

New experimental proposal for
neutrino cross sections with J-PARC
neutrino beam,
WAGASCI

A. Minamino (Kyoto Univ.)

May 22, 2014

NuInt14 @ Surrey, UK

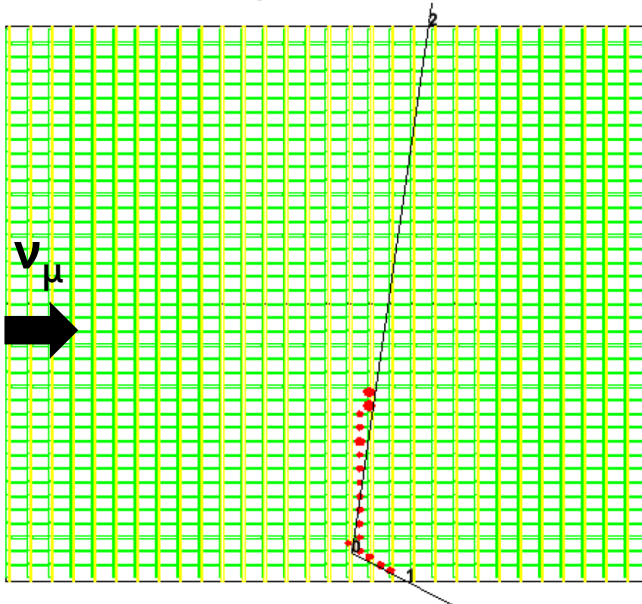
Outline

- Motivation
- Candidate site
- Detector configuration
- Goals
- MC study
- Test of the detector components
- Schedule

Water Grid And SCIntillator detector **WAGASCI**

H₂O/CH detector
(3D grid-like structure)

topview



Box for
Japanese sweets (Wagashi)



We have submitted a proposal of the project to J-PARC PAC
as an independent test experiment from T2K.

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Motivation

- T2K have non-canceling systematic errors on neutrino cross sections because of different primary nuclear targets^(*) of Super-K (H_2O) and T2K off-axis near detector, ND280 (CH).

Uncertainties on the predicted number of signal ν events

ν_e appearance analysis (PRL 112, 061802 (2014))

Error source [%]	$\sin^2 2\theta_{13} = 0.1$
Beam flux and near detector (without ND280 constraint)	2.9 (25.9)
Uncorrelated ν interaction	7.5
Far detector and FSI + SI + PN	3.5
Total	8.8

ν_μ disappearance analysis (PRL 112, 181801 (2014))

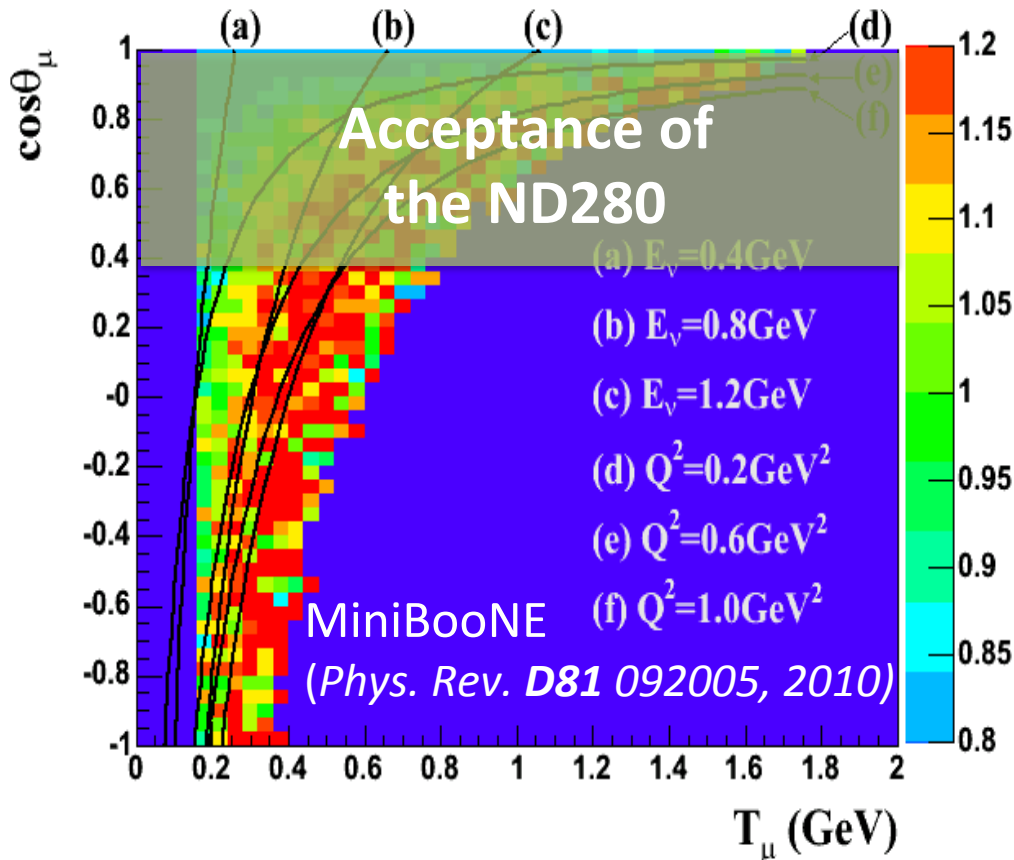
Source of uncertainty (number of parameters)	$\delta n_{\text{SK}}^{\text{exp}} / n_{\text{SK}}^{\text{exp}}$
ND280-independent cross section (11)	4.9%
Flux and ND280-common cross section (23)	2.7%
SK detector and FSI + SI systematics (7)	5.6%
$\sin^2(\theta_{13})$, $\sin^2(\theta_{12})$, Δm_{21}^2 , δ_{CP} (4)	0.2%
Total (45)	8.1%

(*) The ND280 has water target regions, and there are ongoing efforts to measure neutrino cross sections on water.

Motivation (continue)

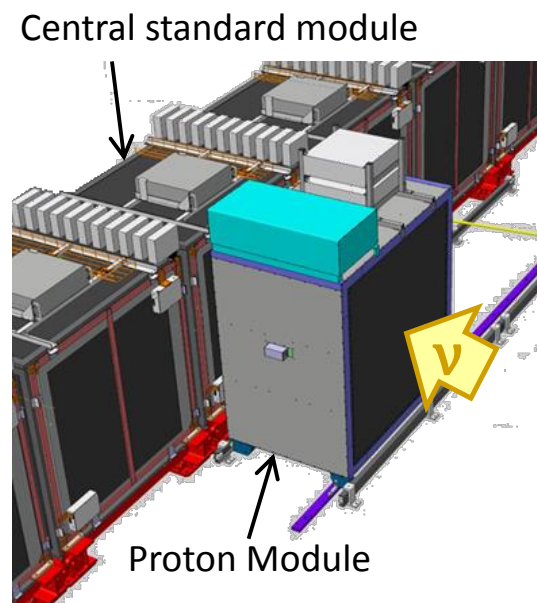
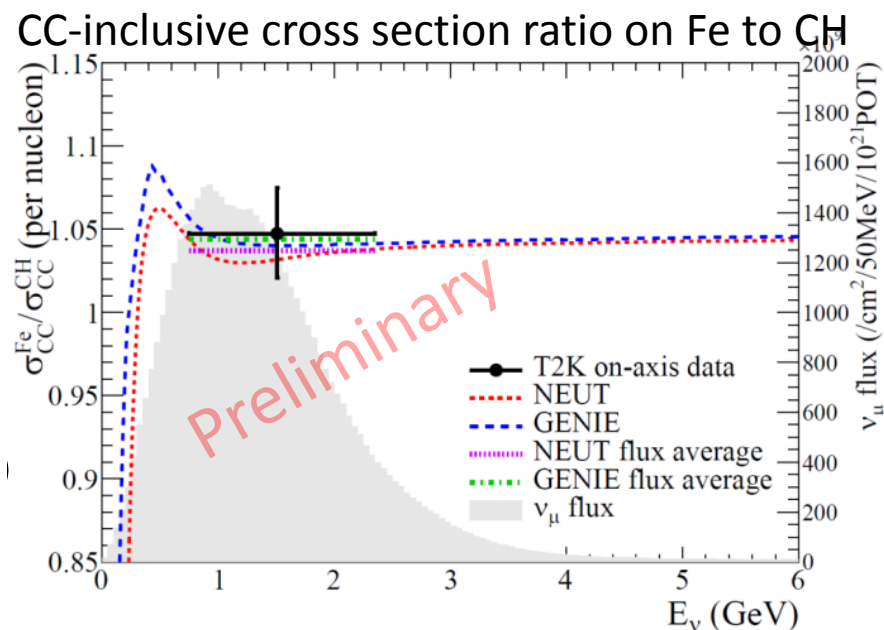
- Acceptance of the ND280 is smaller than that of Super-K ($= 4\pi$).
 - T2K need to rely on external data sets (MiniBooNE, etc.).

ν_μ QQCE double differential cross section
discrepancies between DATA and Model



Motivation (continue)

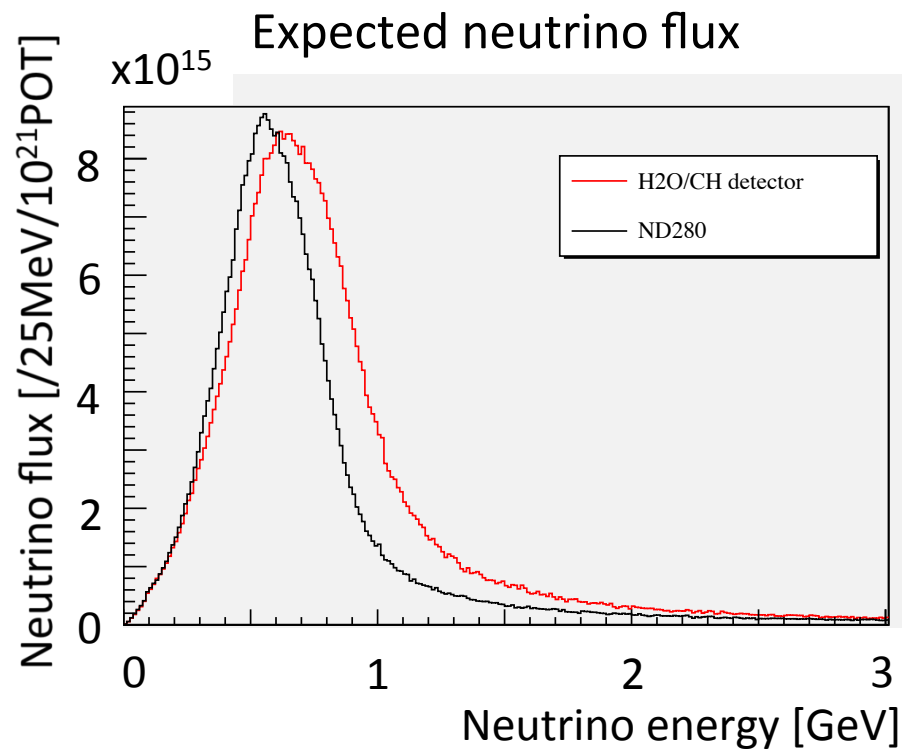
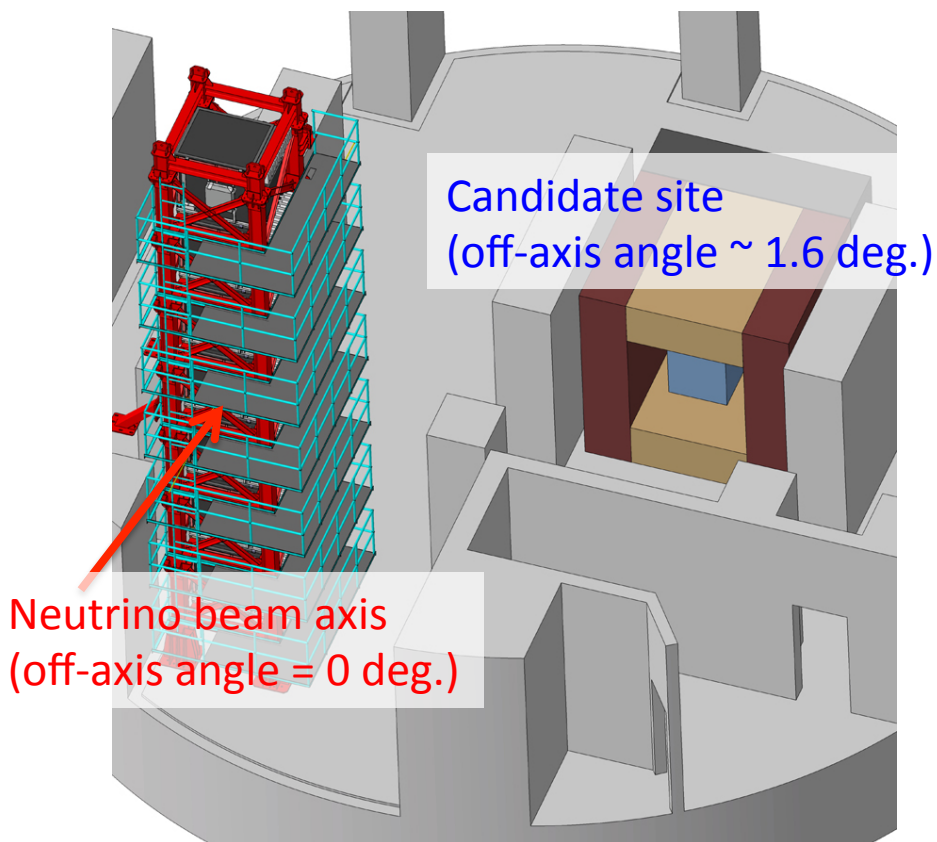
- We have measured an Fe to CH neutrino cross section ratio with an accuracy of **2.7%** using the T2K on-axis near detector, INGRID. (T. Kikawa's talk @ NuInt14 on May 19)



$$\frac{\sigma_{CC}^{Fe}}{\sigma_{CC}^{CH}} = 1.047 \pm 0.007(stat.)_{-0.027}^{+0.028} (syst.)$$

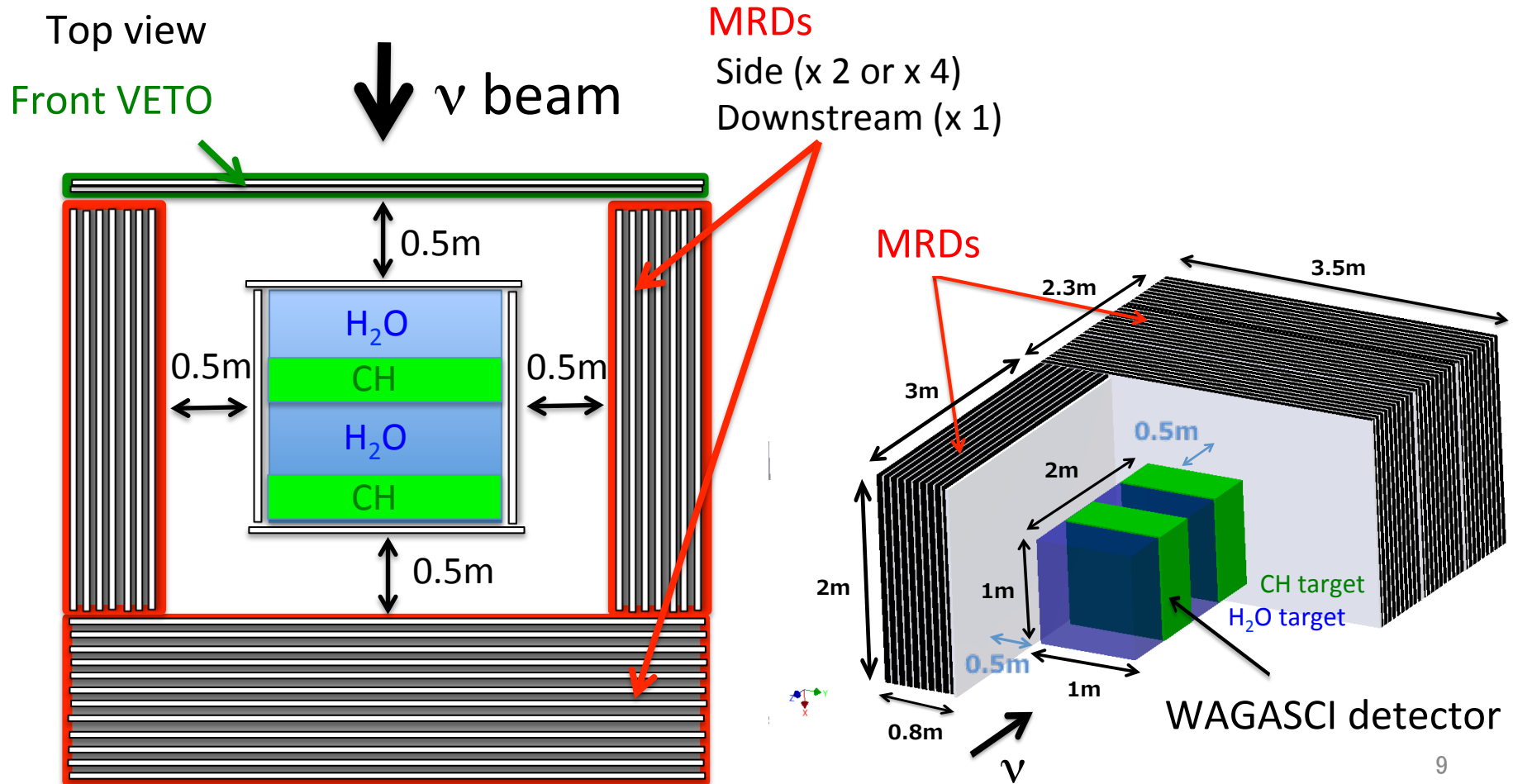
Candidate site

- The B2 floor of the T2K near detector hall as a test facility of neutrino beam
 - Off-axis angle ~ 1.6 degree
 - Neutrino energy spectrum is similar to the ND280/Super-K.



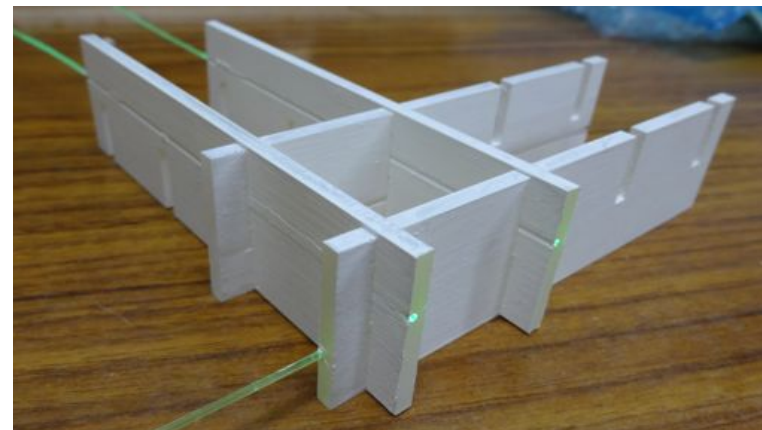
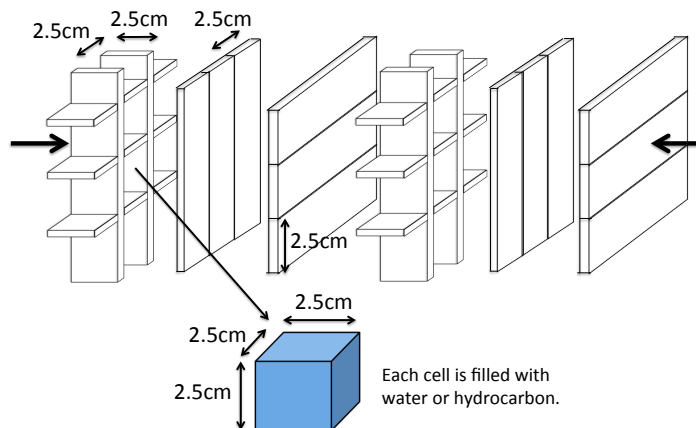
Detector configuration

- WAGASCI detector + muon range detectors (MRDs)
 - MRDs are located 50cm away from the WAGASCI detector to identify the charged particle directions from hit-timing diff. between the two detectors.



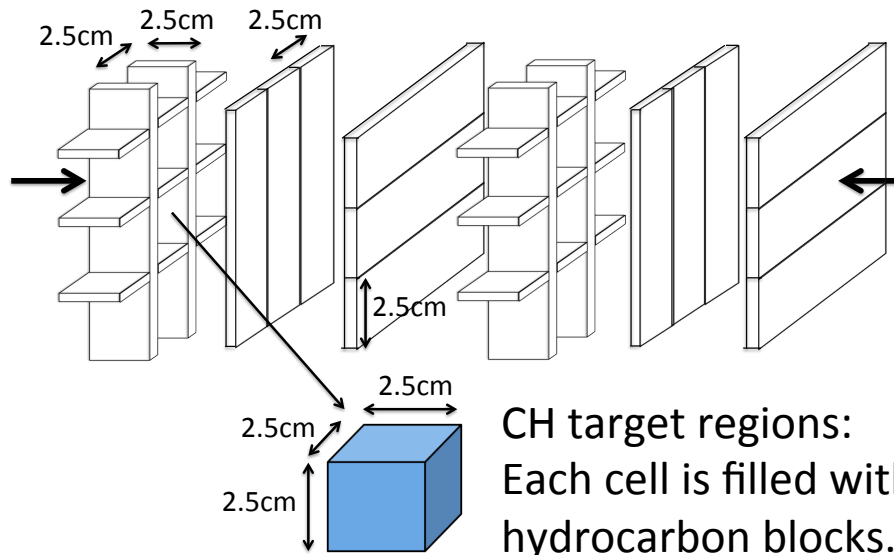
WAGASCI detector

- Dimensions
 - 100cm x 100cm in section and 200cm along the beam direction
 - H₂O/CH target mass is ~2 ton in total. (Total weight ~ 3 ton.)
- 3D grid-like structure (x, y, grid layers + WLS fibers + MPPCs)
 - **4 π angular acceptance** for charged particles
 - 2.5cm grid spacing enables us to reconstruct short tracks originated from protons and charged pions with high efficiency.
 - Thin plastic scintillator bars (thickness ~ 0.3cm) will be used for the detector to increase the mass ratio of H₂O (signal) to CH (background).
 - The WAGASCI detector can be made possible if we have high light yield from the thin scintillator bars in water with the MPPC readout.



Advantages of the WAGASCI detector

- 4π angular-acceptance
- $\text{H}_2\text{O}(\text{signal}):\text{CH}(\text{BG}) = 70:30$
 - T2K ND280: $\text{H}_2\text{O}:\text{CH} = 46:54$
- Similar detector systematics for $\text{H}_2\text{O}/\text{CH}$ measurements
 - Each cell of the 3D grid is filled with hydrocarbon blocks in the CH target regions.



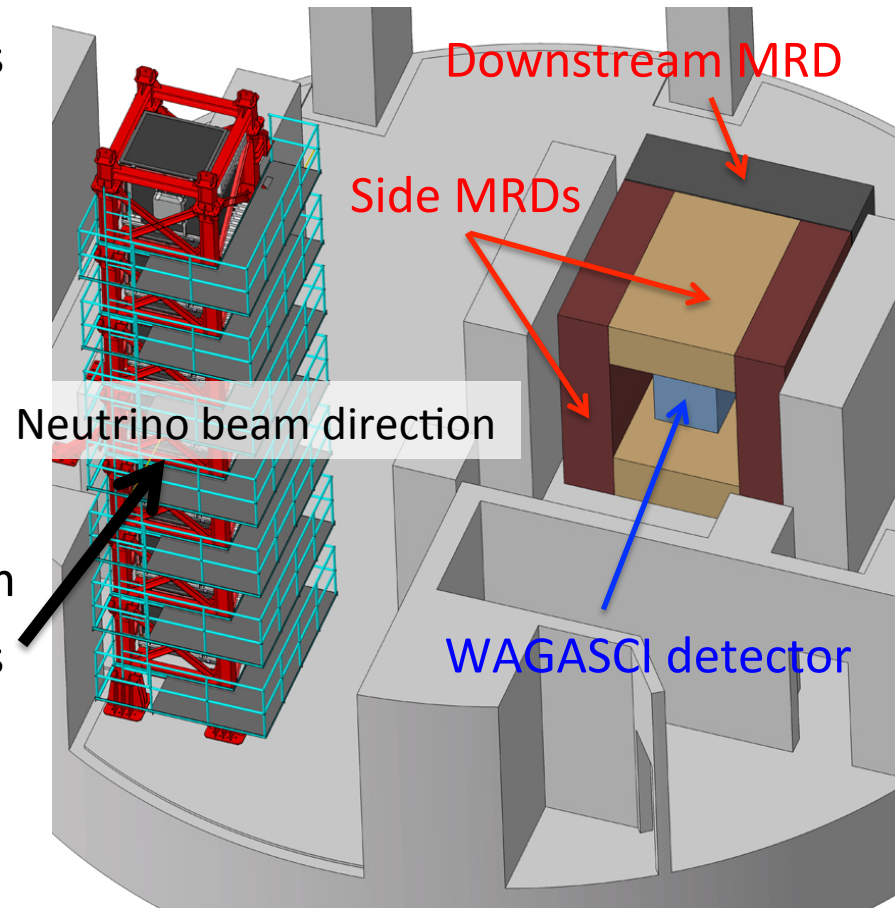
muon range detectors (MRDs)

- Side MRDs

- Dimensions $\sim 300\text{cm} \times 200\text{cm} \times 100\text{cm}$
- 14 tracking planes and 12 steel plates
 - Weight of a steel plate: 1.4 ton
 - Weight of a tracking plane: 160kg
- Total weight for each: ~ 21 tons
- Can measure p_μ up to $\sim 1 \text{ GeV}/c$

- Downstream MRD

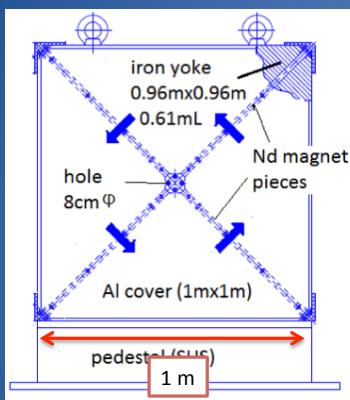
- Dimensions $\sim 350\text{cm} \times 200\text{cm} \times 220\text{cm}$
- 32 tracking planes and 30 steel plates
 - Weight of a steel plate: 1.7 ton
 - Weight of a tracking planes: 190kg
- Total weight: ~ 60 tons
- Can measure p_μ up to $\sim 2 \text{ GeV}/c$



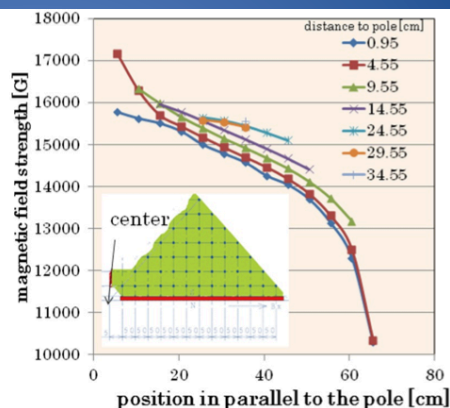
Downstream muon detector

- Another option for the downstream muon detector
 - We are considering the possibility to reuse the detector which is developed for muon radiography as the downstream muon detector.
 - Scintillator tracking planes + magnetic field using permanent magnets
 - Advantages
 - Can identify muon charges (Good for anti- ν beam data.)
 - Can measure p_μ up to 5 GeV/c

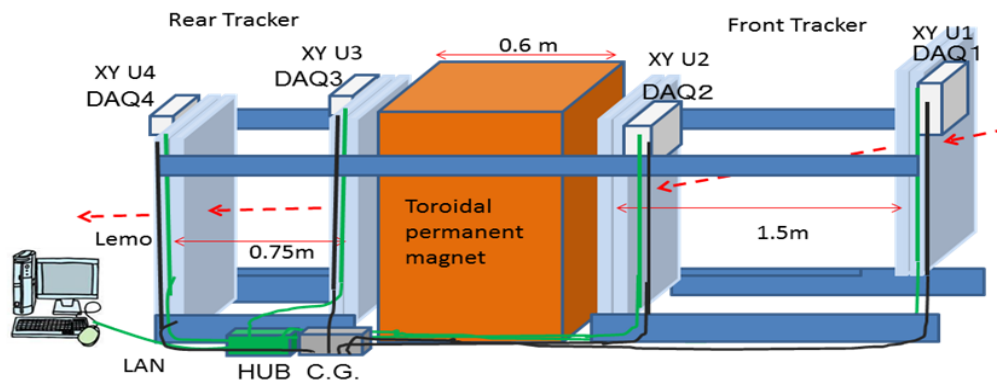
Permanent Toroid Magnet



Sketch of the toroid magnet



Simulation of the field strength



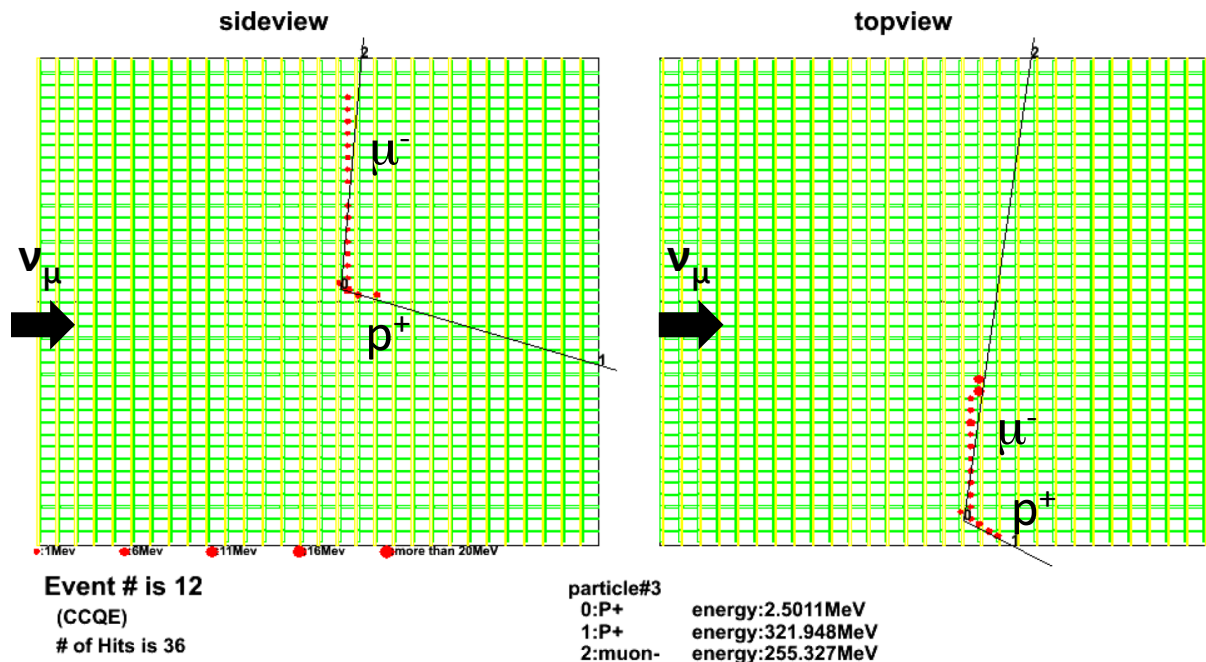
Goals

- H_2O to CH cross section ratios with 3% accuracy
 - Neutrino interaction models predict that the target dependence between H_2O and CH is small, but no high precision measurement so far.
 - Test the correctness of the target dependence in the models. Then, constrain the target-dependent neutrino cross section errors by the ND280 measurement.
 - The analysis technique is established in the INGRID measurement.
 - CC-inclusive channel. Then, exclusive channels.
- Cross sections on H_2O and CH with 10% accuracy.
 - Neutrino flux uncertainties are dominant errors.
 - Double differential cross sections for $(T_\mu, \cos\theta_\mu)$
 - CC-inclusive channel. Then, exclusive channels.

MC study (CC-inclusive)

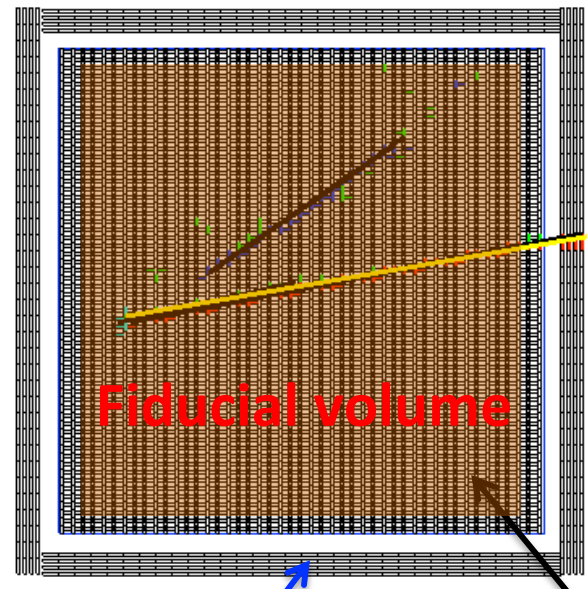
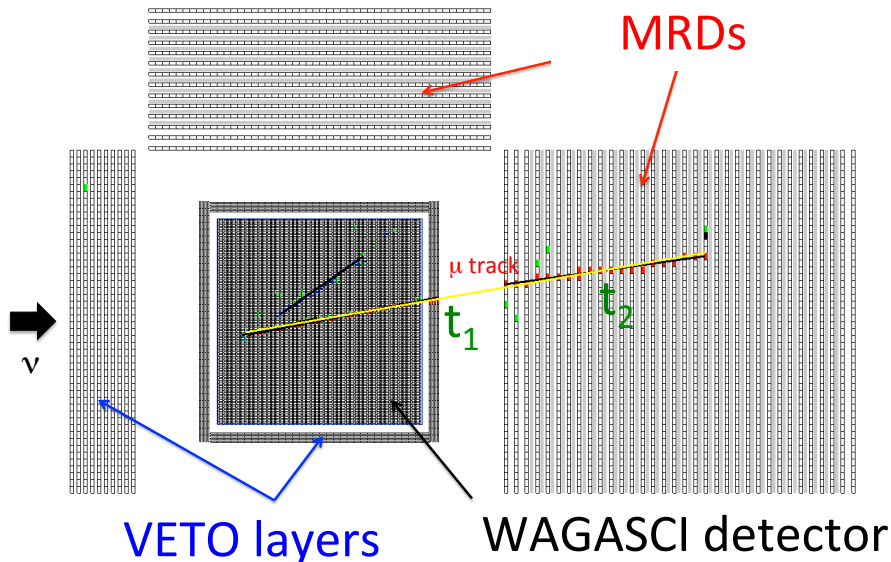
- Neutrino flux prediction
 - Hadron production (NA61@CERN) & Proton/ ν beam monitoring
- Neutrino interaction generator: NEUT
- Detector MC: Geant4
 - Geometry in the MC is slightly different from the one in p. 9. (Better performance is expected by adapting the geometry in p.9 to the MC.)

A event display of the WAGASCI detector (CCQE event)



MC study (CC-inclusive) (Continue.)

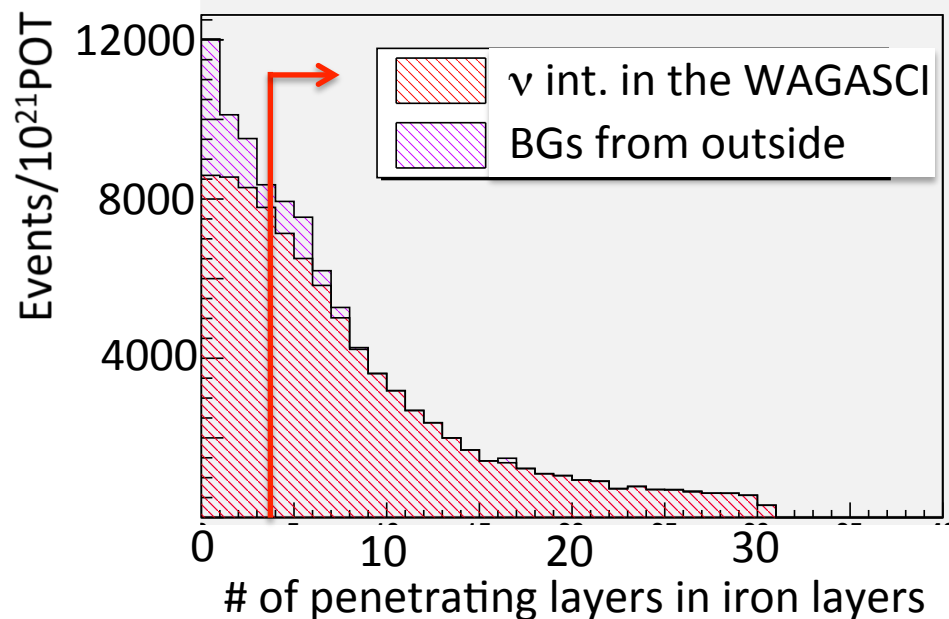
- Event selection
 - Reconst. tracks/vertices in the WAGASCI detector and the MRDs.
 - Require a track to be matched between two detectors and be stopped in the MRDs.
 - Select a long muon track from CC interaction.
 - Remove charged particle BGs from VETO layer hits & TOF ($t_1 < t_2$).
 - Vertices are in the fiducial volume of the WAGASCI detector.



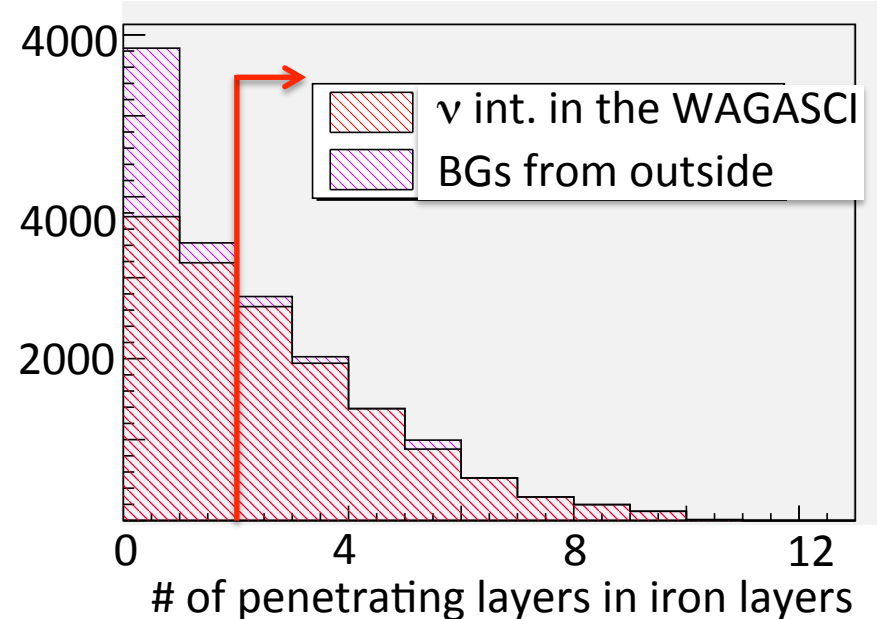
MC study (CC-inclusive) (Continue.)

- BGs originate from neutrino interactions in the material surrounding the WAGASCI detector
 - Dominant BG source is found to be neutral particles (n, γ) from neutrino interactions in the walls of the near detector hall.

Events with a matched track
in the downstream MRD



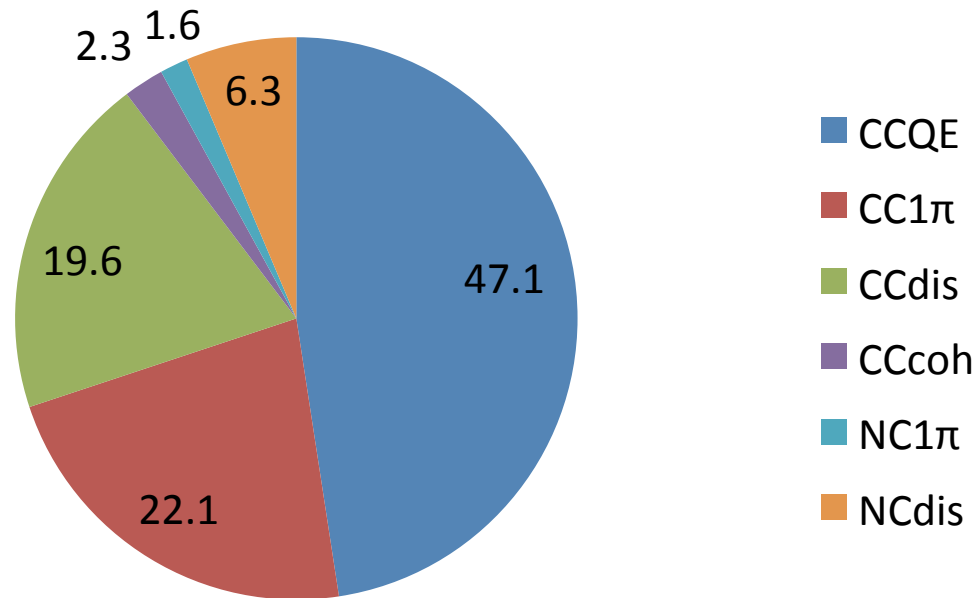
Events with a matched track
in the side MRDs



BG contamination can be reduced to a **5%** level, if events with ≥ 4 (2) penetrating iron layers in the downstream (side) MRDs are selected.

MC study (CC-inclusive) (Continue.)

- Selected interaction types after applying the selection on # of penetrating iron layers in the MRDs



Purity of CC-inclusive interactions is **92%**

- The expected # of ν_μ CC event candidates in the WAGASCI detector is 42000 in total in 1×10^{21} POT of ν beam data.
 - Stat. error will be less than 1%.

MC study (CC-inclusive) (Continue.)

- Analysis strategy
 - Flux averaged CC-inclusive is calculated with background subtraction and efficiency correction.

$$\sigma_{CC} = \frac{N_{sel} - N_{BG}}{\Phi T \varepsilon_{CC}}$$

N_{sel} : Number of selected events (data)

N_{BG} : Number of selected BG events (MC)

Φ : Integrated ν_μ flux (MC)

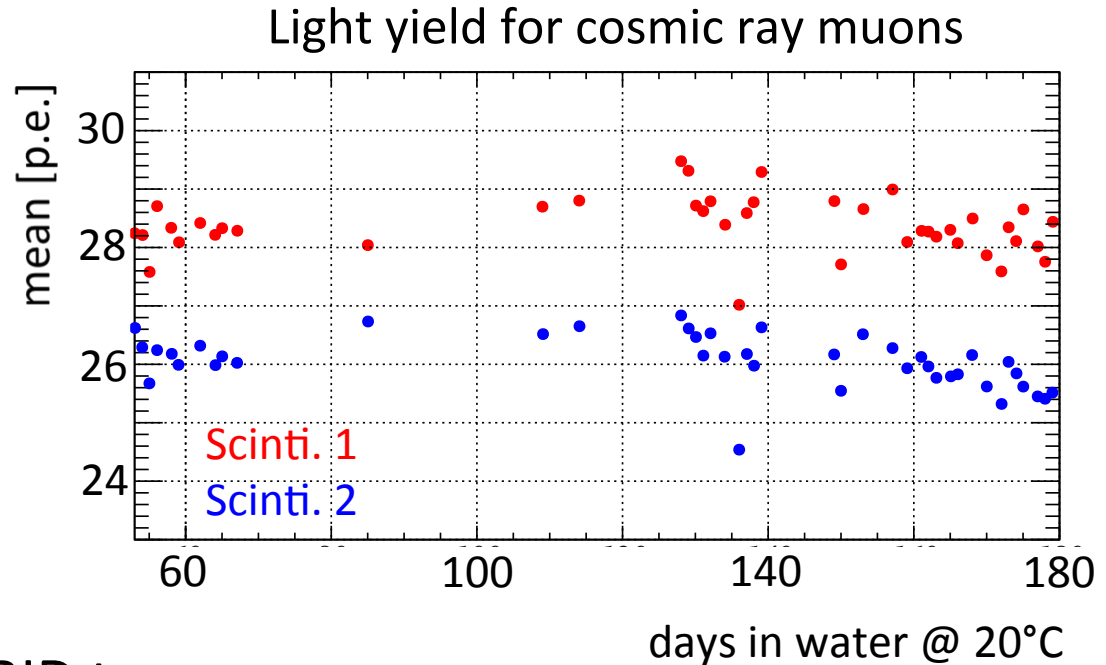
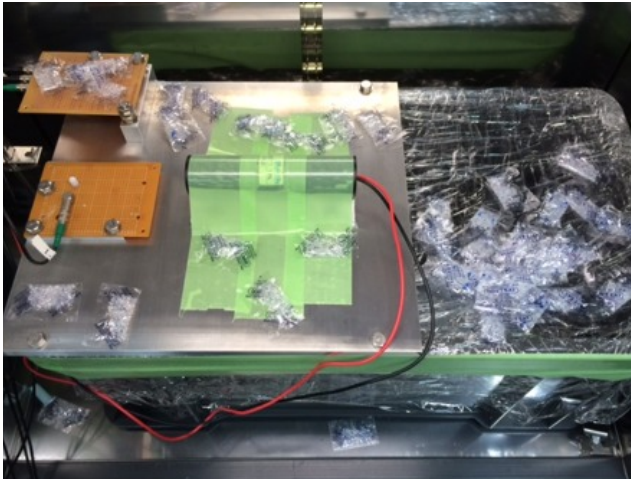
T : Number of target nucleons

ε_{CC} : Detection efficiency of CC events (MC)

- This calculation is applied to the H₂O target regions and the CH target regions to measure $\sigma_{CC}^{H_2O}$ and σ_{CC}^{CH} .
- Then, $\sigma_{CC}^{H_2O} / \sigma_{CC}^{CH}$ is calculated.
 - The dominant systematic error, the neutrino flux error is canceled.

Test of the detector components

- Long-term durability test of scintillator bars & WLS fibers in water

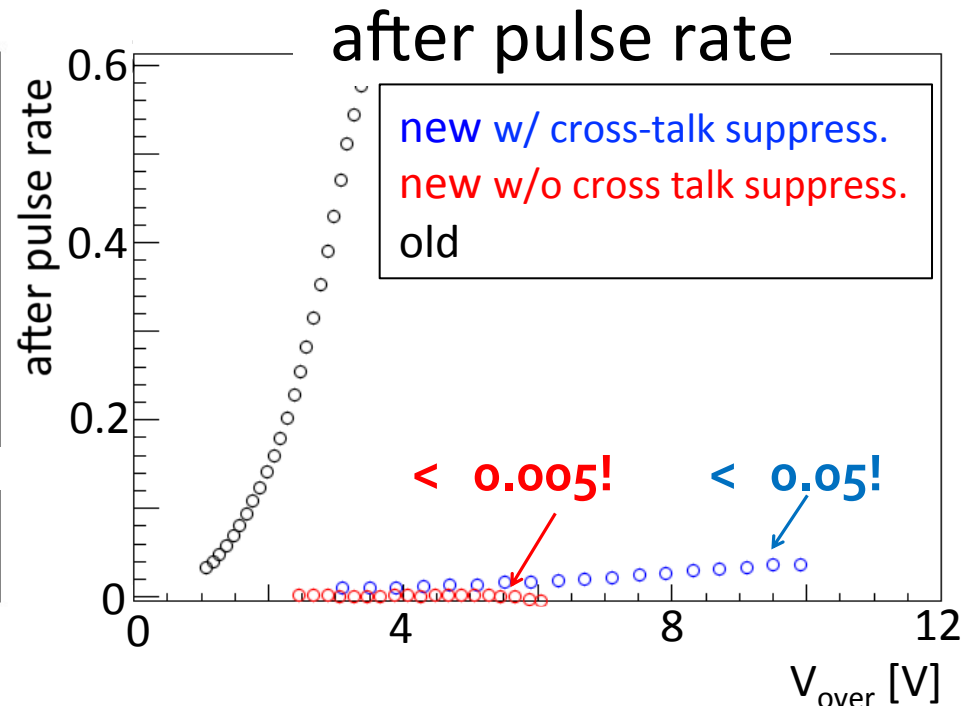
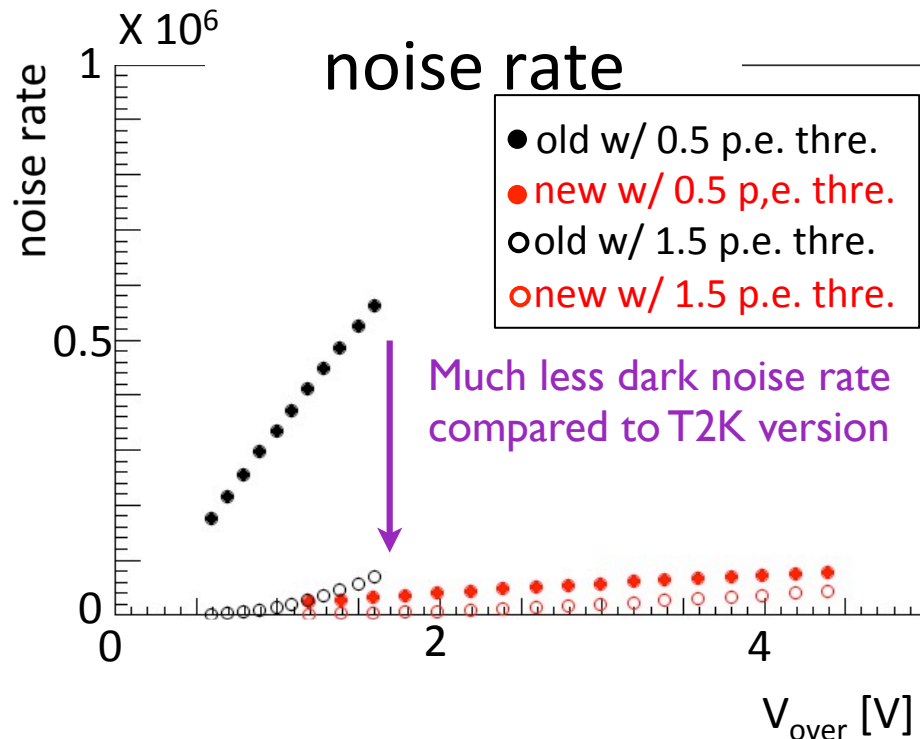


- Scintillator bars: T2K INGRID type
- WLS fiber: Kuraray Y11
- MPPCs: T2K ND type ($1.3 \times 1.3 \text{ mm}^2$), $V_{\text{over}} = 1.1\text{V}$

Stable for 180 days

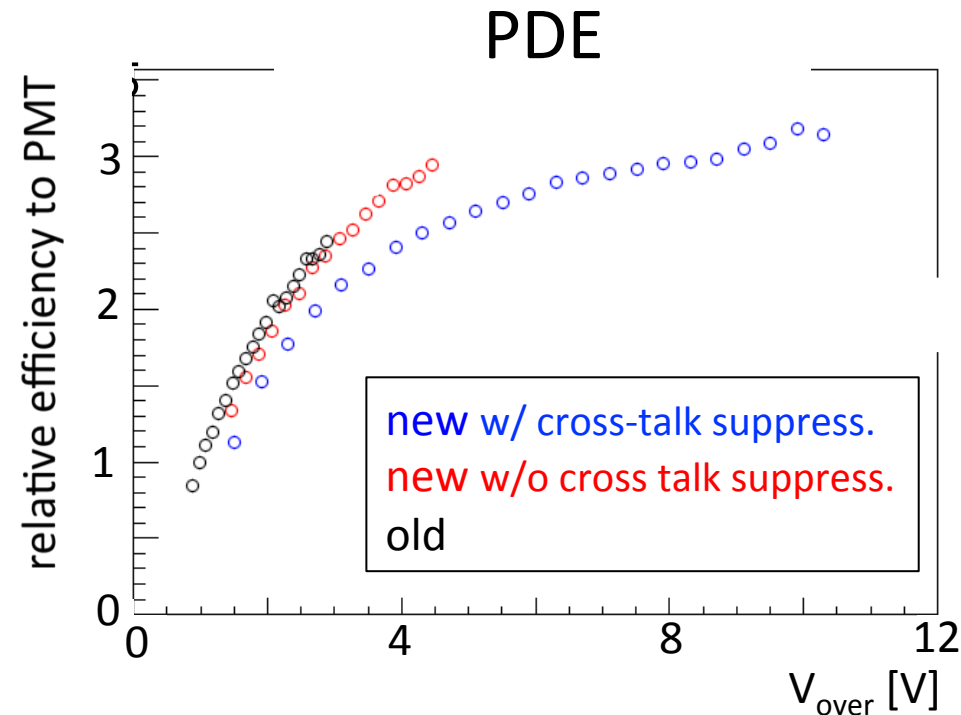
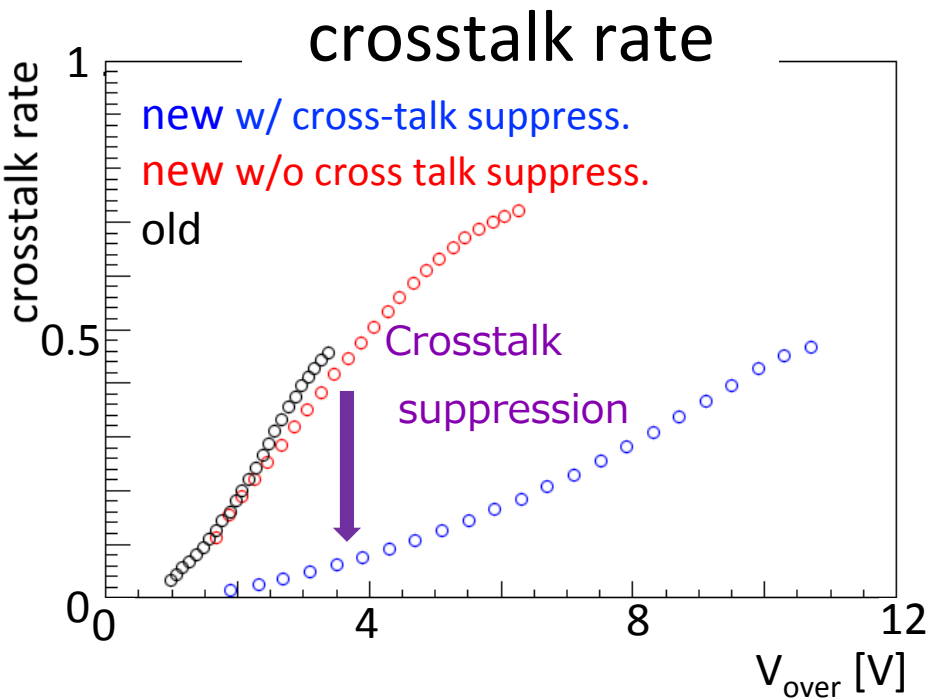
Test of the detector components (Continue.)

- Performance of new MPPCs developed by Hamamatsu
 - Low noise ($\sim 1/10$ compared to T2K version)
 - Much less after pulse
 - Wider operation voltage
 - Low cross-talk (optional)
- Improved wafer and processing
- Special structure



Test of the detector components (Continue.)

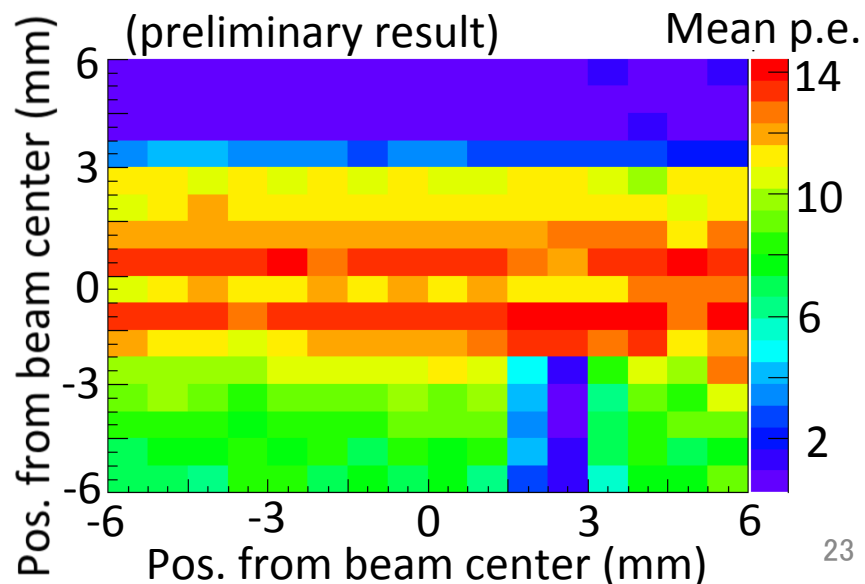
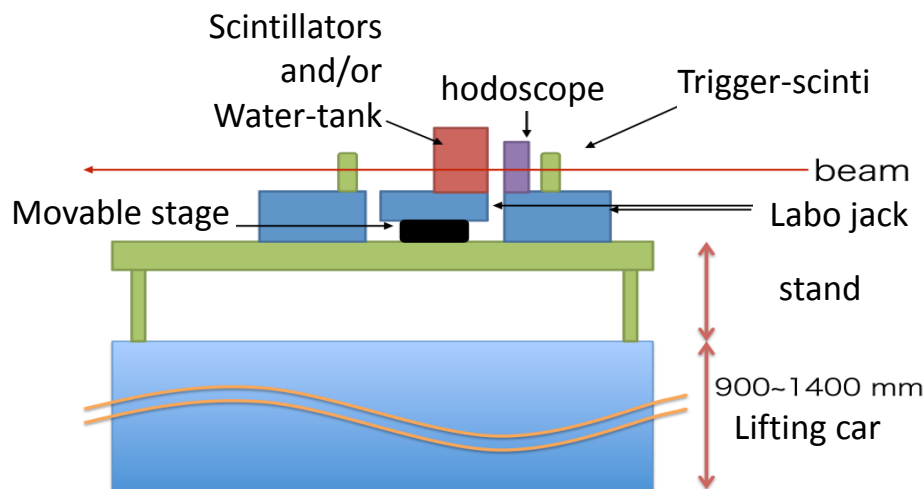
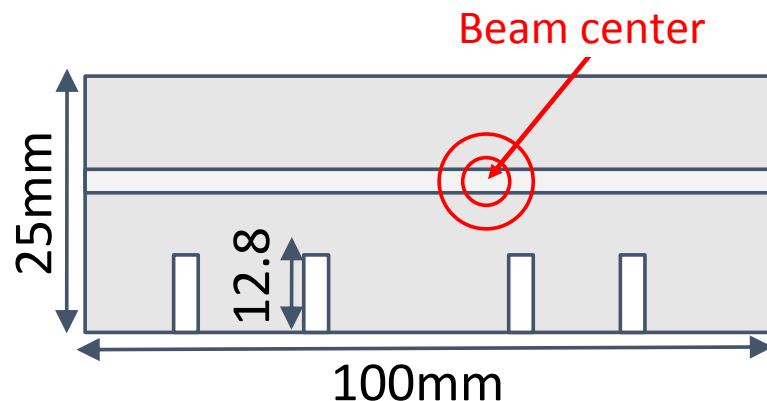
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 - Low noise ($\sim 1/10$ compared to T2K version)
 - Much less after pulse
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- Improved wafer and processing
- Special structure



We will operate the new MPPC at a high V_{over} . (High PDE is achieved.)

Test of the detector components (Continue.)

- We have tested 3mm-thick scintillator bars which have the groove/slits for the 3D grid-like structure by using positron beam at Tohoku Univ. on May, 2014.
 - Fermi-lab's scinti. (maybe be degraded)
 - MPPCs: T2K ND type
- Check items
 - Hit efficiency for MIP
 - Light yield for MIP
 - Optical cross talks



Schedule

- May – Jun., 2014: Neutrino beam measure. w/ an existing INGRID mod. at the candidate site.
 - BG study at the candidate site.
- Oct., 2014: 2nd beam test at Tohoku Univ.
 - Finish the performance test of the detector components (Scintillator bars, WLS fibers, MPPCs, ...)
 - Test a prototype of the WAGASCI detector (~ 100ch)
- Dec., 2014: Completion of the detector design
- Jan. – May, 2015: Order/delivery of the detector components
- Jun. – Oct., 2015: Detector construction/installation
- Nov., 2015: Detector commissioning
- Dec., 2015: Start operation

Summary

- We propose a test experiment, **WAGASCI**, to develop a 3D grid-like neutrino detector with a water target at the near detector hall of J-PARC neutrino beamline.
- Goals of the project
 - Measure the H_2O to CH charged current cross section ratio with 3% precision.
 - Double differential cross sections on H_2O and CH with 10% precision.
- MC studies/test of the detector components are on-going.
- Start operation on Dec., 2015.

Backup