NINJA Experiment :

Neutrino Interaction research with Nuclear emulsion and J-PARC Accelerator

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on behalf of the NINJA Collaboration

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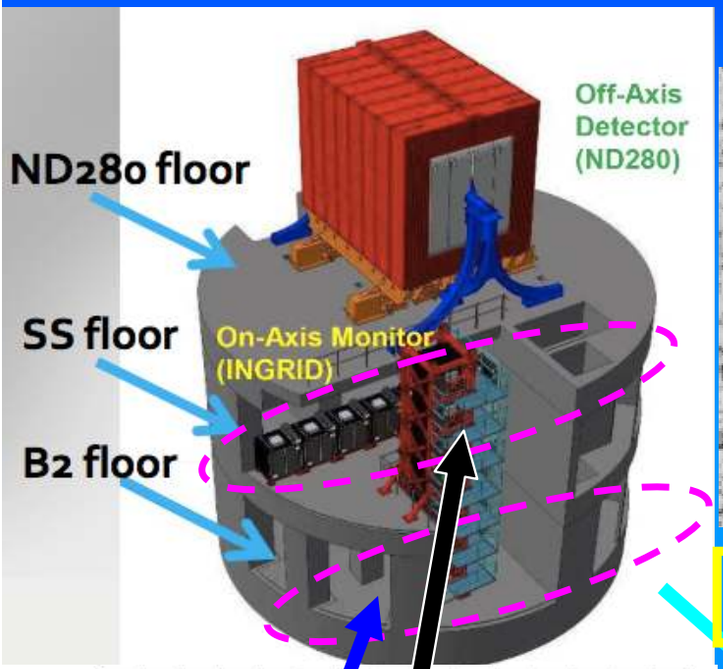
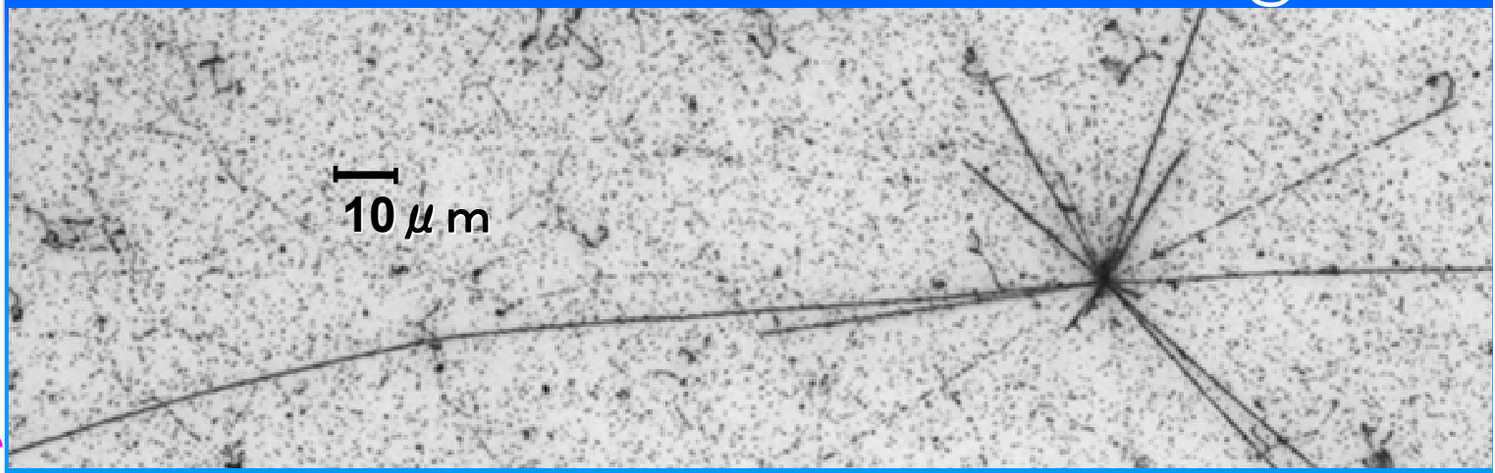
NINJA Experiment

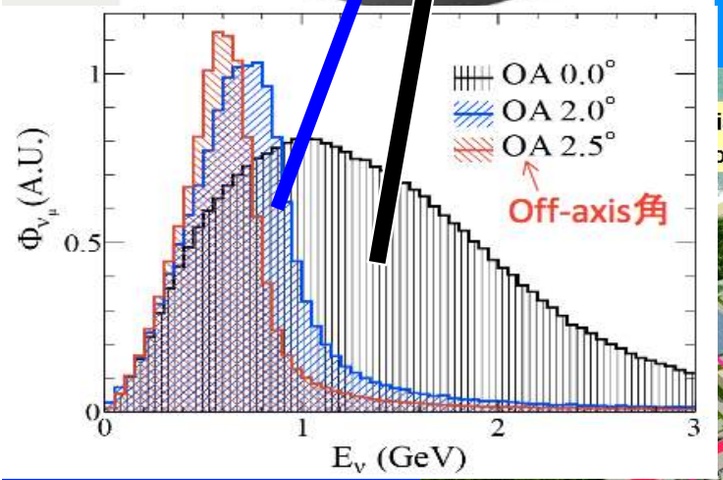
Neutrino **I**nteraction research with **N**uclear emulsion and **J**-PARC **A**ccelerator

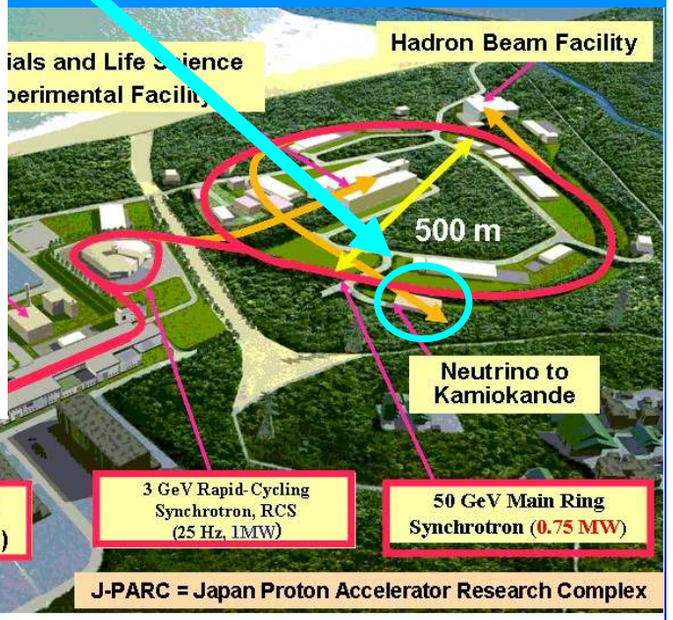


A neutrino interaction in emulsion @J-PARC



A collaborative project with some member of OPERA and T2K





Working group

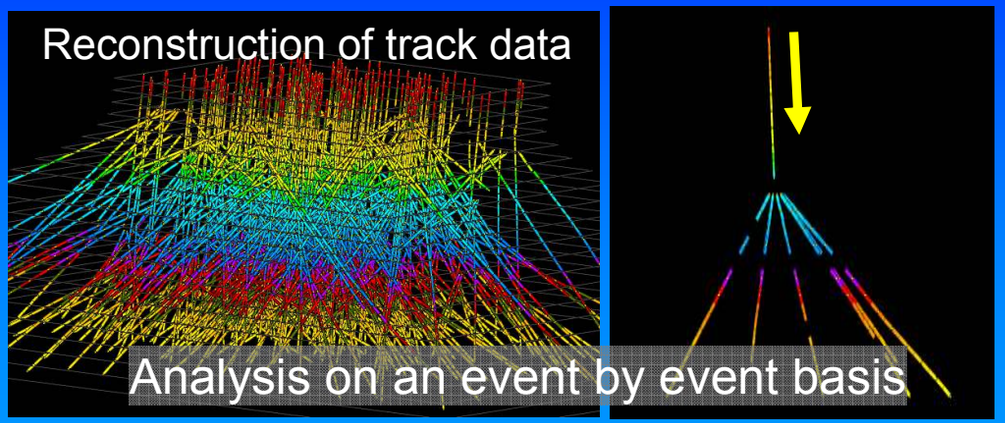
OPERA — **J-PARC** — **T2K**

Experimental site, Neutrino beam

- **Nihon Univ.** — Emulsion development
- **Nagoya Univ.** — Film production, Scan
- **Toho Univ.** — Film production, Scan
- **Univ. Tokyo** — T2K near detector
- **Kyoto Univ.** — T2K near detector
- **Yokohama N Univ.** — T2K near detector
- **Kobe Univ.** — Emulsion Shifter

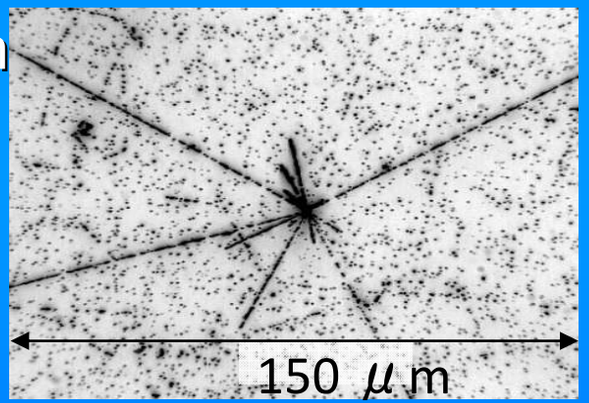
Nuclear Emulsion Detector

3D reconstruction

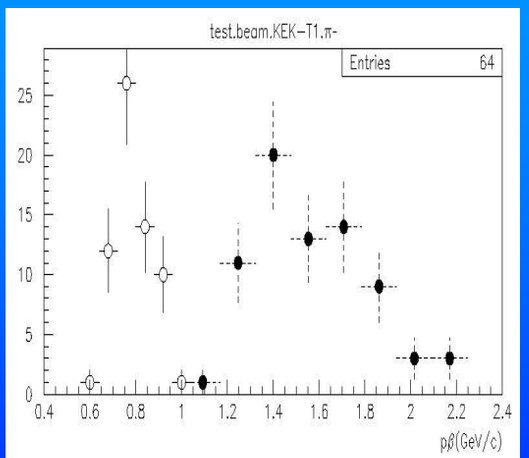


Scalability

4 π detection

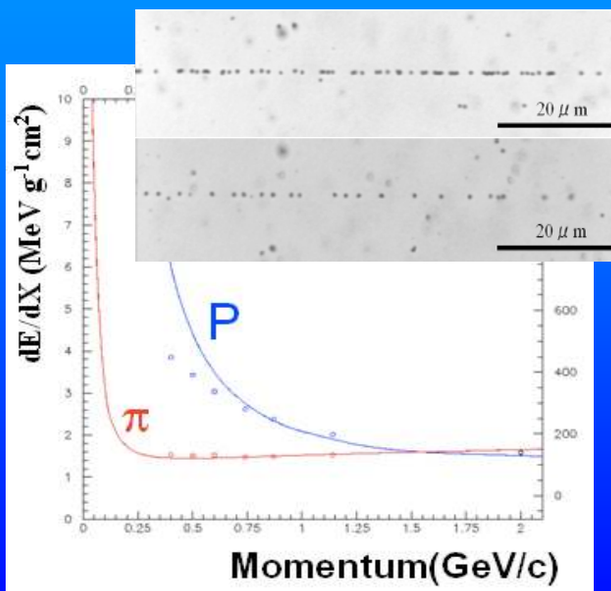


Momentum, dE/dx measurement

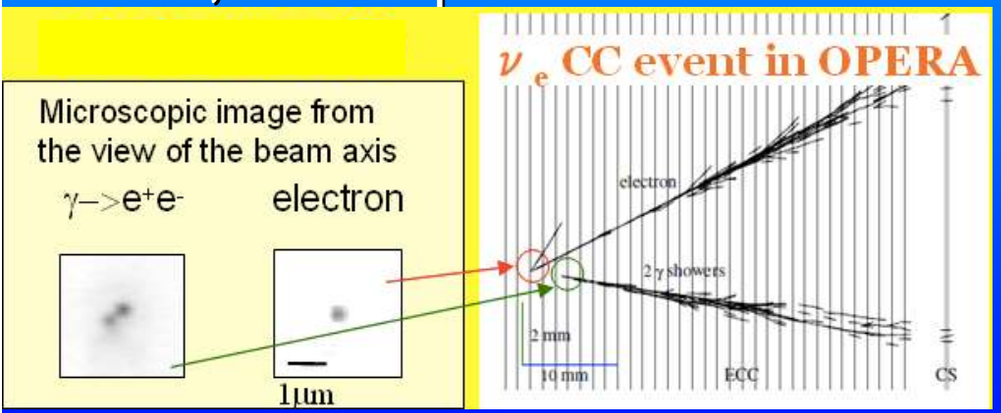


0.8GeV/c π : P =0.79(GeV/c), dP/P =**11**%

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



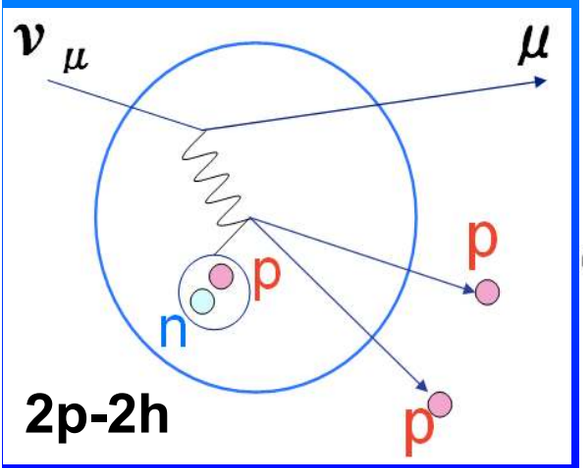
Good γ / π^0 separation

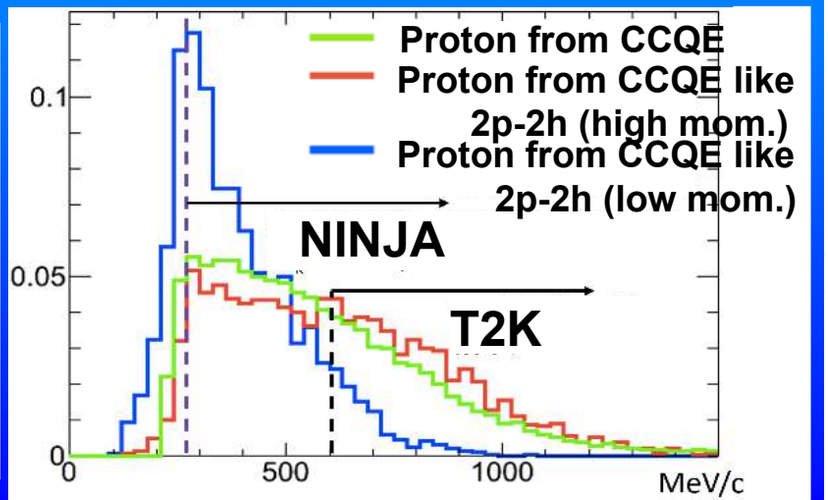


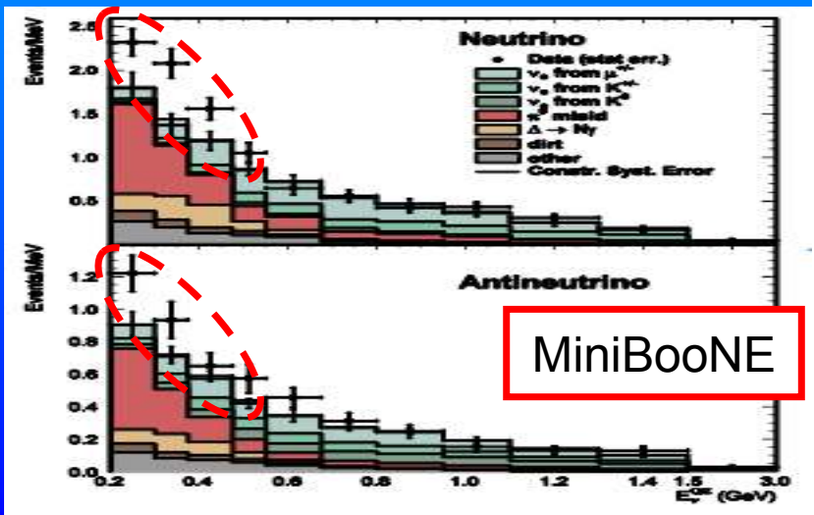
Low BG from ν_μ NC π^0 production

Physics motivation

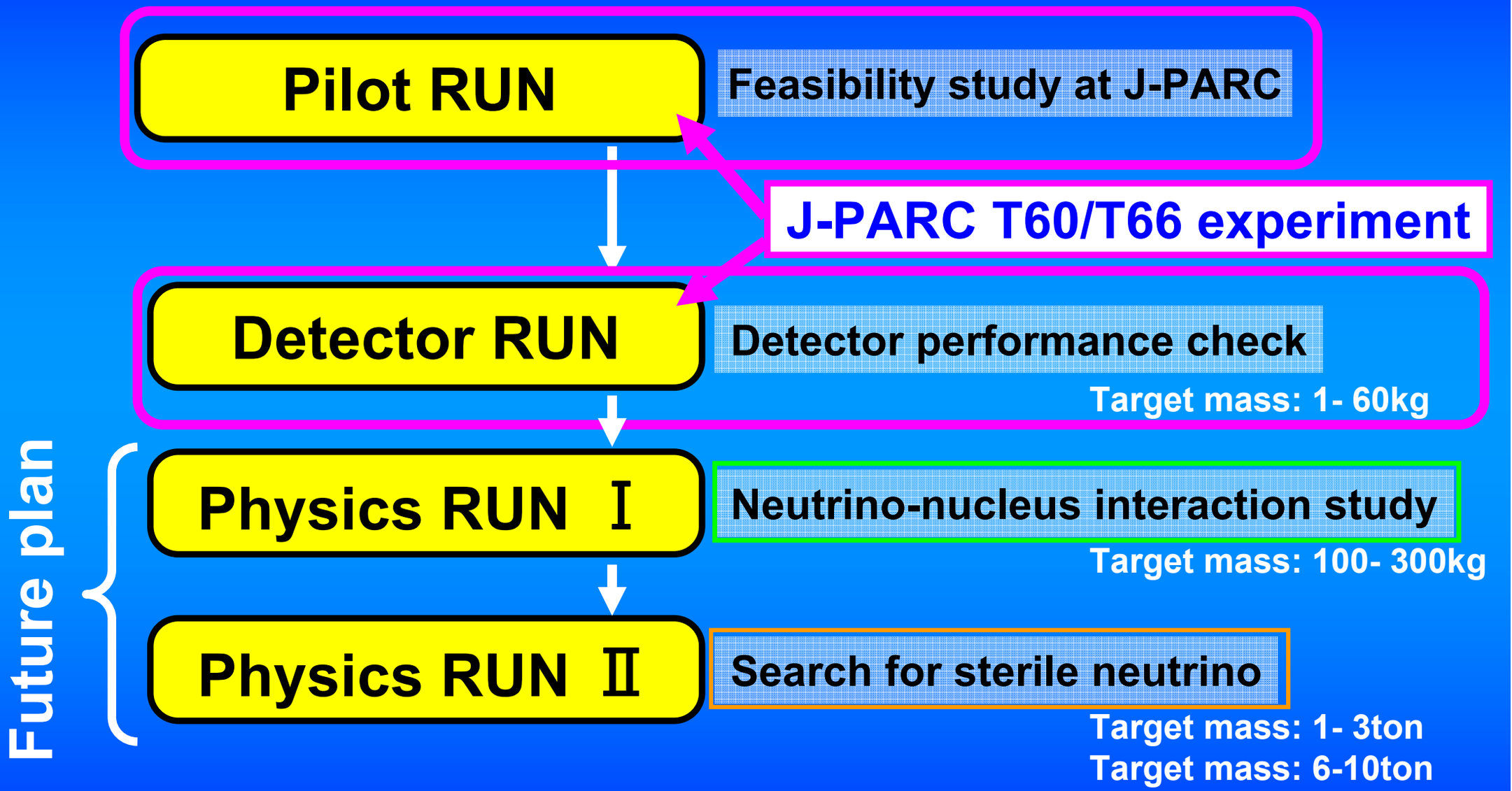
- Precise neutrino-nucleus interaction measurement is important to reduce the systematic uncertainty in future neutrino oscillation experiments.
- We started a new experiment at J-PARC to study low energy neutrino interactions by introducing nuclear emulsion technique.
- The emulsion technique can measure 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.







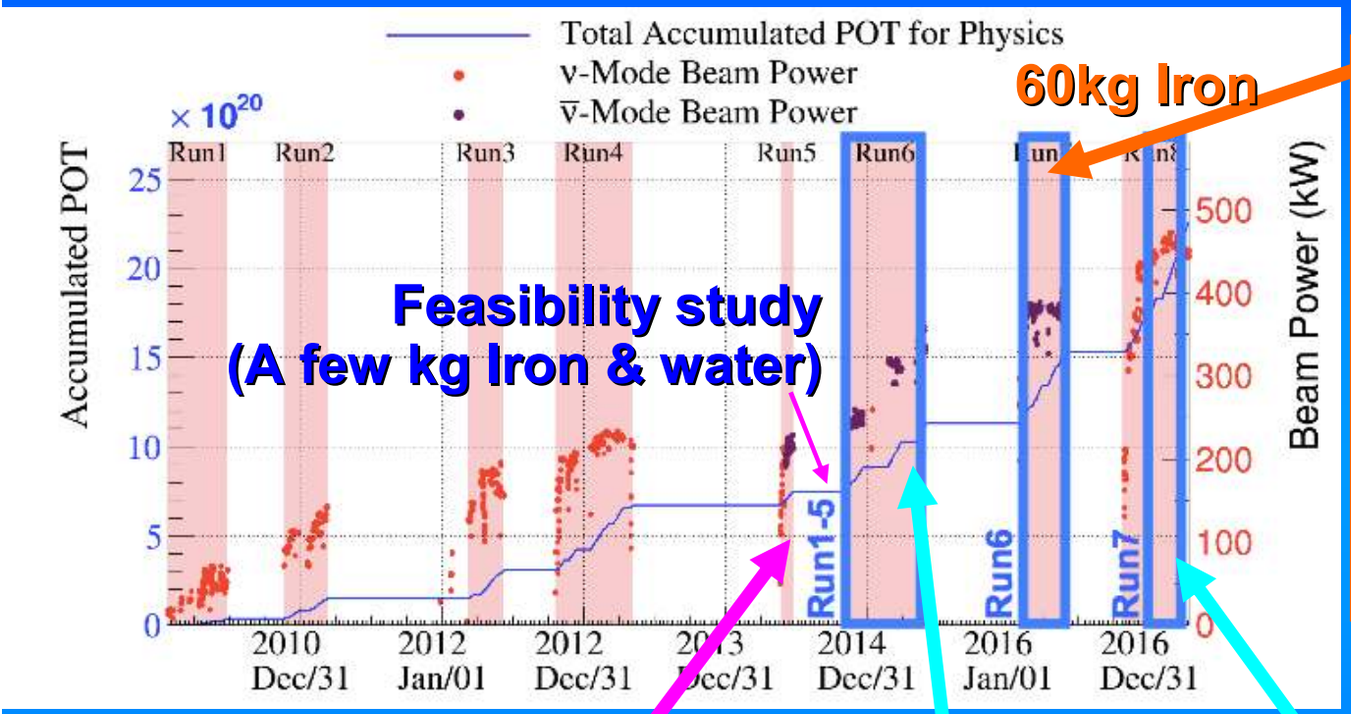
NINJA Roadmap



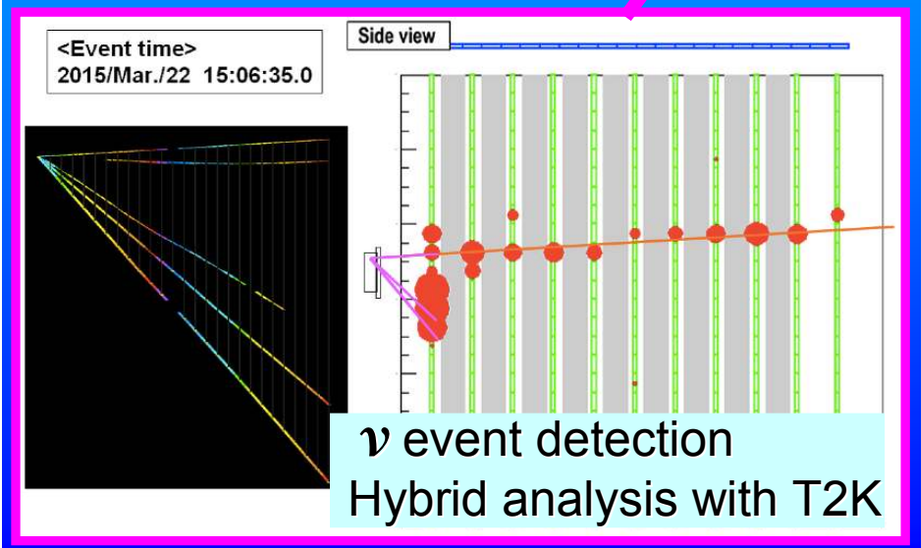
- The aim of T60/T66 is a feasibility study and detector performance check to make a future plan.
- We will expand the scale of detector gradually, step by step.

ν exposure status of NINJA

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

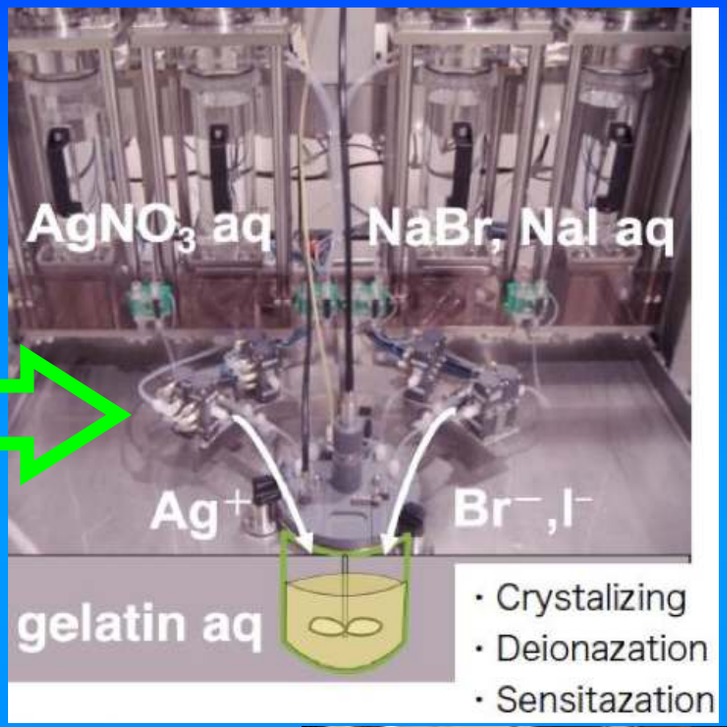


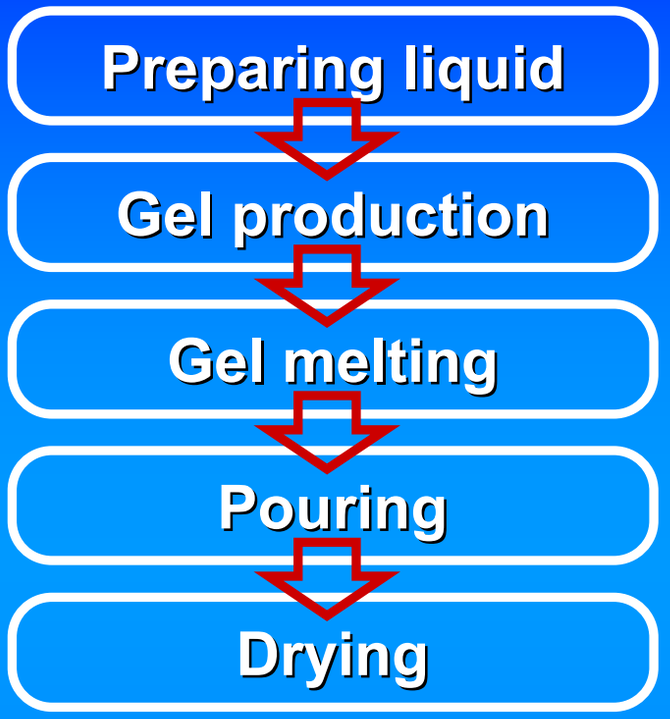
Analysis is now on progress

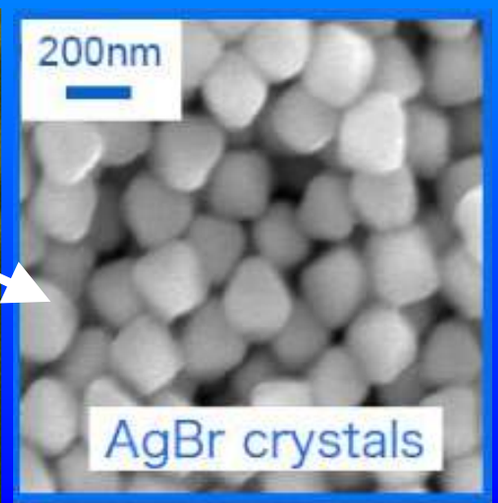


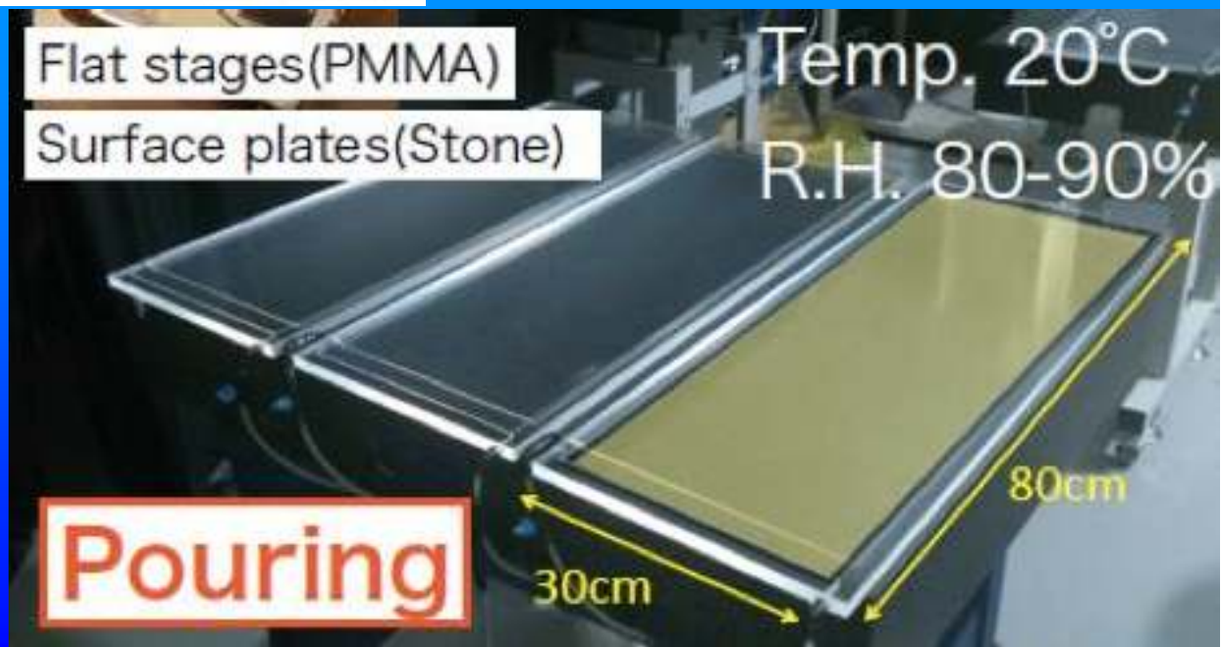
Emulsion film production in the lab

Nuclear emulsion films were made by ourselves

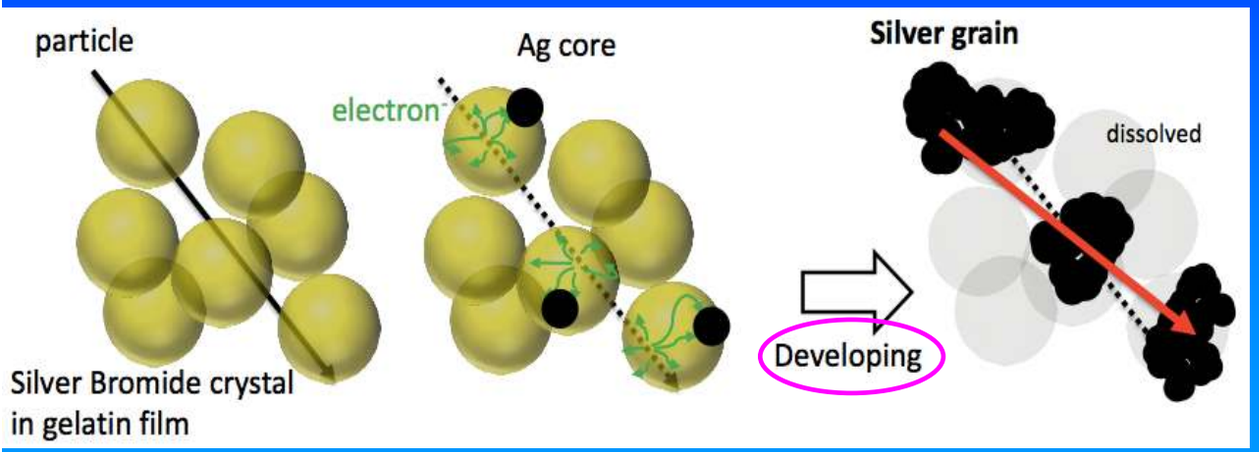






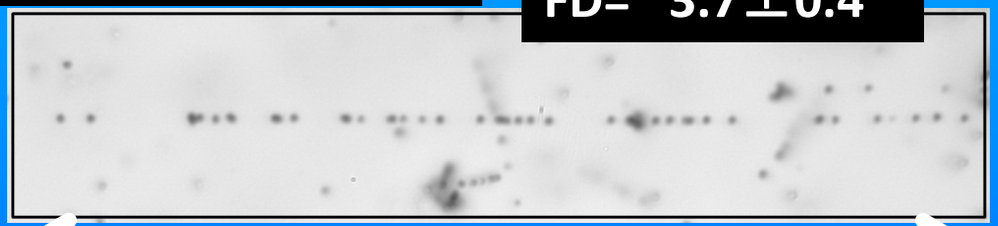


- Nuclear Emulsion is a special photographic film.
- Signal is amplified by chemical process.



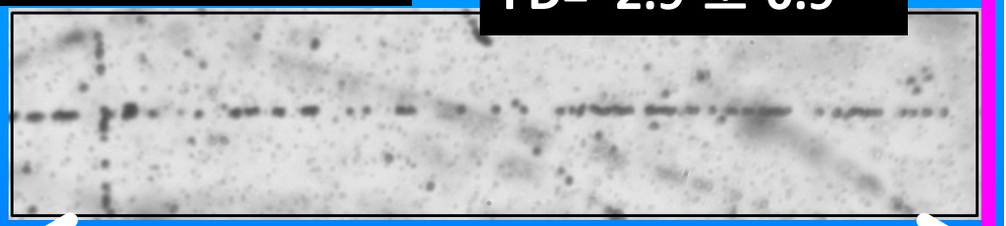
OPERA type

GD=34.8±0.6
FD= 3.7±0.4



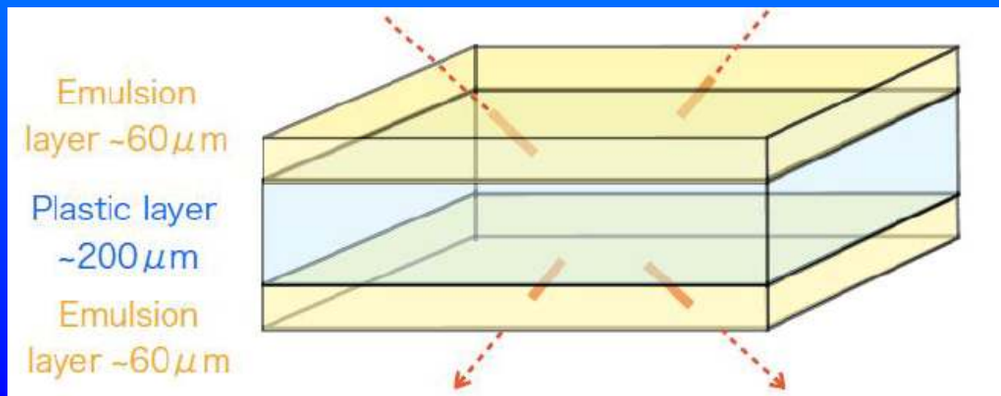
New type

GD= 86.1± 4.7
FD= 2.9 ± 0.9



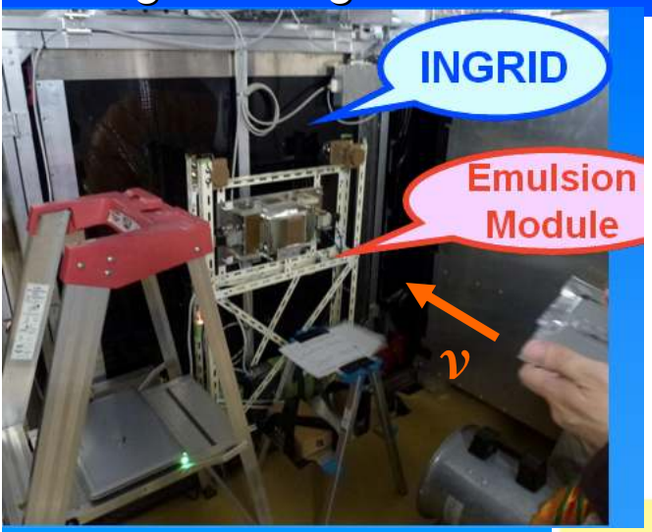
We can control the signal density in the films.

3 dimensional tracking detector with submicron position resolution

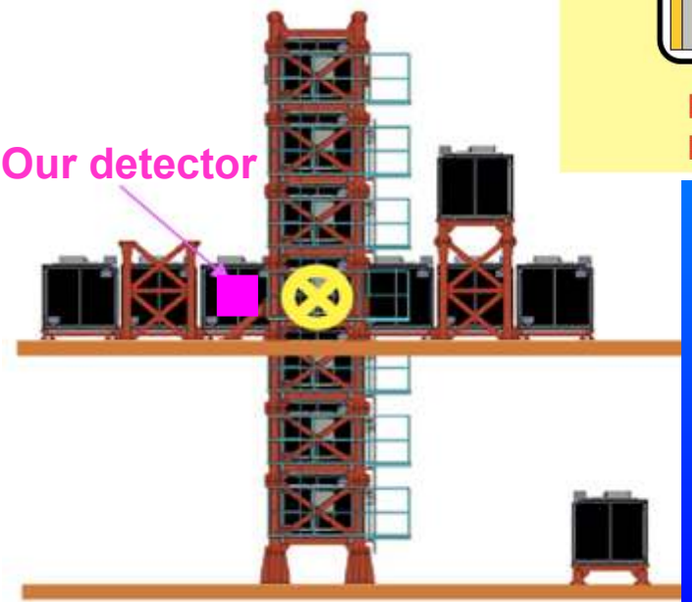


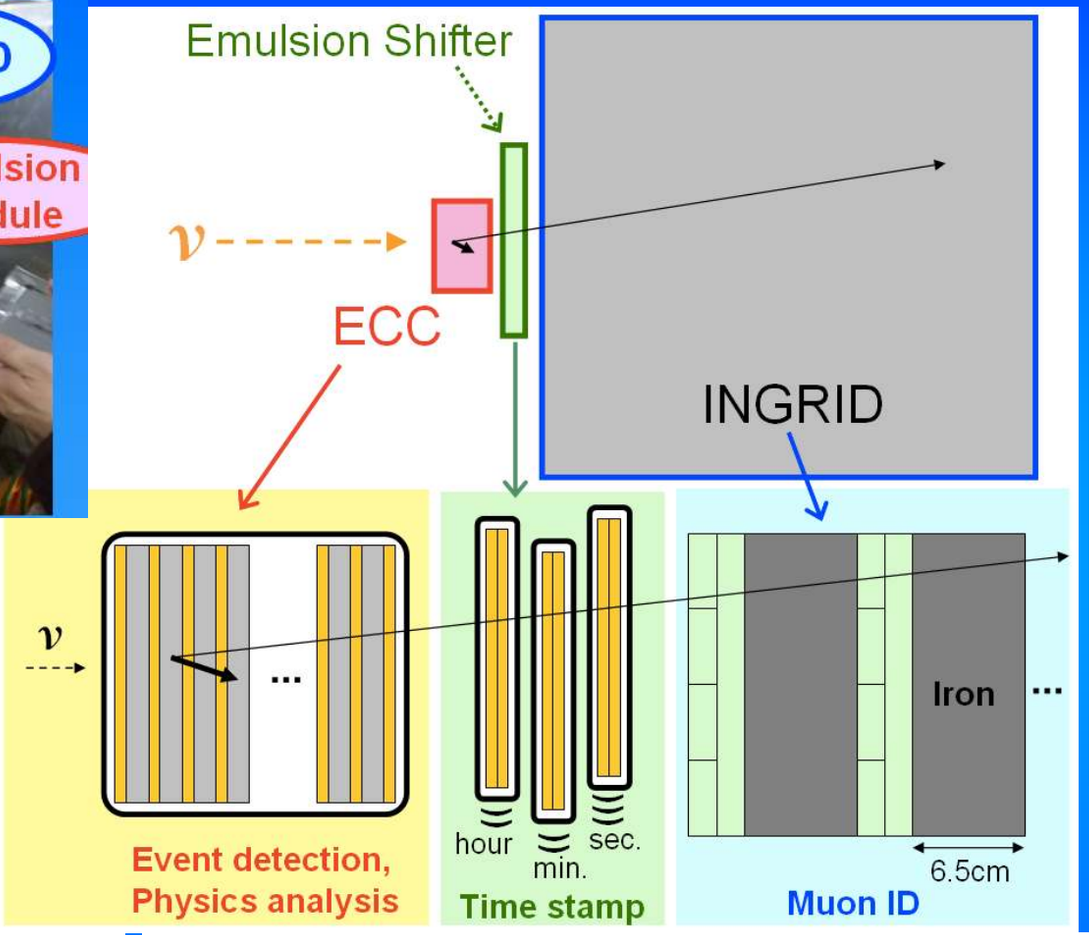
Conceptual design of the detector

2kg iron target ECC

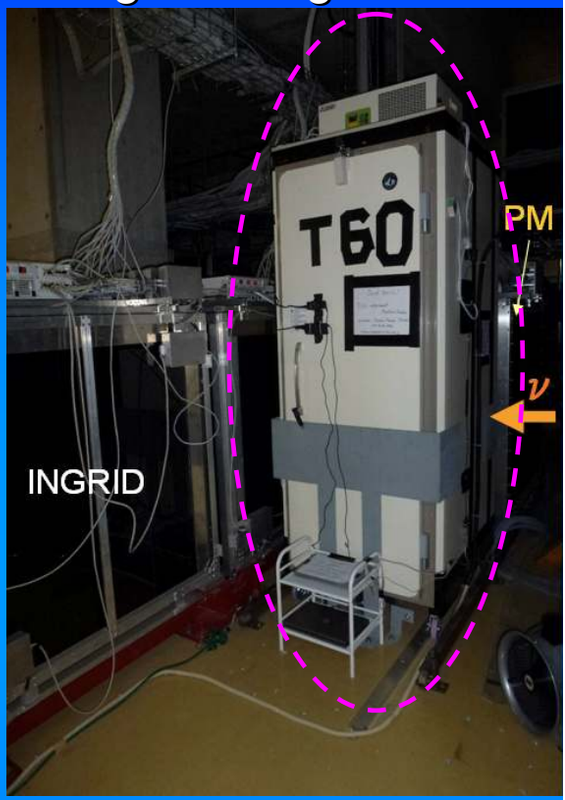


SS floor @J-PARC
(Jan. 2015)





60kg iron target ECC

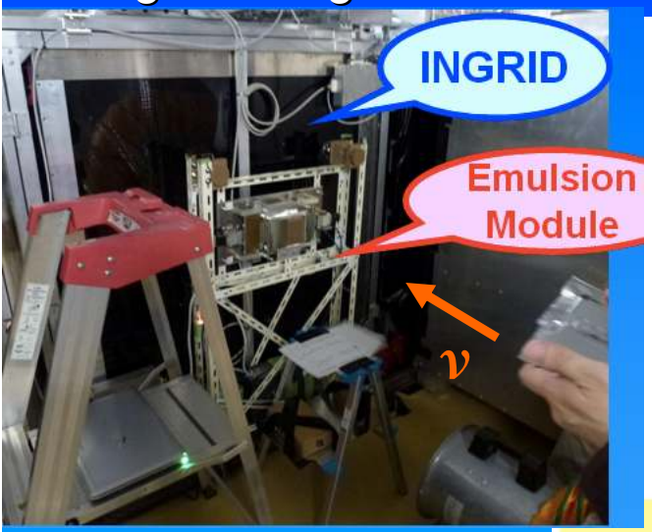


SS floor @J-PARC
(Jan. 2016)

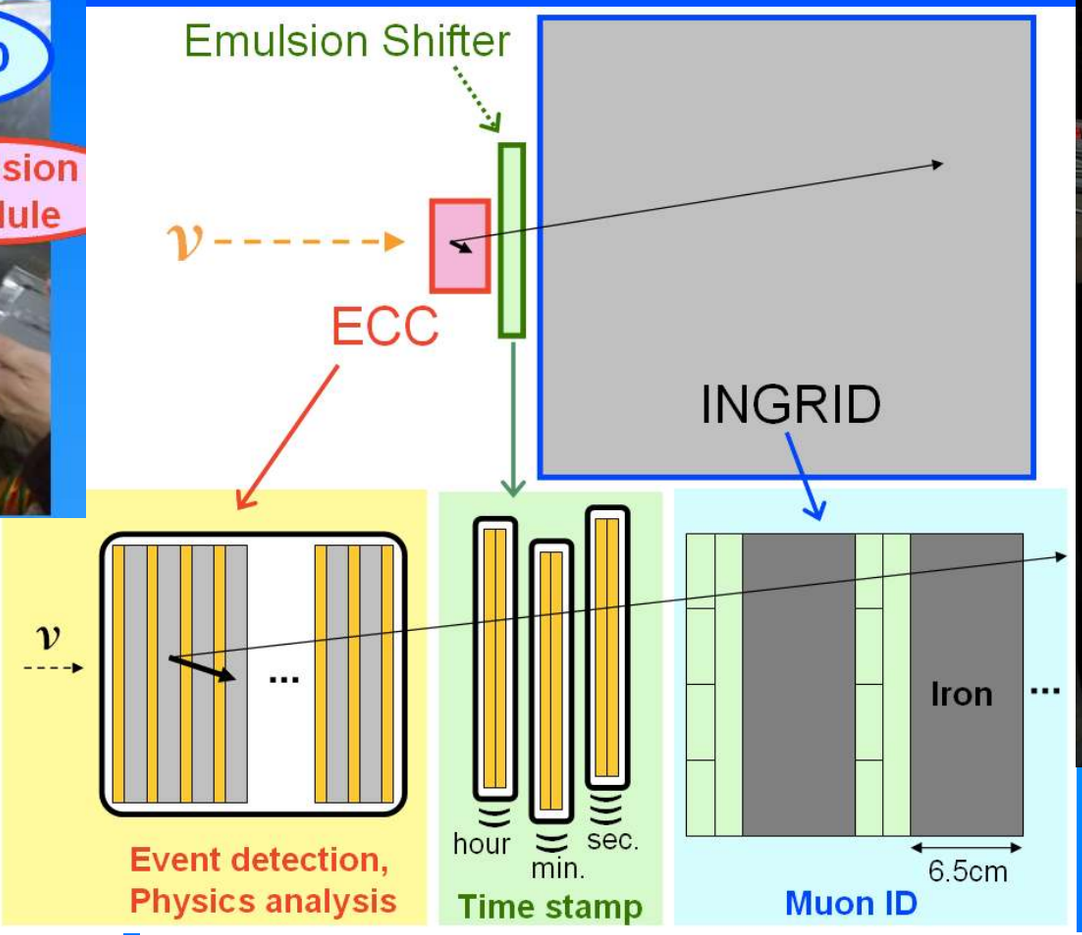
- **E**mulsion **C**loud **C**hamber (**ECC**) is a sandwich structure of emulsion films and materials.
- Emulsion detector is placed in front of T2K near detector, INGRID.
- Emulsion Shifter is re-used from a balloon project with emulsion to give a timing info. to emulsion tracks.
- Muon ID is possible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

Conceptual design of the detector

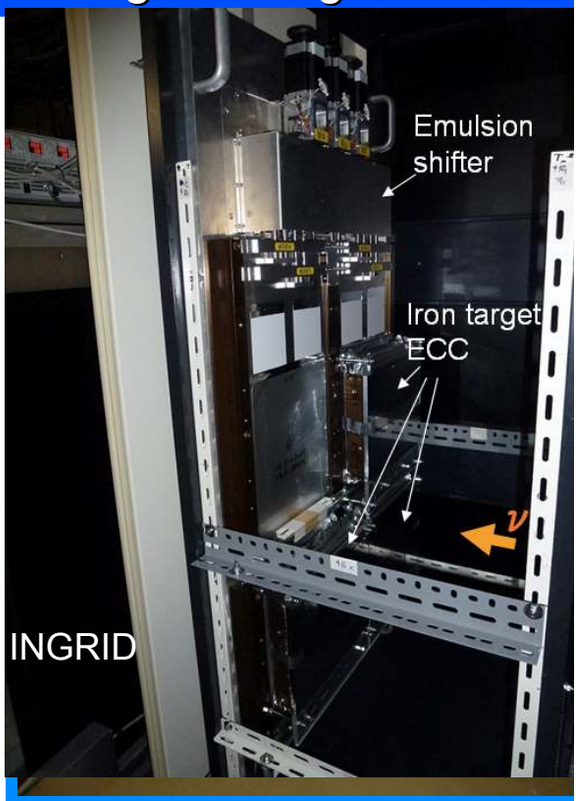
2kg iron target ECC



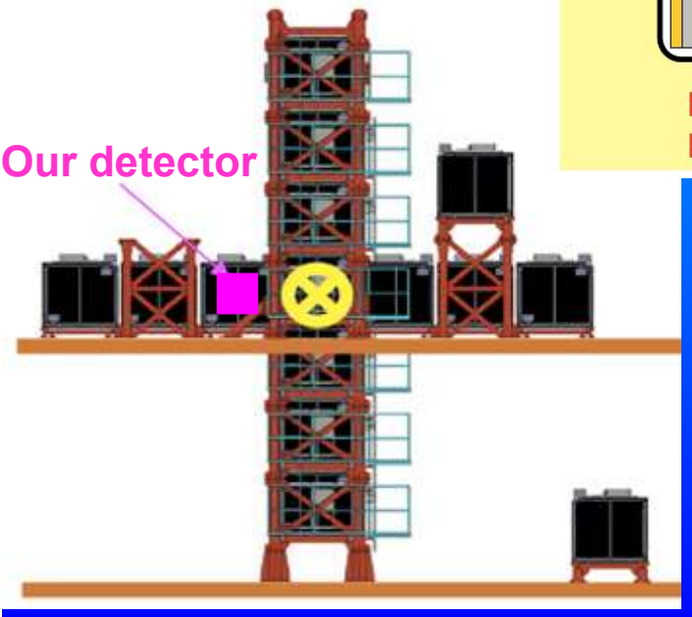
SS floor @J-PARC (Jan. 2015)



60kg iron target ECC



SS floor @J-PARC (Jan. 2016)



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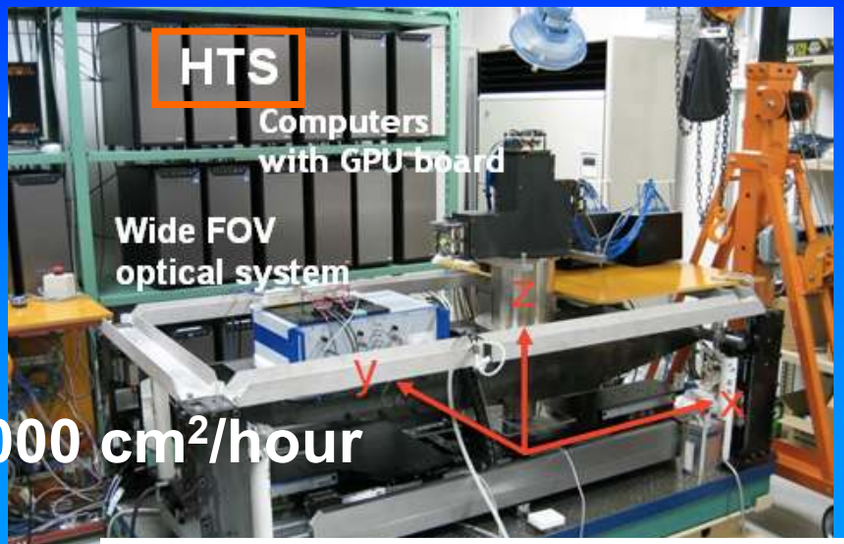
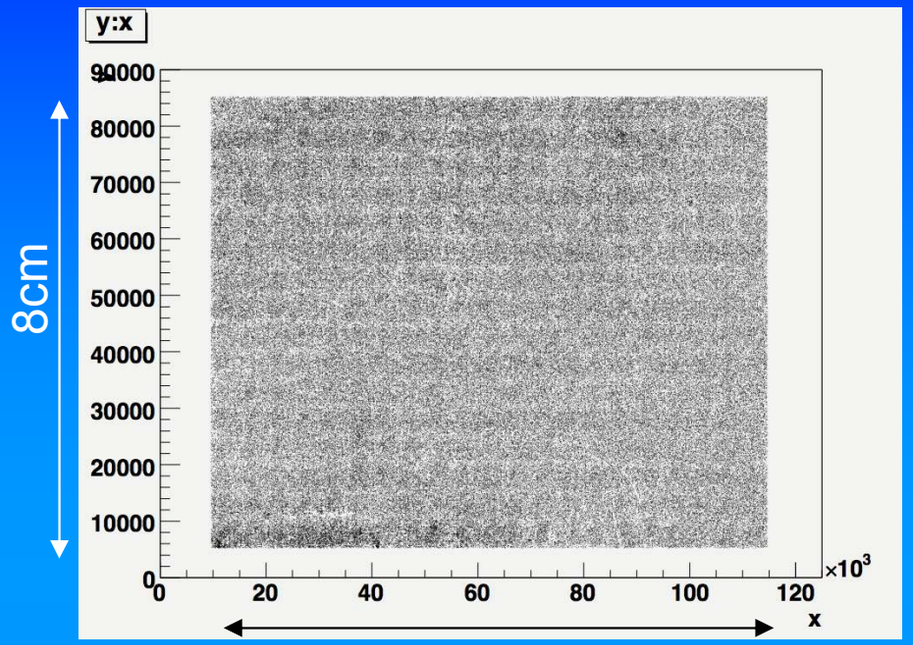
Data taking by emulsion scanning system



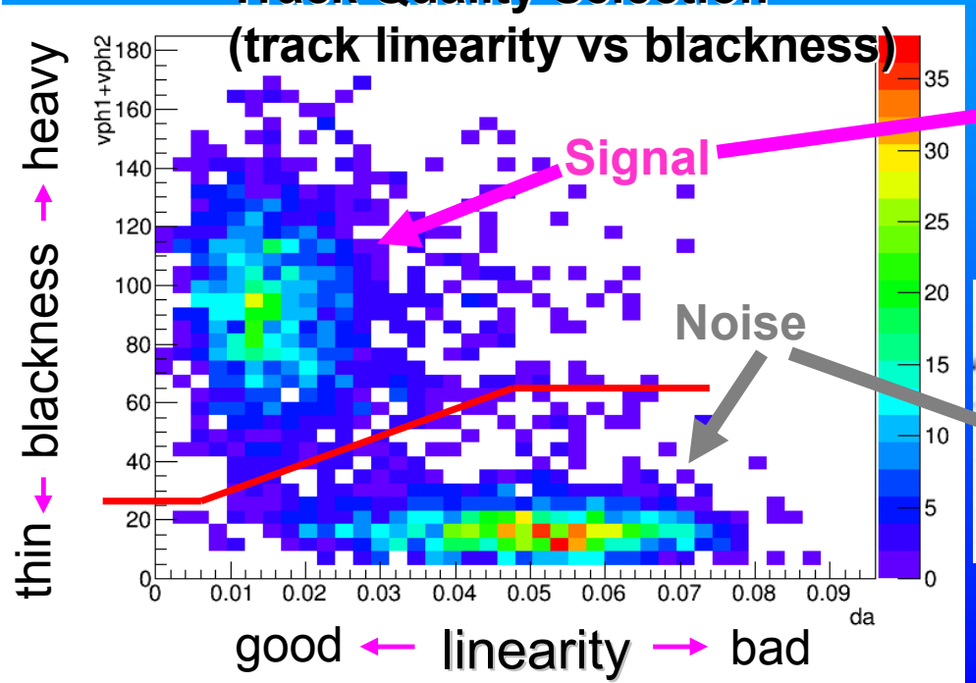
5,000 cm²/hour

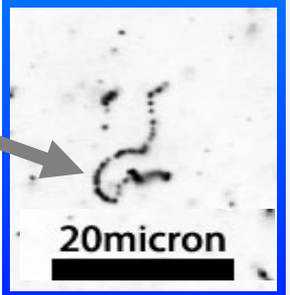
Latest high speed scanning system developed in Nagoya Univ.

Position distribution

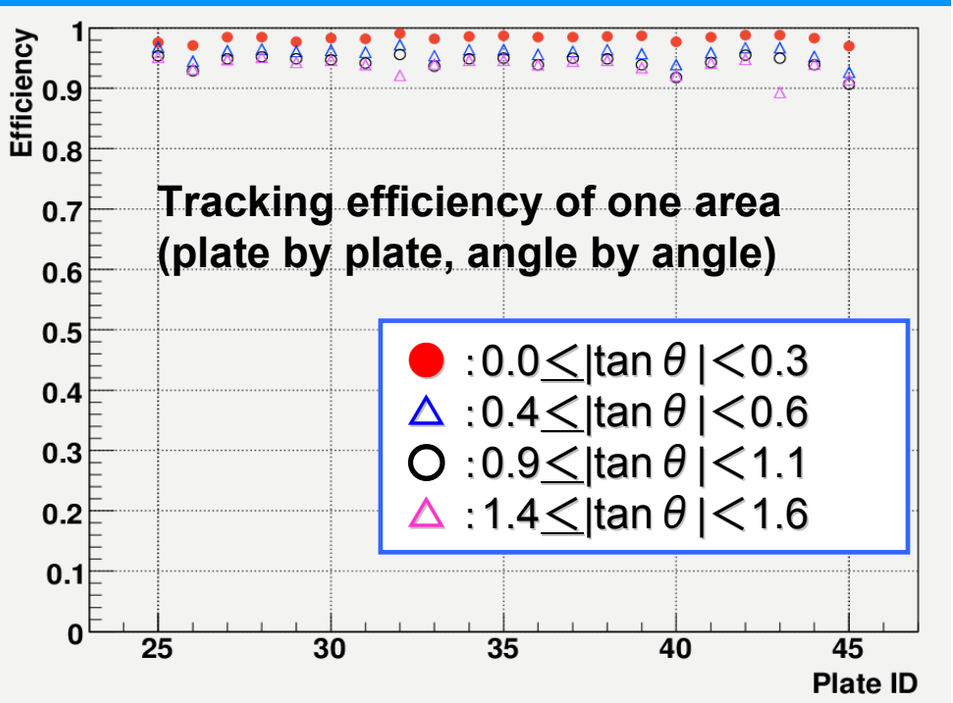


Track Quality Selection
(track linearity vs blackness)

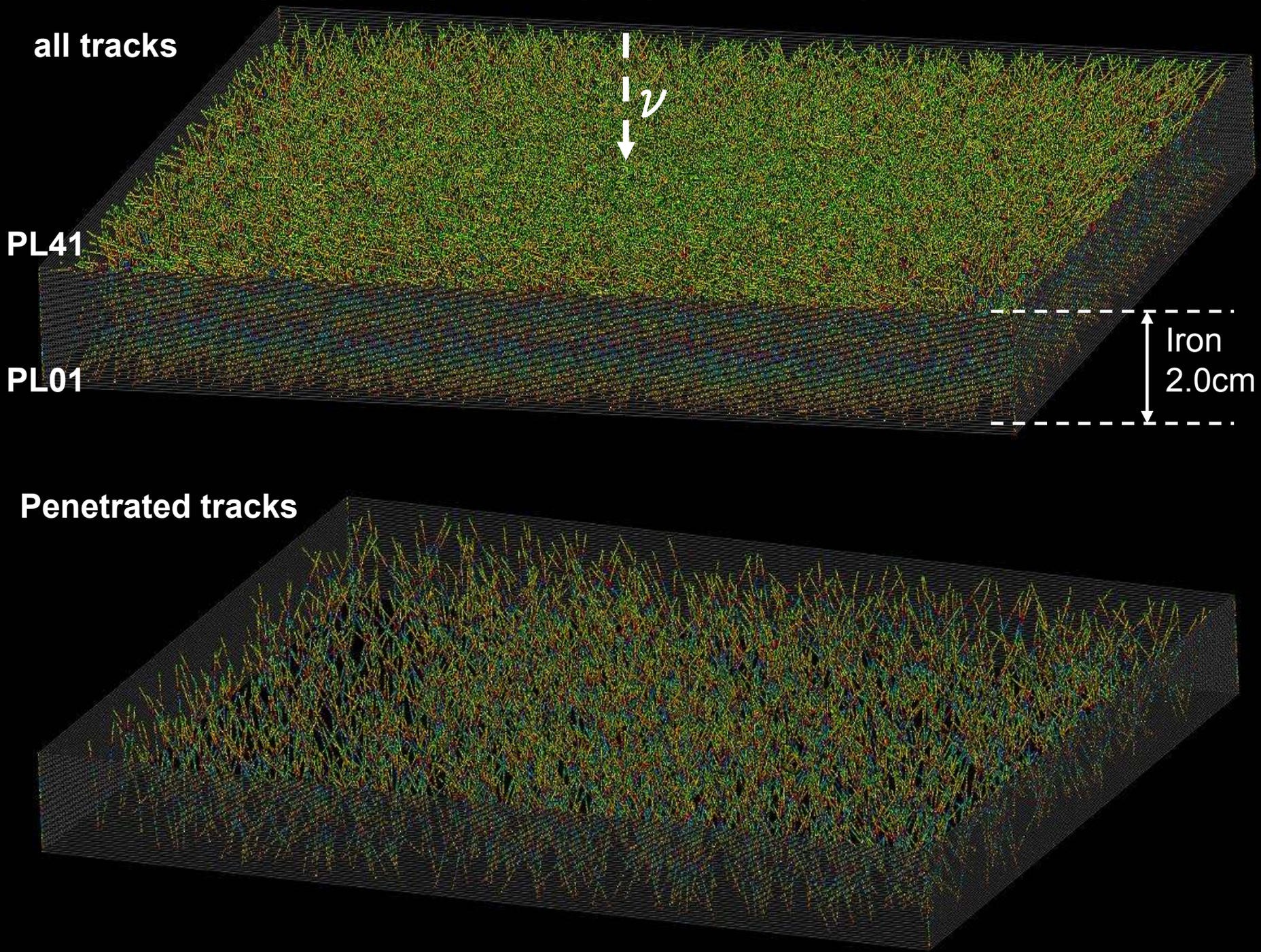




Sub-MeV electron

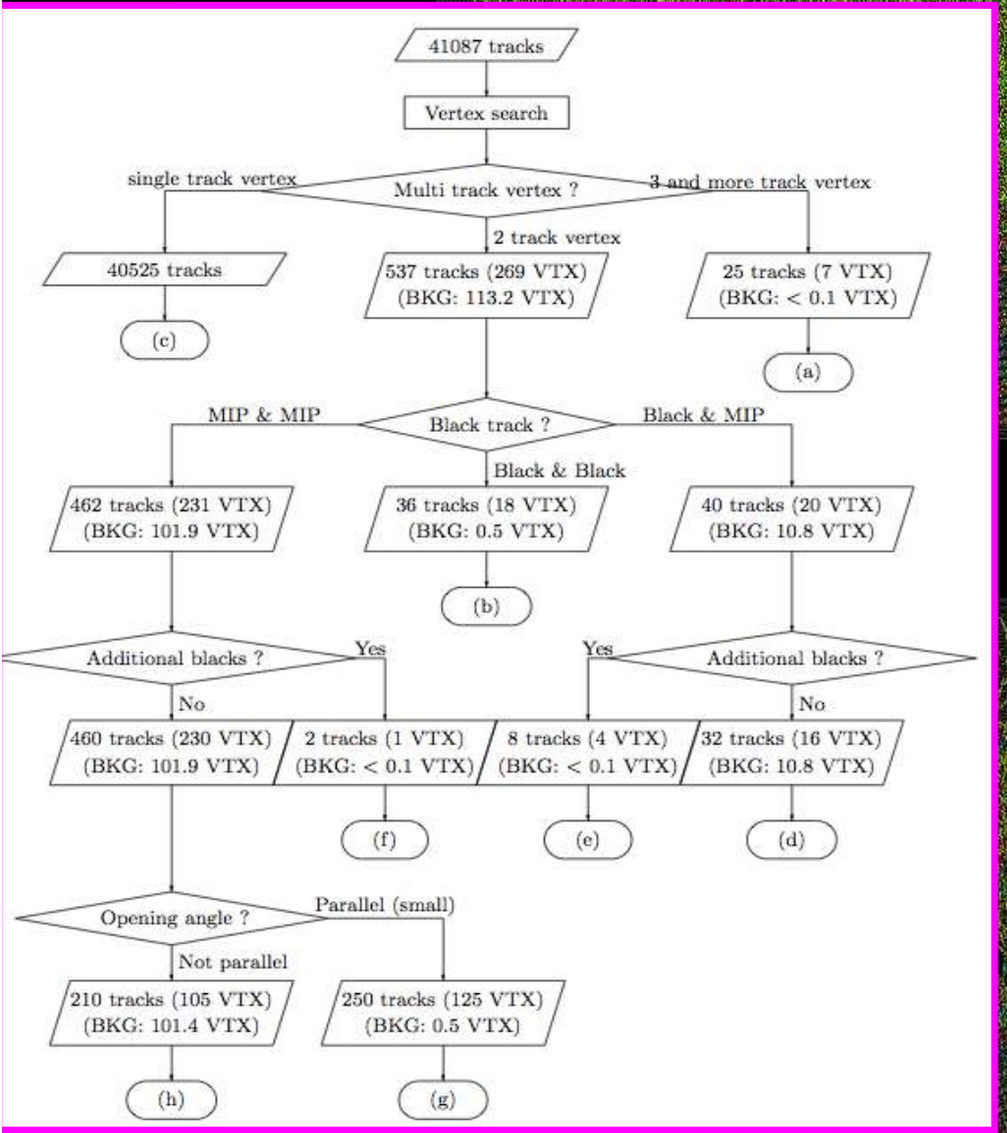


Reconstructed track data



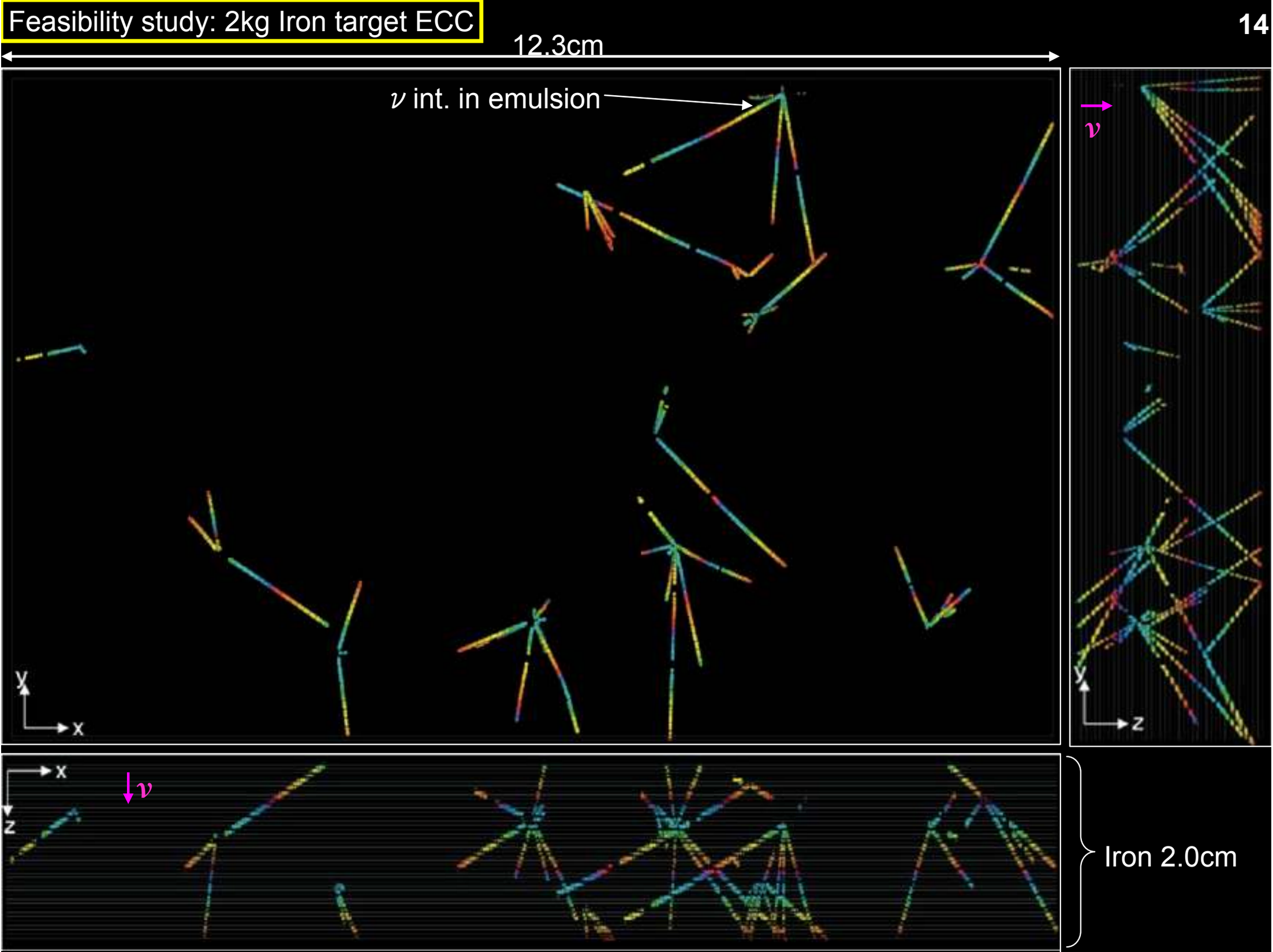
Reconstructed track data

all tracks



Multi-track vertex selection criteria

Feasibility study: 2kg Iron target ECC



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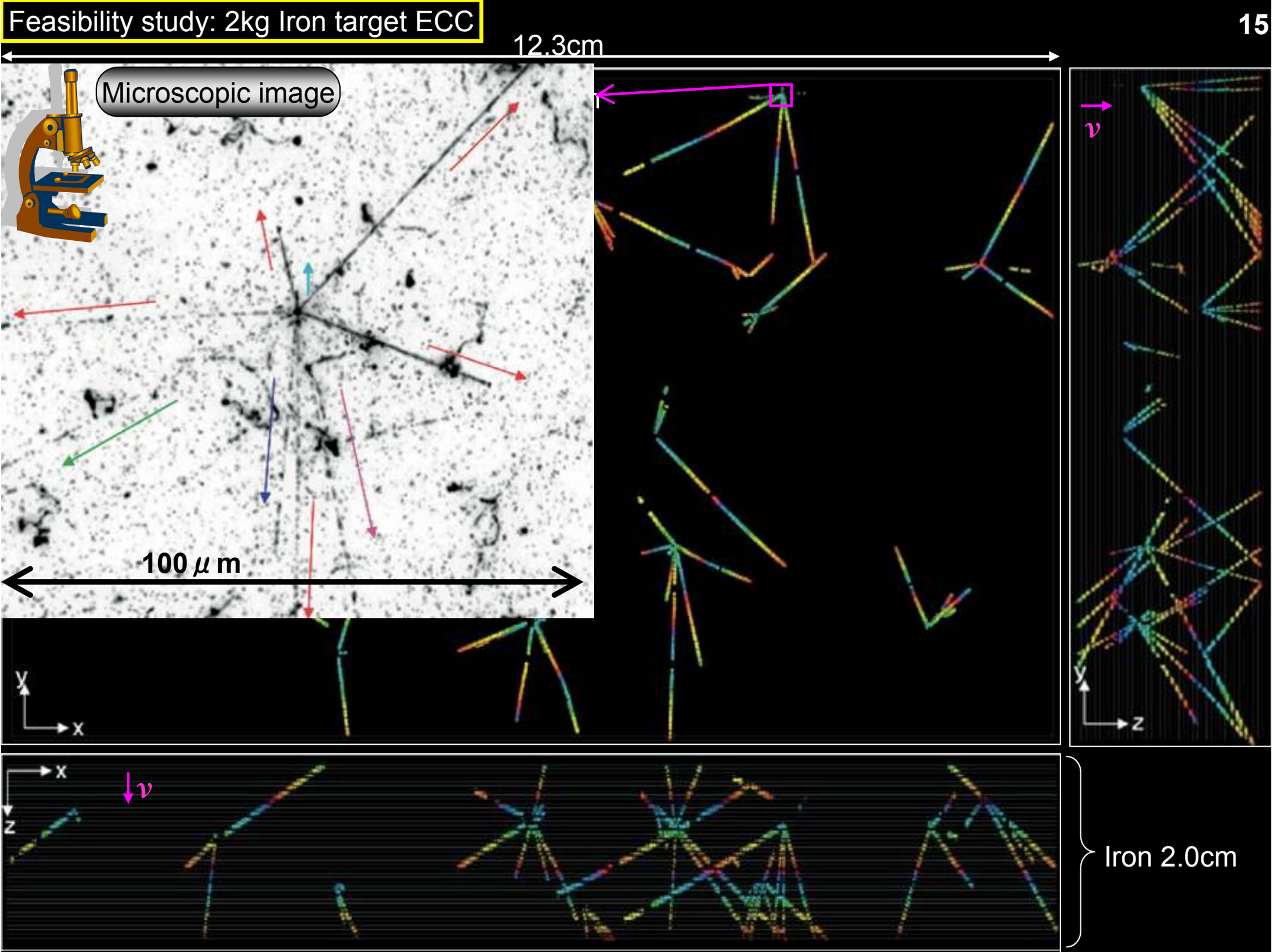
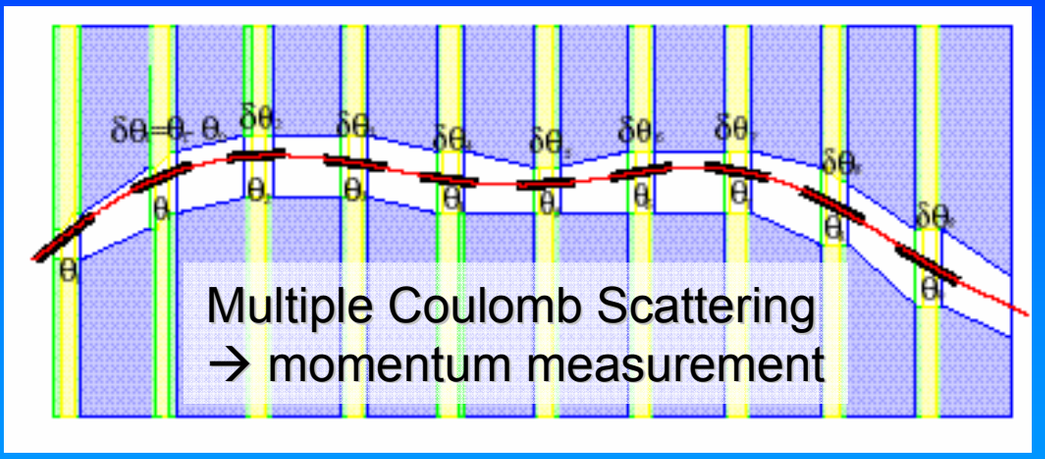


Proton identification

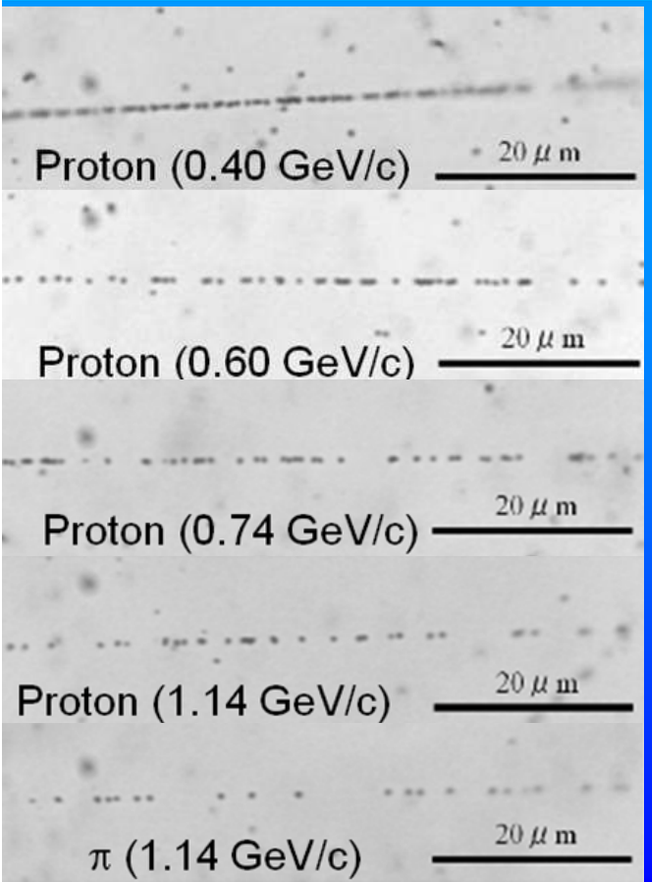
p β measurement by the MCS method

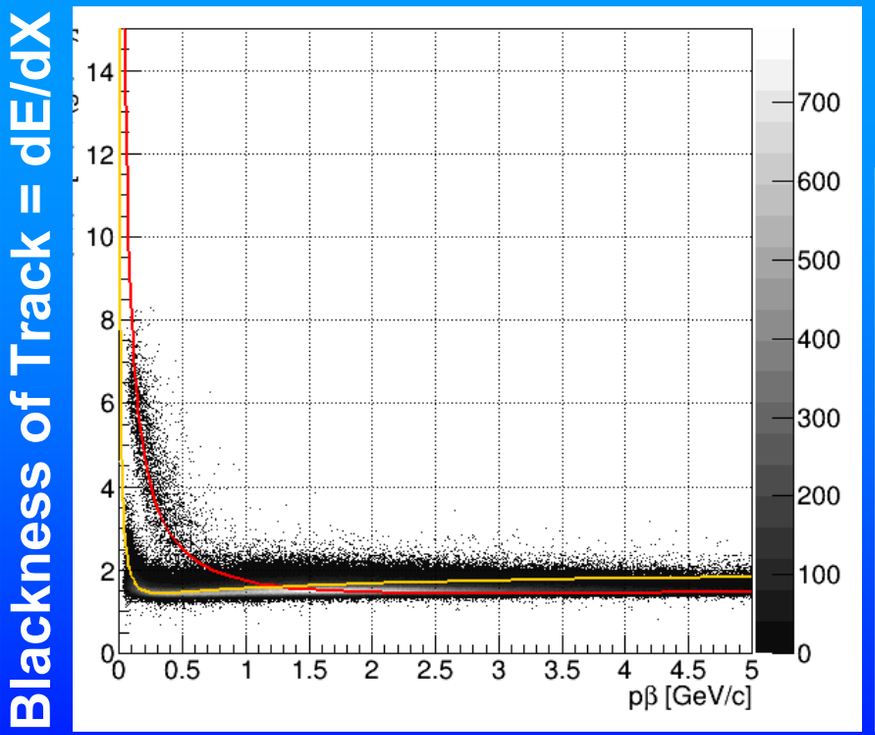
$$P\beta = \frac{13.6\ (\mathrm{MeV/c})}{\sigma_{\delta\theta}}\sqrt{\frac{x}{X_0}}\left(1+0.038\ln\frac{x}{X_0}\right)$$

Measurement accuracy ~ 20%

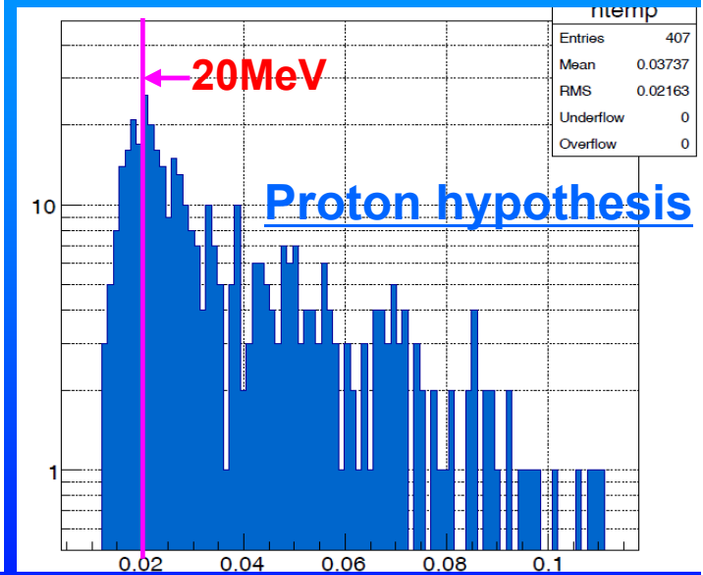


dE/dx measurement by track blackness

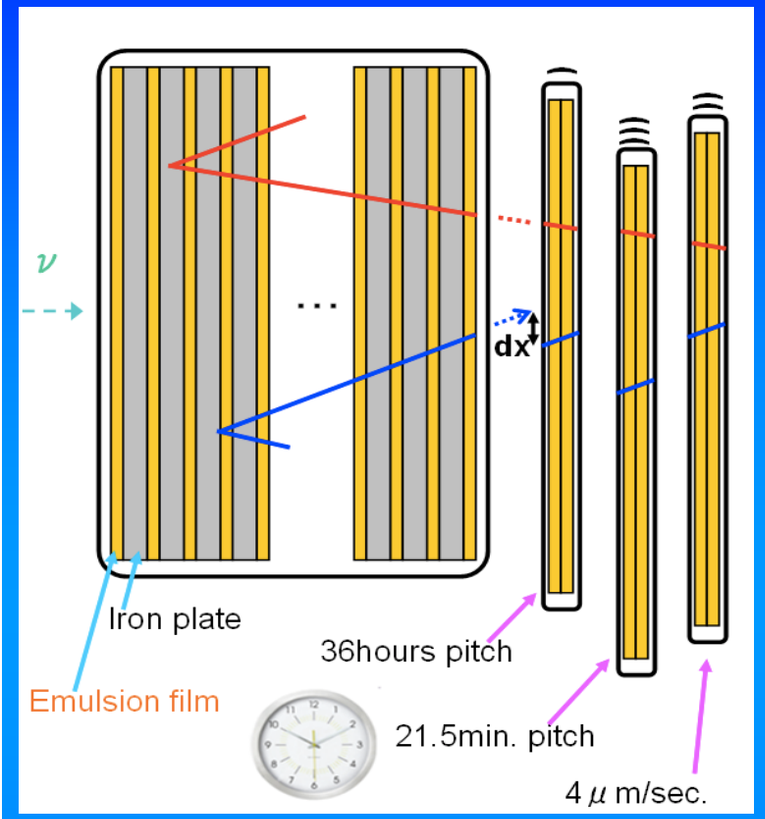


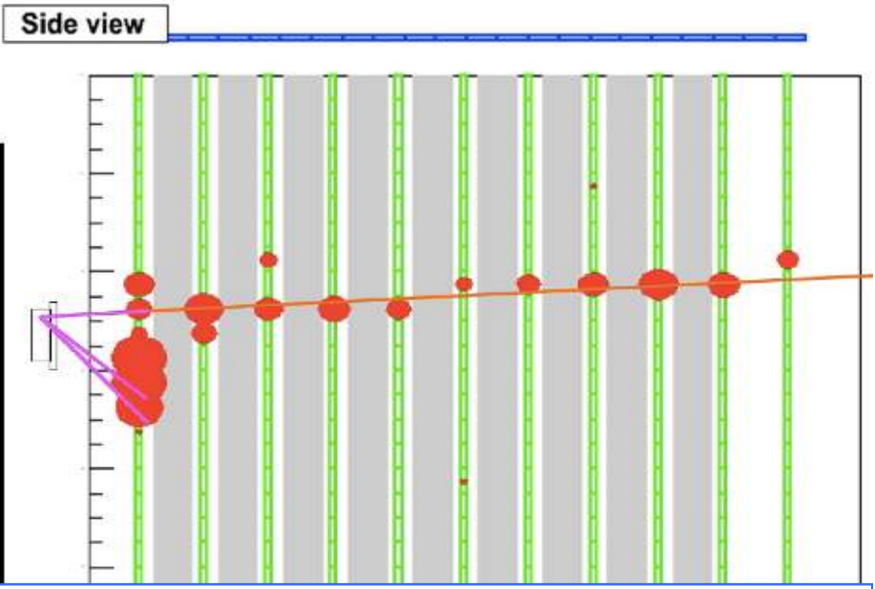


Low energy proton
→ Range measurement
→ Kinematical energy



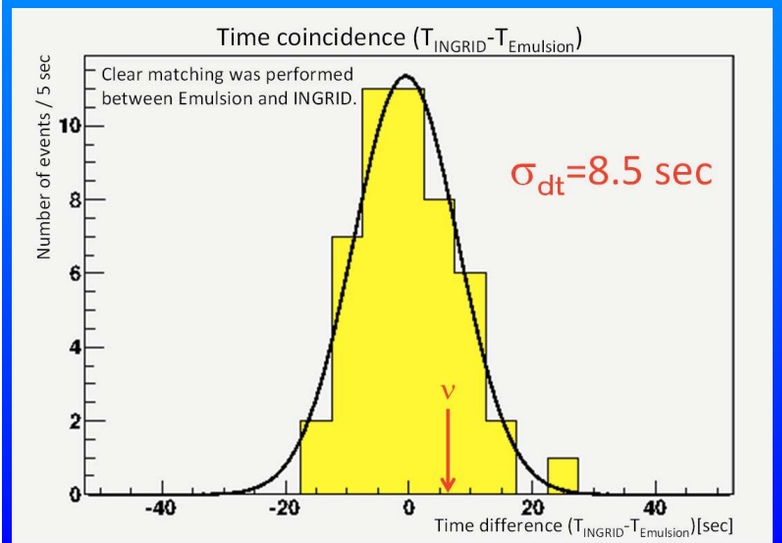
Emulsion-INGRID Hybrid analysis

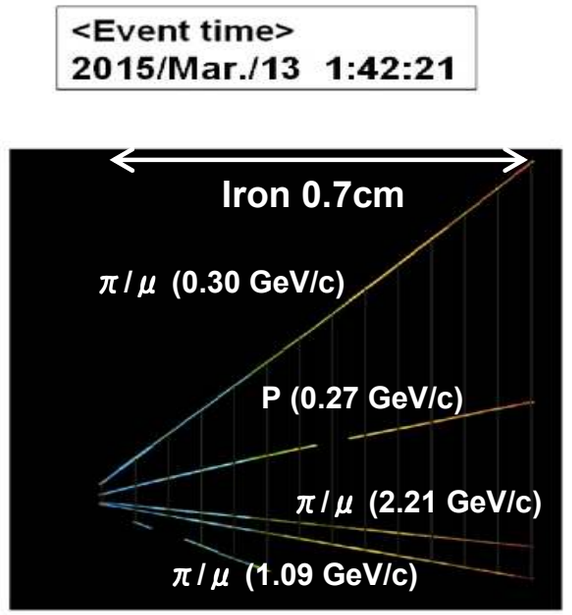


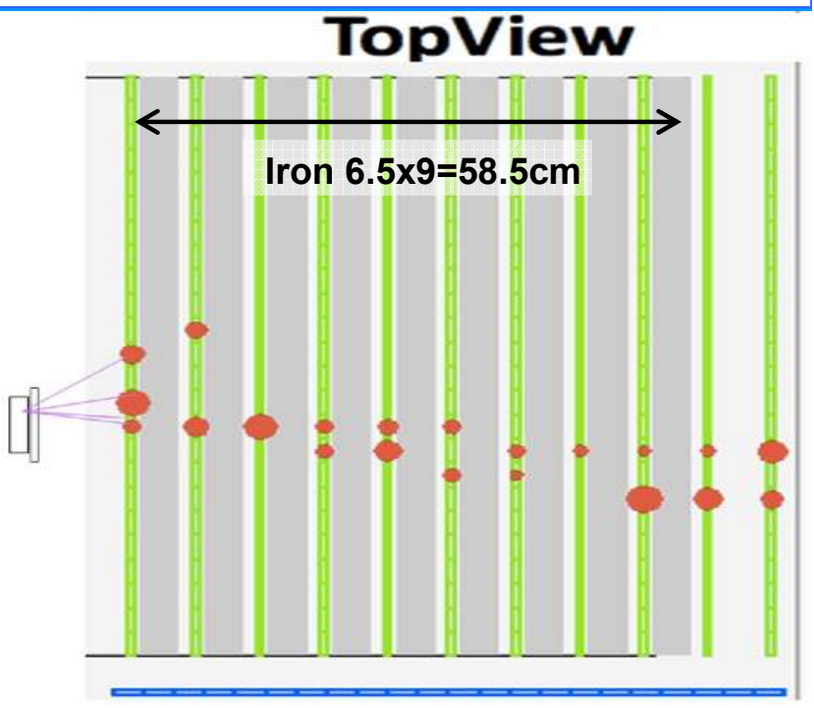


Event topology is clearly matched.
Expected range for each tracks is consistent with INGRID hits.

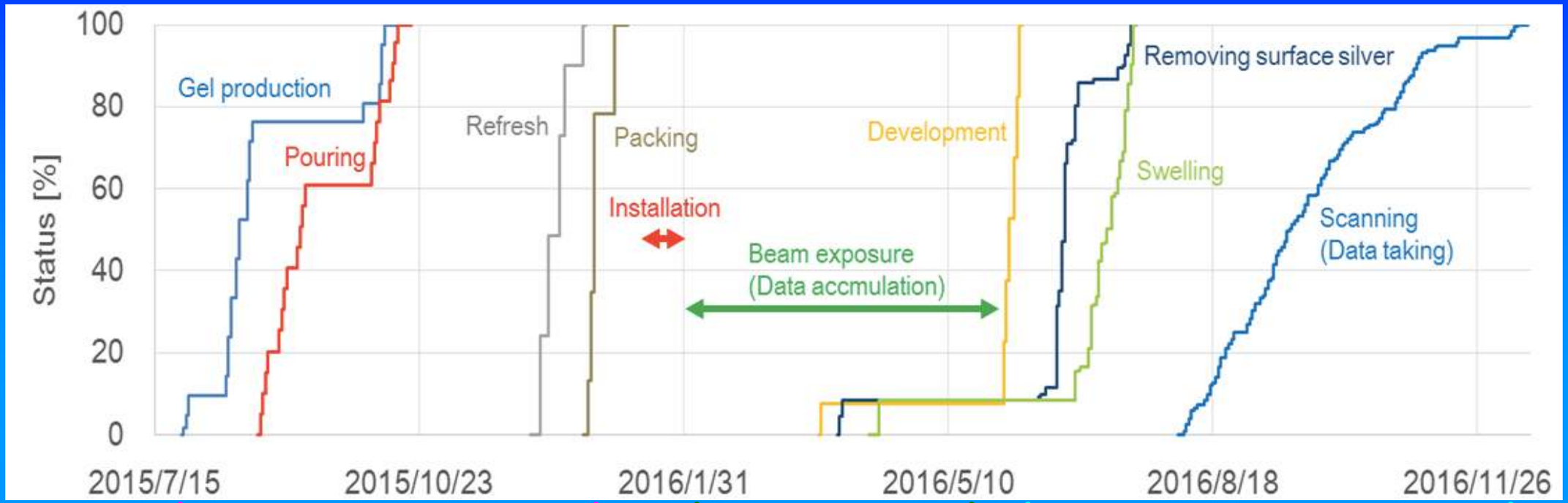
Time resolution for emulsion tracks



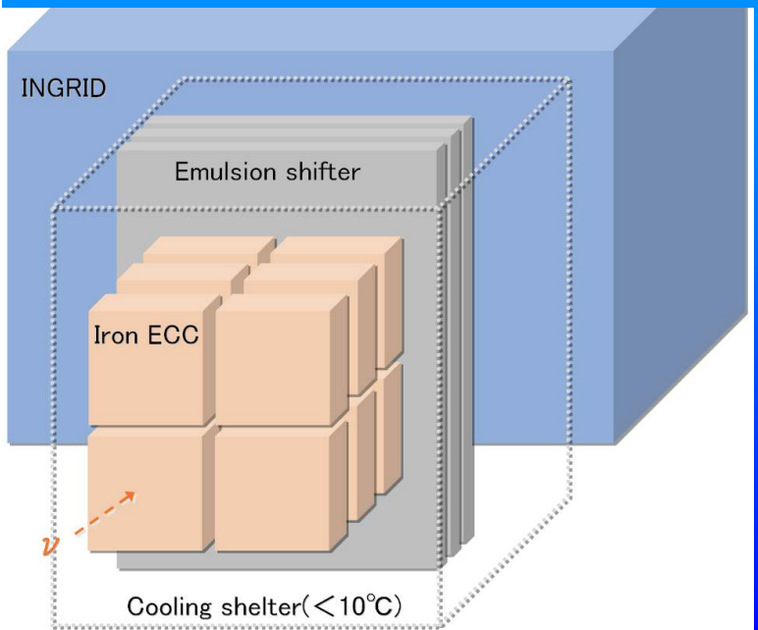




Detector Run



Detector construction | $\bar{\nu}$ beam exposure | Hardware treatment and Scan



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

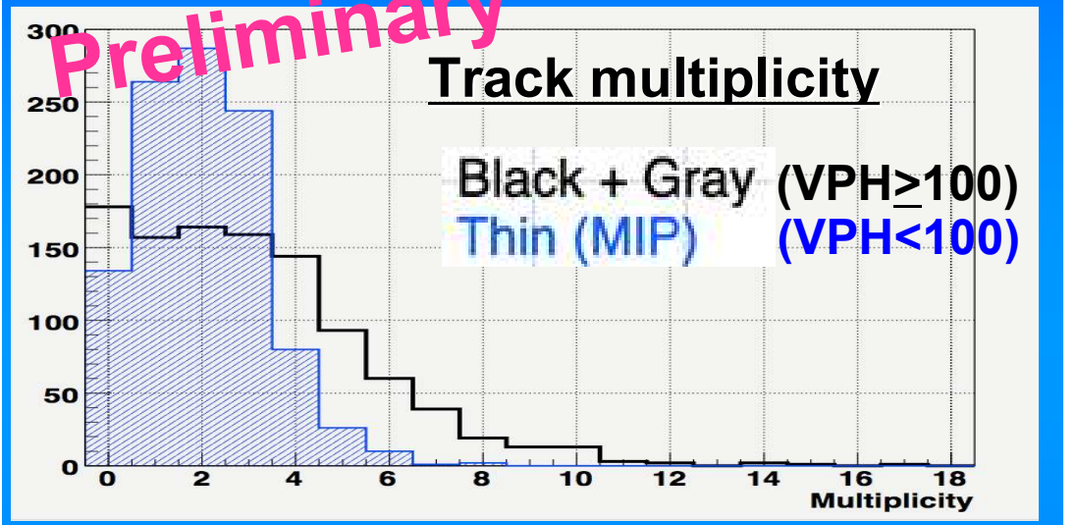
$\bar{\nu}$ exposure : 2016 @SS floor (near on-axis)
end of Jan. → end of May（4.0 x 10^{20} POT）
- **Iron target (total~60kg with 500 μm segmentation)**
- **High statistics (~3 k $\bar{\nu}_\mu$ events)**
- **$\bar{\nu}_e$ detection（~20 $\bar{\nu}_e$ CC events）**

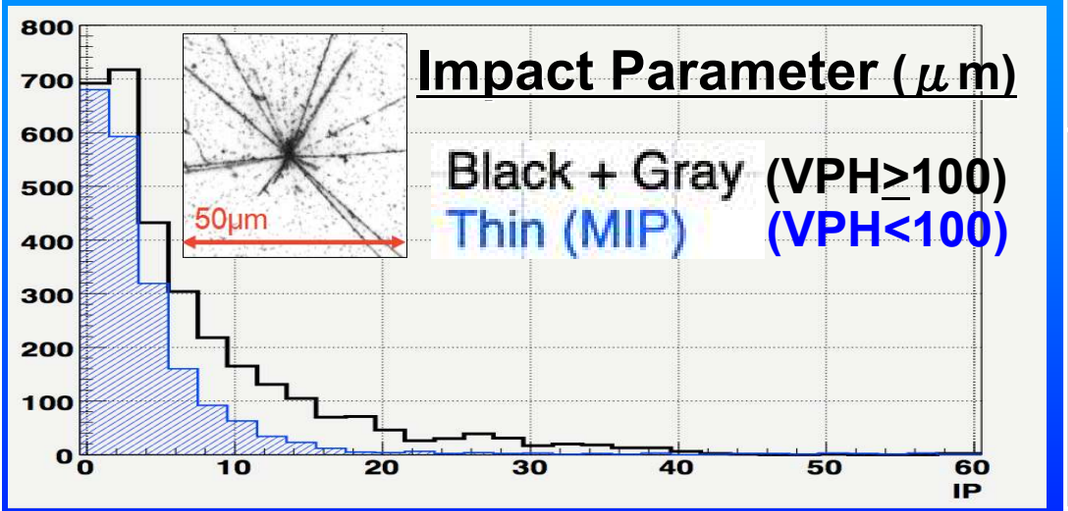
Multi-track vertex event search

1048 vtx candidate events

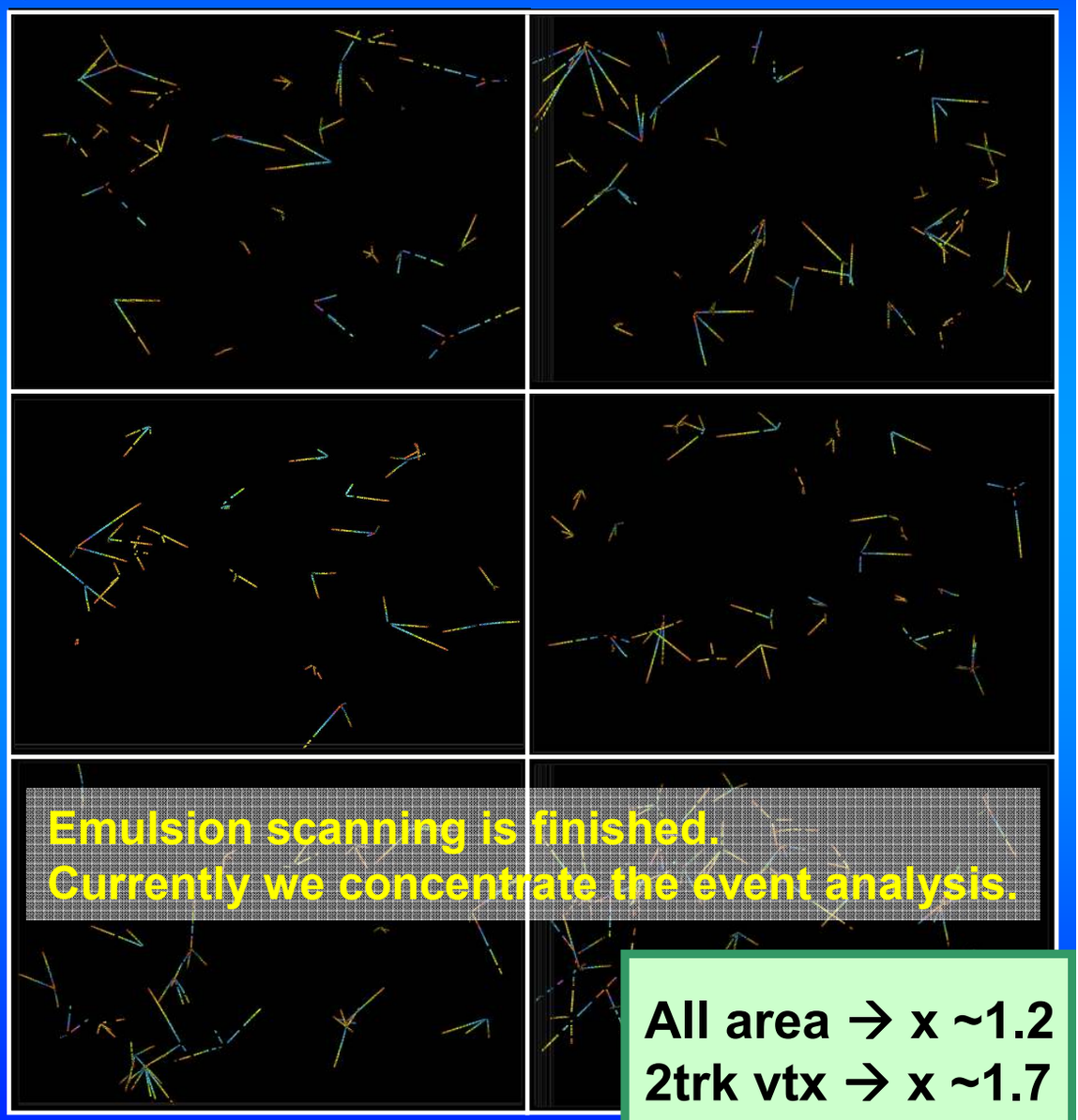
(Multiplicity≥3, BKG is under estimation)

Preliminary





~25cm



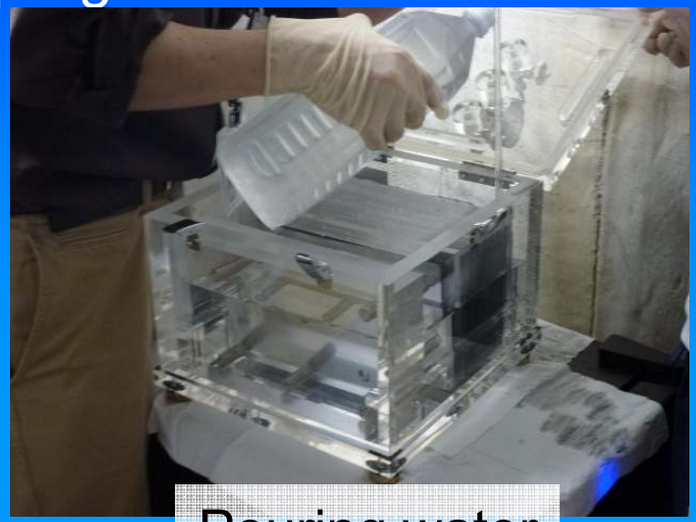
Emulsion scanning is finished.
Currently we concentrate the event analysis.

All area → x ~1.2
2trk vtx → x ~1.7
Single → x ~1.7

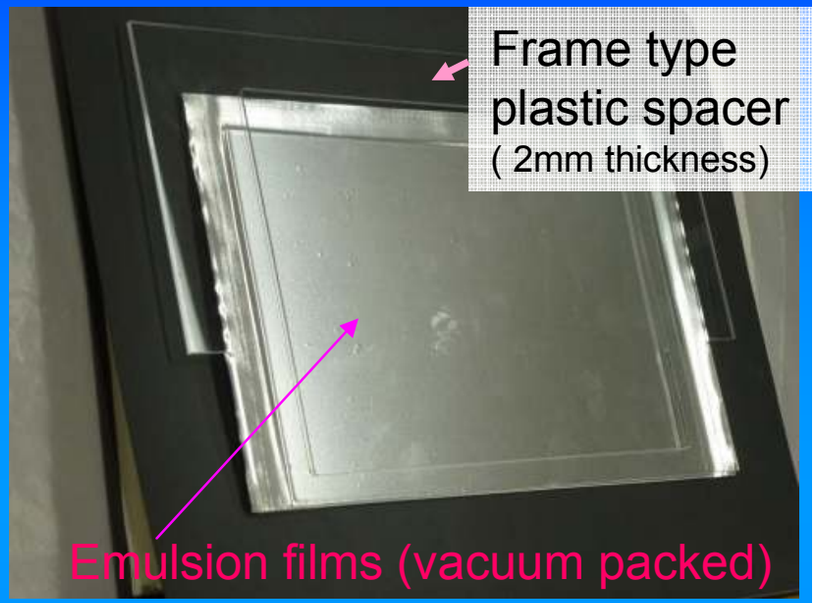
Water target emulsion chamber

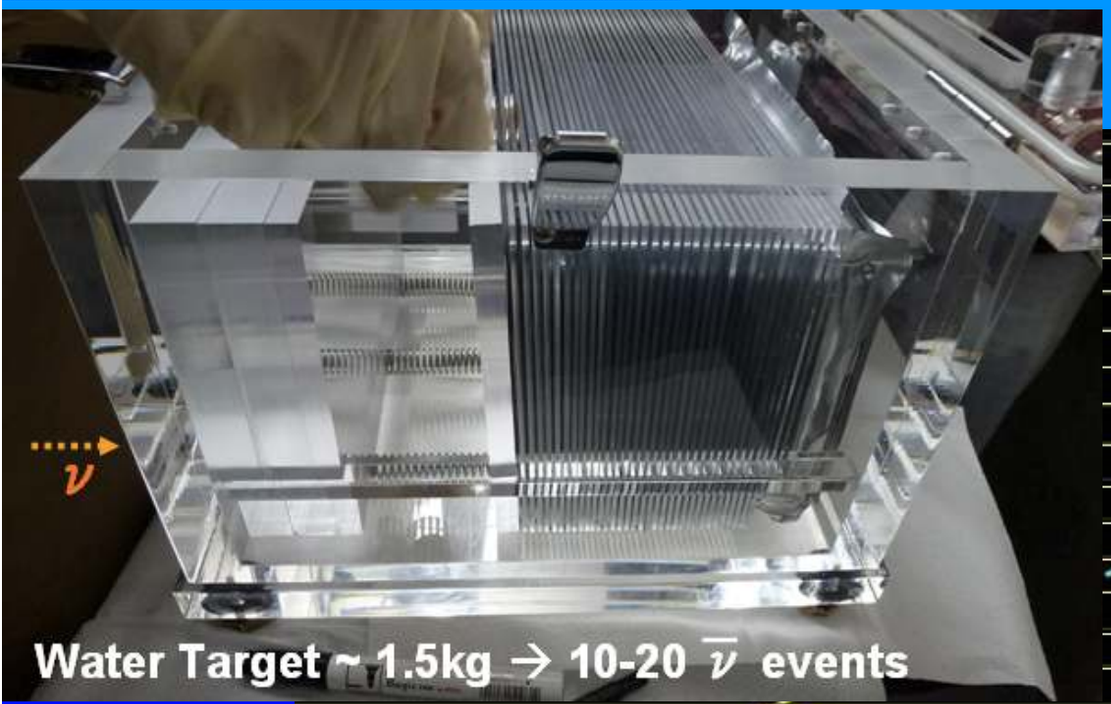
We installed a water target emulsion chamber during May 2015 and 2016-2017.
Detector R&D is now in progress.

Sandwich structure of Emulsion films and Frame type spacers

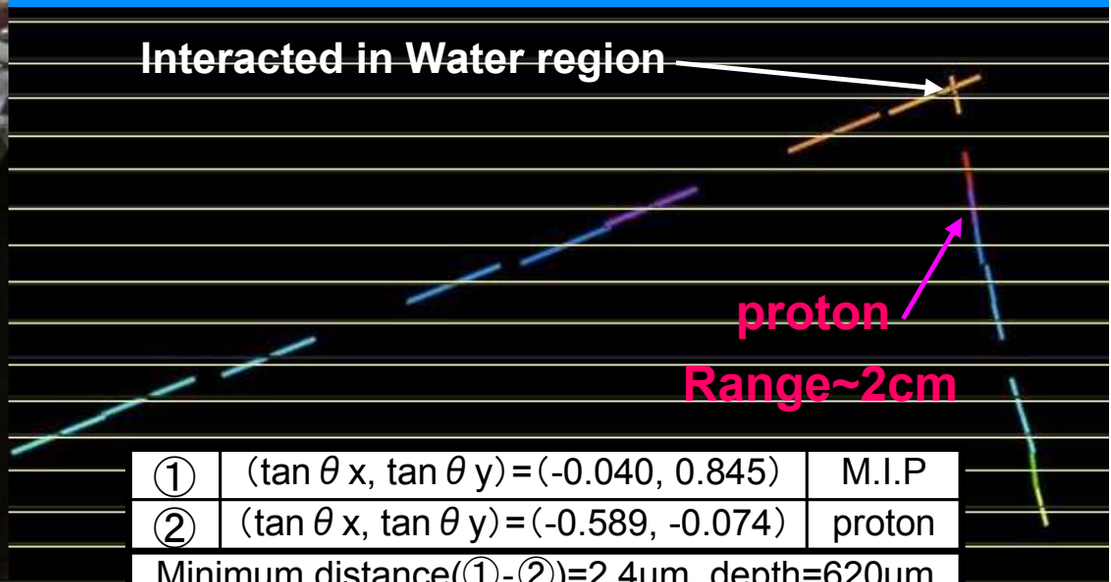


Pouring water





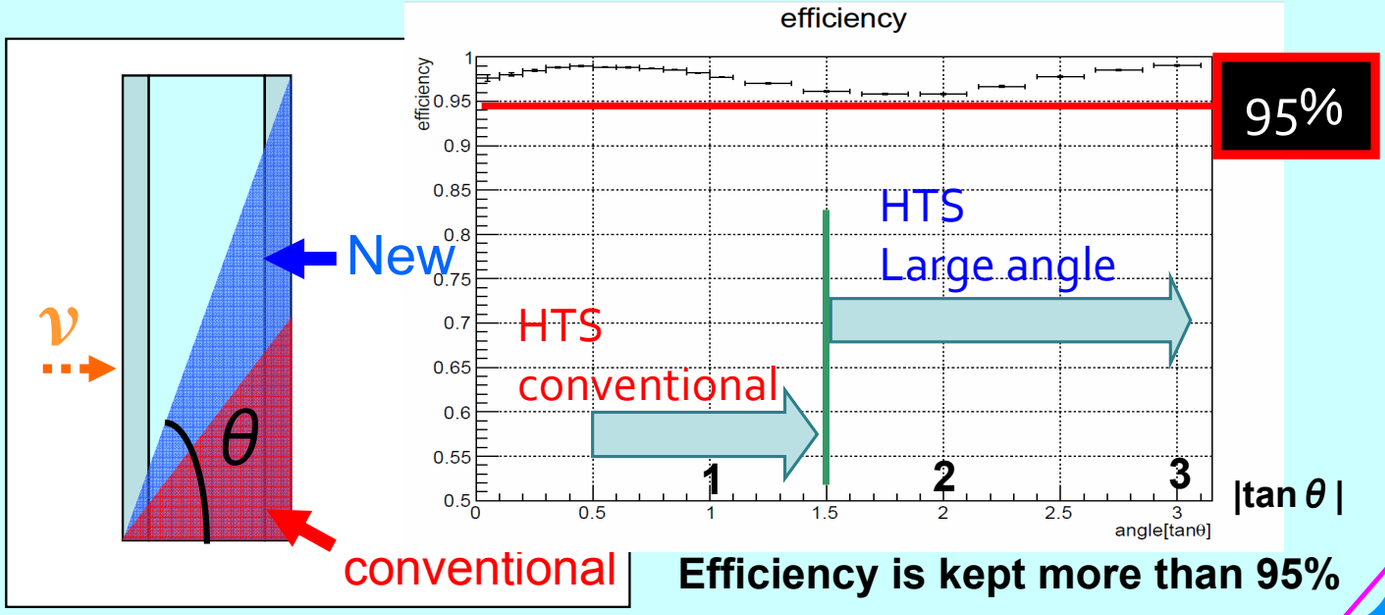
First detection of ν - Water interaction with Emulsion Detector



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		

Technical improvements & Future prospects

High speed Large angle Scanning in emulsion

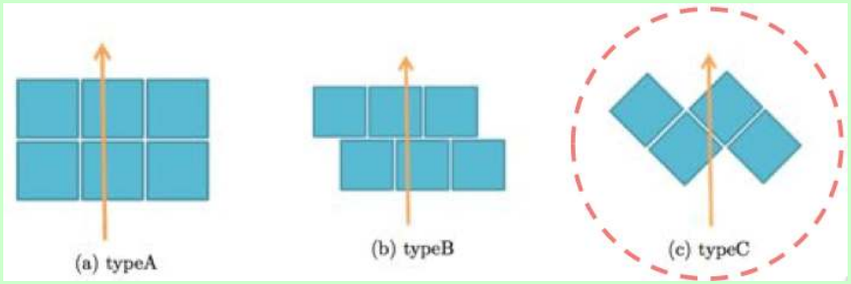


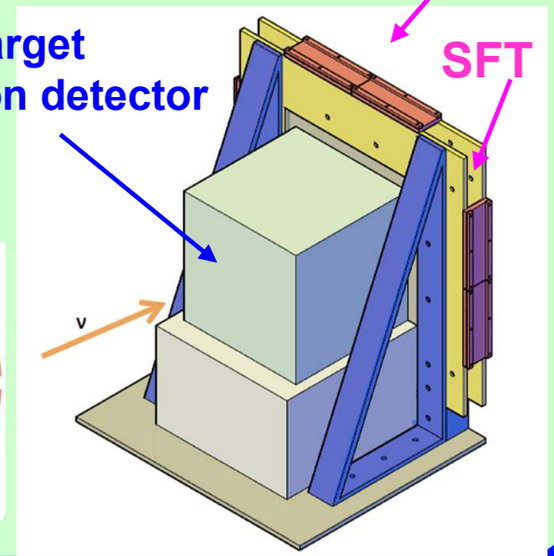
Efficiency is kept more than 95%

New type of Scintillating Fiber Tracker

Fibers are arranged in a slanting lattice pattern to achieve higher position resolution

~580μm ~290μm 163.2μm





Experimental Plan

2017 autumn ~

Detector Run

- 4 kg Water ECC test
- SFT test
- Water ECC – INGRID hybrid analysis

2018 autumn ~

1st Physics Run

- 100-200 kg Water ECC
- @B2 floor (off axis)
- hybrid option is under discussion

※
Schedules may be changed, depend on J-PARC neutrino beam schedule.

Summary

- We are performing a neutrino experiments at J-PARC to study low energy neutrino - nucleus interactions with nuclear emulsion.
- We are carrying out a test experiment at J-PARC (**T60/T66**) to check the feasibility and detector performance.
- The event analysis of the 60kg iron target ECC is now in progress.
- R&D for Water target ECC is also performing.
- Now we are planning about next test run and physics run with Water ECC and SFT system.

NuINT 2017
June 23-29, 2017
Toronto, Canada

Special thanks J-PARC Accelerator Group, Neutrino Group and the T2K Collaboration for their strong support !

Thank you for your attention !

Un-official logo. Official one coming soon

Japanese “shuriken”

About the detailed information for particle ID in emulsion, you can find in the State of Nu-Tion WS.
https://meetings.triumf.ca/indico/event/12/session/2/contribution/8/material/slides/0.pdf