The event analysis in NINJA experiment

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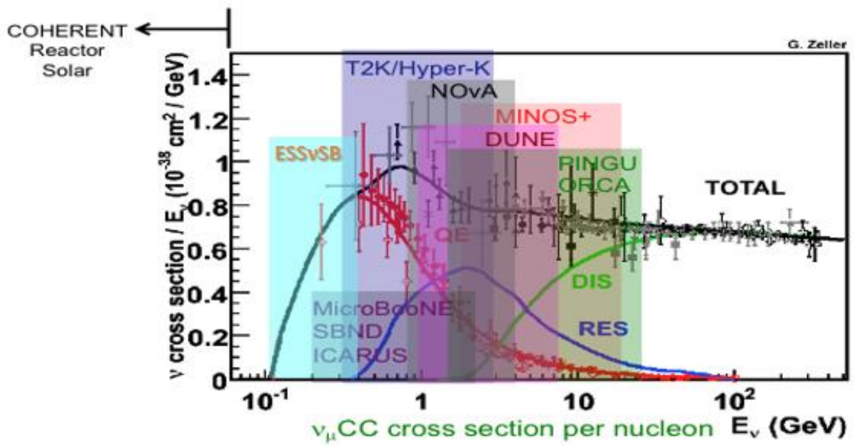
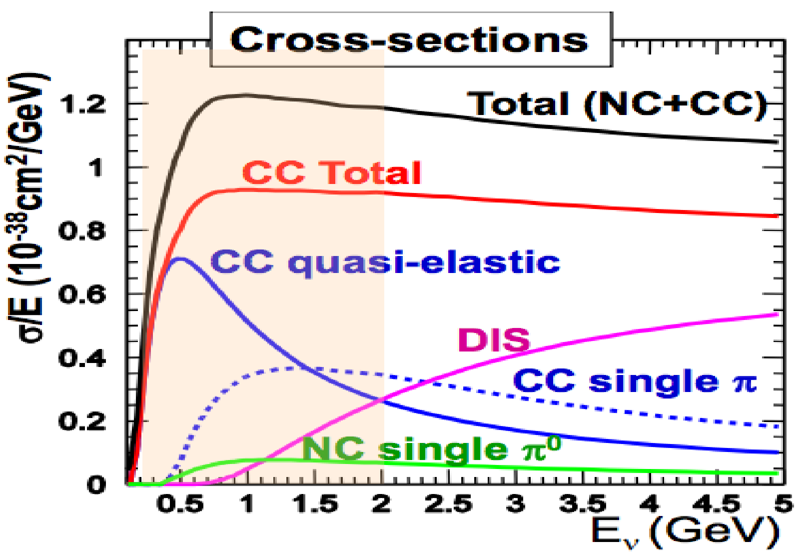
on behalf of the NINJA Collaboration

新学術領域「ニュートリノで拓く素粒子と宇宙」研究会, 8th Mar. 2022

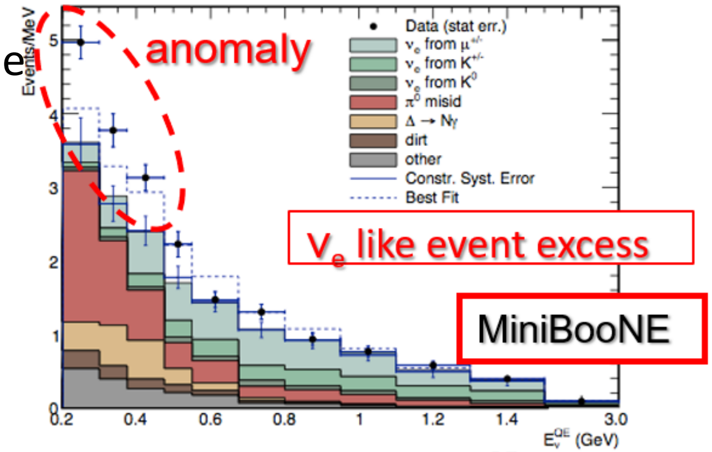
Neutrino physics on sub-multi GeV

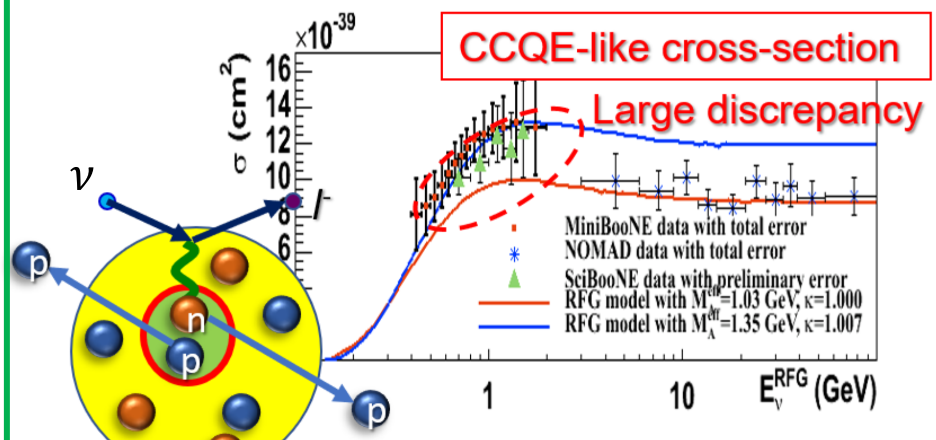
Current and future neutrino oscillation experiments are in this energy region





One of the cause is Sterile neutrino.

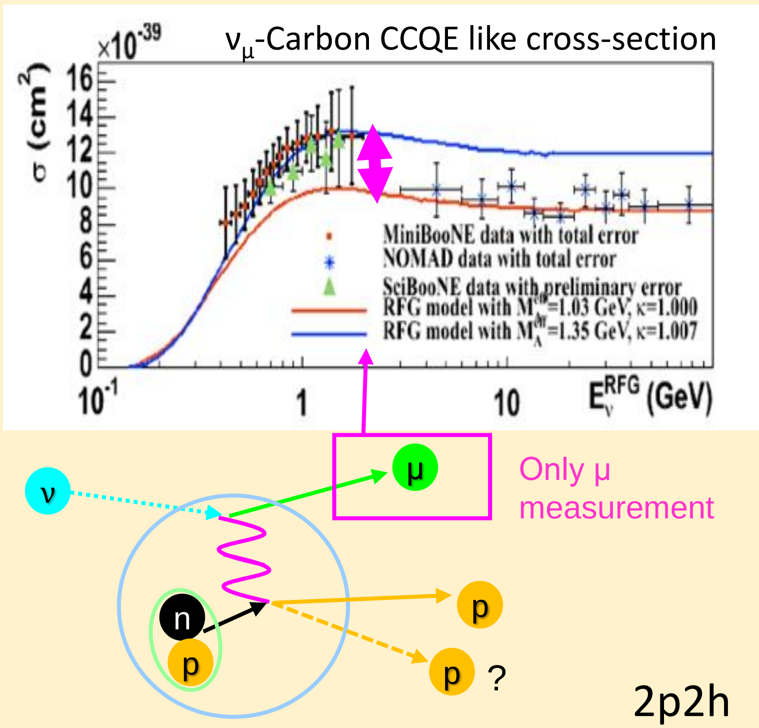




ν multi-nucleon interaction?

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

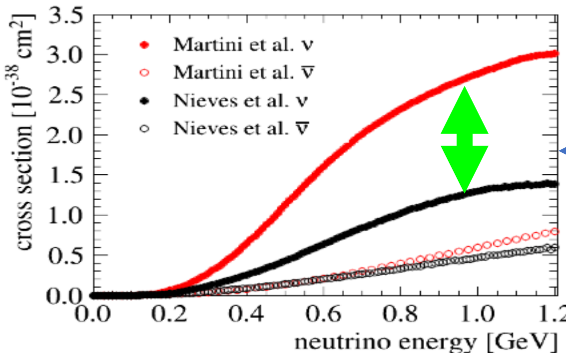
Neutrino multi-nucleon interaction



Detected in electron scattering experiment.

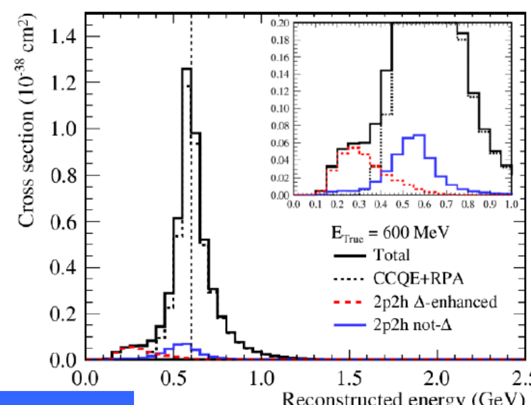
→ in case neutrino scattering?

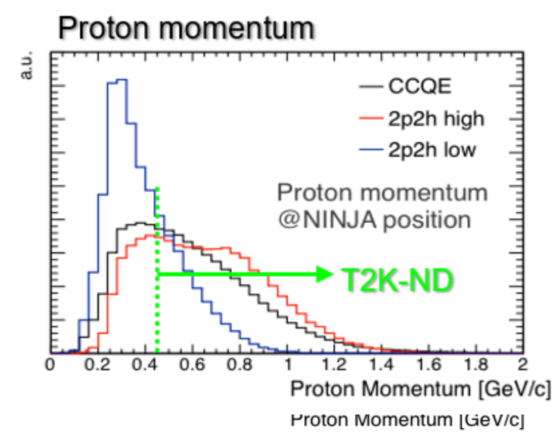
Can explain the excess of CCQE-like event?



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

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





CCQE: $\nu_\mu + n \rightarrow \mu^- + p$ → 2 body reaction

2p2h: 2proton emission

$\nu_\mu + (n, p) \rightarrow \mu^- + p + p$ → 3 body reaction

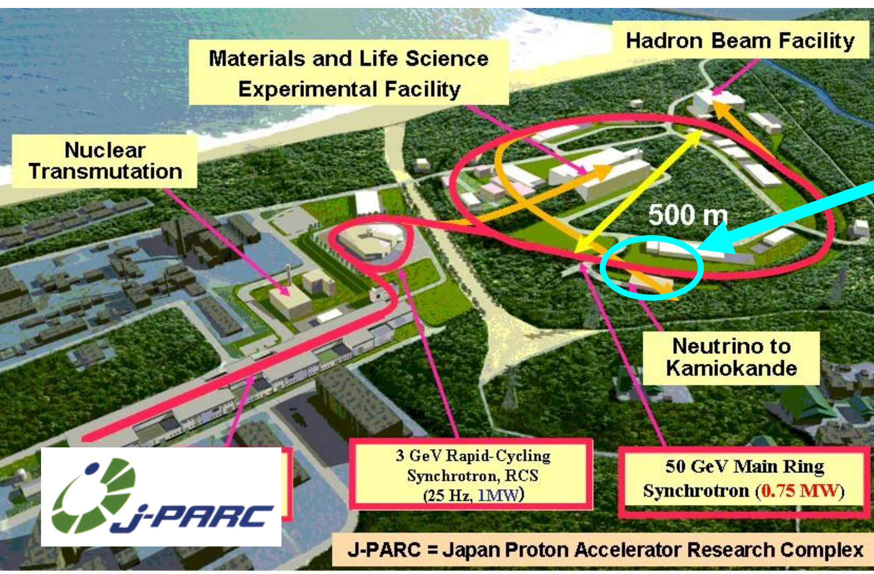
→ wrong reconstruction of neutrino energy

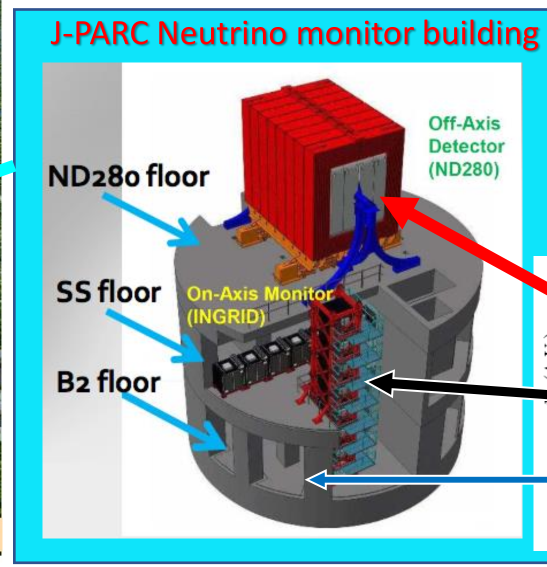
NINJA Experiment

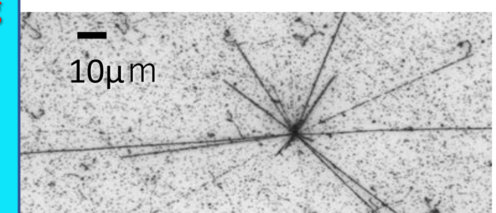
Neutrino Interaction research with Nuclear emulsion and J-PARC Accelerator

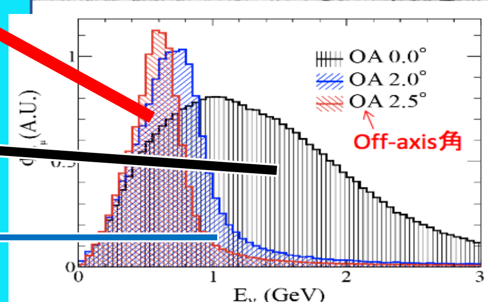
- Precise measurement of neutrino-nucleus cross-sections in Sub-Multi GeV ν_μ
- Electron neutrino cross-section measurement
- Sterile neutrino search

50 researchers from 10 institutions





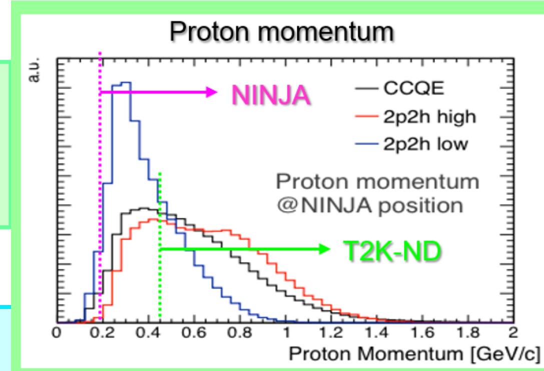


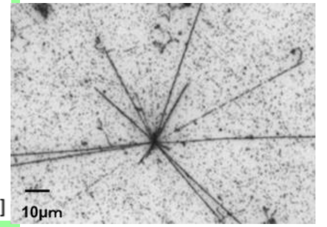


Merits using nuclear emulsion

- Low energy hadron measurement

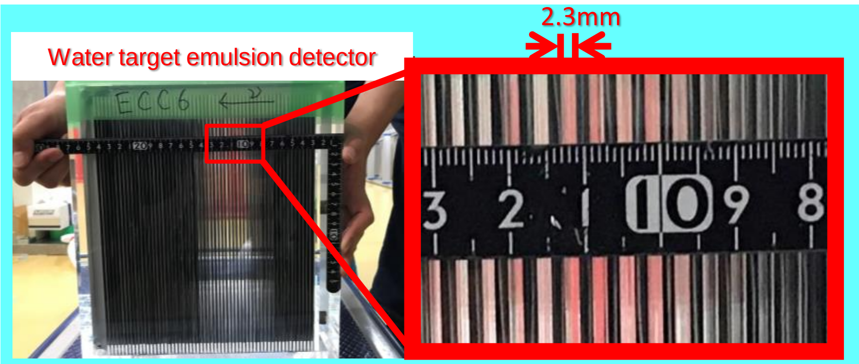
  ← difficult to measure so far



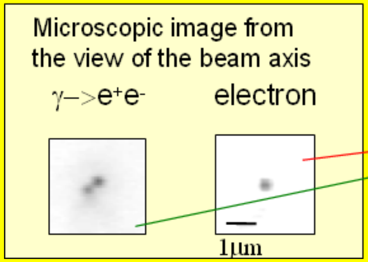


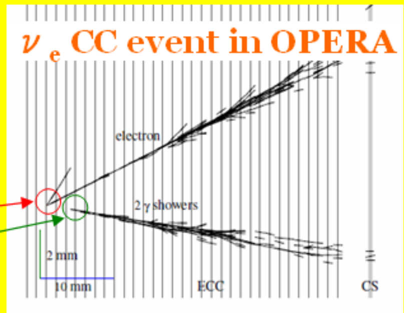
- Neutrino-water interactions

  ← same target as the large water Cherenkov detector



γ / electron ID





Low BG from ν_μ NC π^0 production

- Low background for $\boldsymbol{\nu}_e$ measurement

  ← clear verification of sterile neutrino

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

NINJA ROADMAP

Pilot RUN

Feasibility study
at J-PARC

Detector RUN

Detector performance check

Target mass: 1- 60kg

J-PARC
T60/T66/T68/T81

Physics RUN Ⅰ

Neutrino-nucleus
interaction study

Target mass: 200-300kg

Now
(E71)

Physics RUN Ⅱ

Search for sterile neutrino

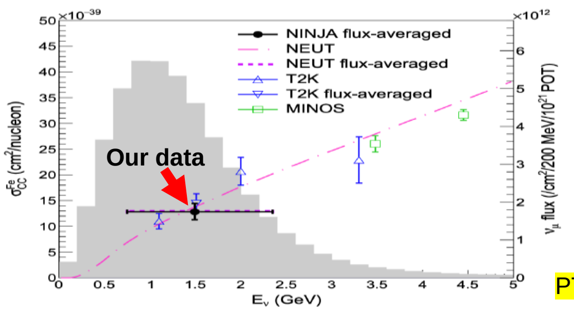
Target mass: 1- 3ton
Target mass: 6-10ton

Currently, Physics Run I is underway.

Results of Detector Run (T60)

ν_μ-Iron CC inclusive cross-section and detailed information was reported.

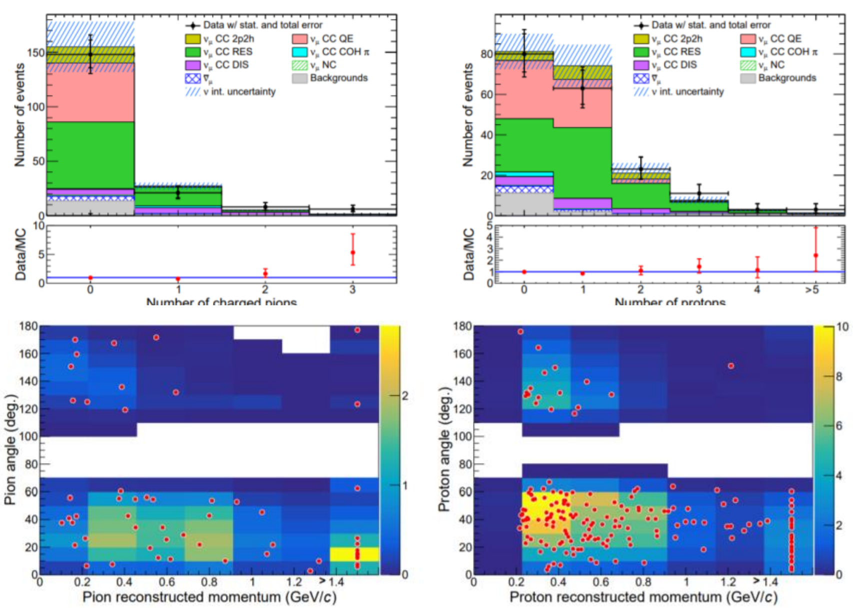
Cross-section measurement



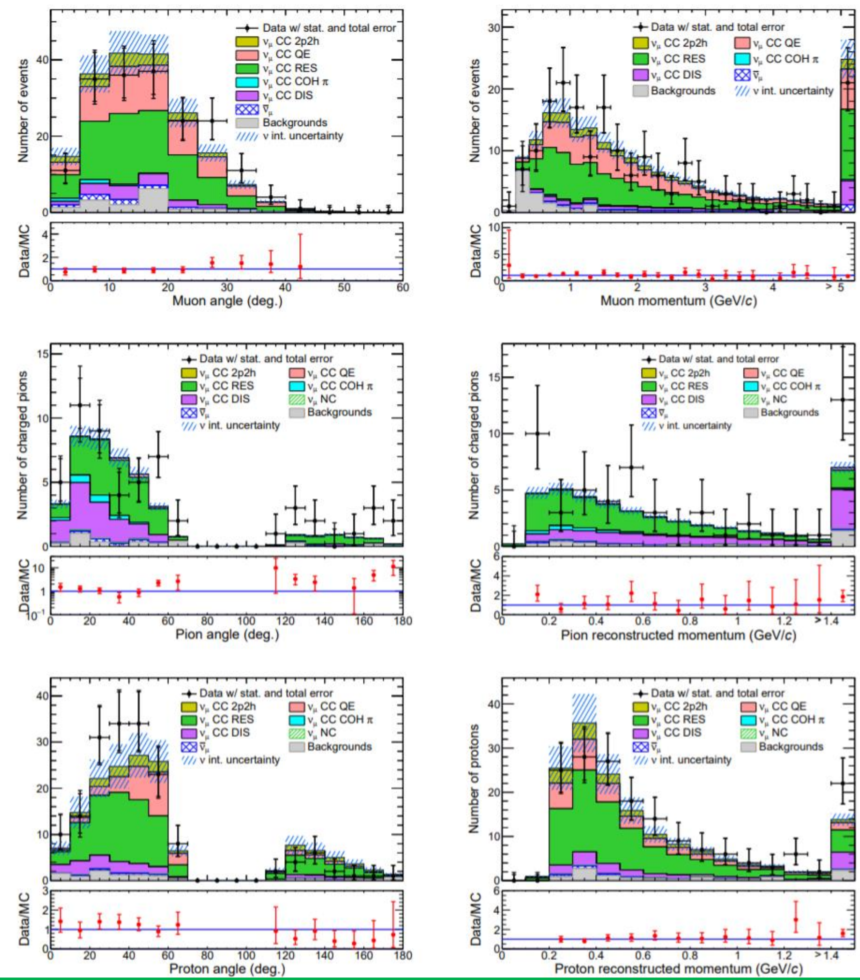
H. Oshima et al.,
PTEP 2021,033C01 (2021)

183 CC events in 65kg iron target ECC

Observed protons and charged pions data



Emission angle and momenta



Physics Run (E71a)

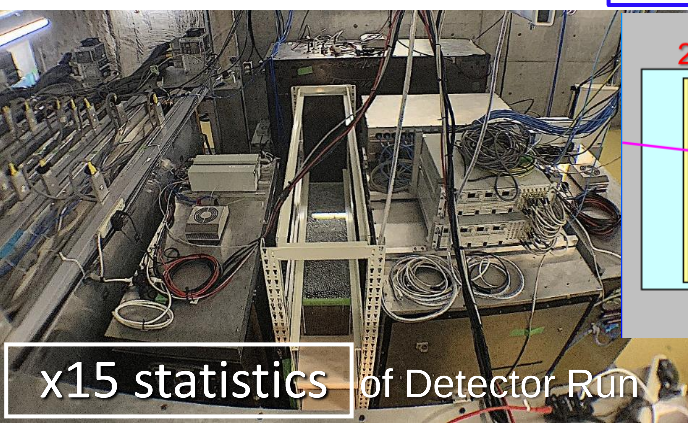
- First measurement of ν-multi nucleon interactions
- Exclusive cross-section measurement of ν_μ-water interactions

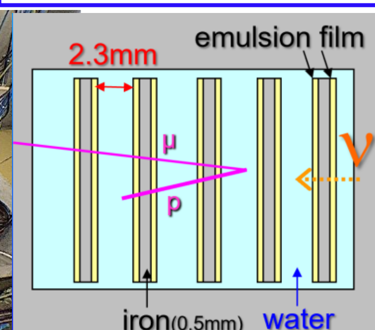
Neutrino beam :
Nov. 2019-Feb. 2020
Total POT : 4.8×10^{20}

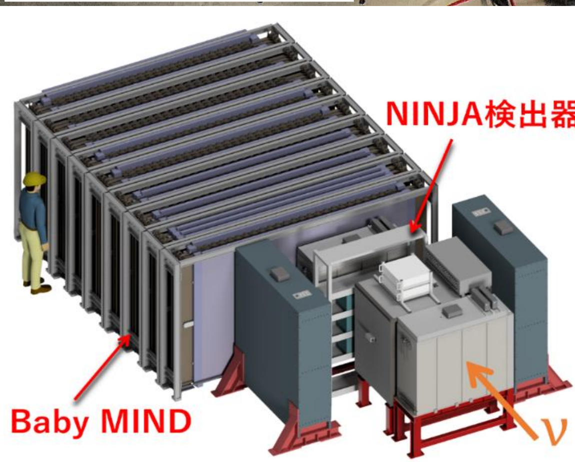
250kg Target
Film 130m^2

H_2O :	75kg
Fe :	130kg
CH :	15kg
emulsion gel :	30kg

→ 5,000 events

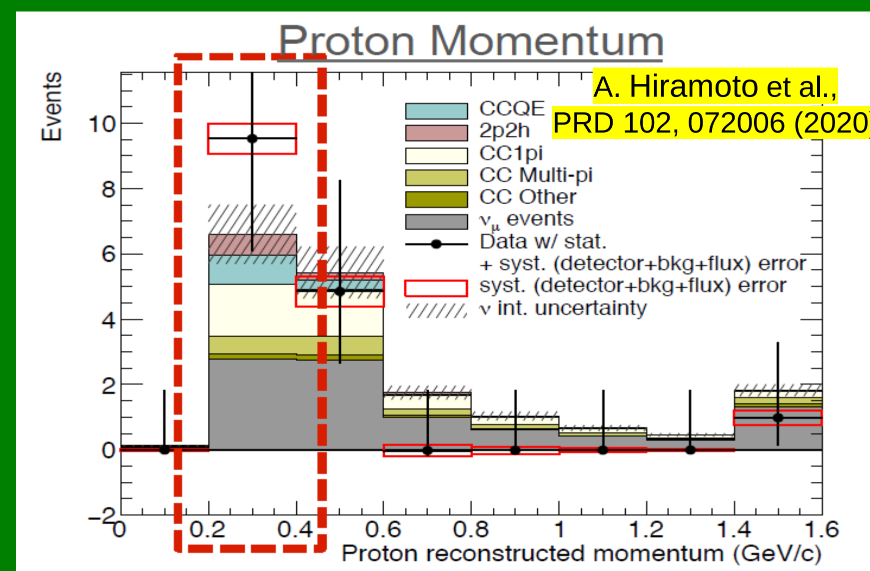






Sandwich structure of the frame type acrylic spacer and emulsion trackers

Detection of low energy protons from ν-water CC interactions at Detector Run (T68)

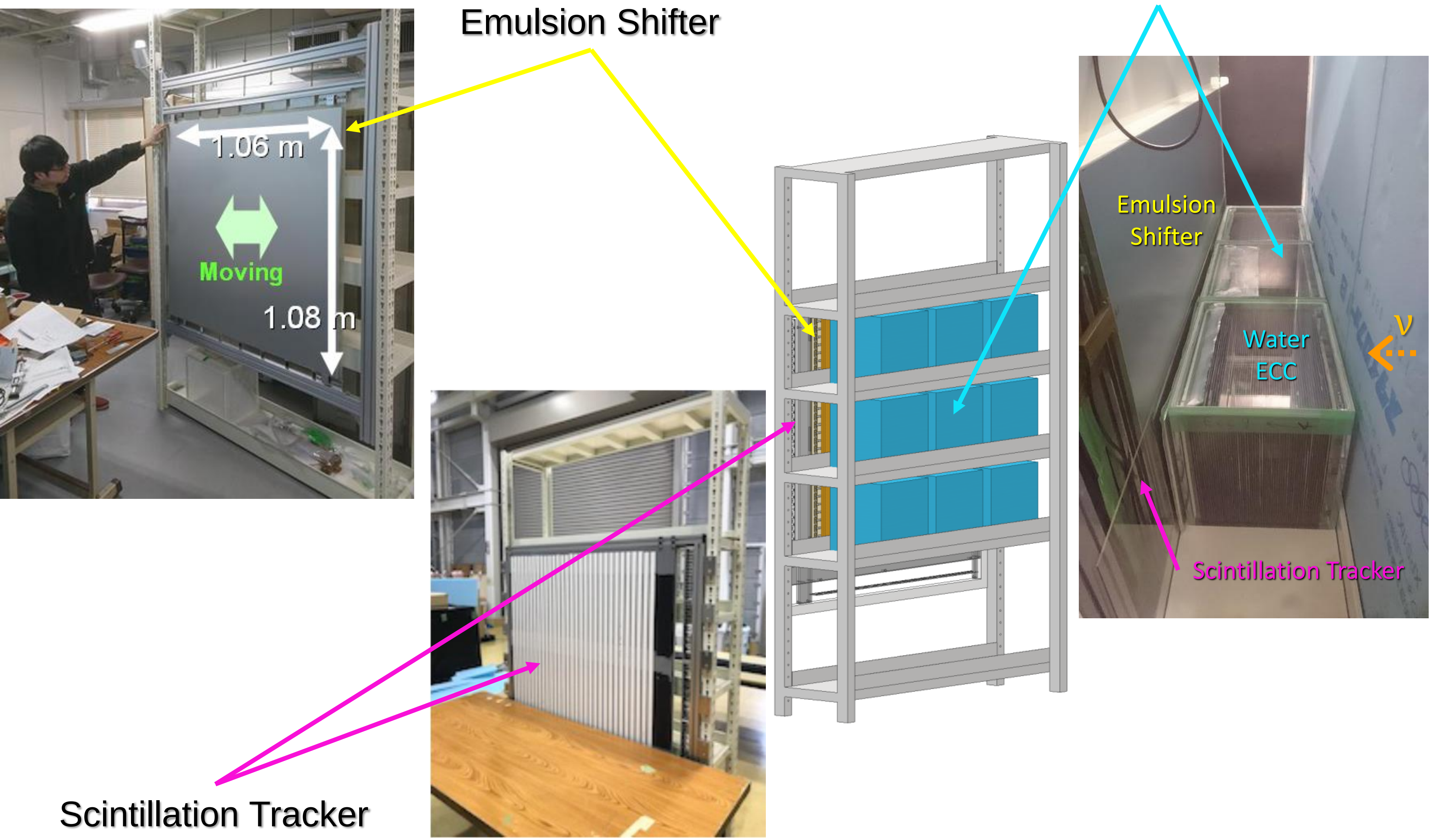


2021年度 高エネルギー物理学奨励賞
2022年 日本物理学会若手奨励賞

NINJA detector (E71a)

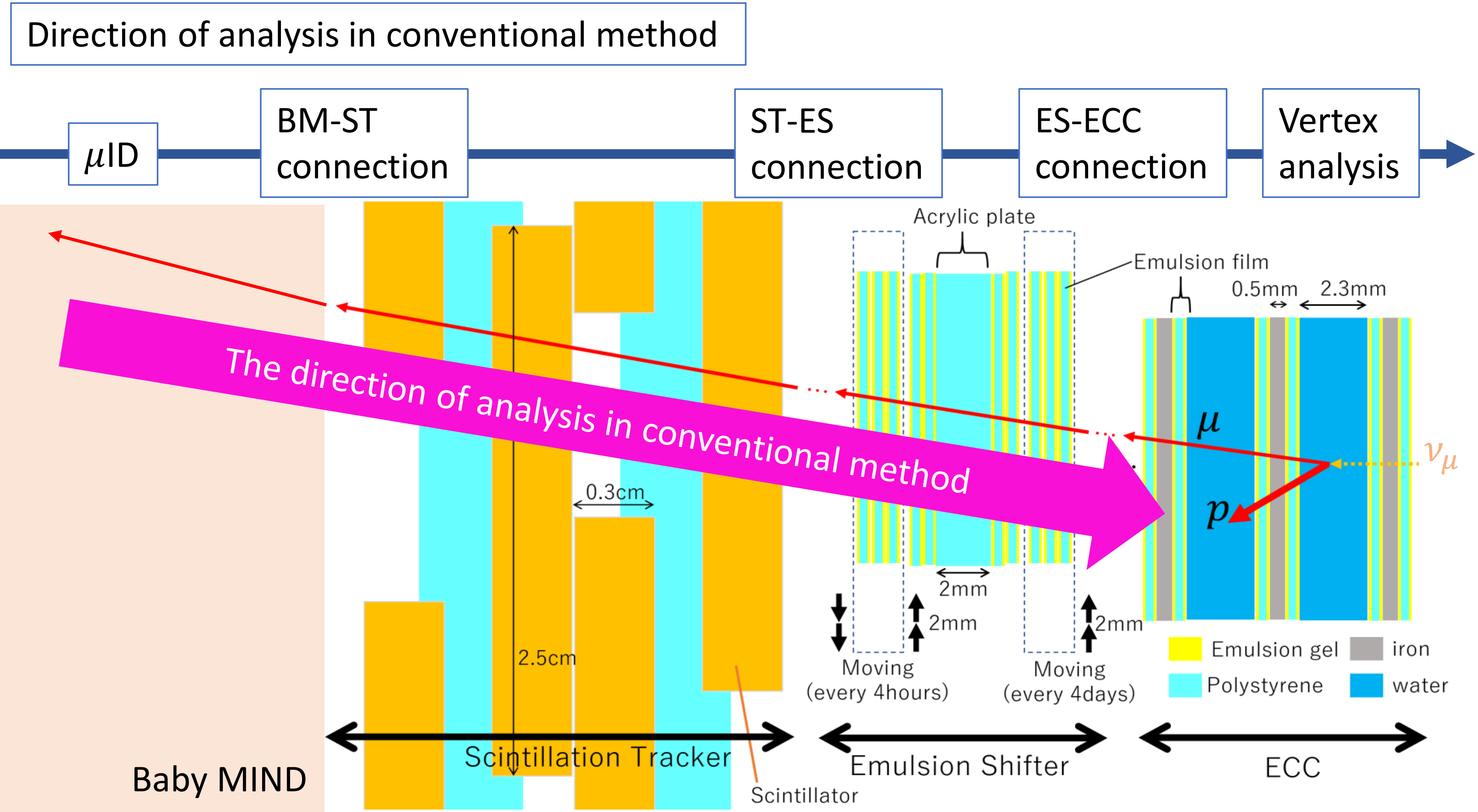
Water ECC

※ ECC(Emulsion Cloud Chamber)



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

NINJA detector (E71a)



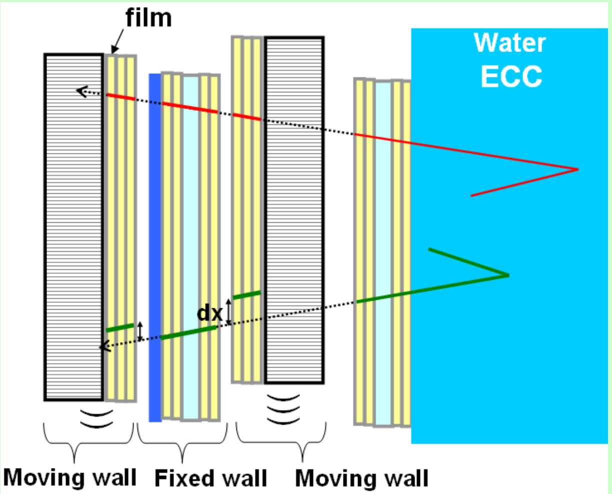
Target :

- Water 75kg (1,200 ν_μCC events)
- Iron 130kg
- CH 15kg
- Emulsion 30kg

Emulsion Shifter

H.Kawahar (Nagoya Univ.)

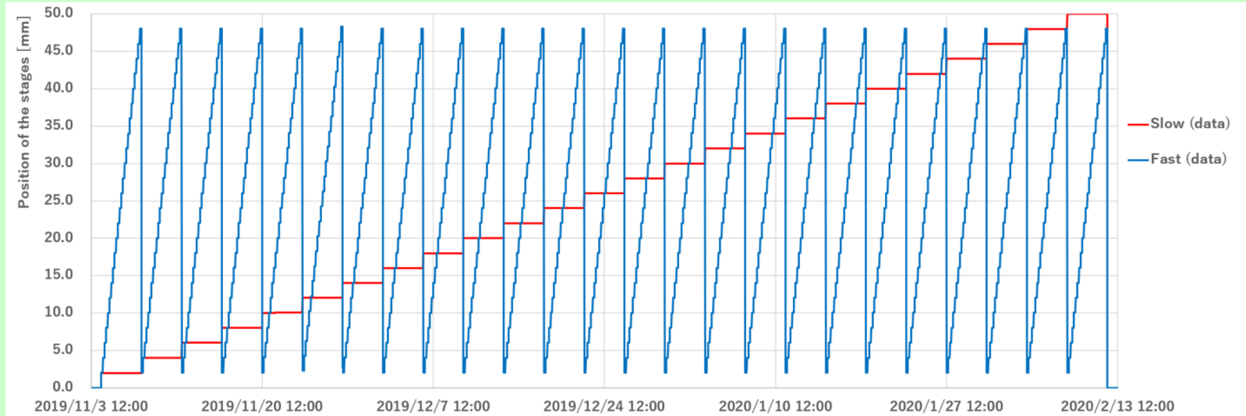
4 films are used for a wall of emulsion shifter



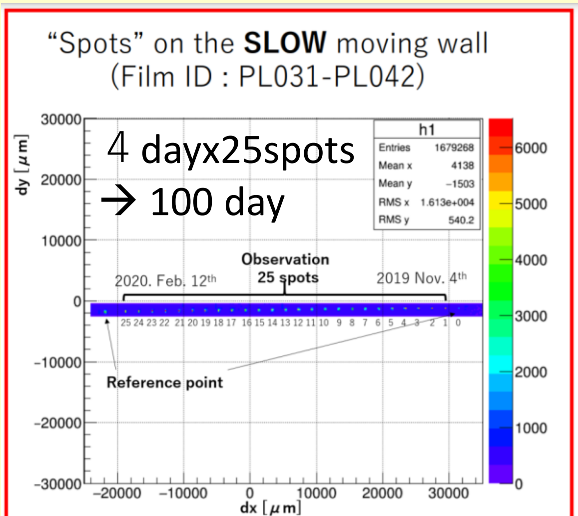
4 hour/step

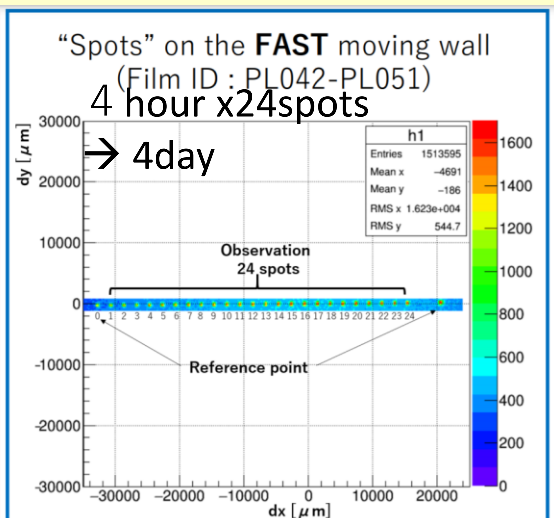
4 day/step

Operation of the Emulsion Shifter → Stable



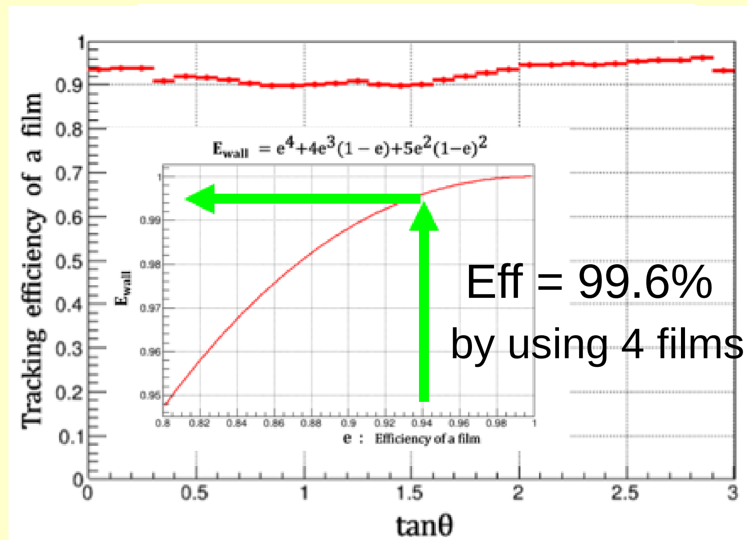
Each spot corresponds to the time information.





Position difference between Moving wall and Fixed wall

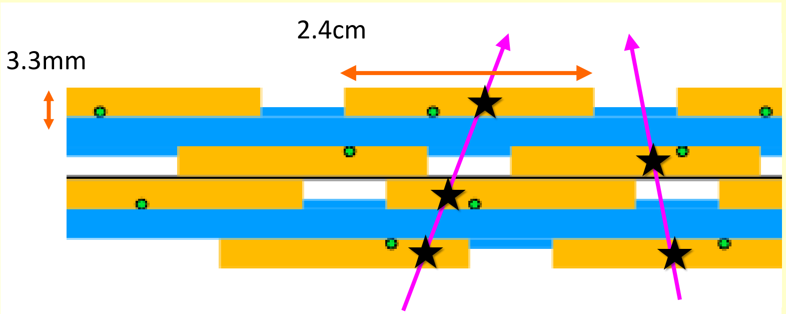
Tracking efficiency （angle dependence）
for one film

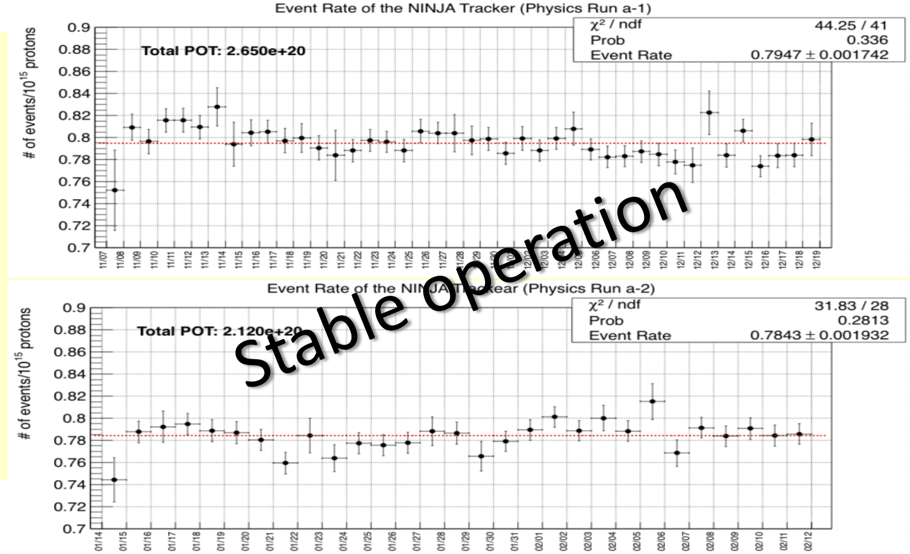


T. Odagawa (Kyoto Univ.)

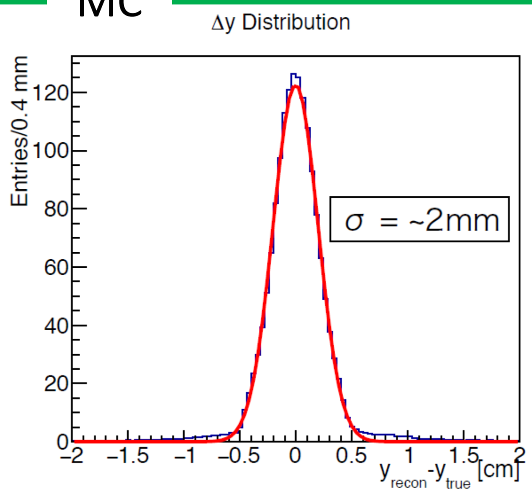
Scintillation Tracker

↓Operation result during neutrino beam exposure



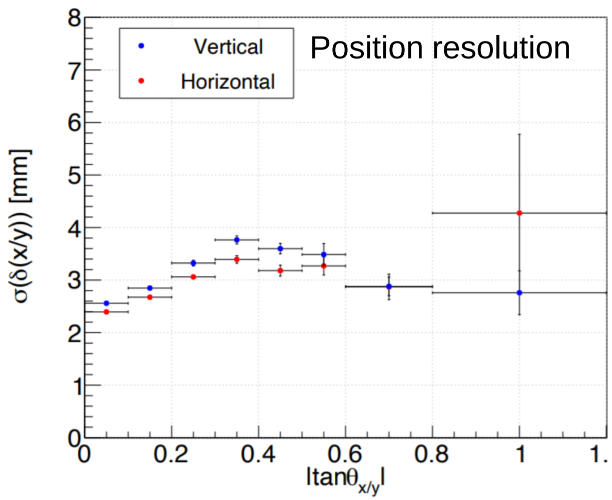


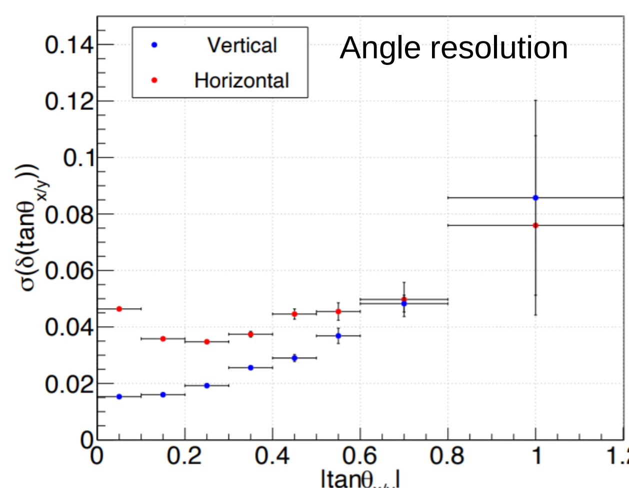
MC



Position resolution of Scintillation Tracker for straight tracks

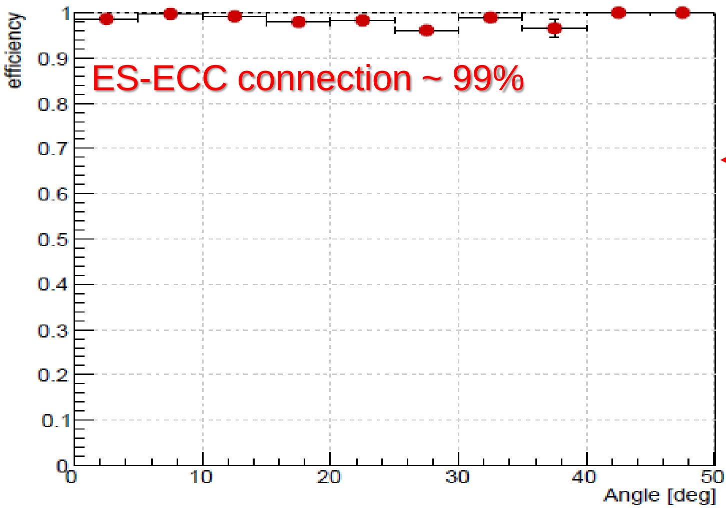
DATA

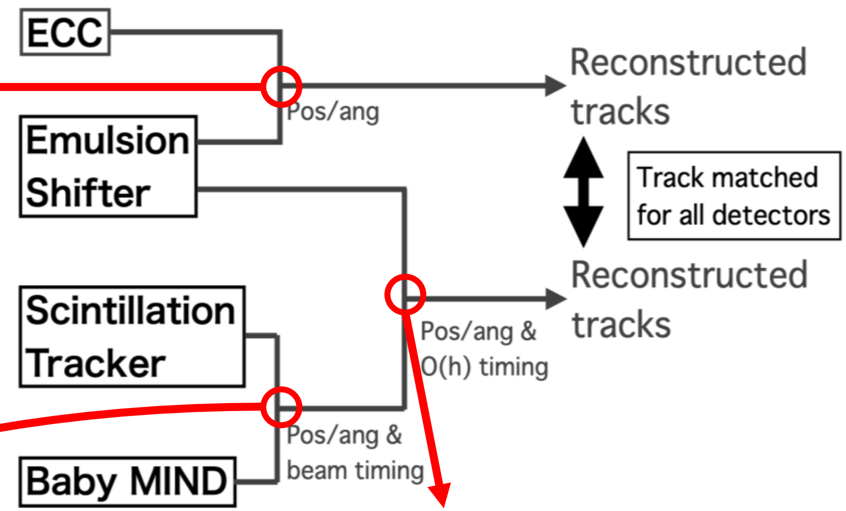


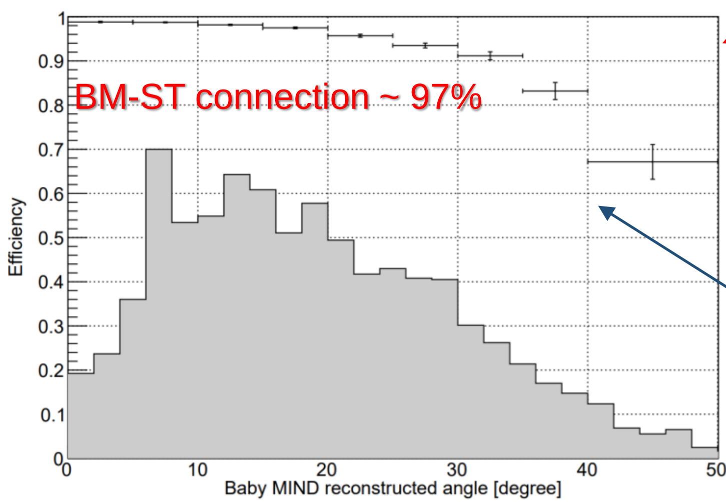


The performance (position and angle resolution) of the Scintillation Tracker was as expected.

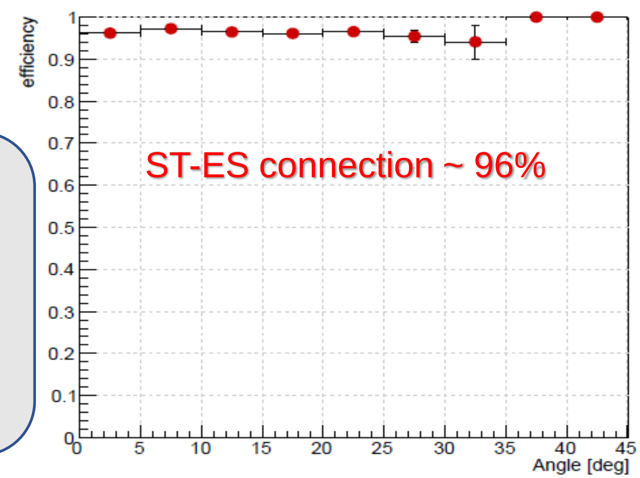
Track matching efficiency







Connection efficiency in large angle can be recovered by using a loosen selection

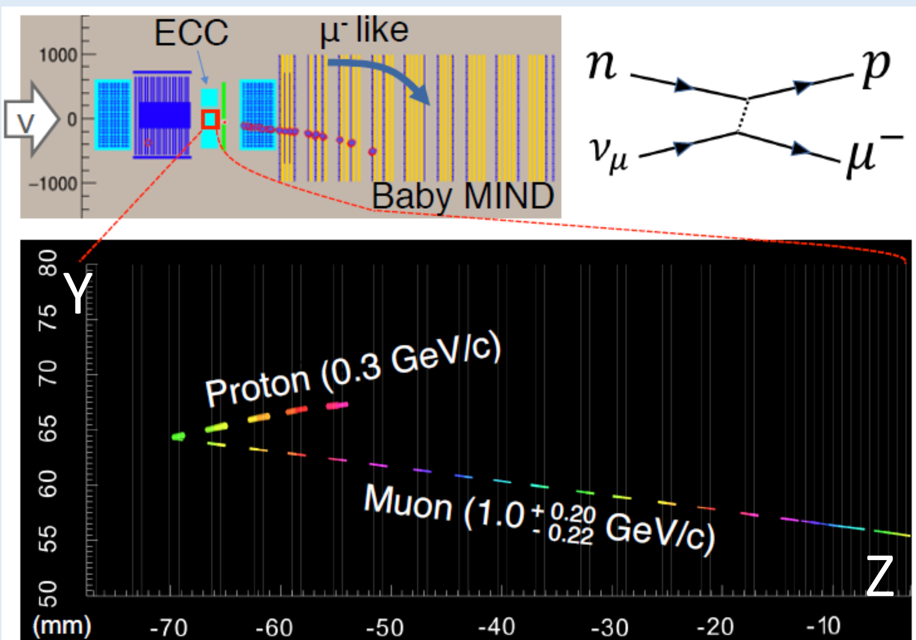


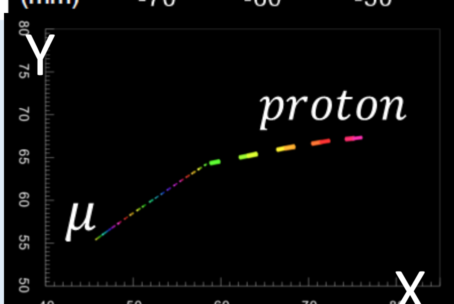
High detection and connection efficiencies have been achieved at each stage.

Detected neutrino events

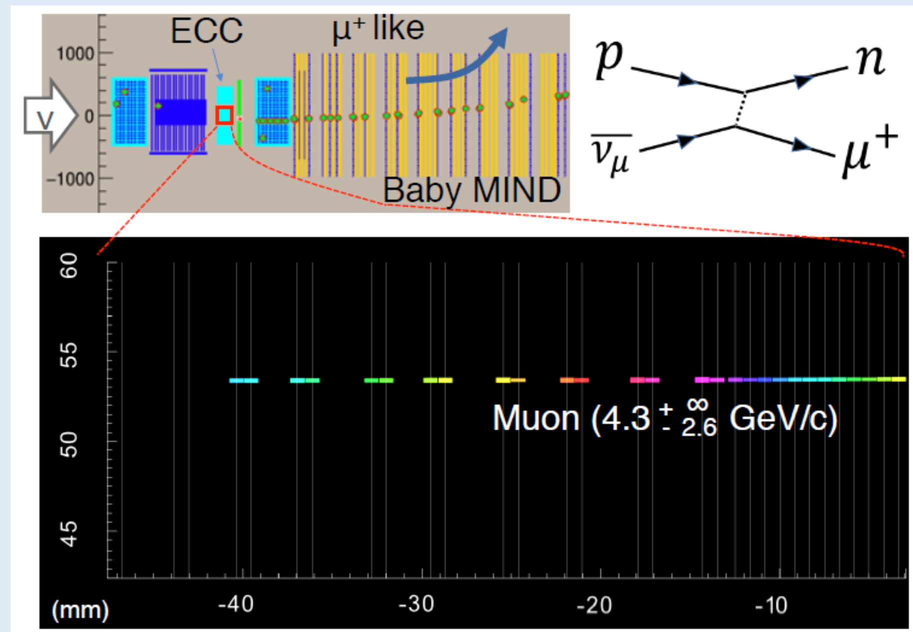
ECC – Emulsion Shifter – Scintillation Tracker – Baby MIND worked well and succeeded in μID and measuring their charge.

Neutrino event



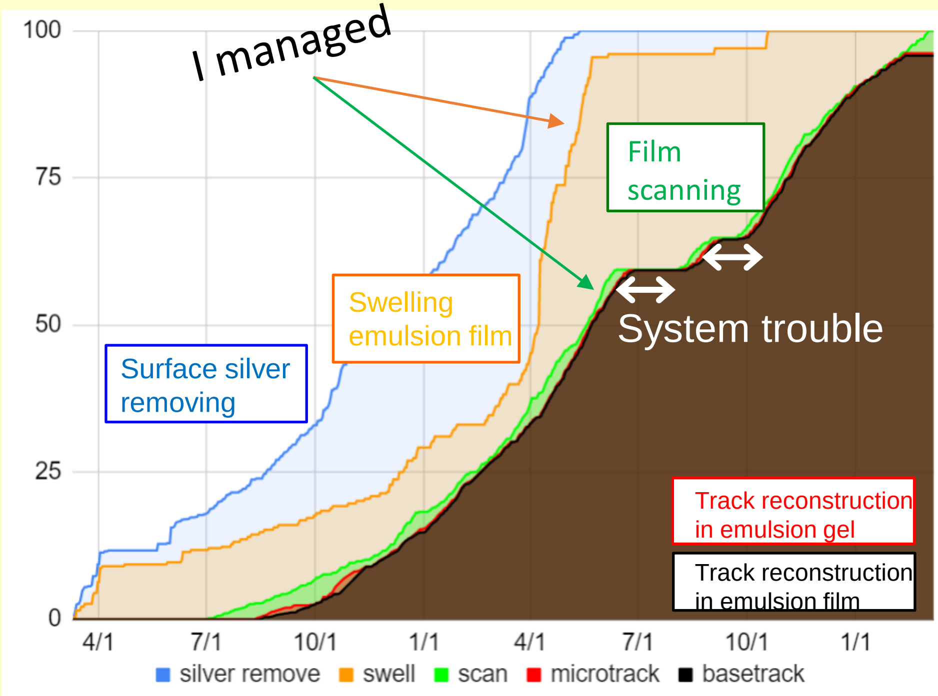


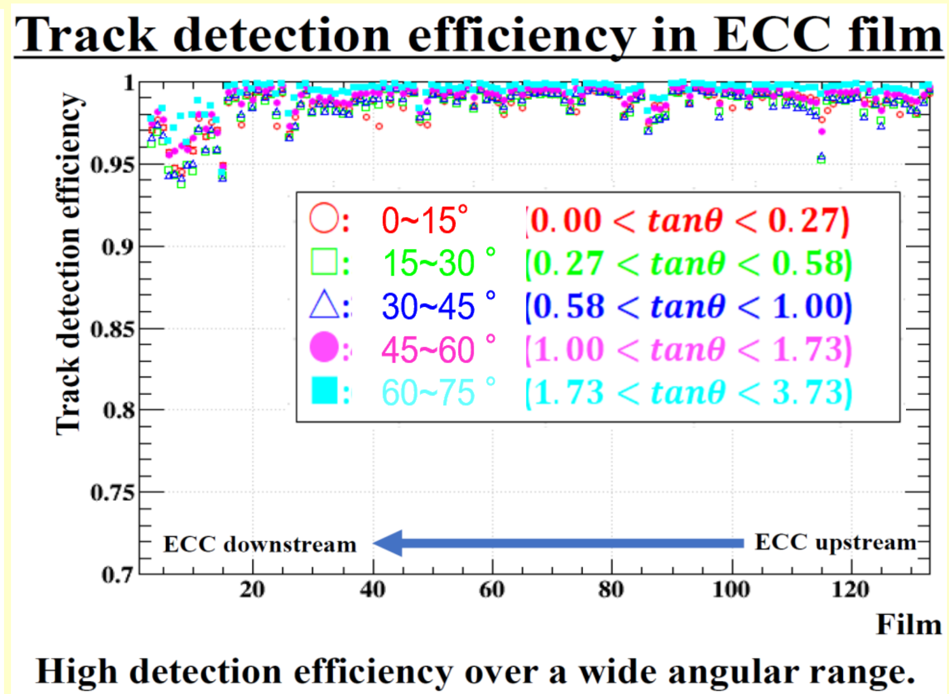
Anti neutrino event



The event pictures (number of protons) in ECC and the μ charge measured by Baby MIND are consistent.

Emulsion scanning status





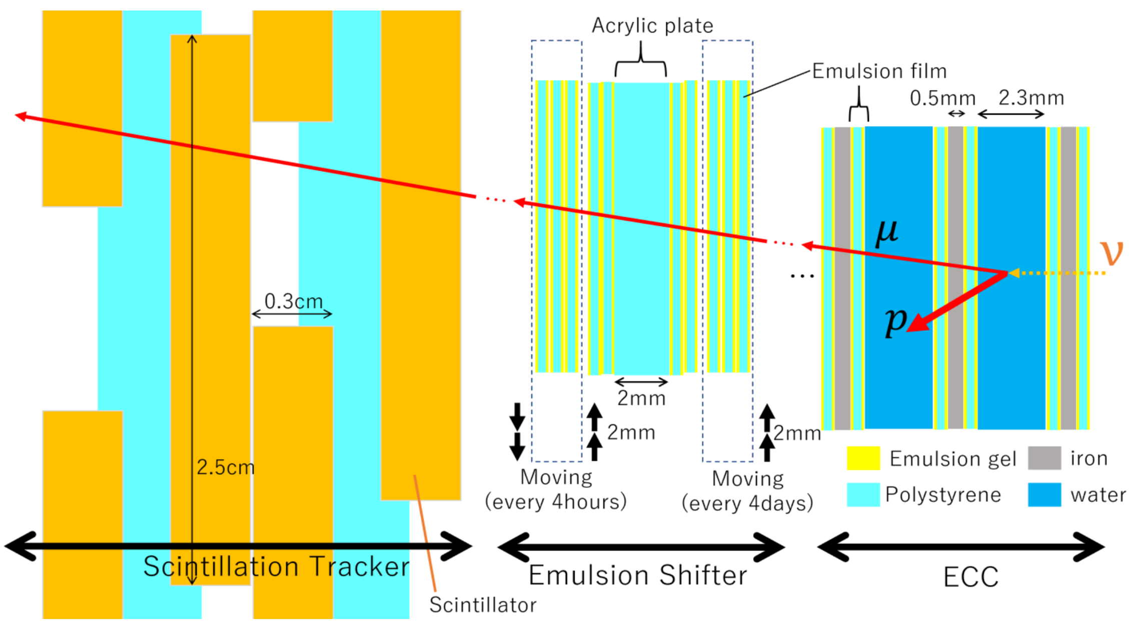
- Emulsion scanning was completed.
  → First result will be shown in this summer.
- Emulsion data taking is progressing as planned except for the effect from COVID-19 in 2020 and the hardware troubles of the scanning system that occurred last year.
- Tracking efficiency is sufficiently high.

Event analysis

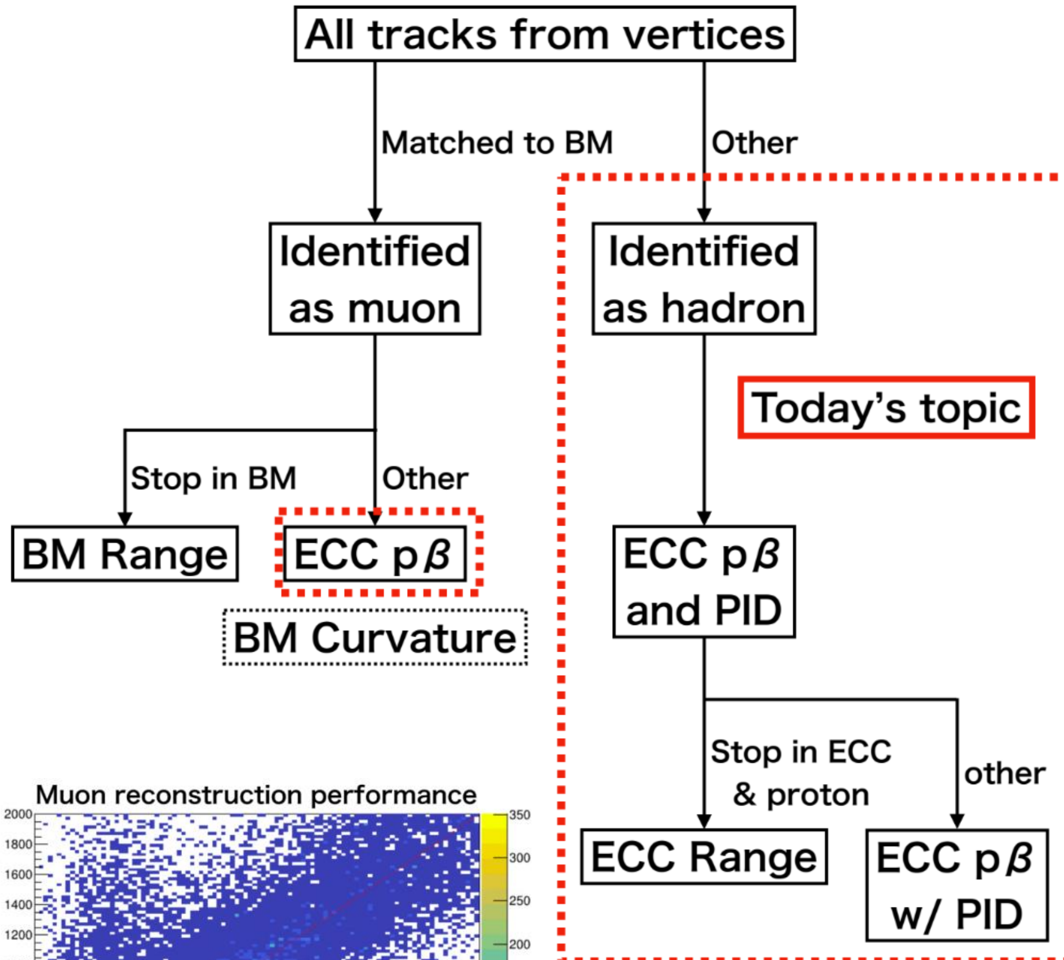
BM muon track

Connect to ECC?

- exist 8899
  - Classify @ECC
    - Penetrate 4994+some
    - Edge out 1842+some
    - stop 216
      - Event candidate
        - Fe : 121
        - Water : 95
    - Downstream stop (Out of fiducial) 37
- Not

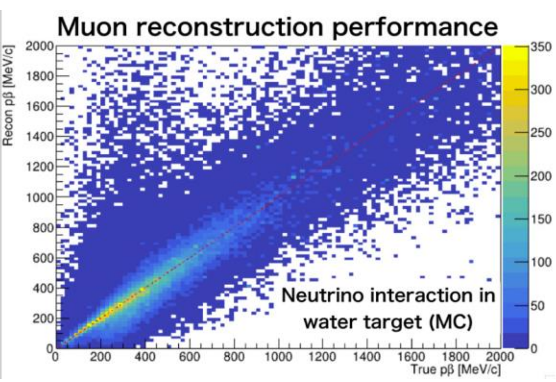


Particle Identification

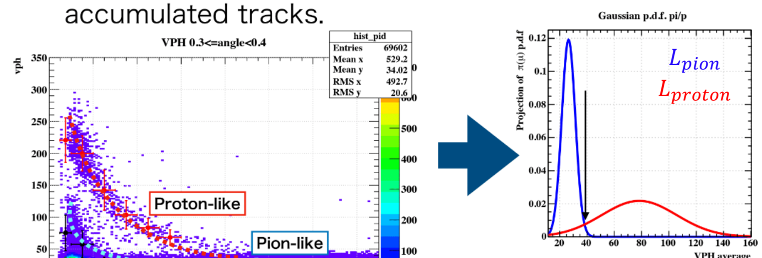


- dE/dx →
  Track blackness in ECC

- Momentum →
  Multiple Coulomb Scattering in ECC
  Range in ECC
  Range in Baby MIND



- Proton/pion PDF (gaussian) is obtained from the accumulated tracks.

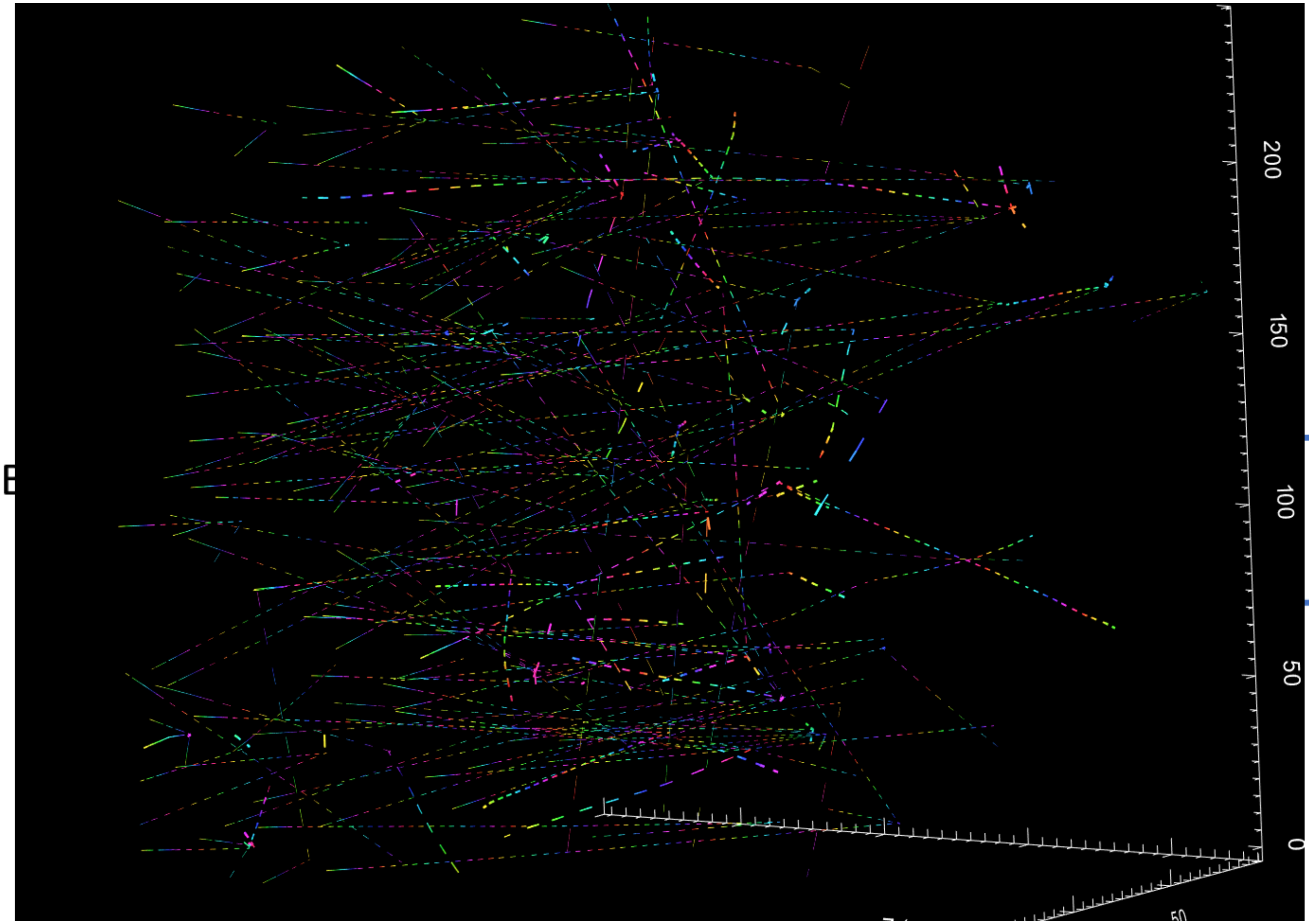


$$\frac{L_\pi}{L_\pi + L_p} = 0.5$$

The detailed was presented by Odagawa-san in young talk.

Event Viewer

Iron event (121 events)



Event candidate

Fe : 121

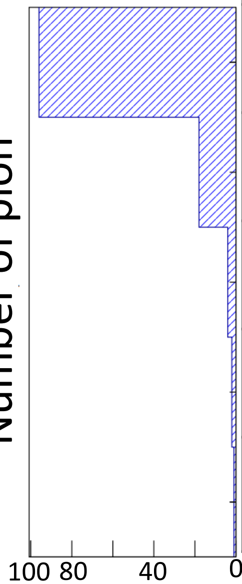
Water : 95

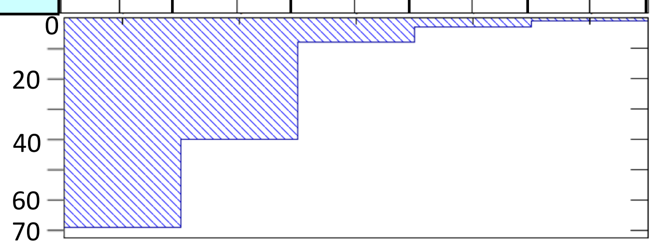
Very preliminary result in sub-sample

Iron 121events

Pi \ P	0	1	2	3	4
0	57	31	5	2	1
1	9	8	1		
2	2		1	1	
3	1		1		
4		1			

Number of pion



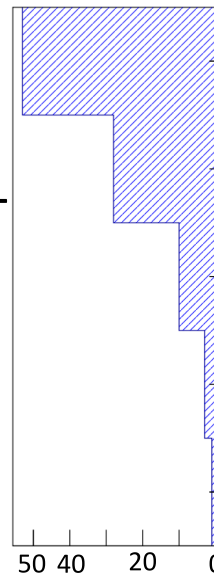


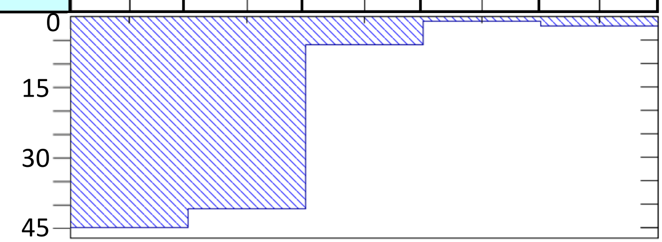
Number of proton

Water 95events

Pi \ P	0	1	2	3	4
0	25	24	3	1	
1	13	14			1
2	5	2	2		1
3	2		1		
4		1			

Number of pion





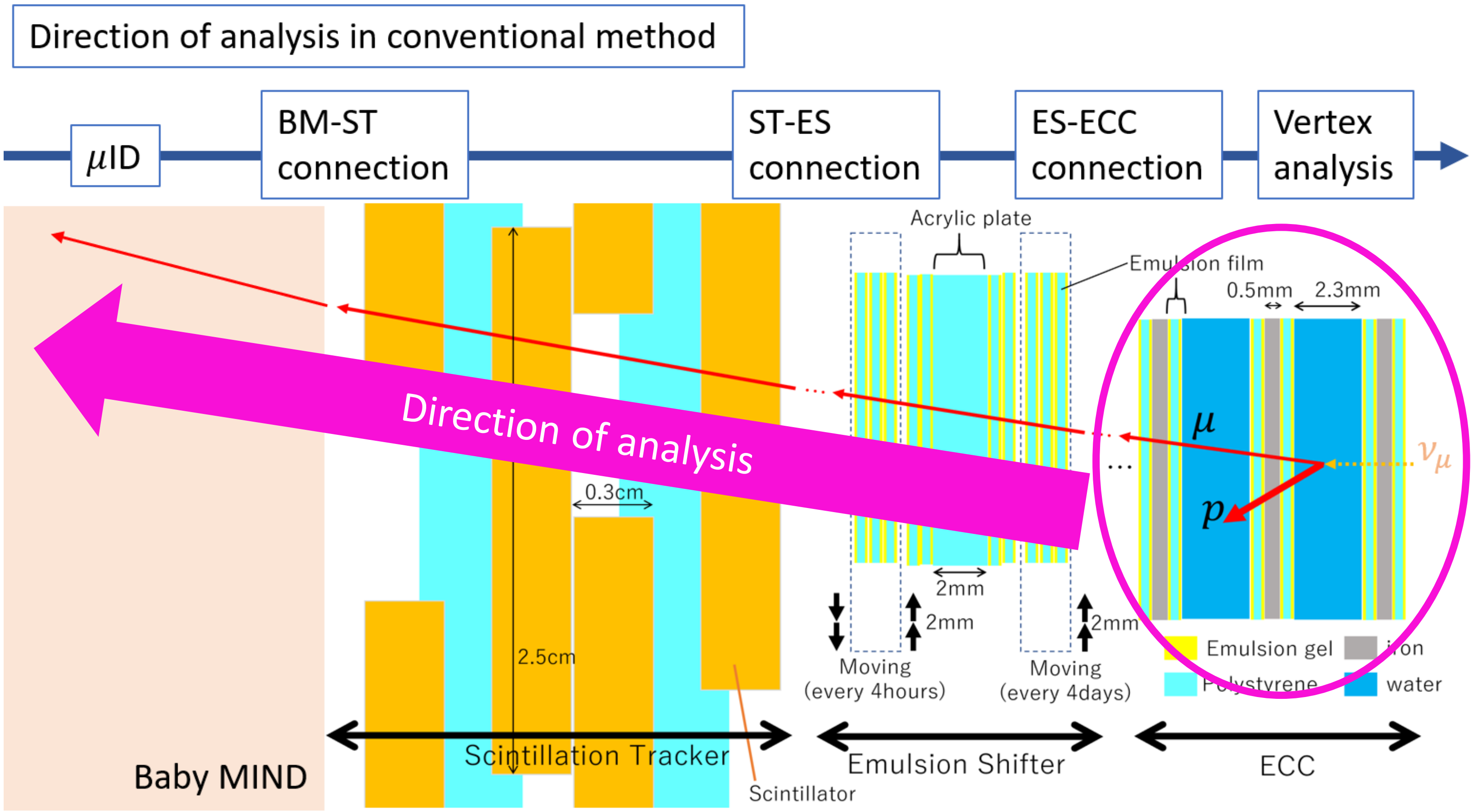
Number of proton

※Emulsion gel,base, packing interaction are included

Direct vertex hunting in ECC

My master thesis

- **Cross-check of muon prediction based analysis**
- **Electron neutrino event search**



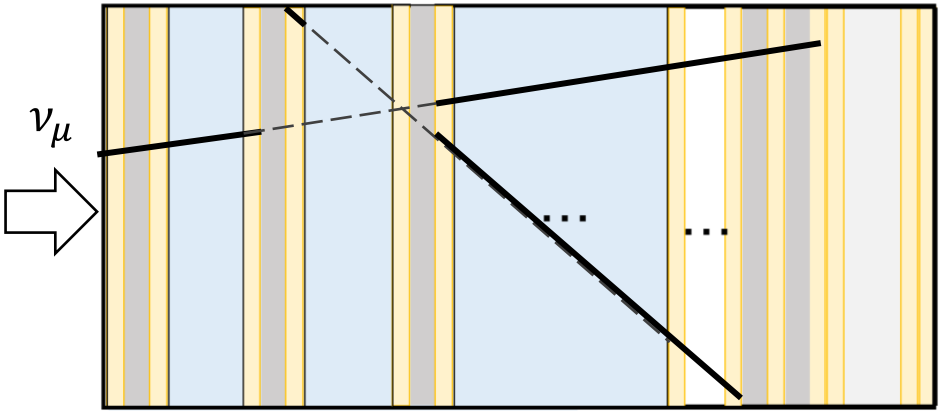
In this method, vertices are reconstructed using only ECC tracks

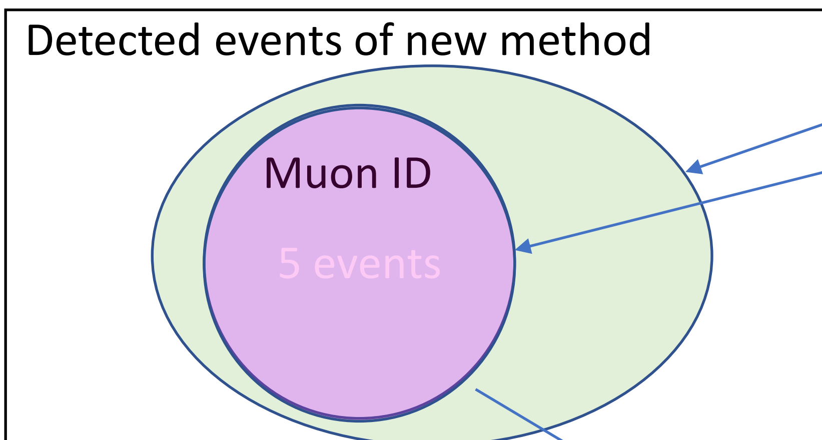
・・・the direction of analysis is the opposite of the conventional method

・・・analysis is not biased by electrical detectors

Direct vertex hunting in ECC

My master thesis





Estimation of random background

※Do the same reconstruction using the data with the track information replaced.

Pick up low background data from event candidates

Check
- time information of shifter
- muon ID of Baby MIND

- Electron neutrino like events had detected
- 5 events have muon ID

all of them have detected in conventional method
= Independent analysis confirms conventional methods.

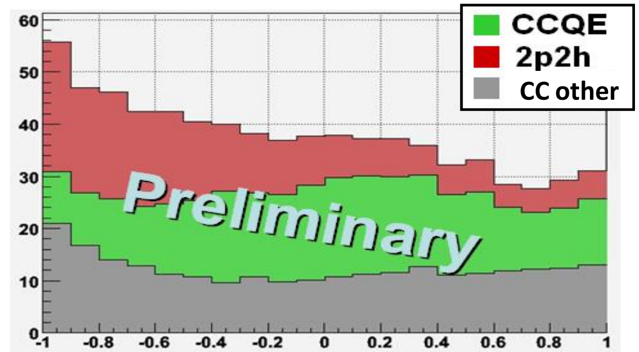
By increasing the statistics, we can guarantee the correctness of the conventional method and also search for electron-neutrino interactions.

Schedule

The emulsion scanning of E71a will be completed.
→We plan to concentrate on its physics analysis in 2022.
→First physics output hope to be shown in this summer.
The next physics run （E71b） will be implemented in JFY2023.

Requested POT	10×10^{20}
E71a	4.8×10^{20}
Done!	
E71b	5.2×10^{20}

Proton-Proton opening angle



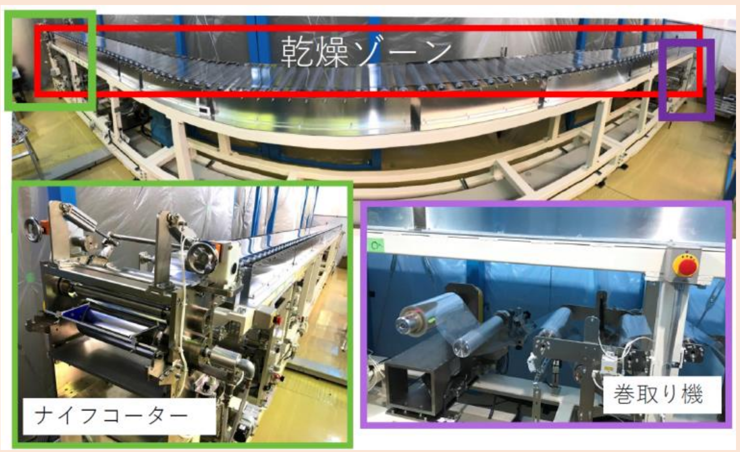
$\cos\theta_{pp}$

E71a analysis:
As shown in results of detector run, cross-section and proton/pion kinematics information on ν_μ-water and iron interactions will be obtained with more than 10 times statistics from detector run.
Also, if 2p2h is the cause of the excess of CCQE like event, back-to-back proton would be increased clearly in 0pi2p events.

Toward next physics run (E71b)

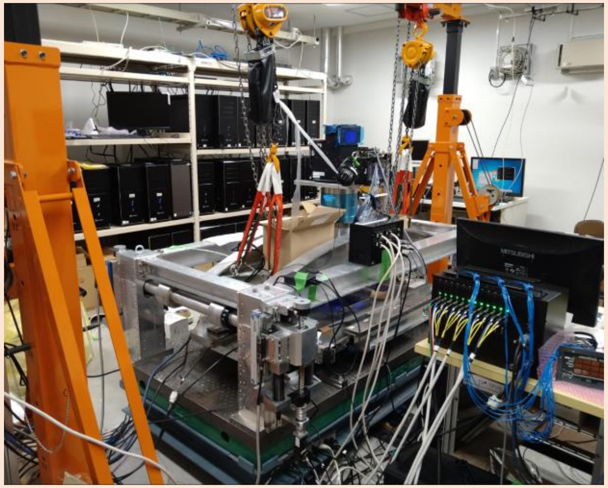
We have developed an automatic emulsion pouring system
and a new higher speed emulsion scanning system in Nagoya U.

Automatic emulsion pouring system



x10 faster than hand made

New automatic emulsion scanning system



x5 faster than current system

It is still under discussion, but we probably can install
about Four times larger detectors in next run to increase statistics.

Summary

- Precise measurement of sub-multi GeV neutrino-water interactions is important for future neutrino oscillation analysis (especially, 2p2h and ν_e) and proton information is a key to improve neutrino-nucleus interaction model.
- We have demonstrated the analysis of NINJA experiment in detector runs.
- The data taking of our first physics run (E71a) was completed.
- The hybrid analysis between emulsion detectors and electronic detectors works well, and PID analysis was also done well.
- Non-bias analysis method has been developed for cross-check of conventional analysis method and ν_e CC event search.
- We will start physics analysis with full statistics of E71a, corresponds to 4.8×10^{20} POT. The first physics result will be reported in this summer.
- Second physics run (E71b) is scheduled in JFY2023. The new emulsion production systems and readout system allow us to make a detector four times larger.

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