The NEWSdm experiment for directional dark matter searches

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NEWSdm COLLABORATION

81 physicists / 23 institutes

NEWSdm

Nuclear Emulsions for WIMP Search with Directional Measurement

Website:
news-dm.lngs.infn.it

Letter of intent:
https://arxiv.org/pdf/1604.04199.pdf

ITALY
LNGS, GSSI
INFN: Napoli, Roma, Padova
Univ.: Napoli, Roma, Padova, Potenza, Benevento

JAPAN
Chiba, Nagoya, Toho, Tsukuba

RUSSIA
LPI RAS Moscow
JINR Dubna
SINP MSU Moscow
INR RAS Moscow
NUST MISiS Moscow
NRU HSE Moscow

SOUTH KOREA
Gyeongsang University

TURKEY
METU Ankara

The NEWSdm experiment

NEWSdm

Nuclear Emulsions for WIMP Search with Directional Measurement

- Direct dark matter search with **directionality**
- Target: **nuclear emulsion film**
- Combination of **high-speed** scanning / **high-precision** scanning
- Current status: pilot run and system update toward scale up
- Goal
  - 10 kg·year → DAMA region
  - 10–100 ton·year → neutrino floor

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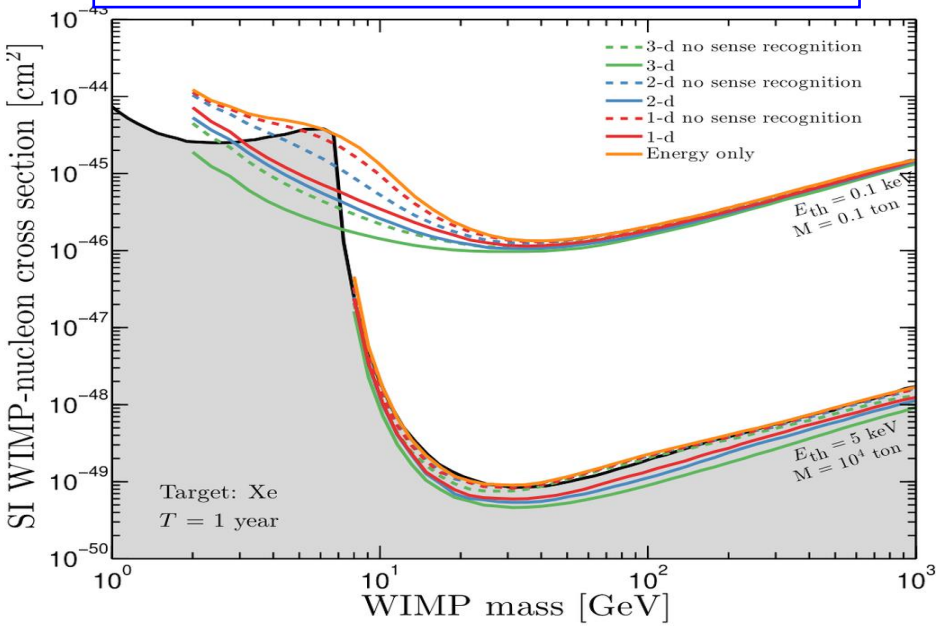
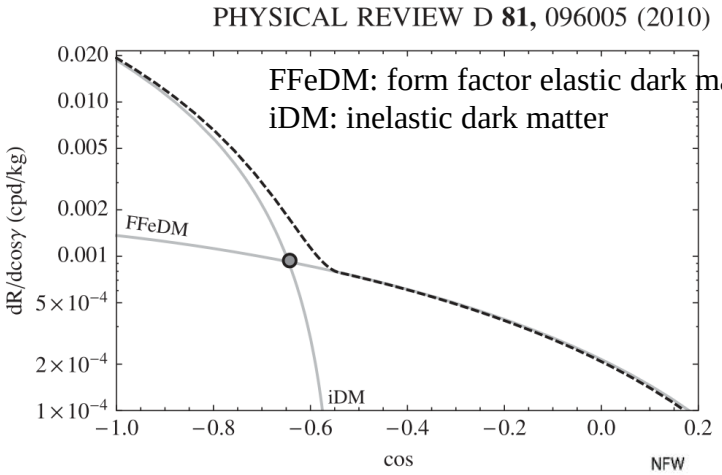
The Advantage of Directionality for dark matter search

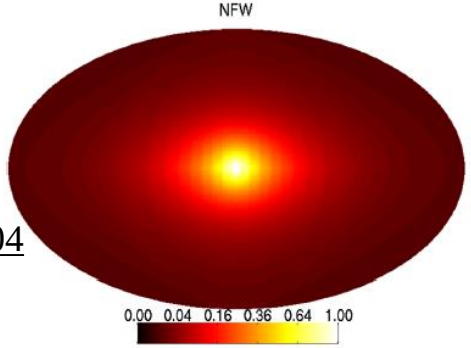
Overcoming the Neutrino Floor



Physics Reports 627 (2016) 1

Directional property



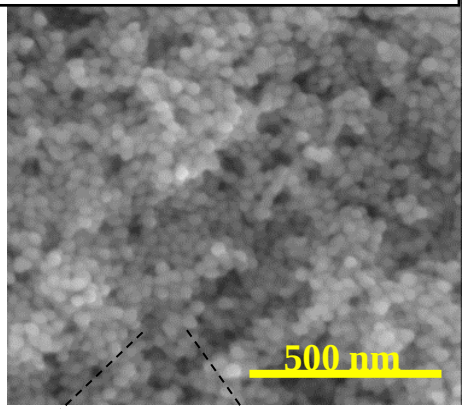


Boosted dark matter
10.1103/PhysRevLett.126.091804

- Unique possibility to overcome the “neutrino floor”, where coherent neutrino scattering creates an irreducible background
- Directional information is helpful in understanding the DM model

Detection principle of Nuclear emulsion

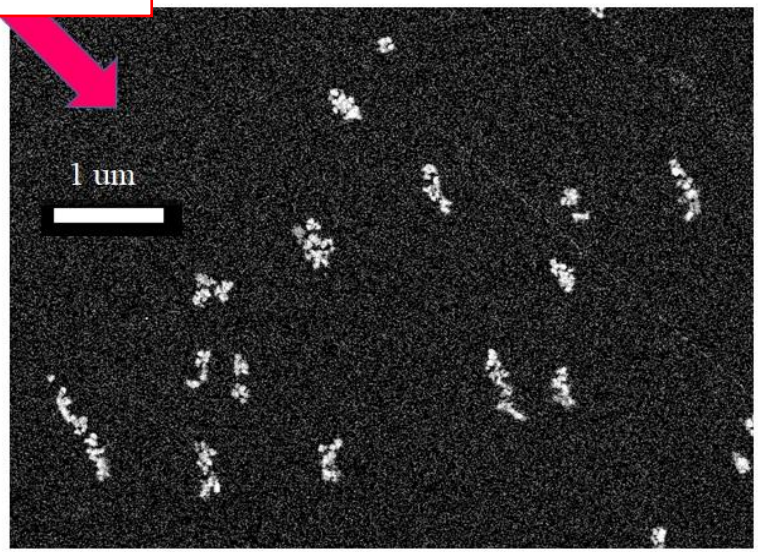
AgBr(I) Crystals in SEM

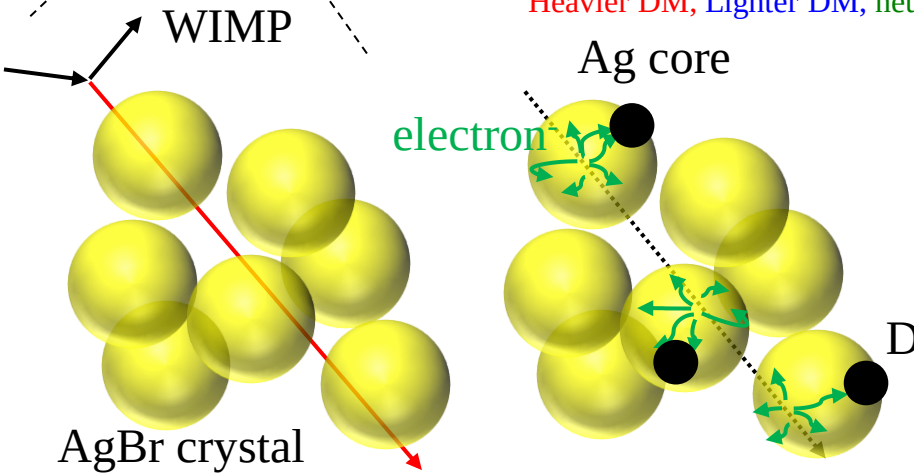


Element	Mass%	Atom%
Ag	44.5	10.5
Br	31.8	10.1
I	1.9	0.4
C	10.1	21.4
N	2.7	4.9
O	7.4	11.7
H	1.6	41.1

Ingredient of emulsion
Multi component target for
Heavier DM, Lighter DM, neutron

Carbon



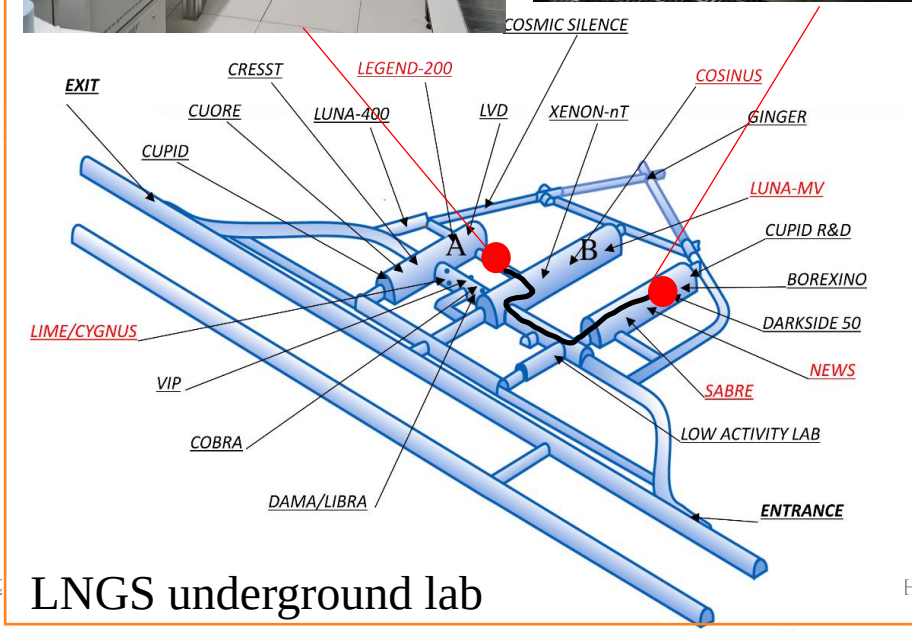


Run Report in 2021-2022

NEWSdm Run

Production room /development room

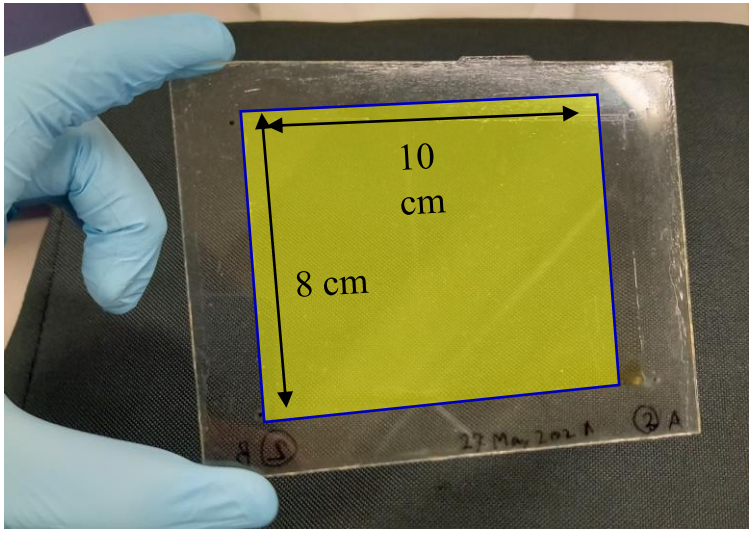
Shield/exposure



LNGS underground lab

Scanning with multi-type optical microscope (Napoli, Nagoya, Toho)

Detector



productive capacity:
100g/batch, 1–2 batches/day
→2–5 kg/month

NIT : 40μm on both sides, 2g/plate
COP base : 2 mm, 24 g/plate

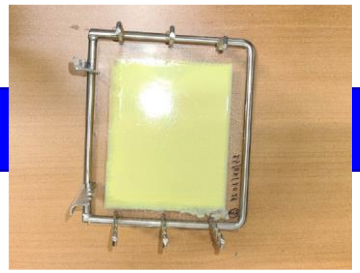
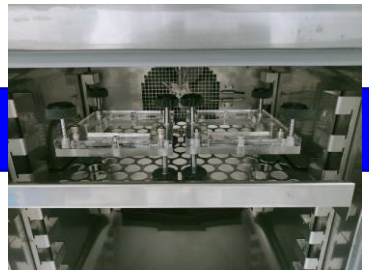
Effective radioactivity per plate[mBq]

U-238	Th-232	K-40	Ag-108m	Ag-110m	C-14
0.084	0.014-0.043	0.08-0.26	0.1	-	**48**

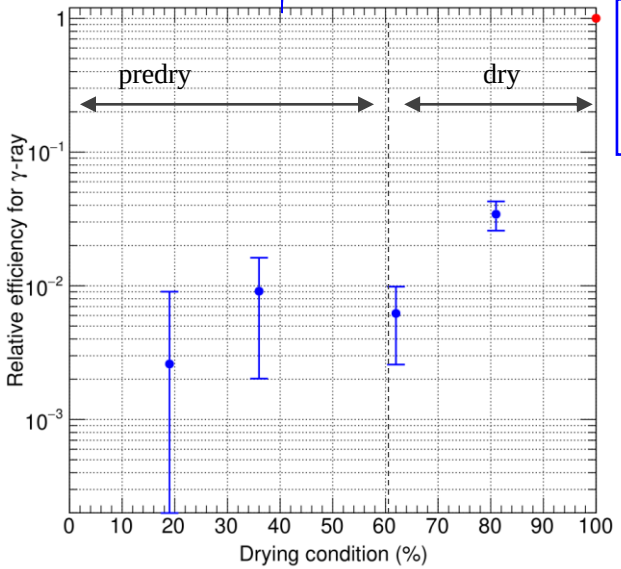
Run operation process and background calibration data

In-shield

Pouring process | Pre-dry process | Dry process | Run | Extraction + Development

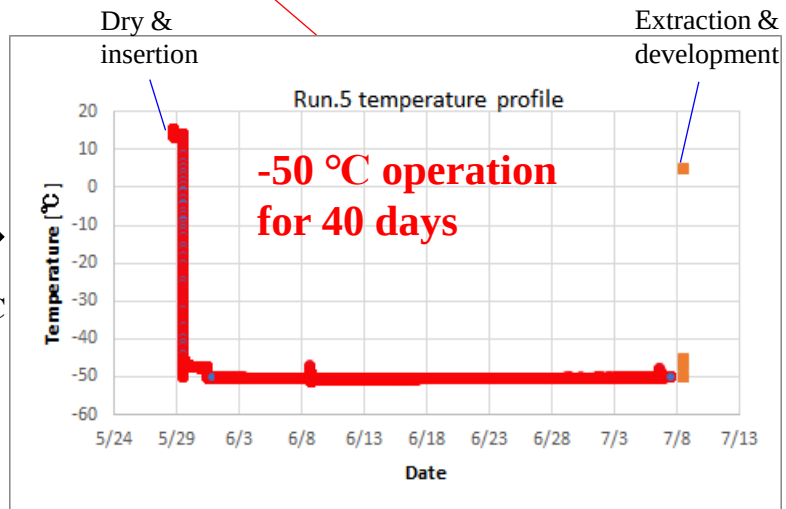



Electron BG expectation is O(1) /g (environmental gamma / ^{14}C)



New attempt: insert detector at wet and dry it in the shield (detector is completed when it is dried inside the shield)
→ Elimination of offset accumulation

Sensitivity→
10^{-4} @ room
10^{-6} @ -50℃



Electron efficiency is relatively 10^{-2} or lower than dry condition (absolutely 10^{-6} or more rejection)

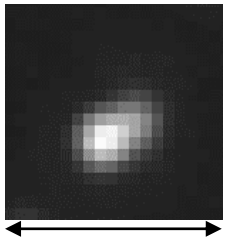
Data analysis flow

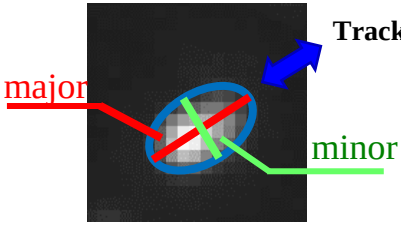
Automatic readout
1st trigger

Elliptical shape trigger

Requirement

- High speed scanning
- Low energy threshold
- Single noise (fog) reduction





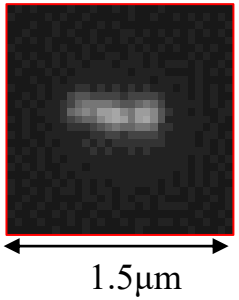
CNO : > 30 keV

Electron efficiency: 0.05

CNN
(machine learning)

≧ 3 grain track recognition

- Candidate selection and narrow down the number of event
- Image feature extraction



Training sample :
neutron induce recoil nuclei
@AIST (880keV, -50℃)

Manual check

Confirmation

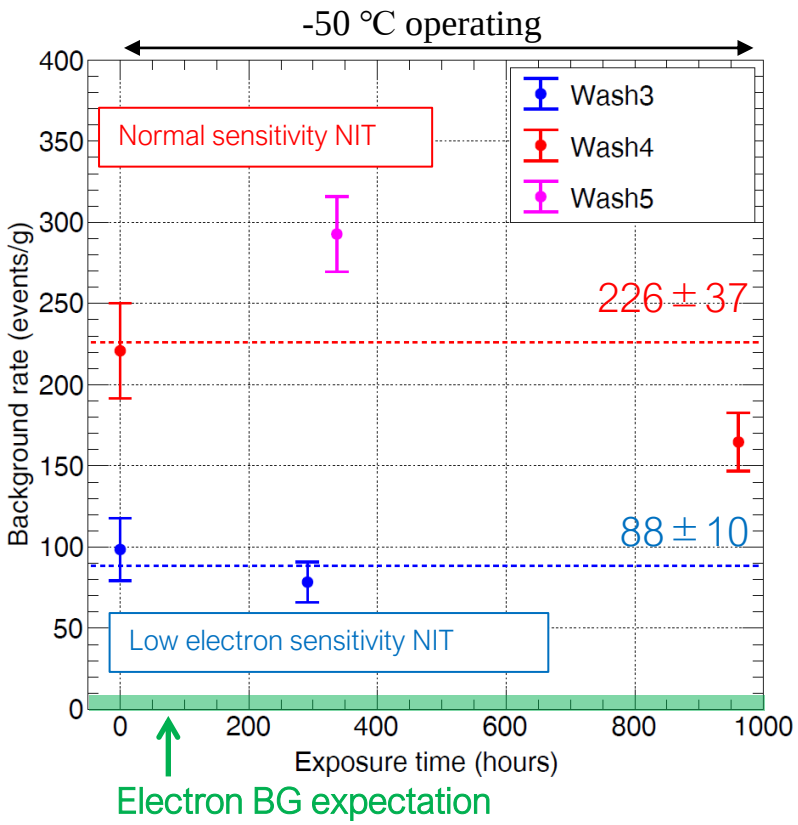
Electron rejection power :

10^{-4} @ room temperature

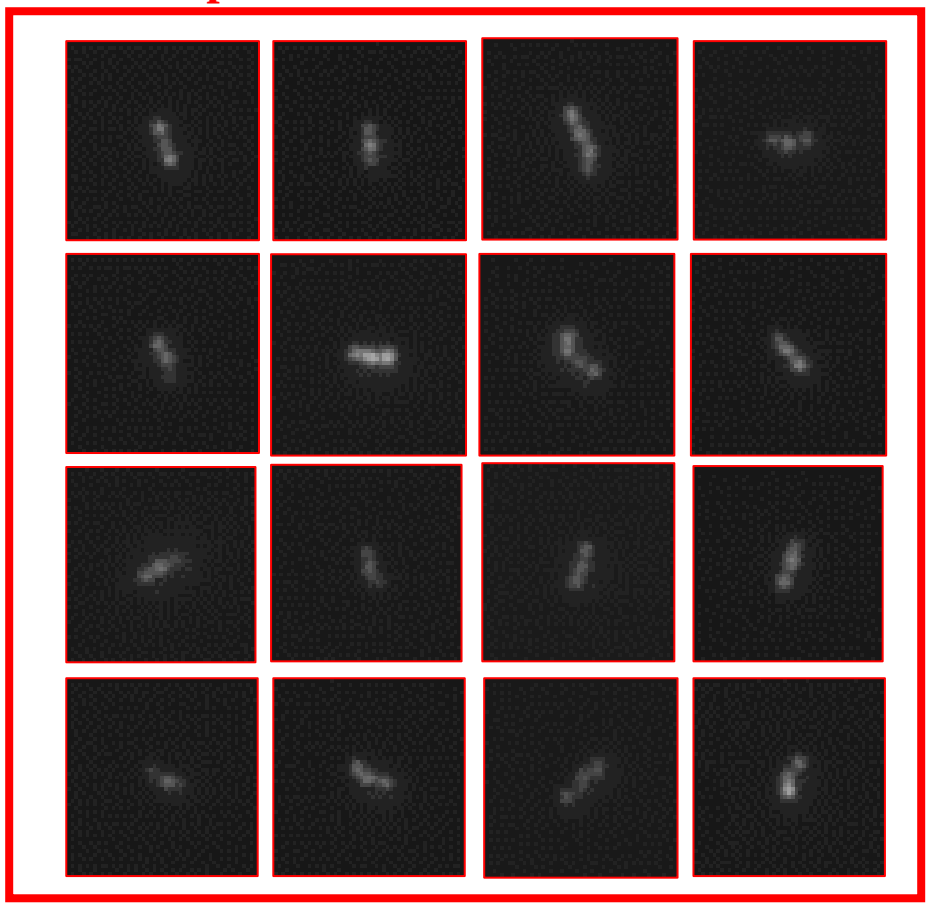
10^{-6} @ -50℃

Current Selection

Underground BG run status



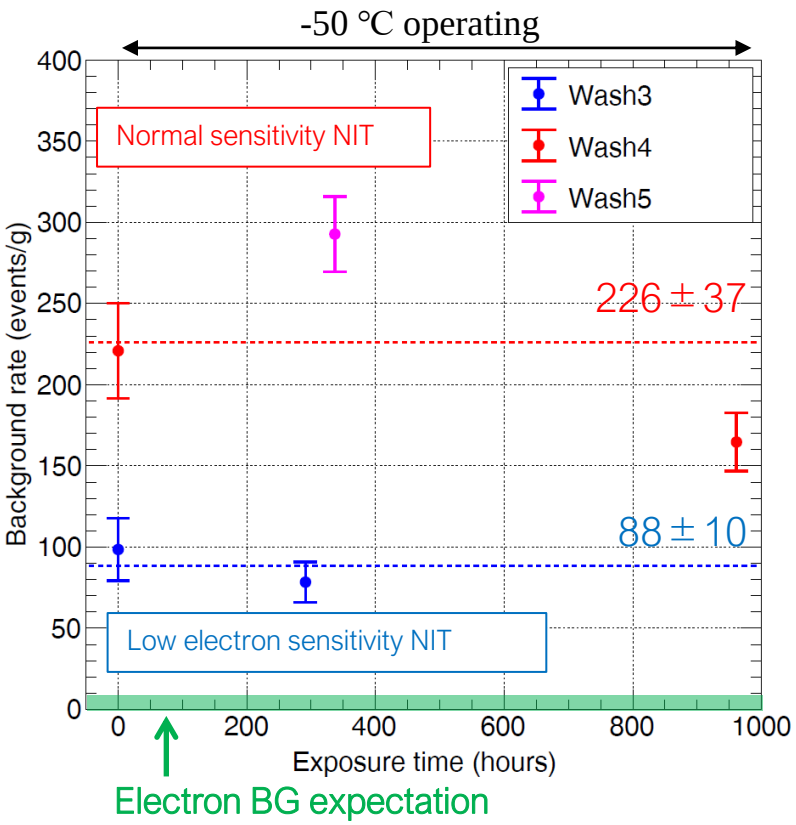
Example of Selected candidate events



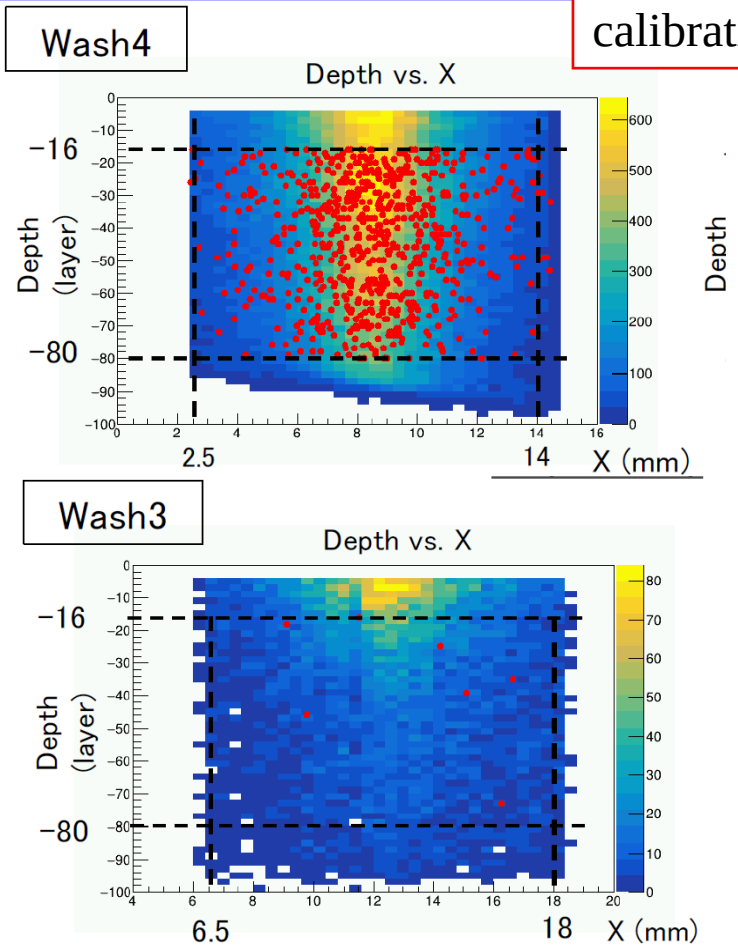
Current Selection

→Strict selection of signal-like events

Underground BG run status



Am^{241} gamma calibration

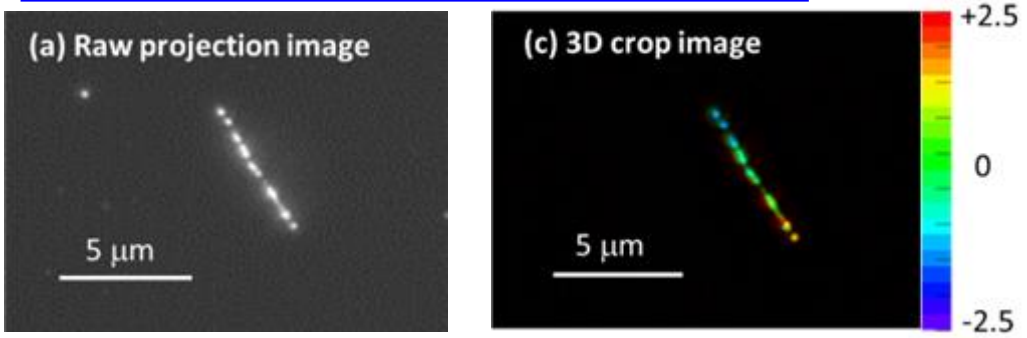


Difference in sensitivity is 130x
→Results (2.6x) are not electron-like events

Neutron Measurement at LNGS surface

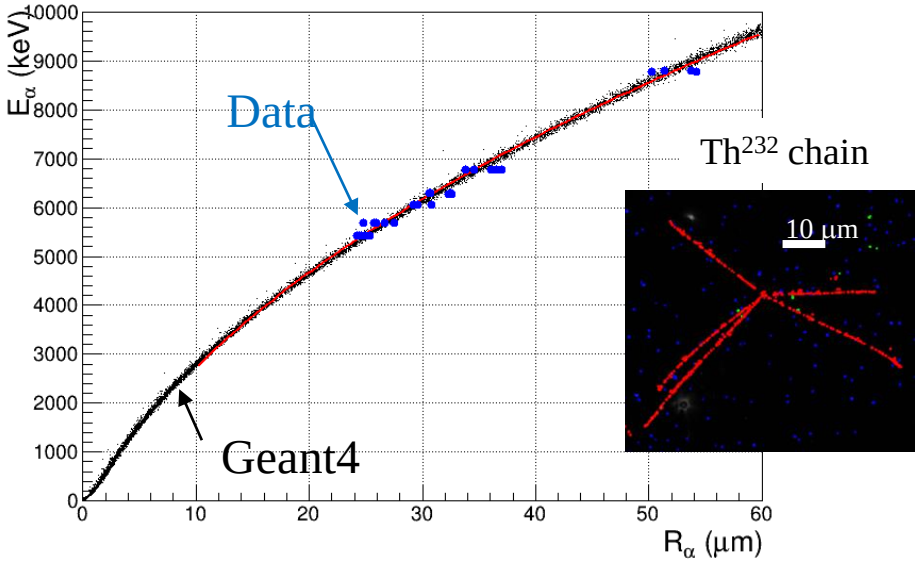
LNGS external lab

3D detection of >240 keV protons



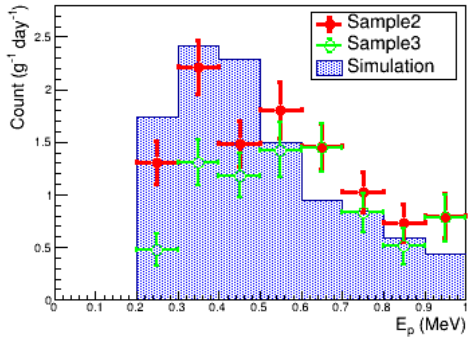
No shield, -20℃ with freezer

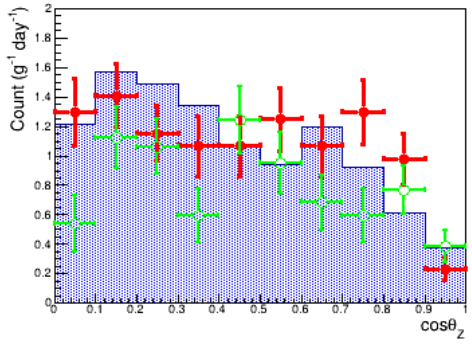
Range-energy calibration

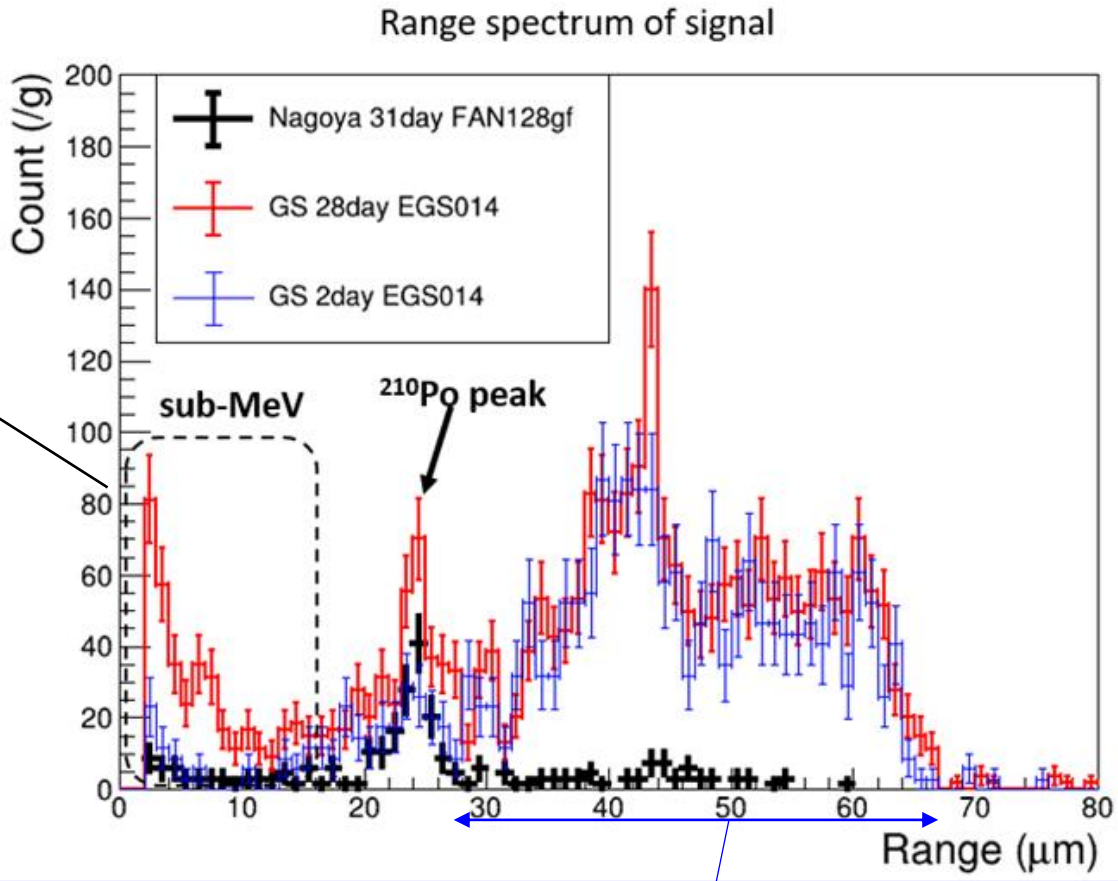


Neutron Measurement Result

The sub-MeV region and ^{210}Po showed good agreement as the time-dependent integral signal and simulation angle







We also found that these regions are likely to be induced by Rn daughters at the film production term (wet condition)
Effect to the underground Run BG is under study
Rn-free upgrade and scale-up operation are underway

R&D and upgrade

Upgrade of high-speed scanning machine

Current Run analysis result (PTS3)
Average scanning efficiency : 92.3%
Total Scanning Time : 61.4days
Total Scanned Mass : 10.5 g
Effective Scanning Speed : **62.3 g/year/system** (ideal: 105 g/year/system)

PTS3

PTS5

1st Step : **Realize wide field imaging**

Introduce wide field camera
(・Area 9 times
・taking speed : 1/3)
< task >
・fix optical aberration
・light intensity flatness

Scanning speed : x **4.42**
-> **464** g/year/PTS

2nd Step : **Recover effective taking speed**

Scan with multiple cameras
-> increase effective taking speed
(284 fps × 4 camera => 1136 fps)
Scan time par view : 1/2.24
< task >
Develop
beam splitter and optical system
for multiple camera

Scanning speed : x2.24
-> **1.04** kg/year/PTS

3rd Step : **Parallelize move・taking・tracking**

Execute
・Taking
・moving
・tracking
at same timing
Scan time par view : 1/2.42

Scanning speed : x2.42
-> **2.52** kg/year/PTS

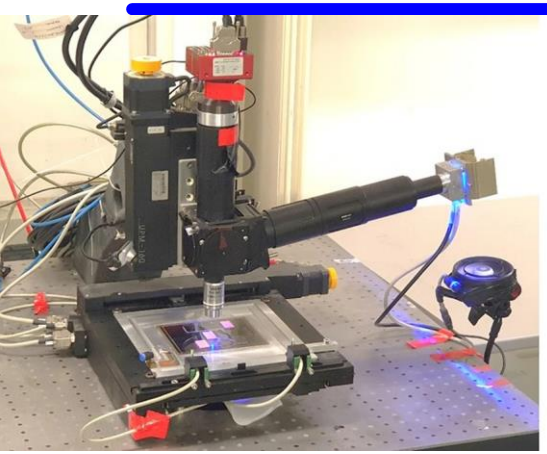
4th Step : **Expand view by low magnification**

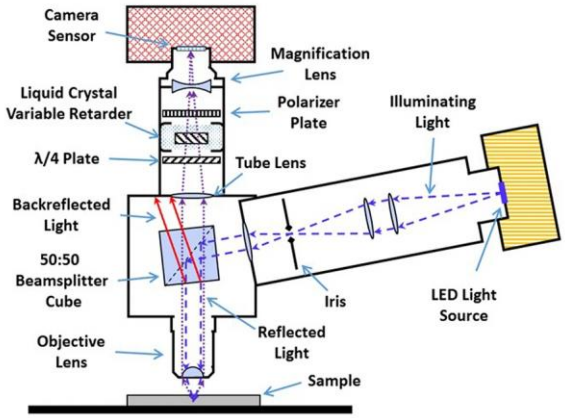
Change objective lens
(x60 -> x 40; view x2.25)
< task >
Develop new high resolution
Readout technique
with low magnification lens.

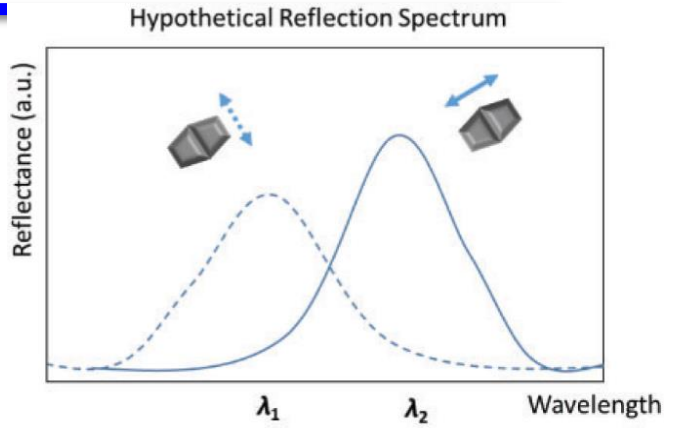
Scanning speed: x2.25
-> **5.66** kg/year/PTS

And multiple system

High resolution analysis with LSPR







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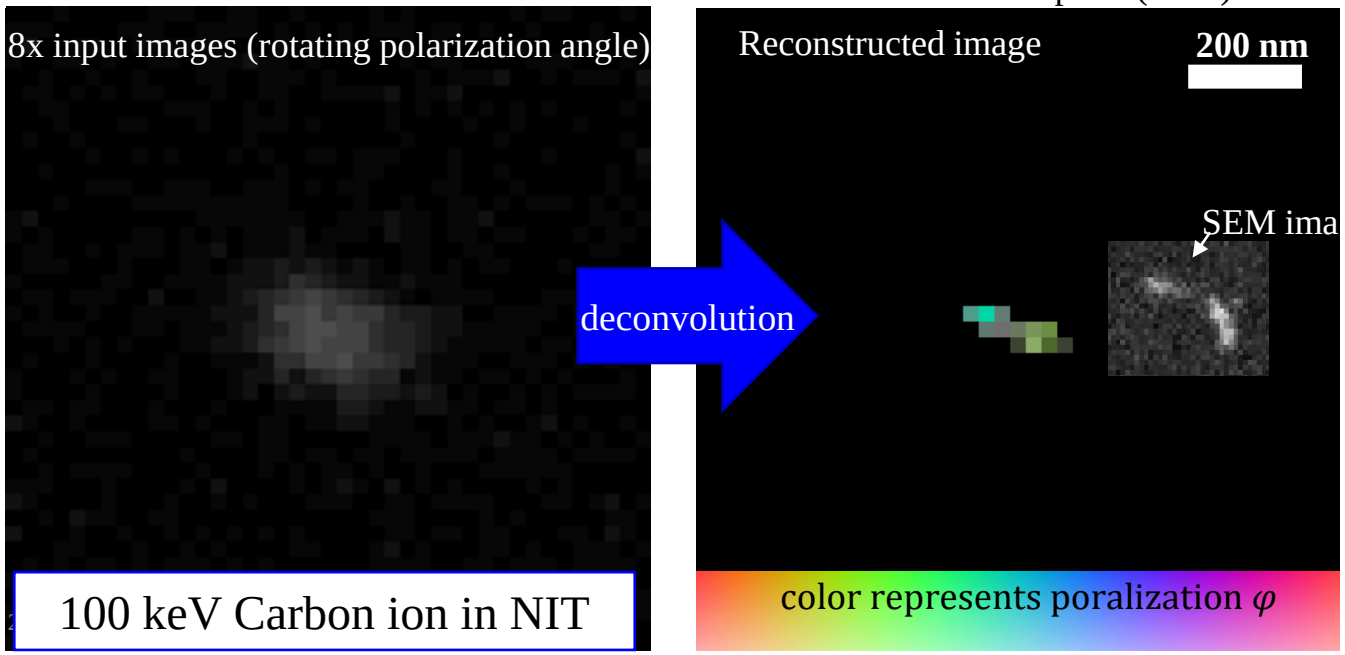


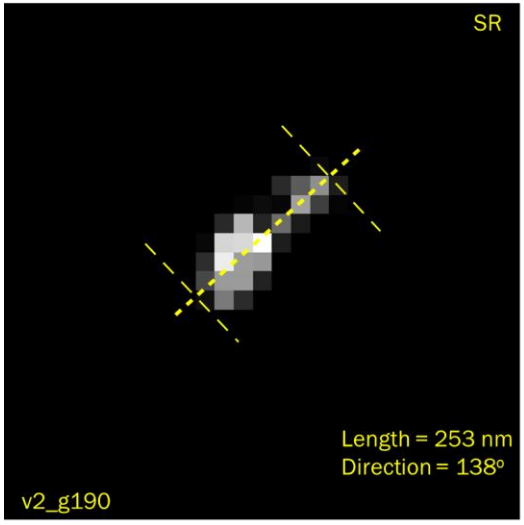
Localized **S**urface **P**lasmon **R**esonance

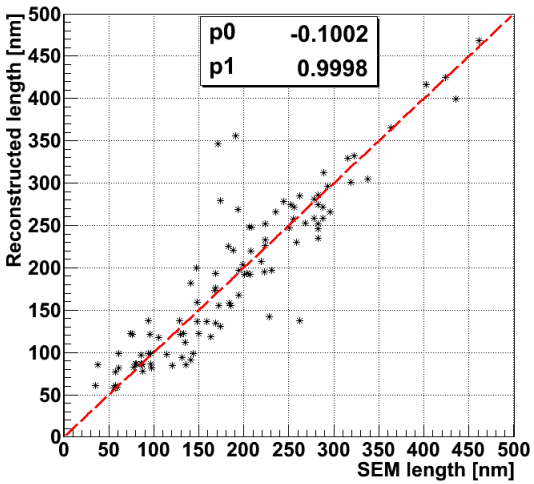
- Clustered electron oscillation exited by light
- Sensitive to wavelength, particle length, etc.

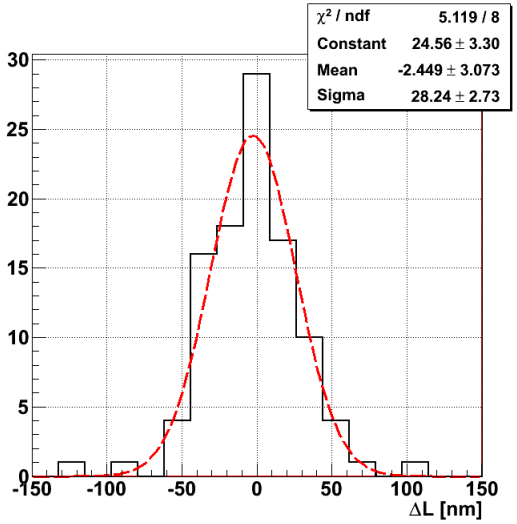
Resonance point changes by **polarization**

Deconvolution with point spread function provides super **resolution**

Joint Image Deconvolution
Event Length comparison with SEM





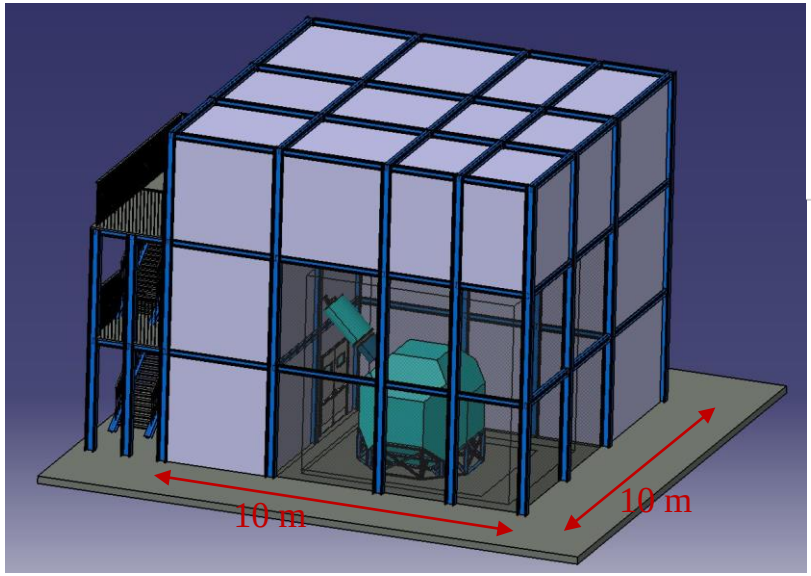


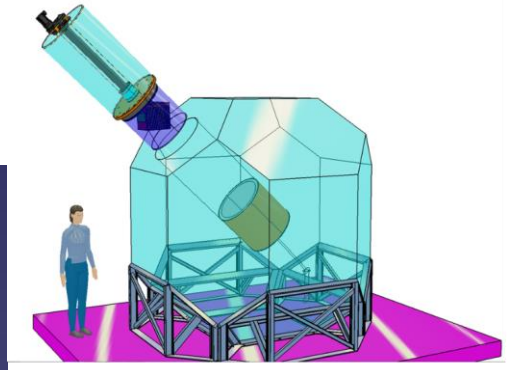
Pearson Coefficient	Matched	Unmatched
Length	0.912	-0.009
Width	0.713	-0.007

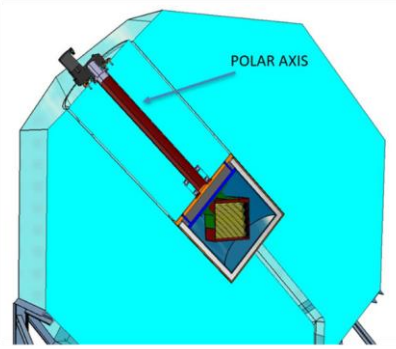
Length accuracy: 28 nm ≈ pixel size (27.5 nm)
Spatial resolution: 80 nm (Nyquist theorem)
→ proton >4keV, carbon >20 keV at mean flight in SRIM

Future facility for NEWSdm: 10kg and beyond

Emulsion facility and shielding with an equatorial telescope




(a)



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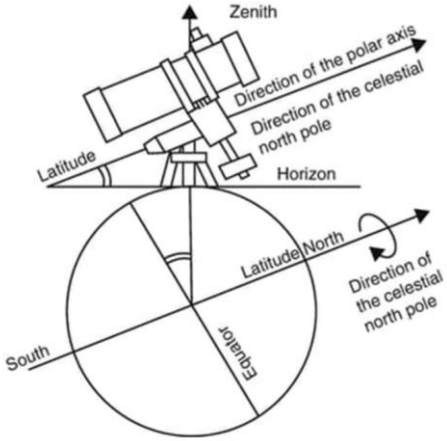

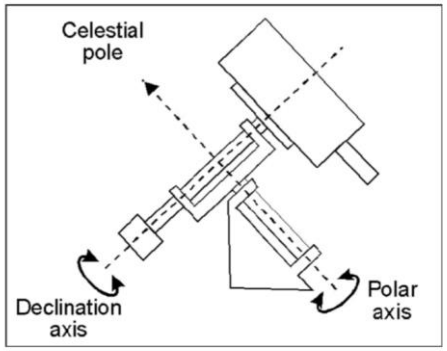

- Shield + Equatorial mount
- shield through detector production–exposure–development
- Purification of environment (Rn, dust)

summary

- NEWSdm is directional dark matter search experiment using nuclear emulsion
- Pilot run is underway at LNGS
  - 10g scale is operational and scale-up is underway. Inner and Environmental background are estimated, offset BG is under study
  - Purification of suspicious Radon etc. are ongoing
- Neutron measurement at LNGS
  - Good agreement at low energy region (proton recoil >240 keV)
  - BG free/scale up operation is underway
- Upgrade study in progress
  - Scanning speed: ~400g/year/system is under test and kg scale machine is designed
  - high precision analysis (LSPR+polarization+deconvolution) shows the potential for the resolution of proton >4keV, carbon >20 keV
  - CDR for 10 kg scale experiment is in progress