NEWSdm experiment

Directional Dark Matter Search with Super-high resolution Nuclear Emulsion

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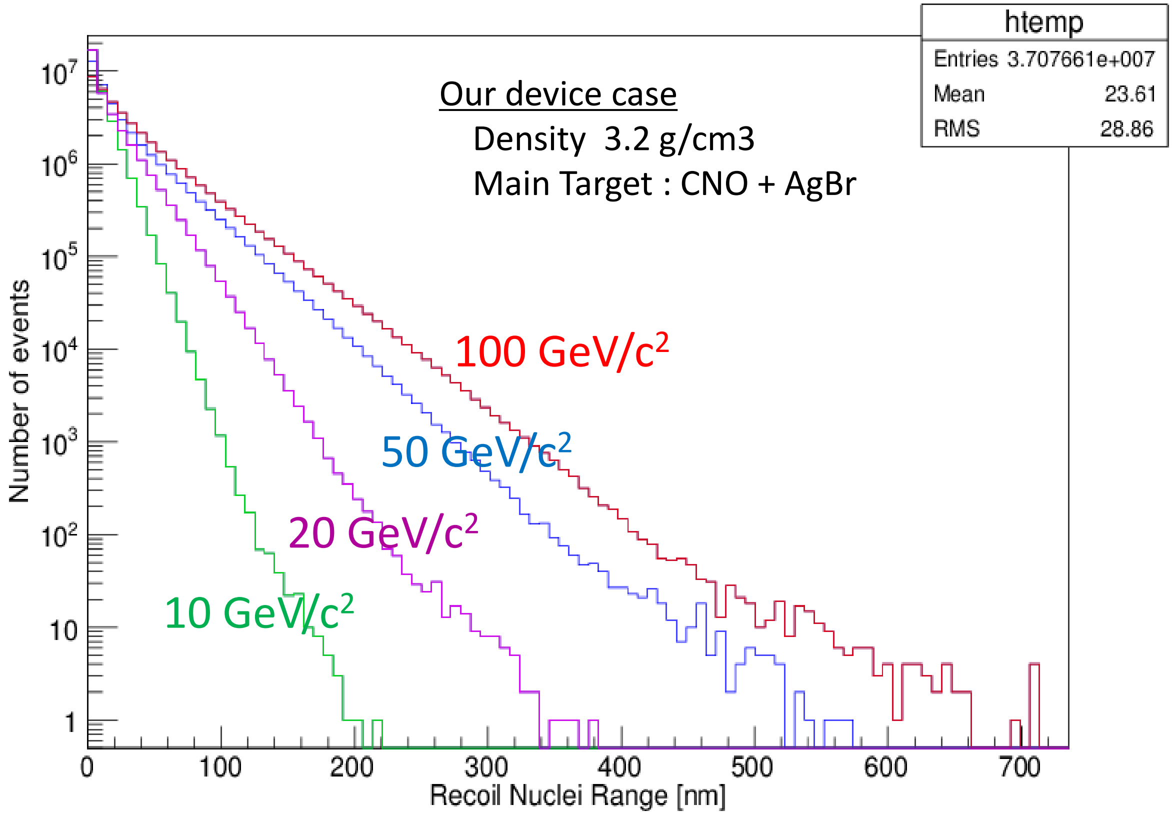
on behalf of NEWSdm collaboration

Direction sensitive dark matter with solid detector

- Super-high resolution device using capability of detecting nano-scale tracl
- Readout technologies for such very short length tracks
- Understanding and rejection of backgrounds



Direction sensitive dark matter with solid detector

This talk

Super-fine grained Nuclear emulsion (Nano Imaging Tracker : NIT)

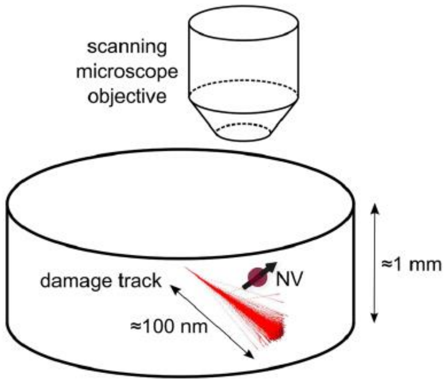
First detector demonstrated capability of tracking to low-velocity nuclear recoil

New Idea amd on studying

- **Diamond**

Microscope imaging of luminescence due to N-V center in diamond

Phys. Rev. D. 96 035009 (2017)

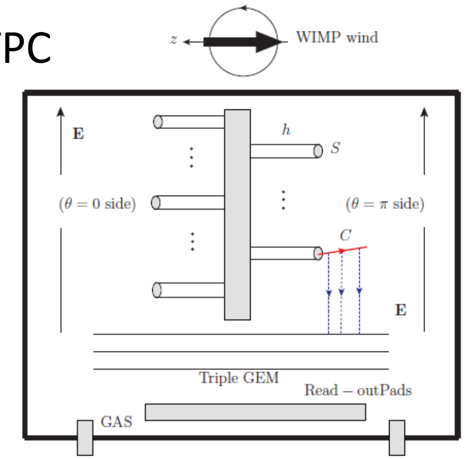


- **Anisotorpic crystal (e.g., ZnWO4)**

- **Carbon nano tube**

Carbon nanotube target + gaseous TPC

arXiv:1412.8213 [physics.ins-det]



- **Rock (but not directional search**

Crystal defect tracking in Ancient mineral

→ already M or G year exposure

arXiv:1811.06844v1 [astro-ph.CO] 16 Nov 2018

NEWSdm experiment
[Nuclear Emulsion for WIMPs Search – directional measurement]

http://news-dm.lngs.infn.it

<u>LOI under review by the LNGS science committee</u>

NEWS: Nuclear Emulsions for WIMP Search
Letter of Intent
(NEWS Collaboration)

Chiba
Nagoya

METU Ankara

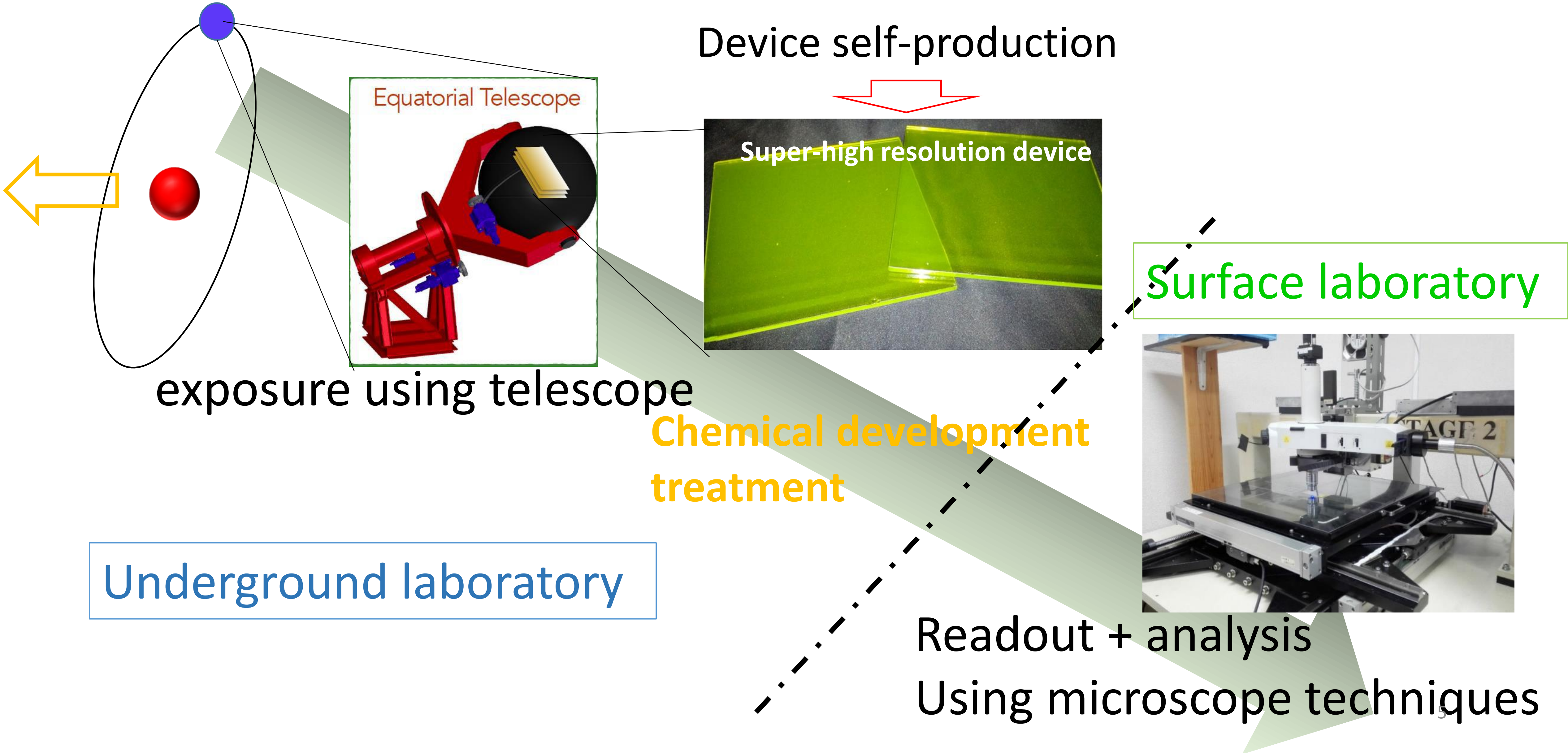
Bari
GSSI
LNGS
Napoli
Roma

LPI RAS Moscow
JINR Dubna
SINP MSU Moscow
INR Moscow
Yandex School of Data Analysis

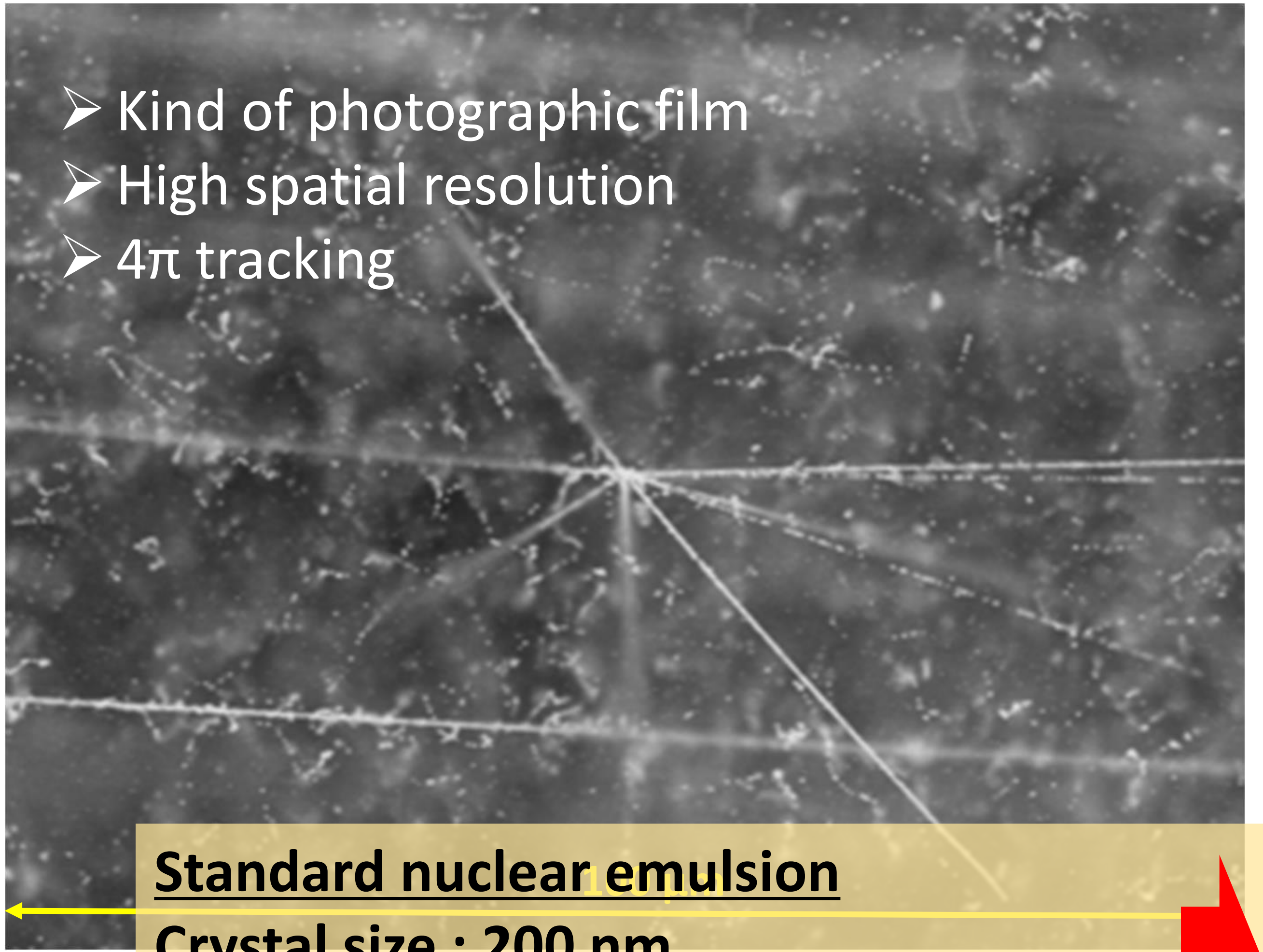
Gyeongsang

https://arxiv.org/abs/1604.04199

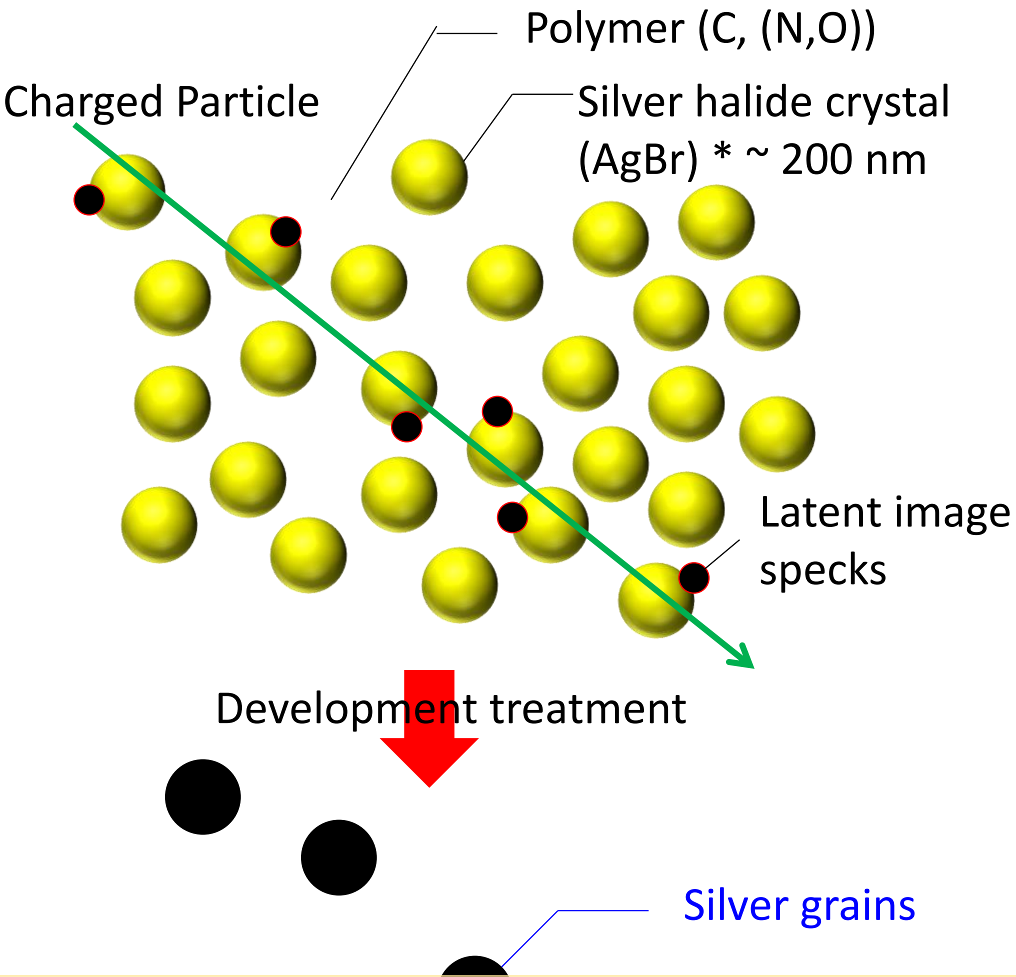
Concept of NEWSdm experiment



Nuclear Emulsion Device



- Kind of photographic film
- High spatial resolution
- 4π tracking



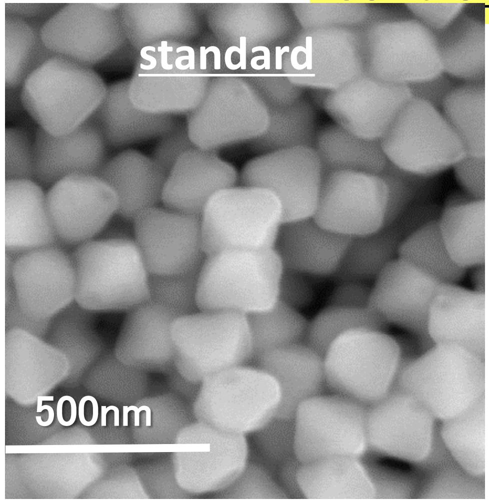
Standard nuclear emulsion
Crystal size : 200 nm
Detectable track length : > O(1) μm

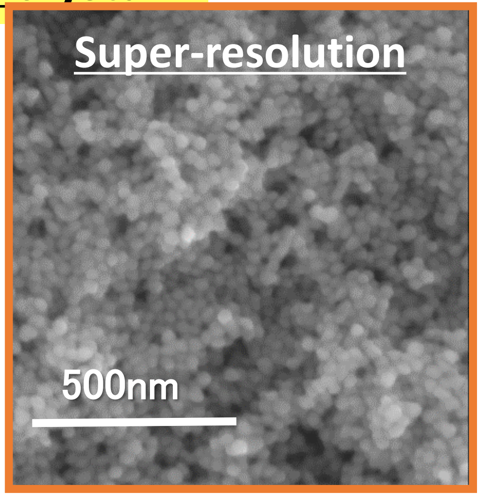
Very fine crystal controlled about 10 nm to detect 100 nm scale tracks

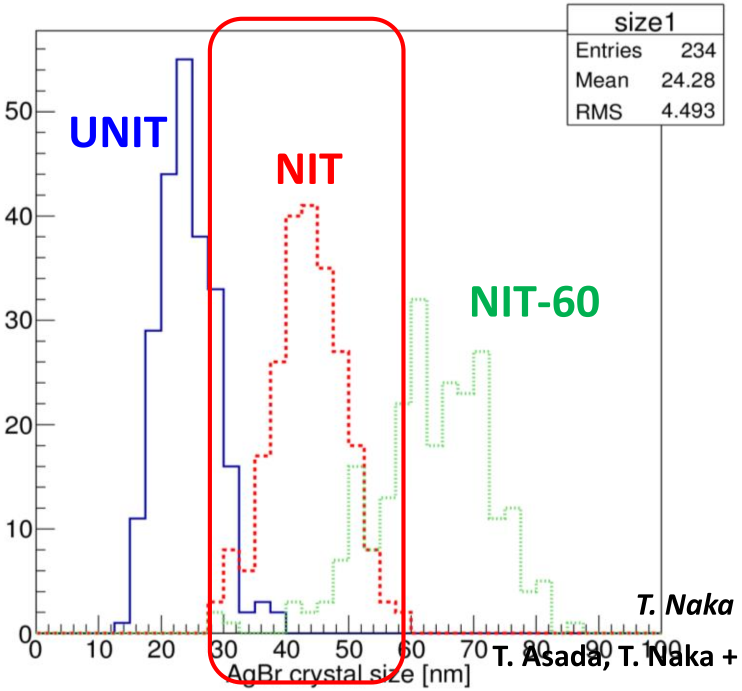
Self-production of Nano Imaging Tracker(NIT)

・Production time : 4-5 hours /batch
・One butch : ~ 100 g (+ 300 g)
(there are 2 type machines)
⇒ kg scale production is possible using this machine.

Controlled AgBr crystal







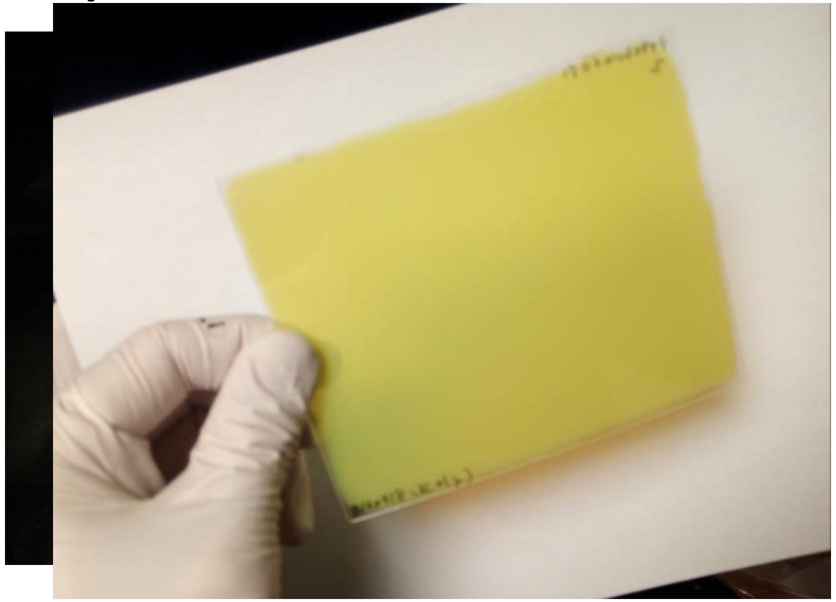
Current standard Device :
Nano Imaging Tracker [NIT]
crystal size : 44 nm

Finest grain emulsion :
Ultra-NIT [UNIT]
crystal size : 25 nm

T. Naka et al., Nucl. Inst. Meth. A 718 (2013) 519-521

T. Asada, T. Naka + , Prog Theor Exp Phys (2017) 2017 (6): 063H01

Properties of NIT device



Elemental composition of NIT

For high-mass DMs: Ag, Br, I

For low-mass DM: C, O, N, H, S, Na + others

	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

◆ Intrinsic radioactivity :

U-238	Th-232	K-40	Ag-110m	C-14
27	6	35	(~400)	24000

[mBq/kg]

- K-40 reduction : 69020 (first type) → 35 mBq/kg

  by KBr → NaBr for AgBr creation and use high deionized gelatin
- Ag-110m : not confirmed yet
  - first measured batch : ~ 400 mBq/kg
  - recent batch : < 150 mBq/kg
- C-14 : AMS measurement result. Consistent with natural abundance.

  → if replace to synthetic polymer, it will be reduced more than 10^{-3}

◆ Intrinsic neutron background (SOURCES + Geant4):

	Emission [/kg/y]	Rate for > 100 nm tracks [/kg/y]
Intrinsic neutron	~ 1.2	~ 0.1

Detail shown in Astropart. Phys. 80 (2016)16-21

Low-velocity ion tracking

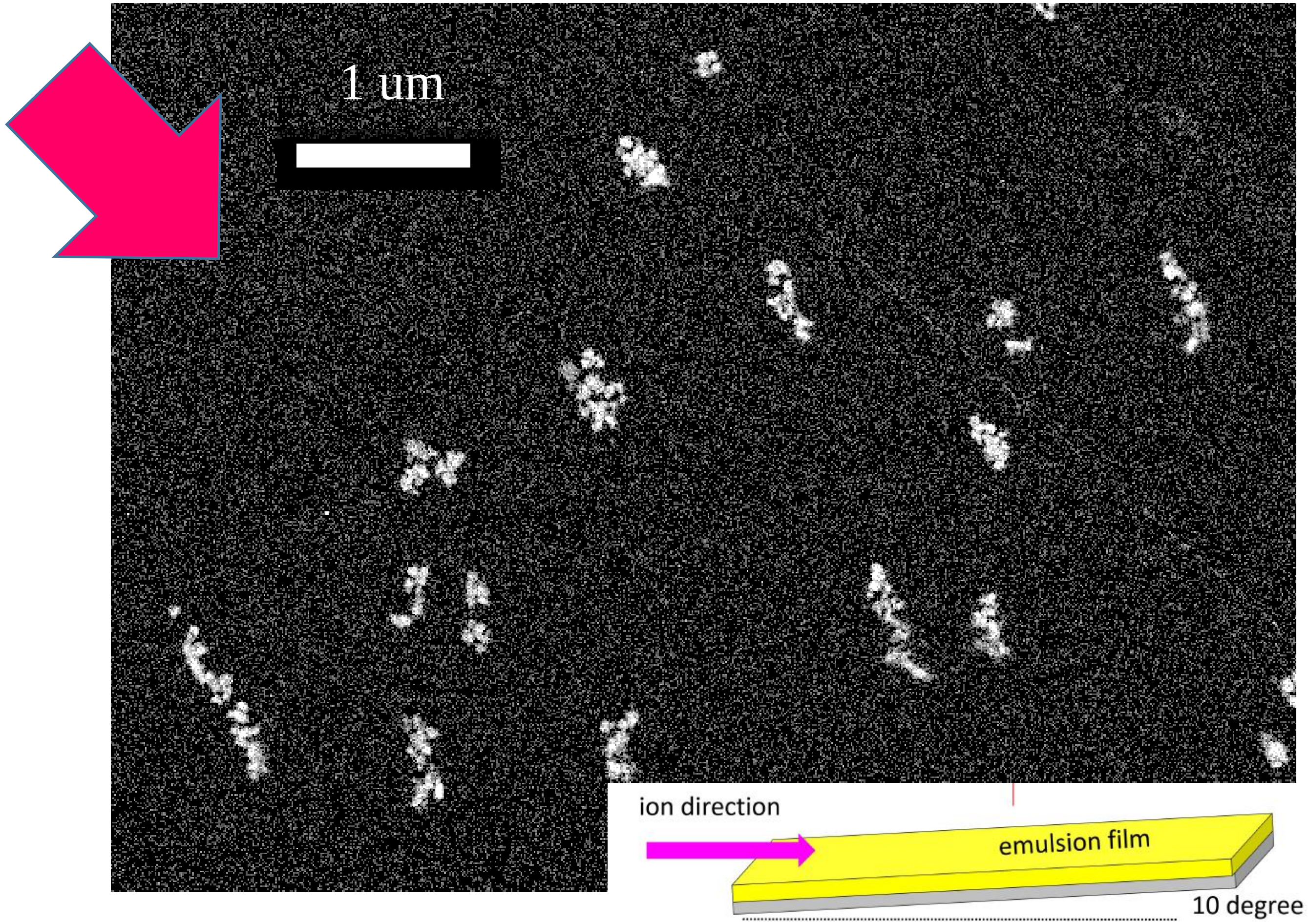
Can use ion implantation as calibration source

- Mono energy (±0.1 keV)
- Good direction uniformity (<10 mrad)
- Now, C from CO_2・Ar, Kr

(various kind ions are also possible)

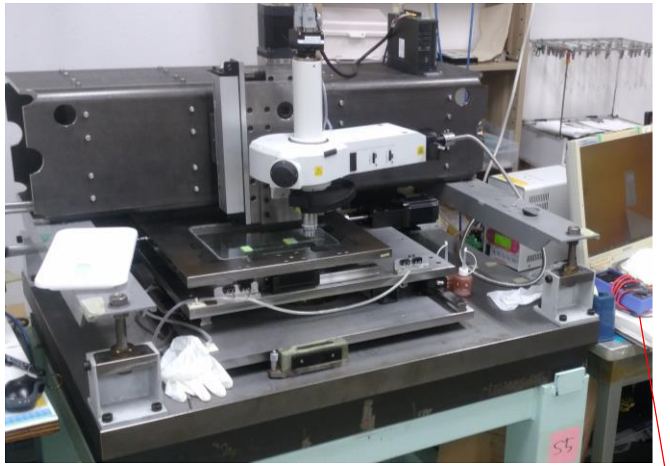
Low velocity ion created by an ion-implantation system at Nagoya University

SEM image of low-velocity Carbon ion (100keV)

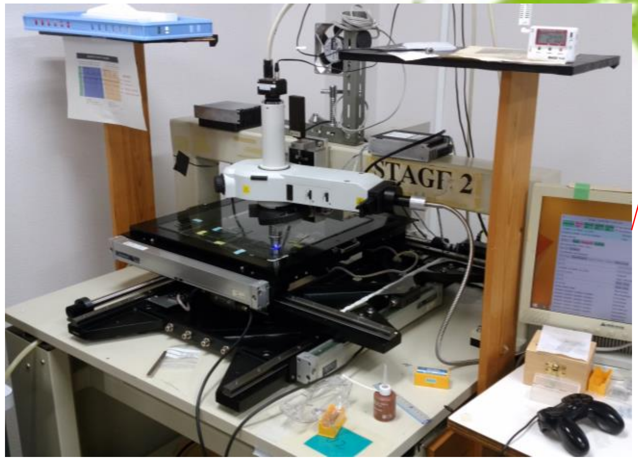


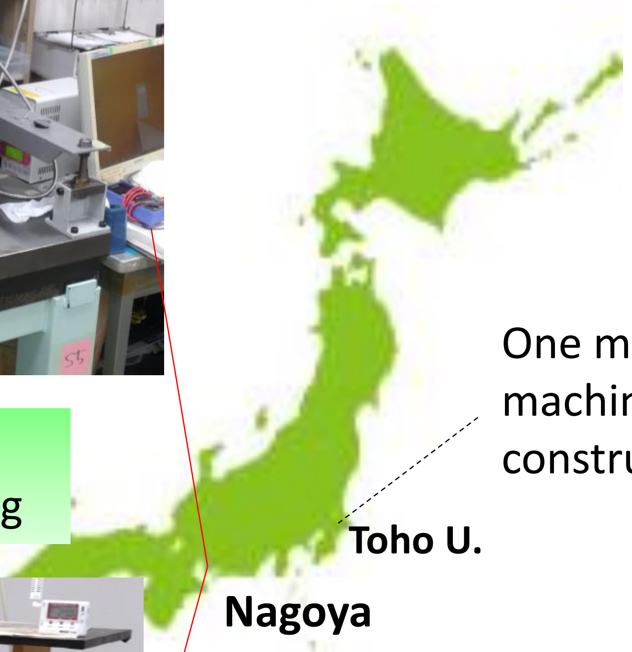
AgBr crystal has good sensitivity about Carbon (100 % consistent sensitivityy)

Readout technologies

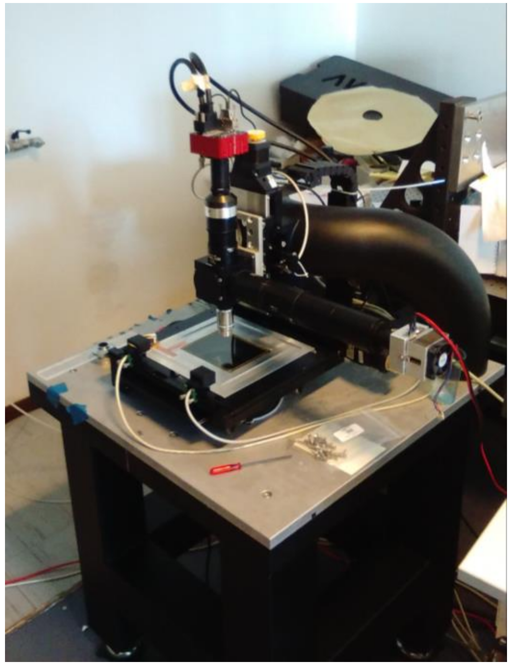


- Event selection
- Phase contrast imaging

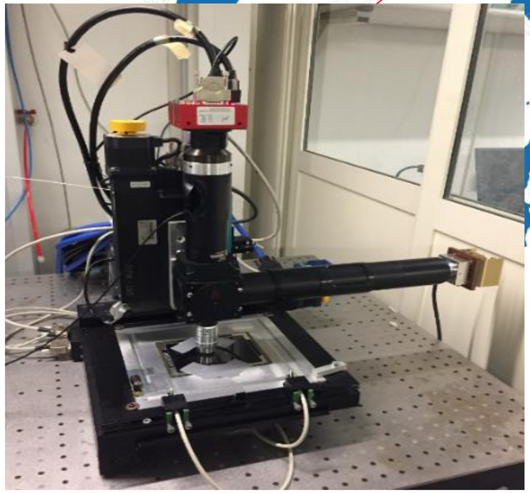




One more machine will be constructed



Machine for device quality check



- Event selection
- Plasmon analysis

x 2

Optical microscope system and analysis flow

Standard optical microscope scanning [on going]

Current Speed : ~30 g/y

- Elliptical event selection
- Roughly event selection with high speed
- On-line event analysis

~ 100 g/month scale (~ kg/y)

~ kg /month scale (~ 10 kg/y)

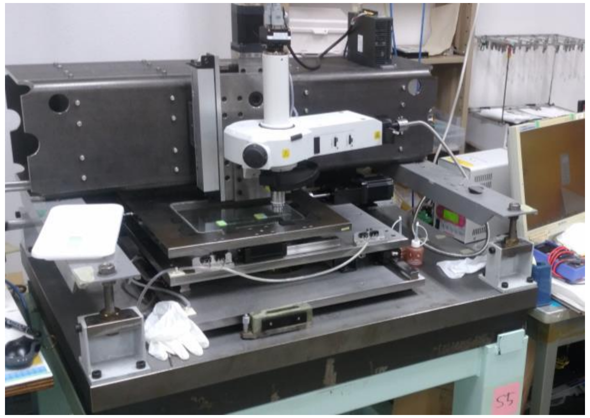
T. Katsuragawa *et al.*, JINST 12, T04002(2017)

Phase contrast imaging [will be newly installed]

10^7 events/month

- Phase contrast imaging
- Contaminated dust discrimination

To be constructed soon

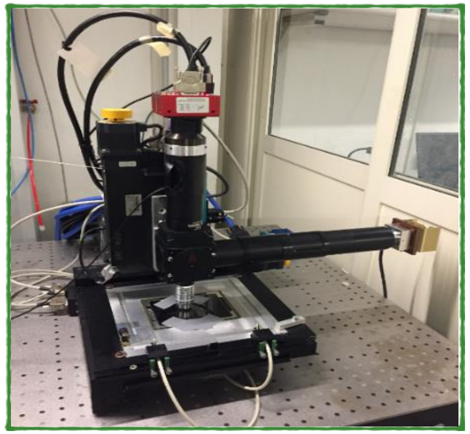


LSPR analysis [under studying]

10^5 events/month

- Super-resolution : ~10 nm
- Spectrum analysis
- Machine learning

Yandex@Russia, Napoli



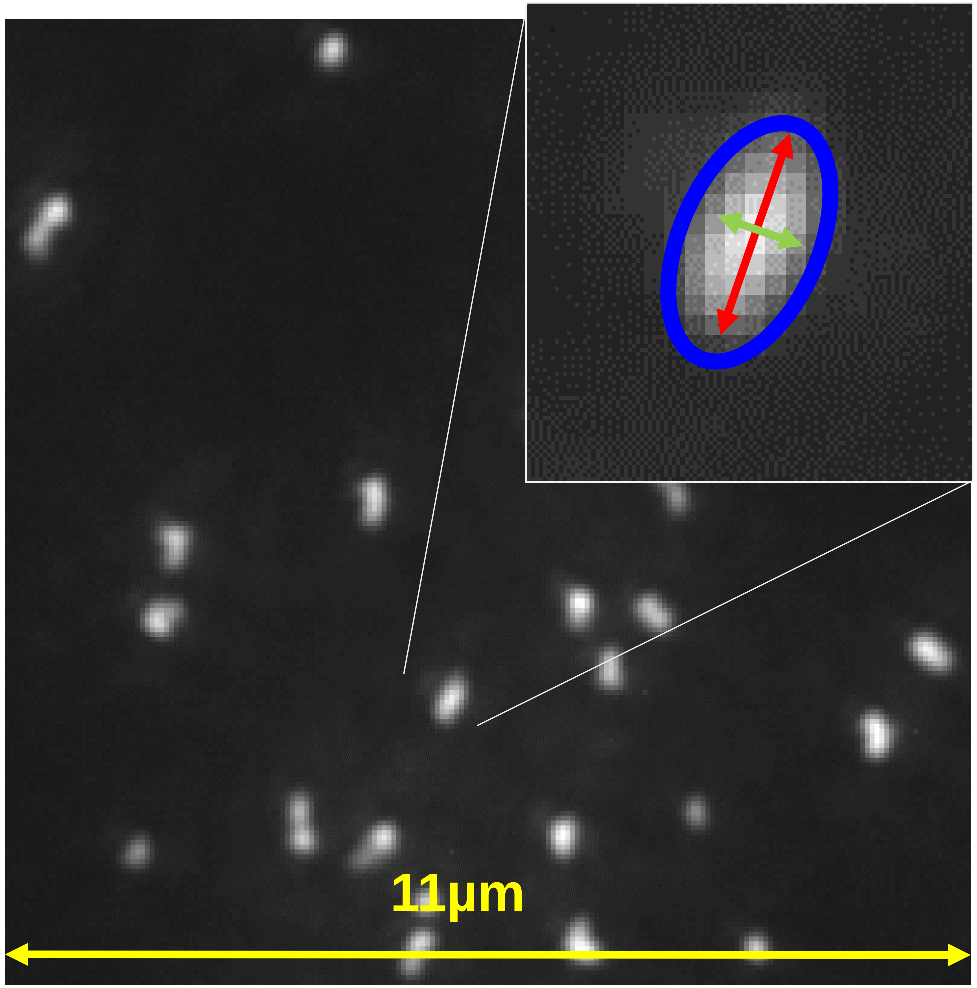
Further new analysis [under studying]

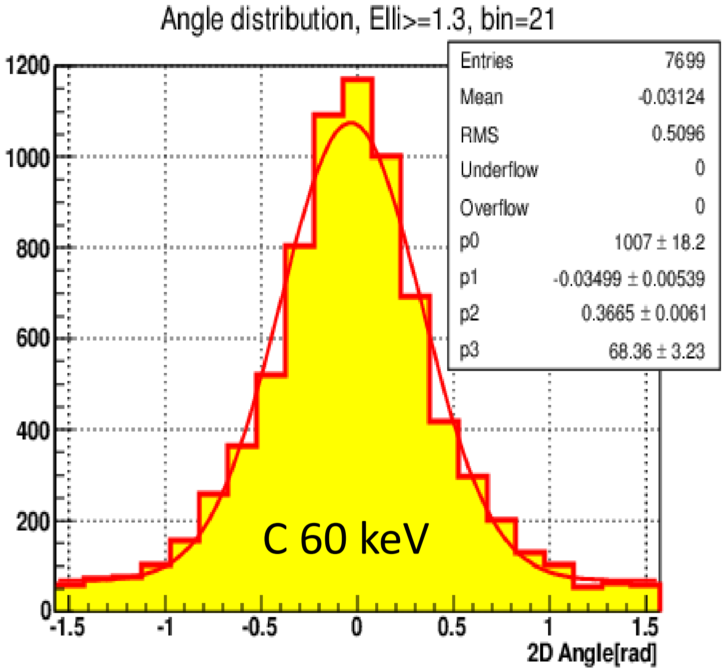
~10^3 events/month

- 3D super-resolution analysis with plasmonics
- Destructive analysis using oxidation method
- Expansion method

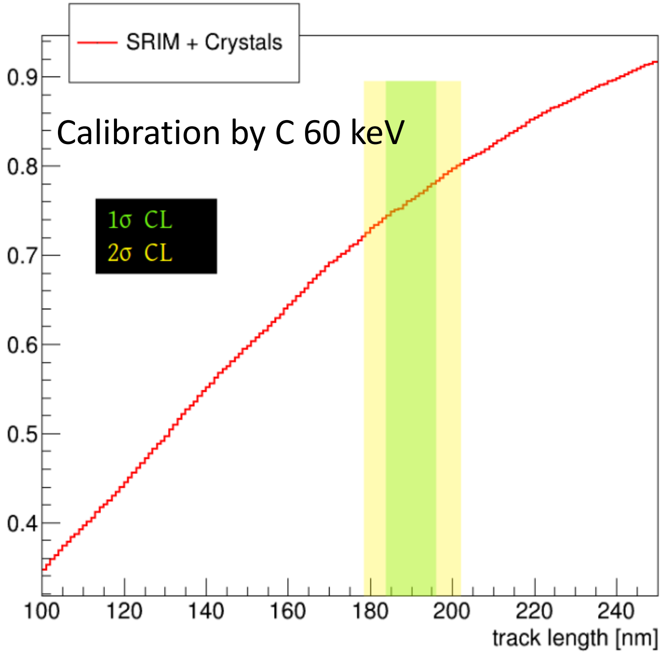
Cutting-edge technologies will be installed

Sub-micron length track readout capability





Cleary observed angular distribution
⇒ angular resolution ~ 30 deg.



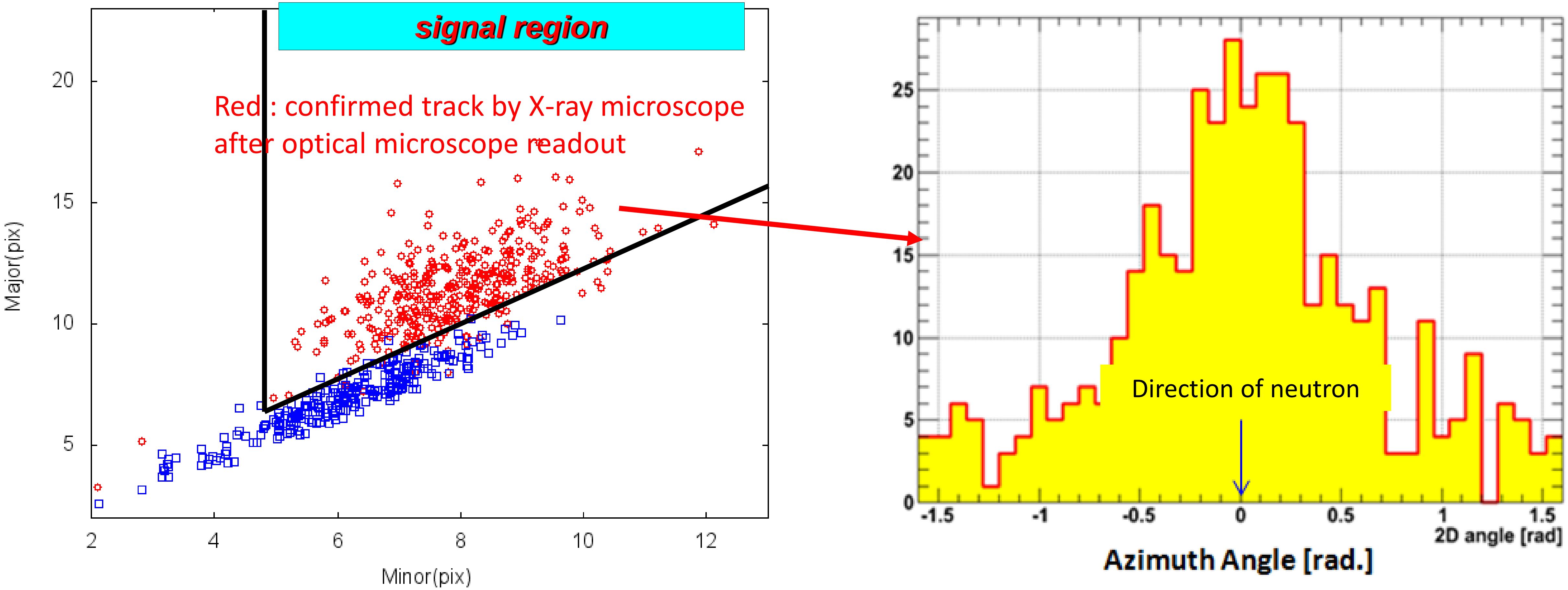
Direction sensitive track length threshold in this algorithm
⇒ > ~ 190 nm

Energy threshold
> ~ 60 keV (eff. ~ 10 % ⇒ to be improve by upgrade optical condition)

K. Kimura and T. Naka, Nucl. Inst. Meth. A 680 (2012) 12-17

T. Katsuragawa et al, JINST 12 T04002 (2017)

Demonstration of direction sensitive nuclear recoil detection due to 14.8 MeV neutrons



Mostly detected target was Br recoil [< 200 keV] → difference condition from current one
Now on studying CNO recoil demonstration due to 565-700 keV (Li-p nuclear fission reaction)

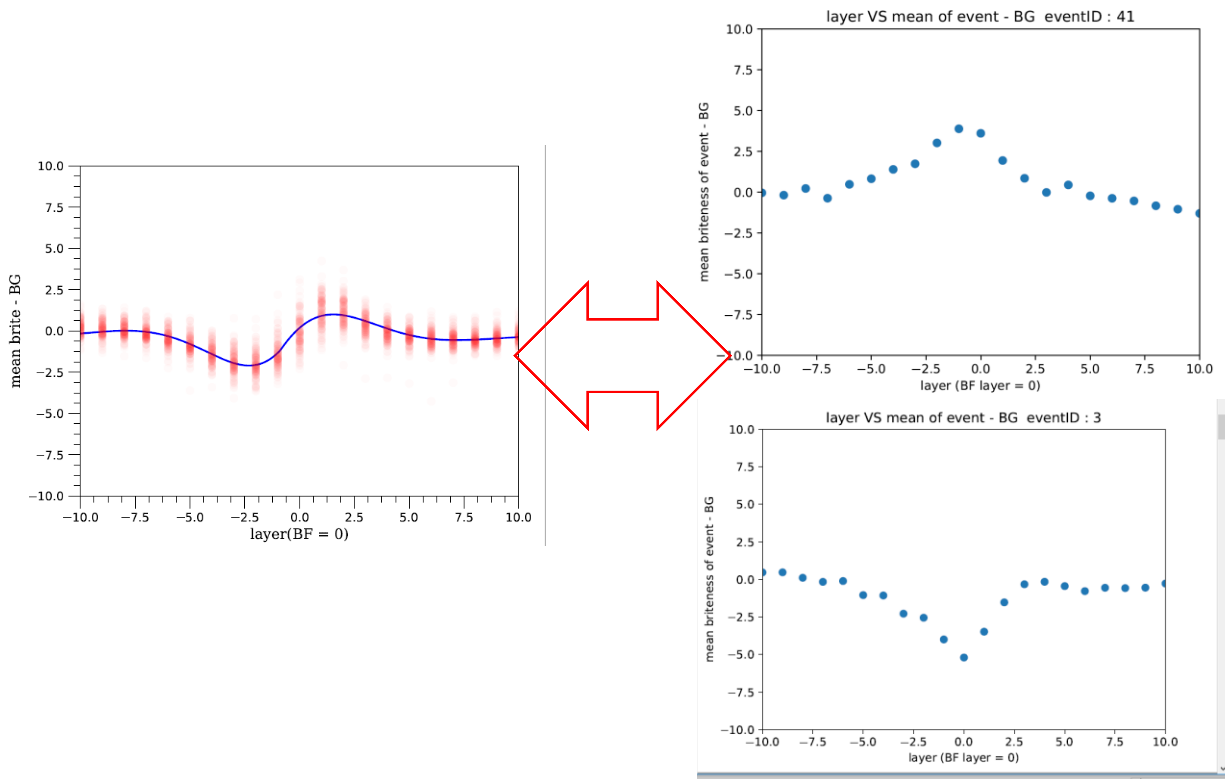
	Main source	Technologies	Expected rejection power or event rate
Physical BG			
Electrons	C-14 β Environment gamma	Crystal temperature dependence (*M. Kimura et al., NIM A 845 (2017) 373*) Crystal sensitivity control Image and plasmonic analysis	(> 10^6 or more rejection power (< O(1) /kg/day)) *now on studying
		Synthetic Polymer	> 10^3 or more
Neutron	Intrinsic (α, n)	-	~ 3 x 10^{-4} /kg/day or less Astropart. Phys. 80 (2016)16-21
	Environment	Water shield	< 1E-4/kg/day
Cosmic-ray	Recoiled nuclei	Coincidence with MIP sensitive emulsion	*on studying using simulation
	Spallation neutron	(under studying with simulation)	(~O(10^{-4})/kg/day * now on study)
Nonphysical BG			
Contaminated dust	(under studying)	Clean room Phase contrast imaging Plasmonic analysis and image processing Machine learning Chemical treatment	Under studying (at least > 10^6 or more, in principle it should not be background)

Further signal discrimination from backgrounds

Phase contrast imaging

Low-velocity ion (signal)

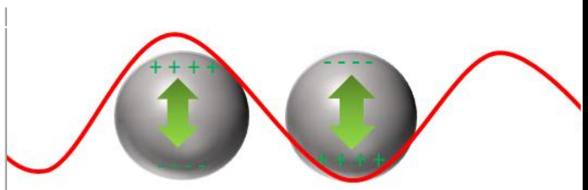
Contaminated background



New information to distinguish signal from background by phase-contrast imaging

Plasmonic optical response + machine learning

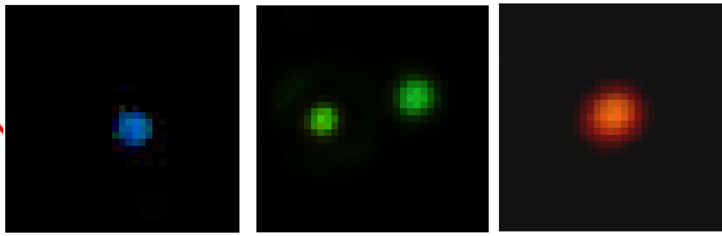
Localized Surface Plasmon Resonance



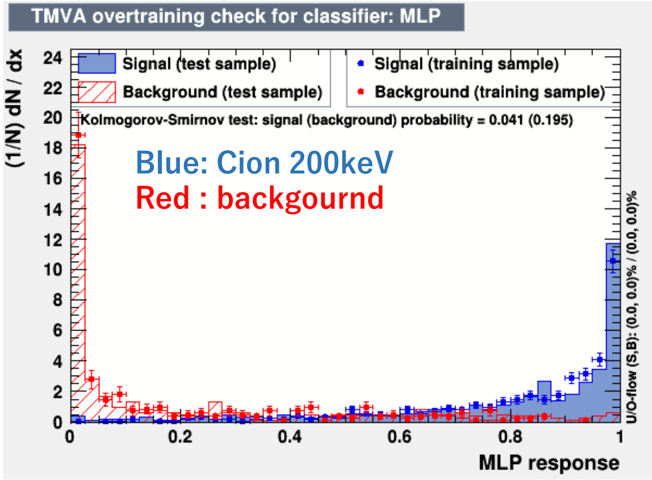
silver nano particle

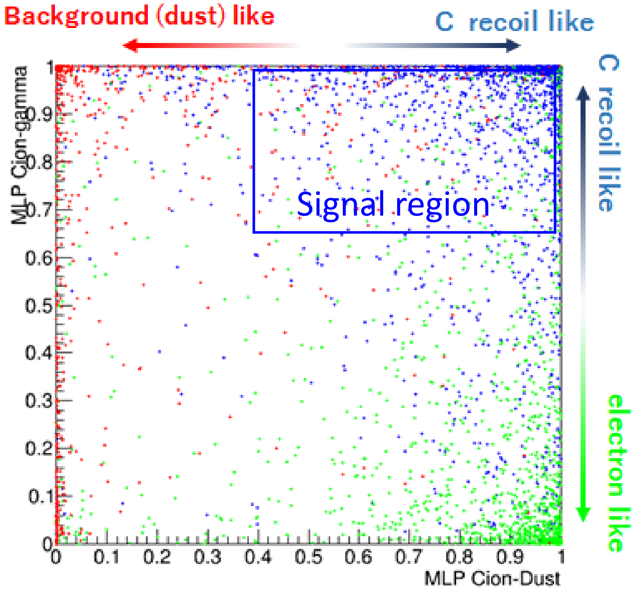
$$p = 4\pi\varepsilon_m a^3 \frac{\varepsilon_1(\lambda) - \varepsilon_m(\lambda)}{\varepsilon_1(\lambda) + 2\varepsilon_m(\lambda)} E_0$$

$$\varepsilon_1(\lambda_1) + 2\varepsilon_m(\lambda_1) \approx 0$$



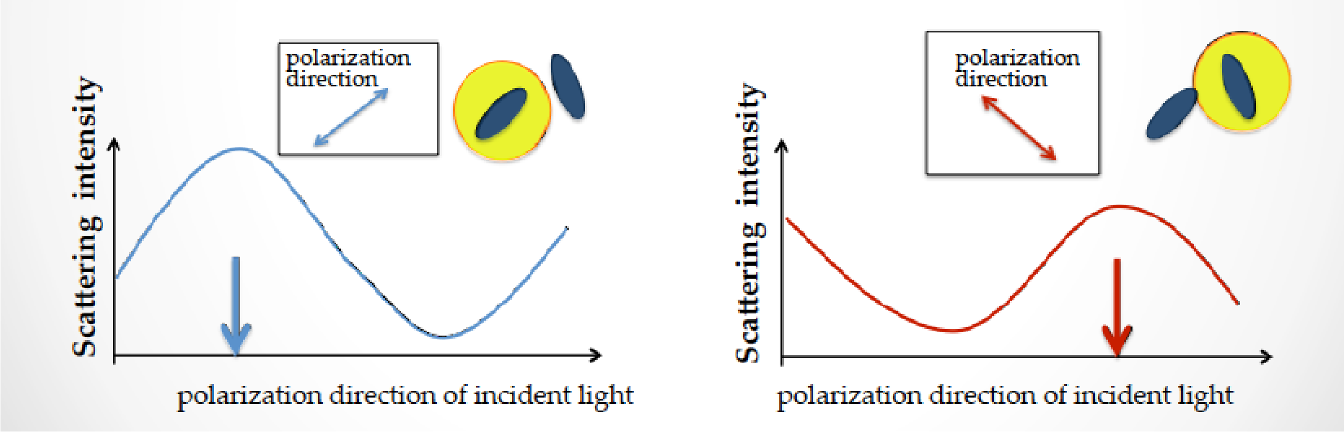
Scatter light spectrum information due to plasmonic effect

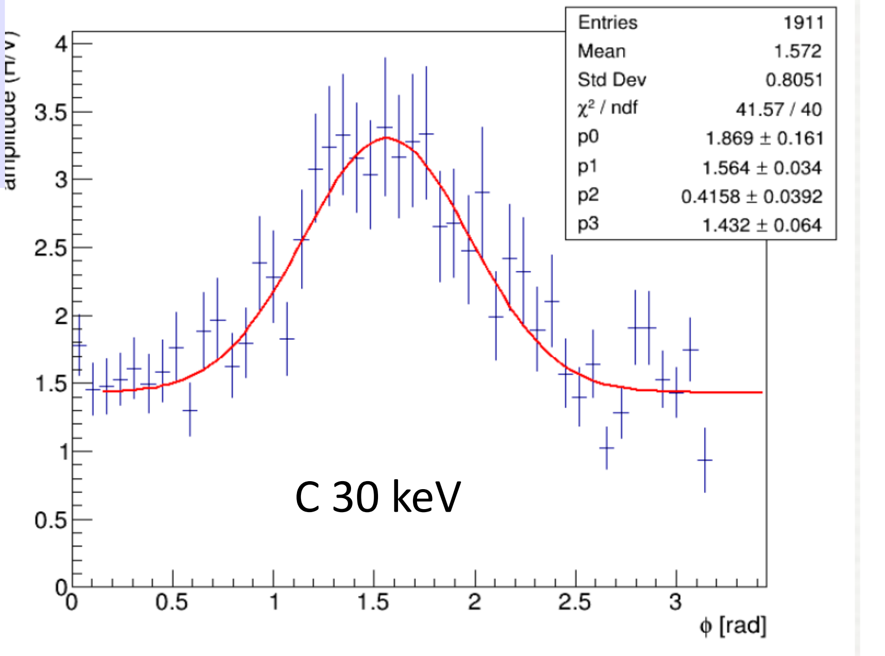


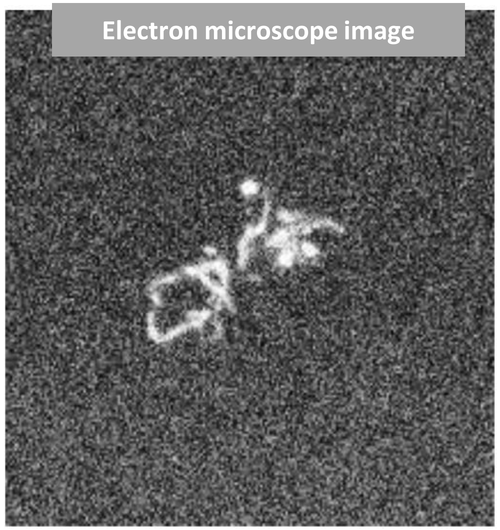


Such new analysis studies are now on going

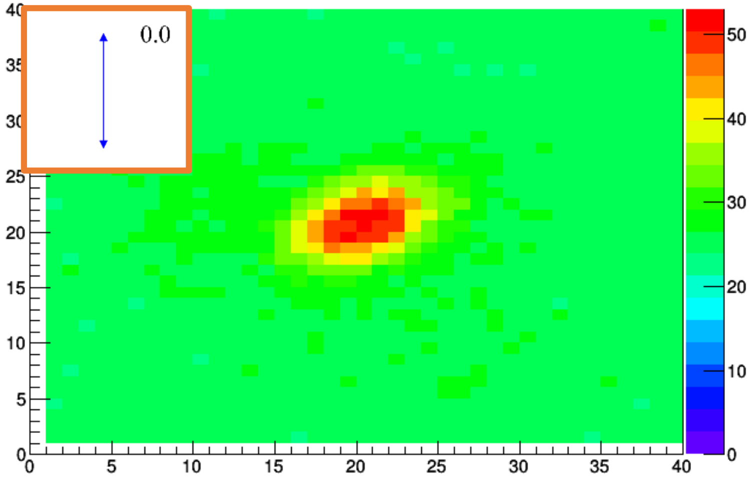
Super-resolution microscopy using LSPR information toward lower-threshold tracking



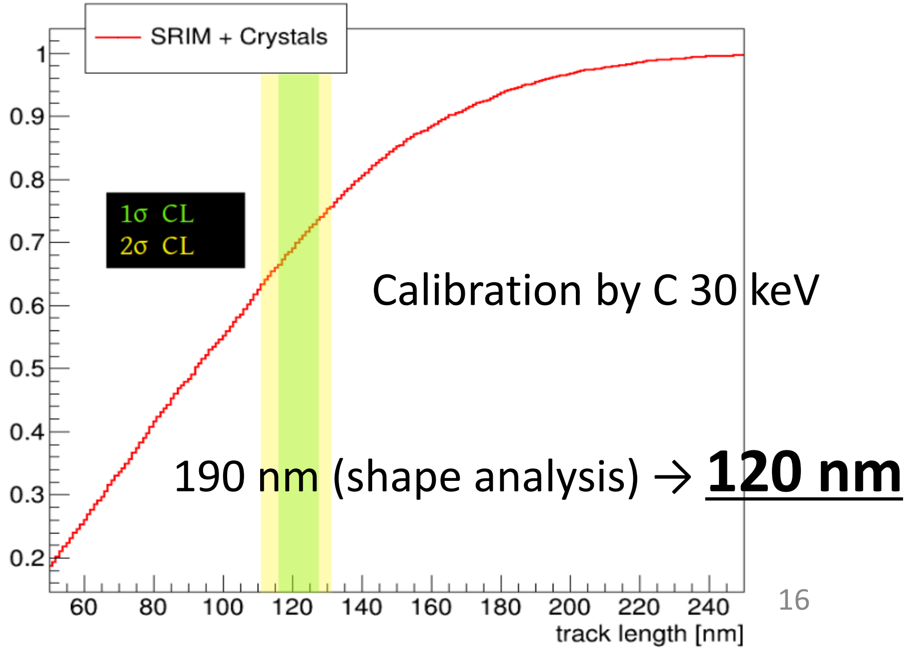




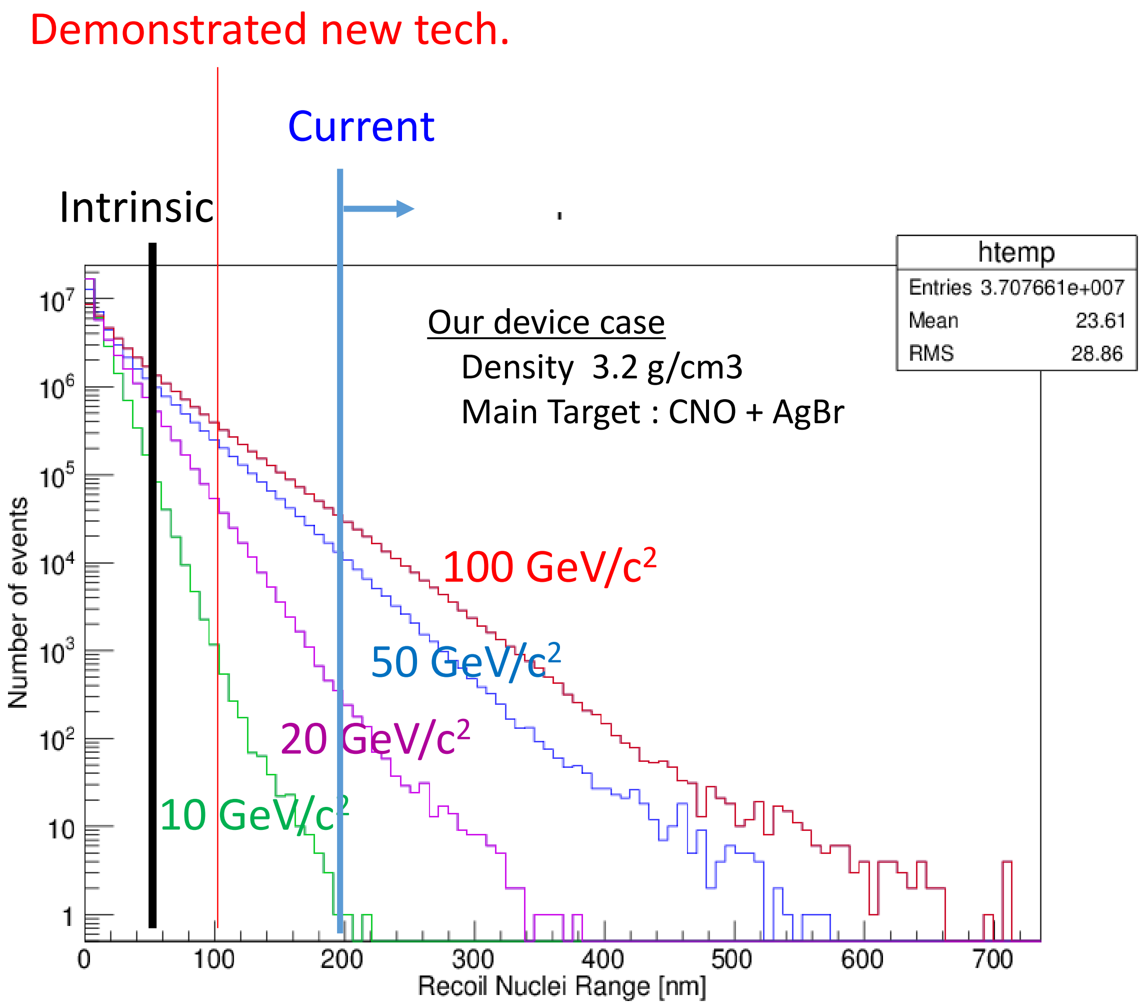
Polarization light dependence



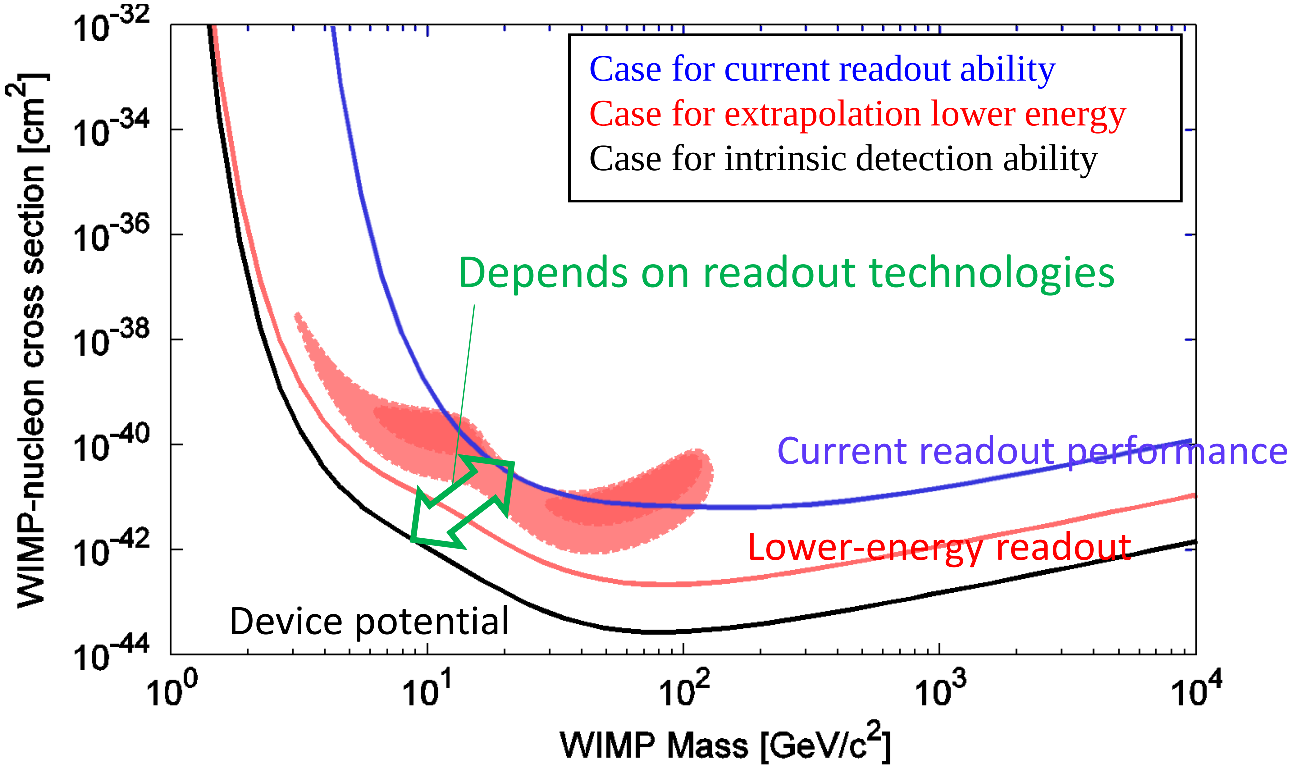
Shift of barycenter is important information for nano-scale structure



Dark matter sensitivity



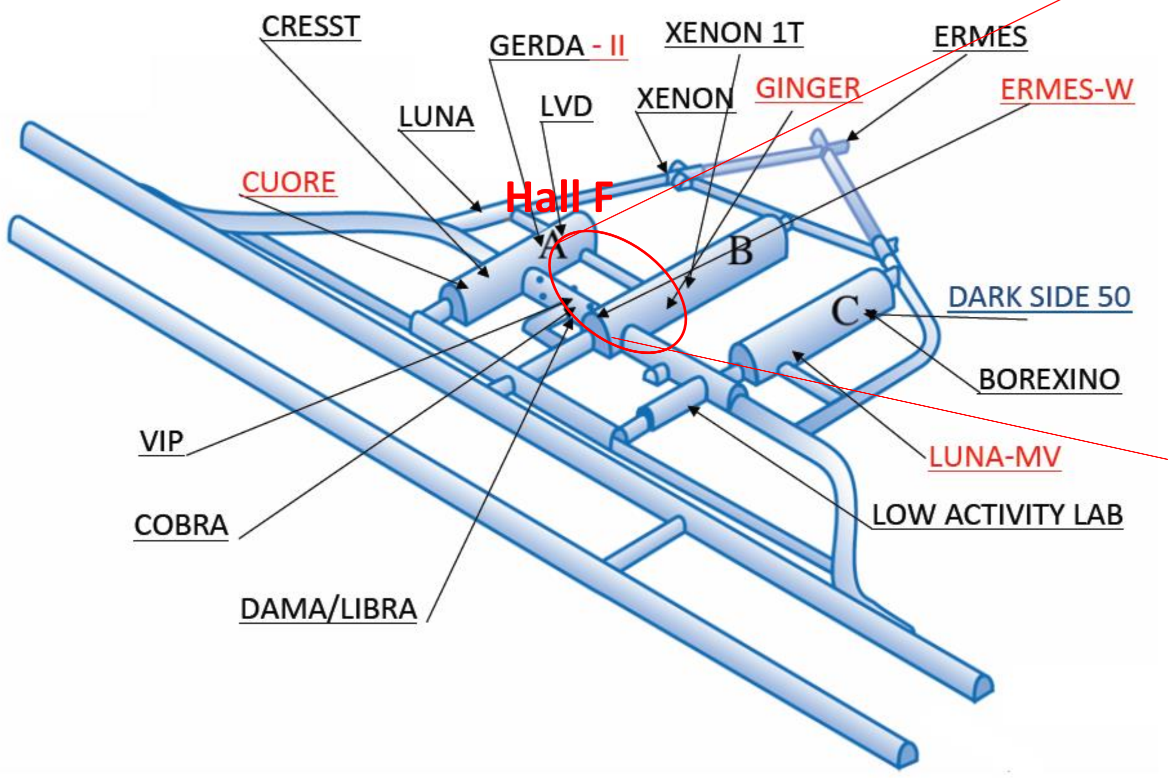
10 kg·year simulated sensitivity [90 % C.L.] + zero BG



NIT detector / CNO sensitive / no Bkg no directionality
Simulation limit is “energy > 5 keV for all atoms (SRIM limit)”
& “Sensitivity > 0.1 % (Simulation statistics limit;10 event)”

Device potential : 10 keV of C recoil (> ~ 10% eff. and 45 ° angl. Res.

Underground laboratory at LNGS



Device Production facility

New production machine

Motivation of New Underground facility

- Device self-production in underground
- Device handling in clean room
- Chemical development

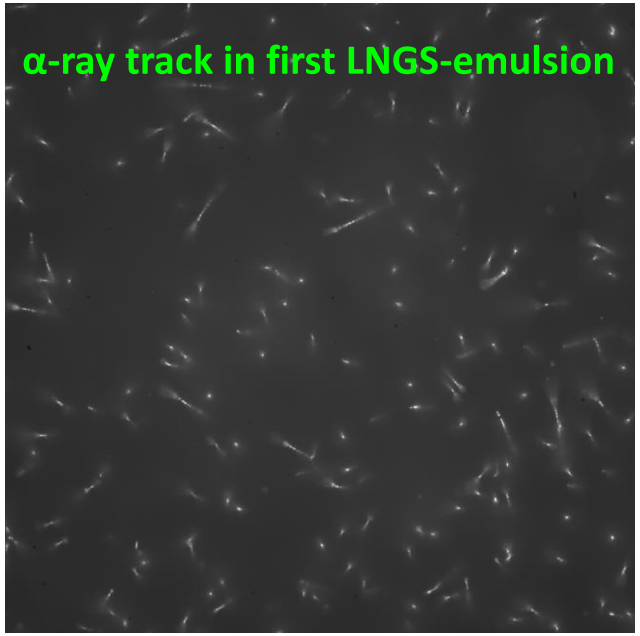
Discussion started from 2017, and construction from beginning of 2018

New Underground emulsion facility

Feb. 2018 ~ : started construction and commissioning of the production machine at Nagoya (⇒ transported to LNGS from Sep. 2018)

Feb. 2019 ~ : Started test production first time at underground
+ clean room and other infrastructure are on constructing

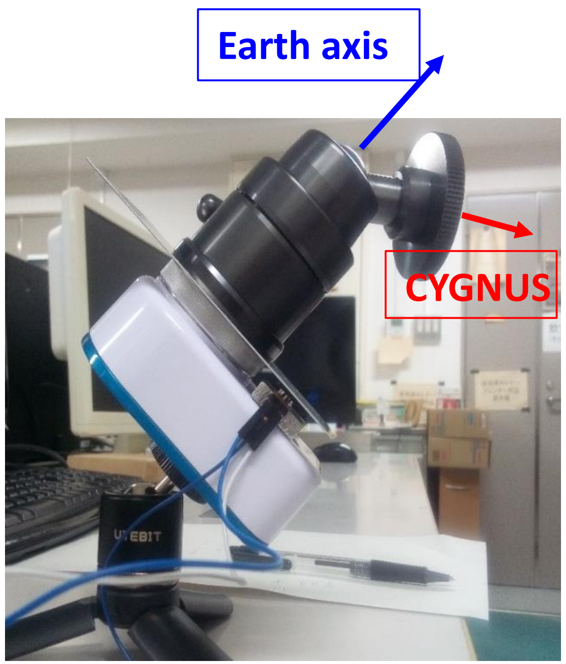
Up to April : overall confirmation of underground emulsion facility with clean room



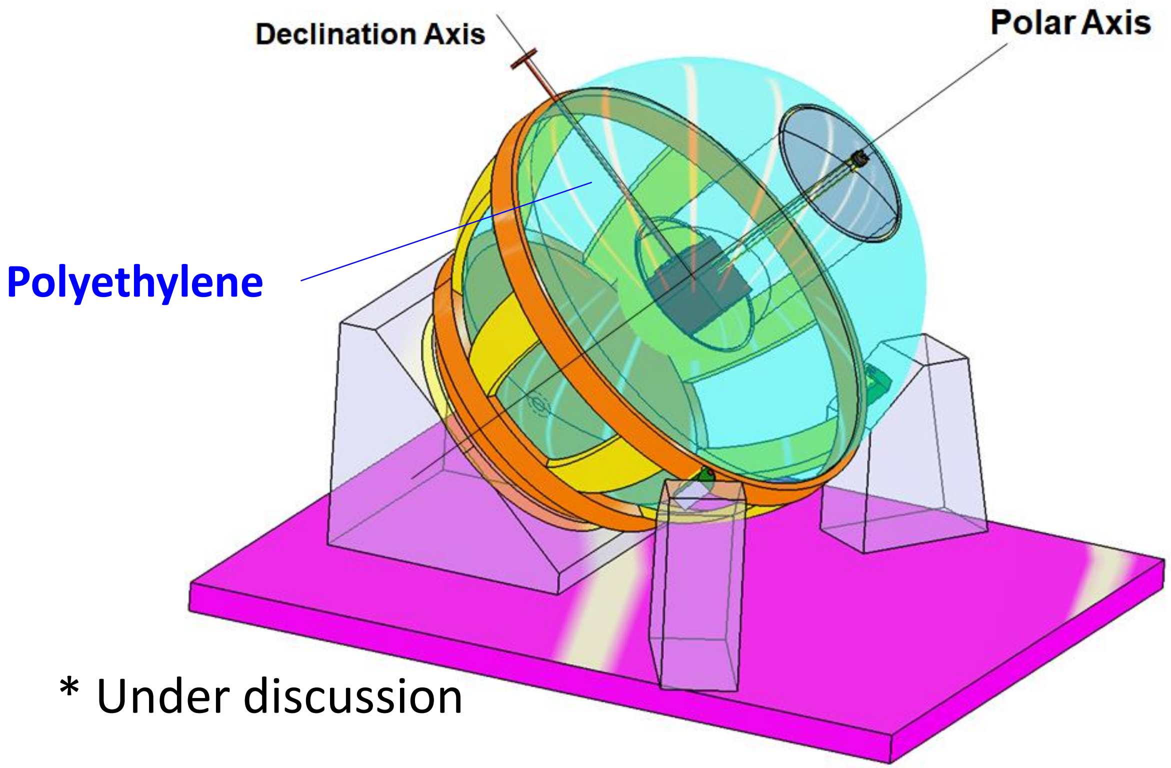
First production in LNGS succeeded !!

Equatorial telescope for directional search

Future prospect for ~ 10-100 g scale detector



Future prospect for > 1kg scale detector



* Under discussion

Source	Rate [/10kg/y]
Environmental γ-rays	(2.0 +- 0.2) x 10^4
Environmental neutrons	O(10^{-2})
Cosmogenic neutrons	1.4 +- 0.1

Conclusion

- NEWSdm project is for direction-sensitive dark matter search with super-resolution nuclear emulsions as solid detector
- Device production and readout system demonstration have been done, and optimization and overall system are now on constructing and commissioning
- New underground facility with device production machine and clean room is now on constructing, and it will be ready around June, 2019.
- We will do underground experiment test there, and go forward for larger scale directional dark matter search

2019 2020 2021

Underground facility construction

Underground run with 10 g
→ test of overall process
[production -> chem. Dev.]

Telescope run for directional dark matter search

Confirmation of readout chain

Surface run for background study

Data analysis for underground run

Improvement of system and background rejection performance

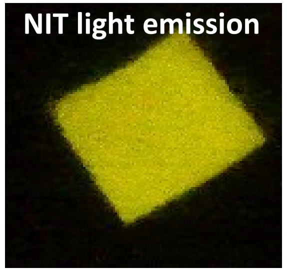
10-100 g scale analysis by scanning speed improved

Back up

Detector Application

[Scintillation light emission]

- ✓ High emission efficiency
  → possibility as scintillator
- ✓ Study for fundamental mechanism of AgBr nano crystal



T. Shiraishi, H. Ichiki, TN al., accepted (2019)

low-velocity heavy particle detector

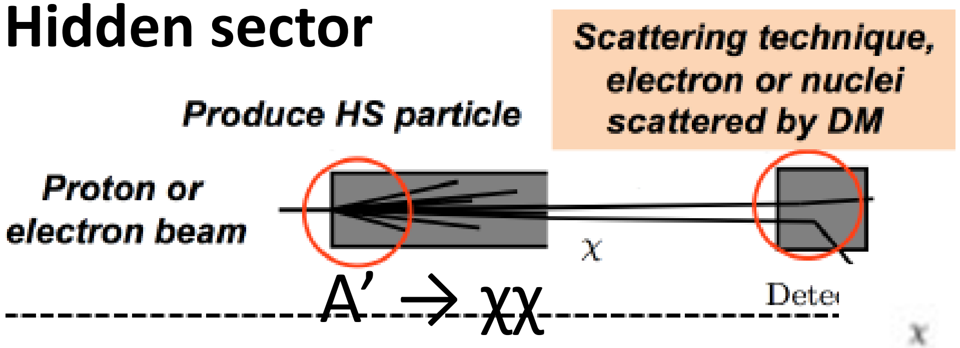
- ✓ Exotic heavy low-velocity particle (e.g., monopole)
- ✓ Medical therapy
- ✓ Energy loss mechanism

[Neutron detector]

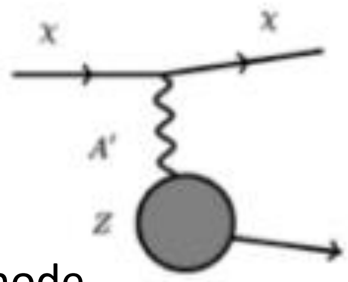
- ✓ Environment neutron measurement with direction information
- ✓ Low-energy (sub-MeV, UCN) neutron detector

NEWSdm Application

Hidden sector

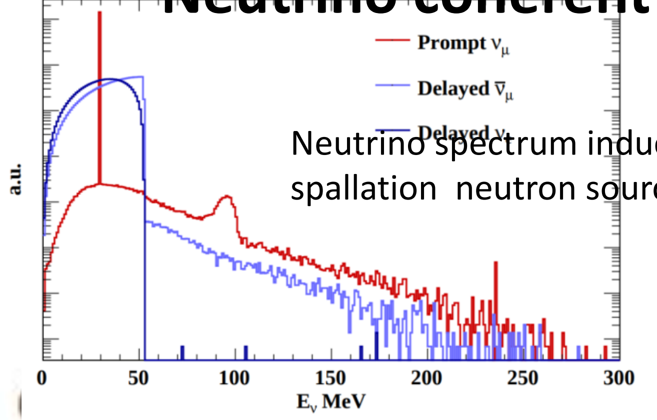


e.g., : SHiP-NEWSdm collaboration

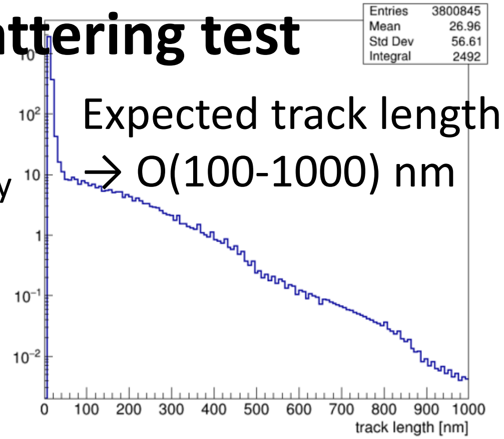


Coherent scattering mode

Neutrino coherent scattering test



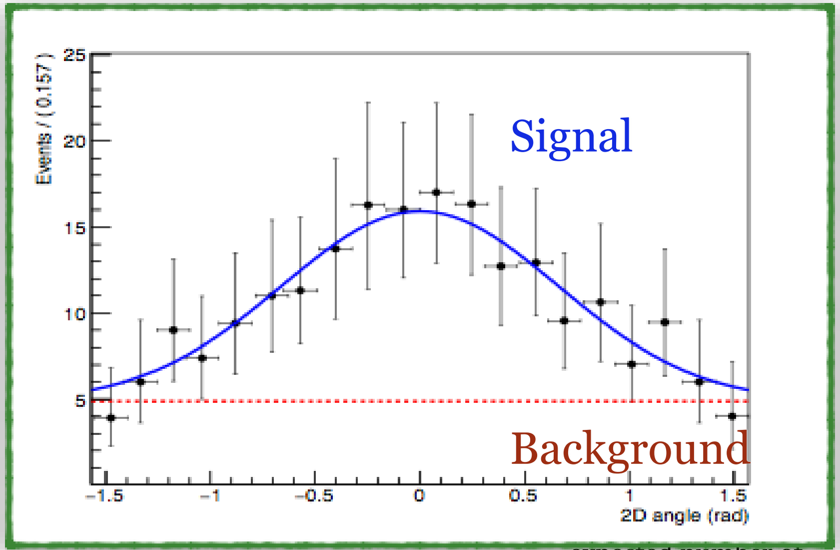
Neutrino spectrum induced by spallation neutron source



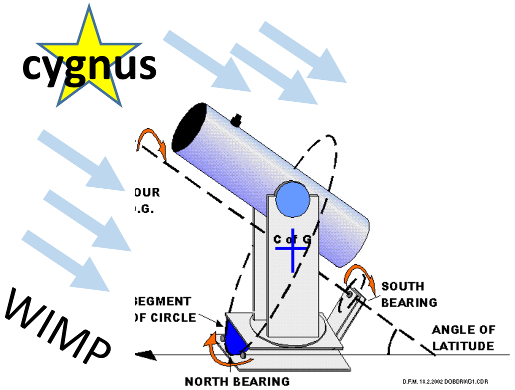
Expected track length → O(100-1000) nm

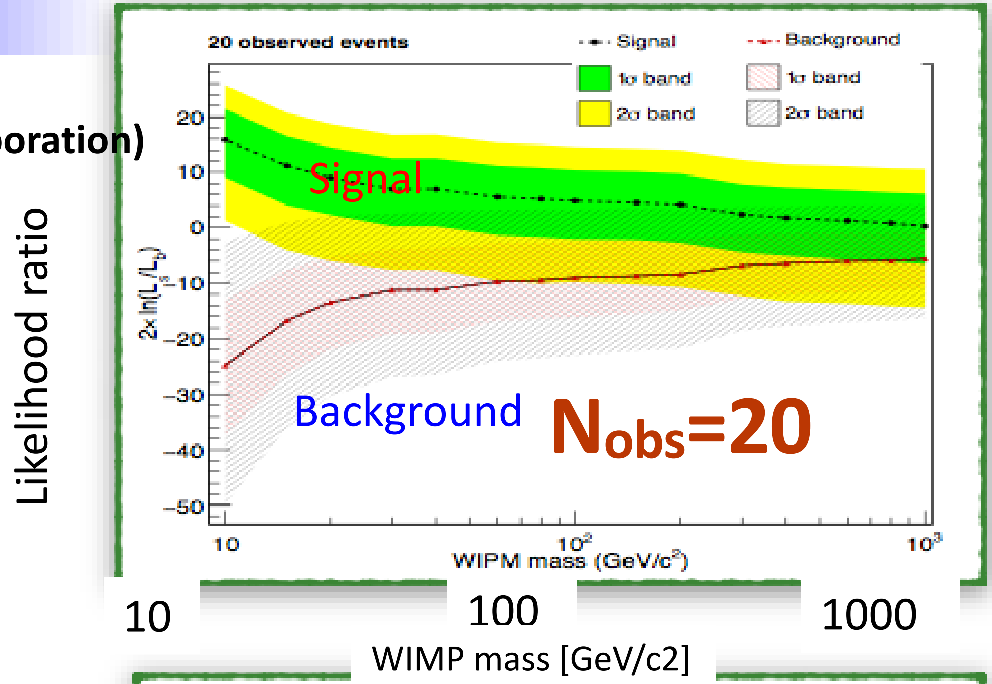
- ✓ Demonstration of neutrino floor for dark matter search
- ✓ High precision Demonstration using weak interaction of Dark matter search

Potential of Directional Sensitive Search



N. Agfanova *et al.* (NEWSdm collaboration)
Eur. Phys. J. C (2018) 78: 578





expected number of WIMP events

expected number of background events

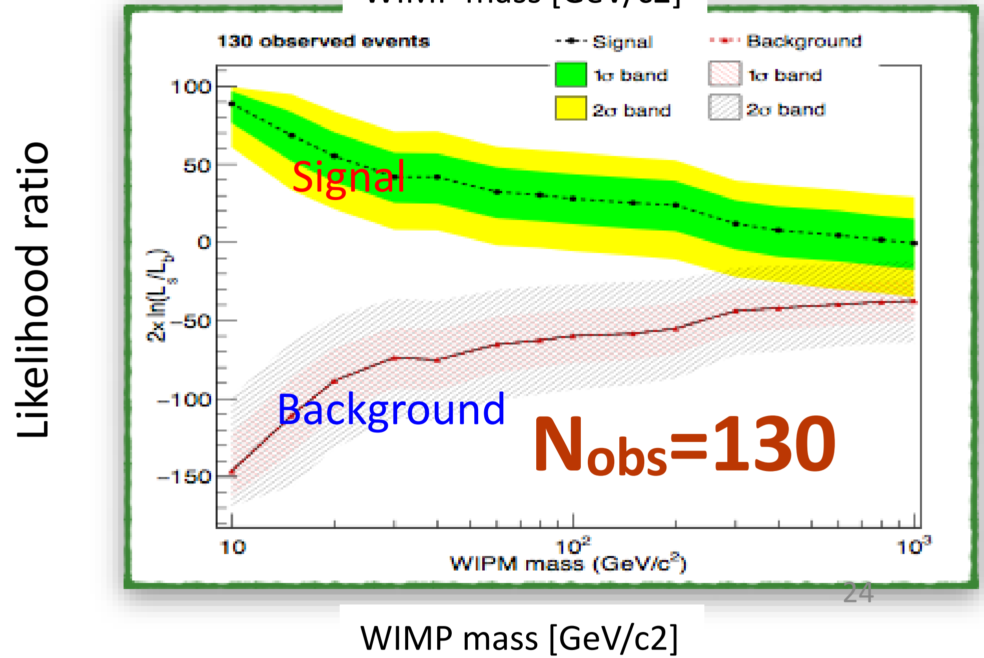
signal pdf

background pdf

$$\mathscr{L}(\sigma_{\chi-n}, R_b) = \frac{e^{-(\mu_\chi+\mu_b)}}{N!} \times \prod_{i=1}^{N} [\mu_\chi f_\chi(\vec{q}_i; t_i) + \mu_b f_b(\vec{q}_i)]$$

total number of observed events

set of observables



<u>Direction information : Several 10 events</u>

Gain of 100 times

<u>Annual modulation : Several 1000 events</u>