Research and development for the exploration of unknown cosmic ray events using billion-year-scale mineral track detectors

Yuki IDO, Tatsuhiro NAKA^A^, Kaito TAKAMATU^B^, Tohma ORI^B^, Shota FUTAMURA^C^,
Hiroto SAITO^A^, Shota Takenori KATO^D^, Shigenobu HIROSE^E^, Kohta MURASE^F^^G^,
Takuya SHIRAISHI^H^, Yoshitaka ITOW^D^^I^, Shingo KAZAMA^I^, Youhei IGAMI^J^

Graduate School of Environmental Studies Nagoya University, Faculty of Science Toho University^A^, National Institute of Technology Suzuka College^B^, Faculty of Science Nagoya University^C^, ISEE Nagoya University^D^, Japan Agency for Marine-Earth Science and Technology^E^, The Pennsylvania State University^F^, Yukawa Institute for Theoretical Physics Kyoto University^G^, Graduate School of Science Kanagawa University^H^, KMI Nagoya University^I^, Graduate School of Science Kyoto University^J^

Important Problem in Particle Physics

- Asymmetrical Matter and Anti Matter

  Matter＞Anti Matter

- Existence of Dark Matter

  Unknown gravitational force in the galaxy

  large - scale structure of the cosmos

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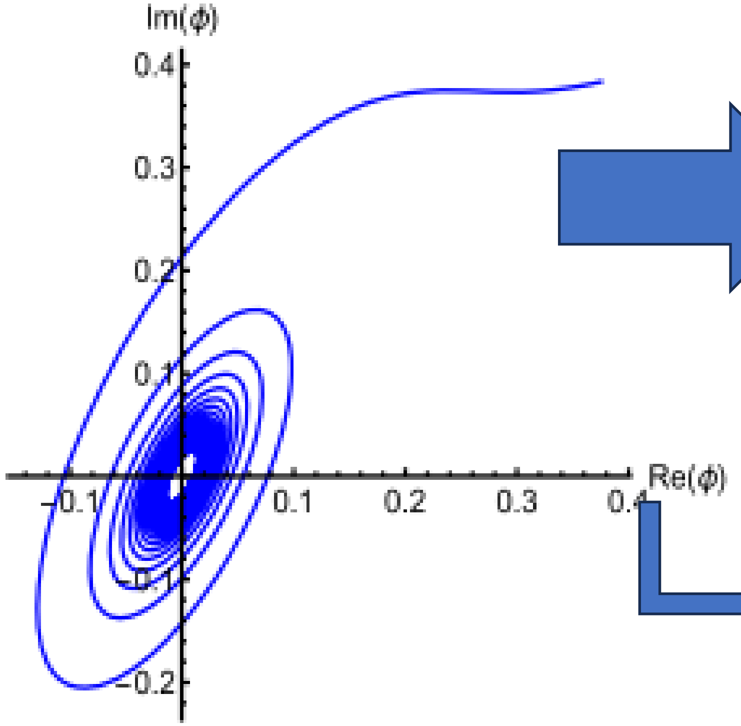
Affleck – Dine mechanism



Generate
Baryons and Leptons

Baryon

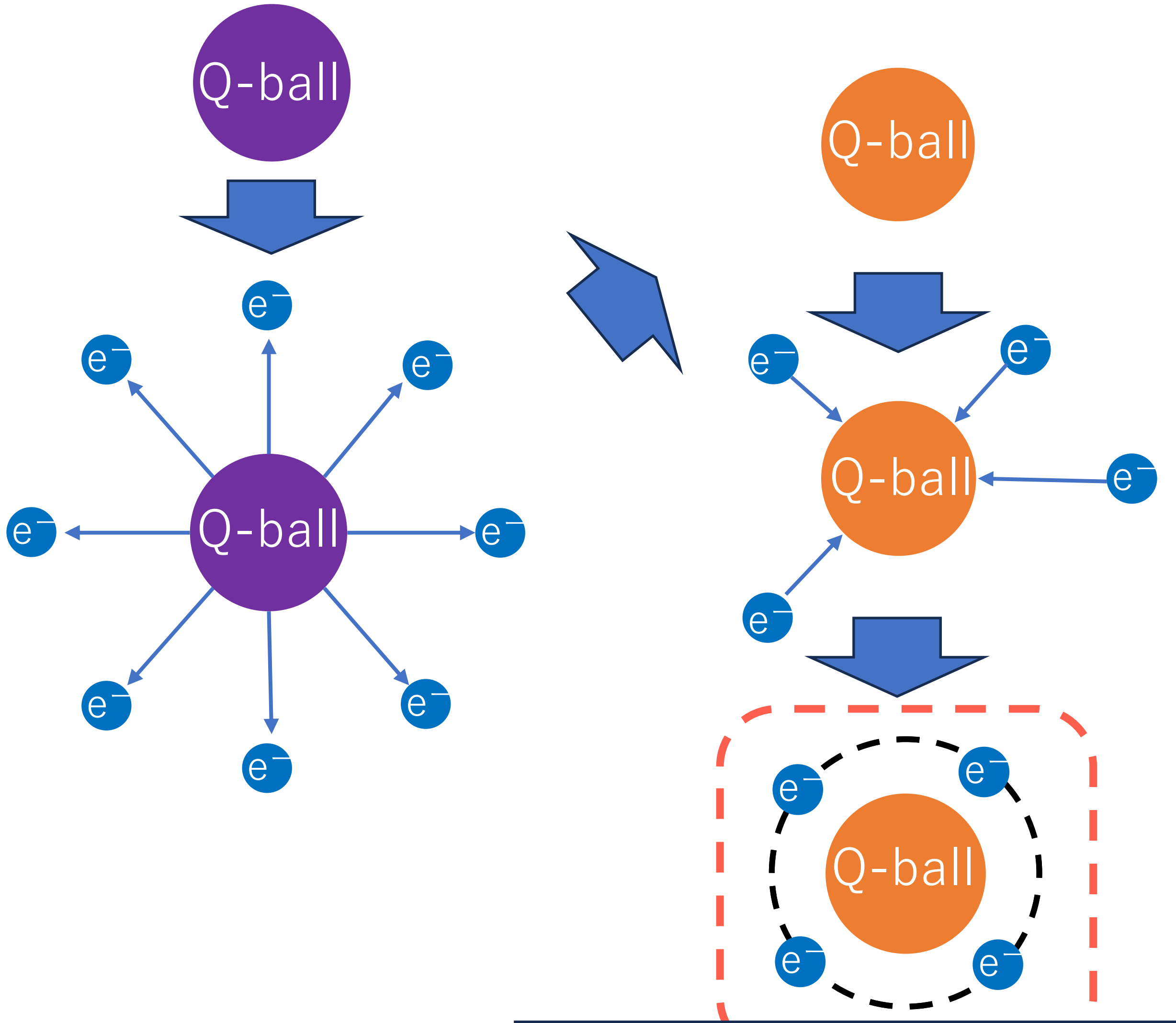
Lepton

Q-ball

Spatial instability
→ Qball

Charged Q-ball [1][2][3]

[1] J. P. Hong, et al.,(2015) arXiv : 1505.02594
[2] J. P. Hong, et al.,(2016) arXiv : 1604.04352
[3] J. P. Hong ＆ M. Kawasaki,(2017) arXiv : 1702.00889



Become $Q^{O(1)}$ ions → Charged Q-ball

- **Mass of Q-ball**

  $M_Q \gtrsim 3.9 \times 10^{26}$ GeV

- **Charge of Q-ball**

  $Z_Q < \alpha^{-1} = 137$

  ※Valence is O(1) considering electronic capture of proton

Possibility of extremely heavy Dark Matter

How can we explore Q-ball?

Paleo-Detector (Mica) might be the best solution

Over 10^8yr Since creation
→ Scale of years of the Earth

$$flux = \frac{\rho[GeV/cm^3]}{M_{DM}[GeV/c^2]} \times v[cm/sec]$$

ρ : $0.4\,GeV/cm^3$ (local dark matter density from rotation cureve of galaxy)

v : typically $300 km/sec$ (*dark matter velocity*)

Assume "heavy" DM, Flux is very low

→ we need big exposure

$$Exposure \propto M[kg(\text{ or } area)] \times T[year]$$

Largest detector at current situation

10^6 g × O(1)yr

→10^6 g・yr

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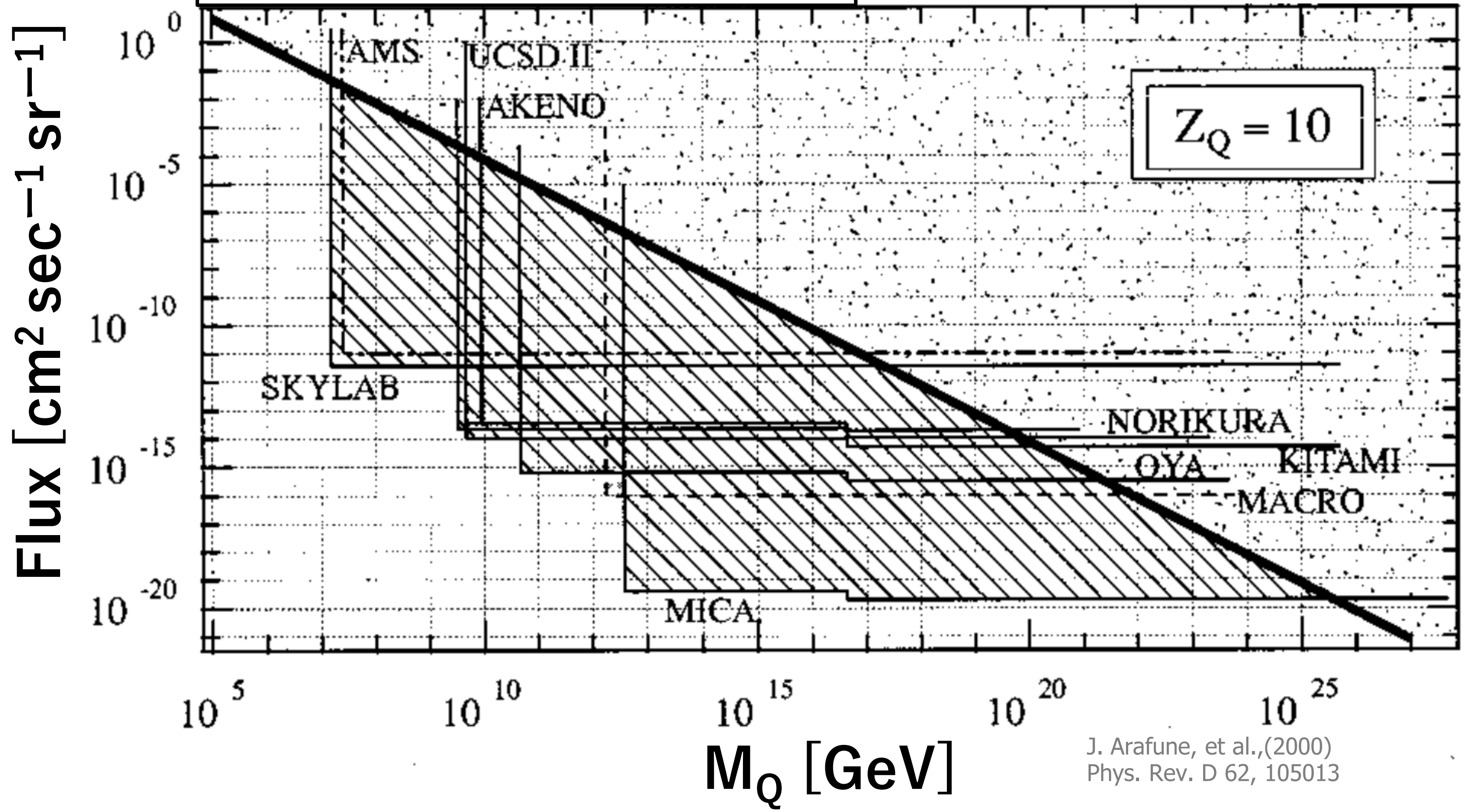
Paleo detector

1 g × >10^8 yr

→ >10^8 g・yr

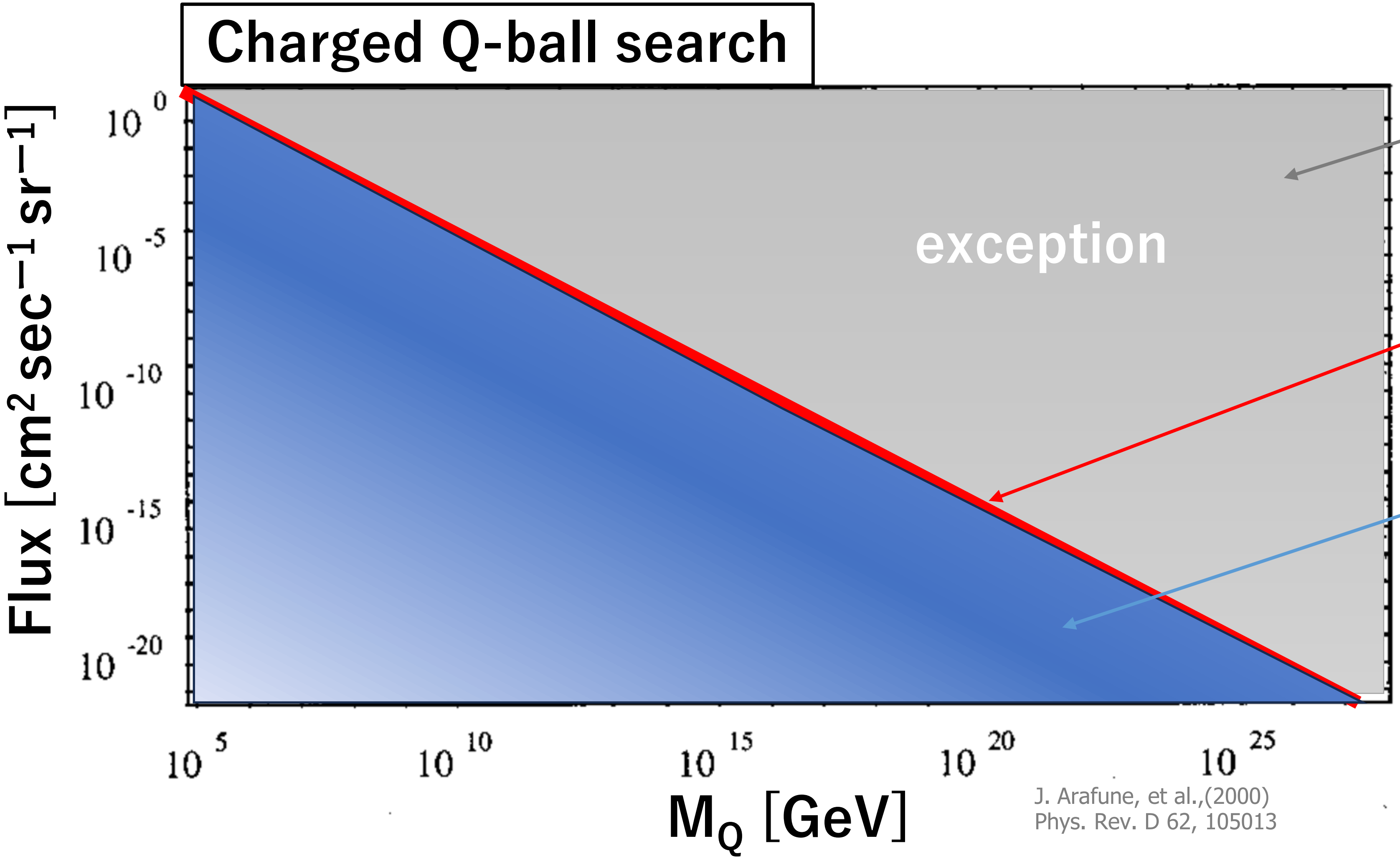
Paleo detector that increases the search amount by time

Charged Q-ball search



J. Arafune, et al.,(2000)
Phys. Rev. D 62, 105013

Paleo detector that increases the search amount by time



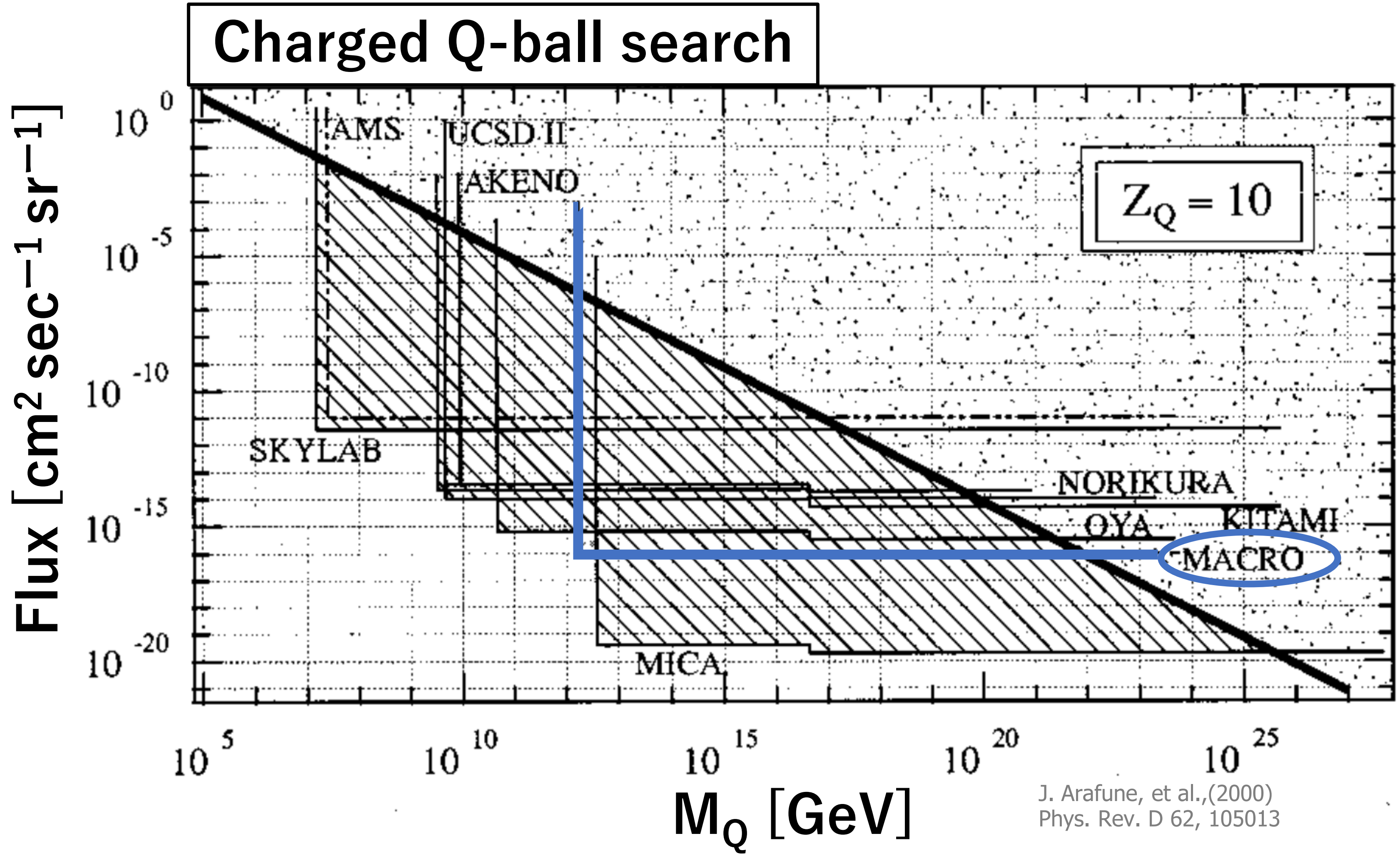
Exclude since it exceeds the amount of Dark Matter that is a gravitational source

If all the Dark Matter was Q-ball

Area of existence

（The farther from the Line, the less it becomes the main component of Dark Matter.）

Paleo detector that increases the search amount by time



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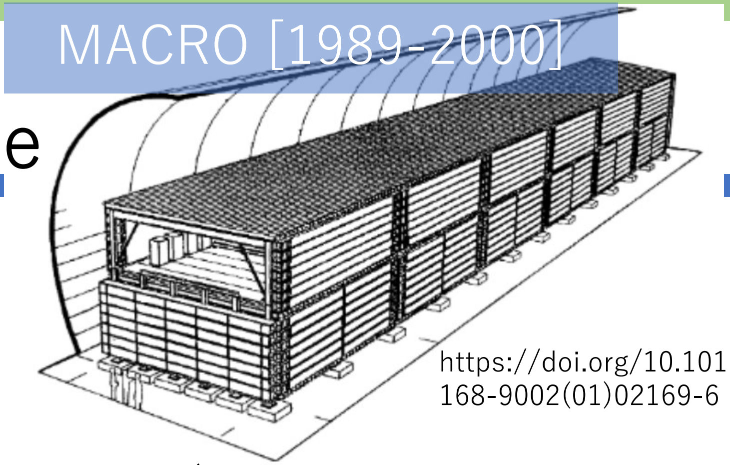


https://doi.org/10.1016/S0168-9002(01)02169-6

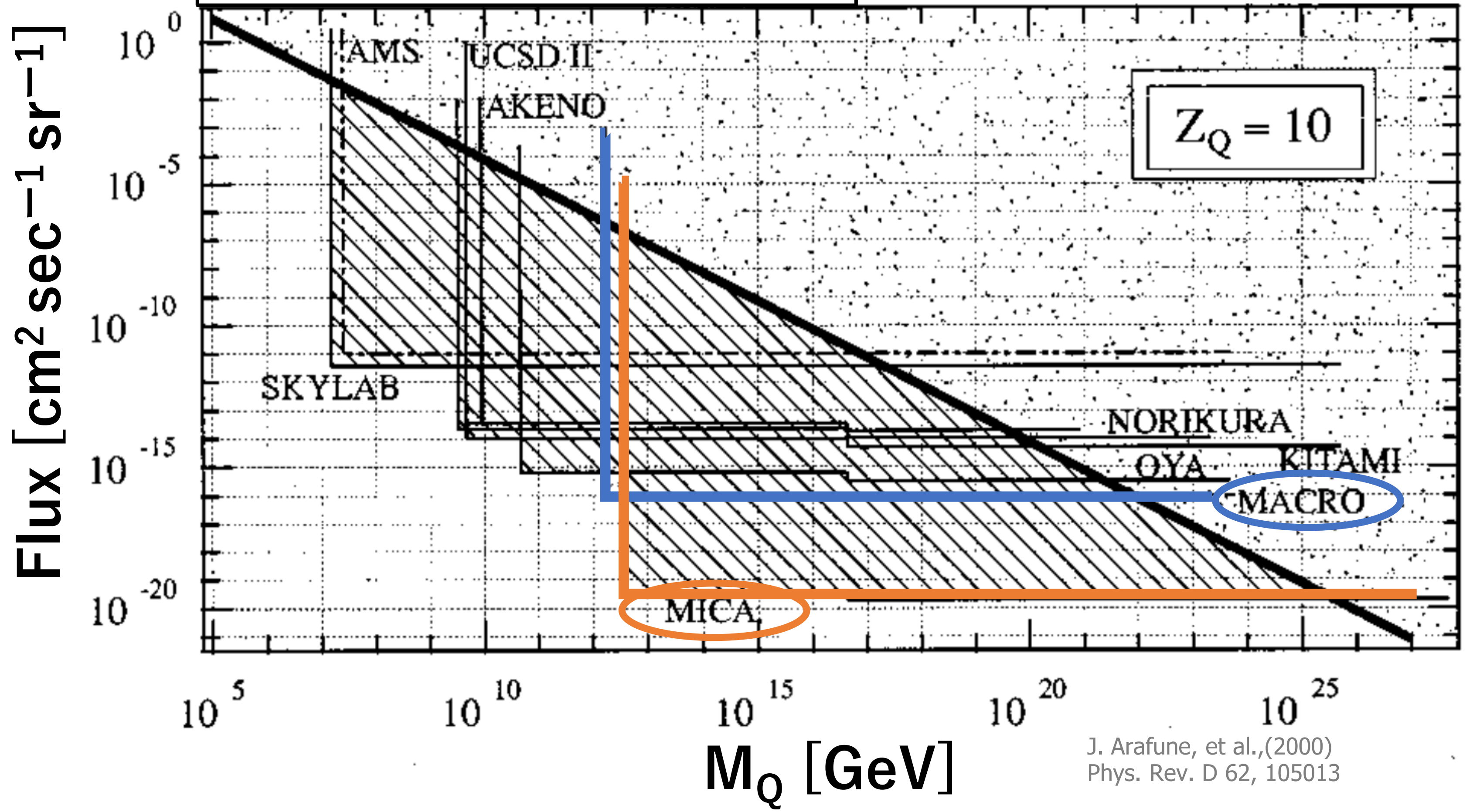
CR-39 (plastic damage detectors)

Observed area : O(10 x 10) m^2

Exposure time : O(1) year

Paleo detector that increases the search amount by time

Charged Q-ball search



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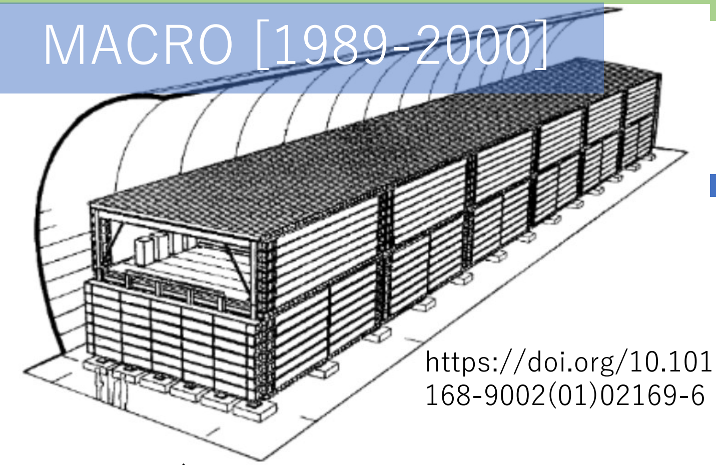
MACRO [1989-2000]



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Exposure time : O(1) year

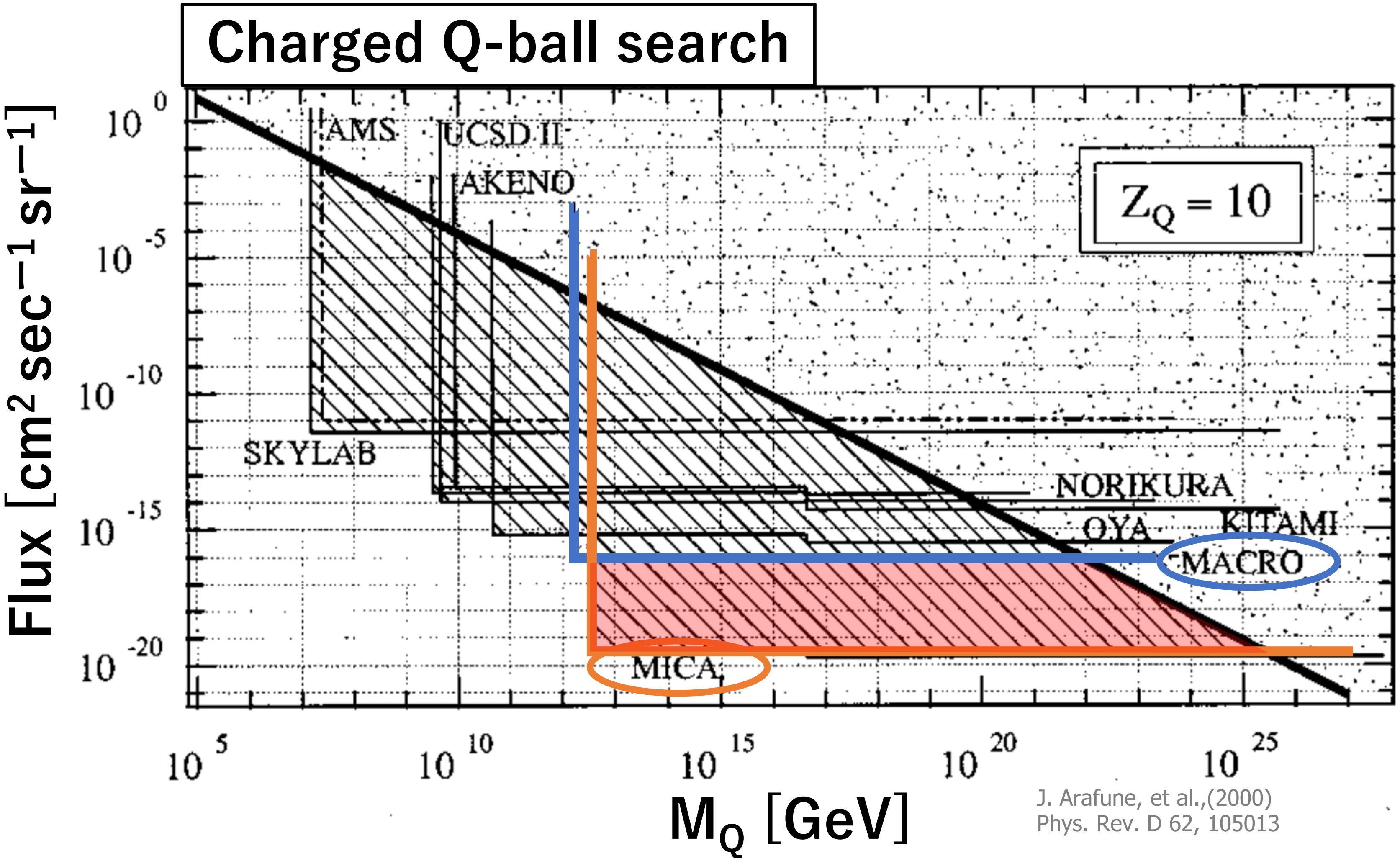
Mica [1986]

Observed area : 595cm^2

Exposure time : 10^8 years

(Extrapolation of the results from Monopole search)

Paleo detector that increases the search amount by time



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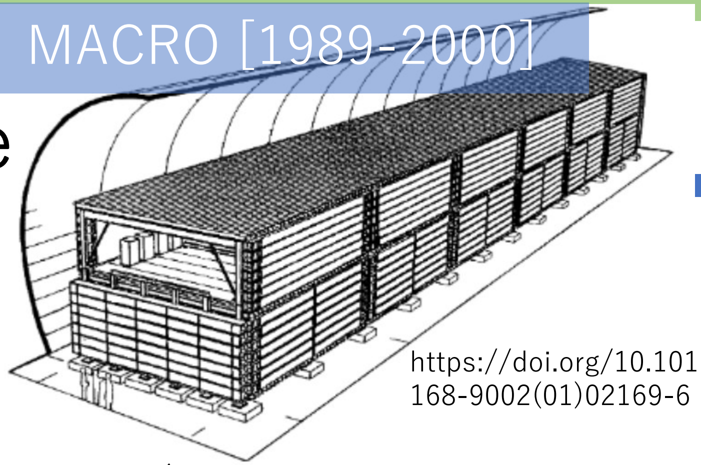

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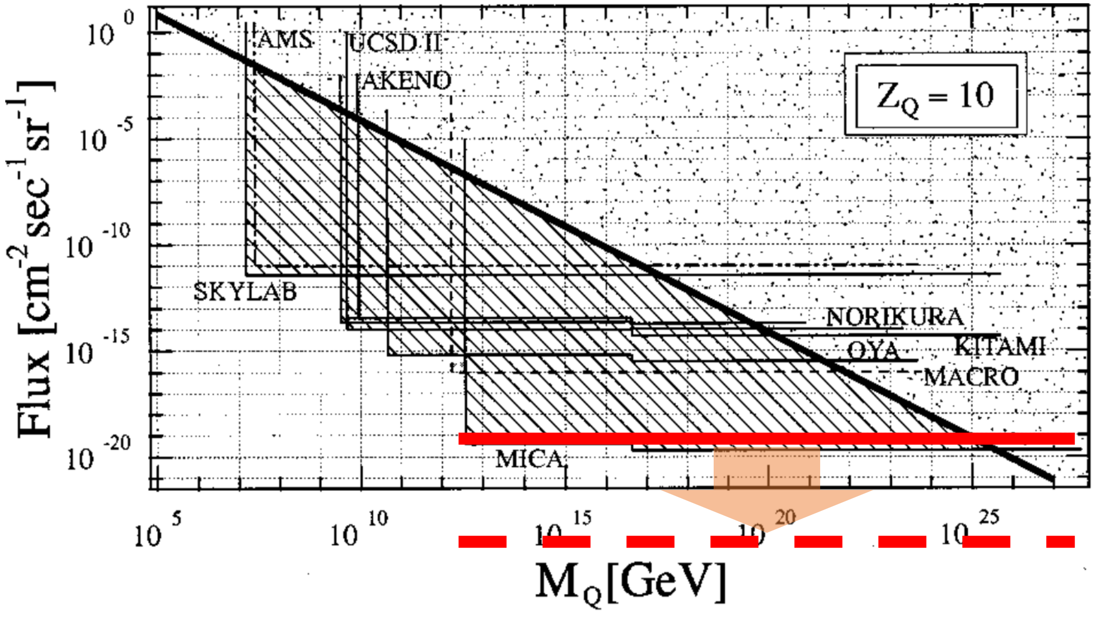
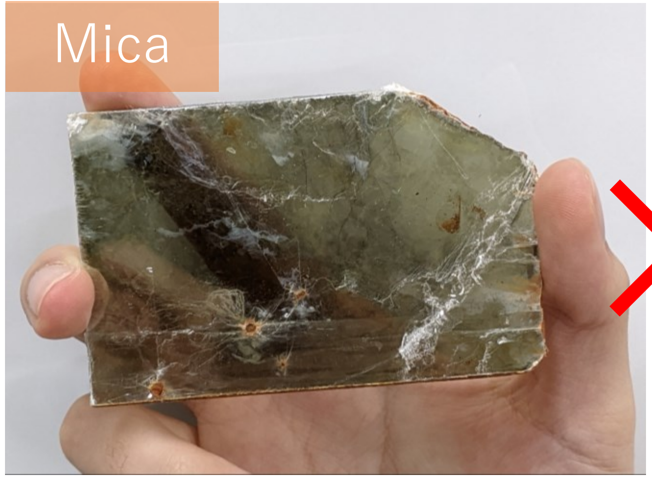
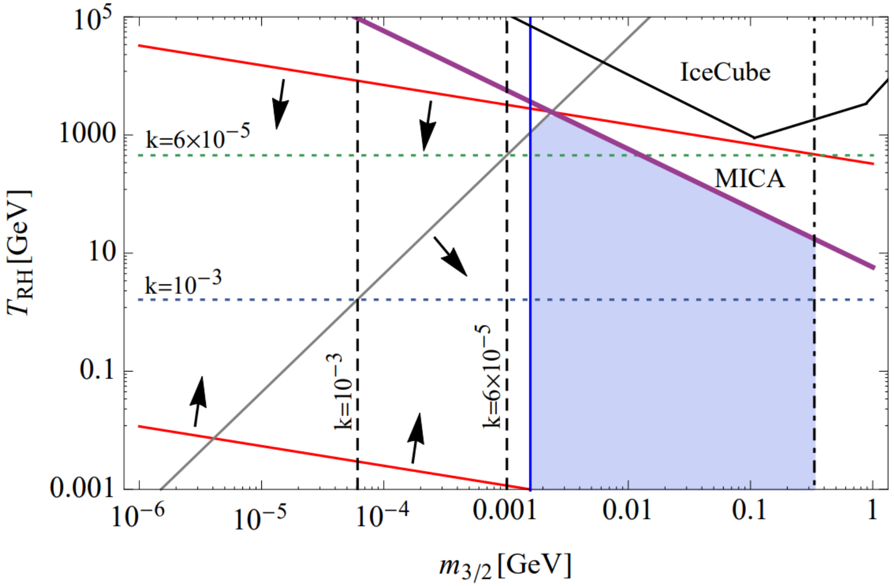


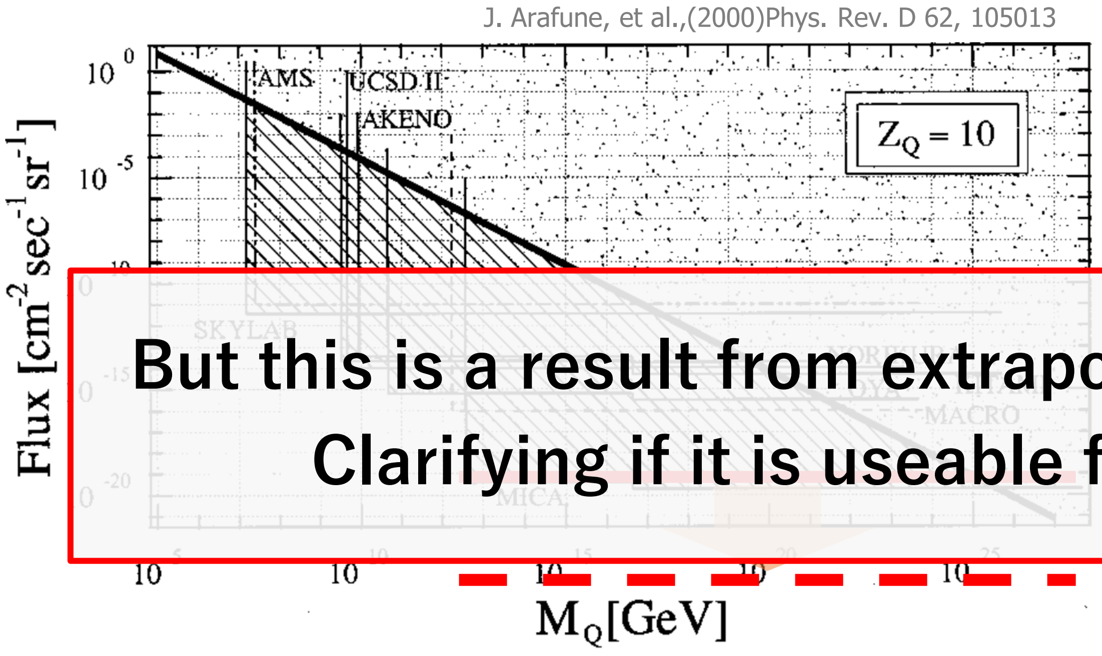


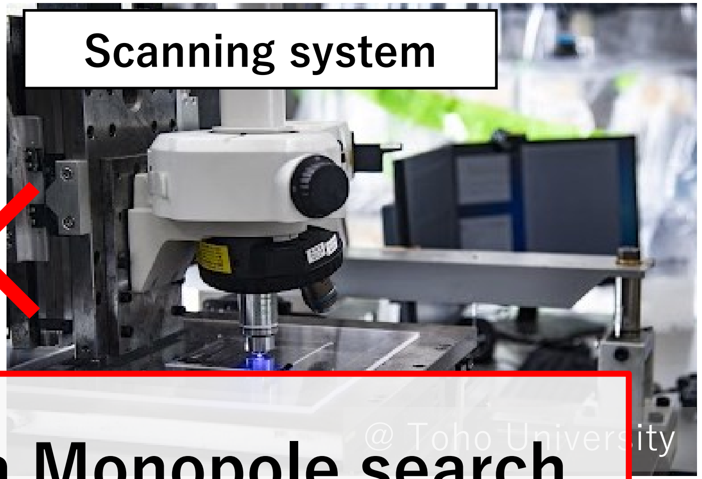


Possibility of putting a new limit against physical quantities.

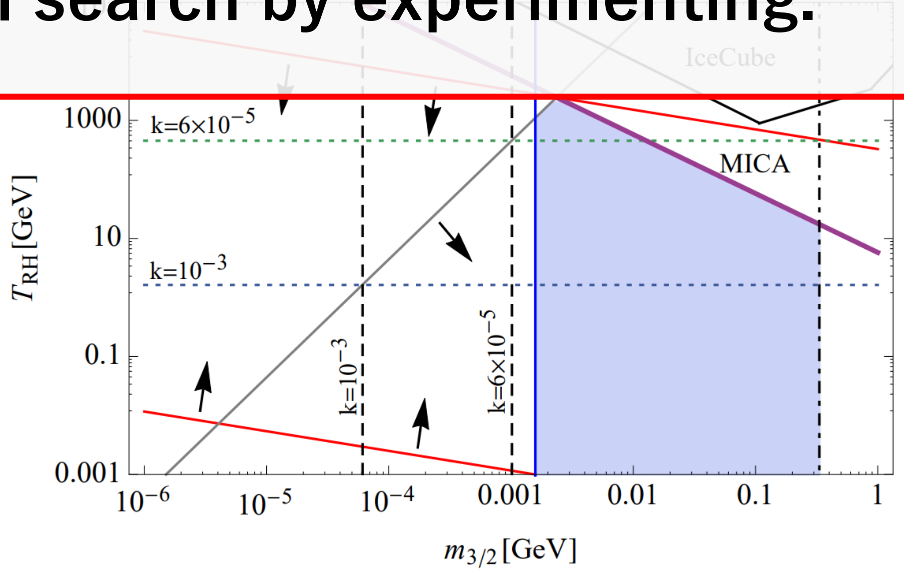
T_{RH} : Re-heating temperature of the universe, $m_{3/2}$: Gravitino mass

ntroducing the scanning system and Optimization





But this is a result from extrapolating the results from a Monopole search
Clarifying if it is useable for a Q-ball search by experimenting.



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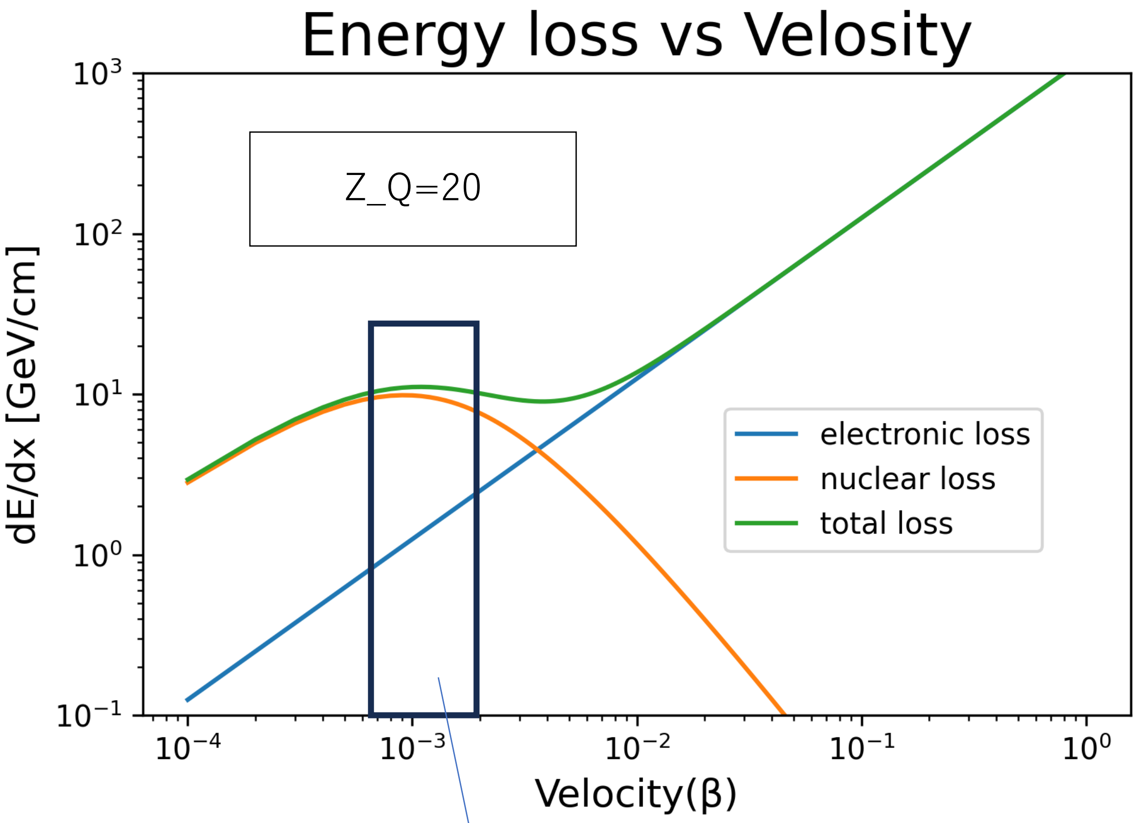
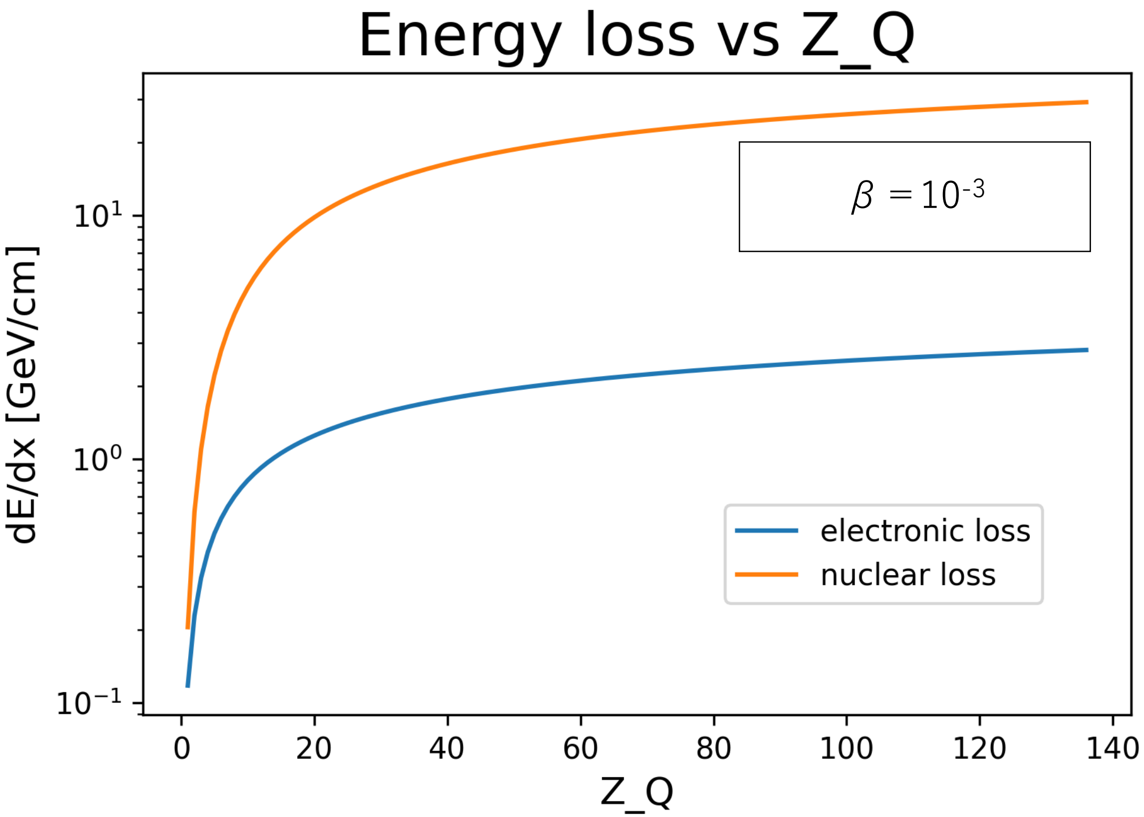
Stopping power of charged Q-ball





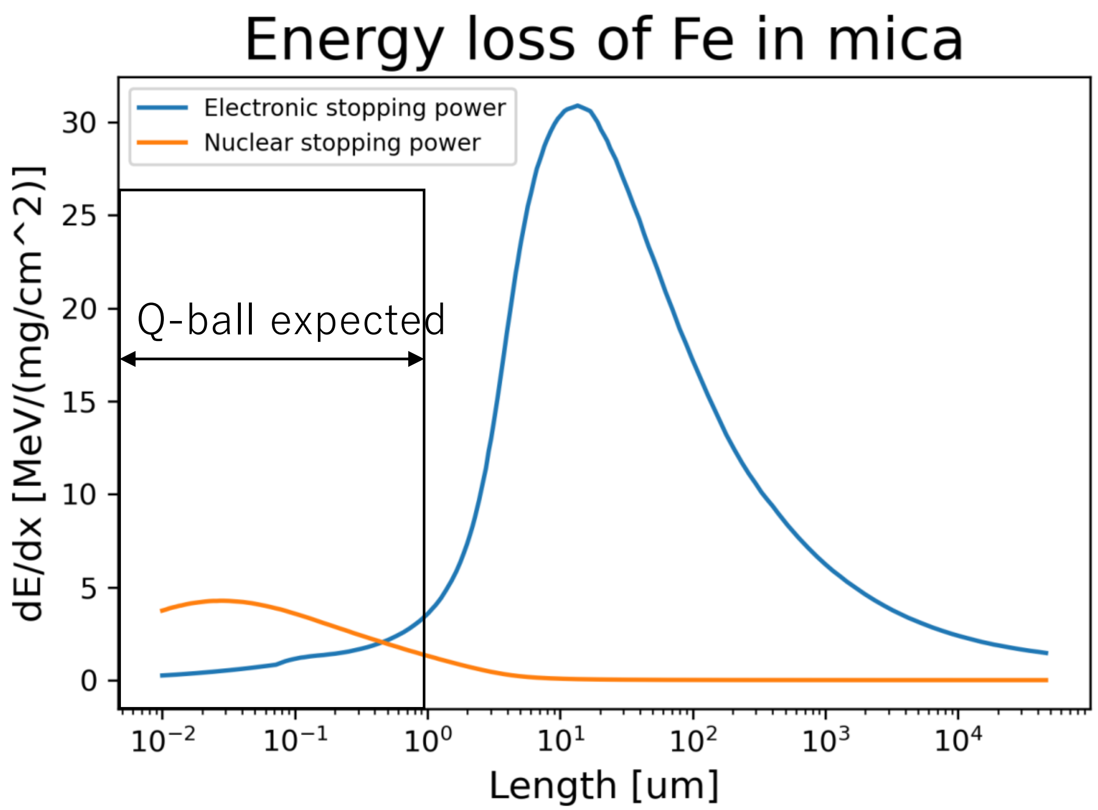
J. Arafune, et al., Phys. Rev. D **62**, 105013 より算出

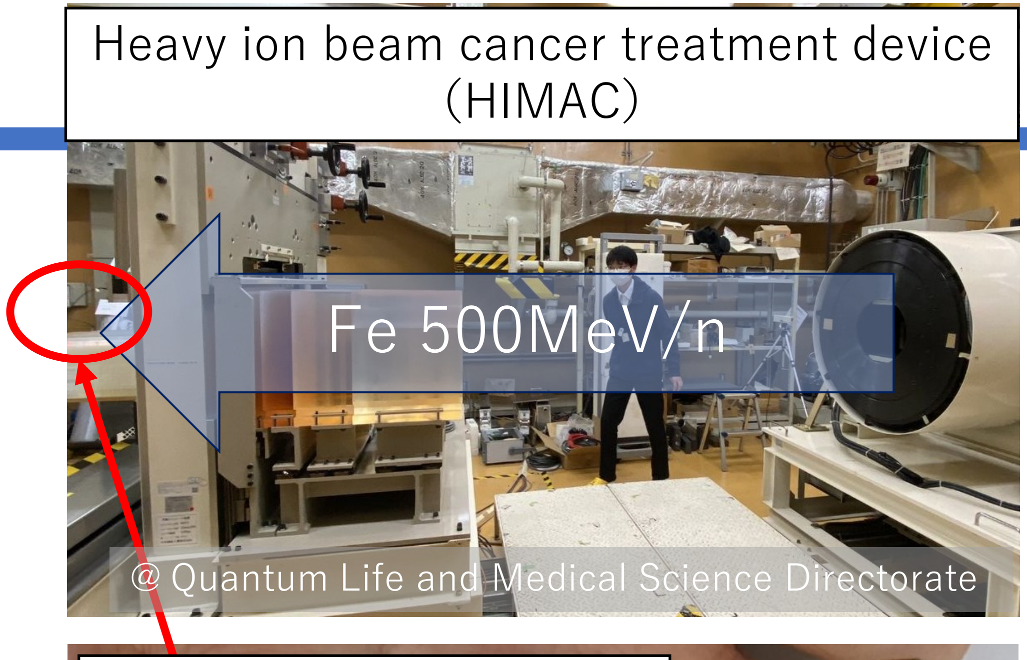
Existence area of Dark Matter

Nuclear stopping power is dominant in this area

Evaluating the track formation threshold
and optical track image in this area

Calibration using Fe ions





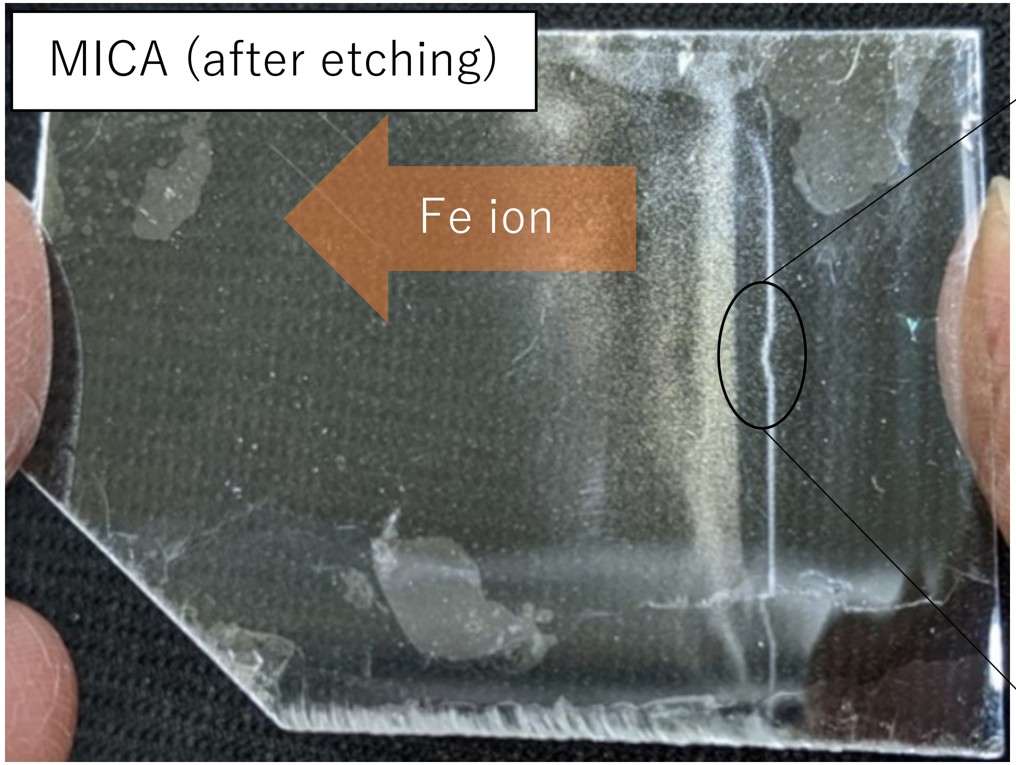
- Exposure of Fe ions that have similar stopping power as Q-ball

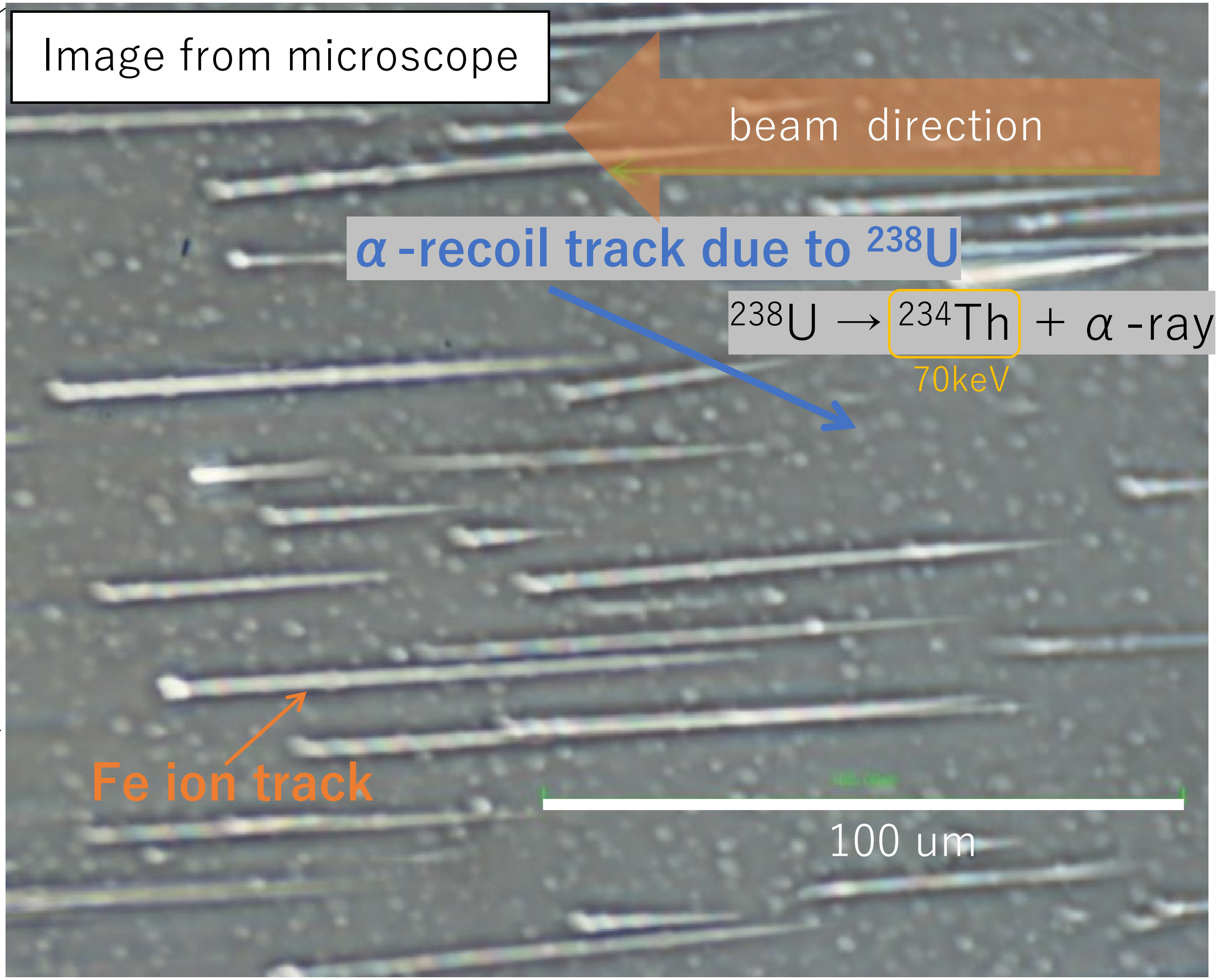
Whole tracks：Calculation od threshold from length (Described later)

First half：Evaluating the track form for before and after the Bragg-peak

End of tracks：Calibration as an imitation signal of Q-ball

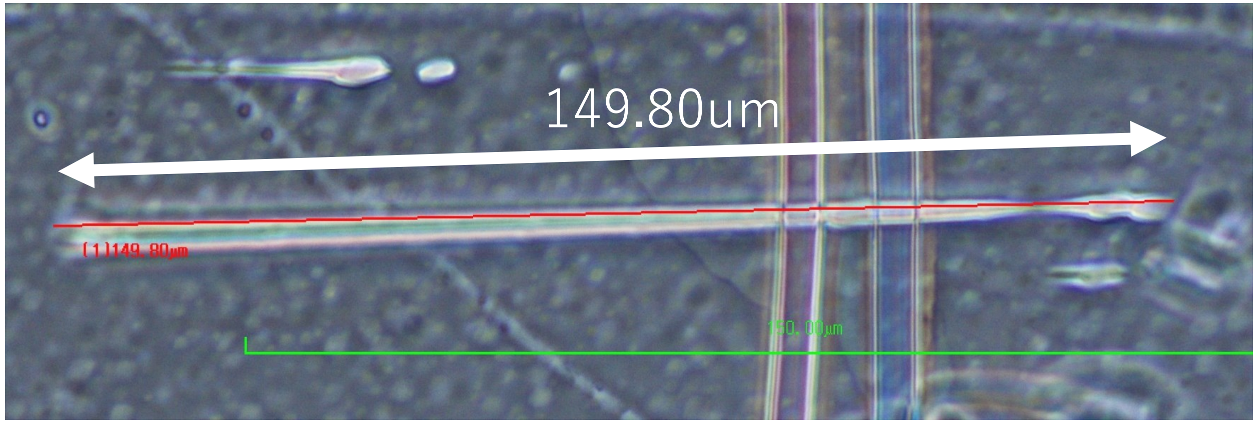
The surface of mica when using an optical microscope





- Etching conditions：HF(45%), 25°C, 80min
- Long tracks could not be seen in reference samples
- Point like is α -recoil track

Calculation of threshold from the Fe tracks

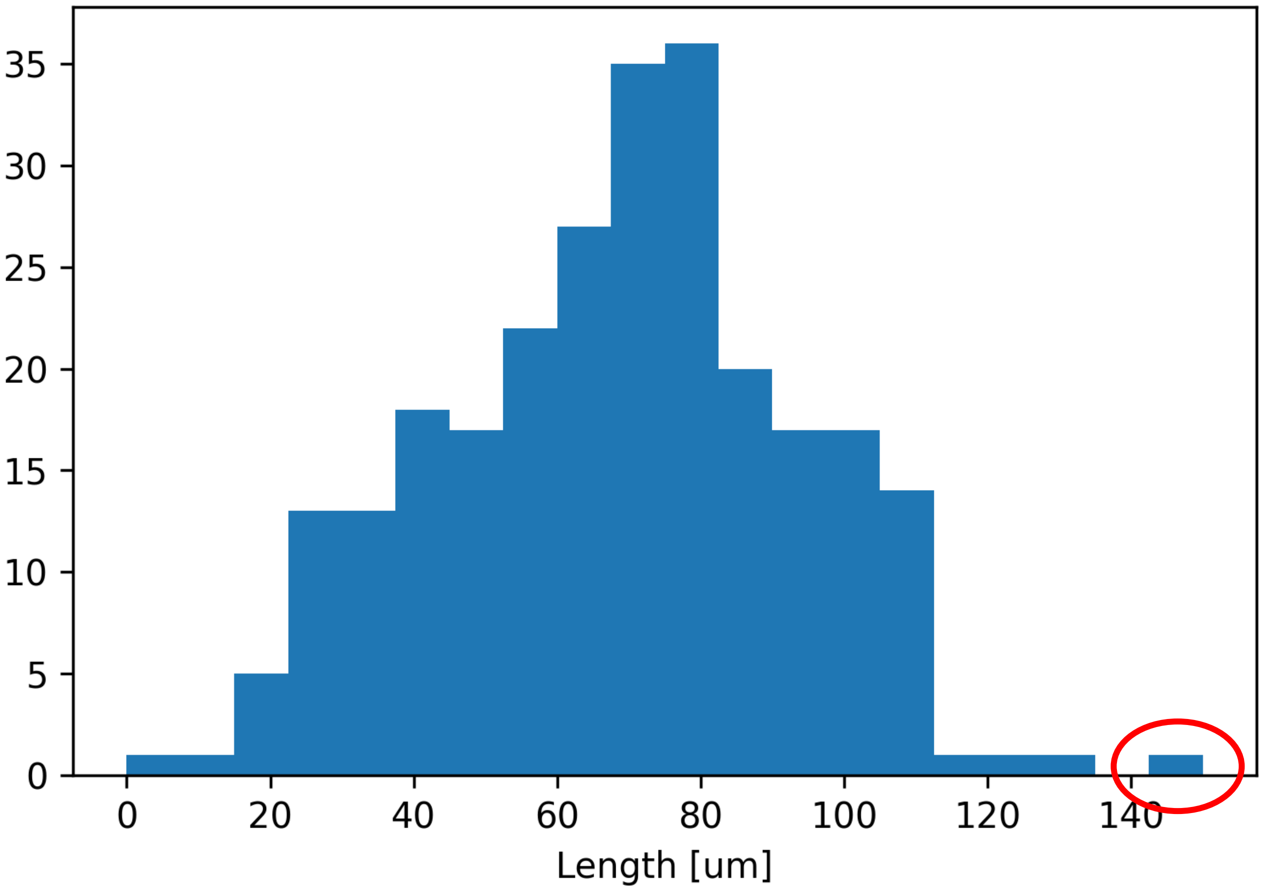


$$l_{\text{origin}} = l_{\text{Experimental value}} - 2v_{EC}t_{EC}$$
$$= 147.05\ [\text{um}]$$

l_{origin} : original length v_{EC} : etching velocity t_{EC} : etching time

$l_{\text{Experimental value}}$: experimental track length by microscope

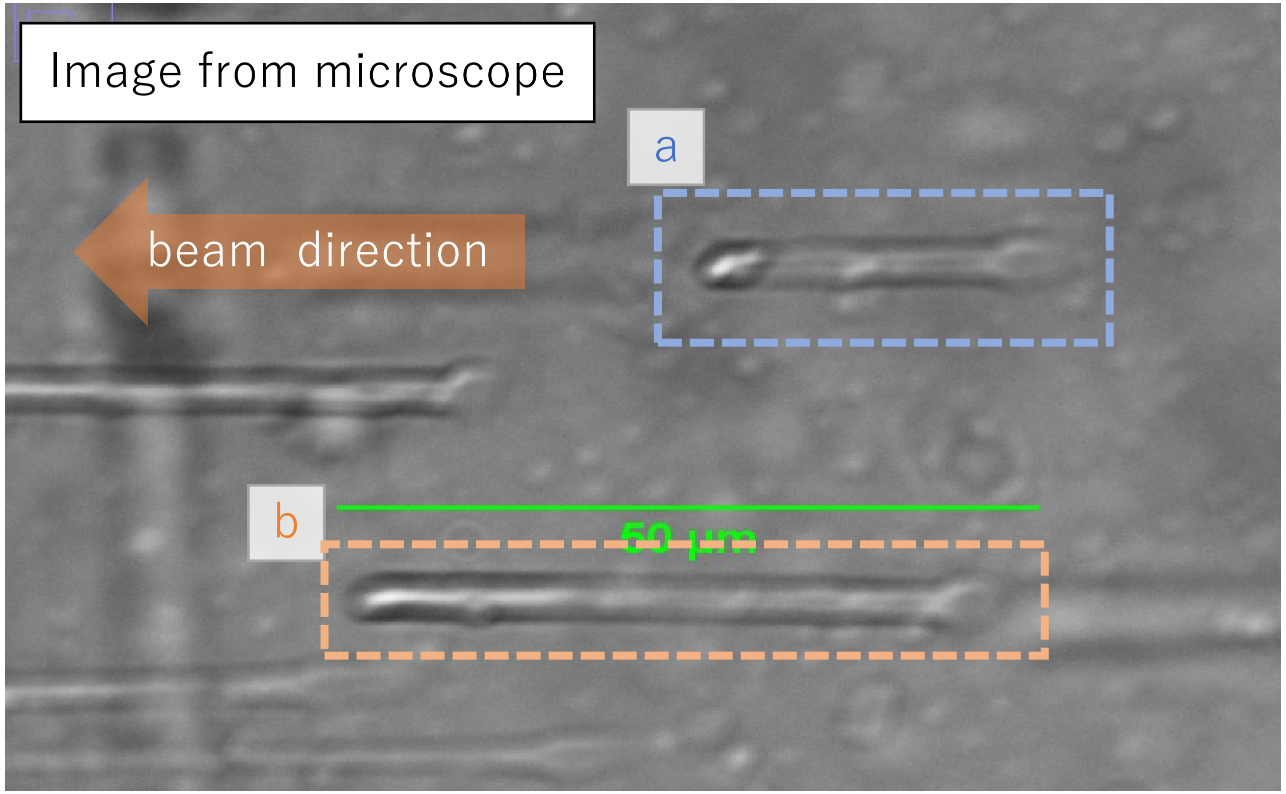
Histogram of track lengths for Fe ion in mica

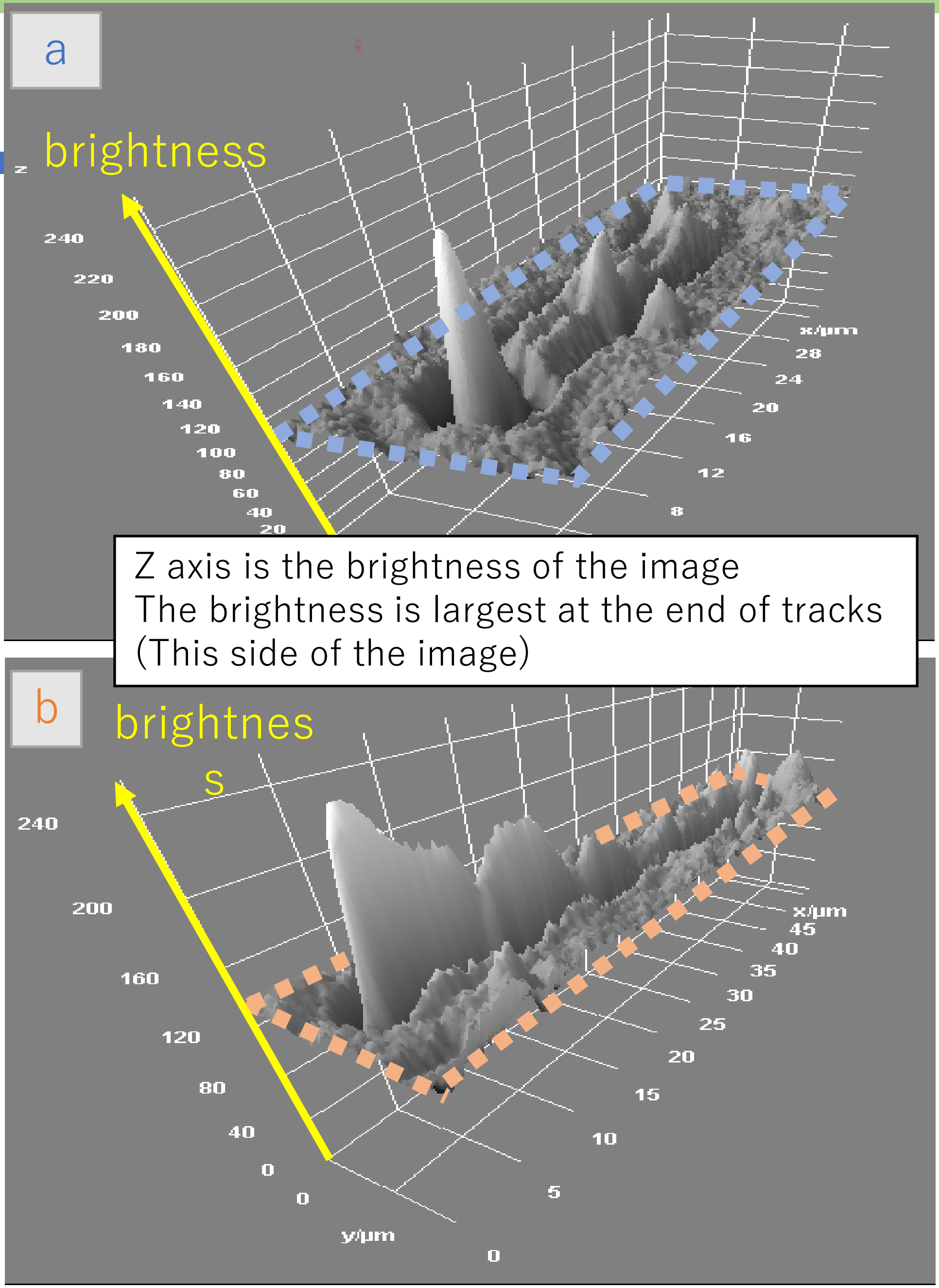


Threshold in high-speed area→ 14.26 ～ 14.43 MeV/mg/cm²

SRIM2013より

An increase in brightness at the end of tracks

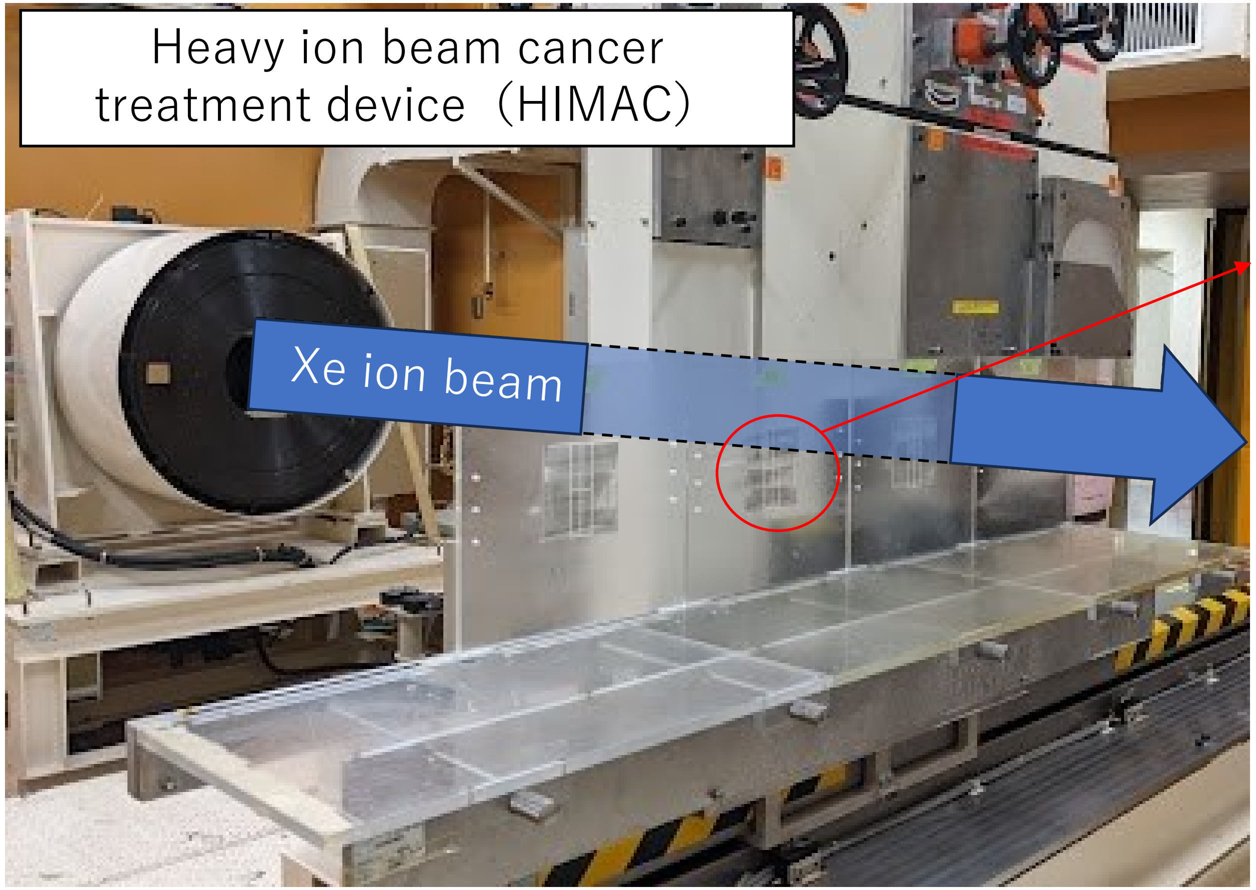


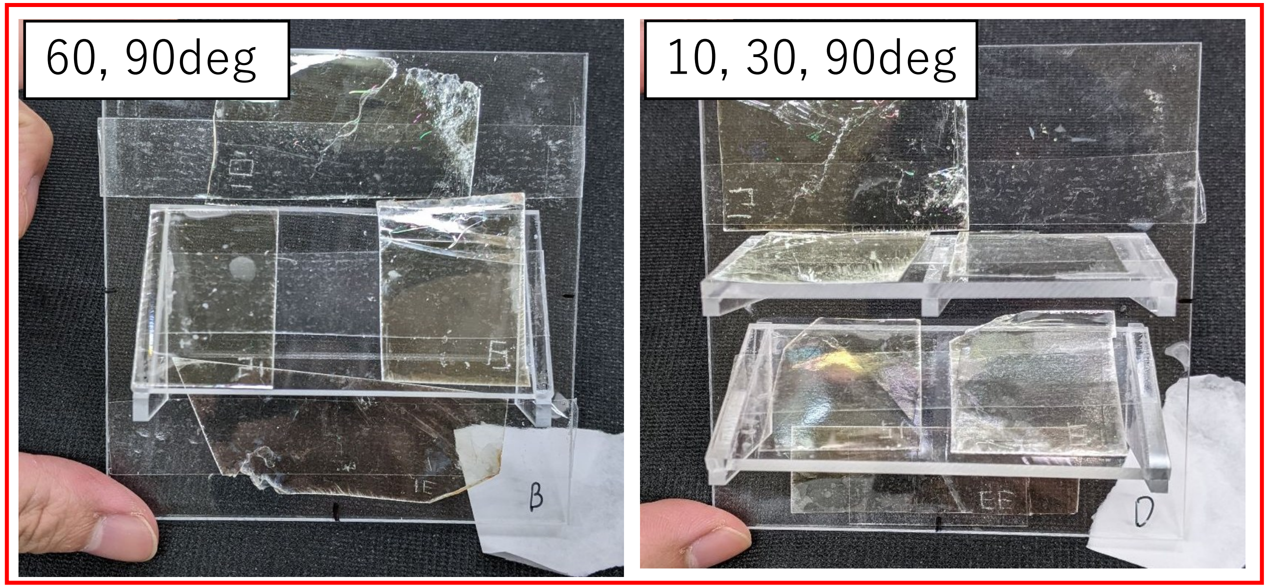


- Possibility of seeing the point where the stopping power is largest (Bragg peak)
- Possible change in track form from a change in the dominant stopping power

→ It might have a lower threshold against slower tracks?

Angle dependence in track formation efficiency and optical track image



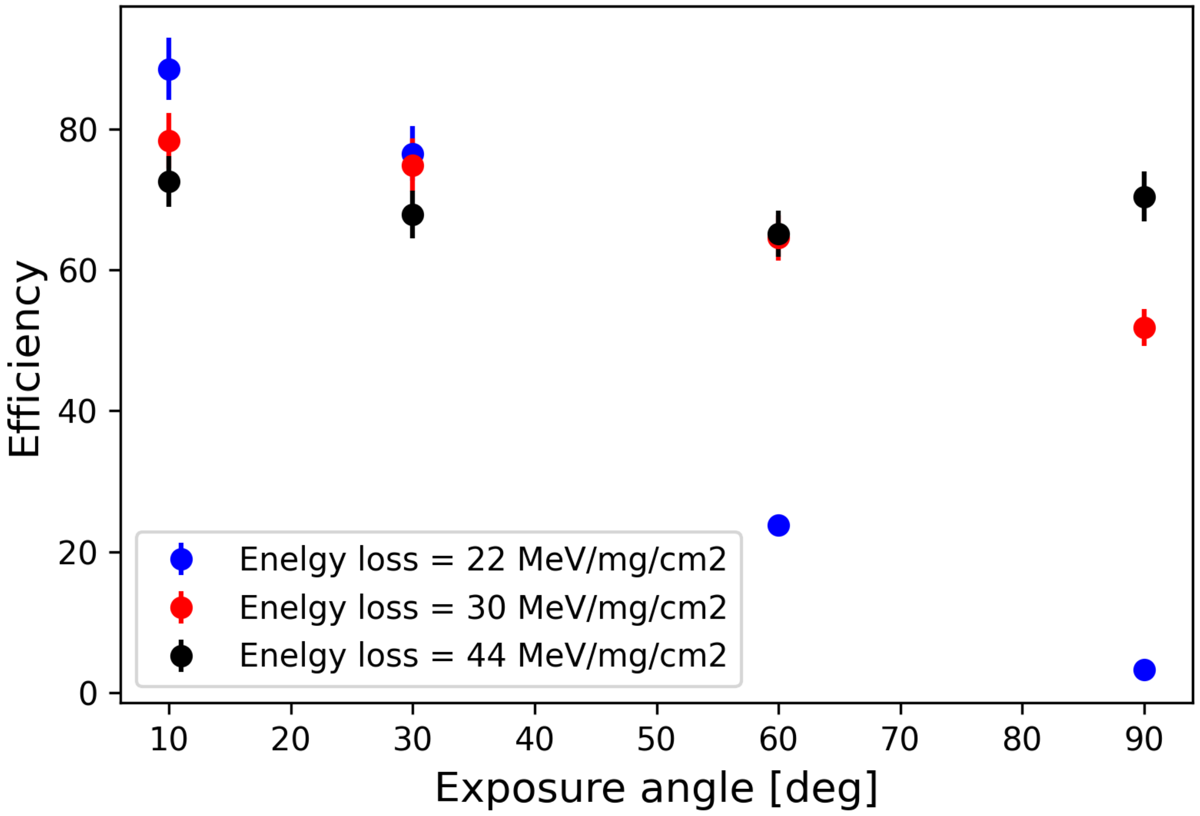


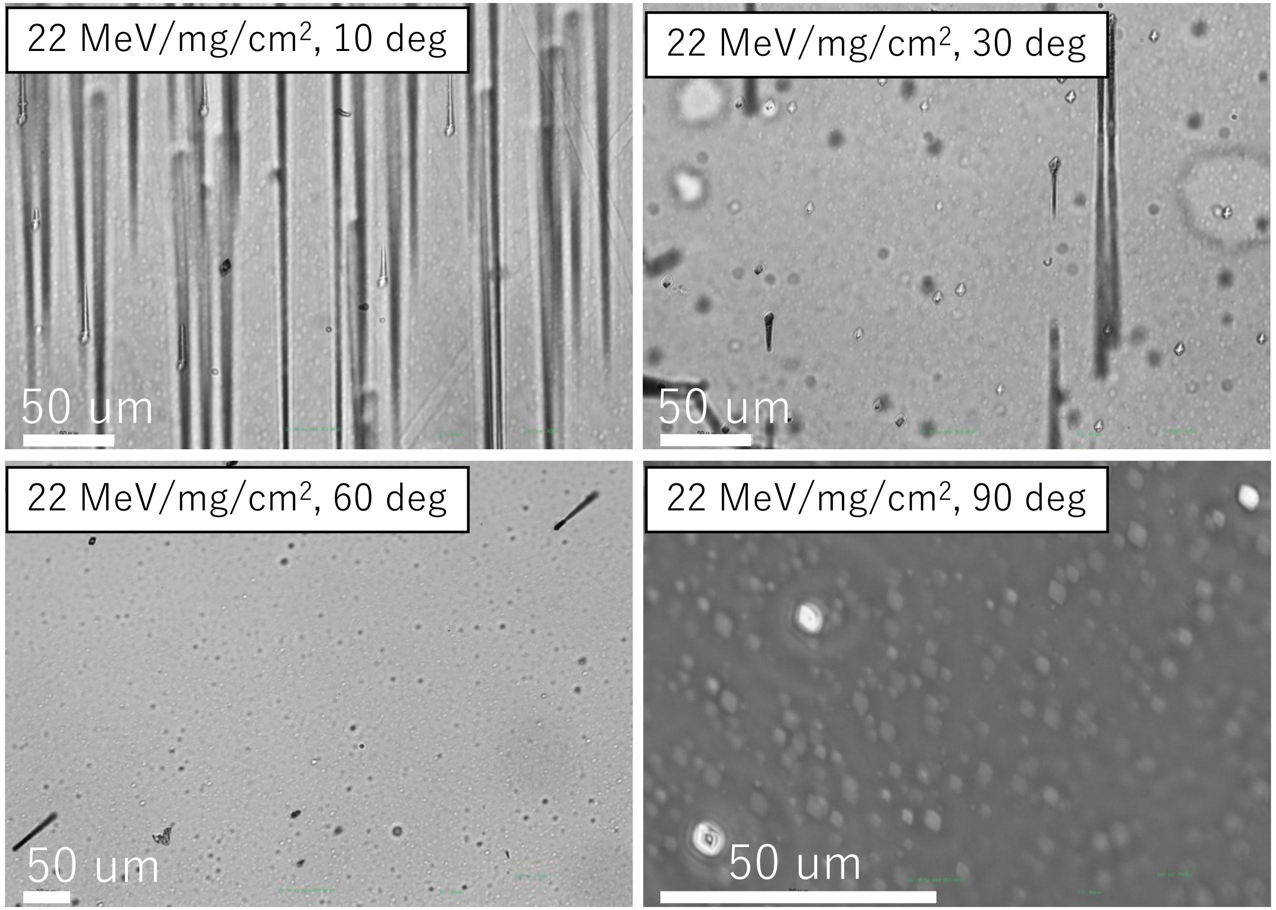
- Energy : Adjusted by moderator
- Angle : Adjusted by platforms set at an angle

- Xe ion is more hevier than Fe.

  It means more simirer Q-ball track than Fe track.

Angle dependence in track formation efficiency and optical track image





- Potential track volume related to etching might be related?
- Not much change in angle because the potential tracks are already developed where the stopping power is large?

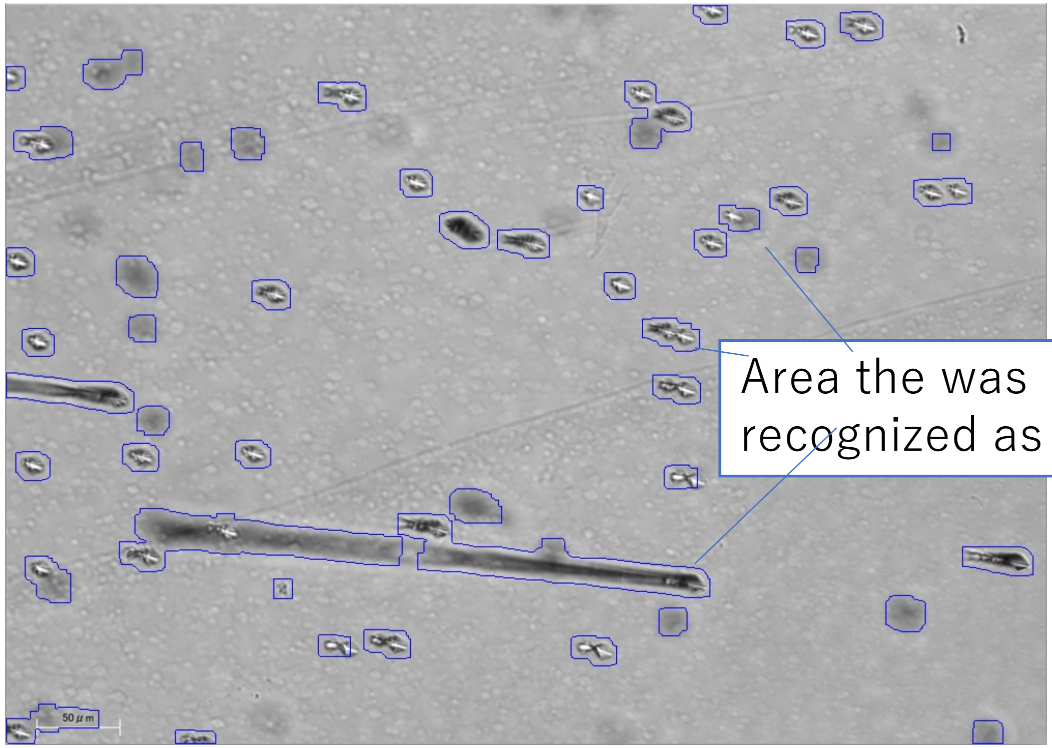
Brightness at the end of Fe tracks

Development of a scanning

xy coordinates：Deciding the position by moving the stage

Z coordinates：Fault imaging by piezo

Development of a software to acquire tracks from the images



✓ Threshold is already determined in the high-speed area

✓ Already acquired optical track images with an angle

→If we can decipher between backgrounds, a search can be done at a certain condition

Summary

Q-balls are particles with the potential to solve current particle physics problems

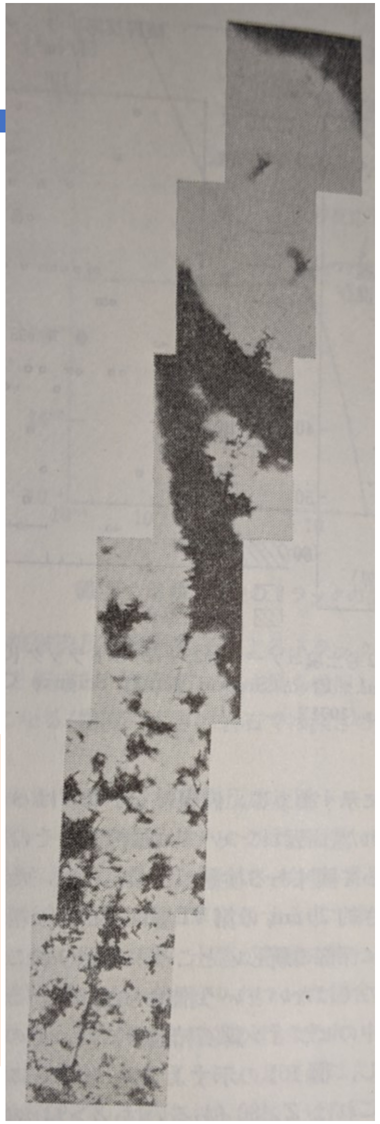
Paleo detectors can be a powerful tool in the search for Q-balls.

Scanning system is under development and can be conditionally searched as soon as hardware development is complete.

- Basic data acquisition of threshold values and optical images for slow particles
- Development of scanning system

Aim to achieve the world's highest sensitivity in the search for Q-balls.

→ Once the technology is established, it can be applied to other particles!



1 mm track seen on a lunar sample ↑
What kind of particles leave such long trails?