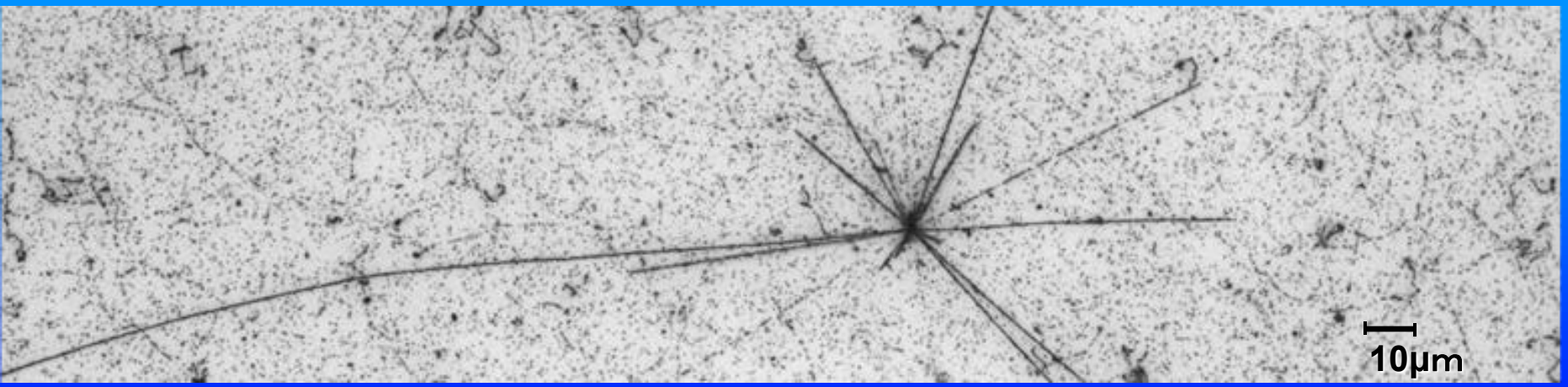
KMI2017
International Symposium

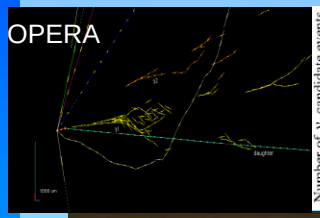
Neutrino research program with Nuclear Emulsion at J-PARC

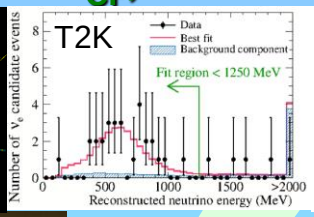
Tsutomu Fukuda（Nagoya Univ. Japan）
on behalf of J-PARC T60 collaboration

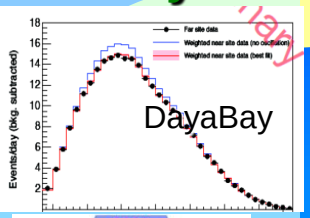


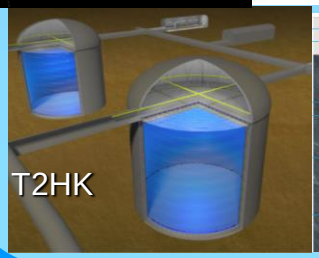
Current situation on neutrino physics

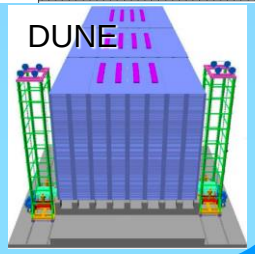
Neutrino oscillation
→ δ_{CP}, mass hierarchy



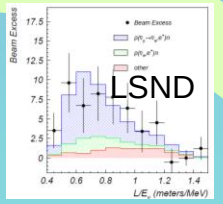


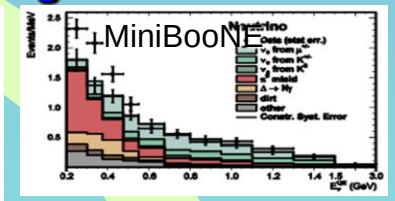


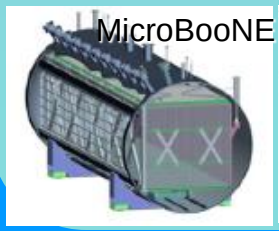




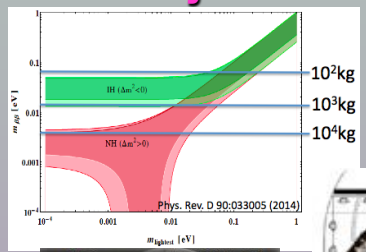
Sterile Neutrinos
→ 4th generation ? Dark matter ?

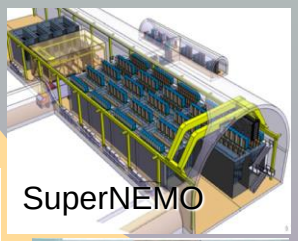




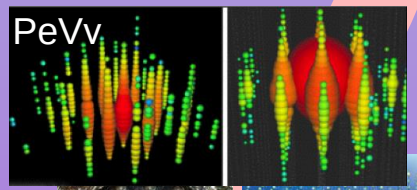


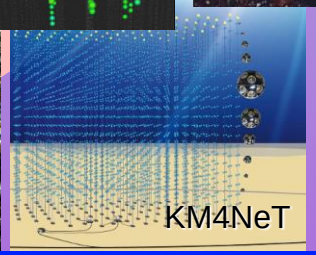
0vdouble beta decay
→ majorana / dirac ? vmass meas.

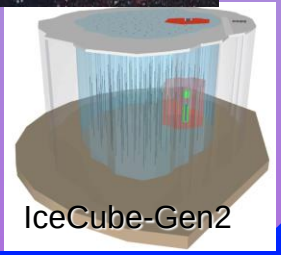




Cosmic neutrinos
→ Ultra-high energy, Supernova,…







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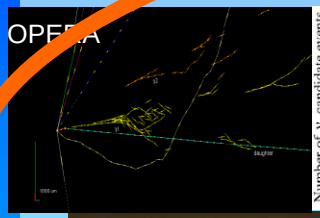

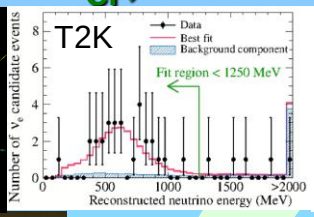

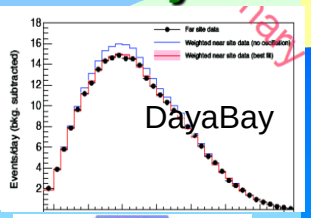

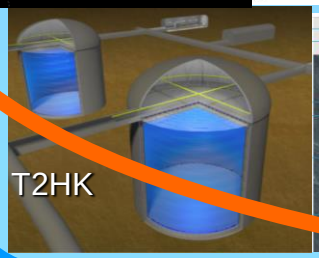

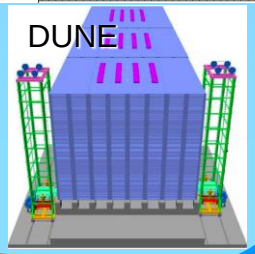

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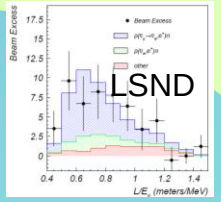

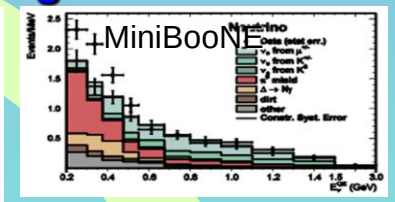

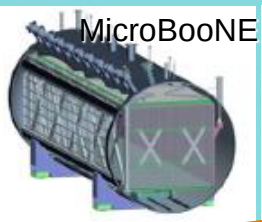

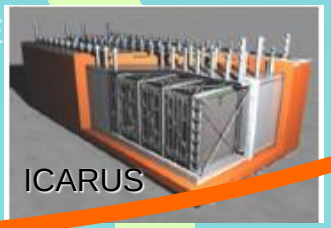

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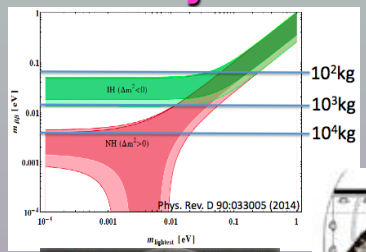

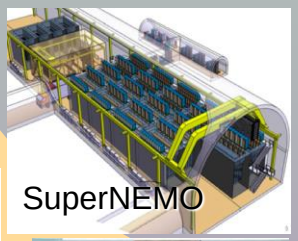

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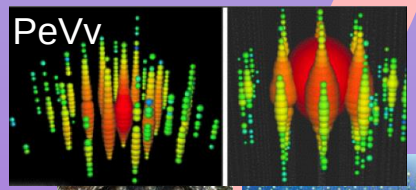
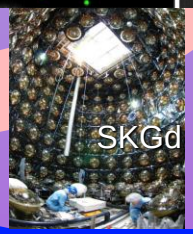
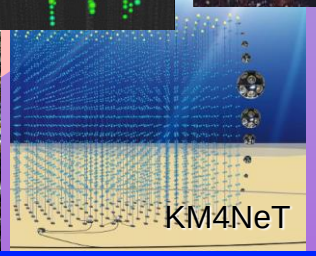
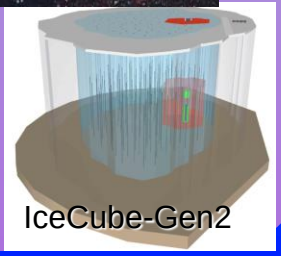




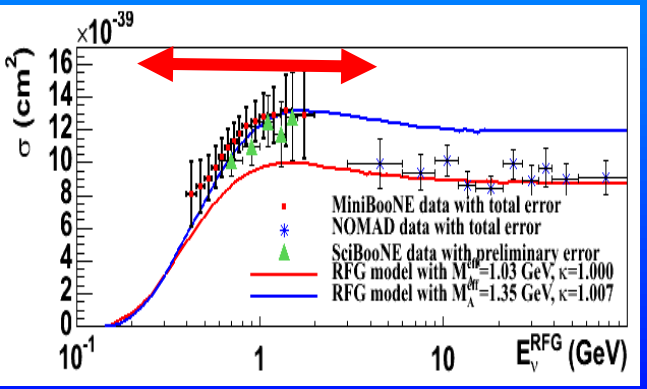


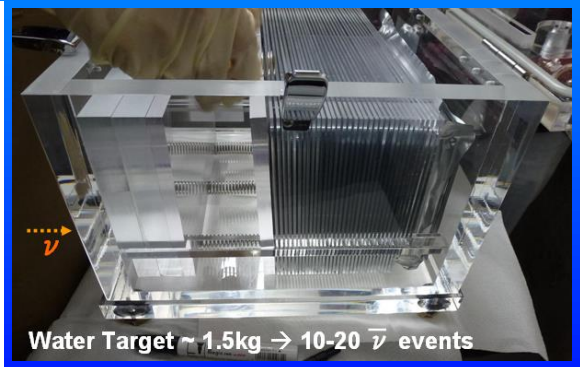


Of course many other neutrino projects are also carrying out or planned.

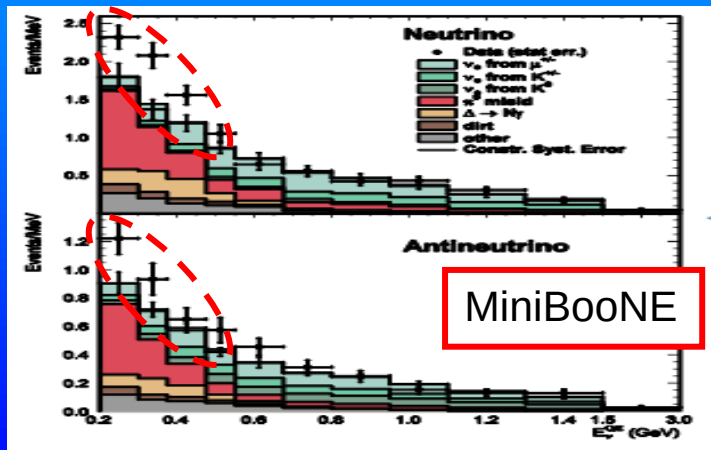
Motivation

- 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.





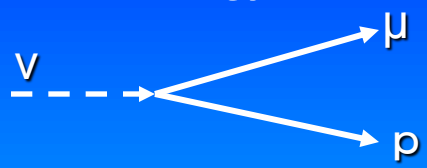
Water Target Emulsion Chamber



Precise measurement of neutrino-nucleus interactions

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

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

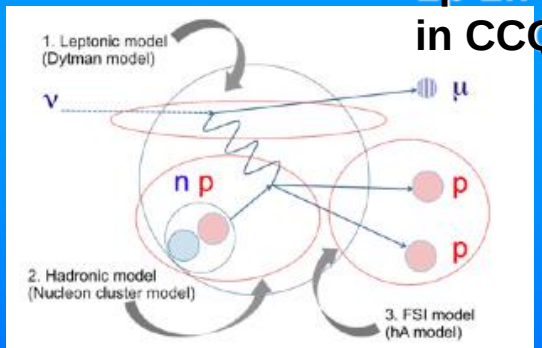


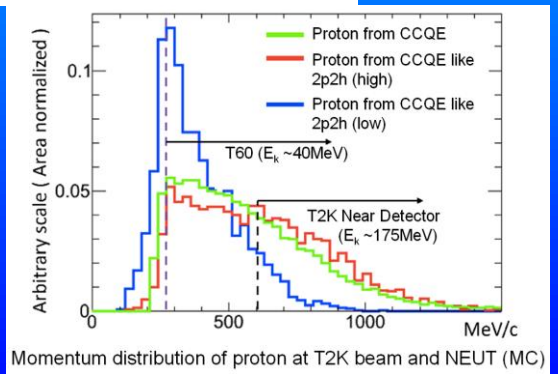
- Other interaction modes contaminate due to Final state interaction in nucleon and detector inefficiency.
- Energy can't be reconstructed correctly with these interaction modes.
  → Need precise understanding about neutrino interaction.

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

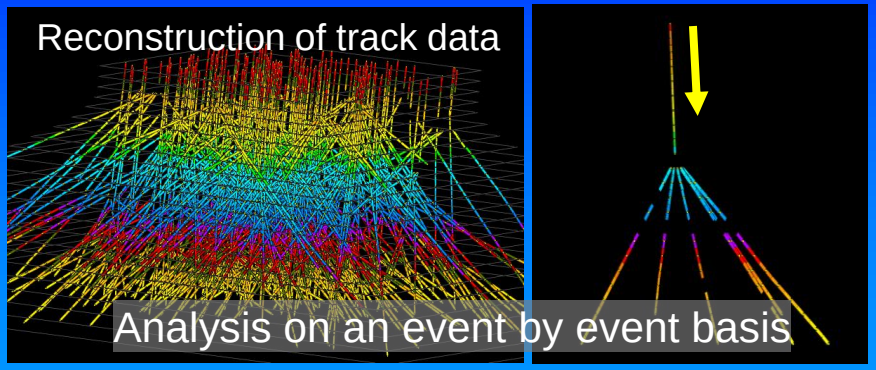




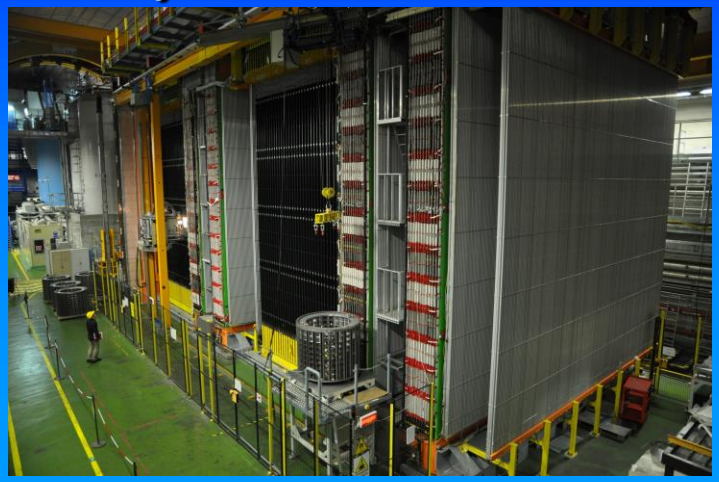
Momentum distribution of proton at T2K beam and NEUT (MC)

Nuclear Emulsion Detector

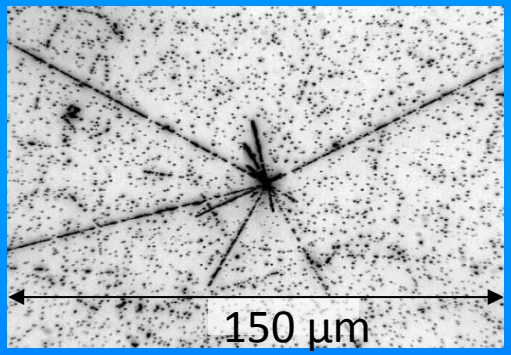
3D reconstruction



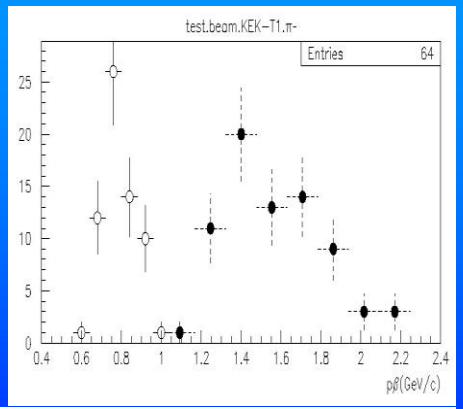
Scalability



4π detection

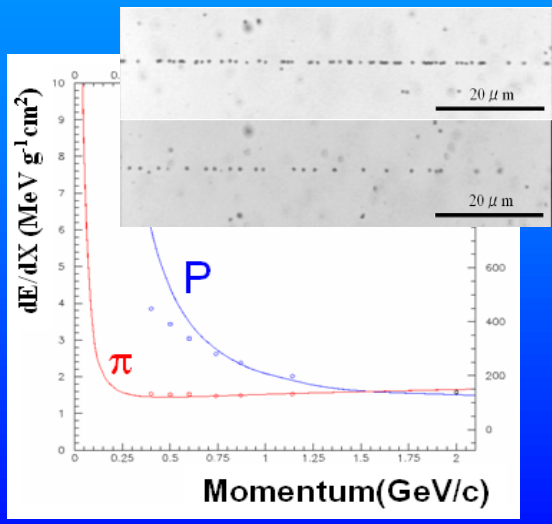


Momentum, dE/dx measurement



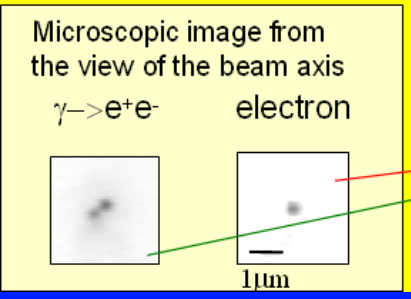
0.8GeV/c π : P =0.79(GeV/c), dP/P =**11**%

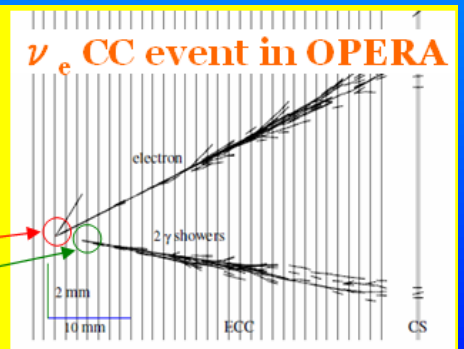
1.5GeV/c π : P =1.53(GeV/c), dP/P =**16**%



Ultra precise measurement

γ / electron ID



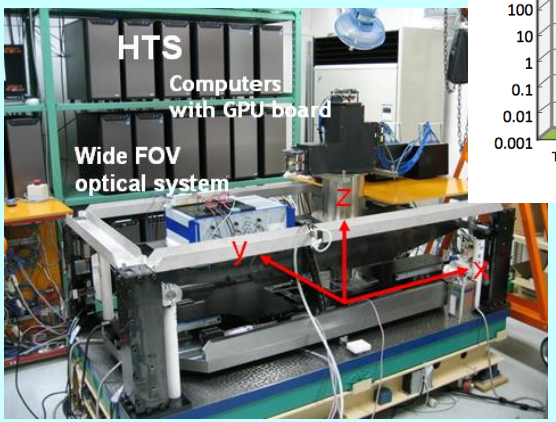


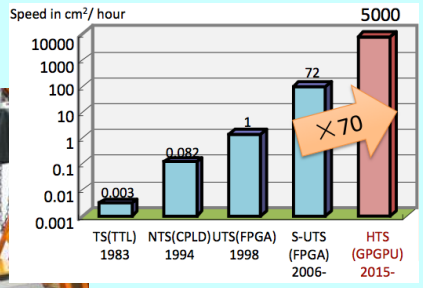
Low BG from ν_μ NC π^0 production

Recent technical improvements

Readout technique

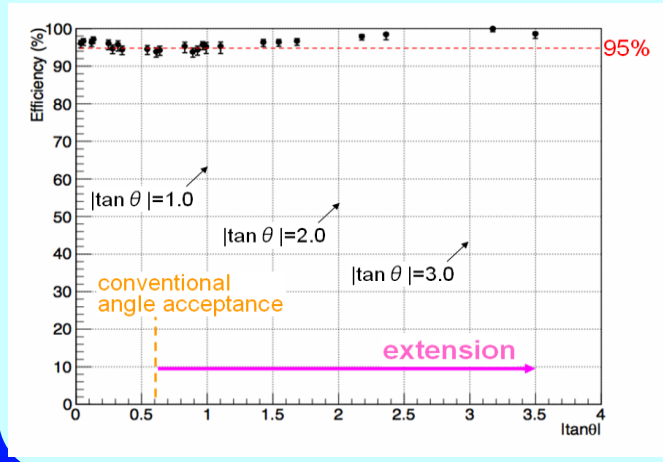
High Speed Scanning

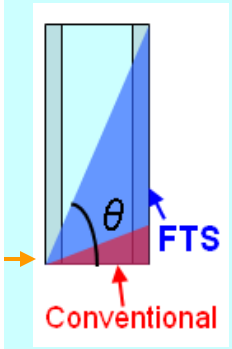




HTS
5,000cm²/h
x70 faster

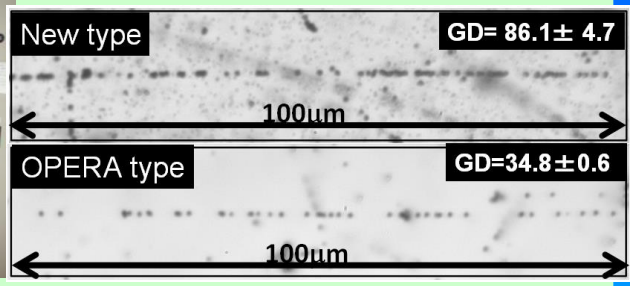
Large angle tracking technique



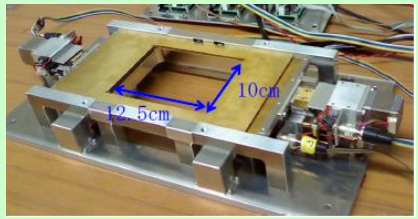


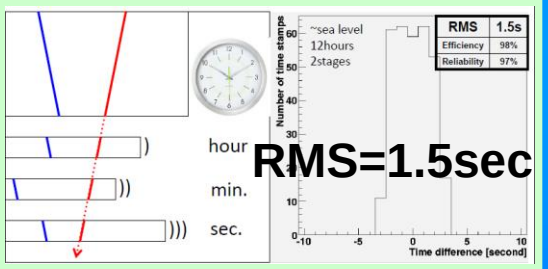
Detector technique

High Sensitive film



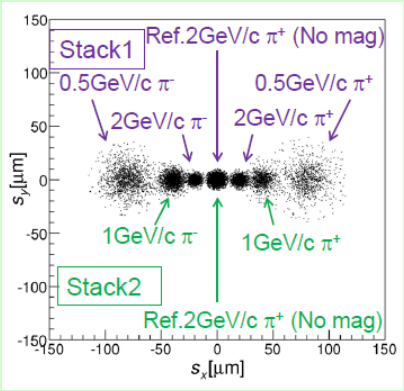
Time resolution



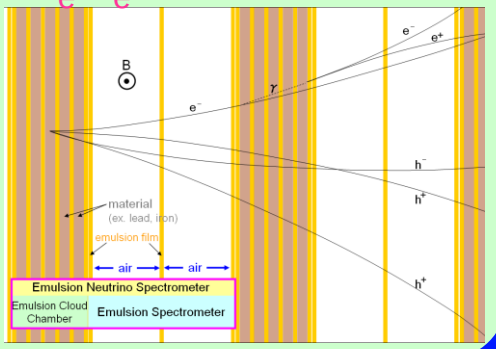


RMS=1.5sec

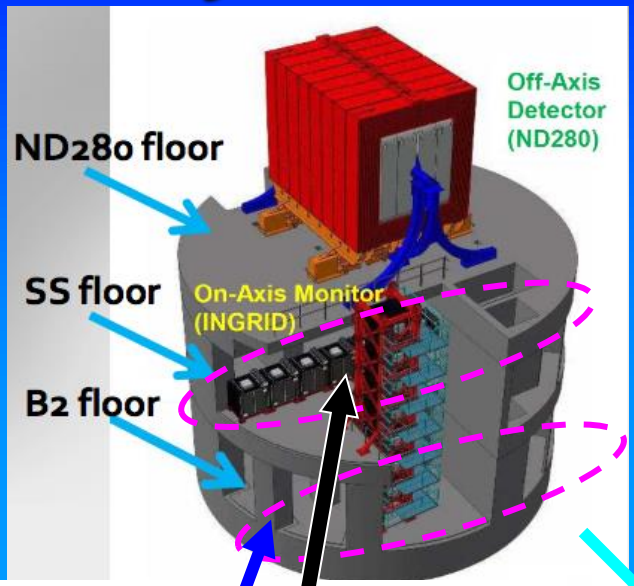
Charge sign ID



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



J-PARC T60 Experiment

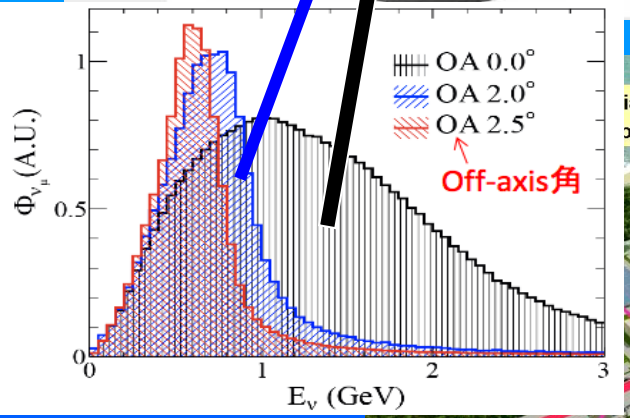


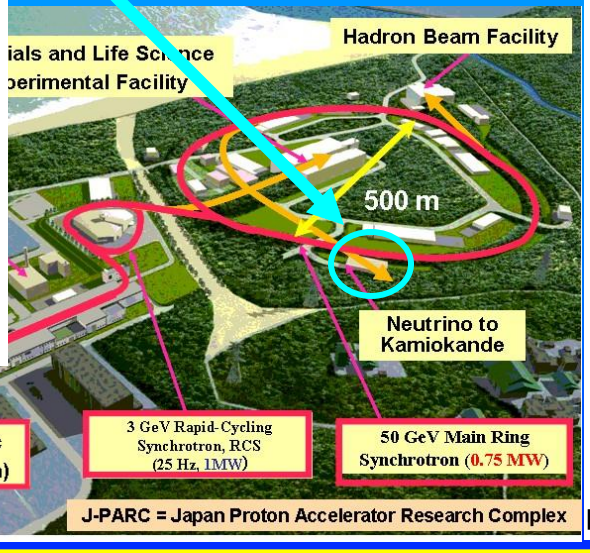
Proposal of an emulsion-based test experiment at J-PARC

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)**



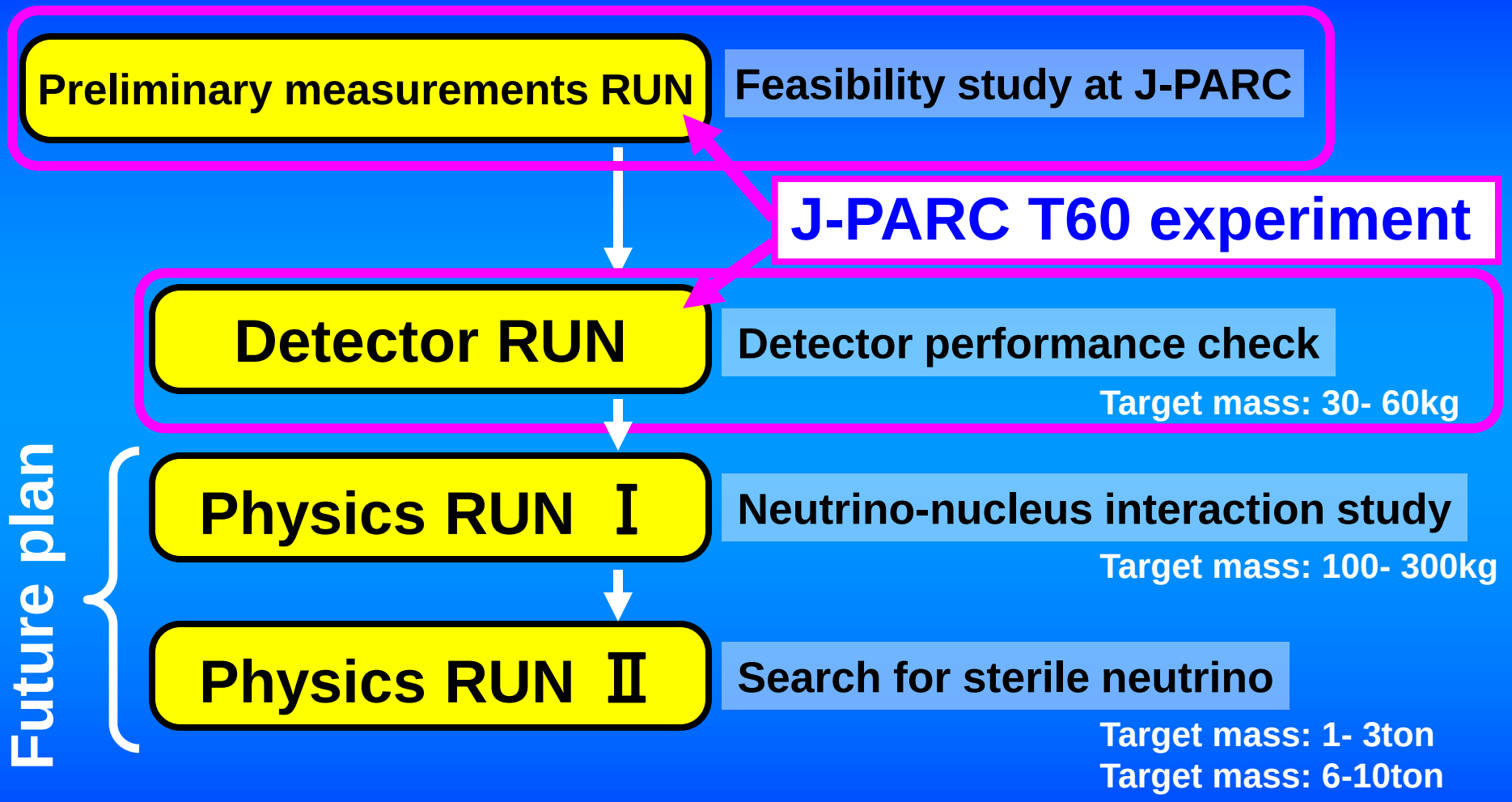


Working group

- **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

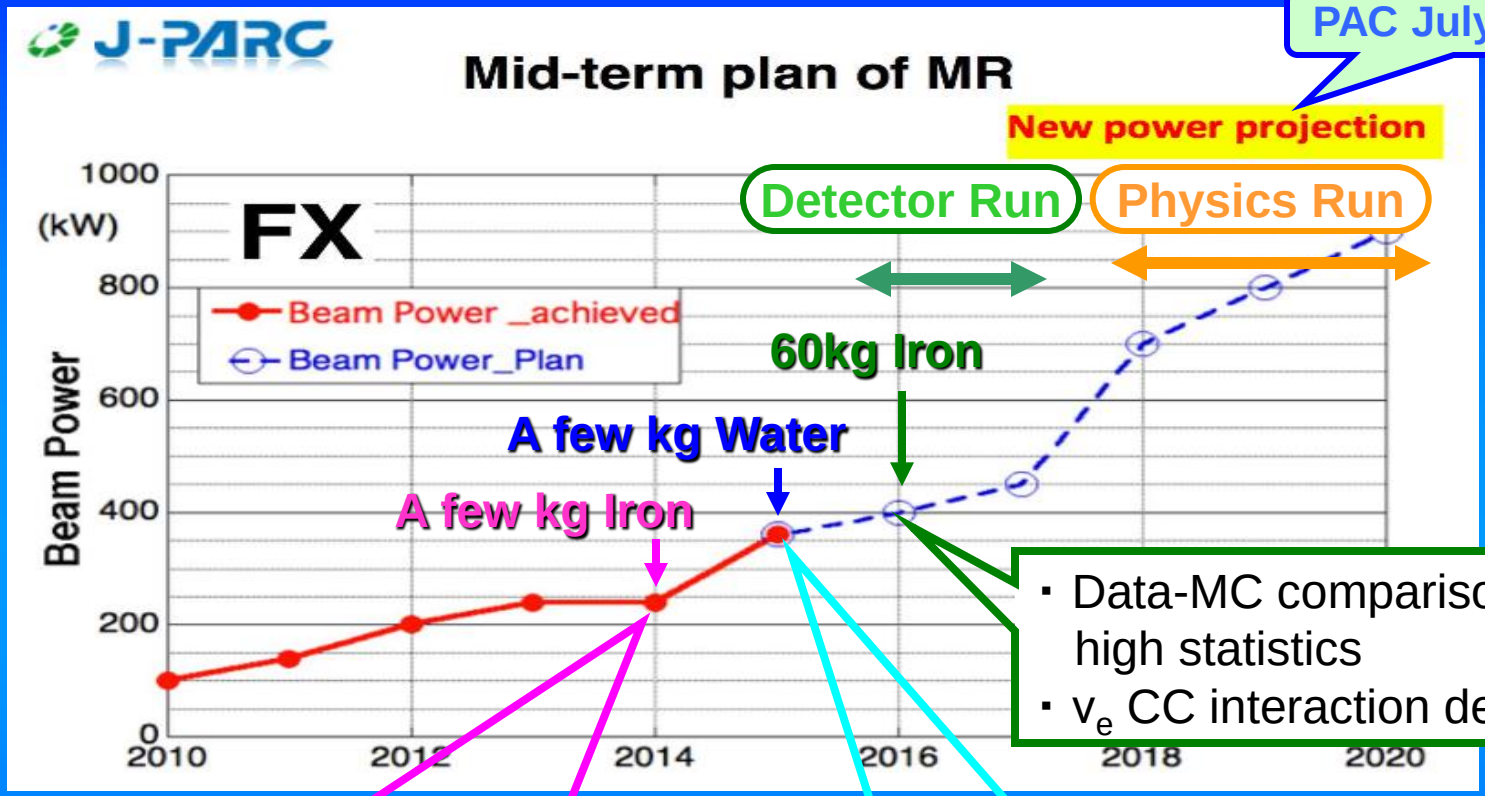
A collaborative project with some member of OPERA and T2K

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

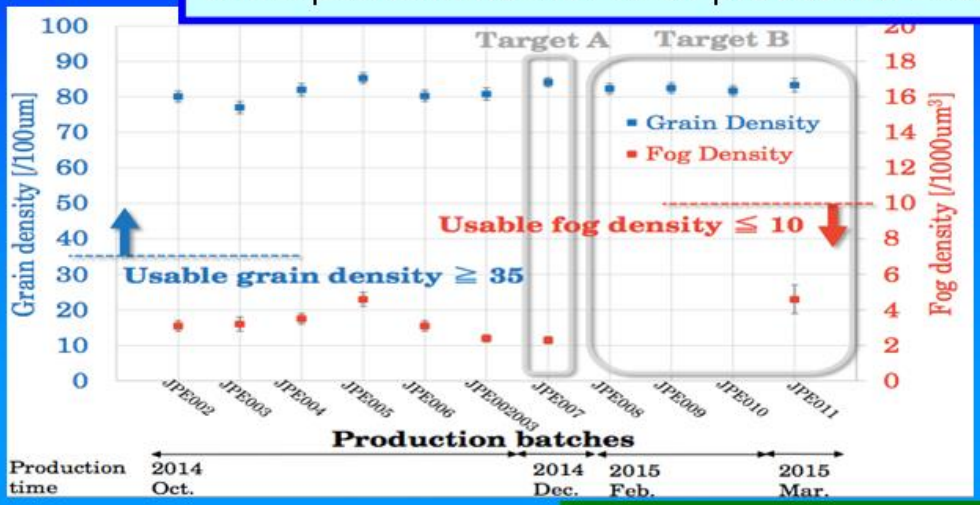


- We have demonstrated the basic experimental concept at J-PARC site.
- “Detector performance run” was started from last Jan.

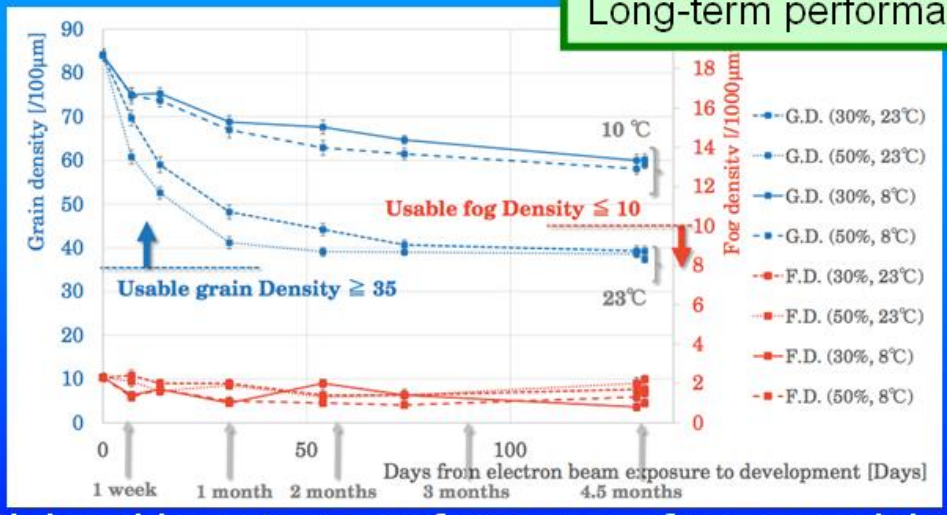
Emulsion gel production in the lab

Nuclear emulsion films were made by ourselves.

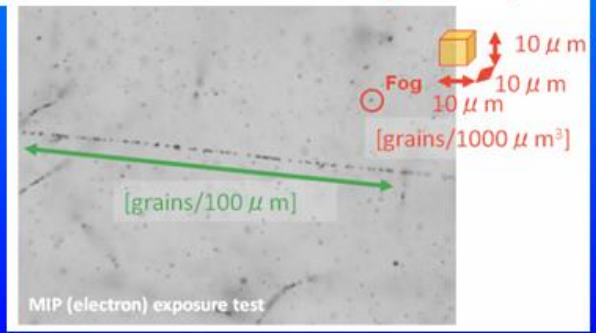
Initial performance for each production batch



Long-term performance

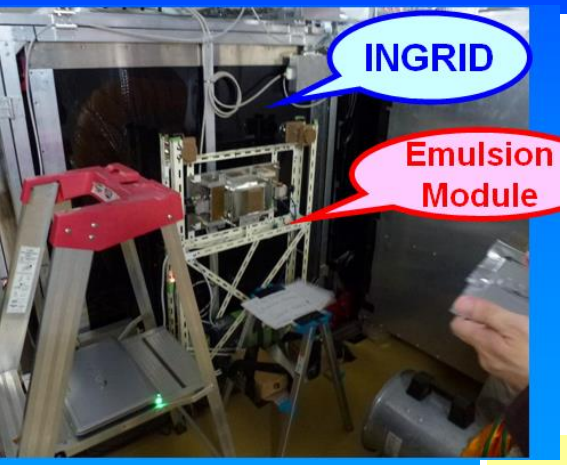


Signal efficiency → Grain density
Isolated random noise → Fog density

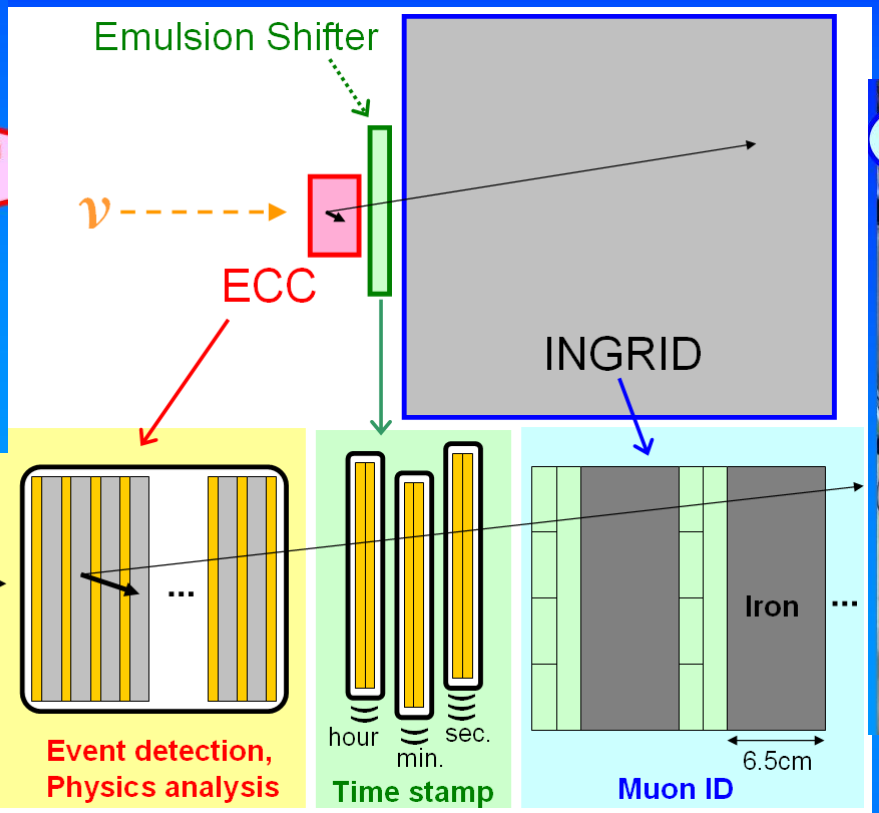


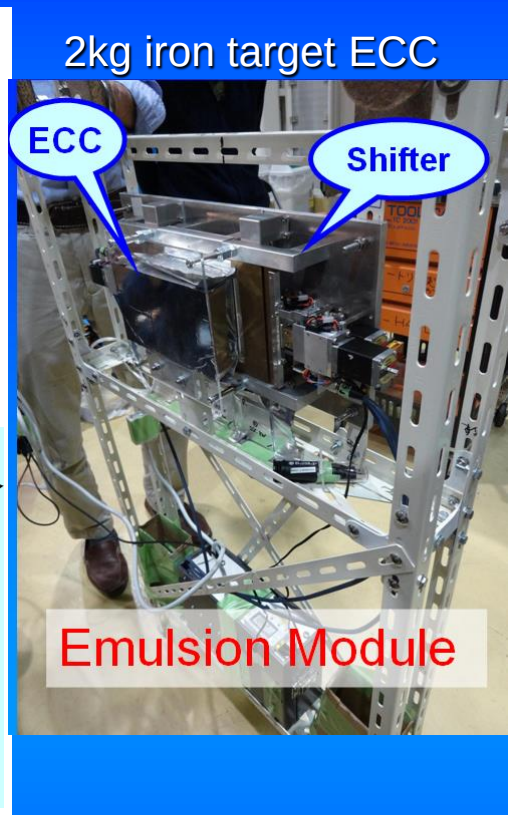
Initial and long-term performance of new emulsion gel is kept at safety level for signal and noise.

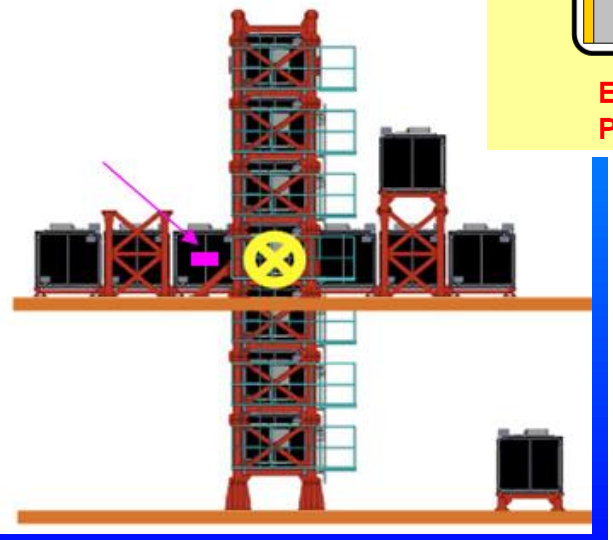
Conceptual detector design



SS floor @J-PARC
(Jan. 2015)





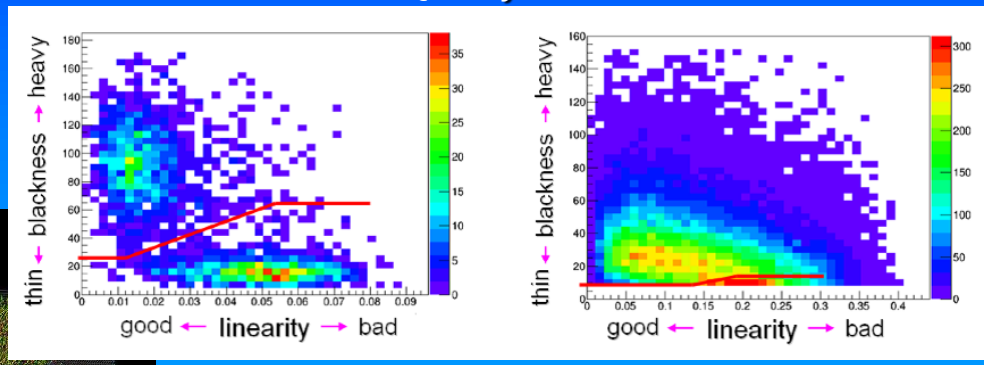


- **E**mulsion **C**loud **C**hamber is a sandwich structure of emulsion films and iron plates.
- Emulsion detector is placed in front of T2K near detector, INGRID.
- Emulsion Shifter is re-used from GRAINE project to give a timing info. to emulsion tracks.
- Muon ID is possible by combined analysis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

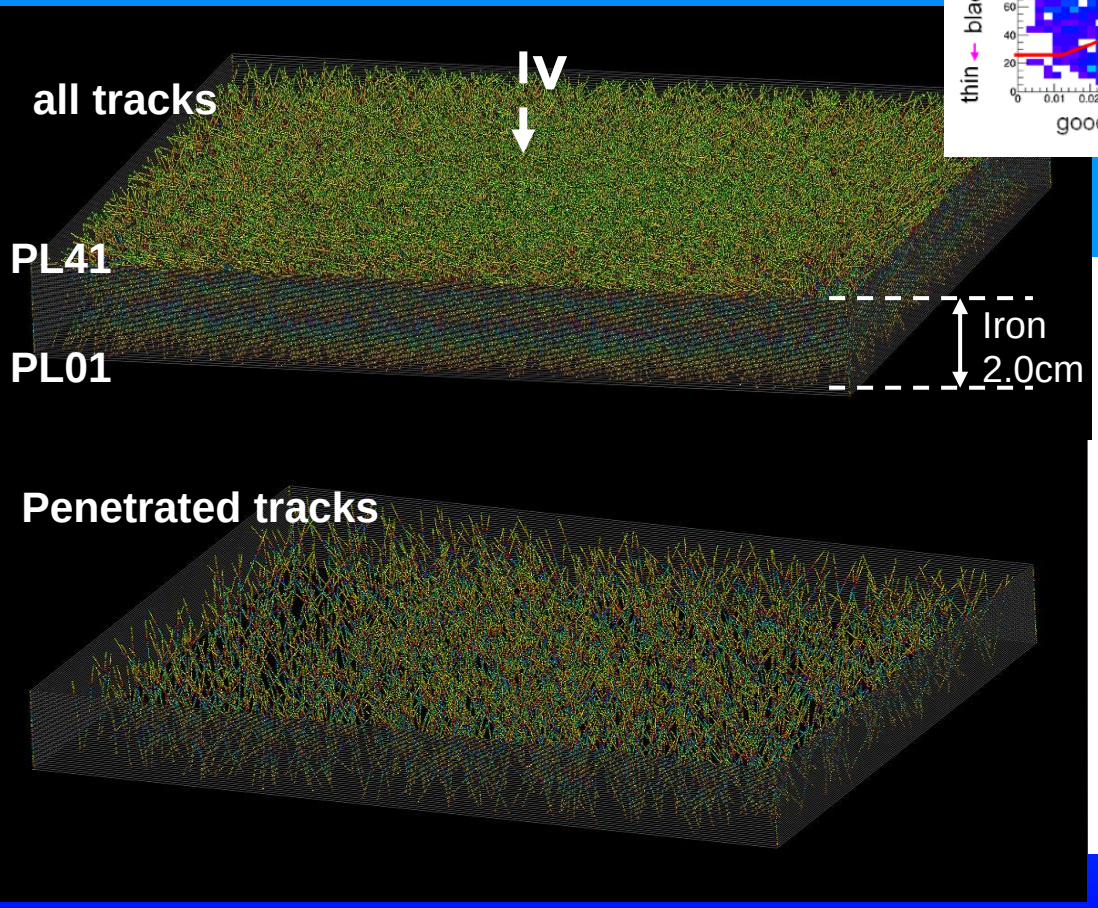
Reconstructed track data

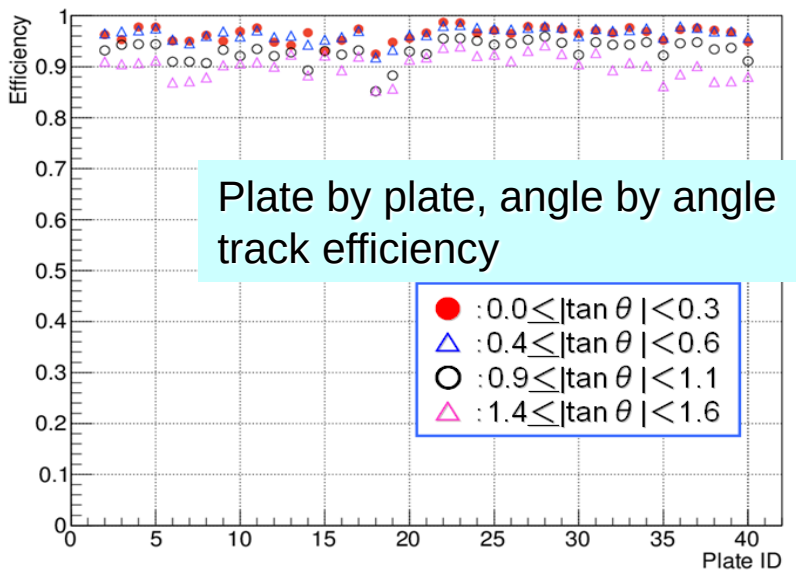
All emulsion films were scanned by HTS.
First of all, noise tracks were rejected by evaluating the quality of each tracks.
Then tracks were reconstructed.

Track Quality Selection



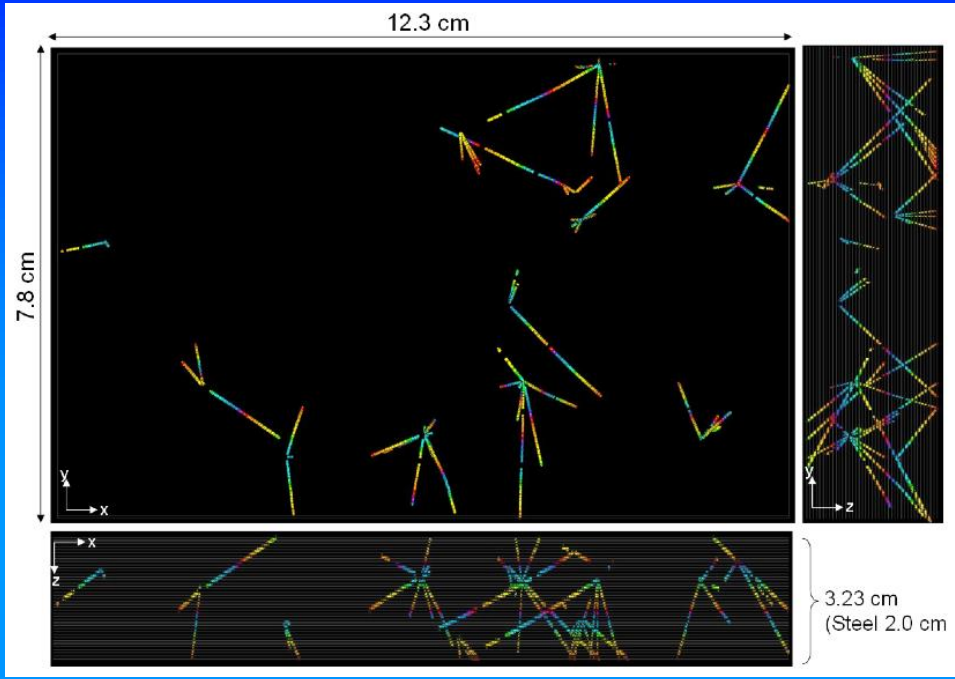
（|tanθ| ≦ 0.1 ）　　（1.4≦ |tanθ| ）

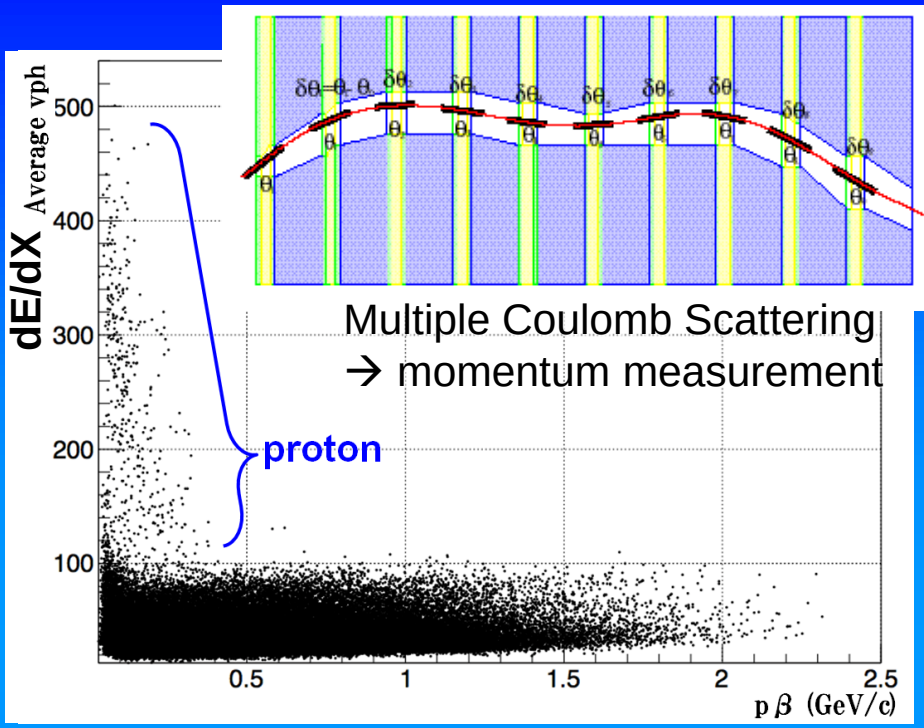




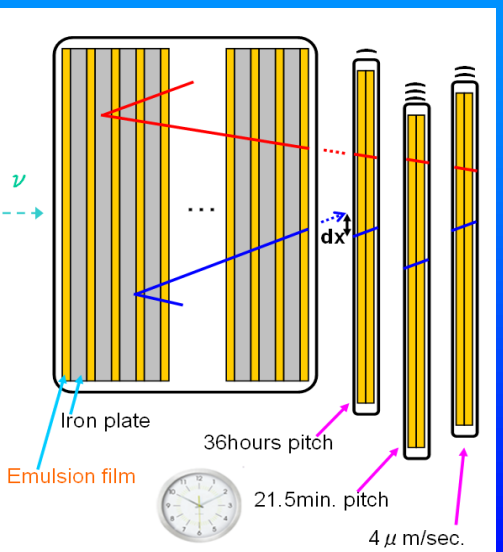
Status review of T60

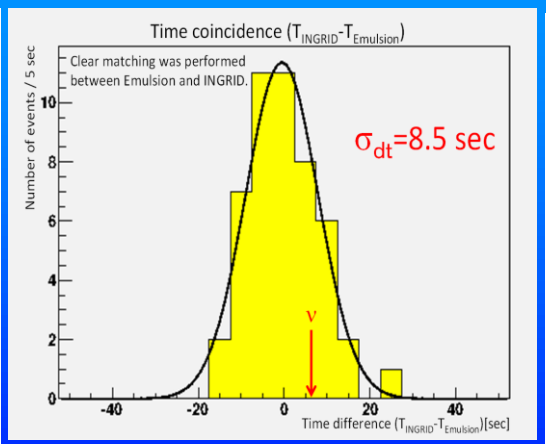
Systematic emulsion analysis





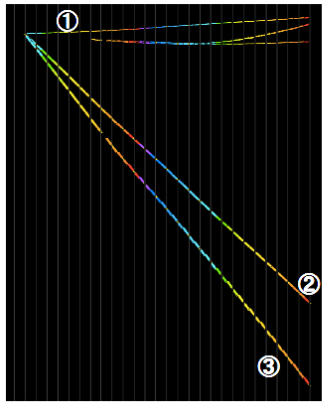
Hybrid analysis with T2K near detector

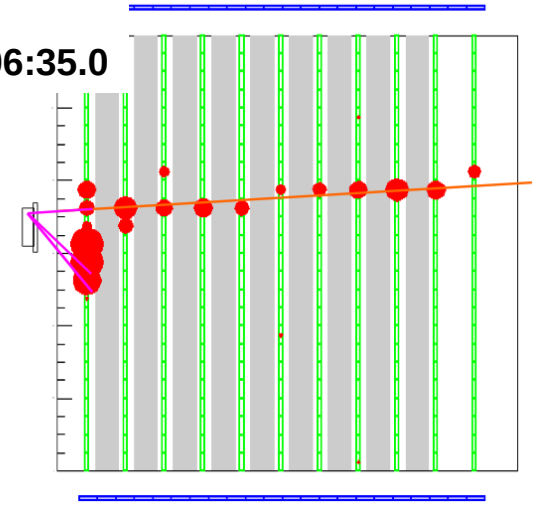




Estimated time resolution using penetrated muons

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

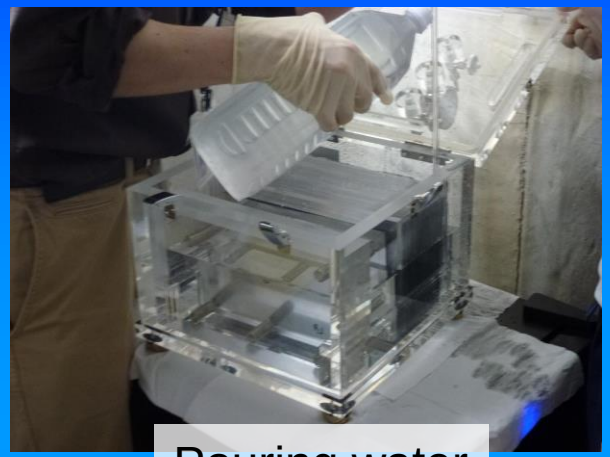




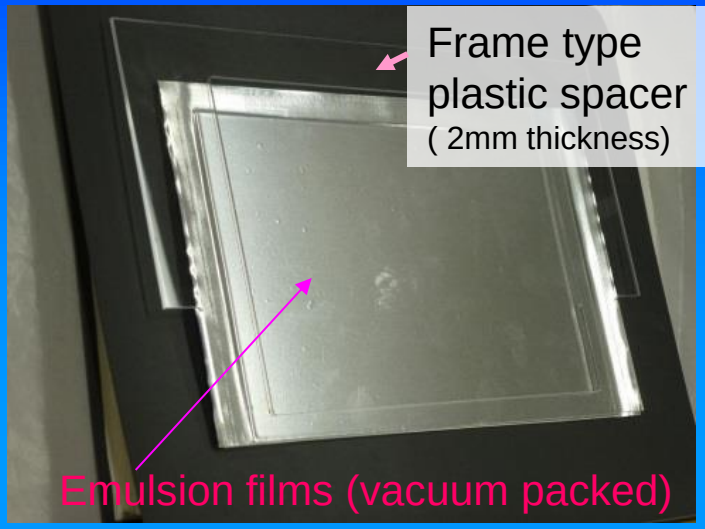
Water target emulsion chamber

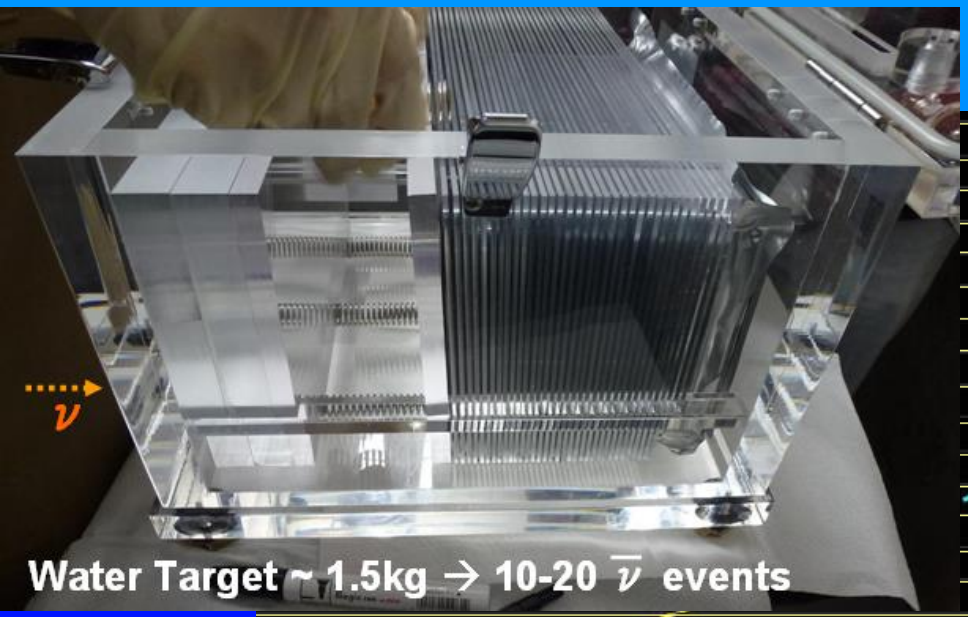
We installed a water target emulsion chamber during $\bar{\nu}$ exposure in May 2015.

Sandwich structure of Emulsion films and Frame type spacers

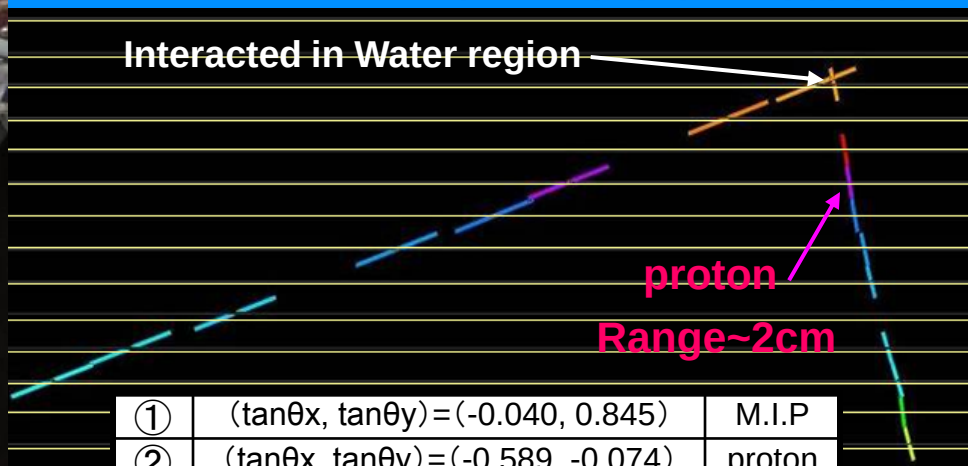


Pouring water





First detection of ν- Water interaction with Emulsion Detector

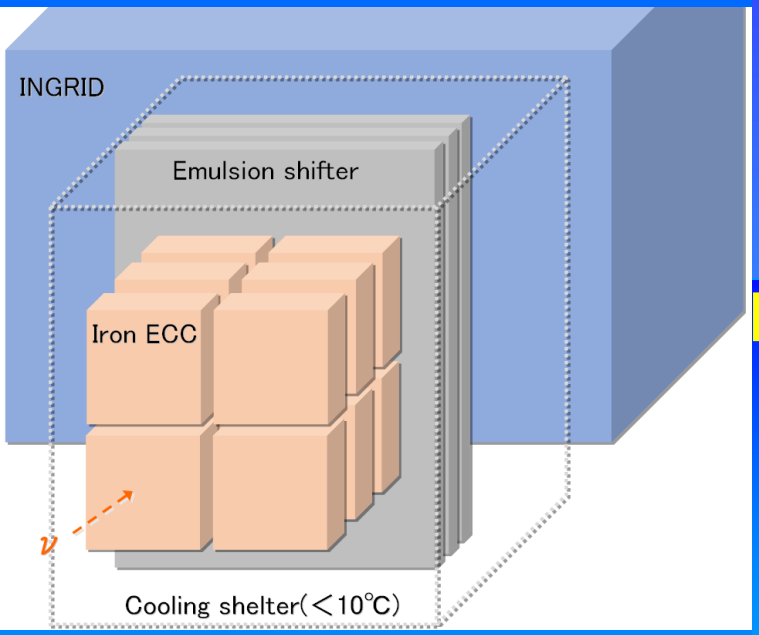


①	(tanθx, tanθy)=(-0.040, 0.845)	M.I.P
②	(tanθx, tanθy)=(-0.589, -0.074)	proton
Minimum distance(① - ②)=2.4um, depth=620um		

Status review of T60

Detector Run

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



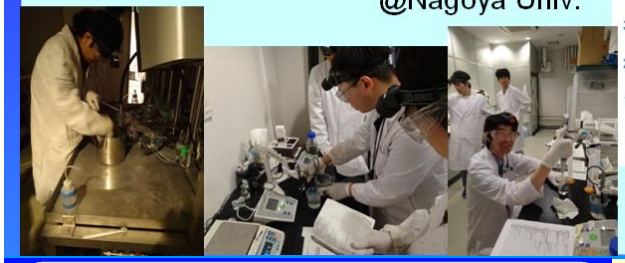
- $\bar{\nu}$ exposure : 2016 @SS floor
  end of Jan. → beam end
- Iron target (total~60kg : 500 μm seg.)
- High statistics (3-4k $\bar{\nu}_\mu$ events)
- ν_e detection (20-30 $\bar{\nu}_e$ CC events)

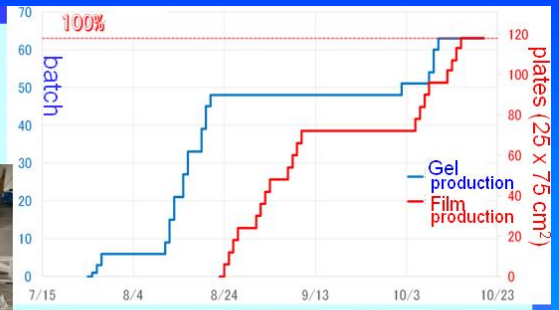
→ Data – MC comparison with high statistics to check the performance.

Emulsion film production

2015. July→Oct.

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

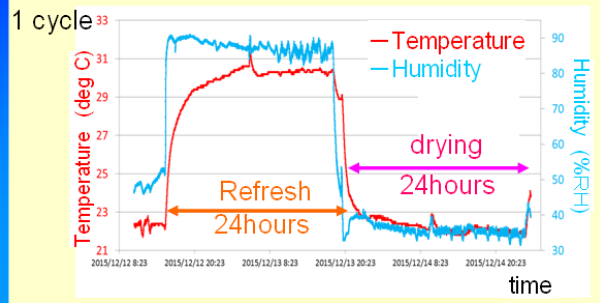


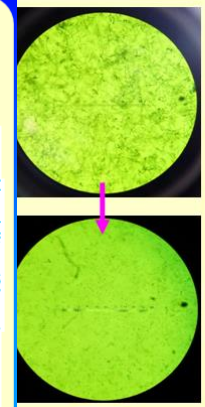


~52kg gel and ~359 films (25 x 25cm²) production is completed.

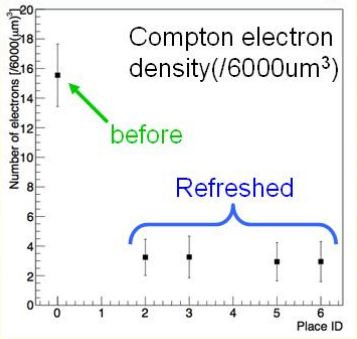
Emulsion film Refresh

Noise reduction at 30deg C, 90%humi



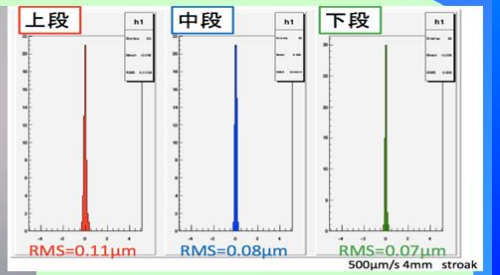


$Ag_4 + 2H_2O + O_2 \rightarrow 4Ag^+ + 4OH^-$



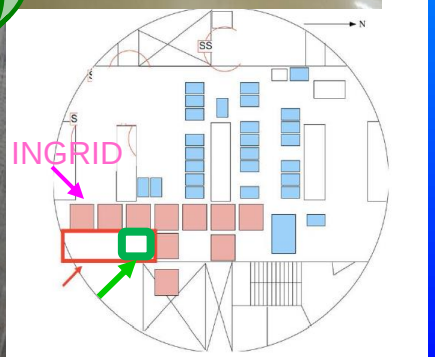
Large size Emulsion Shifter

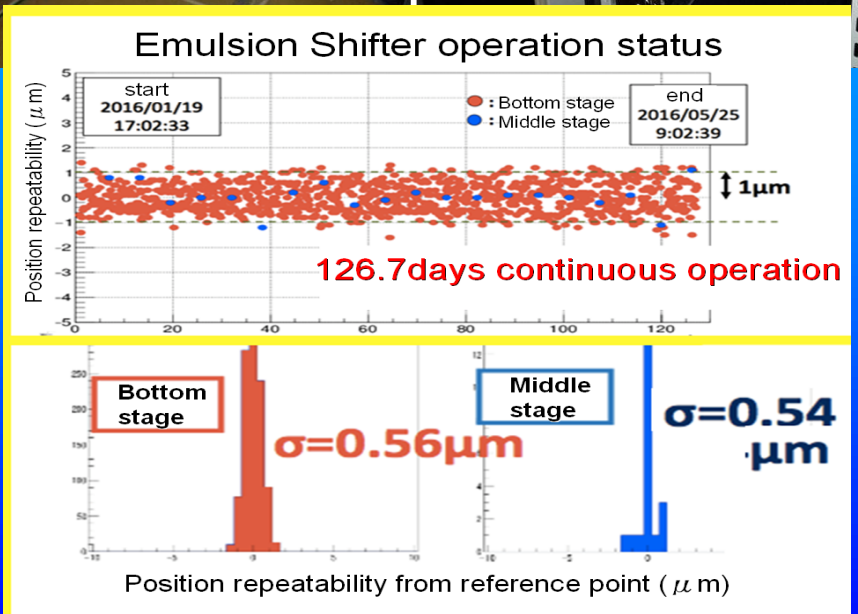
Operation test @Kobe Univ.



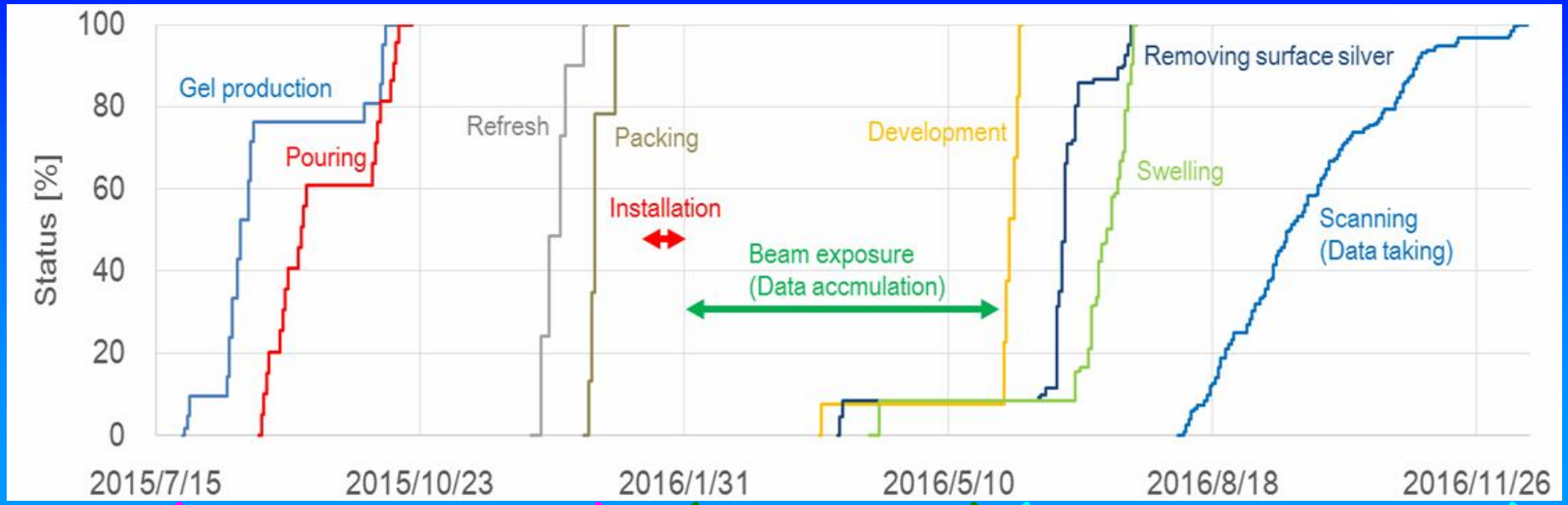
Repeatability for driving in each stage is well below 0.5 μm.

Detector installation & ν exposure

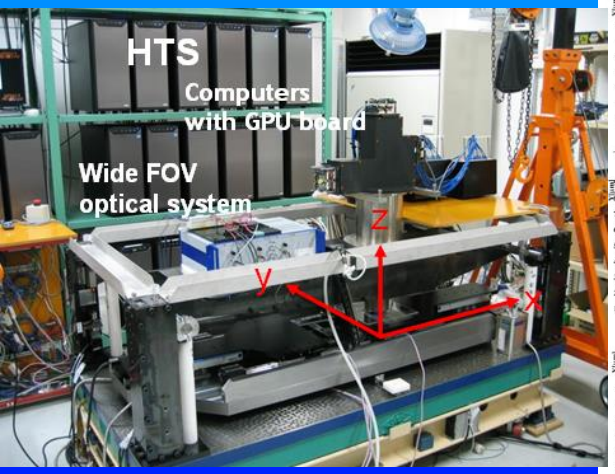


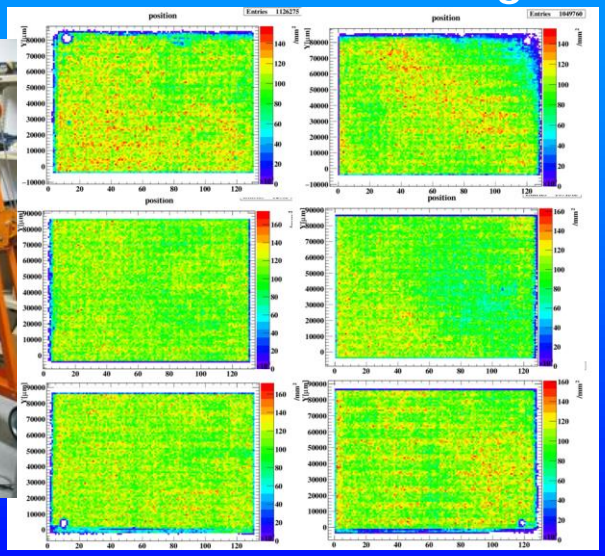


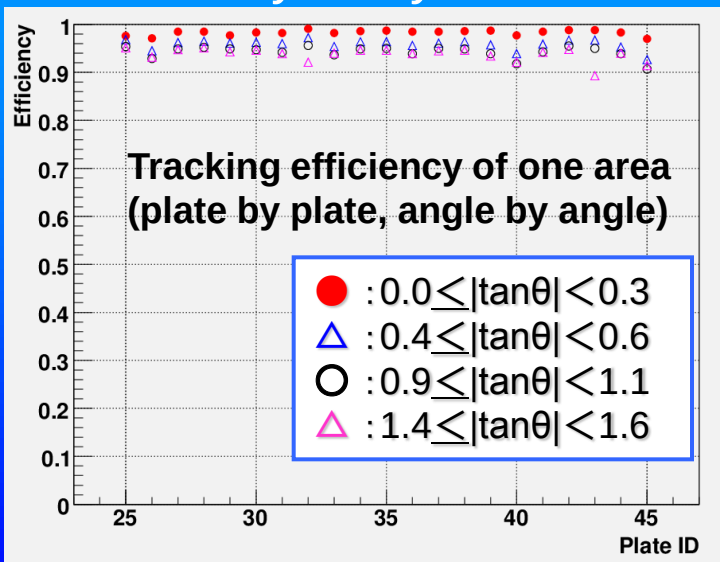
Status review of T60



The beam exposure and film scanning was finished by last year.



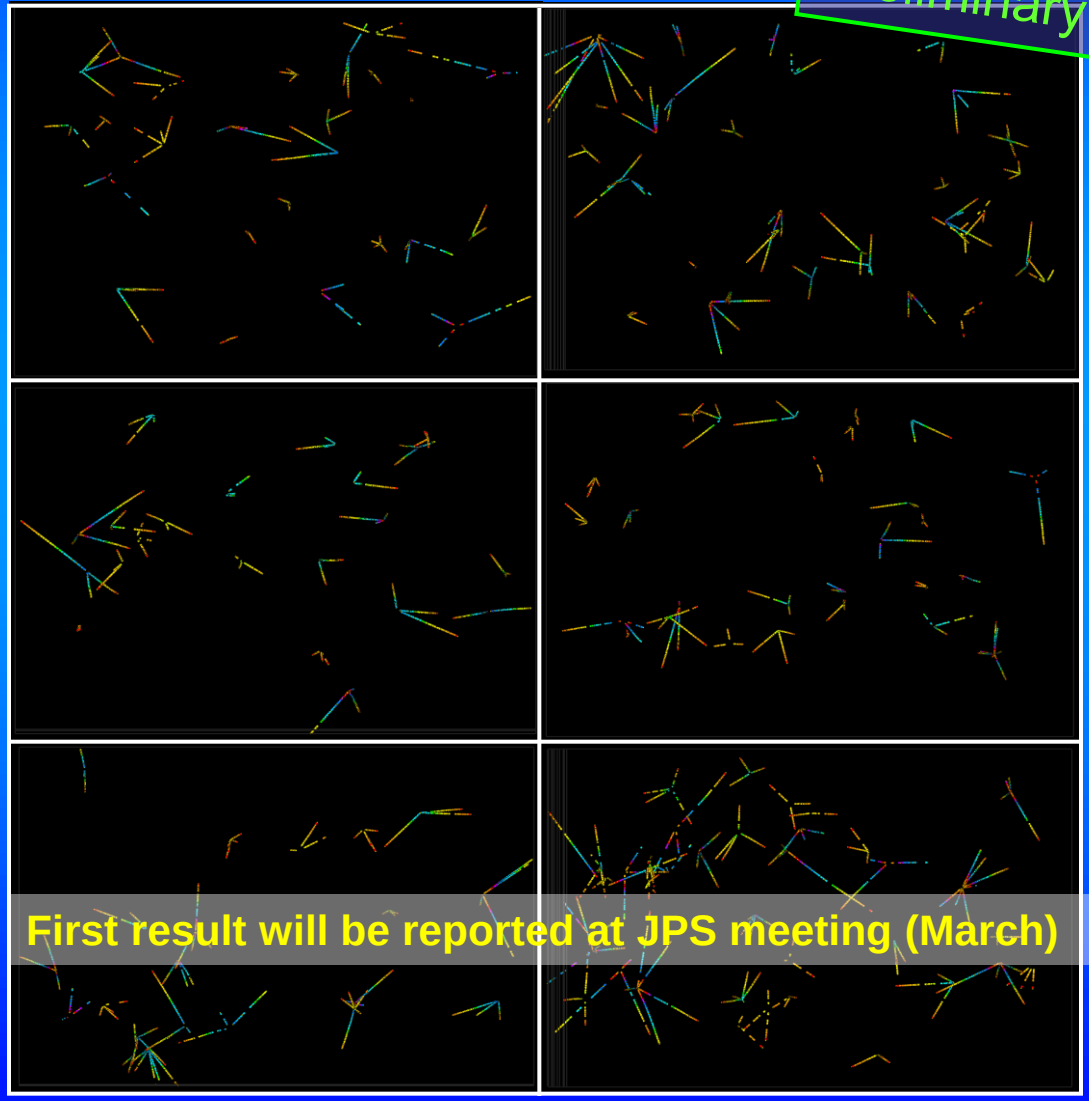




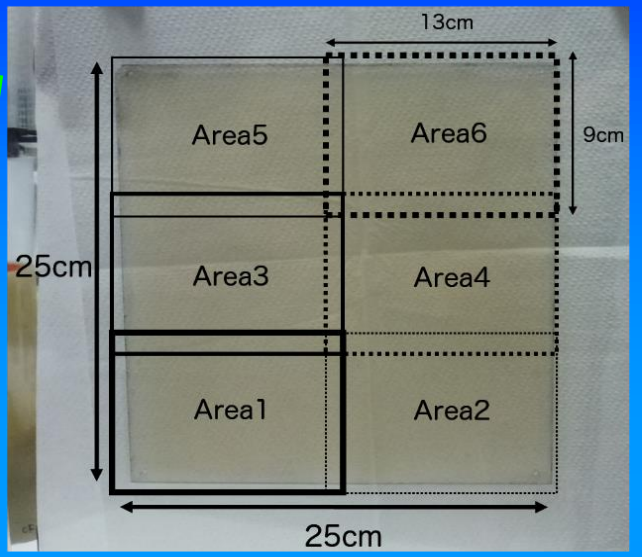
Event analysis is now in progress !

Neutrino event candidates

Preliminary result



First result will be reported at JPS meeting (March)



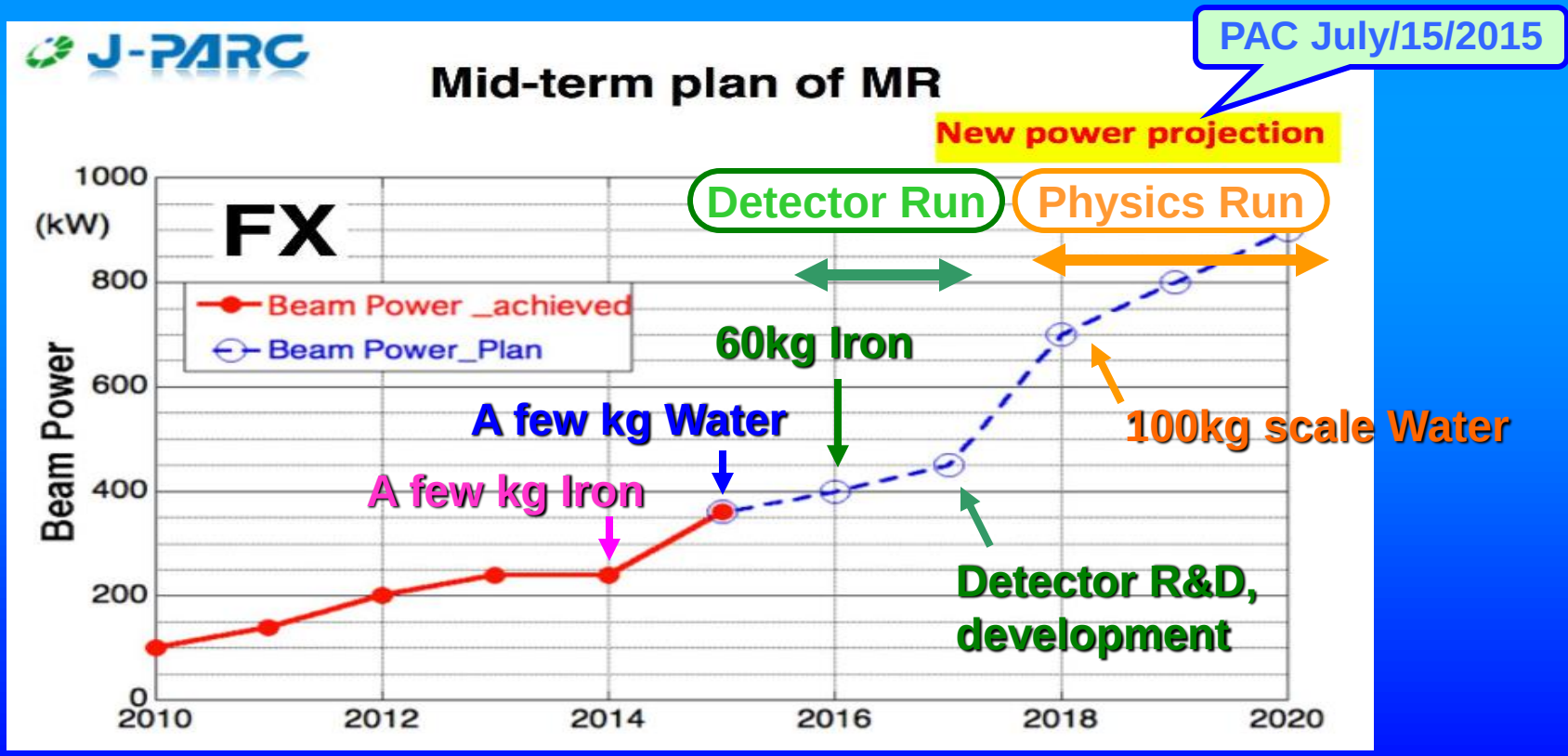
Current status (1ECC, ~1/12 of all)

	Area 1	Area 2	Are a3	Are a4	Are a5	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 future Physics Run.

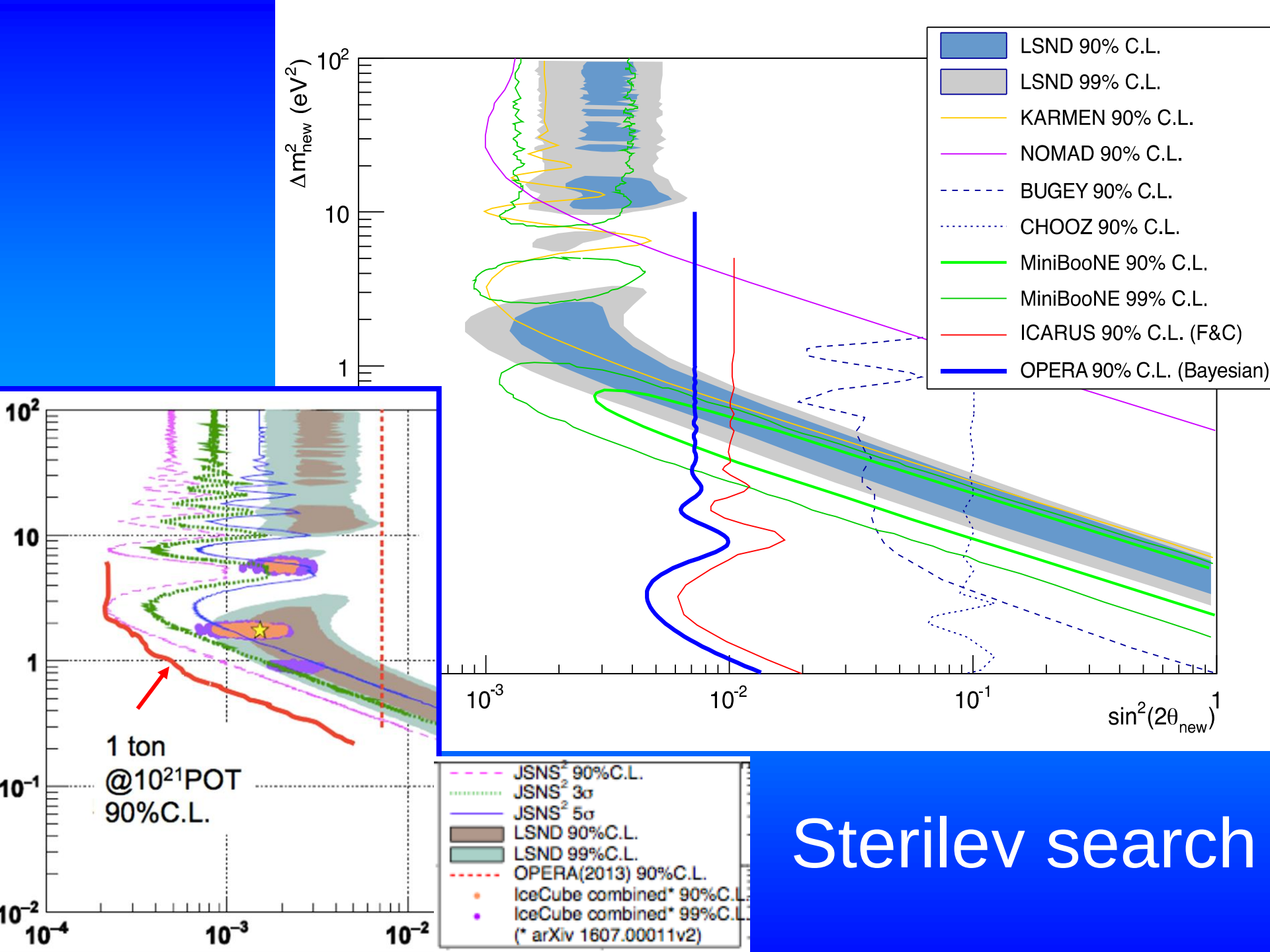
- R&D of the water target ECC is carrying out in this year.
- 100kg scale Water ECC is assumed. 10k order ν_μ int. and hundred order ν_e int. study in 2018-2019. Plan is optimized by the results of Detector Run.
- Then we will propose an experiment to explore sterile neutrinos with ton scale detector around 2020.



Summary

- There are many projects of next generation neutrino experiments which aim at finding the CP violating phase in the PMNS matrix, probing the neutrino mass hierarchy, search for sterile neutrinos and so on.
- These experiment plan to discover the rare effects and study them by measuring neutrino interactions precisely.
  Toward these goals, a lot of R&D activities for novel (near) detectors are going on in order to reduce systematic uncertainties.
- 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 by introducing nuclear emulsion.
- We are carrying out a test experiment at J-PARC (**T60**) to check the feasibility and detector performance.
- Beam exposure, film development and film scanning (data taking) for the 60kg iron target ECC was successfully done. The analysis is now in progress.
- We continue to expose ν beam for R&D of water target ECC and will make a detailed plan of future Physics Run.

backup



Sterilev search

Workshop on Hadron Production Measurements with Nuclear Emulsions

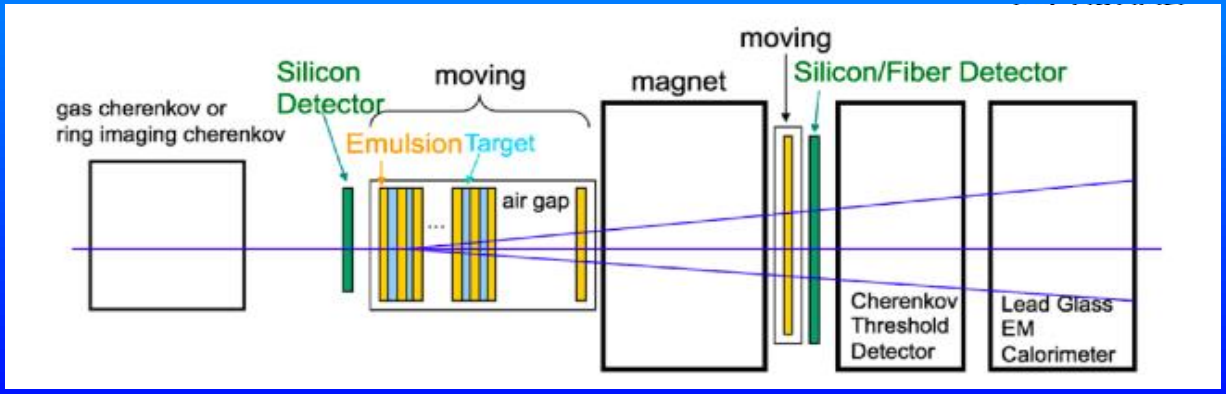
3-4 October 2016 *Nagoya University*
Asia/Tokyo timezone

http://indico.ipmu.jp/indico/conferenceDisplay.py?confId=108
(access key: "emulsionhadron")

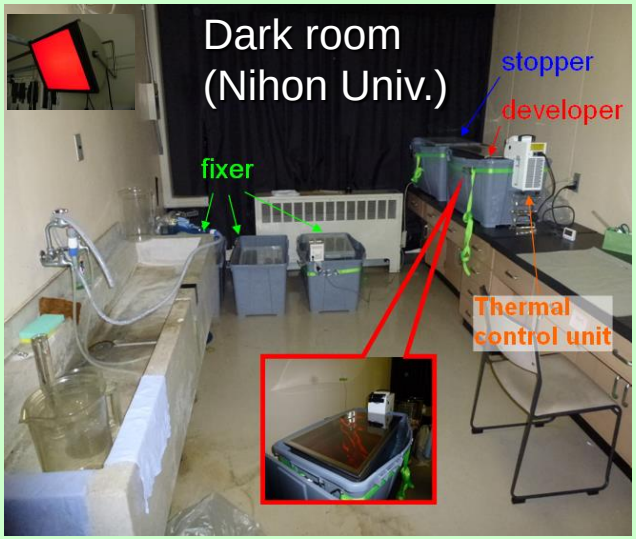
The large scale deployment, scanning and analysis of nuclear emulsion films has been proven with the successful detection of tau neutrinos in the OPERA experiment. Nuclear emulsion detectors may be applied to other measurements, including the measurement of hadron production in proton-nucleus scattering. Hadron production measurements for proton-nucleus collisions are critical for current and future neutrino oscillation experiments using atmospheric or accelerator neutrinos since the hadron production measurements feed directly into the calculation of neutrino fluxes. This workshop will focus and the plans and prospects for hadron production measurements using detectors with nuclear emulsion films.

Dates: from 03 October 2016 14:00 to 04 October 2016 17:00
Timezone: Asia/Tokyo
Location: *Nagoya University*
Room: ES635 KMI Science Symposia

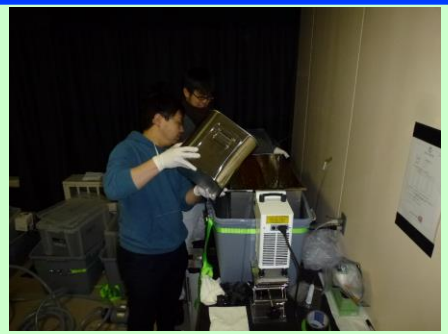
- We discussed about the possibility of future hadron production experiment with nuclear emulsion.

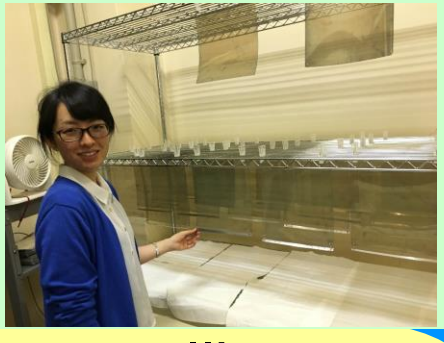


Hardware treatment of the emulsion films



1. Developing

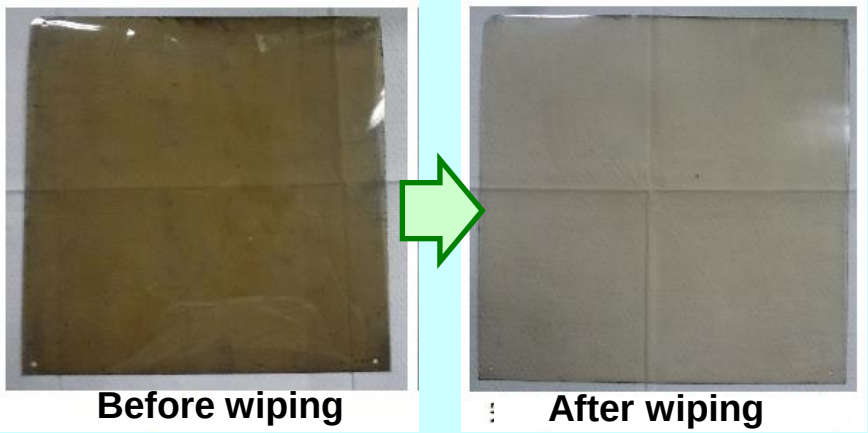





Development process

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

2. Surface silver cleaning



Before wiping　　After wiping

More than 300 films were completed.

3. Emulsion swelling

Recovering of emulsion thickness