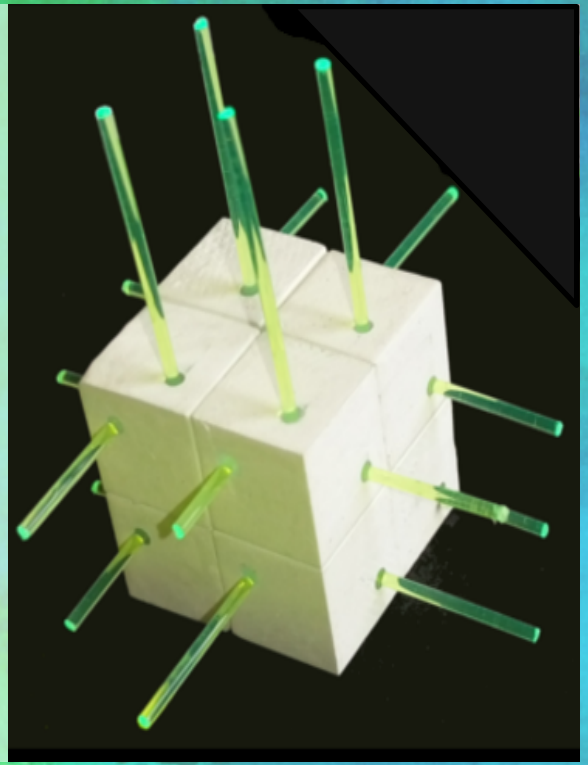
UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES
Section de physique

T2K

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

Vienna Conference on Instrumentation
20 Feb 2019

Saba PARSA
University of Geneva
on behalf of T2K ND280 Upgrade Collaboration



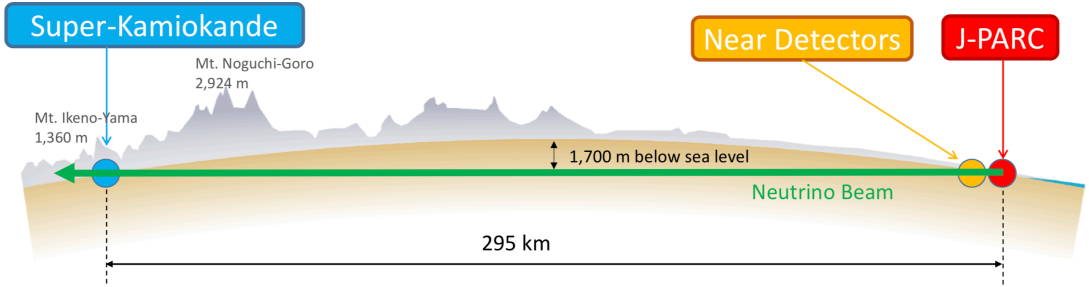
Out line

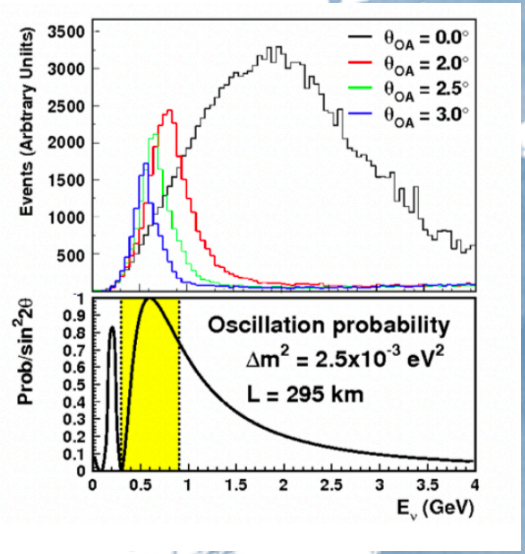
- Introduction
  - Current Near Detector (ND280)
  - Motivation for Upgrade
  - ND280 upgrade configuration
- Super FGD
  - 3D scintillating detector
  - Expected performance from simulations
  - Production and Assembly challenges
  - Optical interface and Electronics Readout
- Prototype at CERN beam test
  - beam test setup
  - Events examples
  - Detector response results

1.
Introduction

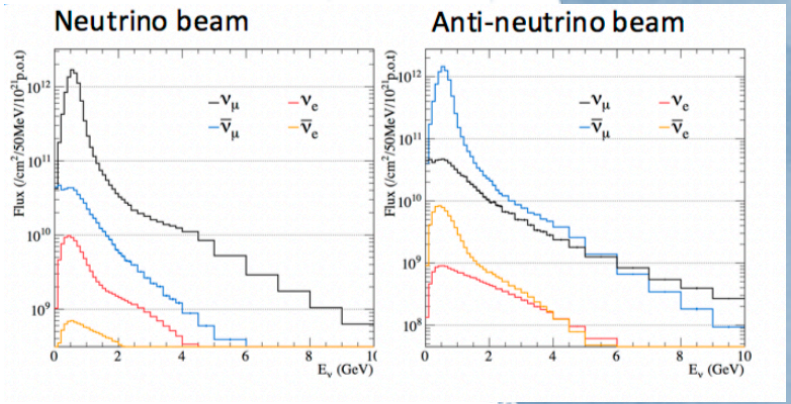
T2K experiment Near Detectors
Motivation for Upgrade
ND280 Upgrade Configuration

T2K Experiment





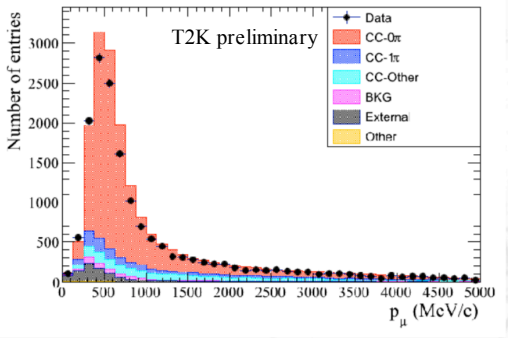
- ✓ Oscillation analysis of ν_μ->ν_e and ν_μ->ν_μ with high intensity accelerator beam.
- ✓ Off axis technique (2.5 degree) ensures a narrower beam energy spectrum
- ✓ E_ν~700 MeV, Oscillation distance: 295 Km
- × Large backgrounds in neutrino and Anti-neutrino beams mode.



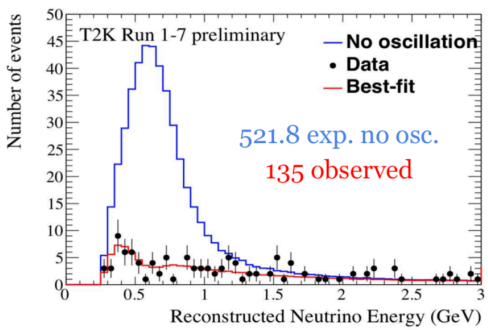
Current Near Detector (ND280)

The ND280 detectors play a significant role in the reduction of flux and cross-section systematics in T2K oscillation analyses.

Since 2009 they have performed very well. However the current design configuration does have Limitations.



Neutrino interactions at near detector (Quasi-elastic candidate)



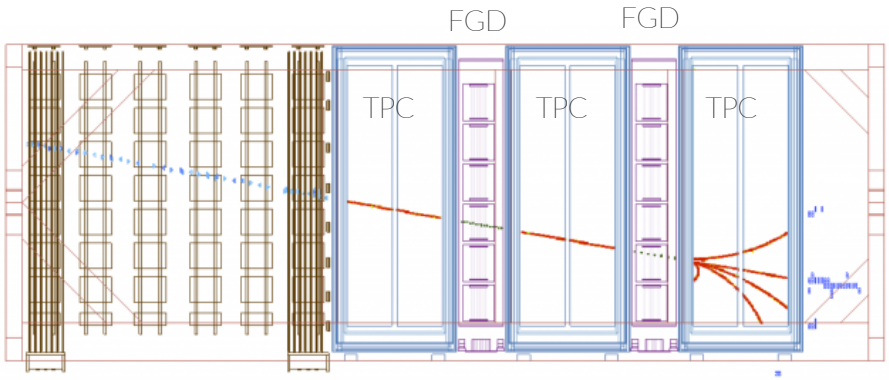
Neutrino interactions at far detector

Systematics for FHC

Source of uncertainty	ν_e CCQE-like $\delta N/N$	ν_μ $\delta N/N$	ν_e CC1π^+ $\delta N/N$
Flux (w/ ND280 constraint)	3.7%	3.6%	3.6%
Cross section (w/ ND280 constraint)	5.1%	4.0%	4.9%
Flux+cross section (w/o ND280 constraint)	11.3%	10.8%	16.4%
(w/ ND280 constraint)	4.2%	2.9%	5.0%
FSI + SI + PN at SK	2.5%	1.5%	10.5%
SK detector	2.4%	3.9%	9.3%
All (w/o ND280 constraint)	12.7%	12.0%	21.9%
(w/ ND280 constraint)	5.5%	5.1%	14.8%

Current Near Detector (ND280)

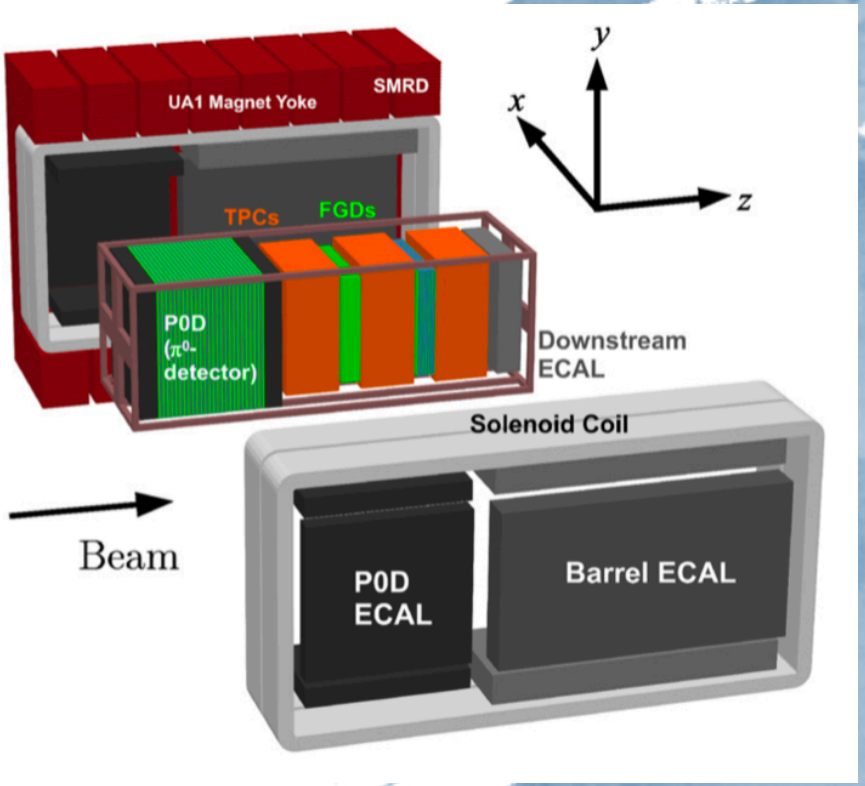
Basket Components:



P0D (π^0 detector):
Scintillator planes interleaved with lead/brass

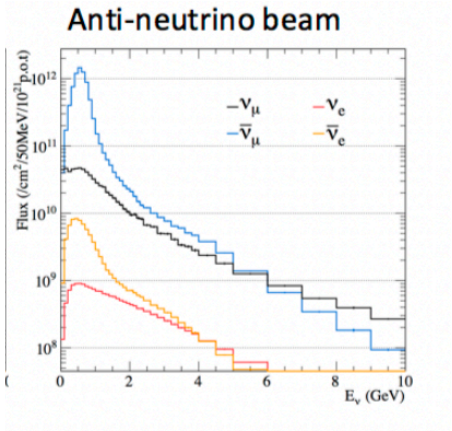
Tracker section:
Two FGDs (Fine Grained Detectors)
- Thin, wide scintillating planes.
- Provides active target mass

Three TPCs (Time Projection Chambers)
- Excellent measurement of charged particles.

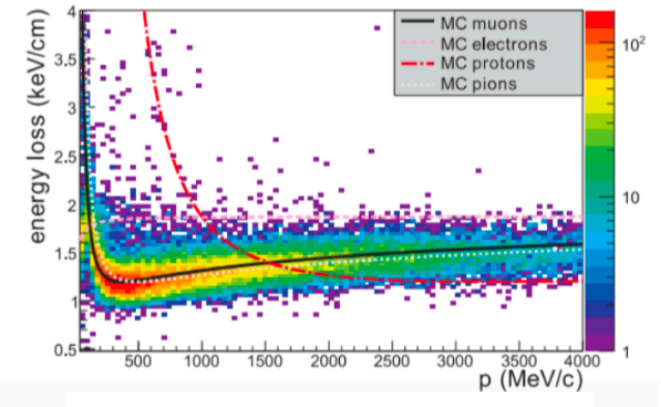


ND280 Advantages and Limitations

- ✓ Magnetized -> Rejection of wrong sign beam component by magnetic field
- ✓ Active target (FGD) -> Interaction vertex detection
- ✓ TPCs -> 3D track reconstruction, charge, momentum and particle ID

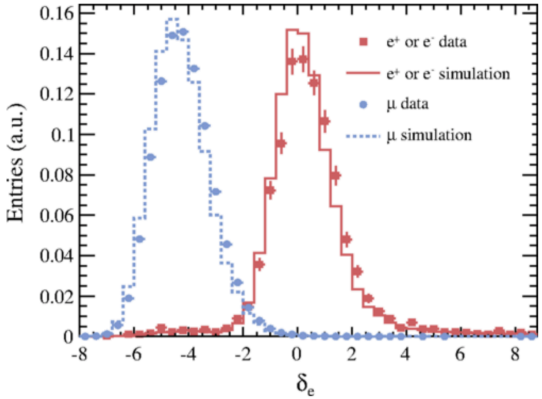


Nucl.Instrum.Meth. A637 (2011) 25-46



Particle ID from dE/dx in TPC

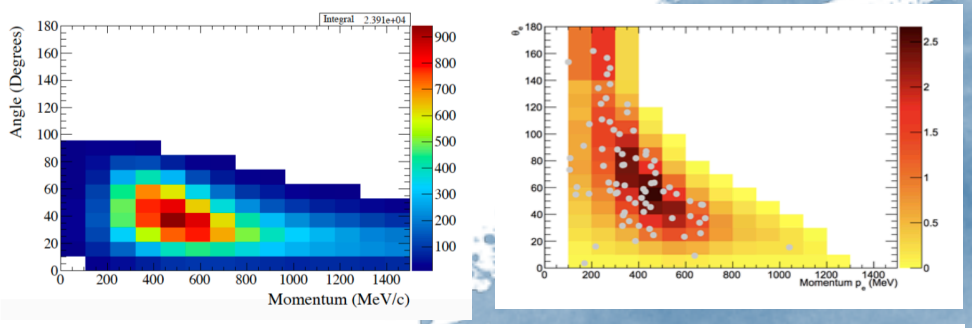
Phys. Rev. D 89, 092003 (2014).



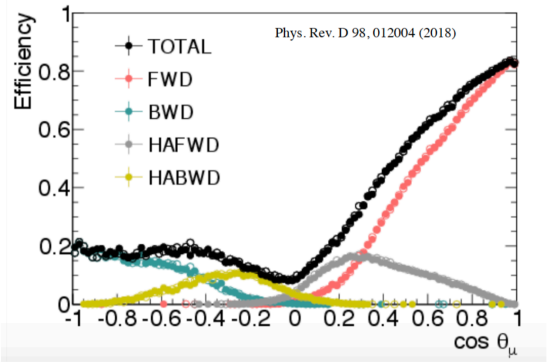
TPC Particle ID for electrons and muons

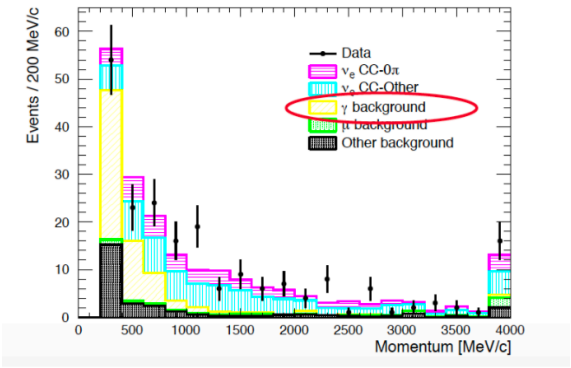
ND280 Advantages and Limitations

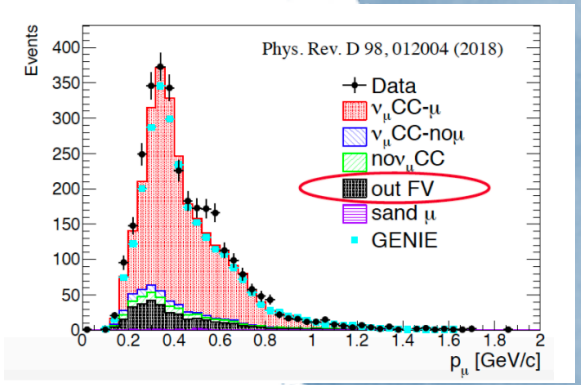
- ND280 has Limited angular acceptance for high angle and backward tracks, SK has 4π acceptance.
- Poor detection efficiency for e <1 GeV (γ conversion contamination)
- No track direction determination: Large out of Fiducial Volume background



Reconstructed momentum and angle for muons selected at ND280 (Left) and electrons selected at SK (right).

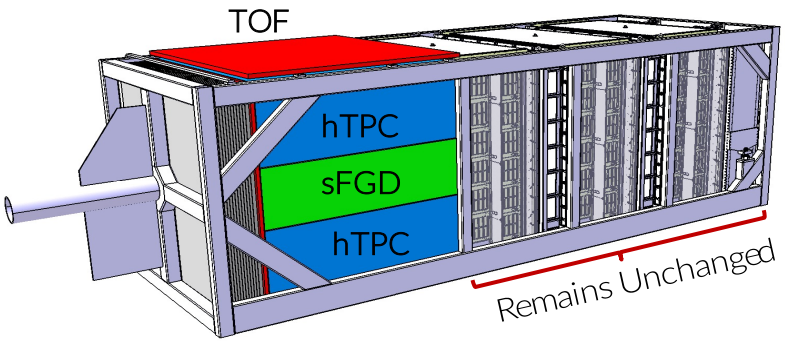


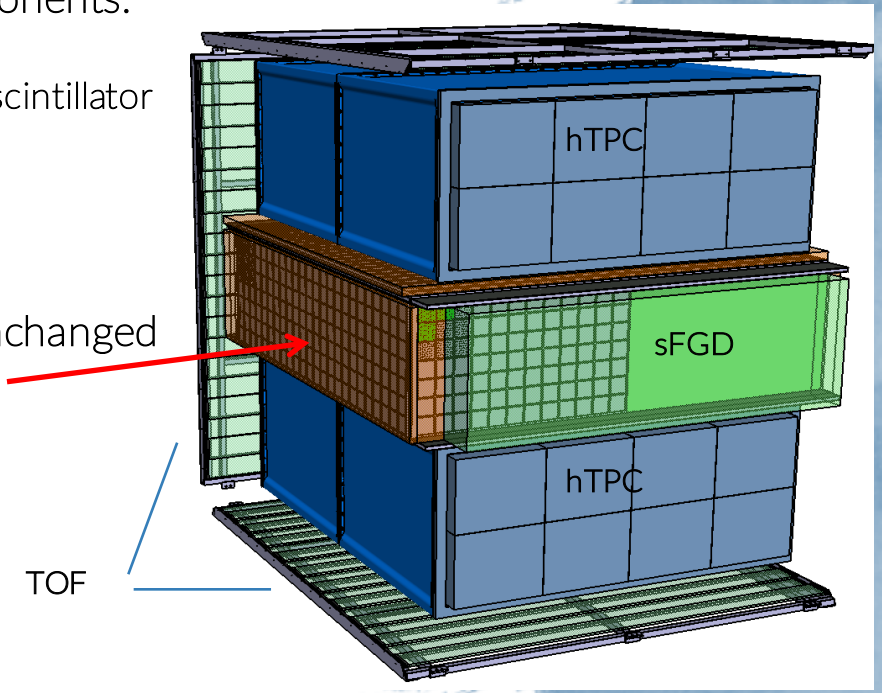




ND280 upgrade configuration

- Re-design of the upstream part of Basket components:
  - Super FGD: A novel 3D highly granular plastic scintillator target
  - Two horizontal High-Angle TPCs
  - Time of Flight planes all around
- Current downstream tracker (FGDs + TPCs) unchanged



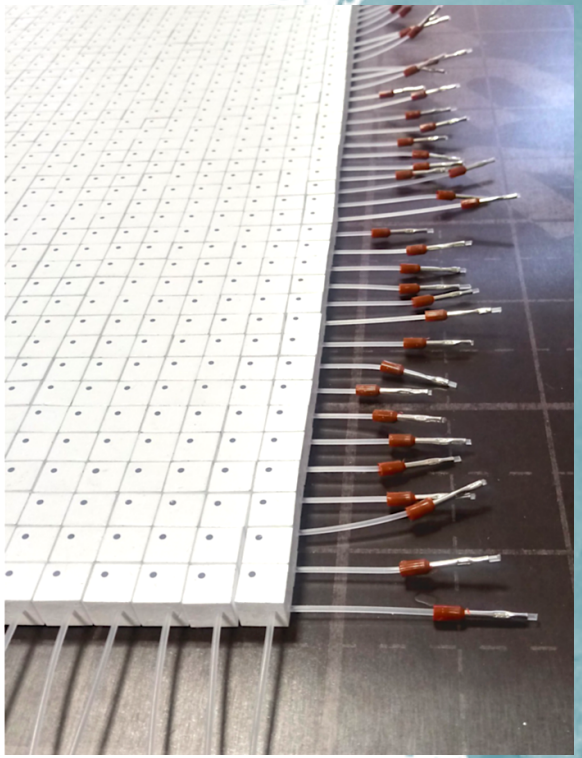


2.

Super FGD

A 3D plastic scintillator detector

Expected performance from simulations
Assembly Challenges
Optical Interface
Electronics

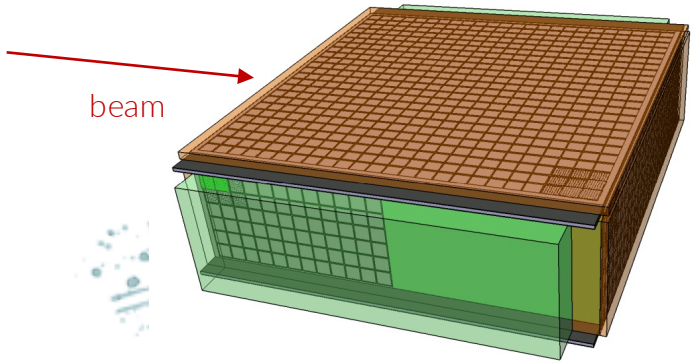


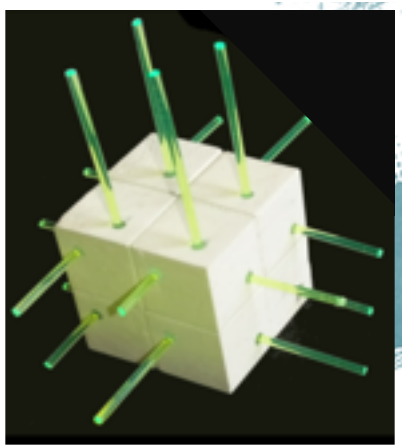
3D plastic scintillator detector

Super FGD is a novel detector design consisting of small scintillating cubes read out with WLS fibers in three orthogonal directions.

- Active tracking volume consist of 2 Million 1 cm-sized plastic scintillator cubes
- Mass 2 tons (1.92 × 1.92 × 0.56 m^3).
- Clean measures of momentum-balance in transverse plane
- 4π acceptance
- 3D readout with 6 × 10^4 channels (MPPC).
- Detection of activity around vertex

Super FGD schematics



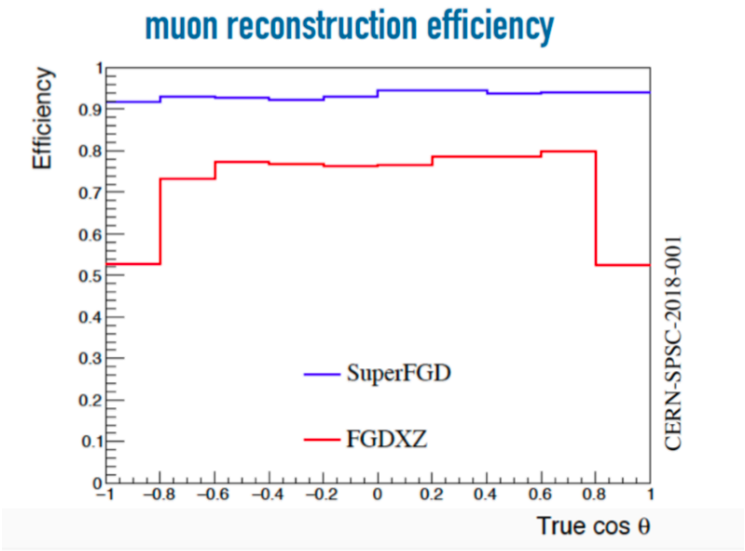


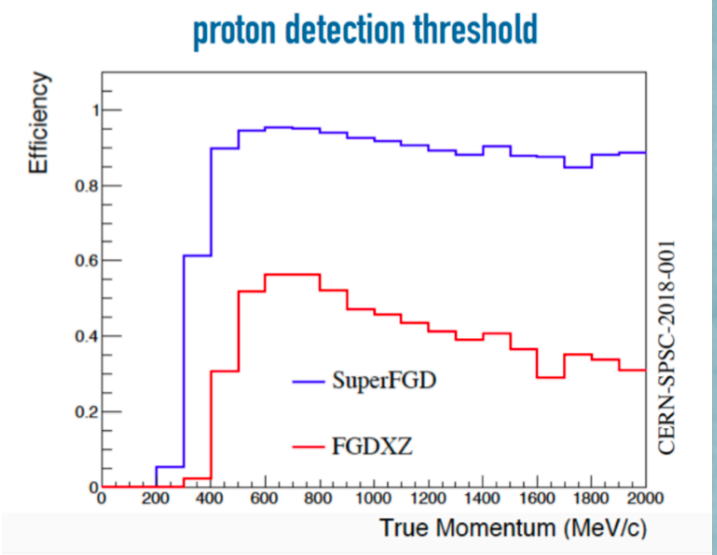
Each cube: 1 cm^3
Read out by 3 WLS fibers

Expected performance from simulations

Reconstruction efficiency

- ✓ **High reconstruction efficiency** in all directions (90% for muons)
- ✓ **Lower detection threshold** for protons (~300 MeV)

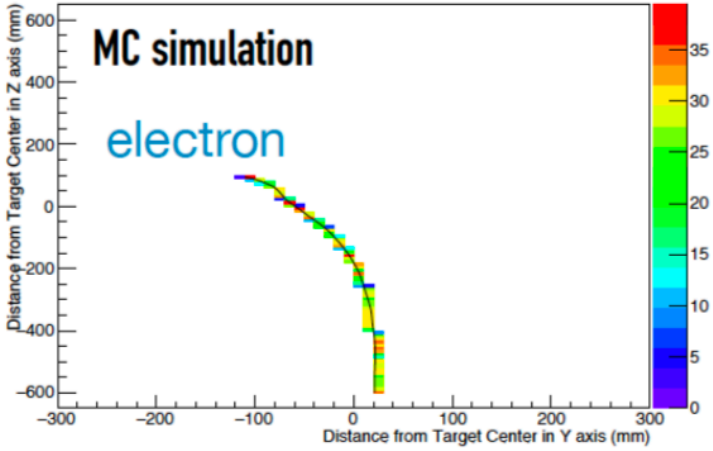


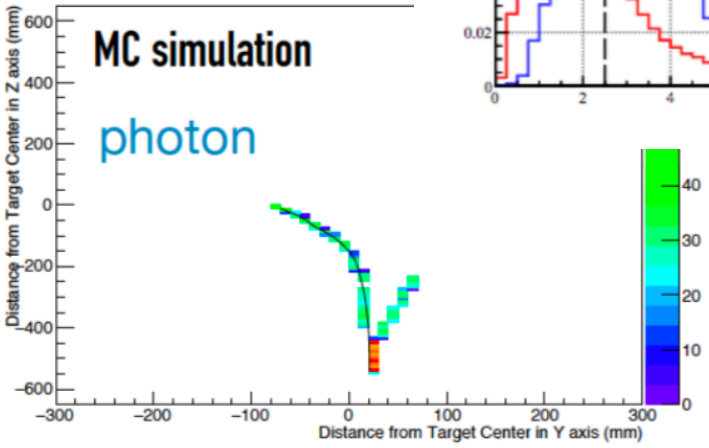


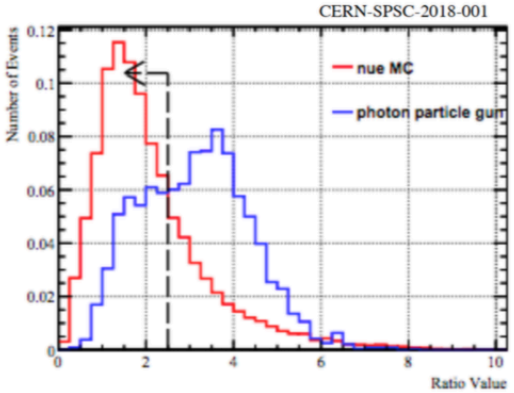
Expected performance from simulations

γ Conversion background

- ✓ Disentangling electrons (ν_e signal) from **photon conversion**.
- ✓ Disentangling one/two track in a cube by comparing energy deposit.



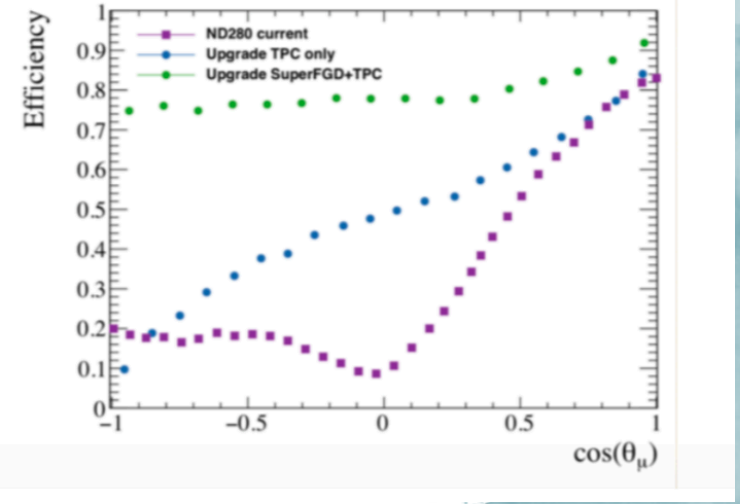




Expected performance from simulations

Angular acceptance

- ✓ Larger **angular acceptance** with new TPCs and TOF



Nuclear effects

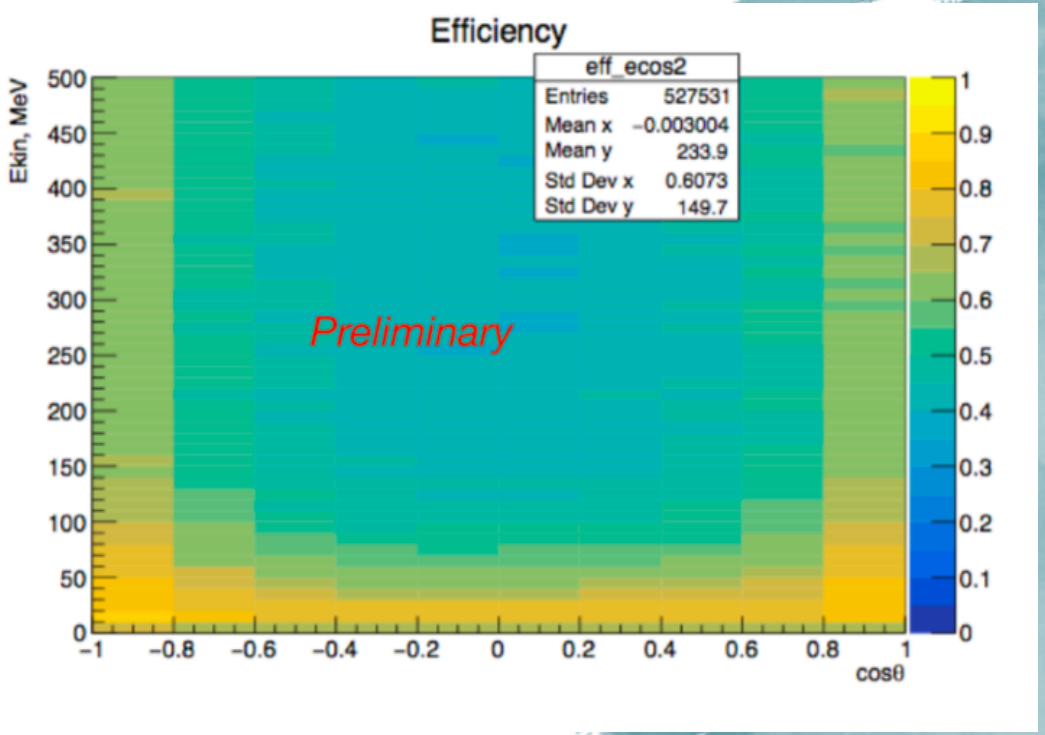
- ✓ Better studying of nuclear effects thanks to low momentum threshold and full angle coverage.
- ✓ Impact on T2K oscillation analysis:

Parameters	Reduction of the uncertainty
Flux	20 %
σ_ν (CCQE/2p2h)	20% - 40%
FSI	45 %
σ_ν (Q^2 dependent)	25 %

Expected performance from simulations

Neutron Detection

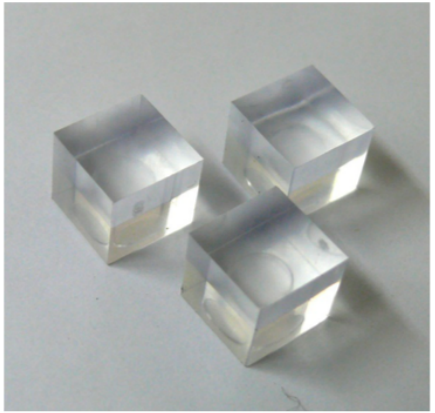
- ✓ Preliminary study shows high Neutron detection efficiency in Super FGD



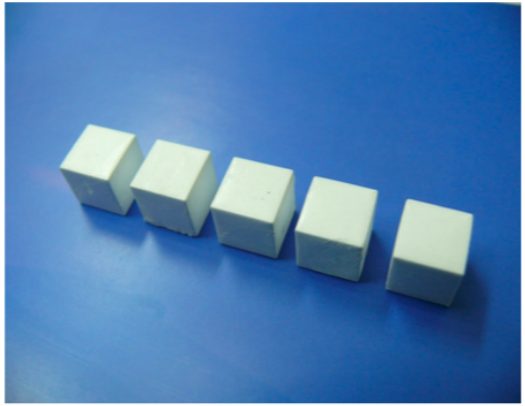
->A Neutron beam test is foreseen at Los Alamos (LANSCE) to validate this study

Production and assembly challenges

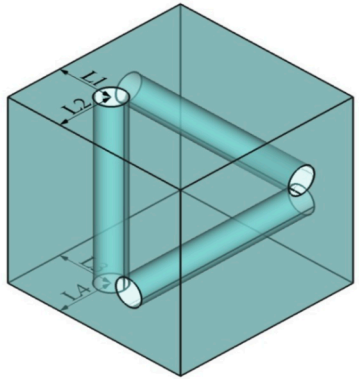
-> Happening now at INR

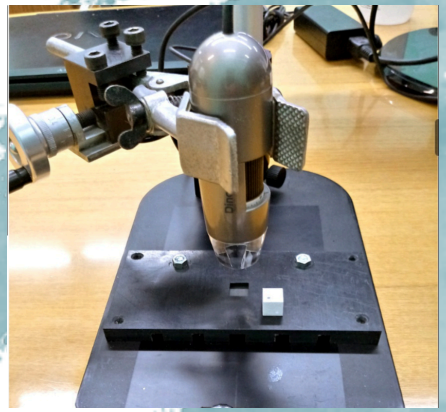


1. Injection
   (12 cube mold)



2. Etching
   (Chemical reflector)



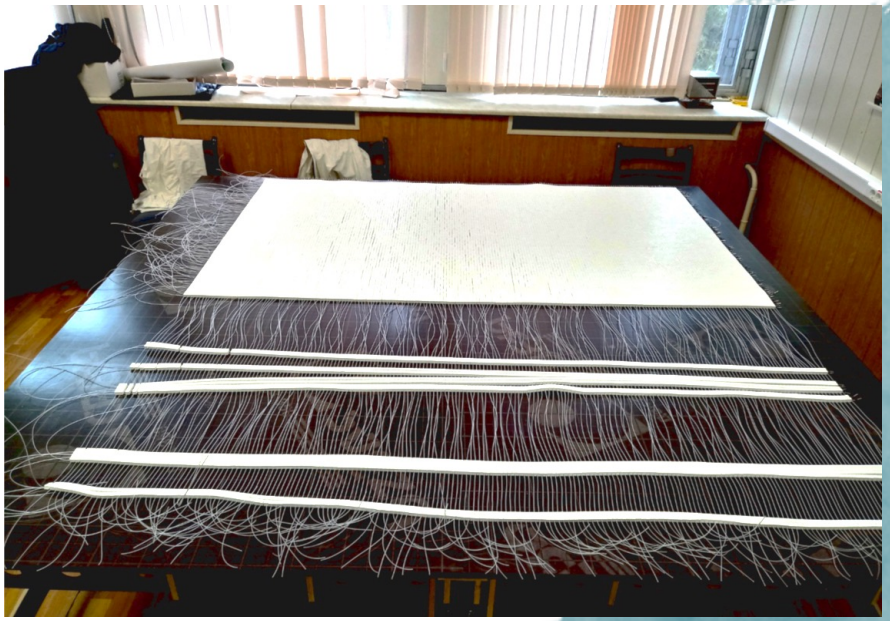


3. Drilling
   (3 holes per cube)

Production and assembly challenges

-> Happening now at INR

4. Cube beads
   (192 cubes on a fishing line)

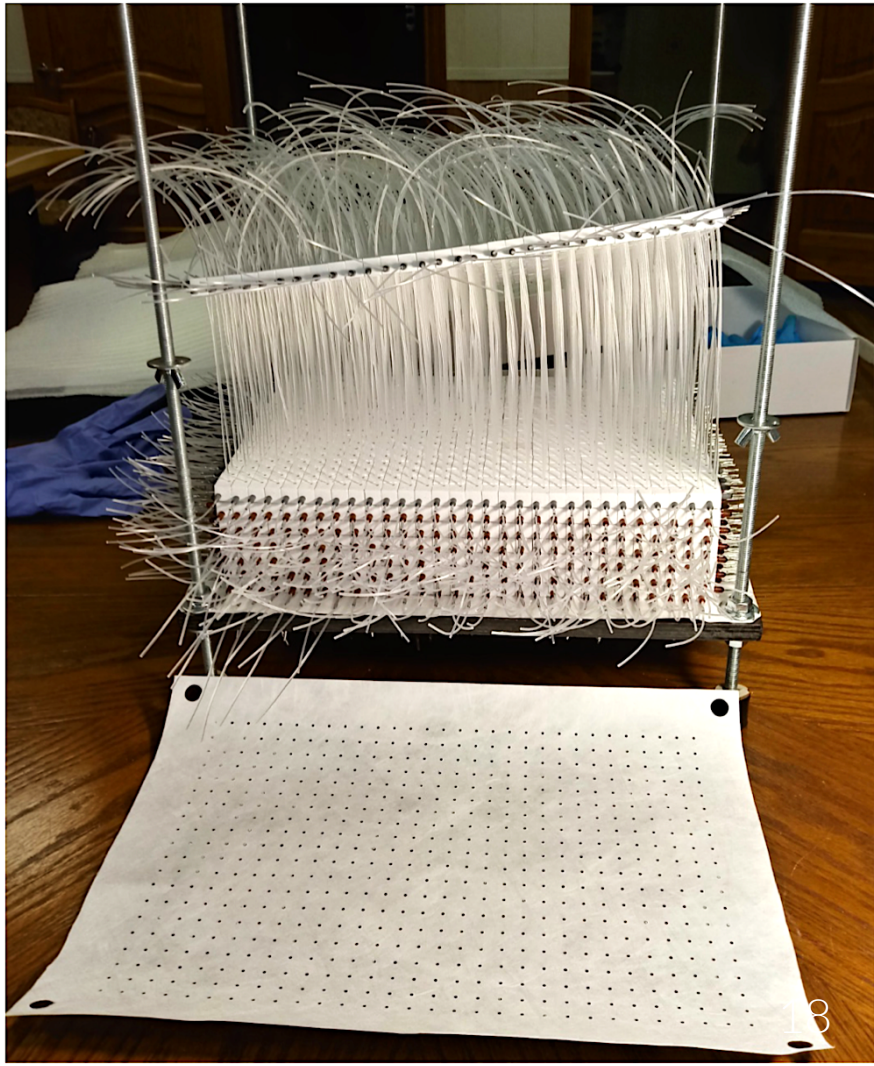


5. Cube Sheet
   (192 x 192 cubes)

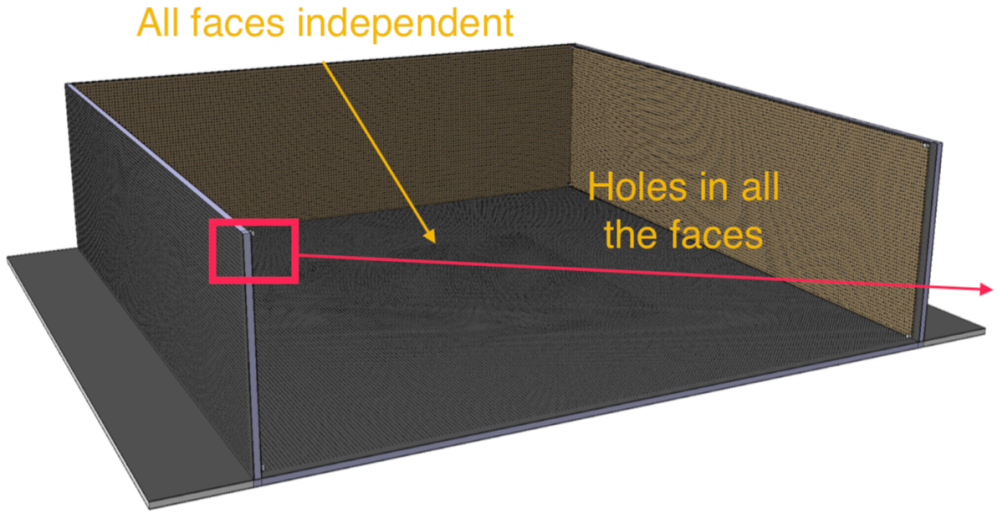
Production and assembly challenges!!!

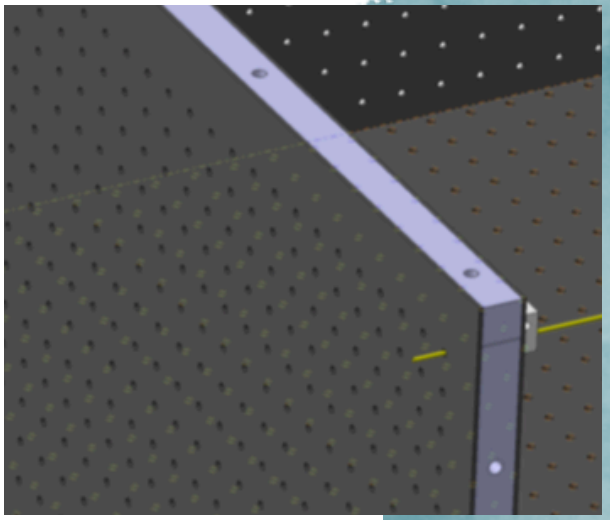
5. Sewing the layers
   (~ 2 Million cubes!)
6. Replace fishing line with WLS fiber
   (~ 60k fibers!)

This is the prototype assembly for CERN beam test (size: 48x24x8 cm^3)



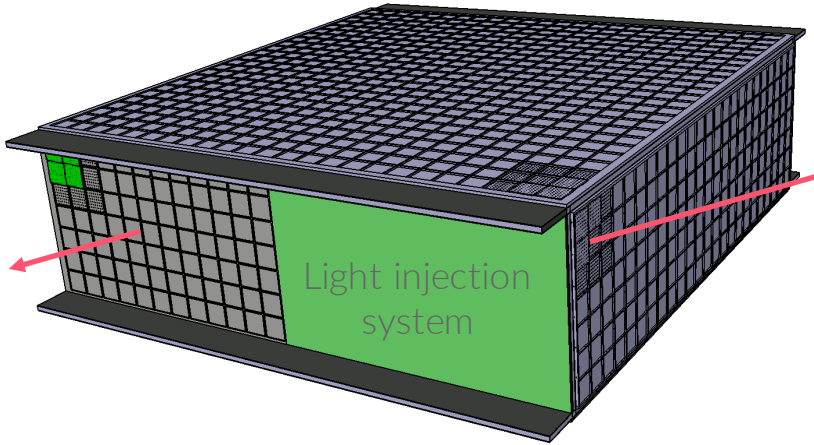
Mechanical box Carbon Fiber + AIREX

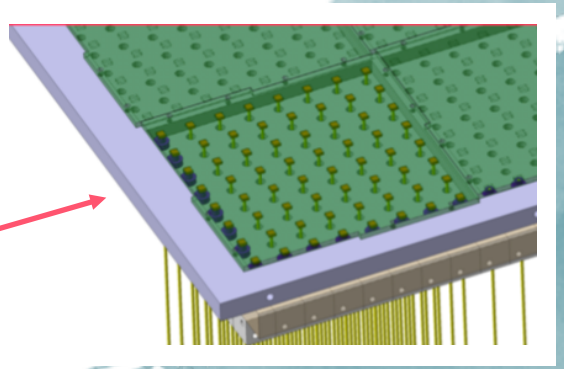


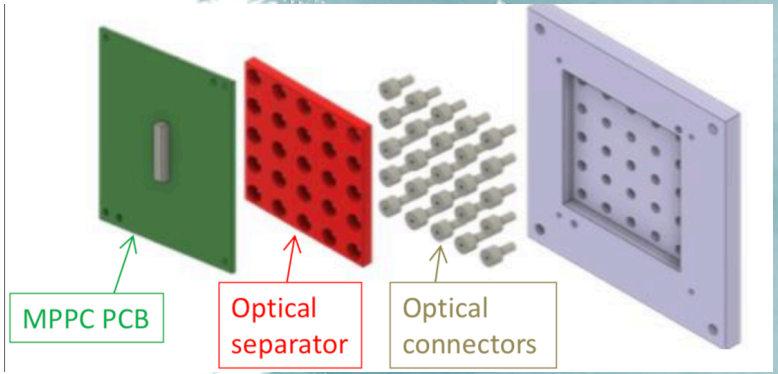


- The cubes are to be held mechanically in place
- Carbon Fiber sandwich with AIREX foam cover all faces
- There are holes on all faces for the fiber to go through

Optical interface



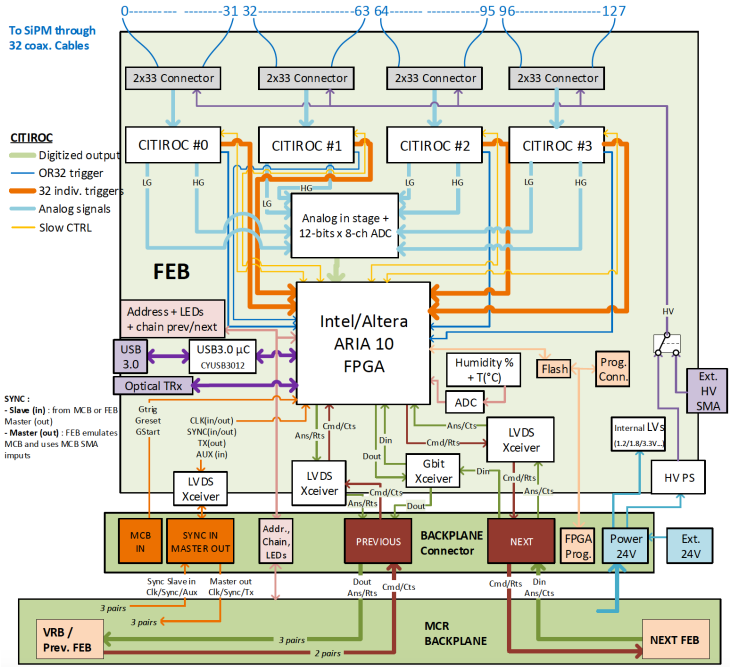




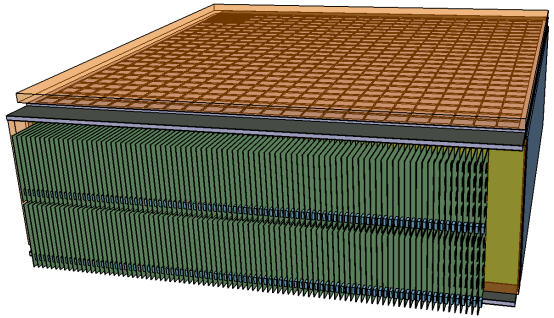
- PCB units with 8x8 surface mount MPPCs
- Hamamatsu MPPC : (S13360-1325PE)
- Fibers are read out from one end
- Light injection system on the free end of fiber for calibration

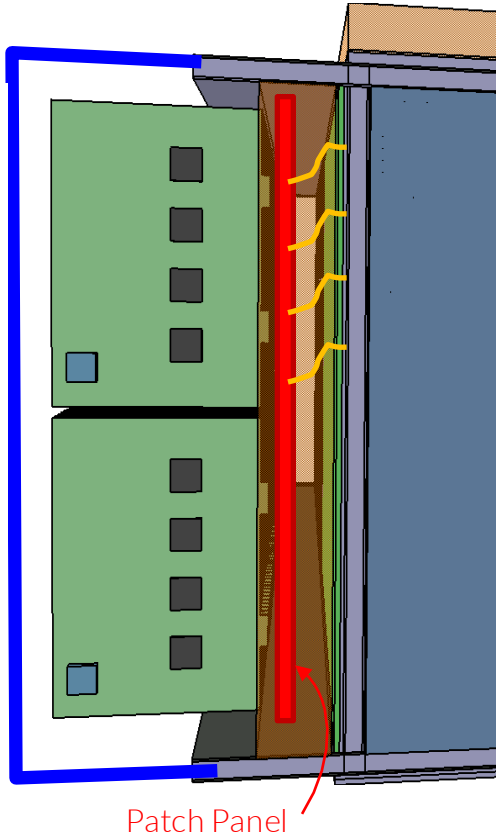
Electronics

- 4 CITIROC chips per FEB (Based on Baby Mind electronics)



- FEB size: 20cm x 27.5cm
- FEB's per side: 228… (456 in total!!)
- Cooling is required

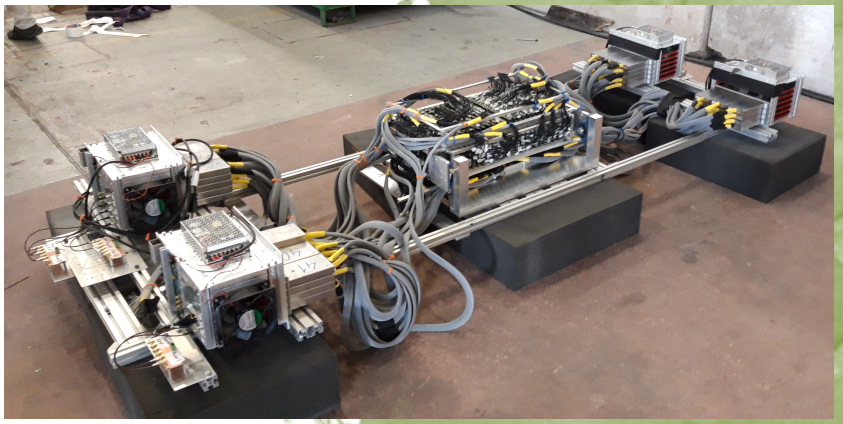




3.

Super FGD Prototype

At CERN beam test 2018



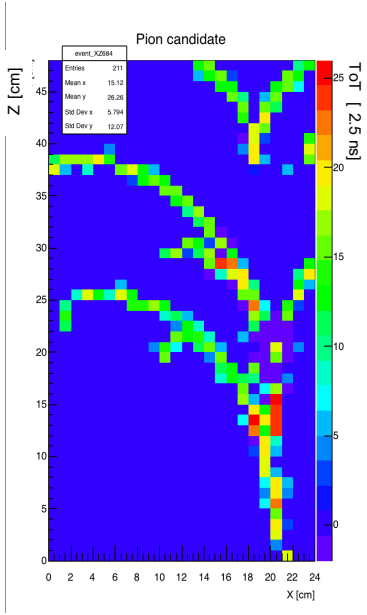
Beam test setup
Event displays
Cube response to MIP
Stopping Proton
Time resolution

Beam test at CERN-PS

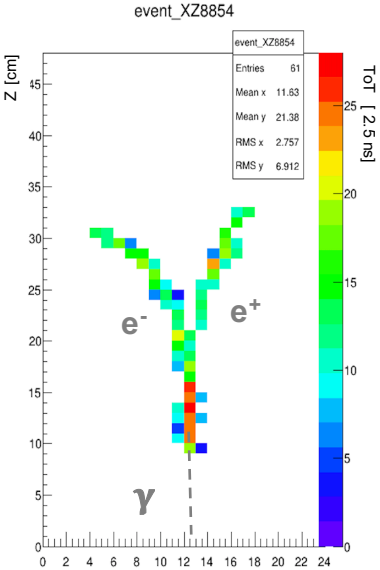
- 48x24x8 cubes assembled in INR
- Photo detection with Hamamatsu MPPCs
- Readout electronic based on CITIROC chip (BabyMIND electronics)
- Calibration with LED pulse generator
- Beam energy 0.5 – 8 GeV
- Magnetic field 0.2-0.7 T

Event displays

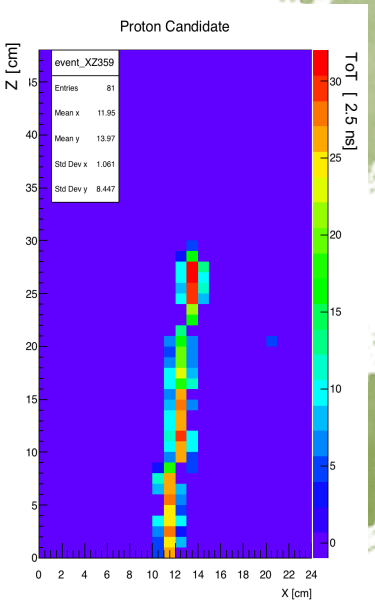
Pion (π^-) candidate



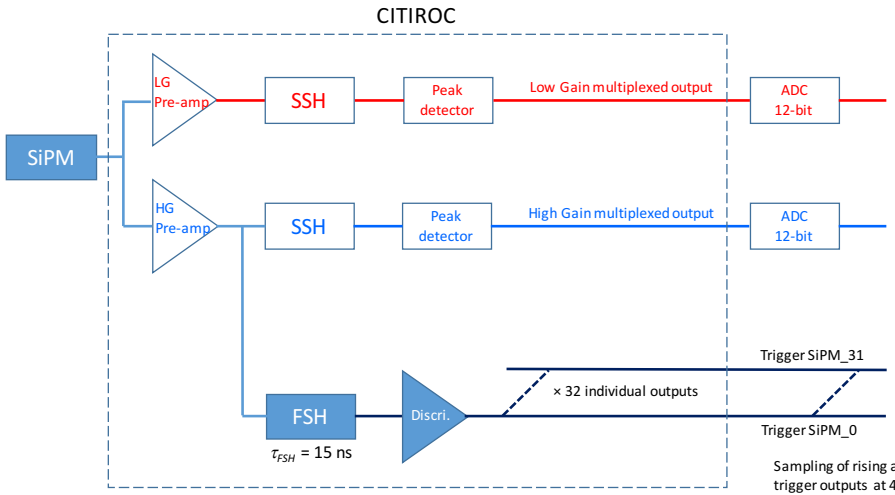
γ conversion candidate



Stopping proton candidate



Signal path and Calibration method



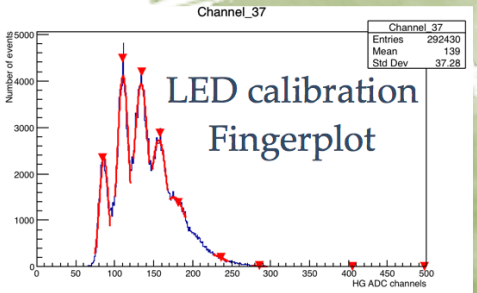
Sampling of rising and falling edges of individual trigger outputs at 400 MHz
Provides:
- Time stamp
- Amplitude from time-over-threshold

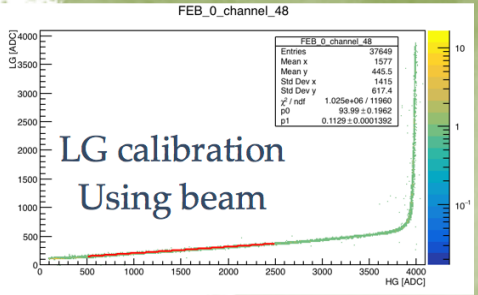
Calibration method

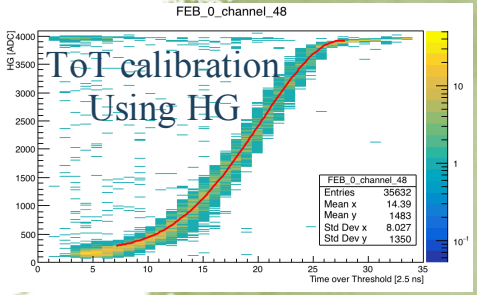
Extract LG calibration factors by fitting against HG data (roughly linear)

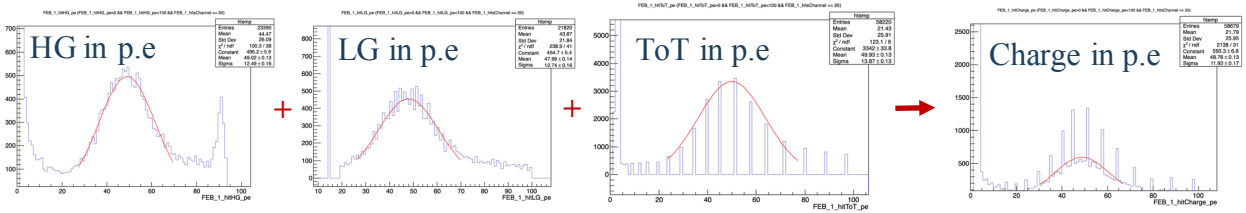
Extract HG calibration ratio ADC/pe from MPPC fingerplots

Extract ToT calibration factors by fitting against HG and LG data (non-linear)





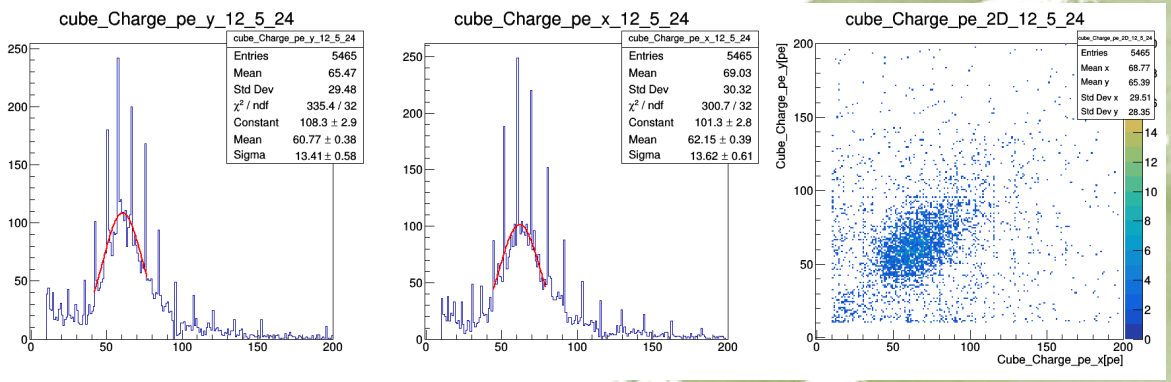


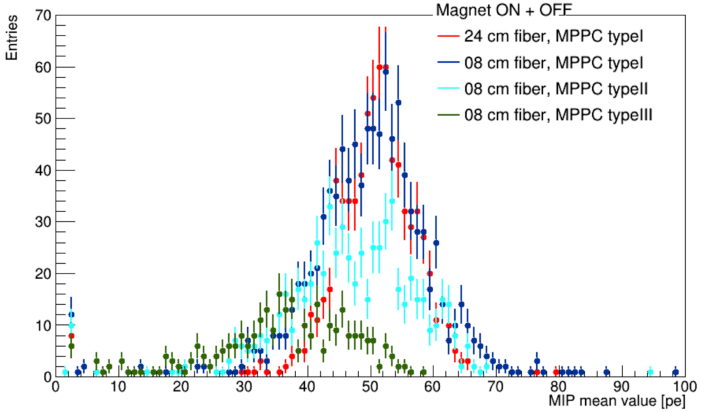


Cube response to MIP

2GeV Muons

- Cube LY from horizontal and vertical fibers. Example
- Average LY ~ 50 p.e (for MPPC type I)





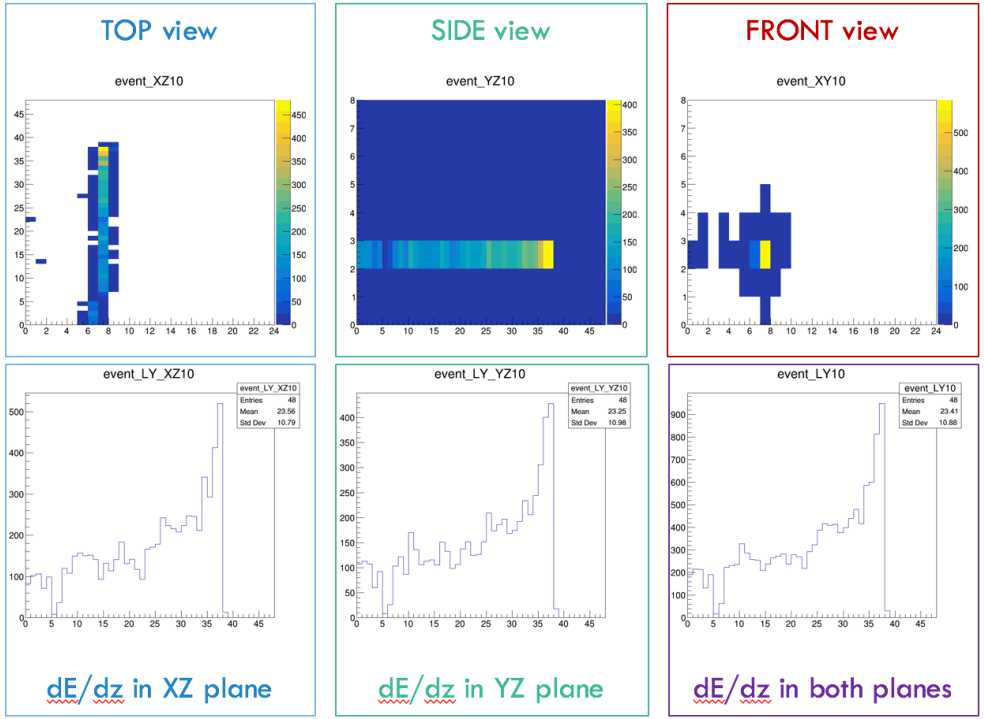
Mean

By Eirik GRAMSTAD

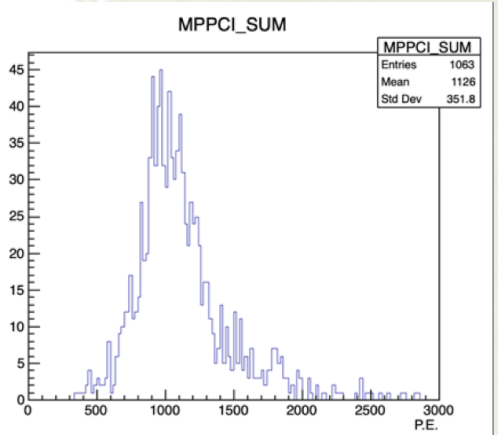
	MPPC type	Fiber length [cm]	Mean [pe]	Sigma
S13360-1325CS	I	24	51.3	5.9
	I	8	50.2	8.0
S13081-050C	II	8	47.4	9.3
S12571-025C	III	8	38.0	10

Stopping Protons 0.8 GeV

By Dana DOUQA



- Distribution of Energy Deposited in the stopping cube (1063 Events)

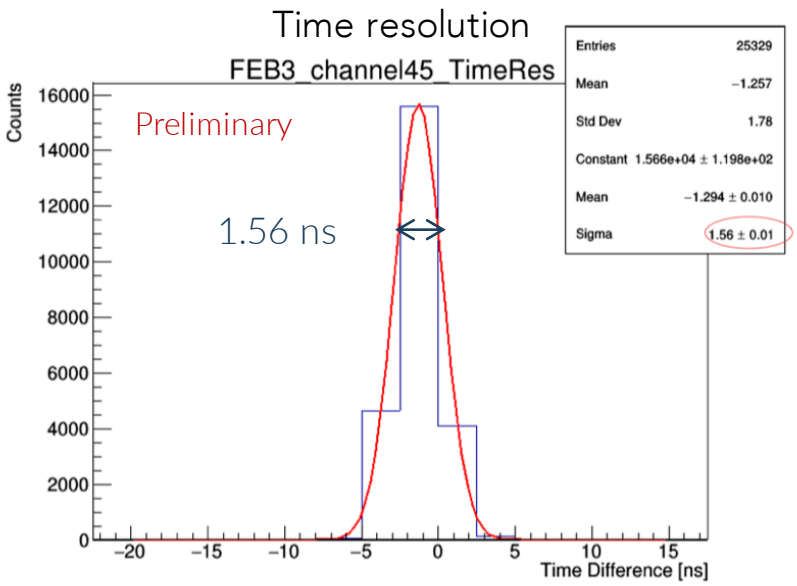


Sum of energy taken by both sets of fibers.

Time resolution

By Wilf SHORROCK

- Event median hit time is used as reference time
- Time resolution ~ 1.5 ns
  - Sample: 10^5 muon events
  - Hits with charge > 20 p.e
  - Walk time correction is not applied



--> a lower time resolution with **walk time correction** is expected.

Summary

- An upgrade of the T2K near detector suite is underway to strengthen T2K physics potential
- A novel 3D plastic scintillator detector called *Super FGD* is under development to serve as an active target
- There are many challenges ahead to realize this detector
- Various prototyping and validation tests are on the way
- A 48x24x8 prototype was tested at CERN beam test; Results are promising

...Still much to do

- Installation of final detectors foreseen at J-PARC for summer 2021.

Back up

Alternative assembly procedure

Techniques

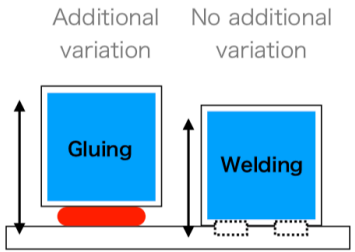
Ideas by Ichikawa-san & Aoki-san

Ultrasonic welding on a sheet

Polystyrene sheet

- PLAPAPER (TAMIYA INC.)
  - Thickness : 0.2 mm
  - Size : 257 mm x 364 mm
  - Low cost: ~100 Yen/sheet
  - Holes can be easily made

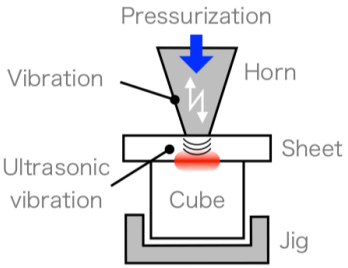
Welding (No glue!!)



- Fabrication to join thermoplastics (or metal) by melting parts together

→ Good joint strength w/o additional variation

Ultrasonic welding



- Technique to apply ultra-sonic vibration for jointing workpieces by welding

→ Good precision with less denatured at low T

Total 2688 sheets (192/24 x 192/32 x 56)

- Readout from Front face, Top face and half of Right and Left faces.
- Flat cables connect MPPC PCB to the Patch Panel
- The Patch panel and FEB towers located on two sides of the Super FGD

SAMTEC cable