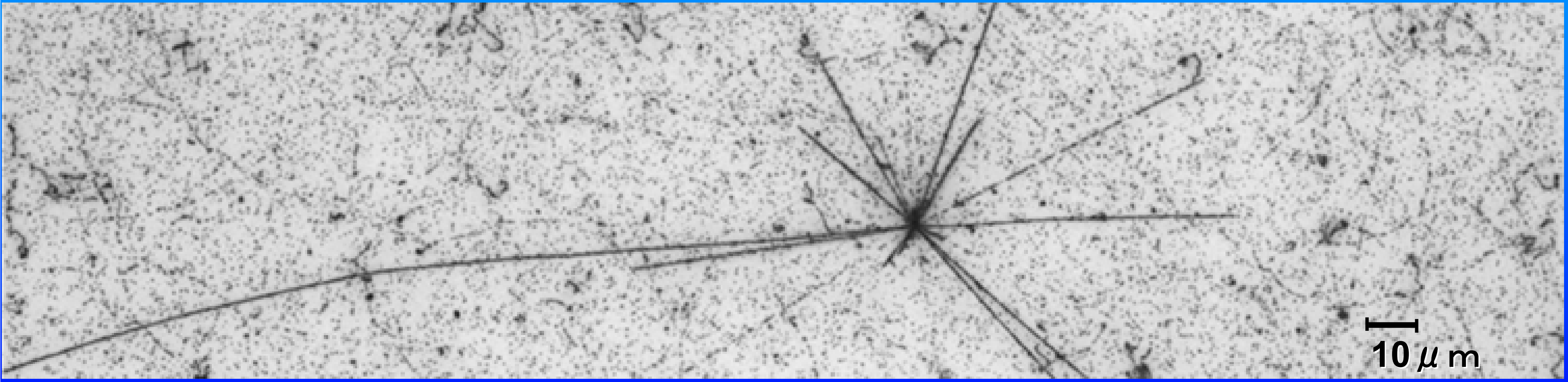
NINJA Experiment *and* EMPHATIC Experiment

Tsutomu Fukuda (Institute for Advanced Research, Nagoya Univ.)

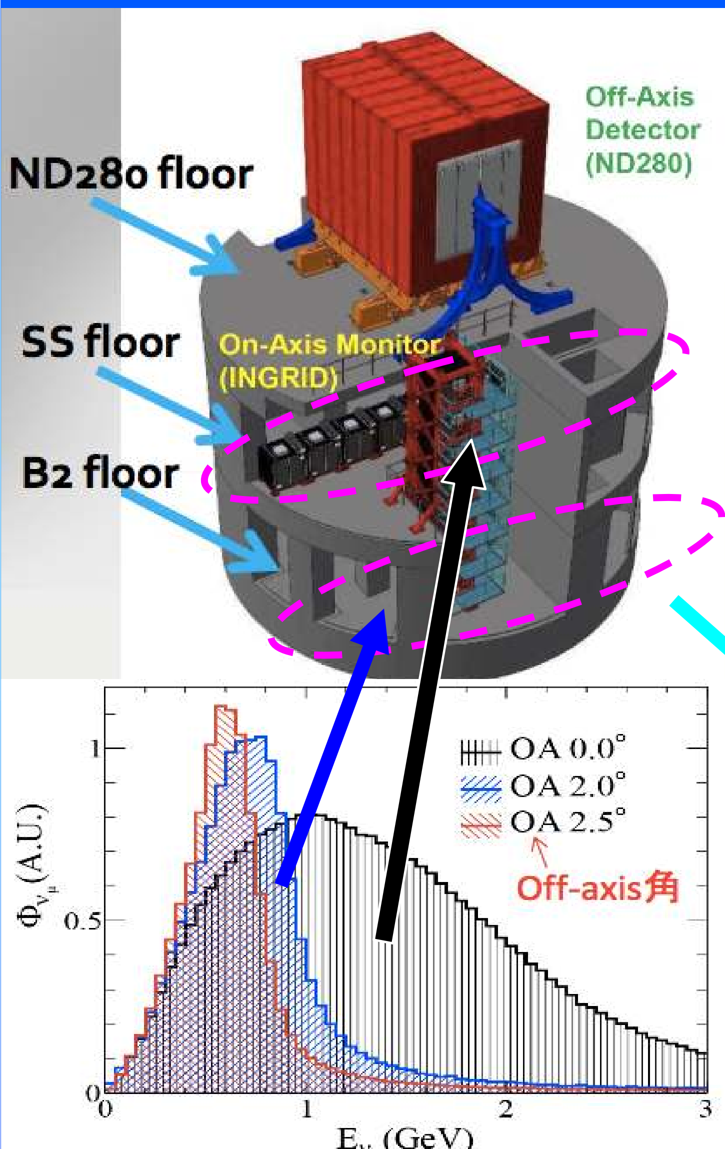


tfukuda@flab.phys.nagoya-u.ac.jp

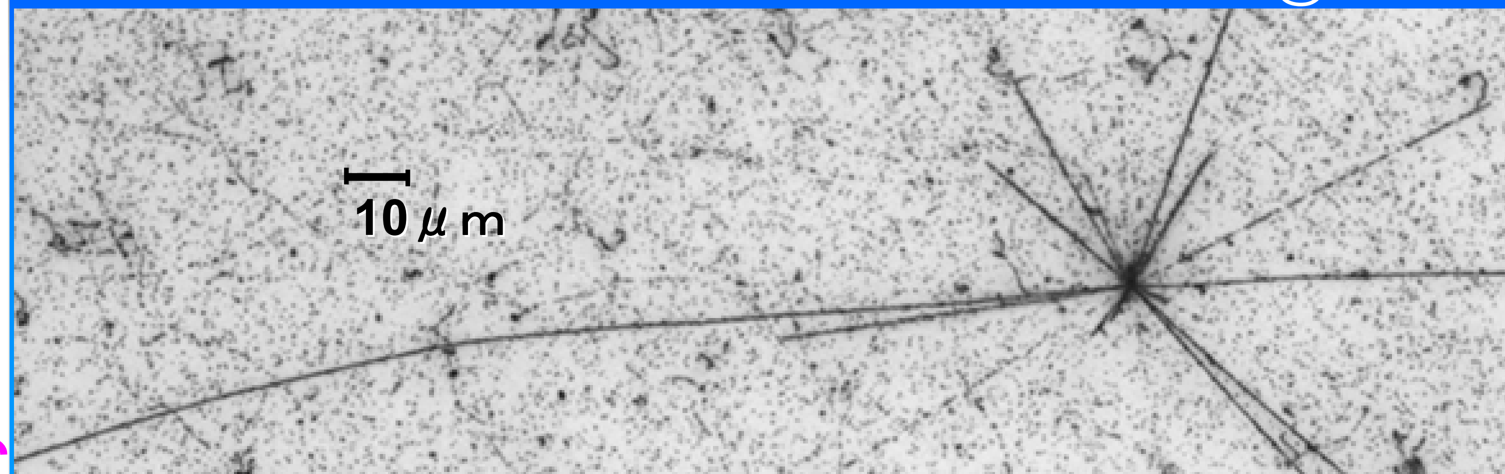
NINJA

NINJA Experiment

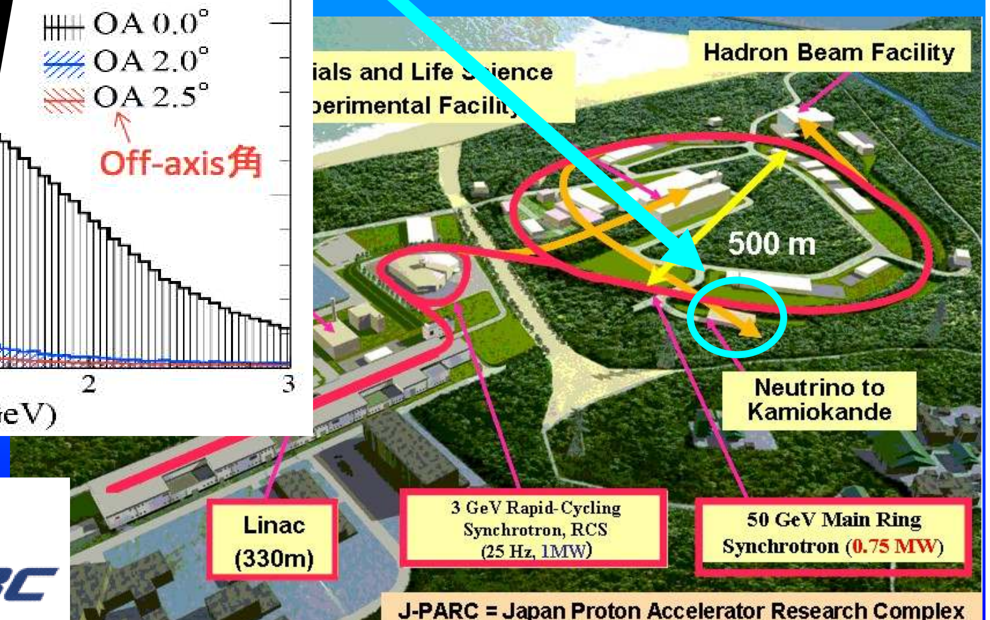
Neutrino **I**nteraction research with **N**uclear emulsion and **J**-PARC **A**ccelerator



A neutrino interaction in emulsion @J-PARC



A collaborative project with some member of OPERA and T2K



Working group

OPERA — **T2K**

- **J-PARC**: Experimental site, Neutrino beam
- **Nihon Univ.**: Emulsion development
- **Nagoya Univ.**: Film production, Scan
- **Toho Univ.**: Film production, Scan
- **Kobe Univ.**: Emulsion Shifter
- **Univ. Tokyo**: T2K near detector
- **Kyoto Univ.**: T2K near detector
- **Yokohama N Univ.**: T2K near detector
- **ICRR**: Neutrino simulation

NINJA Collaboration

(＊Spokesperson)

Nihon University: S. Mikado, Y. Hanaoka
Nagoya University: T. Fukuda*, T. Ishizuka, H. Kawahara, N. Kitagawa, R. Komatani, M.Komatsu, M. Komiyama, K. Morishima, M. Morishita, M. Nakamura, Y. Nakamura, N. Naganawa, T. Nakano, A. Nishio, H. Rokujo, O. Sato, T. Shiraishi, K. Sugimura, Y. Suzuki, T. Takao
Toho University: T. Matsuo, Y. Morimoto, S. Ogawa, H. Oshima, H. Shibuya
Kobe University: S. Aoki, K. Kuretsubo, T. Marushima, S. Takahashi
ICRR, University of Tokyo: Y. Hayato
Yokohama National University: A. Minamino, D. Yamaguchi
Kyoto University: T. Hayashino, A. Hiramoto, A. K. Ichikawa, K. Nakamura, T. Nakaya, I. Sanjana, K. Yasutome
University of Tokyo: N. Chikuma, T. Koga, M. Yokoyama

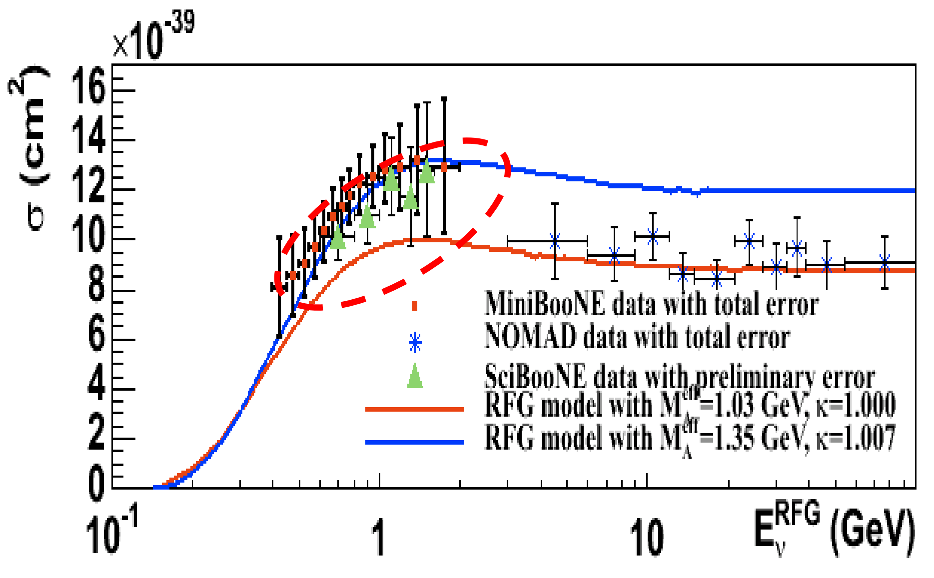
Physics Motivation

Sub-Multi GeV Neutrino interaction

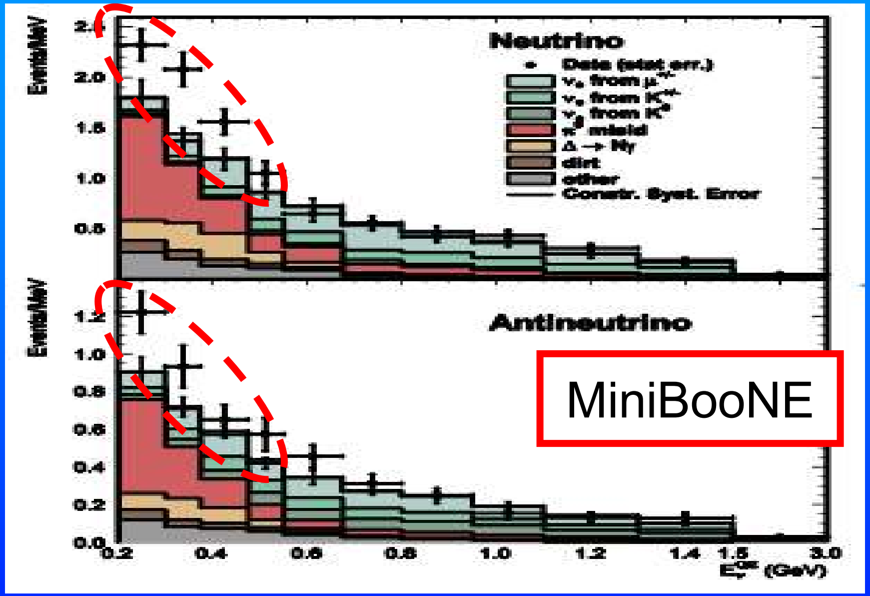
- Major source of uncertainty in ν oscillation analysis
- ν_e anomaly from several experiments (sterile ν ?)

Need to more understand the neutrino-nucleus interaction !

1. First observation of new type of neutrino-nucleus interaction
2. Exclusive and precise measurement of ν_e cross-sections



Unknown ν N interaction ?

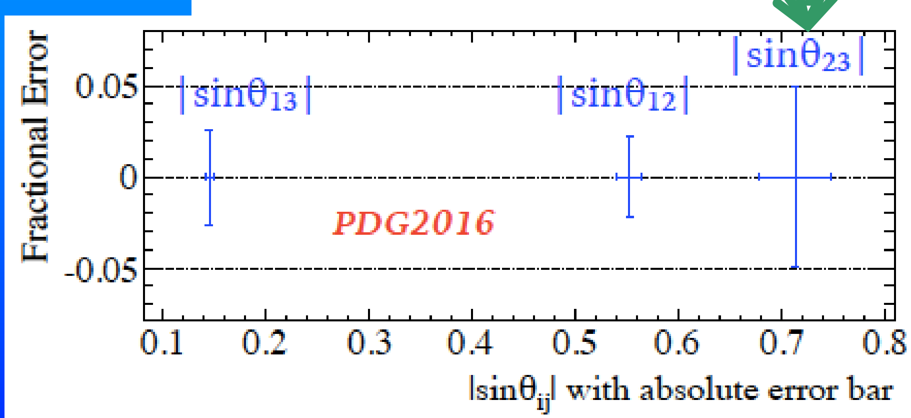


Effect from Sterile Neutrino ?

Current issues for ν CPV

In current long-baseline neutrino oscillation experiment, the number of neutrino events at far detector is predicted by simulations modified by near detector data, not directly subtracting
because the energy spectrum is different at near and far by oscillation.
So the understanding of neutrino interaction model is very important.

$$P(\overline{\nu_\mu} \to \overline{\nu_e}) \simeq \sin^2\theta_{23}\sin^2 2\theta_{13}\sin^2\frac{\Delta m^2_{31}L}{4E}$$
$$+\frac{\sin 2\theta_{12}\sin 2\theta_{23}}{2\sin\theta_{13}}\sin\frac{\Delta m^2_{21}L}{4E}\sin^2 2\theta_{13}\sin^2\frac{\Delta m^2_{31}L}{4E}\sin\delta_{CP}$$
$$+(CP\,\text{even term, solar term, matter effect term})$$



θ_{23} (ν_μ disappearance) has a largest error. This is from inconsistency between data and model in ν_μCC interaction.

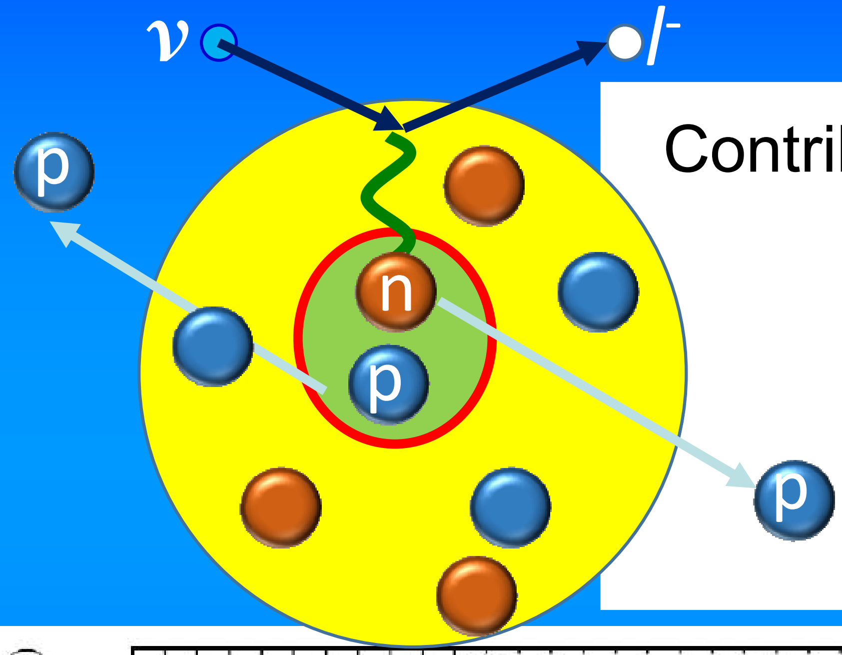
Statistics of ν_e appearance

Neutrino oscillation (interaction) is not "Precise Science" yet.

Current issues for ν CPV

Cross-section of CCQE-like events

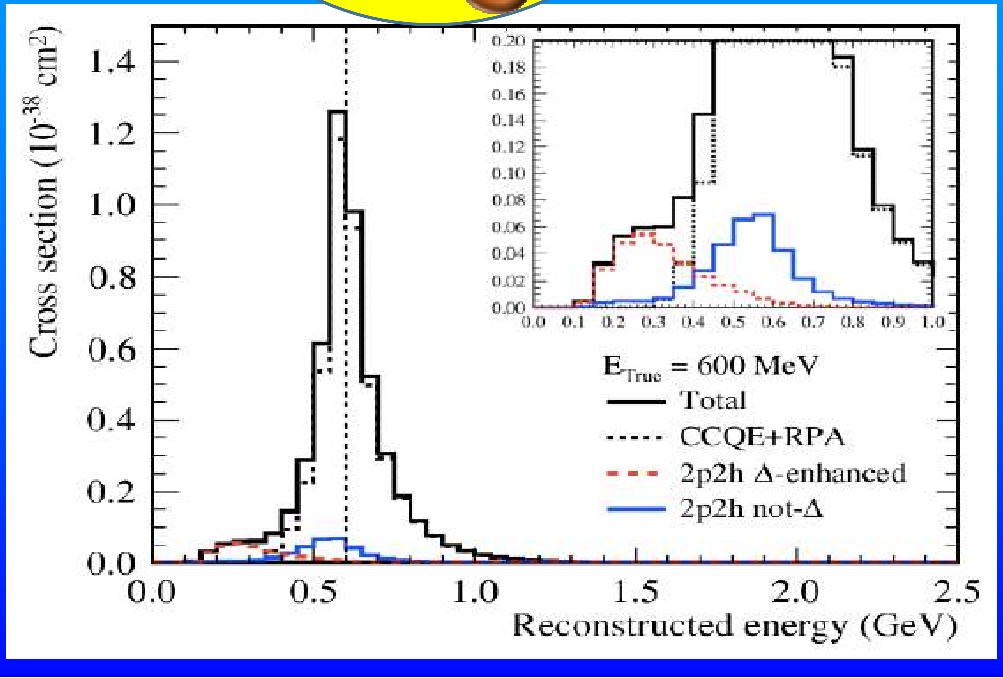
Measured value is much larger than the simple model predictions



Contribution from 2 nucleon interaction (2p2h) ?

Recent experiments did not measure low momentum nucleons.

→ It is not possible to discriminate single nucleon interaction from multi nucleon interactions.



If 2p2h interaction is exist,
Neutrino energy reconstruction of CCQE like event at far detector is wrong because the neutrino energy is reconstructed by only leptons in water cherenkov detector.

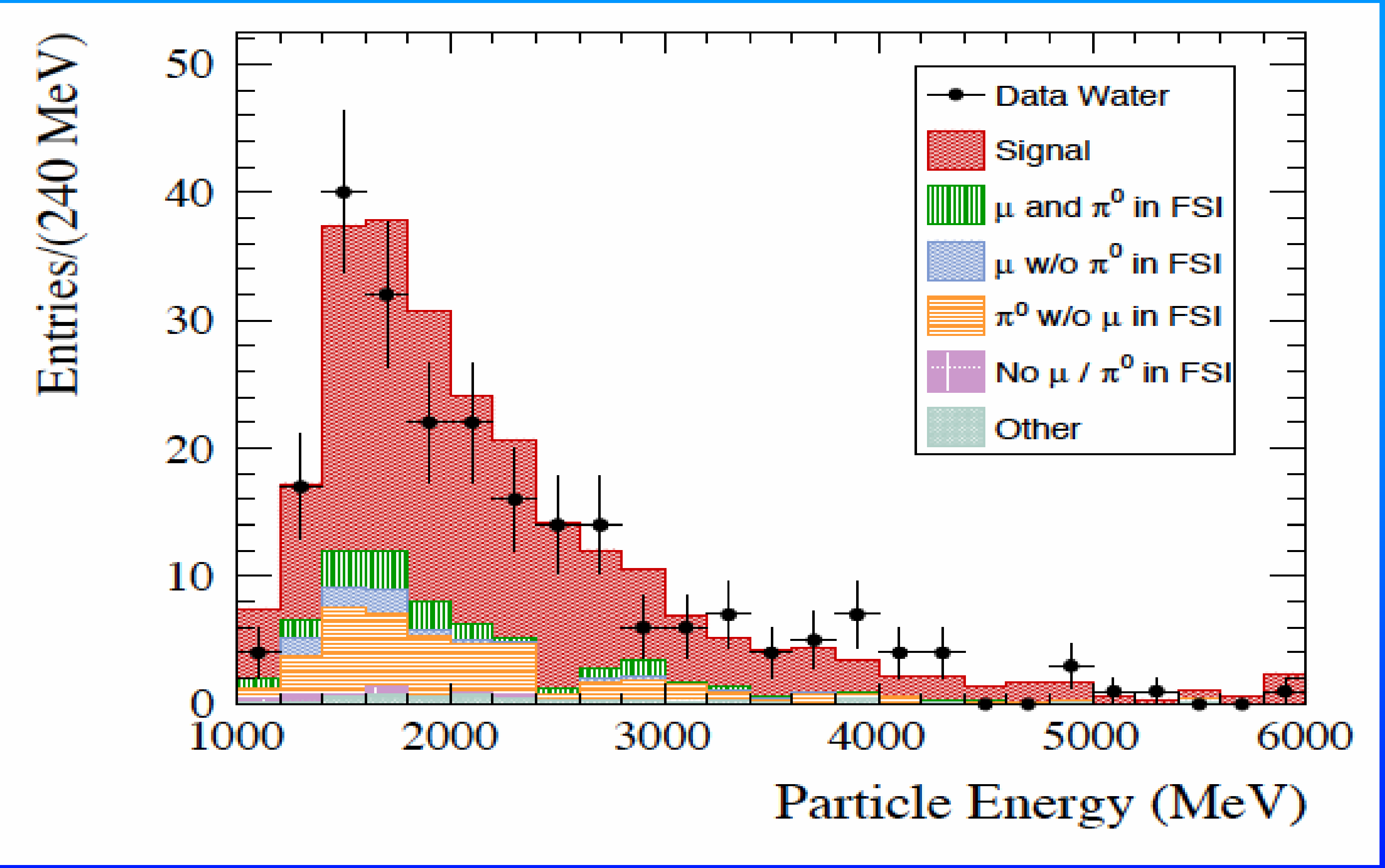
$$E_\nu^{\rm rec} = \frac{m_p^2 - (m_n - E_b)^2 - m_e^2 + 2(m_n - E_b)E_e}{2(m_n - E_b - E_e + p_e \cos\theta_e)}$$

→ Main systematic uncertainty.

Current issues for ν CPV

Difficulty in measuring Sub-Multi GeV ν_e cross-section
~ rejection of π^0 contamination

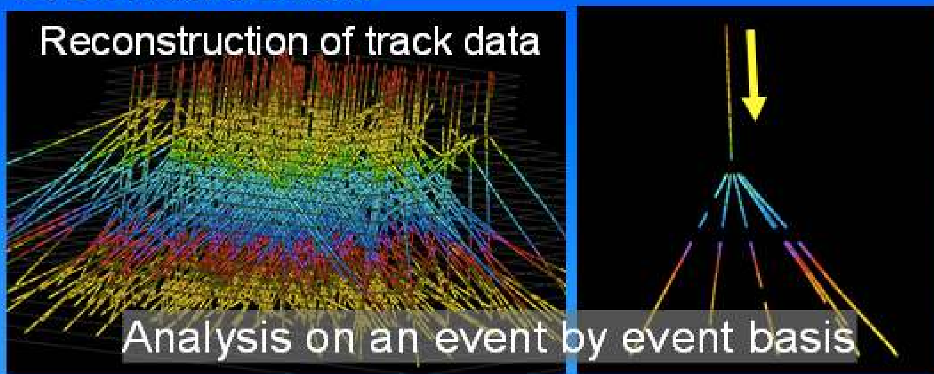
Existing near detector always suffer from contamination from π^0. It is important to collect clean ν_e events for precise ν_e cross-section measurement.



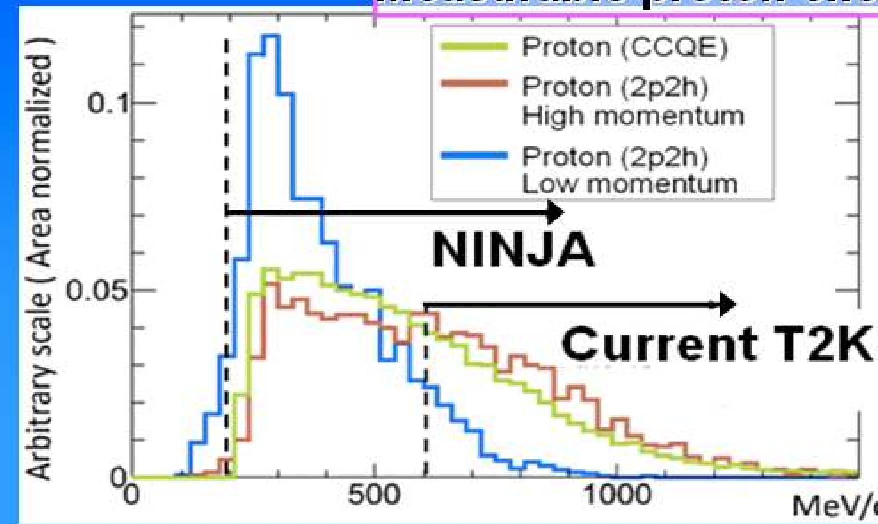
Phys. Rev. D 91, 112010

Advantage of NINJA

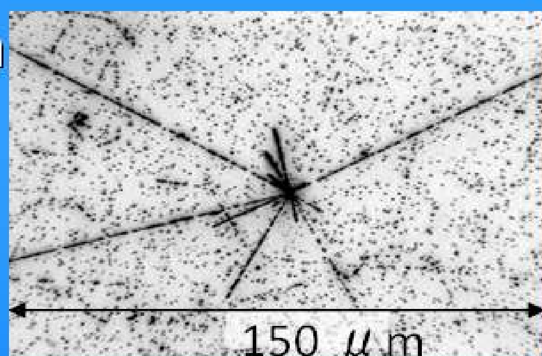
3D reconstruction



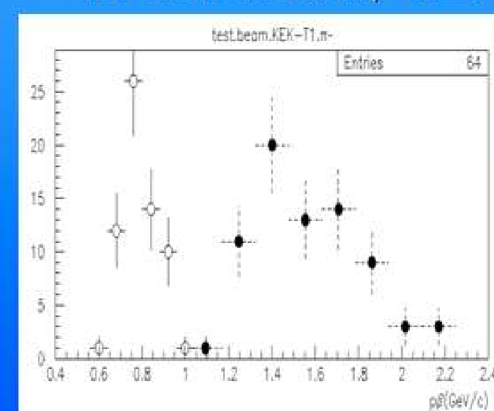
Measurable proton energy



4π detection

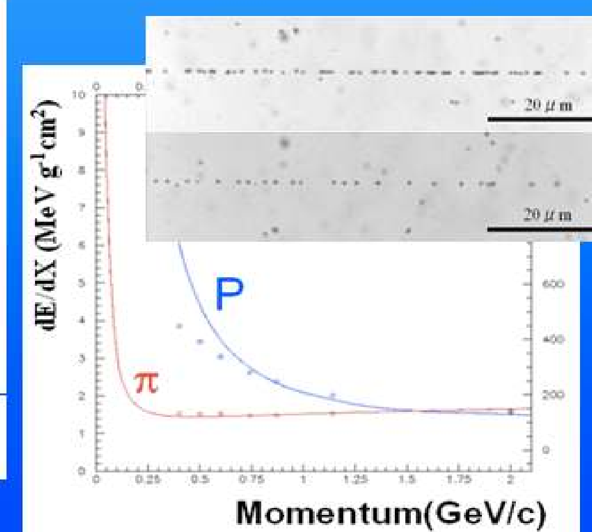


Momentum, dE/dx measurement

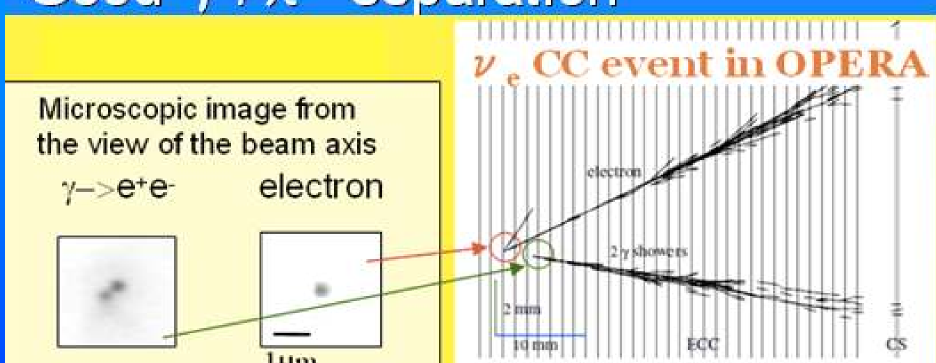


0.8GeV/c π : P =0.79(GeV/c), dP/P =11%

1.5GeV/c π : P =1.53(GeV/c), dP/P =16%



Good γ / π⁰ separation



Low BG from ν_μ NC π^0 production

This is usual for us. But these are unique feature for other neutrino detectors.
Actually, I gave talks in Neutrino 2016, NuFact 2016, and NuInt 2017 as invited talk.

NINJA Roadmap

Since the end of 2014, we have demonstrated the basic performance in test experiments.

Pilot RUN — Feasibility study at J-PARC

J-PARC T60/T66/T68 experiment

Detector RUN — Detector performance check

Target mass: 1- 60kg

Physics RUN Ⅰ — Neutrino-nucleus interaction study

Target mass: 100- 300kg

New proposal (E71)

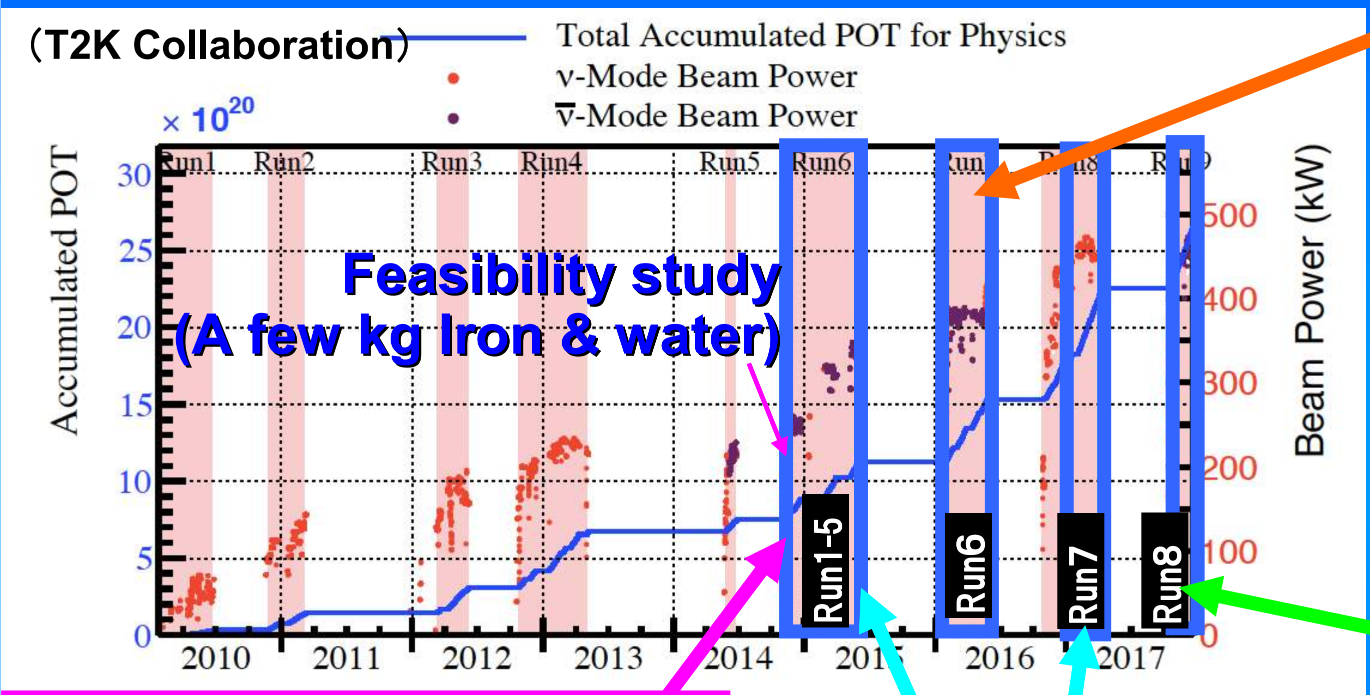
Physics RUN Ⅱ — Search for sterile neutrino

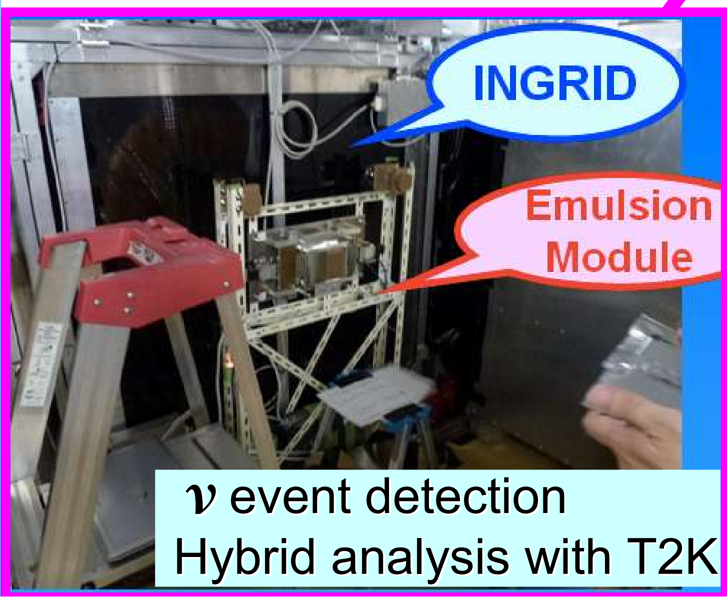
Target mass: several tons

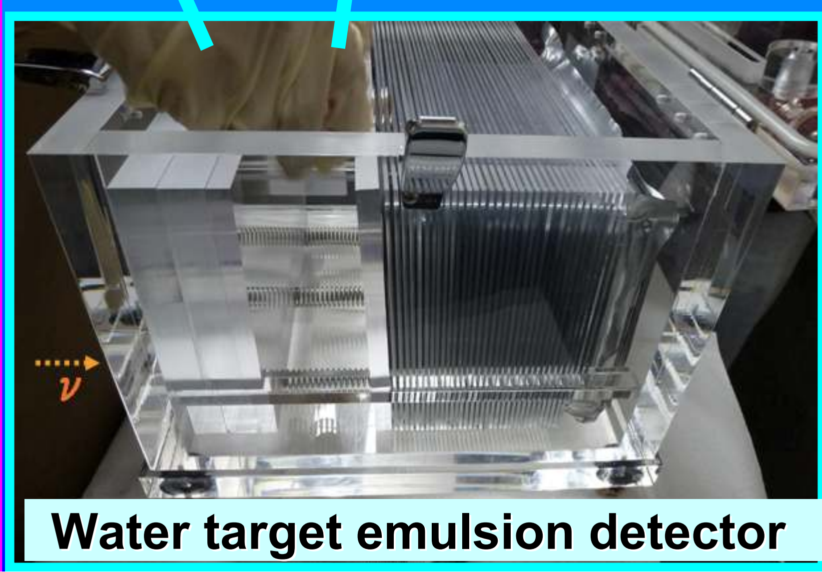
Physics run is planned to start in 2019.

ν exposure of NINJA

Since the end of 2014, we have demonstrated the basic performance in test experiments.

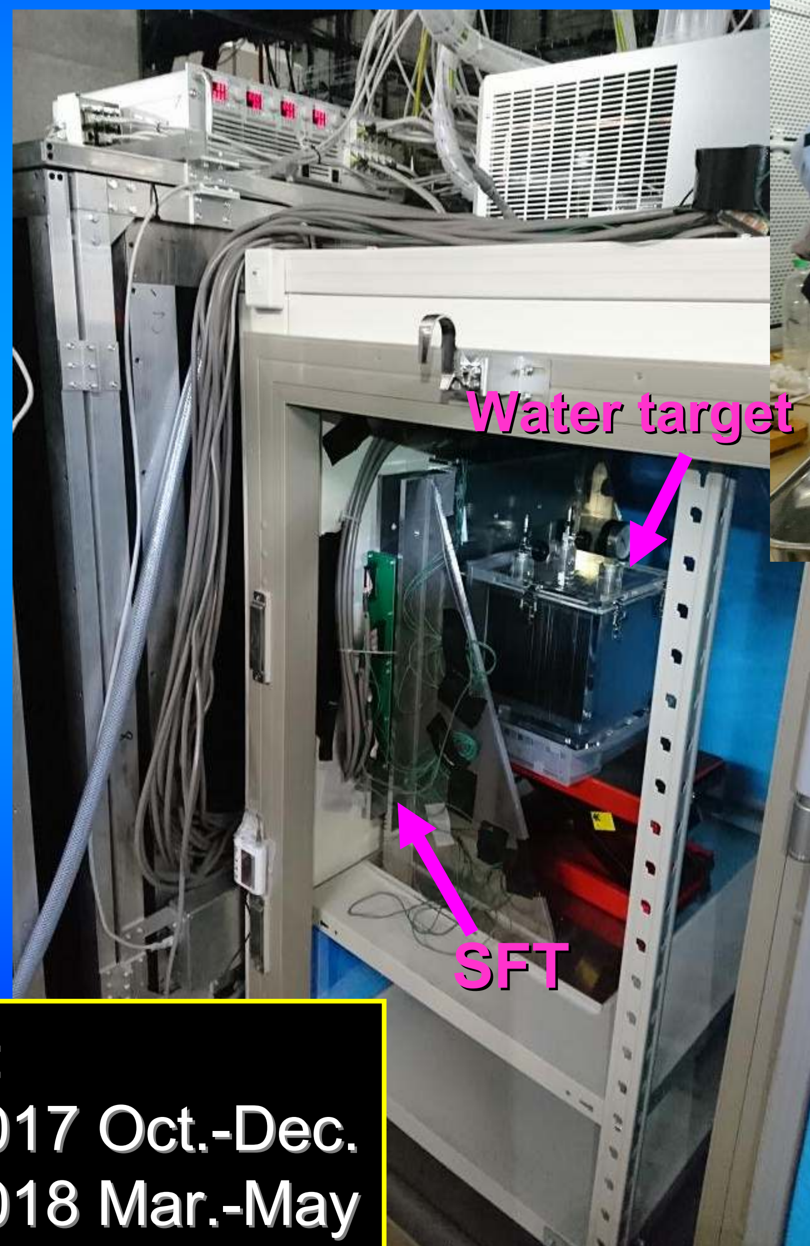


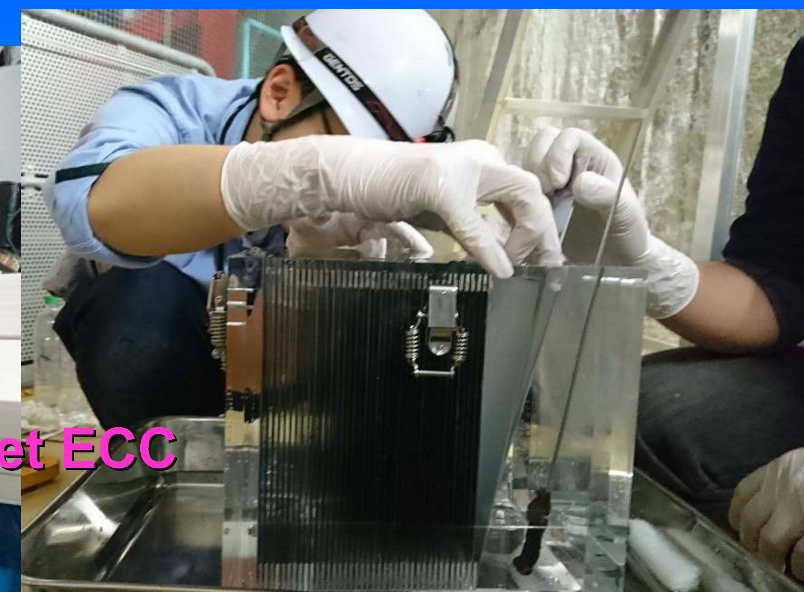




Current ν exposure of NINJA

Detector setup is Water target ECC + SFT + INGRID.
Neutrino Beam exposure was already finished → developing now

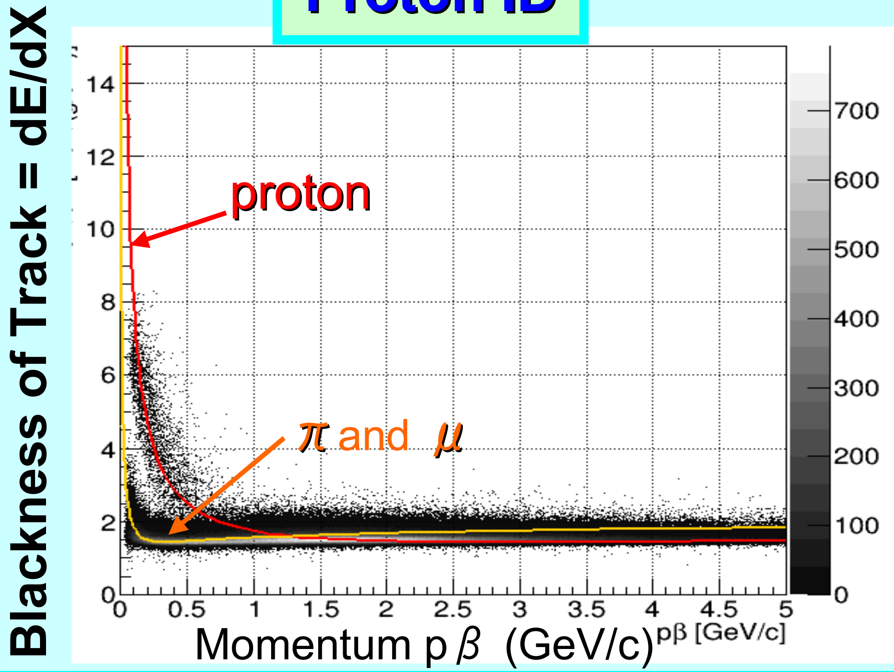




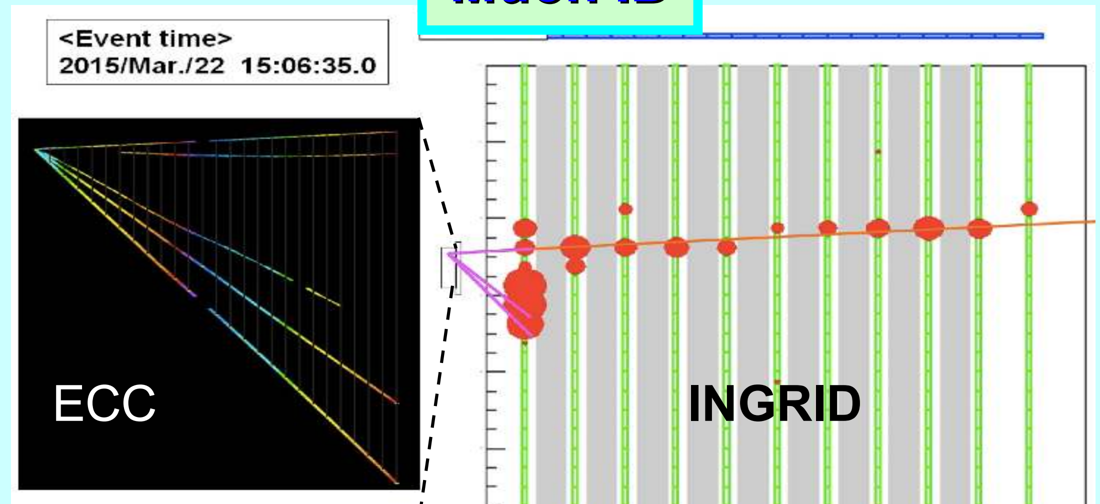
Exposure:
Run8a: 2017 Oct.-Dec.
Run8b: 2018 Mar.-May

Analysis status of NINJA

Proton ID

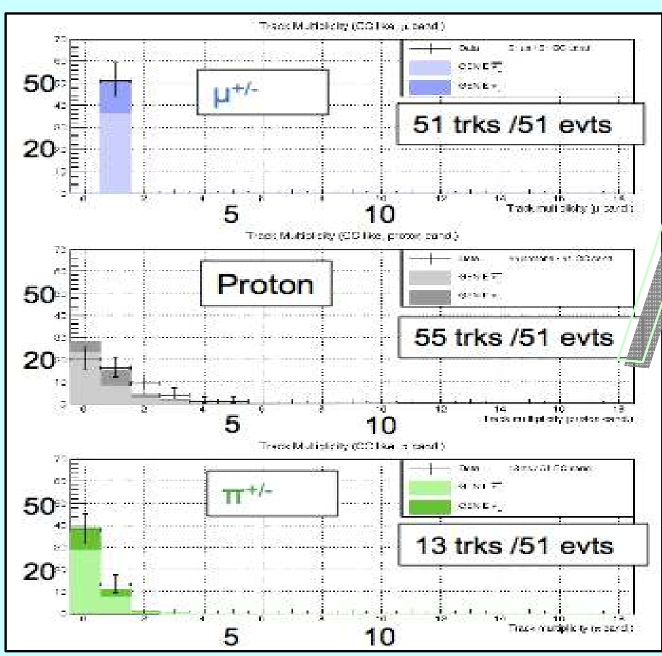


Muon ID

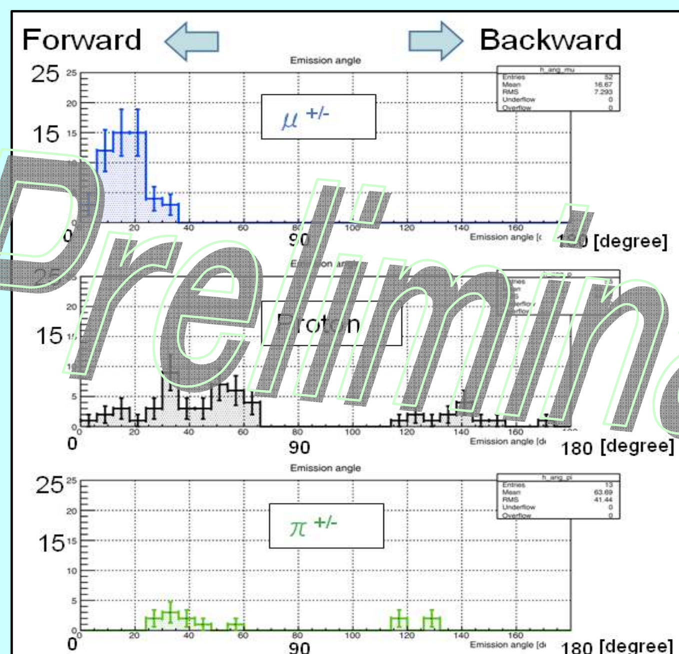


Event topology is matched with timing info. Expected range for each tracks is consistent with INGRID hits.

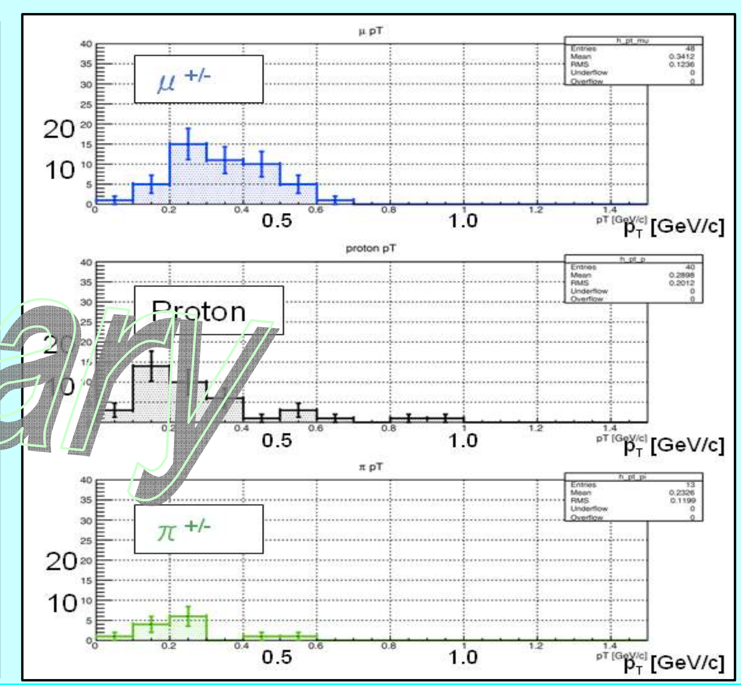
Track multiplicity (CC like)



Emission angle

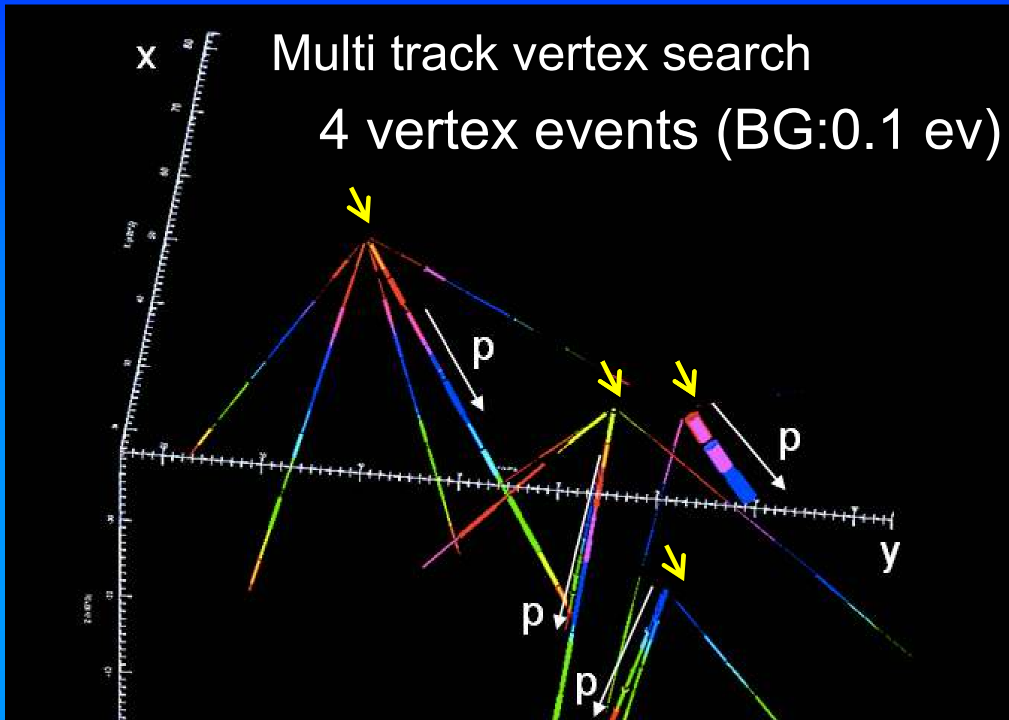


Transverse momentum

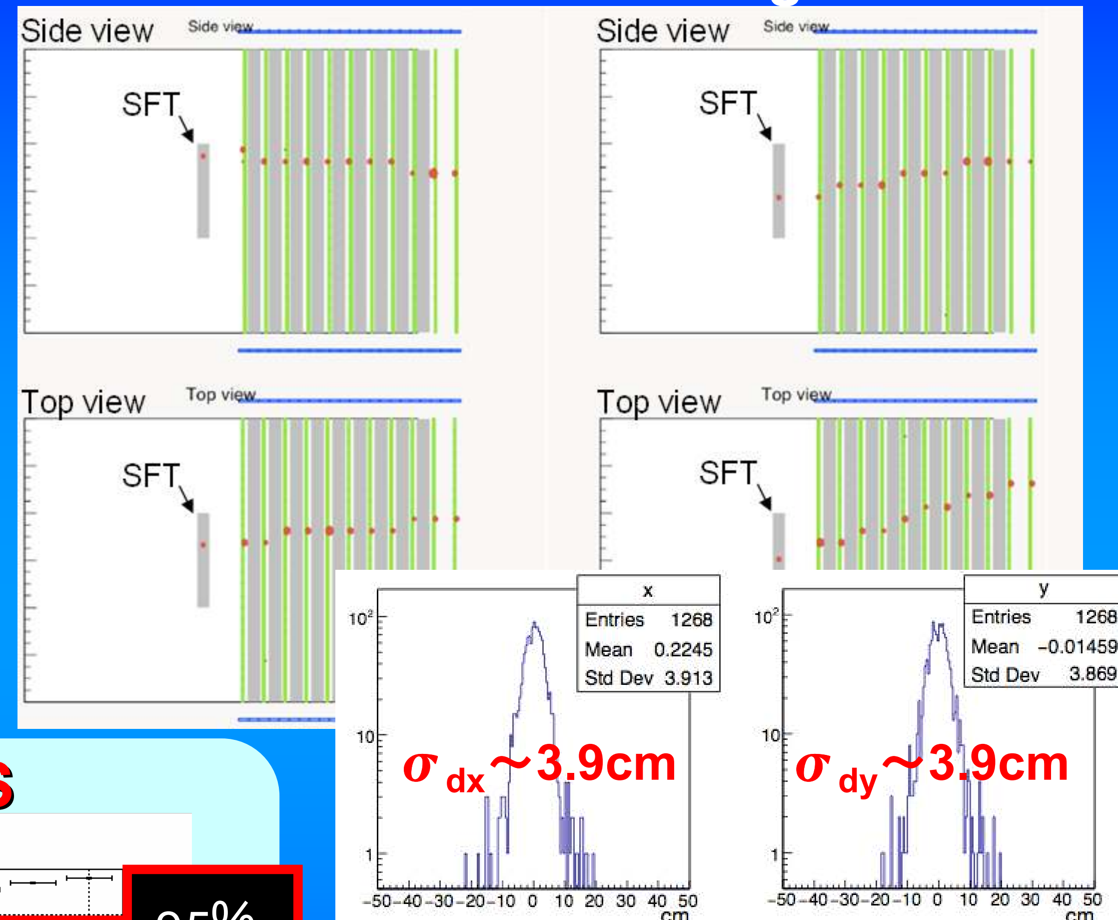


Analysis status of NINJA

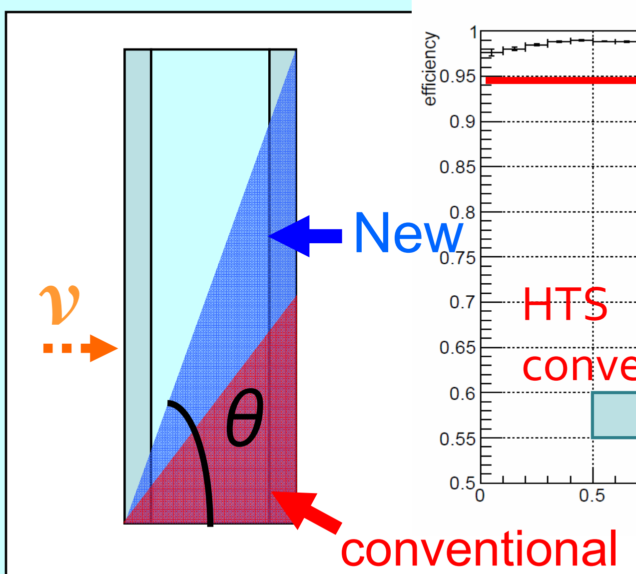
ν - water interactions were detected.

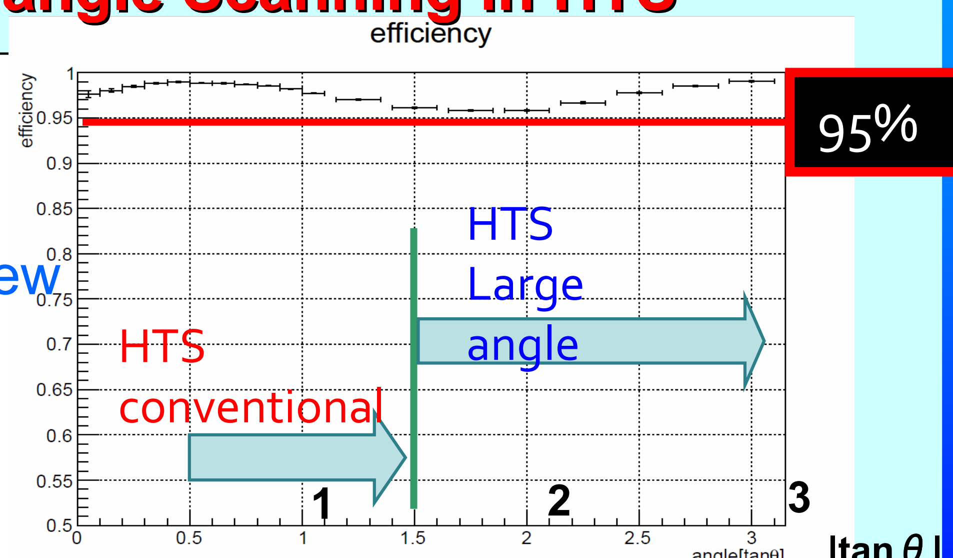


SFT- INGRID matching well.



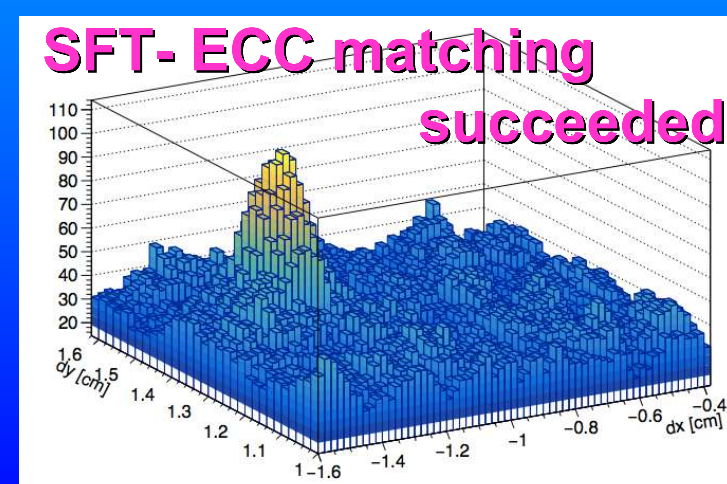
Large angle Scanning in HTS





Efficiency is kept more than 95%

SFT- ECC matching succeeded.



Physics Run (E71)

We proposed a new experiment (P71: Physics Run) at last J-PARC PAC meeting to study neutrino-water interactions with large statistics in 2019.

NINJA

Proposal for precise measurement of neutrino-water cross-section in NINJA physics run

December 14, 2017

The NINJA Collaboration

S. Aoki[1], N.Chikuma[2], T. Fukuda[3,*], Y. Hanaoka[4], T. Hayashino[5], Y. Hayato[6], A. Hiramoto[5], A. K. Ichikawa[5], H. Kawahara[3], N. Kitagawa[3], T. Koga[2], R. Komatani[3], M. Komatsu[3], M. Komiyama[3], K. Kuretsubo[1], T. Marushima[1], T. Matsuo[7], S. Mikado[4], A. Minamino[8], Y. Morimoto[7], K. Morishima[3], M. Morishita[3], K. Nakamura[5], M. Nakamura[3], Y. Nakamura[3], N. Naganawa[3], T. Nakano[3], T. Nakaya[5], A. Nishio[3], S. Ogawa[7], H. Oshima[7], H. Rokujo[3], I. Sanjana[5], O. Sato[3], H. Shibuya[7], T. Shiraishi[3], K. Sugimura[3], Y. Suzuki[3], S. Takahashi[1], T. Takao[3], R. Tamura[2], D. Yamaguchi[8], ... Yokoyama[2]

[1]Kobe University, Kobe, Japan
[2]University of Tokyo, Tokyo, Japan
[3]Nagoya University, Nagoya, Japan
[4]Nihon University, Narashino, Japan
[5]Kyoto University, Kyoto, Japan
[6]University of Tokyo, ICRR, Kamioka, Japan
[7]Toho University, Funabashi, Japan
[8]Yokohama National University, Yokohama, Japan

* Spokes person, Email: tfukuda@flab.phys.nagoya-u.ac.jp

Abstract

We propose a neutrino experiment which aims at measuring neutrino-water cross-sections with nuclear emulsion based detector at J-PARC neutrino beamline. Precise measurement of neutrino-water interactions is important to reduce systematic uncertainties in current and future neutrino oscillation experiments which search for

Submitted on Dec. 15th 2017

Goal:

- Validation of the existence of 2p2h reaction
- Cross-section measurement of 2p2h with accuracy of 10%
- Exclusive ν_μ and ν_e cross-section measurement

25th J-PARC PAC meeting https://kds.kek.jp/indico/event/26624/

from Monday, January 15, 2018 at **08:00** to Wednesday, January 17, 2018 at **16:00** (Asia/Tokyo)
at **J-PARC Research Building (2F Conference room)**

Manage

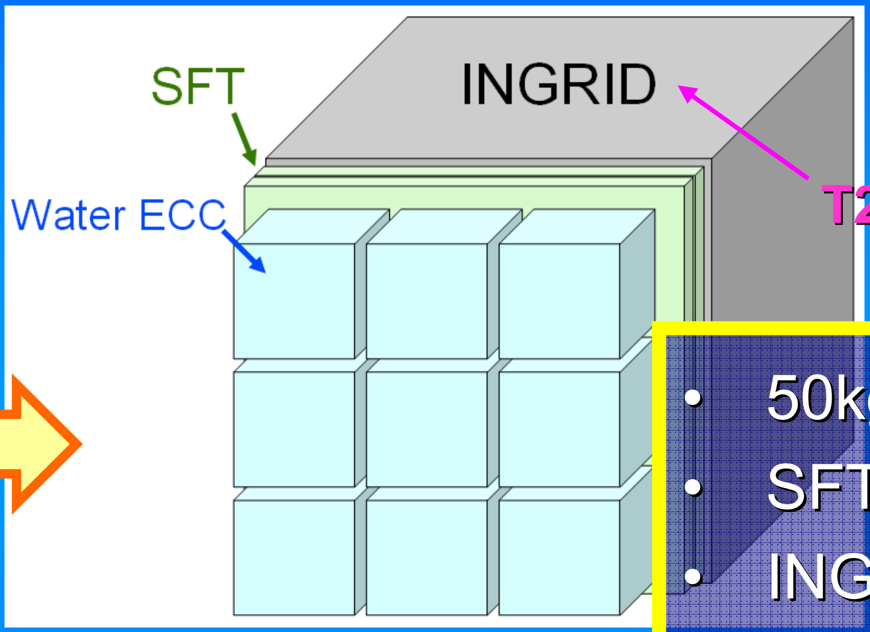
Description All the presentations should include the discussion time of 5 to 10 minutes.

10:50 - 11:10	Break
11:10 - 11:30	E61(NuPRISM) 20' Speaker: Mark Hartz (IPMU) Material: Slides
11:30 - 12:00	P69 (Study of neutrino-nucleus interaction at around 1 GeV) 30' Speaker: Akihiro Minamino (Yokohama National University) Material: Slides
12:00 - 12:30	P71 (Precise measurement of neutrino-water cross-section) 30' Speaker: Tsutomu Fukuda (Nagoya University) Material: Slides
12:30 - 13:30	Lunch
13:30 - 14:00	P70 (Proposal for the next E05 run with the S−2S spectrometer) 30' Speaker: Tomofumi Nagae (Kyoto University) Material: Slides

Physics Run (E71)

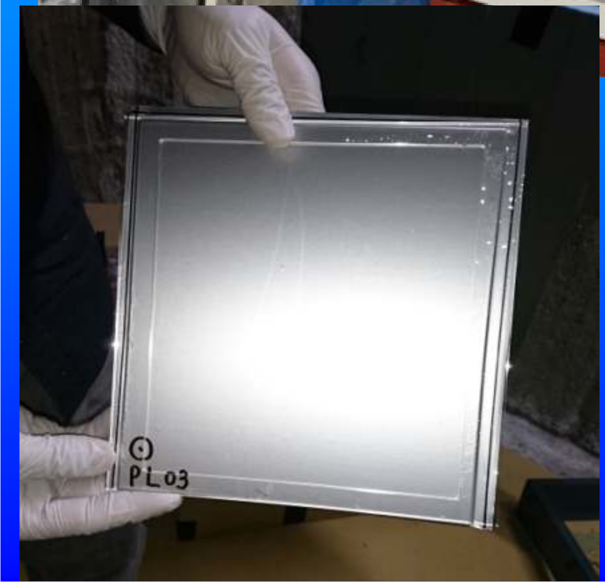
Detector is Water ECCs, SFT and INGRID.
This configuration is already tested in the past experiment.

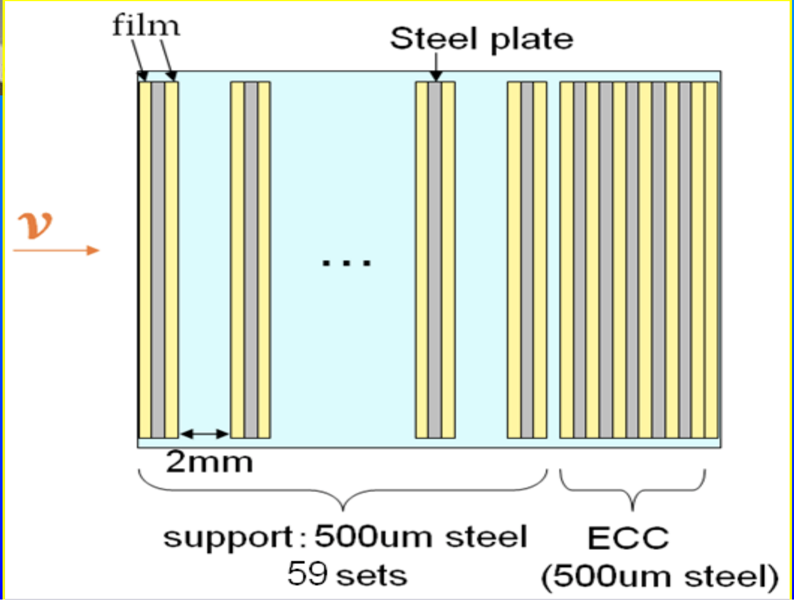
x 9

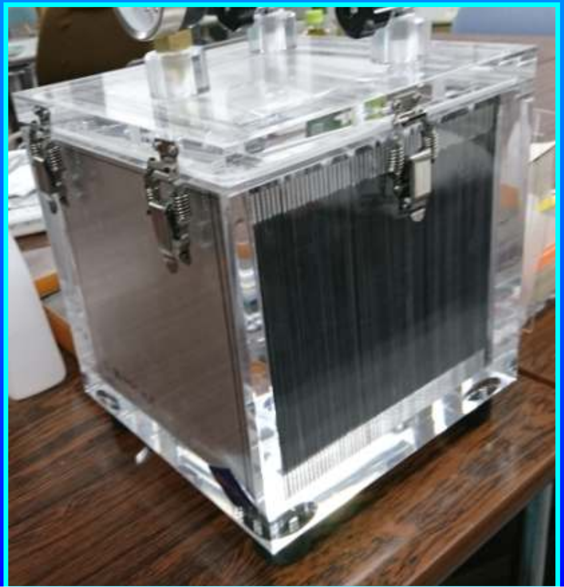


T2K near detector

- 50kg Water ECC
- SFT
- INGRID

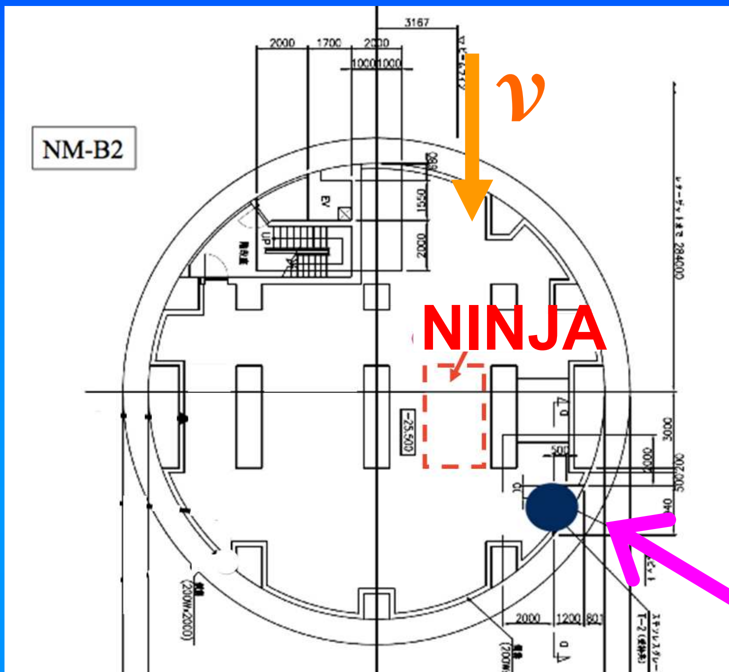


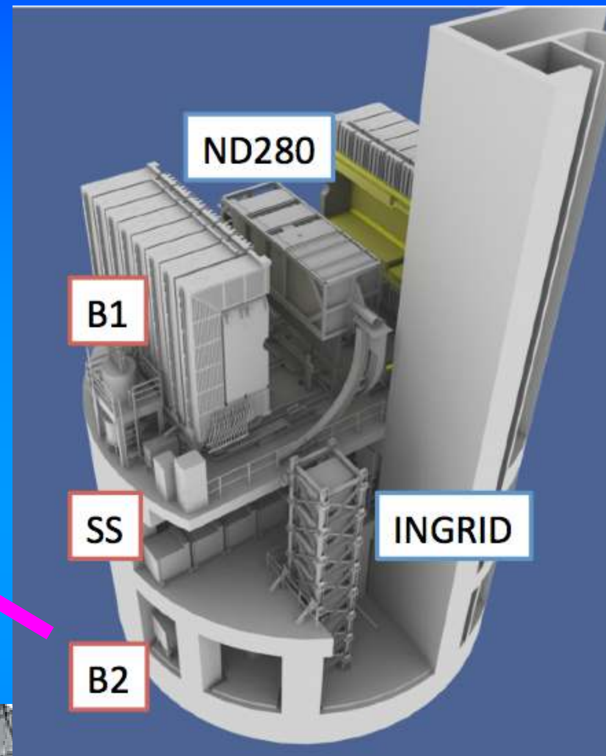


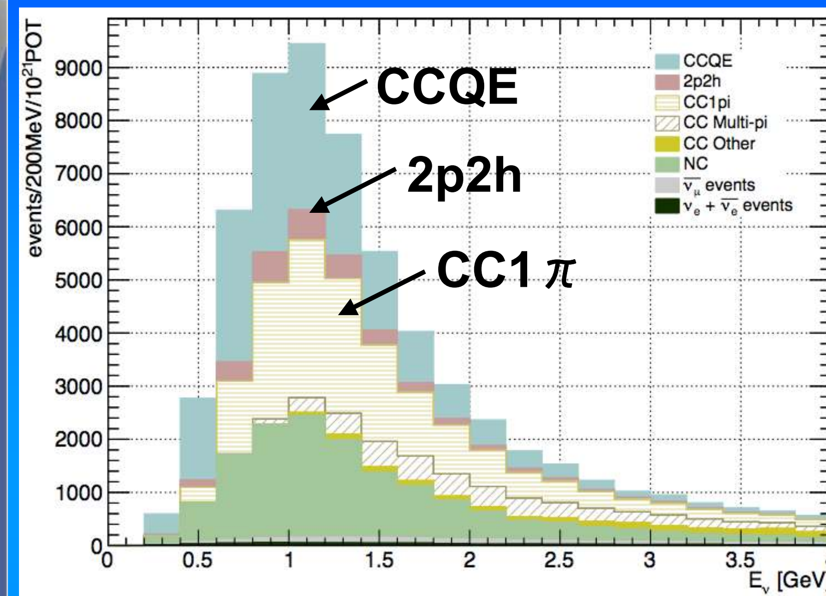


Physics Run (E71)

Two times exposure in 2019 and 2020(2021?). Totally 1.0x10^{21} POT.







Off-axis angle=1.0 deg.

> 200 2p2h events
@ 100kg water target,
1.0 x 10^{21} POT
(model dependent)

Current status of E71

Won stage-1 approval as a Physics Experiment in J-PARC in this March.
(judging the scientific merit and experimental method: P71 → E71)

A hearing for stage-2 (final) approval is set in the middle of July.

MoU between NINJA and T2K

Memorandum of Understanding (MoU)
between the T2K collaboration and the NINJA collaboration

Tsuyoshi NAKAYA
Spokesperson
The T2K Collaboration
Professor of Physics
Kyoto University (Japan)

Tsutomu FUKUDA
Spokesperson
The NINJA Collaboration
Designated assistant professor
Nagoya University (Japan)

Morgan Wascko
International Co-Spokesperson
The T2K Collaboration
Senior Lecturer in Physics
Imperial College of London (U.K.)

Date: May 12, 2018

Submitted TDR to J-PARC PAC

NINJA

J-PARC E71
Techinical Design Report

NINJA Collaboration

May 14 ,2018

Acquired the fund for the project from JSPS → ~ 500,000 €

Schedule

	7	8	9	10	11	12	1	2	3
	2018						2019		
Emulsion film production									
Refresh& Packing		Setup @J-PARC					Installation		
SFT production					Commissioning				
INGRID test									
Developing room @Nihon U.									
Neutrino beam exposure									

→ 3x large SFT

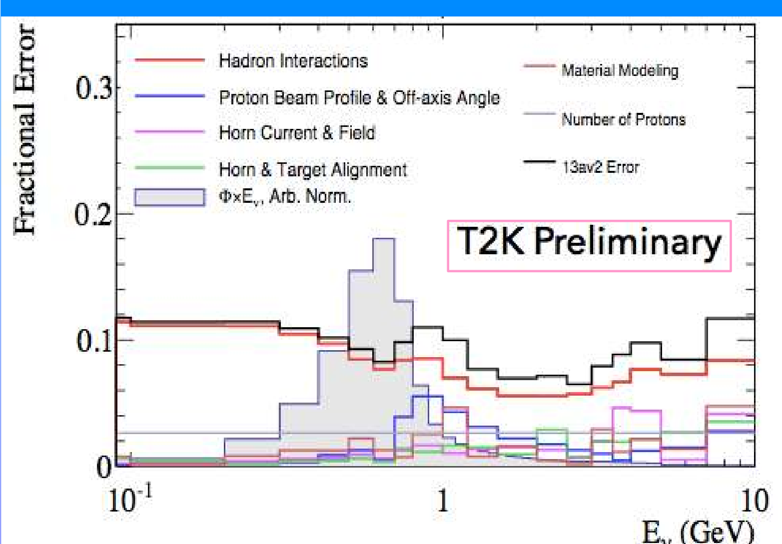
- First exposure is assumed to start from Jan. 2019.
- Production of emulsion films will start from the middle of July.
- Film refresh and packing will be done at J-PARC.
- Finally, we plan to install all emulsion detector by the end of year.

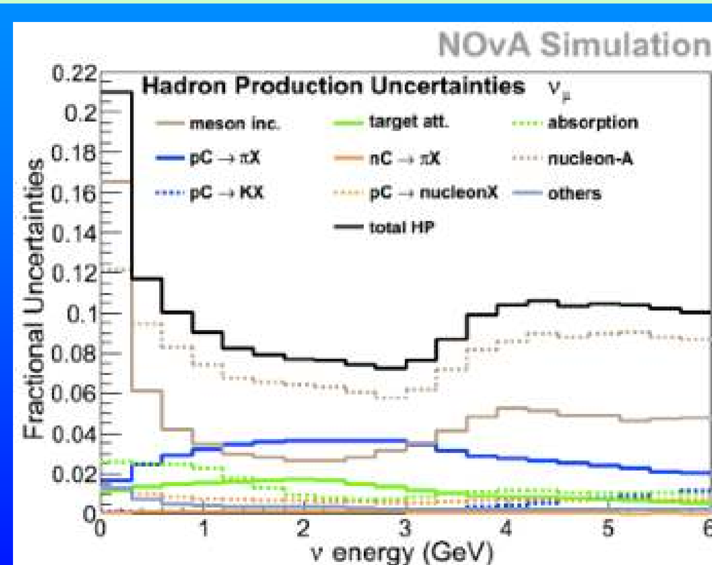
EMPHATIC experiment

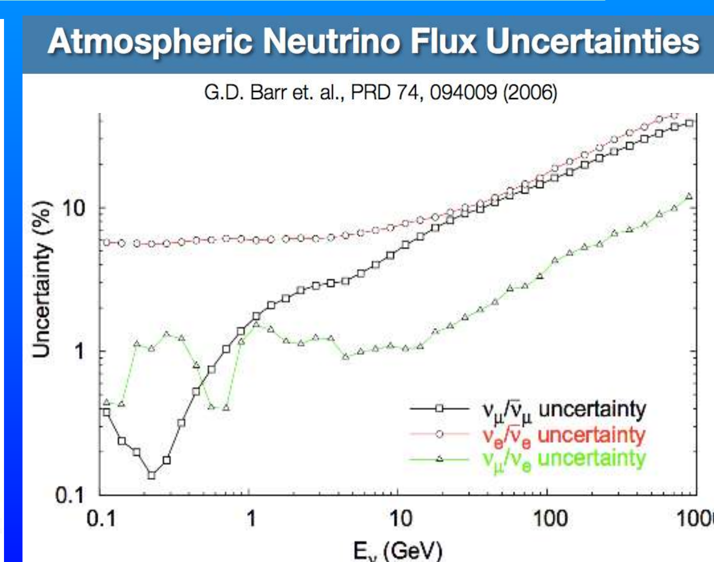
Emulsion-based Measurement of Production of Hadron At a Test beam In Chicagoland (Fermilab T1396)

Motivation

- The uncertainty of neutrino cross-section and neutrino flux is two large main systematic error for neutrino oscillation analysis.
- Precise measurement of hadron production will reduce the uncertainties for accelerator and atmospheric neutrino flux, and also improve the accuracy of the absolute neutrino cross-section measurements. → **Feedback to NINJA**







Overview

We have an experience of hadron interaction study with lead-target ECC.

PTEP

Prog. Theor. Exp. Phys. **2014**, 093C01 (13 pages)
DOI: 10.1093/ptep/ptu119

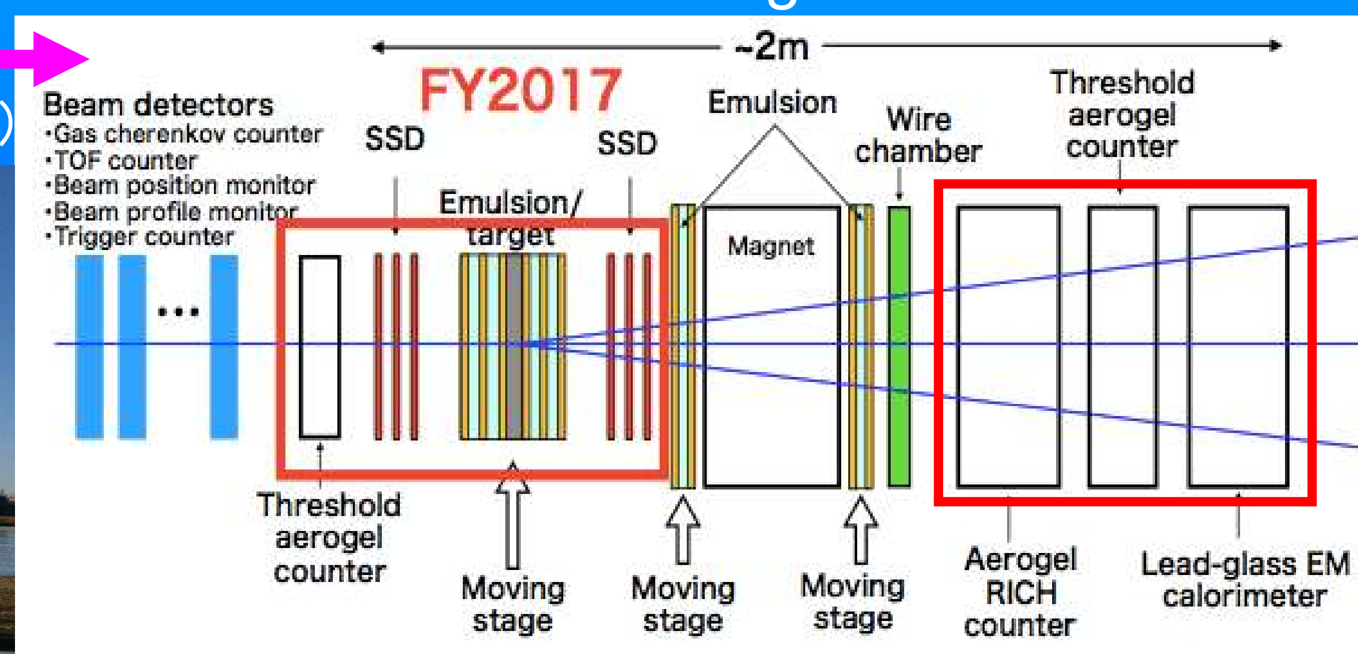
Study of hadron interactions in a lead–emulsion target

Hirokazu Ishida[1], Tsutomu Fukuda[1], Takafumi Kajiwara[1], Koichi Kodama[2], Masahiro Komatsu[3], Tomokazu Matsuo[1], Shoji Mikado[4], Mitsuhiro Nakamura[3], Satoru Ogawa[1], Andrey Sheshukov[5], Hiroshi Shibuya[1,*], Jun Sudou[1], Taira Suzuki[1], and Yusuke Tsuchida[1]

One of important papers in OPERA for confirming Hadron background

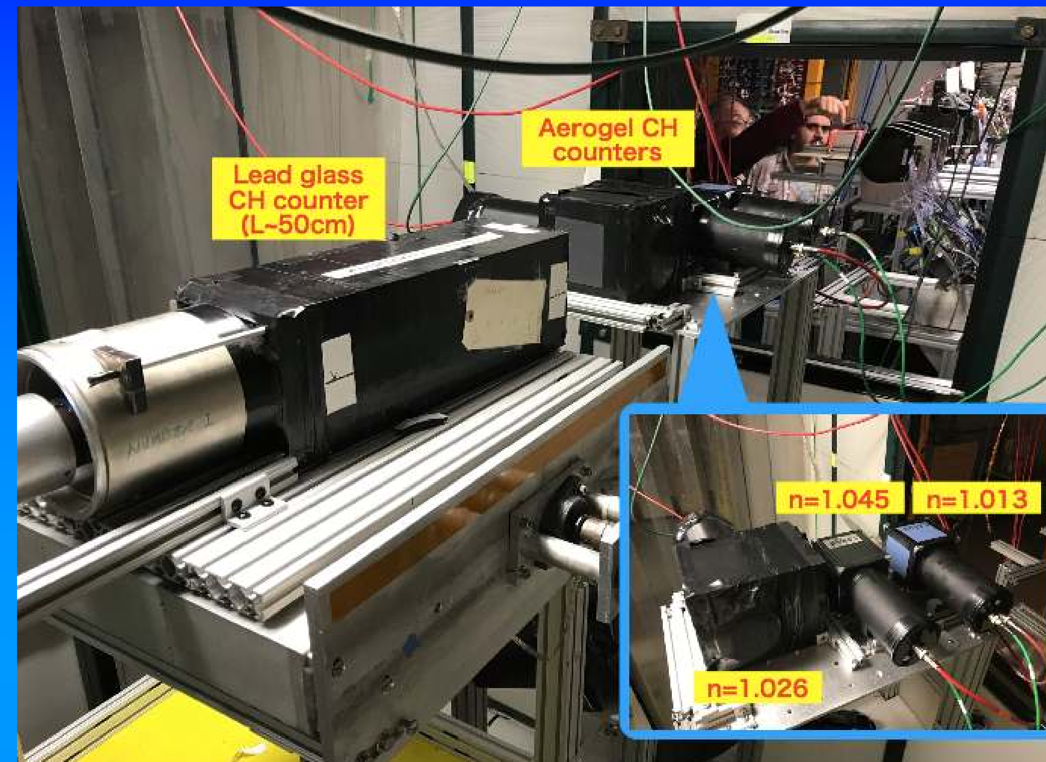
- Uses the FNAL Test Beam Facility (FTBF): 0.2-120 GeV.
- Emulsion can measure the interacted vertices with high resolution.
- Ultimate setup

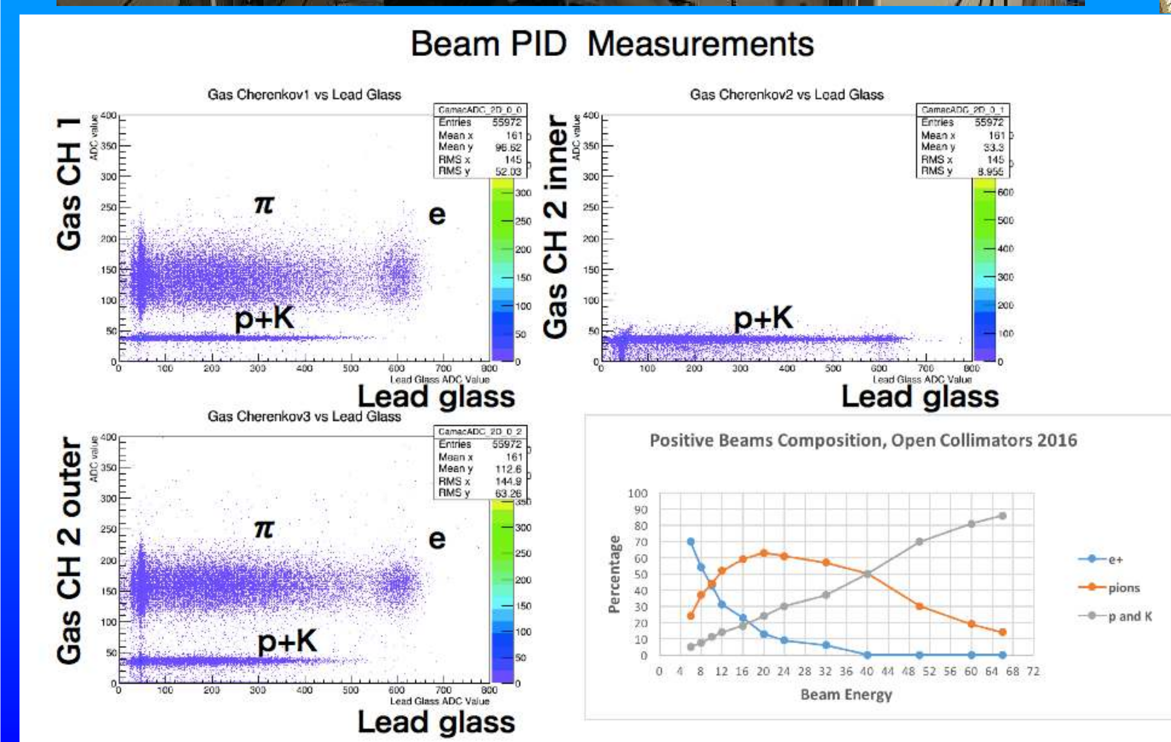
(Total ~10^8int. for C,Al,Fe target)

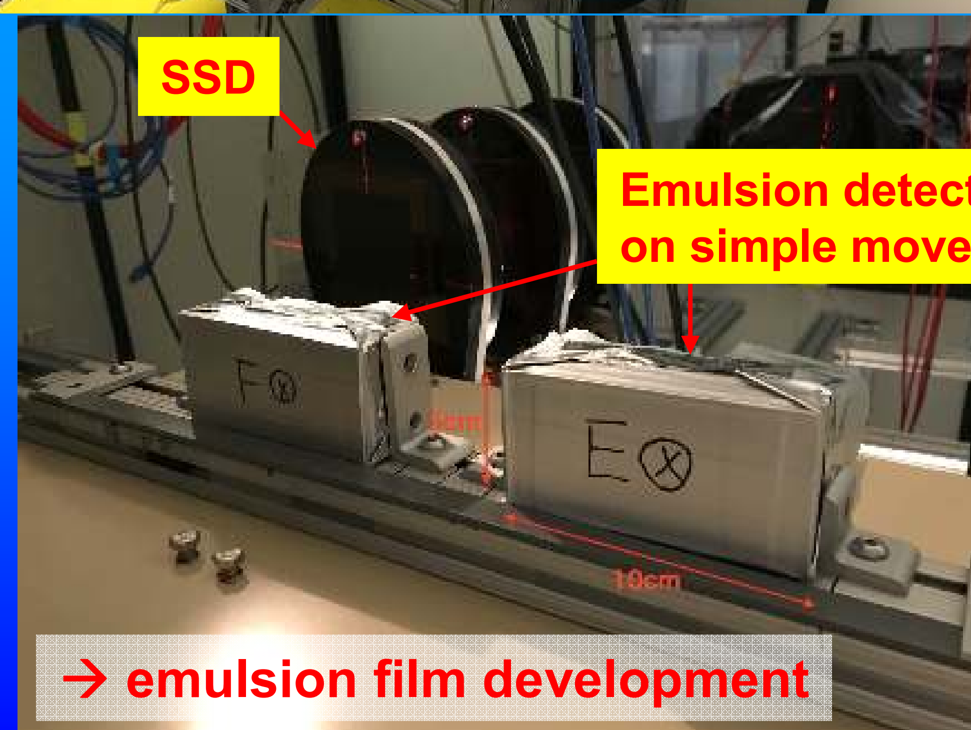


EMPHATIC

Initial beam test in Jan. 2018



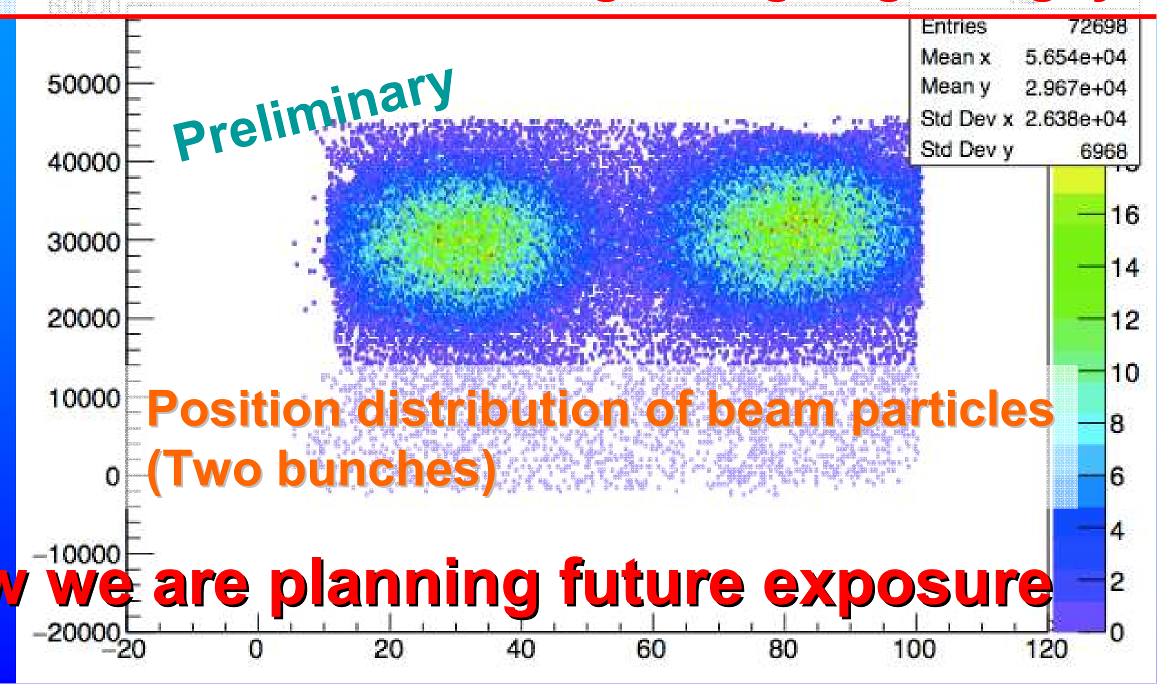




EMPHATIC

Preparation of dark room for emulsion handling and development @Fermilab

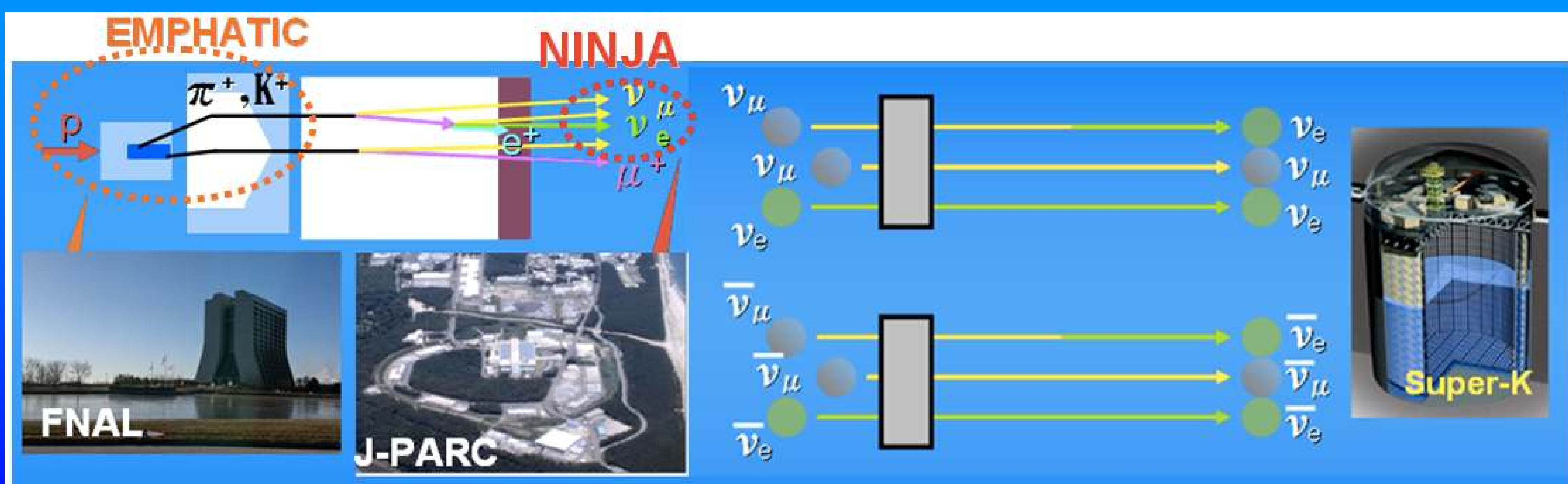
→ emulsion film scanning is ongoing@Nagoya



Now we are planning future exposure

Summary

- Neutrino Cross-section and Neutrino Flux are two dominated sources of systematic uncertainties in neutrino oscillation analysis for ν CPV.
- **NINJA@J-PARC** and **EMPHATIC@FNAL** will measure exclusive neutrino and hadron cross-section very precisely, and make ν oscillation physics "Precise Science".
- Emulsion plays an important role for neutrino oscillation analysis for ν CPV.



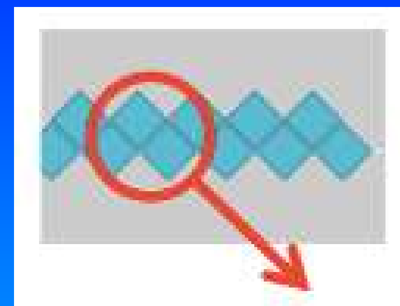
Back up

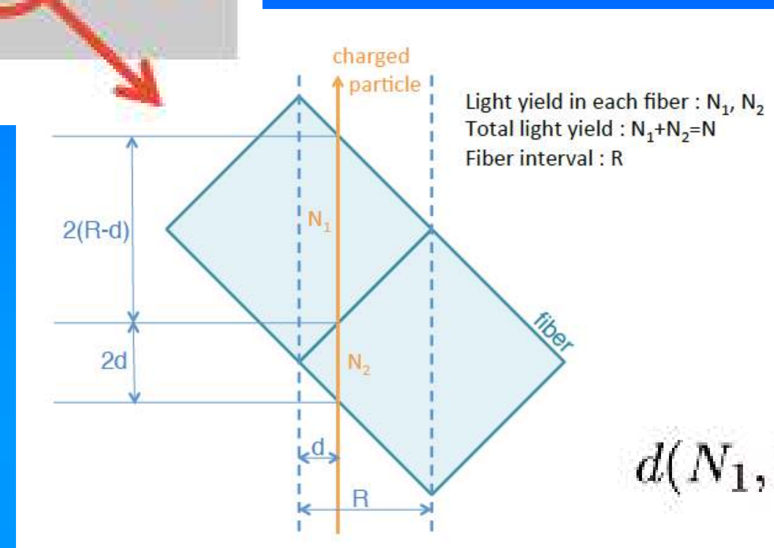
SFT

- Basically same type of SFT

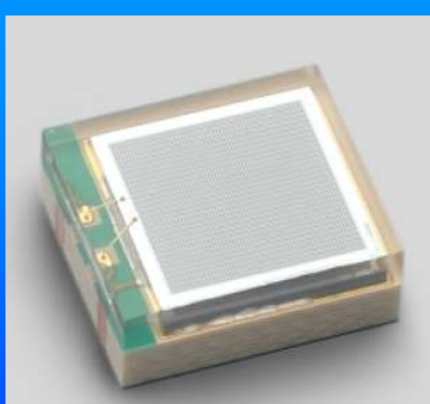
→ 3 times larger system

2.5mm square fibers are use.

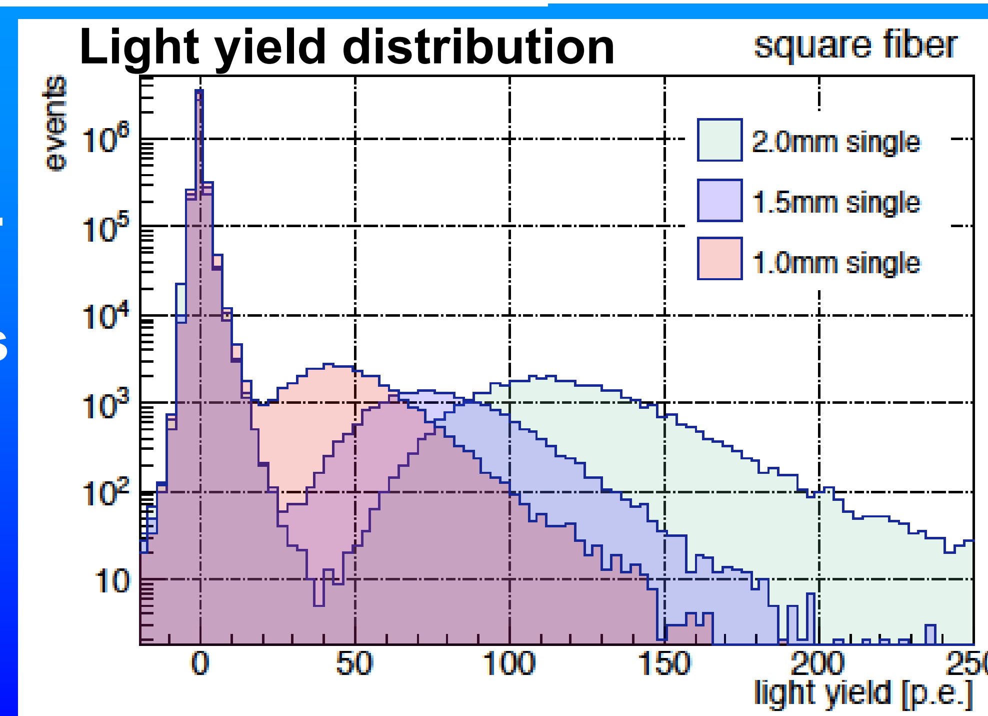




$$d(N_1, N_2) = \frac{N_2}{N_1 + N_2} R$$



Single type MPPCs are used. (3mm x 3mm)
2,560 channels for both ends readout



We plan to use same type of WAGASCI electronics for SFT.