NAGOYA UNIVERSITY

Kobayashi-Maskawa Institute
for the Origin of Particles and the Universe

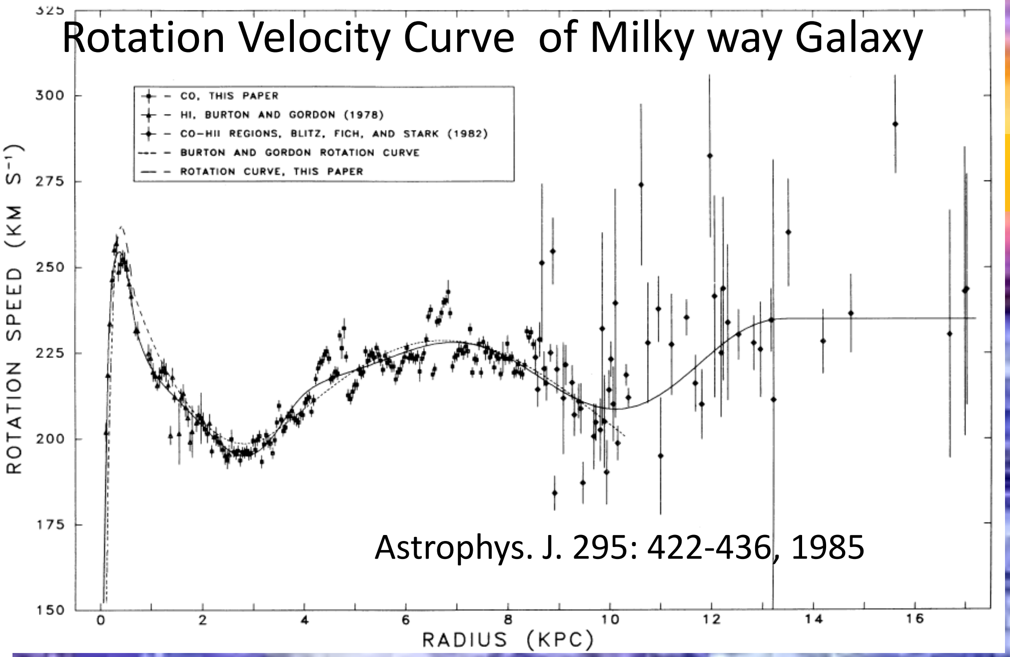
NEWSdm
Direction Sensitive Dark Matter Search with Super-high Resolution Nuclear Emulsion

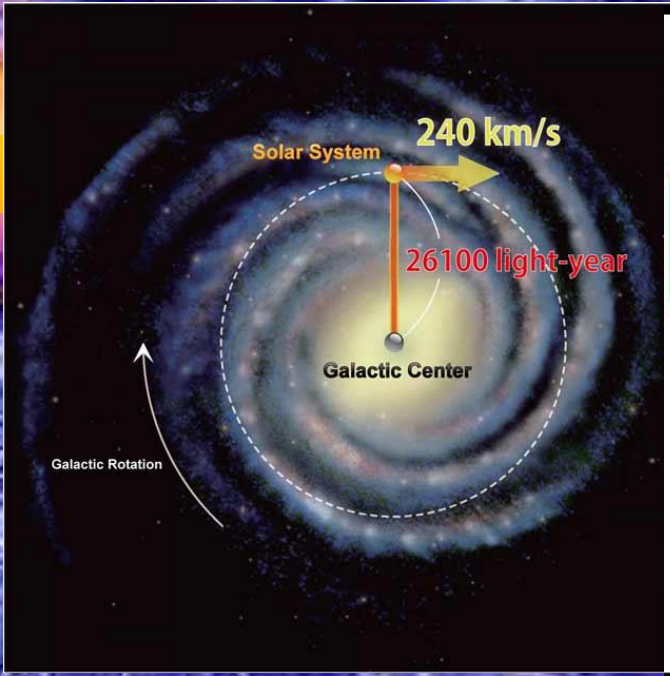
Tatsuhiro Naka

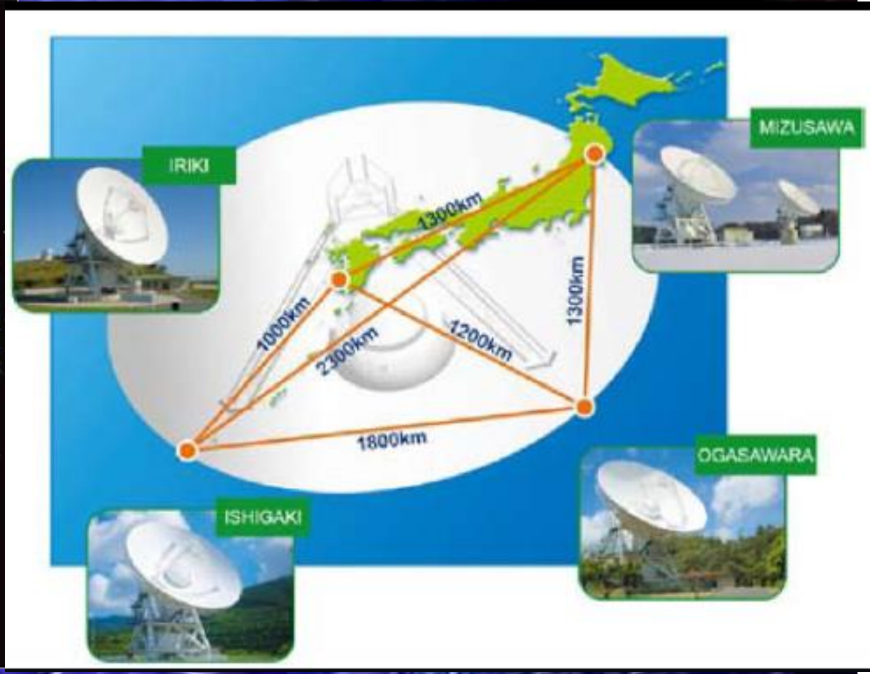
Nagoya University@Japan

On behalf of NEWSdm collaboration

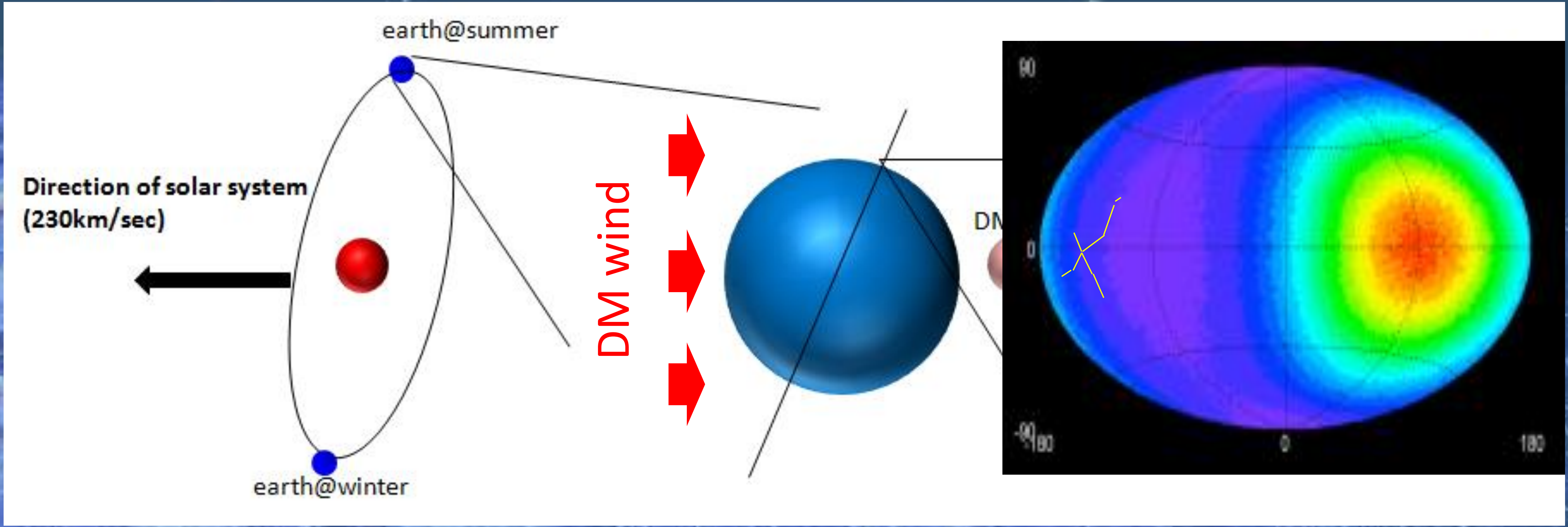
5 June 2018 Blois Conference @ Blois, France







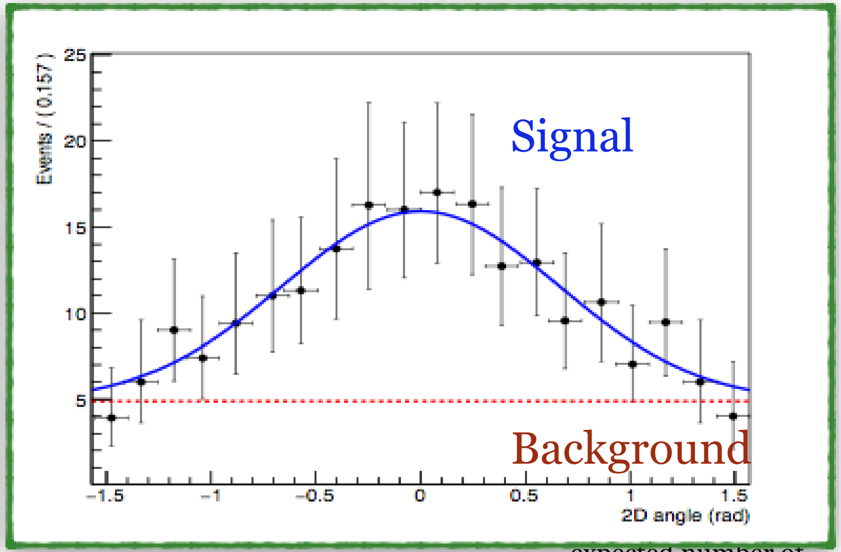
- Rotation velocity curve : 240 +- 14 km/sec
- Expected local dark matter density : 0.4 GeV/cm3
  (270000 times dense than the average of overall dark matter density in the universe)
- Dark matter flux on the earth : 1000000 /cm2/sec for 100 GeV/c2 dark matter mass



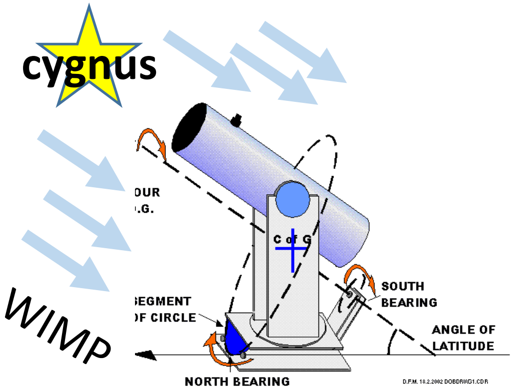
Direction Information → new information for new generation dark matter search experiment

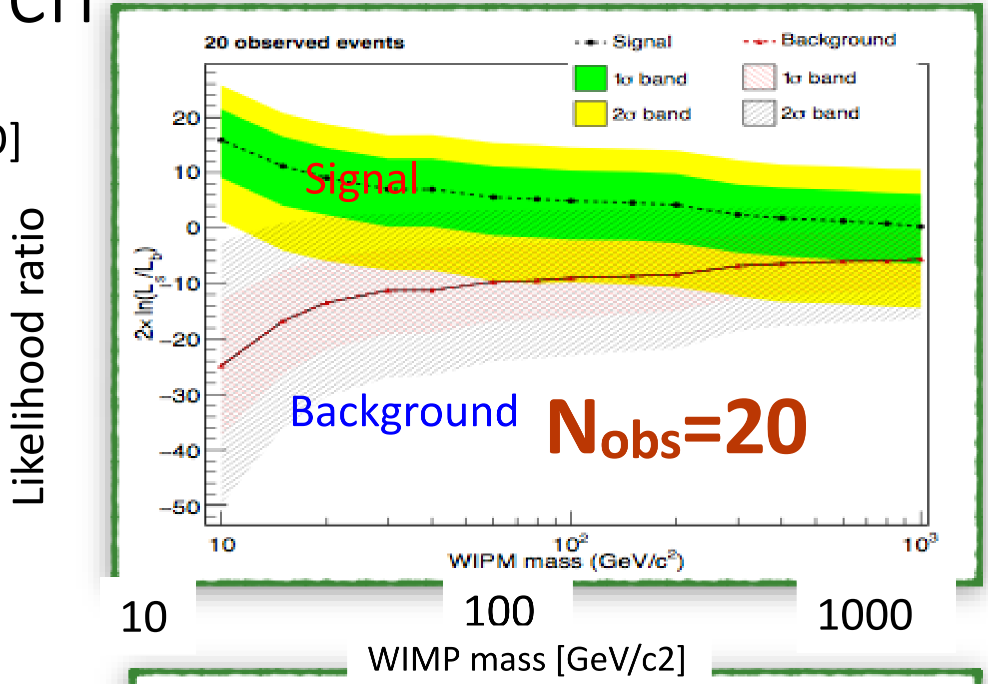
- **Beyond neutrino floor**
- **Dark Matte Astronomy**

Potential of Directional Sensitive Search



arXiv:1705.00613 [astro-ph.CO]





expected number of WIMP events

expected number of background events

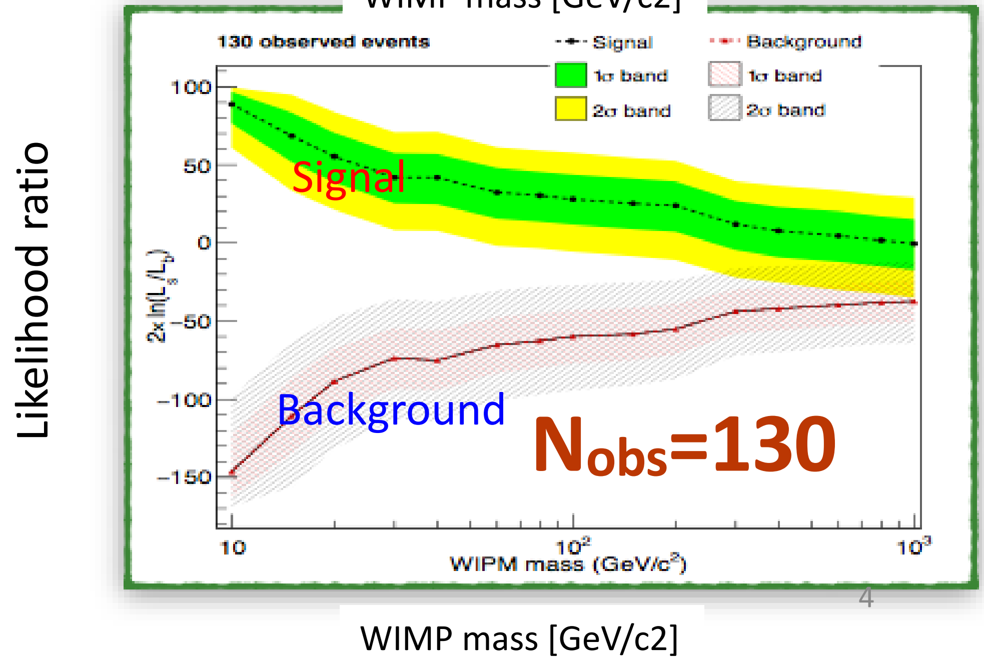
signal pdf

background pdf

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

total number of observed events

set of observables



Direction information : Several 10 events

Gain of 100 times

Annual modulation : Several 1000 events

Challenge for Direction Sensitive Dark Matter technologies

Can the solid (or liquid) detector have directional sensitivity to nuclear recoil signal due to WIMPs ?

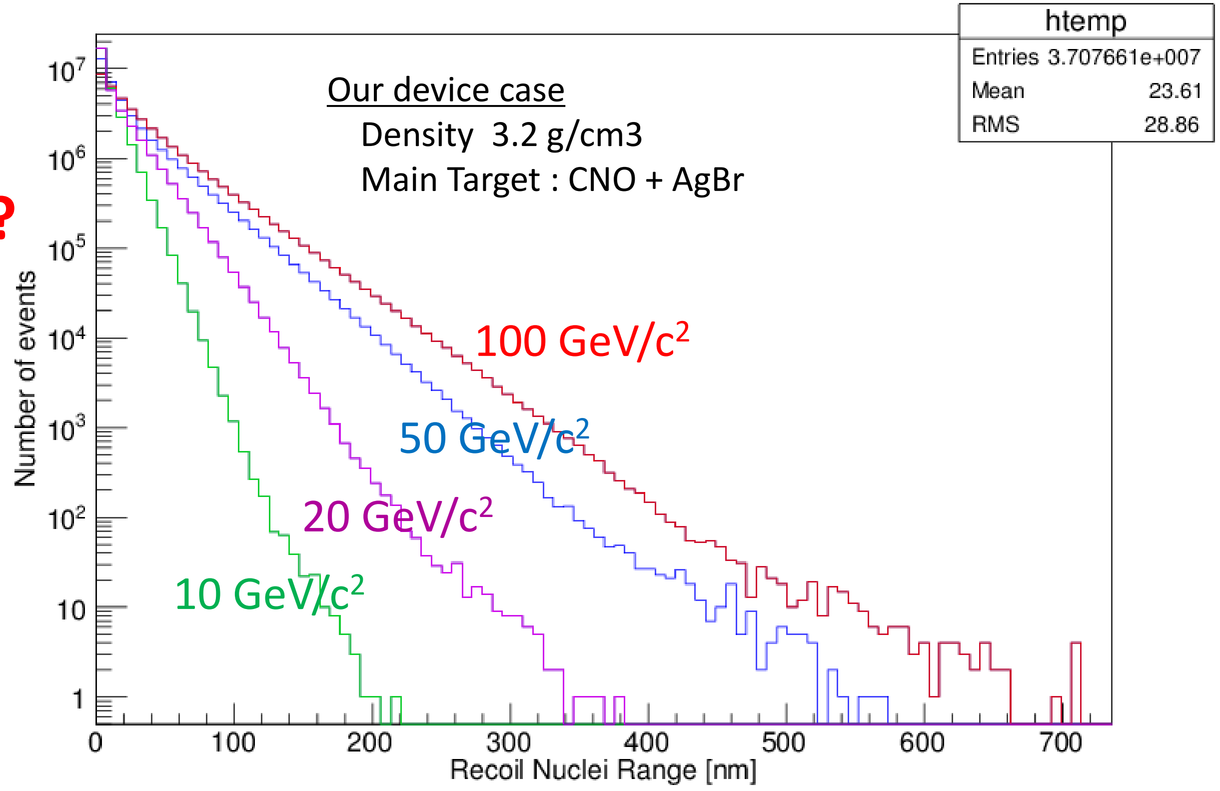
- **Track length of recoiled nuclei < ~ 1 μm**
- **Angular dispersion due to straggling ~ 25deg.**

As dark matter detector ･･

☑ low-background

☑ scalability

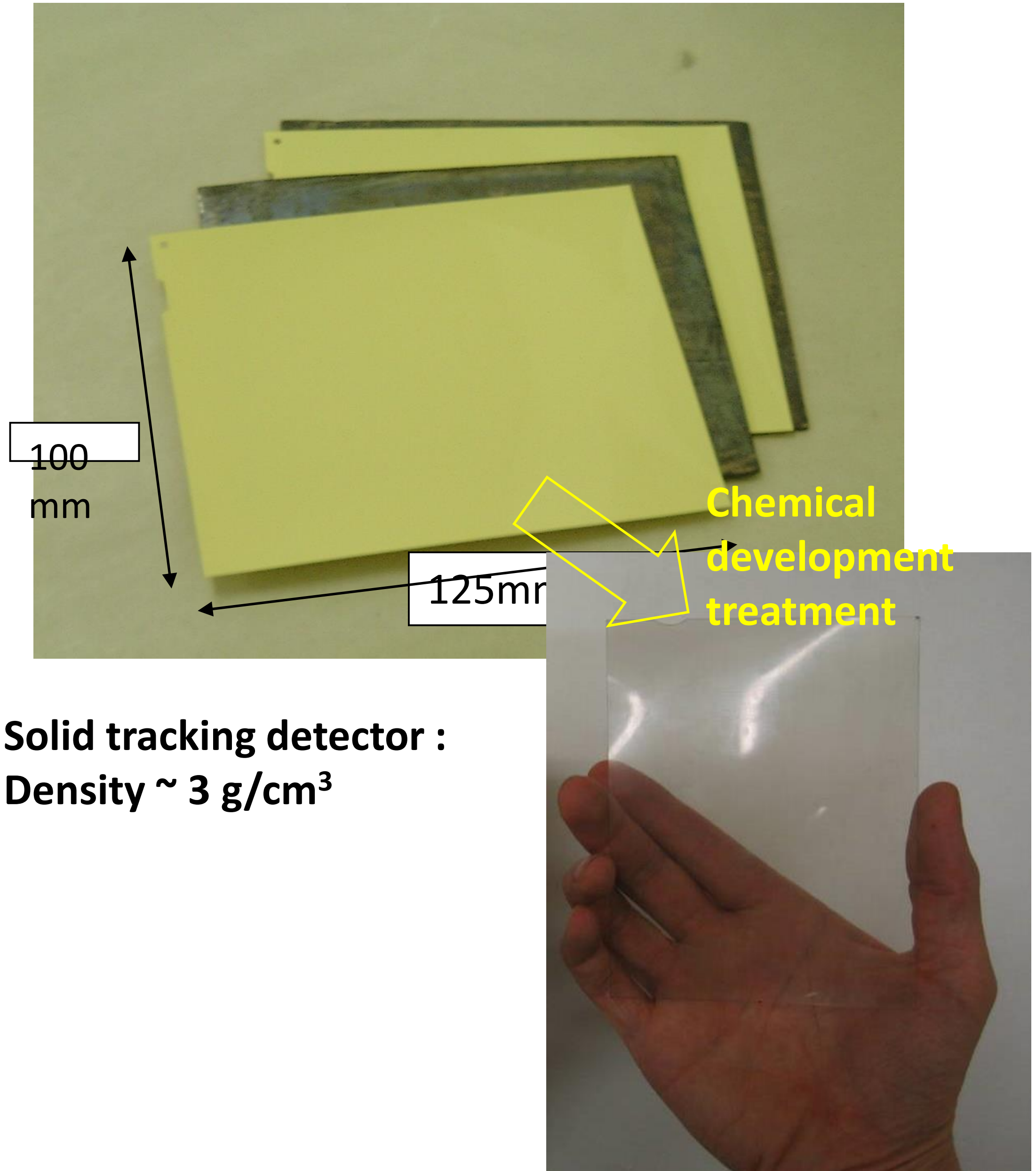
New technical challenge !!



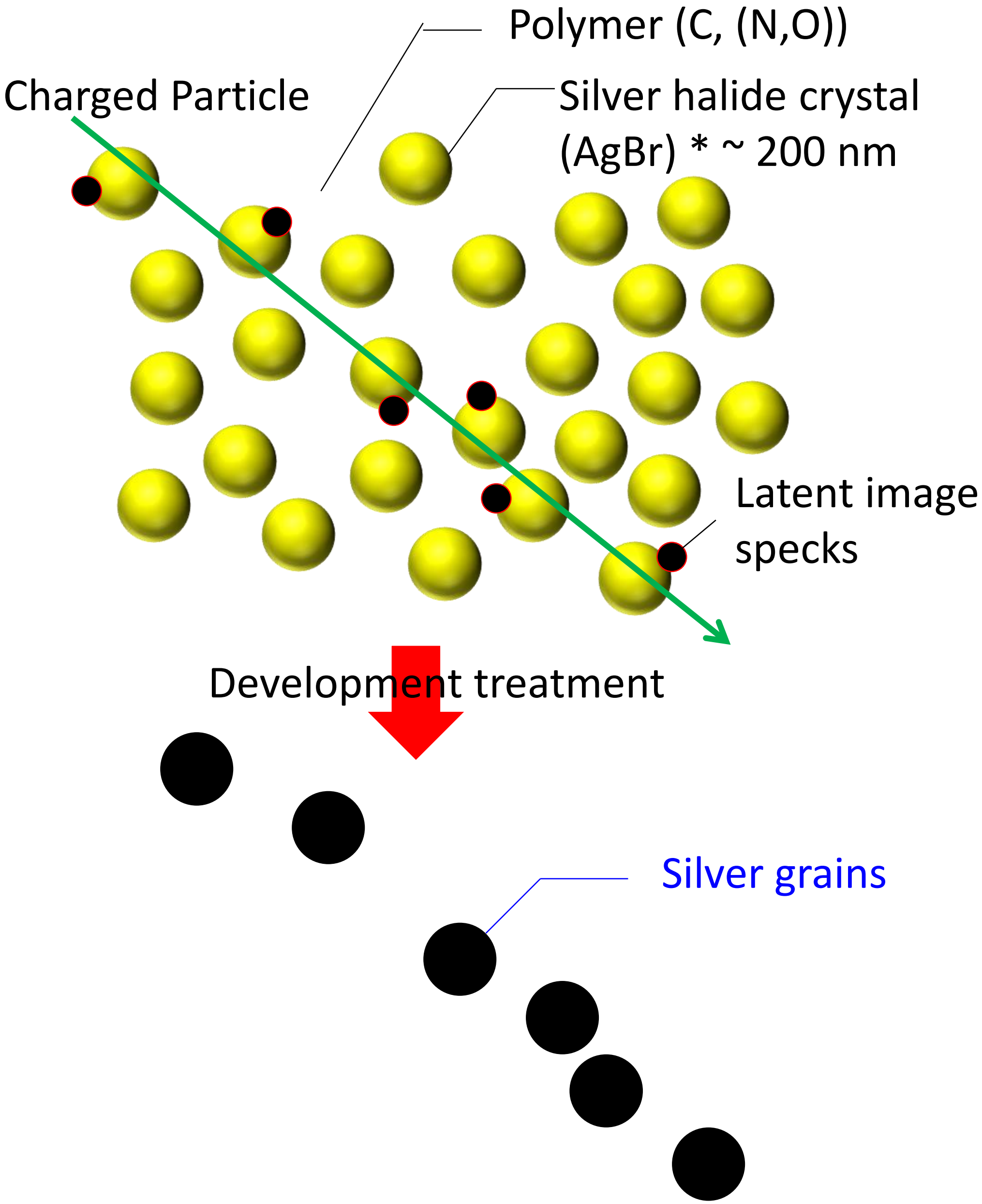
Low mass (~10 GeV/c2) search : light target + < 200 nm length

High mass (> 100 GeV/c2) search : heavy target + < ~700 nm

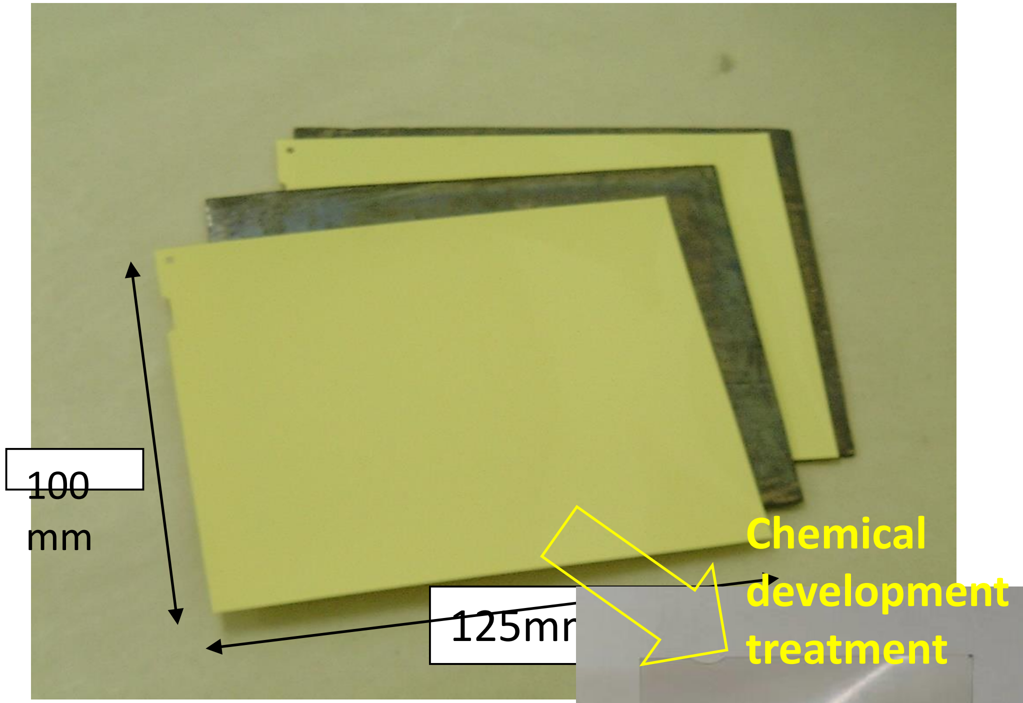
Nuclear Emulsion



Solid tracking detector :
Density ~ 3 g/cm^3



Nuclear Emulsion



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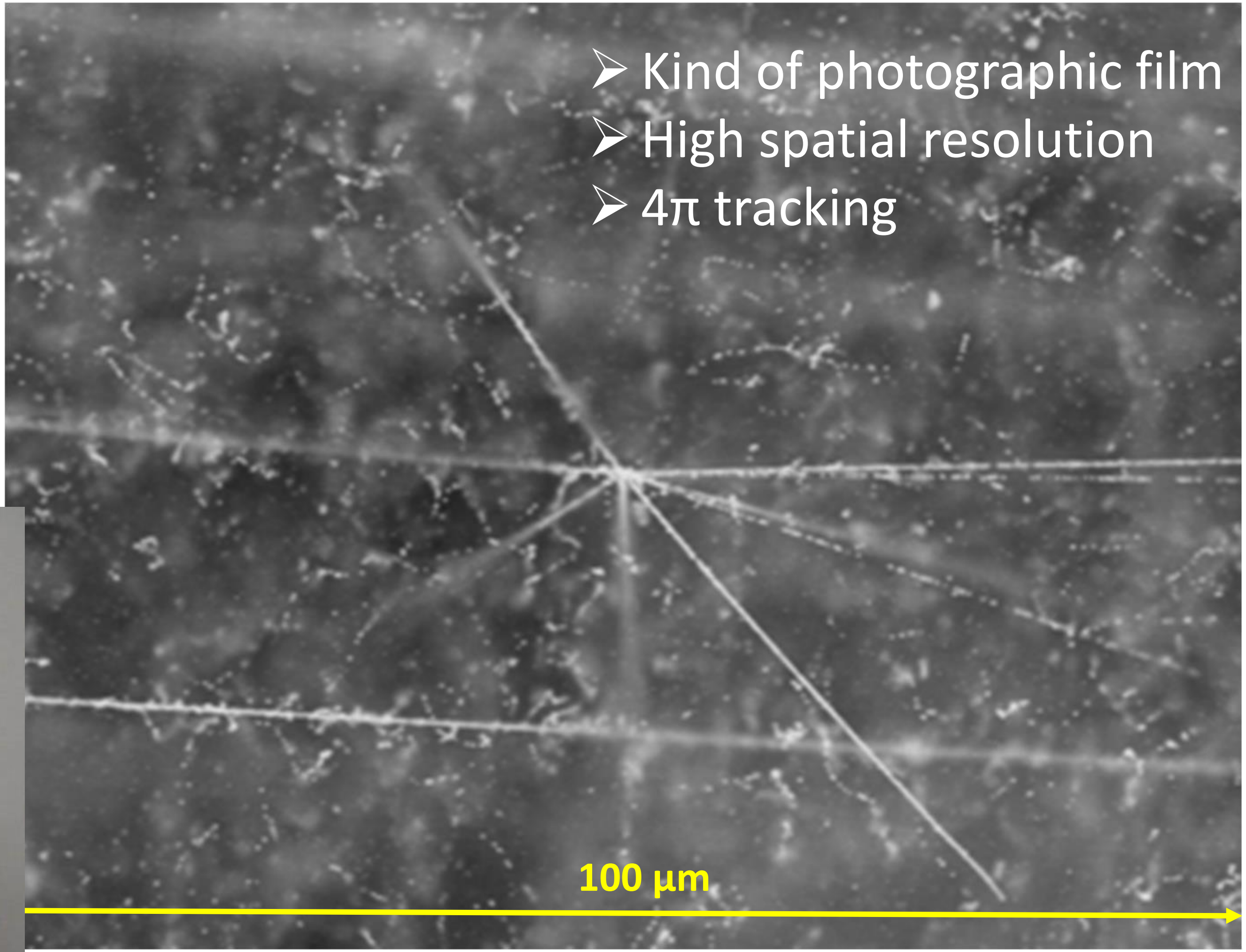
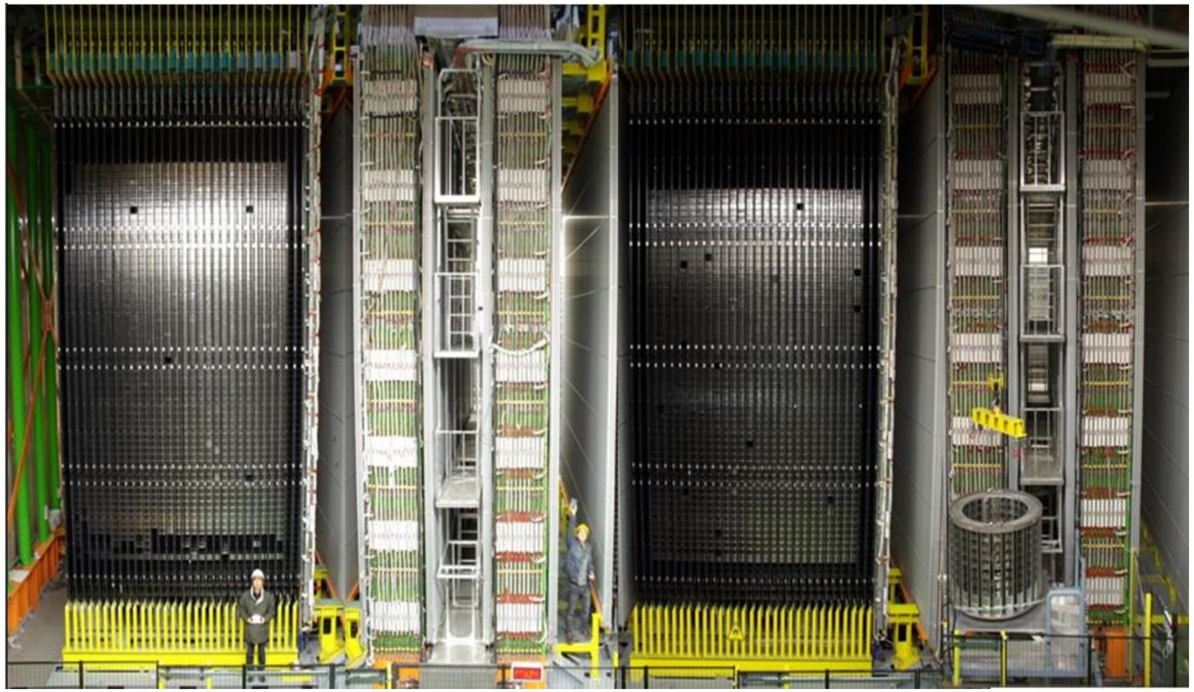


Latest the nuclear emulsion experiment and readout

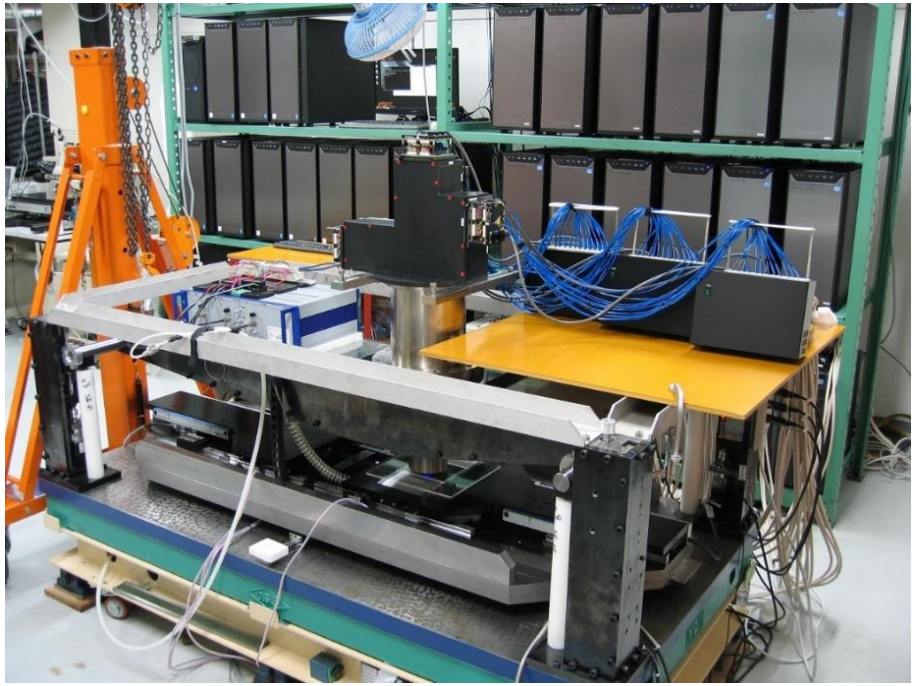
OPERA detector



20 m

Observed neutrino oscillation with
30 ton emulsion detector x 5 years (150 ton･year)
(Emulsions are 20 % volume in this picture)

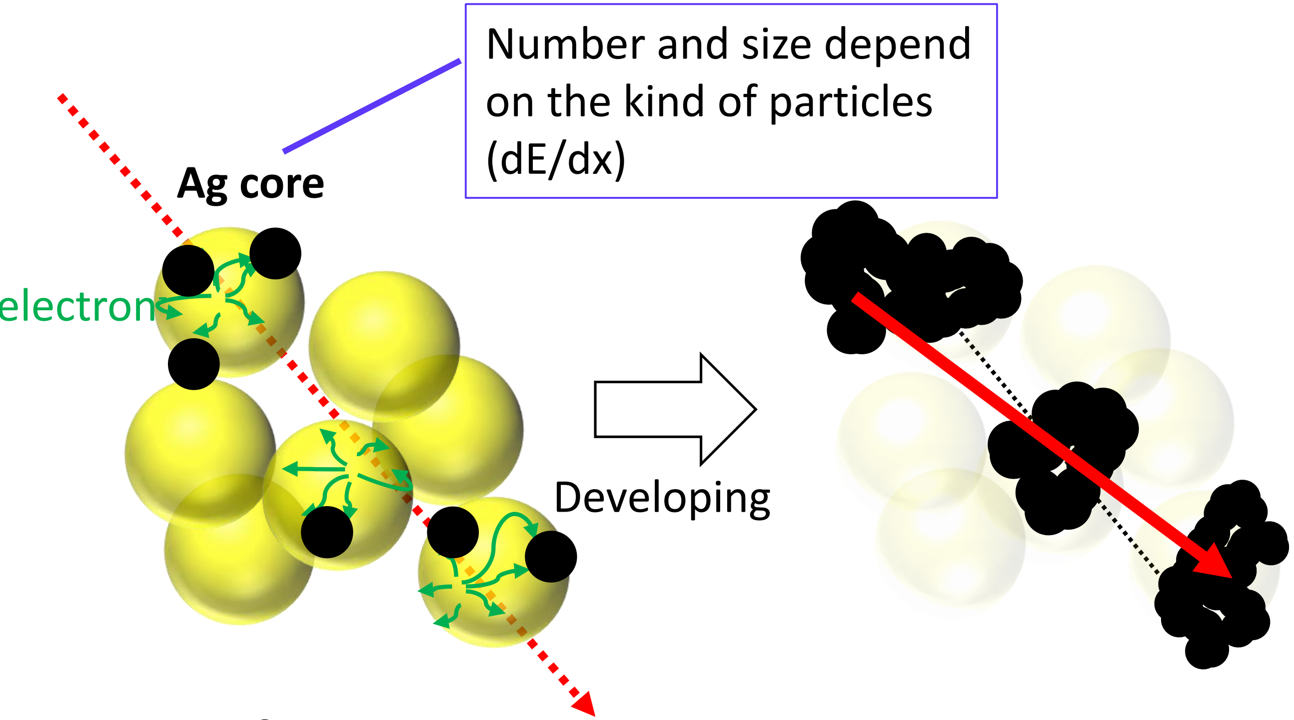
Current highest speed readout system



Scanning speed ~ several ton /year

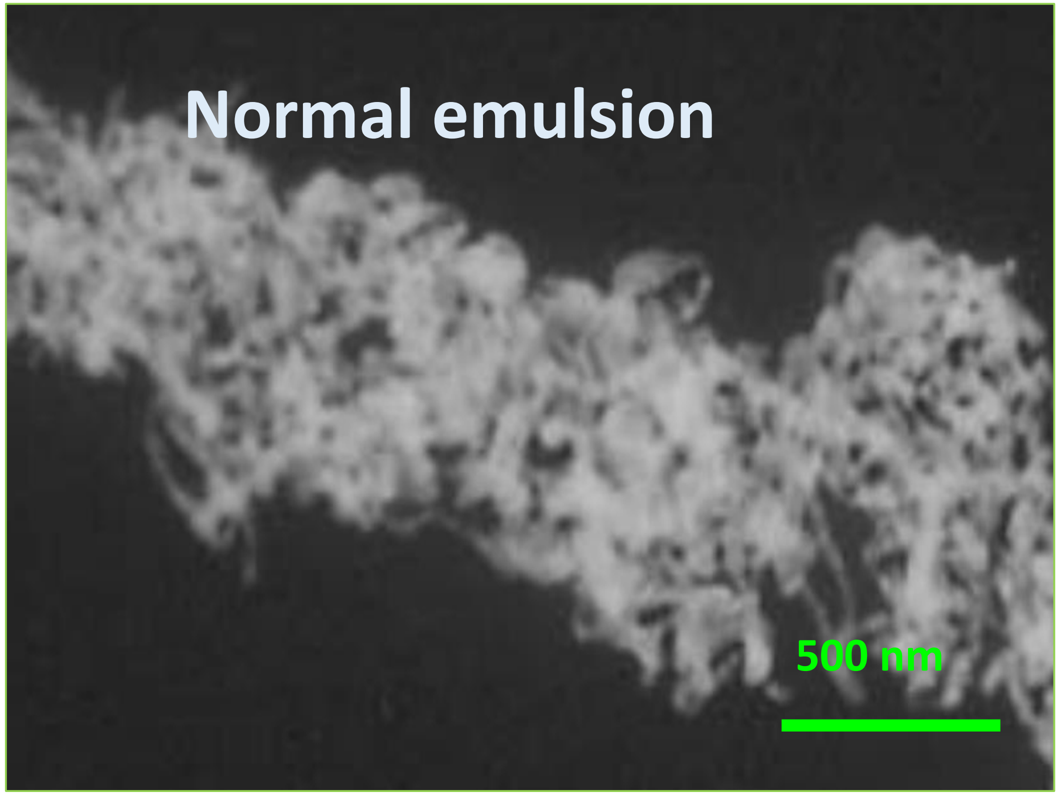
Ref : M. Yoshimoto el al., **arXiv:1704.06814 [physics.ins-det]**

Tracking for nuclear emulsion

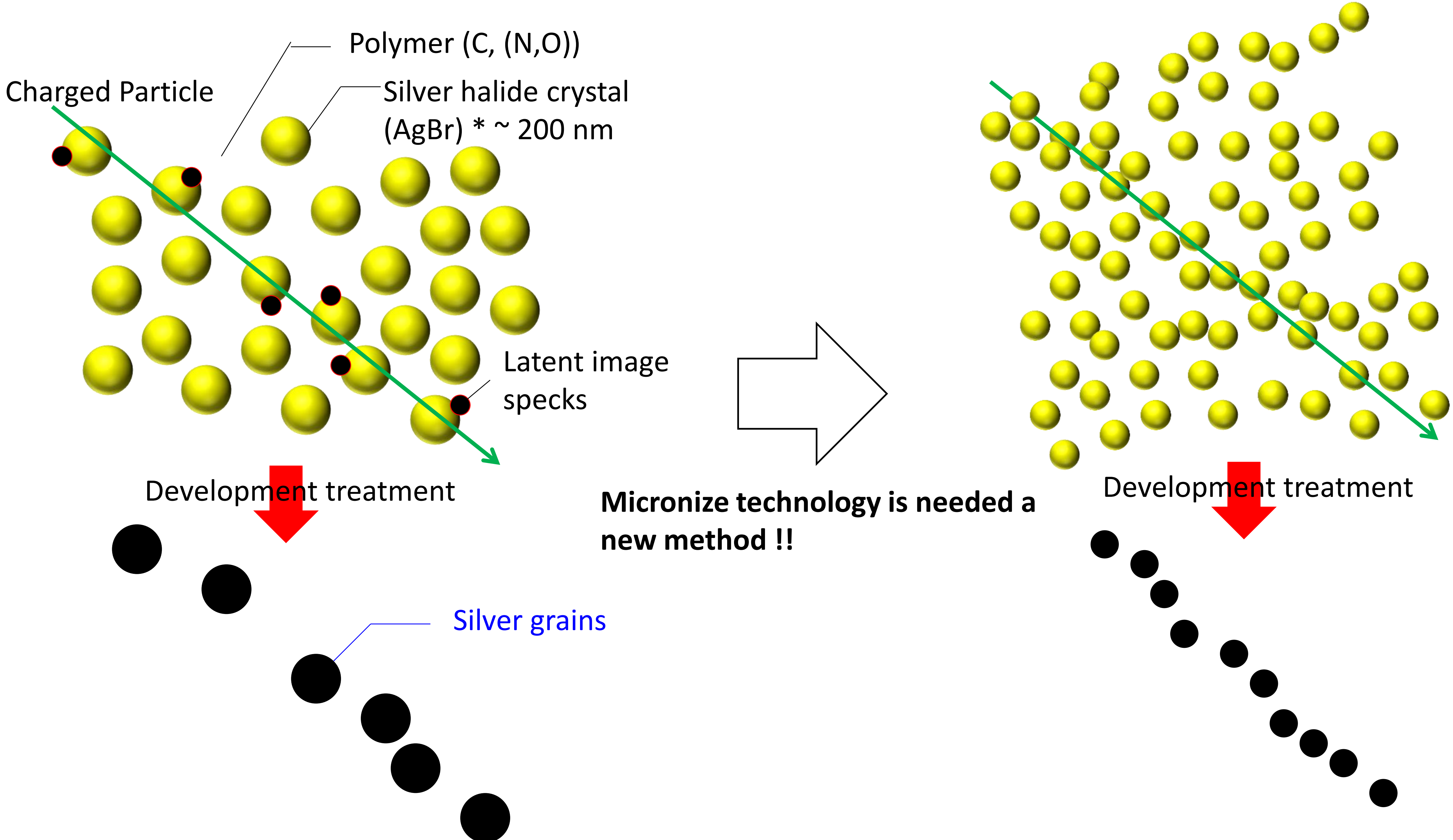


Crystal size : ~ 200 nm

Electron microscope image of α-ray



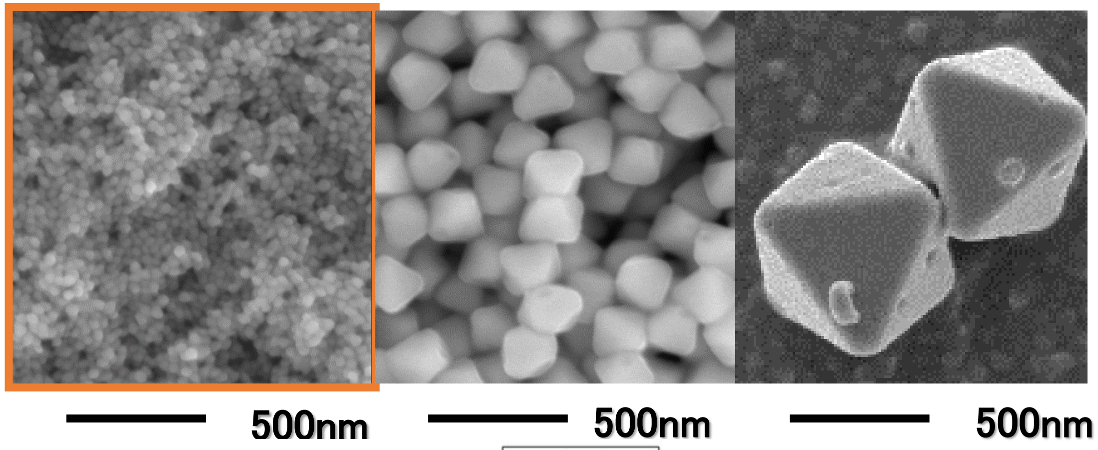
Concept of super-high resolution

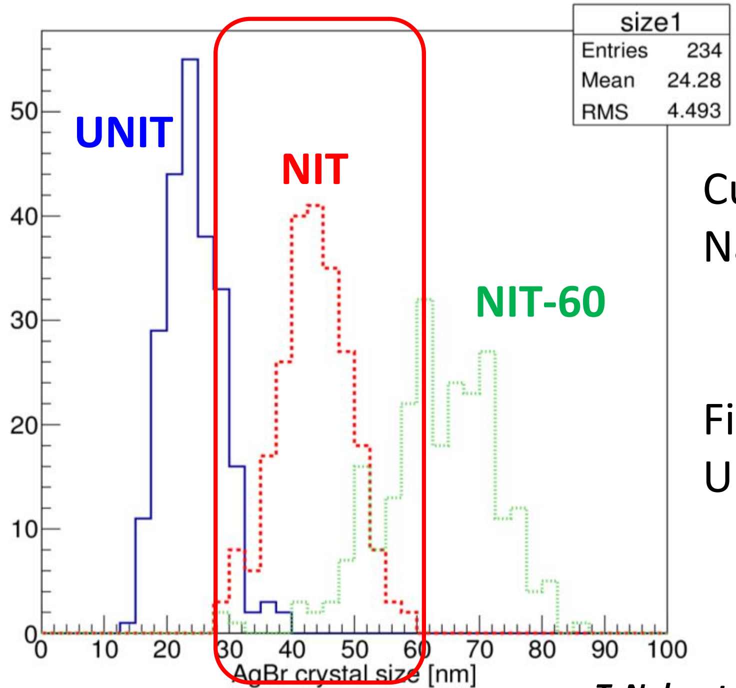


Micronize technology is needed a new method !!

Self-production of Nano Imaging Tracker(NIT)

Controlled AgBr crystal





- 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.

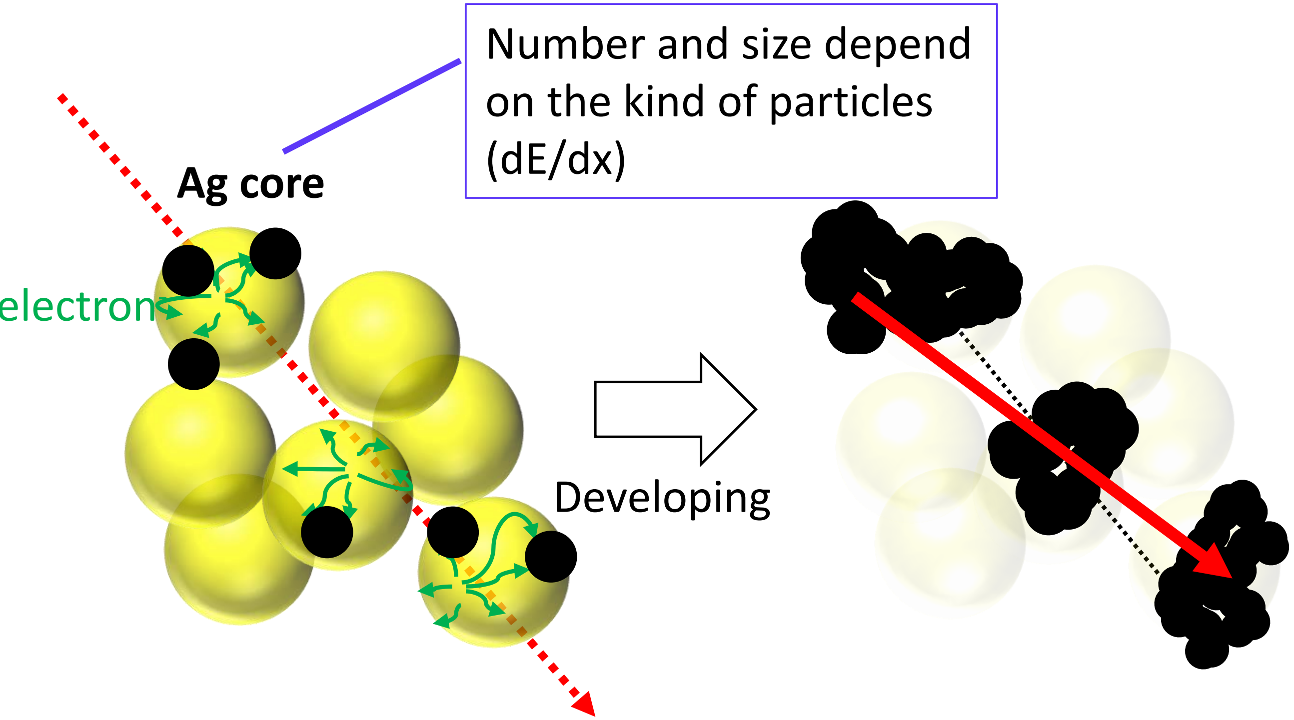
Current standard Device :
Nano Imaging Tracker [NIT]
crystal size : 44 nm

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

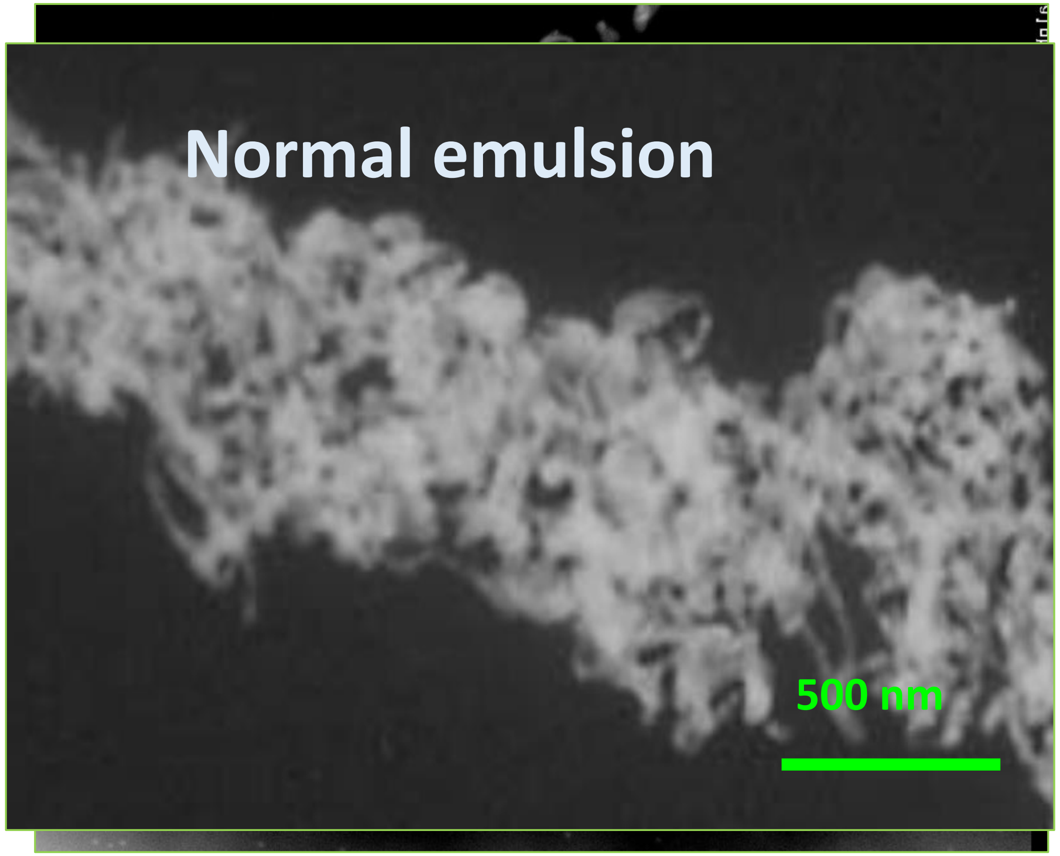
T. Naka et al., Nucl. Inst. Meth. A 718 (2013) 519-521

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

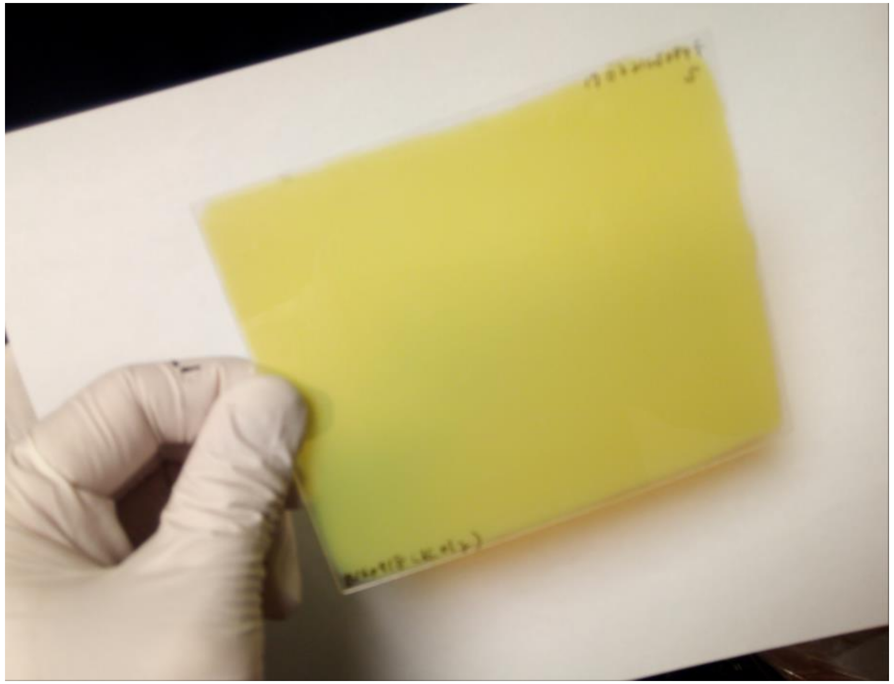
Tracking for nuclear emulsion



Electron microscope image of α-ray



prototype NIT film for dark matter experiment



Elemental composition of NIT

	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]

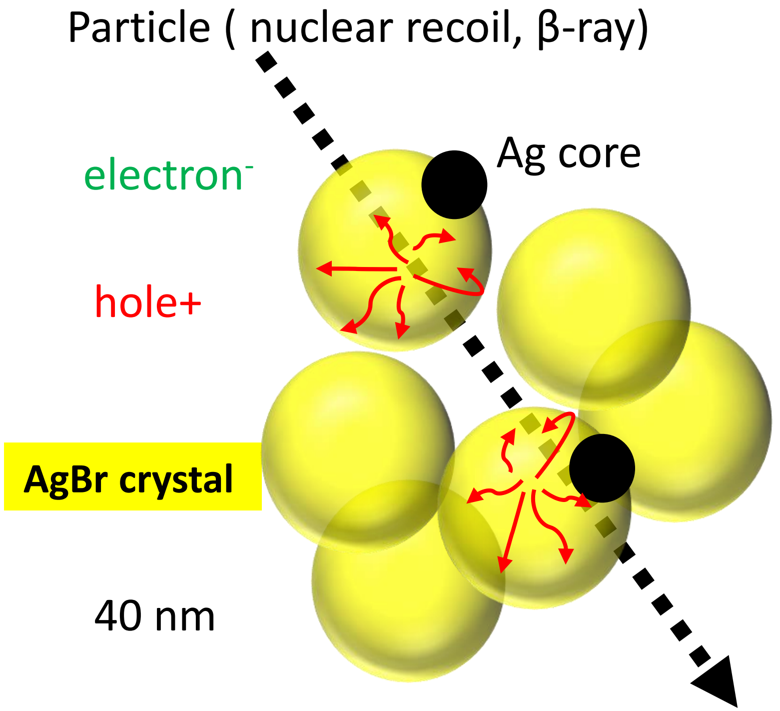
◆ Intrinsic neutron emission:

~ 1.2 /kg/y (by SOURCE simulation)

⇒ ~ 0.1 /kg/y (> 100 nm nuclear recoil)

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

β-ray event rejection potential



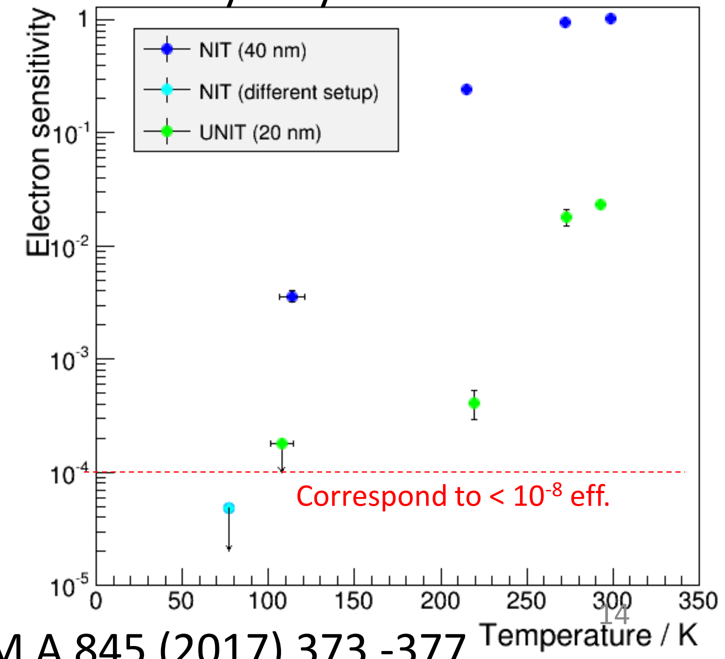
- **Cryogenic crystal effect**
  - crystal quantum efficiency is drastically decrease by lower temperature
  - nuclear recoil is not by the thermal spike

⇒ Powerful discrimination between nuclear recoil and electron
  e.g.) expected BG signal eff. due to electron < 10^{-9} @80K

- **Chemical treatment**
  - Nuclear recoil can create enough number of e-h pair for the Ag core
  - Dopant in the AgBr crystal to suppress the sensitivity only electron

- **Low background material**
  - gelatin have high C-14 level
  - replacement to the synthetic polymer

  ⇒ at least > 10^3 rejection
  (aleady measured byAMS)



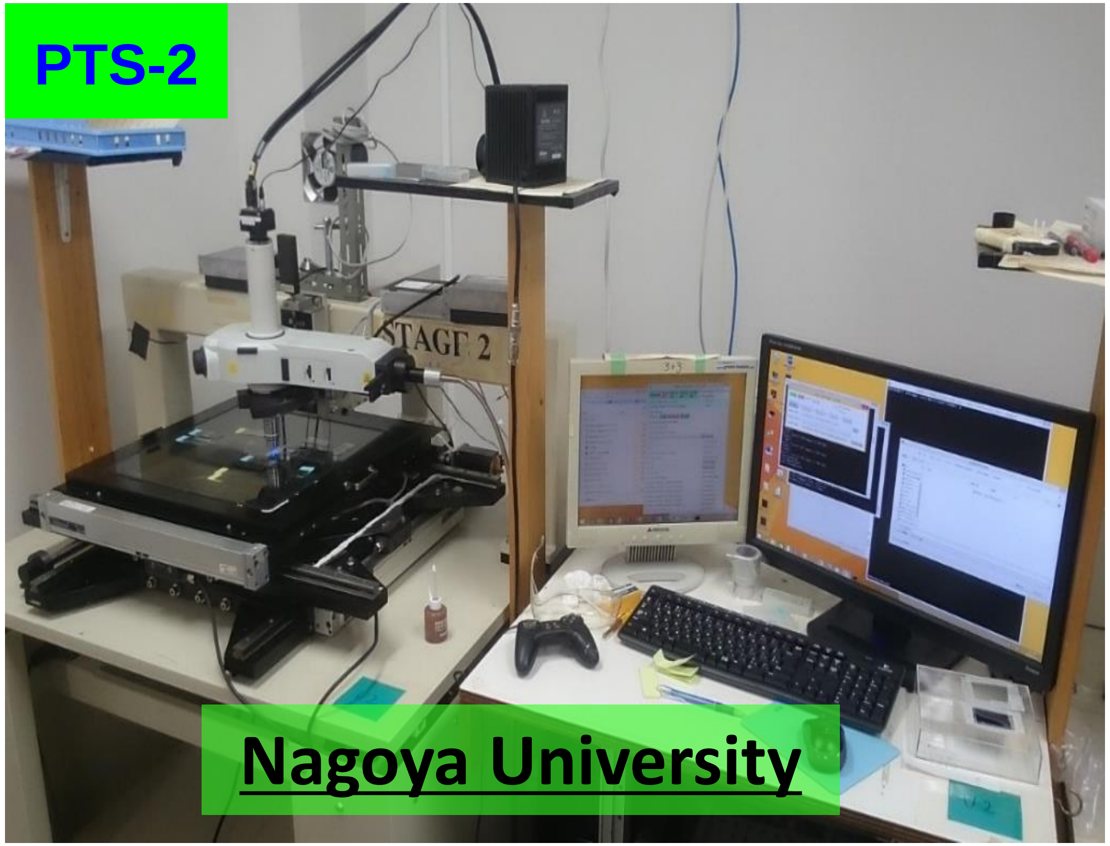
NIM A 845 (2017) 373 -377

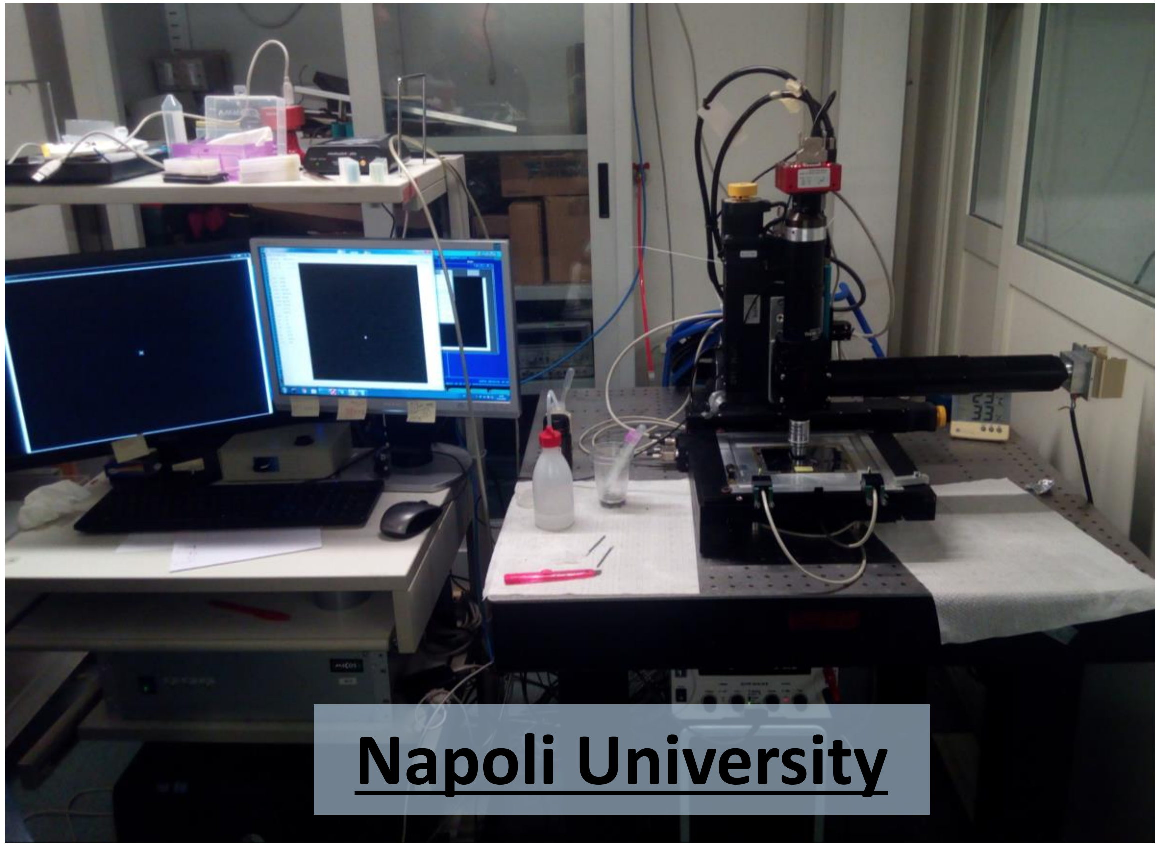
As potential, > 10^9 rejection power is expected by combination of some techniques

⇒ Now, constructing the calibration system in the LNGS

Development of New Readout System

Prototype R&D system @Nagoya and Napoli





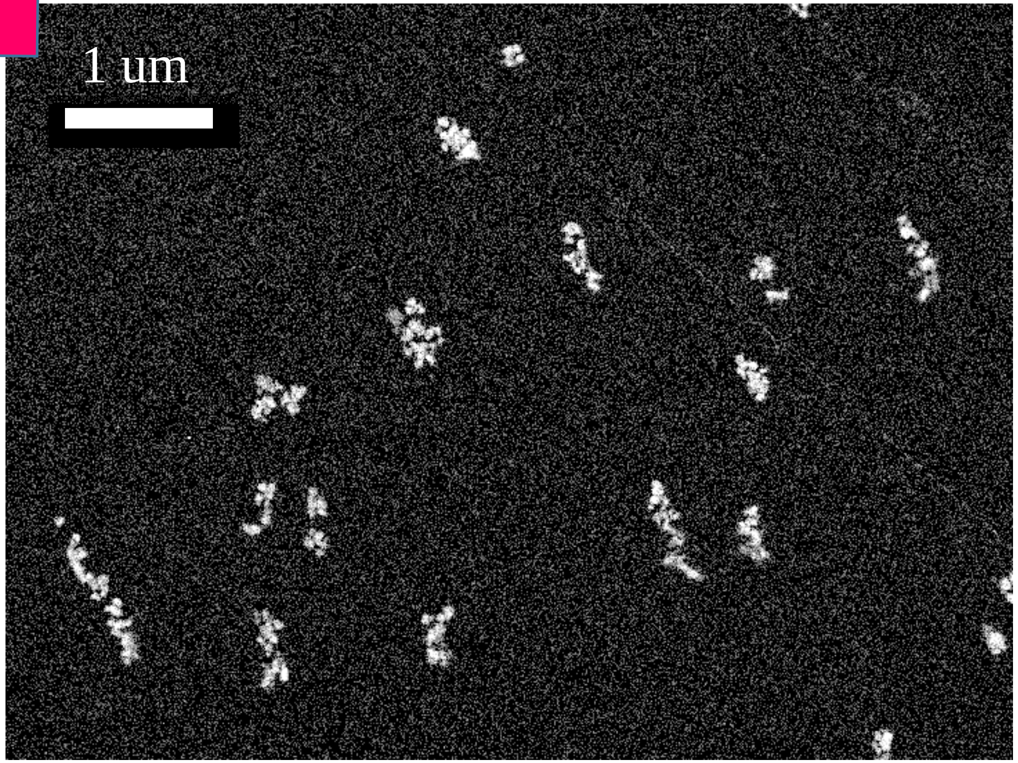
Low-velocity ion tracking

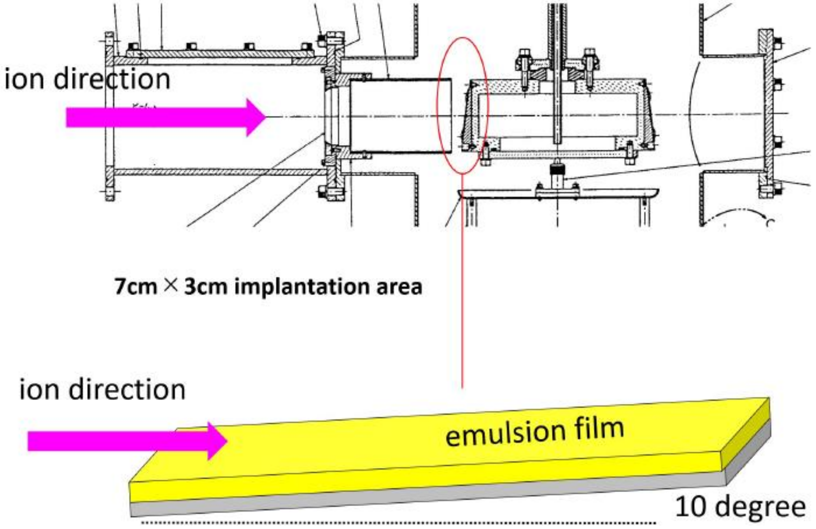
Can use ion implantation as calibration source

- Mono energy (±0.1 keV)
- Good direction uniformity (<10 mrad)
- Now, C from CO_2・Ar, Kr (but other various ion is possible)

Side view of i

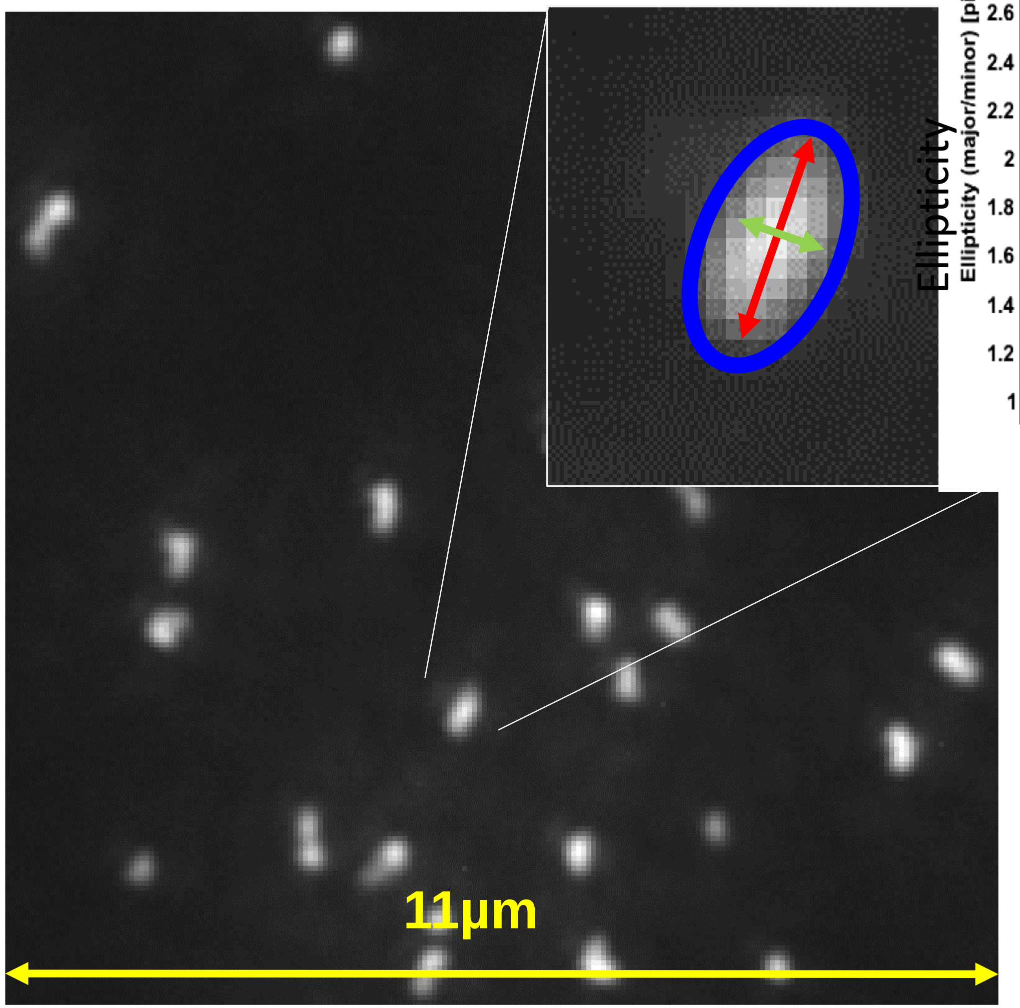
100 keV Carbon SEM image

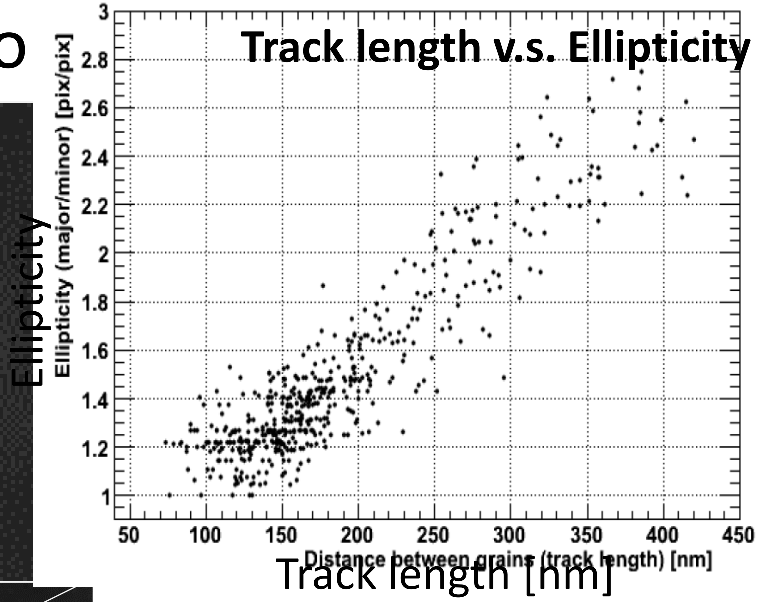




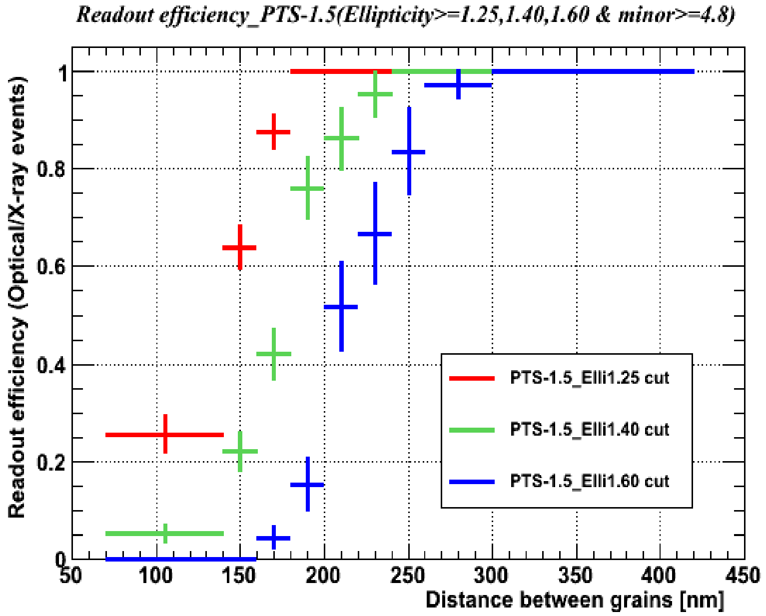
AgBr crystal has good sensitivity about Carbon (~ 100 % efficiency)

Candidate selection method using epi-illuminated optical microsco



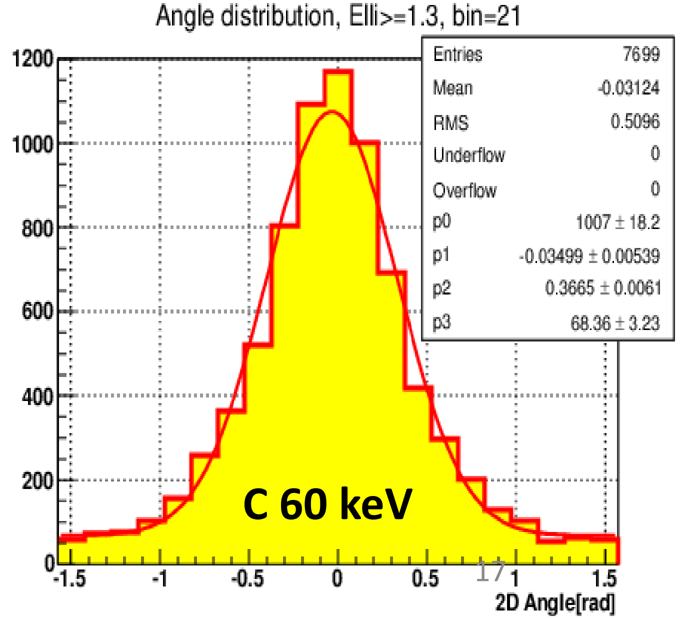


Performance using only elliptical shape analysis



Current microscope has the potential to select > 100 nm length tracks

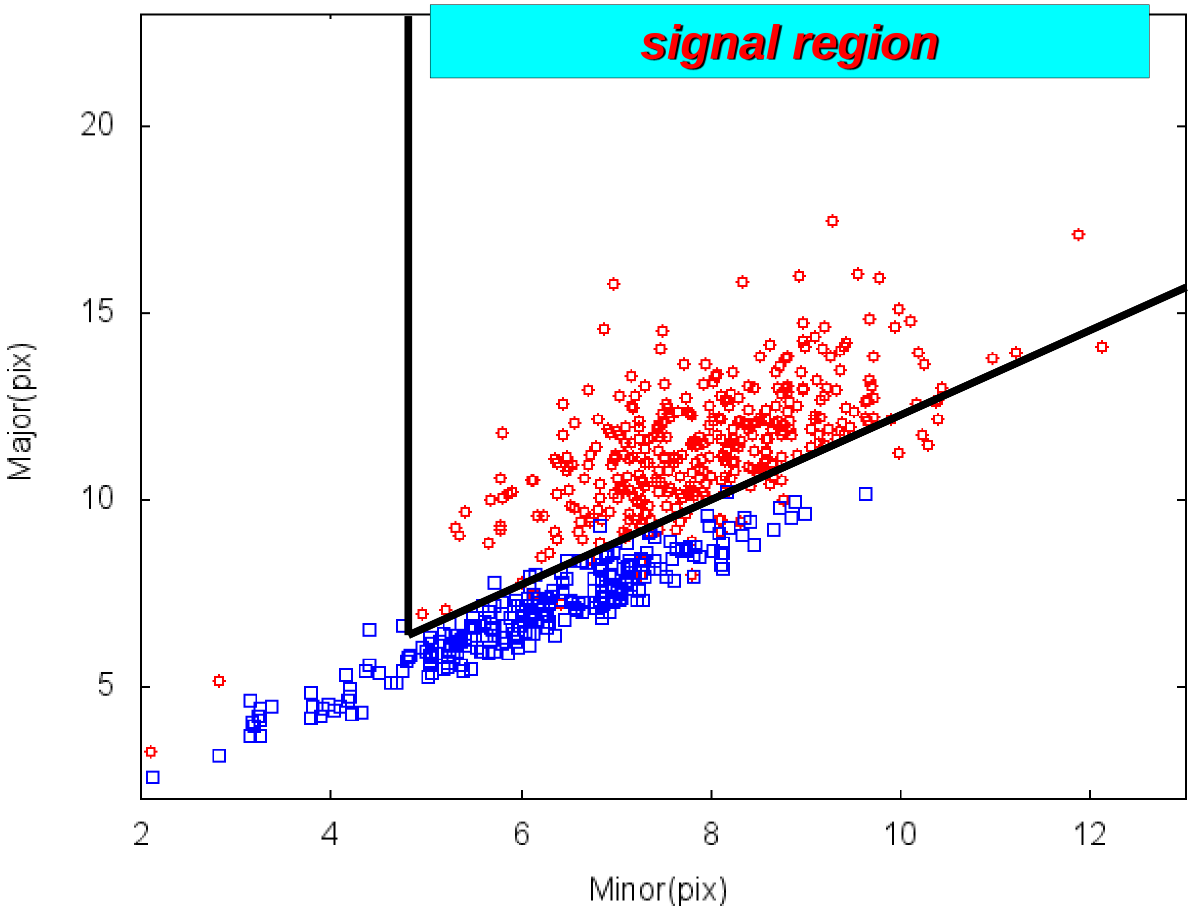
Direction sensitive eff. :
~30 % @60 keV
(now on studying)
Angular resolution :
~30 deg. @60 keV

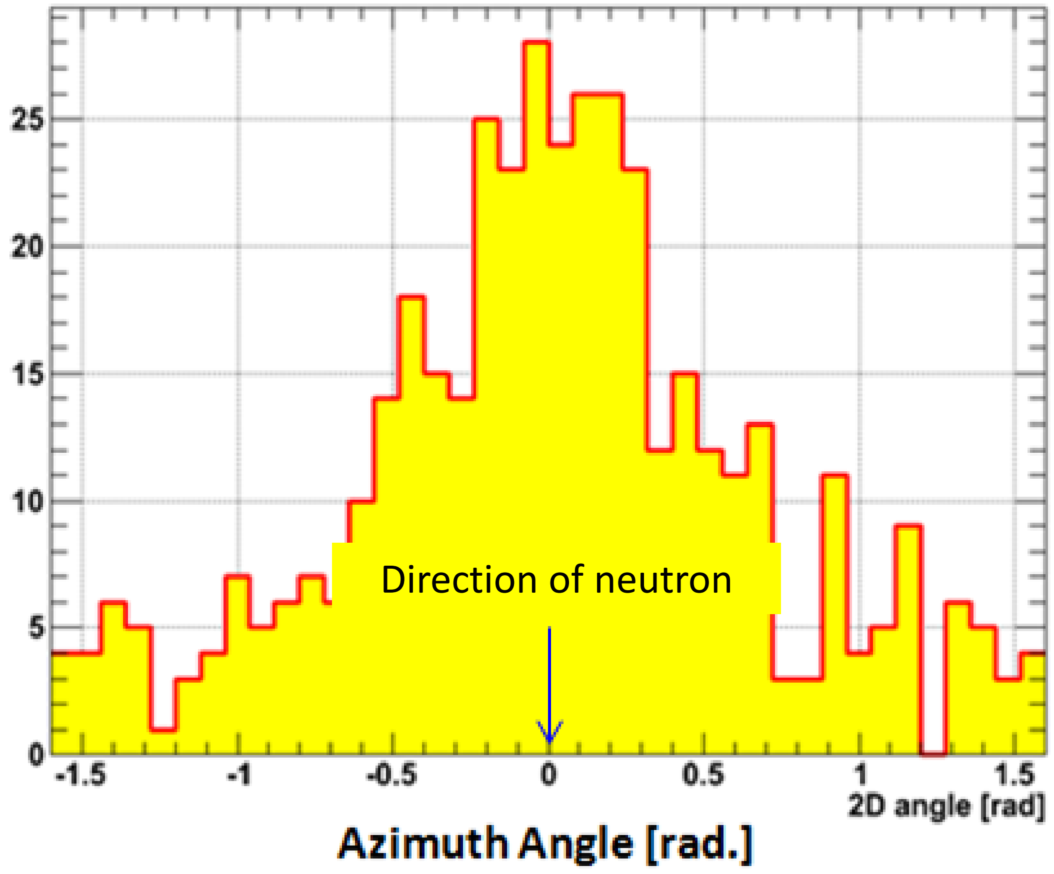


K. Kimura and T. Naka, Nucl. Inst. Meth. A 680 (2012) 12-17

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

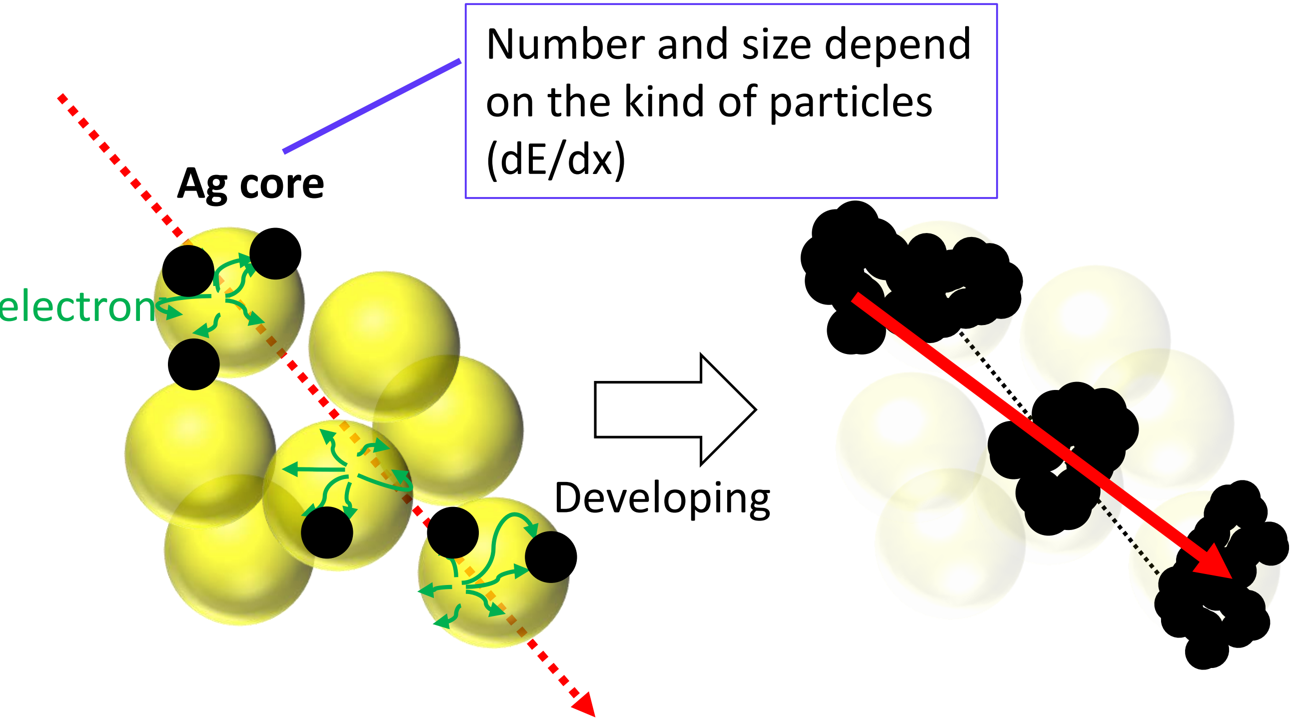
Demonstration of direction sensitive nuclear recoil detection due to 14.8 MeV neutrons

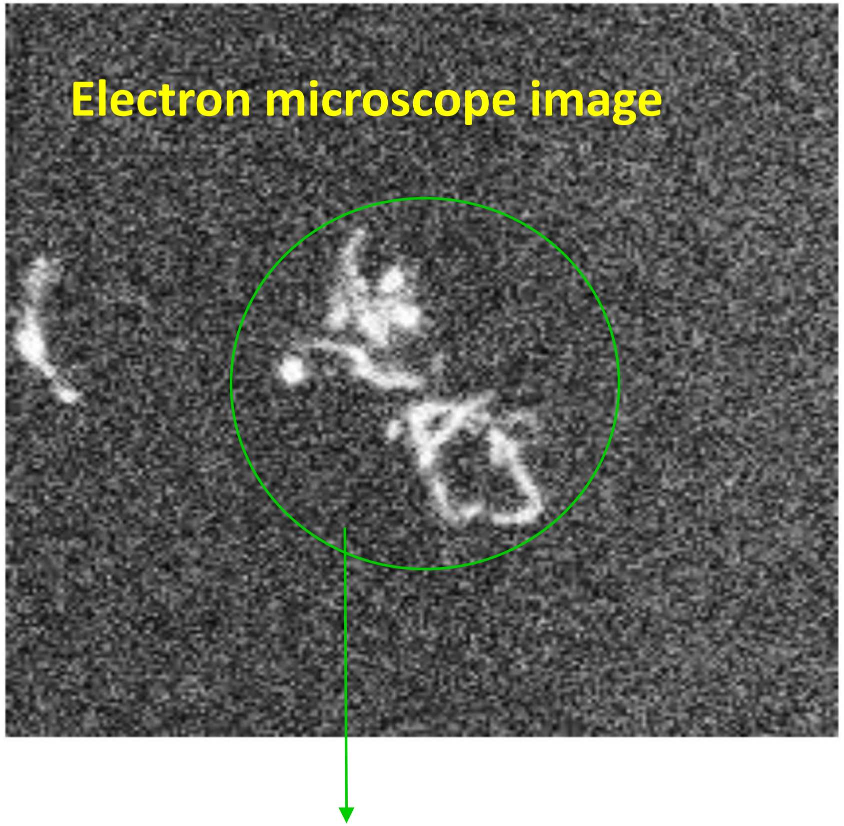




Mostly detected target was Br recoil [< 200 keV]
Now, we are preparing CNO recoil demonstration due to 565 keV (Li-p nuclear fission reaction)

Concept of confirmation of signal





☑ complicate Ag filament structure ⇒ unique information as signal
☑ this structure depends on the dE/dx and controlled by the type of development treatment

silver filament structure in nano-scale. Is unique information as nuclear recoil signal

Beyond optical resolution analysis

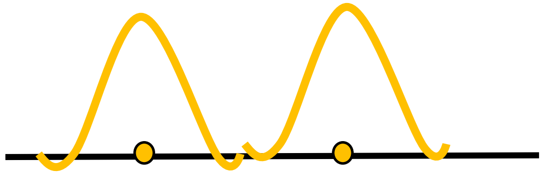
2014 Nobel Prize in Chemistry

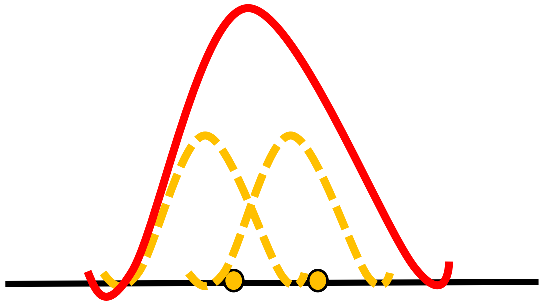
  

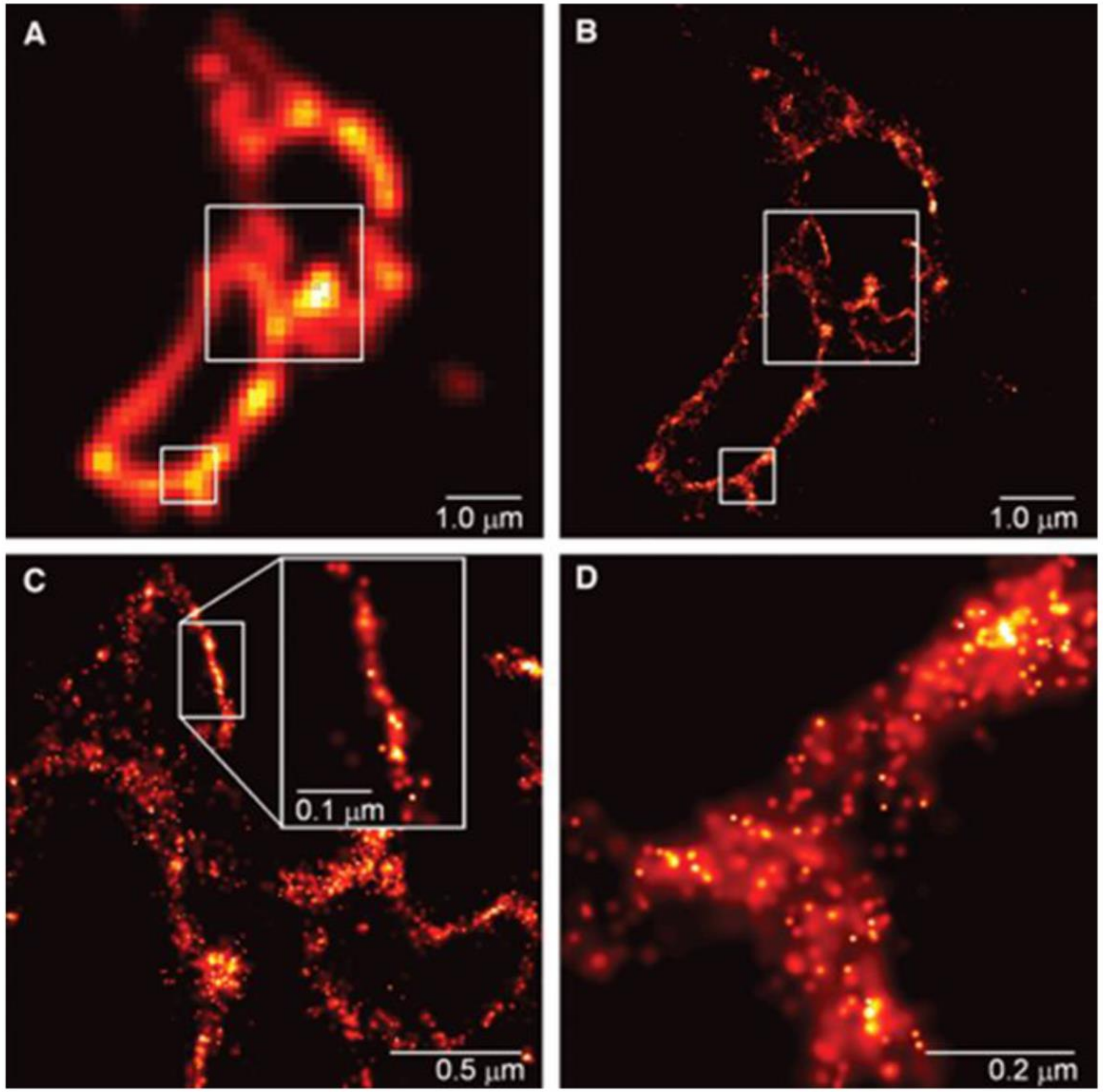
The Nobel Prize in Chemistry 2014 was awarded jointly to Eric Betzig, Stefan W. Hel William E. Moerner *"for the development of super-resolved fluorescence microscop*

- **Beyond diffraction limit concept**

e.g., STED、STORM

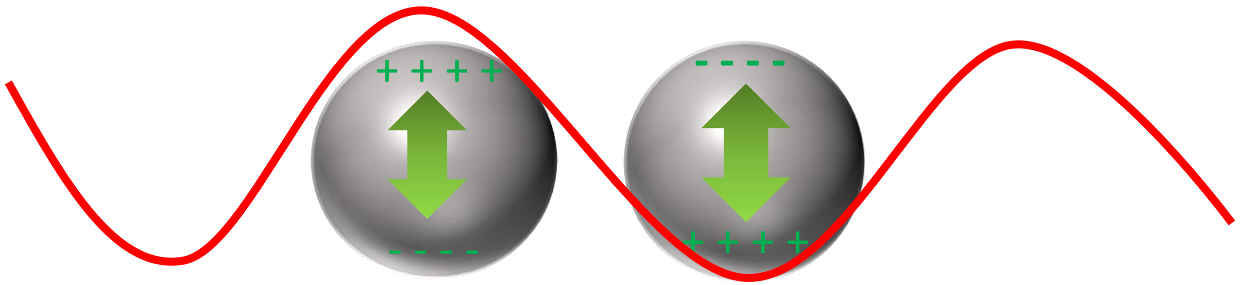






Localised Surface Plasmon resonance

Localized Surface Plasmon Resonance



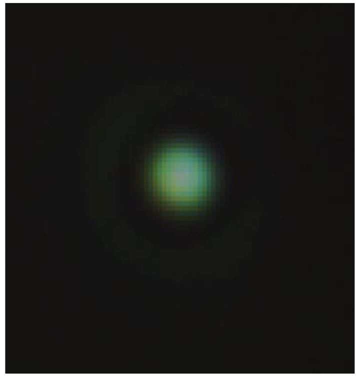
silver nano particle

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

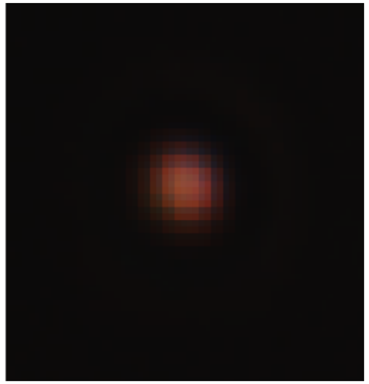
$$\boxed{\varepsilon_1(\lambda_l) + 2\varepsilon_m(\lambda_l) \approx 0}$$

Silver-nano particle

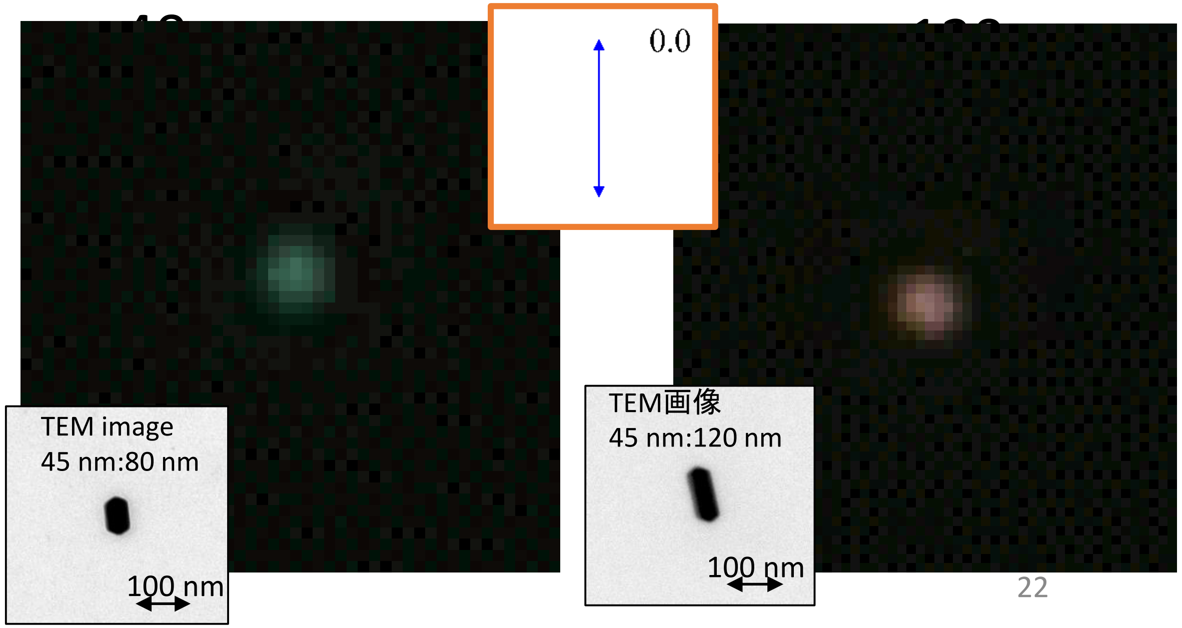
40 nm



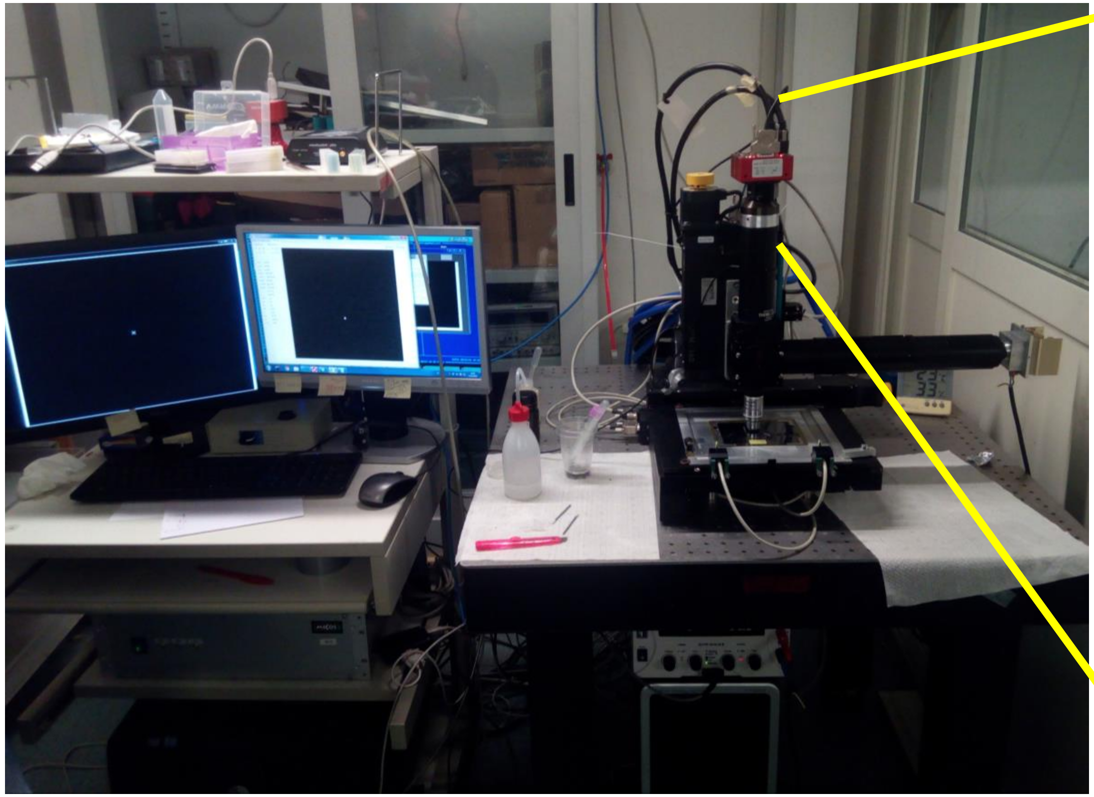
80 nm

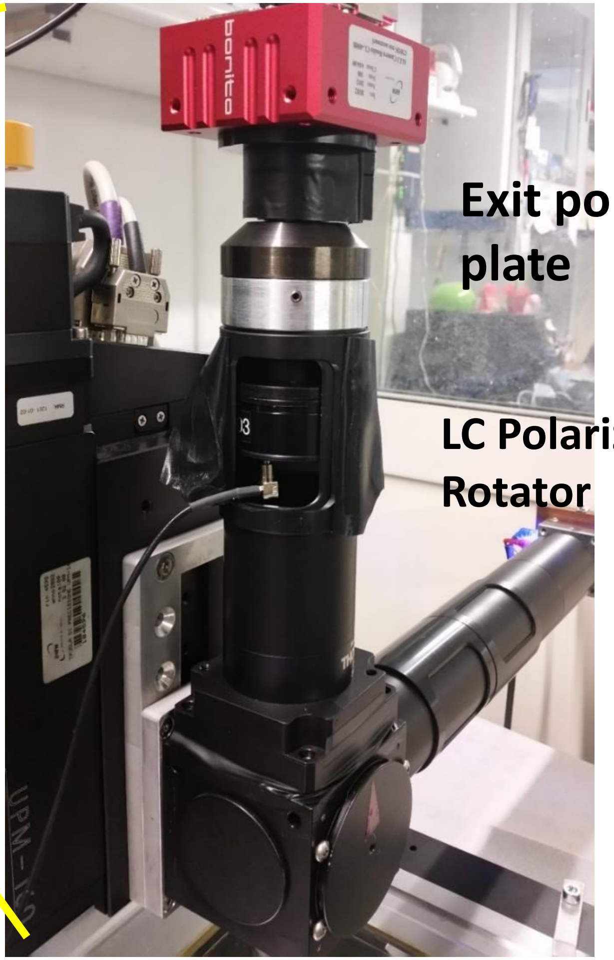


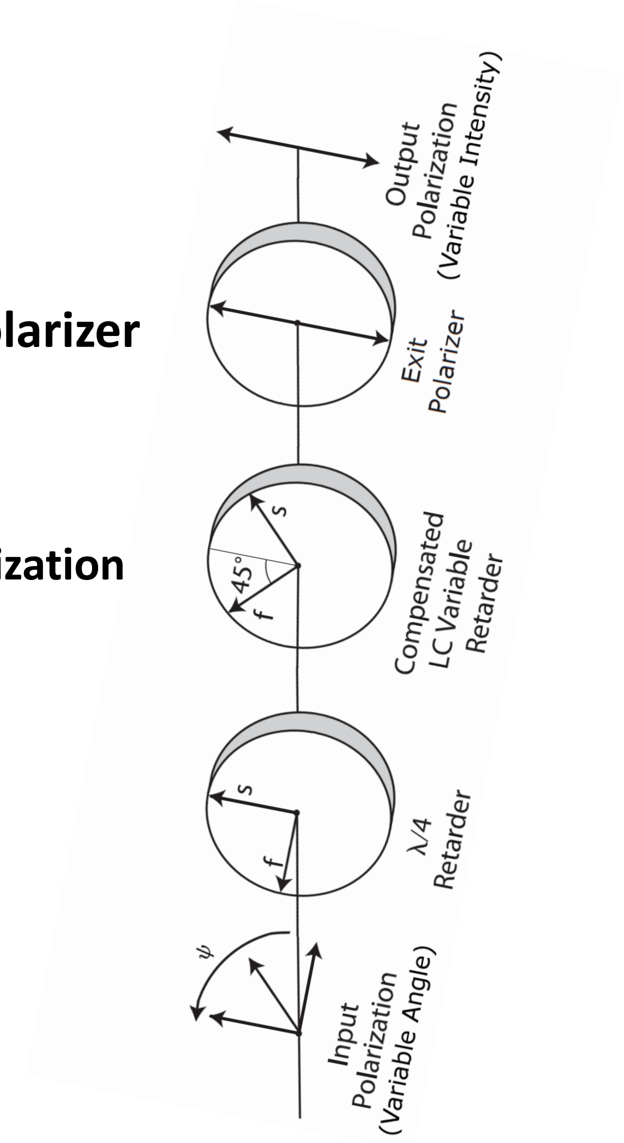
120 nm



New plasmon nano-tracking system [prototype]

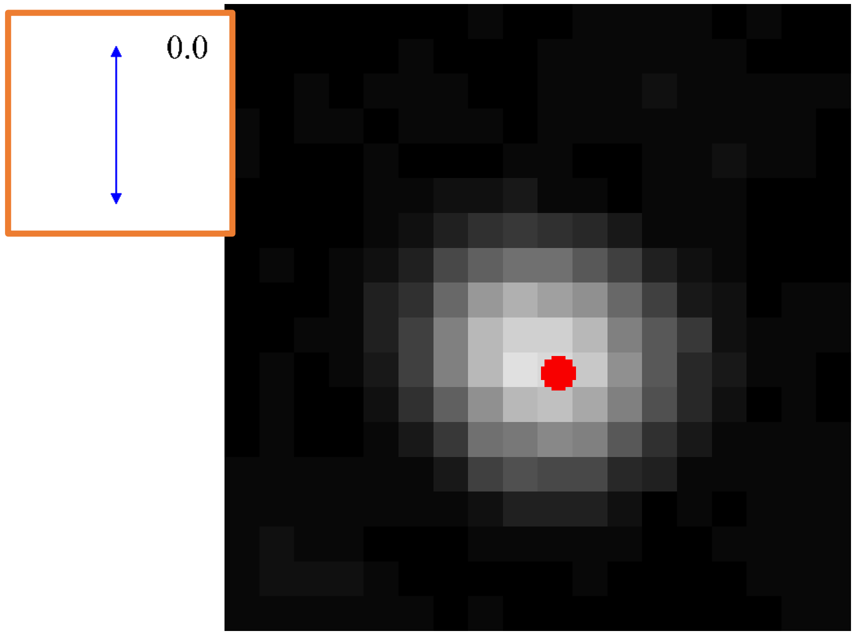




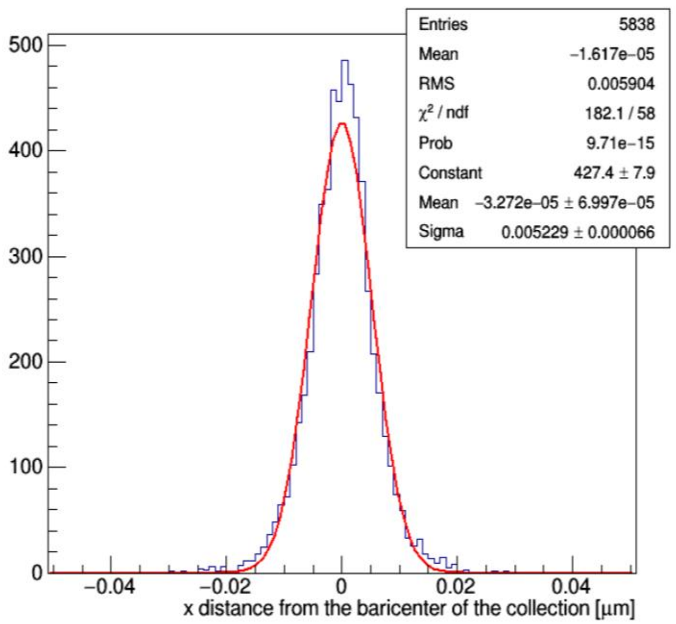


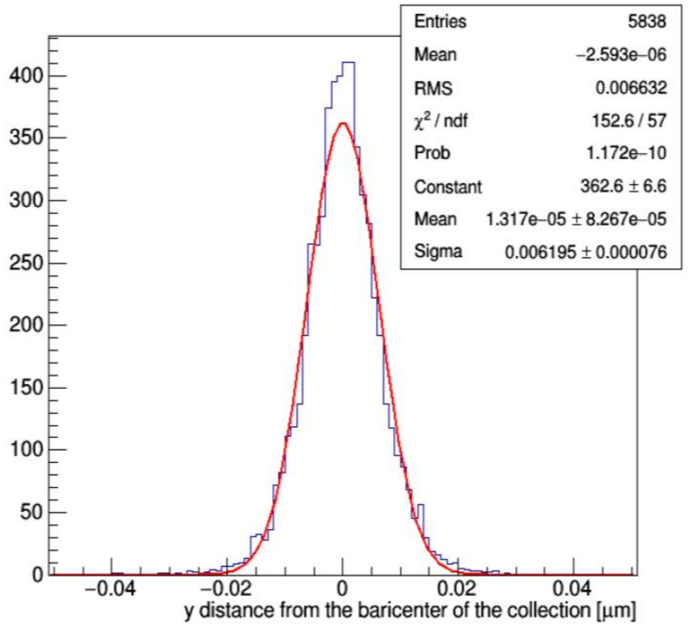
New epi-illuminated optical microscope system @ Napoli University, Italy

Calibration of spatial resolution using single silver grain



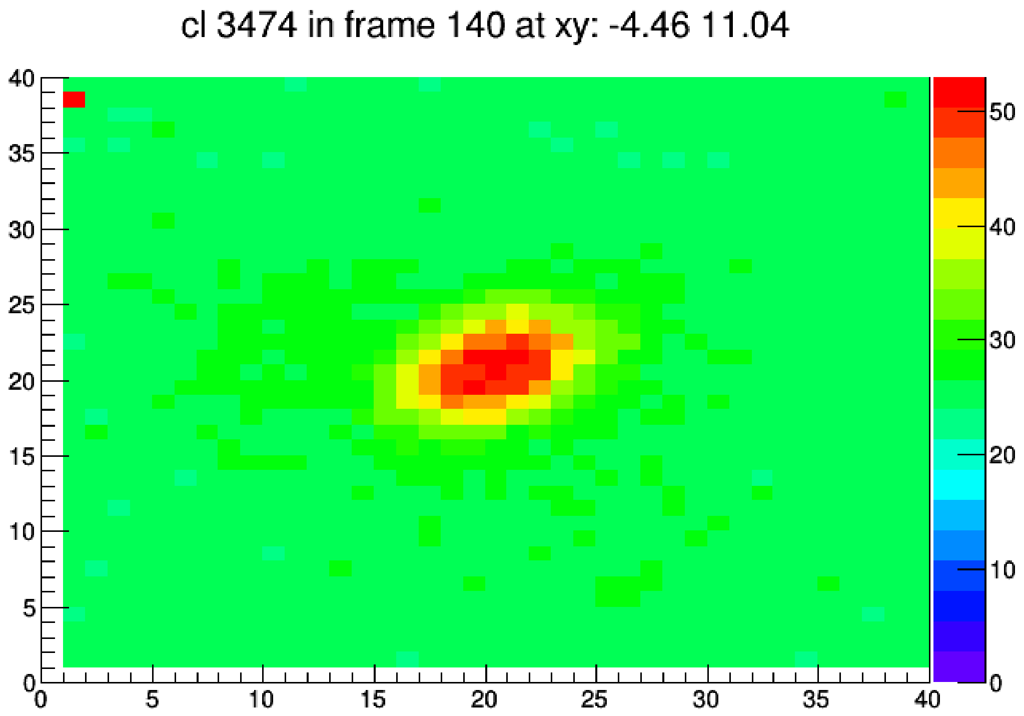
Bary-center shift → resolution



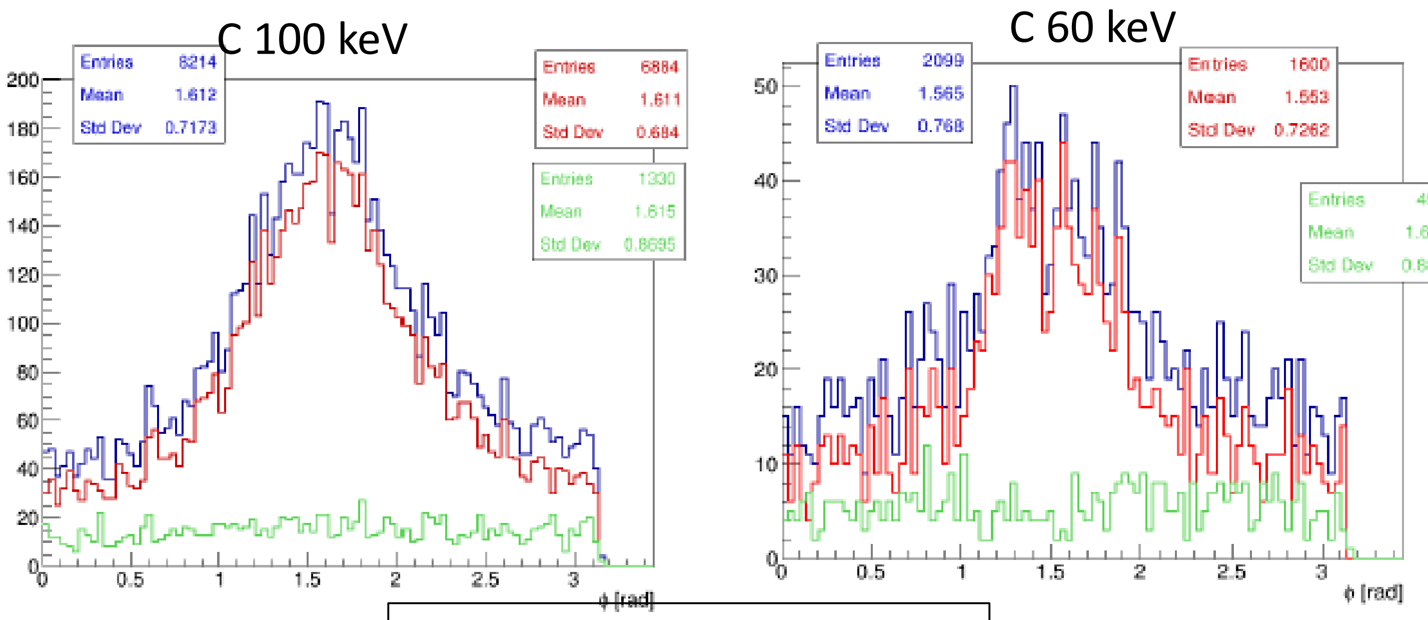


Position accuracy ~ 5 nm
≒spatial resolution
※usual optical resolution > ～200nm

Automatic analysis system for the plasmonics



Direction sensitivity using plasmon analysis



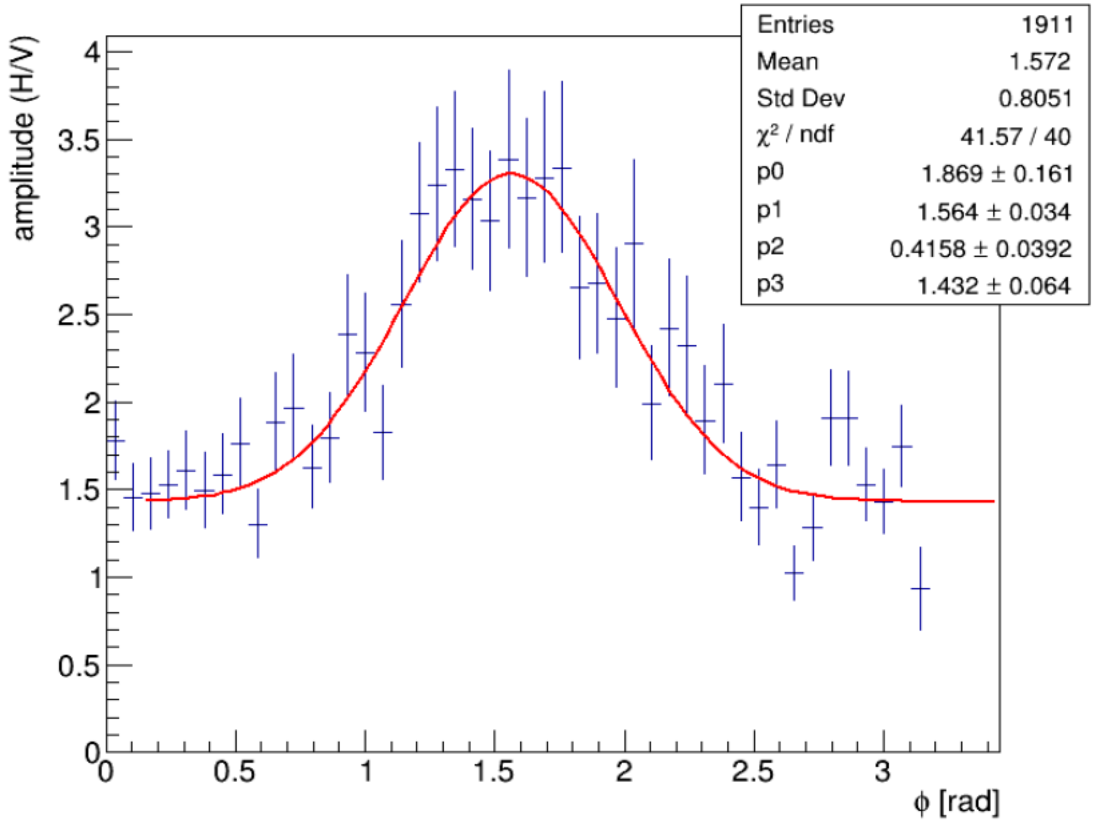
Blue : total
Red : Bari-center shift > 30 nm
Green : Bari-center shift < 30 nm

Shift of barycenter is important information for nano-scale structure

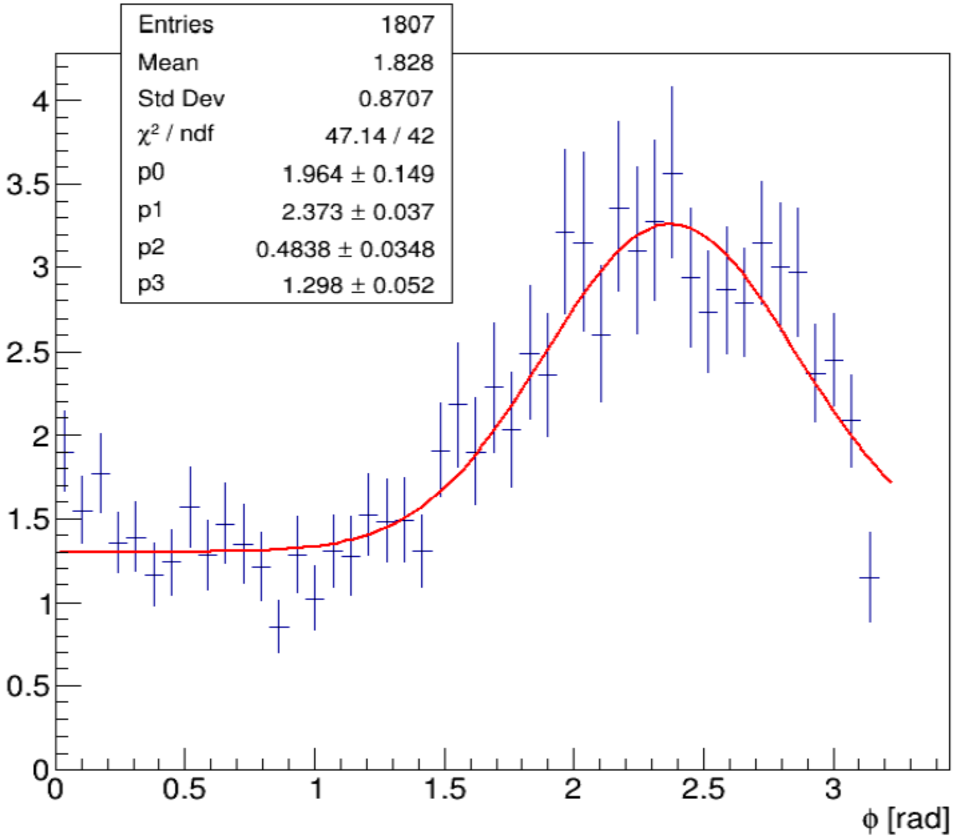
Demonstration of the direction sensitivity have been done .

Direction sensitivity of low-energy C ion [30 keV]

Expected : 90 ° -> Measured : 90°

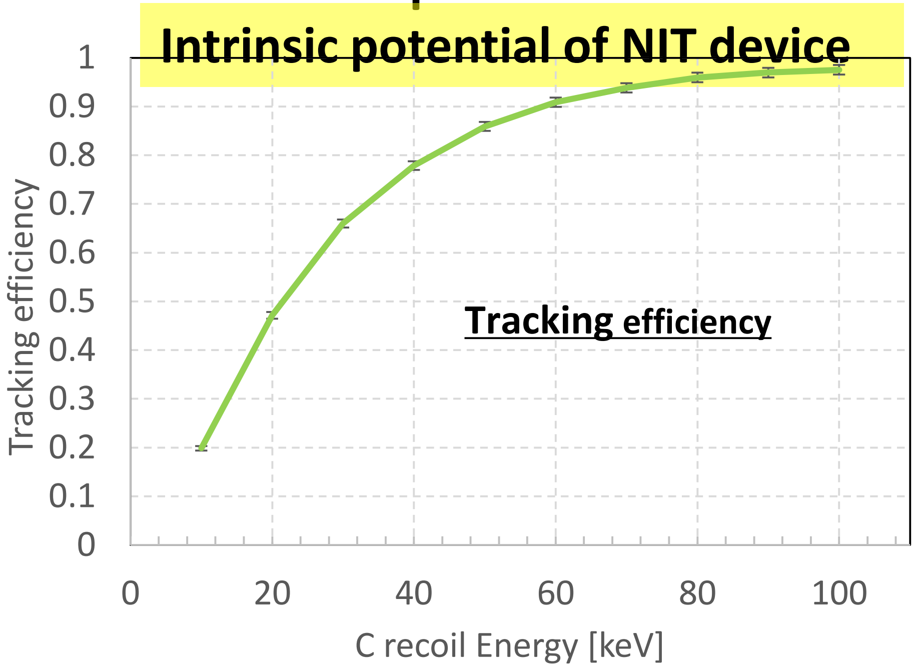


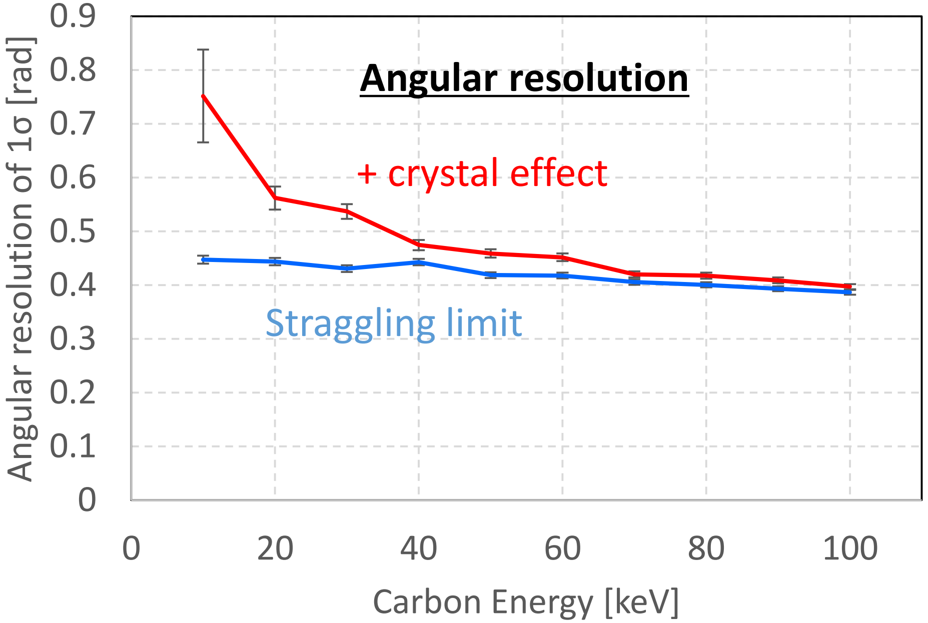
Expected : 135 ° -> Measured : 136°



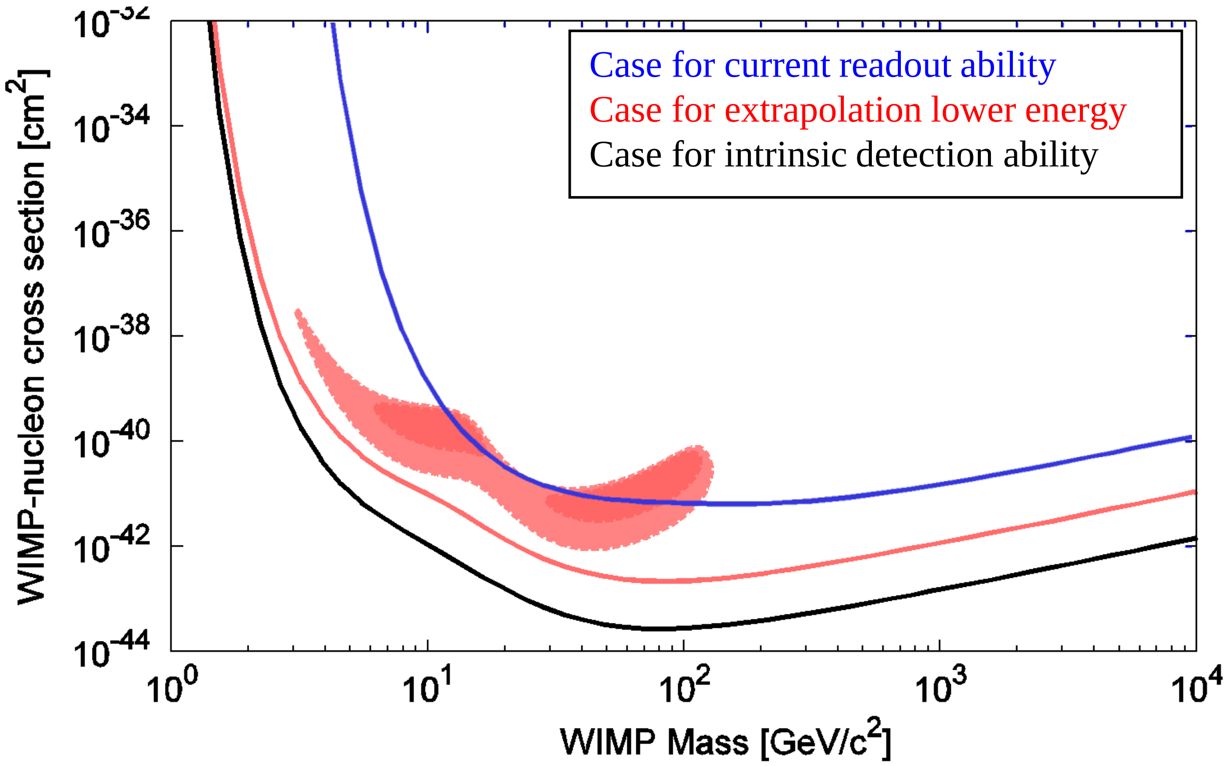
Indication that we can see low-mass dark matter less than 10 GeV/c2 with direction sensitivity

NEWSdm potential using NIT device





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

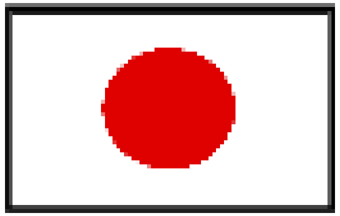


NIT detector / CNO sensitive / no Bkg no directionality
Simulation limit is “energy > 5 keV for all atoms (SRIM limit)”
& “Sensitivity > 0.1 % (Simulation statistics limit;10 event)”

NEWSdm ~Nuclear Emulsions for WIMP Search + directional measurement

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

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

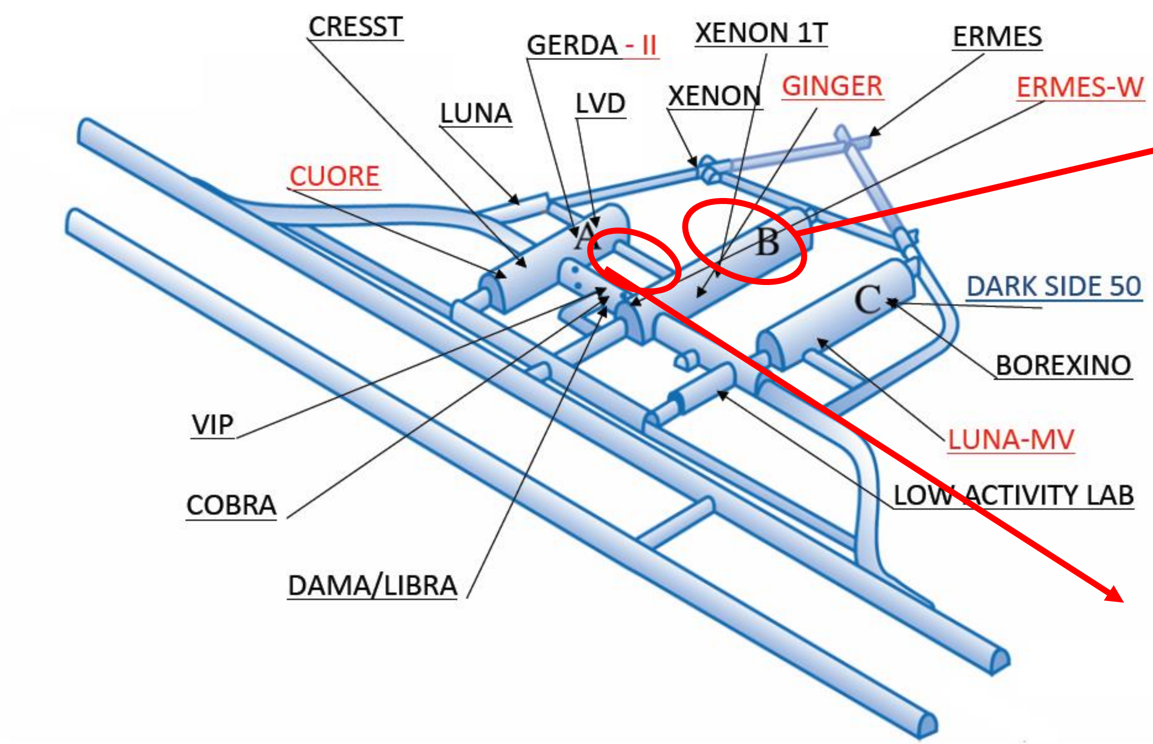
Gyeongsang

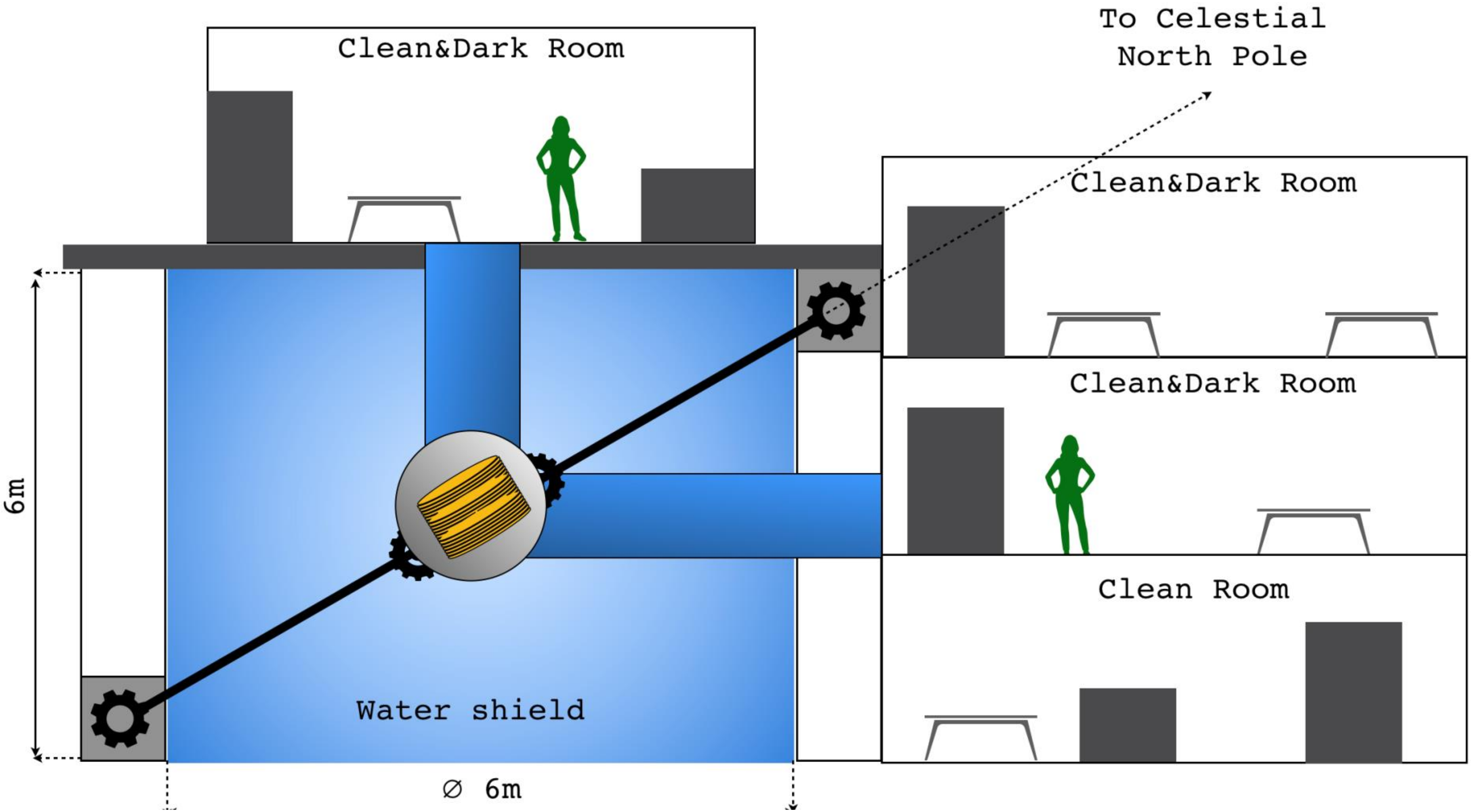
LOI under review by the LNGS scince committee

https://arxiv.org/abs/1604.04199

Test experiment environment

Gran Sasso underground laboratory, Italy





Clean&Dark Room
To Celestial
North Pole
Clean&Dark Room
Clean&Dark Room
Clean Room
6m
Water shield
∅ 6m

Conclusion

- **Dark matter is one of the most important subject in nature science**
- **Directional sensitive search is new methodology to obtain new information for direct dark matter search**
- **Super-fine grained nuclear emulsion (Nano Imaging Tracker : NIT) is capable of detecting nano-track, and very promising detector for direction-sensitive dark matter detection**
- **NEWSdm project is now on going as international experiment toward directional dark matter search in the LNGS**
- **Quite new technologies are continued to produce as "nano-tracking technologies"**