GRAINE2023実験の原子核乾板画像を用いた機械学習による宇宙線原子核の同定

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31st ICEPP symposium, Shiga Lake Hotel, Feb. 16th to 19th 2025

Chemical Composition of the Universe

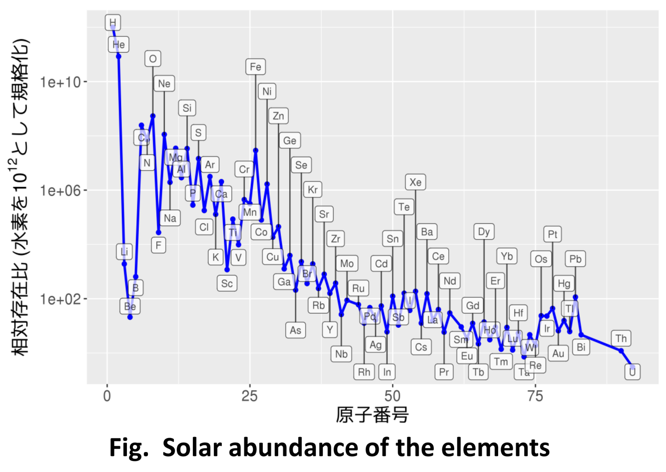


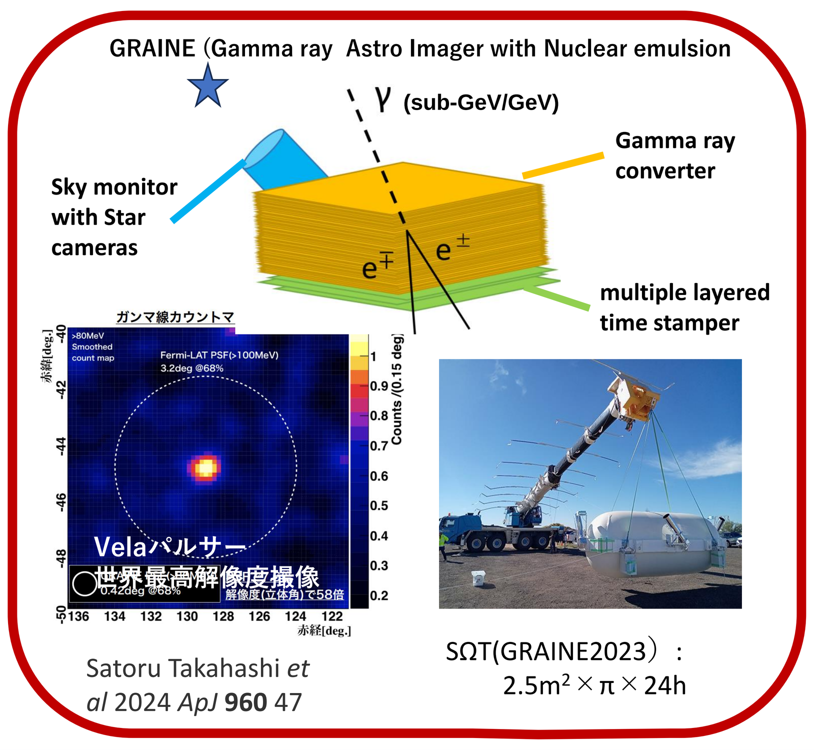
Fig. Solar abundance of the elements
引用：http://akari.c.u-tokyo.ac.jp/~doi/Astronomy/intro.html#/5/3

Big Bang Nucleosynthesis
⇒Hydrogen and Helium nuclei
Stellar Nucleosynthesis
⇒Helium to Iron nuclei
Cosmic rays
⇒ Li, Be, B due to fragmentation process
"Origin of Heavier element than Iron group "

Supernova of massive stars?
Binary Neutron Star Mergers?

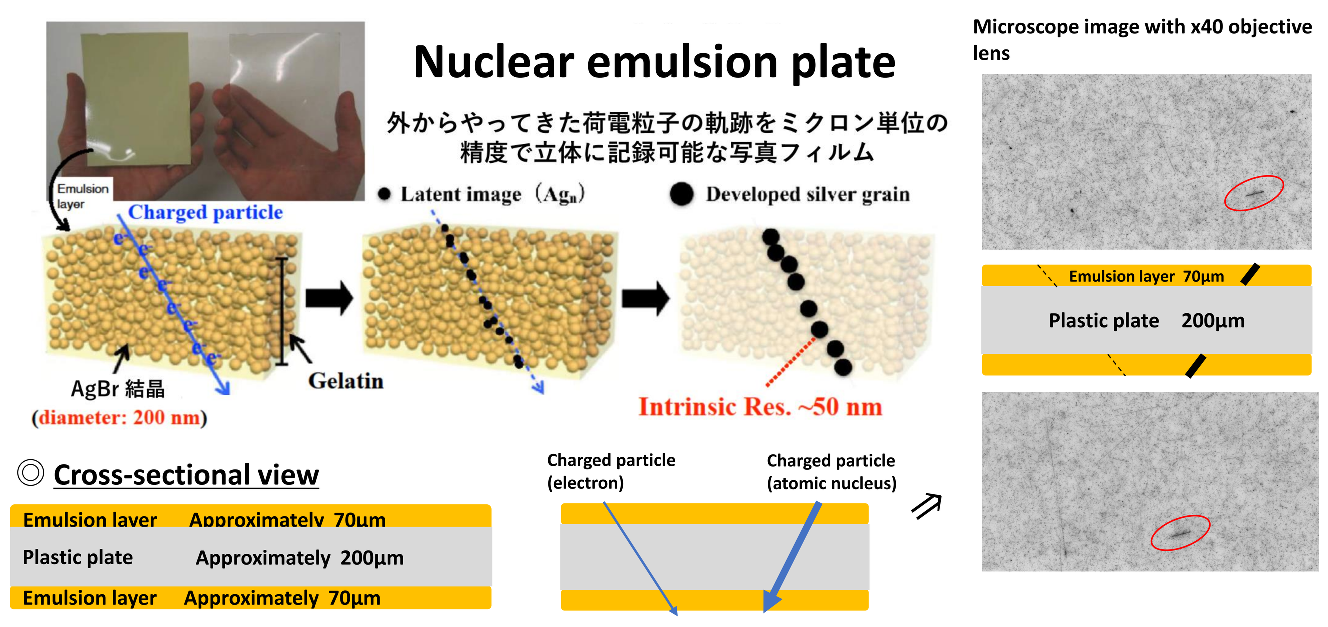
Neutron rich environments are needed to accomplish rapid neutron capture in space!

Key observations : much heavier elements than Iron group ⇒Large SΩT needed!



Satoru Takahashi *et al* 2024 *ApJ* **960** 47
SΩT(GRAINE2023) : 2.5m² × π × 24h

A detector for direct observation (= nuclear emulsion plate) ⇒ Advantageous in SΩ



◎ Introduction to GRAINE project

【 *Gamma-Ray Astro Imager with Nuclear Emulsion* 】

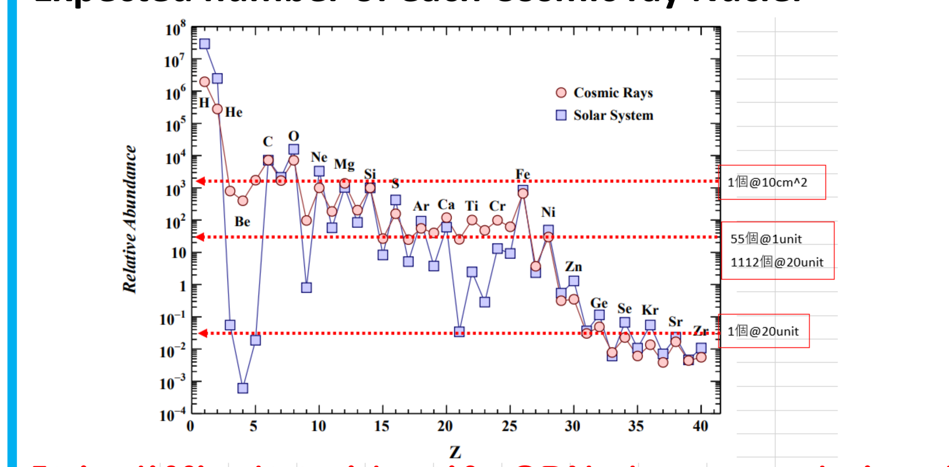
In the GRAINE experiment, plastic-based plates coated with nuclear emulsion containing microcrystals of silver bromide mixed in gelatin are used as track detectors for cosmic rays and gamma rays. Charged particles passing through the nuclear emulsion plate generate latent image nucleus, which renders tracks through a development process. The charge of cosmic ray nuclei can be determined from the track darkness and width of tracks, allowing for an investigation of the chemical composition of cosmic ray nuclei.

In order to detect cosmic gamma-rays, the nuclear emulsion plates capture the phenomenon of electron-positron pair production converted by gamma rays in the nuclear emulsion plate. By tracking these electrons, it is possible to determine the energy, arrival time, and arrival direction of cosmic gamma-rays coming from Vela Pulsar and the Galactic center.

The GRAINE experiment carried out the balloon flight in Alice Springs, Australia, from April 30 to May 1, 2023. The flight duration was approximately 24 hours, and the balloon reached an altitude of about 40 km. The aperture area is about 2.5 square meters.

In GRAINE2018 experiments, we have already successfully detected the astronomical gamma rays from Vela pulsar in sub-GeV energy ranges(Satoru Takahashi *et al* 2024 *ApJ* **960** 47).

Expected number of each Cosmic ray Nuclei

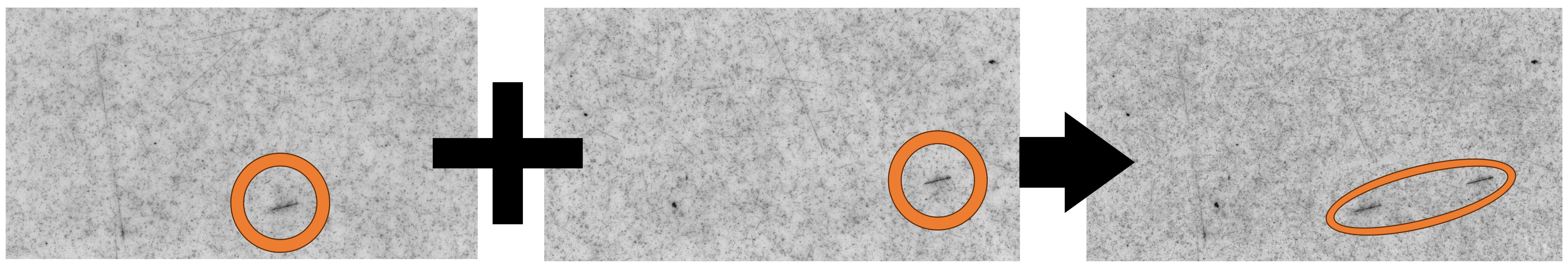


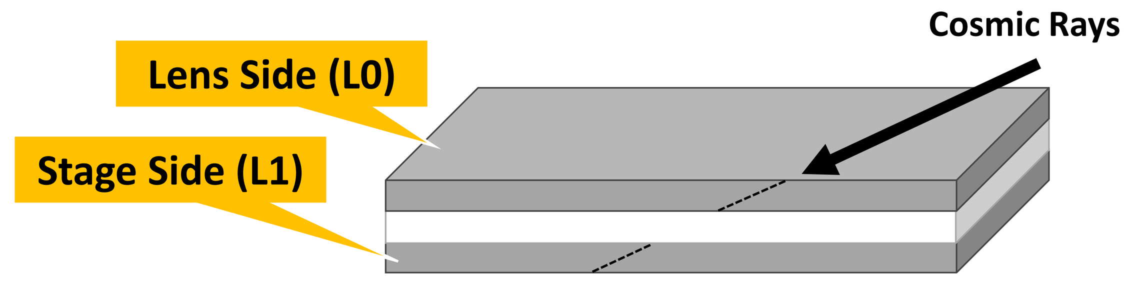
It is difficult to identify CRNs by manual visual inspection ➡ machine learning techniques

★Effectiveness of multifocal imaging approach for cosmic ray nuclei for nuclear emulsion films

Multifocal imaging approach is applied for both sides of nuclear emulsion films in order to recognize dark and wide tracks originated by cosmic ray nuclei such as Carbon, Fe etc. As those tracks are accompanied with knock-on electrons(delta rays) along their trajectory, the width of tracks are wider and darkened as well as high ionization losses of their charge. The composite image of both side have clear feature such as track darkness, wider-width, number of delta-rays and length of tracks and track gap in base-film.


Scanning system for nuclear emulsion films (HTS2).

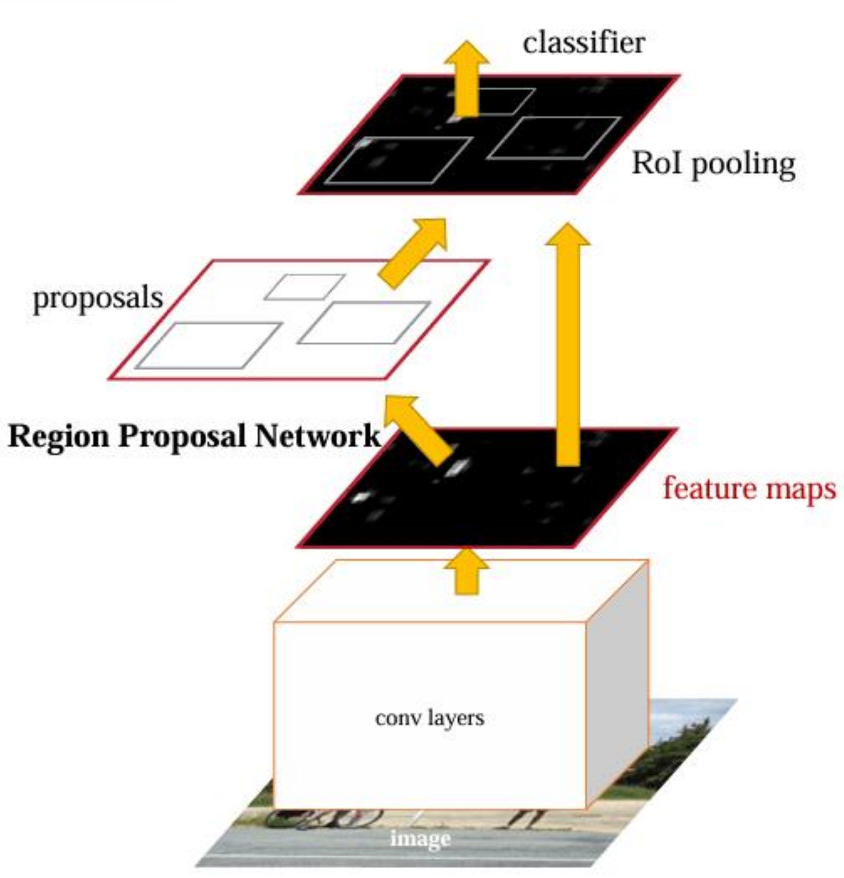

Multifocal image of L1 side
Multifocal image of L0 side
Multifocal image of L0 and L1



Cross sectional view of single emulsion plate with the incident of cosmic ray nuclei.

★Machine Learning with Faster R-CNN

Faster R-CNN is a CNN-based object detection and identification algorithm, of which architectures consist of feature extraction network, region proposal network(RPN) and object detection network mainly. The convolutional neural network(CNN) for feature extraction for image data and the RPN for object location detection are included in this algorithm. Consequently, high speed and high precision processing have been achieved in this algorithm.

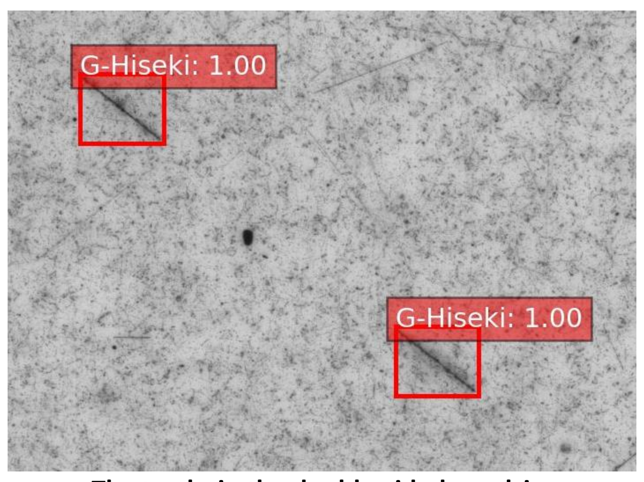


論文引用: Faster R-CNN: Towards Real-Time Object Detection with Region Proposal Networks
Shaoqing Ren, Kaiming He, Ross Girshick, and Jian Sun

★Results

- Scanning area:10cm x 10cm image (x40 obj. lens of microscope view)
- Searching CRN tracks

Ground Truth (Number of Tracks)	1348
Untrained Images prepared	1488
Tracks Identified by Direct Observation	105
Track Candidates by Machine Learning	831
Tracks Detected by Machine Learning	102



The tracks in the double-sided emulsion layer were successfully recognized.

The 97% of the number of manual visual inspected tracks were successfully detected with faster R-CNN. At this moment, tracks of which zenith angle were very small (nearly vertical) could not be sufficiently detected, due to the limited statistics of training data in the angle region.

Efficiency	97.1%
Purity	12.3%

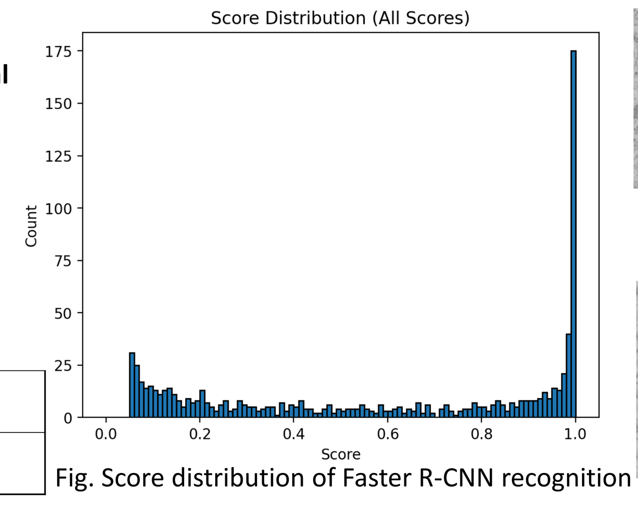
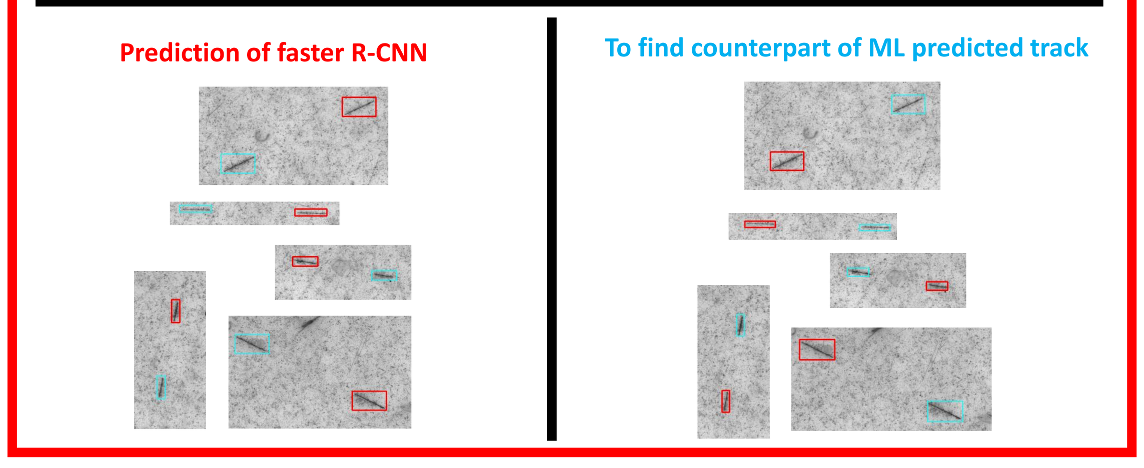


Fig. Score distribution of Faster R-CNN recognition

The tracks were recognized only in the single-sided emulsion layer.

Misrecognized (on the left side of the screen).

★Confirmation of Zenith angle for each CRN track



★ Track length(zenith angle) distribution

- For both training data(in 10x10cm²) and ML predicted tracks(in 3x3cm²) in single side nuclear emulsion layer(75um)
- Predictable tracks angle is larger than 15 degree.

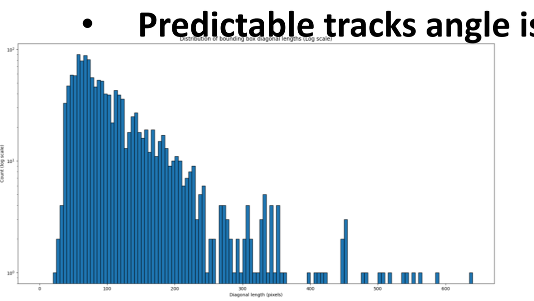


Fig. Track length distribution for training data in 10x10cm² by manual visual inspections.

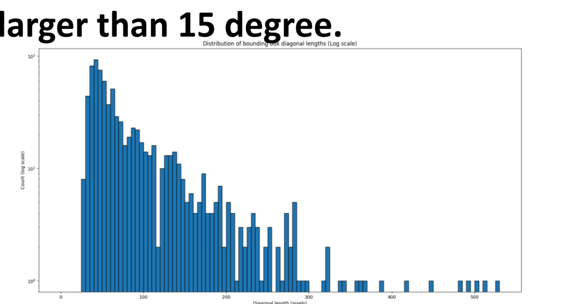
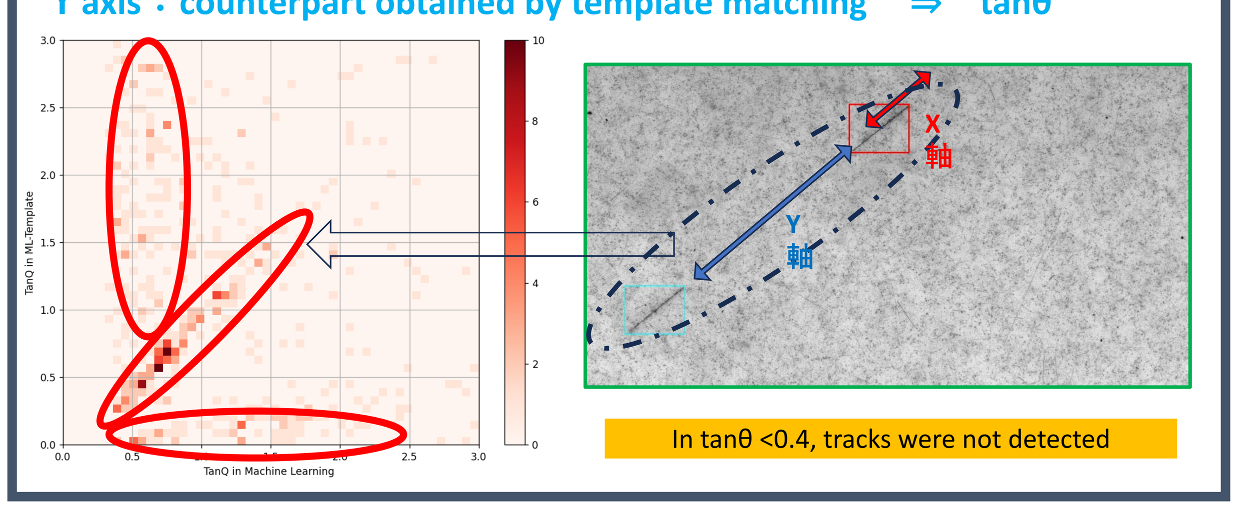


Fig. Track length distribution for track candidates predicted by machine learning in 3x3cm².

X axis：Bounding box predicted by machine learning ⇒ tanθ
Y axis：counterpart obtained by template matching ⇒ tanθ



In tanθ <0.4, tracks were not detected

★Summary

In the GRAINE2023 experiment, the exposed nuclear emulsion films were inspected with Faster R-CNN approach to identify track features and locations. By using microscope images of a 10 cm × 10 cm nuclear emulsion films, 1480 training data(tracks) were collected. In a detection evaluation using untrained images from a 3 cm × 3 cm section of a different emulsion film, the detection efficiency was approximately 97% and the purity was about 12%.
We also examined the zenith angle dependency of accuracies of track detections.