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

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May 22, 2014

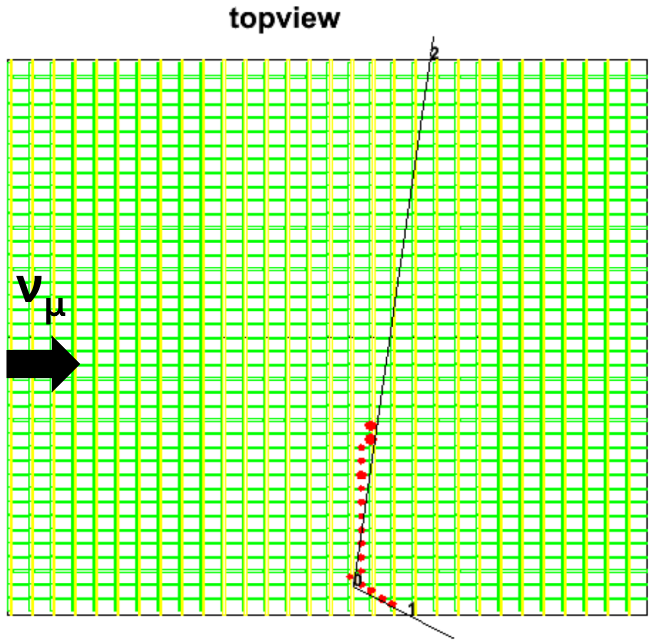
NuInt14 @ Surrey, UK

Outline

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

Water Grid And SCIntillator detector
WAGASCI

H_2O/CH detector
(3D grid-like structure)



Box for
Japanese sweets (Wagashi)

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

Project members

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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	2.9
(without ND280 constraint)	(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))

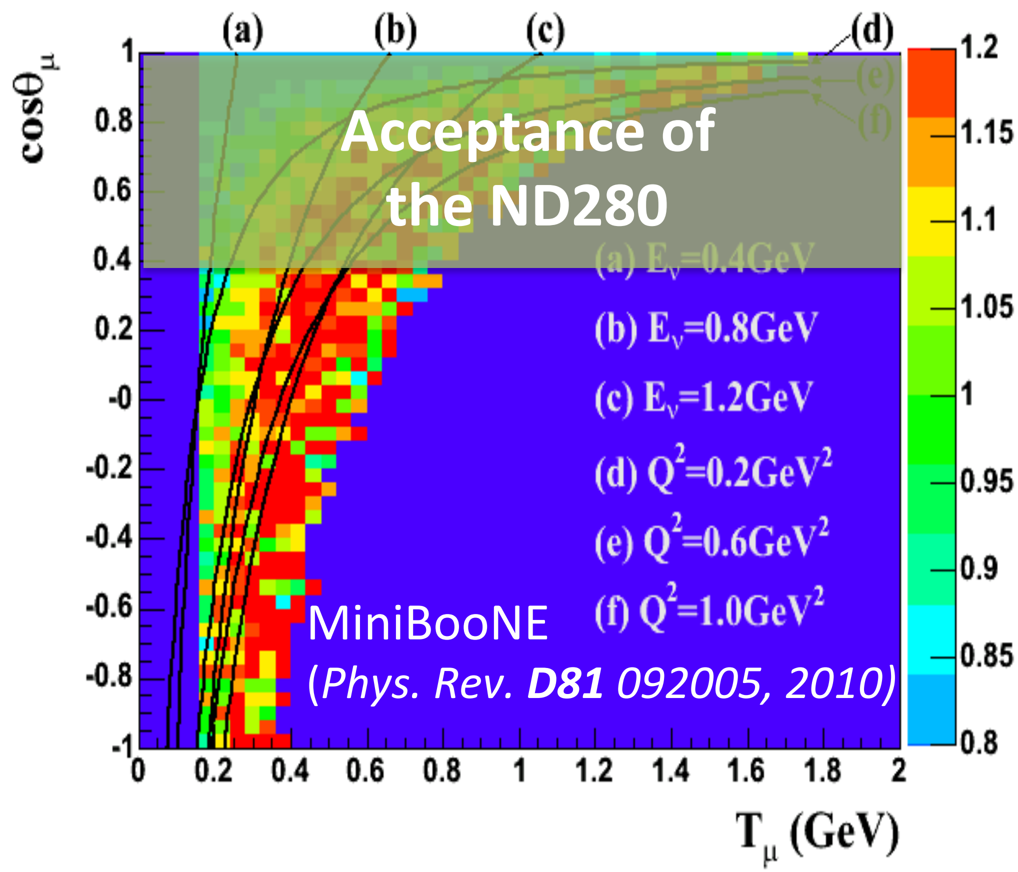
Source of uncertainty (number of parameters)	$\delta n_{SK}^{exp} / n_{SK}^{exp}$
ND280-independent cross section (11)	4.9%
Flux and ND280-common cross section (23)	2.7%
SK detector and FSI + SI systematics (7)	5.6%
$\sin^2(\theta_{13})$, $\sin^2(\theta_{12})$, Δm^2_{21}, δ_{CP} (4)	0.2%
Total (45)	8.1%

(*) 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 (= 4π).
  - T2K need to reply on external data sets (MiniBooNE, etc.).

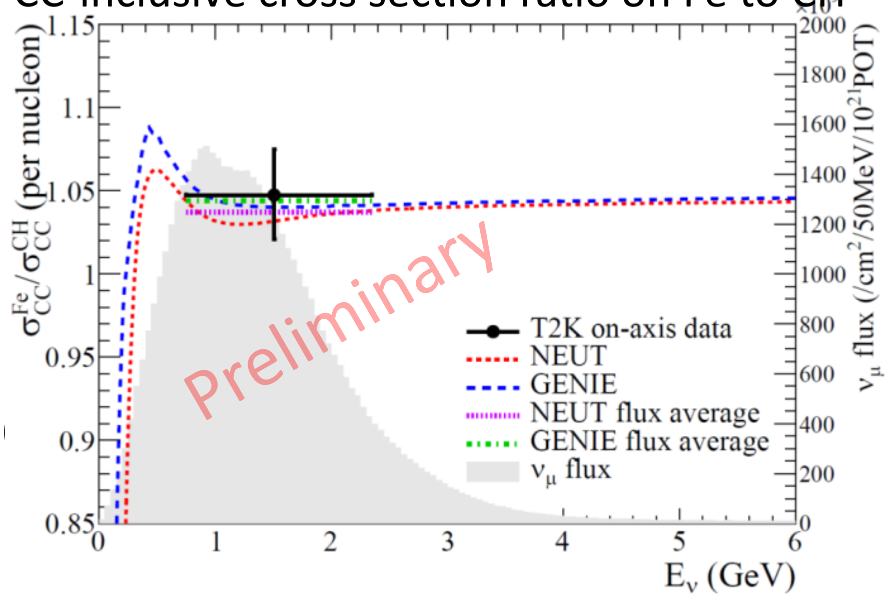
N_μ CCQE double differential cross section
discrepancies between DATA and Model



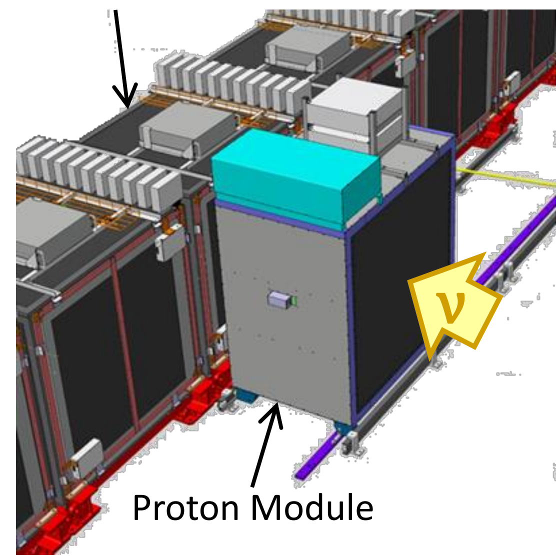
Motivation (continue)

- 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)

CC-inclusive cross section ratio on Fe to CH



Central standard module

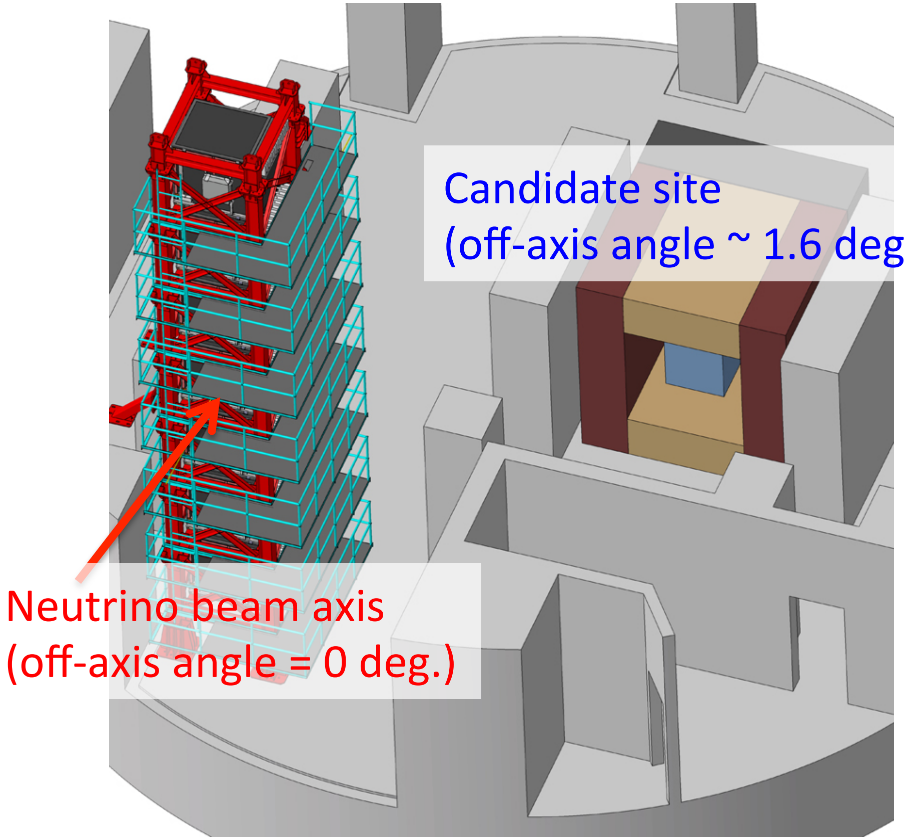


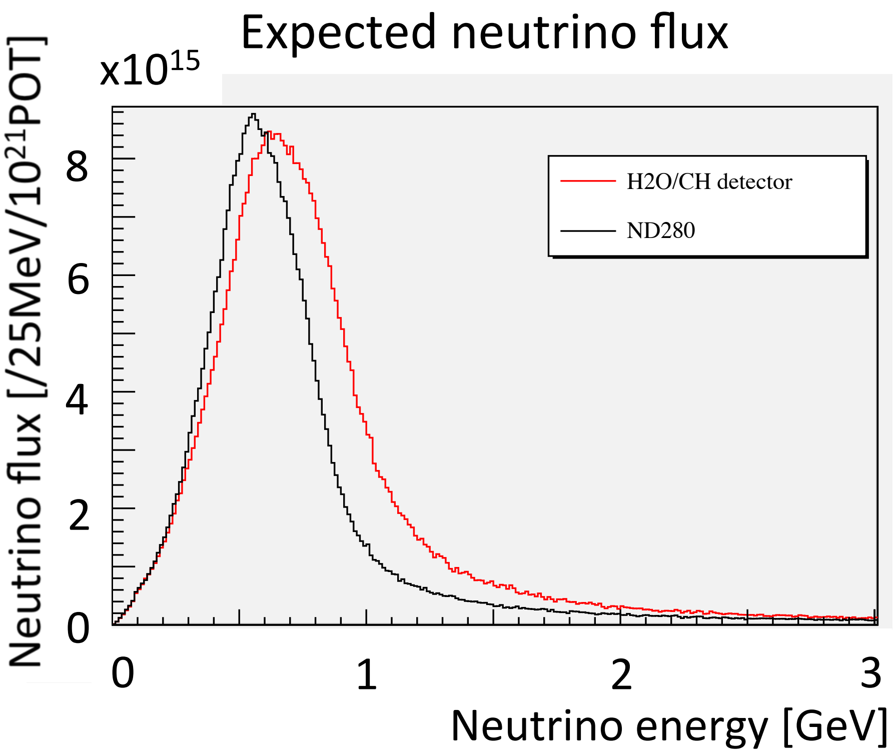
Proton Module

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

Candidate site

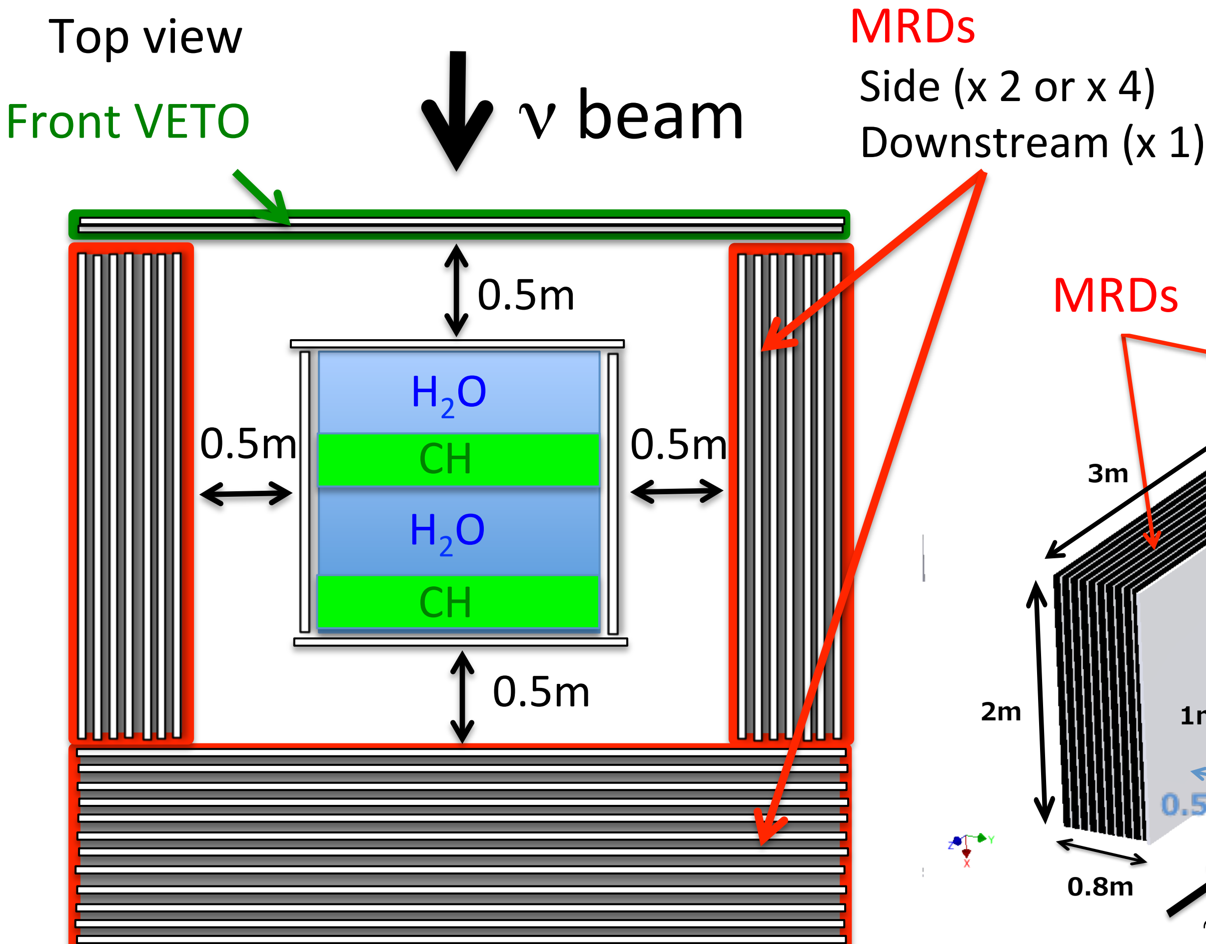
- The B2 floor of the T2K near detector hall as a test facility of neutrino beam
  - Off-axis angle ~ 1.6 degree
  - Neutrino energy spectrum is similar to the ND280/Super-K.

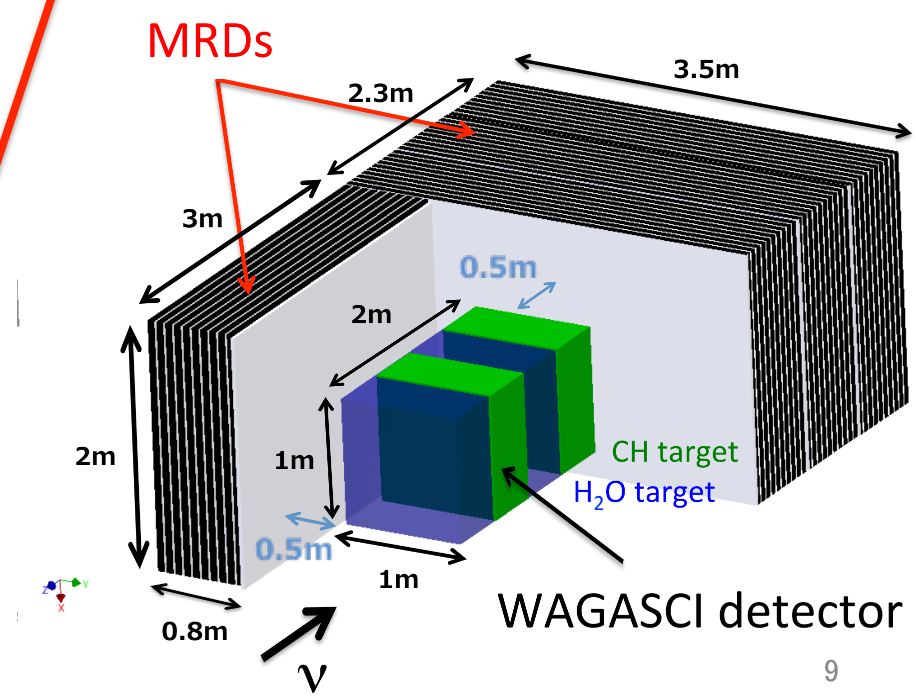




Detector configuration

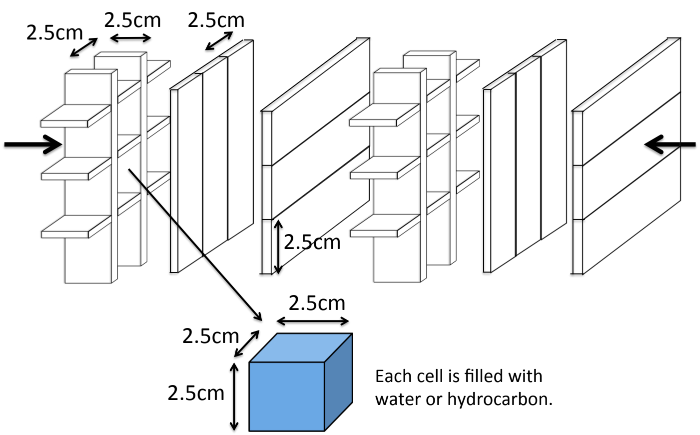
- WAGASCI detector + muon range detectors (MRDs)
  - MRDs are located 50cm away from the WAGASCI detector to identify the charged particle directions from hit-timing diff. between the two detectors.

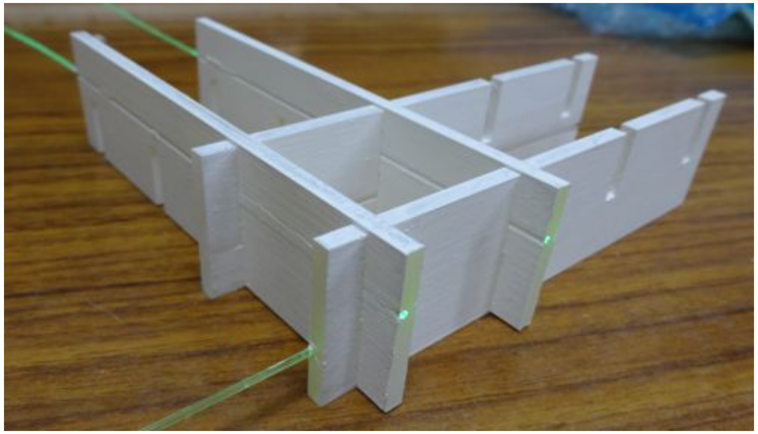




WAGASCI detector

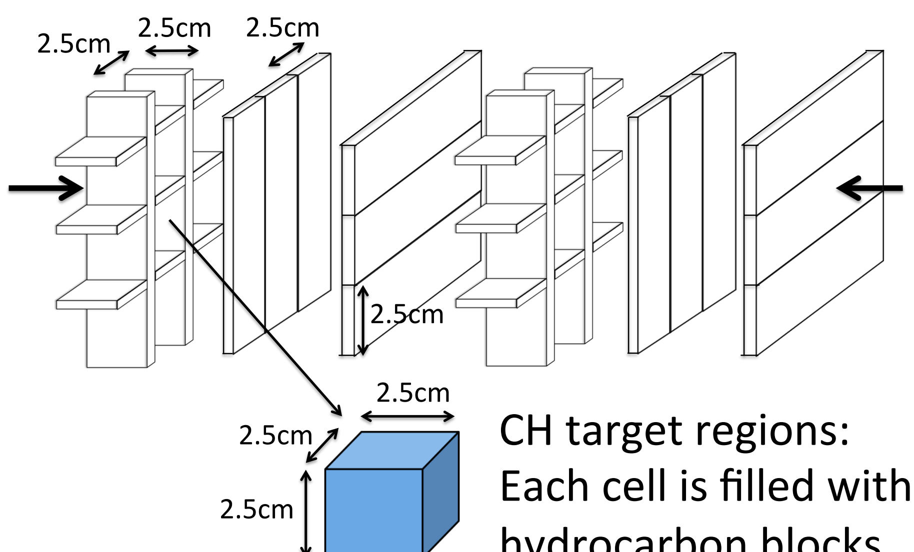
- Dimensions
  - 100cm x 100cm in section and 200cm along the beam direction
  - H_2O/CH target mass is ~2 ton in total. (Total weight ~ 3 ton.)
- 3D grid-like structure (x, y, grid layers + WLS fibers + MPPCs)
  - 4π angular acceptance for charged particles
  - 2.5cm grid spacing enables us to reconstruct 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 H_2O (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

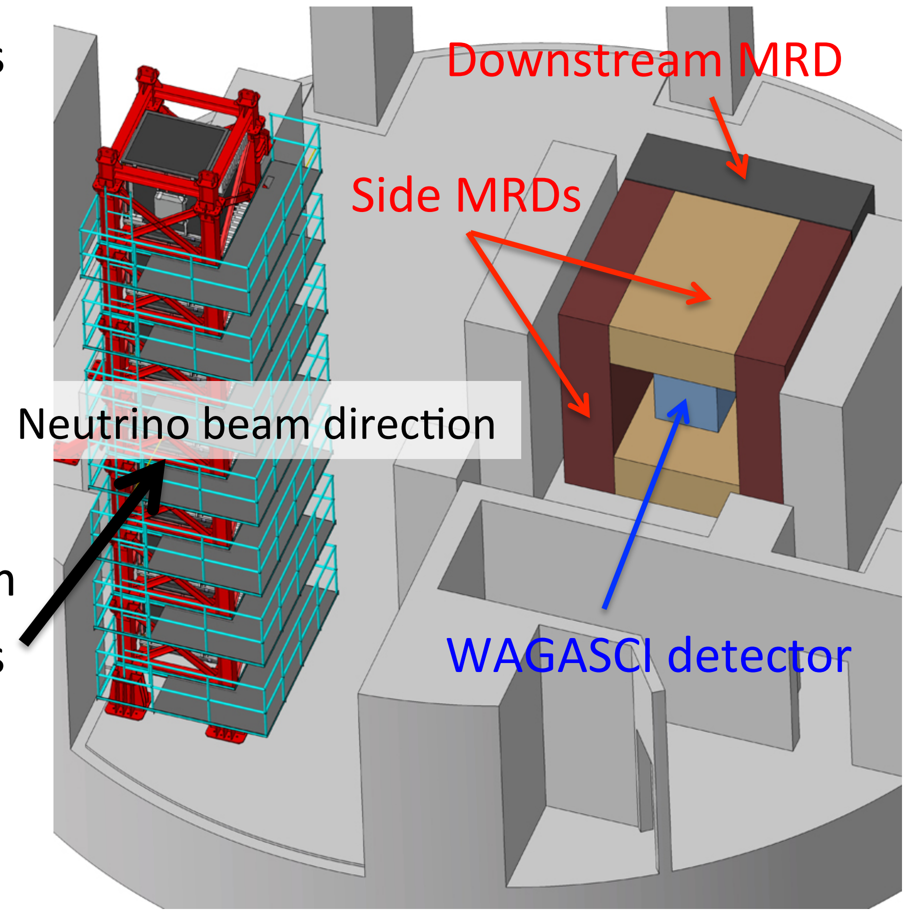
- 4π angular-acceptance
- H_2O(signal):CH(BG) = 70:30
  - T2K ND280: H_2O:CH = 46:54
- Similar detector systematics for H_2O/CH measurements
  - Each cell of the 3D grid is filled with hydrocarbon blocks in the CH target regions.



CH target regions:
Each cell is filled with
hydrocarbon blocks.

muon range detectors (MRDs)

- Side MRDs
  - Dimensions ~ 300cm x 200cm x 100cm
  - 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 ~1 GeV/c

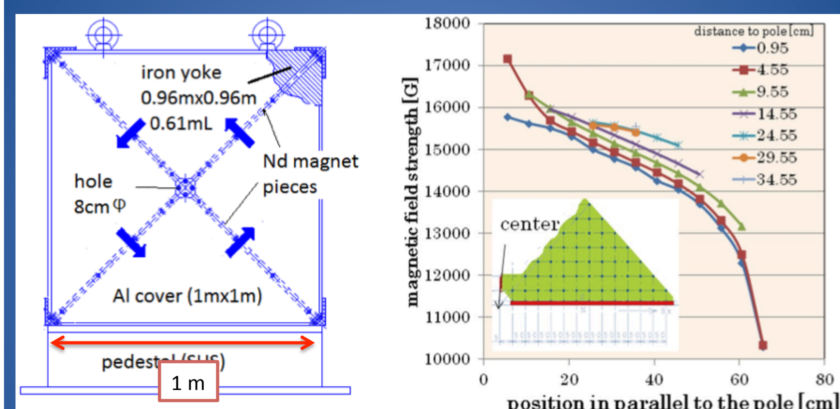


- Downstream MRD
  - Dimensions ~350cm x 200cm x 220cm
  - 32 tracking planes and 30 steel plates
    - Weight of a steel plate: 1.7 ton
    - Weight of a tracking planes: 190kg
  - Total weight: ~60 tons
  - Can measure p_μ up to ~ 2 GeV/c

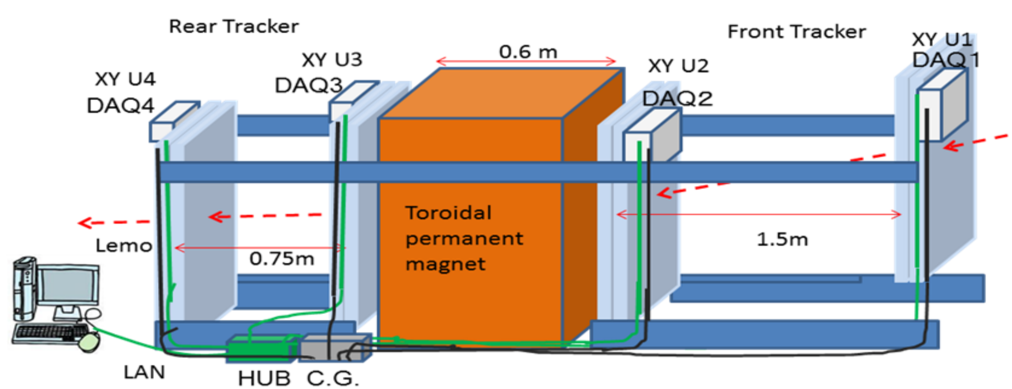
Downstream muon detector

- 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 filed 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



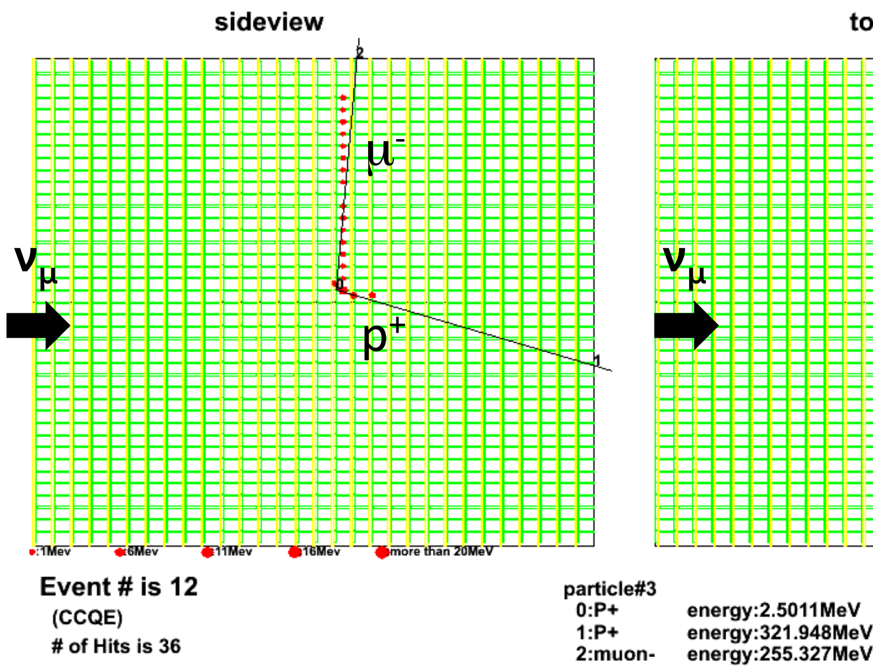
Goals

- 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_μ, $\cos\theta_\mu$)
  - CC-inclusive channel. Then, exclusive channels.

MC study (CC-inclusive)

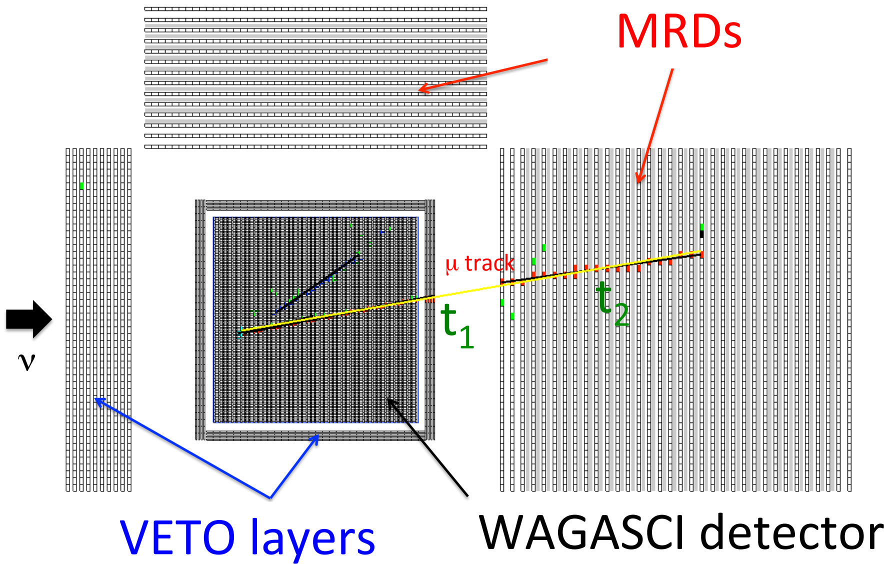
- Neutrino flux prediction
  - Hadron production (NA61@CERN) & Proton/ν beam monitoring
- Neutrino interaction generator: NEUT
- Detector MC: Geant4
  - Geometry in the MC is slightly different from the one in p. 9. (Better performance is expected by adapting the geometry in p.9 to the MC.)

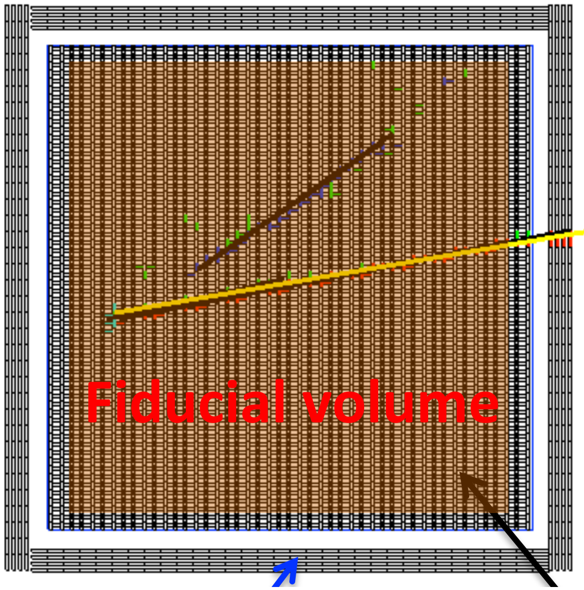
A event display of the WAGASCI detector (CCQE event)



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 form VETO layer hits & TOF ($t_1 < t_2$).
  - Vertices are in the fiducial volume of the WAGASCI detector.

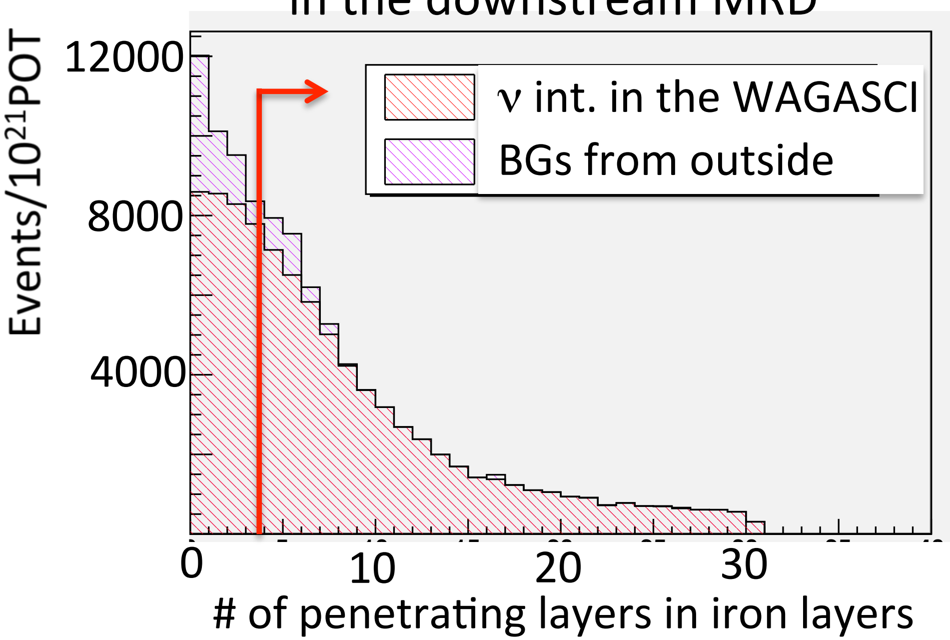




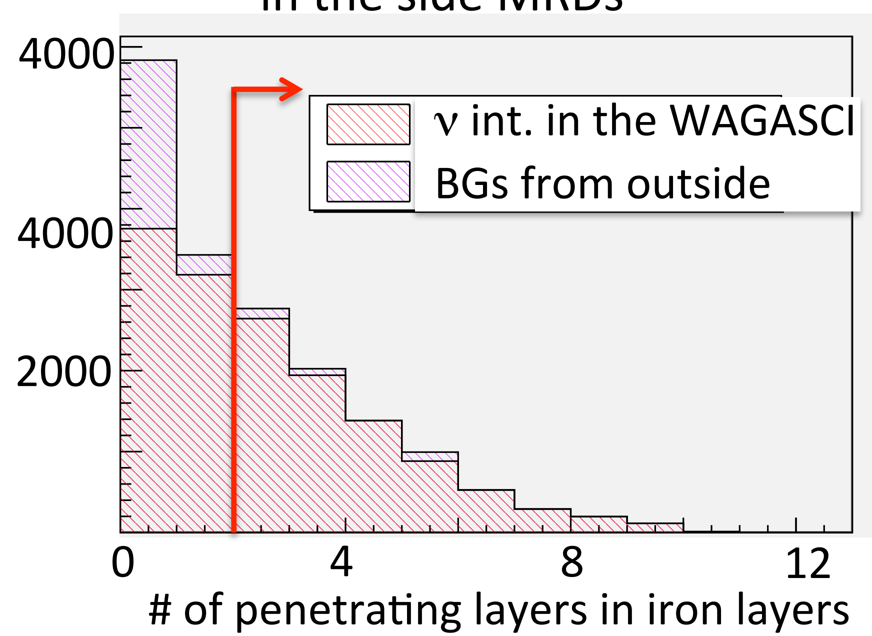
MC study (CC-inclusive) (Continue.)

- 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



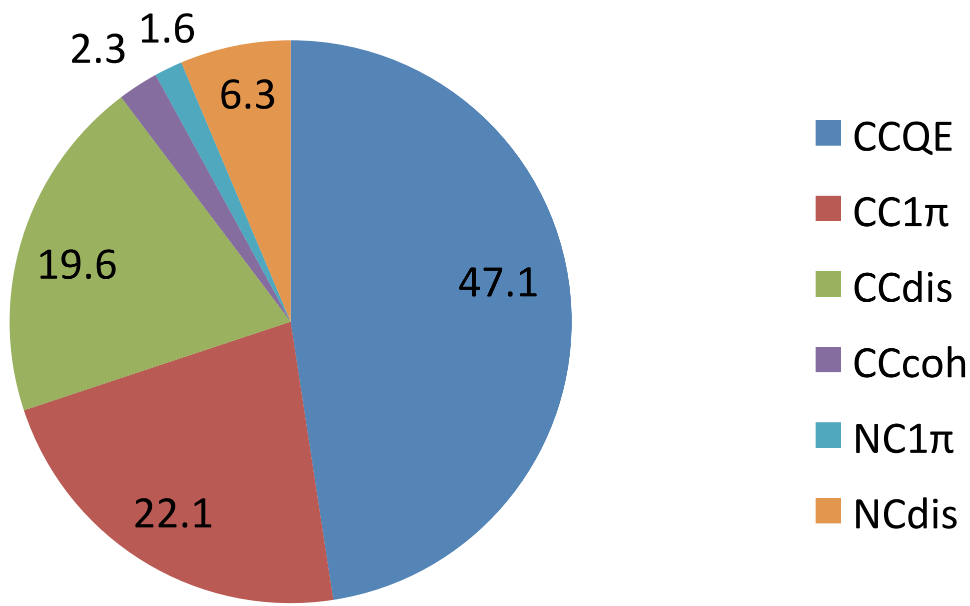
Events with a matched track in the side MRDs



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.

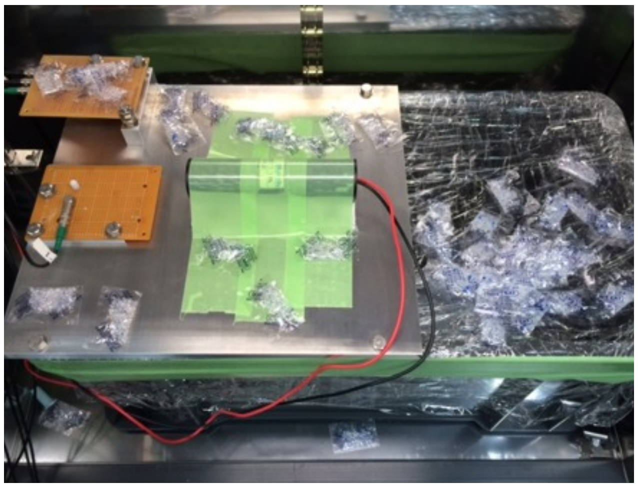
$$\sigma_{CC} = \frac{N_{sel} - N_{BG}}{\Phi T \varepsilon_{CC}}$$

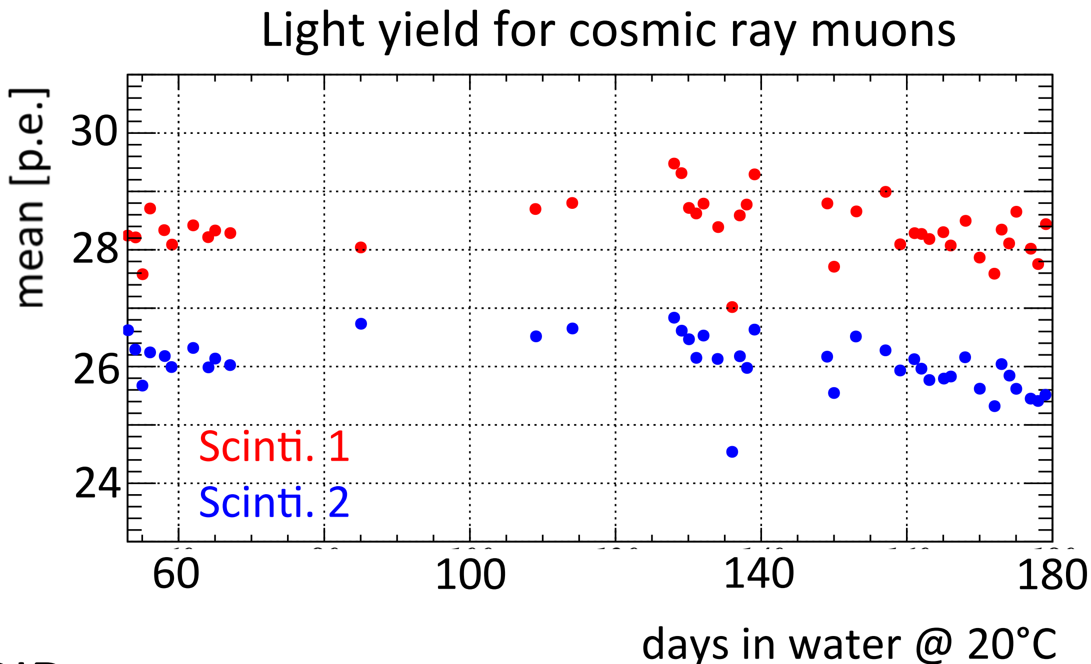
N_{sel}	: Number of selected events (data)
N_{BG}	: Number of selected BG events (MC)
Φ	: Integrated ν_μ flux (MC)
T	: Number of target nucleons
ε_{CC}	: Detection efficiency of CC events (MC)

  - This calculation is applied to the H_2O 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 x 1.3 mm^2), V_{over} = 1.1V

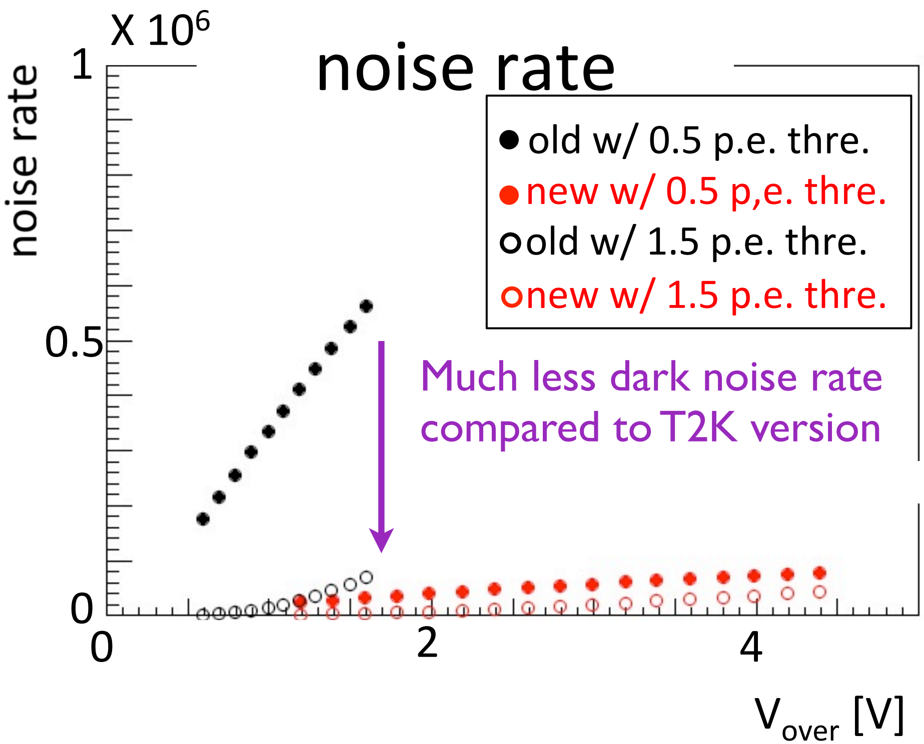
Stable for 180 days

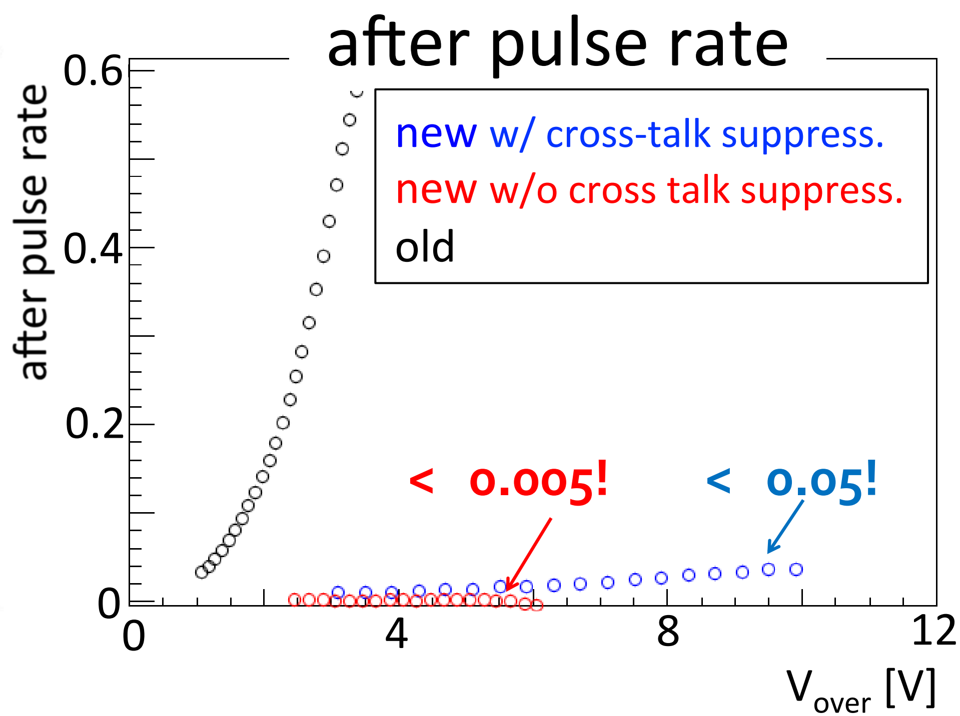
Test of the detector components (Continue.)

- Performance of new MPPCs developed by Hamamatsu
  - Low noise (~1/10 compared to T2K version)
  - Much less after pulse
  - Wider operation voltage
  - Low cross-talk (optional)

} Improved wafer and processing

→ Special structure





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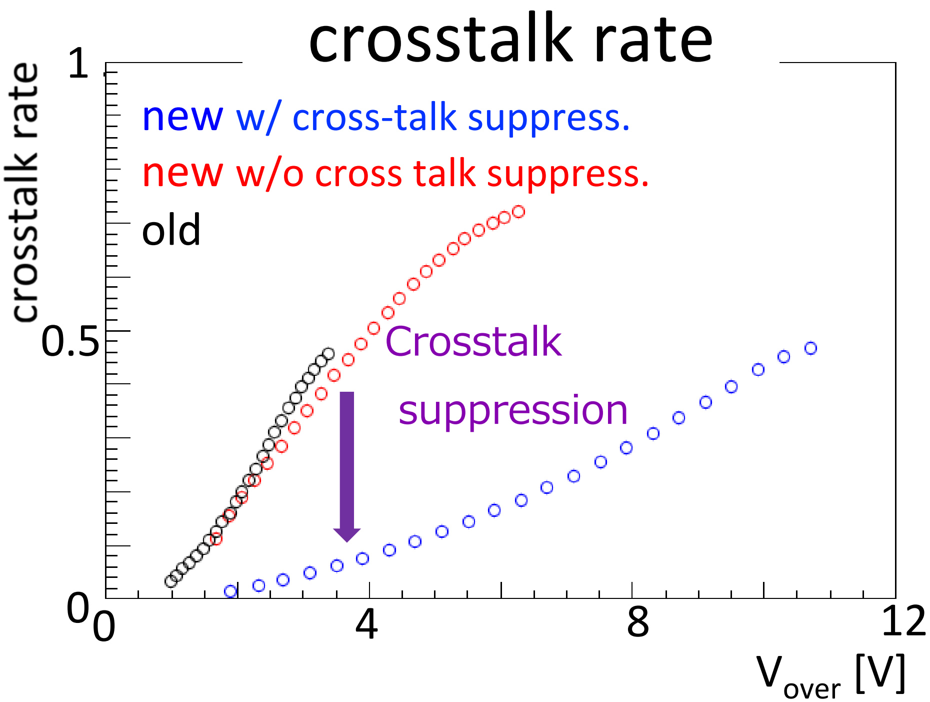
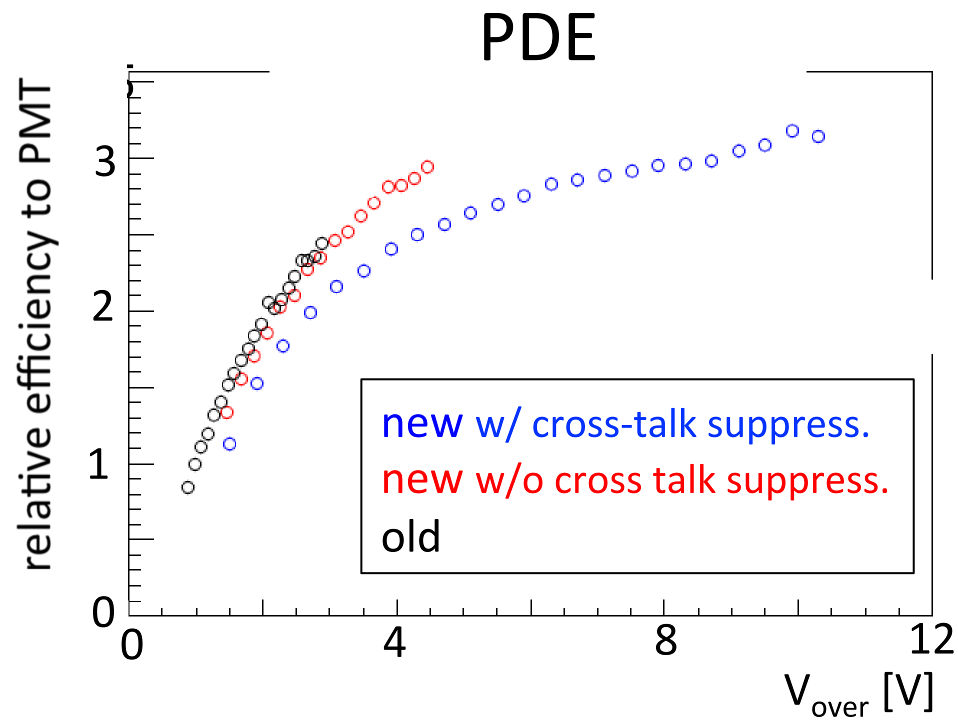
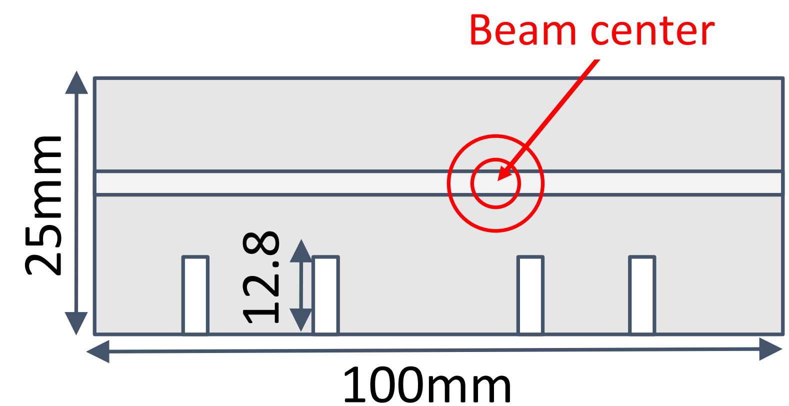


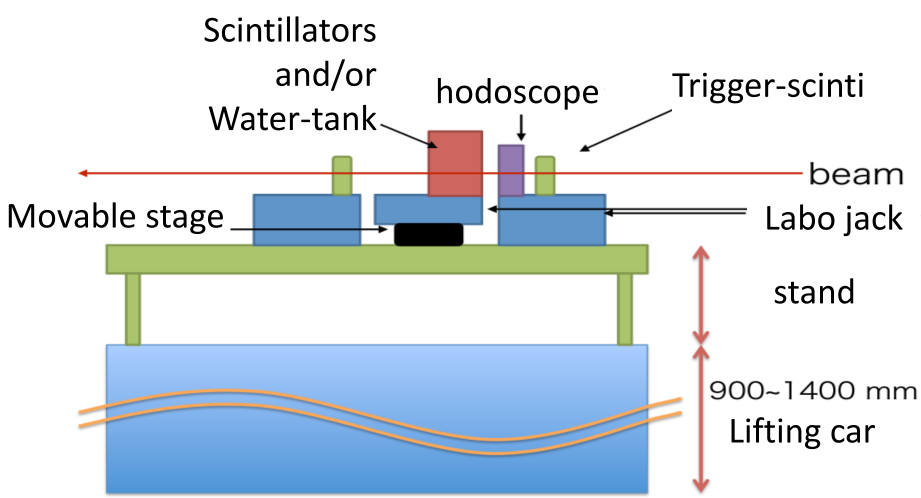


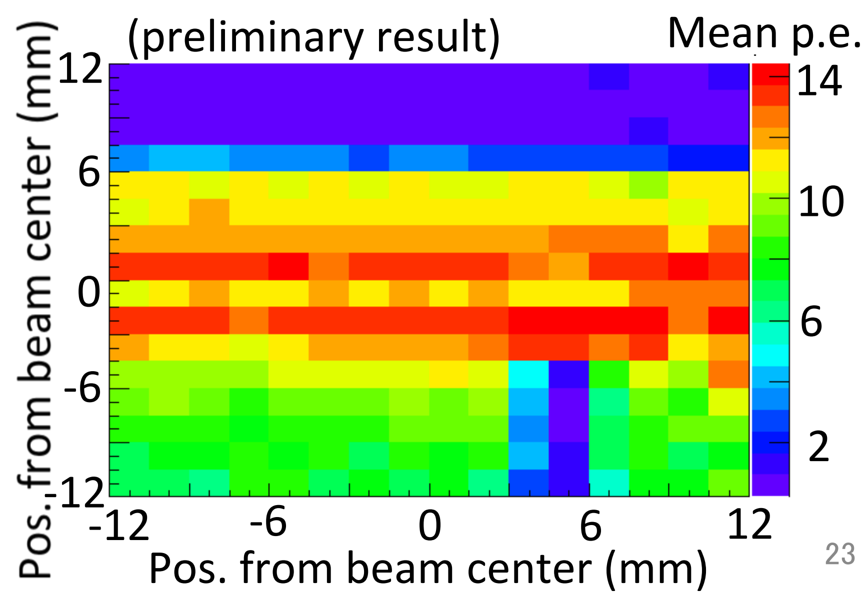
We will operate the new MPPC at a high V_{over}. (High PDE is achieved.)

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