5th International Workshop on New Photon-Detectors (PD18)

Application of MPPC for T2K near detector upgrade

27 November 2018

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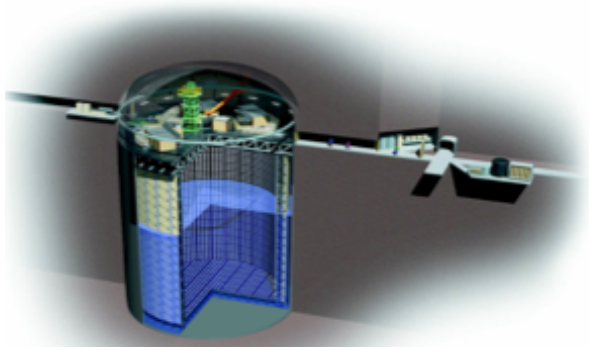
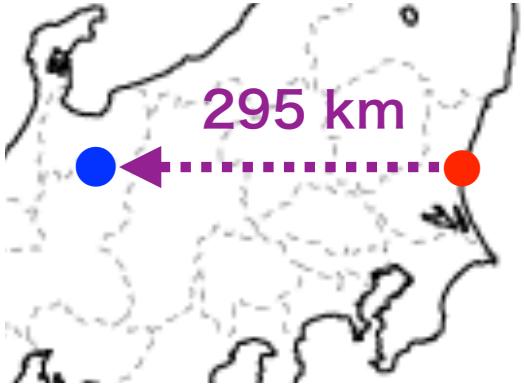
for the T2K ND280 upgrade group

T2K experiment

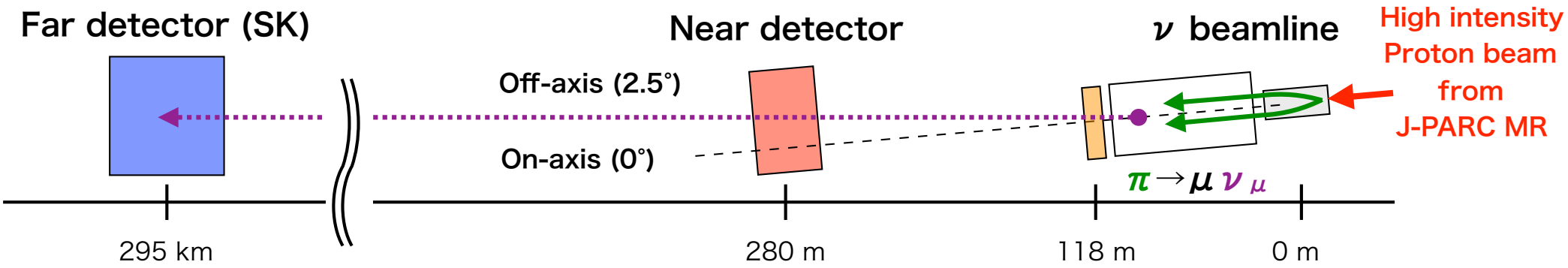
A Long baseline neutrino oscillation experiment

Super-K @ Kamioka





J-PARC @ Tokai



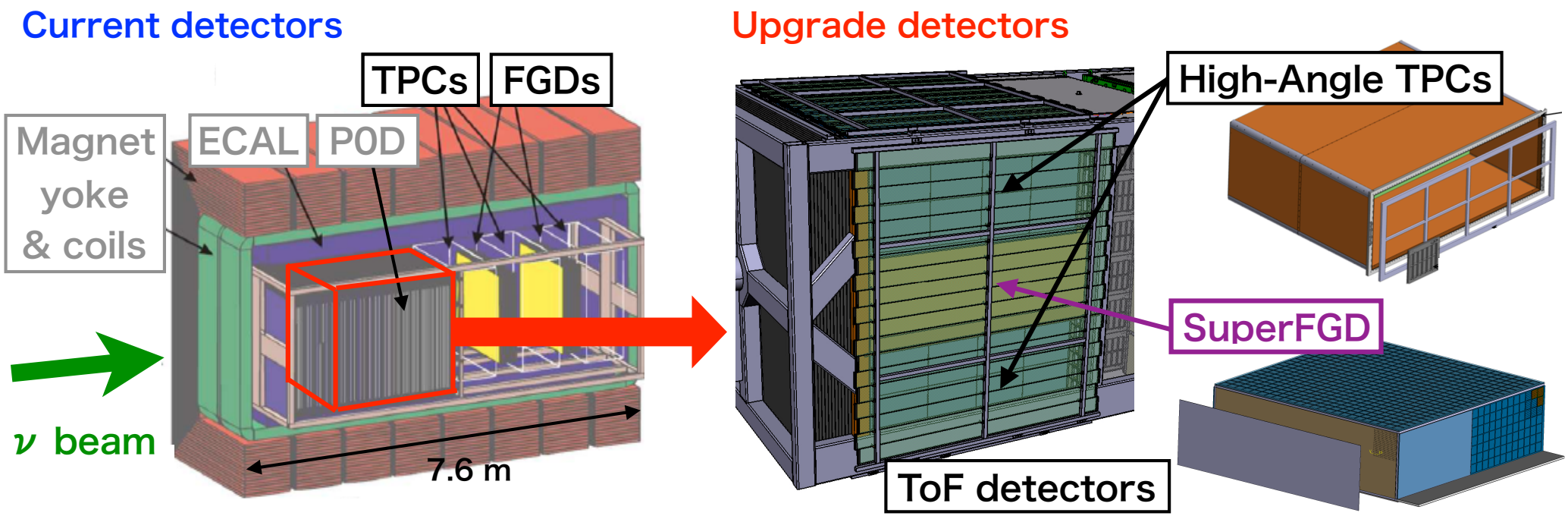
- First indication of ν_e appearance with 2.5 σ significance in 2011, followed by definitive observation with 7.5 σ significance in 2013
- World-leading measurement of oscillation parameters ($\sin^2\theta_{23}$, Δm^2_{32})
- A hint of CP violation in neutrinos with 2.0 σ significance in 2017

→ Plan to upgrade the beam intensity & the near detector until 2021

T2K near detector & its upgrade

ND280 is to suppress systematic error on ν flux + cross section

- Dominant error in a precision measurement after the beamline upgrade
- Current ND280 is not optimized for high angle tracks (unlike 4π acceptance in SK)



New scintillator detector (SuperFGD), 2 High-Angle TPCs, ToF detectors are to replace the P0D, keeping downstream detectors

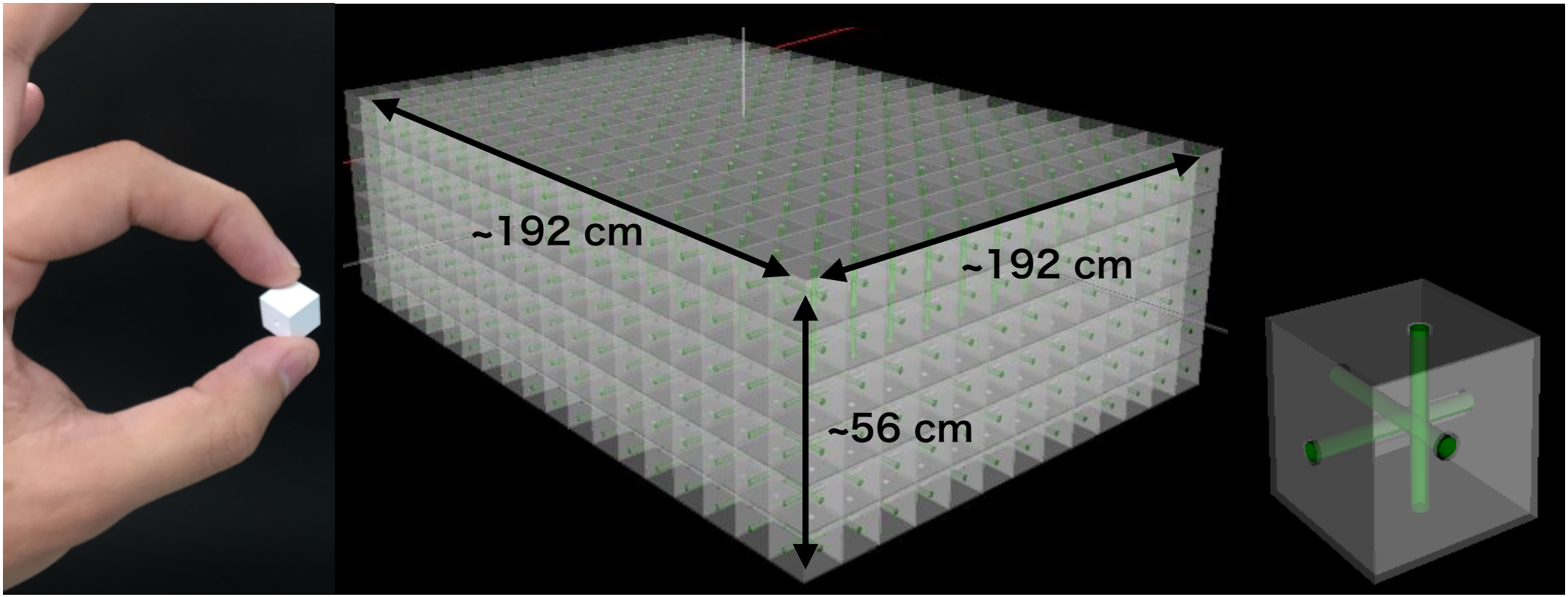
→ Larger acceptance by the new layout

→ Further improvements in SuperFGD (in which many MPPCs are newly equipped)

SuperFGD

A novel plastic scintillator detector with new structure

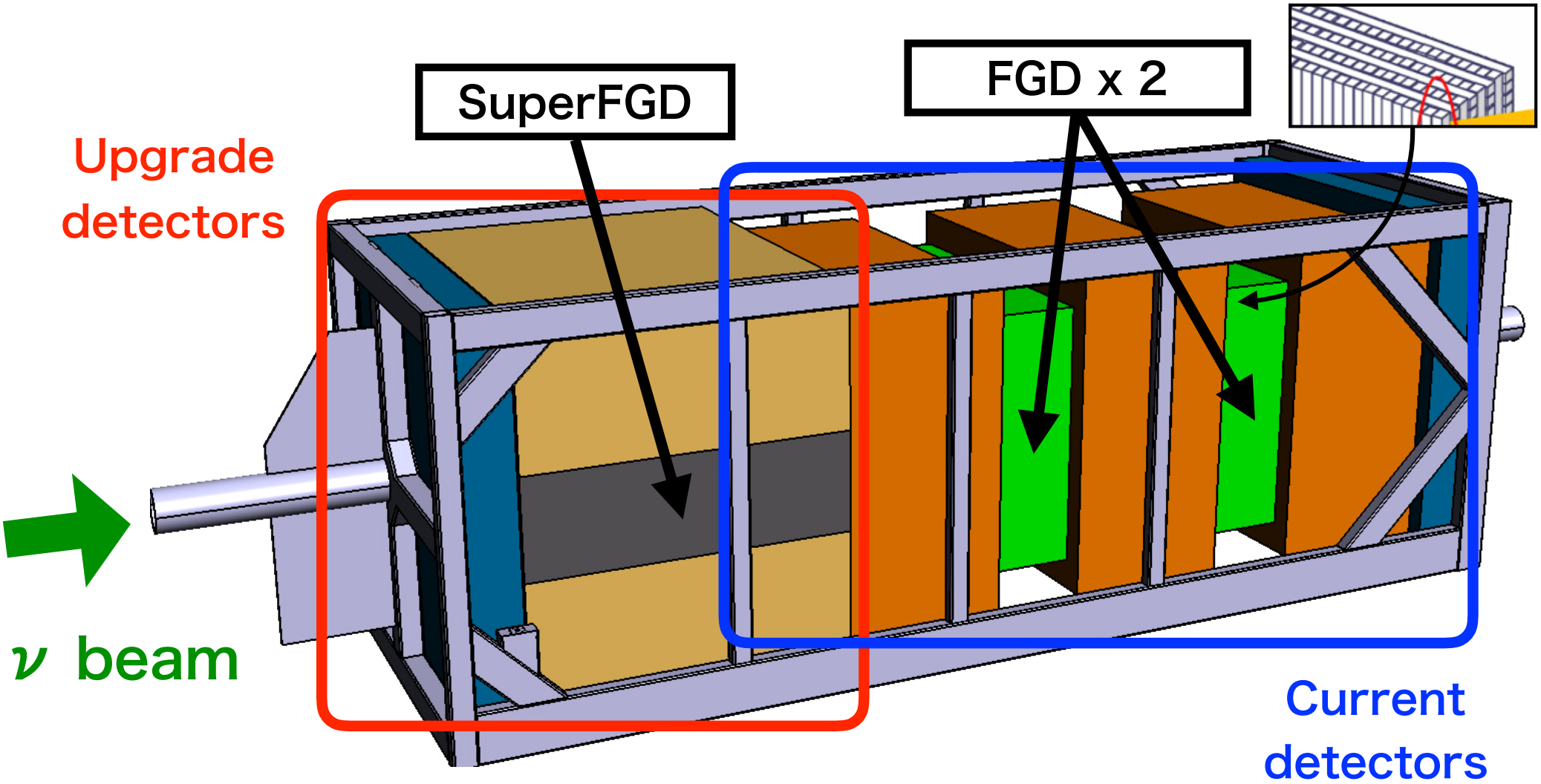
- Proposed in 2017 for the T2K near detector upgrade [JINST 13 (2018) P02006]



- Optically independent ~2,000,000 scintillator cubes (1 cm^3) w/ 3 holes
- Three orthogonal projections with ~60,000 MPPCs via WLS fibers

→ Large active target (~2 t), Fine granularity, 4π acceptance

Challenges for MPPC & its interface

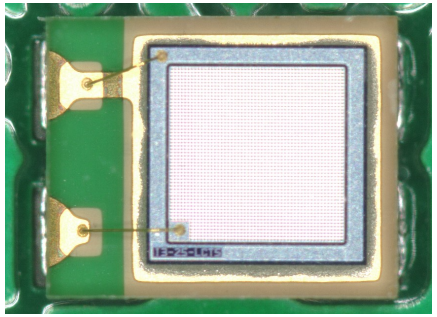


- Current FGD (bar array) has enough space for MPPC & its interface
- On the other hand, SuperFGD has 3 readout view, neighboring to other detectors and electronics → Compact design & less materials are required

Surface-mount MPPC

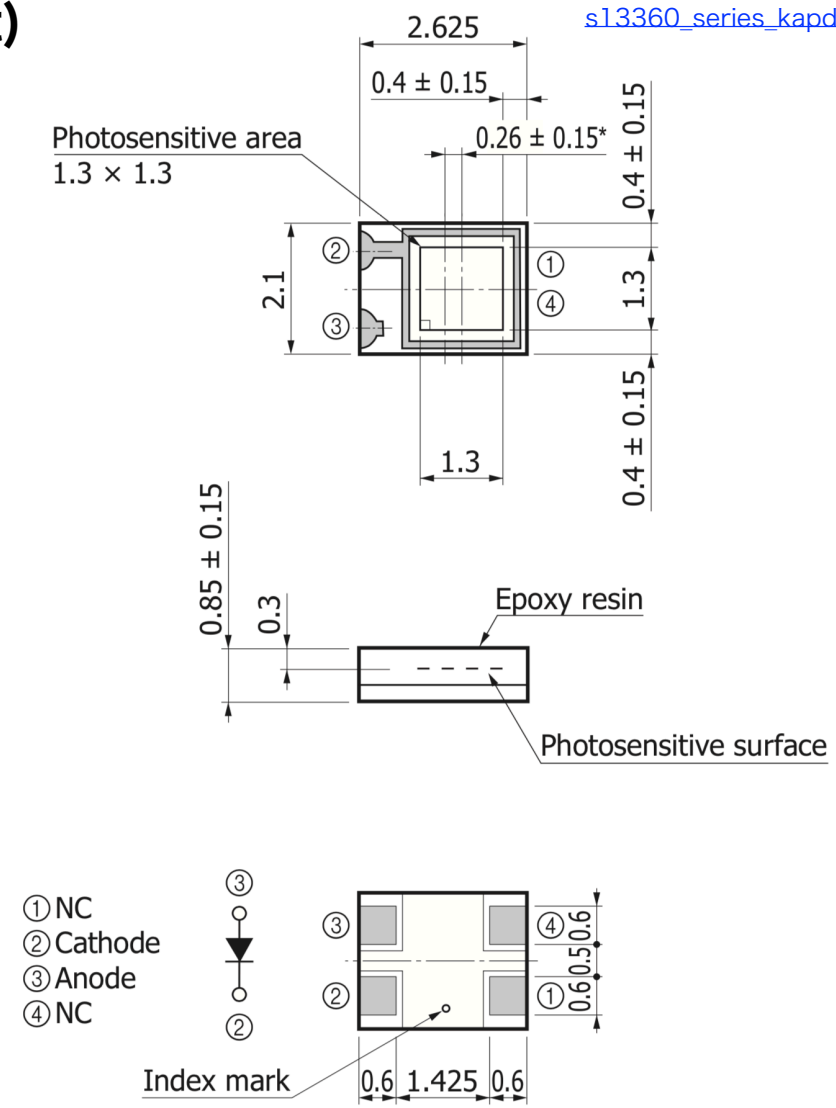
https://www.hamamatsu.com/resources/pdf/ssd/s13360_series_kapd1052e.pdf

S13360-1325PE (Commercial product)



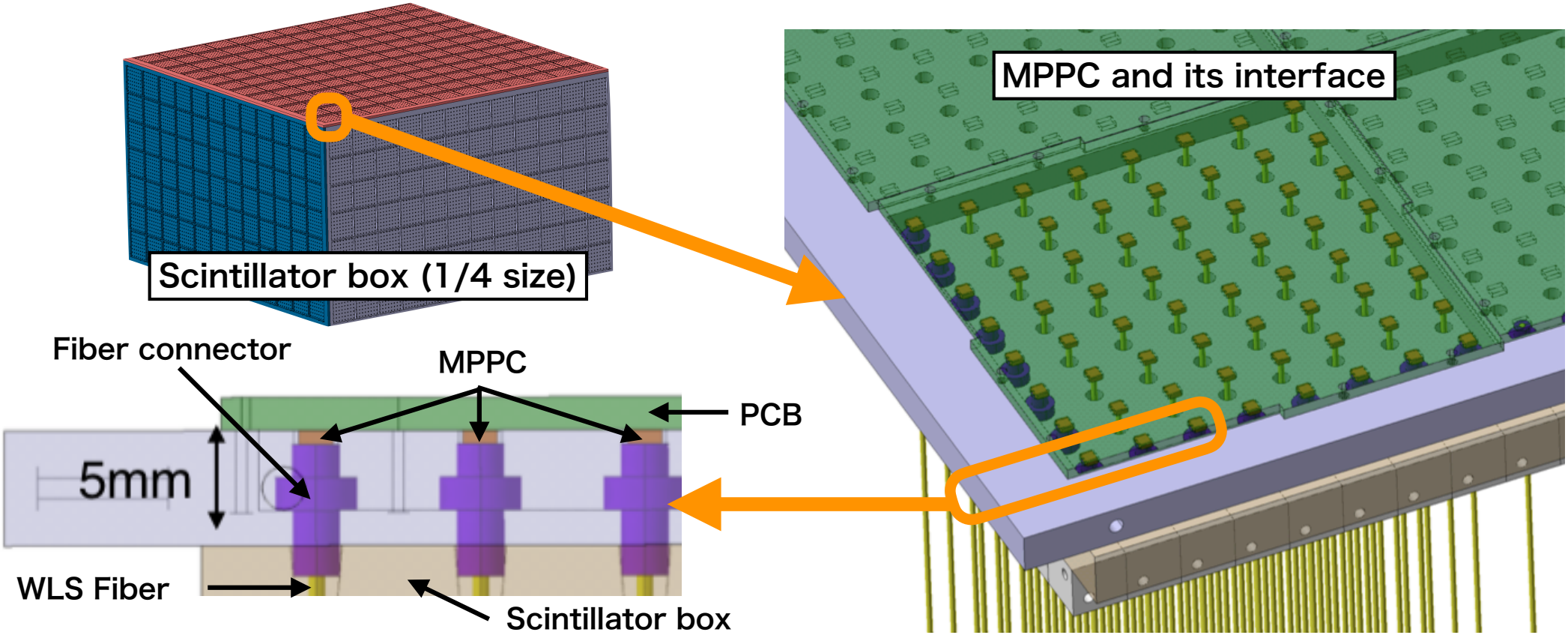
Item	Specification
Effective photosensitive area	1.3 mm x 1.3 mm
Pixel pitch	25 μm
Number of pixels	2668 pixels
Fill factor	47%
Package type	Surface mount
Breakdown voltage (V_{BR})	53 ± 5 V
Peak sensitivity wavelength	450 nm
Photo detection efficiency	25%
Gain	7.0 x 10^5
Dark count	70 kcps (typ.)
Crosstalk probability	1%

at V_{BR}+5 V & 25℃



- Compact package with less materials, matching diameter of WLS fiber
- Enough gain, high dynamic range, less dark count & less cross-talk

Design of optical interface

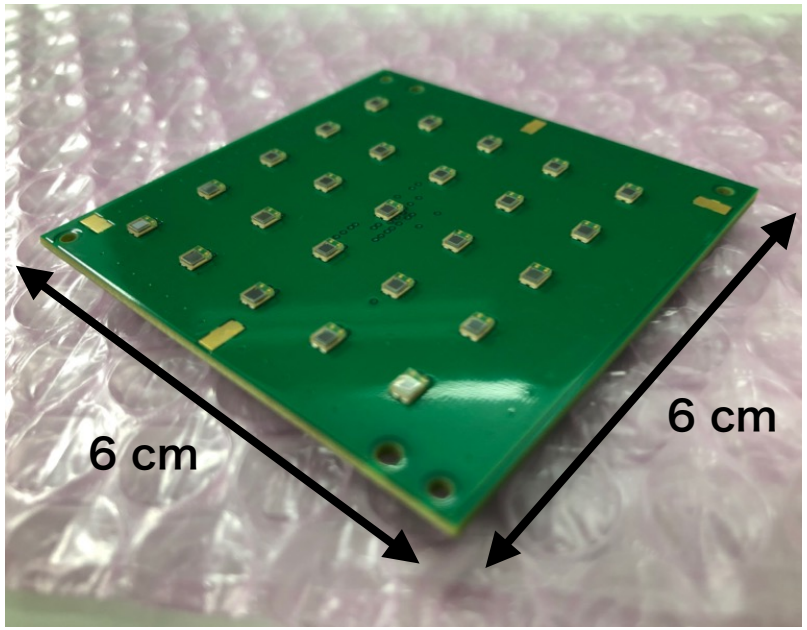


- WLS fibers (1.0 mm diameter) are glued and polished with fiber connectors and individually inserted to holes on the box surface
- MPPCs (1.3 mm x 1.3 mm) are precisely mounted on PCB with 1 cm pitch and MPPC-PCB (8x8 or 8x16) is fixed on box to contact with fiber-end

→ Need mechanical accuracy to provide uniform light collection

Prototype of MPPC-PCB

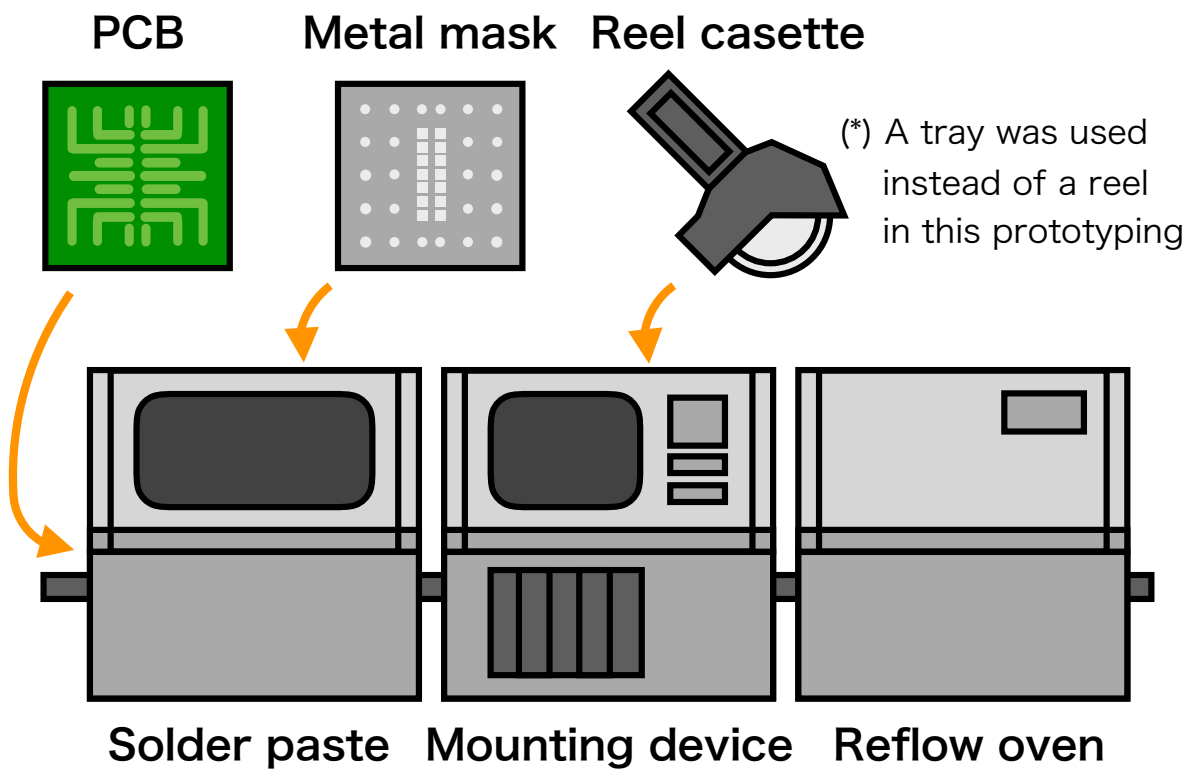
Prototype of 5x5 MPPC array



PCB

- 4 layers (1.6 mm thickness)
- Signal and bias lines are printed
- Surface-mount connector is mounted in a back face
- Holes for screw & alignment are also prepared

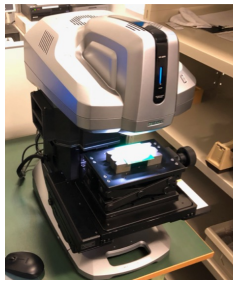
Manufacturing steps



1. Solder is pasted on the PCB with a metal mask and a dedicated device
2. MPPCs are mounted with good accuracy

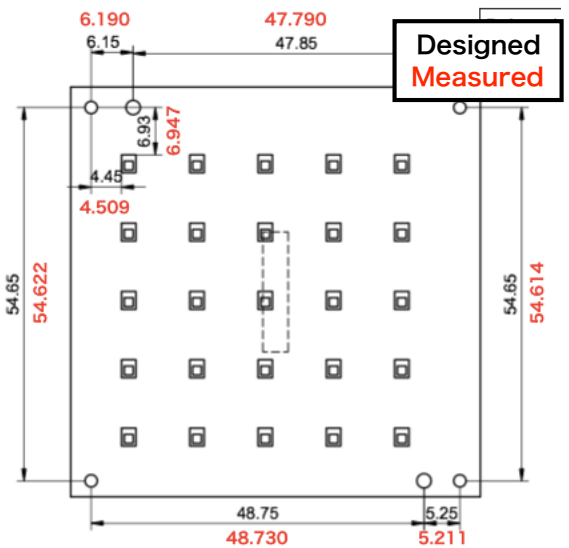
   (*) 50 μm precision by laser and image recognitions
3. Solder paste is cured by a reflow oven

Test of mechanical accuracy

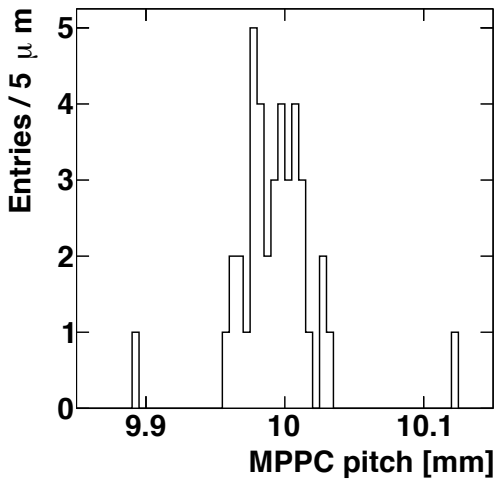


- 3D measurement device (KEYENCE VR-3000 series) was used, configuring the device to provide 5 μm precision

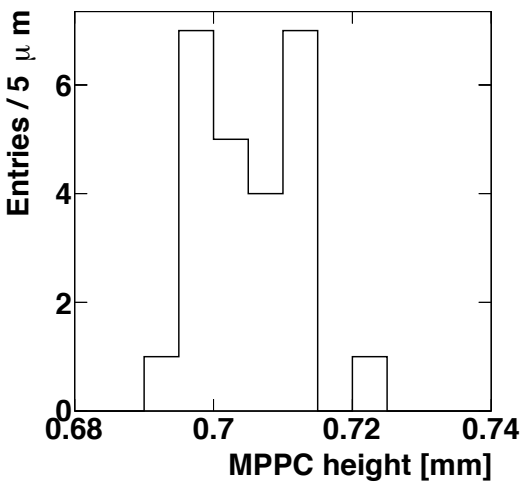
Dimension of the PCB



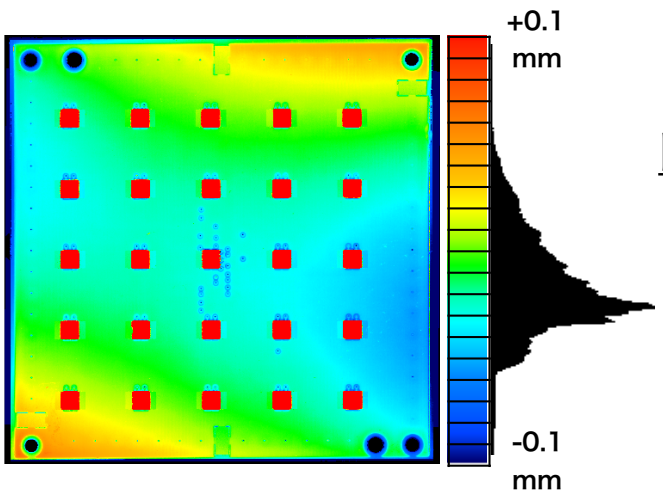
Pitch b/w MPPCs



Height of the MPPCs



Flatness of the PCB



Result of the measurement

Dimension of the PCB
… < ±60 μm accuracy
Pitch b/w MPPCs
… Mean: 9993.6 μm
… RMS: 31.3 μm

} Horizontal direction

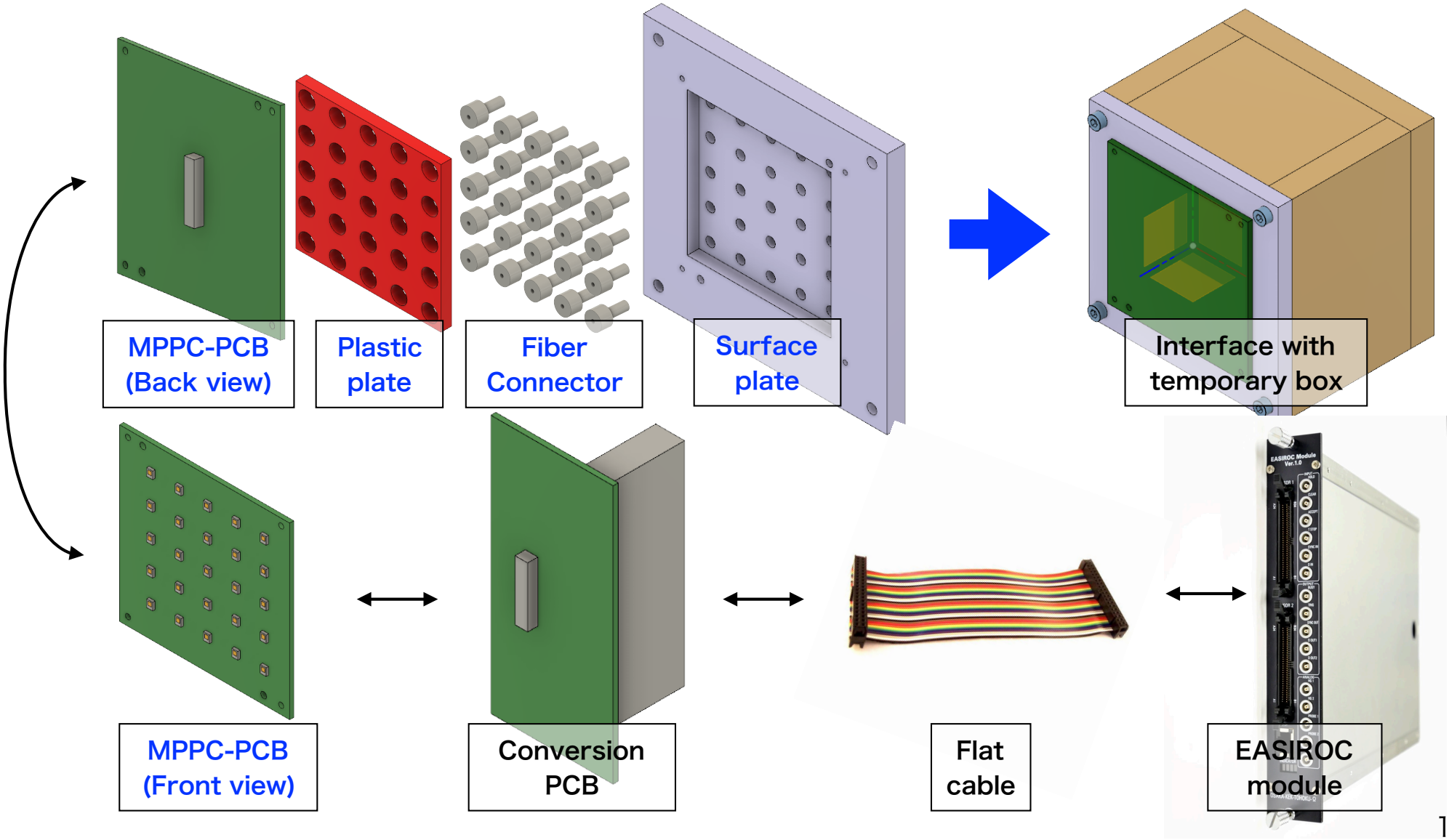
Height of MPPCs
(*) Excluding deformation effect
… Mean: 0.705 μm
… RMS: 7.3 μm
Flatness of the PCB
… < ±50 μm accuracy

} Vertical direction

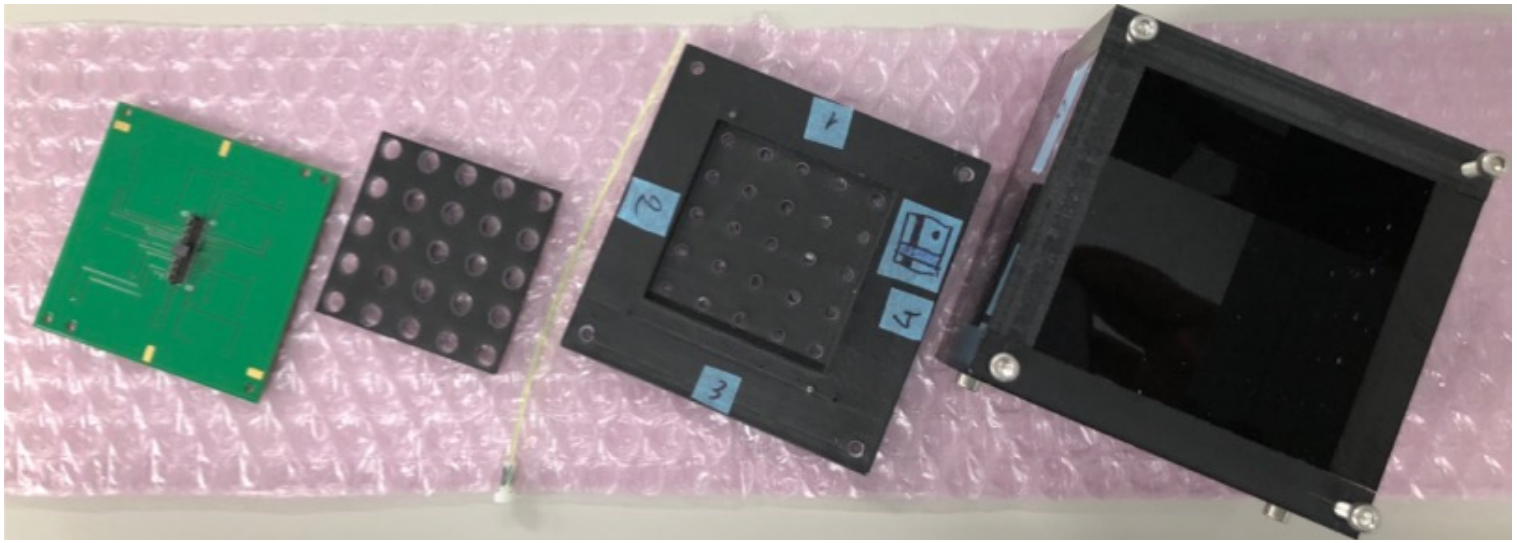
→ No critical problem in mechanical specifications

Prototype of MPPC optical interface

First prototype of 1D interface was designed to validate optical & electric specifications, to be connected with available electronics

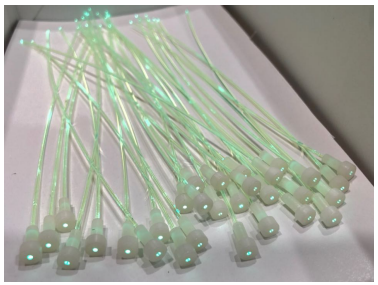


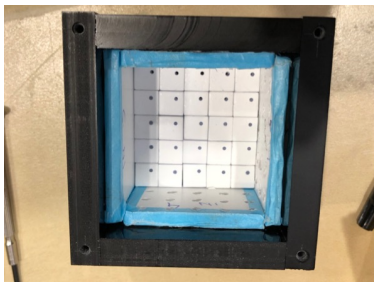
Assembly of the MPPC optical interface

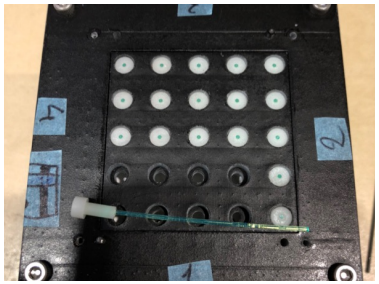


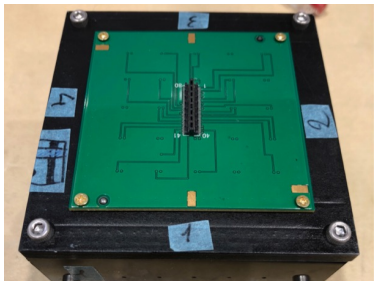
Prototype of the optical interface was assembled w/ scintillator cubes

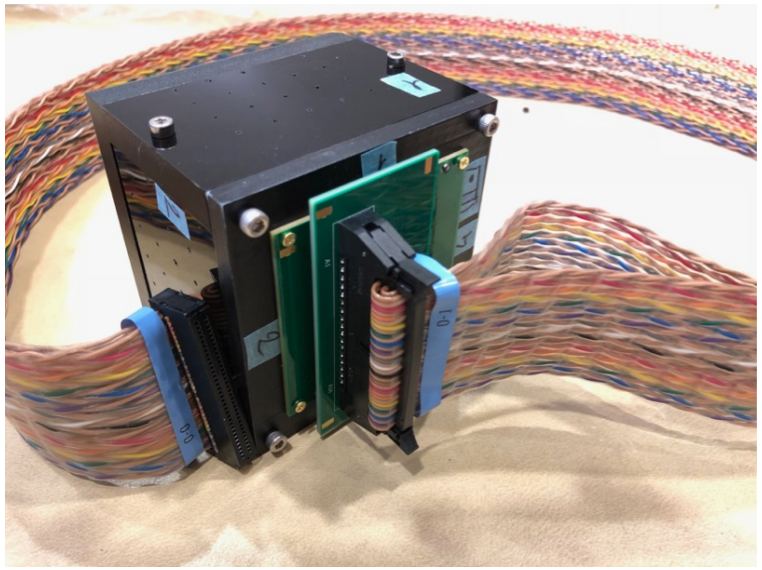
Gain & observed PE for 25 MPPCs were then measured using comic rays





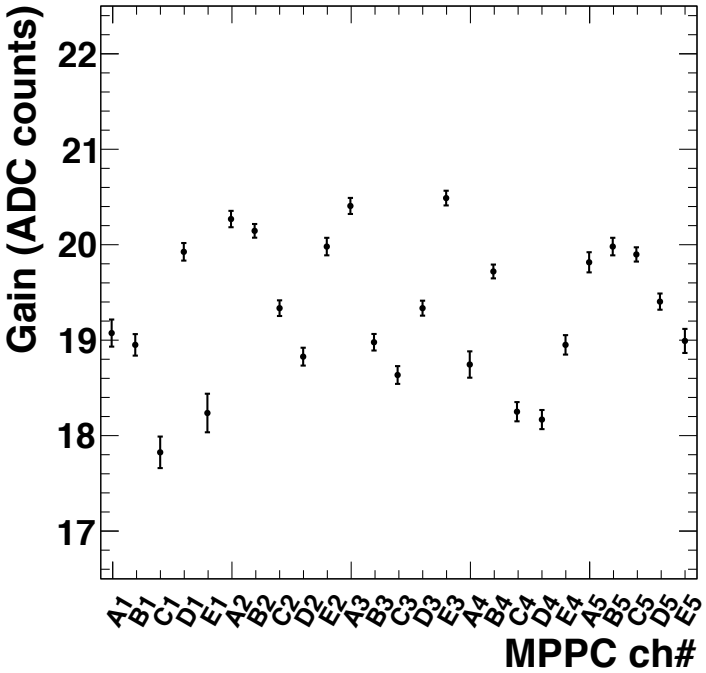


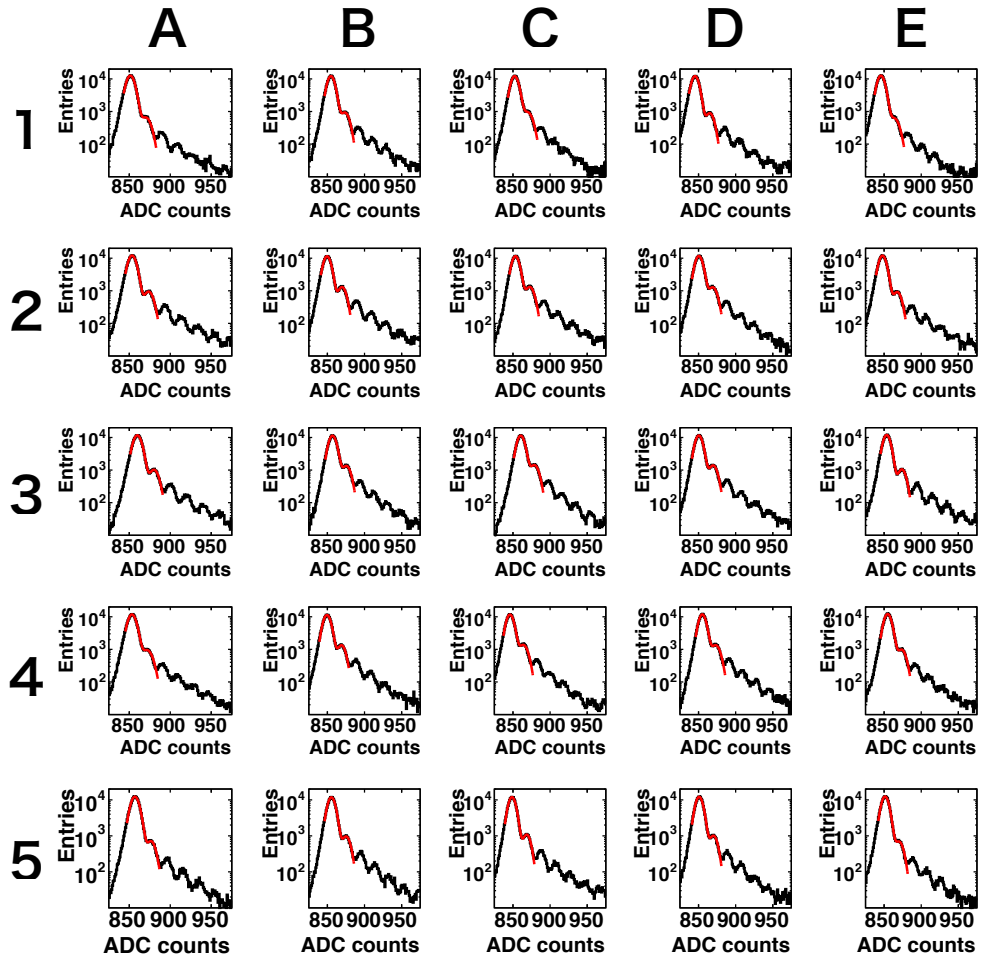




Test results

- Calculated gain from 0 and 1 PE by fitting the Double Gaussian



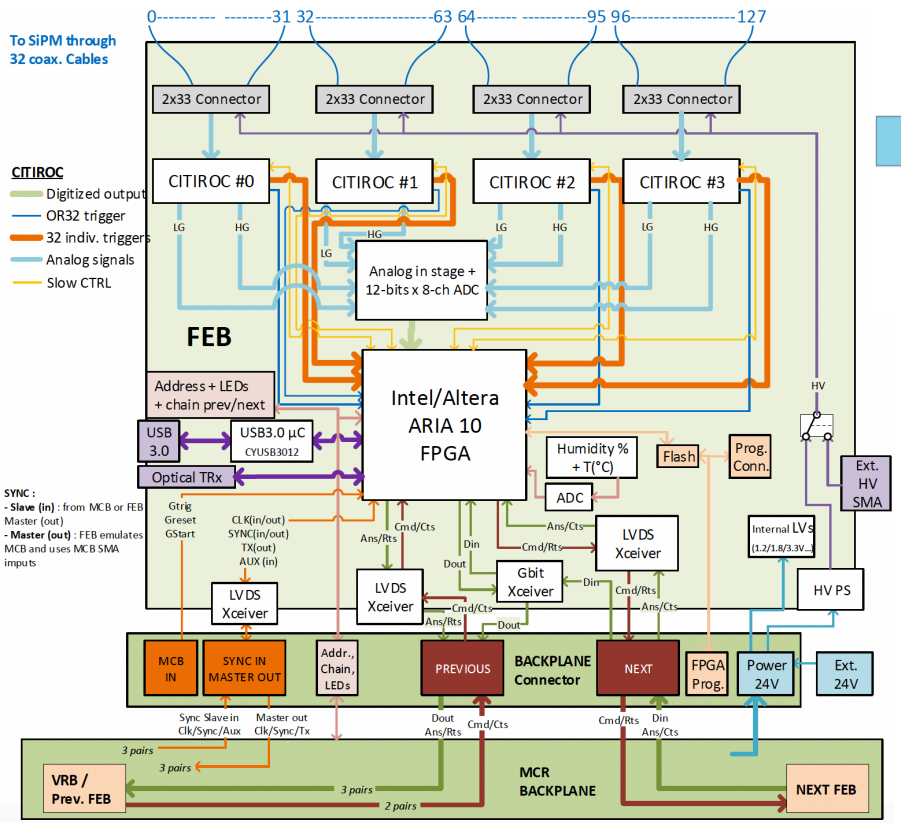


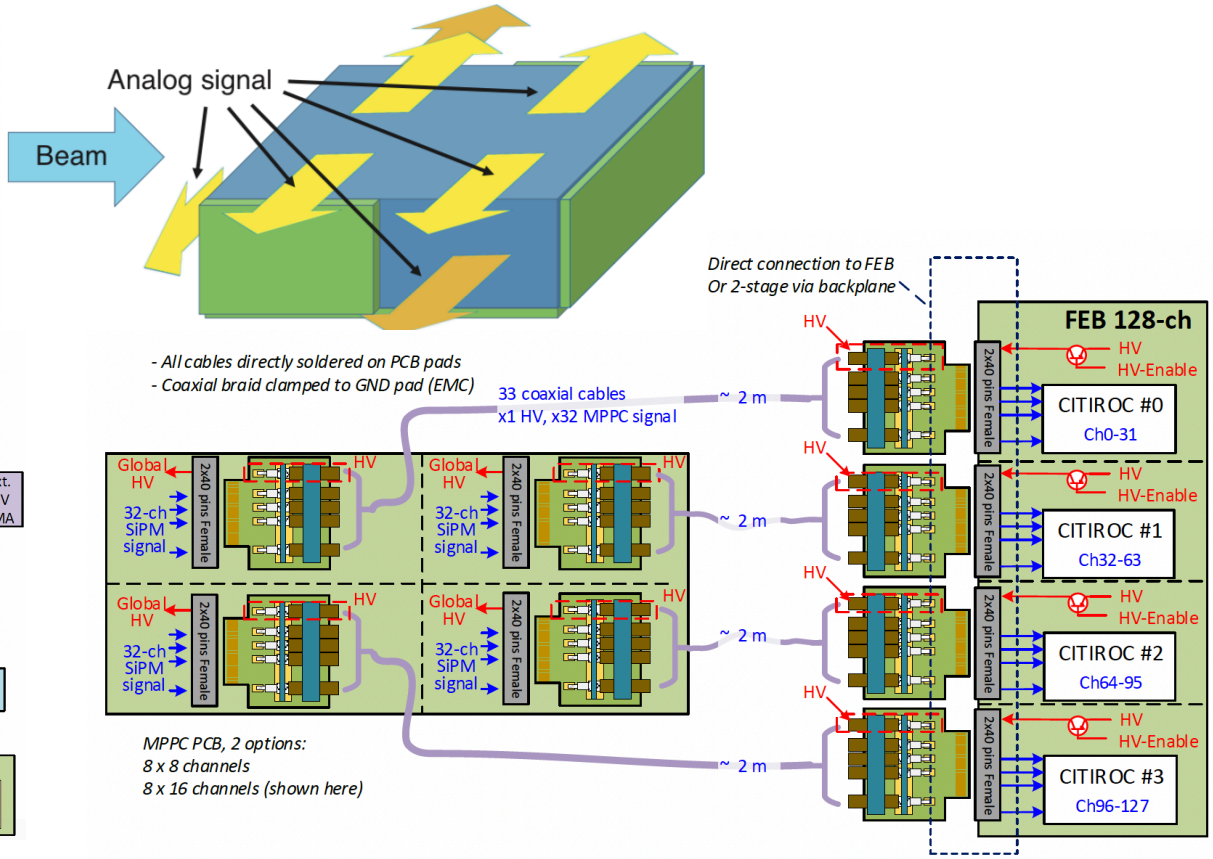
- Photon counting capability for all MPPC channels
- Less ch-to-ch variation of gain (RMS/Mean = ~4%)
- Small variation of observed PE at MIP peak (RMS/Mean = ~7.3%)
- No optical cross-talk between MPPCs

→ Confirmed no problem in electrical & optical specifications

Electronics

- The electronics will be a customized system based on CITIROC readout system used in the BabyMIND detector (Currently operative in the ND site at J-PARC)
  - 4 CITIROC chips on board (32 x 4 MPPC channels, Low/high gain, Charge)
  - FPGA at 400 MHz (Time Stamp, Time-over-Threshold)



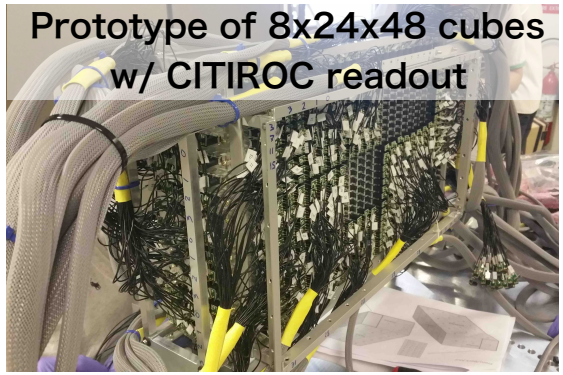


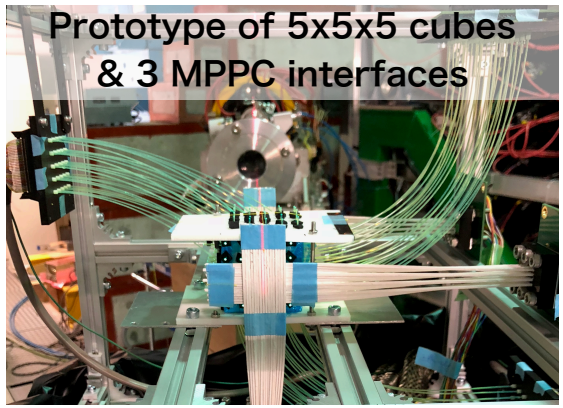
- FEBs are placed on left/right side of SuperFGD
- Analogue signal from MPPCs to FEB via micro-coaxial cables

Status & Prospects (related w/ SuperFGD)

2018

- CDR submitted to J-PARC/PAC & CERN/SPSC in January
- Beam tests of SuperFGD prototype
  - 8x24x48 cubes & BabyMIND electronics at CERN T9 (June 27 - July 11)
  - 5x5x5 cubes & 3 MPPC interfaces in Nov. at ELPH, Tohoku (Nov. 13-15)
- TDR submitted to J-PARC/PAC in November


Prototype of 8x24x48 cubes w/ CITIROC readout


Prototype of 5x5x5 cubes & 3 MPPC interfaces

2019-2020

- Further R&D to finalize detector design
- Production/integration of detector components (e.g. Ship complete for all MPPCs by early 2020)

2021

- SuperFGD will be ready for installation in mid-2021
- Install the upgrade detector & start commissioning

Plan to implement ND280 upgrade timely with the beamline upgrade

Summary

- We plan to equip ~60,000 MPPCs to build novel plastic scintillator detector, called SuperFGD, for T2K near detector upgrade

- Surface-mount MPPC is a perfect device for this purpose to provide very compact design & less material budget

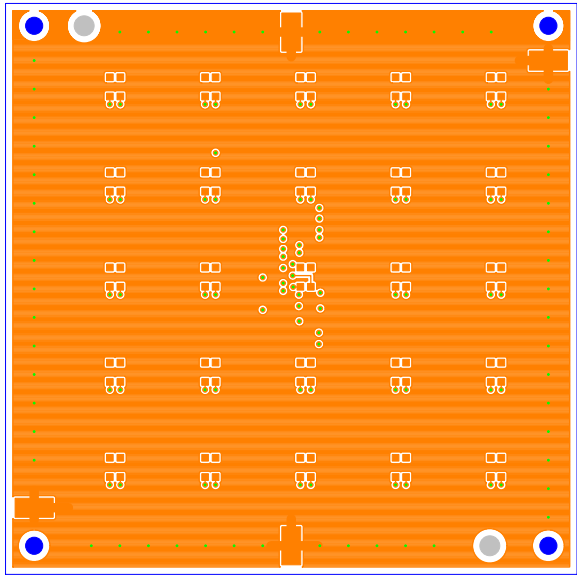
- We developed MPPC-PCB & optical interface and then validated mechanical, electrical and optical specifications

- We will finalize R&D and proceed production/integration toward full detector in order to install the upgrade detector in 2021

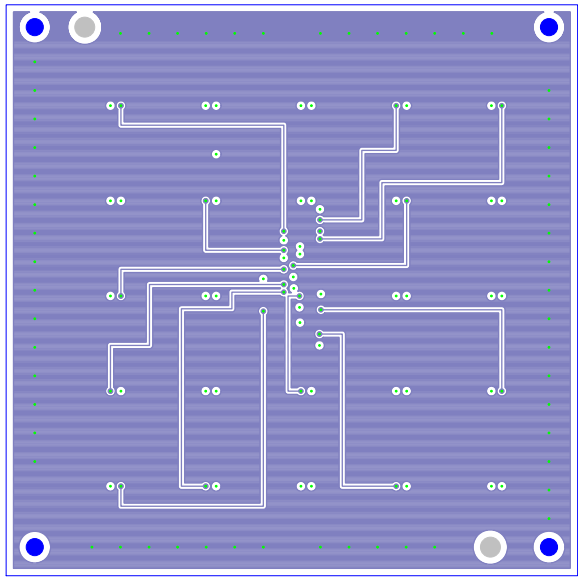
Backup

Designs & devices for MPPC-PCB prototype

Front layer

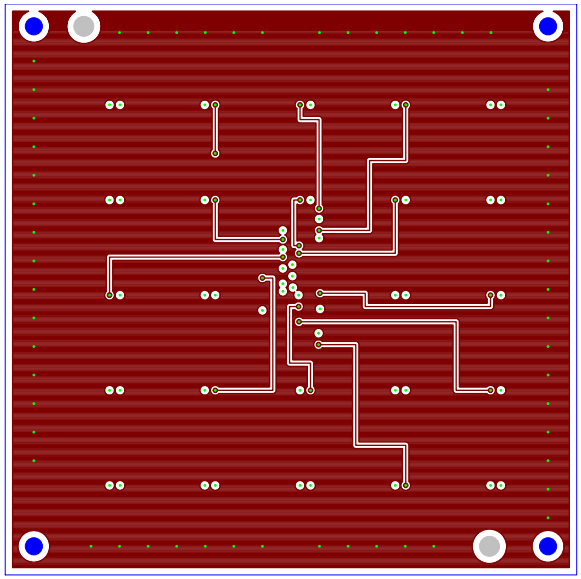


2nd layer

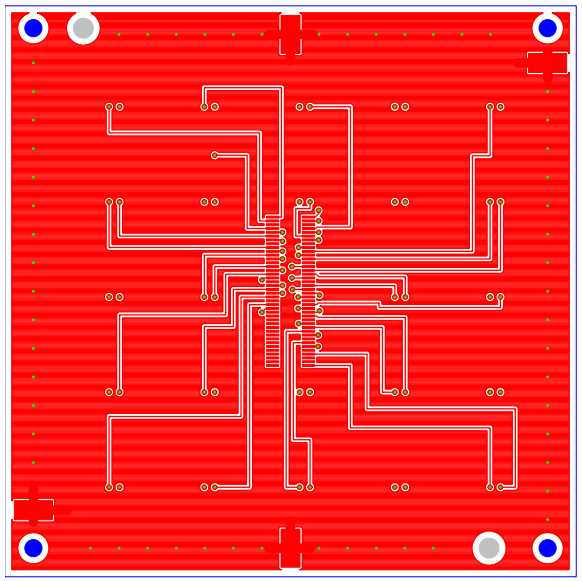


Chip mounting device
(JUKI KE-2060M)

3rd layer



Back layer



Reflow oven
(ANTOM SOLSYS-6310IR)

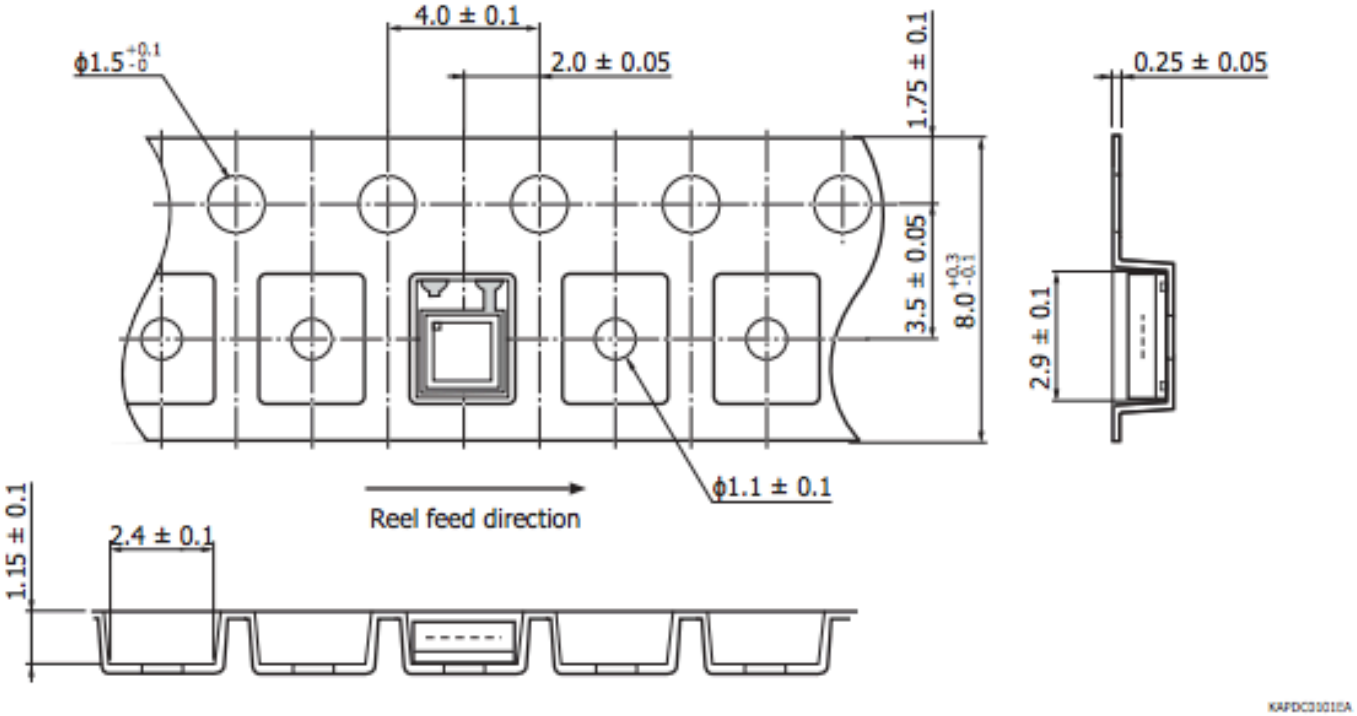
Reel packing

Standard packing specifications (S13720-1325PS)

■ Reel (conforms to JEITA ET-7200)

Dimensions	Hub diameter	Tape width	Material	Electrostatic characteristics
180 mm	60 mm	8 mm	PS	Conductive

■ Embossed tape (unit: mm, material: PS, conductive)



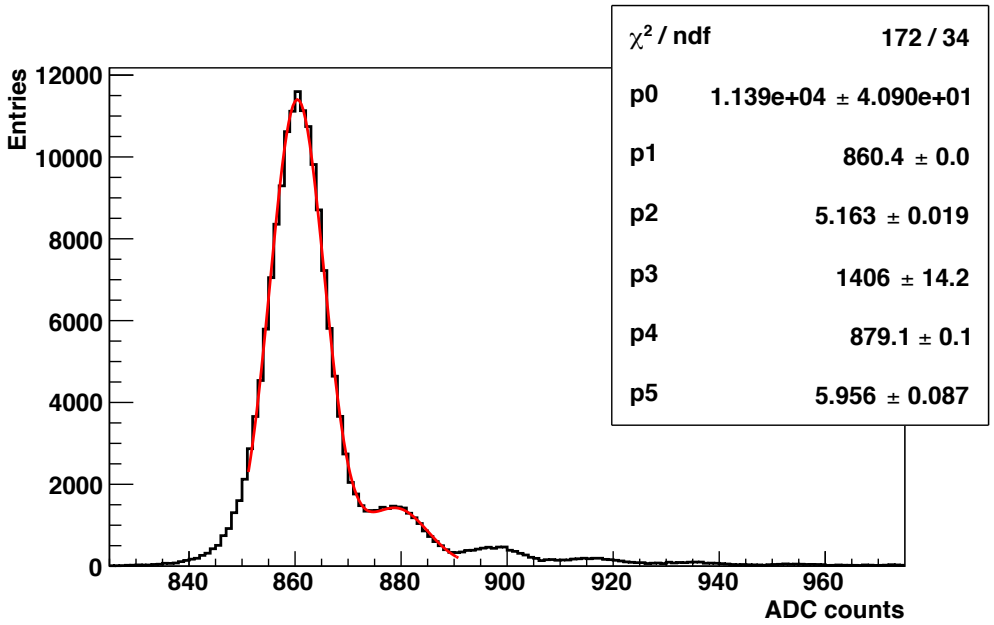
■ Packing quantity
1000 pcs/reel

■ Packing type
Reel and desiccant in moisture-proof packaging (vacuum-sealed)

https://www.hamamatsu.com/resources/pdf/ssd/s13720_series_kapd1060e.pdf

Gain calibration & photon counting capability

Test with scintillation light + EASIROC module



Test with LED + CITIROC module