WAter Grid And SCIntillator detector (WAGASCI, J-PARC T59)

An optimized detector for measurements on water

A. Minamino (YNU) for J-PARC T59 collaboration

Jun. 29, 2017

NuINT17 @ Univ. Toronto

J-PARC T59 collaboration

- 13 institutes, 69 collaborators
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  - **Institute for Nuclear Research of the Russian Academy of Science (INR):** M. Antonova, A.Izmaylov, M.Khabibullin, A.Khotjantsev, A. Kostin, Y. Kudenko, A. Mefodiev, O. Mineev, T. Ovsjannikova, S. Suvorov, N. Yershov
  - **KEK:** S. Cao, T. Kobayashi
  - **Kyoto University:** T. Hayashino, A. Hiramoto, A.K. Ichikawa, B. Quilain, K. Nakamura, T. Nakaya, K. Yoshida
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  - **University of Geneva:** A. Blondel, F. Cadoux, K. Karadzhov, Y. Favre, E. Noah, L. Nicola, S. Parsa, M. Rayner
  - **University of Sofia:** M. Bogomilov, E. Mateev, R. Tsenov, G. Vankova
  - **University of Tokyo:** N. Chikuma, F. Hosomi, T. Koga, R. Tamura, M. Yokoyama
  - **Institute of Cosmic-Ray Research, University of Tokyo:** Y. Hayato
  - **University of Uppsala:** T. Ekelof, P. Simon
  - **University of Valencia:** A. Cervera
  - **Yokohama National University:** Y. Asada, K. Matsushita, A. Minamino, K. Okamoto, D. Yamaguchi

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- Detector configuration/location
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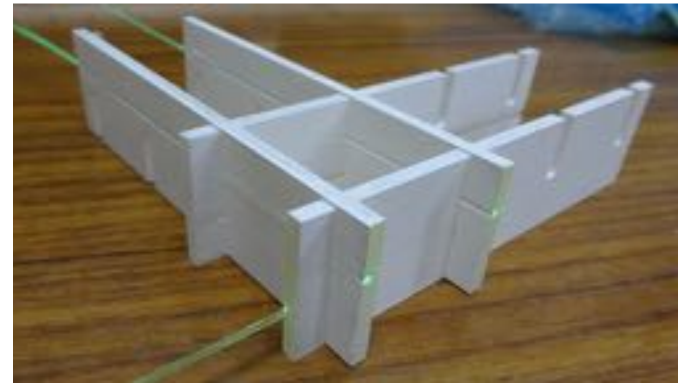
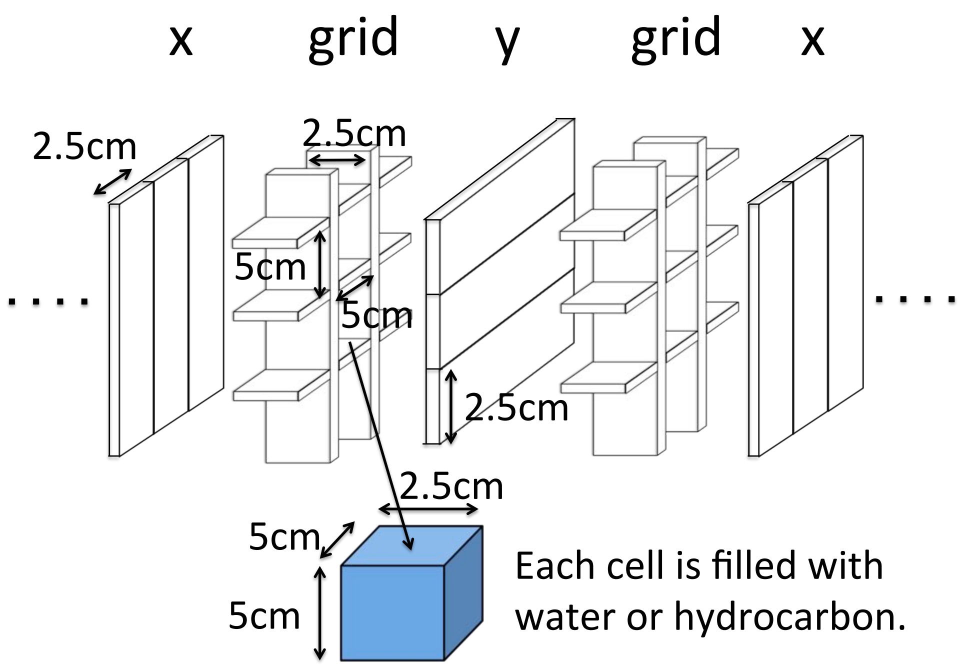
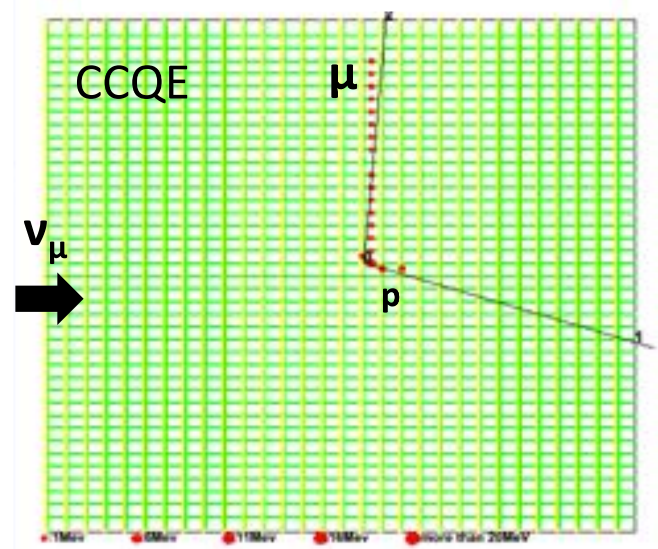
WAGASCI concept

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





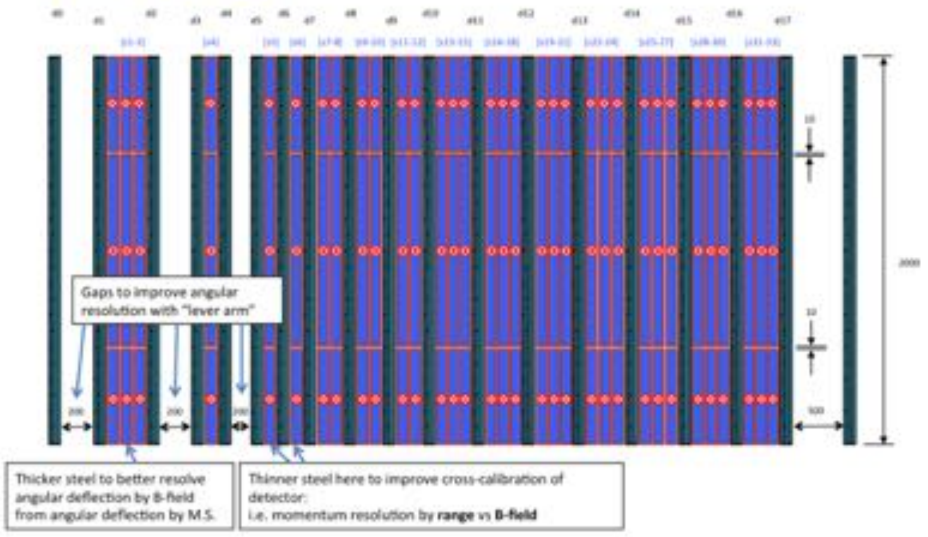
Event display (MC)



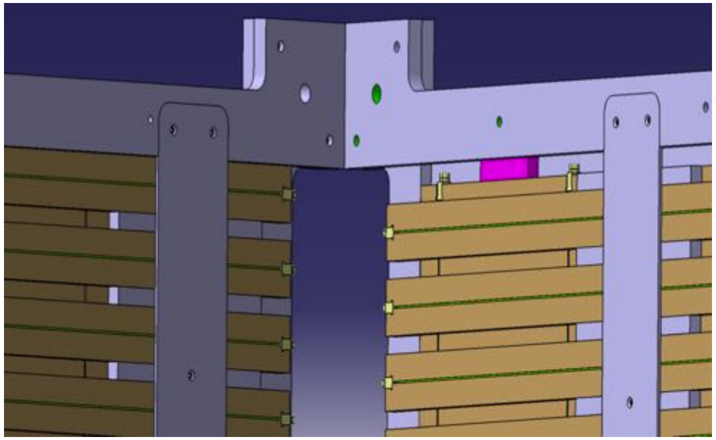
Baby-MIND concept

- **Magnetized Muon Spectrometer**
  - Can realize charge ID of muons
    - Essential in RHC mode where wrong-sign contamination is up-to 30%
  - Born from prototyping activities carried out within AIDA project
    - **Proposal to the CERN SPS committee:** Design, build and test the detector at CERN, then ship it to Japan.

33 magnet modules: 30mm Fe
18 scintillator modules: 31mm CH

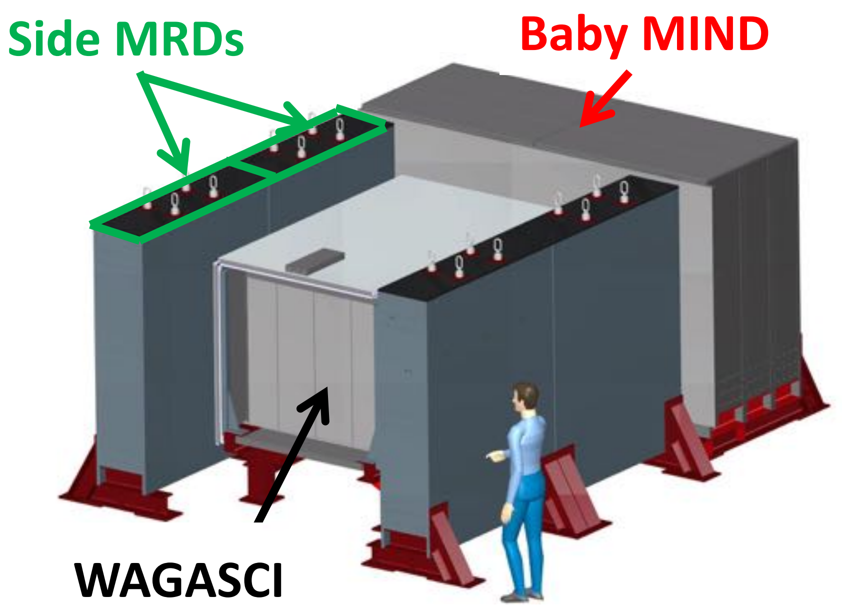


A half of scintillator module =
95 horizontal bars: 3000 mm x 31 mm x 7.5 mm
8 vertical bars: 1950 mm x 210 mm x 7.5 mm



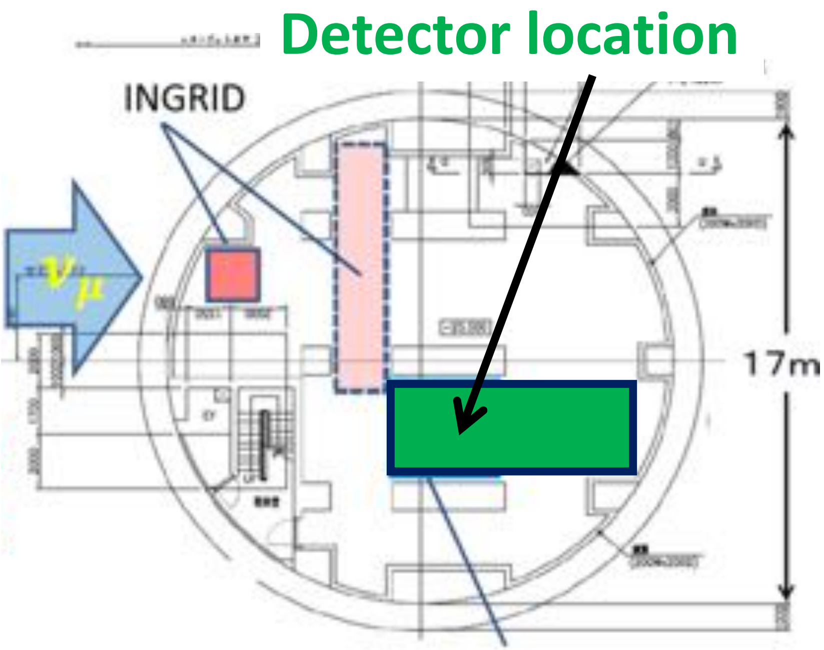
Detector configuration

- 3D-grid detector = WAGASCI
  - H_2O in fiducial volume: 0.4 ton x 2 modules = 0.8 ton
- Side muon-range detector (Side MRDs)
- Downstream magnetized MRD = Baby MIND

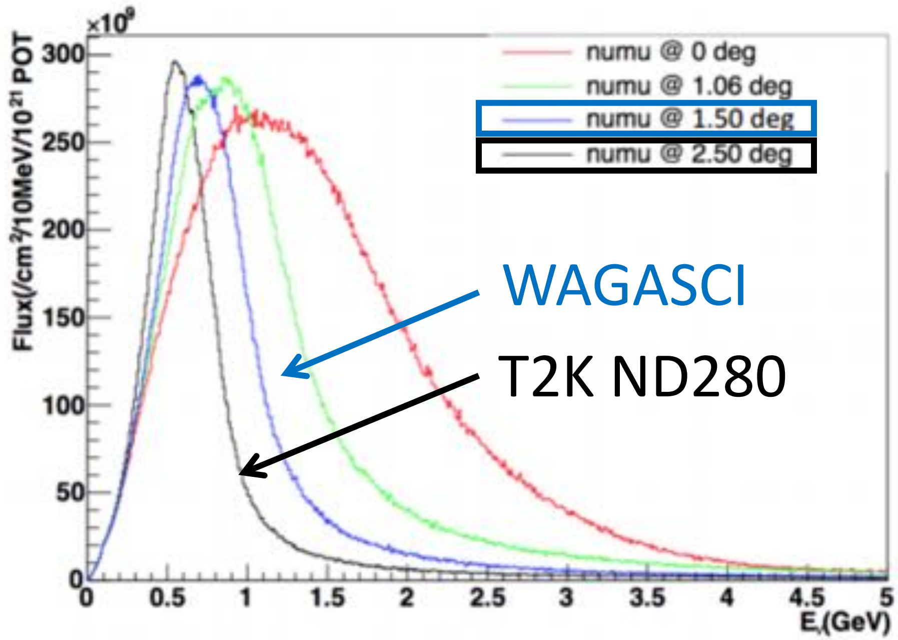


Detector location

B2 floor of T2K ND pit



Neutrino flux



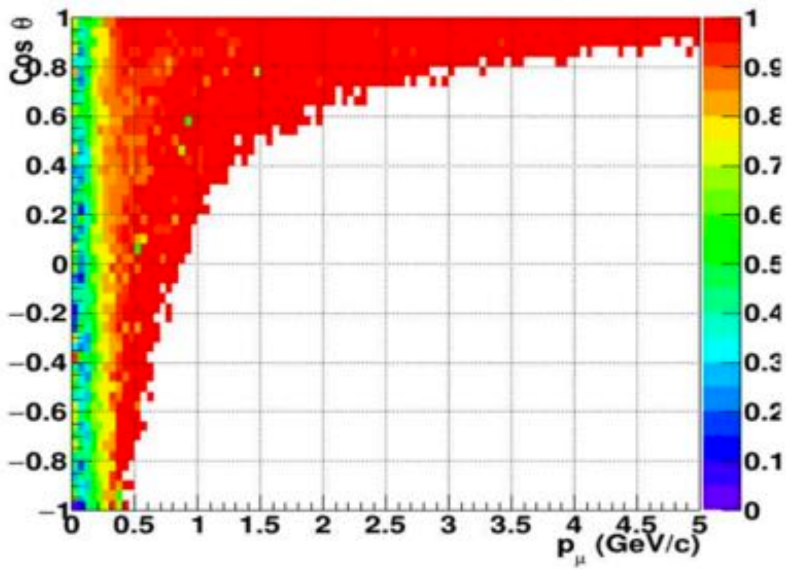
- After or at the same time as this project, the location may be used for dedicated cross-section measurements with new detector systems: prototype target detectors of ND280 upgrade, High Pressure TPC, thin target gas tracker, ... with Baby-MIND and Side-MRDs.

Motivation

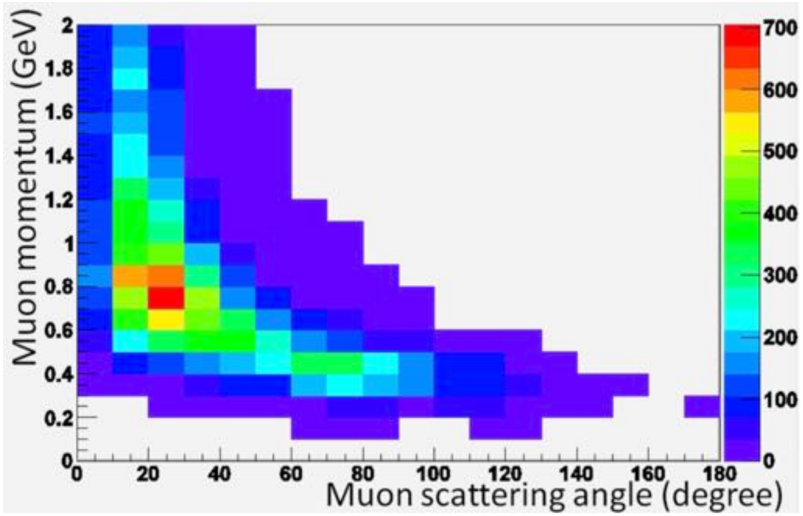
- **Detector performance test (as J-PARC T59)**
  - Uniform reconstruction efficiency in 4π dir.
  - Muon charge ID in Baby-MIND
  - Particle direction ID using TOF for identifying backward scatterings
  - Energy resolution/migration using a sharp falling edge of neutrino flux
- **Physics analyses (as J-PARC E##)**
  - Cross section measurements on H_2O/CH w/ 4π acceptance
    - CC-inclusive, then exclusive channels (CC-0π, CC-1π, …)
    - ~10% syst. errors (mainly from neutrino flux)
    - ~3% syst. errors for their ratios (flux error is canceled)
  - Studies w/ sharp neutrino spectra by a liner combination of WAGASCI/ND280 data (simple NuPRISM-like measure.)

Expected performance (1)

Reconst. efficiencies in WAGASCI



Reconst. events in WAGASCI



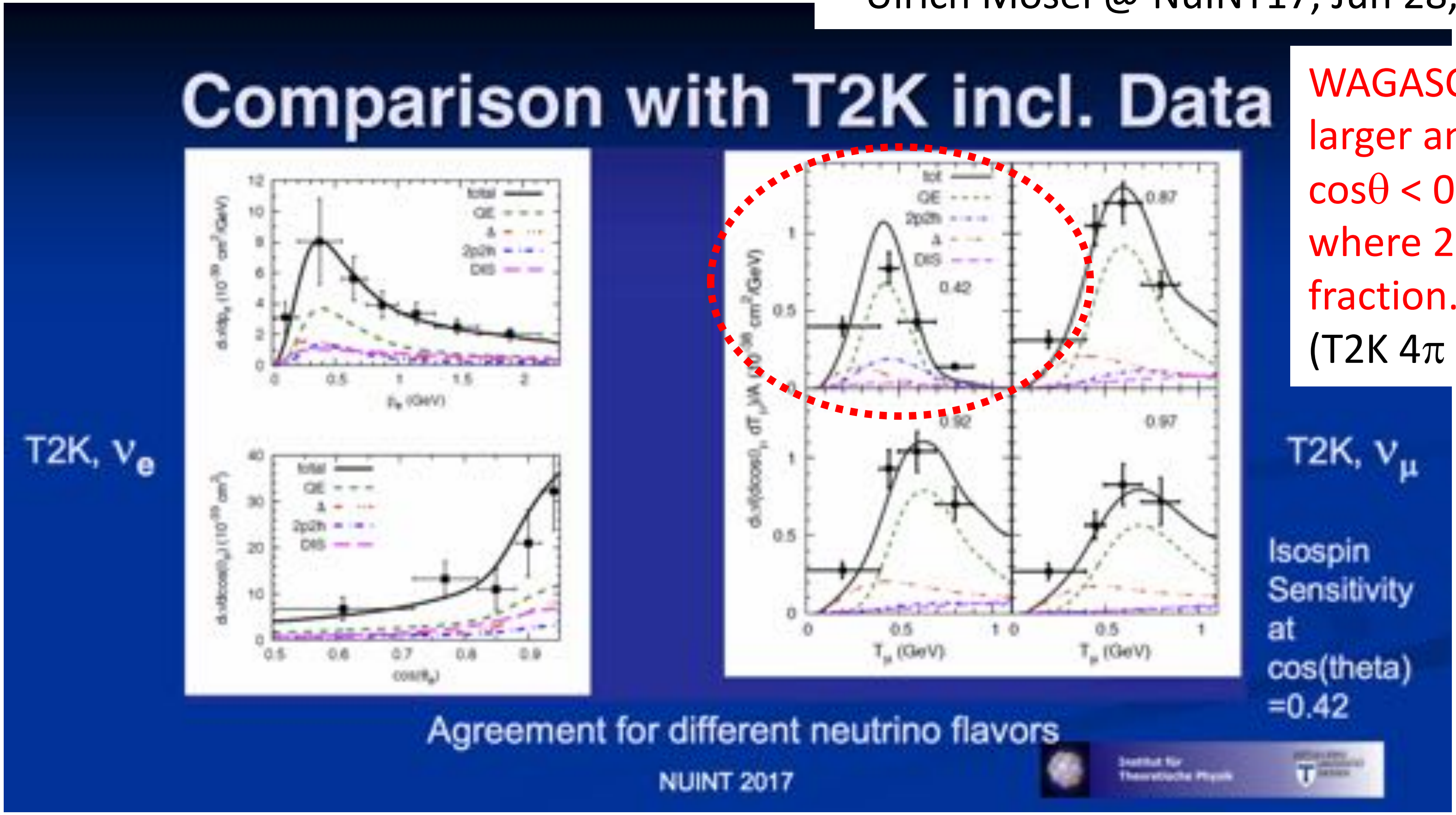
0.8 ton H_2O target	CC (signal)	NC	BG from Scintillator	BG from outside	All
Event rate /10^{21} POT	24100	865	6190	1640	31900
Fraction	75.5%	2.7%	19.4%	5.1%	100%

High statistics & Low background contamination with 4π acceptance

Expected performance (1)

- High statistics & Low background contamination with 4π acceptance

* Ulrich Mosel @ NuINT17, Jun 28, 2017

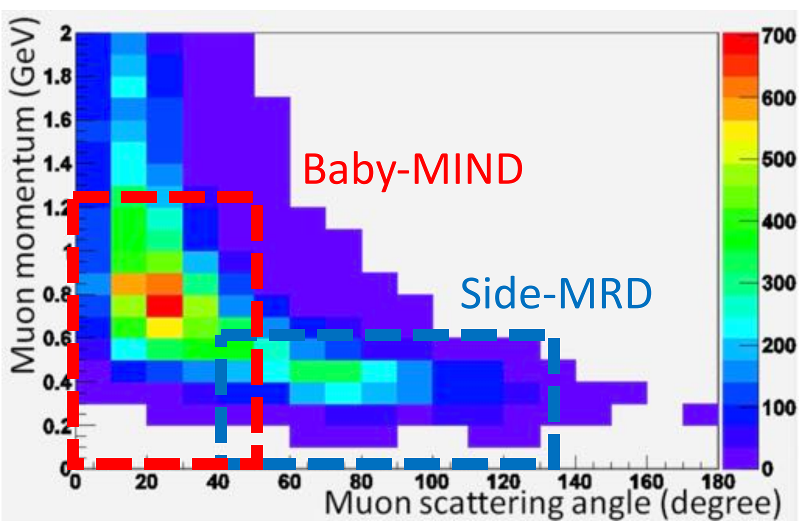


WAGASCI can test larger angles, $\cos\theta < 0.42$, where 2p2h has larger fraction.
(T2K 4π analyses too)

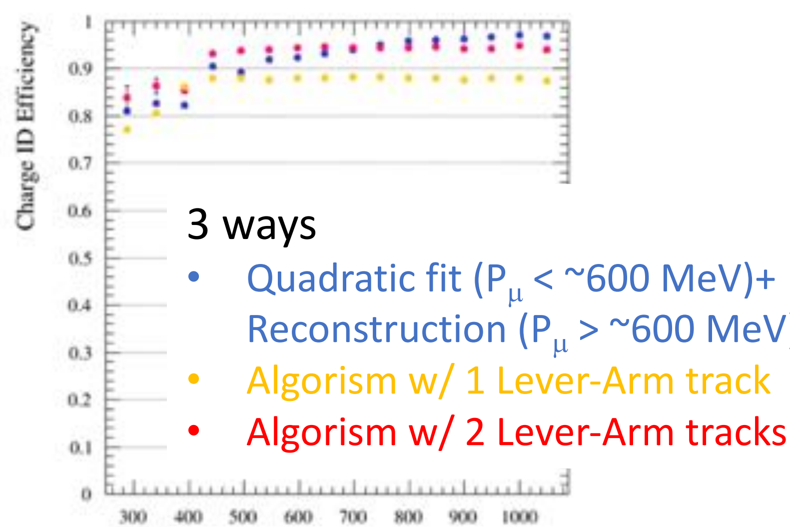
Expected performance (2)

- **Muon momentum measurement**
  - resolution ~ 50 MeV/c (~10% @ 0.5 GeV/c)
  - up to ~0.5 GeV/c (Side-MRDs), ~1.2 GeV/c (Baby-MIND)
- **Muon charge ID efficiency** w/ Baby-MIND
  - >76% (P_μ = 300 - 440 MeV/c), >94% (P_μ > 440 MeV/c)

Reconstructed events in WAGASCI



Muon charge ID efficiency

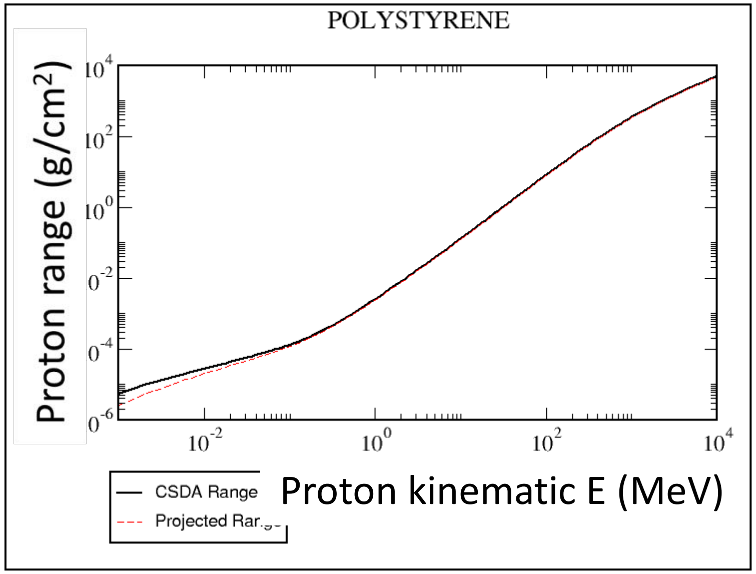


muon momentum (MeV/c)

Expected performance (3)

- Optional: **Proton track detection** w/ **water-out** WAGASCI
  - 3mm thick scintillators are the CH active target
  - Proton momentum threshold ~ 300 MeV/c

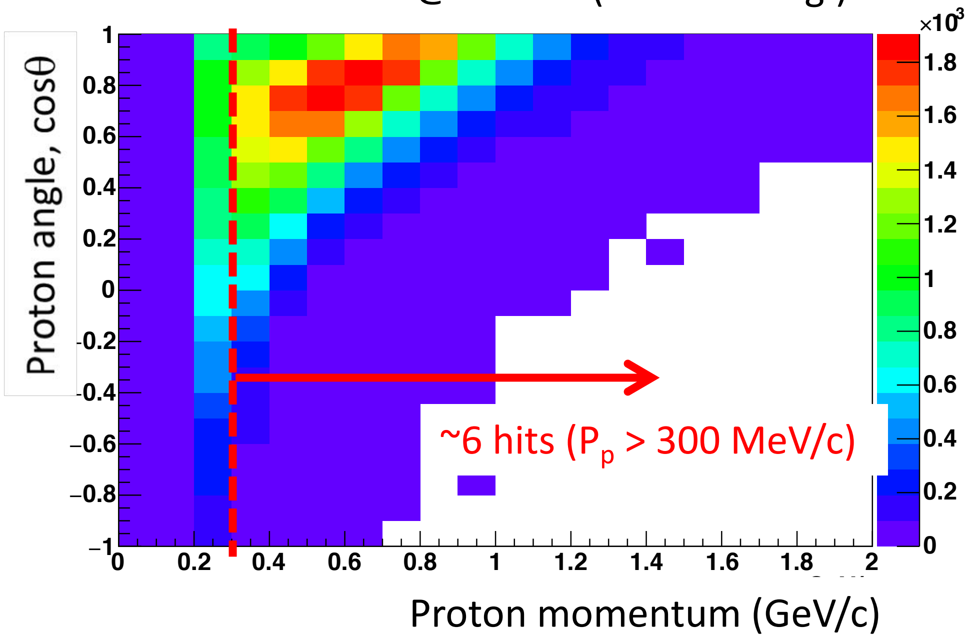
Proton range (NIST)



P=250 MeV/c -> K~30 MeV -> range ~0.9cm
P=300 MeV/c -> K~50 MeV -> range ~2.3cm

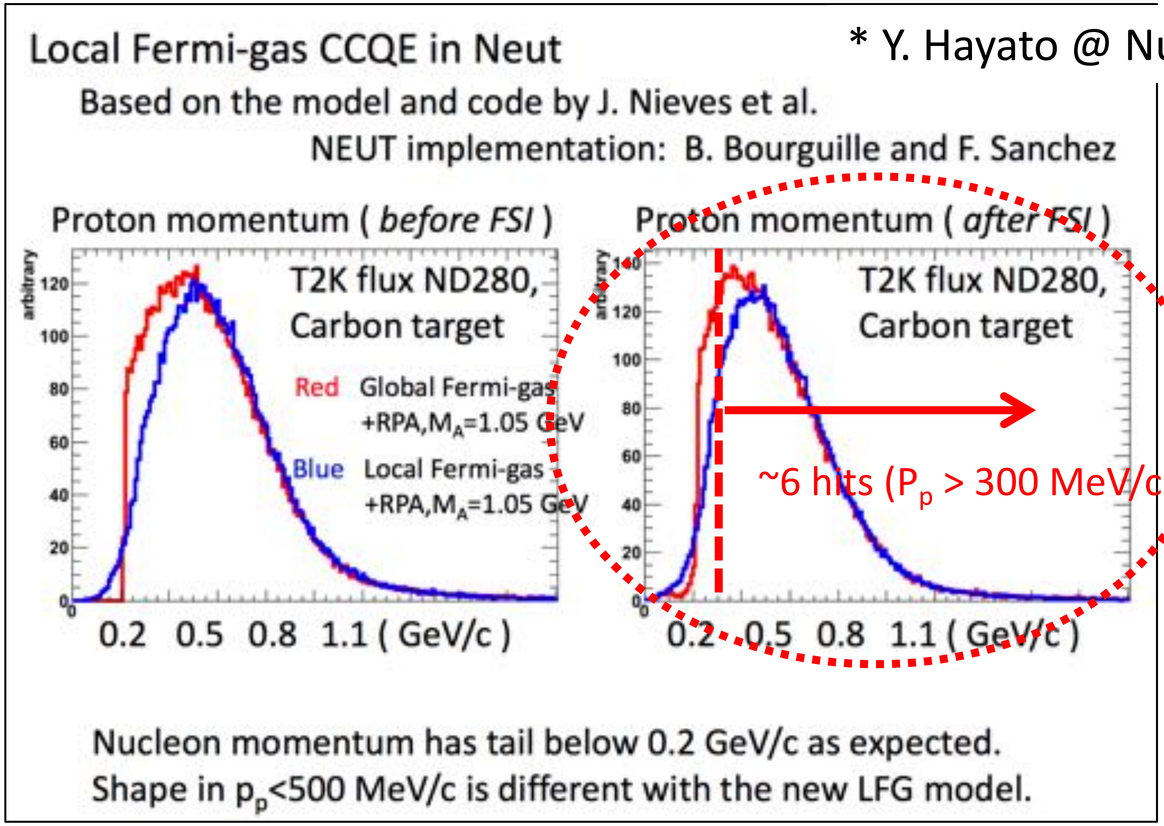
Proton tracks after FSI (CCQE events)

Neutrino flux @ ND280 (OA = 2.5 deg.)



Expected performance (3)

- Optional: **Proton track detection** w/ **water-out** WAGASCI
  - Pros: Proton momentum threshold ~ 300 MeV/c
  - Cons: Low statistics ~ 6000 events/10^{21} POT



* Y. Hayato @ NuINT17, Jun 28, 2017

Clear signature
-> Could be tested w/ low statistics.

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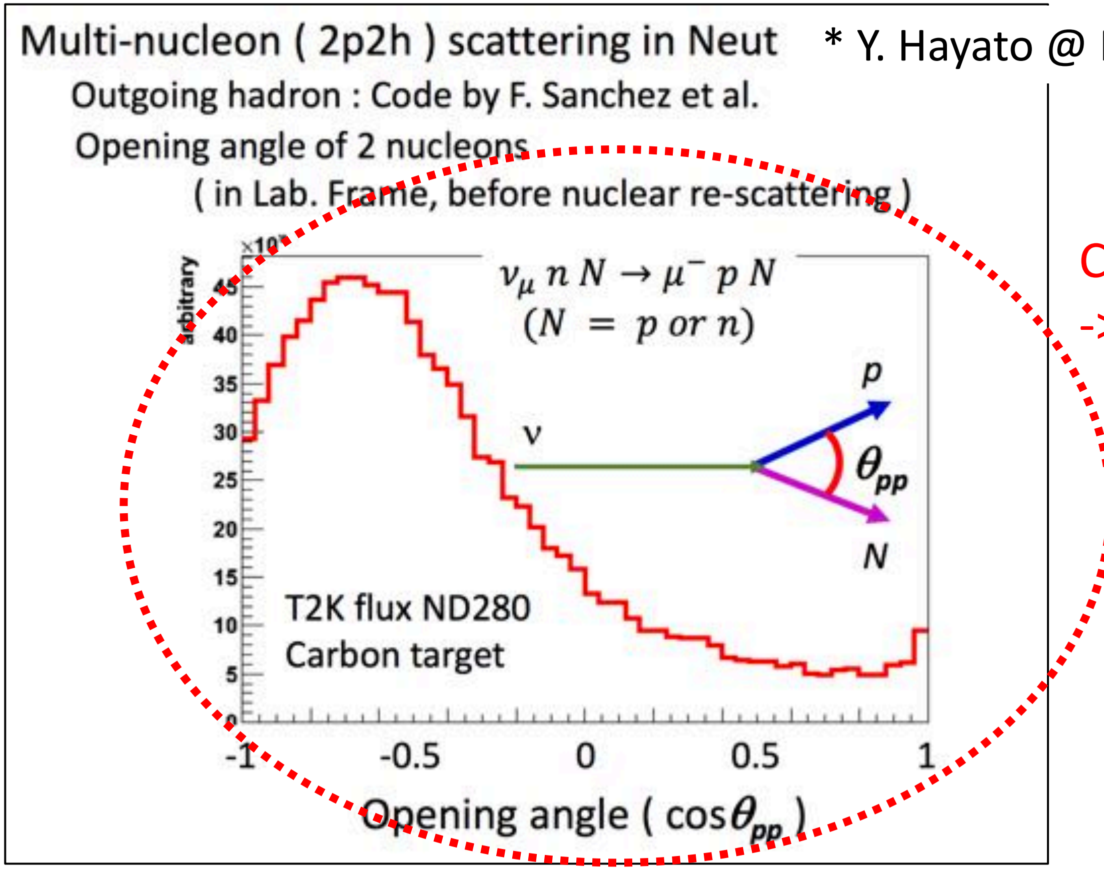

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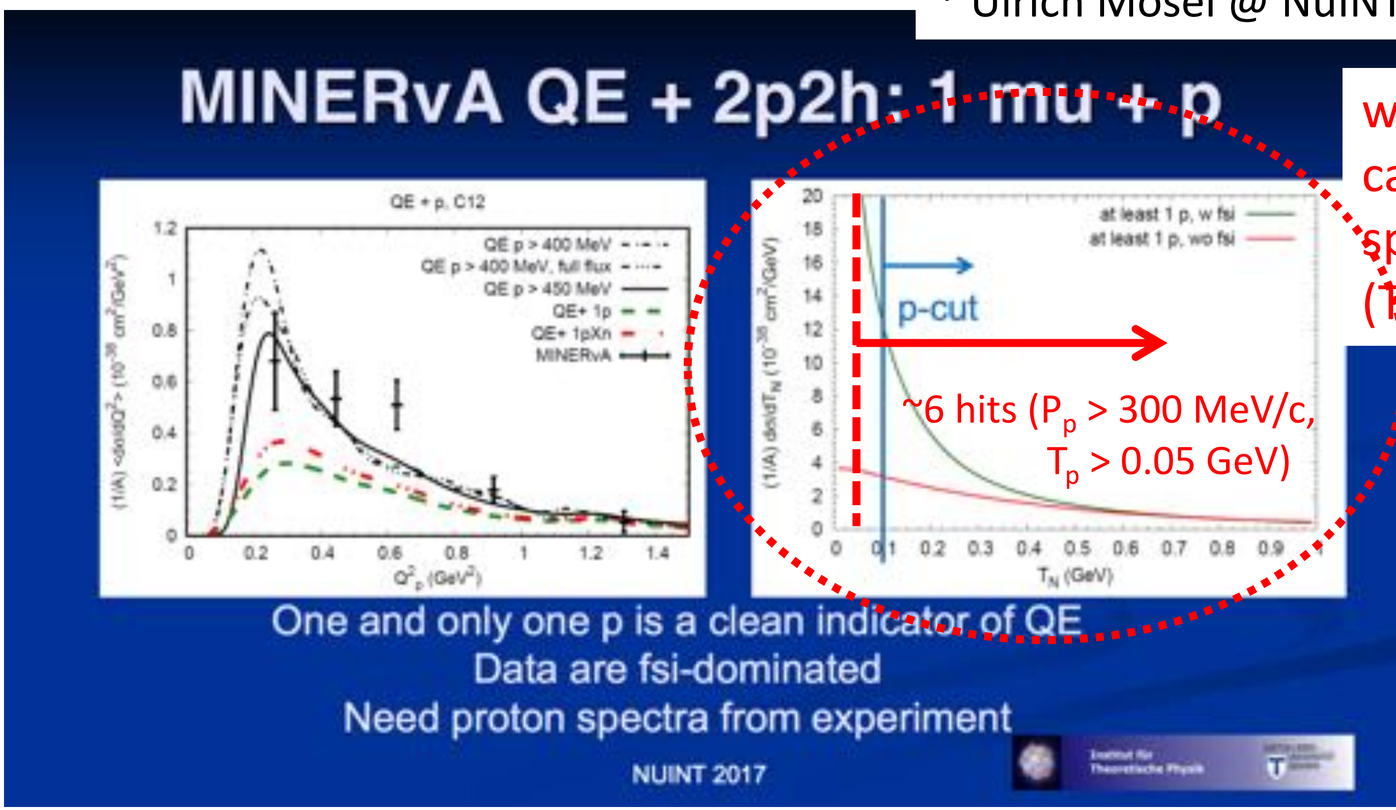
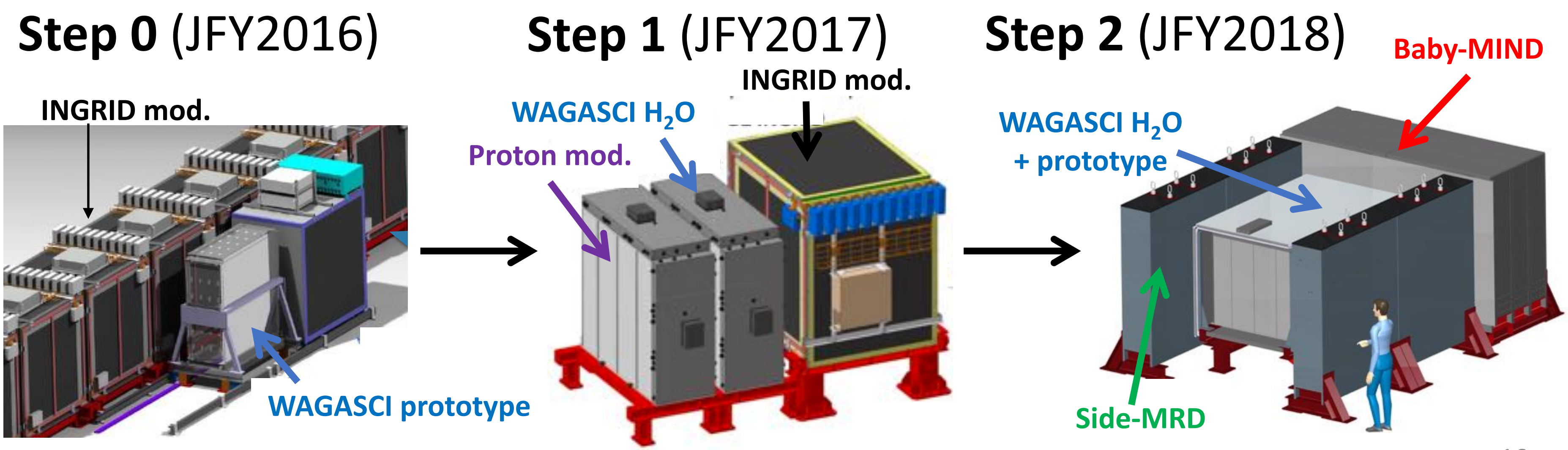


water-out WAGASCI can measure proton spectra.
(T2K ND also will do.)

Staging approach

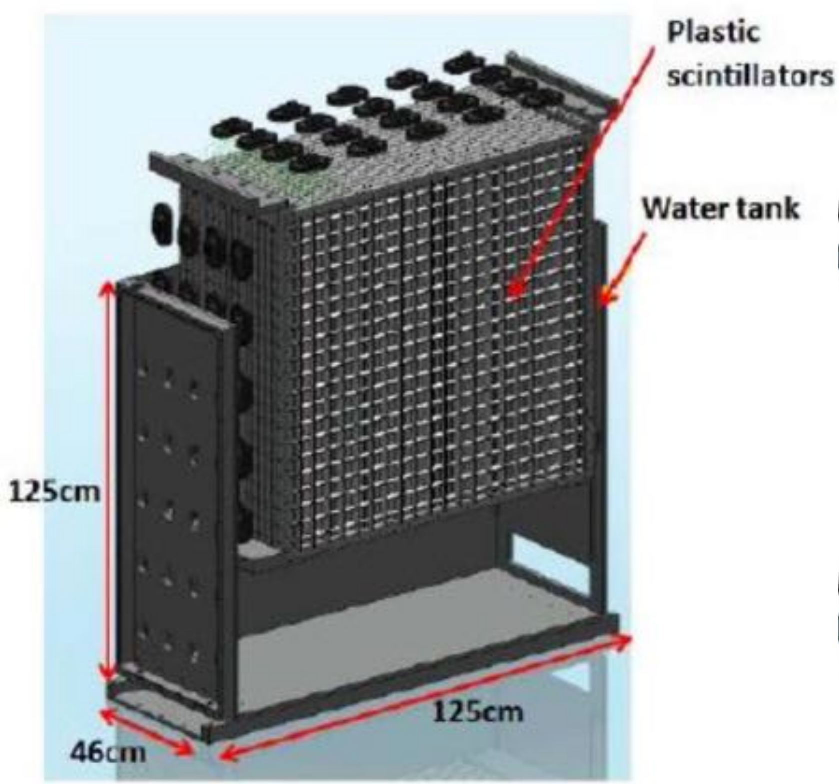
*1 on-axis beam: 0 deg., Peak E_ν ~ 1.2 GeV
*2 off-axis beam: 1.5 deg., Peak E_ν ~ 0.7 GeV

- **Step 0: on-axis beam**[*1], Oct. 2016 – Apr. 2017 (JFY2016)
  - WAGASCI prototype + INGRID mod. **Done!**
- **Step 1: off-axis beam**[*2], Oct. 2017 - Mar. 2018 (JFY2017)
  - WAGASCI H_2O mod. + Proton mod. + INGRID mod.
- **Step 2: off-axis beam**[*2], Arp. 2018 – (JFY2018 -)
  - WAGASCI H_2O/prototype mod. + Baby-MIND + Side-MRDs

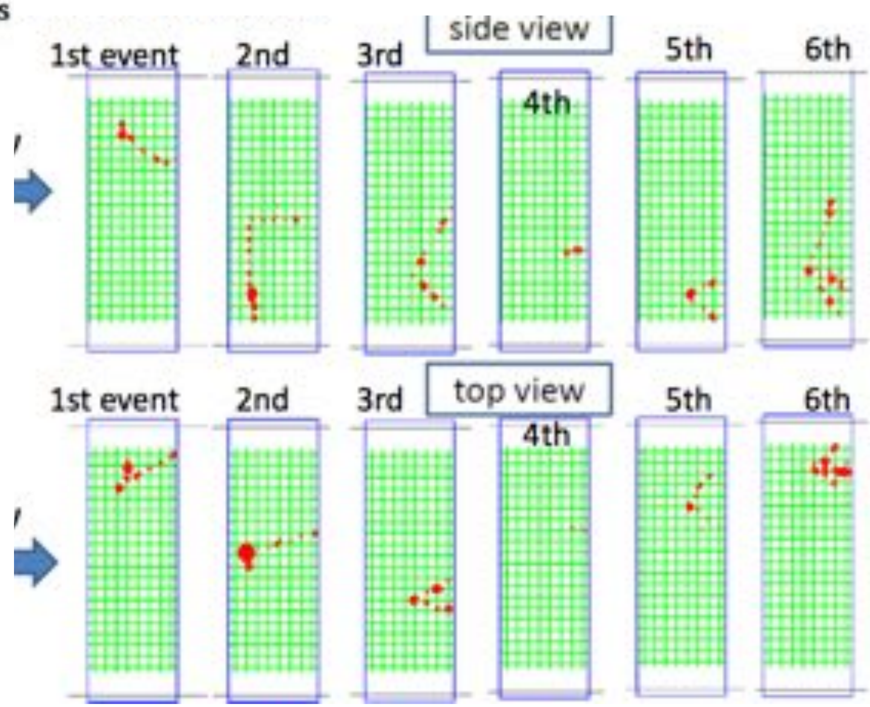


Outcomes from the prototype (1)

- Prototype started beam measurement on SS floor of the T2K ND pit in Oct. 2016.
  - More than 3×10^{20} POT data has been collected.



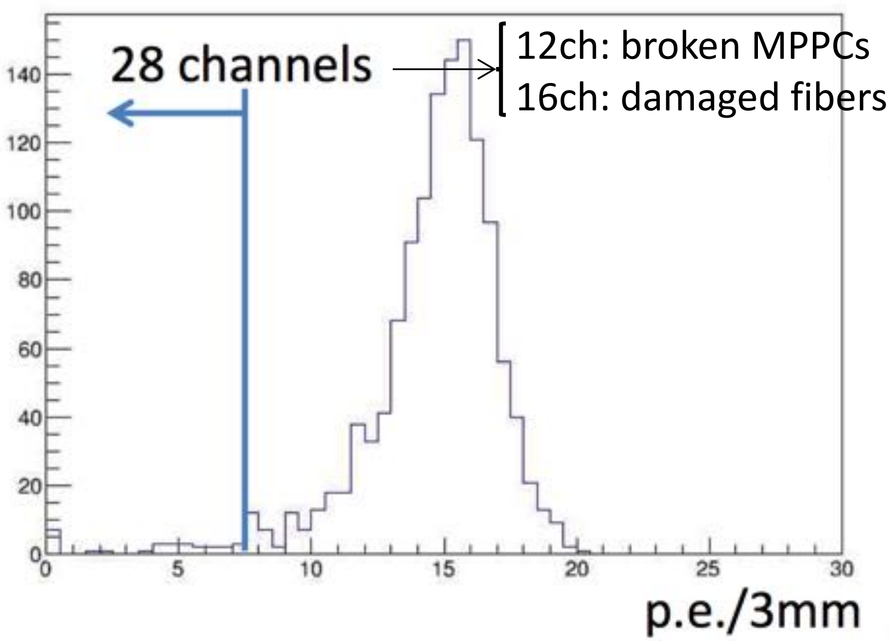
Observed candidate ν events



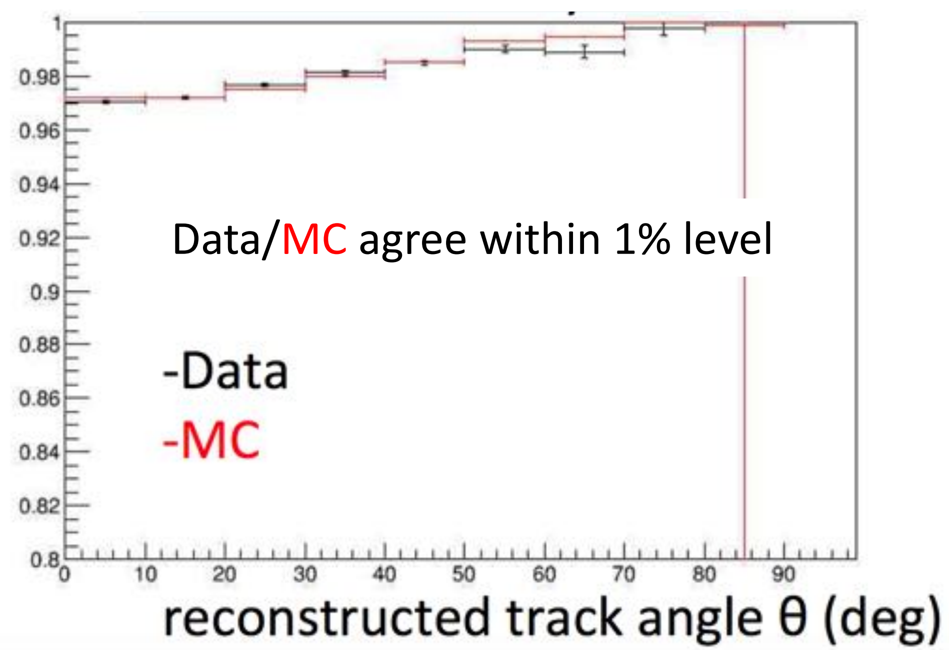
Outcomes from the prototype (2)

- **Light yield**
  - Mean ~ 15 p.e.
- **Hit efficiency**
  - > 97% for all the angles

Light yield/3mm for MIP



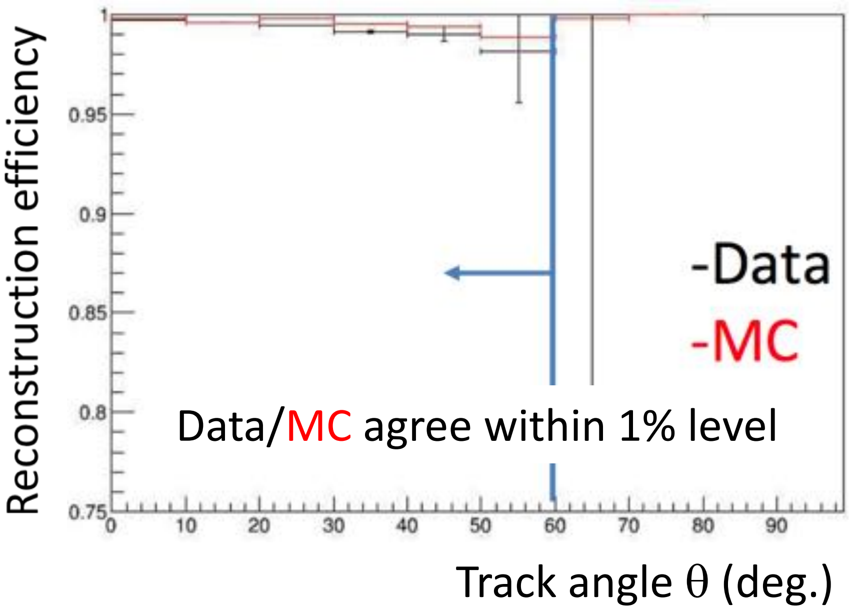
Hit efficiency



Outcomes from the prototype (3)

- **Track reconstruction efficiency**
  - > 97% for $\theta < 60$ deg.
- **Cross section measurements** (coming soon)
  - **CC-inclusive**, CC-0π, **CC-1π** on H_2O, CH, Fe and **their ratios**

Track reconstruction efficiency



$$\sigma_{\mathrm{H_2O}} = \frac{N^{\mathrm{sel}}_{\mathrm{WM}} - N^{\mathrm{BG}}_{\mathrm{WM}}}{\Phi^{\mathrm{H_2O}}_{\mathrm{WM}} T^{\mathrm{H_2O}}_{\mathrm{WM}} \varepsilon^{\mathrm{H_2O}}_{\mathrm{WM}}}$$

$$\sigma_{\mathrm{CH}} = \frac{N^{\mathrm{sel}}_{\mathrm{PM}} - N^{\mathrm{BG}}_{\mathrm{PM}}}{\Phi^{\mathrm{CH}}_{\mathrm{PM}} T^{\mathrm{CH}}_{\mathrm{PM}} \varepsilon^{\mathrm{CH}}_{\mathrm{PM}}}$$

$$\sigma_{\mathrm{Fe}} = \frac{N^{\mathrm{sel}}_{\mathrm{ING}} - N^{\mathrm{BG}}_{\mathrm{ING}}}{\Phi^{\mathrm{Fe}}_{\mathrm{ING}} T^{\mathrm{Fe}}_{\mathrm{ING}} \varepsilon^{\mathrm{Fe}}_{\mathrm{ING}}}$$

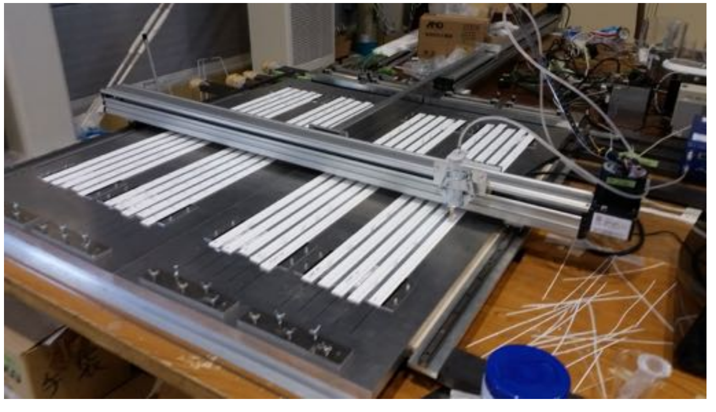
$$\frac{\sigma_{\mathrm{H_2O}}}{\sigma_{\mathrm{CH}}} \qquad \frac{\sigma_{\mathrm{H_2O}}}{\sigma_{\mathrm{Fe}}}$$

Readiness for the next step (1)

- WAGASCI
  - One WAGASCI module was constructed as a prototype.
  - The prototype started on-axis beam measurement from Oct. 2016 as T2K INGRID water module.
  - Construction of another H_2O module is just completed.
    - Commissioning is on-going, then will be installed in the NM pit in the Summer of 2017.

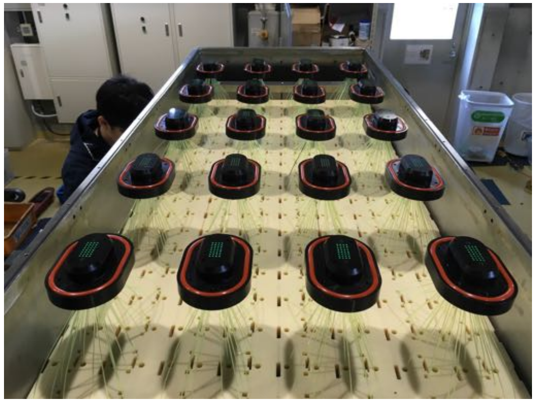
OCU team

Glue WLS fibers to grooves of scintillators



Done!

Assembly of H_2O module

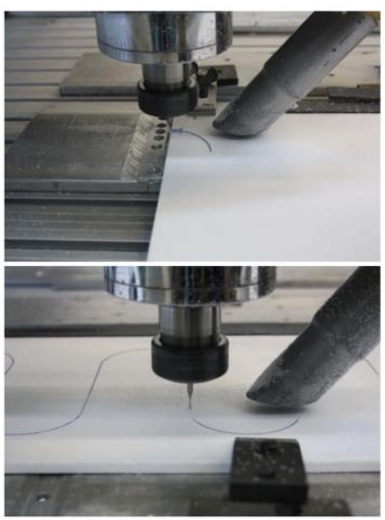


Done!

Readiness for the next step (2)

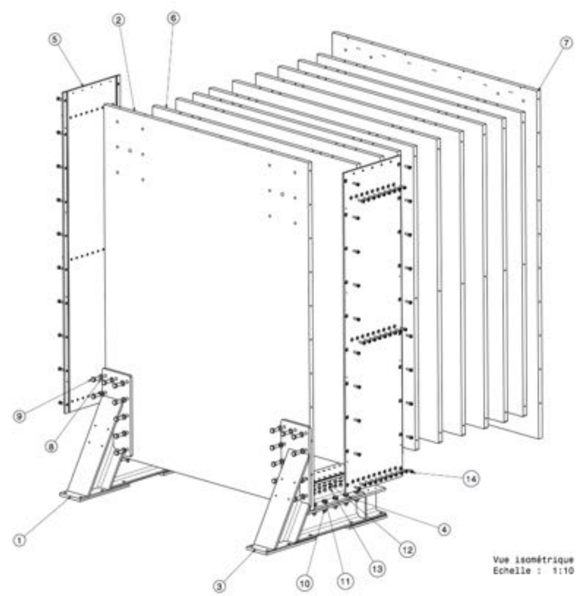
- Side MRD
  - 330 scintillators (200x7x1800mm) were produced.
  - Milling of the scintillators, fiber gluing and polishing of optical connector were completed in Russia.
  - The mechanical structure is being designed by LLR team.
  - Detector construction will be completed in JFY2017.

INR team



Done!

LLR team



Readiness for the next step (3)

- Baby MIND
  - Construction of the 33 magnet modules and 18 scintillator modules is completed.
  - 1st beam test at CERN was held in May 2017.
  - 2nd beam tests at CERN in June/July 2017, then transport to J-PARC.

Geneva + INR + CERN team

Beam test @ CERN

Readiness for the next step (4)

- Electronics/DAQ
  - WAGASCI, side MRD: FEB w/ SPIROC2D(ASIC) + BEBs
    - Mass production of FEBs is completed.
  - Baby MIND: FEB w/ CTIROC(ASIC)

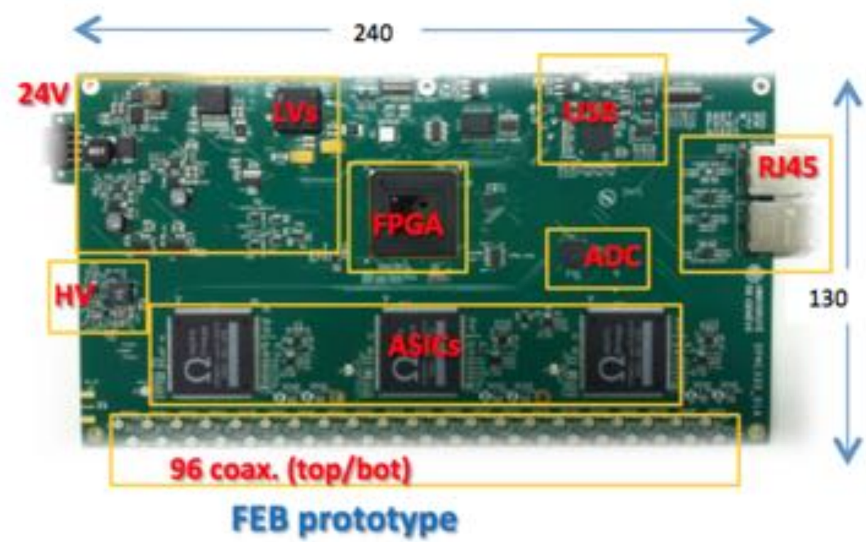
Different DAQs

LLR + Univ. Tokyo team

Electronics for WAGASCI and side MRD:

Geneva team

FEB for BabyMIND:
fully tested w/ CERN beam test



Summary

- We are developing a new neutrino detector aiming to increase T2K sensitivities.
- Staging approach
  - **Step 0**: on-axis beam[*1] w/ Prototype + INGRID (Done!)
  - **Step 1**: off-axis beam[*2] w/ WAGASCI + INGRIDs (JFY2017)
  - **Step 2**: off-axis beam[*2] w/ baseline configuration (JFY2018-)
- We can’t wait to show first physics results at the next NuINT.

*1 on-axis beam: 0 deg., Peak E_ν ~ 1.2 GeV
*2 off-axis beam: 1.5 deg., Peak E_ν ~ 0.7 GeV