Development of a 3D highly granular scintillator neutrino detector for the T2K experiment

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for ND280 upgrade team

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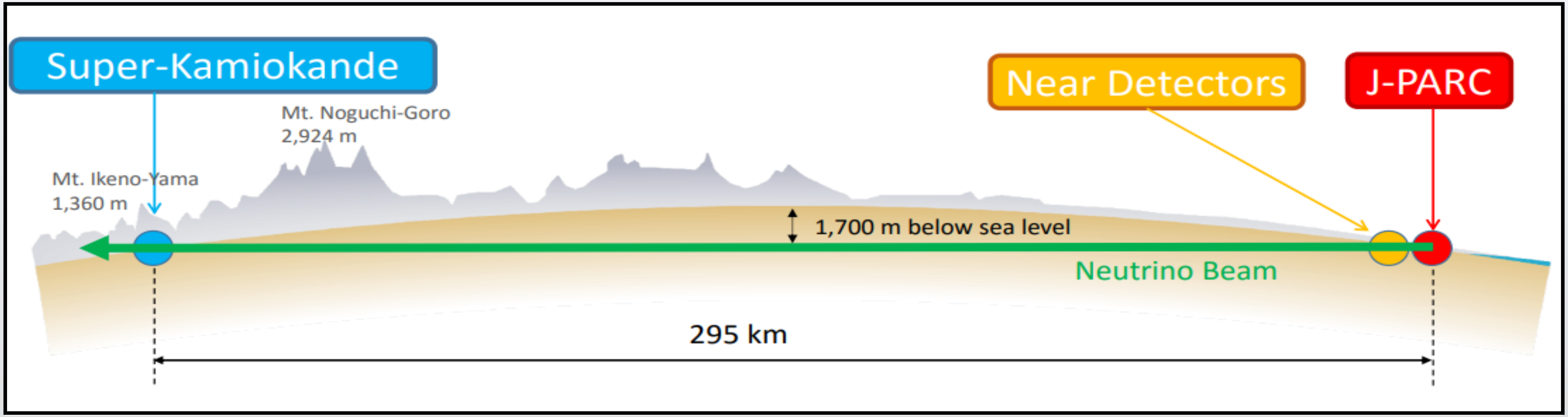
T2K experiment

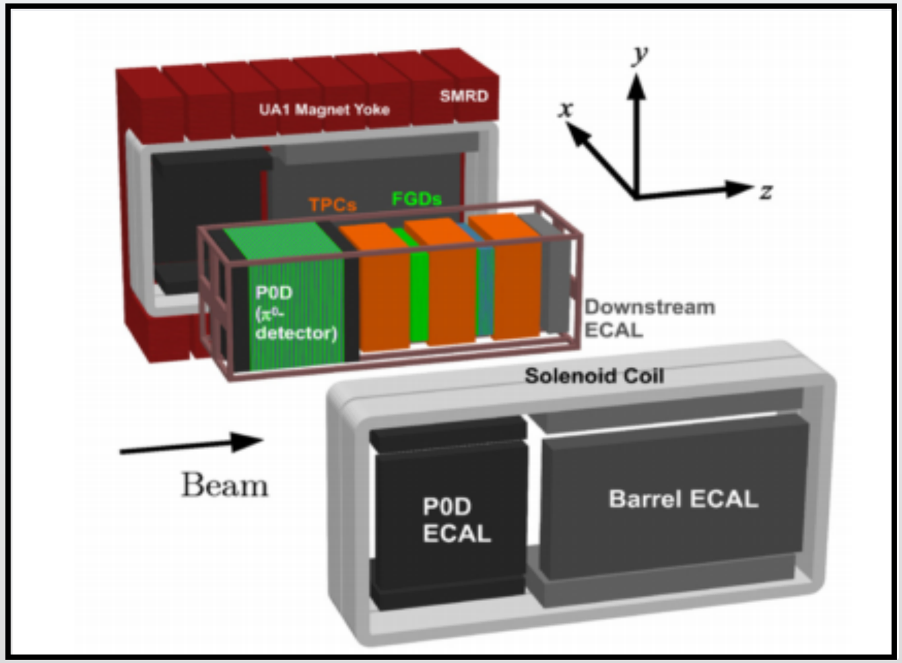


The T2K long baseline neutrino experiment has the primary goal to precisely measure neutrino oscillation parameters through measurements of ν_e appearance and ν_μ disappearance from a ν_μ beam. T2K began accumulating the data for physics analysis in January 2010. Discovery and the study of neutrino oscillations resulted in awarding of "Breakthrough Prize for Fundamental Physics" in 2016 to about 1300 scientists from the T2K and other neutrino experiments. In 2017 the T2K collaboration launched the Near Detector Upgrade project. The upgrade is targeted at reducing systematic errors in T2K's search for CP violation in the neutrino sector.

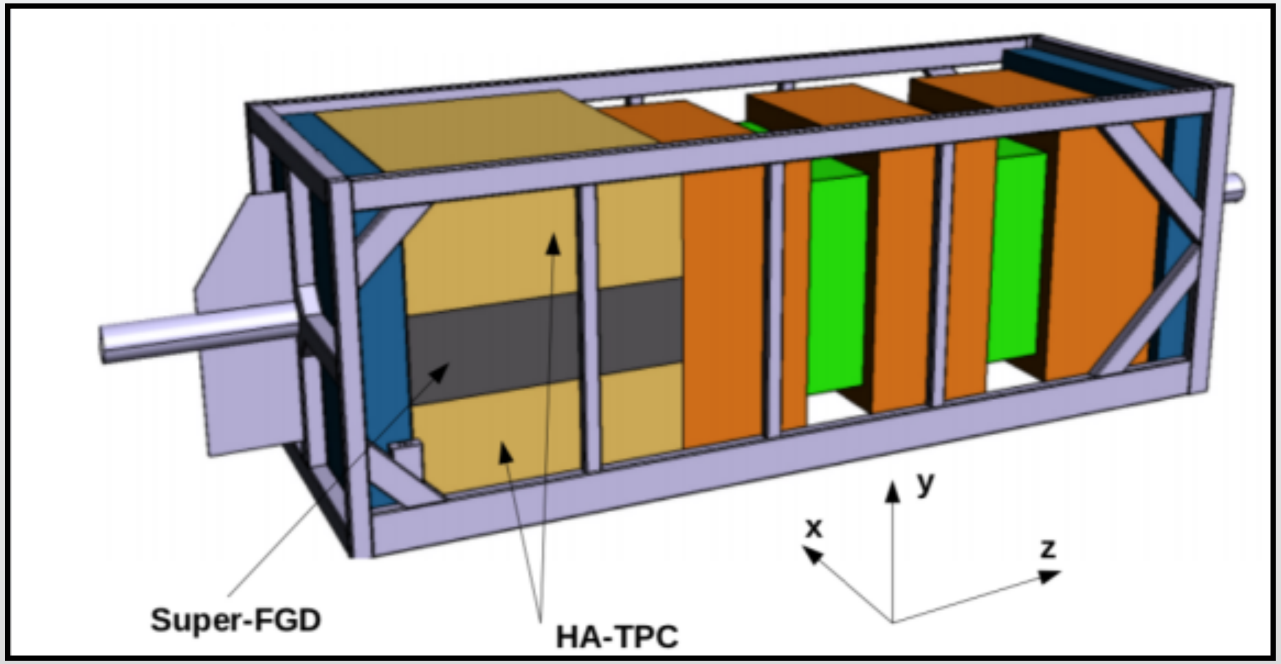
ND280 upgrade

Time Projection Chambers (TPCs), Fine Grained Detectors (FGD), Electromagnetic Calorimeter (ECAL) will stay in place

Now



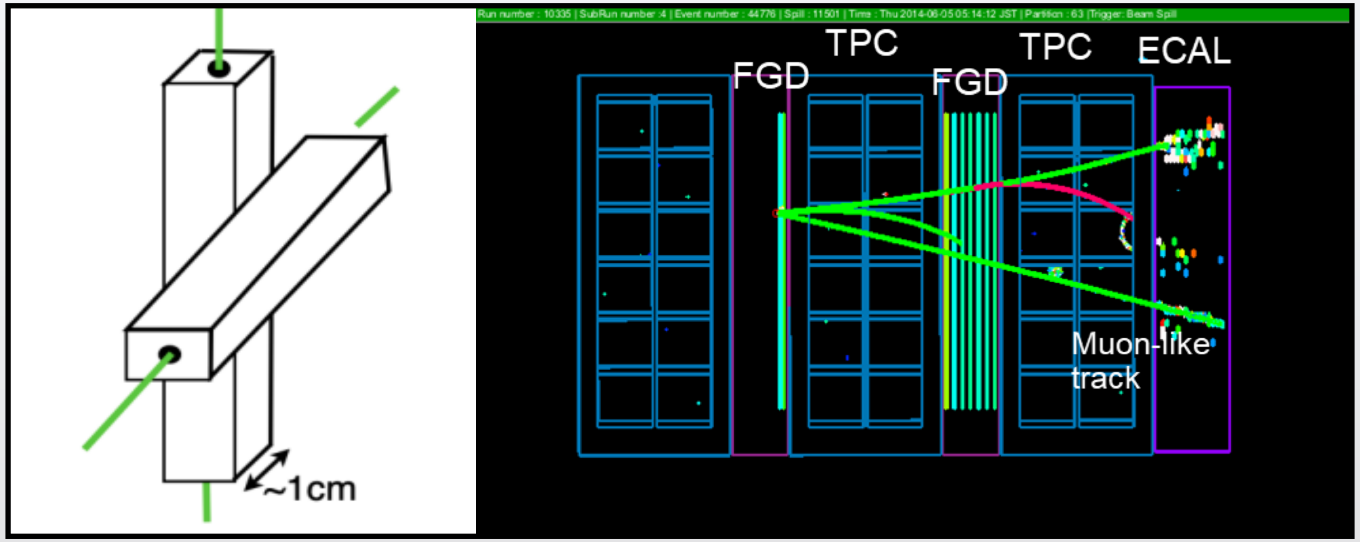
After upgrade



π^0 detector will be replaced

- Fully 3D active target (Super FGD)
- 2 High angle TPCs
- Time of Flight detectors

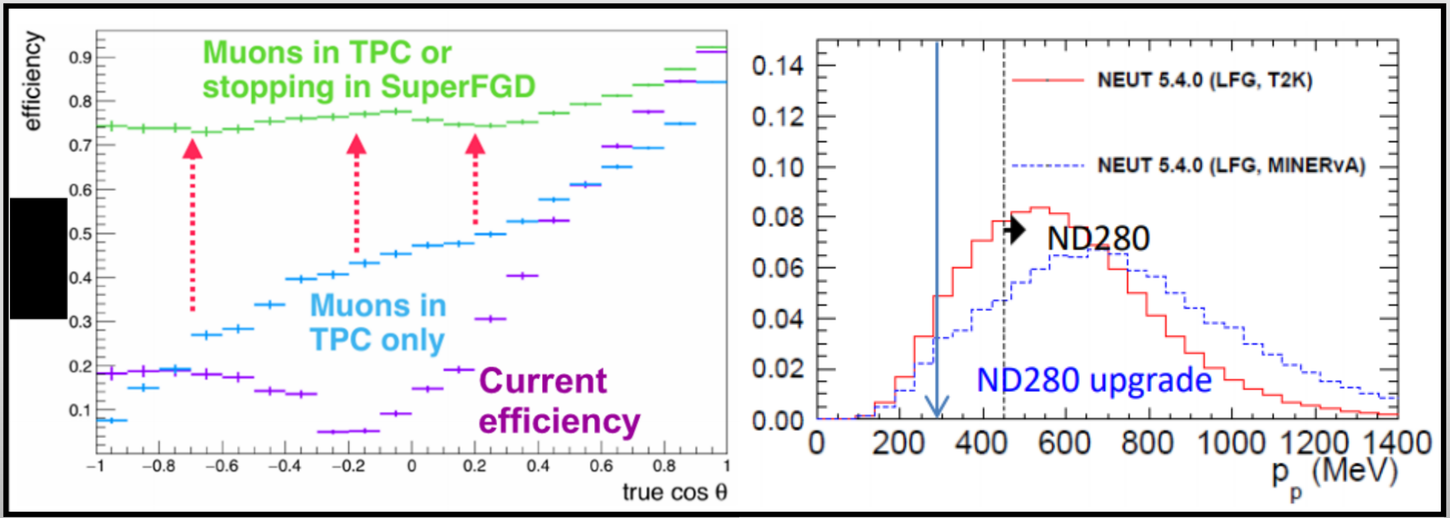
ND280 upgrade



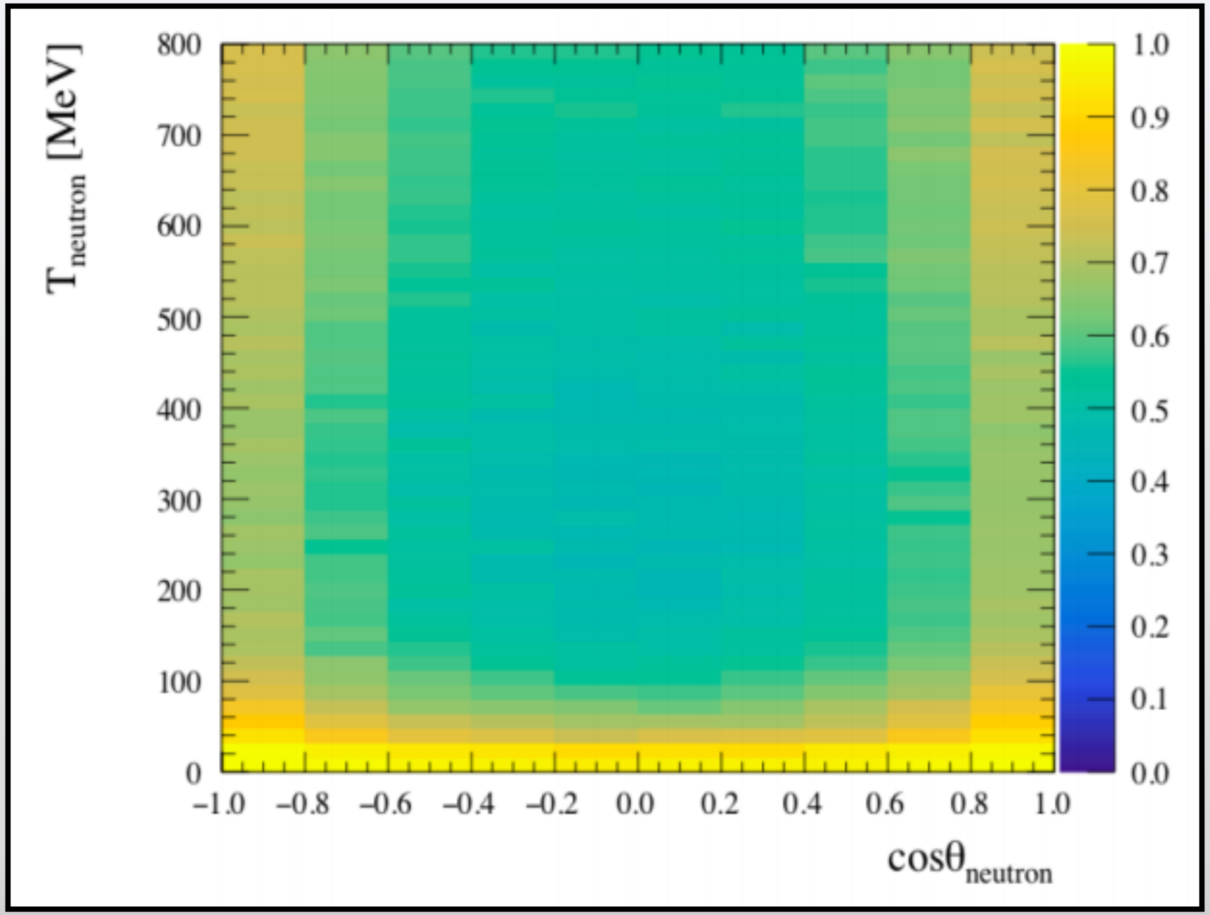
ND280 scintillator detectors (FGD) were designed as arrays of bars located perpendicular to the beam axis. Geometry is optimized to detect particles propagating in the forward direction that resulted in direction-dependence of acceptance and resolution for neutrino events.

- The phase space coverage up to 4 π
- Low threshold for protons/pions

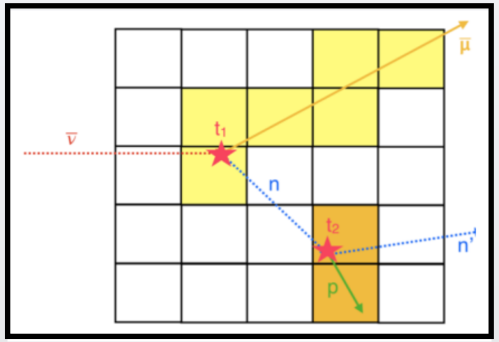
Reduce the systematic uncertainty in the oscillation analysis from 6-7% down to less 4%



SuperFGD for neutron detection (MC simulation)

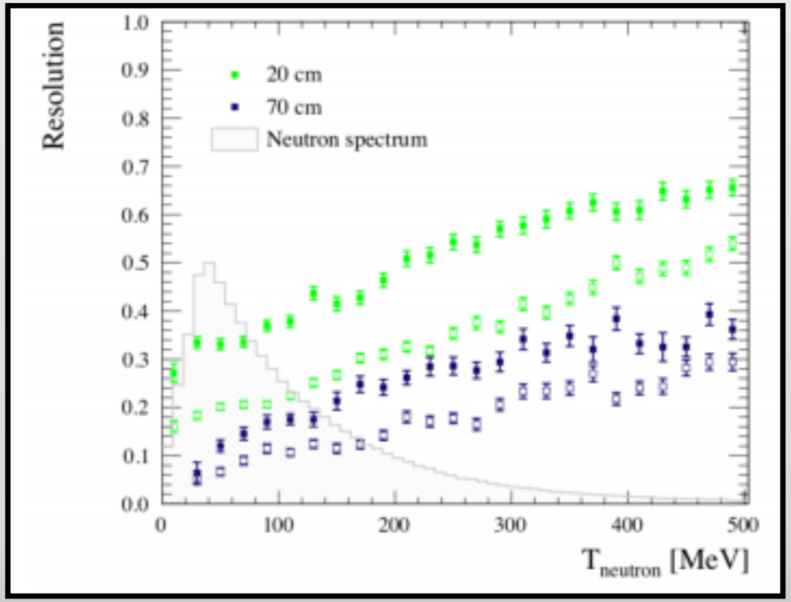


The detection efficiency is relatively high



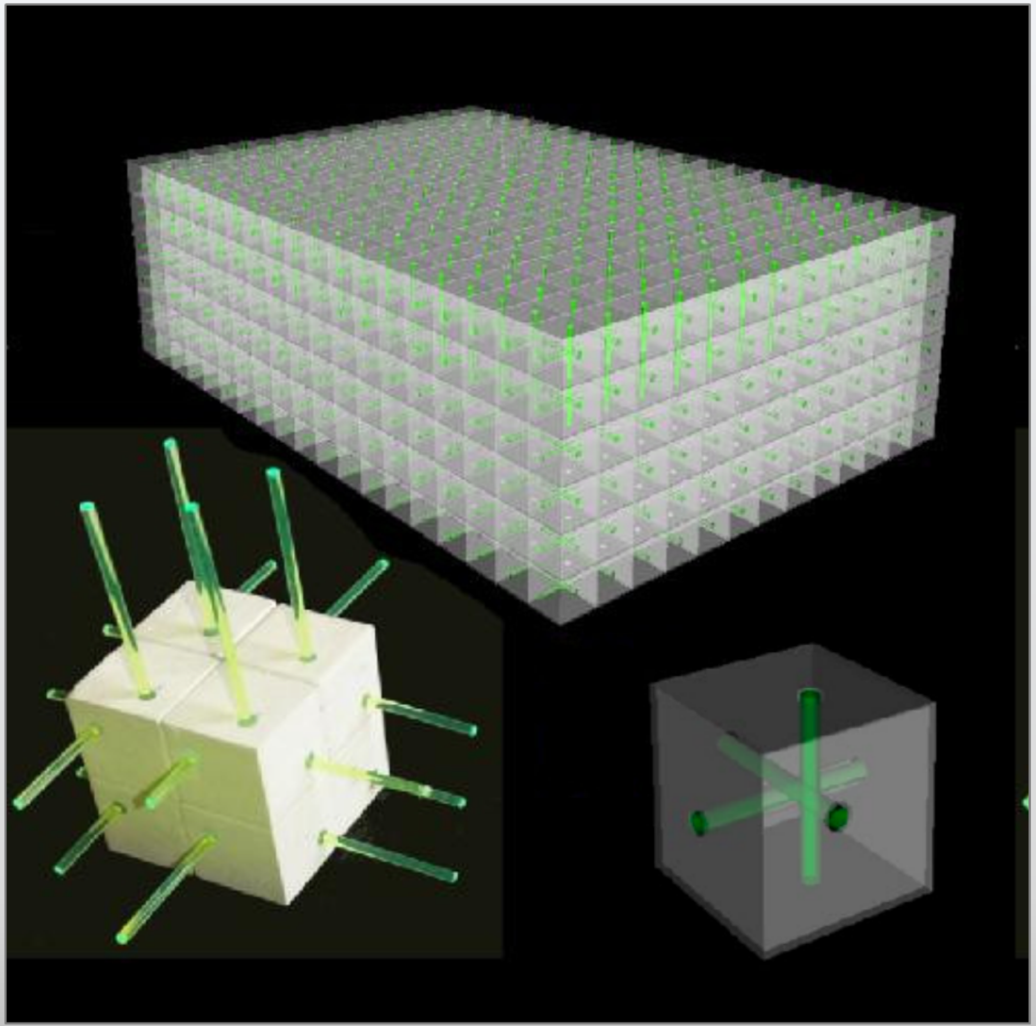
arXiv:1912.01511

Example of the neutron detection through the observation of secondary protons



Energy resolution for different neutron travel distances

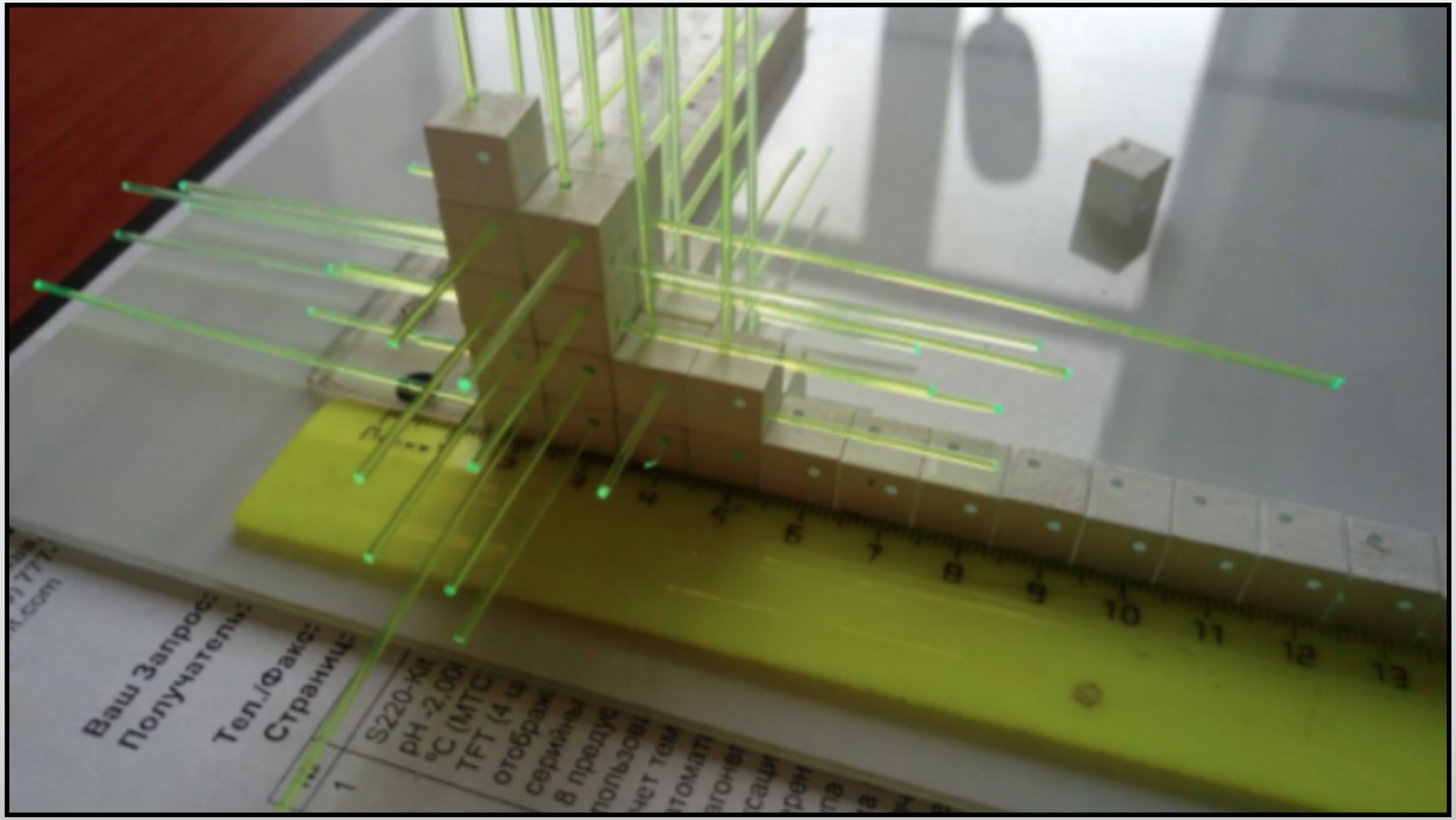
SuperFGD concept with 3D fiber readout



SuperFGD will be installed upstream of the beam between two TPCs (time-projection chambers) in addition to the existing FGD detectors. The size is limited by available space inside the UA1 magnet.

- **Detector size: 192x184x56 cm^3**
- **Granularity: 1x1x1 cm^3 cubes**
- **Number of cubes: ~ 2’000’000**
- **Number of readout channels: ~ 60’000**
- **Readout: Y11 Kuraray WLS fibers of 1 mm diameter viewed at single end with surface mount Hamamatsu MPPCs.**

SuperFGD concept with 3D fiber readout



The picture illustrates the readout method. A single WLS fiber is going through a raw of cubes. One end of the fiber is viewed by a photosensor, another end is covered by a reflector. Each cube is viewed by 3 orthogonal fibers.

arXiv:1707.01785

Production of the cubes

Scintillation cubes are made in UNIPLAST, Vladimir

Injection (12-cube mold)

Etching (chemical reflector)

Drilling the holes (3 holes per a cube)

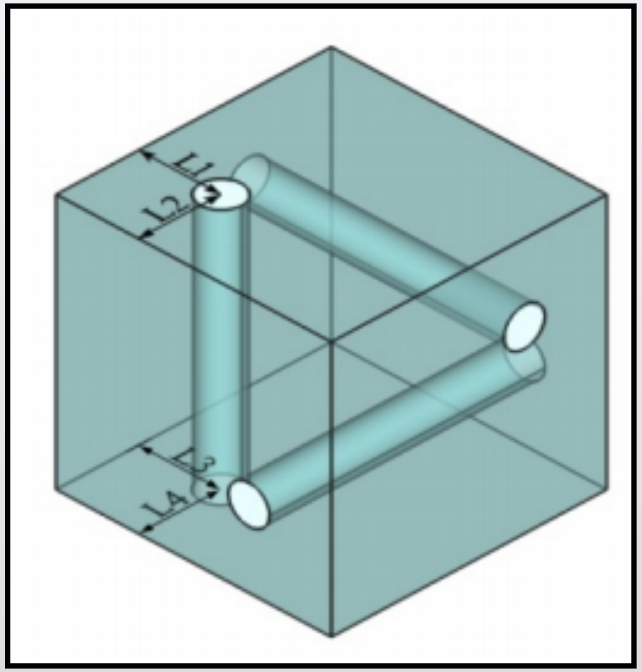
Production of the cubes

Cube size

The cubes after the mold have the precise dimensions. After etching the size of cube side is **10.26 mm ± σ=6 µm**.

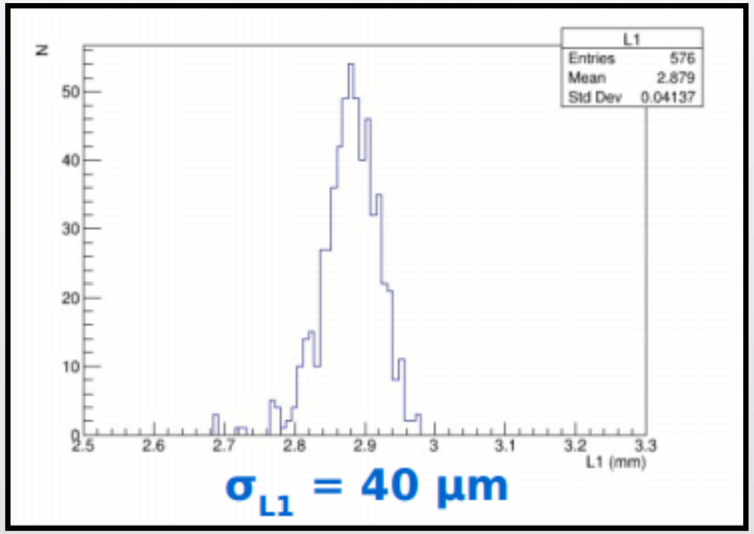
After chemical etching the micropore **diffuse reflector of 60-70 µm thickness** is formed over all surface. The cube size becomes **10.167 mm with σ=30 µm**

Production of the cubes

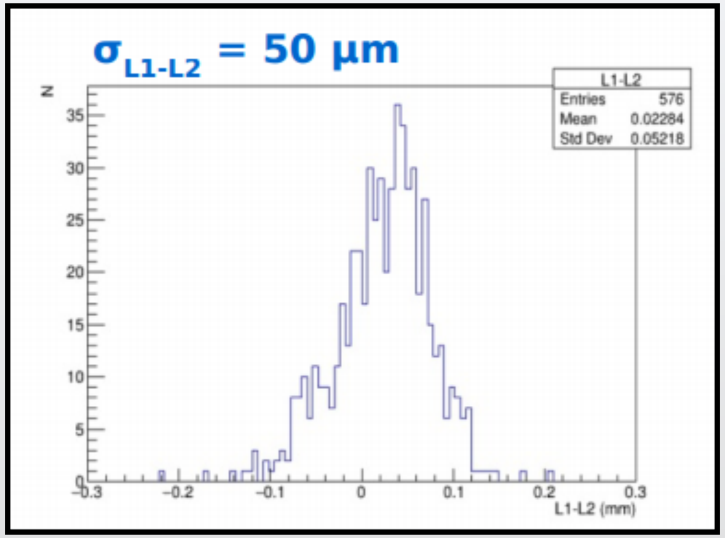


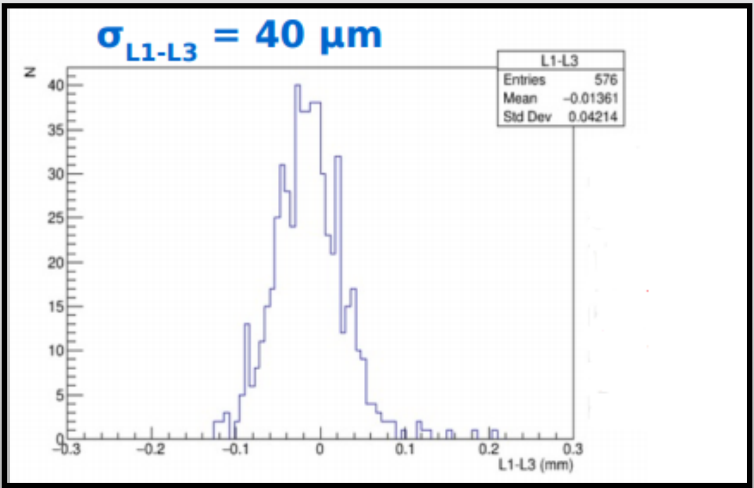
For the full assembly of SuperFGD, the precision of a hole positions should be ***40-50 µm***

Precision of the hole position vs side of a cube



Precision of the hole position vs corner of a cube

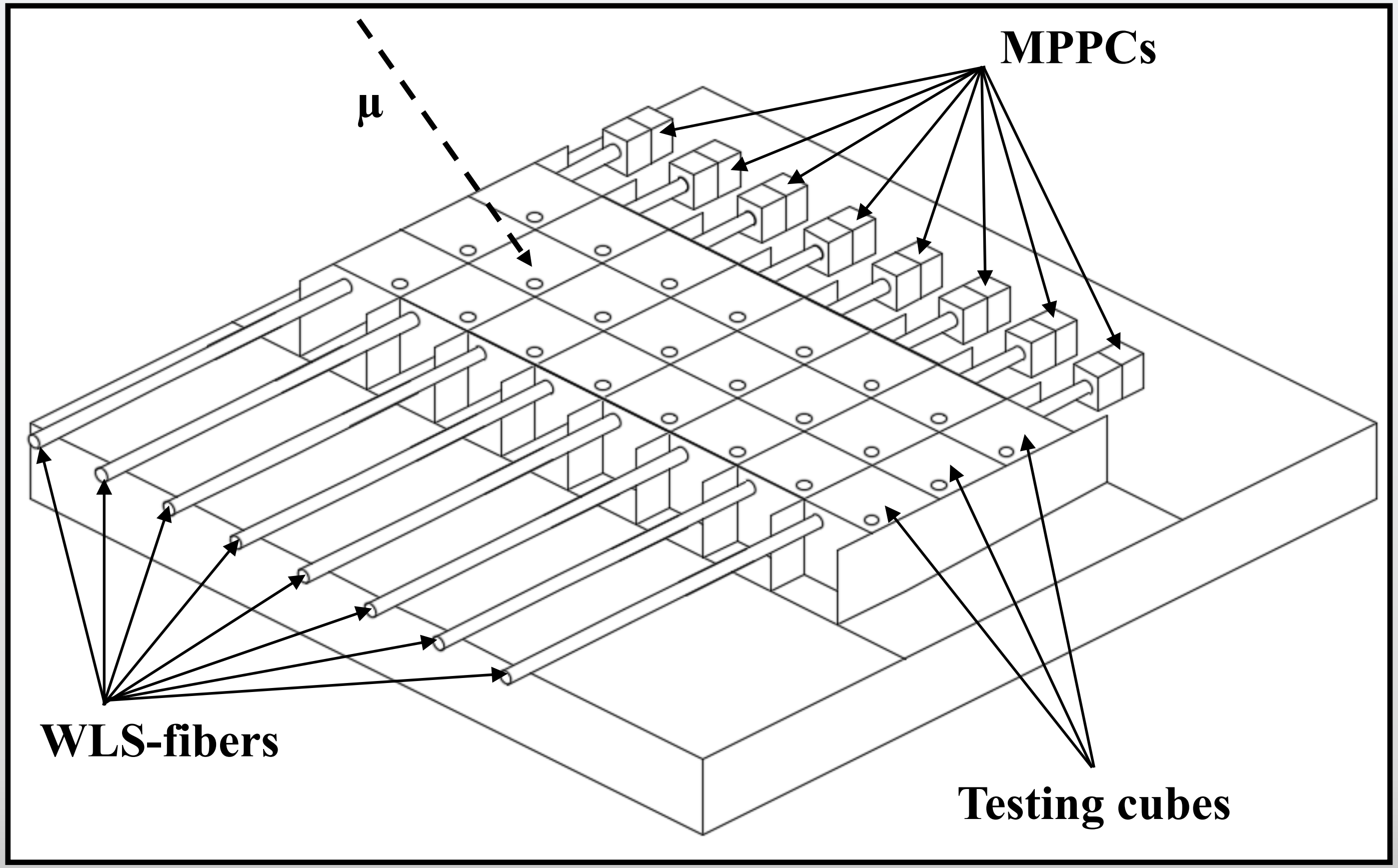




Precision of hole position for two opposite sides of a cube. The main parameter that determines the angle of inclination of the hole

Quality control

All time of assembly L.Y. were controlled



Average L.Y. ~ 35.7 p.e./MIP

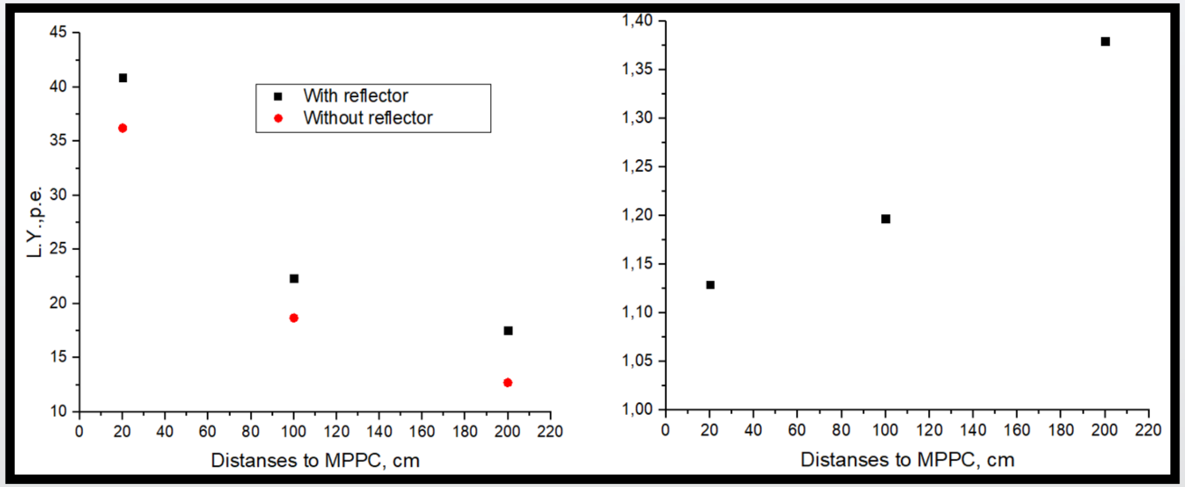
Experimental setup

- Testing with cosmic muons
- Top trigger size 100x100 mm^2
- Bottom trigger size 120x100 mm^2
- Testing 8 groups of 3 cube on 1 fiber
- T ~ 20 - 25°C
- Fibers length 35 cm
- Testing fibers were polished and without reflector

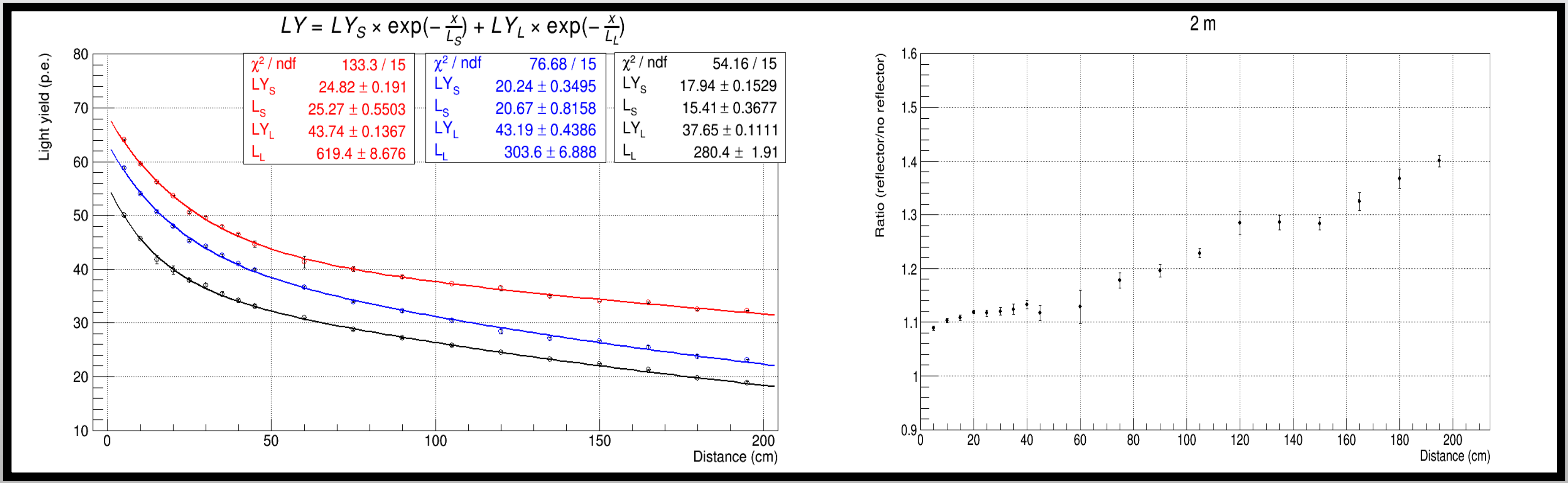
MPPC Hamamatsu S13081-050C

- Sensitive area size: 1.3x1.3 mm^2
- Number of pixels: 667
- Pixel size: 50x50 μm^2
- Gain: $1.5x10^6$
- Operation voltage: ~54.6 V
- Peak spectral sensitivity: 450 nm
- Dark count: 90 kHz (typical)
- Crosstalk: ~ 1%
- PDE at 450 nm: 35%

Tests of 2 m WLS-fibers (Kuraray Y11)

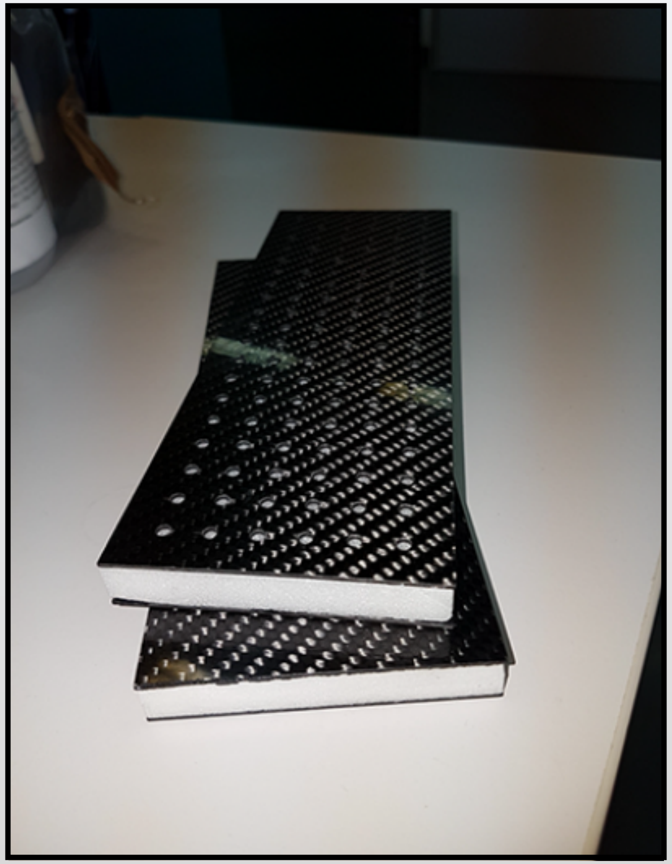


Testing with cosmic muons.
Left: L.Y./MIP vs distances to MPPC for fiber with and w/o reflector.
Right: ratio of L.Y./MIP for fibers with and w/o reflector

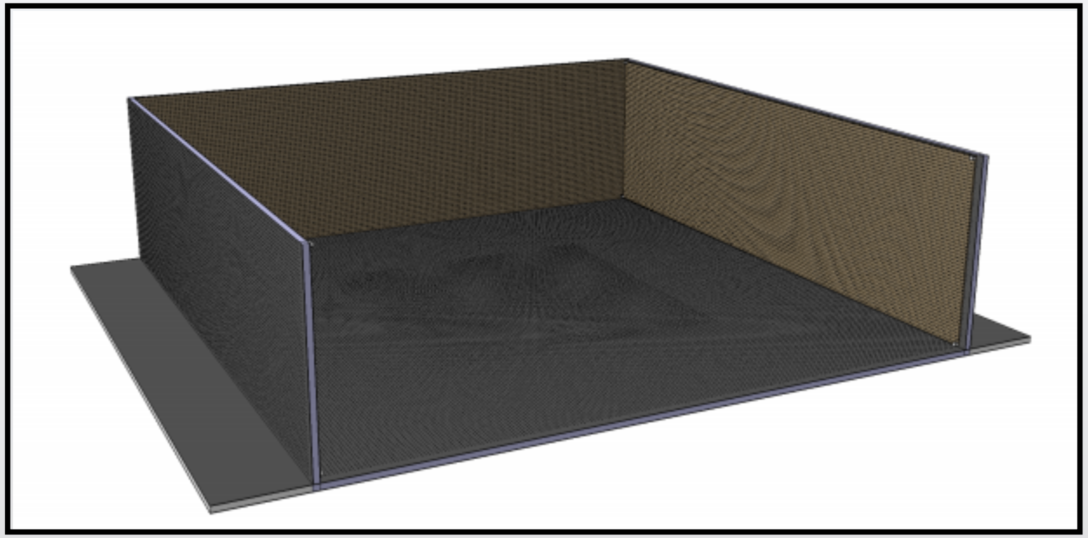


The single cube was flashed by LED. Fibers with/without reflector – red and blue line and with black paint on the end of fiber – black line.
Right picture: ratio of L.Y. for fibers with and w/o reflector

Box mechanics and calibration system



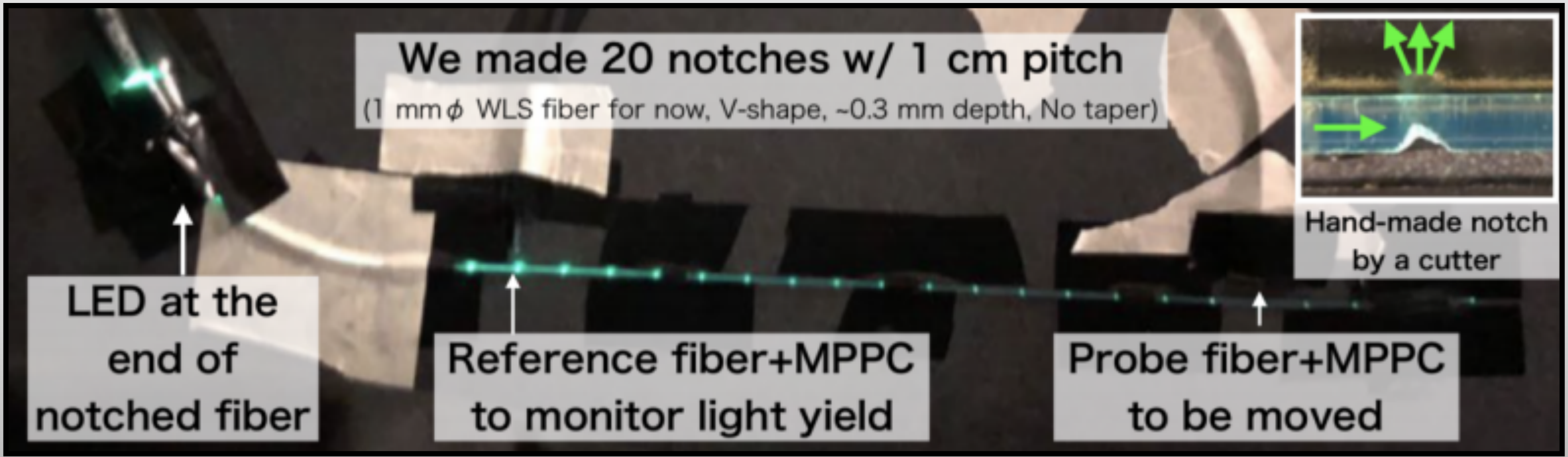
CF sandwich samples. An AIREX foam is sandwiched by CF skins.



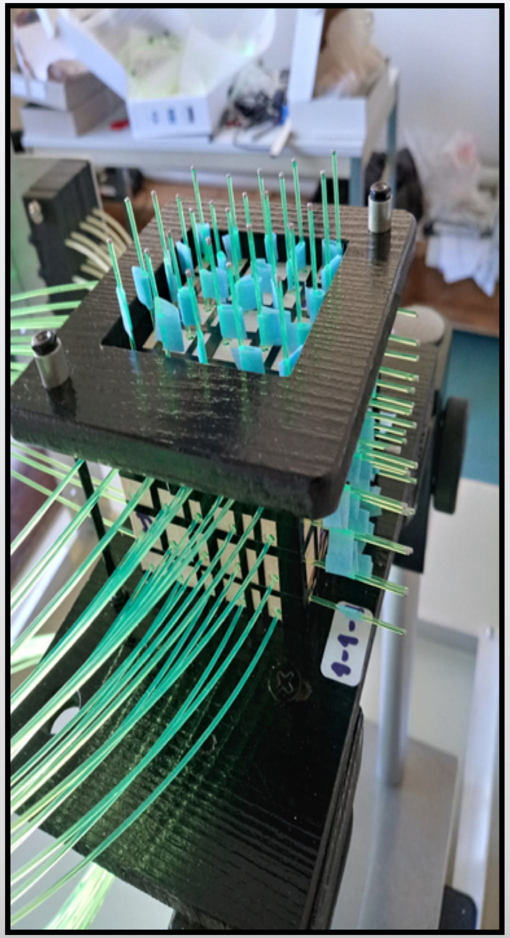
arXiv:1901.03750

Left: The SuperFGD mechanical box made of the CF-based panels

Bottom: Proposed LED calibration system



Beam tests



arXiv:1808.08829

Two prototypes: **125** (5x5x5) cubes with **75** fibers and **9216** (48x24x8) cubes with **1728** was tested in the charge particles beam at CERN.

For 1st configuration: fiber **Kuraray Y11 1.3 m** long; MPPCs **Hamamatsu S12571-025C**.

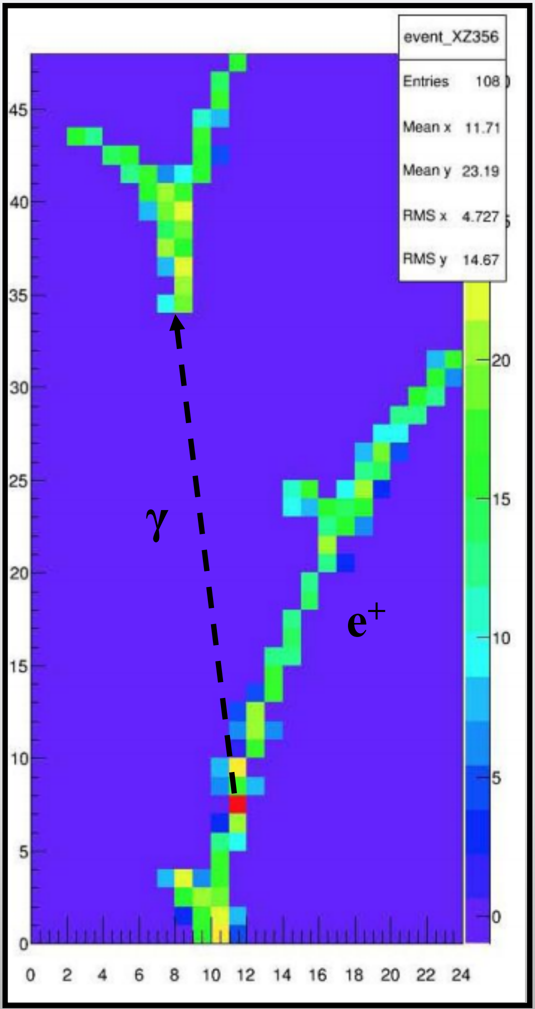
Typical light yield per one fiber ~ **42 p.e.**

Average time resolution per one fiber ~ **0.92 ns**

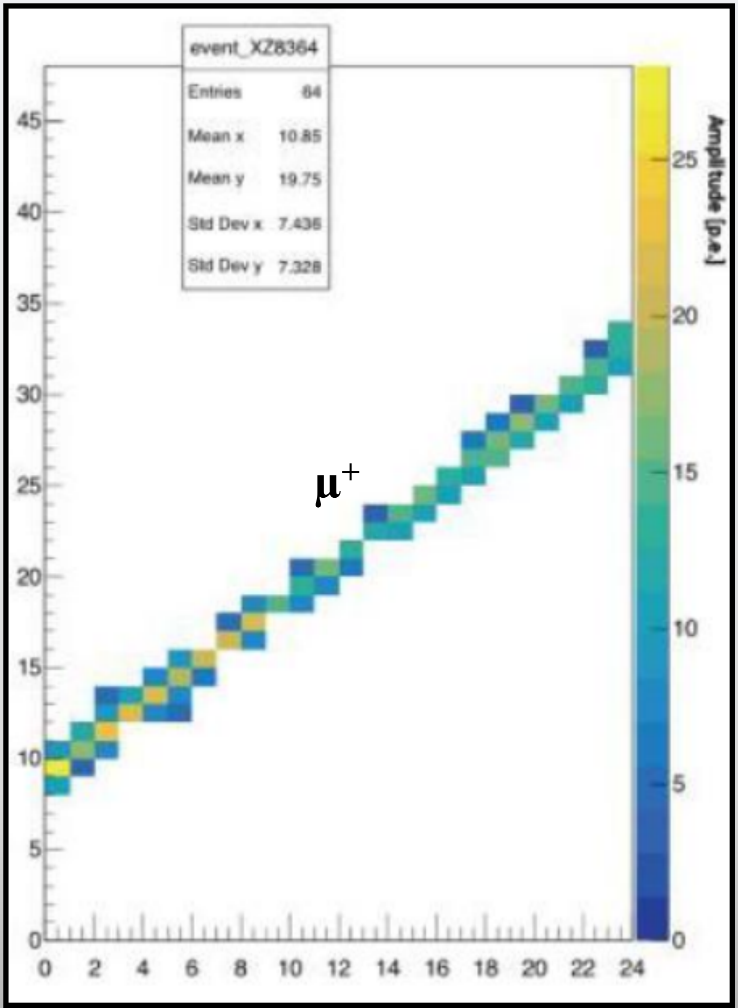
Crosstalk ~ **3%**

Examples of events from the 2nd beam test

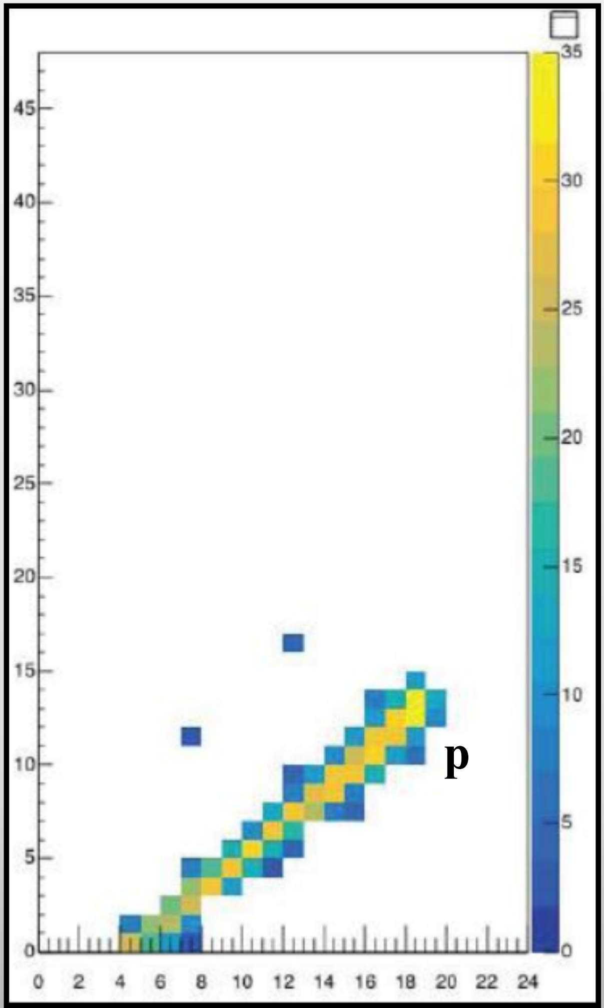
Positron, 1 GeV, B = 0.2 T



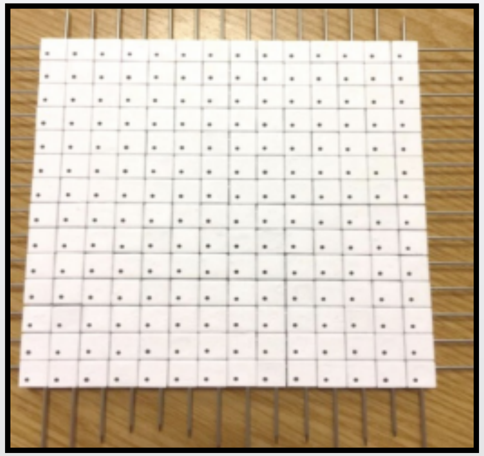
Muon, 5 GeV, 45 deg

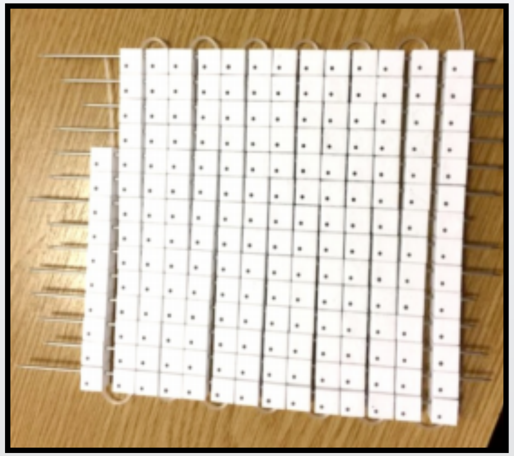


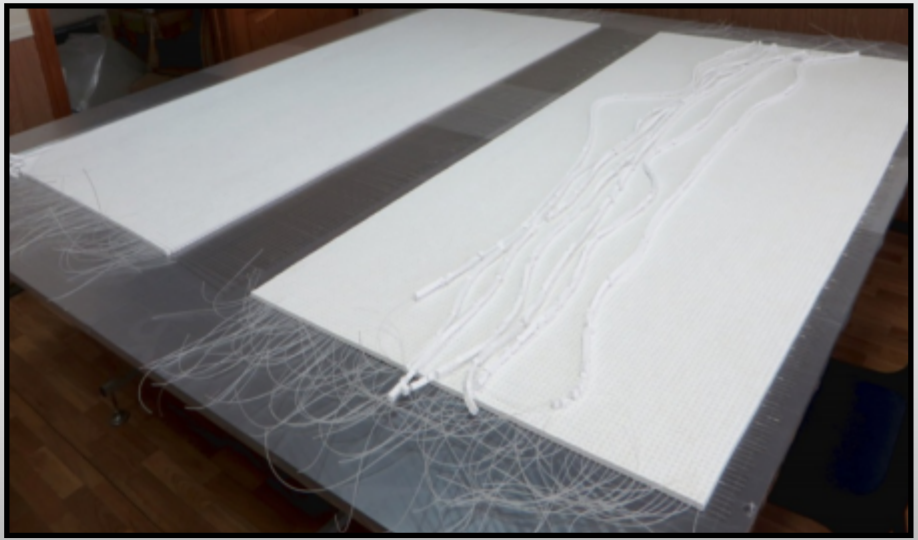
Stopped proton, 0.5 GeV, 45 deg

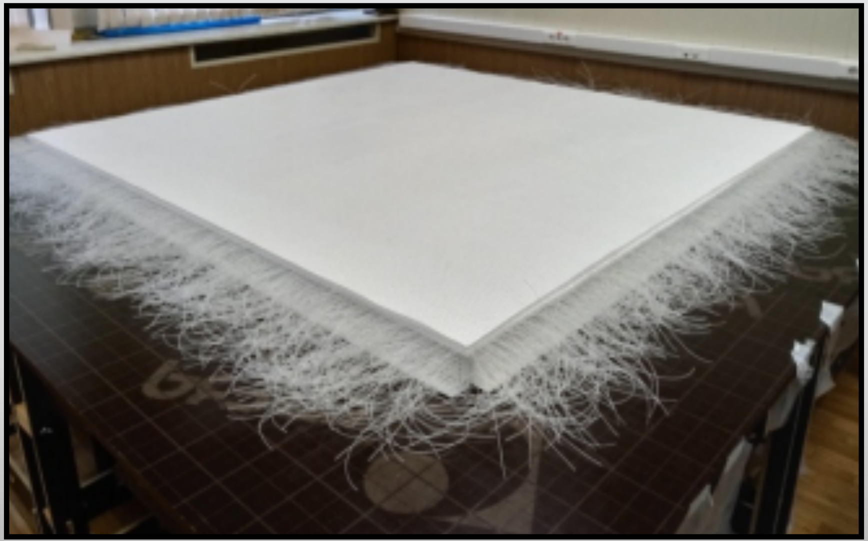


Assembly

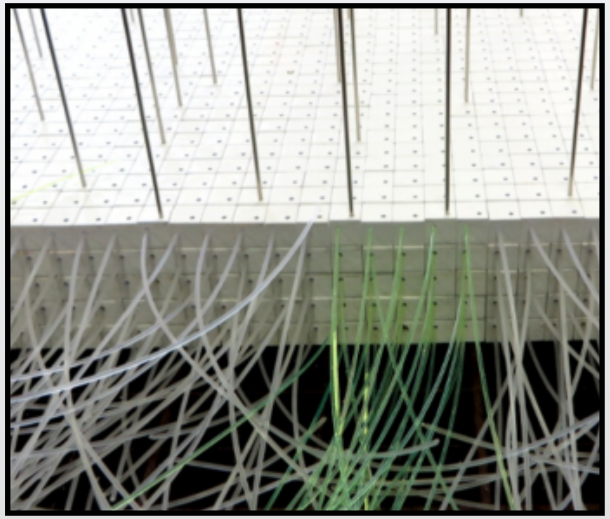




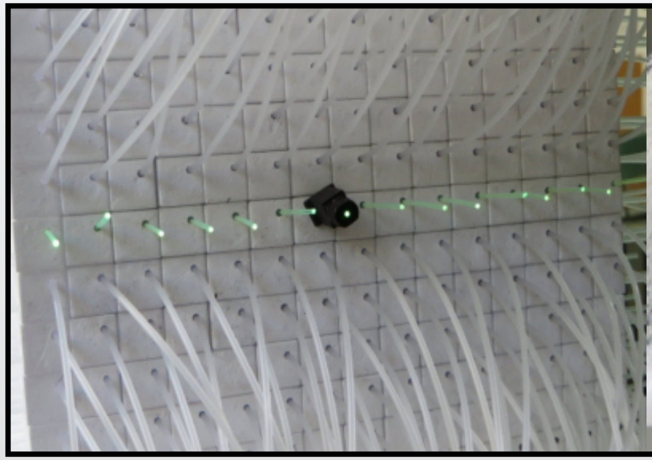


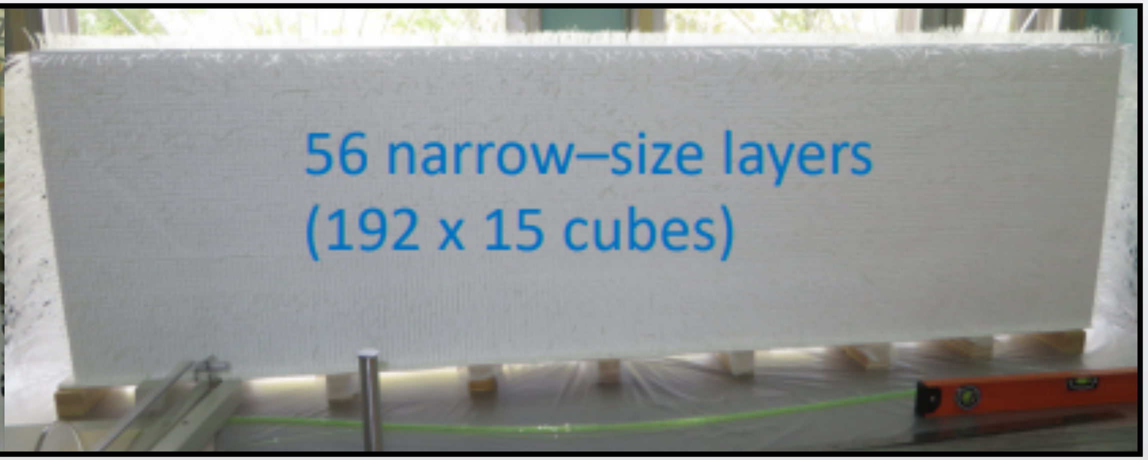


Replace the fishing lines by WLS fibers



Set of 5 planes (each 184x192 cubes)

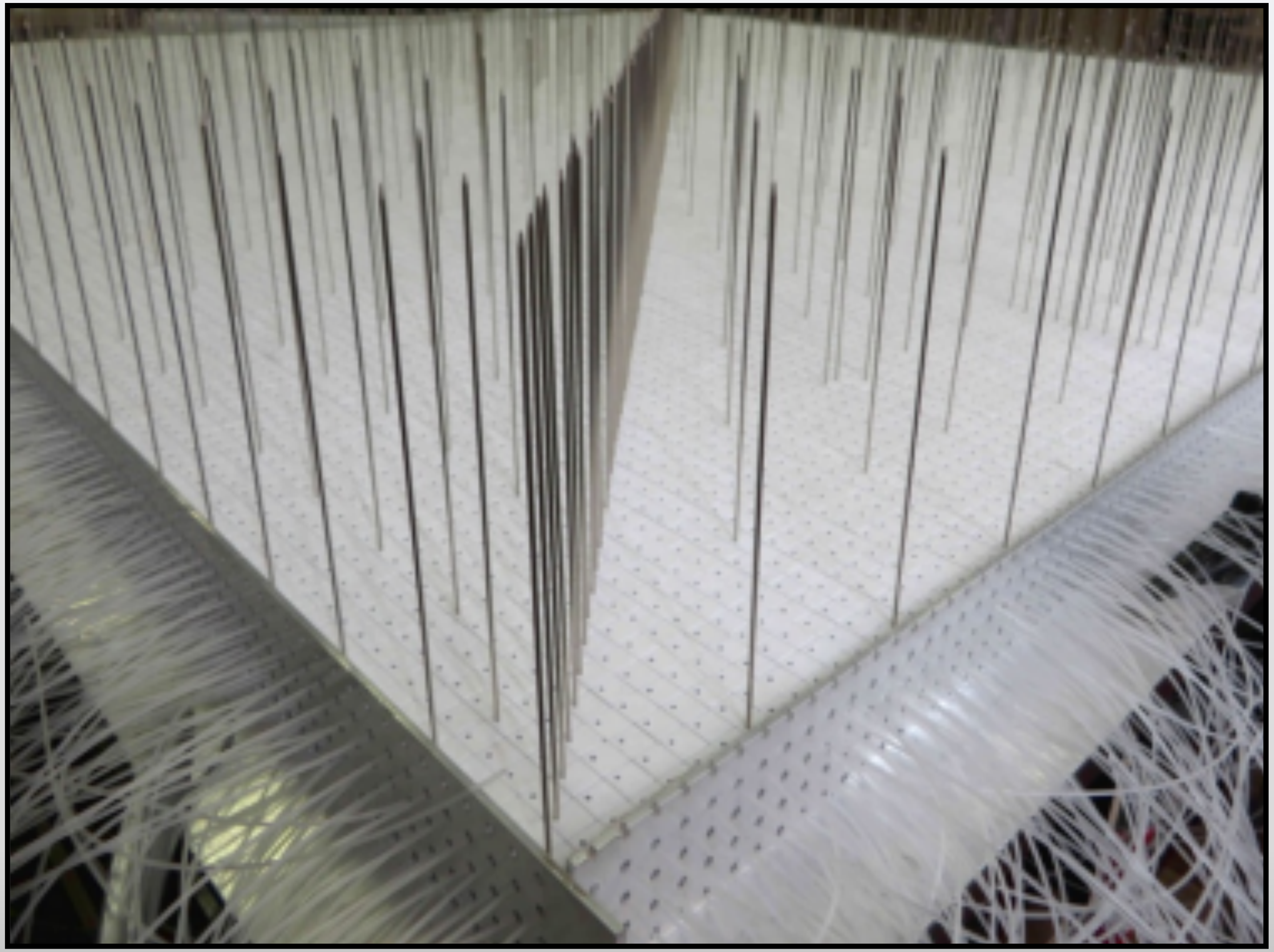




Array of 15x56x192 cubes

We were able to replace the fishing lines by WLS fibers at the full detector length of 192 cubes without any problem in all tested channels including the large prototype of 15x56x192 cubes with a sag of 2 cm. Altogether we tested >100 channels.

Conclusion



- *Assembly of **25 planes by 192x184** cubes was completed*
- *Typical light signal in a cube was about **40 p.e./MIP** per a single fiber*
- *Average time resolution about **0.9 ns** per a single fiber*
- *Average size of cube about **10.26 mm***
- *Position of the holes relative to two cube sides is currently **σ=40-50 μm***

SuperFGD should be installation into the magnet at October 2021

Reference

- *Blondel, … , S. Fedotov et al. A fully-active fine-grained detector with three readout views JINST 2018*
- *O. Mineev, S. Fedotov,.. et al. Parameters of a fine-grained scintillator detector prototype with 3D WLS fiber readout for a T2K ND280 neutrino active target, NIM 2018*
- *O. Mineev, S. Fedotov,.. et al. Beam test results of 3D fine-grained scintillator detector prototype for a T2K ND280 neutrino active target NIM Volume 2019*