

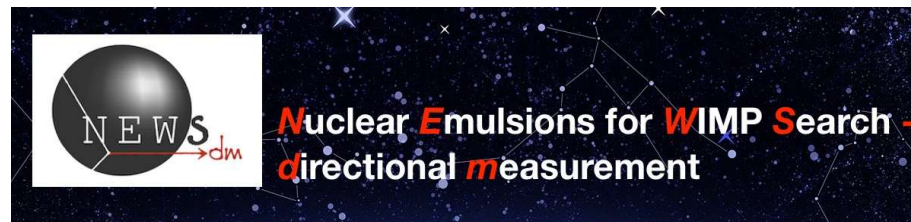
Status Report on the Directional Search for Boosted Dark Matter with NIT in the NEWSdm Experiment

B03

Natsuki CHIN

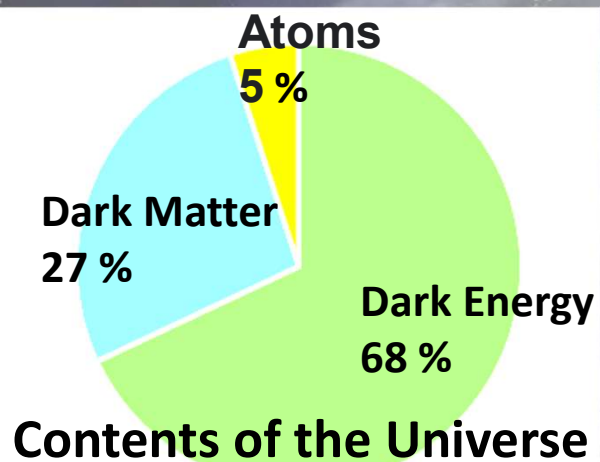
on behalf of NEWSdm collaboration

Nagoya University



Directional Direct Search for Dark Matter

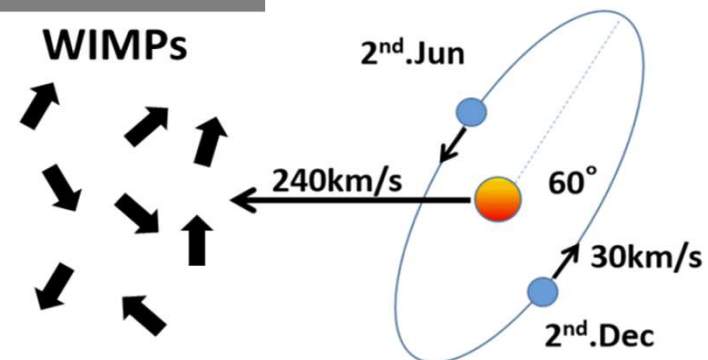
- Electrical neutral
- Massive
- Long-lived and stable
- Non-relativistic motion (Cold DM)



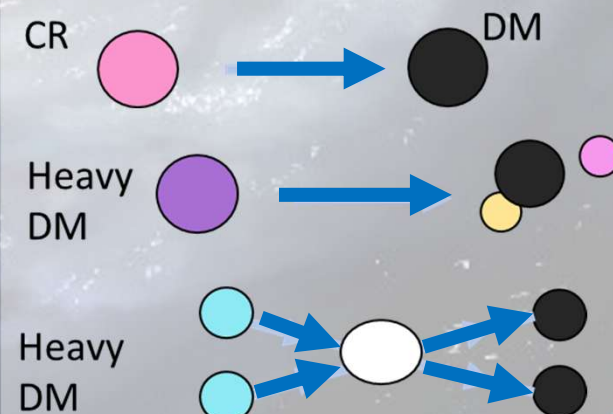
**Expected Describes beyond
the Standard Model**



WIMP

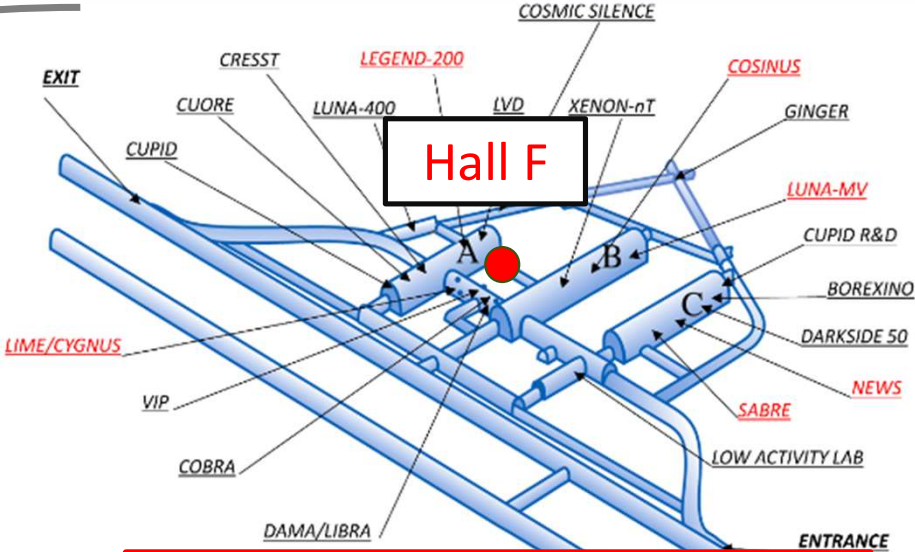
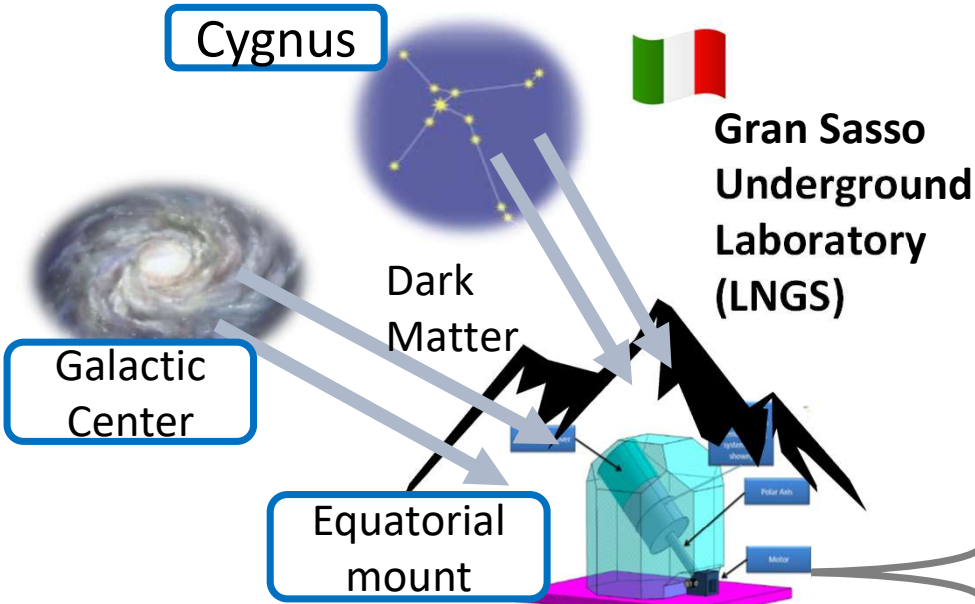


Boosted Dark Matter



Talk : S1-3 Motoko Fujiwara

NEWSdm experiment



Located 1000 m underground

All processes can be performed underground.



NIT Production

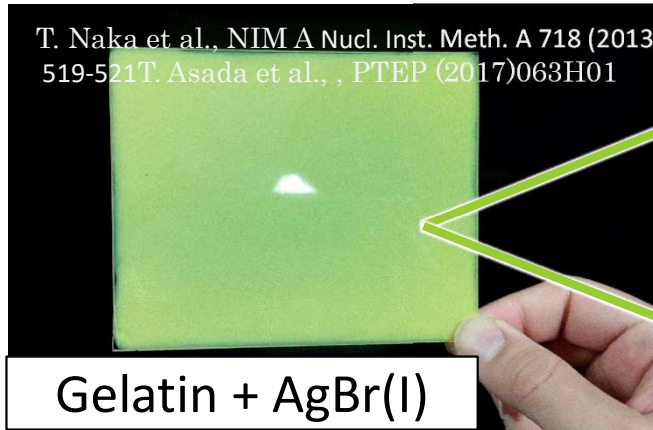
Run ~ Development

	Surface	1000 m Under ground
	Flux	
muon	$\sim 10^{-2} / \text{cm}^2 / \text{s}$	$\sim 10^{-8} / \text{cm}^2 / \text{s}$
neutron	$\sim 10^{-3} / \text{cm}^2 / \text{s}$	$\sim 10^{-6} / \text{cm}^2 / \text{s}$
γ (environment)	$\sim 0.3 / \text{cm}^2 / \text{s}$	$\sim 0.3 / \text{cm}^2 / \text{s}$
α (Rn)	$\sim 10 / \text{cm}^2 / \text{s}$	$\sim 10 / \text{cm}^2 / \text{s}$

Nano Imaging Tracker : NIT^[1] [1/2]

[1]Takashi Asada, Tatsuhiro Naka, et.al, PTEP(2017)063H01

T. Naka et al., NIM A Nucl. Inst. Meth. A 718 (2013) 519-521
T. Asada et al., PTEP (2017)063H01



Gelatin + AgBr(I)

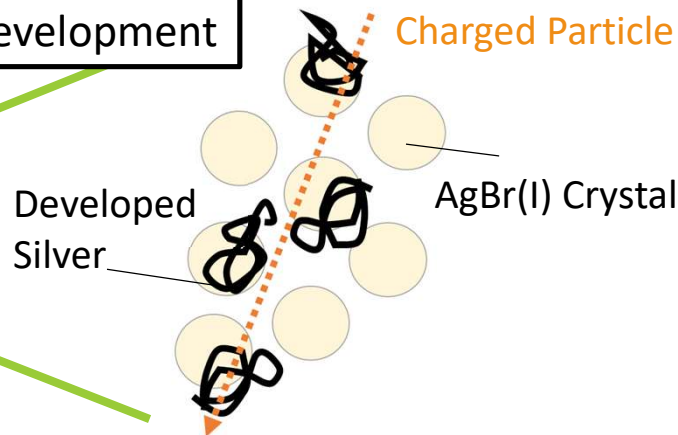
Nuclear Emulsion

Development

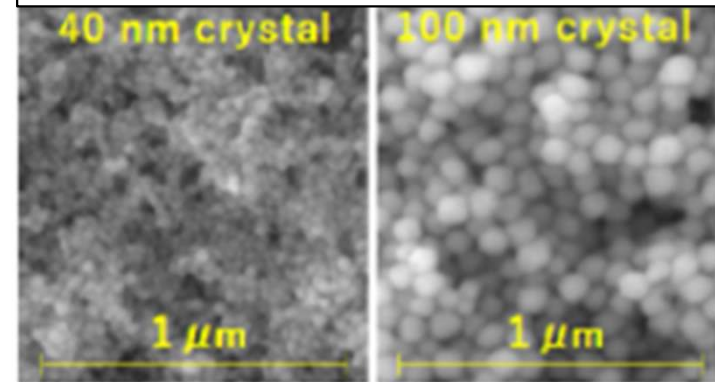
Developed
Silver

Charged Particle

AgBr(I) Crystal



SEM Image of the crystals



- 3D track information can be preserved within the detector
- Sub-micron spatial resolution (Currently using 70 nm crystals)

■ Optical readout



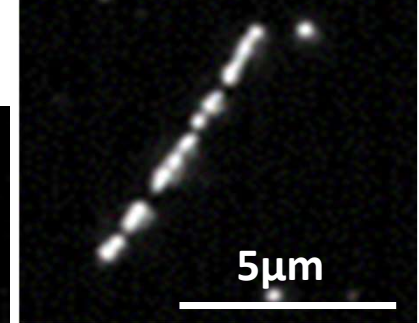
10 keV@proton
30 keV@CNO



WIMP signal

Higher energy signal e.g., Boosted DM

>500 keV @proton



Proton recoil or alpha

■ Advantages of NIT for DM Search

- Contains both light and heavy target nuclei
→ Enables dark matter searches over a wide mass range
- **NIT density: 3.1 g/cm^3**
→ $\sim 10^3$ times higher than gas-based detectors
- **Easily scalable to large detector volumes**

【 Composition of NIT 】

Element		Atomic fraction [%]	
Ag		8.4	
Br	Heavier DM	8.1	
I		0.3	
C		22.7	
N	Main Target	5.2	Standard WIMP
O		12.5	
H	Lighter, Boosted DM	42.8	Boosted DM

Track selection procedure

“Short” Tracks

$R > 0.3 - 1.0 \mu\text{m}$

Elliptical Analysis

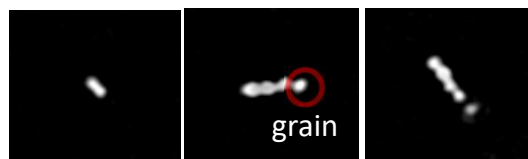
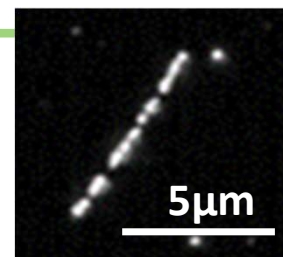


Image data
3D position data
Elliptical fitting data
Brightness



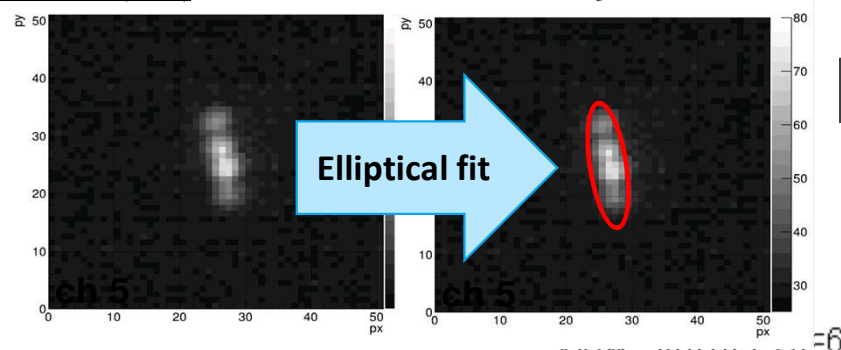
“Long” Tracks

$R > 1 \mu\text{m}$

Chain Analysis

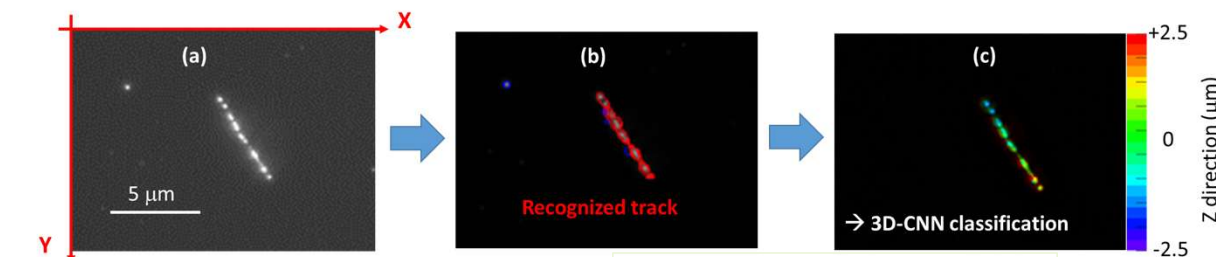
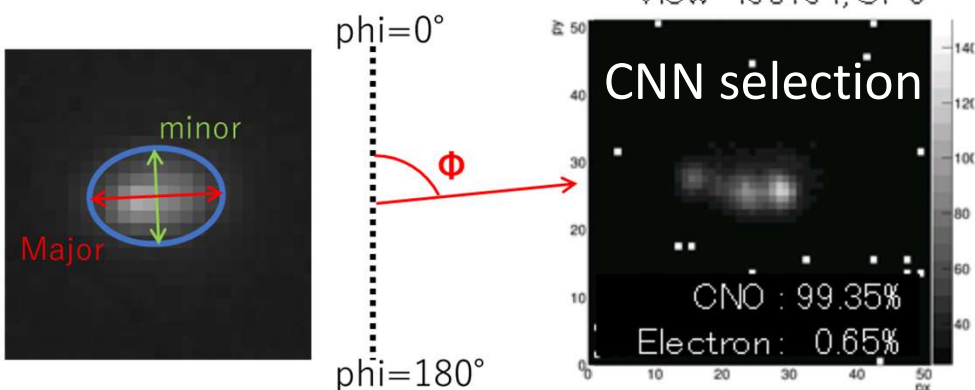
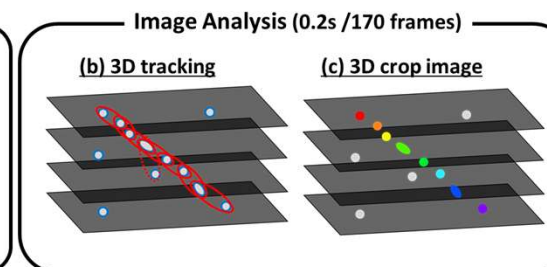
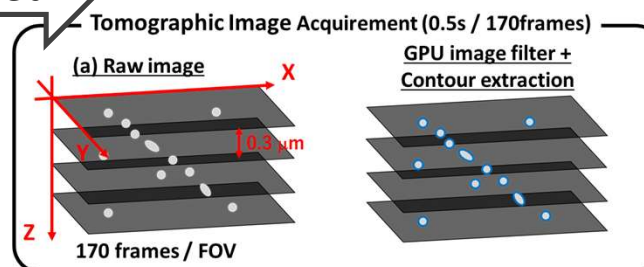
3D reconstruction

JINST 12 T04002 (2017) Nucl. Inst. Meth. A 680 (2012) 12-17



applied

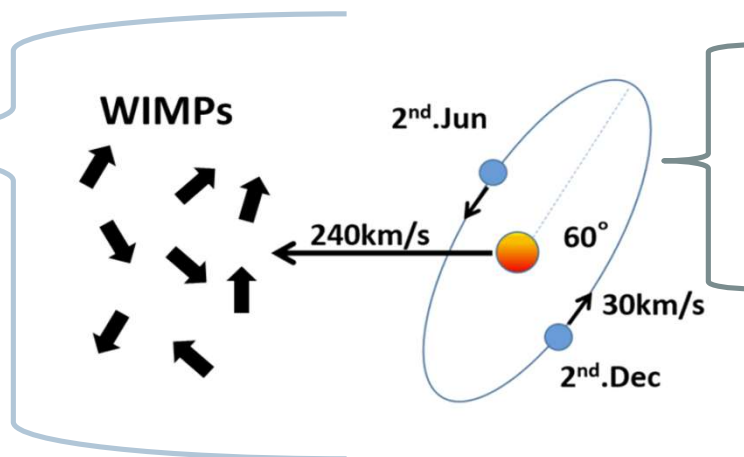
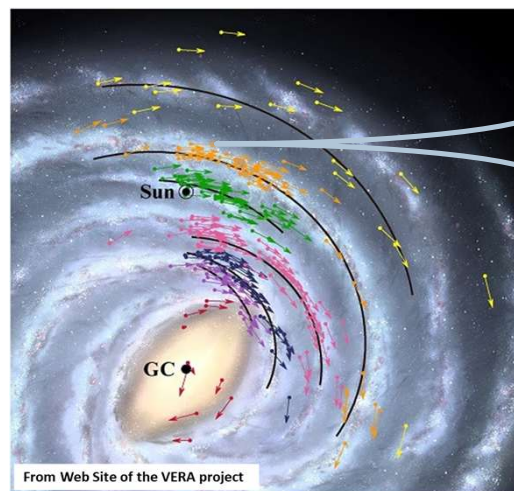
T. Shiraishi, S. Akamatsu, et al, PHYSICAL REVIEW C 107,014608 (2023),
T. Shiraishi, et al., PTEP 2021 (2021) 4, 043H01,



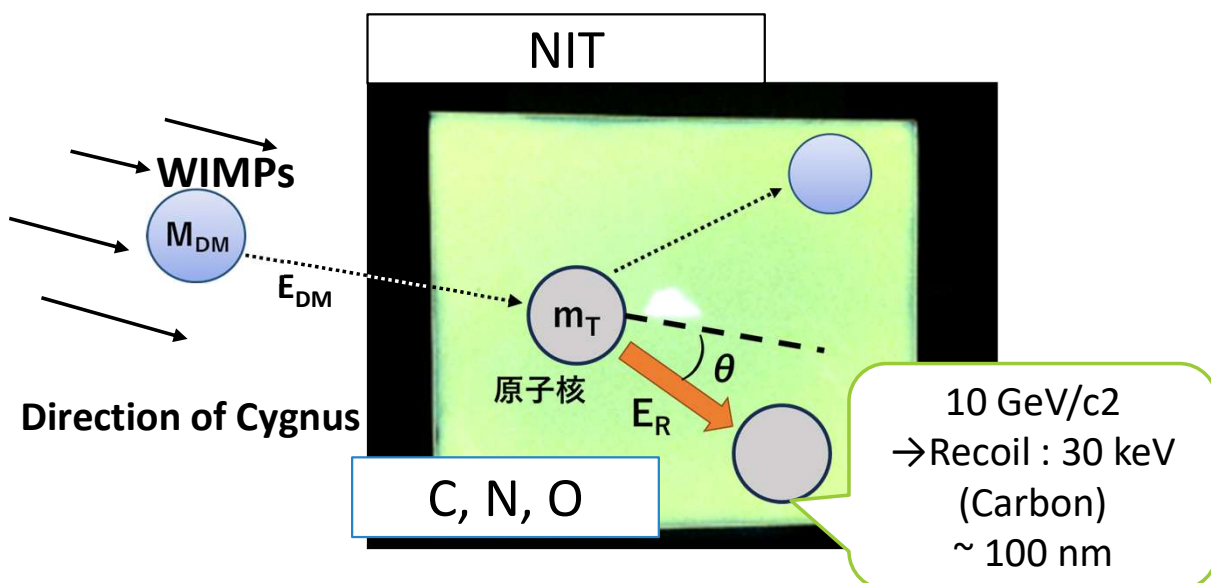
+3D CNN selection (on going)

→Poster
P49 : Mai Morizawa

WIMP: Weakly Interactive Massive Particles



Mass: $1 \text{ GeV}/c^2 - 10 \text{ TeV}/c^2$
 Direction: Cygnus.
 Velocity : 240 km/s
 Local DM Density : $0.4 \text{ GeV}/c^3$



First WIMP Search by NEWSdm (Surface Lab. Run)

→ A. Umemoto et. al., JCAP02(2025)012

- Demonstration of solid tracking detector and directly tracking analysis
- First Directional search around $10 \text{ GeV}/c^2$ region

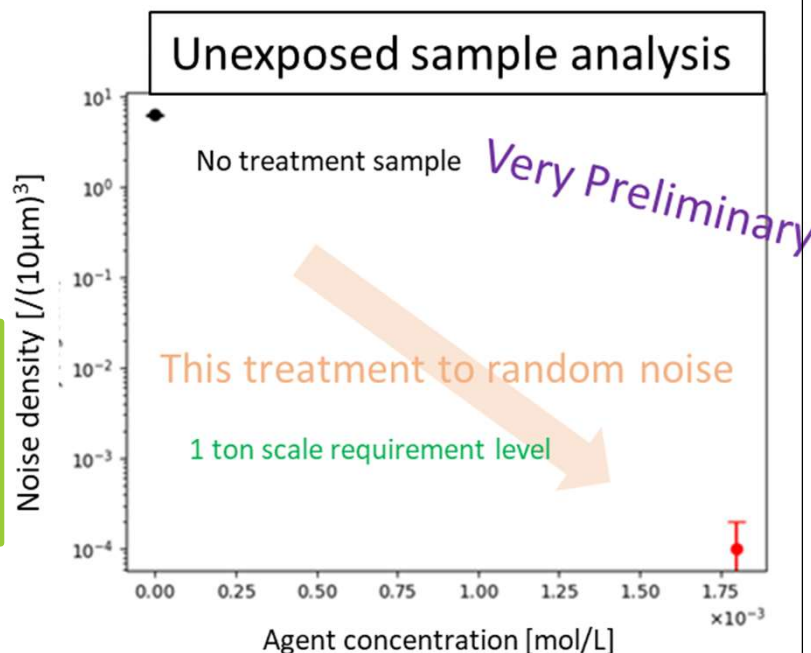
$10 \text{ GeV}/c^2$
 → Recoil : 30 keV
 (Carbon)
 $\sim 100 \text{ nm}$

Further Developments for Underground DM Searches

■ Low-background device development

- Chemical method for **noise reduction**

Noise level is reduced
by **5 orders** of
magnitude!



In parallel

- **Enabling searches with larger statistics**
 - Both DM and Environment neutron
 - ton scale search
- **Reduced BG enables faster scanning.**
 - Development and implementation of a new scanning approach

■ Scale up

- Emulsion coat area
- Chemical Development facility
- Scanning machine speed

- **Scaling up enables searches for DM models beyond standard WIMP.**

main
topic

Recent Timeline of NEWSdm

FY2024-2025

FY2026

~FY2028

Under Ground Neutron*** , Background Measurement (with group D01)

WIMP Search*

*A. Umemoto et al JCAP02(2025)012

MCBDM Search

main
topic

Scaling up of the device

1 year

- 500 g • day

1 kg • day Scale

10 kg • day

main
topic

- Equatorial mount
- Coating technique & area
- Development facility

Scanning machine (PTS)

Ellipticity

PTS3 @ Nagoya Univ. ... 250 g/year

chain

PTS2.2 @ Kanagawa Univ. ... 1.3 kg/year (1 μm <)**

PTS4 @ Toho Univ. ... 250 g/year ***

Total
1.8 kg /year

Under development : PTS5 @ Toho Univ.

**T. Shiraishi , JPS

***T. Shiraishi , S. Akamatsu, et al, PHYSICAL REVIEW C 107,014608

2026/9/28-30(talk in 30 min)

UGRP2026@Institute of Science Tokyo, Natsuki CHIN

Boosted DM

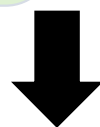
■ Non-relativistic Dark Matter

→ Low Kinetic Energy

e.g. : $m_{DM} = 1 \text{ GeV}/c^2$, $v_{DM} = 240 \text{ km/s}$

$$\frac{1}{2}(m_{DM})(v_{DM})^2 \sim 0.3 \text{ keV}$$

→ **Challenging with existing detectors
(DM-baryon interaction)**



■ Boosted Dark Matter

Dark Matter acceleration mechanisms have been actively discussed in recent years.

In UGRP 2026

Talk : S1-3 Motoko Fujiwara
Poster : P12 Takashi Toma

- G. Elor, et. al., Phys. Rev. D 91 (2015), [arXiv:1503.01773 [hep-ph]].
- K. Agashe, et. al., JCAP 10 (2014), 062, [arXiv:1405.7370 [hep-ph]].
- M. Aoki and T. Toma, JCAP 10 (2018), 020, [arXiv:1806.09154 [hep-ph]].
- J. Li, T., et. al., Phys. Rev. D 108 (2023) no.3, [arXiv:2302.09839 [hep-ph]].
- A. Basu, et. al., [arXiv:2310.09349 [hep-ph]].

When Light Dark Matter is **Accelerated**
→ Gains sufficient kinetic energy for detection

Boosted DM Mechanisms

■ Acceleration Mechanism in the Highest-Density DM Region (Galactic Center)

• Cosmic Ray Scattering



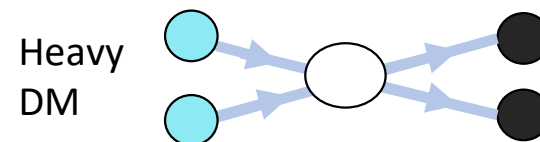
Y. Ema, F. Sala, R. Sato 1811.00520
T. Bringmann et.al.1810.10543

• Heavy DM particle Decay



K. Agashe et al. 1405.7370 J.Berger et al. 1410.2246

★ Heavy DM particle Annihilation



■ Advantages of Directional Search

- WIMP: Cygnus direction
- Boosted DM: Galactic Center direction

→ Directional sensitivity enables discrimination

■ Multi Component Boosted DM (MCBDM)

with Group E01

Keiko I. Nagao, Tatsuhiro Naka, and Takaaki Nomura, JCAP04(2025)030

Multi Component Boosted Dark Matter (MCBDM)

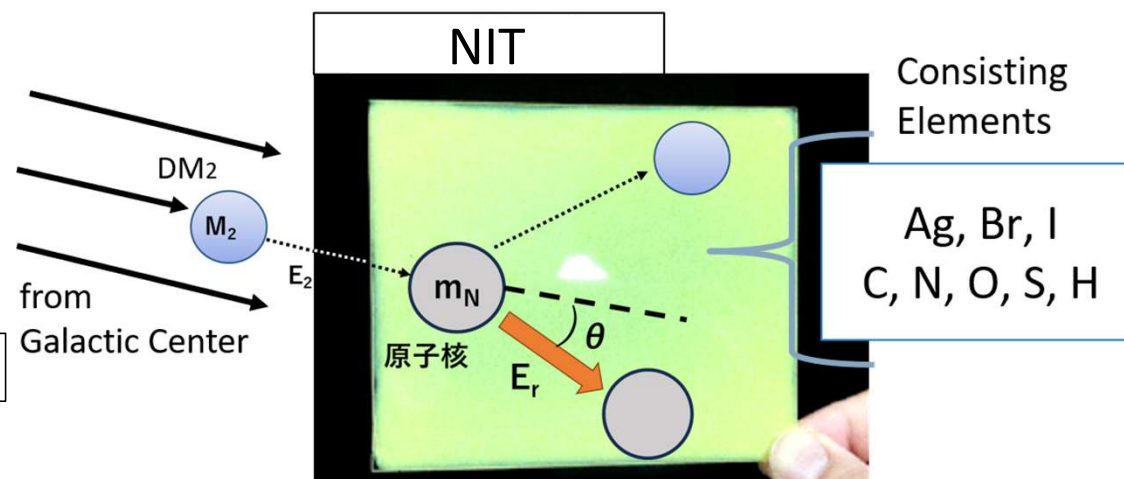
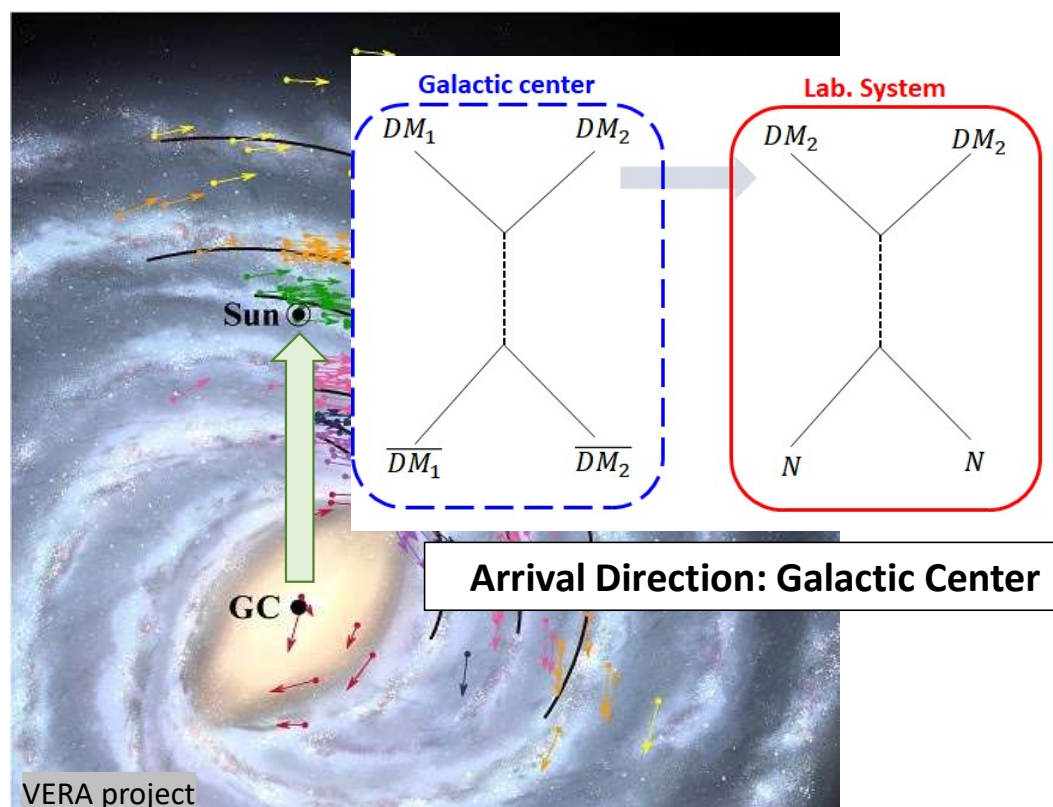
Dark Matter Acceleration via Annihilation $\rightarrow$ MeV/c² Dark Matter Search

Heavy DM₁ : Thermal freeze-out in the early Universe determines its relic abundance, while avoiding direct-detection constraints.

Kinetic Energy of Incoming DM₂ : DM₁-DM₂ Mass Difference

$$\rightarrow \boxed{T_2 = M_1 - M_2} \quad M_1 > M_2$$

DM₂ : **Mass : MeV/c²-Scale**
Kinetic Energy : MeV-Scale

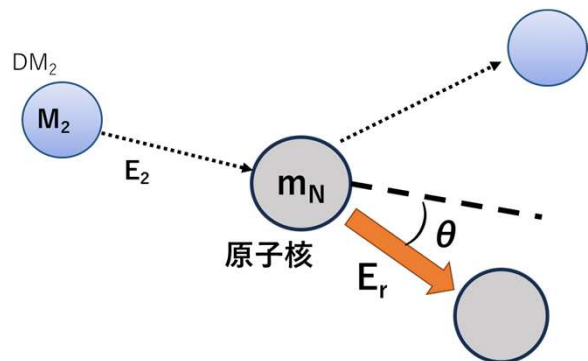


T. Naka et al., NIM A Nucl. Inst. Meth. A 718 (2013) 519-521 T. Asada et al., PTEP (2017)063H01

$\rightarrow$ Detection of DM₂ in the Detector

Scattering Energy between Boosted DM and Target Nuclei

DM₂–Nucleon Elastic Scattering



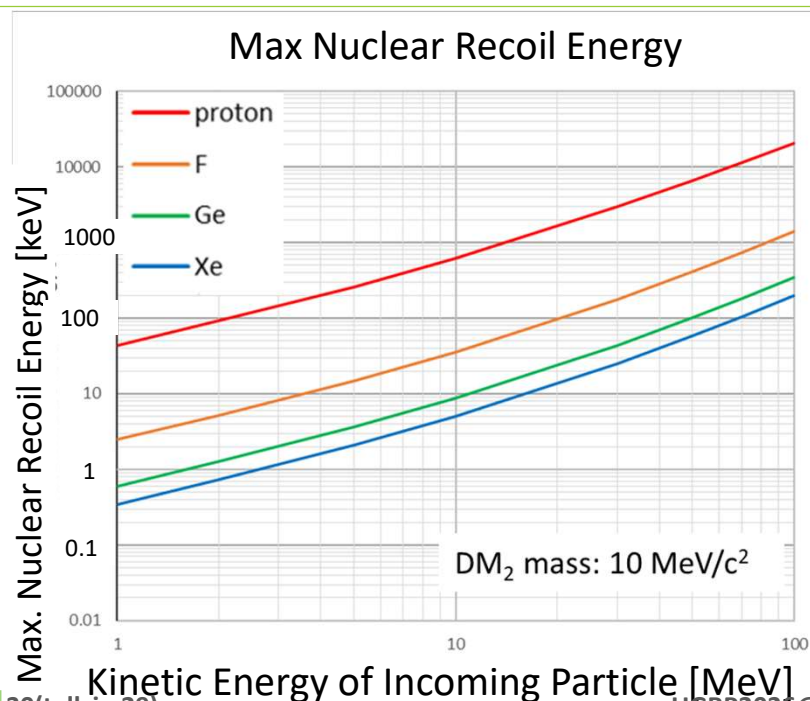
$$E_r = \frac{2m_N\beta^2 E_2^2 \cos^2 \theta}{(E_2 + m_N)^2 - \beta^2 E_2^2 \cos^2 \theta}$$

DM₂ mass: MeV/c²

The velocity reaches relativistic values.

M₂: DM₂ mass、m_N: Target nuclear mass、
E_r: Kinetic Energy of recoil nuclei、
E₂: Total Energy of DM₂、β: v/c

MCBDM searches using baryons as targets
→ Detectors with **hydrogen** nuclei as targets are ideal



Proton

F

Ge

Xe

【Elemental Composition of NIT】

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

Lighter,
Boosted DM

Measurement of Underground Neutrons

Environmental neutron measurements were performed using NIT and chain analysis.

- **Underground neutron measurements are important for understanding the background.**

Nuclear recoil by Neutron → Background in direct DM search

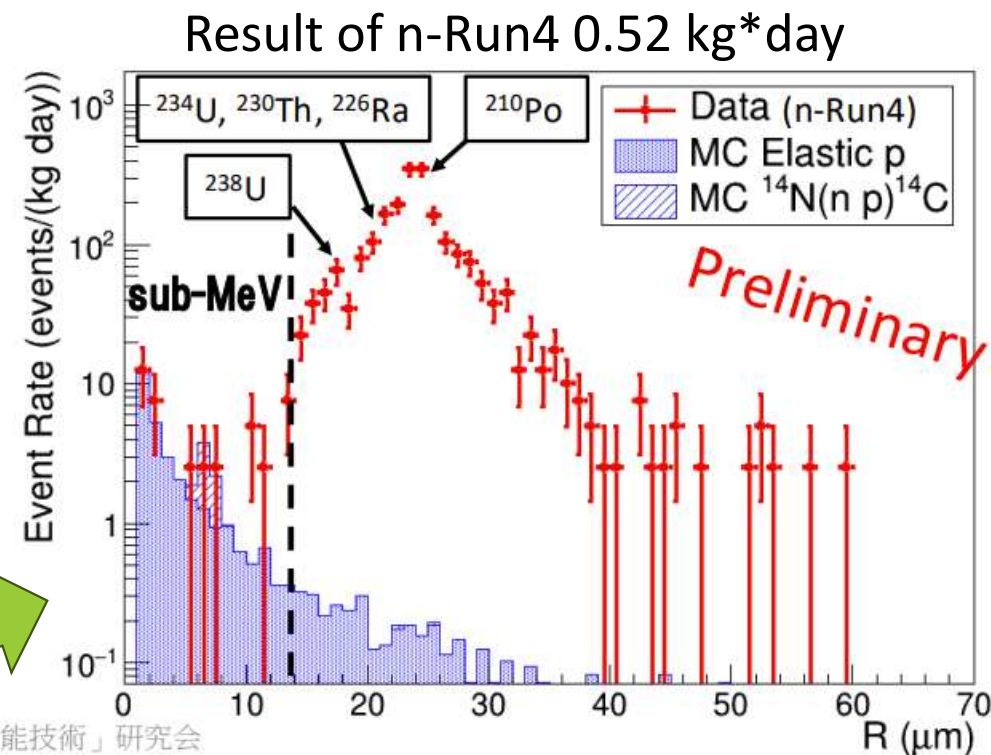
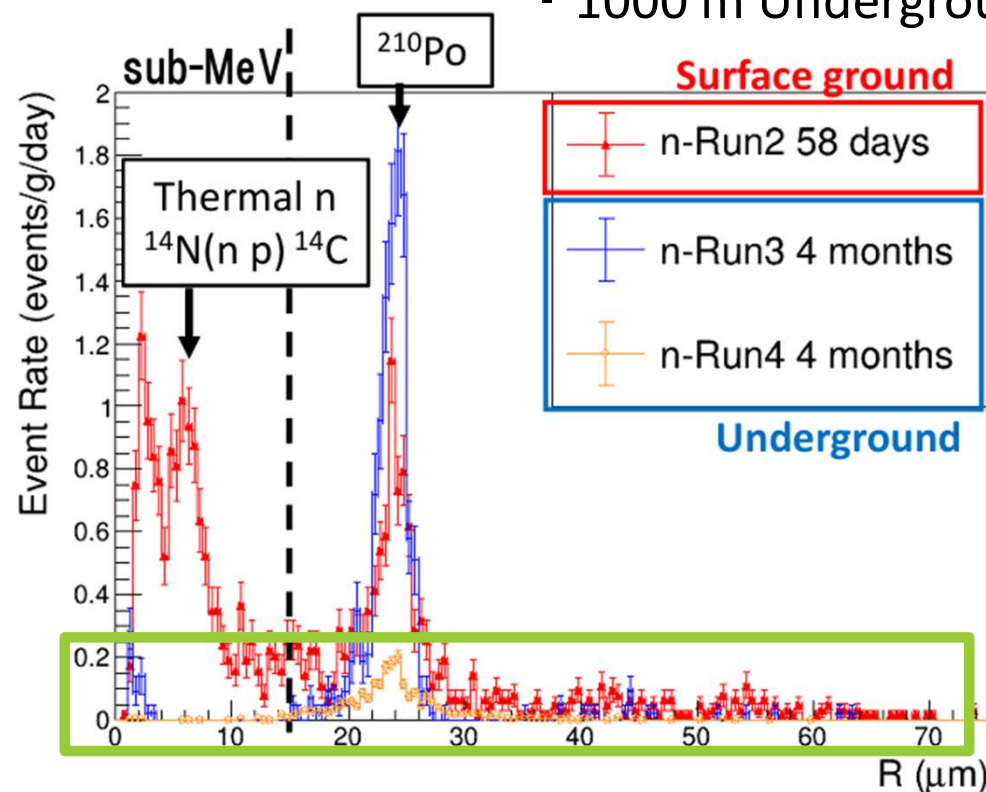
- **Verification of the DAMA annual modulation**
- **Demonstration of low mass dark matter search (e.g. Boosted DM)**

Measurement of Underground Neutrons in the Sub-MeV Range

NIT & Chain Analysis

- Surface ground of LNGS
- 1000 m Underground of LNGS

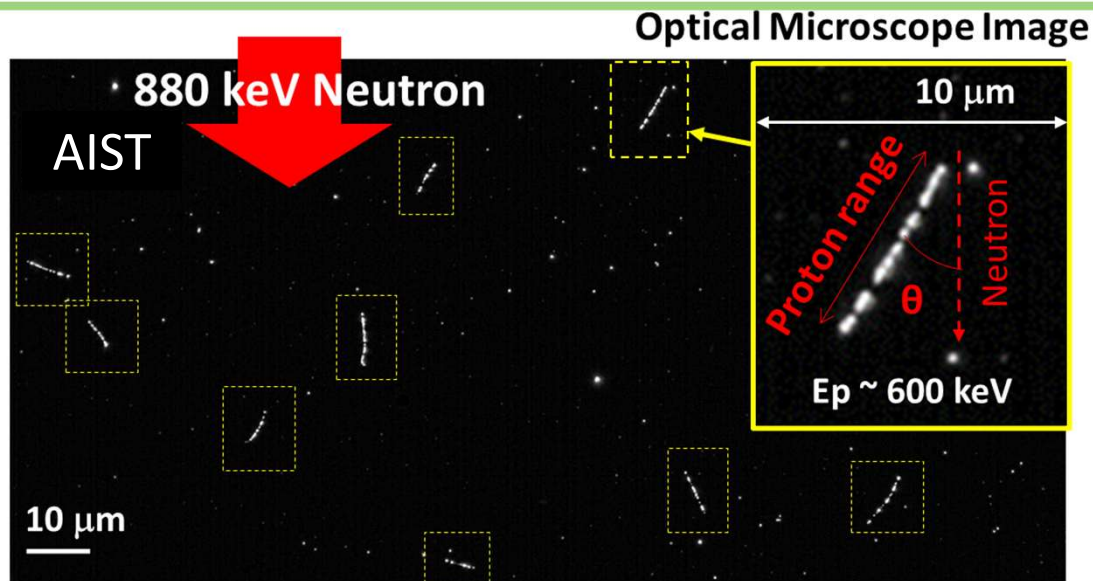
B03 & D01



In sub-MeV region, both surface ground and underground measurements are consistent with predictions

Reported by T. Shiraishi, CYGNUS2026

Potential for MCBDM Searches with Neutron Analysis

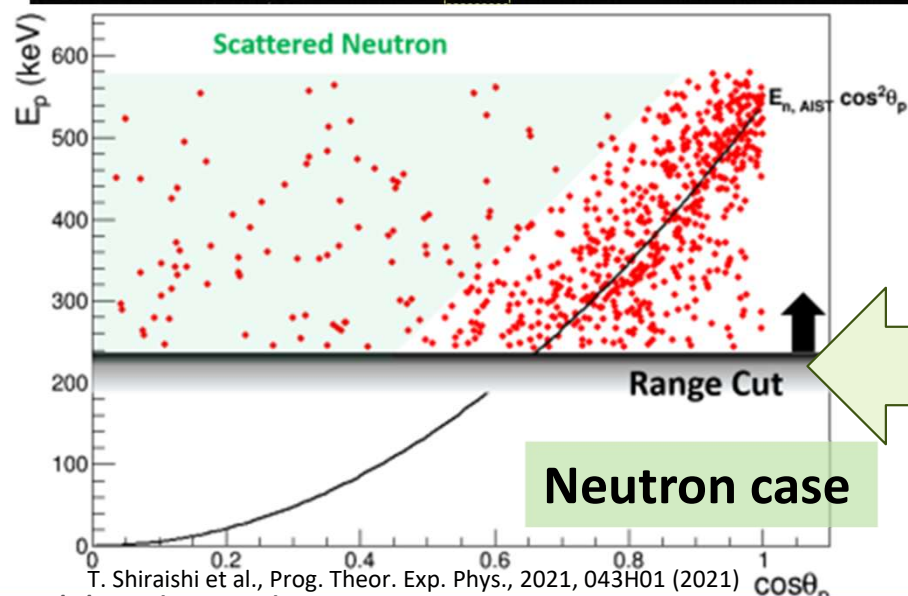


Galactic Center

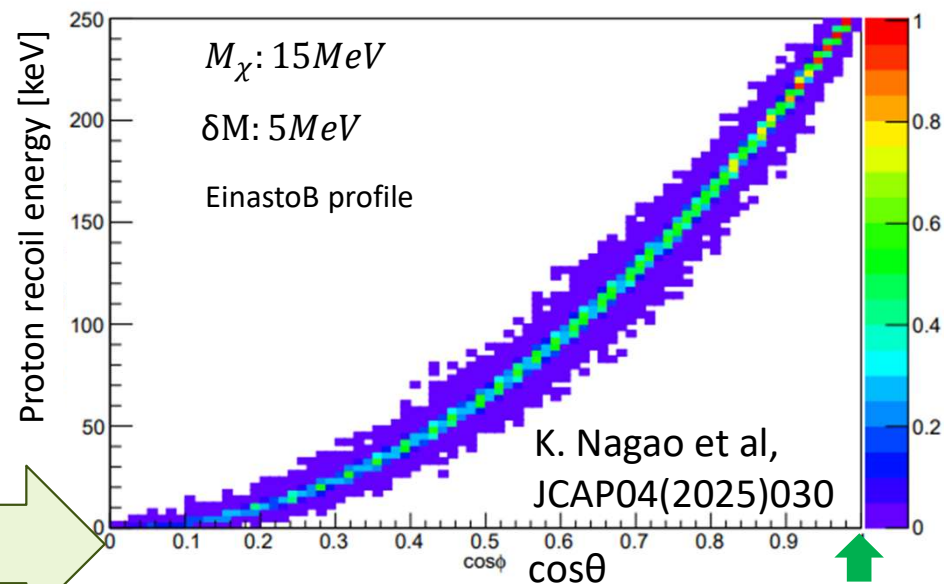
→ Effectively a point source

Point-source neutron event detection has already been demonstrated with AIST Neutron

MCBDM Signal Expectation (without the range threshold)



NIT has the potential for **directional** searches for MCBDM.



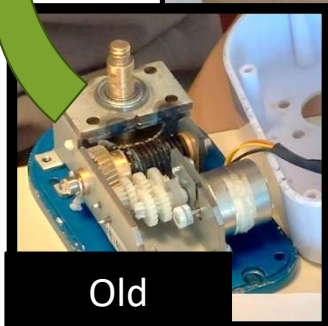
Jul. – Nov. 2026: First run currently underway at LNGS

T. Shiraishi et al., Prog. Theor. Exp. Phys., 2021, 043H01 (2021)

UGRP2026@Institute of Science Tokyo, Natsuki CHIN

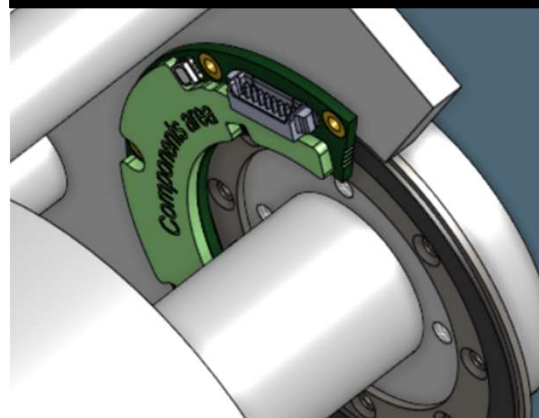
15/28

2026 Update from Current Search : Equatorial Mount



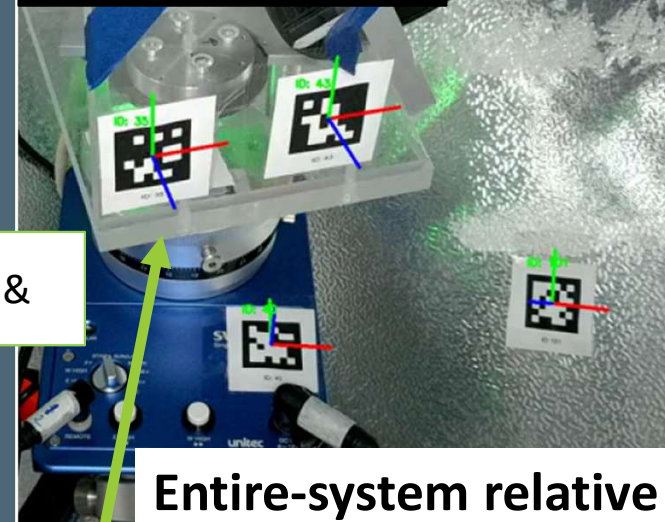
Rotation Angle Reading System

Magnetic Sensor Ring



Rotation can be
measured precisely

AR Marker



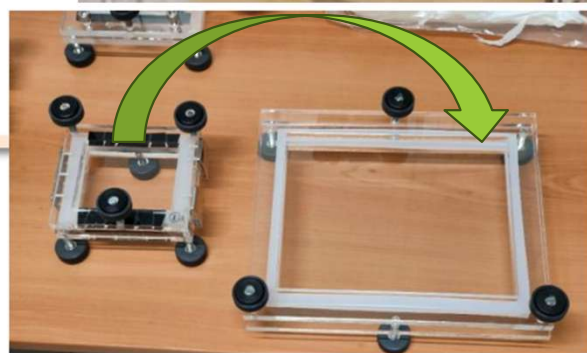
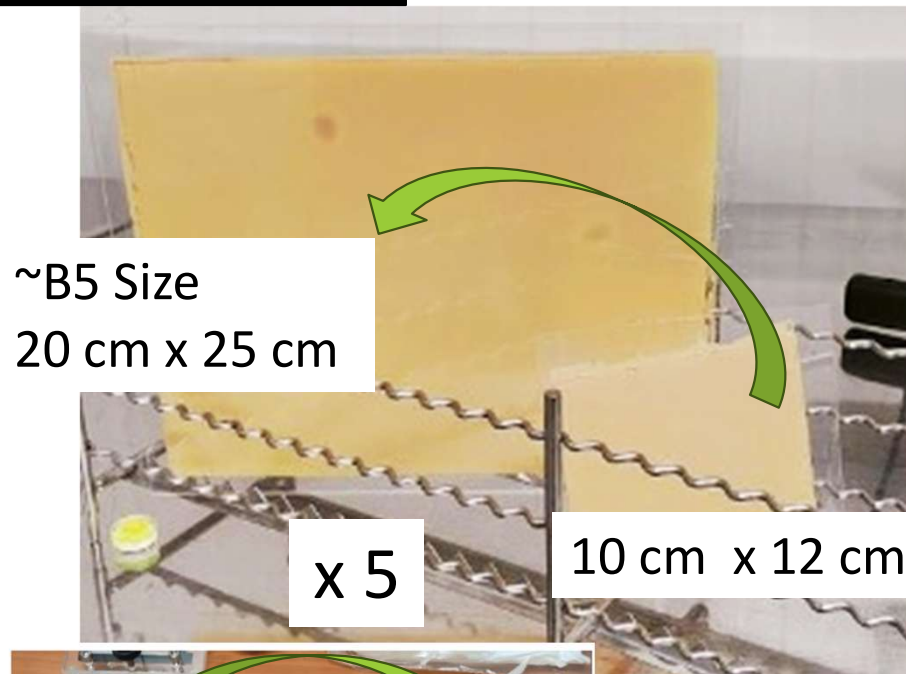
**Real-time recording and
monitoring from Japan!**

Current status is described later.

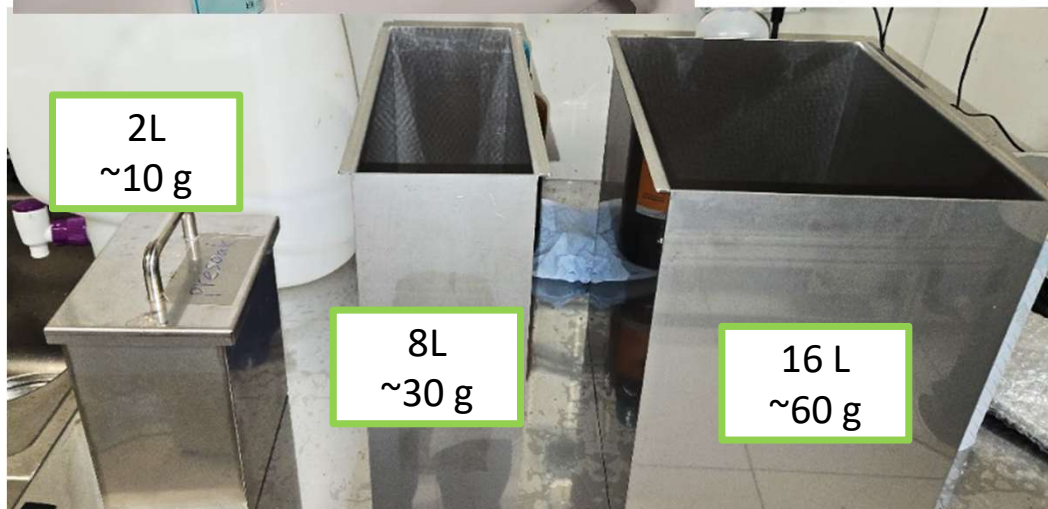
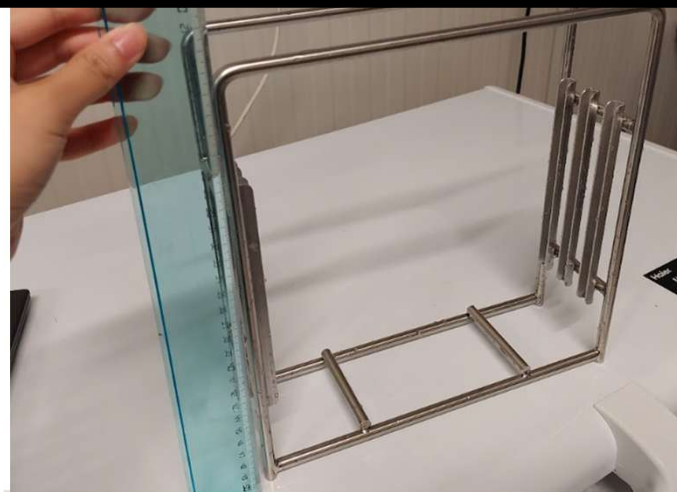


~2026 Update from Current Search : Emulsion

Emulsion Film



Development Equipment



1 kg ▪ day Pilot Run Conducted in 2025 → 10 kg ▪ day Scale in 2026

↓ MCBDM Run 2026 Current Status ↓

MCBDM 2026 Run : Status

Run Start : 2026/7/17

0 day sample was developed

Conservative scan-volume estimate

→ **8.5 kg·day**

Exposure in 4 months!

The largest run to date!

Total Emulsion Mass : ~73 g

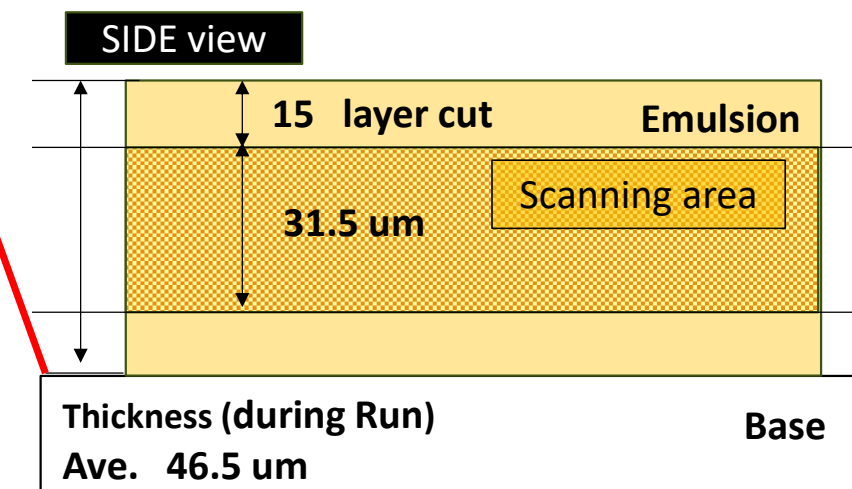
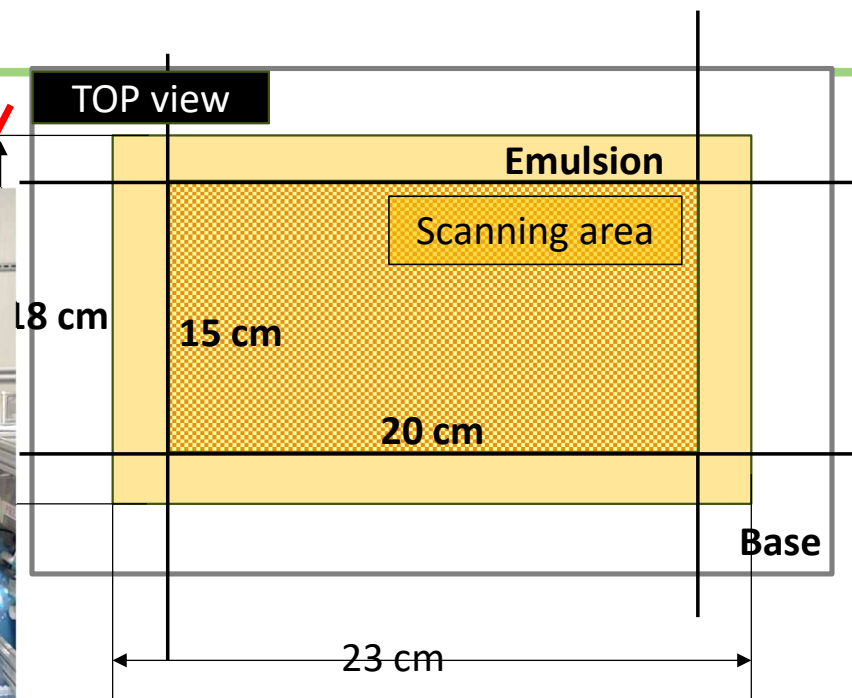
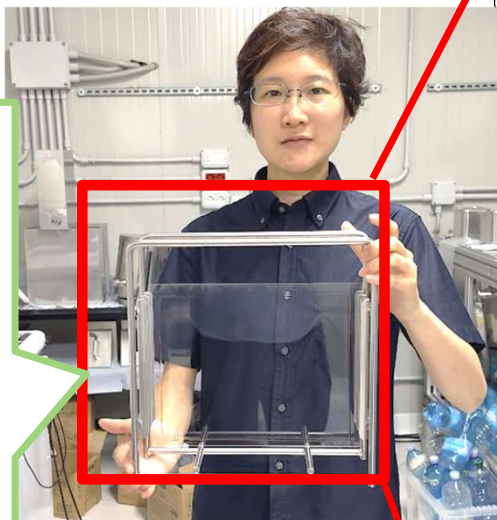
Development : Early **November!**

~4 month Run

Scanning speed: PTS4 : 250 g/(year machine)*

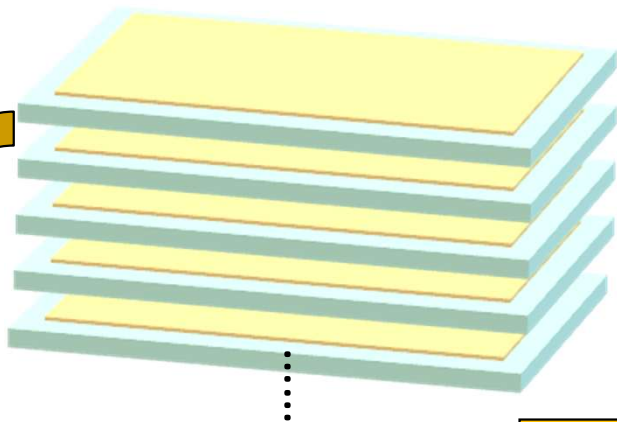
→ **1 PTS ... 100 days** (full capacity)

*T. Shiraishi , S. Akamatsu, et al, PHYSICAL REVIEW C 107,014608 (2023)



MCBDM Run 2026 : Setup [1/2]

Emulsion Plates stack



13 Emulsion
Films inside

~25 cm

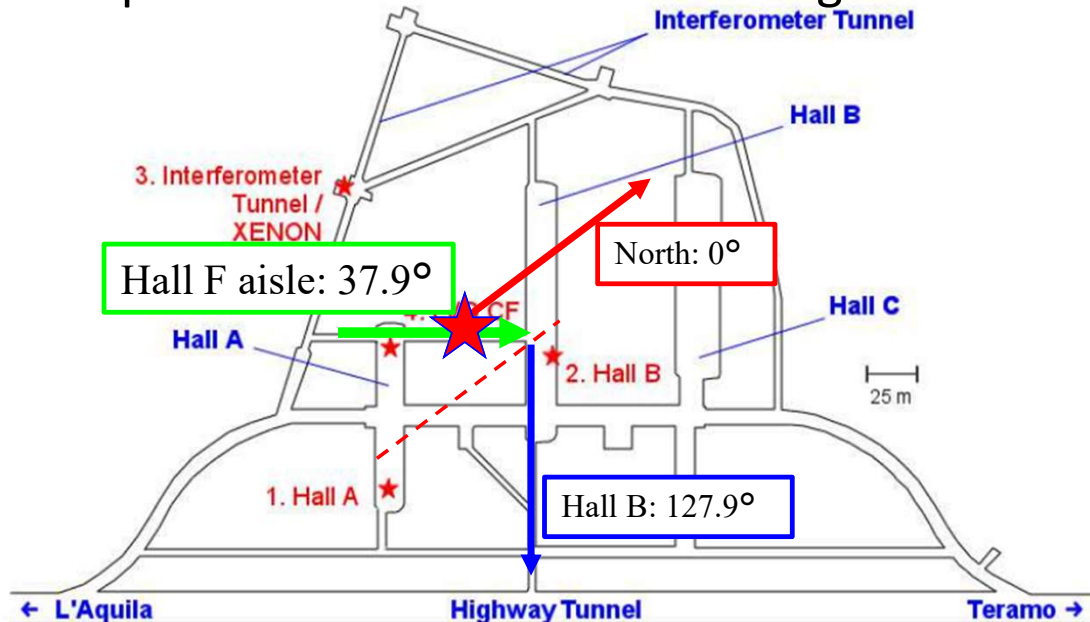


Placed in a
-20 °C freezer



MCBDM Run 2026 : Setup [2/2]

Equatorial Mount Installation Angle



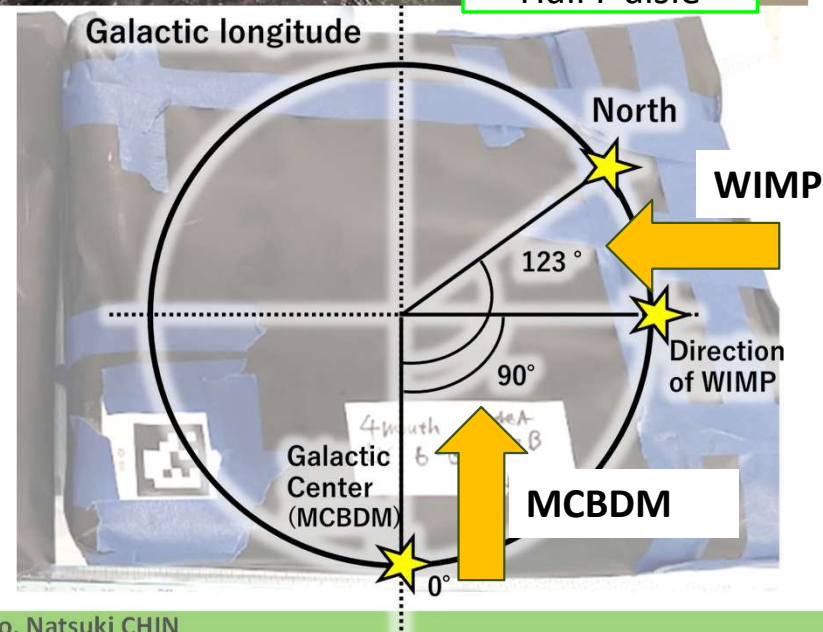
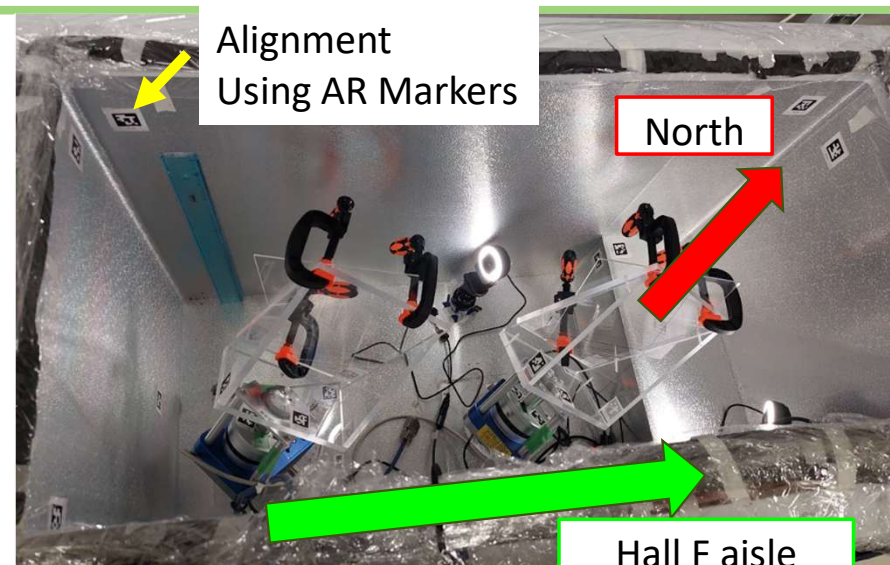
arXiv:1101.5298

Rotation parallel to the Galactic plane

→ Enables observations of both

Cygnus and the Galactic Center.

Optimal installation angle: being determined
To be rechecked before removal



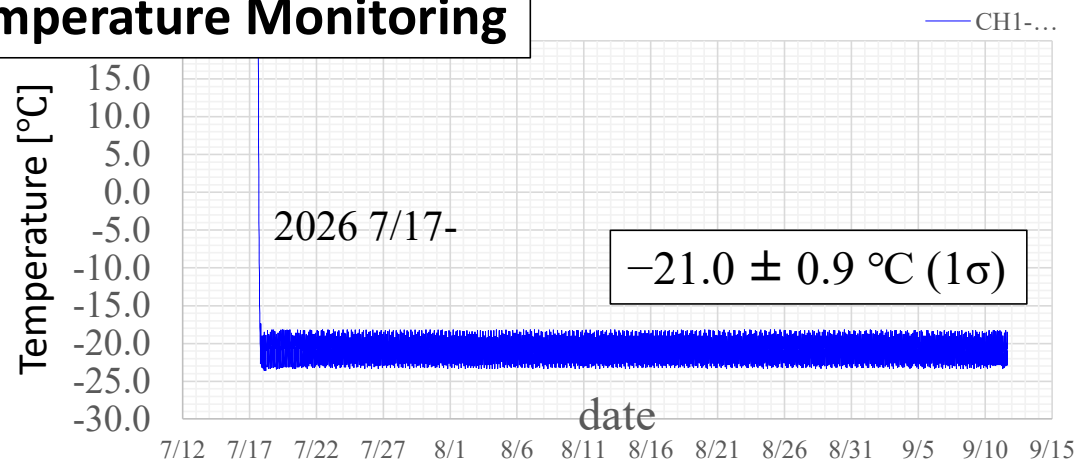
MCBDM Run 2026 : Equatorial Mount and Temperature data (Sep.)



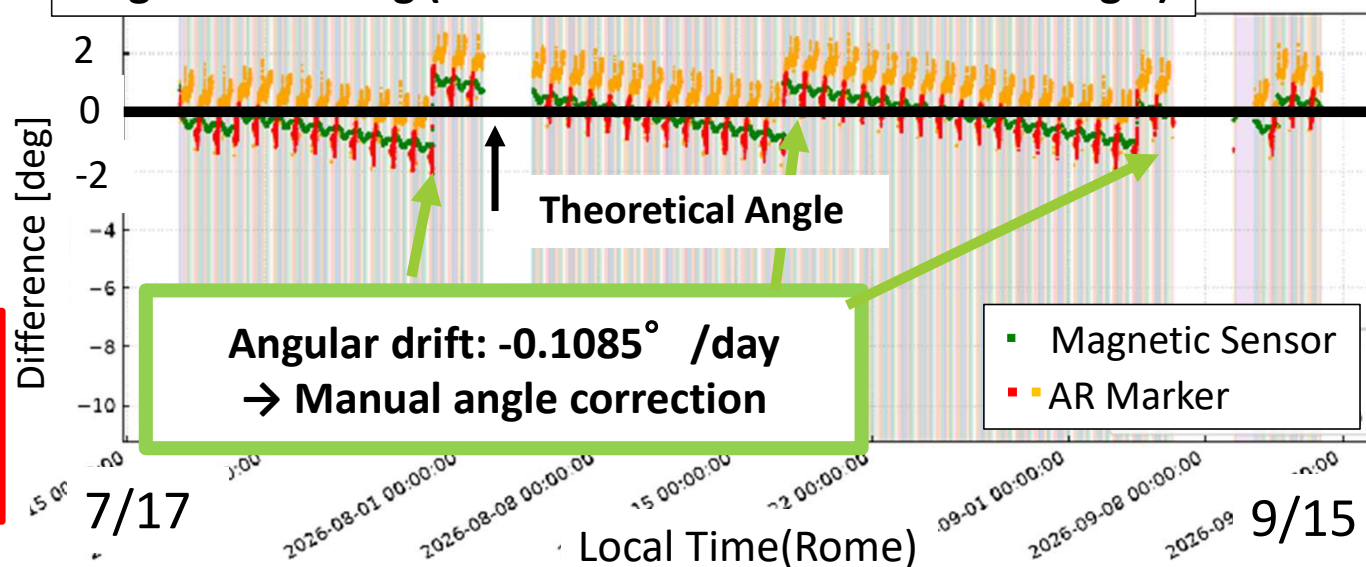
**Tracking accuracy of $<2^\circ$
achieved**

During long-term underground operation

Temperature Monitoring



Angle Monitoring (Deviation from the Theoretical Angle)

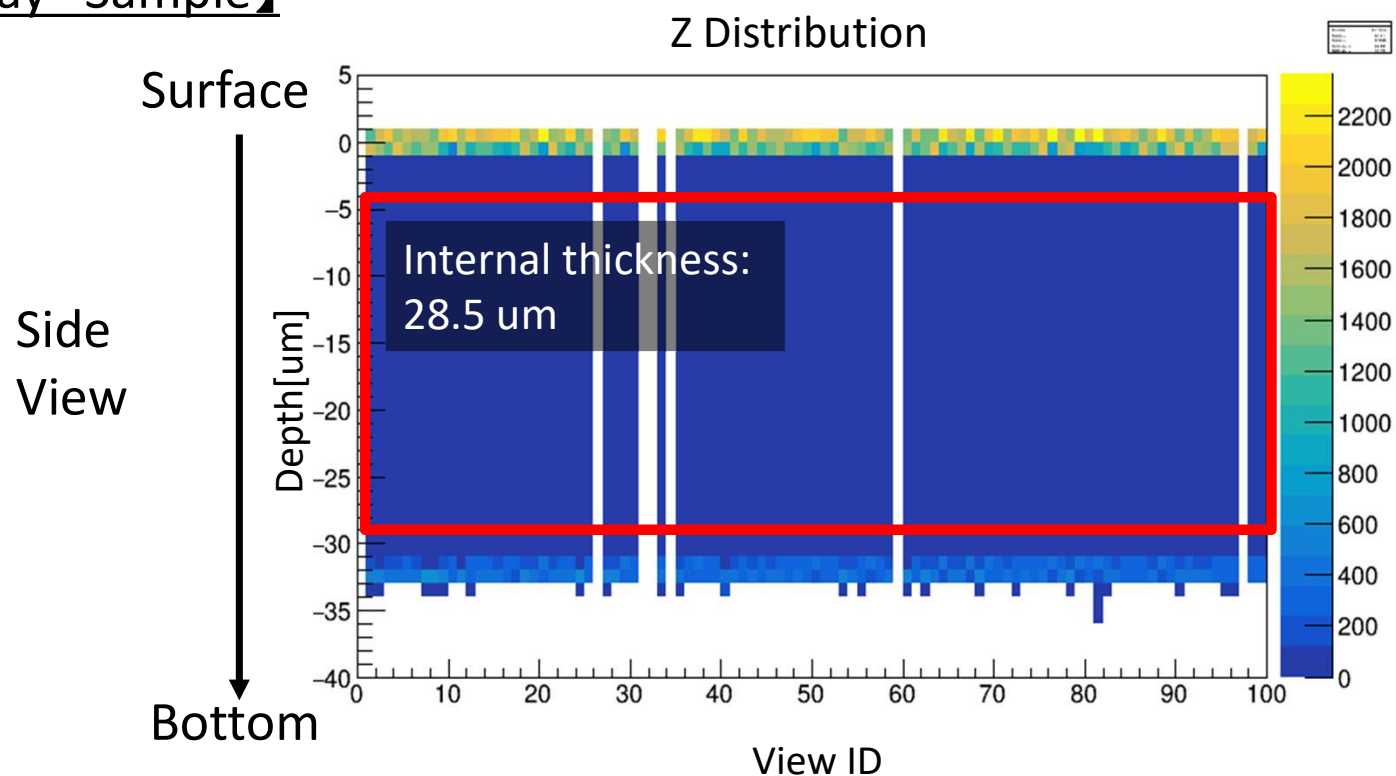


MCBDM Run 2026 : Emulsion Status, Fog Density

■ Fog Density(FD): Event density in unirradiated samples (events / 1000 μm^3)

→ 0 day sample (Reference Sample)

【Run 0 day Sample】

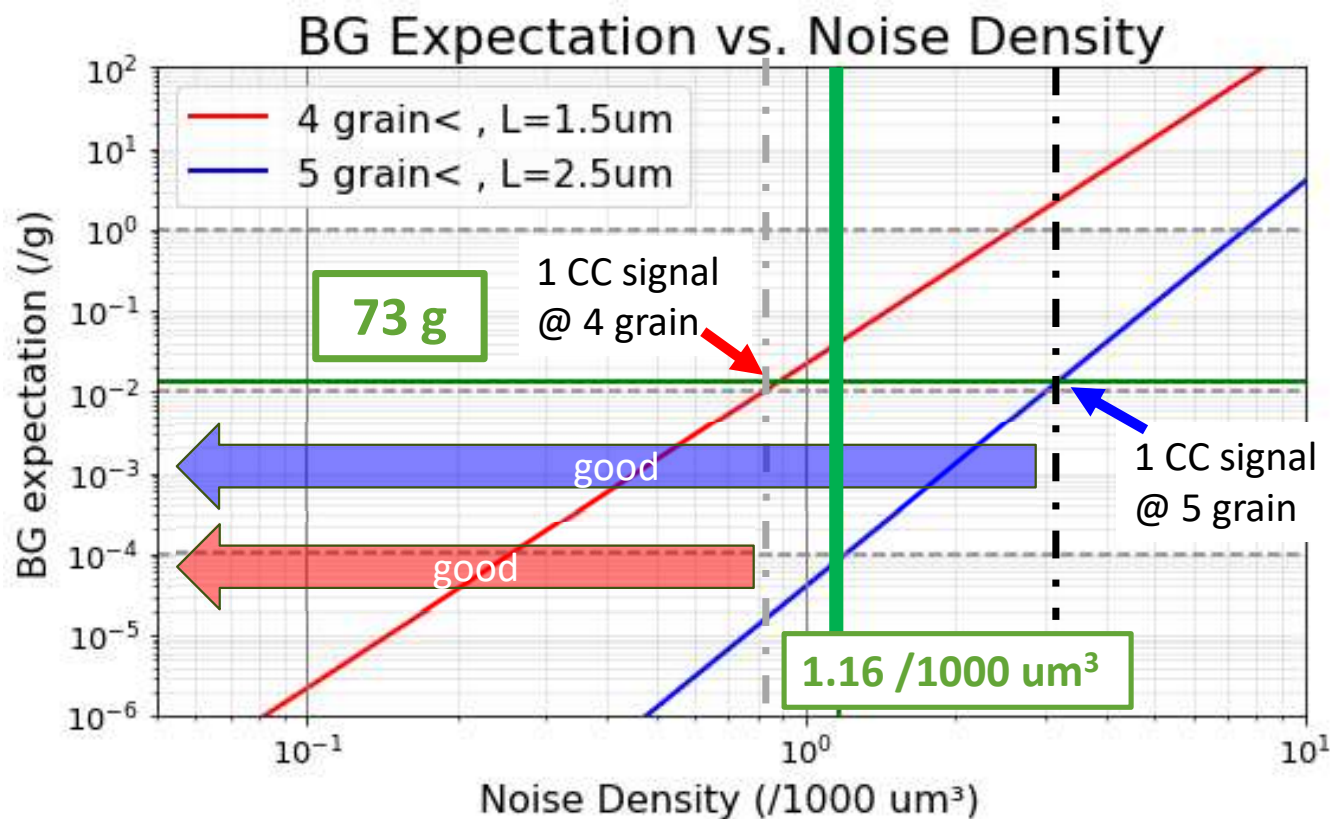


PTS 4 Scan & Count

FD $1.16 \pm 0.06 / 1000\mu\text{m}^3$

MCBDM Run 2026 : Emulsion Status Fog Density

Estimation of the Probability of Background Chance Coincidences (CC)



Lower Detection
Threshold (length)
for This Run:

5 grain length $3.3 \pm 0.8 \mu\text{m}^*$

→ Track length $2.5 \mu\text{m} <$ & 5 grain <

*

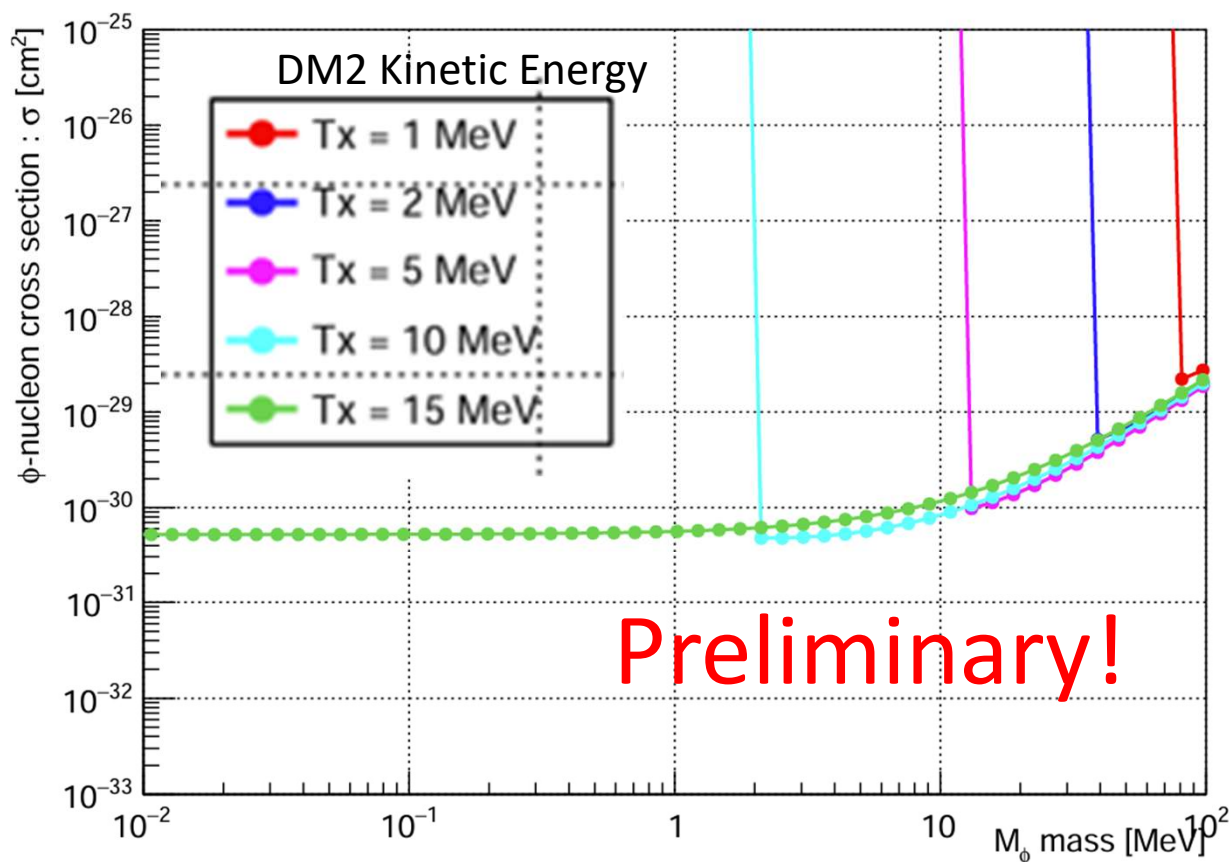
- Run emulsion
- ^{252}Cf -20°C
- Measured from the endpoint

Sensitivity Estimation(10 kg·day)

→Track length 2.5 μm < & 5 grain <

Under limit of proton recoil energy: ~ 270 keV
from SRIM 2008
▪ DM2 Mass: 10 MeV/c²

MCBDM sensitivity, 10kg_day, PTS2.2 R $\geq$ 2.5 μm



$$E_r = \frac{2m_N\beta^2 E_2^2 \cos^2 \theta}{(E_2 + m_N)^2 - \beta^2 E_2^2 \cos^2 \theta}$$

→DM2 Kinetic Energy 5 MeV

- Einast profile
- BG free
- track length 2.5 μm cut
- Recent PTS2.2's Neutron Analysis Efficiency
- Hydrogen nuclei scatter only
- Directional sensitivity is not taken into account.
- $\langle \delta v \rangle = 10^{-26} \text{ cm}^3/\text{s}$

Search sensitivity and flux estimation is ongoing.

MCBDM Run 2026 : Near-Future Prospect for analysis

■ Evaluation of signal sensitivity

Quality check (done)

- ^{241}Am γ -ray Sensitivity @RT
Slightly lower than in the pre-test ...?

Calibration for MCBDM
Signal Detection

- AIST neutron @ -20°C
- fading effect

→ In this autumn ~ winter

■ Simulation of Attenuation

We need to consider

- Attenuation due to 1000 m rock
- Effect of mountain topography

→ Estimate the **search sensitivity and flux for MCBDM.**

Timeline of NEWSdm : Near-Future prospect

FY2026

~FY2028

■ Scanning & Analysis

Nov. Development

Scan ~100 days

Run 2026 is almost finished!
Data taking & Analysis phase

- Dec. Calibration Run (AIST neutron)
- **Simulation of Attenuation**

Analysis

■ S/N ratio improvement

- Development of a new developer to **improve track contrast**
- Chemical method for **noise reduction**

■ Scanning machine

- PTS3: Ellipticity & Chain Analysis
- PTS2.2: 1.3kg/year → 2.5 kg/year**
- PTS5: Development

**T. Shiraishi, JPS 2026

- 4 PTSs available
- Scan speed -> 2 - 3 × faster

Summary

- **NEWSdm**: Direction-sensitive dark matter search using super fine-grained nuclear emulsion (NIT)
 - Target: Low-mass dark matter accelerated by annihilation (**MCBDM**)
 - An **8.5 kg·day run** is currently underway at the LNGS underground laboratory.
 - For the 0-day sample, the track density is **1.16 / 1000 μm^3** , corresponding to a **proton recoil detection threshold of 270 keV**.
- For a DM_2 mass of **10 MeV/c²**, signals with a DM_2 kinetic energy down to **5 MeV** can be searched for.

◇ Run Prospects

- **Emulsion development in November**
- Determine detection performance including fading effects
- Calibration with AIST neutrons under the same conditions
- **Attenuation effect**, including the mountain topography, will be taken into account.

→ Estimate the **search sensitivity and flux for MCBDM**.

◇ Near Future Prospects

- **Post-development chemical treatment** for S/N improvement
- **Improvement of the scanning-system speed**