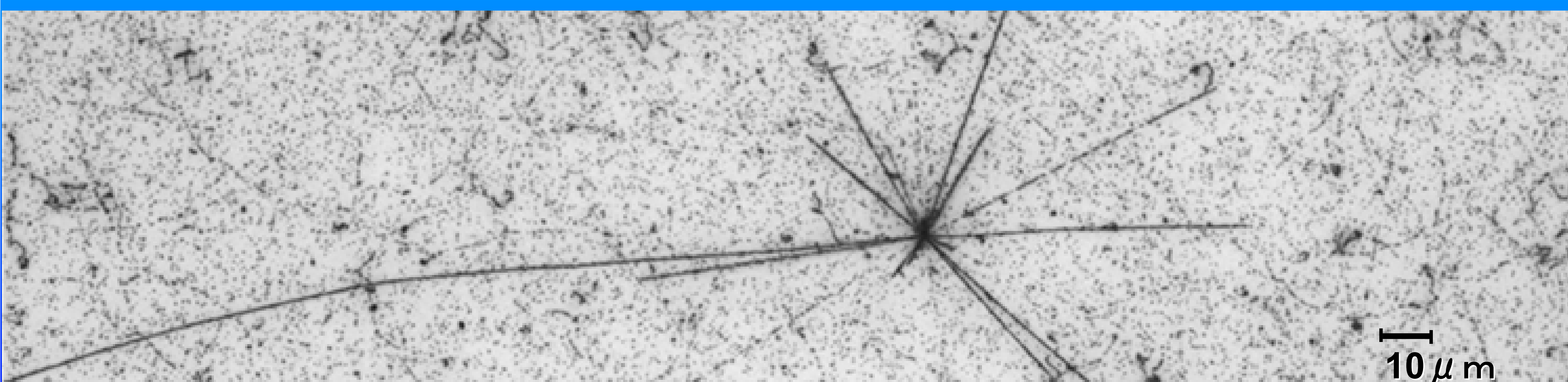
NINJA

NINJA Experiment :

Neutrino Interaction research with Nuclear emulsion and J-PARC Accelerator

Tsutomu Fukuda (IAR/Flab, Nagoya Univ. Japan)
on behalf of the NINJA Collaboration



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NuInt 2018, 18th Oct. 2018 @GSSI, L' Aquila

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- NINJA Experiment
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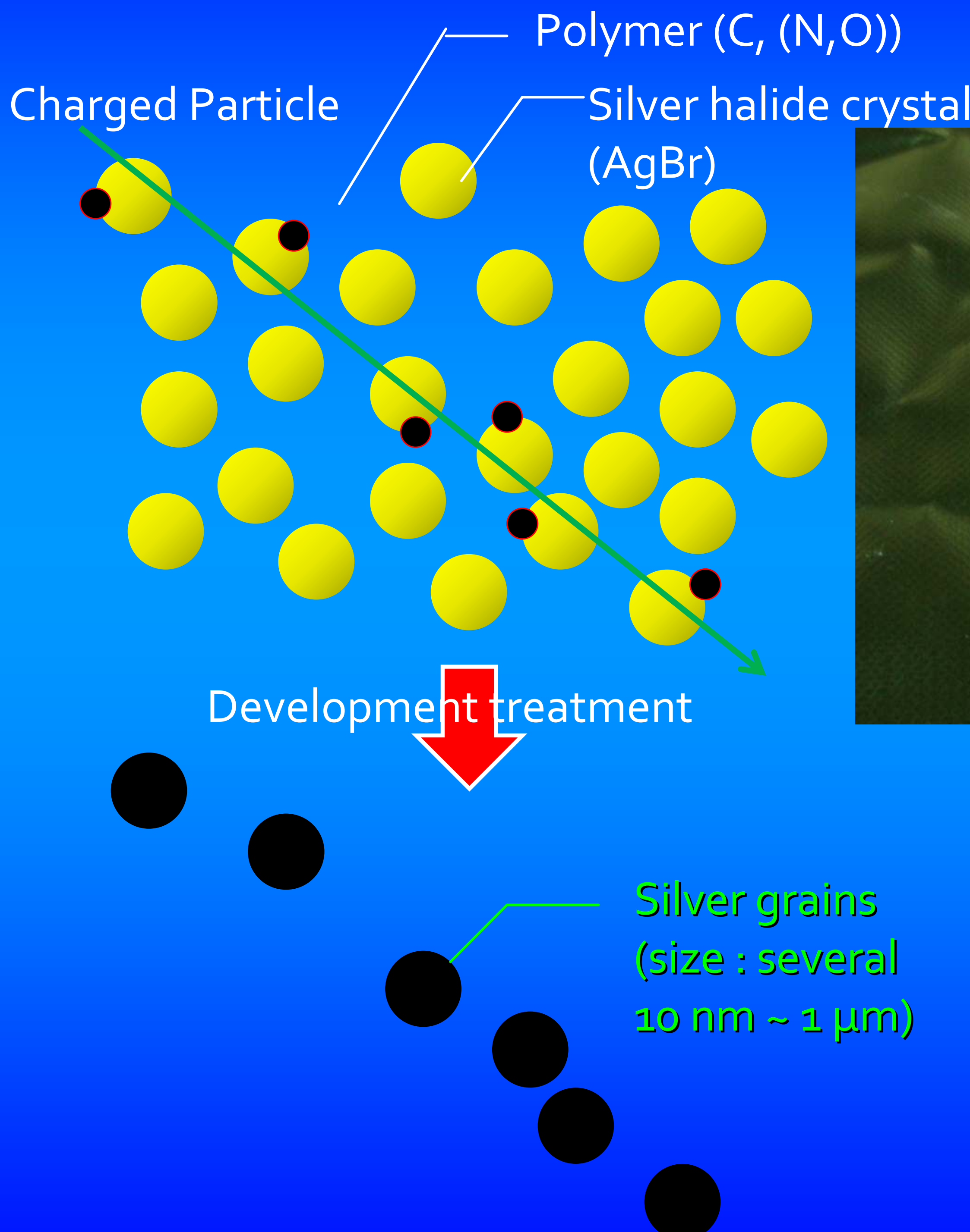
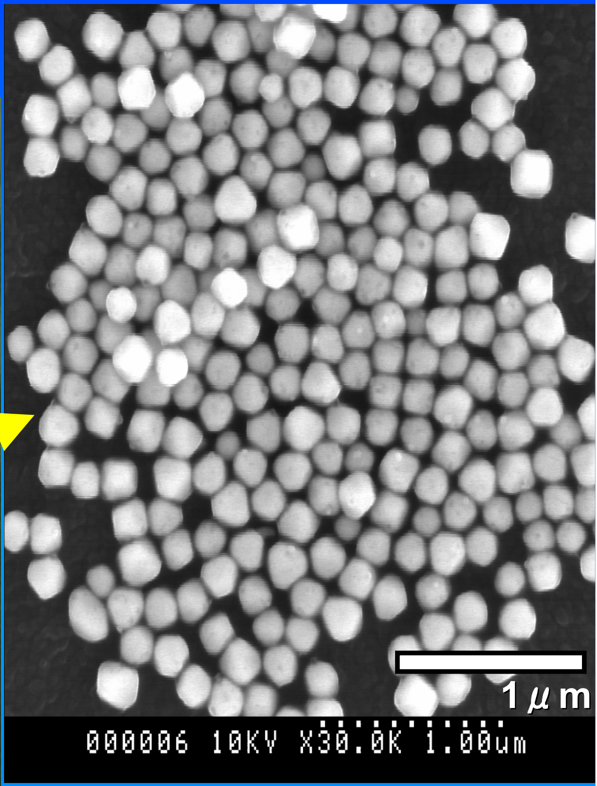
Nuclear Emulsion



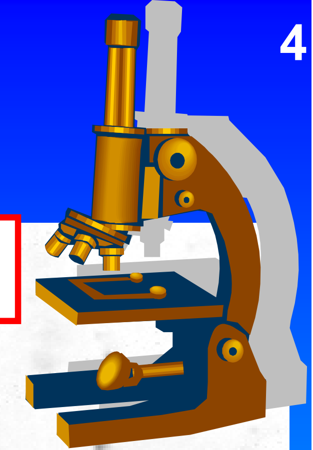
AgBr・I crystal



Spatial resolution
- silver halide crystal size
- number density of silver halide crystal

Sensitivity
- Chemical treatment
- Crystal defect and doping etc.

Nuclear Emulsion



1896 (A.H.Becquerel)
Discovery of Radioactivity

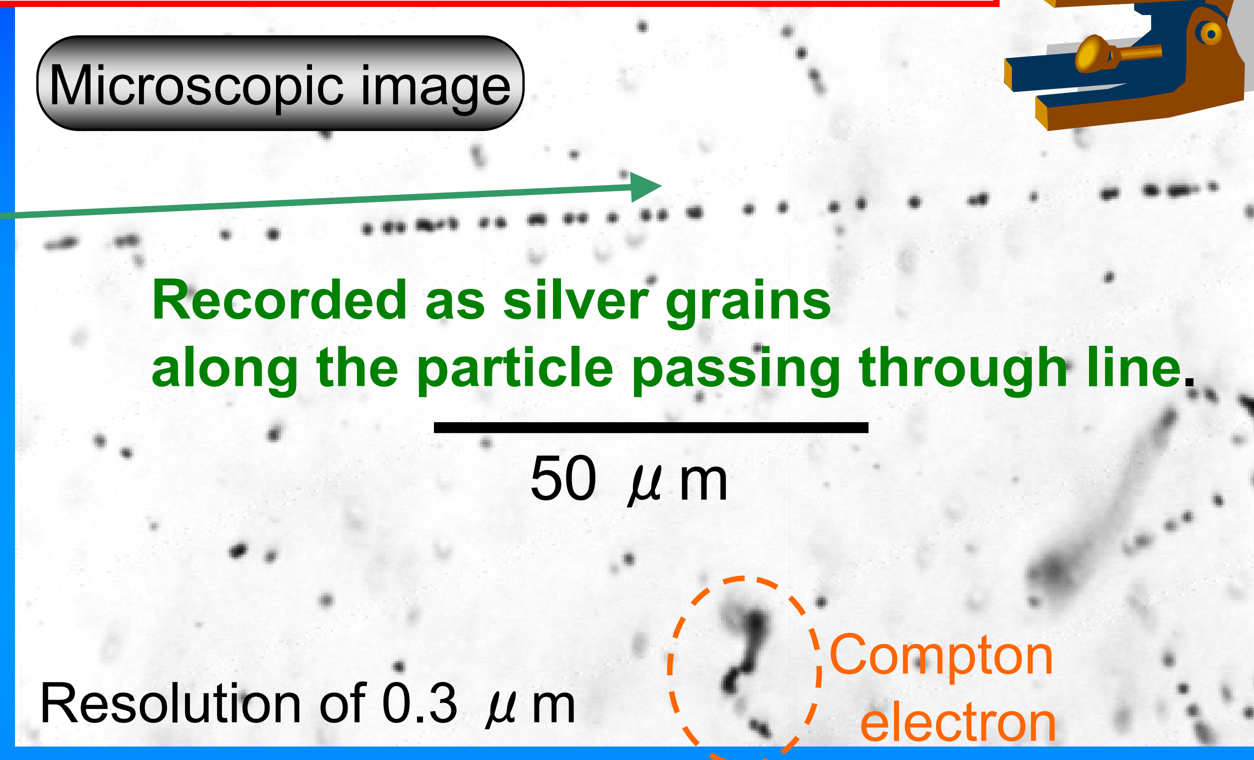
1947 (C.Powell et al.)
Discovery of π

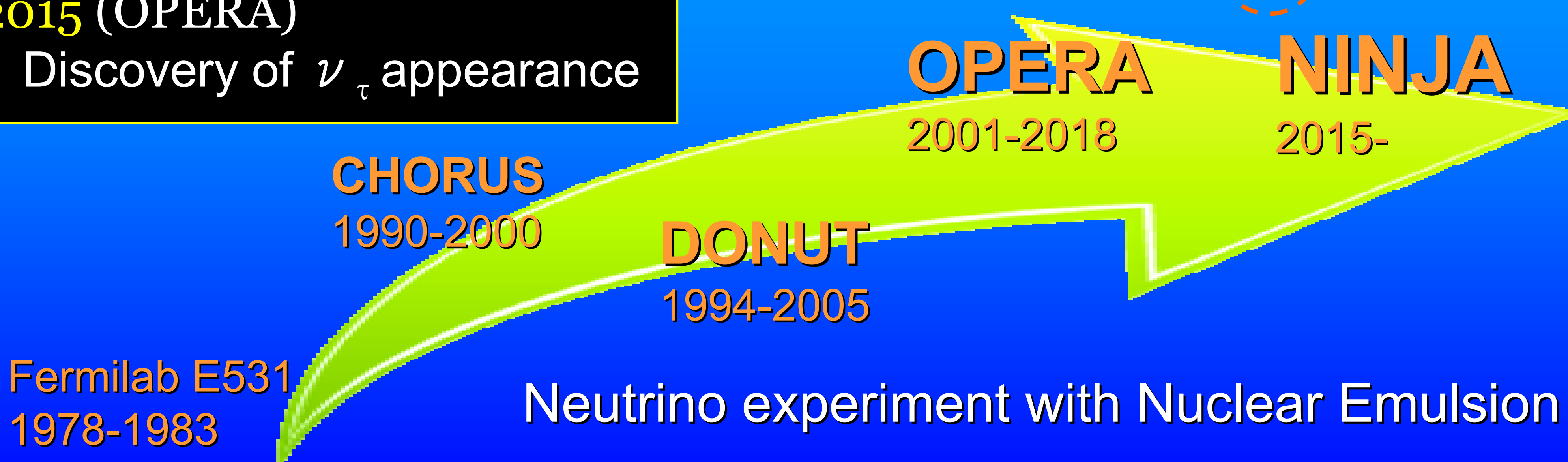
1971 (K.Niu et al.)
Discovery of charm particle in cosmic-ray

2001 (K.Niwa et al.)
Direct observation of ν_τ

2015 (OPERA)
Discovery of ν_τ appearance

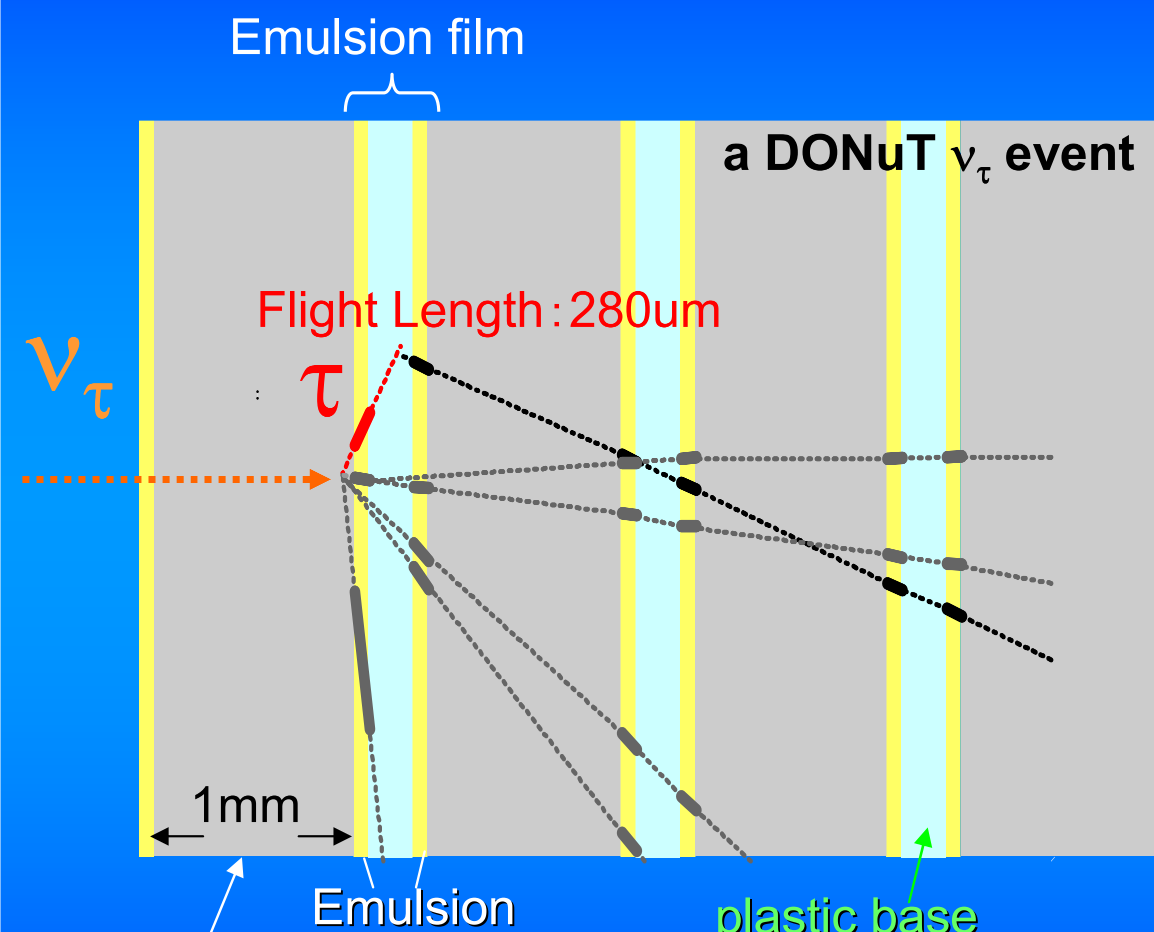
Sub micron resolution 3D tracker





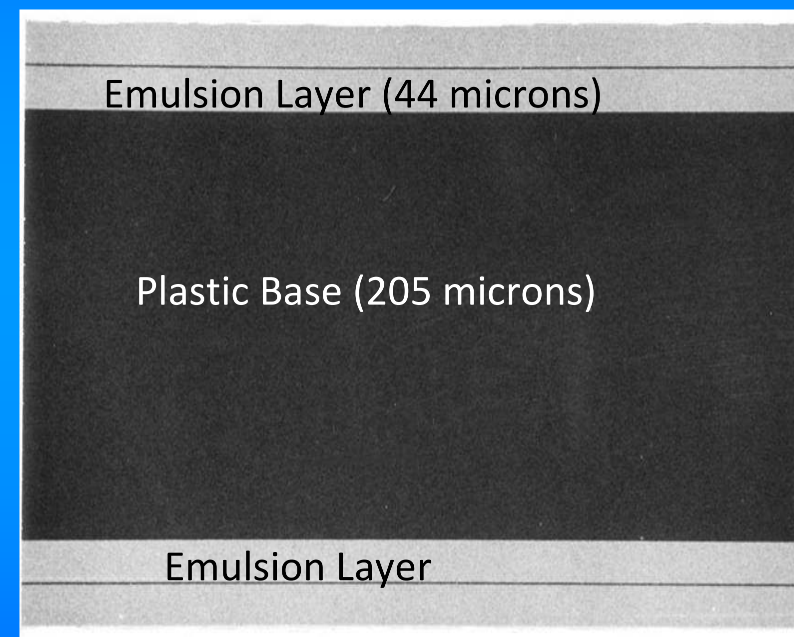
Neutrino experiment with Nuclear Emulsion

Emulsion Cloud Chamber (ECC)



DONuT : Iron 1mm
OPERA : Lead 1mm
NINJA : Iron 0.5mm, Water 2mm

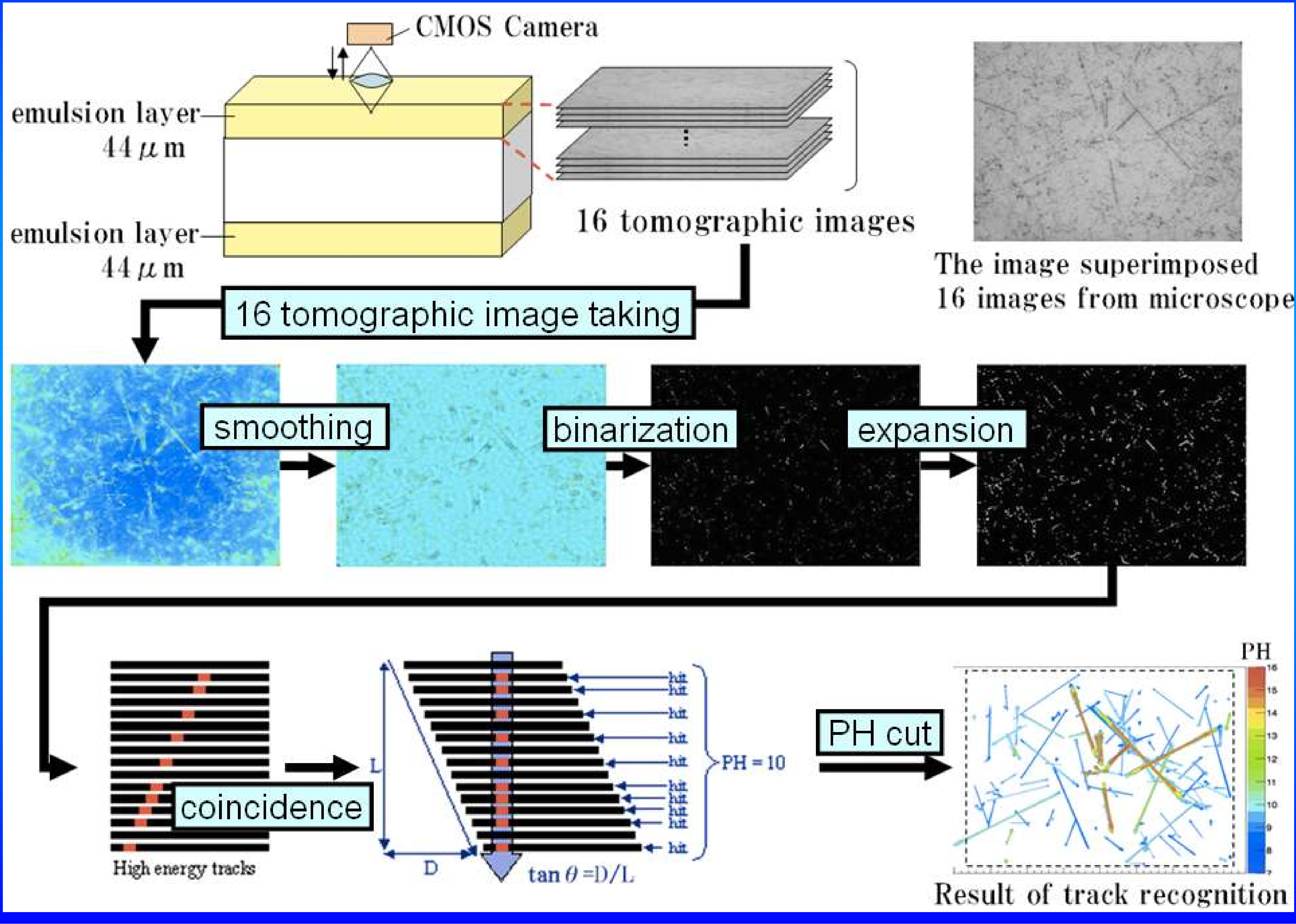
basic detector: AgBr crystal,
size = 0.2 micron
detection eff.= 0.16/crystal
10^{13} "detectors" per film



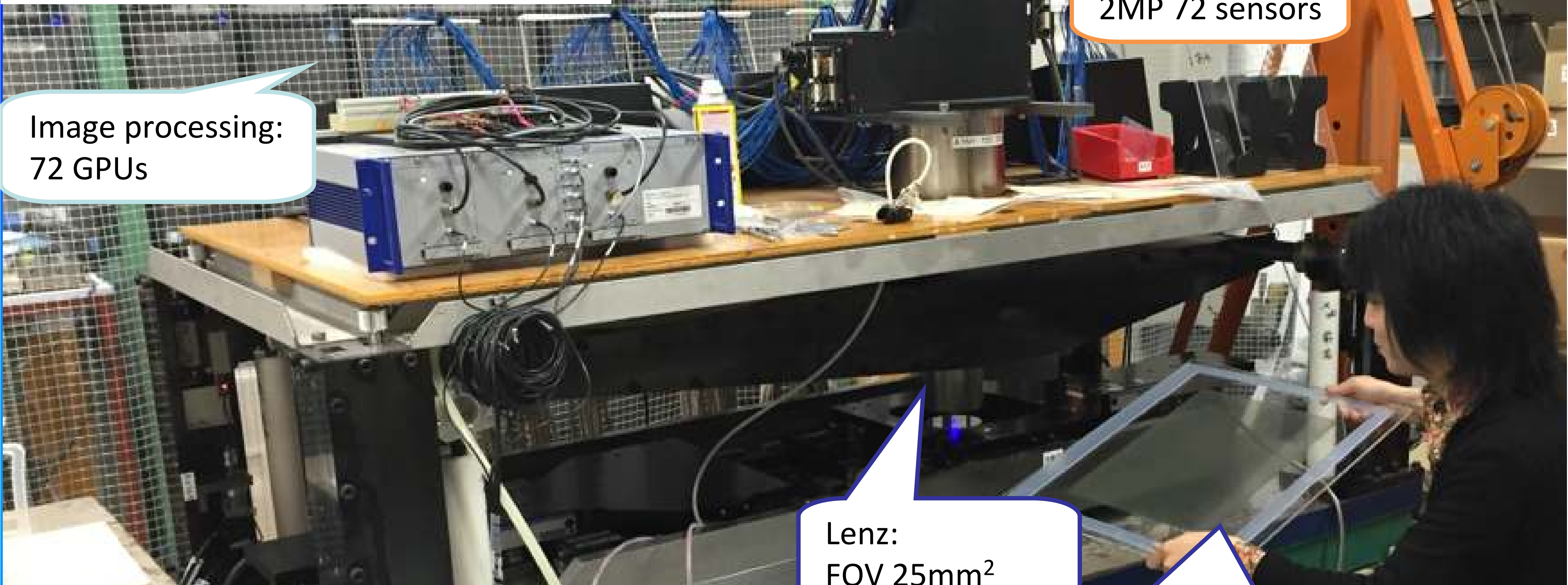
44-70 μ m emulsion gel were coated on both sides of the ~200 μ m-thick plastic base.

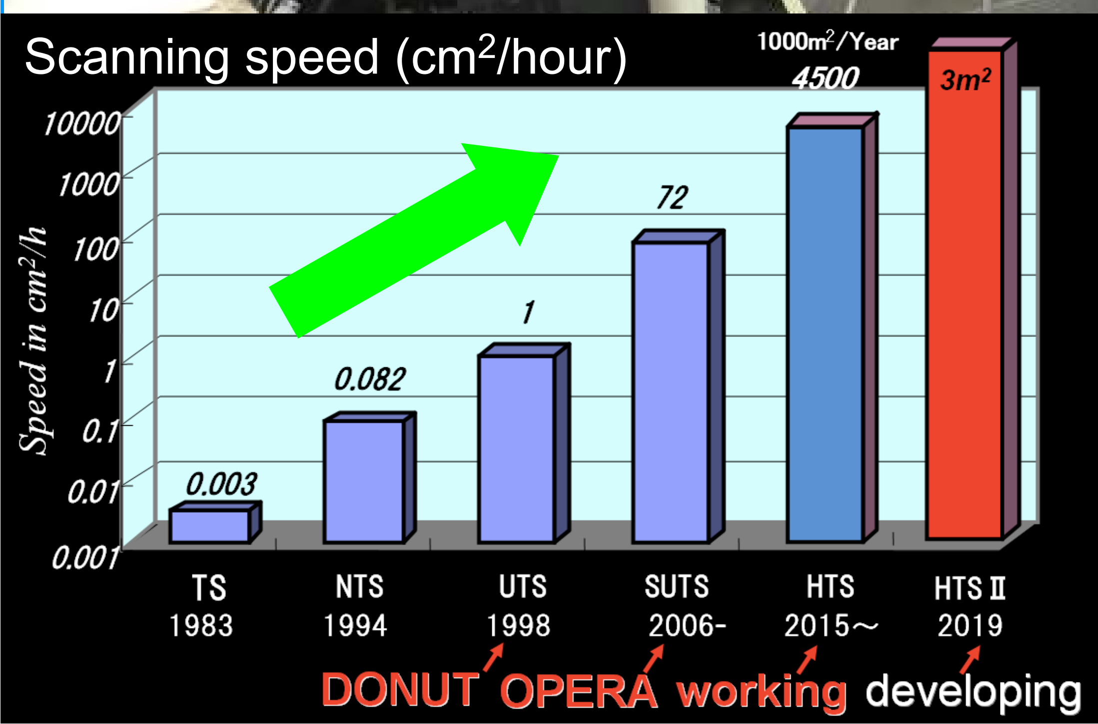
Sandwich structure of emulsion films and target material.

Automatic track recognition

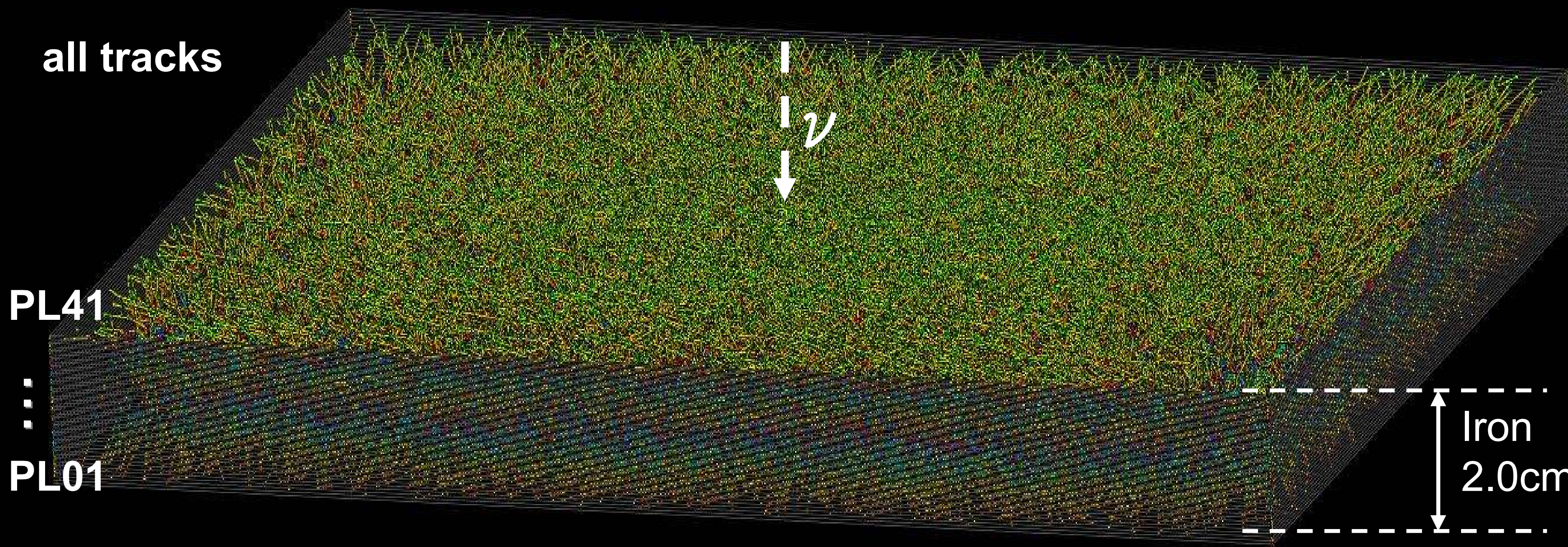


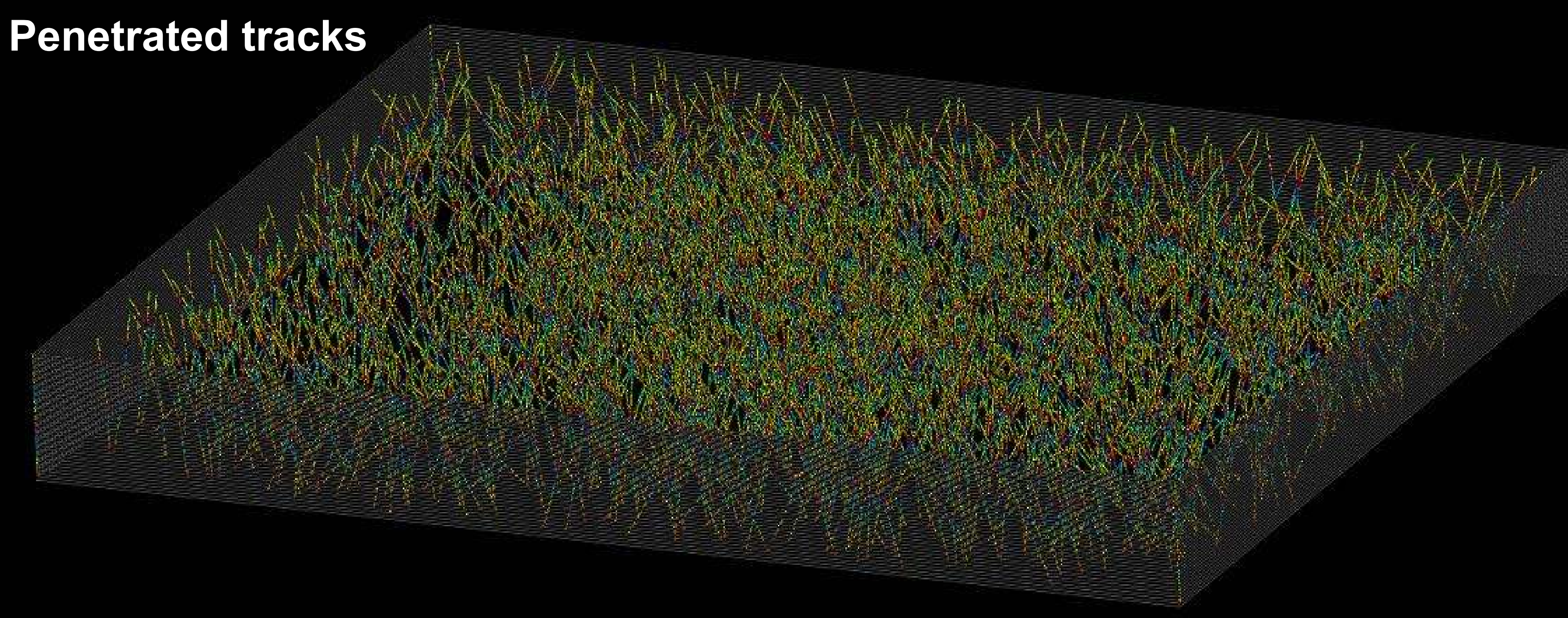
Hyper Track Selector



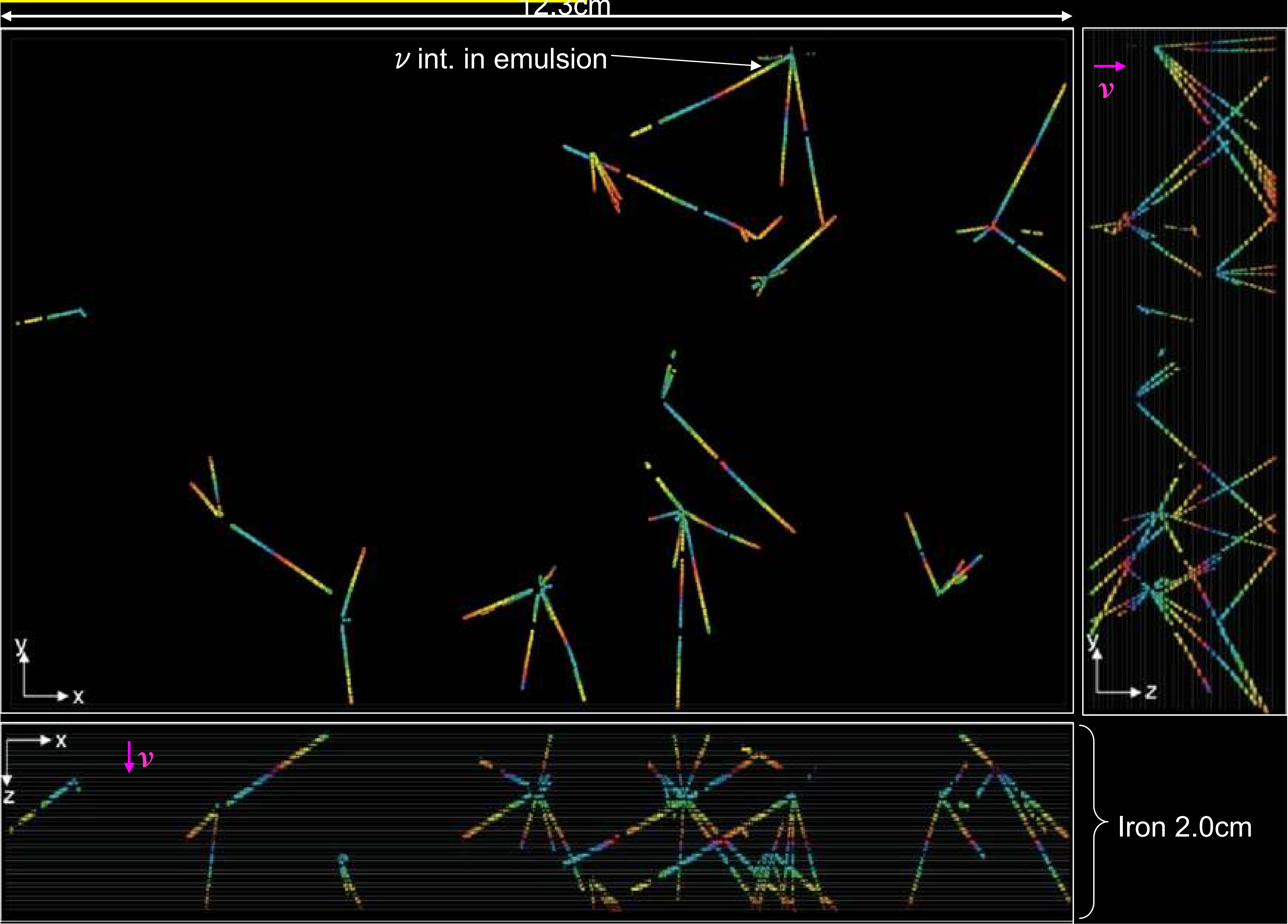


Reconstructed track data





NINJA: Feasibility study: 2kg Iron target ECC



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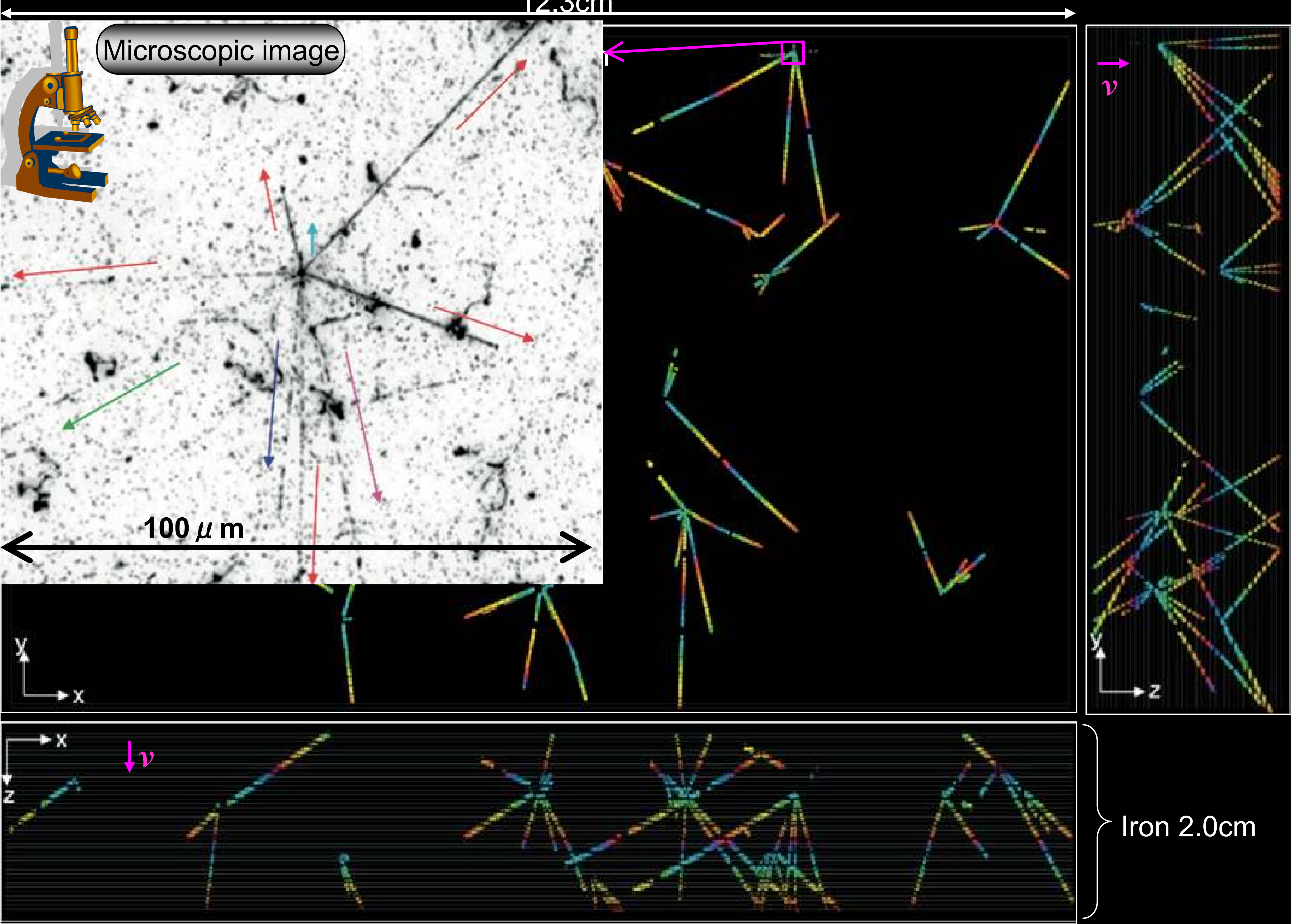
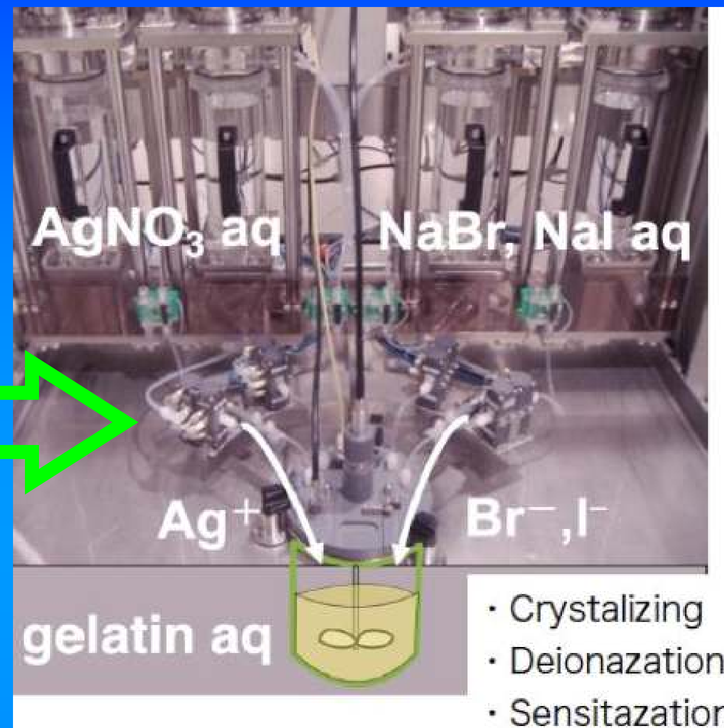


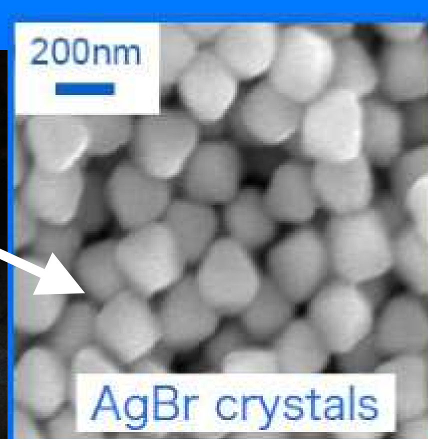
Emulsion film production in the lab

Nuclear emulsion films were made by ourselves

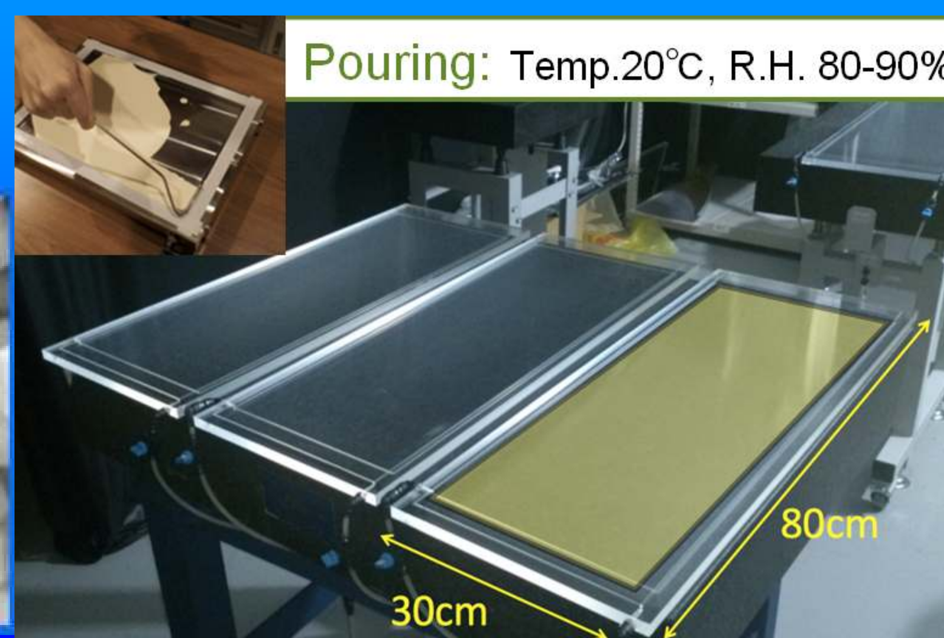


Preparing liquid ⇩ **Gel production** ⇩ **Gel melting** ⇩ **Pouring** ⇩ **Drying**

Gelatin + crystal



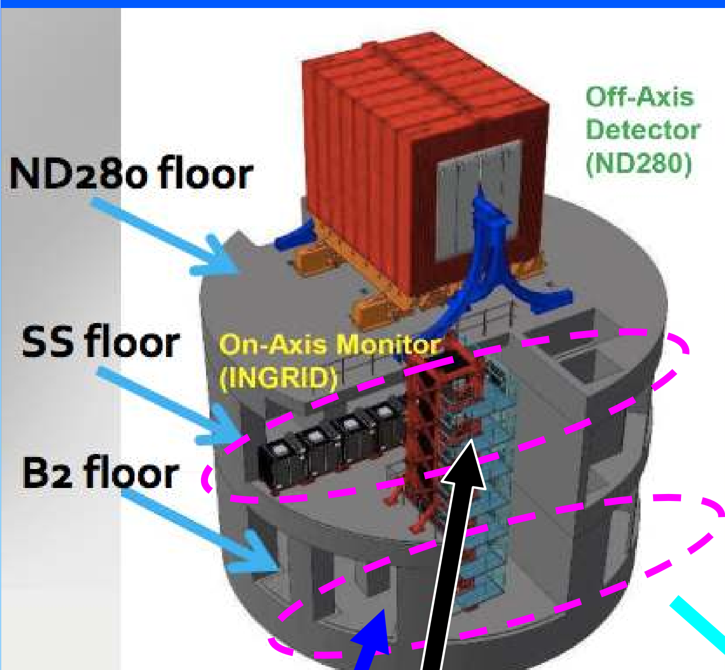
Pouring: Temp.20℃, R.H. 80-90%



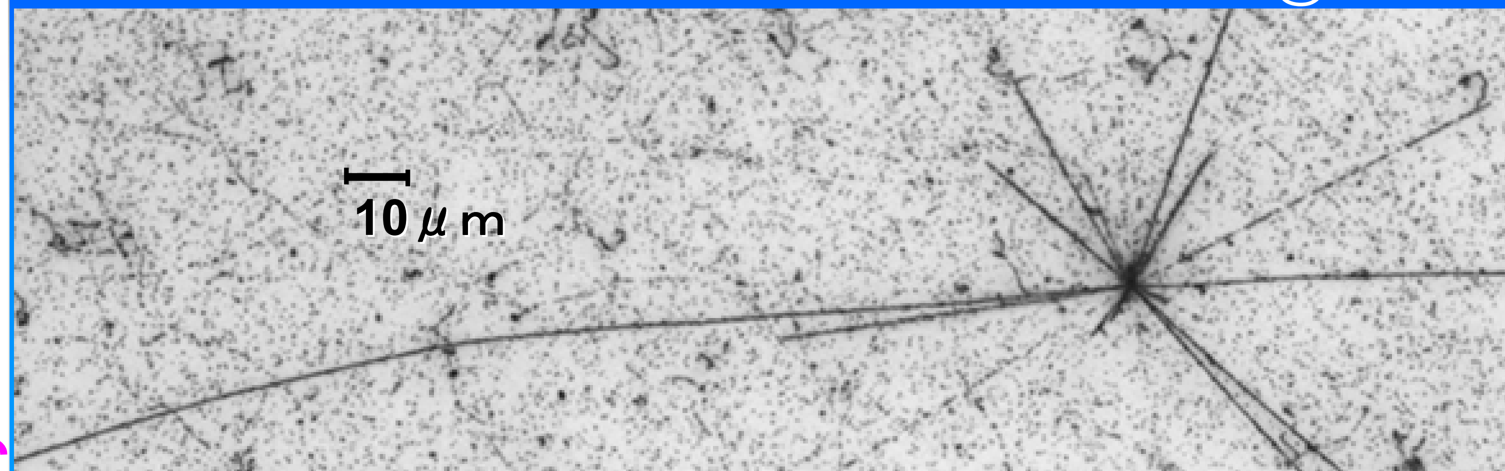
Drying: Temp. 30℃ R.H. 70-80%

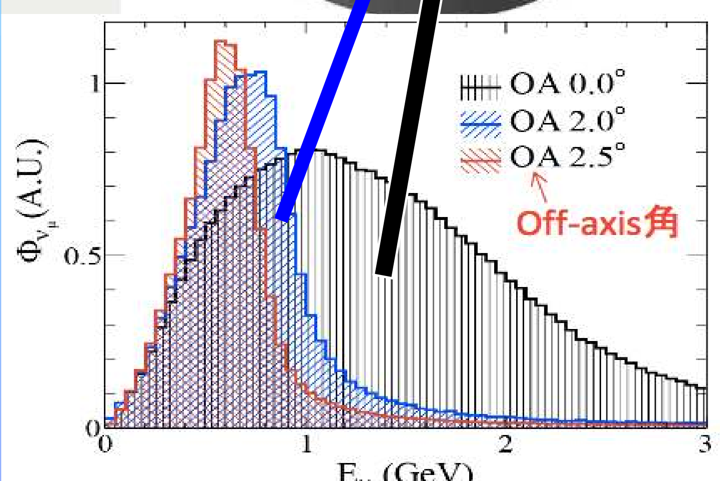
NINJA Experiment

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

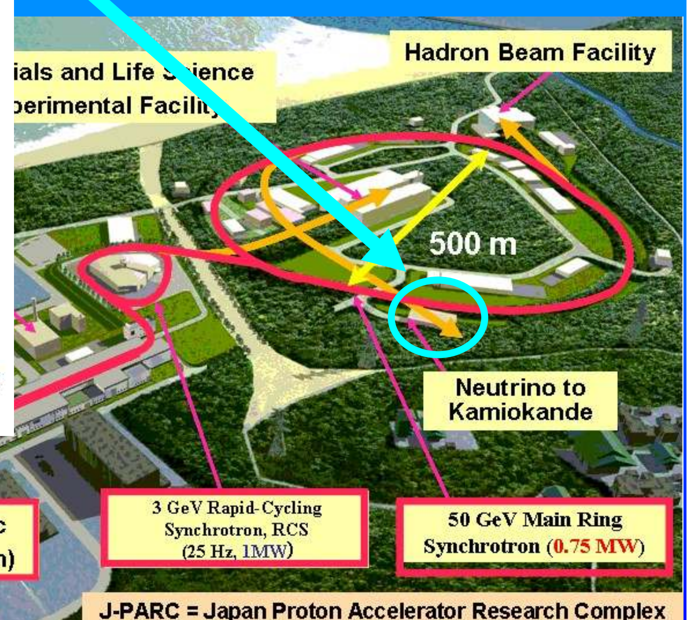


A neutrino interaction in emulsion @J-PARC





A collaborative project with some member of OPERA and T2K



Working group

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

NINJA Experiment

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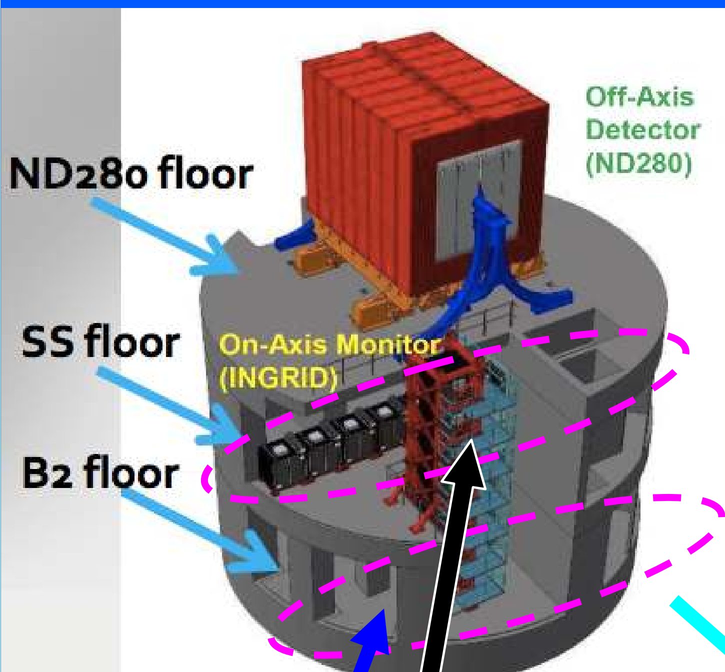

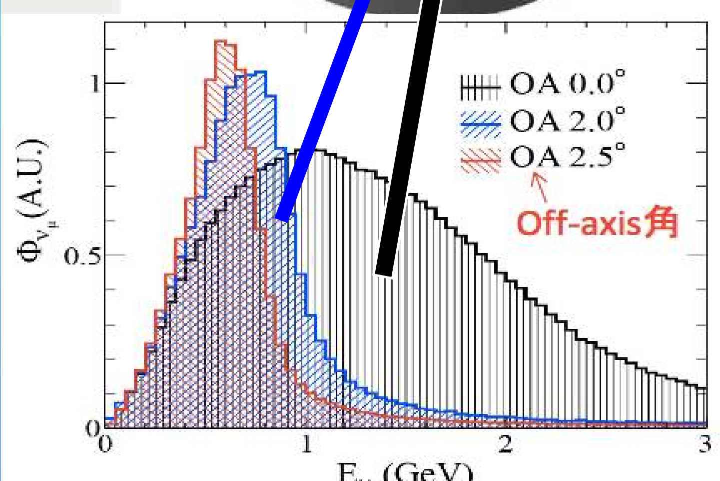

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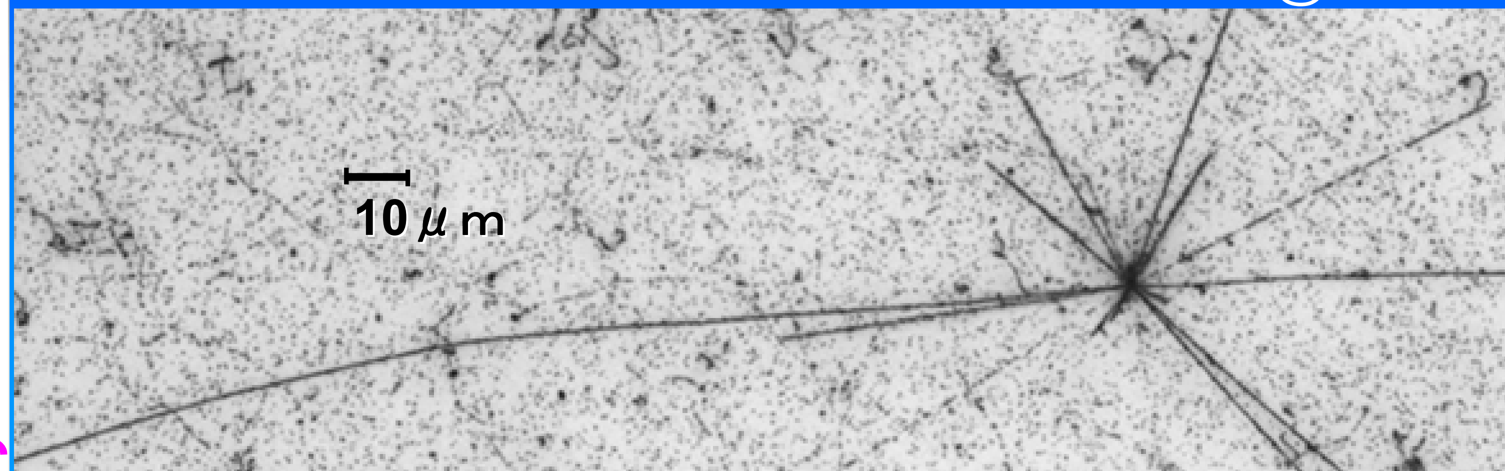

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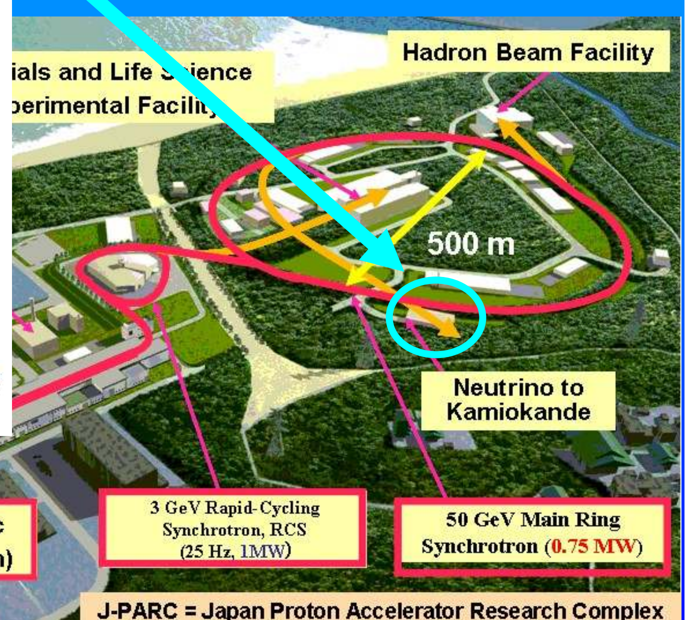
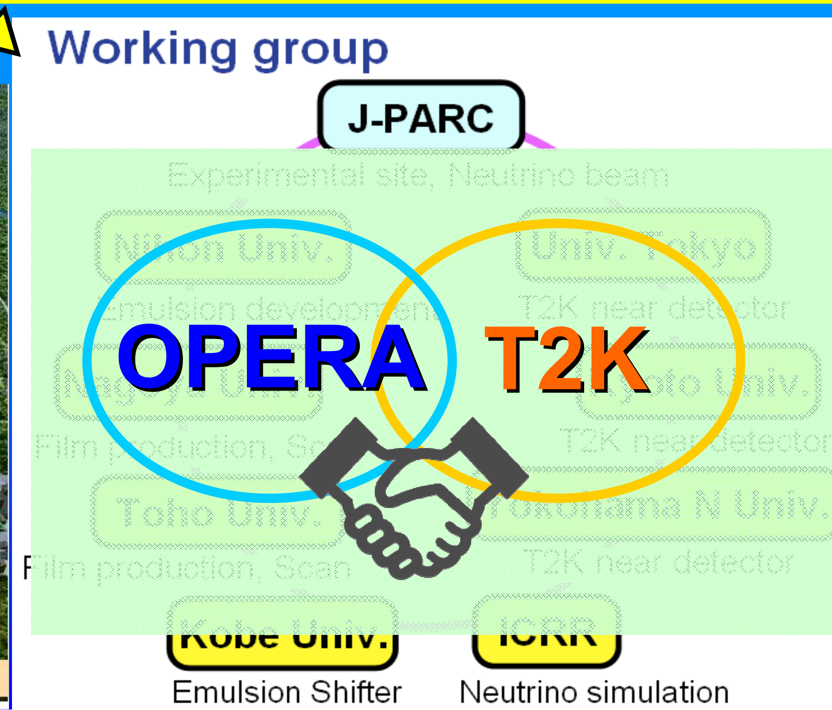




NINJA Collaboration

(* 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, N. Nakano, 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
ICRR, University of Tokyo: Y. Hayato
Yokohama National University: A. Minamino, Y. Tanihara
Kyoto University: A. Hiramoto, A. K. Ichikawa, T. Kikawa, K. Nakamura, T. Nakaya, T. Odagawa, I. Sanjana, K. Yasutome
University of Tokyo: N. Chikuma, M. Yokoyama

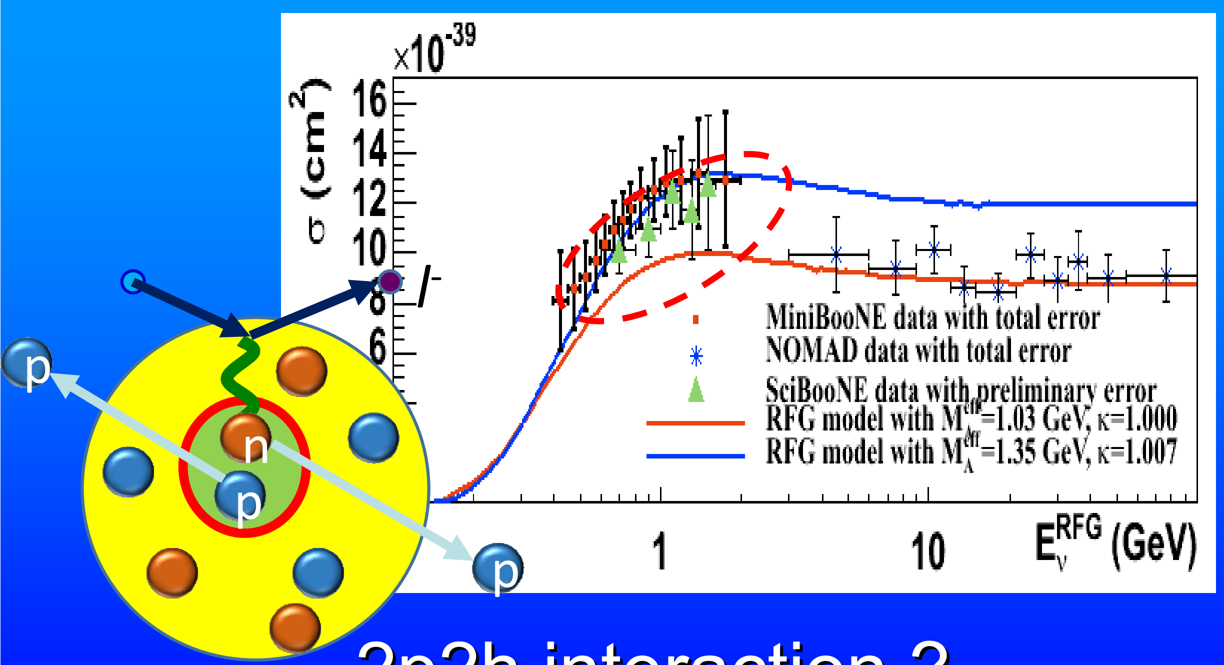
Physics Motivation

Sub-Multi GeV Neutrino interaction

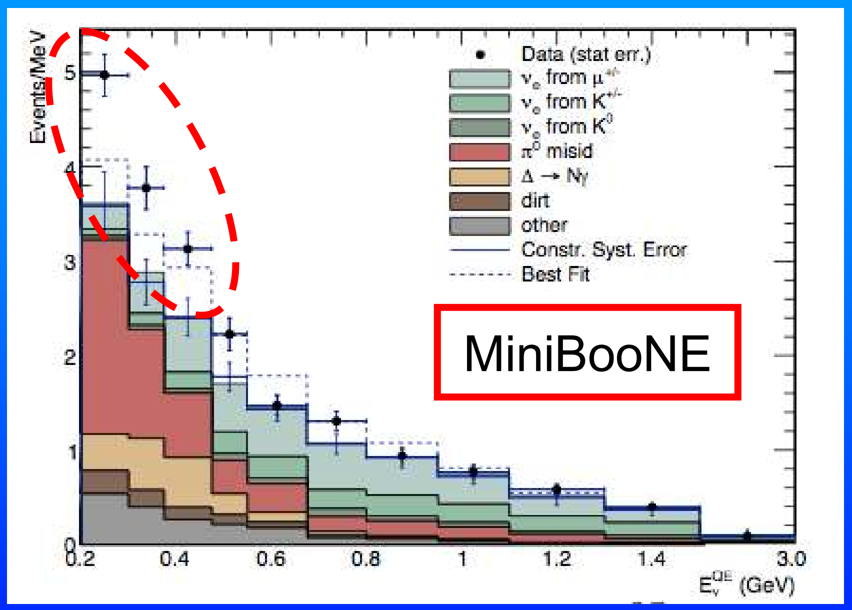
- Major source of uncertainty in ν oscillation analysis
- ν_e anomaly from several experiments (sterile ν ?)

Need to more understand the neutrino-nucleus interaction !

1. To measure hadronic final state with low energy threshold
2. Exclusive measurement of ν_μ, ν_e - water cross-sections



2p2h interaction ?



Effect from Sterile Neutrino ?

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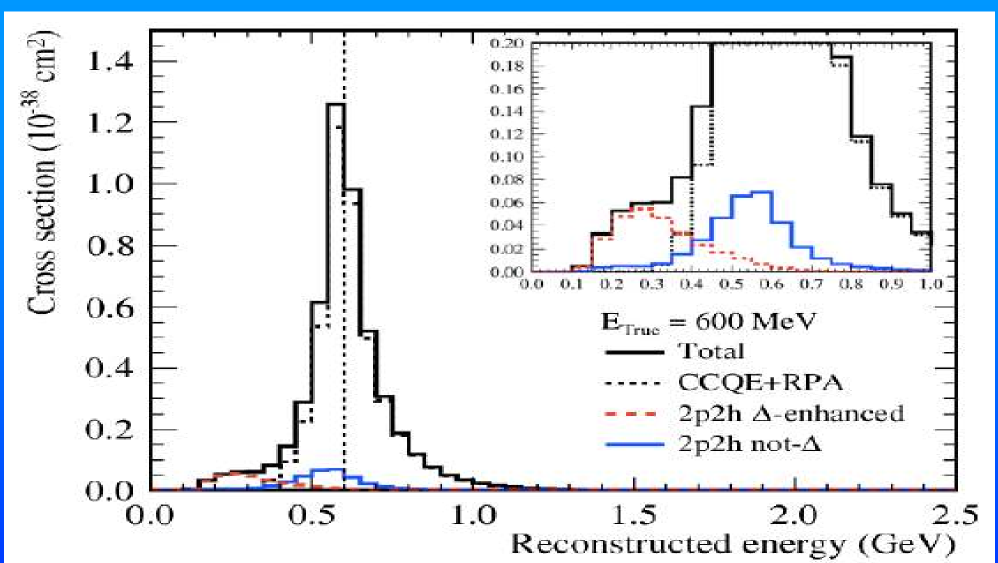
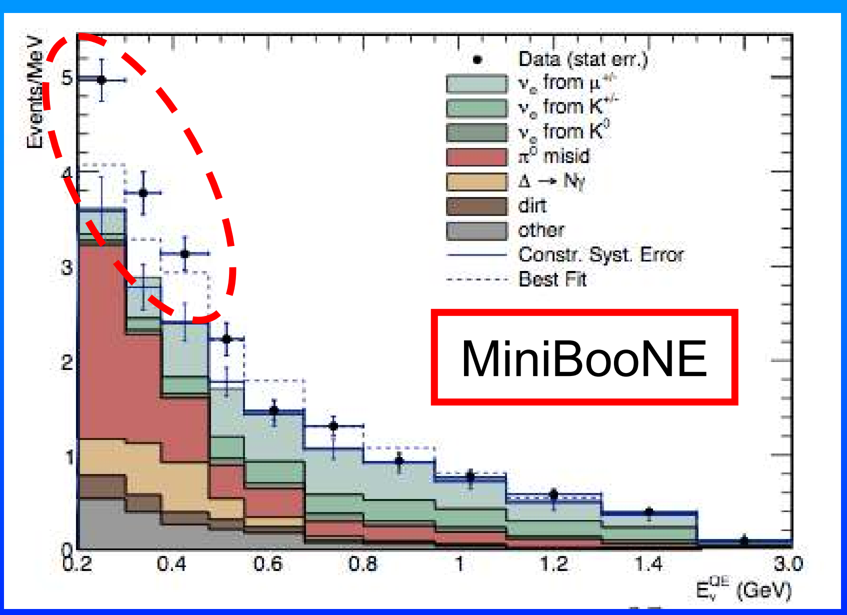


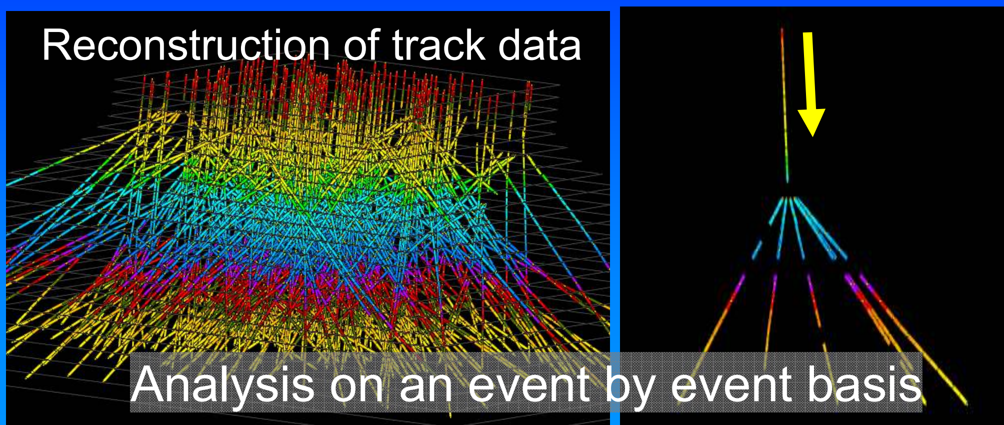
$$E_\nu^{rec} = \frac{m_p^2 - (m_n - E_b)^2 - m_e^2 + 2(m_n - E_b)E_e}{2(m_n - E_b - E_e + p_e \cos\theta_e)}$$



Effect from Sterile Neutrino ?

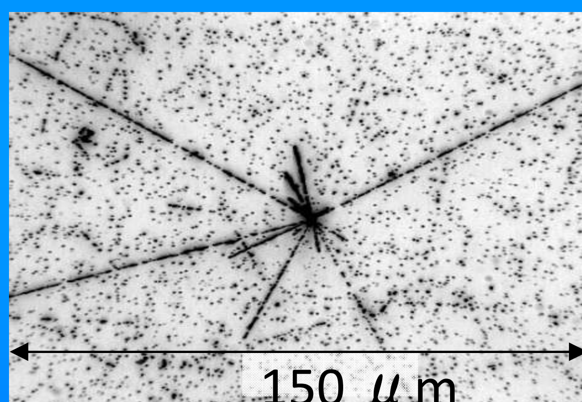
Nuclear Emulsion Detector

3D reconstruction

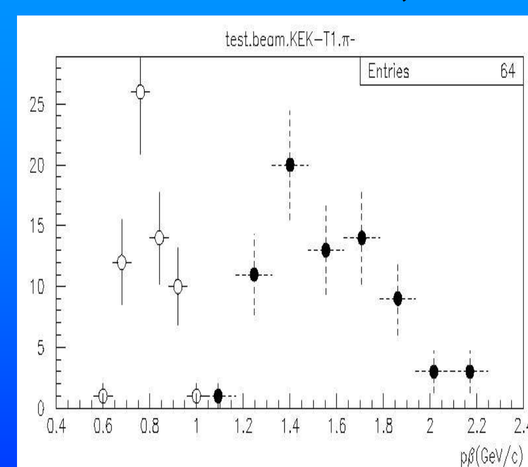


Scalability

4π detection

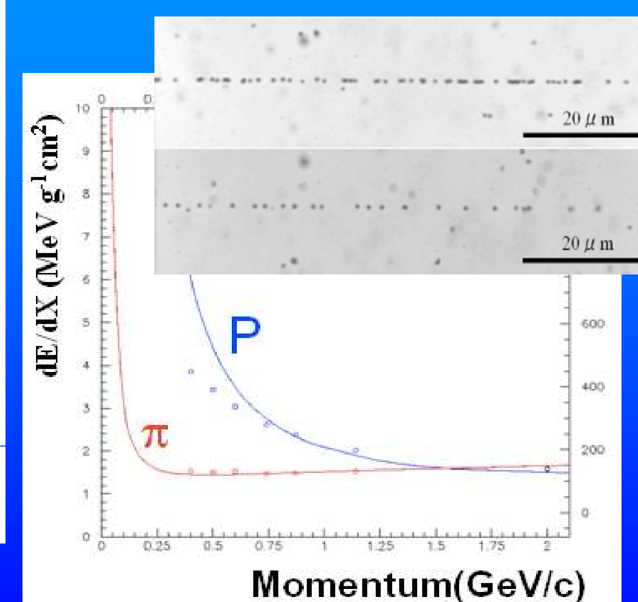


Momentum, dE/dx measurement

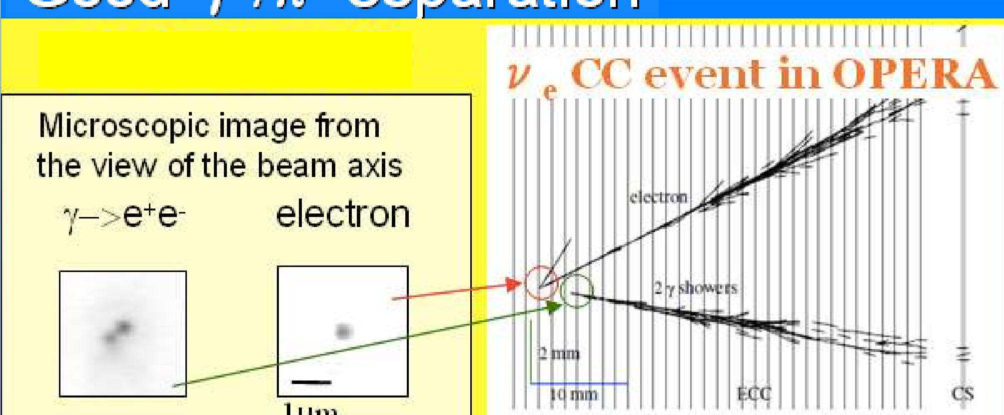


0.8GeV/c π : P =0.79(GeV/c), dP/P =**11**%

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



Good γ/π^0 separation



Low BG from ν_μ NC π^0 production

NINJA Roadmap

In 2014, plan was proposed and the collaboration started to be established.

Pilot RUN — Feasibility study at J-PARC

J-PARC T60/T66/T68 experiment

Detector RUN — Detector performance check

Target mass: 1- 60kg

Physics RUN — Neutrino-nucleus interaction study

New proposal (E71)

Target mass: 100- 300kg

Physics RUN — Search for sterile neutrino

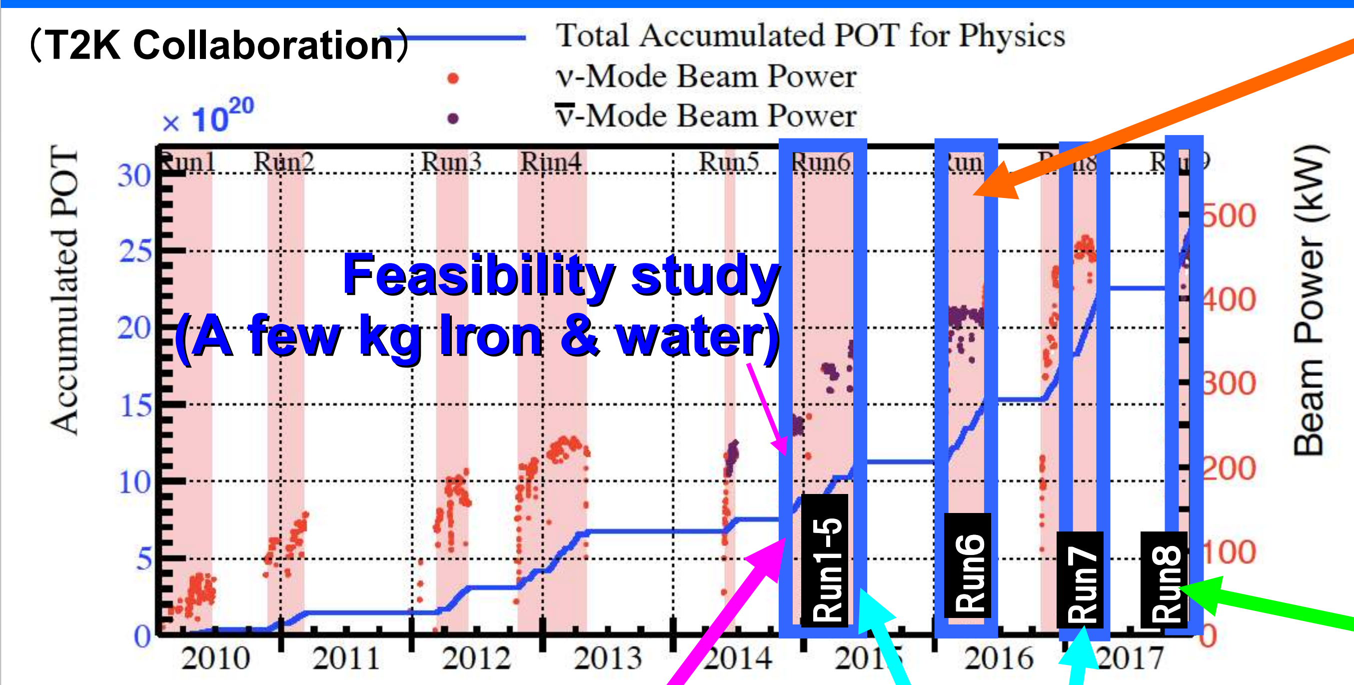
Target mass: 1- 3ton

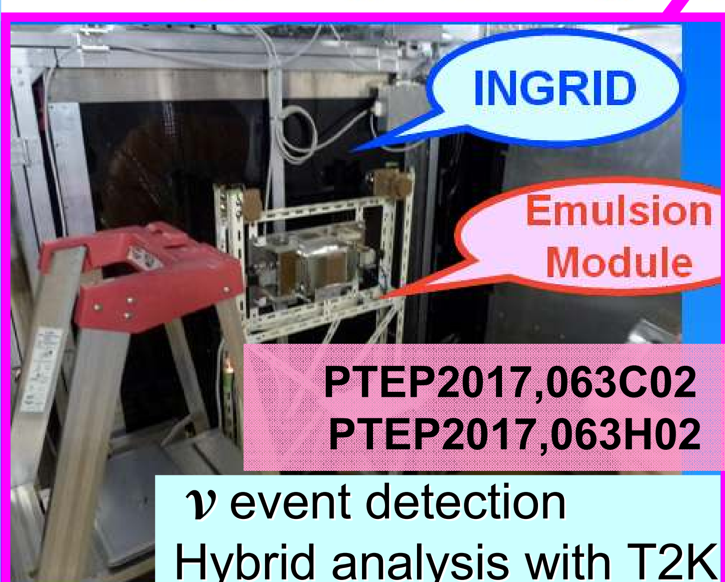
Target mass: 6-10ton

The aim of T60/T66/T68 is a feasibility study and detector performance check.
In this time, we propose the physics run to study neutrino-nucleus interactions.

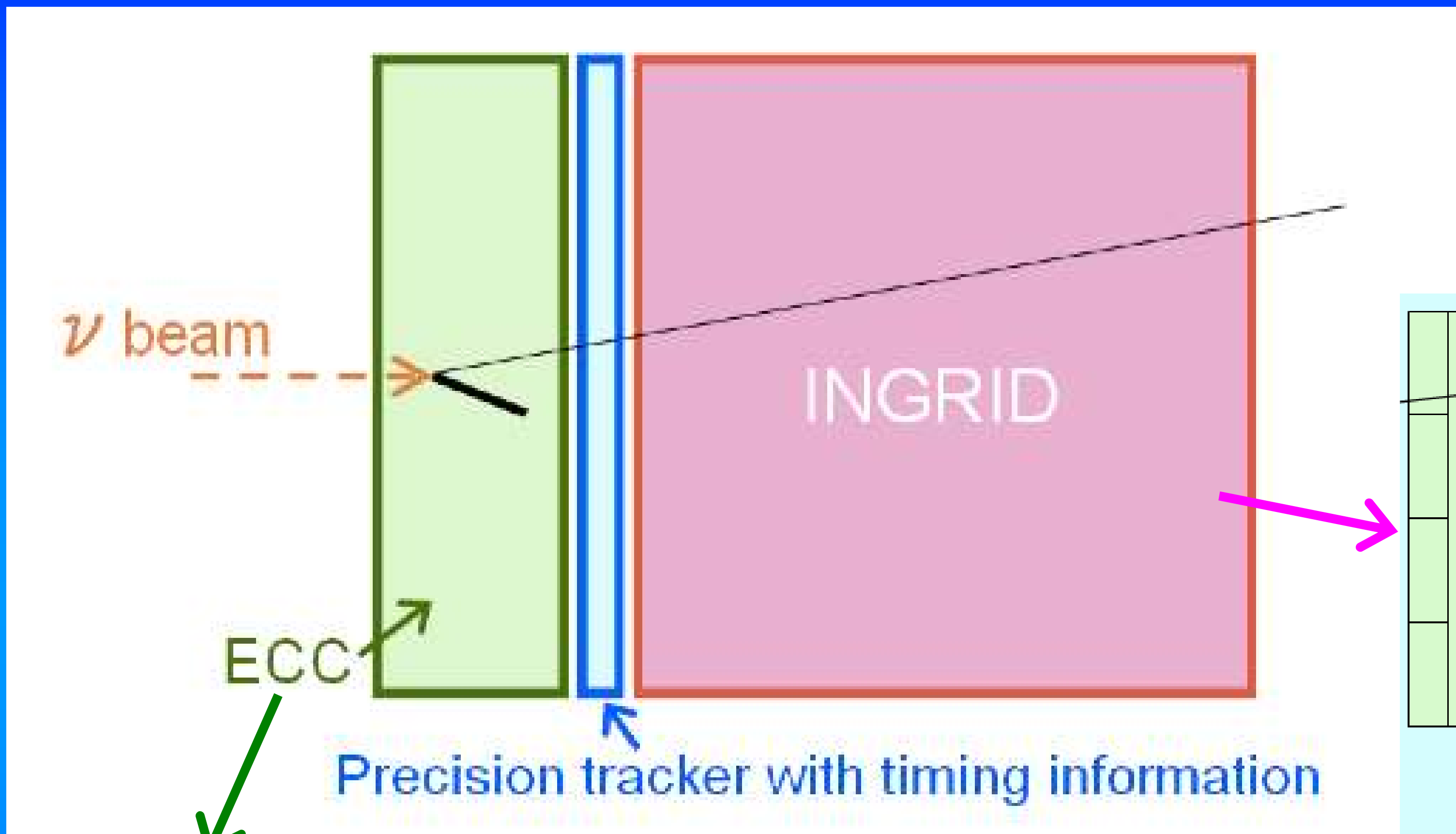
ν exposure of NINJA

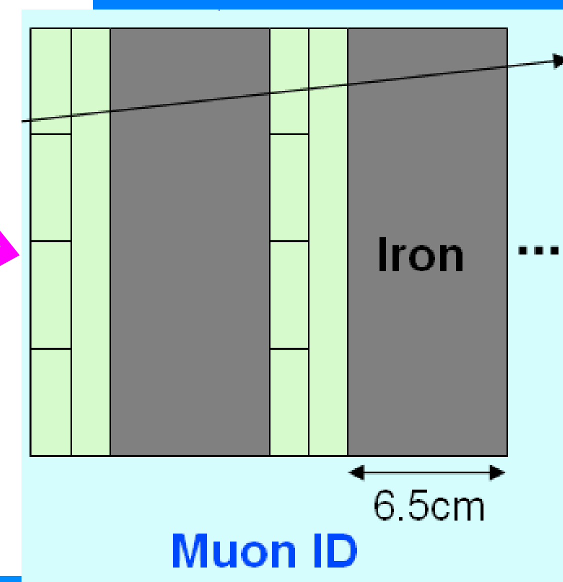
Since the end of 2014, we have demonstrated the basic performance in test experiments.

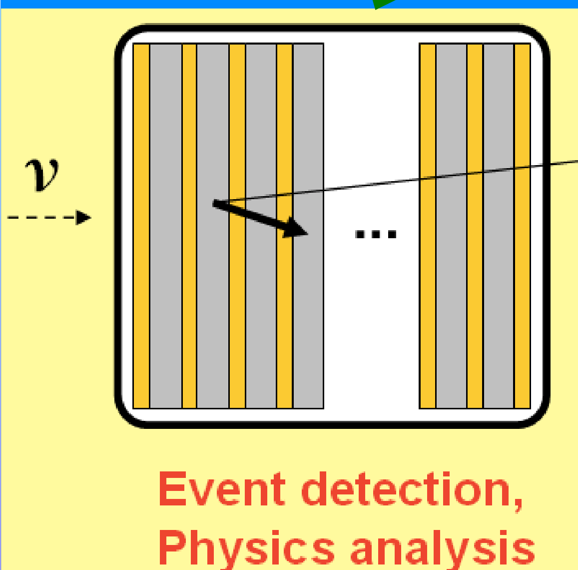




Conceptual design of the detector



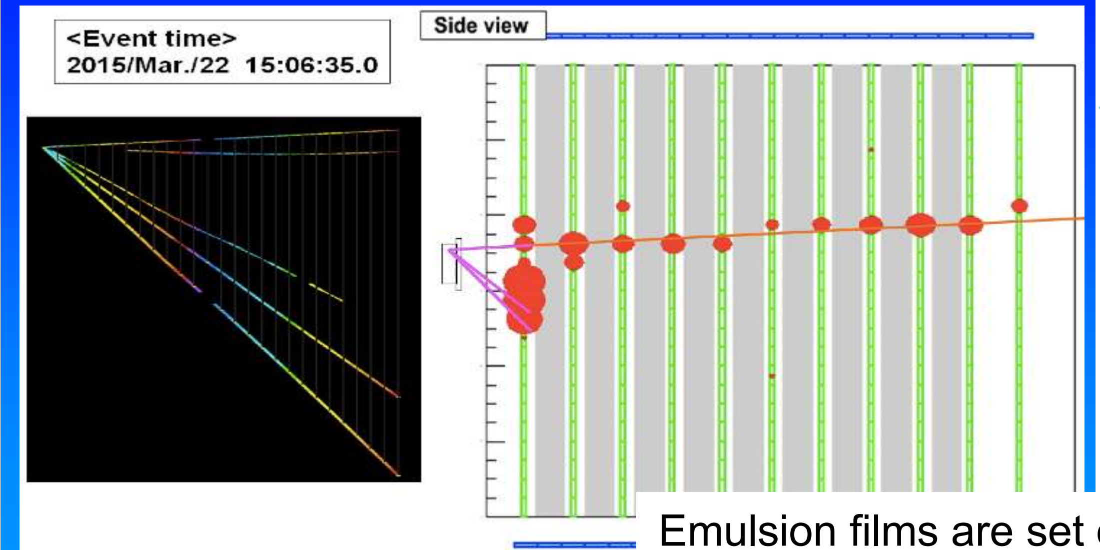




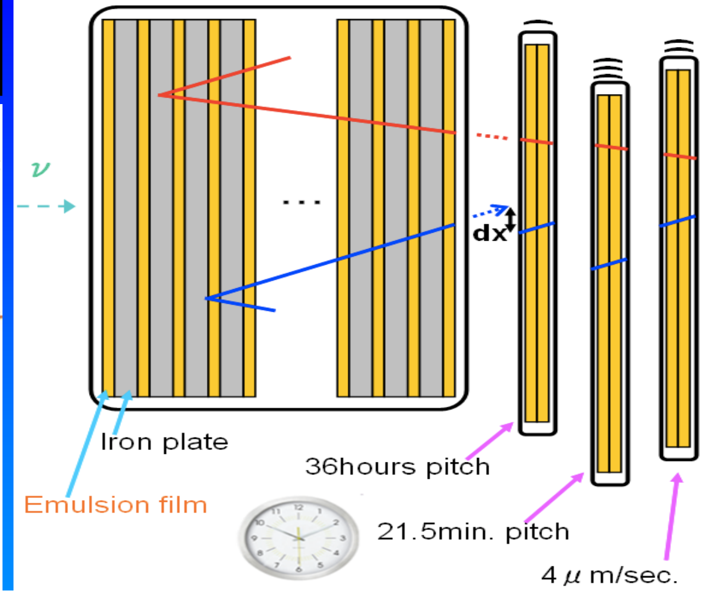
- **E**mulsion **C**loud **C**hamber (**ECC**) is a sandwich structure of emulsion films and materials.
- ECC is placed in front of T2K near detector, INGRID.
- Precise Tracker is placed between ECC and INGRID to give a timing information to emulsion tracks.
- Muon ID is possible by combined analysis with INGRID.

Precise Tracker → 2 options (Emulsion Shifter/ Scintillating Fiber Tracker)

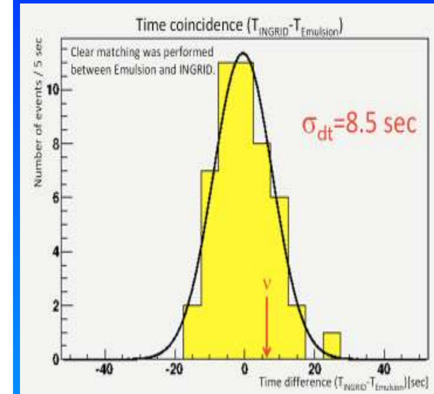
Emulsion-INGRID hybrid analysis with Shifter



NINJA Pilot Run



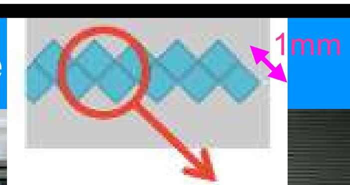
Time resolution

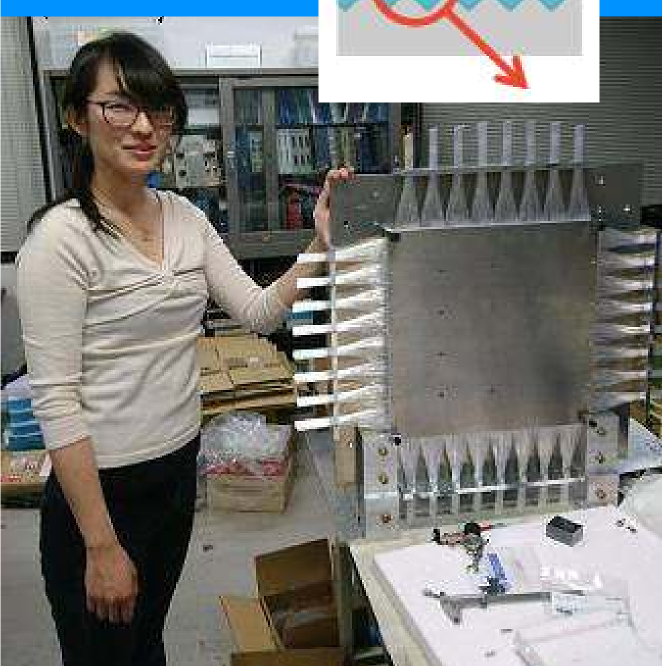


Emulsion films are set on moving stages controlled by stepping motor.
Time stamp is given by coincidence of tracks on each stage.
→ Position difference from reference point = Timing information

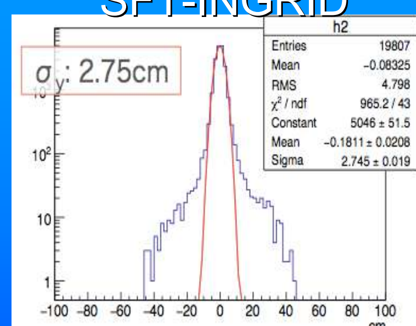
Emulsion-INGRID hybrid analysis with SFT

Zigzag style

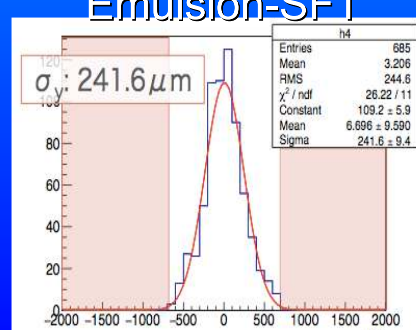




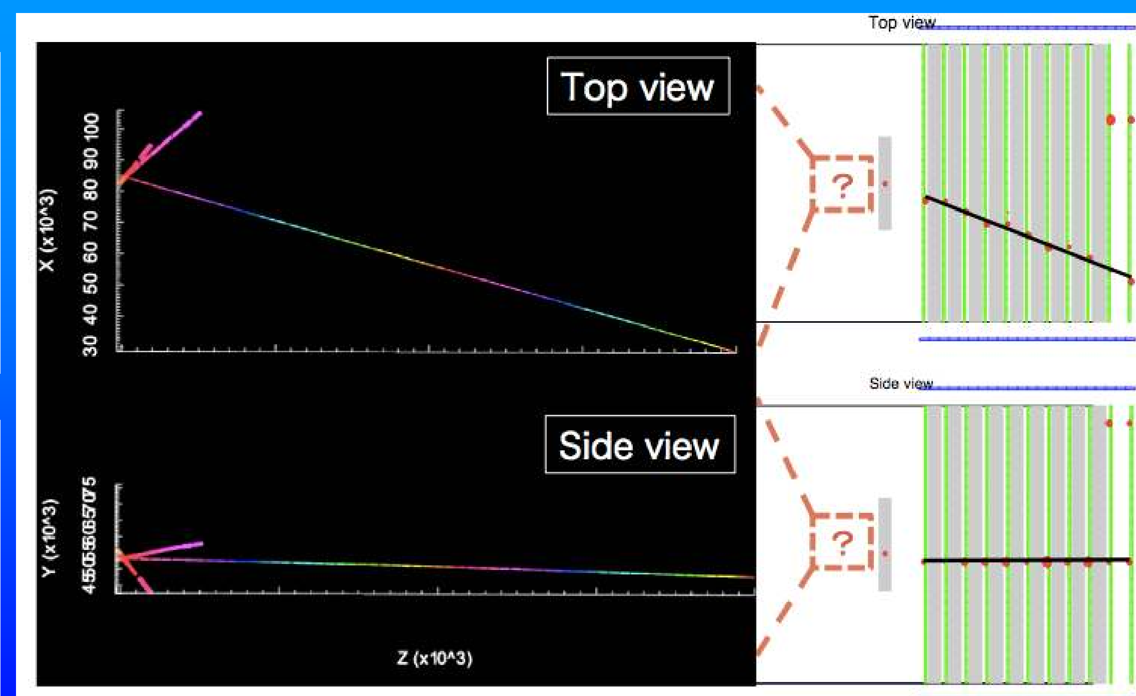
SFT-INGRID



Emulsion-SFT

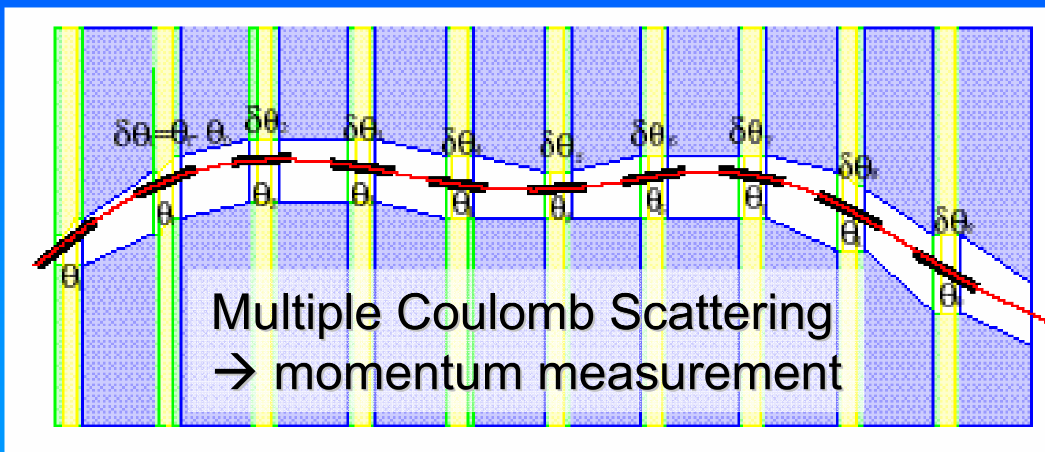


NINJA Detector Run

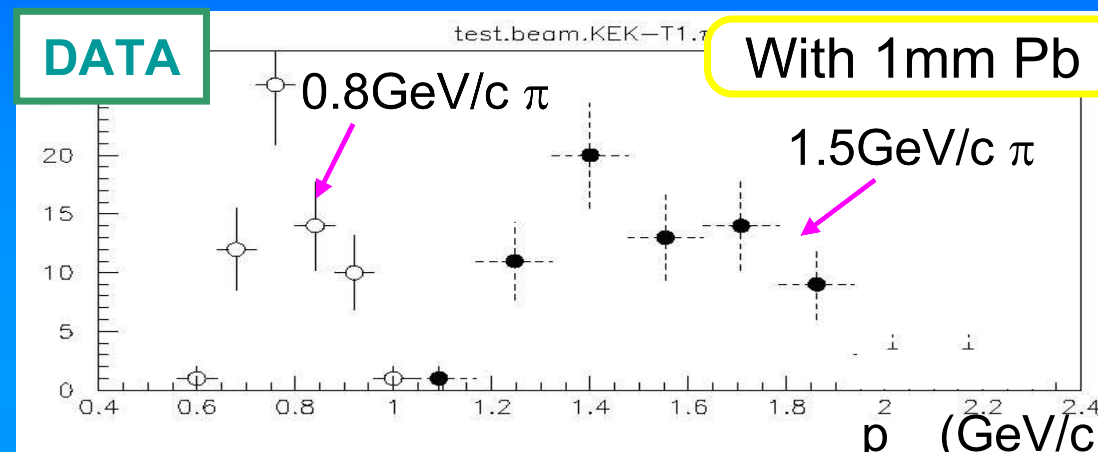


Momentum measurement

p β measurement by the MCS method



$$P\beta = \frac{13.6\ (\mathrm{MeV/c})}{\sigma_{\delta\theta}} \sqrt{\frac{x}{X_0}} \left(1 + 0.038 \ln \frac{x}{X_0}\right)$$



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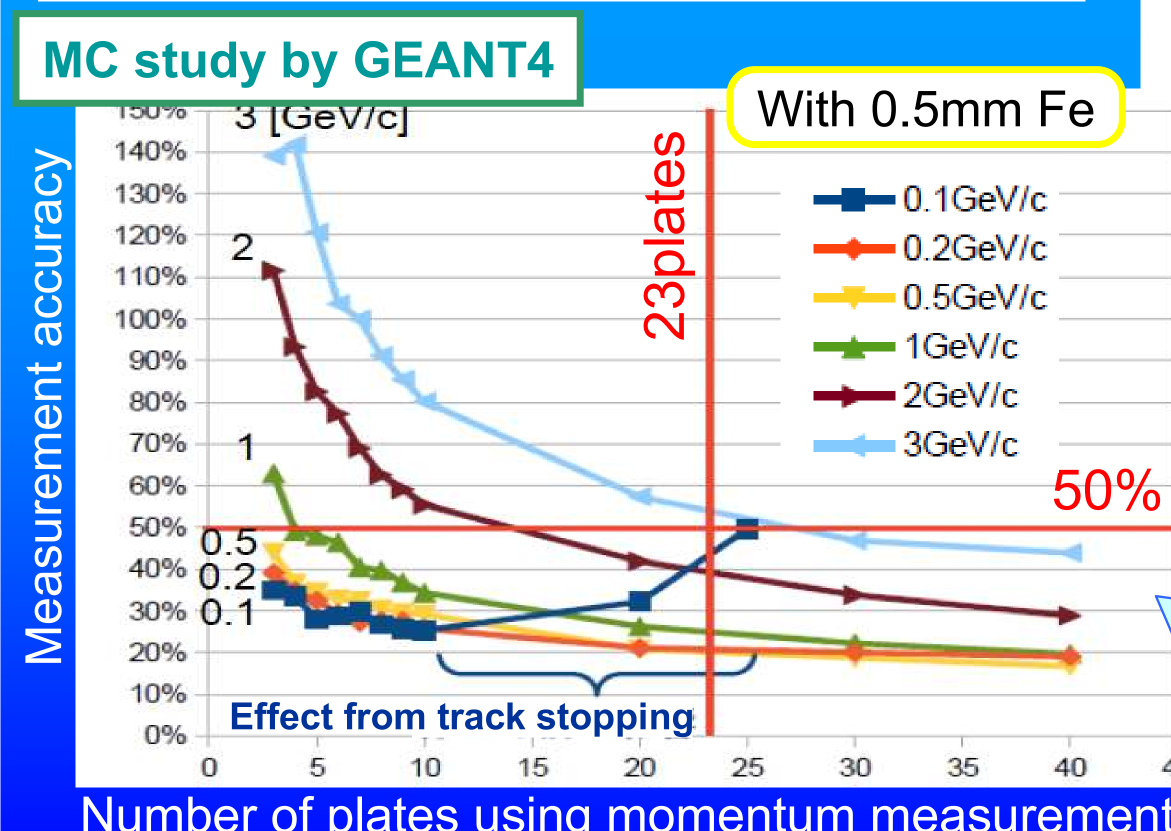
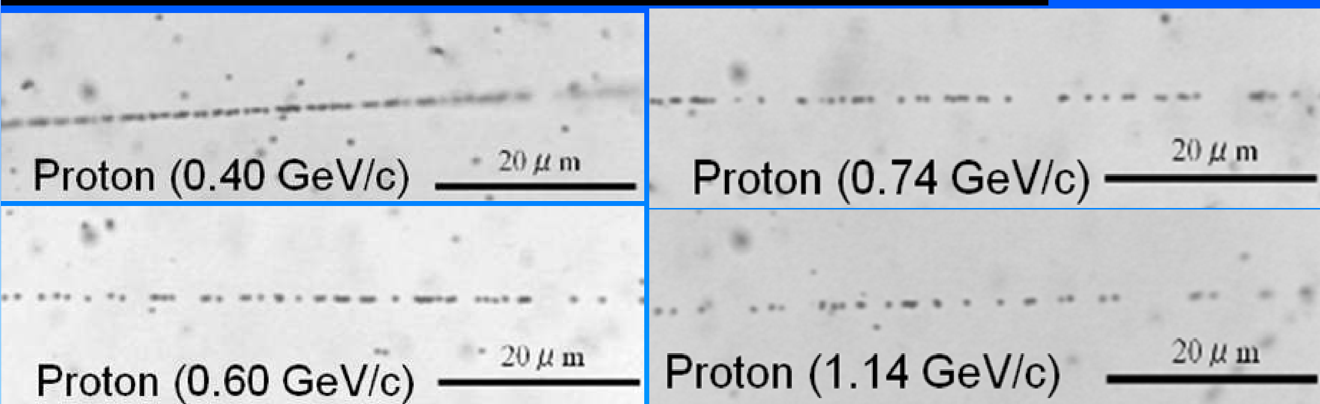


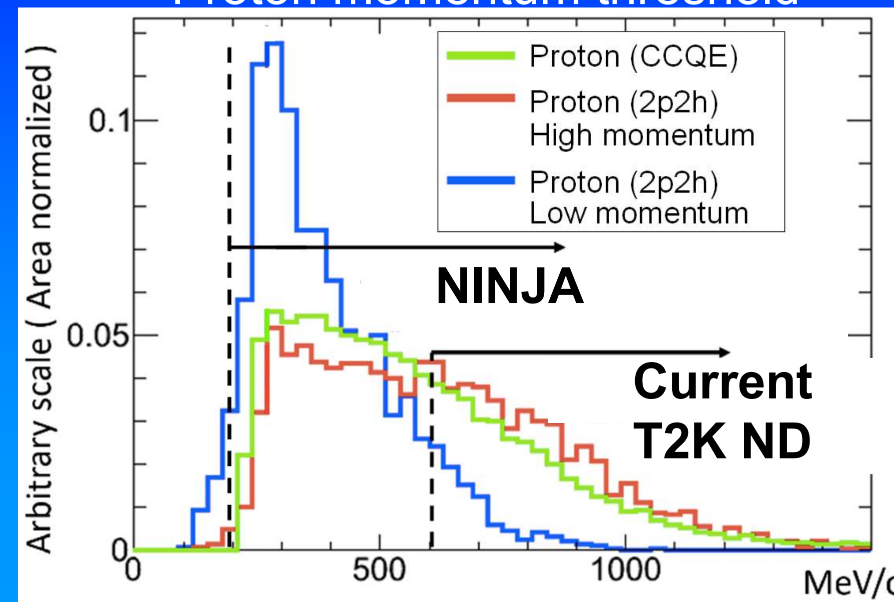
- **More measured plates, better measurement accuracy.**
- **lower momentums have better accuracy because of their large scattering.**
- **measurement accuracy gets worse just before particles stop.**

Proton identification

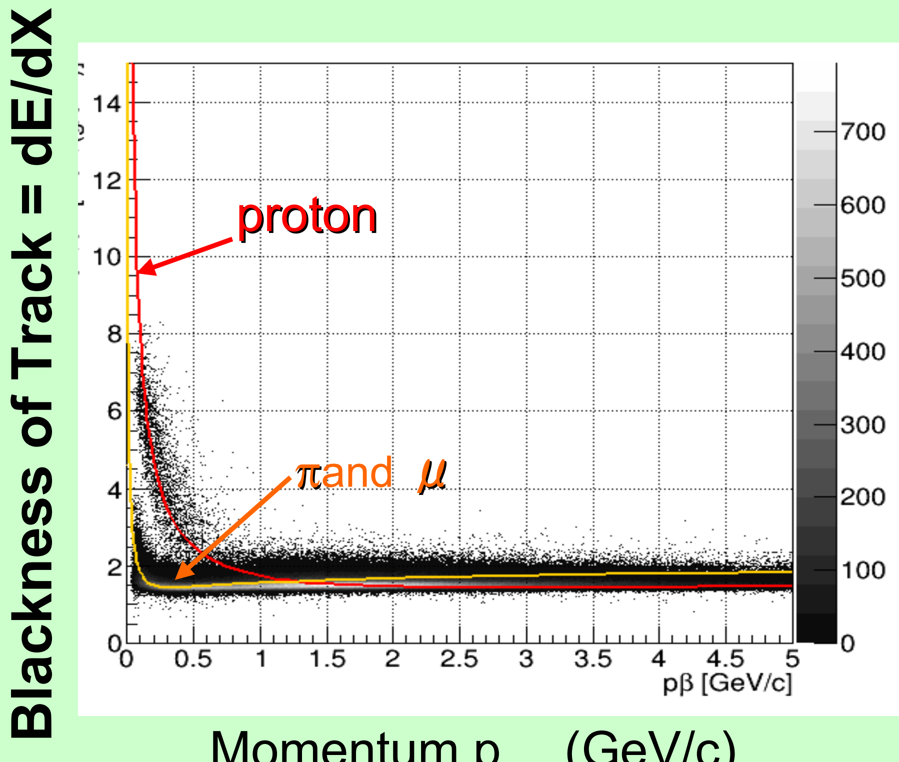
dE/dx measurement by track blackness



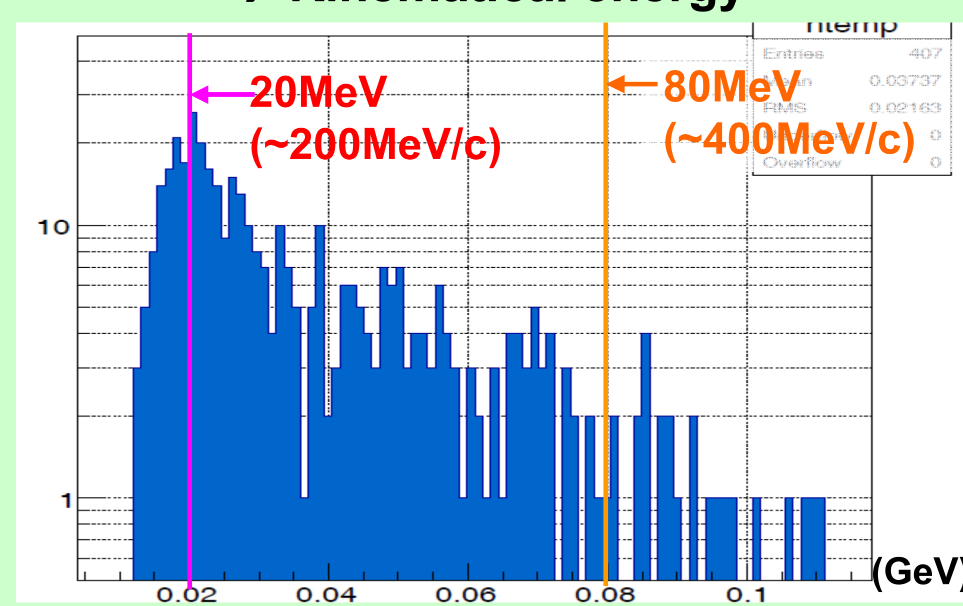
Proton momentum threshold



NINJA Detector RUN



Low energy proton
→ Range measurement
→ Kinematical energy

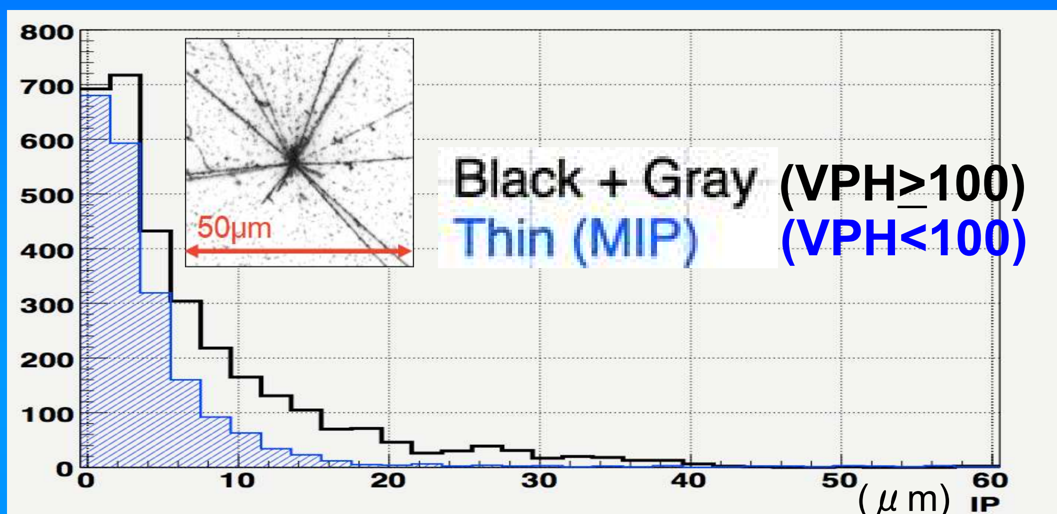


Status of event analysis in Detector RUN

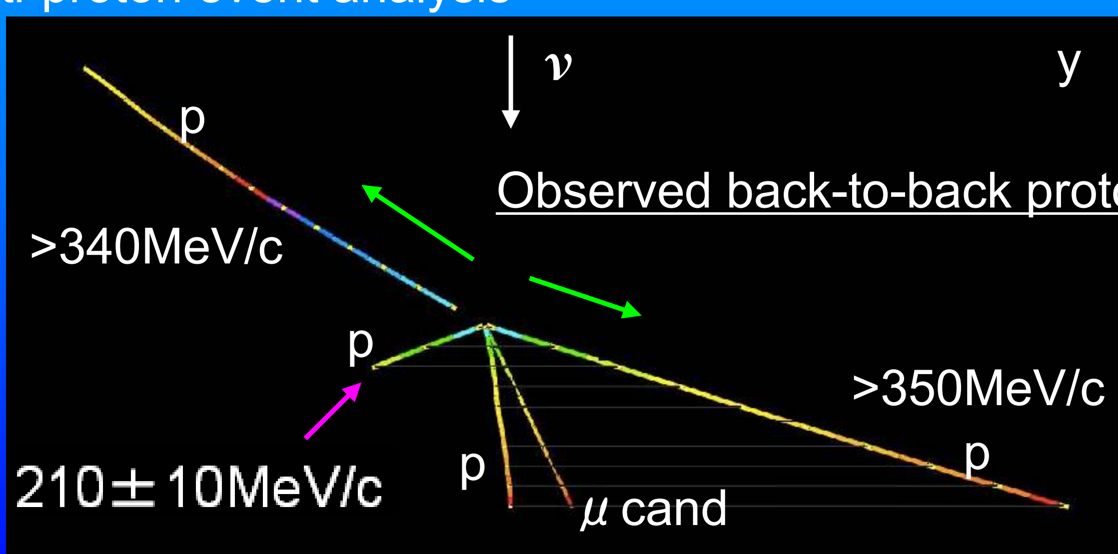
Anti neutrino mode

- Iron interactions

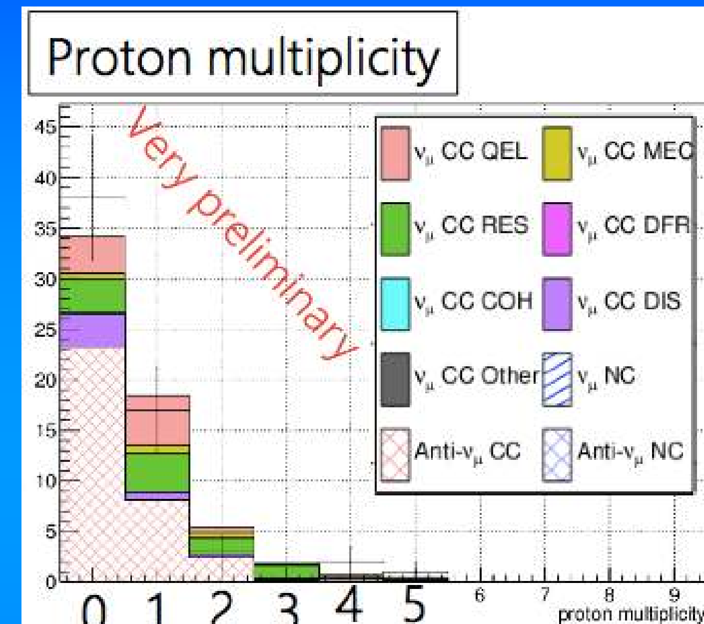
Impact Parameter in vertexing events

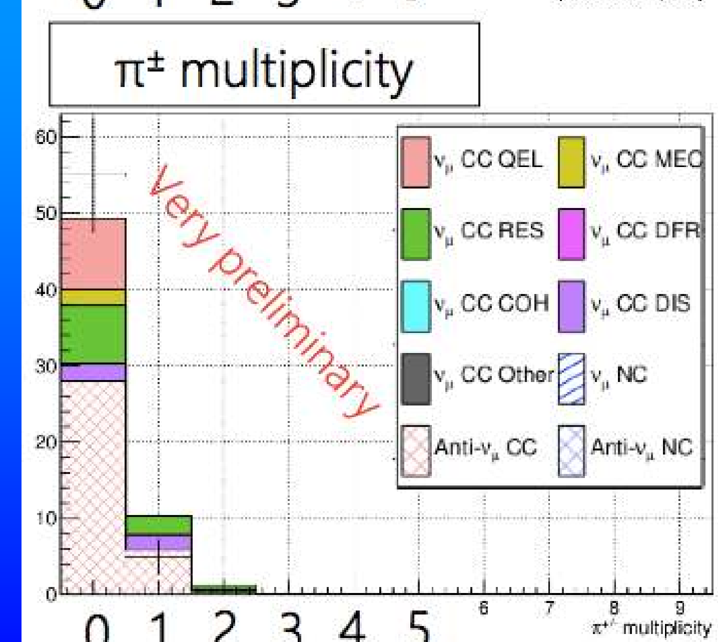


Multi-proton event analysis



Track multiplicity of CC event

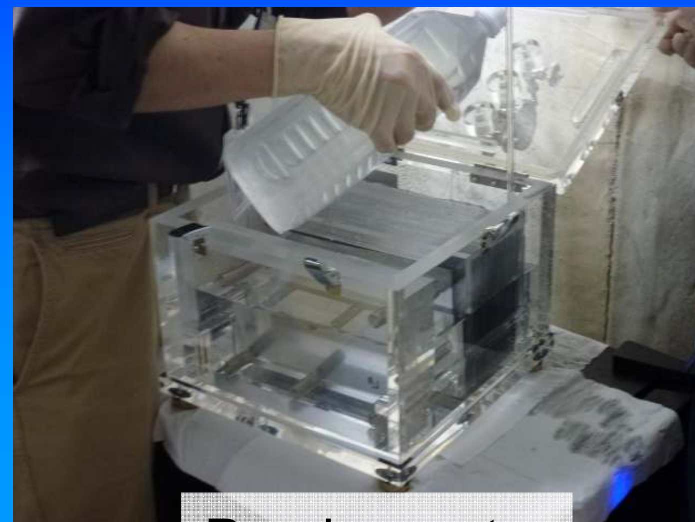




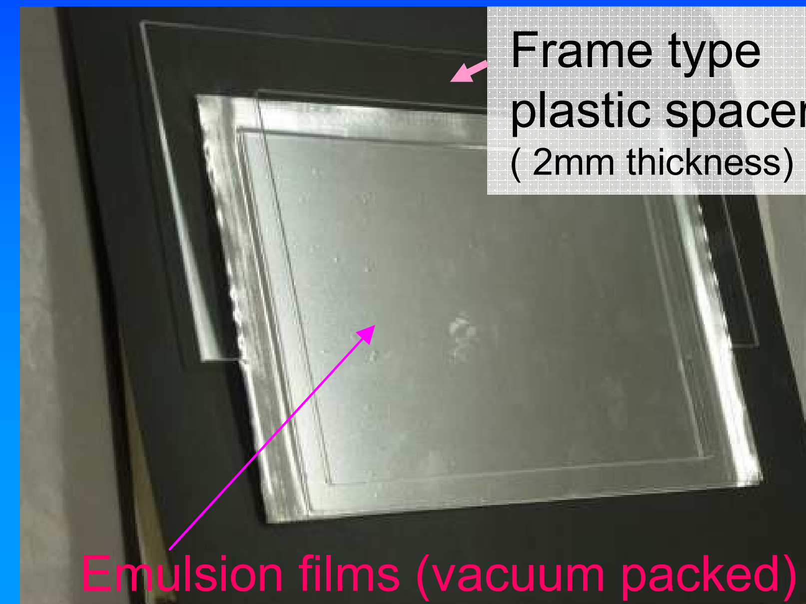
Water target emulsion chamber

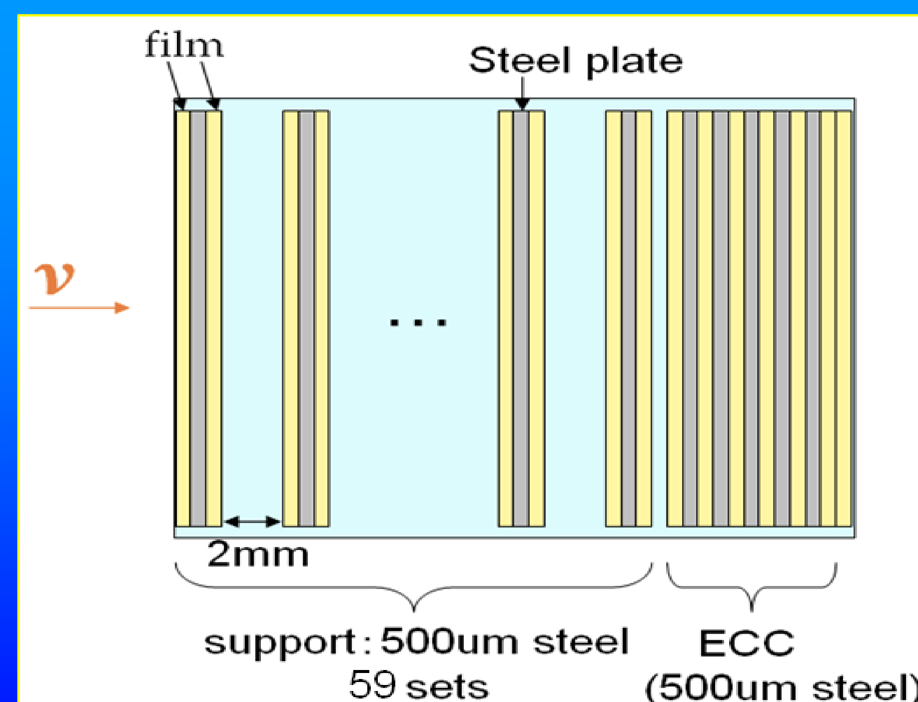
We installed a water target emulsion chamber.

Sandwich structure of Emulsion films and Frame type spacers



Pouring water





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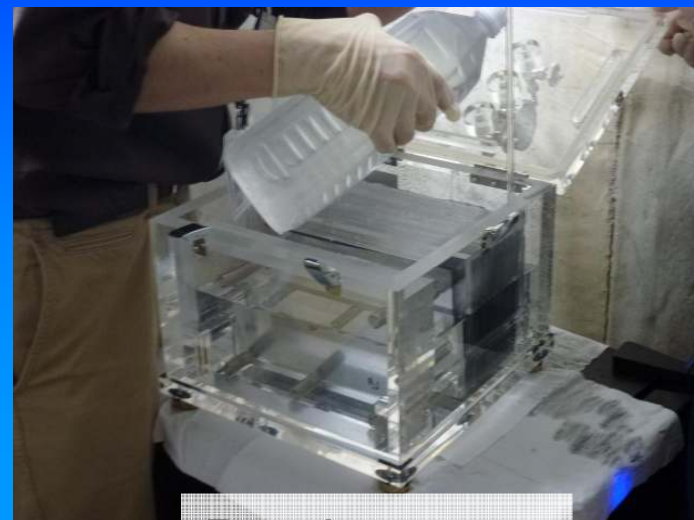
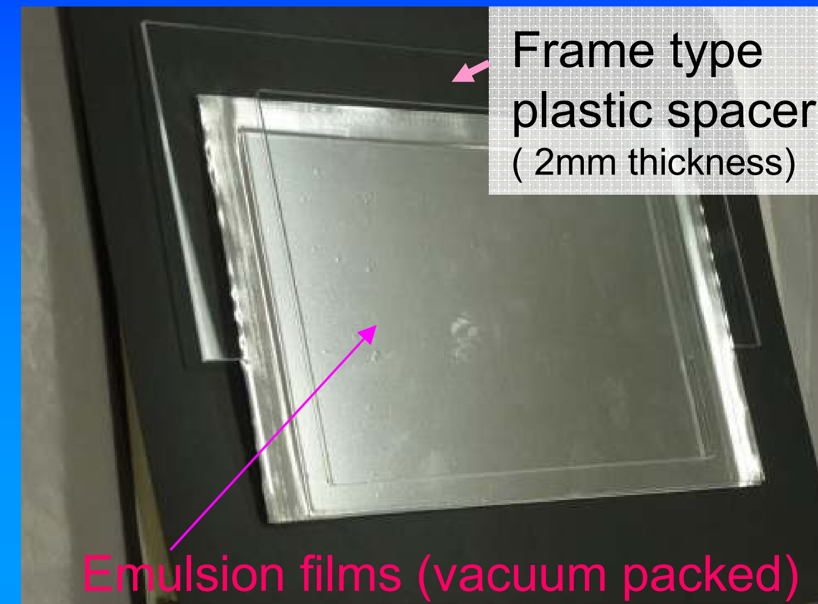
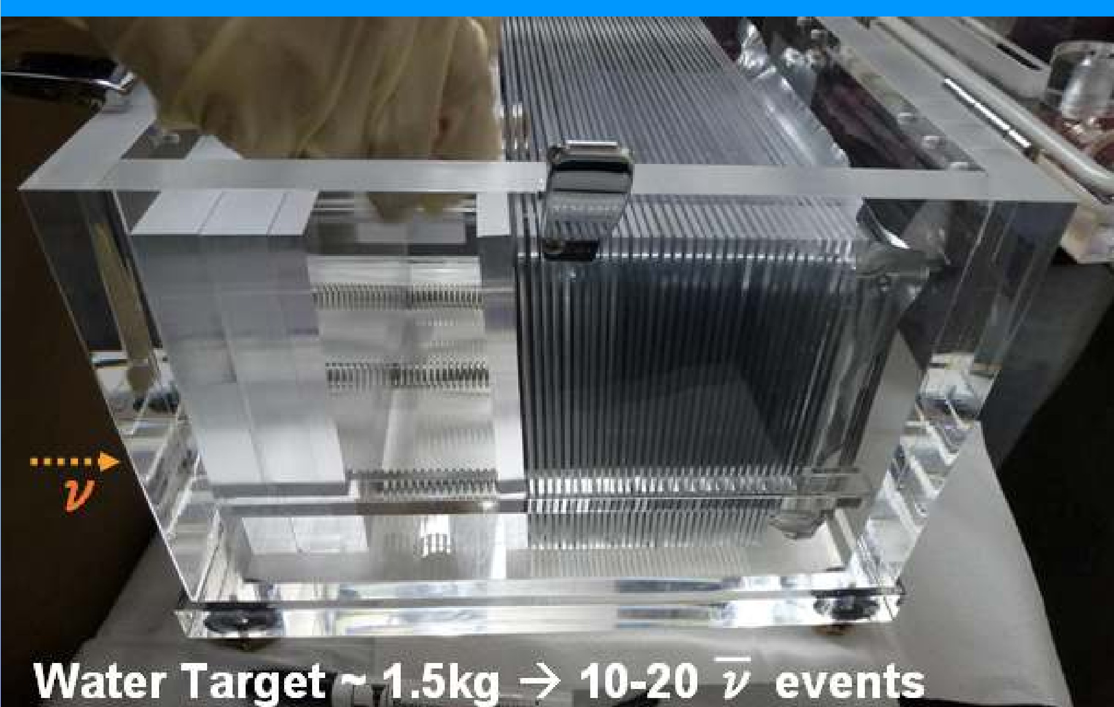
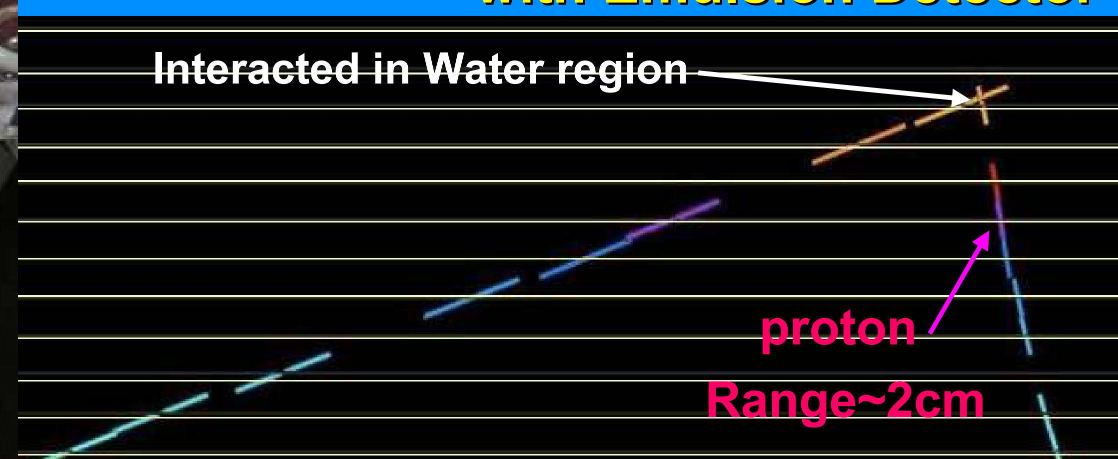


Pouring water





First detection of ν - Water interaction with Emulsion Detector

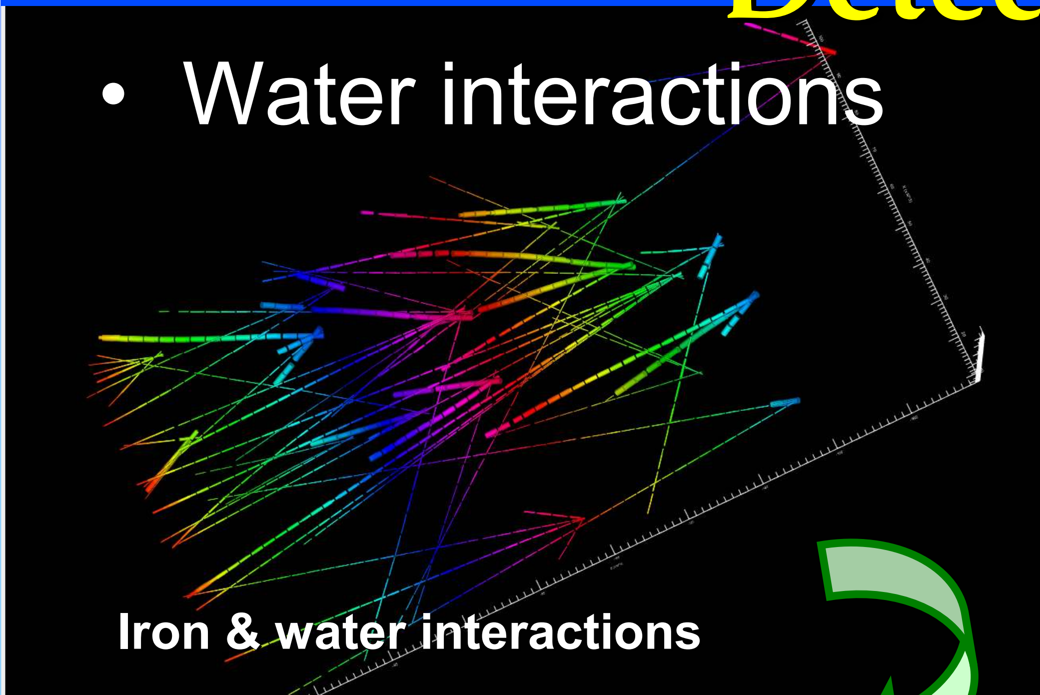


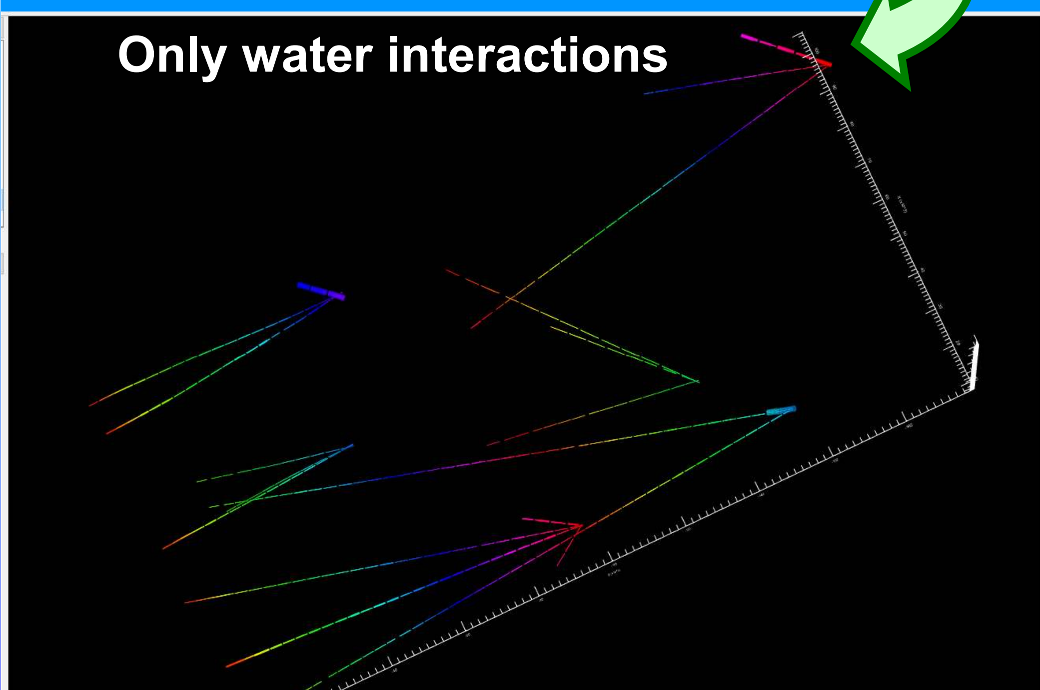
	(tan x, tan y)=(-0.040, 0.845)	M.I.P
	(tan x, tan y)=(-0.589, -0.074)	proton
Minimum distance( )=2.4um, depth=620um		

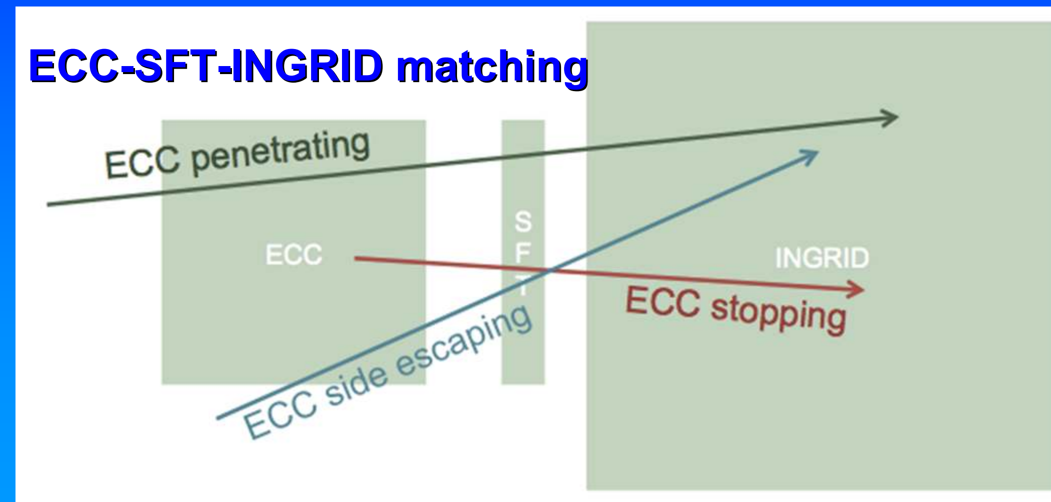
Status of event analysis in Detector RUN

Anti neutrino mode

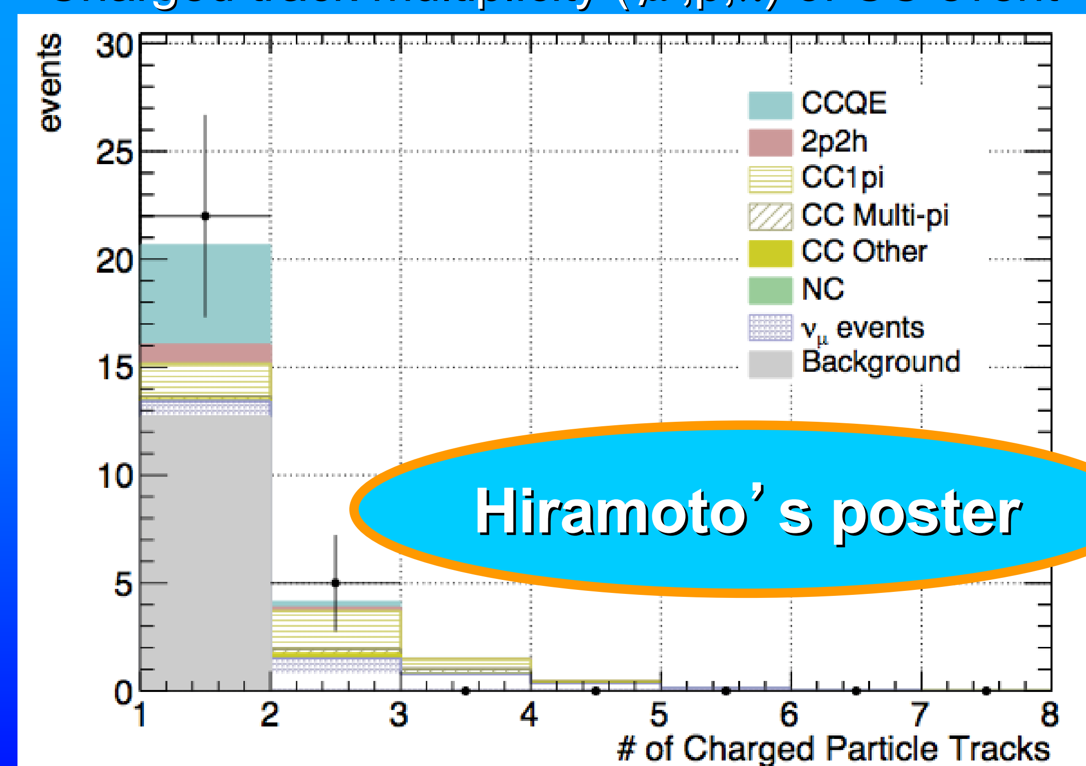
- Water interactions







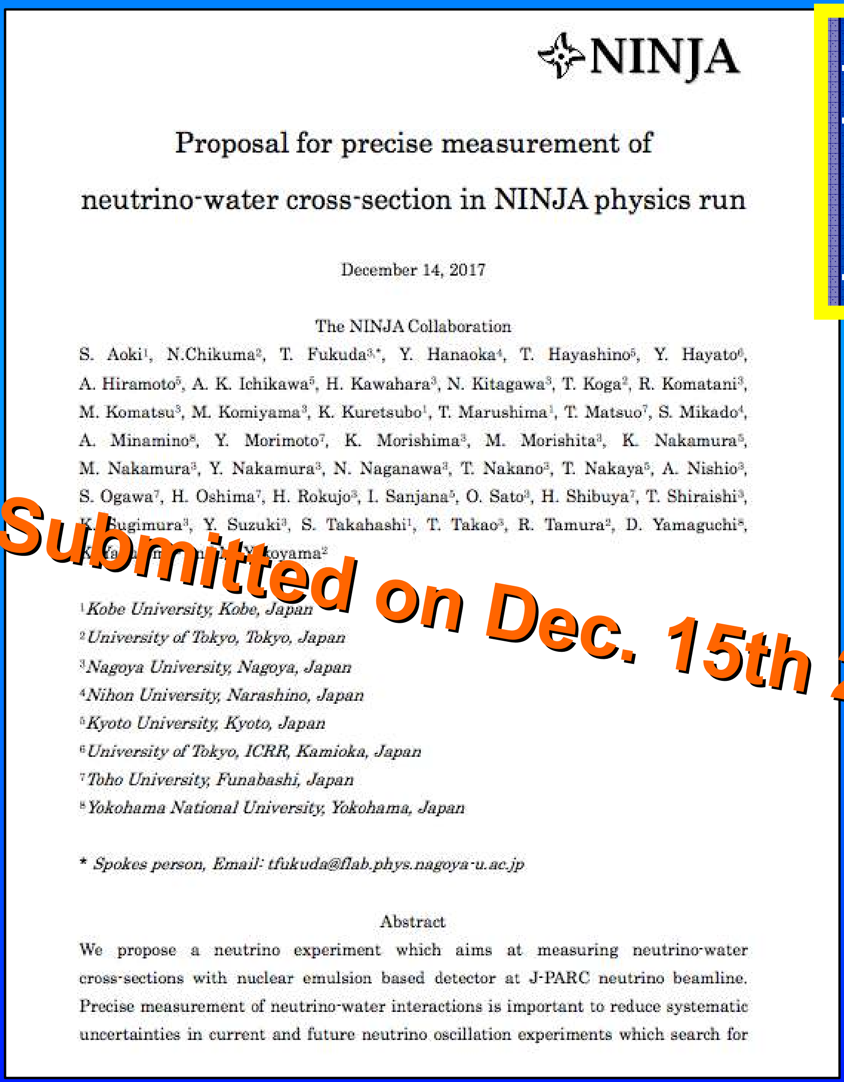
Charged track multiplicity (μ, p, π) of CC event



Hiramoto's poster

Physics Run (J-PARC E71)

We proposed a new experiment (Physics Run) 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], K. ... Y. 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*

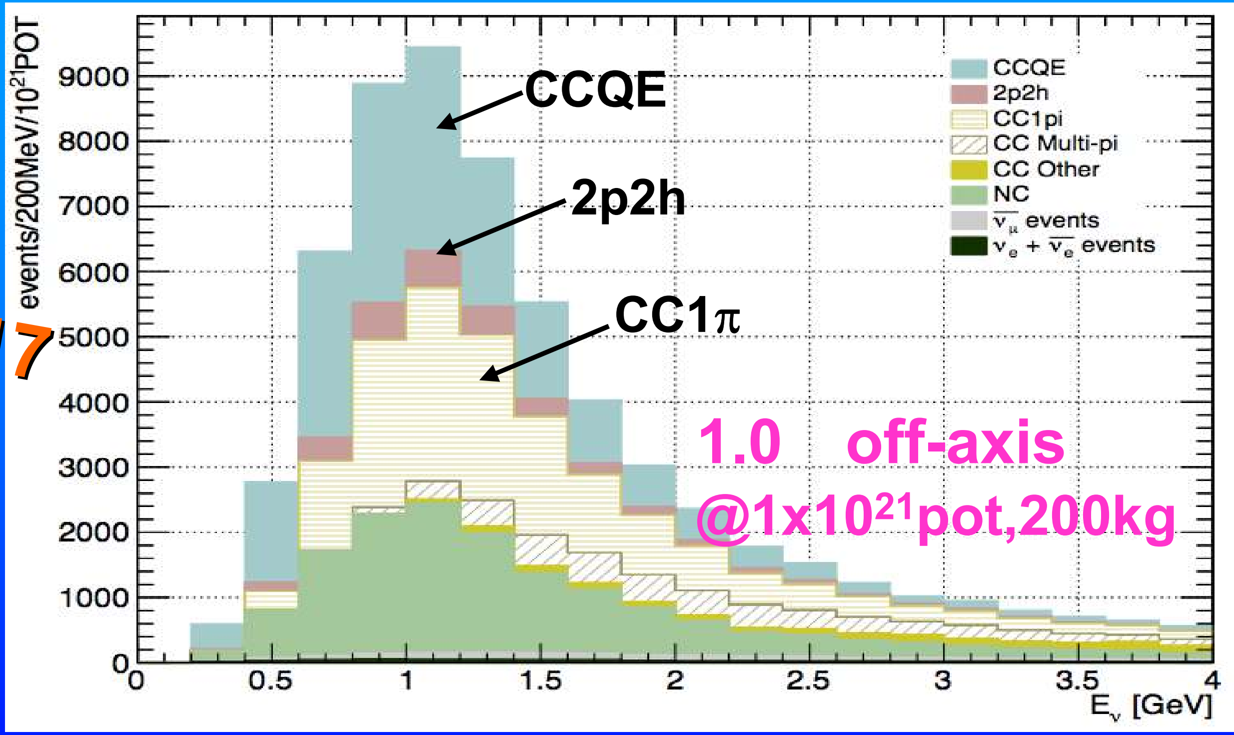
* *Spokes person, Email: tfukuda@flab.phys.nagoya-u.ac.jp*

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

- Measurement of hadronic final state with low energy threshold
- Detailed analysis of 2p2h-like neutrino interactions
  → flux-integrated cross-section for events with two proton
  → ratio of the two-proton to single-proton CC0π events
- Exclusive ν_μ and ν_e cross-section measurement with high stat.



Status of E71

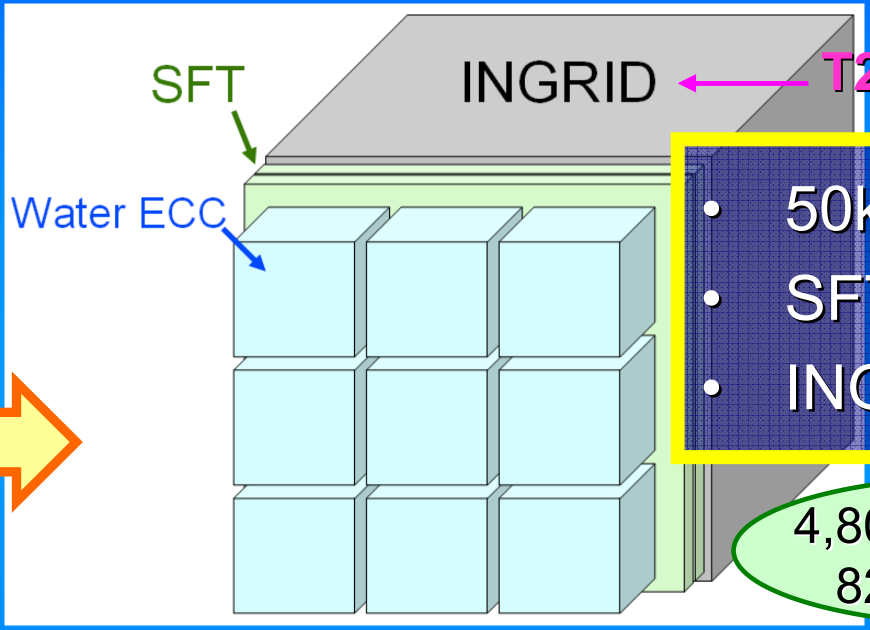
- Dec. 2017: Proposal was submitted.
- Jan. 2018: Requested stage-1 status at J-PARC PAC meeting.
- Apr. 2018: Won the fund for the project from JSPS (Kiban-A).
- May 2018: Updated MoU between NINJA-T2K.
- May 2018: TDR was submitted.
- Jun. 2018: Explained technical details at J-PARC FIFC meeting
- Jul. 2018: Won stage-1 status
- Jul. 2018: Requested stage-2 status at J-PARC PAC meeting.

We requested neutrino mode exposure with total 10^{21} pot for two times exposure.
1st exposure (E71a) was requested to be done in 2019.

Plan: Detector setup

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

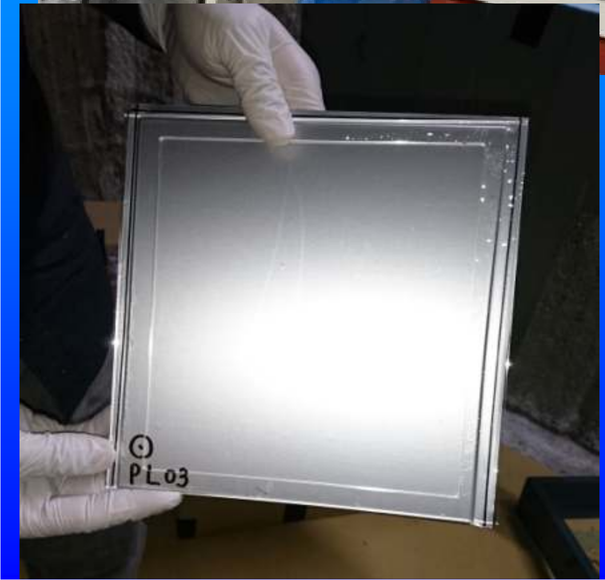
x 9

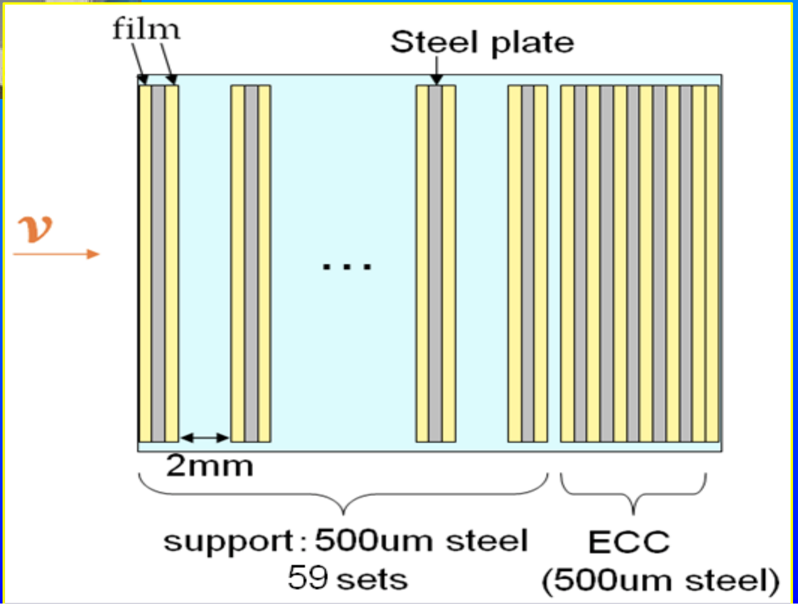


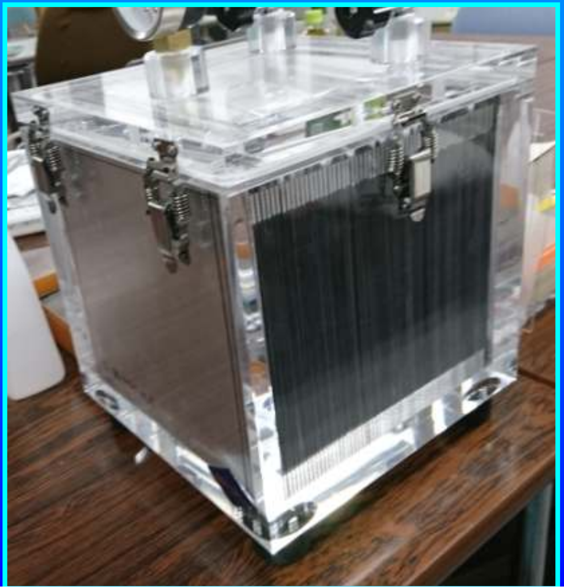
T2K near detector

- 50kg Water ECC
- SFT
- INGRID

4,800 CCQE
820 2p2h @10^{21}POT (100% eff.)

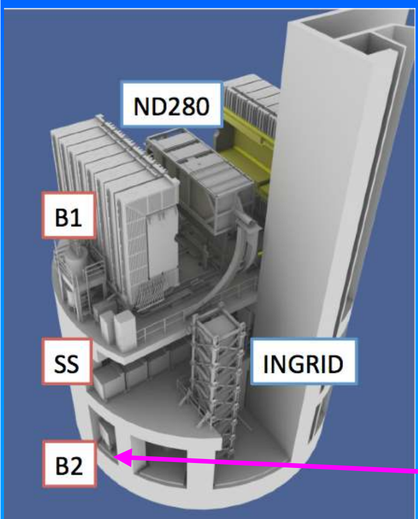


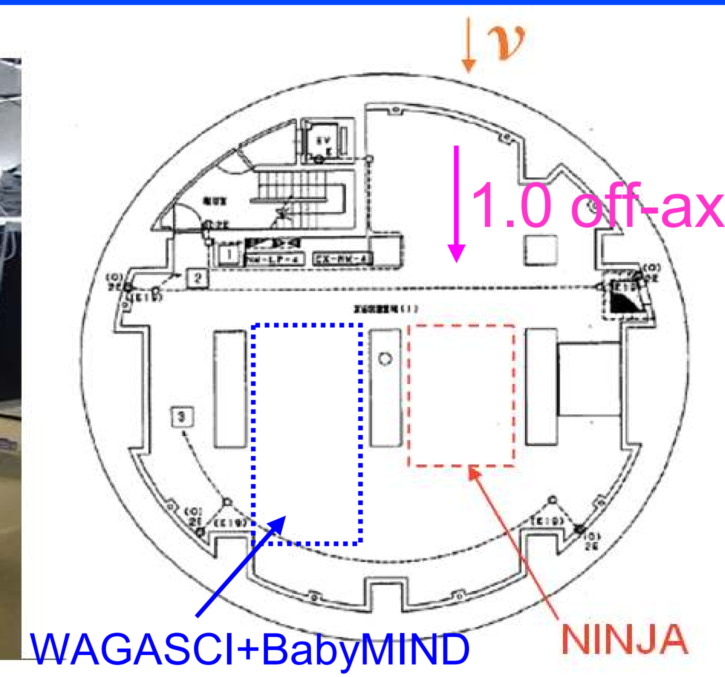


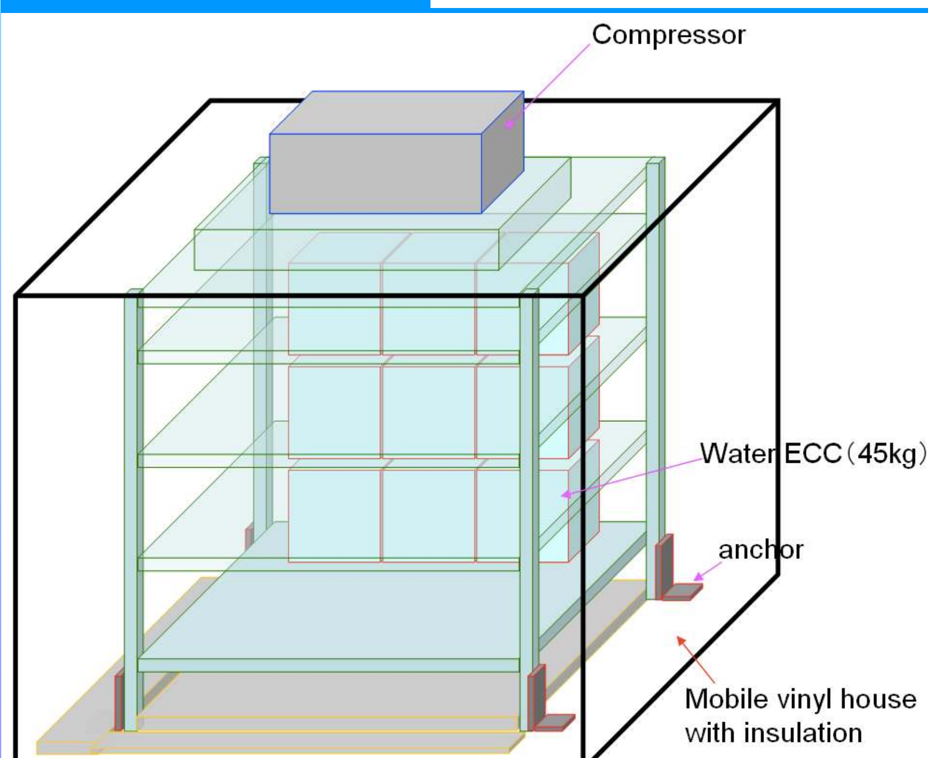


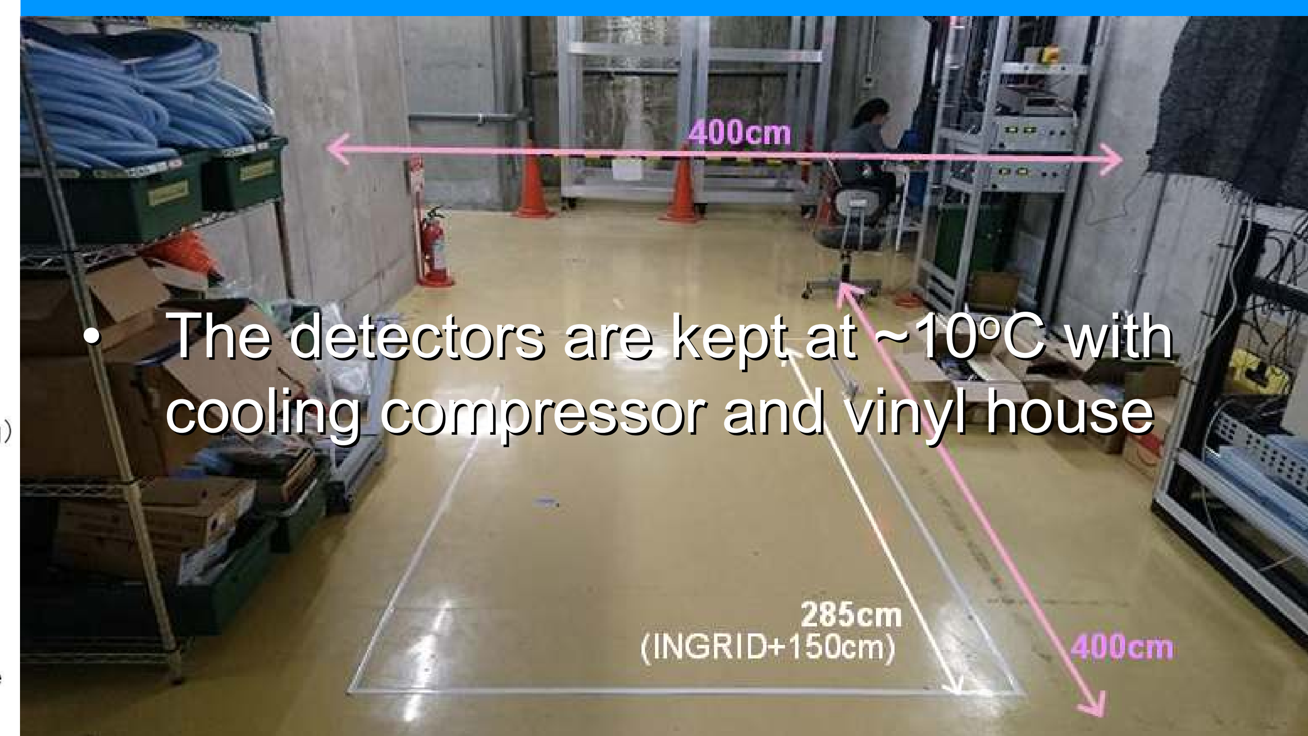
Plan: Experimental site

B2 floor





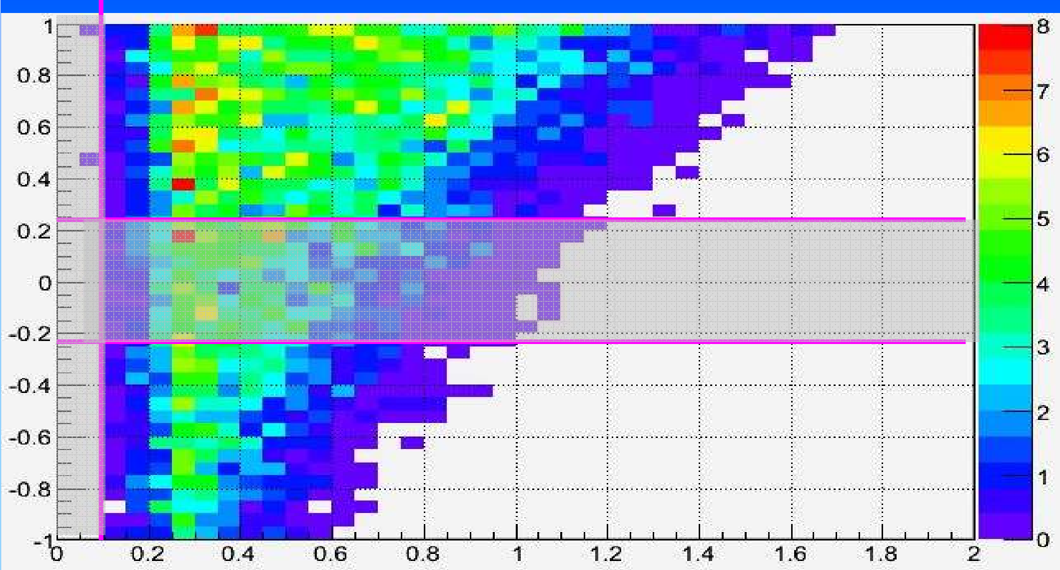


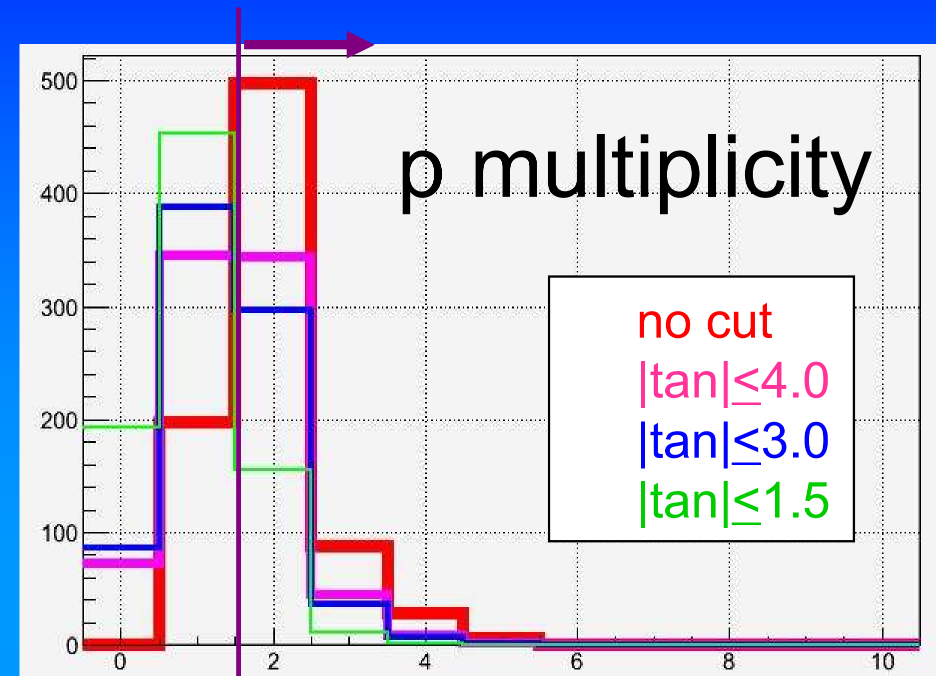


- The detectors are kept at ~10°C with cooling compressor and vinyl house

Toward measurement at off-axis

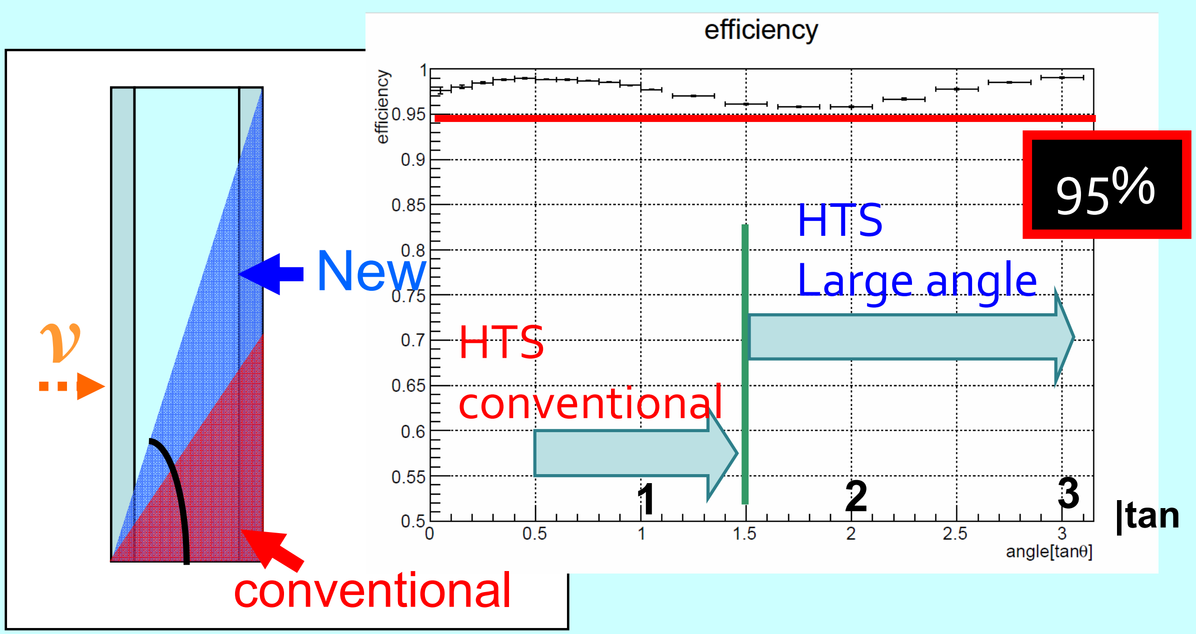
- Slow proton detection





Proton @2p2h (NEUT 5.3.7_INGRIDFIX)

High speed Large angle Scanning



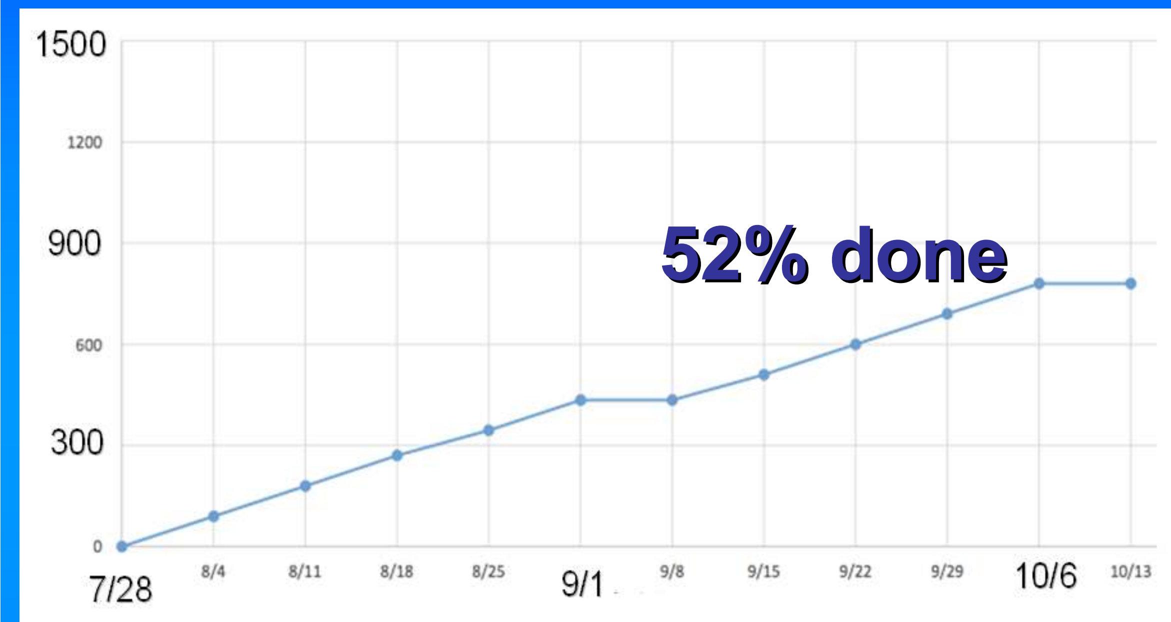
No cut	|tan |≤4.0	|tan |≤3.0	|tan |≤1.5
100%	46.6%	41.7%	20.8%
820 evt	380 evt	340 evt	170 evt

50kg water target, 1.0x10^{21}POT

High speed && large angle Scanning will be applied near future.

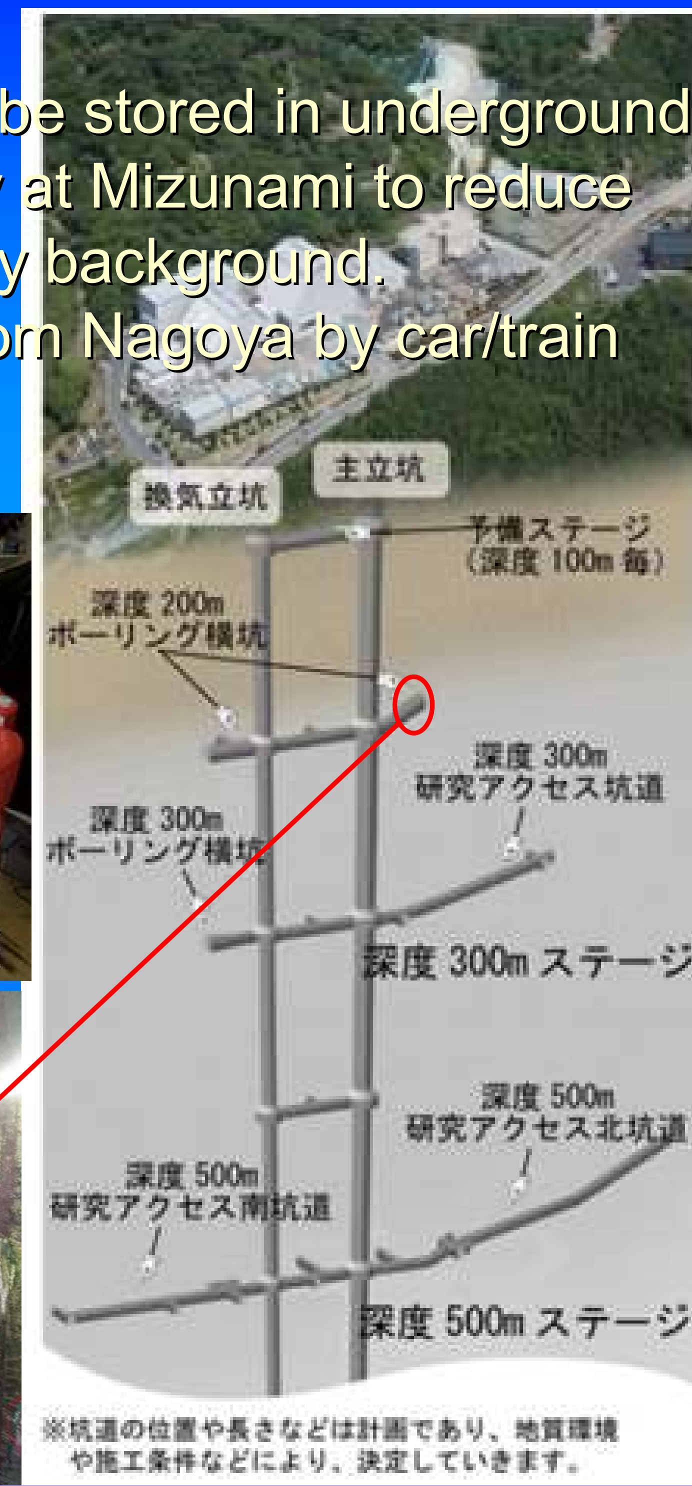
Emulsion film production

Production status



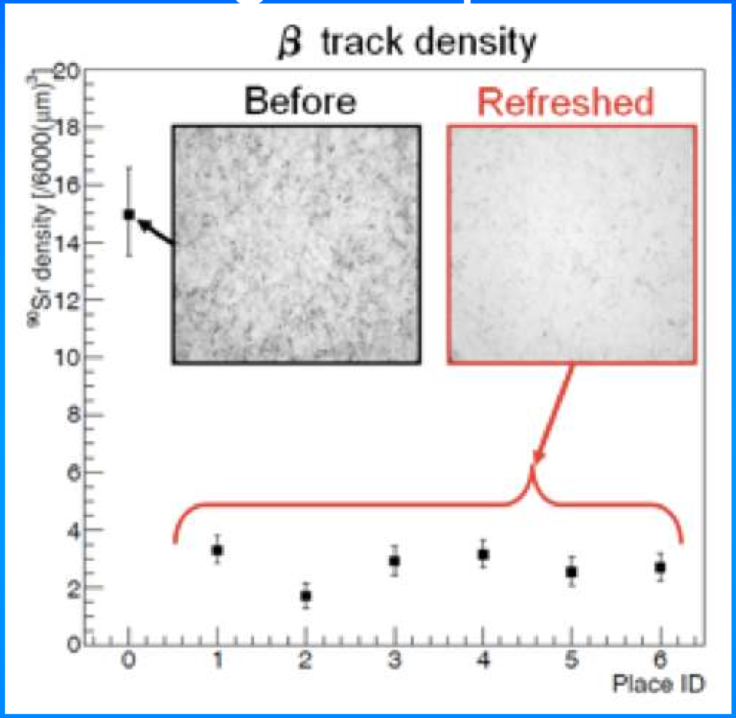
- ~5.6 m^2/week@ Nagoya
- Jul.-Dec.
- Totally 94 m^2

Films will be stored in underground laboratory at Mizunami to reduce cosmic-ray background.
~1hour from Nagoya by car/train

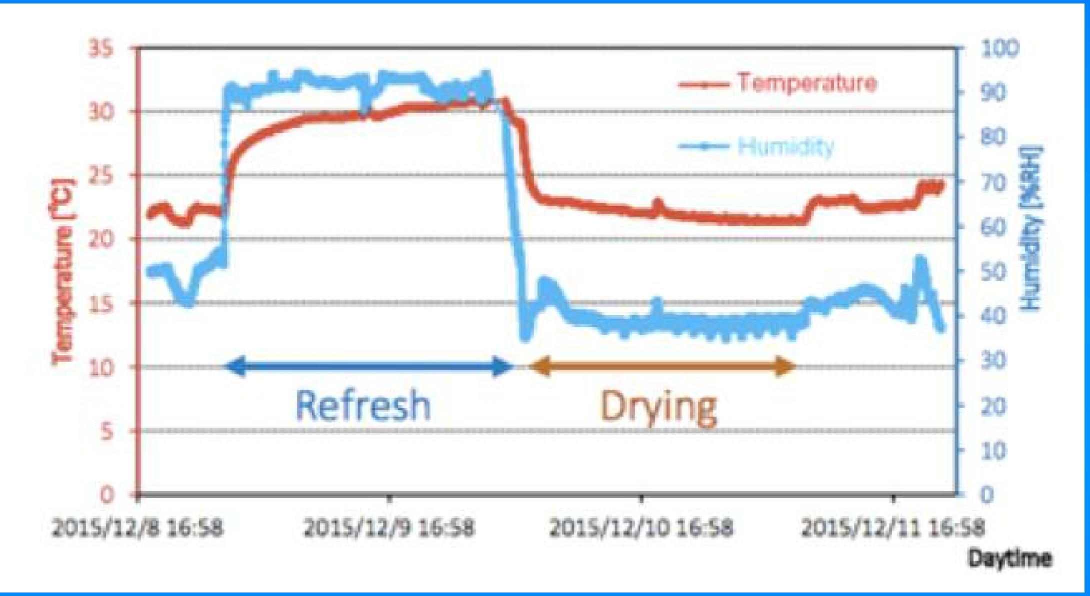


Plan: Film refreshing

- Accumulated noise tracks after producing films are deleted with high temp. and high humi. condition (fading effect)



$$(Ag_4 + 2H_2O + O_2 \rightarrow 4Ag^+ + 4OH^-)$$



We will request one room on ground at J-PARC for film refreshing.

This work will be done before two months from beam start

Current plan

Schedule for preparation

The case of neutrino beam exposure from next May

	2018					2019			
	8	9	10	11	12	1	2	3	4
Emulsion film production									
Refresh& Packing					Setup@J-PARC				
SFT production								Commissioning	
INGRID test									

$\nu \rightarrow$

It depends on the beam schedule (FHC/RHC)

Summary

- We are performing a neutrino experiments at J-PARC to study low energy neutrino - nucleus interactions with nuclear emulsion.
- We are carrying out a test experiment at J-PARC to check the feasibility and detector performance.
- The event analysis of the iron and water target ECC is now in progress.
- We proposed a Physics Run based on experience of Pilot Run and Detector Run to investigate ν -water int. with low energy threshold, large statistics.
- Now we are improving our analysis and producing large amount of emulsion films for coming Physics Run.

Thank you very much.