Report of the NU_05 group

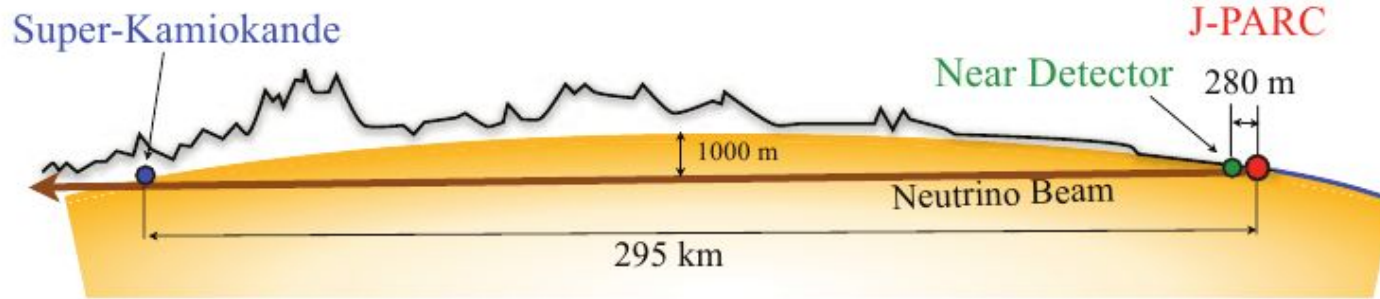# T2K near detectors and their upgrade for neutrino cross-section measurements

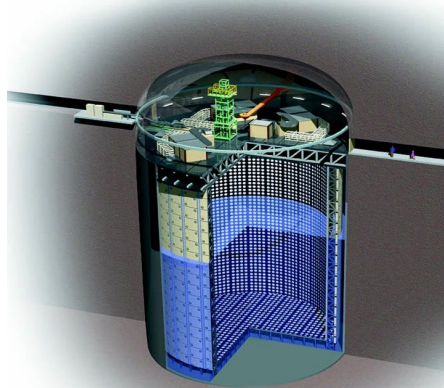## Matthieu Licciardi

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ÉCOLE POLYTECHNIQUE
UNIVERSITÉ PARIS-SACLAY

FRANCE-JAPAN PARTICLE PHYSICS
TOSHIKO YUASA LAB.

Matthieu Licciardi – LLR – CNRS/IN2P3
FJPPL annual workshop – IPHC, Strasbourg - 10th of May 2017

T2K

The Tokai-to-Kamioka (T2K) experiment
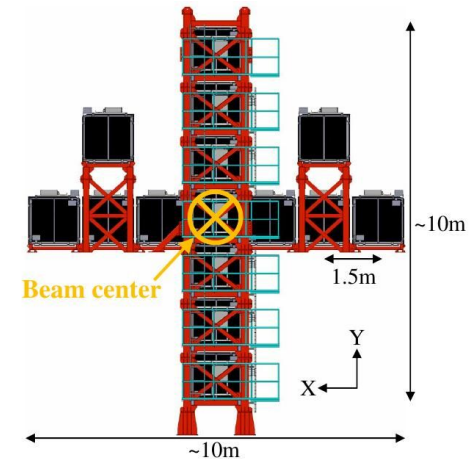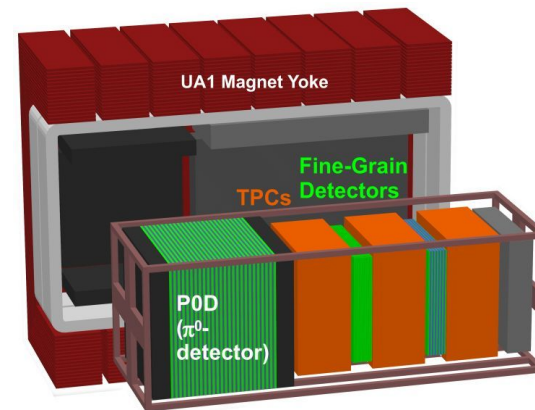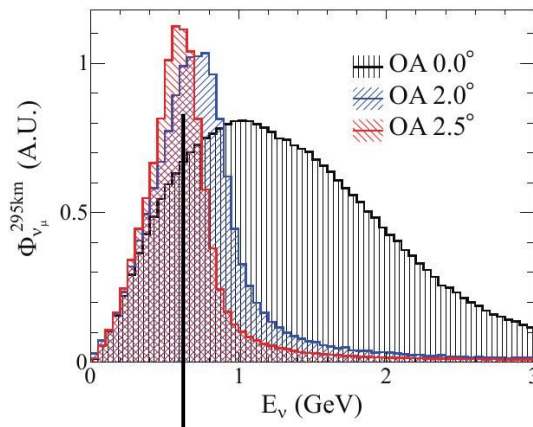

Far detector (295km)
Super-Kamiokande

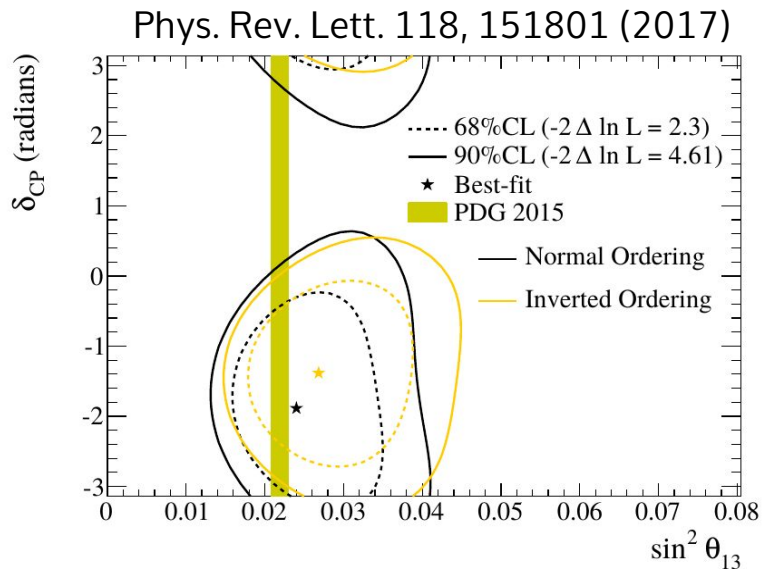Near detectors (280m)

Off axis (→ SK): ND280

On axis: INGRID

600 MeV: energy for the maximum of oscillation

Oscillation analyses with T2K

Goal: measure oscillation parameters and CP violating phase δ

Sources of systematic errors:

➢ Flux — cancel between near and far detectors ✓

➢ Cross section models

➢ Detector

} near and far detectors are different ✗

Phys. Rev. Lett. 118, 151801 (2017)

68%CL (-2 Δ ln L = 2.3)
90%CL (-2 Δ ln L = 4.61)
★ Best-fit
PDG 2015
Normal Ordering
Inverted Ordering

	Near Dets	Far Det
acceptance	forward	4π
target material	mainly CH	water

→ Need for new cross-section measurement and detector upgrades

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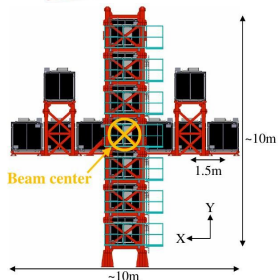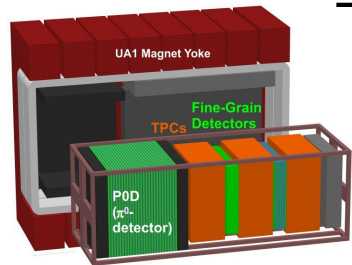
New cross-section measurements

What's interesting?

➢ Wide E_ν range

➢ Water target, water/C ratio

➢ Exclusive channels (CC0π, CC1π)

→ Very intense and fruitful work

on-axis flux
off-axis flux
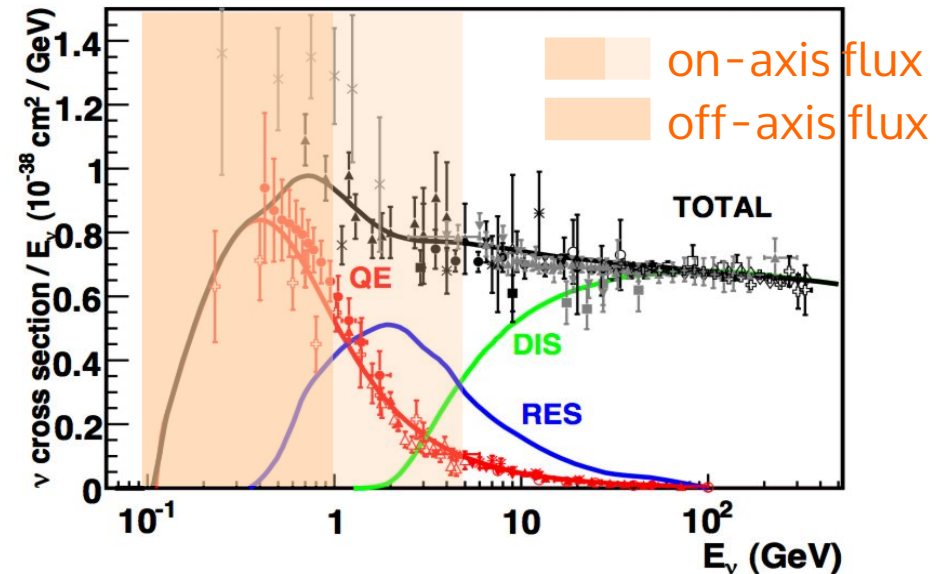
Analyses from NU_05 members:

> CC0π on C (S.Bolognesi, CEA/IRFU) **Phys.Rev. D93 (2016), 112012** ✓

> CC0π on C w.r.t. proton multiplicity (P.Bartet, LPNHE) ✓

> CC0π water/CH ratio (F.Gizzarelli, CEA/IRFU) } Publication expected soon ✓

> CC0π on O, C, and O/C ratio (M.Buizza-Avanzini, LLR)   In progress

> CCQE on C (T.Kikawa, Kyoto U.)   **Phys.Rev. D91 (2015) no.11, 112002** ✓

> CC0π on C (B.Quilain, Kyoto U.)

> CC1π on C, water and ratio (M.Licciardi, LLR) } In progress

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T2K

CC0π cross section w.r.t. proton multiplicity & kin.

- **Proton multiplicity**

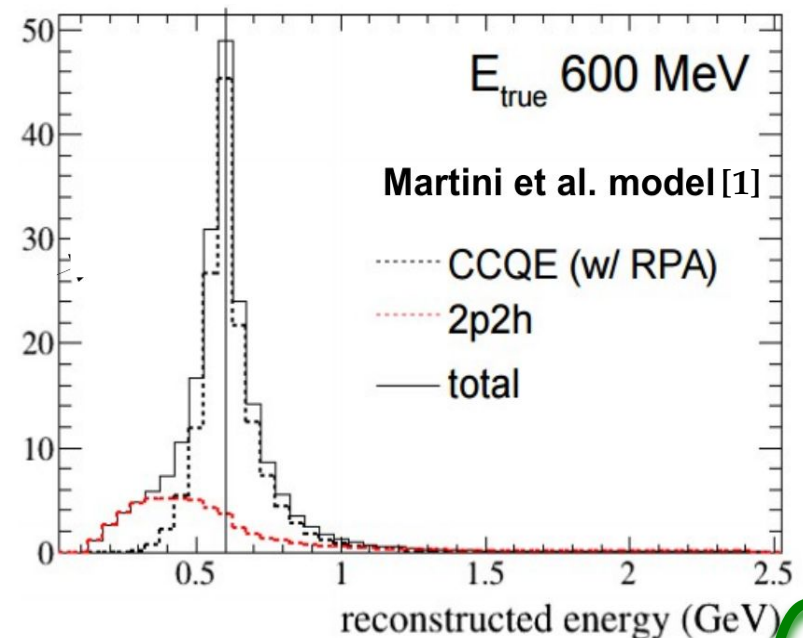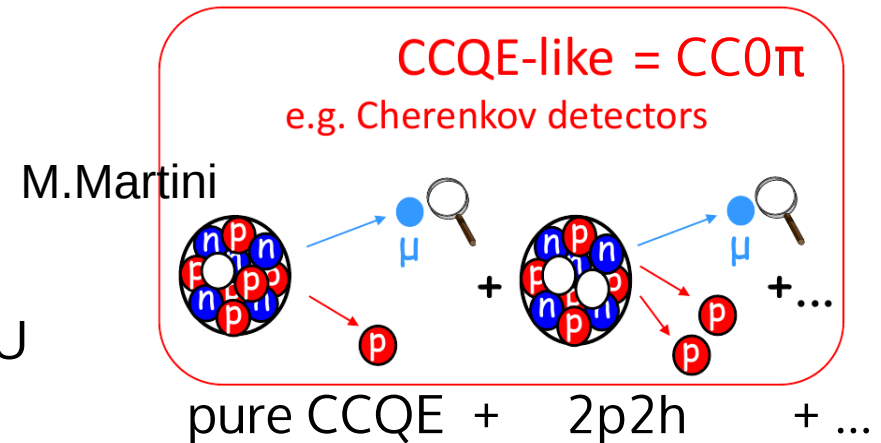 → probe the nuclear structure (2p2h)

  and Final State Interactions

  * successful workshop was held at CEA/IRFU
  in April 2016 on the 2p2h topic

CCQE-like = CC0π
e.g. Cherenkov detectors

M.Martini

pure CCQE + 2p2h + ...

- **Proton kinematics**

  → better reconstruction of E_ν

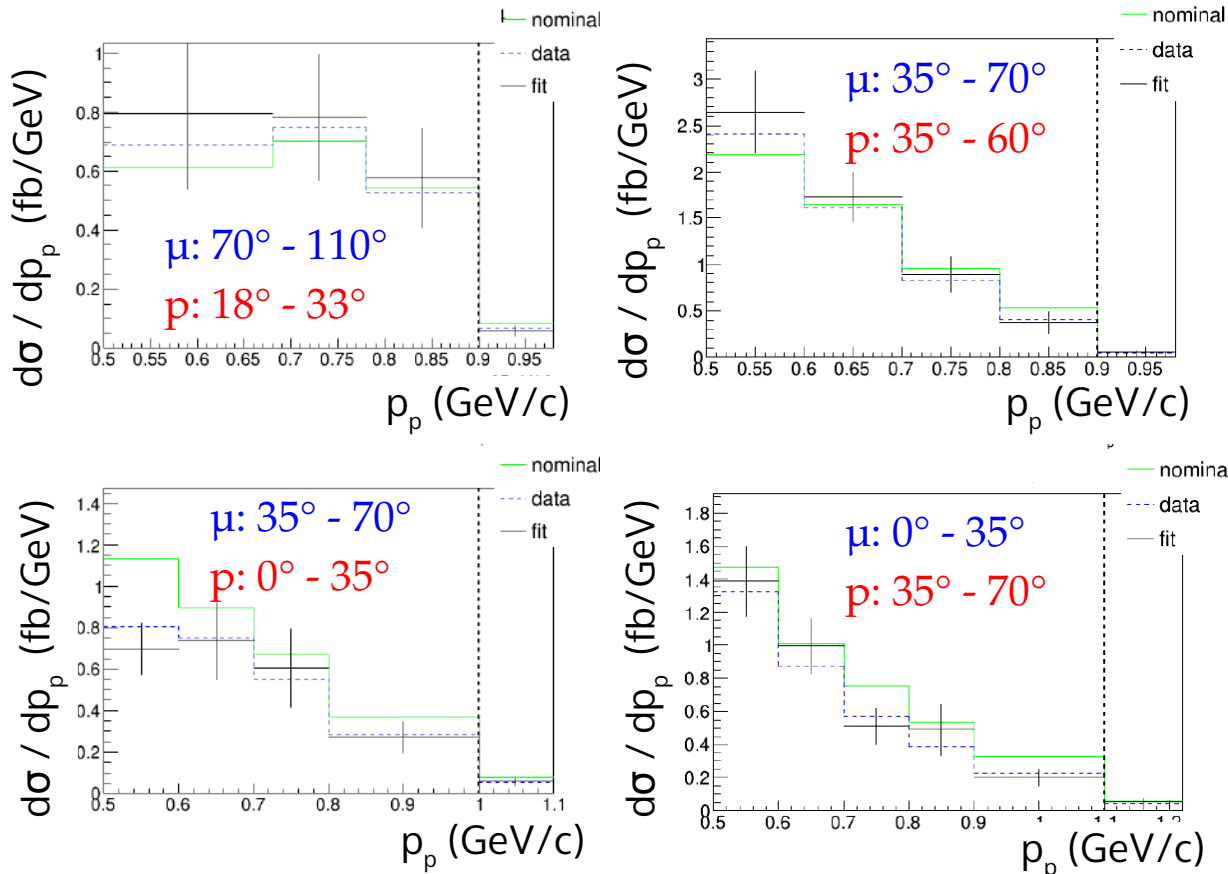 So far (at SK): quasi-elastic assumption
  from only muon kinematics

$$\bar{E}_\nu = \frac{E_\mu - m_\mu^2/(2M)}{1 - (E_\mu - P_\mu \cos\theta)/M}$$
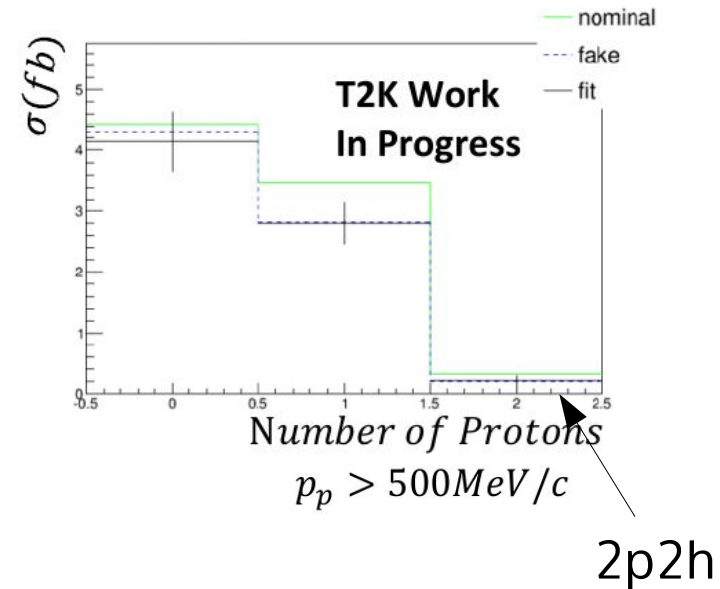

E_{true} 600 MeV

Martini et al. model [1]

...... CCQE (w/ RPA)
...... 2p2h
—— total

reconstructed energy (GeV)

CC0π cross section w.r.t. proton multiplicity & kin.

- ## Proton kinematics (CC0π-1p sample)

- ## Proton multiplicity

2p2h

Results with T2K data under collab. review
→ Publication soon !

Nominal: NEUT
Fake data: GENIE

Pierre Bartet et al.

Detector upgrades – the WAGASCI project

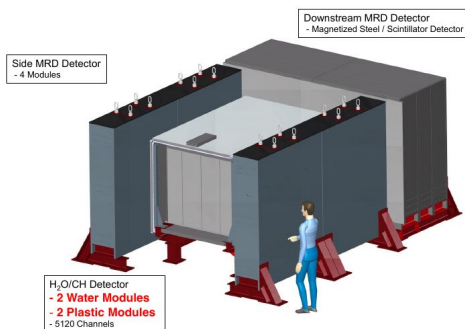## Goal: build a near detector with water target and 4π acceptance

In the coming years
- T2K–phase II: increased beam power
- Hyper–Kamiokande
  → Need a competitive set of near detectors!

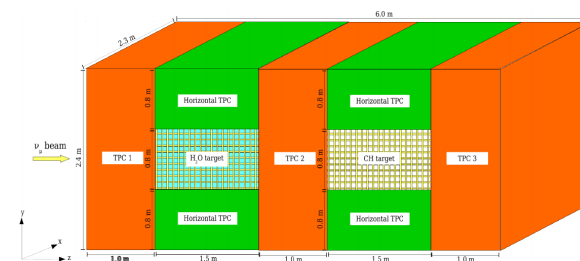|	Near Dets	Far Det
acceptance	forward	4π
target material	mainly CH	water

Prototype module
(installed)

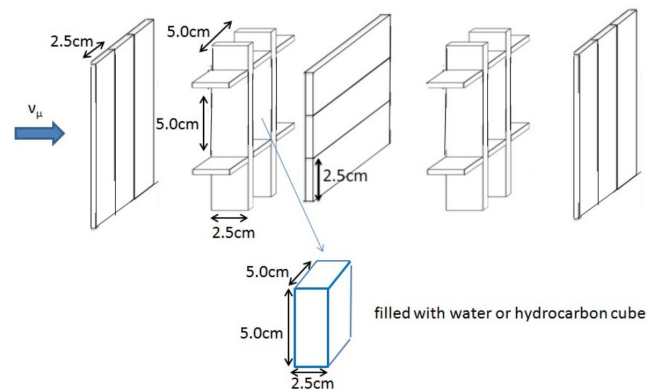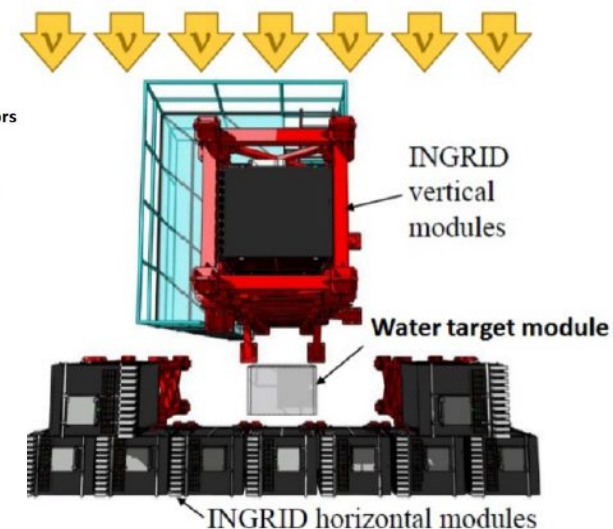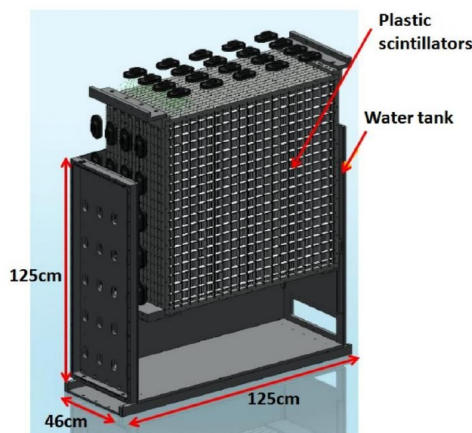WAGASCI project
(Fall 2017)

Upgraded ND280
(~2020)

...

...

→ Long term effort but already intense work on this 3 phases

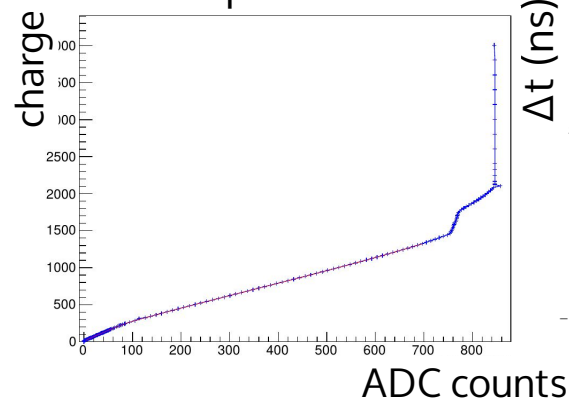# Prototype module: commissionning & data taking

- ## New structure

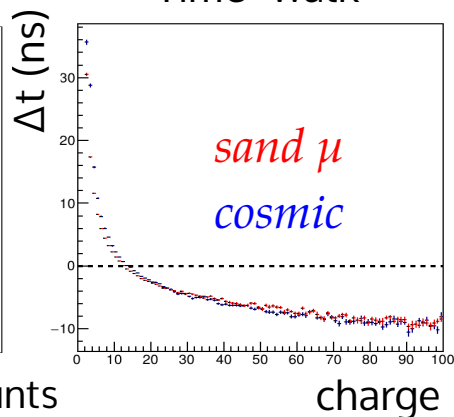filled with water or hydrocarbon cube

- ## Electronics calibration

ADC response function

ADC counts

Time-walk

sand μ

cosmic

charge

- ## Installation

Plastic scintillators

Water tank

125cm

125cm

46cm

INGRID vertical modules

Water target module

INGRID horizontal modules

- ## Algorithms development

- ## Data taking (T2K Run8, ~ 7 10^{20} POT)

- ## Cross-section measurements
  - ➢ CC inclusive on water and water/C ratio (T.Koga, U. Tokyo) → under review ✔
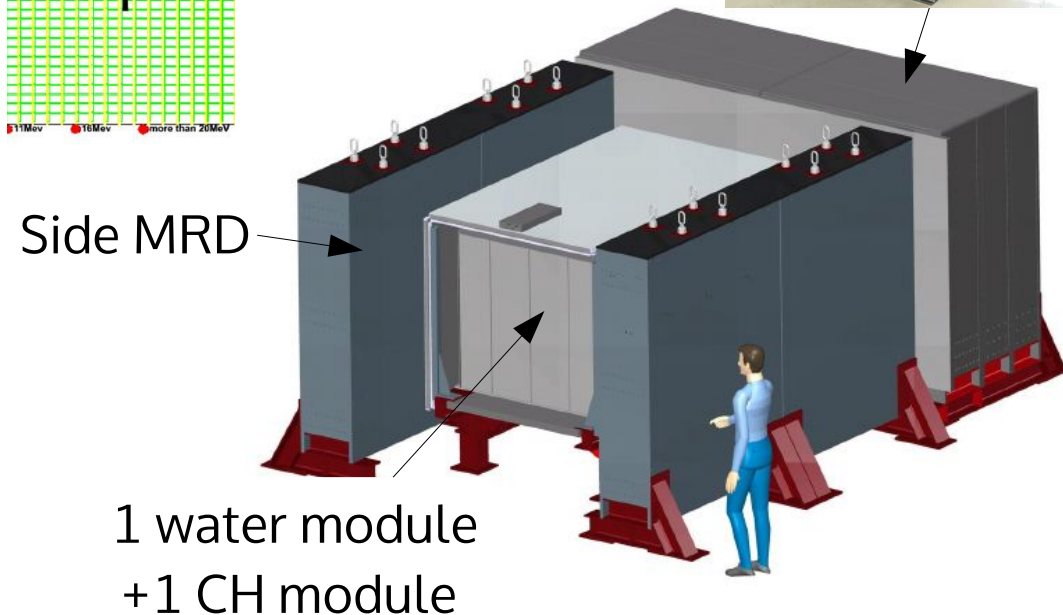 - ➢ CC1π on water, C and water/C ratio (ML)

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The WAGASCI test experiment

"Real size" test of the innovative detector structure

Water **G**rid **A**nd **SCI**ntillator

Baby-MIND
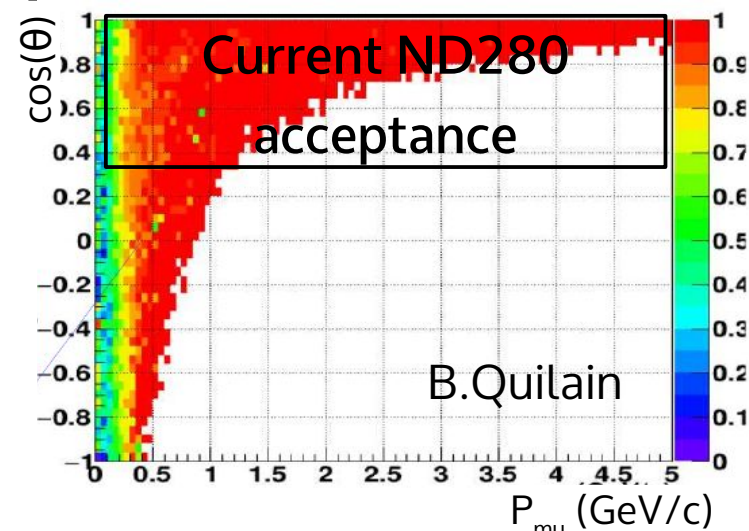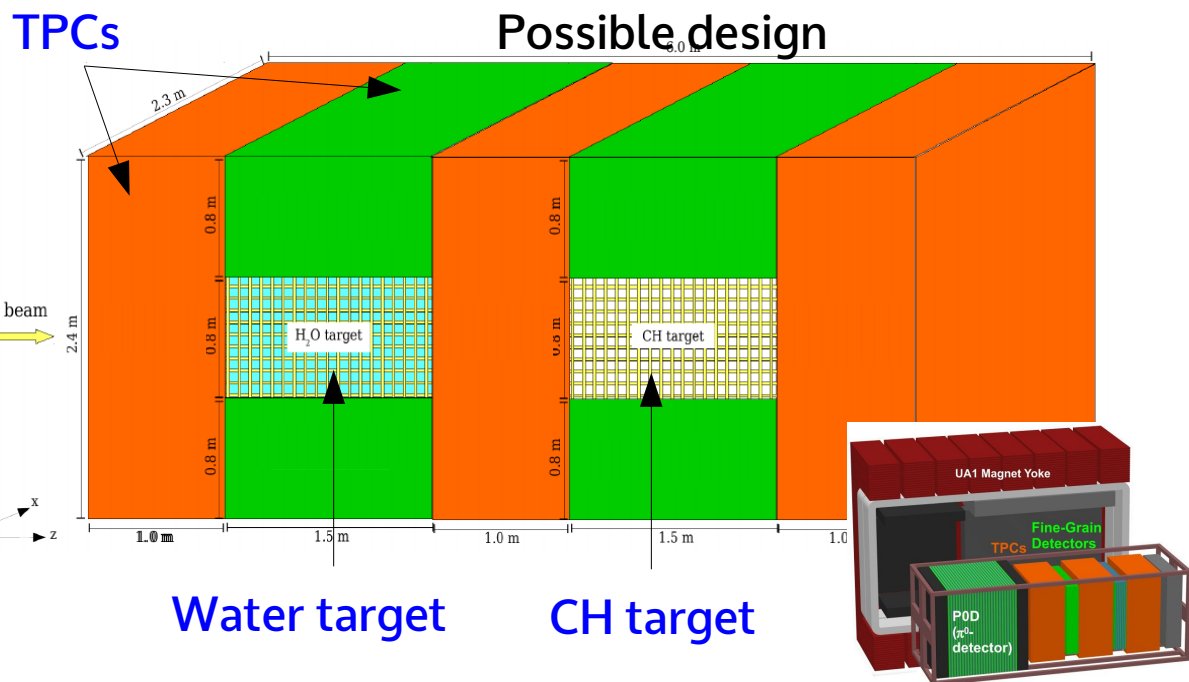(Ready at CERN)

Side MRD

1 water module
+1 CH module
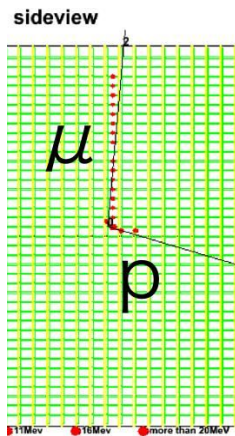
This year:
- Modules assembly
- Side MRD design, construction
- DAQ development
  → be ready for beam (winter 17)

WAGASCI will help to:
→ gain experience on assembly methods, calibration...
→ develop tools for future cross-section measurements

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T2K

ND280 Upgrade

Goal: build a near detector with water target and 4π acceptance

TPCs   Possible design

Water target   **CH target**

Current ND280 acceptance

B.Quilain

$\cos(\theta)$ vs P_{mu} (GeV/c)

Reconstruction efficiency:
- >80% for p_{mu} > 300 MeV/c
- uniform wrt $\cos(\theta)$!

CC0 π selection	Purity	Efficiency
Current ND280	70%	48%
Upgrade	**75%**	**74%**

- Feasability study → Design Report this year
→ Promising detector and measurements coming!

T2K

New TPCs for ND280 upgrade

new horizontal TPCs → to improve high angle reconstruction efficiency
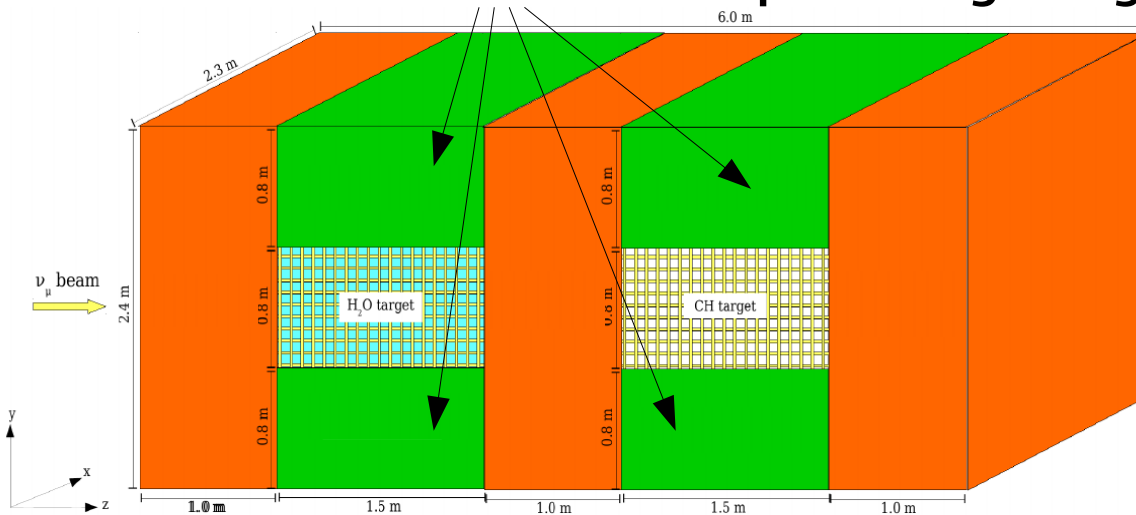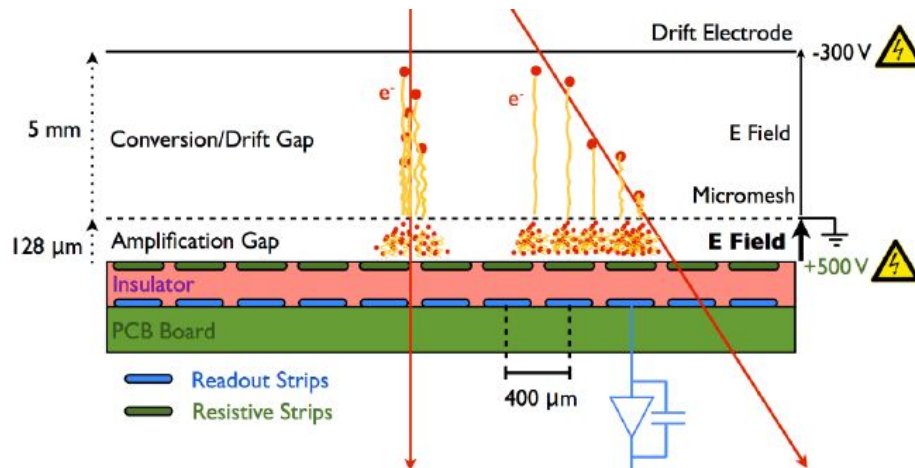

New activity in the NU_05 group!

Development of :
* <u>resistive bulk Micromegas for the TPC read-out</u> (CEA/IRFU)
→ improve spatial resolution and/or decrease the number of channels

* <u>Front and back-end TPC electronics</u> (CEA/IRFU and LPNHE)

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Summary

We explore 2 interconnected ways to reduce T2K systematic errors :

1) Neutrino-nucleus <u>cross section models</u>

→ Intensive work to check and develop interaction models (2p2h)

→ 3/4 new results should be published this year

2) <u>Upgraded near detector</u> (water target, large acceptance)

→ Innovative scintillator grid structure

→ The prototype module has taken data, first publication expected this year

→ The WAGASCI detector will be mounted and ready for next T2K run

→ Hardware development of TPCs for the ND280 upgrade

We are working together towards exciting results!

Thank you!

Prototype module assembly, oct-dec 2015, J-PARC, Japan

And thank you for your support!