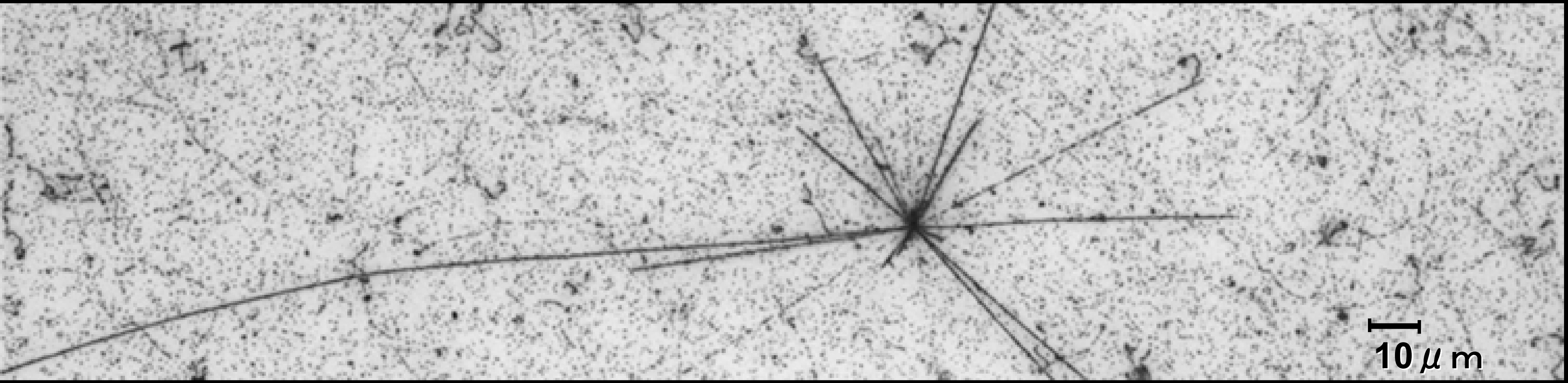
Particle ID with modern emulsion detectors

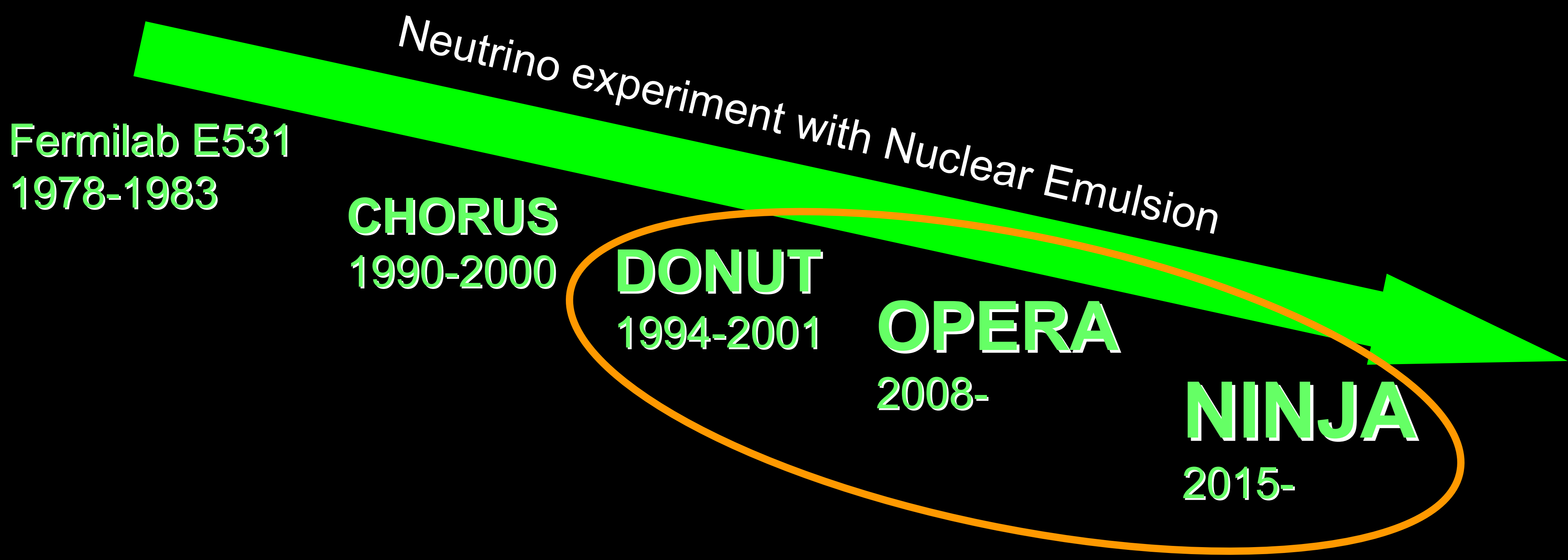
Tsutomu Fukuda (Nagoya Univ.)



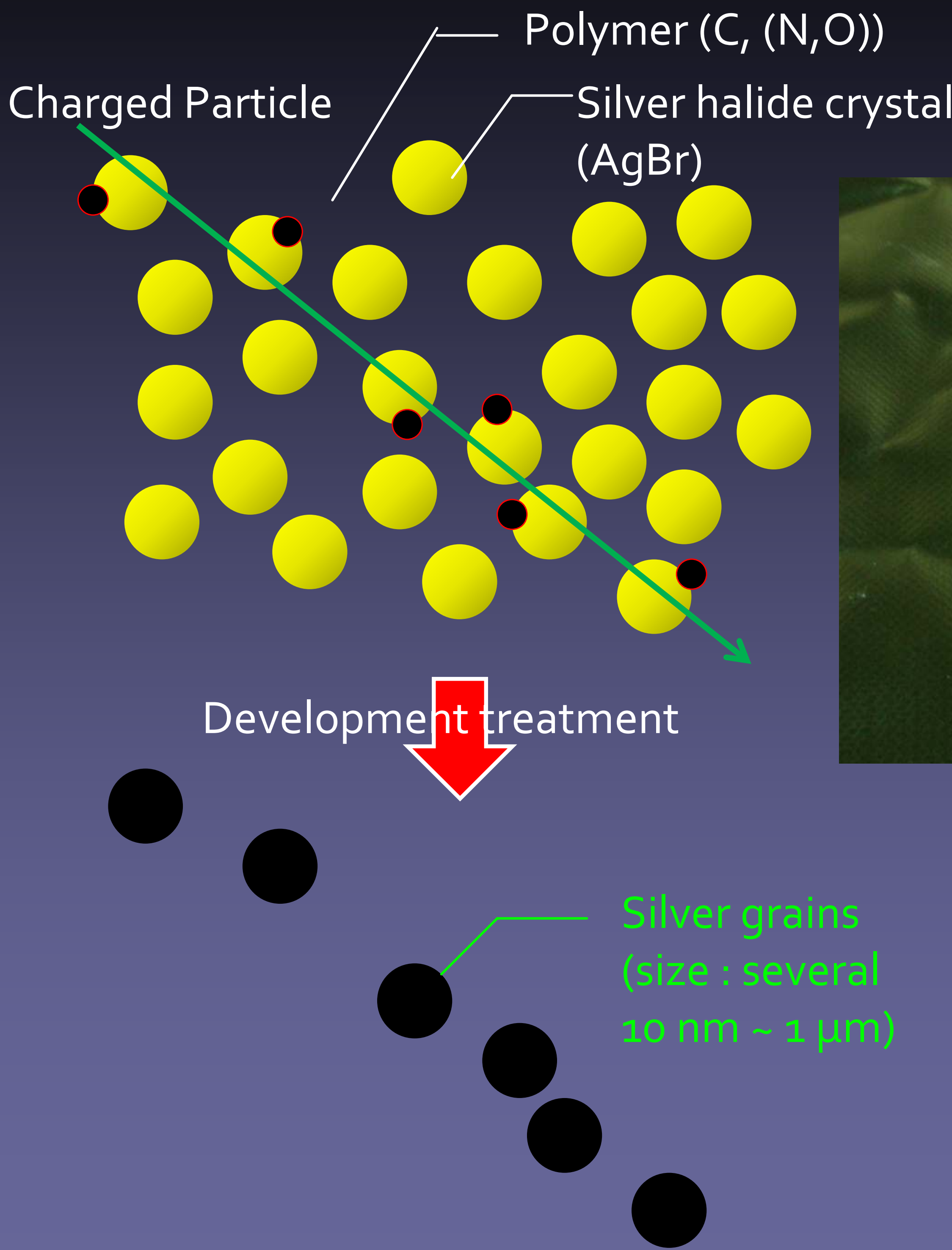
2017.Jun. 23 State of the Nu-tion workshop @University of Toronto

Today's talk

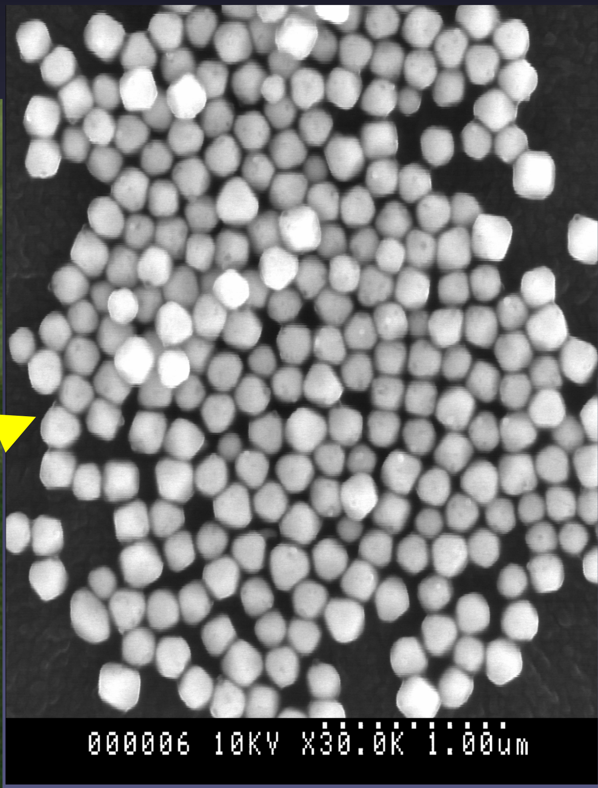
- I will introduce about the modern technology of nuclear emulsion detectors and its PID capability in this talk.



Nuclear Emulsion Detector



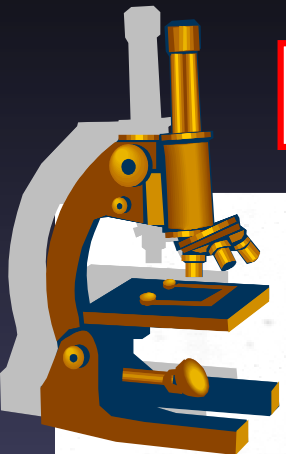
AgBr･I crystal



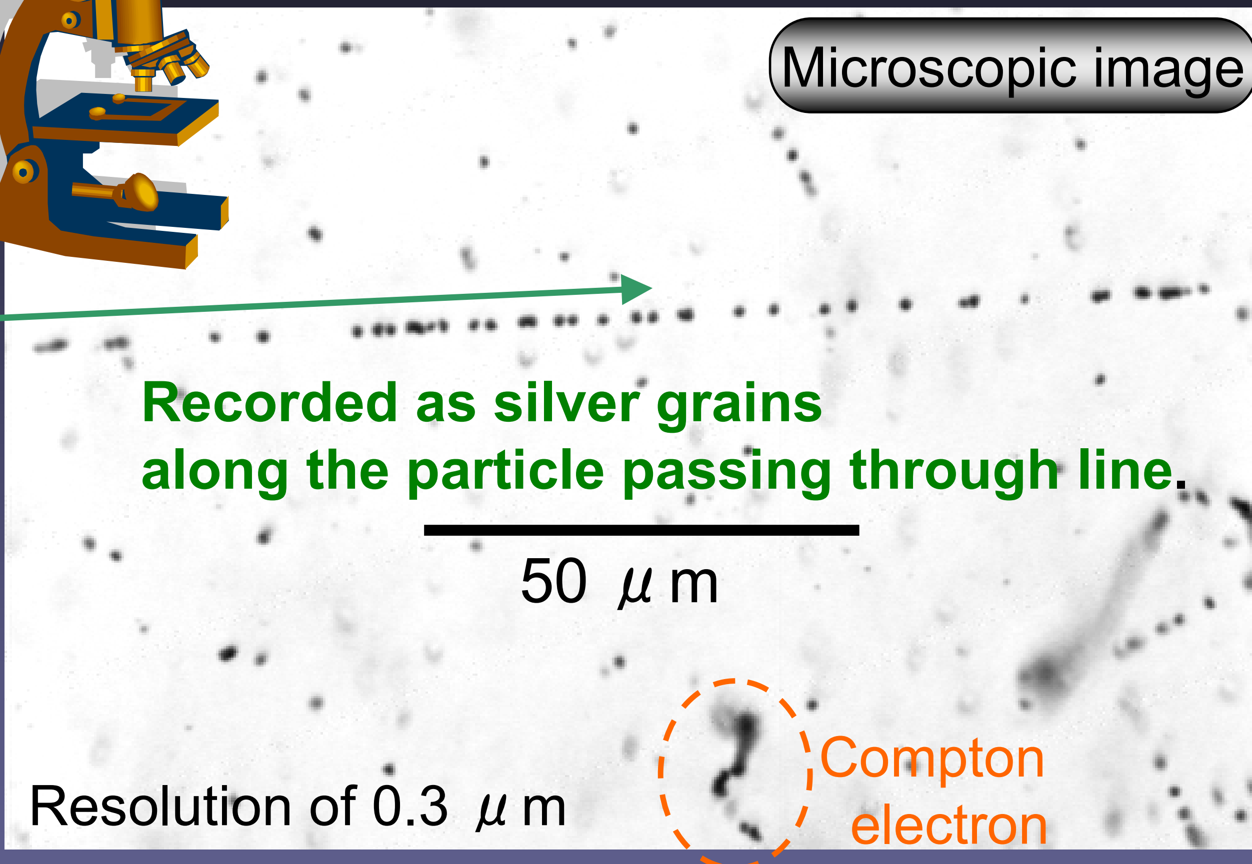
Spatial resolution
- silver halide crystal size
- number density of silver halide crystal

Sensitivity
- Chemical treatment
- Crystal defect and doping etc.

Nuclear Emulsion Detector



Sub micron resolution 3D tracker



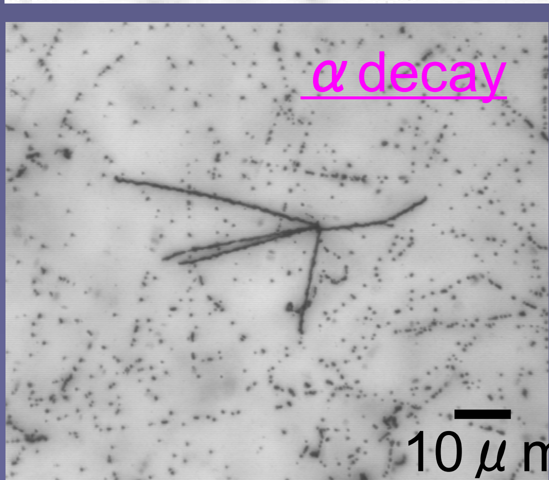
1896 (A.H.Becquerel)
Discovery of Radioactivity

1947 (C.Powell et al.)
Discovery of π

1971 (K.Niu et al.)
Discovery of charm particle in cosmic-ray

2001 (K.Niwa et al.)
Direct observation of ν_τ

2015 (OPERA)
Discovery of ν_τ appearance

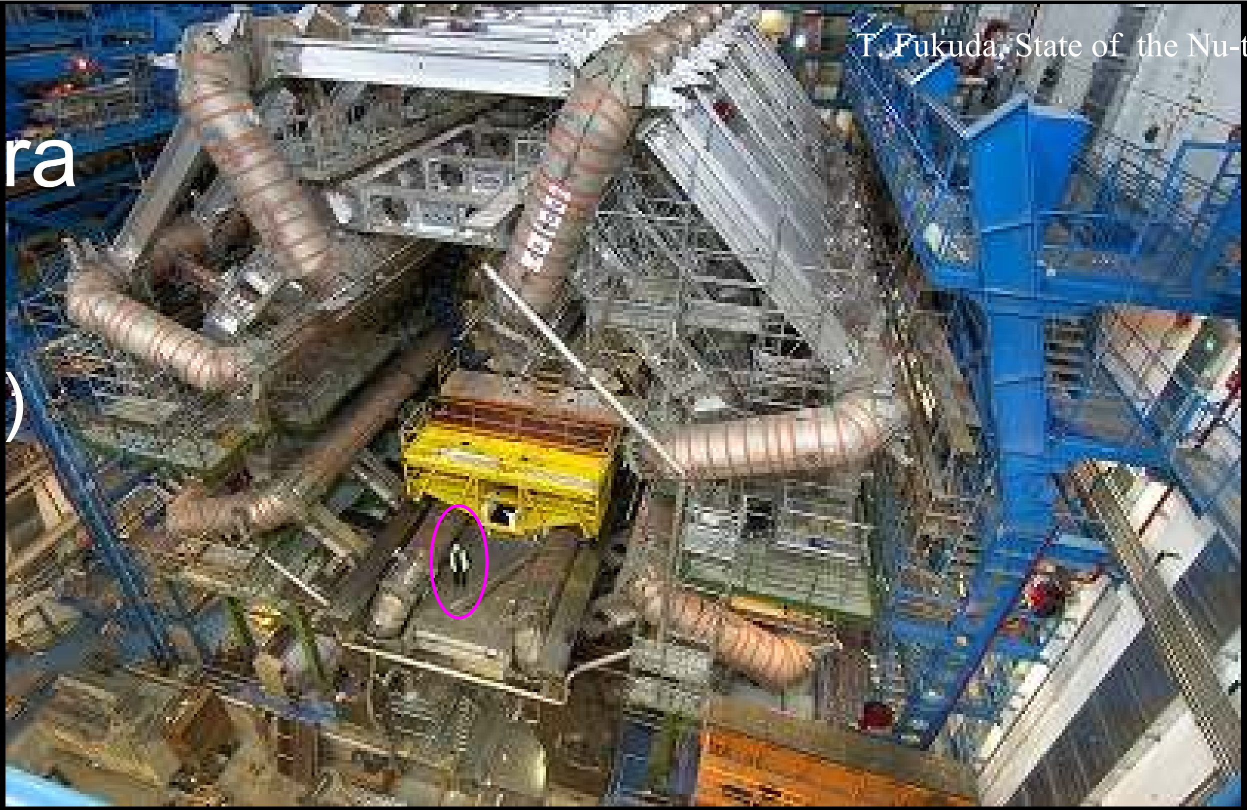


Photographic technique

Largest Digital Camera

ATLAS detector

(~1.6 x 10^8 image sensors)



Largest Film Camera

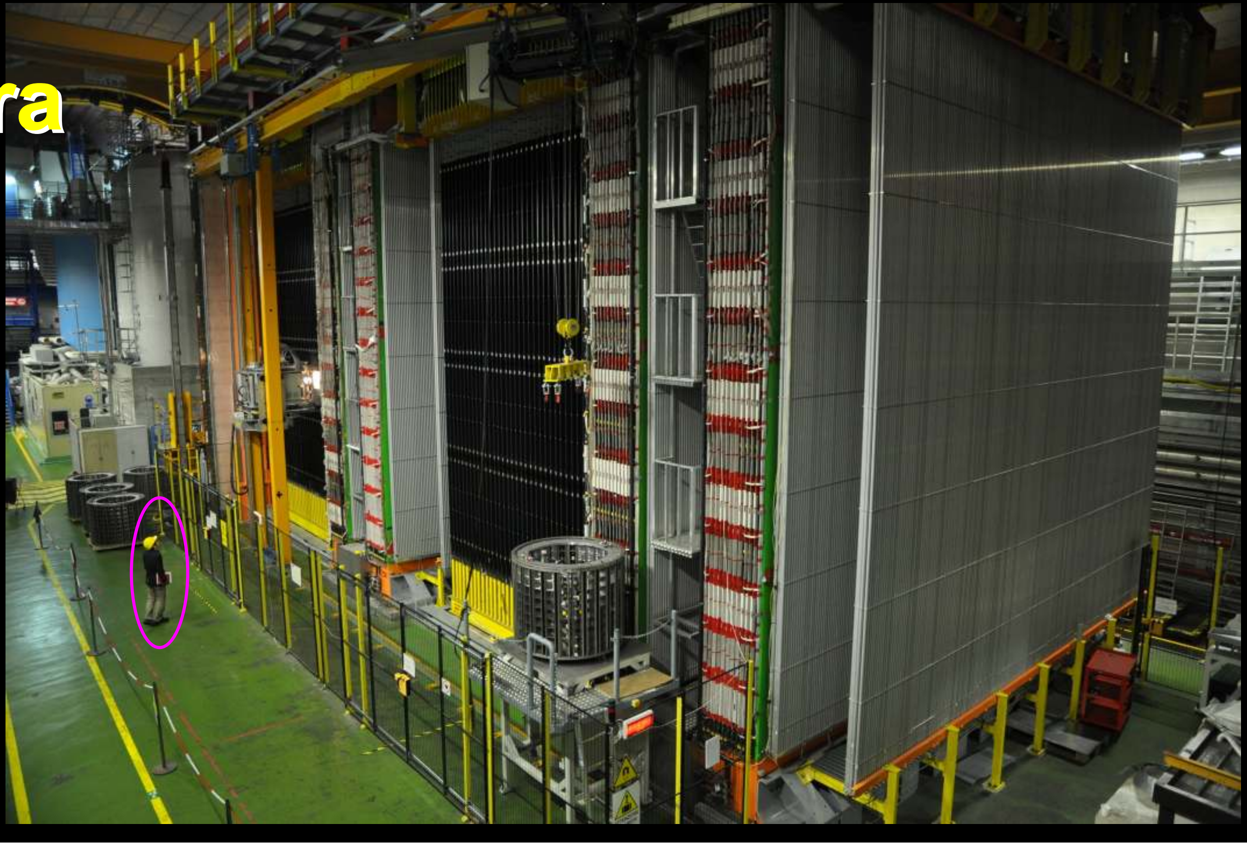
OPERA detector

(~10^{20} AgBr crystals)

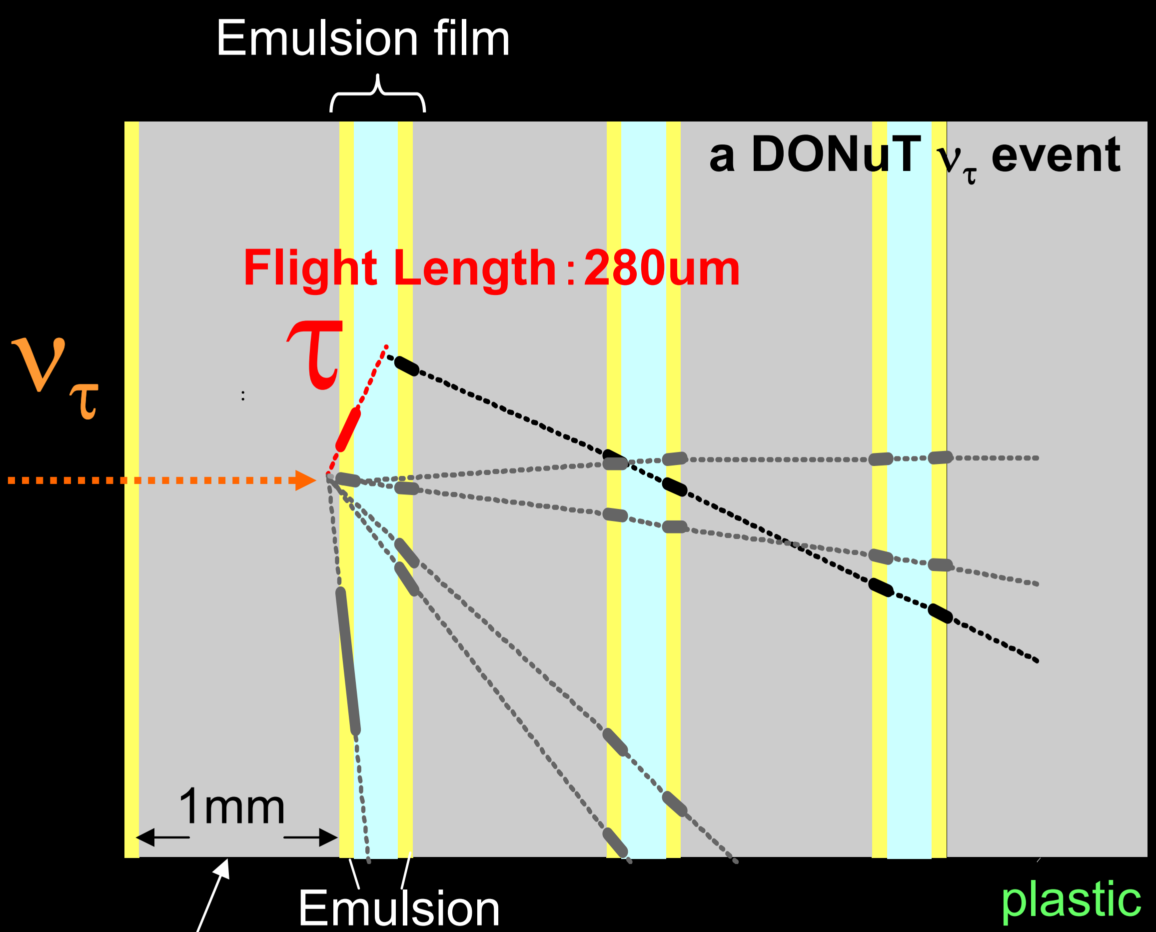
↑

9000,000 emulsion films

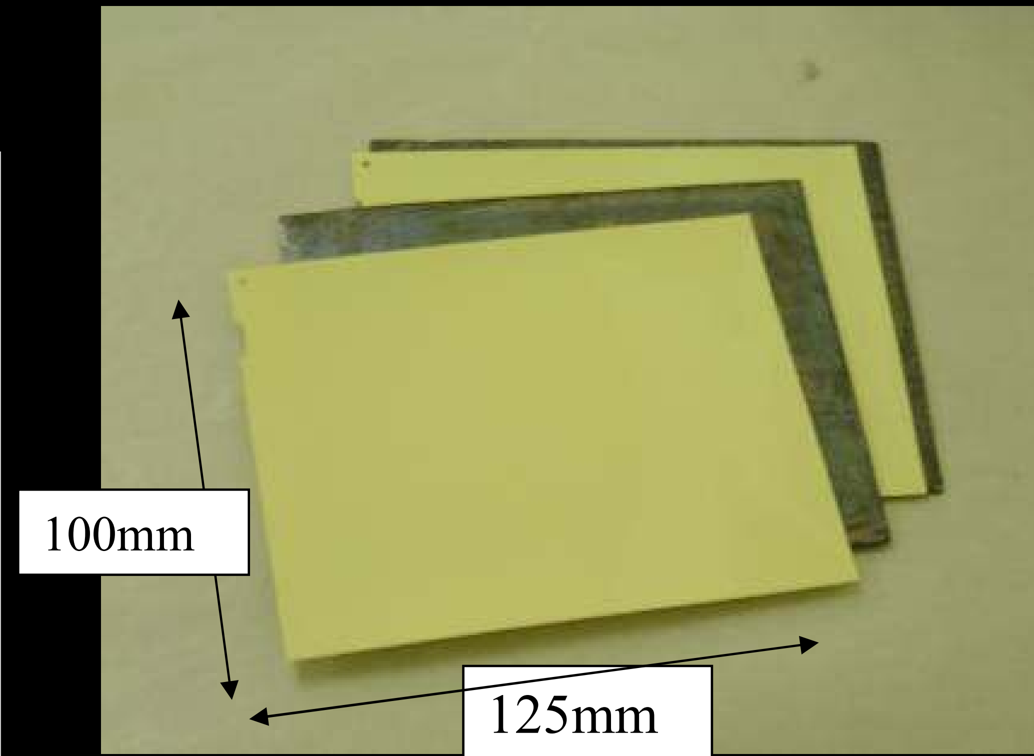
150,000 ECCs

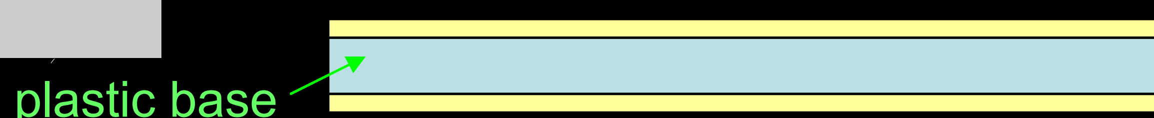


Emulsion Cloud Chamber



DONuT : Iron 1mm
OPERA : Lead 1mm
NINJA : Iron 0.5mm, Water 2mm

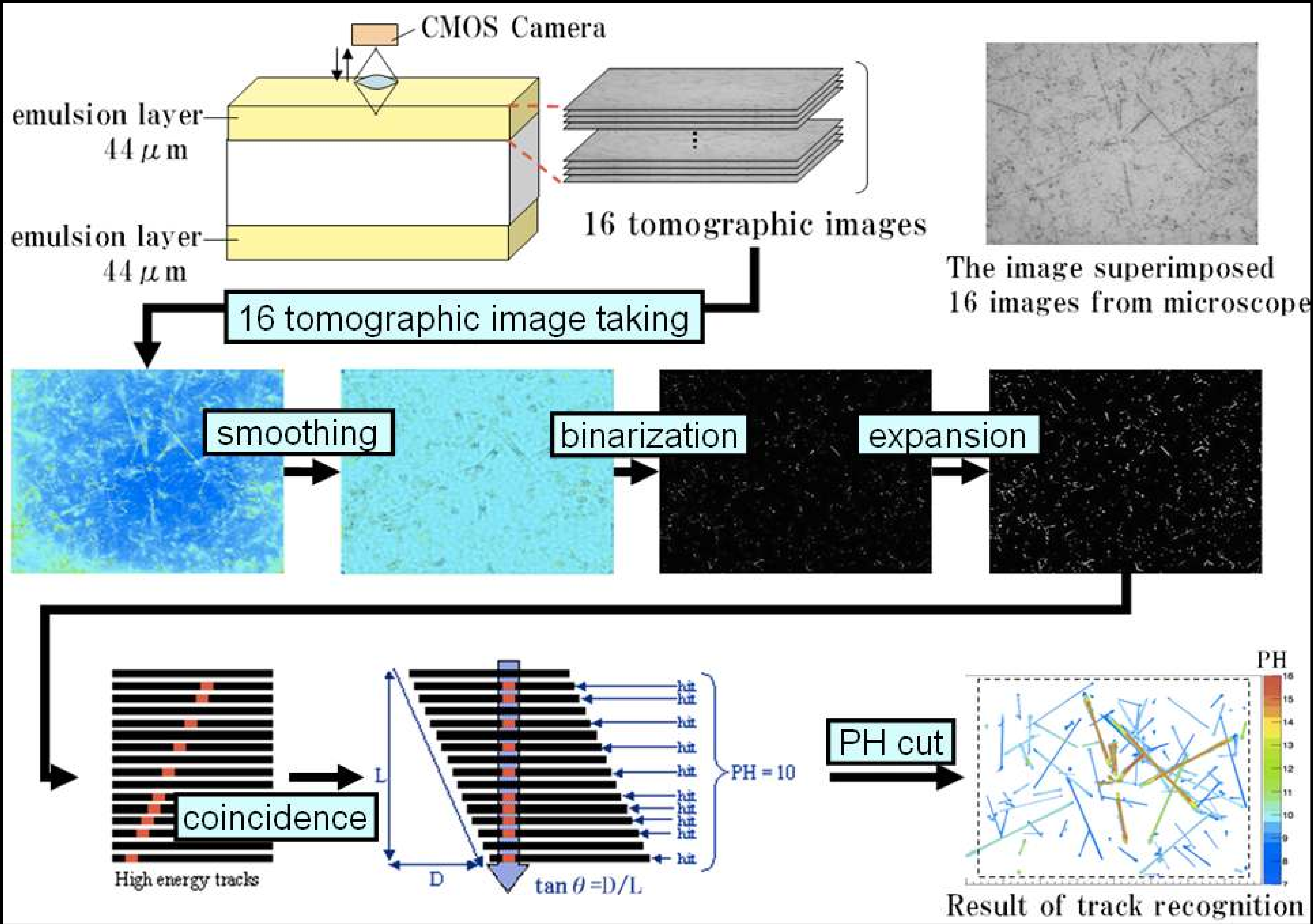


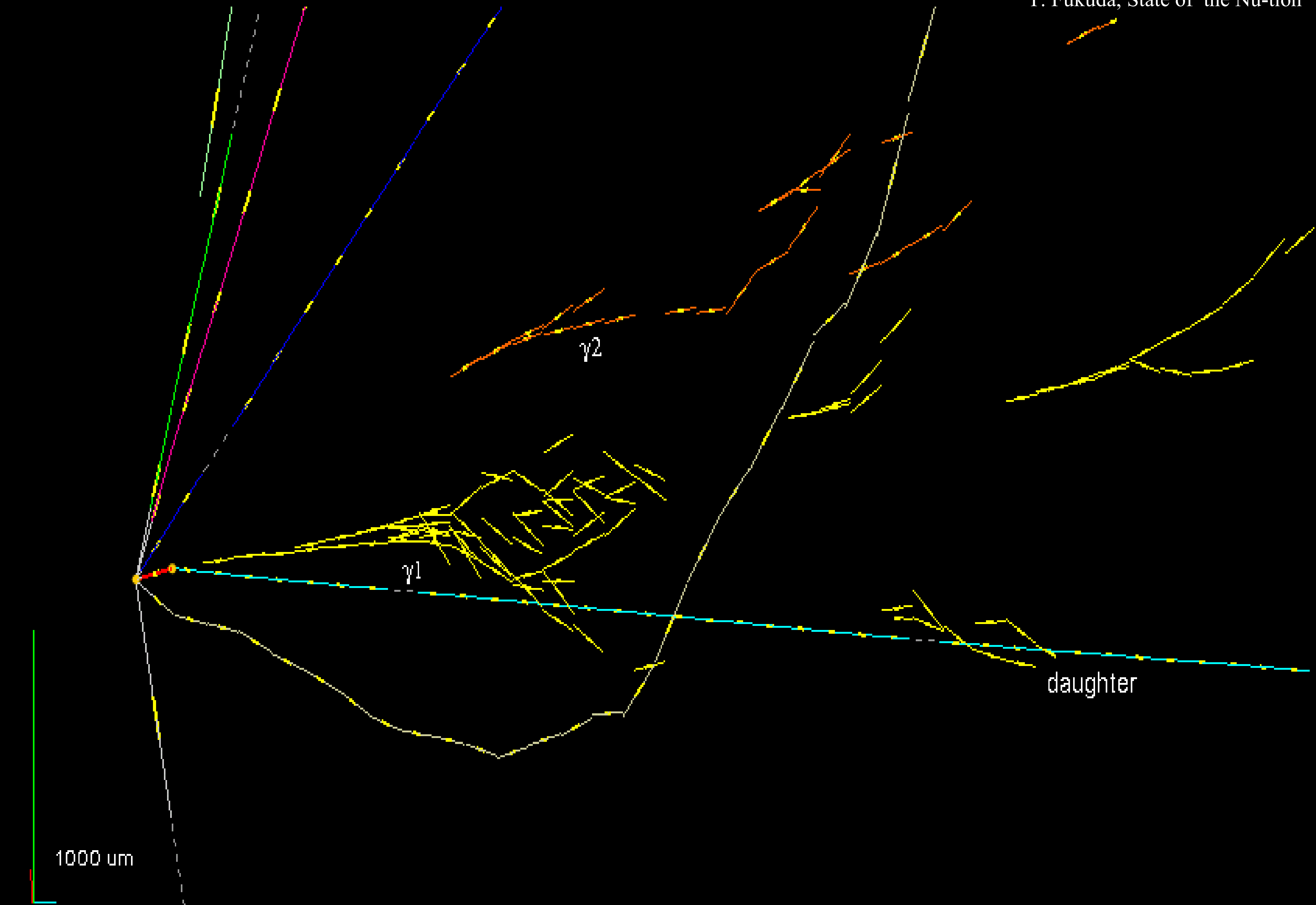


45-70 μ m emulsion gel were coated on both sides of the ~200 μ m plastic base.

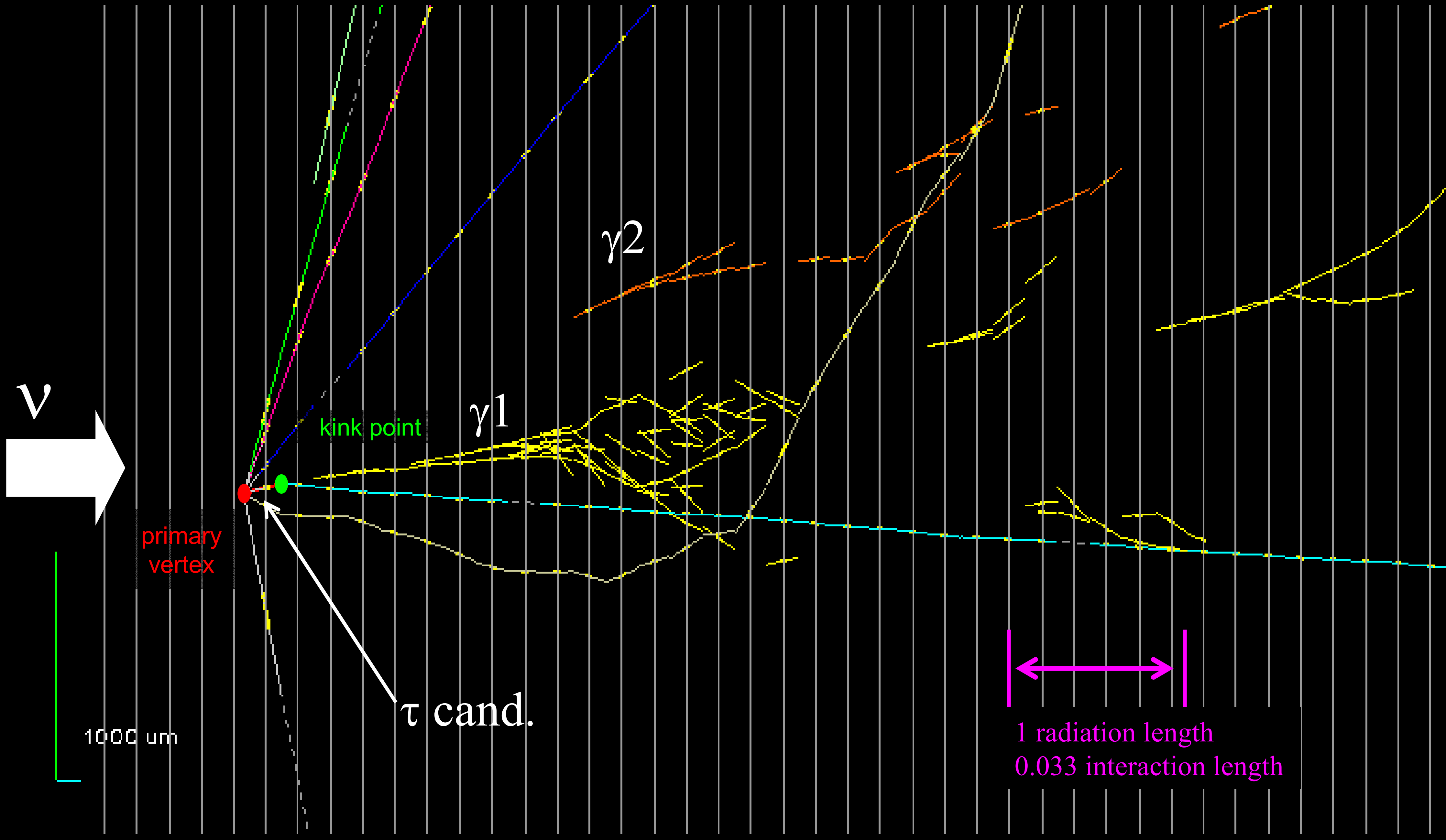
Sandwich structure of emulsion films and target material.

Automatic track recognition



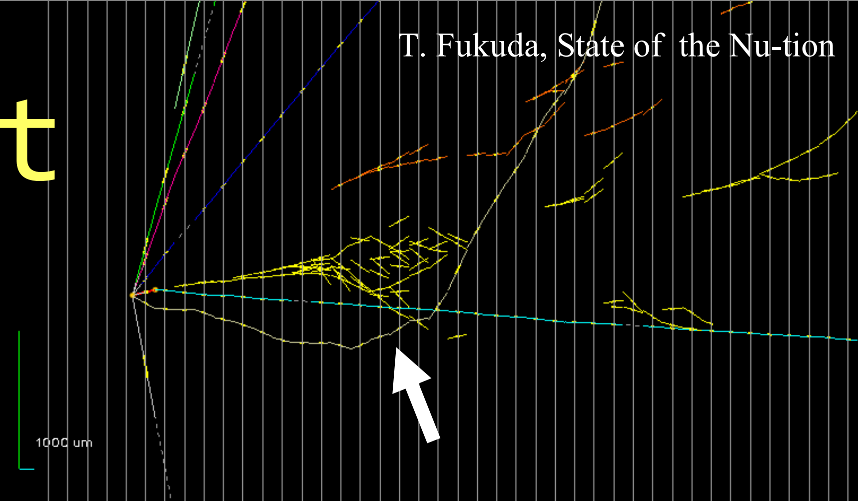


OPERA 1st ν_τ candidate event



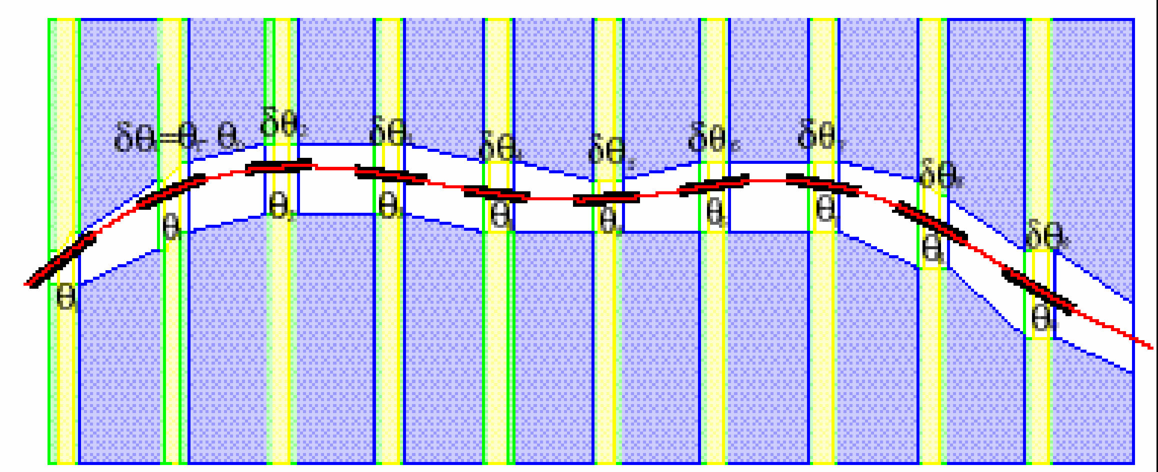
OPERA 1st ν_τ candidate event

Momentum measurement

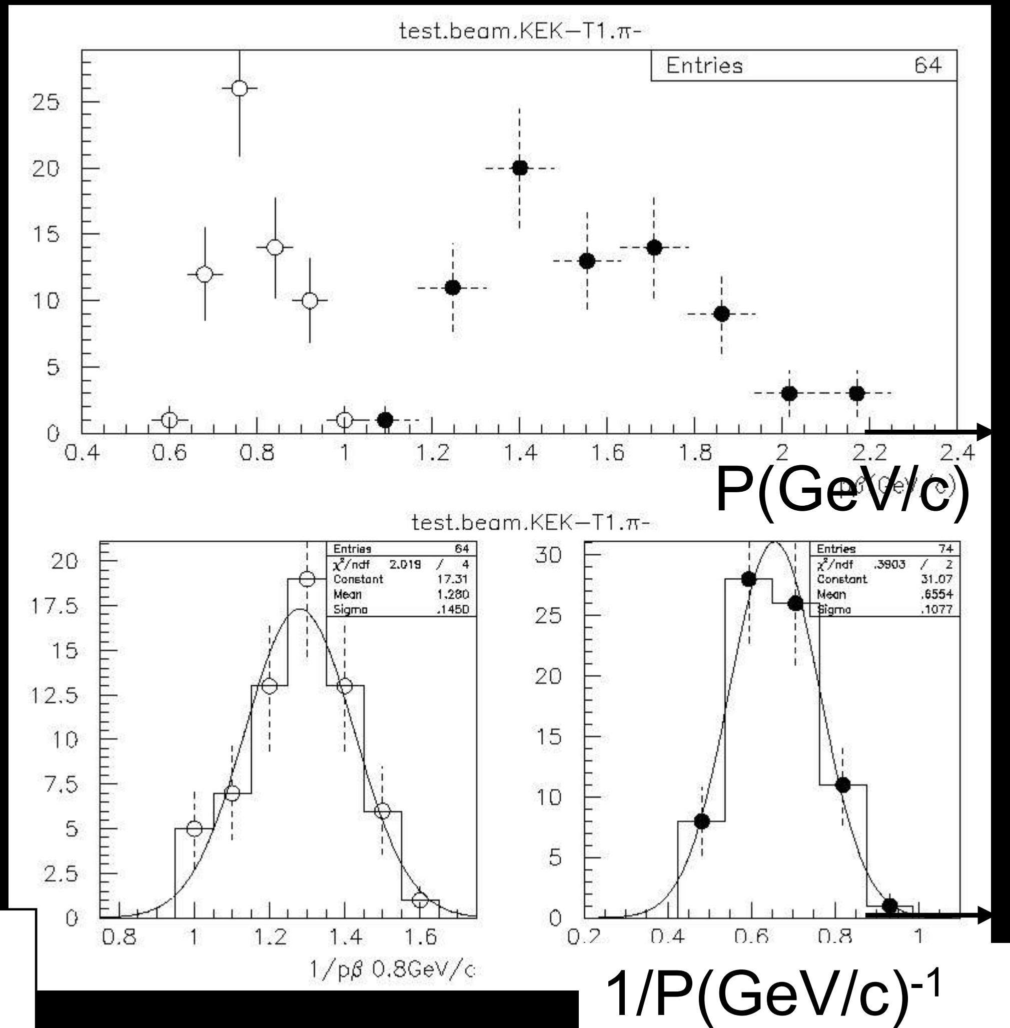


Multiple coulomb scattering

[Angle Method]



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



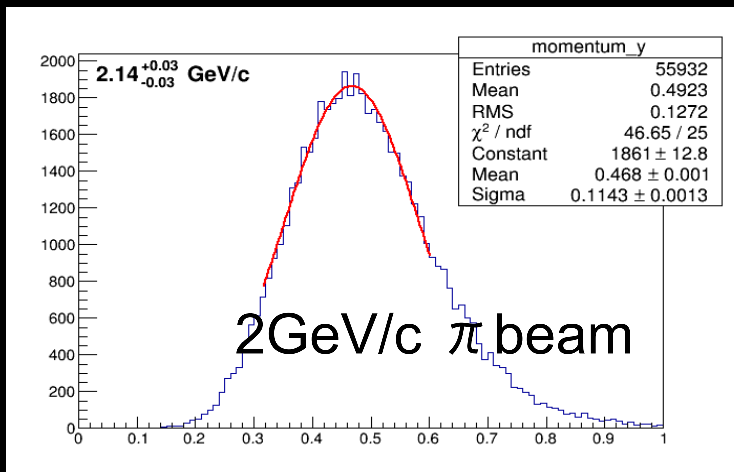
0.8GeV/c pion : P =0.79(GeV/c), dP/P =**11**%

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

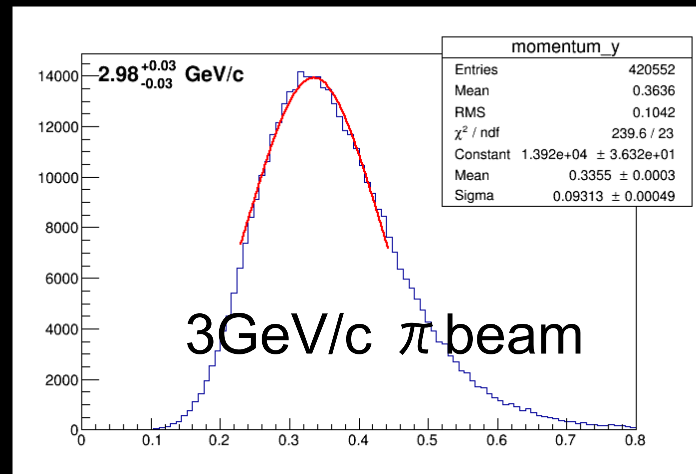
With 1mm Pb ECC

Momentum measurement@High energy

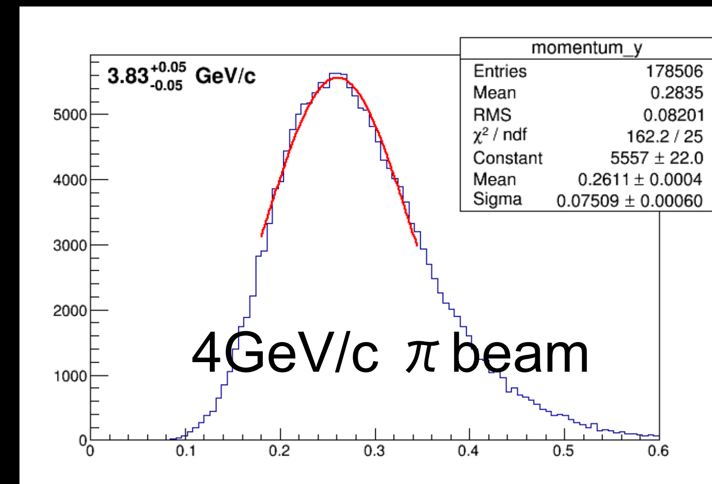
With 1mm Pb ECC



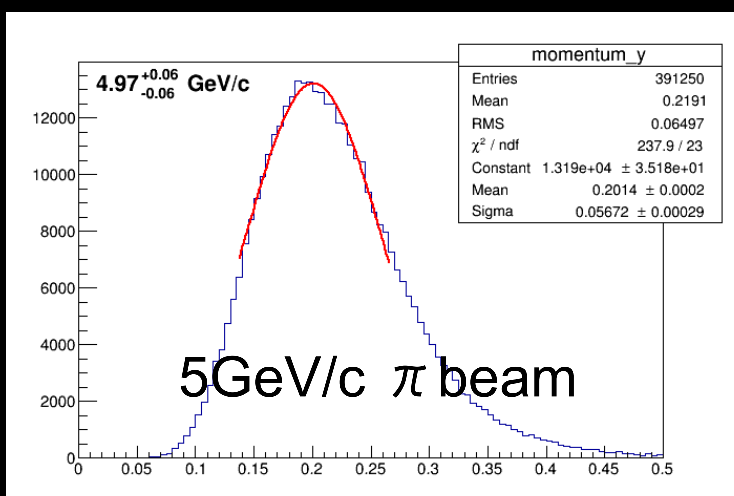
by using 57 emulsion films



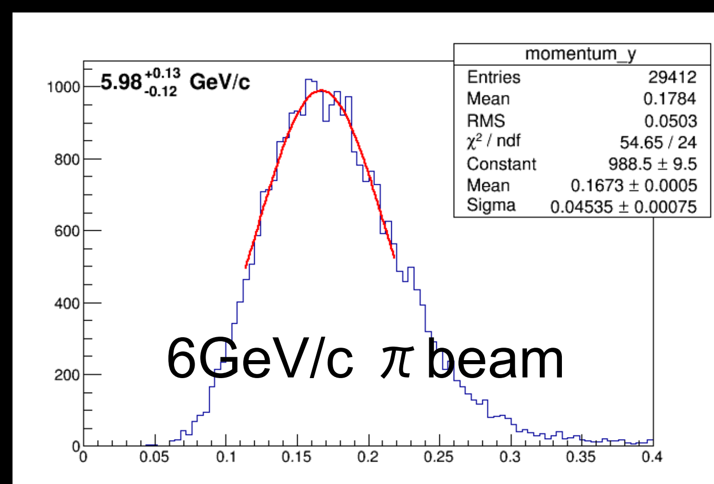
by using 57 emulsion films



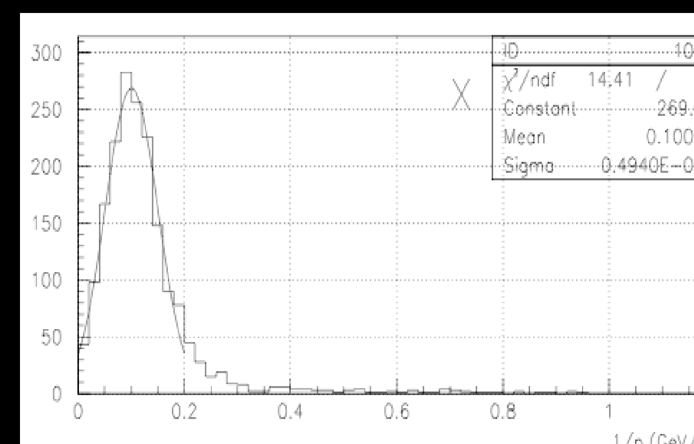
by using 57 emulsion films



by using 57 emulsion films



by using 57 emulsion films



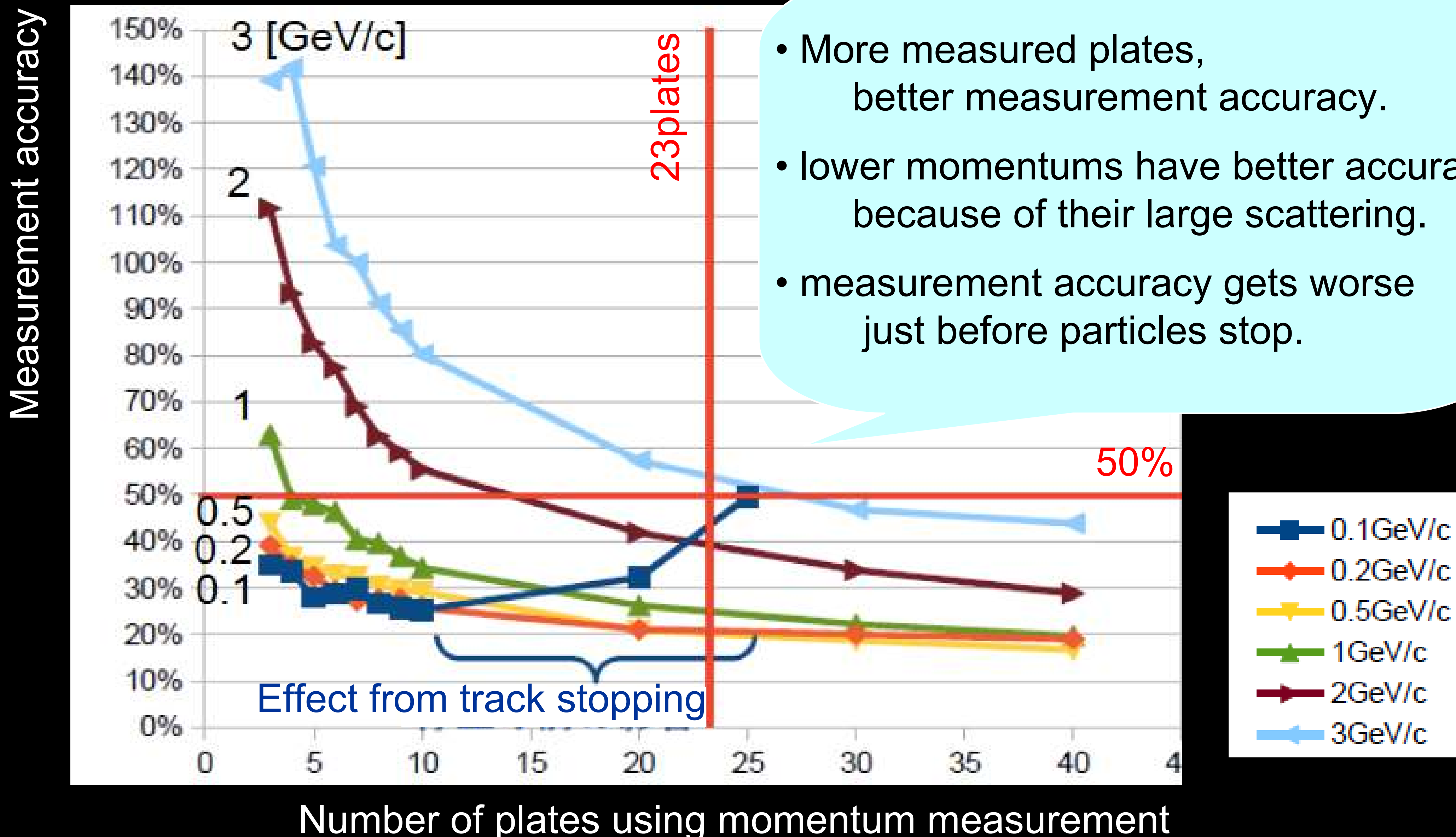
10GeV/c pion : P =9.94 (GeV/c)
dP/P =49%
by using 23 emulsion films

Momentum measurement

MC study by GEANT4

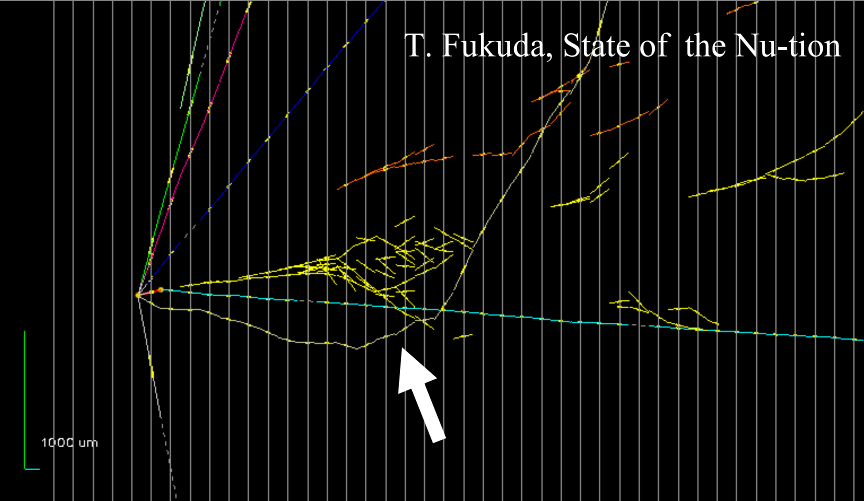
- Measurement accuracy

With 0.5mm Fe ECC

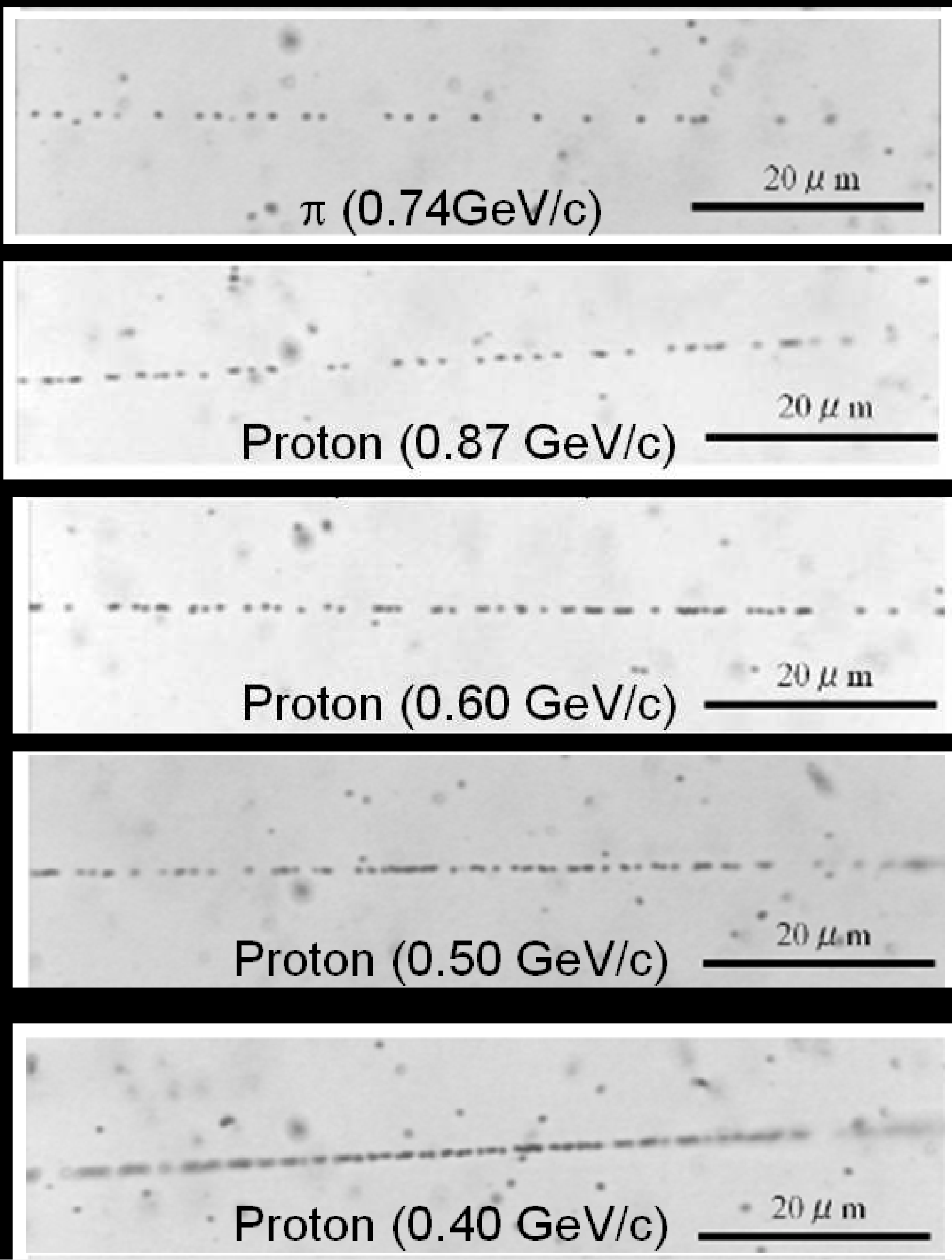


- More measured plates, better measurement accuracy.
- lower momentums have better accuracy because of their large scattering.
- measurement accuracy gets worse just before particles stop.

dE/dX measurement



Darkness of tracks



β = 0.98

β = 0.68

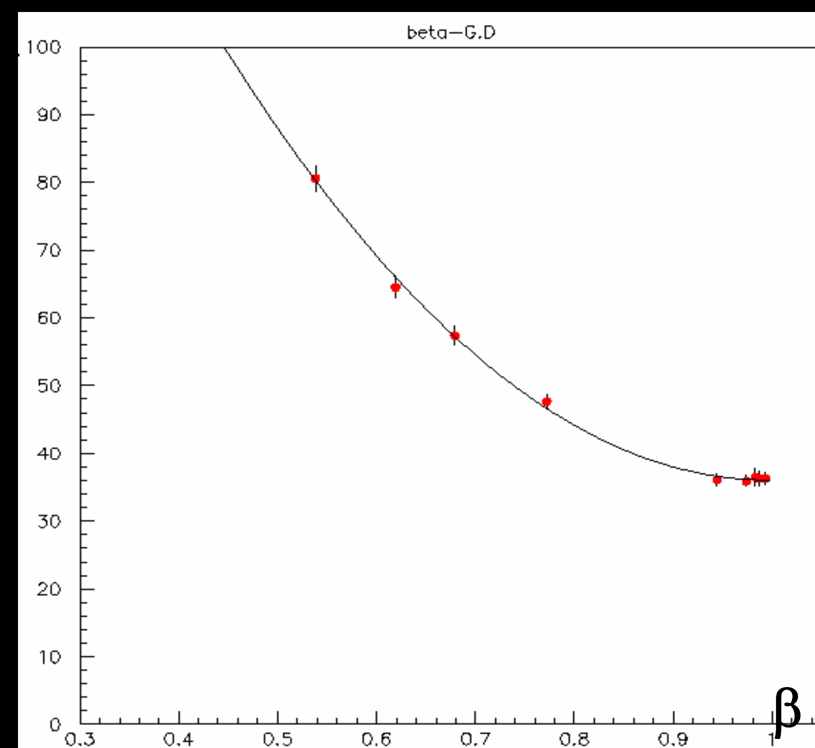
β = 0.54

β = 0.47

β = 0.39

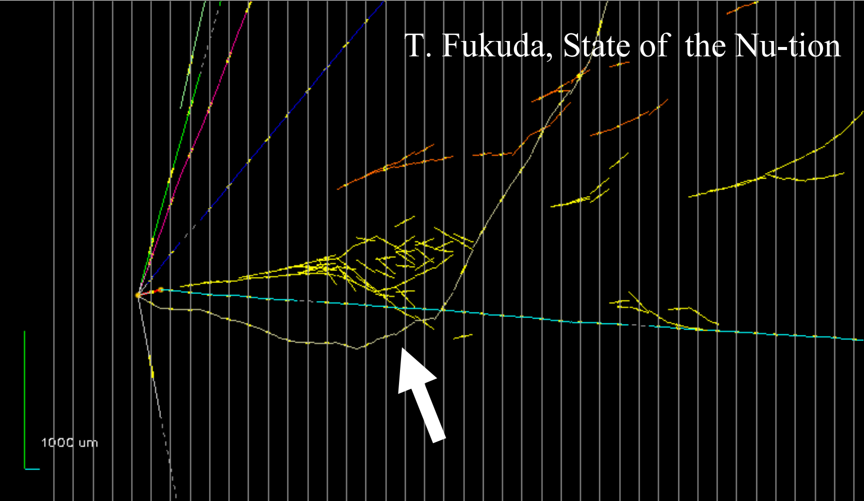
Darkness

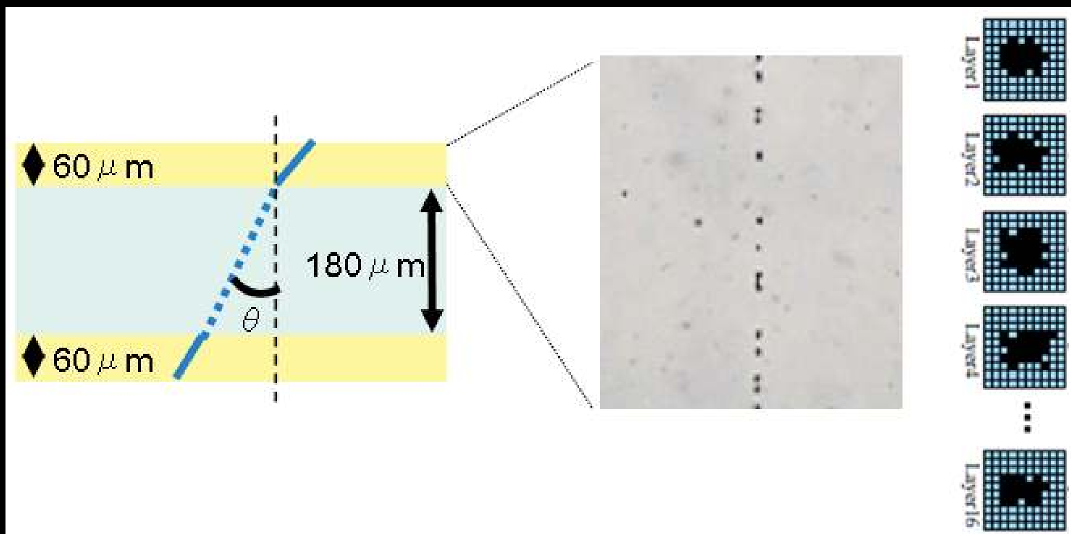
Number of grains/100 μm

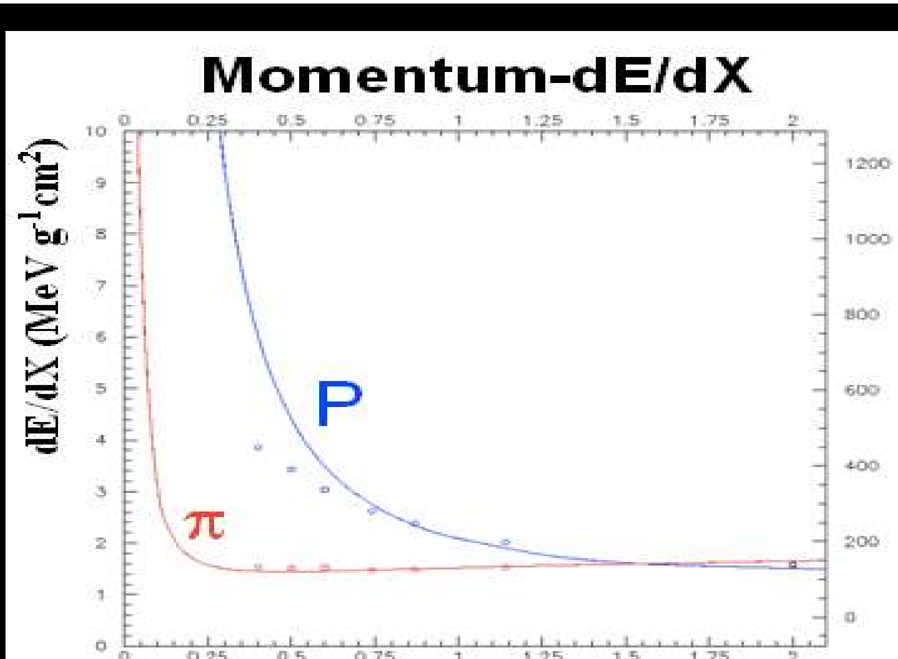


dE/dX measurement

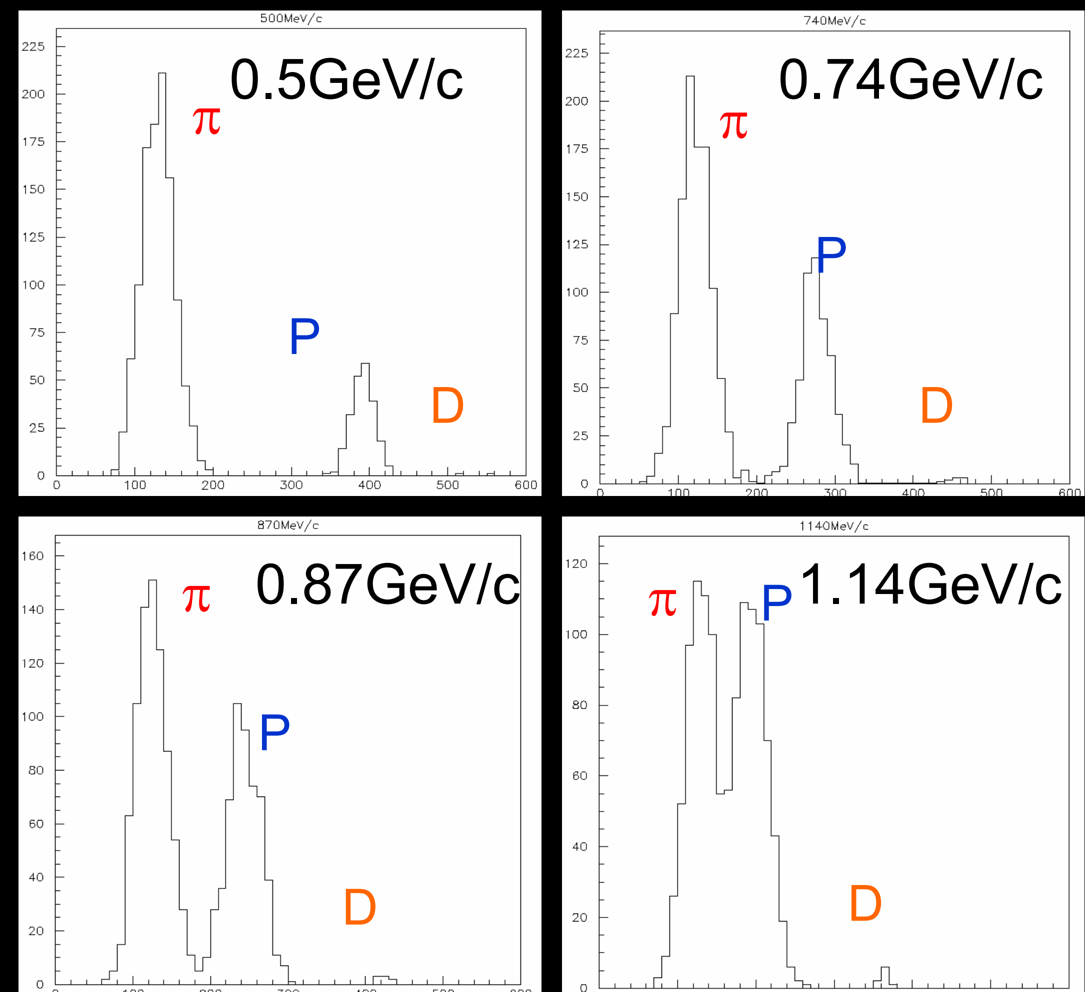
Darkness of tracks







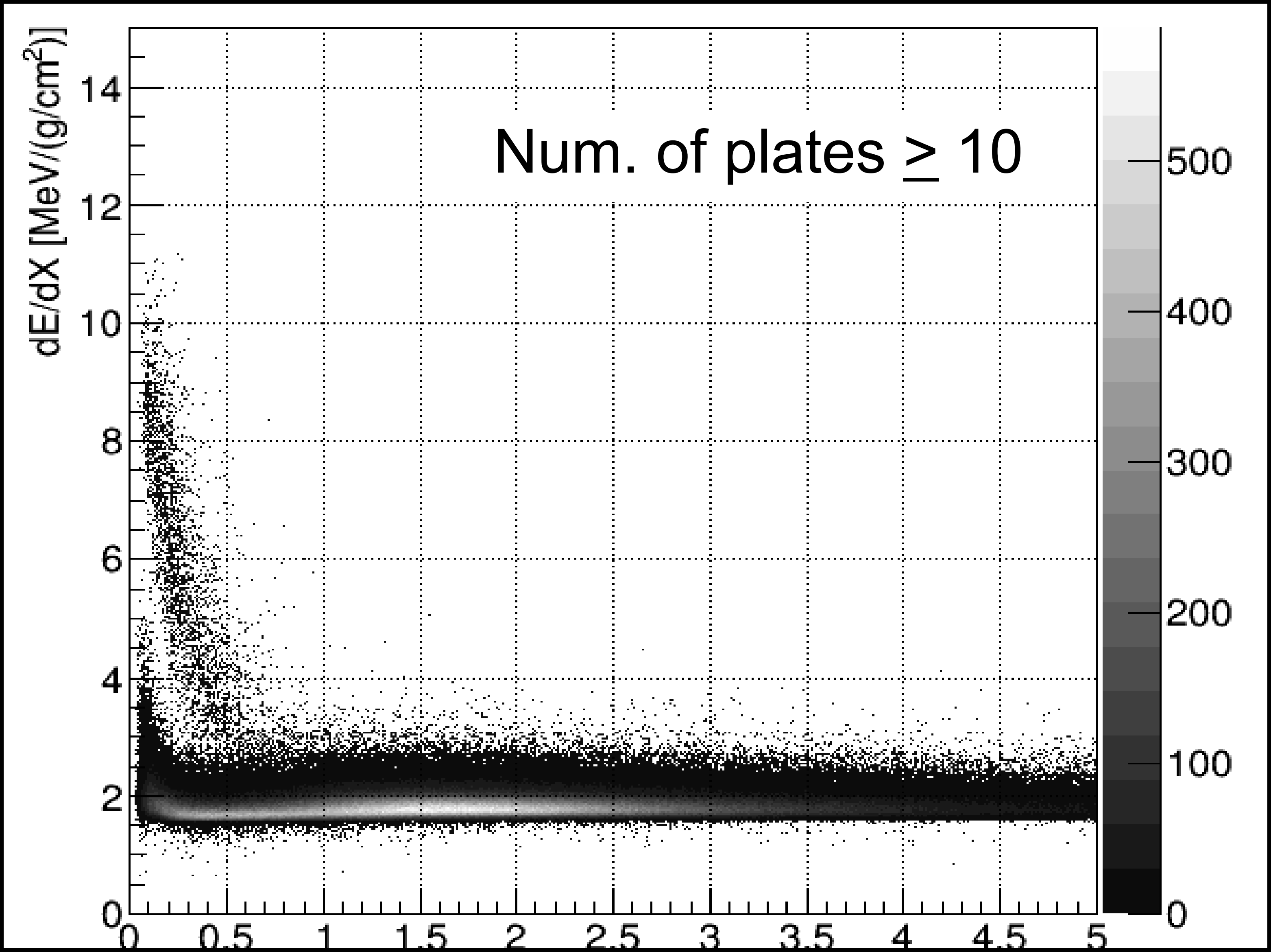
Number of pixels associated track data



Using 20 plates

Practical application

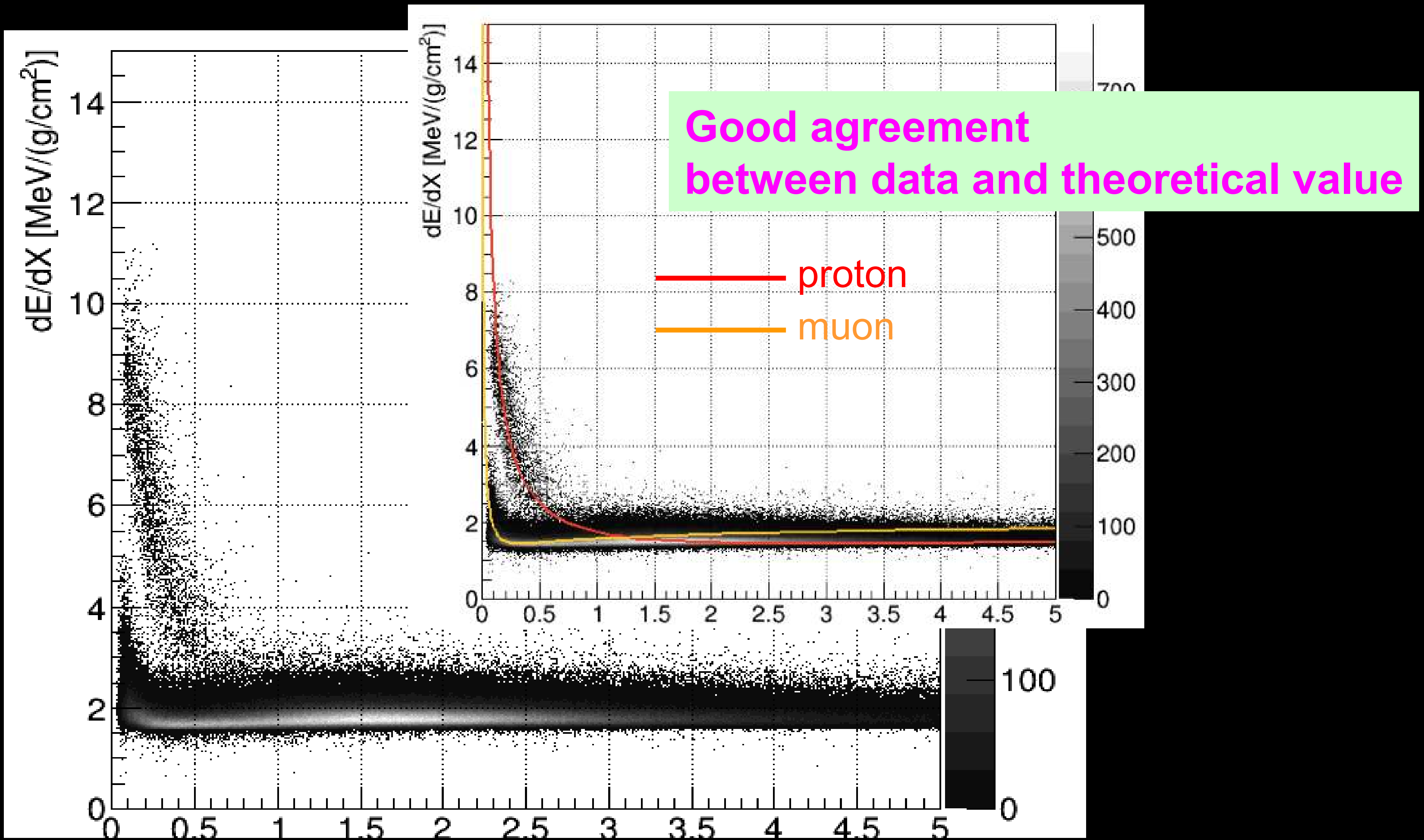
NINJA Experiment @J-PARC



Momentum(p β) (GeV/c)

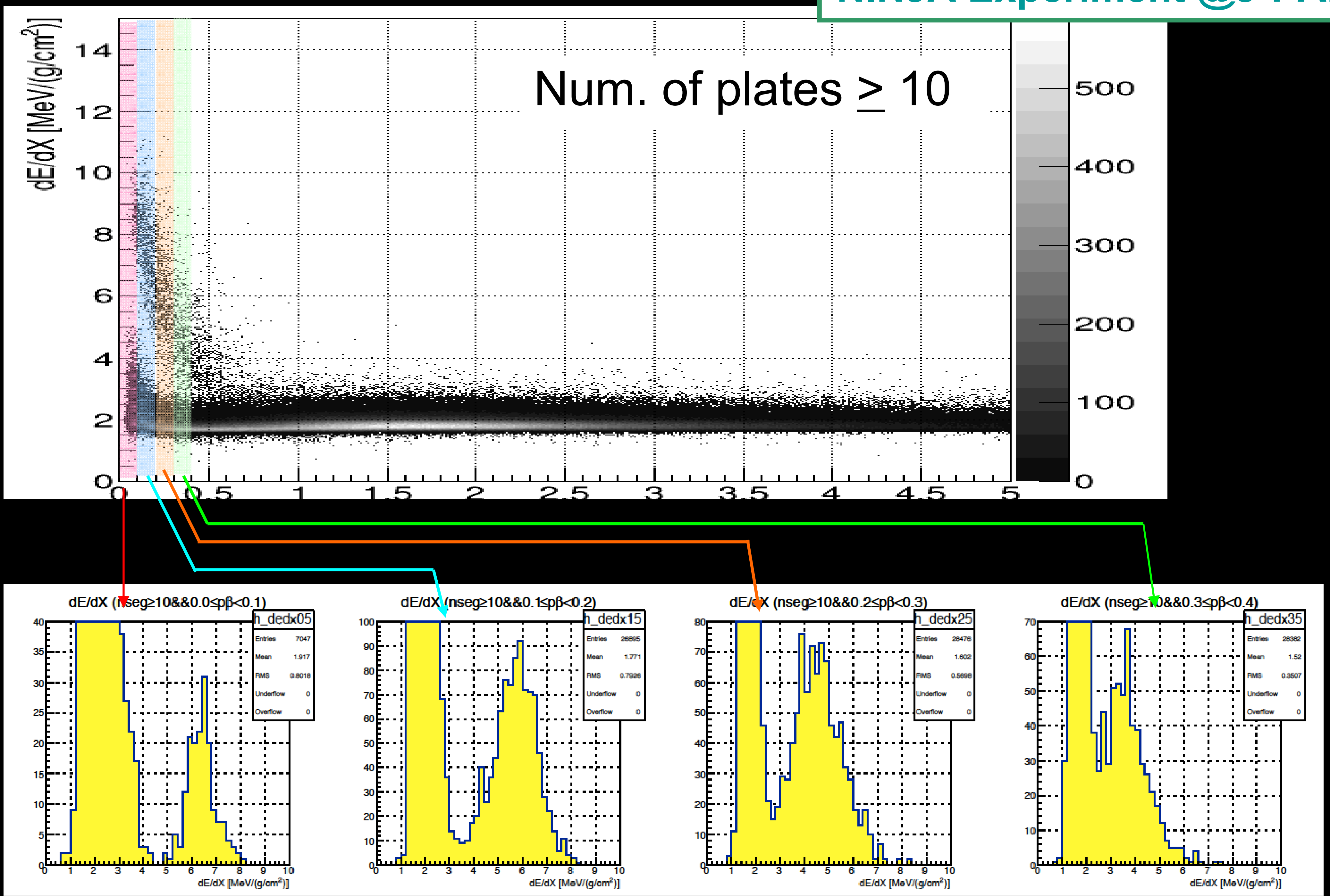
Practical application

NINJA Experiment @J-PARC



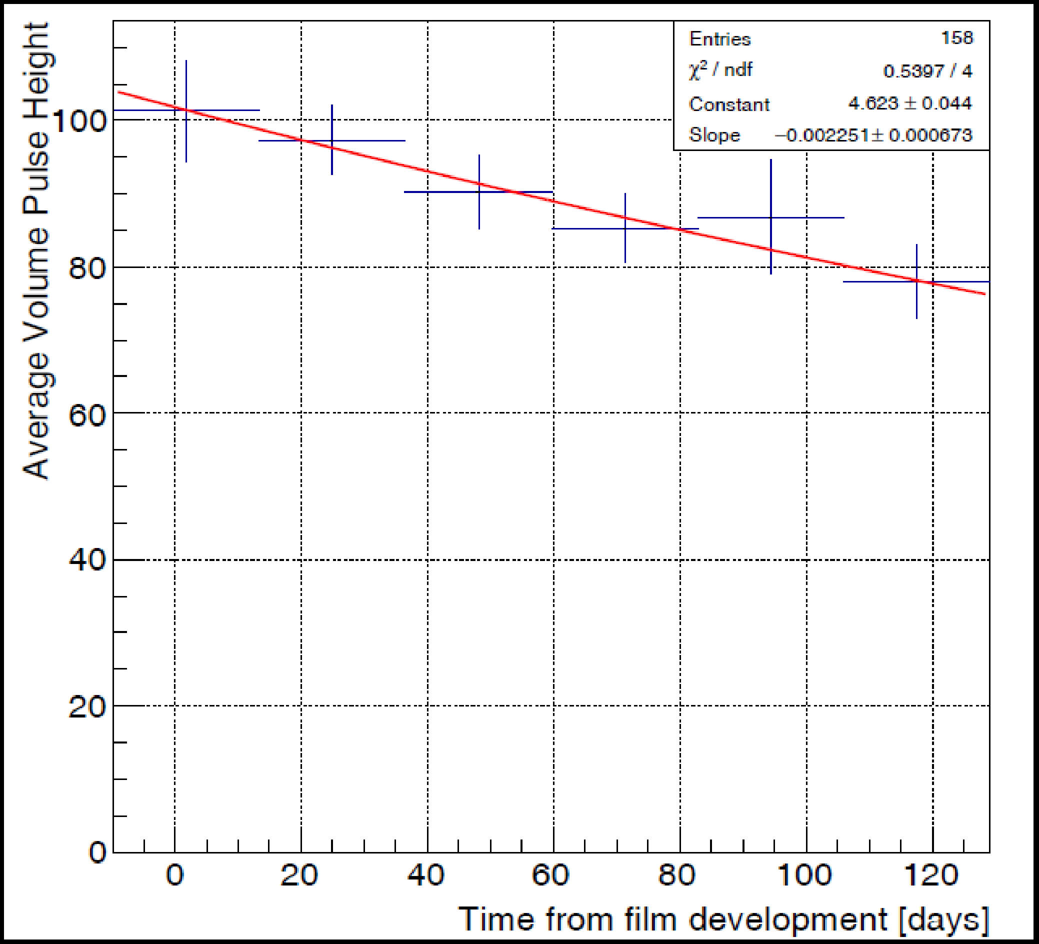
Practical application

NINJA Experiment @J-PARC



Future improvement

Track darkness for MIP



Aging of the emulsion tracks.

Silver grains were disappeared. (fading effect)

~20% of track darkness is lowered after 120 days.

Near future, such effect will be corrected by using timing information.

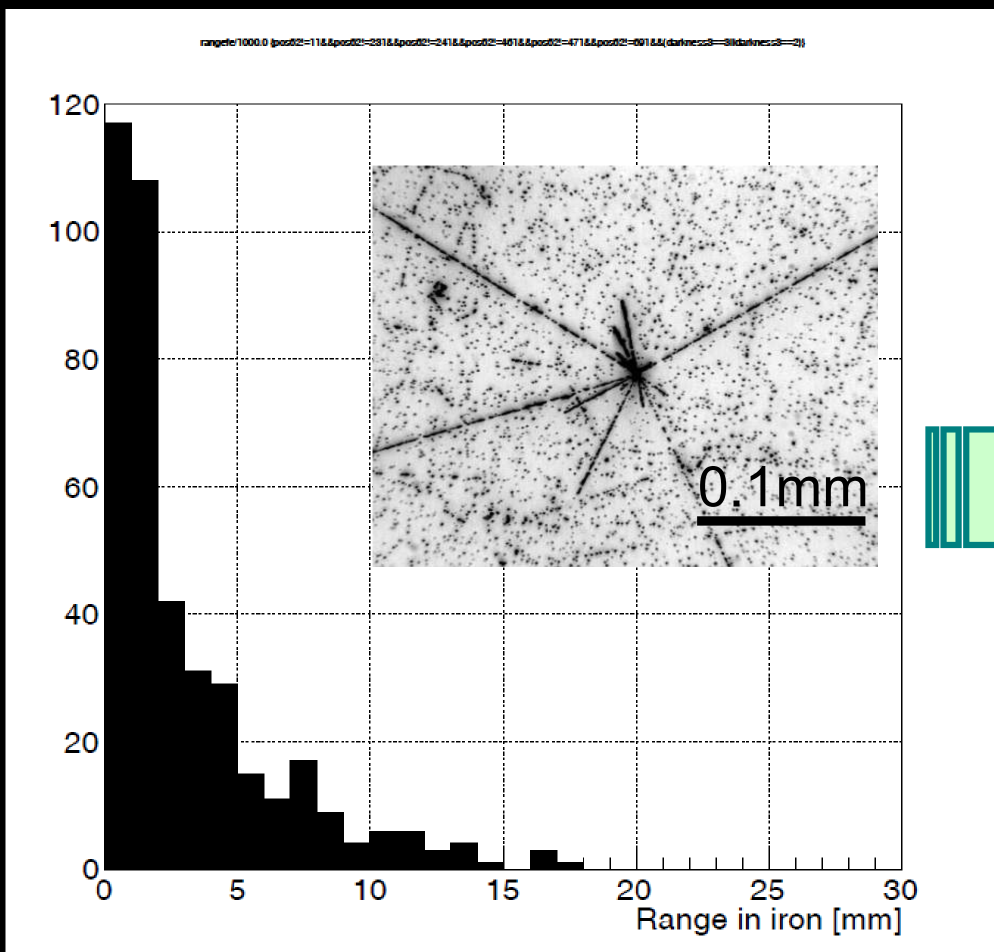
The elapsed days after tracks were recorded to development

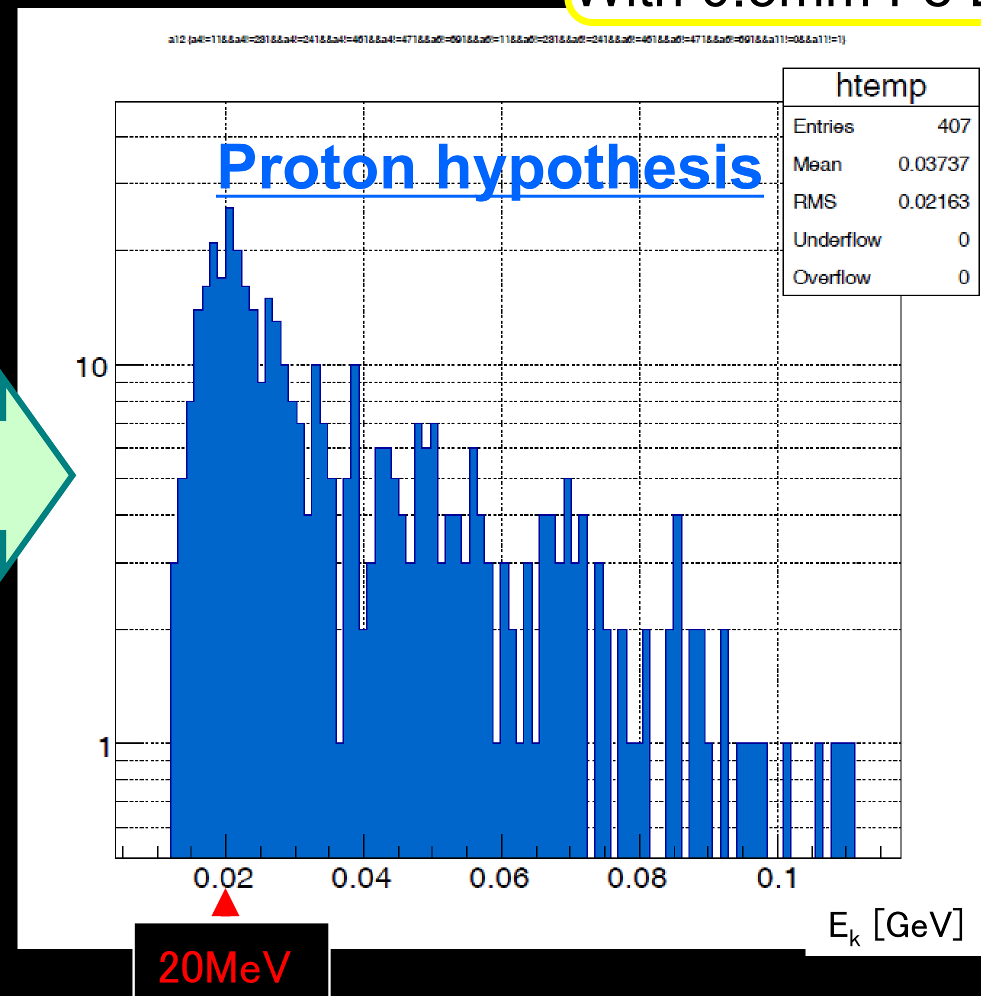
Low energy proton

Range measurement

NINJA Experiment @J-PARC

With 0.5mm Fe ECC



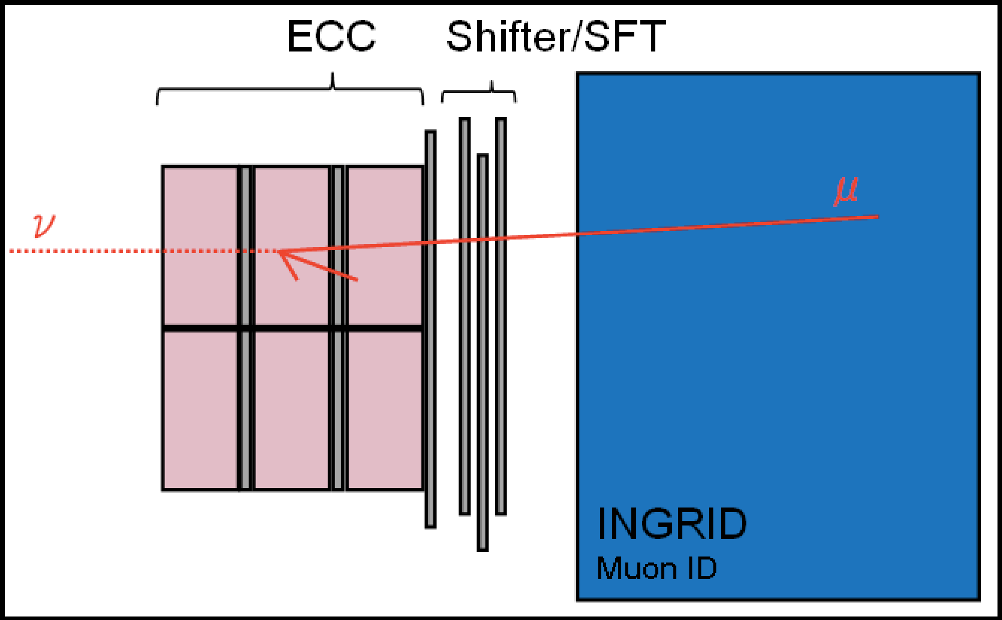


Measurement error is depend on the thickness of target material.

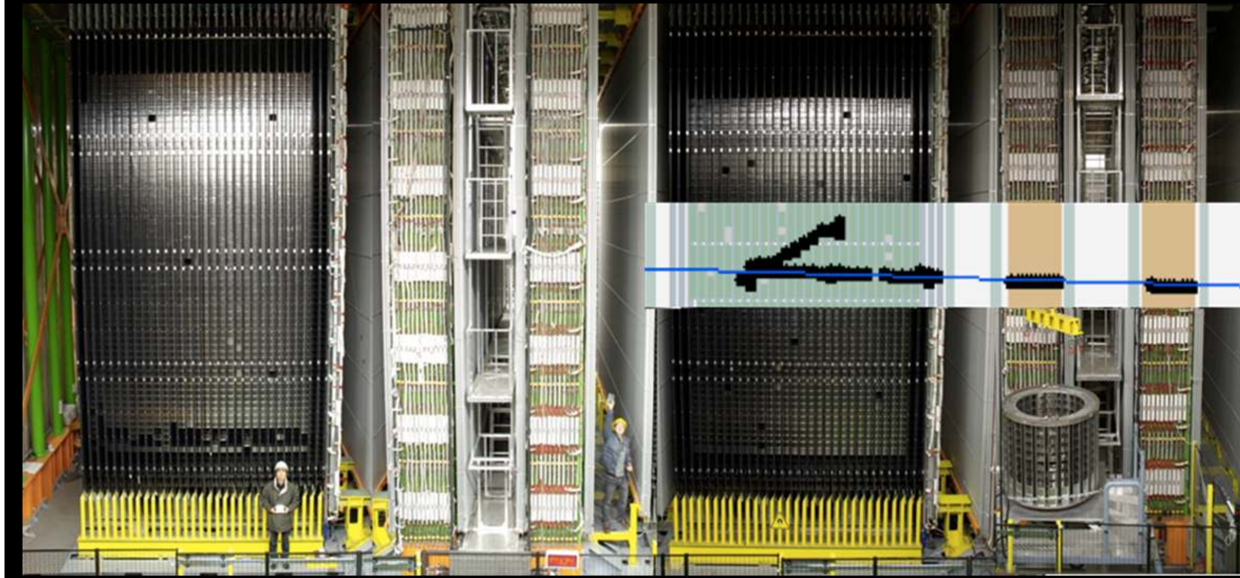
Muon identification

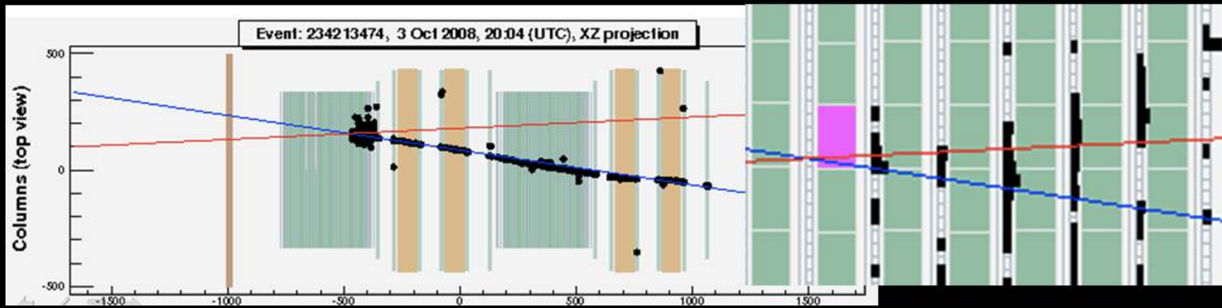
- Hybrid analysis with MRD

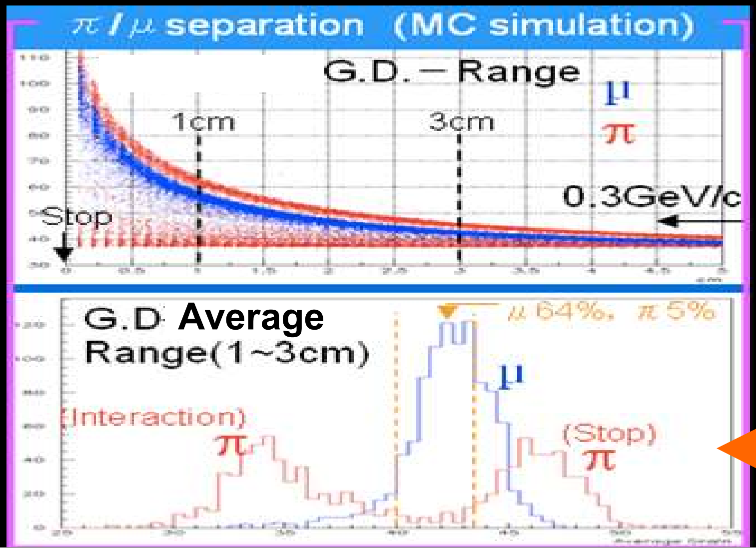
NINJA



OPERA



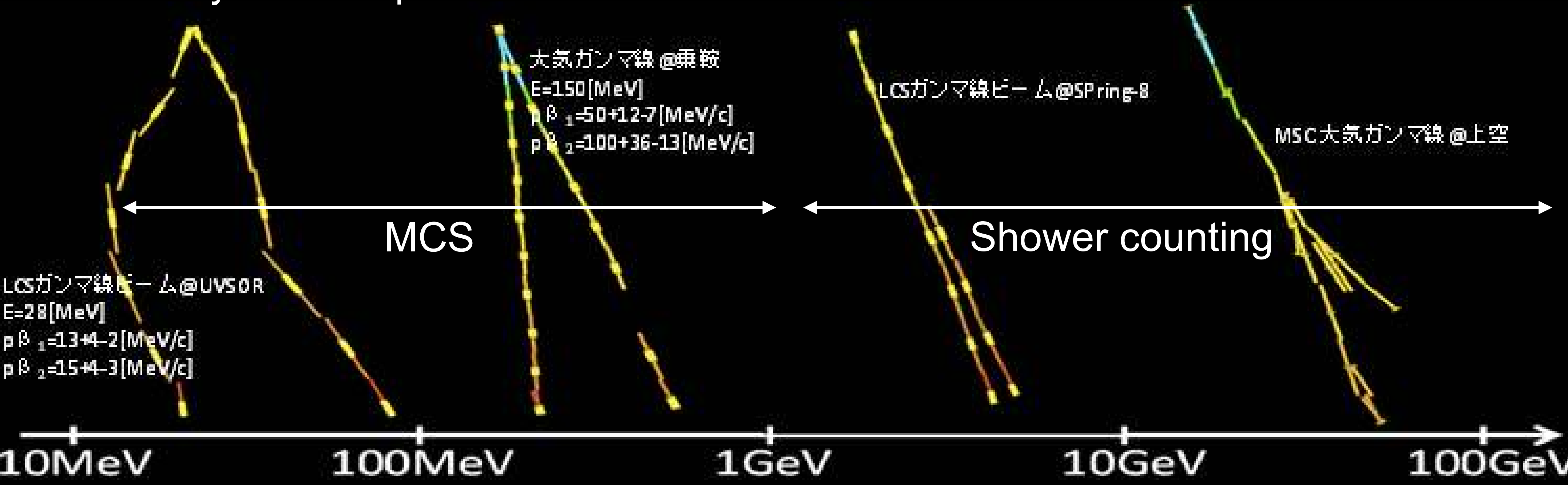


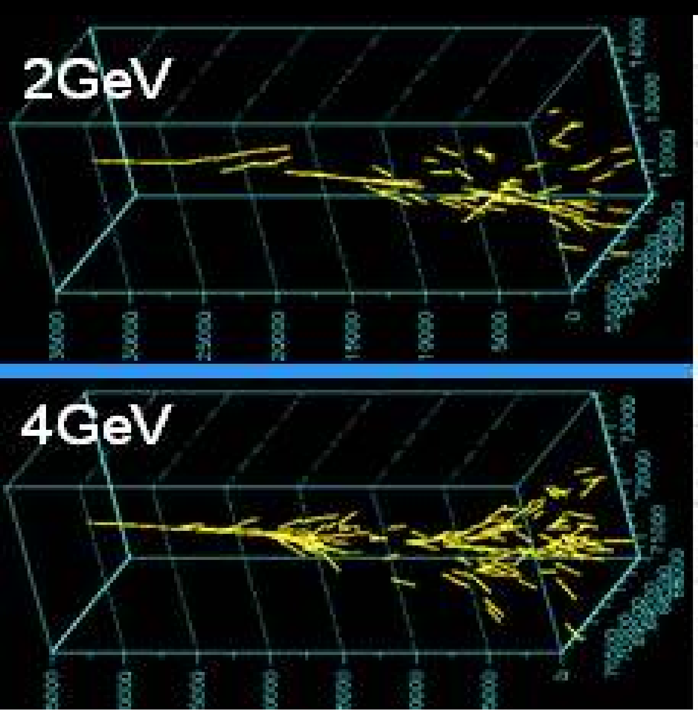


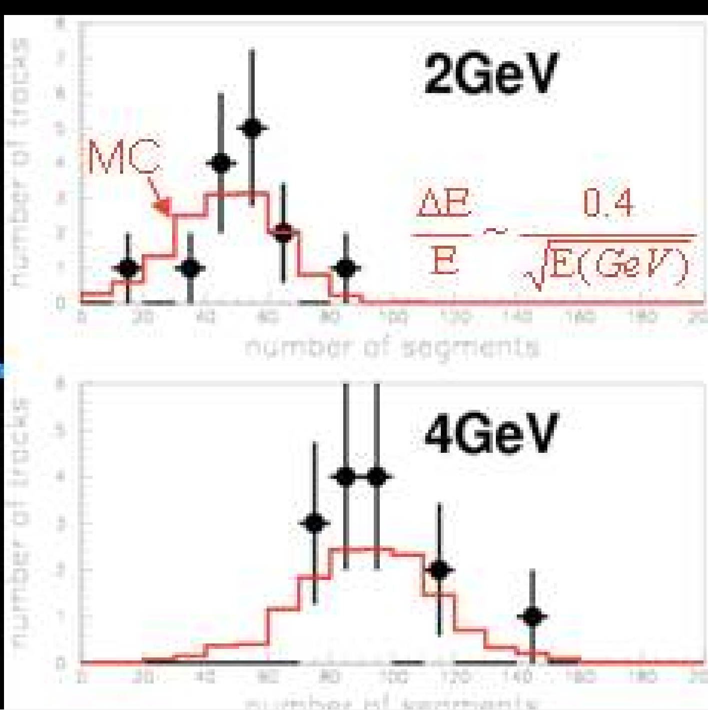
R&D for stopping π / μ ID using only dE/dx and Range

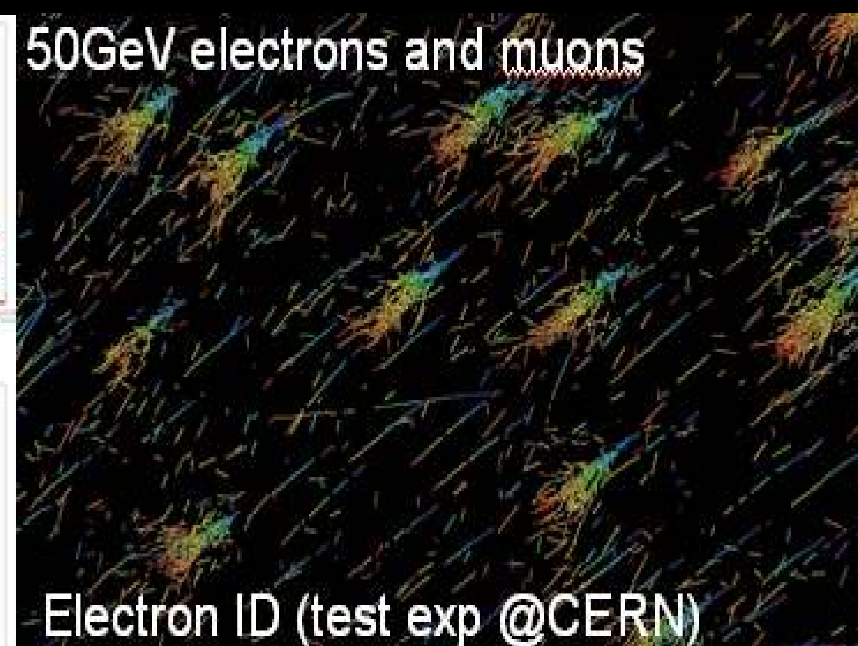
Electron energy measurement

Gamma rays → e^+e^- pair creation

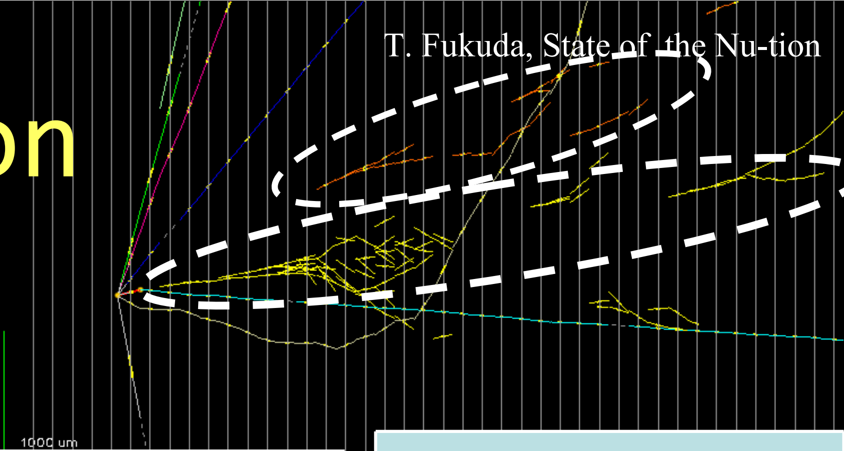


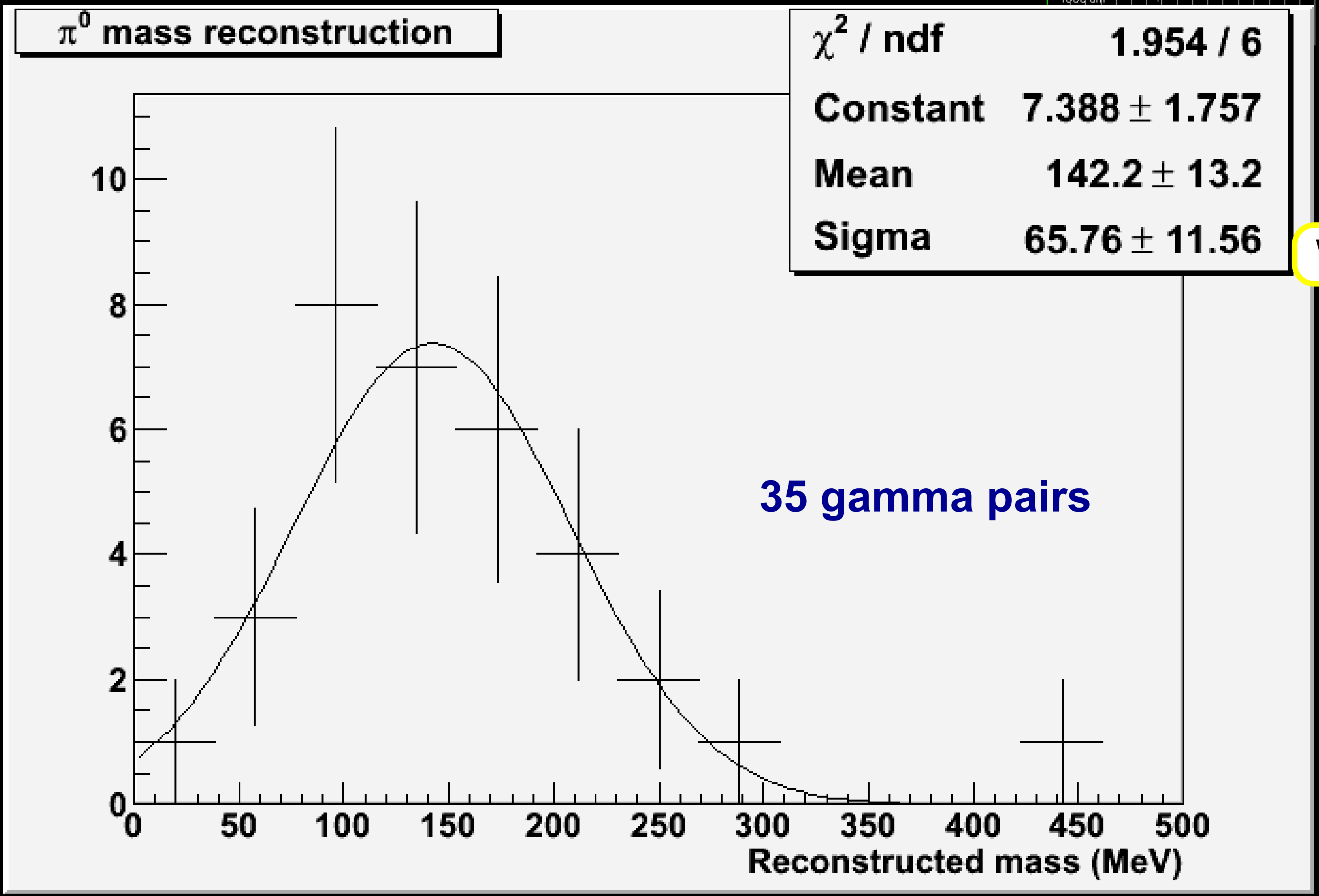






π^0 mass reconstruction





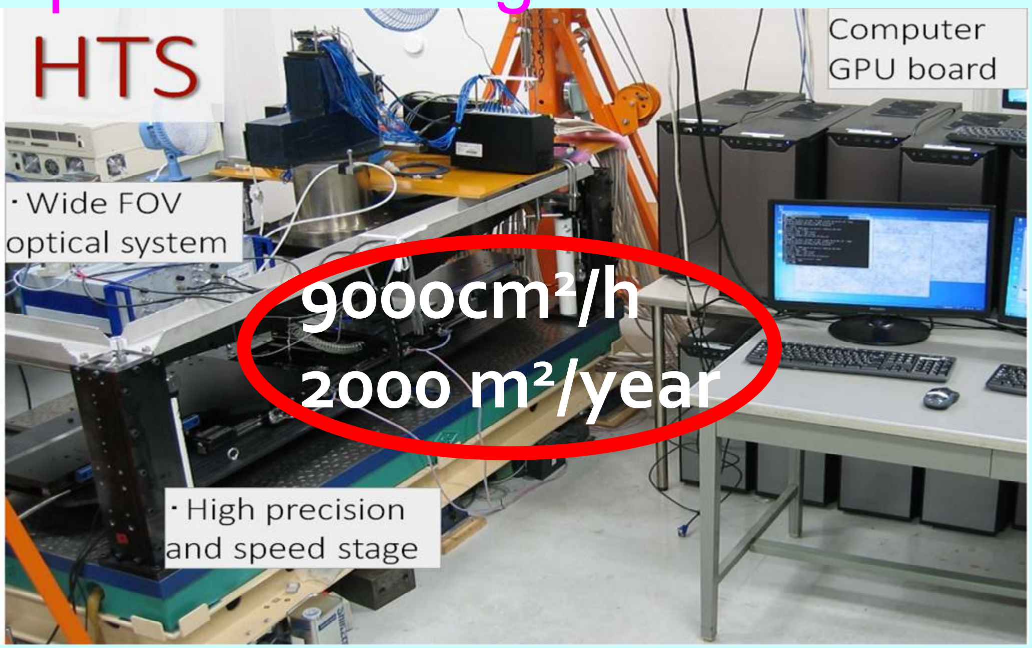
$\gamma 1 + \gamma 2$
$120 \pm 20 \pm 35$ MeV

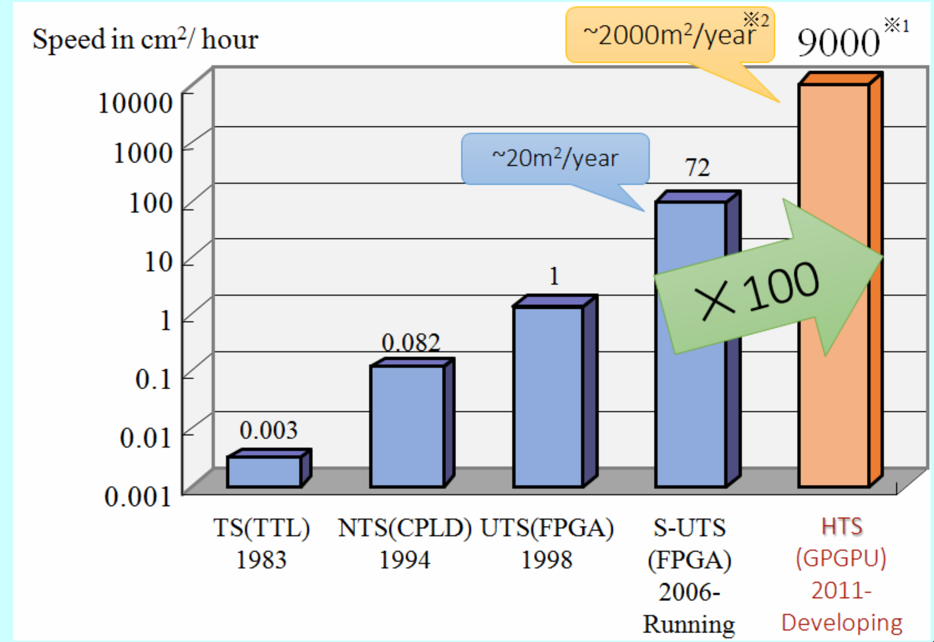
With 1mm Pb ECC

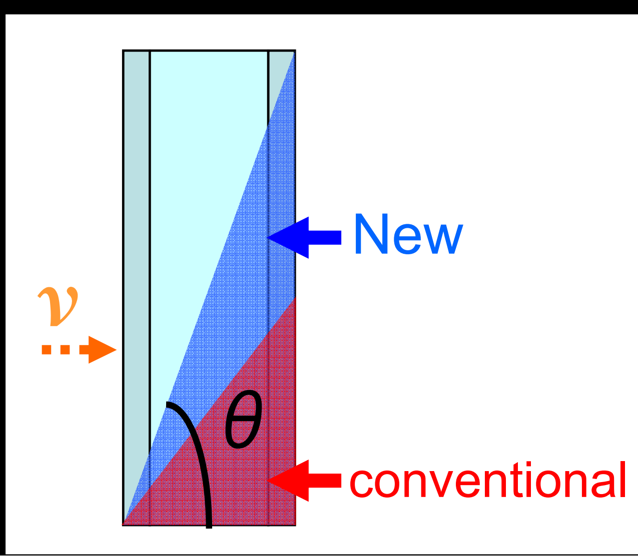
1 σ mass resolution: ~ 45%

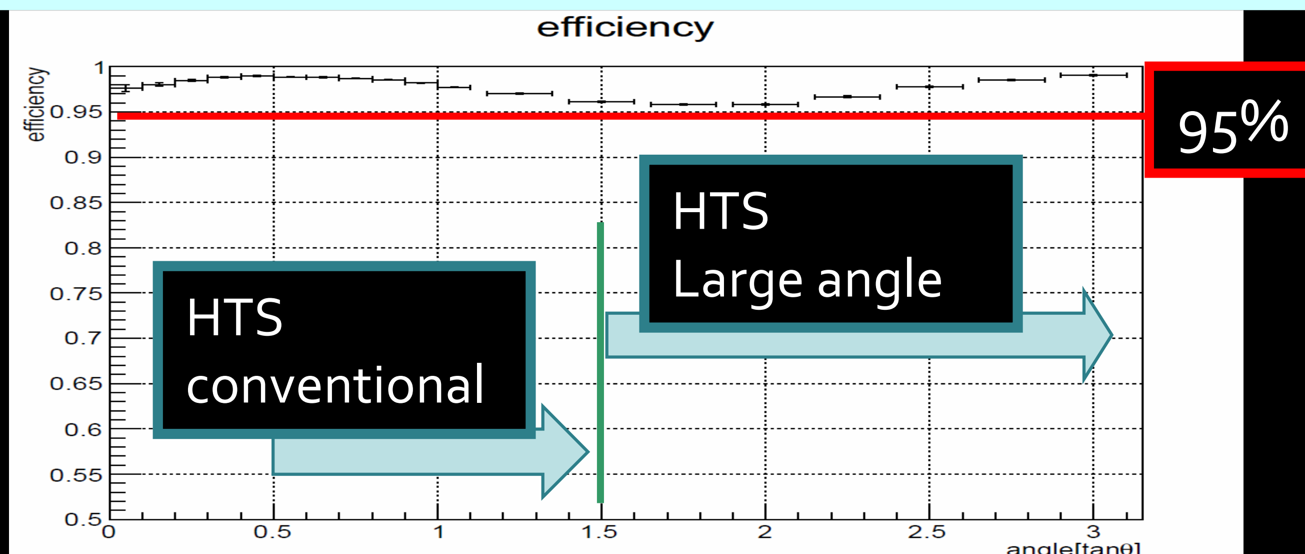
New technique: High speed Large angle scanning

High speed scanning

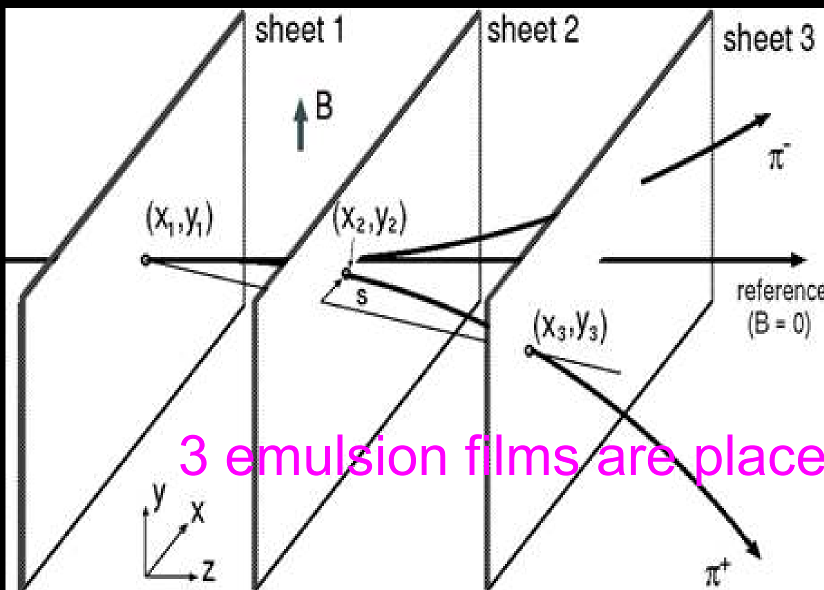




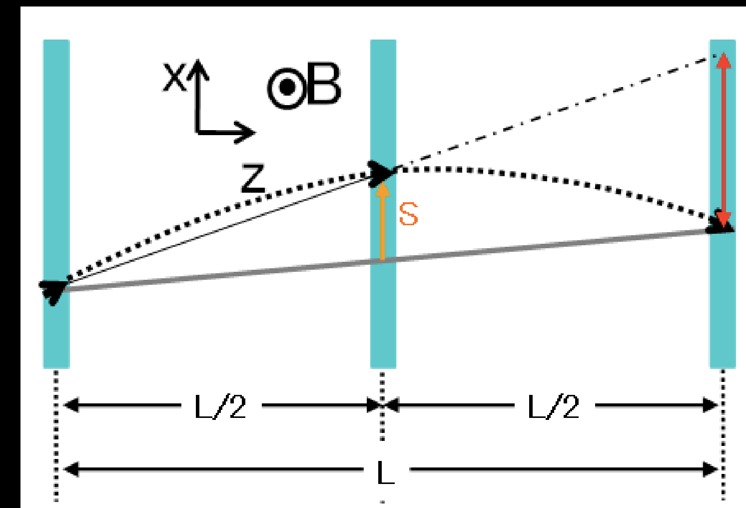




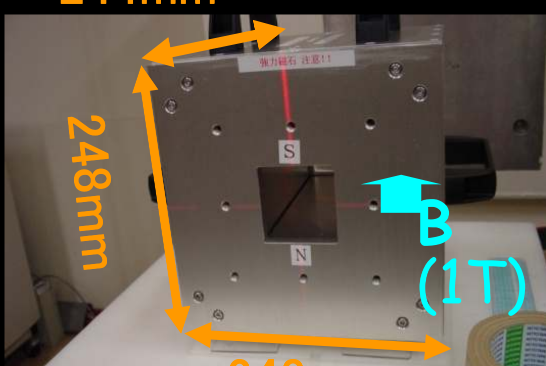
New technique: Emulsion spectrometer



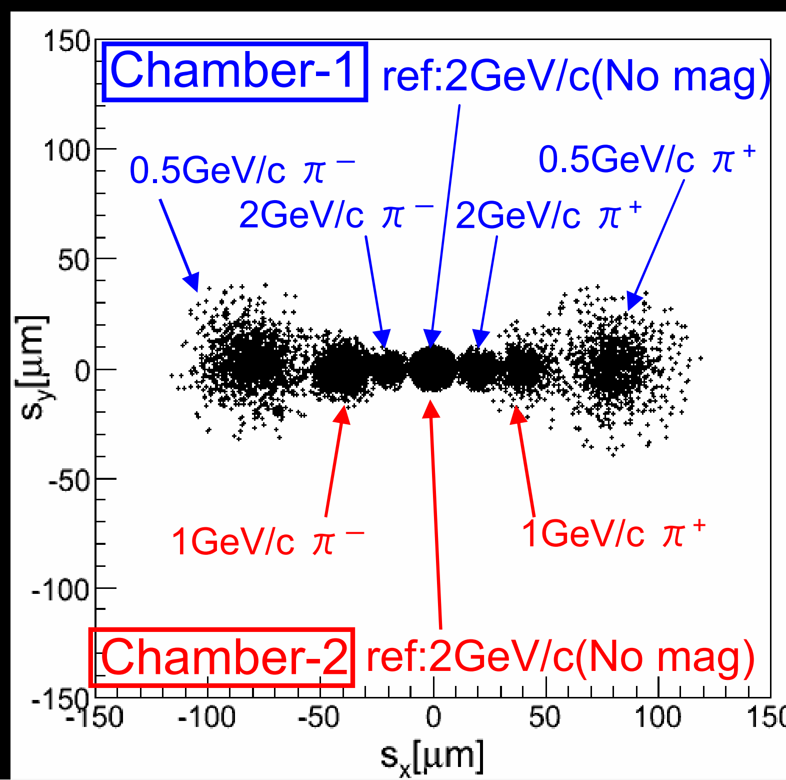
3 emulsion films are placed in magnet field.

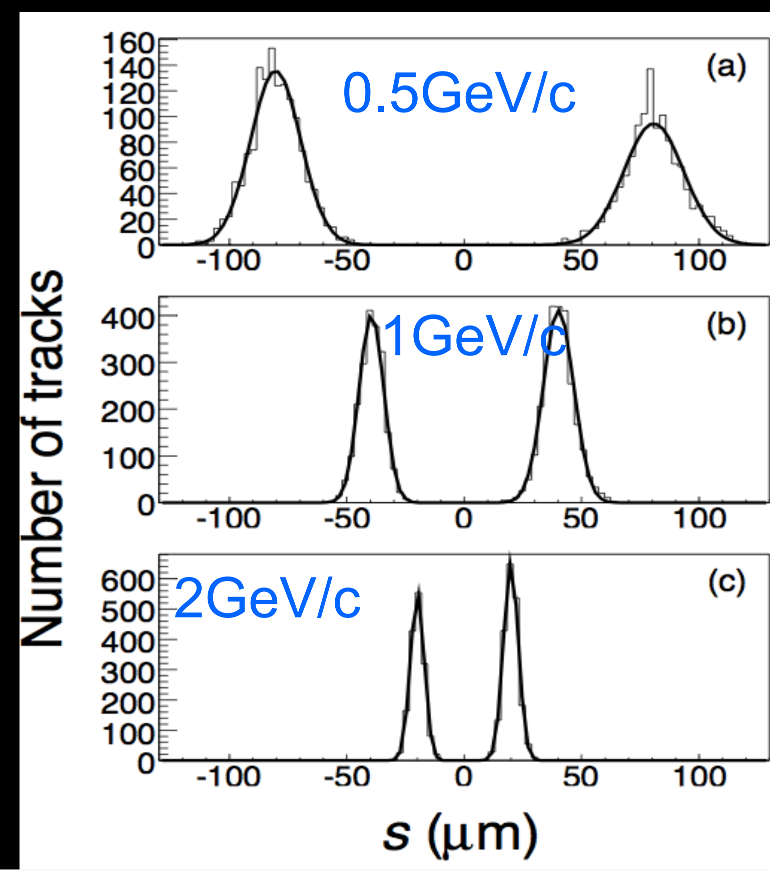


Experimental Data



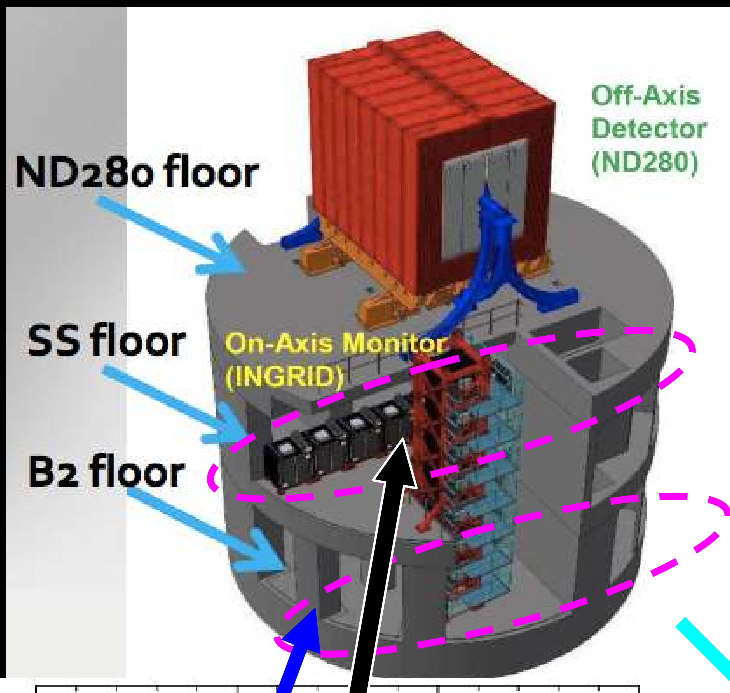
Permanent magnet for test experiment

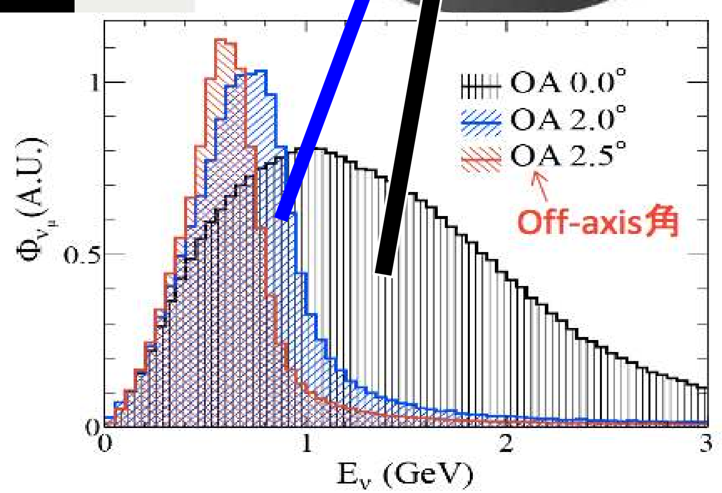




NINJA Experiment

Neutrino Interaction research with Nuclear emulsion and J-PARC Accelerator

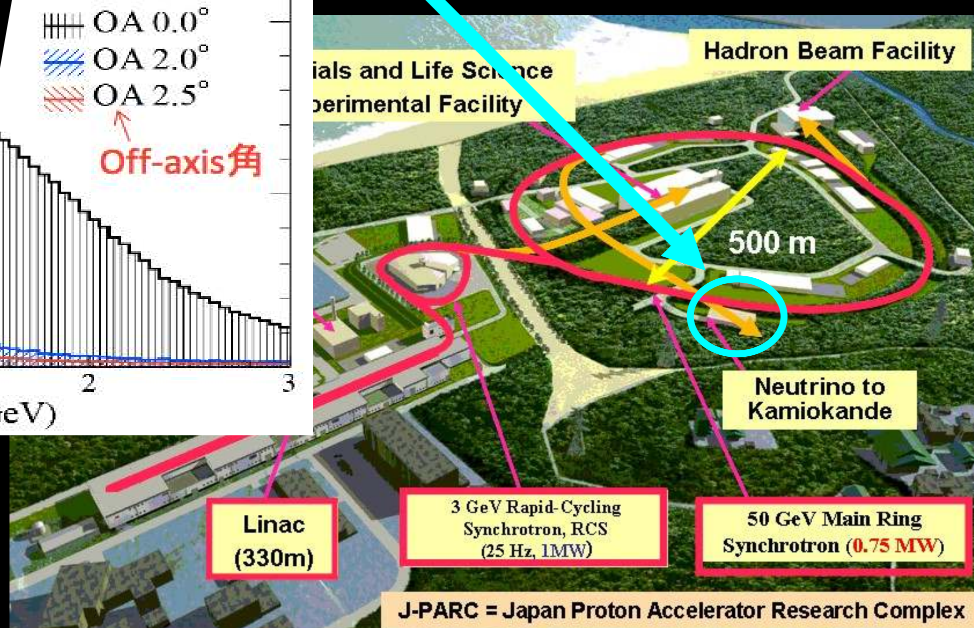




Working group

OPERA | **T2K**

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



I' ll report the status on 29th.

Summary

- Nuclear emulsion
- Momentum measurement
- dE/dx, Range measurement
- Muon ID
- Electron energy measurement
- New technology (Large angle, Charge sign)
- NINJA Experiment

That's all. Thank you !

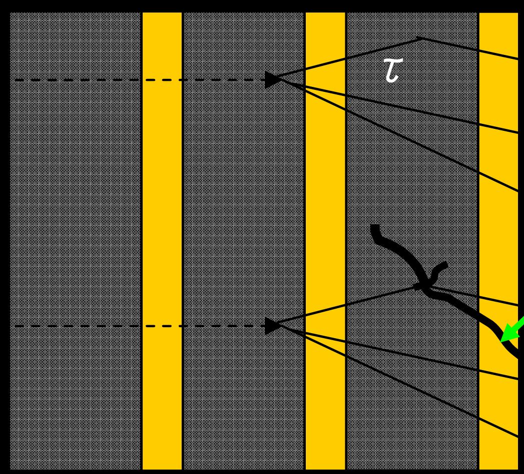
Supplements

Nuclear fragments from hadron int.

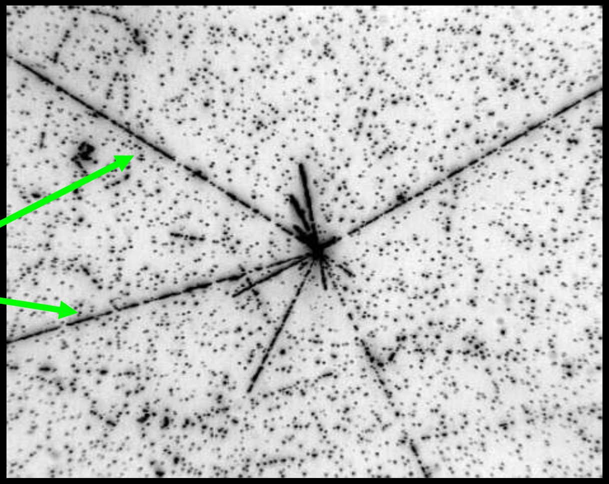
- The existence of nuclear fragments is strong proof for hadron interaction, not ν_τ decay.

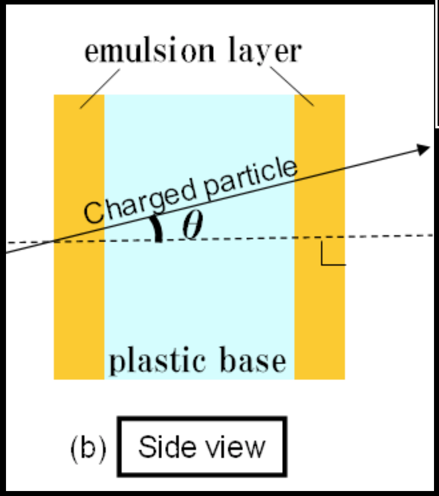
Signal (ν_τCC) ν_τ

BG (ν_μNC) ν_μ



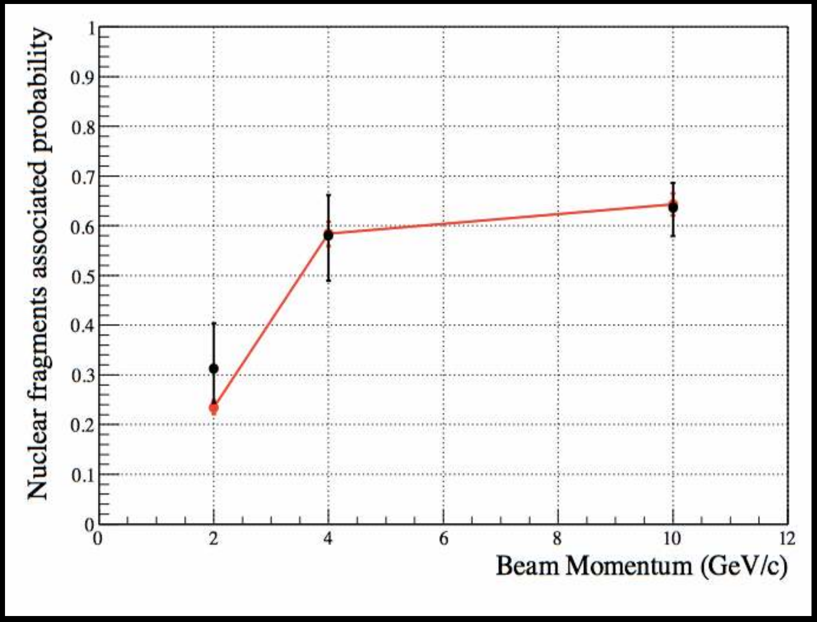
Nuclear fragment





Associated probability of nuclear fragments

Angle acceptance : $|\tan\theta| \lesssim 3.0$



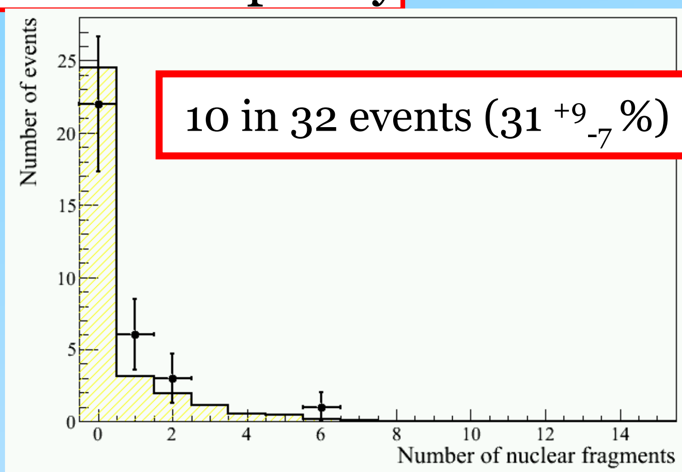
Property of nuclear fragments

2, 4 GeV/c : IP < 100 + 0.01dz
10 GeV/c : IP < 50 + 0.01dz

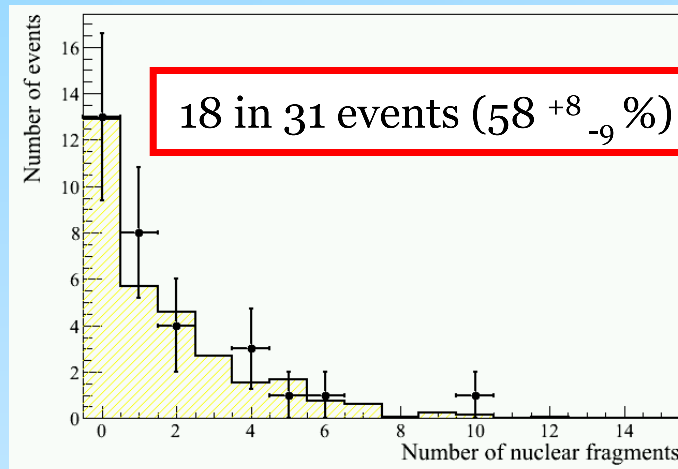
2GeV/c	4GeV/c	10GeV/c

Black multiplicity

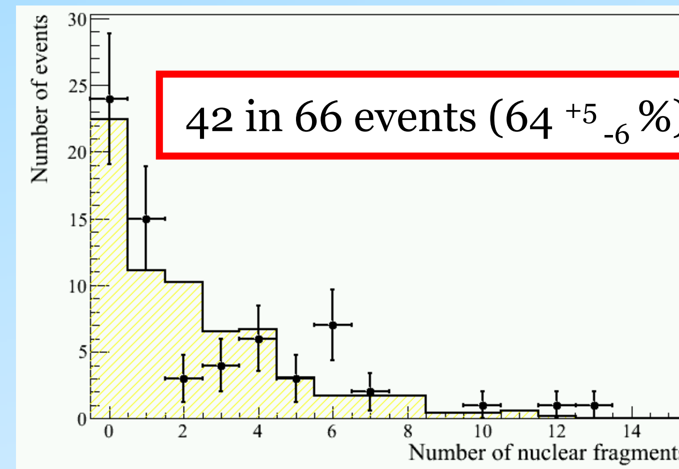
10 in 32 events (31^{+9}_{-7} %)



18 in 31 events (58^{+8}_{-9} %)

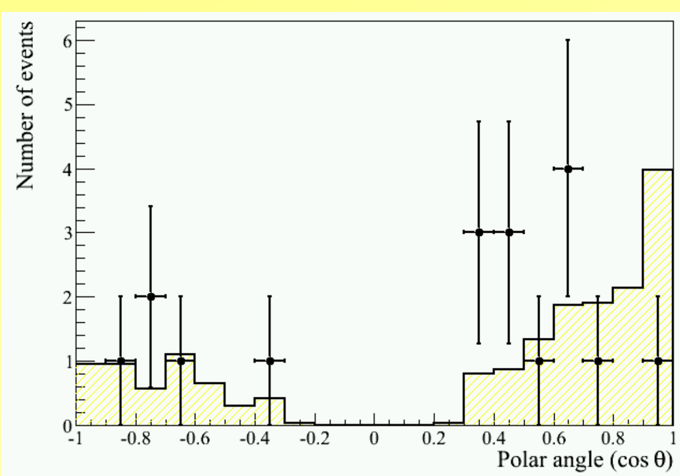


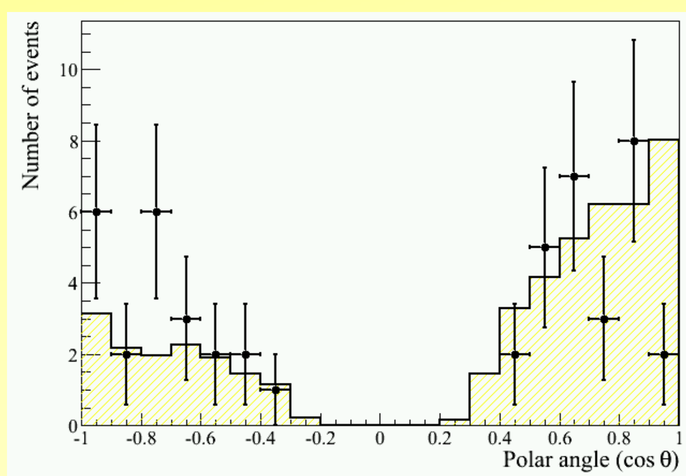
42 in 66 events (64^{+5}_{-6} %)

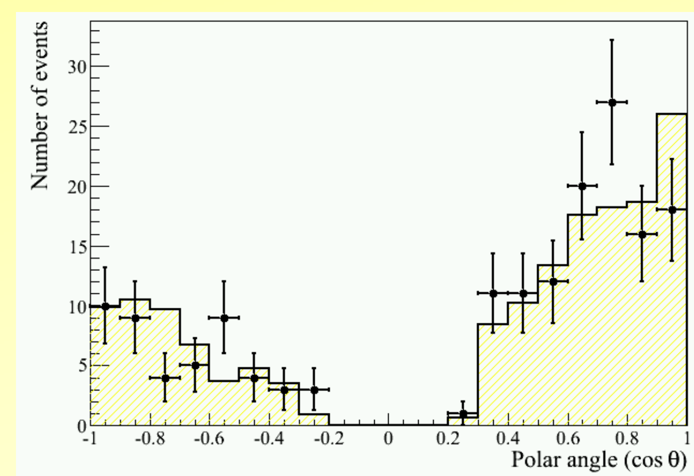


Error bars : Experimental data
Histogram : Simulated data

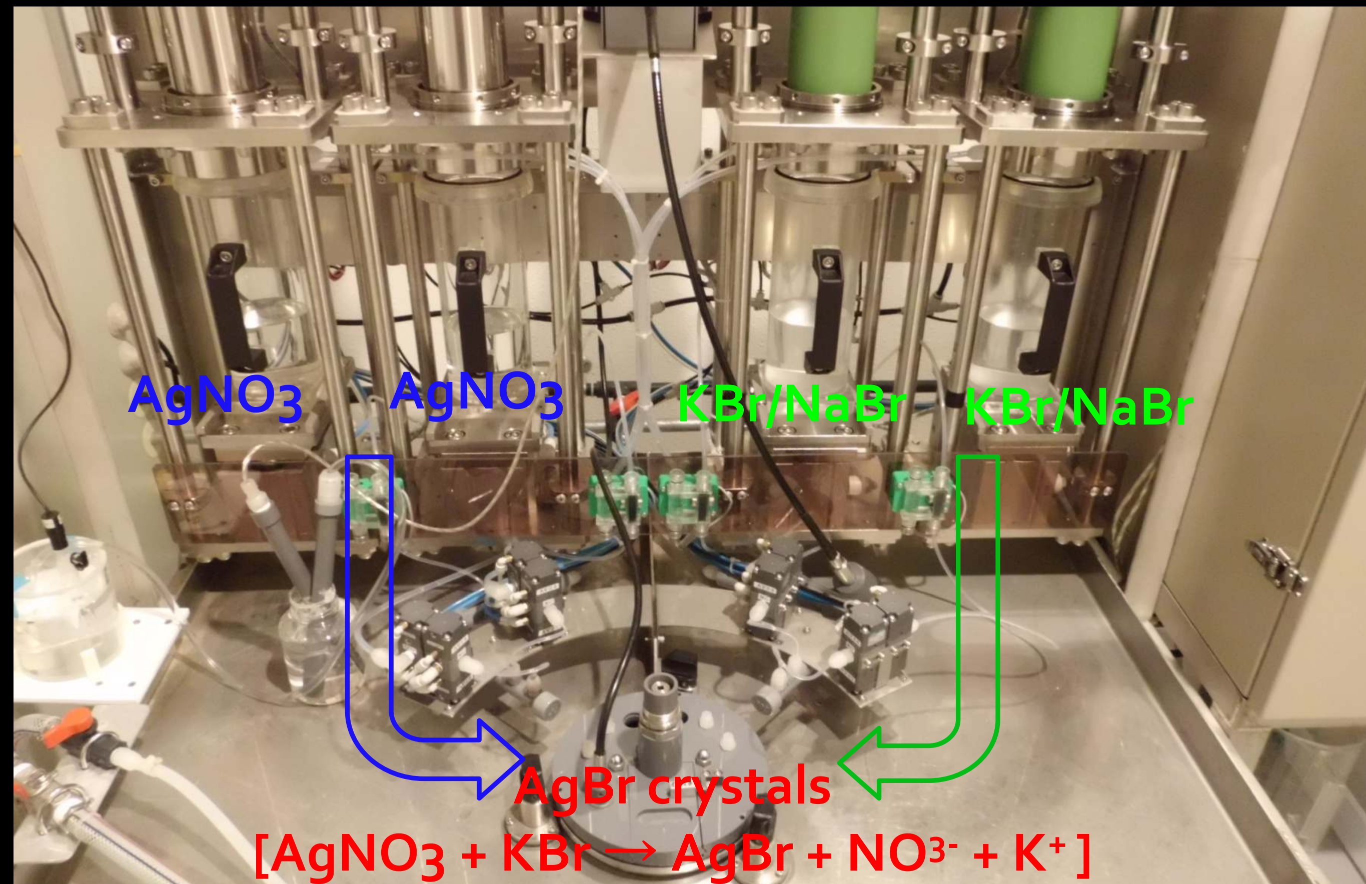
Slope distribution







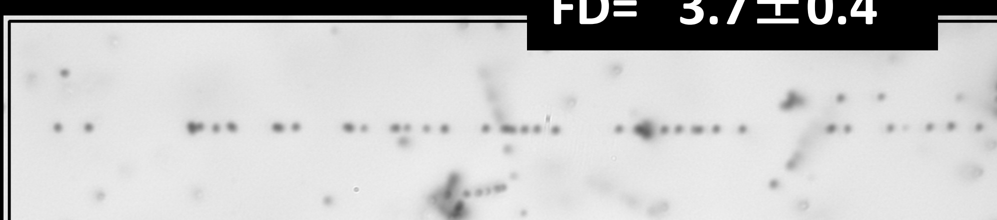
Emulsion Self-Production



Production scale ~ 1 kg detector/week

OPERA type

GD=34.8±0.6
FD= 3.7±0.4

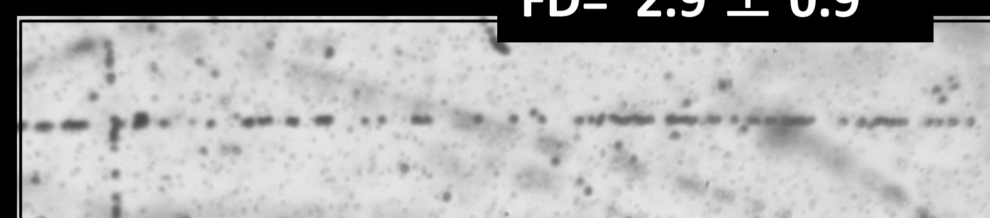


100μm

→

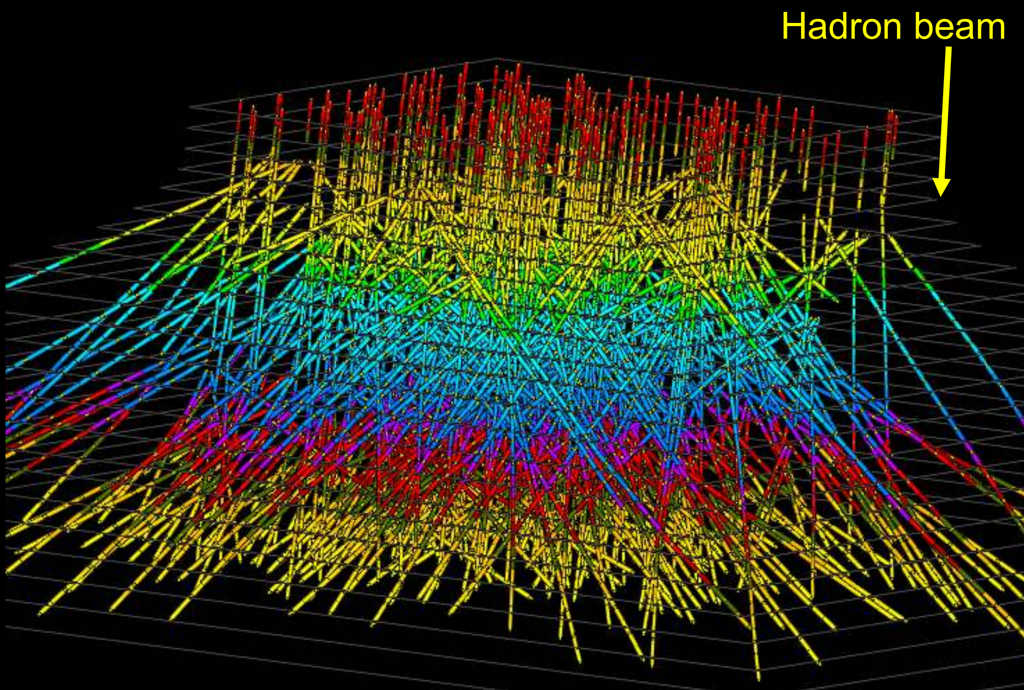
New type

GD= 86.1± 4.7
FD= 2.9 ± 0.9

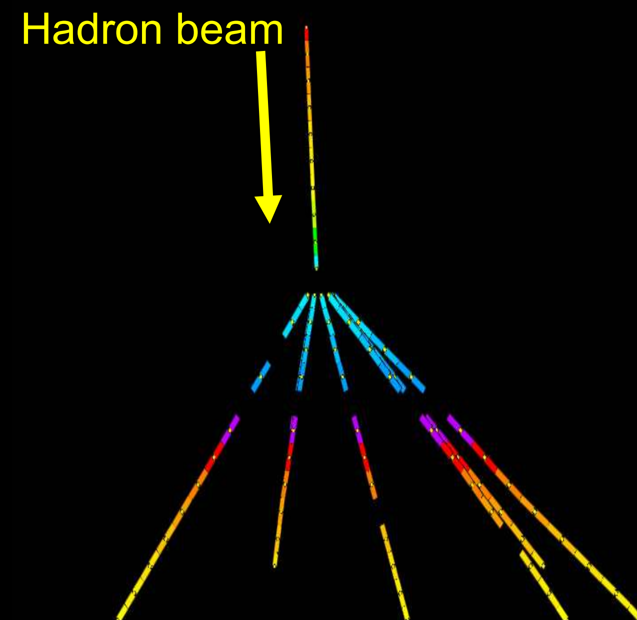


100μm

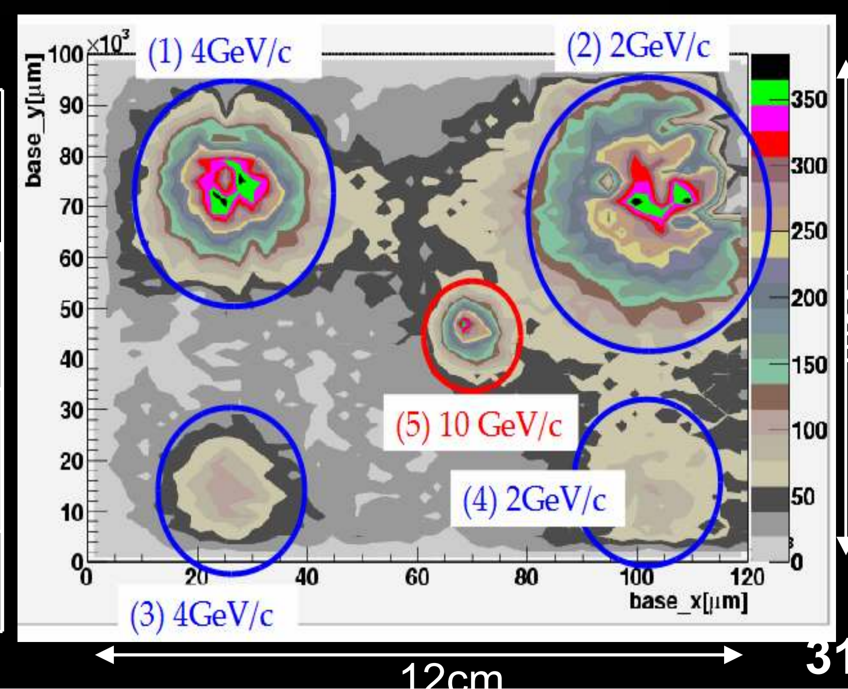
Hadron interaction study



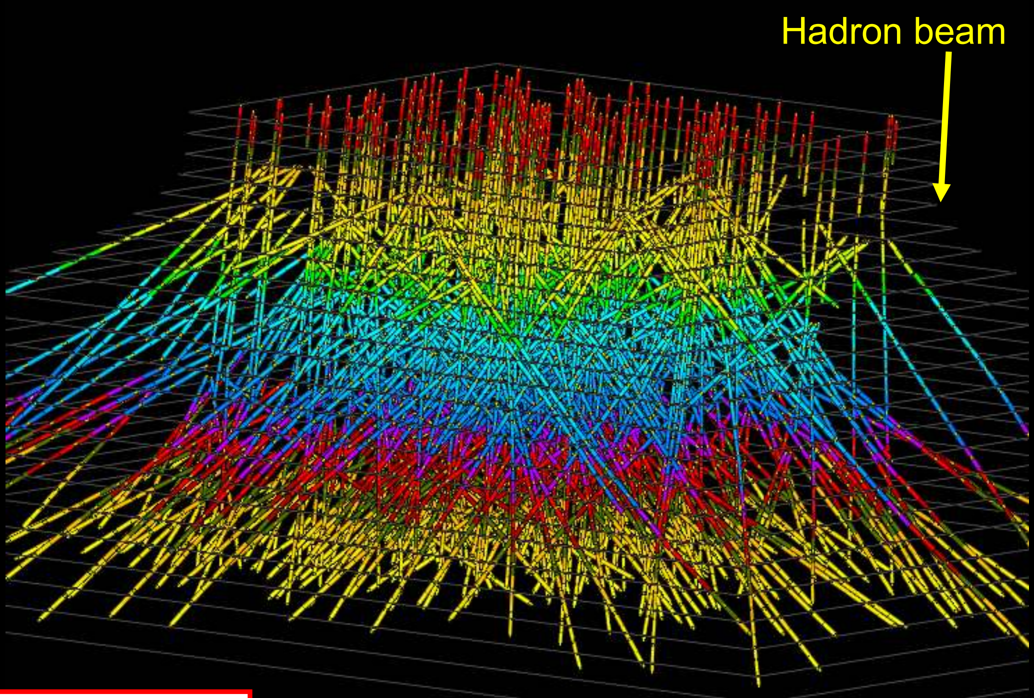
Event by event analysis



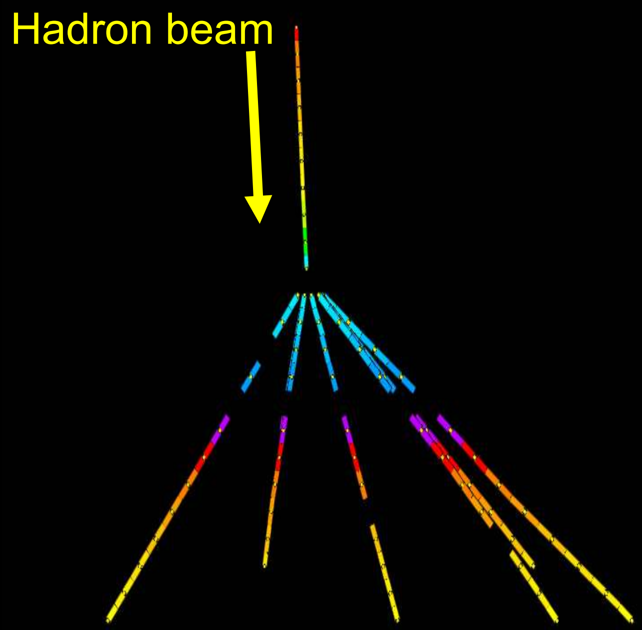
	10GeV	4GeV	2GeV
Reconstructed tracks	2215 tracks	907 tracks	584 tracks
Total track length	38.5 m	12.6 m	8.5 m
Interactions	173 events	68 events	77 events



Hadron interaction study

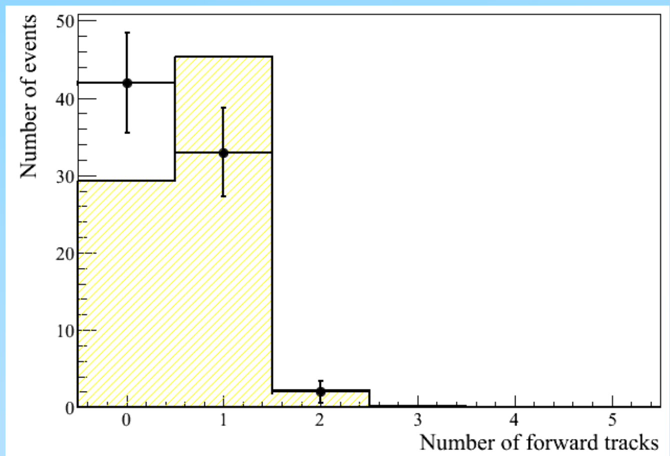


Event by event analysis

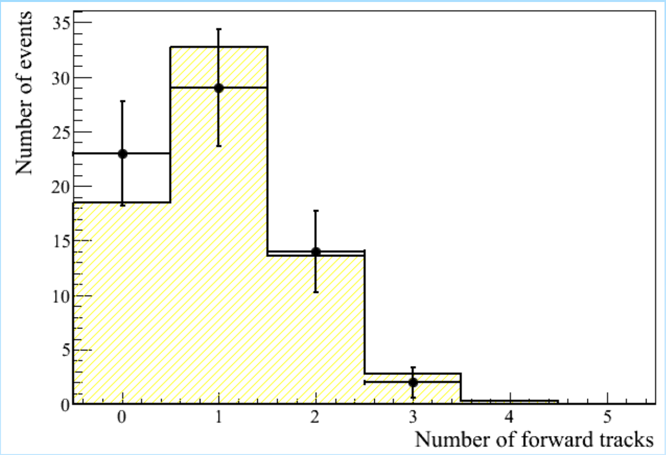


Multiplicity

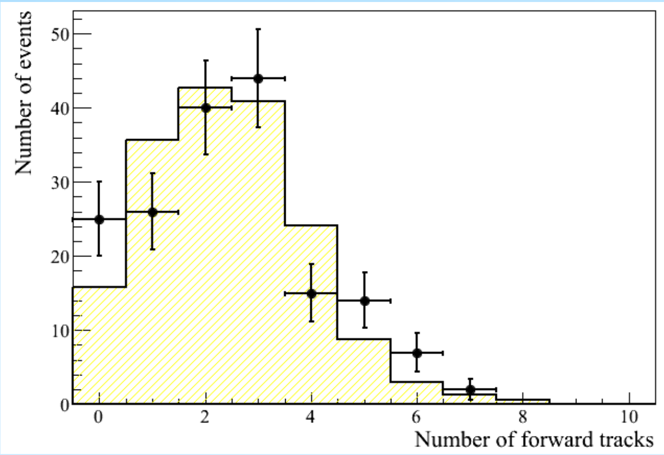
2GeV/c



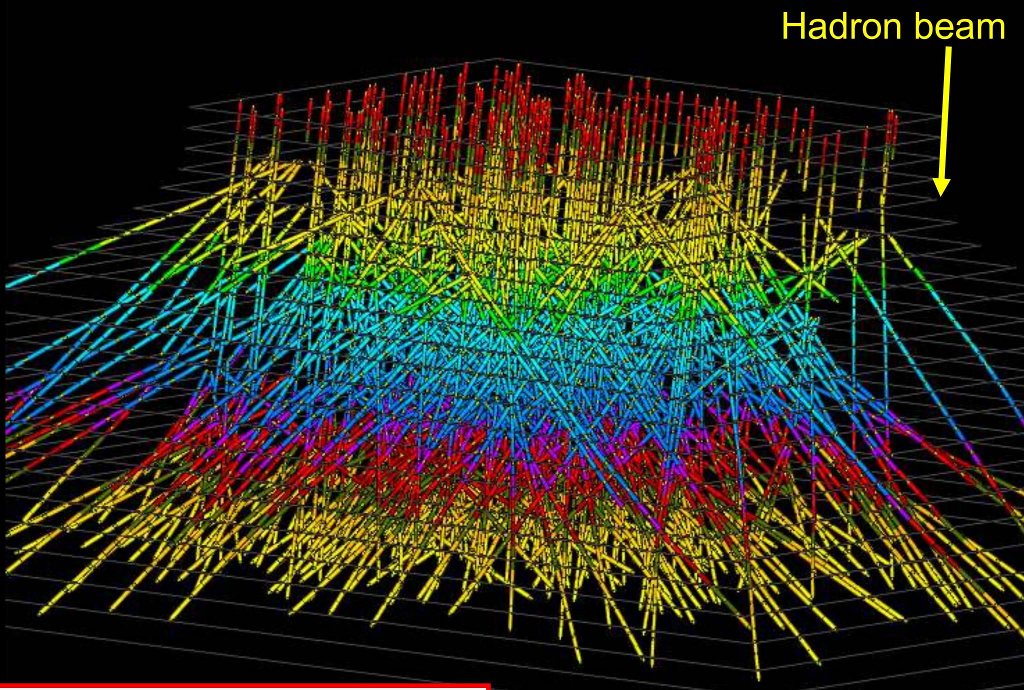
4GeV/c



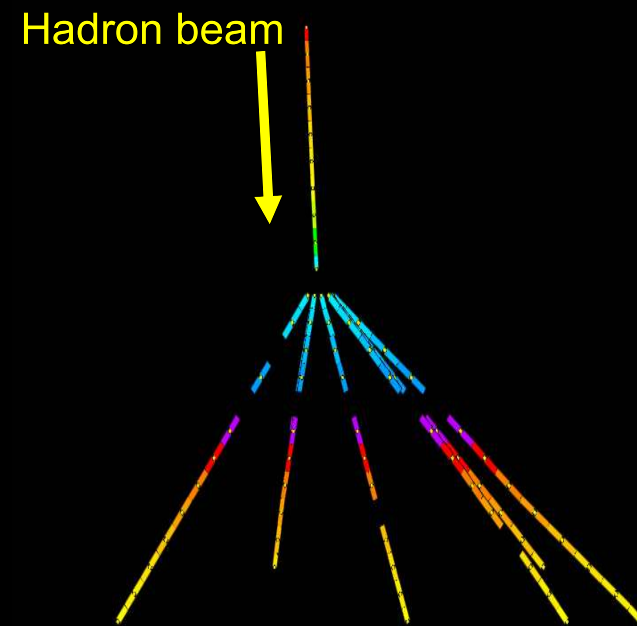
10GeV/c



Hadron interaction study

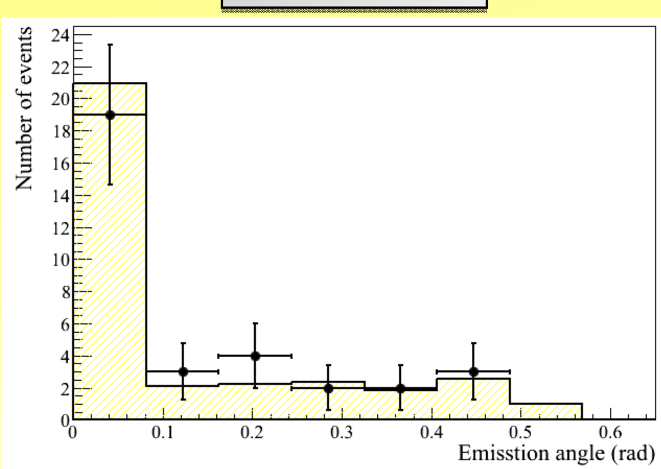


Event by event analysis

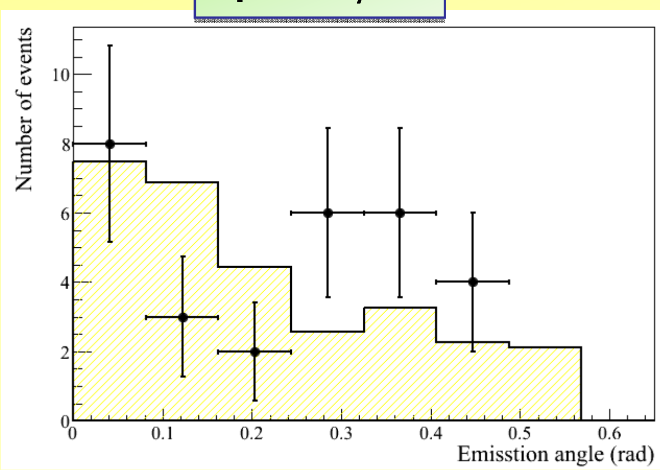


Kink angle (1-prong)

2GeV/c



4GeV/c



10GeV/c