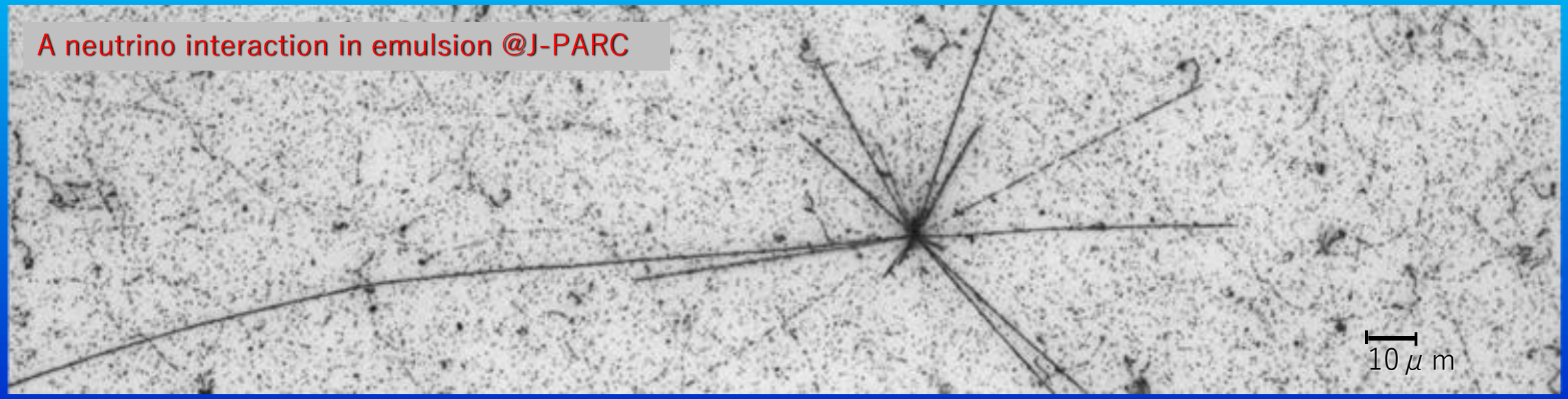
The NINJA Experiment and its future prospects

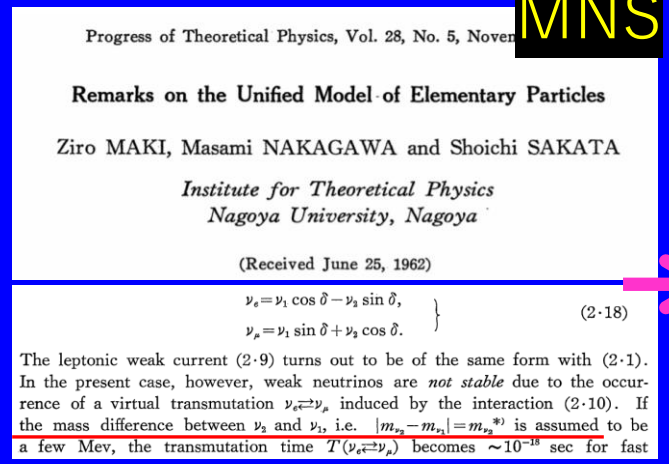
Tsutomu FUKUDA (Institute for Advanced Research/F-lab, Nagoya Univ.)
on behalf of the NINJA Collaboration



Neutrino oscillation

- First experimental result beyond the standard model in the particle physics

MNS



Progress of Theoretical Physics, Vol. 28, No. 5, Nover

Remarks on the Unified Model of Elementary Particles

Ziro MAKI, Masami NAKAGAWA and Shoichi SAKATA

Institute for Theoretical Physics
Nagoya University, Nagoya

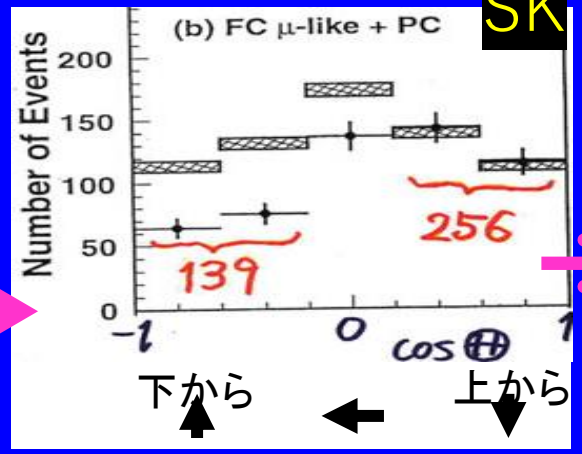
(Received June 25, 1962)

$$\left.\begin{aligned}\nu_e &= \nu_1 \cos\delta - \nu_2 \sin\delta,\\ \nu_\mu &= \nu_1 \sin\delta + \nu_2 \cos\delta.\end{aligned}\right\} \quad (2\cdot18)$$

The leptonic weak current (2·9) turns out to be of the same form with (2·1). In the present case, however, weak neutrinos are *not stable* due to the occurrence of a virtual transmutation $\nu_e \rightleftarrows \nu_\mu$ induced by the interaction (2·10). If the mass difference between ν_2 and ν_1, i.e. $|m_{\nu_2} - m_{\nu_1}| = m_{\nu_2}$*) is assumed to be a few Mev, the transmutation time $T(\nu_e \rightleftarrows \nu_\mu)$ becomes $\sim 10^{-18}$ sec for fast

Theory (1962)

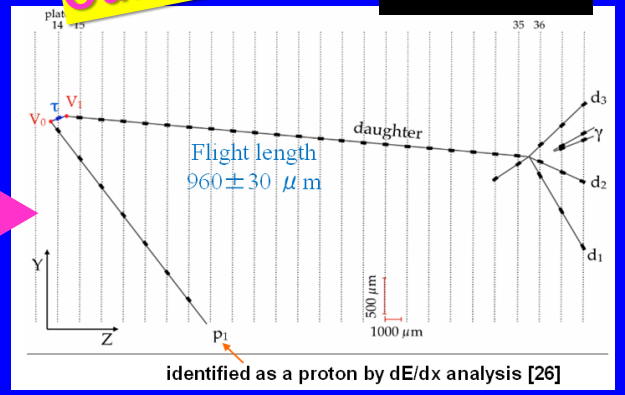
SK



First experimental evidence (1998)

Our work

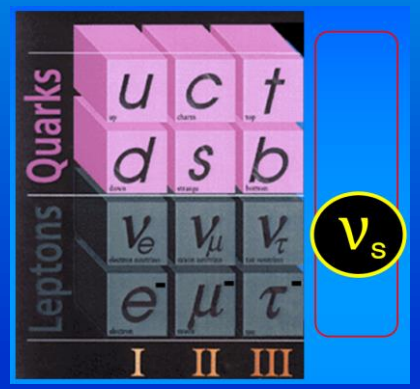
OPERA



Final demonstration (2015)

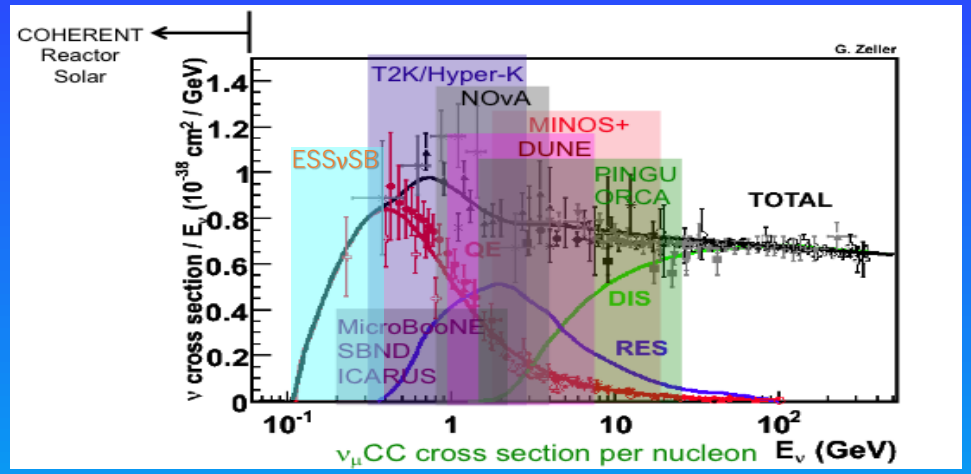
First track detected in emulsion film

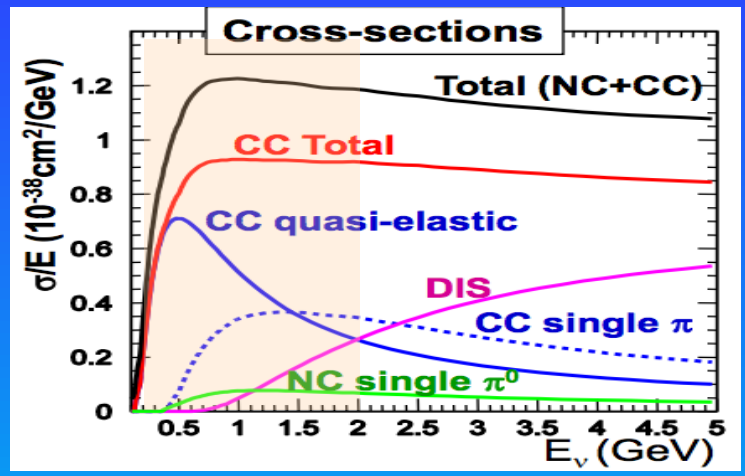
Precise measurement of neutrino oscillation
→ Open the door to new physics of the particle physics and the universe.



Sterile neutrino!?
→ fourth generation
dark matter?

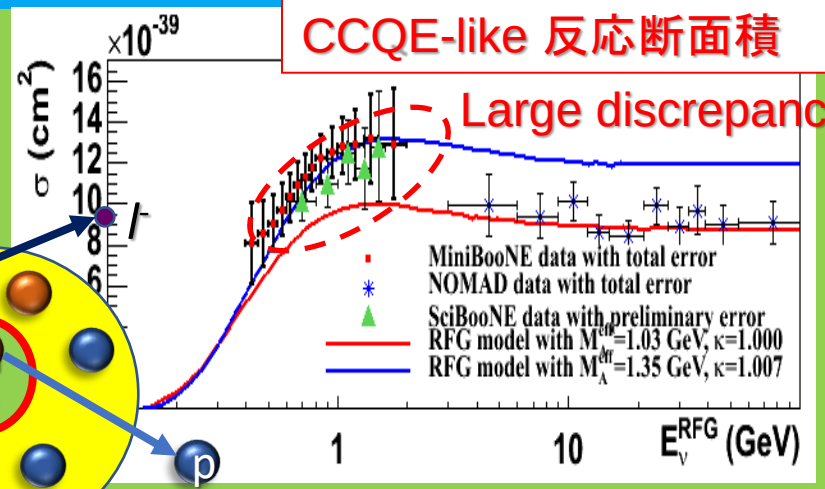
Neutrino physics on sub-multi GeV

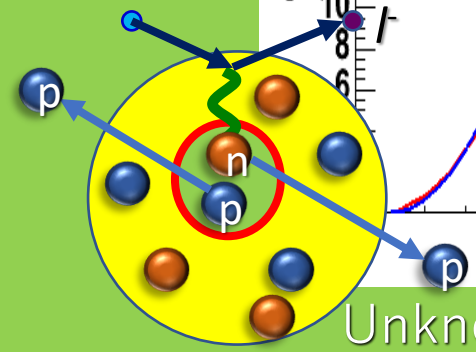




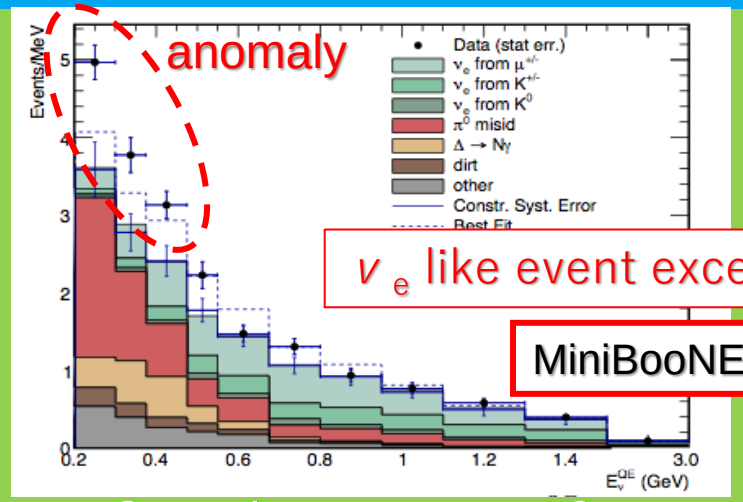
Most current and future neutrino oscillation experiments are in this energy region

CCQE-like 反応断面積





Unknown neutrino interaction?



ν e like event excess

MiniBooNE

Sterile neutrino?

The uncertainty of ν-nucleus is a barrier to the precise measurement of neutrino oscillations.

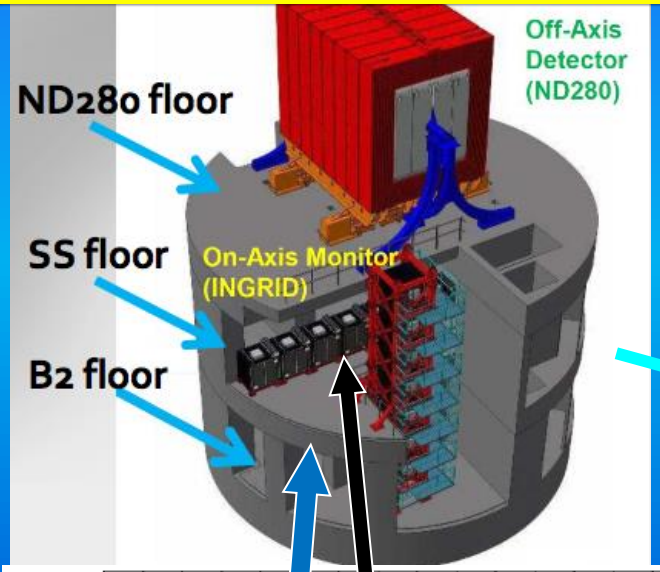
NINJA Experiment

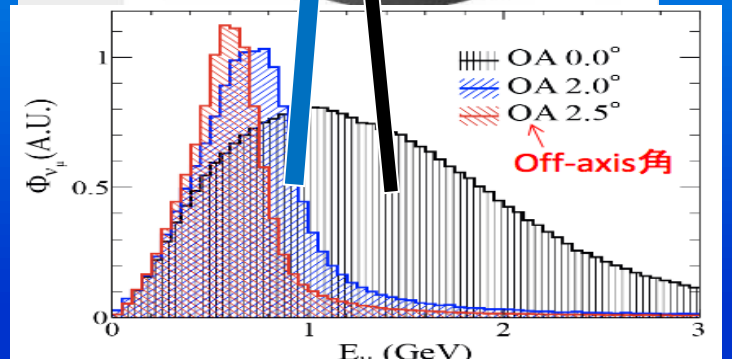
Neutrino **I**nteraction research with **N**uclear emulsion and **J**-PARC **A**ccelerator

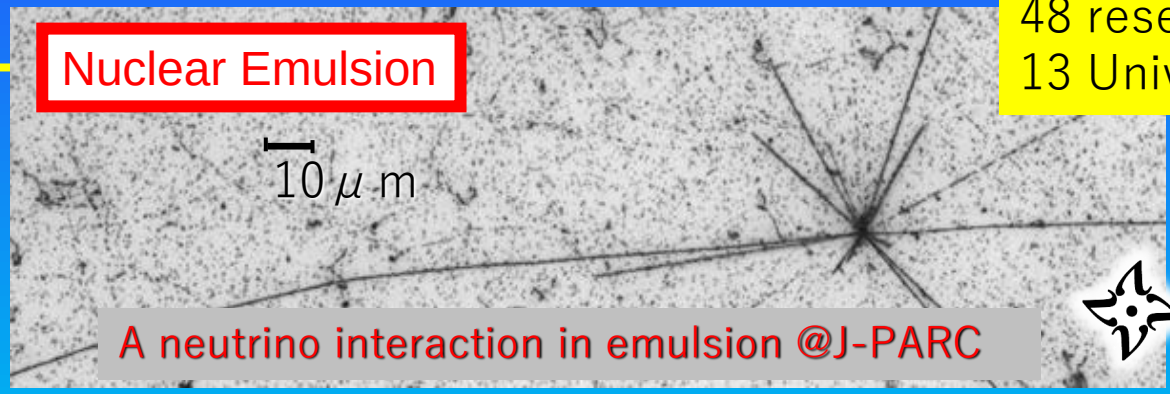
- Precise measurement of neutrino-nucleus cross-sections in Sub-Multi GeV
- Electron neutrino cross-section measurement
- Sterile neutrino search

48 researchers from
13 Univ., 3 countries

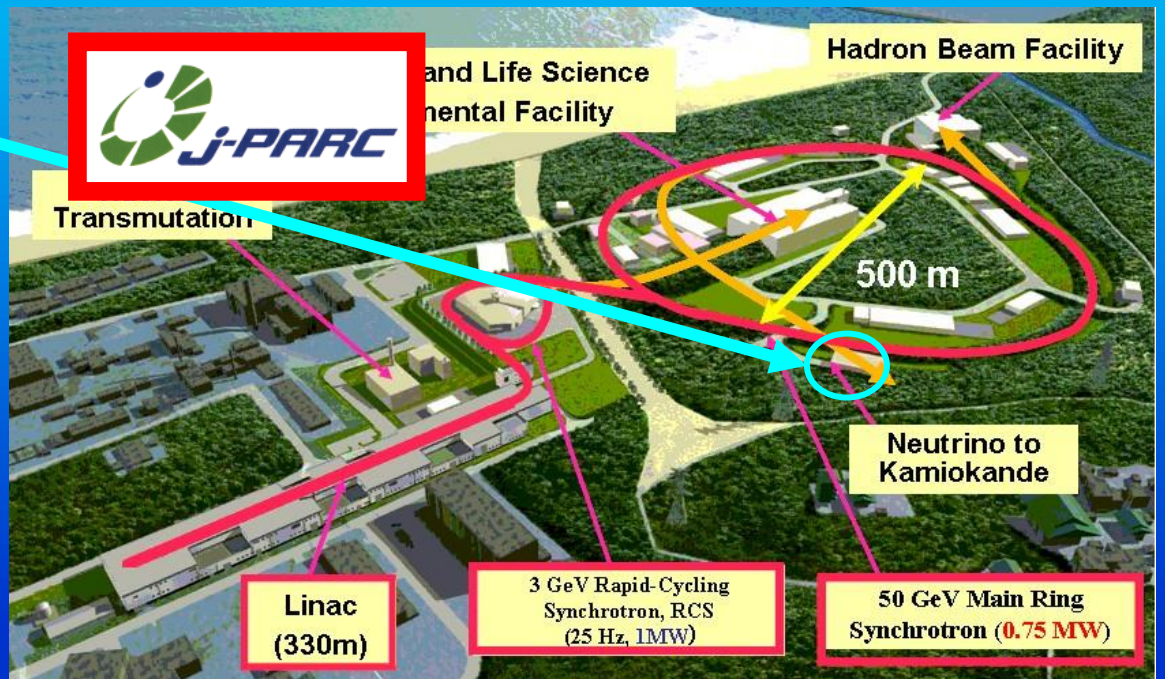
J-PARC Neutrino Monitor Building

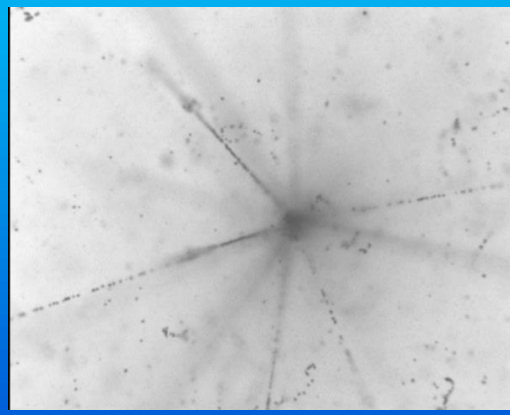






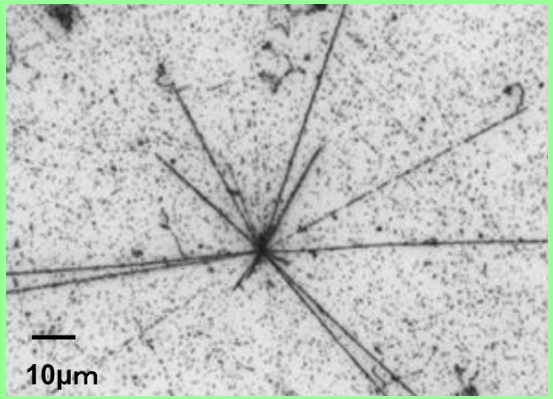
NINJA

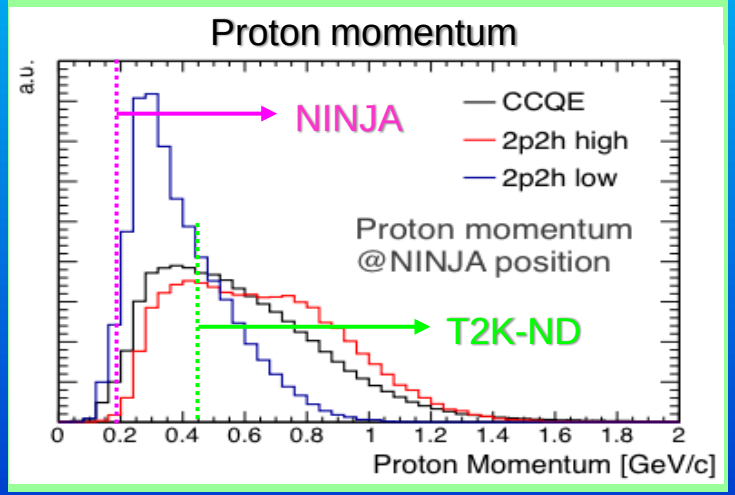


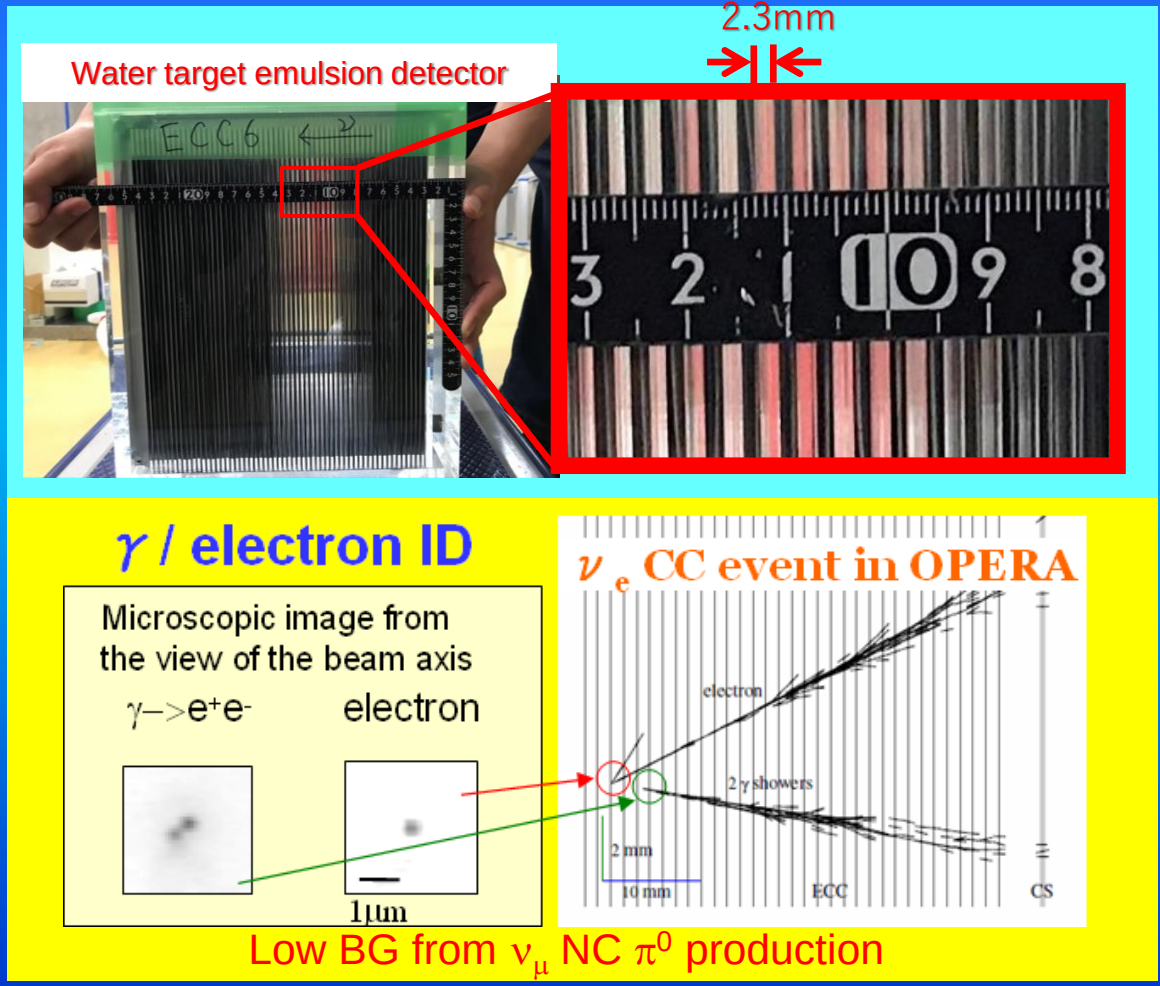


Merits using nuclear emulsion

- Low energy hadron measurement ← difficult to measure so far
- Neutrino-water interactions ← same target as the large water Cherenkov detector
- Low background for ν_e measurement ← clear verification of sterile neutrino





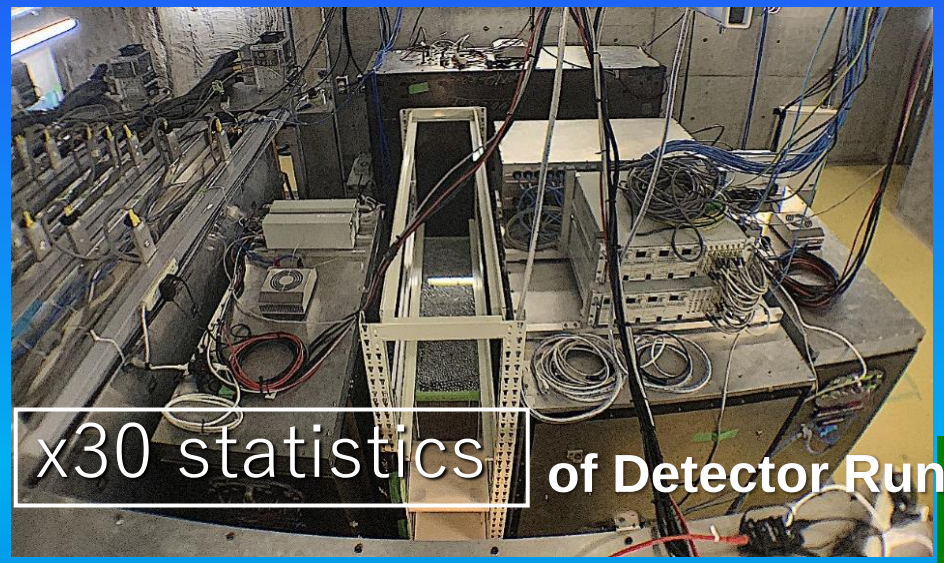


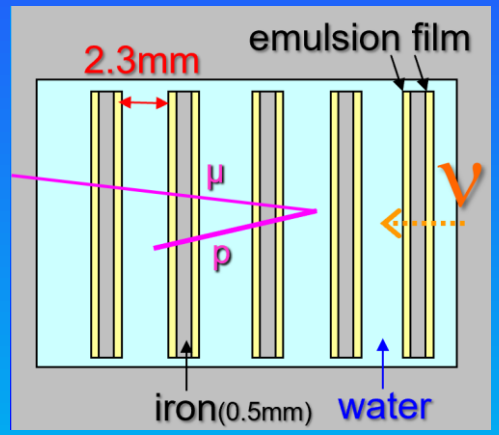
The nuclear emulsion has all the essential elements for low energy neutrino study.

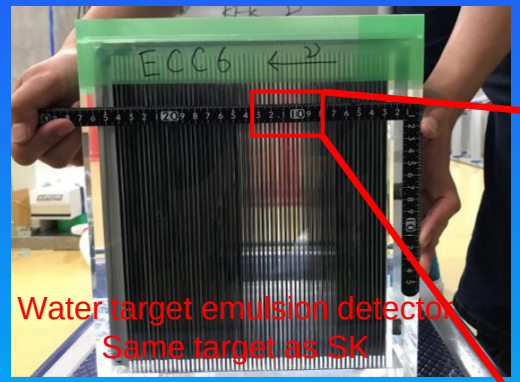
Physics Run (E71a)

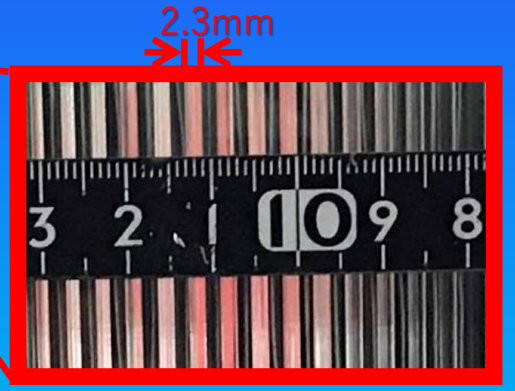
Neutrino beam exposure : 4.8 x 10^{20} POT
@ 2019-2020 (1st Physics Run: E71a)
2nd Physics Run (E71b) → 2023

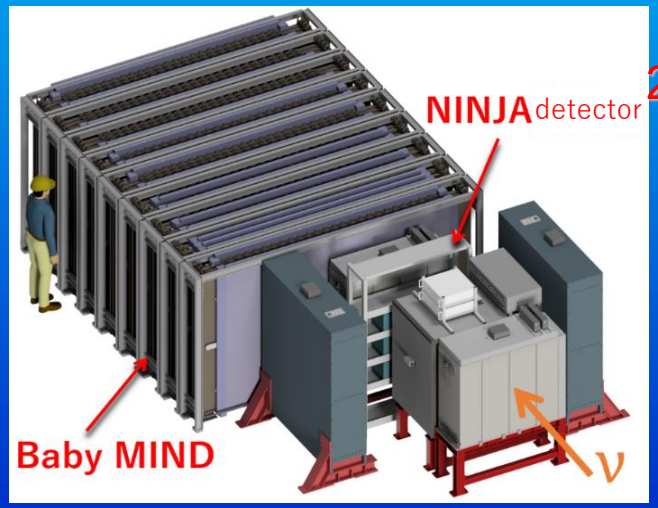
- First measurement of ν-multi nucleon interactions
- Exclusive cross-section measurement of ν-water interactions











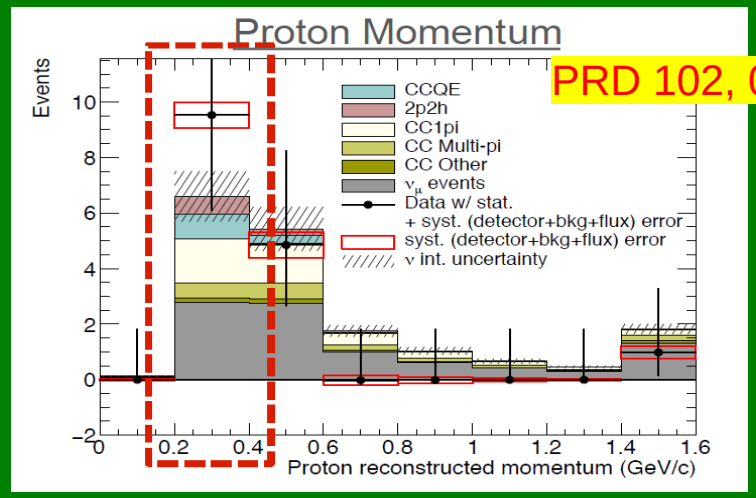
250kg Target

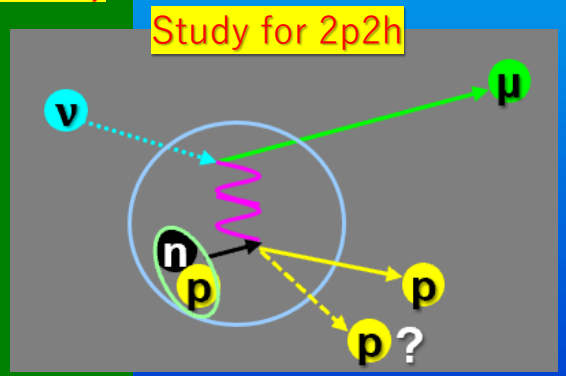
H_2O : 75kg
Fe : 130kg
CH : 15kg
em : 30kg

Film 130m²

↓

5,000 events

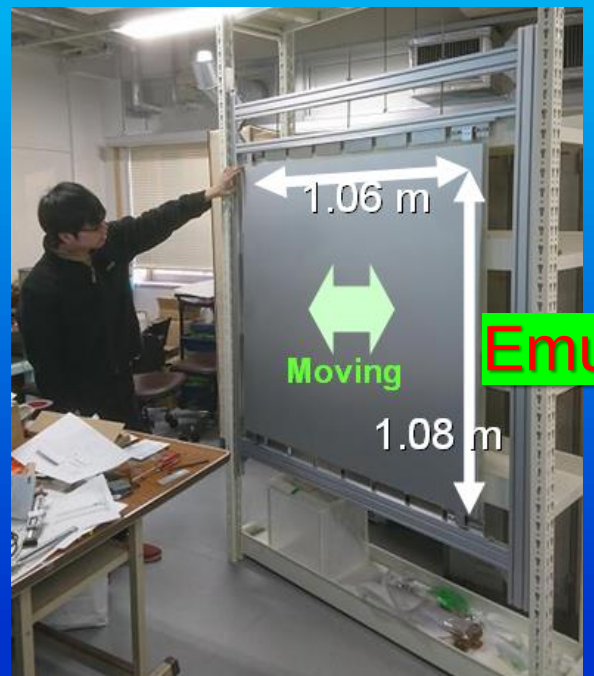




Detection of low energy protons from ν-water int. at Detector Run (T68)

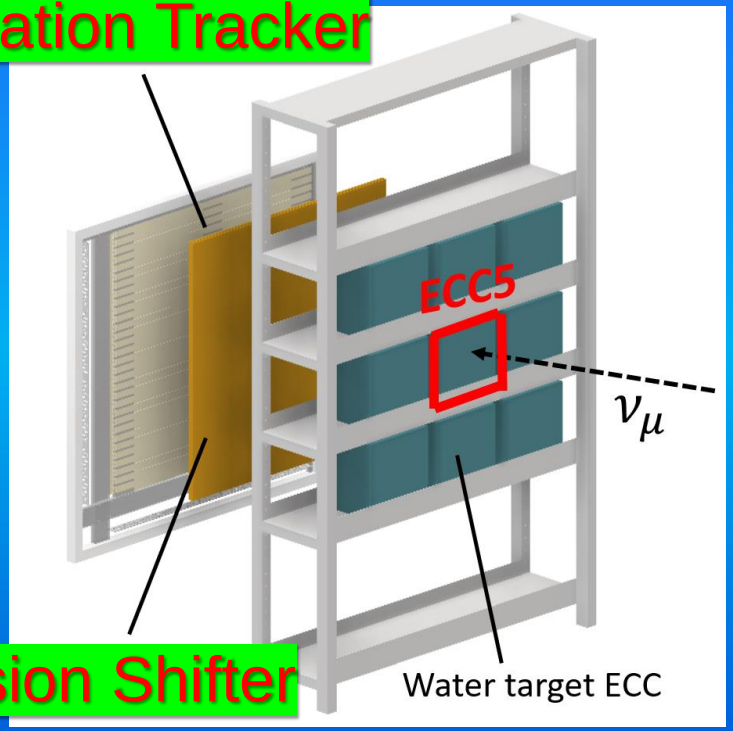
NINJA detectors

Emulsion Shifter and Scintillation Tracker give time stamps to emulsion track in ECC to identify μ with Baby MIND.



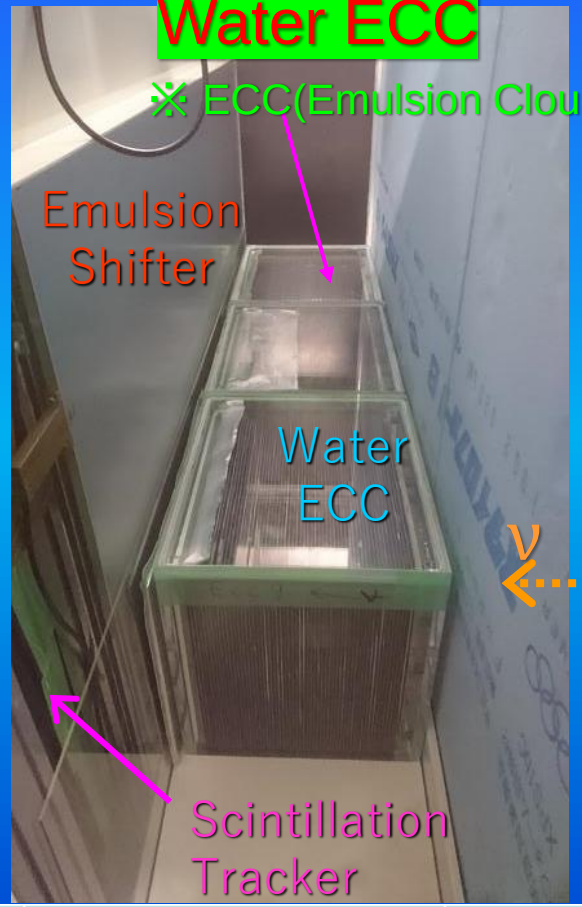
Scintillation Tracker

Emulsion Shifter



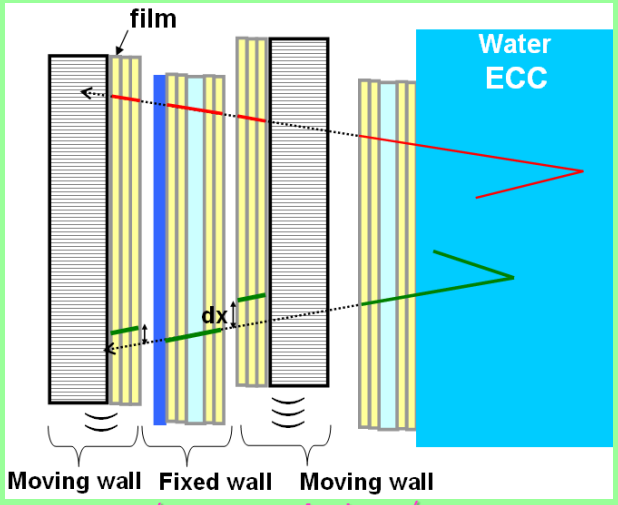
Water ECC

※ ECC(Emulsion Cloud Chamber)



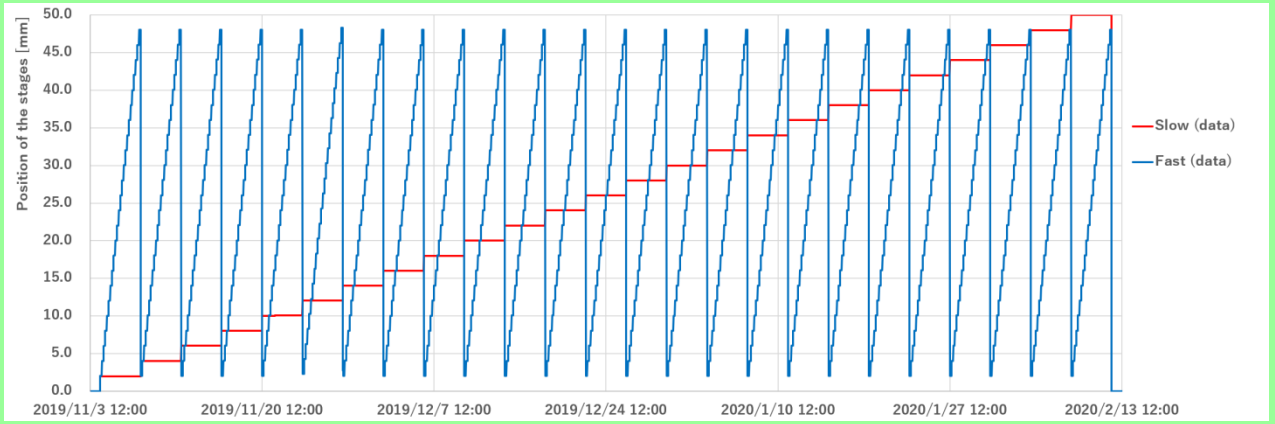
	Scintillation Tracker	Emulsion Shifter	Water ECC
Time resolution	10 nsec level	4 hour	--- (100 day)
Position resolution	2.1 mm	1 μm level	1 μm level

Emulsion Shifter

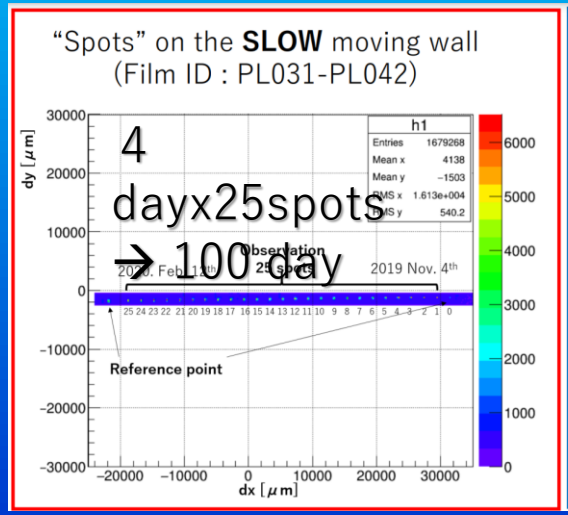


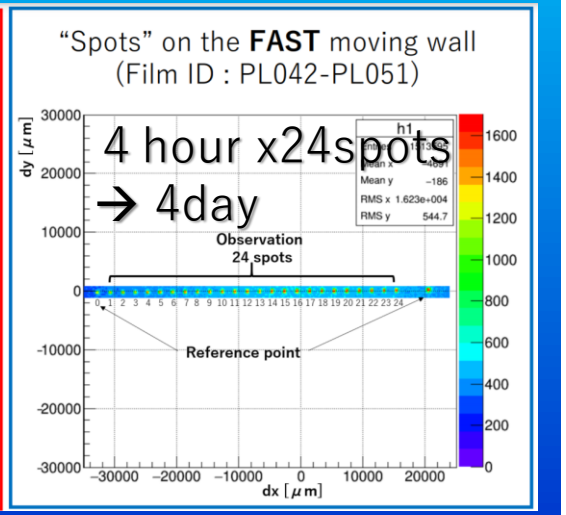
4 hour/step 4 day/step

Operation of the Emulsion Shifter → Stable



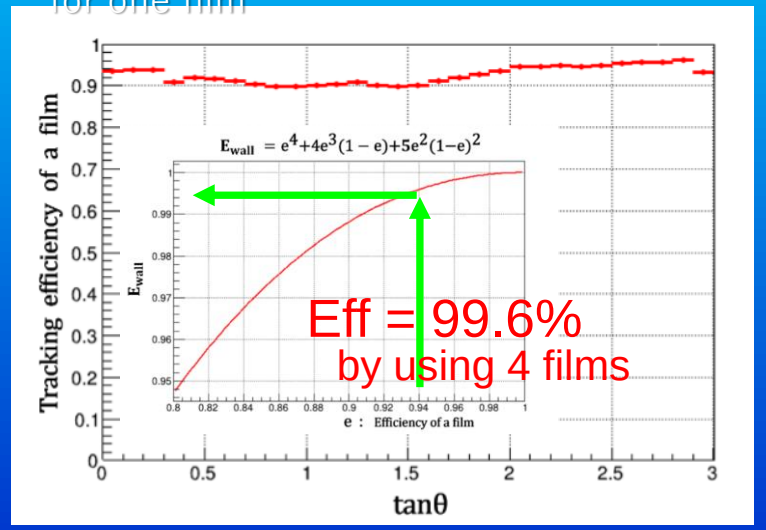
Position difference between Moving wall and Fixed wall





Each spot corresponds to the time information.

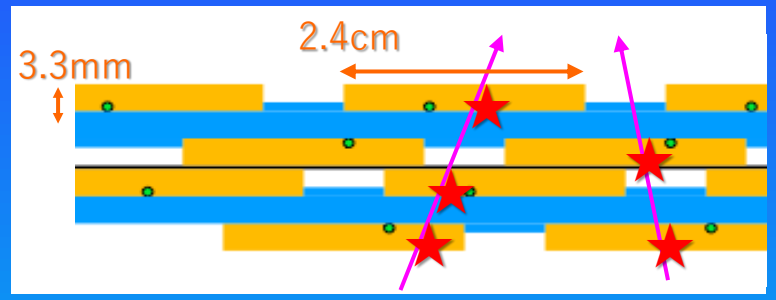
Tracking efficiency (angle dependence) for one film

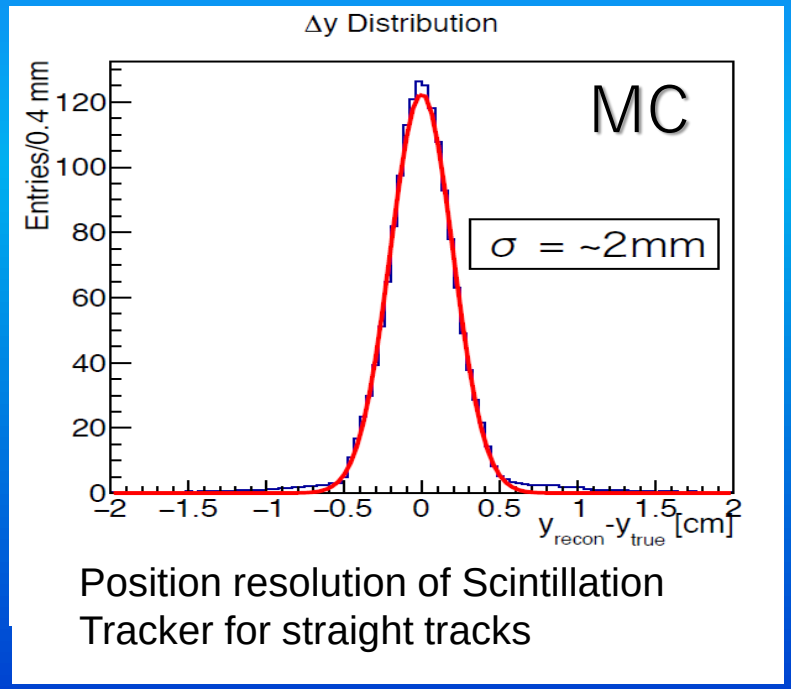


3hold tracks are used.

Scintillation Tracker

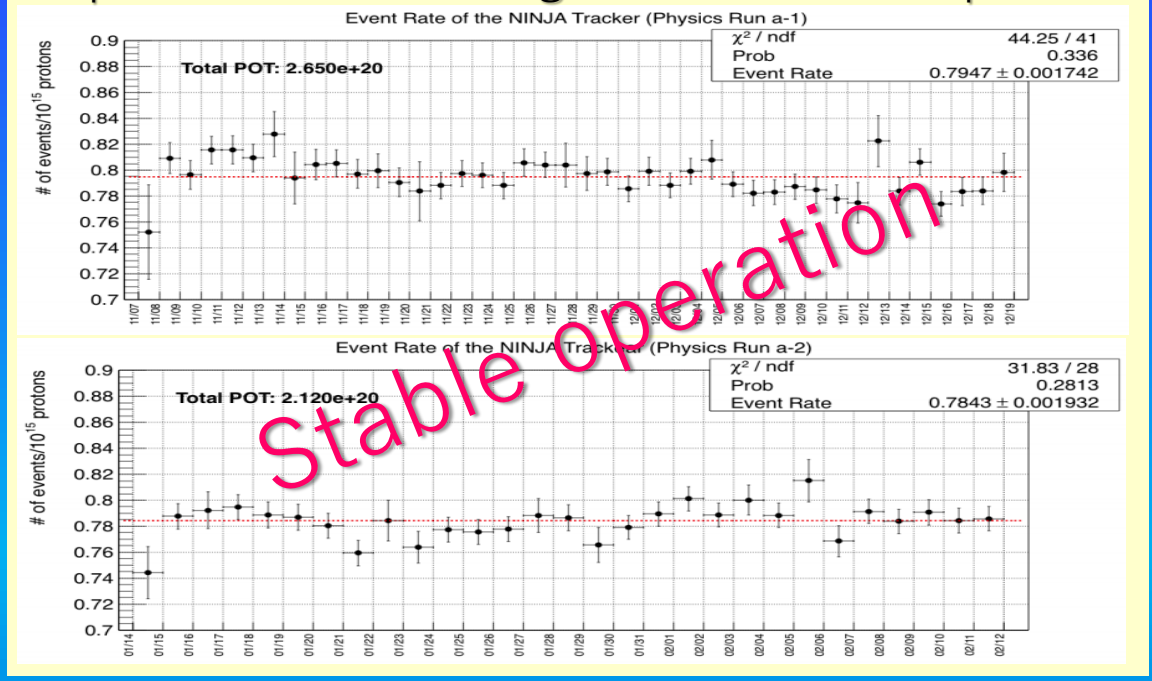
2mm position resolution with novel structure of 2cm-width scintillation bar.



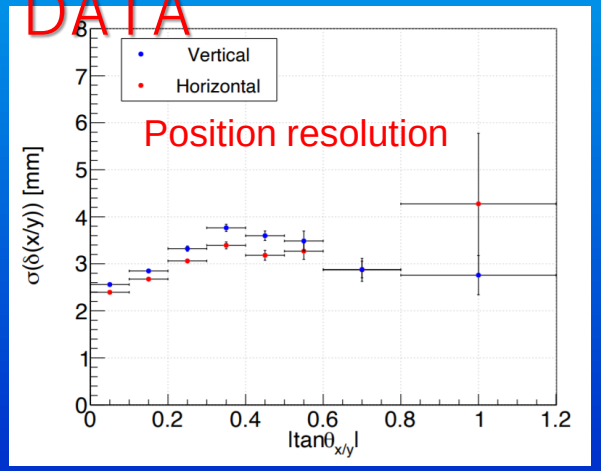


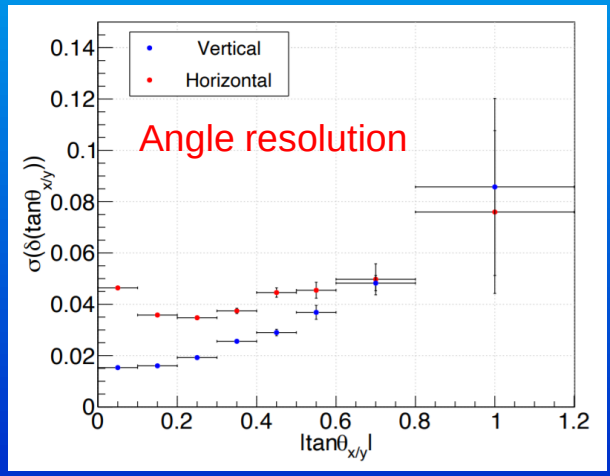
Position resolution of Scintillation Tracker for straight tracks

Operation result during neutrino beam exposure



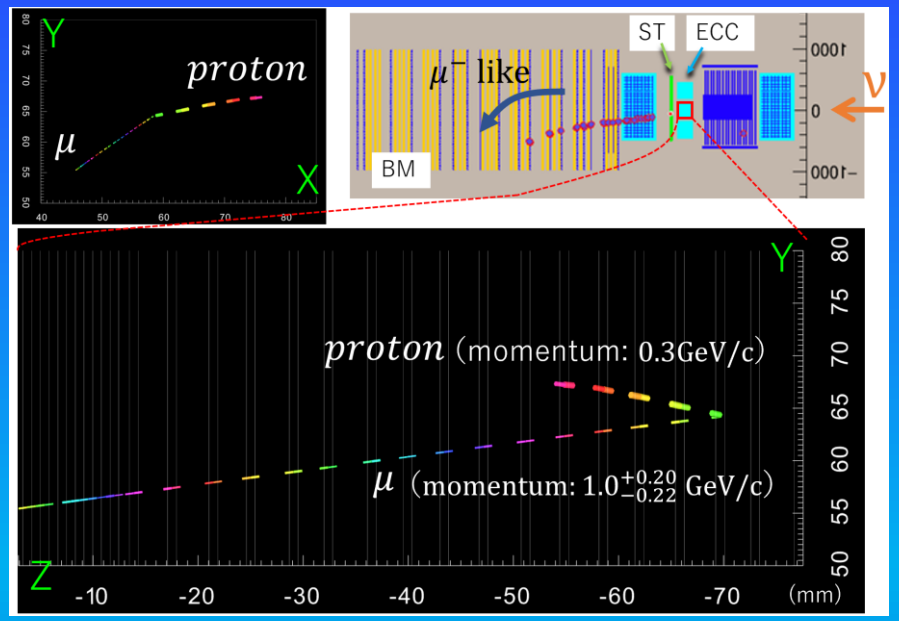
DATA



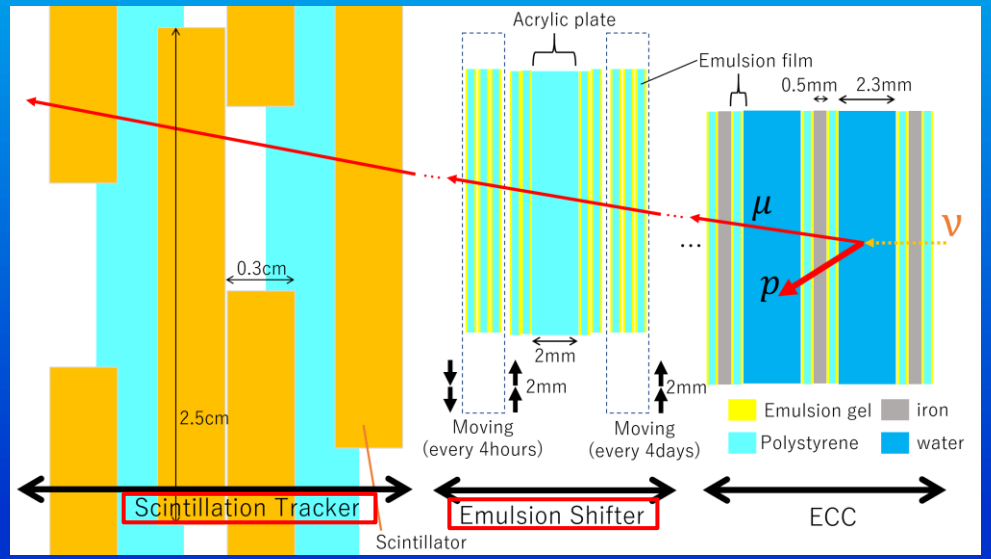


The performance (position and angle resolution) of the Scintillation Tracker was as expected.

Status of Physics Run(E71a)

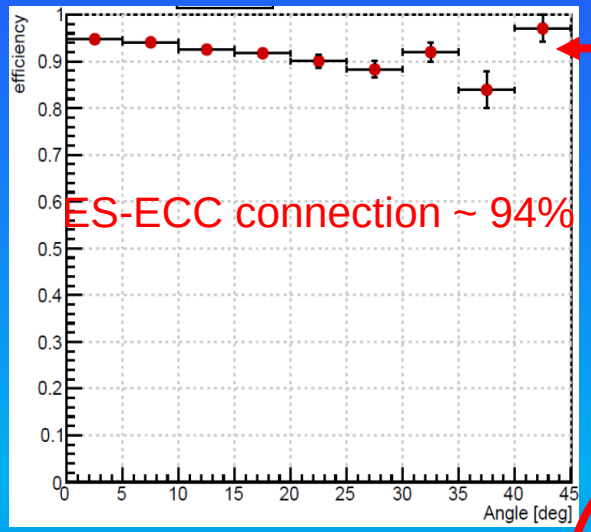


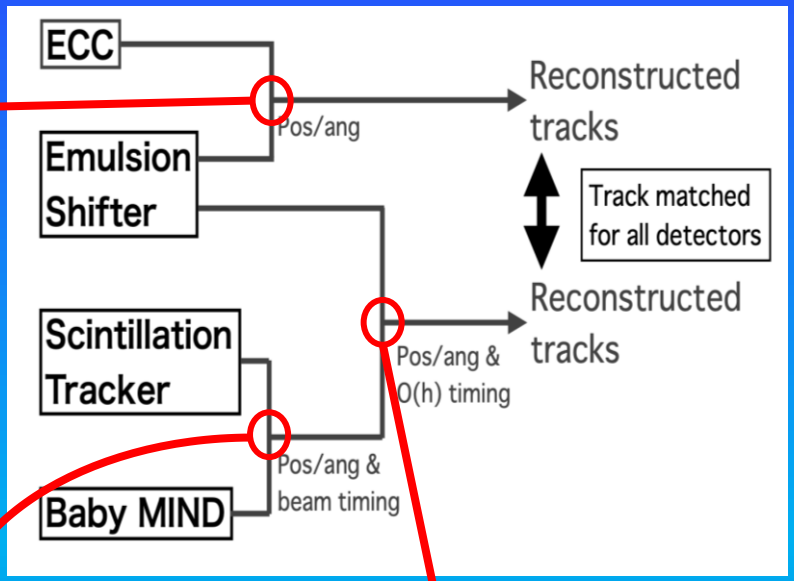
Connected muon tracks between ECC-BM with ES and ST

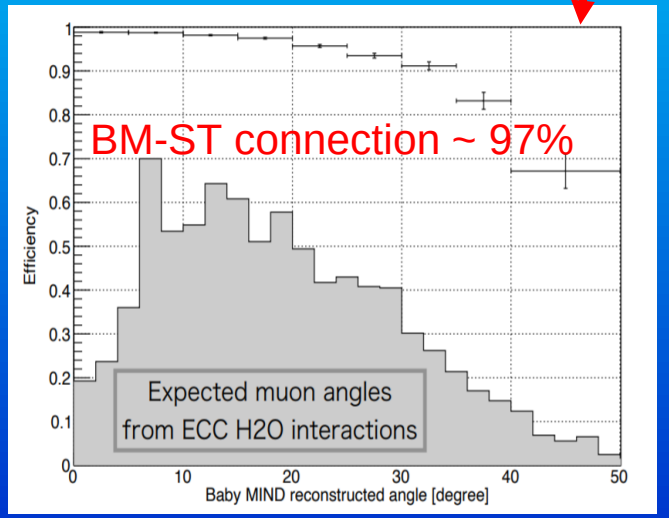


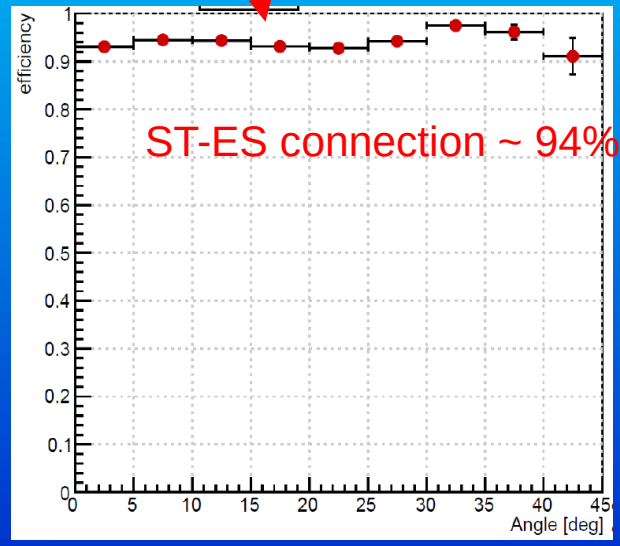
Track matching

estimated by sand-muon



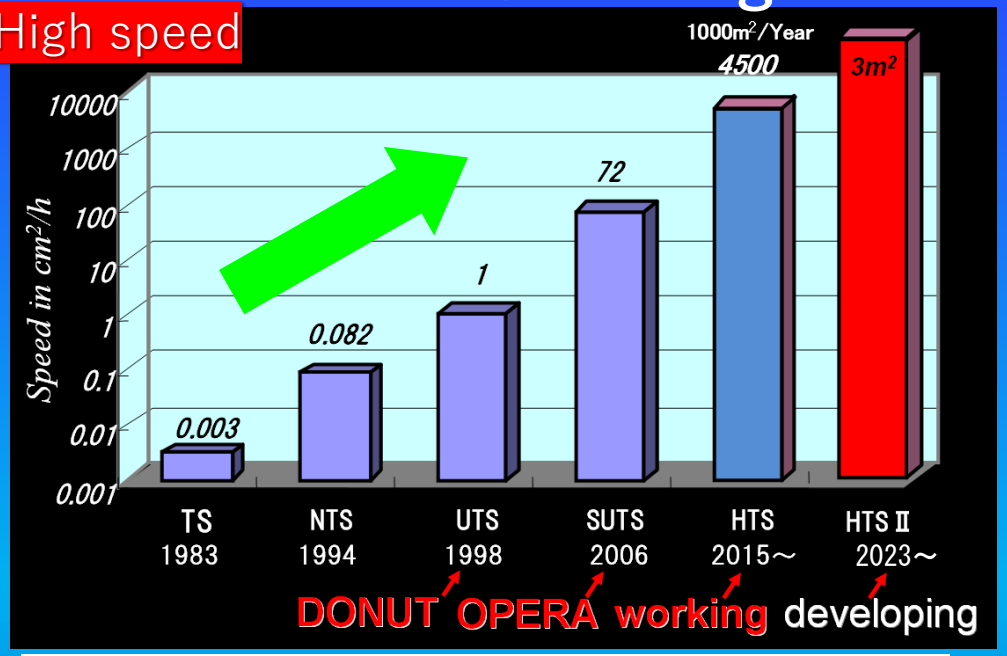


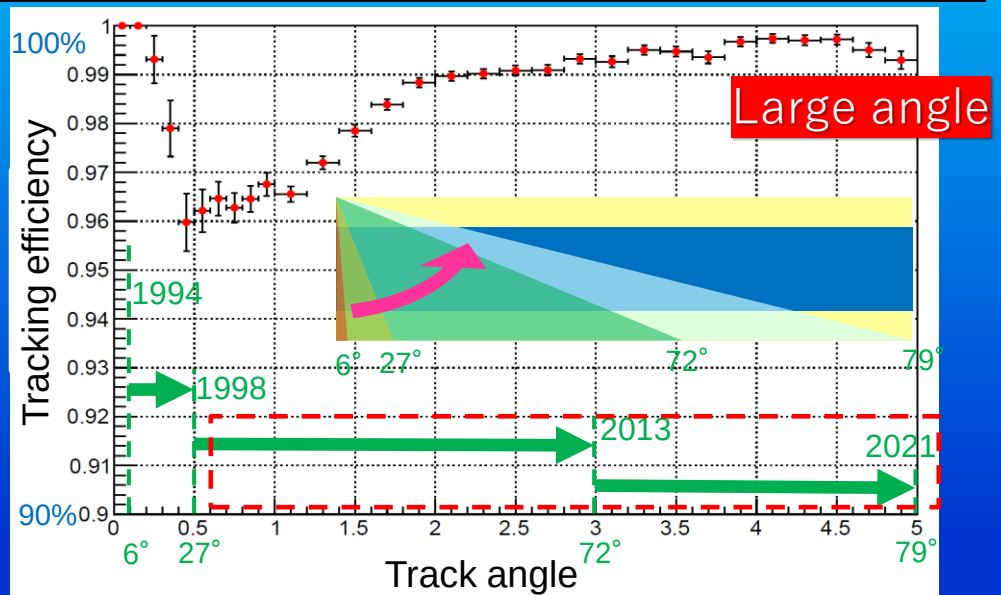




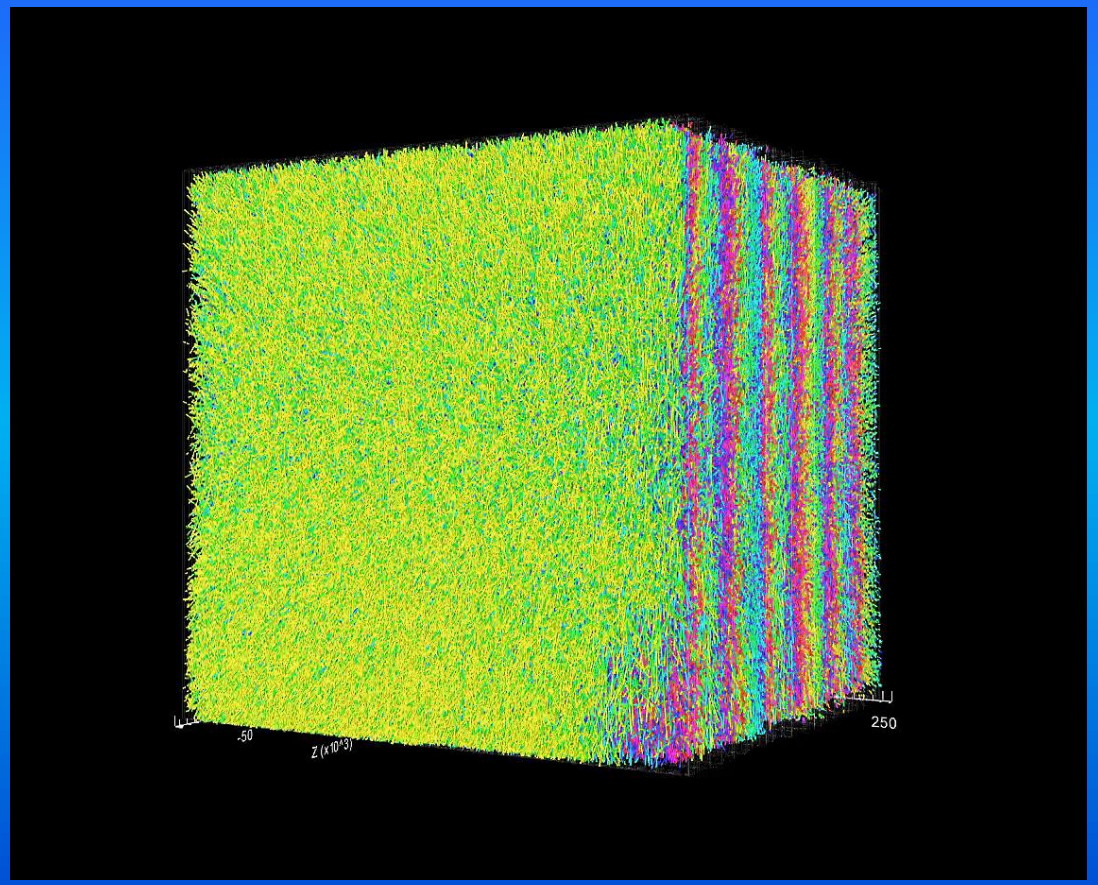
Status of Physics Run(E71a)

Emulsion Scanning





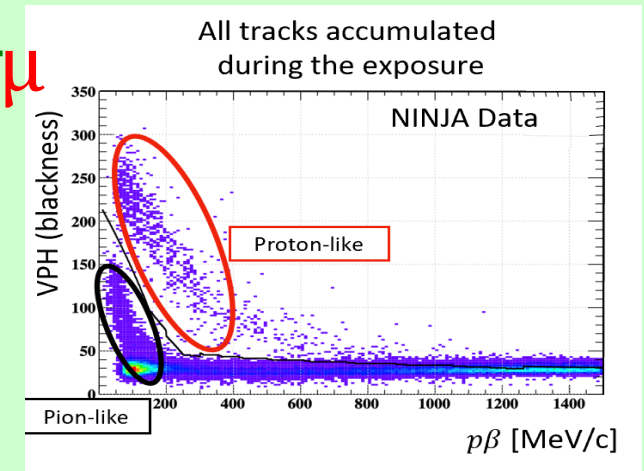
Neutrino event search and reconstruction

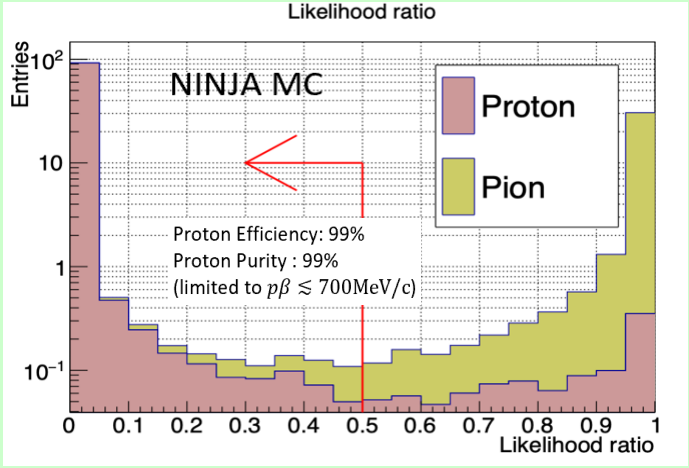


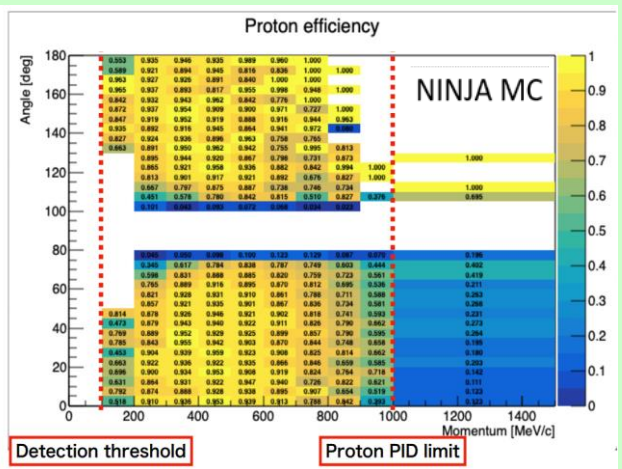
Systematic partner track search is performed well.

Status of Physics Run(E71a)

Particle ID $p/\pi\mu$

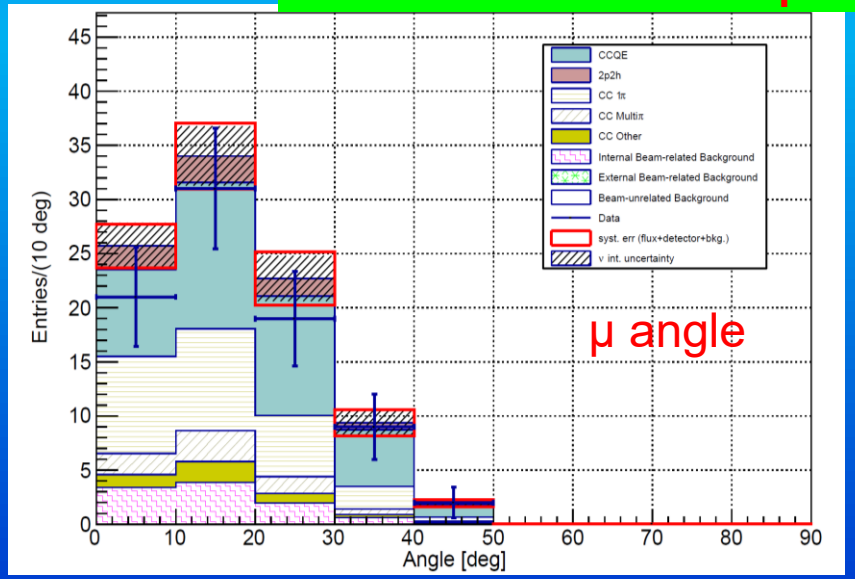


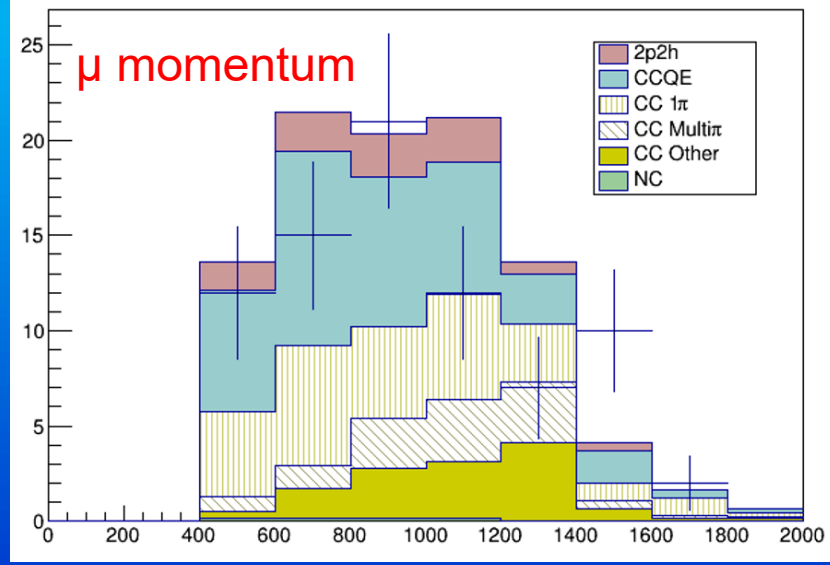


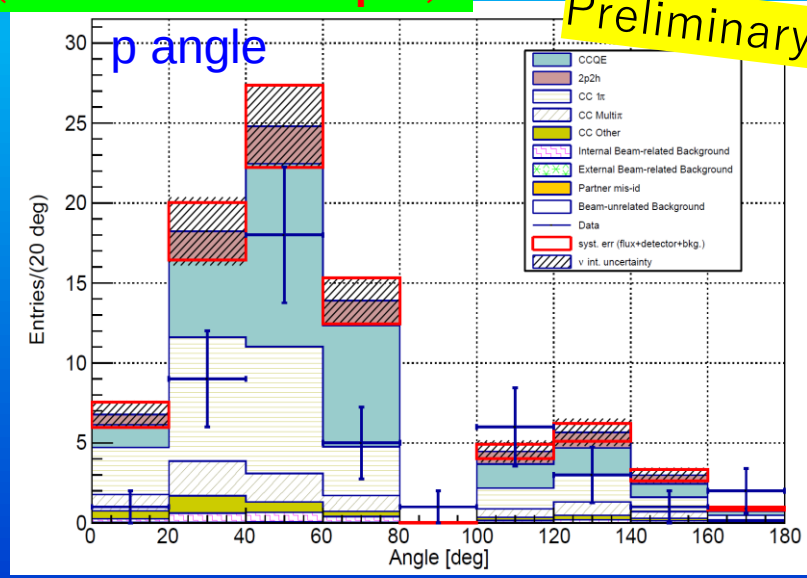


Detected muons and protons in neutrino-water interactions（~10% sub-sample）

Preliminary







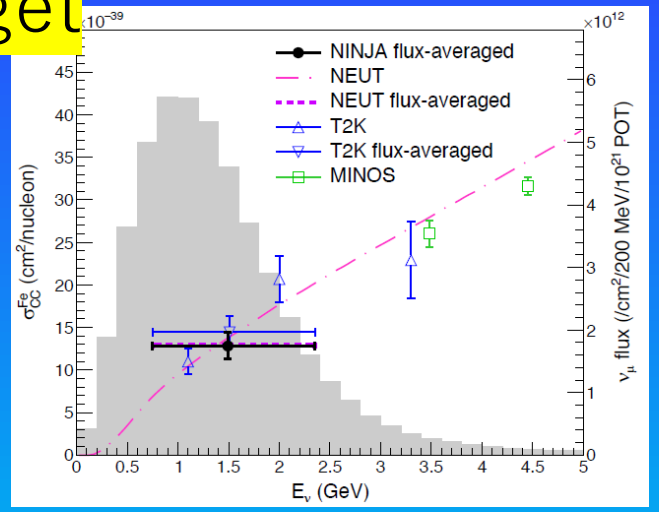
μ → almost consistent, proton→ deviations are observed. → **to be confirmed future**

Recent NINJA results

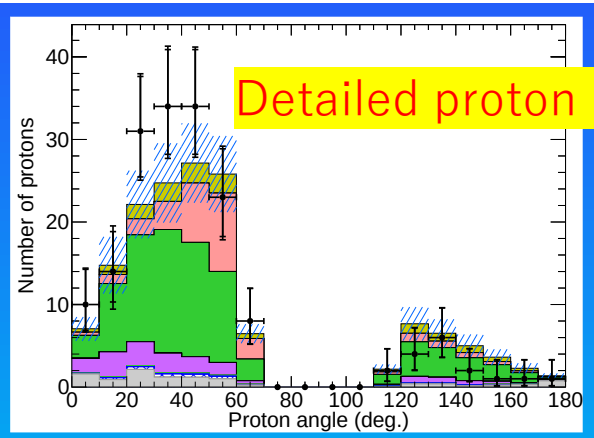
- Iron target

H. Oshima et al., Prog. Theor. Exp. Phys. 2021, 033C01 (2021)
H. Oshima et al., Phys. Rev. D 106, 032016 (2022)

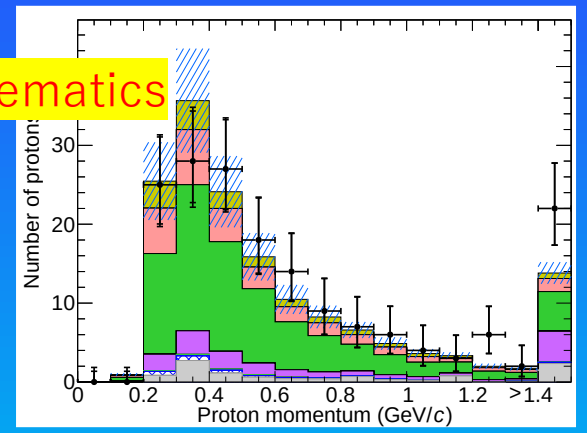
ν mode



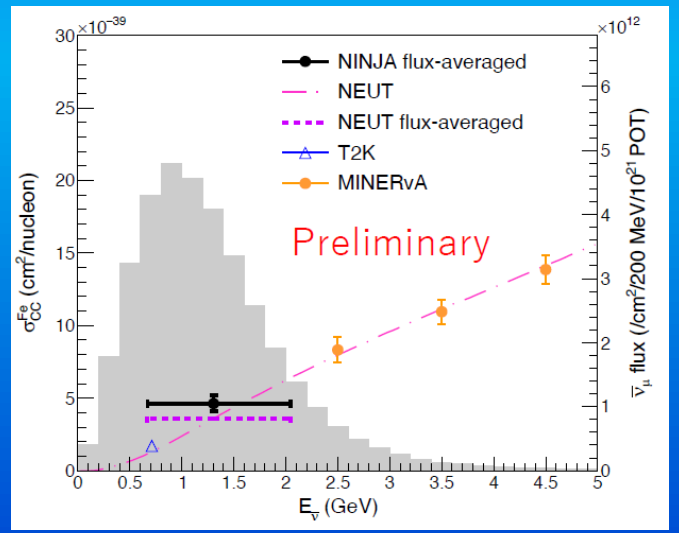
Detailed proton kinematics



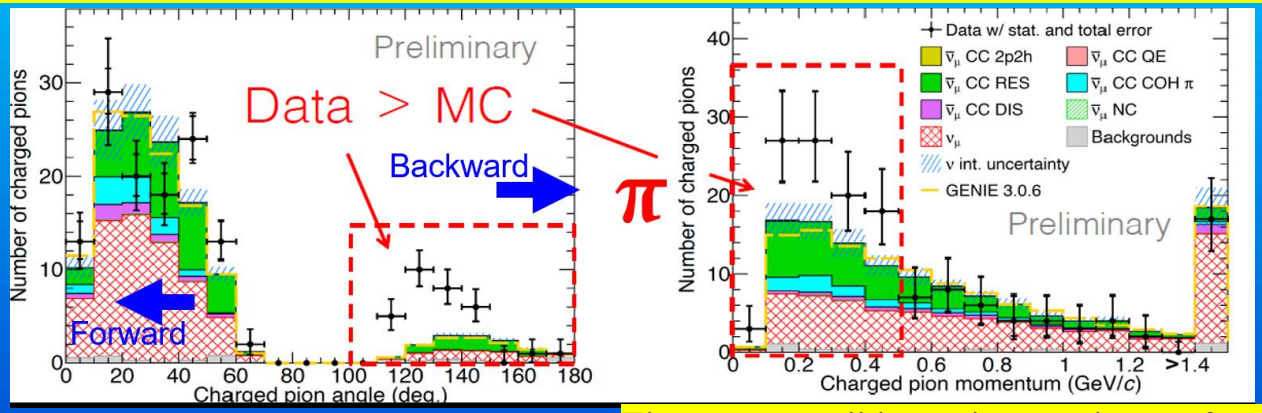
p



anti-ν mode



Charged pion production (backward) is larger than prediction.



The paper will be submitted near future

Data of charged pion production (backward) in anti-neutrino int. is larger than the MC prediction.

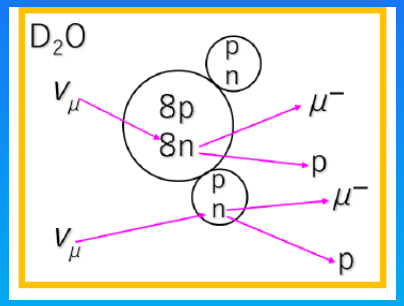
→ Still not fully understood neutrino-nucleus interactions.

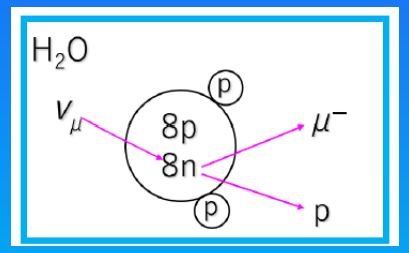
Unknown effect in neutrino-nucleon interaction? Secondary interaction in nucleus?

Future prospects: heavy water run

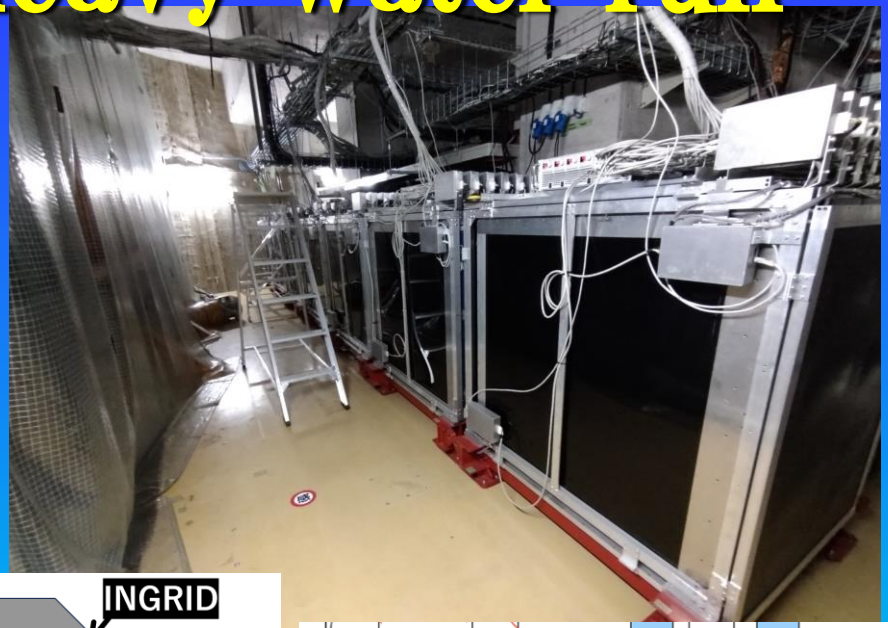
Study of neutrino-nucleon interactions without nuclear effect

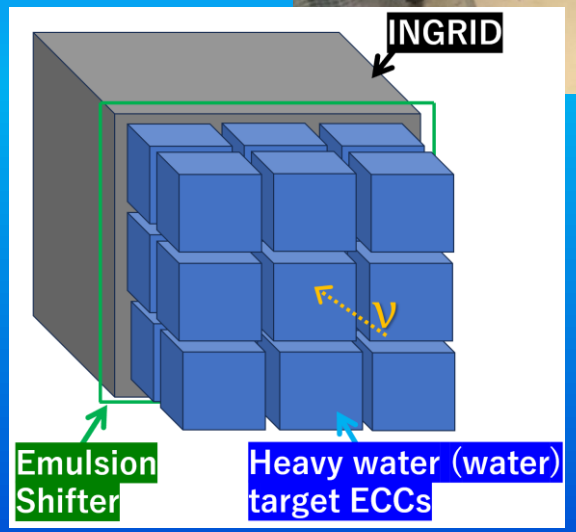
Proposed new physics run in front of T2K NDs

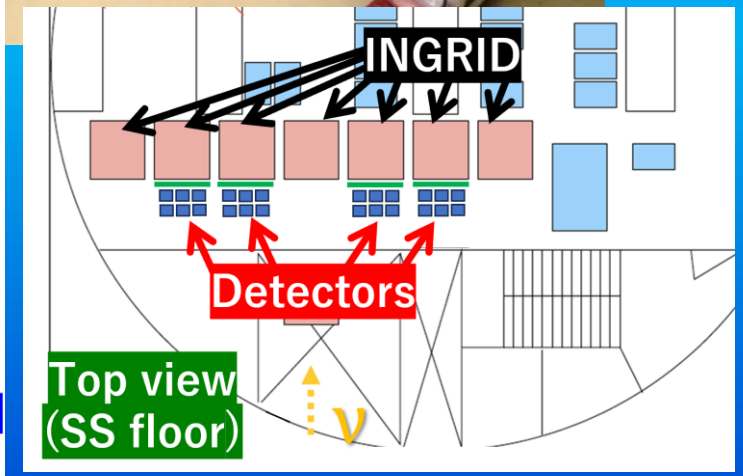


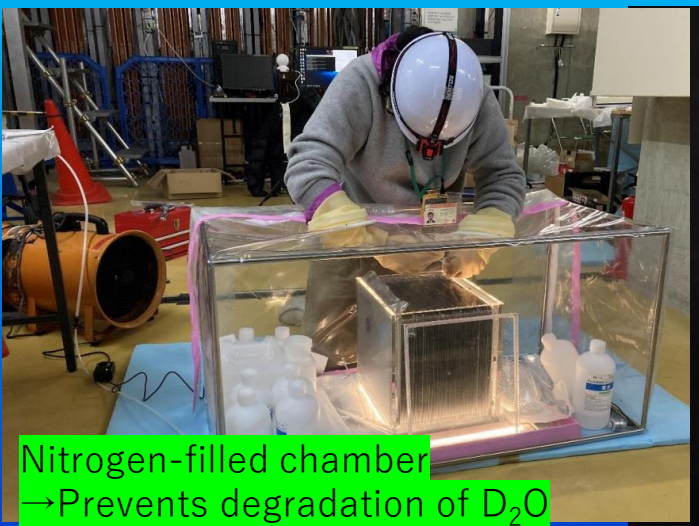


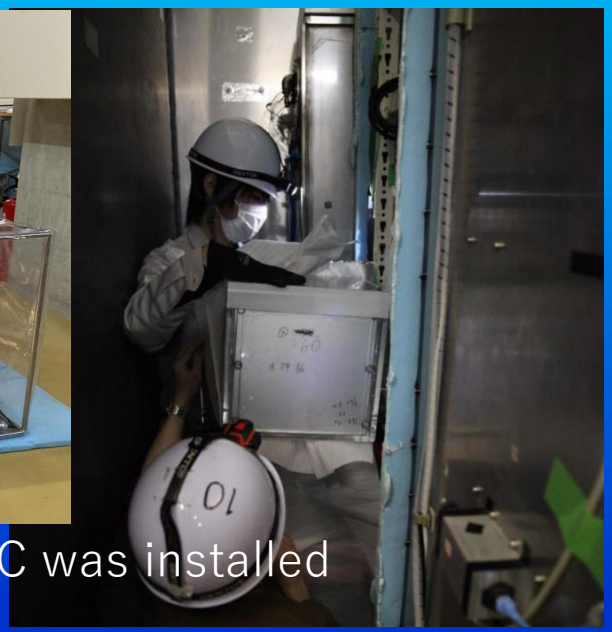
$= (\nu_\mu\text{-n})$











Actually, a heavy water ECC was installed in T81 (2021).

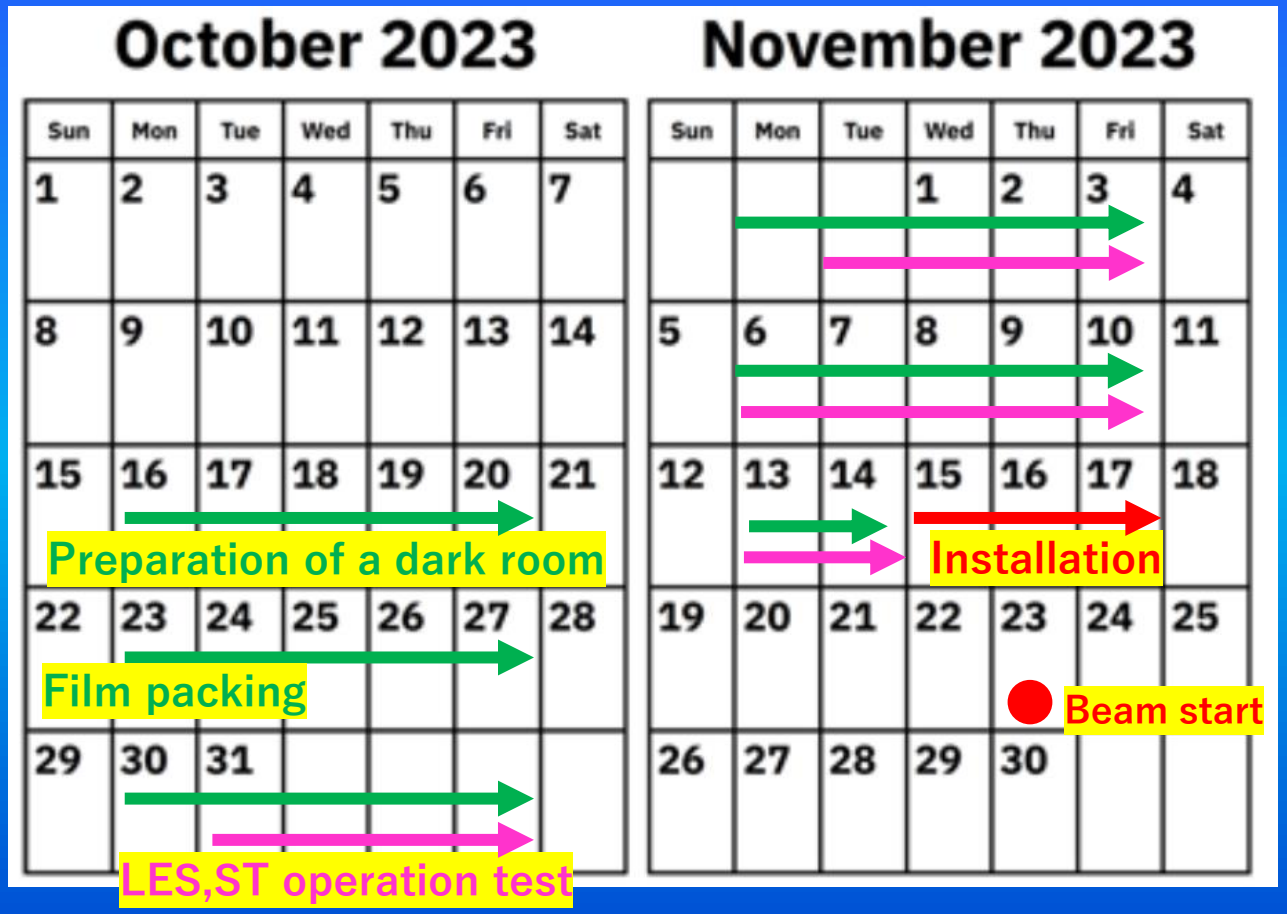
36,000 heavy water interactions and 31,200 water interactions @2.5x10^{21}POT

→ 4,800 ± 230 (ν-n) interactions

Status of Physics Run(E71b)

Last week, neutrino beam exposure was started (NINJA 2nd physics run)

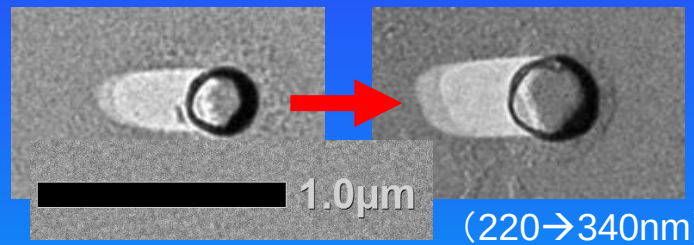
Nov. 8th



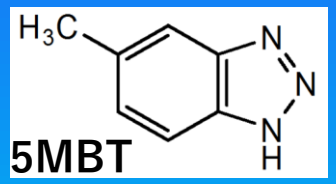
Preparation status

Emulsion films for water ECC

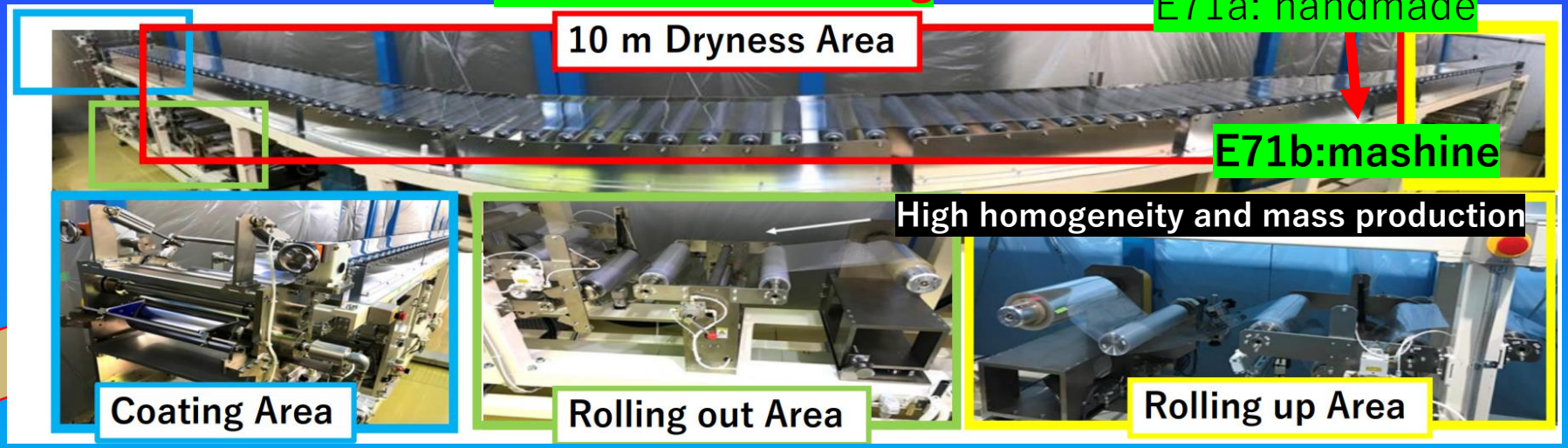
Refreshable large crystal emulsion



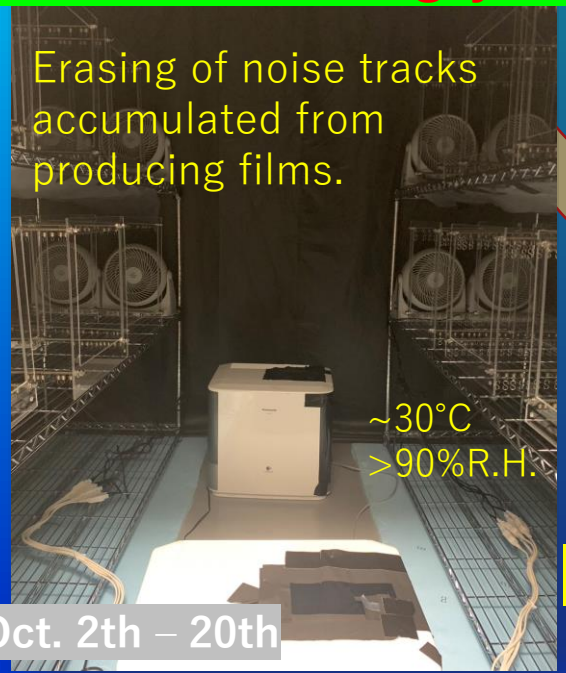
(220→340nm)



Emulsion film coating



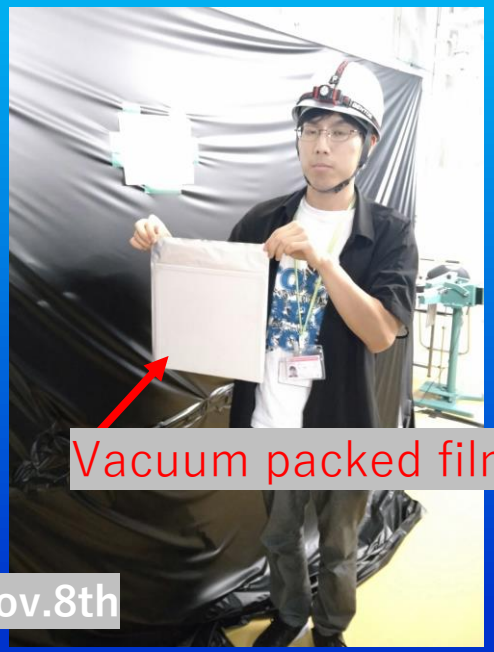
Film refresh at Nagoya U.



Transport to J-PARC

~1200 emulsion films

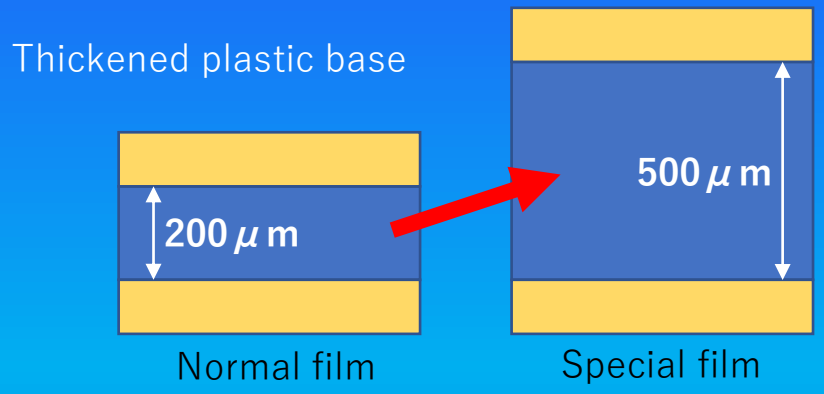
Emulsion film vacuum packing

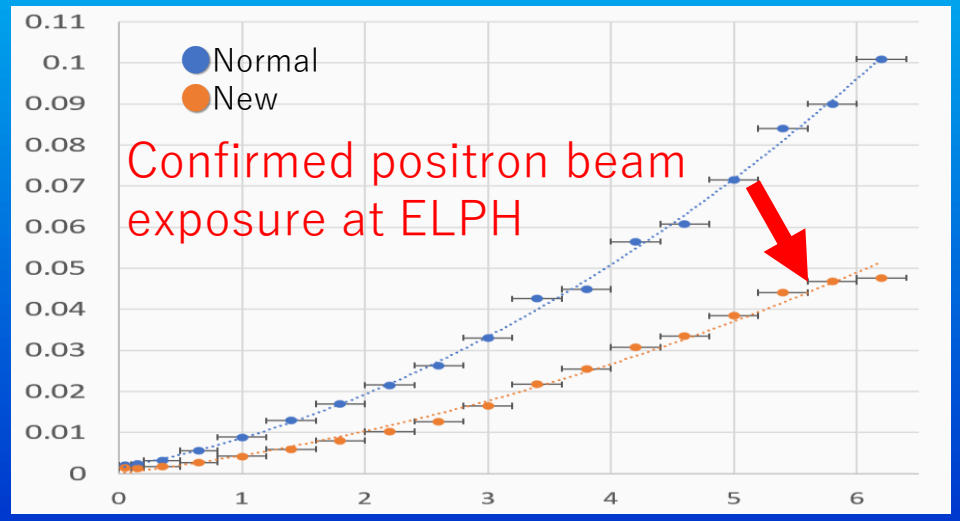


Preparation status

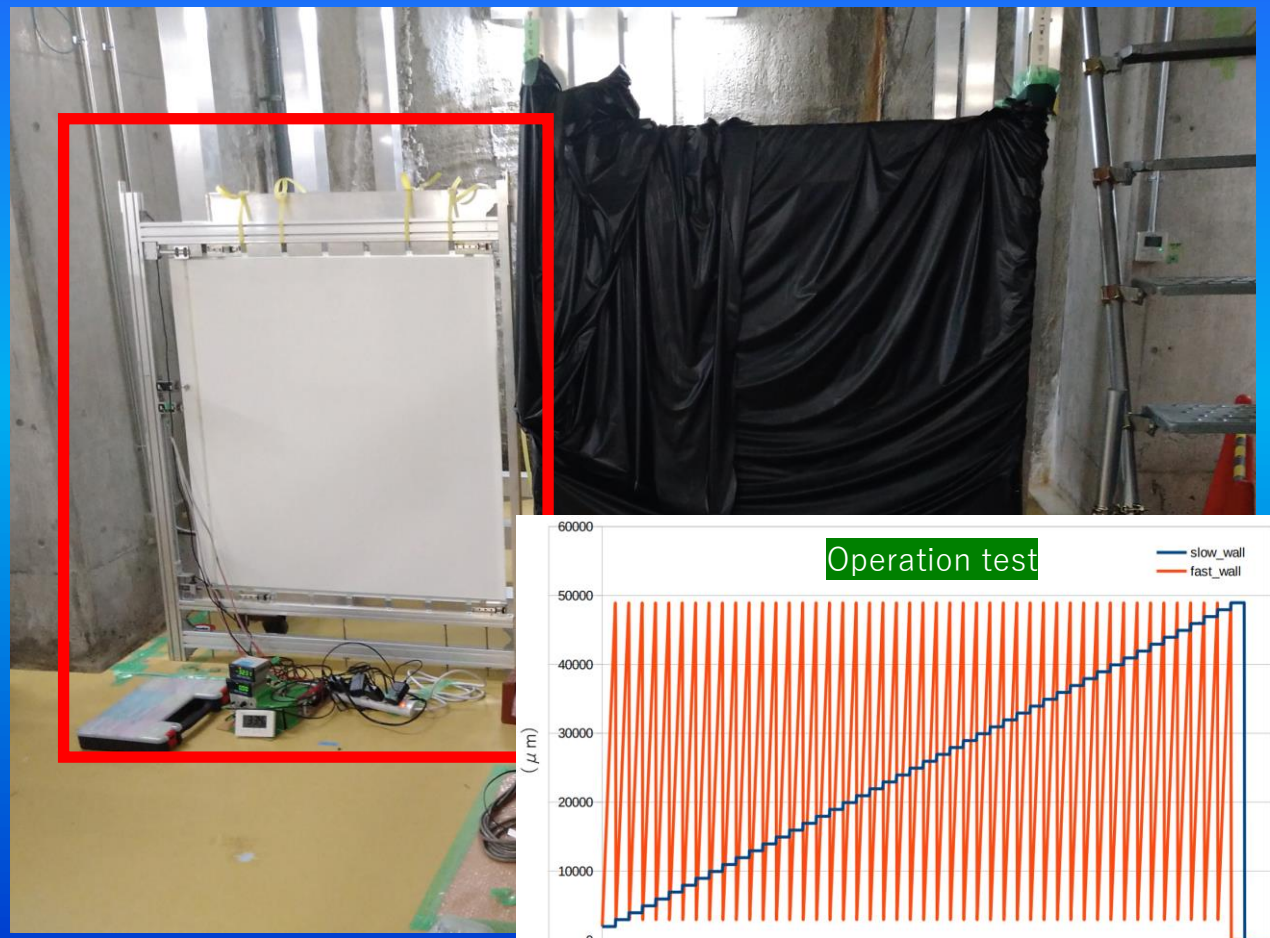
COP based emulsion film for emulsion shifter

Hand-made special film with high angle accuracy for emulsion shifter





Operation test @B2 floor (Oct. 31th~)

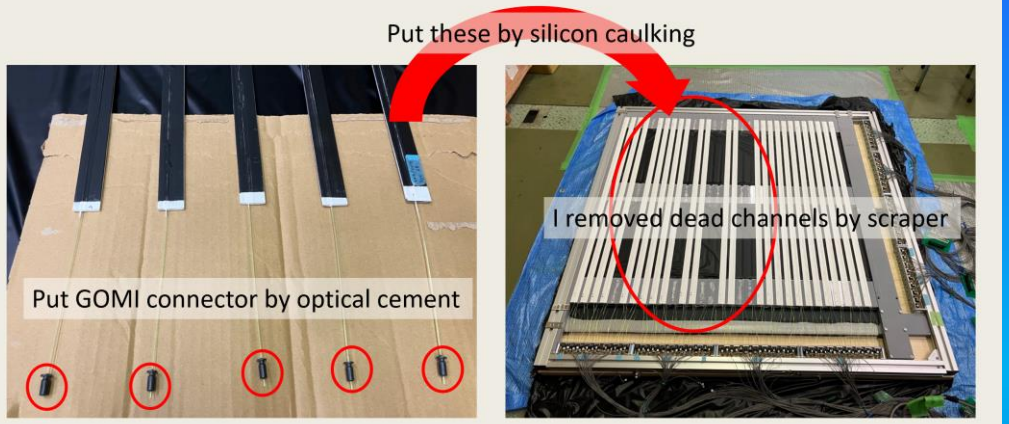


Preparation status

Scintillation Tracker

Repairing of dead channels

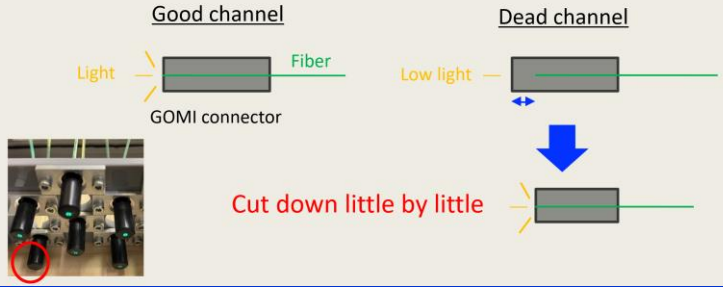
Repair of dead channels – fiber damage



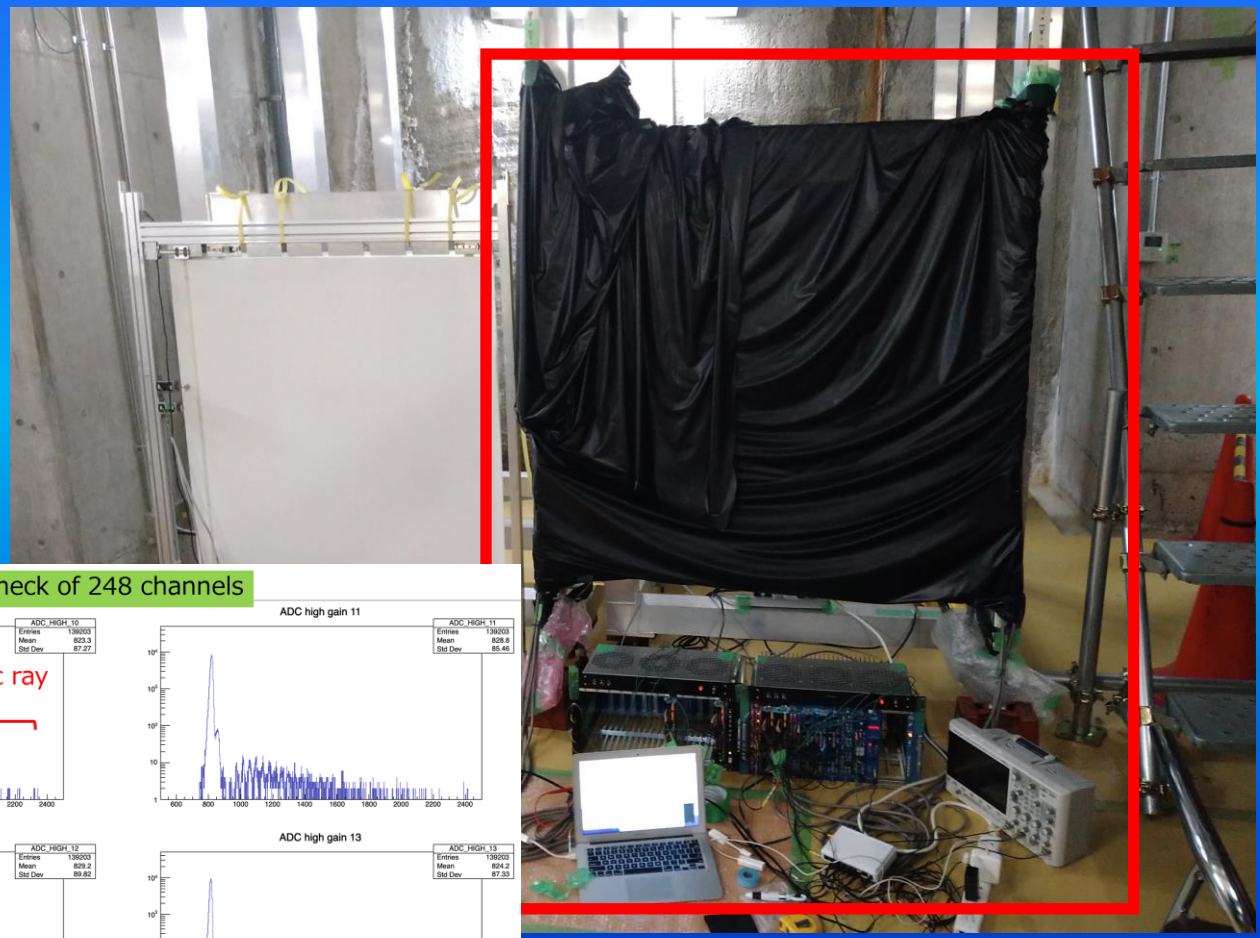
Repair of dead channels – fiber inside of GOMI connector

- There is low light from the edge of fiber in ch92, 156, 157, 163

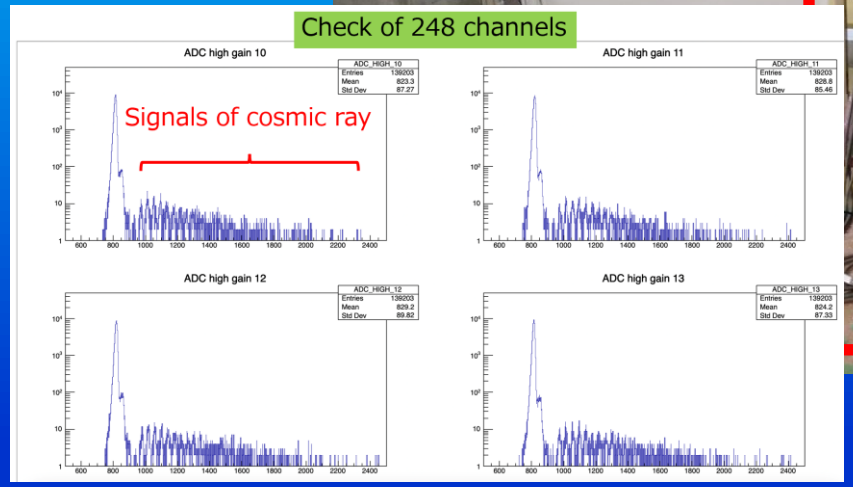
Because…



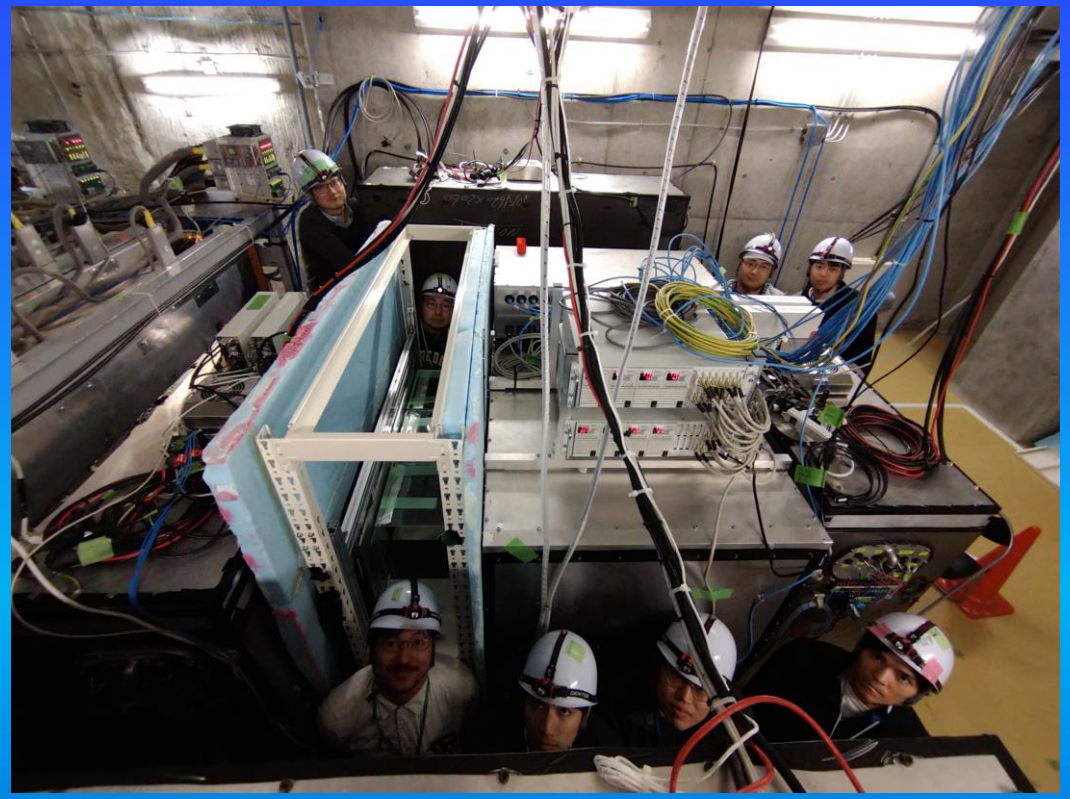
Operation test @B2 floor (Oct. 27th~)



Check of 248 channels

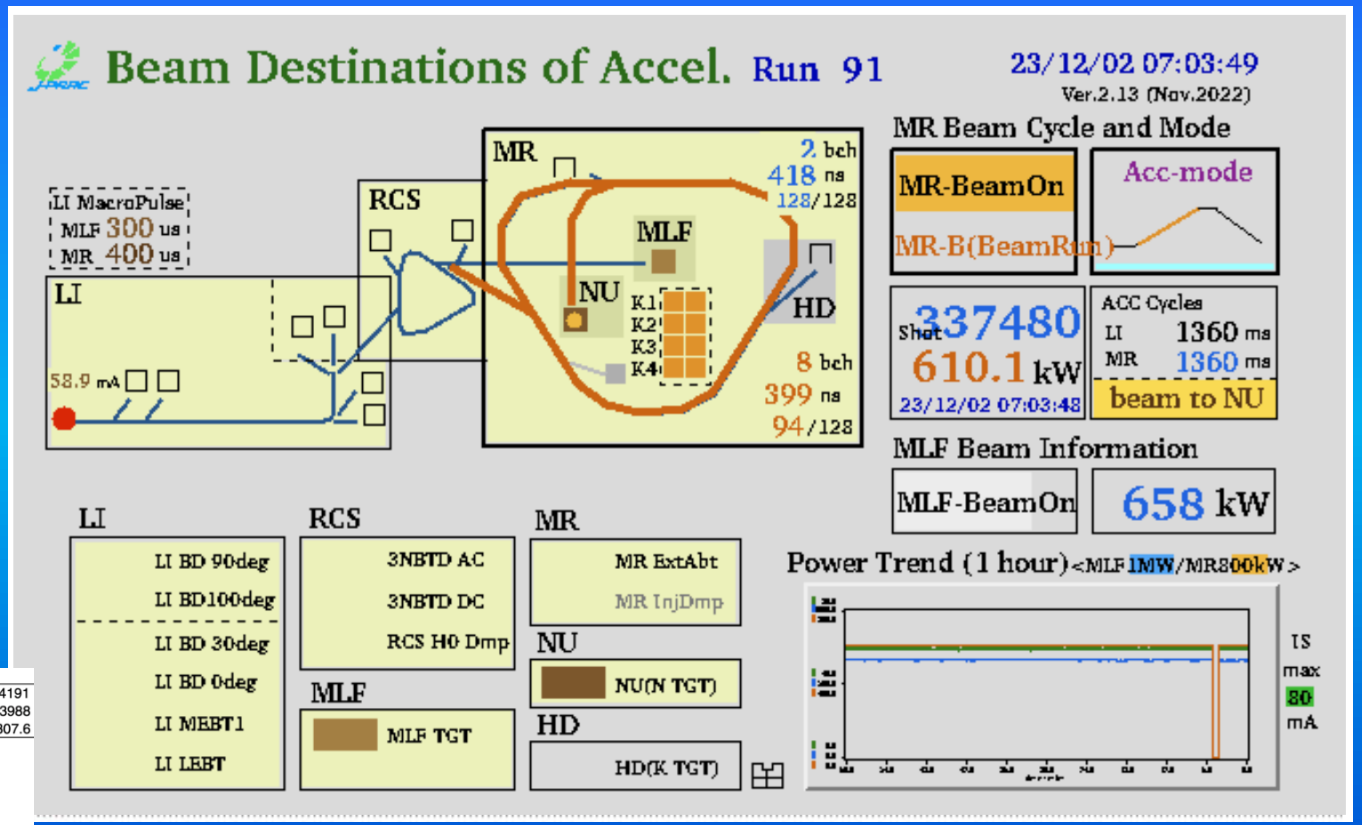


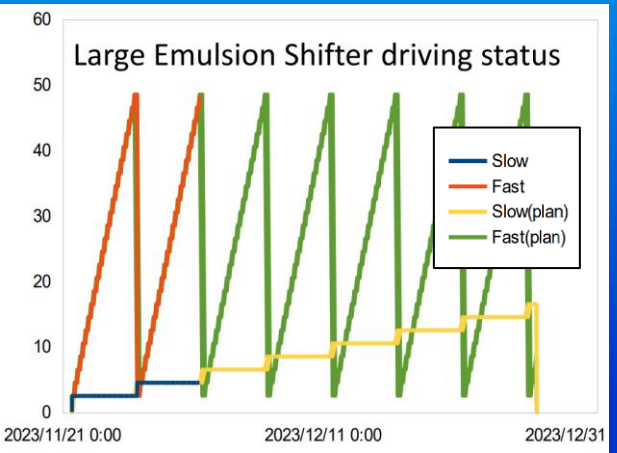
Status of Physics Run(E71b)

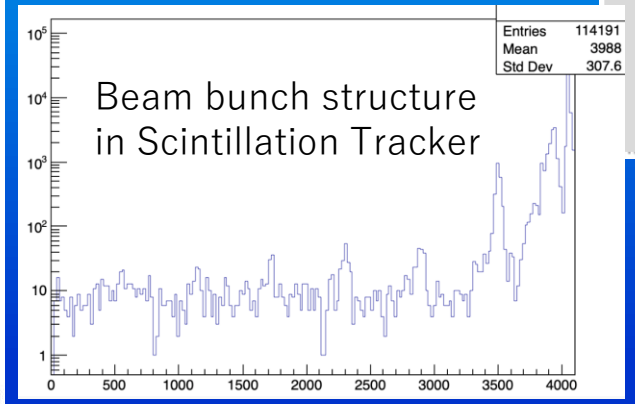


Nov. 20th

Beam exposure status (this morning)







Last week, neutrino beam exposure was started (NINJA 2nd physics run)

Snowmass2021 process at US

NINJA

Snowmass 2021

DPF Community Planning Exercise

Search

- Welcome page
- Announcements
- Snowmass Calendar
- Ethics Guidelines
- Snowmass Report

Organization

- Snowmass Steering Group
- Snowmass Advisory Group
- Frontier Conveners
- APS DPF Snowmass page
- Snowmass Early Career

Snowmass Frontiers

- Energy Frontier
- Neutrino Physics Frontier

Trace: • **start**

Welcome to Snow

The Snowmass Community Plann
COVID-19 pandemic, resumed ful
Community Summer Study Work
https://snowmass21.org/annou
individual frontiers can be found
the activity by signing up to the re
menu if you haven't already done

The Particle Physics Community P
of Particles and Fields (DPF) of the
provides an opportunity for the e
document a scientific vision for th
partners. Snowmass will define th
identify promising opportunities
Snowmass here "How to Snow
Prioritization Panel, will take the s

Snowmass Neutrino Frontier: Neutrino Interaction Cross Sections (NF06) Topical Group Report

Submitted to the Proceedings of the US Community Study on the Future of Particle Physics (Snowmass 2021)

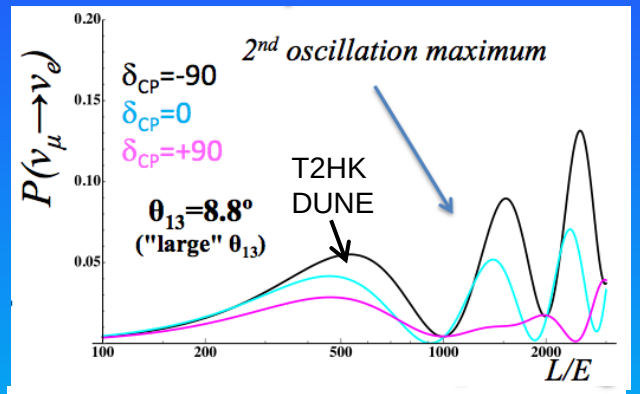
arXiv:2209.06872v1 [hep-ex]

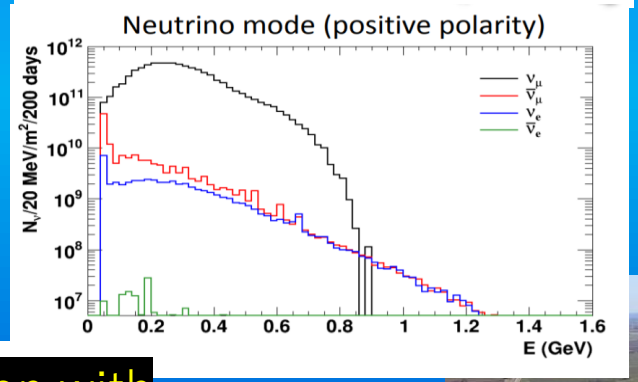
Future prospect: ESS ν SB

ESS Neutrino Super Beam Plus

Co-funded by the European Union

Ultra precision measurement of neutrino oscillation at EU (2037~)





The European Spallation Source neutrino Super Beam Conceptual Design Report

A. Alekou[f,r], E. Baussan[o,**], A.K. Bhattacharyya[j], N. Blaskovic Kraljevic[l], M. Blennow[p,q], M. Bogomilov[n], B. Bolling[l], E. Bouquerel[o], O. Buchan[l], A. Burgman[b,**], C.J. Carlile[e], J. Cederkall[b], P. Christiansen[b], M. Collins[d,j], E. Cristaldo Morales[l], P. Cupial[a], L. D'Alessi[o], H. Danared[l], D. Dancila[t], J. P. A. M. de André[o], J.P. Delahaye[f], M. Dracos[o,*], I. Efthymiopoulos[f], T. Ekelöf[t,*], M. Eshraqi[s,**], G. Fanourakis[d], A. Farricker[s], E. Fernandez-Martinez[k,**], B. Folsom[j,**], T. Fukuda[w], N. Gazis[s,**], B. Gålnander[t], Th. Geralis[d], M. Ghosh[i,u,**], G. Gokbulut[b], L. Halić[l], M. Jenssen[f], A. Kayis Topaksu[b], B. Kildetoft[l], B. Kliček[x,**], M. Kozioł[a], K. Krhač[t], Ł. Łacny[a], M. Lindroos[l], C. Maiano[l], C. Marrelli[j], C. Martins[l], M. Mezzetto[m], N. Milas[l], M. Oglakci[b], T. Ohlsson[p,q], M. Olvegård[r,**], T. Ota[k], J. Park[h,l], D. Patrzalek[l], G. Petkov[n], P. Poussot[o], R. Johansson[l], S. Rosauro-Alcaraz[v], D. Saiang[c], B. Szybiński[a], J. Snamina[a], G. Stavropoulos[d], M. Stipčević[i], R. Tarkeshian[l], F. Terranova[l], J. Thomas[o], T. Tolba[g,**], E. Trachanas[l], R. Tsenov[n], G. Vankova-Kirilova[n], N. Vassilopoulos[e], E. Wildner[f], J. Wurtz[o], O. Zormpa[d], Y. Zou[f]

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[q] The Oskar Klein Centre, AlbaNova University Center, Roslagstullsbacken 21, 106 91 Stockholm, Sweden
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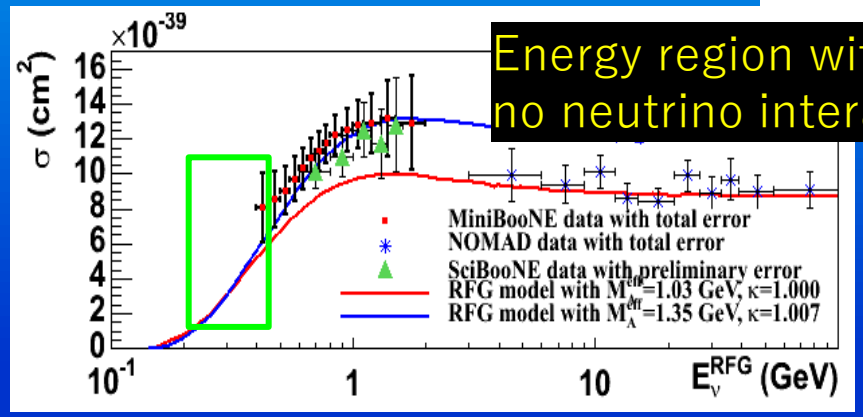
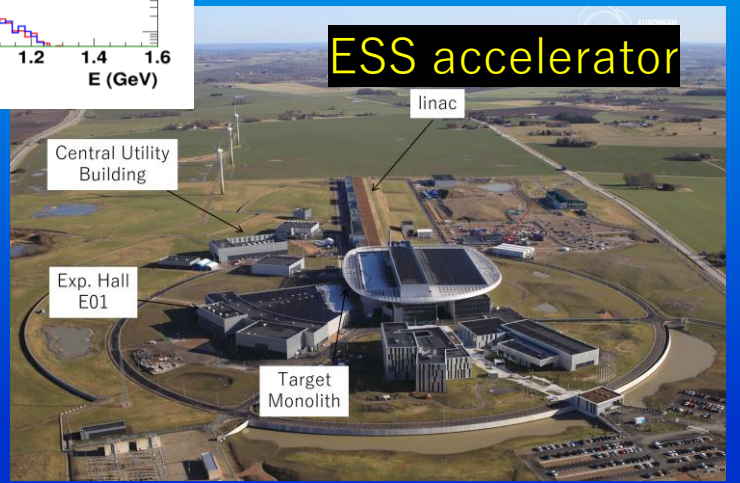
arXiv:2206.01208v1 [hep-ex] 2 Jun 2022

Keywords: ESS, ESSnuSB, Super Beam, neutrino, oscillations, long baseline

Conceptual Design Report
2022. 6/2



Energy region with
no neutrino interaction data!



Future prospect: ESS ν SB

ESS Neutrino Super Beam Plus

Co-funded by the European Union

Ultra-precision measurement of neutrino oscillation at EU (2037~)

NINJA

νIKING

1ton wate
3,000 m²

NINJA type water ECC

Near detectors

European Spallation Source neutrino Super Beam Conceptual Design Report

Kick off meeting at Lund, Jan. 2023

20 Institutes from 11 countries

Proposal Evaluation Form

	EUROPEAN COMMISSION Horizon Europe (HORIZON)	Evaluation Summary Report - Research and innovation actions

Call:	HORIZON-INFRA-2022-DEV-01
Type of action:	HORIZON-RIA
Proposal number:	101094628
Proposal acronym:	ESSnuSBplus
Duration (months):	48
Proposal title:	Study of the use of the ESS facility to accurately measure the neutrino cross-sections for ESSnuSBplus leptonic CP violation measurements and to perform sterile neutrino searches and astroparticle physics
Activity:	HORIZON-INFRA-2022-DEV-01-01

European Commission

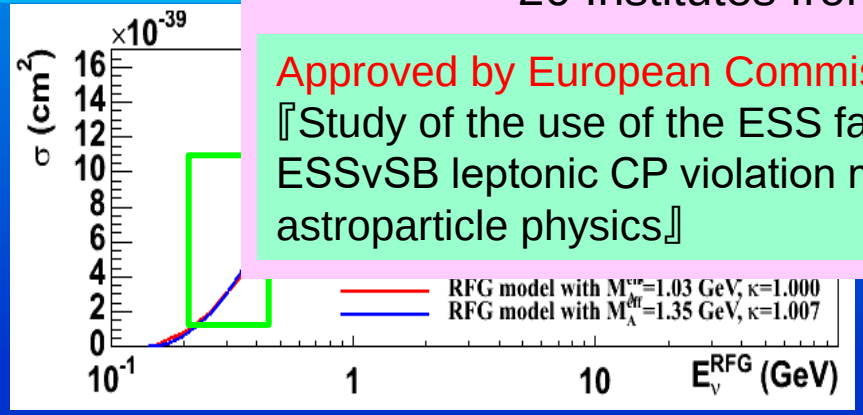
FUNDING & TENDERS PORTAL E-RECEIPT

Digitally sealed by the European Commission
Date: 2022.07.18 12:51:08 CEST

Approved by European Commission
『Study of the use of the ESS facility to accurately measure the neutrino cross-sections for ESSvSB leptonic CP violation measurements and to perform sterile neutrino search and astroparticle physics』

ign Report
2022. 6/2

detector site



Future prospect: ESS ν SB

ESS Neutrino Super Beam Plus

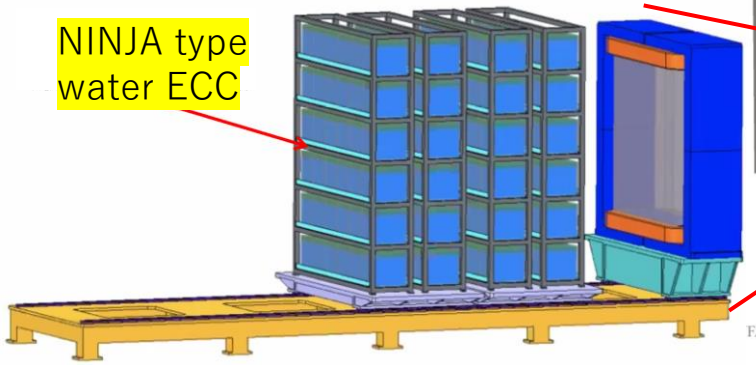
Co-funded by the European Union

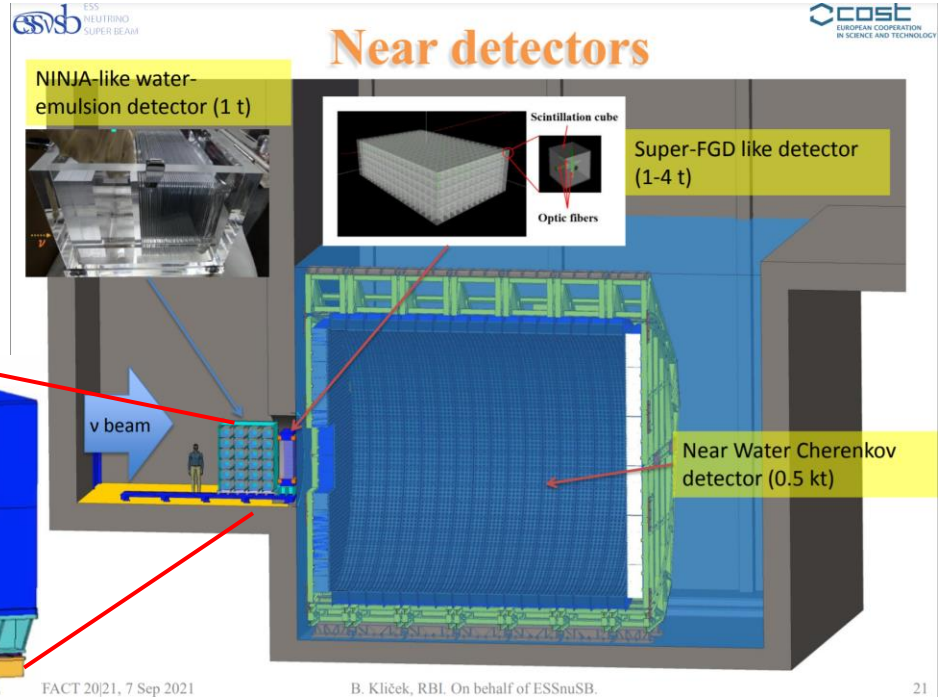
Ultra-precision measurement of neutrino oscillation at EU (2037~)

NINJA

ν IKING detector

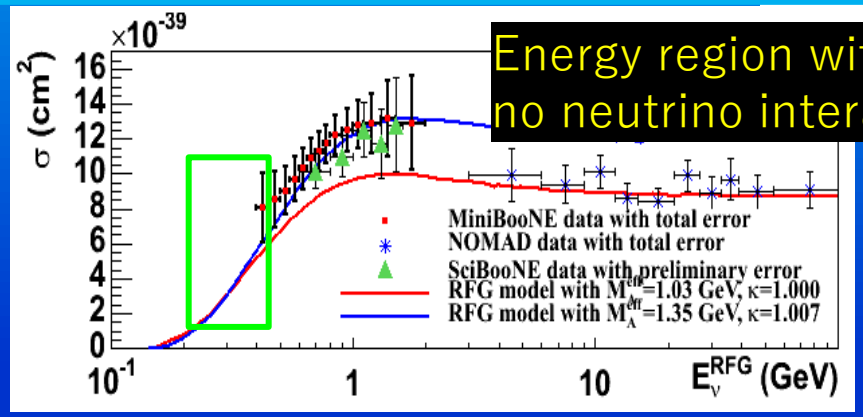
1ton water target
3,000 m^2 x 5times/10years





European Spallation Source neutrino Super Beam Conceptual Design Report

Conceptual Design Report
2022. 6/2



Energy region with
no neutrino interaction data!

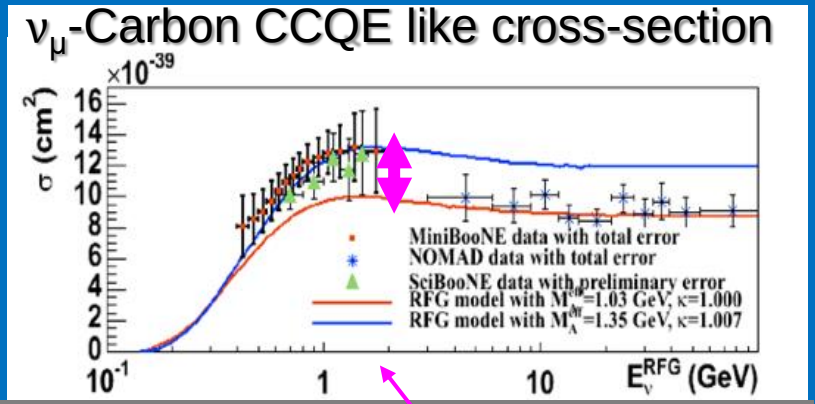
ESS accelerator

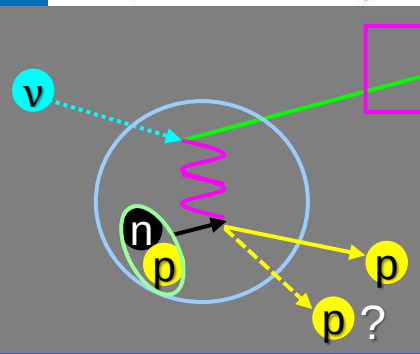
Summary

- Precise measurement of neutrino-water interactions is important for future neutrino oscillation analysis (especially, CC2p2h and ν_eCC) and proton information is key to improving the neutrino-nucleus interaction model.
- NINJA has introduced nuclear emulsion to study low-energy neutrino interactions for this purpose.
- The results of neutrino and anti neutrino-iron interactions were reported. We found a discrepancy between data and MC in backward pion production.
- The analysis of the physics run (E71a) is ongoing and we will open the full data set, corresponding to 4.8 x 10^{20} POT near future.
- The 2nd physics run (E71b) is just started.
- A new experiment using heavy water ECC is being proposed.
- NINJA-type water ECC will be installed as a ND of ESSνSB project.

Back up

Neutrino multi-nucleon interaction



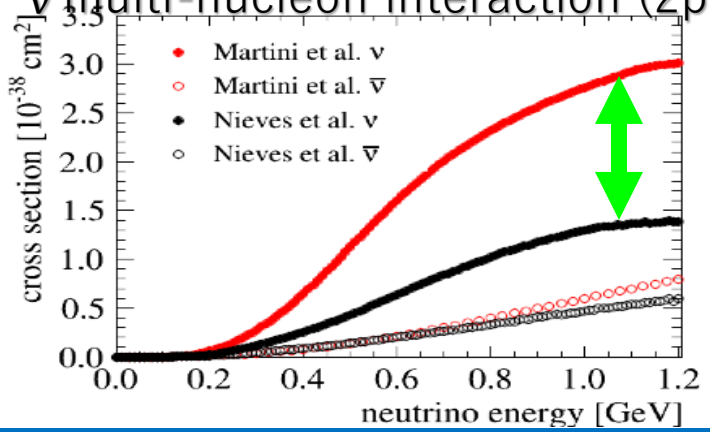


Only μ measurement

CCQE-like event is NOT CCQE event.
Contamination from unknown interaction?

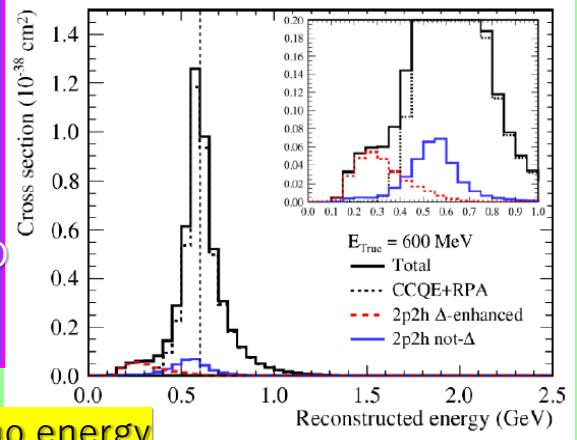
Detected in electron scattering experiment.
→ in case neutrino scattering?
Can explain the excess of CCQE-like event?

Theoretical prediction of cross-section of ν multi-nucleon interaction (2p2h)

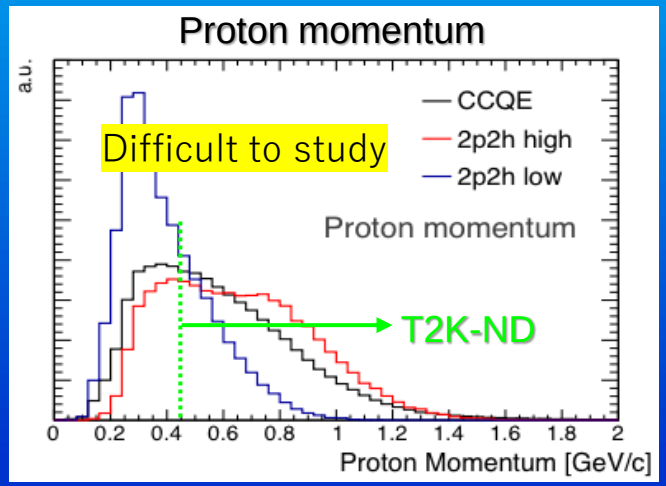


CCQE: $\nu_\mu + n \rightarrow \mu^- + p$

2p2h: → 2 body reaction
2proton emission
$\nu_\mu + (n, p) \rightarrow \mu^- + p + p$
→ 3 body reaction



→ wrong reconstruction of neutrino energy



Future prospect ：D_2O target

There is a discussion to further understand ν-nucleus interactions, the study of ν-nucleon interactions is important.

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Neutrino Scattering Measurements on Hydrogen and Deuterium: A Snowmass White Paper

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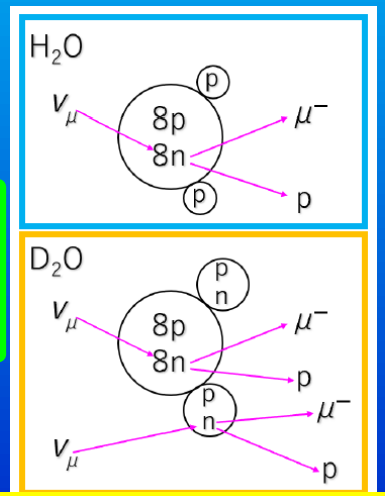
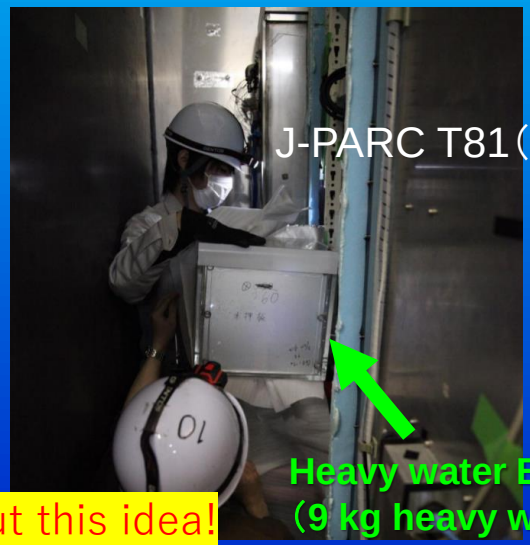
arXiv:2203.11298 [hep-ex].

→ Development of a bubble chamber is being considered in US.

In NINJA, by introducing a heavy water target, we are developing a method to study ν-nucleon interactions by analyzing the subtraction between a heavy water events and a water events.

Conceptual principle:
$(\nu\text{-}D_2O) - (\nu\text{-}H_2O) \rightarrow (\nu\text{-}n)$





→ Actually, a heavy water ECC was produced in T81.
So, technically feasible.

We would like to discuss about this idea!