THE 16TH VIENNA CONFERENCE ON INSTRUMENTATION

From 21 to 25 February, 2022

3D SuperFGD detector for T2K experiment

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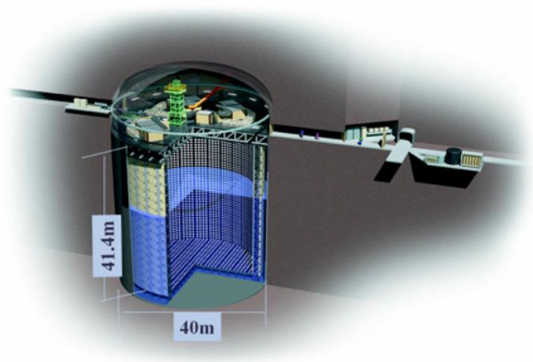
T2K experiment ("Tokai to Kamioka")

The main experiment goals:

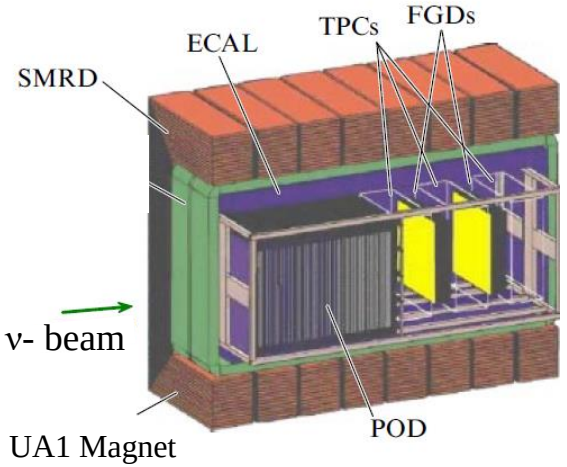
-- precision measurements of oscillation parameters on the ν_μ ($\overline{\nu}_\mu$) beam;

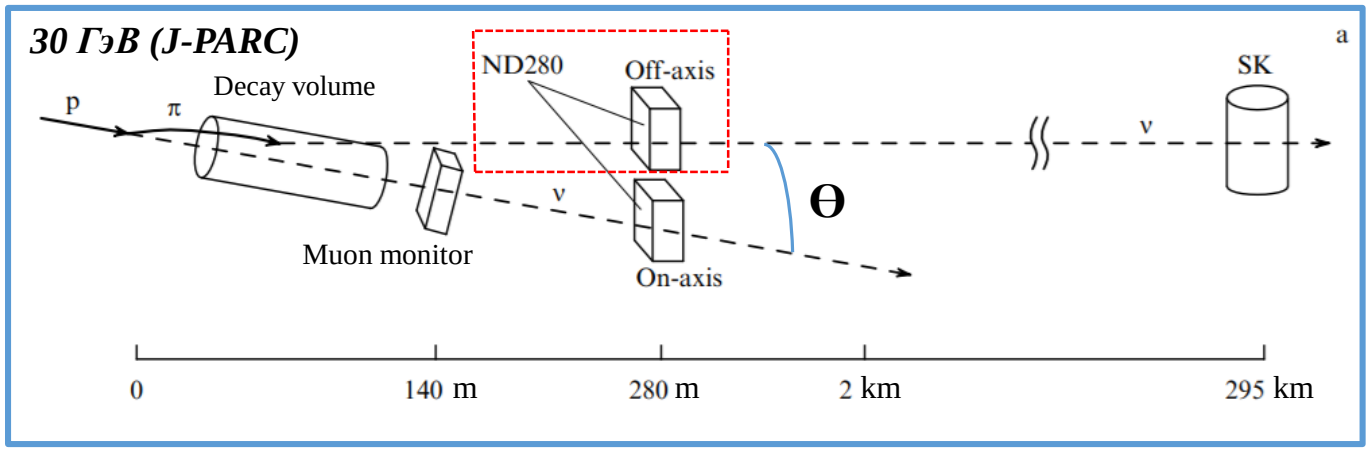
-- the search for CP violation in the neutrino sector

SuperK



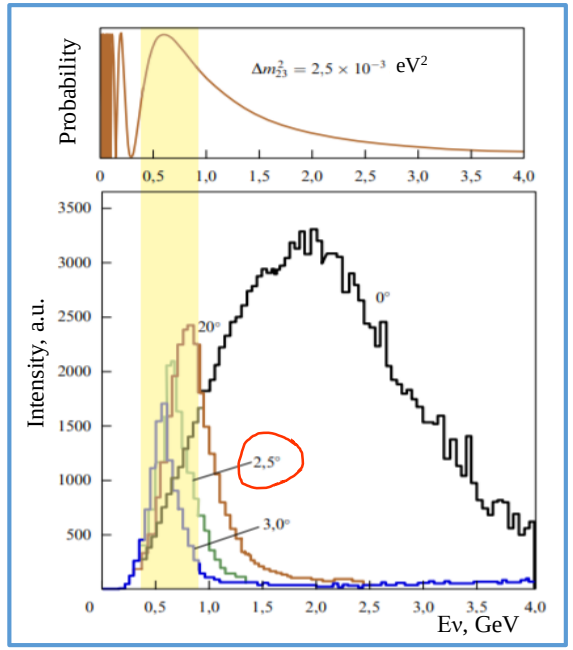
Near ν-detector (ND280)



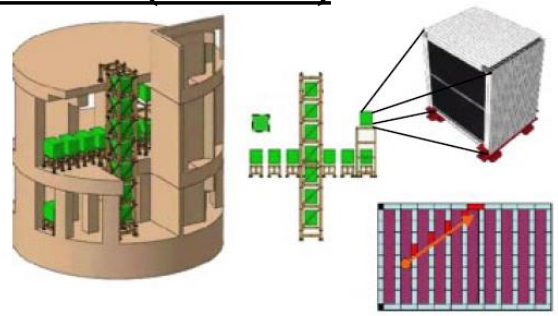


T2K experiment scheme

Off –axis ν-beam



Monitor of the ν – beam (INGRID)



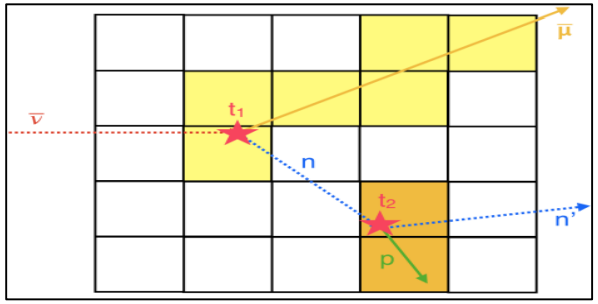
Θ = 2.5° ⟹ $E(\nu)_{max}$ = 0.6 GeV

to improve a sensitivity to δ_{CP}

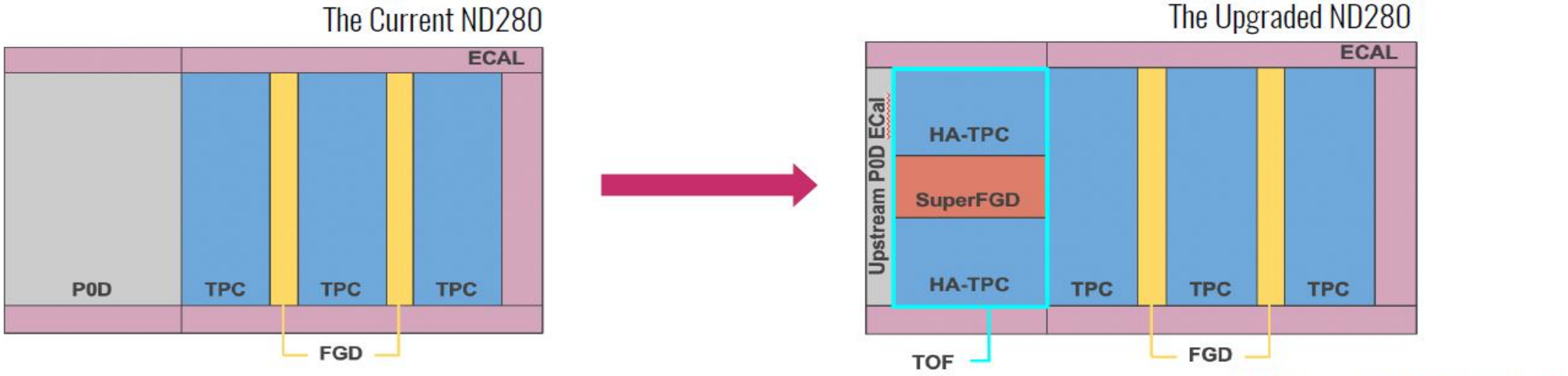
we need to reduce systematic uncertainties

ND280 upgrade program. Physics motivation

- 4π-acceptance for charged particles
- a low threshold for proton and pion detection
- electron/gamma separation
- reduce systematics for T2K to < 4% level
- detection of neutrons



New upstream tracker:
+ Two Horizontal TPCs
+ One 3D fine-grained scintillator target SuperFGD
+ TOF system around new tracker
- *π-zero* detector *P0D*

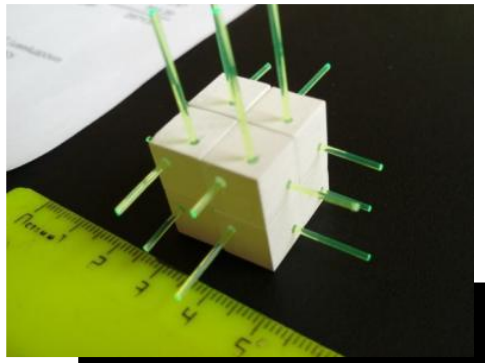


TDR at arXiv:1901.03750

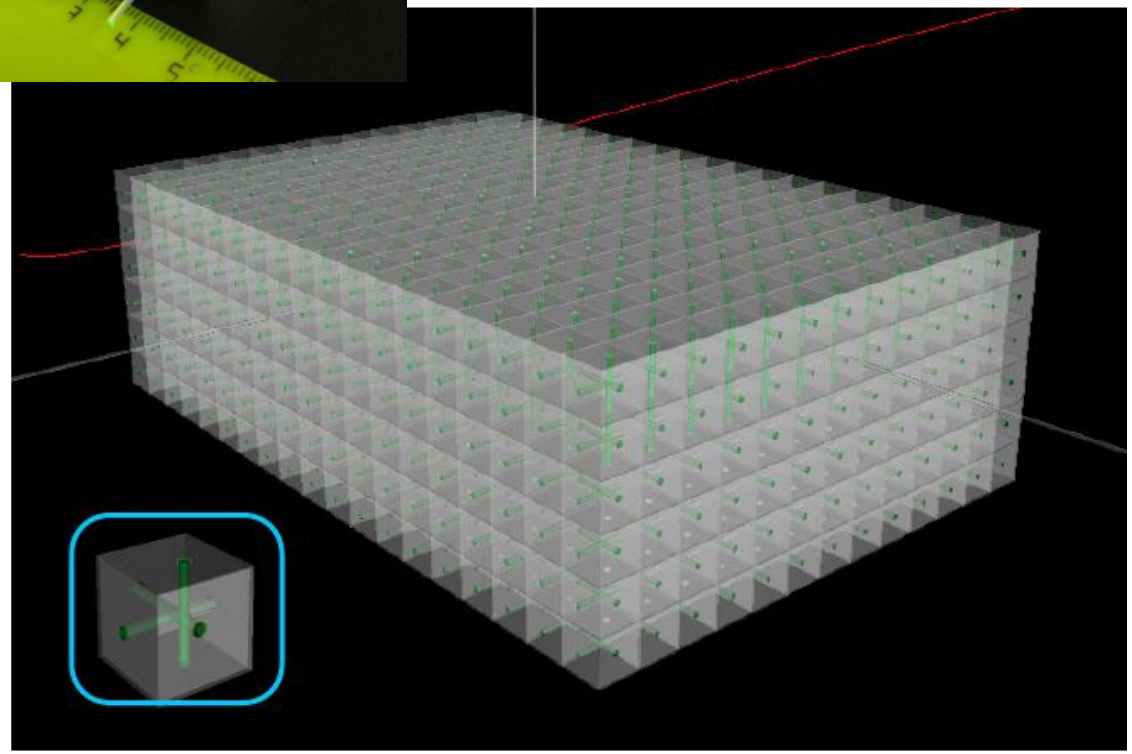
HA (Horizontal) TPC –accurate measurement of particle kinematics
TOF (Time – of – Flight) detector - the particle track accurate determination

SuperFGD (Super Fine-Grained Detector)

The detector was finally assembled with fishing lines in January 2021 (56 layers) at the INR RAS (Troitsk, Moscow)



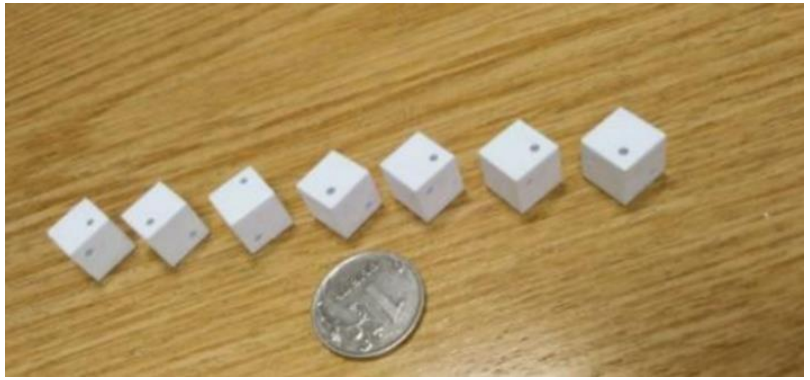
arXiv: 2005.11048



- SuperFGD size: **192(x)x182(z)x56(y) cm^3**
- **1,978,368** optically-isolated plastic scintillaton cubes with a **1 cm side**
- Three orthogonal through holes in each cube with a diameter of 1.5 mm
- **56,384** readout channels for WLS MPPCs
- Detector **active mass** ~ 2 tons
- **Electronics:** MPPC-PCBs and FEBs ***based on CITIROC chips***
- **Calibration:** Light-Guide Plate (LGP) + LED
- **Mechanical box:** sandwich of CF and other materials

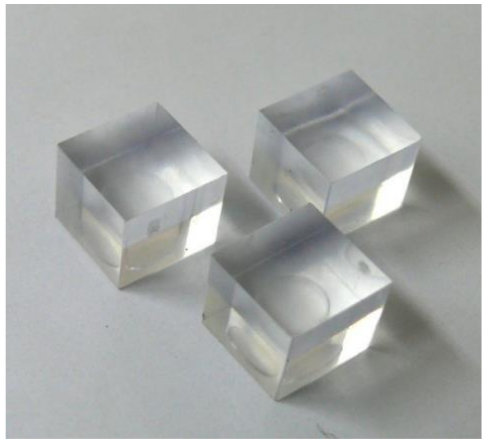
** **WLS** = Wave-Length Shifting (fiber); **MPPC** = Multi-Pixel Photon Counter; **PCB** = Printed Circuit Board
CITIROC = Cherenkov Imaging Telescope Integrated Read Out Chip; **FEB** = Front-End Board; **CF** = Carbon Fiber

Cubes manufacturing

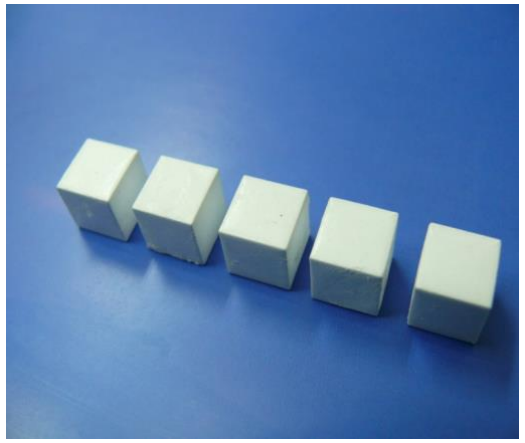


-- Vladimir, Russia (UNIPLAST Co.)
-- Cubes size: 10x10x10 мм^3
-- Material: extruded polystyrene doped with 1.5% of paraterphenyl (PTP) and 0.01% of 1,4-bis benzene (POPOP)
-- Method: injection molding
-- A white reflective layer: 50–80 μm-thick
-- Holes for WLS fibers: three in each cube, 1.5 mm in diameter

injection molding method

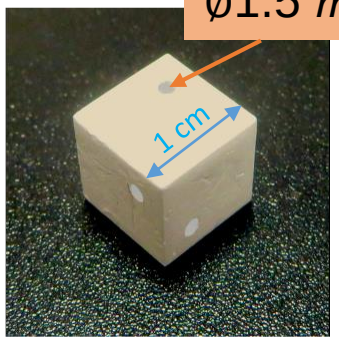


etching in a chemical substance (a reflective layer formation)

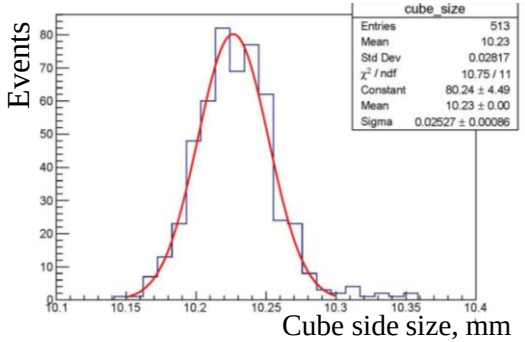


drilling three orthogonal through holes in each cube on the machine

Parameters of SFGD cubes

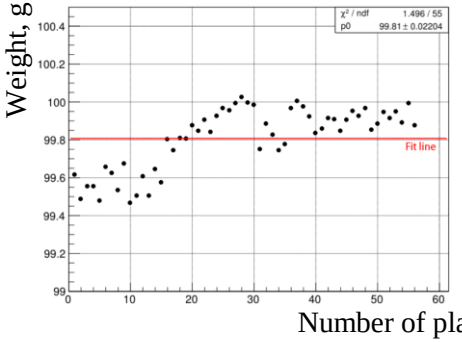


Distribution of cube dimensions



each side (after reflector) = **10.23 mm** +/- σ_x **=0.025 mm**

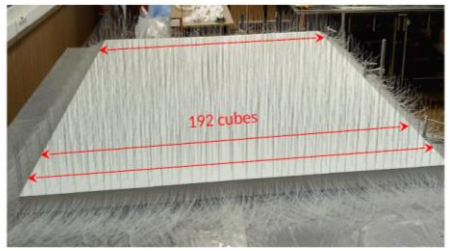
Weight of 100 cubes vs number of plane



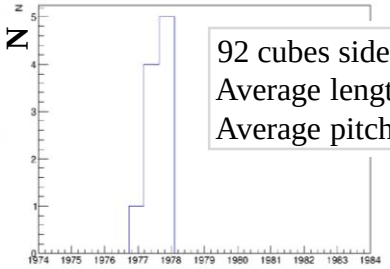
Groups of the scintillation cubes were weighted from the 1th to the 40th layer

Weight of a single cube is **0.9977 g +/- 0.0002 g**

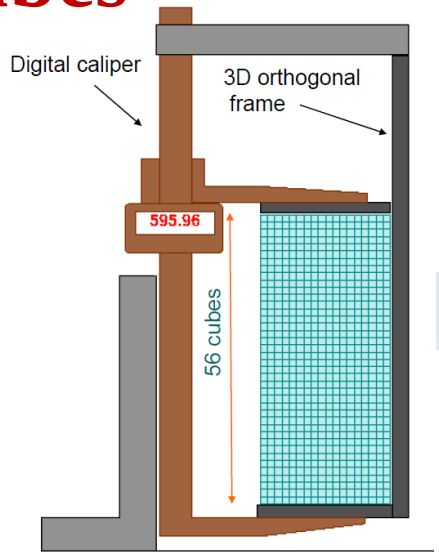
Side length and horizontal pitch measurement



a scintillation plane



92 cubes side:
Average length = 1977.7 mm
Average pitch = 10.301 mm

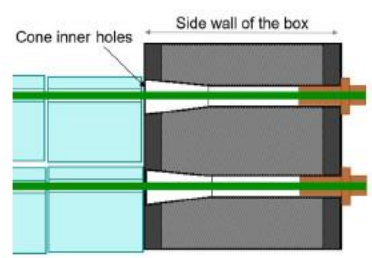


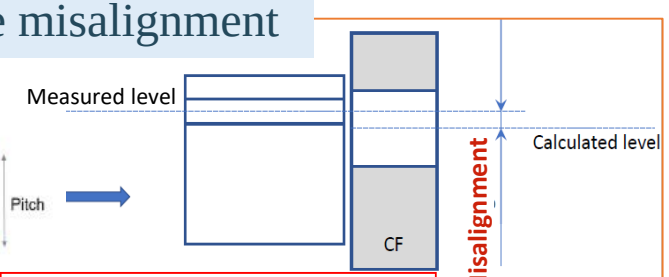
The setup scheme

Measurement of the vertical pitch

56 layers of **18x15** cube pads were assembled on **1 mm** fishing lines in horizontal direction. The 1 mm fishing line imitates the WLS fiber. No vertical fishing lines.

The meaning of the misalignment

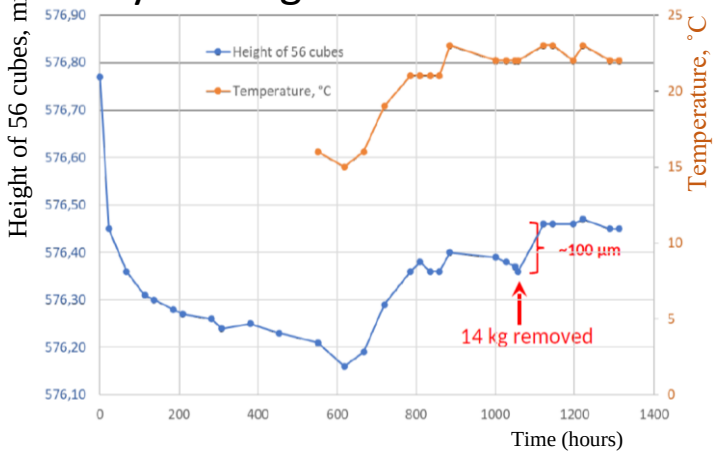




Calculated level = number of layer x Vertical pitch

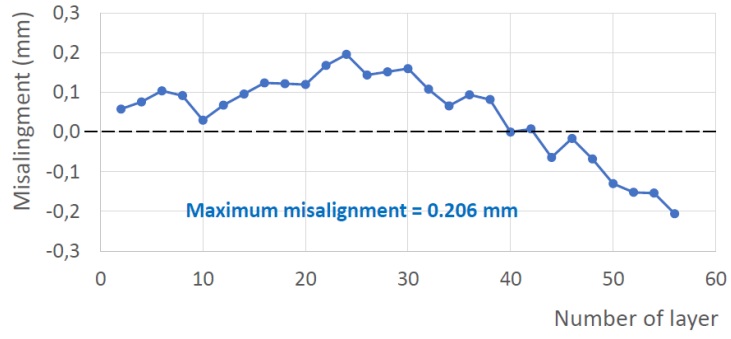
Misalignment = Measured level – Calculated level

Layers height over time

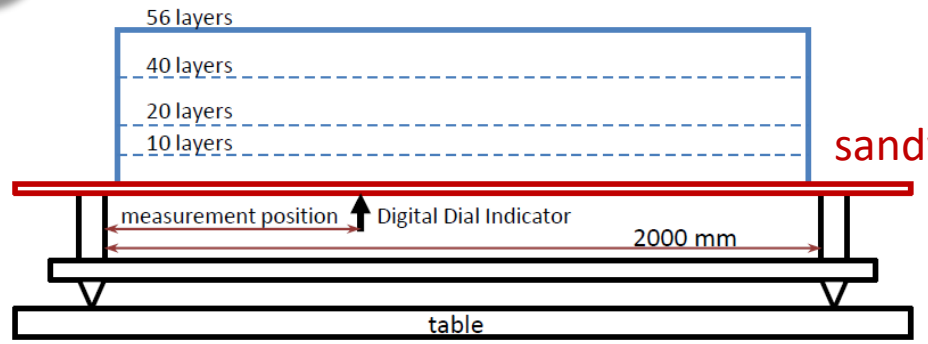


The coefficient of vertical expansion was estimated to be 52 µm/(m · °C).

Optimal vertical pitch = 10.281

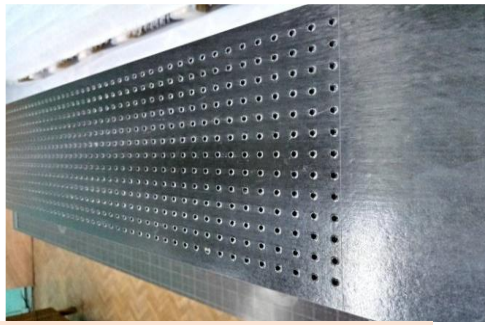


Sag panel measurements



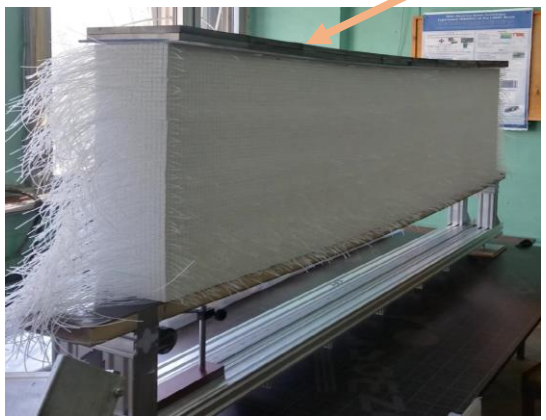
Measurement scheme

sandwich panel



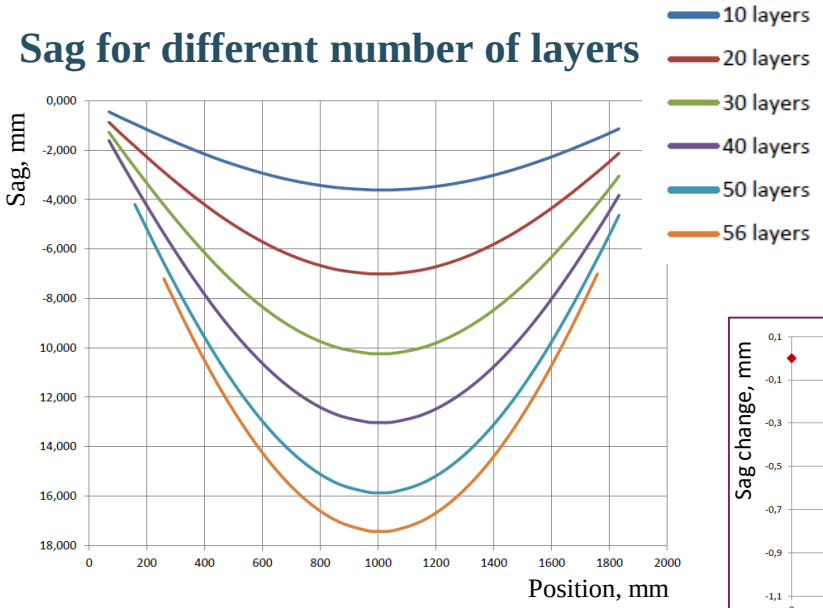
Parameters of the sandwich panel:
CF-AIREX-CF (consist of 3 layers)
Panel size: 4.1 x 15 x 230 cm^3
Weight: 6 kg
Matrix of holes: 13 x 192
step 10.3 mm, D = 3 mm.

Pb, 136kg +3 kg +136 kg



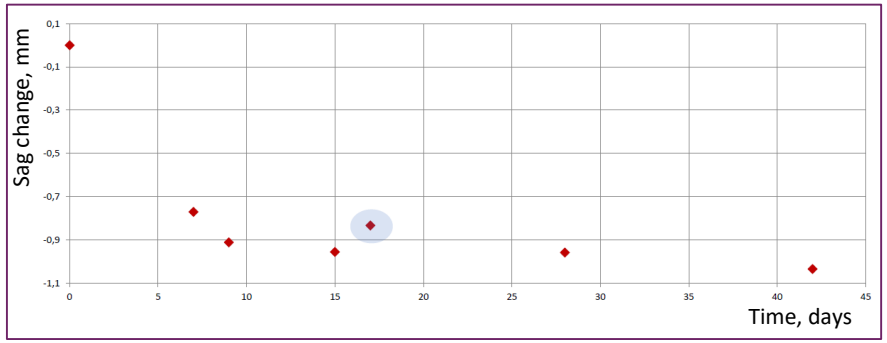
mockup system

Sag for different number of layers



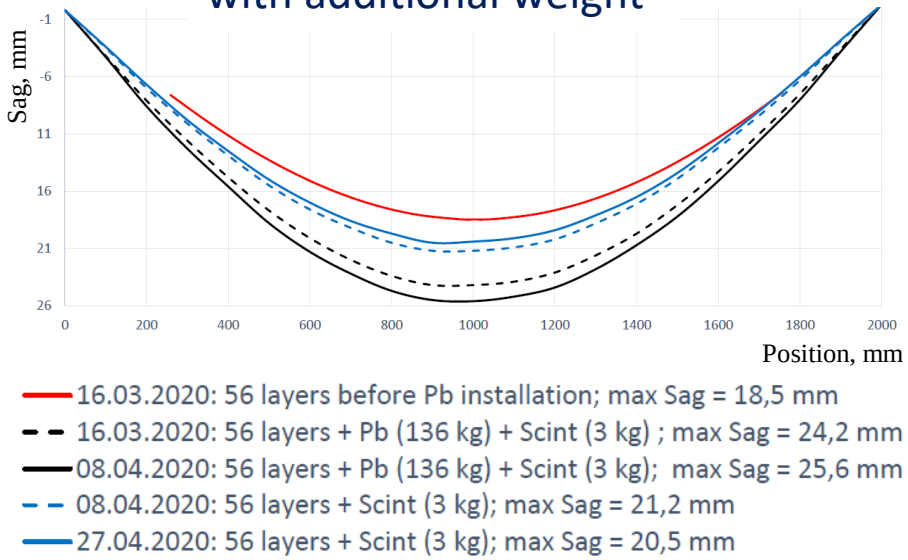
The maximum sag value is -17.43 mm for 56 layers.

Change of sag in the center of the panel with 56 layers over time



- Sag was -17.4 mm on the day installation (0 day).
- Sag increased by -0.96 mm in 28 days.
- The absolute sag value is -18.4 mm.

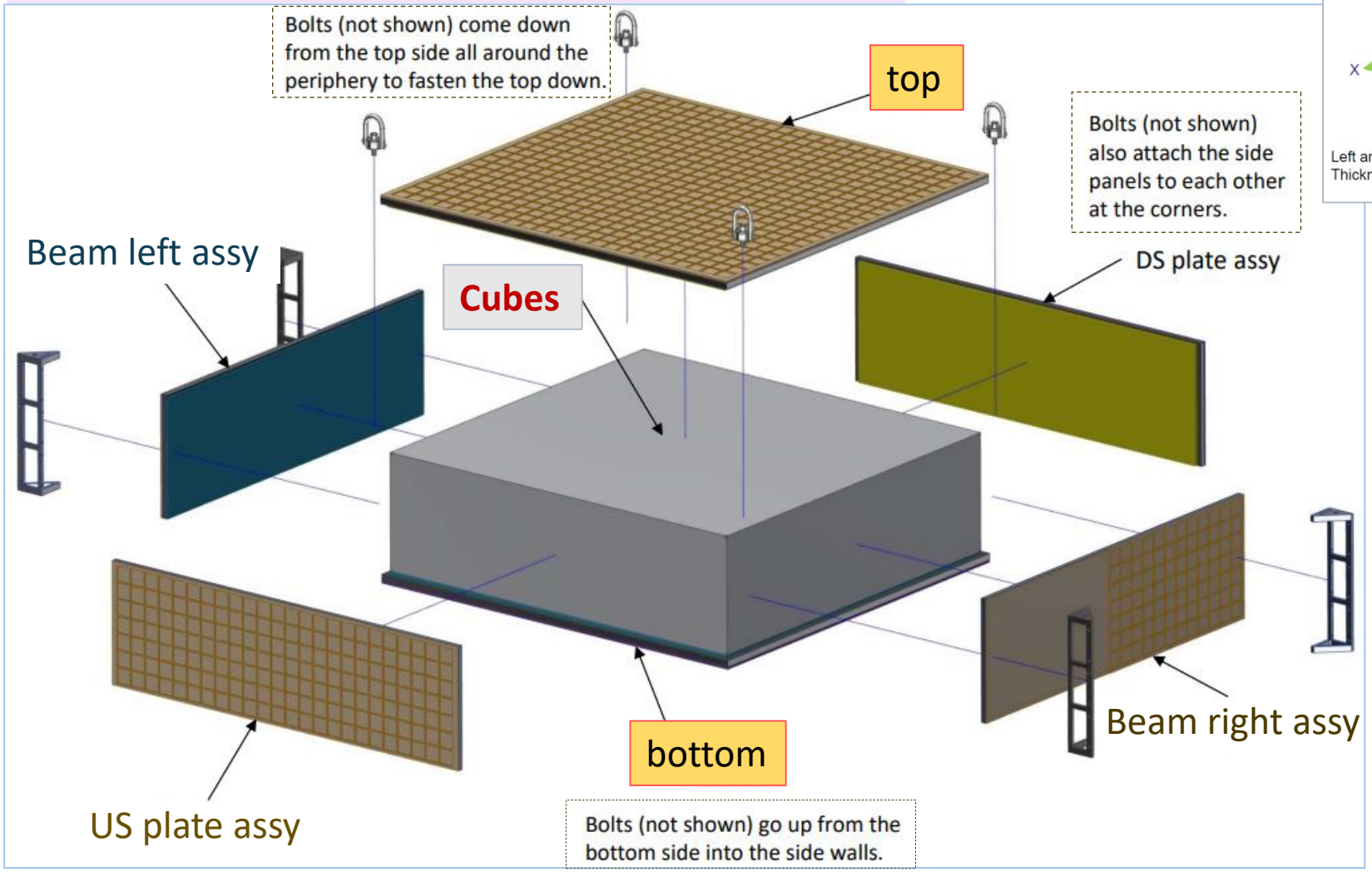
Sag measurements with additional weight



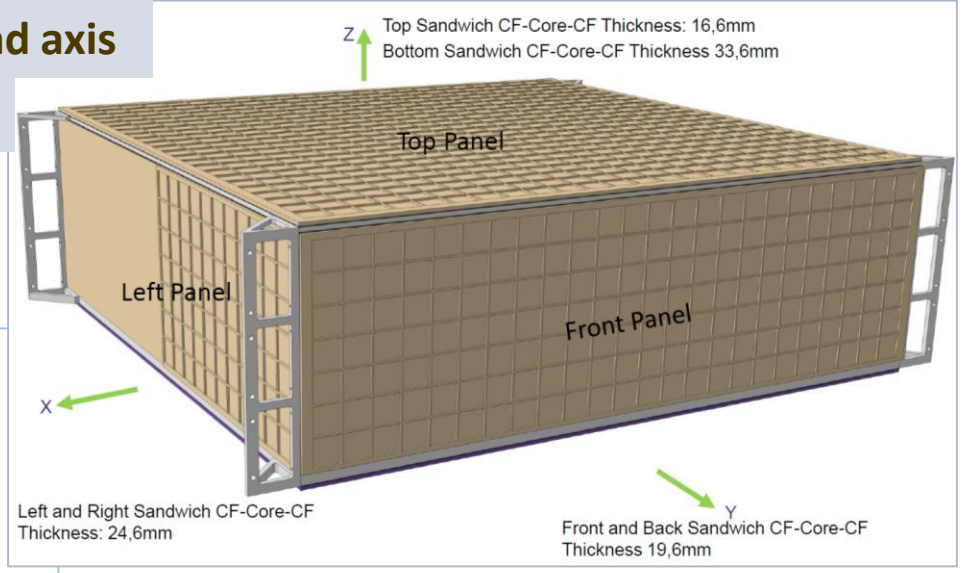
*CF – Carbon Fiber

Box design

Exploaded view of the plates that make up the SFGD box



Box Design and axis orientation

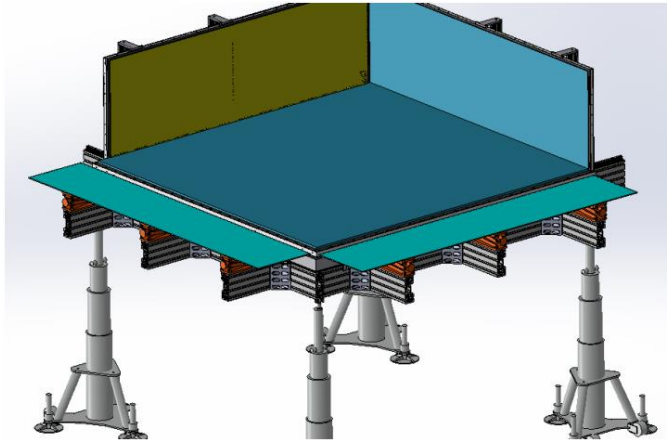


- # of holes per plate (channels)
  - Front: 10,752
  - Rear: 10,752
  - Left: 10,304
  - Right: 10,304
  - Top: 35328
  - Bottom: 35328

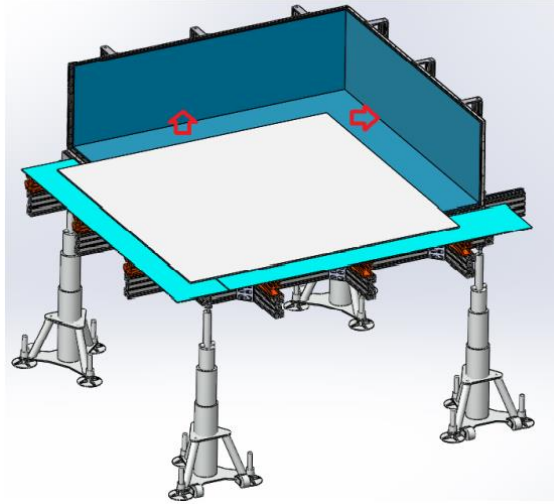
SFGD detector assembly platform.

Installing cube layers of the detector

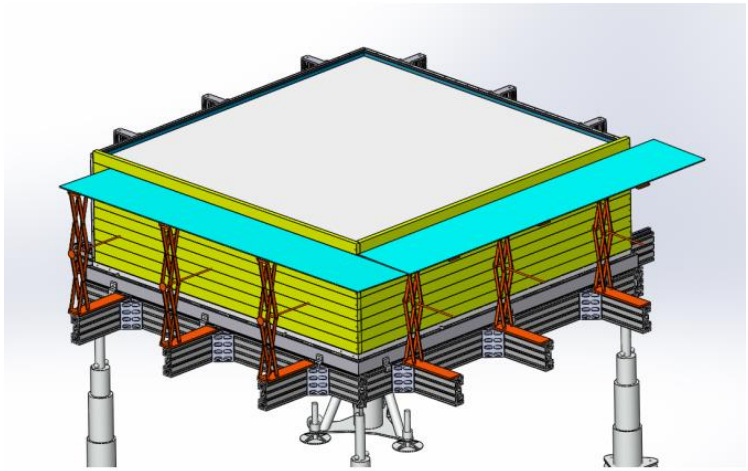
Moving the first layer to the side panels of the box:



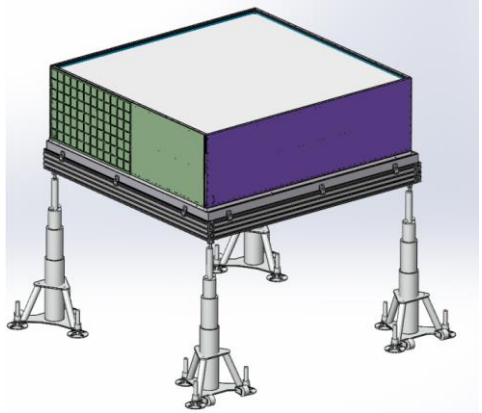
The assembled two side panels and the bottom panel



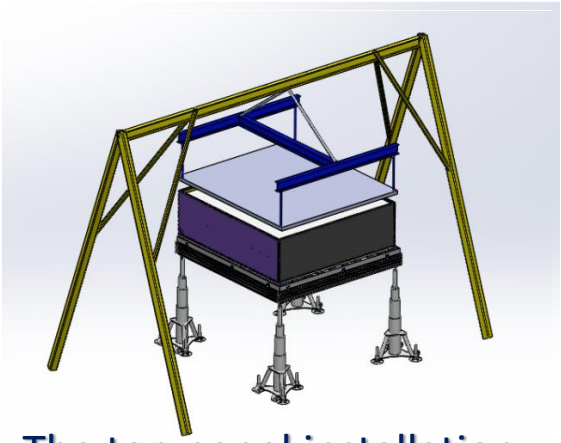
Moving the first layer



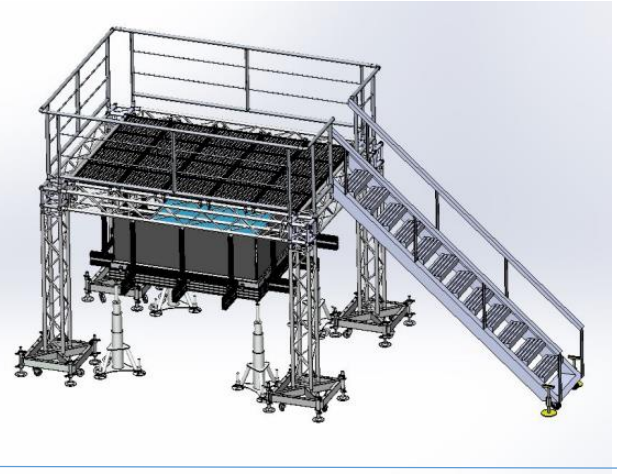
Collected layers of cubes



Box with four panels installed



The top panel installation

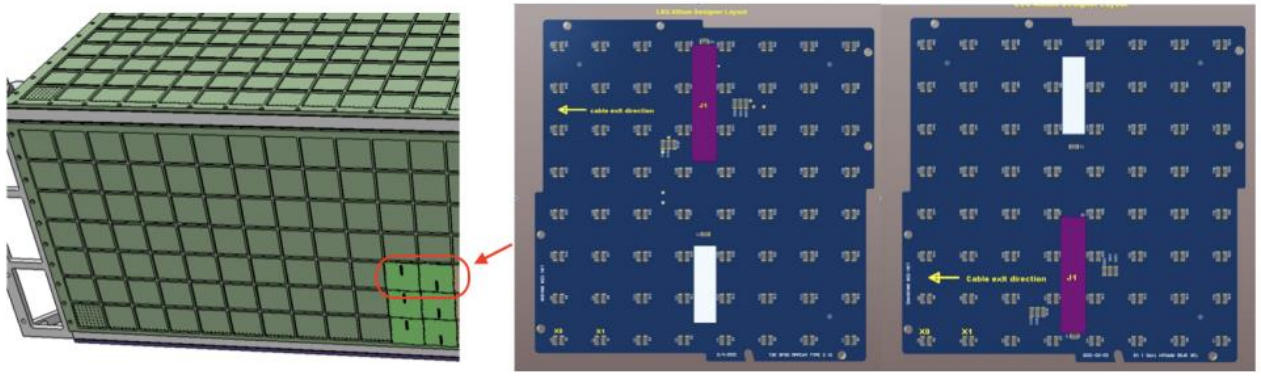


The top access system will be actively used when assembling layers, especially when access to the central part of the detector is required.

MPPC64 – PSB. MPPC's characteristics

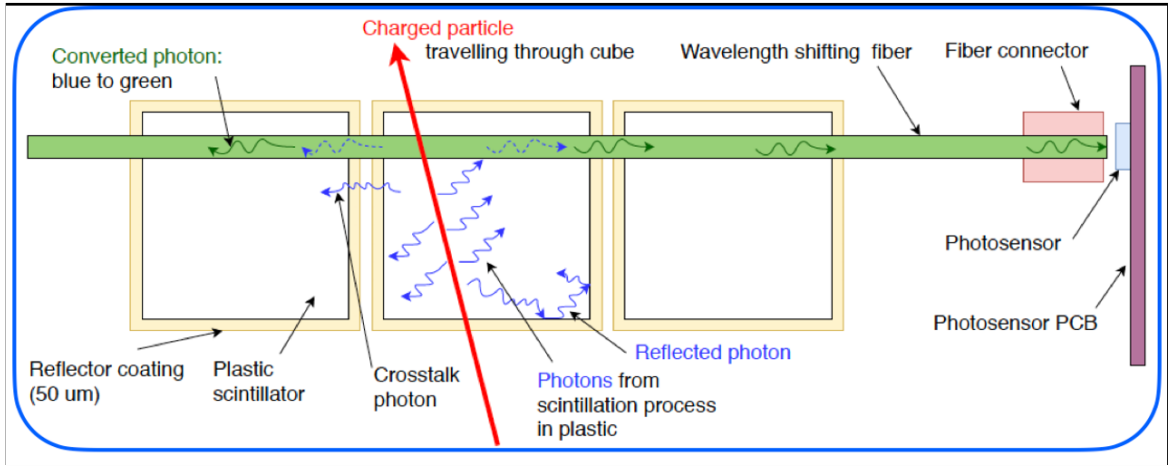
- 56,384 Multi-Pixel Photon Counters (MPPC) will be used for scintillation light
- MPPC S13360-1325PE (Hamamatsu Photonics K.K)
- 8 X 8 arrayed MPPCs on a printed circuit board (PCB)
- 881 MPPC-PCBSs in SFGD

MPPC64-PCB designs for the two connector positions

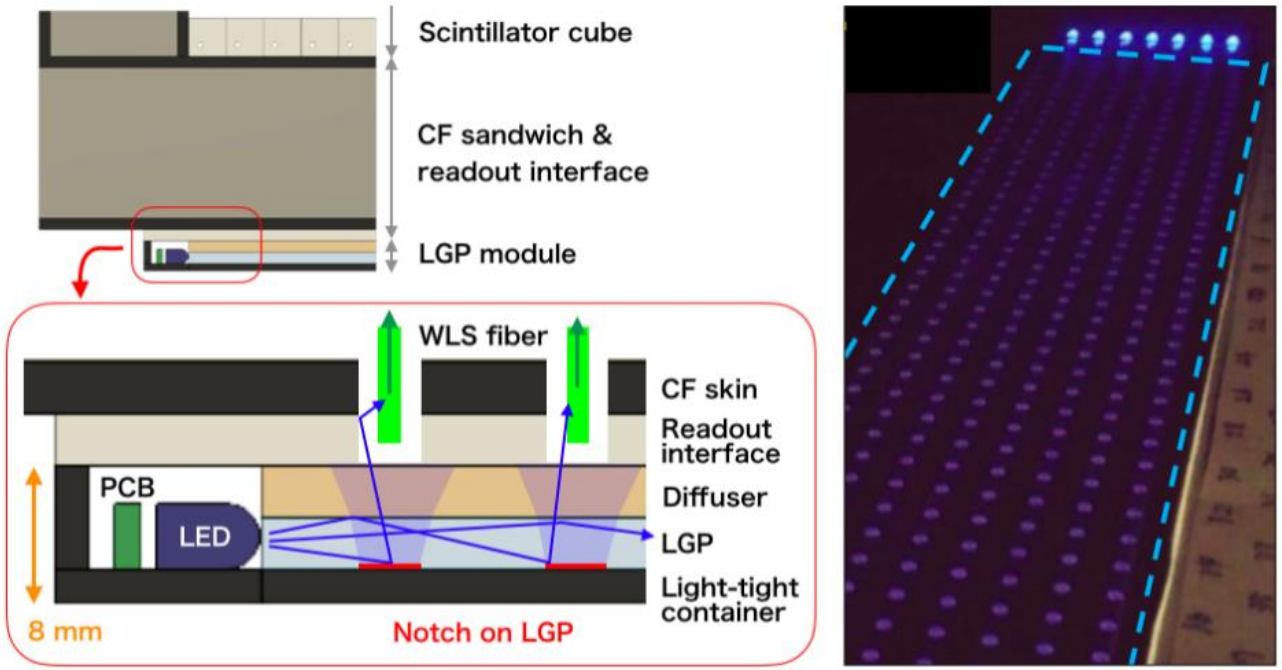


Item	Specification
Pixel pitch (μm)	25
Effective photosensitive area (mm)	1.3 * 1.3
Number of pixels	2668
Package	Surface mount type
Fill factor (%)	47
Breakdown voltage (V)	53 ± 5
Photon detection efficiency (%)	25
Gain	$7*10^5$
Dark noise rate (kHz)	70
Crosstalk (%)	1

The general scheme of interaction of a charged particle with the detector substance (as in SuperFGD) and as a result, the propagation of light through fibers to electronics

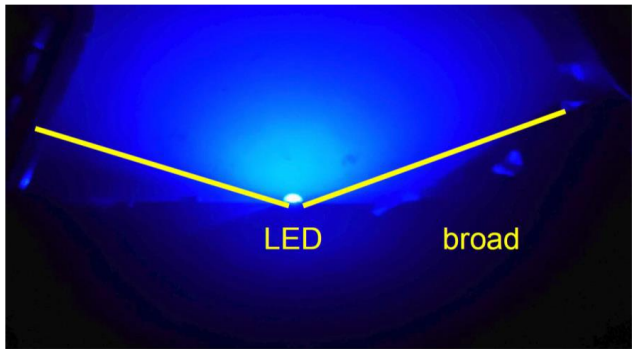


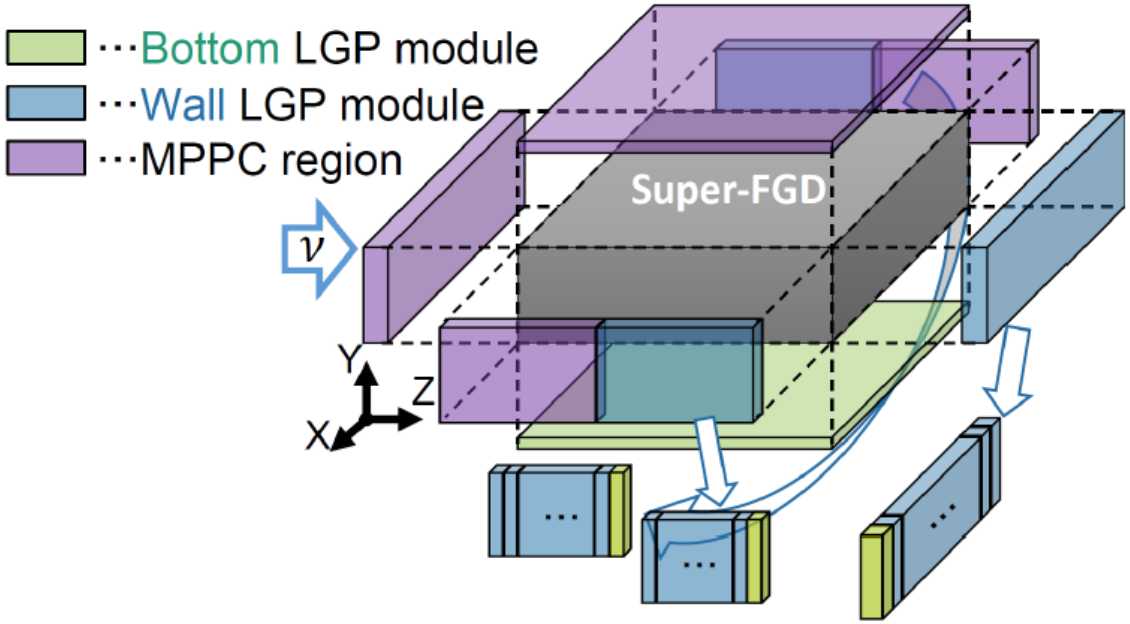
LED calibration system

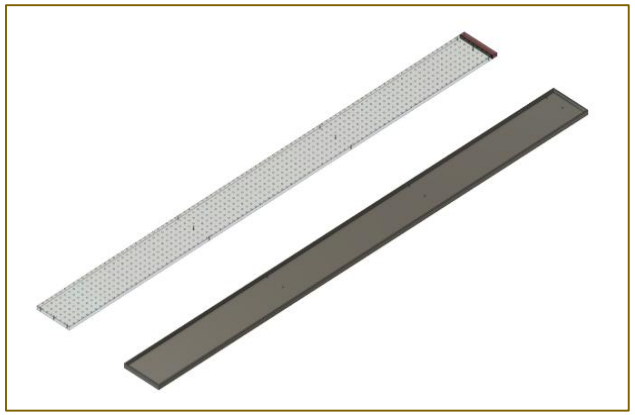


Concept of the LED calibration system with LGP (left) and a picture of the LGP prototype (right). Location of a LGP module on the box surface is shown.

LED light source







Design of the LGP long module (970×78×8 mm).

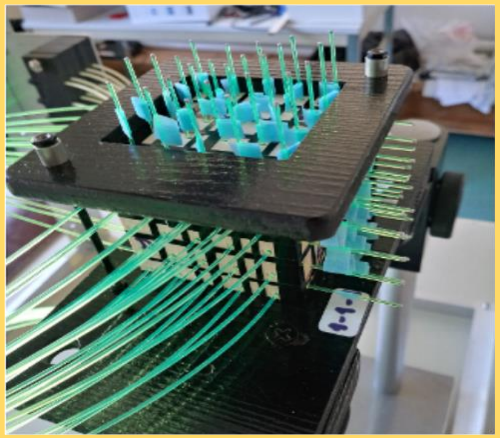
Left: PCB with 7 LEDs array (red) and LGP (transparent)

Right: a black acrylic container to integrate those with a diffuser plate.

** **LGP -L**ight **G**uide **P**late

Studying parameters of scintillation cubes. SFGD Prototype_1. Setup

For a more detailed study of the properties of scintillation cubes, a prototype SFGD, which is a matrix of 5x5x5 cubes, was tested on a beam of charged particles at CERN T10 area (October, 2017)



75 readout channels
WLS + MPPC's
WLS fibers: Kuraray Y11(200) S-type, 1mm diameter, 1.3 m long

125 cubes
with 3D optical reading,
5x5x5 cubes matrix

Test schematic view

Digitizer Caen DT5742

T10 area of the CERN Proto-Synchrotron (PS), muons (+)

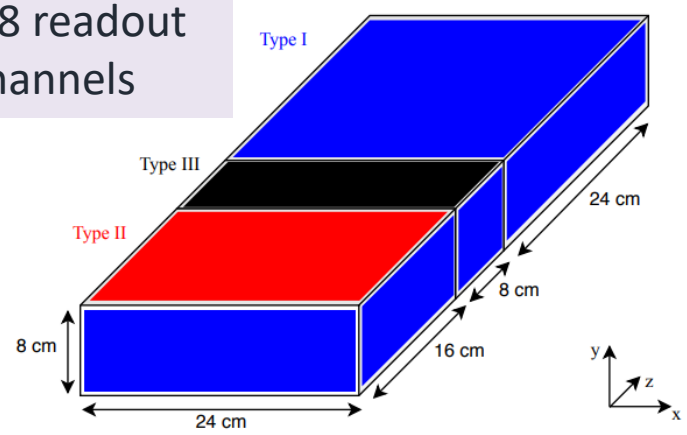
Results

Typical light yield per one fiber ~ **42 p.e.**
Average time resolution per one fiber ~ **0.92 ns**
Crosstalk ~ **3%**

SuperFGD Prototype_2. Setup

Prototype size: 24*8*48 cm³

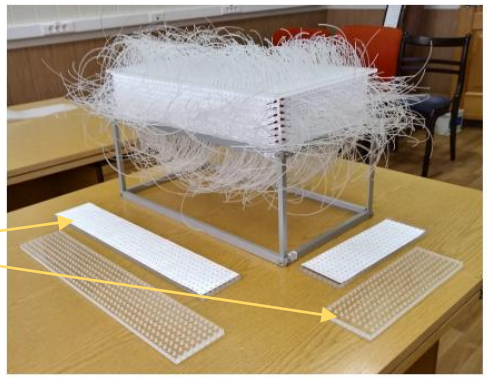
9,216 cubes
1,728 readout channels



1,152 – **Type I** S13360-1325CS ,
384 – **Type II** S13081-050CS),
192 – **Type III** (S12571-025C) MPPCs

Description	Type I	Type II	Type III
Manufacturer ref.	S13360-1325CS	S13081-050CS	S12571-025C
No. in Prototype	1152	384	192
Pixel pitch [μm]	25	50	25
Number of pixels	2668	667	1600
Active area [mm^2]	1.3 × 1.3	1.3 × 1.3	1.0 × 1.0
Operating voltage [V]	56–58	53–55	67–68
Photon detection eff. [%]	25	35	35
Dark count rate [kHz]	70	90	100
Gain	7×10^5	1.5×10^6	5.15×10^5
Crosstalk probability [%]	1	1	10

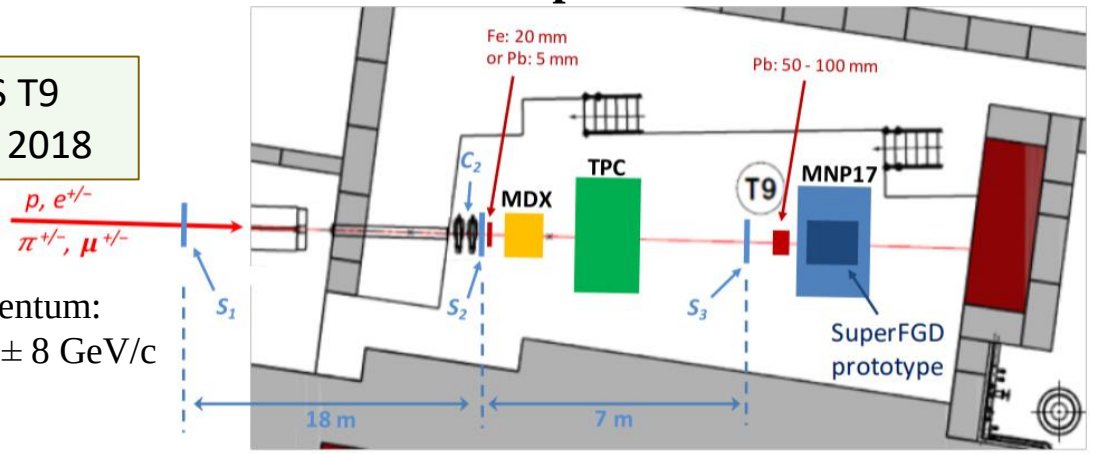
an external box:
8 mm-thick
acrylic plates



Left: the SuperFGD Prototype assembled with the fishing line method
Right: the partially instrumented SuperFGD Prototype bottom face

Beamline setup

CERN-PS T9
beamline, 2018



The beam momentum:
±400 MeV/c to ± 8 GeV/c

Beam mode	Particle trigger	Trigger setup	Purity
Hadrons	All	$S_{2L} \times S_3 \times S_1$	N/A
Hadrons	p	$S_{2S} \times S_3 \times S_1$	> 90%
Hadrons	e^+	$S_{2L} \times S_3 \times C_2$	> 90%
Hadrons	π/μ	All $\times \bar{e} \times \bar{p}$	[e^+ (40–50%)]
Muons	μ	All $\times \bar{e} \times \bar{p}$	[e^+ (10–20%)]

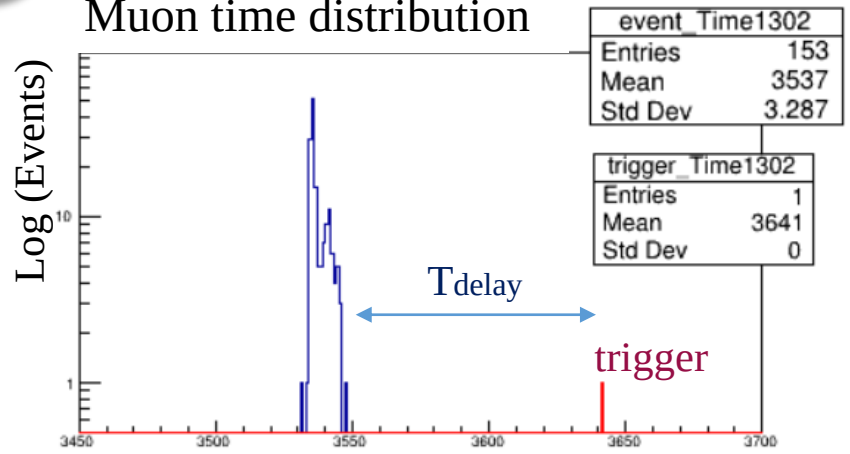
A trigger system based on:
- scintillator detectors ($S1$, $S2$, $S3$)
- a Cherenkov detector ($C2$)

was used to discriminate different particle types.

Muons, 2GeV/*c*

B field, 0.7 T

Muon time distribution

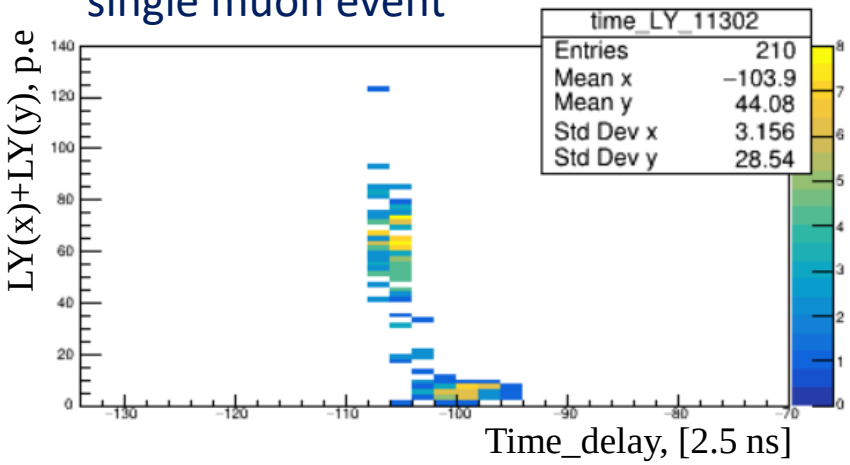


one time channel corresponds to 2.5 ns

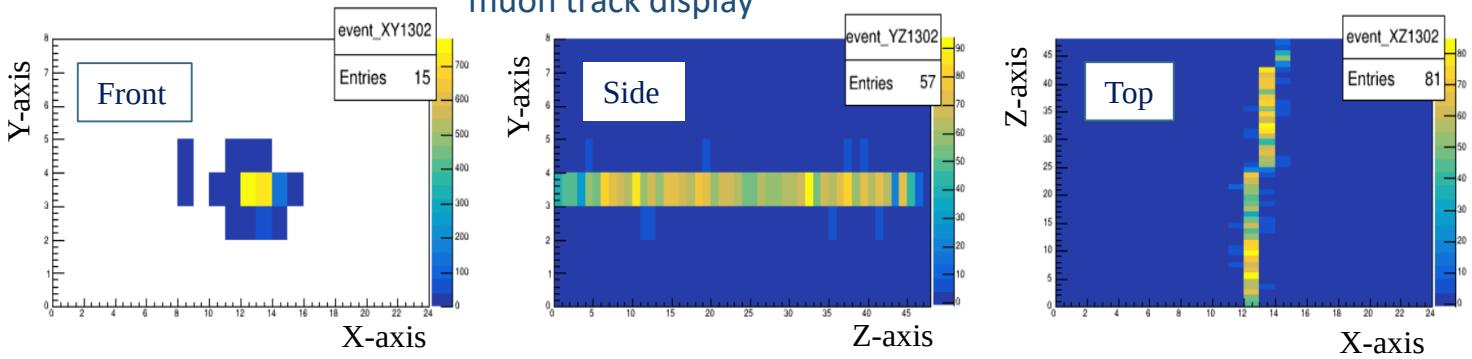
selection of events by time delay relative to the trigger: 200 ns < Tdelay < 300 ns

$T_{delay} = T_{trigger} - T_{event}$

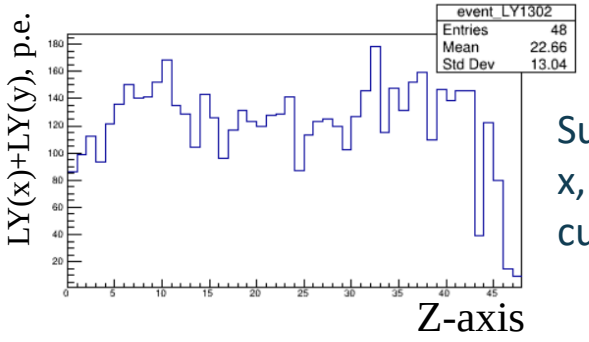
single muon event



muon track display



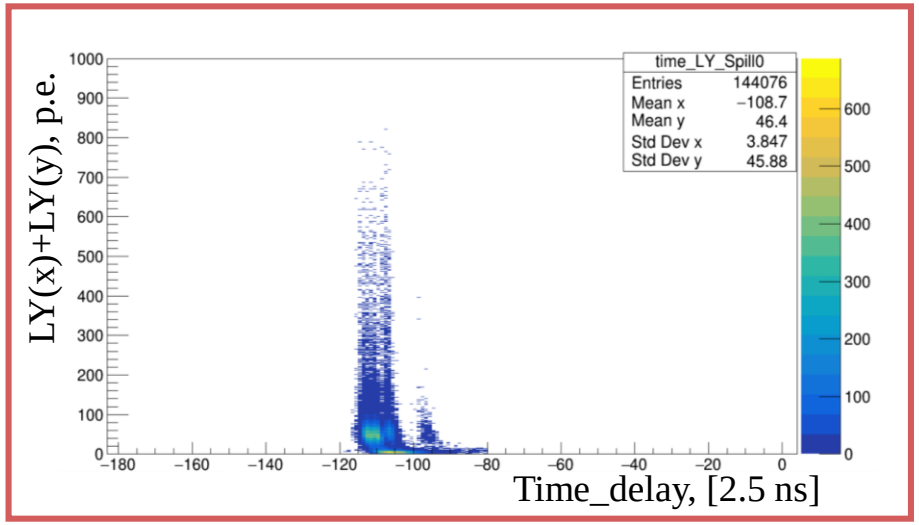
one of the muon events was chosen as an example



Sum Light yield from x, y fibers for individual cubes

Sum Light yield from x, y fibers
vs
time delay relative to the trigger time

For all events in the Spill



Conclusion

- The ND280 Upgrade is necessary to reduce systematics of the T2K and improve its sensitivity to δCP.
- The 3D active plastic neutrino scintillator detector SuperFGD is a part of the ND280 Upgrade in T2K.
- The production of all $2x10^6$ scintillator cubes was completed, detector is assembled using fishing lines.
- The parameters of individual cubes were studied, as a result of tests several prototypes of SuperFGD in beams with charged particles at CERN.
- SFGD will be placed in a special light-protected box which is under construction. Detector electronics and mechanics for SFGD assembly are also under construction.