2019/ July 10 – July 12
Cygnus work shop

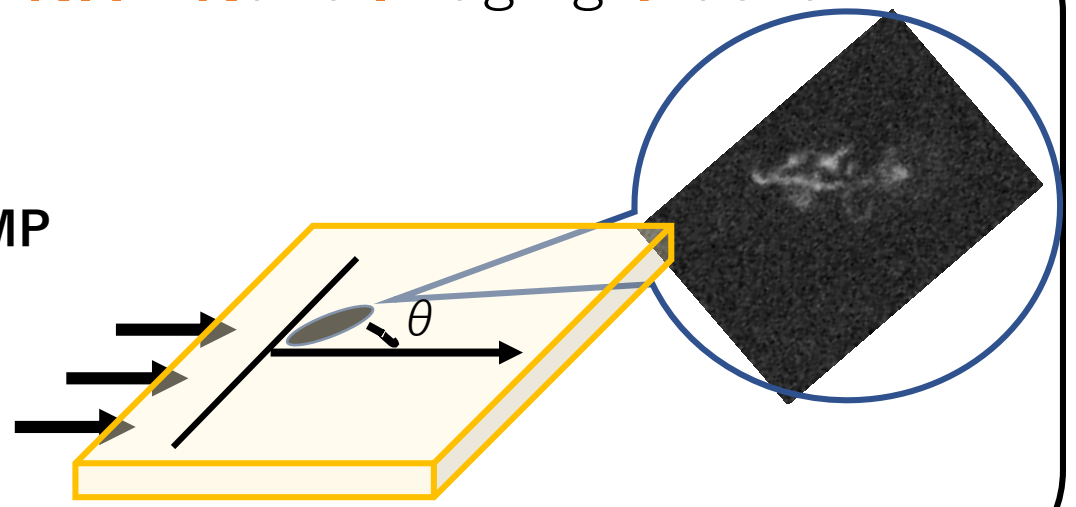
Analysis Chain for NEWSdm Experiment

Ryuta Kobayashi
Nagoya University, Japan
On behalf of the NEWSdm Collaboration

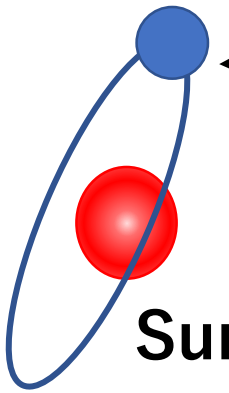
NEWSdm experiment

Detector

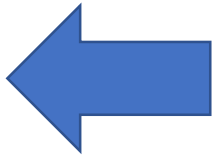
NIT : Nano Imaging Tracker



Get direction of WIMP

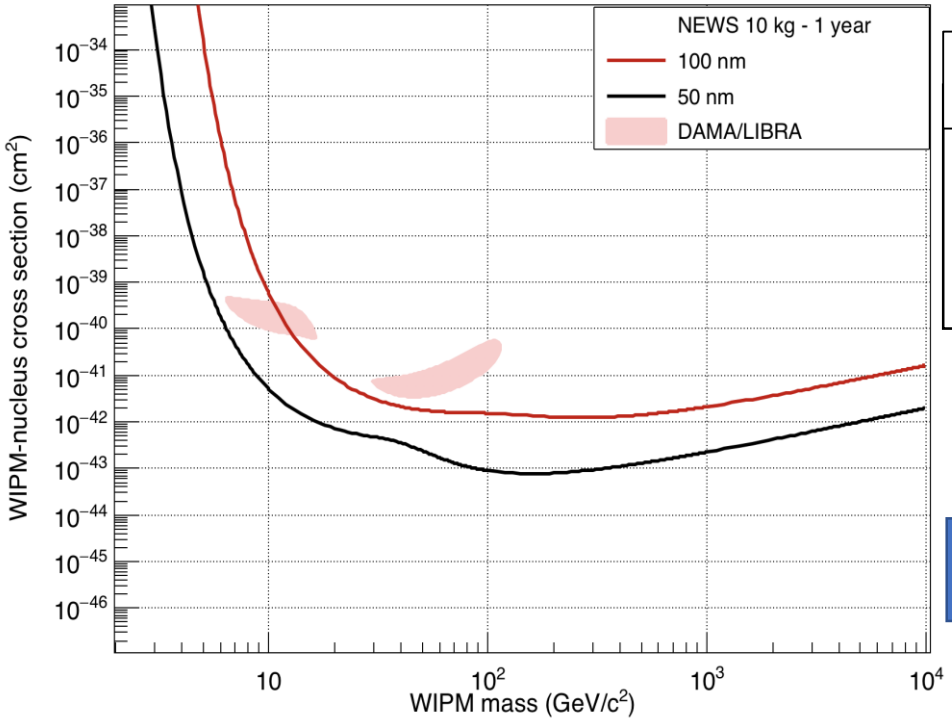


Cygnus



240 km/s

Sensitivity curve



assumption

- Exposure : 10 kg ・ year
- 0 background event

To search DAMA region

->Need to 10 kg・year exposure at least

Feature of NIT

1. High mass density

2. nanometric spatial resolution

3. Analyze Tracks by various methods

Feature1 : High mass density

NIT : **N**ano **I**maging **T**racker
(Super fined grained nuclear emulsion)

T.Asada et al, PTEP, 063H01, (2017)

Mass density : 3.44 $\mathrm{g/cm^3}$

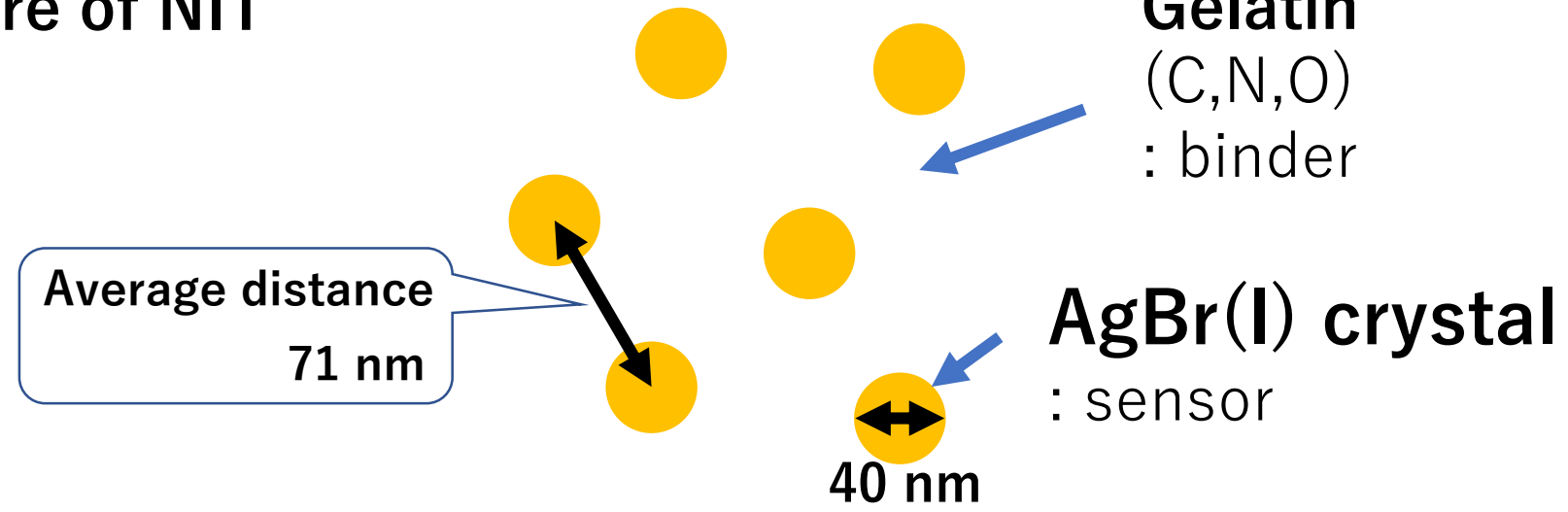
+

Production time : 1 month /10 kg NIT

NIT has high scalability

Feature2 : High spatial resolution

Structure of NIT

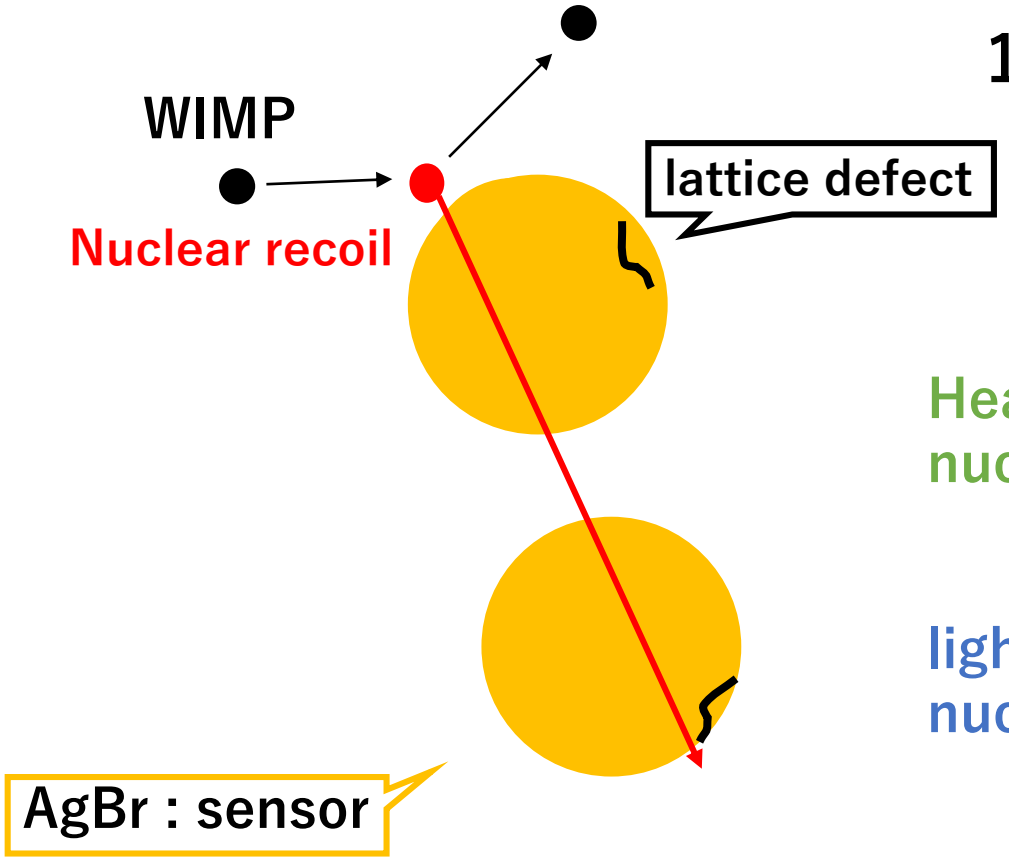


- **small sensor size (40 nm)**
- **high numerical density** (O(10^4) /um^3)

Make high spatial resolution

NIT can record direction of **more than 71 nm track intrinsic**

Track generation in NIT



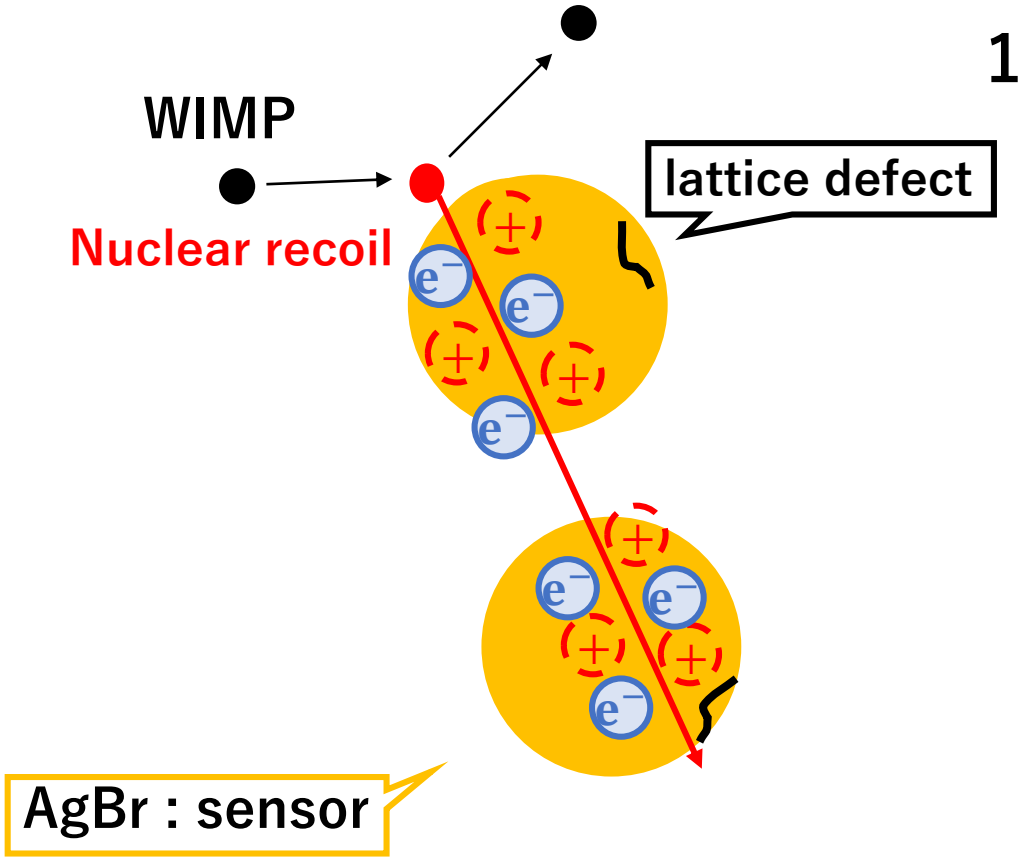
1. Ionized by charged particles

Components of NIT

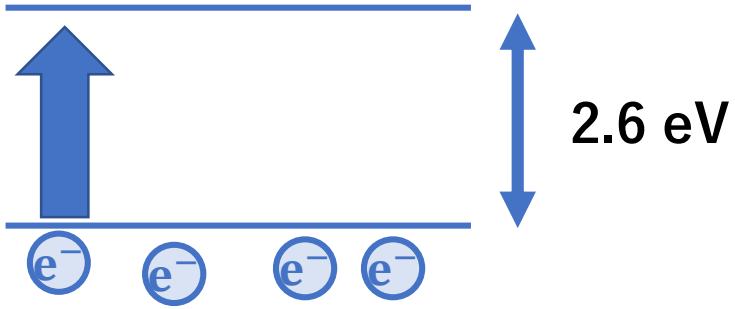
	Element	Mass%	Atom%
Heavy nucleus	Ag	44.5	10.5
	Br	31.8	10.1
	I	1.9	0.4
light nucleus	C	10.1	21.4
	N	2.7	4.9
	O	7.4	11.7
	H	1.6	41.1

T.Asada et al, PTEP, 063H01, (2017)

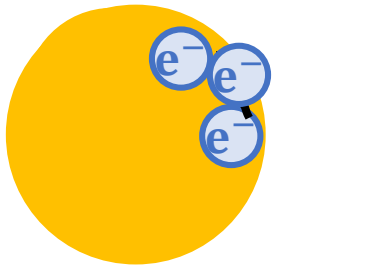
Track generation in NIT

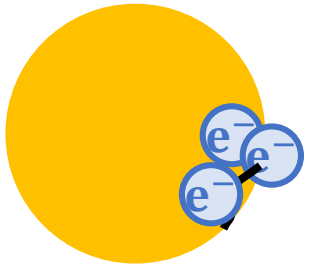


1. Ionized by charged particles



Track generation in NIT



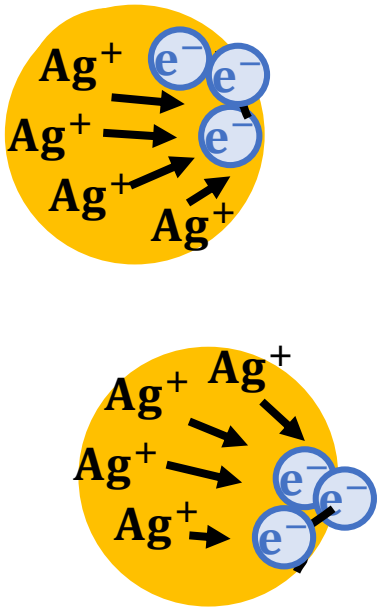


AgBr : sensor

1. Ionized by charged particles

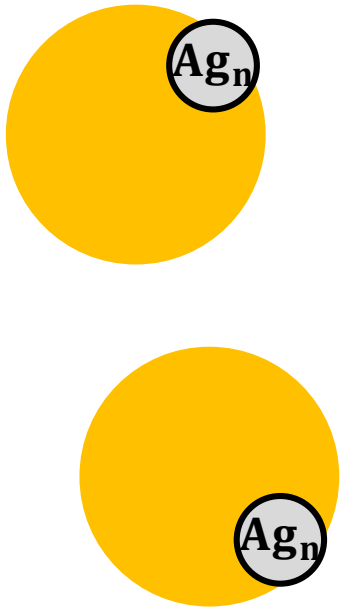
2. Electrons are trapped in lattice defect

Track generation in NIT



1. **Ionized by charged particles**
2. **Electrons are trapped in lattice defect**
3. **Ag^+ gathere to lattice defect and produce latent images**

Track generation in NIT



1. **Ionized by charged particles**
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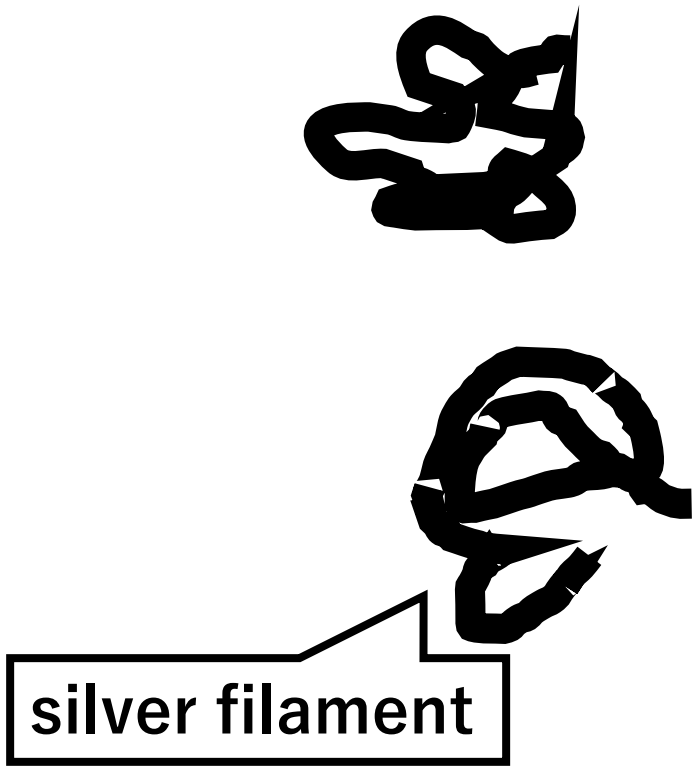
Track generation in NIT



1. **Ionized by charged particles**
2. **Electrons are trapped in lattice defect**
3. **Ag^+ gathere to lattice defect and produce latent images**
4. **Chemical development**
   amplitude Ag size
   to be possible to observe in microscope

But ⋯ Cannot analyze without readout

NIT + scanning system -> work as detector

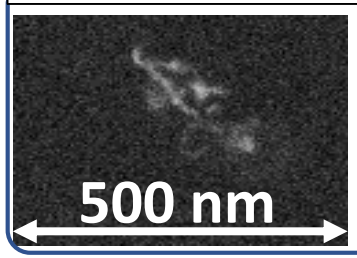
How can we readout nano scale information?

Readout requirement

- **fast readout**
- **get nanoscale information as detailed as possible**

Which microscope system should we use for getting nano scale information?

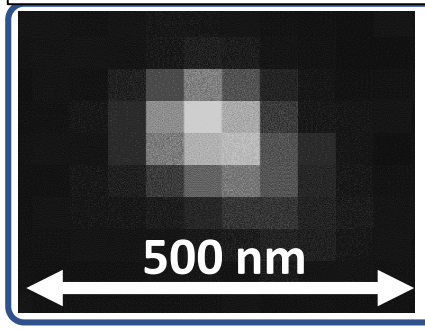
Electron microscope (SEM)



- **Have high resolution** (less than O(1)nm)
- **Takes too long time to scan full volume of NIT.** (~O(10^5) year/ 10kgNIT)

-> **not realistic to scan by SEM**

Optical microscope



- **Need short time for readout**
- **Resolution is limited by Rayleigh's limit** (more than 200 nm)

Aim to readout nm scale track information beyond Rayleigh's limit by optical microscope

Nano scale information tracking system

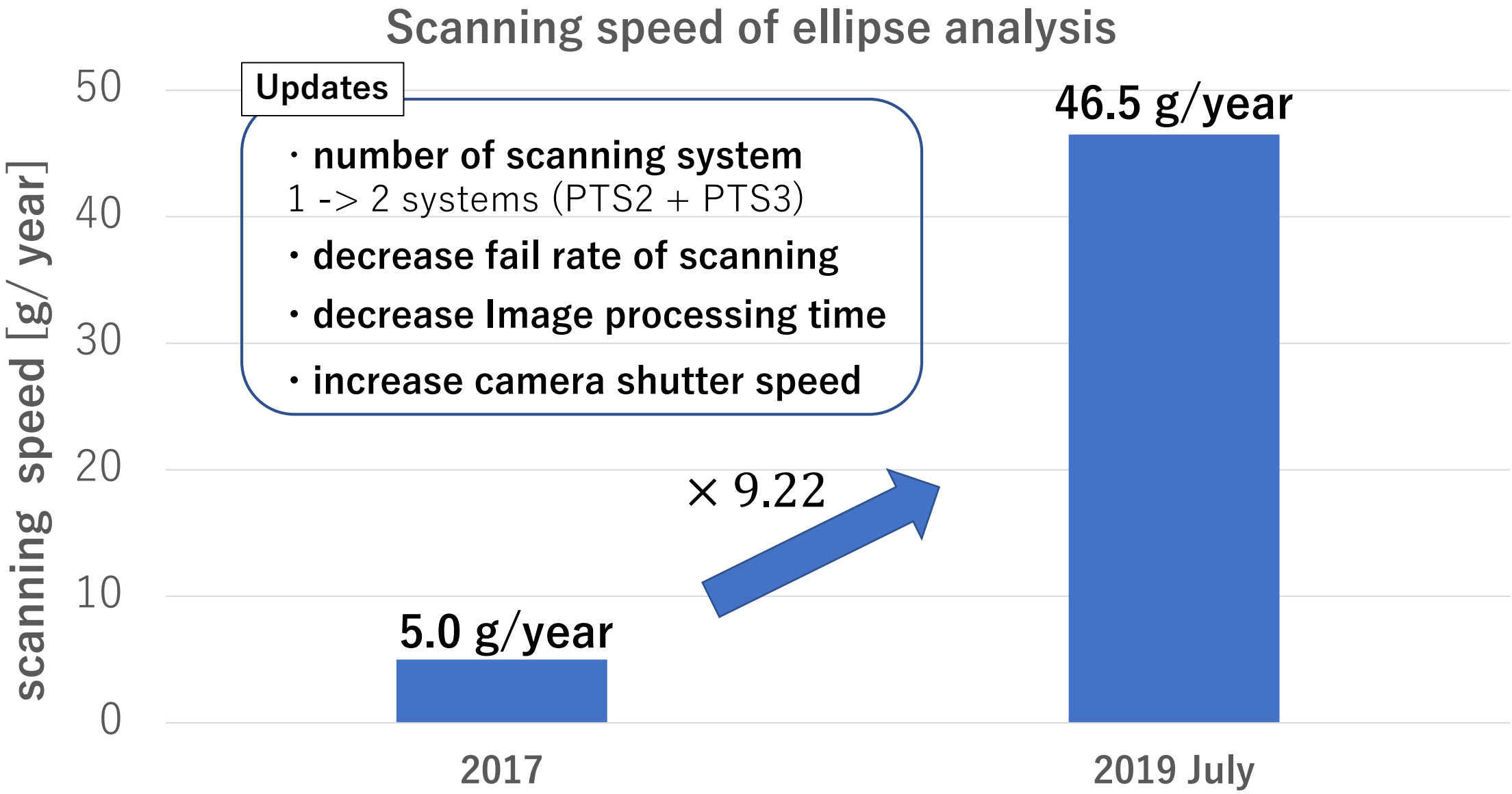
Readout system : PTS (Post Track Selector)

PTS2

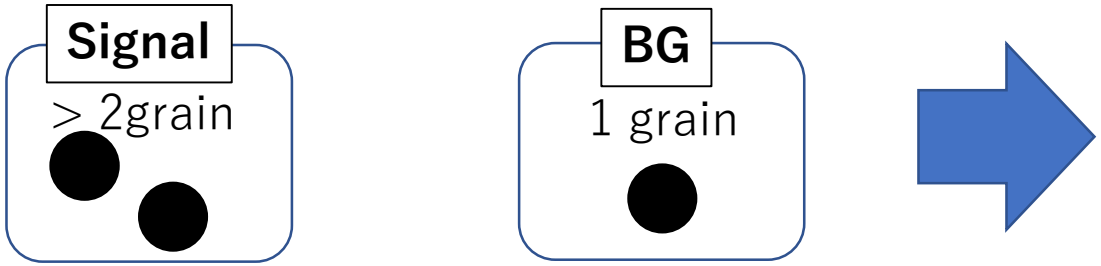
PTS3

Objective lens	: Magnification 100x N.A 1.45
CMOS camera	: 4M pixel, 160 fps (PTS2) 2M pixel , 300 fps(PTS3) 55 nm / pix
Light source	: LED lamp w/ λ ~460 nm
Spatial resolution	: ~230 nm

Scanning speed

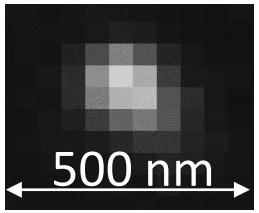


Readout nanoscale information: shape analysis

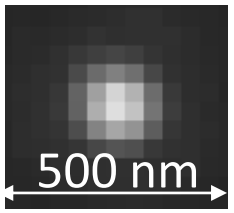


Distinguish by event shape

Ellipse analysis

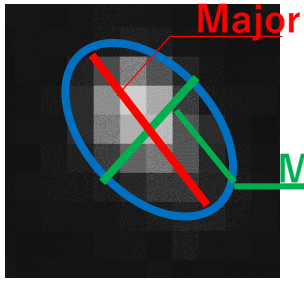


C ion Tracks



Ag nano particle

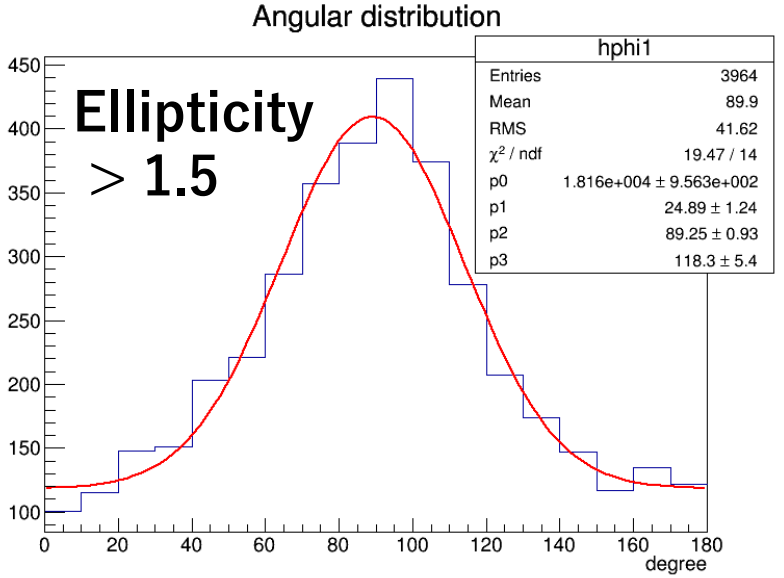
Get information of track by ellipse fitting



- **major angle** <- track direction
- **ellipticity** = major / minor <- related to track length

T. Katsuragawa et al., JINST, 12, 04, T04002 (2017).

60 keV C ion Angle distribution

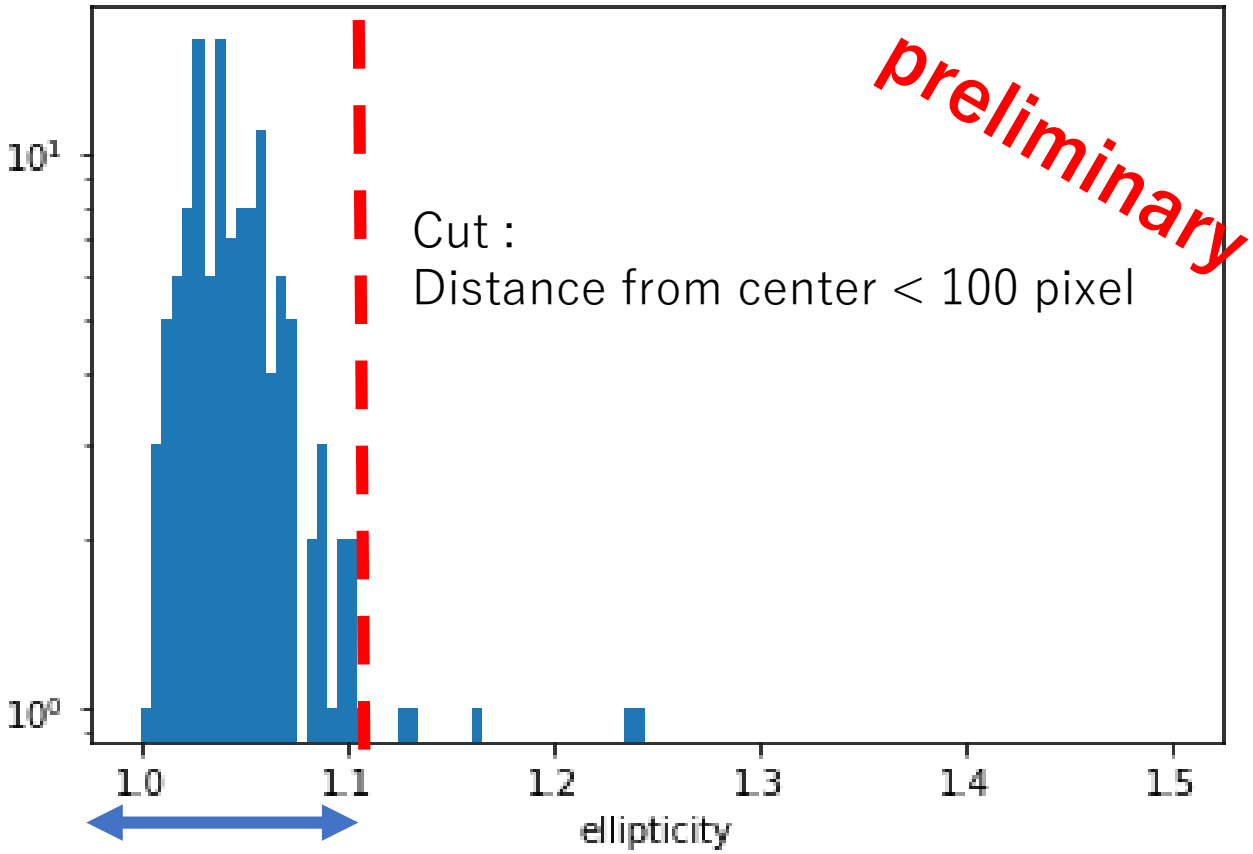


Detect angle information of nano scale tracks

Setting the threshold to maximize efficiency: look at background distribution

Measured ellipticity distribution of 1grain events (Ag nano particle)

40nm Ag nano particle ellipticity distribution



1 grain event region

1.1 < ellipticity
Can use for signal region

Existing events in NIT

Events existing in NIT

Non physical events

Dust : O (10^{10}) / kg

Contamination during production

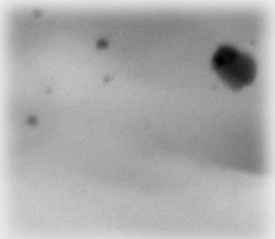
not Silver

not filament

Fog

Noise induced by developing

sphere Silver



・ element
・ shape

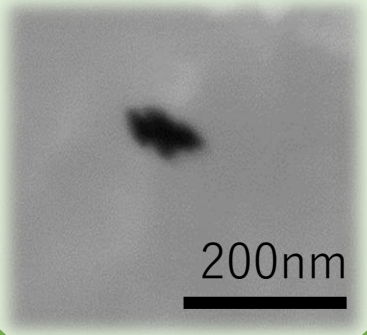
・ shape

Physical events

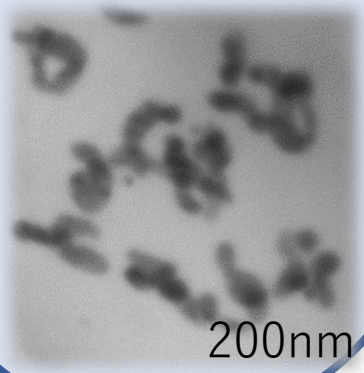
Silver with filament

Intrinsic BG event
O(10^{8}) / kg・year

Electron event



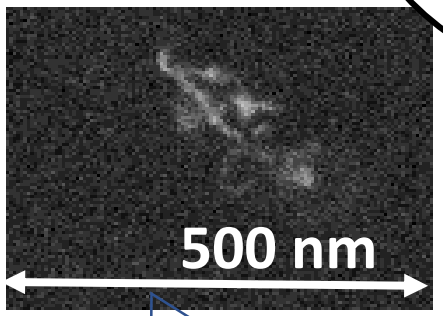
Nuclear Recoil event



Difficult to distinguish events by elliptical fitting -> how to?

Feature 3 Analyze track by various methods

Real track information

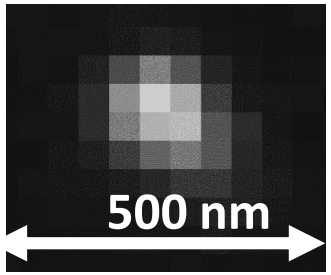


Difficult to read out

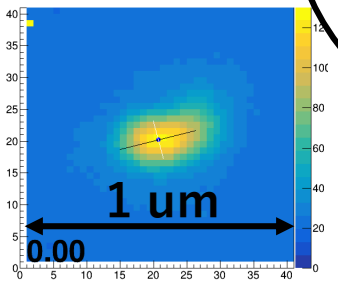
Be kept semi permanently

→ **possible to analyze by various methods**

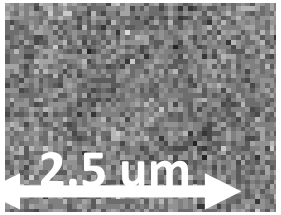
Epi-illumination



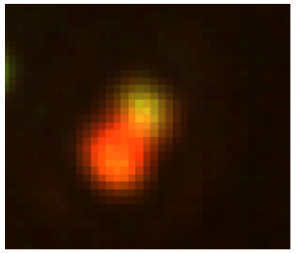
polarization



Phase contrast



color



Observable information

\+ **Machine learning**

get real track information

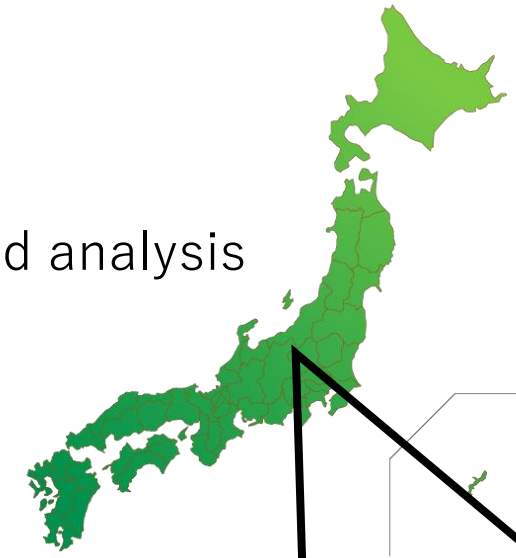
- **BG rejection**
- **Super-resolution analysis**

Scanning system for NIT

There are 5 scanning systems for NIT

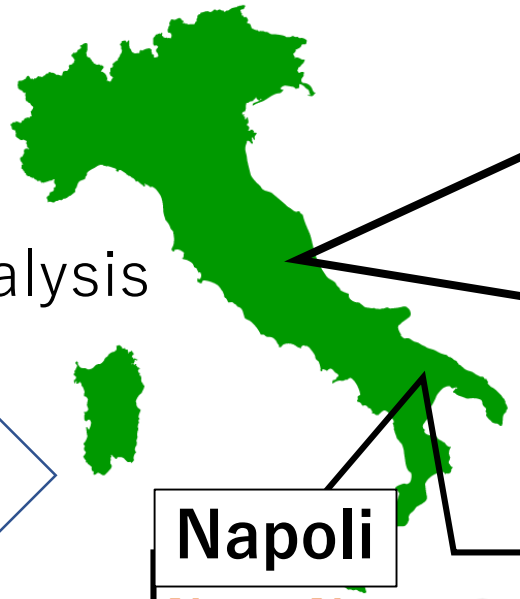
Japan

・High speed analysis



Italia

Detail analysis

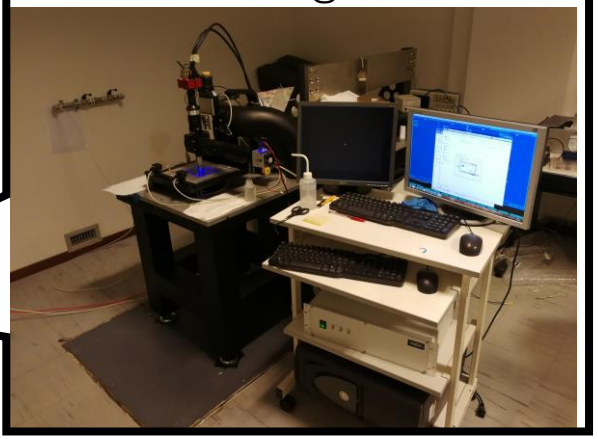


Send samples

LNGS

NSSgs1

– constructing now

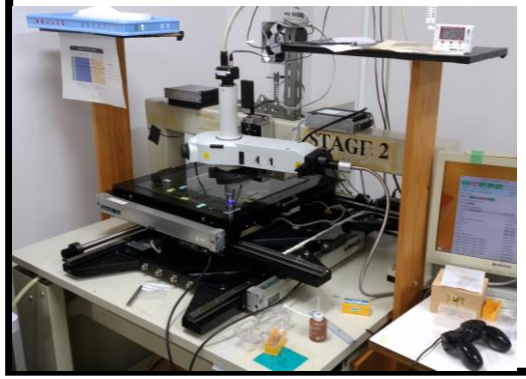


Nagoya

PTS : **P**ost **T**rack **S**elector

PTS2

– ellipse fitting



PTS3

– ellipse fitting

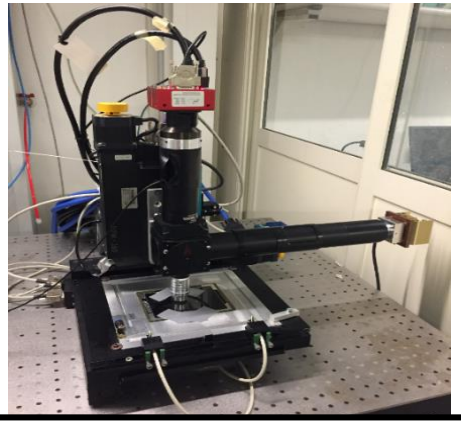
– phase contrast

Napoli

NSS : **N**apoli **S**canning **S**ystem

NSSna1 – polarization analysis

NSSna2 – color analysis

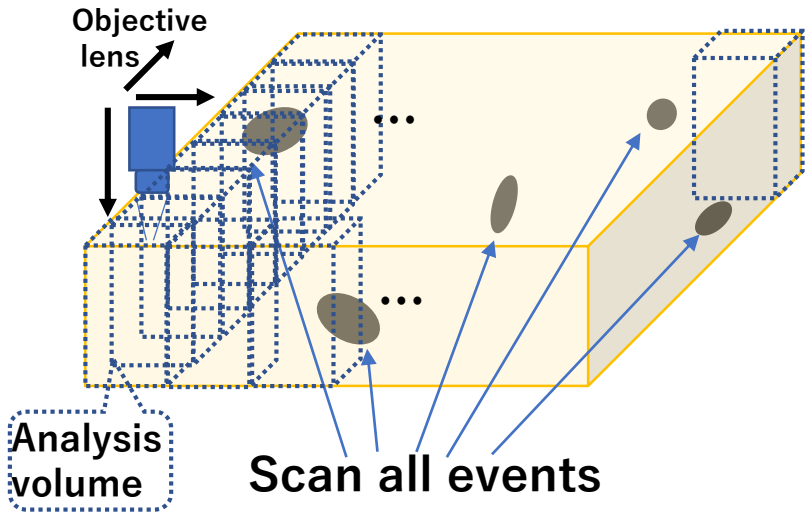


Analysis concept in NEWSdm experiment

Full Volume scanning

High speed and rough event selection

Search full volume NIT for tracks



Analysis time is almost occupied by this scanning
-> **limit experiment scale.**

Analysis technique

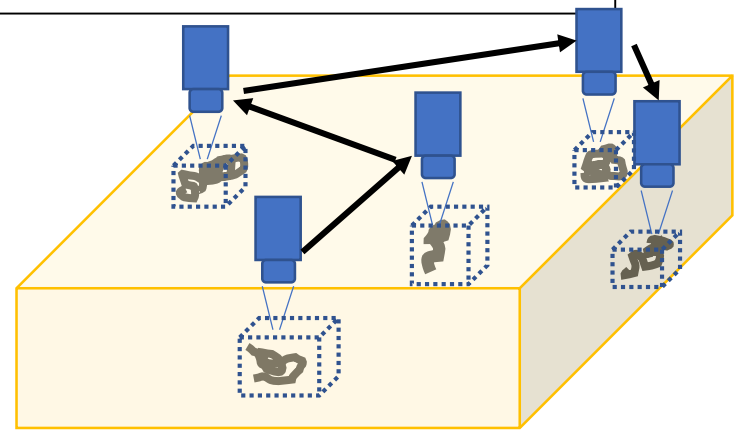
- **Ellipse analysis**

Selected candidates

Detail Event analysis (Point scanning)

Reconstruct nanoscale information

Analysis only candidate events



- **Get various detail information**
  - length、direction、element etc.
- **reject BG events**

Analysis technique

- **Polarization analysis**
- **Multi wave length analysis**
- **phase contrast**

} Under developing

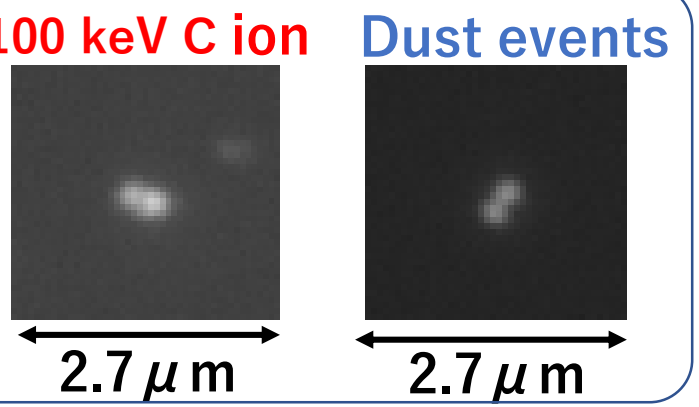
Detail event analysis : Phase contrast analysis

Concept : event selection by its nature (silver/dust) and shape

What is dust event

Event comes during NIT production
<- not made by physics event

→ impossible to separate these events
by epi-illumination optics



Features of event

	Track	Dust
element	silver	Not silver (metal oxide?)
shape	filament	Not filament

How to distinguish ?

Phase contrast analysis

How to distinguish？

use **phase information**

- refractive index
- shape

Get phase information as brightness by phase contrast microscope

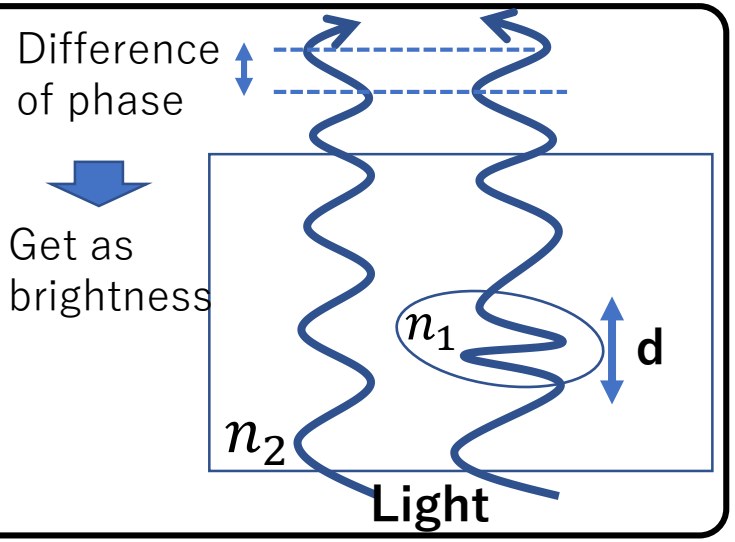
Difference of optical path

$(n_2 - n_1)d$

-> this make difference of phase

n_i: reflective index

d：event size



Phase contrast analysis

How to distinguish ?

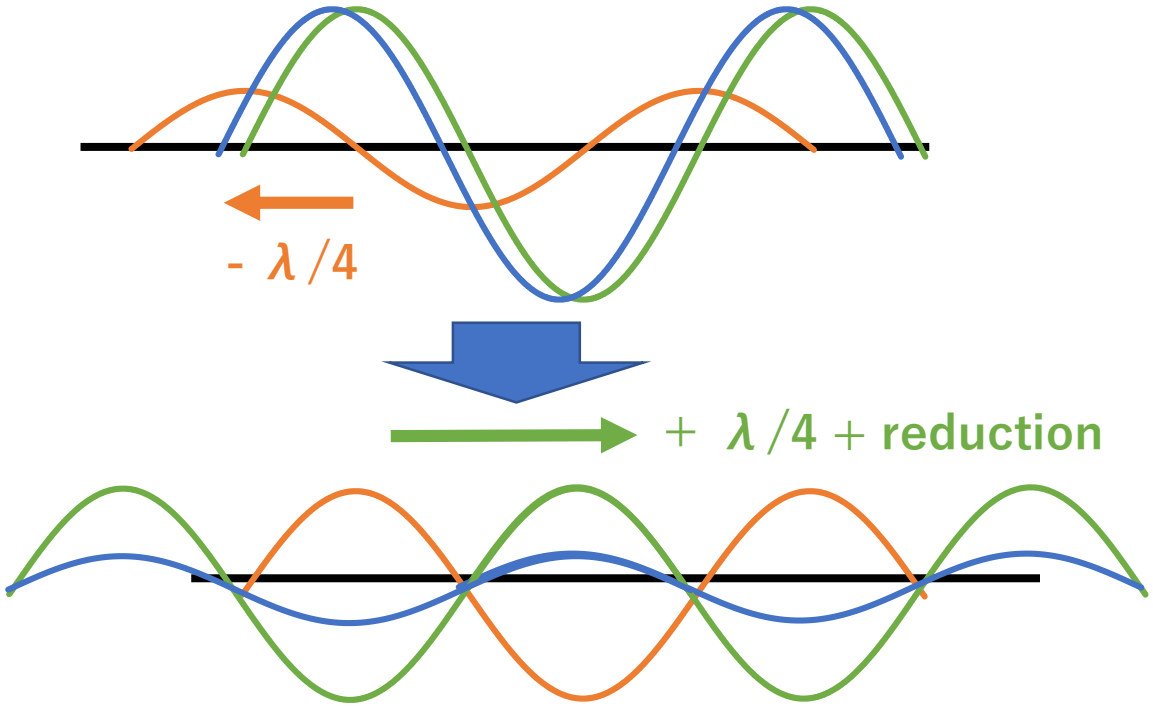
use **phase information**

- refractive index
- shape

Get phase information as brightness by phase contrast microscope

Imaging light

= Direct light + Diffracted light



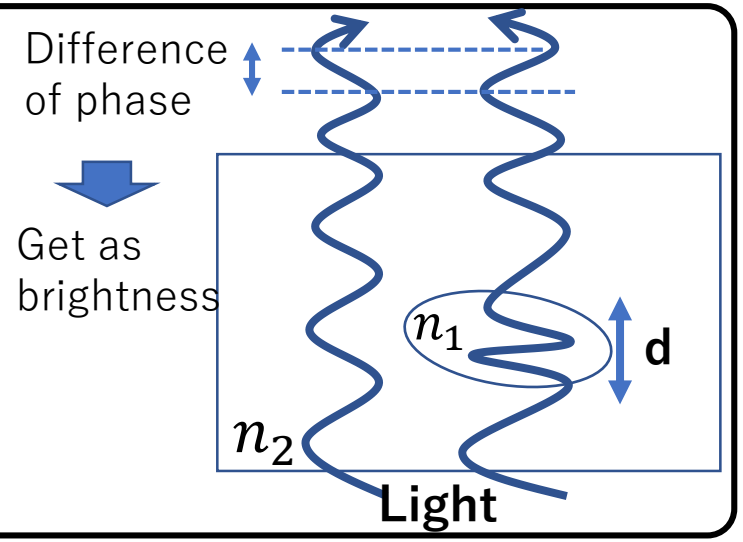
Difference of optical path

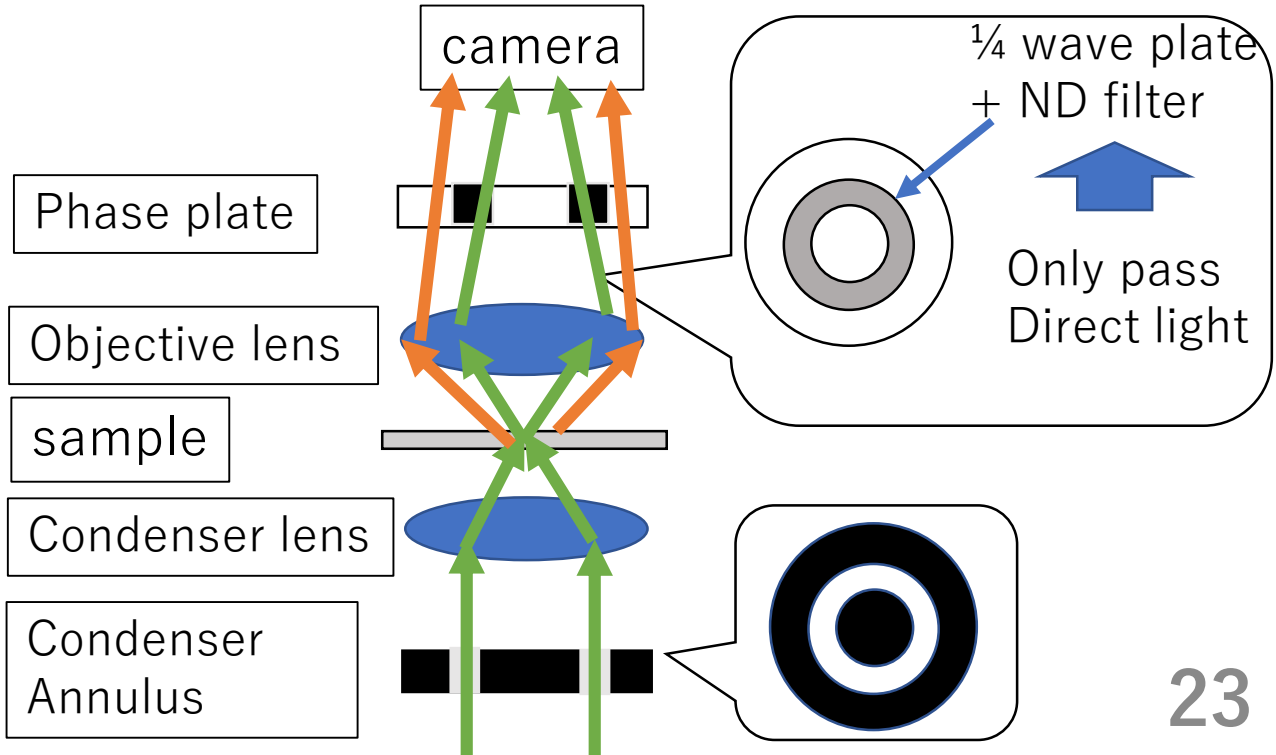
$(n_2 - n_1)d$

-> this make difference of phase

n_i: reflective index

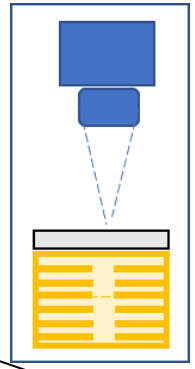
d : event size





Phase contrast analysis

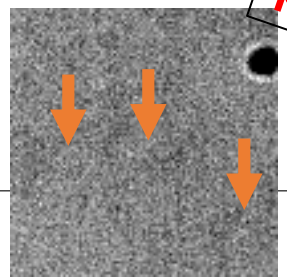
Take tomographic images of phase contrast



Observe **phase (color) change** by changing layer.

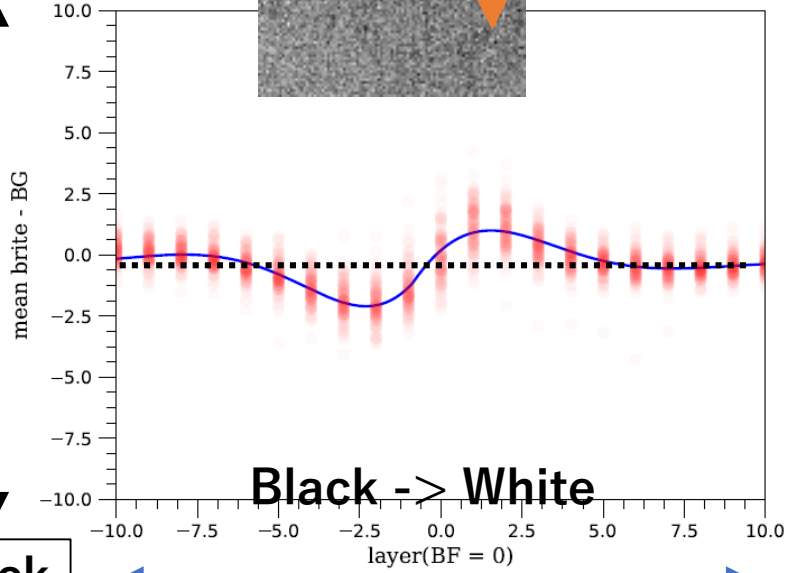
100 keV C ion

preliminary



White

Brightness (phase)



Black

Black -> White

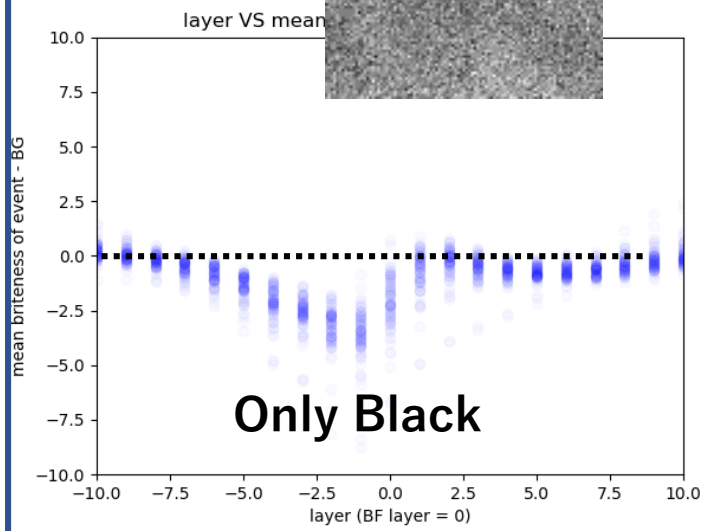
-3um

Layer

3um

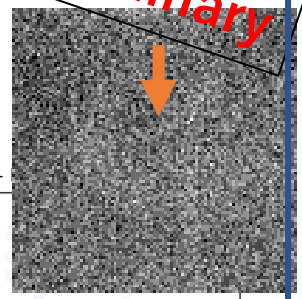
dust events

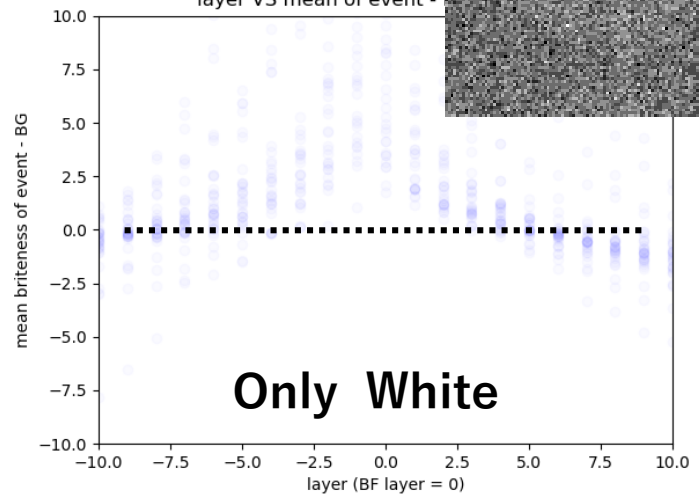
preliminary



Only Black

Layer





Only White

Layer

LSPR : Localized Surface Plasmon Resonance

Detail analysis technique

- **phase contrast**
- **Multi wave length analysis**
- **Polarization analysis**

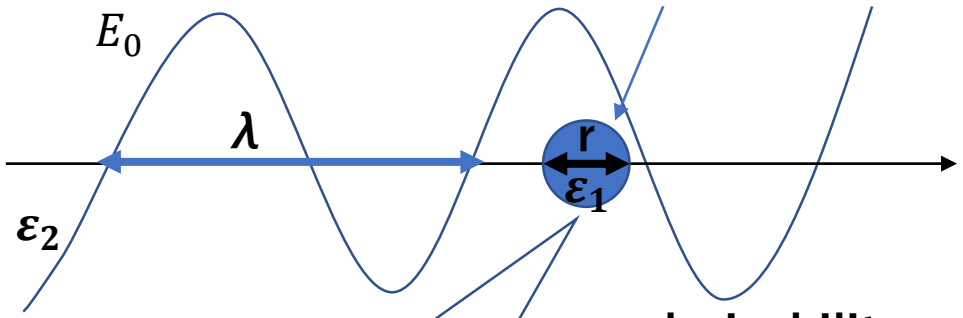
→ Use **LSPR** : **L**ocalized **S**urface **P**lasmon **R**esonance

What is LSPR？

Unique to metal nanoparticles

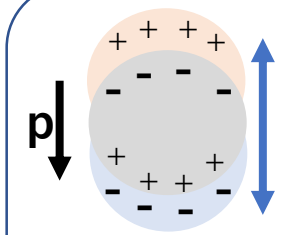
If R < λ

metal nanoparticle



polarizability

$$\alpha = 4\pi r_1^3 \frac{\varepsilon_1(\omega) - \varepsilon_2}{\varepsilon_1(\omega) + 2\varepsilon_2}$$



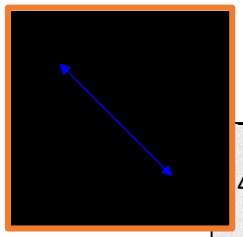
$$\mathbf{p} = \varepsilon_2 \alpha E_0$$

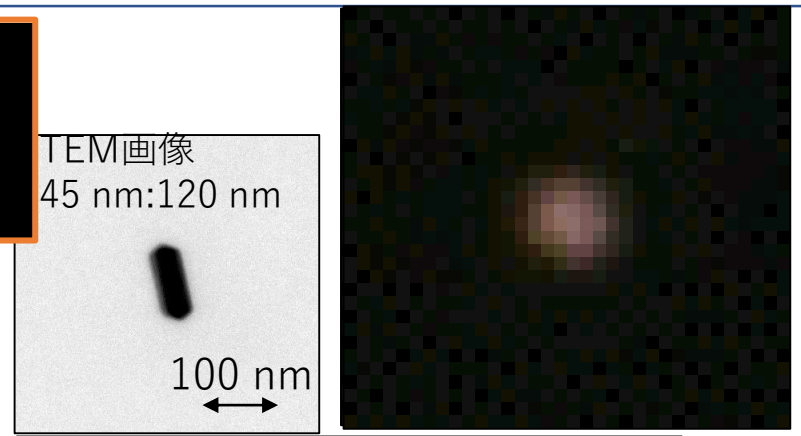
Free electron vibration
Caused by light

Resonance condition

$$Re(\varepsilon_1(\omega) + 2\varepsilon_2) \sim 0$$

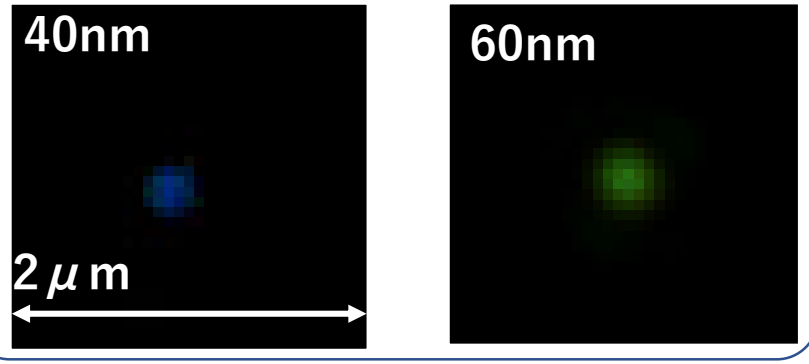
decide by
- wavelength
- shape, size





Size effect of event's color

Ex)Ag Nano particle



Multi wave length and Machine learning analysis

Concept : get shape information
less than optical resolution

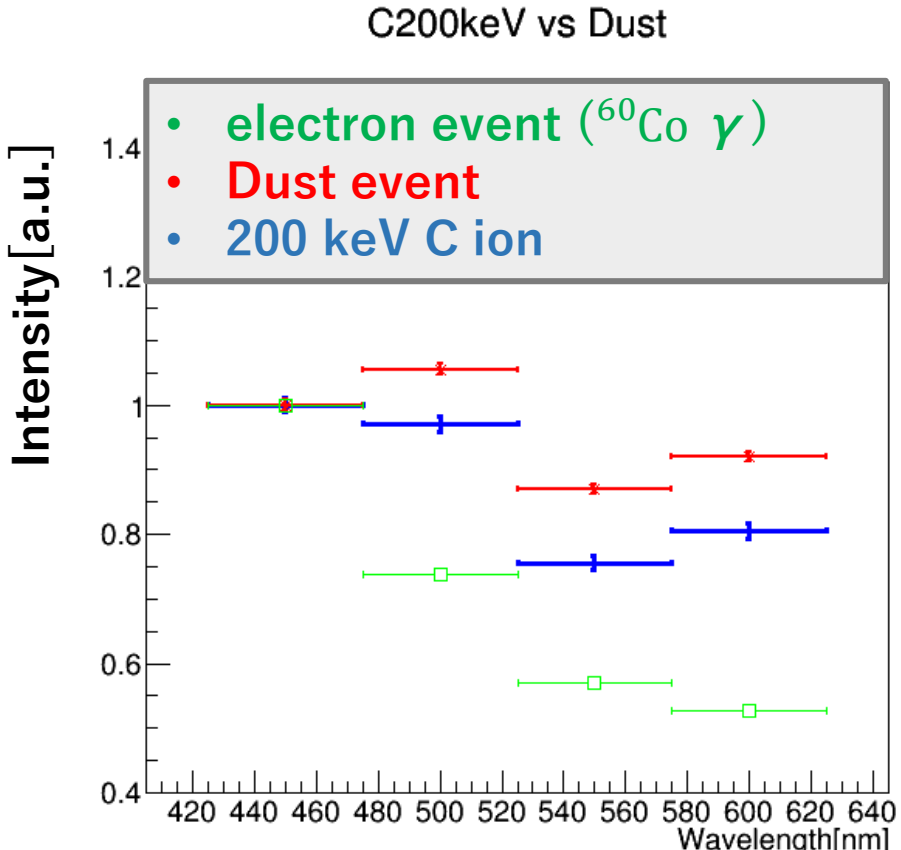
Use color information caused by LSPR

Reject { ・dust ・electron } event

Color spectra is different event by event
-> show each event has different shape

BG rejection

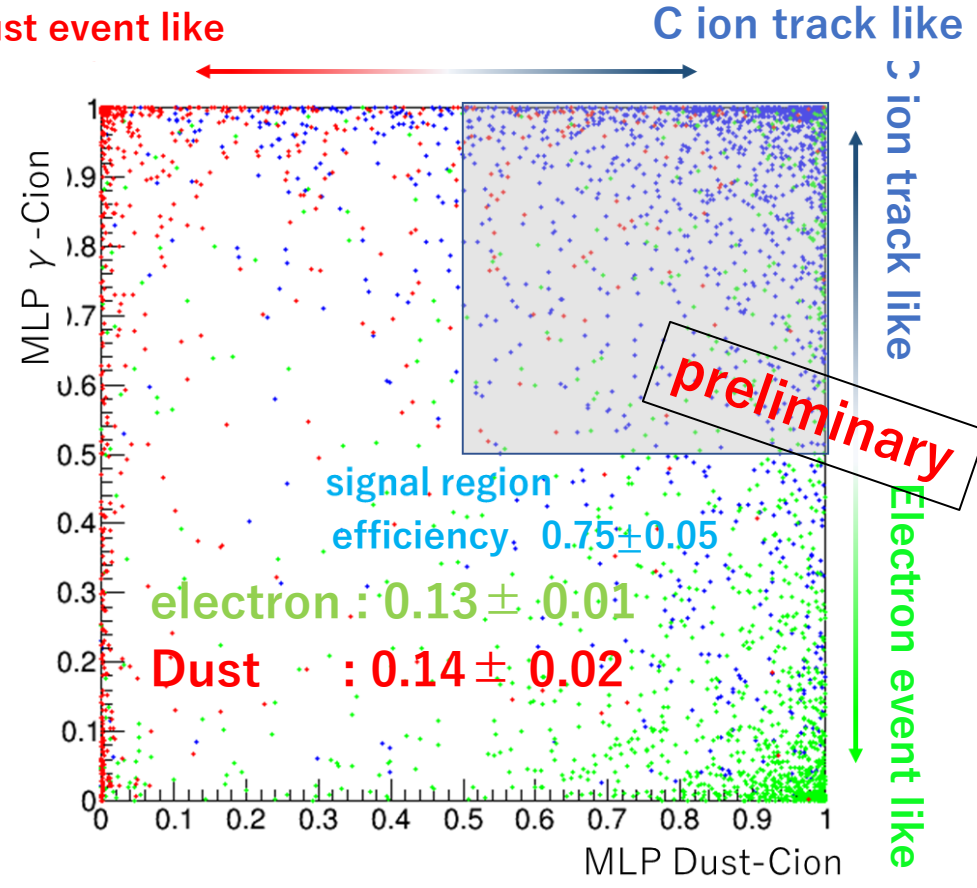
Multi wave length analysis



Multi variable Analyze
by machine learning

Give parameter
・brightness
・size

In each wavelength

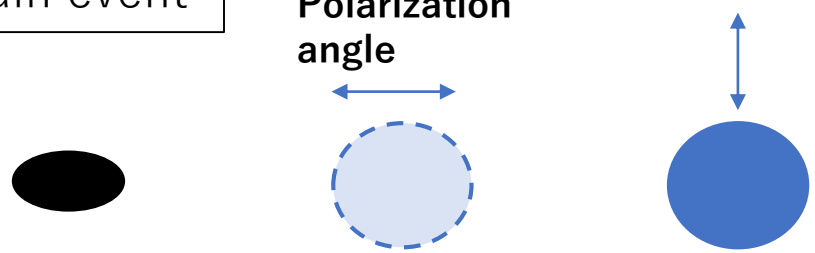


Polarization scanning

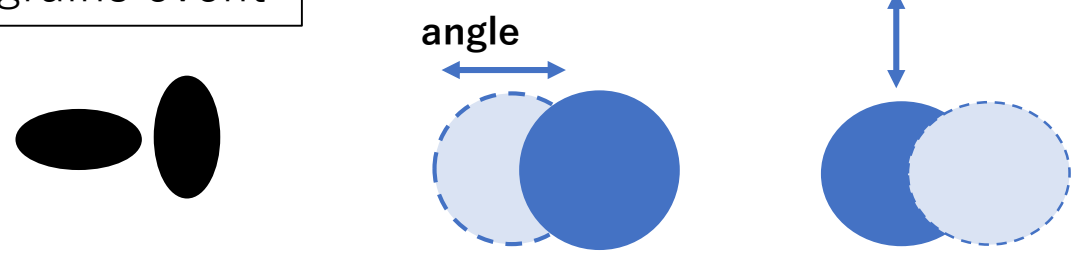
Concept : **Super resolution analysis**
by using polarization information of optical image

Select events consist of more than 2 grains

1grain event



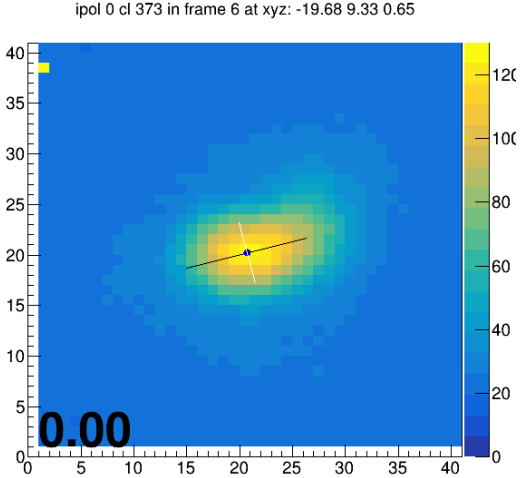
2grains event



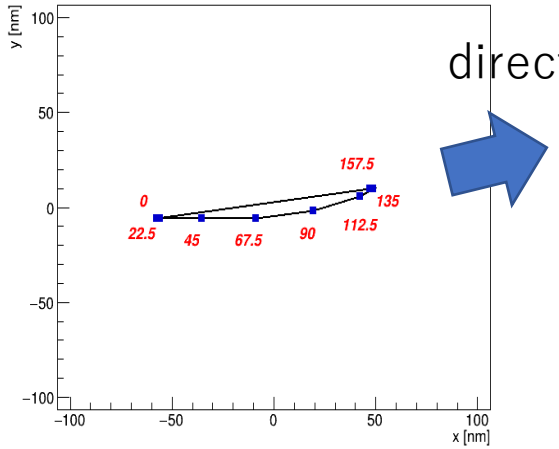
Looks like barycenter change

Method

Barycenter of event is changed by polarization angle



Barycenter position of each polarization angle



direction

Possible to readout information beyond Rayleigh's limit.

Analysis chain in NEWSdm

Full Volume scanning

Detail Event analysis (point scanning)

Ellipse analysis

Select candidate

Shape & optical
- direction
- length
- brightness

1 s/view

Reject BG

Phase contrast analysis

Candidate

Phase information
- substance
- structure

1 s/event

Reject BG

Multi wave length analysis

candidate

Color information
- structure

5 s/event

Reject BG

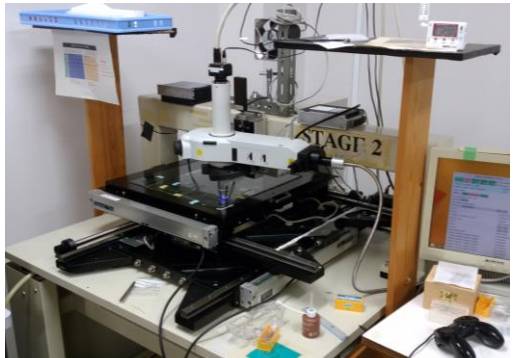
Polarization analysis

Candidate

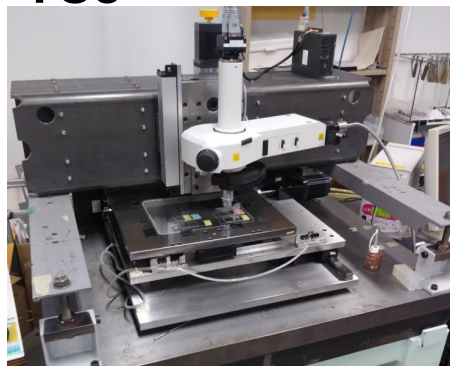
Super resolution
- structure
- direction

1 min/event

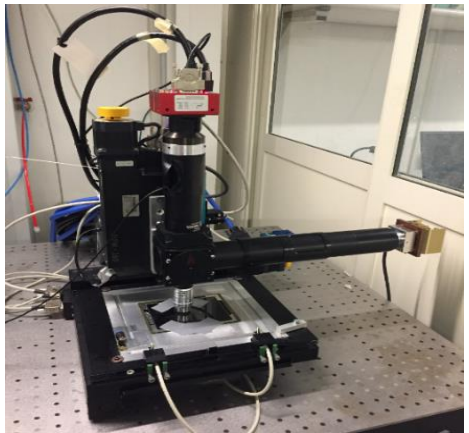
PTS2



PTS3



NSSna1



Future plan toward 10 kg scale experiment

First Goal :

search DAMA region
-> at least need to 10 kg・year NIT explore

put it into practice

need 10kg/y scanning speed

Time schedule of increasing 1st Scanning speed (kg/year/system)

2019 July

0.026 kg/y/
×2 systems

2020 Apr

0.166 kg/y
×3 systems

2021 Apr

1.06 kg/y
×More than 3 systems

After achieving 1kg/year/system

1kg/year/ system × 10 system
-> total scanning speed 10 kg/year

Shorten scanning time

Goal : 1.25 -> 0.2 s/view

- **High speed camera**
  (300 fps -> 1000 fps)
- **Increase stage speed**

Expand scan volume

Goal : expand 6.4 times

- **high pixel camera or add camera**
  (2M -> 4 M pixel)
- **use low magnification lens**
  (x100 -> x60; with image complement)

Summary

Readout nanoscale information

Use multiple analysis -> get super resolution information

Full volume scanning

・ellipse fitting

Detail event analysis

・ Polarization
・ multi wavelength
・ phase contrast

Combine all information by machine learning

・reconstruct Nano scale information
・reject BG events

full volume scanning speed

Recently velocity : 26.5 g/year -> limit experimental scale

Toward 10 kg scanning

Goal : 26.5 g/year/machine -> 1kg/year/machine

・ **Shorten scanning time** : 1.25 -> 0.2 s/view
・ **Expand scanning volume** : 6.4 times

Finally 10 scanning machine use for analysis

1kg/year/machine * 10 = 10 kg /year