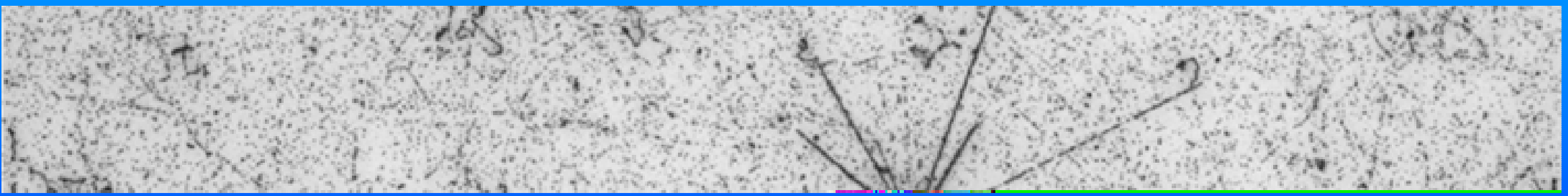
C DEF GHIJ G:

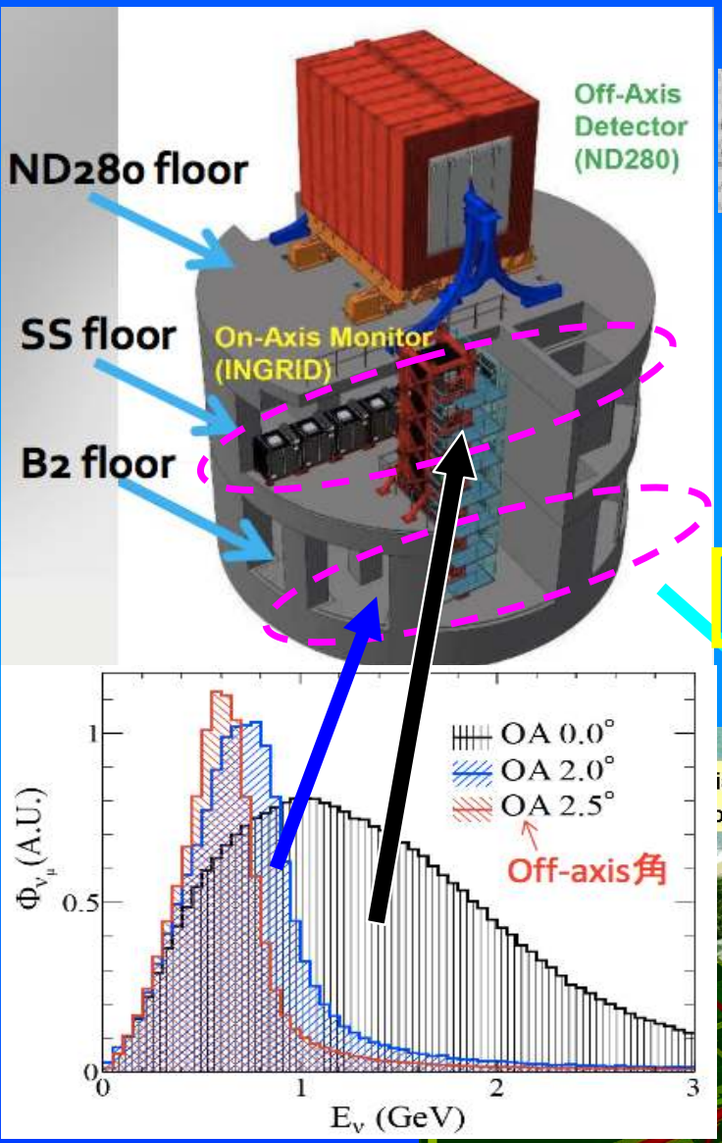
A Neutrino Experiment with Nuclear Emulsion at J-PARC for revealing the matter-dominated universe

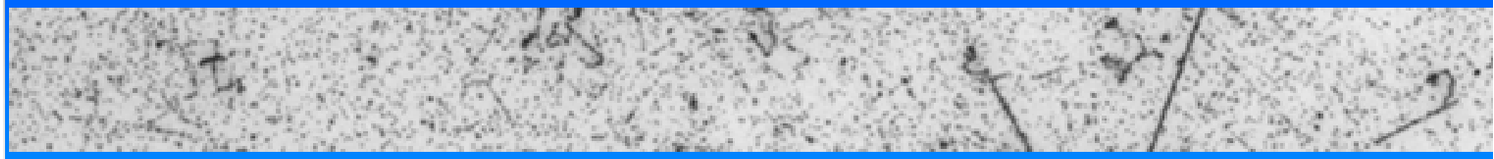
Tsutomu Fukuda (IAR, Nagoya University)
on behalf of NINJA collaboration



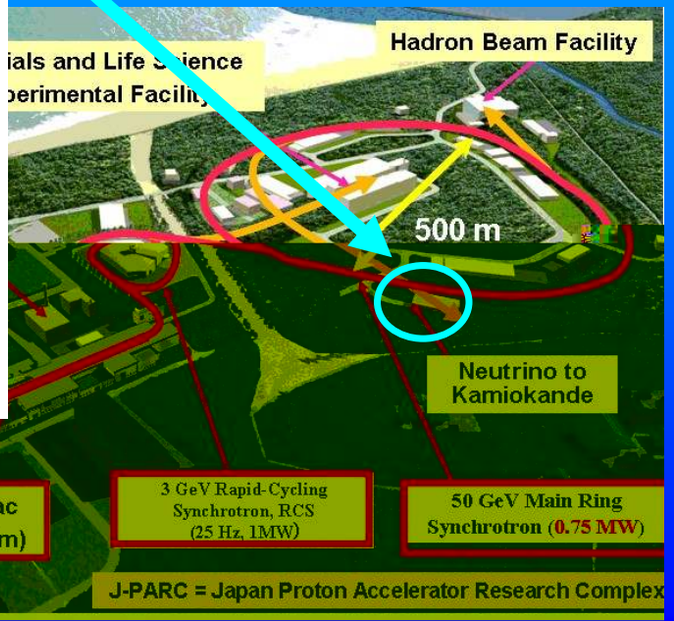
NINJA

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



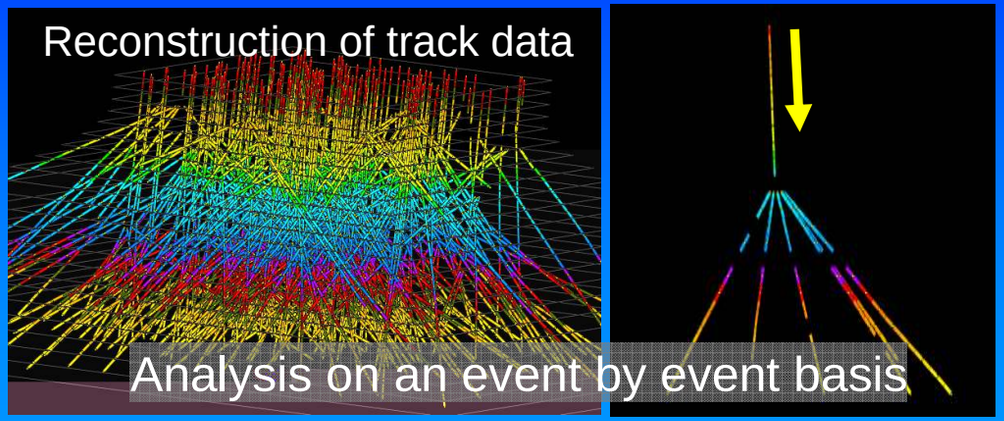


A collaborative project with some member of OPERA and T2K



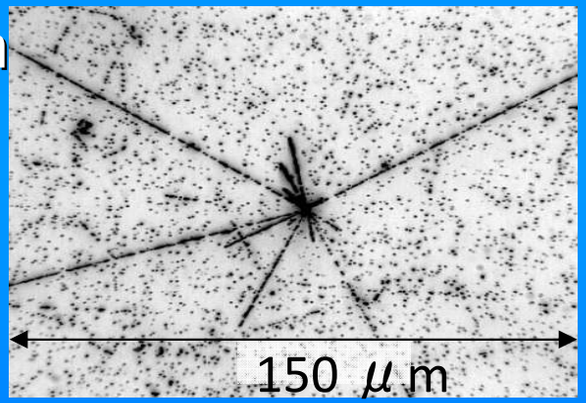
NPGVHJ NPRSMT GG S H

3D reconstruction

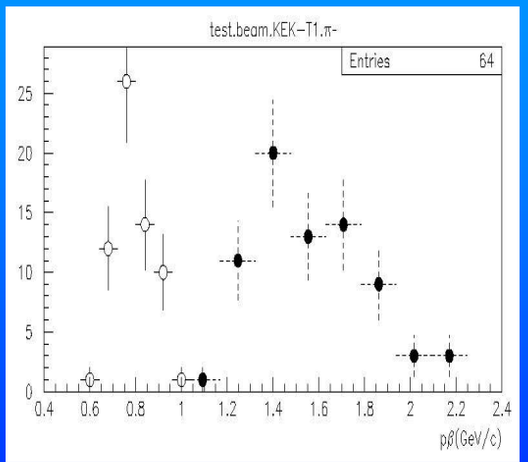


Scalability

4π detection

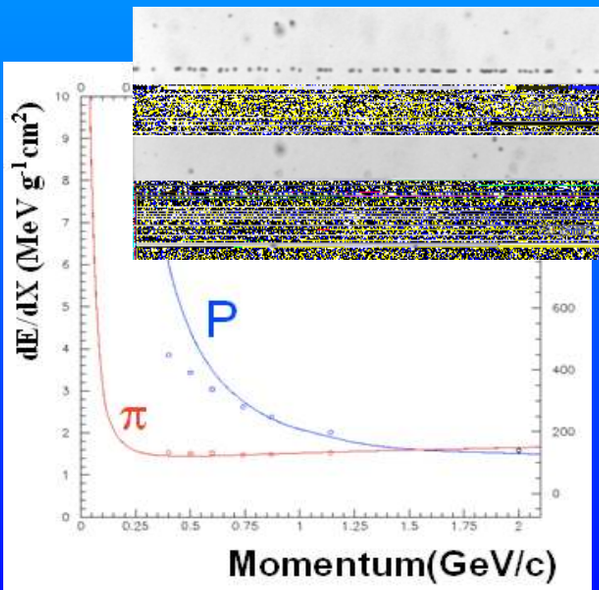


Momentum, dE/dx measurement

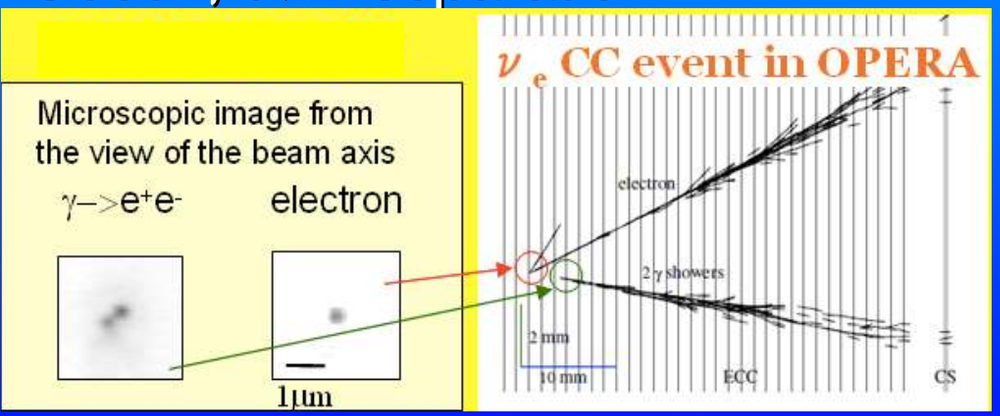


0.8GeV/c π : P =0.79(GeV/c), dP/P =**11**%

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



Good γ / π⁰ separation



Low BG from ν_μ NC π^0 production

NHGMR NISMSM GNHSMFWR

Neutrino osc → (

OPERA

T2HK

0 ν double b → majorana

CANDLES

s

tion ? Dark matter ?

JSNS^2

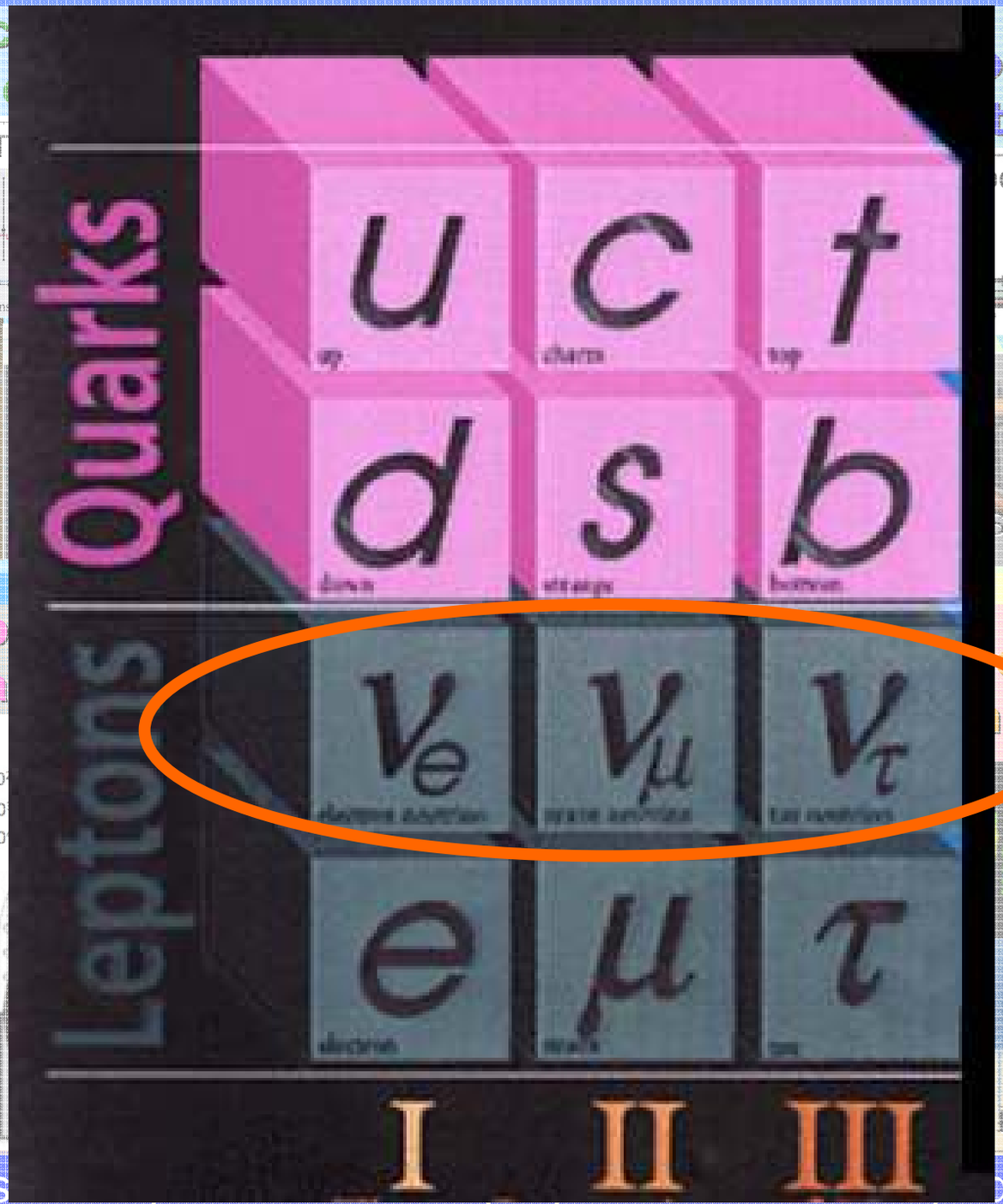
ergy, Supernova,...

SN1987A

KM4NeT

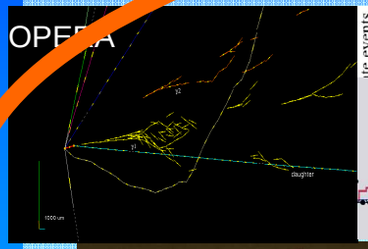
IceCube-Gen2

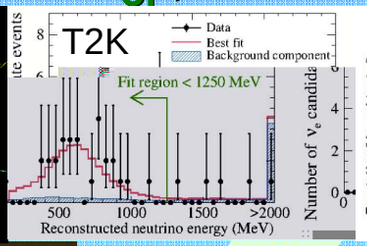
Of cours g out or planned.

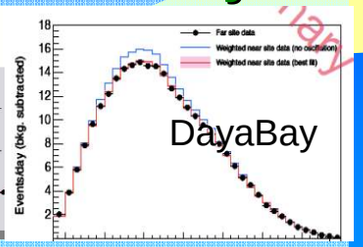


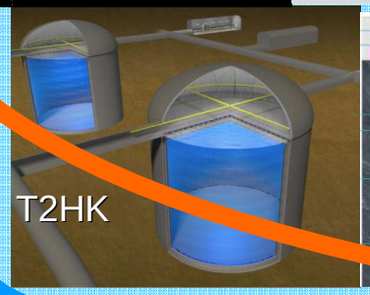
NHGMR NISMSM GNHSMFWR

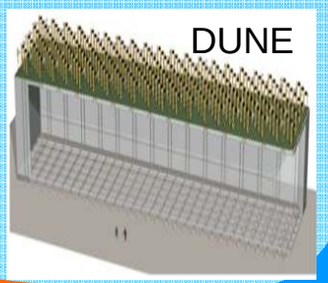
Neutrino oscillation
→ δ_{CP}, mass hierarchy



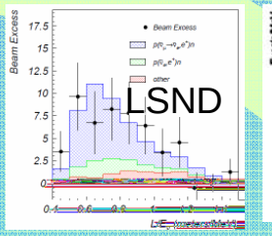


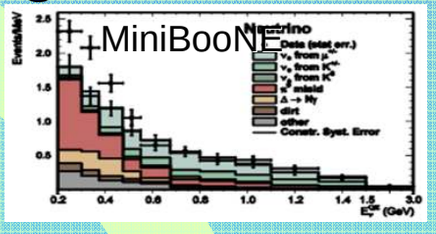


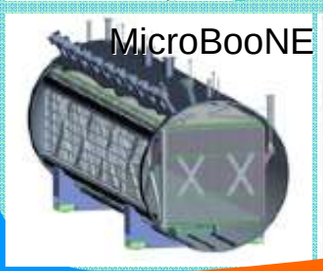




Sterile Neutrinos
→ 4th generation ? Dark matter ?

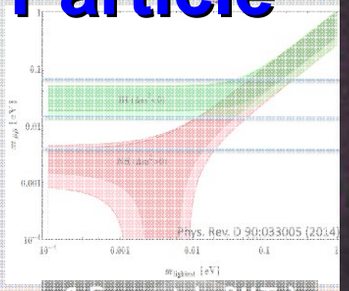


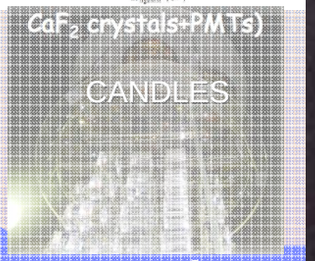




0 ν double

Particle





Anti Particle

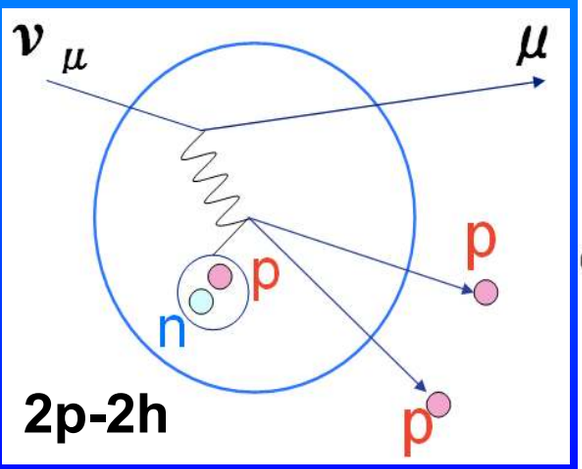
Super Nova,...

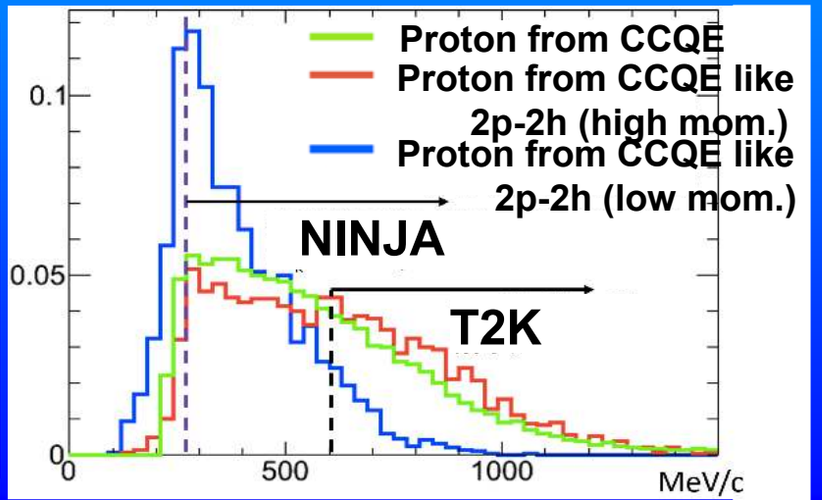
987A

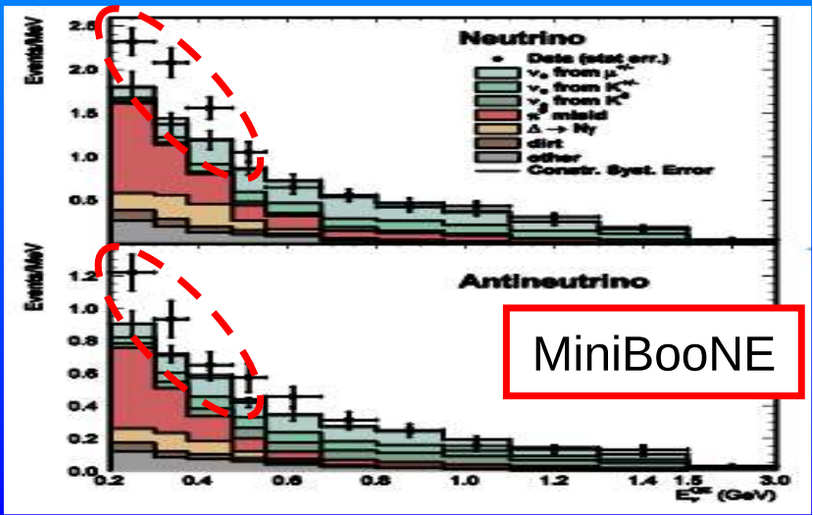
Of cou projects planned.

WRMJ SI IS

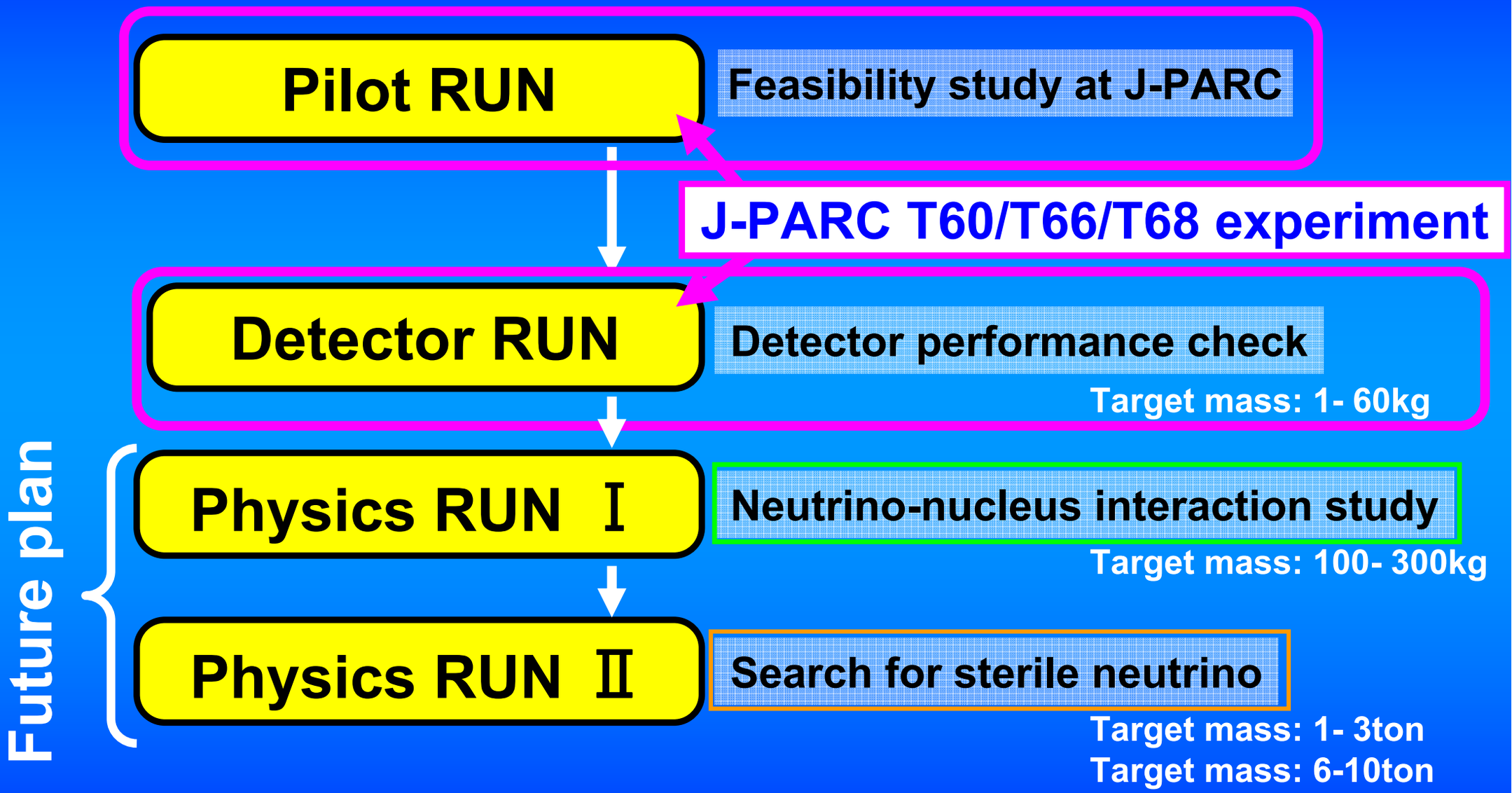
- Precise neutrino-nucleus interaction measurement is important to reduce the systematic uncertainty in future neutrino oscillation experiments.
- We started a new experiment at J-PARC to study low energy neutrino interactions by introducing nuclear emulsion technique.
- The emulsion technique can measure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







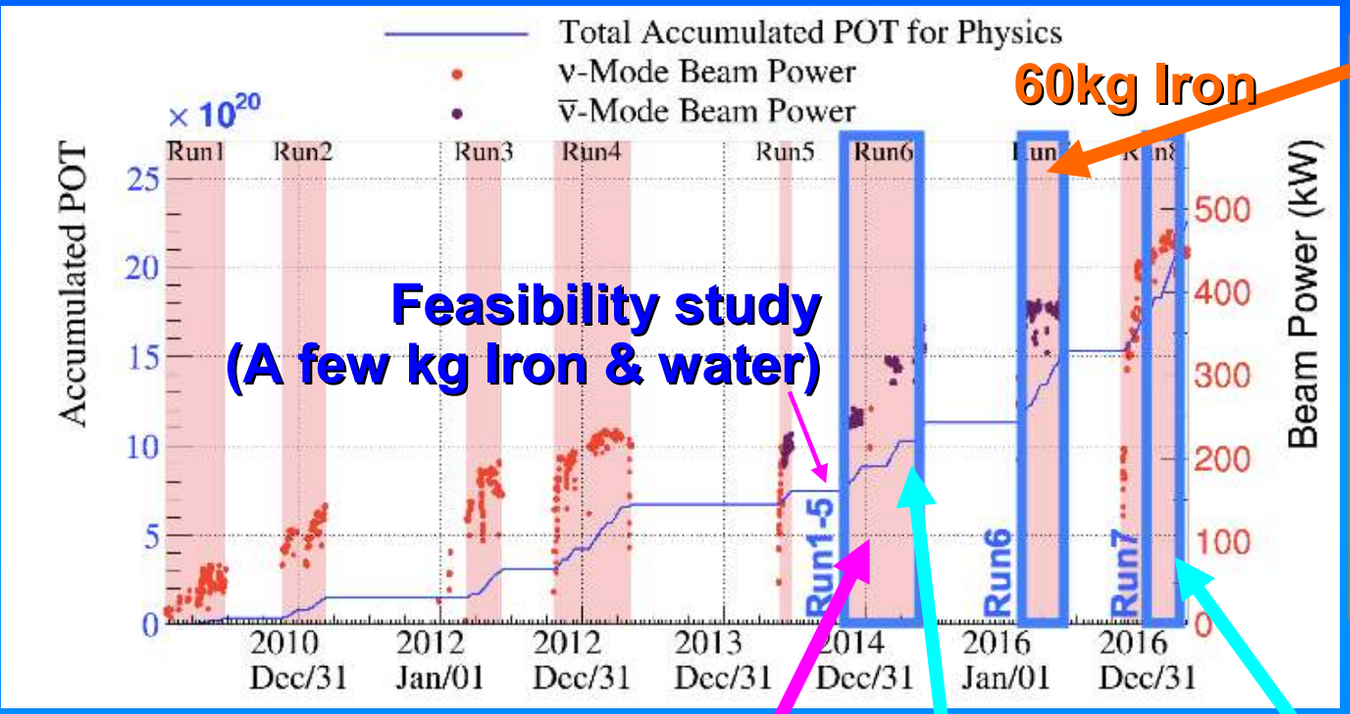
MSJF



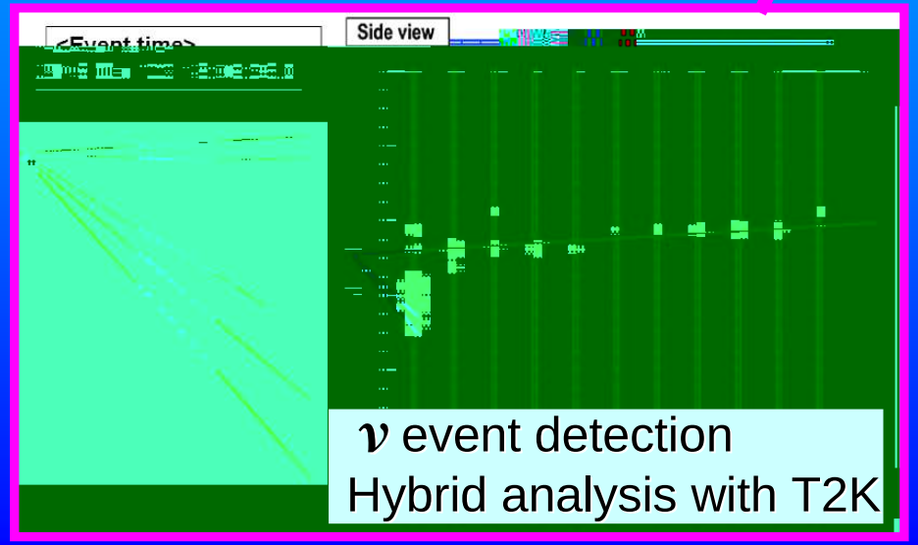
- The aim of T60/T66/T68 is a feasibility study and detector performance check to make a future plan.
- We will expand the scale of detector gradually, step by step.

ν CERN NEUTRINO BEAM

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

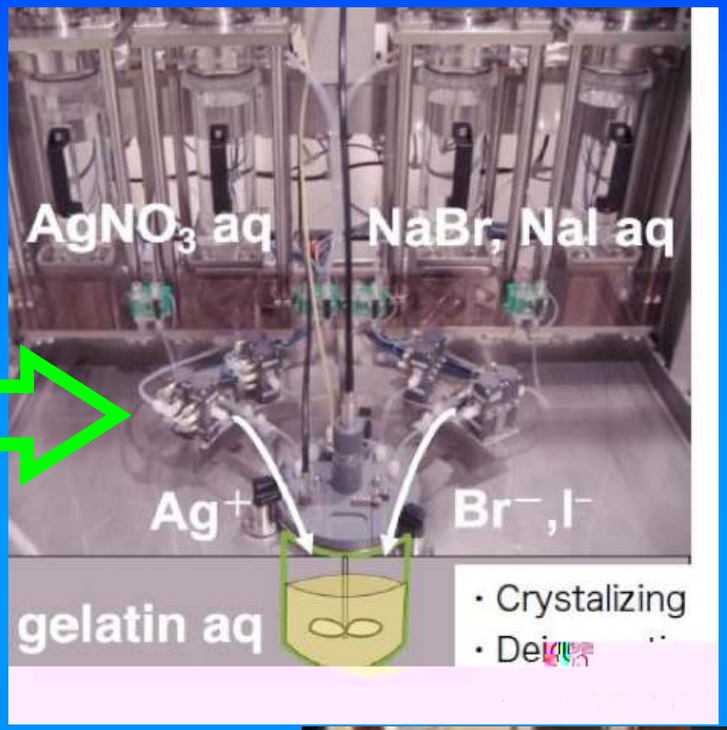


Analysis is now on progress



Production mechanism of nuclear emulsion

Nuclear emulsion films were made by ourselves



Preparing liquid

⇩

Gel production

⇩

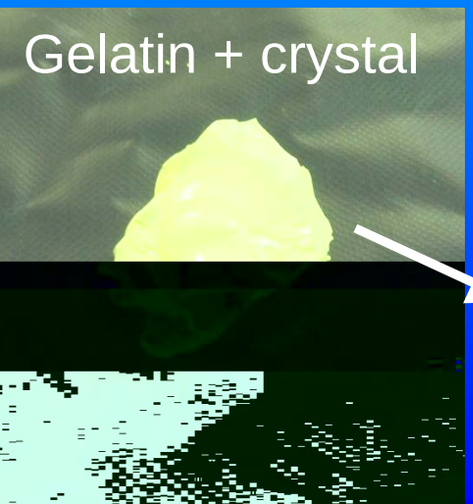
Gel melting

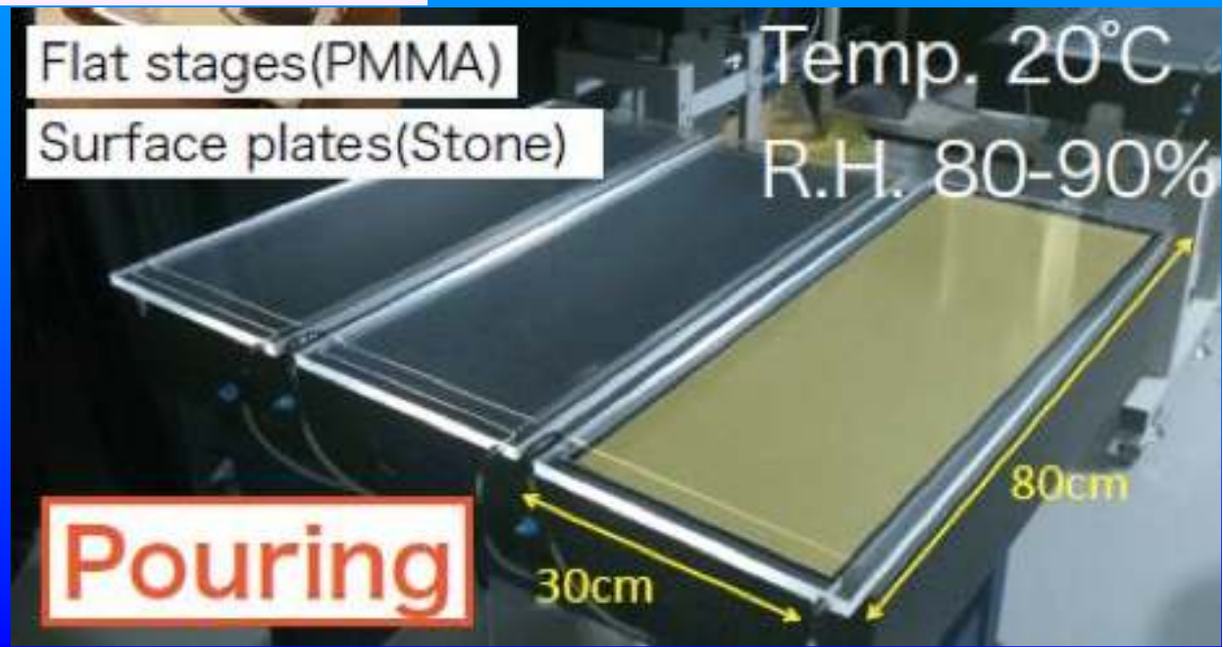
⇩

Pouring

⇩

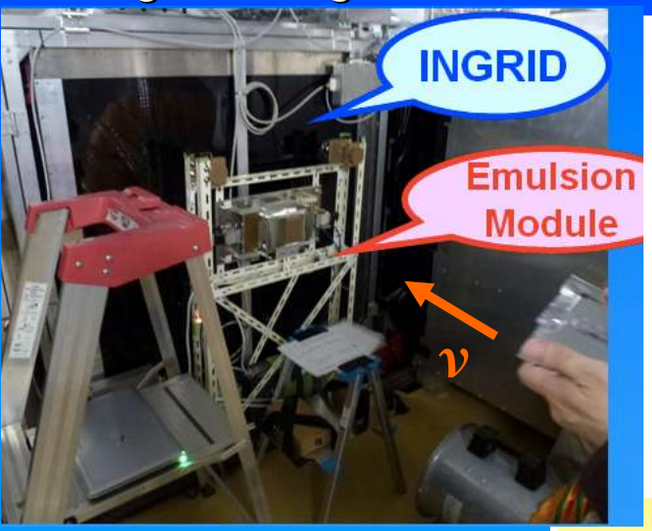
Drying



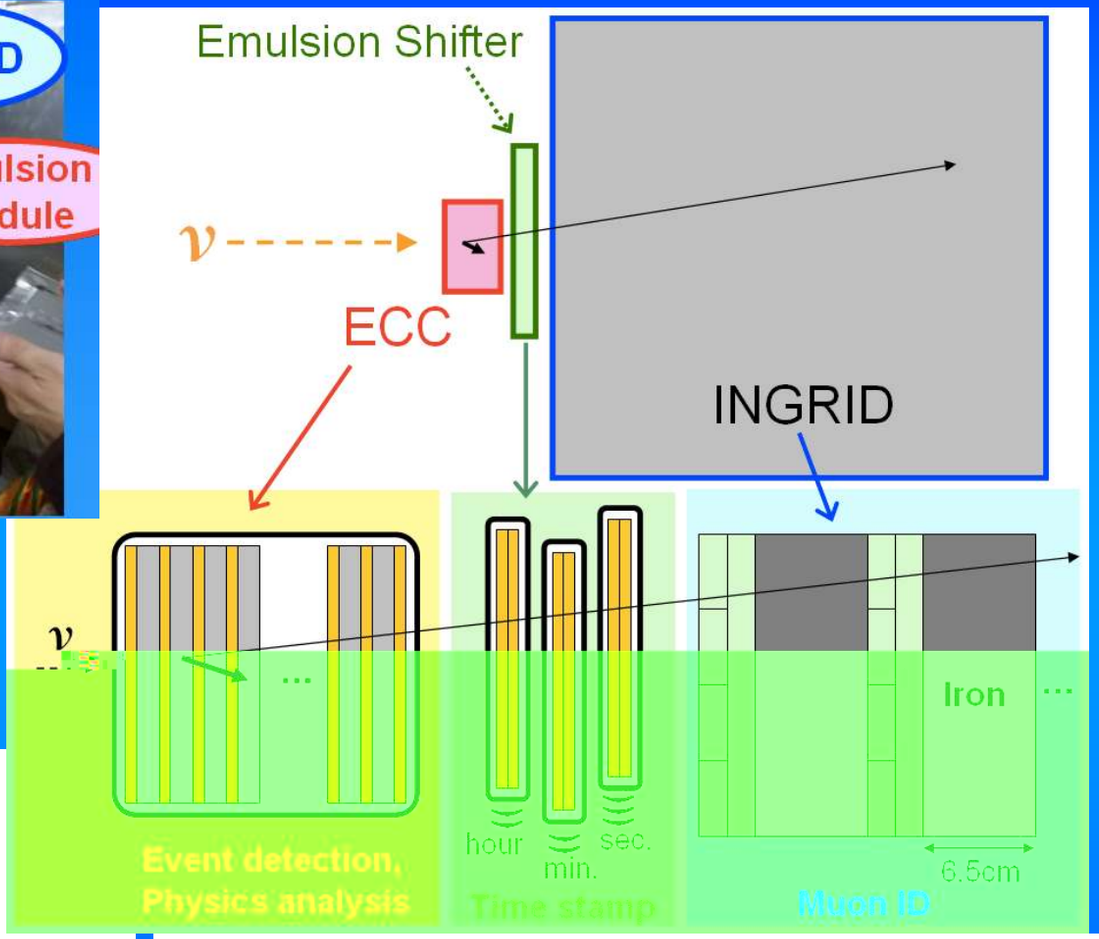


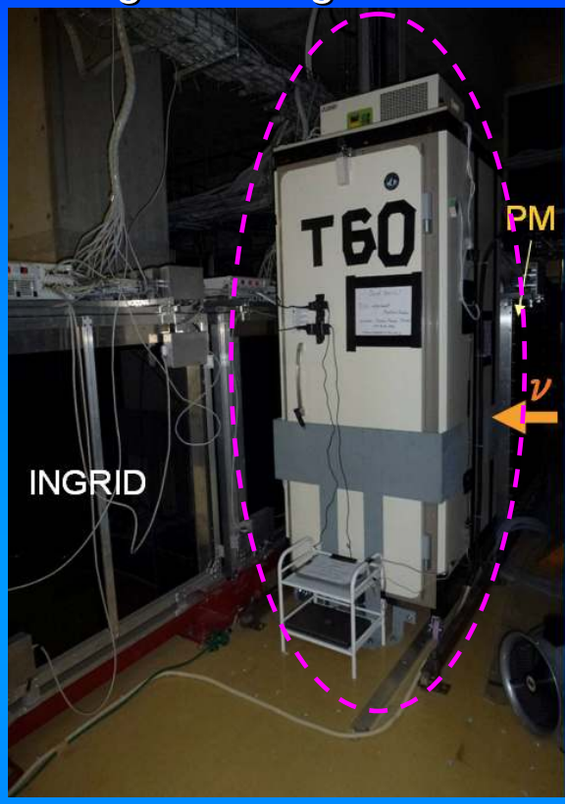
S G N M C R MS M M G G S H

2kg iron target ECC → 60kg iron target ECC

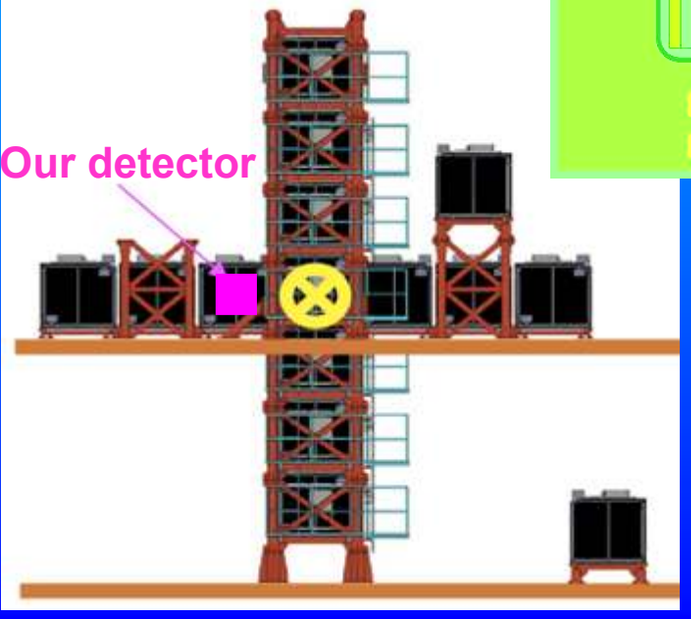


SS floor @J-PARC (Jan. 2015)





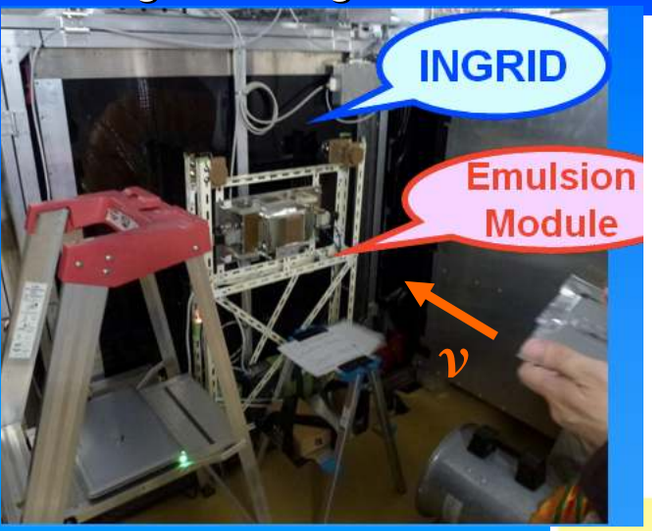
SS floor @J-PARC (Jan. 2016)



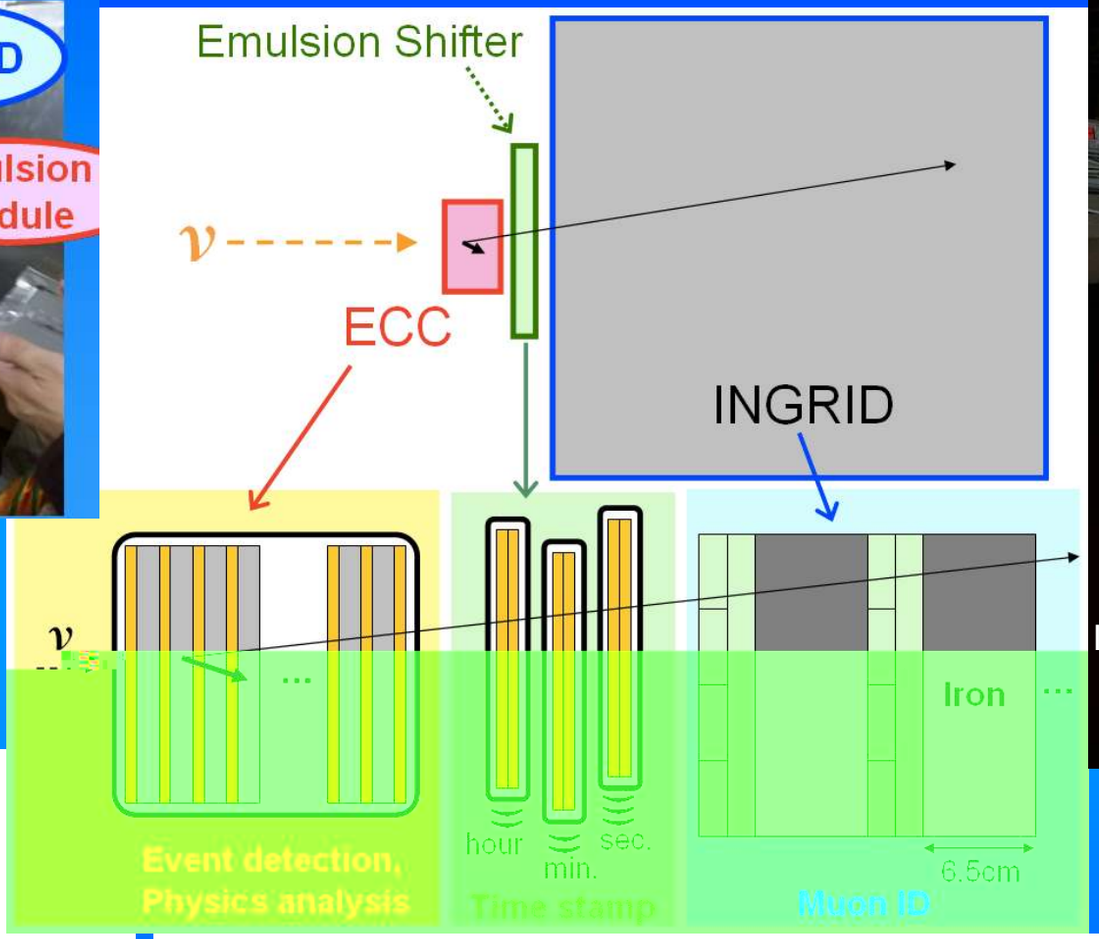
- **E**mulsion **C**loud **C**hamber (**ECC**) is a sandwich structure of emulsion films and materials.
- Emulsion detector is placed in front of T2K near detector, INGRID.
- Emulsion Shifter is re-used from a balloon project with emulsion to give a timing info. to emulsion tracks.
- Muon ID is possible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

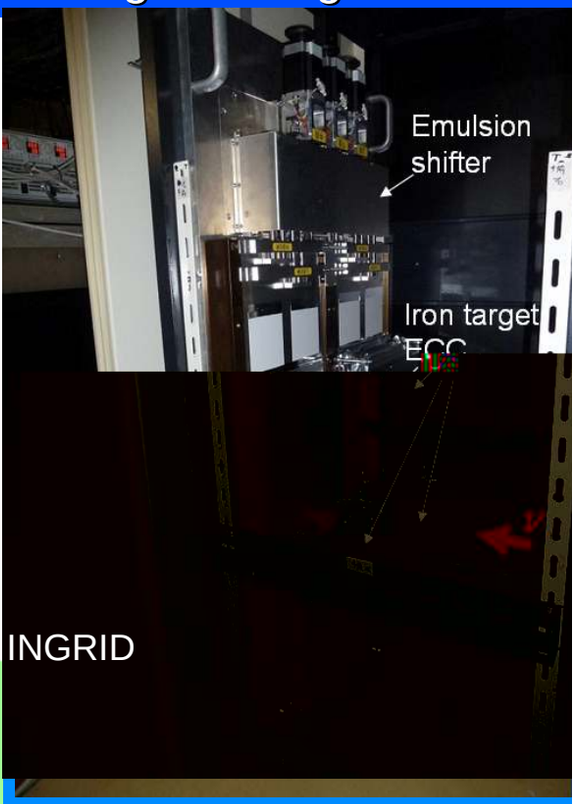
S G N M C R M S M M G G S H

2kg iron target ECC → 60kg iron target ECC

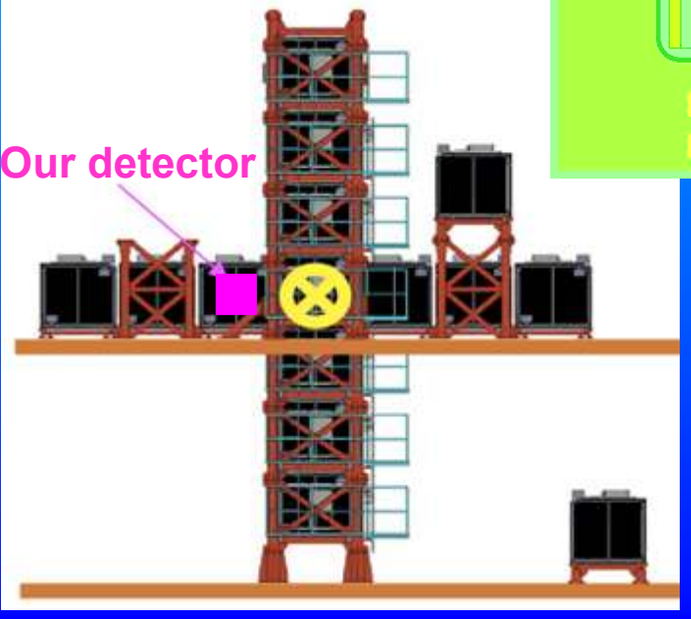


SS floor @J-PARC (Jan. 2015)



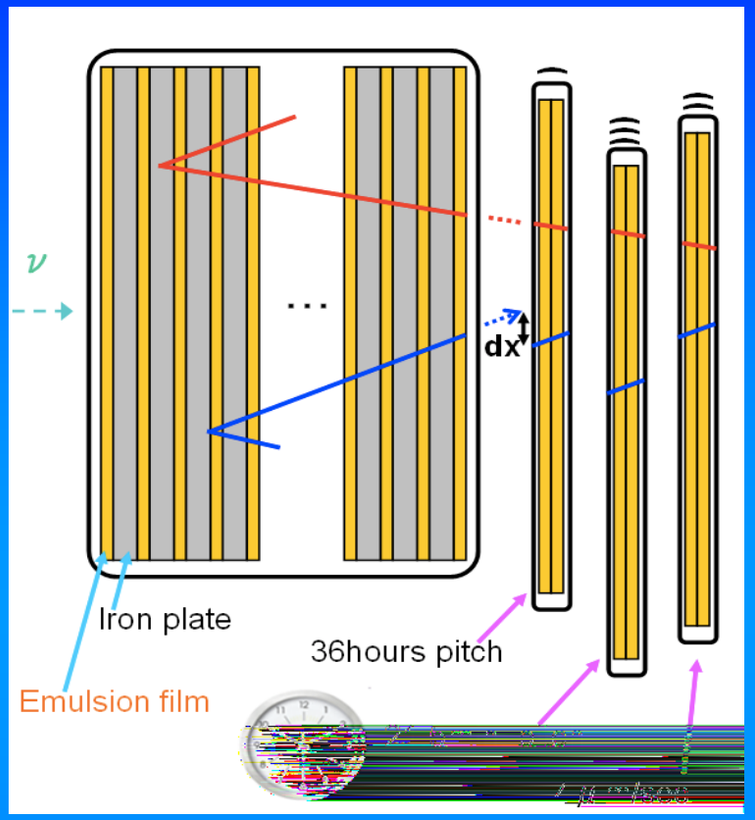


SS floor @J-PARC (Jan. 2016)

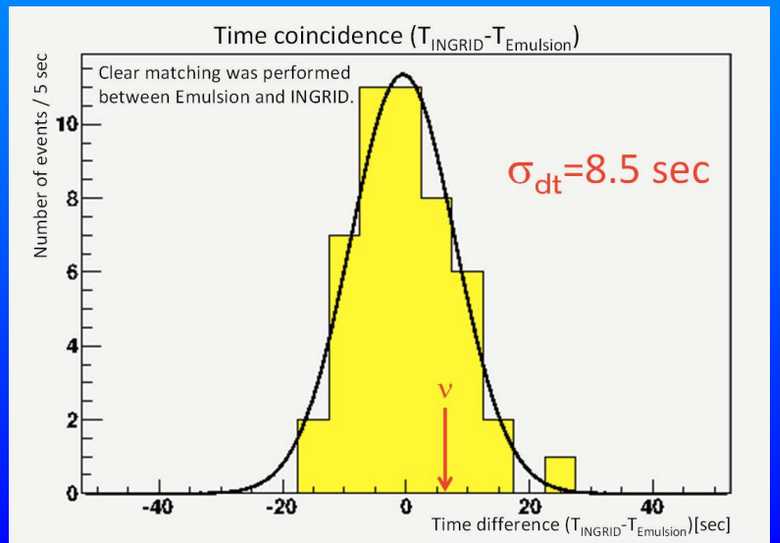


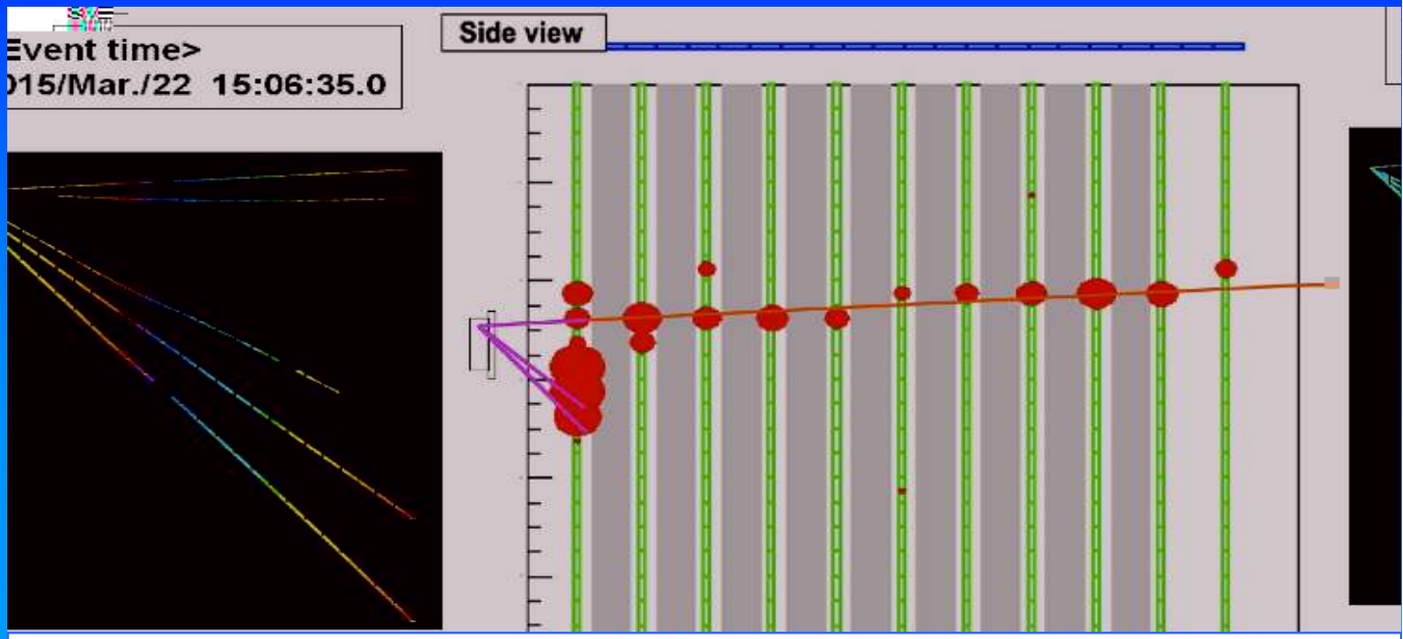
- **E**mulsion **C**loud **C**hamber (**ECC**) is a sandwich structure of emulsion films and materials.
- Emulsion detector is placed in front of T2K near detector, INGRID.
- Emulsion Shifter is re-used from a balloon project with emulsion to give a timing info. to emulsion tracks.
- Muon ID is possible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

ND NPRS MW HM WRR

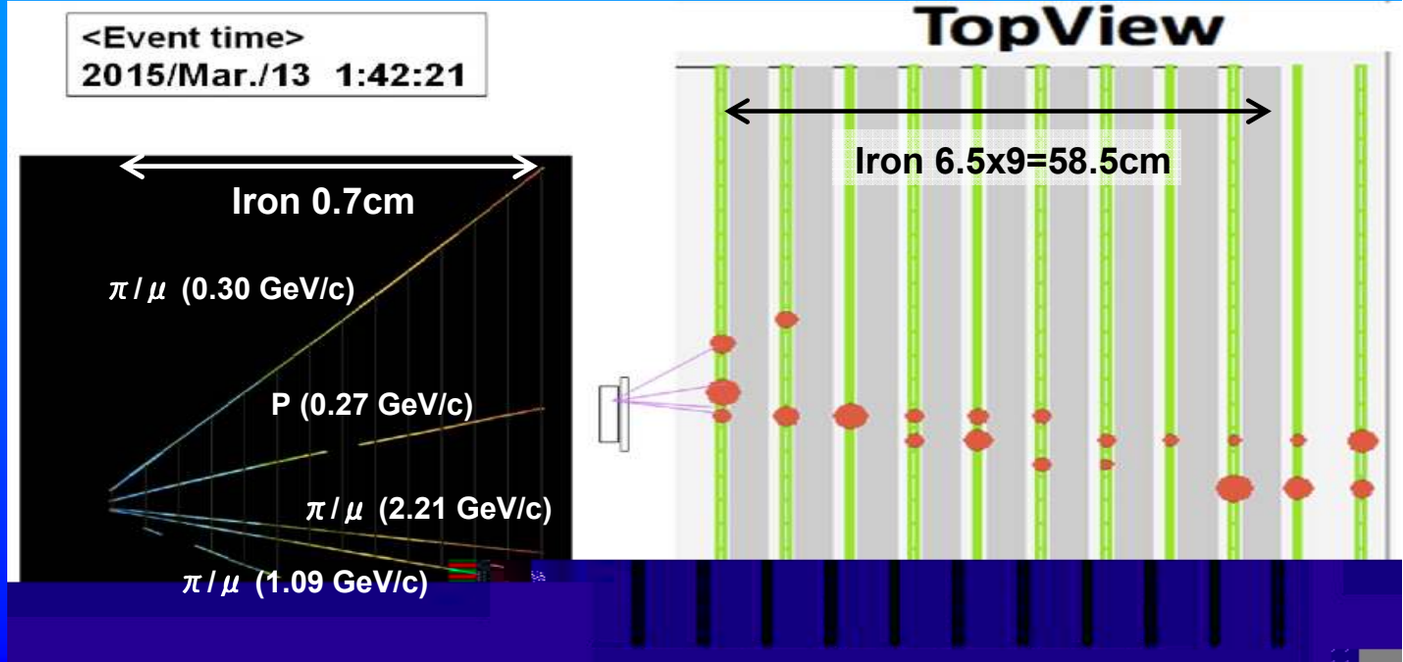


Time resolution for emulsion tracks





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

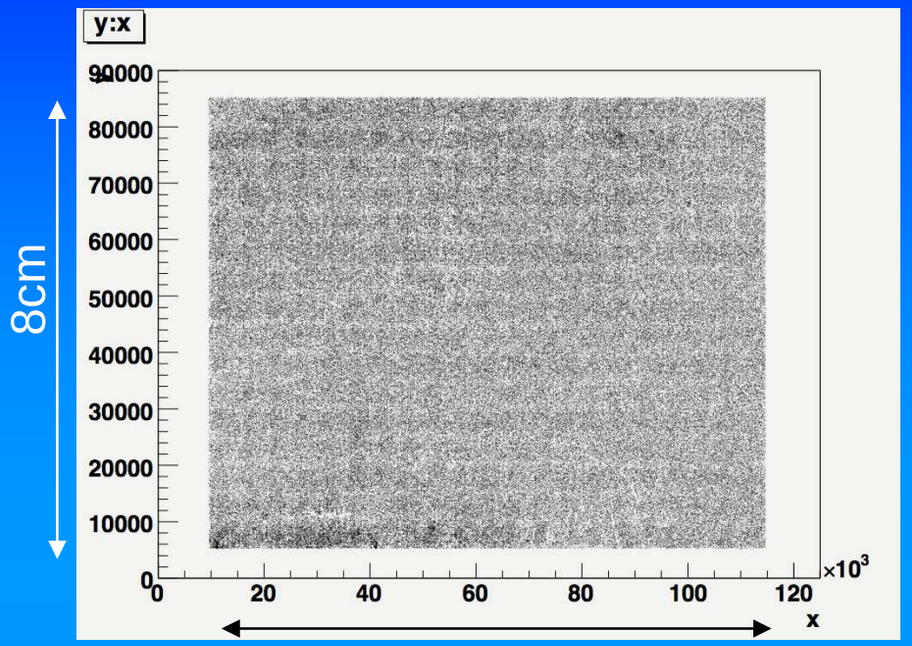


T M I MWWMG NPRSMR I MWNRG

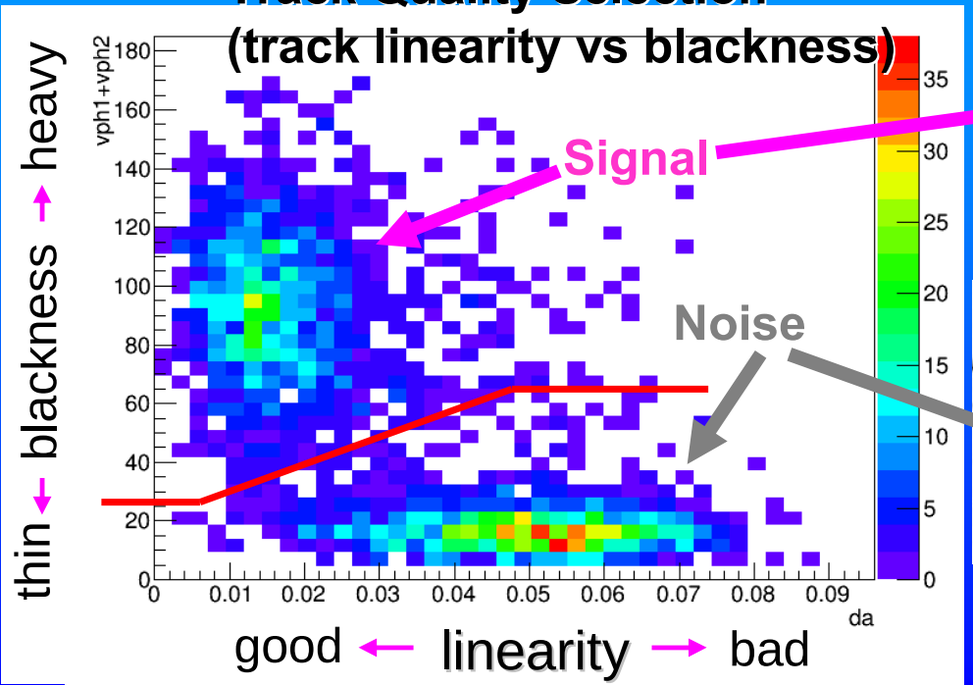
5,000 cm²/hour

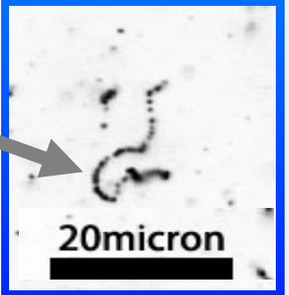
Latest high speed scanning system developed in Nagoya Univ.

Position distribution

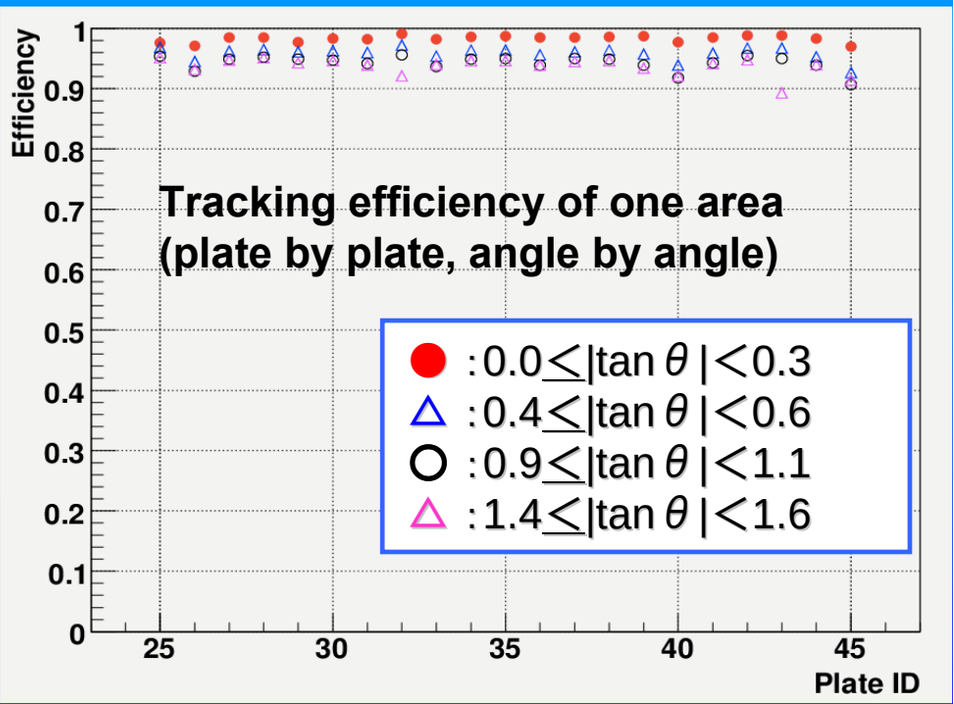


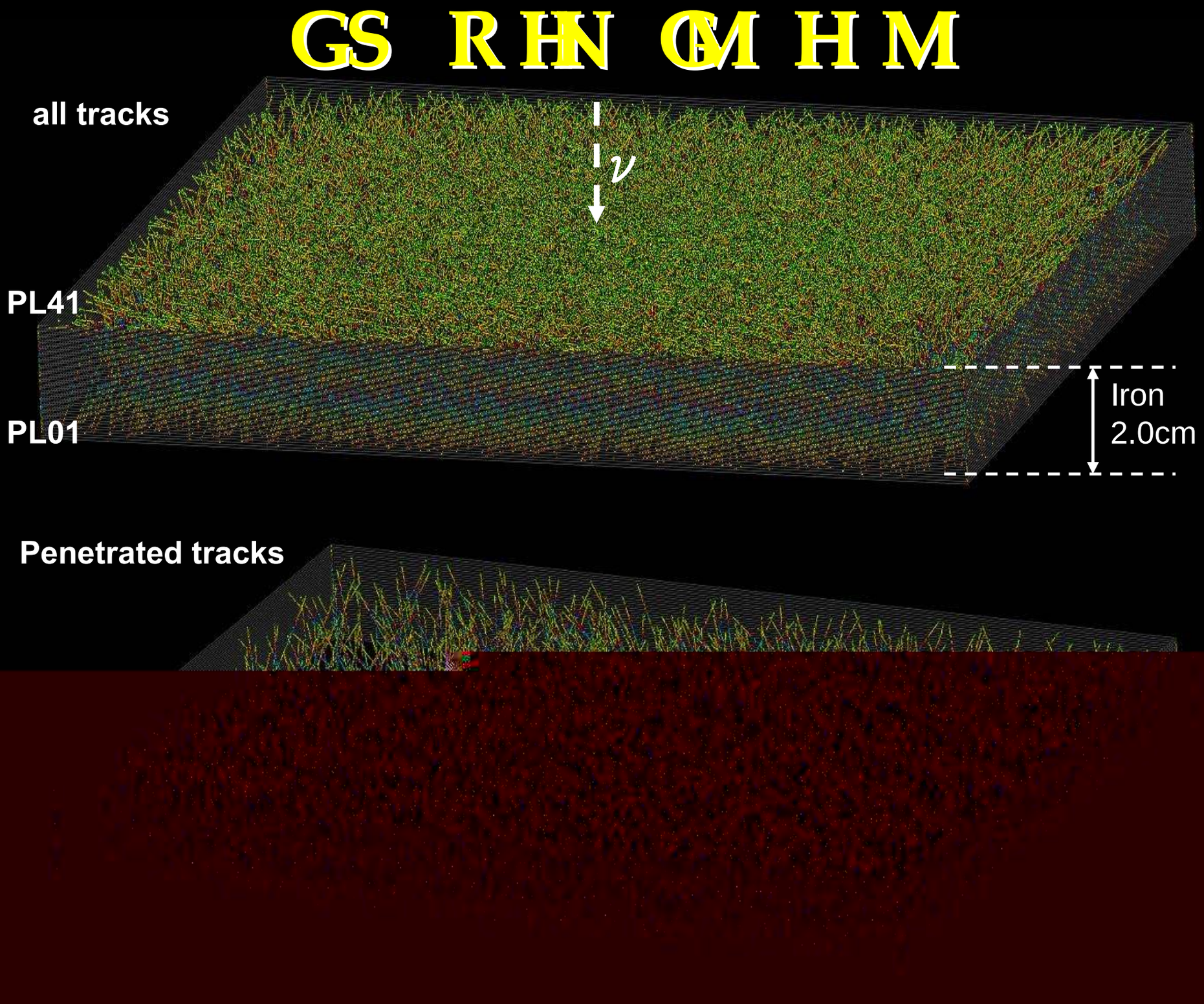
Track Quality Selection
(track linearity vs blackness)





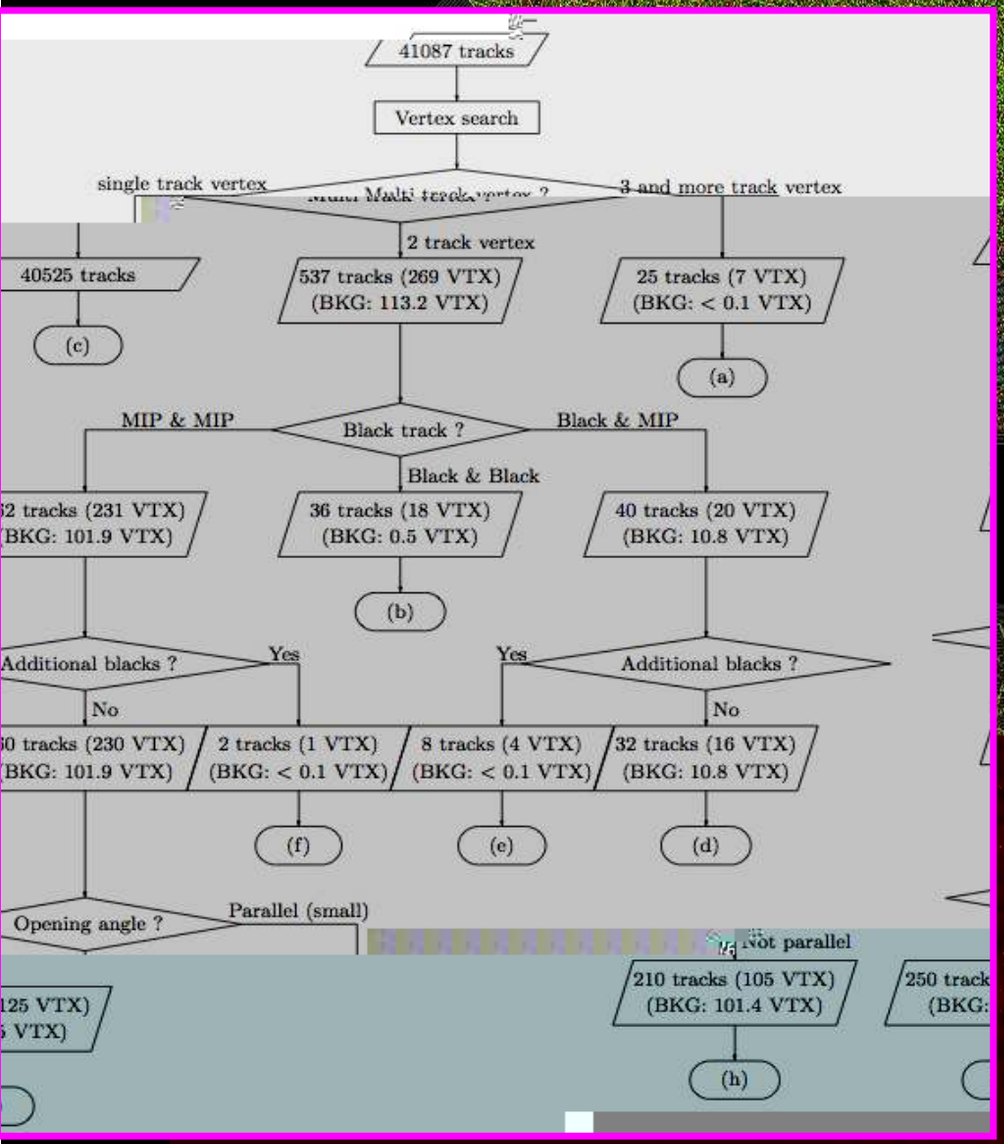
Sub-MeV electron




all tracks
PL41
PL01
Iron
2.0cm
Penetrated tracks

GSRHNCMHM

all tracks



Multi-track vertex selection criteria

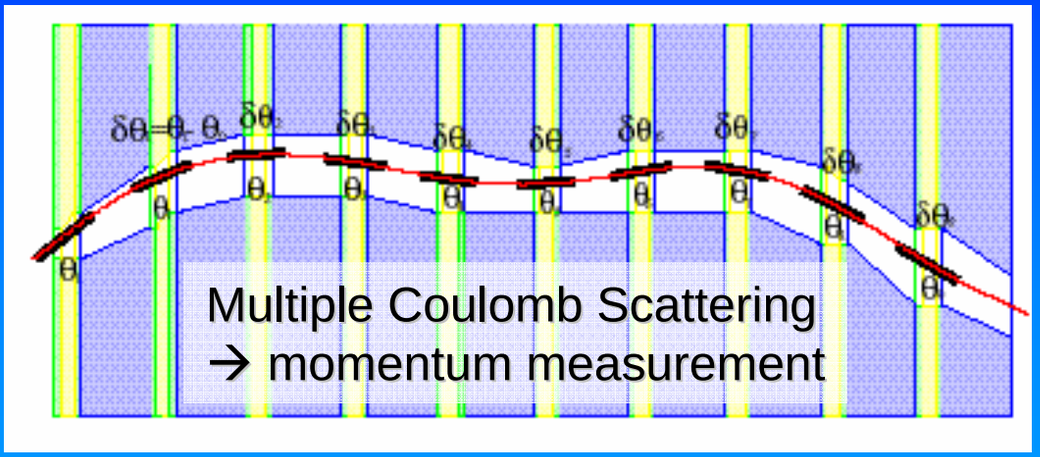
Multi-Track Vertex search

HSM GII IS

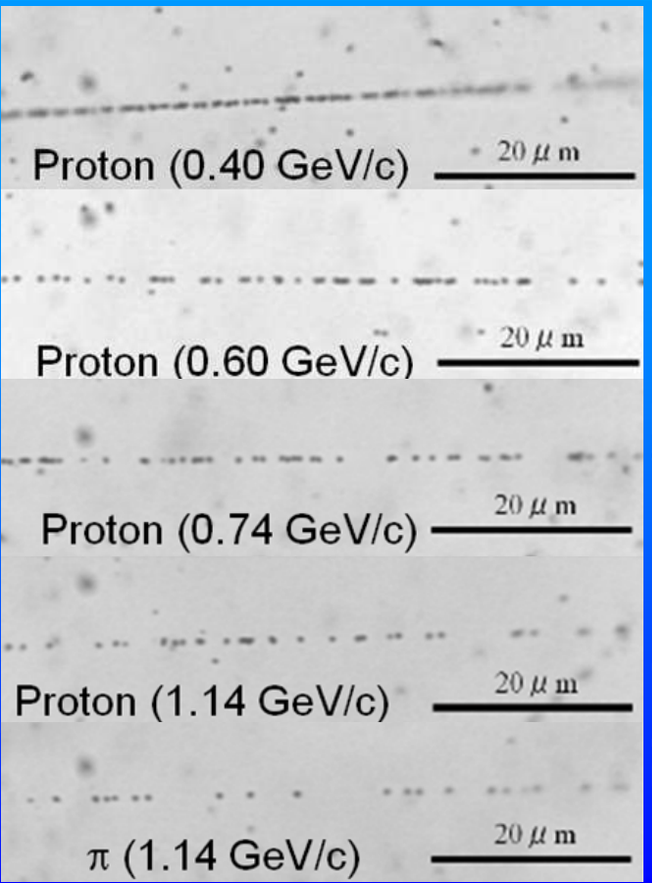
p β measurement by the MCS method

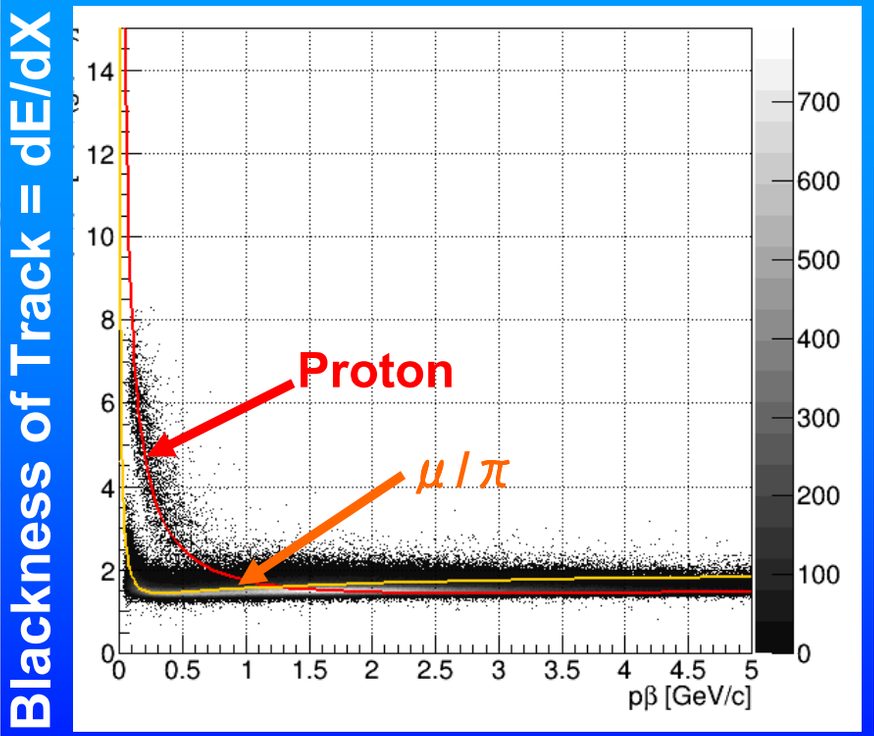
$$P\beta = \frac{13.6\ (\mathrm{MeV/c})}{\sigma_{\delta\theta}}\sqrt{\frac{x}{X_0}}\left(1+0.038\ln\frac{x}{X_0}\right)$$

Measurement accuracy ~ 20%

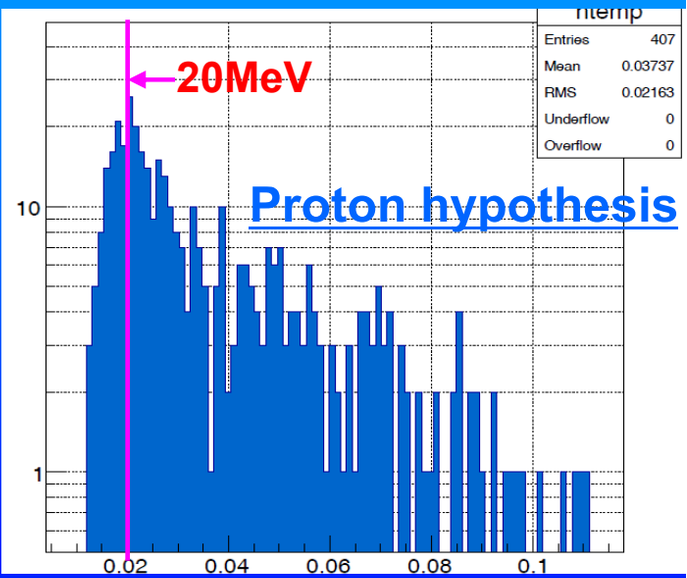


dE/dx measurement by track blackness

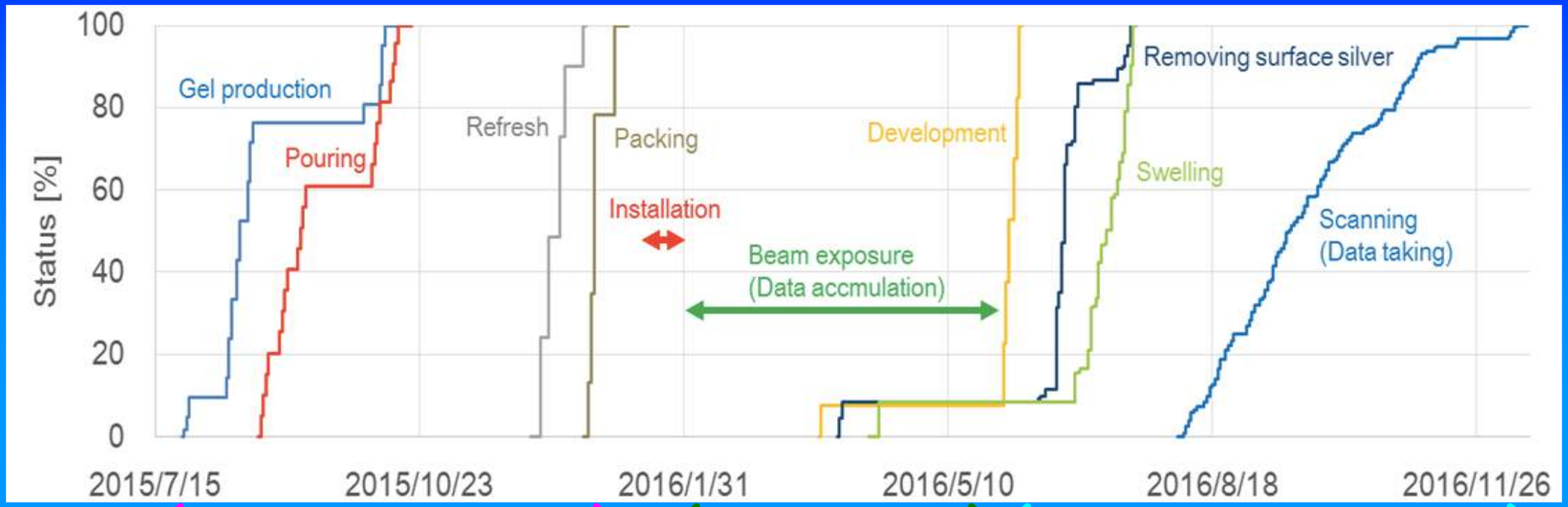




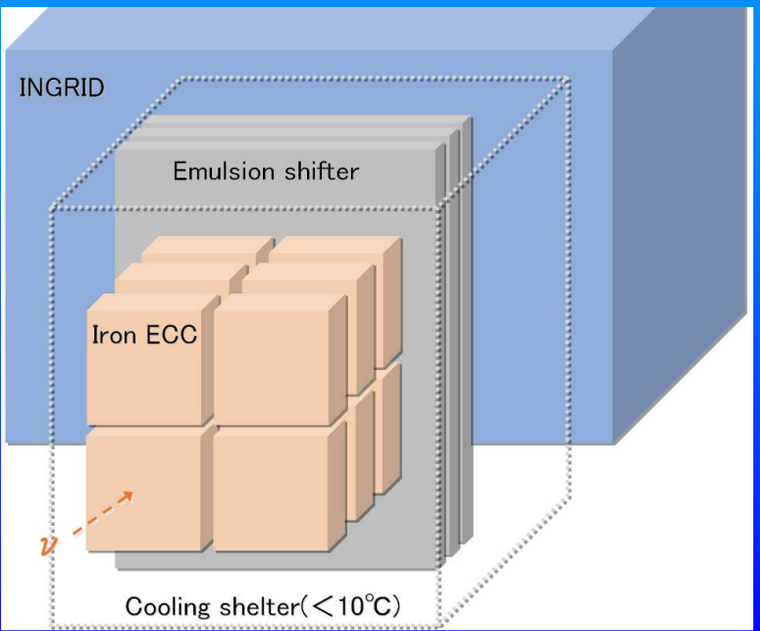
Low energy proton
→ Range measurement
→ Kinematical energy



T GG SMH N



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

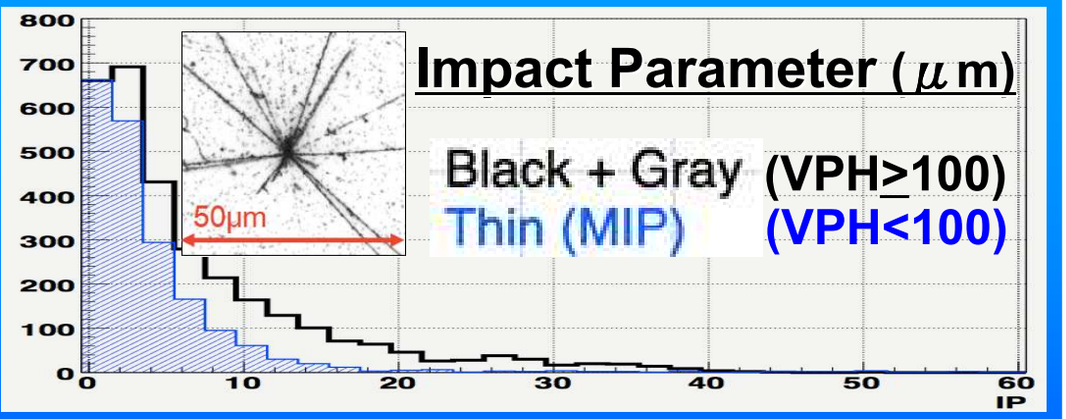


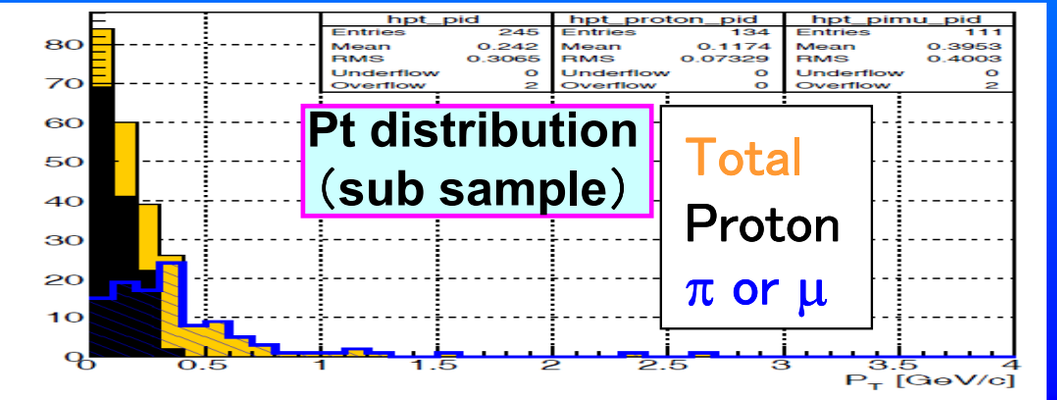
We are performing Detector Run to compare MC with high statistics.

$\bar{\nu}$ 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）**

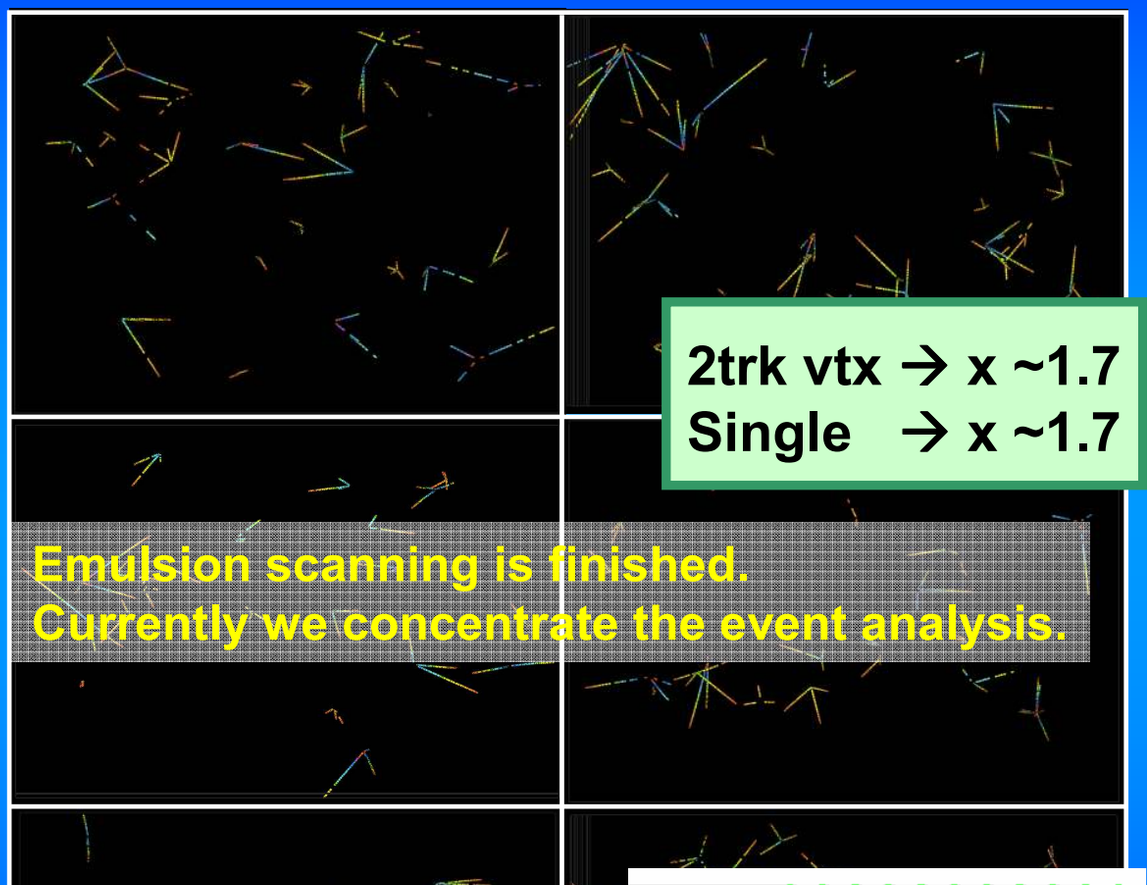
NEUTRINO INTERACTION VERTEX IN WAGASCI

1021 vtx candidate events
(Multiplicity≥3)





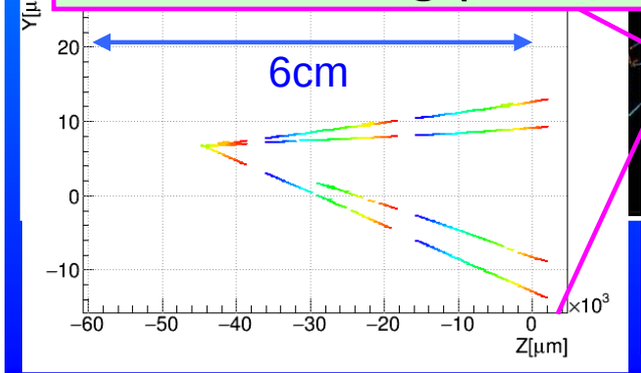
~25cm

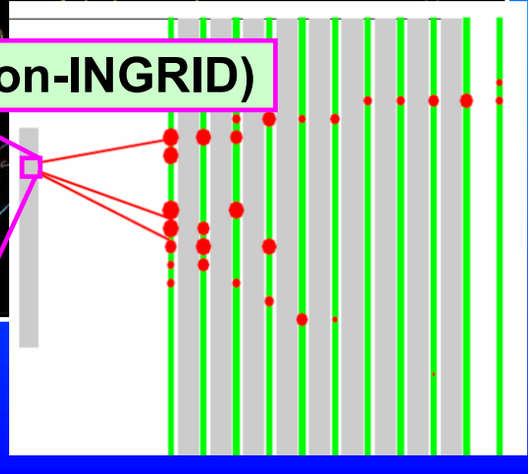


2trk vtx → x ~1.7
Single → x ~1.7

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

Event matching (emulsion-INGRID)



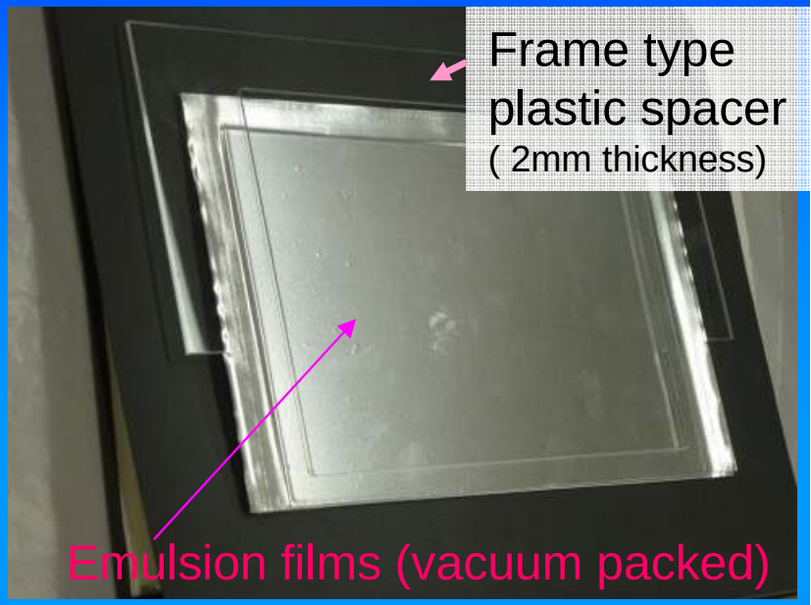


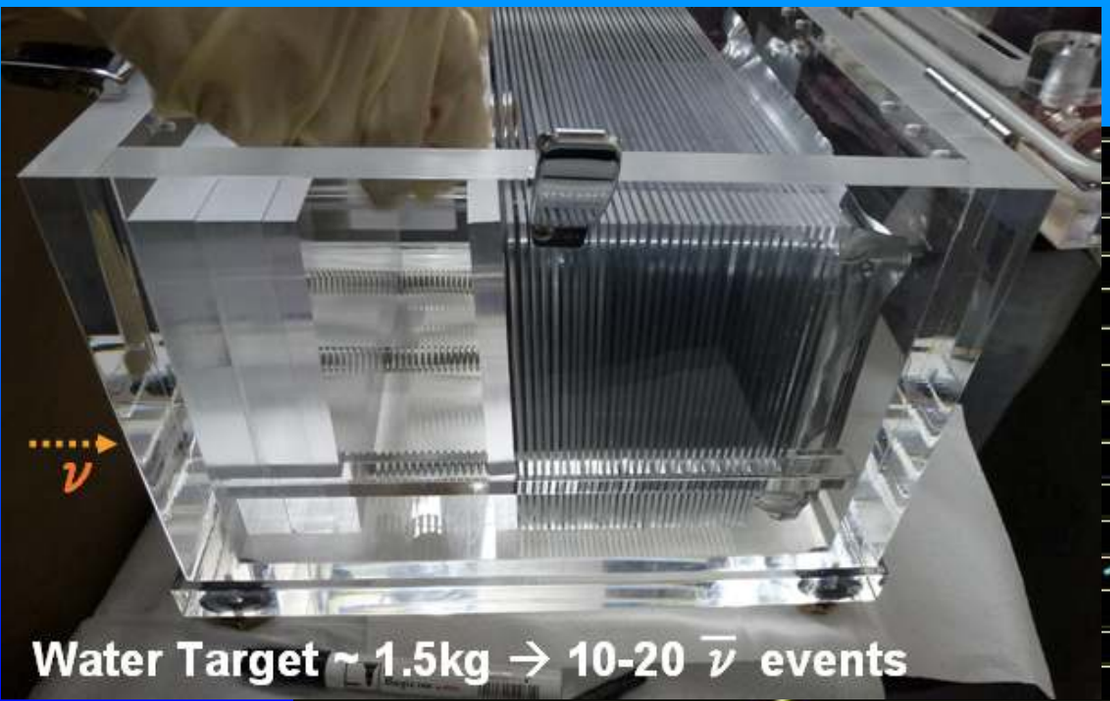
NH HMG NRSM J GH

We installed a water target emulsion chamber during May 2015 and 2016-2017 for feasibility study.

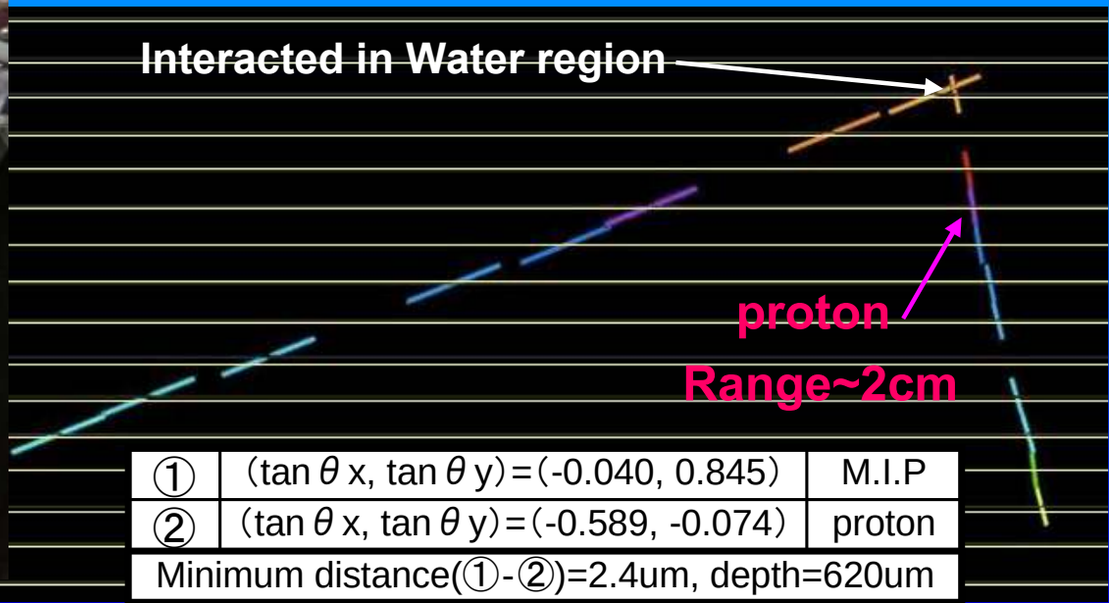
Sandwich structure of Emulsion films and Frame type spacers

Pouring water





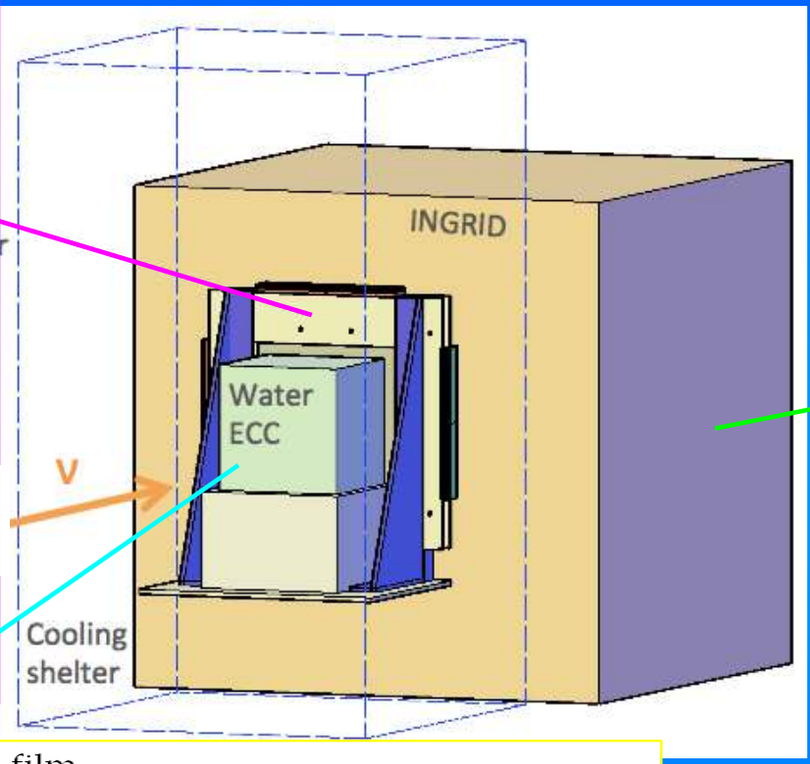
First detection of ν - Water interaction with Emulsion Detector

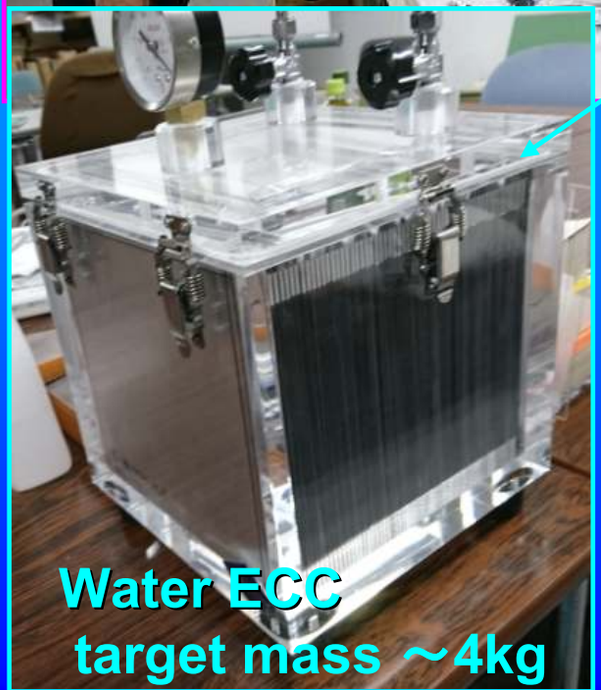


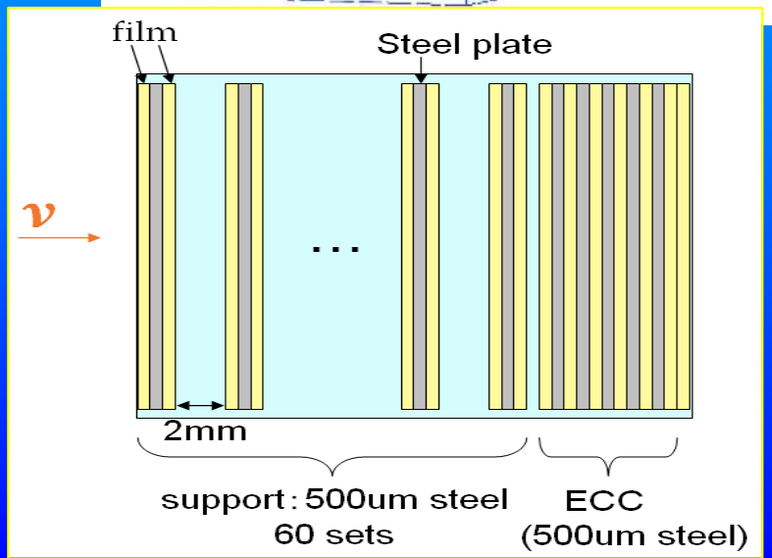
①	(tan θ x, tan θ y)=(-0.040, 0.845)	M.I.P
②	(tan θ x, tan θ y)=(-0.589, -0.074)	proton
Minimum distance(①-②)=2.4um, depth=620um		

MT GG SMH N

- Hybrid analysis with INGRID for Water ECC-SFT system



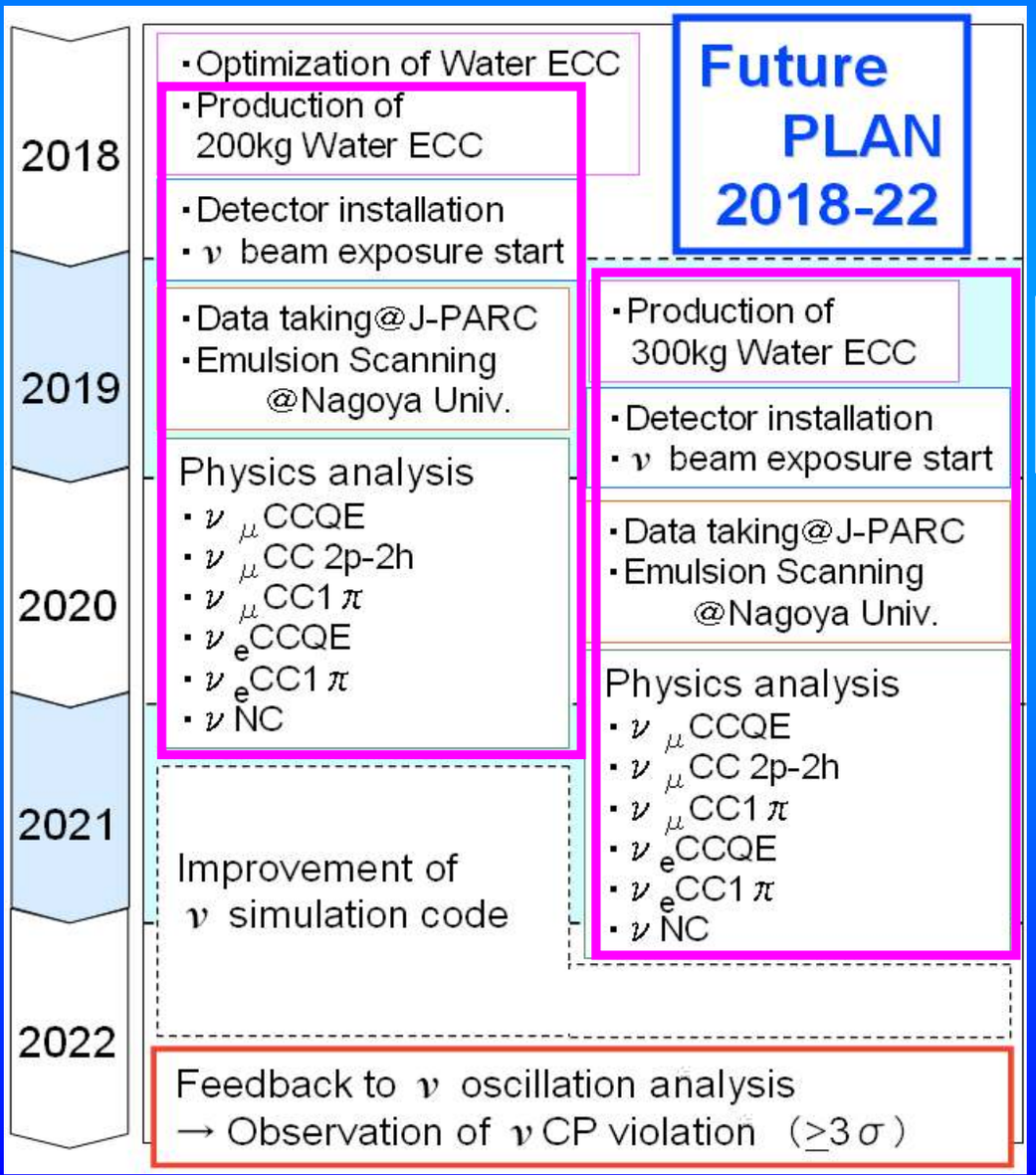




Exposure:
Run1: 2017 Oct.-Dec.
Run2: 2018 Apr.-Jun.

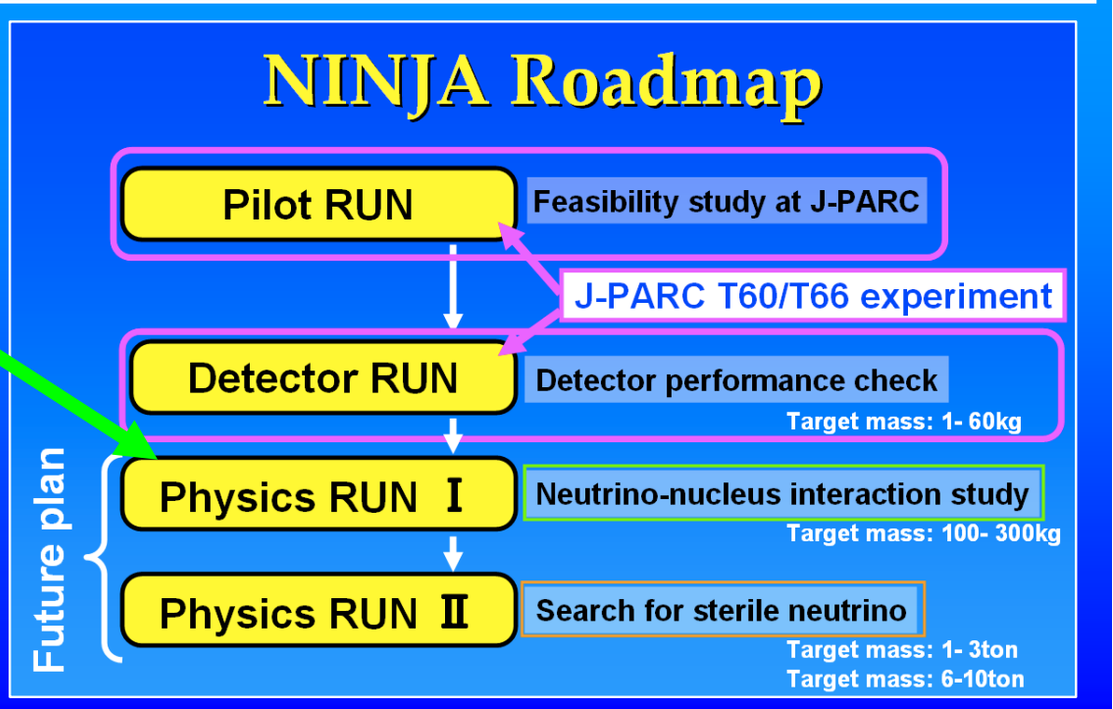
NINJA: Future Plan

- We are planning the Physics Run to investigate ν – water interactions with large detector.



- Precise measurement of 2p-2h.
- Exclusive measurement of ν_e int.

Reduction of systematic uncertainty of neutrino oscillation measurements



NJ WA

- 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 (MDEF GHJ G).
- We are carrying out a test experiment at J-PARC ( ) 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.