Measurement of low energy recoiled proton tracks in the Super Fine Grained Nuclear Emulsion for searching Low Mass Dark Matter

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and NEWSdm collaboration

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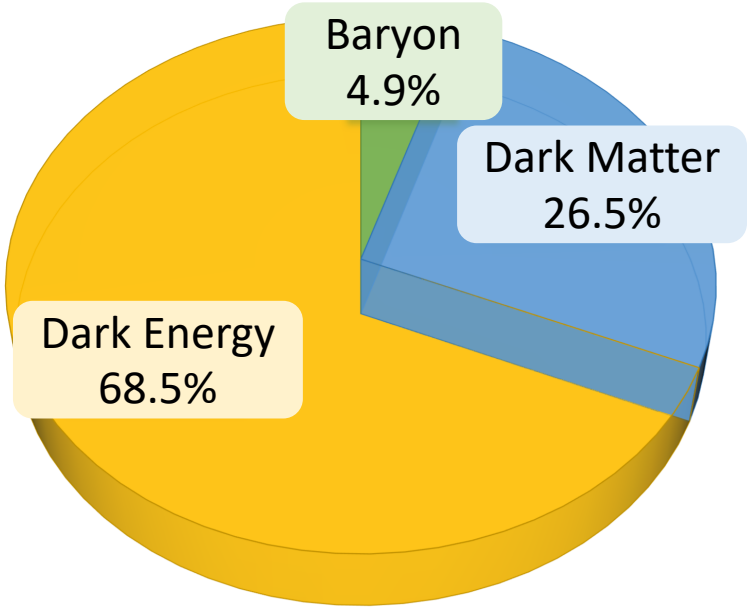
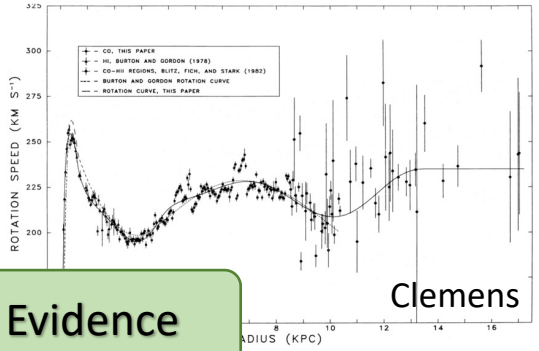
[C]IMASS Nagoya University

Dark Matter & Models

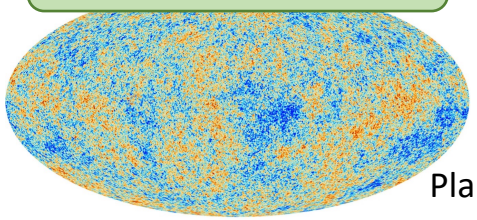
Dark Matter in the Universe

An unknown gravitational source





Much Evidence



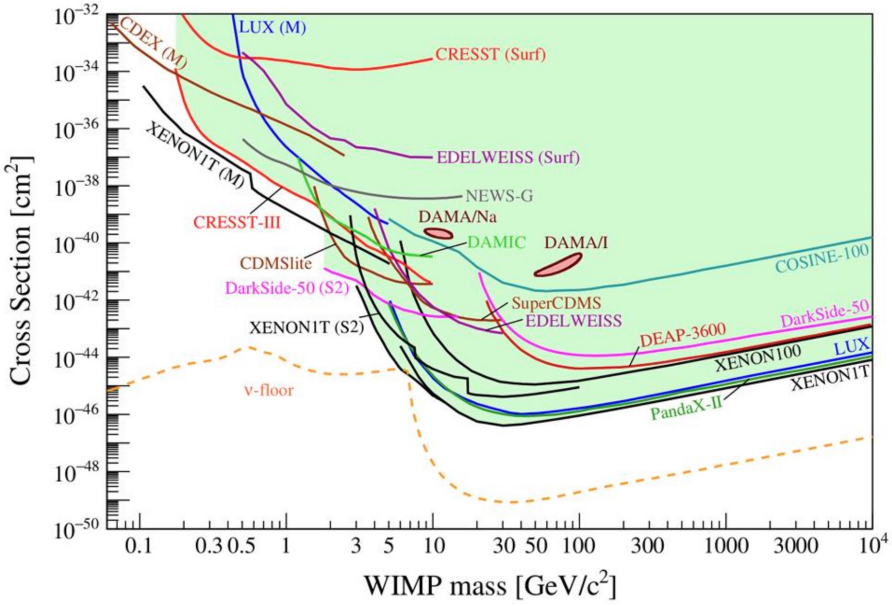
Standard WIMPs search

Mass Scale : GeV/c^2 – TeV/c^2

Not yet discovered !

Different areas should be considered

→MeV region search

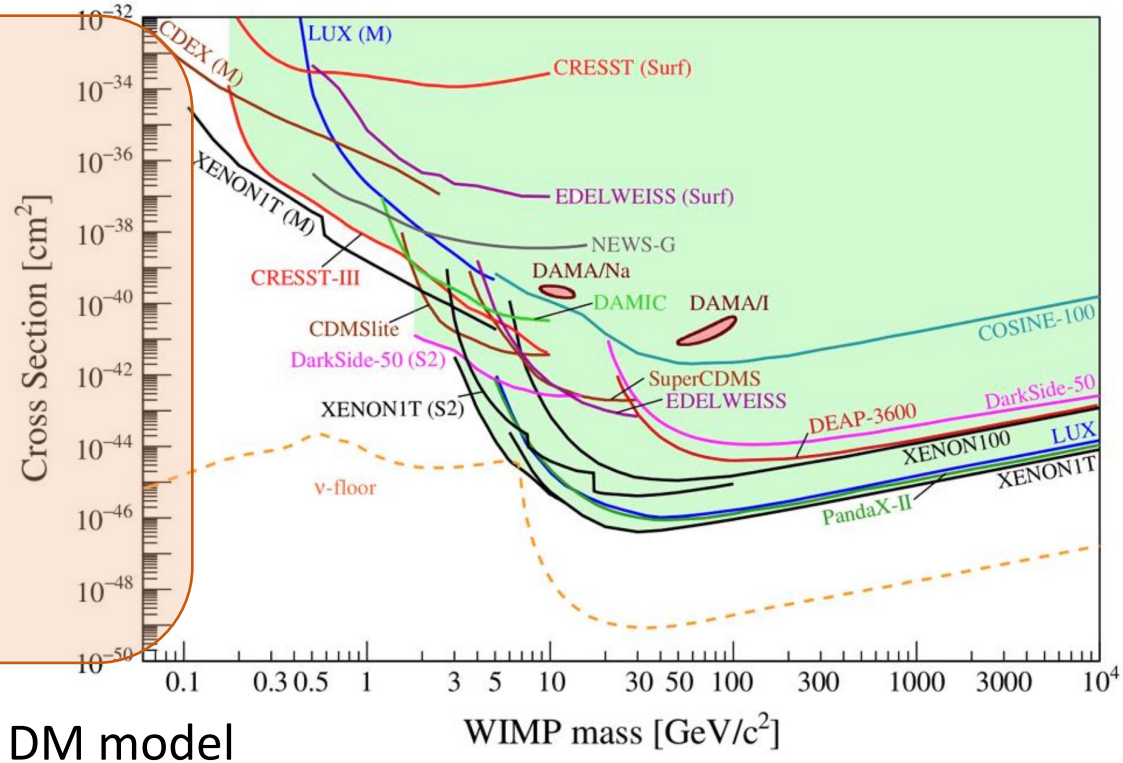


Low Mass Boosted Dark Matter

Recently, Boosted sub-GeV DM is actively discussed

- No Astrophysical constraints in the MeV region

Pre-existing methods can't search this region ! (Baryon interaction)



Examples of the Boosted DM model

- Cosmic Ray Boosted DM (CRDM)
- Multi - Component DM
- Warm DM
- SIMP

etc.

MeV scale DM detection needs boosted processes

Multi - Component Dark Matter

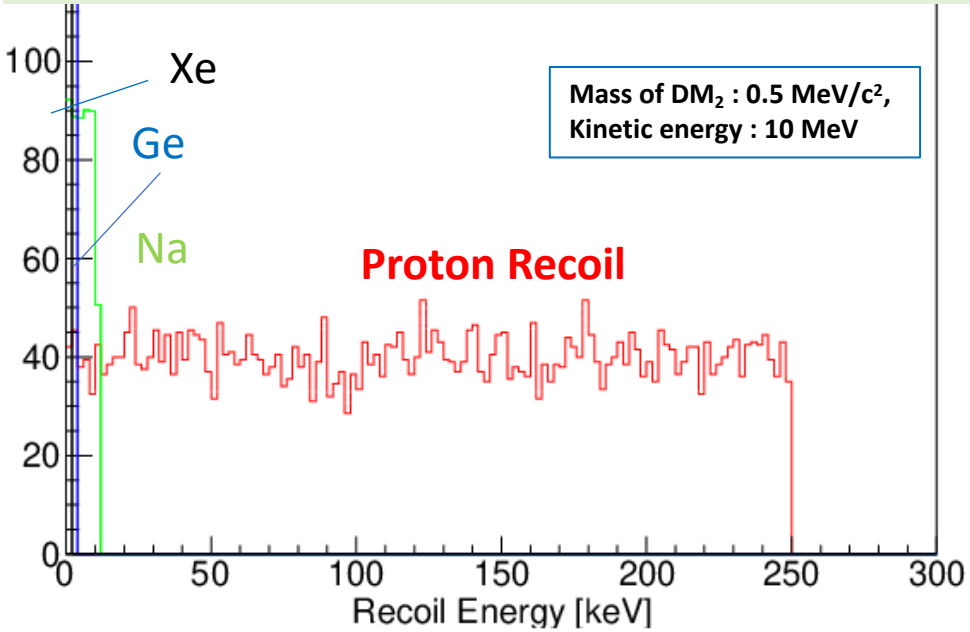
DM is more dense at the Galactic Center

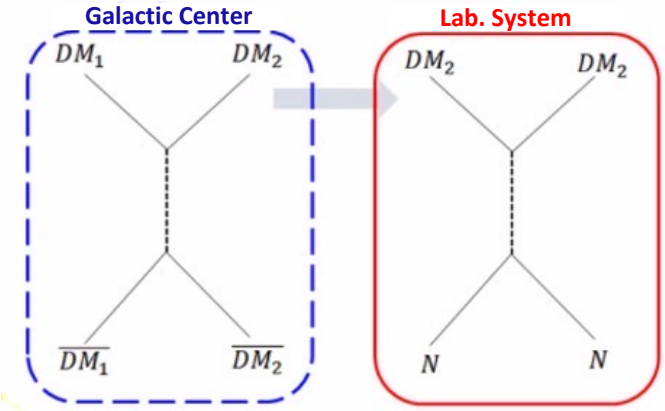
Flux from the Galactic Center

$$\Phi \sim 1.6\ cm^{-2}s^{-1}\left(\frac{<\sigma v>}{5\times10^{-26}\ cm^3/s}\right)\left(\frac{5\ MeV/c^2}{M_1}\right)^2$$

Target Nuclei & Recoil Energy

New parameter space search for MeV scale DM





Annihilation Process

$$DM_1 + \overline{DM_1} \rightarrow DM_2 + \overline{DM_2}$$

$M_1 > M_2$: DM_2 is boosted

→Observe the Elastic scattering with Baryons

https://arxiv.org/pdf/1405.7370.pdf

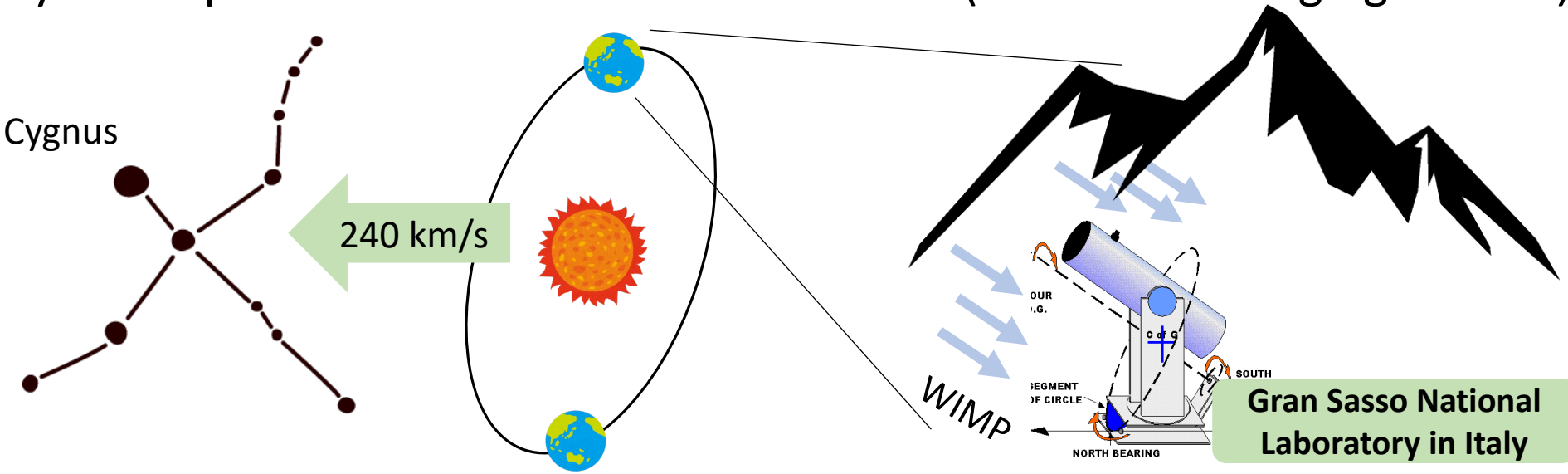
Protons with a larger recoil energy are advantageous

NEWS-dm Experiment

NEWS-dm Experiment

(Nuclear Emulsions for WIMP Search-directional measurement)

→ Direct detection experiment of Dark Matter with **Direction Sensitivity** by the Super Fine Grained Nuclear Emulsion (NIT : Nano Imaging Tracker)



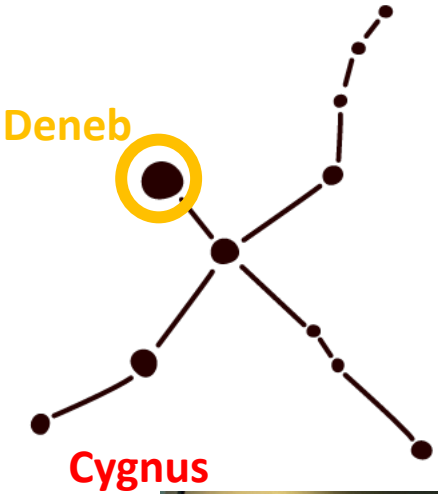
Gran Sasso National Laboratory in Italy

Production

Experiment

Analyze

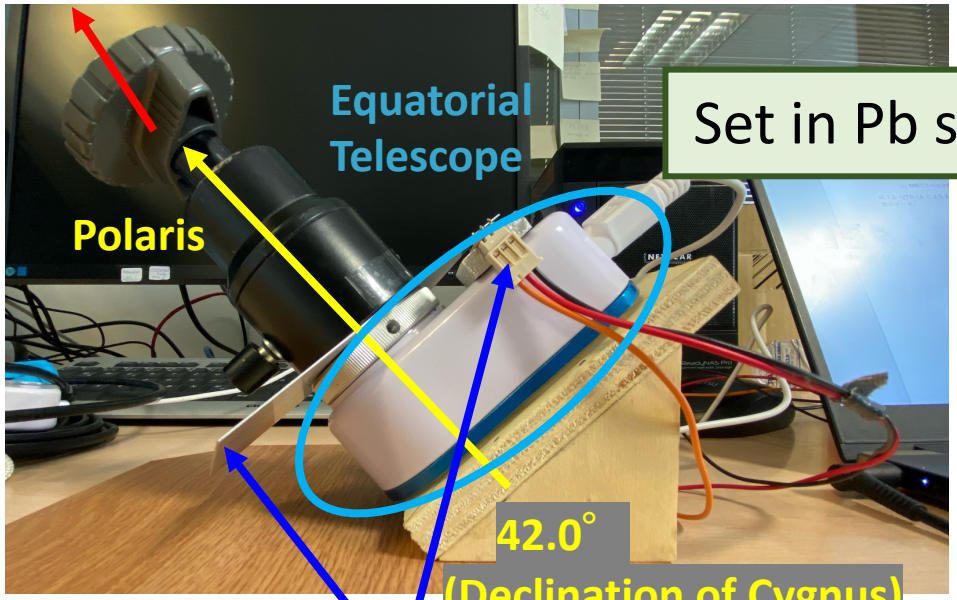
Equatorial Telescope Run (Small - Scale Demo)



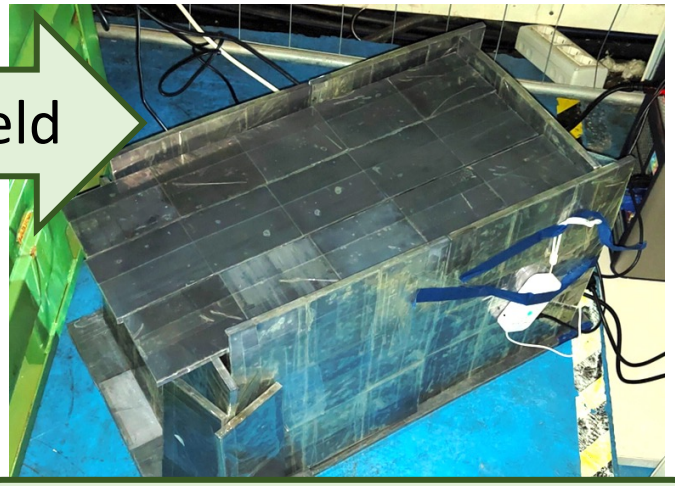
Temperature : -15℃

- Lower electron background
- Suppression of the fading effect
- Already in use for neutron measurements

～1 g/month



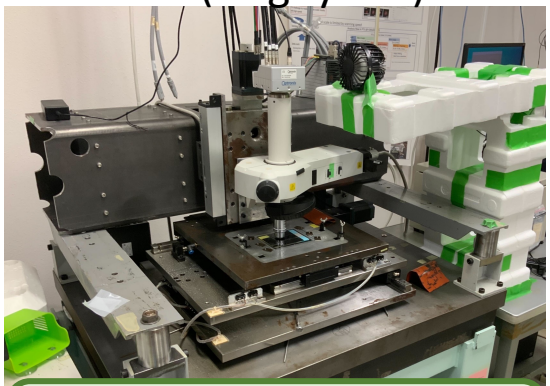
Set in Pb shield



Samples mounted to the telescope inside a freezer

Analysis Method : Scanning System and Speed

PTS-3 (Nagoya U.)

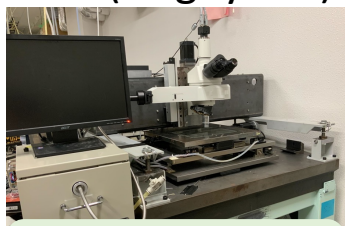


0.44 kg/year
O(100)nm track readout

PTS-4 (Toho U.)

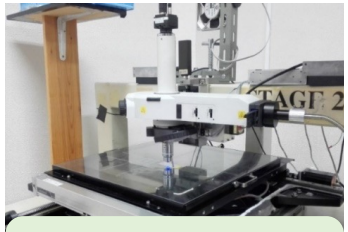
0.5 kg/year
1 um track threshold

PTS-5 (Nagoya U.)



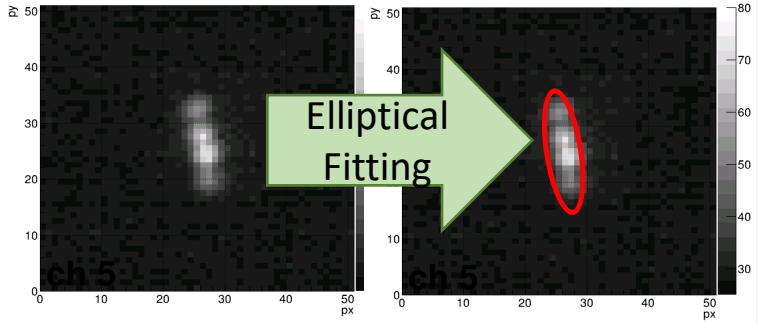
Under Construction

PTS-2 (Kanagawa U.)



Upgrading

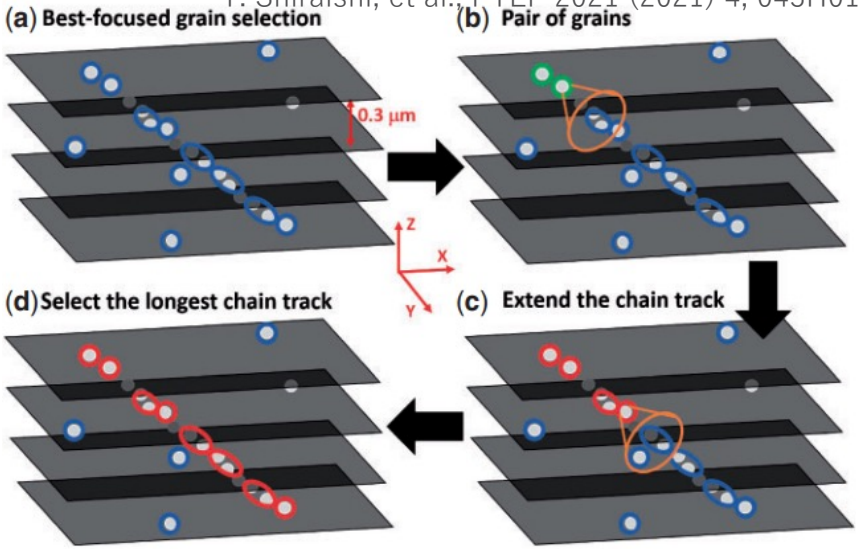
＜Elliptical＞



Shorter Tracks
Target : WIMPs, ions etc.

＜Chain＞

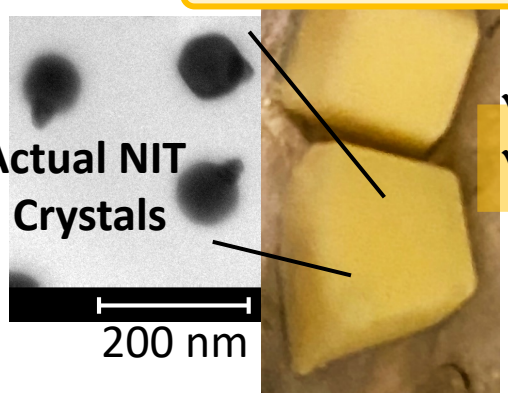
*T. Shiraishi, et al., PTEP 2021 (2021) 4, 043H01



Longer Tracks
Target : neutron, proton etc.

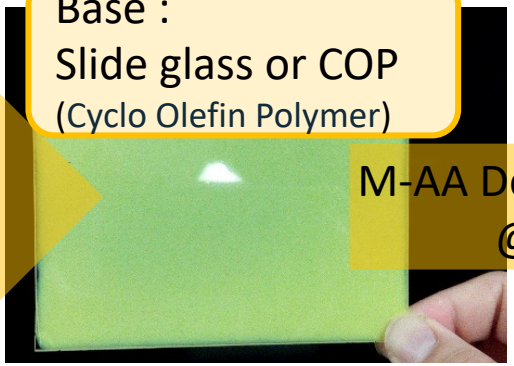
Nano Imaging Tracker : NIT

Emulsion Blocks



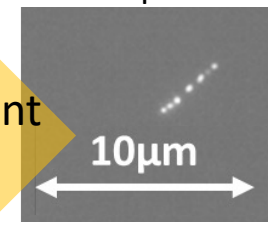
✓ Noodle Washing
✓ Halogen Accepter Sensitization

Base :
Slide glass or COP
(Cyclo Olefin Polymer)



M-AA Development @5 ℃

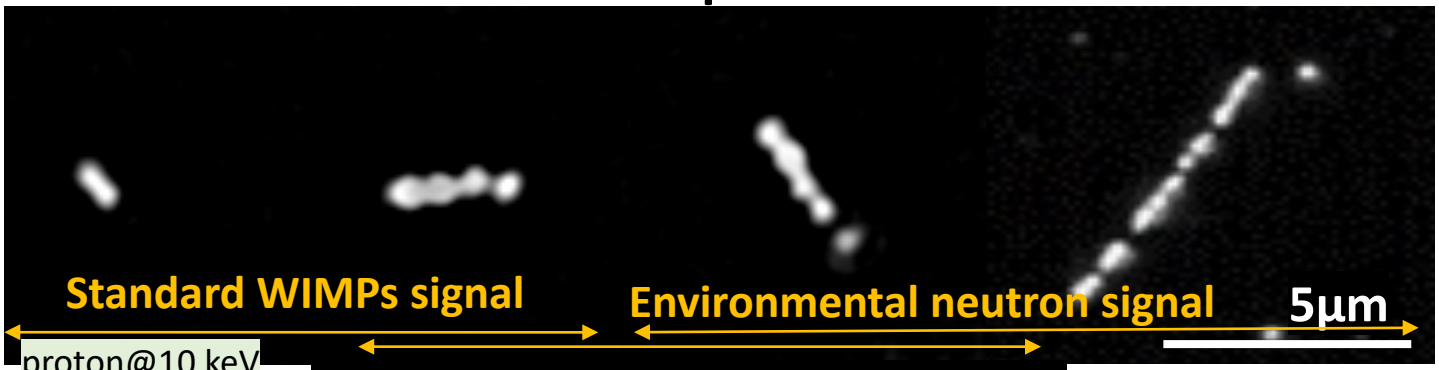
recoil proton



By making the crystal size 70 nm…
- Sub-micron track recognition
- Lower sensitivity for background electrons

Great Spatial Resolution !

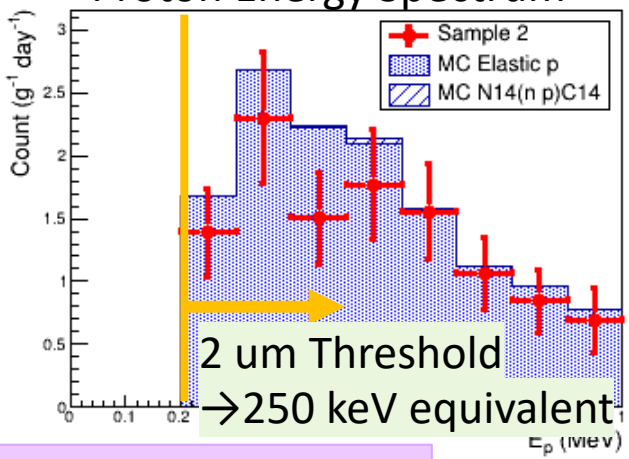
Elements	Atomic fraction [%]
Ag	8.4
Br	8.1
I	0.3
C	22.7
H	42.8
N	5.2
O	12.5



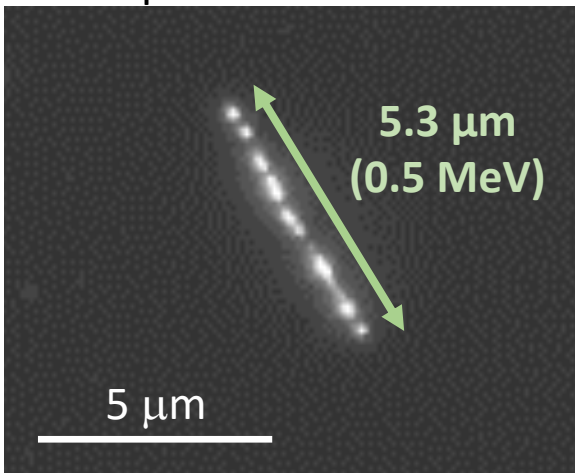
Hydrogen (Proton) target must be considered

Recoil Proton Tracks in Practical Use

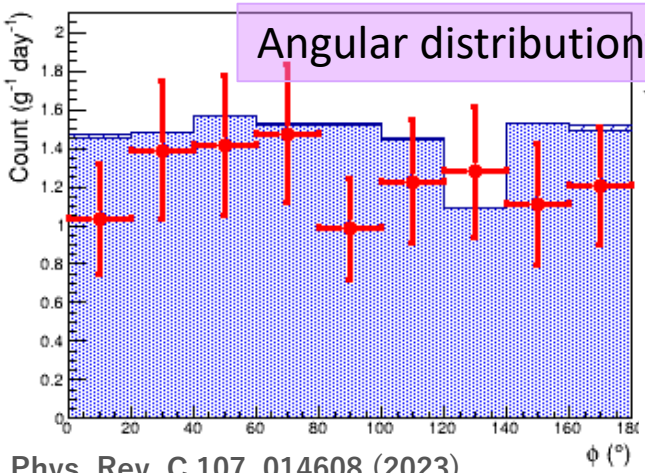
Proton Energy Spectrum

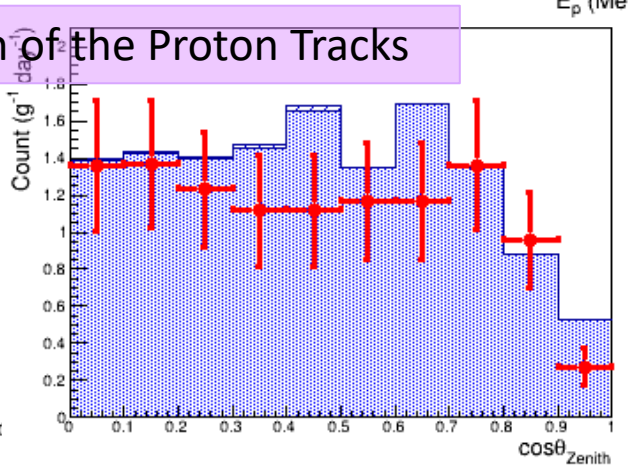


Example of a Proton Track



Angular distribution of the Proton Tracks





Phys. Rev. C 107, 014608 (2023)

Easy to decipher between the electrons & protons from the geometry

Detection of the direction and the energy reconstruction of sub-MeV neutron is proven

→**Proton Recoil is usable as a light DM target ！**

Analyzing Protons

Dark Matter Search and Proton Recoil Energy

Detection Threshold : 250 keV →Free of electron backgrounds

Demonstrated by neutron measurement

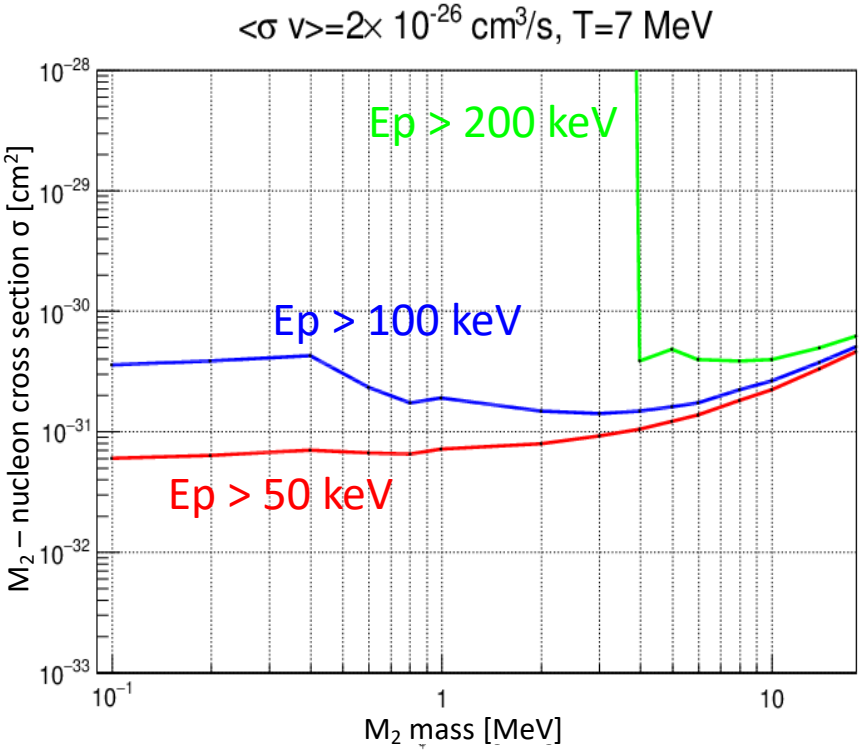
Preliminary

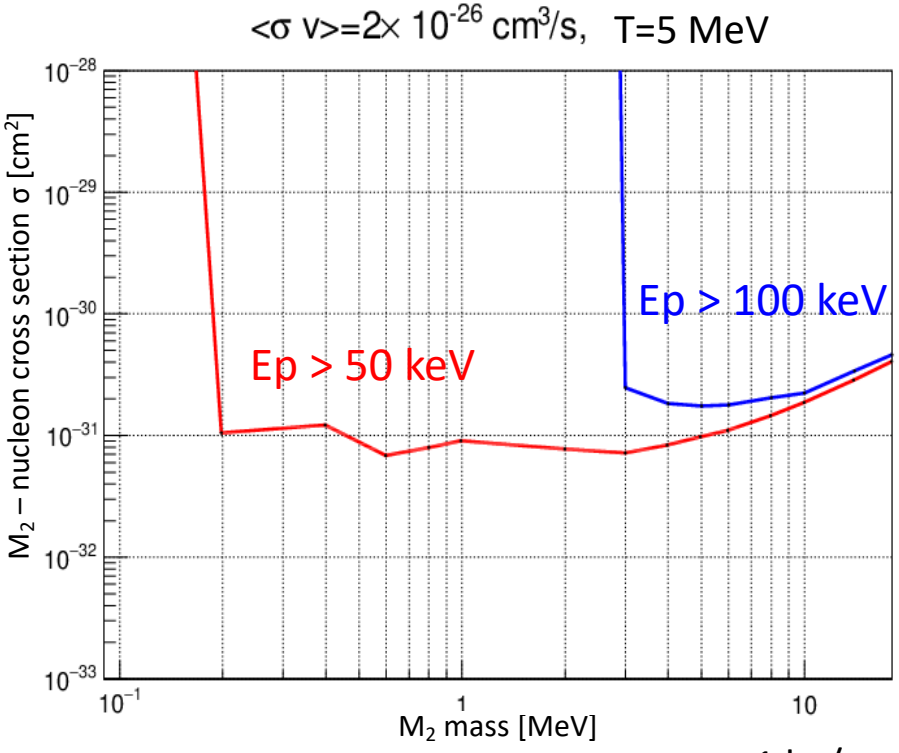
Annihilation Process

$$DM_1 + \overline{DM_1} \rightarrow DM_2 + \overline{DM_2}$$

T : Kinetic energy of DM2

Horizontal axis : Mass of DM2





exposure : 1 kg/month

➢ Evaluate the detection capability of the lower energy protons

Detecting the Directly Exposed Protons @-15℃

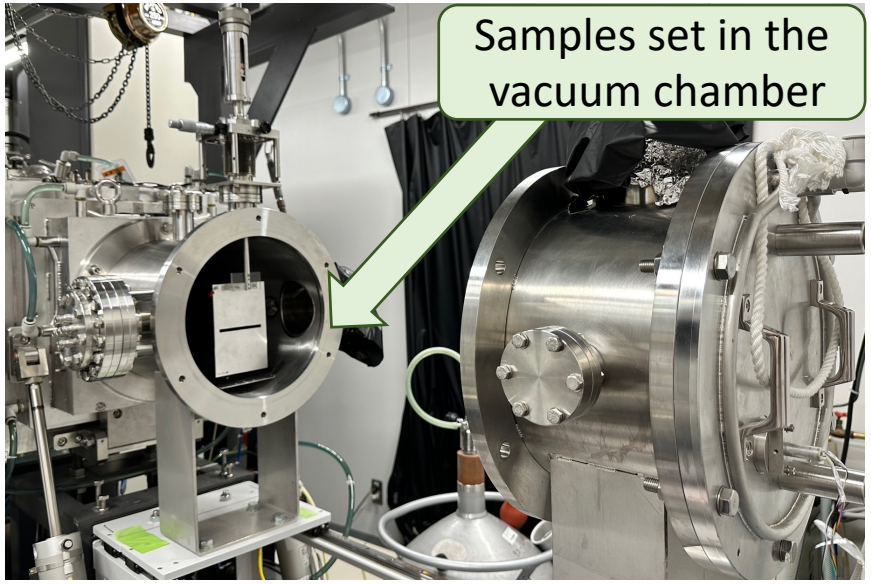
The Under Ground Run is done at a low temperature (-15℃)

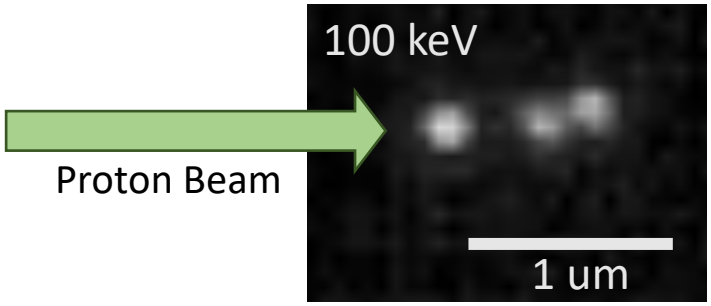
➢ Evaluate the detection capability at this temperature

Exposure energy : 50, 70, 100, 150 200 keV

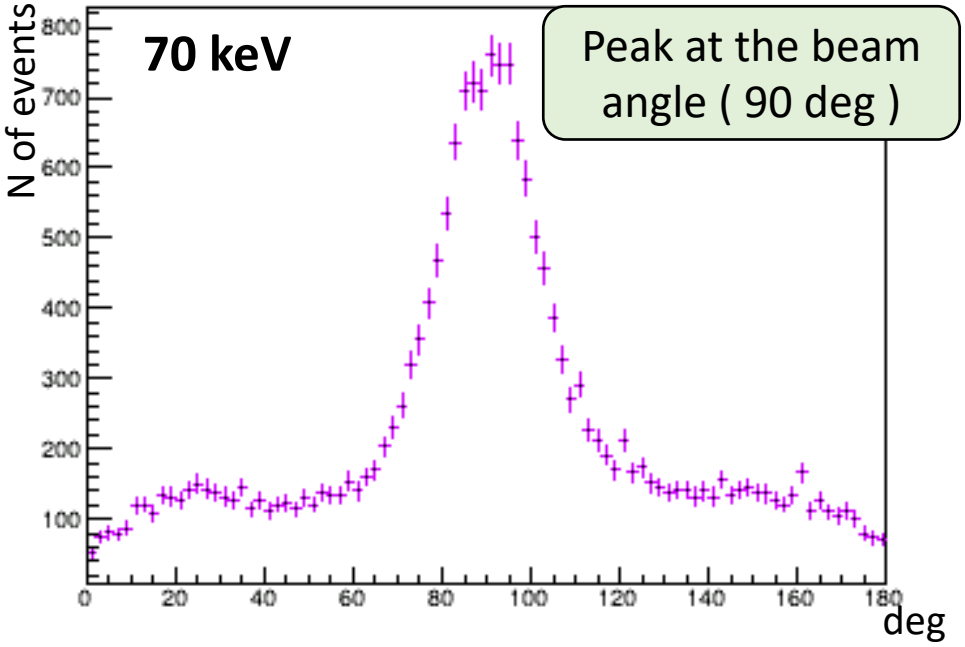
Preliminary

Ion implanter @ Kanagawa Univ. Hoshino lab





Angular Distribution against the beam



The low energy protons can be detected with direction

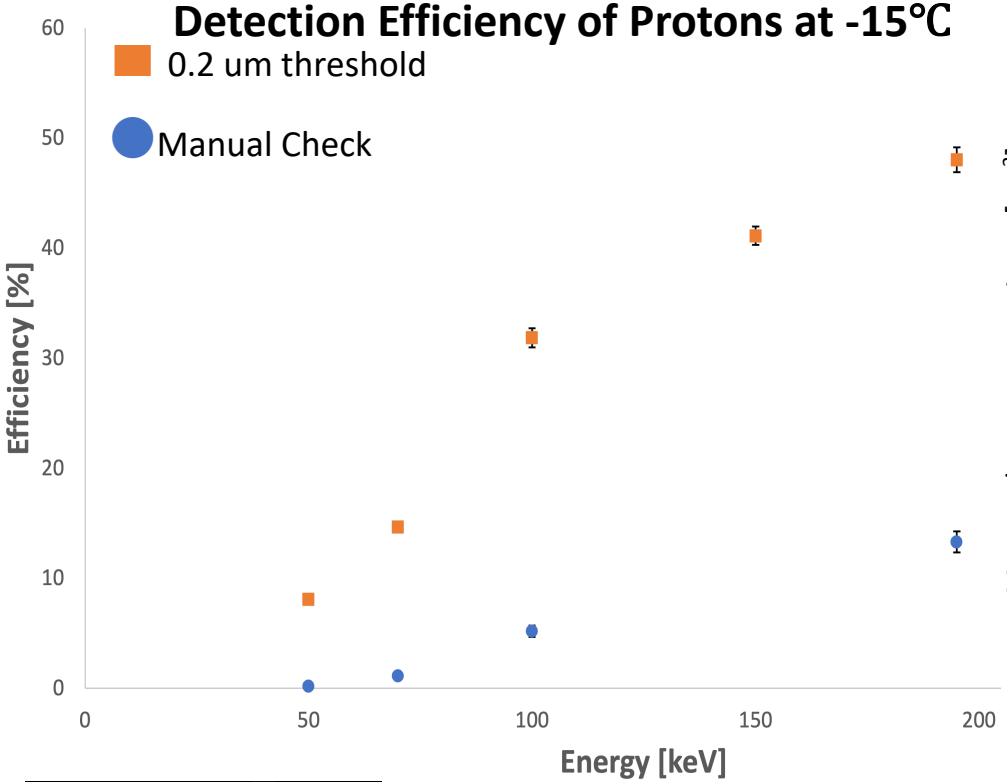
Detecting the Directly Exposed Protons @-15℃

Manual Checking

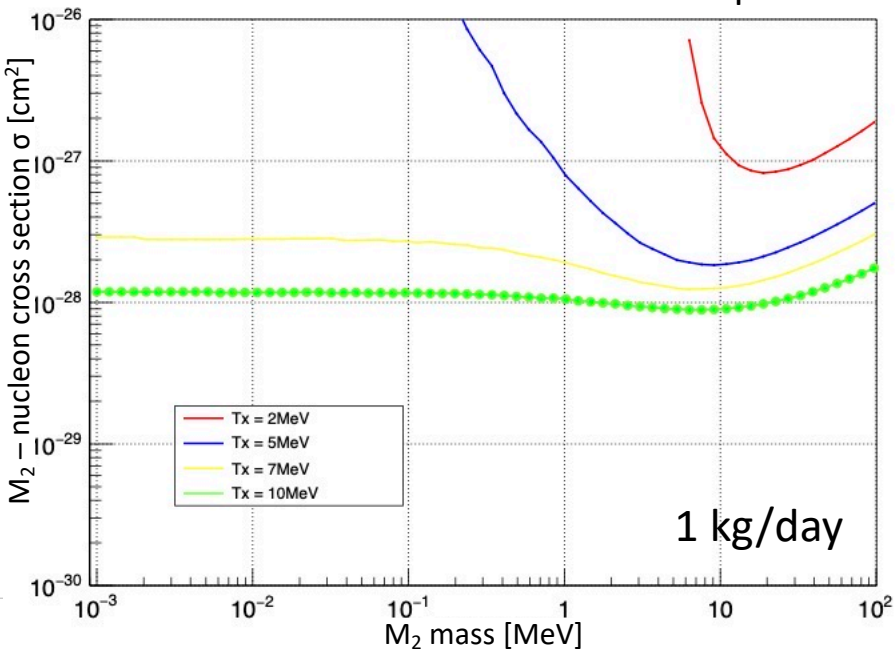
0.2 um threshold & over 3grain tracks

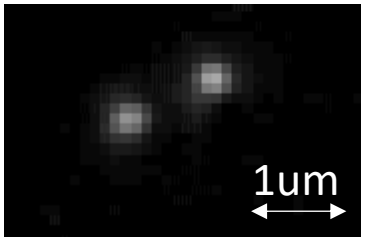
→rejection of chance coincidence from fog & electron background

Preliminary



Possible detection with 50 keV recoil protons





Many 2 grain tracks detected

→An upgrade of the emulsion might be beneficial

✓ Smaller crystals

✓ Denser emulsion etc.

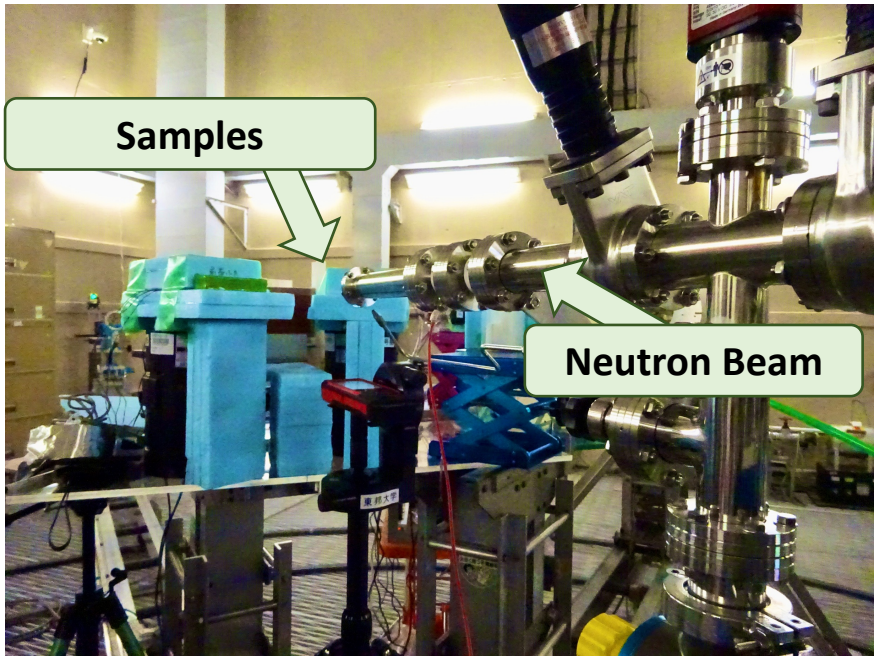
Longer tracks → Better efficiency

880 keV Neutron Experiment (@AIST)

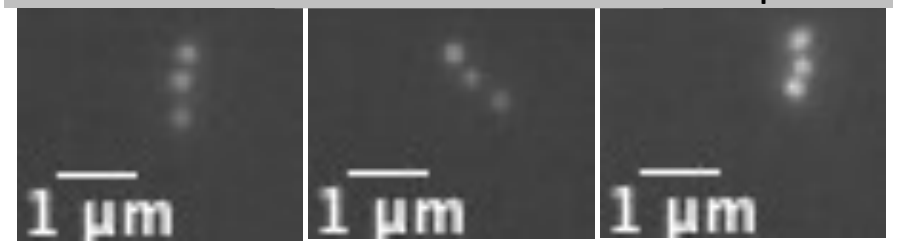
- Detection of Low Energy Protons are demonstrated

➢Evaluating the detection capability of the recoil protons from neutrons

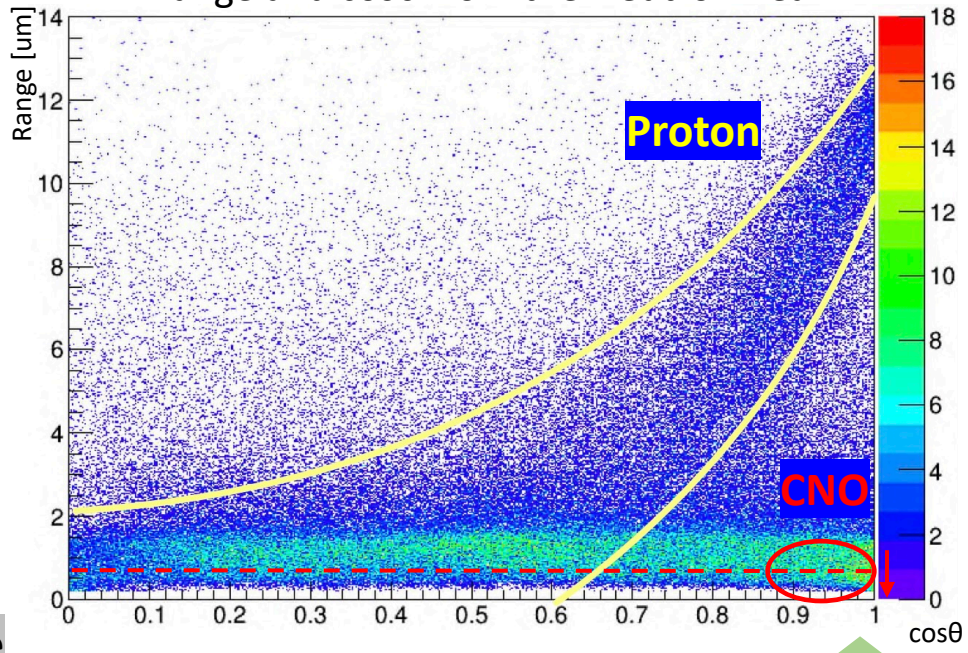
→Further imitating the signals from the actual DM search experiments



Recoil Proton Tracks from 200 keV-n exposure



Range and cosθ from the Neutron Beam



Analysis is ongoing

Beam Direction
cosθ = 1

Summary and Prospects (MCBDM small scale run)

- Summary

✓Nuclear emulsion with Hydrogen has a potential for detecting light DM

✓NIT can detect low energy protons down to 50 keV with direction

Detection capability of Boosted Dark Matter in the MeV region !

- Short Term Goal

First Demonstration of the method for putting a limit to

the DM cross section using Low Energy Protons

- BG contamination rate must be understood (Ongoing…)

✓250 keV threshold is electron background free (Proven by neutron)

- Use the equatorial telescope samples (0day, 6day, 1month, 2months)

➢Fixed against galactic coordinates, ～1 g/month

This is a small-scale demonstration. Even larger scale runs in the future !