Directional Dark Matter Search With Ultra Fine Grain Nuclear Emulsion

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  - About dark matter
  - Dark matter search experiments
- **Emulsion R&D**
  - New production method
  - Sensitivity control
- **Readout R&D**
  - Optical microscope
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- **Activity**

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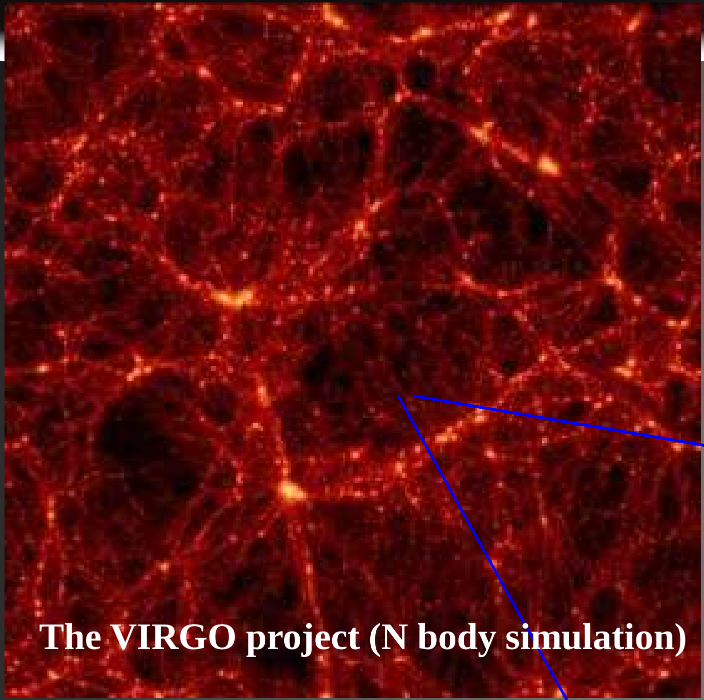
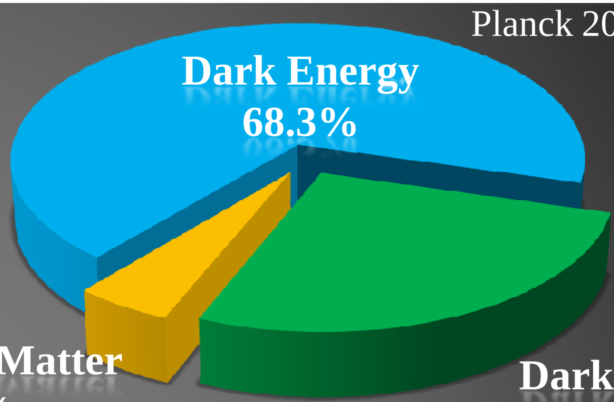
Dark Matter Problem



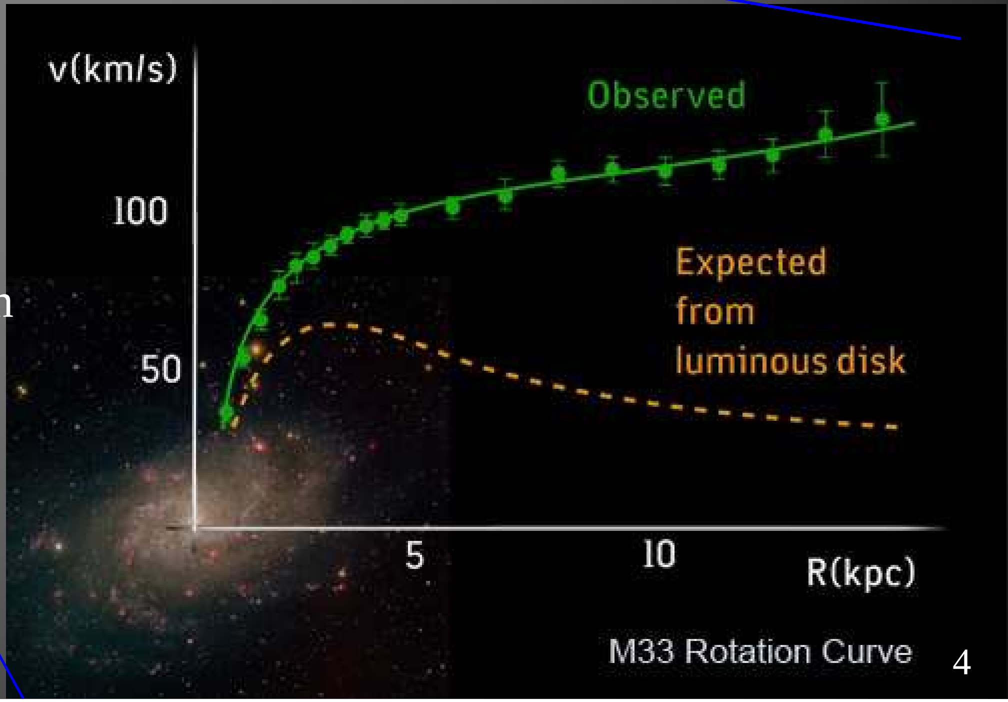
The VIRGO project (N body simulation)



-The universe needs the cold dark matter to construct the current structure.

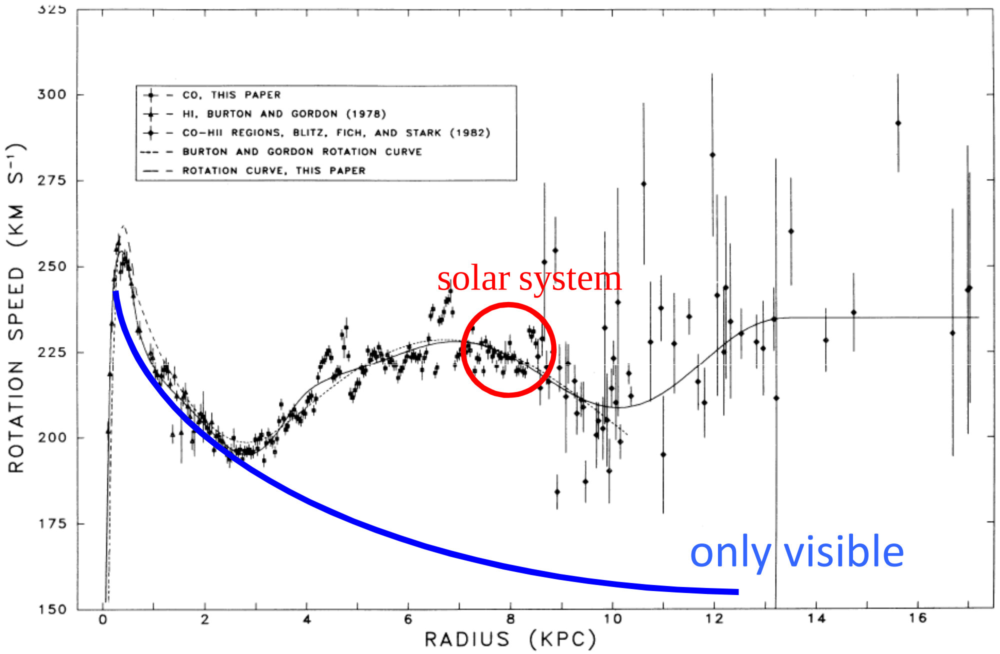
- Initial unevenness of dark matter distribution affects CMB
⇒ Dark matter density from WMAP / Plank observation

- Rotation velocity curve of galaxy indicates the existence of dark matter in local scale.



Existence of Dark Matter around Solar System

Rotation Velocity Curve of Milky way Galaxy



Astrophys. J. 295: 422-436, 1985

Local Dark matter
- density : <u>0.3-0.5 GeV/cm^3</u>

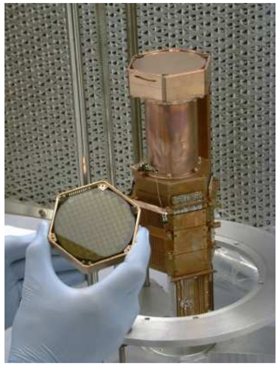
~10000/cm2/sec flux @ earth
(DM mass ~ 100GeV/c^2)

- velocity distribution
⇒ <u>Maxwellian</u> ??
(astrophysical parameter)

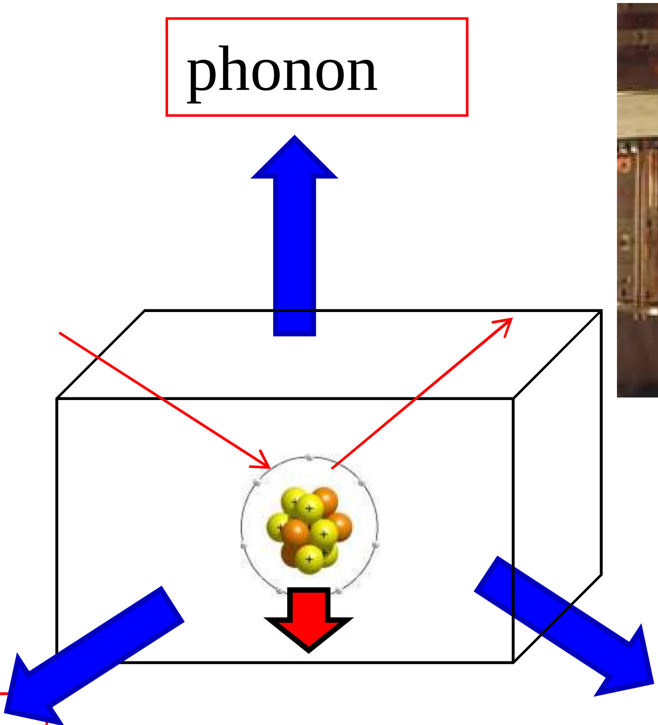
High accuracy measurement by VERA (2012)
rotation velocity of solar system : 240 +- 14 km/sec

Direct Dark Matter Search

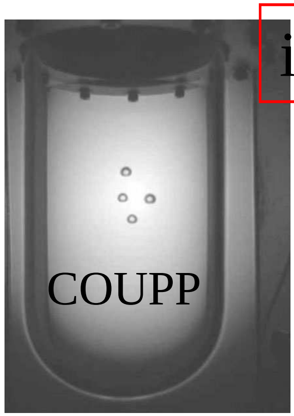
Target : Xe, Ge, Si, NaI, Ar etc



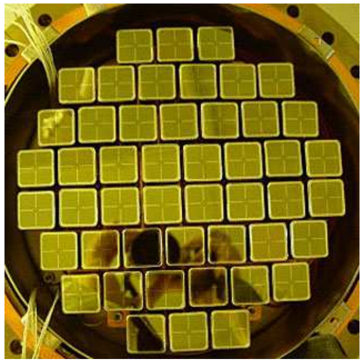
CDMS, EDELWEISS



CRESST



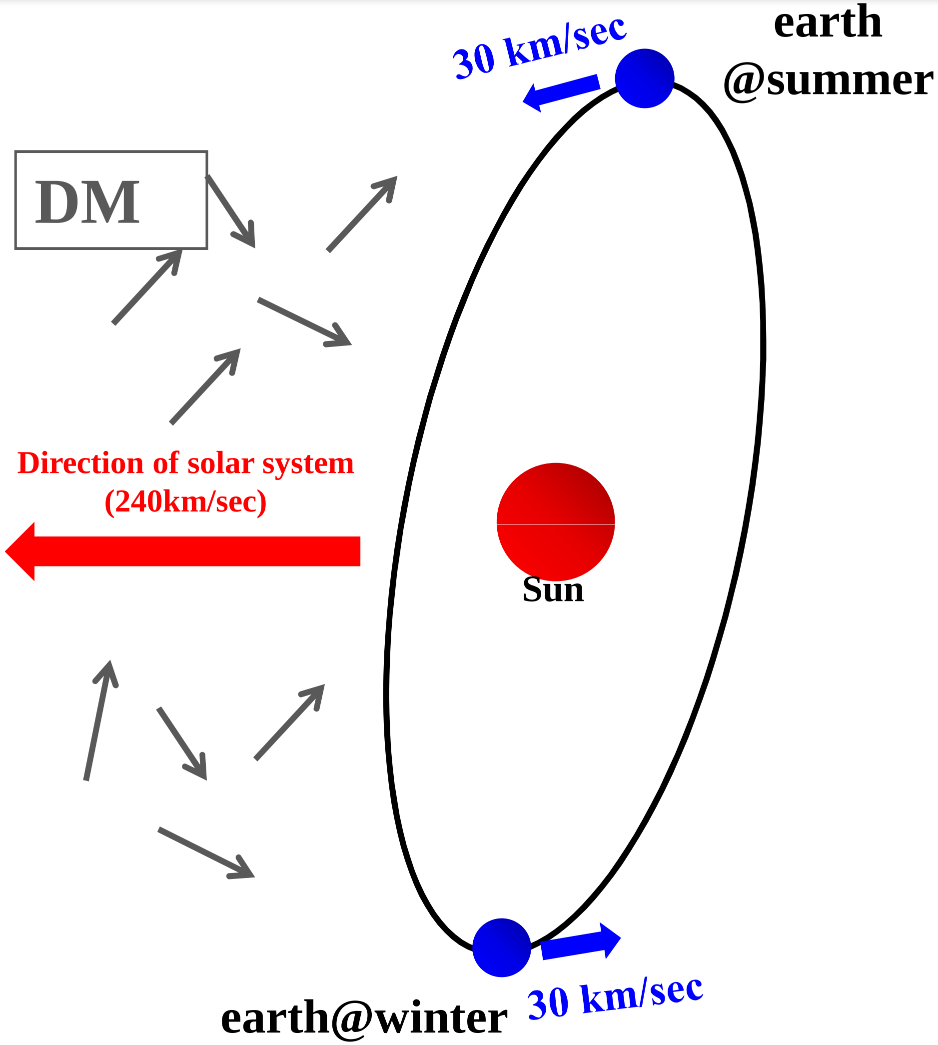
COUPP

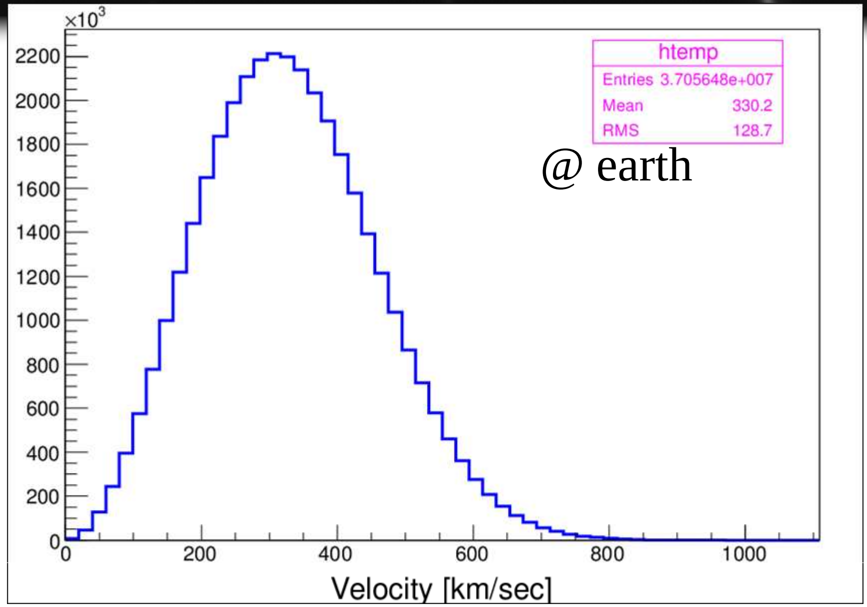


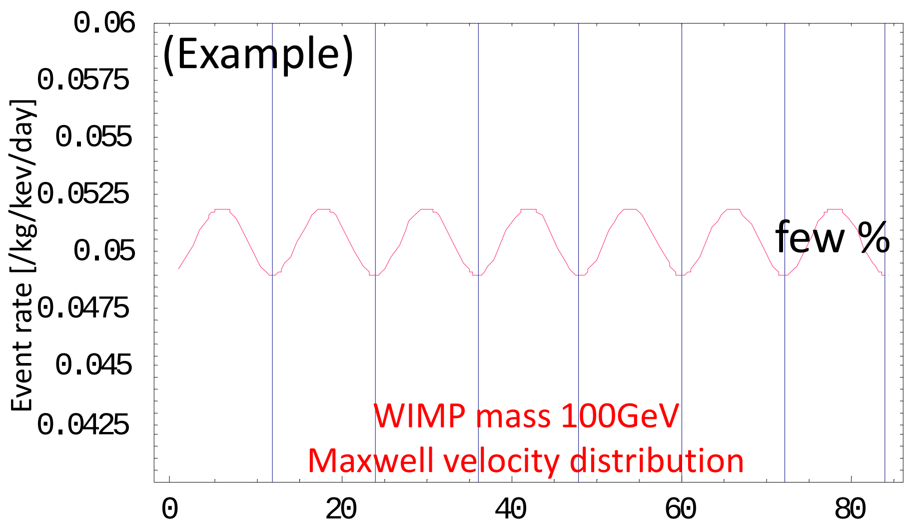
XENON, WArP, ZEPELIN

XMASS, DAMA, KIMs

Current Method of Dark Matter Identification



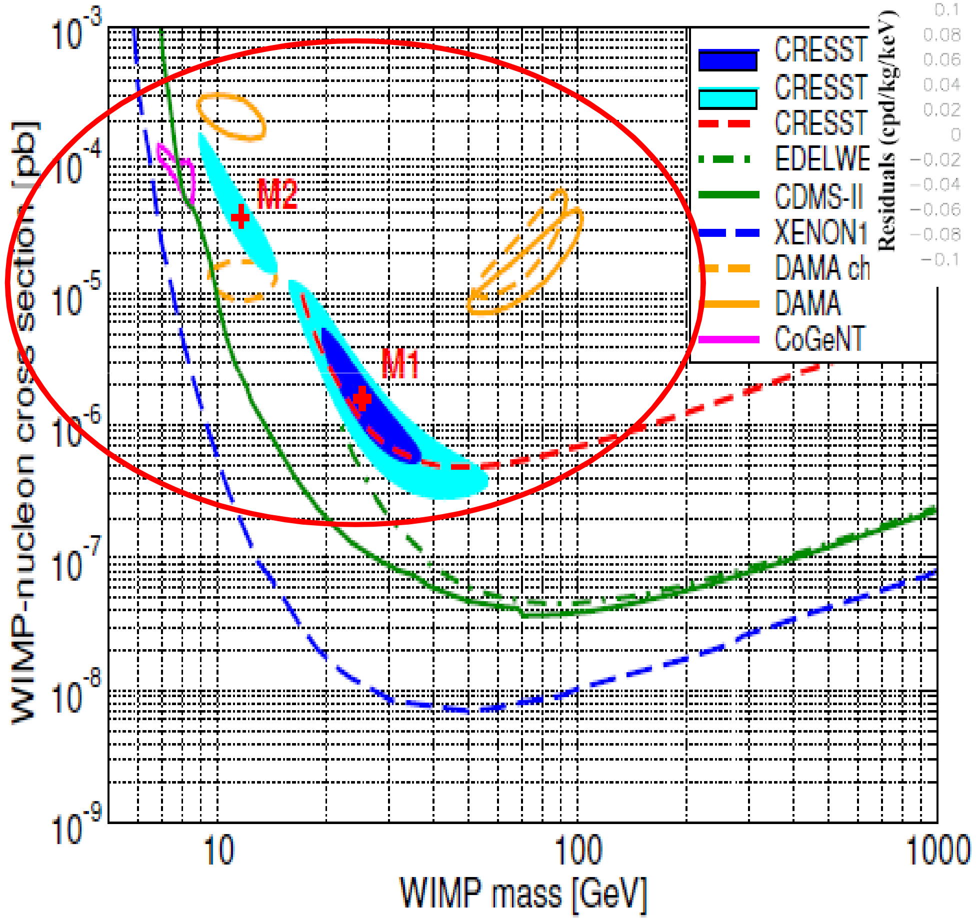




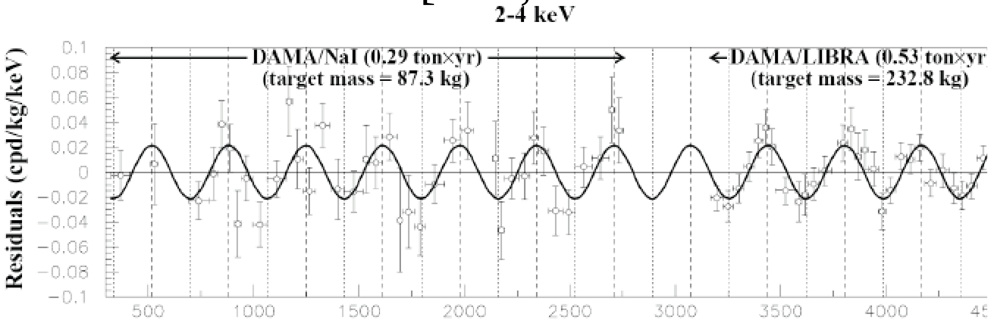
Relative velocity of earth to dark matter is variable by revolution around sun

➡ Annual modulation

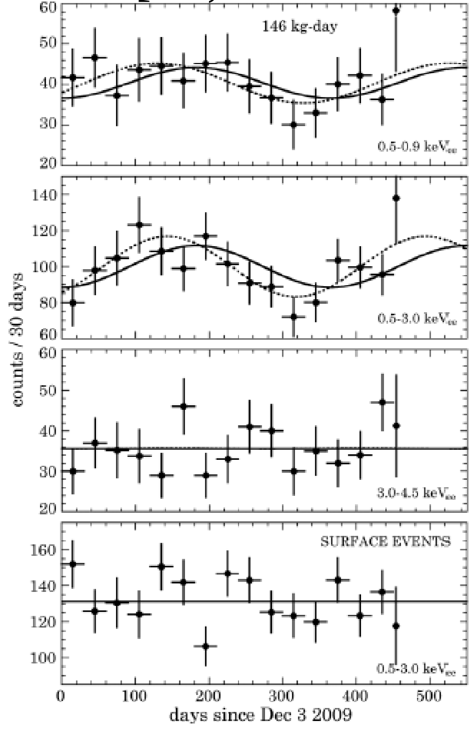
Status Cross Section Limit



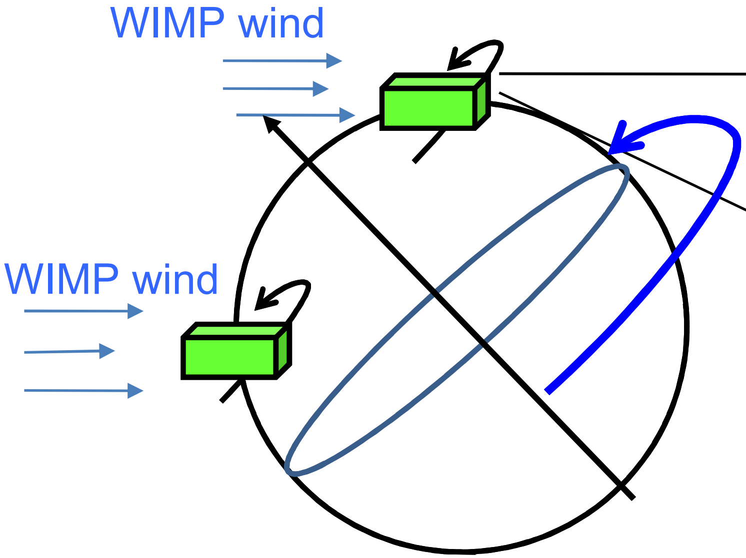
DAMA/LIBRA [NaI, 8.9σ annual modulatio

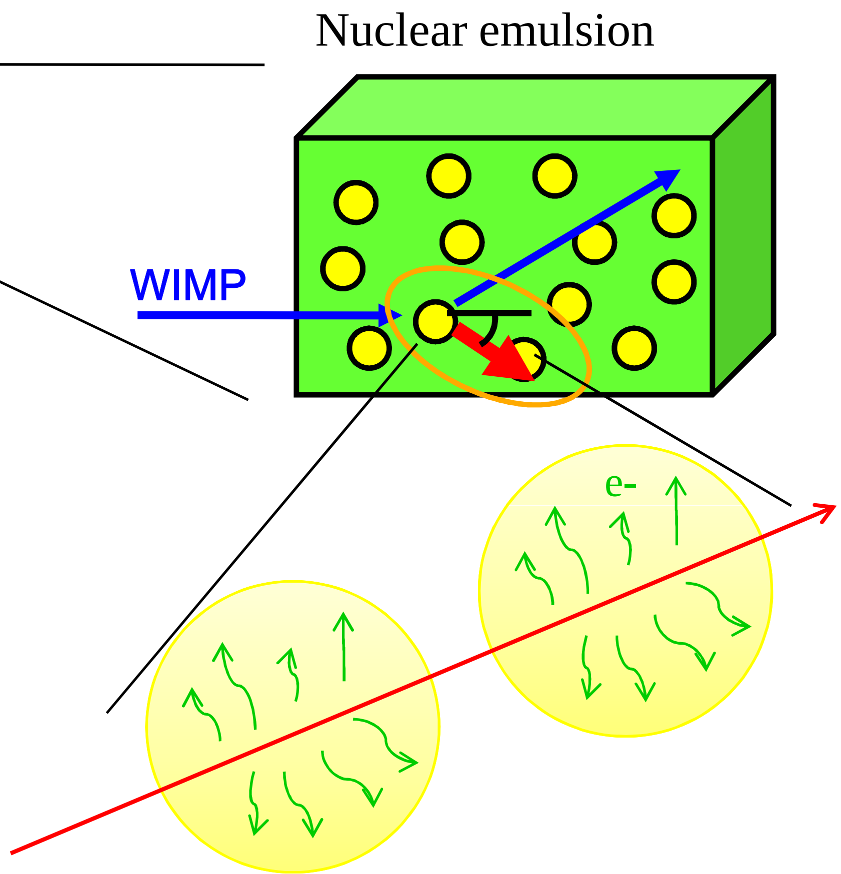


CoGent [Ge, 2.86σ Ann. Mod.]

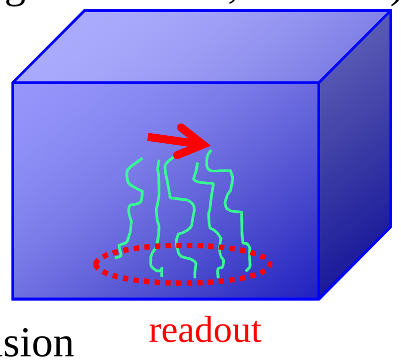


Directional Dark Matter Search with Nuclear Emulsion





cf. Gaseous Detector
(All other directional DM search experiments use gaseous detector . e.g. gaseous TPC, MWPC)

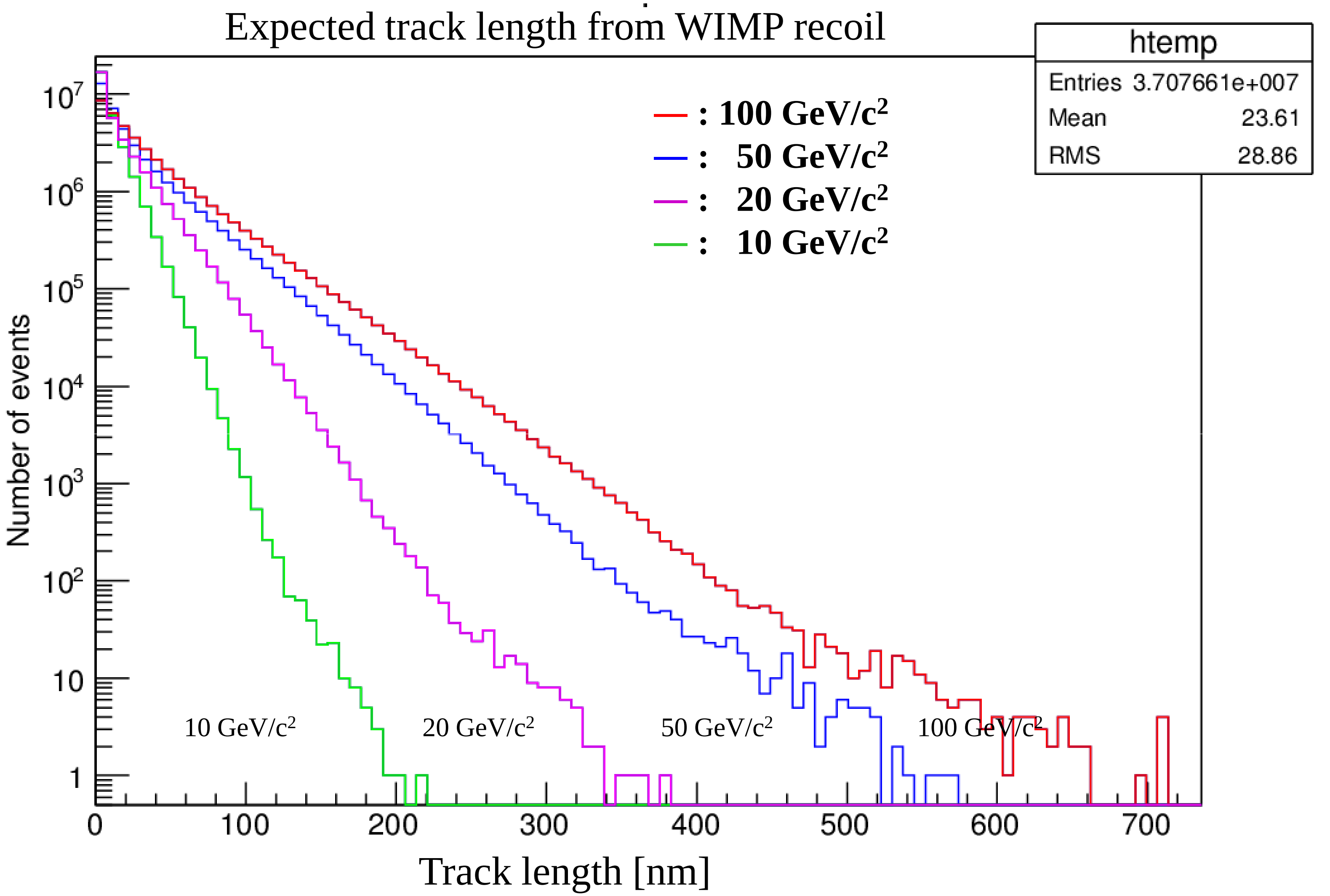


Diffusion
⇒ problem of **size limit**

Ionized electrons closed in the crystal
⇒ diffusion problems are nothing .

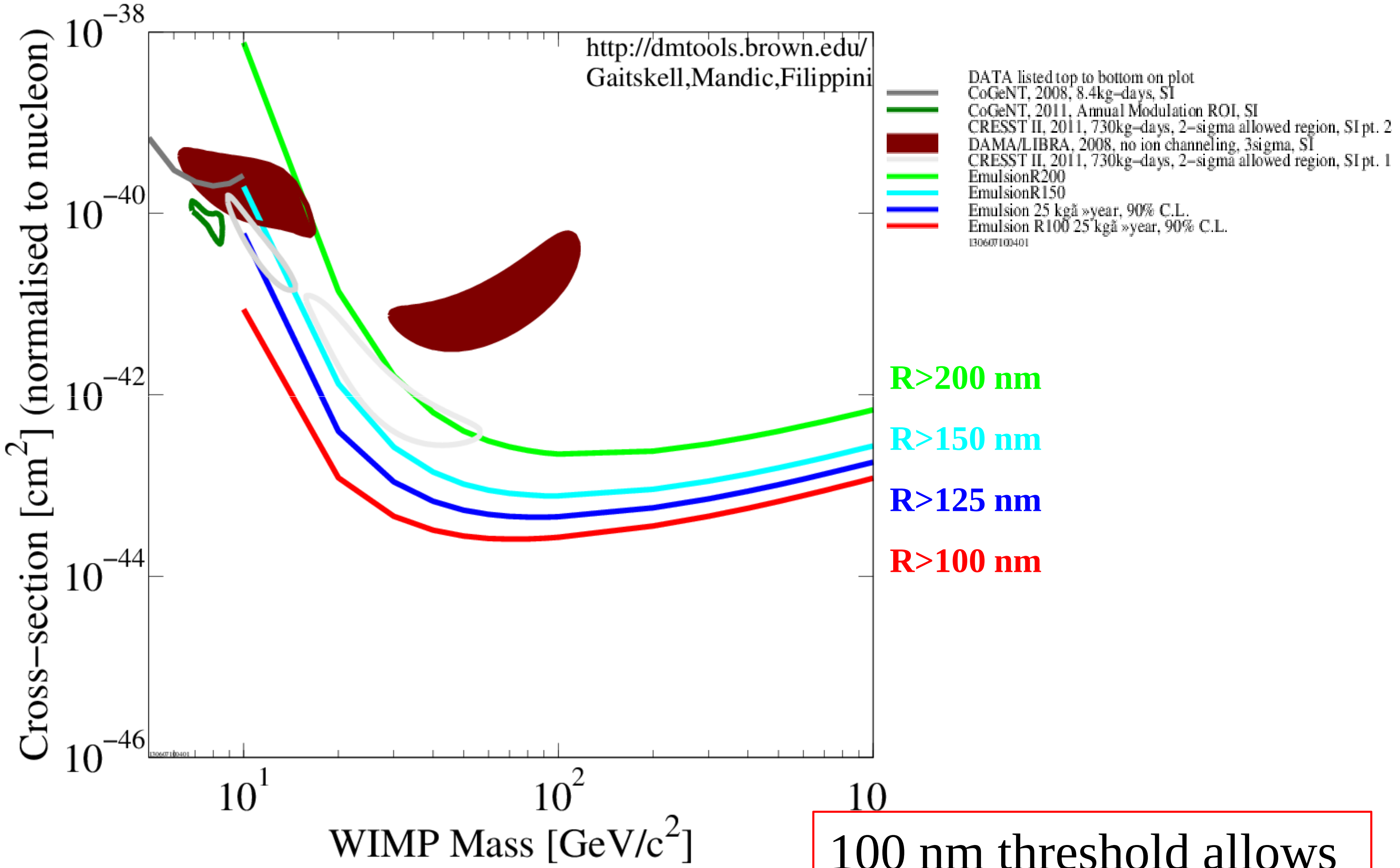
if extreme short tracks is detectable,
Large mass experiment is relative easy

Expected Range of Signal Tracks



The ranges of our target tracks are only several 100 nm

Ideal Cross Section Simulation
[spin independent, 25kg・ y, 90% C.L.]



100 nm threshold allows to cover DAMA region !

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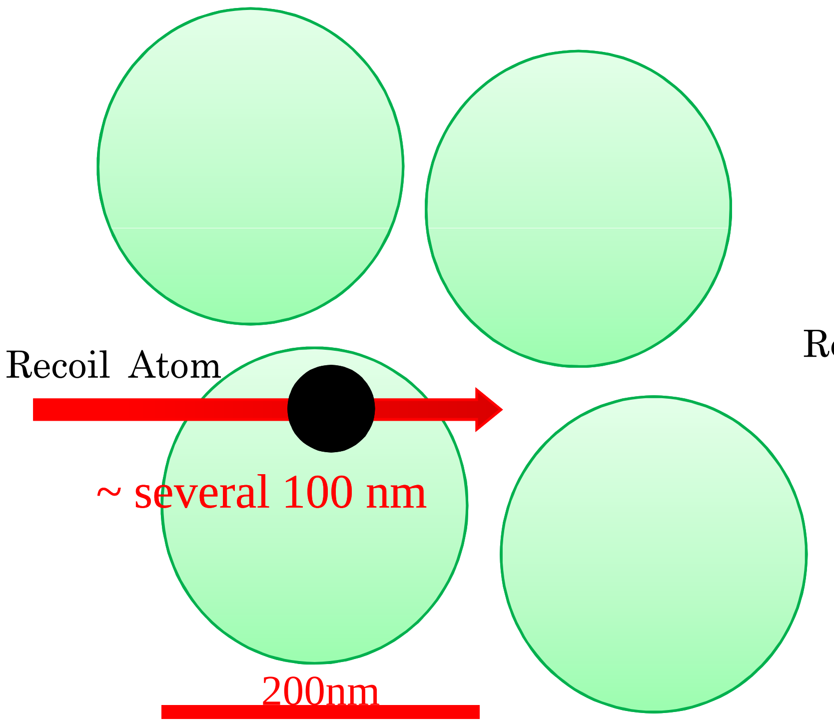
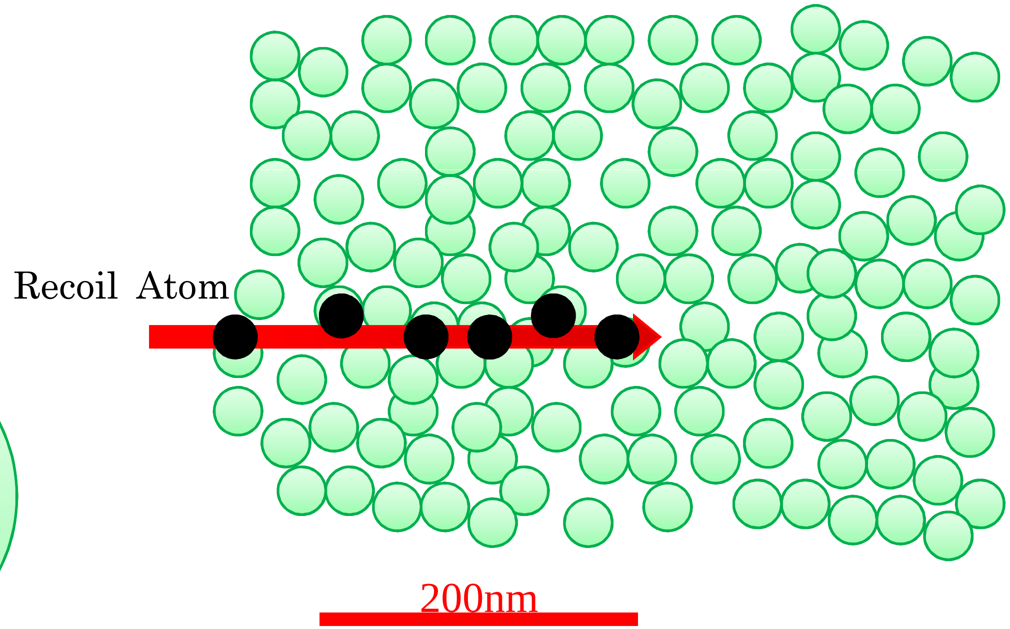
How we detect short tracks?

existing emulsion
(ex. OPERA emulsion)

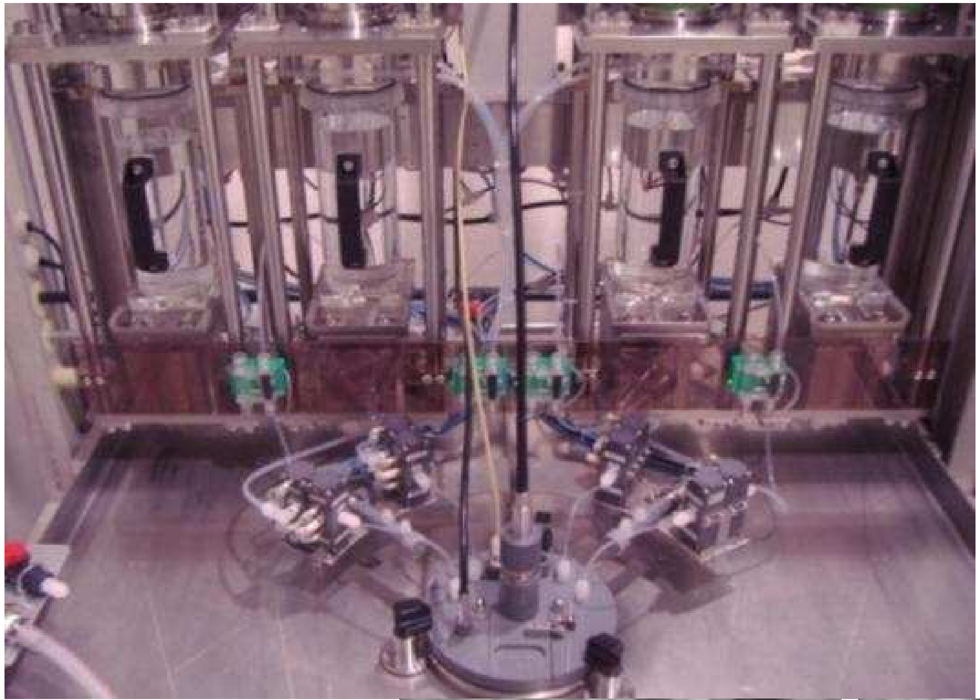


fine grain emulsion



Micronization of crystals is the key to detect short tracks

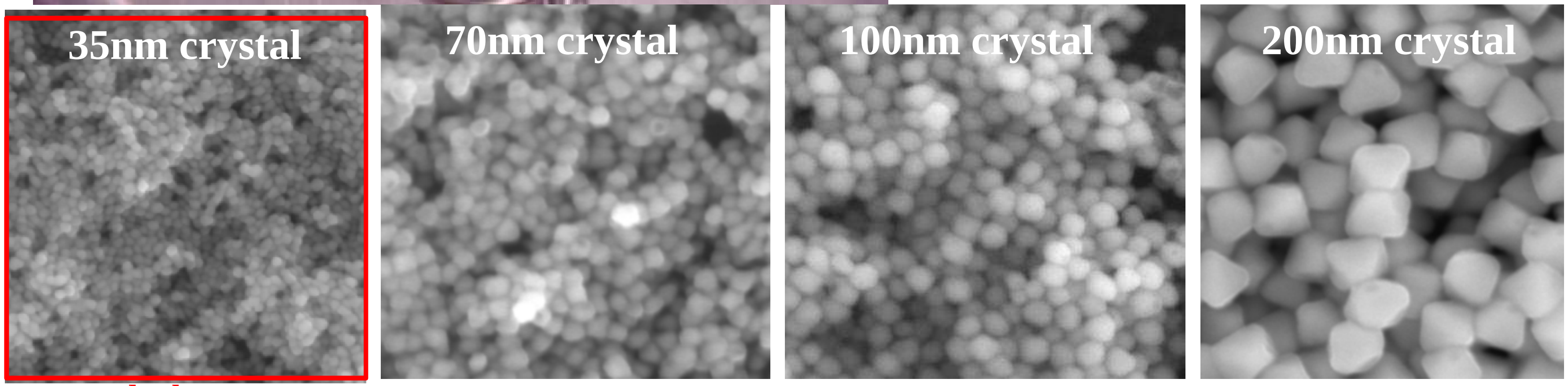
Production of Emulsion in Nagoya (2010~)



Production term: **4h**
Scale: **100g/batch** (dry condition)

We are planning new machine of the tripled volume (2013-14).
→20kg/month
~100kg experiment is possible

- cooperation of Fuji Film OB for machine and production



For dark matter

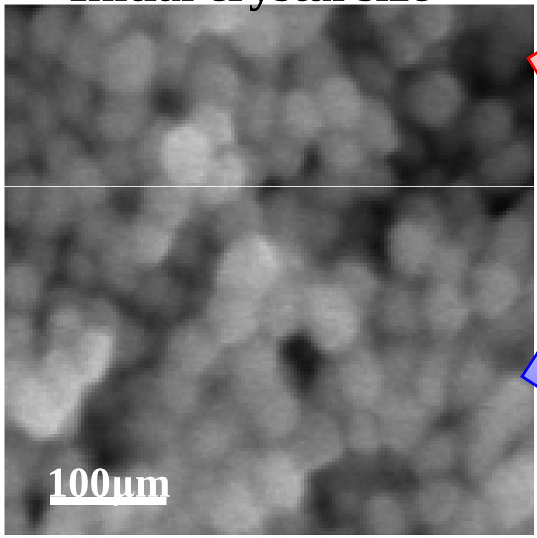
500nm

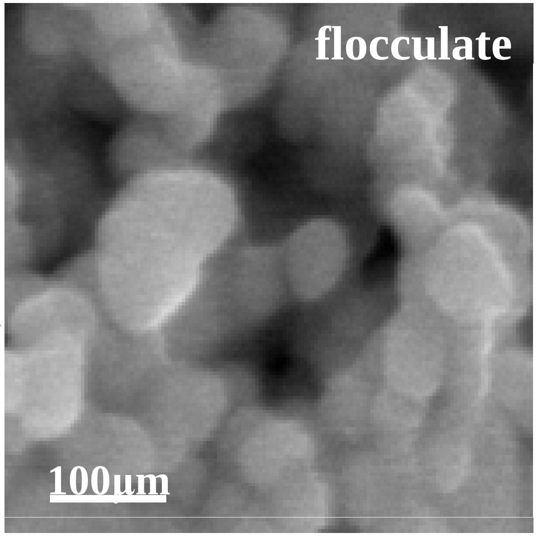
SEM Image without Gelatin

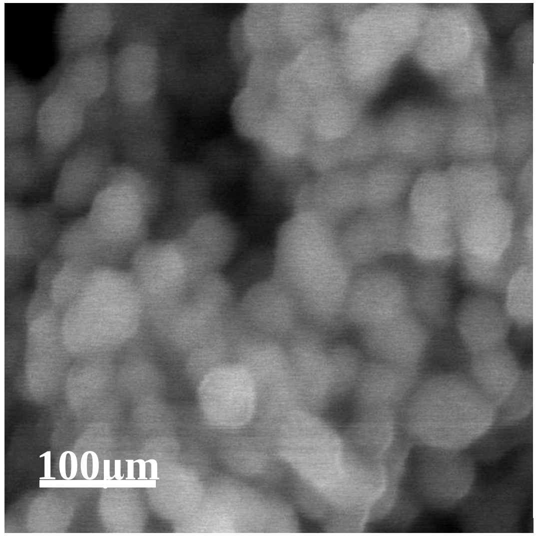
New production method for micronization

Some process
(ex. washing, sensitizing)

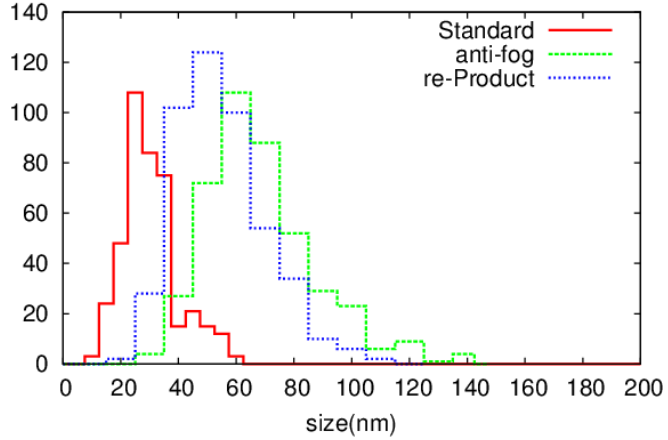
Initial crystal size



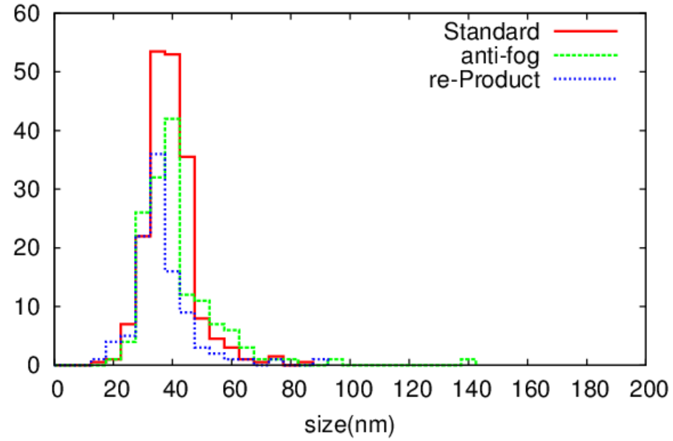




ex-method

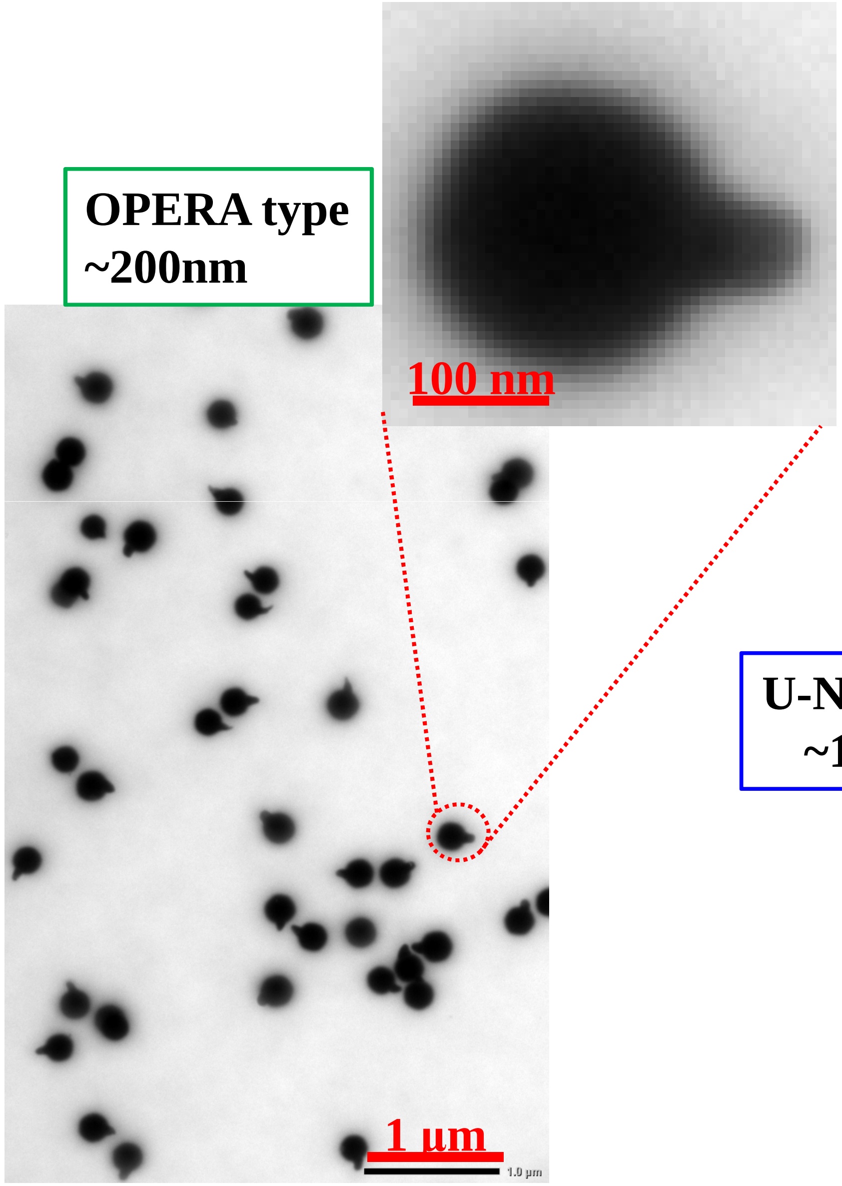


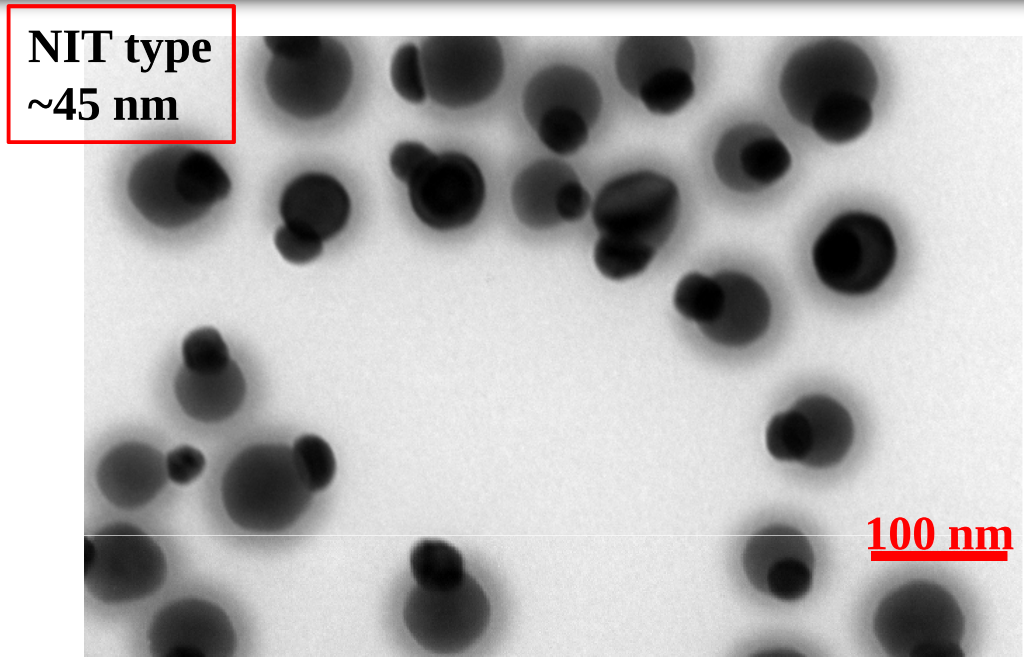
new-method

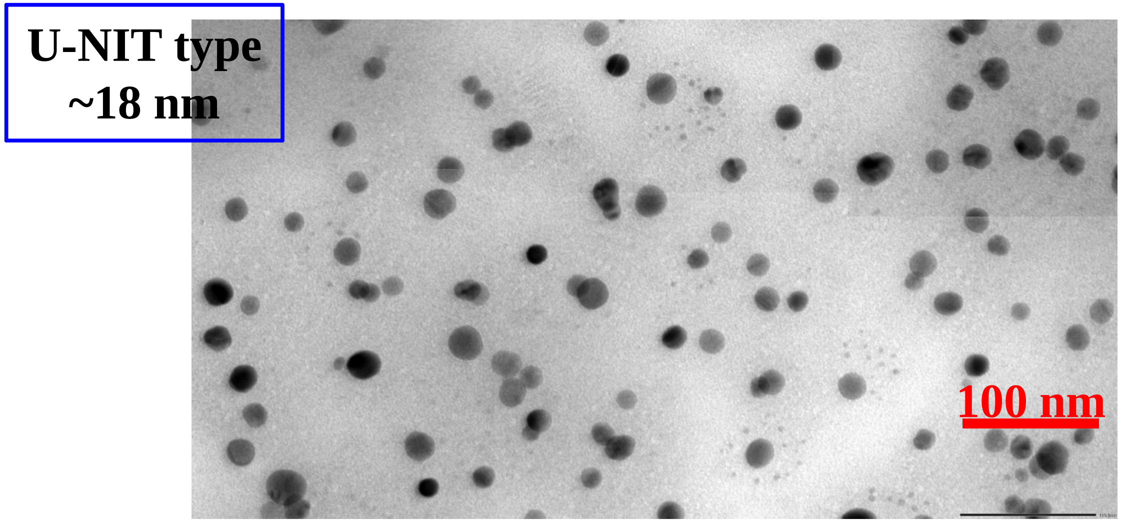


New producing method with polymer
Polymer strongly covers crystals surface, and disturbs their flocculate

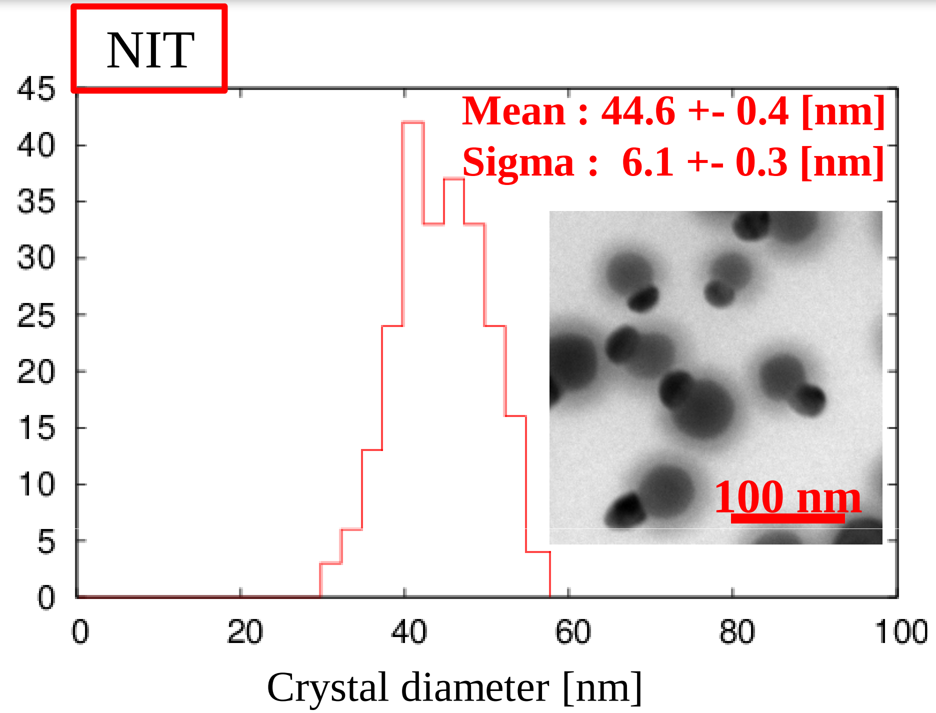
Produced emulsions



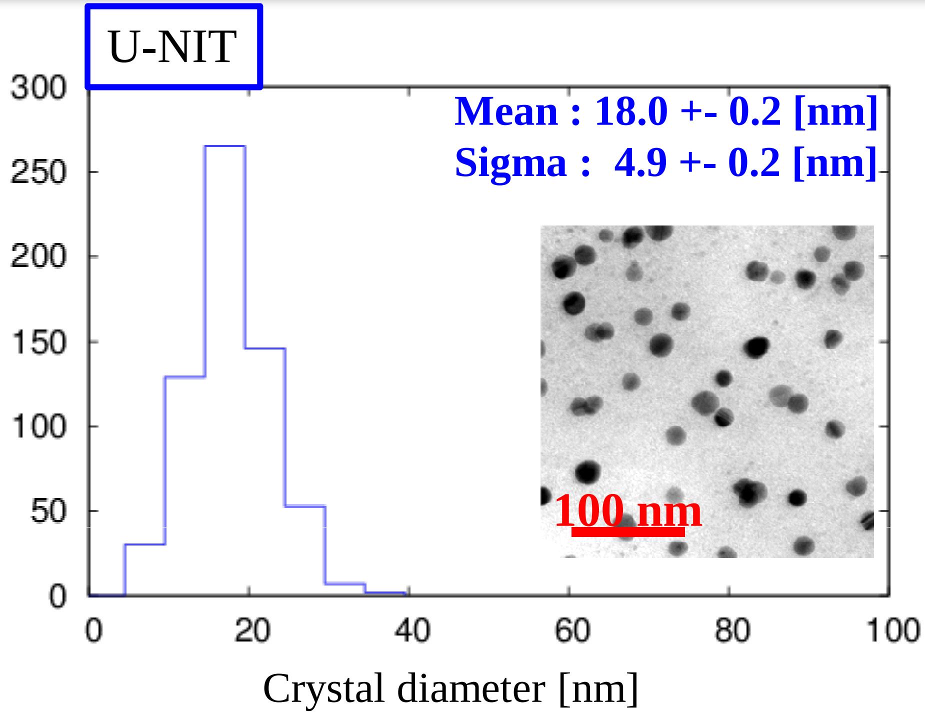




Current Fine-grain detector



current main R&D for test run



Finest grain emulsion for physics run

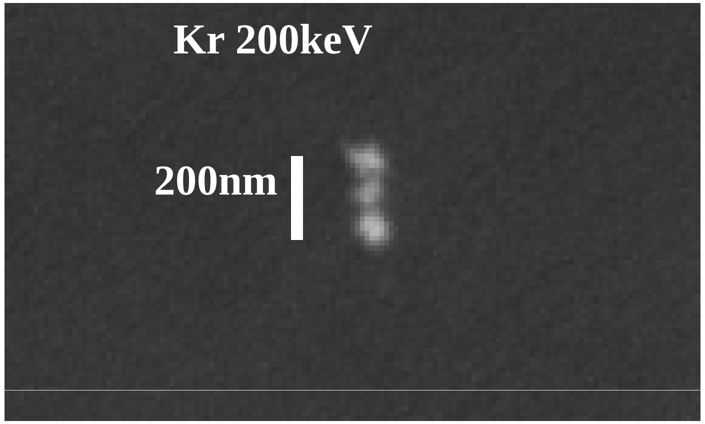
- Reproducibility of them is good
- Size is stable while 3.0-3.7 g/cm^3

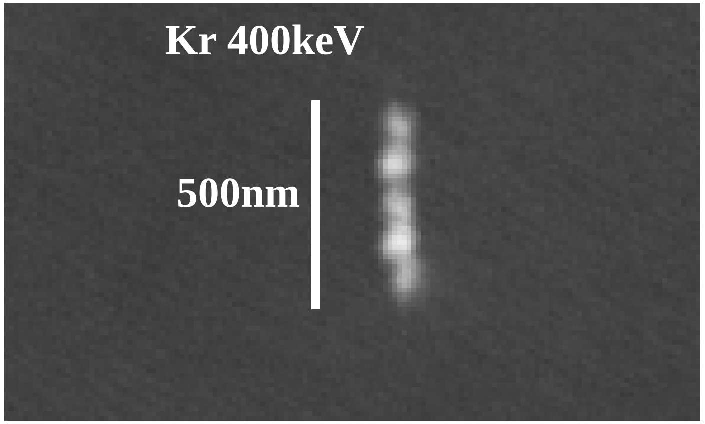
	NIT	U-NIT
crystal density	12 crystal/µm	29 crystal/µm
Detectable range	> 200 nm @ C	> 100 nm @ C
Tracking E threshold	> 80 keV @ C	> 35-40 keV @ C

Short Track sensitivity

Ion implantation machine
Low energy ion is same to recoil signals

implanted ions on emulsion surface





Scanning Electron Microscope

preliminary

Tracking efficiency of NIT :

175keV (520nm expected): 80%
80keV (250nm expected) : 50%
→each crystal sensitivity : 50%?

U-NIT sensitivity is quite low

Our next task is **Sensitizing**

sensitivity control

- Main background :
  intrinsic radio isotope
  (e.g. C-14, Th・ U families etc.)
  → γ・ β backgrounds

- Target nuclei to DM : C, N, O
  → Total dE/dx > ~100 keV/μm

⇩

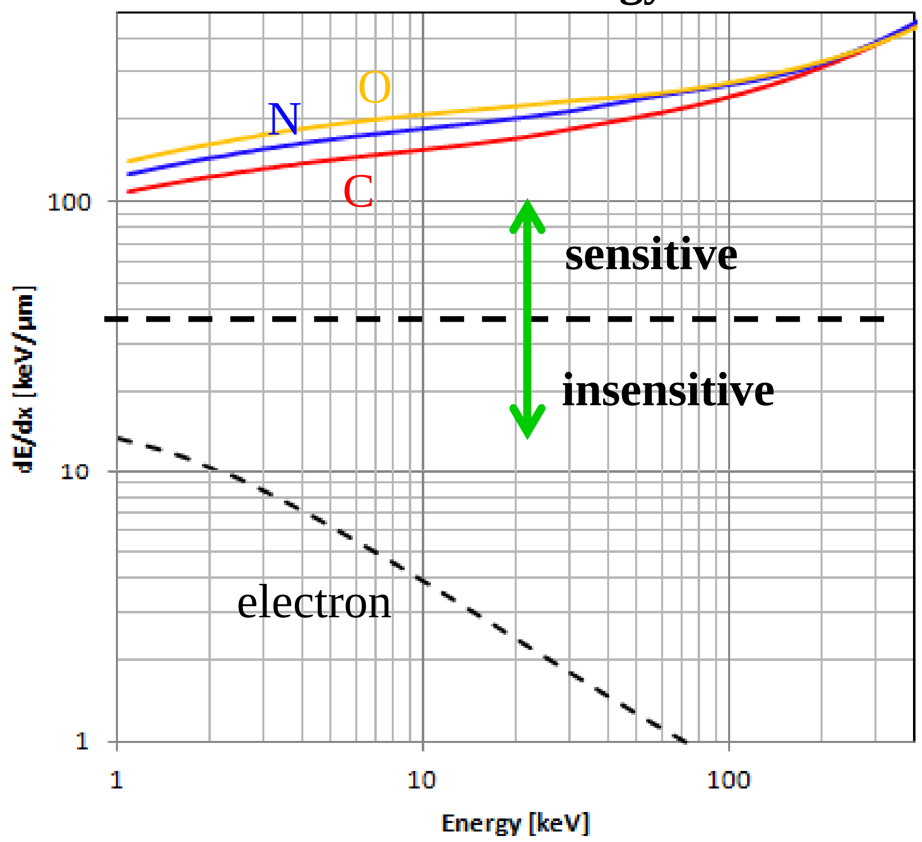
<u>To make high contrast threshold of dE/dx</u>

e.g.

- doping impurities to capture electron / hole
- adding pigments or chemicals on surface for sensitizing and anti-fog
- upgrade of developing method for sensitivity control and to develop fine grains (for resolution)

→now studying

dE/dx vs. energy



dE/dx difference will appear as the <u>number of exited electron</u> and the <u>size of latent image speck</u>

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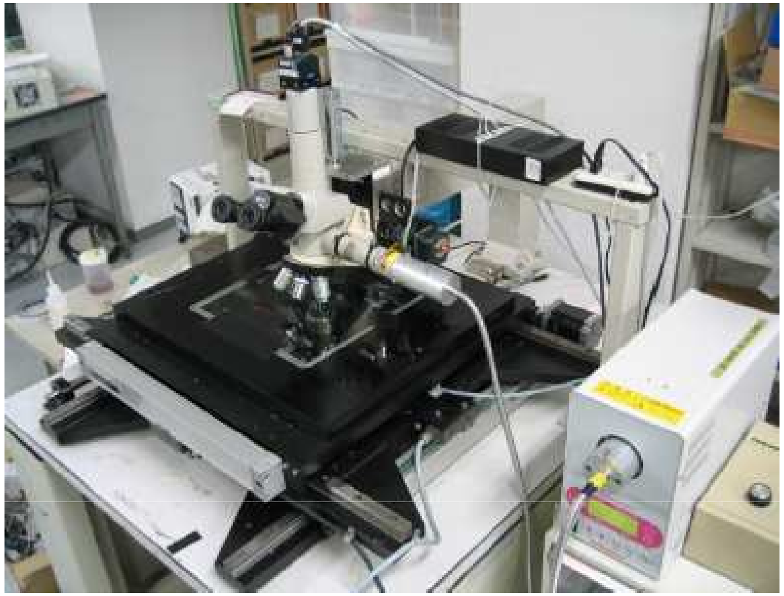
Readout Concept



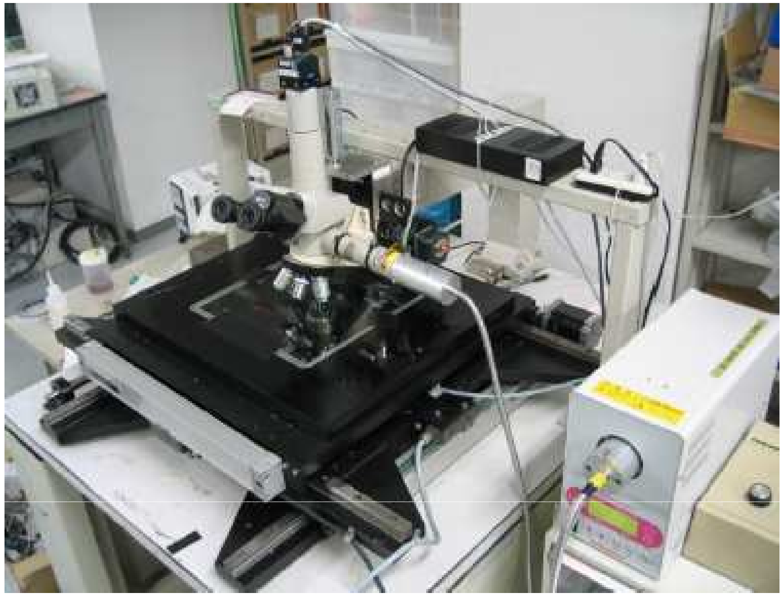
Optical microscope

candidate selection
- fast & automatic 3D selection
- ellipse-fitting for candidates
- $\Delta x \sim 250$ nm

X-ray microscope

signal confirmation
- non-destructive & high resolution
- observing grains one by one
- $\Delta x < 70$nm

Readout Concept



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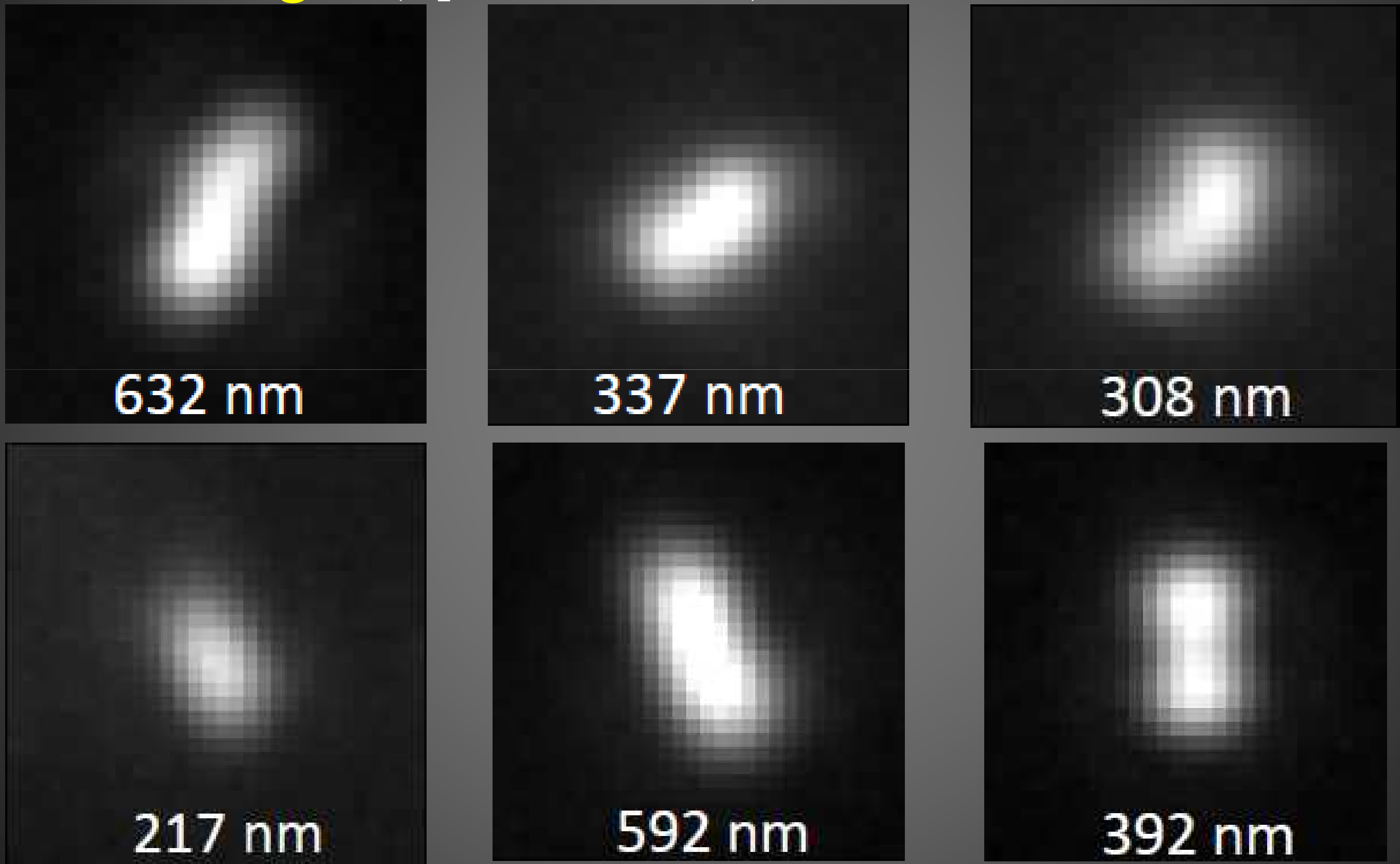
Demonstration using heavy nuclei recoil tracks induced by 14MeV neutron (D-T reaction)

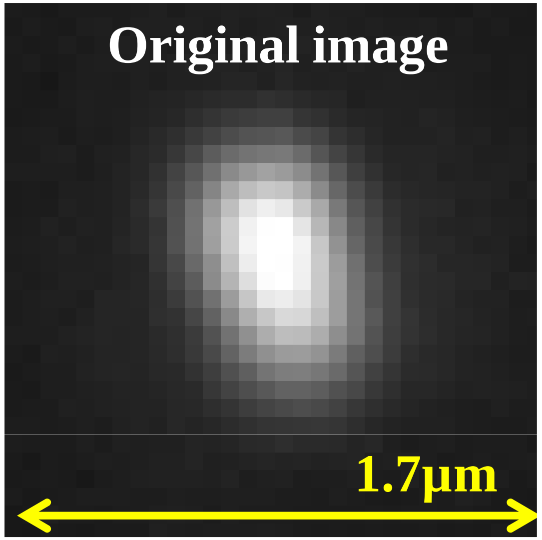
Optical image (Epi-illuminated)

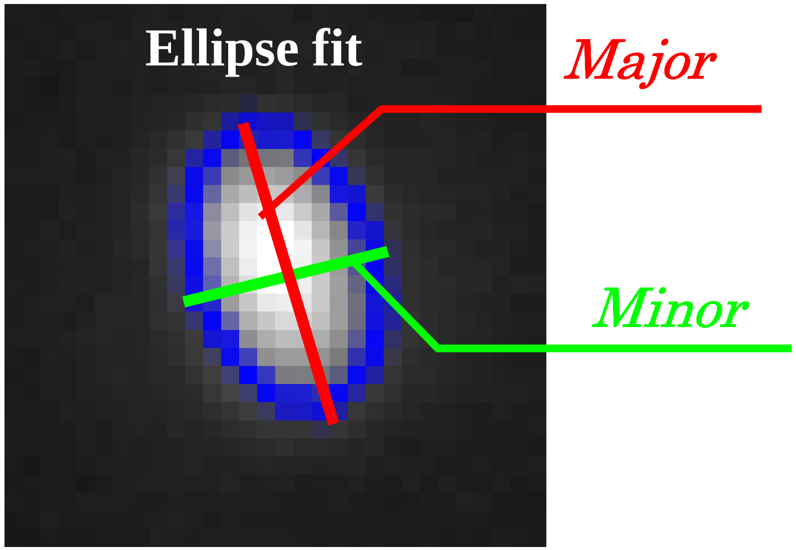


Mostly Br recoil (170 - 600 keV), because of low sensitivity tuning

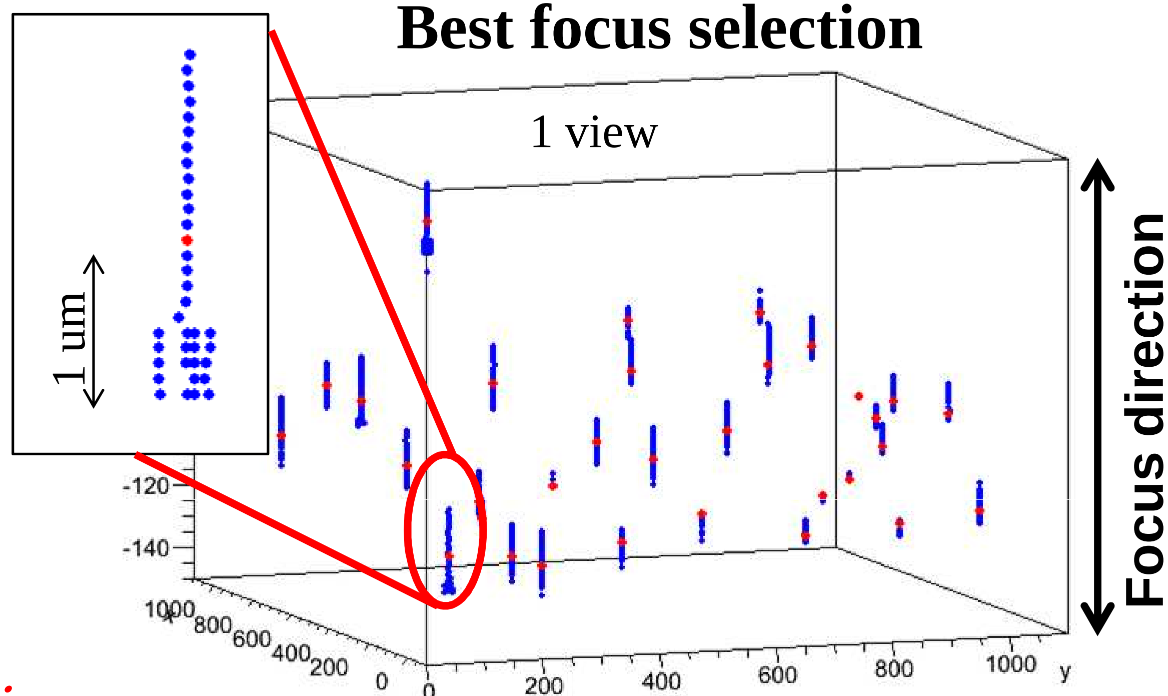
Automatic Candidate Selection

Fitting as ellipse





Best focus selection



Red : best focus layer
Blue : defocus layer

Candidate events are automatically detected mainly with **Ellipticity**.

-3D position information
-Brightness, Shape, Area
-Angle etc.

Readout Concept

Optical microscope

candidate selection

- fast & automatic 3D selection
- ellipse-fitting for candidates
- ⊿x ~ 250 nm

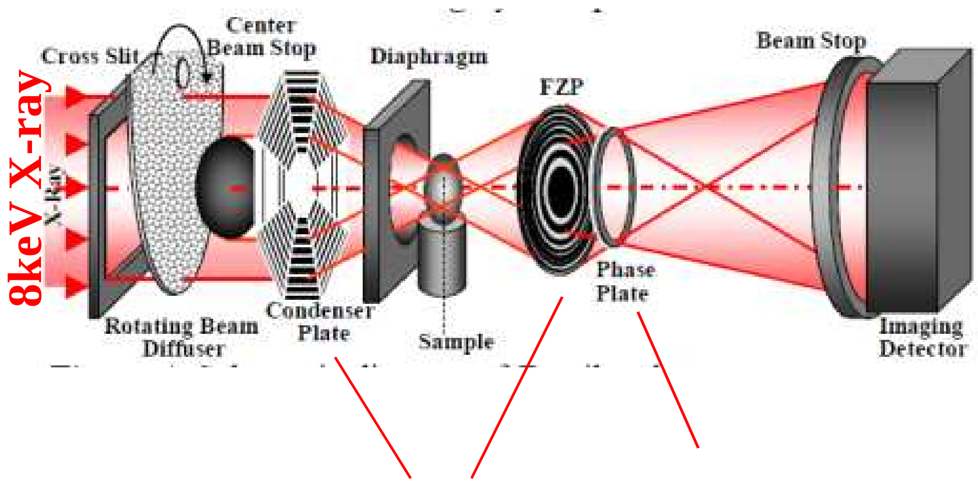
X-ray microscope

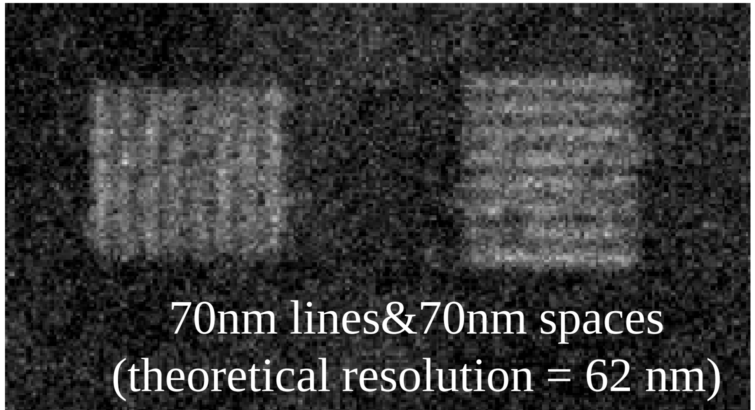
signal confirmation

- non-destructive & high resolution
- observing grains one by one
- ⊿x < 70nm

Confirmation by X-ray microscope

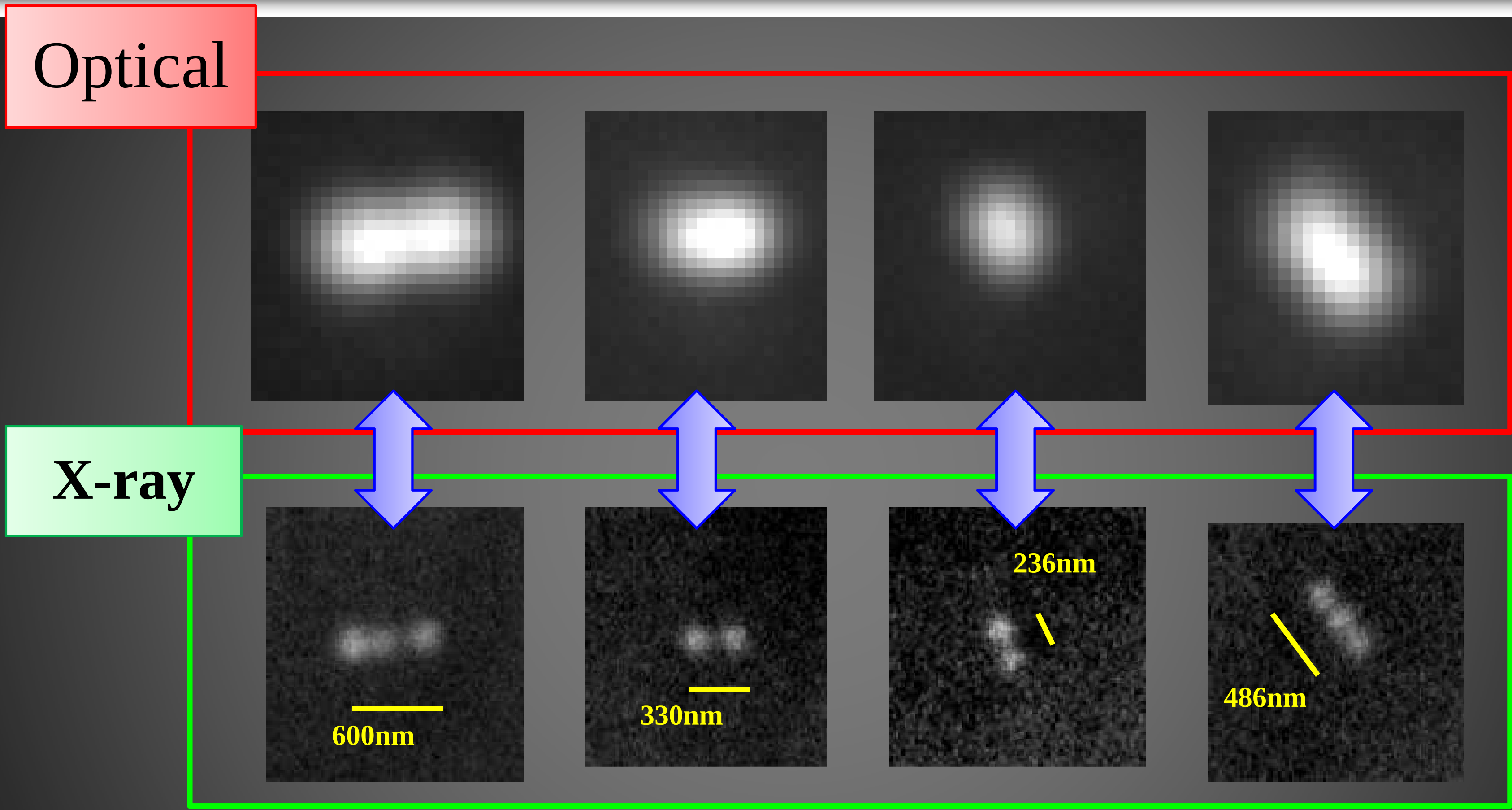
-Thickness of film : 100μm
-Focal depth : 70μm
-Type of optics: phase contrast
-X-ray Energy : 8keV





<u>System is almost ready</u>
<u>for realistic dark matter search.</u>

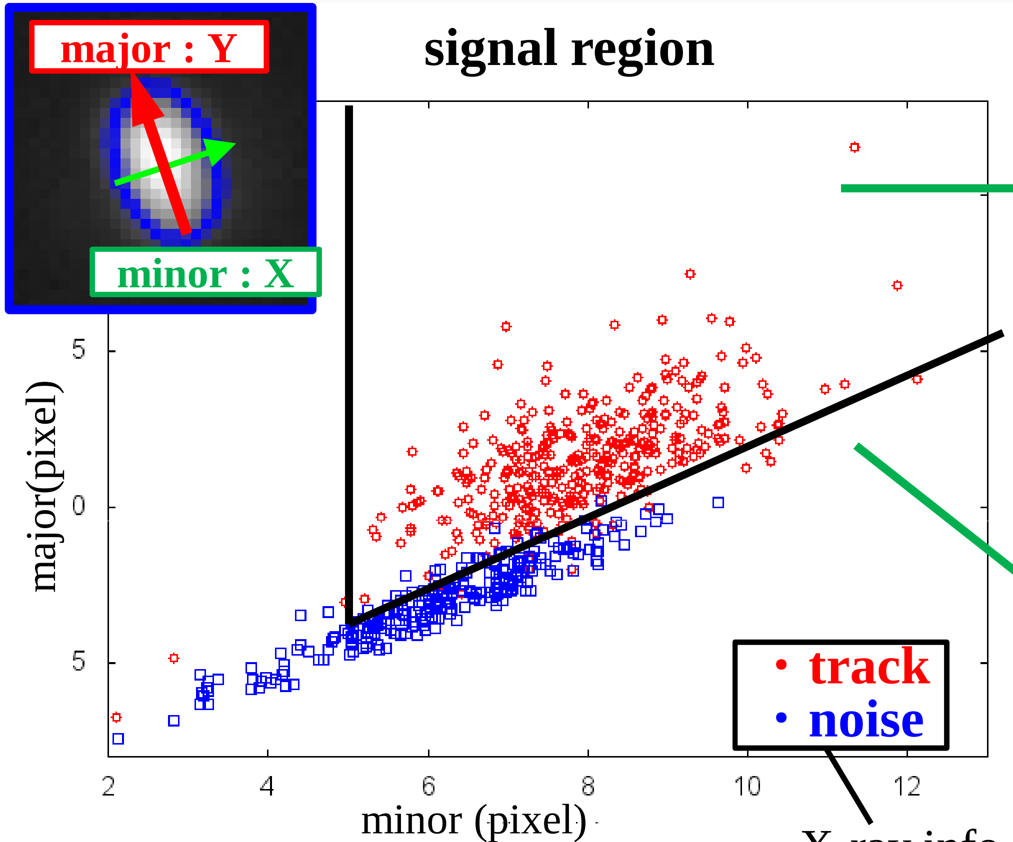
Tracks Matching between Optical and X-ray Micro Scope

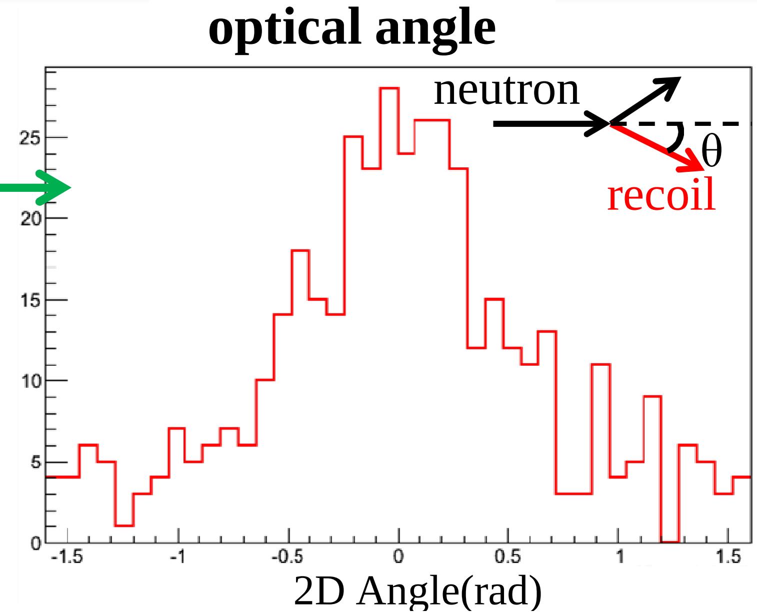


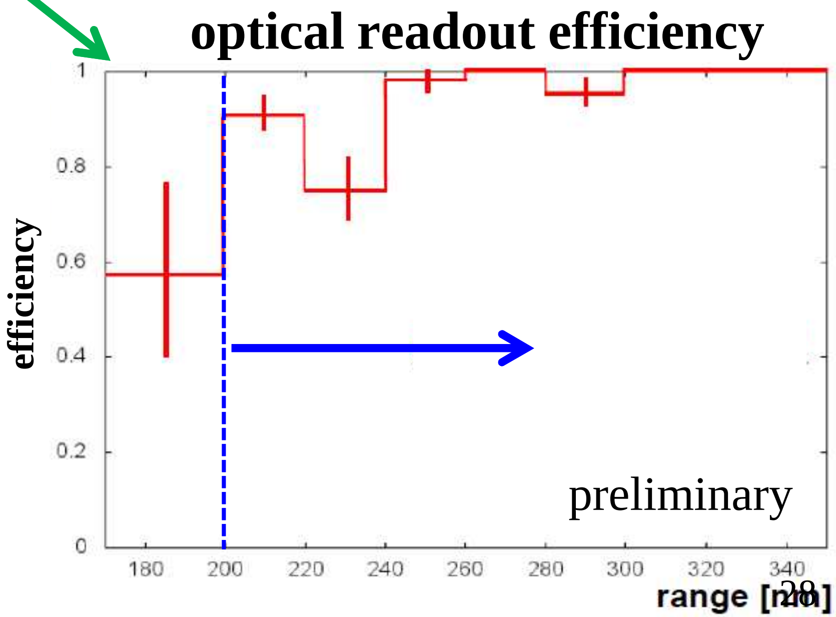
recoil tracks 14 MeV neutron (D-T nuclear fission)

- Matching efficiency : 572 / 579 event = 99%
- the shift from predicted position (Optical→Xray) : < 5μm
- 7800 event / day

Signal selection efficiency with optical microscope





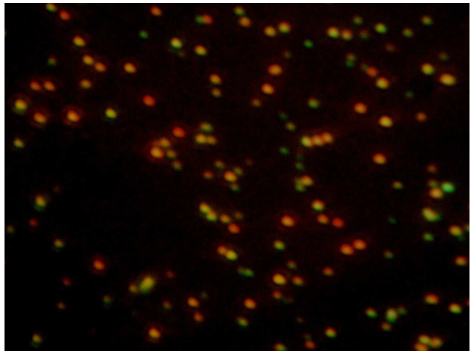


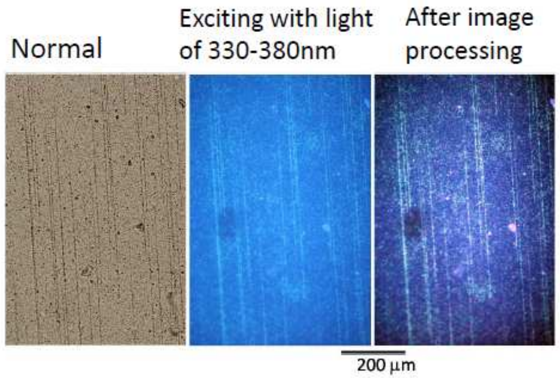
The efficiency of optical microscope is measured with comparing both optical and X-ray event data.

- track angle is well measured by optical.
- We can select signals longer than **200 nm**.

Study for upgrade

- Read out speed up
  - now : 0.1g/day → 10~100g scale
- Optics upgrade
  - objective lens and wavelength
- Plasmon analysis
  - Selection of dE/dx from scattering light
- Fluorescence analysis
  - Super resolution;~50 nm is expected !





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Near Future Plan

2013

study in Lab

developing sensitivity

new readout methods

crystal sensitivity control

2014

understanding for BG

1g scale test run
at LNGS

BG insensitive crystal

readout BG rejection

2015

high sensitive U-NIT

high speed system

10-100 g scale
physics run.1

2016

equatorial telescope

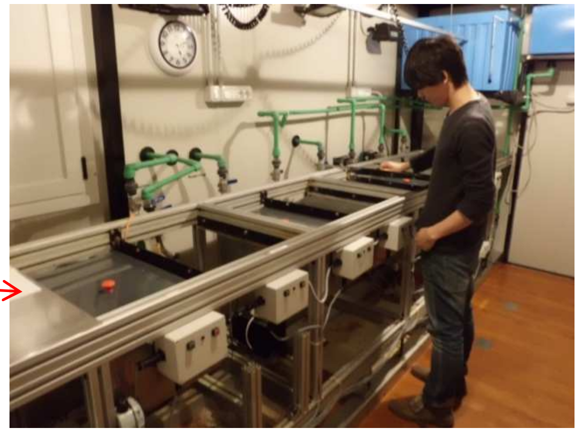
kg scale run for DAMA region

R&D underground facility in Gran Sasso

Gran Sasso (LNGS), Italy

2nd Floor: Detector Production

1st Floor : Development Facility



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)
K. Kuwabara (R&D of emulsion)
A. Umemoto (Plasmon analysis)
S. Furuya (detector R&D)
S. Machii (optical microscpe)

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 (LNGS activity)

LNGS

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

Chiba University

K. Kuge (emulsion and development study)

Fuji Film researcher

T. Tani (Emulsion and phenomenology)
K. Ozeki (Emulsion and phenomenology)
S. Takada (the emulsion sensitivity)

SPring8

Y. Suzuki, A. Takeuchi, K. Uesugi and Y. Terada

1st DM collaboration meeting @ LNGS

participants
Nagoya, Napoli, LNGS, Padova, Dubuna, Moscow

-Sensitivity simulation
- Intrinsic backgrounds
- neutron study
- R&D of emulsion and development
- Readout technology

2nd meeting will be held on November 2013

If you become interesting in our study, Let's join the meeting .

Summary

- We try to survey WIMP wind direction with nuclear emulsion.
- We succeeded to make stable fine grain.
  - current challenge : sensitivity control
- Fundamental readout method is demonstrated.
  - current challenge : higher resolution readout method
- We plan to do gram scale test run soon

  and < 100 g physics run within several years.