

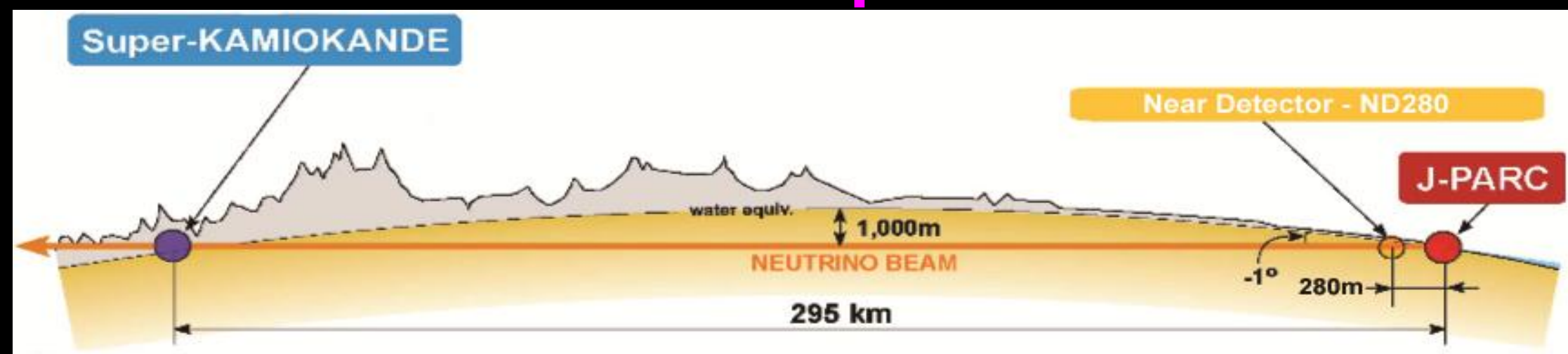
# Development of a 3D highly granular scintillator neutrino detector for the T2K experiment



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## T2K experiment



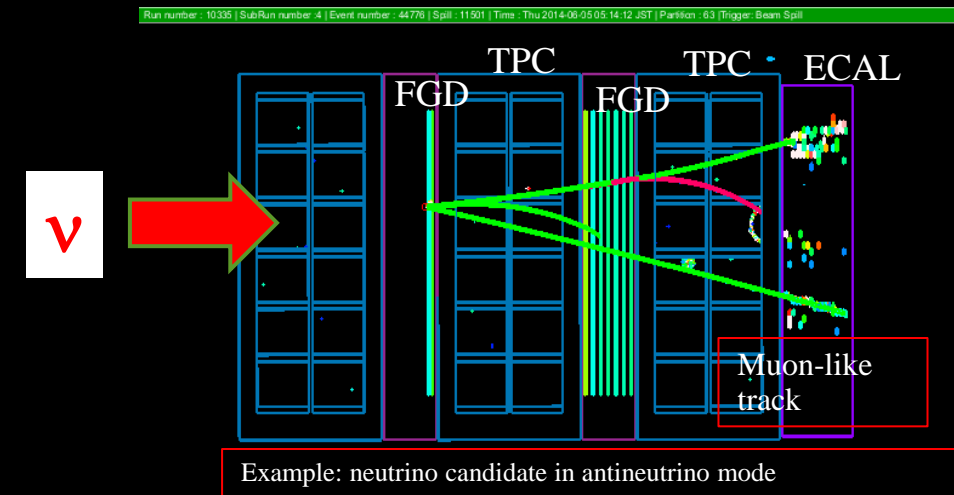
**Main goals of the T2K experiment:**  
- search for CP violation in neutrino oscillations;  
- precise measurement of oscillation parameters;  
- measurement of neutrino cross section.  
T2K began accumulating physics data in January 2010

### Near neutrino detector ND280



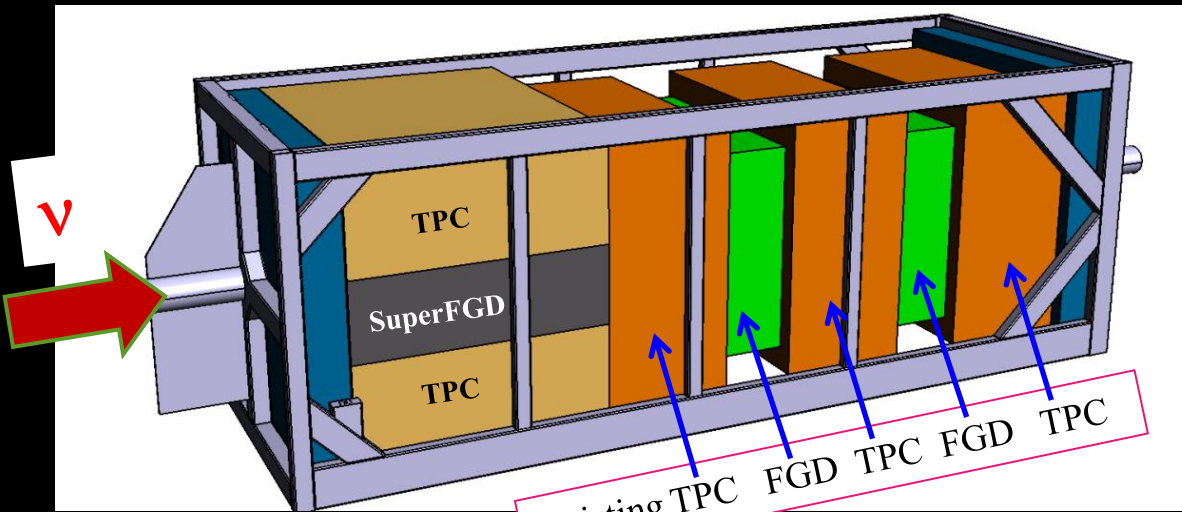
ND280 Fine Grained Scintillator Detectors (FGD) were designed as arrays of bars located perpendicular to the beam axis. The configuration was optimized to detect particles propagating in the forward direction. The proposed 3D highly granular scintillator detector (SuperFGD) is expected to address the needs of the T2K, T2K-II and T2HK oscillation program:

- precise measurement of neutrino energy;
- cover full solid angle and low momentum for charged particles from neutrino interactions;
- measure electron neutrino cross sections;
- measure nuclear effects in neutrino interactions

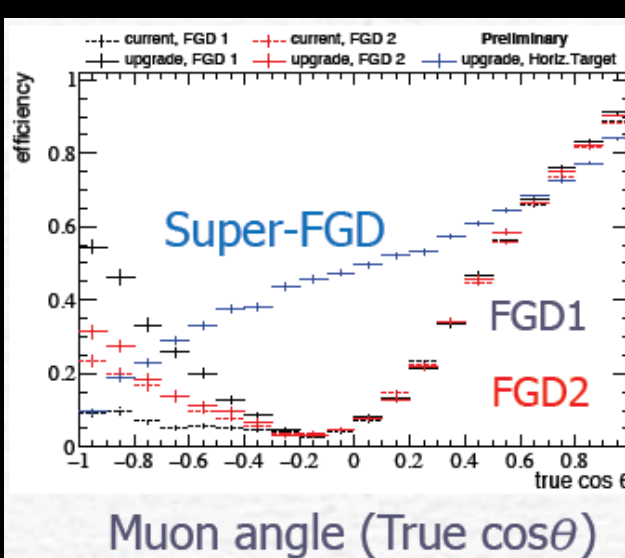


## Upgrade of ND280

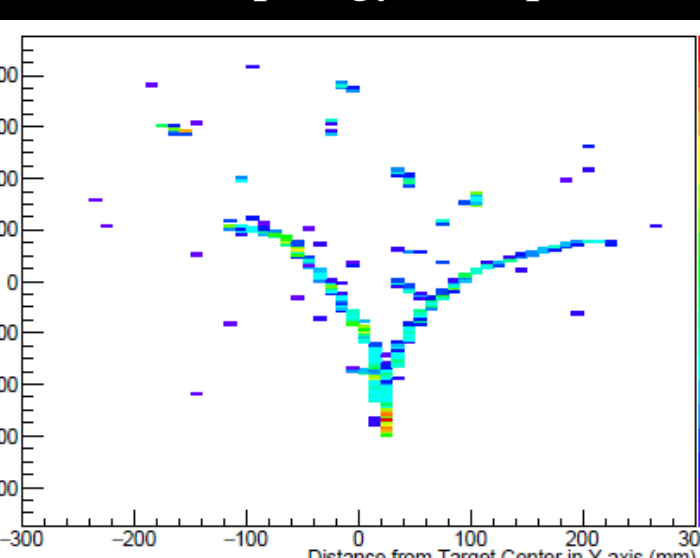
**3D highly granular scintillator detector (SuperFGD)** will be installed upstream of the beam between two TPCs (time-projection chambers) in addition to the existing FGD detectors. TOF planes will be installed around new detectors. The size of the detector is limited by the available space inside the UA1 magnet.



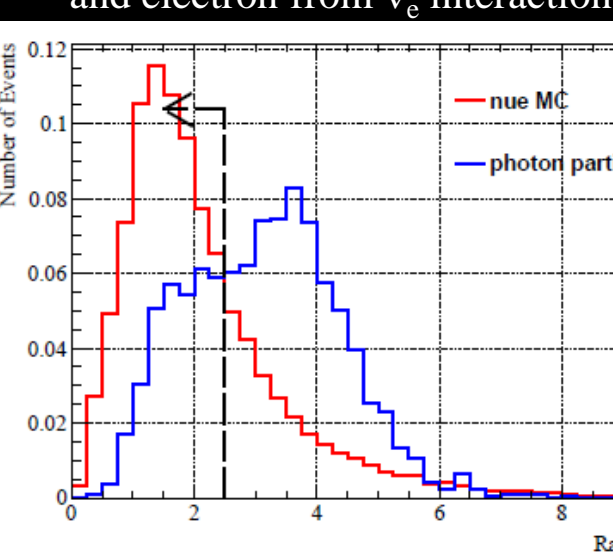
### Efficiency to CCQE muons



### Photon topology in SuperFGD

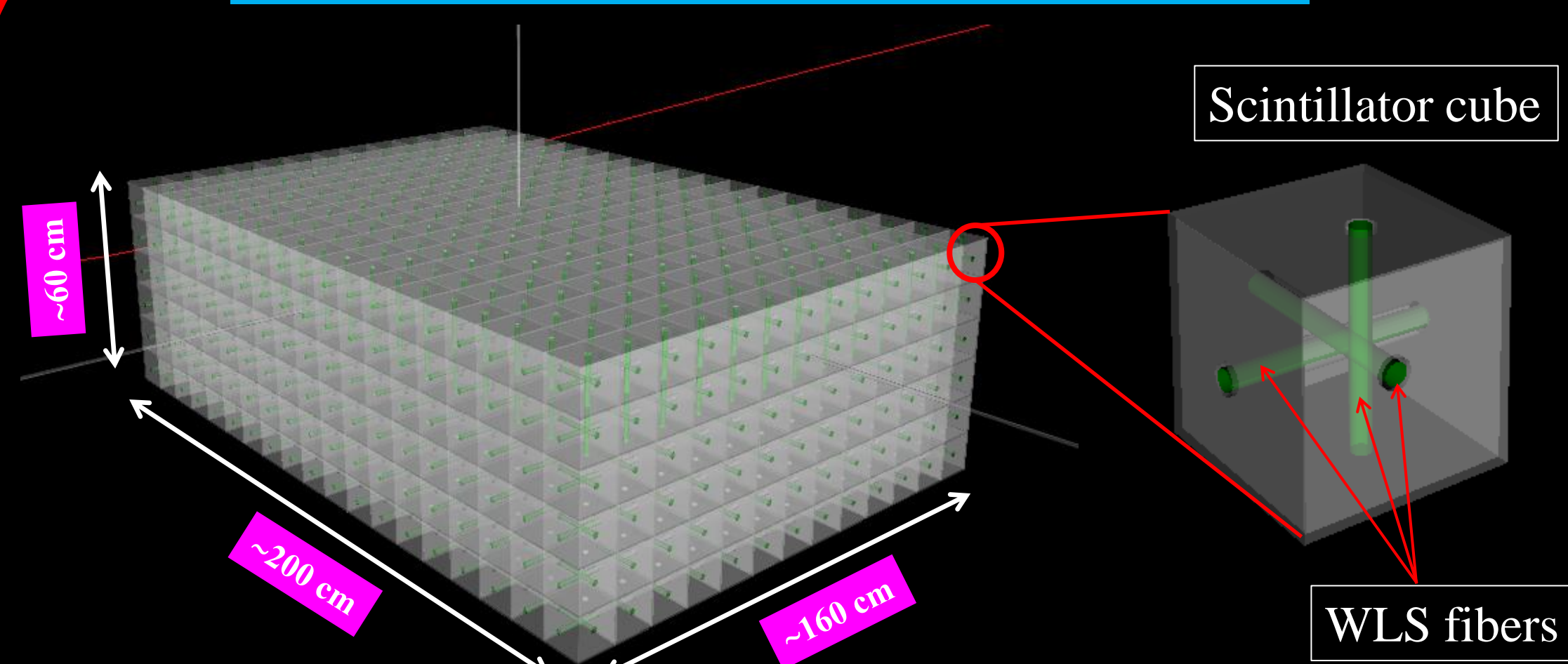


### dE/dx ratio for converted gamma and electron from nu\_e interaction



Expected parameters:  
efficiency of reconstruction of muon track ~90%; proton detection threshold ~300 MeV/c  
 $\nu_e$  detection efficiency ~77%, probability of  $\gamma$  misidentification as a  $\nu_e$  event ~19%

## Baseline configuration of SuperFGD

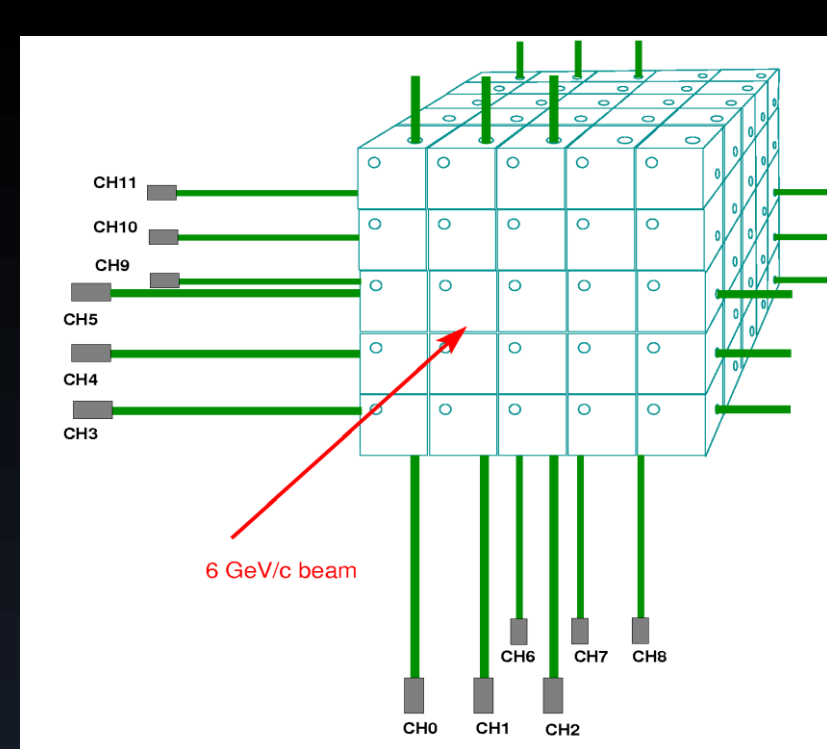
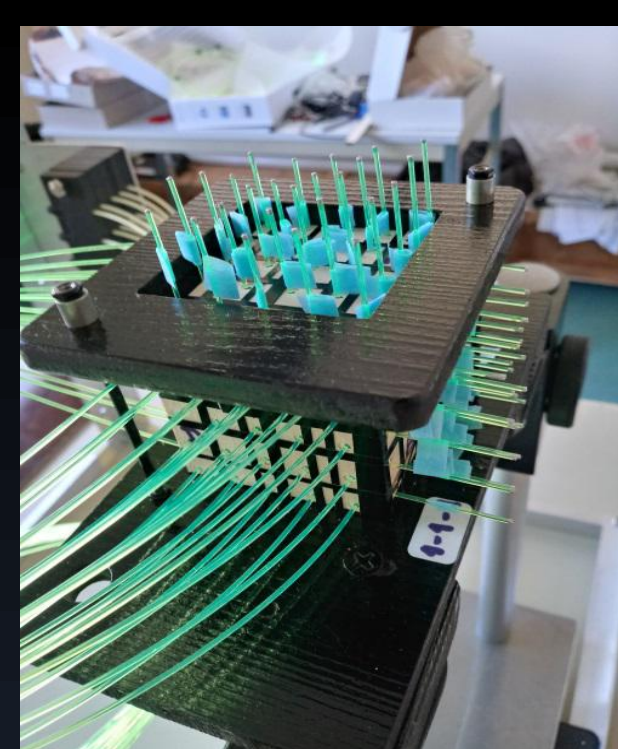


**Detector size:** ~0.6 x 1.6 x 2.0 m<sup>3</sup>  
**Granularity:** 1x1x1 cm<sup>3</sup> cubes, each cube is viewed by 3 orthogonal fibers  
**Number of cubes:** ~2000000  
**Weight:** ~2.2 t  
**Number of readout channels:** ~60000  
**Readout:** 1mm Y11 Kuraray WLS fibers viewed at one end with surface-mount Hamamatsu MPPCs

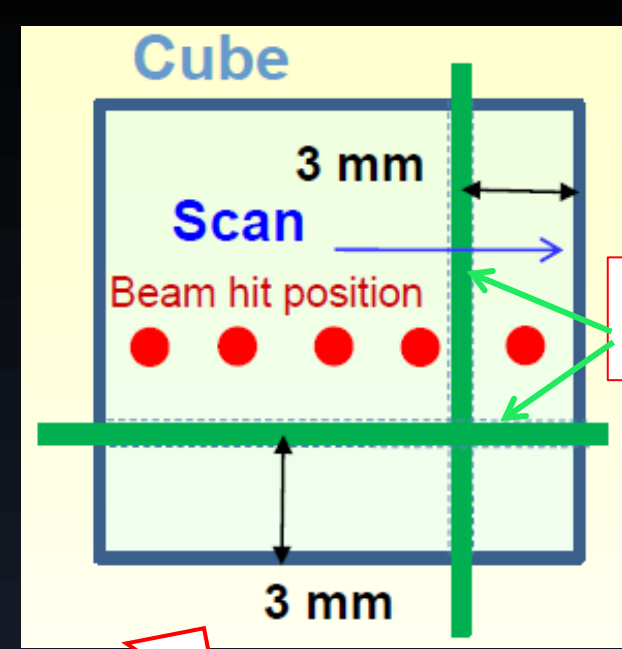
## Performance of a small prototype

Prototype of 125 cubes (5x5x5) with 75 fibers was tested in a charge particle beam at CERN in 2017. The readout was implemented with 1.3 m long Kuraray Y11 WLS fibers and Hamamatsu MPPCs S12571-02 5C. MPPC sensitive area is 1x1 mm<sup>2</sup>, number of pixels is 1600. Open end of the fiber was covered by aluminized reflective paint Silvershine. Beam spot was localized by two small trigger counters of 3x3x10 mm<sup>3</sup> size. Two types of front-end electronics were used sequentially:  
- multi-channel boards developed on CITIROC ASICs for the Baby MIND spectrometer  
- 16-ch CAEN digitizer DT5742 with 5 GHz sampling rate and 12-bit resolution

### Prototype: array of 5x5x5 cubes

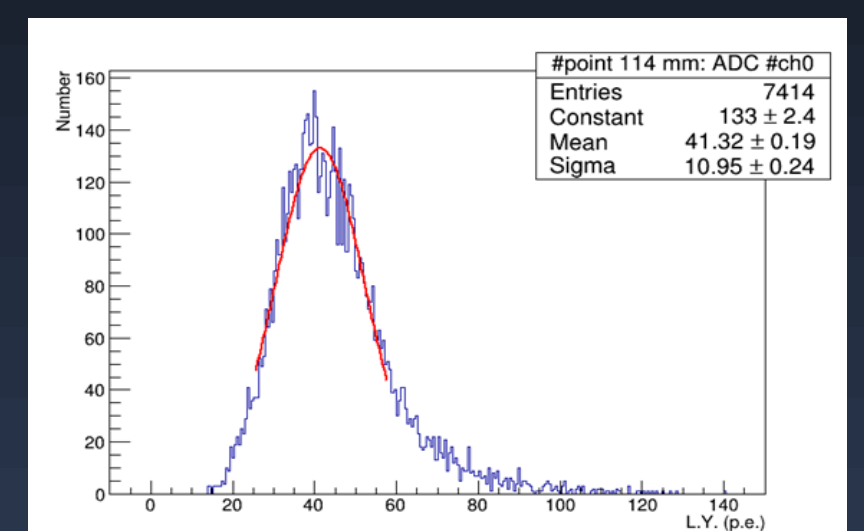


Scan over cube with a 3x3 mm<sup>2</sup> counter

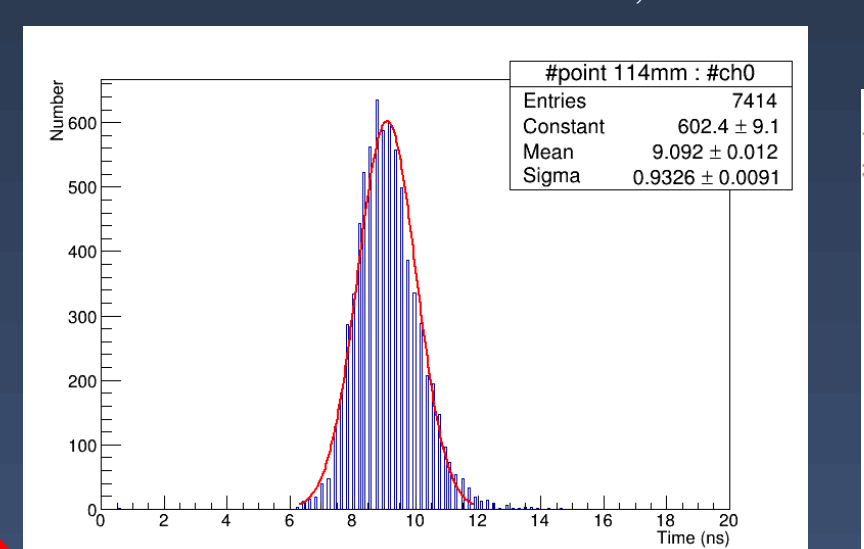


Y11 WLS fibers in X, Y directions

### MIP light yield from one cube and one fiber



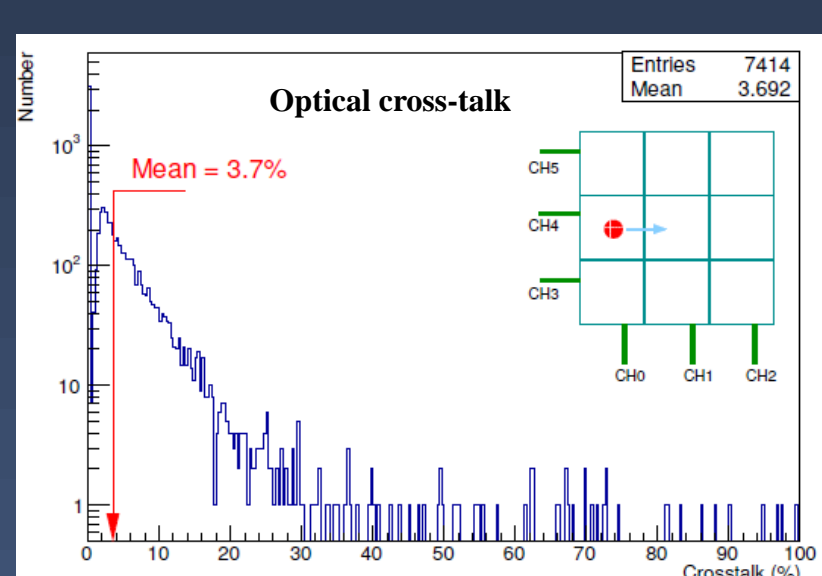
### MIP time resolution: one cube, one fiber



Beam scan with **step of 2 mm** was done across a few cubes in horizontal direction. Beam spot is limited by the trigger counters of 3x3 mm<sup>2</sup>.

- Light yield of 1 cube/1 fiber ~42 p.e./MIP
- Light yield of 1 cube/2 fibers ~80 p.e./MIP
- Time resolution ( $\sigma$ )

1 fiber:	0.92 ns
1 cube/2 fibers:	0.68 ns
2 cubes/4 fibers:	0.48 ns
3 cubes/6 fibers:	0.39 ns



Optical cross-talk between the cubes: mainly due to penetration of scintillating light through the chemical reflector. Average value is 3.7% (MPPC dark rate is included in the cross-talk value)

## Detector Technology

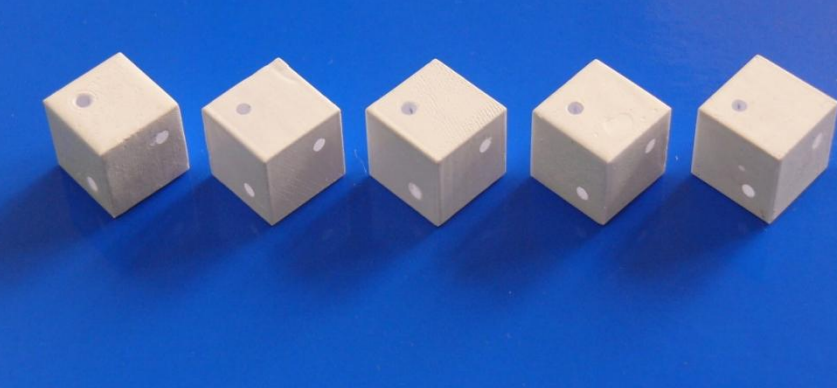
**Press-form with 4 chambers, 10x10x10 mm<sup>3</sup> each**



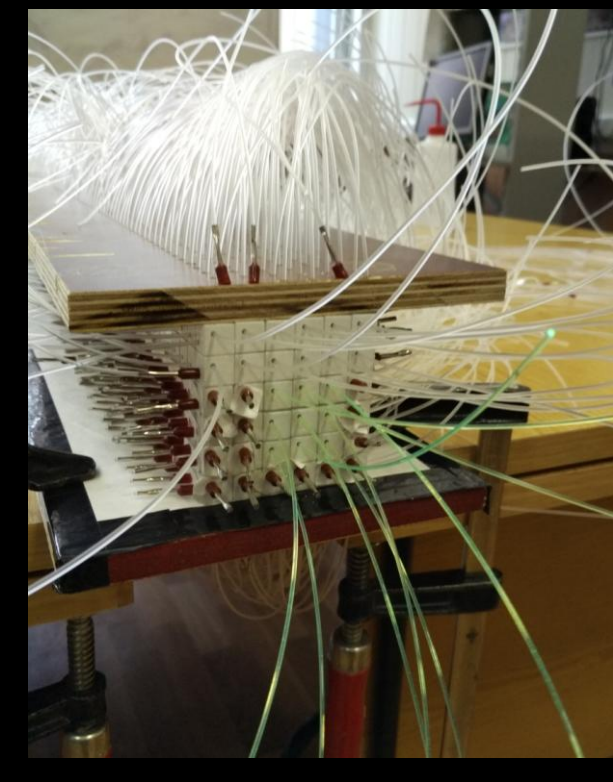
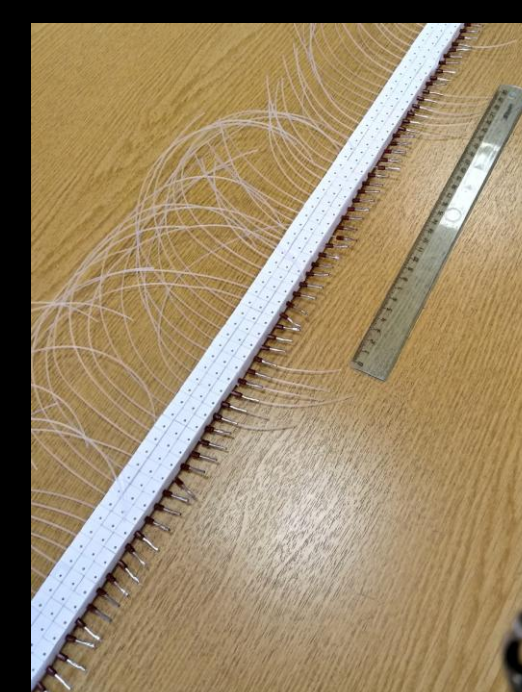
### Injection molding

**Scintillator Cubes:** made by injection molding from polystyrene with PTP+POPOP dopants covered by a chemical diffuse reflector (by etching the surface in a chemical solution) of ~50  $\mu$ m thickness at Uniplast, Vladimir, Russia. Cube size tolerance is  $\leq 35 \mu$ m. Three orthogonal holes of 1.5 mm diameter are drilled through each side.

### Scintillator cubes



## Assembly method: fishing lines



WLS fibers easily inserted in the detector after removal of 2 m long fishing lines

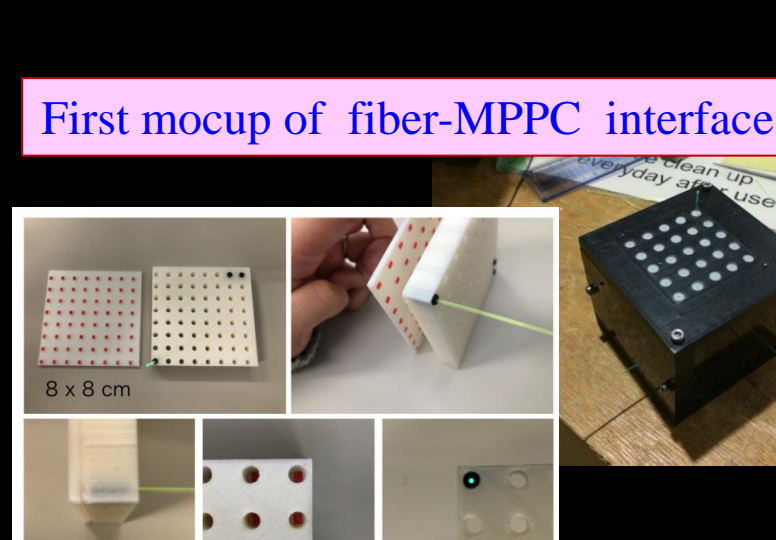
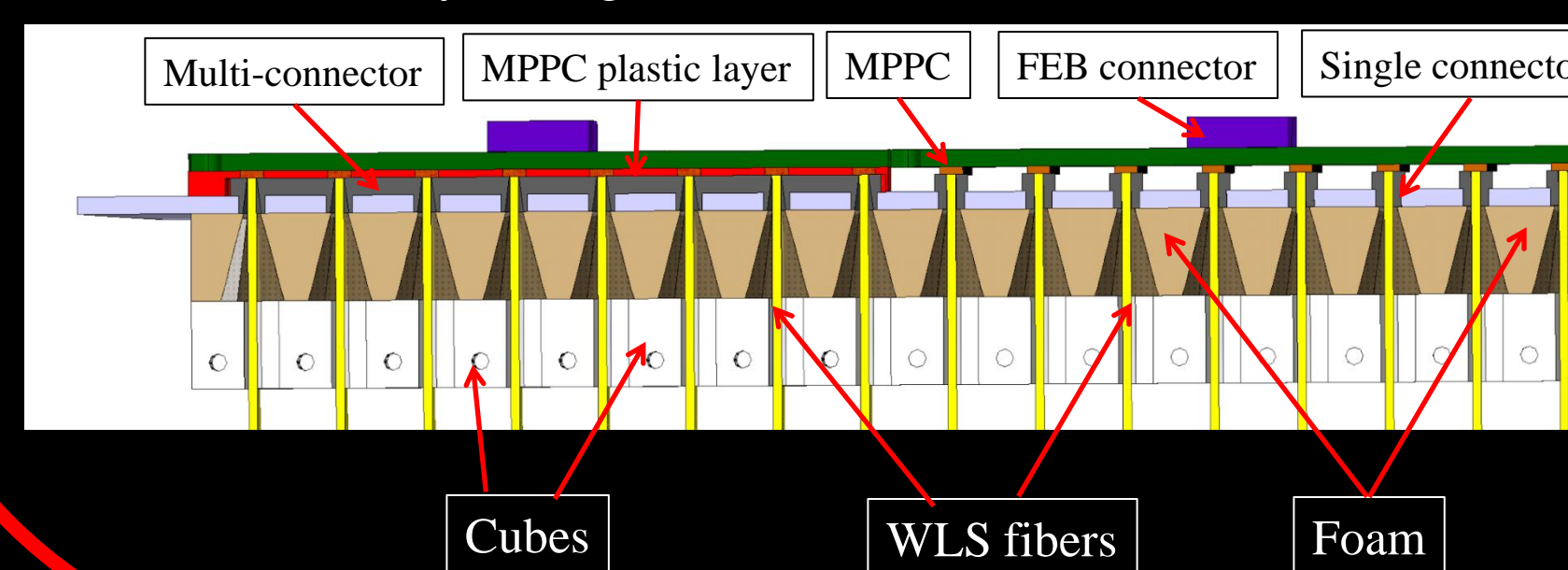
Insert fishing lines of 1.3 mm diameter

Making planes

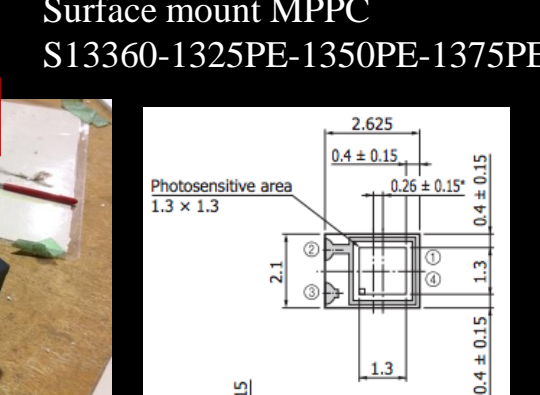
Assembly of long module

Replacement of fishing lines by 1 mm WLS fibers

### Preliminary design of Box-fiber-MPPC interface



First mockup of fiber-MPPC interface



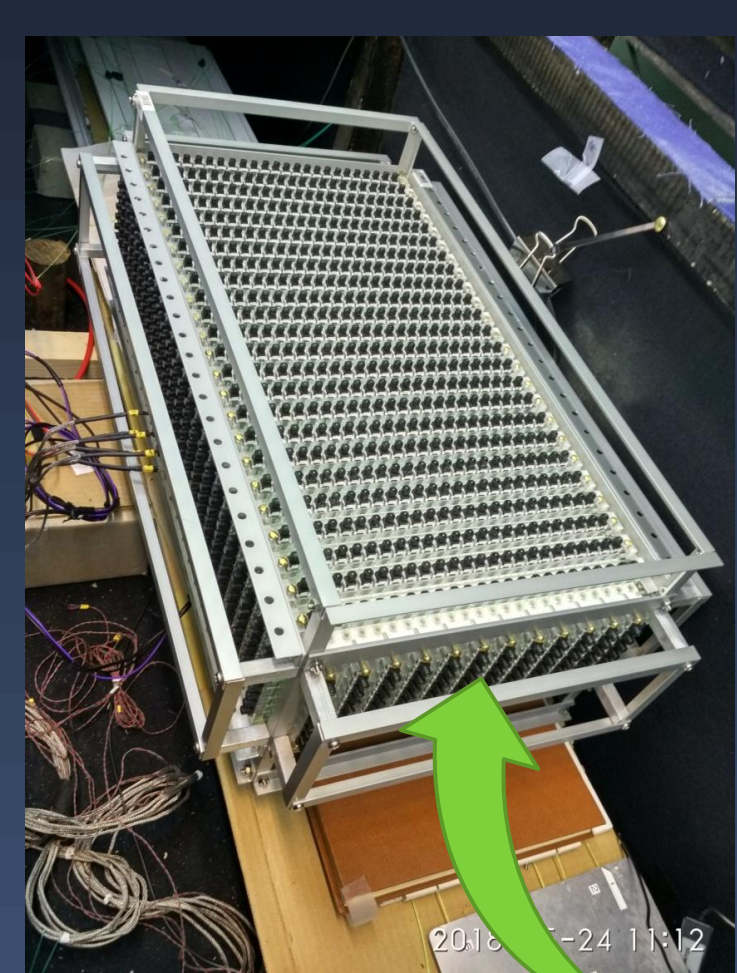
## Beam test at CERN

**T9 beam channel:**  
Electrons, muons, pions, protons  
Momentum ~0.5 – 3.0 GeV  
Beam of tagged photons is under consideration

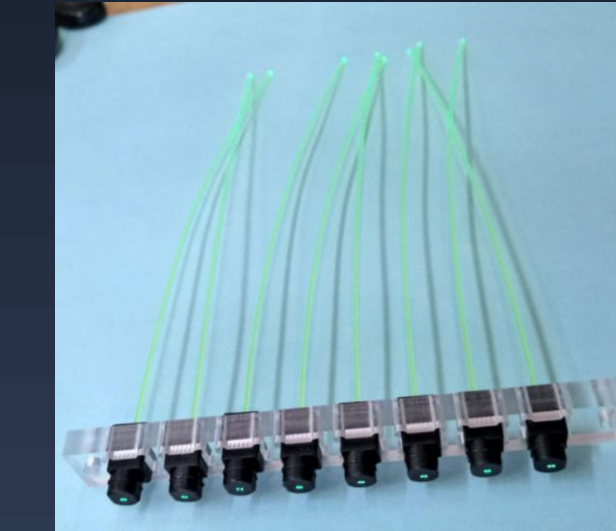
**Detector will be installed in the MNP17 magnet B ~0.2 T**



### Prototype of SuperFGD for beam test at CERN

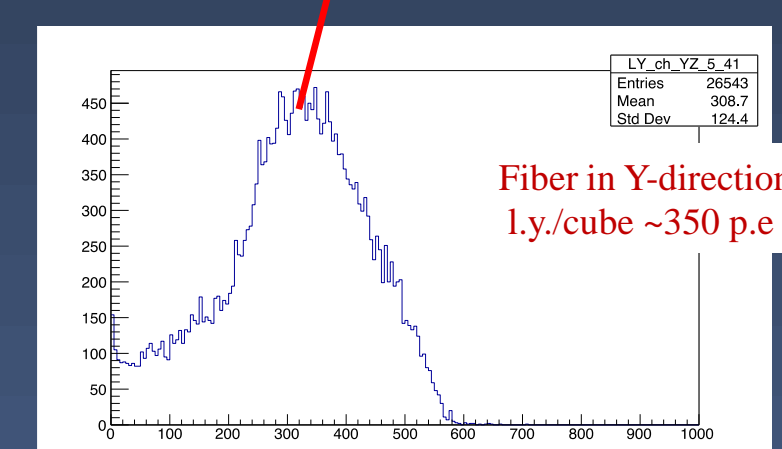
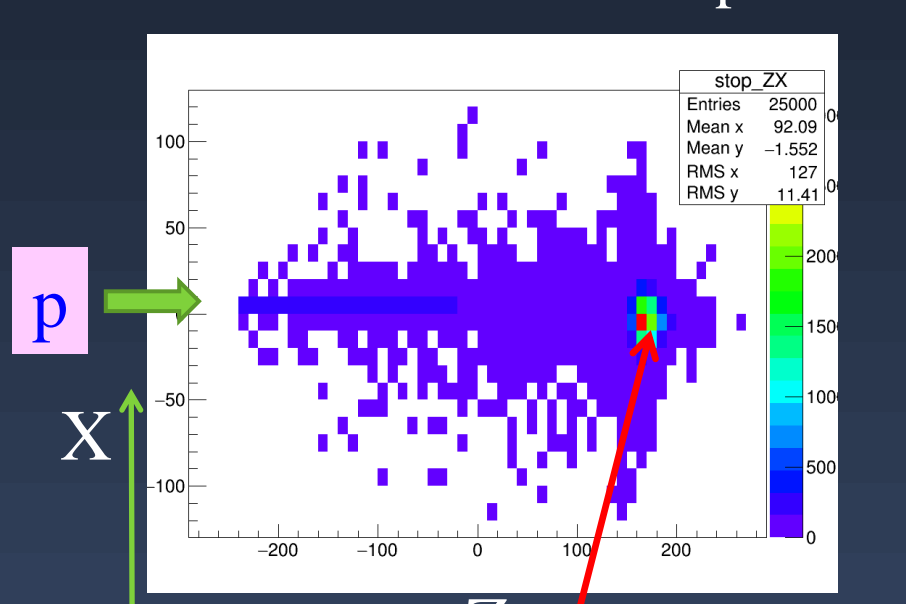


Y11 WLS fibers with optical connectors



Length 48 cm  
Width 24 cm  
Height 8 cm  
9216 cubes, each 1x1x1 cm<sup>3</sup>  
1728 Y11 WLS fibers, 1 mm diameter  
Readout: 1728 MPPC's  
S13360-1325CS, S13081-050CS, S12571-025C

### Simulation of 750 MeV/c protons



Energy deposit in the proton stopping point (one cube) per one fiber  
1.y./cube/fiber of 1 GeV muon is expected to be about 50 p.e.

## References

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