T2K Near Detector Upgrade: Super Fine-Grained Detector

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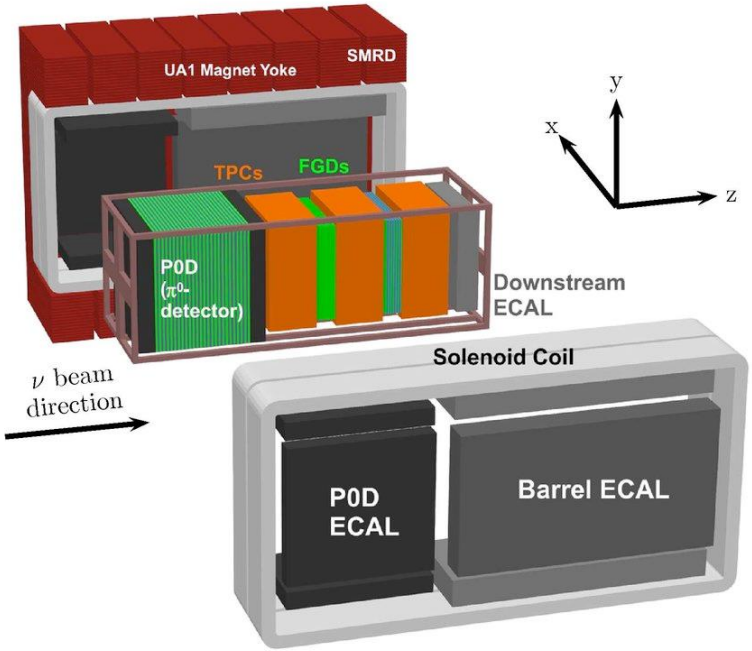
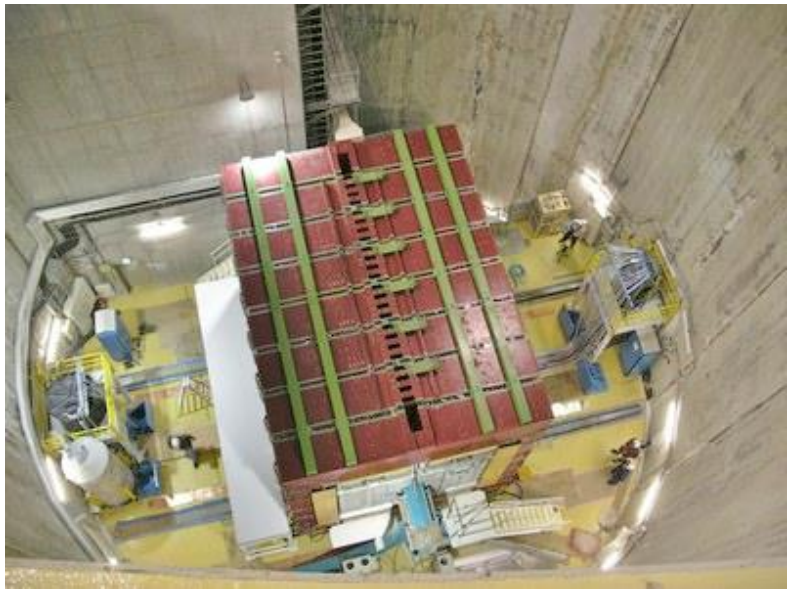
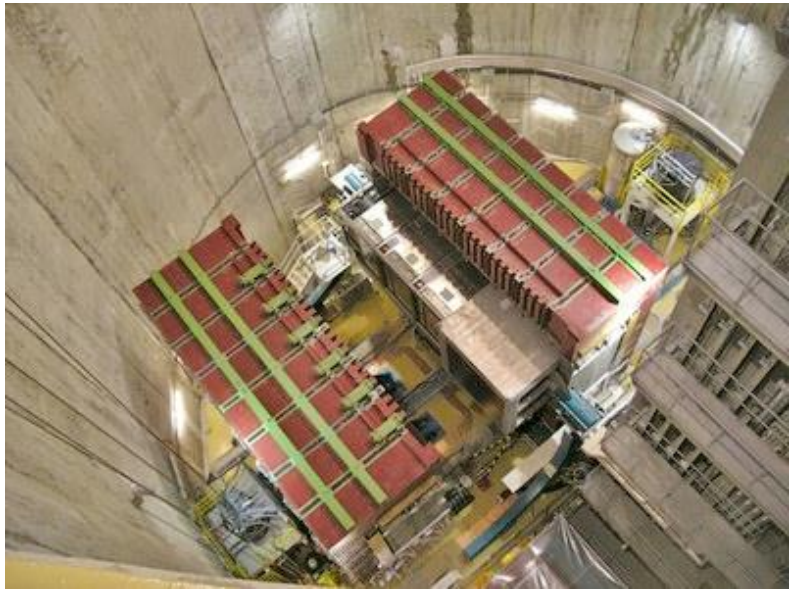
University of Pennsylvania
5 August 2022

T2K Experiment and Near Detector

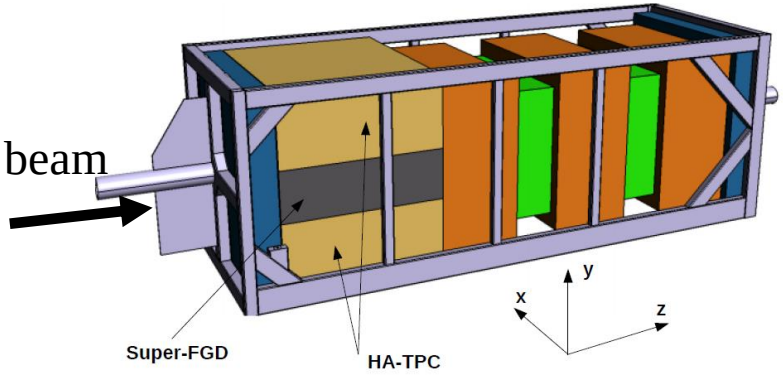


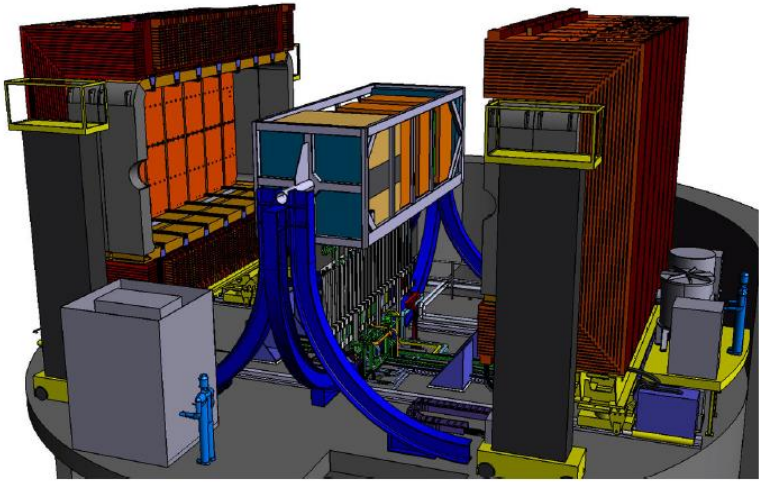


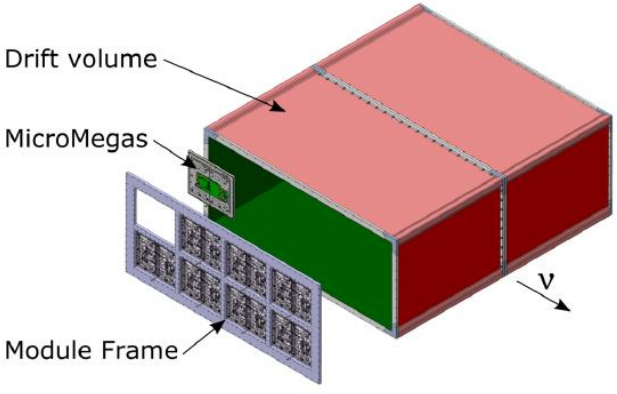


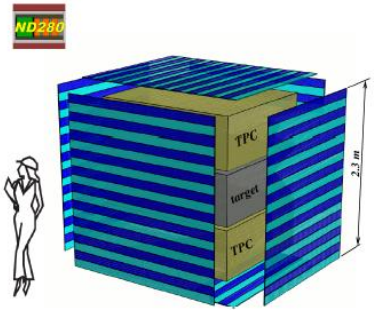
- Near Detector – detailed studies of neutrino and anti-neutrino beams in high flux environment
- Excellent forward-particle measurements
- Far detector – isotropic measurement of event signatures

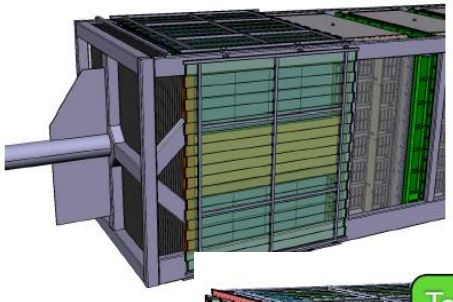
Overview of the Upgrade Detector
(See talk by A. Eguchi)

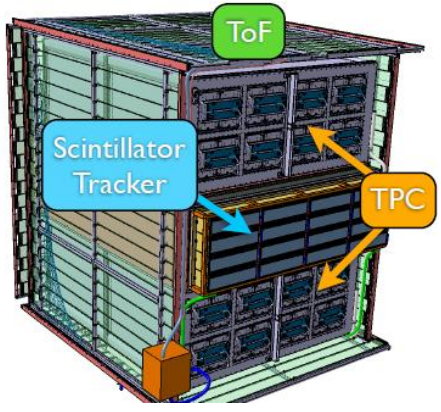






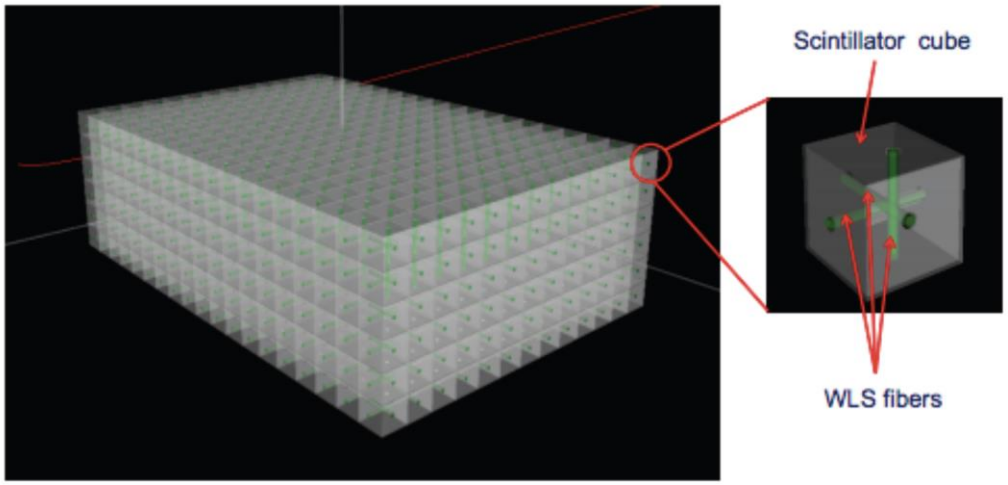


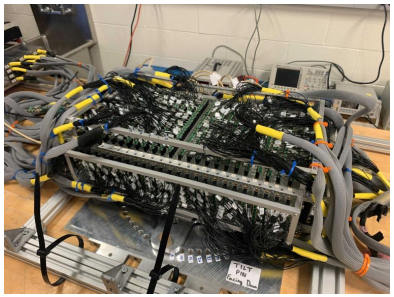


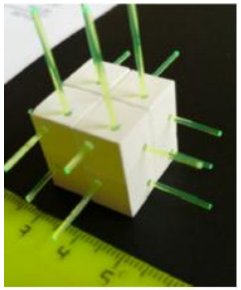


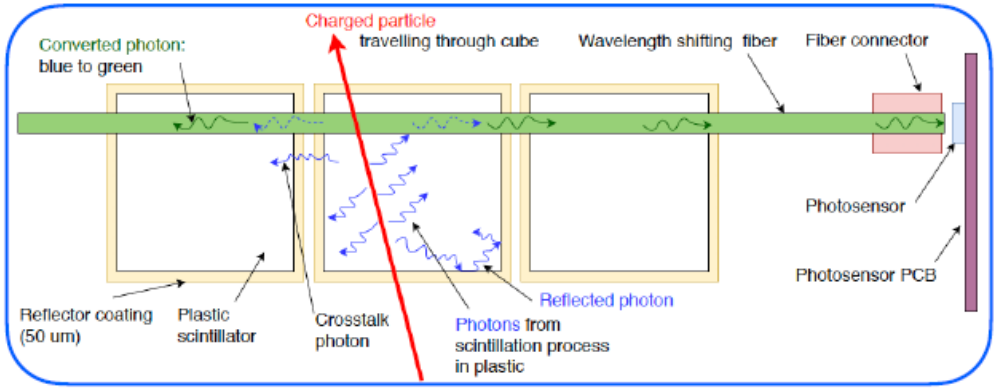
- Super Fine-Grained Detector (SFGD)
  - Primary target – solid scintillator detector composed of 1-cm cubes
  - Groups on 3 continents contributing to this detector
- High-Angle Time-projection chambers (HA-TPC)
- Time of flight detectors (ToF)

Super Fine-Grained Detector: SFGD









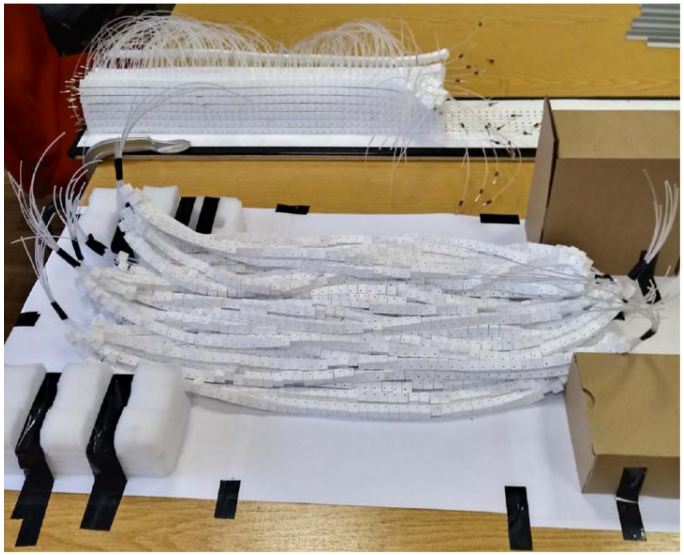
1x1x1 cm³ cubes
Polystyrene scintillator
1.5% paraterphenyl
0.01% POPOP
Chemical etched reflector
WLS fiber Kuraray Y11
2-clad (⌀=1mm)

- 3D-array of 1-cm scintillator cubes (184x192x56)
- Fibers run the length (or width or height) of the detector – 3-fibers in each cube
- Low-occupancy experiment – 3D view of events (4π– like acceptance)
- Prototype detectors – neutron measurements described in C. Riccio's talk

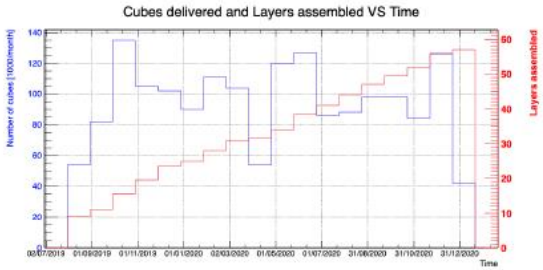
Cube Production/Assembly Completed!

First layers

All (56) layers



1 Layer = 184 x 192 cubes (baseline design)

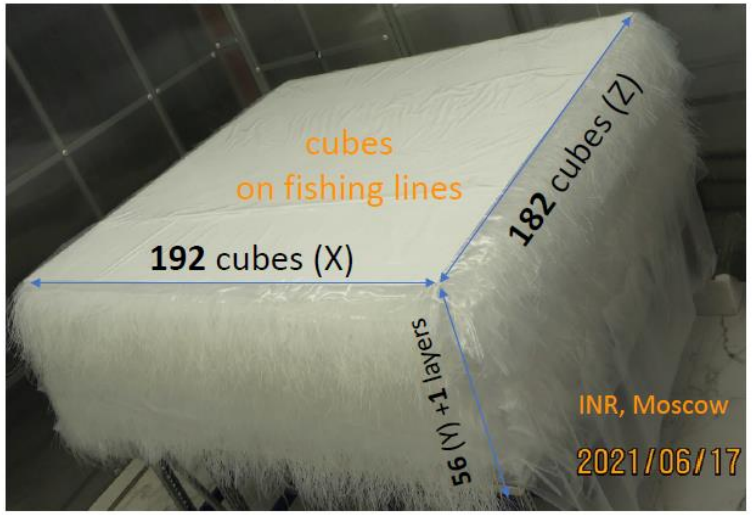


All cubes have been produced by Uniplast and layers have been assembly at INR

- Cube production, finishing, QC completed – about 2 million cubes
- Initial assembly completed with fishing line (completed on schedule during the pandemic)
- Cubes aligned in strings
- Assembled into planes
- Planes stacked and aligned for the full detector
- Final optical fiber insertion done at J-PARC

Cubes Delivered to J-PARC

56 (Y) +**1** spare layers x **192** cubes (X) x **182** cubes (Z)
[1,991,808 cubes in total]

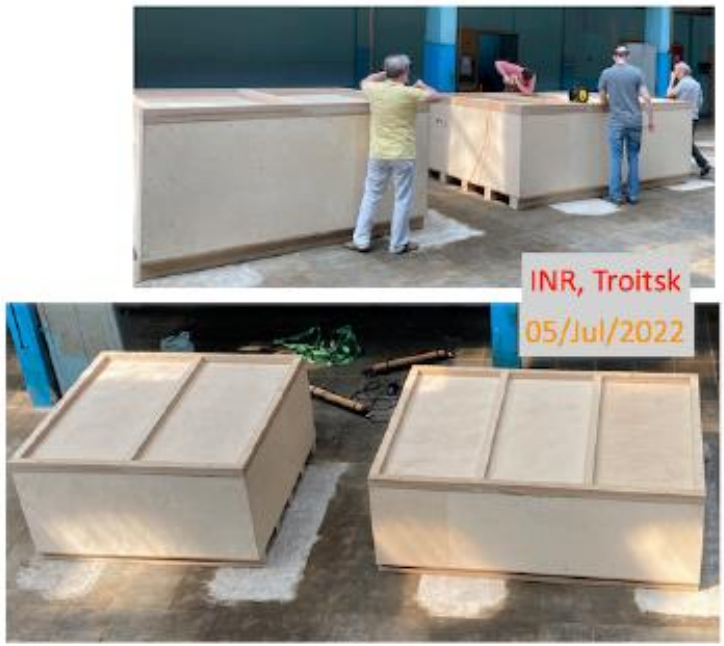


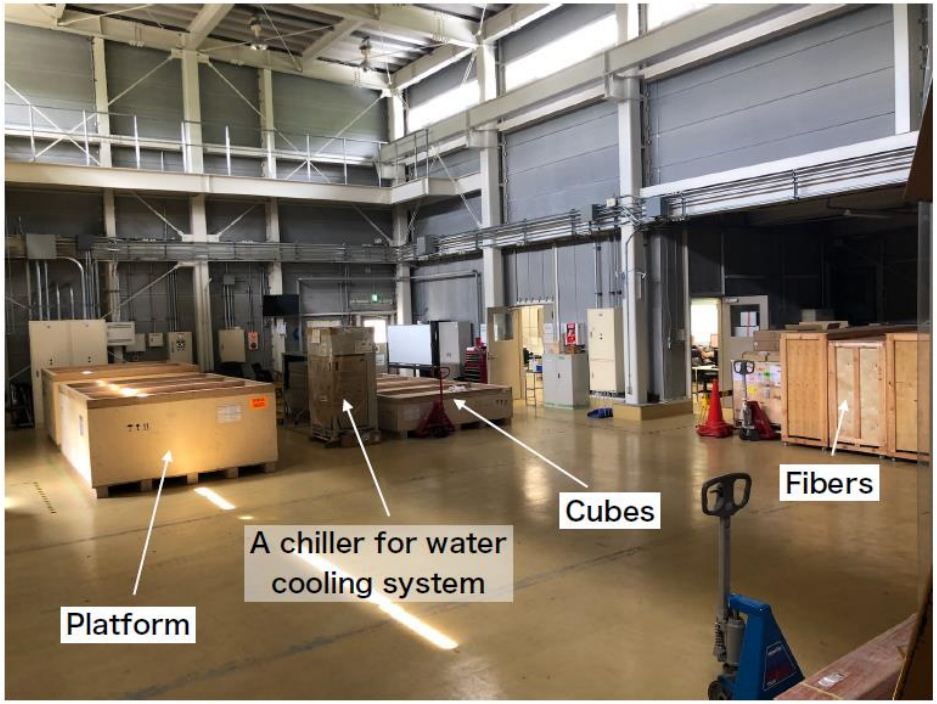
Box 2

Box 1

- All cubes have been delivered to J-PARC – arrived safe and sound!
- Massive undertaking in normal times
- Herculean effort in current times

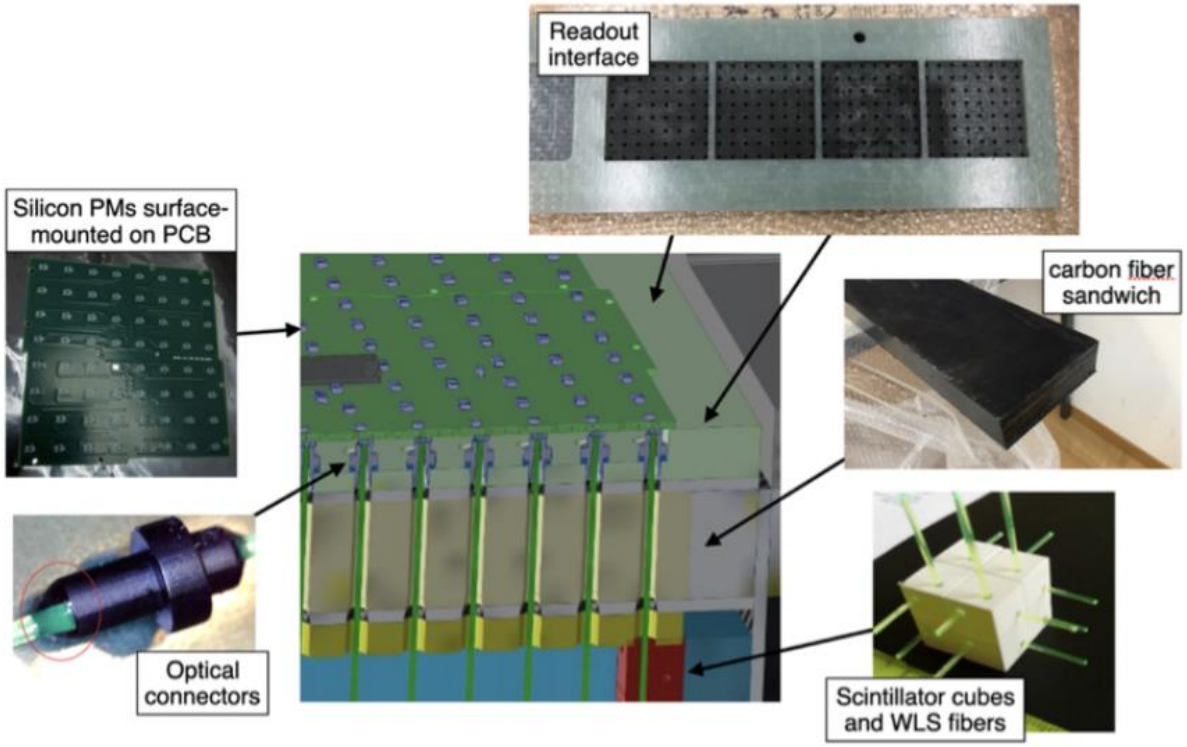
Many items at J-PARC awaiting assembly





- Cubes, assembly stand, fibers, chiller all await assembly
- Major mechanical items mostly in hand

Light-readout scheme



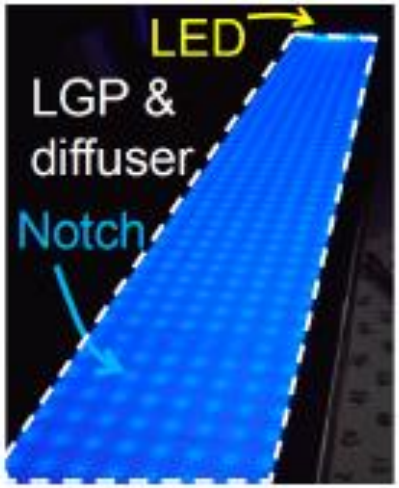
- Wave-length shifting fiber aligned with the Multi-Pixel Photon Counters (MPPCs) via hardware design
- MPPC is surface mounted onto the PCB screwed into the box plate
- Fibers glued to optical connectors – total of 56,382 fibers

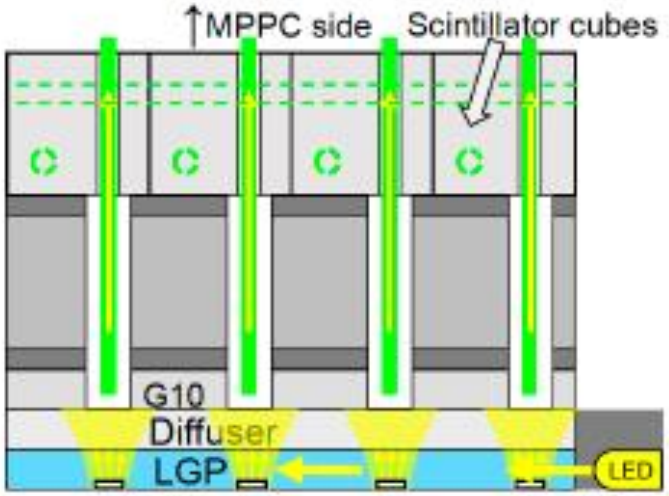
LED Calibration

Concept of light propagation for the system

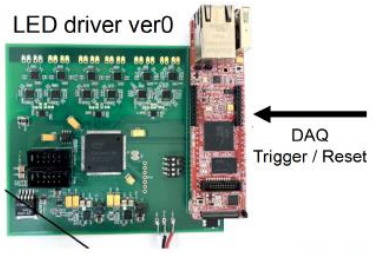
This concept can distribute uniform light with thin space using a small # of LEDs

- The light guide plate (LGP) has notches which scatter light
- Notches on the LGP are placed at the same pitch as the fiber



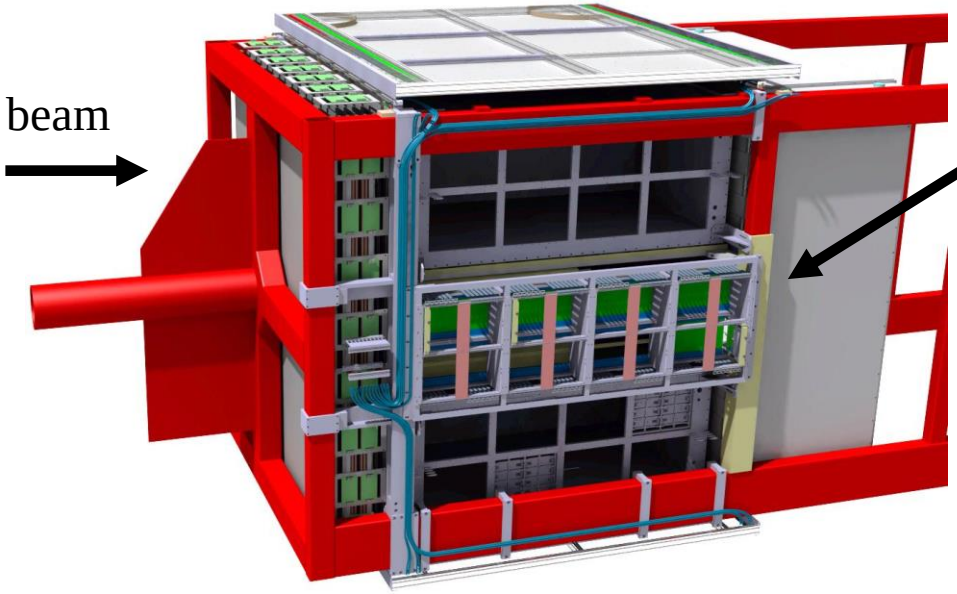


- LED Calibration – employs side of fiber not read out to inject light into the fiber
- System has been prototyped
- LGPs produced
- Other elements will be acquired soon
- QC and assembly in autumn of this year

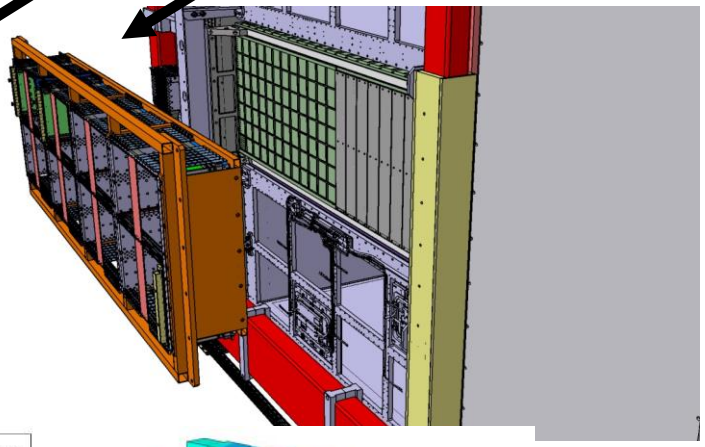


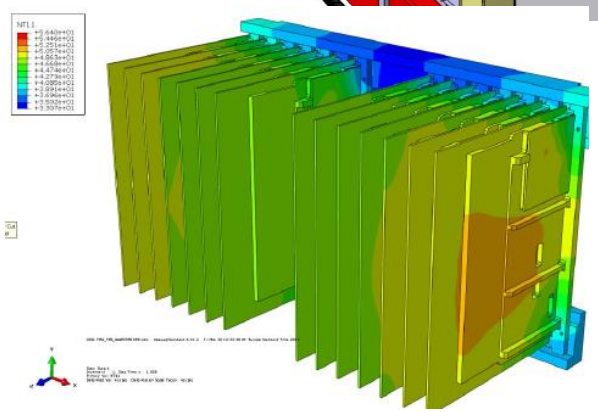
Pulse height and width can be controlled by FPGA
One LED driver covers 12 LGP modules
There are 8 LED drivers to cover all modules

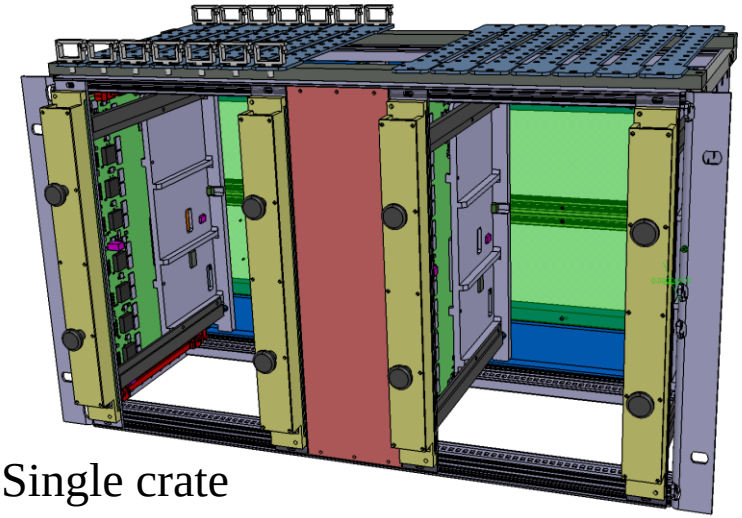
Electronics I



8-crate assembly





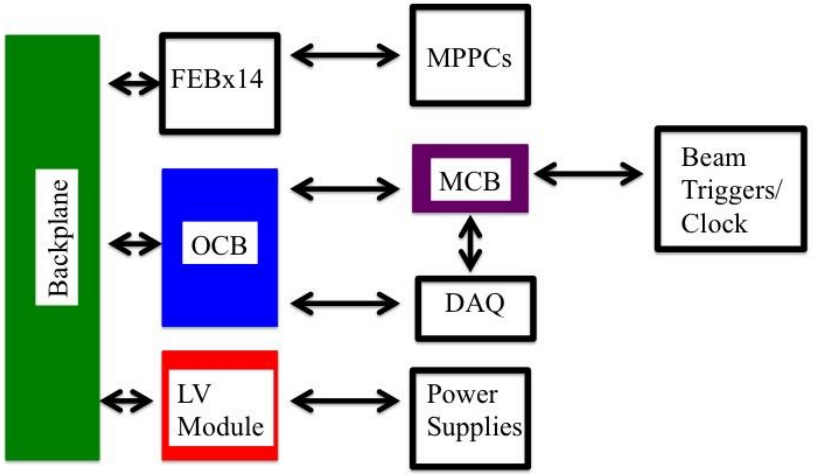


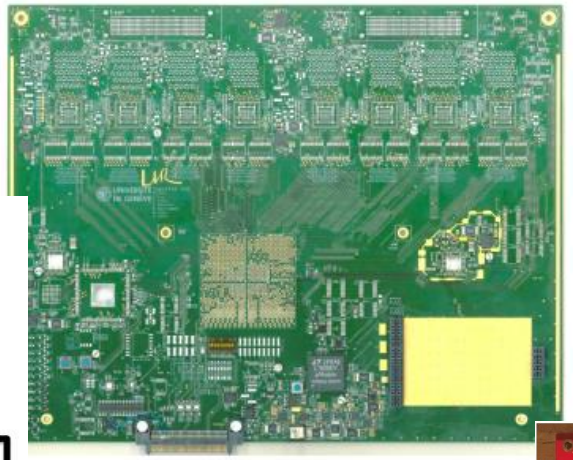
Single crate

- 16 crates – 8 on each side of the detector
- Single crate – 14 Front-end boards, Optical Concentrator Board, Backplane, Power distribution
- Thermal model built to ensure < 60 degrees C

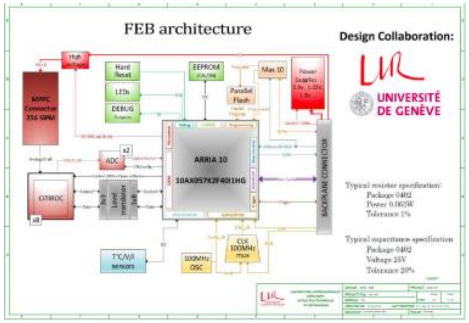
Electronics II

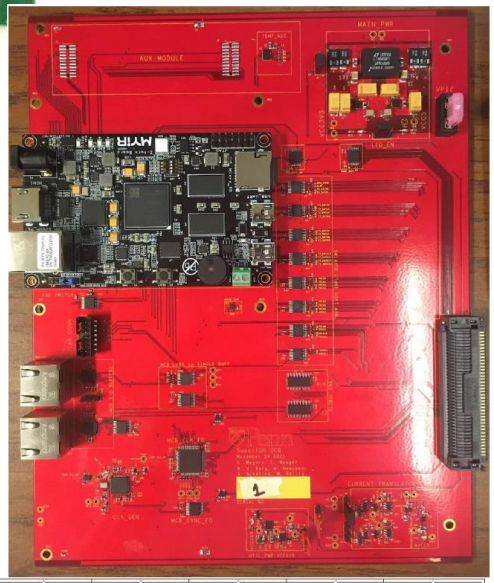
SFGD Electronics Architecture





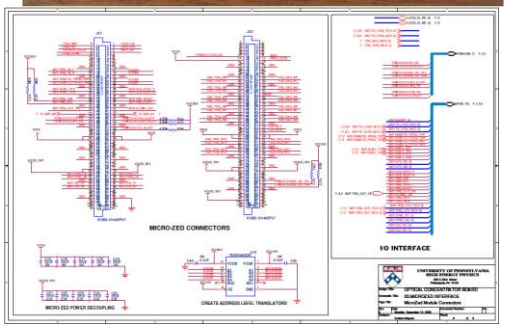
Front-End Board (14 boards per crate) – analog processing, ADC, bias voltage to the MPPCs
8 CITIROC chips per board – 256 channels





Power Distribution – most local DC/DC conversion happens on FEBs, currently testing DC/DC converters in magnetic fields

Optical Concentrator Board (1 board per crate) – initial data aggregation, switchyard to outside world



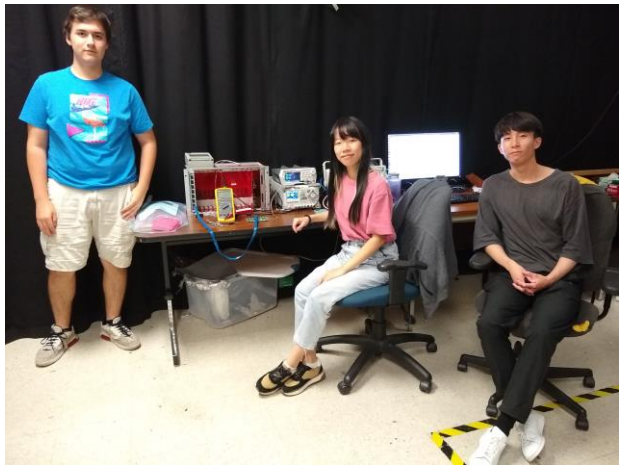
Master Clock Board – external to magnet, hardware connections to the beam triggers

Electronics III

Europe

Japan

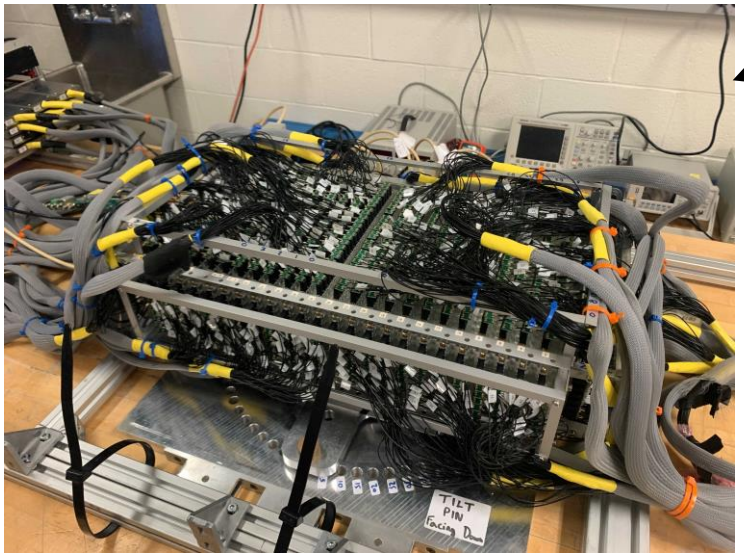
USA



- Extensive FEB testing including charge linearity and timing studies
- Crate-level testing reading out data from FEBs through the backplane and OCB (combines equipment designed by European and US groups)
- FEB QC planning is ongoing
- Worldwide chip shortage has impacted the schedule – electronics team has made design adjustments to ensure the earliest possible delivery
- Electronics on the critical path – expect complete and tested systems in Japan in early 2023

Prototypes

Tests in charged particle and neutron beams

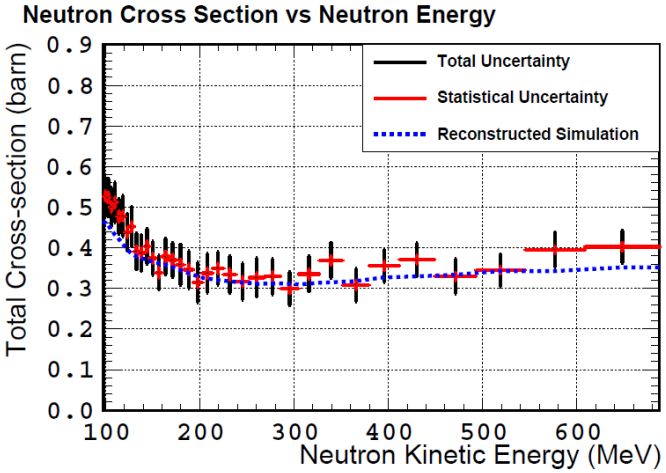


SFGD Prototype (8x24x48):

- Charged particle beam at CERN
- Neutron beam at LANL

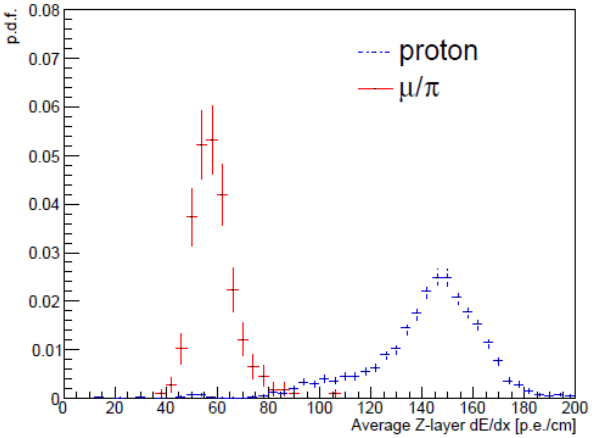
US-Japan Prototype (8x8x32):

- Neutron beam at LANL



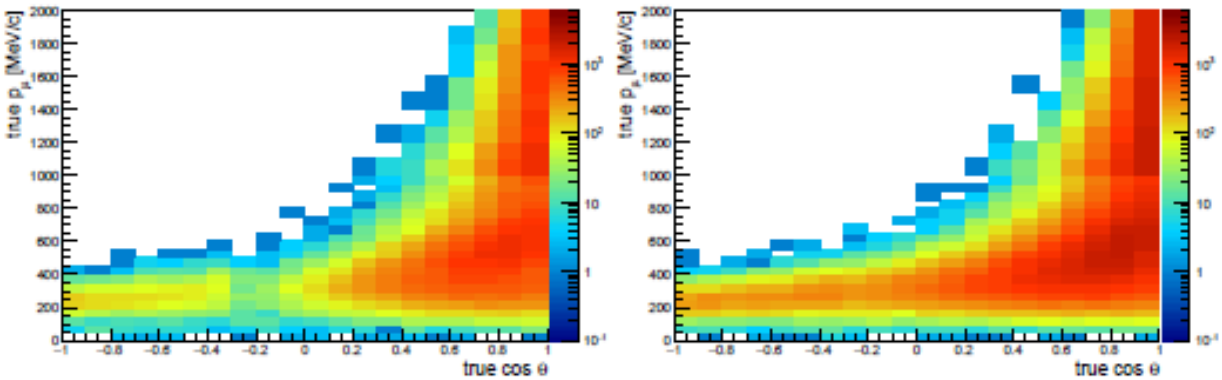
https://arxiv.org/abs/2207.02685

Also, see C. Riccio's talk at this meeting

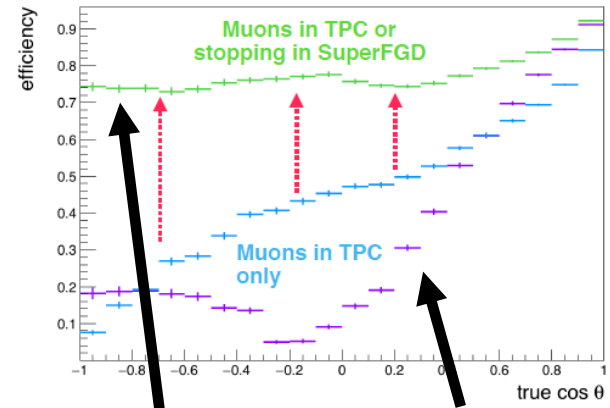


A. Blondel et al 2020 JINST 15 P12003

Performance and Capabilities of Upgraded Detector

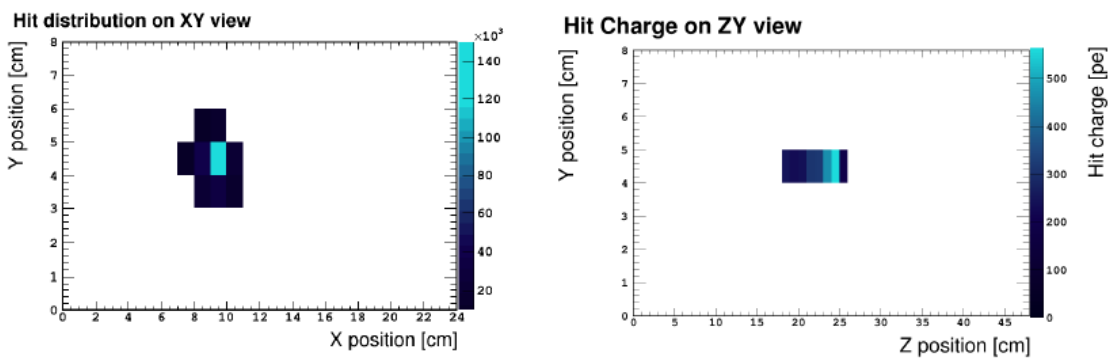


(a) Current ND280 (b) Upgraded ND280



Current ND 280

Upgraded ND 280



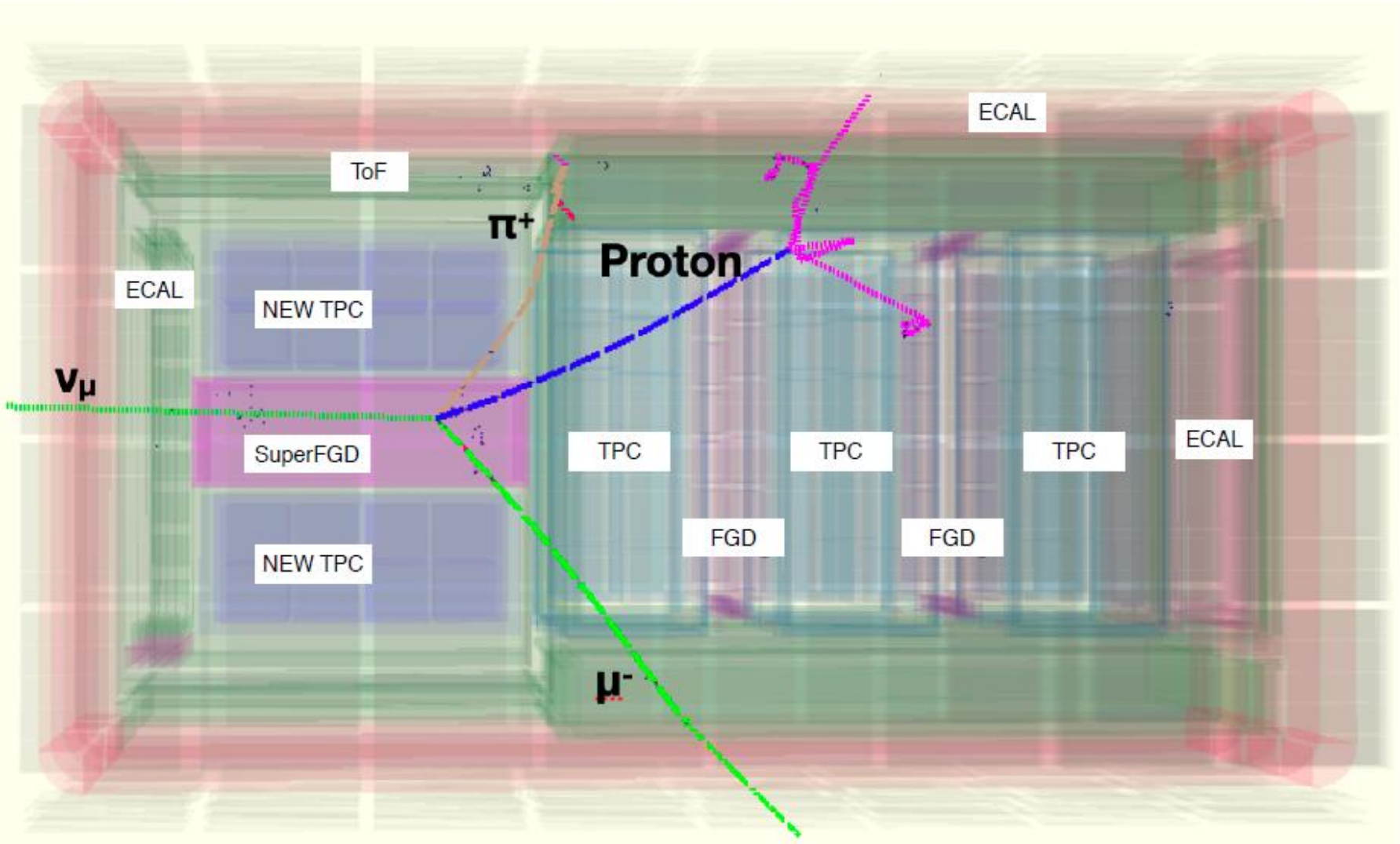
Neutron detection capability demonstrated in the SFGD prototype

~170 MeV KE neutron from prototype run at LANSCE

Time-of-Flight measurement of neutrons from neutrino interactions enabled

- Greatly improved performance for transverse particles
- Excellent neutron detection *and* neutron measurement of kinetic energy via time of flight *within* the SFGD
- Momentum by range – 3% for stopping muons

Simulated Event in Upgraded ND



Schedule

- Original plan
  - Assemble and commission most elements at CERN before shipping to J-PARC
  - Commissioning completed at J-PARC by March 2022
- COVID-19 impacts on design, prototyping efforts
- Current Plan
  - Assemble cubes in the box, insert fibers into the cubes in autumn of 2022 on the surface at J-PARC
  - Initial testing of electronics on the surface
  - Lower everything into the pit
  - Final assembly and commissioning complete in the spring of 2023
- First beam with SFGD in late spring of 2023
- We must remain flexible and adjust to supply-chain and other world events

Summary

- T2K continues to be an exciting experiment
- Upgrade detector employs a novel approach to achieve 3D reconstruction
- New results with well-measured transverse momentum will provide greater constraints on the neutrino interaction models
- The prospect of detailed understanding of outgoing neutron kinematics for the first time in an oscillation experiment is very exciting
- Despite the pandemic and other challenges, efforts are proceeding well – anticipate first beam in calendar 2023

T2K Collaboration

~500 members, 76 institutes, 13 countries (+CERN)