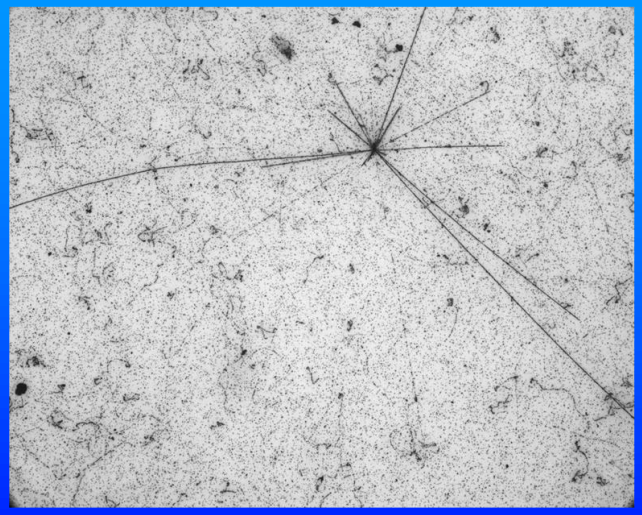
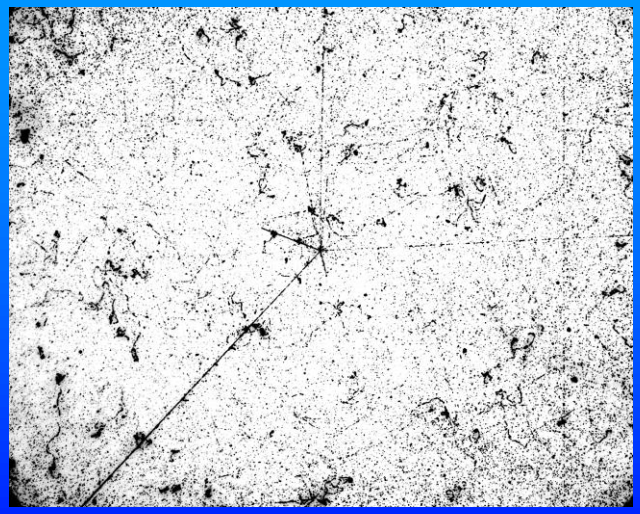
J-PARC T60 : Precise measurement of neutrino-nucleus interactions with Nuclear Emulsion

Tsutomu Fukuda（Nagoya Univ. Japan）
on behalf of J-PARC T60 collaboration

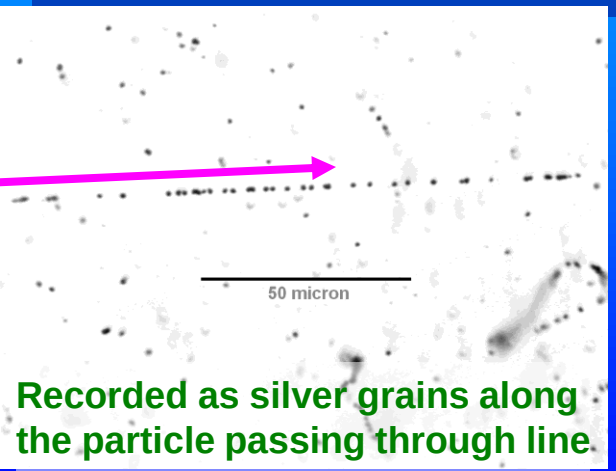




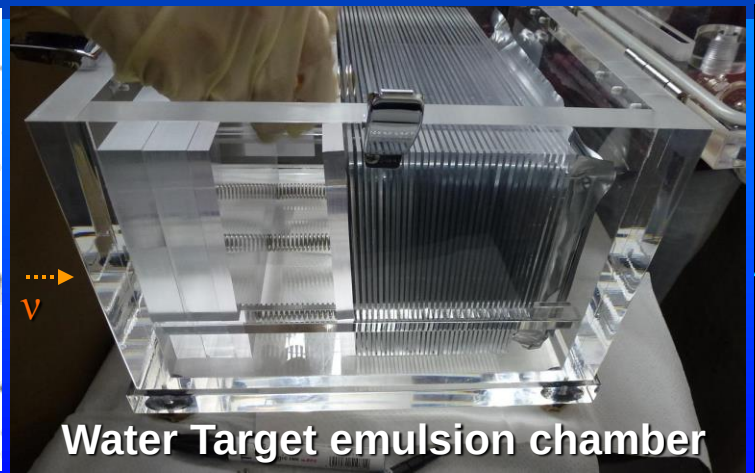
tfukuda@flab.phys.nagoya-u.ac.jp

Motivation

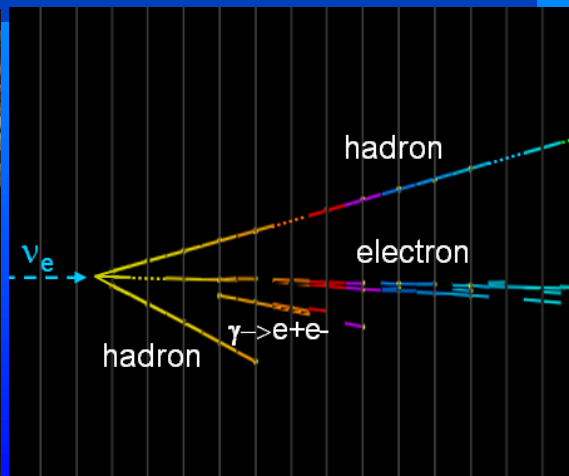
- Precise neutrino-nucleus interaction measurement is important to reduce the systematic uncertainty in future neutrino oscillation experiments.
- We start a new experiment at J-PARC to study low energy neutrino interactions by introducing nuclear emulsion technique.
- The emulsion technique can measure all the final state particles with low energy threshold for a variety of targets (H_2O, Fe, C,…).
- Furthermore its ultimate position resolution allow to measure ν_e cross section with good electron/gamma separation capability.



Recorded as silver grains along the particle passing through line

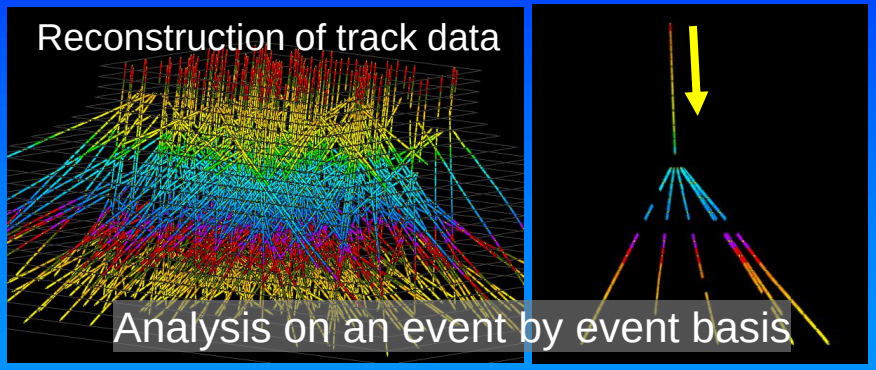


Water Target emulsion chamber

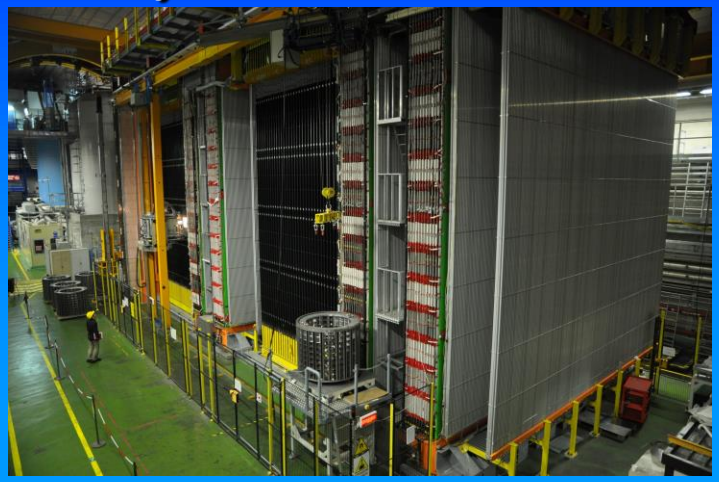


Nuclear Emulsion Detector

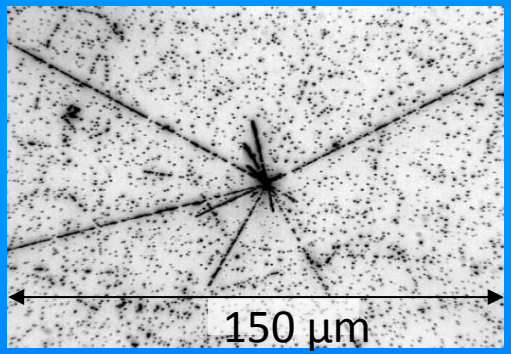
3D reconstruction



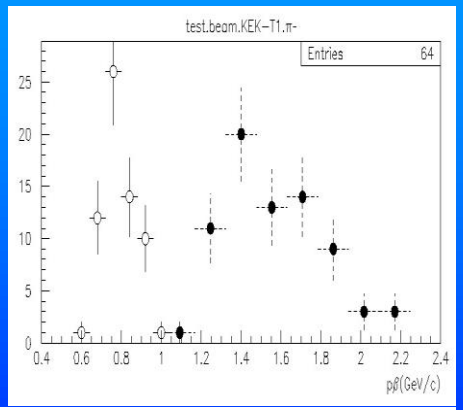
Scalability



4π detection

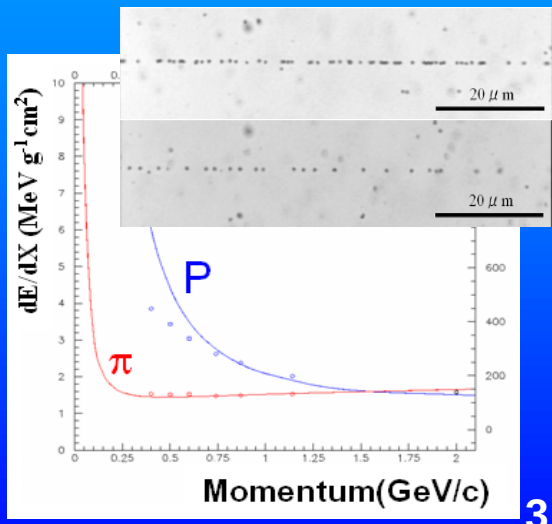


Momentum, dE/dx measurement



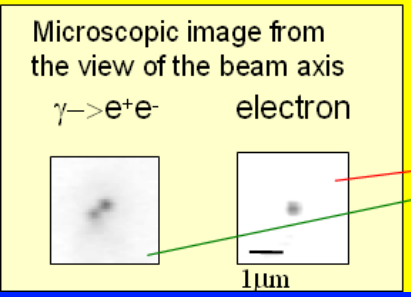
0.8GeV/c π : P =0.79(GeV/c), dP/P =**11**%

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

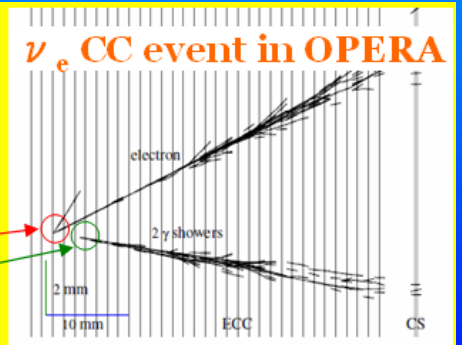


Ultra precise measurement

γ / electron ID



ν_e CC event in OPERA



Low BG from ν_μ NC π^0 production

Nuclear Emulsion Detector

Contribution for fundamental physics

1896 (A. H. Becquerel)
Discovery of Radioactivity

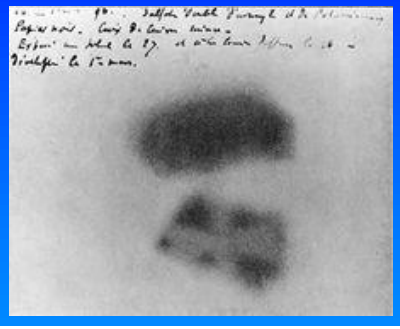
1947 (C. F. Powell et al.)
Discovery of π meson

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

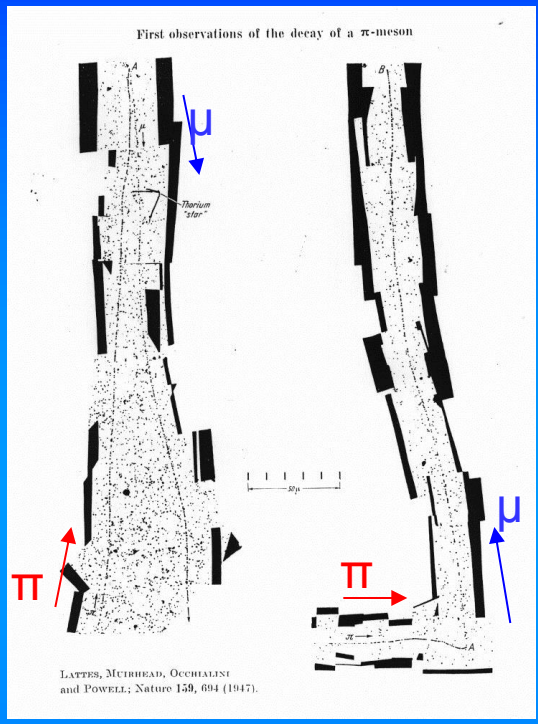
2001 (K. Niwa et al.)
Direct observation of ν_τ

2015 (OPERA)
Discovery of ν_τ appearance

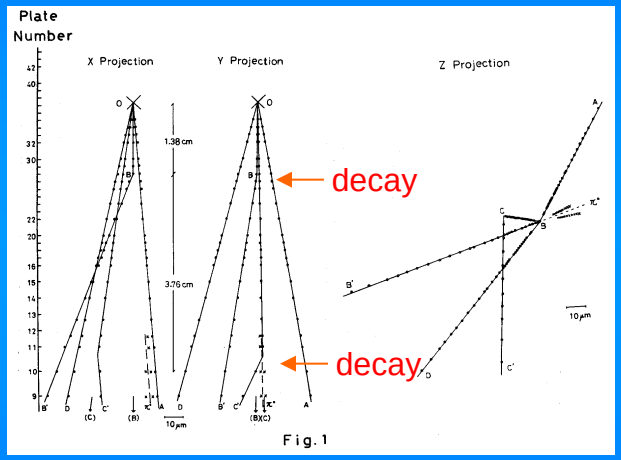
1896



1947



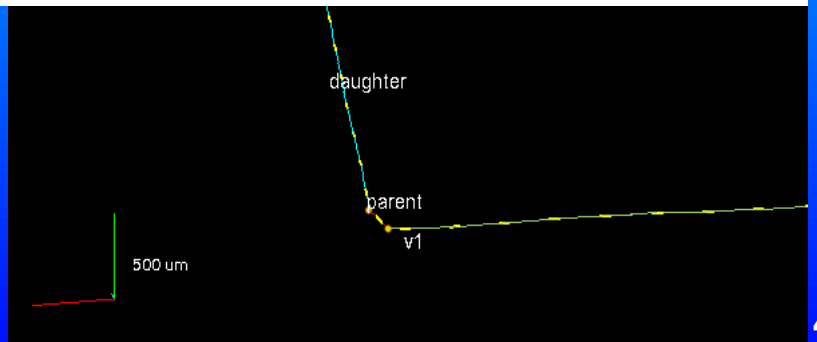
1971

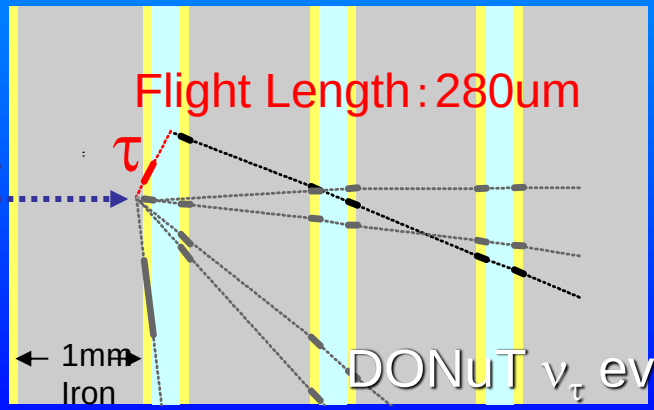


PRL 115, 121802 (2015) PHYSICAL REVIEW LETTERS week ending 18 SEPTEMBER 2015

Discovery of τ Neutrino Appearance in the CNGS Neutrino Beam with the OPERA Experiment

2015



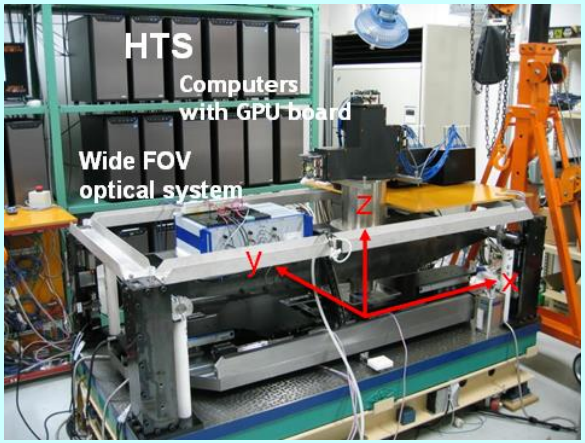


2001 DONuT ν_τ event

Recent technical improvements

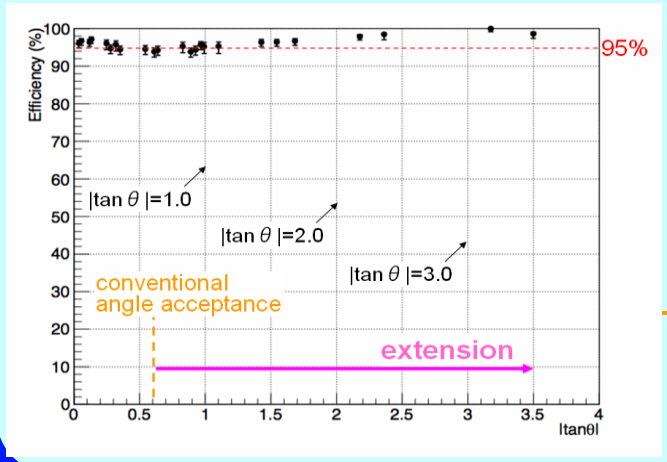
Readout technique

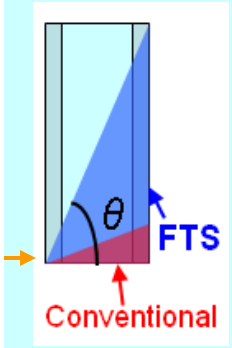
High Speed Scanning



HTS 9,000cm²/h, x100 faster

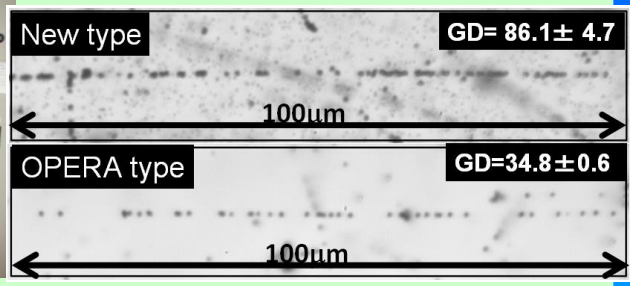
Large angle tracking technique



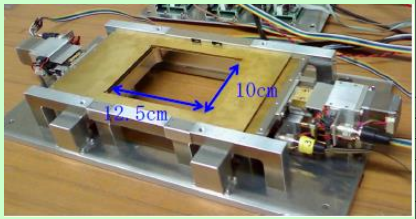


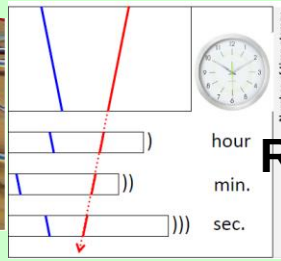
Detector technique

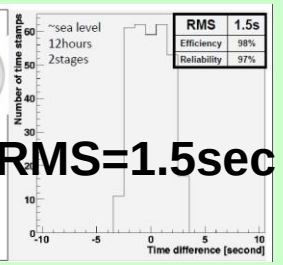
High Sensitive film



Time resolution

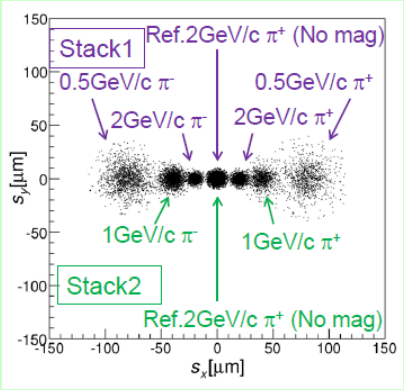




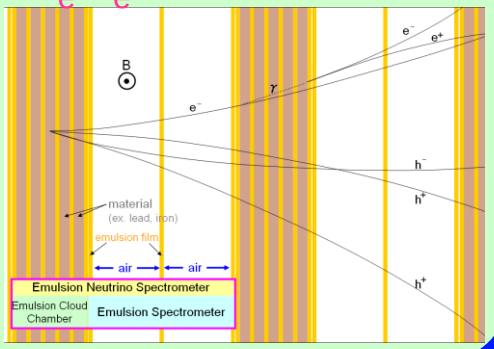


RMS=1.5sec

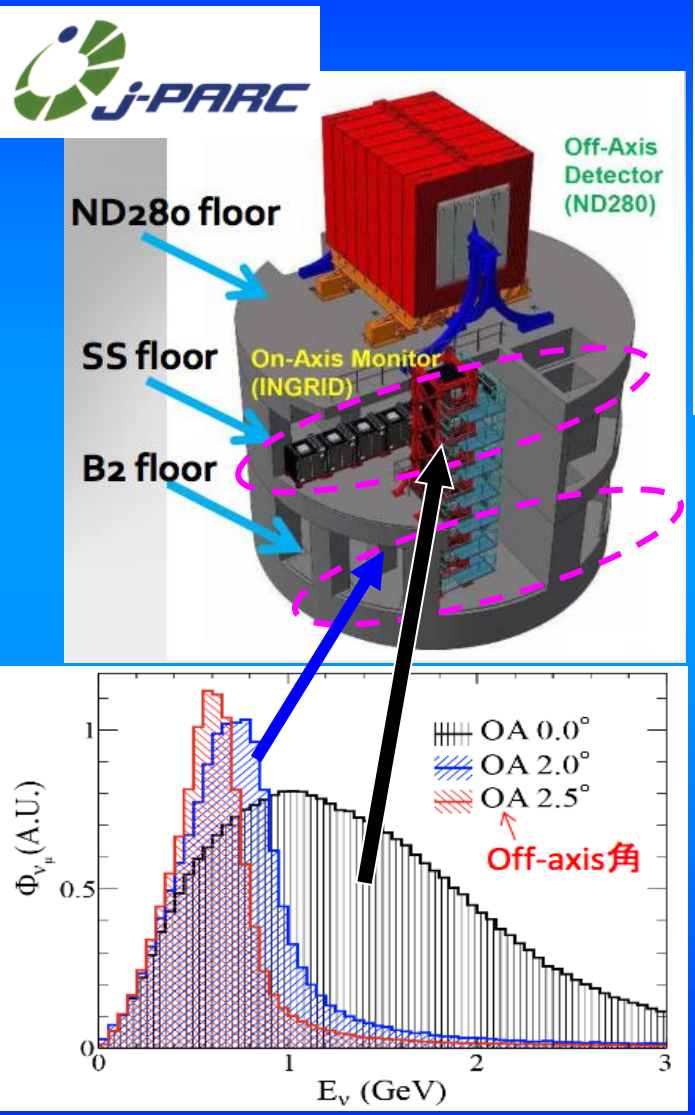
Charge sign ID



$\nu_e/\bar{\nu}_e$ identification



J-PARC T60 Experiment



Proposal of an emulsion-based test experiment at J-PARC

Exclusive summary

A test experiment is proposed that equips Emulsion Cloud Chamber as a main detector in order to investigate environmental and beam associated background at the T2K near detector hall in J-PARC, optimal detector structure, and performance of newly developed nuclear emulsion gel. The aim of the experiment is a feasibility study to make a future experimental plan for the study of low energy neutrino-nucleus interactions and the exploration of a sterile neutrino.

- **J-PARC PAC endorsed as a test experiment.**
  （PI: T. Fukuda）

Working group

J-PARC
Experimental site, Neutrino beam

Nihon Univ.
Emulsion development

Univ. Tokyo
T2K near detector

Nagoya Univ.
Management,
Film production, Scan

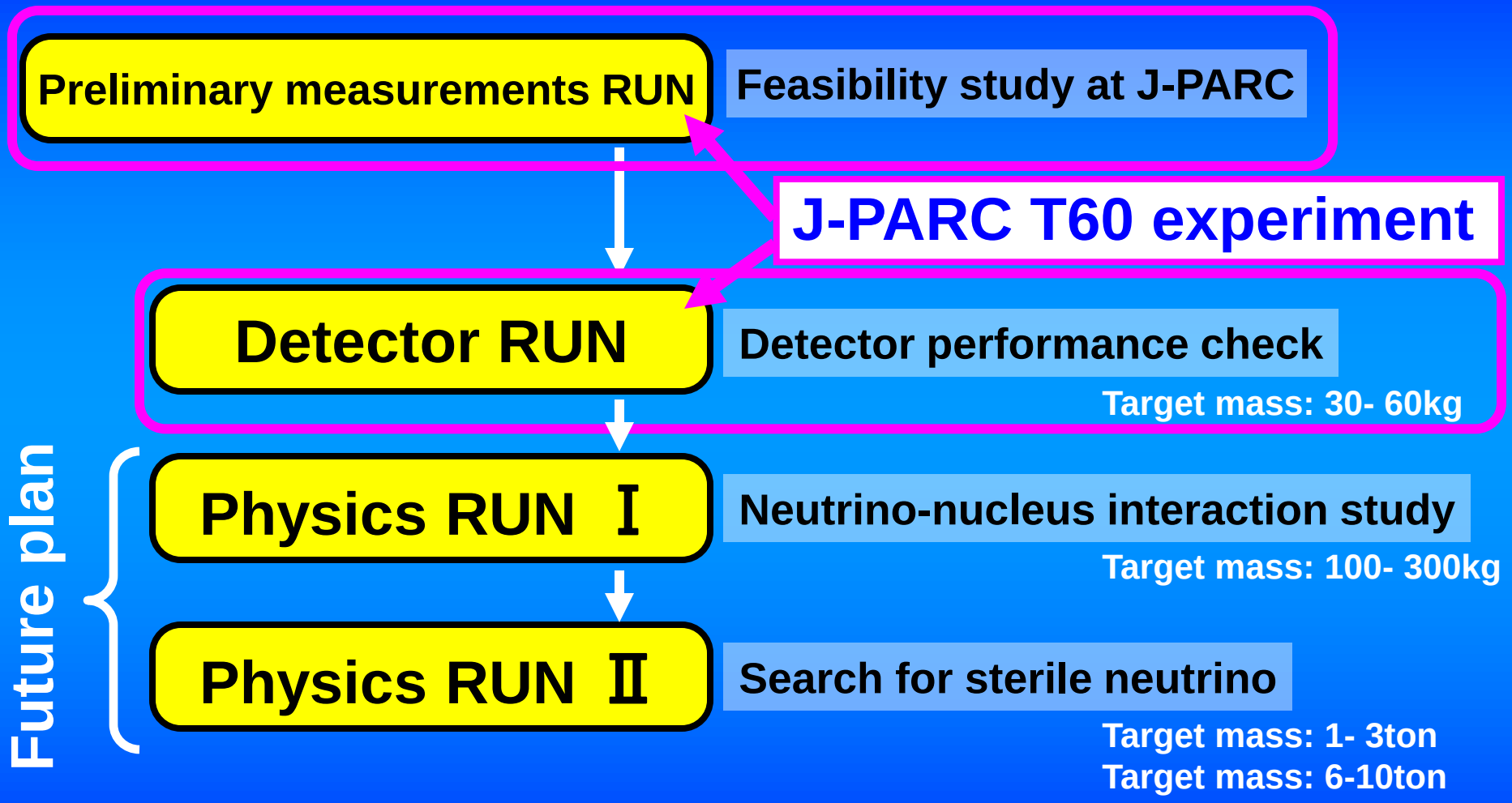
Kyoto Univ.
T2K near detector

Toho Univ.
Film production,
Film quality check, Scan

Kobe Univ.
Emulsion Shifter

A collaborative project with some member of OPERA and T2K

Roadmap



- The aim of T60 is a feasibility study and detector performance check to make a future plan.
- We will expand the scale of detector gradually, step by step.

ν exposure status of T60

exposure	Detector	Aim
2014. Nov – 2015. Mar	2kg Iron target ECC with Emulsion Shifter	・Emulsion film production ・Emulsion handling @J-PARC ・Demonstration of **ν** event detection and analysis ・Hybrid analysis with INGRID
2015. May - Jun	1.5kg Water target ECC	・**ν**- Water int. detection with emulsion detector ・ Optimization of the detector structure
2016. Jan - May	60kg Iron target ECC with Emulsion Shifter	・Data-MC comparison with high statistics. ・ν_e CC event detection

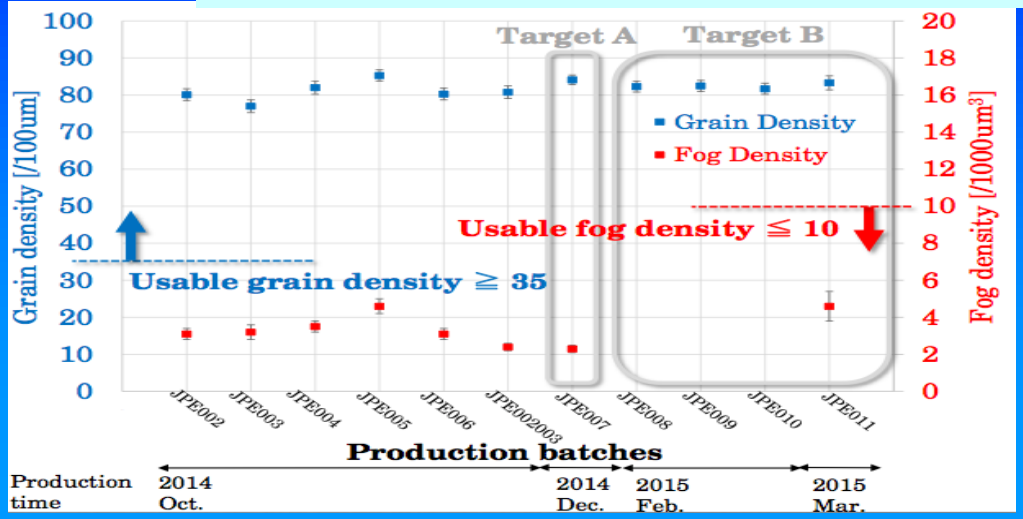
- We have demonstrated the basic experimental concept at J-PARC site.
- “Detector performance run” is started from this Jan.

Status of T60

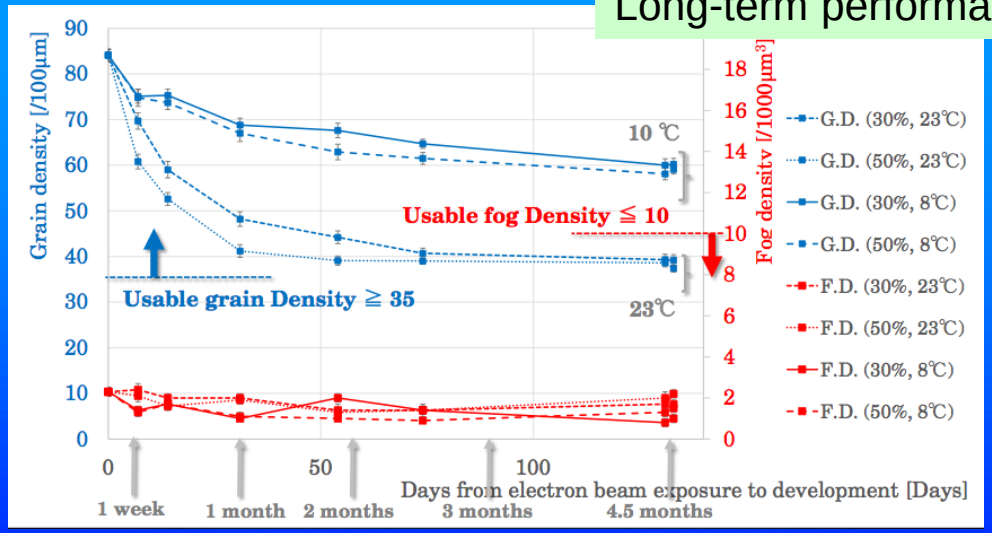
Emulsion gel production in the lab

Nuclear emulsion films were made by ourselves.

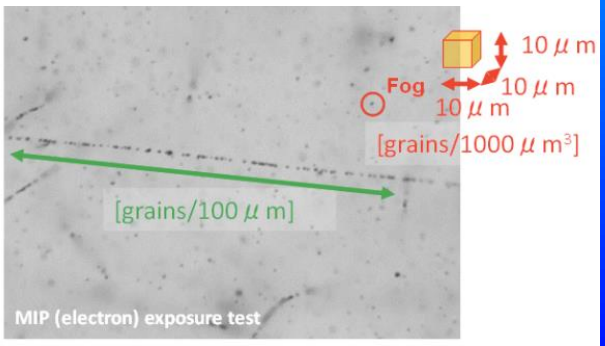
Initial performance for each production batch



Long-term performance

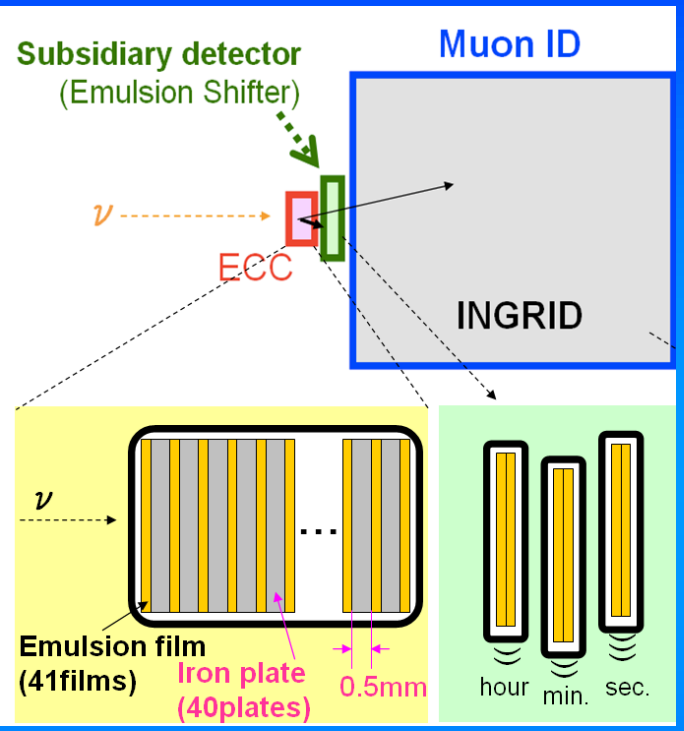


Signal efficiency → Grain density
Isolated random noise → Fog density

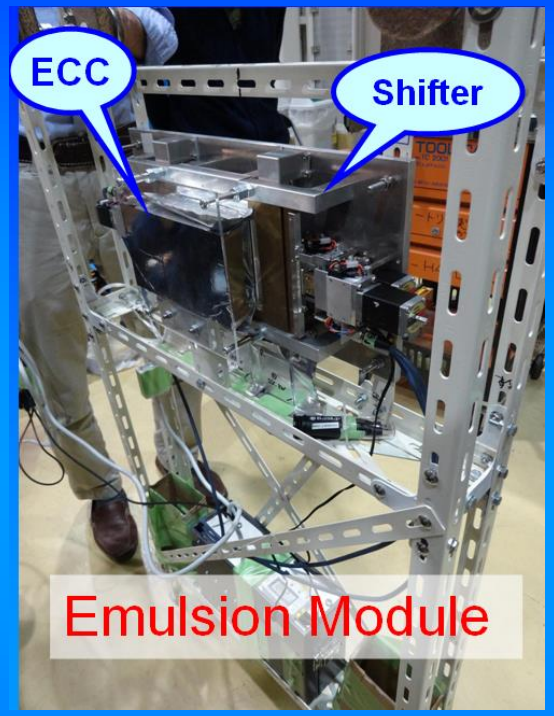


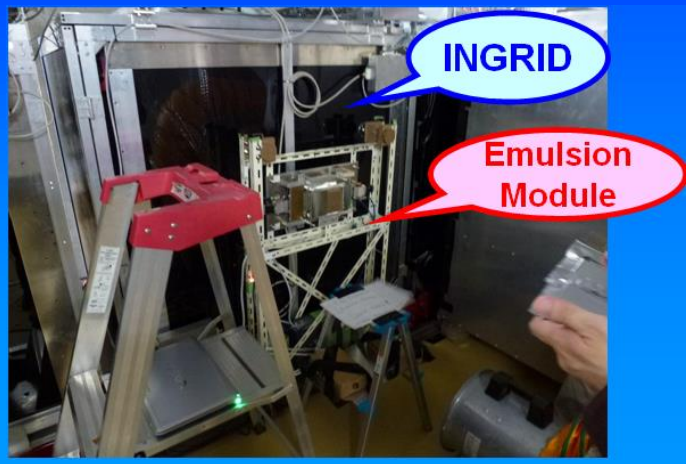
Initial and long-term performance of new emulsion gel is kept at safety level for signal and noise.

Conceptual detector design

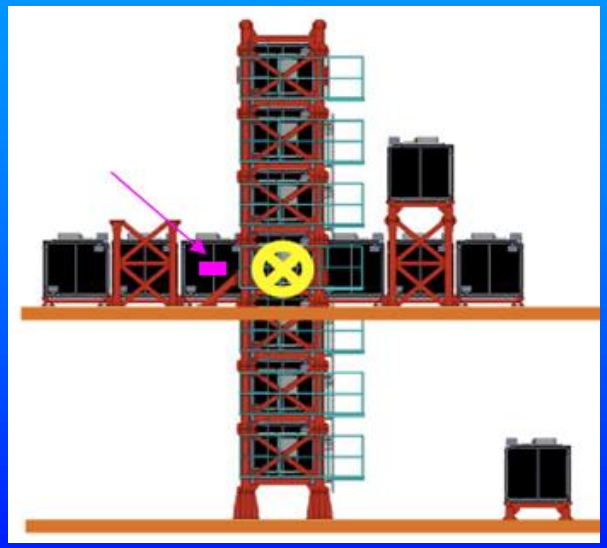


2kg iron target ECC





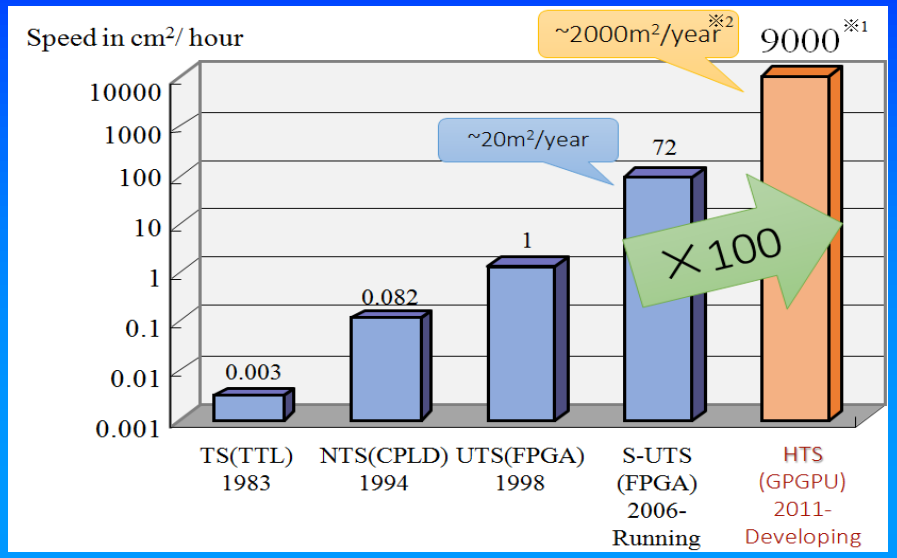
SS floor @J-PARC
(Jan. 2015)



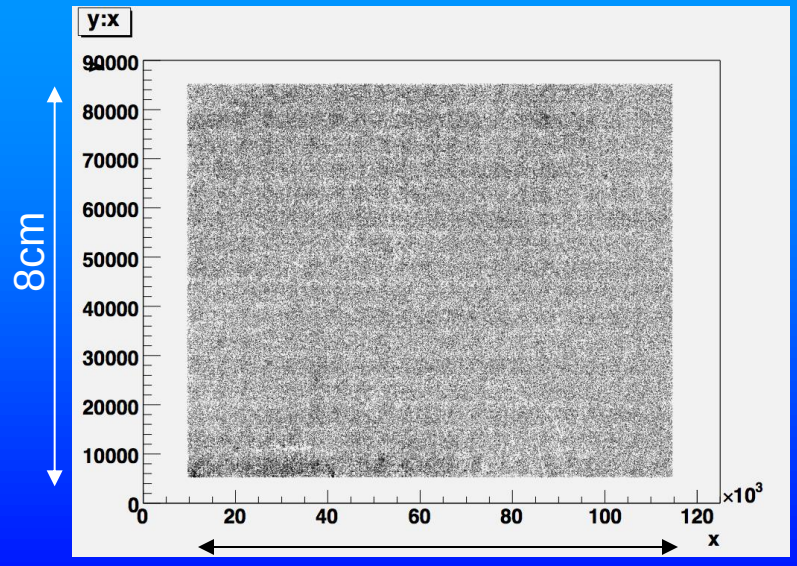
- **E**mulsion **C**loud **C**hamber is a sandwich structure of emulsion films and iron plates.
- Emulsion detector is placed In front of T2K near detector, INGRID.
- Emulsion Shifter give a timing info. to emulsion tracks.
- Muon ID is possible by combined analysis with INGRID.

Data taking by emulsion scanning system

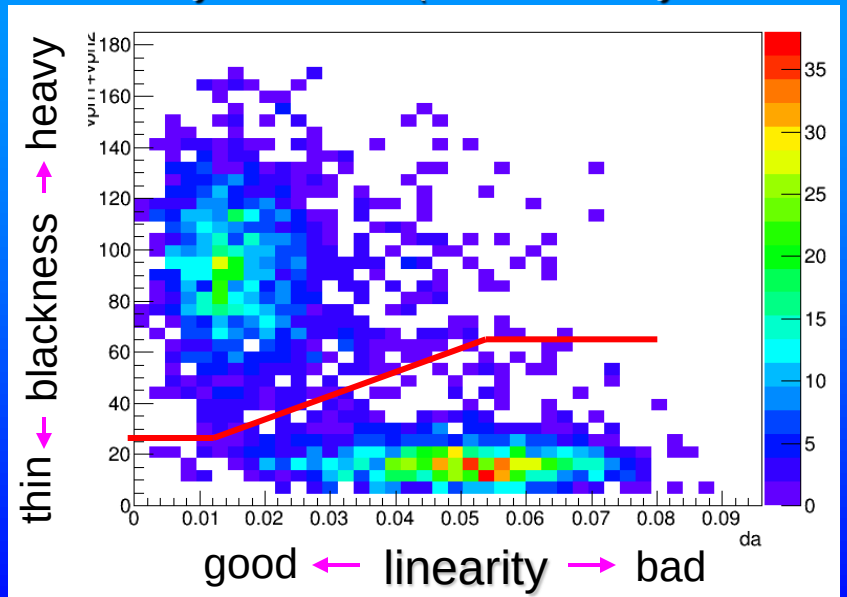
Latest very high speed scanning system developed in Nagoya Univ.



Position distribution

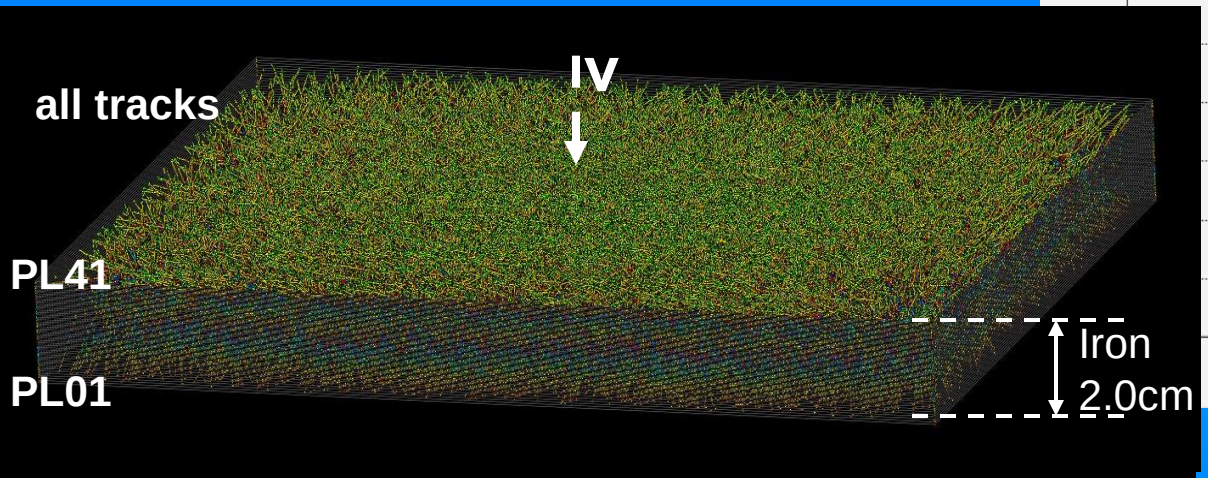


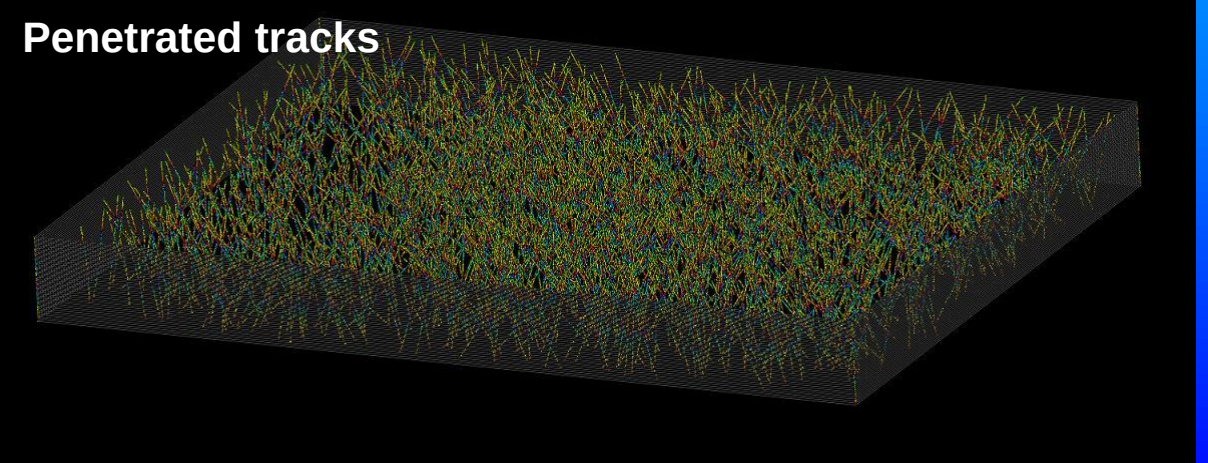
Track Quality Selection (track linearity vs blackness)

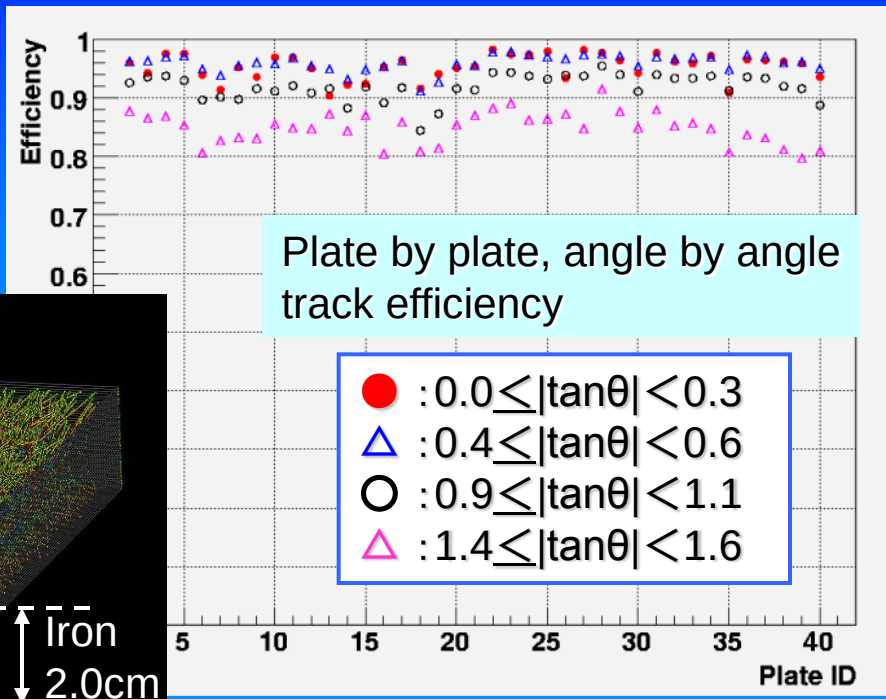


Reconstructed track data

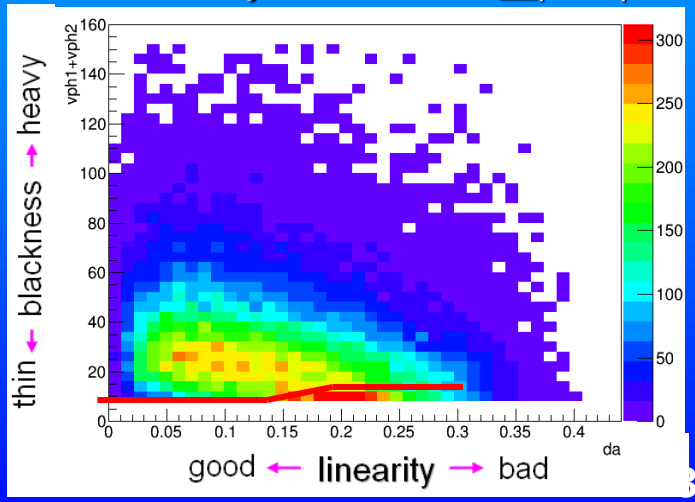
Track efficiency is evaluated each track angle.
The efficiency for large angle tracks is lower than one for small angle tracks.





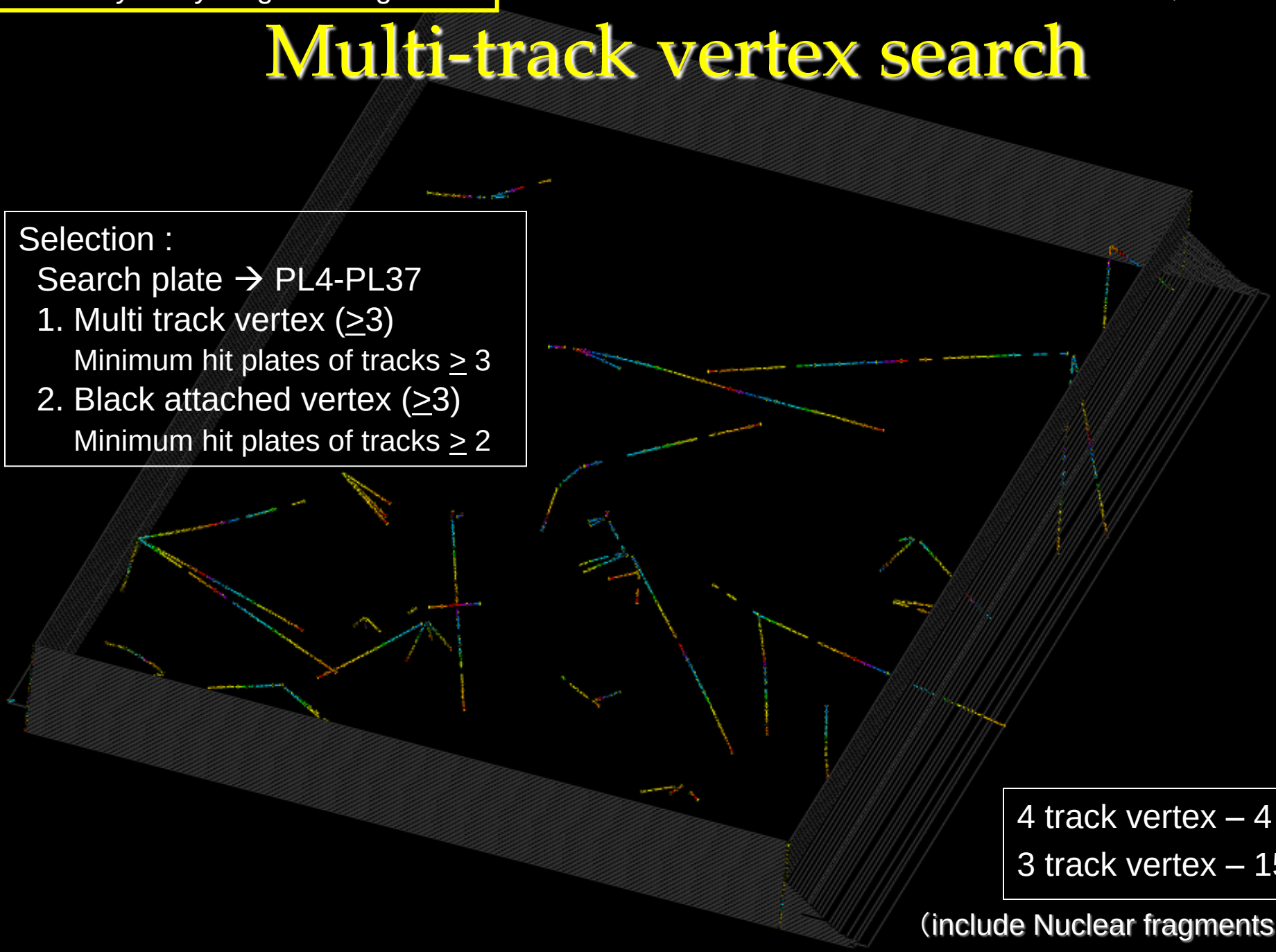


Track Quality Selection（1.4≦|tanθ|）



Multi-track vertex search

Selection :
Search plate → PL4-PL37
1. Multi track vertex (≥3)
   Minimum hit plates of tracks ≥ 3
2. Black attached vertex (≥3)
   Minimum hit plates of tracks ≥ 2

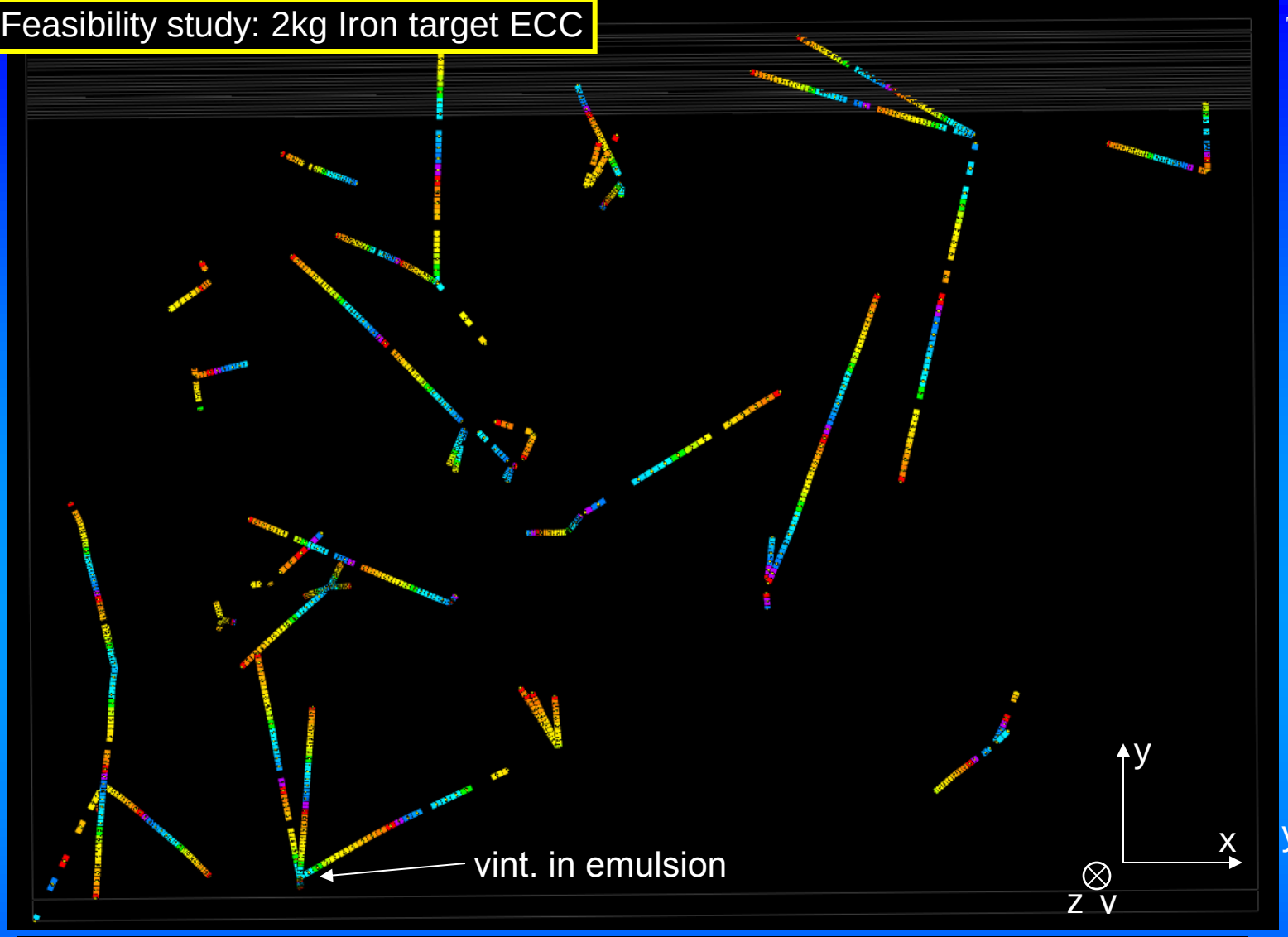


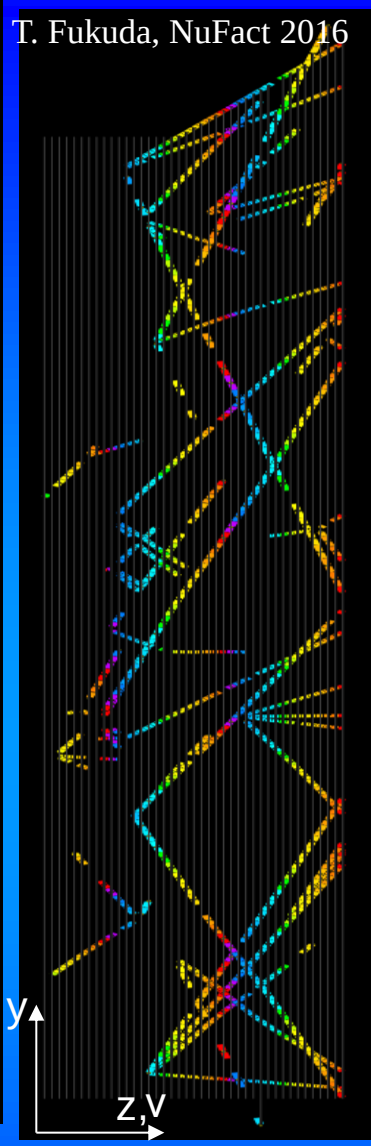
4 track vertex – 4
3 track vertex – 15

（include Nuclear fragments）

Feasibility study: 2kg Iron target ECC

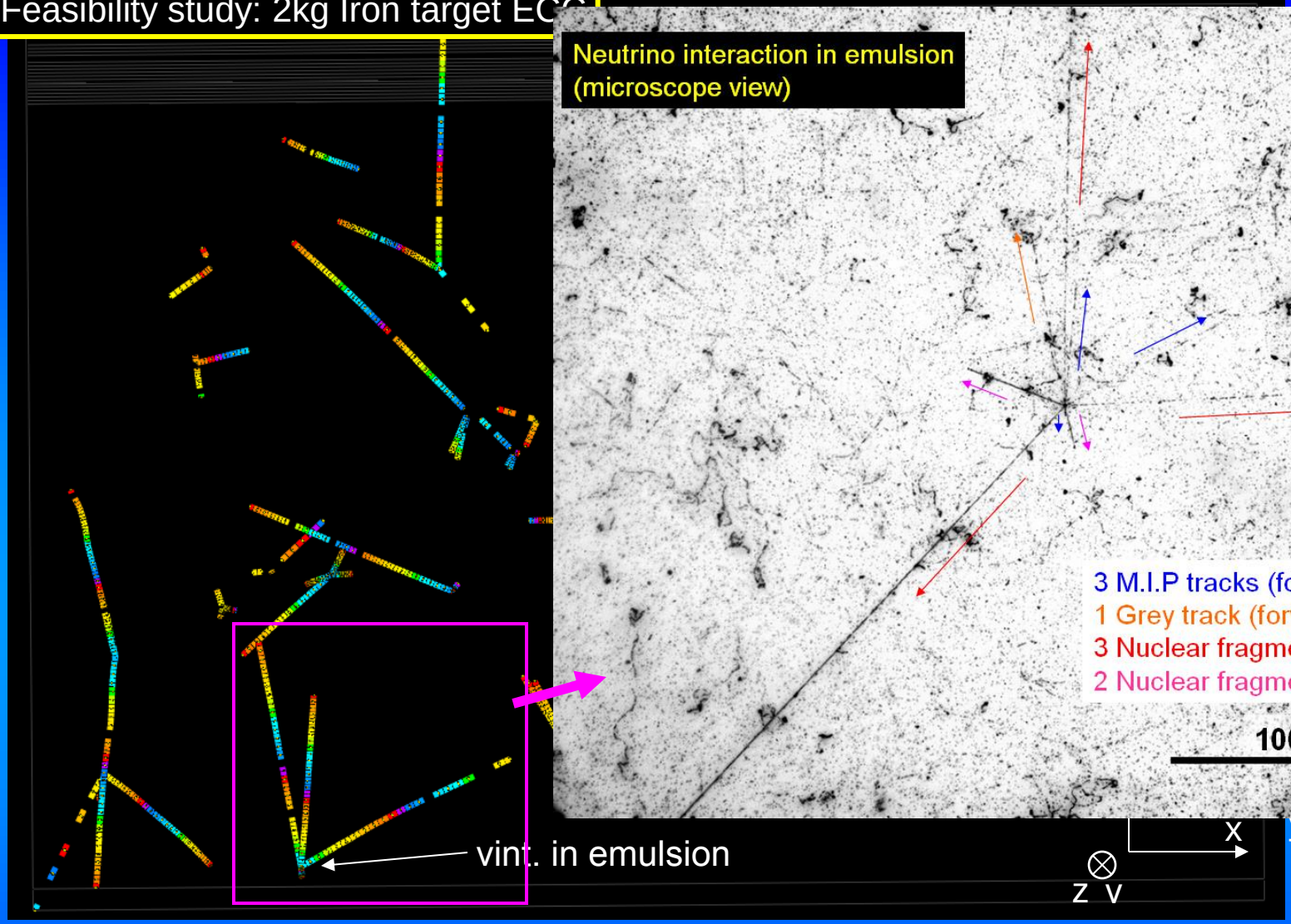
T. Fukuda, NuFact 2016



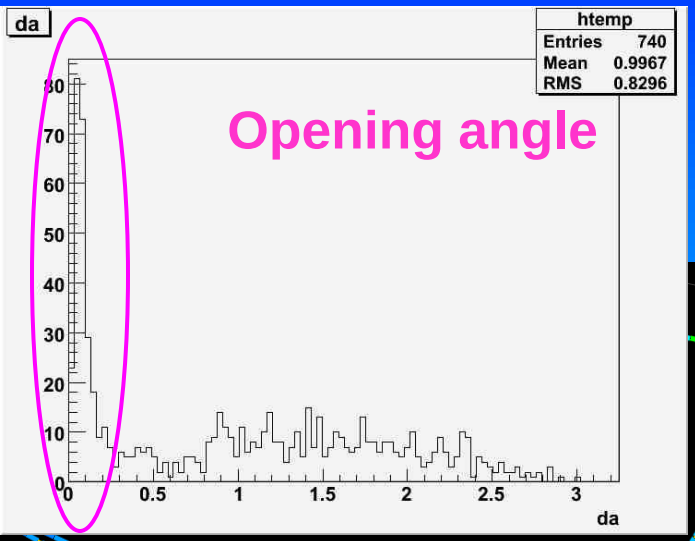


Iron 2.0cm

Feasibility study: 2kg Iron target ECC



e^+e^- pair search



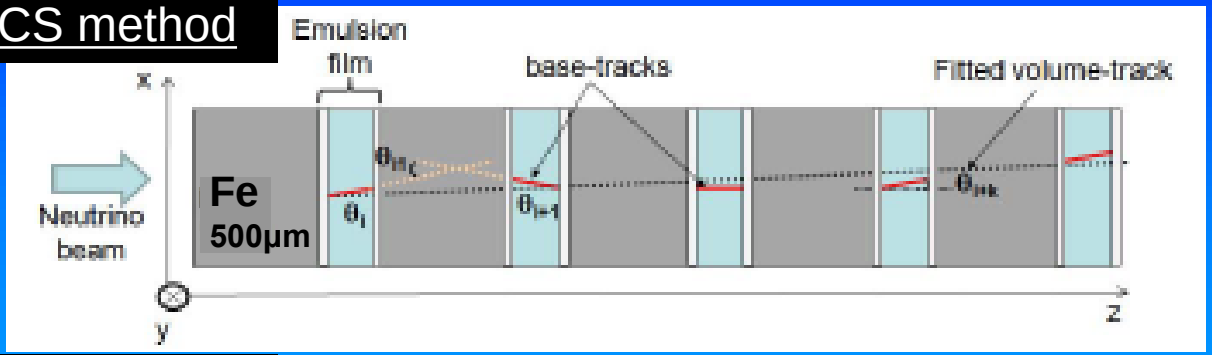
2 Track vertex && da≤0.3

We will estimate their energy and investigate their origin.

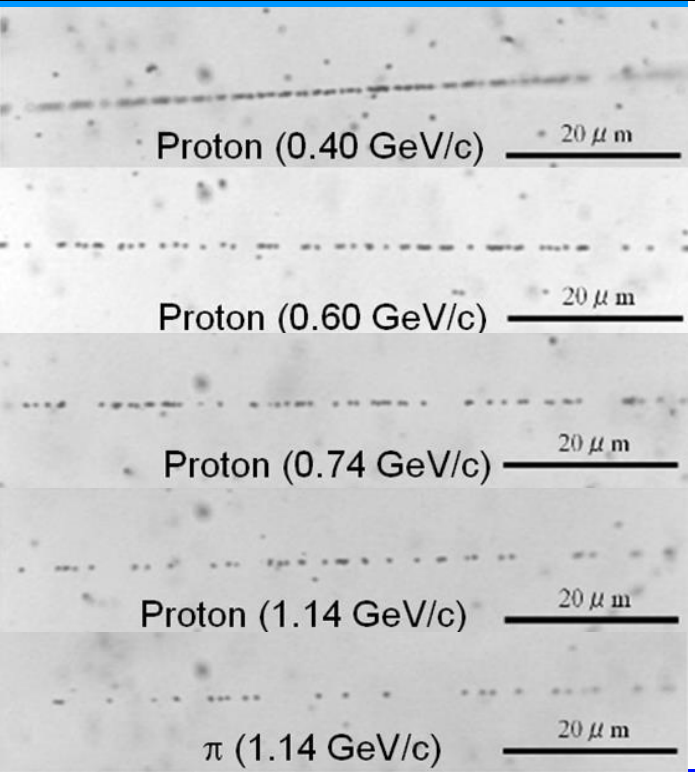
Proton identification

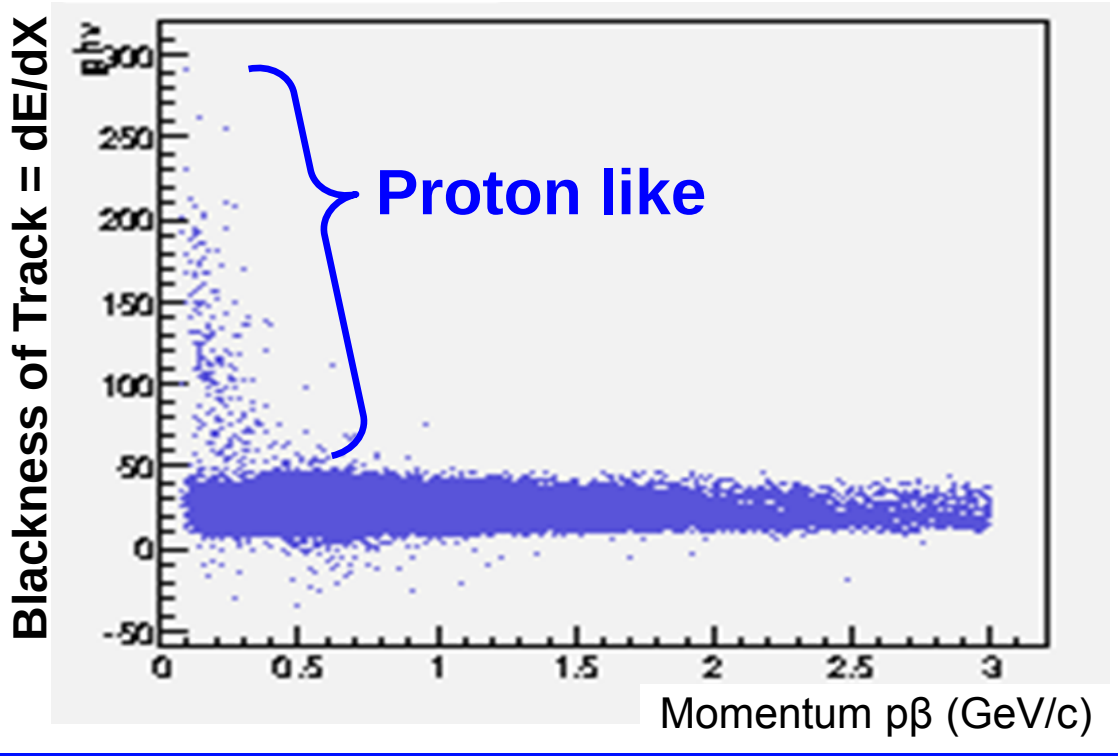
pβ measurement by the MCS method

$$\theta_0 = \frac{13.6}{(pc\beta)} \times \sqrt{\frac{x}{X_0}} \times \left[1 + 0.038 \ln\left(\frac{x}{X_0}\right)\right]$$



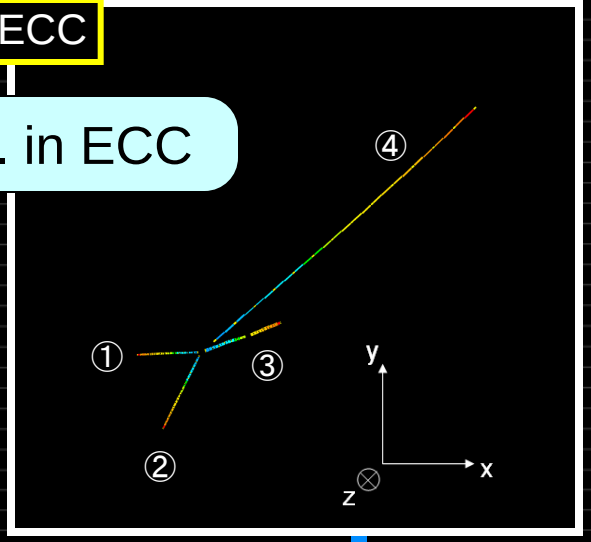
dE/dx measurement by track blackness

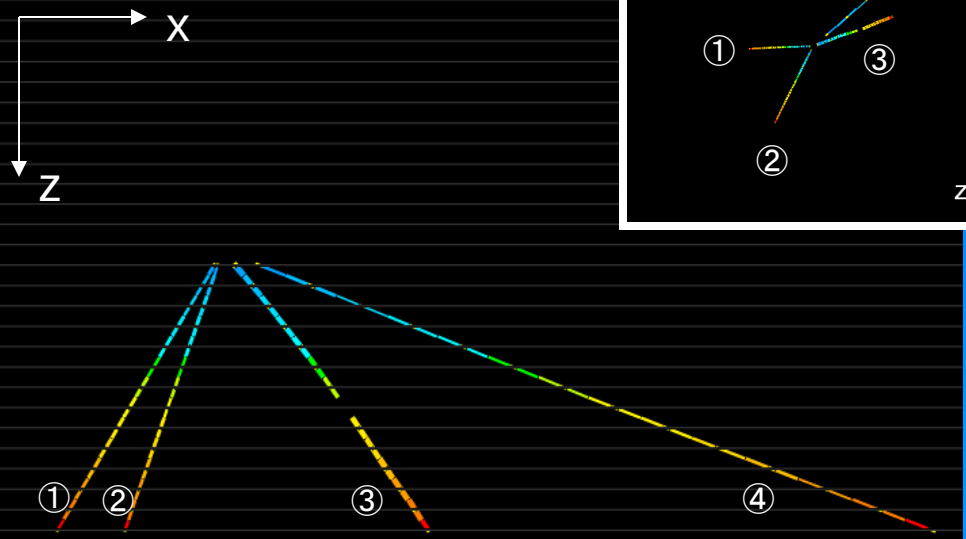


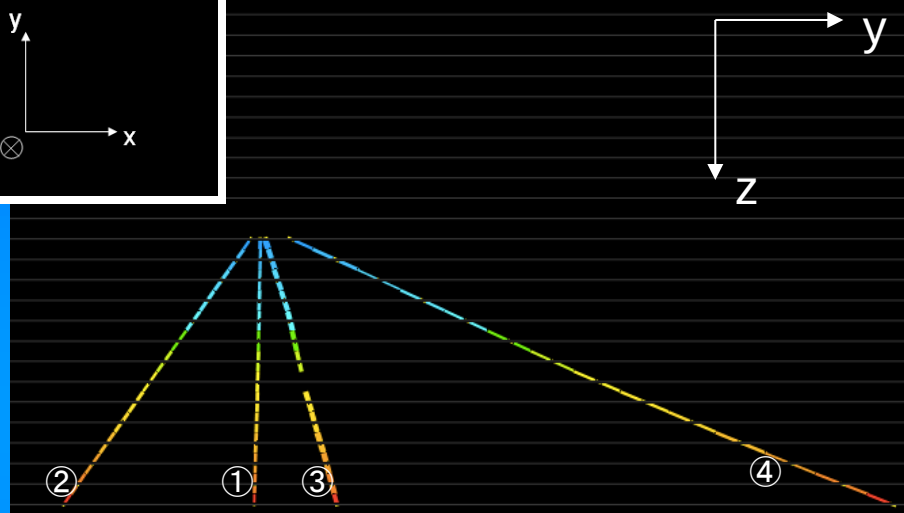


Feasibility study: 2kg Iron target ECC

Event info. in ECC

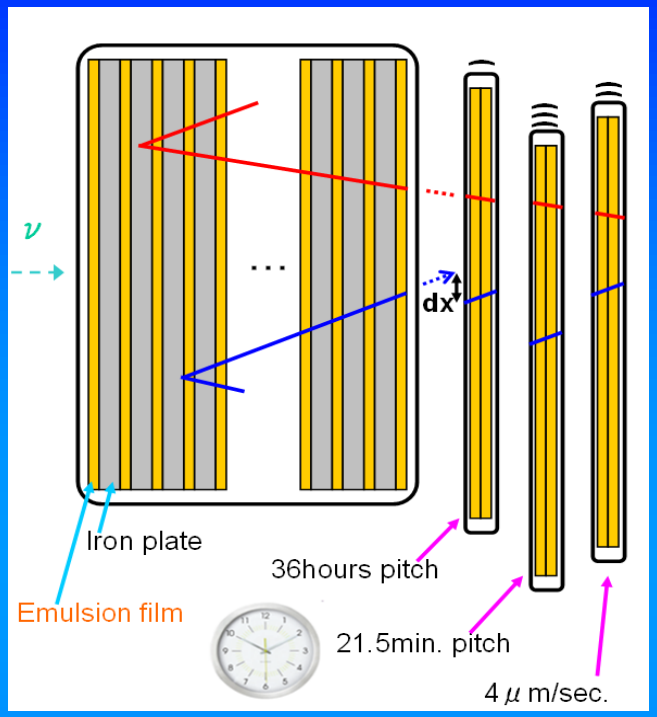






Track #	tanθx @PL01 (rad)	tanθy @PL01 (rad)	VPH (→ dE/dX) (not angle calibration)	pβ (MeV/c) (preliminary)	PID (preliminary)	m.d. (μm)
①	- 0.1668	- 0.0056	38	404^{+380}_{-120}	π/μ	3.1
②	- 0.0959	- 0.1943	34	584^{+370}_{-140}	π/μ	3.4
③	0.1757	0.0836	96	220^{+80}_{-40}	Proton	0.4
④	0.7213	0.7246	17	285^{+180}_{-60}	π/μ	5.7

Time stamp for ν event with Emulsion Shifter



Emulsion films are set on moving stages controlled by stepping motor.

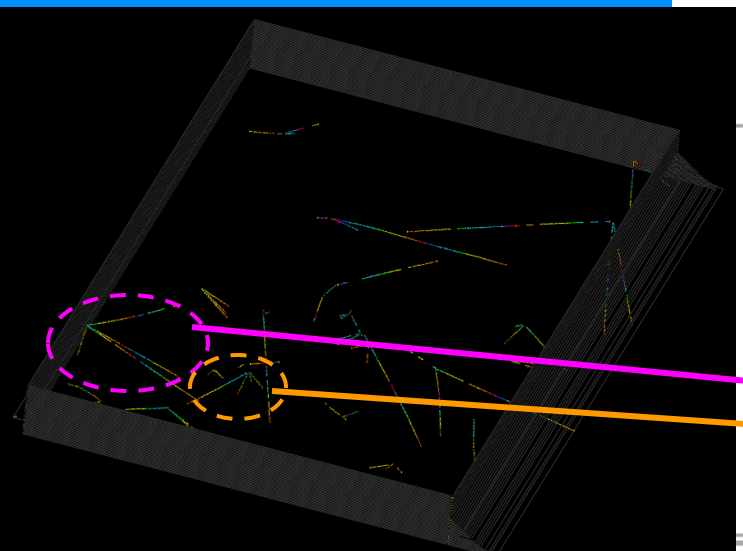
Time stamp is given by coincidence of tracks on each stage.

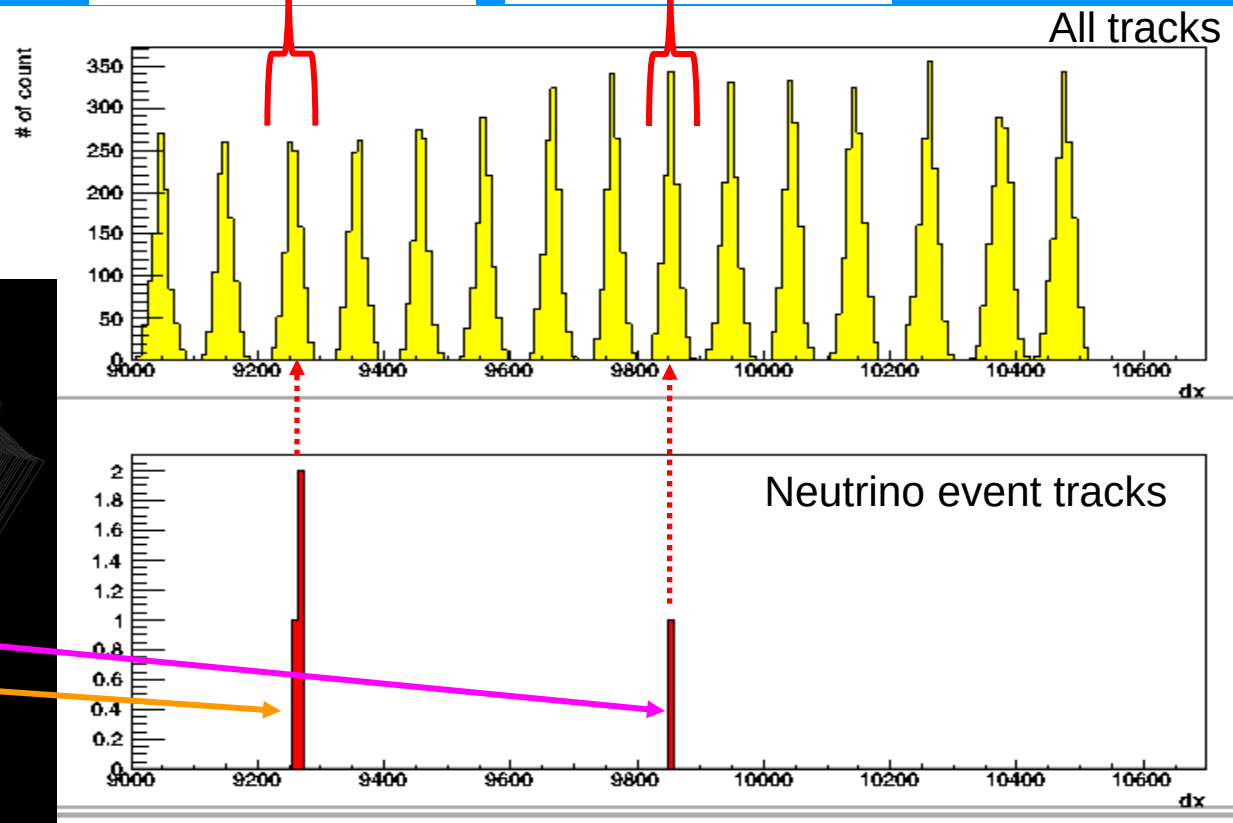
→ Position difference from reference point
= Timing information

Spot 13
Mar.12 2:23:35
~ Mar.14 14:23:57

Spot 7
Mar.21 2:25:49
~ Mar.23 14:26:12

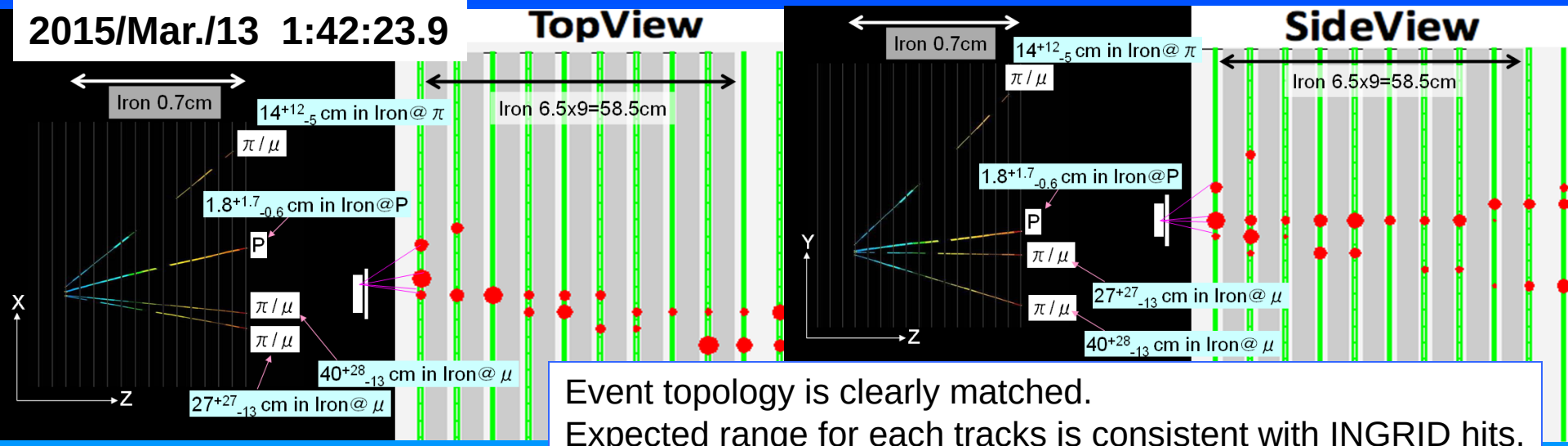
← Information from Top stage





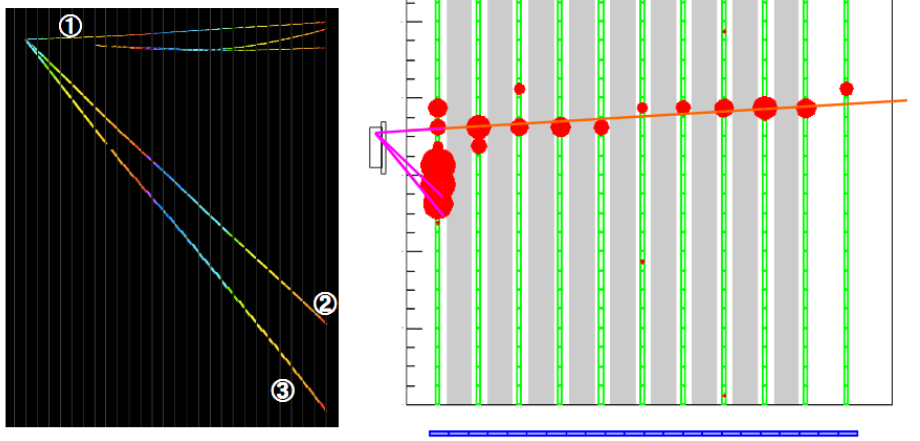
Emulsion-INGRID Hybrid analysis

<Event time>
2015/Mar./13 1:42:23.9

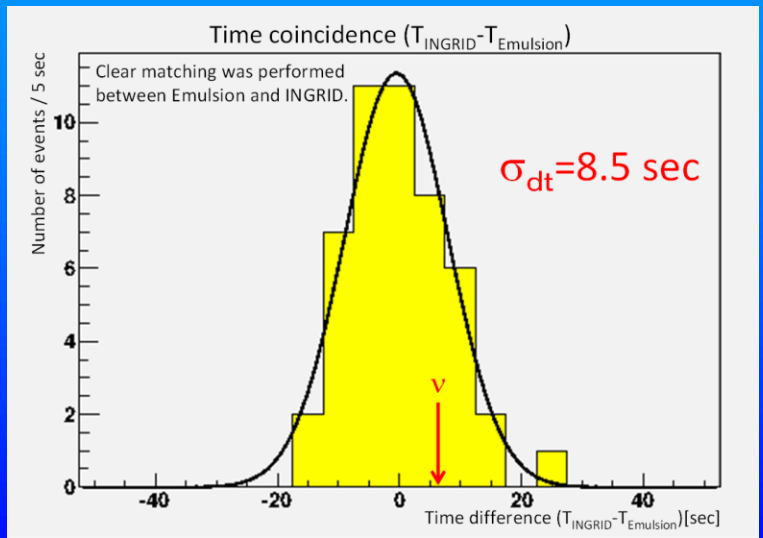


Event topology is clearly matched.
Expected range for each tracks is consistent with INGRID hits.

<Event time>
2015/Mar./22 15:06:35.0

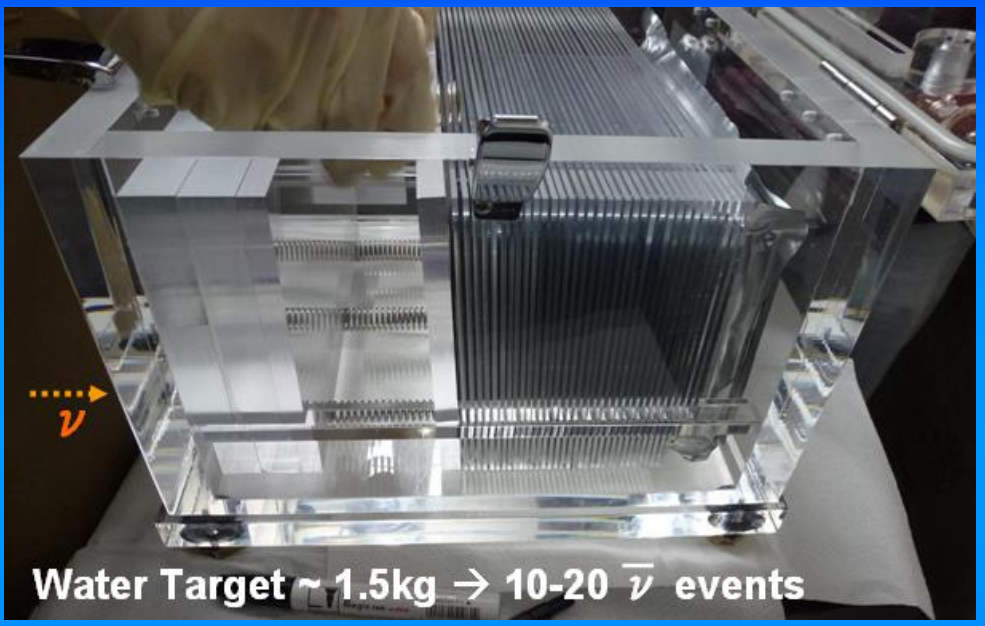


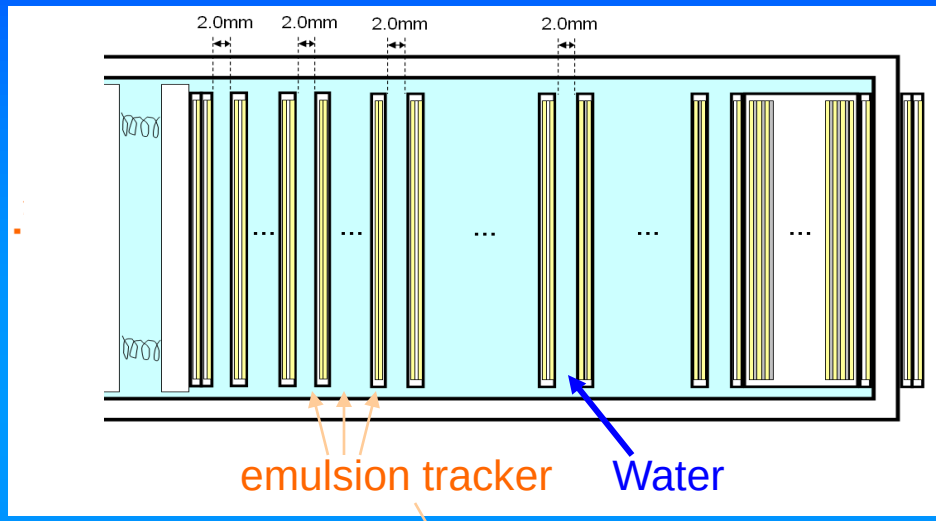
Time resolution for emulsion tracks



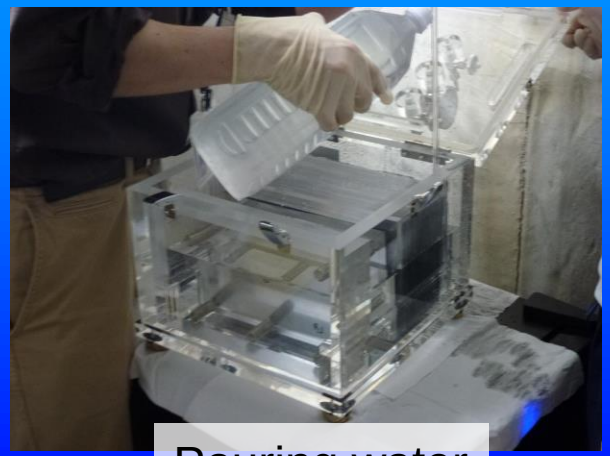
Water target emulsion chamber

We installed a water target emulsion chamber during $\bar{\nu}$ exposure in May 2015.

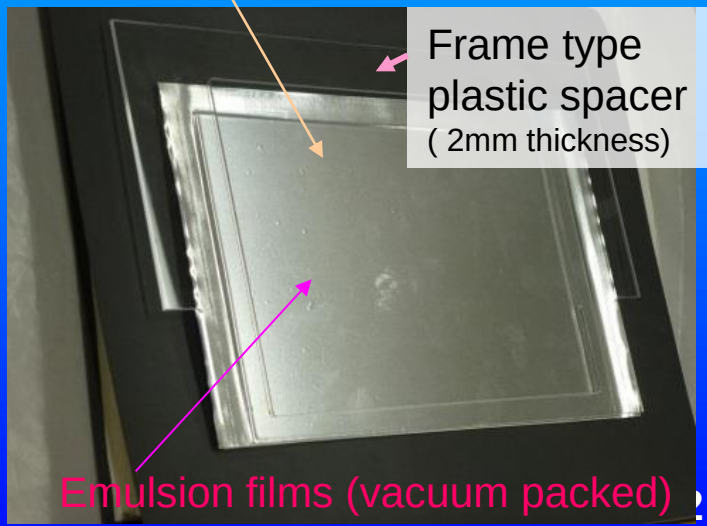




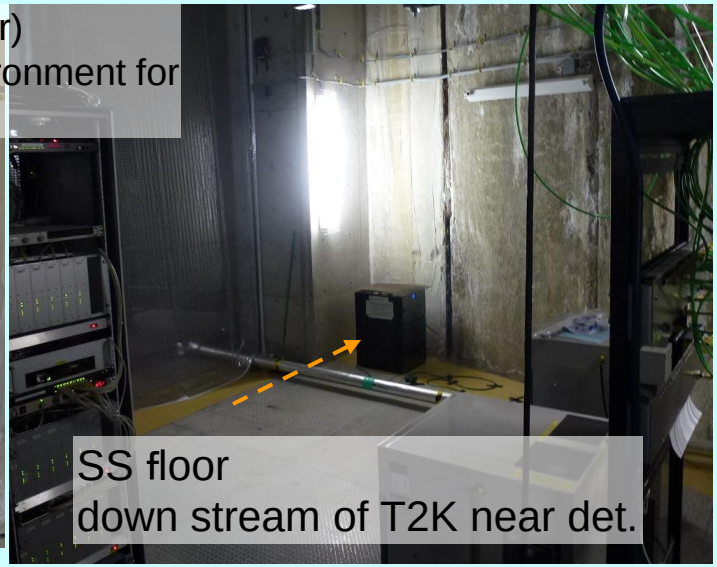
Sandwich structure of Emulsion films and Frame type spacers

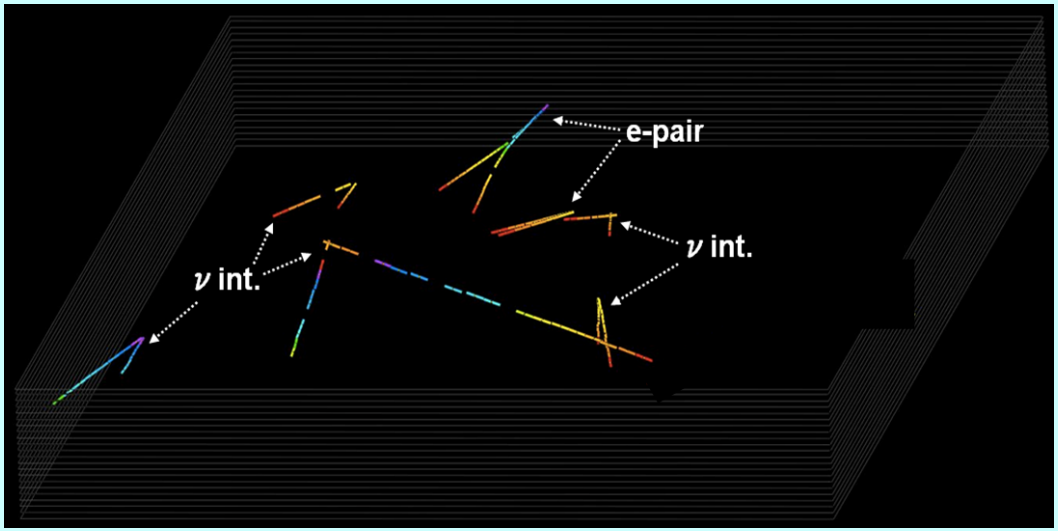


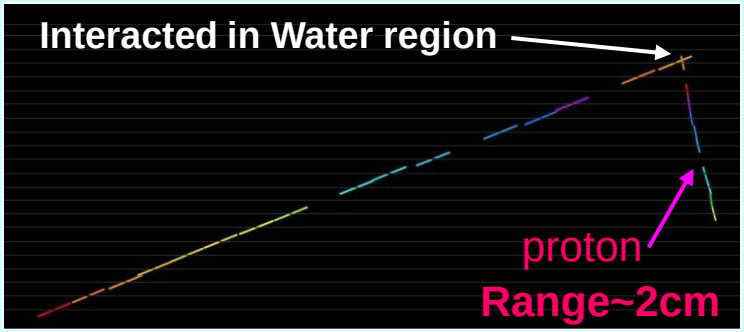
Pouring water



Water target emulsion chamber







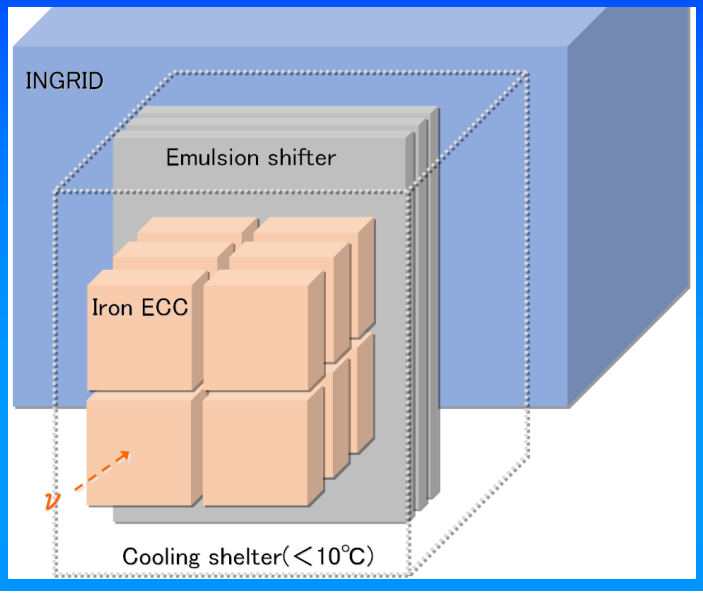
①	(tanθx, tanθy)=(-0.040, 0.845)	M.I.P
②	(tanθx, tanθy)=(-0.589, -0.074)	proton

Minimum distance(① - ②)=2.4um,
depth=620um

First detection of ν - Water interaction with Emulsion Detector

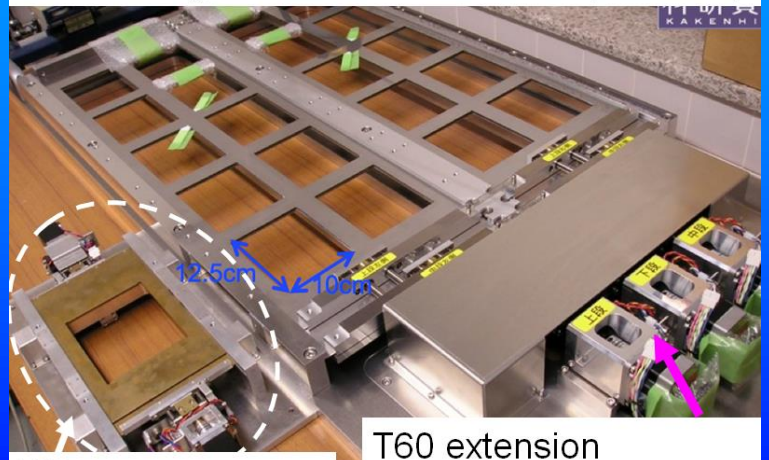
Detector Run

We are starting Detector Run to compare MC with high statistics.



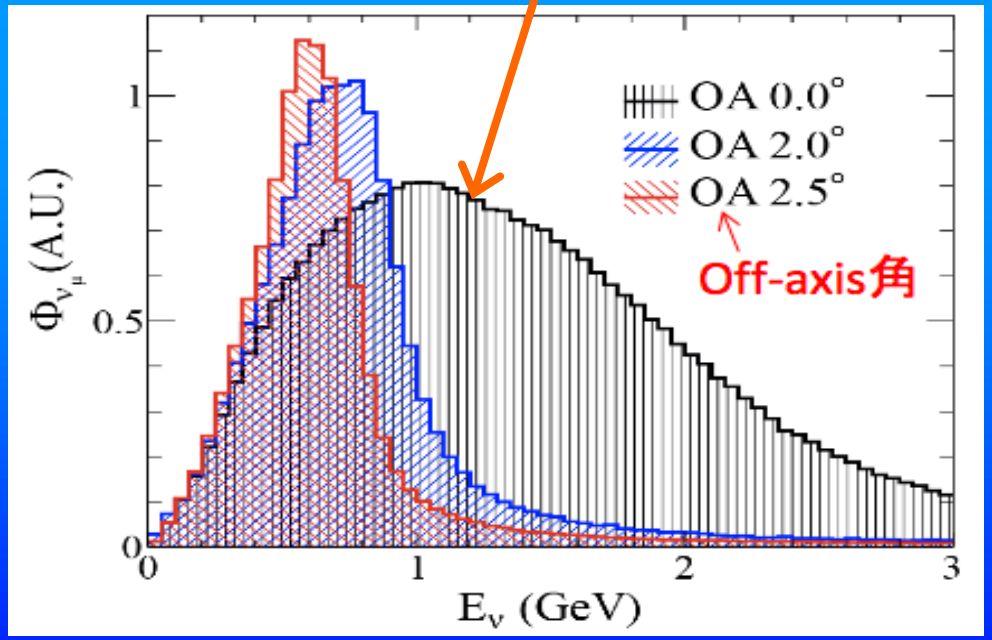
$\bar{\nu}$ exposure : 2016 @SS
end of Jan. → end of May (~4x10^{20}POT)
- Iron target (total~60kg : 500μm seg.)
- High statistics (3-4k $\nu_\mu \bar{\text{C}}\text{C}$ events)
- ν_e detection (20-30 ν_e CC events)

Large size Emulsion Shifter (Kobe U.)



T60:
GRAINE 2011 version

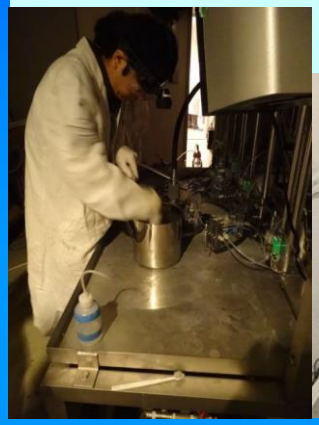
T60 extension
GRAINE 2015 version

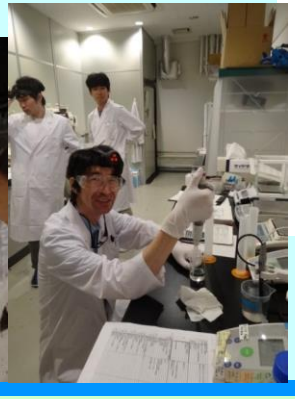


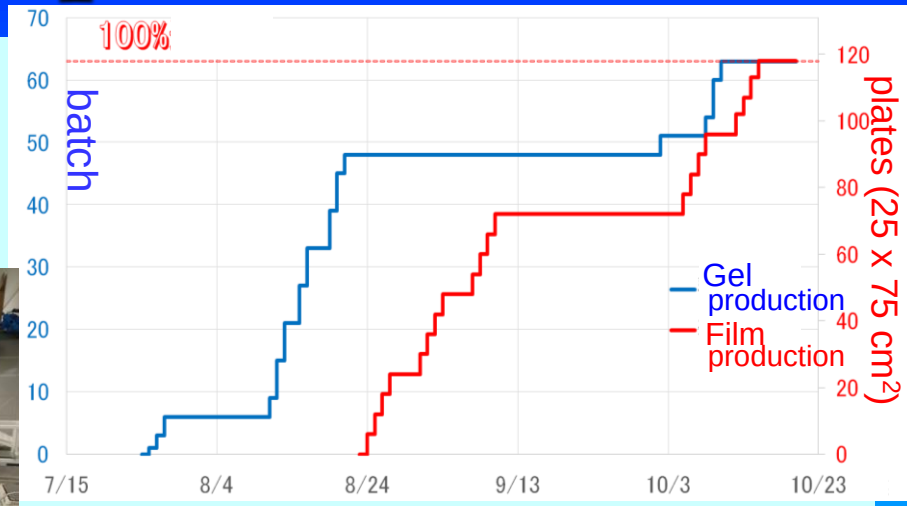
Detector preparation

Emulsion film production 2015. July→Oct.

By Toho Univ. & Nihon Univ. member
@Nagoya Univ.



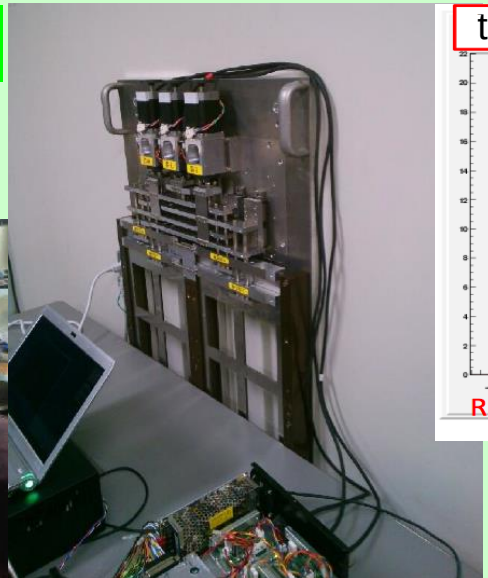


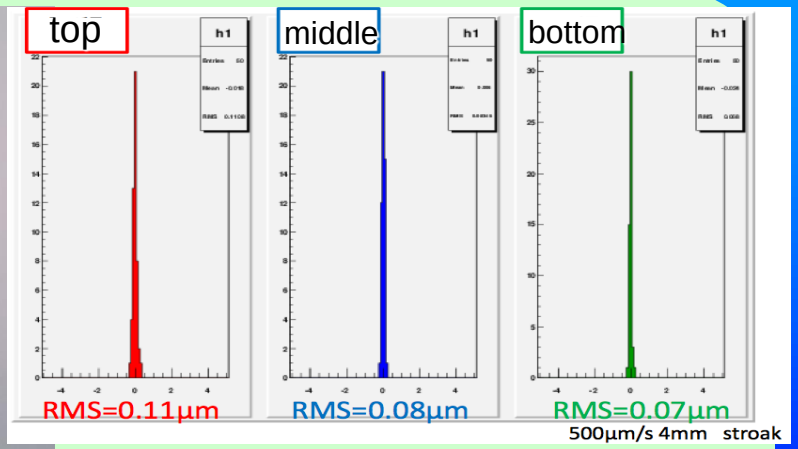


~52kg gel and ~359 films (25 x 25cm²) production is completed.

Large size Emulsion Shifter

Operation test @Kobe Univ.





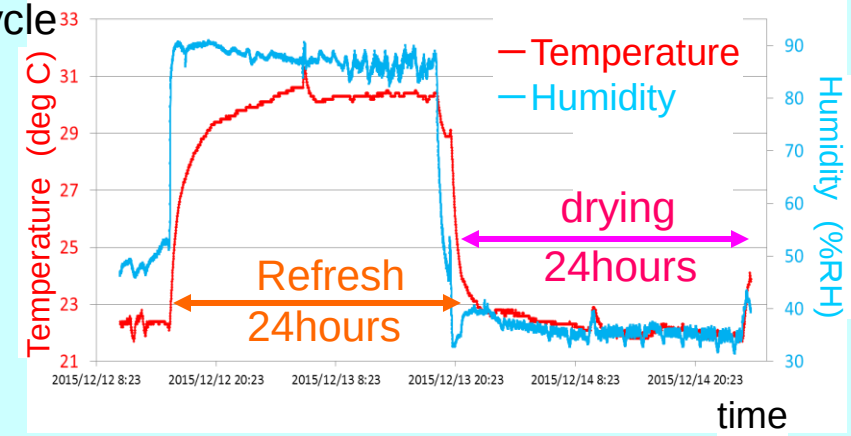
Repeatability for driving in each stage is well below 0.5μm.

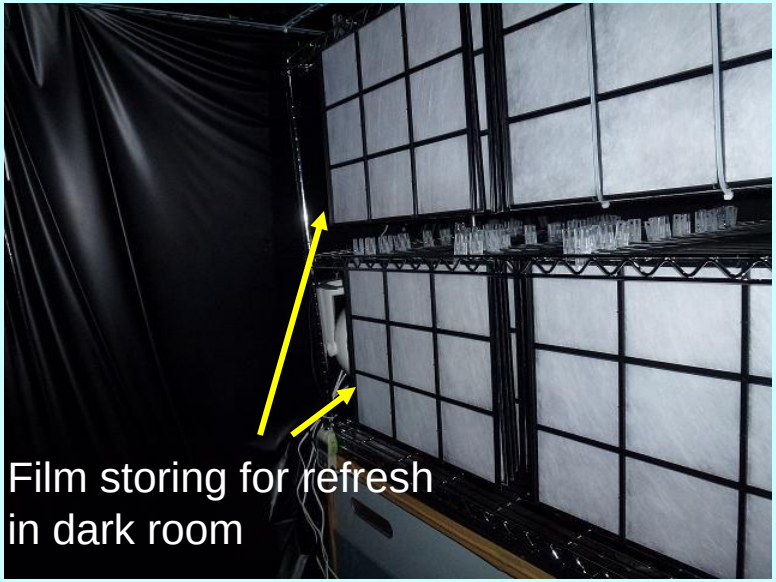
Detector preparation

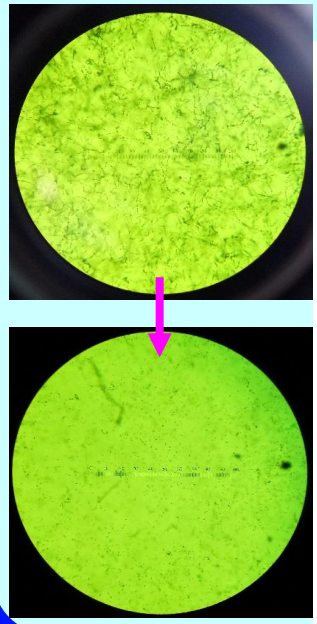
We carried out “Refresh” process to delete noise tracks like OPERA experiment.

Emulsion film Refresh **2015. Dec @Toho Univ.**

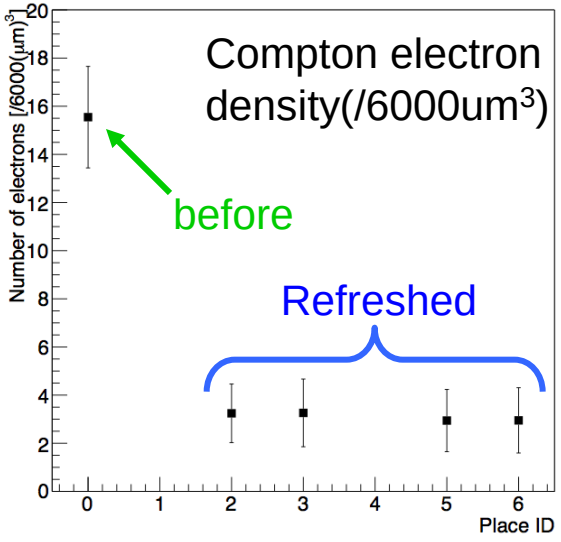
1 cycle

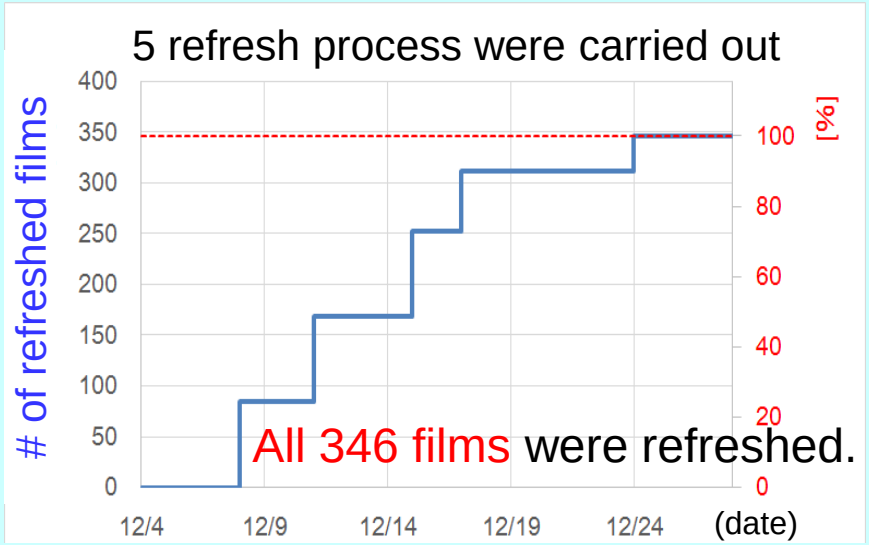






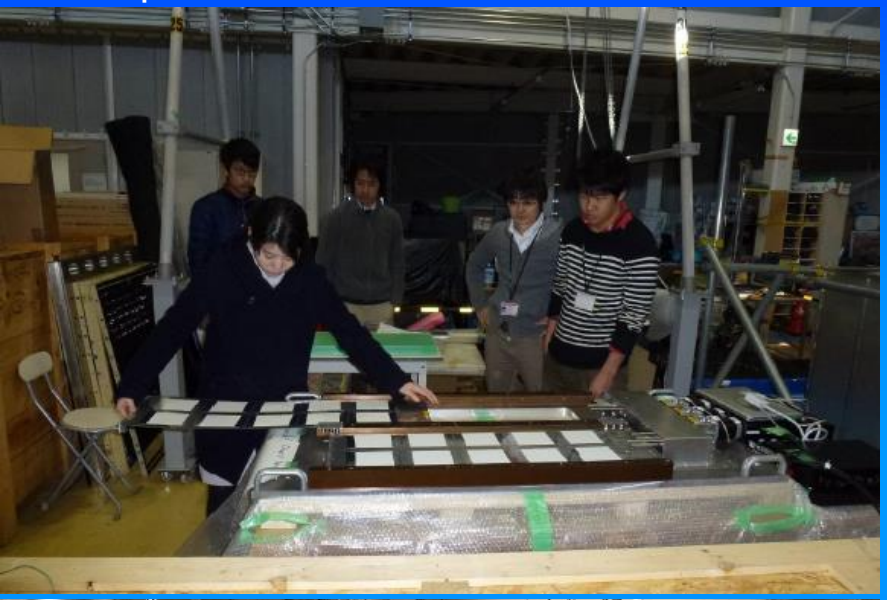
$$Ag_4 + 2H_2O + O_2 \rightarrow 4Ag^+ + 4OH^-$$

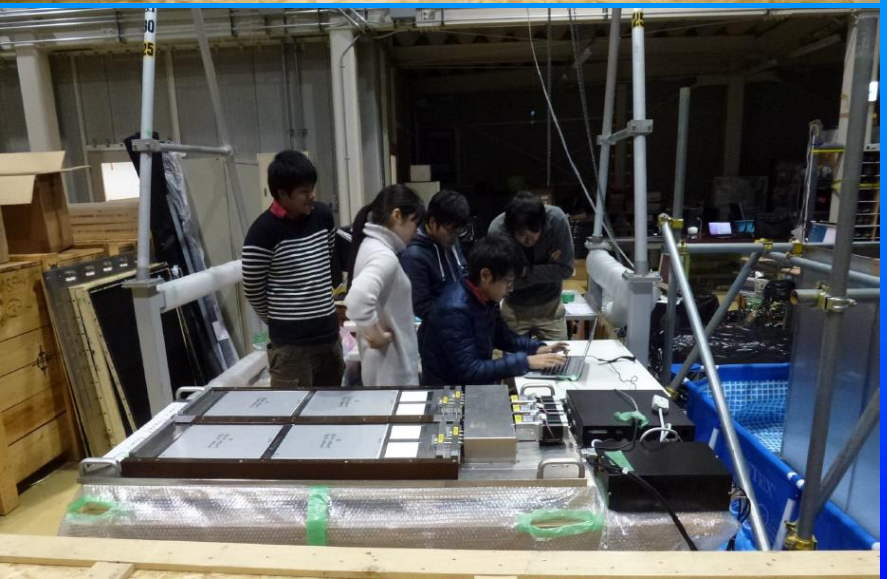




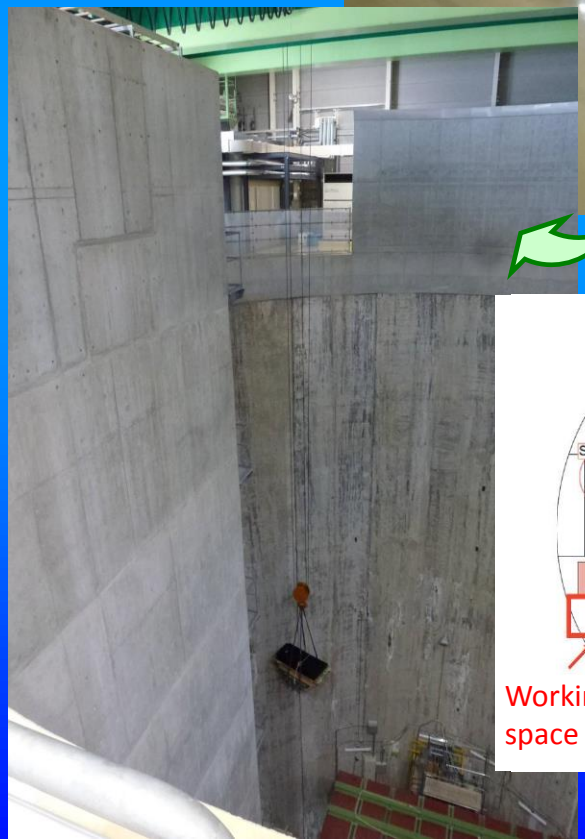
Installation @J-PARC (Jan. 11-20)

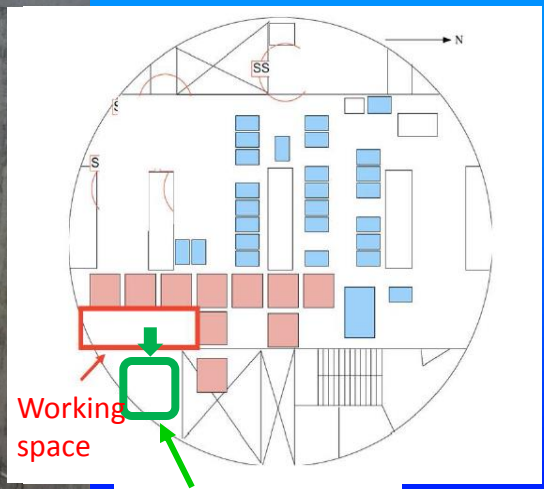
Test operation of the emulsion shifter @NA





Detector components were moved down to SS floor with crane operation.

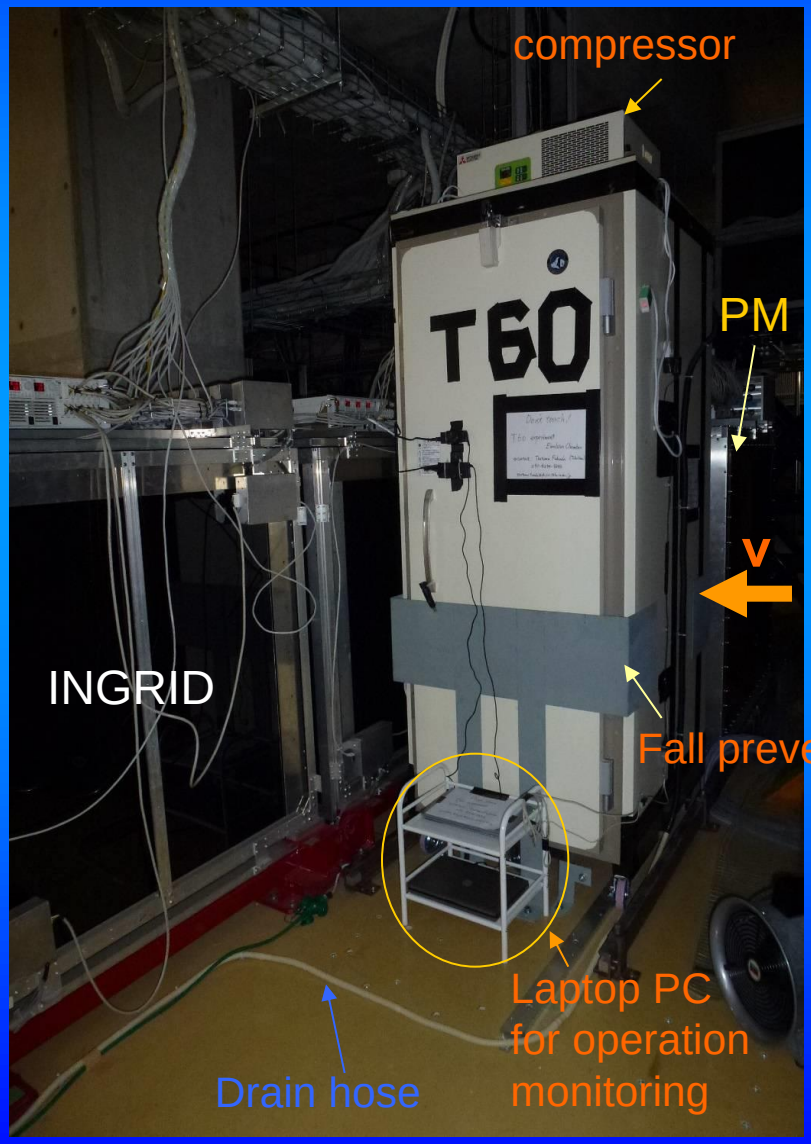


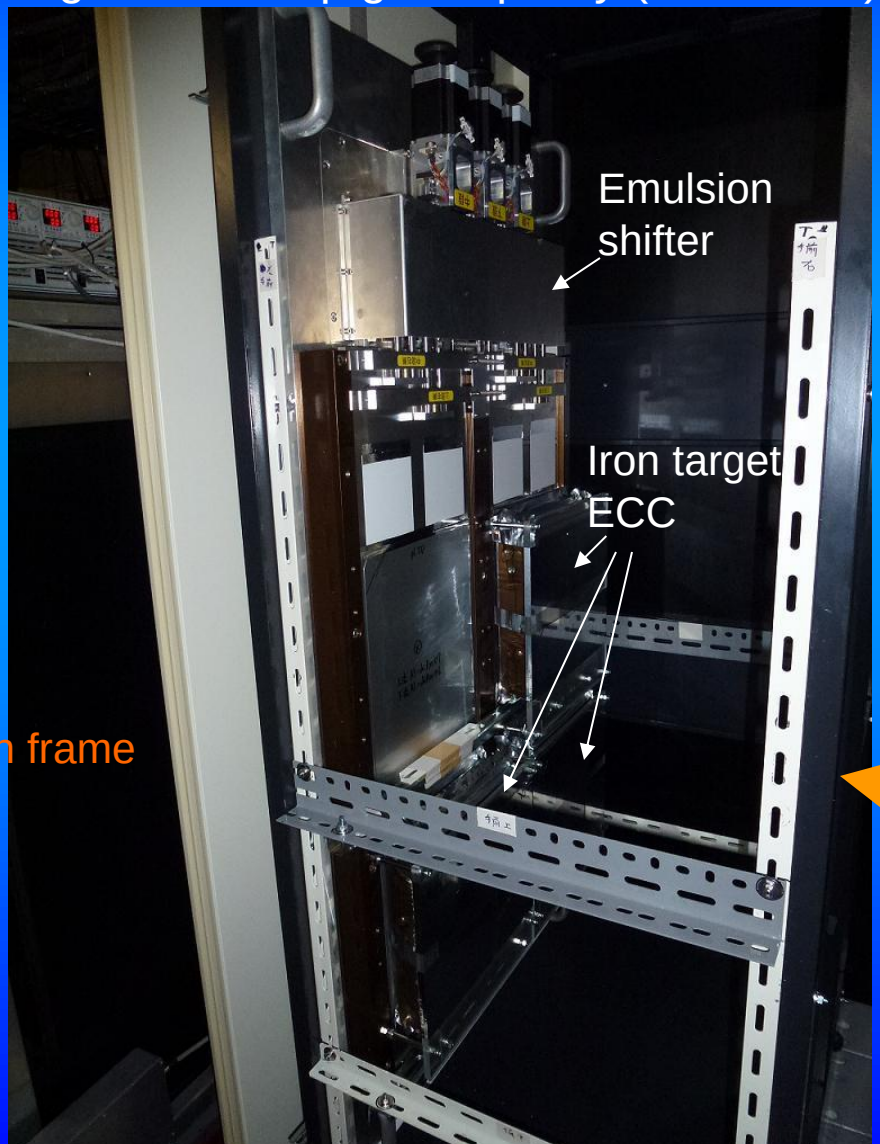


Installation @J-PARC (Jan. 11-20)

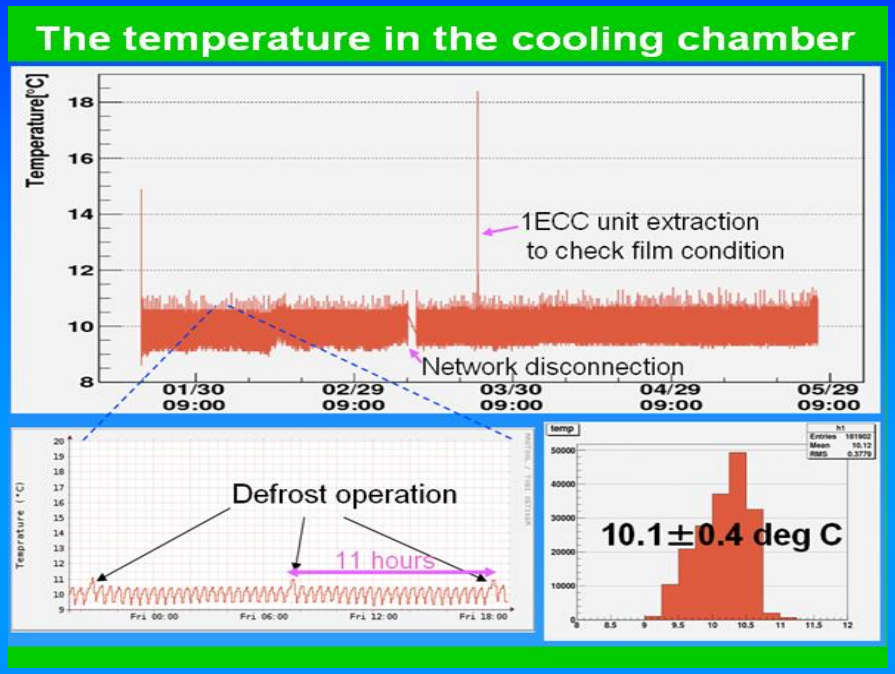
Detector was constructed @SS floor.

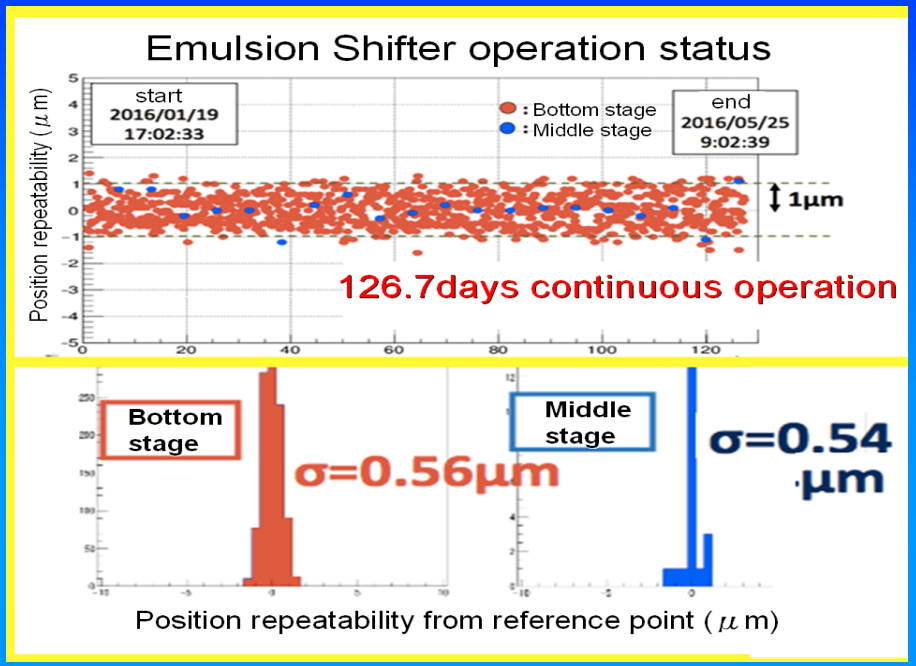
T60 emulsion detector is mounted in cooling box to keep good quality (no refresh).





Operation status (Jan. - Jun)





Hardware treatment after exposure

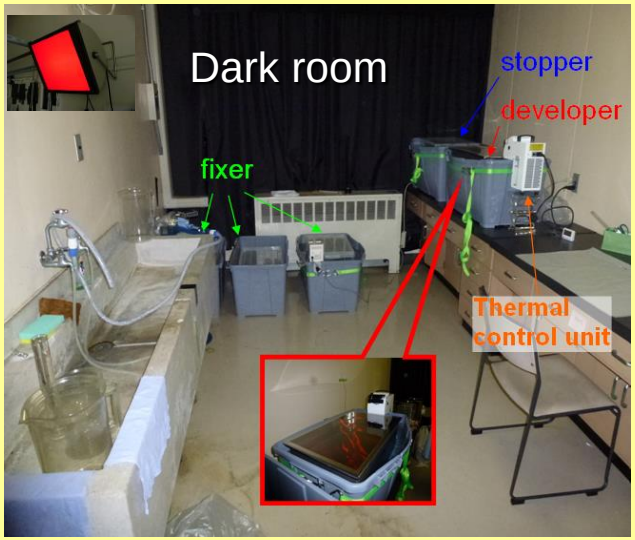
Development

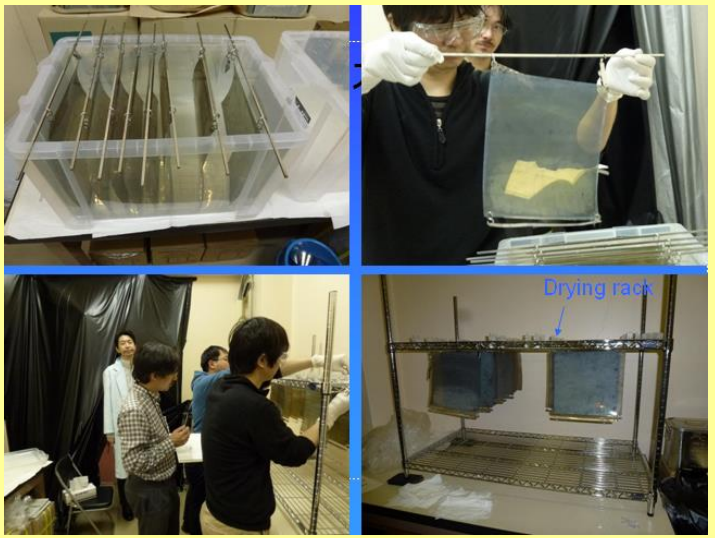
↓

Surface silver cleaning

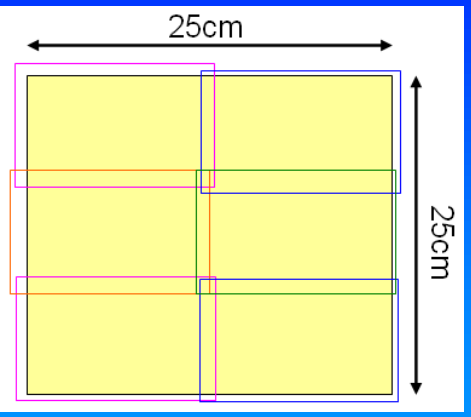
↓

Emulsion swelling

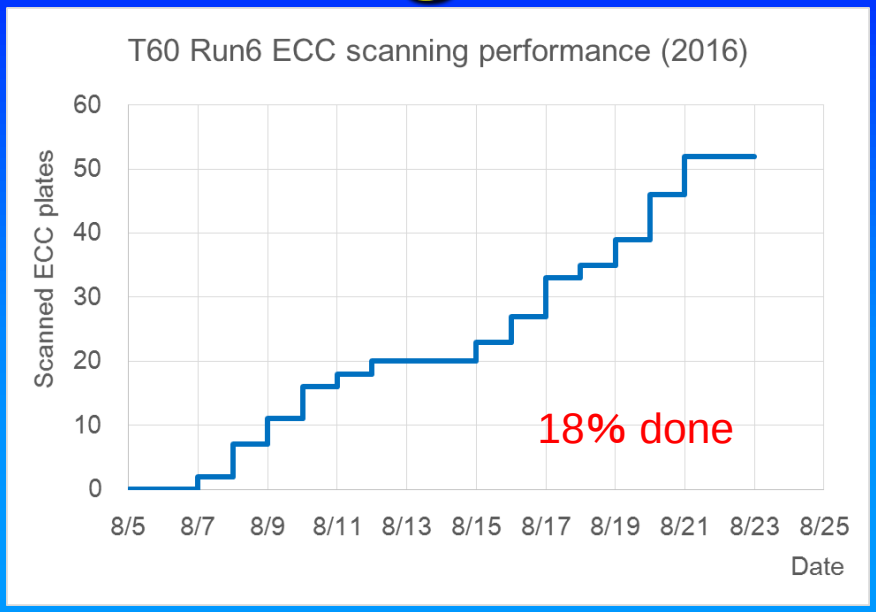




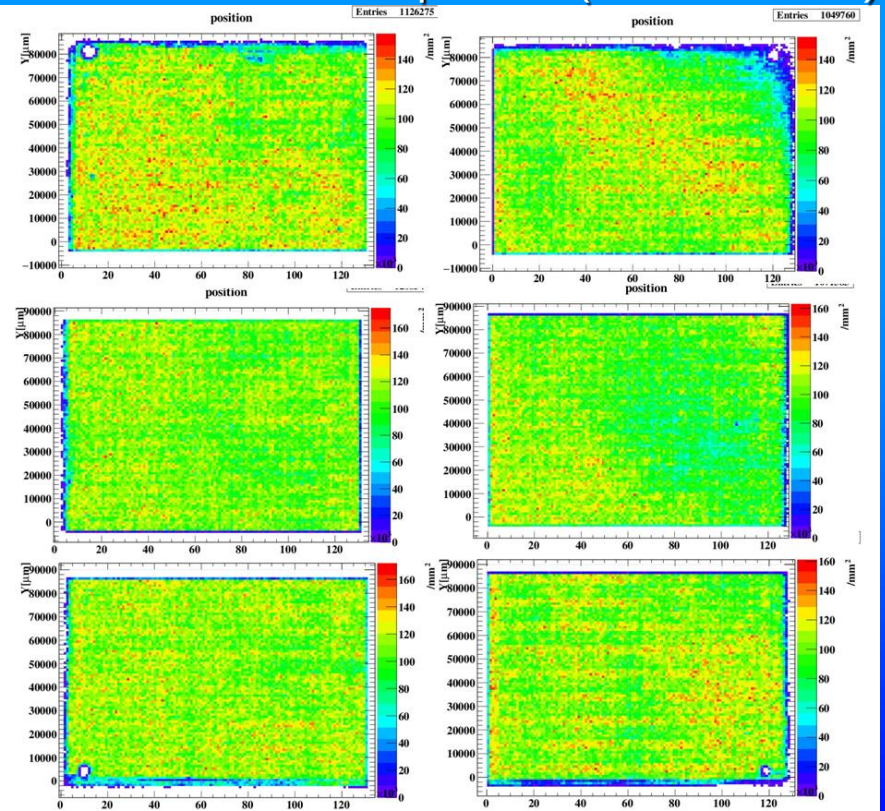
Scanning status

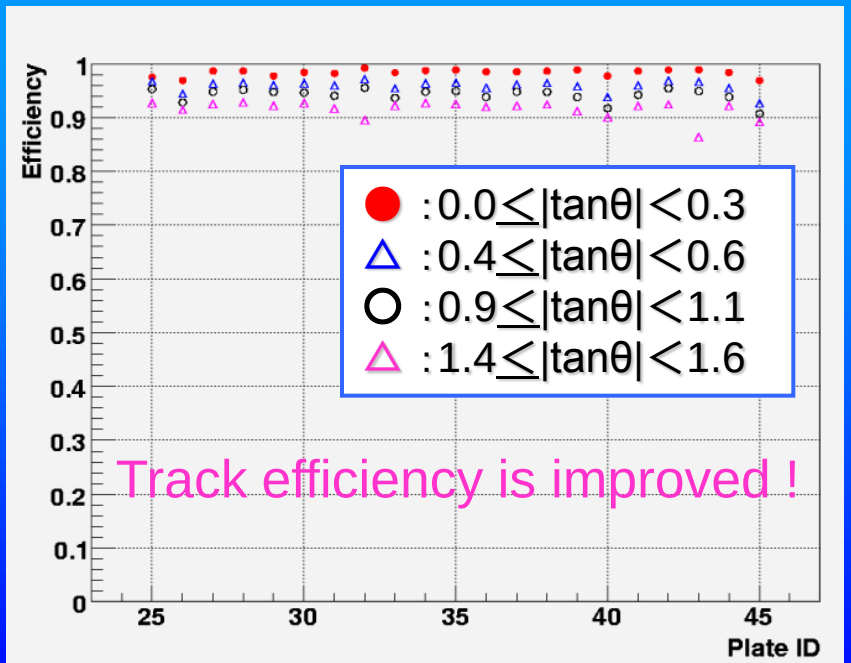


6 scanning area for one films with small overlap area.



Track position (10^4 tracks/cm^2)

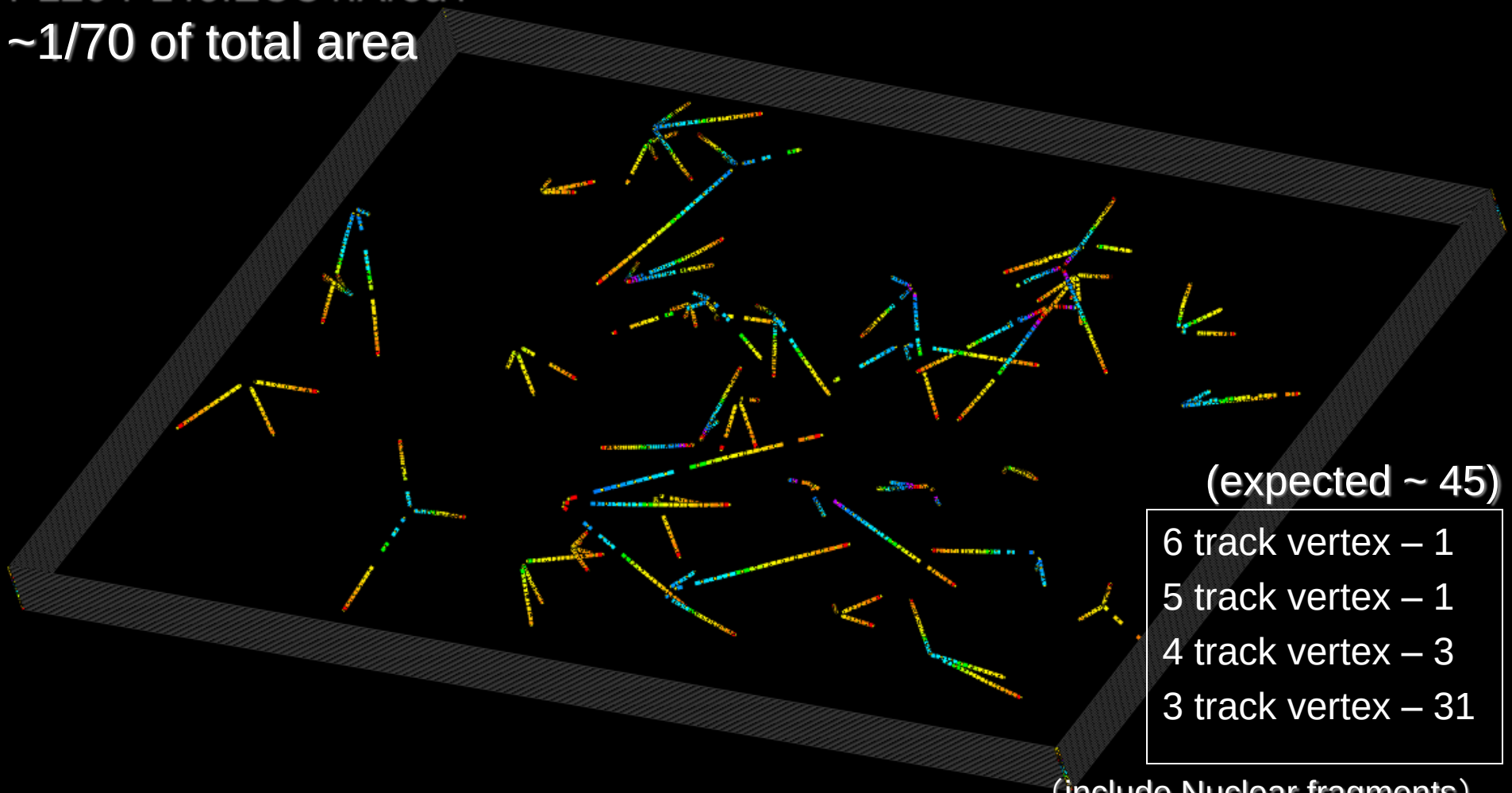




Multi track vertex search

Preliminary result

PL26-PL43:ECC1:Area1
~1/70 of total area



(expected ~ 45)

6 track vertex – 1
5 track vertex – 1
4 track vertex – 3
3 track vertex – 31

（include Nuclear fragments）

Summary

- We are performing a neutrino experiments at J-PARC to study low energy neutrino - nucleus interactions and exploration of a possible existence of sterile neutrinos with nuclear emulsion.
- We are carrying out a test experiment at J-PARC (**T60**) to check the feasibility and detector performance.
- Beam exposure and film development for the 60kg iron target ECC was successfully done and the scanning is now in progress.
- In near future, we plan the next water target exposure.

Discussion for the project is welcome !