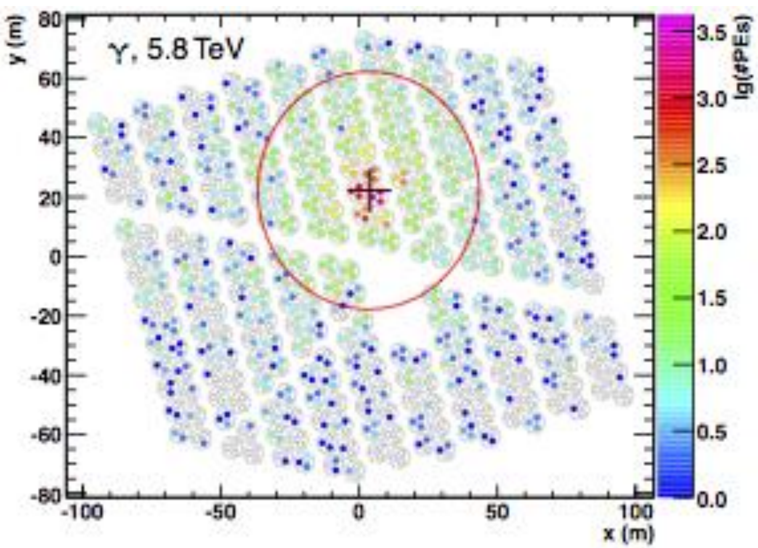
High-energy cosmic rays create extensive air showers. These showers consist of billions of subatomic particles that rain down on the Earth’s surface, spread over a footprint of tens of square kilometres. Each air shower carries information about the primary cosmic-ray particle’s arrival direction, energy and particle type.



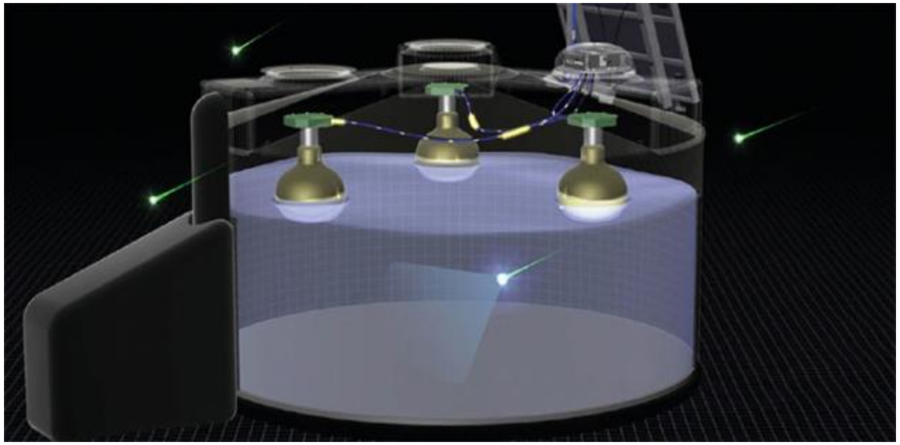
Cosmic Ray Detection

	Cherenkov telescopes	Surface detectors array
Energy Limit	Low (<200 GeV)	High (>10 TeV)
Background signal rejection	Excelent (>99.7%)	Moderate (>50%)
Field of view	Small (<2°)	Big (>45°)
Duty cycle (active time)	Low (5%-10%)	High (>90%)





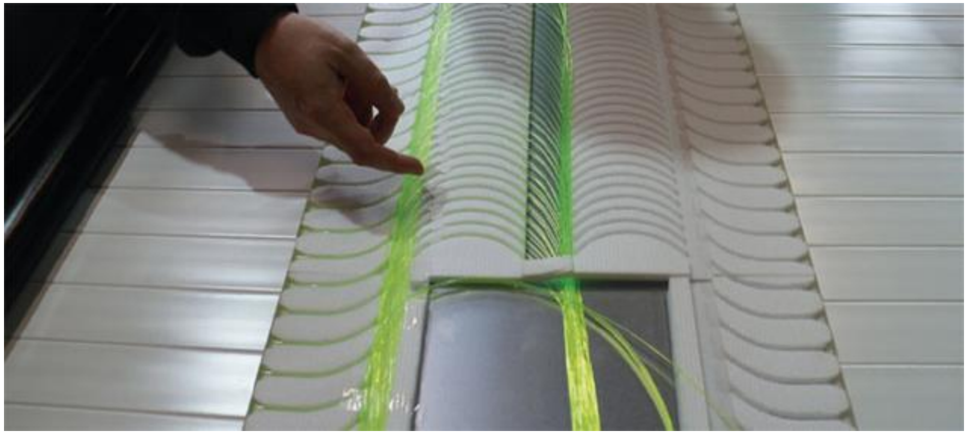
Why use scintillators instead of water tanks and PMT's?



Current Auger Observatory

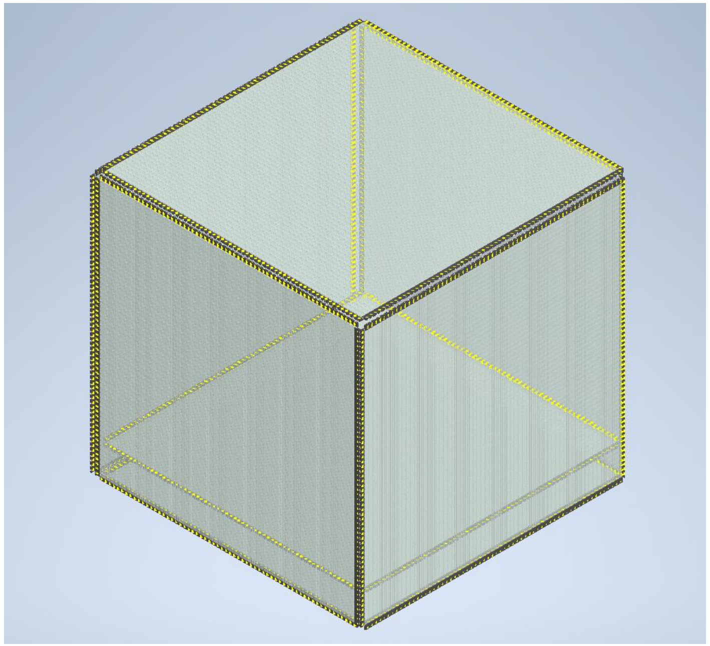
Tank detectors have a high operating cost and limited angular resolution, as well as limited spectral resolution.

Scintillator detectors may have better spectral response, angular resolution, and lower operating cost.



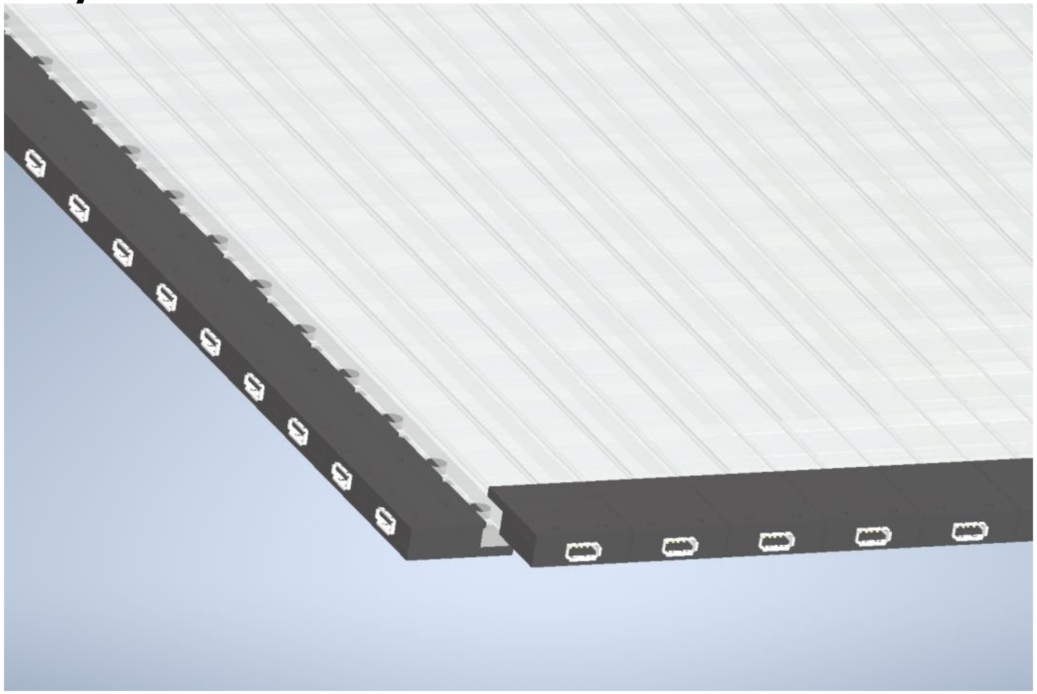
2.5m cubic hodoscope, general characteristics

- Cosmic ray hodoscope with a spatial resolution of at least 10mm on each face, and a joint angular resolution of ≈0.2 deg (5 e-5 sr).
- Cubic configuration with a 2.5m by 2.5m sensitive planes, including a internal 7th detection plane, parallel to the ground, with an underlying Pb or W plate to perform complementary measurements.
- An acquisition system with temporal resolution of at least 200ps is required, and 496 channels per layer (3472 total channels).



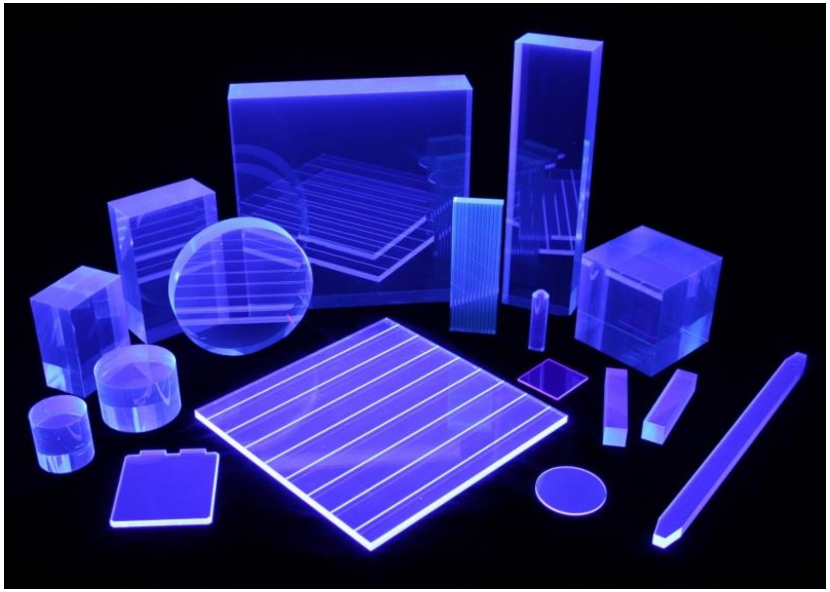
Description of the technology proposed

- Each plane is made up of 62 bars of 40 x 7 x 2500 mm of scintillation material (UNIPLAST or similar).



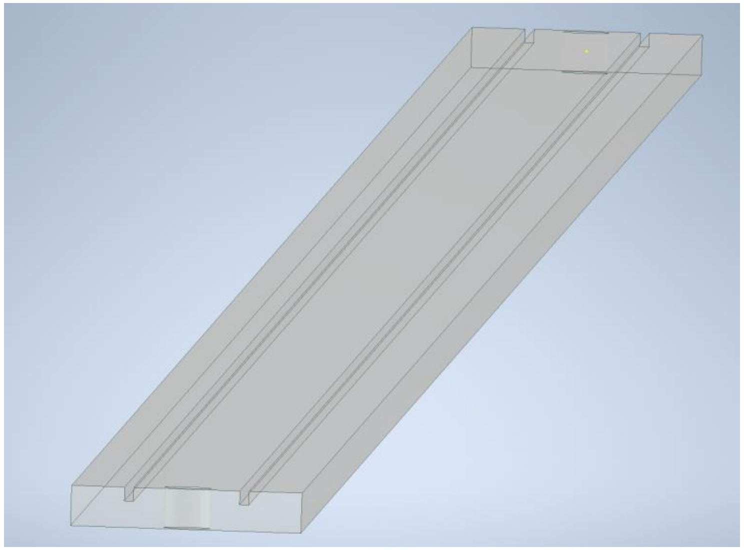
Plastic Scintillatior attenuation problem

The scintillating plastic has an attenuation length of approximately 100 mm. We will not be able to obtain a useful optical signal in our configuration...



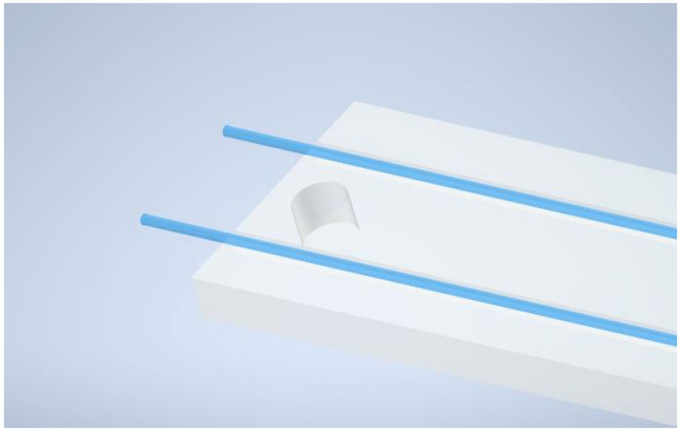
Solution for attenuation problem

- Each bar has 2 grooves, parallel to the longest dimension and equidistant from each other.
- Inside the groove there is a WLS optical fiber of 1.5mm in diameter and 2530mm long.



WLS Fiber

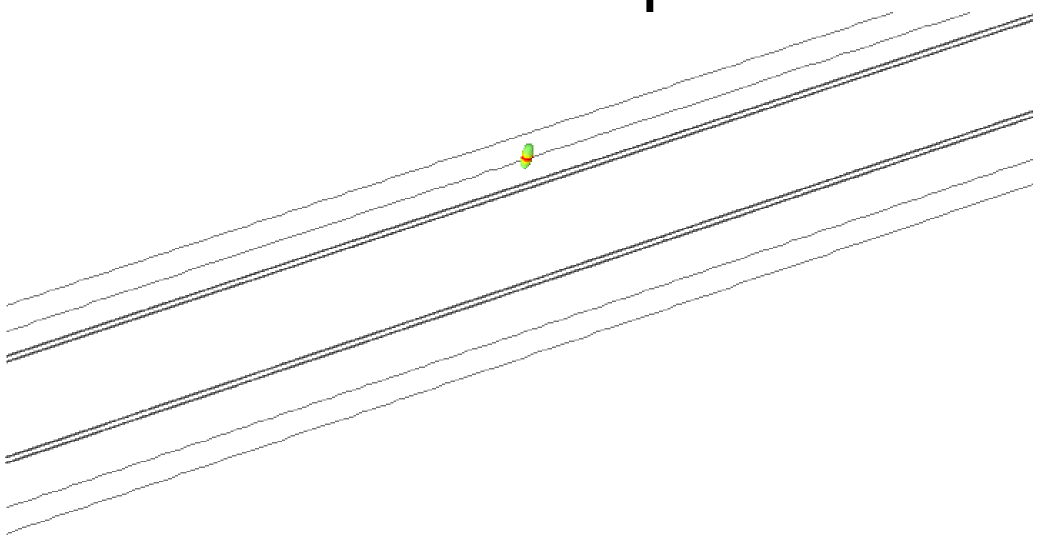
Since the WLS fiber optic has a much greater attenuation length, around 4m, depending on the model and manufacturer, we will be able to have a signal in our configuration.



Description	Emission			Absorption Peak[nm]	Att.Leng.2) [m]	Characteristics
	Color	Spectra	Peak[nm]			
Y-7(100)	green	See the following figure	490	439	>2.8	Blue to Green Shifter
Y-8(100)	green		511	455	>3.0	Blue to Green Shifter
Y-11(200)	green		476	430	>3.5	Blue to Green Shifter (K-27 formulation) Long Attenuation Length and High Light Yield
B-2(200)	blue		437	375	>3.5	UV to Blue shifter
B-3(200)	blue		450	351	>4.0	UV to Blue shifter
O-2(100)	orange		550	535	>1.5	Green to orange shifter
R-3(100)	red		610	577	>2.0	Green to red shifter

Longitudinal resolution

Having an optical signal at both ends is essential, to improve the spatial resolution, when comparing the difference in amplitude and arrival times.



Longitudinal resolution, arrival time comparison

The speed of light is approximately 0.3 m/ns, in a vacuum, or equivalently 3 ns/m.

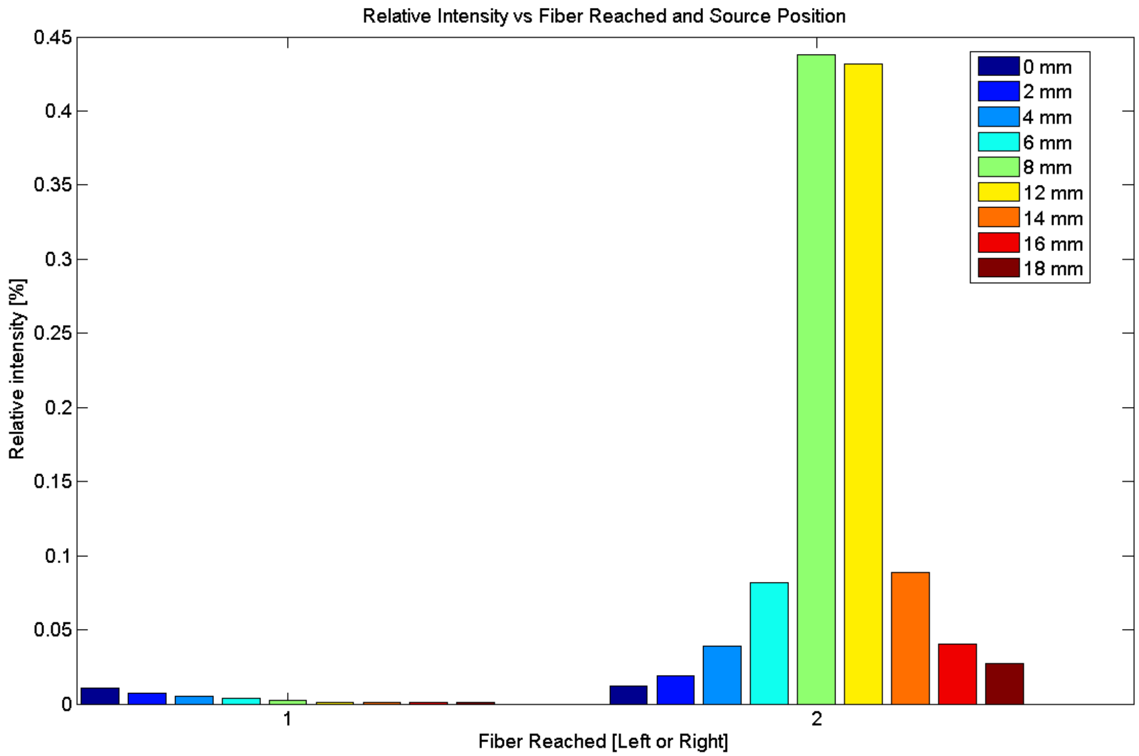
In an optical fiber it is around 5 ns/m, or less.

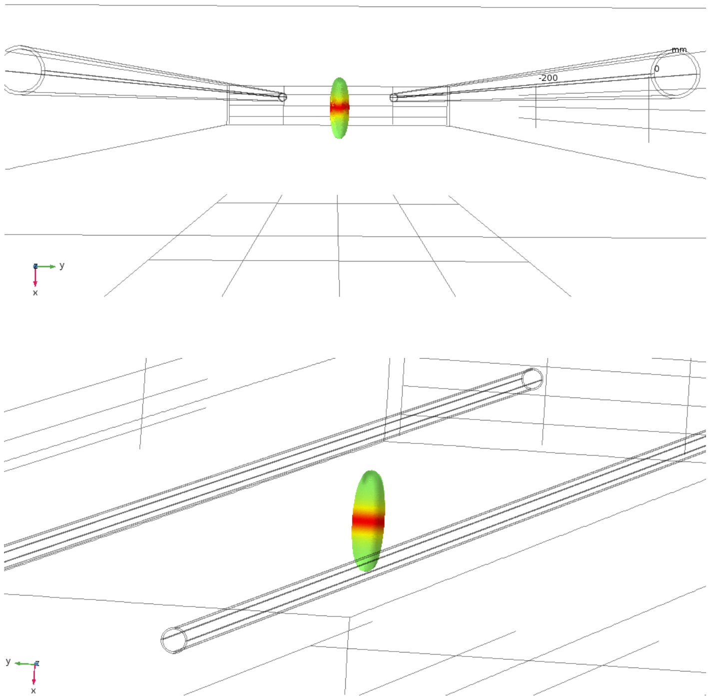
Longitudinal resolution, arrival time comparison

So with 200ps resolution it would be possible to have a longitudinal resolution of only 40mm, which is no better than the available pixel size.

This is why an intensity comparison could give a better way to improve the spatial, longitudinal and transversal resolution.

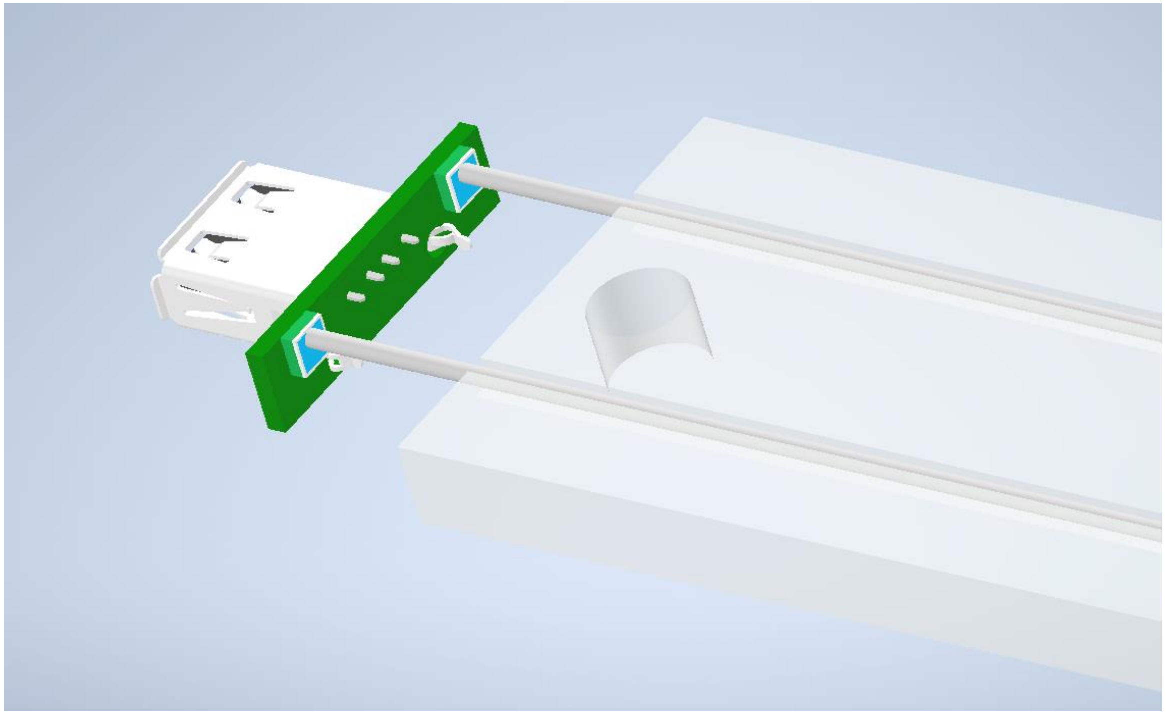
Numerical simulation of the intensity difference versus the transverse position of the particle.



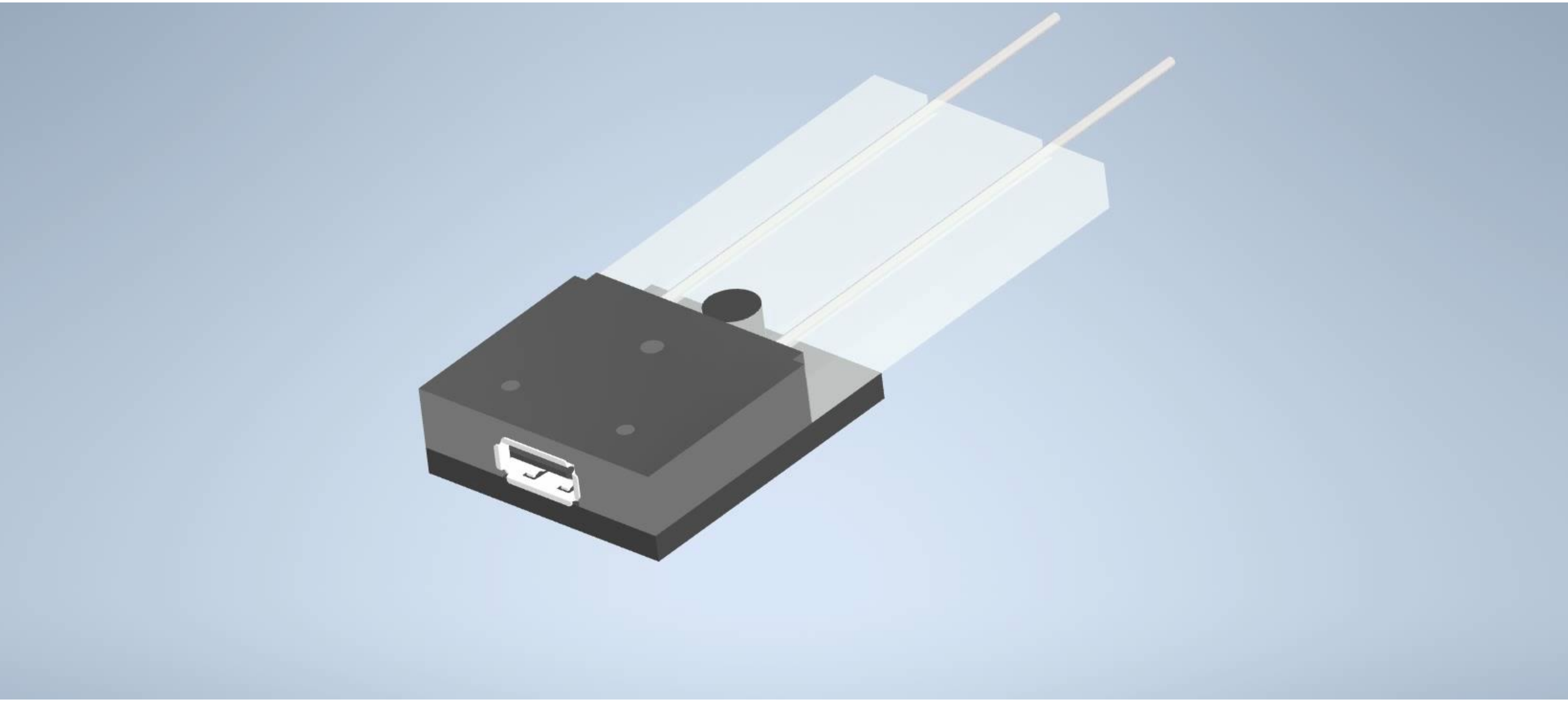


light detection

- At each end of the bar there are 2 MPPCs, optically connected to the output of each WLS fiber.



Assembly of the developed terminal



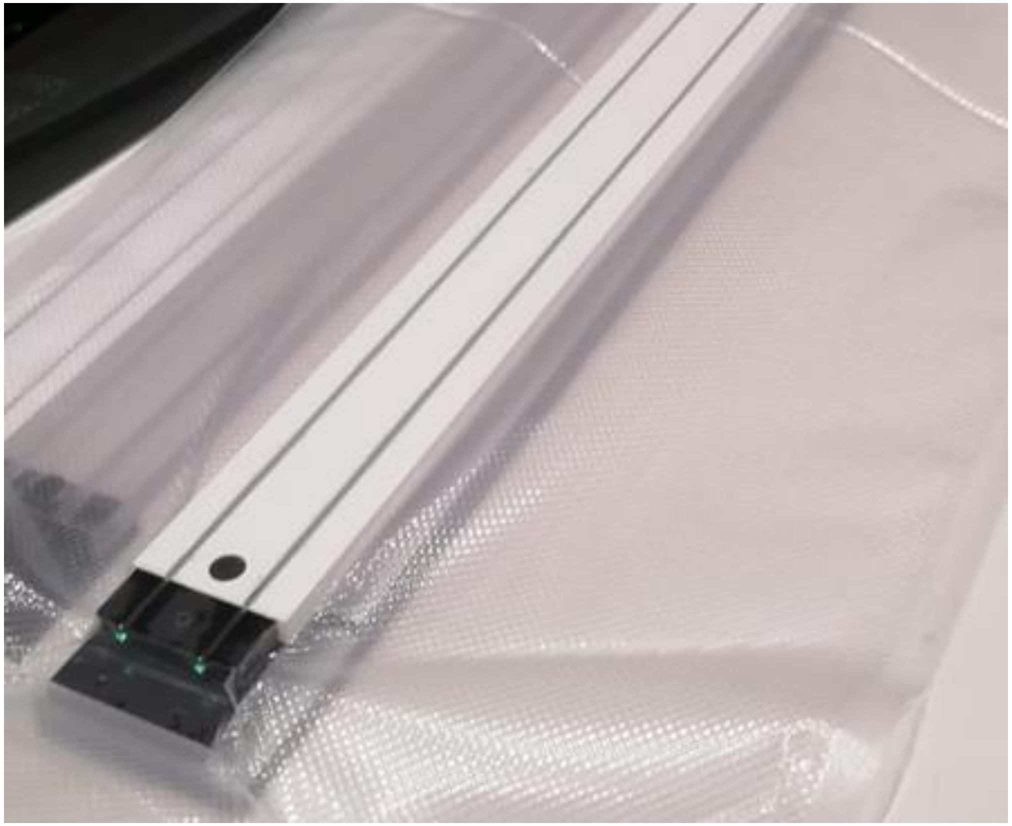
New fiber optic installation method.

The problem is to achieve an effective adhesion of the fiber throughout the entire slot (2.5m), each bubble will generate light losses in the system.

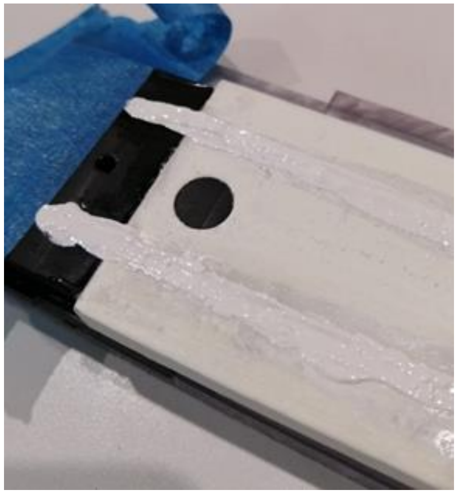
This is the first test of bonding fibers inside grooves using atmospheric pressure to hold the fibers in place during adhesive curing.

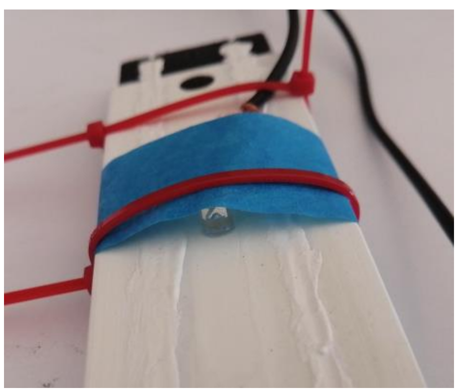
New fiber optic installation method.

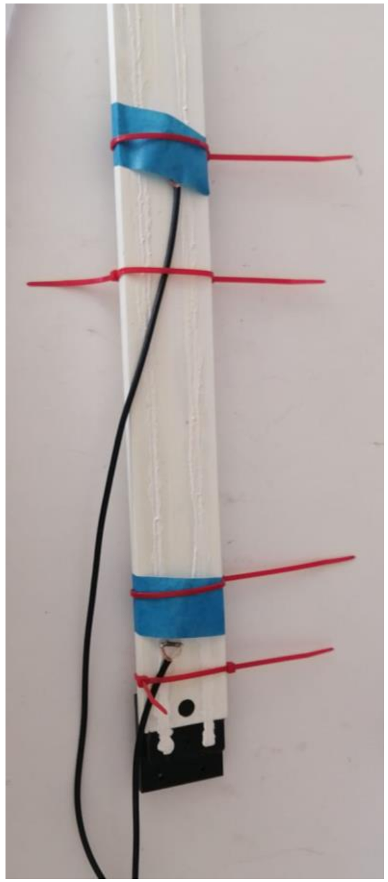
Assembled in a real scintillating plastic with WLS fiber.



Preliminar setup for test

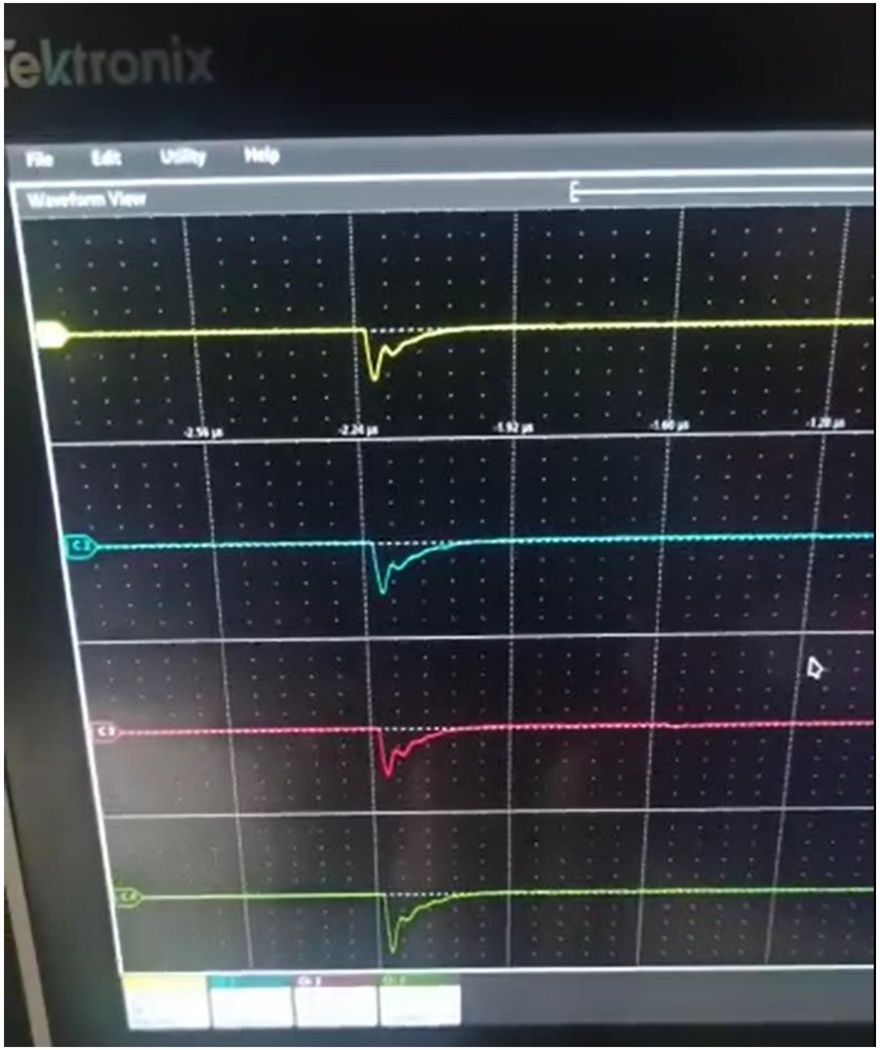




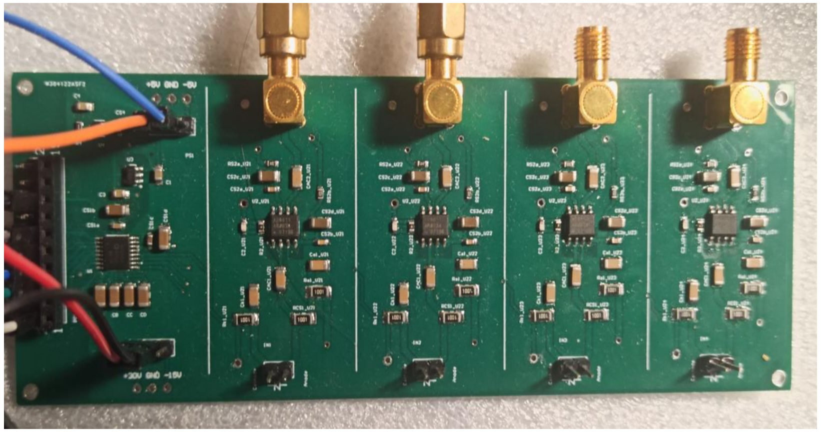


Then the optical fiber is covered with diffuse reflection paint, and 2 LEDs are installed, in optical connection with the scintillator, to carry out preliminary tests.

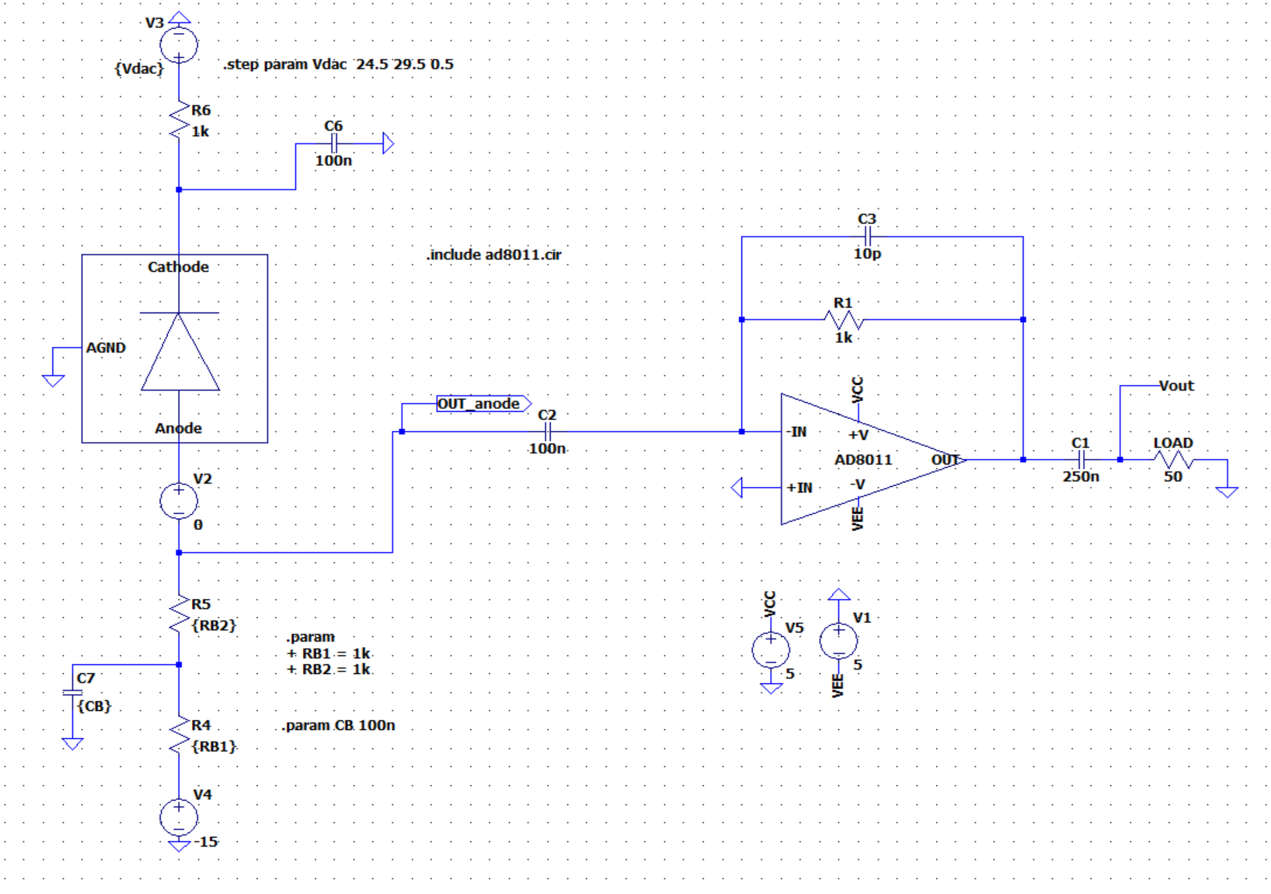
Preliminar test



- But we can't have signals without an electronic....

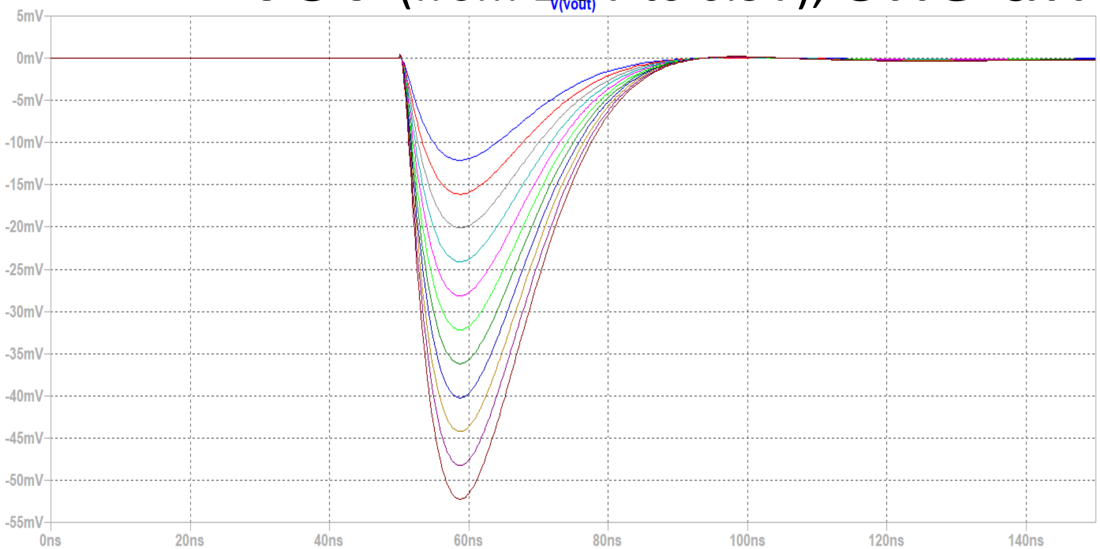


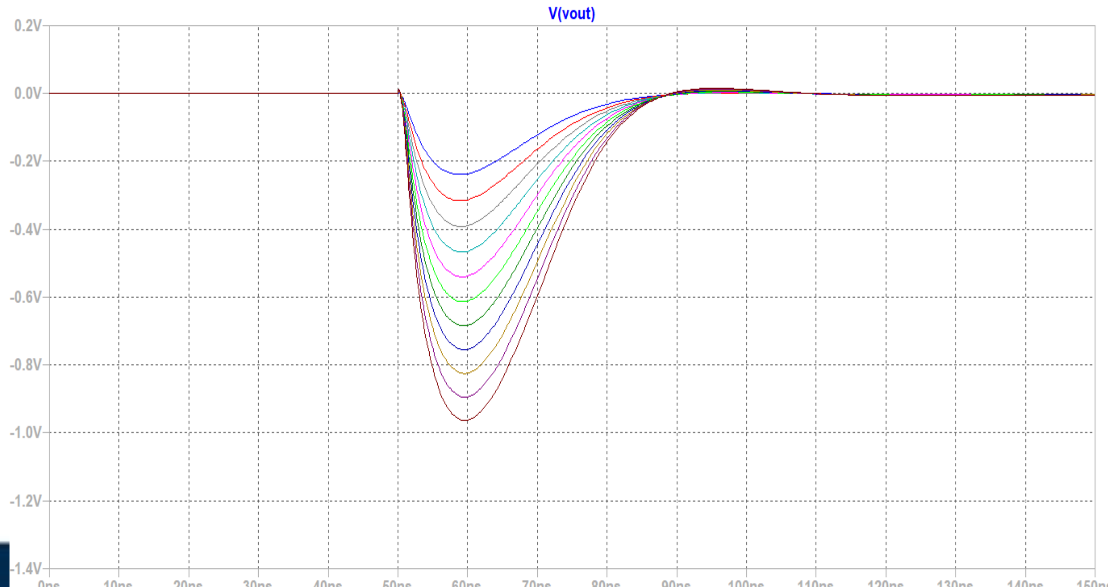
Front end readout circuit, by Matías Henríquez and Sergey Kuleshov.



The developed electronics integrates the adjustable bias voltage (gain) and a transimpedance amplifier with 50 Ω output.

Simulated waveforms (50Ω load) for different Vov (from 1.5V to 6.5V), one and 50 cell fired

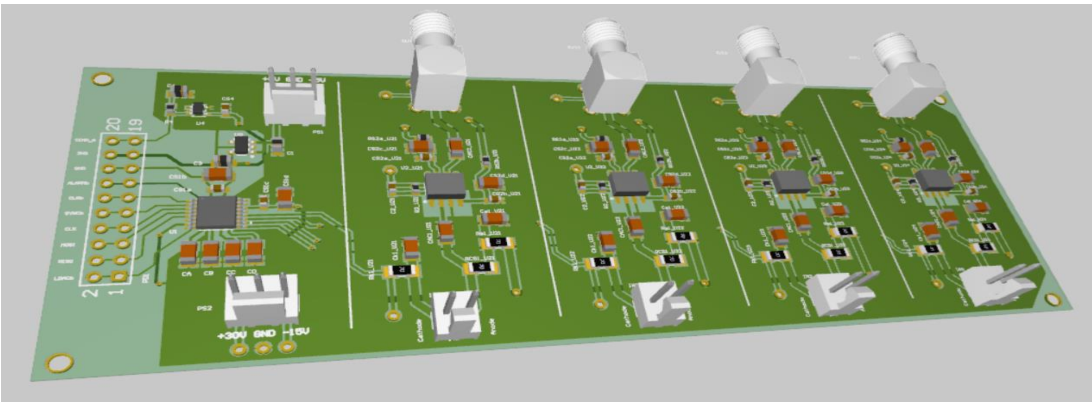


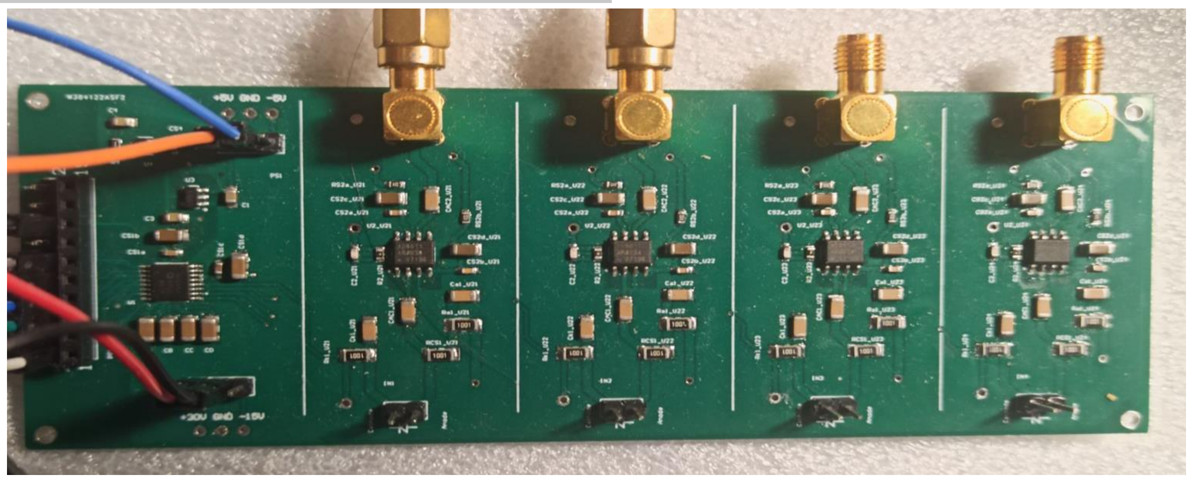


The simulation shows that in this configuration, the system, is operative from 1 cell activation and over 50 cells.

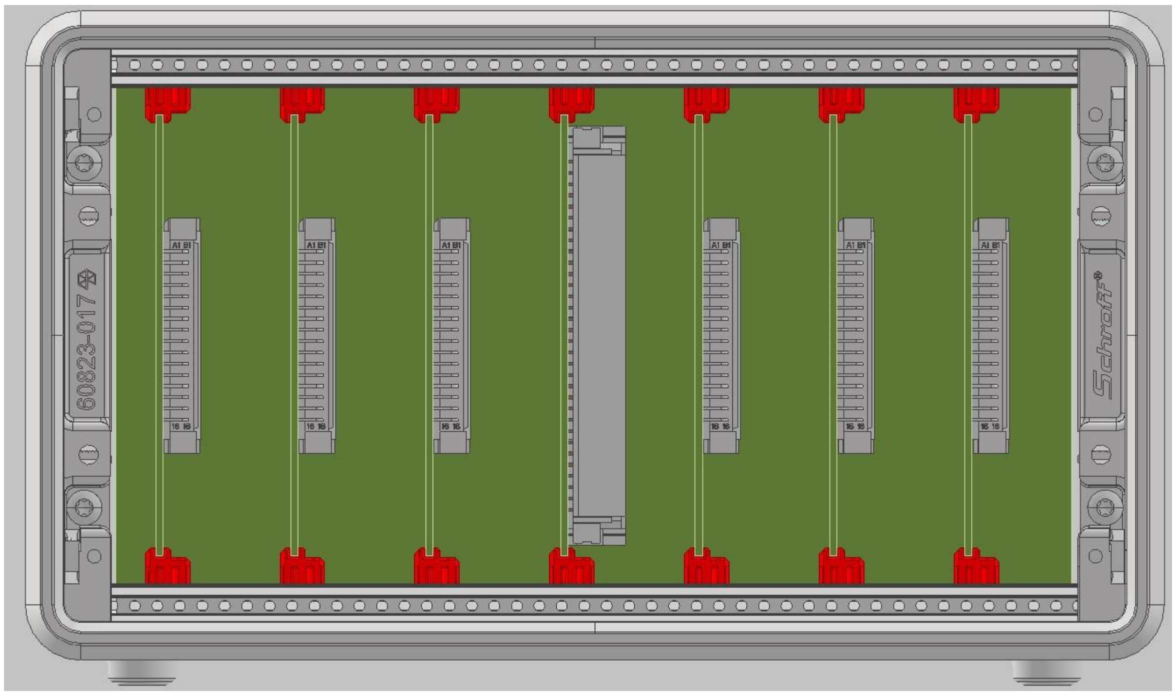
The digital overvoltage setup capability is essential for the correct equalization of the MPPCs and subsequent analysis by the number of "photons" detected.

PCB layout (3D)





Crate development



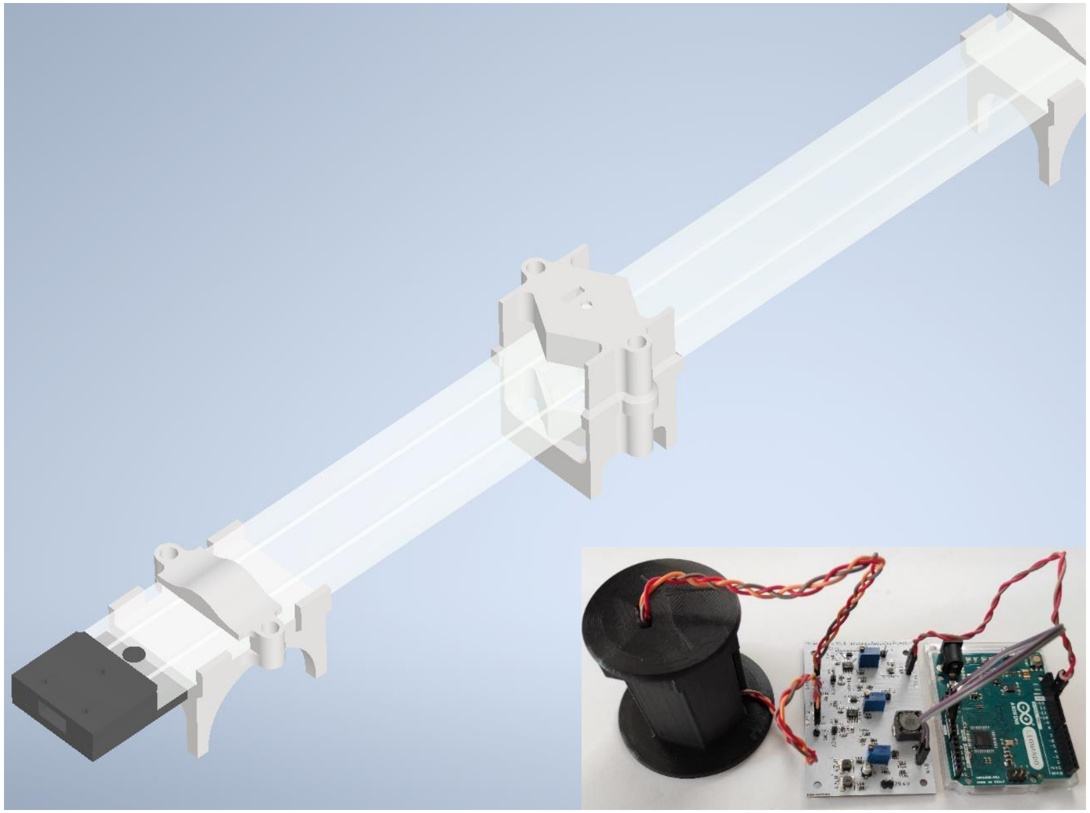
For the large number of channels required, a multi-channel modular system is being developed.

Initially, it will have the capacity to process 48 channels, that is, 12 bars per crate.

Crate development

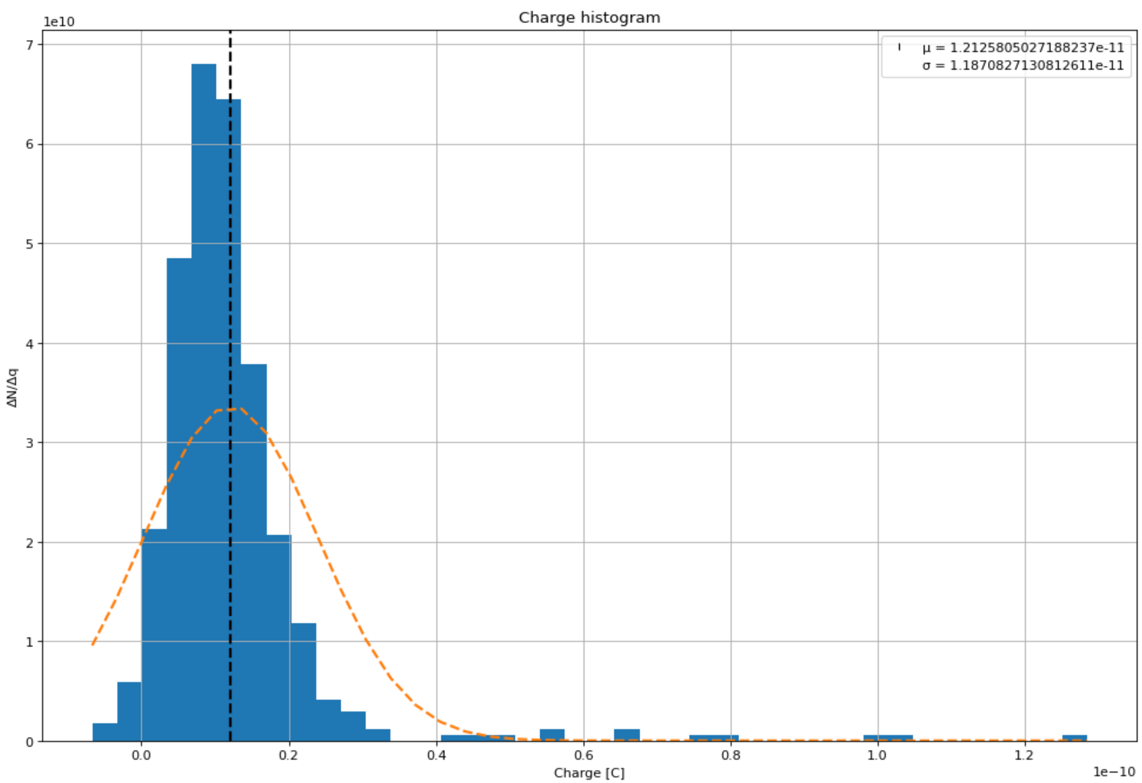
- The system will be modular, so initially comparators will be developed, but different analog-digital processing systems can be implemented.

Cosmic ray characterization



For this preliminar characterization, a muon detector developed for teaching was used, consisting of 2 isolated and vertically stacked hexagonal scintillator plastics.

Resultado preliminar (375mm)



The first results are reasonable and agree with the simulations, but it is a work in progress...