



*Institut
Ruđer
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NINJA

Neutrino Interaction research with
Nuclear Emulsion and J-PARC Accelerator

The NINJA experiment

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Ruđer Bošković Institute

1st annual MAPS meeting
02-07-2026



**Swiss National
Science Foundation**



HrZZ

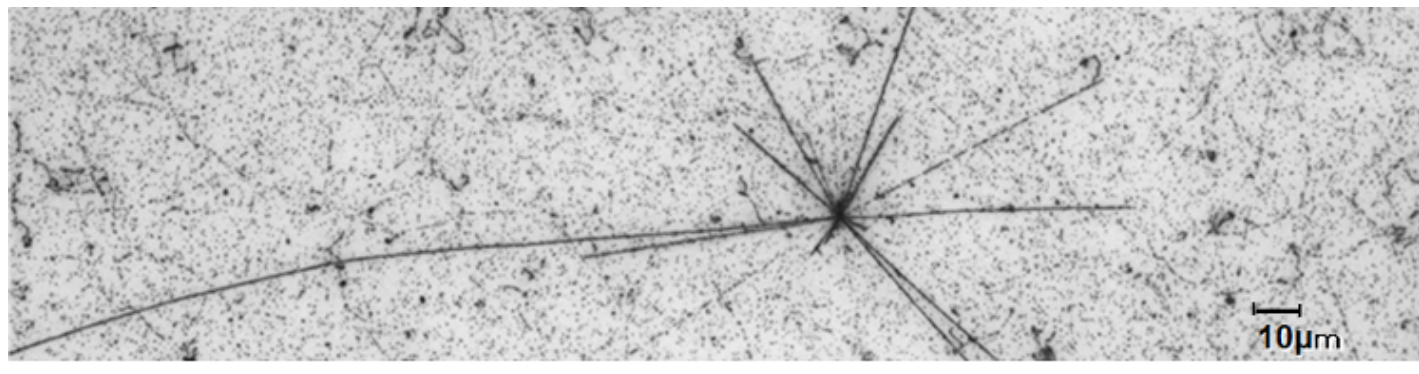
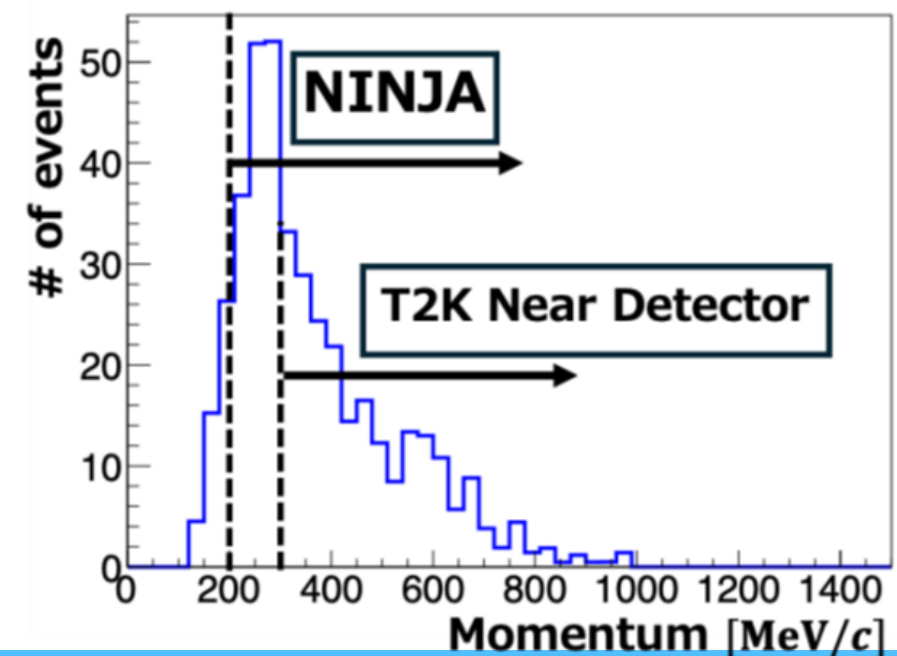
Croatian Science
Foundation

NINJA

(Neutrino Interaction research with Nuclear emulsion and J-PARC Accelerator

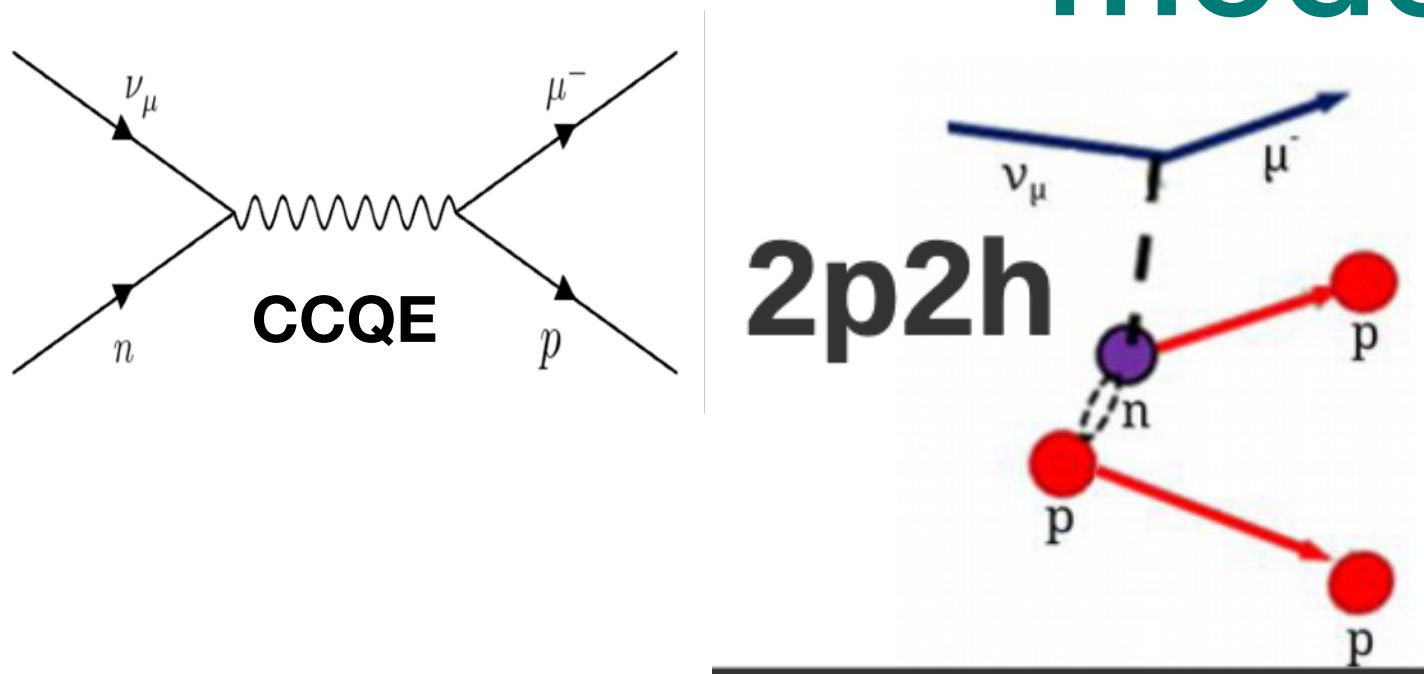
- Precisely measure neutrino interaction using nuclear emulsion.
 - Able to reconstruct tracks with sub-micron position resolution.
 - Detect low momentum protons(>200MeV/c)
- Reduce the uncertainty of neutrino interaction models.
 - Major systematics in experiments such as T2K.

Proton momentum



Microscopic view of tracks in nuclear emulsion

Uncertainty of interaction models



- CCQE is the dominant interaction mode at low energies.
- 2p2h can mimic the CCQE signal.
- Important to reconstruct the low momentum protons.

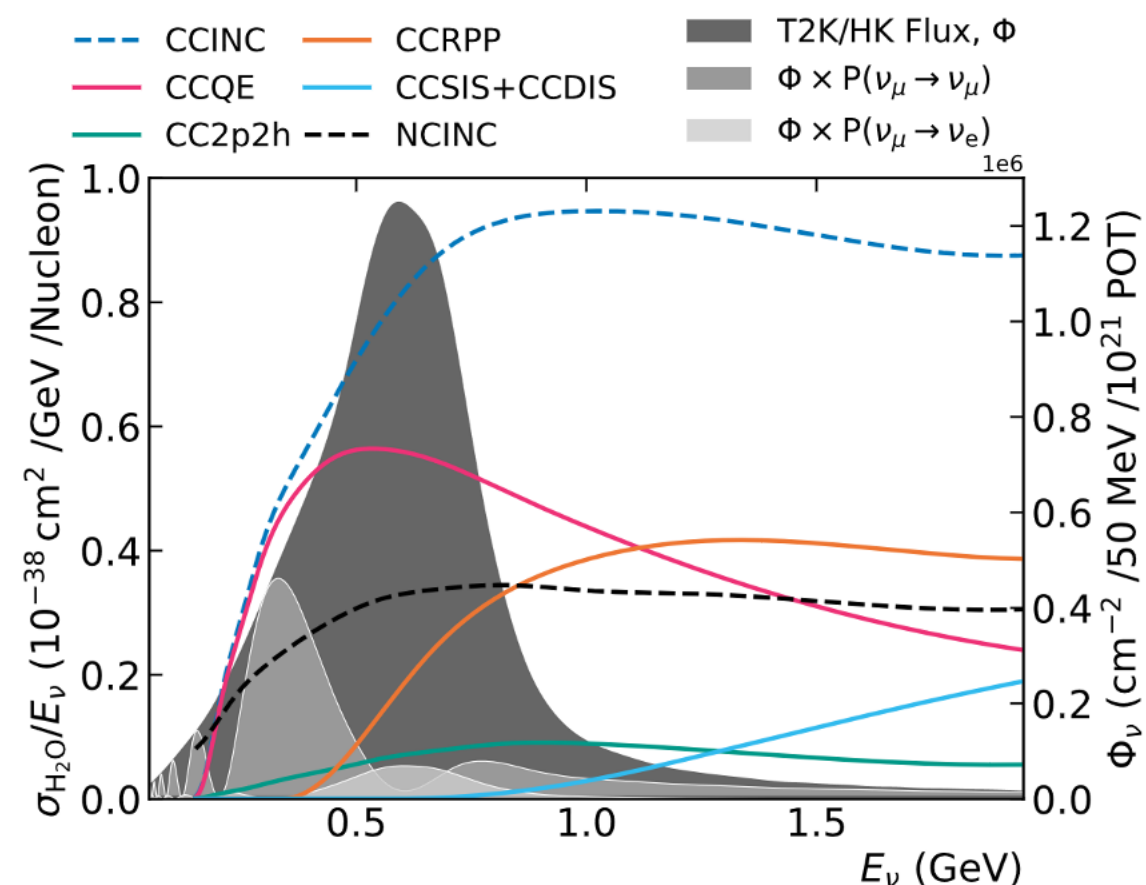


Fig. 11: The cross section for neutrino–water interactions for a variety of interaction channels as simulated by the NEUT event generator. Also shown is the unoscillated neutrino-mode Hyper-K/T2K FD ν_μ flux, as well as the $\nu_\mu \rightarrow \nu_\mu$ and $\nu_\mu \rightarrow \nu_e$ oscillated fluxes.

<https://arxiv.org/pdf/2605.28671>

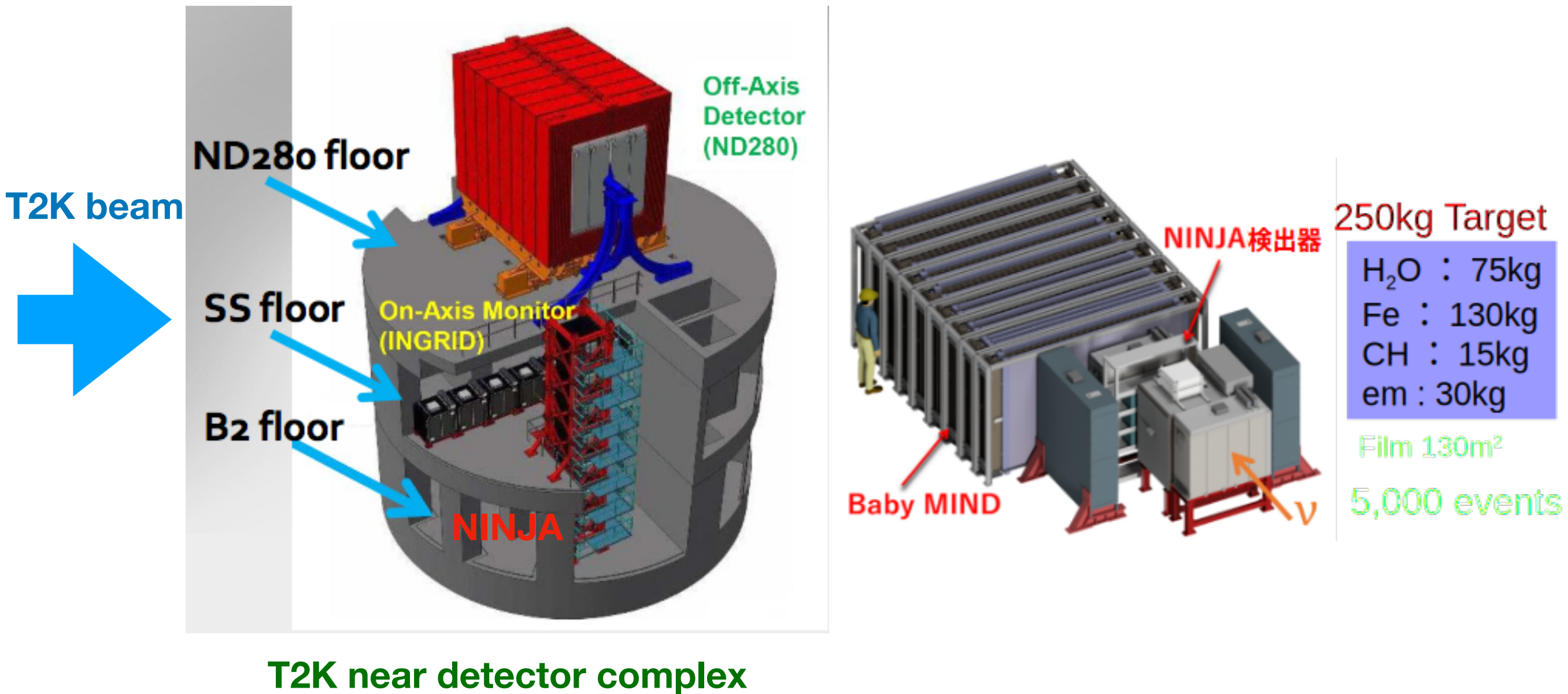
NINJA data taken so far

Table 1: Emulsion detector exposure history

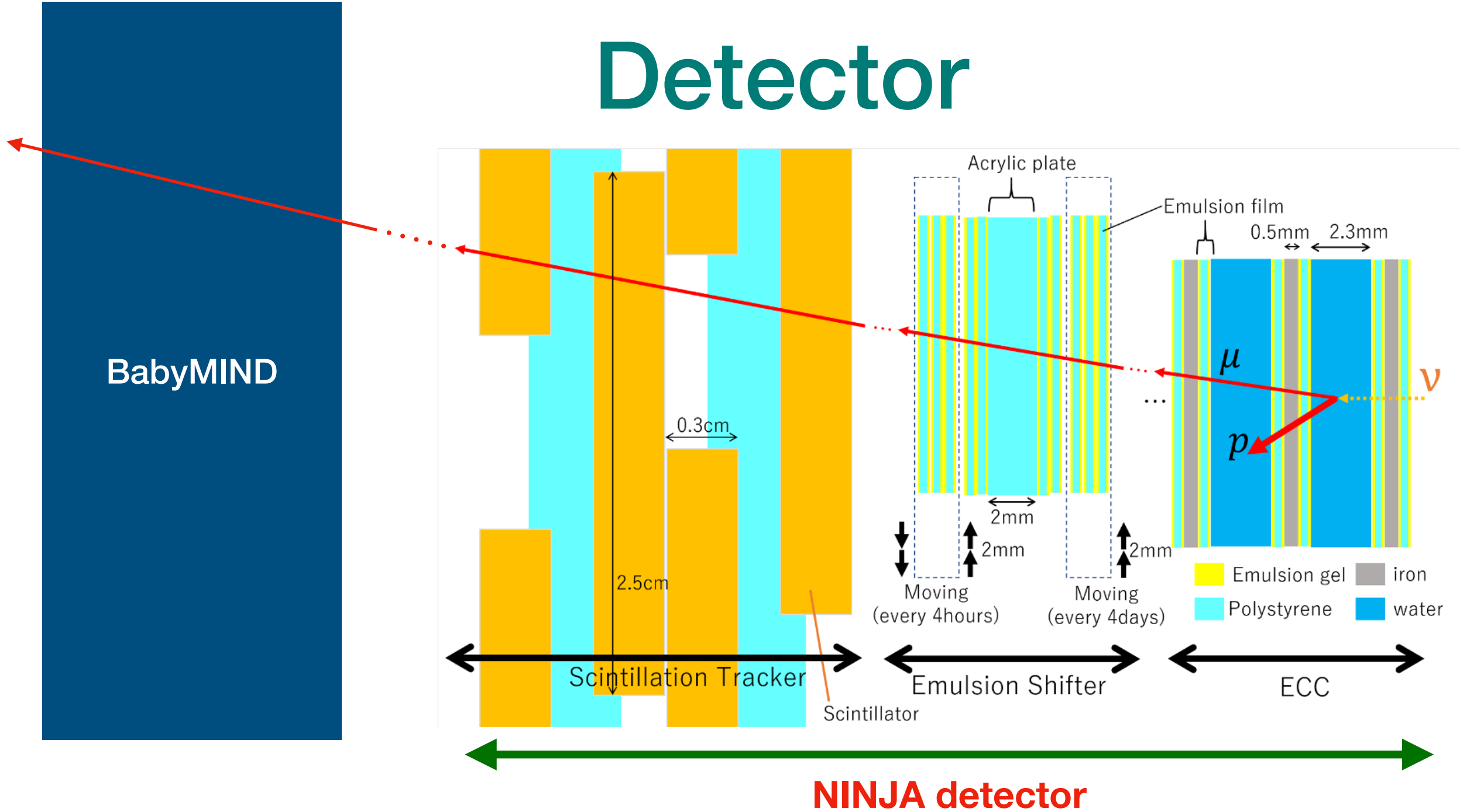
Period	POT	Detector	Site
Oct. 2014- Dec. 2014	1.3×10^{20}	2 kg iron detector, Emulsion shifter, INGRID	SS floor at NM
Jan. 2015- Apr. 2015	1.4×10^{20}	2 kg iron detector, Emulsion shifter, INGRID	SS floor at NM
May 2015- Jun. 2015	0.8×10^{20}	1.5 kg water target ECC	SS floor at NM
Jan. 2016- May. 2016	4.0×10^{20}	60 kg water target ECC, Medium emulsion shifter, INGRID	SS floor at NM
Dec. 2016- Apr. 2017	5.9×10^{20}	1.5 kg water target ECC	SS floor at NM
Nov. 2017- May. 2018	7.1×10^{20}	3 kg water target ECC, Scintillator fiber tracker, INGRID	SS floor at NM
Nov. 2019- Feb. 2020	4.8×10^{20}	75 kg water, 130 kg iron and 15 kg CH target ECC, Large emulsion shifter, Scintillator fiber tracker, Baby MIND	B2 floor at NM
Mar. 2021- Apr. 2021	1.8×10^{20}	9 kg heavy water ECC	B2 floor at NM
Nov. 2023- Feb. 2024	2.9×10^{20}	75 kg water, 130 kg iron and 15 kg CH target ECC, Large emulsion shifter, Scintillator fiber tracker, Baby MIND	B2 floor at NM
Nov. 2025- Mar. 2026	10.3×10^{20}	100 kg water, 175 kg iron and 20 kg CH target ECC, Large emulsion shifter, New scintillator fiber tracker (FROST), Baby MIND	B2 floor at NM

- NINJA performed several runs including 3 physics runs.
- E71 collected $\sim 1.76 \times 10^{21}$ POT
- FHC (ν mode) $\sim 1.24 \times 10^{21}$ POT
- RHC ($\bar{\nu}$ mode) $\sim 0.55 \times 10^{21}$ POT
- $\sim 4000 \nu_{\mu} CC$ events

Detector location

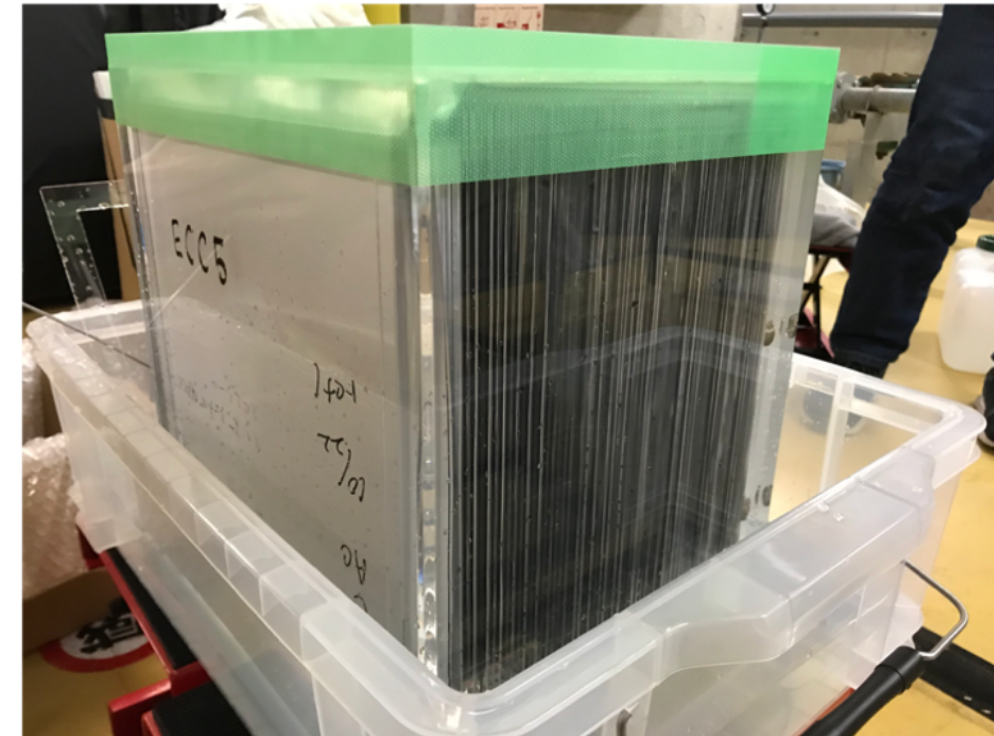
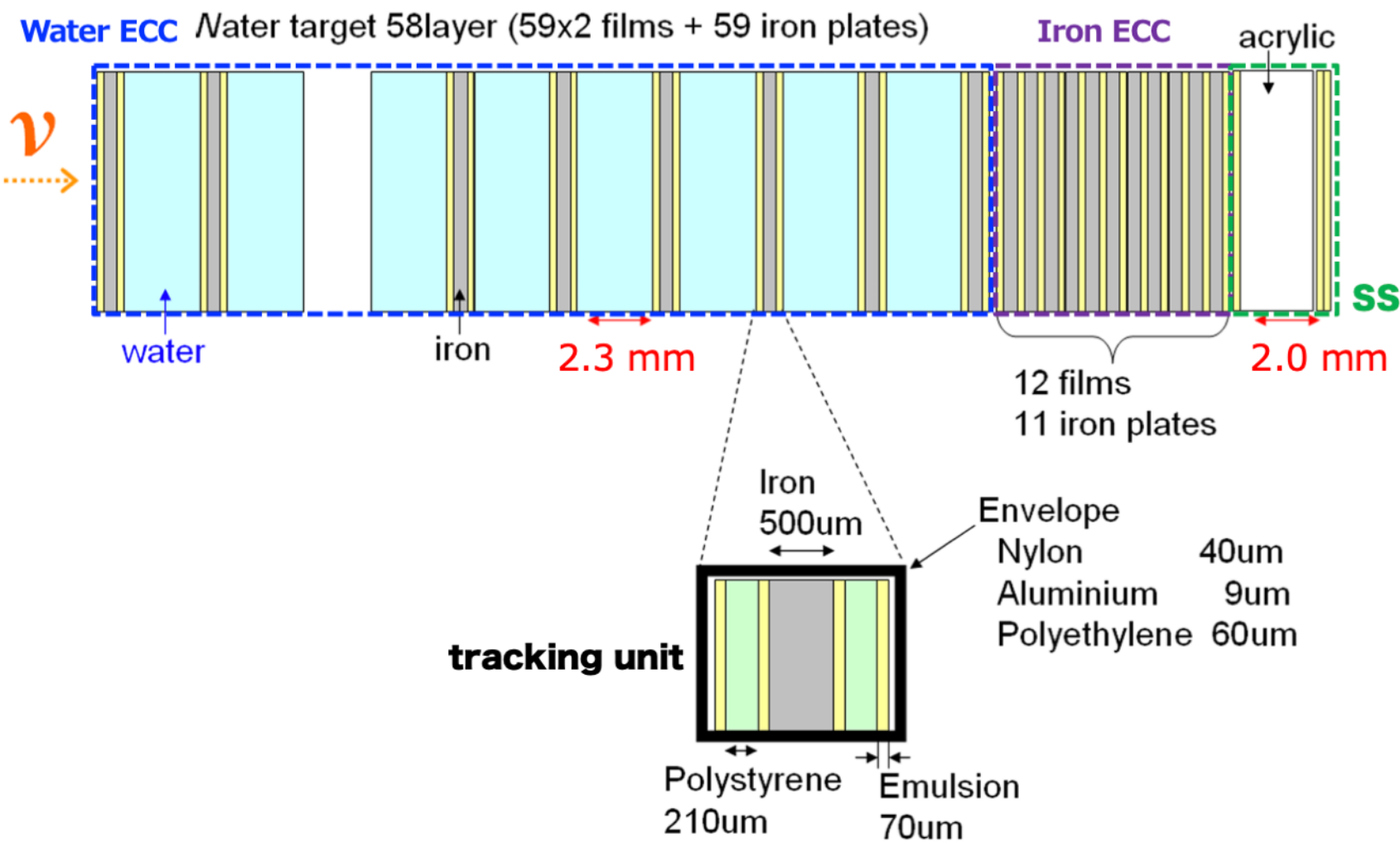


Detector



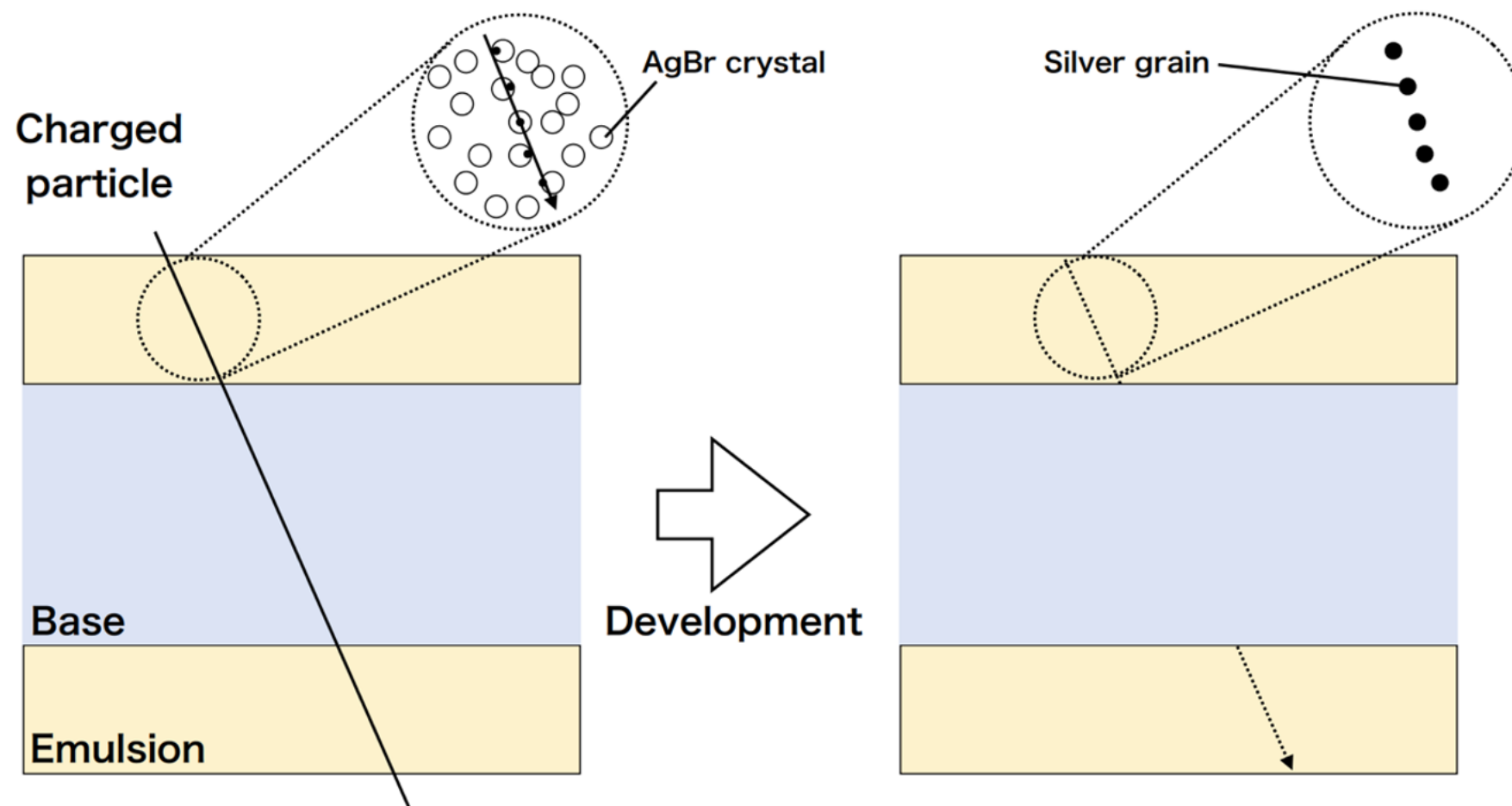
Detector	Position	Time resolution
ECC	O(μm)	∞
Emulsion Shifter	O(μm)	O(min-hour)
Scintillation Tracker	O(mm)	O(ns)
Baby MIND	O(cm)	O(ns)

ECC



- Made of nuclear emulsion films and iron plates submerged in water.
- E71a and E71b have 9 ECCs (3 X 3)
- E71c has 12 ECCs (4 X 3)

Nuclear emulsion

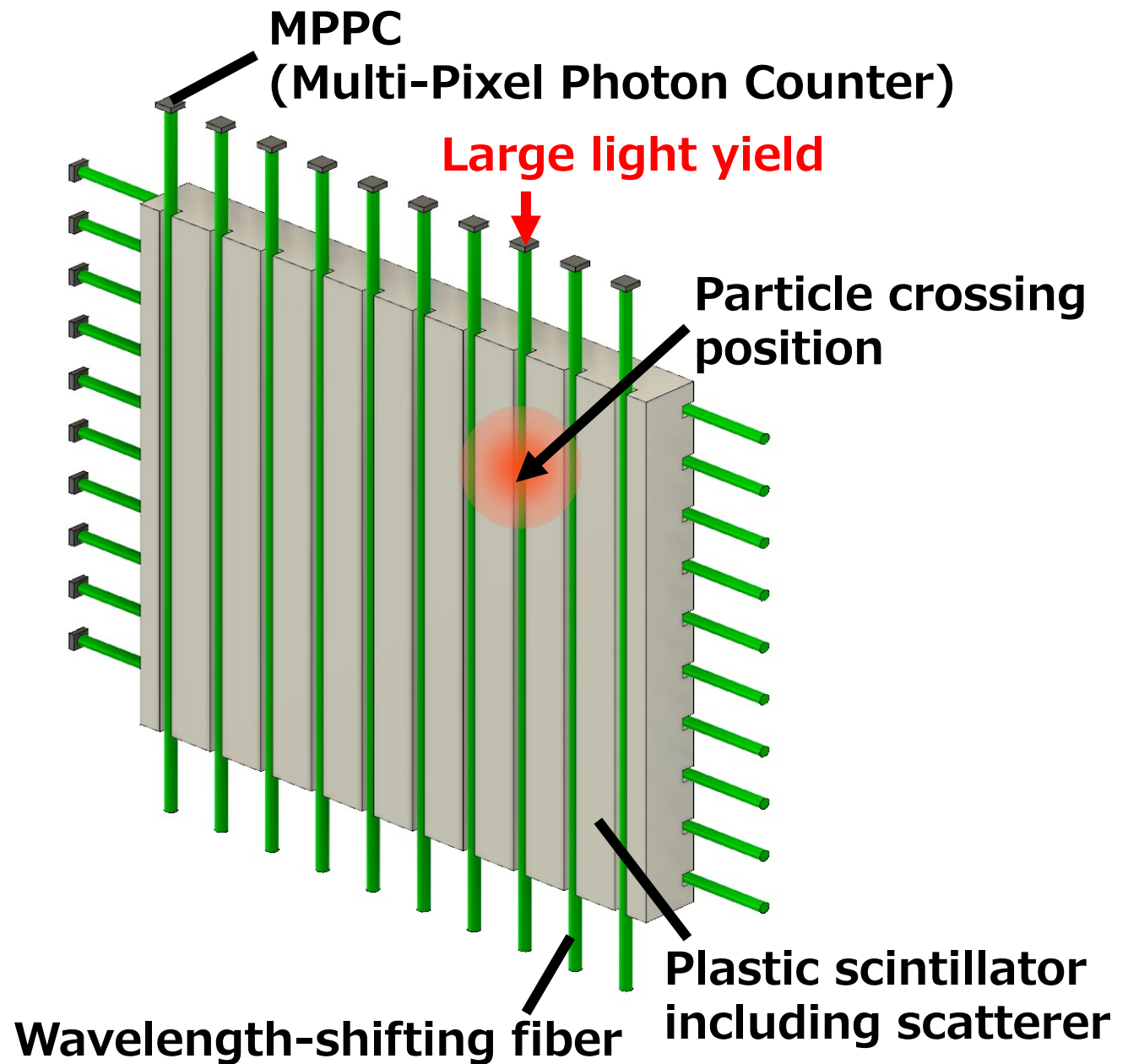


- Charge particles passing through will generate electrons which get trapped in the AgBr crystal.
- Development process attracts nearby silver ions to activated crystal and create silver grains.

FROST

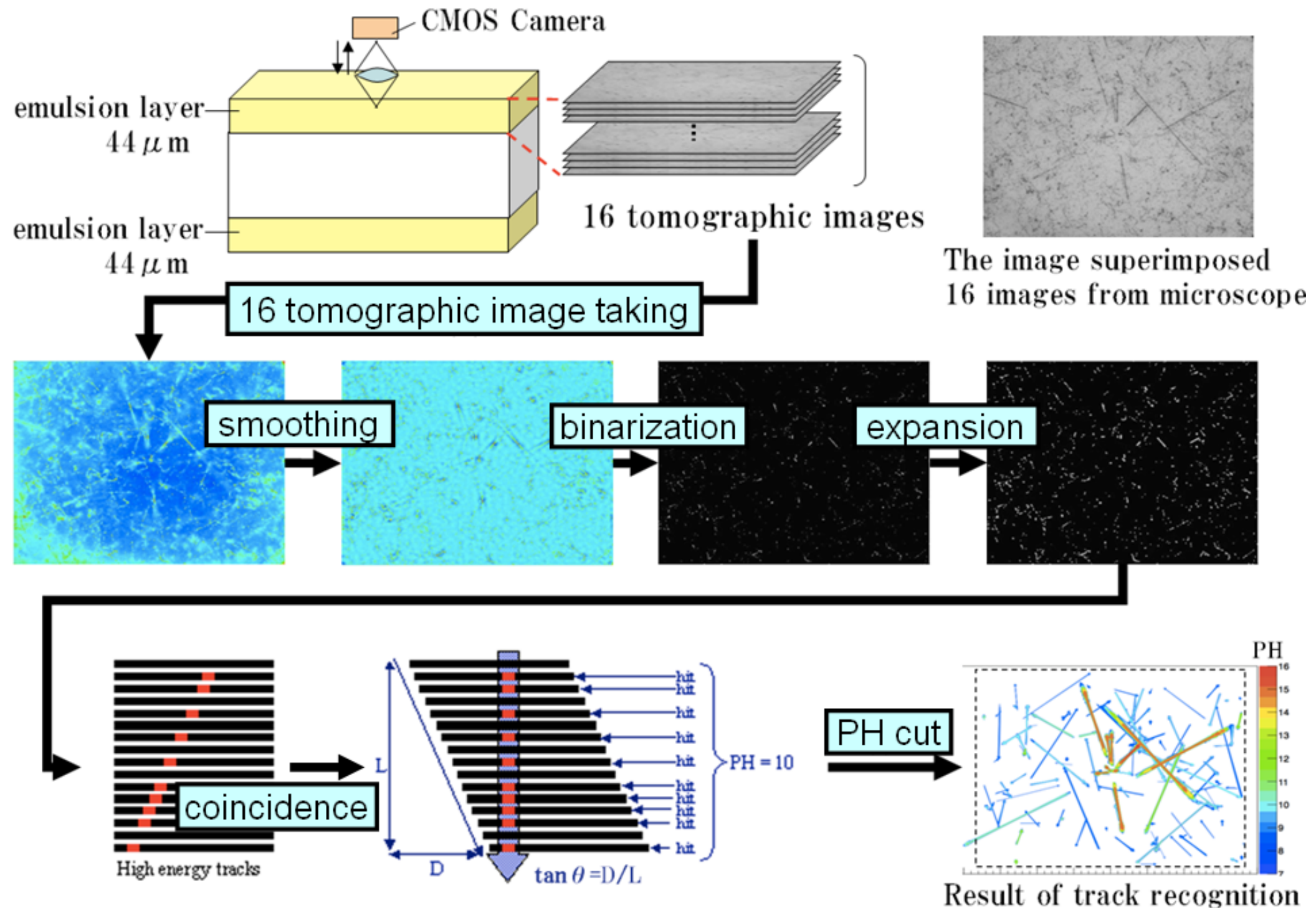
(Fiber-Readout mOnolithic and Scatterer-embedded scintillator Tracker)

- Tracker used to assign timing information to the ECC tracks.
- Position resolution $\sim 1.5\text{mm}$
- Tracks are matched with emulsion shifter and BabyMIND to assign the beam time to tracks.



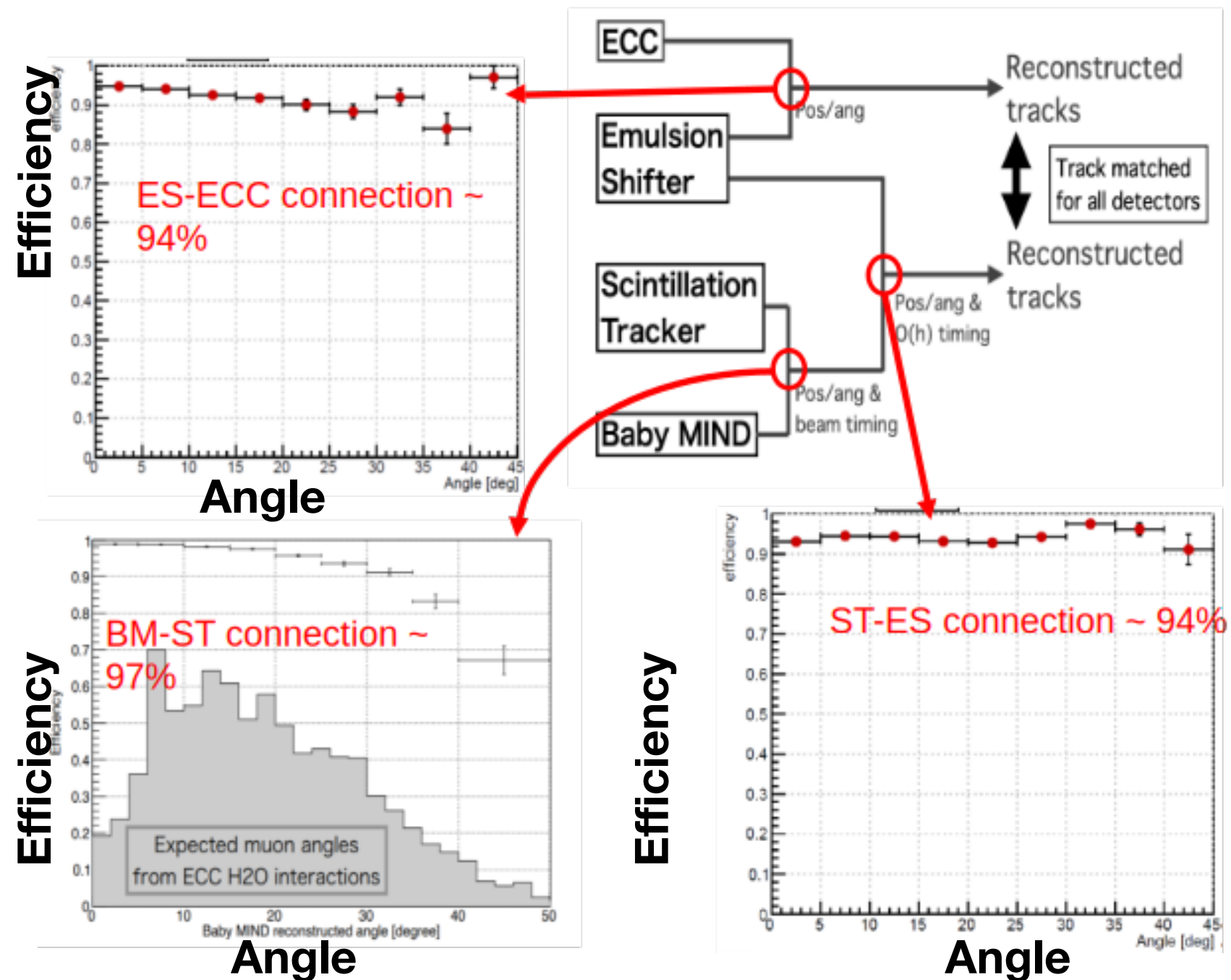
<https://arxiv.org/abs/2604.03107>

Emulsion film scanning system



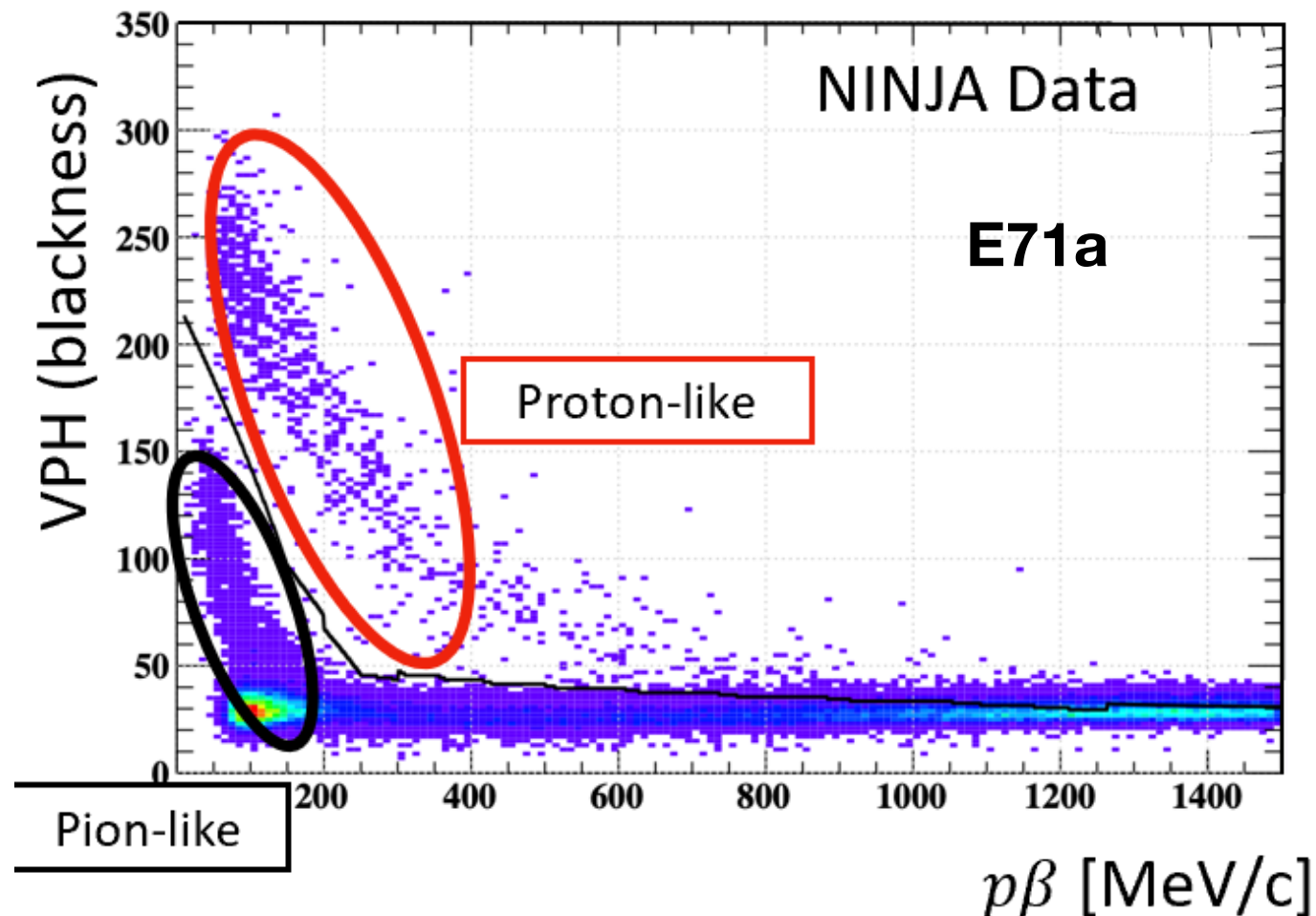
Track reconstruction

- Tracks are matched between ECC, Emulsion Shifter(ES), Scintillator Tracker(ST) and BabyMIND.
- 80-90% muon track connection efficiency with BabyMIND and $< 50^\circ$ angular acceptance wrt beam axis.



Momentum reconstruction

All tracks accumulated
during the exposure



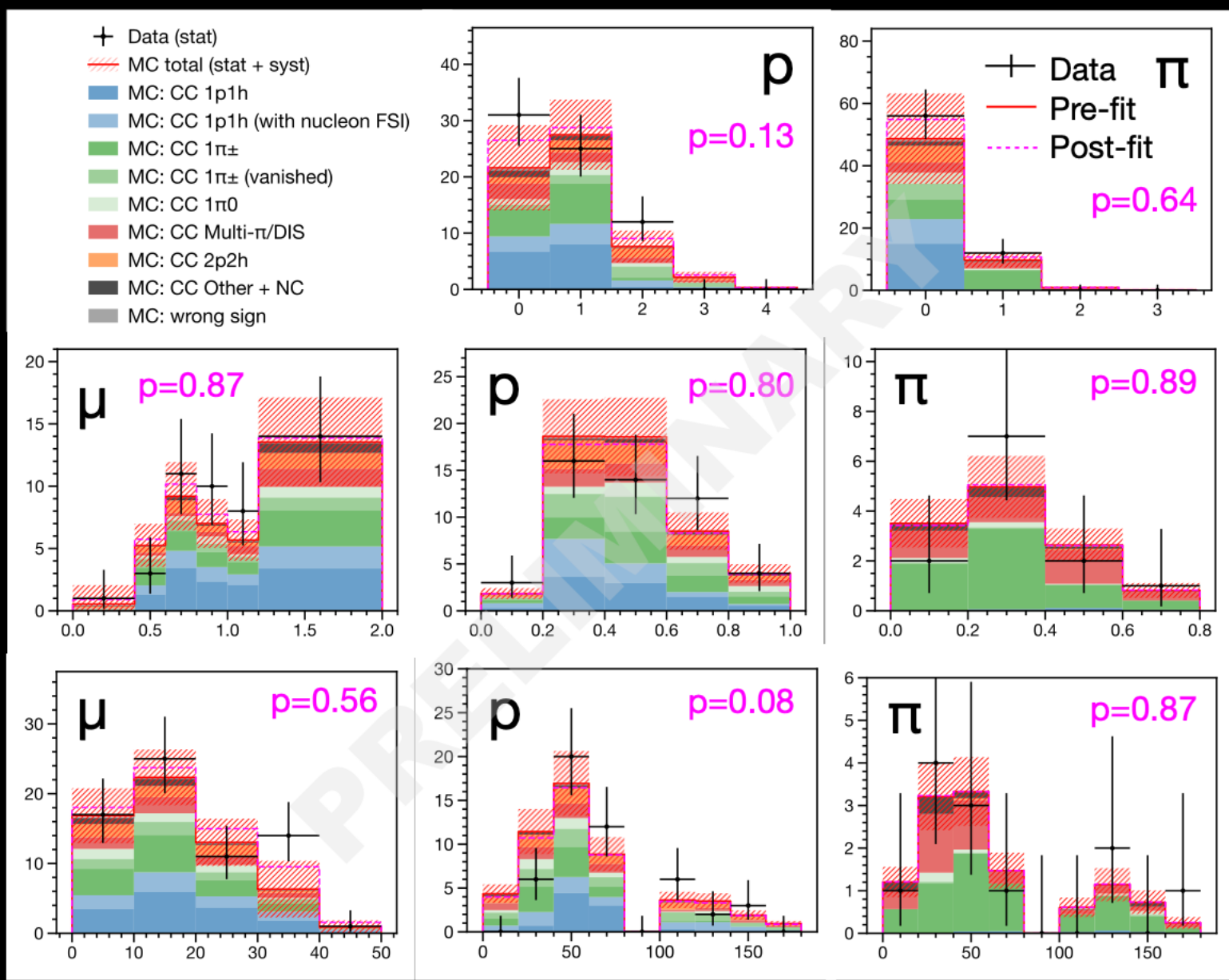
PID purity
Muons ~ 97%
Protons ~ 99%
Pions ~ 93%

- Momentum reconstruction in ECC is done using multiple coulomb scattering.
- The momentum is reconstructed using highland formula.
- Effective momentum
$$p\beta \approx 0.14 \times \frac{13.6 \text{ MeV}/c}{\theta_{RMS}}$$
- Uncertainty for μ below 1 GeV/c ~ 15%.

E71a results at Neutrino 2026

(poster by S. Han)

Minimized Binned Poisson χ^2 + Gaussian nuisance penalty POT normalized

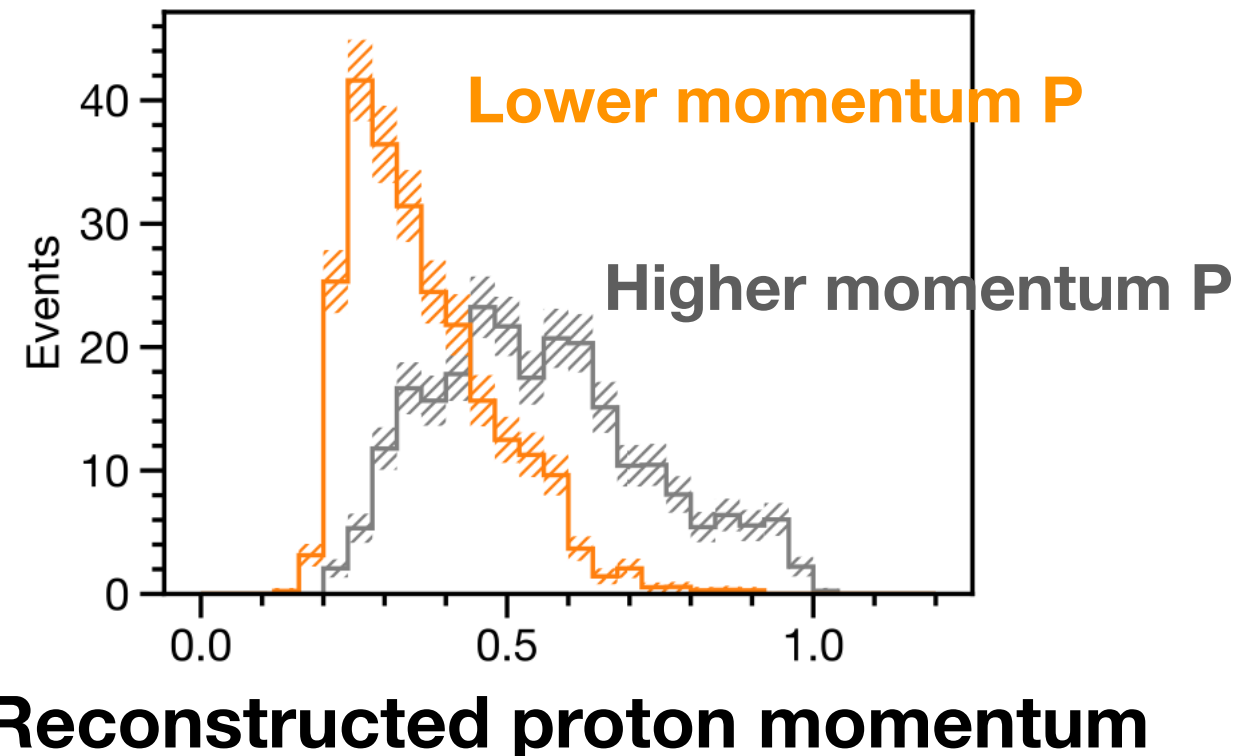
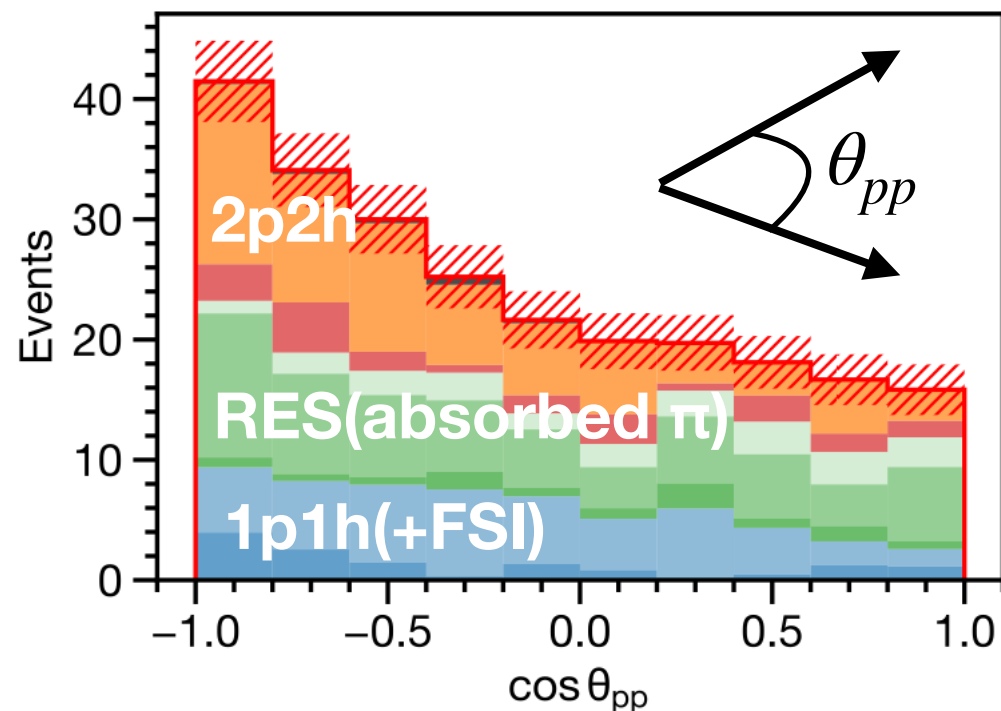


- Muon, proton and pion kinematics of 68 CC inclusive events (4×10^{20} POT on 4 kg water)
- Only 2% of collected data.
- Many uncertainties still need to be reduced especially muon connection efficiency and momentum systematics (~20%)

Future prospects

- Once the full data is ready for analysis, we expect ~ 4000 $\nu_\mu CC$ events and ~ 300 $\nu_\mu CC0\pi2p$ events.
- These event are crucial in studying 2p2h interaction models.

$\nu_\mu CC0\pi2p$ like events (MC)



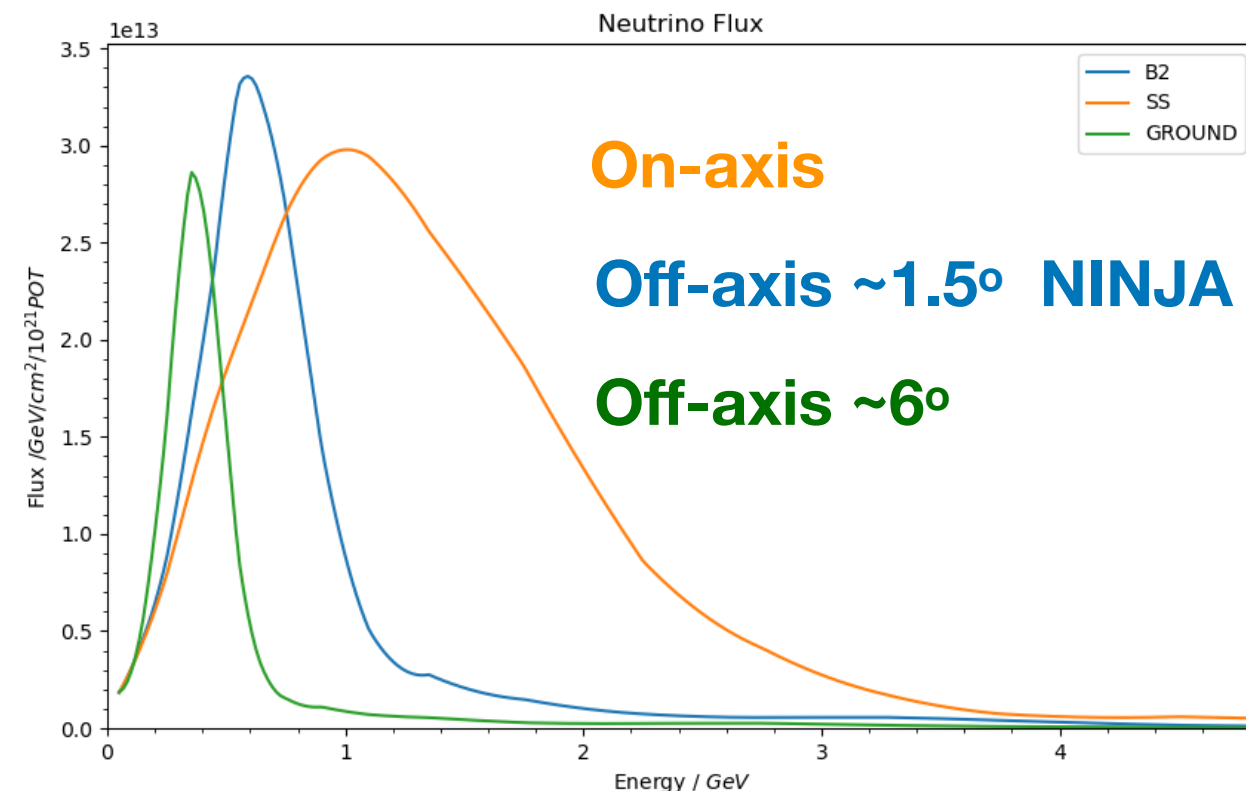
Activities related to MAPS

T114 test experiment

- Last year we submitted the test experiment proposal to J-PARC neutrino group.
- Place a small emulsion detector at the ground floor(off-axis 6°) of ND280 building.
- Study various background to asses the feasibility of future physics run.
- Data collected during Mar-Apr 2026, emulsion films being scanned now.

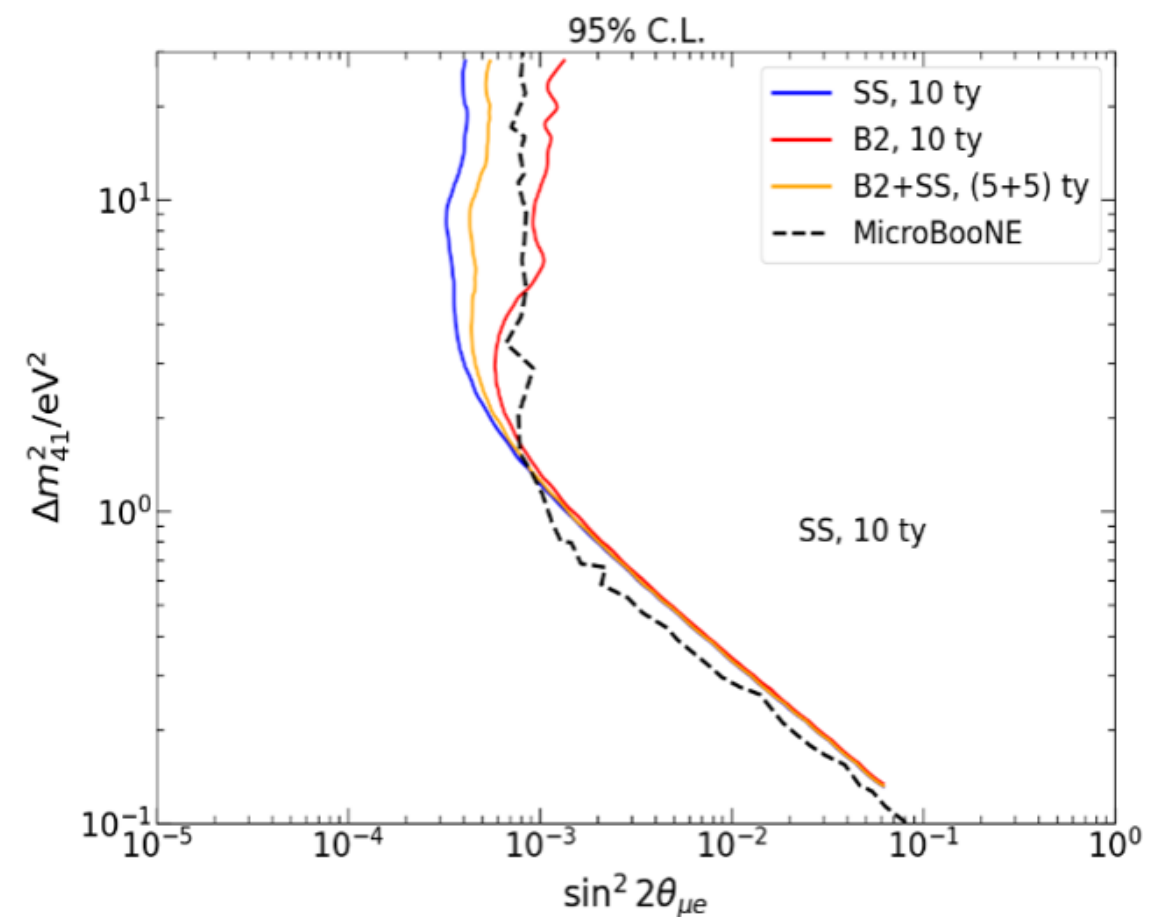
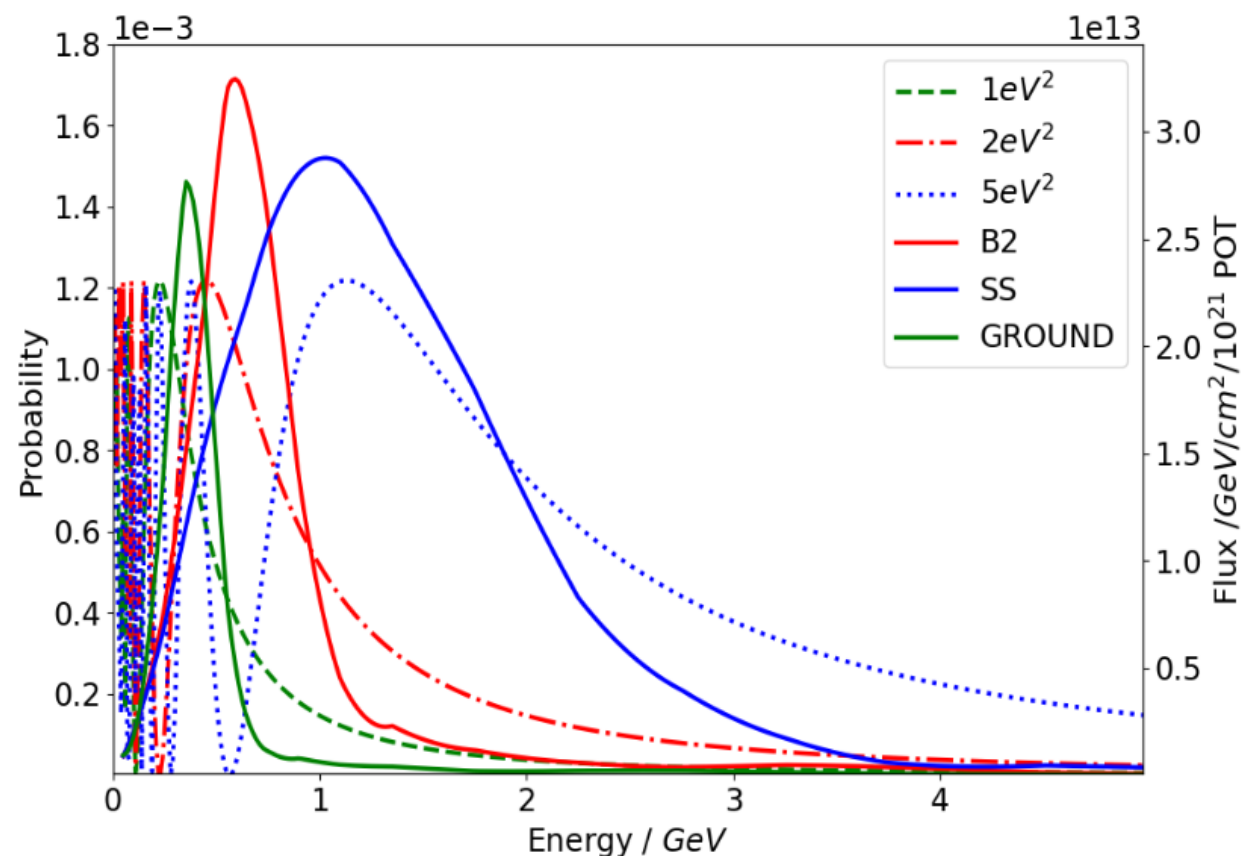
Emulsion bricks

Muon counter



Sterile sensitivity with NINJA

- Doris and Monojit have done a study on sterile neutrino probing capability of NINJA like detector with T2K flux.
- Change locations of detector -> different off-axis beam
- The paper discussing the result is submitted to arXiv this week. (<https://arxiv.org/abs/2606.30135>)



Future plans

- T114
 - Finish scanning the films by the end of summer.
 - Start data analysis and have preliminary results towards the end of year.
- NINJA analysis
 - E71a -> data is reconstructed and ready for physics analysis - Bruno will likely start analysing this data set.
 - E71b -> Global reconstruction needs to be finished by combining NINJA and BabyMIND tracks - I am working on this.
- We can discuss more possible cross-section related studies with NINJA data.

Backup

E71 run summary

E71a

POT summary

Period	Tracker Recorded	Delivered
2019/11/07-2019/12/19	2.64841E20	2.64957E20
2020/01/14-2020/02/12	2.11531E20	2.11645E20
Total	4.76372E20	4.76602E20

E71b

POT summary

Period	Tracker Recorded	Delivered
2023/11/23 - 12/25, 2024/2/4 - 2/24	2.88694E20	3.12073E20

E71c

Period	Neutrino mode	Delivered POT
2025/11/29-12/22, 2026/01/17-01/28, 2026/03/11-03/25	FHC	4.74065E20
2026/01/28-03/11	RHC	5.51798E20
2025/11/29-12/22, 2026/01/17-03/25	Total	10.25863E20