Fundamental Particle Physics Lab.
Division of Particle and Astrophysical Sciences
School of Science of Nagoya University

Status and Analysis System of Directional Dark Matter Search with Nuclear Emulsion

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Workshop on Directional Detection of Dark Matter, 10-12, June, 2013

Outline of the talk

-Introduction

-Detector (Nuclear emulsion)

-Analysis system

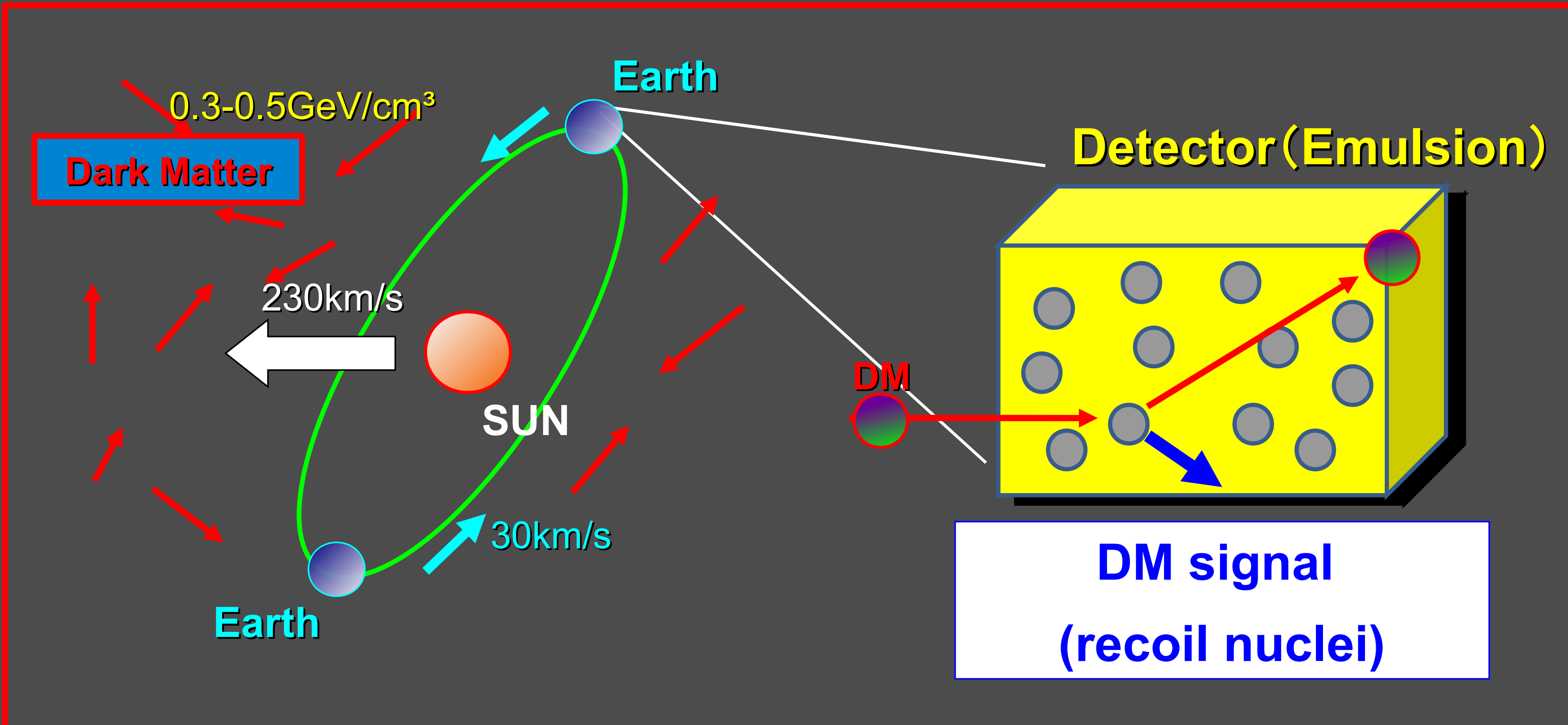
-Facility for test run

-Near future plan

-Summary

  -Collaborator

Directional Dark Matter Search with Emulsion



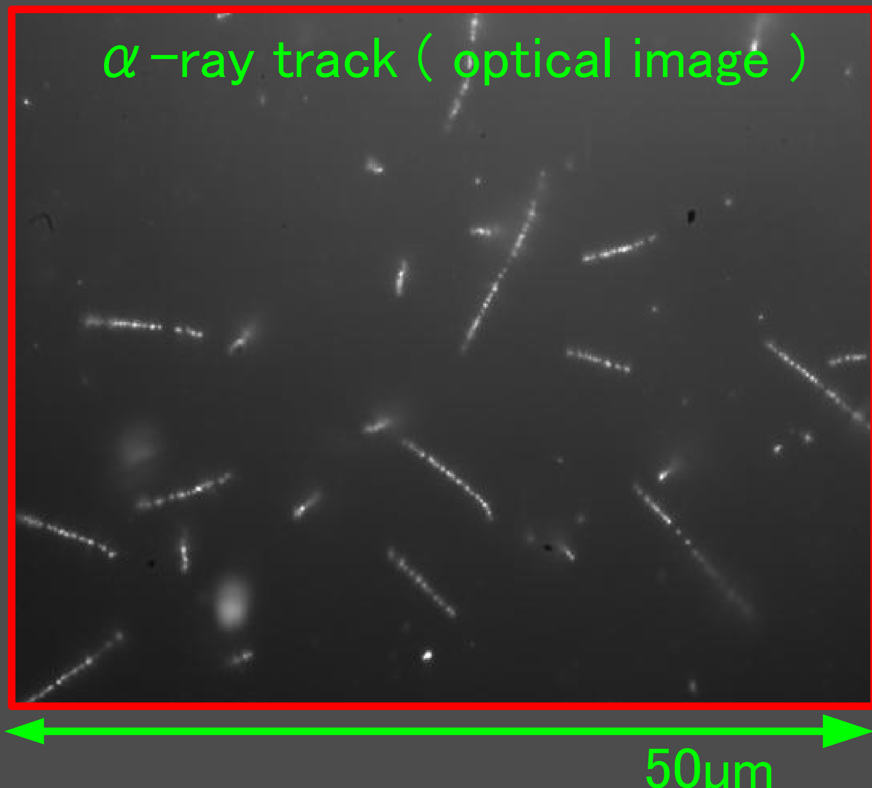
-Emulsion detector don't have time resolution.

⇒ -We control direction to Cygnus by using the equatorial telescope

Detector

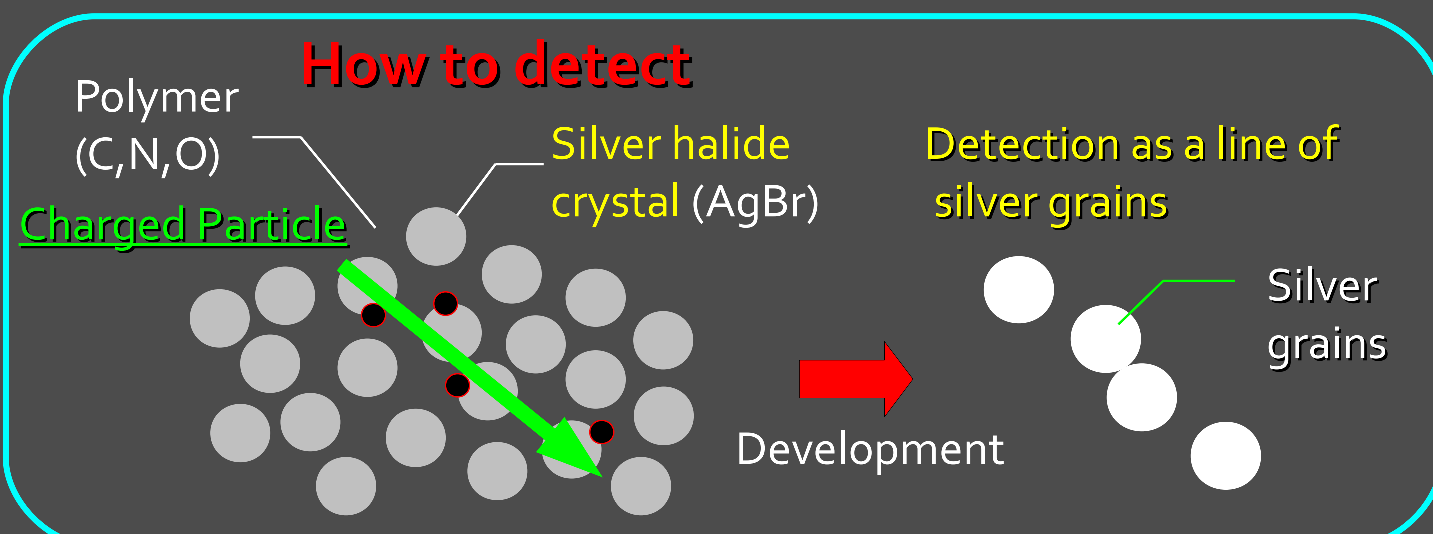
(Emulsion)

What is Nuclear Emulsion?



- Nuclear Emulsion is a kind of photographic film, and 3D tracking detector for charged particle.
- Advantages
  - -solid detector (3g/cc)
  - -high spatial resolution
  - -Low cost (150,000yen/kg)

= 1,500 USD = 1,150 EUR

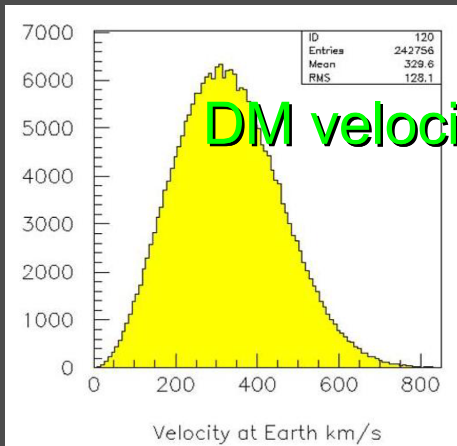


Case of DM search

Target Nuclei is...
- —Ag(46%)
- —Br(34%)
- —C(N,O)(19%)

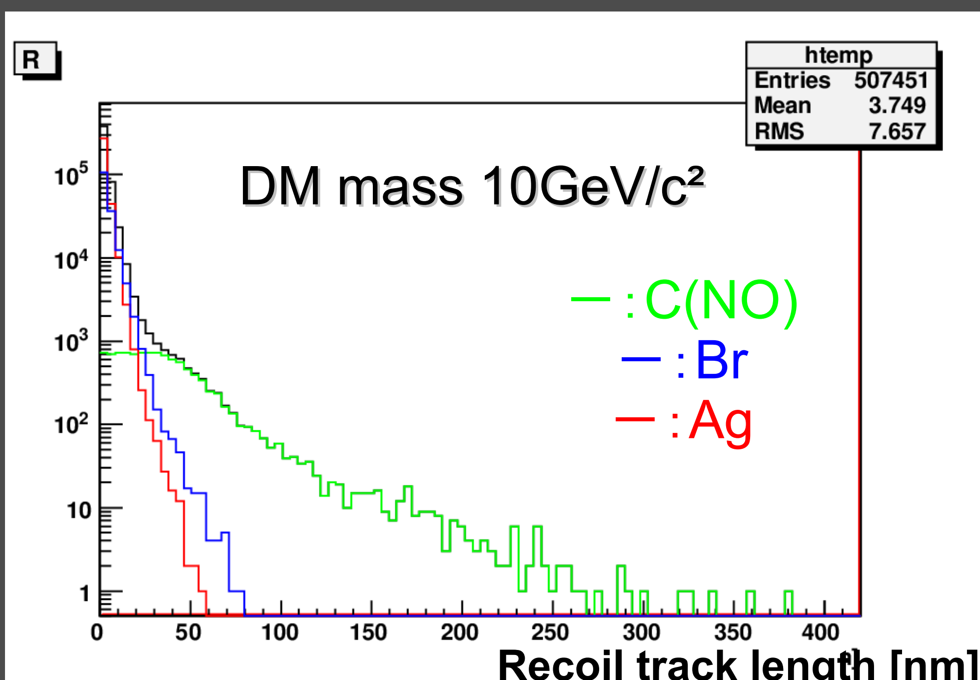
(Mass ratio)

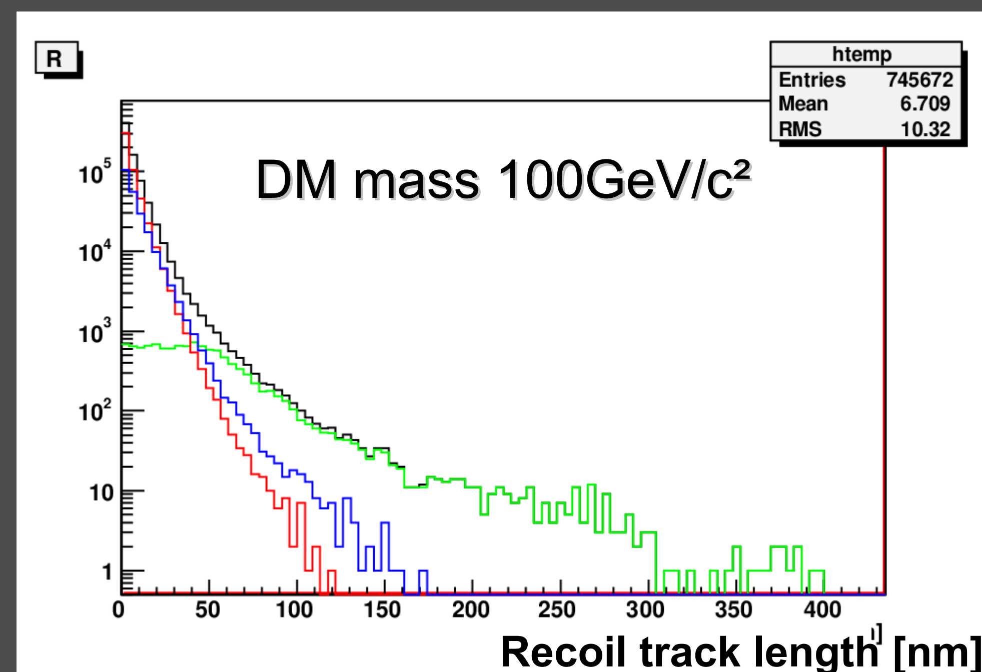
Track length in Nuclear Emulsion



DM velocity distribution

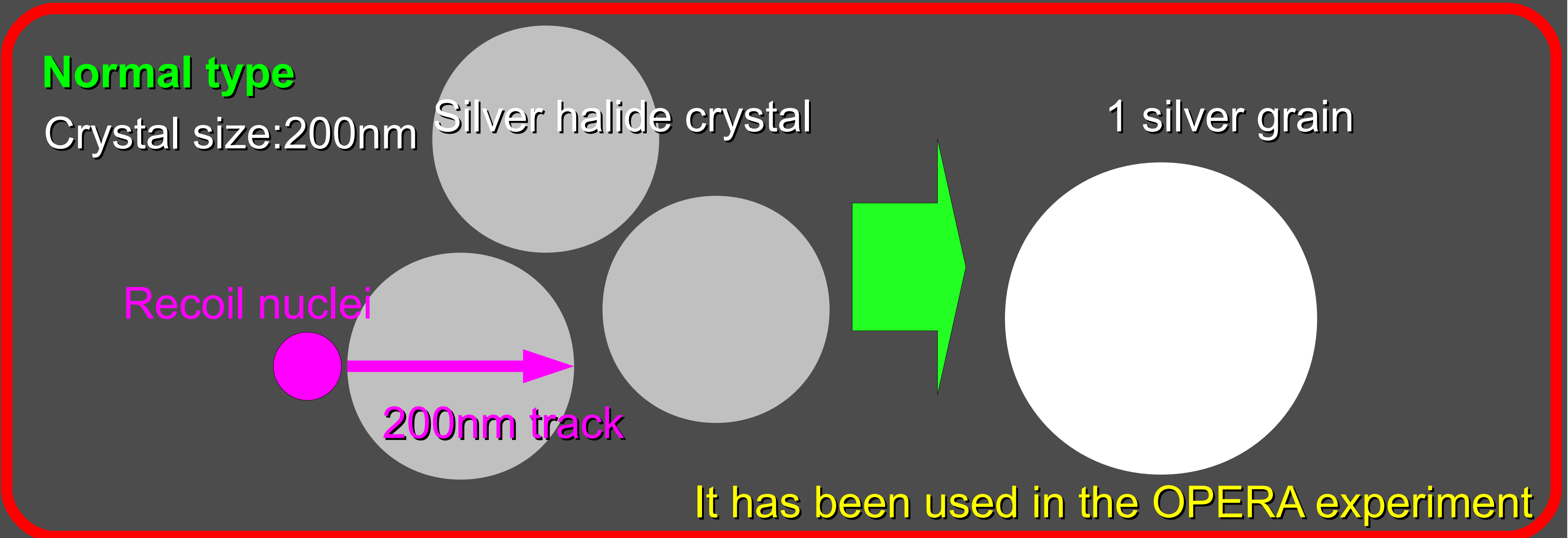
If assuming a Maxwell distribution

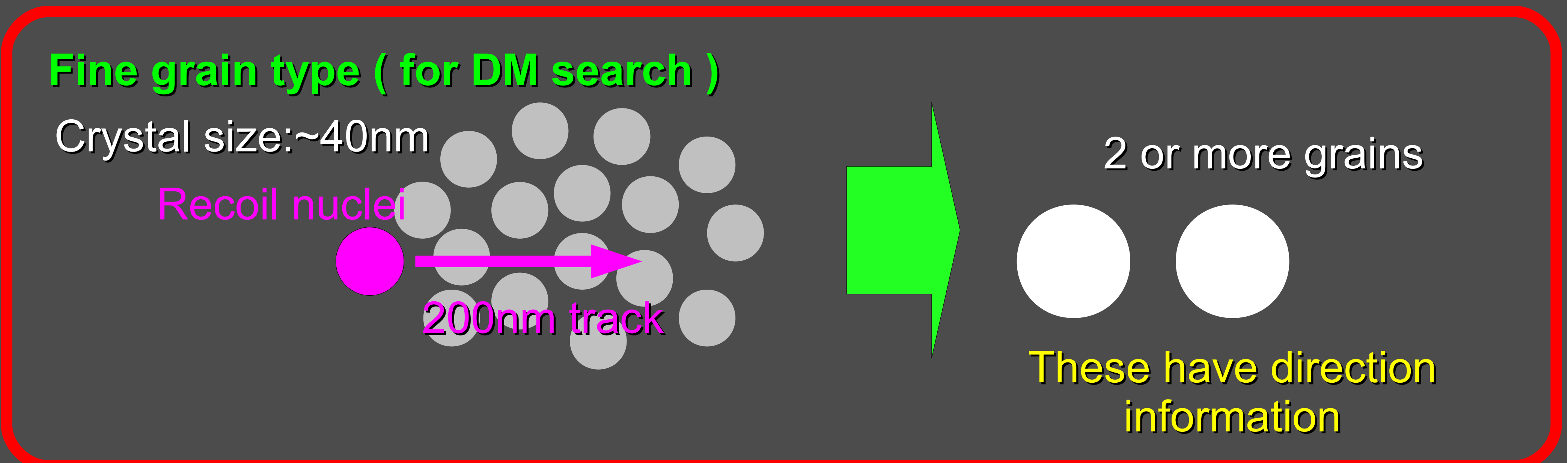




It is necessary to detect the <400nm tracks

Emulsion Detector for DM search





Emulsion Production

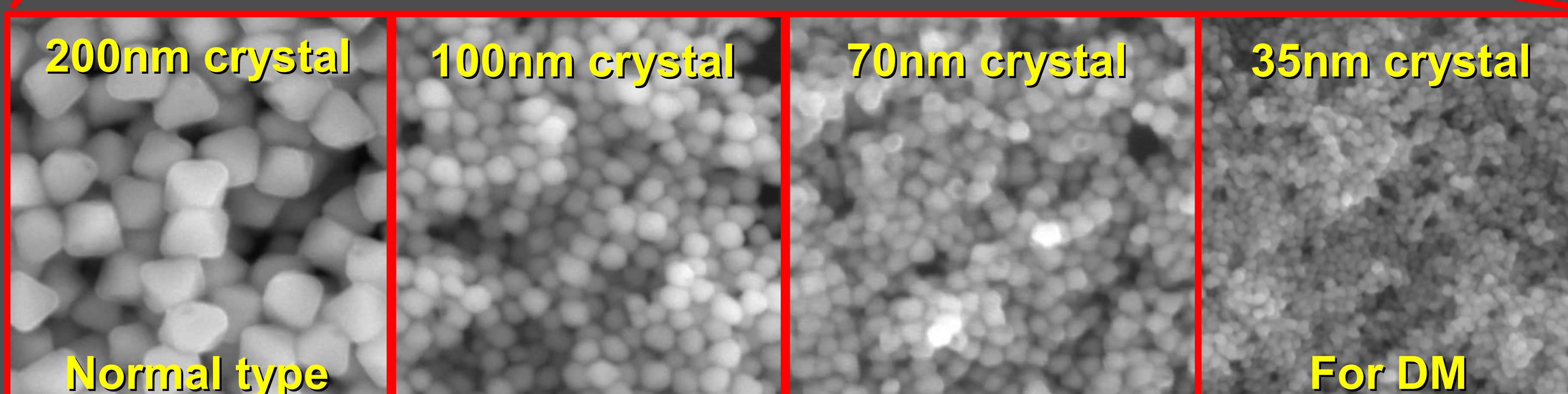
・Self production and R&D in Nagoya University, Japan from Apr 2010

Production ability :
~1kg Emulsion / week

Product

Pouring on base

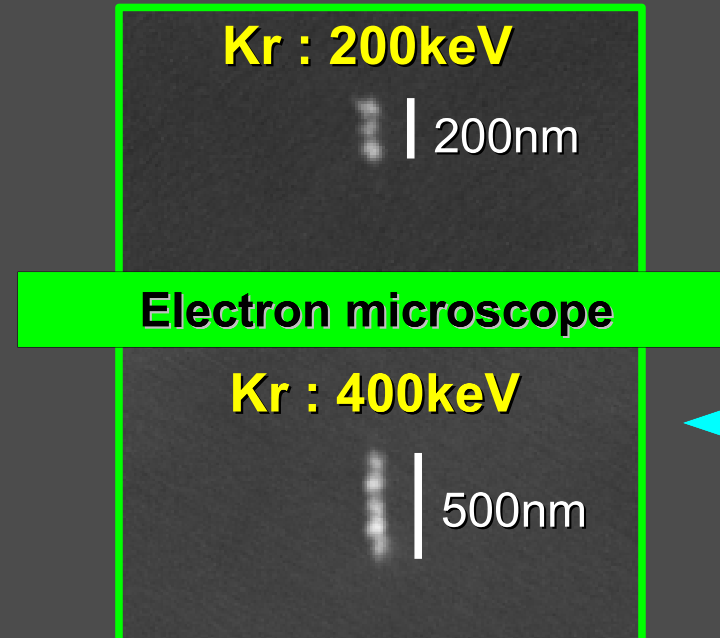
Emulsion Production

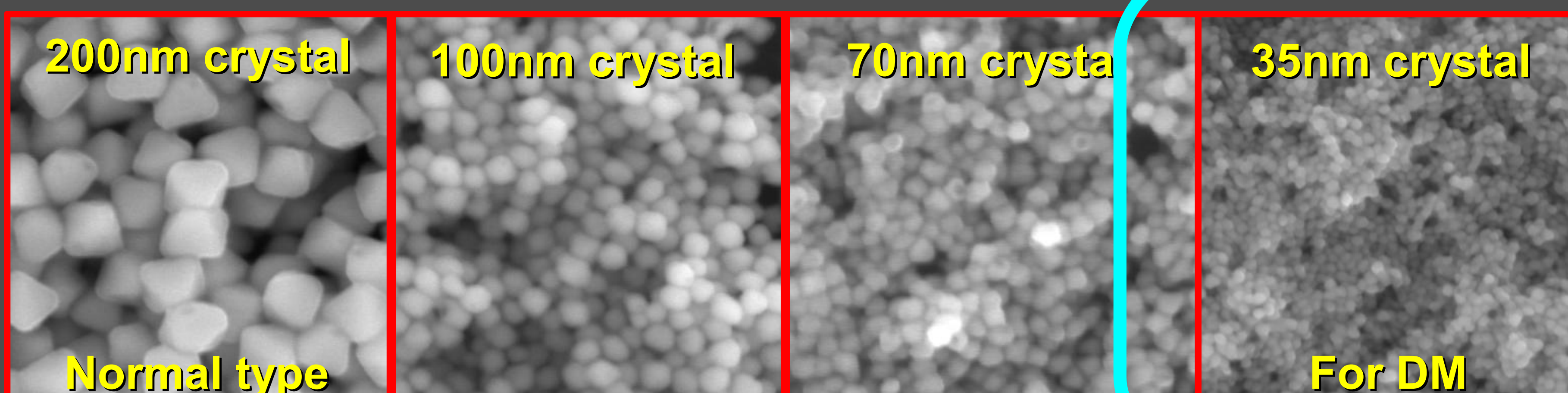


500nm

Size control

Emulsion Production





Size control

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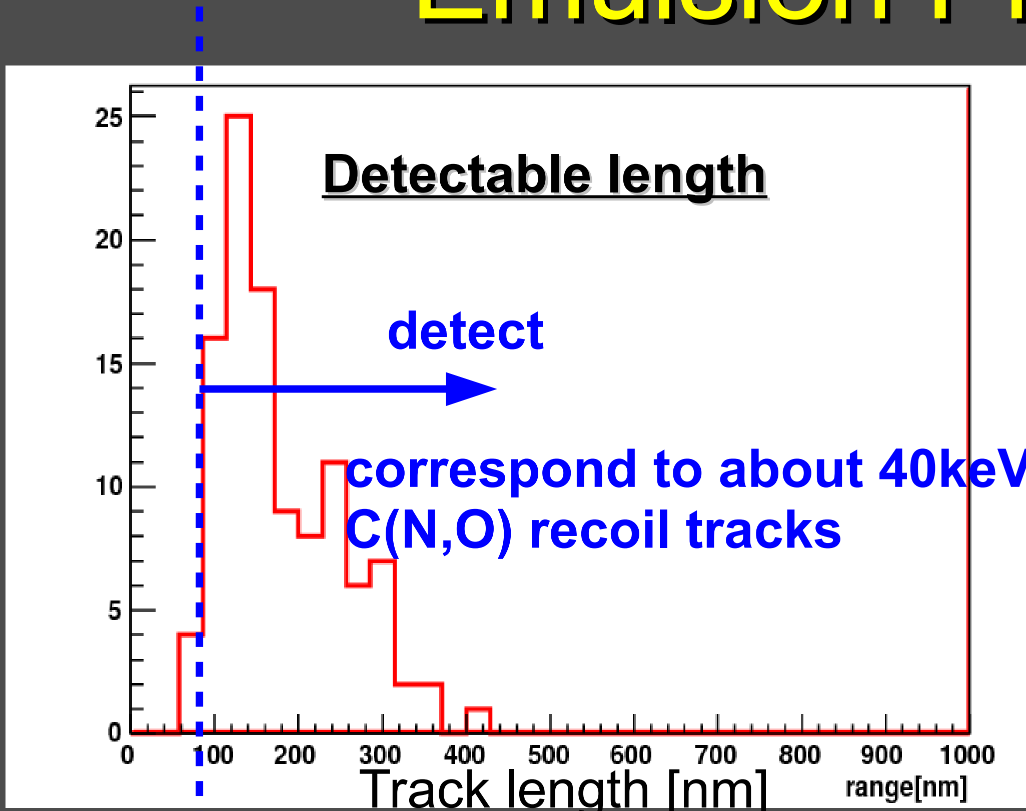
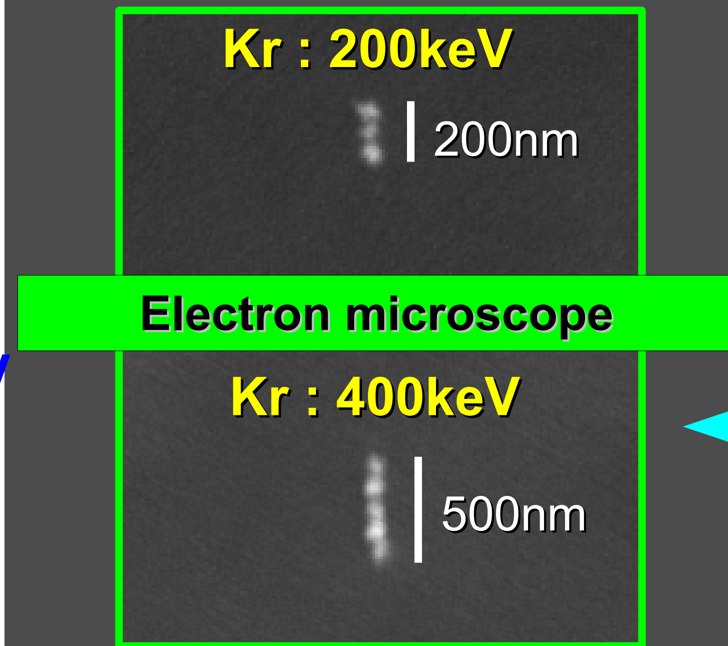
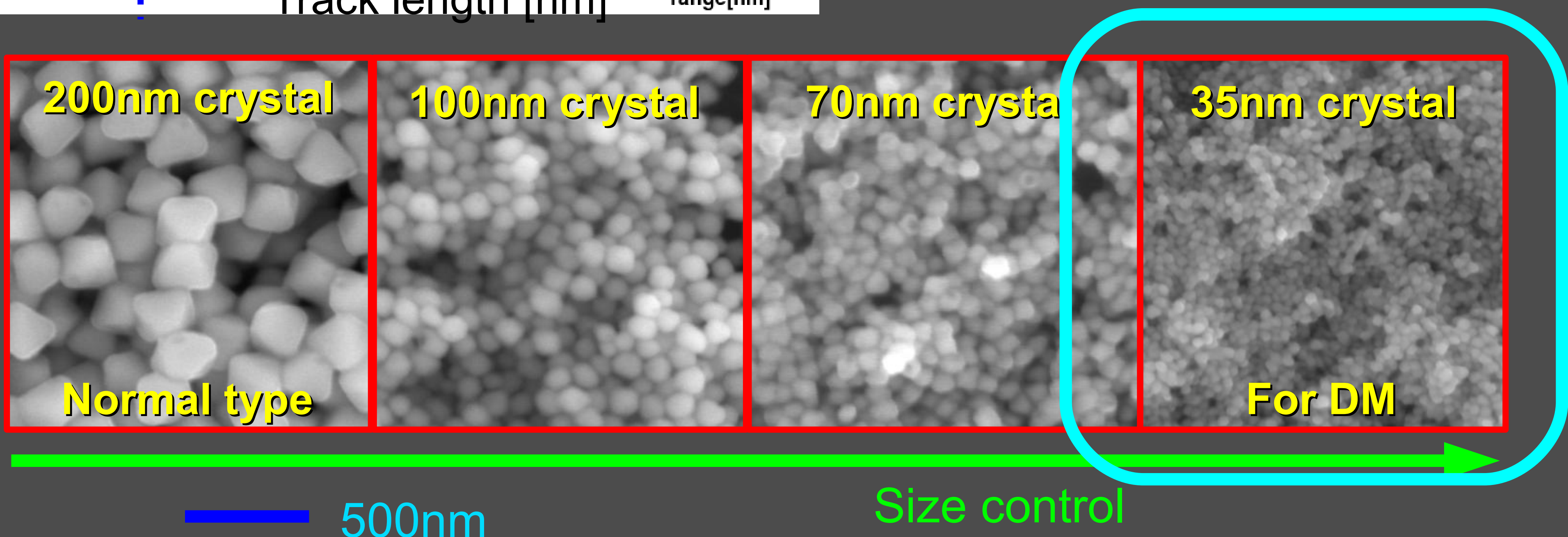
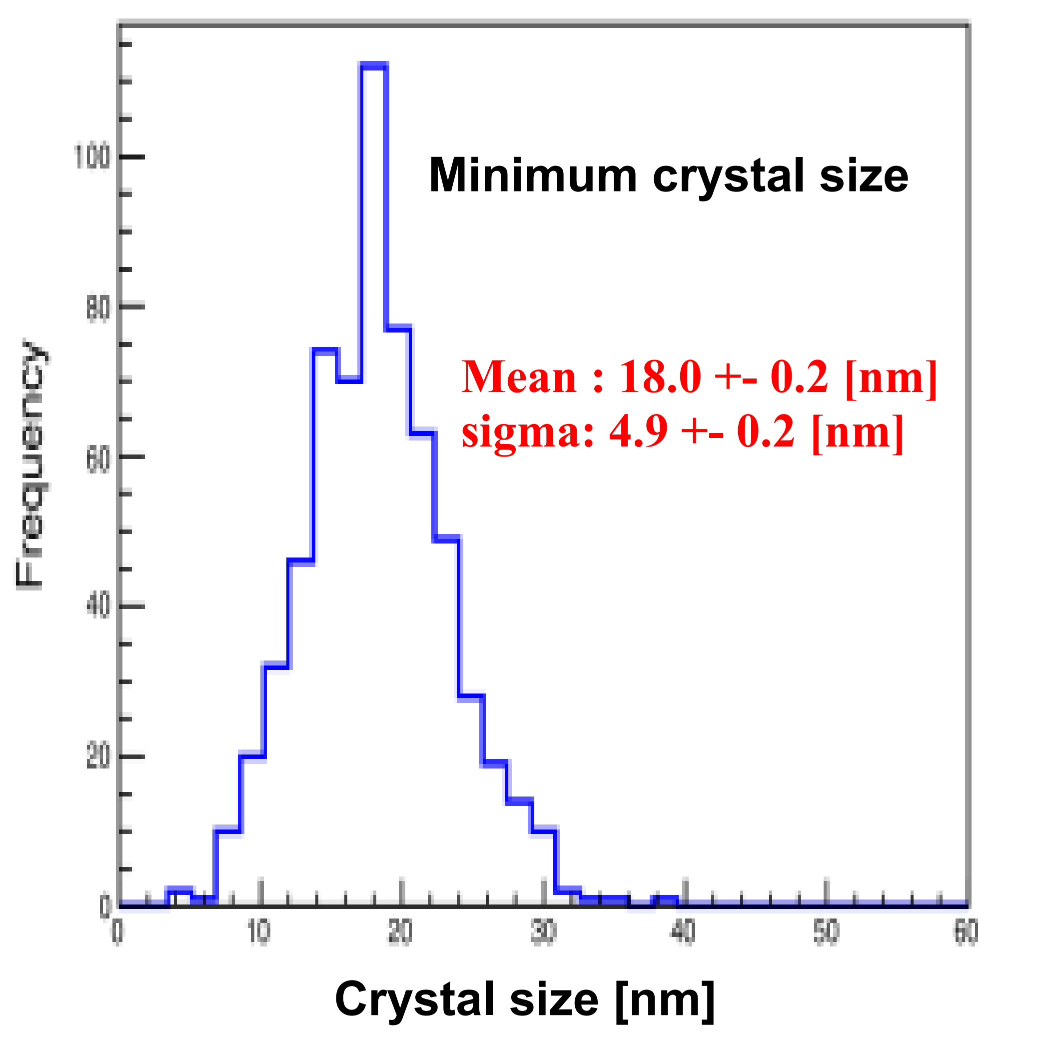






In development

We aim more micronization in order to improve the energy threshold.



-Possible to produce stable very fine crystals by using the PVA

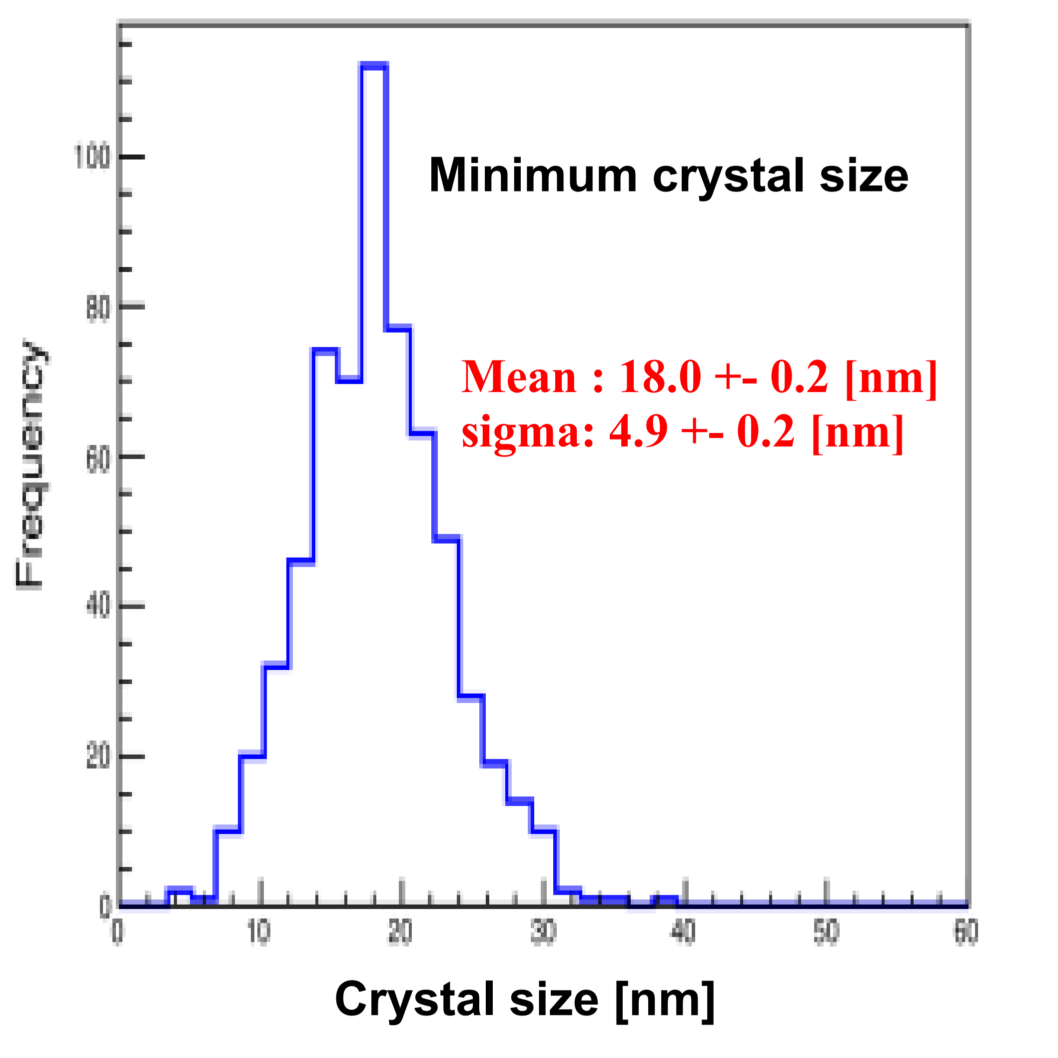
-We already established method to control crystal size.

Challenge

-We study about sensitivity control for practical application

In development

We aiming more micronization in order to improve the energy threshold.



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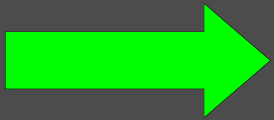


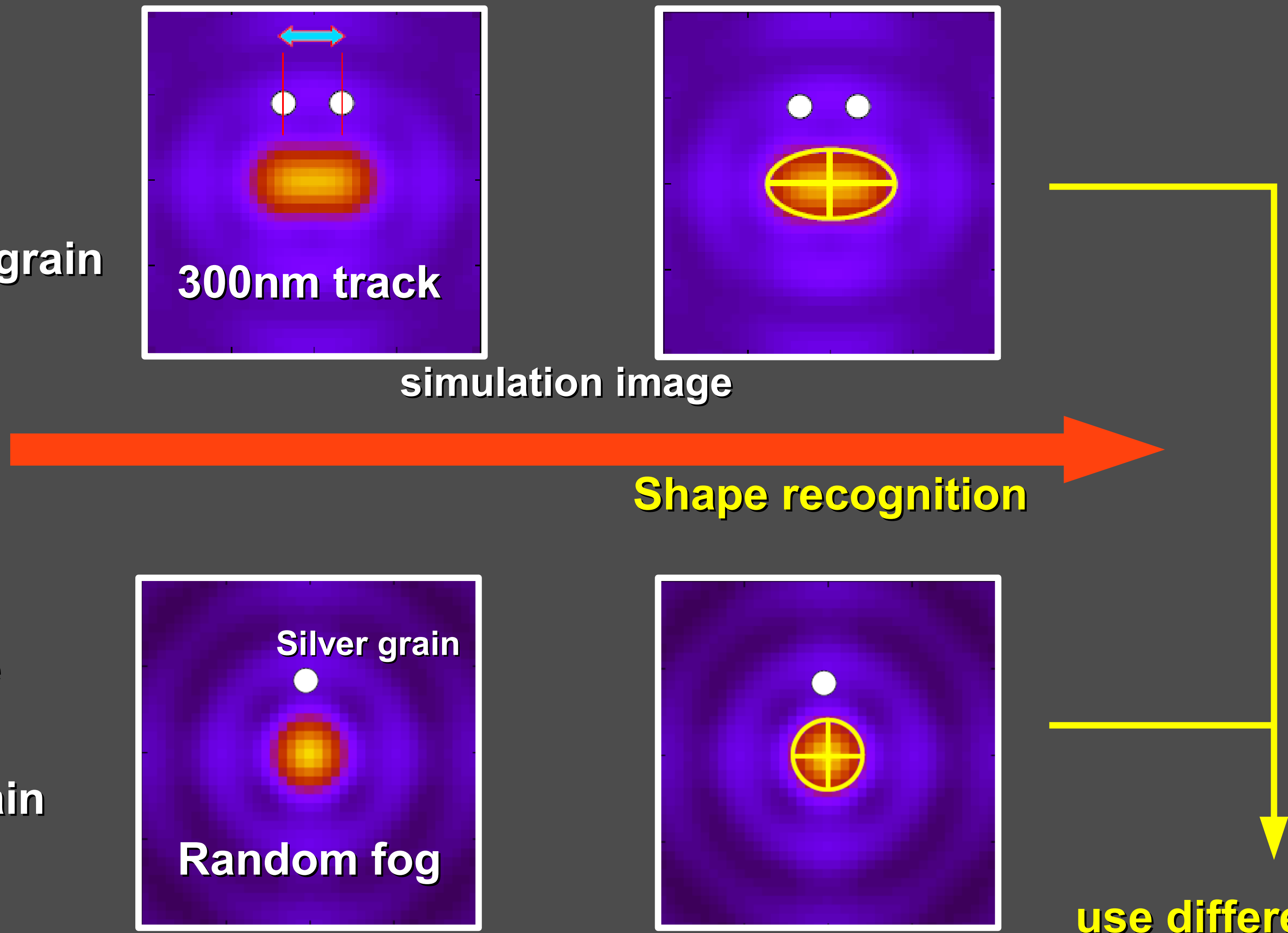
2013/06/11
11A6 Takashi ASADA

Analysis system

Selection of candidate with optical microscope
~ concept ~

Tracks

2 or more silver grain



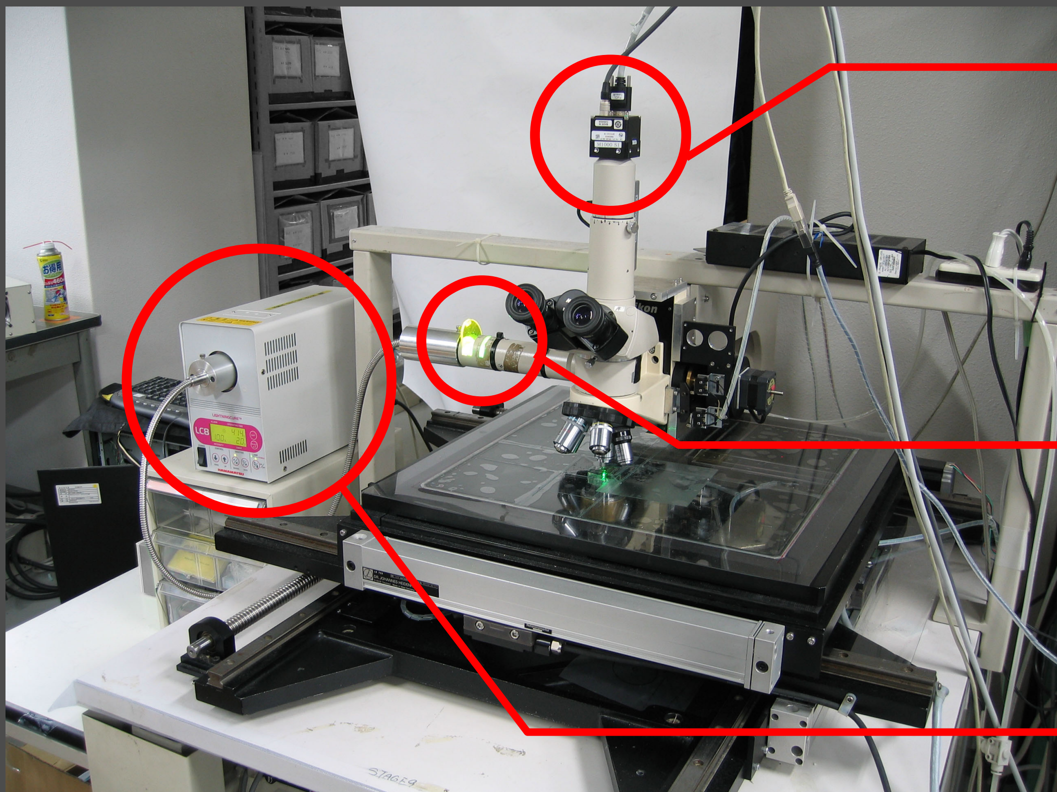
Main noise

1 silver grain

use difference in shape

Attention ! It's not actual image

Prototype of readout system



Readout stage for R&D

Camera

DALSA 1M 120fps

Cell size : 7.4[μm]

Filter

550nm band-pass

Light

Source : Hg-Xe lamp

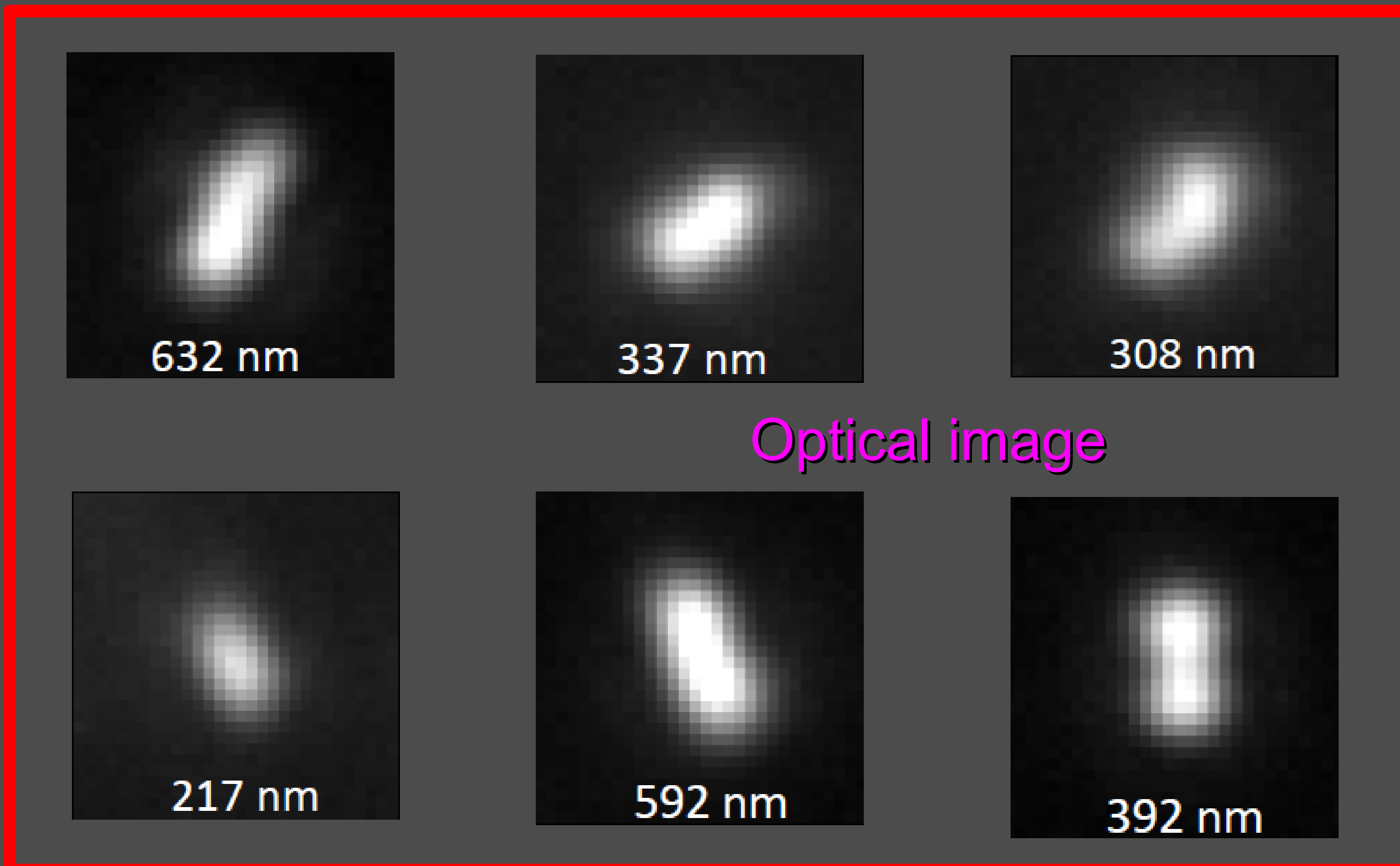
Spacial resolution : 270nm

Pixel resolution : 57nm / pix

1 view : 58μm × 58μm

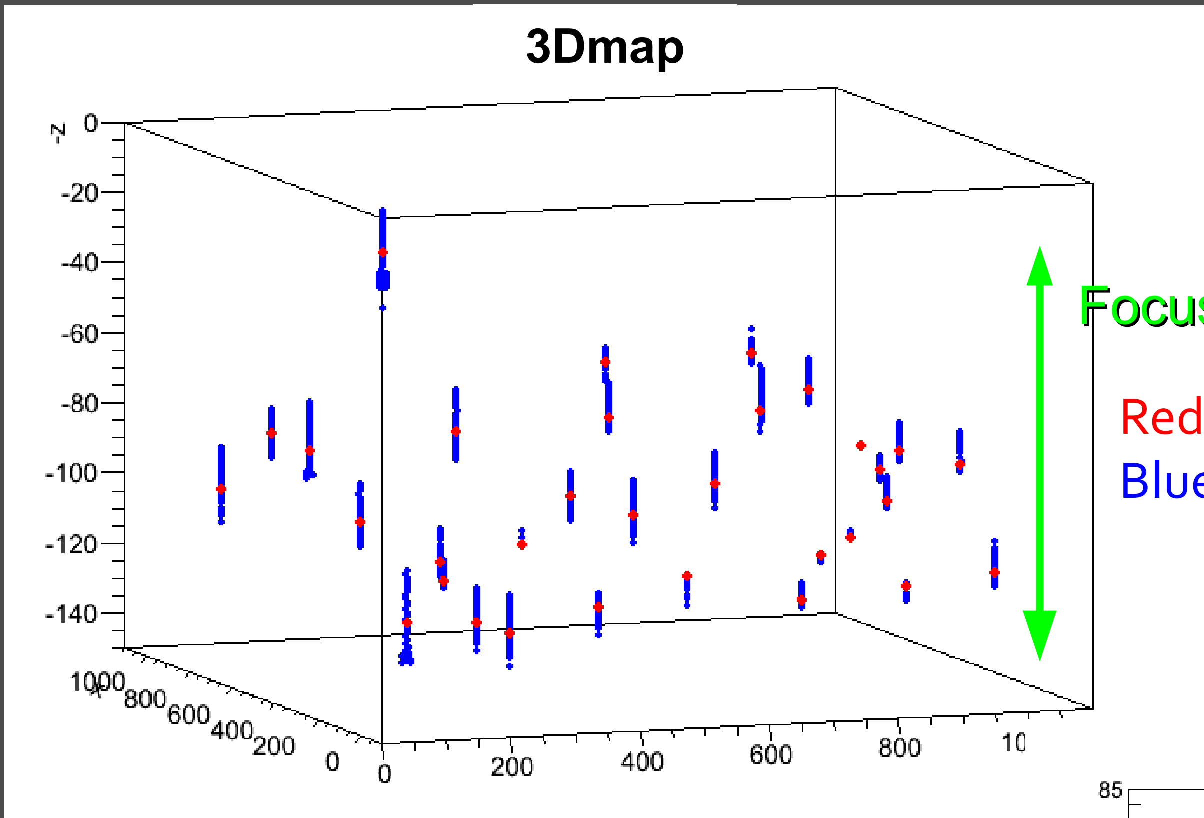
It is not best condition

Demonstration using heavy nuclei recoil tracks induced by 14MeV neutron (D-T reaction)



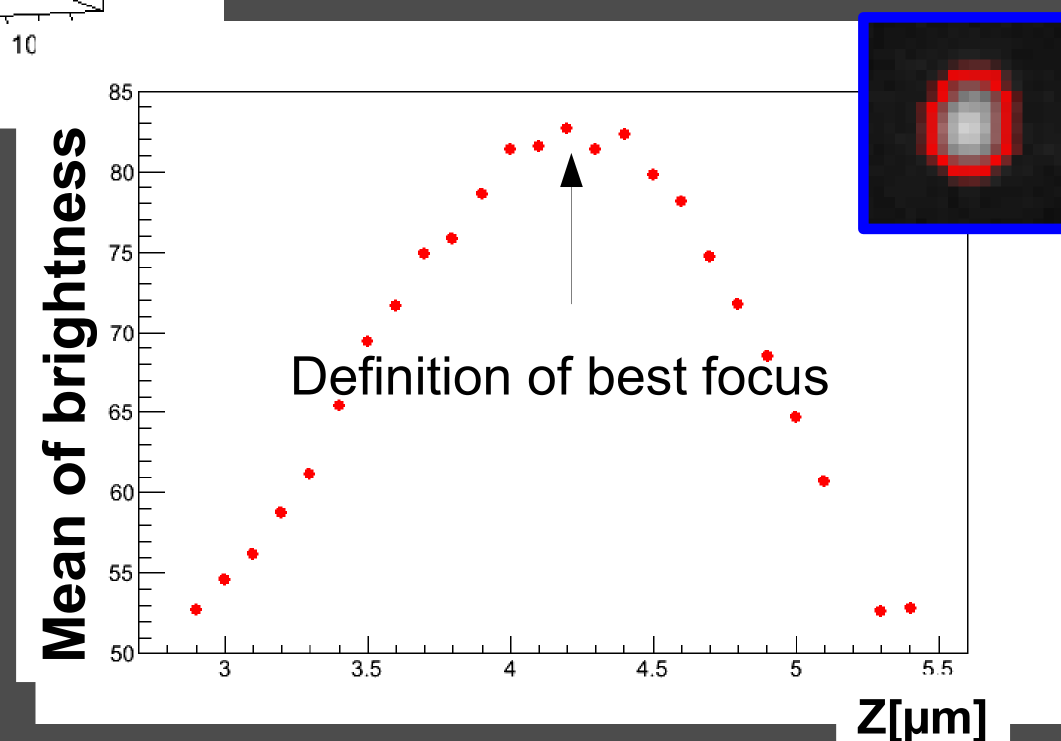
Mostly Br recoil (170 - 600 keV), because of low sensitivity tuning

Best focus selection

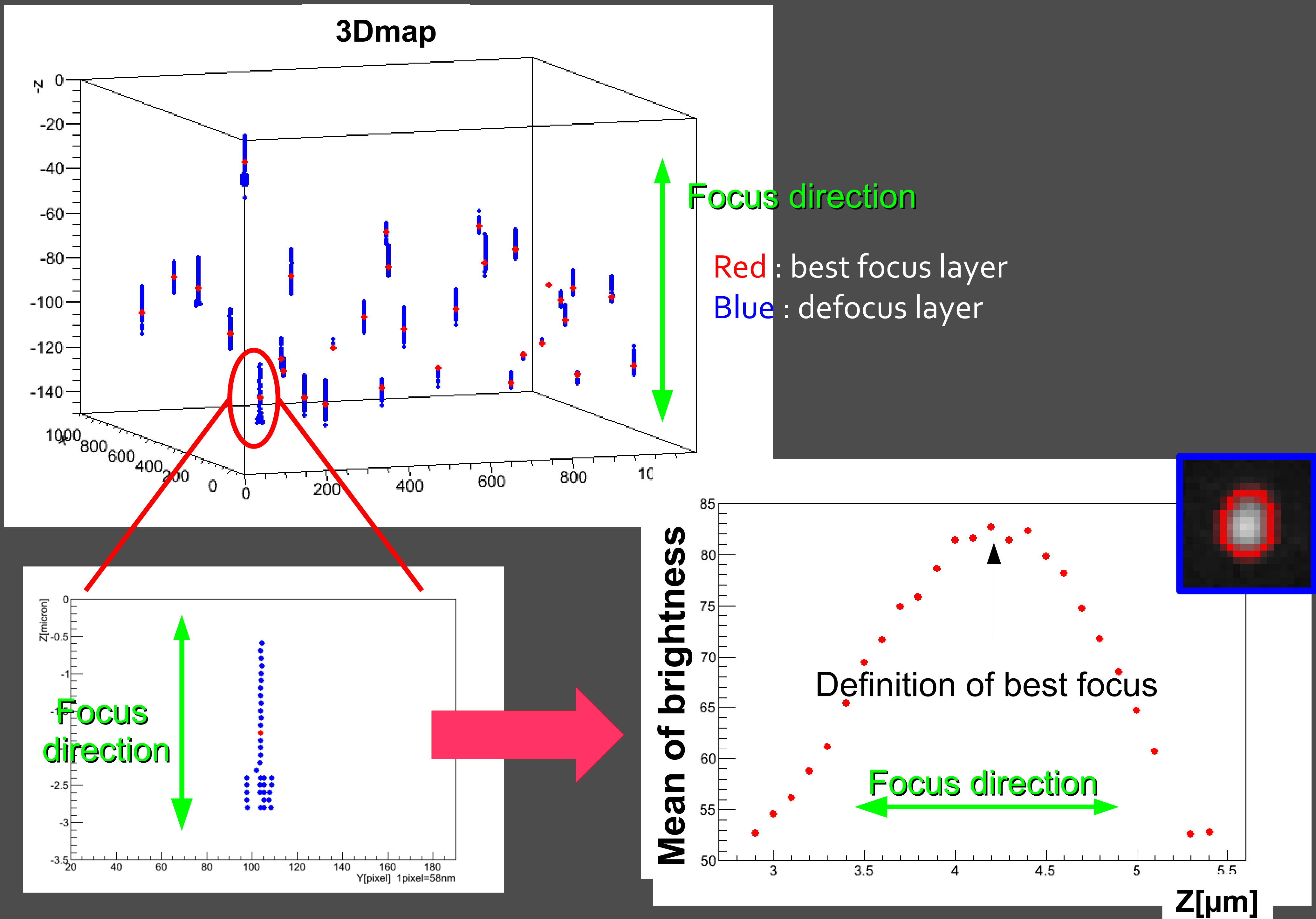


Focus direction

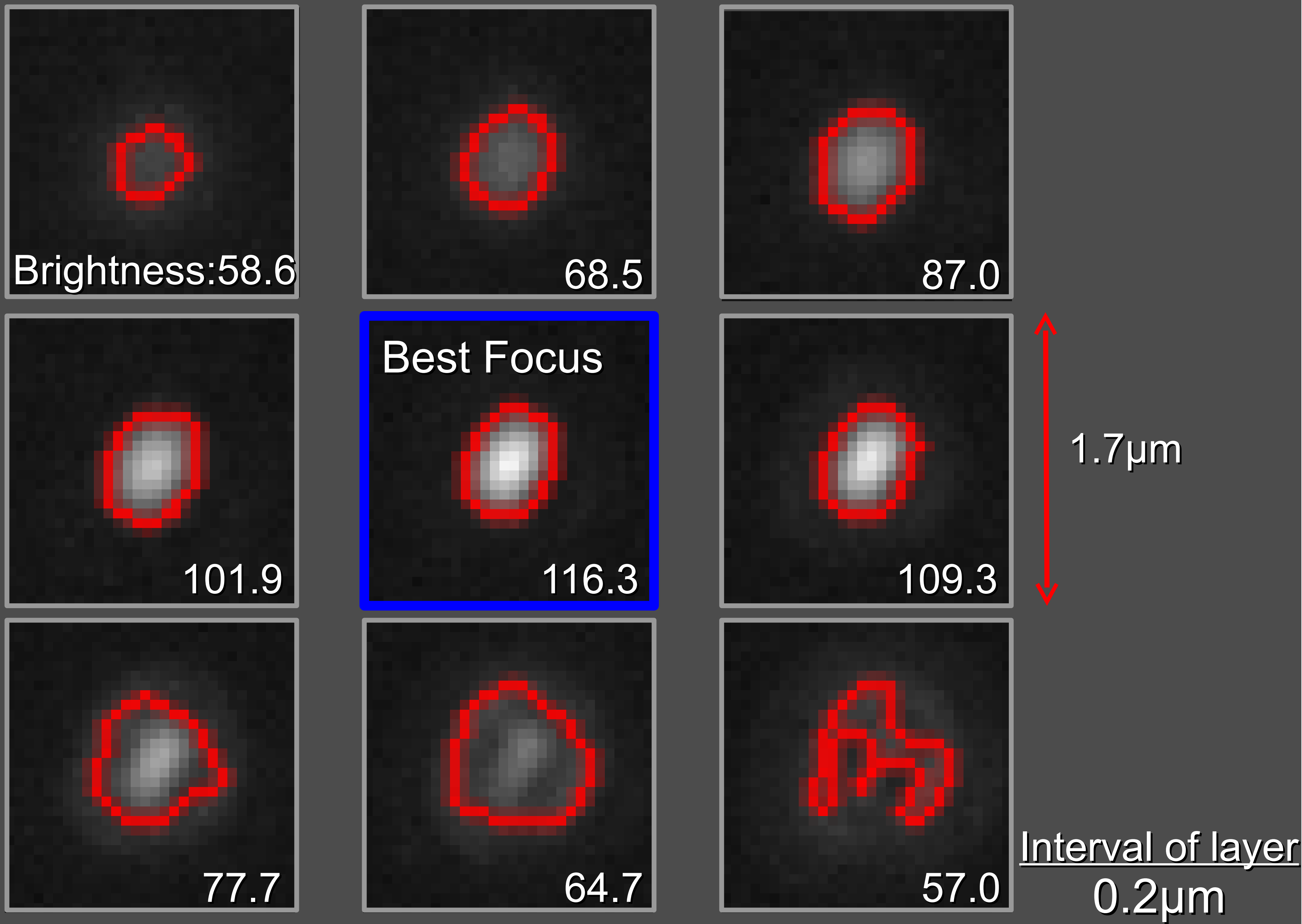
Red : best focus layer
Blue : defocus layer



Best focus selection



Scanned image (Layer image of one event)



Selection of candidate
~ parameterization of shape ~

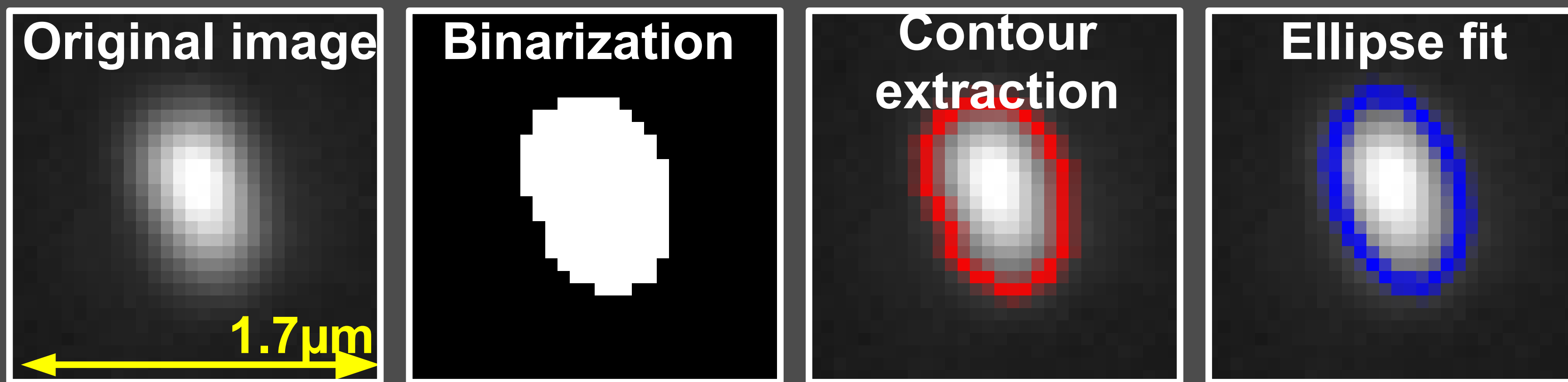
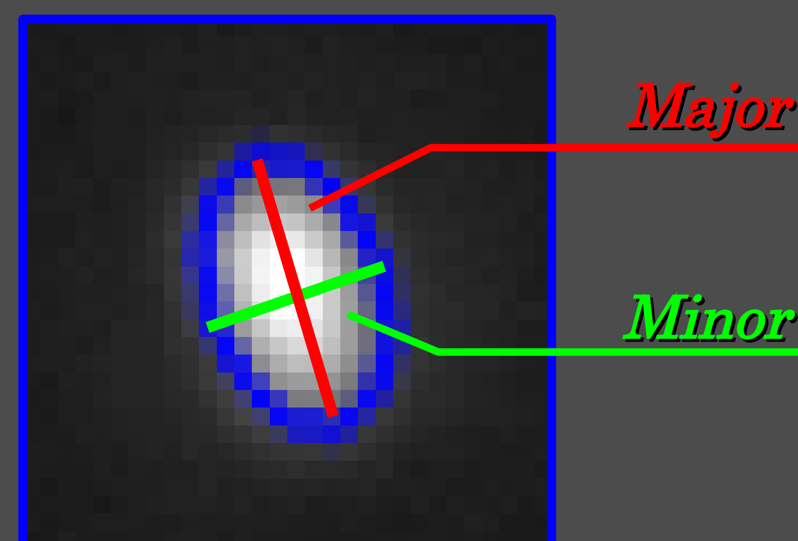


Image analysis

Main parameters of readout

Ellipticity

=Major/Minor

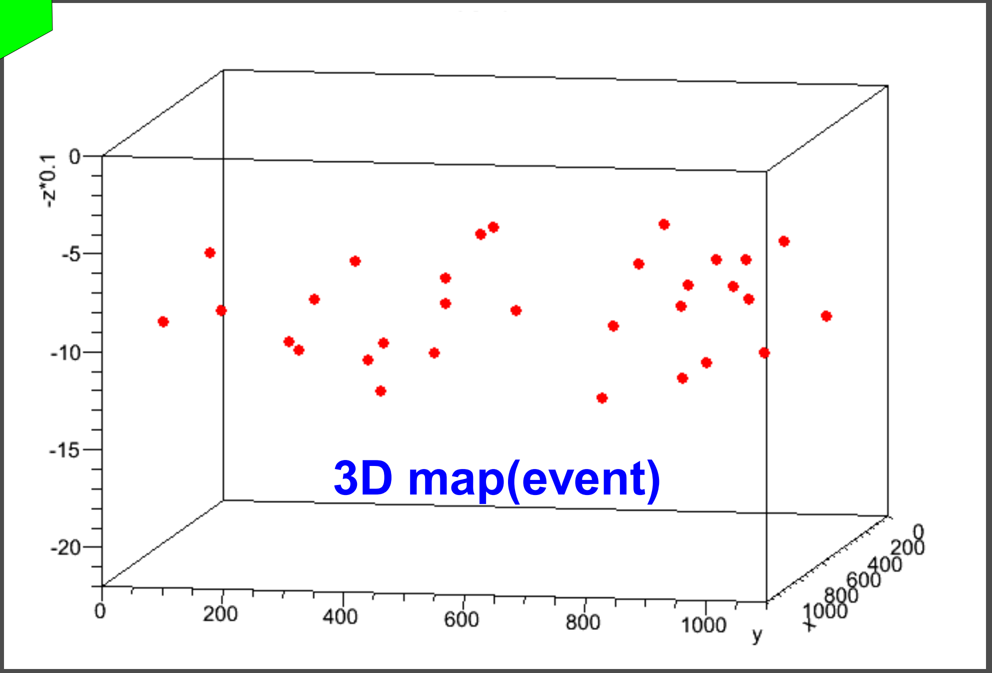


put out the parameters of all events that are in the image automatically

Prototype of readout system

Readout stage for R&D

Scan



-3D position information
-Brightness
-Shape
-Area
-Angle

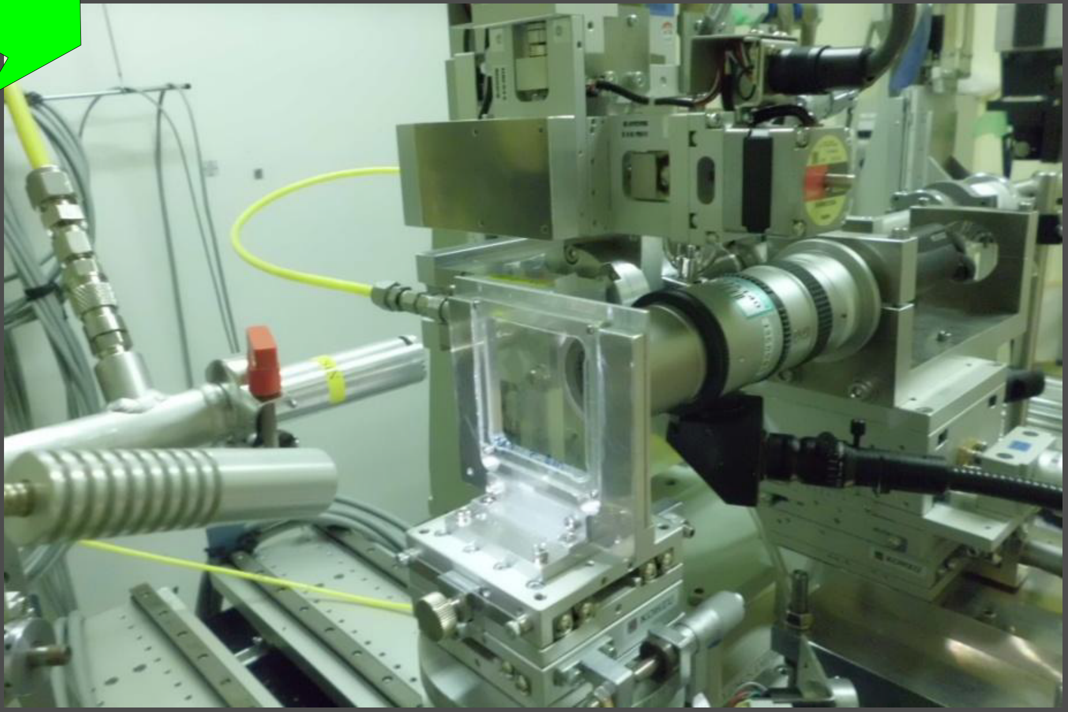
etc...

Scanning power : 10day / g

Process of track decision

Optical microscope
(First scan)

- High speed scan (large volume)
- Shape recognition
- 3D position ...

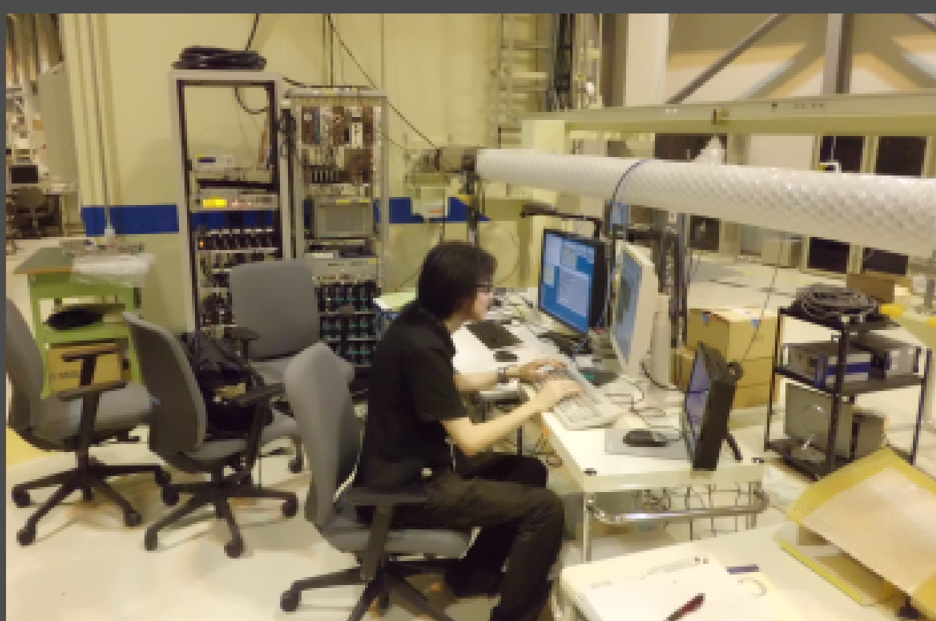


X-ray microscope
(Second scan)

- High resolution
- pinpoint check (event by event)
- Signal or Noise ?

X-ray microscope

Spring-8(Hyogo, in Japan)：BL37XU, BL47XU



- -Resolution : 70nm
- -pixel resolution : 25nm / pix
- -Exposure time : 6-10sec / view
- -1view size : 44μm×29μm
- -Depth of field : 70μm
- -X-ray Energy : 8keV

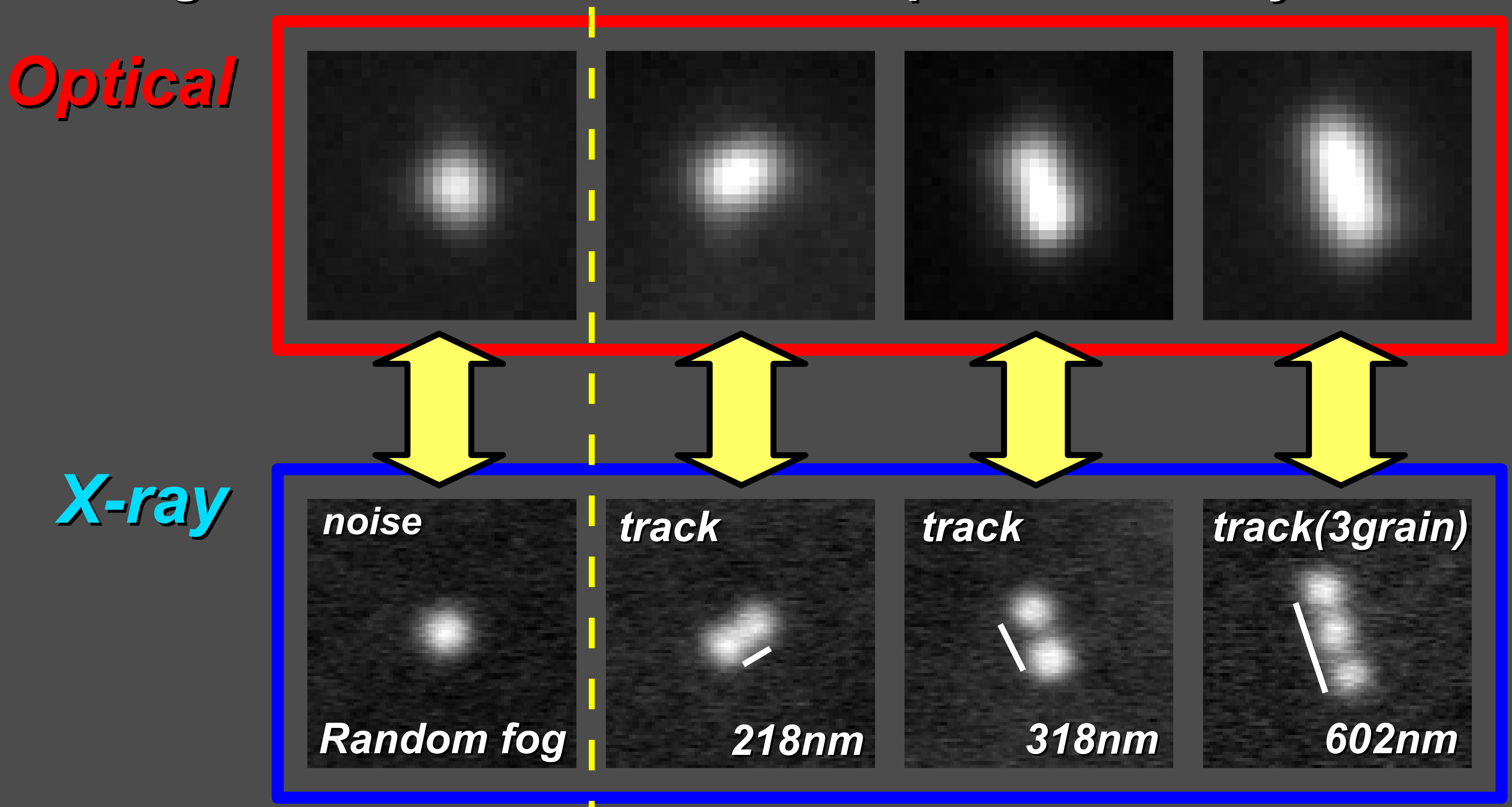
Ta 100nm thickness on SiN Membrane

-There is recruitment of machine time per six months

-Status of machine time that we gained in recently :
18 Shift / half year
= 144 hour / half year

-The last three years, we have been able to gain constant machine time.

Matching of recoil tracks between Optical and Xray microscope



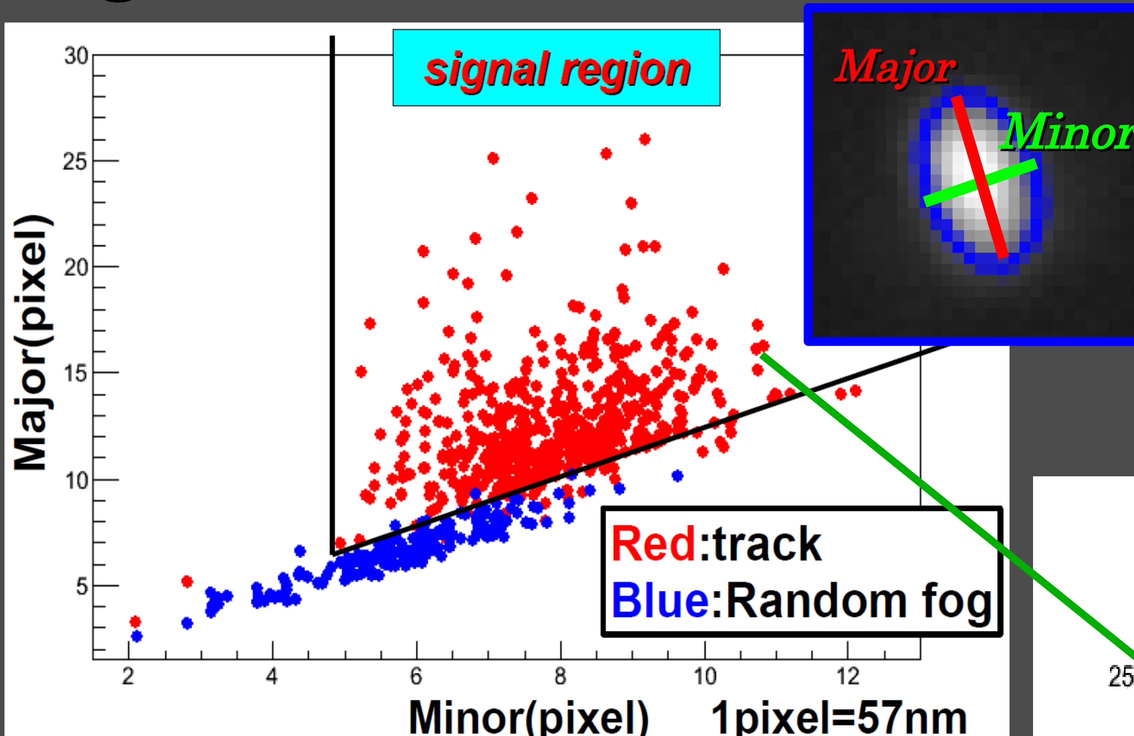
-Matching efficiency : **99% (572 event / 579 event)**

-Possible to automatic analysis of **7800 event / day**

-Amount of shifting from expected position(Optical→Xray) :

<5μm ⇒ This shift is small amount enough to compare with one view

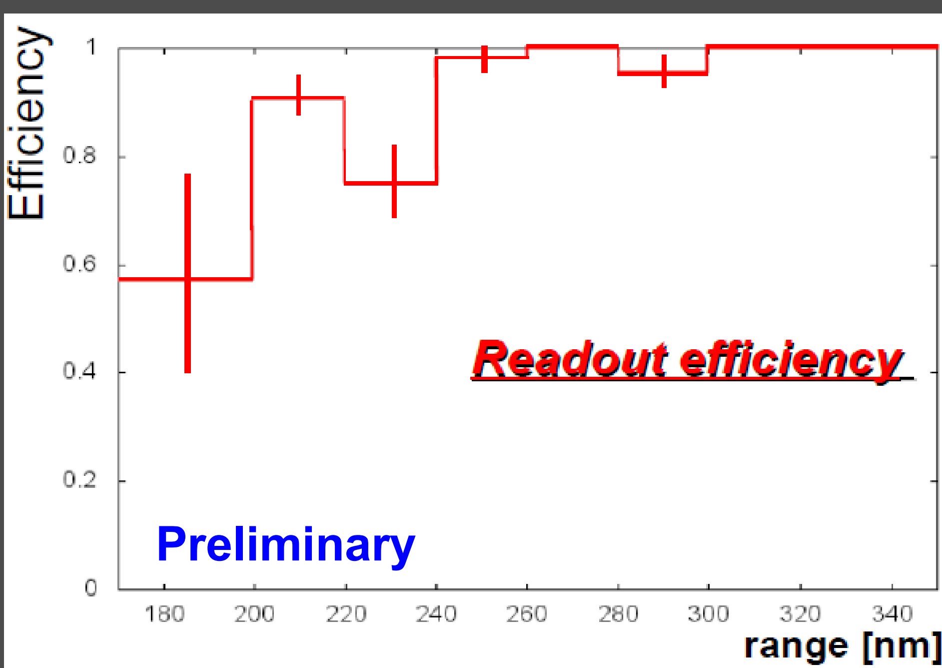
Signal selection with optical microscope

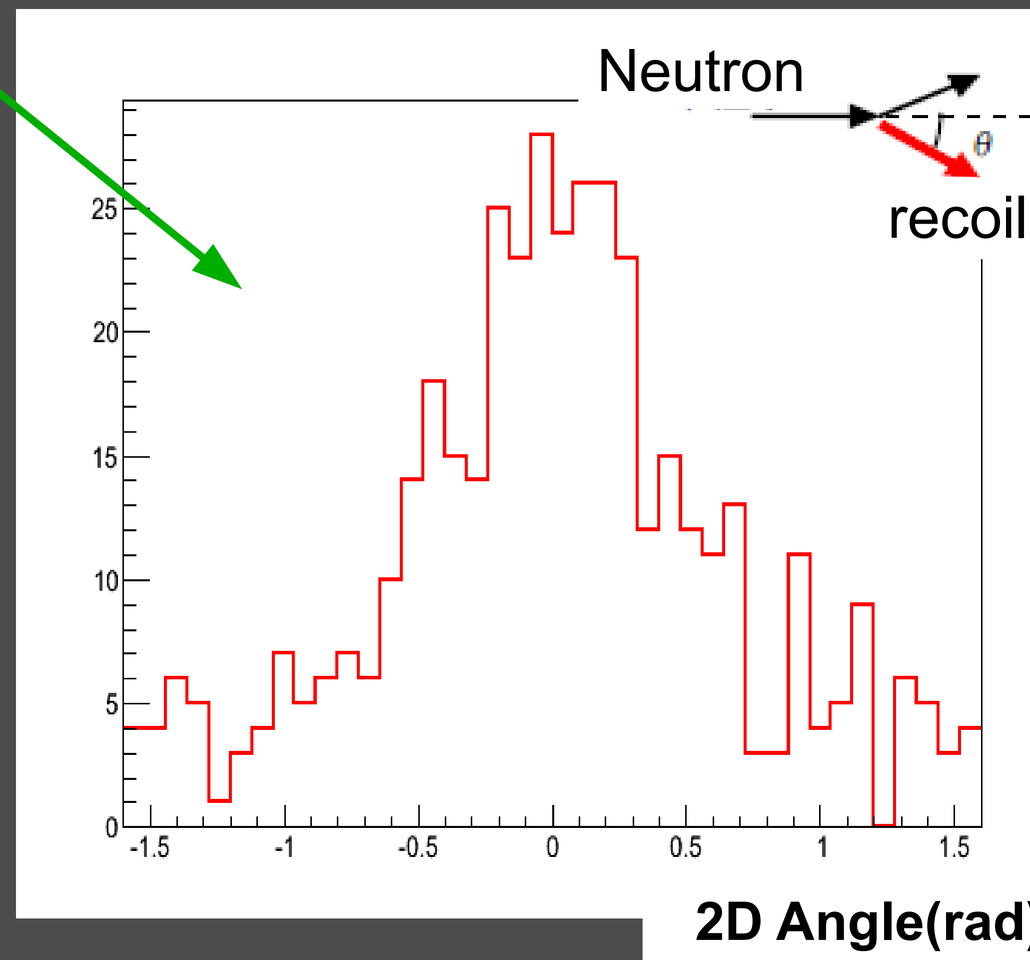


-Optical readout results of events already confirmed as tracks and noises by X-ray microscopy analysis.

X-ray MS → **Optical MS**

Analyze





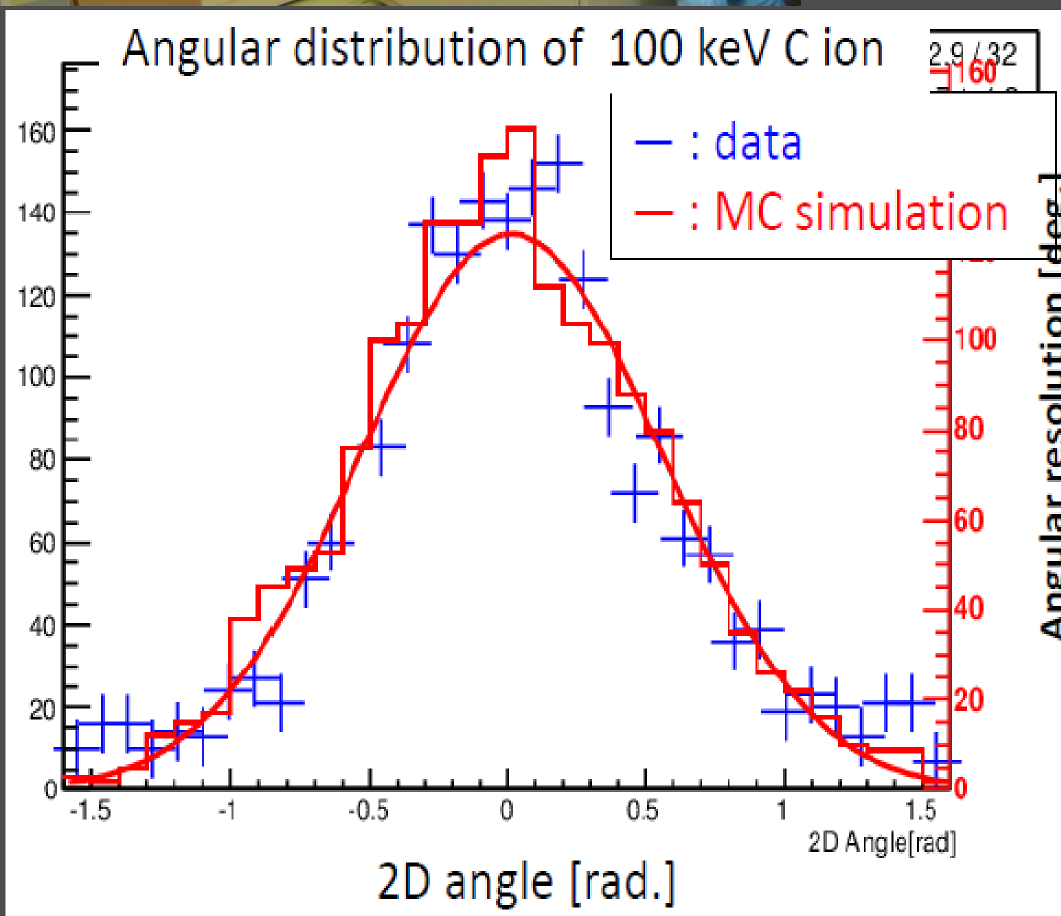
Angular resolution of optical readout

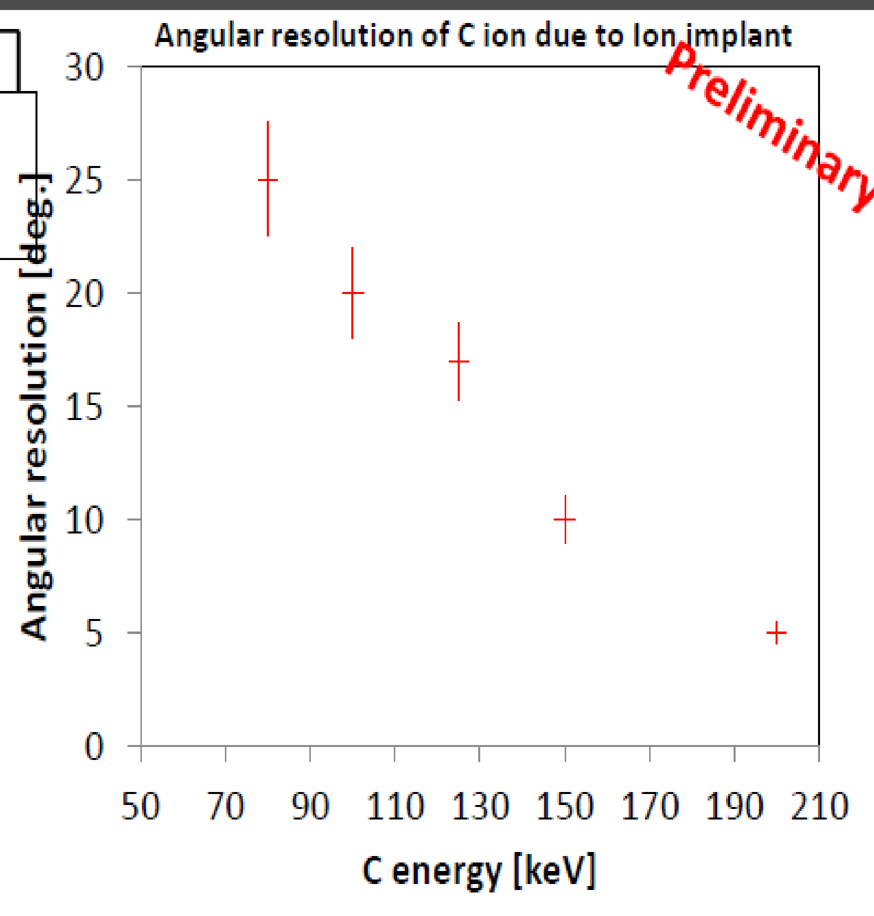
Low velocity ion created by an ion-implantation system

Angular resolution is better than about 25 deg. for 80 keV C recoil tracks.

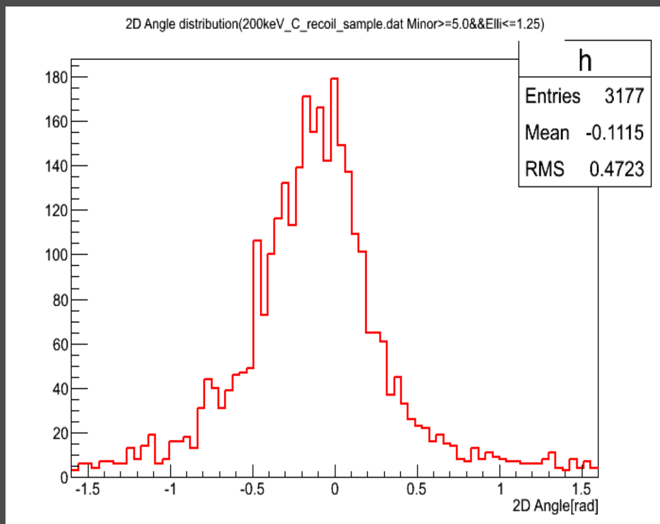
⬇

Angular resolution will be better with confirmation of X-ray microscope.

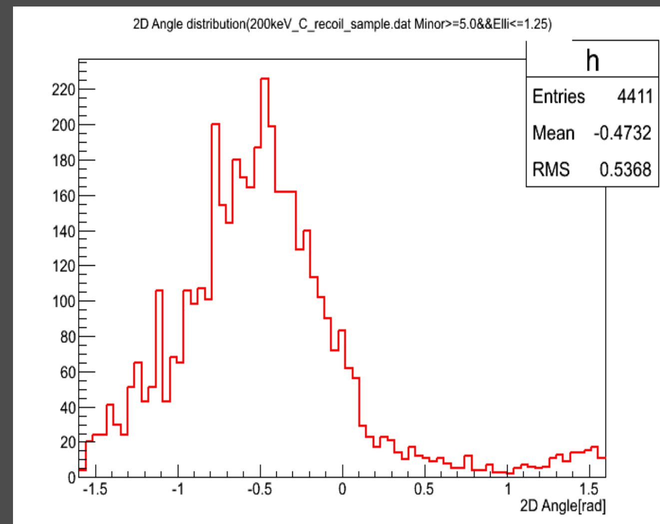




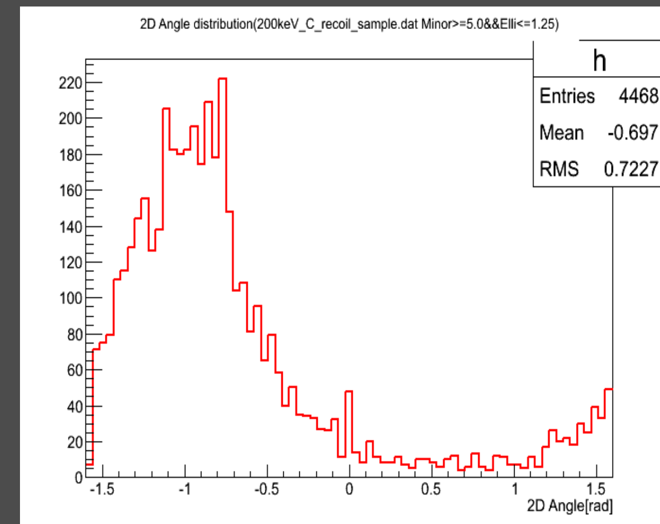
confirmed that it is possible to detect the incident direction of the ion (C 150keV)



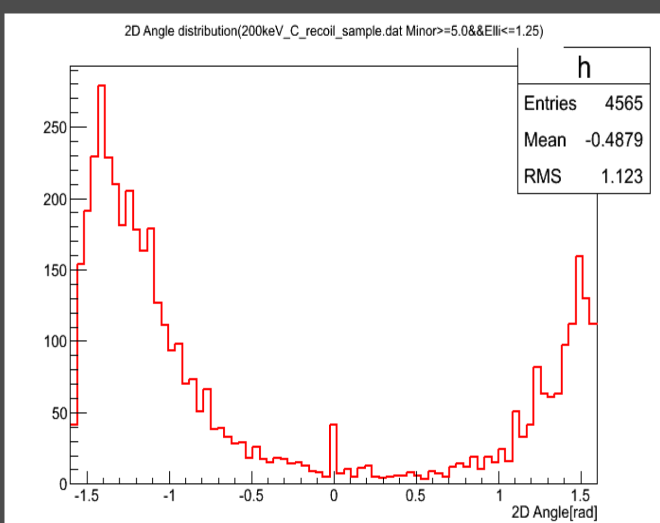
base



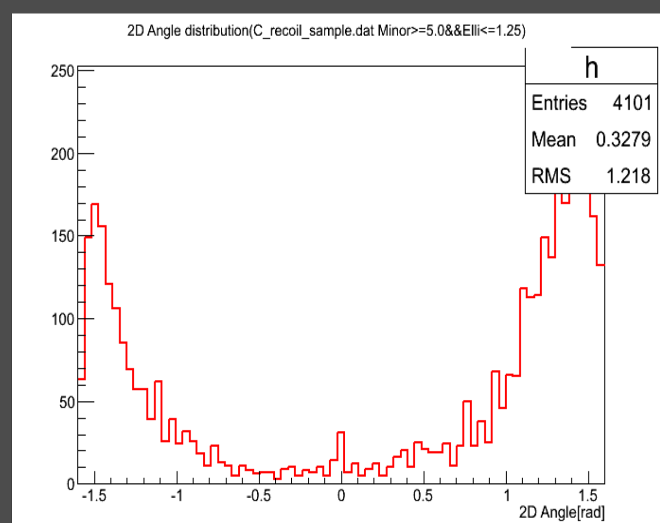
+22.5[deg]



+45[deg]



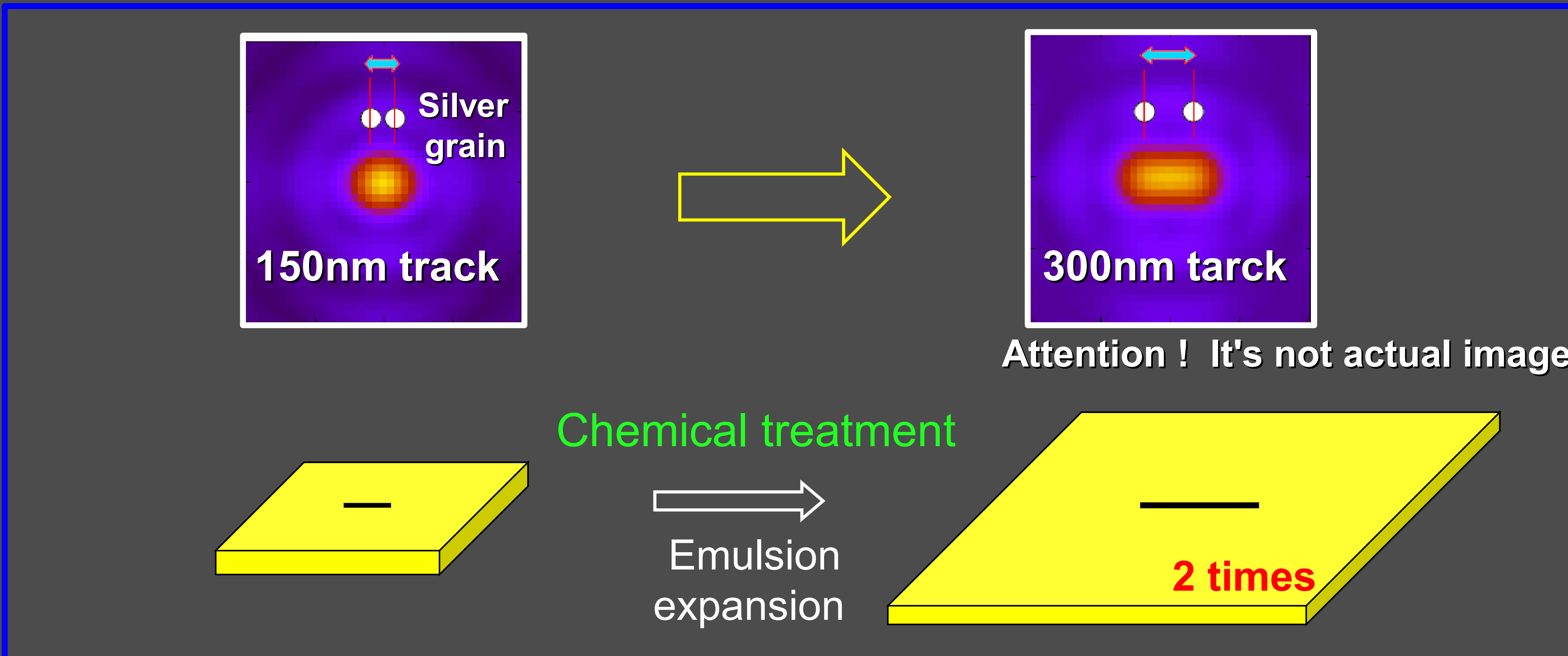
+77.5[deg]

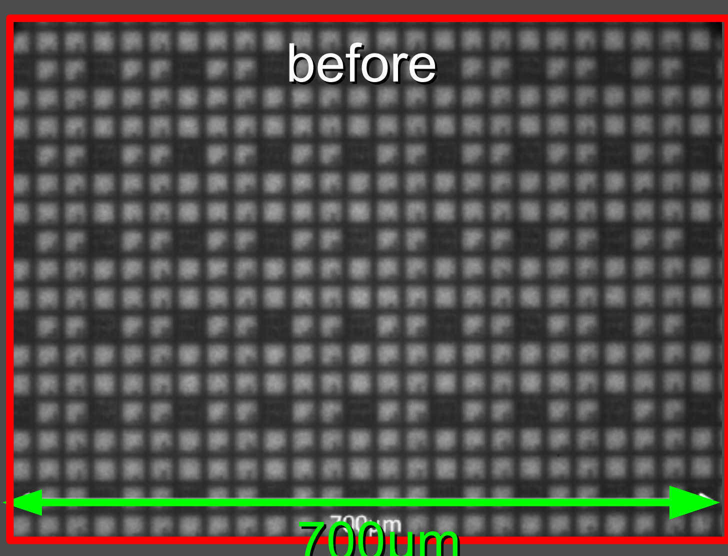


+90[deg]

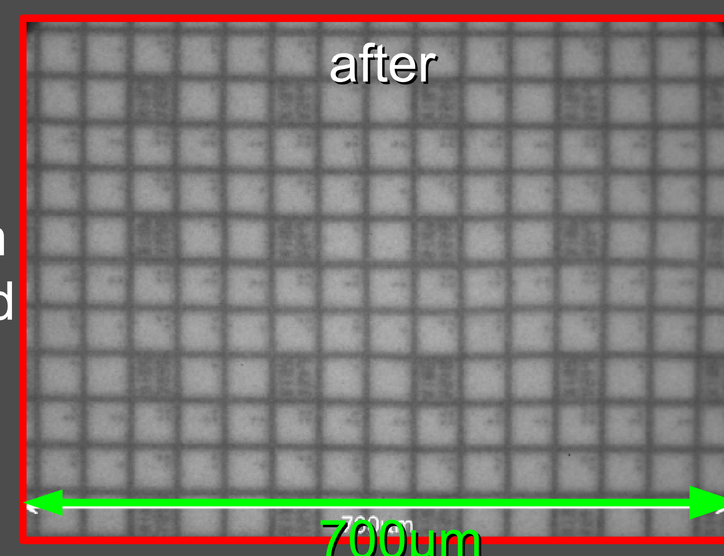
rotate sample by 22.5 degrees as compared to the stage

Expansion technique





Mask pattern was expanded



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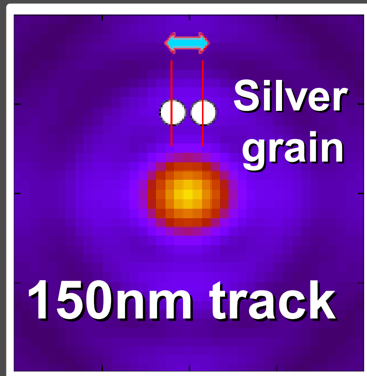

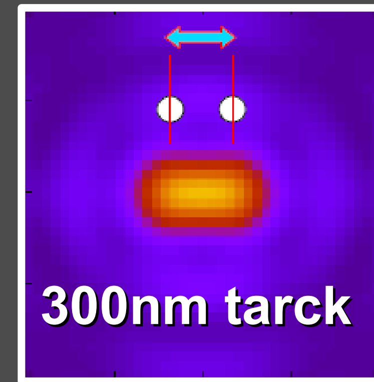

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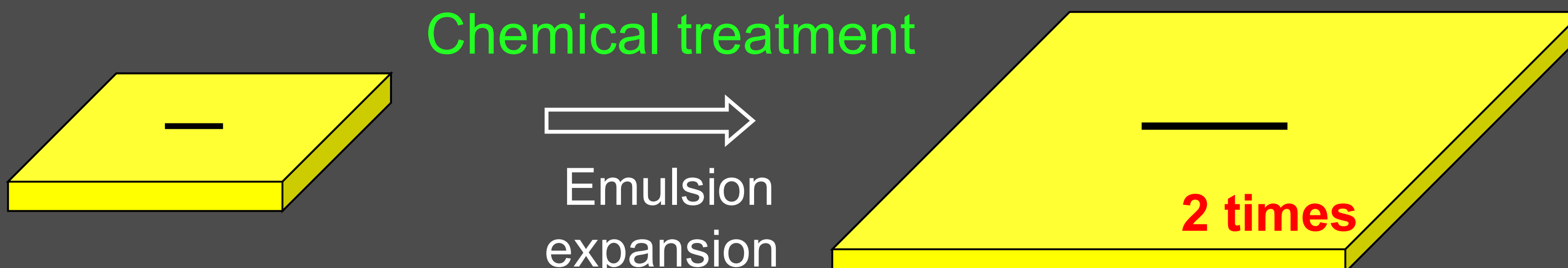

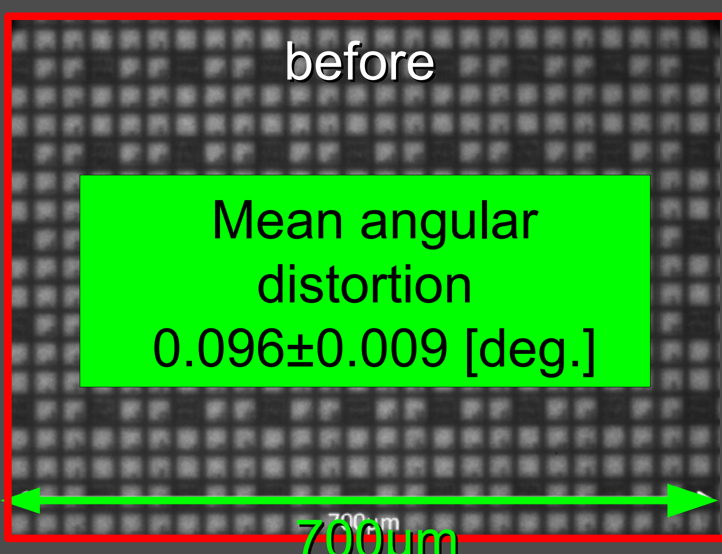

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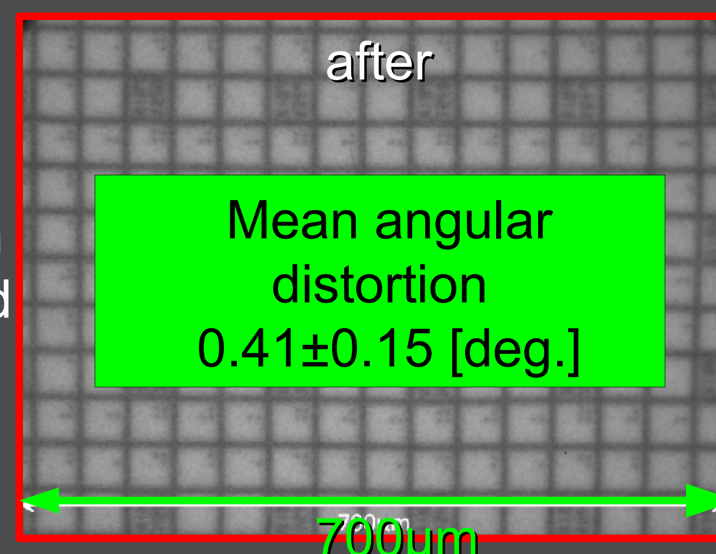
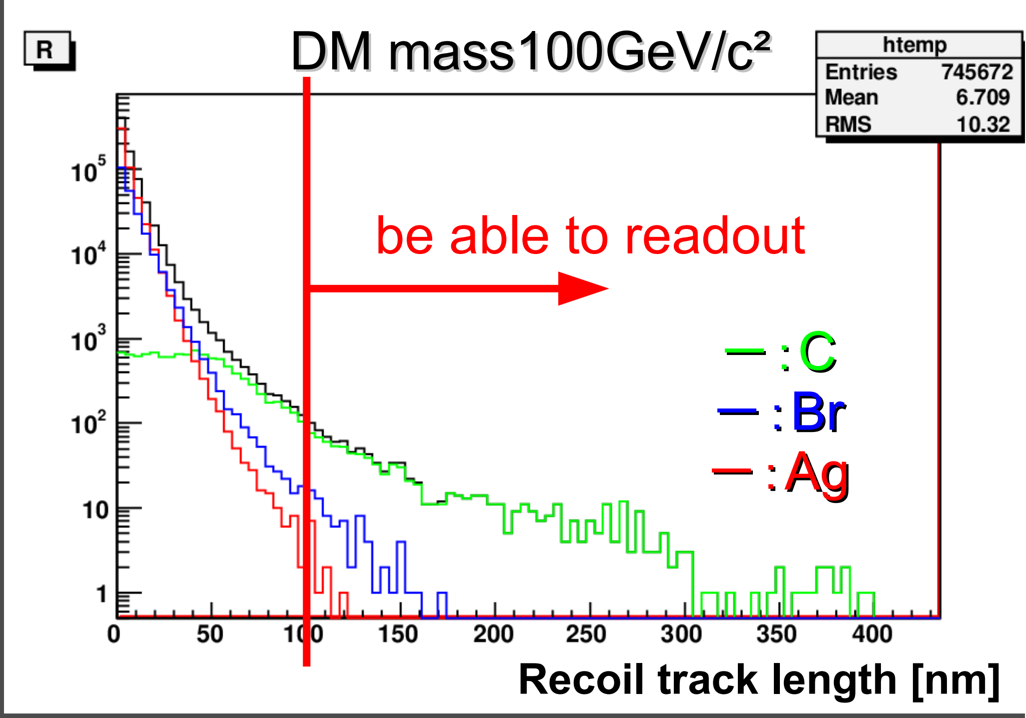


Readout efficiency by using expansion technique

Readout efficiency :
200~220nm : 70%
220~240nm : 80%
>240nm : >90%
(visible length)

Readout efficiency :
100~110nm : 70%
110~120nm : 80%
>120nm : >90%
(using expansion)

Energy :
Ag : 200 keV
Br : 160 keV
C(NO) : 37 keV
(>=100nm)



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Preliminary

Energy :

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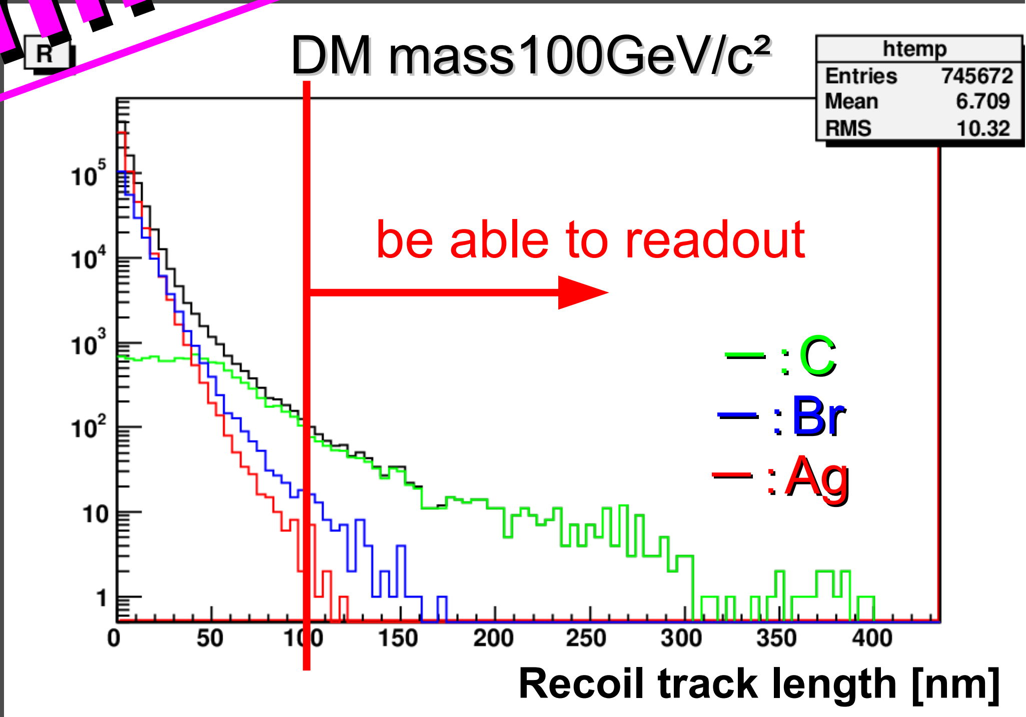
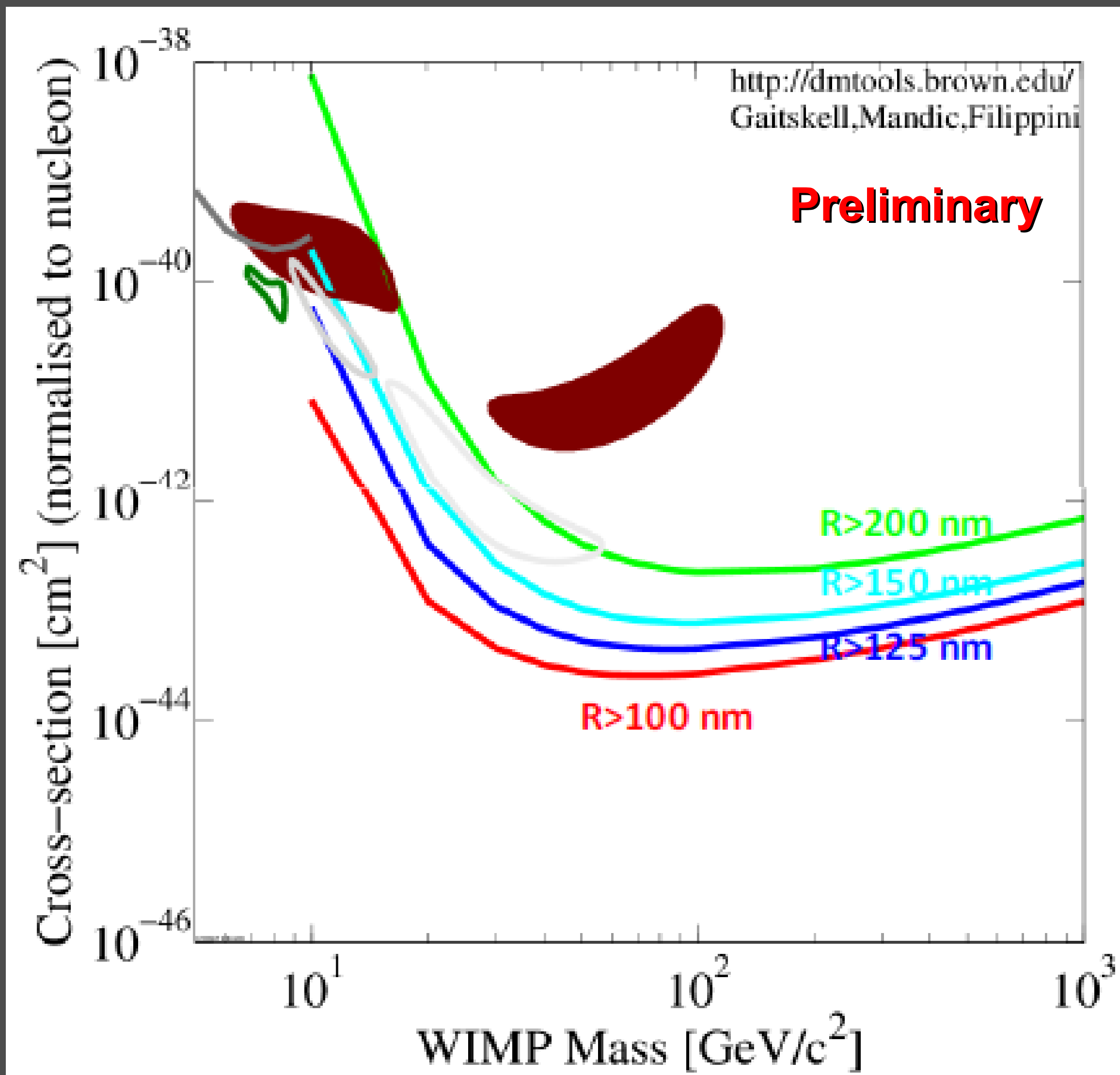
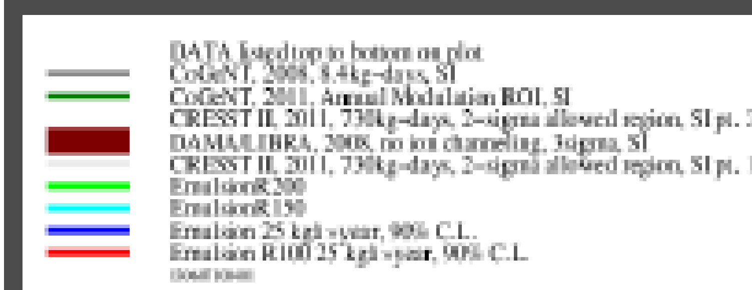
(>=100nm)



Ideal SI cross section limit by using Emulsion detector

SI limit [25 kg・year, R>100, 125, 150, 200nm, 90%C.L.]

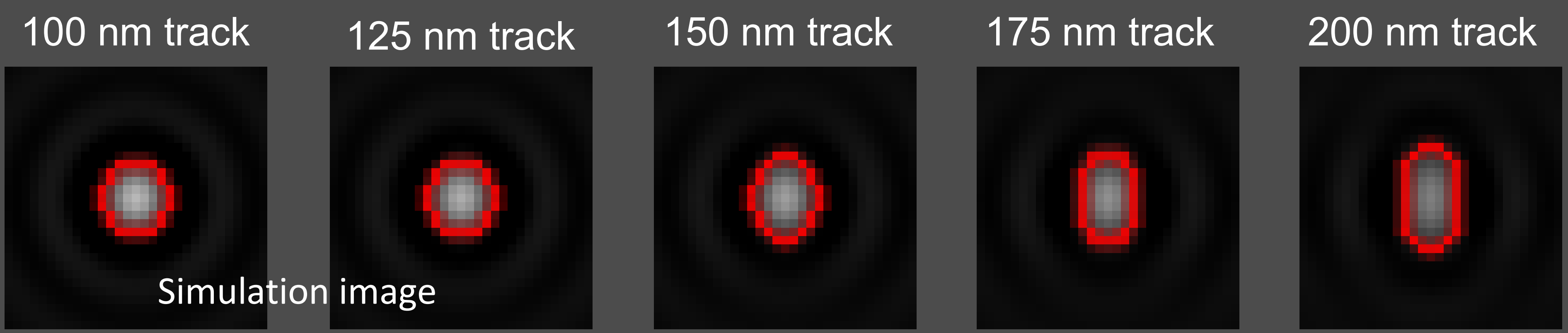


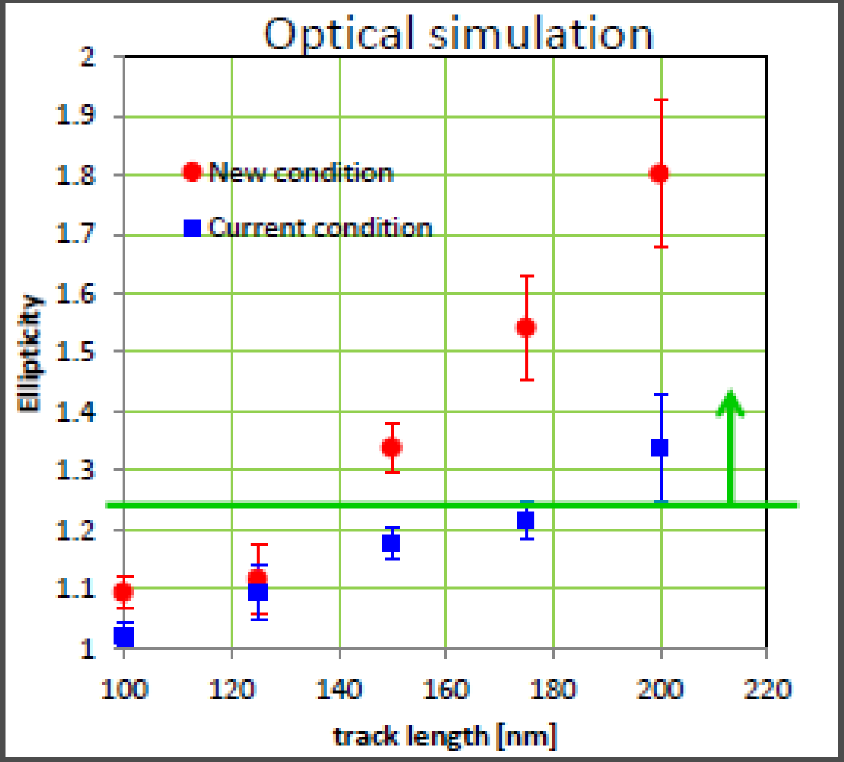


Upgrade plan about Analysis System

Current setup **New setup**

- DALSA1M120 (cell size : 7.5 x 7.5 μm2) → **SENTECH CMB4MCL (cell size : 5.0 x 5.0 μm2)**
- Wavelength for readout : 550 nm (green) → **450 nm (blue)**
- Numerical Aperture : 1.25 → **1.40**



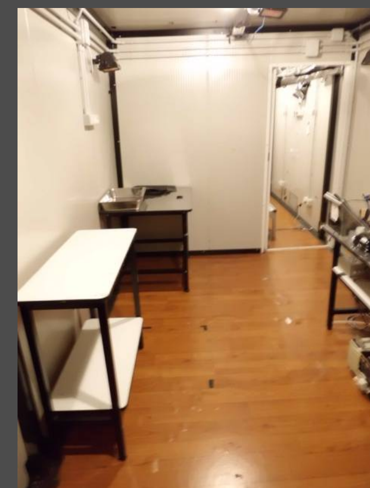


- We are aiming to improve the reading efficiency by changing the setup of the optical microscope.
- As a result, there is expected to be possible to selection 150nm tracks.
- Through the expansion technique of 1.2 times, we can search up to 10GeV in principle.
- In addition, we are challenging to the selection of another approach now.

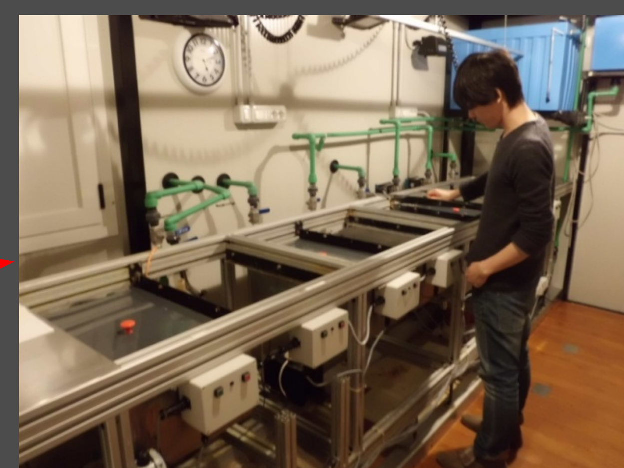
Underground facility in Gran Sasso for R&D

Gran Sasso (LNGS), Italy

2nd Floor: Detector Production



1st Floor : Development Facility



LNGS activity

- Preparing the measurement of low radio activity in the our material (ppb – ppt level).
  ⇒ ICP-MS (obtain cooperation from DarkSide)

- Temperature and humidity monitor and control system.

- Rn monitor and N2 purge system

We are preparing the application of official R&D project for LNGS.

- (Test of monochromatic neutron source in CERN)

Near future plan

~2013 | 2014 | 2015 | 2016

Detector (Emulsion)

Development of fine grained Emulsion with self-production.

Sensitivity turning and stability check for test run.

Sensitivity turning for fine grained emulsion

gram scale BG study at Gran sasso

Analysis System

Base of readout system was constructed about the optical microscope and X-ray microscope.

Start of BG study and R&D for BG discrimination (gamma, beta, neutron)

BG study and upgrade for high-speed and high-resolution

Summary

- We have developed a detector for dark matter search which can detect the tracks of 100nm or more.
- Base of fully automatic analysis system was also completed.
- We are evaluating the performance by using an ion-implantation system.
- Our experiment is transitioning to phase of BG study.
- Currently , we are preparing for small scale BG run.

Collaborator and Technical Supporter

Nagoya University

T. Naka (Organizer of Japan and all)
T. Asada (R&D of fine-grained emulsion)
T. Katsuragawa (Readout system)
M. Yoshimoto (Optical Readout Stage)
K. Hakamata (Development treatment)
M. Ishikawa (Plasmon analysis study)
A. Umemoto (Plasmon analysis study)
K. Kuwabara (R&D of emulsion)
M. Nakamura (PI)
T. Nakano (Scanning system)
O. Sato (analysis)

Nagoya University [X-ray Astronomy]

Y. Tawara (X-ray microscope)

University of Napoli

G. de Lellis (Organizer of Europe)
A. Di Crescenzo (DM simulation)
A. Sheshukov (Emulsion simulation)
A. Aleksandrov (Optical stage study)
V. Tioukov (tracking algorithm)

University of Padova

C. Sirignano (Development and emulsion study in Gran Sasso)

LNGS

N. D'Ambrossio
(Optical microscope study in LNGS)
N. Di Marco
F. Pupilli

SPring.8

Y. Suzuki (X-ray MS @ BL47, 37XU)
Y. Terada (X-ray MS @ BL37XU)
A. Takeuchi (X-ray MS @ BL47XU)
K. Uesugi (X-ray MS @ BL47XU)

Chiba University

K. Kuge (emulsion and development study)

Fuji Film researcher

T. Tani (Emulsion and phenomenology)
K. Ozeki (Emulsion and phenomenology)
Saito (the machine technology)

Fin.