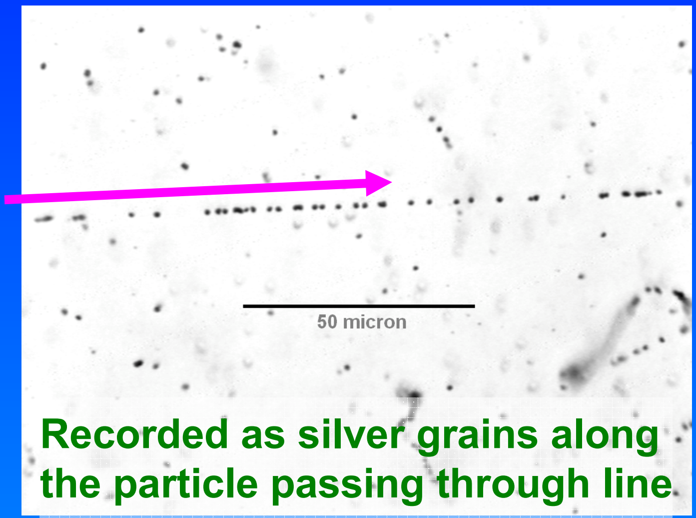
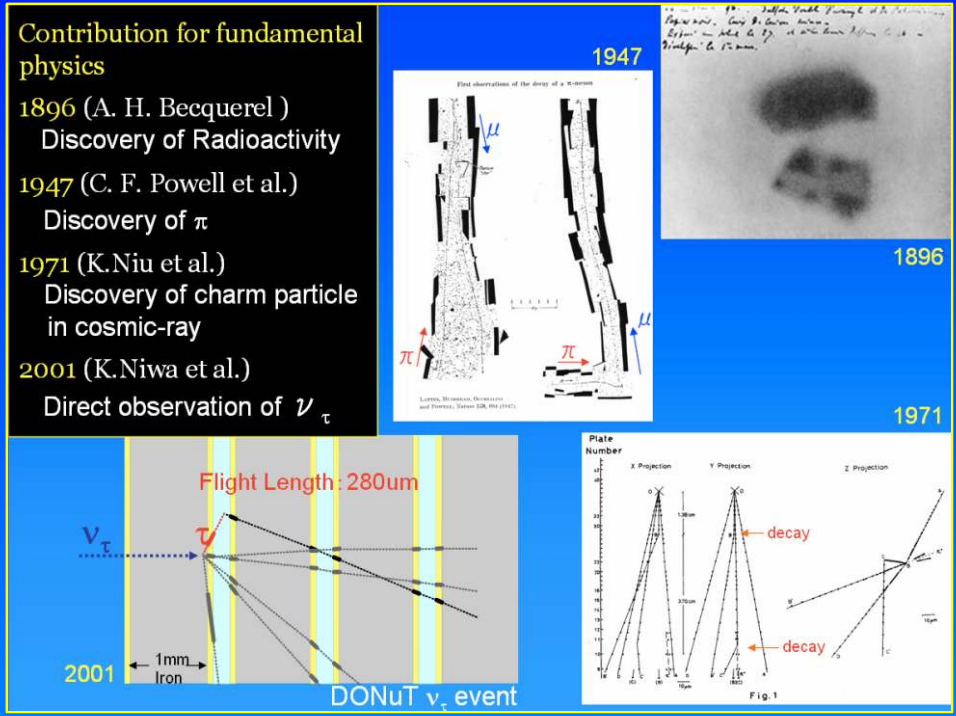
J-PARC T60
Emulsion based test experiment in Neutrino beamline @J-PARC

<u>Tsutomu Fukuda（Toho Univ.）</u>
on behalf of the T60 group

Nuclear emulsion

Nuclear emulsion is 3D tracking detector with sub-micron position accuracy.





Neutrino experiments with nuclear emulsion

	Target mass
• **1978-1983 Fermilab E531** charm physics, $\nu_\mu \to \nu_\tau$ oscillation	~ 100kg
• **1990-2000 CERN WA95 CHORUS** $\nu_\mu \to \nu_\tau$ oscillation, charm physics	~ 1 ton
• **1994-2001 Fermilab E872 DONUT** First ν_τ observation	~ 1 ton
• **2008- CERN CNGS01 OPERA** $\nu_\mu \to \nu_\tau$ oscillation, $\nu_\mu \to \nu_e$ oscillation	**1250 ton**

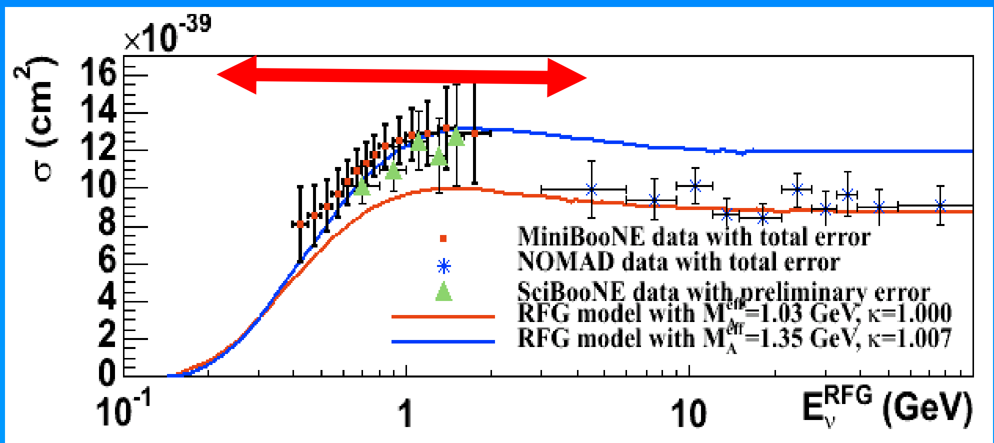
Discovery of ν_τ appearance

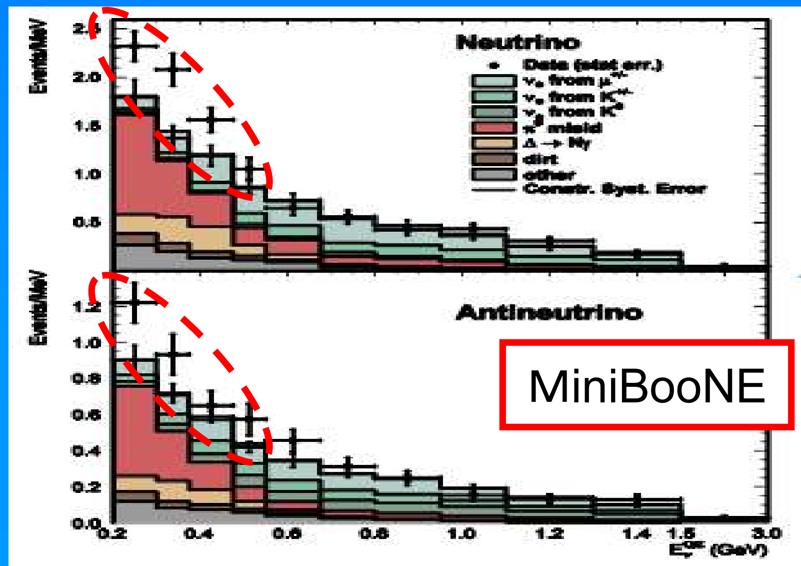
Submitted to PRL (arXiv:1507.01417)

Motivation

- We are planning new experiments at J-PARC to study low energy neutrino interactions by introducing nuclear emulsion technique.
- The emulsion technique can provide good measurements with ultimate position resolution.
- Physics motivation is a detailed (exclusive) study of low energy neutrino – nucleus interactions for a variety of target (H_2O,Fe,C) and

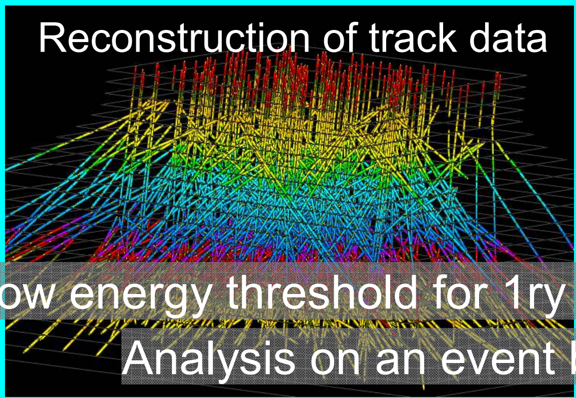
  cross section measurement of low energy ν_e interaction and the exploration of a sterile neutrino.

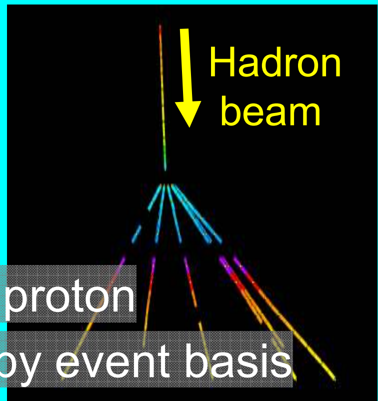




Advantage of Emulsion

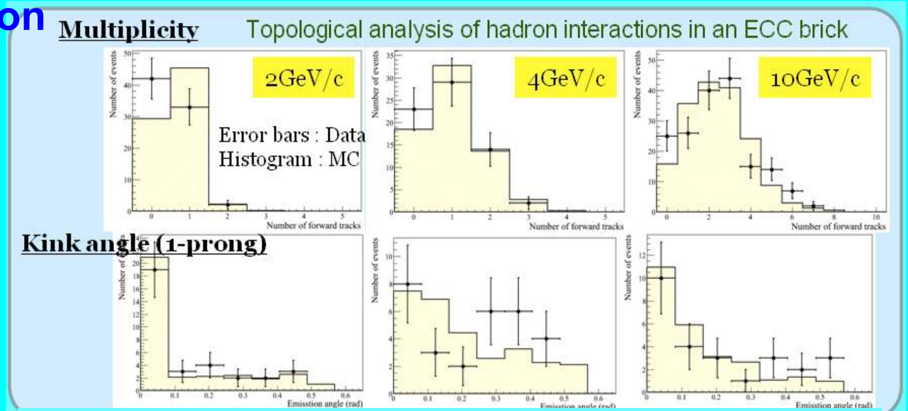
Systematic analysis with sub-micron position resolution





Low energy threshold for 1ry proton

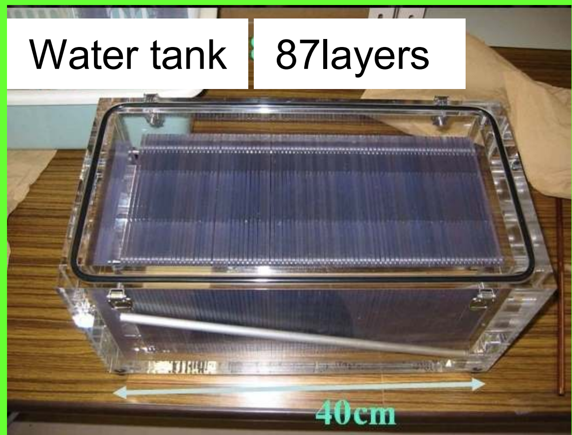
Analysis on an event by event basis

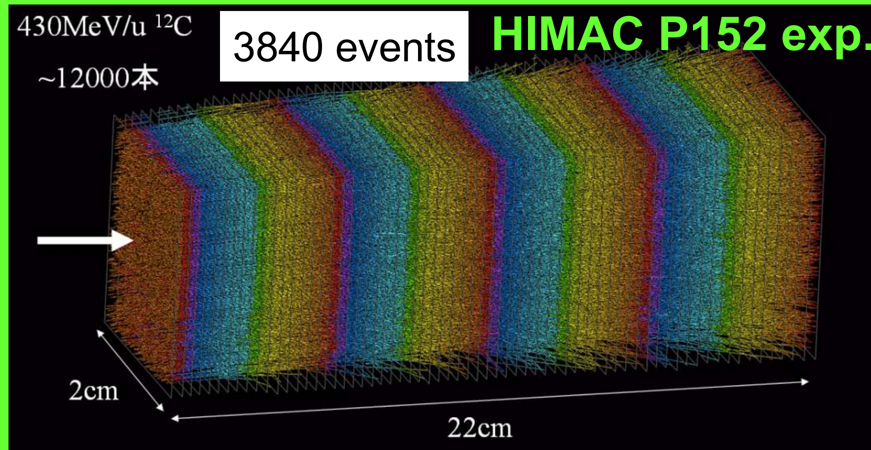


H. Ishida, T. Fukuda et al., *Prog. Theor. Exp. Phys.* 2014, 093C01

Flexibility for target material

A sandwich structure



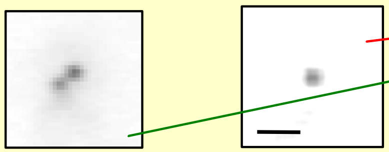


HIMAC P152 exp.

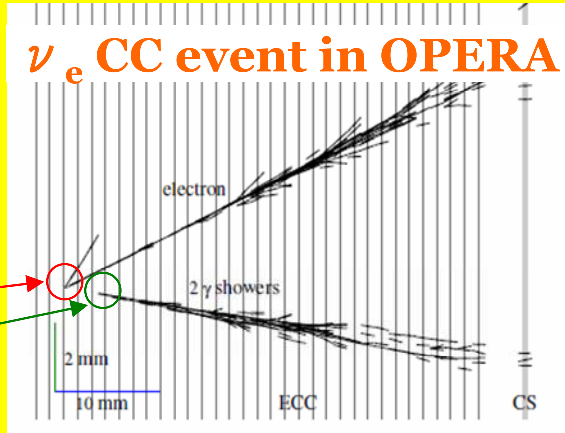
γ / electron ID

Microscopic image from the view of the beam axis

$\gamma \rightarrow e^+e^-$ electron



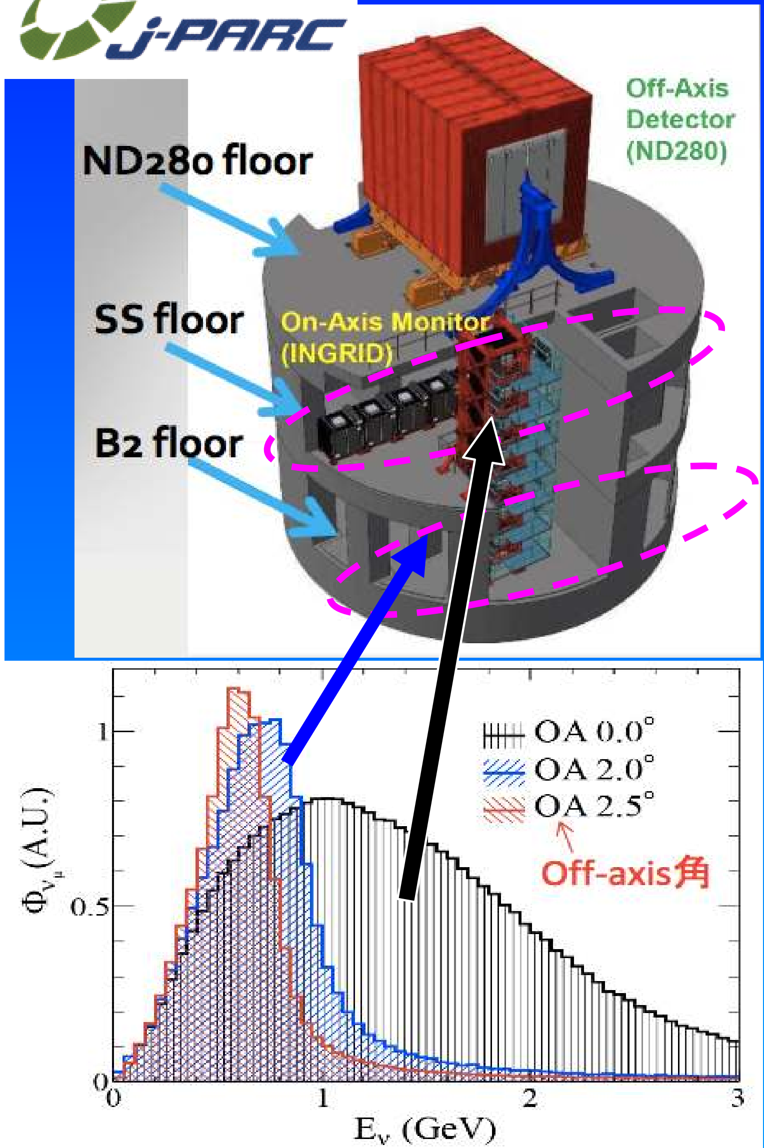
ν_e **CC event in OPERA**



Low background from $\nu_\mu NC\pi^0$ production

Primary electron track is observed as a isolated track, not as a pair of tracks.

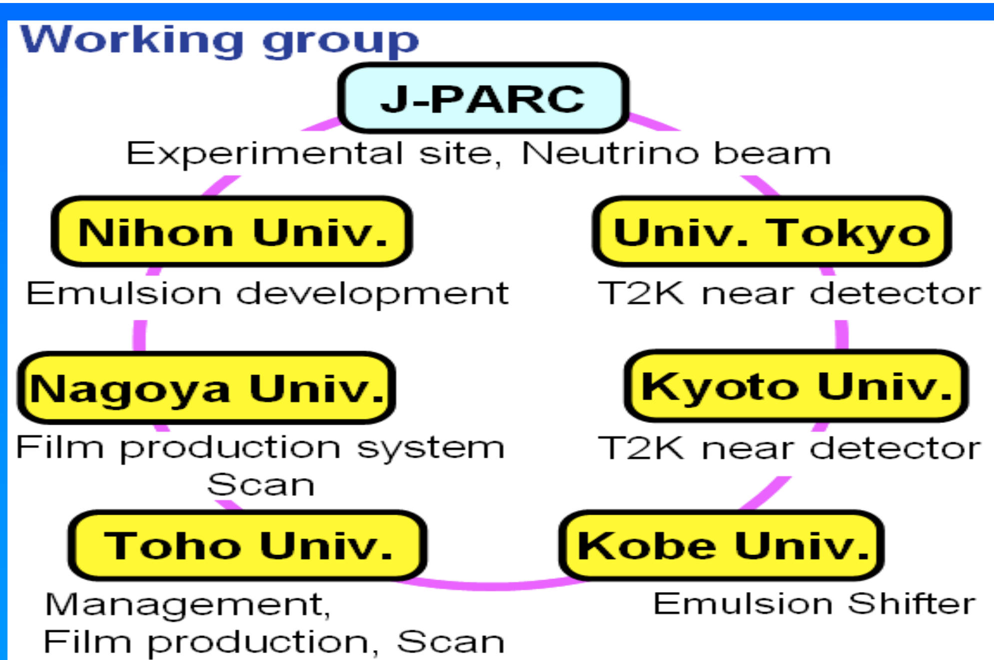
J-PARC T60 experiment



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.



A collaborative project with some member of OPERA and T2K.

Roadmap

Preliminary measurements RUN — **Feasibility study at J-PARC**

J-PARC T60 experiment

Future plan

Detector RUN — **Detector performance check**

Target mass: 10- 30kg

Physics RUN Ⅰ — **Neutrino-nucleus interaction study**

Target mass: 100- 300kg

Physics RUN Ⅱ — **Search for sterile neutrino**

Target mass: 1- 3ton
Target mass: 6-10ton

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

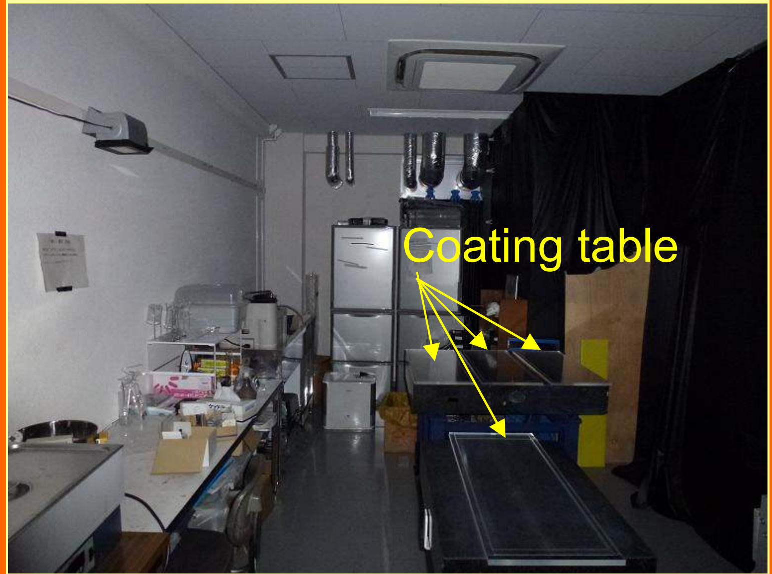
Status of T60

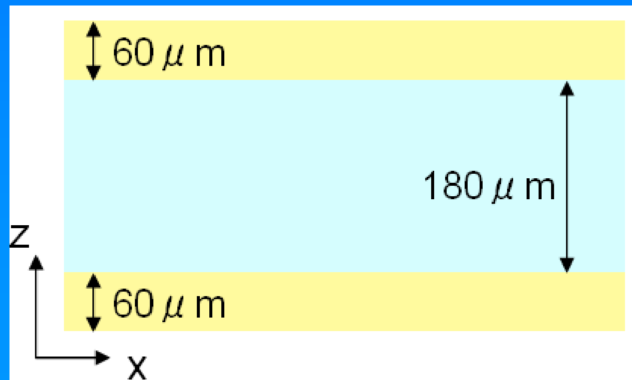
Preparation of emulsion films

Nuclear emulsion films were made by ourselves in this time.

@Nagoya Univ.

Emulsion coating

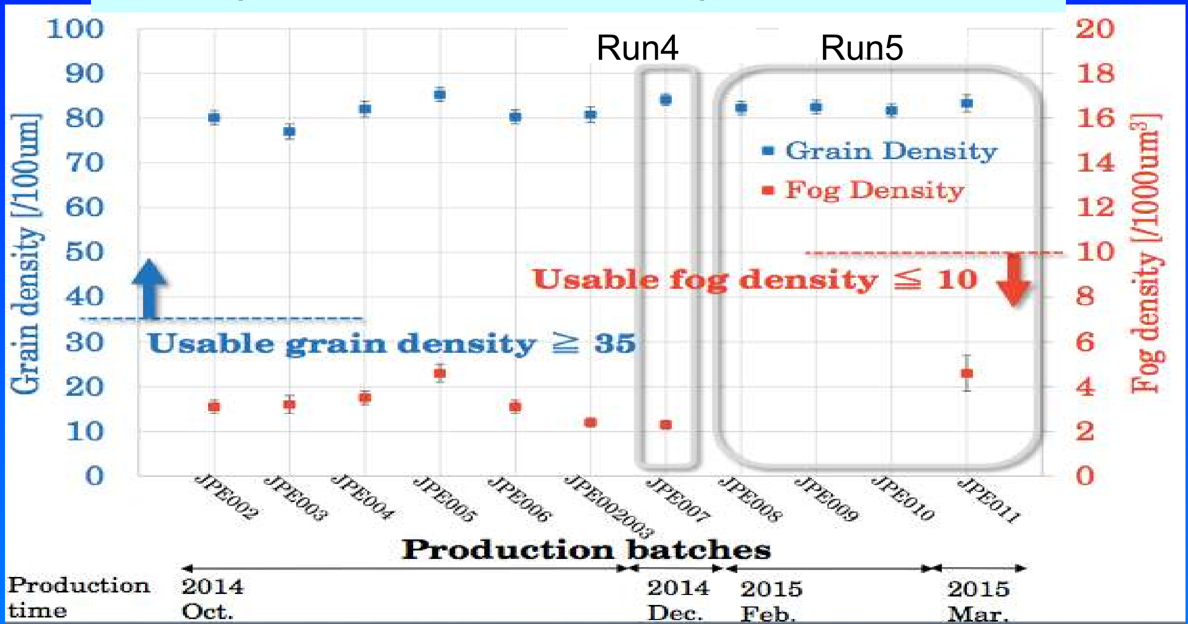


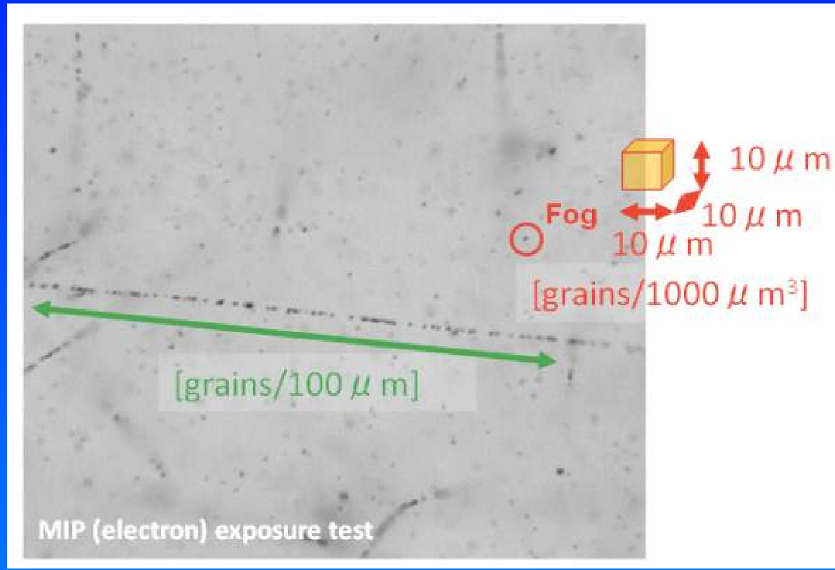


Emulsion coating:
Both sides of plastic base

Performance of emulsion

Initial performance for each production batch

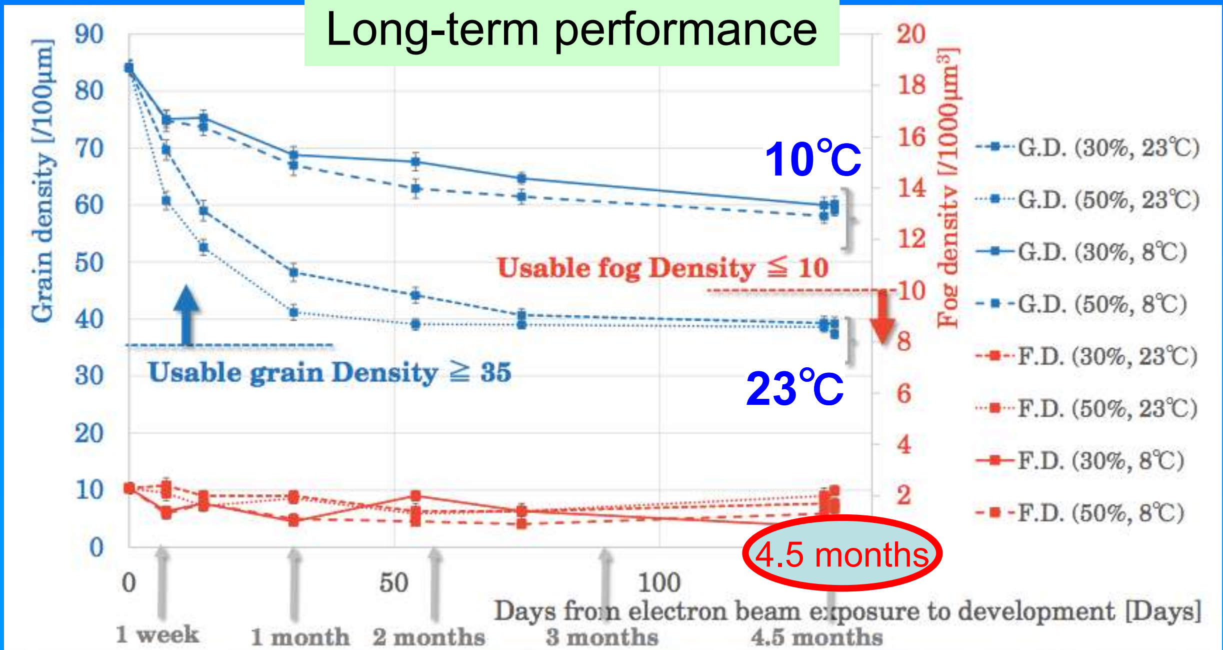




Signal efficiency → Grain density

Isolated random noise → Fog density

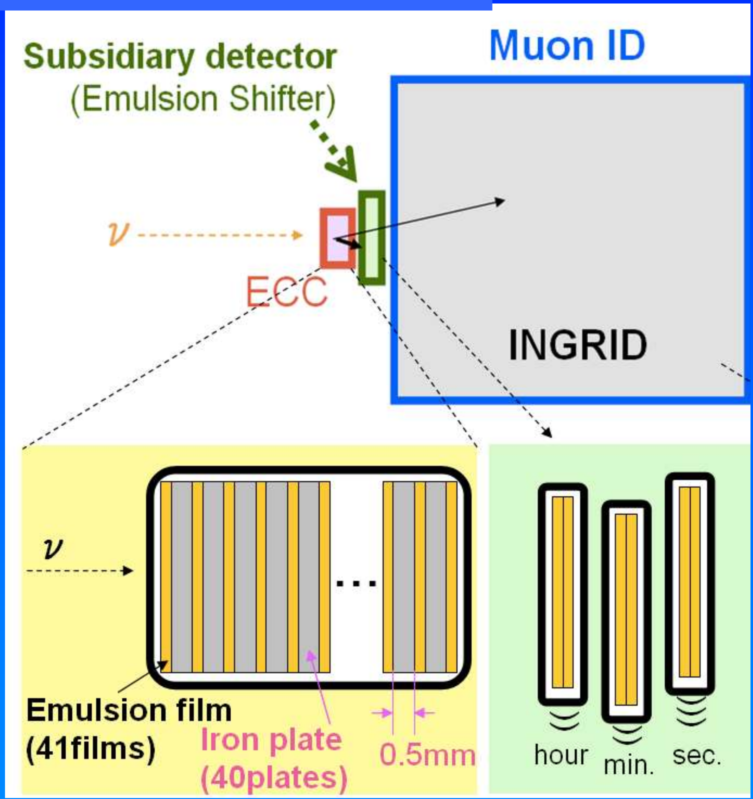
Long-term performance



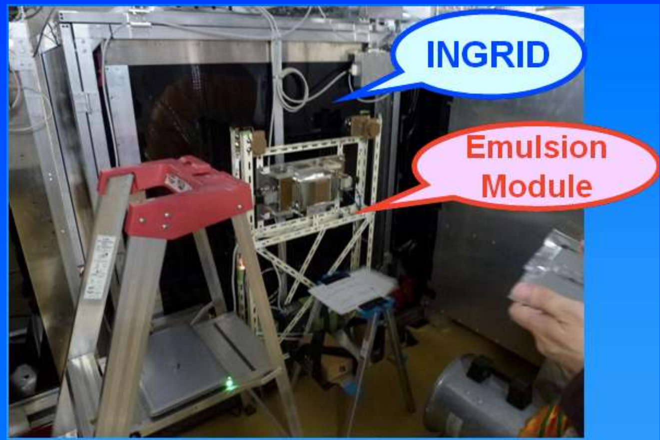
For signal efficiency and noise density, initial and long-term performance of new emulsion gel is kept at safety level.

Detector install and Run

Conceptual design

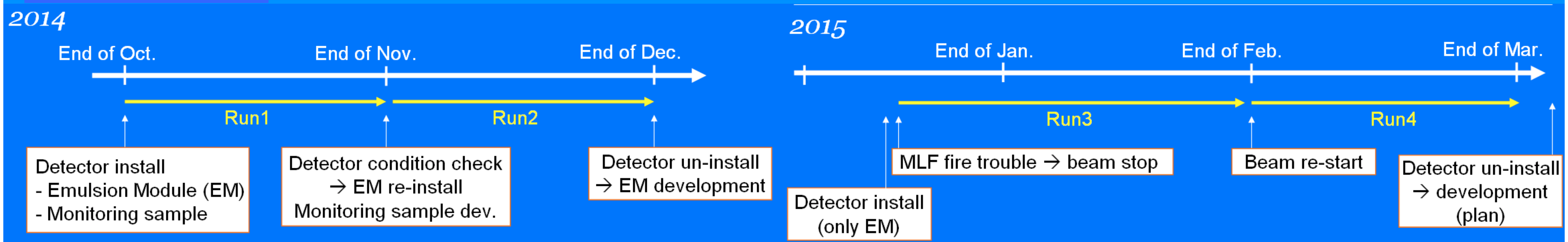


Detector Install



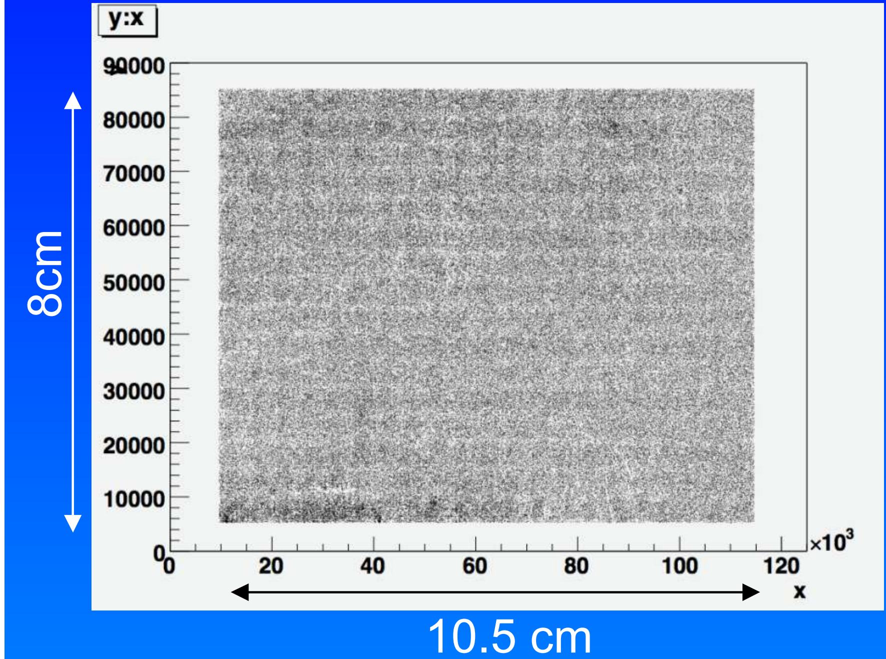
- **E**mulsion **C**loud **C**hamber is a sandwich structure of emulsion films and iron plates.
- Emulsion Shifter give a timing info. to emulsion tracks.
- Muon ID is possible by combined analysis with INGRID.
- After MLF trouble, neutrino events (~1.4 x 10^{20} POT) are accumulated in ECC. → expected ~30 events

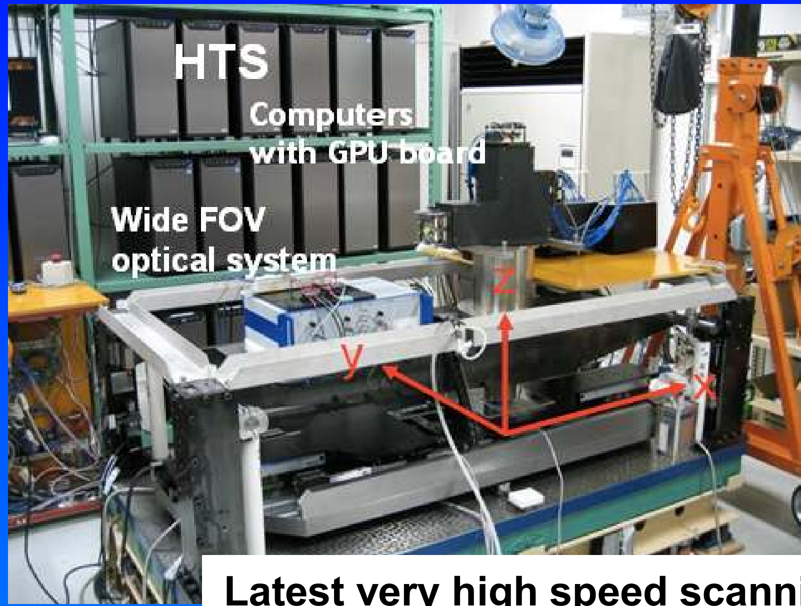
Run Status



Data taking by emulsion scanning system

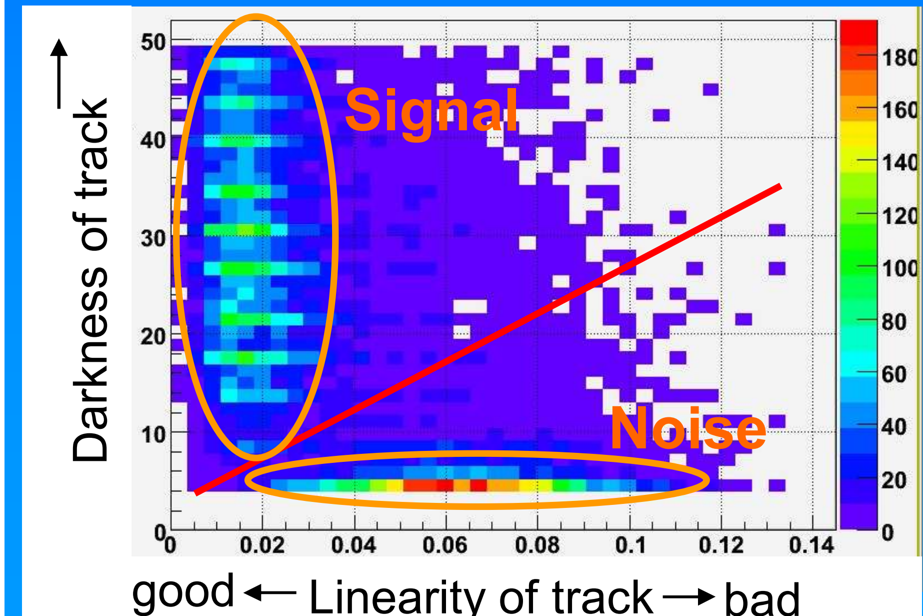
Position distribution



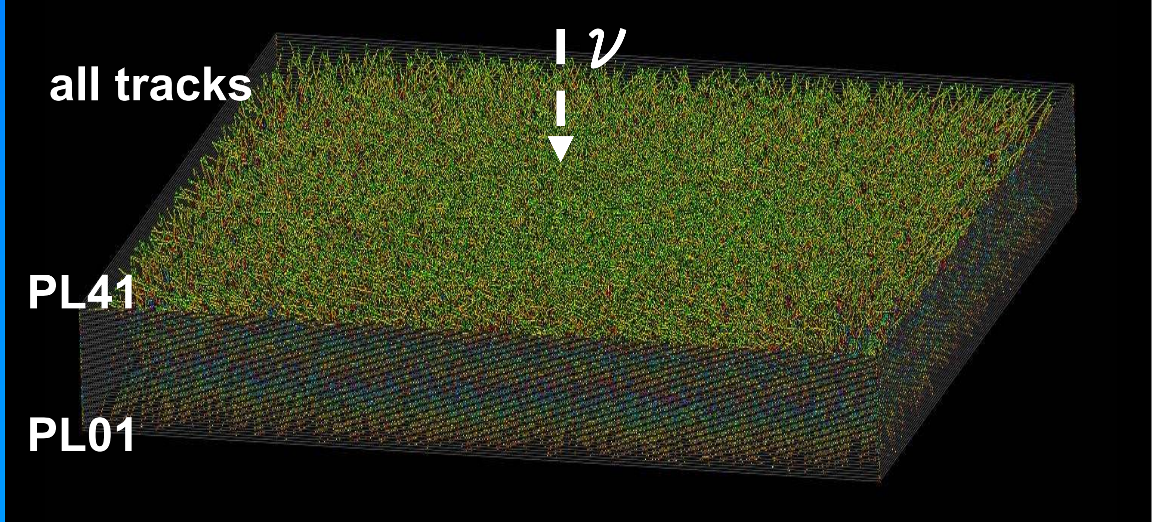


Latest very high speed scanning system developed in Nagoya univ.

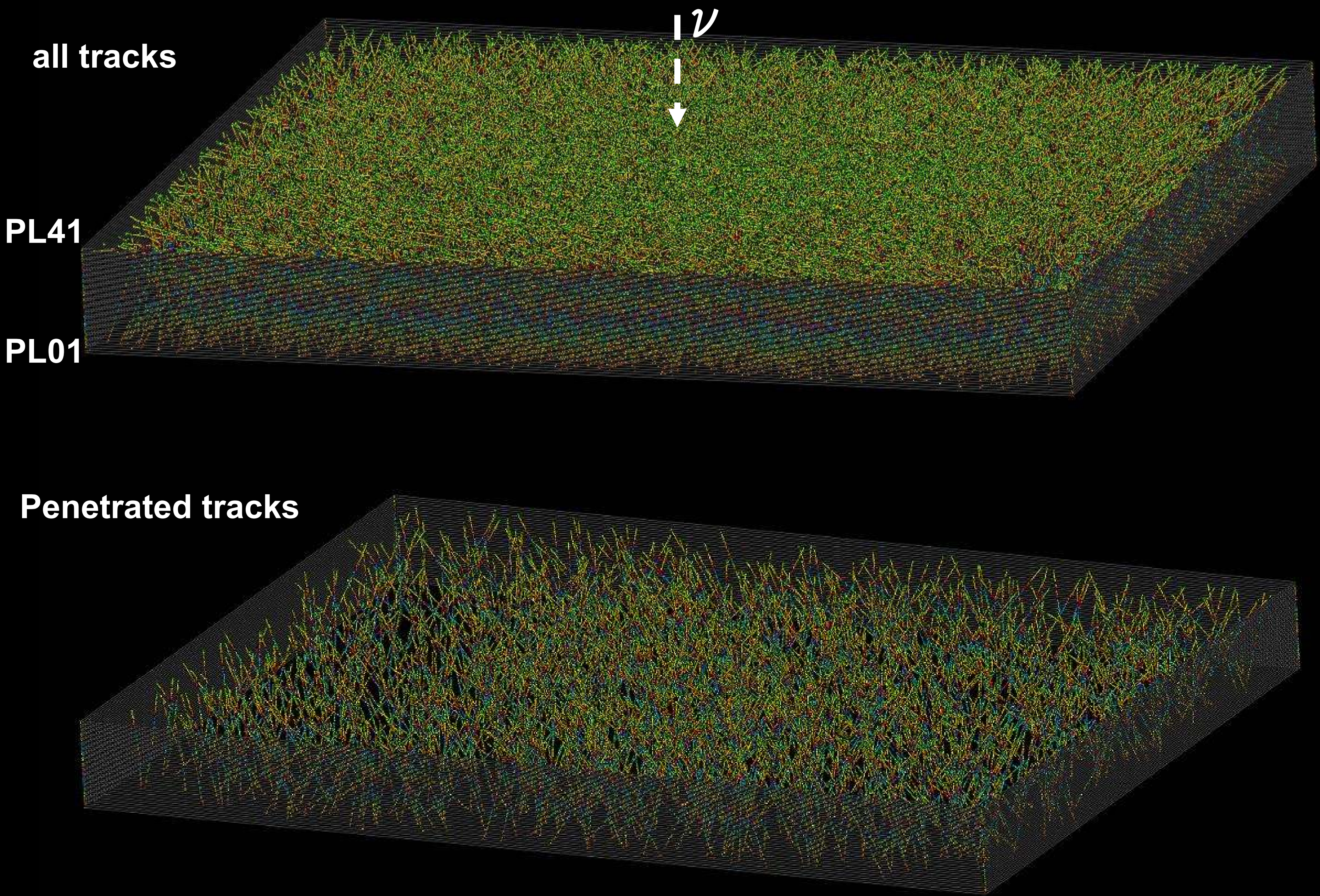
Track quality selection



Reconstructed track data of Iron ECC



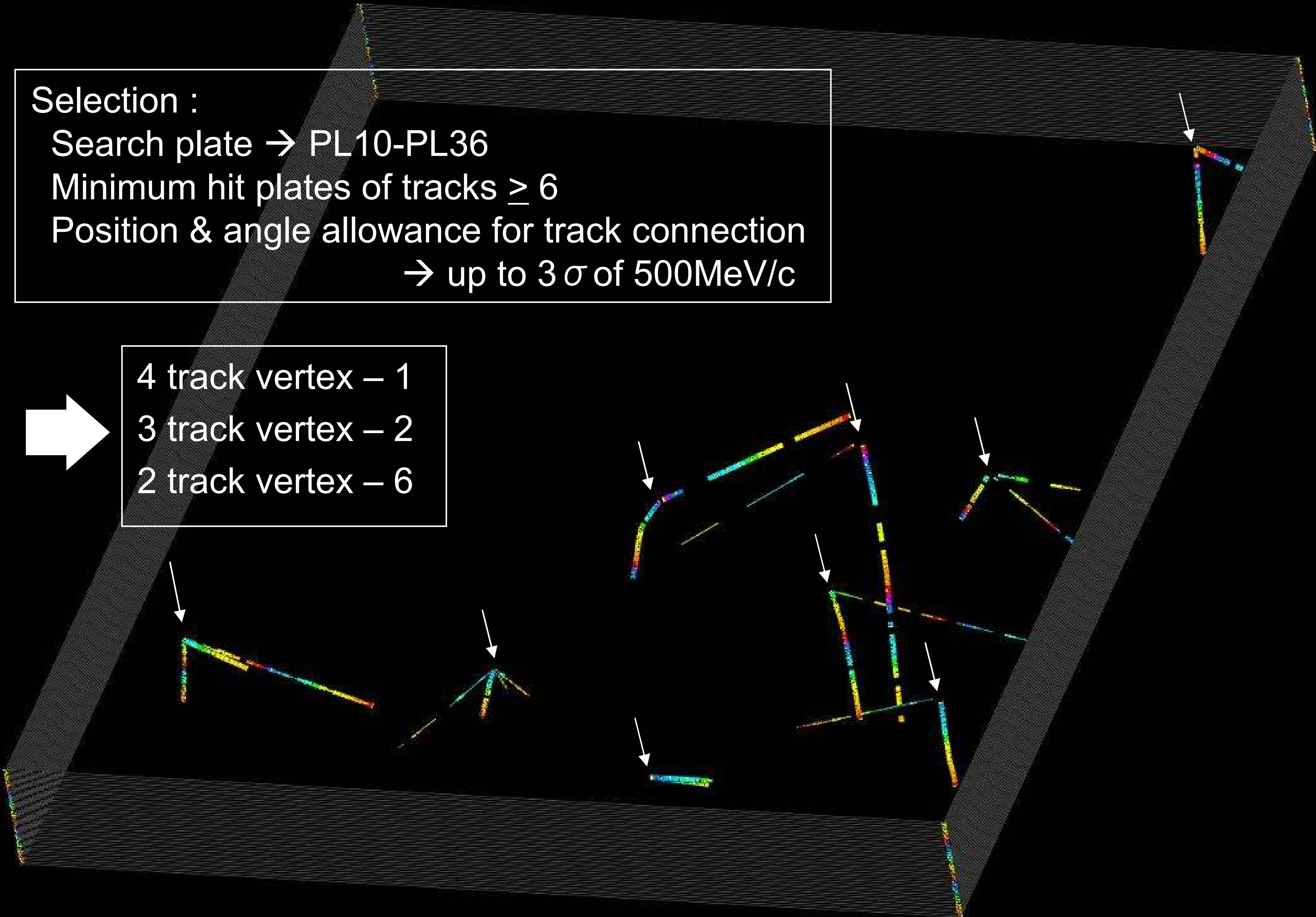
Reconstructed track data



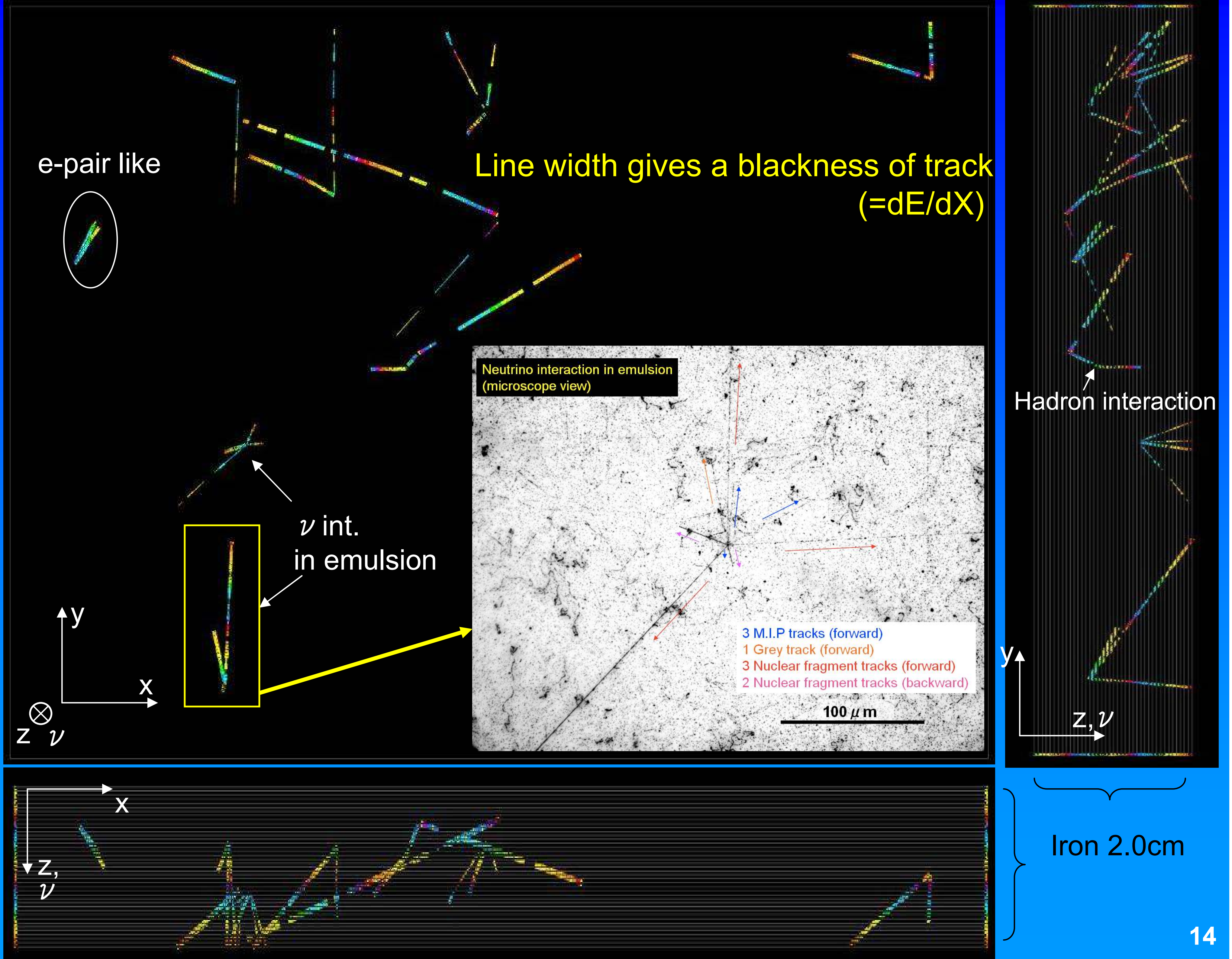
Pilot analysis: *Multi-track vertex search*

Selection :
  Search plate → PL10-PL36
  Minimum hit plates of tracks ≥ 6
  Position & angle allowance for track connection
  → up to 3σ of 500MeV/c

4 track vertex – 1
3 track vertex – 2
2 track vertex – 6



Expected ν int. ~ 10 events for this selection

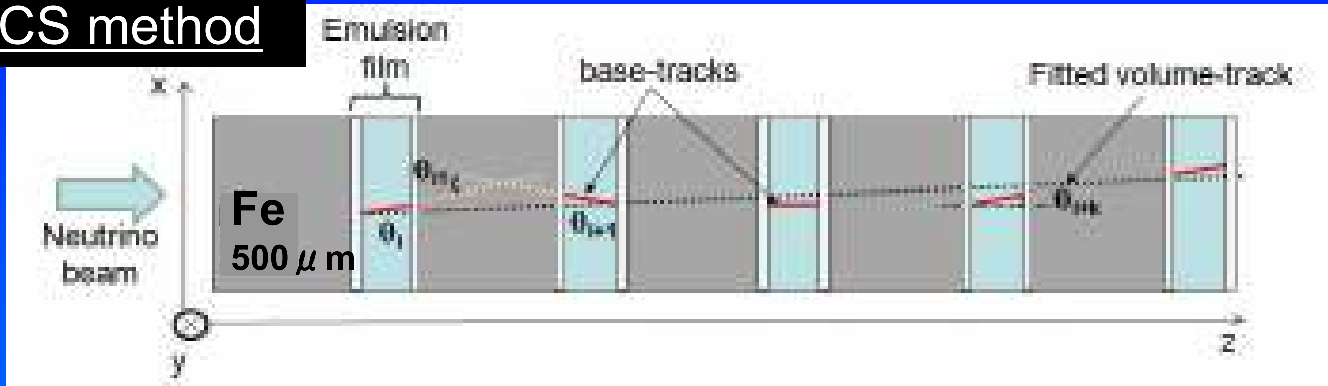


e-pair like
Line width gives a blackness of track
(=dE/dX)
Neutrino interaction in emulsion
(microscope view)
3 M.I.P tracks (forward)
1 Grey track (forward)
3 Nuclear fragment tracks (forward)
2 Nuclear fragment tracks (backward)
100 μm
ν int.
in emulsion
y
x
z ν
Hadron interaction
y
z, ν
x
z,
ν
Iron 2.0cm

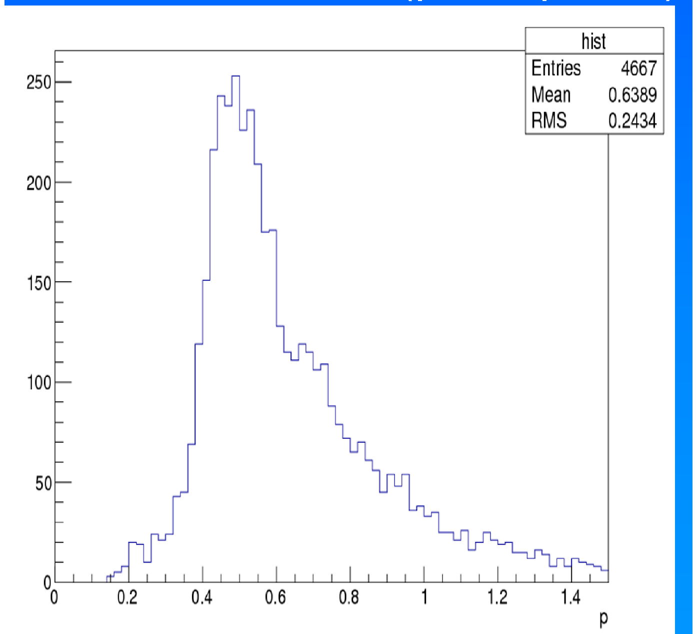
Proton identification

$p\beta$ measurement by the MCS method

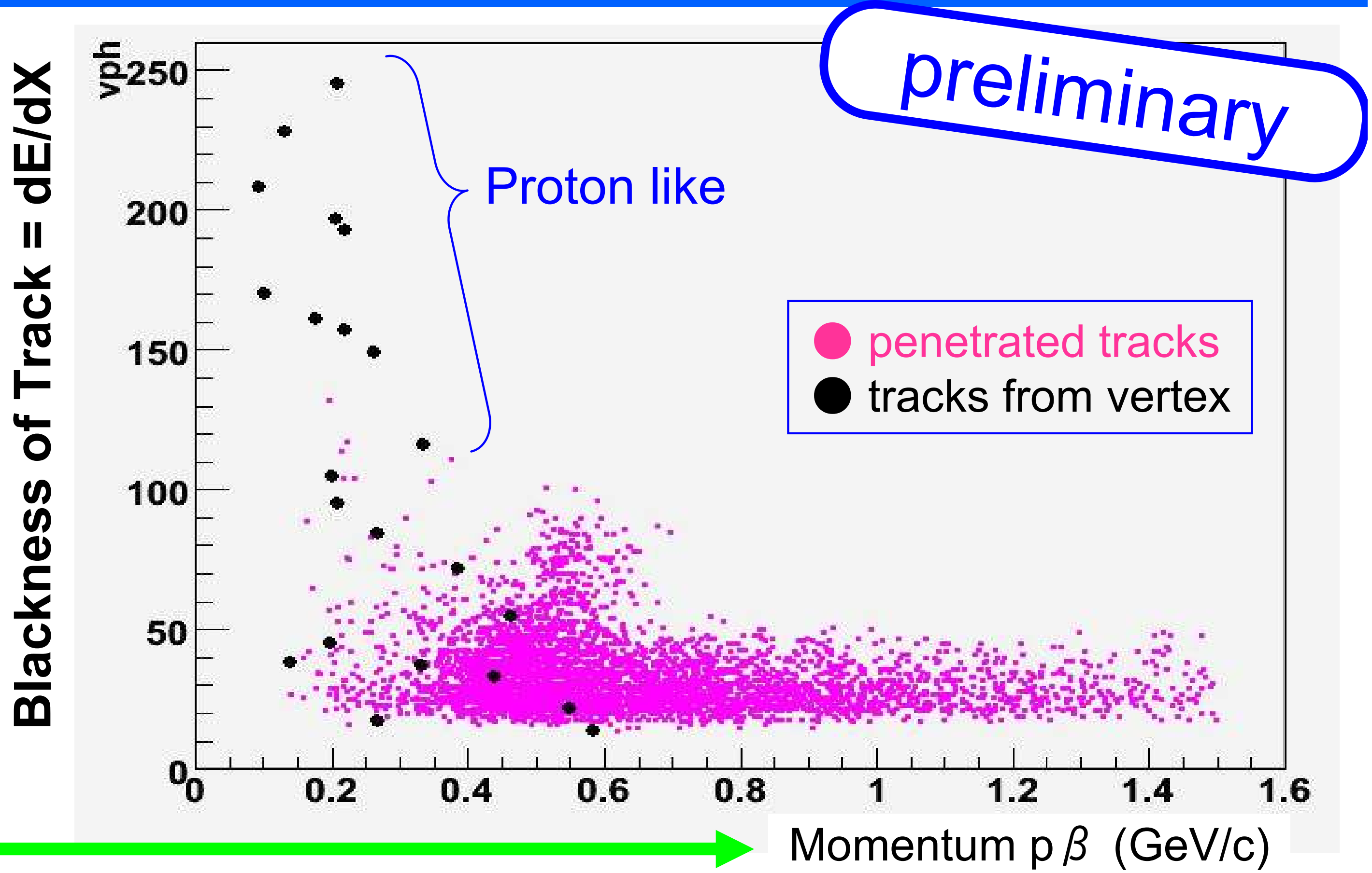
$$\theta_0 = \frac{13.6}{(pc\beta)} \times \sqrt{\frac{x}{X_0}} \times \left[1 + 0.038 \ln\left(\frac{x}{X_0}\right)\right]$$



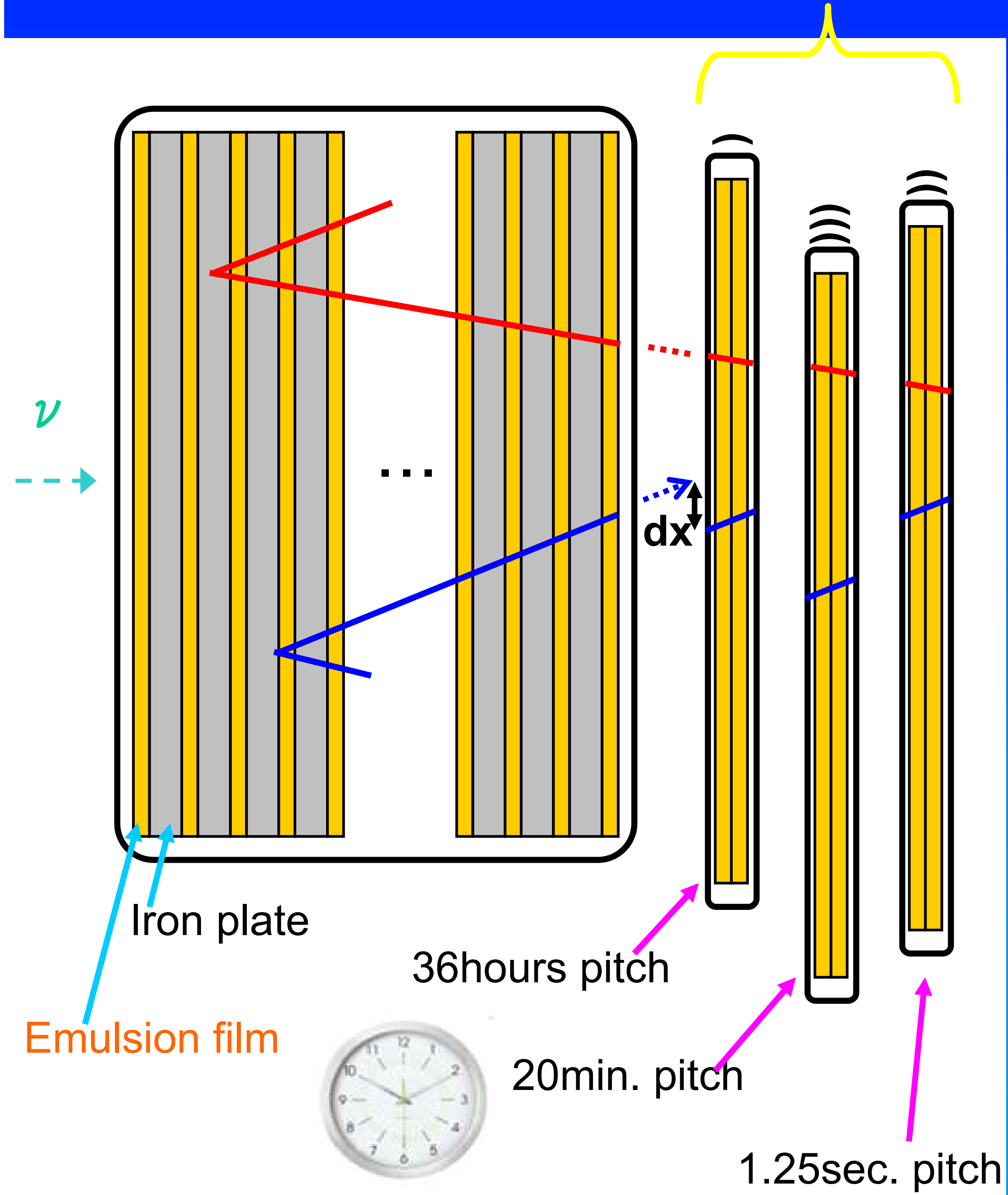
Momentum of penetrated tracks
($|\tan\theta| < 0.2$)

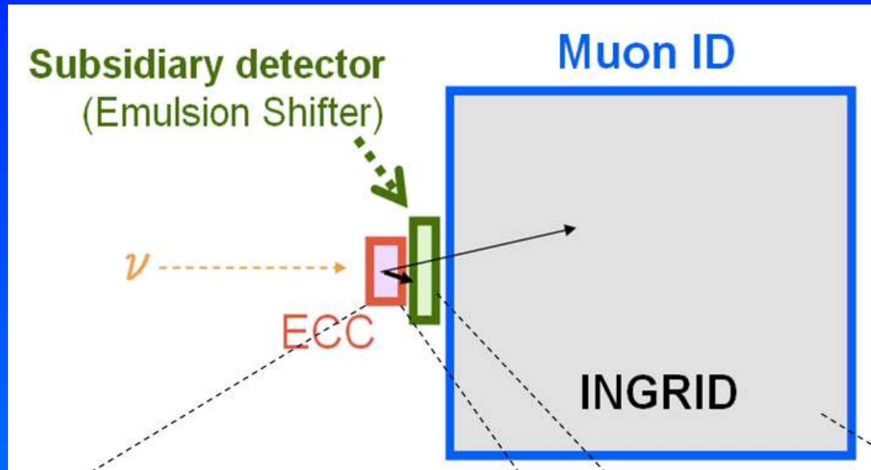


Momentum p β (GeV/c)



Emulsion Shifter





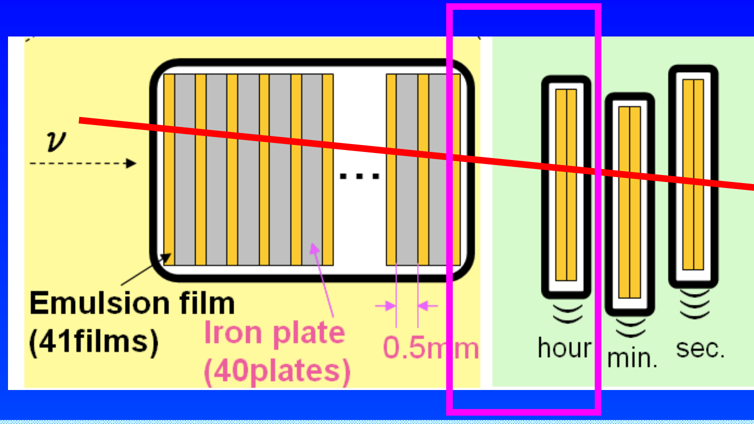
Emulsion Shifter was placed at between ECC and INGRID.

Doublet emulsion films are set on moving stages controlled by stepping motor.

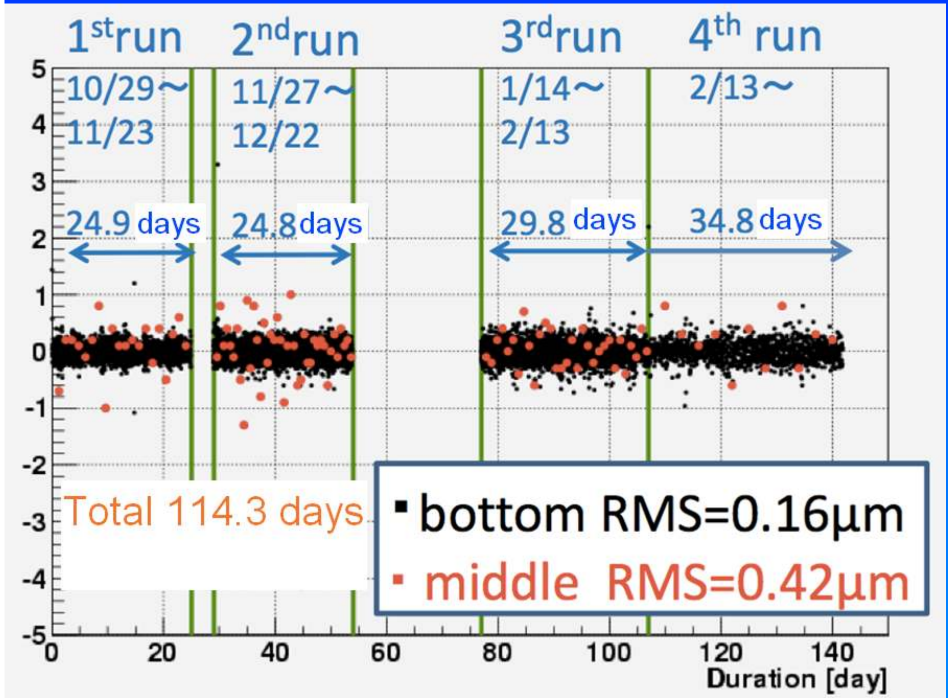
- Top stage → 36 hours / step
- Middle stage → 20 min. / step
- Bottom stage → 1.25 sec. / step

Time stamp is given by coincidence of tracks on each stage.
→ Position difference from reference point
= Timing information

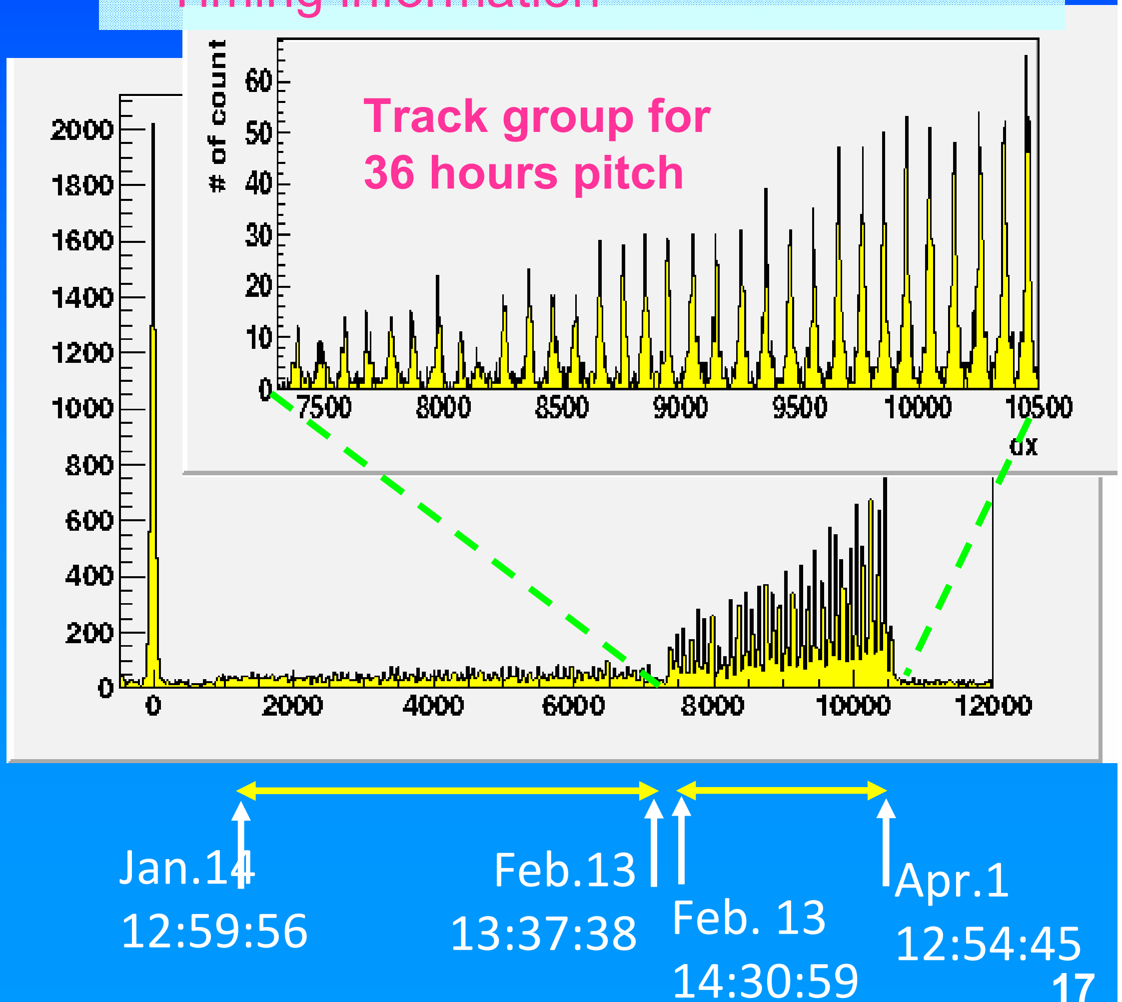
Status of shifter



Mechanical reproducibility of moving stage



Position difference from reference point
= Timing information



Emulsion Shifter is working very well.

Shifter analysis of top stage is done.
Tracks in ECC is given 36 hours pitch timing information.

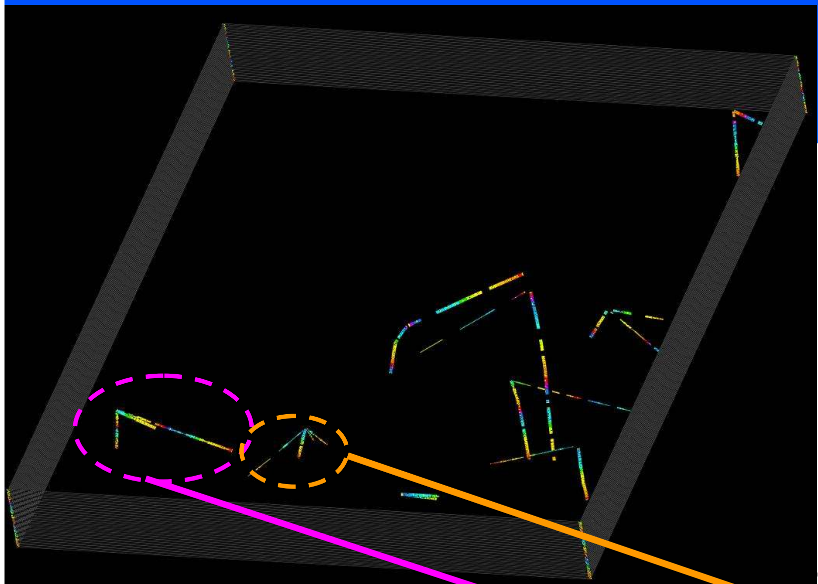
Time stamp for neutrino events

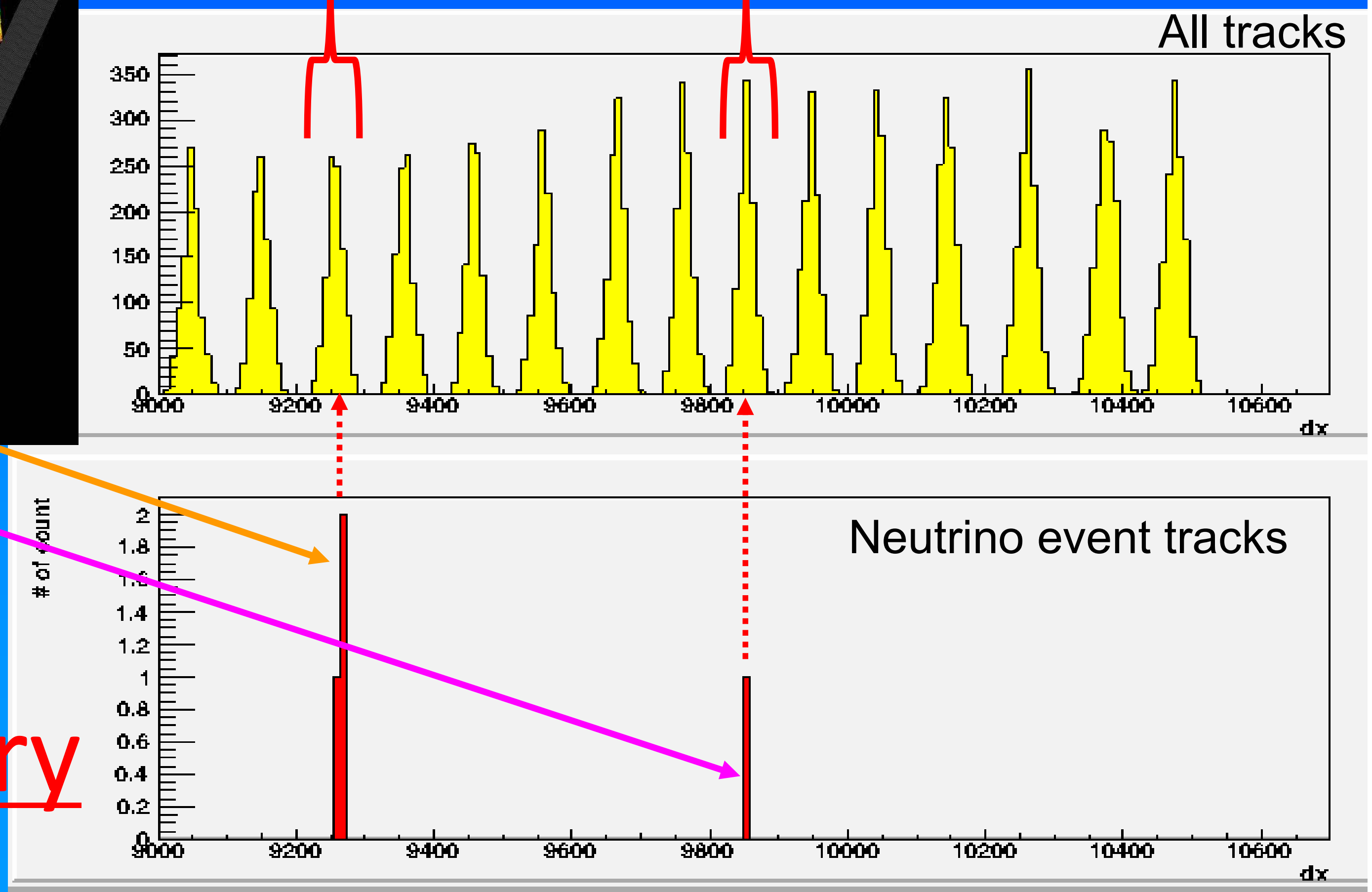
2 neutrino events are given their time stamp in the pilot analysis !

Other events will also be given their time stamp and if we analyzed middle and bottom stage, time resolution will be reached second level.

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

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



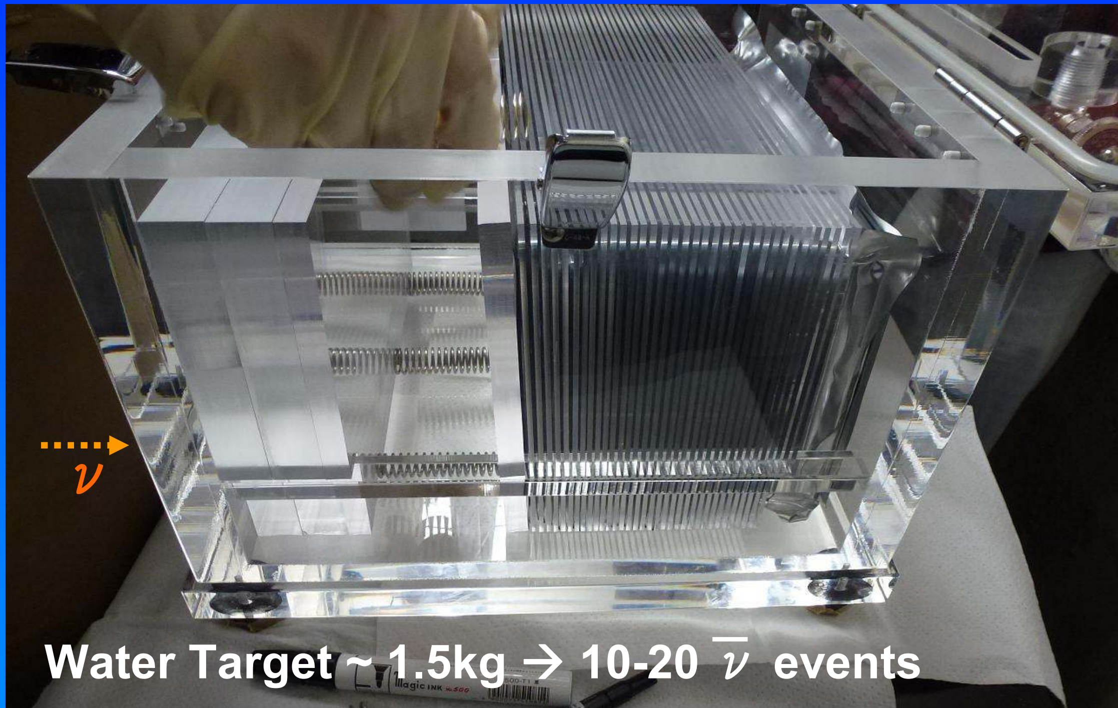


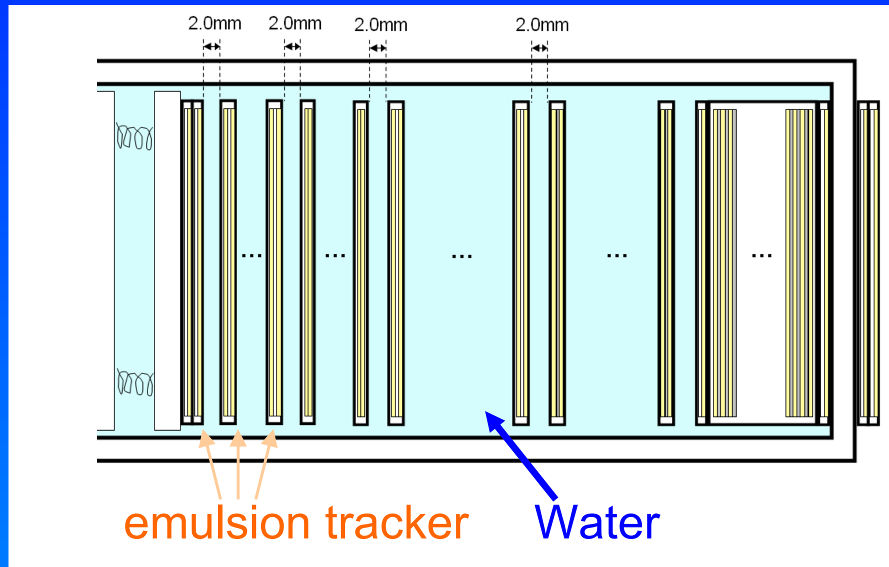
Very Preliminary

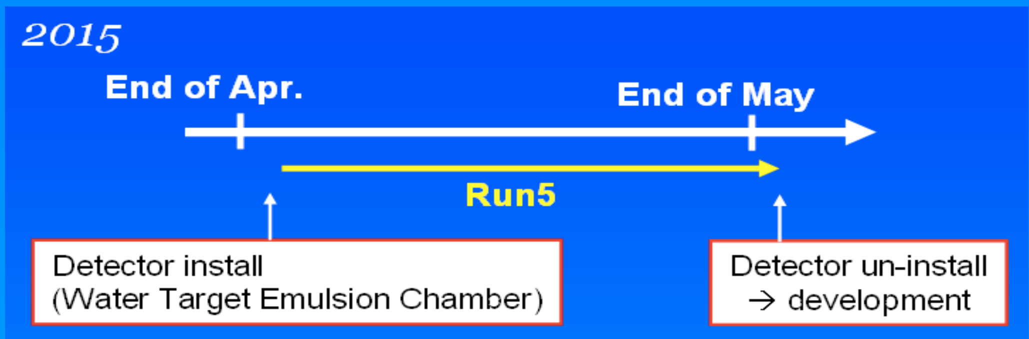
Future prospects

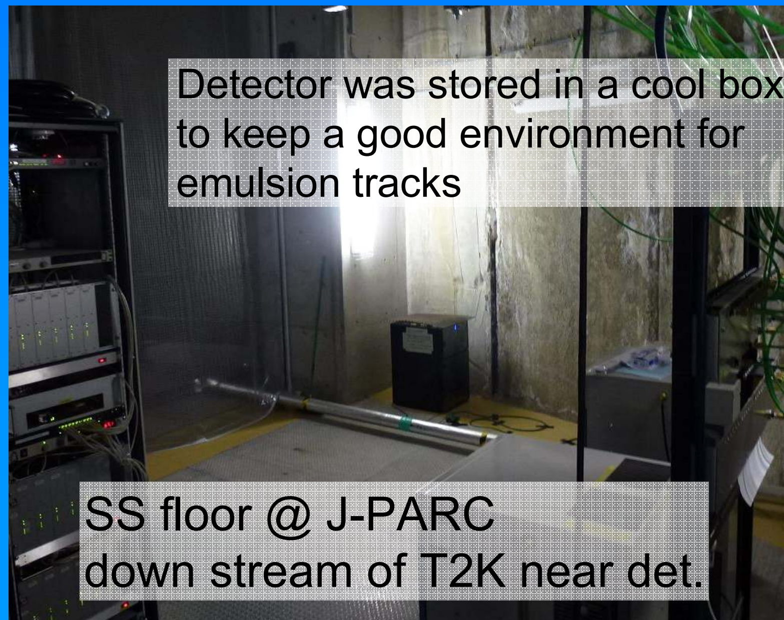
Water target emulsion chamber install and Run

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





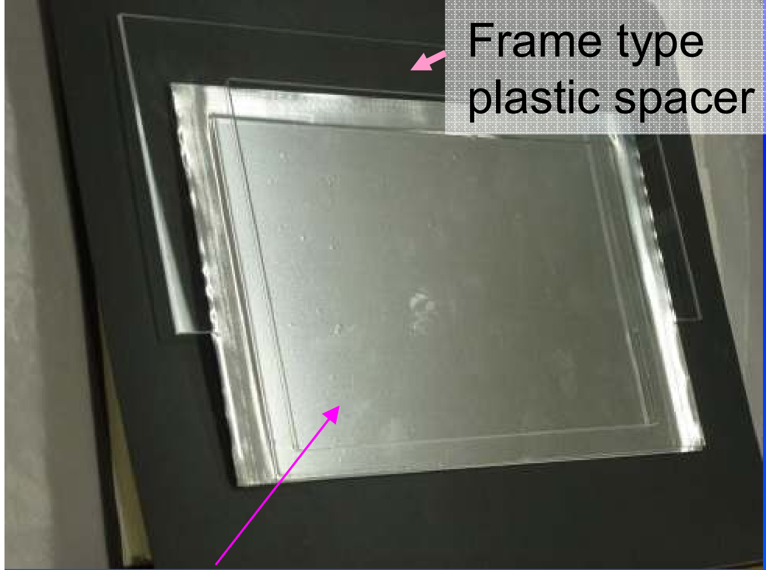




Neutrino exposure was done.

First results will be reported → End of Sep.

Setup

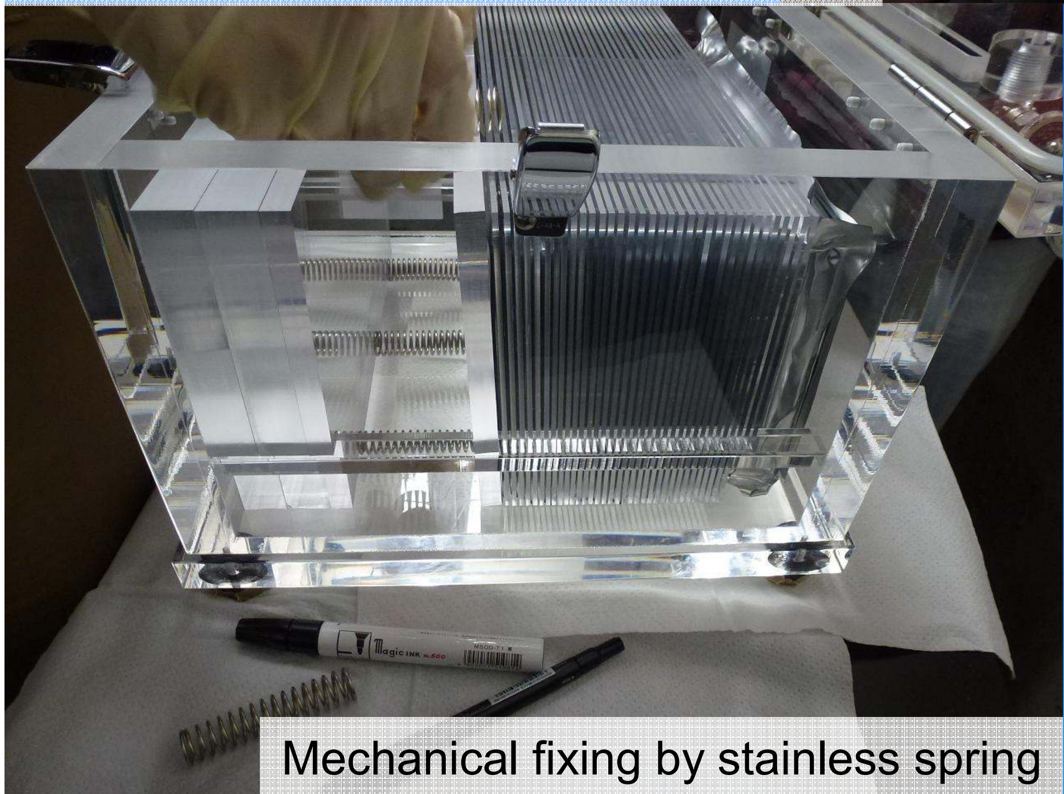


Frame type plastic spacer

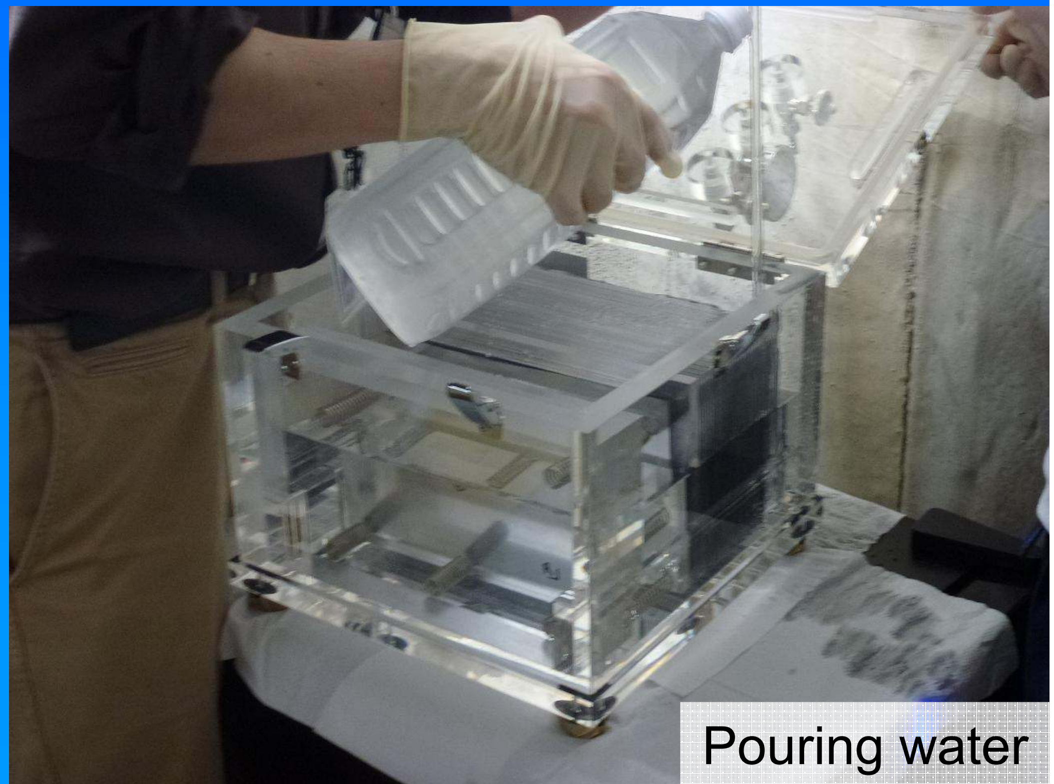
Emulsion films (vacuum packed)

Sandwich structure of Emulsion films and Frame type spacers

Target mass : H_2O 1.5kg (2.0 mm pitch)



Mechanical fixing by stainless spring

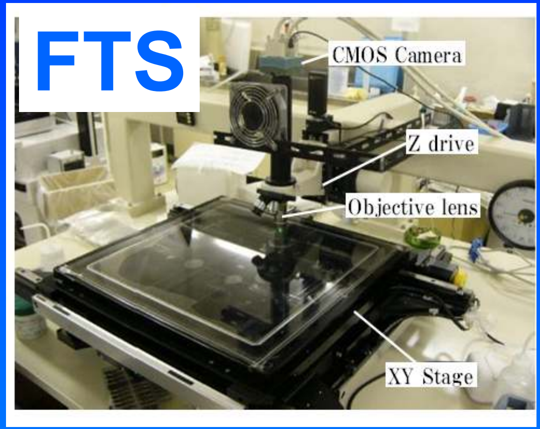


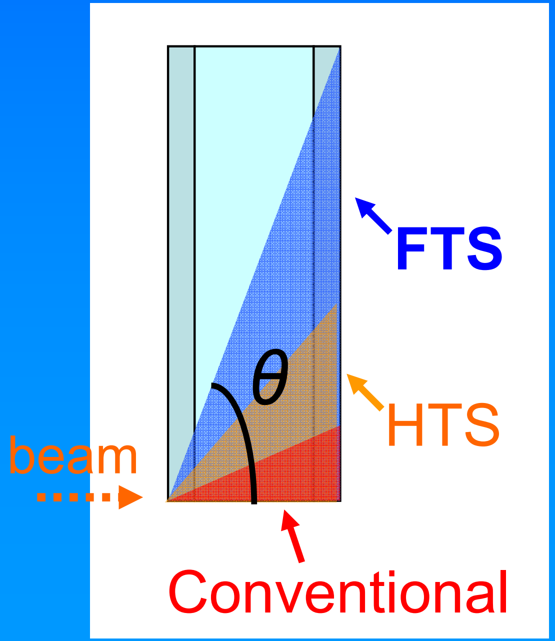
Pouring water

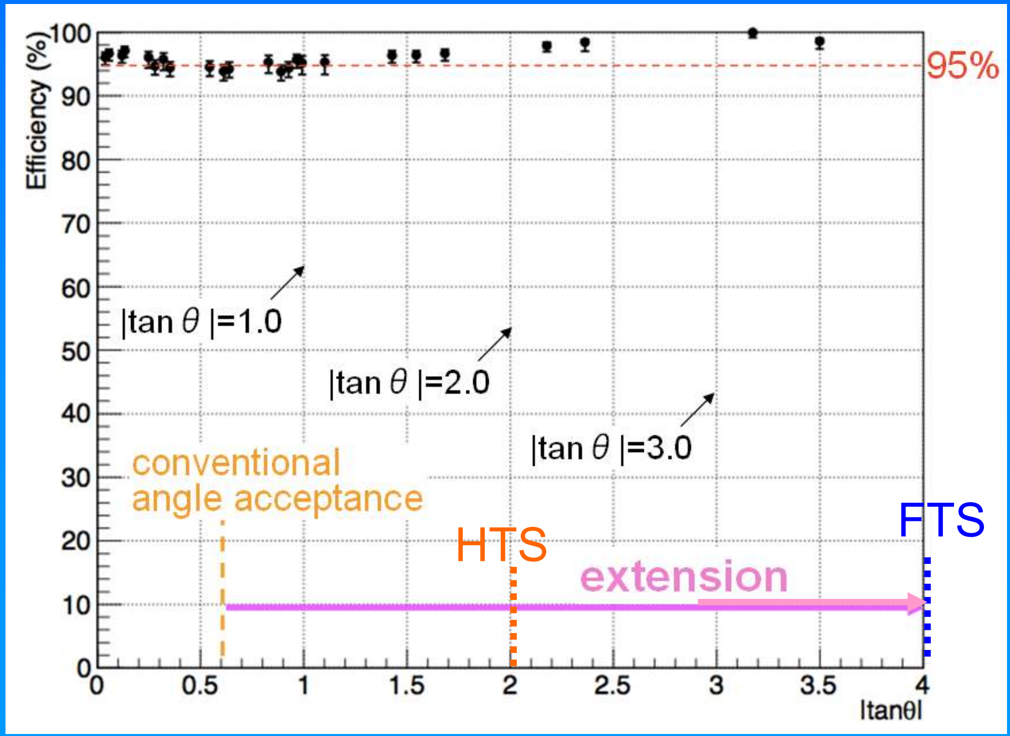
Large angle scanning

In current high speed scanning system (HTS), angle acceptance is limited by $|\tan\theta| \leq 2.0$.

Angle acceptance will be widen by $|\tan\theta| \leq 4.0$ for detected neutrino events by using Large angle scanning system.

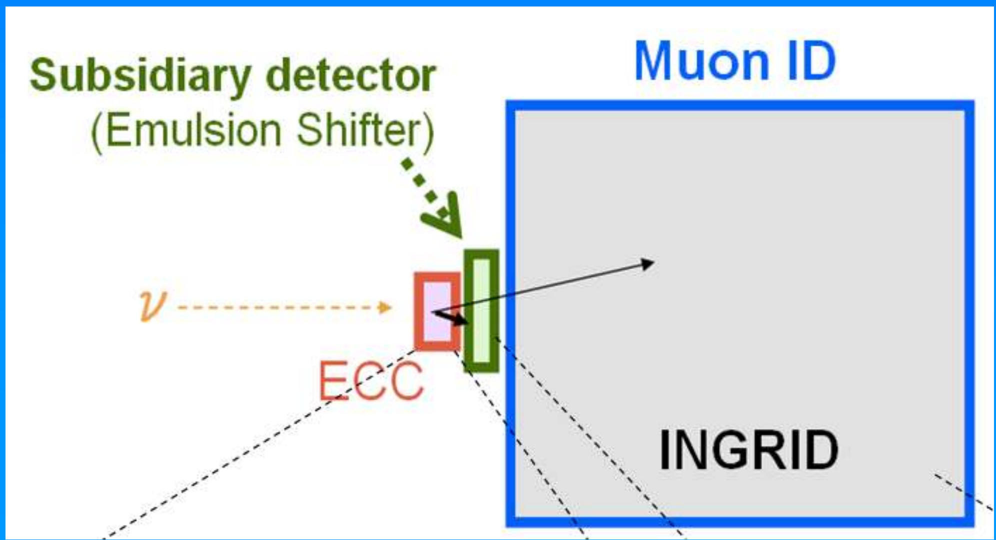






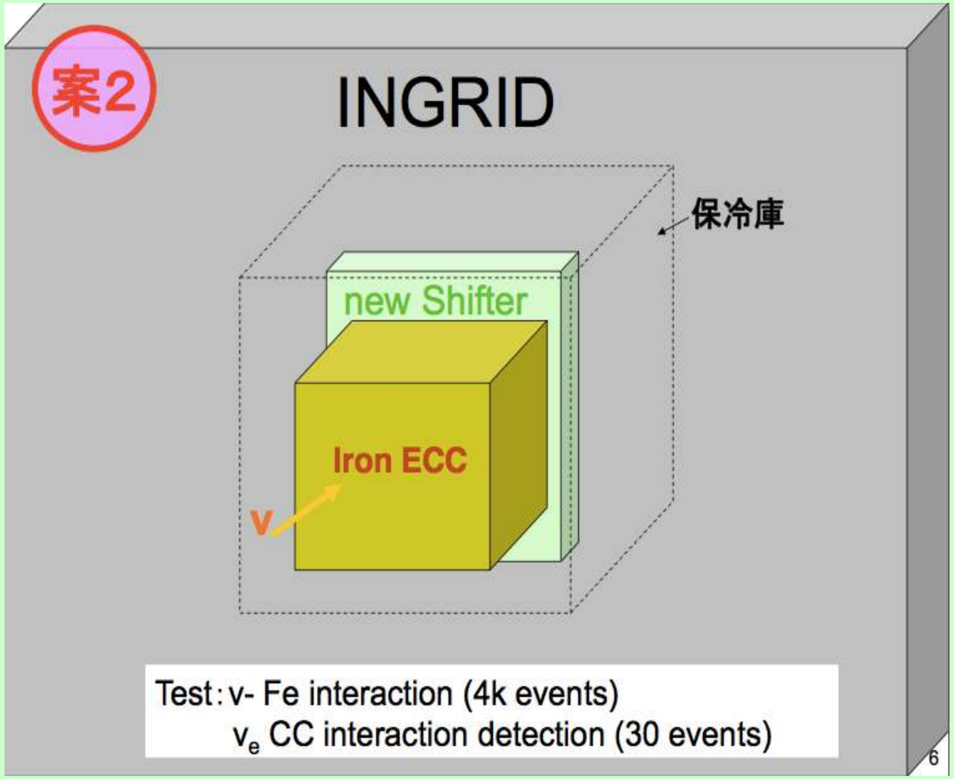
Possibility of hybrid analysis with INGRID

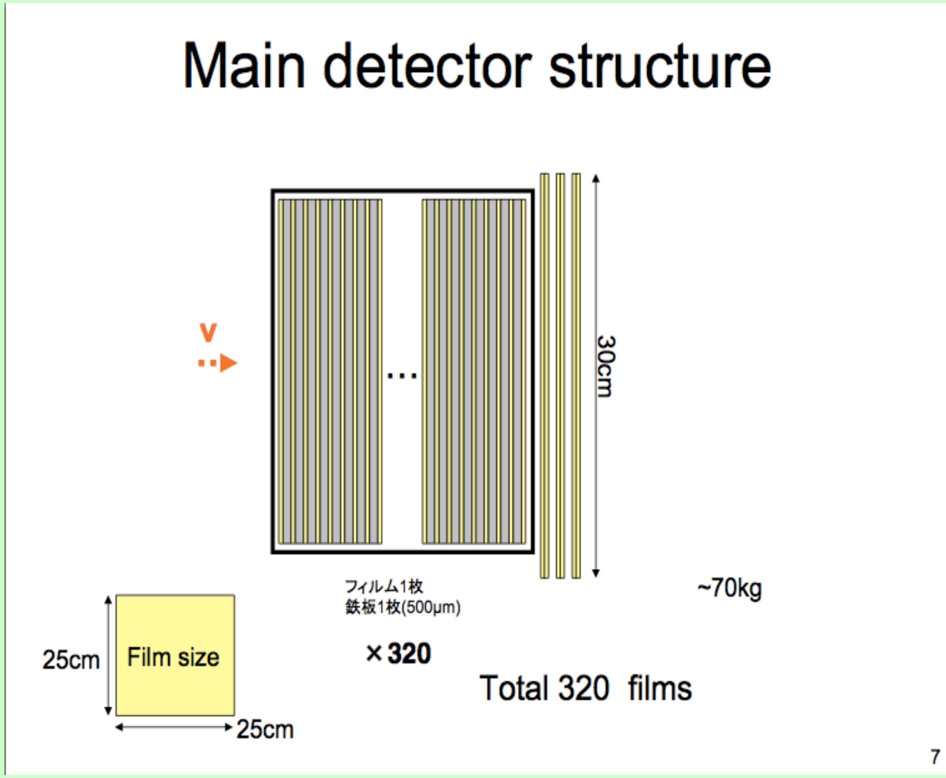
- T60 emulsion detector don’t have a capability of muon identification.
- Near future, timing information of tracks in emulsion det. will be reached second level by shifter analysis.
- If track by track - timing matching between T60 and INGRID could be done, muon id for neutrino event in T60 det. will become available.



Is it possible ?
This is one of discussion points from T60

Next run: *Detector run 1*

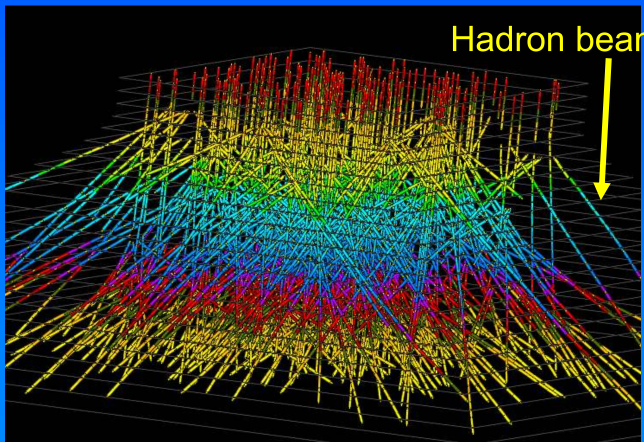




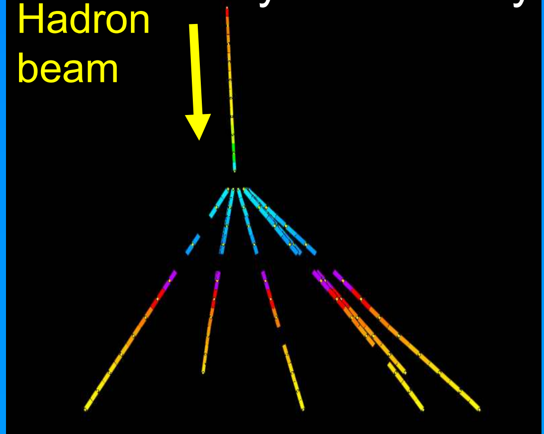
We plan a neutrino exposure after summer shut down. Aim is Data – MC comparison at high statistics of more than 1k events with large scale Iron-ECC (20x target mass).

Consideration of future hadron study with emulsion detector

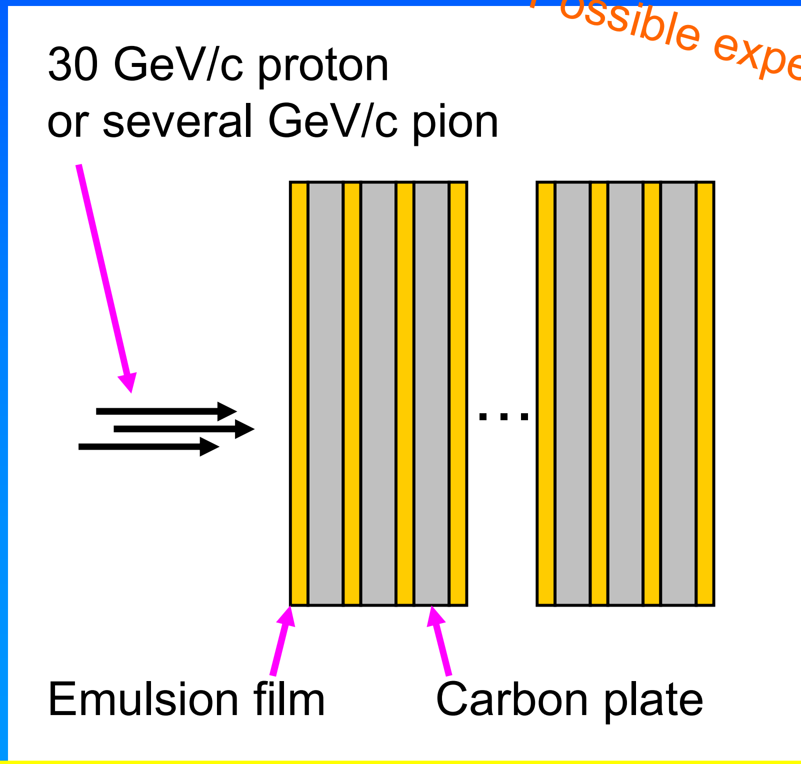
We have an experience of the study of 2,4,10 GeV/c pion – lead int. with emulsion detector.



Event by event analysis



Possible experiment



→ **useful information for reduction of uncertainly of neutrino flux ?**

Consideration of future hadron study with emulsion detector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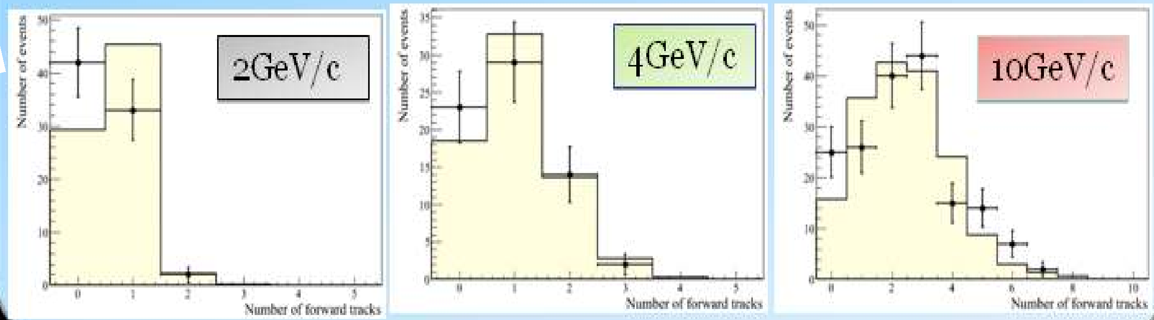
PTEP

Study of hadron interactions in a lead–emulsion target

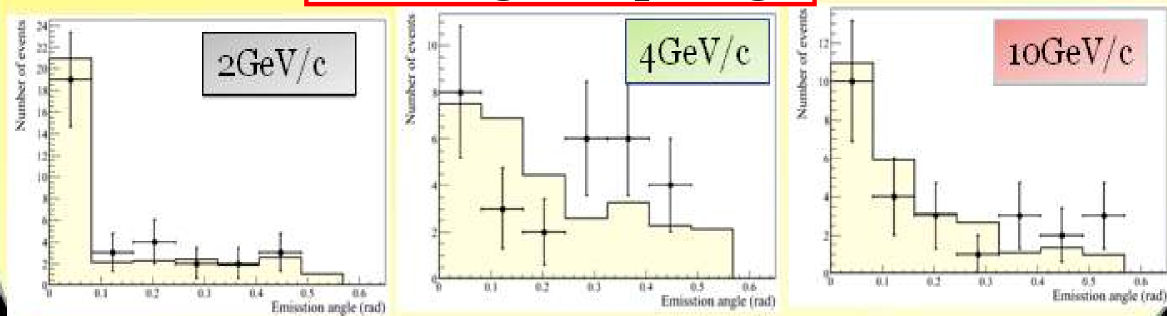
Hirokazu Ishida[1], Tsutomu Fukuda[1], Takafumi Kajiwara[1], Koichi Kodama[2], Masahiro Komatsu[3], Tomokazu Matsuo[1], Shoji Mikado[4], Mitsuhiro Nakamura[3], Satoru Ogawa[1], Andrey Sheshukov[5], Hiroshi Shibuya[1,*], Jun Sudou[1], Taira Suzuki[1], and Yusuke Tsuchida[1]

Example: Topological data of pion-lead interaction

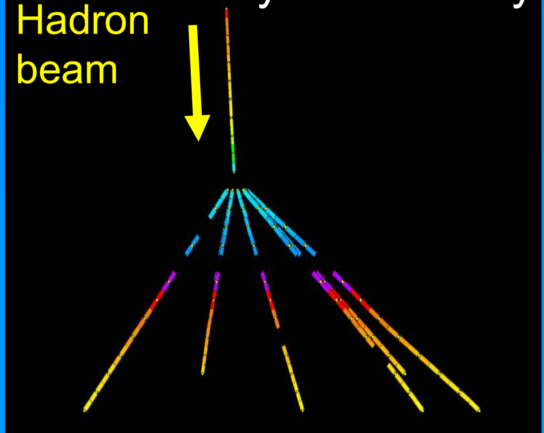
Multiplicity



Kink angle (1-prong)



Event by event analysis

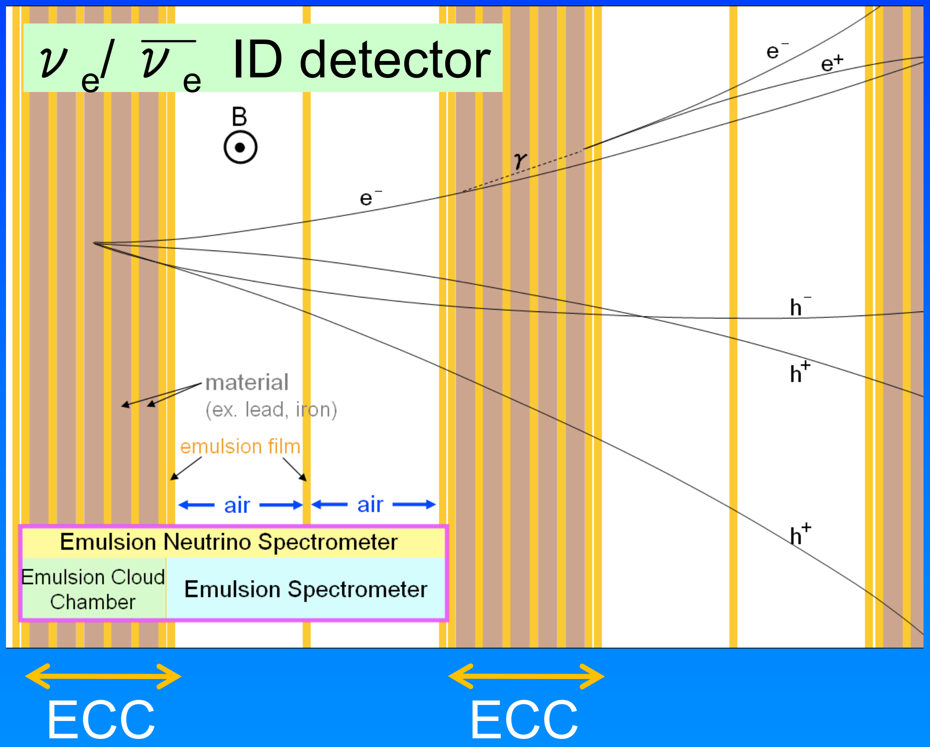


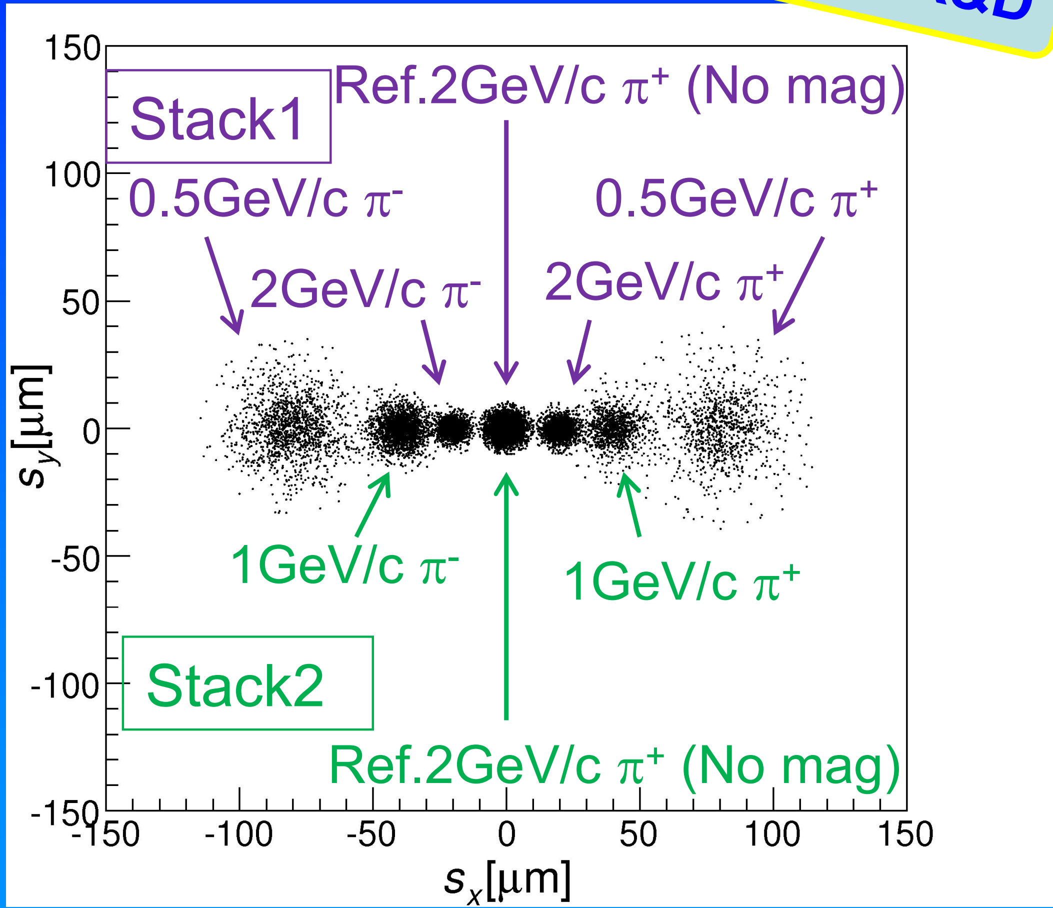
Kinematical data is also given.

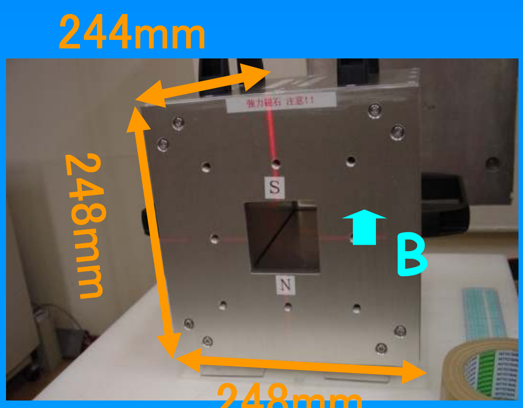
Emulsion Spectrometer

(emulsion in magnetized field)

Basic R&D







Test beam : 15mm gap, B = 1T

Electron charge could be measured !

Schedule

- Emulsion scanning optimized based on the pilot analysis will be started and the emulsion analysis will be improved.
- The results will be reported on the end of September.

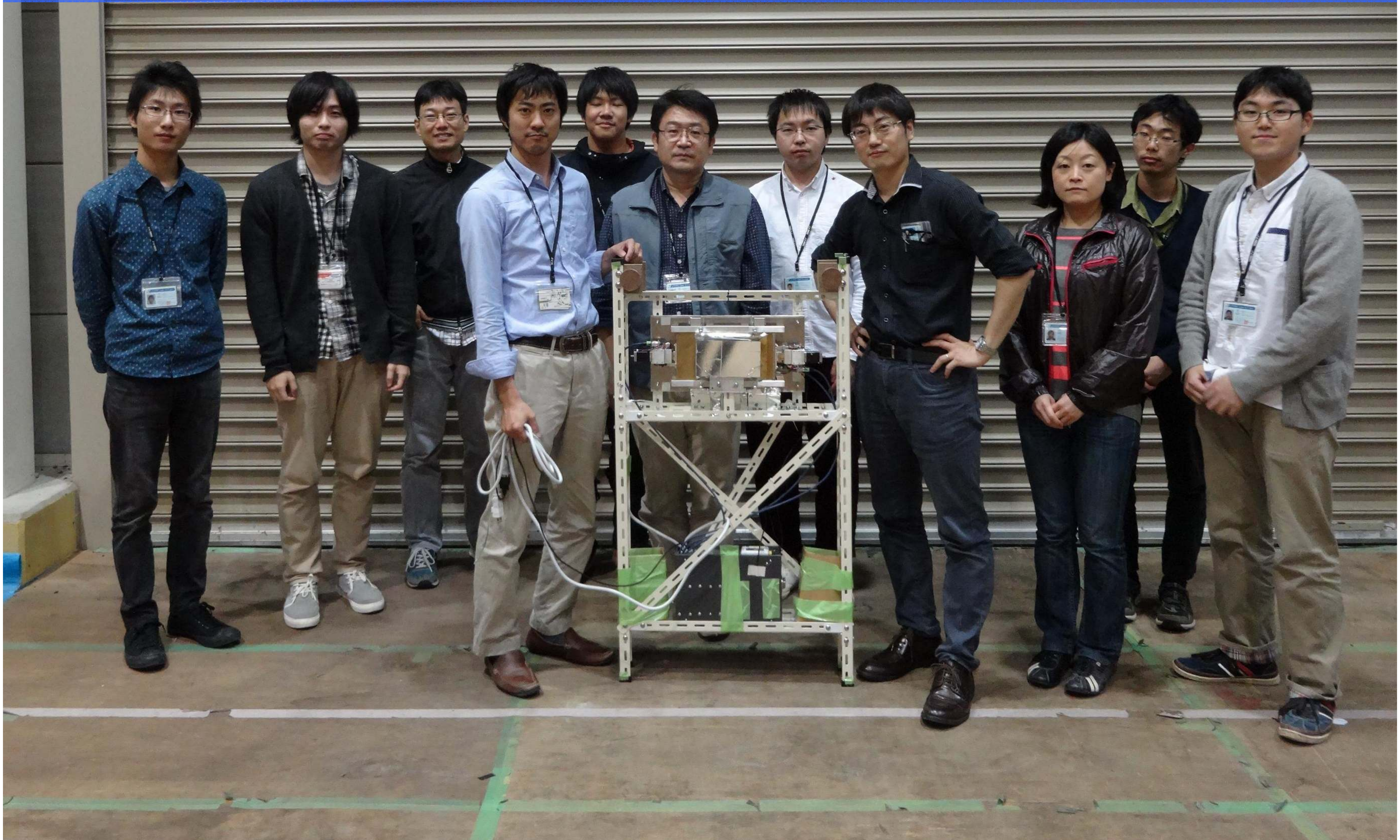
- Larger size iron target emulsion chamber (~20x. target mass) is planned to install after summer shut down.
- About several thousands of muon neutrino events and several dozen of electron neutrino event will be detected.
- Test experiment can run parasitically with T2K.
(we request no dedicated beam time nor beam condition)

- We will expand the scale of detector gradually, step by step. Then we start to consider a future experiment for hadron - carbon interaction study with emulsion chamber.

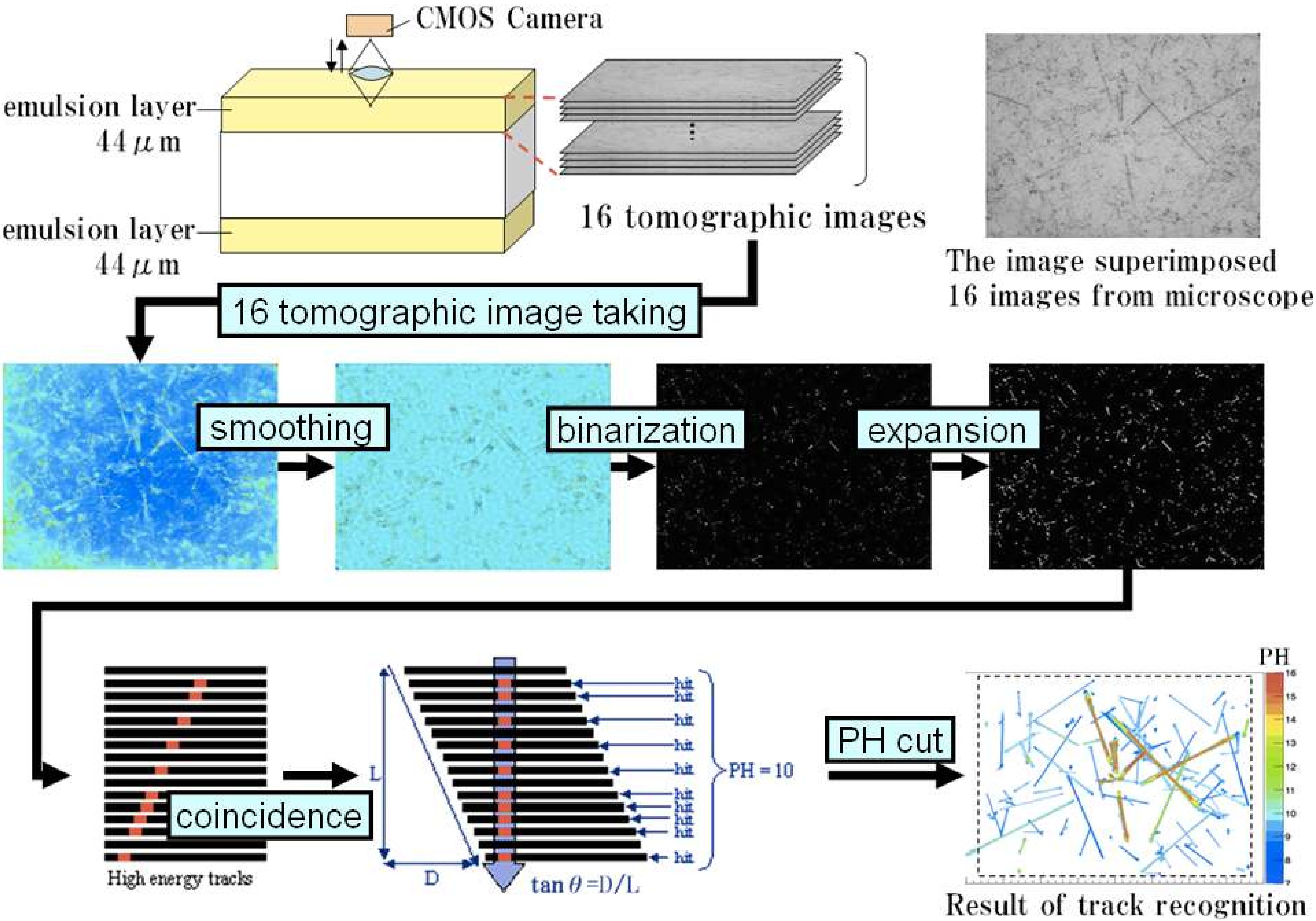
Summary

- We proposed an experiment series to investigate low energy neutrino interactions for the understanding of ν int. itself and sterile neutrino search with Nuclear Emulsion at J-PARC.
- First of all, we performed to expose neutrino to the iron-target and water-target ECC for the feasibility study.
- We confirmed to proceed an emulsion based experiment in safety. Then some of neutrino interaction events were detected and physics analysis was also demonstrated.
- We proposed next step of the test experiment to increase statistics of neutrino events and hope to verify the neutrino interaction model and detect electron neutrino events.

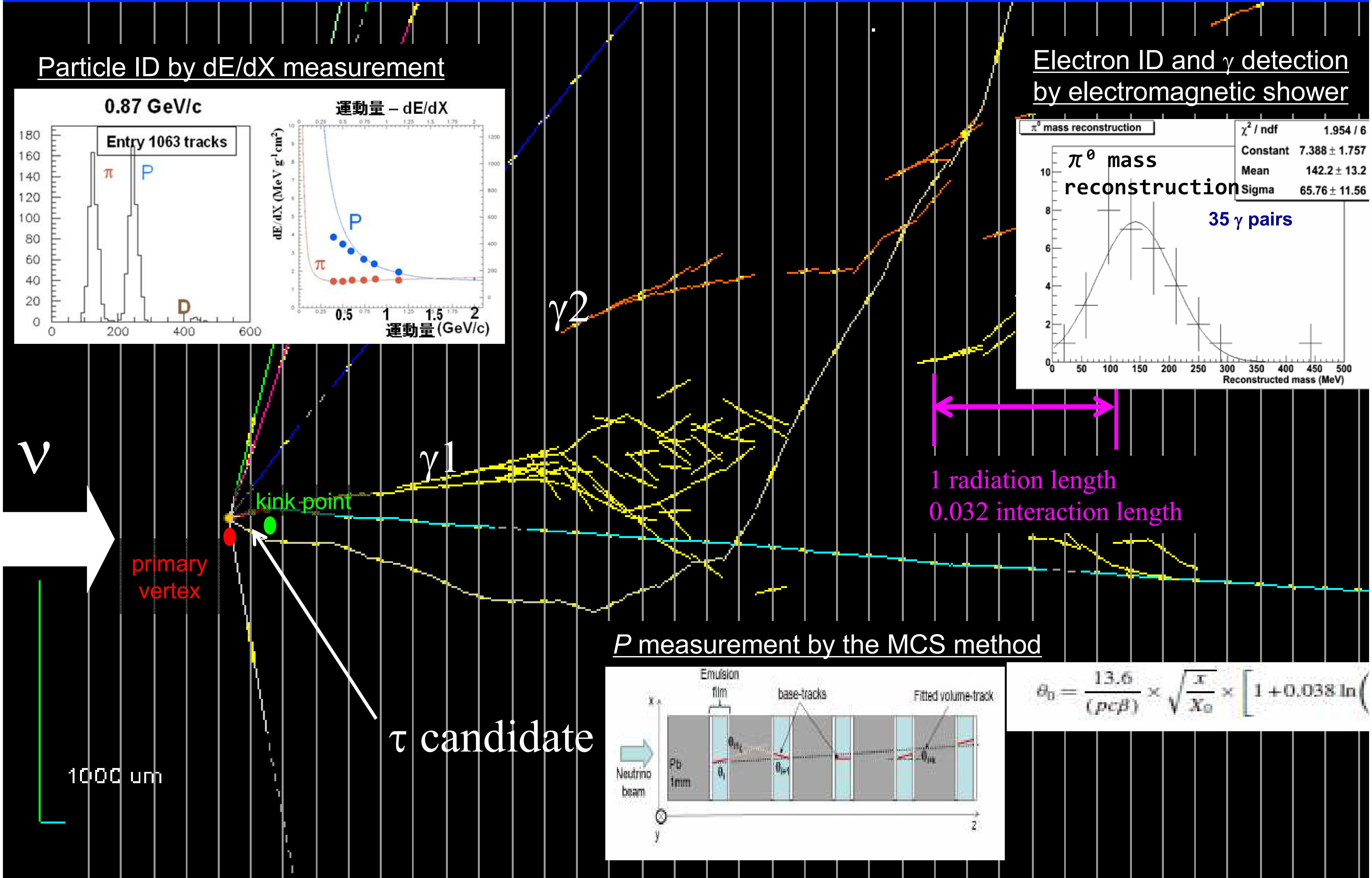
Thank you for your kind attention



Supplements

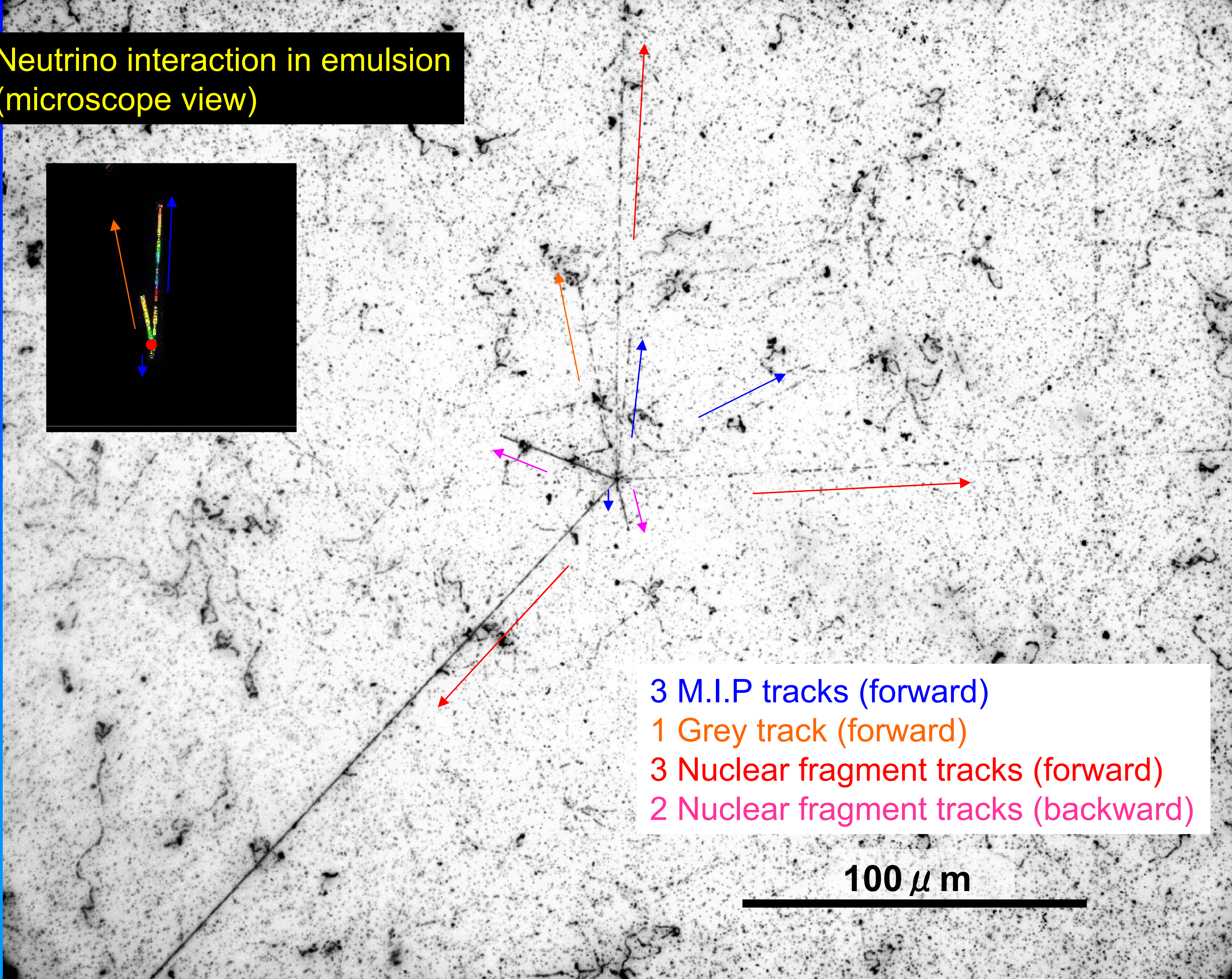

CMOS Camera
emulsion layer
44 μm
emulsion layer
44 μm
16 tomographic images
The image superimposed
16 images from microscope
16 tomographic image taking
smoothing
binarization
expansion
PH
hit
PH = 10
L
D
tan θ = D/L
High energy tracks
coincidence
PH cut
Result of track recognition

Particle ID

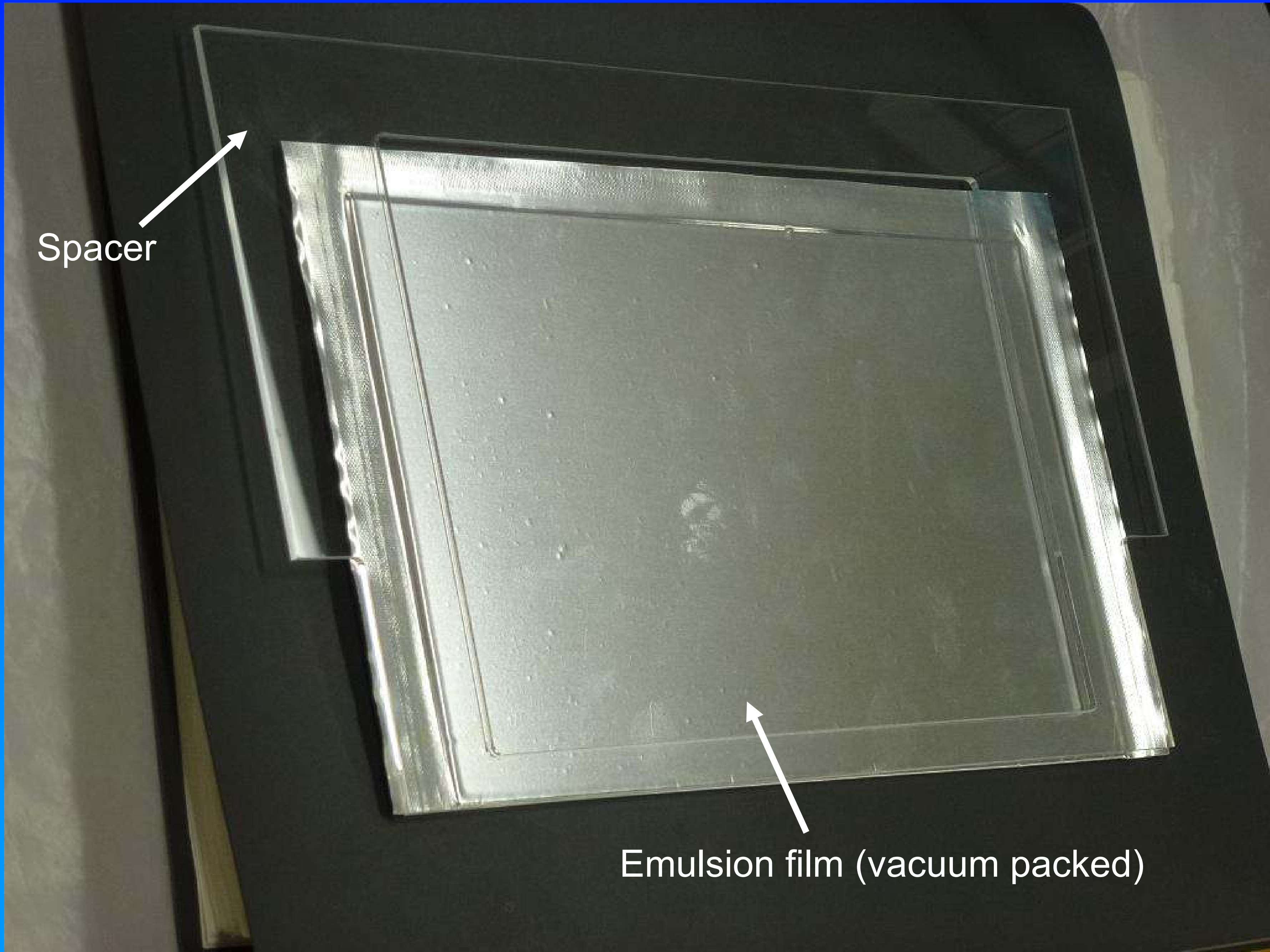


Particle ID by dE/dX measurement
0.87 GeV/c
Entry 1063 tracks
π
P
D
運動量 – dE/dX
dE/dX (MeV g-1cm2)
運動量(GeV/c)
Electron ID and γ detection by electromagnetic shower
π0 mass reconstruction
χ2 / ndf 1.954 / 6
Constant 7.388 ± 1.757
Mean 142.2 ± 13.2
Sigma 65.76 ± 11.56
35 γ pairs
Reconstructed mass (MeV)
γ2
γ1
ν
kink point
primary vertex
τ candidate
1 radiation length
0.032 interaction length
1000 um
P measurement by the MCS method
Emulsion film
base-tracks
Fitted volume-track
Pb 1mm
Neutrino beam
$\theta_0 = \frac{13.6}{(pc\beta)} \times \sqrt{\frac{x}{X_0}} \times [1 + 0.038 \ln($

Neutrino interaction in emulsion (microscope view)



Spacer



Track reconstruction