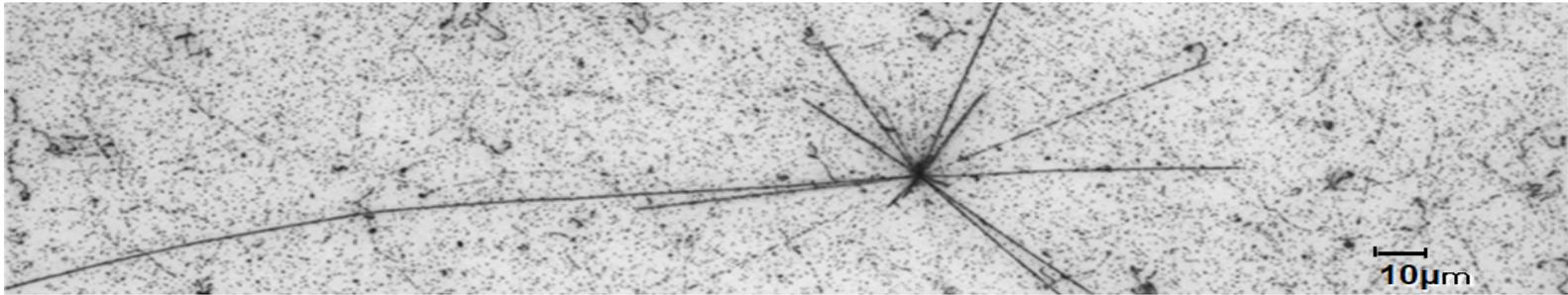


# Neutrino interaction measurement using emulsion based detector at NINJA experiment



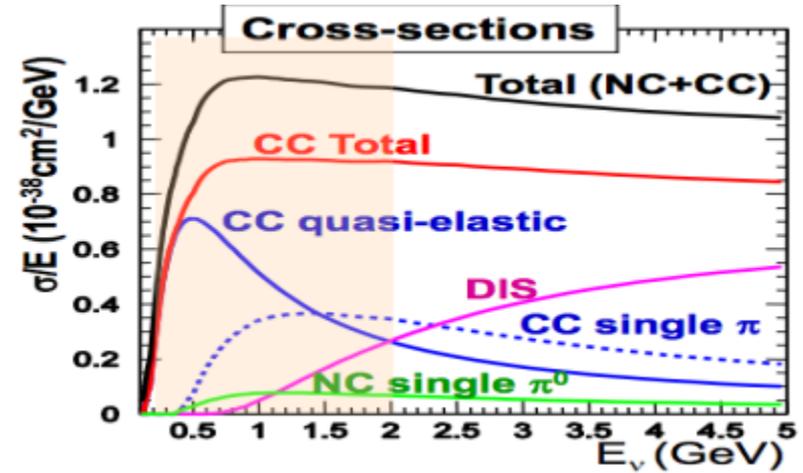
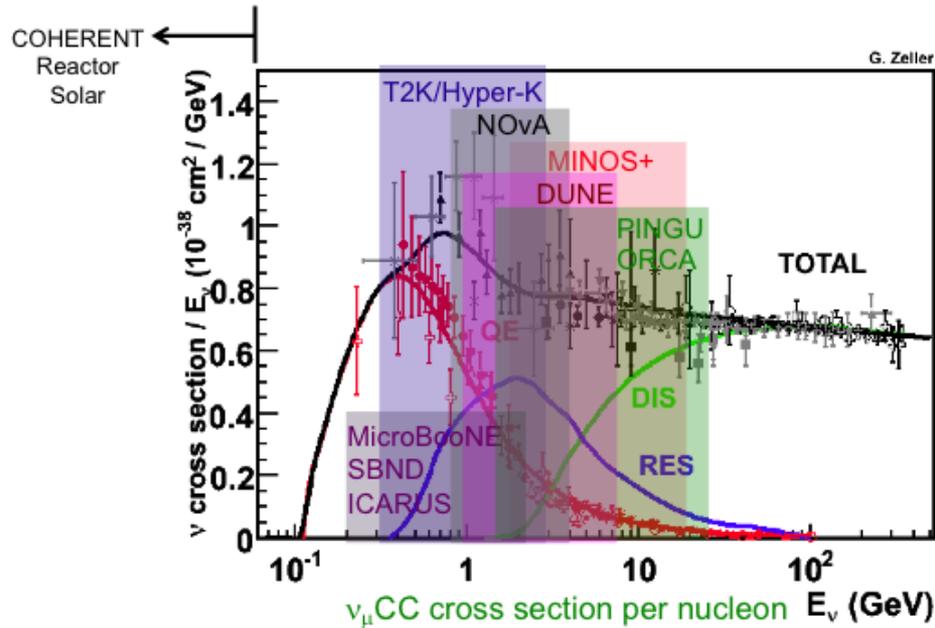
21st Rencontres du Vietnam

Mahesh Jakkapu

(Ruder Bošković Institute, Croatia)

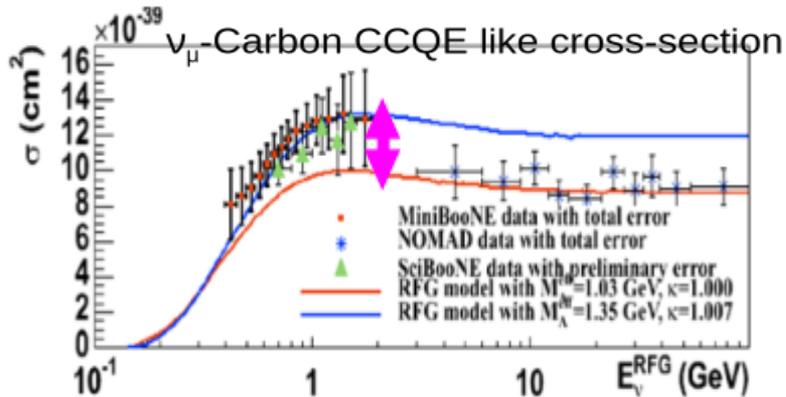
On behalf of NINJA collaboration

# Experimental Neutrino Physics

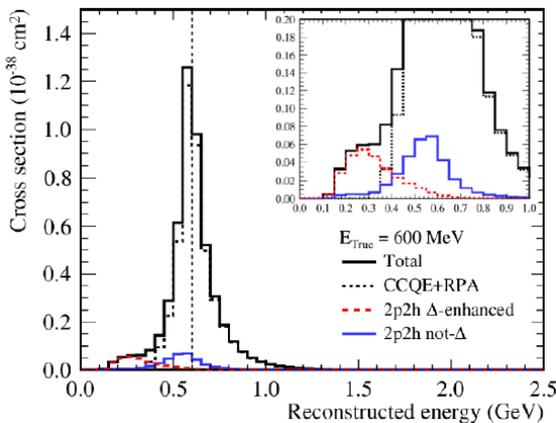


Most of the current and future experiments will probe energy range up to few GeV.

# Neutrino multi nucleon interactions



Discrepancy due to CC2p2h?

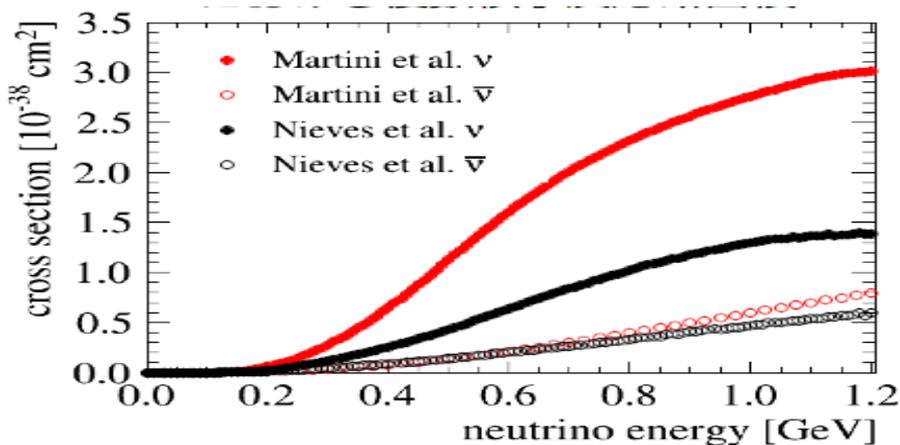


Considering  
2p2h  
interaction can  
explain missing  
cross section

CCQE -



2p2h -

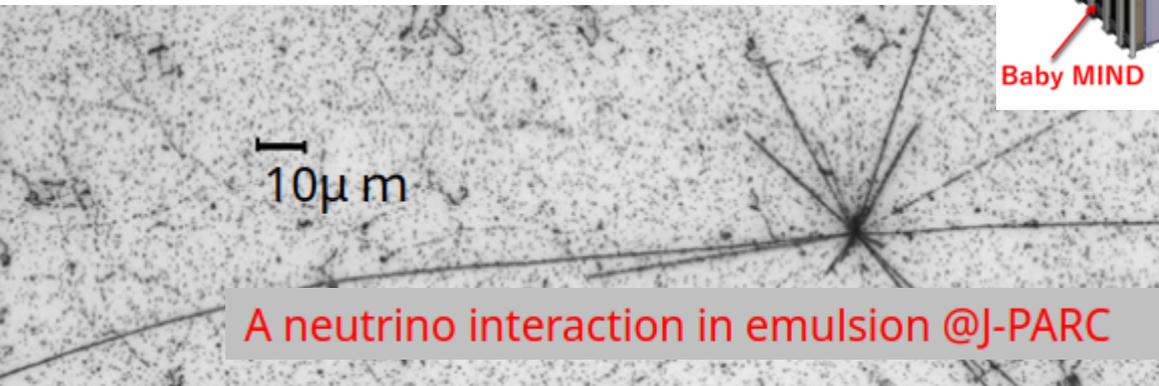
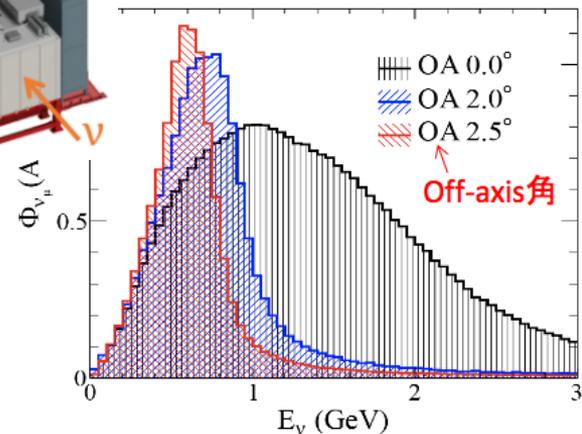
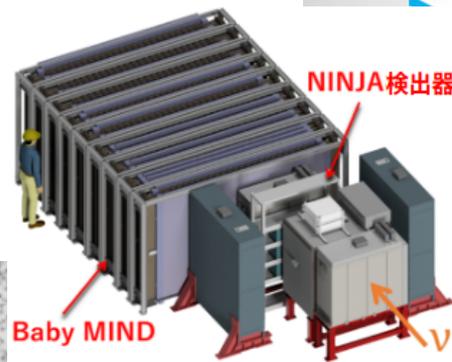
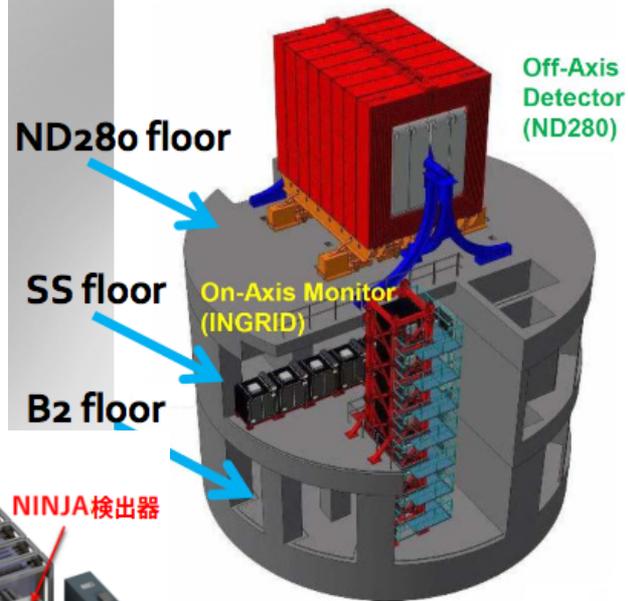


Theoretical  
2p2h cross  
section

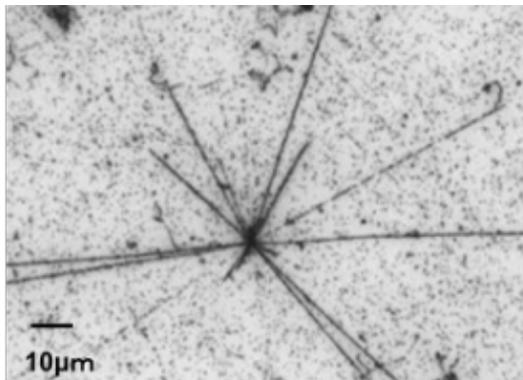
# NINJA experiment

Neutrino Interaction research with Nuclear emulsion and J-PARC Accelerator

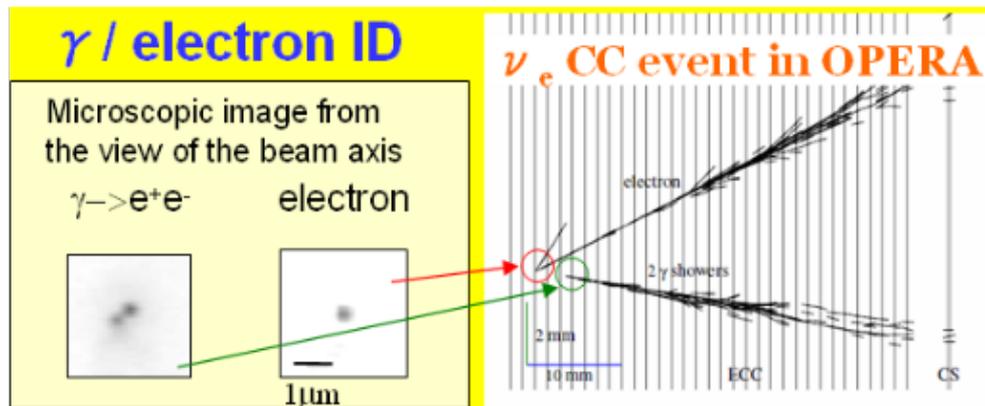
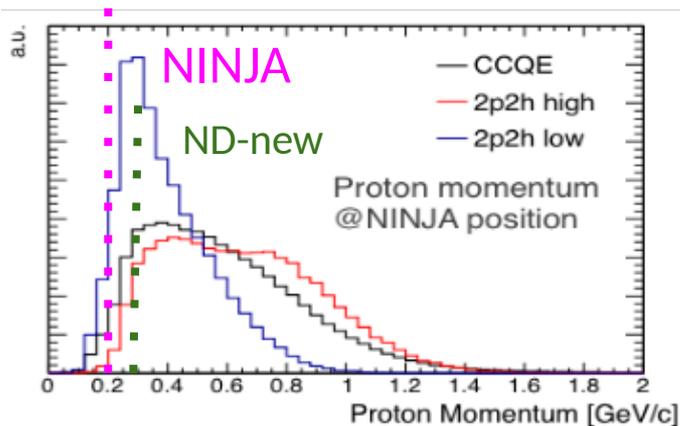
- Precise measurement of  $\nu_\mu$ -nucleus CC cross-sections in Sub-Multi GeV region.
- Electron neutrino cross-section measurement.
- Sterile neutrino search.



# Emulsion detector advantages



- Low momentum proton measurement.
- Neutrino-water interaction - same target as SK, HK.
- Gamma rejection for electrons from  $\nu_e$  events.



# NINJA plan

Pilot run

Detector run

Physics RUN 1  
(E71)

Physics RUN 2

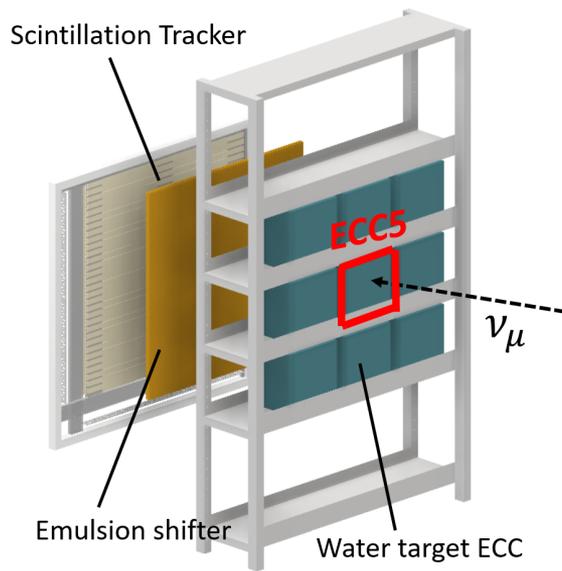
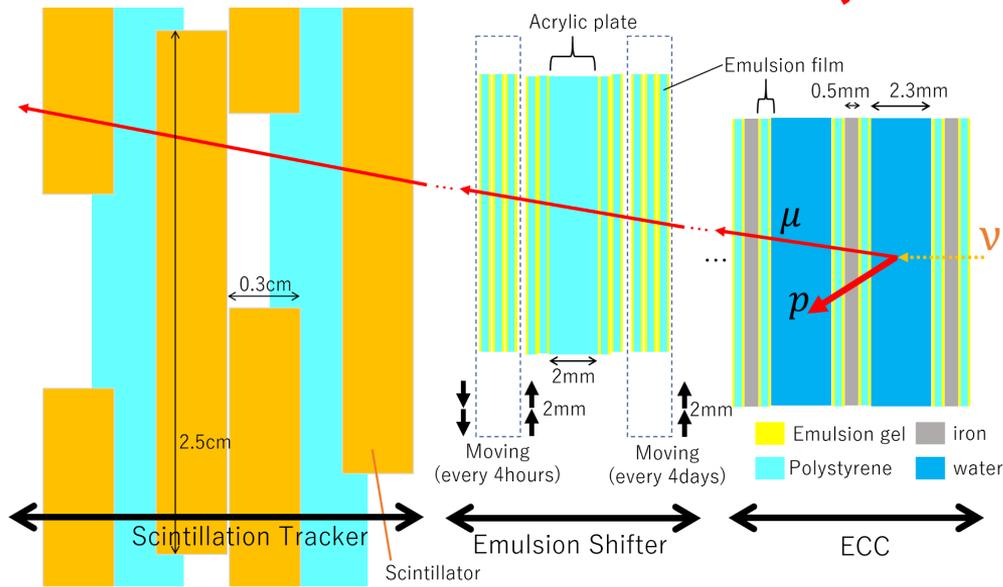
Current  
run

Sterile  
search

Table 1: Emulsion detector exposure history

| Period                  | POT                  | Detector  | Site           |
|-------------------------|----------------------|---|----------------|
| Oct. 2014-<br>Dec. 2014 | $1.3 \times 10^{20}$ | 2 kg iron detector,<br>Emulsion shifter,<br>INGRID  | SS floor at NM |
| Jan. 2015-<br>Apr. 2015 | $1.4 \times 10^{20}$ | 2 kg iron detector,<br>Emulsion shifter,<br>INGRID  | SS floor at NM |
| May 2015-<br>Jun. 2015  | $0.8 \times 10^{20}$ | 1.5 kg water target ECC   | SS floor at NM |
| Jan. 2016-<br>May. 2016 | $4.0 \times 10^{20}$ | 60 kg water target ECC,<br>Medium emulsion shifter,<br>INGRID   | SS floor at NM |
| Dec. 2016-<br>Apr. 2017 | $5.9 \times 10^{20}$ | 1.5 kg water target ECC   | SS floor at NM |
| Nov. 2017-<br>May. 2018 | $7.1 \times 10^{20}$ | 3 kg water target ECC,<br>Scintillator fiber tracker,<br>INGRID   | SS floor at NM |
| Nov. 2019-<br>Feb. 2020 | $4.8 \times 10^{20}$ | 75 kg water, 130 kg iron and 15 kg<br>CH target ECC,<br>Large emulsion shifter,<br>Scintillator fiber tracker,<br>Baby MIND | B2 floor at NM |
| Mar. 2021-<br>Apr. 2021 | $1.8 \times 10^{20}$ | 9 kg heavy water ECC  | B2 floor at NM |
| Nov. 2023-<br>Feb. 2024 | $2.9 \times 10^{20}$ | 75 kg water, 130 kg iron and 15 kg<br>CH target ECC,<br>Large emulsion shifter,<br>Scintillator fiber tracker,<br>Baby MIND | B2 floor at NM |

# NINJA (E71) setup

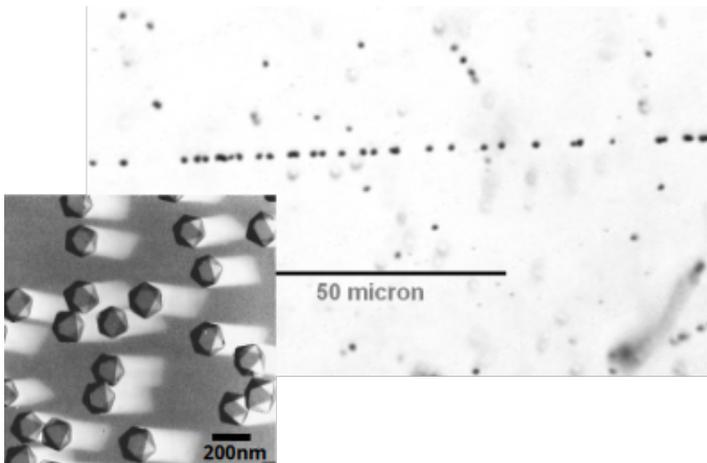
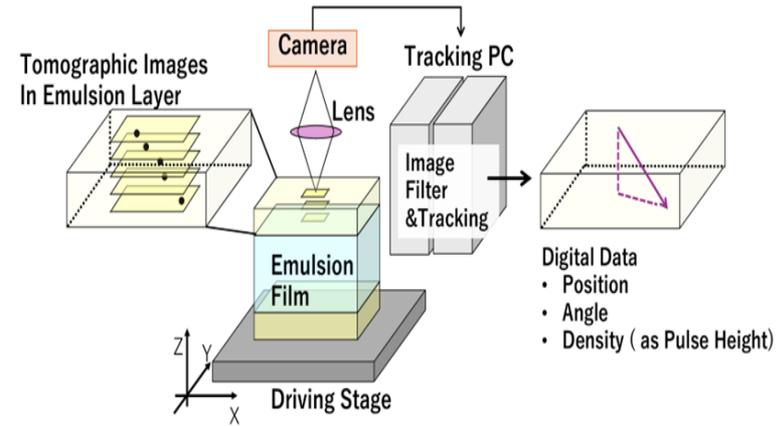


|                     | Scintillation Tracker | Emulsion Shifter | Water ECC       |
|---------------------|-----------------------|------------------|-----------------|
| Time resolution     | 10 nsec level         | 4 hour           | --- (100 day)   |
| Position resolution | 2.1 mm                | 1 $\mu$ m level  | 1 $\mu$ m level |

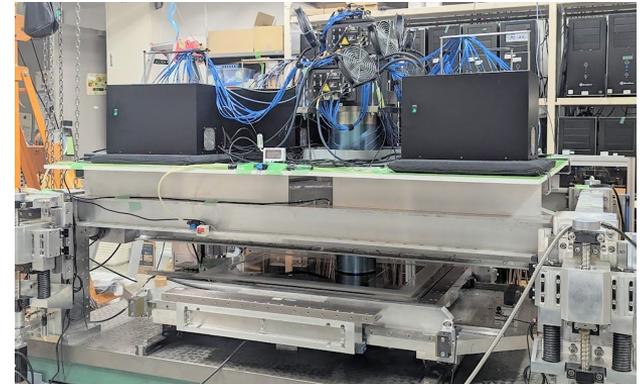
- Consists of ECC, emulsion shifter and scintillator tracker.
- ECC - Emulsion films sandwiching iron plate placed in water.

# Nuclear emulsion film scanning system

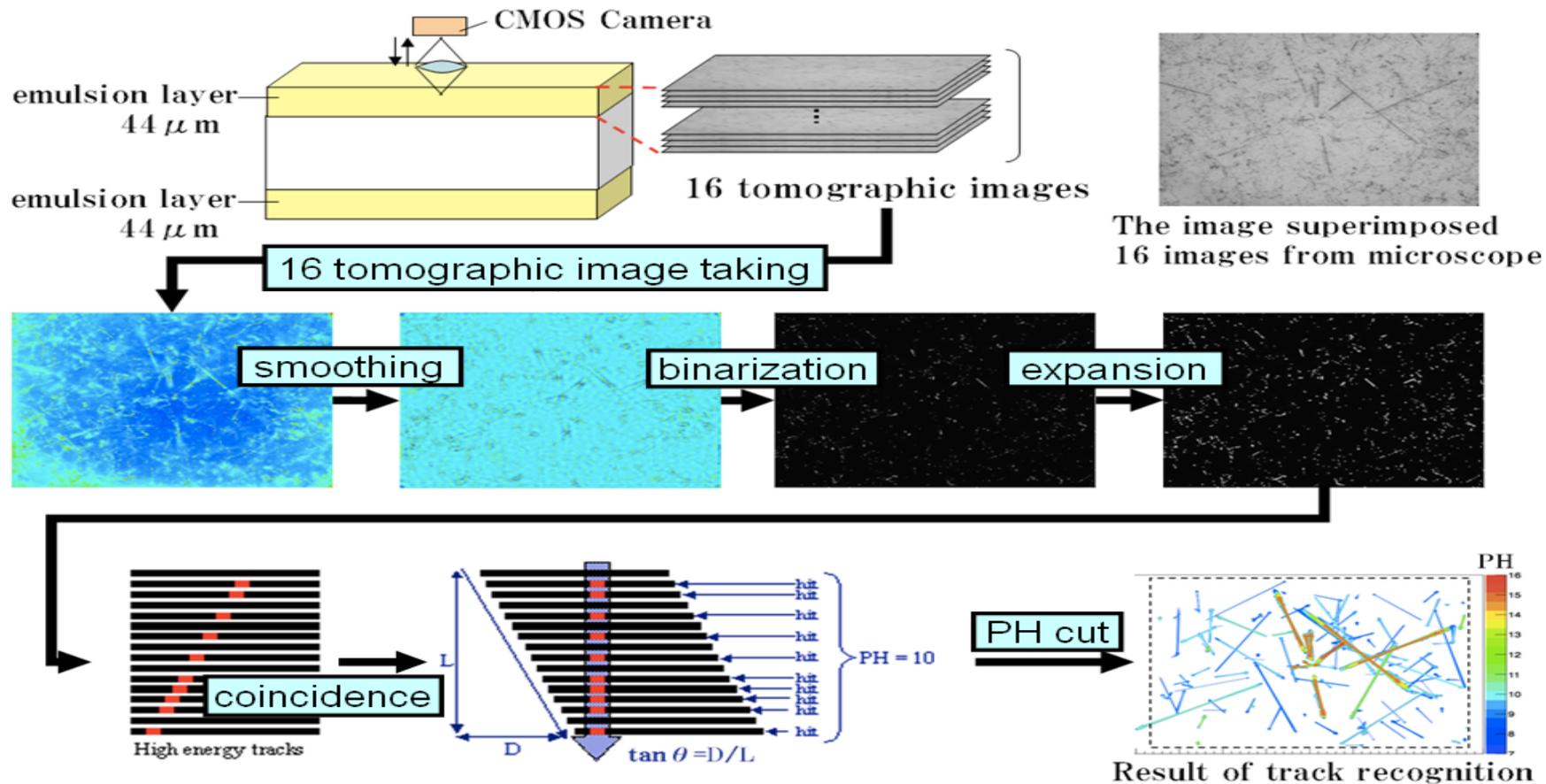
- Emulsion film is special photographic film.
- The charged particle track signal is seen with activated silver halide crystals.
- High resolution images.



HTS  
Scanning  
System @  
Nagoya  
University



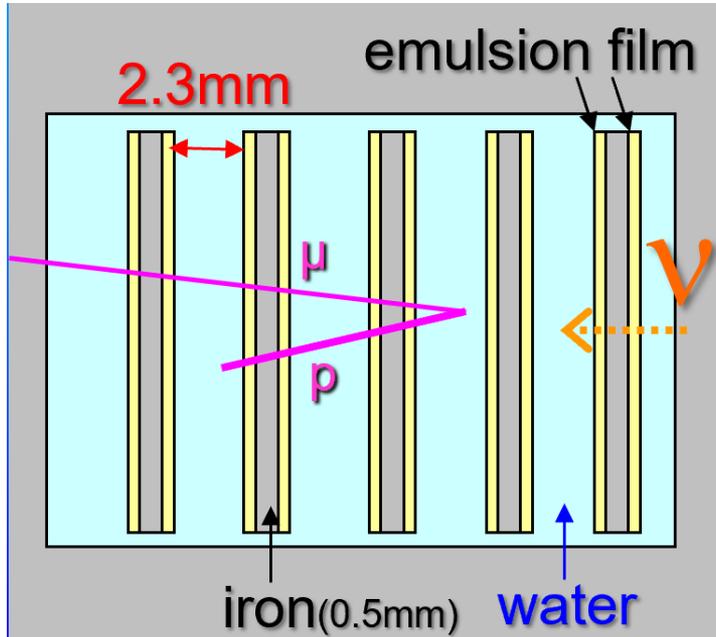
# Scanning procedure



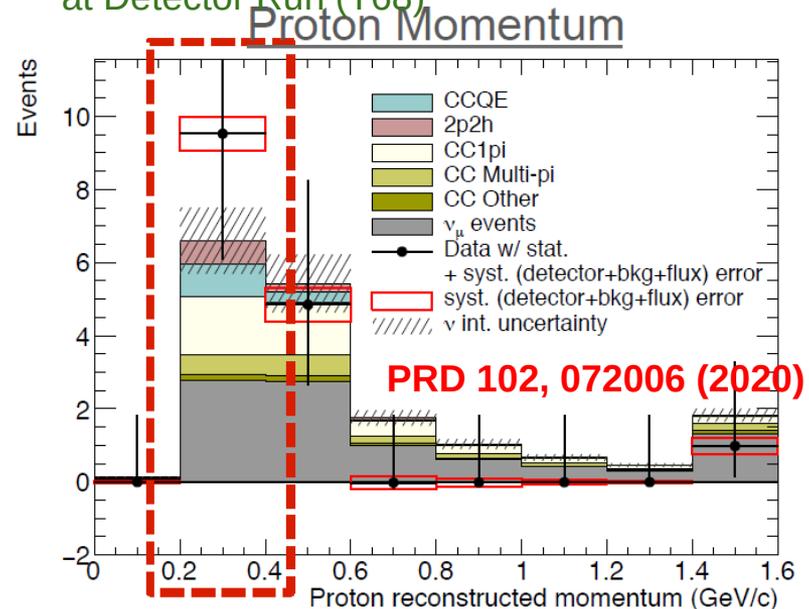
# NINJA physics run E71a

- First measurement of  $\nu$ -multi nucleon interactions
- Exclusive cross-section measurement of  $\nu$ -water interactions
- Beam time: Nov. 2019 - Feb. 2020; POT:  $4.8 \times 10^{20}$

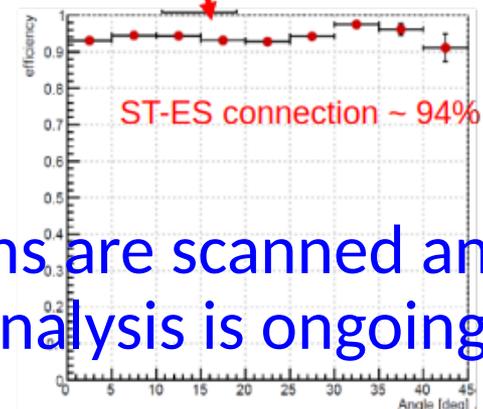
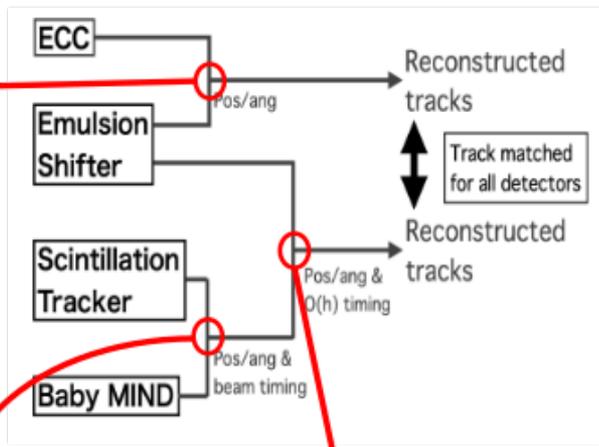
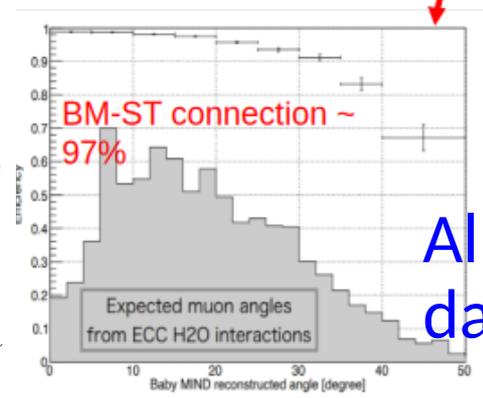
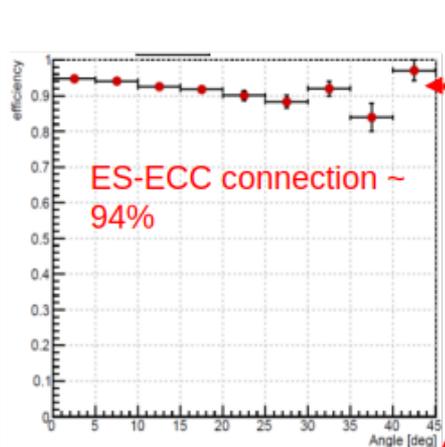
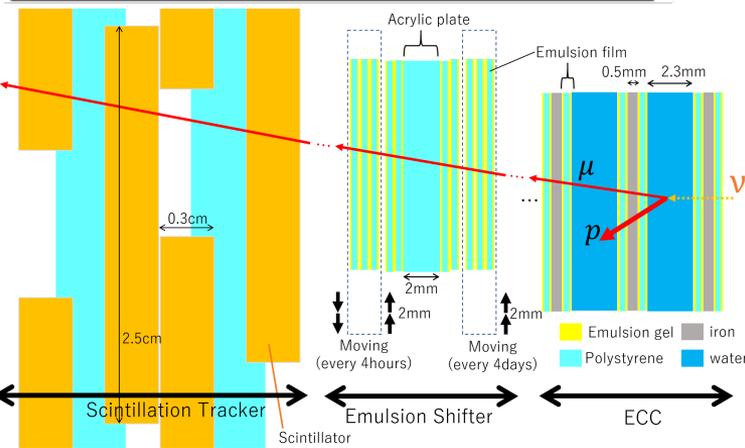
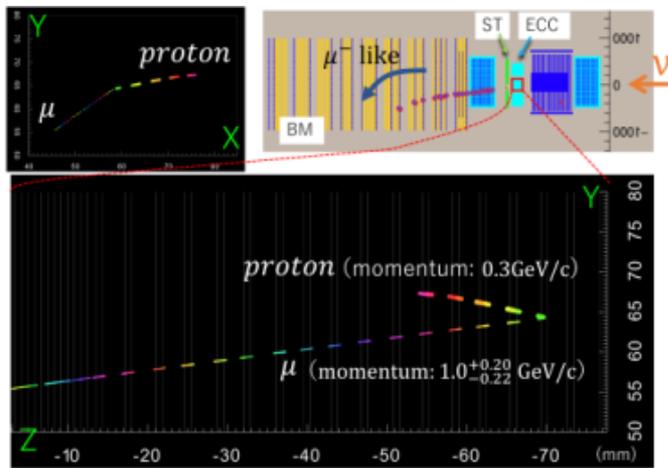
250 kg target  
H<sub>2</sub>O : 75kg  
Fe : 130kg  
CH : 15kg  
em : 30kg



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

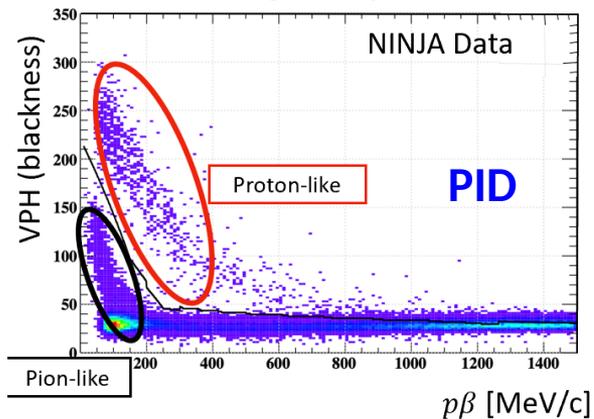


# E71a status



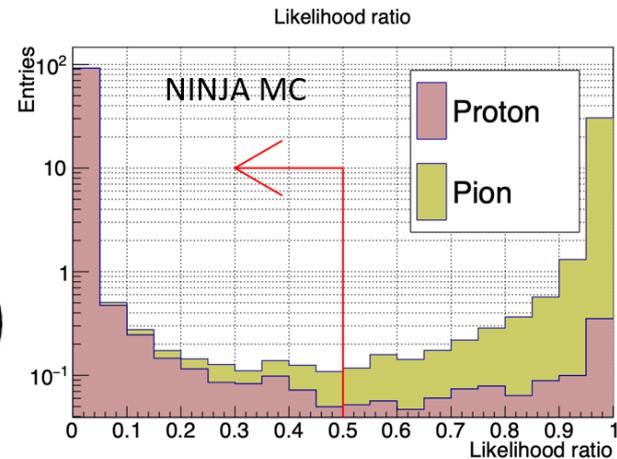
All films are scanned and data analysis is ongoing

All tracks accumulated during the exposure

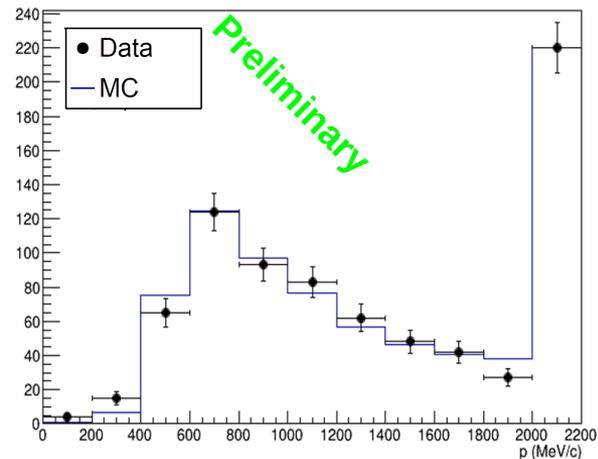


# E71a status

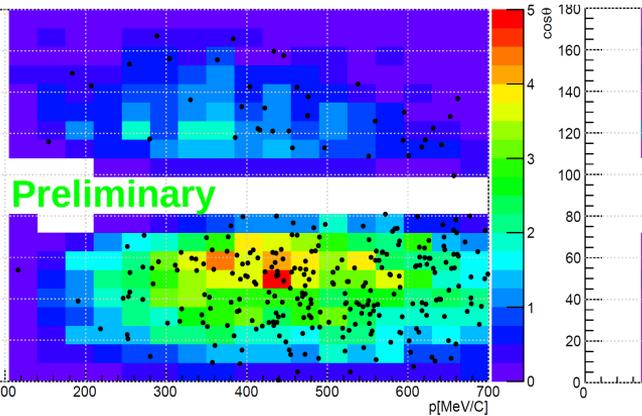
Proton Efficiency: 99%  
Proton Purity : 99%  
(limited to  $p\beta \lesssim 700\text{MeV}/c$ )



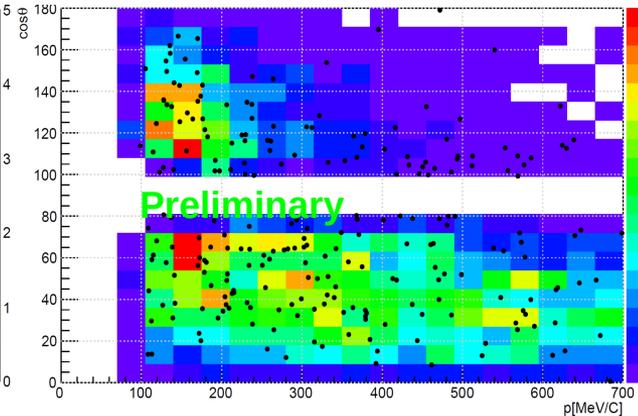
Normalized by # of events



Muon momentum



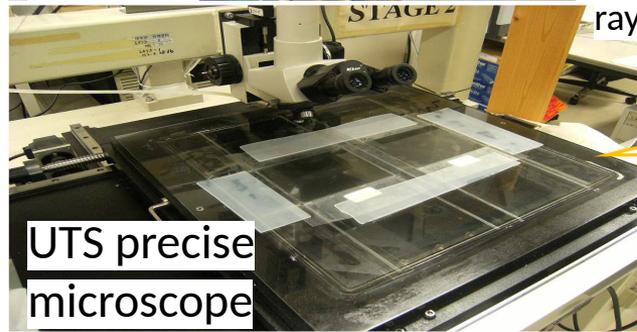
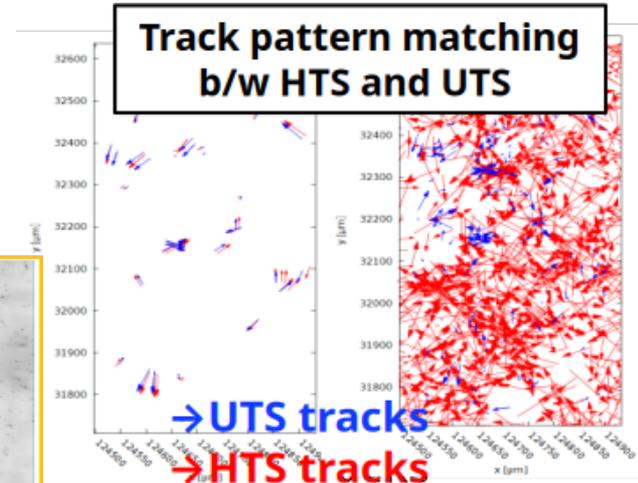
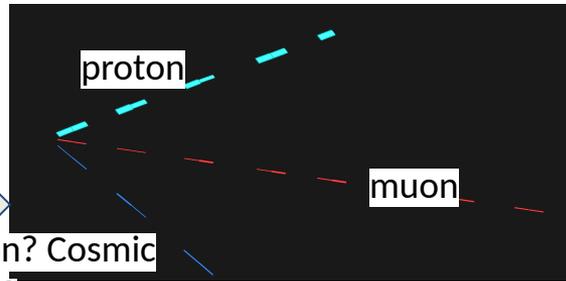
Proton momentum vs angle



Pion momentum vs angle

# E71a status

- An additional analysis is necessary to reject the partner tracks that are too close to the film boundary.
- Microscopic visual inspection has been initiated to perform final confirmation of tracks suspected to be contaminated by cosmic rays, as well as to verify that events with interaction vertices located near the target boundary region indeed correspond to interactions in the water target.
- This visual inspection employs a technique known as “navigation,” which enables micron-level alignment to re-examine tracks acquired during scanning.



# Physics run E71b

We successfully conducted our second physics run!  
(2023-2024)

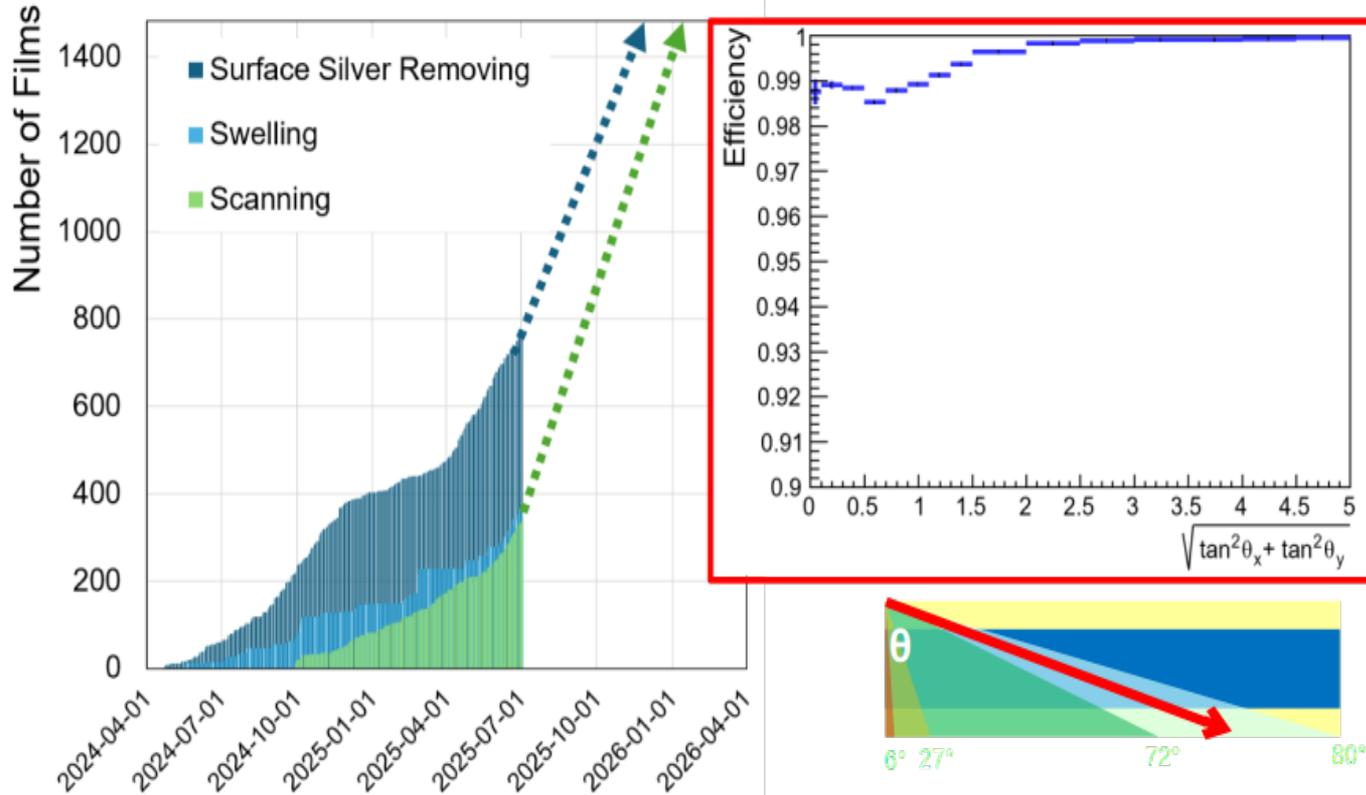
Neutrino beam exposure (Nov. → Feb.)



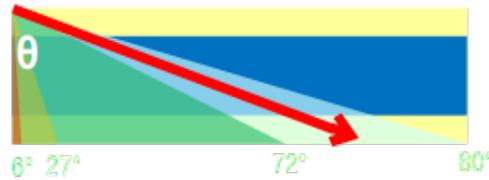
Development of emulsion films  
@Gifu Univ.



# E71b status



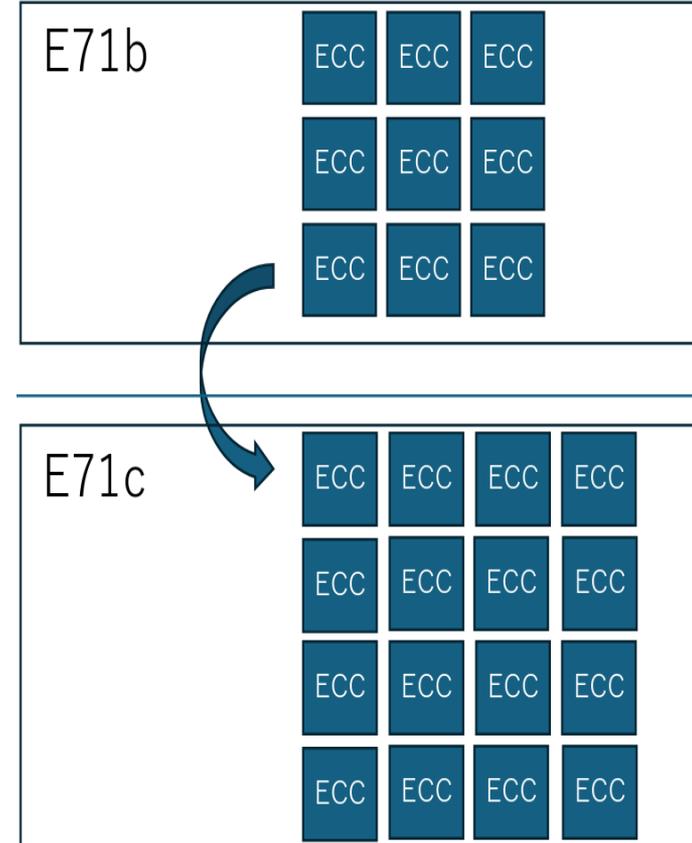
- Emulsion film scanning is on going.
- Tracking efficiency  $\geq 99\%$ .
- Expected to be finished at the beginning of next year.



# E71C (coming run)

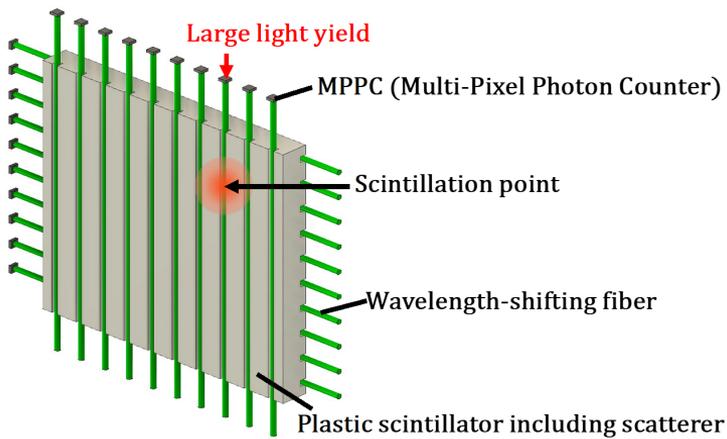
- Next run of NINJA is planned to take place from Nov 2025.
- Production of emulsion has started.
- The target mass  $\sim 2$  times the previous run.
- New scintillator tracker and new scintillator shifter are used to accommodate the increase in ECCs.

|                       | Period     | POT   |
|-----------------------|------------|---|
| 1 <sup>st</sup> :E71a | 2019-2020  | $4.8 \times 10^{20}$                        |
| 2 <sup>nd</sup> :E71b | 2023-2024  | $2.9 \times 10^{20}$                        |
| 3 <sup>rd</sup> :E71c | 2025 fall- | <b><math>&gt; 2.3 \times 10^{20}</math></b> |

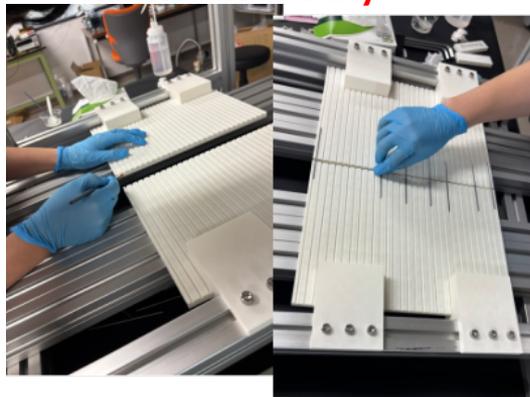


# E71c preparation status

- Emulsion film production started, ~15% of the total produced so far.
- New scintillator tracker and shifter are being prepared and tested.



Tracker assembly



Position resolution including systematic error  
~1.5mm, evaluated at test experiment @RARiS

# Conclusion

- NINJA experiment utilizes emulsion for the precise measurement of neutrino-water interactions.
- So E71a, E71b physics runs are successfully completed.
- Preparations for next physics run E71c with increased detector mass is on going.

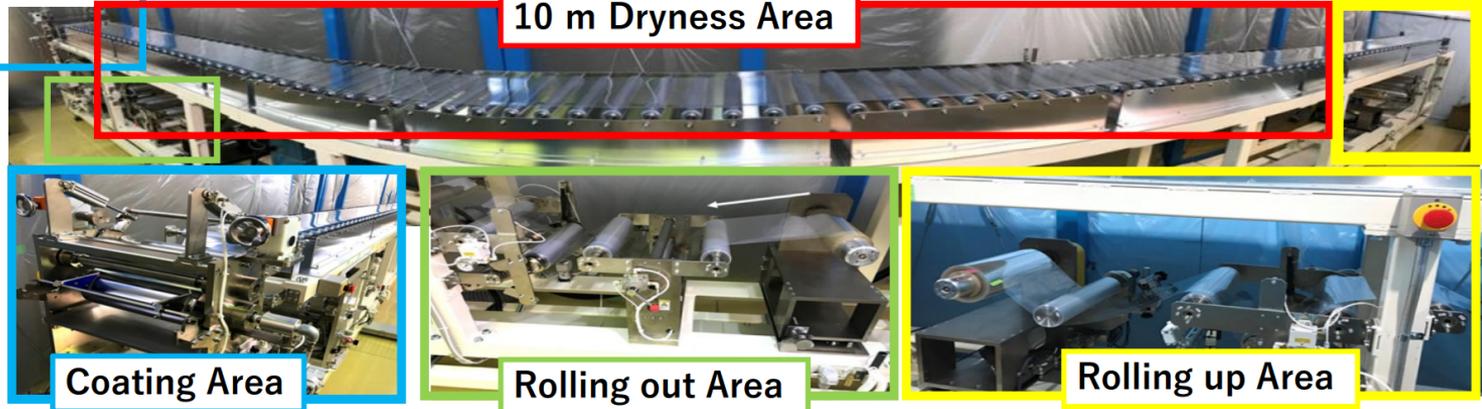
Backup

# Plan for E71c

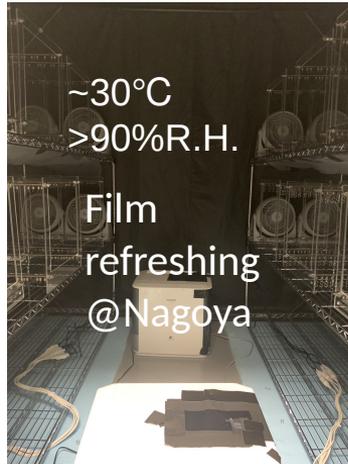
|                      | Jul.   | Aug.                | Sep.                                | Oct.                                 | Nov.                         | Dec.   |
|----------------------|--|---------------------|-------------------------------------|--------------------------------------|------------------------------|--|
| Film production      | mass production & quality check                    |                     |                                     |                                      |                              |  |
| Film refresh         |  | Noise track erasing |                                     |                                      |                              |  |
| ECC preparation      |  |                     |                                     | ECC production & installation        | Cooling shelter building     |  |
| Special film for LES |  |                     | hand-coating                        |                                      |                              |  |
| LES preparation      | Operation test @Nagoya                             |                     | Operation test @J-PARC              |                                      | Installation                 |  |
| ST preparation       | Assembling tracker                                 |                     |                                     |                                      |                              |  |
| DAQ system           | Development of DAQ system using MPPC readout board |                     | DAQ test using cosmic muon at Kyoto | DAQ test using cosmic muon at J-PARC | Installation & commissioning |  |
| <b>Neutrino beam</b> |  |                     |                                     |                                      |                              |  |

# Emulsion films and ECC production

Emulsion  
production  
@Nagoya



Erasing of  
noise tracks  
accumulated  
during film  
production.



ECC  
production  
@J-PARC