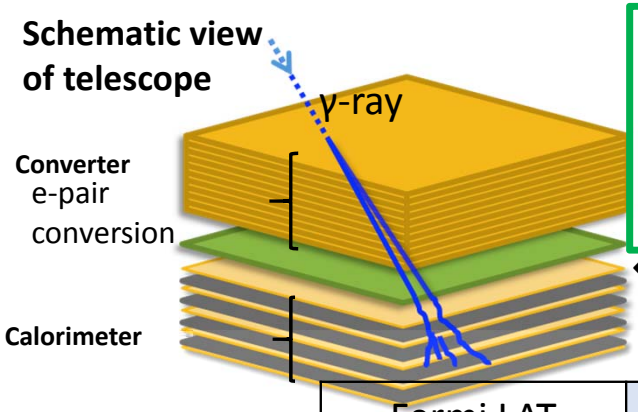
Analyses of high Pulse Height Volume tracks for identifying cosmic ray nuclei with GRAINE2015 experiments

GRAINE(Gamma-Ray Astro-Imager with Nuclear Emulsion) project

Atsushi Iyono, Saya Yamamoto, Takashi Shimizu (Okayama Univ. of Science),
Shigeki Aoki(Kobe Univ.),
Hiroki Rokujo, Toshiyuki Nakako, Kunihiro Morishima, Mitsuhiro Nakamura

(Nagoya Univ.)
and Koichi Kodama (Aichi Univ. of Education)
for the GRAINE experiments

GRAINE project : PI: Shigeki Aoki (Kobe University)

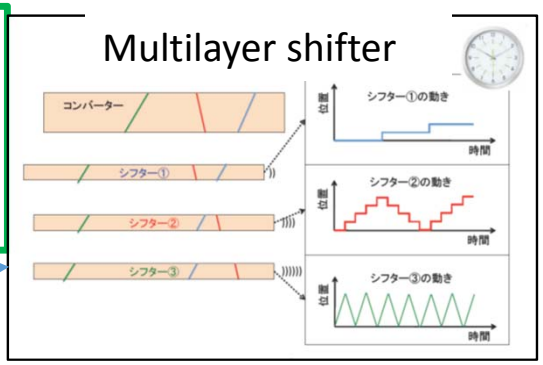


High spatial resolution with Nuclear Emulsion plates

High angular resolution and polarization-sensitive

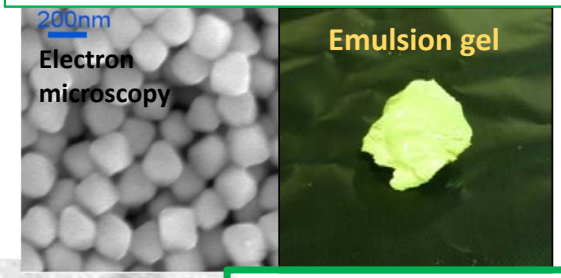
←Multilayer emulsion shifter
Time Stamp for tracks

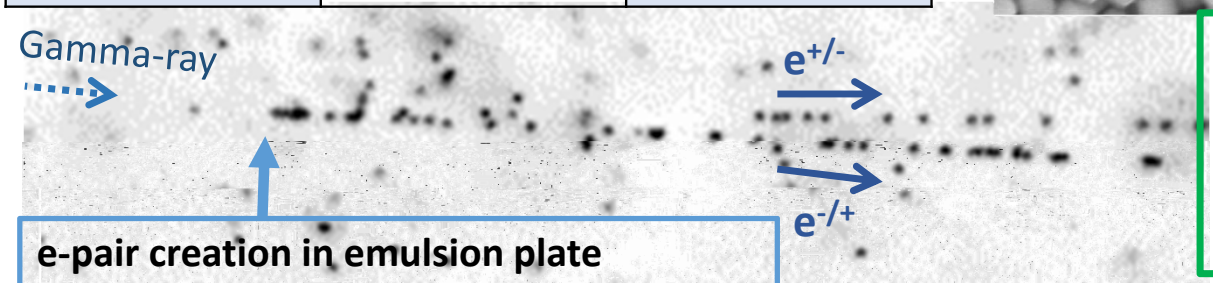
Achieved Balloon flight at Taiki site (JAXA) in 2011



	Fermi LAT	**GRAINE**
Angular resolution @100MeV	6.0deg (105mrad)	**1.0deg (17mrad)**
Energy range	20MeV～300GeV	10MeV～100GeV
polarization	none	**yes**
Dead time	26.5μsec	**free**

Nuclear emulsion production at Nagoya univ.(collaboration with Fuji Film Co., LTD)



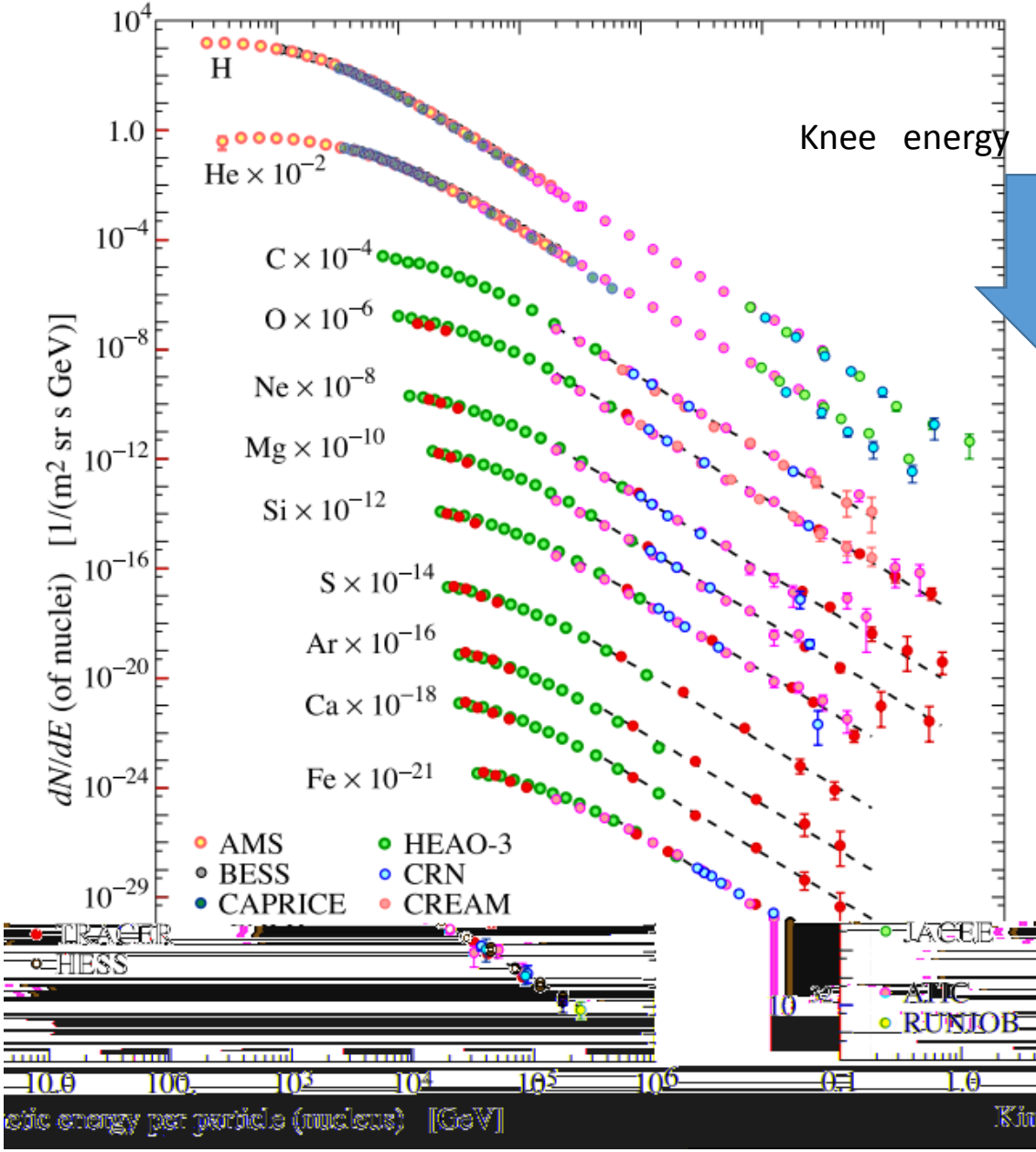


e-pair creation in emulsion plate

Emulsion Technology : Emulsionics
- **Grain density control**
- **Sensitivity control**
- **Refresh technology(fog control)**
- **Chemical processing control**
- **Glycerin Swelling Processing**

Cosmic Ray Nuclei spectra and composition measurements

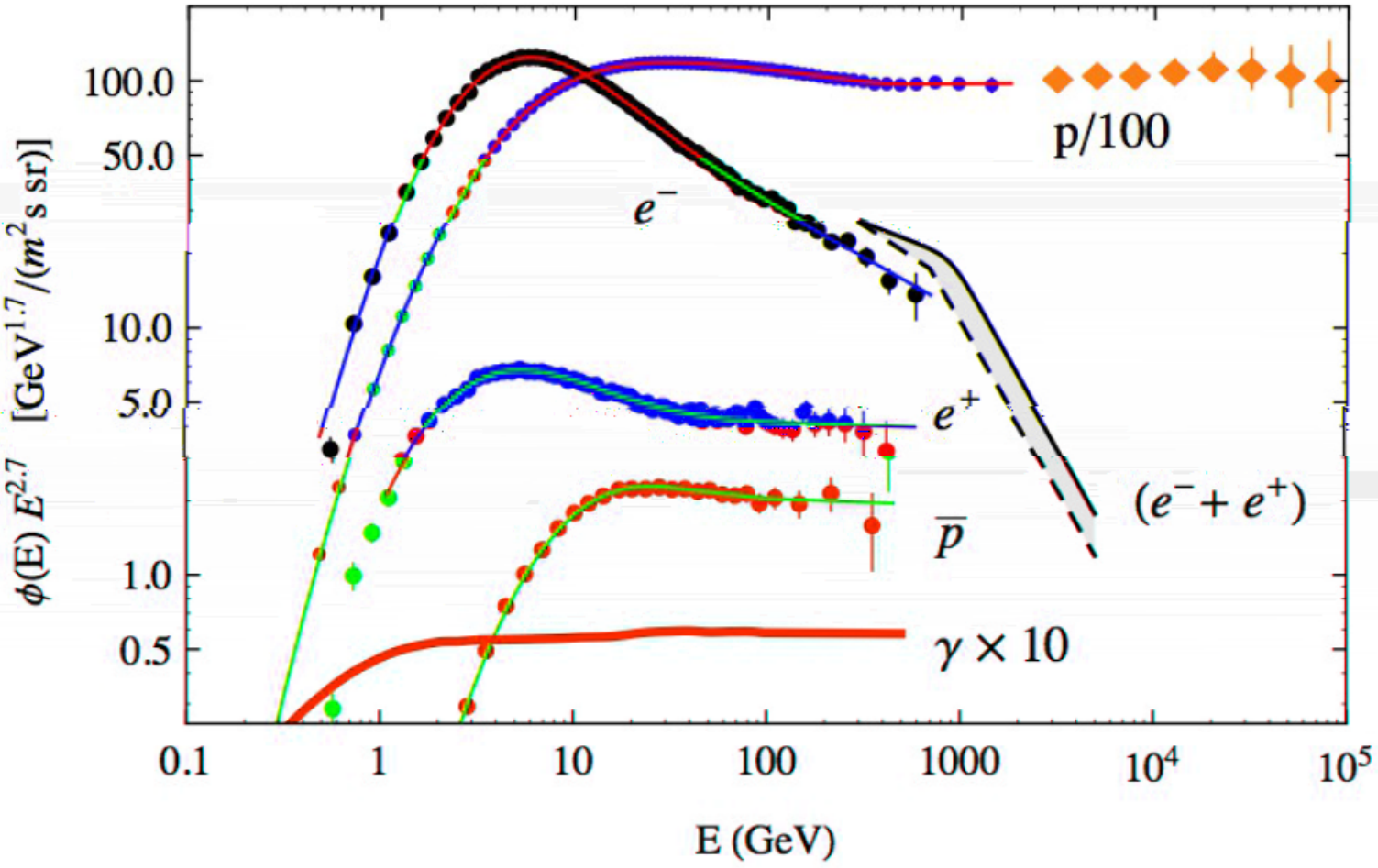
- Direct measurements do not reach to the knee $5x10^{15}$eV so far.
- JACEE/RUNJOB utilized ECC type detectors to measure primary energies in calorimeters because interaction length and absorption length were needed.
- In GRAINE project, thin emulsion chamber are used for precise tracking.
  ->Direct e-pair production can be used to determine cosmic ray nuclei's gamma factor without hadronic interactions.
- EMULSIONICS and GRAINE allow to carry out e-pair tracking(<100MeV) within 30 degree opening angles among noises.
- Direct measurement of cosmic ray nuclei in the GeV energies is the one of the next aim in GRAINE projects to study cosmic ray origin, acceleration and propagation.



AMS02 p e^- e^+ $\overline{p}$

CREAM p data

ICRC2017 Prof. Lipari



ICRC2017

- AMS/PAMELA reported spectral breaks at several hundred GV for cosmic ray nuclei components as well as hydrogen.
  ->rigidity dependence
  ->change of magnetic field in our vicinity

- Prof. Lipari suggests hydrogen/positron/anti-proton and gamma ray have same hard spectral index, on the other hand electron's one is very soft.

-> extended measurements of B/C ratio are required.

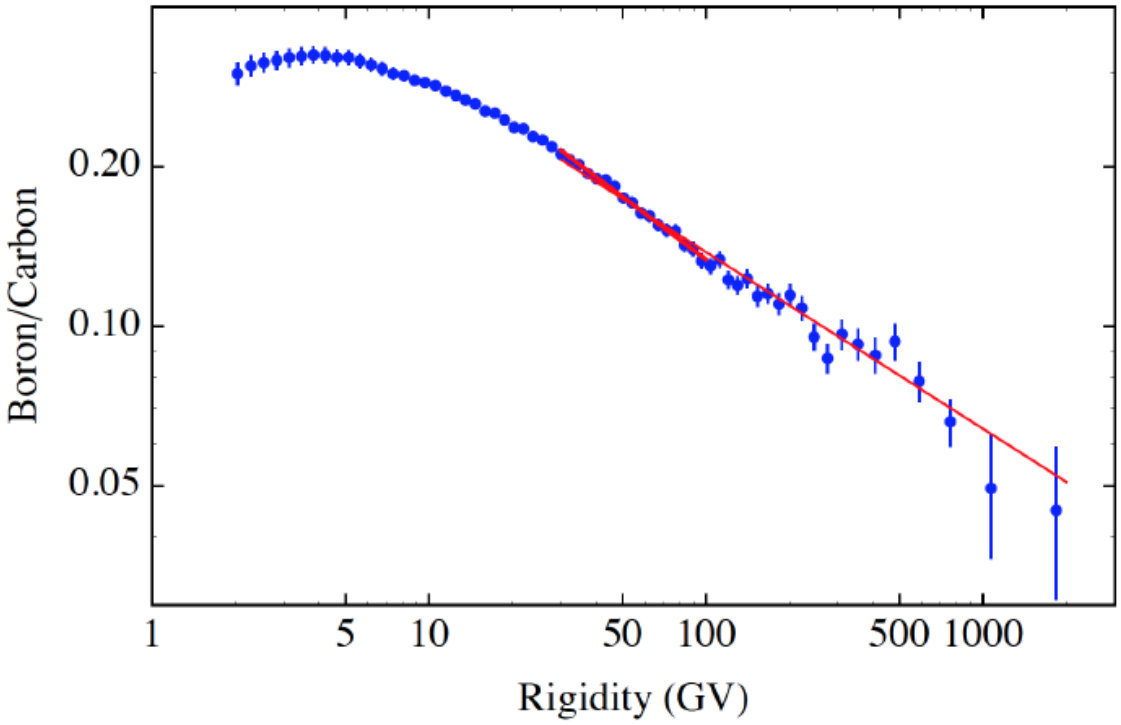
angle averaged diffuse Galactic gamma ray flux (Fermi)

What about secondary/primary nuclei ?

ICRC2017 Prof. Lipari

[normally the "cornerstone" of most propagation models]

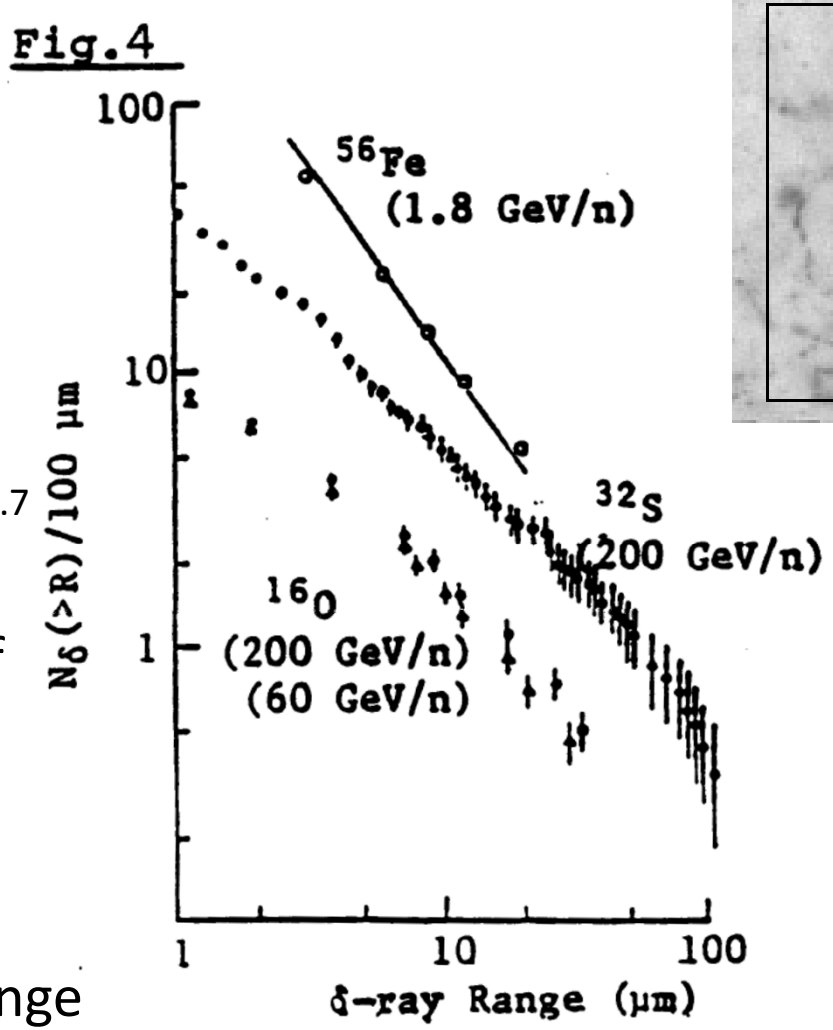
$$\frac{\text{Boron}}{\text{Carbon}} \approx 0.21 \left(\frac{p/Z}{30\ \text{GV}}\right)^{-0.33}$$



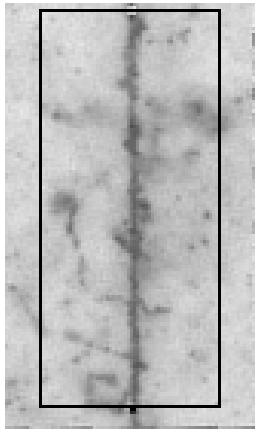
AMS02 data

Identifying CRN with δ-ray range spectrum

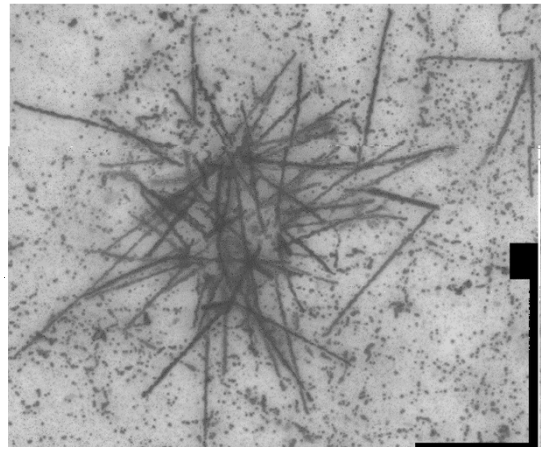
- Empirical formula
  $N_\delta = 2.7z^2/\beta^2\ (1/E_1 - 1/E_2)/100\mu$
  Range-Energy relation : $E \sim R^{0.7}$
- Transversal range spectrum of delta rays
  →Y.Takahashi et al.,1989
  (NASA-CR-184958)
- HTS image can provide this range spectrum?



- Oxygen(200GeV/AMU Z=8)
  index 0.85 +- 0.05
- Sulfur(60,200GeV/AMU Z=16)
  Index 0.97 +- 0.02

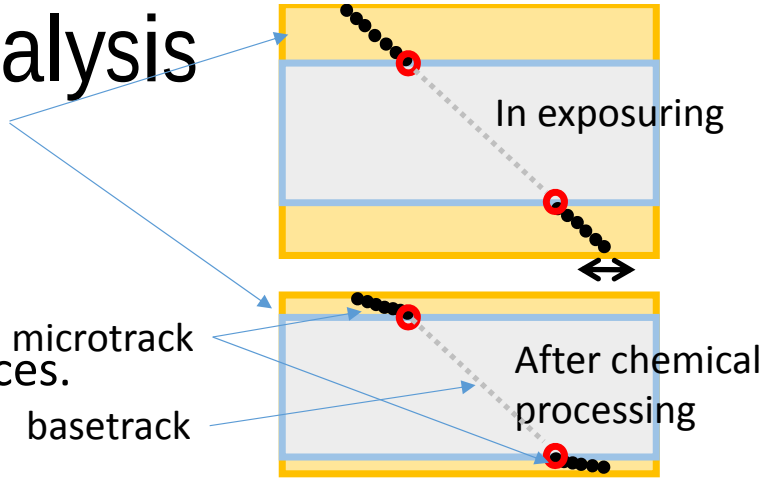


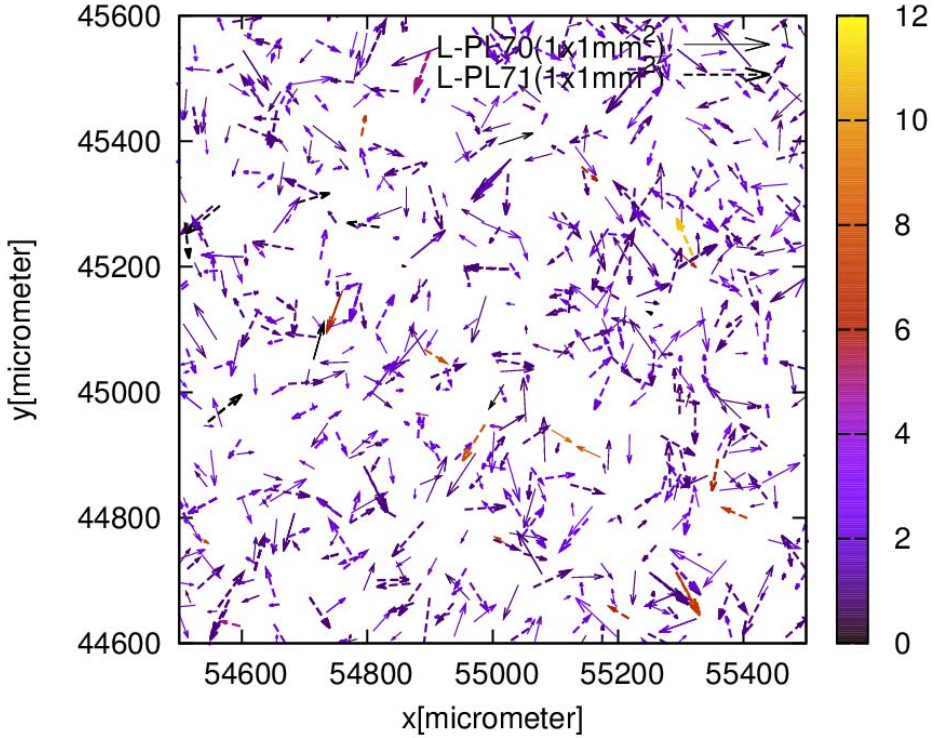
Black tracks(Helium nuclei) came from alpha decays in radiation sources
(THIS IS NOT GRAINE EMULSION)

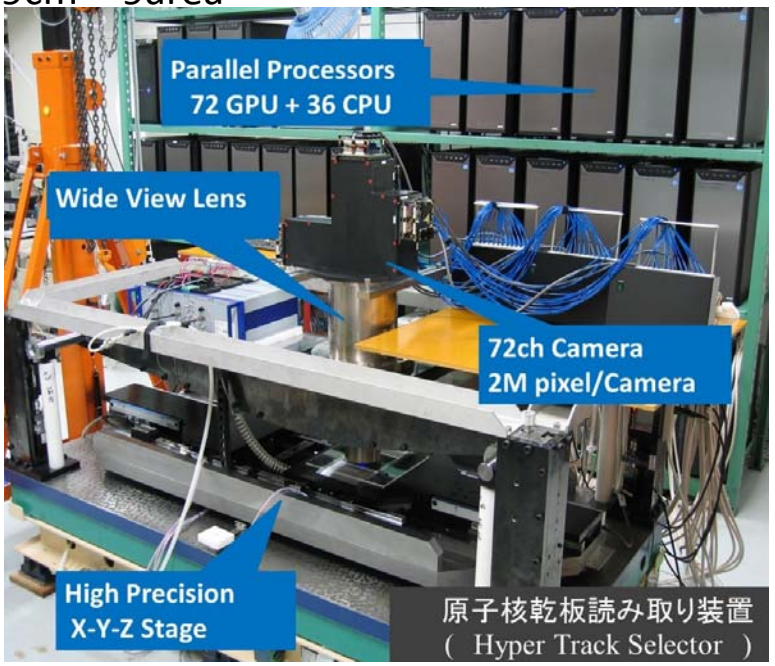


Nuclear Emulsion Track Analysis

- Emulsion layer thickness control
  - Shrinkage ⇒x 0.83
  - Glycerin Swelling Processing ⇒x1.2
  - Distortion correction ⇒software
- Defining Base Track between base plate surfaces.
- HTS(hyper track selector)
  - Digitizing track(<60deg.) in 1.5hour/12cm × 9cm × 9area

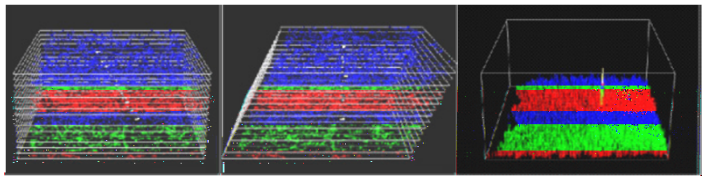






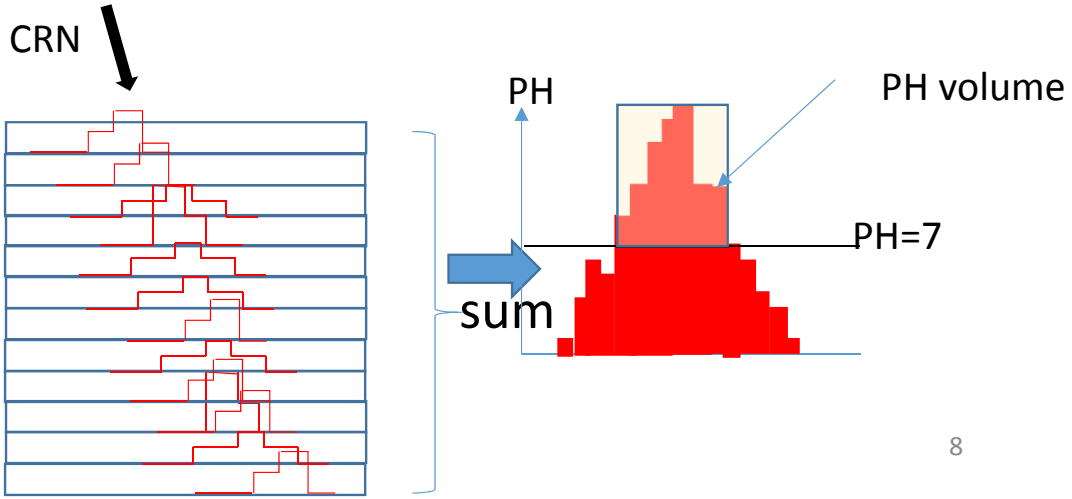
Track recognition in HTS

- HTS(Hyper Track Selector)
  - Track recognition algorithm
    16 layer tomographic images
    →2dimensional shifting images and summing up
    →peak search (pulse height)
  - Pulse Height Volume :
    summing up 16 tomographic images above the threshold PH value.
  - All these algorithm were established in 1974 at Nagoya university by K. Niwa et al. and applied to particle physics such as CHORUS, OPERA experiments to analyze neutrino interactions. MIP track and nearly vertical track detections were focused on in these experiments
- Track efficiency is achieved over 98%
  ⇒tanθ～2 (θ<60degree)
  ⇒Angular allowance becomes wider.



K.Niwa1974

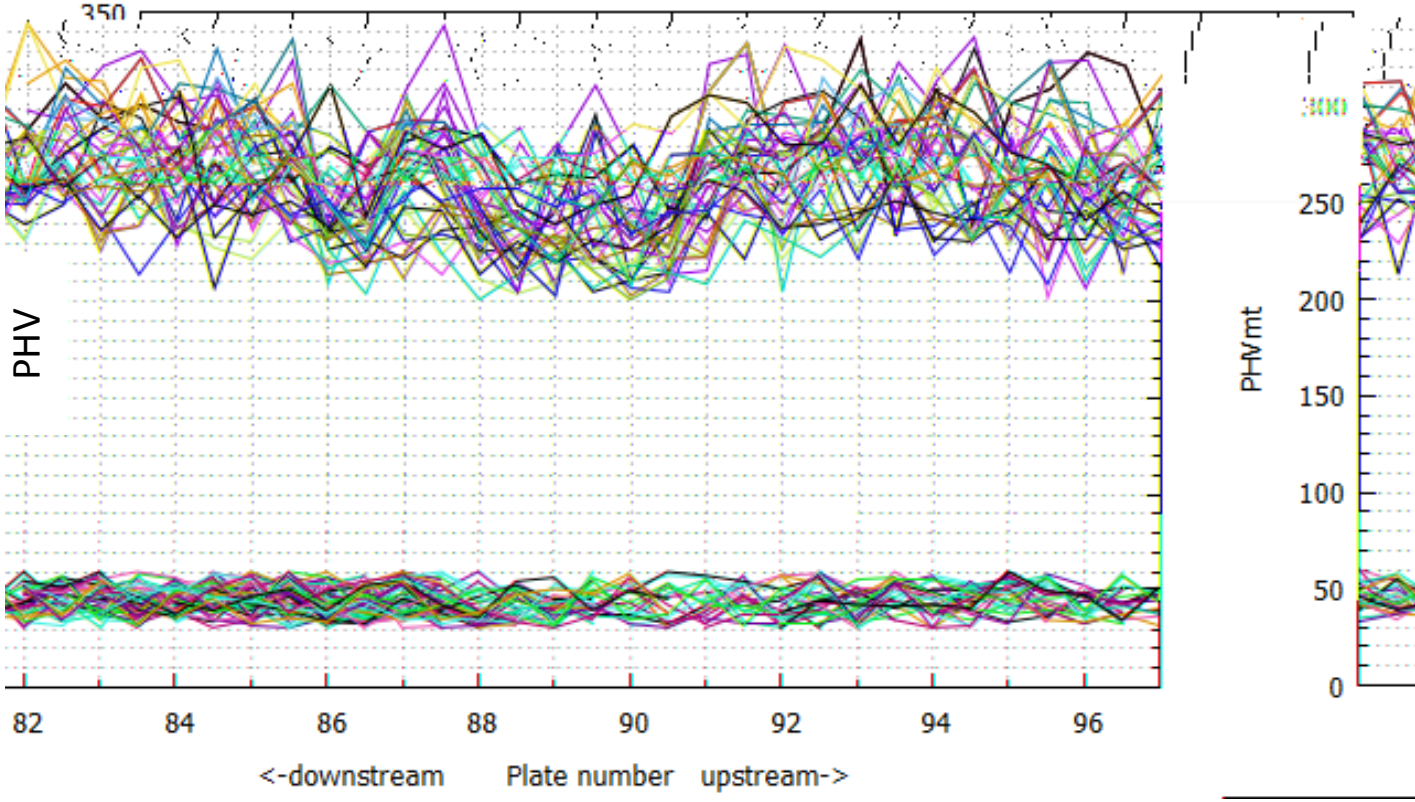
- HTS scanning speed
  - 4500～9000cm^2/h
- Track information from HTS
  - Position : 0.5μm resolution
  - Zenith and azimuthal angles : mrad accuracies
  - Pulse Height(PH) : up to 16 for identifying tacks
  - **Pulse Height Volume(PHV)→ionization**
    (MIP, BACK/GRAY, CR Nuclei・・・)



Stabilities of PHV in emulsion plate scanning

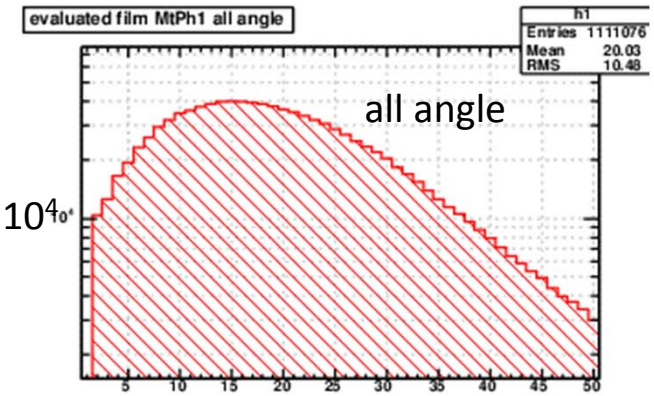
- condition:
  - 50 samples in connected tracks at PL 81-97
  - GROUP1 :
    - PHV>200
    - tanθ>1
  - GROUP2 :
    - 30≦＜PHV＞≦60
    - 0.2<tanθ<0.21

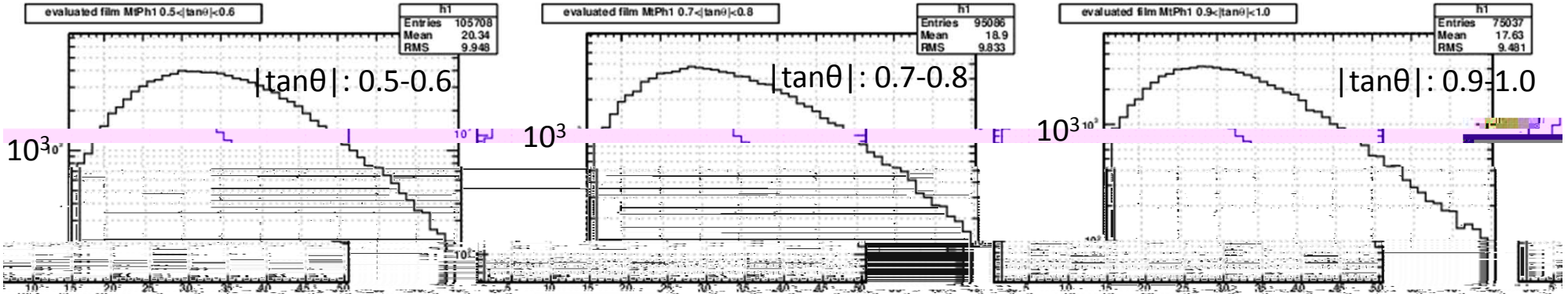
- PHV stability.
  - σ～30@PHV>200
  - σ～15@PHV～45

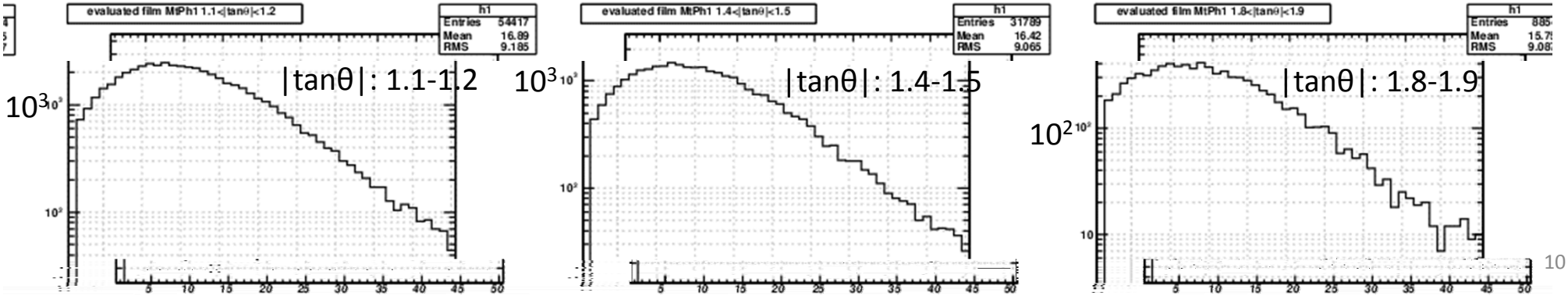


Pulse Height Volume(PHV/microtrack) distribution for single charged tracks

- PHV of single charged particles have been understood well.
- We successfully performed gamma ray analysis using electron pairs(MIP) .

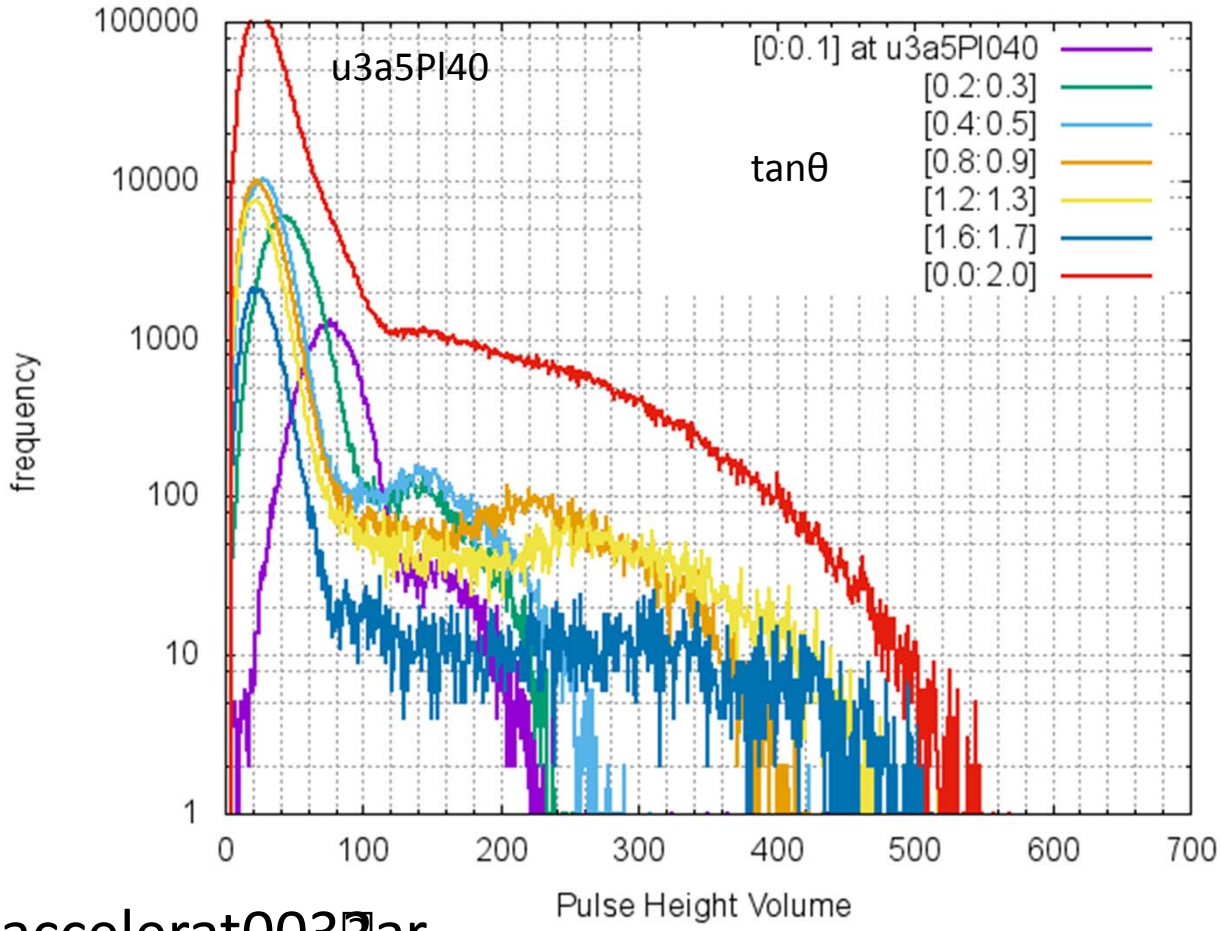






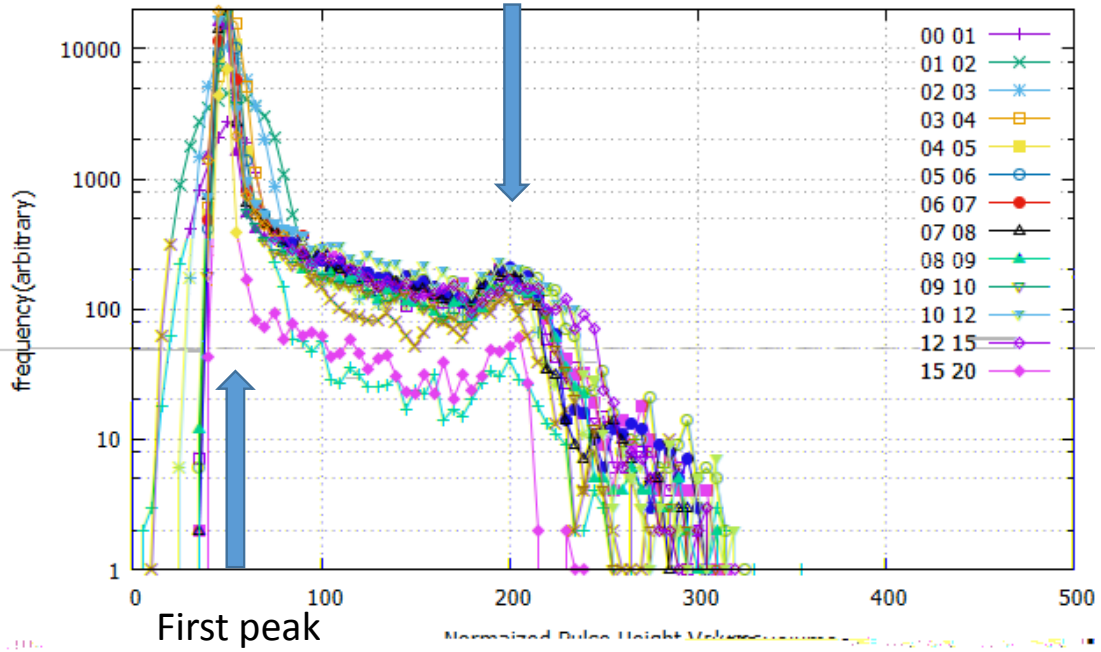
Pulse Height Volume distributions

- PHV for base track
  - PHV<100
    ⇒single charged particles/MIP
    (electrons/protons/muons)
  - **PHV>100**
    ⇒Very high ionization tracks exist in GRAINE2015 emulsions.

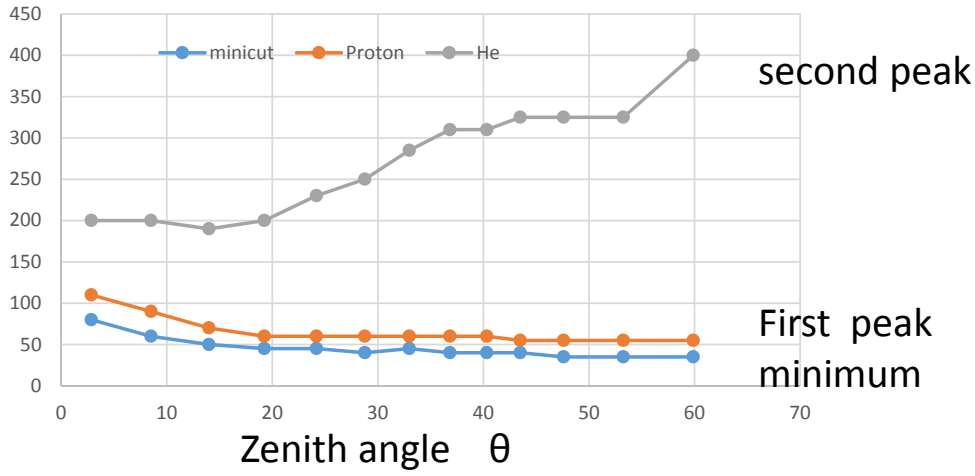


- High PHV track have never been in accelerat0032ar

Second peak



First peak

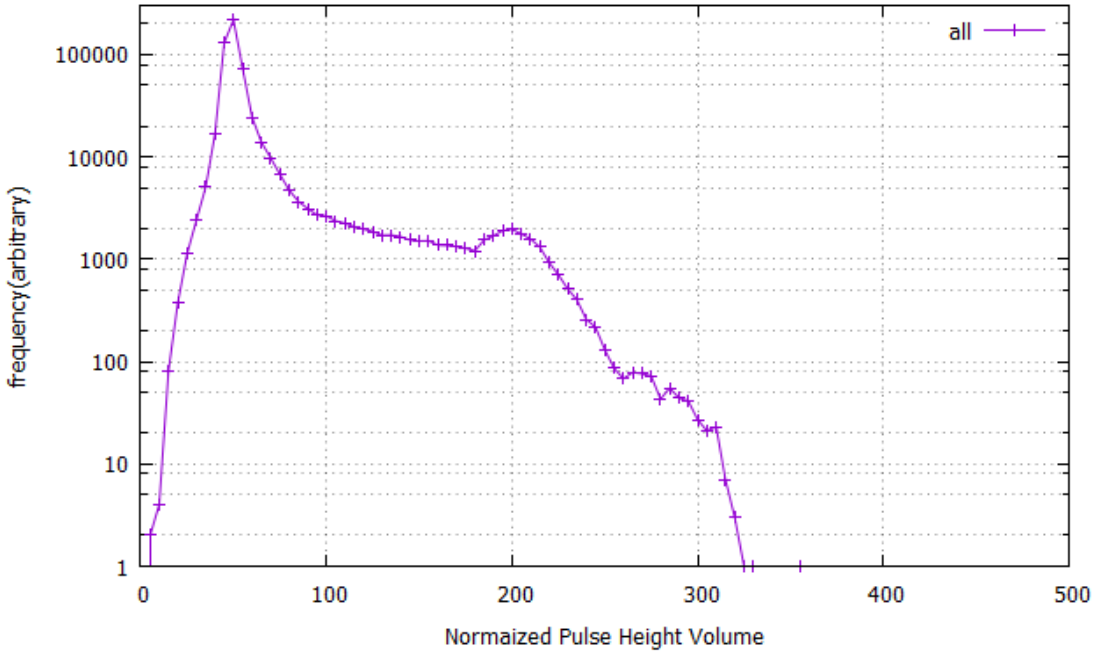


second peak

First peak minimum

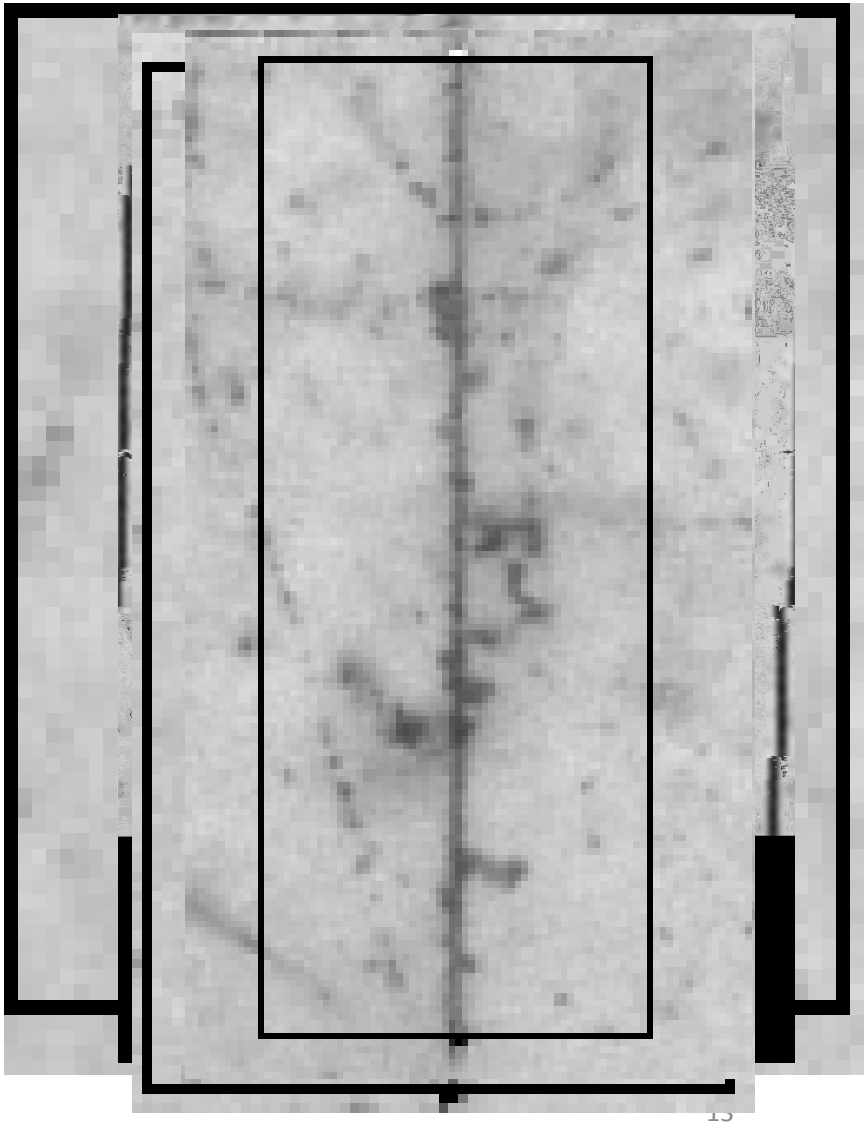
Zenith angle θ

Normalization of zenith angle dependent PHV distribution.



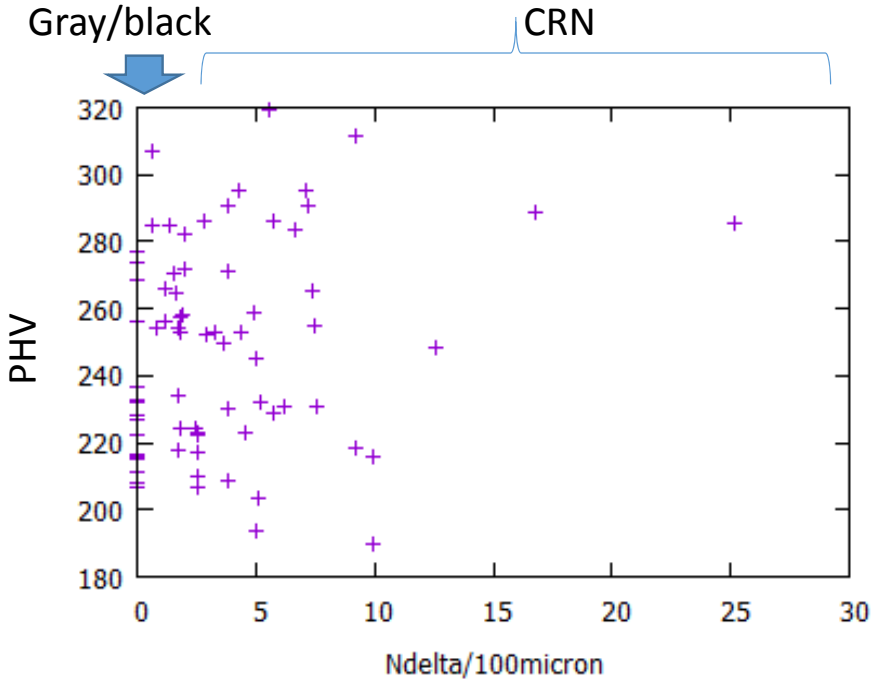
Test analysis: selection :PHV and Zenith angle

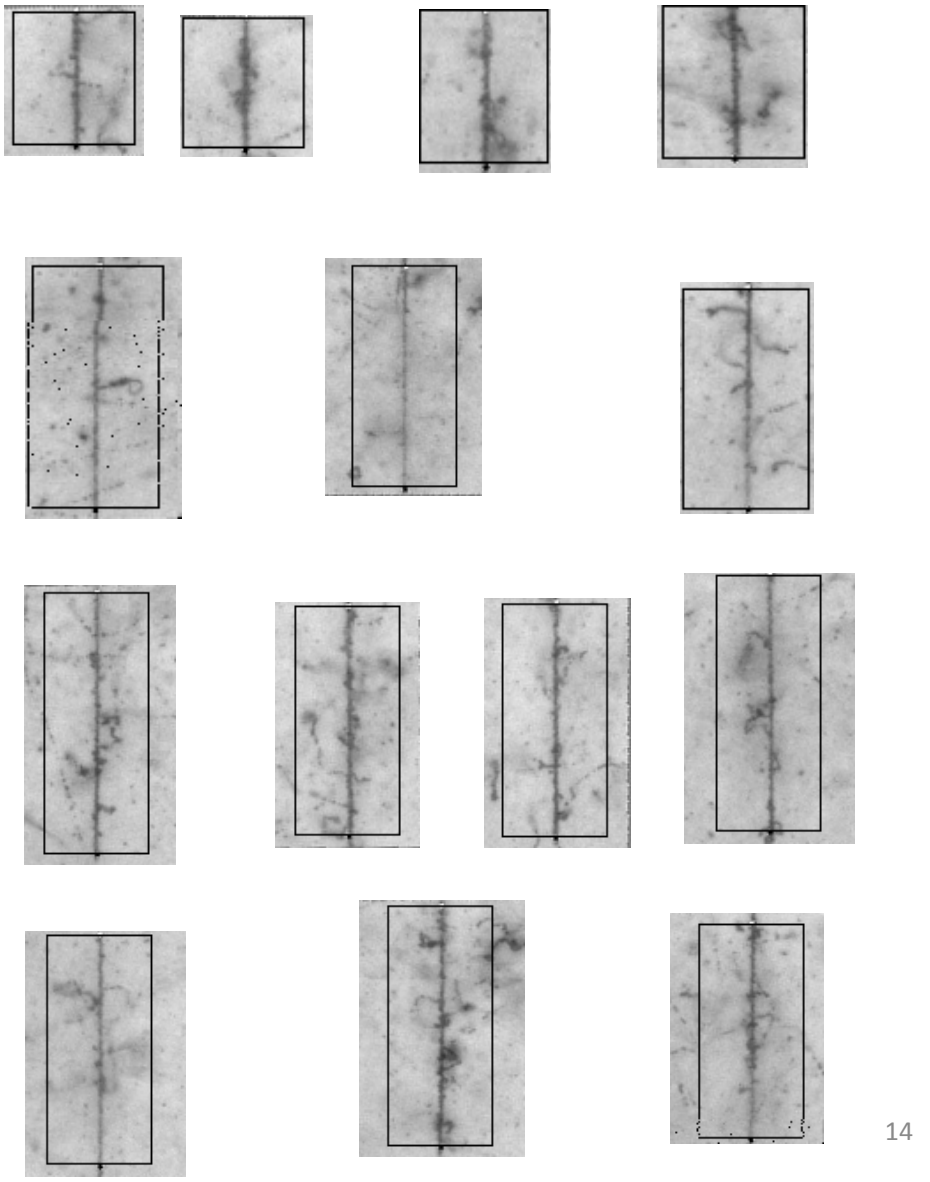
- Criteria
  - height PHV(>100)～$5x10^3/4x10^6$ /13x9cm^2~0.1%
  - PHV>150, Tanθ<0.6⇒PHV highest events(50)
  - PHV>200, Tanθ>1.0⇒PHV highest events(50)
- HTS manual operation mode provides
  - Tomographic 32 raw images both sides.
- Image analysis
  - From 32 images->3D animation
  - Before going into image analysis, traditional δ counting（~200μm emulsion thickness) were performed.



Highest PHV images

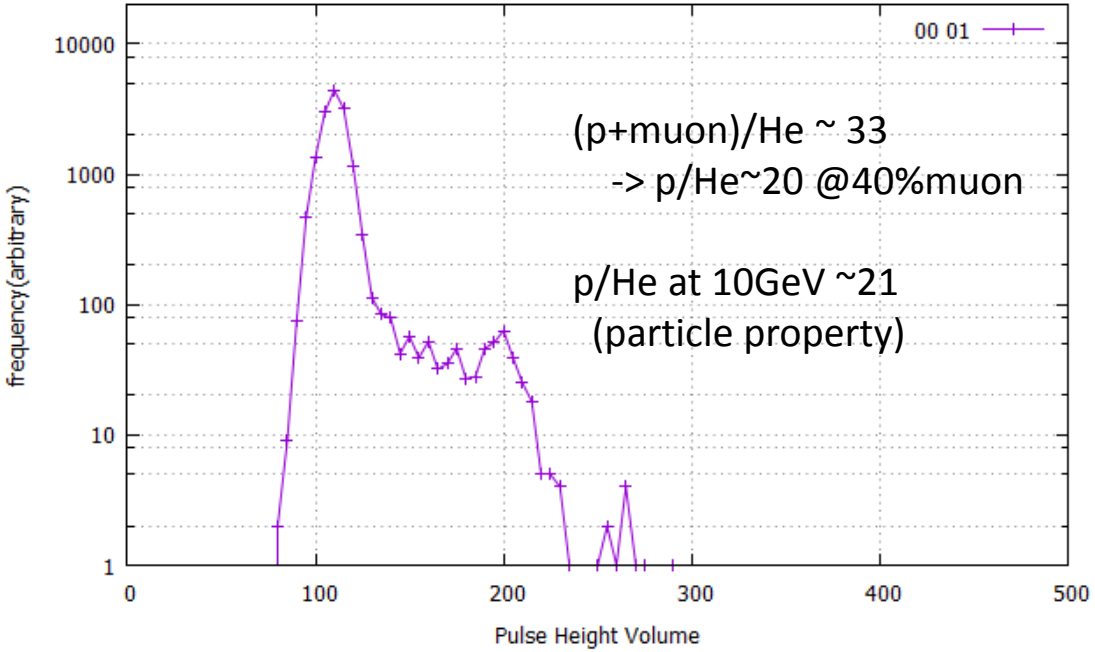
- Most of Tracks have delta-rays along the trajectory.->63/100 →cosmic ray nuclei components
- 25 tracks were gray/black tracks.
- Less than 10 tracks of high PHVs came from back ground noise.

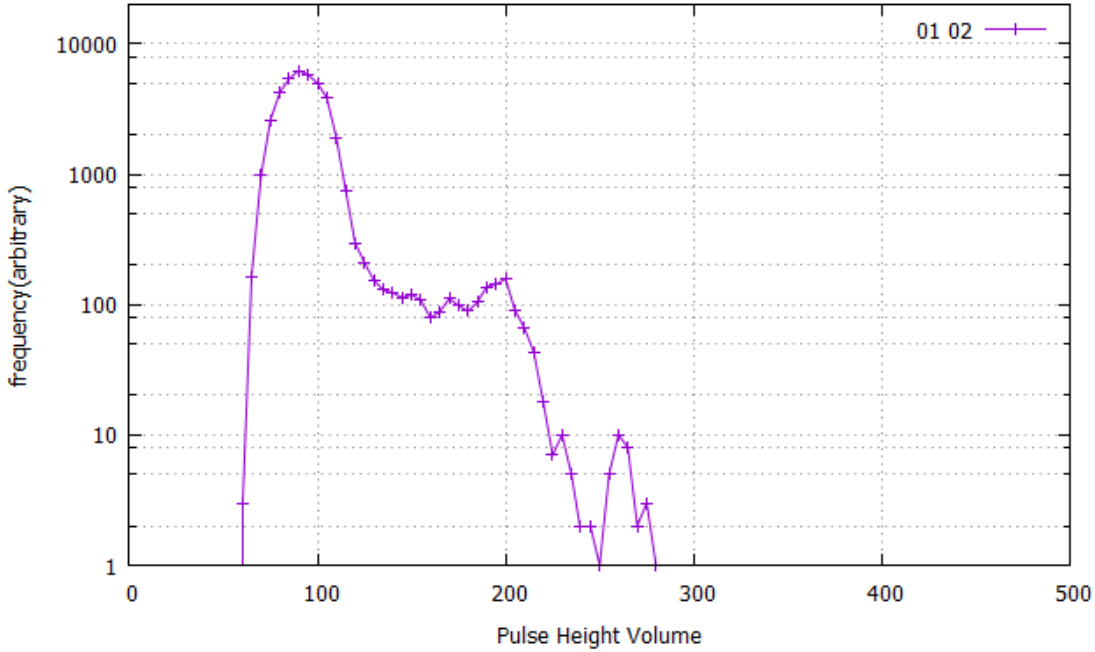




Another trial to understand PHV distribution

- We use penetrating tracks at the bottom plate on emulsion converter chamber. 4M tracks at the top ->0.6M tracks at the bottom which is consistent with track efficiency(0.98)(4M tracks x 098^100=0.5M.)
- Single tracks contain muon tracks(~40%) at ground level
- p/He ration at 10GeV ~ 540/26~ 21 times, but in this analysis by fitting 2 Gaussian

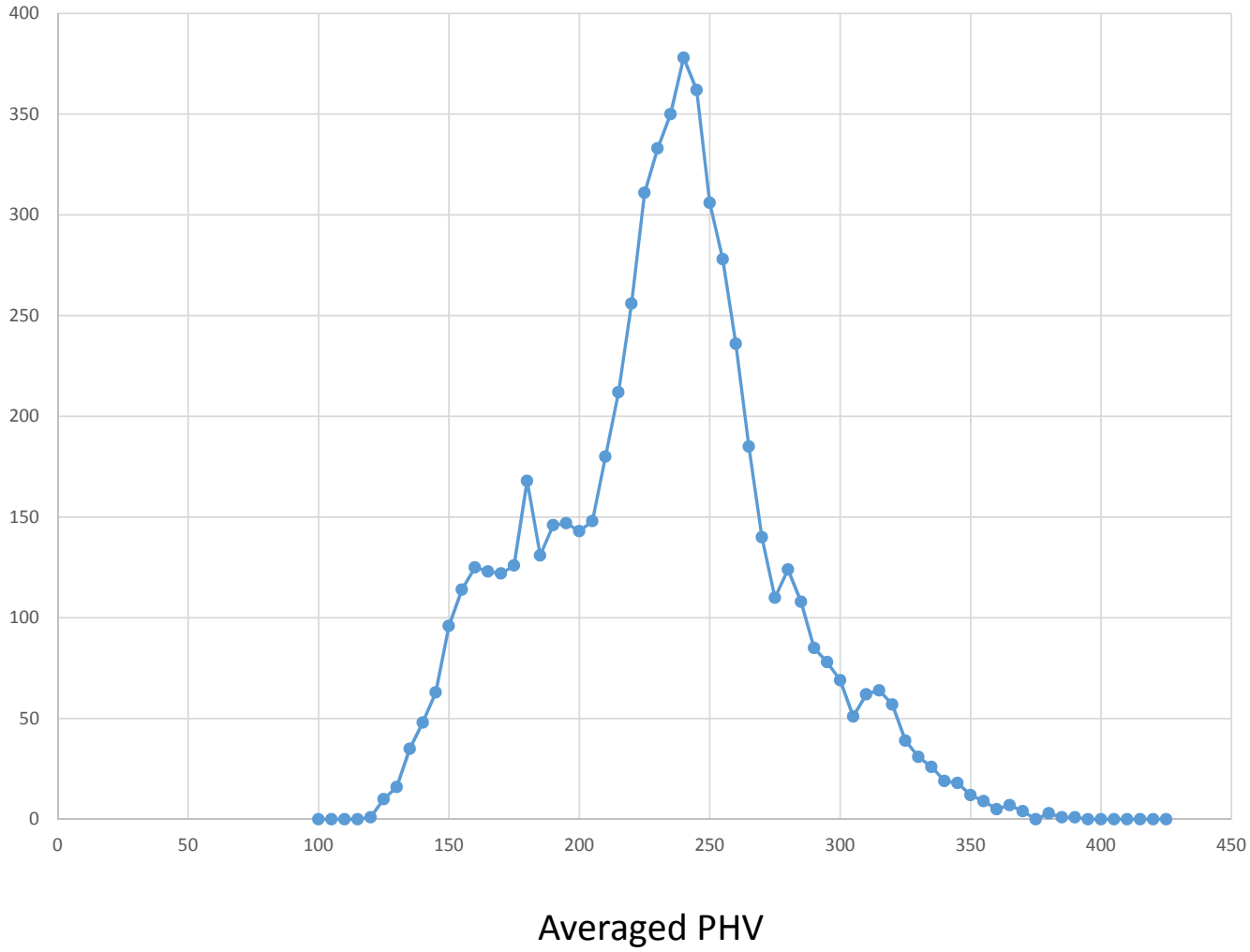




PHV distribution recorded in 11 plates

- Zenith angle θ
  $0.4<\tan\theta<0.5$
- PHV/basetrack > 100
- Averaged PHV

- Some strange peak around PHV ~ 180 exists. At this moment, we understood that this came from track ghosts.



Summary

- The GRAINE project has carried out the 14 hours balloon flight at Alice Spring Australia in May 2015. All emulsion plates have been digitized by using HTS system at Nagoya university, and astrophysical gamma ray search is still going on.

- Pulse Height Volume (PHV) obtained by HTS allows us to detect cosmic ray nuclei among single charged tracks(MIP/gray/black track) comparing to the delta-ray count results.

- In the general scan analysis, proton/Helium ratio obtained by PHV distribution of penetrating tracks is around 20, assuming grand level muon accumulations as 40% of total single charged tracks. This is consistent with p/He~21 @10GeV.

- Continuations:
  - HTS scanning parameter set should be optimized to detect cosmic ray nuclei.
  - Heavy ion beam test should be needed to find conversion function from PHV to Z/beta.