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«Quarks-2024»
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Assembly and in-beam commissioning of the segmented neutrino detector SuperFGD

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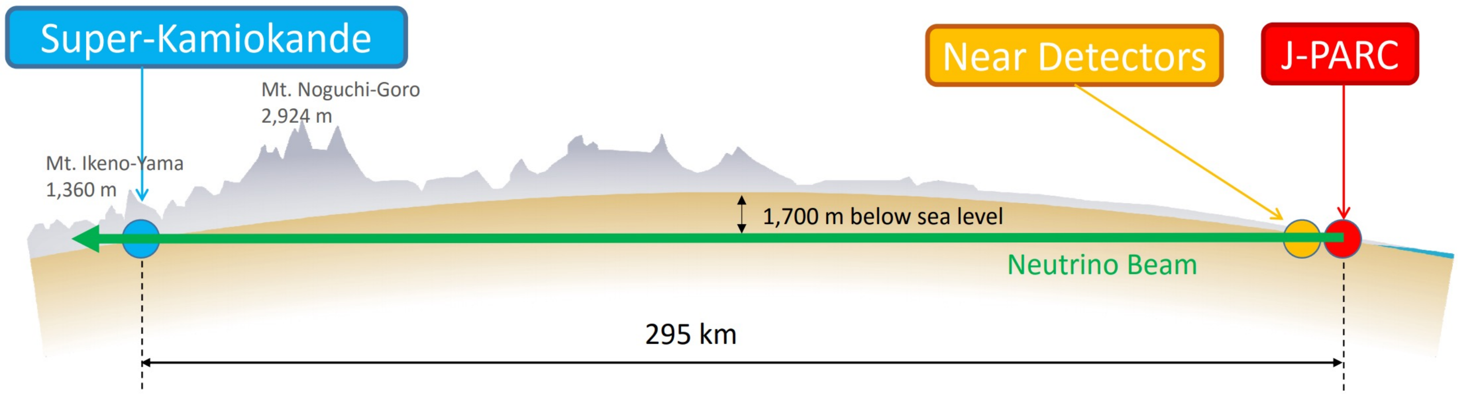
The T2K Experiment

The T2K (Tokai–to–Kamioka) experiment is a long-baseline neutrino experiment in Japan studying neutrino oscillations. The main goals of T2K are:

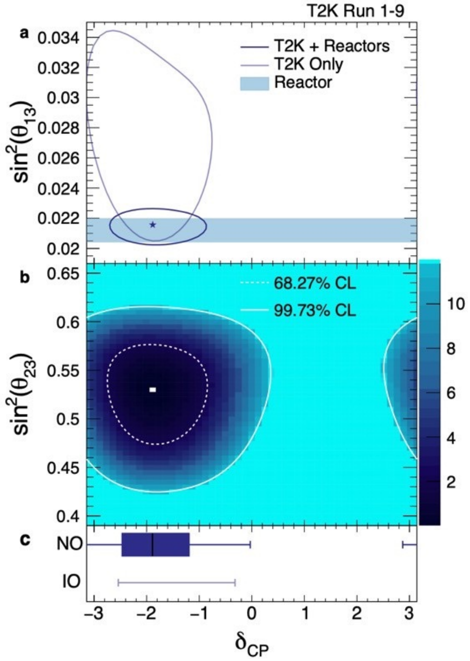
- Study of electron neutrino appearance in the muon neutrino beam (mmeasure θ_{13}),
- Precise measurement of oscillation parameters (Δm^2_{23} and θ_{23}) via disappearance studies,
- Study of CP violation providing further constrain on the δ_{CP} phase,
- Measurements of various neutrino interaction cross-sections for different types targets.

The experiment uses a muon-neutrino beam generated at the J-PARC accelerator in Tokai and sent 295 km to the far detector, Super-Kamiokande, in Kamioka. The focus of this talk will be on the near detector ND280 and its upgrade project.

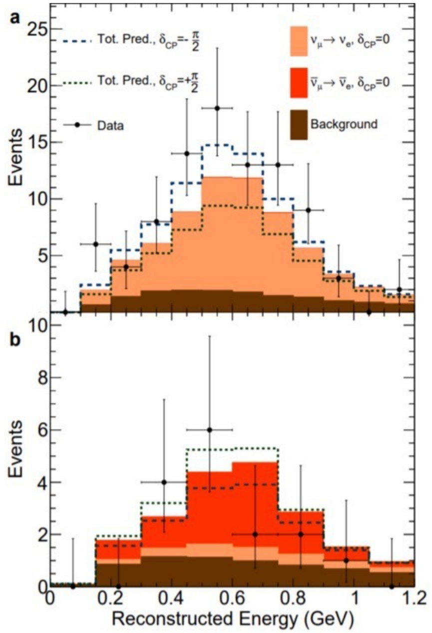


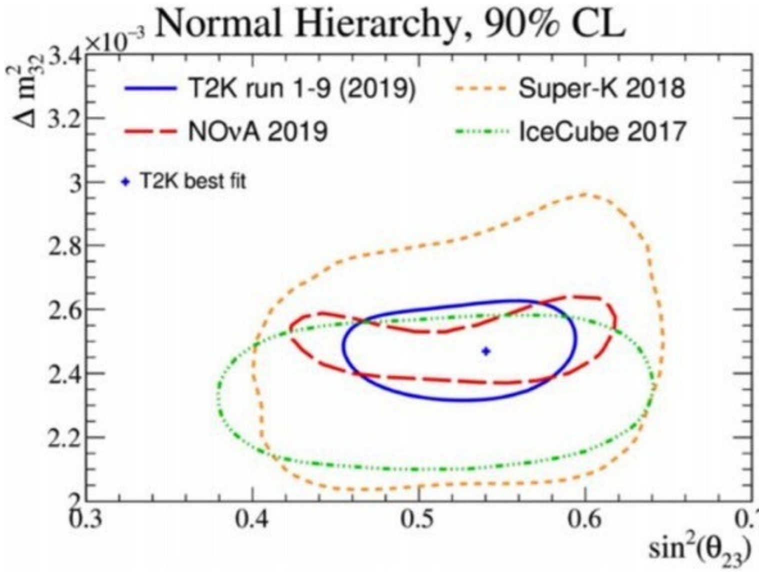
The T2K Results

Constraints on CP violating parameter δ_{CP}

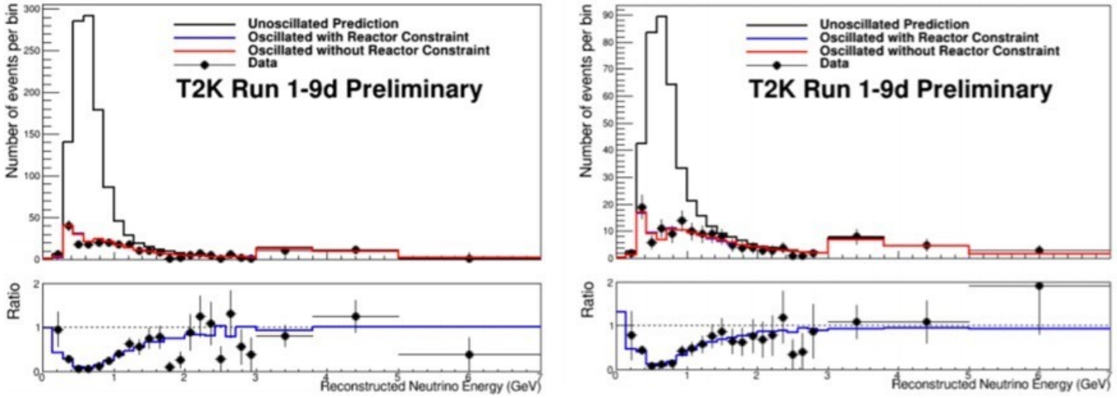


Number of observed electron neutrinos in the beam of the muon neutrinos

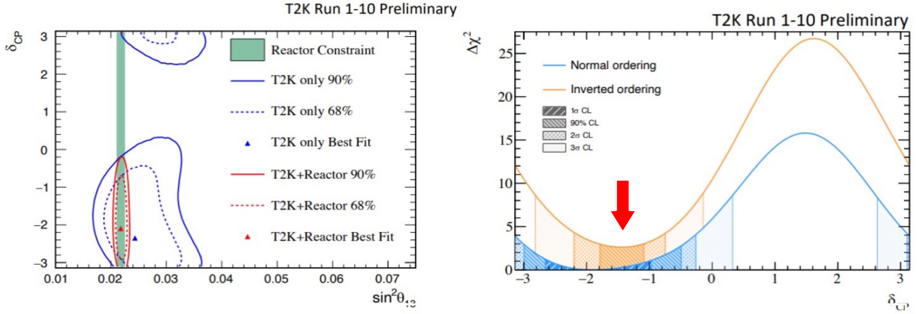




The $\sin^2\theta_{23}$ and Δm^2_{32} restrictions under the normal hierarchy of neutrino masses



Number of observed muon neutrinos and antineutrinos in the far detector with/without oscillations

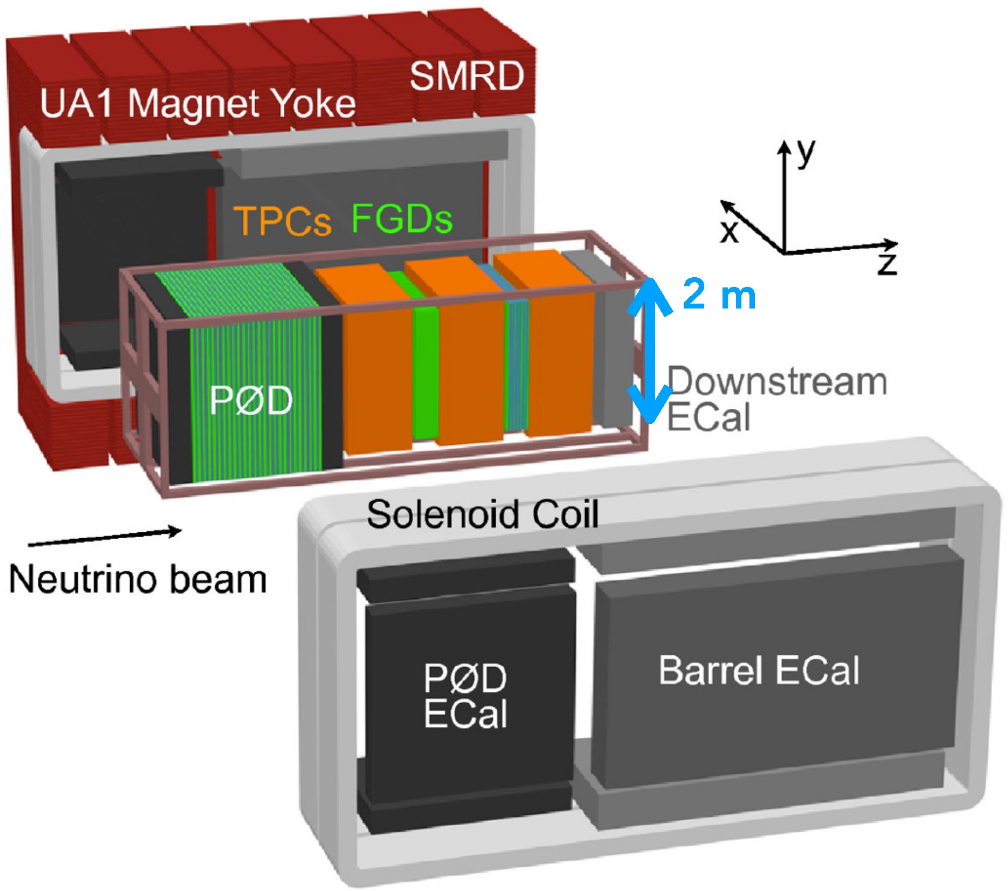


Indication of maximal CP violation in neutrino oscillations $\delta_{CP} \sim -\frac{\pi}{2}$

Motivation of ND280 Upgrade

Uncertainties of current T2K oscillation measurements are dominated by statistics.
However, systematics will limit T2K (and HyperK) sensitivity in the future.

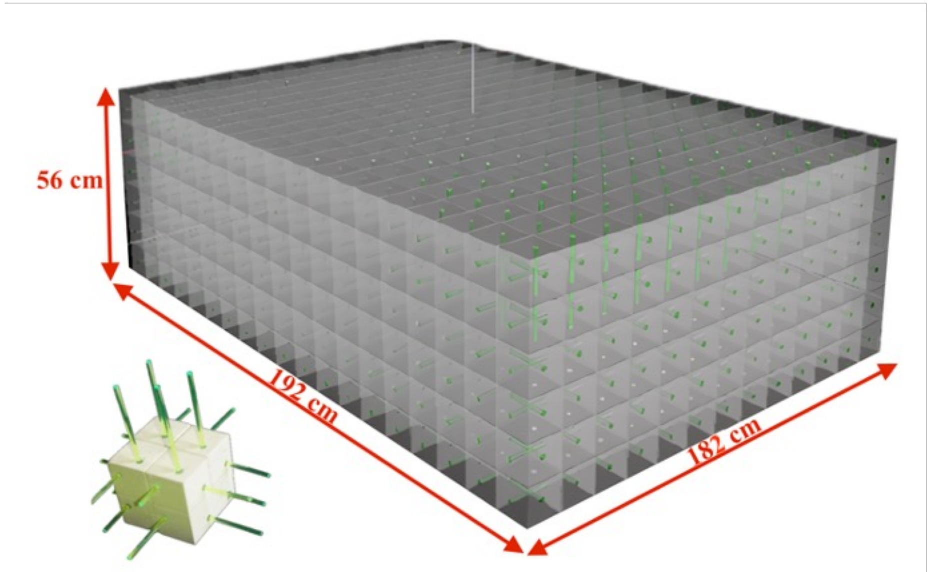
- Important to measure neutrino interactions in all phase space.
- Precisely detect particles produced at any angle.
- Reduce detection threshold, measure protons with low threshold.
- Measure neutrons in anti-ν_μ interactions.
- Reduce background, obtain better track identification using TOF (Time-of-Flight).
- Reduce total systematics to $\leq$ 4% level (from current ~ **6**%) for appearance modes.



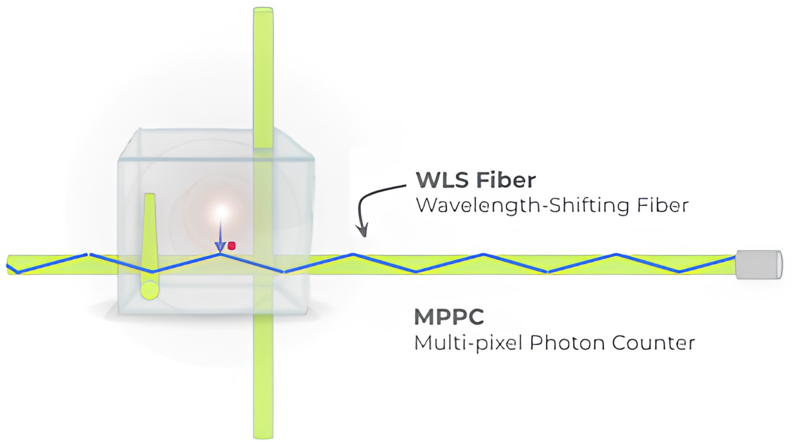
Schematic view of ND280

SuperFGD

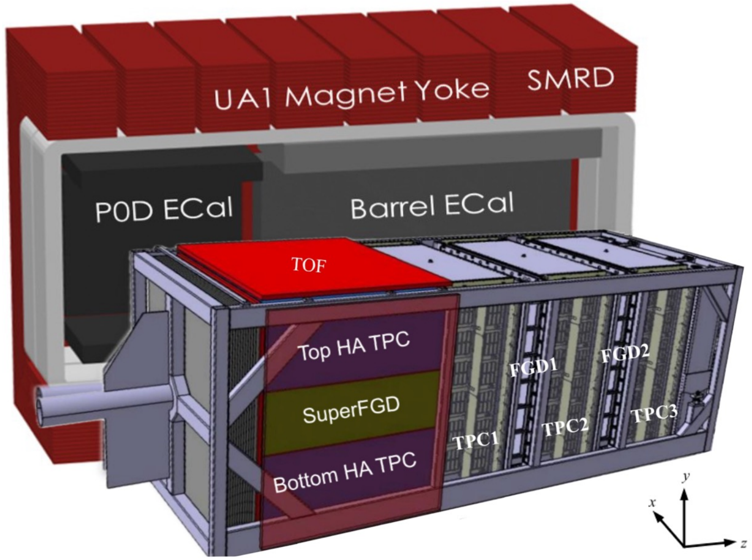
The SuperFine-Grained Detector is the active target for neutrino interactions in the upgraded ND280 detector. It is a plastic scintillator detector composed of a large number of optically independent 1x1x1 cm^3 cubes read out along three orthogonal directions by wavelength shifting fibers.



Detector design

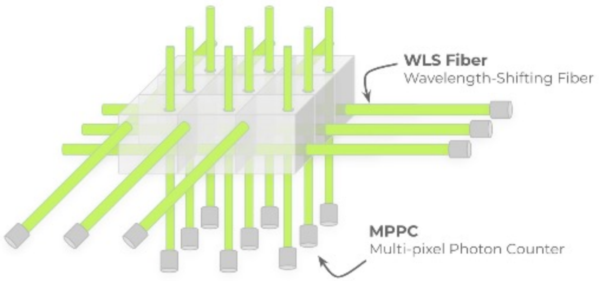


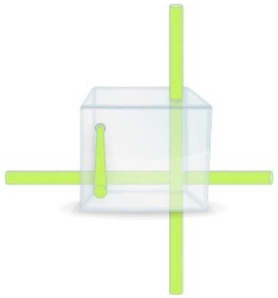
Signal readout



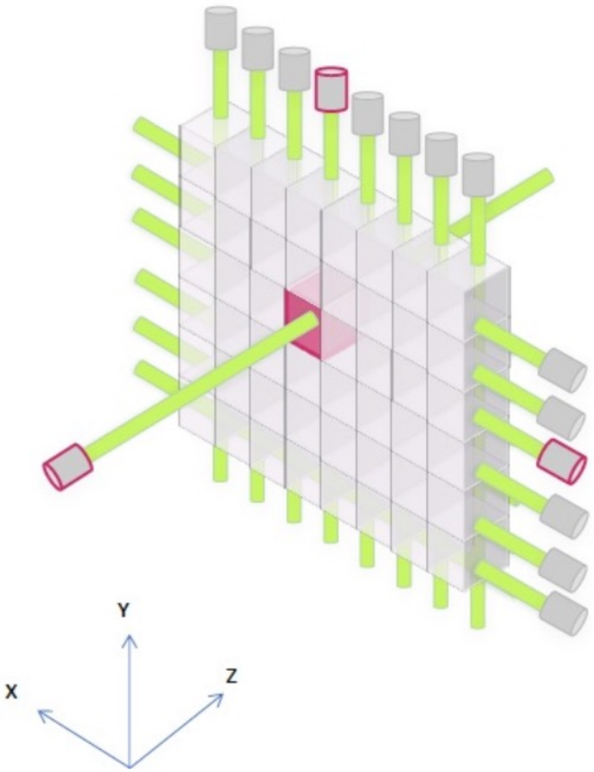
SuperFGD between two HA-TPC cameras

Cubes



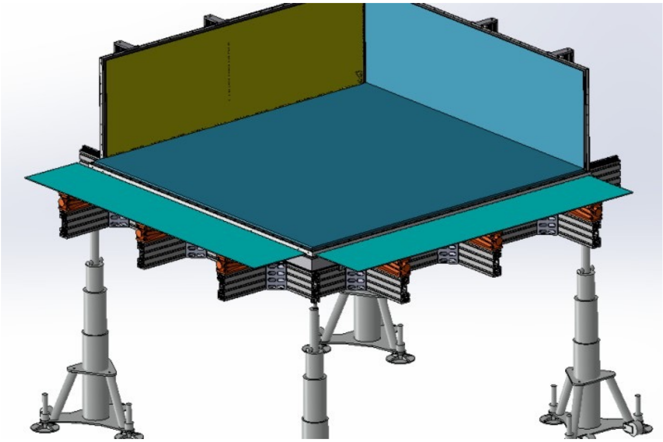


- Cubes produced by injection molding.
- The building blocks of the SuperFGD are the scintillating cubes. The 1 cm cubes are made of polystyrene and doped with 1.5% of paraterphenyl (PTP) and 0.01% of POPOP.
- To make the cubes optically independent, they are coated with a chemical reflector by etching their surface with a chemical agent.
- Produced by Uniplast in Vladimir, Russia.
- The SuperFGD (192 x 56 x 182 cm^3) is about 2 million cubes.

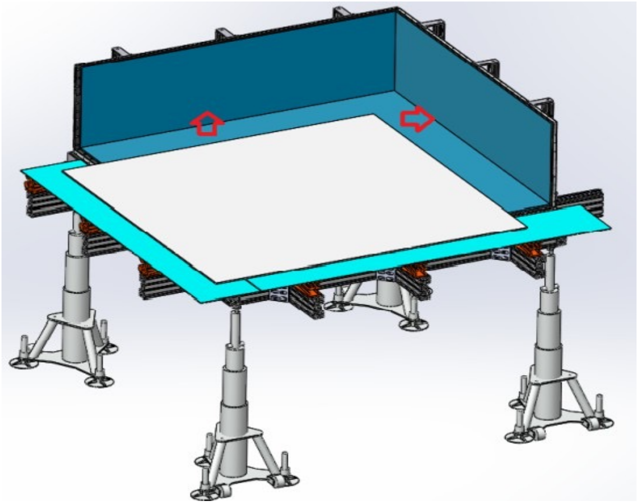


- The SuperFGD provides 3D readout for each cube.
- Each MPPC can give information on 2 of the three coordinates of the cube. This information, along with the amplitude and time of the signal, can be used to create projected 2D event displays.
- Sets of 3 2D hits can be matched in order to locate the cubes where the interaction occurred.

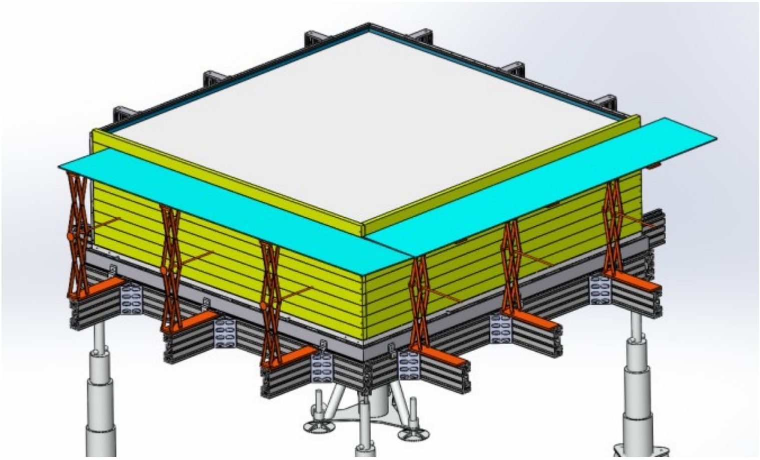
Scintillator Layers Assembly



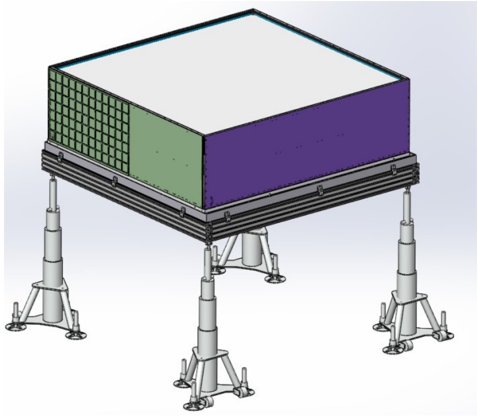
The assembled two side panels
and the bottom panel.



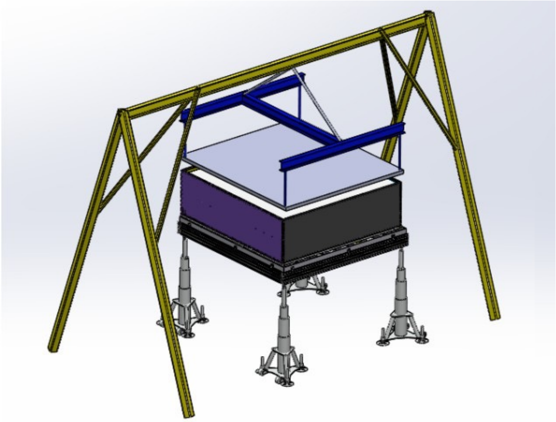
Moving the first layer to the
side panels of the box.



Collected layers of cubes.

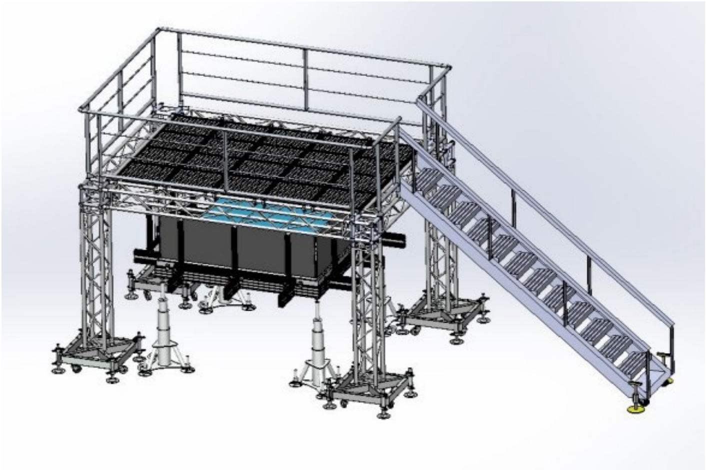


Box with four panels installed.

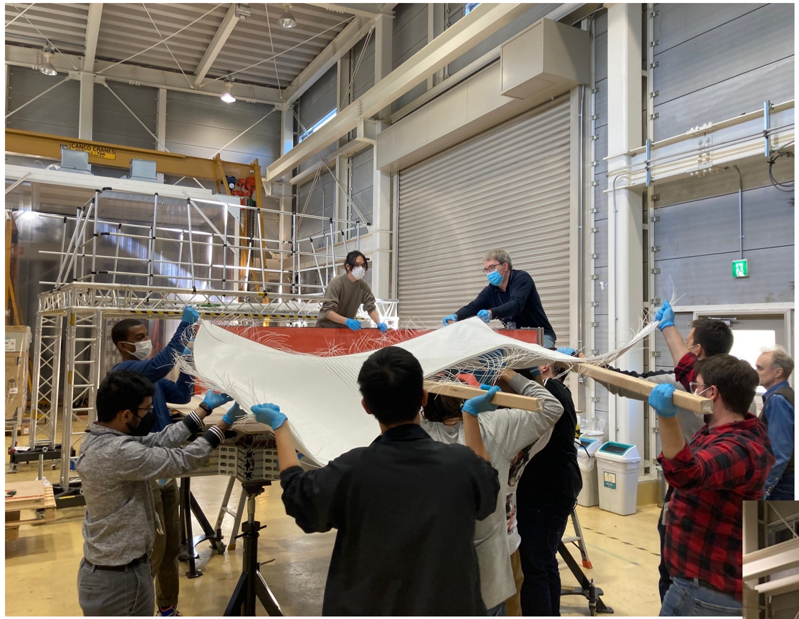


The top panel installation.

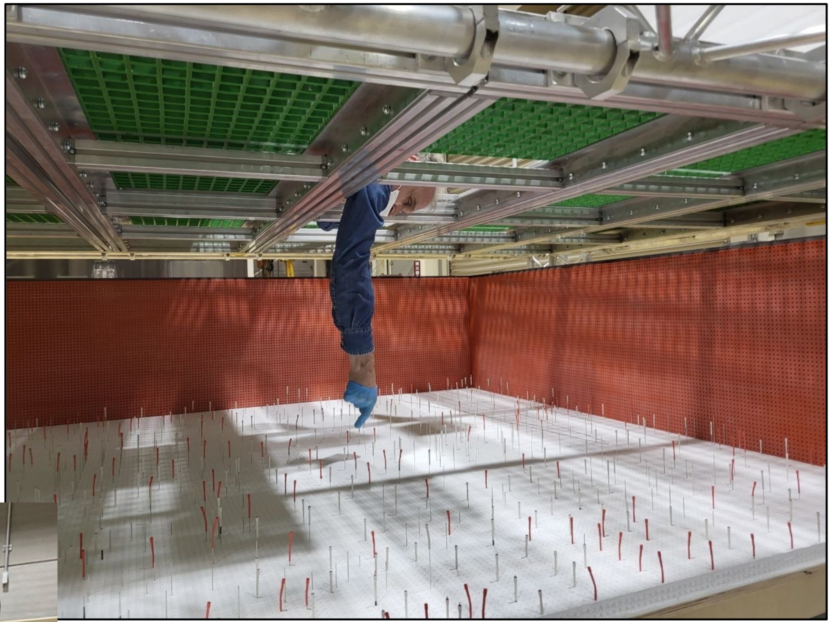
Top Access System was
needed to to access the
central areas of the
detector during assembly.



Scintillator Layers Assembly



Layers with fishing lines was assembled one by one.
Each layer is 192 x 182 cm^2 and contain 35328 cubes.

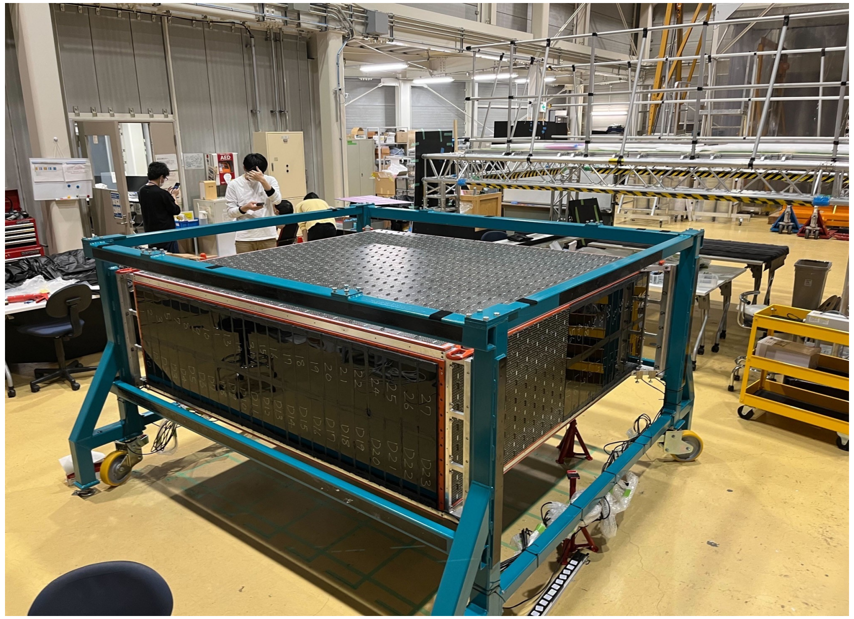


Top Access System

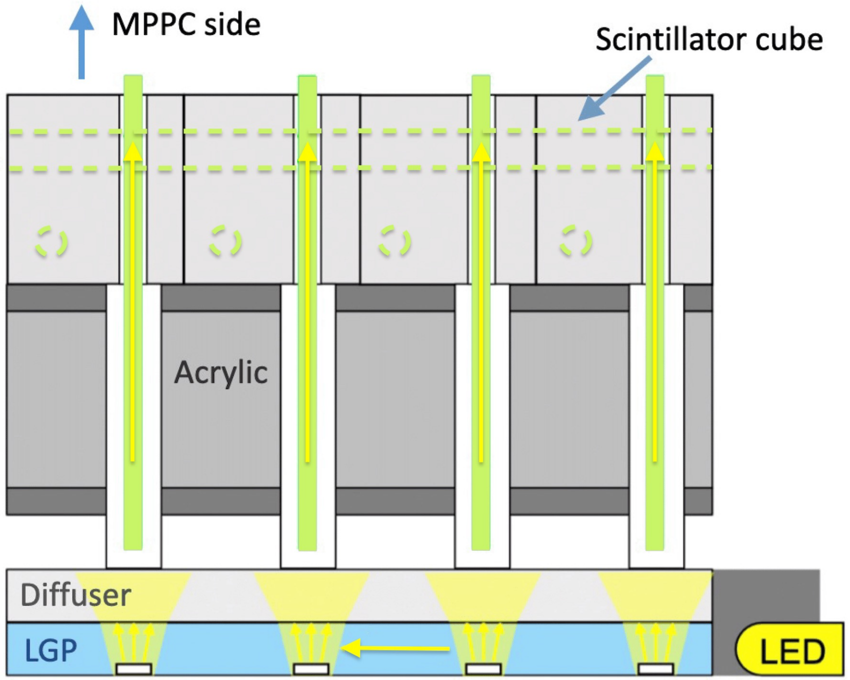
Construction was carried out in J-PARC NA building.
In November 2022, all 56 layers (or two million scintillation cubes) were assembled.

LED calibration system

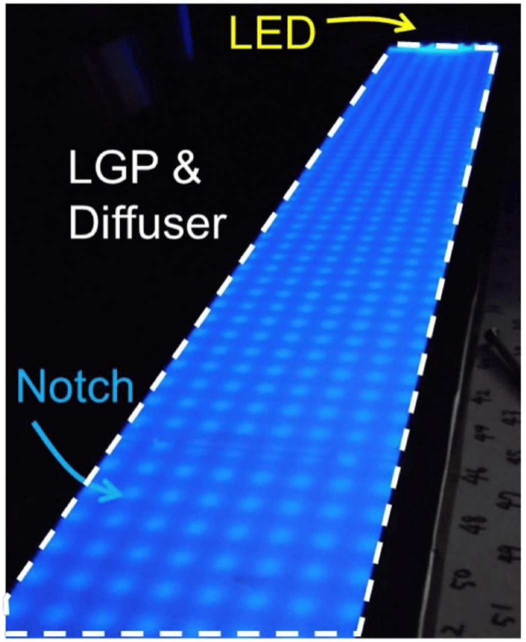
- For MPPCs calibration special LED system was designed.
- This system is contain LED driver, Light-Emitting Diode, Light guide panel and diffuser.



SuperFGD with installed panels



General view of the LED calibration module with LGP

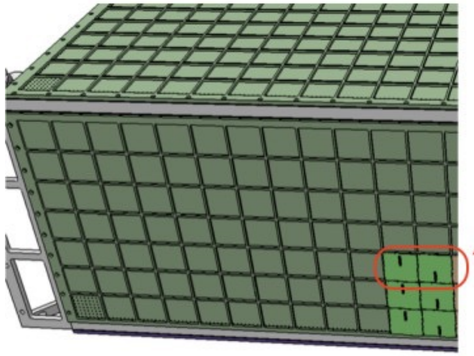


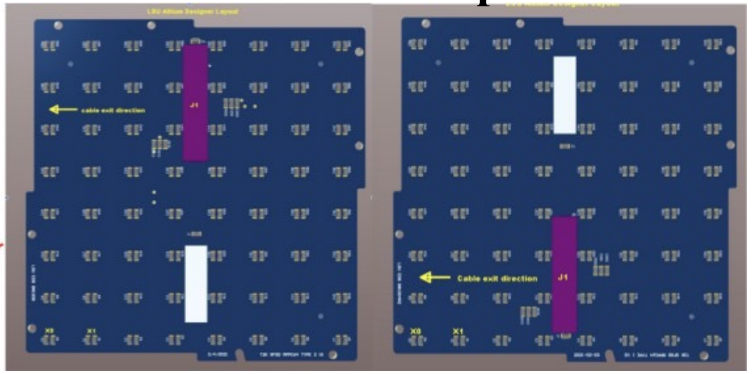
LGP module distributes LED light to all MPPCs

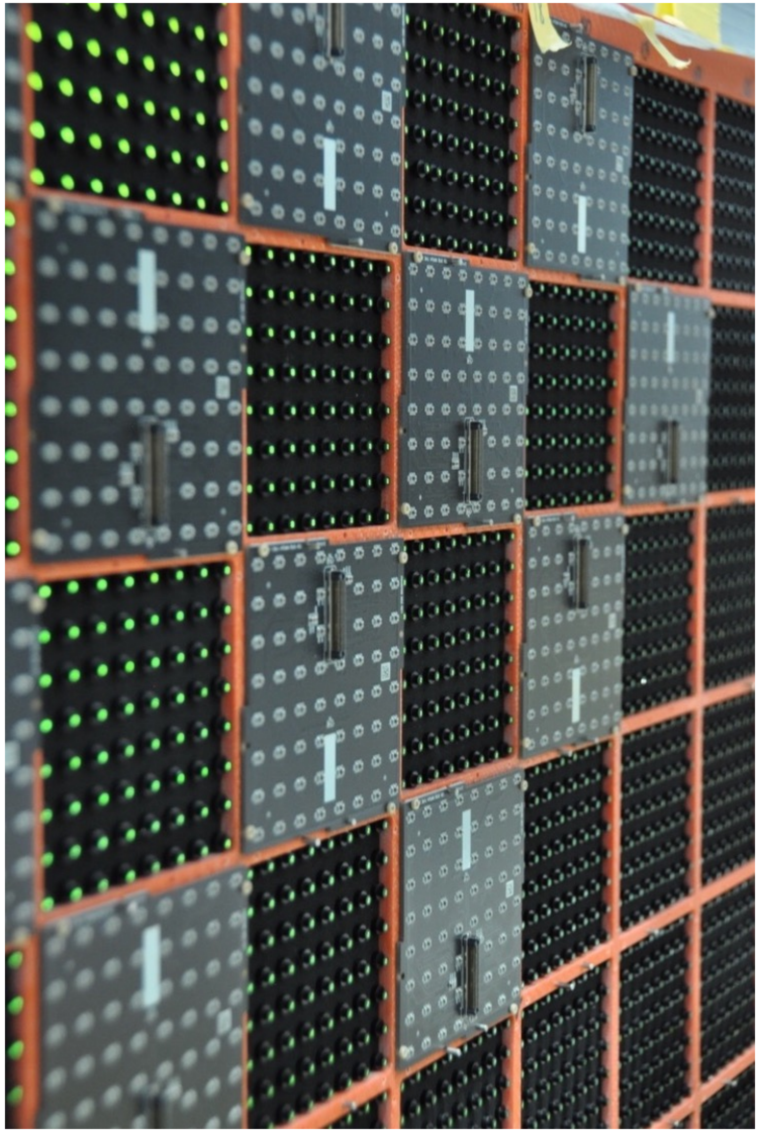
MPPCs PCBs

- 56,384 Multi-Pixel Photon Counters (MPPCs)
- MPPC S13360-1325PE (Hamamatsu Photonics K.K)
- 8 x 8 arrayed MPPCs on a printed circuit board (PCB)
- 881 MPPC-PCBSs in SFGD

MPPC64-PCB designs for the two connector positions





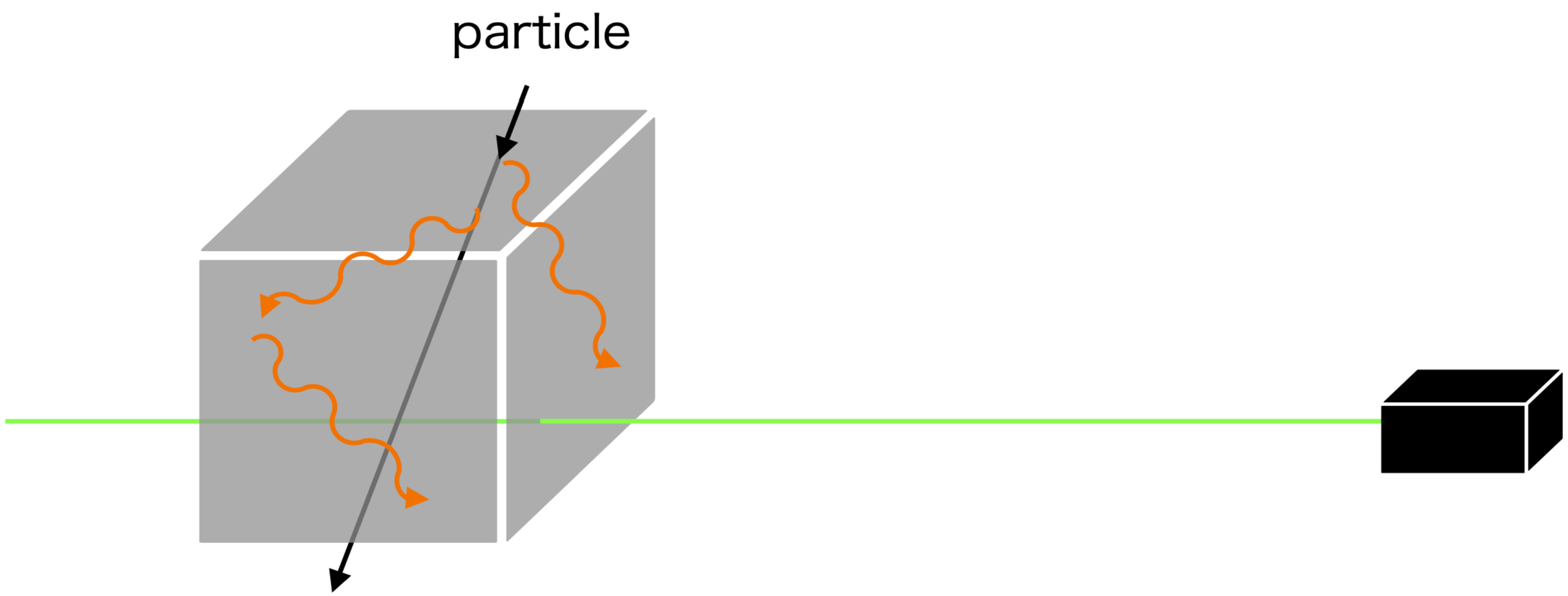


MPPC’s parameters

- Effective photosensitive area: 1.3 x 1.3 mm^2
- Number of pixels: 2668 pixels
- Pixel pitch: 25 µm
- Breakdown voltage: (53 ± 5) V
- Gain: 7.0×10^5
- Dark noise rate: 70 kHz
- Crosstalk: 1 %
- Photon detection efficiency (PDE): 25 %

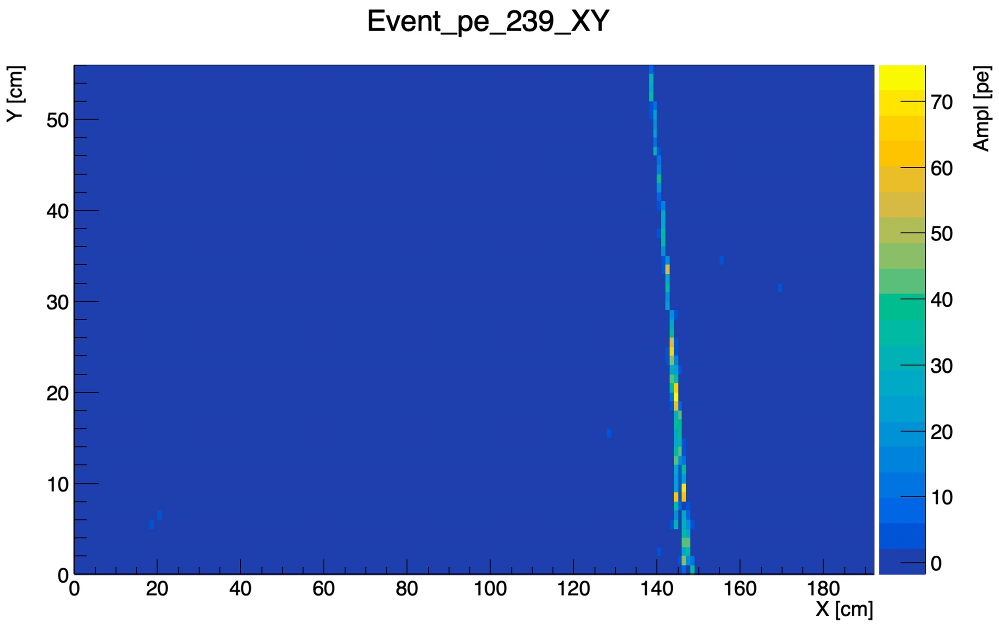
Calibration for signal Attenuation Length

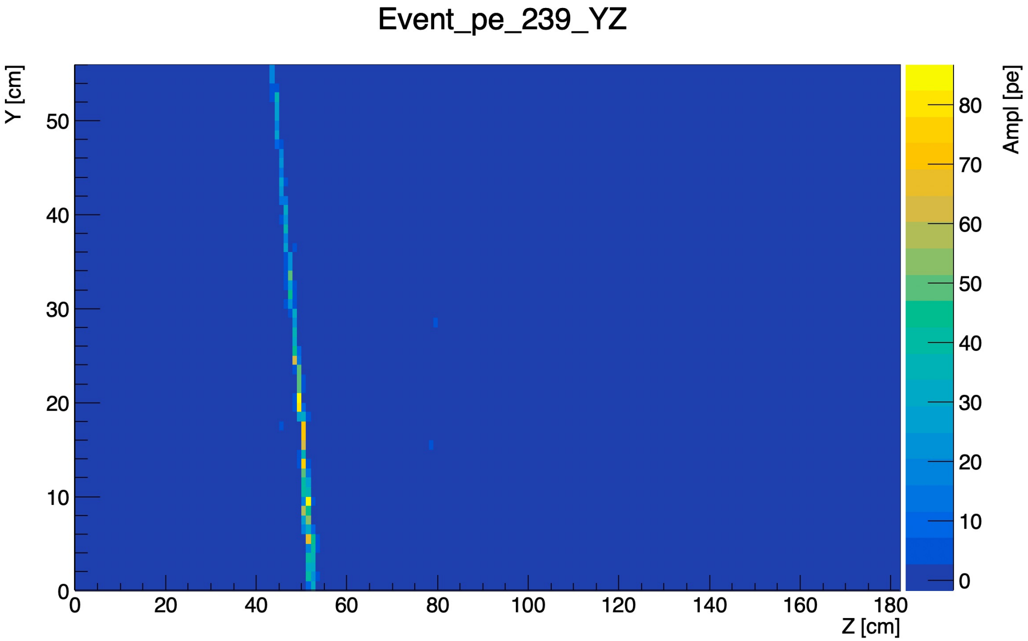
- The location of each energy deposition event
- Get absolute values of Light Yield (LY), not relative
- Take into account the uncertainties that appeared during detector assembly and production of its elements



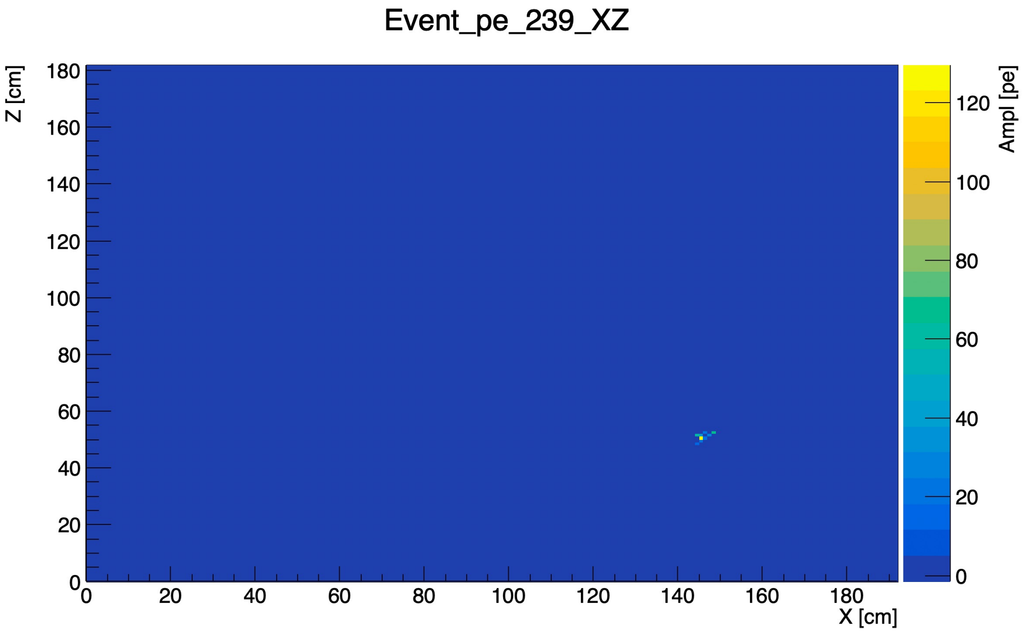
Cube	Cube - Fiber	Fiber	MPPC	FEB
Optical crosstalk	Coupling	Attenuation	PDE	Digitization
		Reflection	Saturation	Saturation

Track example





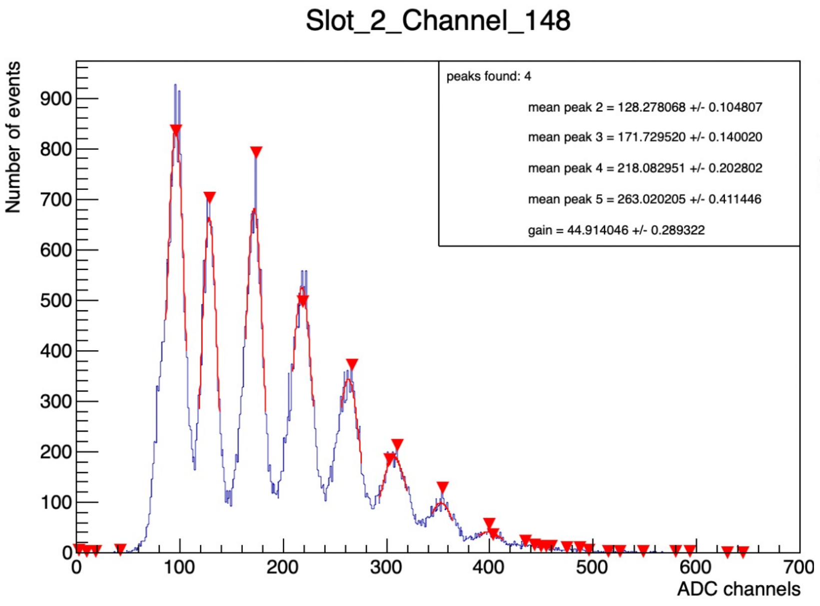
- Self-trigger mode
- 2.6 million of cosmic events

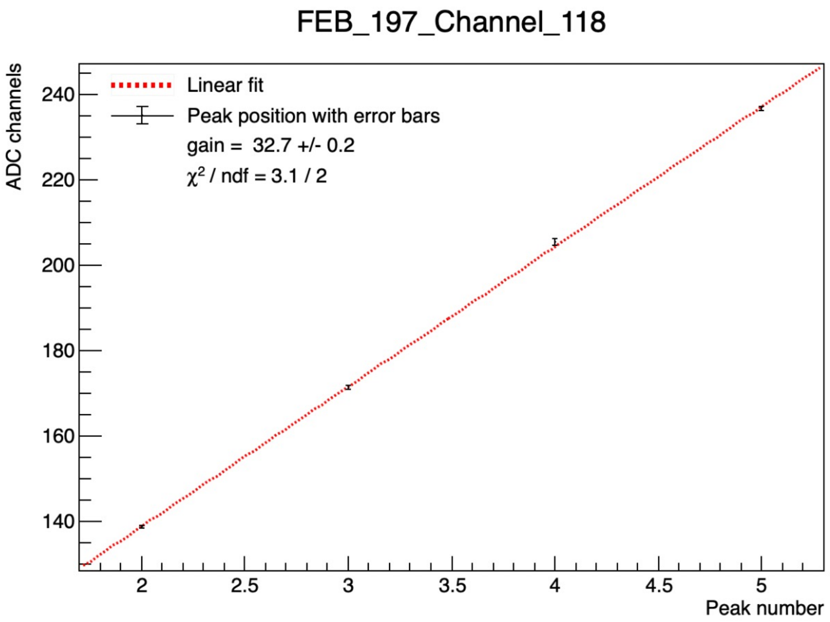


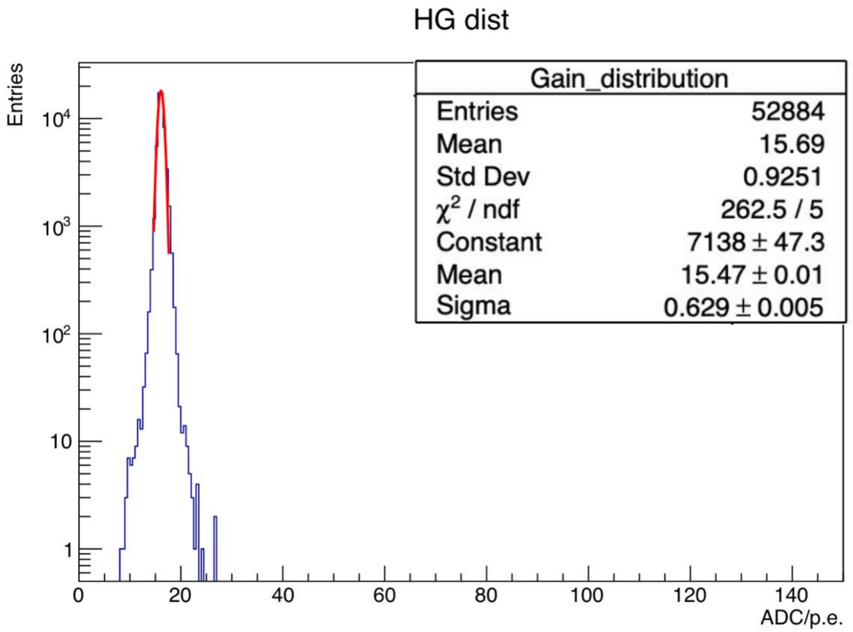
MPPC calibration and Gain calculation

Extract HG calibration ratio ADC/p.e. from MPPC fingerplots.

ROOT library TSpectrum was used to find p.e. peaks, mean distance between peaks: gain value, first peak is not taken into account as it might be cut off by threshold.







Algorithm / Part 1

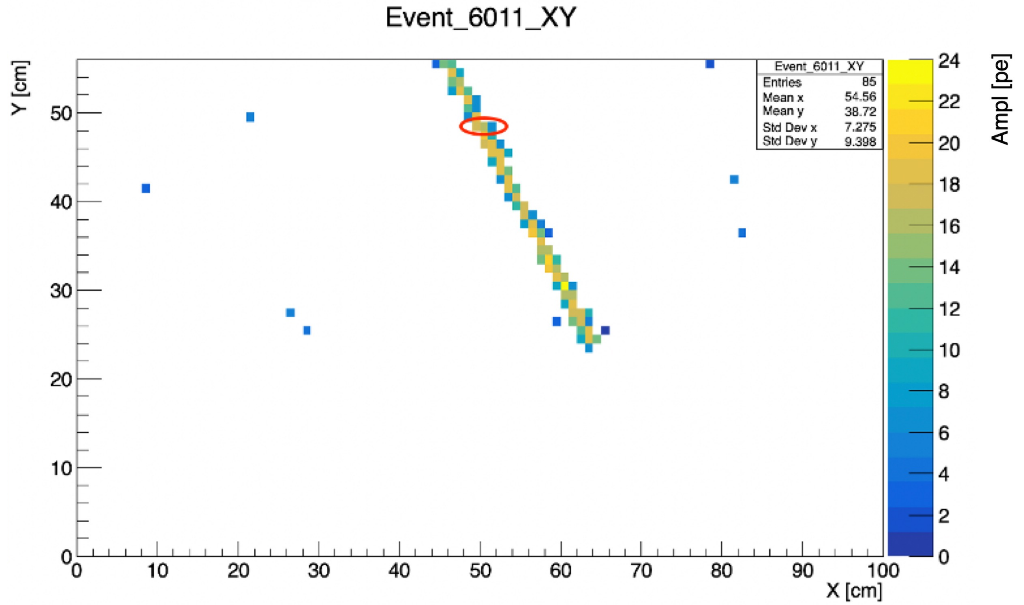
1. Read track projections on the YOX and YOZ planes

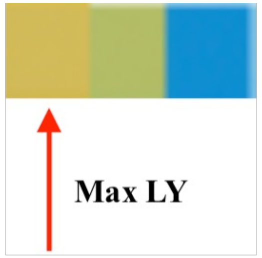
2. For each Y value:

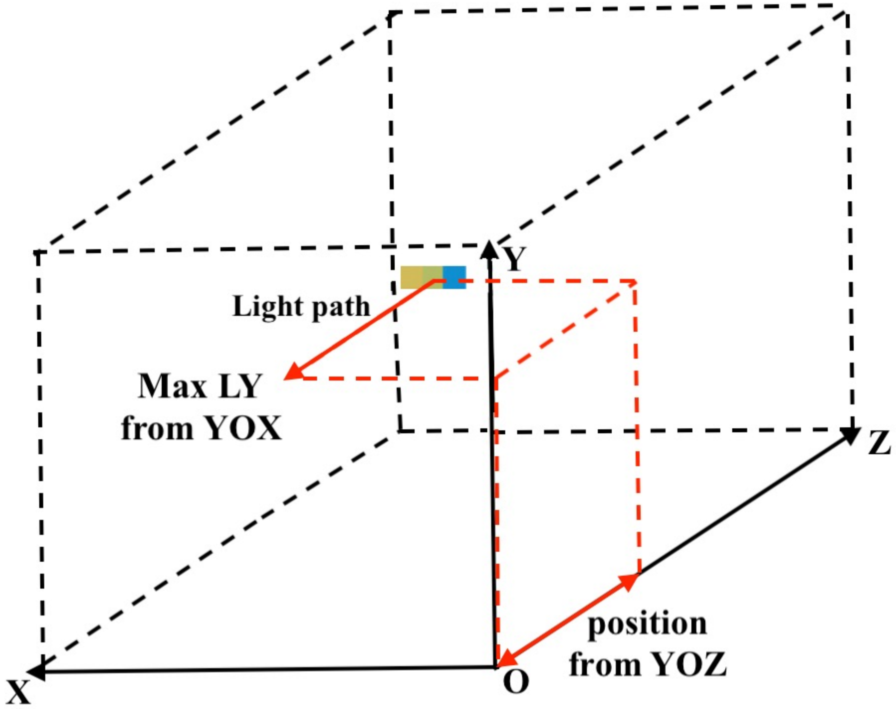
- Max Light Yield along the X (Z) axis
- Find the X (Z) coordinate that corresponds to the maximum Light Yield — position X (Z)

3. Assign Max Light Yield from one plane and position from another plane to each fixed Y value

4. Obtain the dependence of Max Light Yield on position X (Z) – signal attenuation length



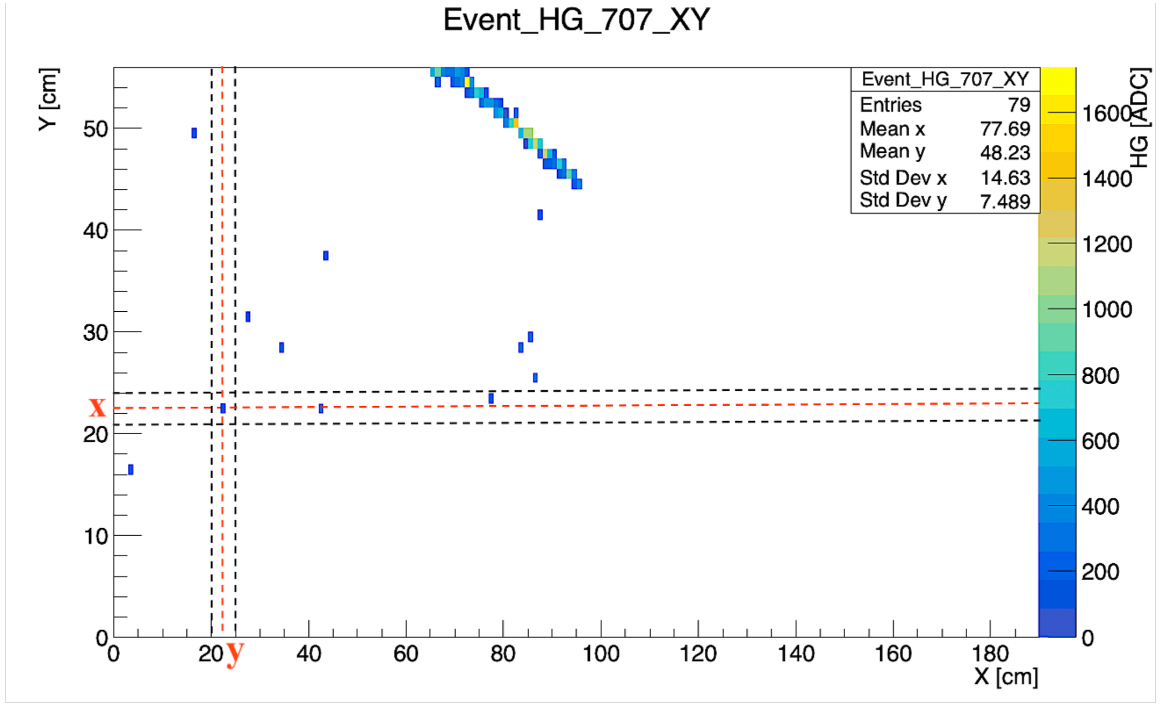




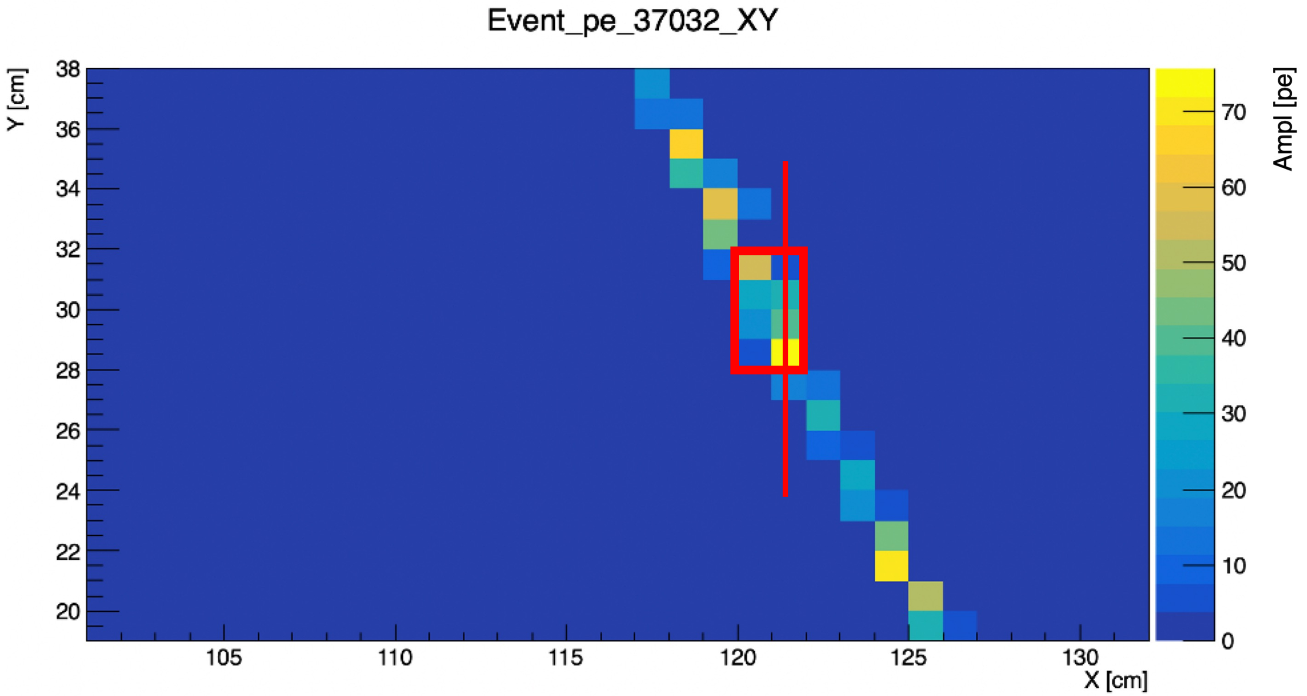
Algorithm / Part 2

Noise cut

If the event occurred at (x, y), look for matches on 4 lines: [x-1] & [x+1] & [y-1] & [y+1].

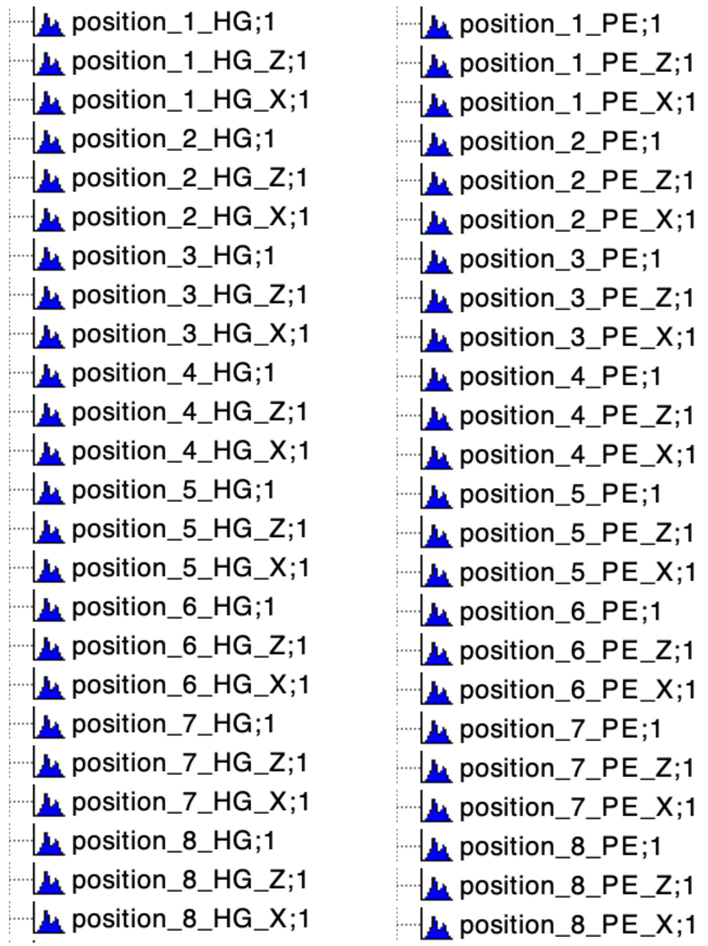


Orientation to vertical tracks: max LY in the same line for [y-1] and [y+1].

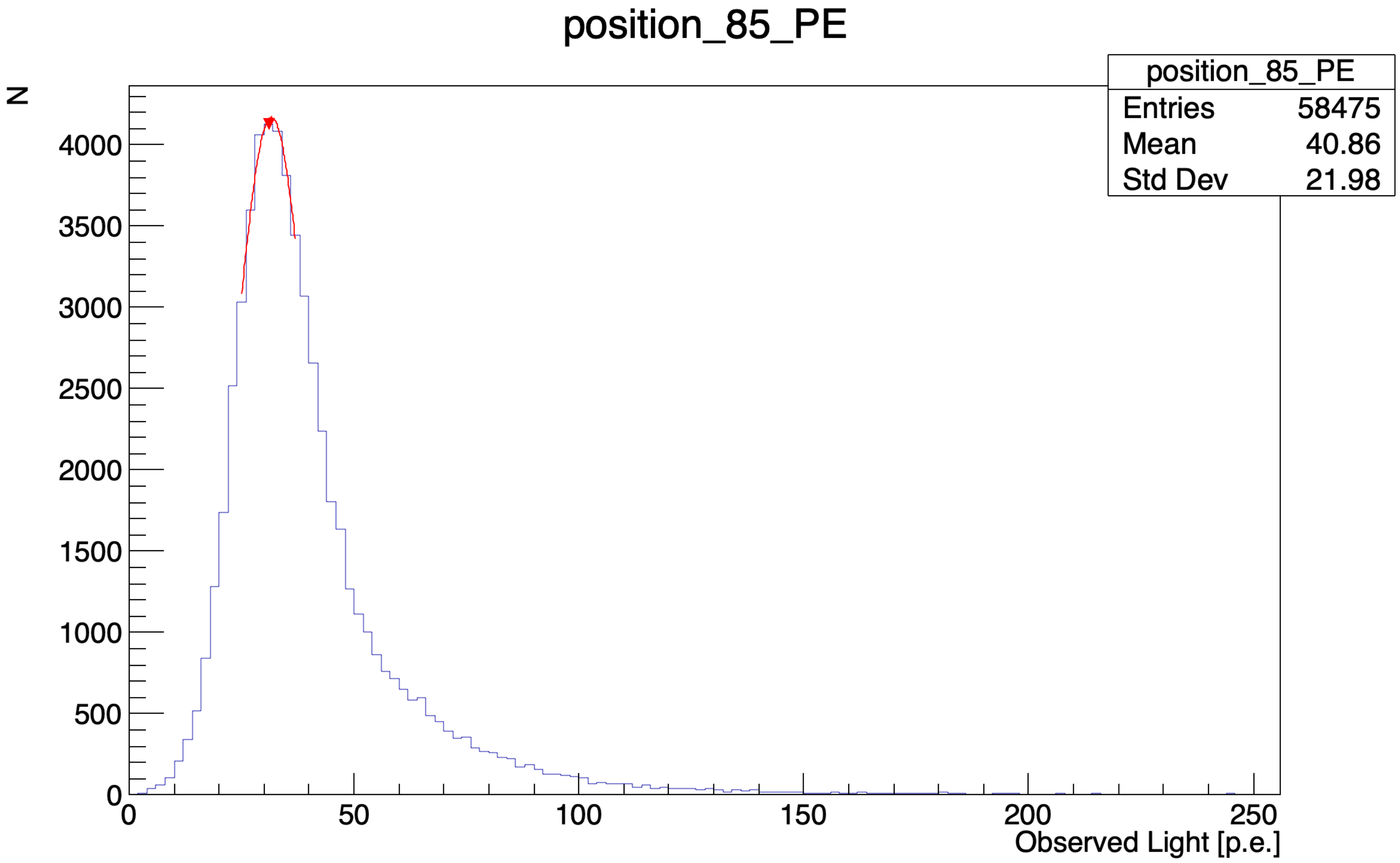


LY distribution for each fixed position

Get distributions for X fibers, Z fibers and all horizontal fibers:



Fit, find average LY and its error:



Attenuation Length for horizontal fibers

$$\mathbf{LY} = \mathbf{LY_S} \cdot \mathbf{e}^{-\frac{\mathbf{x}}{\mathbf{A_S}}} + \mathbf{LY_L} \cdot \mathbf{e}^{-\frac{\mathbf{x}}{\mathbf{A_L}}} + \mathbf{R} \cdot (\mathbf{LY_S} \cdot \mathbf{e}^{-\frac{\mathbf{2L-x}}{\mathbf{A_S}}} + \mathbf{LY_L} \cdot \mathbf{e}^{-\frac{\mathbf{2L-x}}{\mathbf{A_L}}})$$

LY – Light Yield, p.e.

LY_S – short Light Yield coefficient, p.e.

LY_L – long Light Yield coefficient, p.e.

R – reflection coefficient; try to fix this parameter: 15 - 25 %

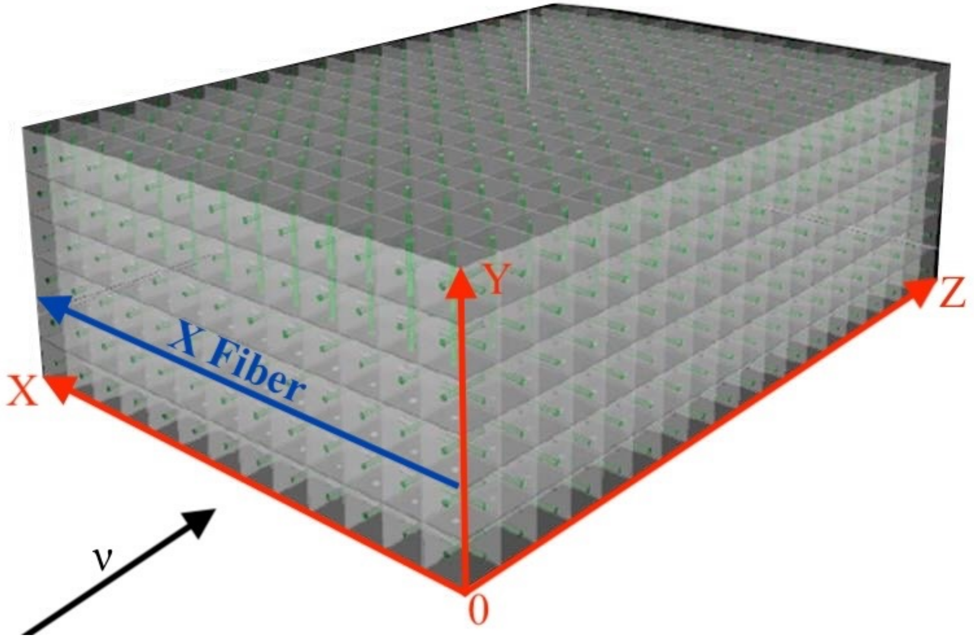
x – distance from photosensor, cm

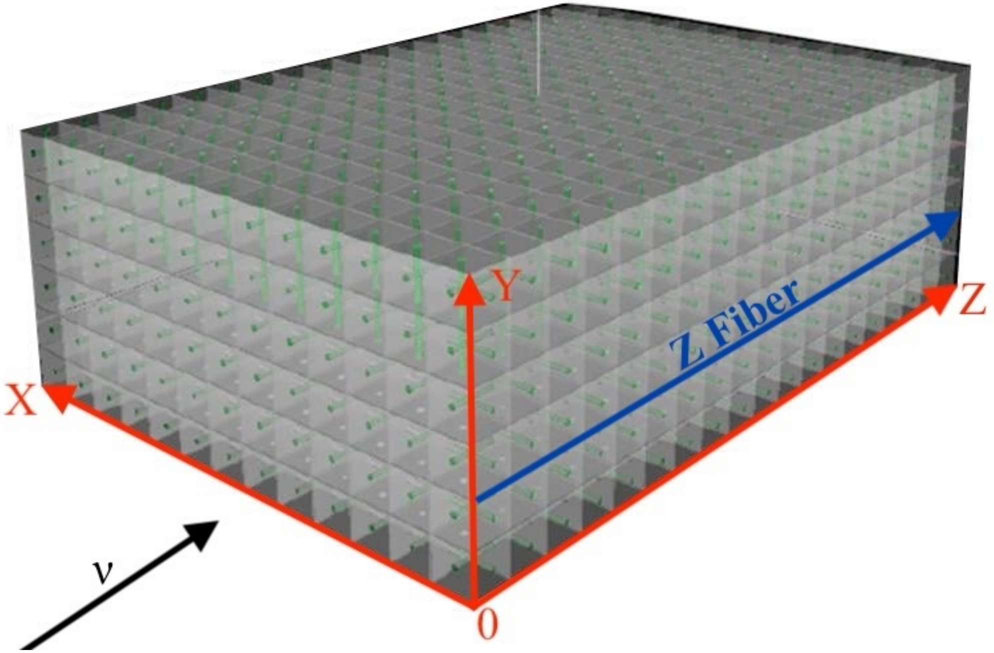
A_S – short attenuation component, cm

A_L – long attenuation component, cm; try to fix this parameter: 250 - 550 cm

X Fiber and Z Fiber

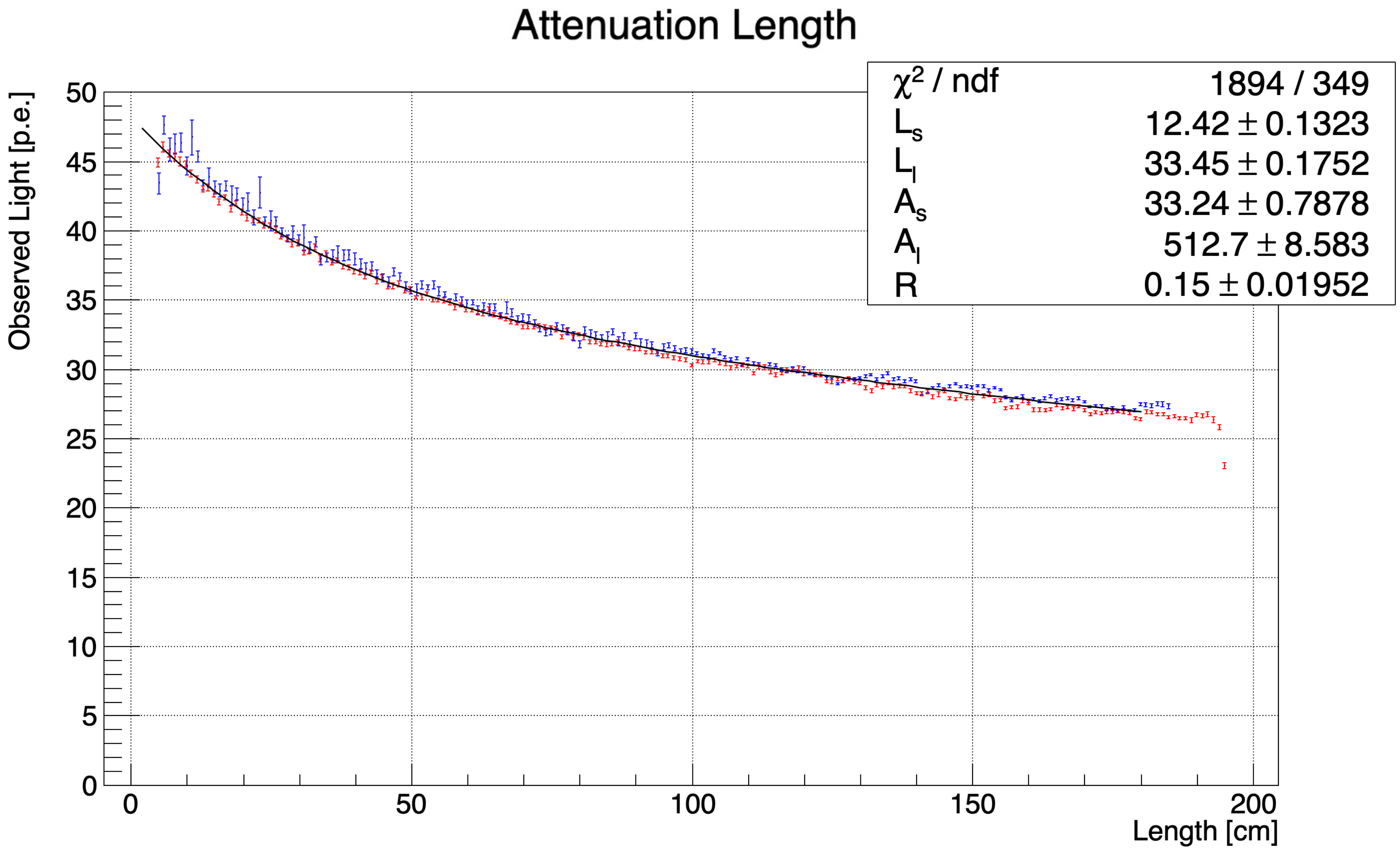
X SIZE:192
Y SIZE: 56
Z SIZE: 182





Observed Average LY vs Length

$$LY = \left(LY_S \cdot e^{-\frac{x}{A_S}} + LY_L \cdot e^{-\frac{x}{A_L}}\right) + R \cdot \left(LY_S \cdot e^{-\frac{2L - x}{A_S}} + LY_L \cdot e^{-\frac{2L - x}{A_L}}\right)$$



X axis

Z axis

Conclusion

3D highly segmented neutrino detector SuperFGD is the central part of the near detector complex of T2K experiment.

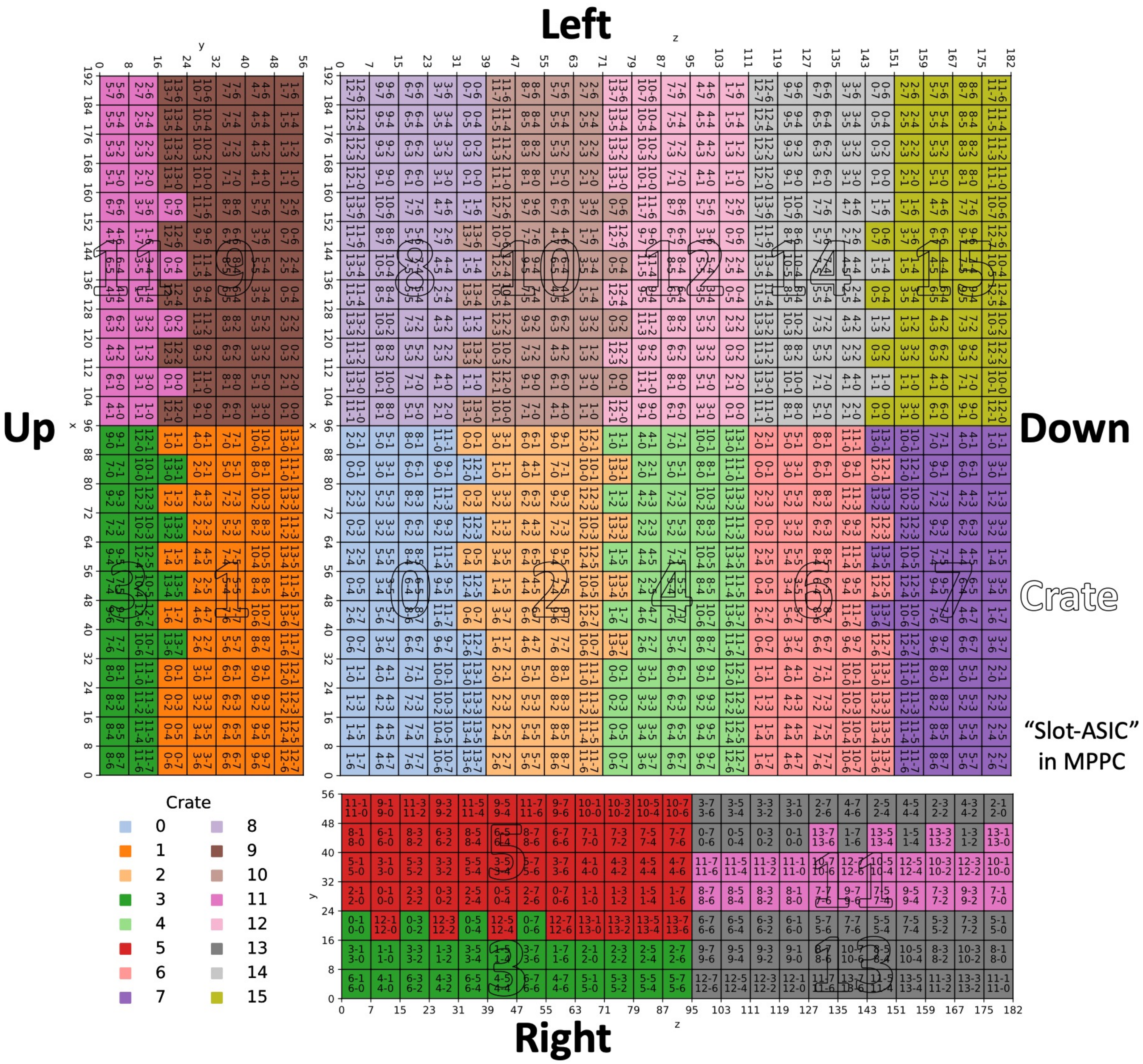
It is the key element for sensitive search for CP violation in T2K and HyperK.

T2K goal to establish CP violation at 3σ level.

- SFGD construction and commissioning are completed.
- Calibrations system and electronics were tested.
- SFGD is installed into ND280 magnet.
- Data on cosmic events is being collected.
- SFGD has begun to collect neutrino data in November 2023.
- The attenuation parameters of WLS fibers are measured.

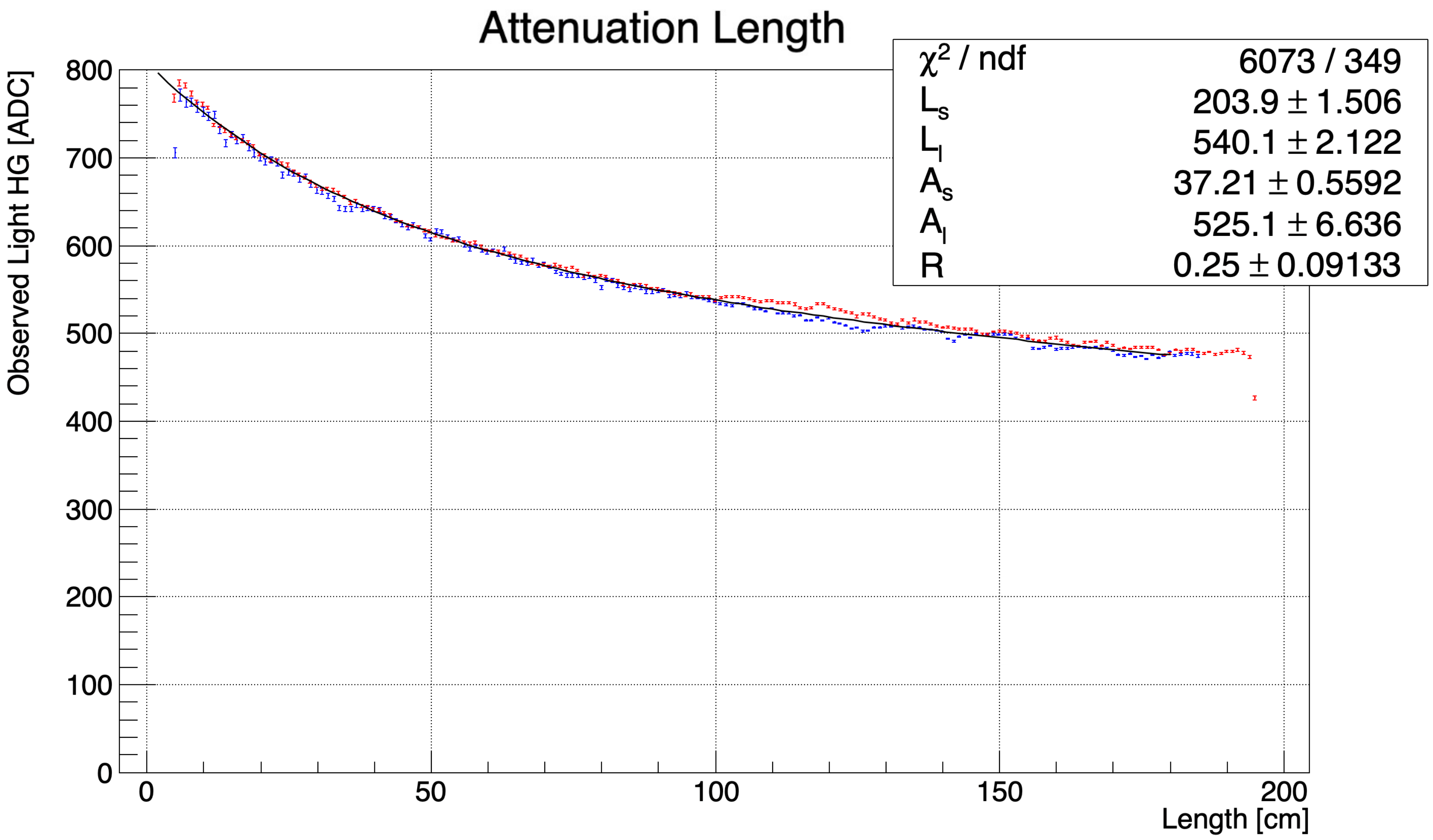
Back up

Crates connection



Observed Average LY (HG ADC) vs Length

$$LY = (LY_S \cdot e^{-\frac{x}{A_S}} + LY_L \cdot e^{-\frac{x}{A_L}}) + R \cdot (LY_S \cdot e^{-\frac{2L-x}{A_S}} + LY_L \cdot e^{-\frac{2L-x}{A_L}})$$

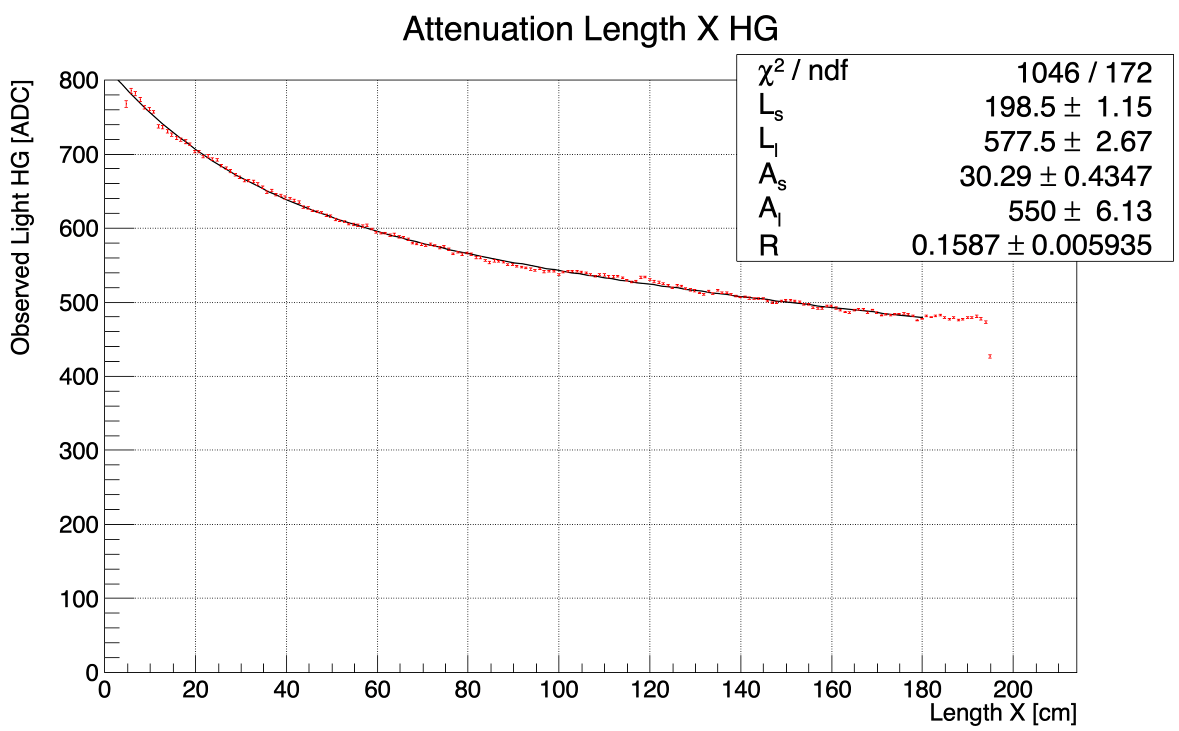


X axis

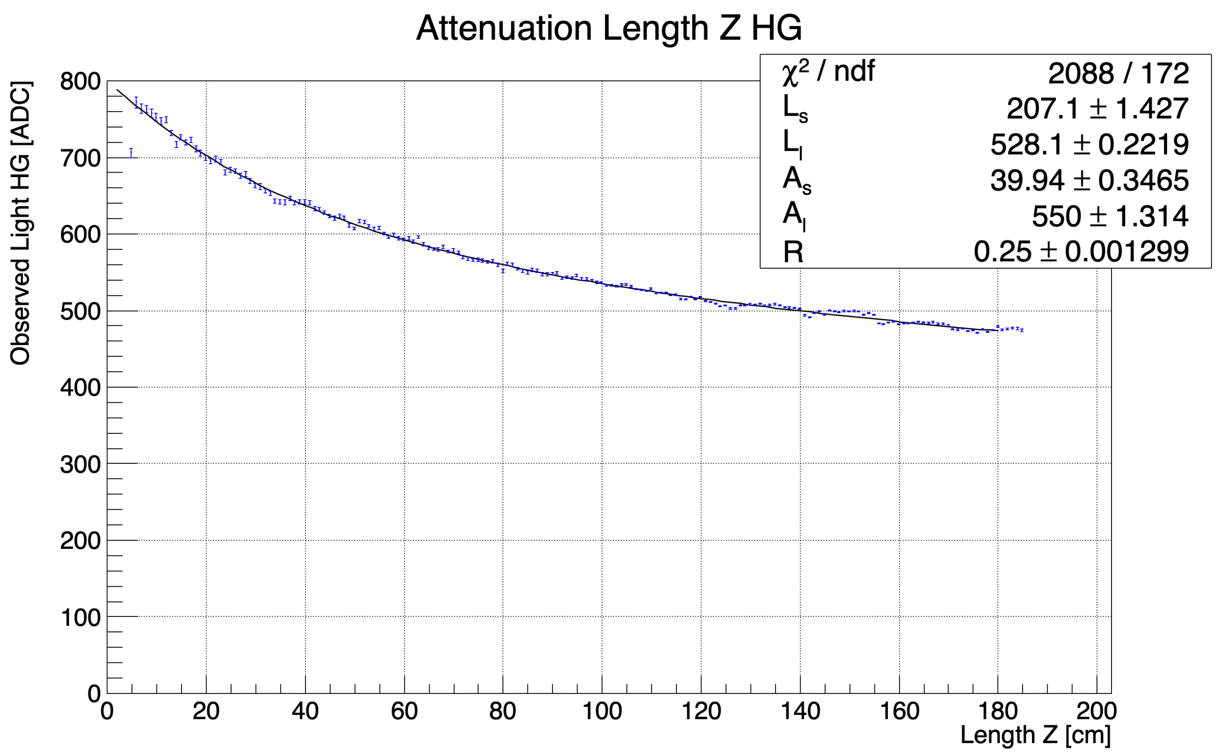
Z axis

Observed Average LY (HG ADC) vs Length
X and Z axis

$$LY = (LY_S \cdot e^{-\frac{x}{A_S}} + LY_L \cdot e^{-\frac{x}{A_L}}) + R \cdot (LY_S \cdot e^{-\frac{2L-x}{A_S}} + LY_L \cdot e^{-\frac{2L-x}{A_L}})$$



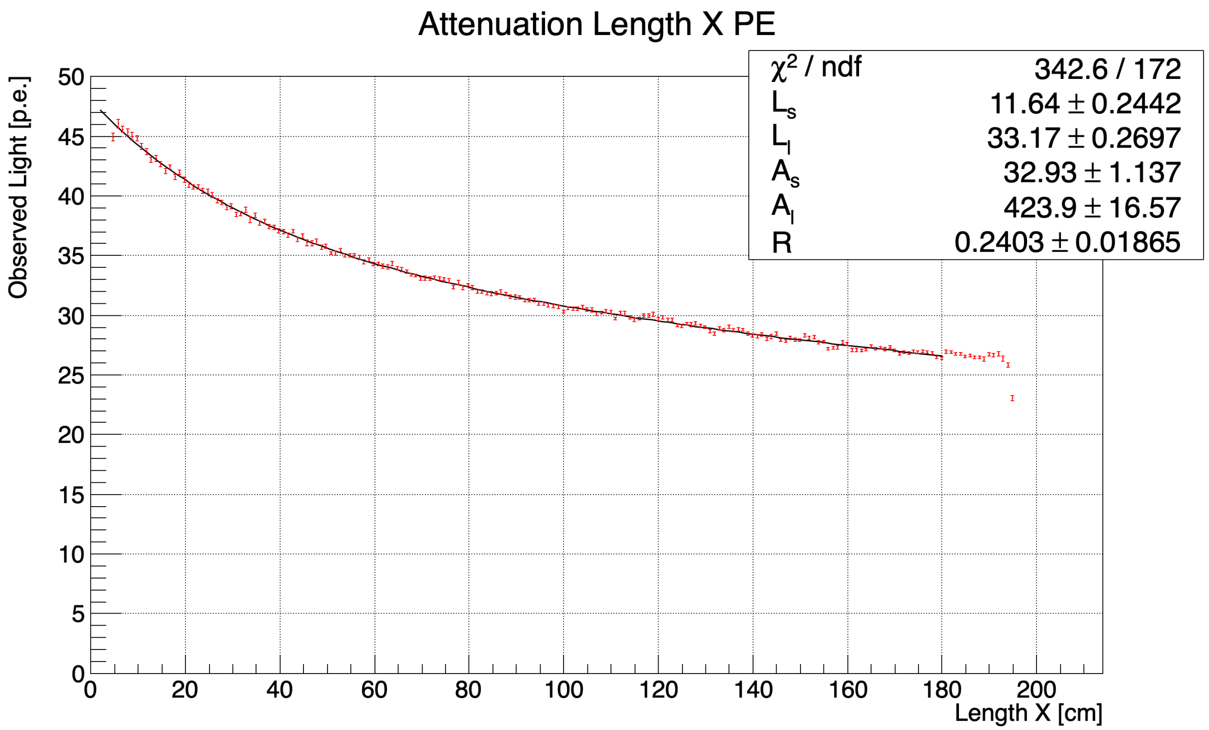
X axis



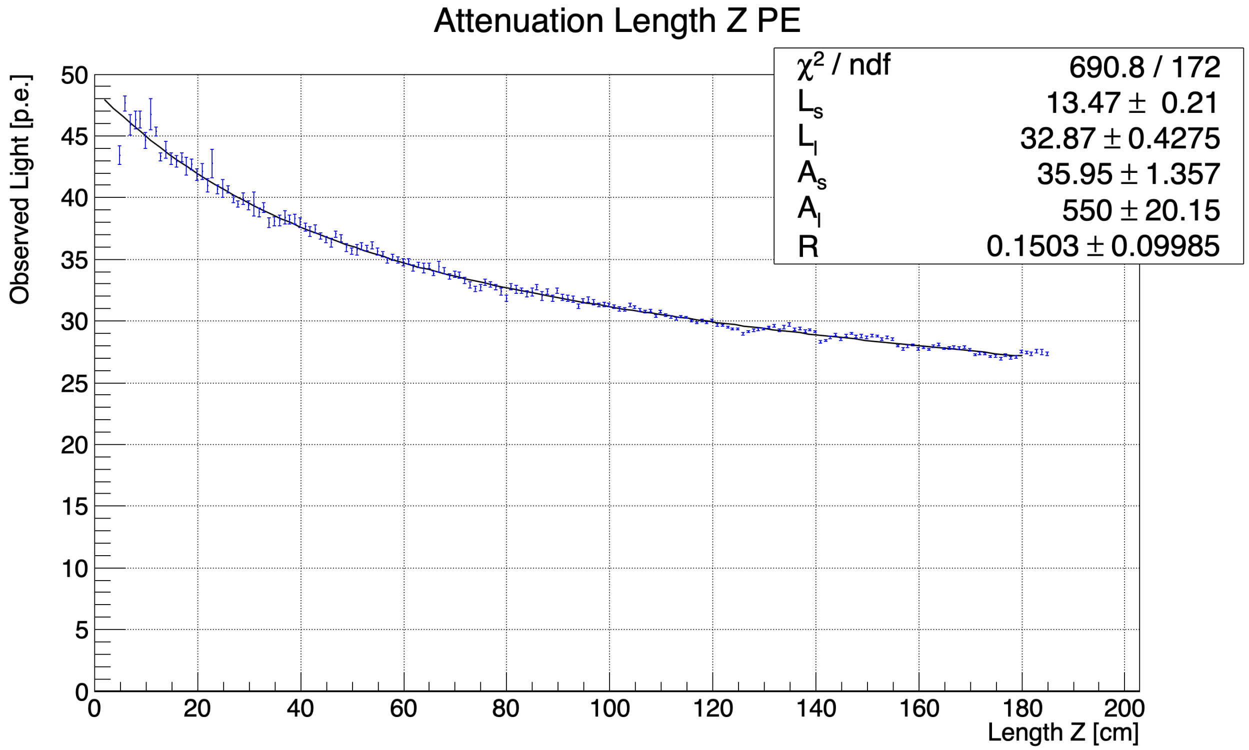
Z axis

Observed Average LY (p.e./MIP) vs Length X and Z axis

$$LY = \left(LY_S \cdot e^{-\frac{x}{A_S}} + LY_L \cdot e^{-\frac{x}{A_L}}\right) + R \cdot \left(LY_S \cdot e^{-\frac{2L-x}{A_S}} + LY_L \cdot e^{-\frac{2L-x}{A_L}}\right)$$



X axis



Z axis