14th International Conference on Identification of Dark Matter

18-22 July 2022
Vienna, Austria

Directional dark matter search with nuclear emulsions

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INFN Napoli

On behalf of NEWSdm collaboration

NEWSdm COLLABORATION

81 physicists
23 Institutes

JAPAN
Chiba, Nagoya, Toho

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

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

SOUTH KOREA
Gyeongsang University

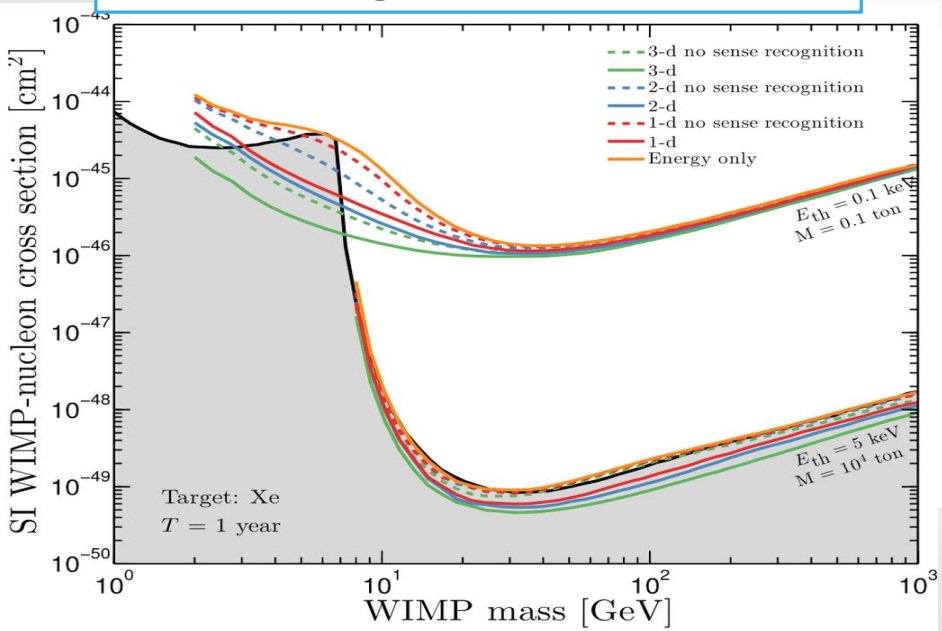
TURKEY
METU Ankara

Website: *news-dm.lngs.infn.it*

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

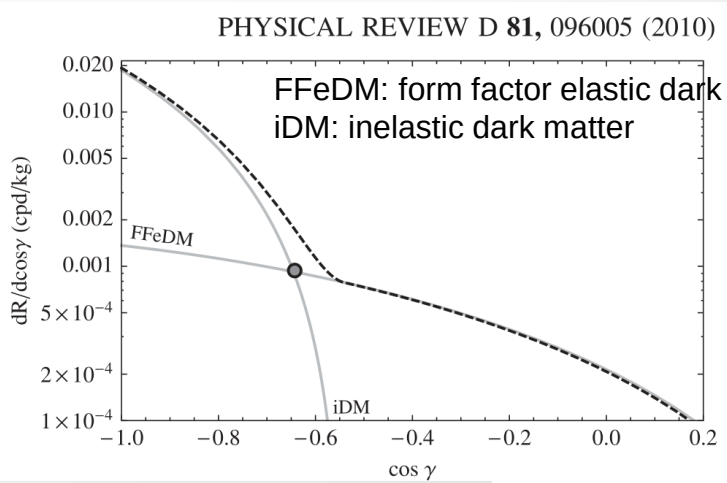
Advantage of DM directionality knowledge

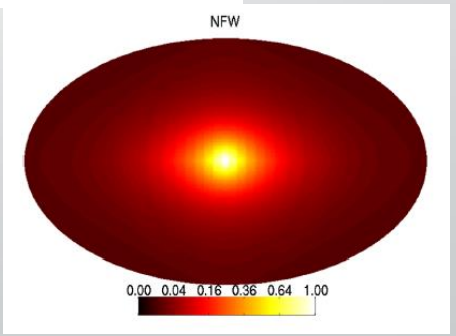
Overcoming the Neutrino Floor



Physics Reports 627 (2016) 1

Directional property



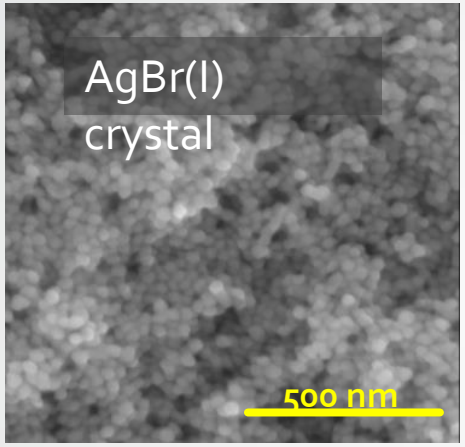


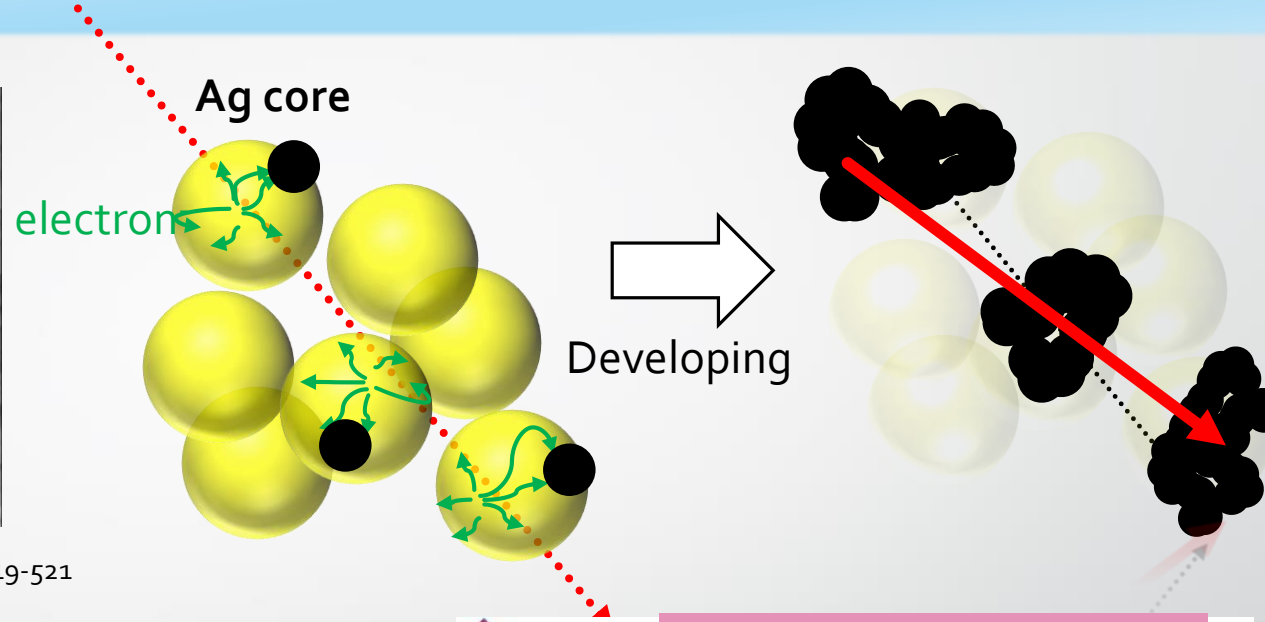
Boosted dark matter
10.1103/PhysRevLett.126.091804

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

Nano Imaging Tracker (NIT) developed for NEWSdm

Density : 3.1 ± 0.1 g/cm3
Crystal size : 20÷80 nm (tunable)





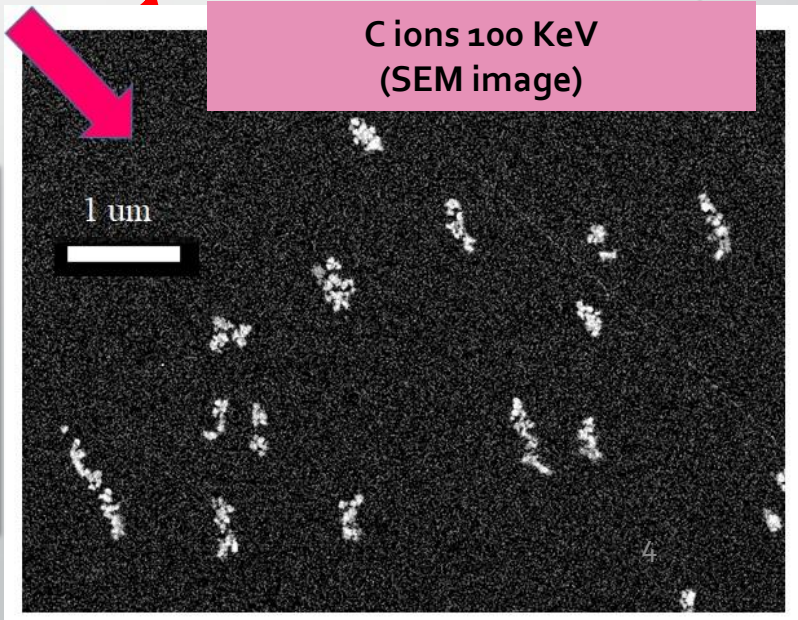
NIM A Nucl. Inst. Meth. A 718 (2013) 519-521
PTEP (2017)063H01

	Mass fraction	Atomic Fraction
Ag	0.44	0.10
Br	0.32	0.10
I	0.019	0.004
C	0.101	0.214
O	0.074	0.118
N	0.027	0.049
H	0.016	0.410
S, Na + others	~ 0.001	~ 0.001

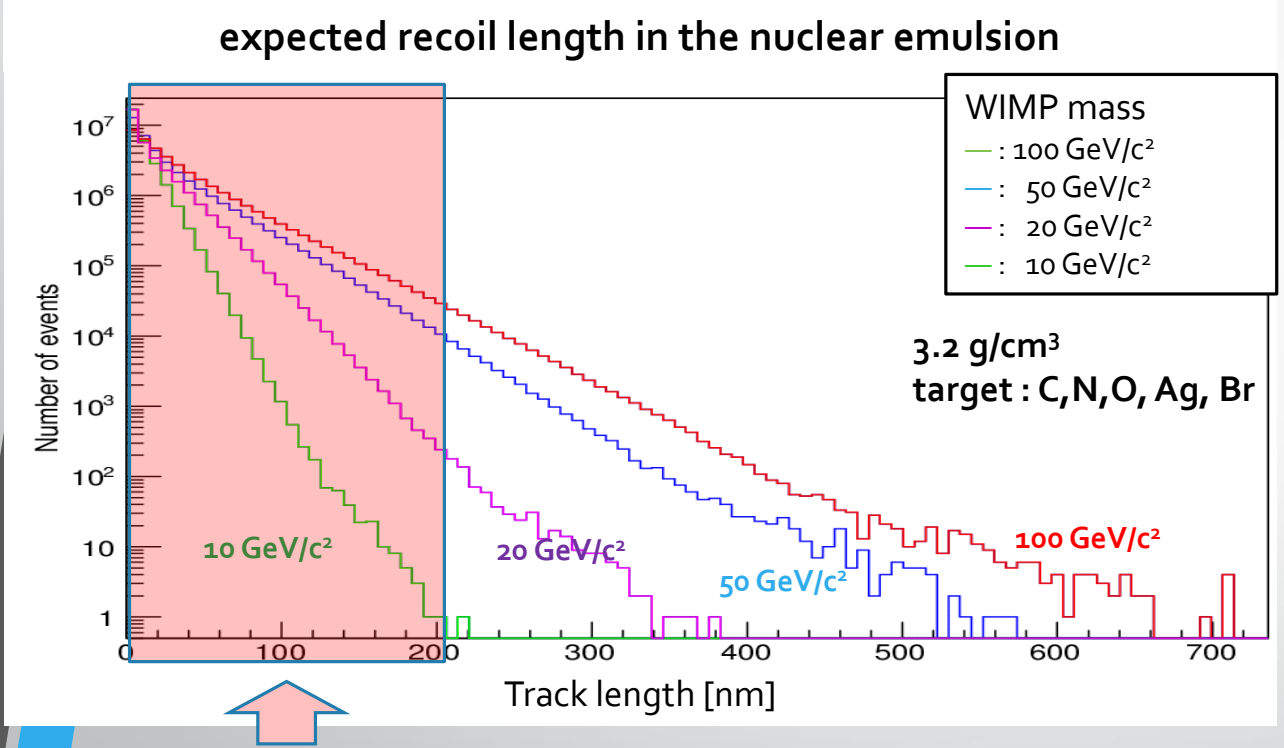
Heavier DM
Lighter DM
neutron

Solid-state detector
Density: 3.1 g/cm³

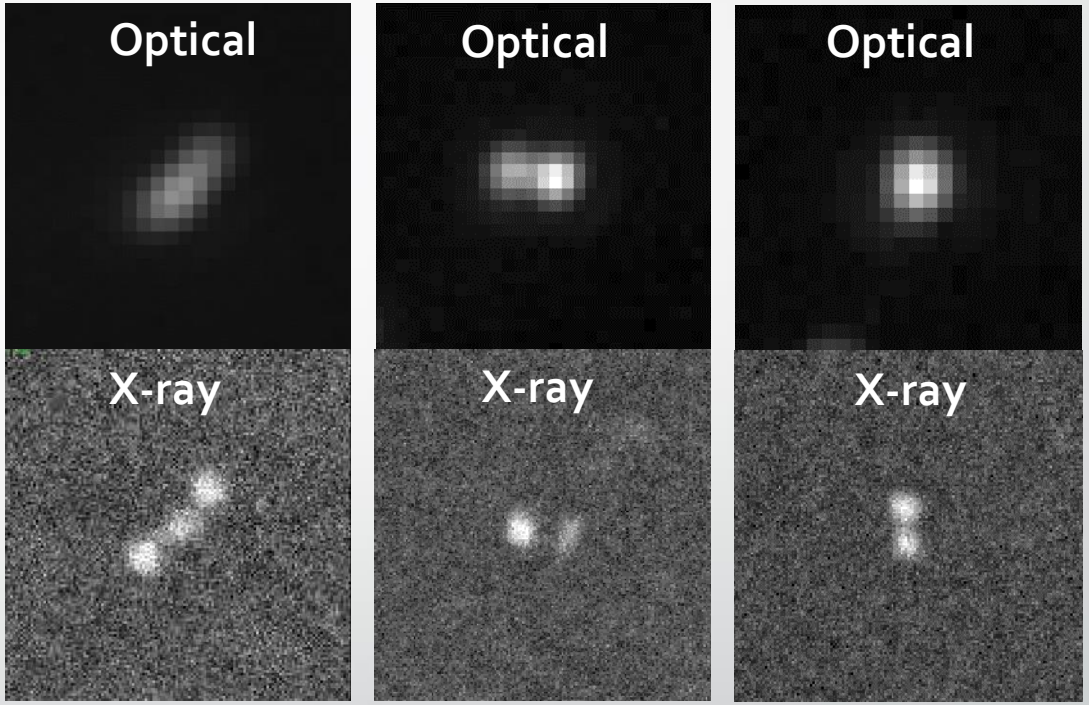
High-speed volume analysis for nanometric tracks is required



Direction detection challenge



Inaccessible due to diffraction limit

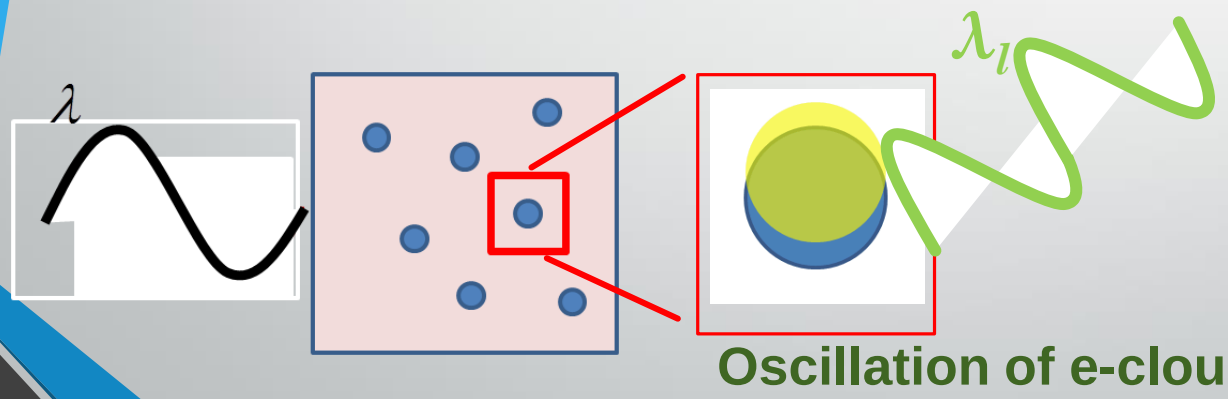


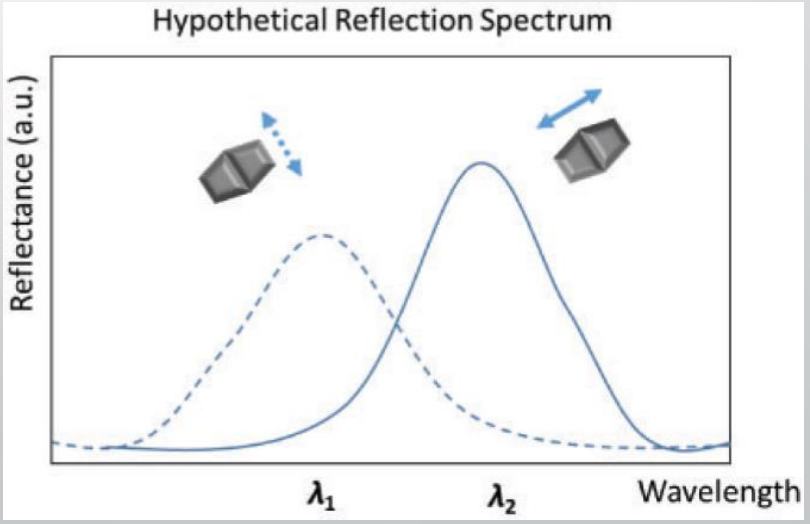
L = 380 nm L = 265 nm L = 160 nm

Need super-resolution to measure tracks shorter than 200 nm

Optical readout beyond the diffraction limit

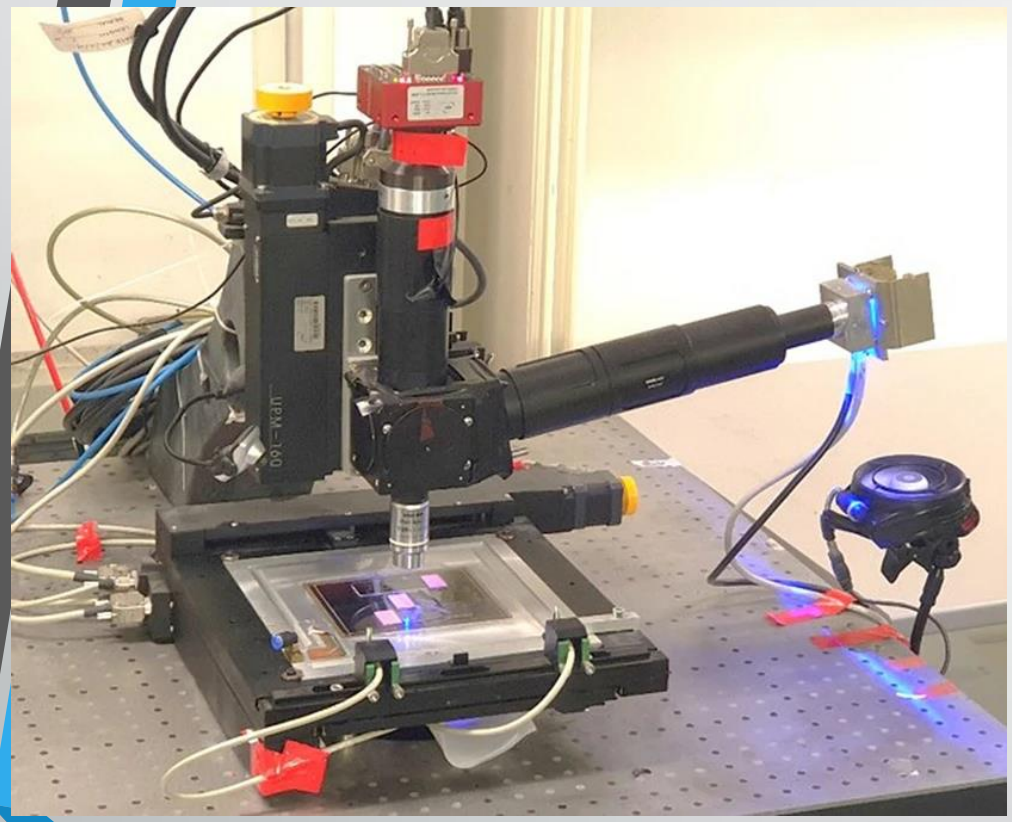
- Super-resolution idea: use the **plasmon resonance** effect to overcome the diffraction limit:
  - generated by a light wave trapped within conductive nanoparticles smaller than the wavelength of light
  - resonant frequency strongly depends on the composition, size, geometry, dielectric environment and distance between nanoparticles
  - occurs in the visible region for Ag and Au nanoparticles!
  - improve resolution by analyzing scattered light **polarization** and **spectrum**

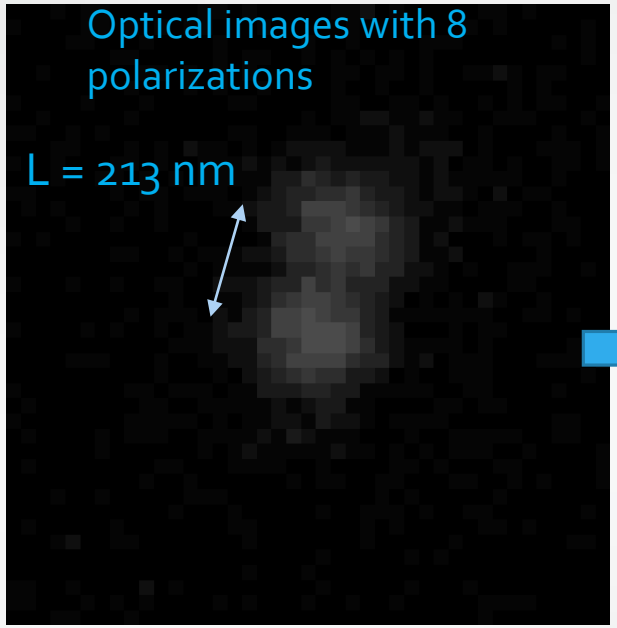


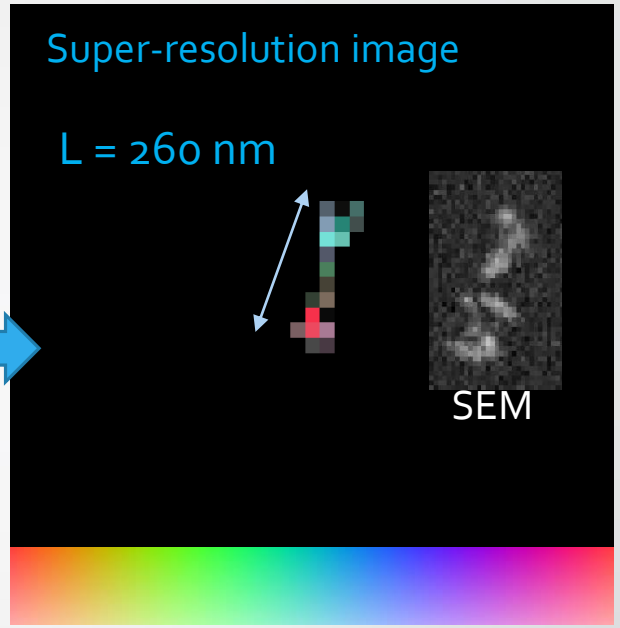


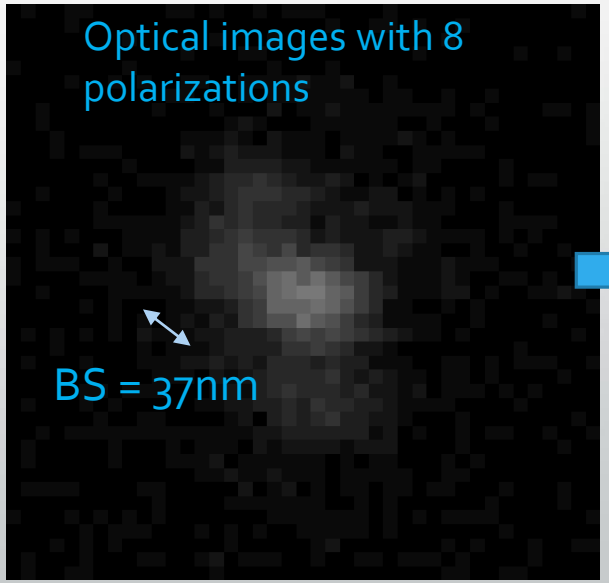
PTEP, Vol. 2019 Issue 62019, 063H02

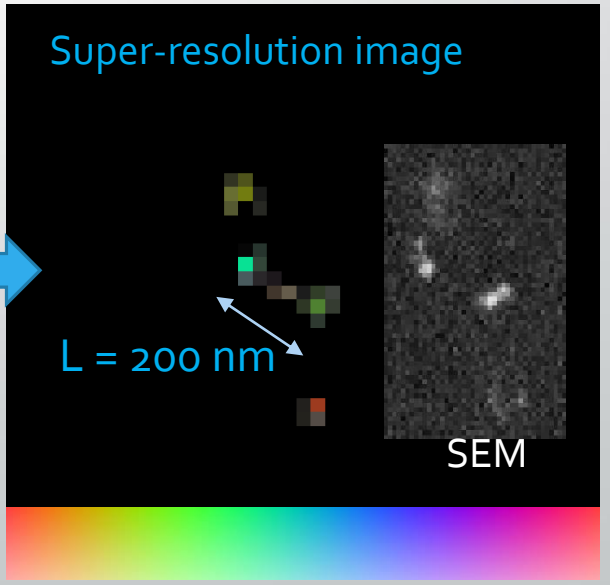
LSPR-based super-resolution imaging based on join deconvolution set of 8 polarized images







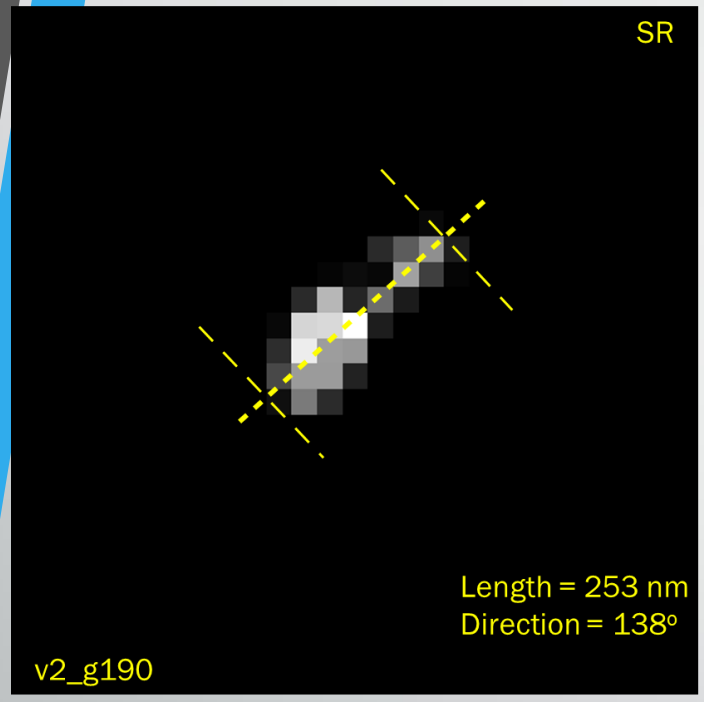


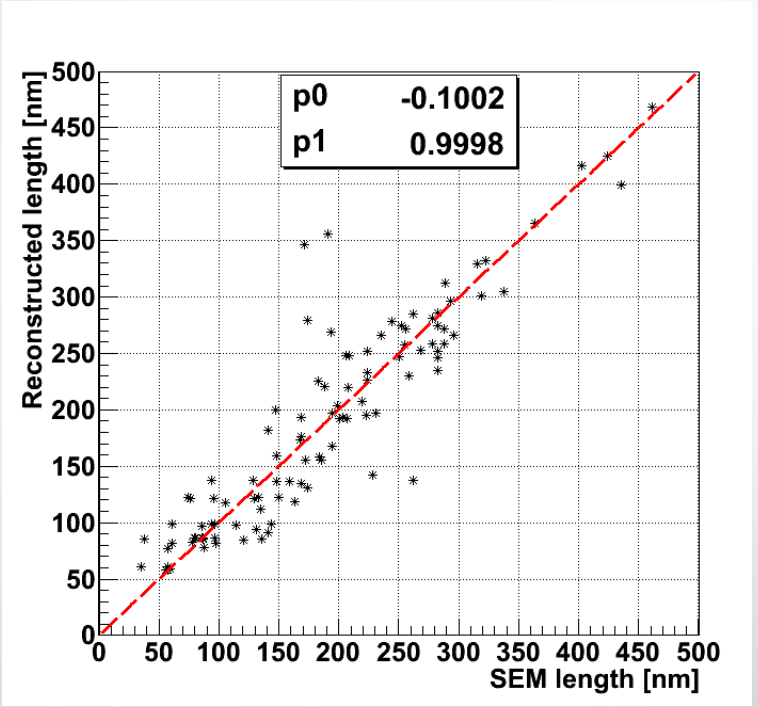


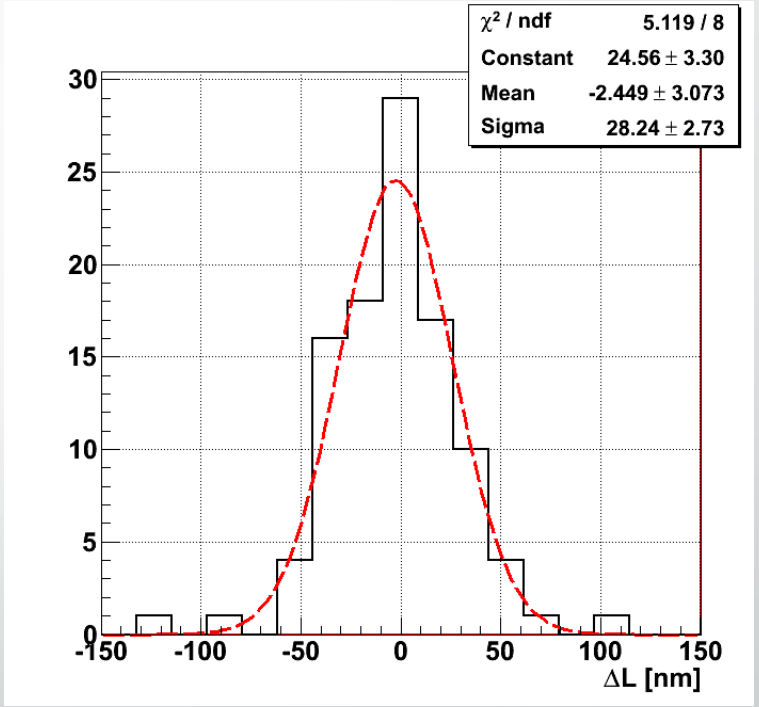
Alexandrov, A., *et al.* Super-resolution high-speed optical microscopy for fully automated readout of metallic nanoparticles and nanostructures. *Sci Rep* 10, 18773 (2020). https://doi.org/10.1038/s41598-020-75883-z

Joint Image Deconvolution

Event Length comparison with SEM



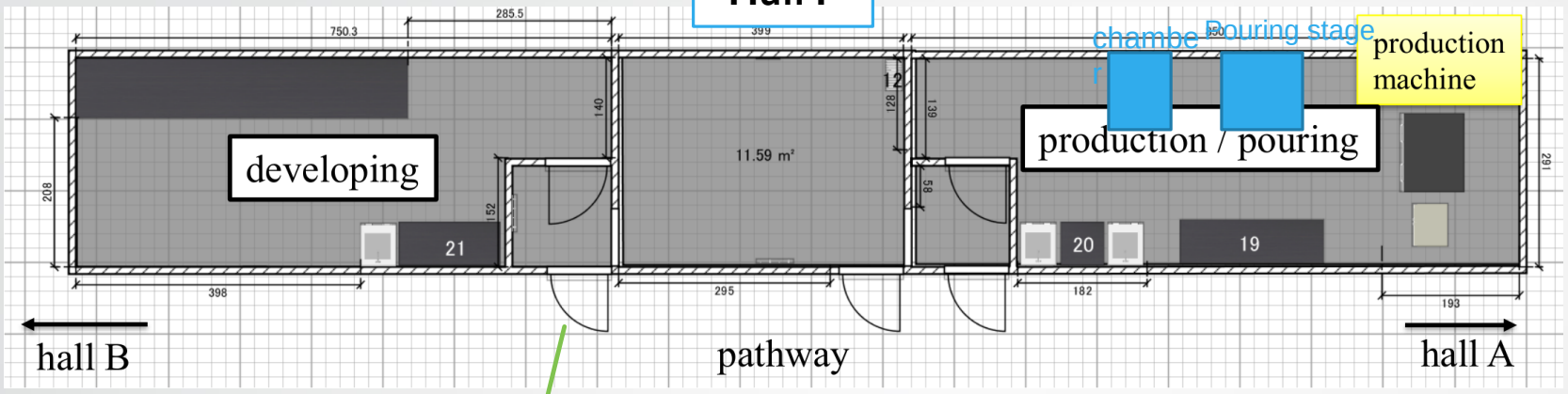


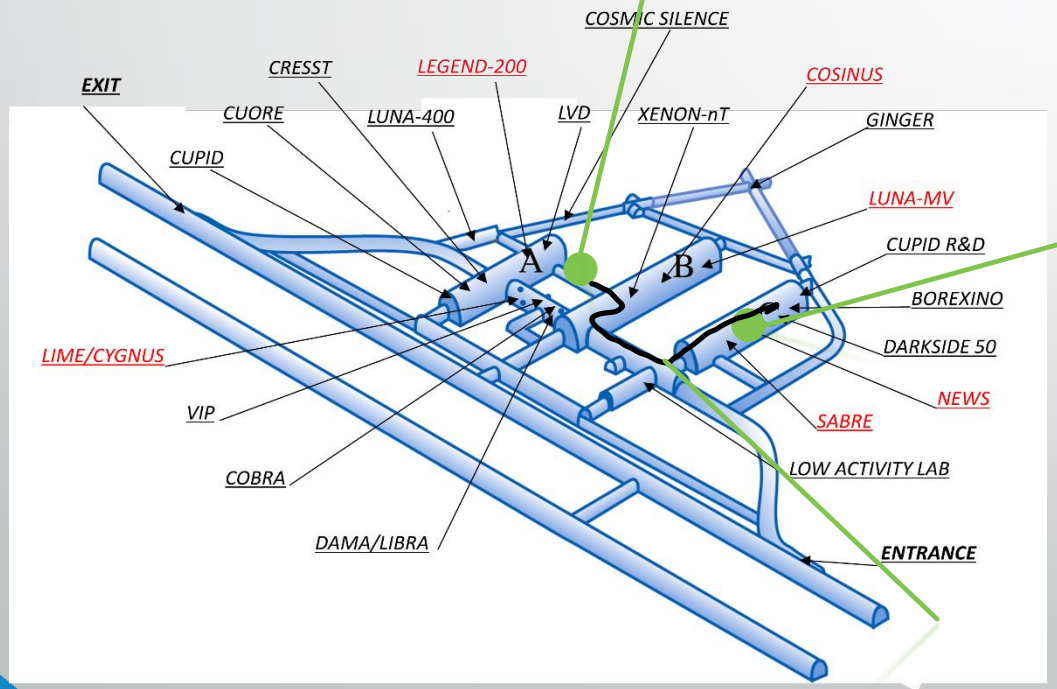


Length accuracy: 28 nm ≈ pixel size (27.5 nm)
Spatial resolution: 60 nm (Nyquist theorem)

Pearson Coefficient	Matched	Cross-test
Length	0.912	-0.009
Width	0.713	-0.007

Hall F


developing
production / pouring
chambe r
Pouring stage
production machine
11.59 m²
21
20
19
hall B
pathway
hall A


EXIT
CRESST
LEGEND-200
COSMIC SILENCE
COSINUS
CUORE
LUNA-400
LVD
XENON-nT
GINGER
CUPID
LUNA-MV
CUPID R&D
A
B
BOREXINO
LIME/CYGNUS
DARKSIDE 50
NEWS
VIP
SABRE
COBRA
LOW ACTIVITY LAB
DAMA/LIBRA
ENTRANCE

Hall C

Underground emulsion production facility @LNGS

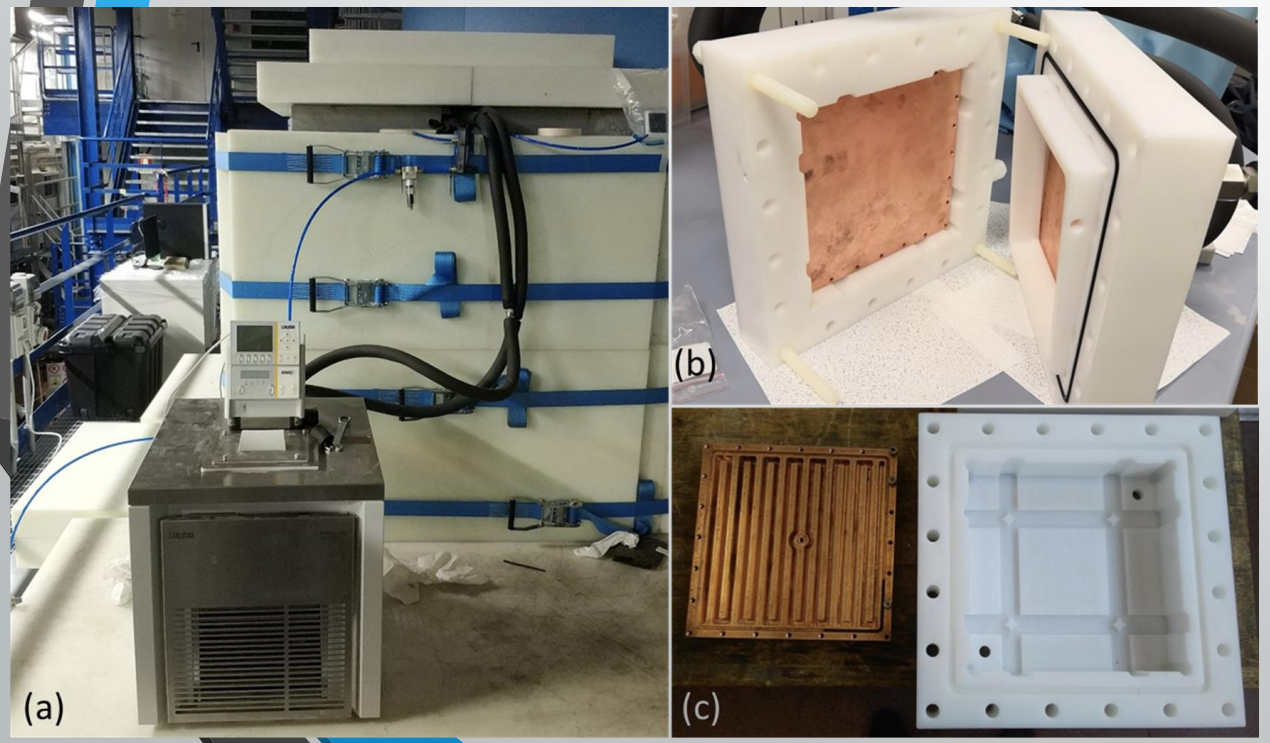
Fully operational since Dec-2020
Production capacity 100-200 g/day

NEWSdm: current setup

Mass	Exposure	Temp.	Shield
~10g	40days	-50°C	40cm PE + 10cm Pb

- Experimental setup in Hall C, close to Borexino
- Assembly of the setup in March 2021
- Test measurements ongoing

- Shielding: 10cmHDPE+10cm Pb+10cm HDPE



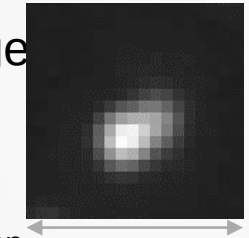
Data analysis flow for test run

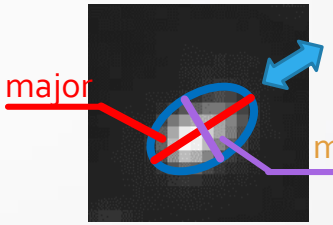
Automatic readout
1st trigger

Elliptical shape trigge

Requirement

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





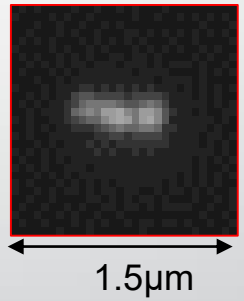
CNO : > 30 keV

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

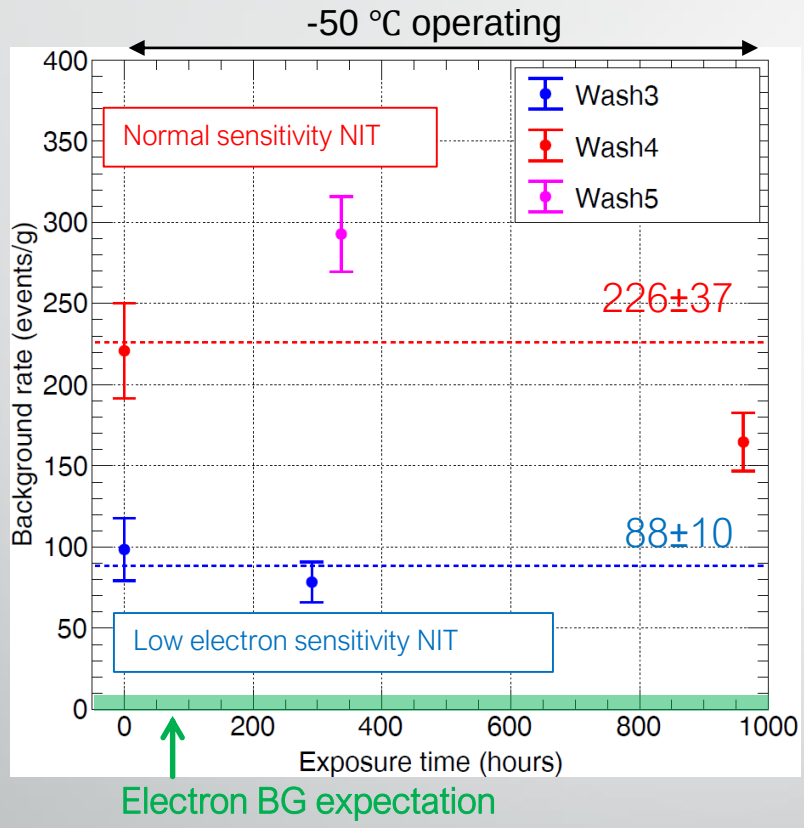
Electron rejection power :

10^{-4} @ room temperature

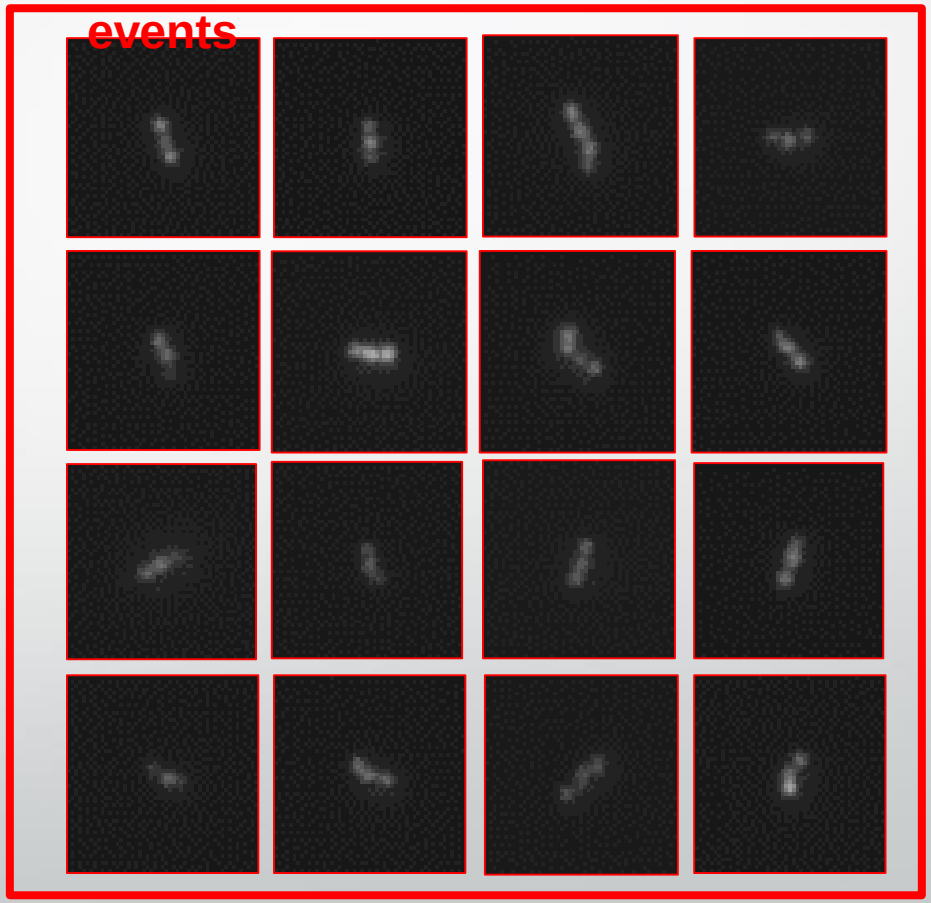
10^{-6} @ -50℃

Current Selection

Underground BG run status



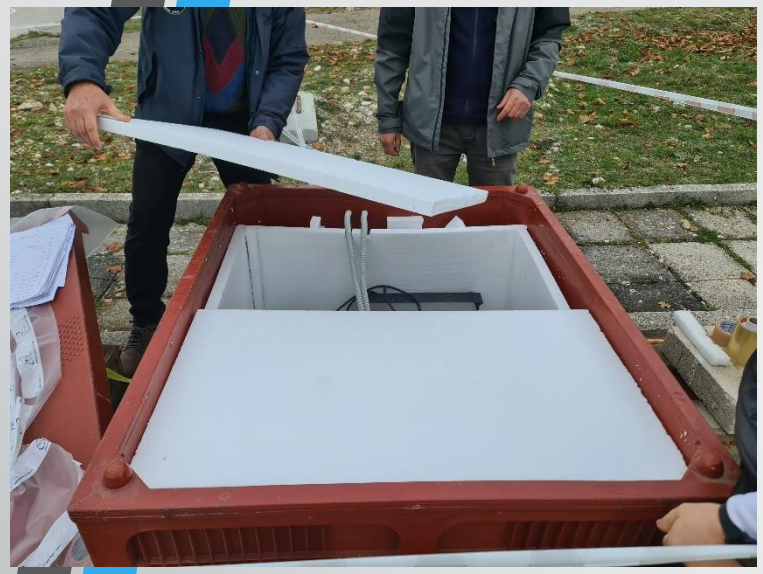
Example of Selected candidate events

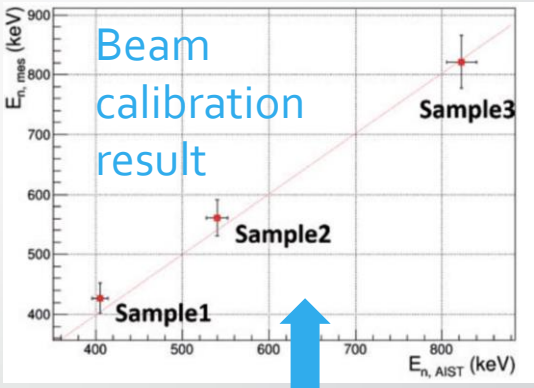


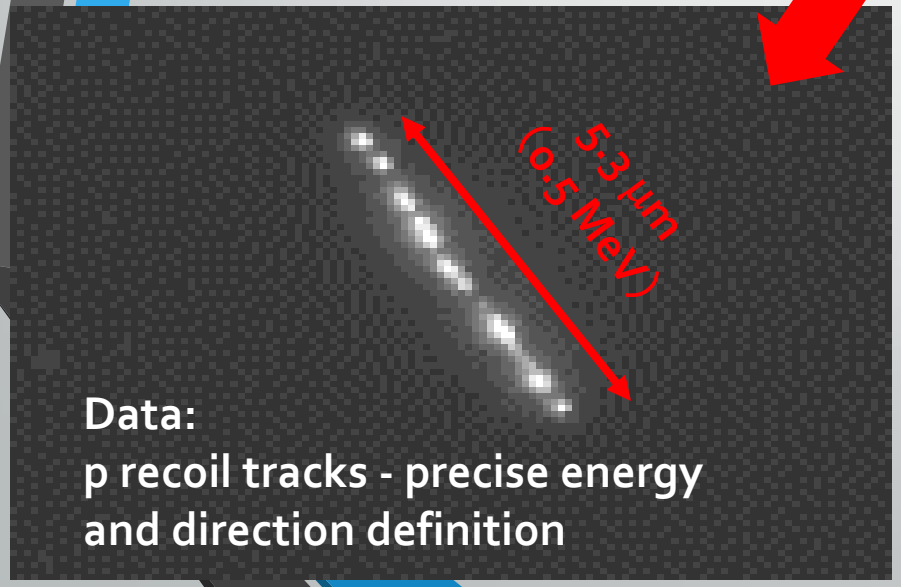
Current Selection
→Strict selection of signal-like events

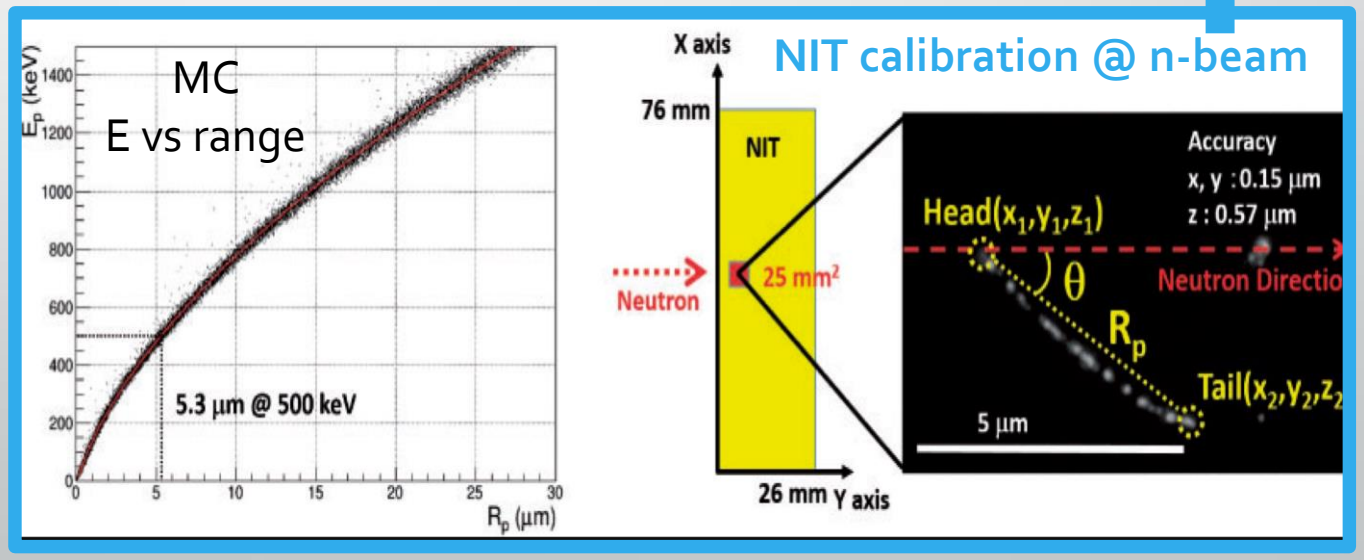
Neutron bg study at LNGS (external and underground)

first sub-MeV energy & direction n-spectrum measurement

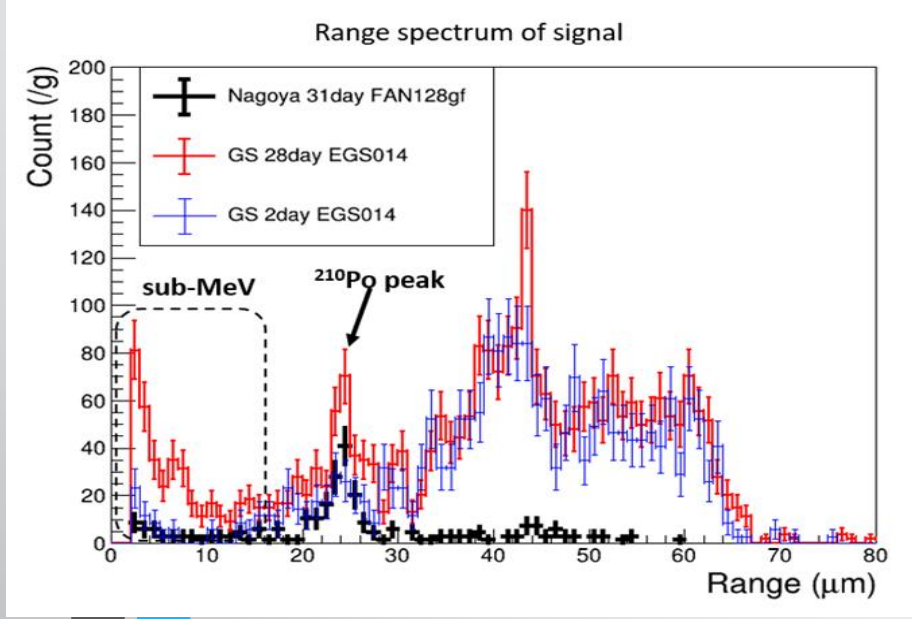


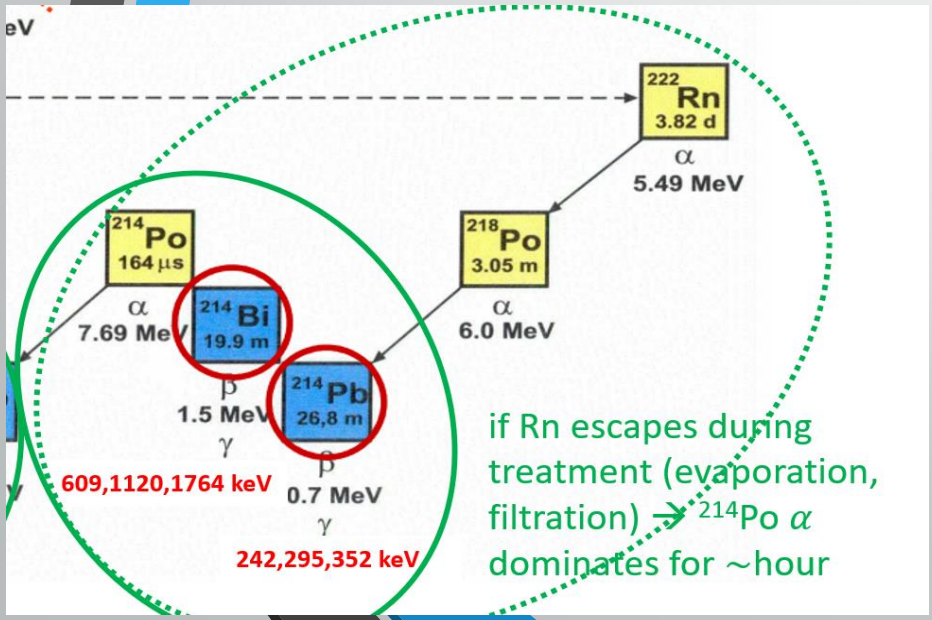


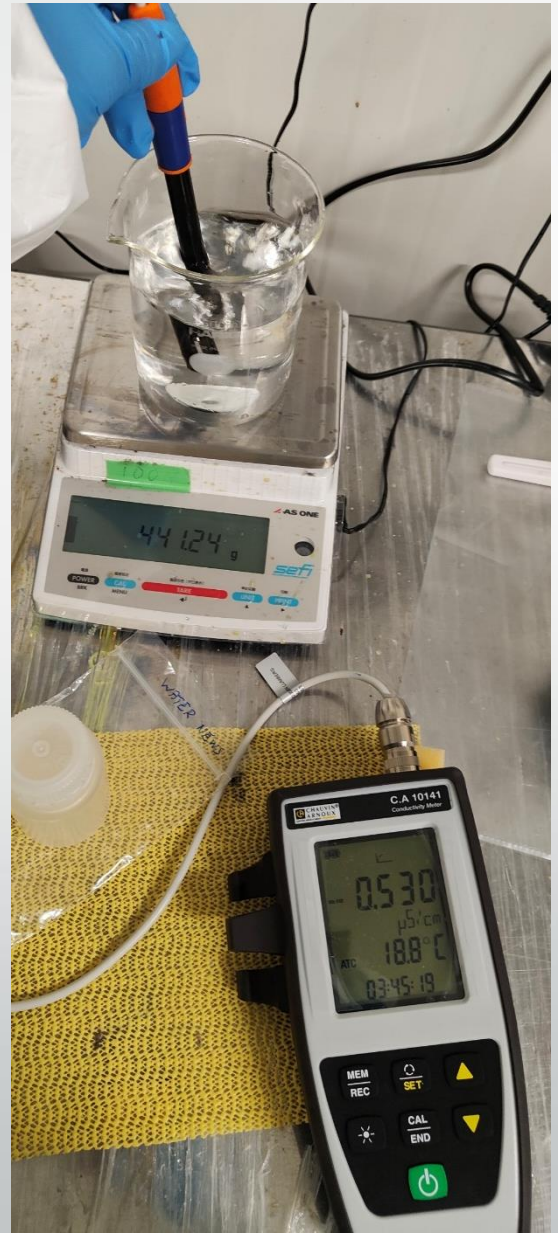




Measurement of Rn content in deionised water used for production in different conditions

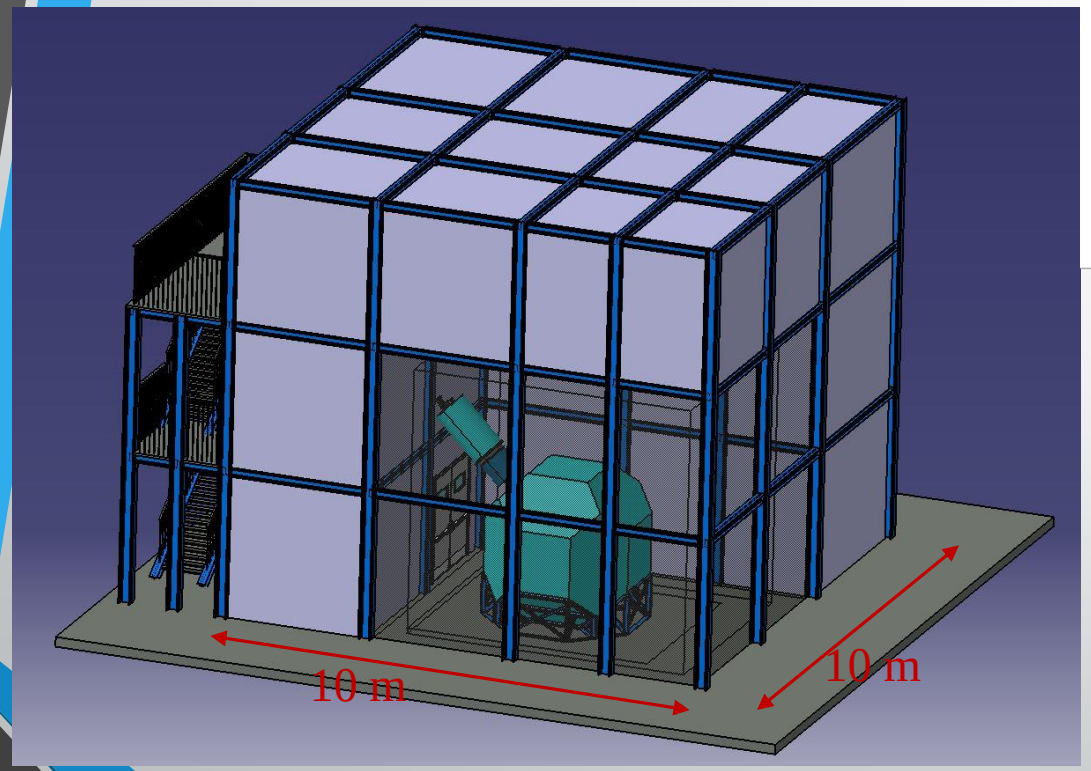


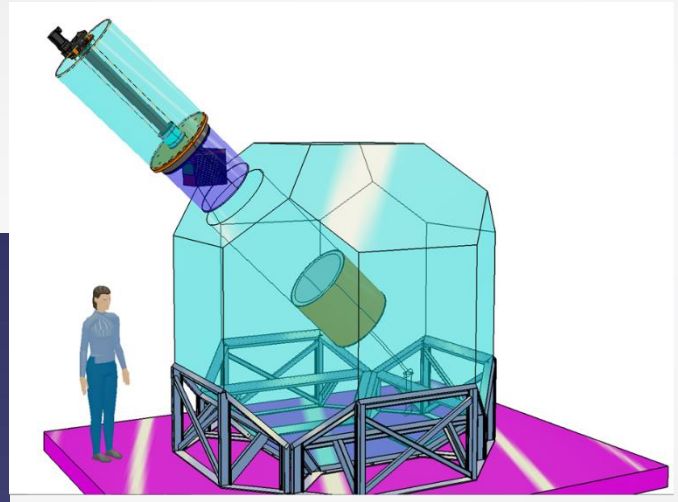




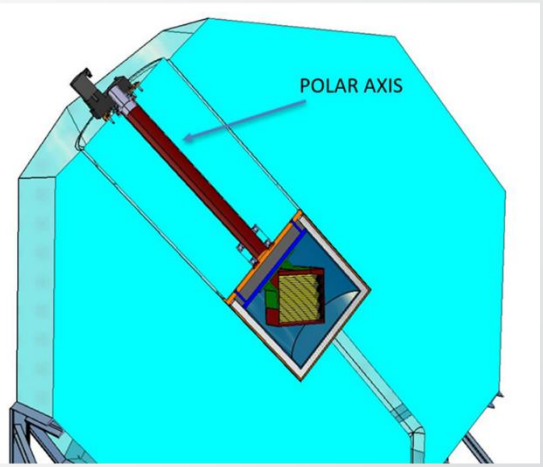
Future facility for NEWSdm: 10kg and beyond

Emulsion facility and shielding with an equatorial telescope

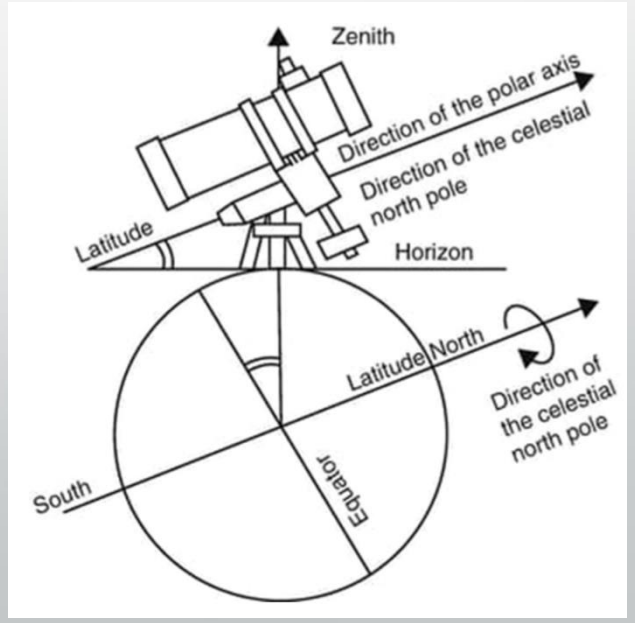


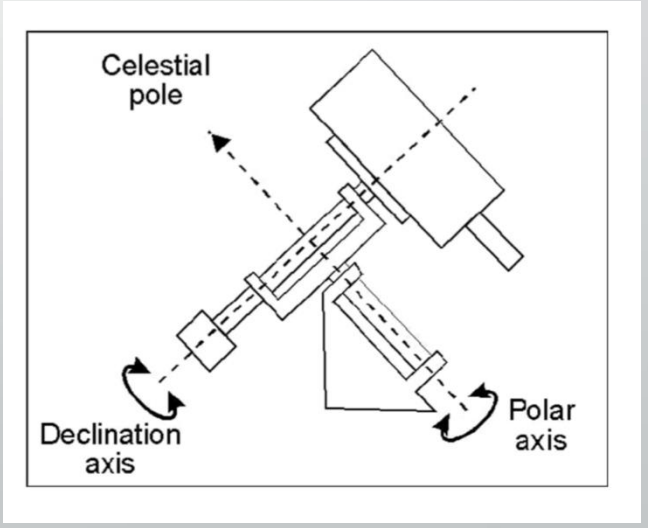


(a)



(b)





Conclusion

- Nano-grain emulsion based, high resolution detector for a directional Dark Matter search with unique compactness and angular resolution is under development
- Technological R&D
  - break-throw for optical readout makes possible fast analysis of O(100nm) tracks
  - 2D and 3D super-resolution, head-tail, color information
  - Machine learning approach to handle the data complexity
- Emulsion production underground and the full analysis chain are established
- Test runs of 10 g scale is ongoing in the underground laboratory for calibration and bg study
  - Rn issue in production phase is observed suggesting the origin of 0-day bg excess. The solutions are elaborating now
- Sensitivity to the boosted DM is under investigation
- By-products of NEWSdm R&D which has an intrinsic value:
  - New method for optical super-resolution
  - Neutron measurements in sub-MeV region with directionality


NEWS
dm
THANK YOU FOR ATTENTION!