NEWSdm
Directional Dark Matter Search

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INFN Post-Doctoral Fellowship at LNGS, Italy

On behalf of the NEWSdm Collaboration

21-Feb-2020 / Astroparticle Physics Science Fair / Ex-ISEF-Building-Library (GSSI)

NEWSdm COLLABORATION

75 physicists / 14 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
University and INFN Bari
LNGS, Gran Sasso
University and INFN Napoli
INFN Roma

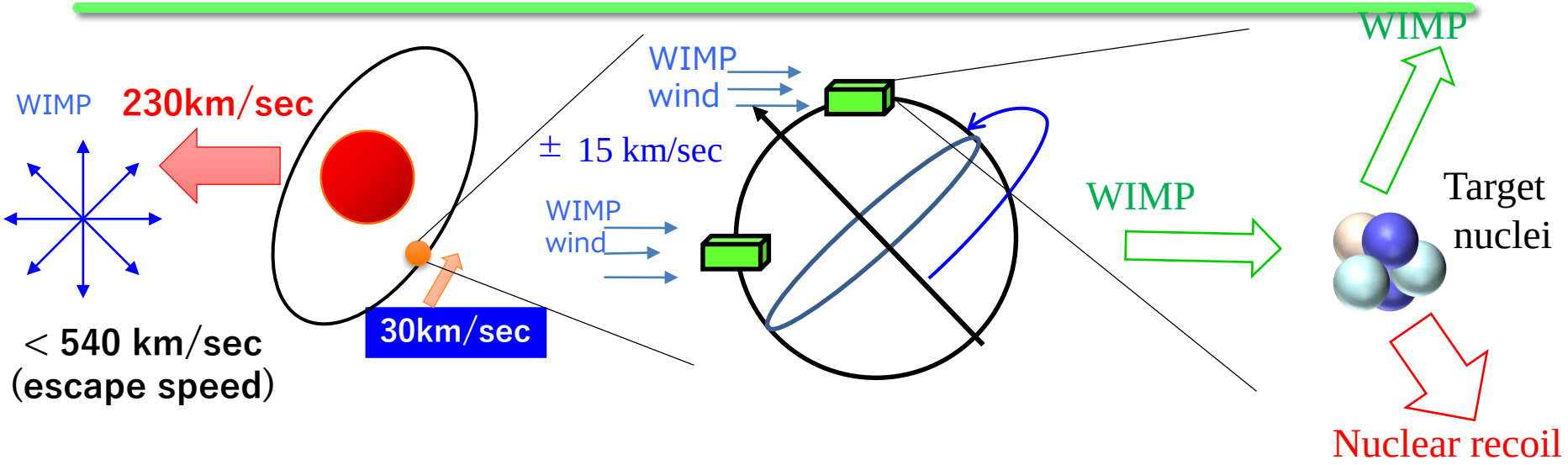
JAPAN
Chiba, Nagoya, Toho

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

SOUTH KOREA
Gyeongsang University

TURKEY
METU Ankara

What is the purpose of NEWSdm experiment?



Annual Modulation | Diurnal Modulation

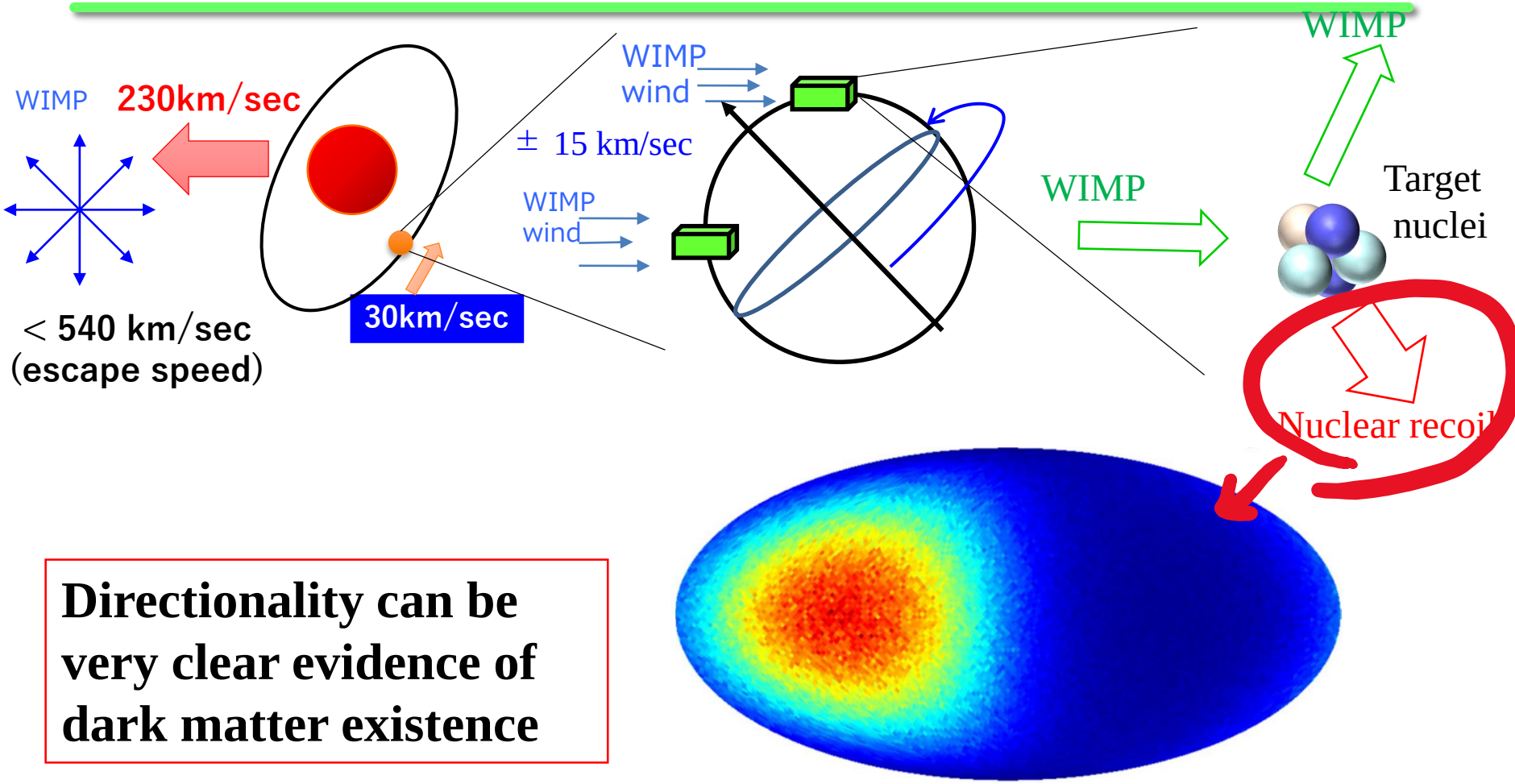
$$S(v_{lab}) \simeq S_k(v_s) + S_{Ann} cos\omega_{rev}(t - t_0) + S_d cos\omega_{rot}(t - t_d)$$

solar
~ 230km/sec

Earth revolution
~ 15 km/sec
2–3 % variation

Earth rotation
~ 0.4 km/sec
0.1–0.01 % variation

What is the purpose of NEWSdm experiment?

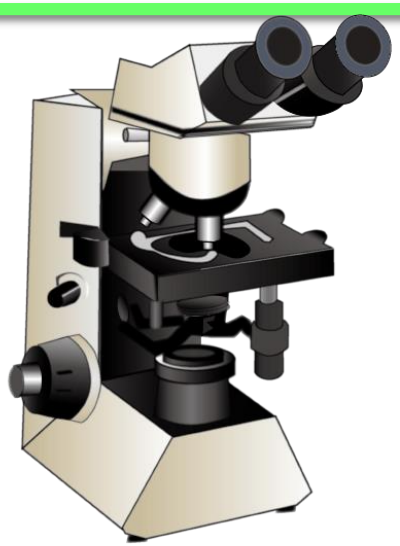


Directionality can be very clear evidence of dark matter existence

(J. Billard et al.(2010))

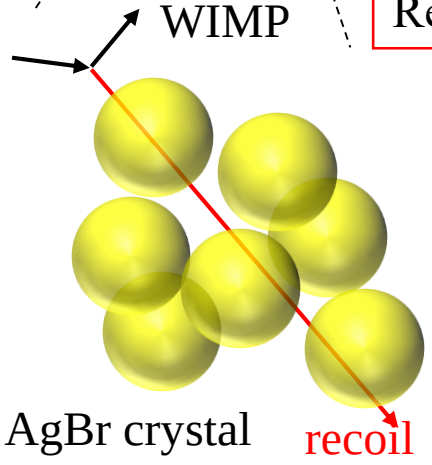
What is the concept of NEWSdm experiment?

Photographic film (**Nuclear Emulsion**)

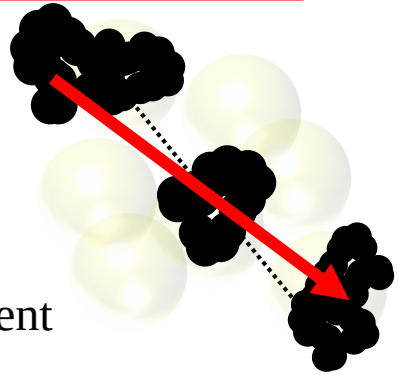


Readout by optical microscope

Record directionality as “track”



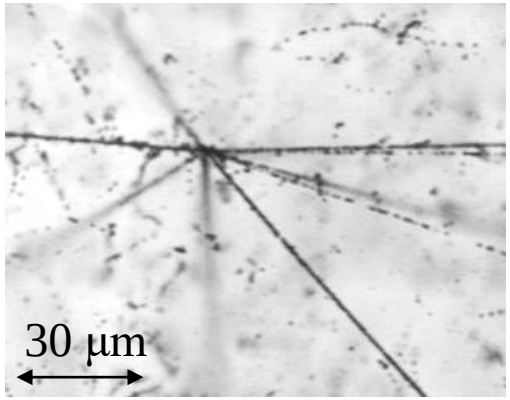
Development



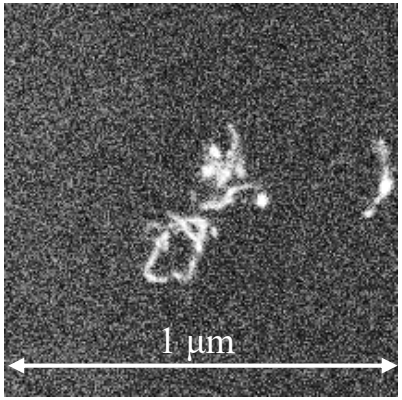
Silver grain

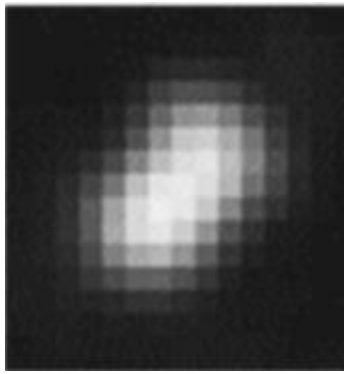
NEWSdm techniques / super fine-grained nuclear emulsion

Past emulsions: targeting >10 um track



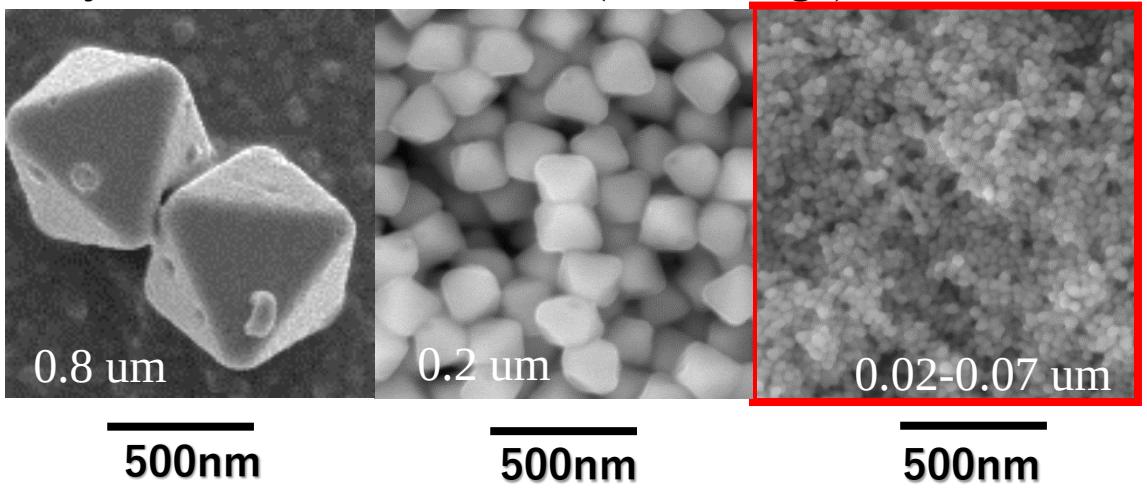
Our target : < 0.5 um





Around the limit of optical resolution

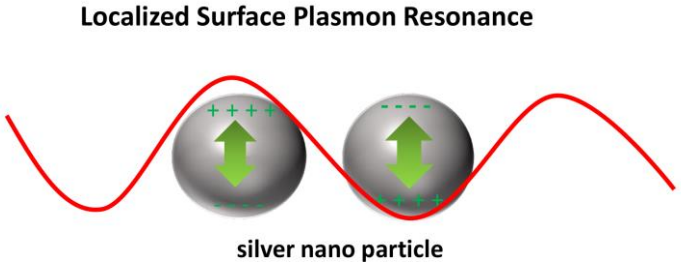
Crystal of Nuclear emulsion (SEM image)



Target signal is 0.1-0.5 μm
New nuclear emulsion (Super fine-grain) is needed

We product and developed by ourselves!

To overcome the optical resolution
LSPR (Localized Surface Plasmon resonance) effect



dipole in metal particle

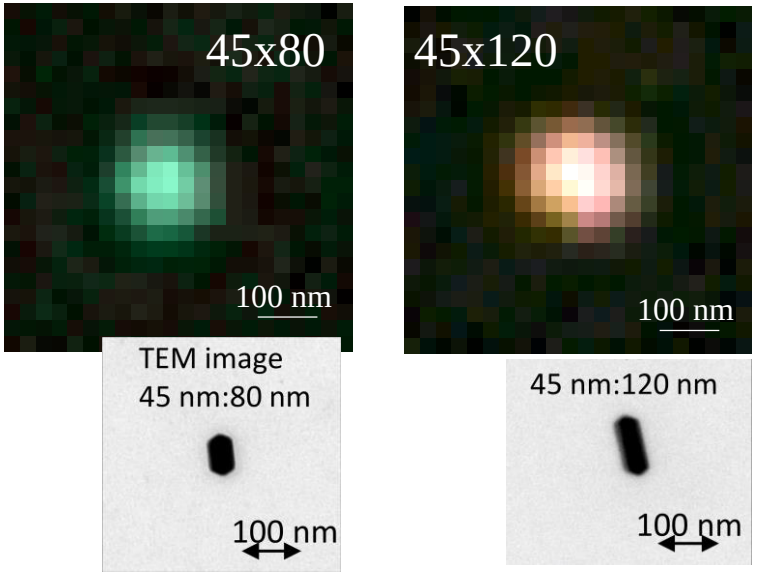
$$p = 4\pi\varepsilon_m a^3 \frac{\varepsilon_1(\lambda) - \varepsilon_m(\lambda)}{\varepsilon_1(\lambda) + 2\varepsilon_m(\lambda)} E_0$$

resonance

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

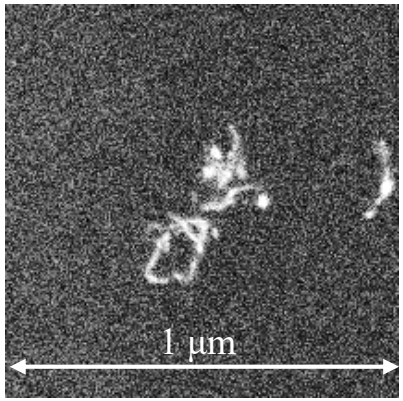
Colored optical image of silver rod

*polarization rotating



~45 nm : blue
~80 nm : green

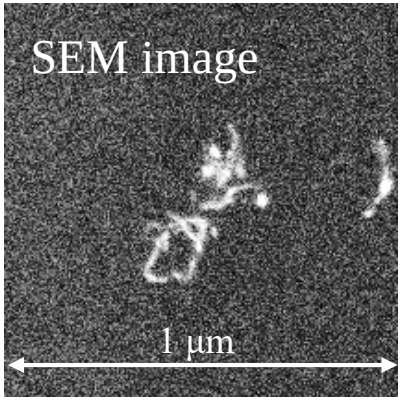
~45 nm : blue
~120 nm :orang–red

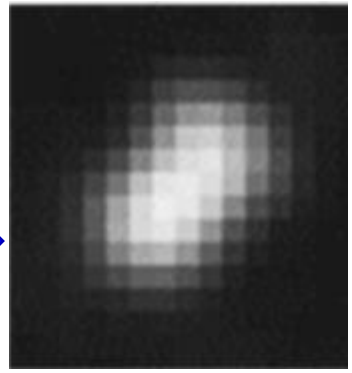


the shape and size of metal particle affect to resonance

- particle direction → resonance polarization
- particle length → resonance wavelength (color)

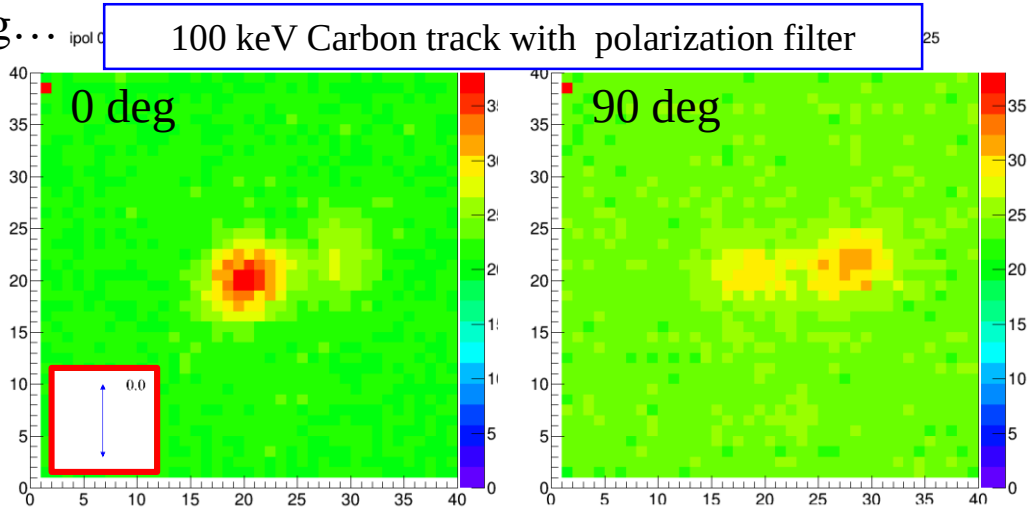
NEWSdm techniques / multi-method analysis





High speed shape analysis
52.5 g/year now, and will be 1kg/year

100,000 years for 1kg…

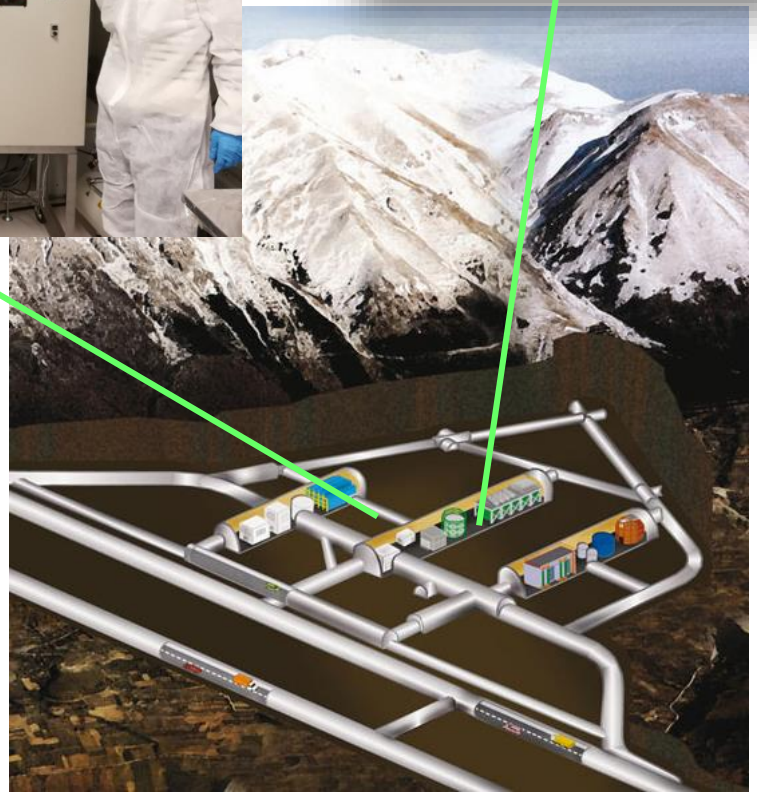


LSPR+pol filter analysis

Recognition limit:
190 nm (shape)
→ 120 nm

+ color analysis, phase contrast analysis, machine learning analysis etc.
→ **Combination analysis to achieve both speed and high precision analysis**

NEWSdm facility / direct emulsion production



Gran Sasso underground laboratory

Dark matter experiment requires extremely low level of background

We are trying to produce and install nuclear emulsion directly in LNGS underground lab!

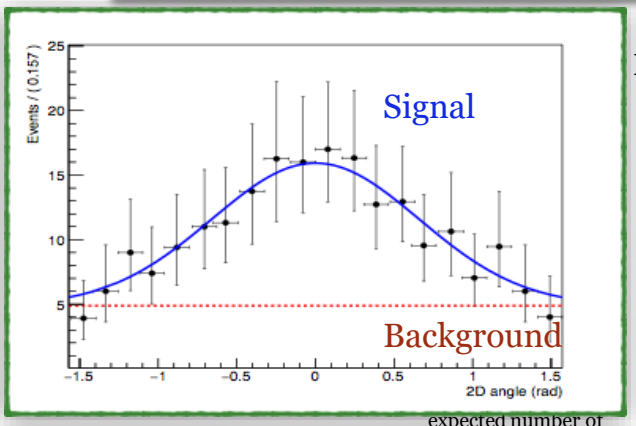
Production machine of nuclear emulsion is setting up at a clean room in LNGS underground lab.

Summary

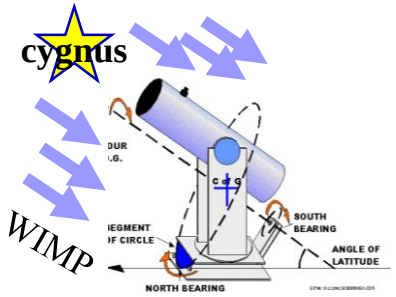
- NEWSdm is a direct dark matter search with directionality using nuclear emulsion
- Nuclear emulsion (a kind of photographic film) records recoil of dark matter, which is readout by microscope
- We are using unique techniques, e.g.
  - Direct emulsion production in the underground / cleanroom
  - New Super fine-grained emulsion
  - Multi-method analysis is applied to achieve both speed and high precision

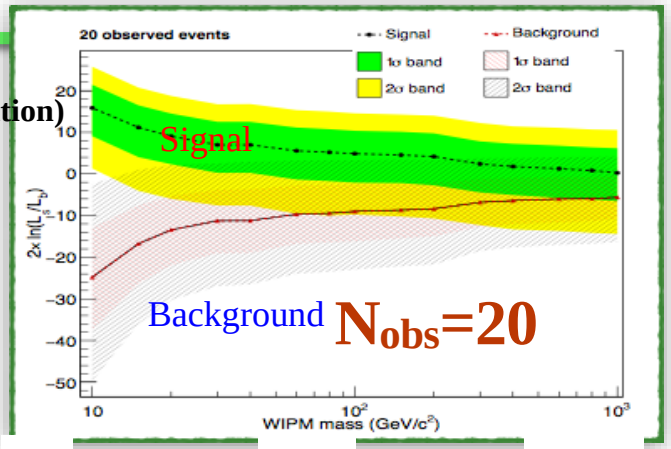
Back up

Potential of Directional Sensitive Search



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

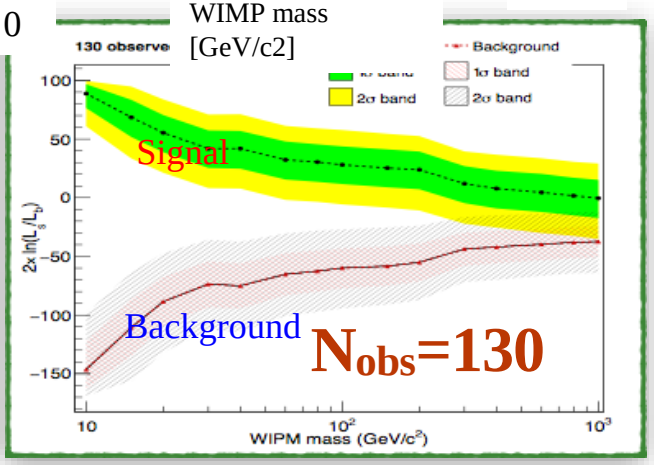




Likelihood ratio

1 100 1000

WIMP mass [GeV/c2]



Likelihood ratio

WIMP mass [GeV/c2]

expected number of WIMP events

expected number of background events

signal pdf

background pdf

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

total number of observed events

set of observables

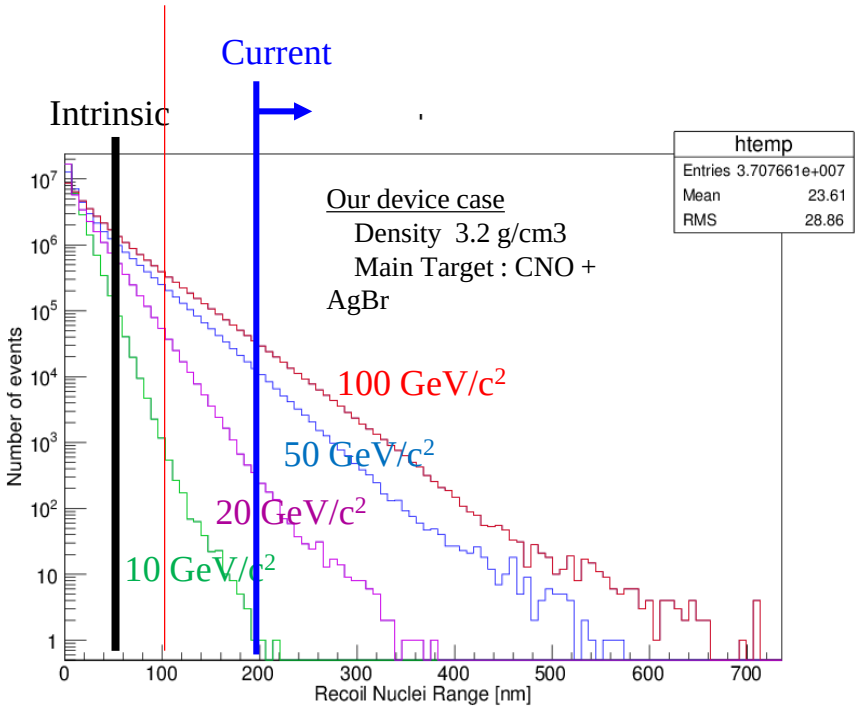
Direction information : Several 10 events

Gain of 100 times

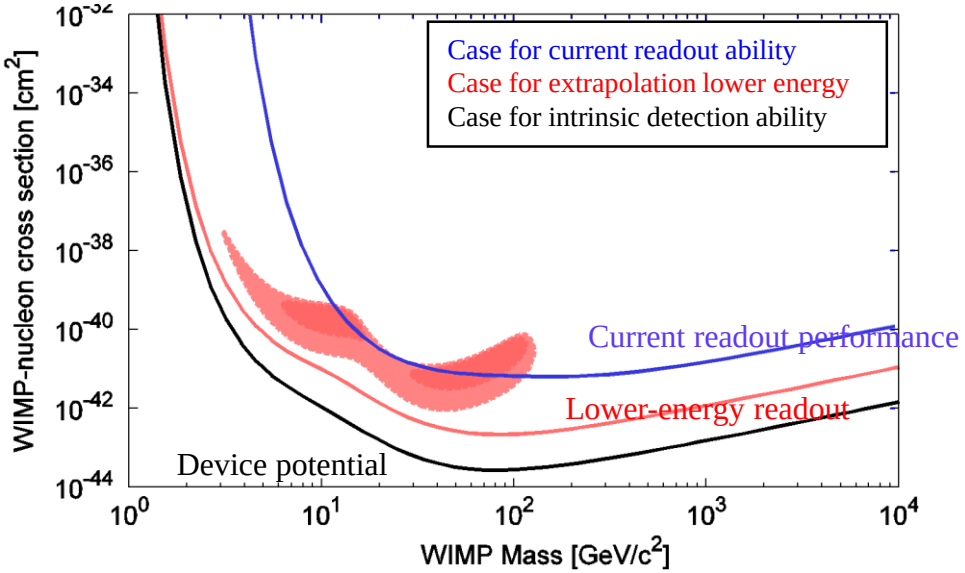
Annual modulation : Several 1000 events

Dark matter sensitivity

Demonstrated new tech.



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)”

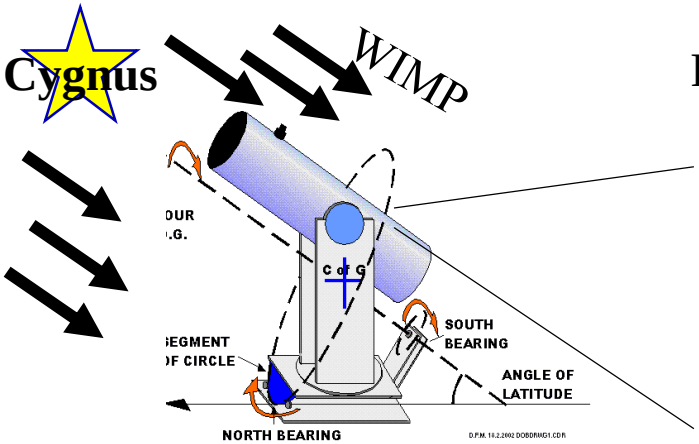
Device potential : 10 keV of C recoil (> ~ 10% eff. and 45 ° angl. Res.

Directional search with nuclear emulsion

- Good scalability
  - Solid state & good uniformity
  - Large scale production
    - Self production (~ 10 kg / month)
  - high scanning power
    - 46.5 g/year at current R&D, and ~kg scale in 2 years
- Good Angular resolution
  - ~ 20 deg (1 sigma) including scattering for Carbon
  - DM direction sensitivity with equatorial telescope

Light & heavy component

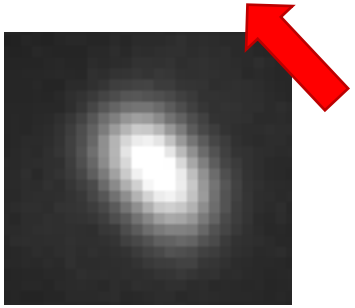
Element	Mass%	Atom%
Ag	44.5	10.5
Br	31.8	10.1
I	1.9	0.4
C	10.1	21.4
N	2.7	4.9
O	7.4	11.7
H	1.6	41.1



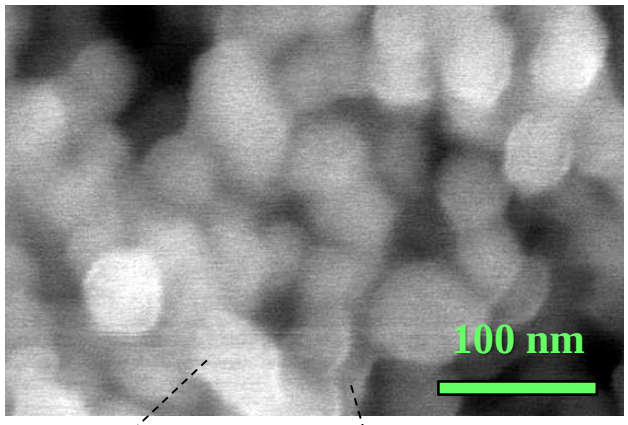
Fine crystal nuclear emulsion

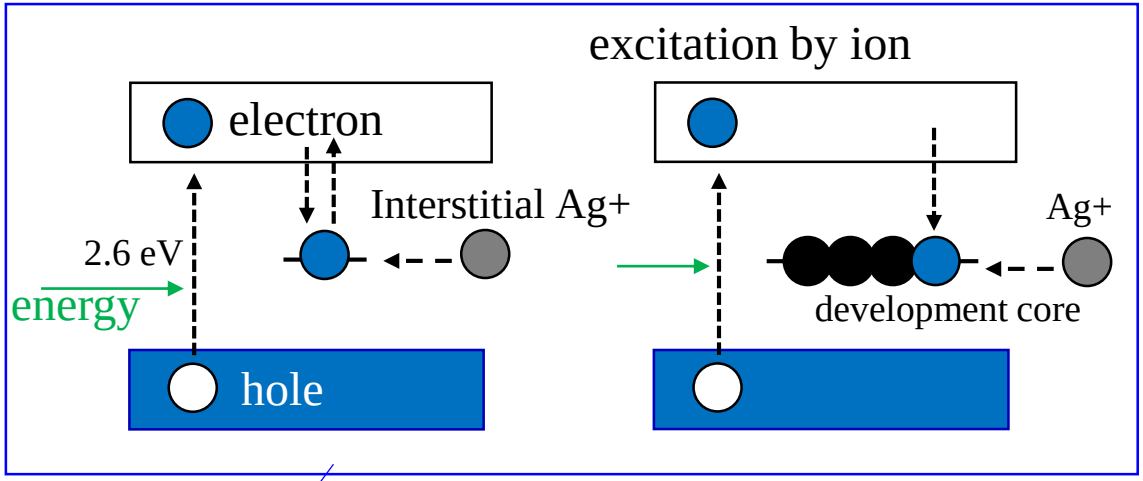
NIT

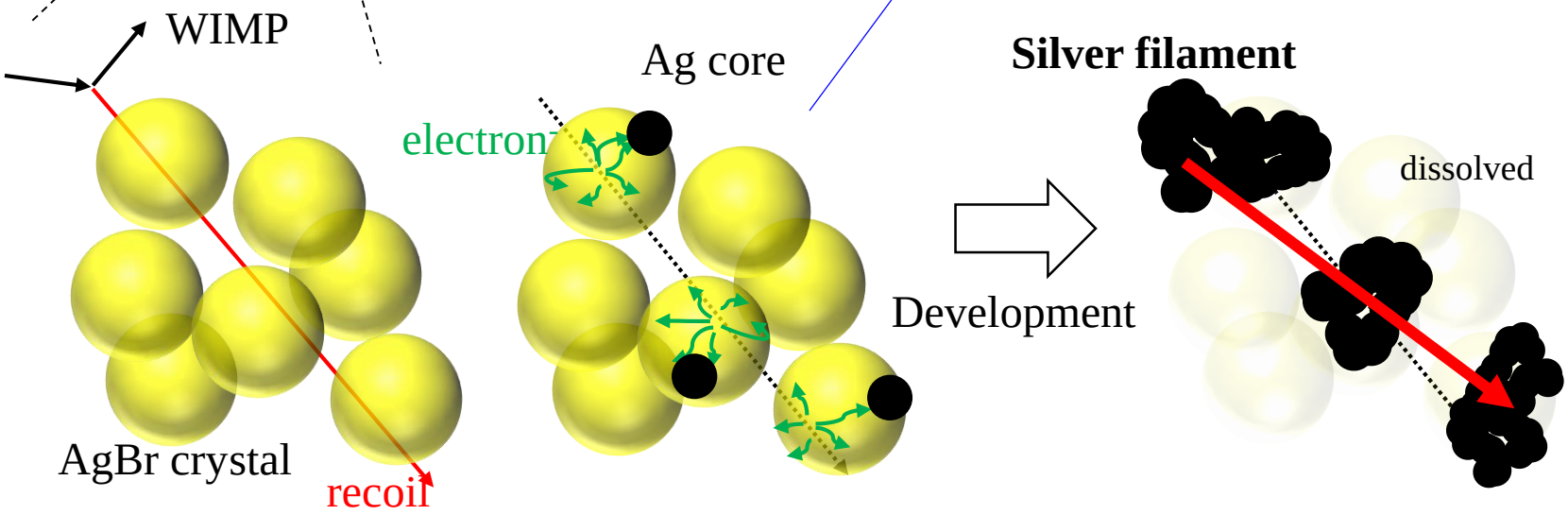
Direction recognizing



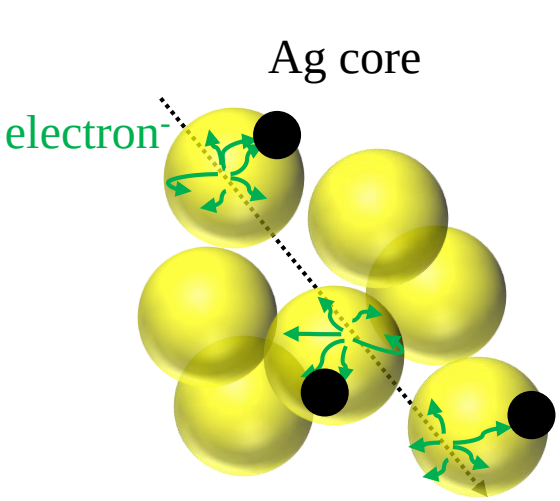
Nuclear emulsion

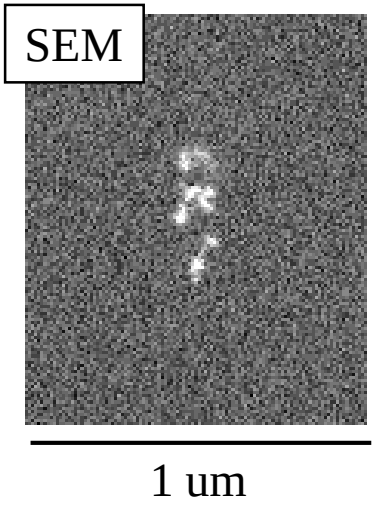


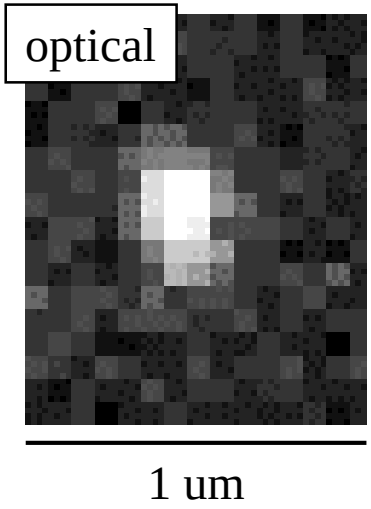




Characteristics of Nuclear Emulsion







- Electron diffusion is limited to crystal scale → Good angular resolution
- Sensitivity of 1 crystal for ions (≥ C) is almost 100% against the recombination.
- Main parameter is flight length. Energy deposit is our future plan (e.g. color analysis reported in 1st and 2nd day)
- Readout of nuclear emulsion is challenging
- Dust reduction is important (not using clean room yet)

Production and study of nuclear emulsion for dark matter search

-2010 Company (Fuji Film in Japan)

- Proto type of fine-grained nuclear emulsion

2010- Nagoya University (Japan)

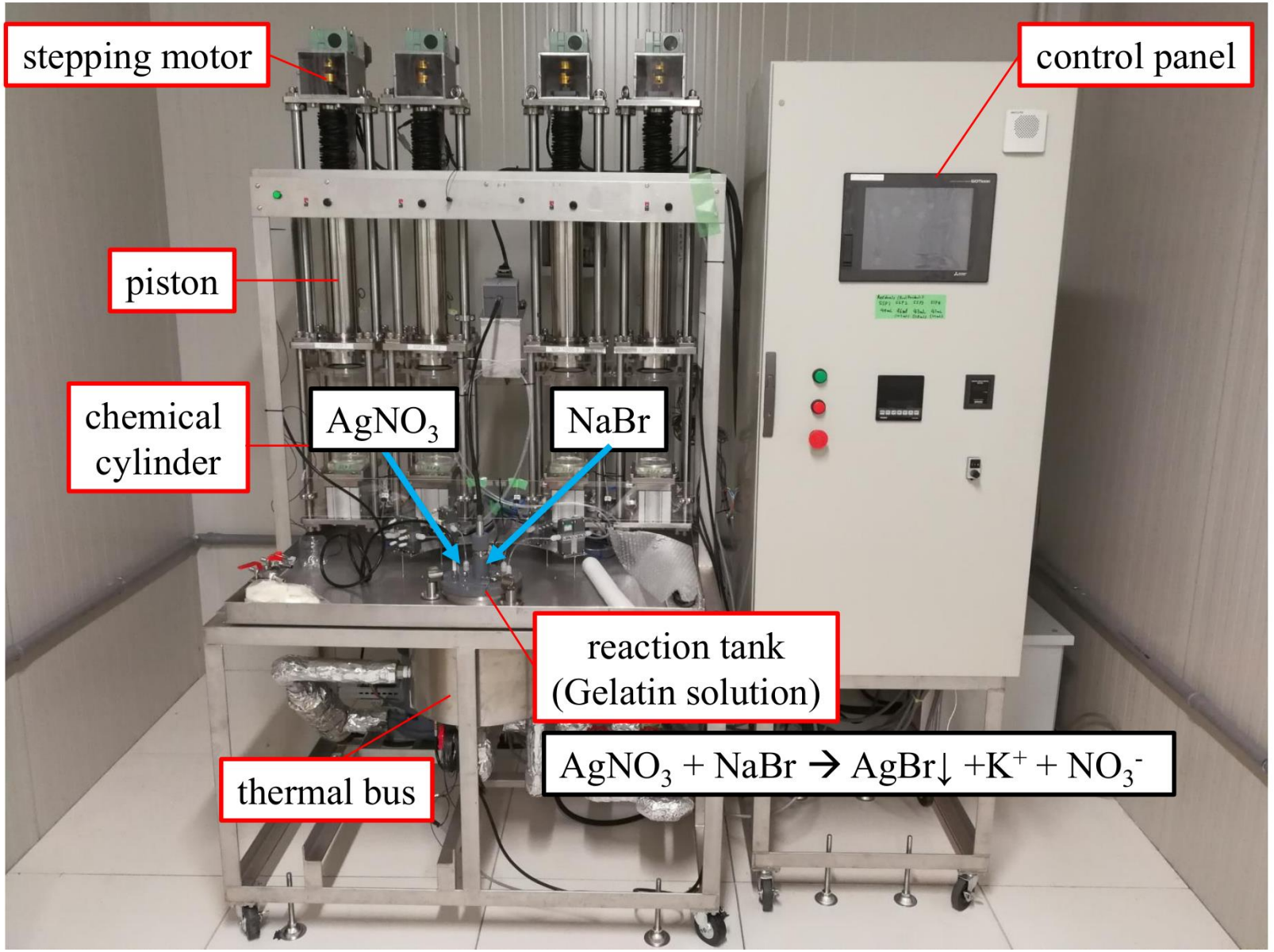
- First direct study of nuclear emulsion by physicist
- Fine-grained nuclear emulsion (NIT/UNIT)
- R&D and fine tuning of production recipe
- Study of material purification

Asada et al. PTEP 063H01 (2017)

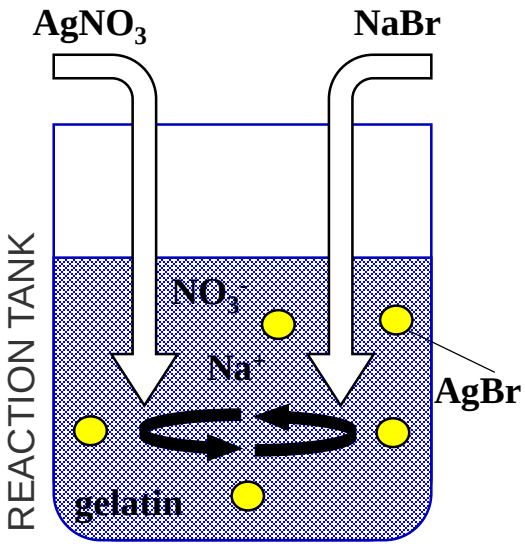
2019- LNGS (Italy)

- Direct production at the underground experimental sites
- Production in a Clean room

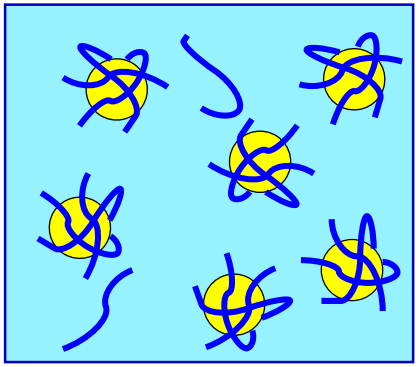
production machine



How to produce nuclear emulsion film



crystal formation



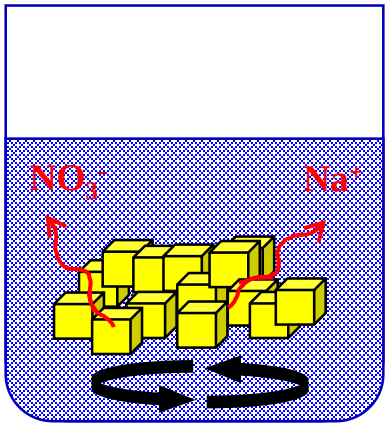
Gelatin protects the crystal and keep small size (protecting colloidal action)

Liquid gel is produced

Frost the liquid by freezer

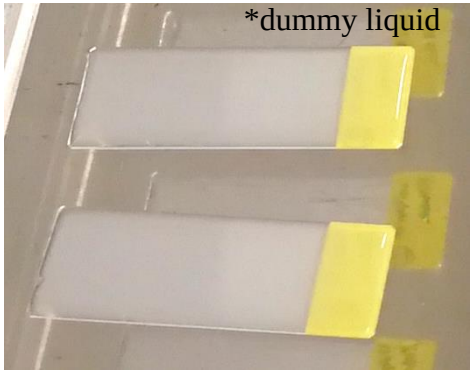
$$AgNO_3 + NaBr \rightarrow AgBr \downarrow + Na^+ + NO_3^-$$

How to produce nuclear emulsion

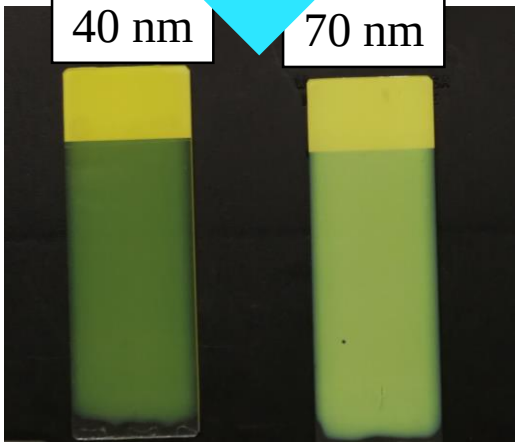


Washing (deionization)

Melting
& pouring



Volume ~1/20 by drying

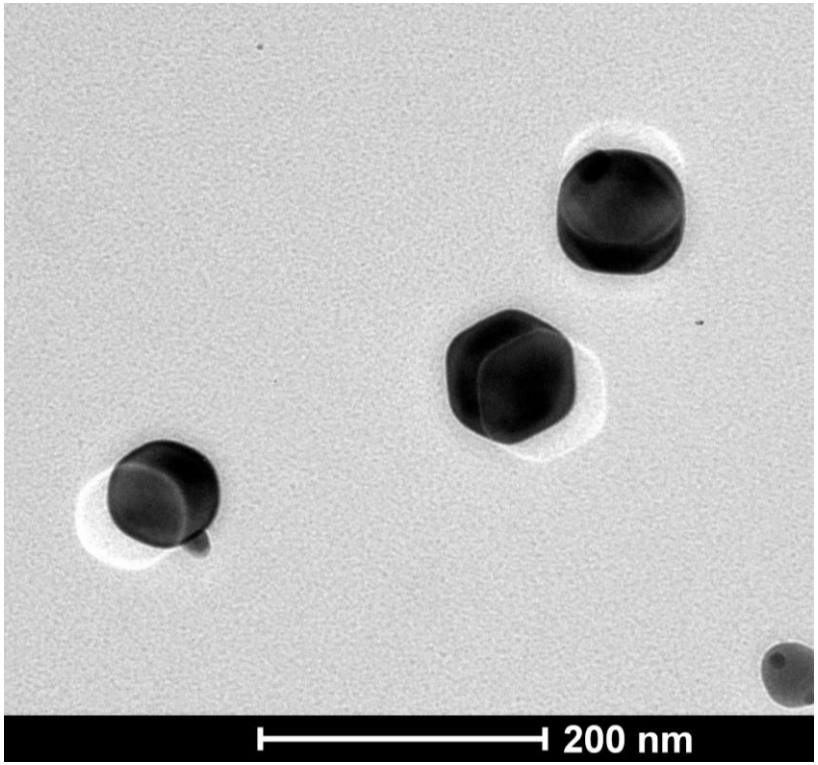


$AgBr \downarrow + Na^+ + NO_3^-$

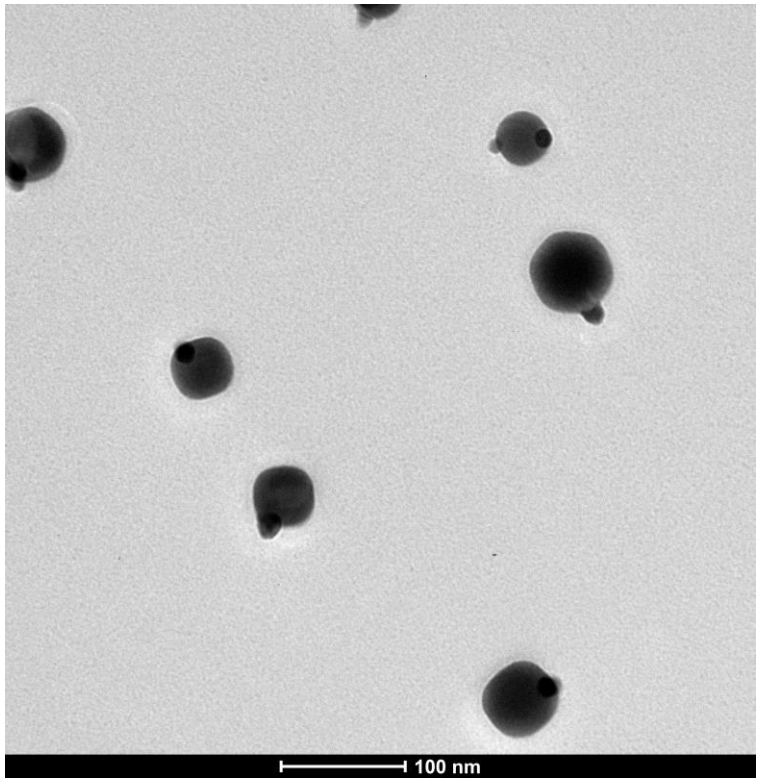
All production process is ready in the underground

TEM images

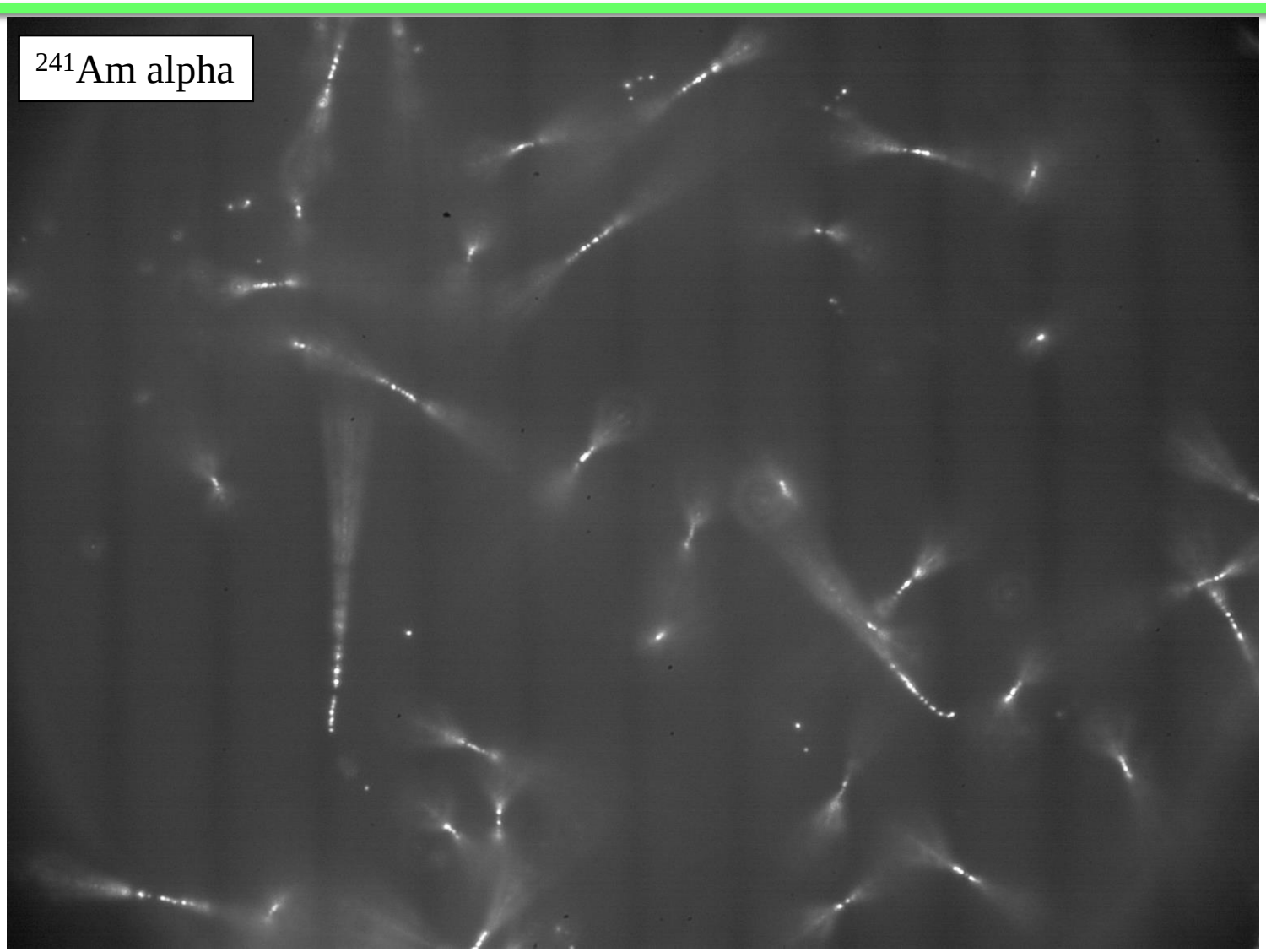
EGS003 (80 nm aiming)



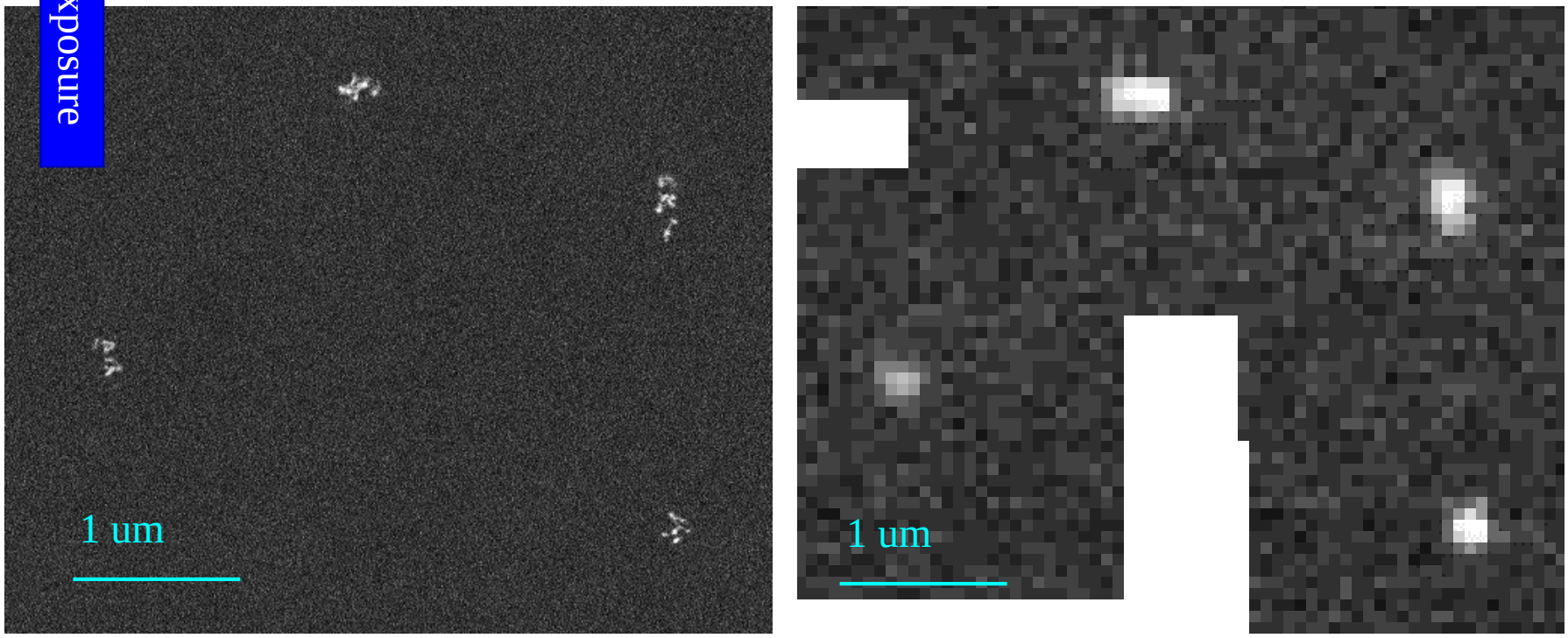
EGS004 (45 nm aiming)



First observation of tracks with new nuclear emulsion films produced at LNGS

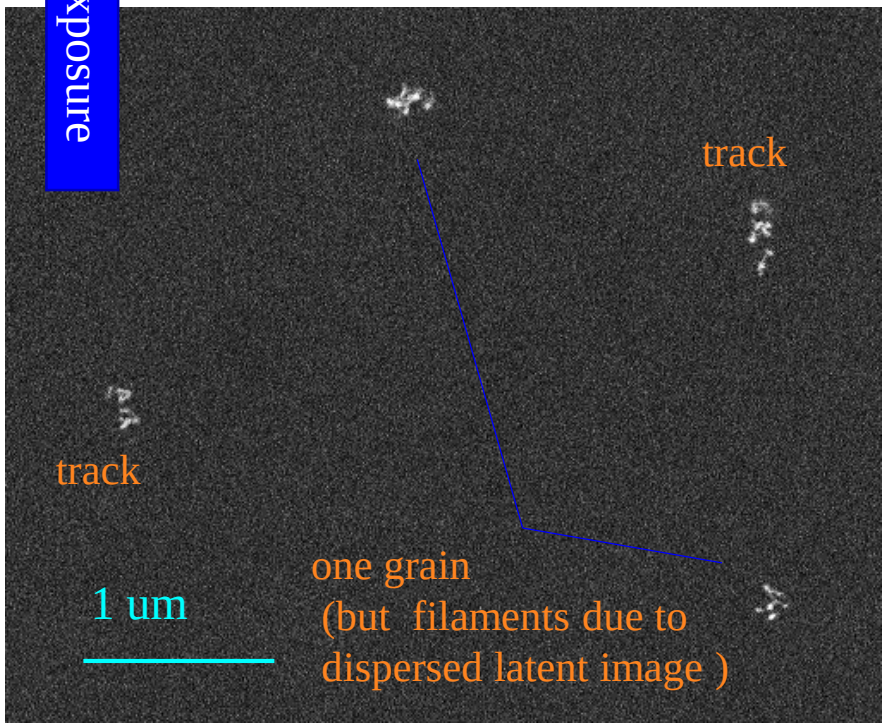


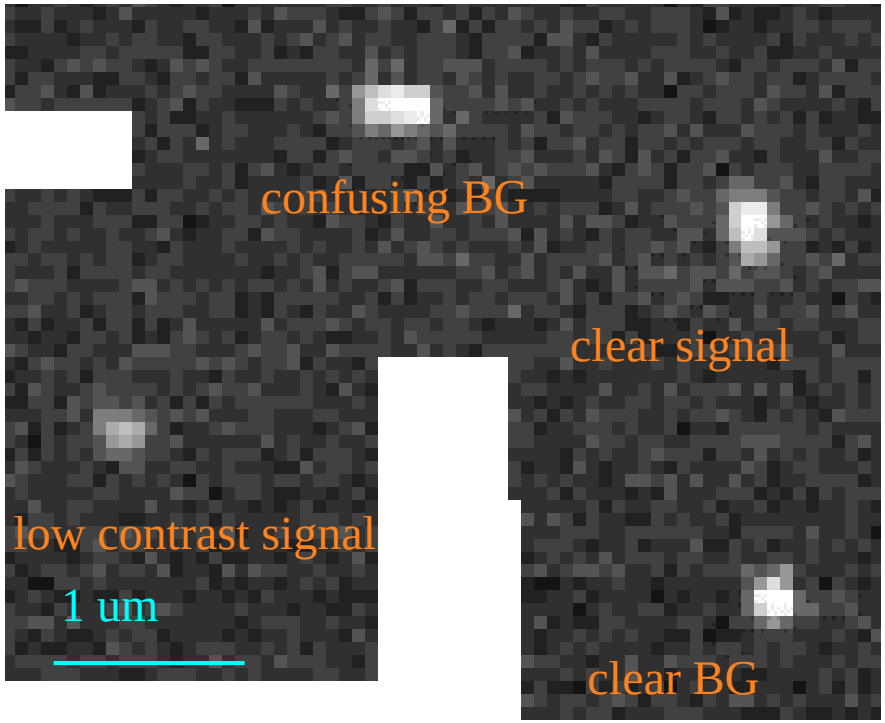
SEM / Optical Images with Position Matching



We found that elliptical shape is not always same with filament row
It maybe due to irregular optical response and non-negligible filament size

SEM / Optical Images with Position Matching

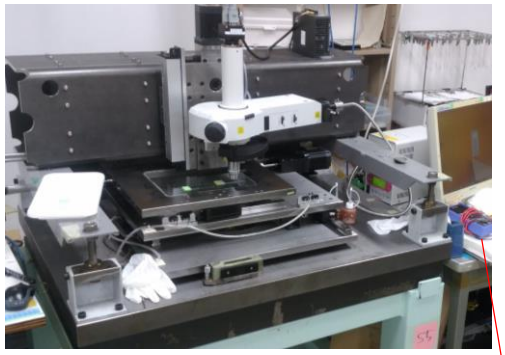


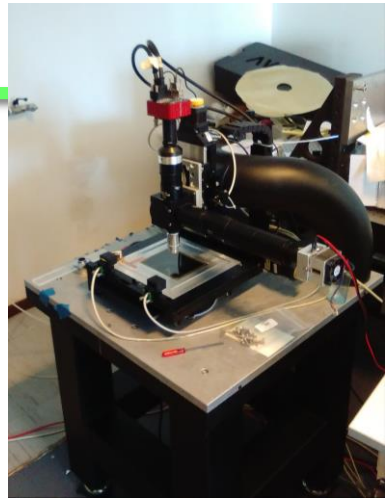


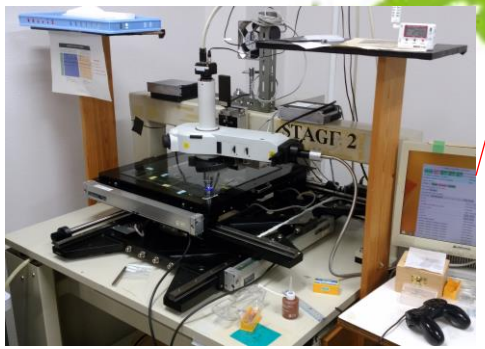
BG: induced event but not track (insensitive to direction)

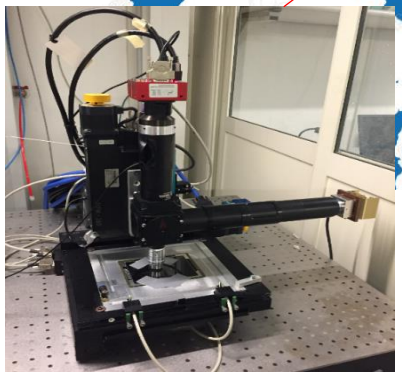
We found that elliptical shape is not always same with filament row
It maybe due to irregular optical response and non-negligible filament size

Readout technologies









One more machine will be constructed

Toho U.

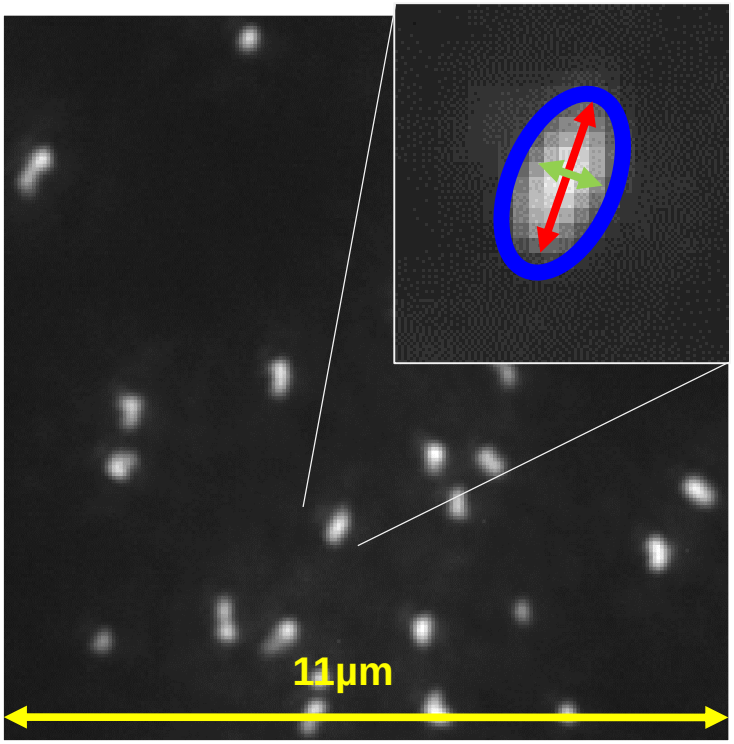
Nagoya

LNGS

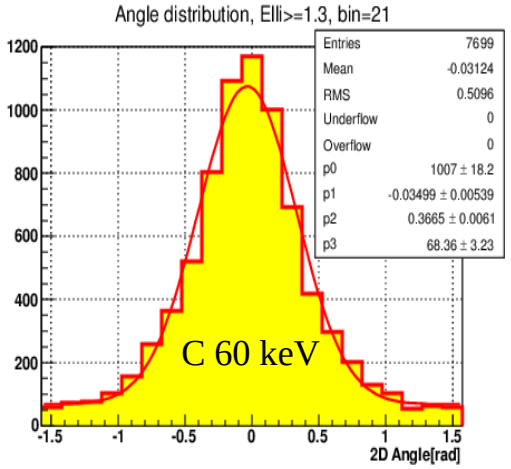
Napoli

x 2

Sub-micron length track readout capability

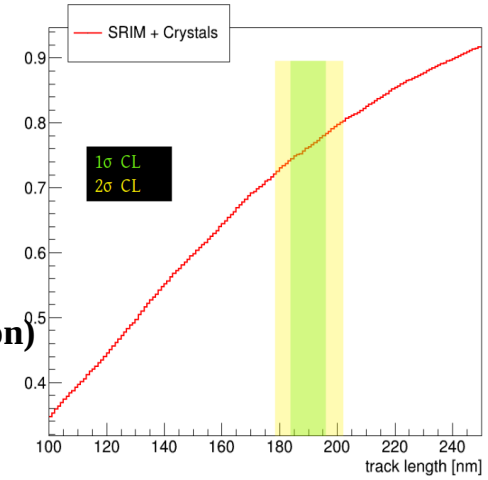


Cleary observed angular distribution
⇒ angular resolution ~ 30 deg.



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

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

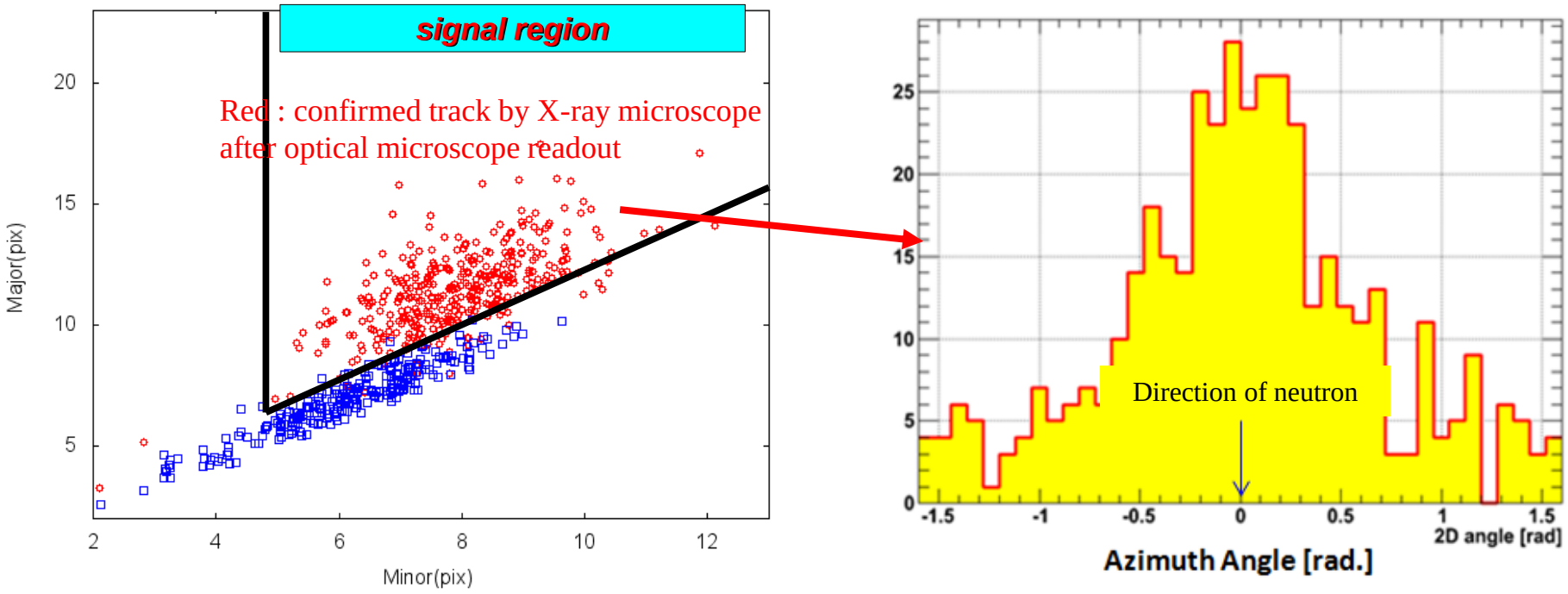


Calibration by C 60 keV

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

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

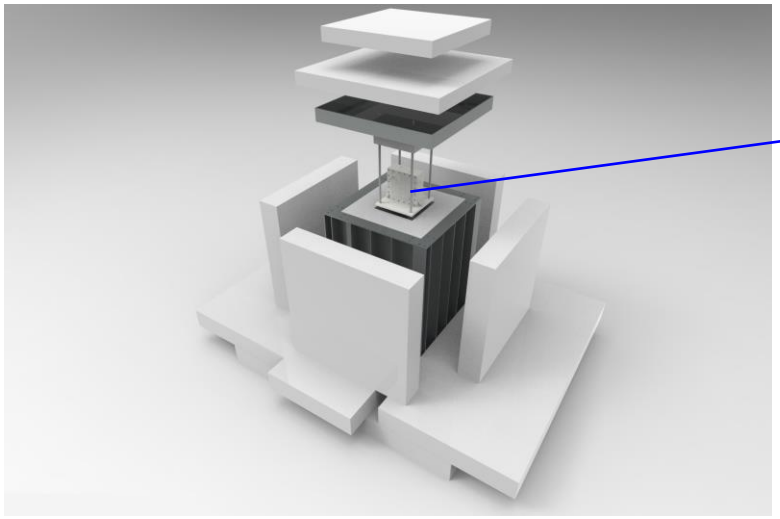
Demonstration of direction sensitive nuclear recoil detection due to 14.8 MeV neutrons

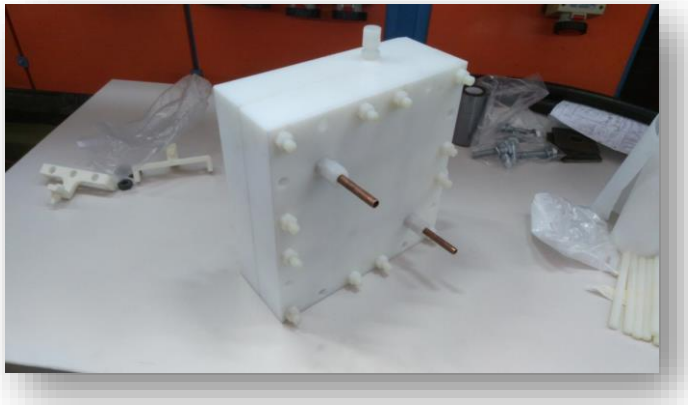


Mostly detected target was Br recoil [< 200 keV]

Now on studying CNO recoil demonstration due to 565 keV (Li-p nuclear fission reaction)

Pilot-run (BG run) system





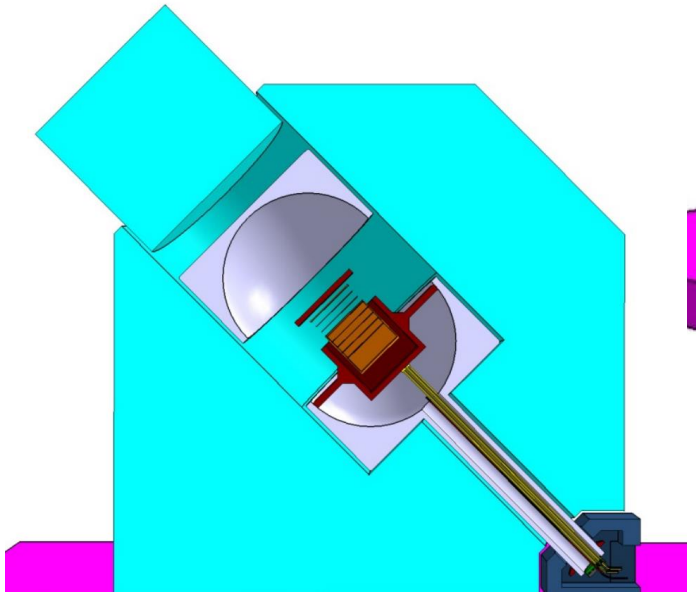
Cooling system to keep the stability of device and improvement of S/N by low-temperature

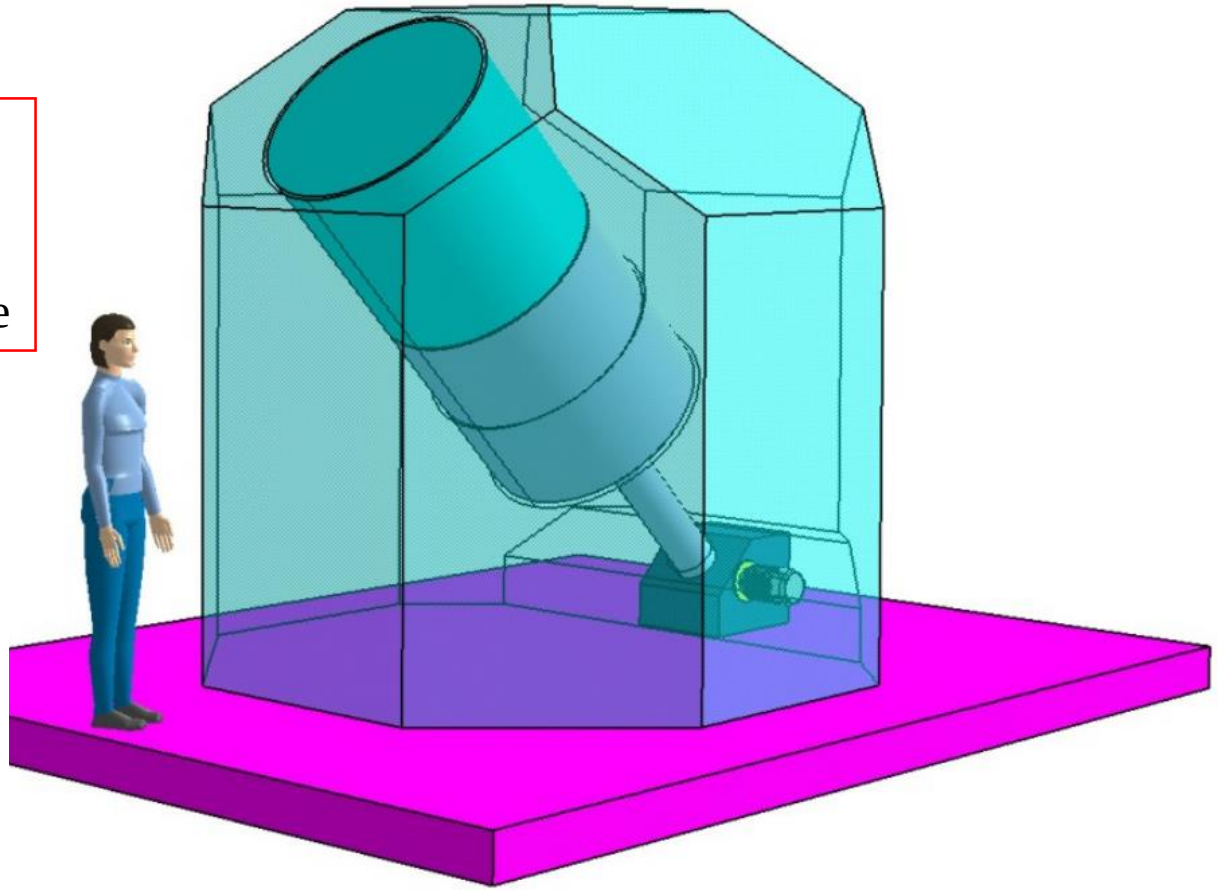
Preliminary

	Event rate [/kg/d] w/o shield	Event rate [/kg/d] w/ shield	method
Environment γ-rays	1 x 10^{7}	5 x 10^{3}	Geant4
Environment neutron	~1-2 /kg/day	< 0.1 /kg/day	Geant4
Cosmogenic neutron	< 1 x 10^{-3} /kg/day	2 x 10^{-3} /kg/day	Geant4

Toward physics run with equatorial telescope

New shield project is going on
- 1 m PE shield
- Cooling system
- Built in Equatorial telescope

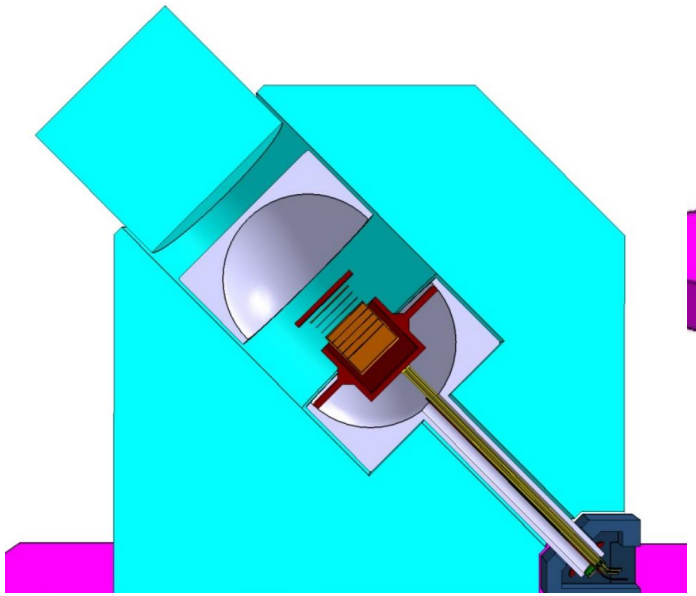


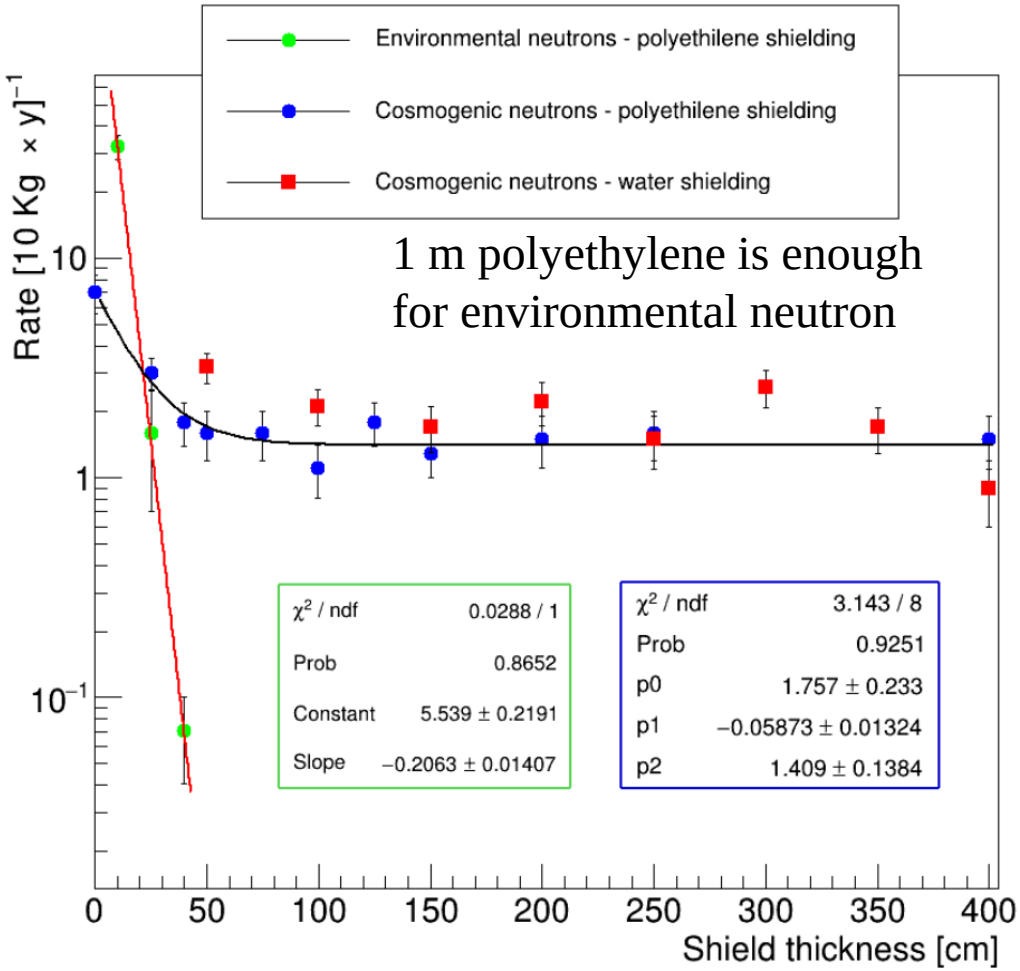


3 m x 3 m

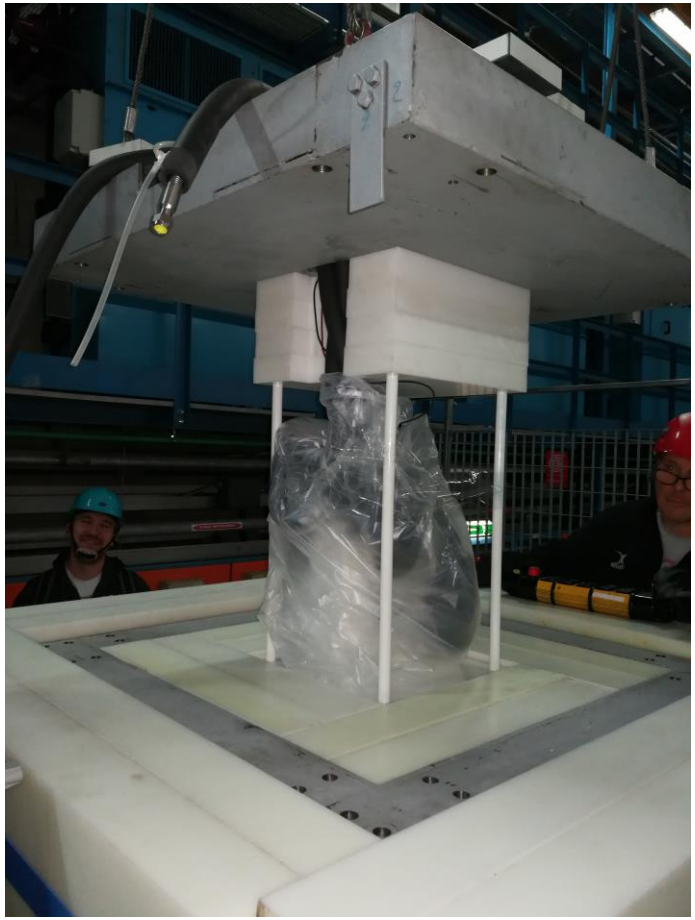
Toward physics run with equatorial telescope

New shield project is going on
- 1 m PE shield
- Cooling system
- Built in Equatorial telescope





installation



Installation completed at 17Jun2019 16:00