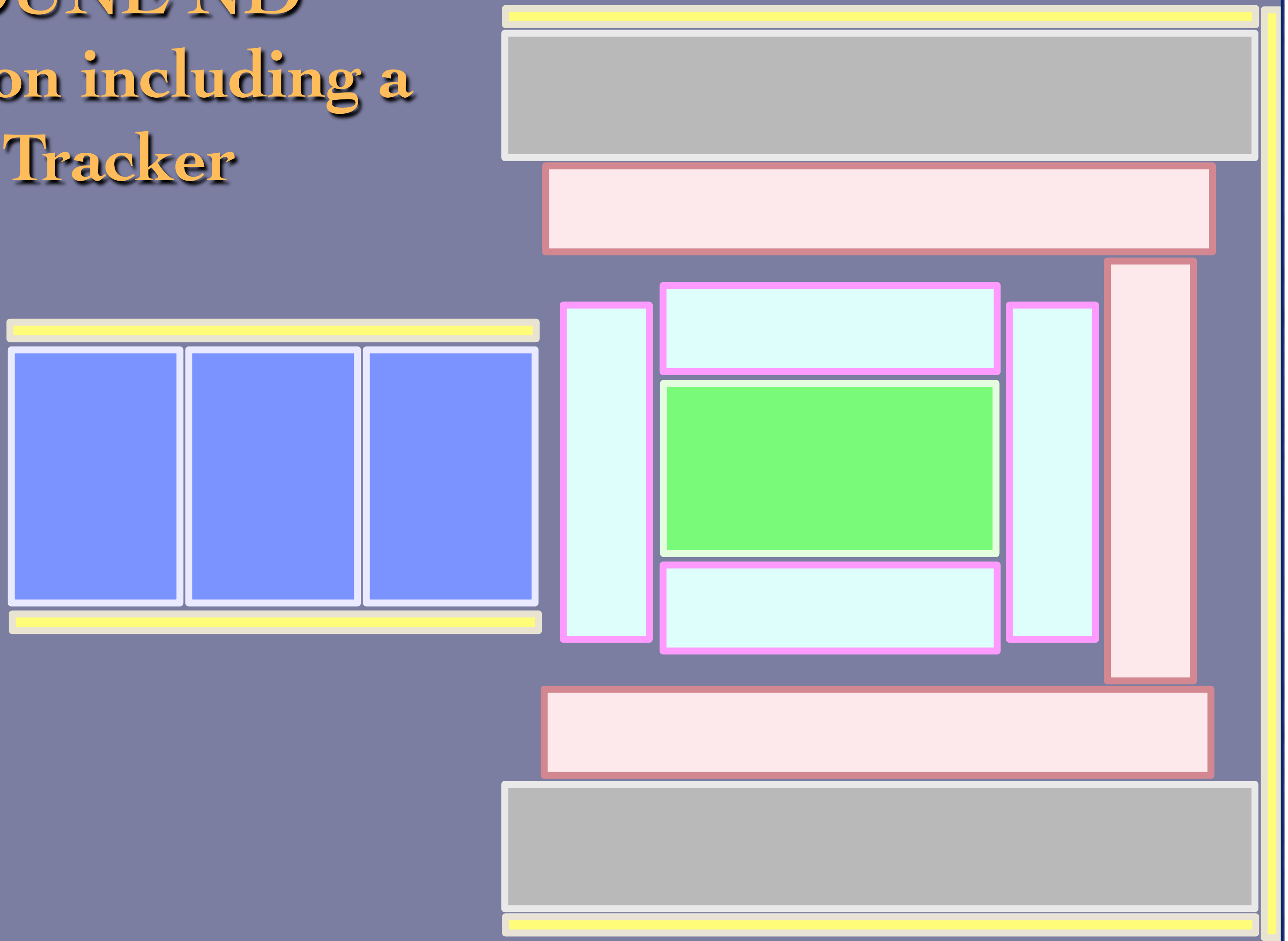
A Hybrid DUNE ND Configuration including a Scintillator Tracker (3DST)



Akihiro Minamino (Yokohama National University)
and
Chang Kee Jung (Stony Brook University)

DUNE ND Workshop
Fermilab
June 9, 2017

Structure of the Presentation

- Introduction/Motivation/Design Strategy - Jung
- Overall Layout of a Hybrid ND w/ 3DST - Jung
- 3DST Options and Performances - Minamino
- A List of Potential Collaborators on 3DST - Jung
- Summary - Jung

Introduction/Motivation/Design Strategy

- ND design should try to incorporate broad knowledge we have gained from the past and current experiments including their shortcomings
  - ¬Take advantage of T2K ND280 upgrade work which shares largely overlapping design goals with the DUNE ND
    - 3rd Workshop on "Near Detectors based on gas TPCs for neutrino long baseline experiments" – An open workshop

      https://indico.cern.ch/event/633840

      (Minamino's slides are based on the materials from this workshop.)

Introduction/Motivation/Design Strategy

- Prepare to adopt the advance in the neutrino physics
  - Projecting to the status of our knowledge in 10 years
    - Utilize the knowledge to be gained from both the LAr TPC experiments (ProtoDUNE, CAPTAIN and SBN detectors) and Scintillator detectors (MINERvA, T2K and NOvA)
    - Prepare to deal with new sources of systematic errors that are unknown today e.g.) 2p2h
    - Include complementary subdetectors that can better address physics requirements and syst. errors in a robust way

Introduction/Motivation/Design Strategy

- Design Strategy
  - ¬ The design should satisfy essential physics requirements including:
    - ν_e and ν_e-bar interaction measurement capability
      - → Charge separation w/ magnetic field, e/γ separation
      - → Control of systematic errors on ν_e / ν_μ and ν / ν-bar cross-section ratios
    - ν e scattering measurement capability
      - → Fully active and fine-grained detector w/ sufficient angular and energy resolutions, and large fiducial mass
      - → Highly desirable for flux constraint

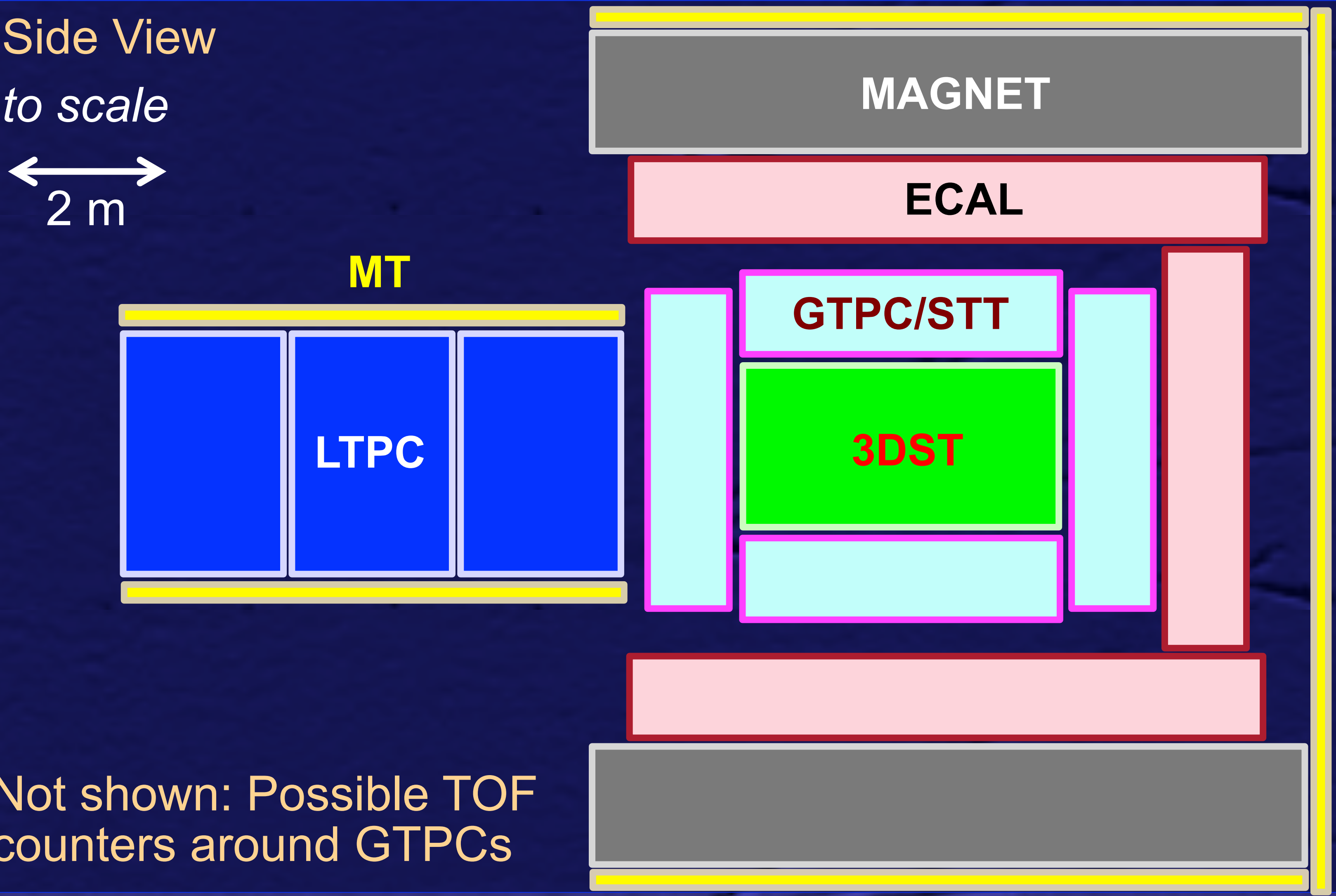
Introduction/Motivation/Design Strategy

- Capability for full investigation of neutrino interaction models including 2p-2h models
  - → Full 4π coverage
  - → Common shortcomings of the current experiments
- The ND should be able to provide meaningful constraints in the early running period of the experiment
- The design elements (sub-detectors) should attract a broad group (consortium) of interested institutions
- The design elements (sub-detectors) should have plausible funding scenario/path

A Hybrid-Detector Configuration w/ 3DST

Side View

to scale

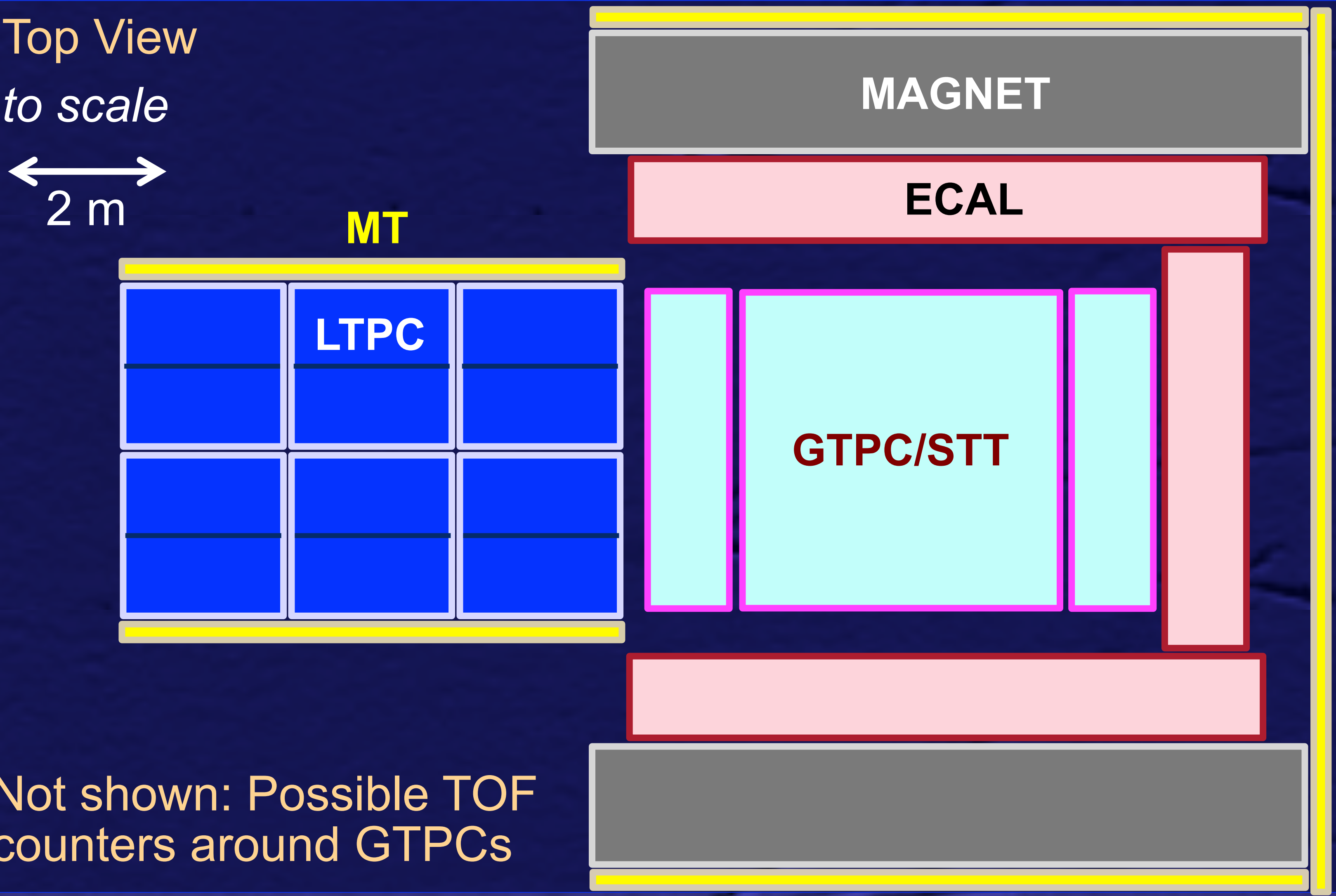


Not shown: Possible TOF counters around GTPCs

A Hybrid-Detector Configuration w/ 3DST

Top View

to scale



Not shown: Possible TOF counters around GTPCs

3D scintillator tracker options/performance

A. Minamino (YNU)

DUNE ND workshop

June 9, 2017

This is a summary of what we have discussed at a T2K near detector upgrade workshop, “3rd Workshop on Near Detectors based on gas TPCs for neutrino long baseline experiments”. Details are found in the indico page of the workshop, https://indico.cern.ch/event/633840/ .

Personal thoughts

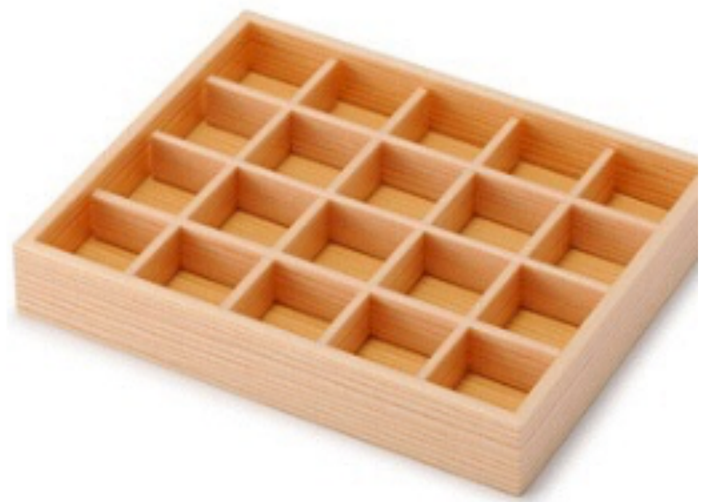
- Current criteria for the T2K ND upgrade design
  - Cover the full muon polar angle
    - 3D scintillator tracker + Top/Bottom/Downstream TPCs
  - With carbon targets
    - 3D scintillator tracker can be used as a full active neutrino target detector.
  - Increase the efficiency for low momentum protons
    - Granularity of 3D scintillator tracker will be optimized.
  - Improve the purity of the nue sample in the low momentum region
    - Gamma-rays induced by neutrino interactions are the main backgrounds.
    - Granularity of 3D scintillator tracker is important to identify the electron/positron pair tracks created by the gamma-ray BGs.
    - We are studying the possibility to identify gamma-ray BGs by counting the light yield. In order to do that energy resolution should be high enough to distinguish a single electron from a electron/position pair.

Personal thoughts

- Discussion points
  - Importance of the full muon polar angle coverage for DUNE is not clear.
    - Muons in DUNE go more forward than T2K because DUNE's neutrino energy is higher than T2K.
      - Phase space of the muons in the DUNE ND should be checked.
    - Neutrino energy reconstruction ways are different.
      - T2K: muon kinematics + CCQE assumption
      - DUNE: Calorimetric
  - The target nucleus of the DUNE near(main)/far detectors is argon, and that of the 3DST is carbon.
    - Chang Kee's idea is to use the 3D scintillator tracker data as a bridge between MINOS/MINERVA/NOVA/T2K and DUNE.
    - It is important to make clear what systematics of the neutrino interactions for DUNE oscillation analyses can be constrained by the 3DST measurements.
    - It is also important to make the decision if nue measurement will be done with the 3DST or not based on the impact for the DUNE oscillation analyses.

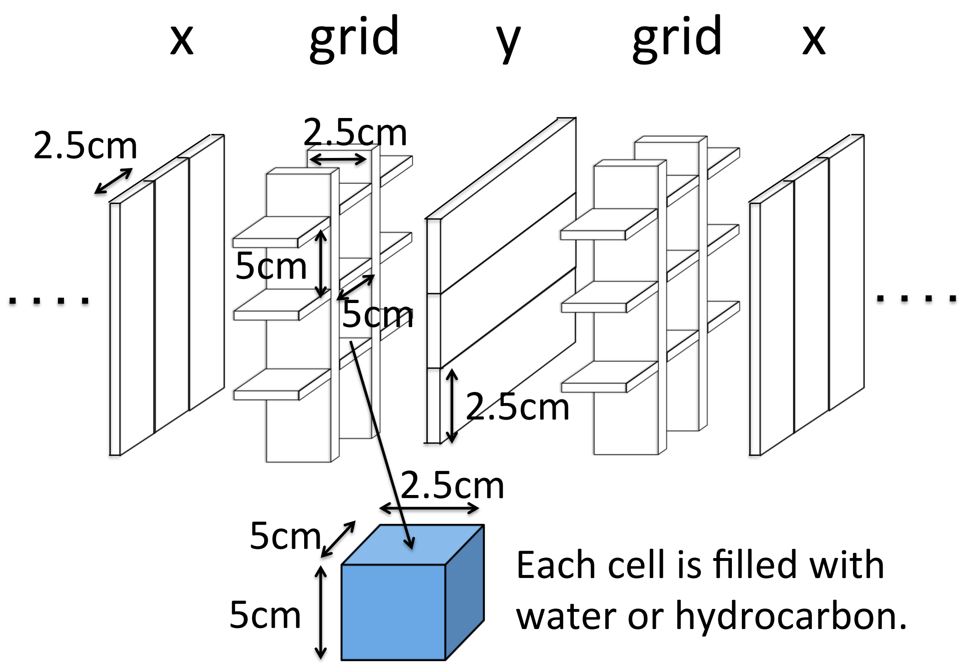
WAter Grid And SCIntillator detector (WAGASCI)

The design is optimized for water target measurements.

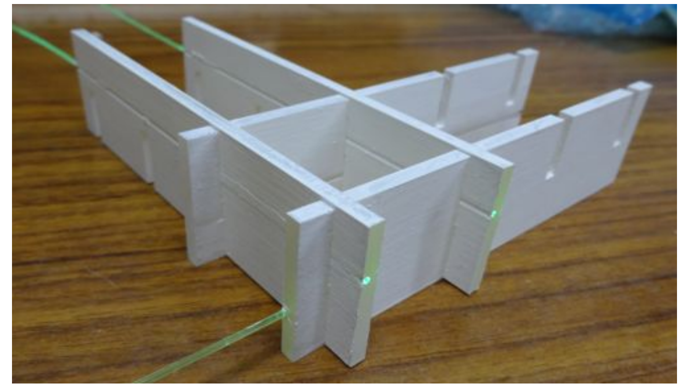


WAGASCI design

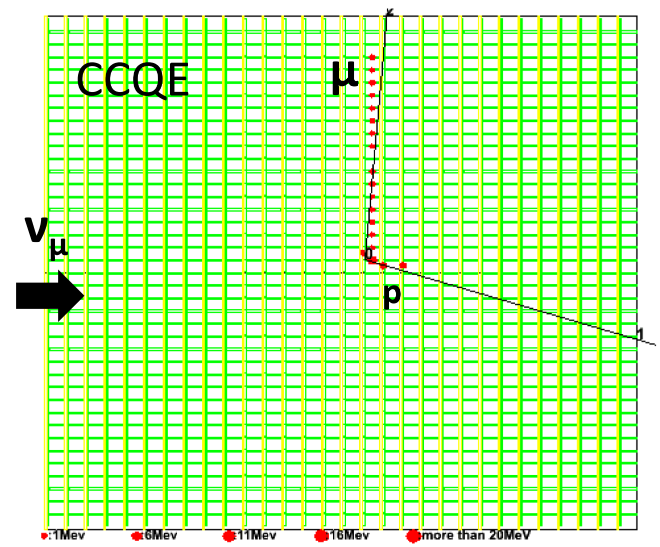
- **3D grid neutrino detector**
  - x + grid + y + grid + … layers
  - **4π angular acceptance**
  - **H_2O(signal):CH(BG) ~ 8:2**



3mm thin scintillator bar made @ Fermi-lab is used.



Event display (MC)

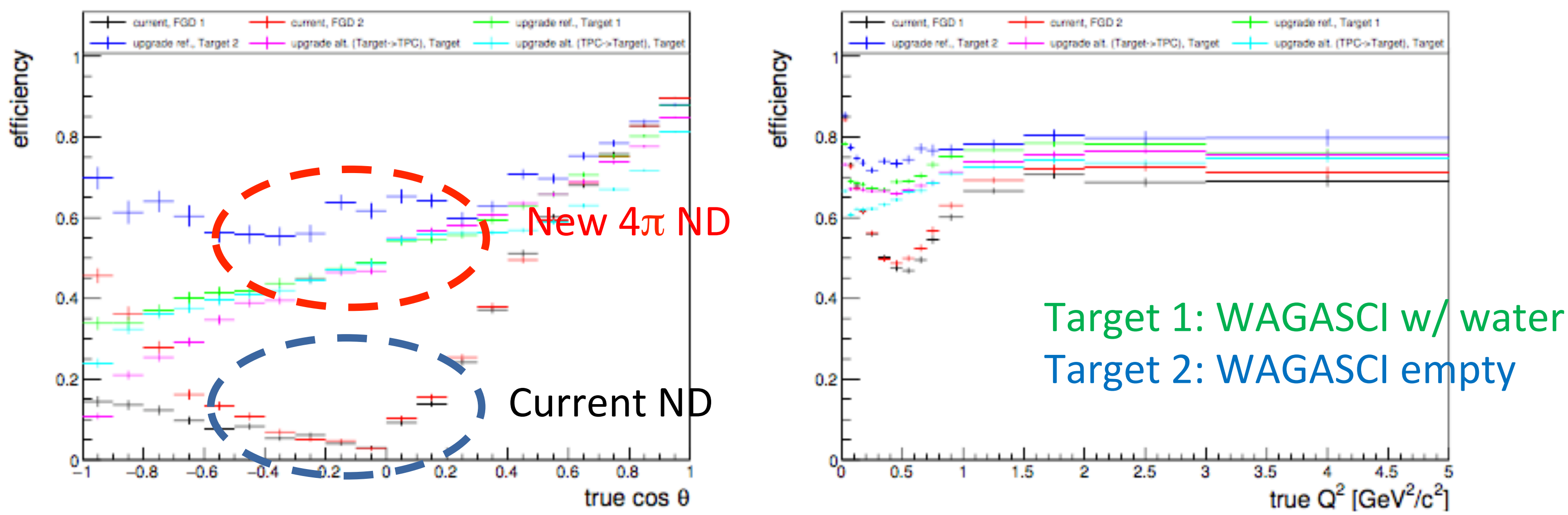


WAGASCI + new TPCs

Efficiencies

ν_μCC-inclusive selection efficiencies

How well can we select the muon from ν_μCC interaction in FGD or Target?



- current-like efficiencies behave as expected (low backward eff)
- upgrade fills the high-angle and backward region

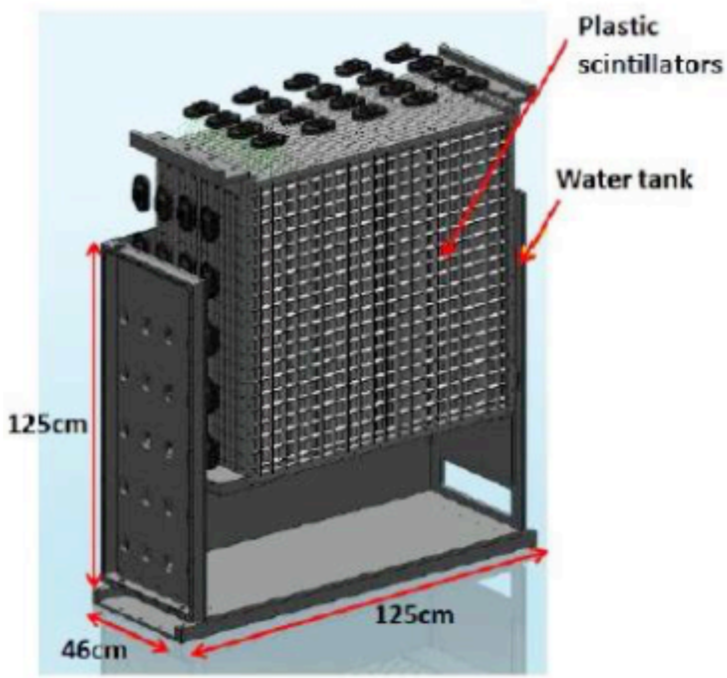
*ToF are assumed with a time resolution of 600 ps

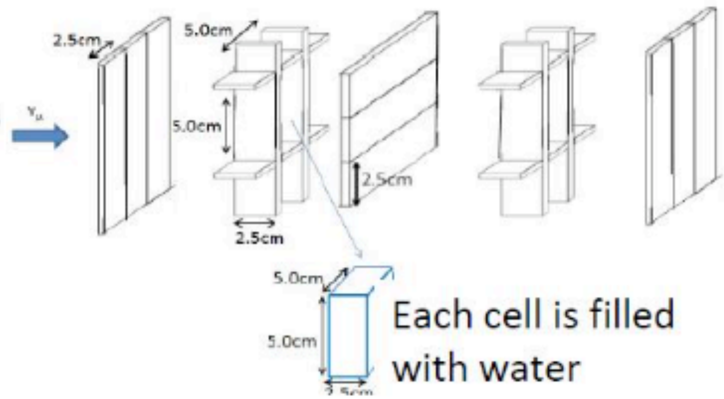
R&D with prototype

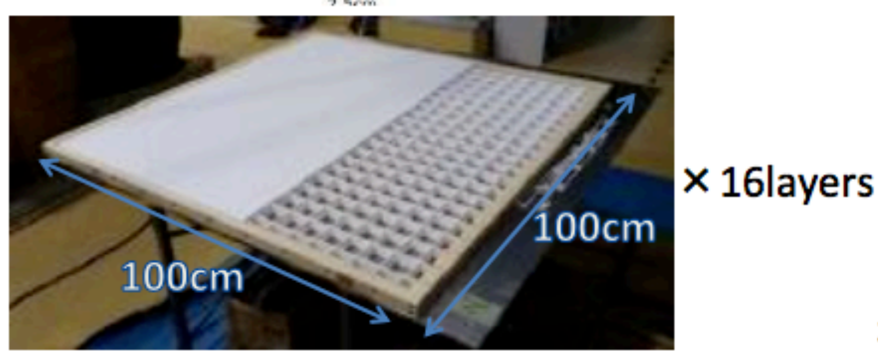
-Target: 1×1×0.5m³ (0.5ton) H_2O

-Plastic scintillators are set in water like grid

- -3mm thickness scintillator --> H_2O:scintillator=80:20
- -WLS fiber + new low noise MPPC readout --> enough light yield
- -Electronics is common as INGRID







R&D with prototype

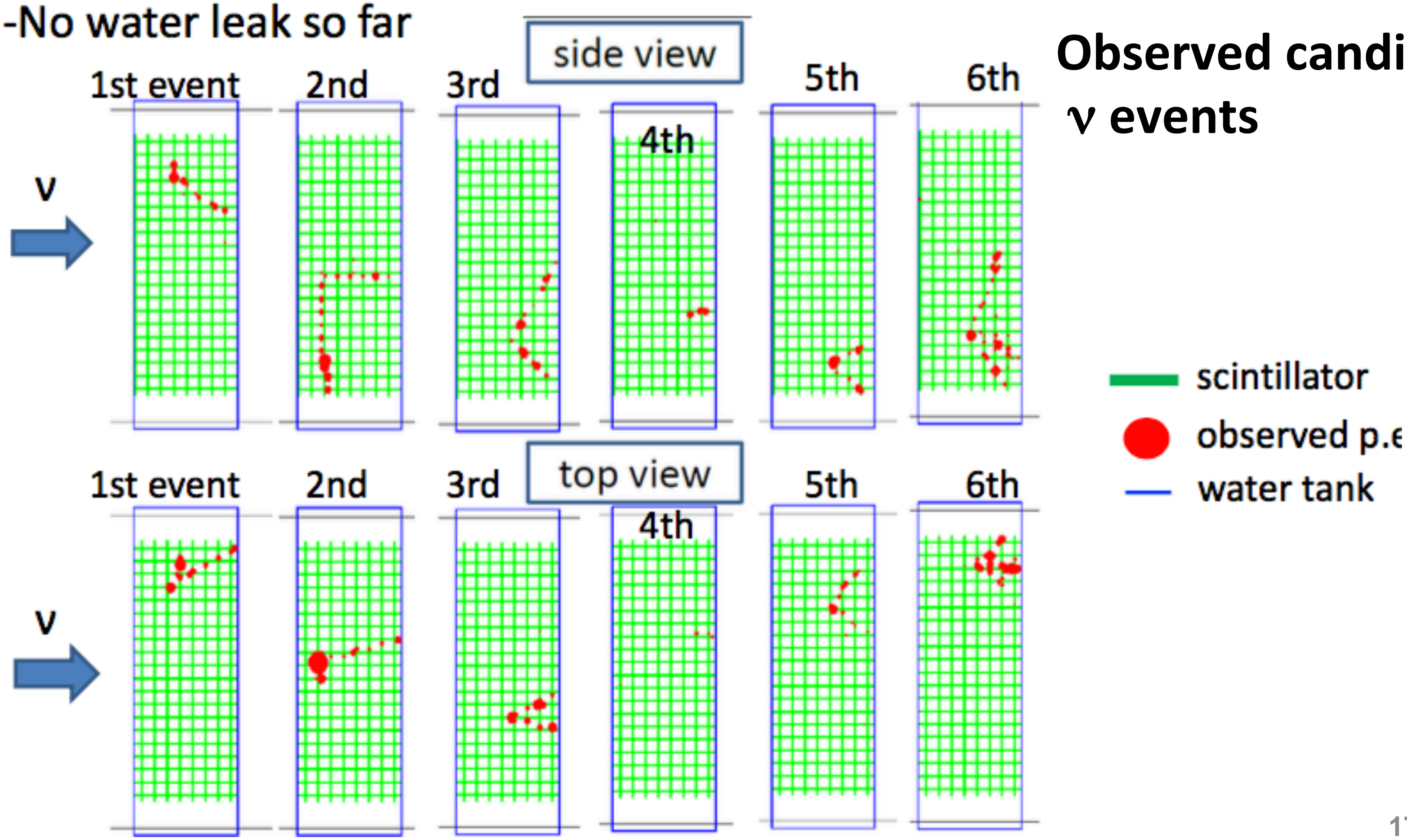
-Detector was installed in July 2016 at on-axis

-First neutrino beam event is observed in 27th October 2016

-More than 3×10^{20}POT has been collected so far with 99% efficiency

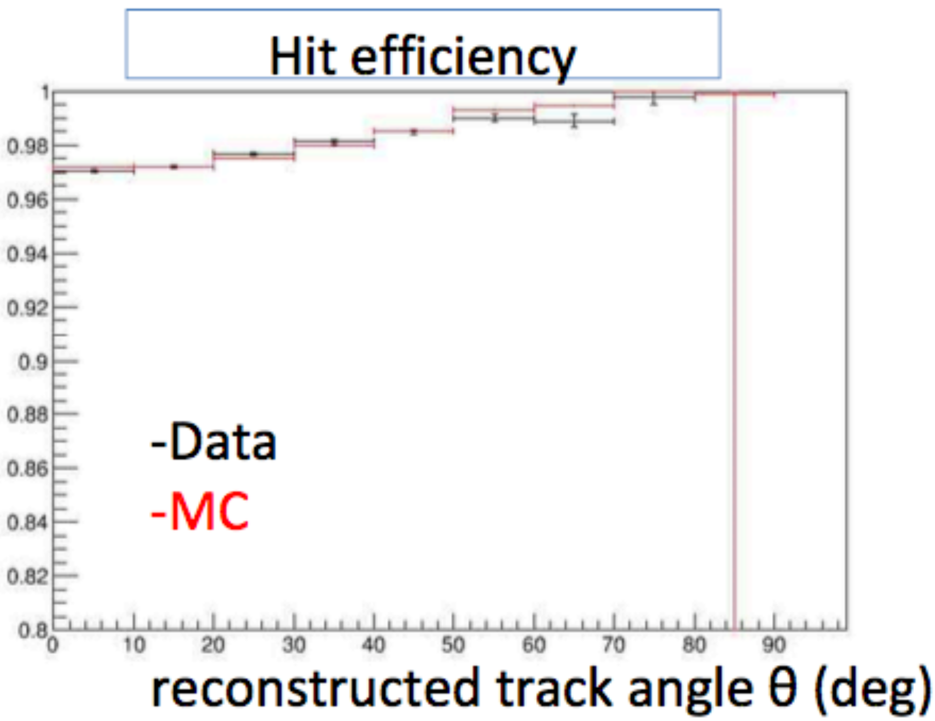
-No water leak so far

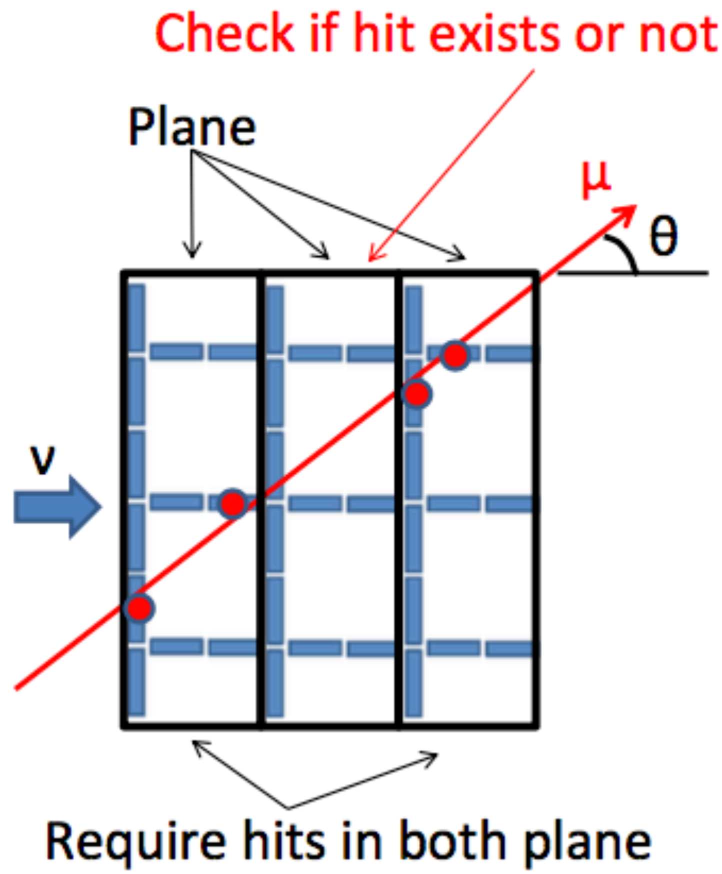
Observed candidate ν events



R&D with prototype

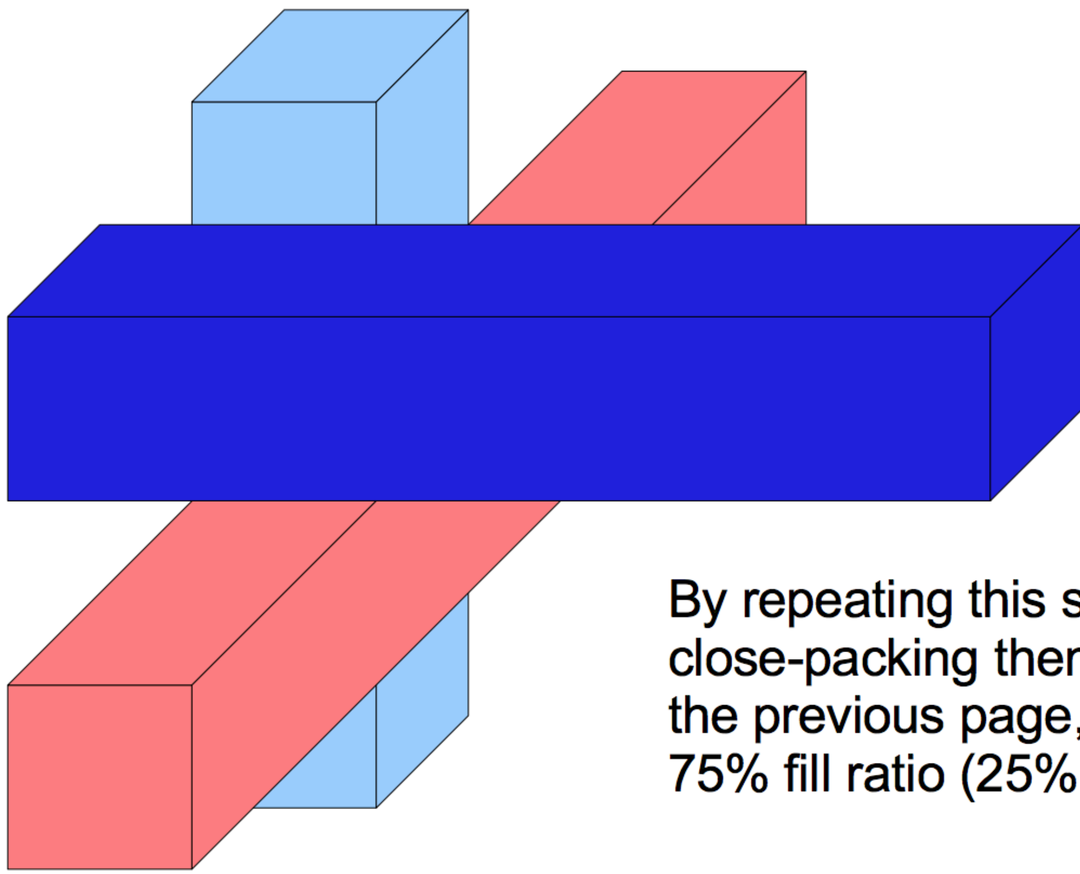
-Hit efficiency along beam axis is measured by sand muon
 -Within 1% agreement





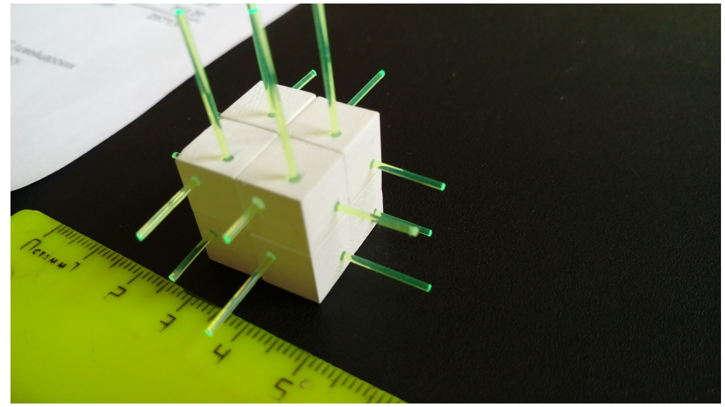
Scott Oser's slide
at ND upgrade TF meeting (Jan. 4, 2016)

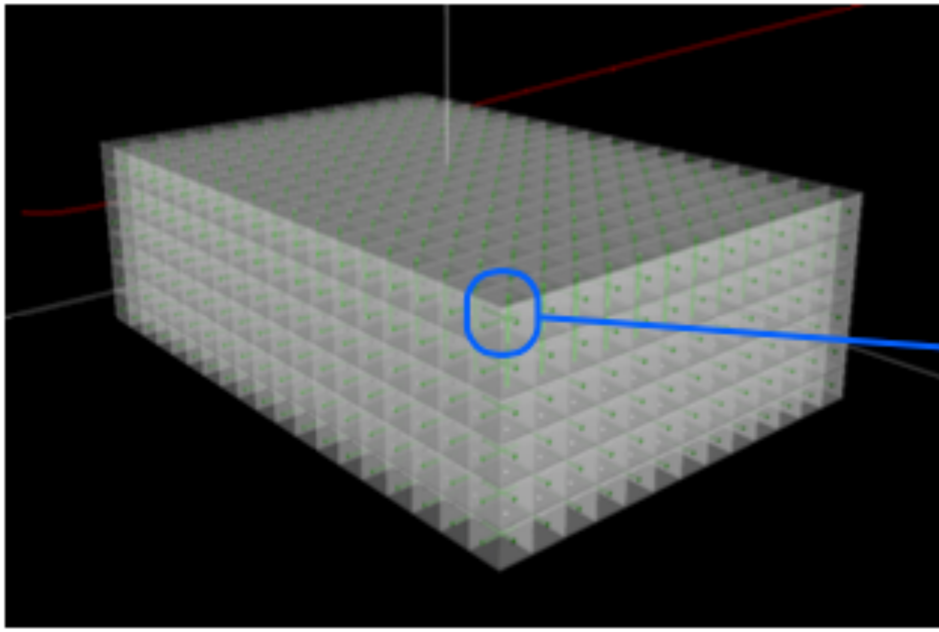
The 3-axis structure



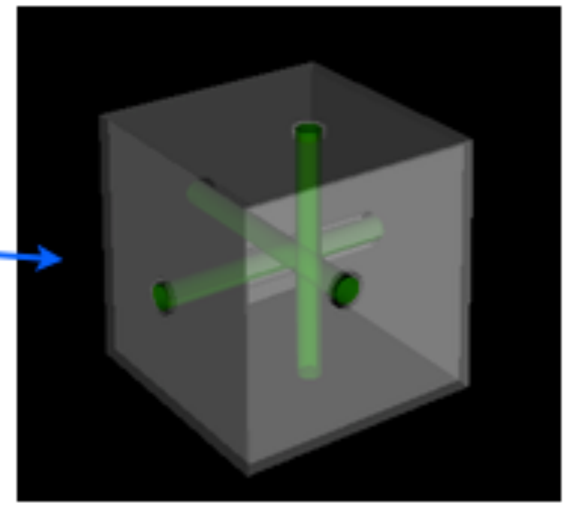
By repeating this structure and close-packing them as shown on the previous page, you can get 75% fill ratio (25% of volume is air)

Super FGD





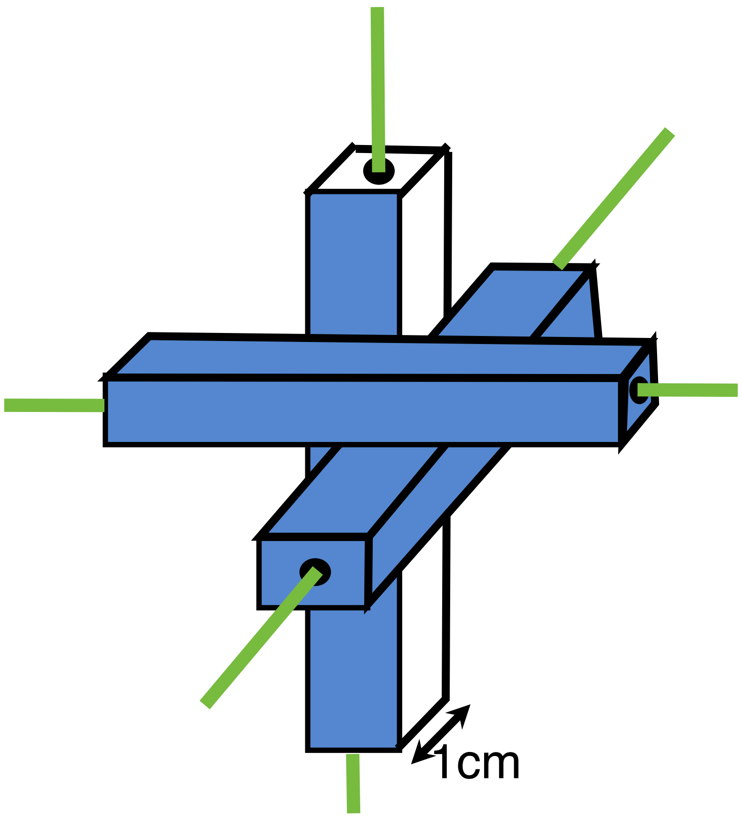
1 cm^3

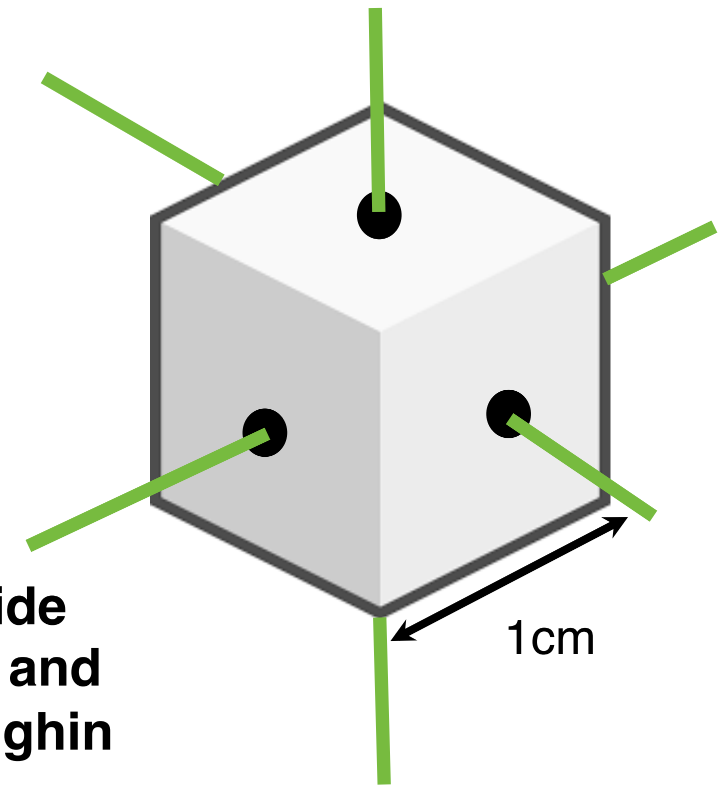


https://indico.cern.ch/event/633840/timetable/

Please check the section “Super-FGD”

SuperFGD



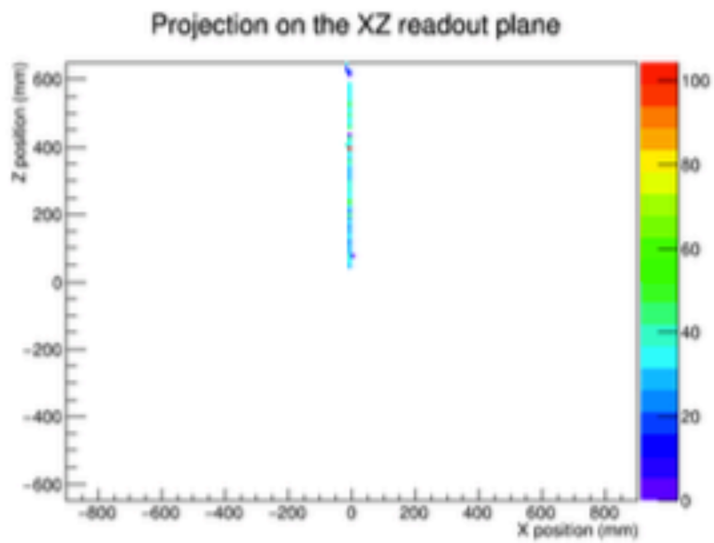


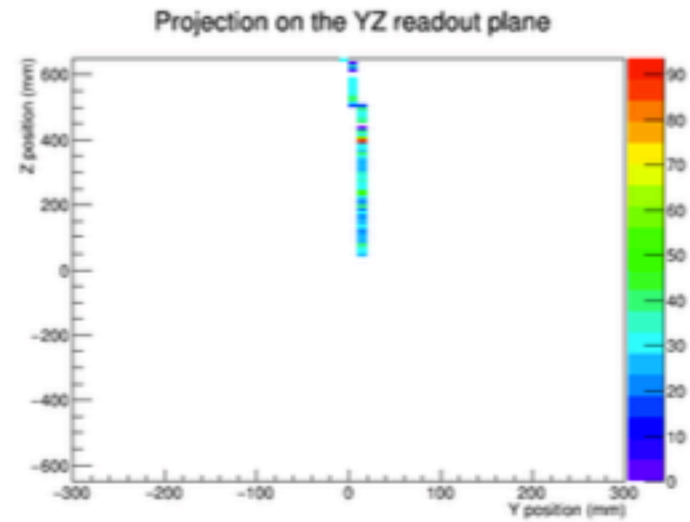
Idea of Davide Sgalaberna and Andrea Longhin

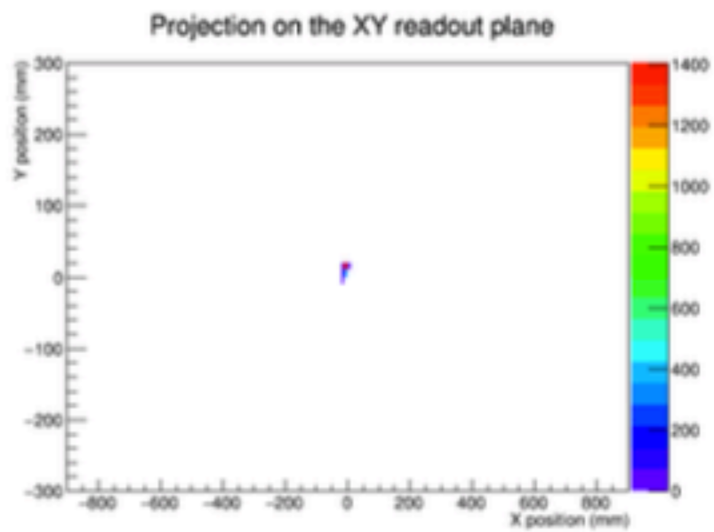
- Extruded plastic scintillator
- Light collected by 3 fibers --> Tot # of p.e. ~x3 than (needs teste)
- Each cube coated with TiO_2 to keep light entrapped inside the cube --> may expect better light yield than long plastic bar (needs test)
- 1 particle interaction (energy released) would produce light collected in the 3 fibers at the same time --> 1 track interaction = 1 hit!!!

Simulation of SuperFGD

Muon particle gun: E_{kin}=400 MeV, Along Z axis







- # of p.e. / cm (MIP) ~ 30-40 p.e. / fiber
- ~x2 than FGD because of new MPPC
- But we have 3 fibers / cm^3 --> ~100 p.e./cm
- Expect very good PID (>~100 p.e. / cm for MIP) and tracking (1cm on the single hit, better than FGD, FGD3D or water-WAGASCI)

Scintillation fiber detector

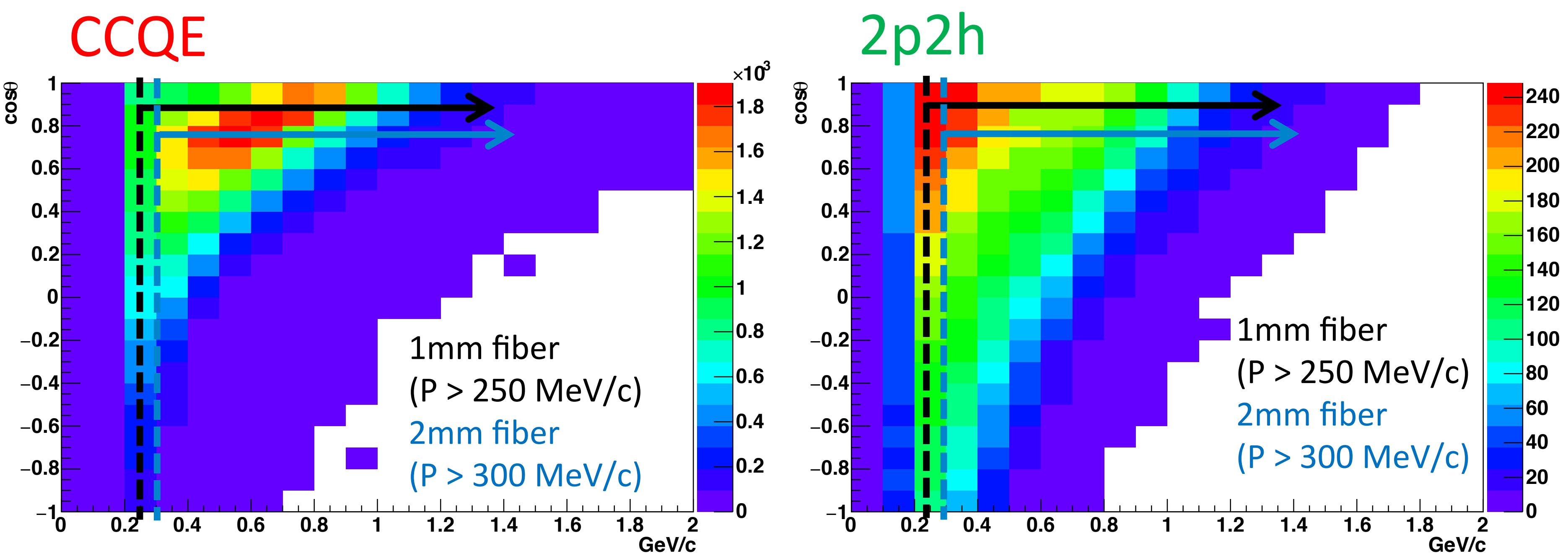
(my personal preference,
but it may be difficult for T2K ND-upgrade, considering the cost issues.)

Advantages of Scintillation fiber detector

- Could distinguish ν_e from γ BGs using track patterns
  - ν_e events: 1 electron track in the target detector
  - γ BGs: 2 electron tracks
- Can operate as a full active CH target
  - Vertex activity can be used to distinguish ν_e from γ BGs
- Can reconstruct large angle tracks with high efficiency
  - even with the conventional XY-layer configuration because of high granularity
  - Higher efficiency could be achieved by adopting the FGD-3D idea proposed by Scott Oser
- Optional: Can reconstruct short proton tracks
  - ~1cm-long track w/ 1mm fiber = 250 MeV/c proton

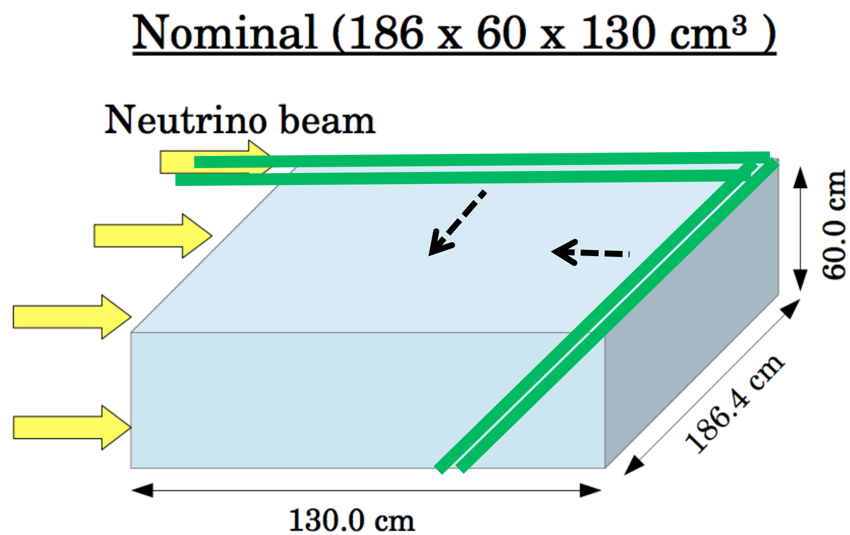
ν_μ events in 0.8 ton target for 10^{21} POT

Proton tracks after FSI



Challenges

- Large number of channels in the limited space

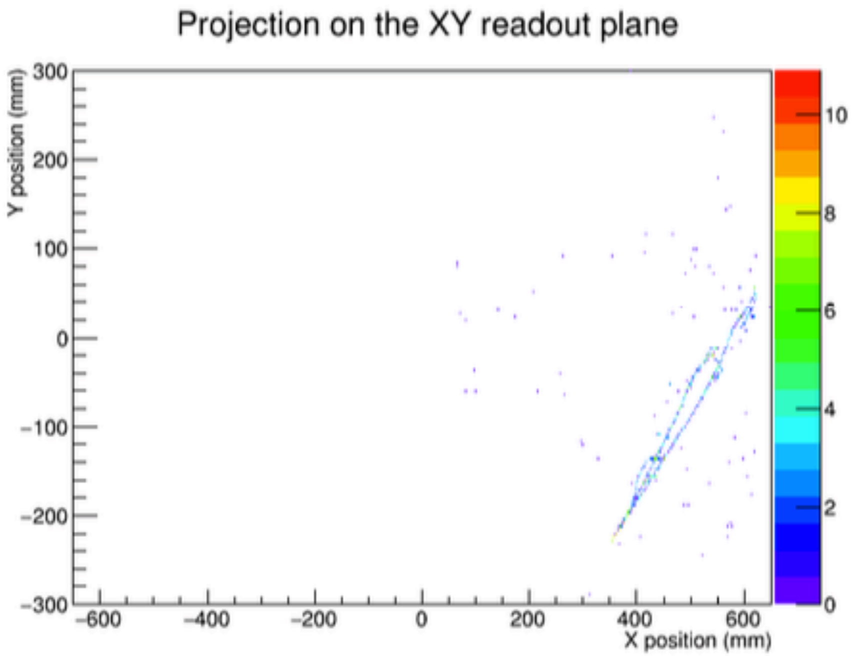


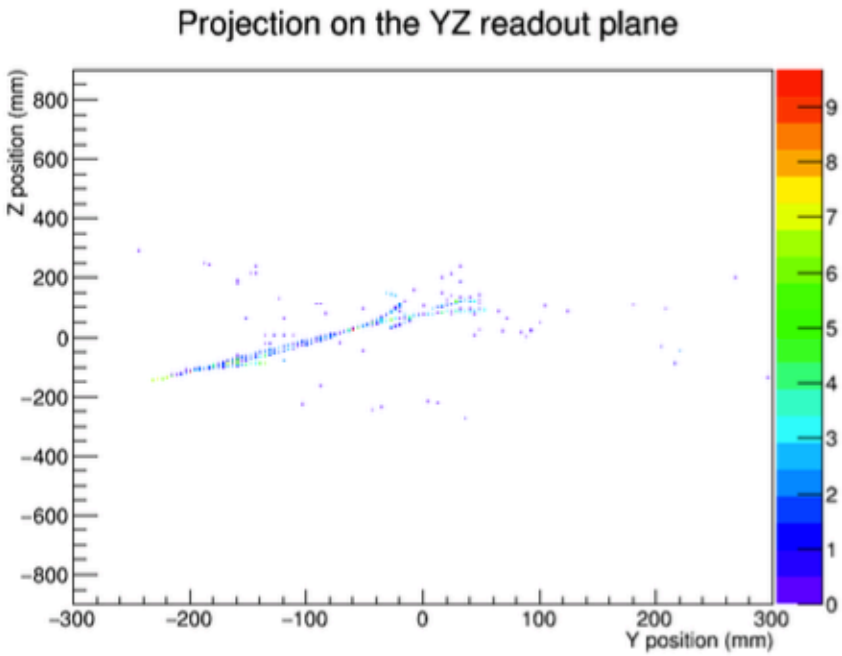
~1.5 tons

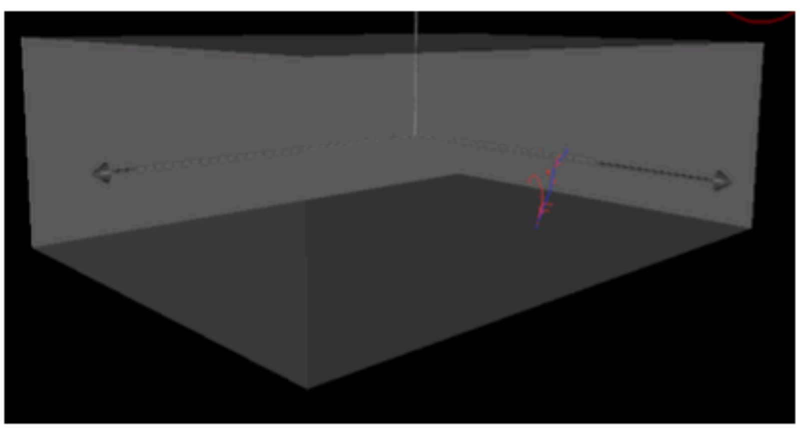
- Assuming 1mm(2mm) fiber w/ YZ readout
  - Y layer x 300(150), Z layer x 300(150)
  - Y layer = 1300(650) fiber, Z layer = 1864(932) fibers
  - Total: 1300 x 300 + 1864 x 300 ~ 1,000,000 fibers
  - (650 x 150 + 932 x 150 ~ 240,000 fibers)

Particle gun: gamma

- Hit position (MPPC) Vs # p.e.







Gamma, E_{kin}=400MeV
Pos(0,-600,-500), Dir(1,1,1)

- The gamma conversion is well visible

Summary (personal thoughts)

	Carbon target	Full angle (muon)	Low thre. for protons	nue measur.	R&D	Cost
WAGASCI (w/o H_2O)	△	○	○	×	○	○
Super-FGD	○	◎	△	△(*1)	(*2)	○
Scinti. fiber	○	○	◎	◎	Not yet	×

(*1) If we can identify gamma-ray BGs by counting the light yield, △ -> ○
(*2) We plan to start R&D of Super-FGD soon, probably next month.

A list of Potential Collaborators on 3DST

- Expressed Initial Interests
  - Yuri Kudenko (INR, Russia)
- Under discussion
  - CERN
  - Chung-Ang University, S. Korea
  - Various U.S. members and institutions
  - …

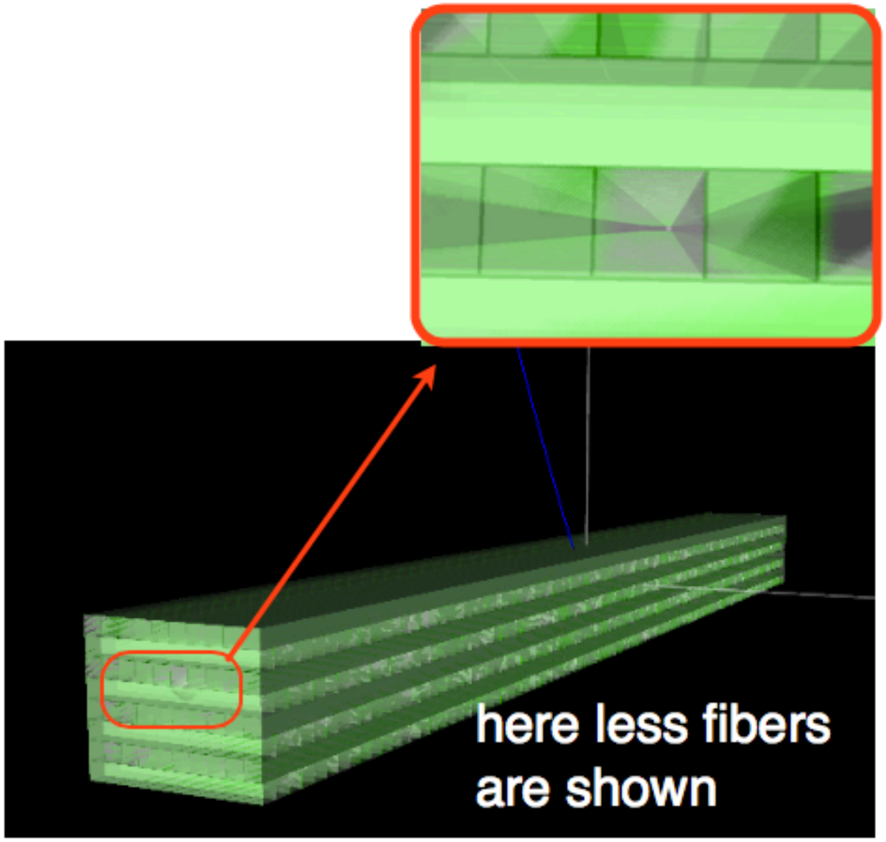
Summary

- A hybrid detector design w/ a 3DST:
  - will be a robust system that is less subject to specific deficiencies of a particular detector technology
  - can be optimized to meet all critical physics/FOM requirements
  - will bring a broad participation of collaborators
  - presents detector elements for which plausible funding scenario/ path can be envisioned (excluding the magnet)

Spplements

Simulation of Tracking Fiber detector

- First implementation of the SciFi detector and response is done
- Scint fibers alog X and Z to measure tracks going upward
- Single-cladding, square, 2mm edge scint fibers
- 3% of cladding on both edge as in Kurakay catalog
- Perfect SciFi: no gap, no glue, etc...



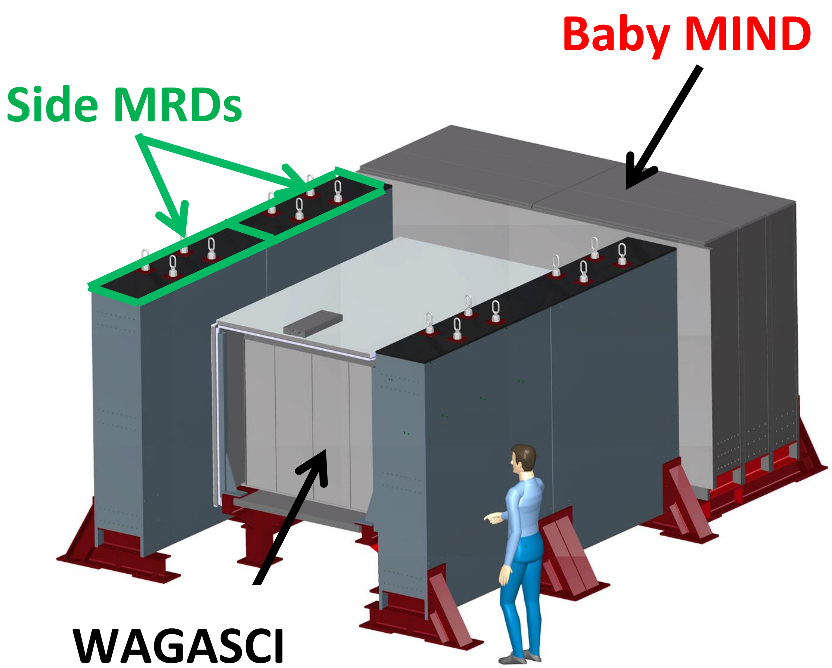
- Total size (mm^3):
  1300 x 600 x 1800
- Fiber edge: 2 mm
- # of fibers:
  900 horizontal (along X)
  650 vertical (along Z)
- # of layers (XZ each): 150
- mass=1489.61 kg

- Reconstructions Edep --> # of p.e. at MPPC is done

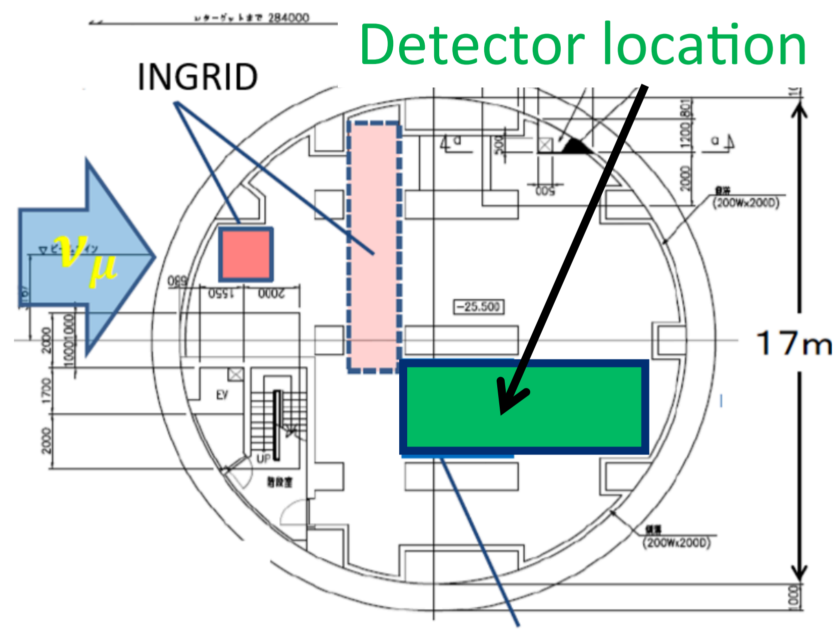
The 3-axis structure (FGD3D)

J-PARC T59: R&D of WAGASCI

- 3D-grid detector = WAGASCI
- Side muon-range detector (Side MRDs)
- Downstream magnetized MRD = Baby MIND

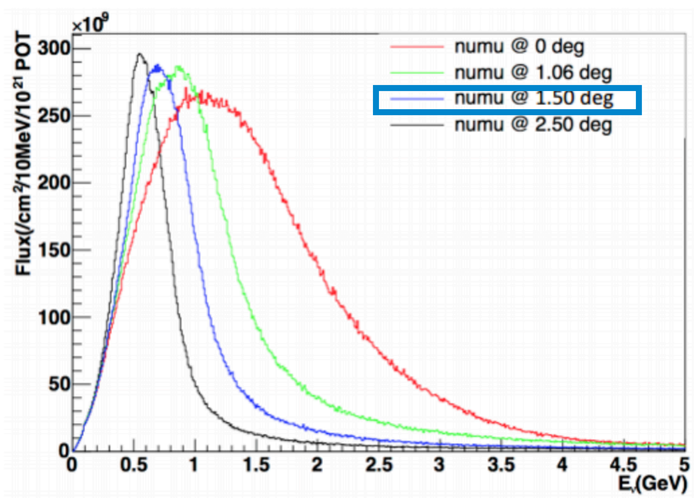


J-PARC NM B2 floor



J-PARC T59: R&D of WAGASCI

- Motivation
  - Test performance of 3D grid neutrino detector.
  - Test particle direction ID capability using TOF between WAGASCI and MRDs.
  - Optional: Test performance of WAGASCI w/o H_2O.
    - Higher efficiency for low momentum protons
  - Neutrino flux is different from ND280.
    - The flux difference/their sharp falling edge can be used to test the energy reconstruction resolution and migrations.



Candidate site

Physics motivation

- Detection of ν_e interaction at low energy with higher purity/efficiency.
- Detection of large angle tracks with higher efficiency
- Optional: Detection of proton tracks with lower threshold

A scintillation fiber detector could provide the solution.

The End