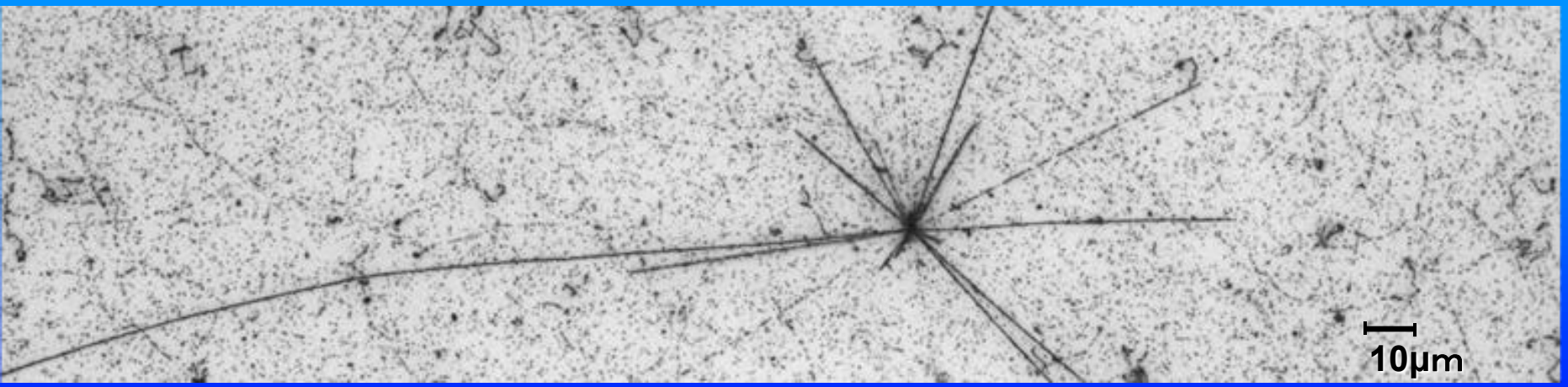
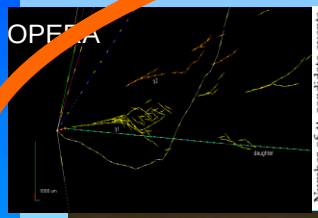
J-PARC T60:
J-PARCでの原子核乾板を用いたニュートリノ反応精密測定実験

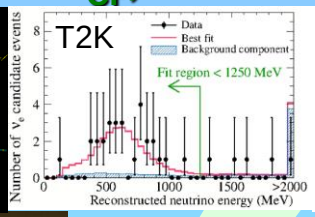
福田　努（名古屋大学）

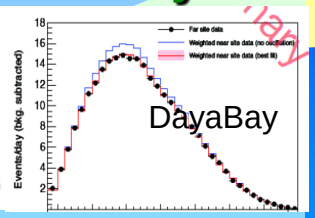


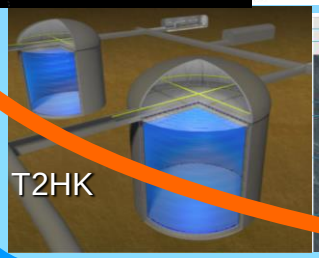
Current situation on neutrino physics

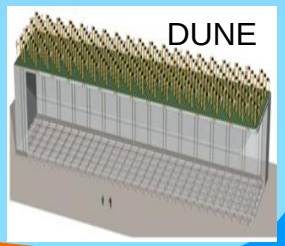
Neutrino oscillation
→ δ_{CP}, mass hierarchy



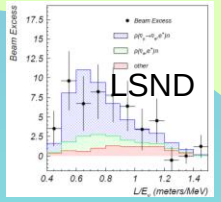


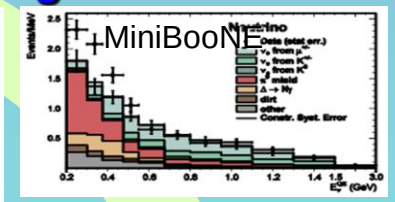


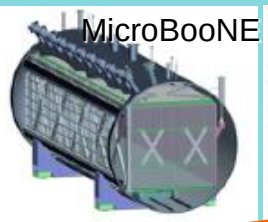


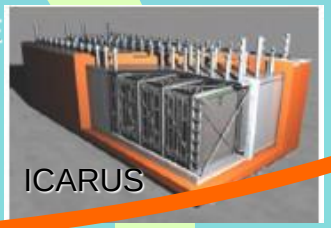


Sterile Neutrinos
→ 4th generation ? Dark matter ?

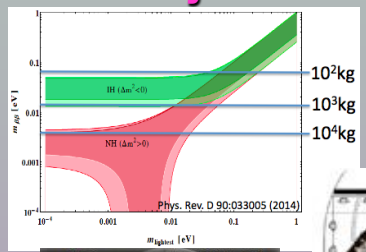


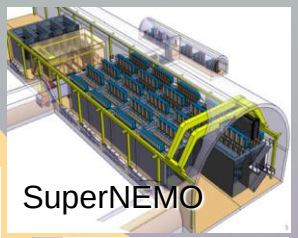




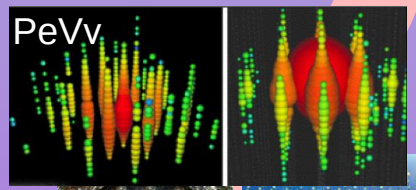


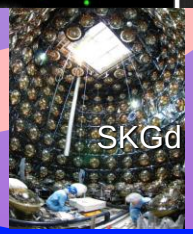
0νdouble beta decay
→ majorana / dirac ? νmass meas.

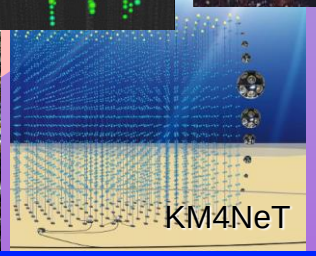


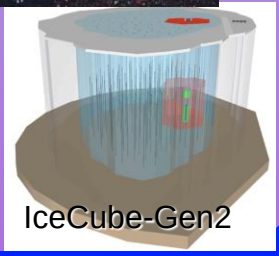


Cosmic neutrinos
→ Ultra-high energy, Supernova,…







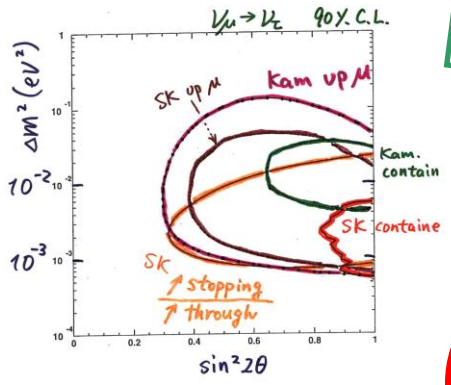


この他にも多くの実験が計画・実施・遂行されている。

1998

Summary

Evidence for ν_μ oscillations



- $\begin{cases} \sin^2 2\theta > 0.8 \\ \Delta m^2 \sim 10^{-3} \sim 10^{-2} \end{cases}$

($\nu_\mu \to \nu_\tau$ or $\nu_\mu \to \nu_s$?)

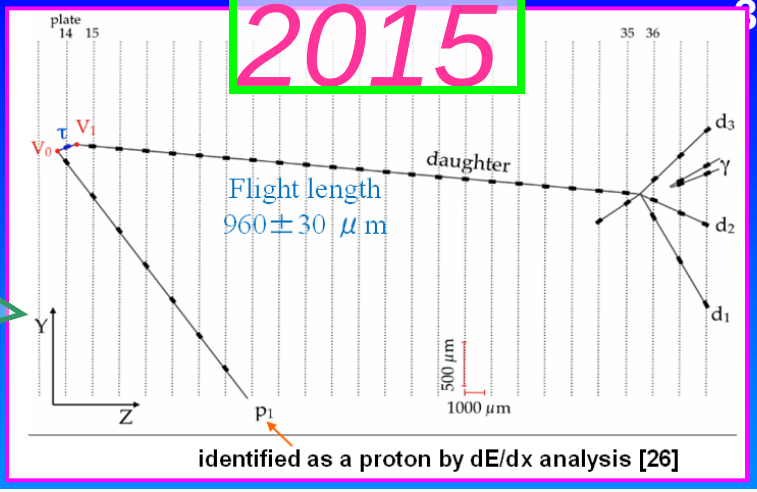
4. Conclusions

So far both $\nu_\mu \leftrightarrow \nu_\tau$ & $\nu_\mu \leftrightarrow \nu_s$ solutions provide a good fit to atmospheric neutrino anomaly for $\begin{cases} 10^{-3}eV^2 \lesssim |\Delta m^2| \lesssim 10^{-2}eV^2 \\ \sin^2 2\theta \sim 1 \end{cases}$.

To be more conclusive, we need more statistics or we have to look for appearance of ν_τ in long baseline experiments.

done

2015

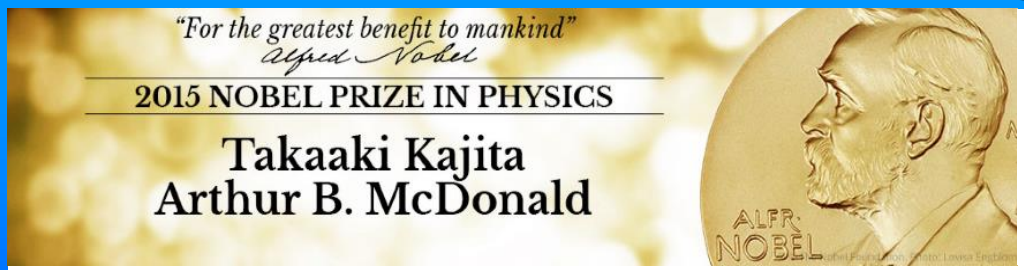


identified as a proton by dE/dx analysis [26]

02 (2015) PHYSICAL REVIEW LETTERS 18 SE

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

A. Aleksandrov,[2] A. Anokhina,[3] S. Aoki,[4] A. Ariga,[5] T. Ariga,[5] D. Bender,[6] A. Bertolin,[7] I. rugnera,[7,10] A. Buonaura,[2,11] S. Buontempo,[2] B. Büttner,[12] M. Chernyavsky,[13] A. Chukanov,[8] [14] G. De Lellis,[2,11] M. De Serio,[15,16] P. Del Amo Sanchez,[17] A. Di Crescenzo,[2] D. Di [14] S. Dmitrievski,[8] M. Dracos,[19] D. Duchesneau,[17] S. Dusini,[7] T. Dzhatdoev,[3] J. Ebert,[12] F. Fornari,[18,20] T. Fukuda,[21] G. Galati,[2,11] A. Garfagnini,[7,10] J. Goldberg,[22] Y. Gornushkin,



Scientific Background on the Nobel Prize in Physics 2015

NEUTRINO OSCILLATIONS

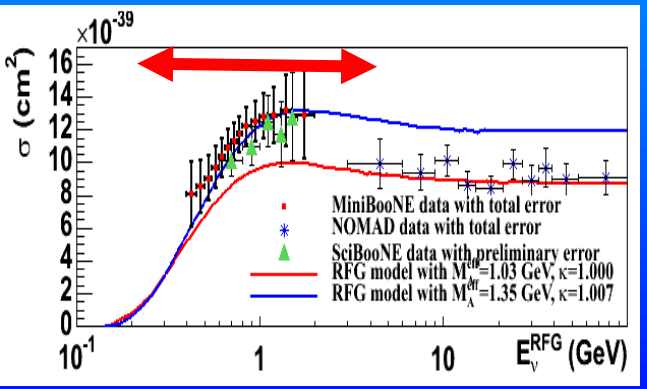
compiled by the Class for Physics of the Royal Swedish Academy of Sciences

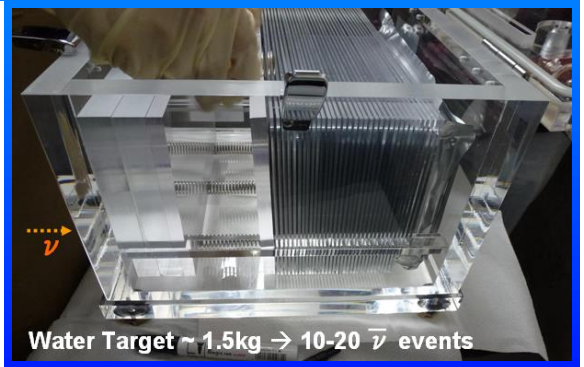
Super-Kamiokande's oscillation results were confirmed by the detectors MACRO [55] and Soudan [56], by the long-baseline accelerator experiments K2K [57], MINOS [58] and T2K [59] and more recently also by the large neutrino telescopes ANTARES [60] and IceCube [61]. Appearance of tau-neutrinos in a muon-neutrino beam has been demonstrated on an event-by-event basis by the OPERA experiment in Gran Sasso, with a neutrino beam from CERN [62].

"発見"から"精密測定"へ

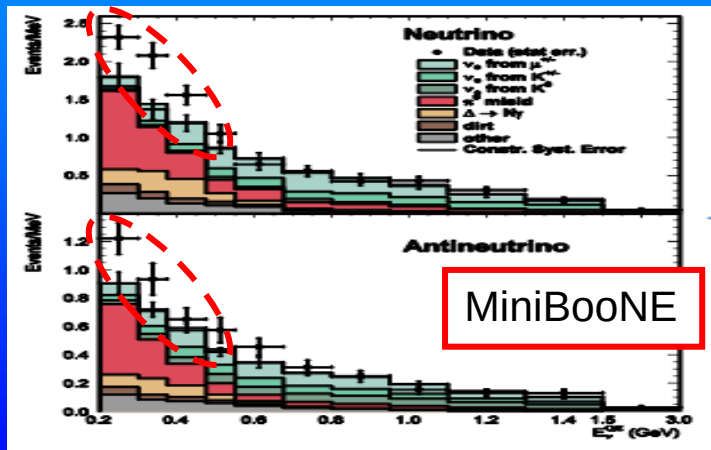
Motivation

- 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.



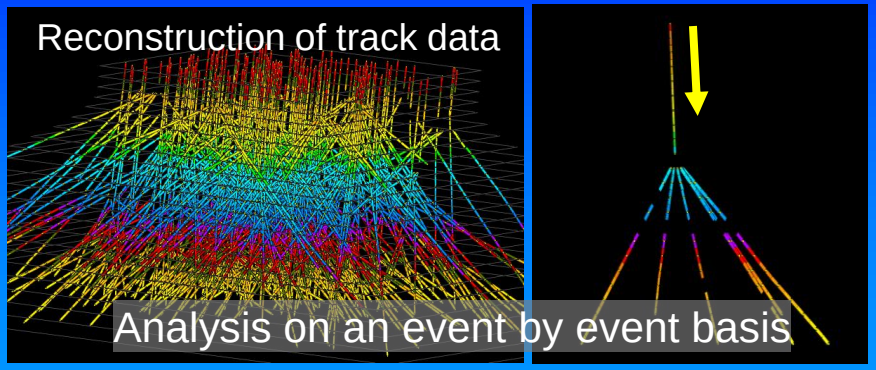


Water Target Emulsion Chamber



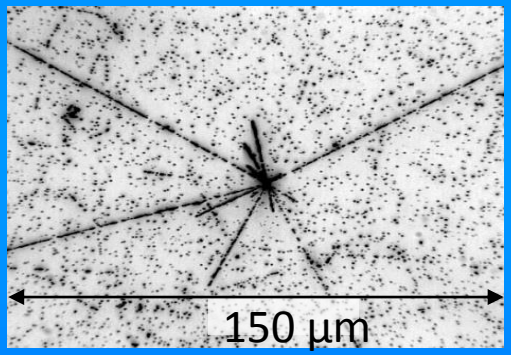
Nuclear Emulsion Detector

3D reconstruction

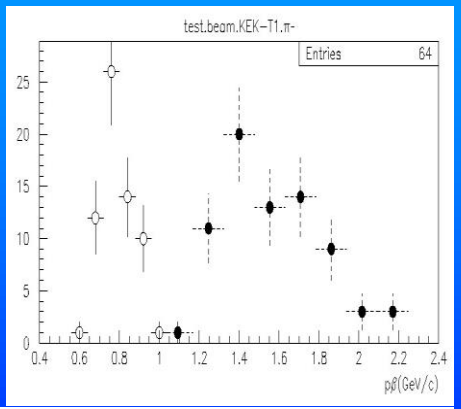


Scalability

4π detection

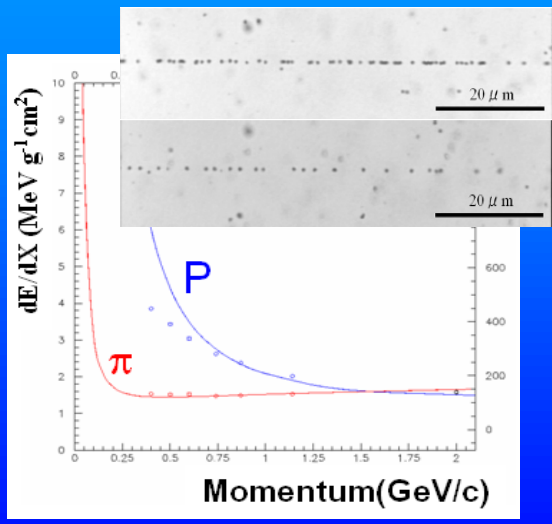


Momentum, dE/dx measurement



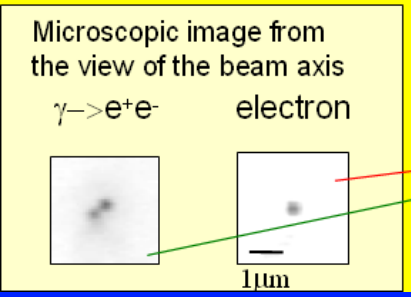
0.8GeV/c π : P =0.79(GeV/c), dP/P =**11**%

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

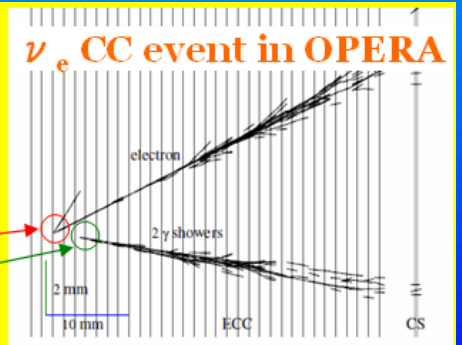


Ultra precise measurement

γ / electron ID



ν_e CC event in OPERA

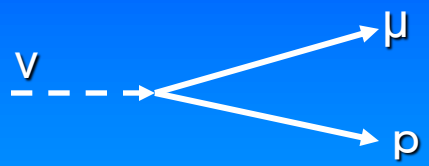


Low BG from ν_μ NC π^0 production

Precise measurement of neutrino-nucleus interactions

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

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

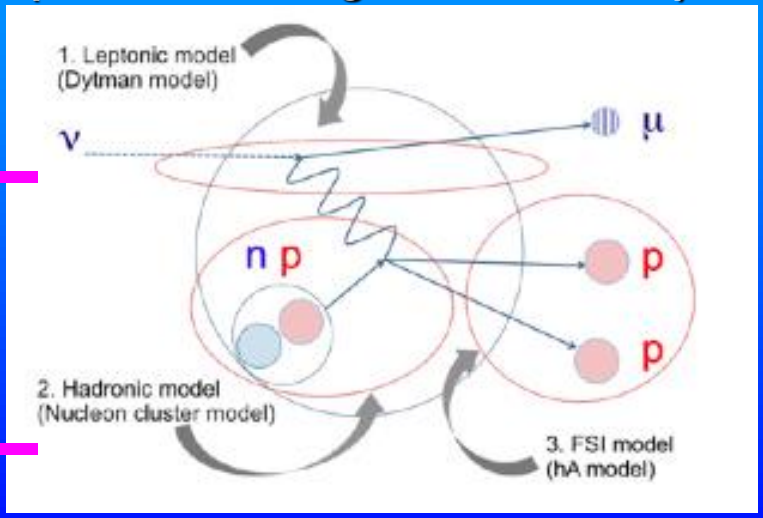


- Other interaction modes contaminate due to final state interaction in nucleon and detector inefficiency.
- Energy can't be reconstructed correctly with these interaction modes.
  → Need precise understanding about neutrino interaction.

uncertainties on predicted events at SK

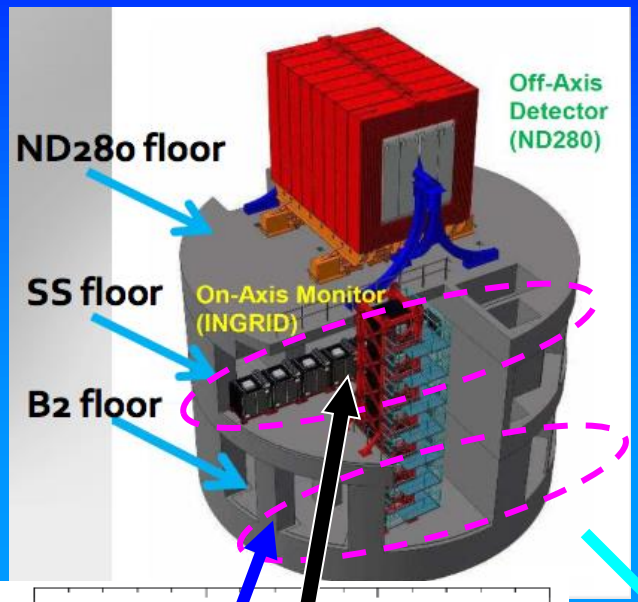
	ν_μ sample 1R$_\mu$ FHC	ν_e sample 1R$_e$ FHC	$\bar{\nu}_\mu$ sample 1R$_\mu$ RHC	$\bar{\nu}_e$ sample 1R$_e$ RHC
ν flux w/o ND280	7,6%	8,9%	7,1%	8,0%
ν flux with ND280	3,6%	3,6%	3,8%	3,8%
ν cross-section w/o ND280	7,7%	7,2%	9,3%	10,1%
ν cross-section with ND280	4,1%	5,1%	4,2%	5,5%
ν flux+cross-section	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%**

2p-2h interaction in CCQE samples (Meson Exchange Current: MEC)



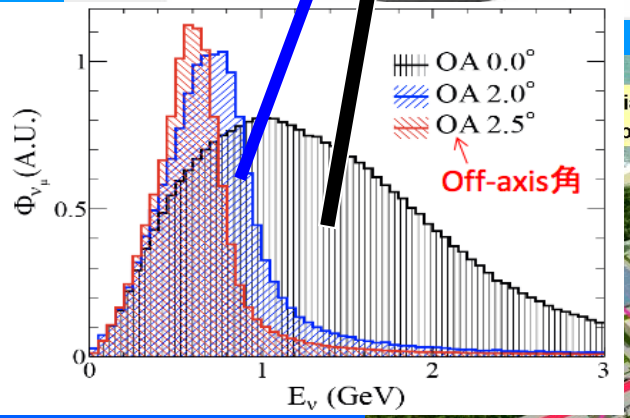
NINJA 実験

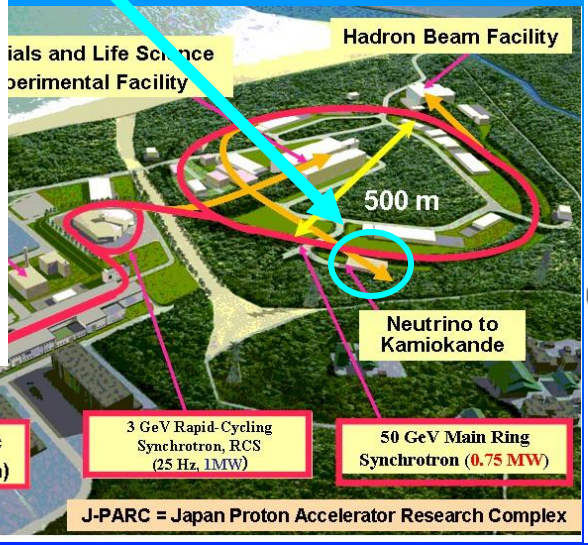
Neutrino **I**nteraction research with **N**uclear emulsion and **J**-PARC **A**ccelerator

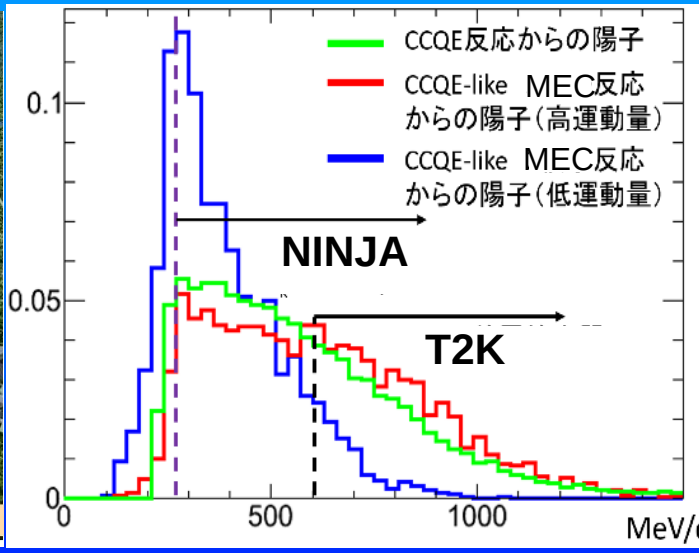


Working group

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

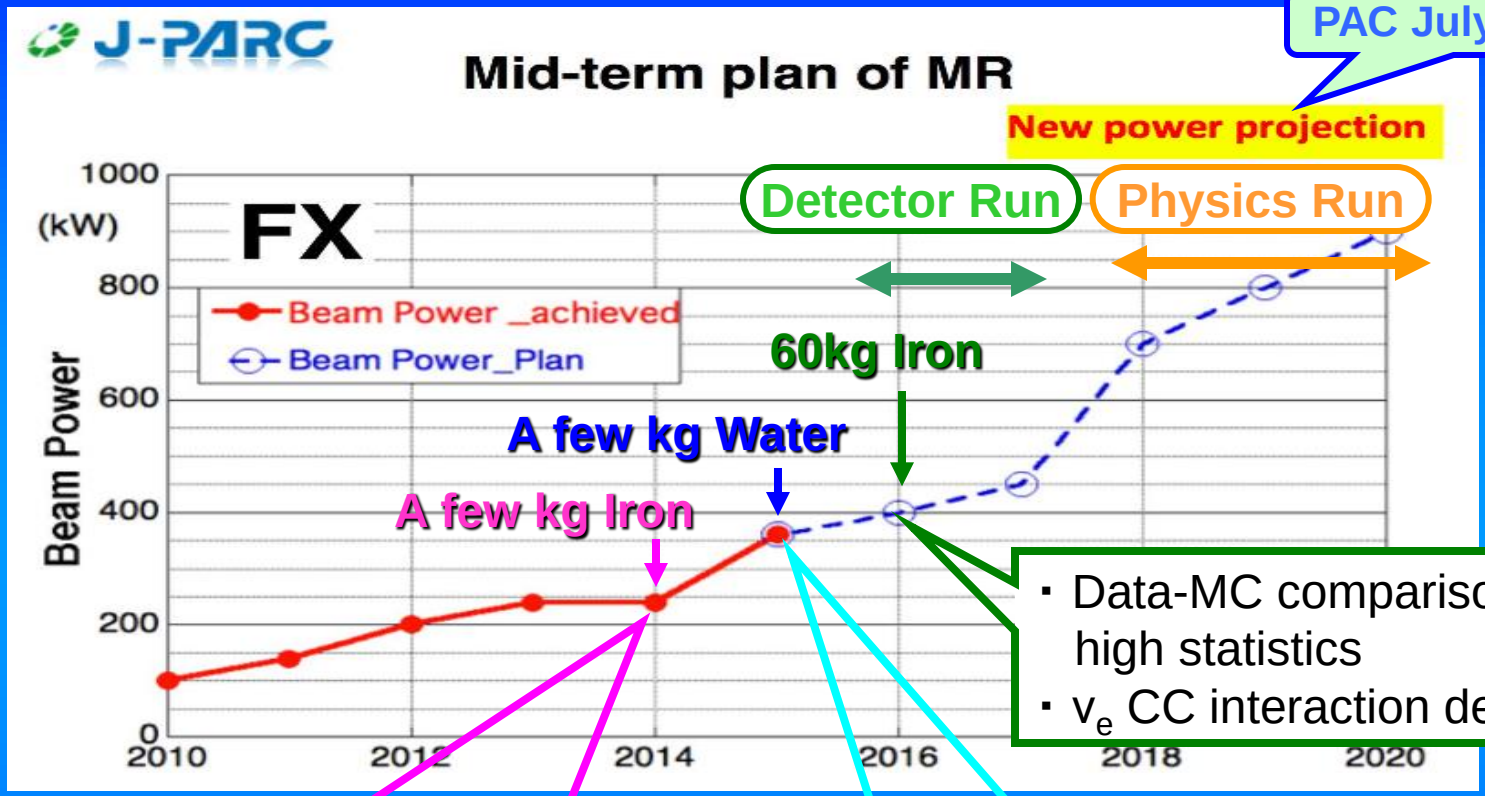






原子核乾板は、MEC反応を測定する**極めて有効な手段** → ニュートリノ反応の精密測定

ν exposure status of NINJA



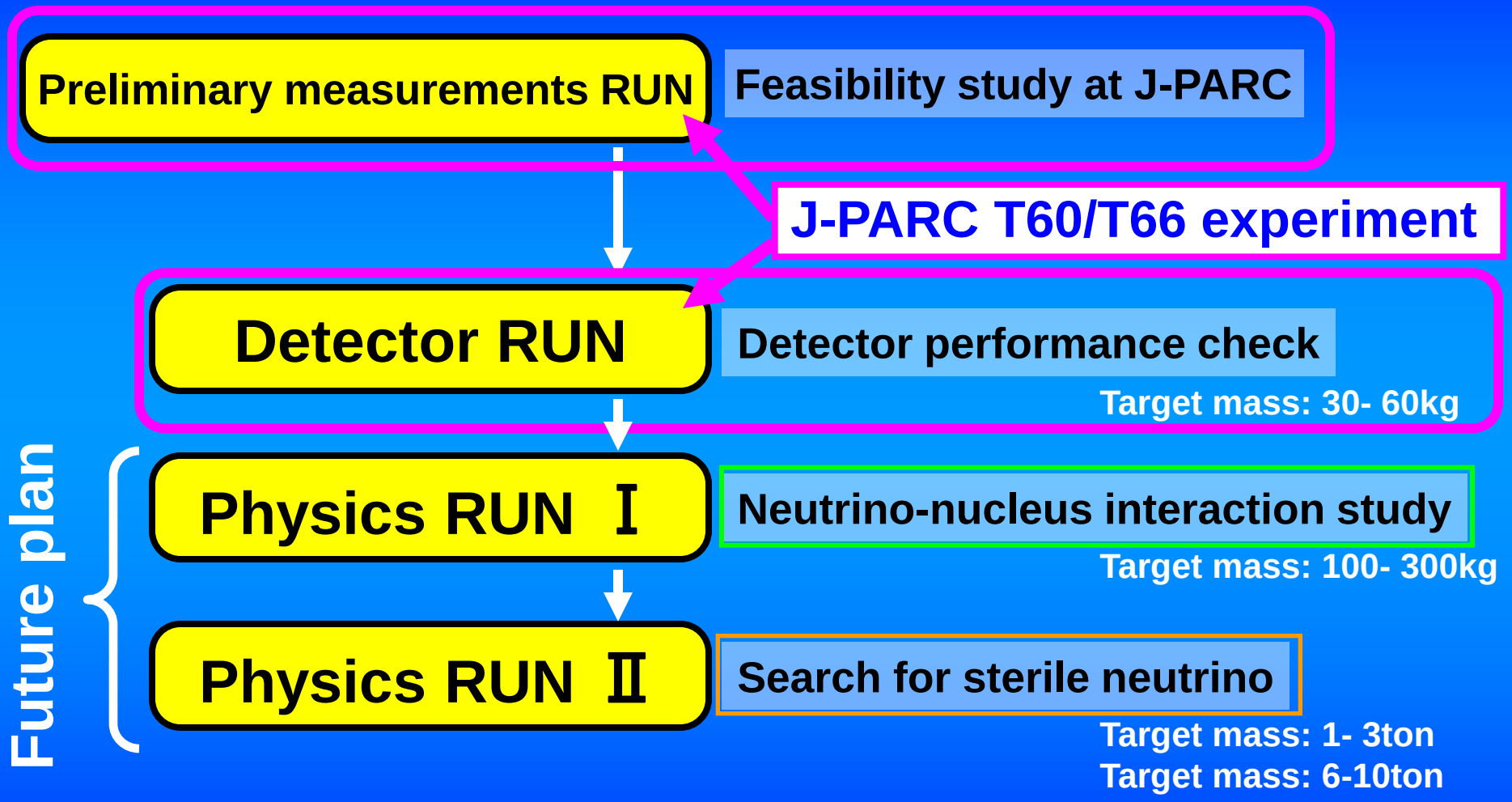
- Data-MC comparison with high statistics
- ν_e CC interaction detection

- Emulsion handling @J-PARC
- Demonstration of ν event detection
- Hybrid analysis with T2K near detector

- ν– Water interaction detection with Emulsion Detector

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

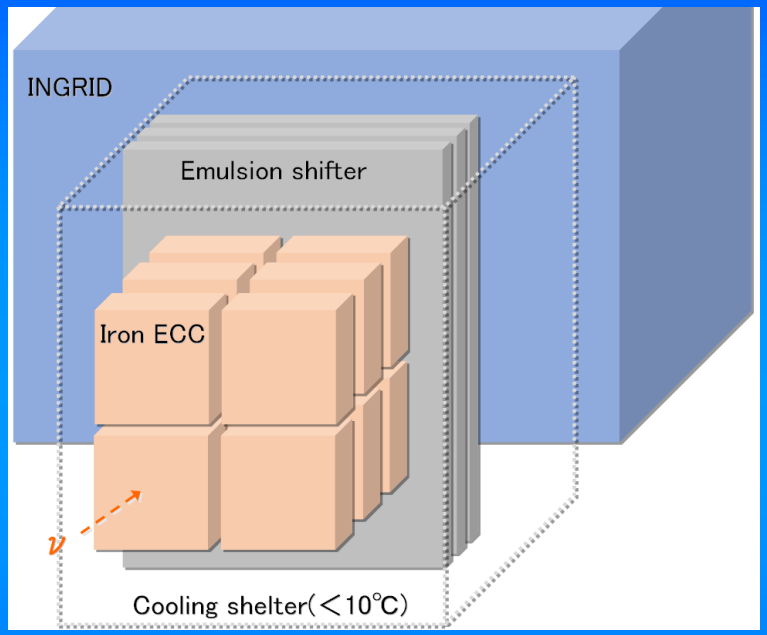
NINJA Roadmap



- The aim of T60/T66 is a feasibility study and detector performance check to make a future plan.
- We will expand the scale of detector gradually, step by step.

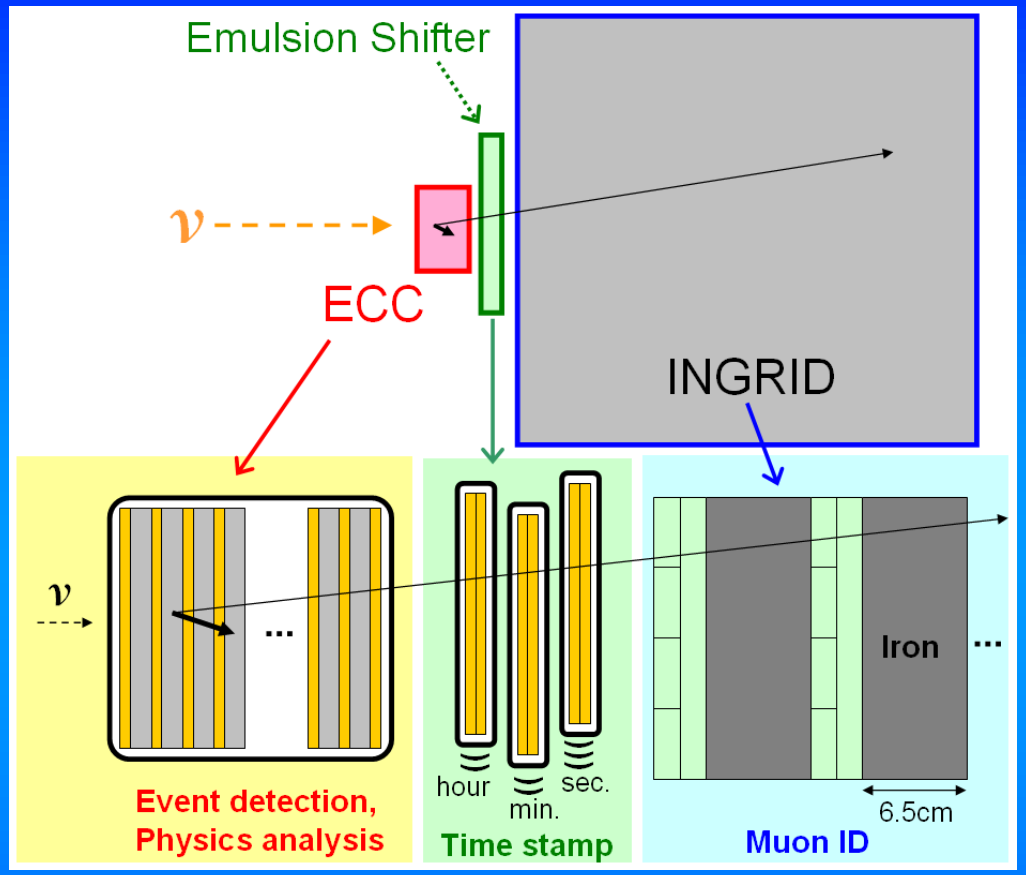
Detector Run

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



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

→ Data – MC comparison with high statistics to check the performance.

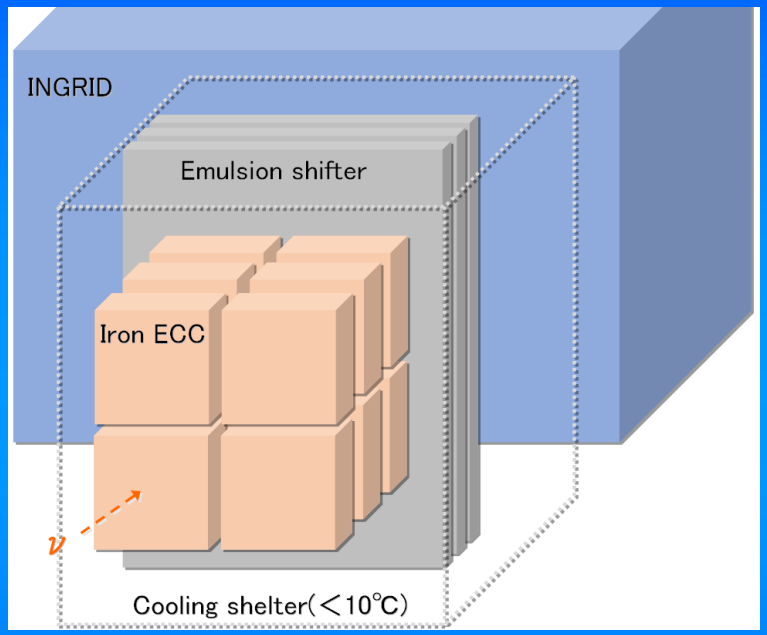


Hybrid detector with T2K Near detector

- **E**mulsion **C**loud **C**hamber → sandwich structure of emulsion films and iron plates.
- INGRID → Muon ID
- Emulsion Shifter → give a timing info. to emulsion tracks.

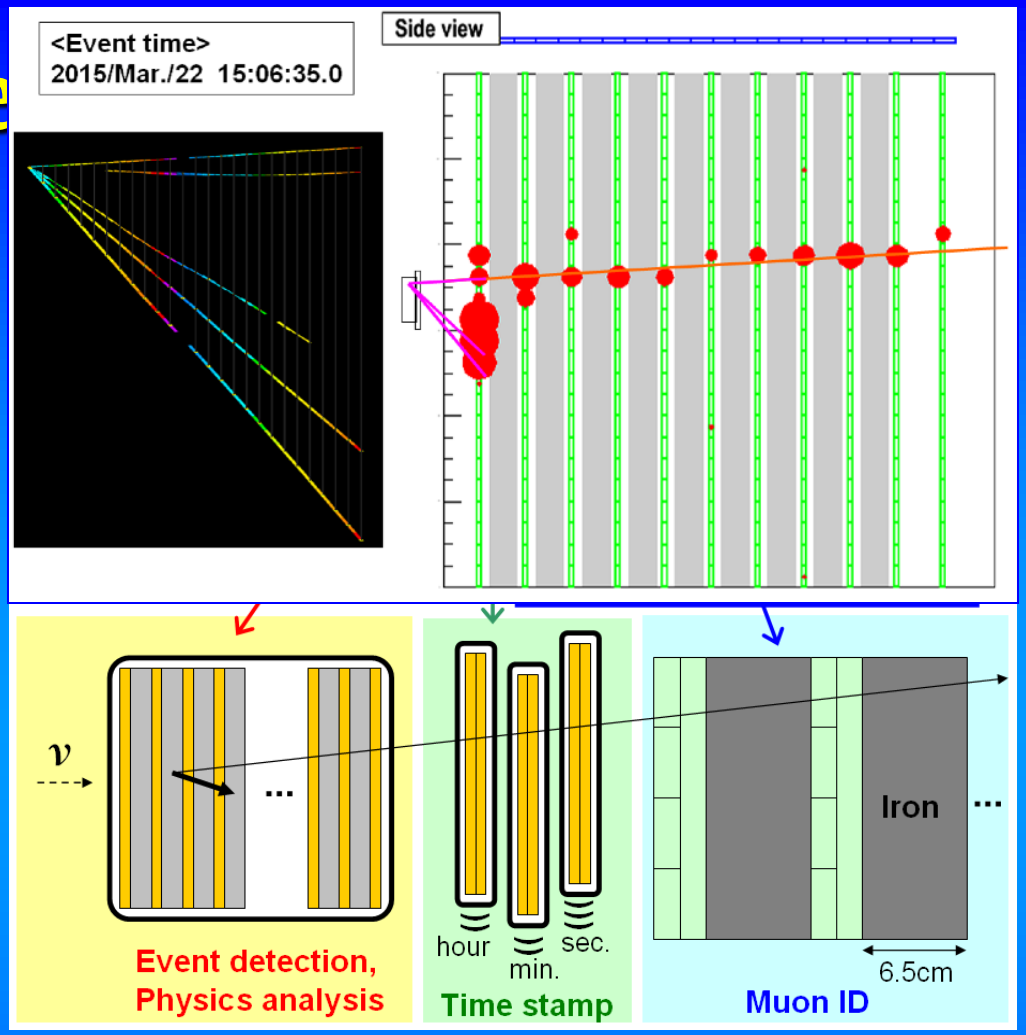
Dete

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



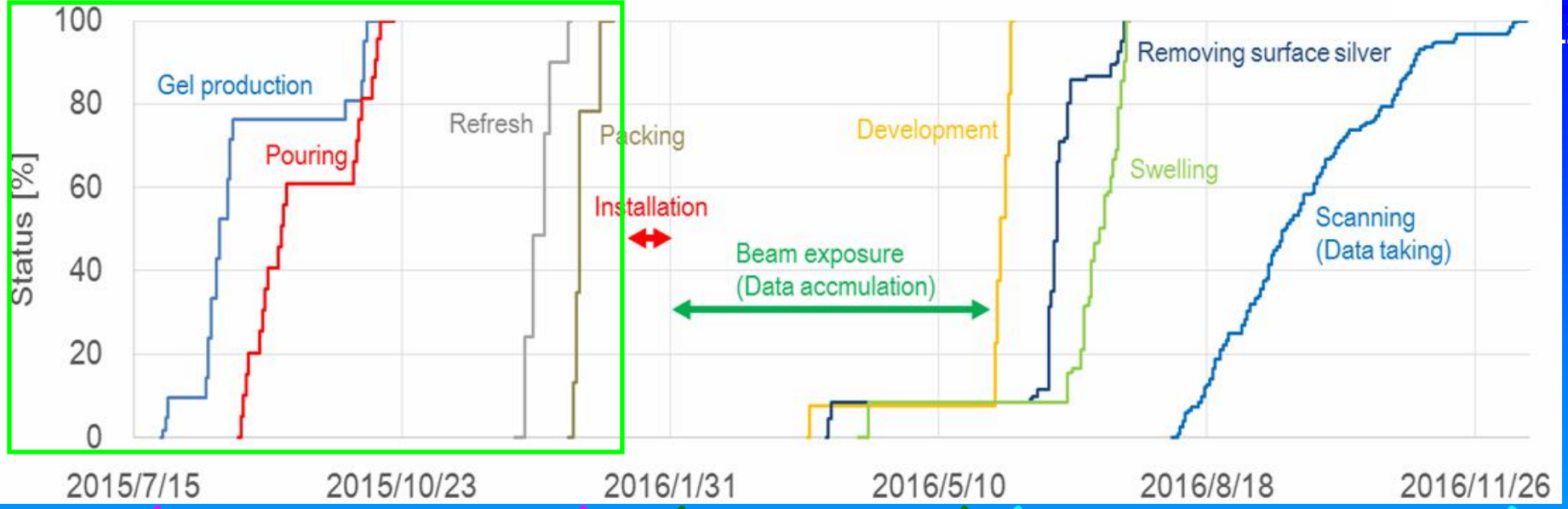
$\bar{\nu}$ exposure : 2016 @SS floor
end of Jan. → beam end
- Iron target (total~60kg : 500 μm seg.)
- High statistics (3-4k $\bar{\nu}_\mu$ events)
- ν_e detection (20-30 $\bar{\nu}_e$ CC events)

→ Data – MC comparison with high statistics to check the performance.



Hybrid detector with T2K Near detector

- **E**mulsion **C**loud **C**hamber → sandwich structure of emulsion films and iron plates.
- INGRID → Muon ID
- Emulsion Shifter → give a timing info. to emulsion tracks.



Detector construction

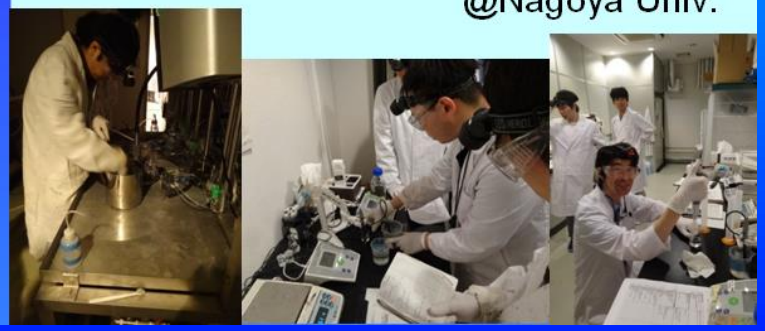
ν beam exposure

Hardware treatment and Scan

Detector preparation

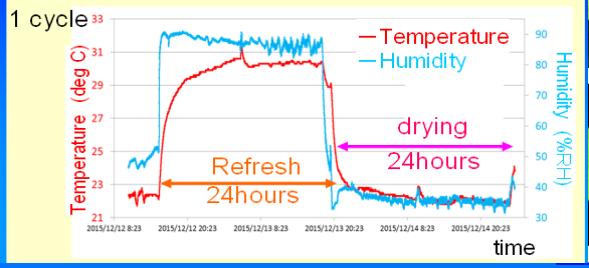
Emulsion film production 2015. July→Oct.

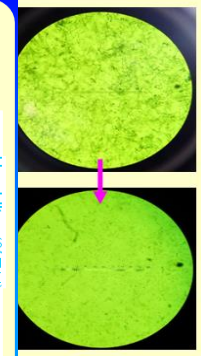
By Toho Univ. & Nihon Univ. member
@Nagoya Univ.

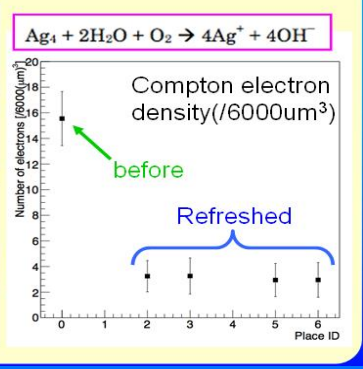


Emulsion film Refresh

Noise reduction at 30deg C, 90%humi

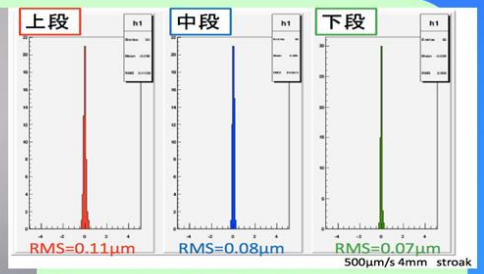




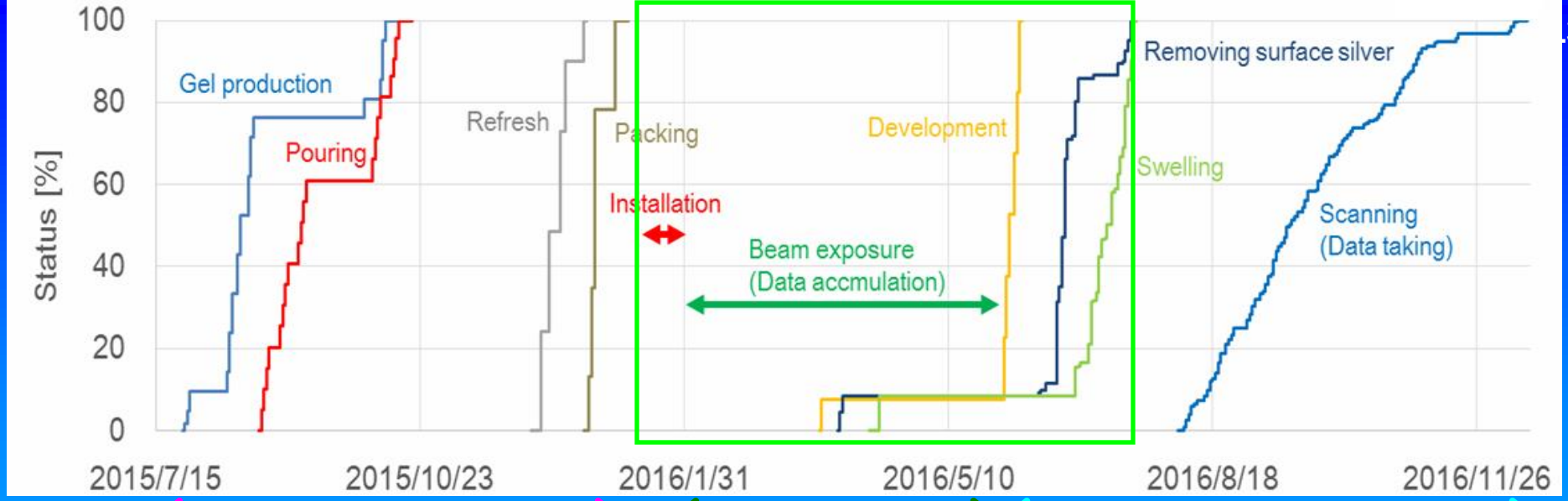


Large size Emulsion Shifter

Operation test @Kobe Univ.

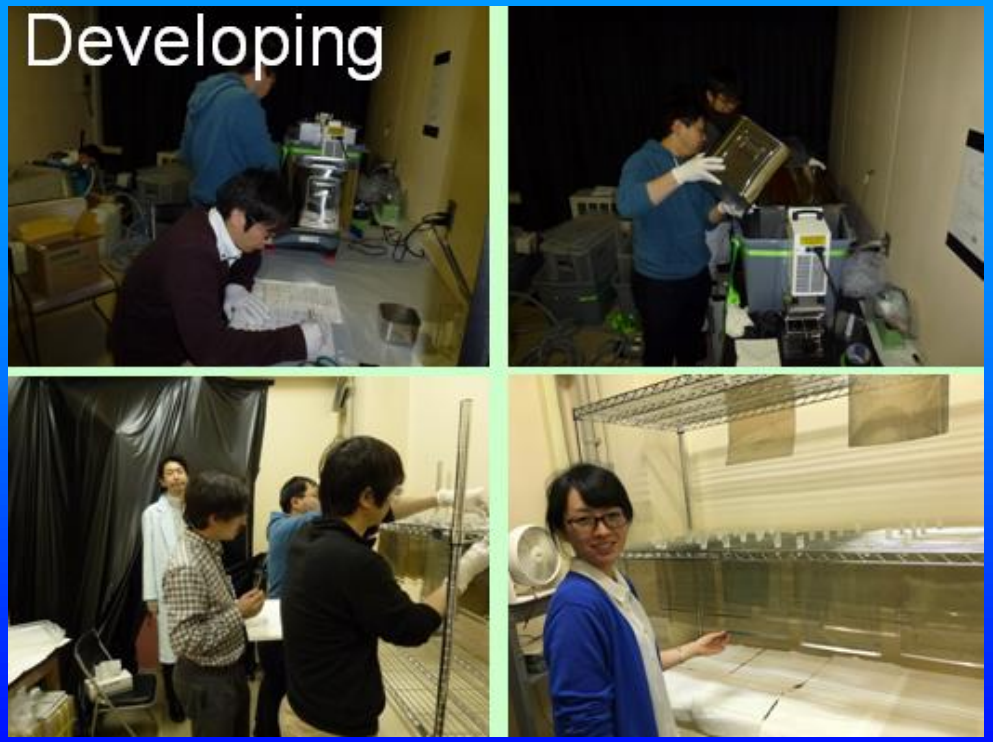


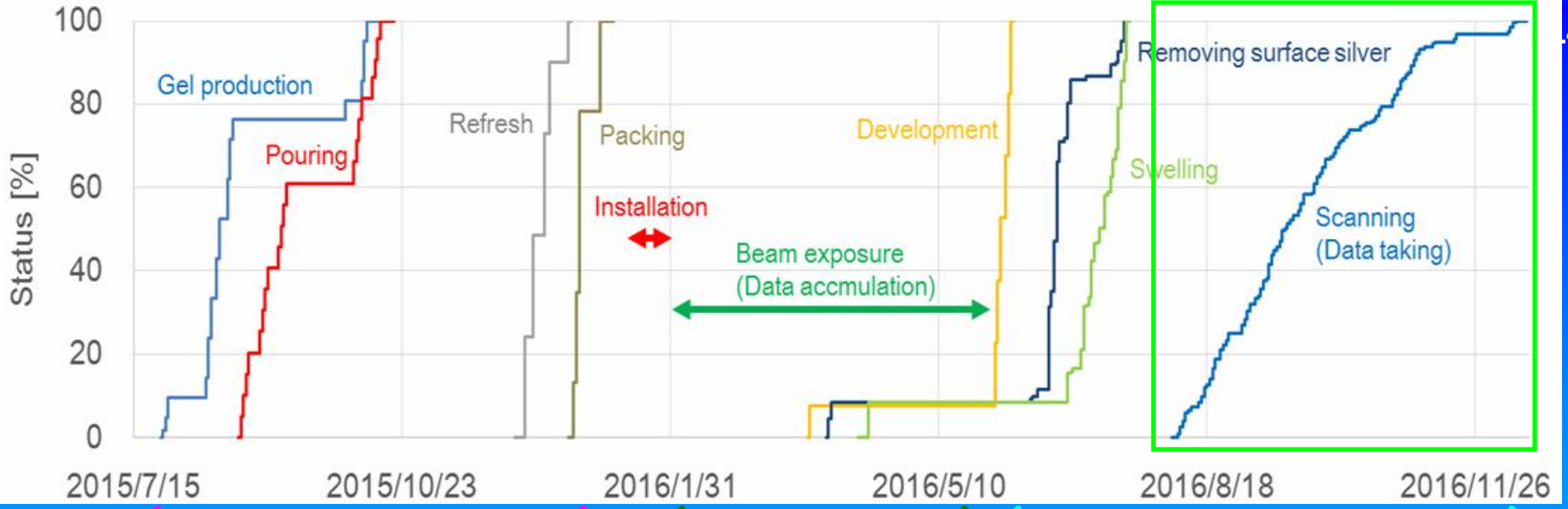
Repeatability for driving in each stage is well below 0.5 μ m.



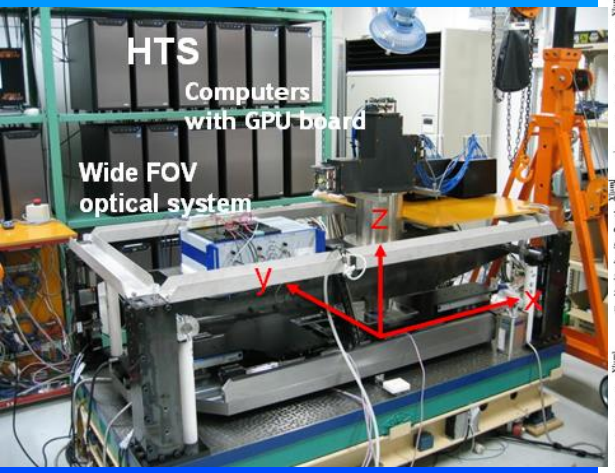
Detector construction | **ν beam exposure** | **Hardware treatment and Scan**

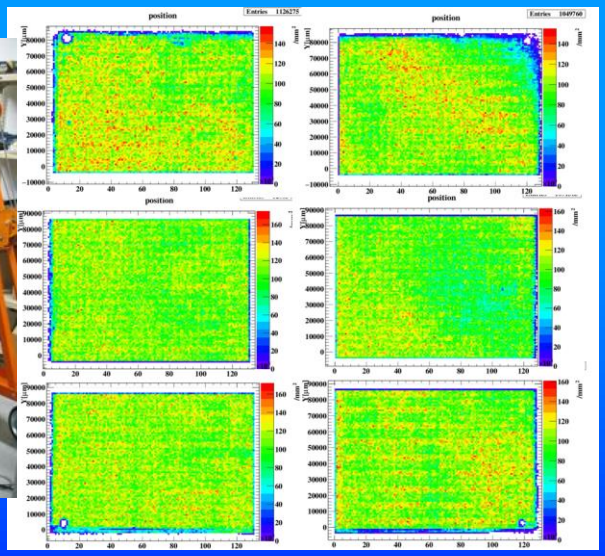
Detector installation

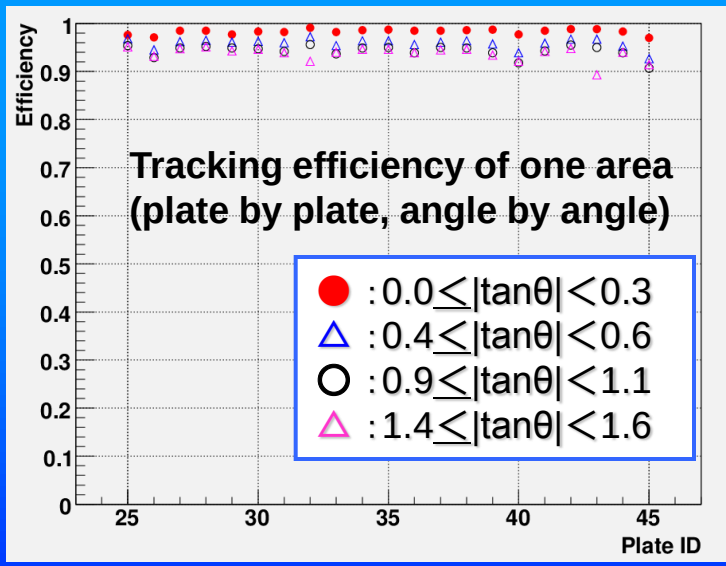




Detector construction | **ν beam exposure** | **Hardware treatment and Scan**







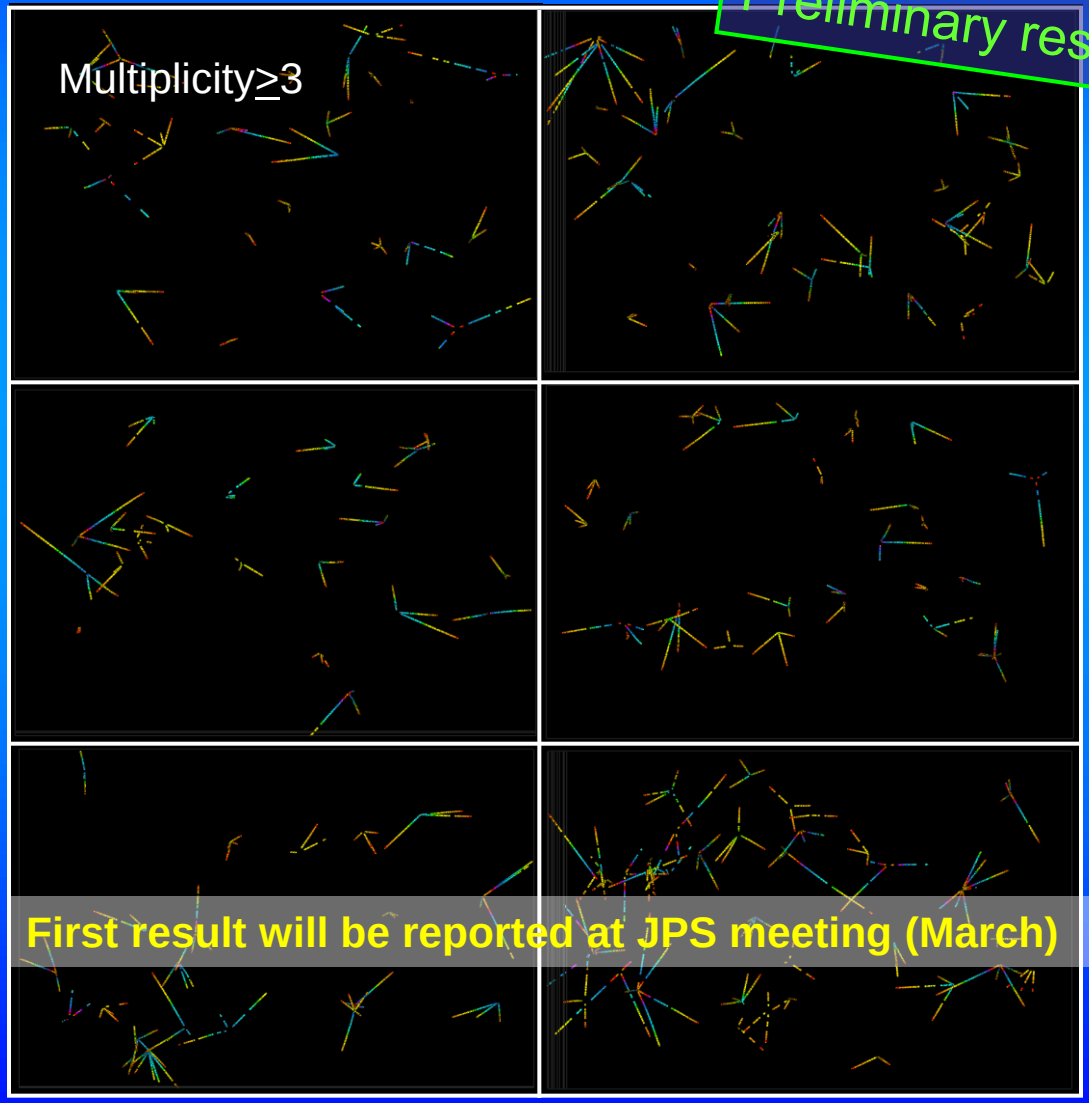
Data quality check and track reconstruction is under progress.

Detector Run (T60)

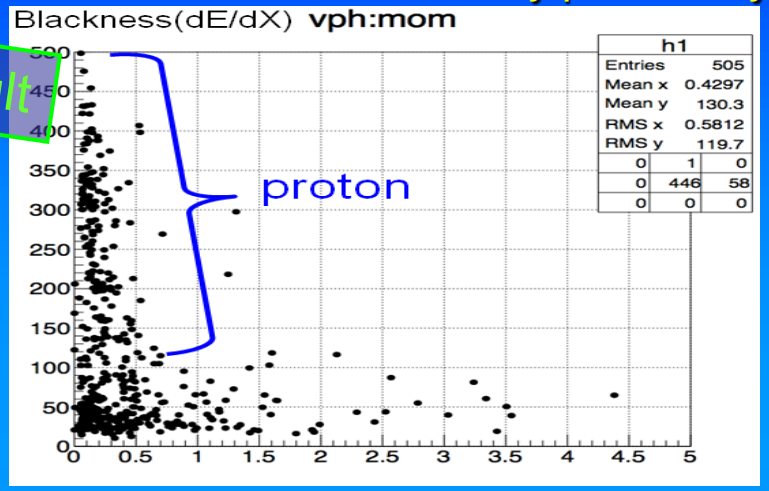
Event analysis is now in progress !

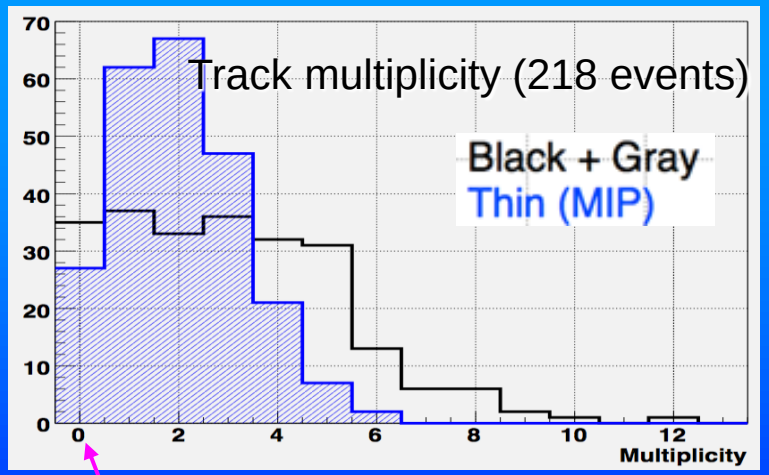
Neutrino event candidates

Preliminary result



Very preliminary





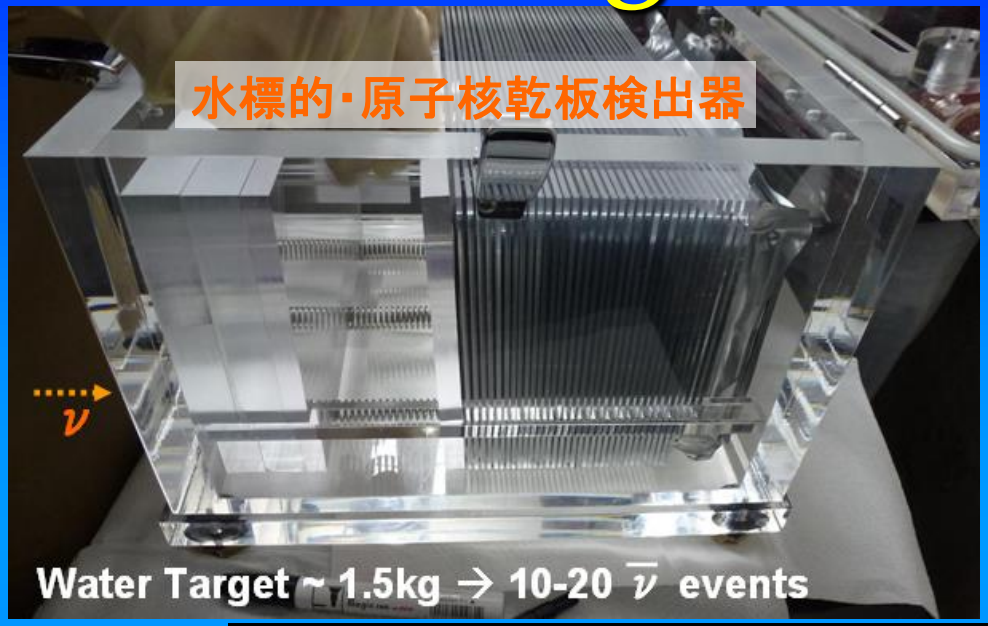
- ~80% of event have proton
- 0 MIP events are detected.
  → neutron interaction ?

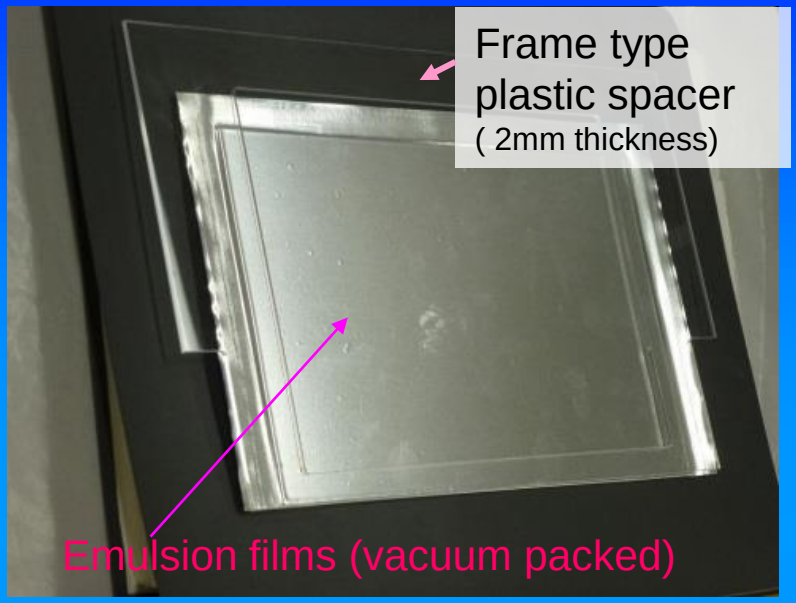
First result will be reported at JPS meeting (March)

Detector Run (T60)

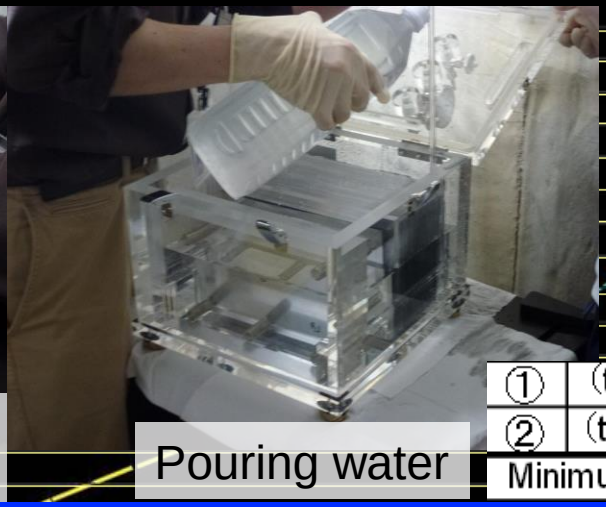
$\bar{\nu}$ exposure in May 2015.

Water target emulsion detector

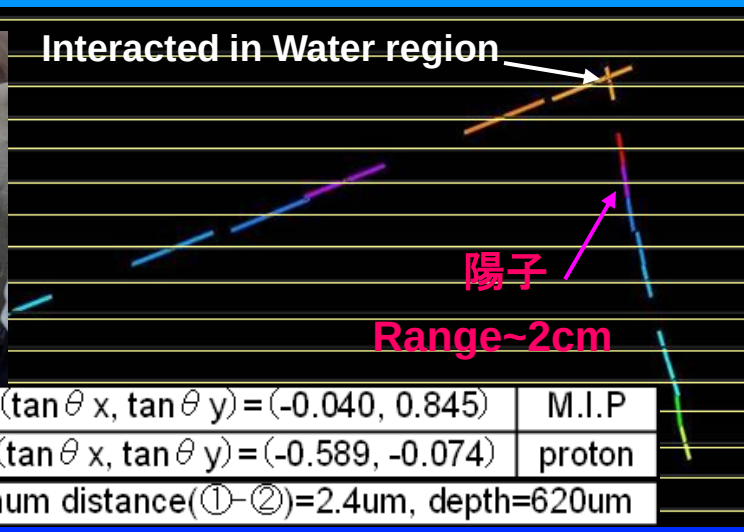




Sandwich structure of Emulsion films and Frame type spacers



Pouring water



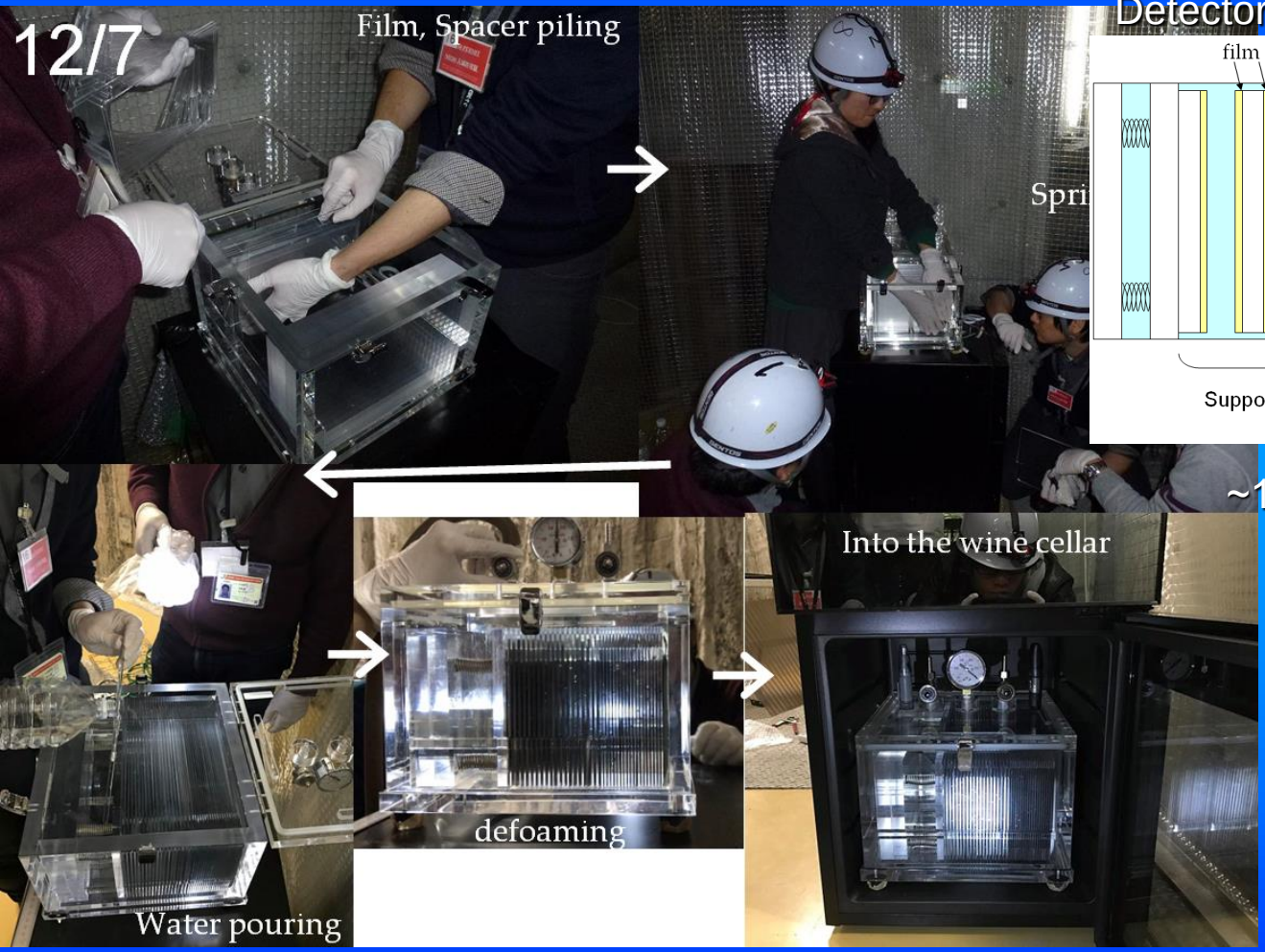
①	(tan θ x, tan θ y) = (-0.040, 0.845)	M.I.P
②	(tan θ x, tan θ y) = (-0.589, -0.074)	proton
Minimum distance(①-②)=2.4um, depth=620um		

First detection of ν - Water interaction with Emulsion Detector

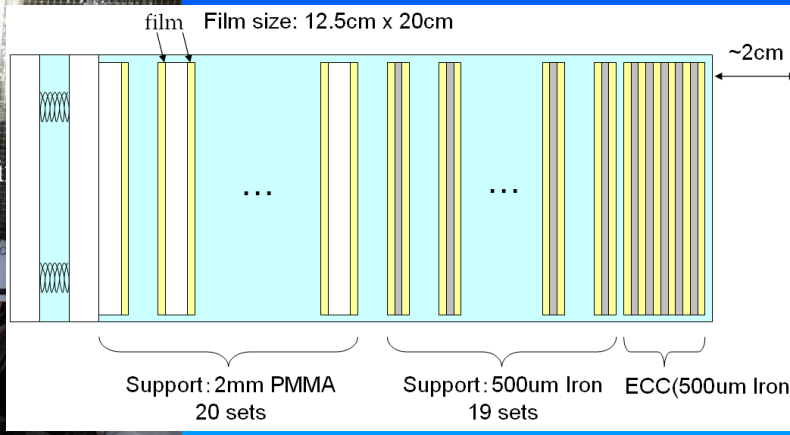
Detector Run(T66)

ν照射 : Dec. 2016- Apr.2017

- R&D for Water target Emulsion detector



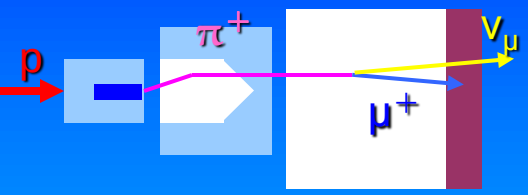
Detector structure



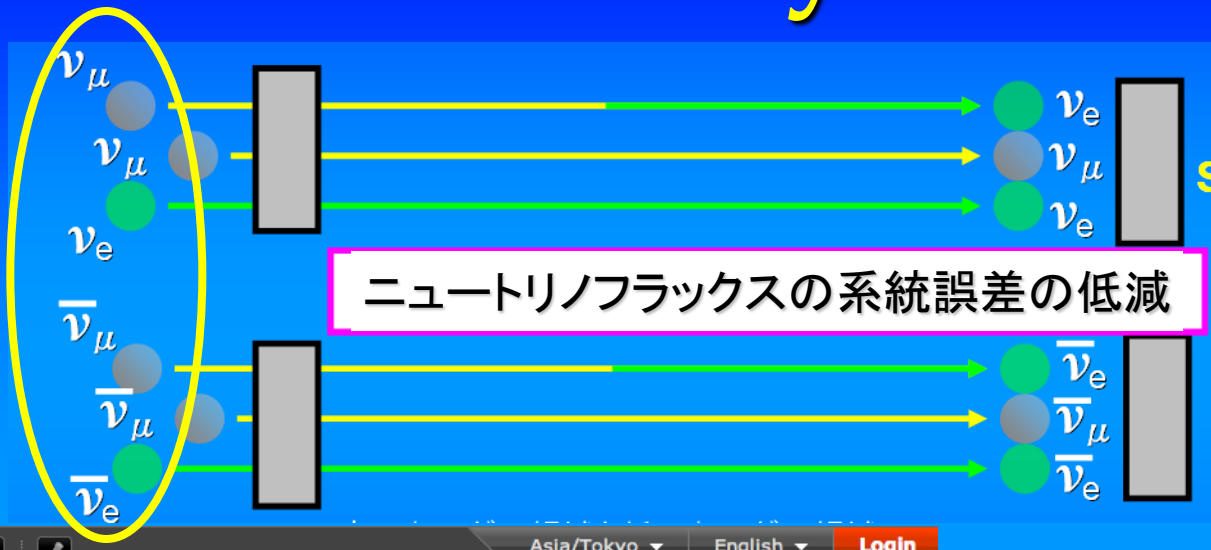
~100 ν- Water int. expected

大型水標的検出器によるニュートリノー水反応の精密測定に向けて検出器R&Dを継続中
2018年後半に100kg 級の検出器を設置予定。

Related activity

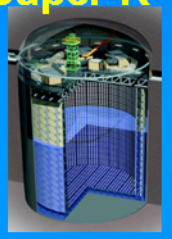


ニュートリノフラックスの推定
↓
ハドロン生成の詳細研究



ニュートリノフラックスの系統誤差の低減

Super-K

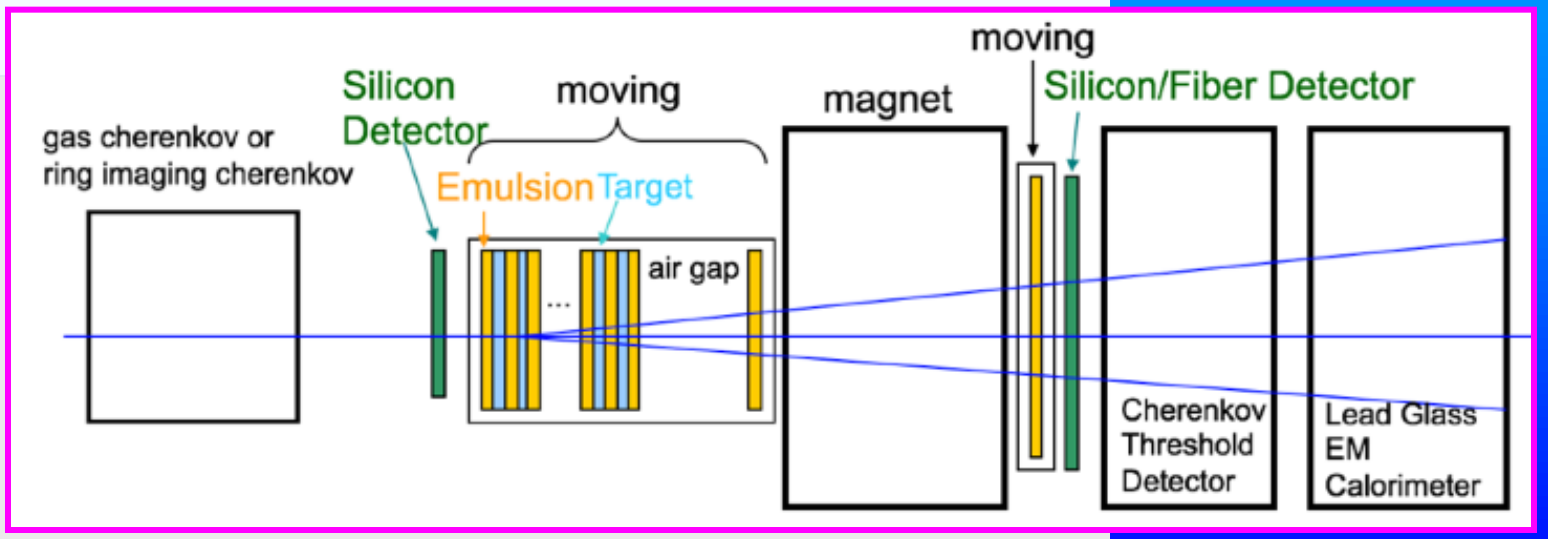


iCal export | More | Asia/Tokyo | English | Login

Workshop on Hadron Production Measurements with Nuclear Emulsions

3-4 October 2016
Nagoya University
Asia/Tokyo timezone

- Overview
- Scientific Programme
- Timetable
- Contribution List
- Author List
- Registration
  - Registration Form
- Accommodation Information



Summary

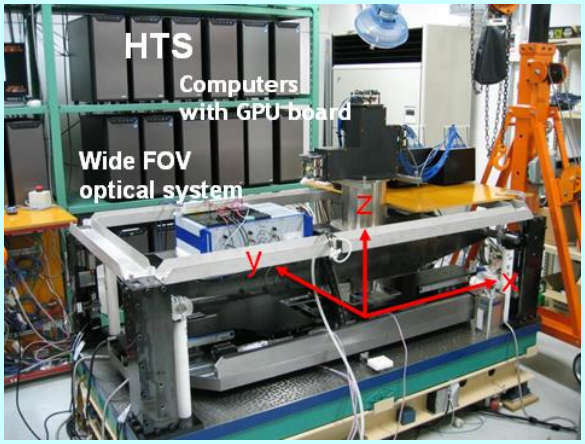
- We are performing a neutrino experiments at J-PARC to study low energy neutrino - nucleus interactions with nuclear emulsion（**NINJA !**）.
- We are carrying out a test experiment at J-PARC to check the feasibility and detector performance.
- Beam exposure and film development for the 60kg iron target ECC was successfully done and the event analysis is now in progress.
- R&D for Water target ECC is performing.
- Now we are discussing about next Physics Run with a large scale water target emulsion detector.

Back up

Recent technical improvements

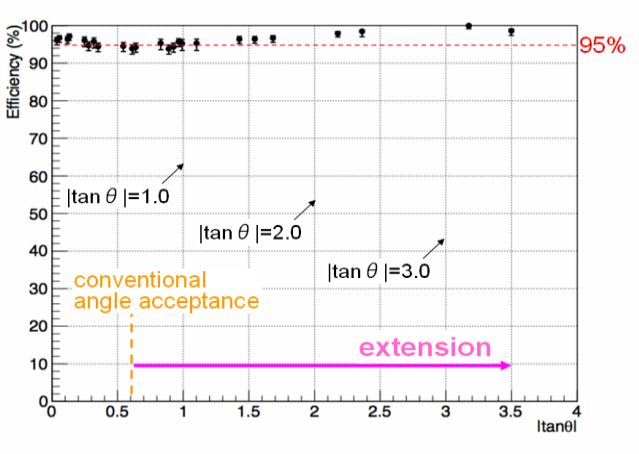
Readout technique

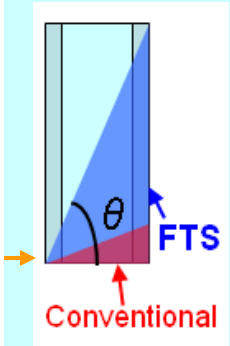
High Speed Scanning



HTS 9,000cm²/h, x100 faster

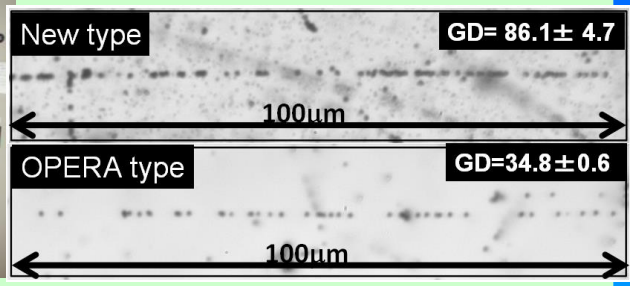
Large angle tracking technique



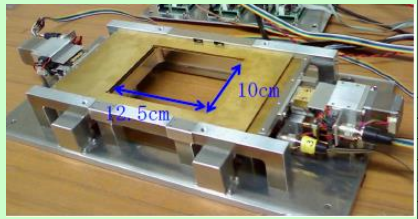


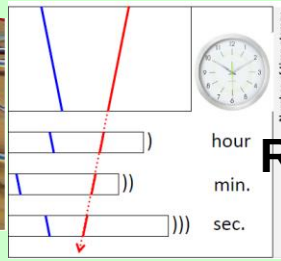
Detector technique

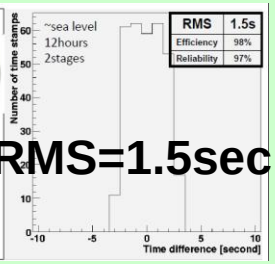
High Sensitive film



Time resolution

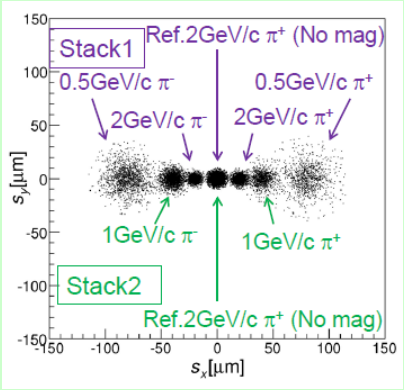




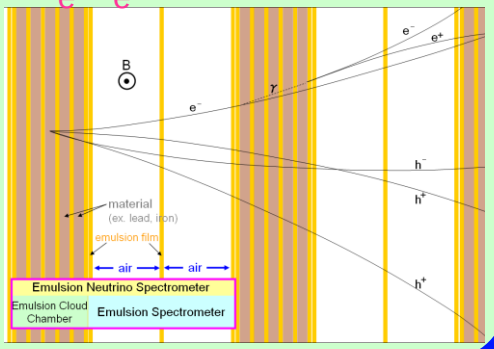


RMS=1.5sec

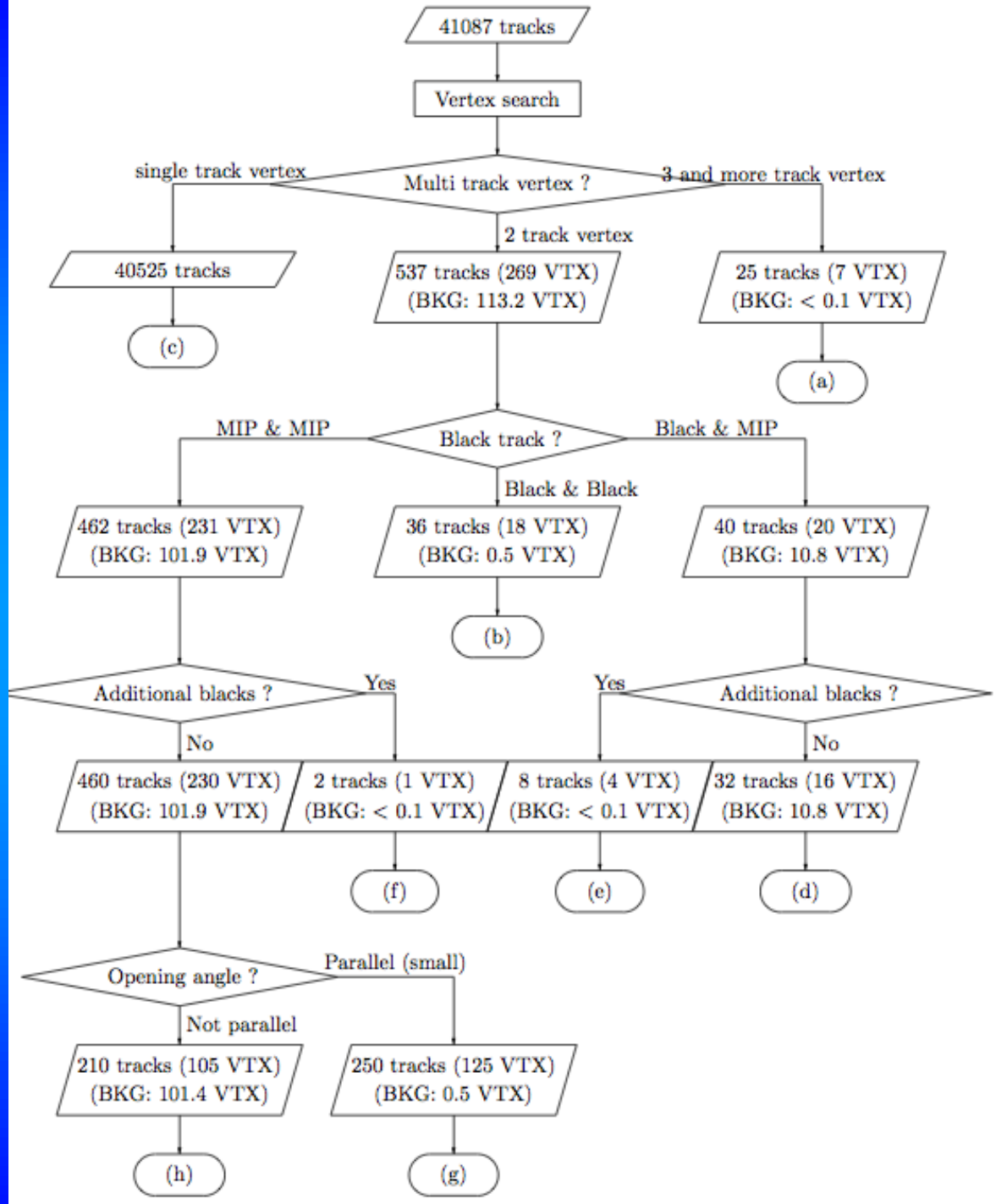
Charge sign ID

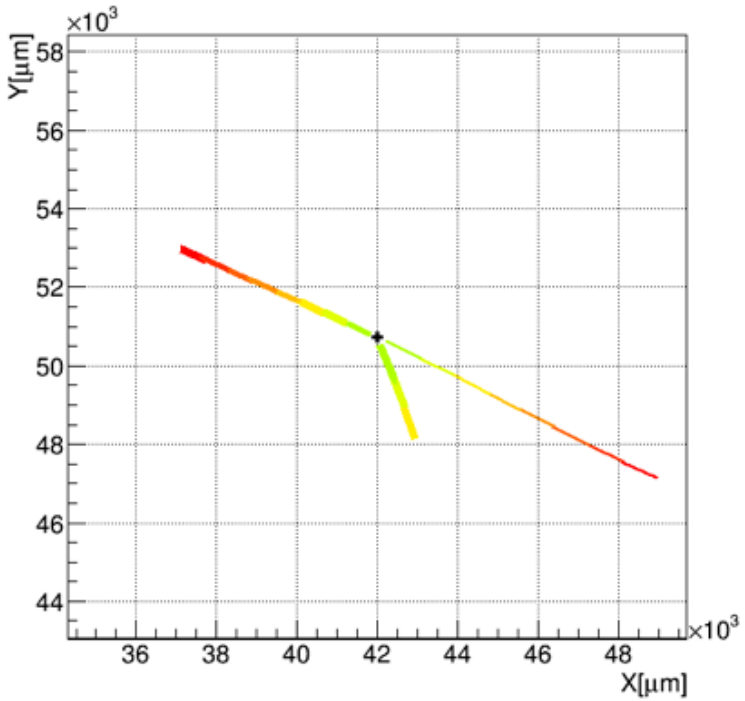


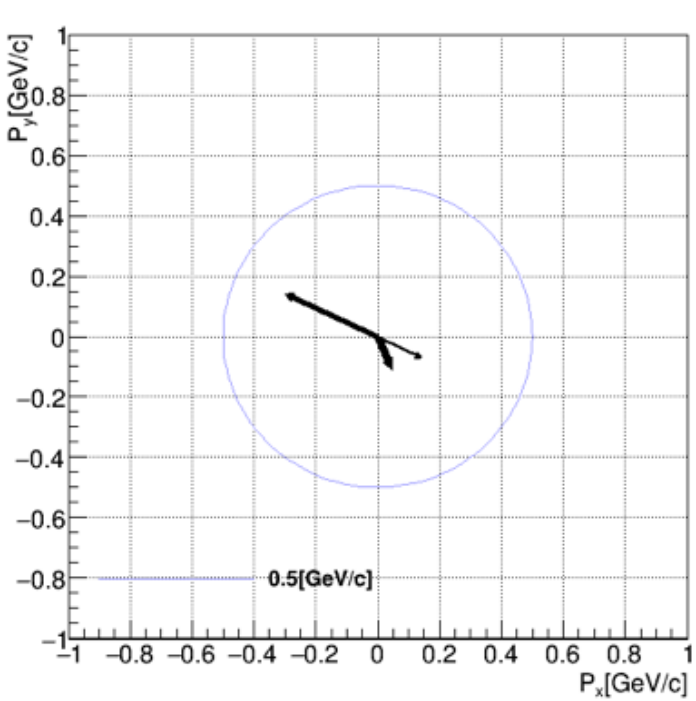
$\nu_e/\bar{\nu}_e$ identification



Automatic procedure







VTX information

36 41978.9 50747.6 -24525.9 -508.9

pl	isg	ph	vph	ax	ay	x	y	z	ip	dz
311	1297671	240051	1.1117	-0.5583	42548.1	50470.8	-24017.0	8.1	-508.9	
311	1476910	310169	-0.7446	0.3523	41596.4	50919.6	-24017.0	8.1	-508.9	
311	1363116	320471	0.4217	-1.0350	42182.2	50224.1	-24017.0	10.4	-508.9	

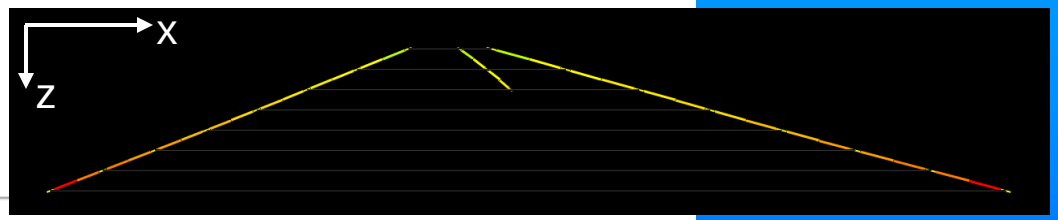
Range information

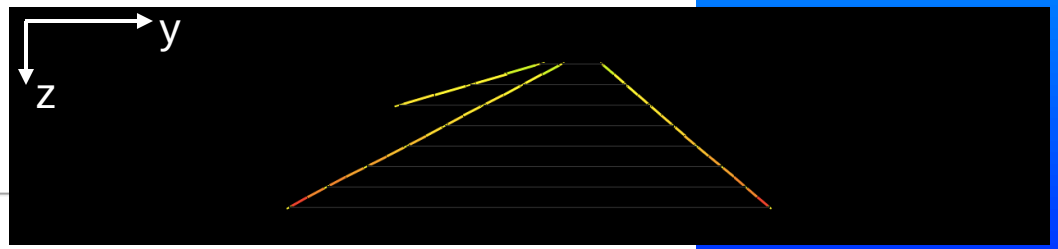
itk	vt	pl1	isg1	pl2	isg2	range	D	B
236971	31	311	1297671	241	1363745	9349.1	1	1
237185	31	311	1476910	241	1408947	7675.6	1	2
266896	31	311	1363116	291	1317375	3046.2	1	3

Direction 1: Forward, 2: Backward
Blackness 1: Thin, 2: Gray, 3: Black, 0: Gamma

Momentum information

itk	n	$\overline{ax}$	$\overline{ay}$	$\overline{ph}$	$\overline{vph}$	mom	momlow	momhi
236971	8	1.1218	-0.5317	23.5	44.0	0.156	0.130	0.183
237185	8	-0.7835	0.3566	30.5	190.1	0.318	0.264	0.376
266896	3	0.3523	-1.0159	32.0	509.0	0.097	0.069	0.128

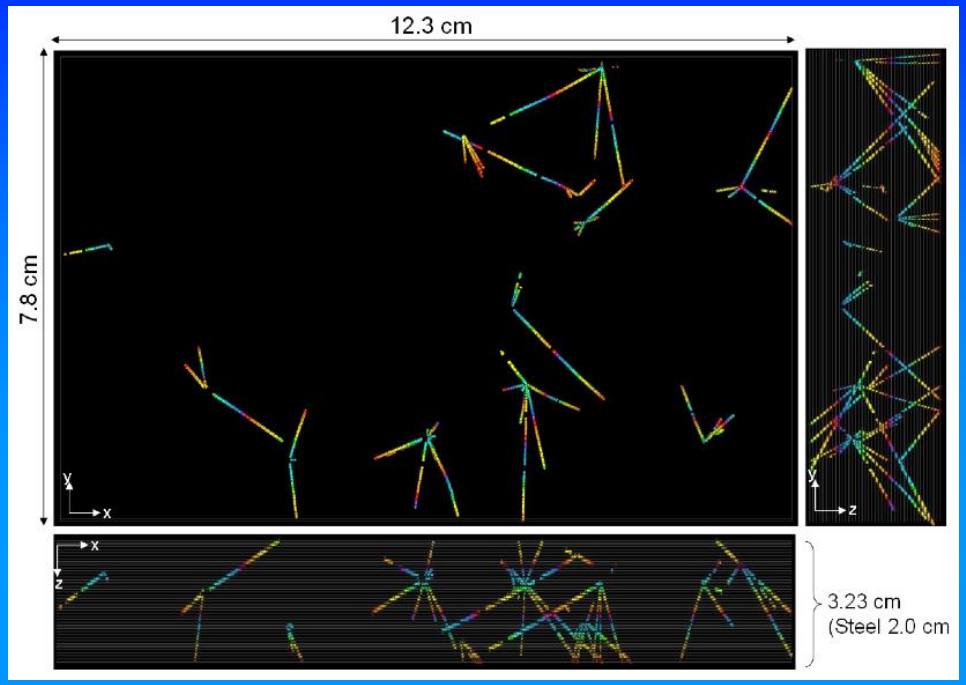


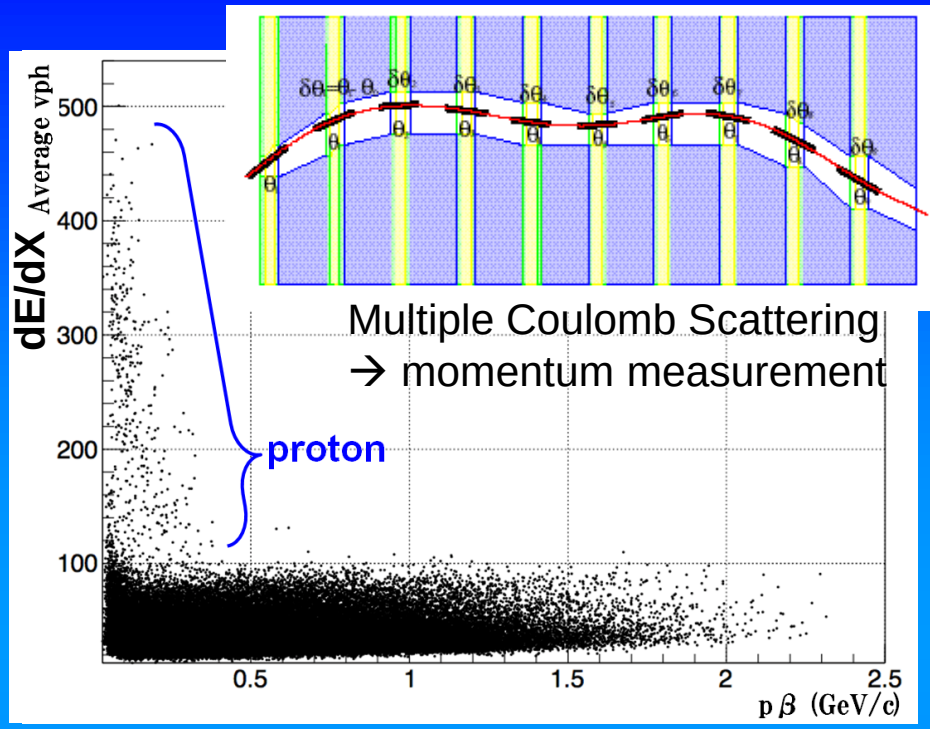


Y. Morimoto

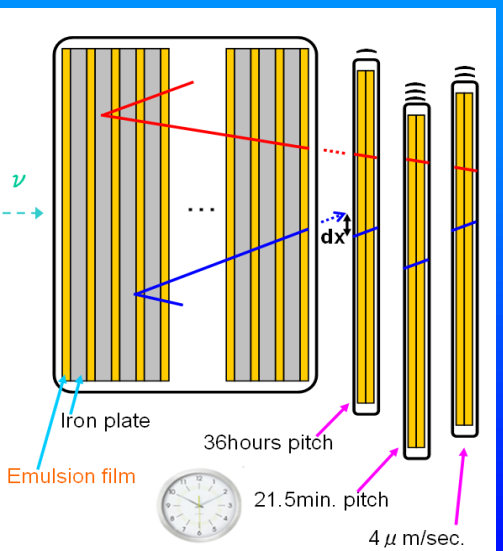
Status review of T60

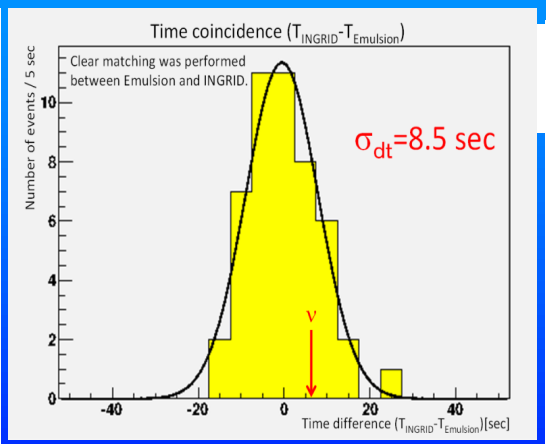
Systematic emulsion analysis





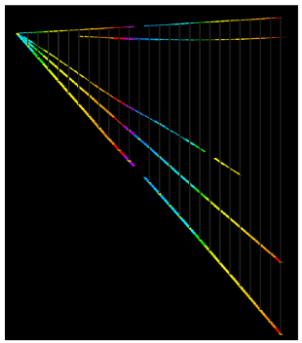
Hybrid analysis with T2K near detector

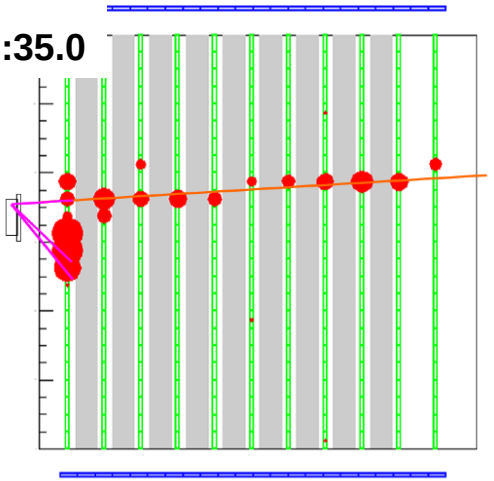




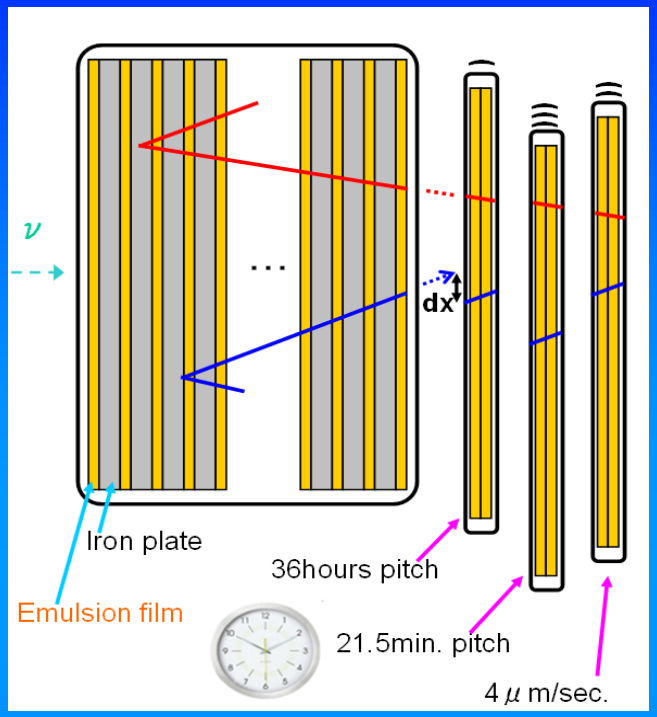
Estimated time resolution using penetrated muons

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





Time stamp for ν event with Emulsion Shifter



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

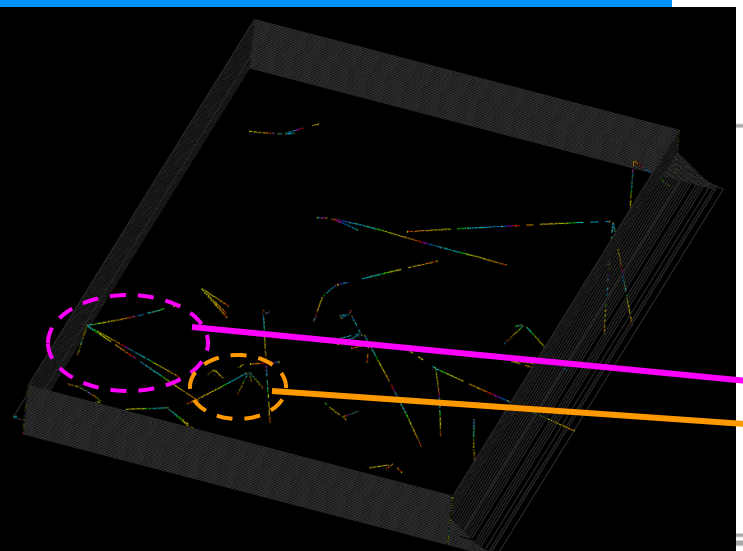
Time stamp is given by coincidence of tracks on each stage.

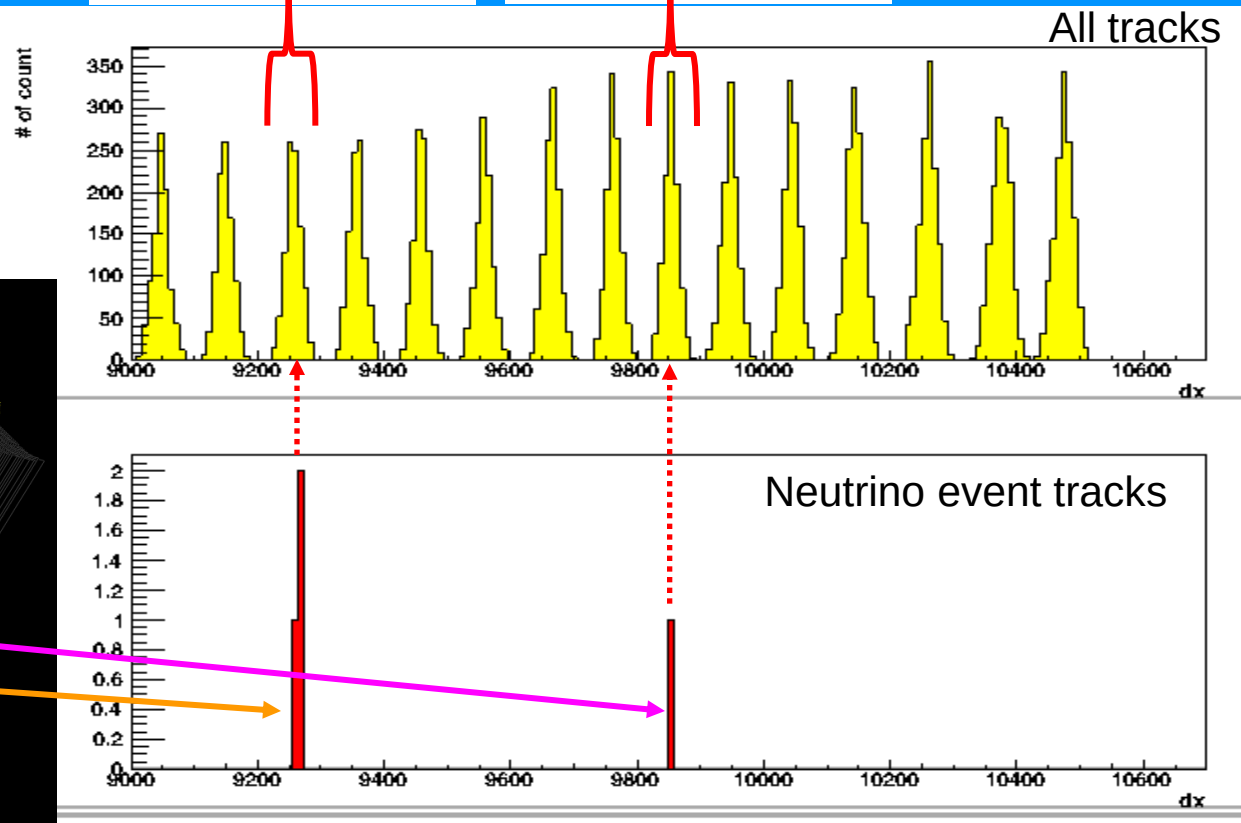
→ Position difference from reference point
= Timing information

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

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

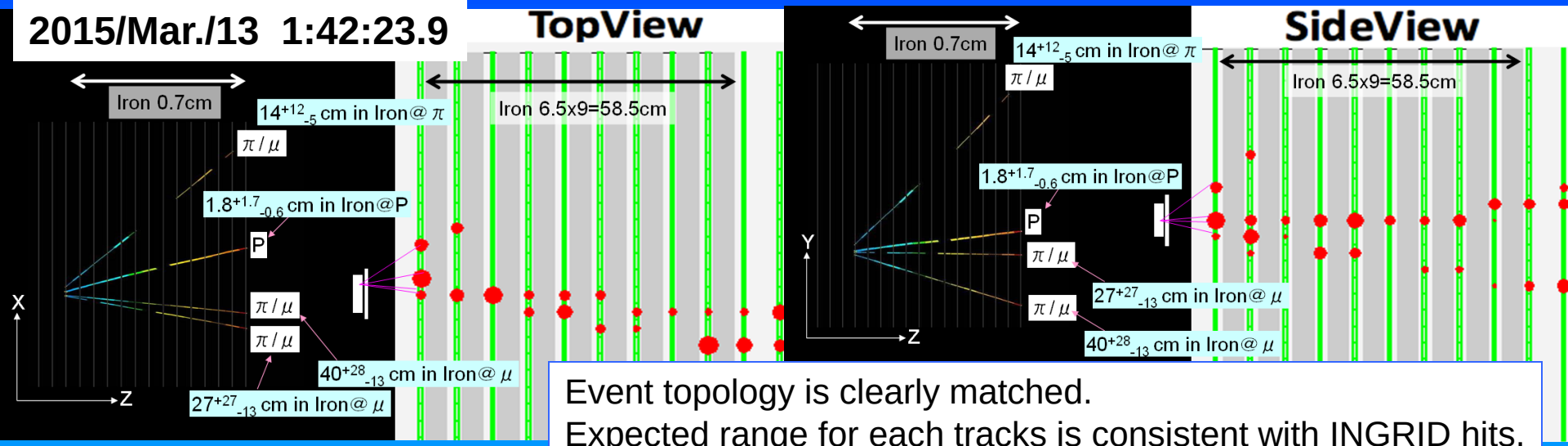
← Information from Top stage





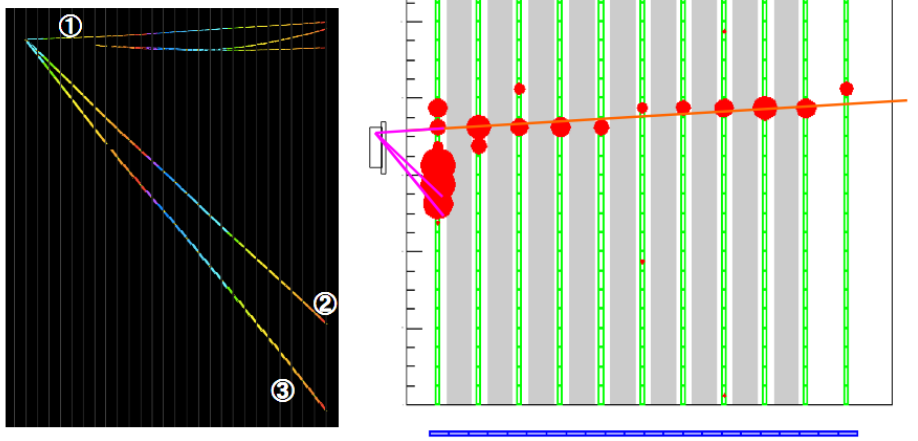
Emulsion-INGRID Hybrid analysis

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

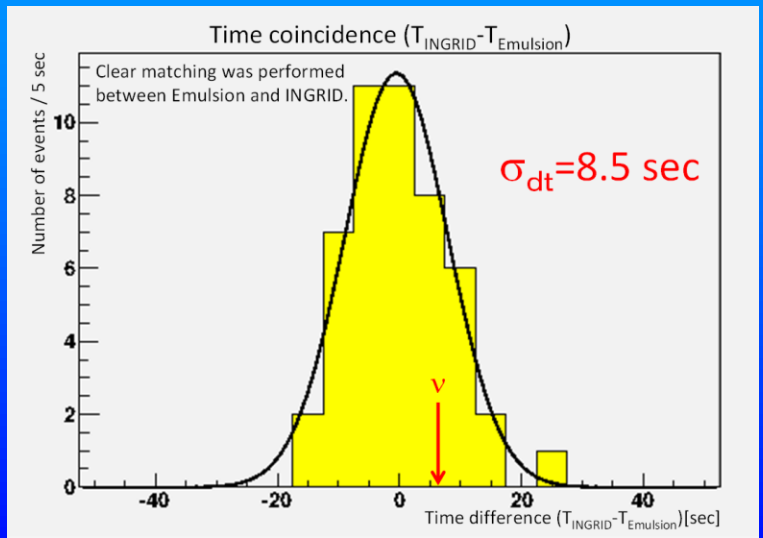


Event topology is clearly matched.
Expected range for each tracks is consistent with INGRID hits.

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



Time resolution for emulsion tracks

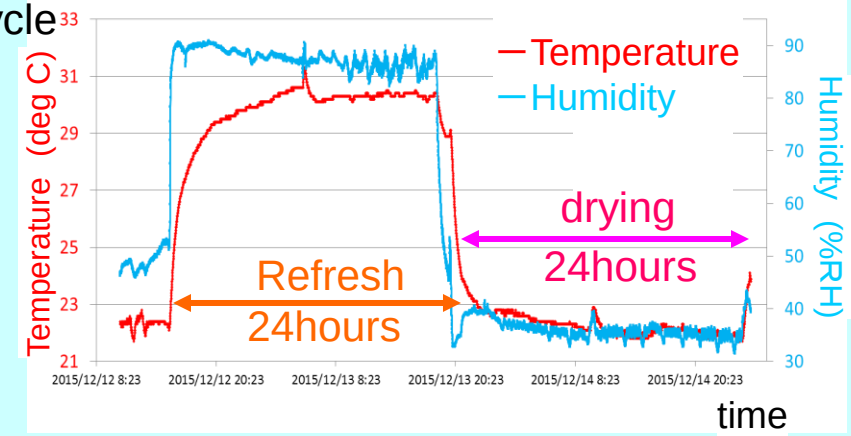


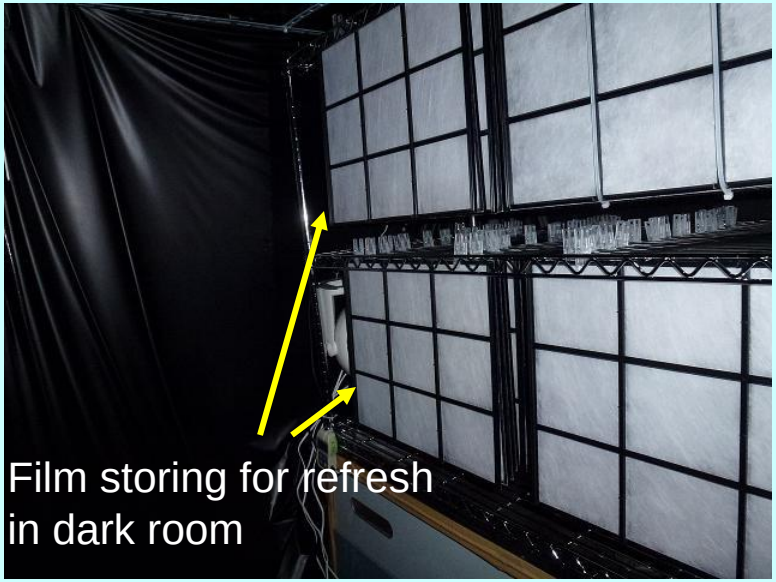
Detector preparation

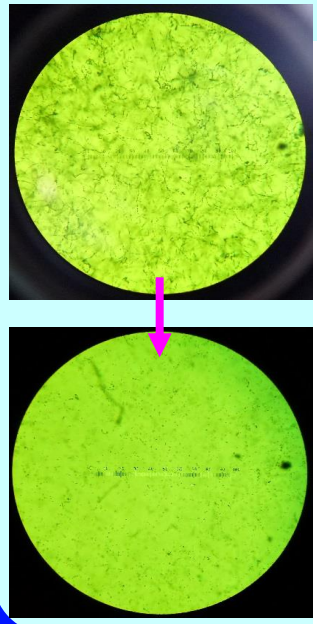
We carried out “Refresh” process to delete noise tracks like OPERA experiment.

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

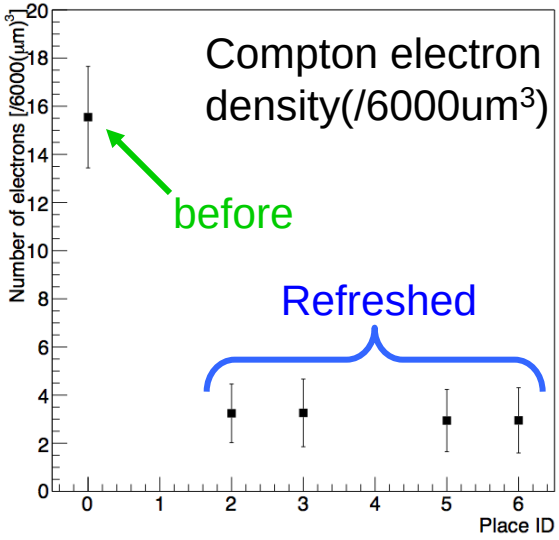
1 cycle

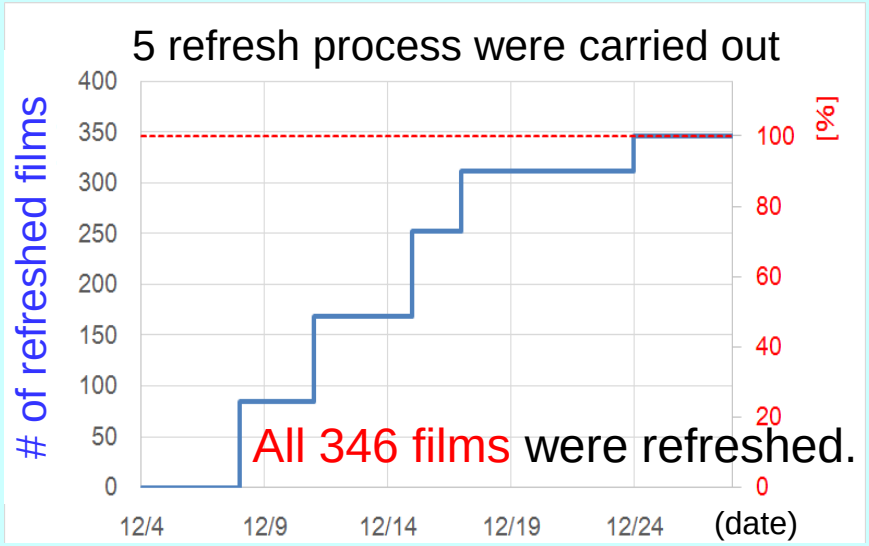






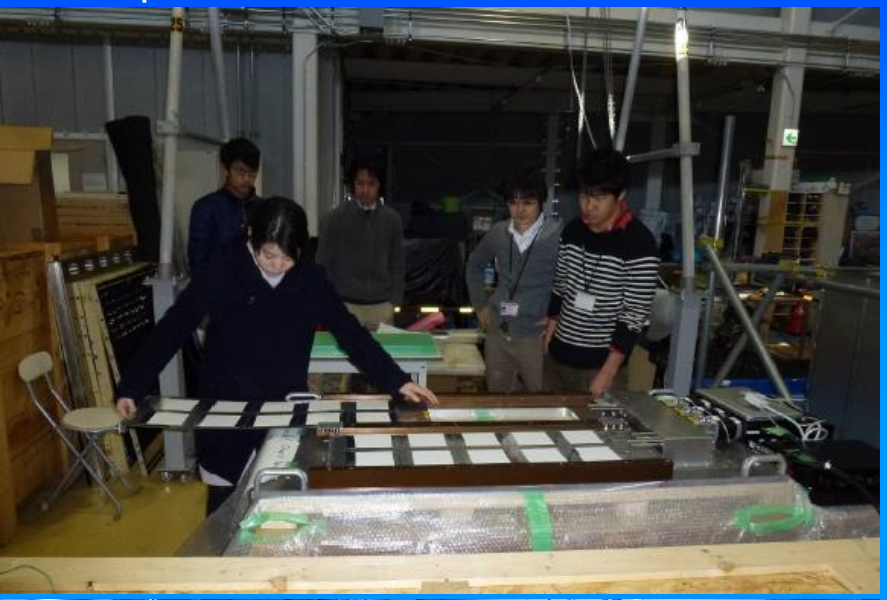
$$Ag_4 + 2H_2O + O_2 \rightarrow 4Ag^+ + 4OH^-$$

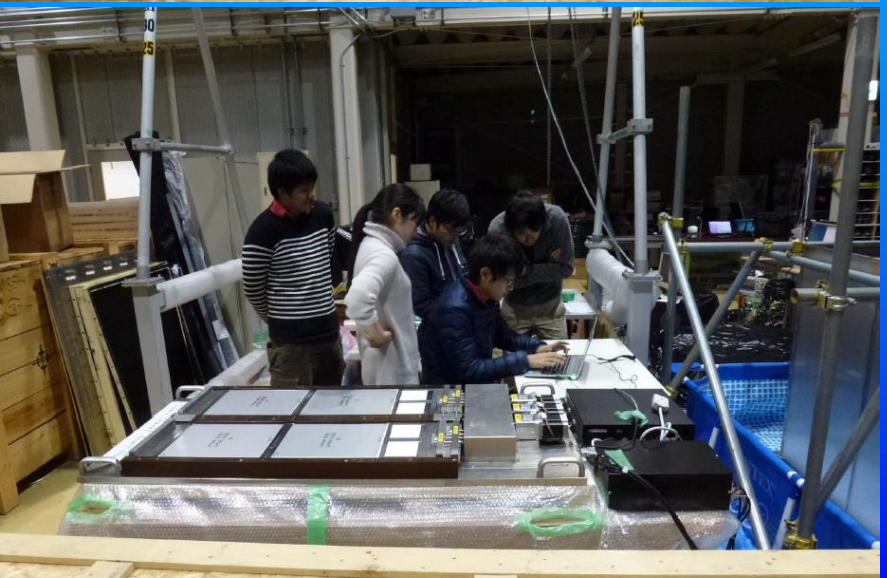




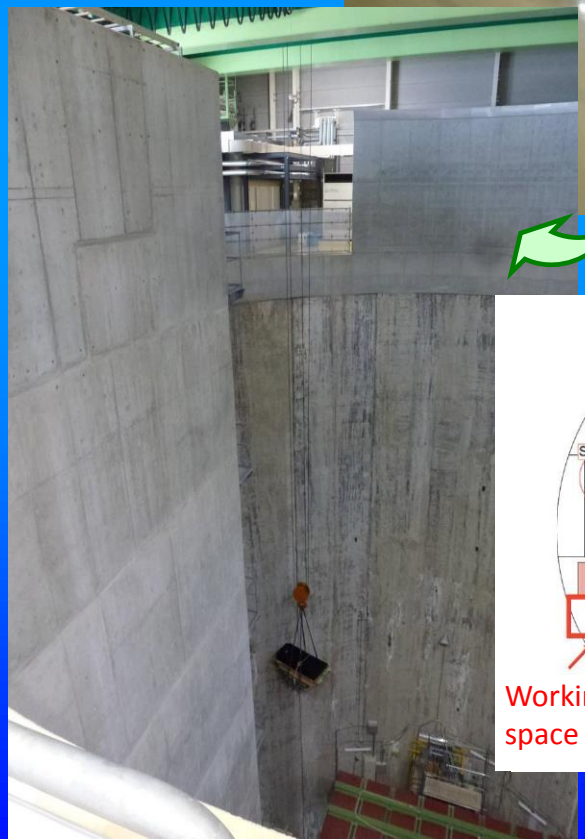
Installation @J-PARC (Jan. 11-20)

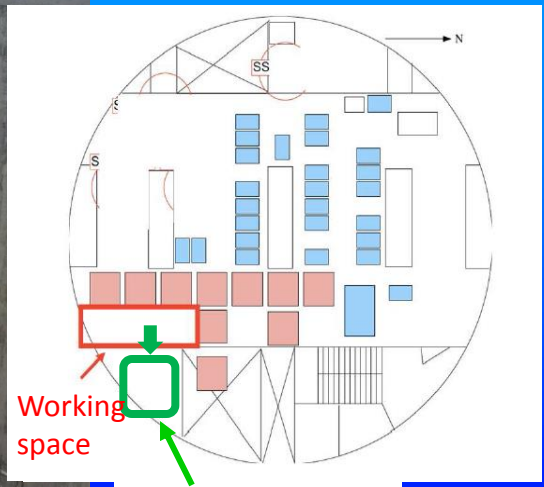
Test operation of the emulsion shifter @NA





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

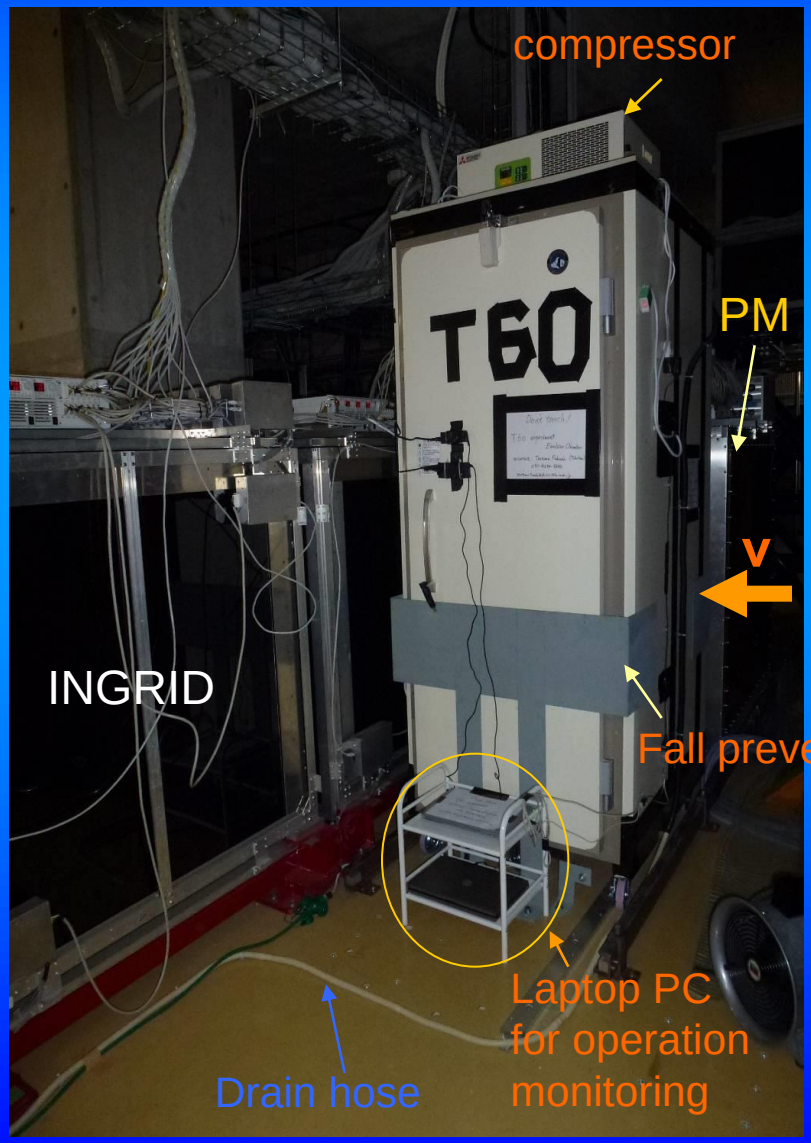


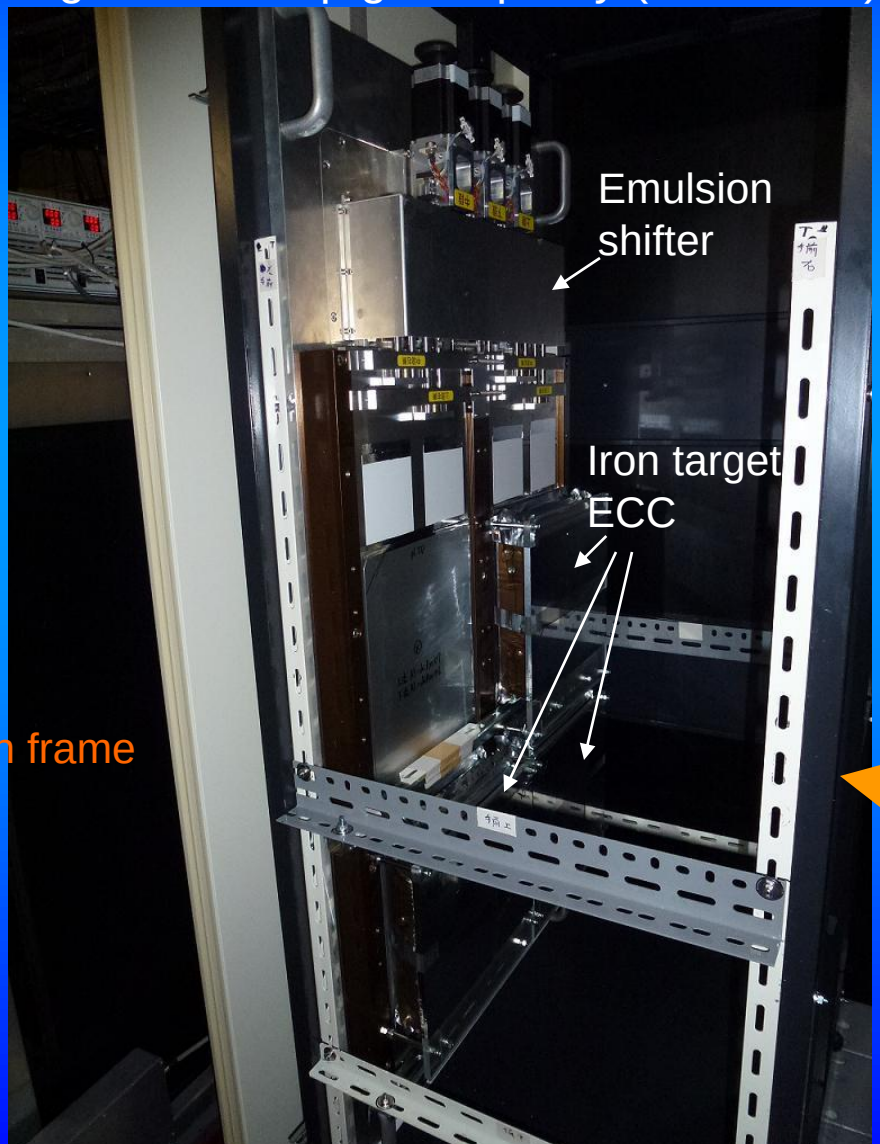


Installation @J-PARC (Jan. 11-20)

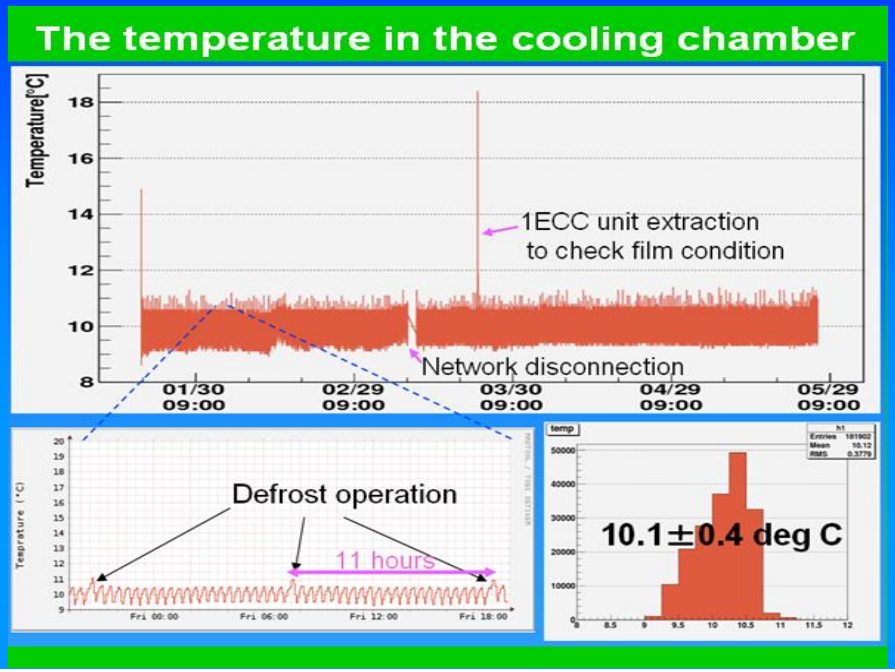
Detector was constructed @SS floor.

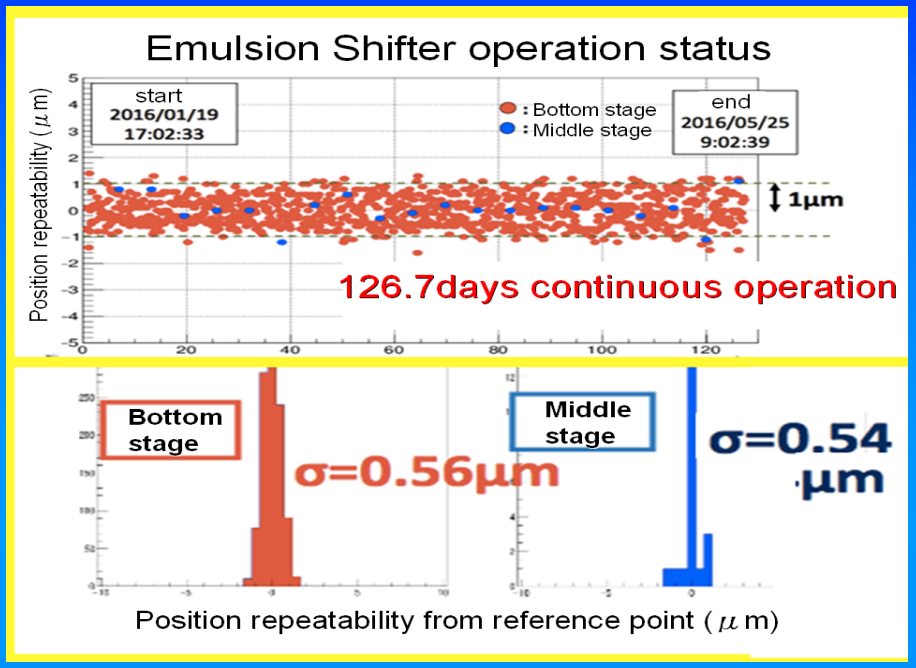
T60 emulsion detector is mounted in cooling box to keep good quality (no refresh).

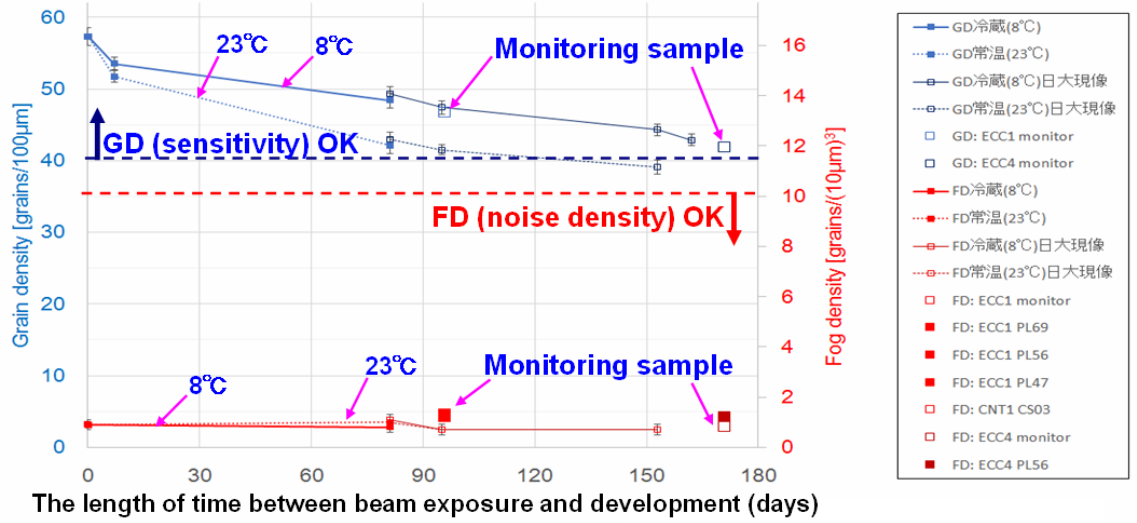




Operation status (Jan. - Jun)

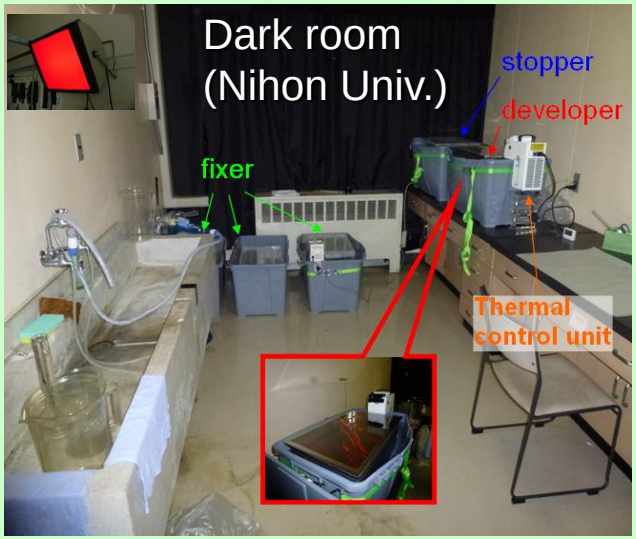


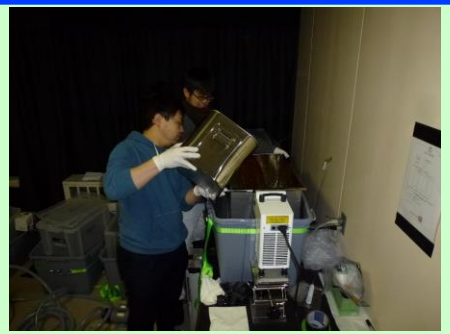


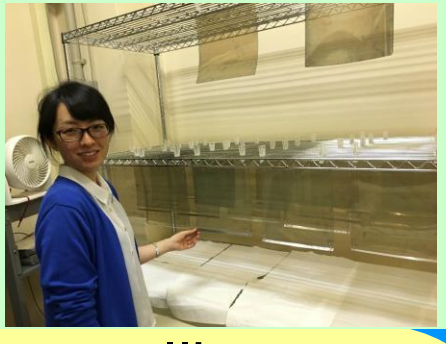


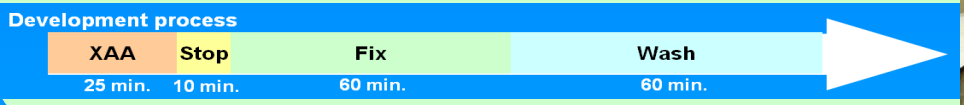
In this time, the detector is placed in the cooling chamber.
The emulsion quality (sensitivity and noise density) is found to keep at safety level from end of Jan. to end of May by checking the monitoring sample.

Hardware treatment of the emulsion films

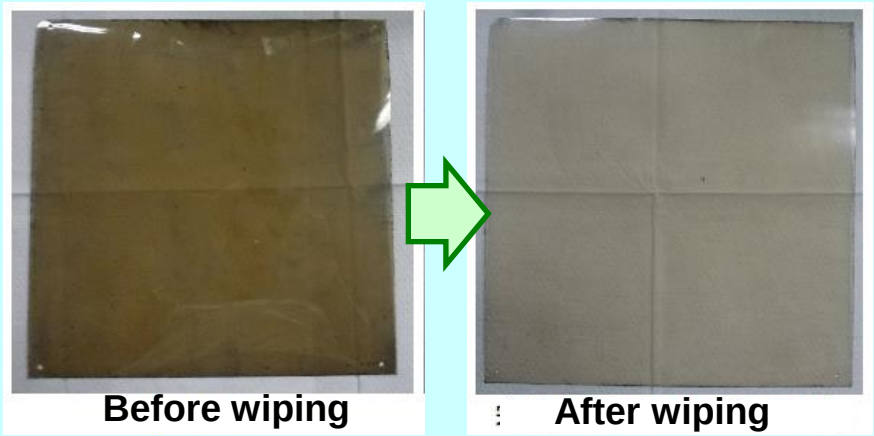








2. Surface silver cleaning



More than 300 films were completed.

Emulsion swelling

Recovering of emulsion thickness