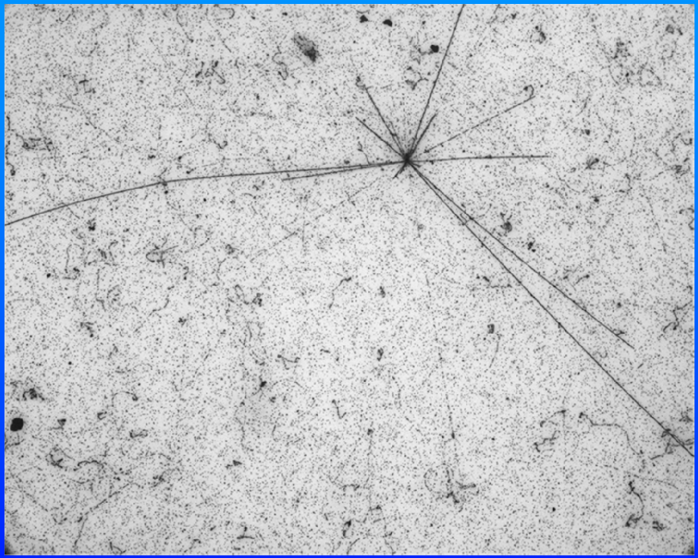
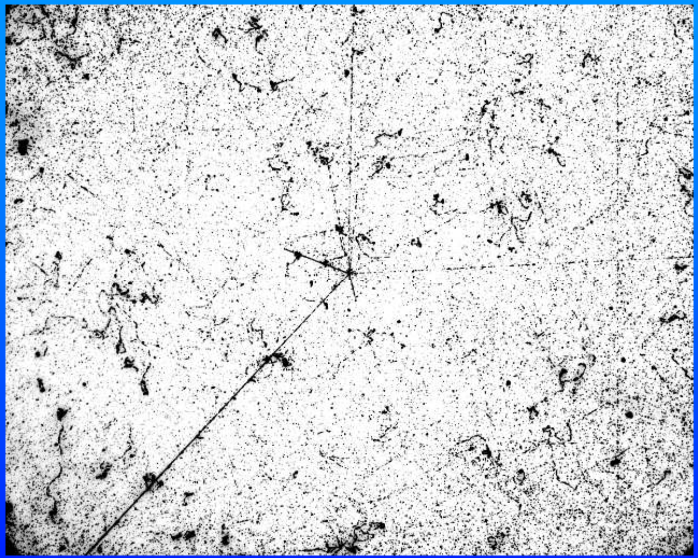
Neutrino-nucleus interactions measurements with Emulsion at J-PARC

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

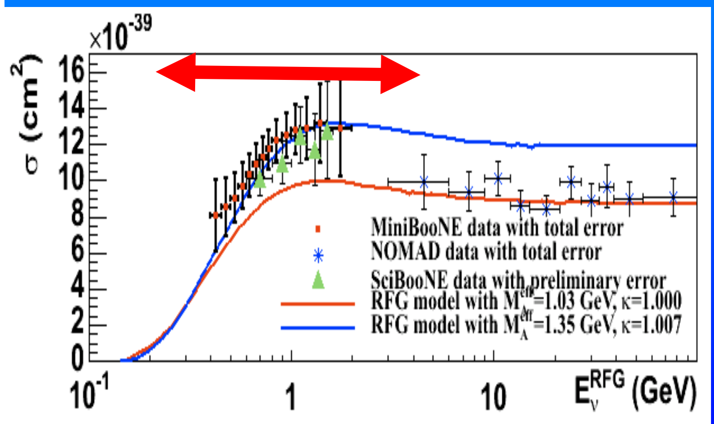


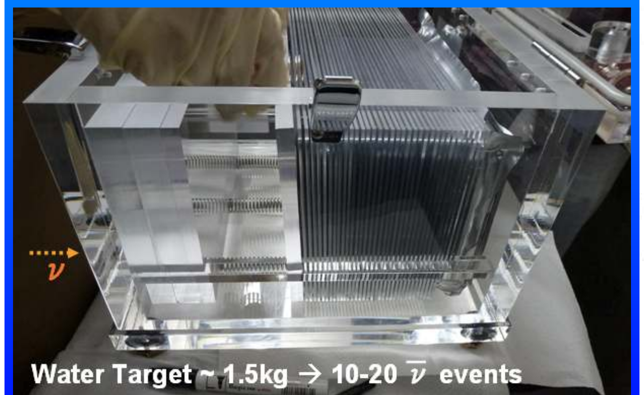


Workshop on Hadron Production Measurements with Nuclear Emulsion, 4th Oct. 2016 @Nagoya Univ.

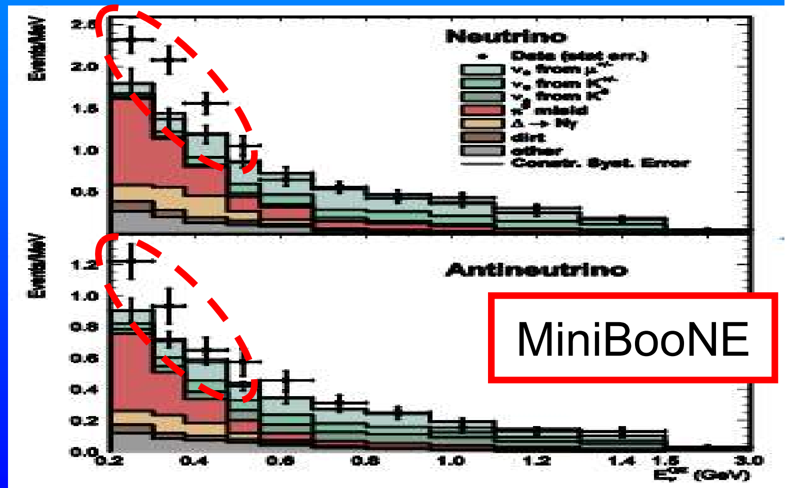
Motivation

- Precise neutrino-nucleus interaction measurement is important to reduce the systematic uncertainty in future neutrino oscillation experiments.
- We started 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 and to explore of a sterile neutrino.





Water Target Emulsion Chamber



First target

- CCQE interaction events are used as signal to reconstruct energy in T2K/SK.

$$E_{QE} = \frac{m_p^2 - (m_n - V)^2 - m_\mu^2 + 2(m_n - V)E_\mu}{2((m_n - V) - E_\mu + p_\mu \cos\theta_\mu)}$$

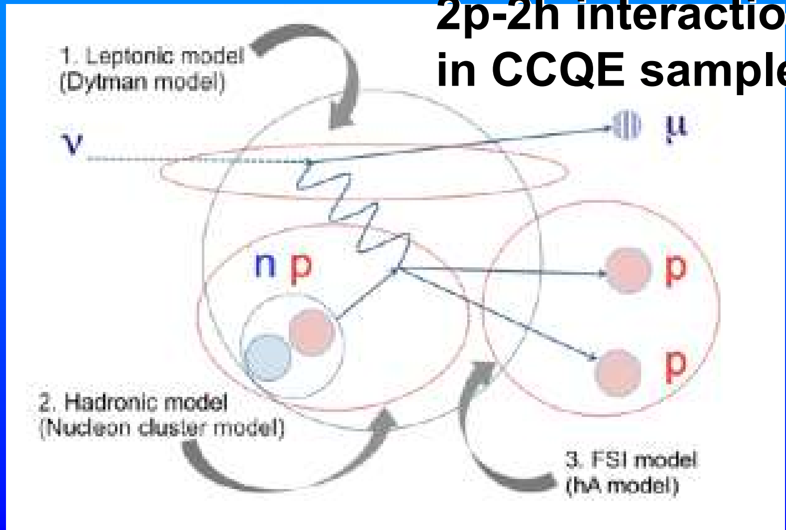
- Other interaction modes contaminate due to Final state interaction in nucleon and detector inefficiency.
- Energy can't be reconstructed correctly with these interaction modes. → Need precise understanding about neutrino interaction.

uncertainties on predicted events at SK

	ν_μ sample $1R_\mu$ FHC	ν_e sample $1R_e$ FHC	$\bar{\nu}_\mu$ sample $1R_\mu$ RHC	$\bar{\nu}_e$ sample $1R_e$ RHC
ν flux w/o ND280	7,6%	8,9%	7,1%	8,0%
ν flux with ND280	3,6%	3,6%	3,8%	3,8%
ν cross-section w/o ND280	7,7%	7,2%	9,3%	10,1%
ν cross-section with ND280	4,1%	5,1%	4,2%	5,5%
ν flux+cross-section	2,9%	4,2%	3,4%	4,6%
Final or secondary hadron int.	1,5%	2,5%	2,1%	2,5%
Super-K detector	3,9%	2,4%	3,3%	3,1%
Total w/o ND280	12,0%	11,9%	12,5%	13,7%
Total with ND280	**5,0%**	**5,4%**	**5,2%**	**6,2%**

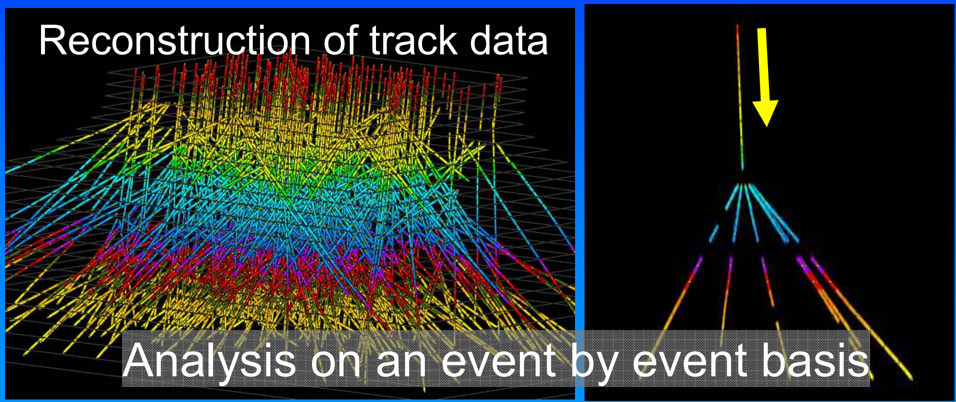
8

2p-2h interaction in CCQE samples



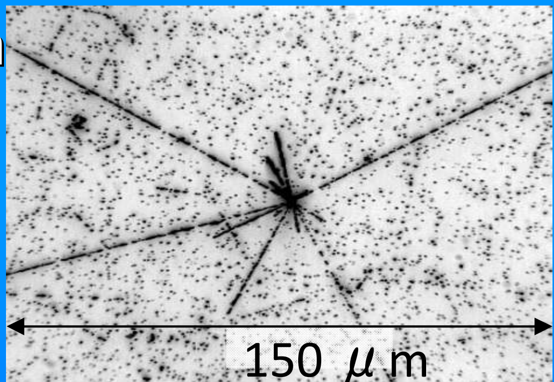
Nuclear Emulsion Detector

3D reconstruction

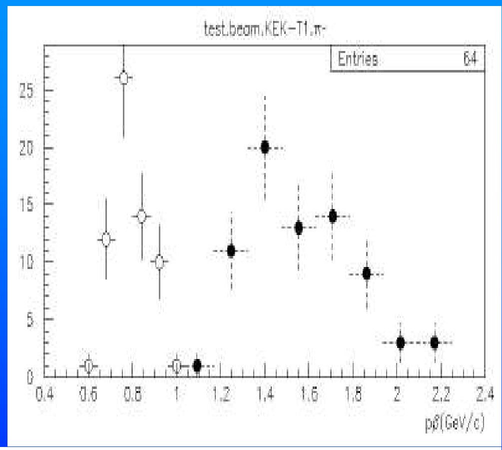


Scalability

4 π detection

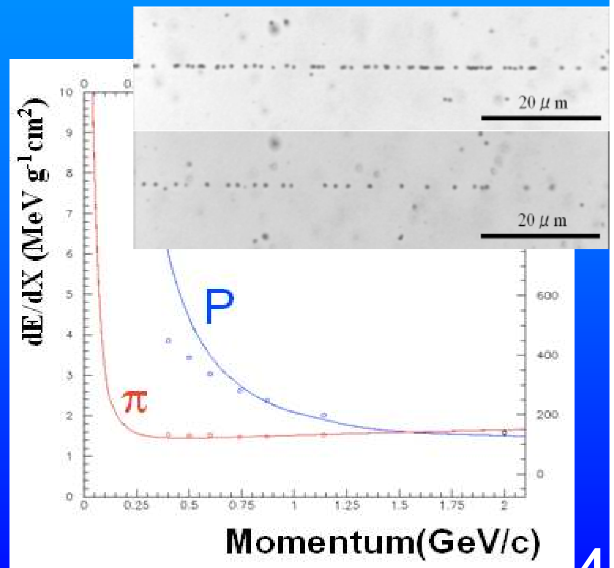


Momentum, dE/dx measurement

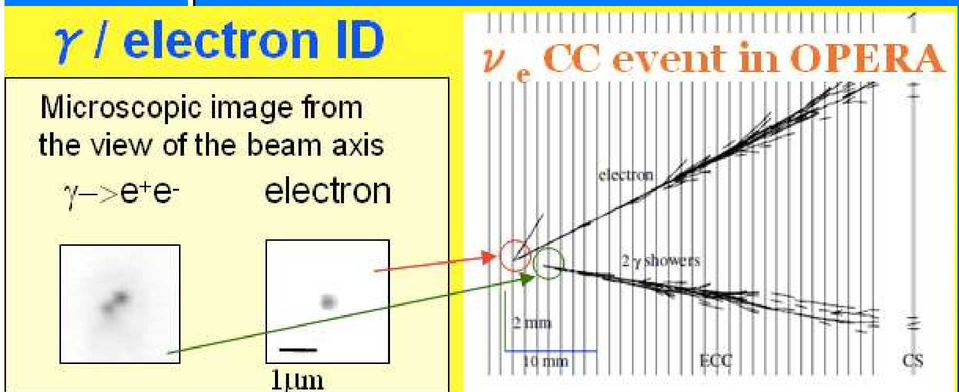


0.8GeV/c π : P =0.79(GeV/c), dP/P =**11**%

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



Ultra precise measurement



Low BG from ν_μ NC π^0 production

Nuclear Emulsion Detector

Contribution for fundamental physics

1896 (A. H. Becquerel)
Discovery of Radioactivity

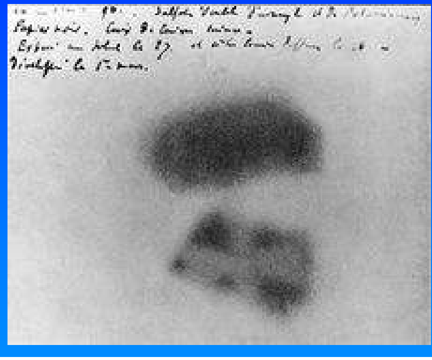
1947 (C. F. Powell et al.)
Discovery of π meson

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

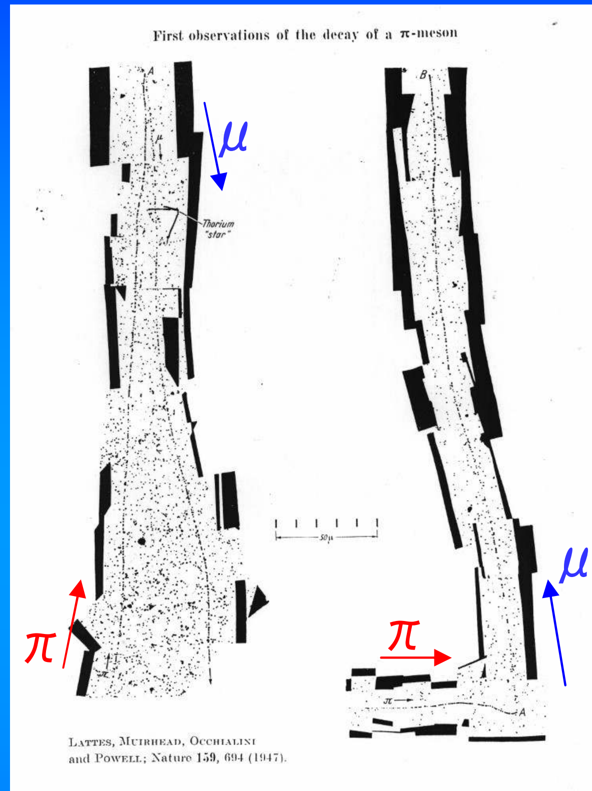
2001 (K. Niwa et al.)
Direct observation of ν_τ

2015 (OPERA)
Discovery of ν_τ appearance

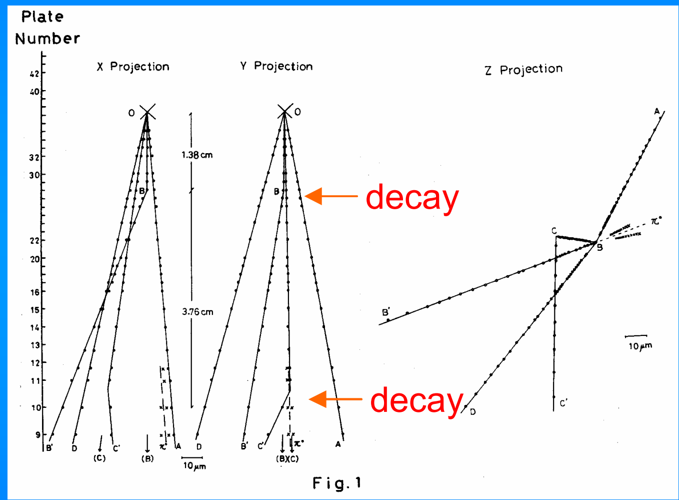
1896



1947



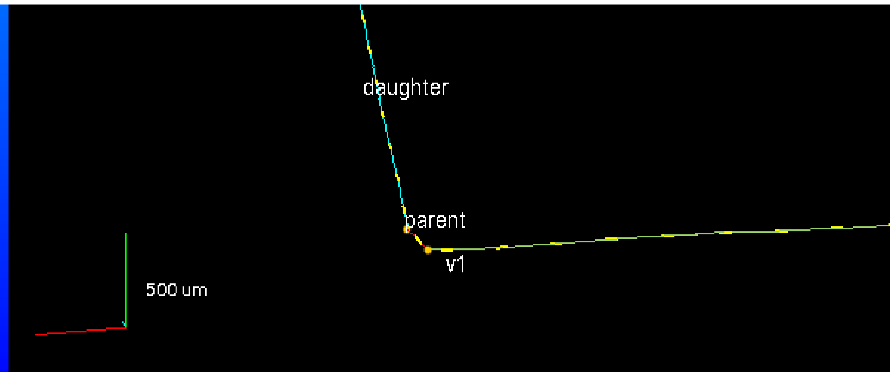
1971

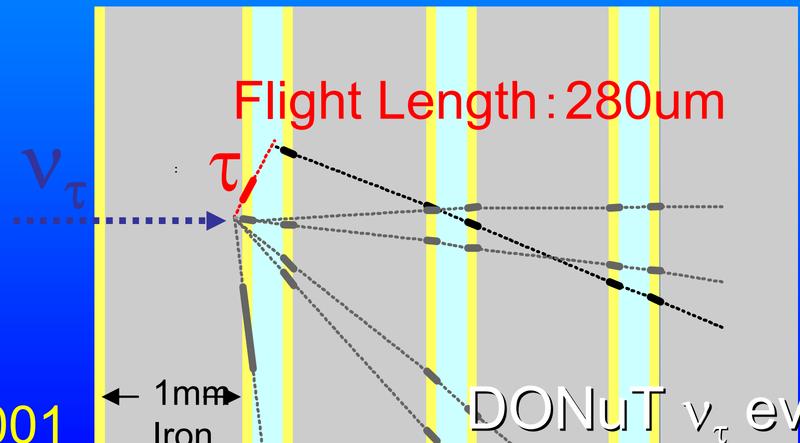


PRL 115, 121802 (2015) PHYSICAL REVIEW LETTERS week ending 18 SEPTEMBER 2015

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

2015





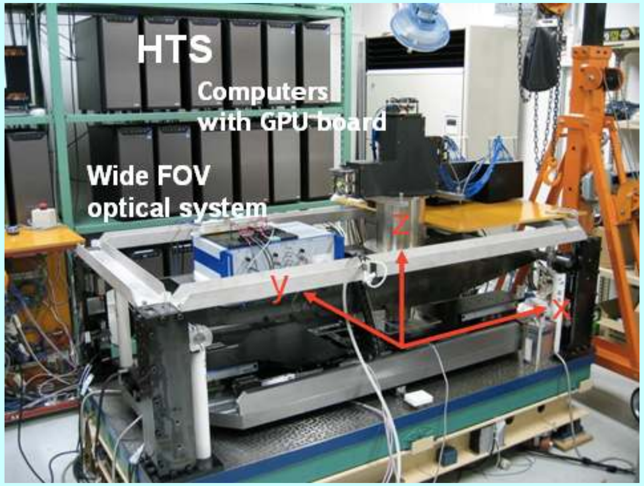
2001

DONuT ν_τ event

Recent technical improvements

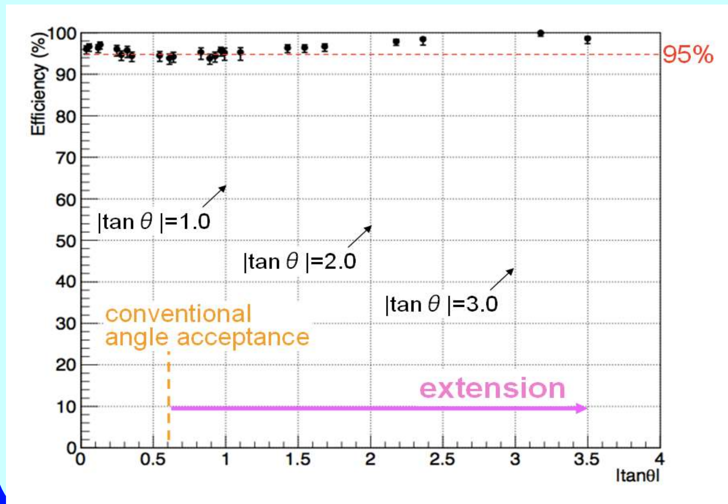
Readout technique

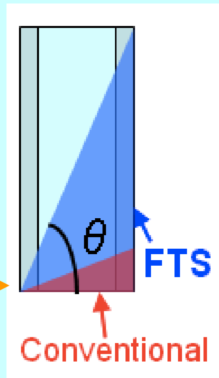
High Speed Scanning



HTS 9,000cm^2/h, x100 faster

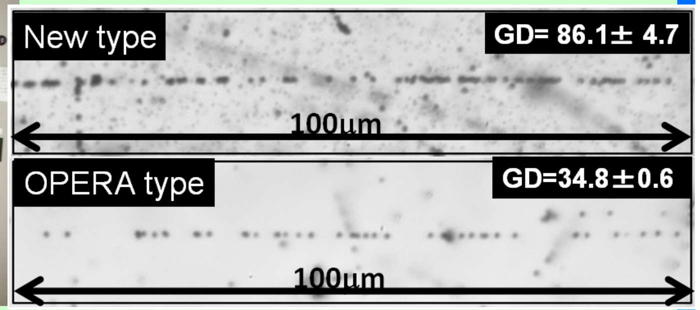
Large angle tracking technique



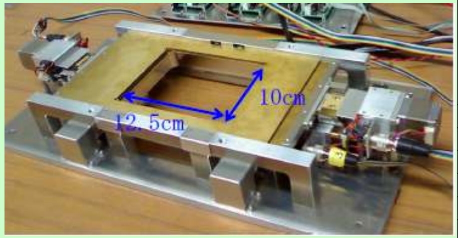


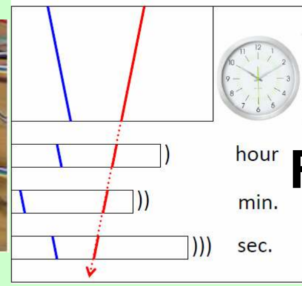
Detector technique

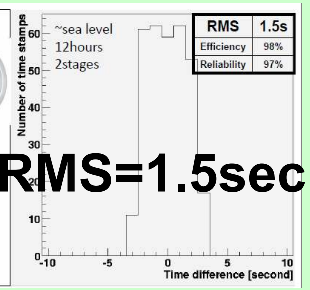
High Sensitive film



Time resolution

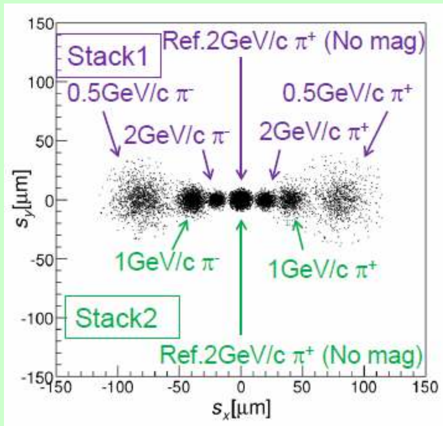




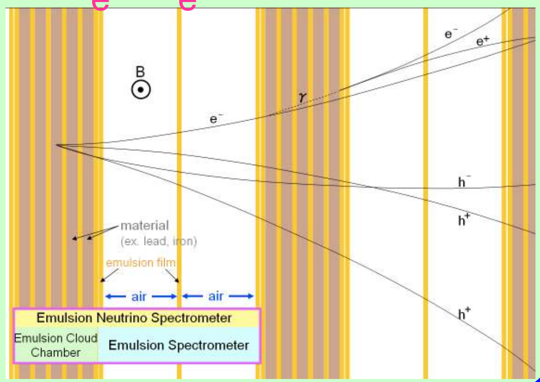


RMS=1.5sec

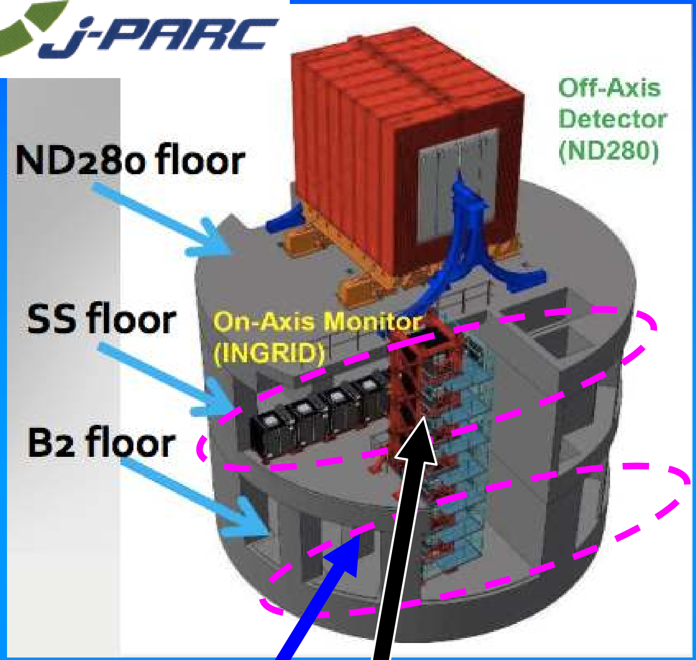
Charge sign ID

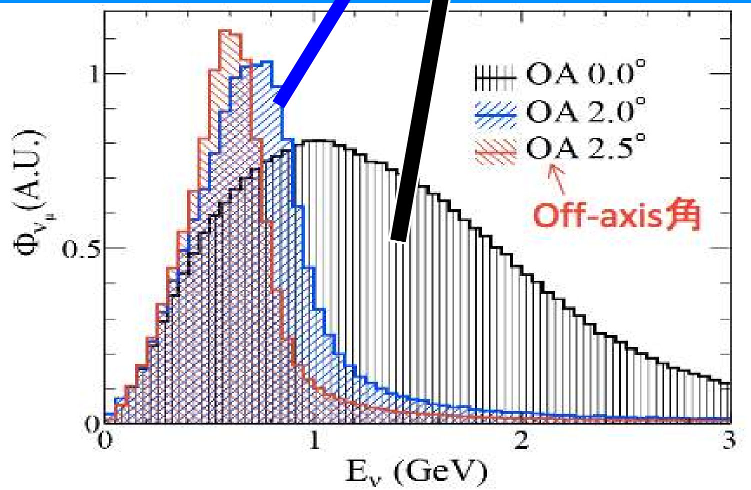


$\nu_e/\overline{\nu}_e$ identification



J-PARC T60 Experiment



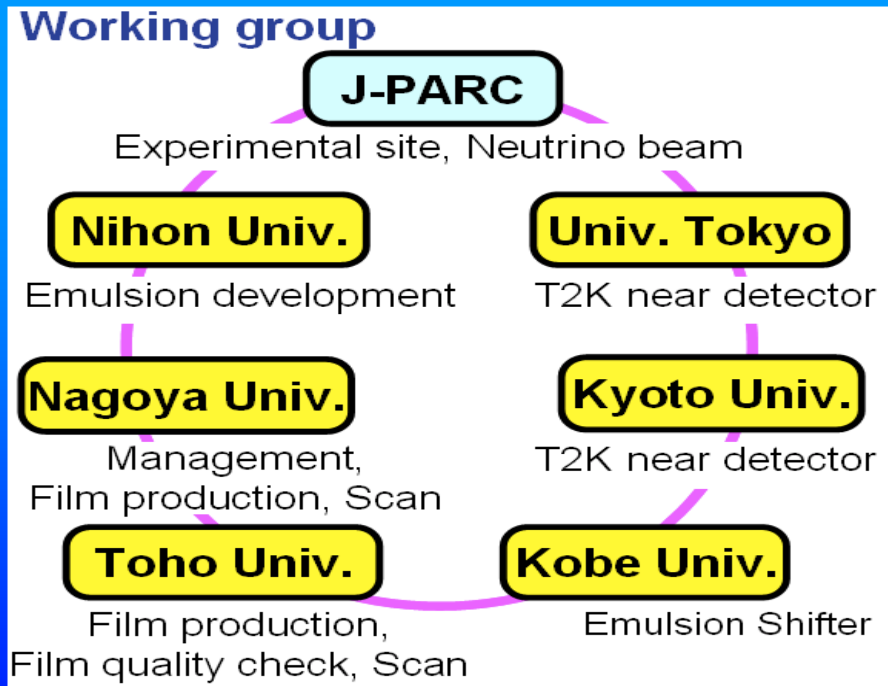


Proposal of an emulsion-based test experiment at J-PARC

Exclusive summary

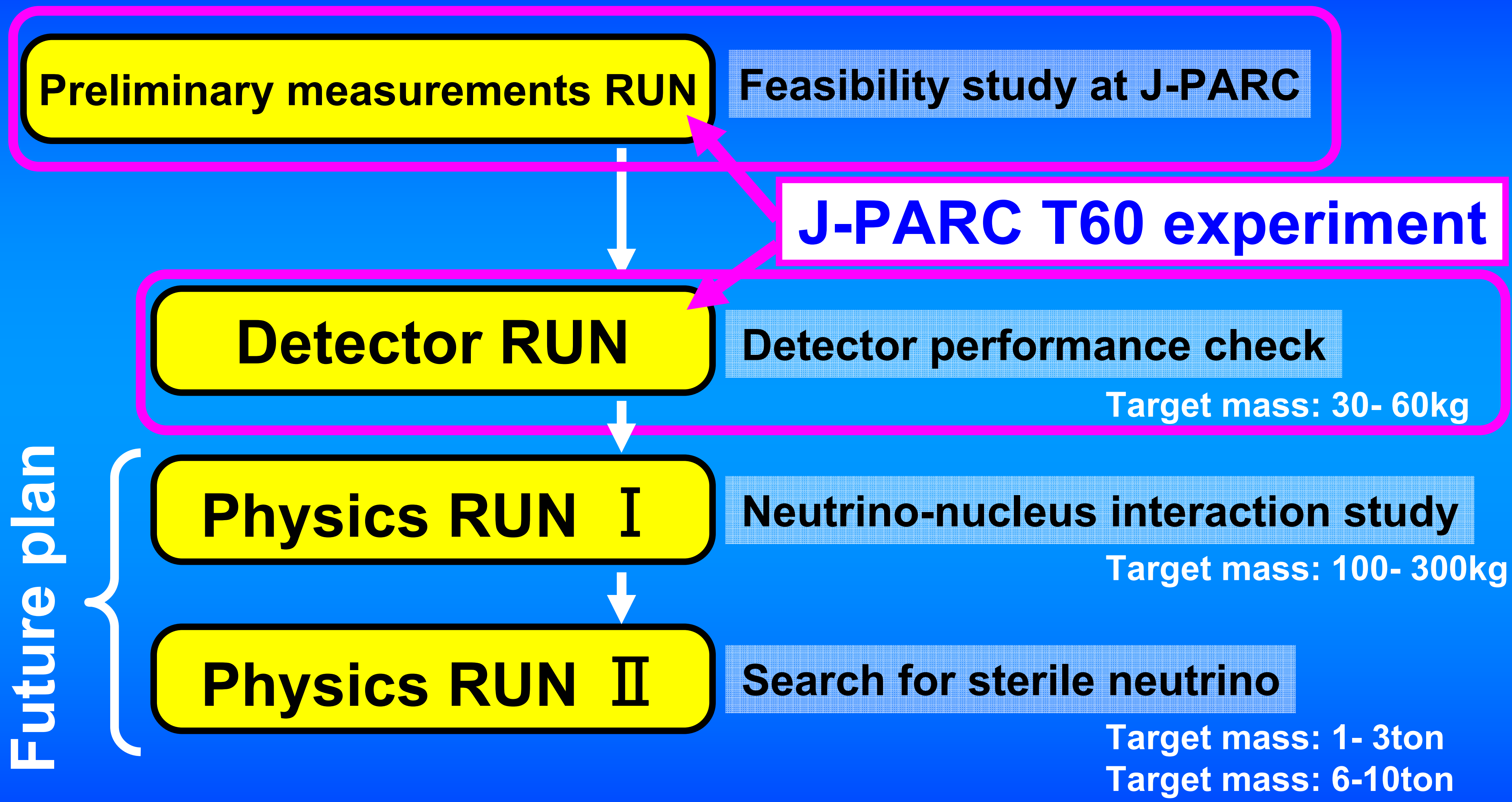
A test experiment is proposed that equips Emulsion Cloud Chamber as a main detector in order to investigate environmental and beam associated background at the T2K near detector hall in J-PARC, optimal detector structure, and performance of newly developed nuclear emulsion gel. The aim of the experiment 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.**



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

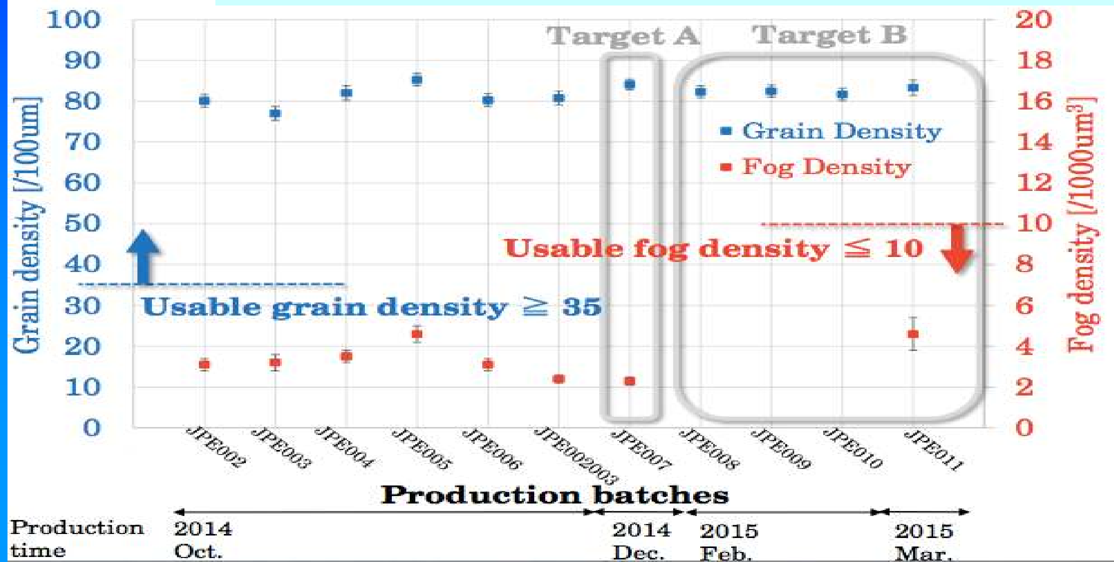
- We have demonstrated the basic experimental concept at J-PARC site.
- "Detector performance run" is started from this Jan.

Status of T60

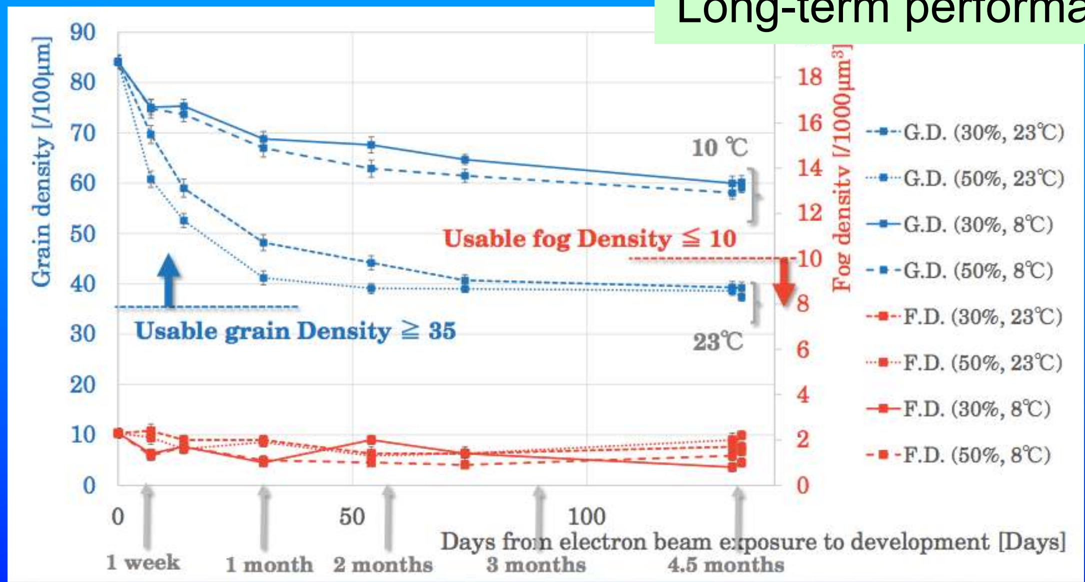
Emulsion gel production in the lab

Nuclear emulsion films were made by ourselves.

Initial performance for each production batch

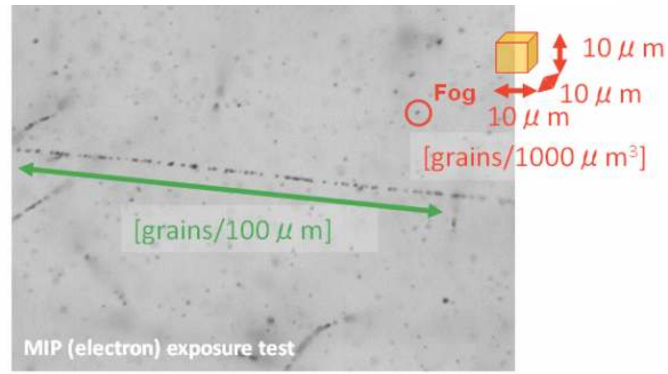


Long-term performance



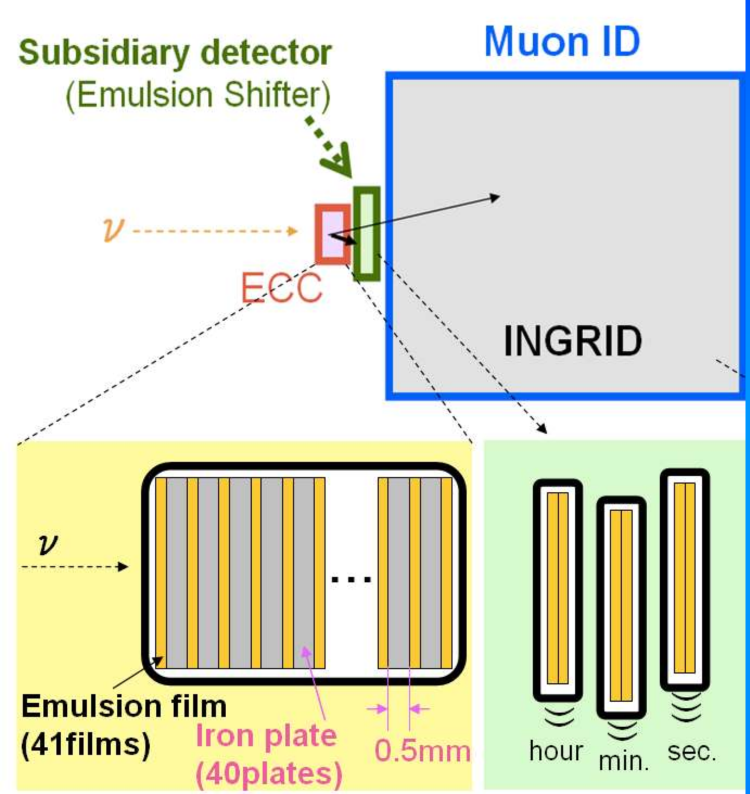
Signal efficiency → Grain density

Isolated random noise → Fog density

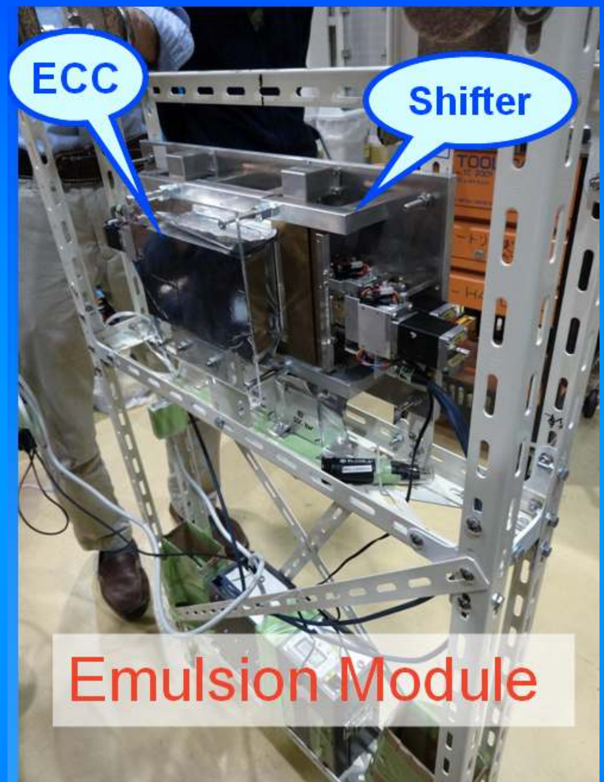


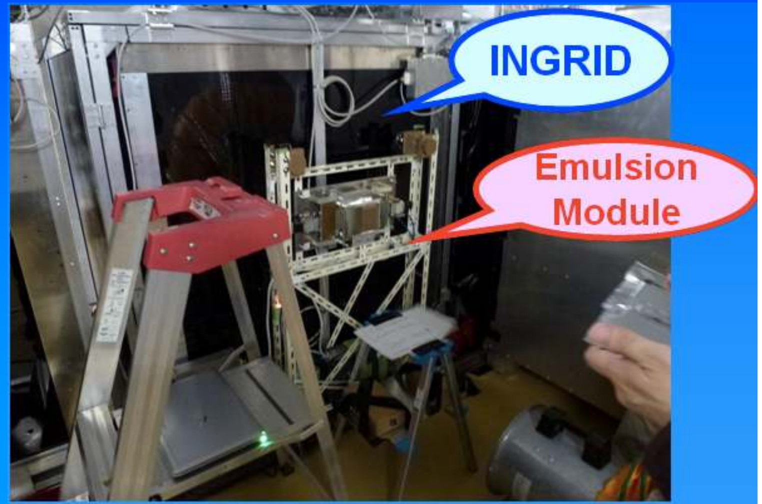
Initial and long-term performance of new emulsion gel is kept at safety level for signal and noise.

Conceptual detector design

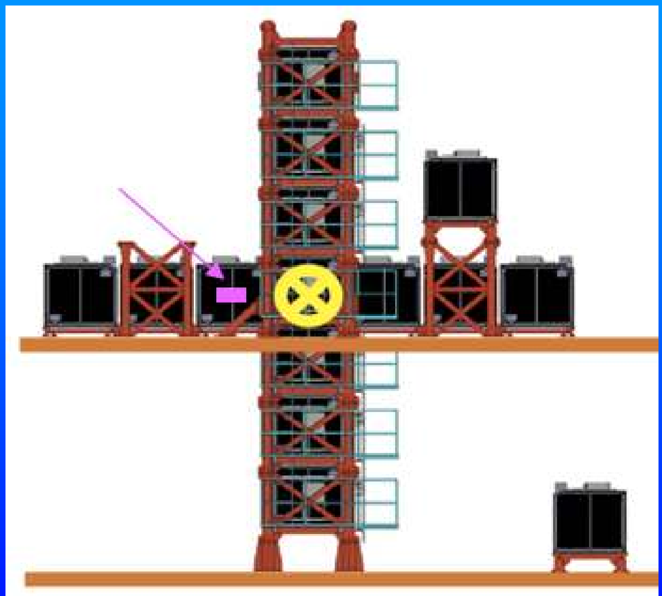


2kg iron target ECC



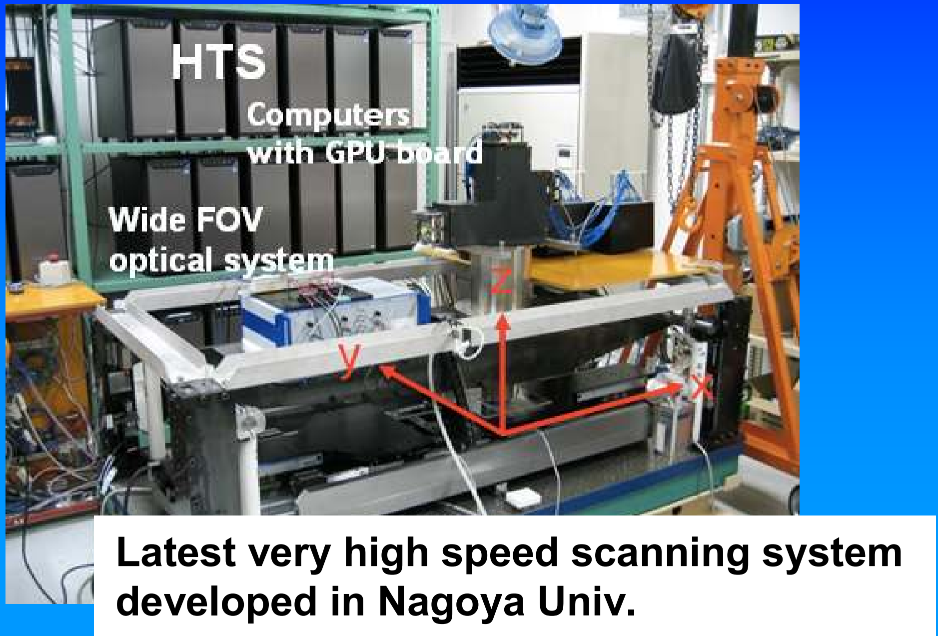


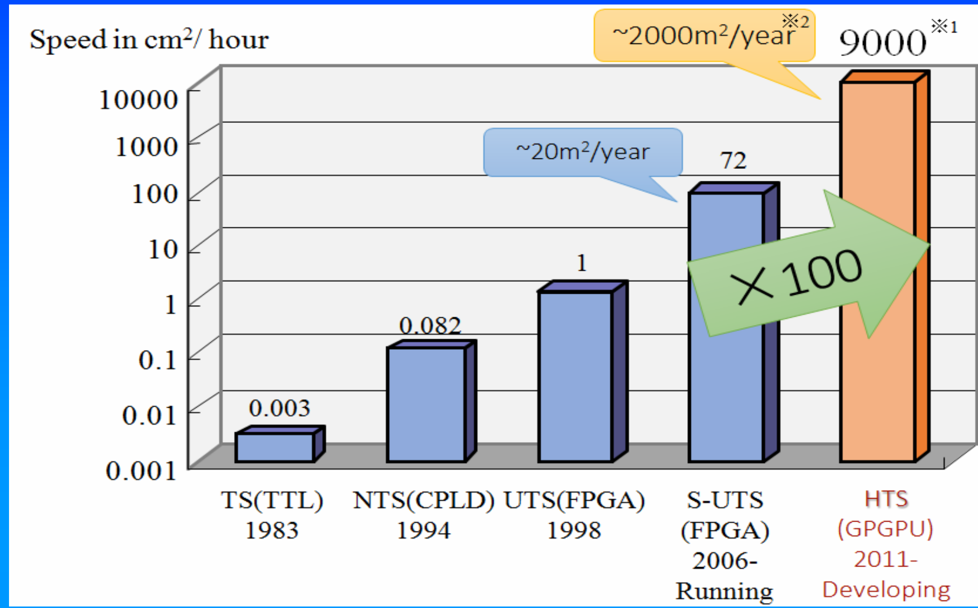
SS floor @J-PARC
(Jan. 2015)



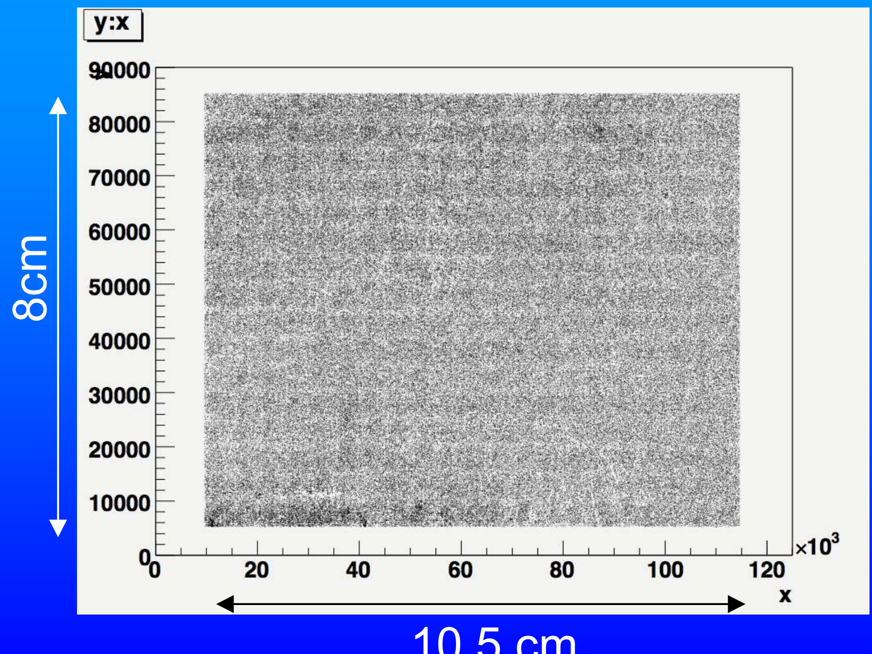
- **E**mulsion **C**loud **C**hamber is a sandwich structure of emulsion films and iron plates.
- Emulsion detector is placed In front of T2K near detector, INGRID.
- Emulsion Shifter give a timing info. to emulsion tracks.
- Muon ID is possible by combined analysis with INGRID.

Data taking by emulsion scanning system

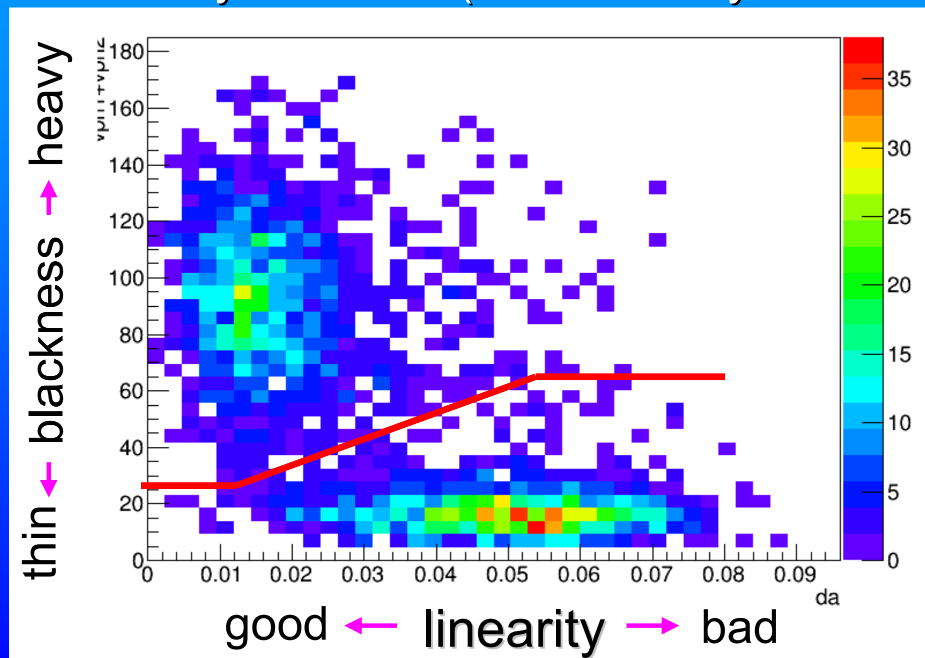




Position distribution

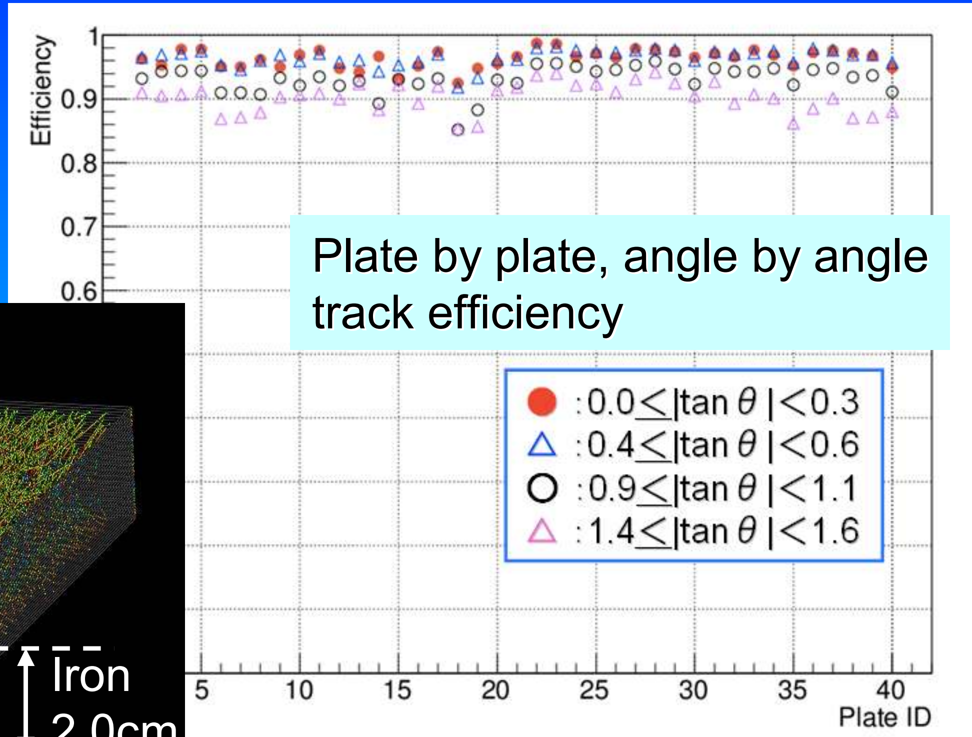


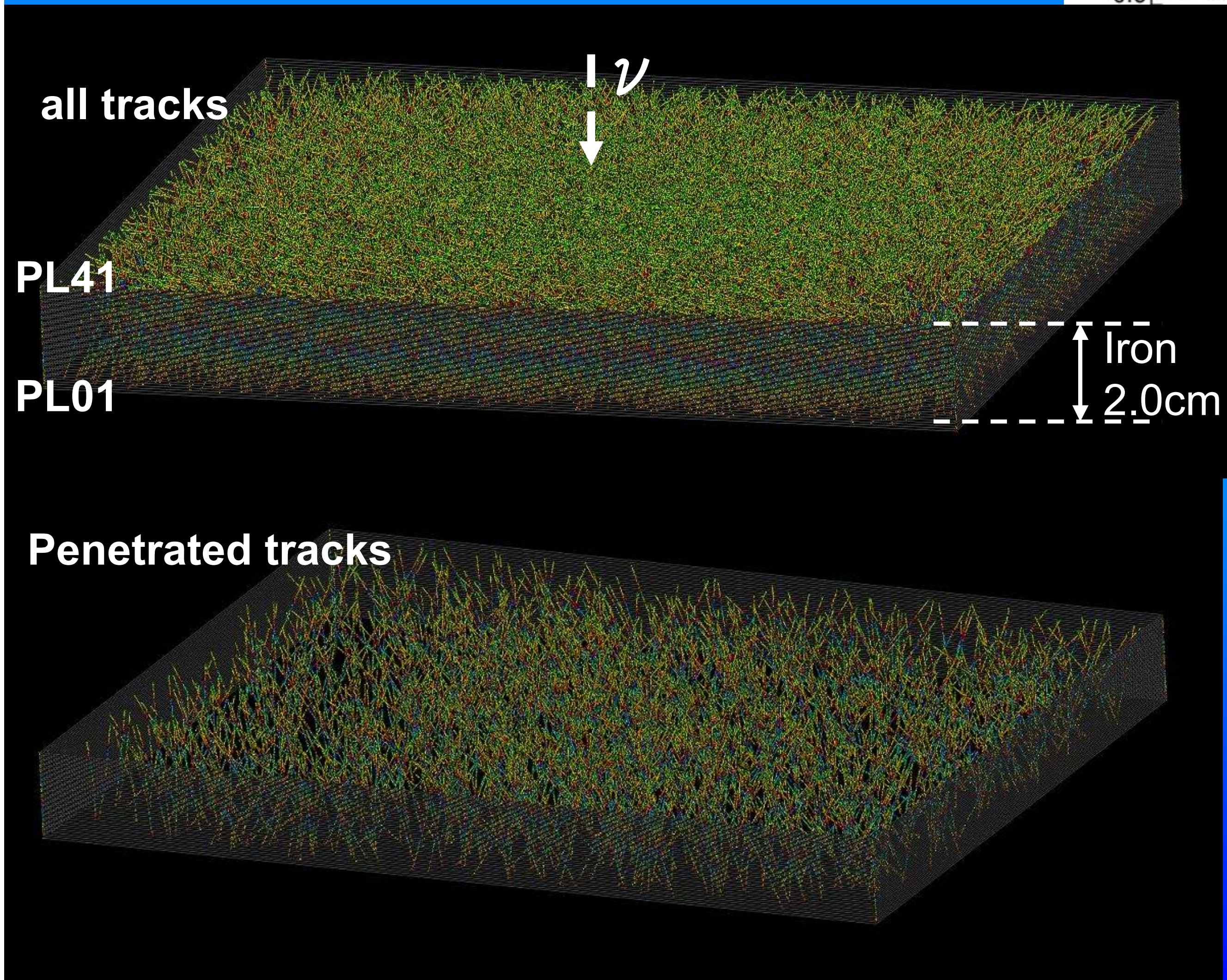
Track Quality Selection (track linearity vs blackness)

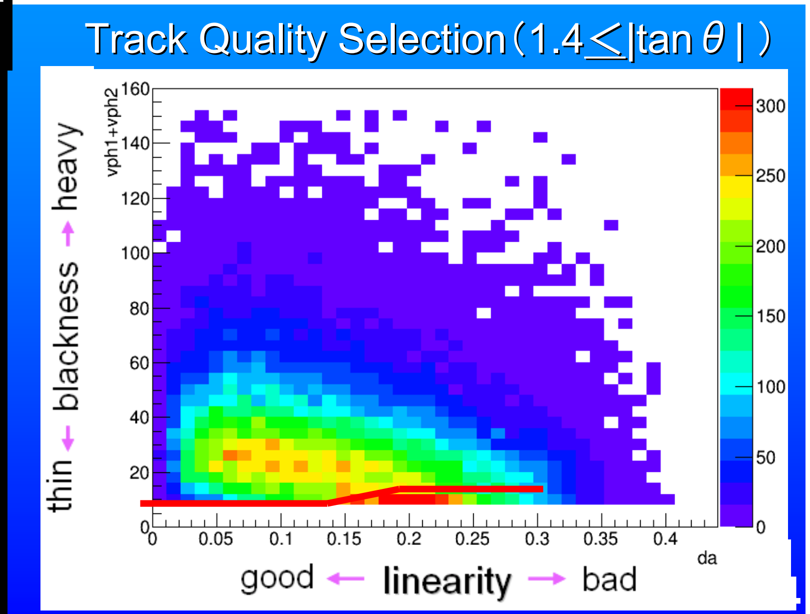


Reconstructed track data

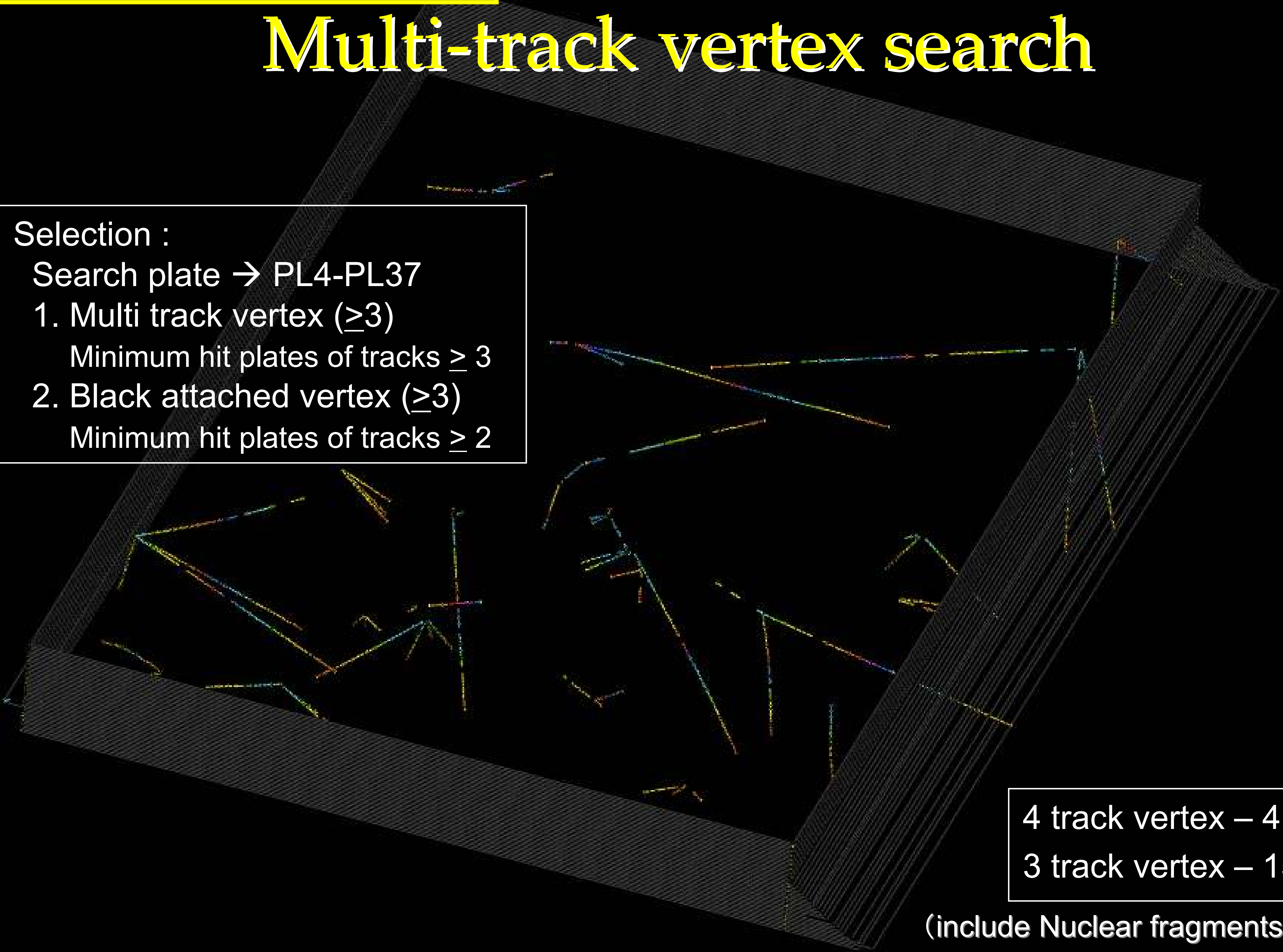
Track efficiency is evaluated each track angle. The efficiency for large angle tracks is lower than one for small angle tracks.







Multi-track vertex search



Selection :

Search plate → PL4-PL37

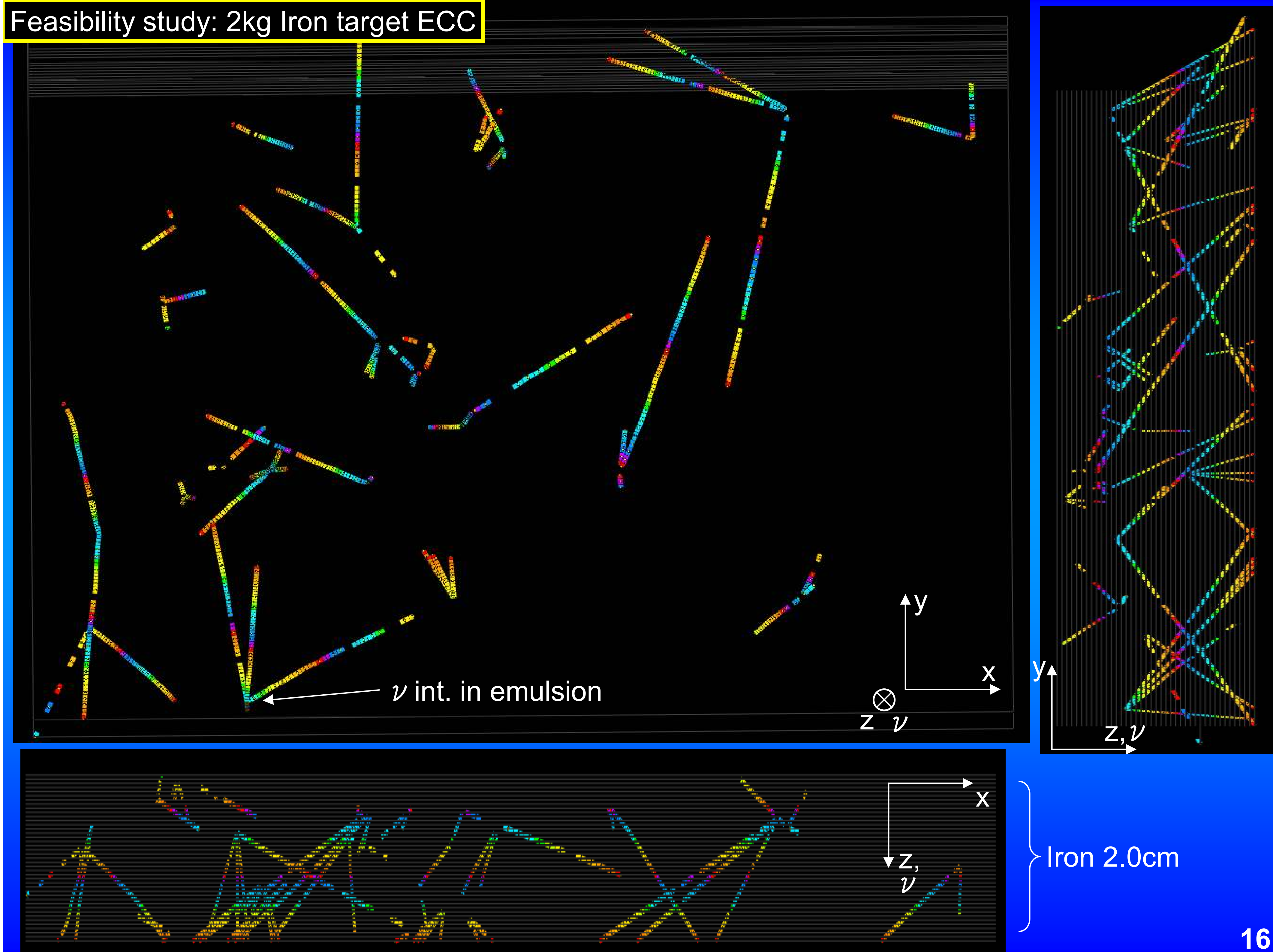
1. Multi track vertex (≥3)
   Minimum hit plates of tracks ≥ 3
2. Black attached vertex (≥3)
   Minimum hit plates of tracks ≥ 2

4 track vertex – 4

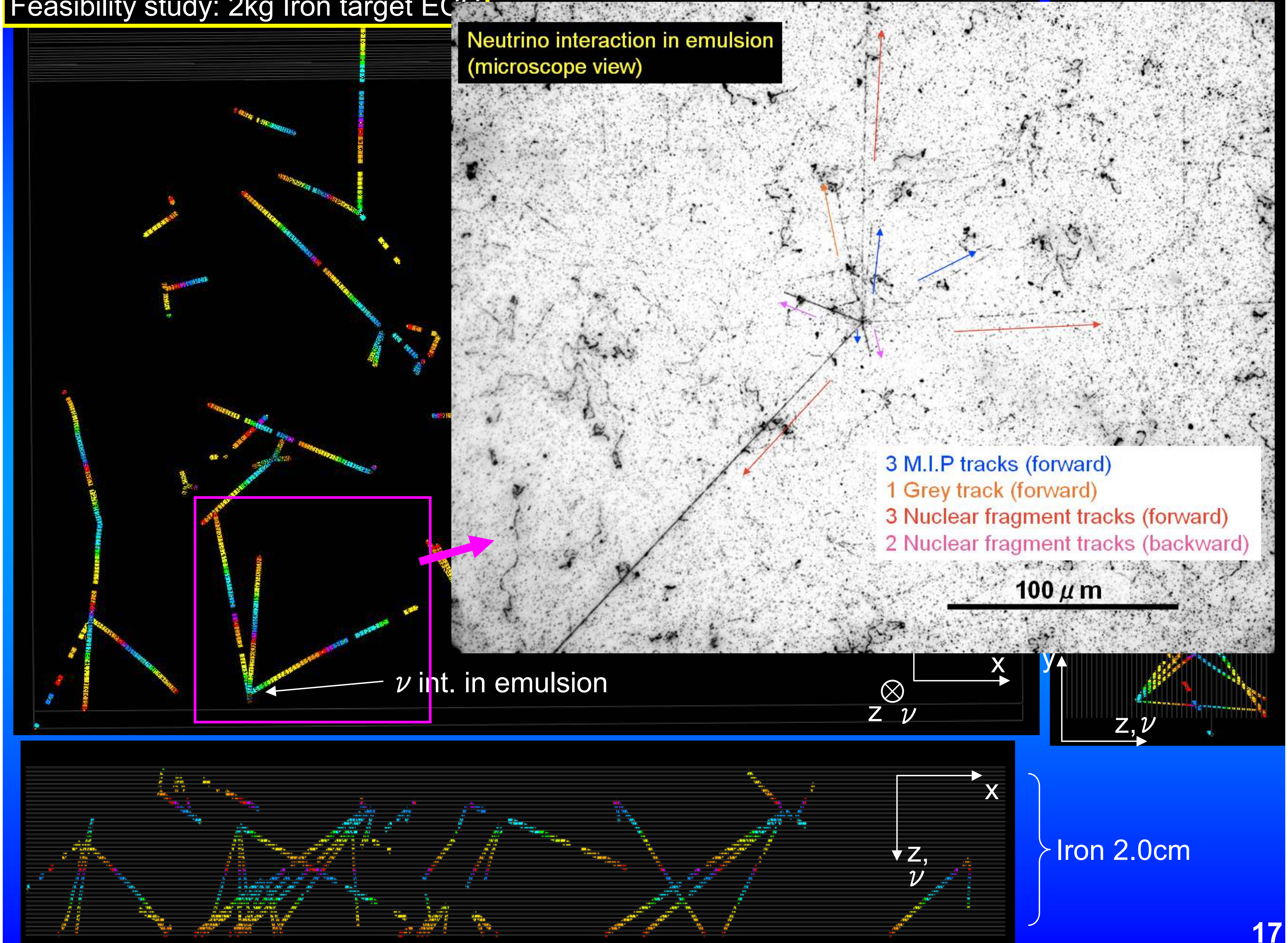
3 track vertex – 15

(include Nuclear fragments)

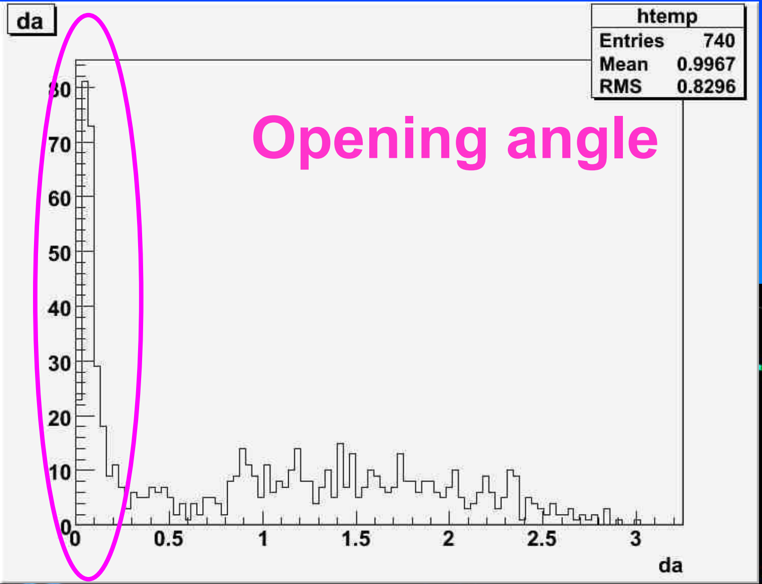
Feasibility study: 2kg Iron target ECC



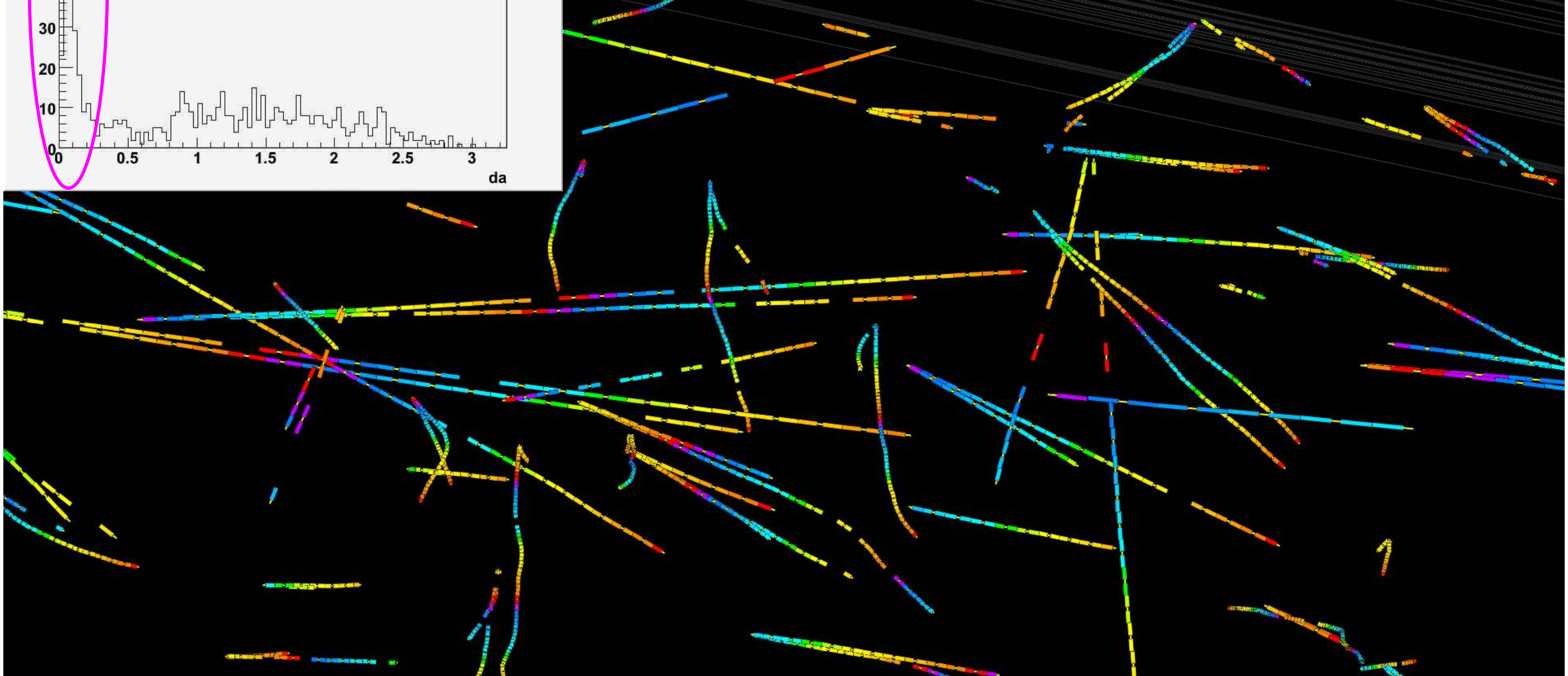
Feasibility study: 2kg Iron target ECC



e^+e^- pair search



2 Track vertex && da≤0.3



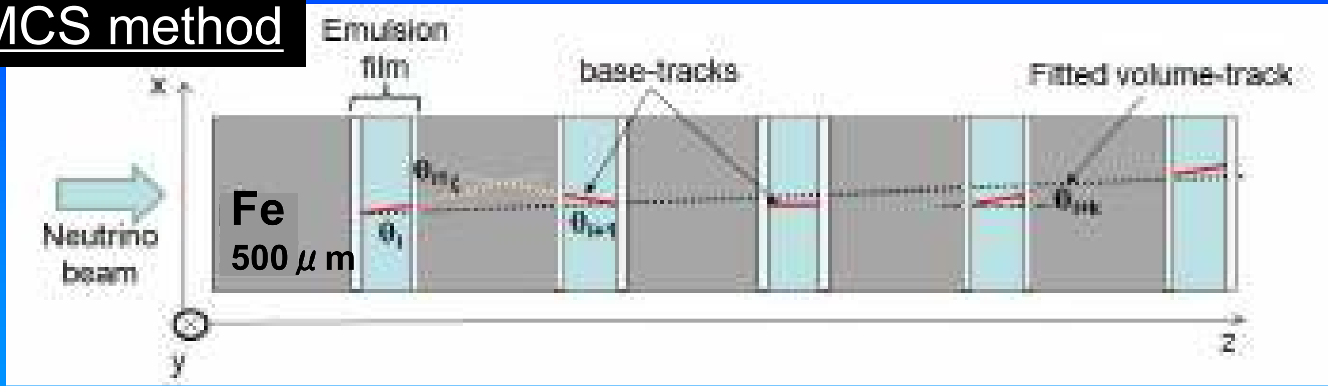
We will estimate their energy and investigate their origin.

Feasibility study: 2kg Iron target ECC

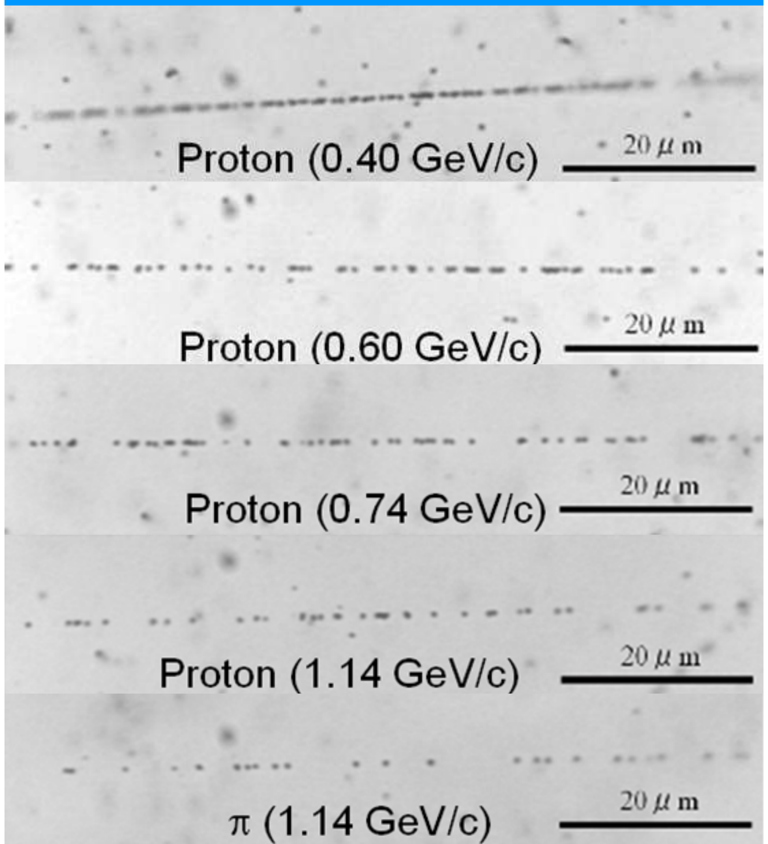
Proton identification

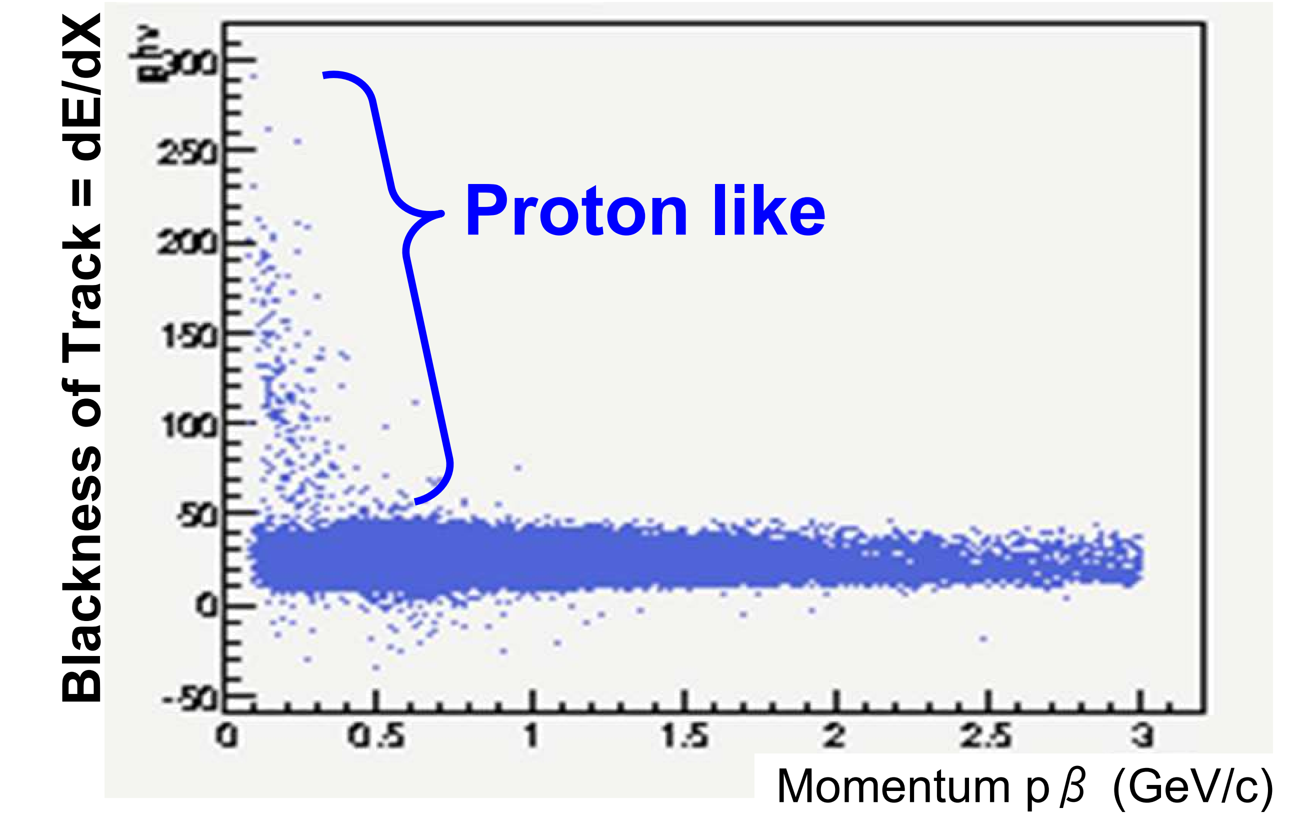
p β measurement by the MCS method

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

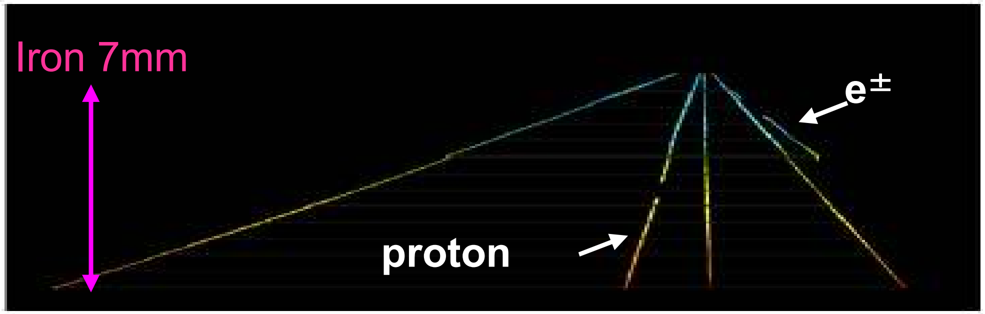


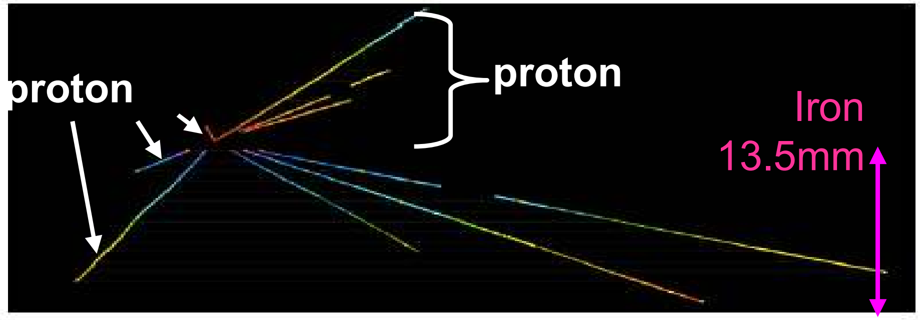
dE/dx measurement by track blackness

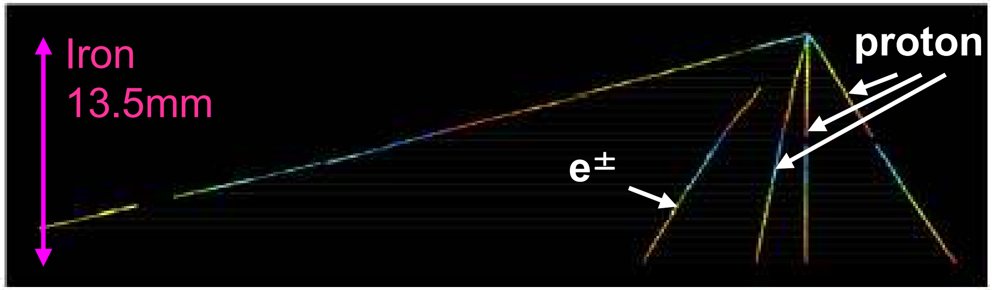


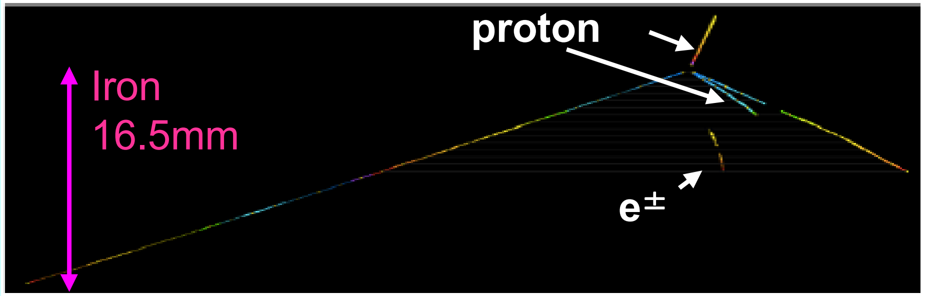


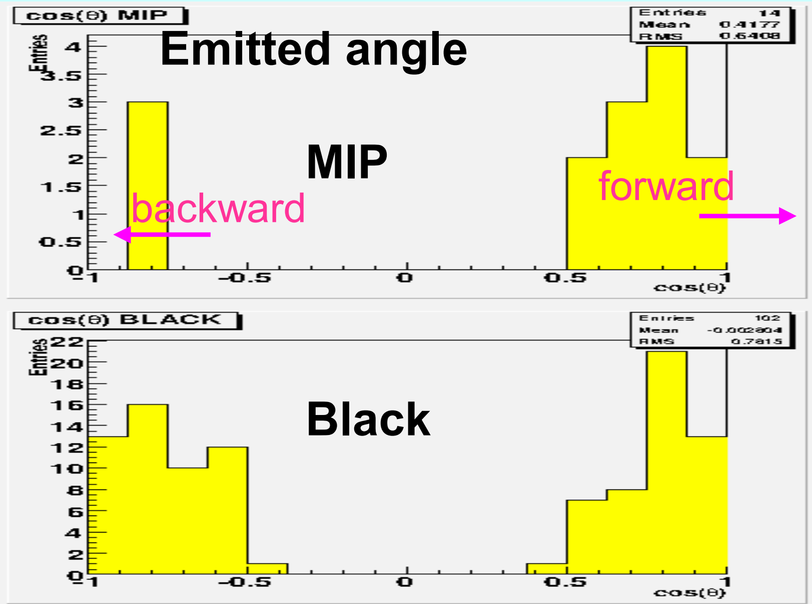
The detailed event analysis





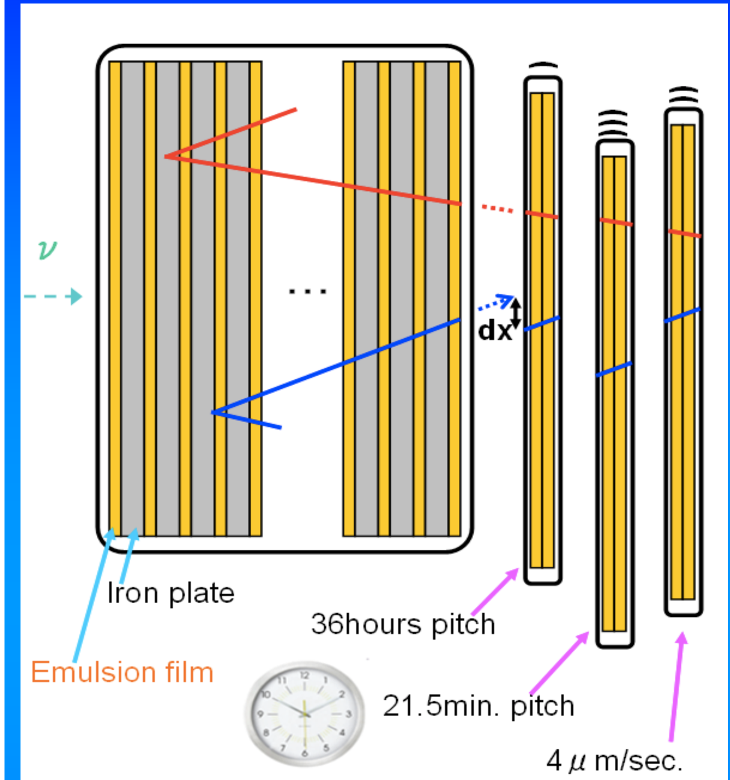






Feasibility study: 2kg Iron target ECC

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.

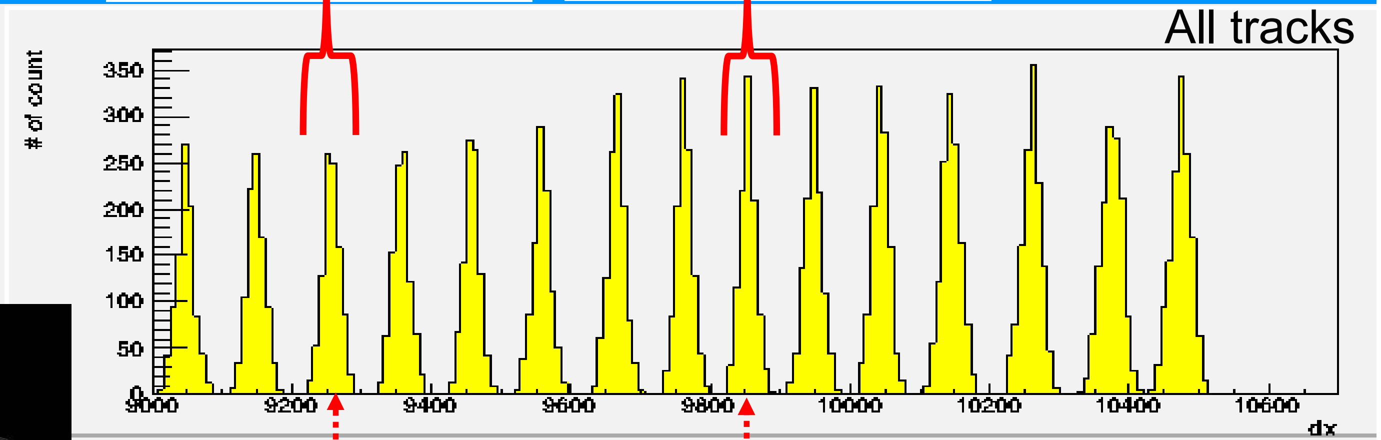
→ Position difference from reference point

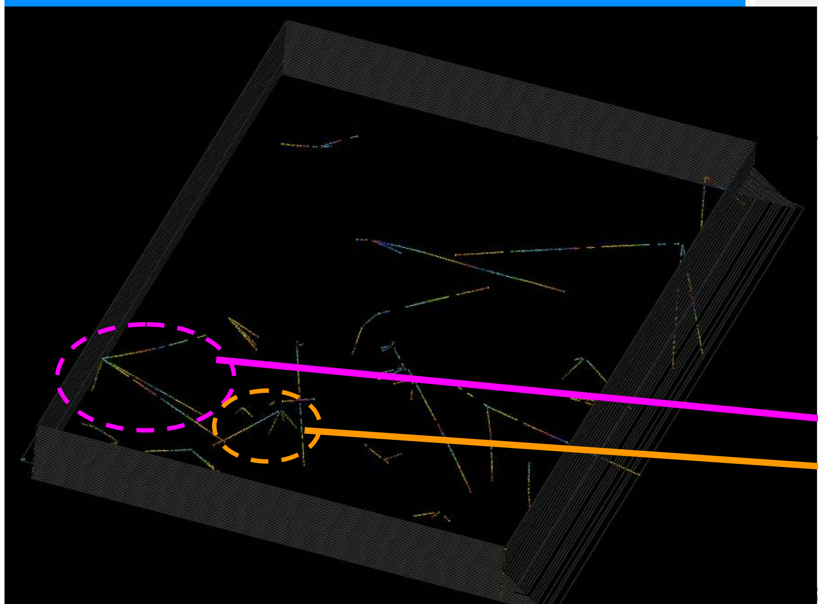
= Timing information

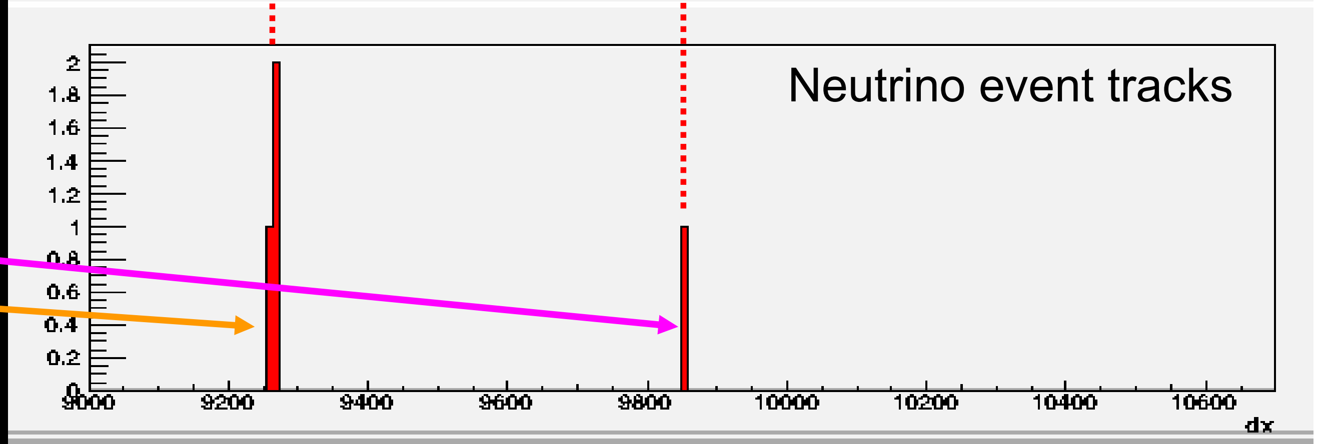
Spot 13
Mar.12 2:23:35
~ Mar.14 14:23:57

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

← Information from Top stage



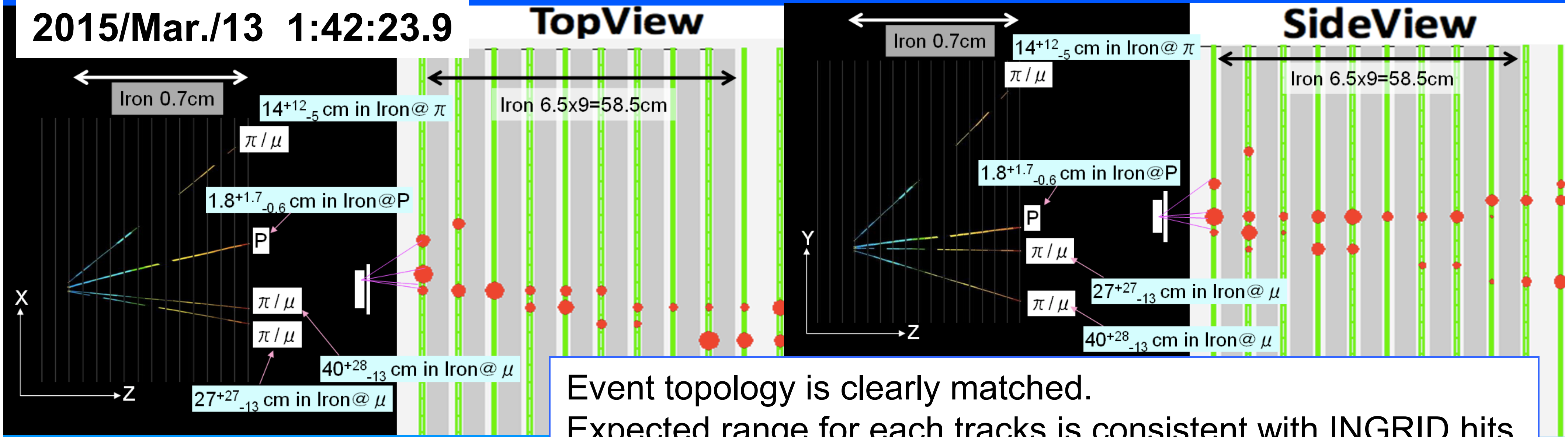




Feasibility study: 2kg Iron target ECC

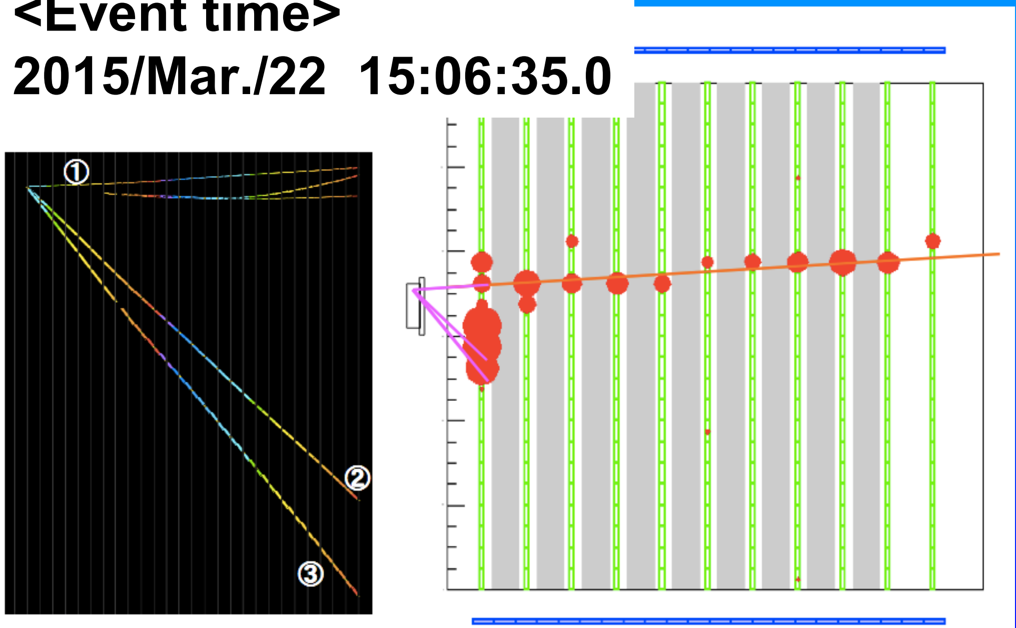
Emulsion-INGRID Hybrid analysis

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

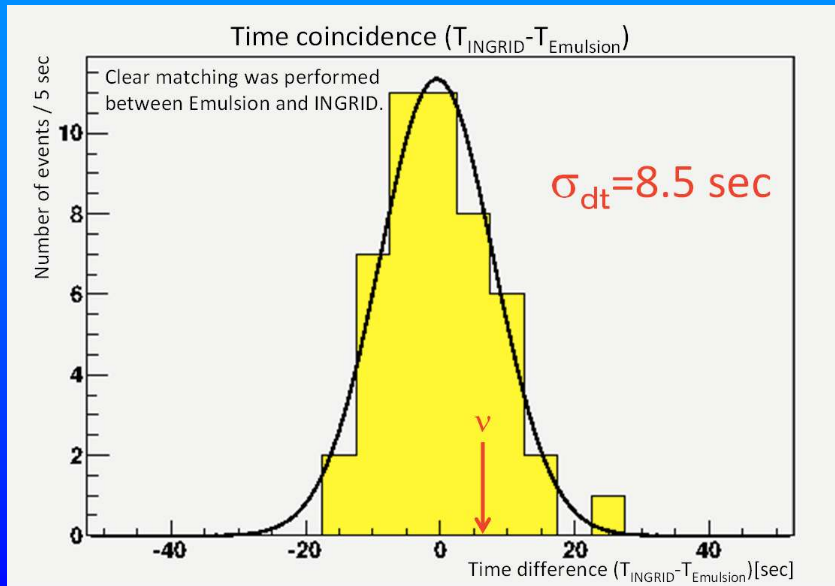


Event topology is clearly matched.
Expected range for each tracks is consistent with INGRID hits.

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



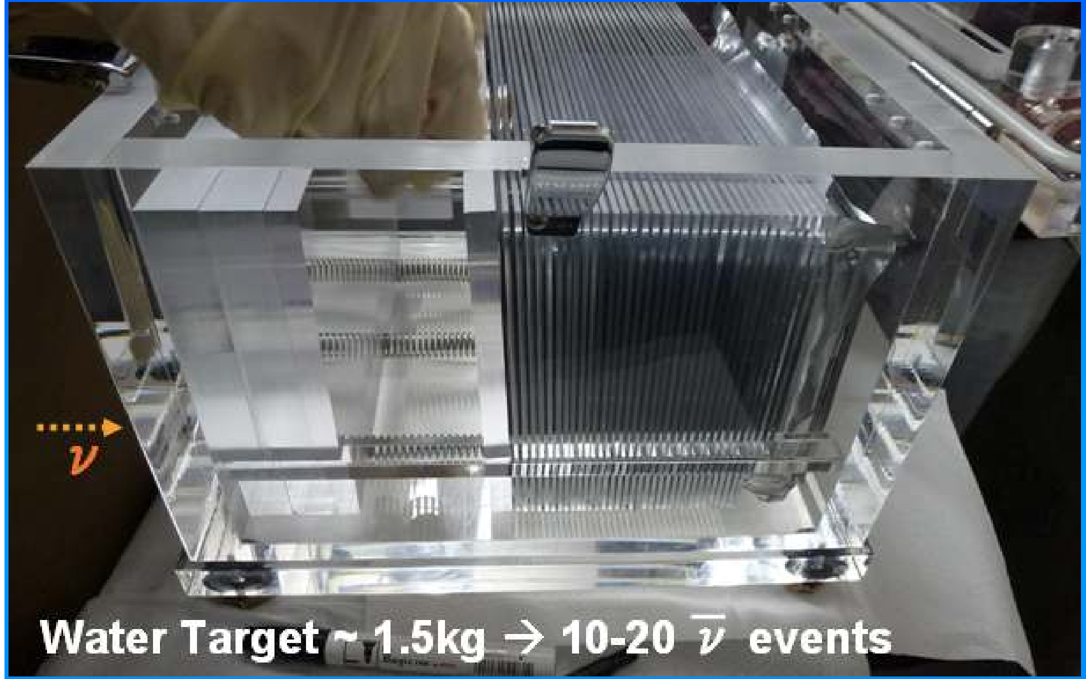
Time resolution for emulsion tracks

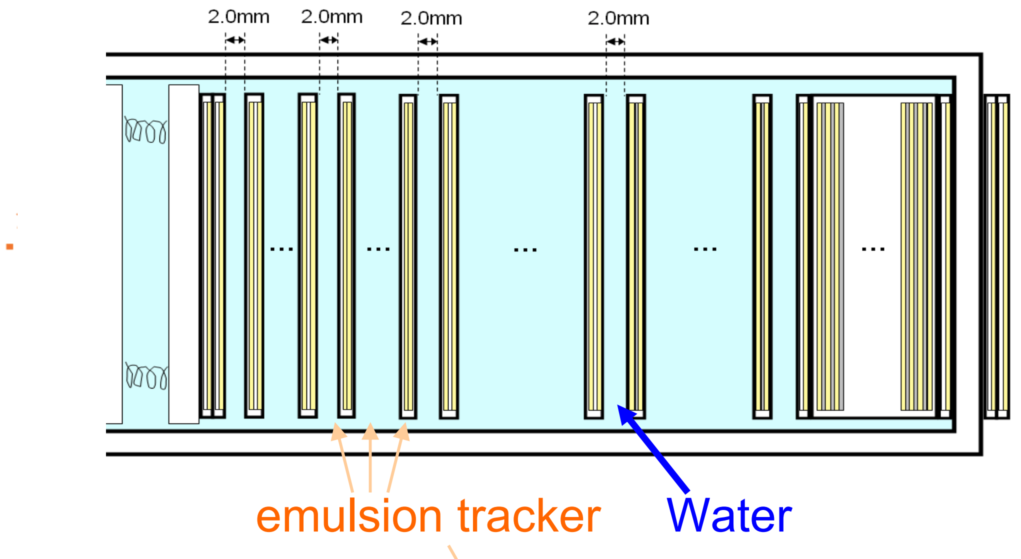


Feasibility study: 1.5kg Water target ECC

Water target emulsion chamber

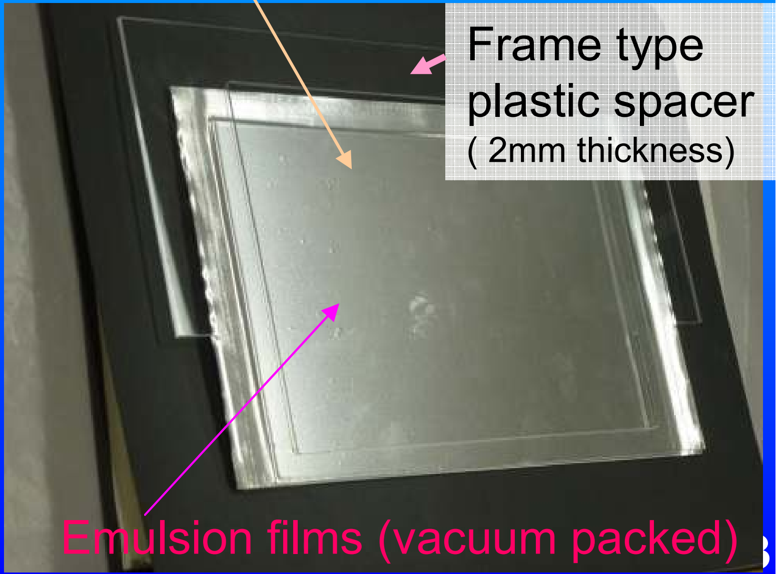
We installed a water target emulsion chamber during $\overline{\nu}$ exposure in May 2015.



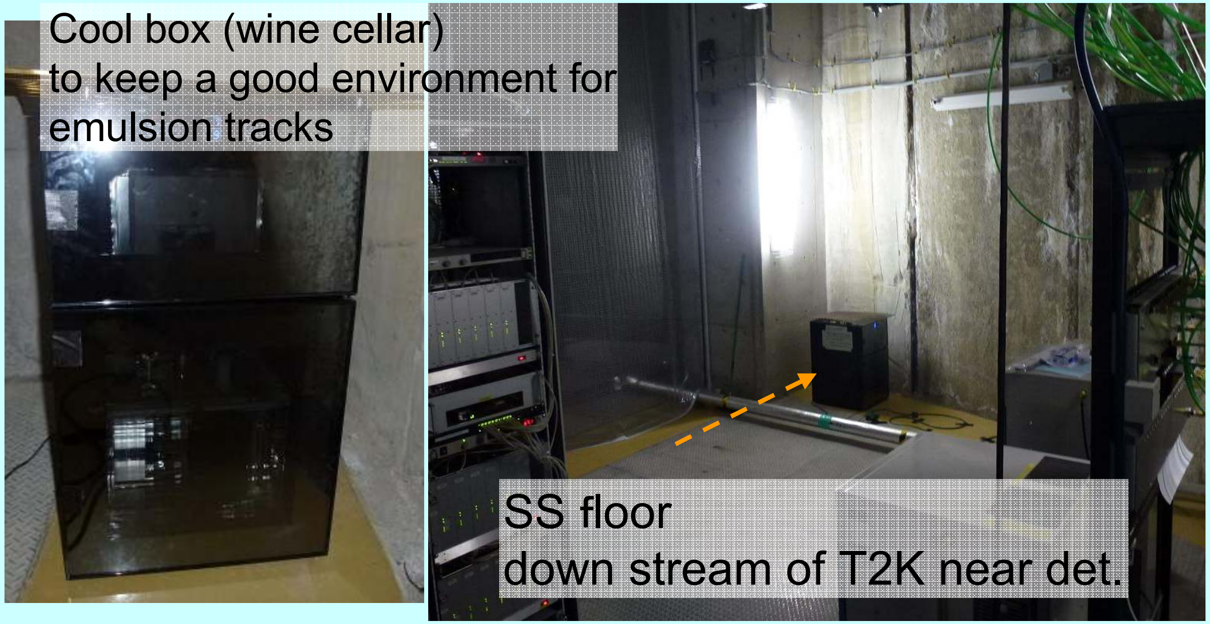


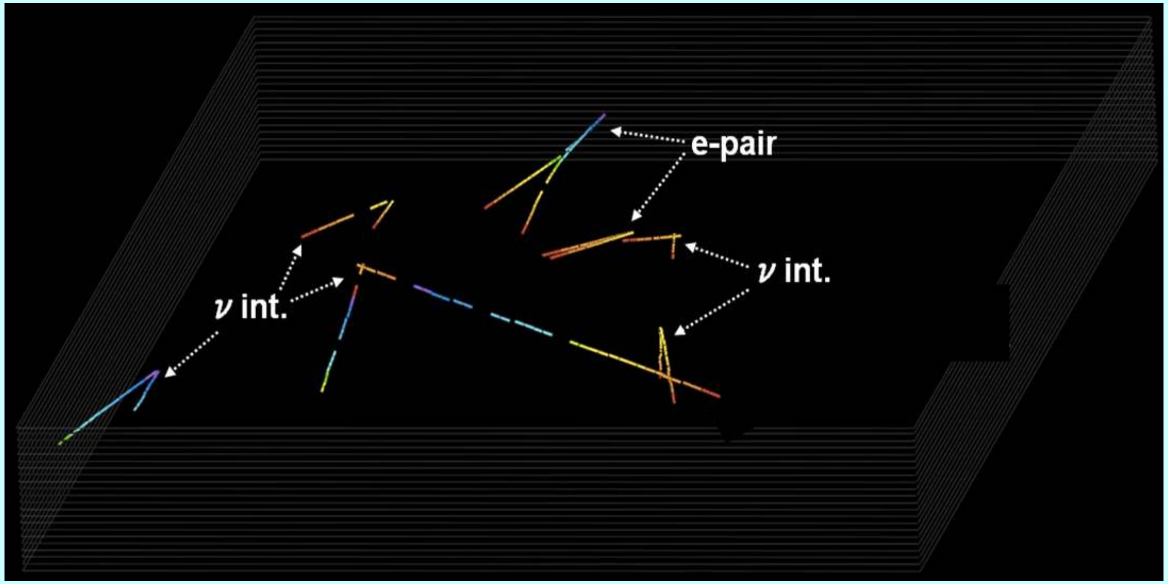
Sandwich structure of Emulsion films and Frame type spacers

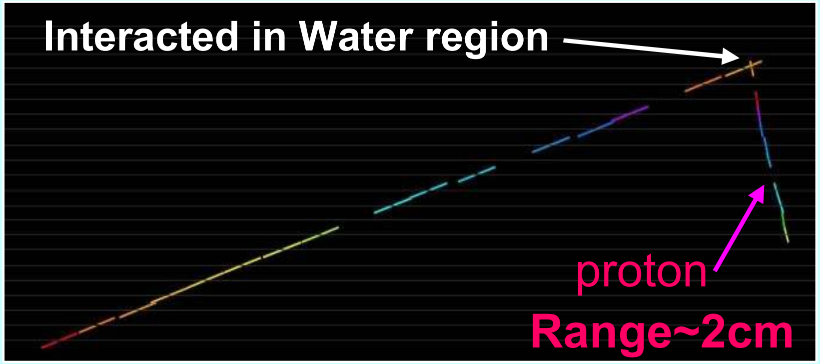
Pouring water



Water target emulsion chamber







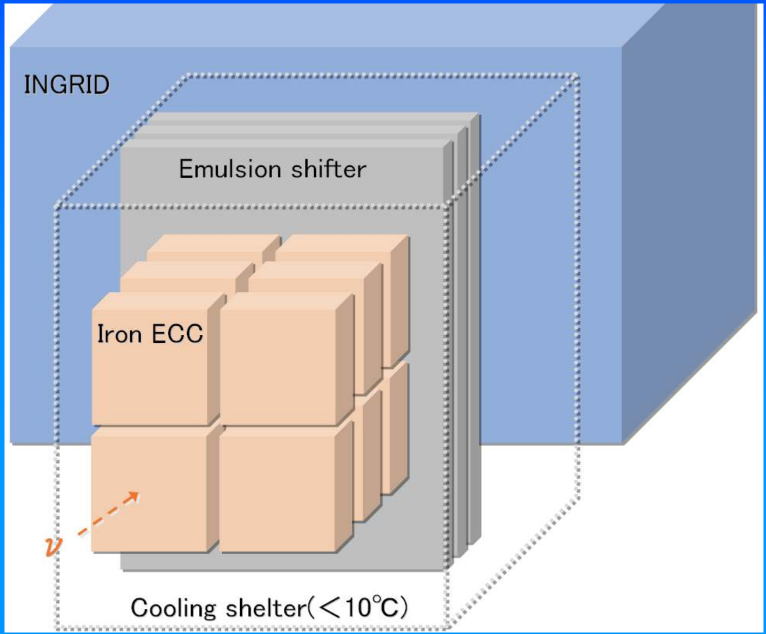
①	(tan θ x, tan θ y) = (-0.040, 0.845)	M.I.P
②	(tan θ x, tan θ y) = (-0.589, -0.074)	proton
Minimum distance(①-②)=2.4um, depth=620um		

First detection of ν - Water interaction with Emulsion Detector

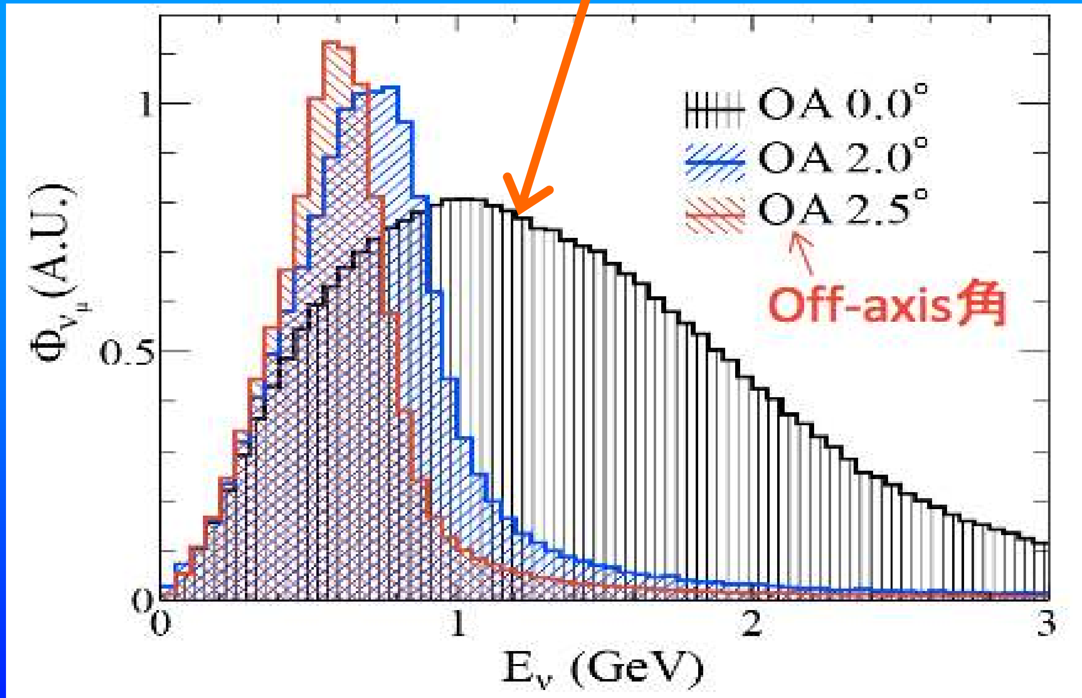
Detector Run: 60kg Iron target ECC

Detector Run

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



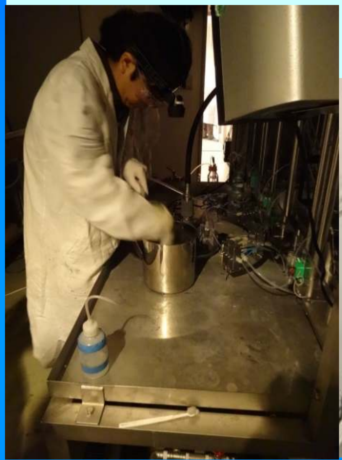
$\bar{\nu}$ exposure : 2016 @SS
end of Jan. → end of May (~4x10^{20}POT)
- Iron target (total~60kg : 500 μ m seg.)
- High statistics (3-4k $\bar{\nu}_\mu$ events)
- ν_e detection (20-30 $\bar{\nu}_e$ CC events)

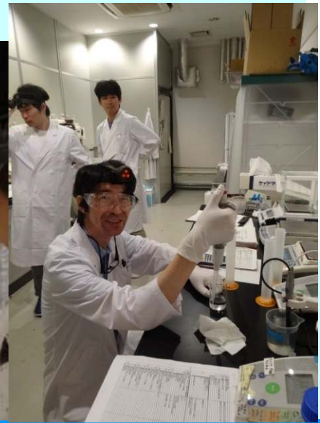


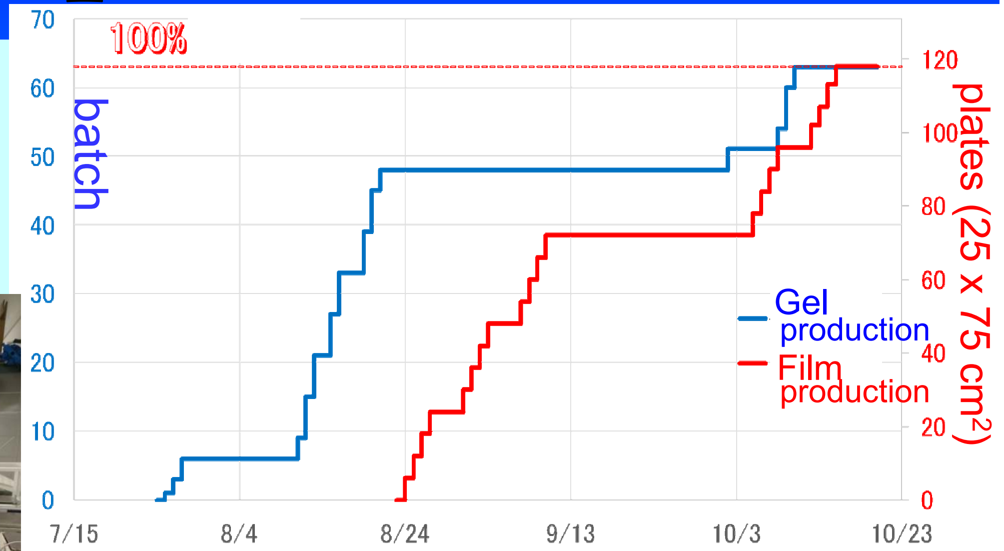
Detector preparation

Emulsion film production 2015. July→Oct.

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



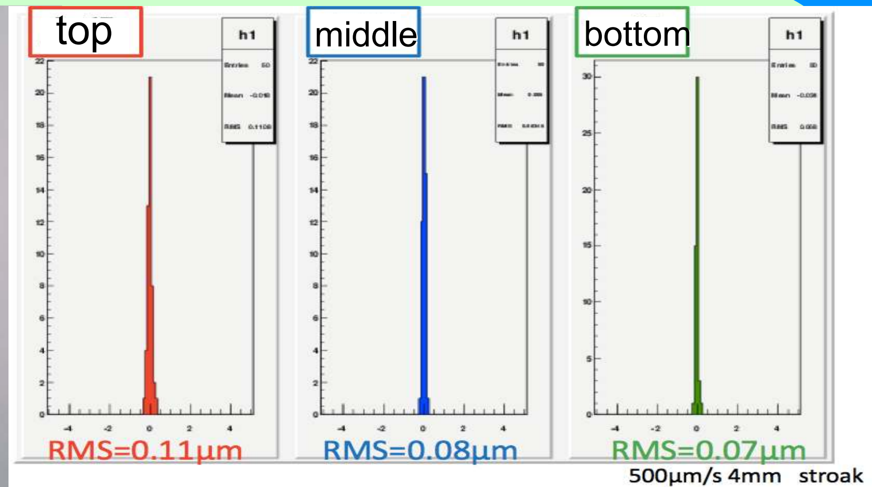




~52kg gel and ~359 films (25 x 25cm^2) production is completed.

Large size Emulsion Shifter

Operation test @Kobe Univ.



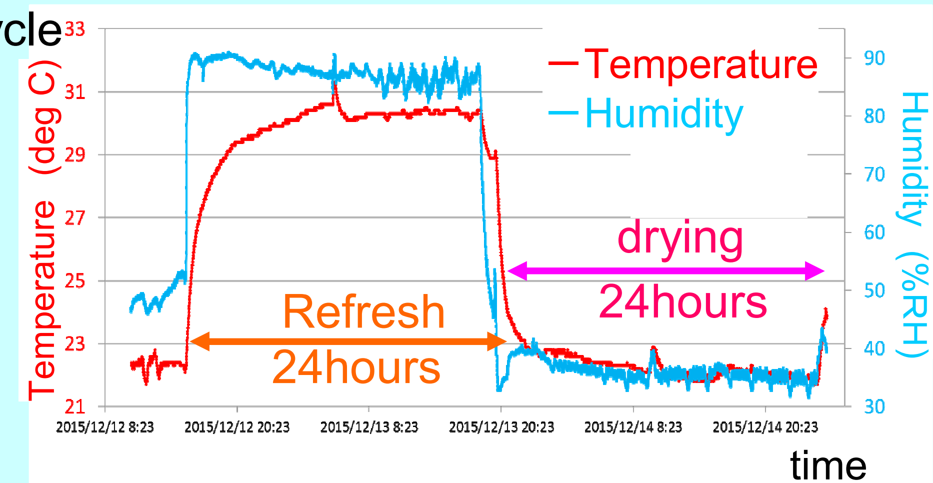
Repeatability for driving in each stage is well below 0.5 μ m.

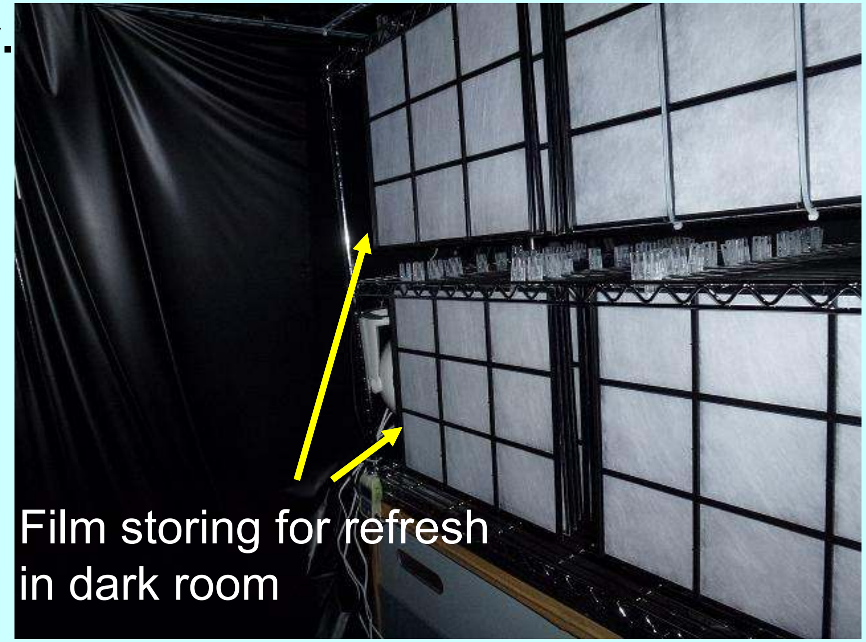
Detector preparation

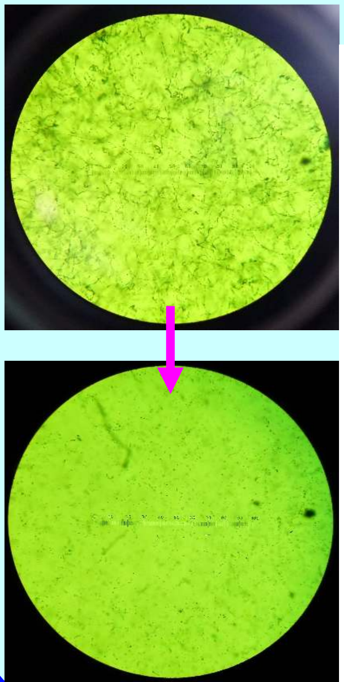
We carried out "Refresh" process to delete noise tracks like OPERA experiment.

Emulsion film Refresh

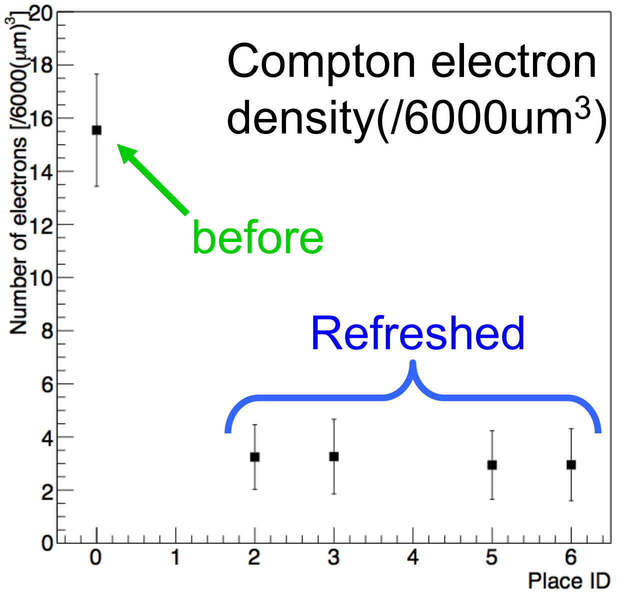
2015. Dec @Toho Univ.

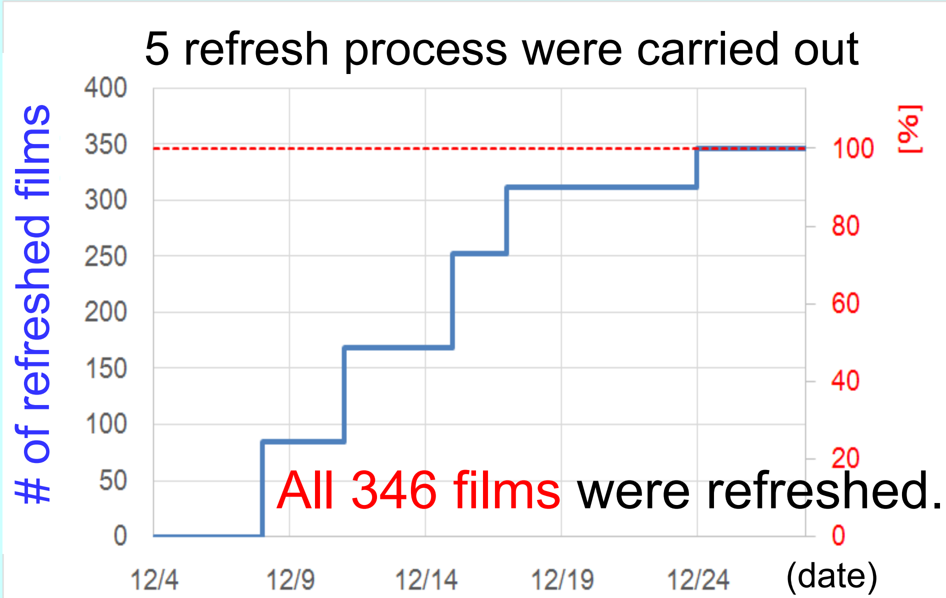






$$Ag_4 + 2H_2O + O_2 \rightarrow 4Ag^+ + 4OH^-$$

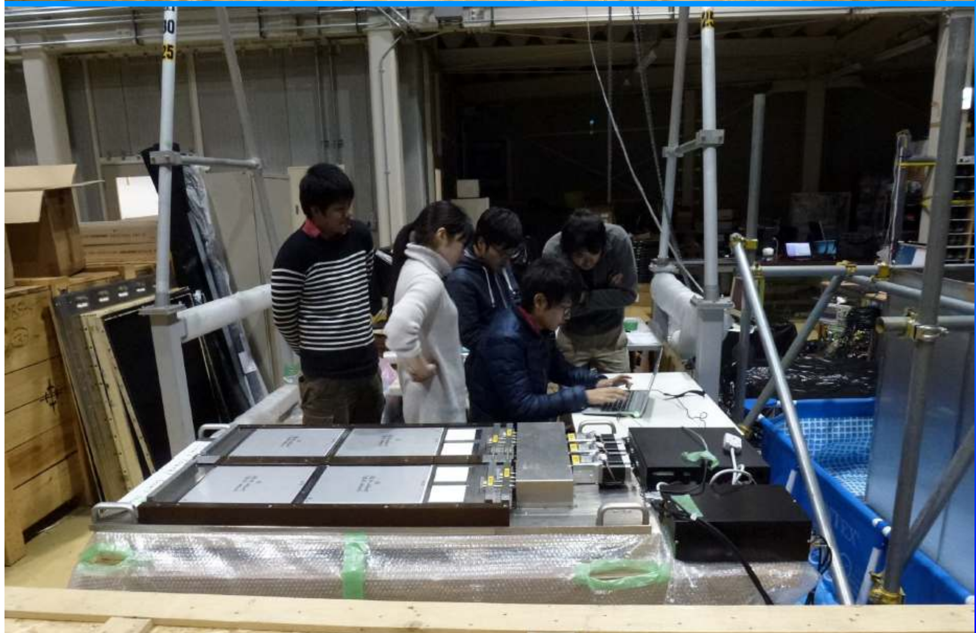




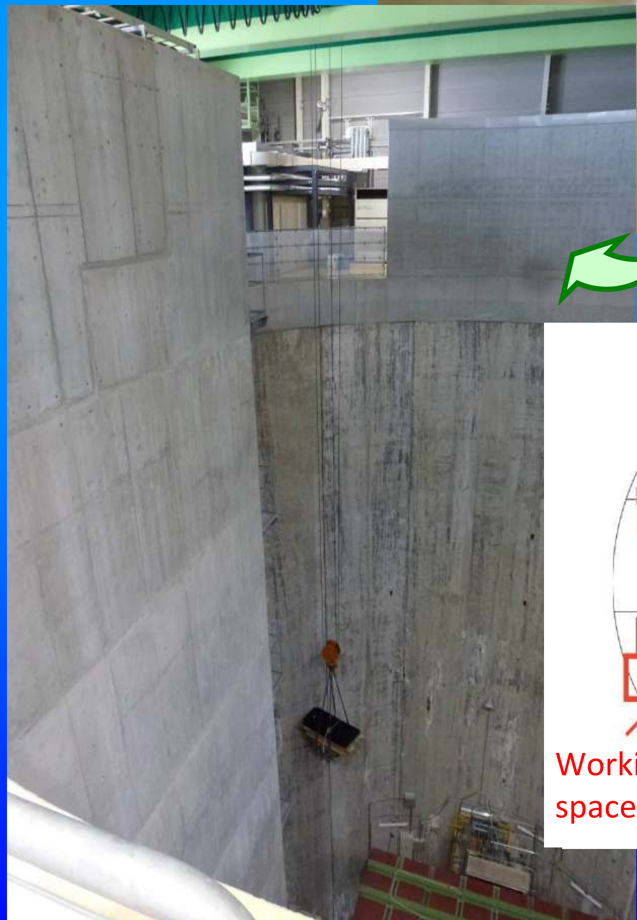
Detector Run: 60kg Iron target ECC

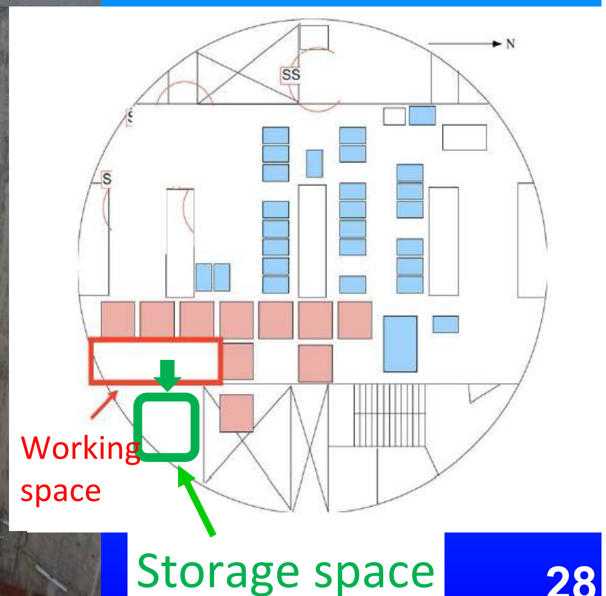
Installation @J-PARC (Jan. 11-20)

Test operation of the emulsion shifter @NA



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



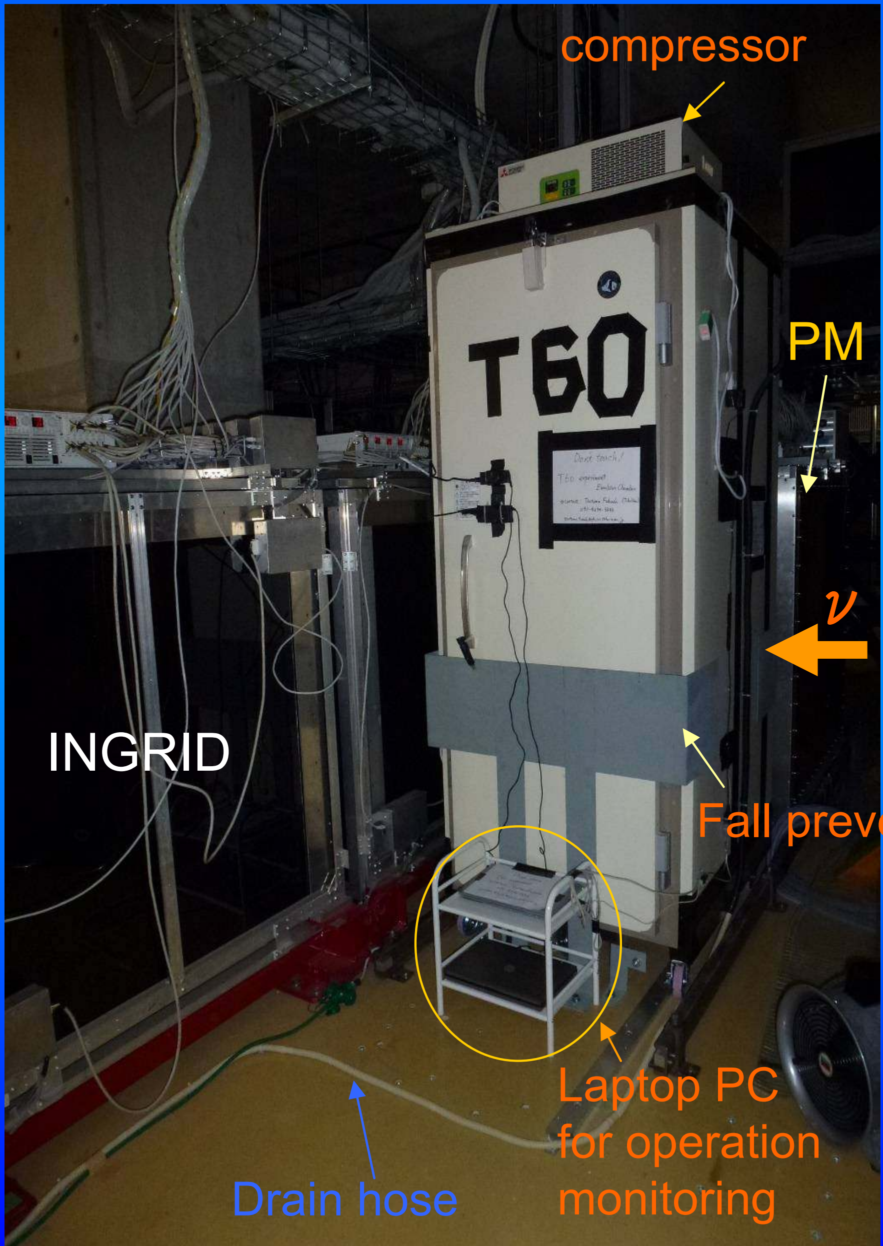


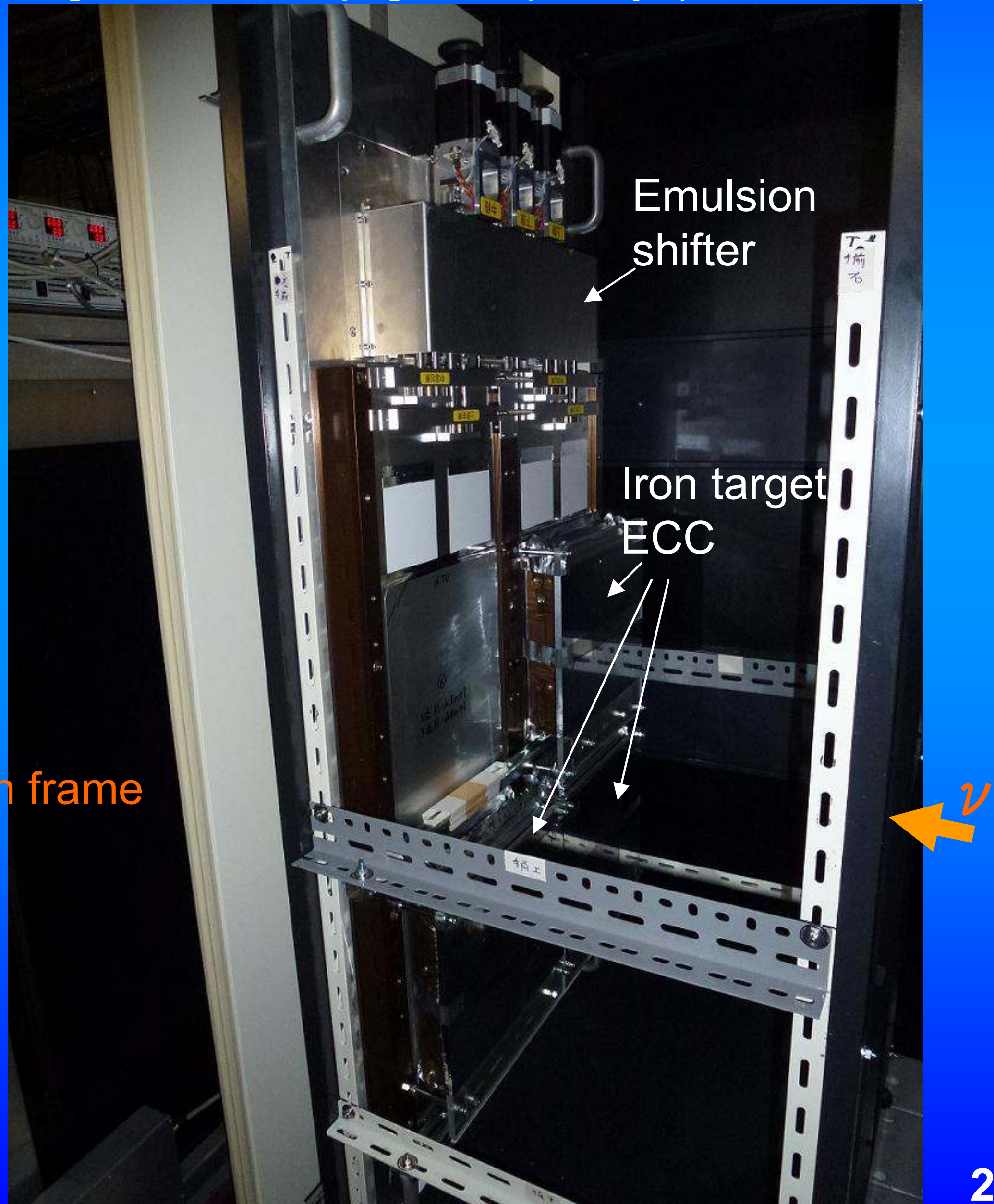
Detector Run: 60kg Iron target ECC

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

Detector was constructed @SS floor.

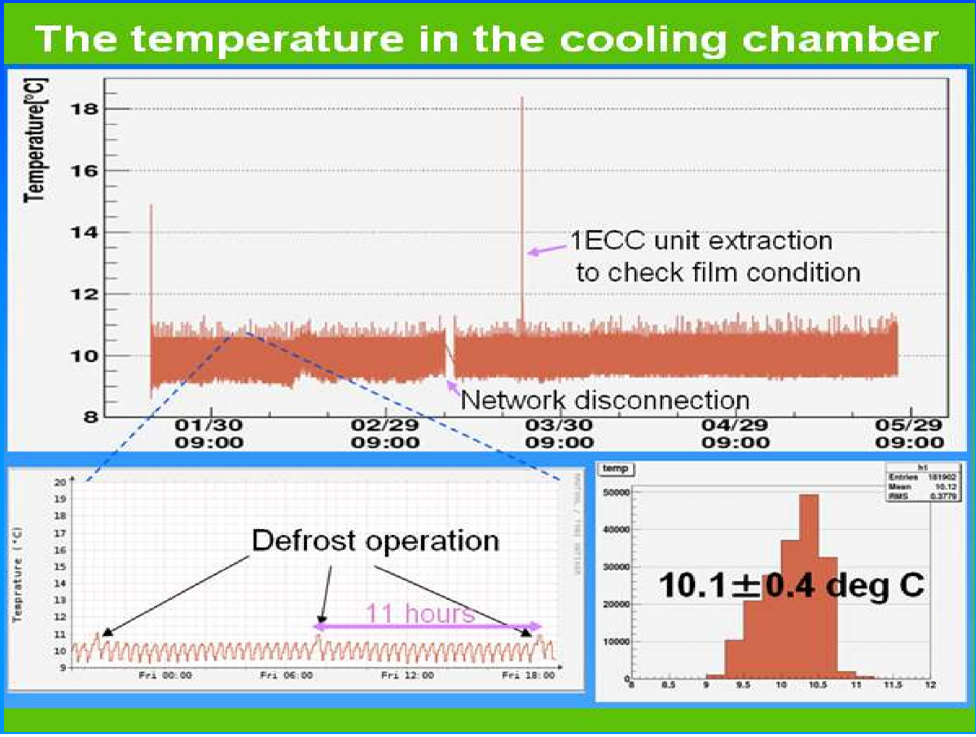
T60 emulsion detector is mounted in cooling box to keep good quality (no refresh).

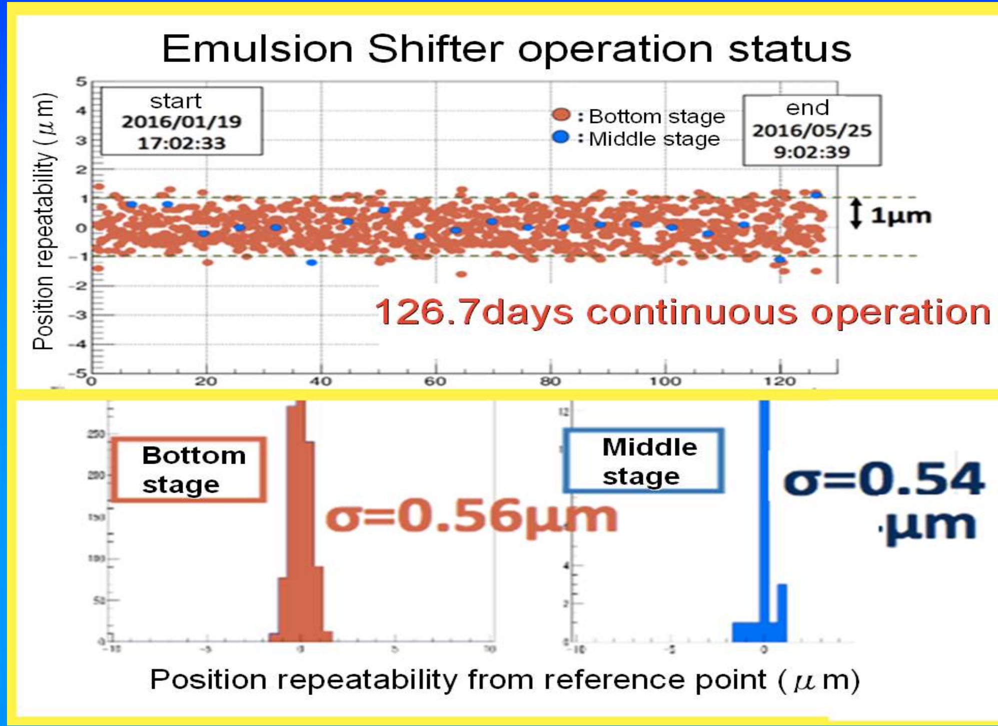


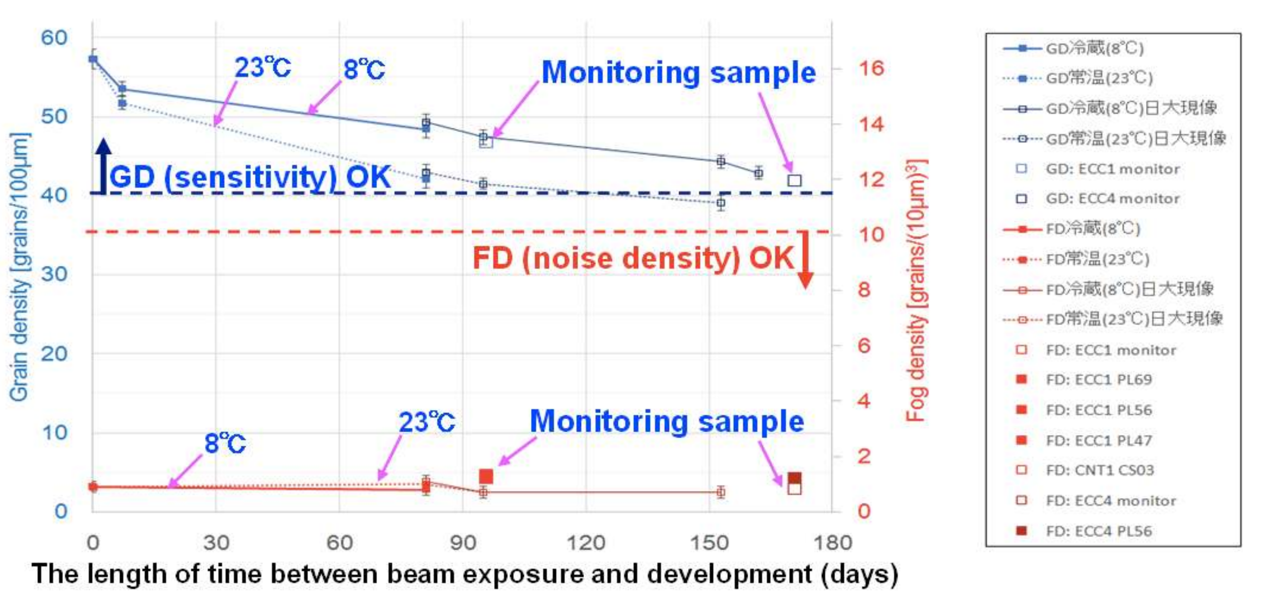


Detector Run: 60kg Iron target ECC

Operation status (Jan. - Jun)

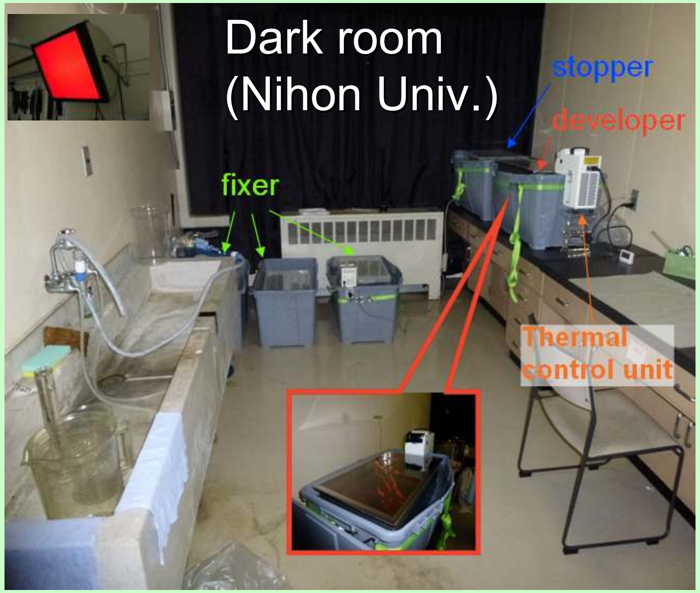






In this time, the detector is placed in the cooling chamber.
The emulsion quality (sensitivity and noise density) is found to keep at safety level from end of Jan. to end of May by checking the monitoring sample.

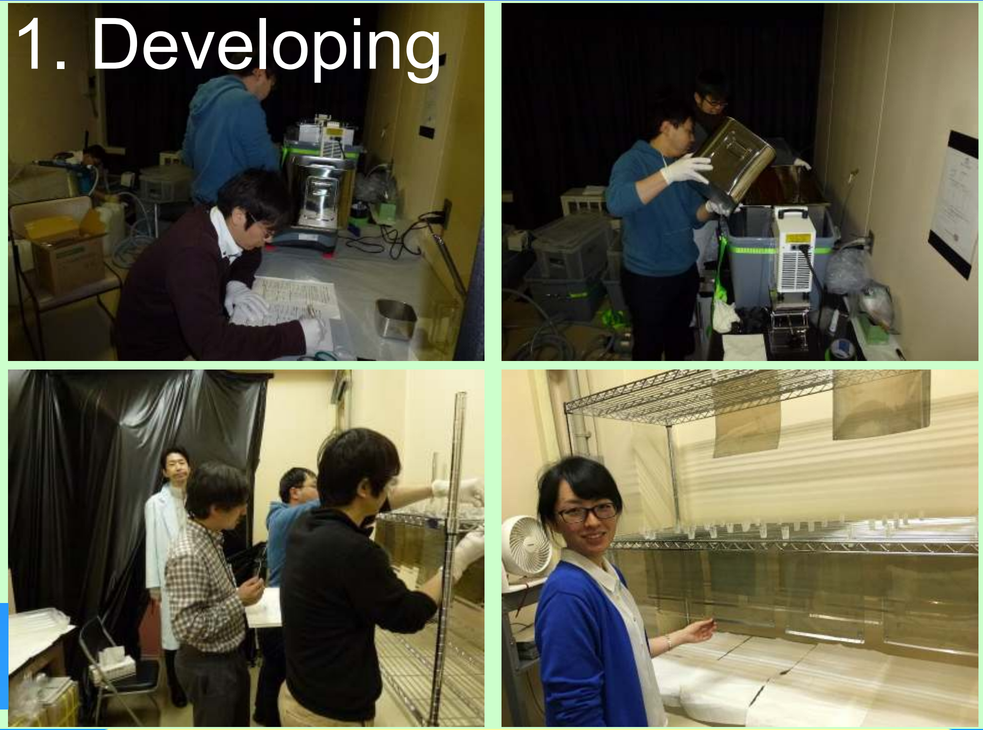
Hardware treatment of the emulsion films



Development process

XAA	Stop	Fix	Wash
25 min.	10 min.	60 min.	60 min.

1. Developing

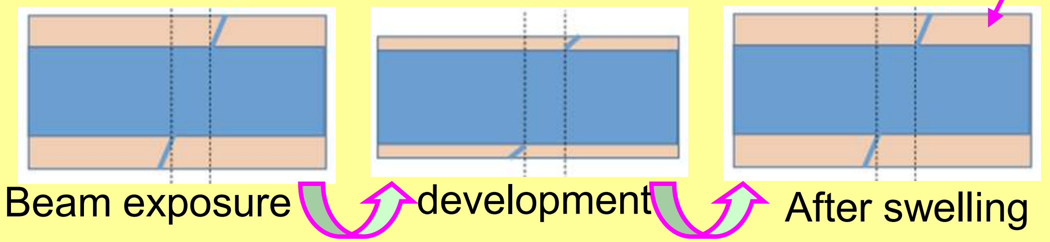


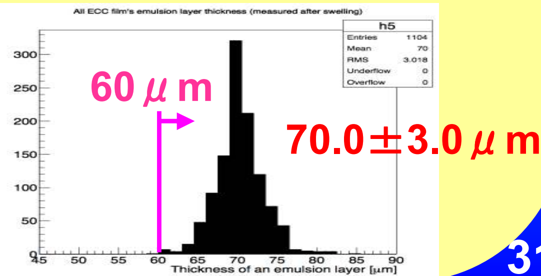
2. Surface silver cleaning

More than 300 films were completed.

3. Emulsion swelling

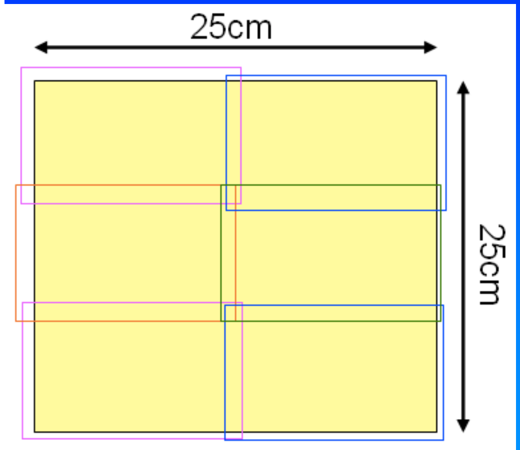
Recovering of emulsion thickness





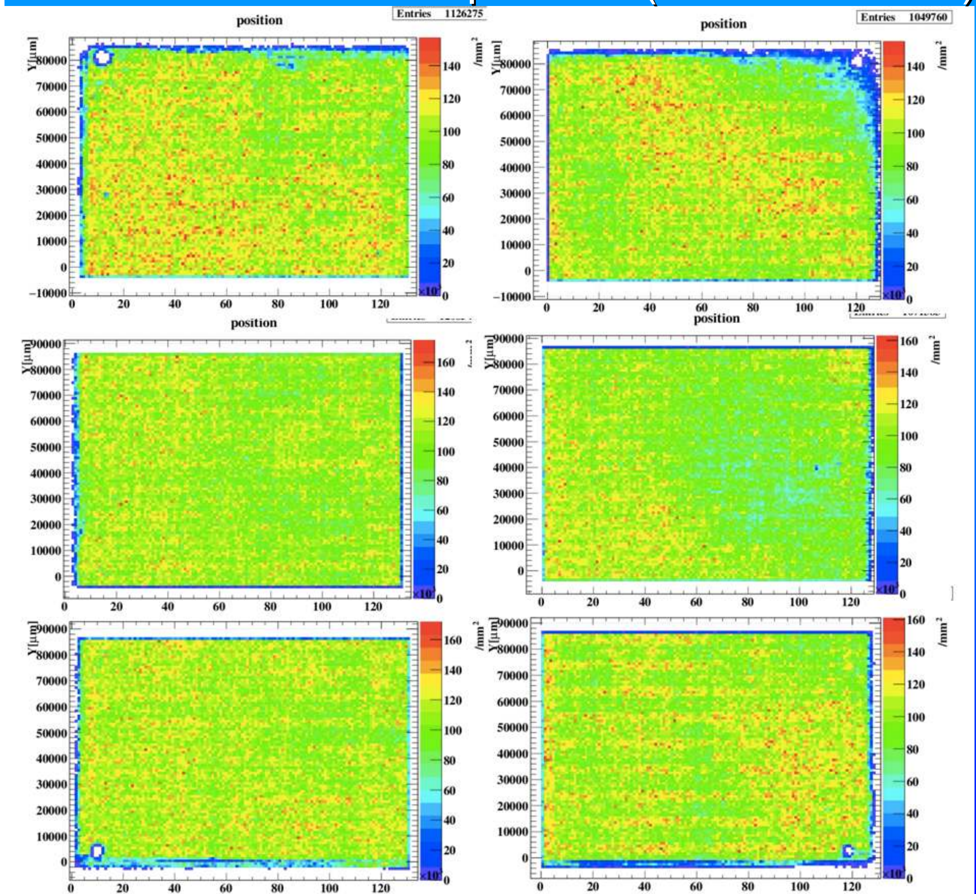
Detector Run: 60kg Iron target ECC

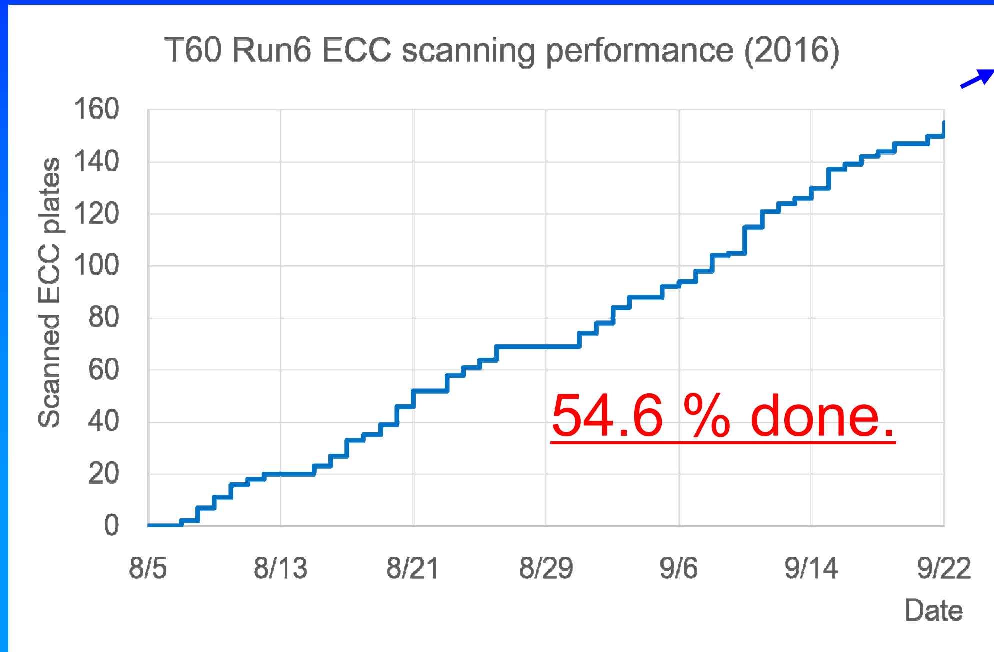
Scanning status

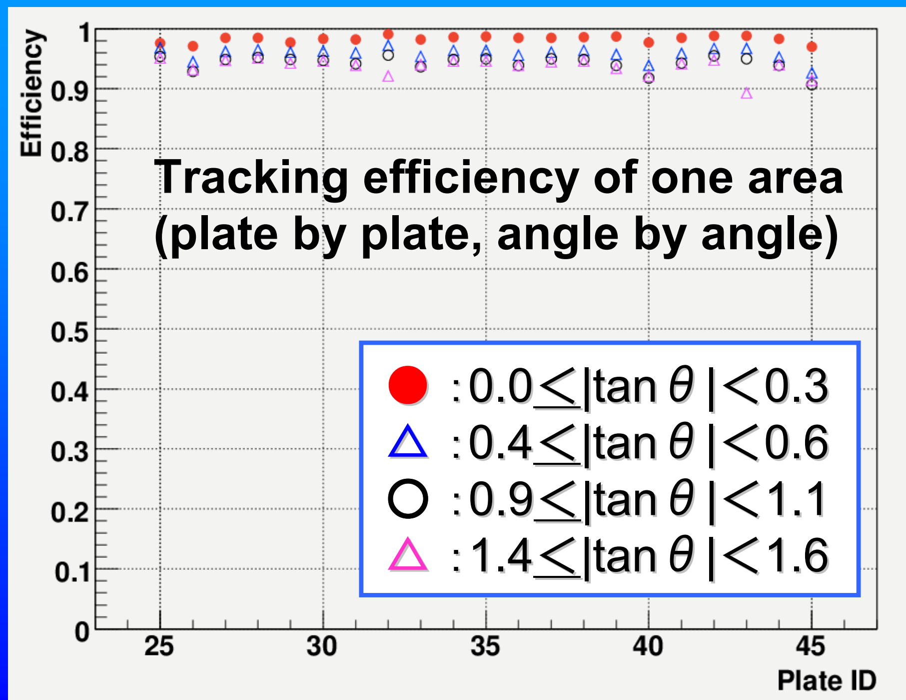


6 scanning area for one films with small overlap area.

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





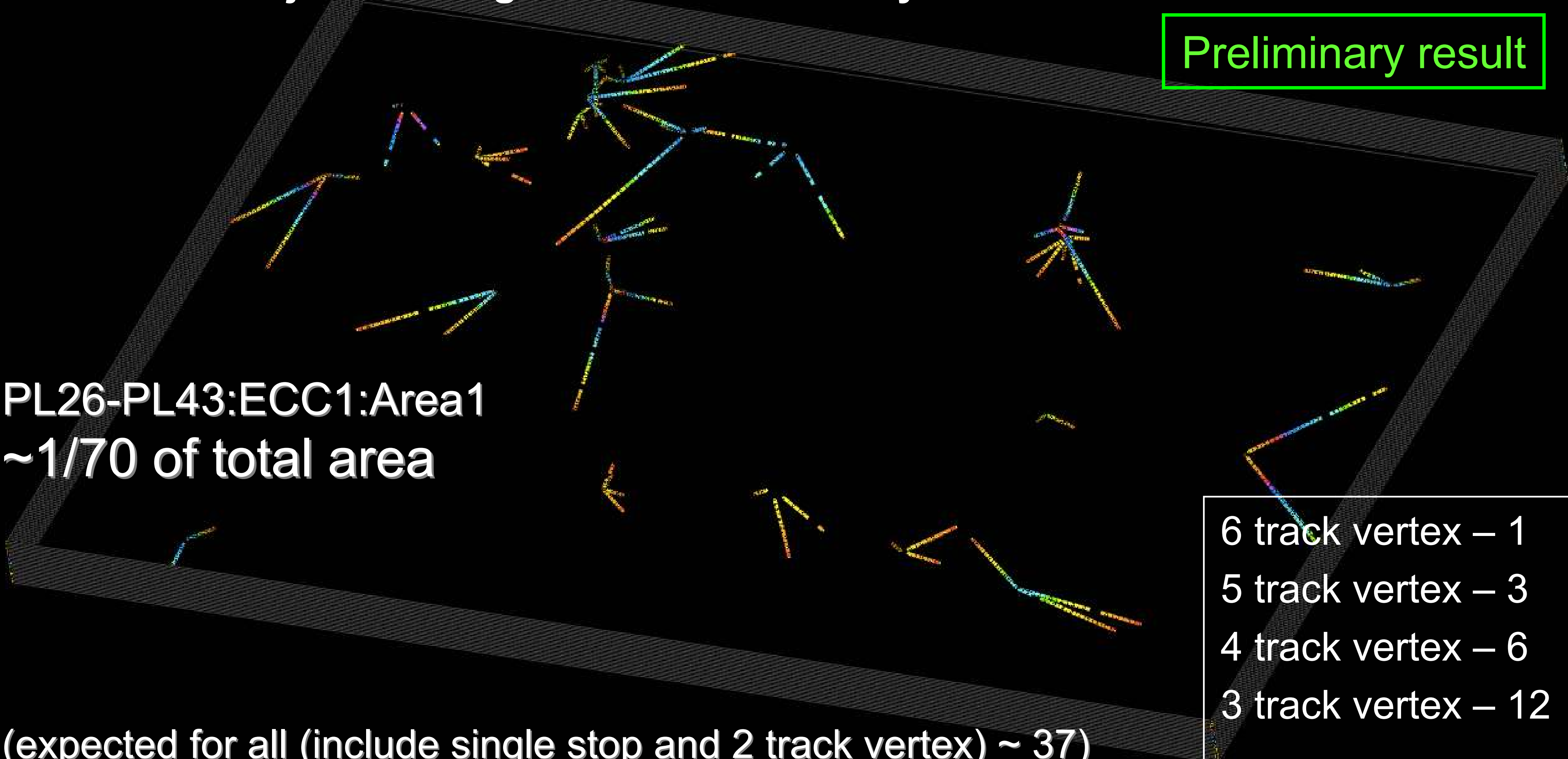


Multi track vertex search

Neutrino event candidates

Now we are just starting neutrino event analysis.

Preliminary result



PL26-PL43:ECC1:Area1

~1/70 of total area

6 track vertex – 1

5 track vertex – 3

4 track vertex – 6

3 track vertex – 12

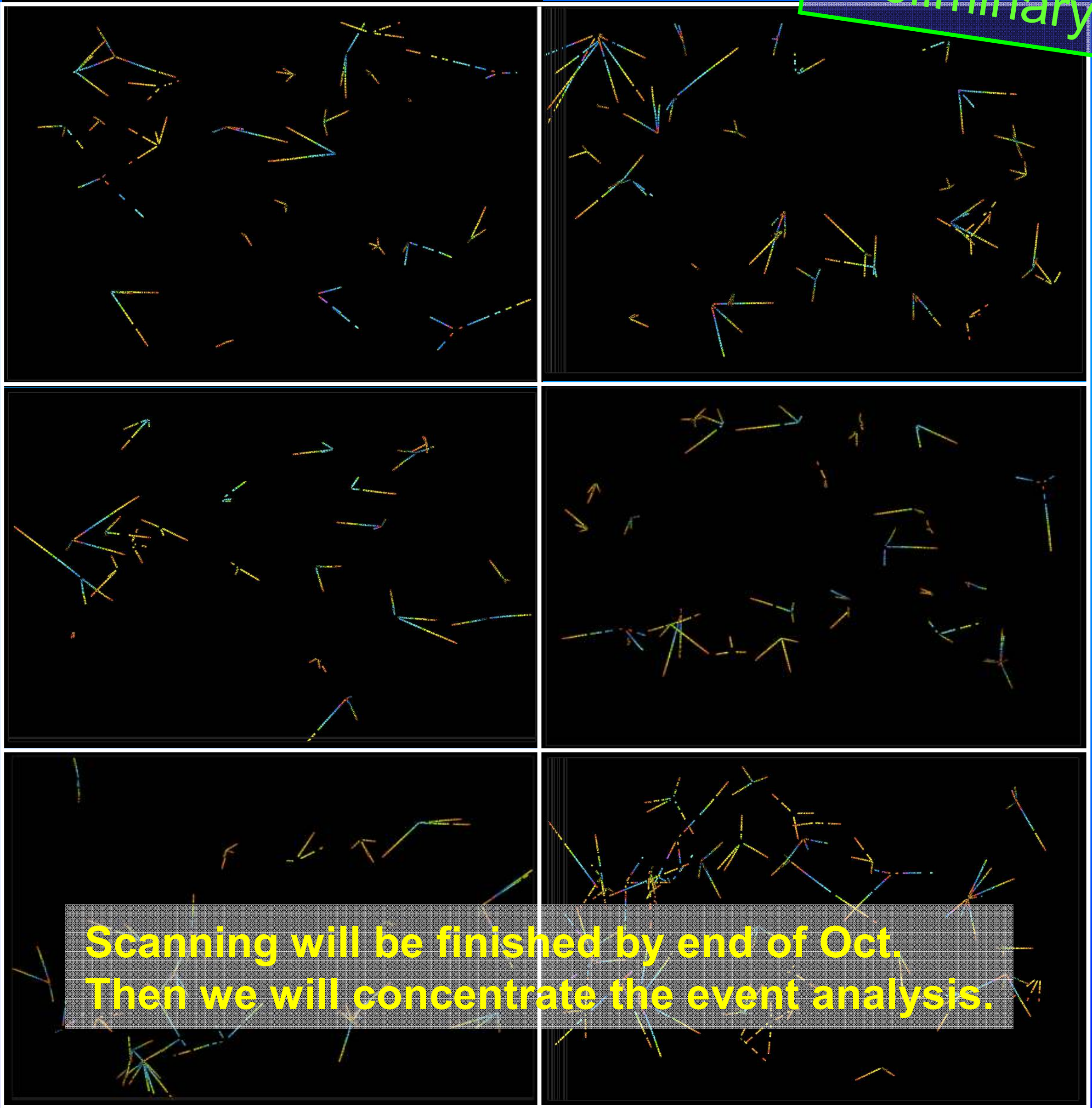
(expected for all (include single stop and 2 track vertex) ~ 37)

（include Nuclear fragments）

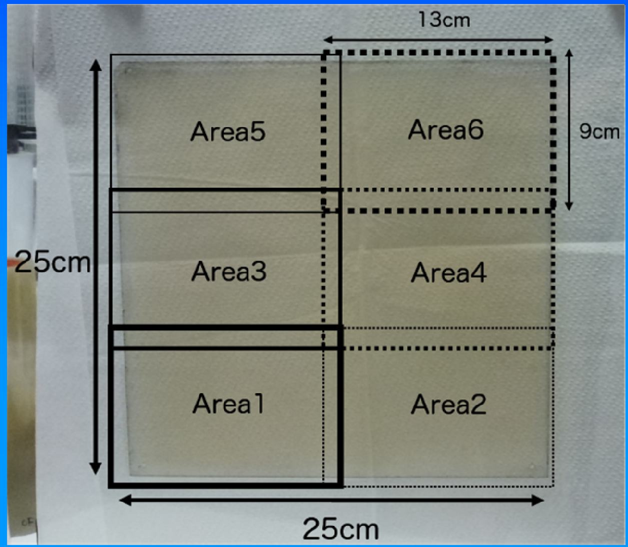
Multi track vertex search

Neutrino event candidates

Preliminary result



Scanning will be finished by end of Oct.
Then we will concentrate the event analysis.

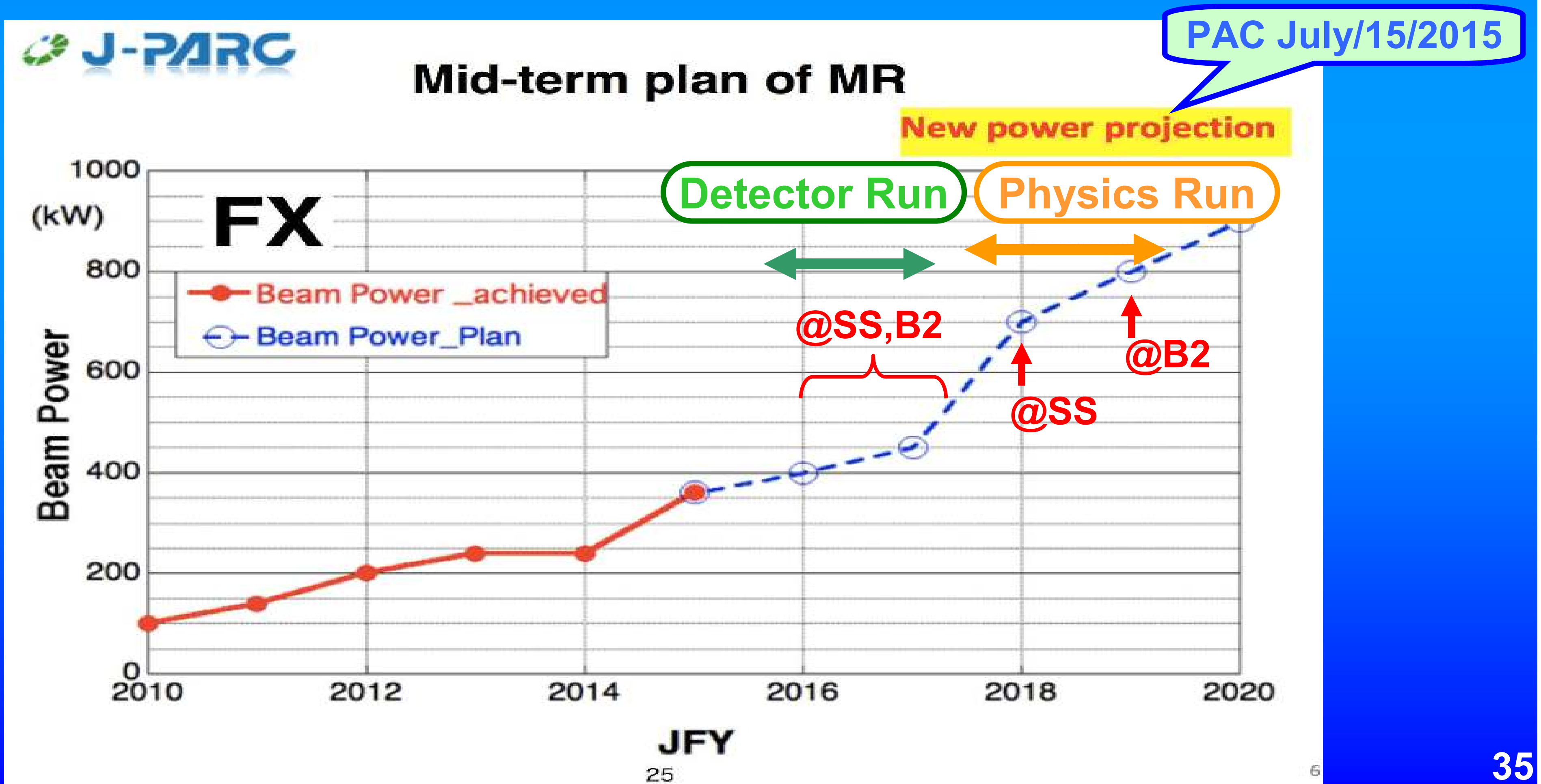


Current status (1ECC, ~1/12 of all)

	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6
3 trks	12	22	19	20	20	25
4	6	10	2	3	5	5
5	3	5	0	3	0	1
6	1	0	0	0	0	2
7	0	1	0	1	0	0
≧ 8	0	0	0	0	0	0
Total	22	38	21	27	25	33

Future prospects

We are discussing about next Detector Run and future Physics Run.
- R&D of the water target ECC are planned in this winter exposure.
- 150kg scale Iron ECC and 100kg scale Water ECC is assumed.
  10k order ν_μ int. and hundred order ν_e int. study in 2018-2019.
  Plan is optimized by the results of Detector Run.



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.
- We are planning the beam exposure for R&D of water target ECC and future Physics Run.