R&D status of Nuclear Emulsion for Directional Dark Matter Search

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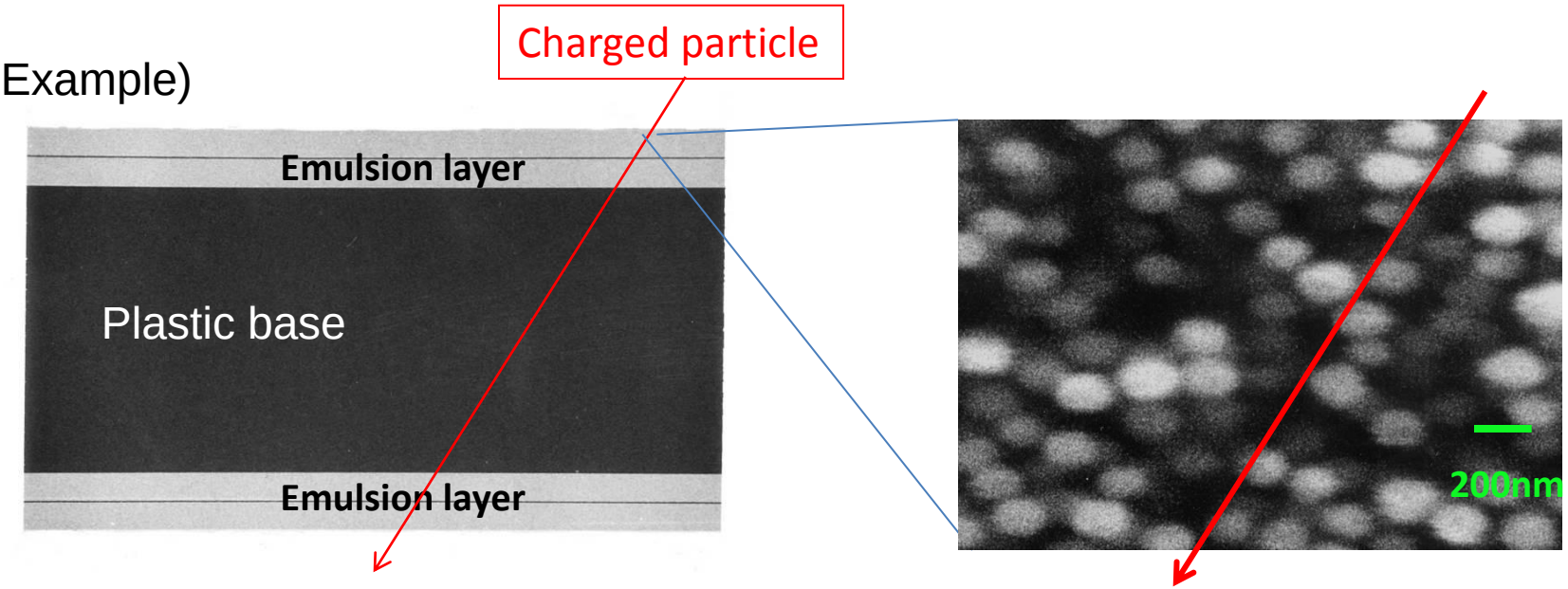
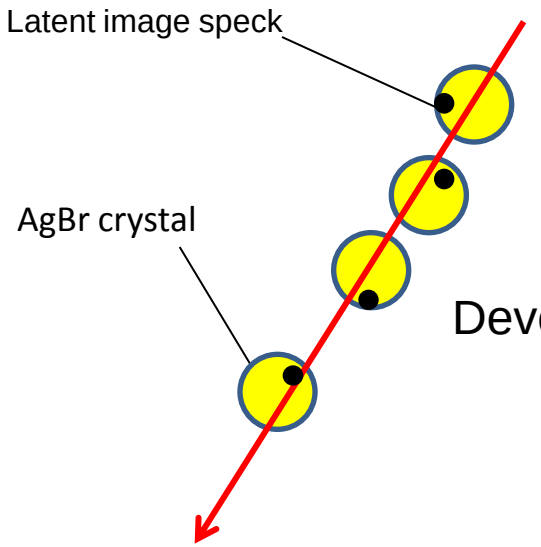
Outline

- About nuclear emulsion
- Production and R&D environment of emulsion
- Readout concept of nuclear recoil tracks
- Neutron recoil track study
- Near future planning

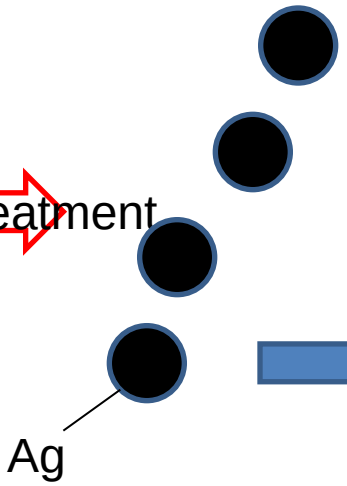
Nuclear Emulsion

Example)





Development treatment



Readout by microscope

Resolution depends on the number of AgBr crystal per length.
⇒crystal size and density.

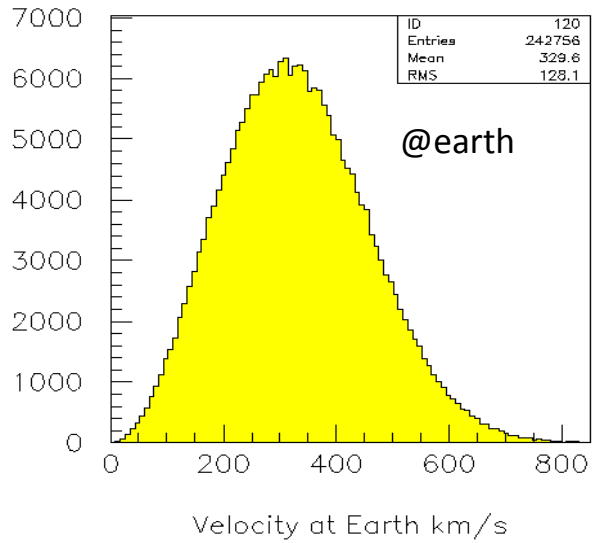
Requirement of resolution

Track length

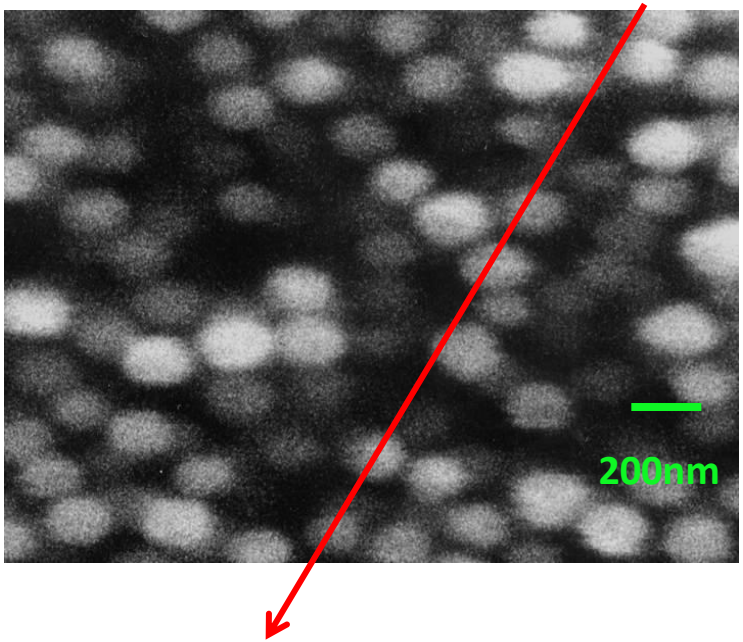
Maximum DM velocity<800km/sec

Recoil energy : 10-100keV order

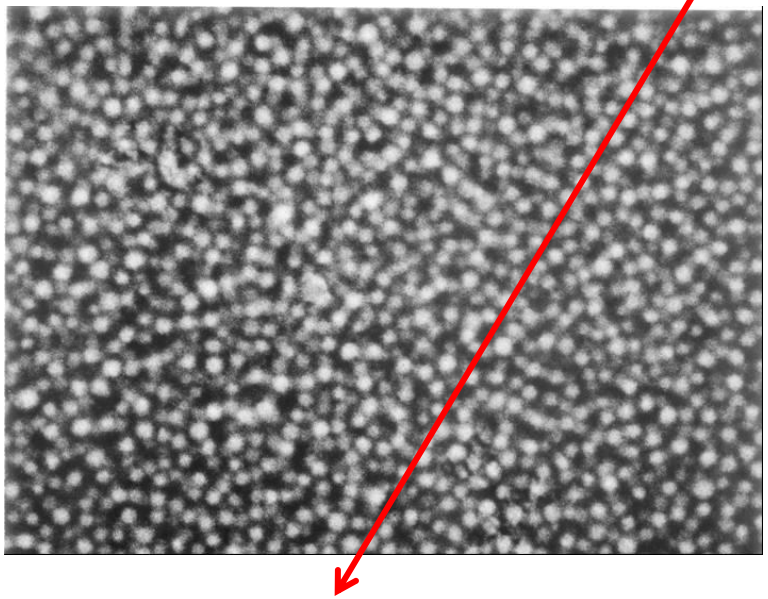
Track length < ~400nm



Usual nuclear emulsion (>μm)



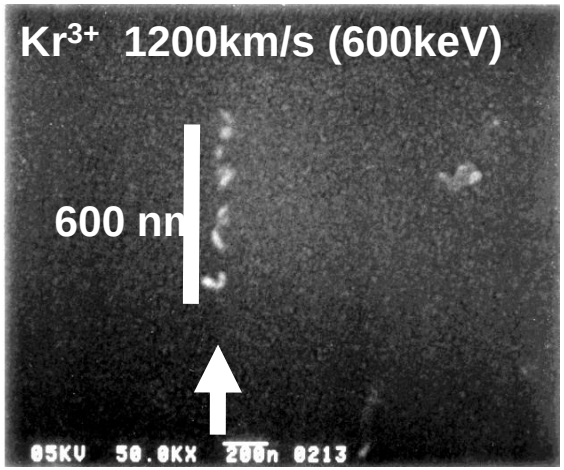
For dark matter detection

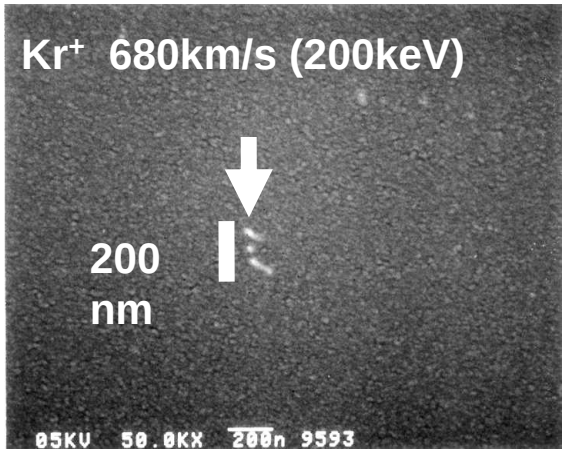


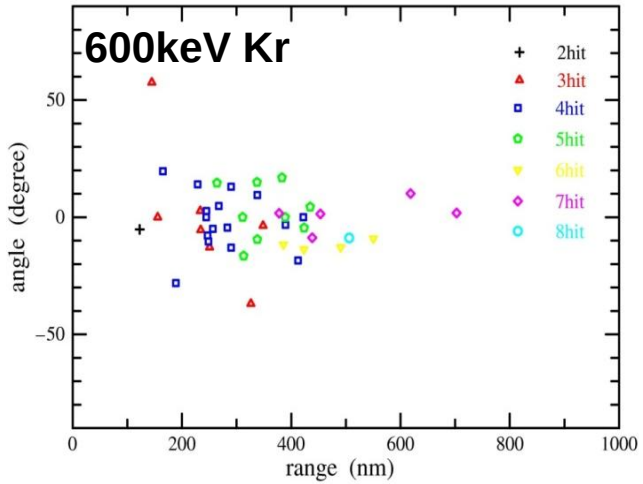
Until now, Fuji Film developed and produced.

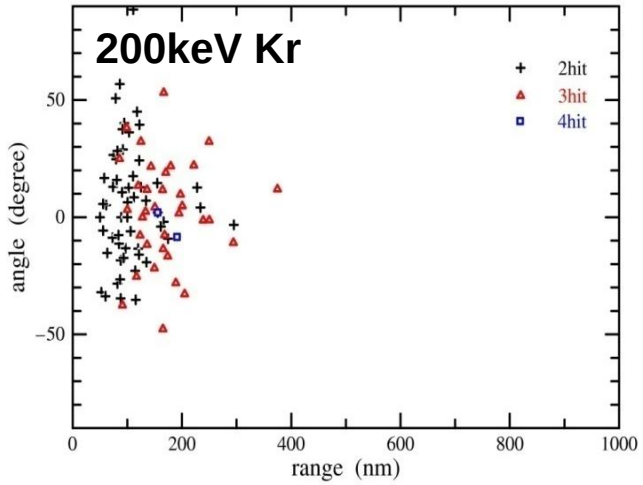
Confirmation of detection of submicron tracks

SEM (Scanning Electron microscope) observation





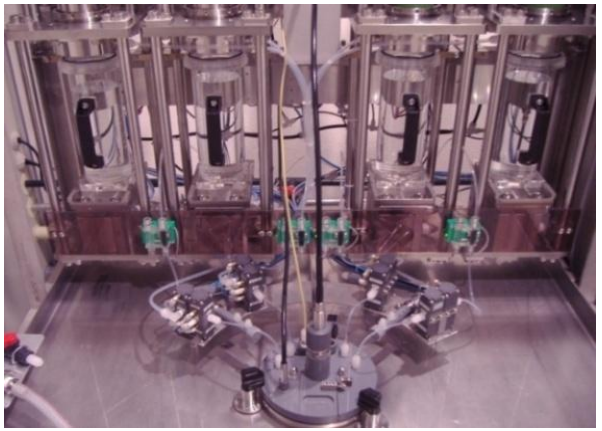




Facility for Emulsion Production at Nagoya

Realization of environment to product the emulsion ourselves.

Collaborate with OB of Fuji Film com. and a machine company same to Fuji Film



Production rate

- status core term : 1week/month
- ability of production rate : 300g target mass/day

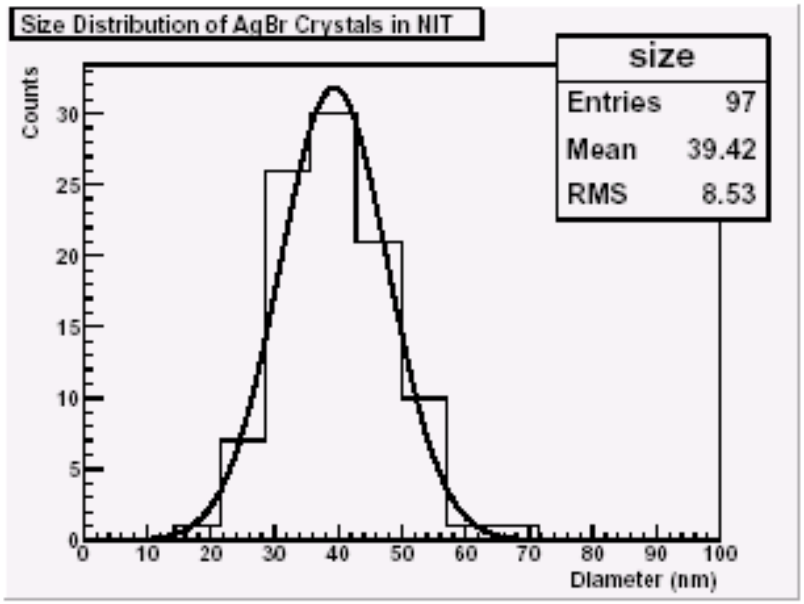
⇒we can produce the some kg detector

↓

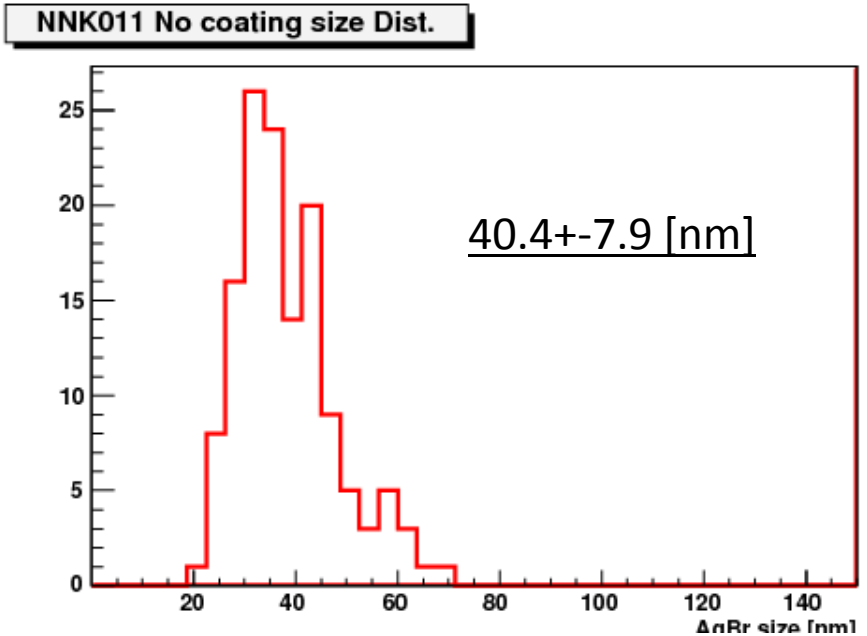
In future, we will be able to do scale-up.

Crystal size of current fine grain emulsion

Fuji Film emulsion(NIT)

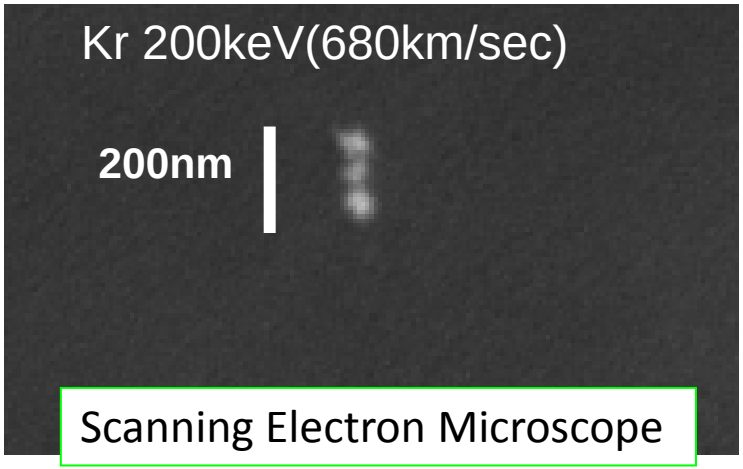


Nagoya emulsion(NNK011)

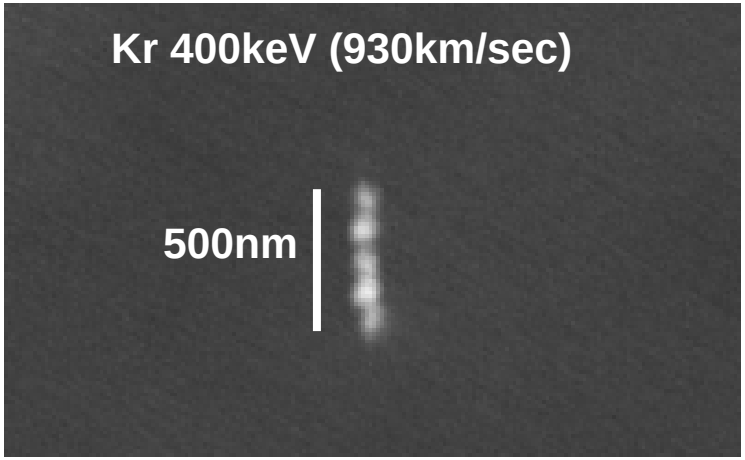


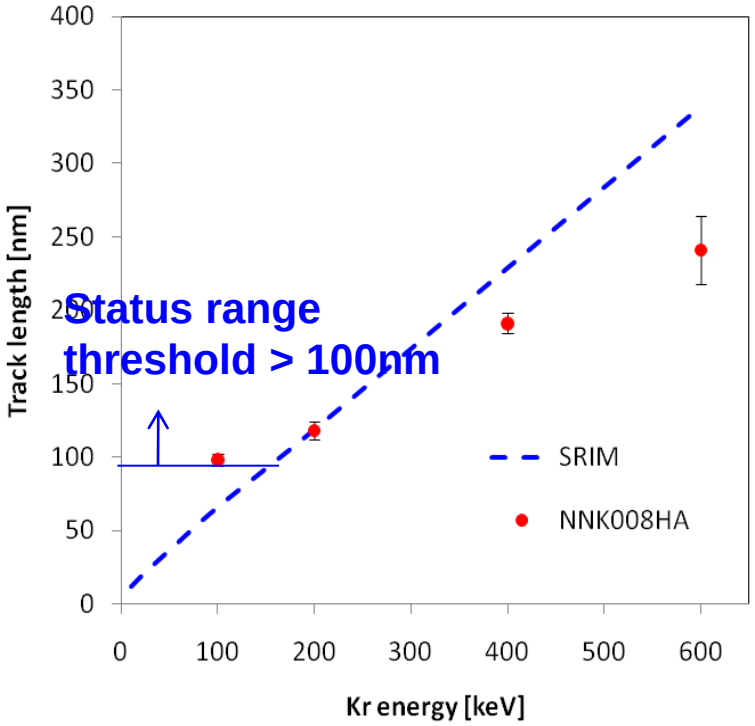
Equivalent to NIT produced by Fuji Film.

Checking of submicron track detection using low velocity Kr ions



Scanning Electron Microscope





Planning of development of detector

Stage.1

Now, we got the skill which is equivalent to Fuji Film for the production of fine grain emulsion .

Stage.2

Stable condition and Sensitivity control

-Gelatin+ polyvinyl alcohol(PVA)

- crystal structure (control of sensitivity for crystal itself)

We could already find good condition. Now father progress .

Stage.3

Low background and low threshold

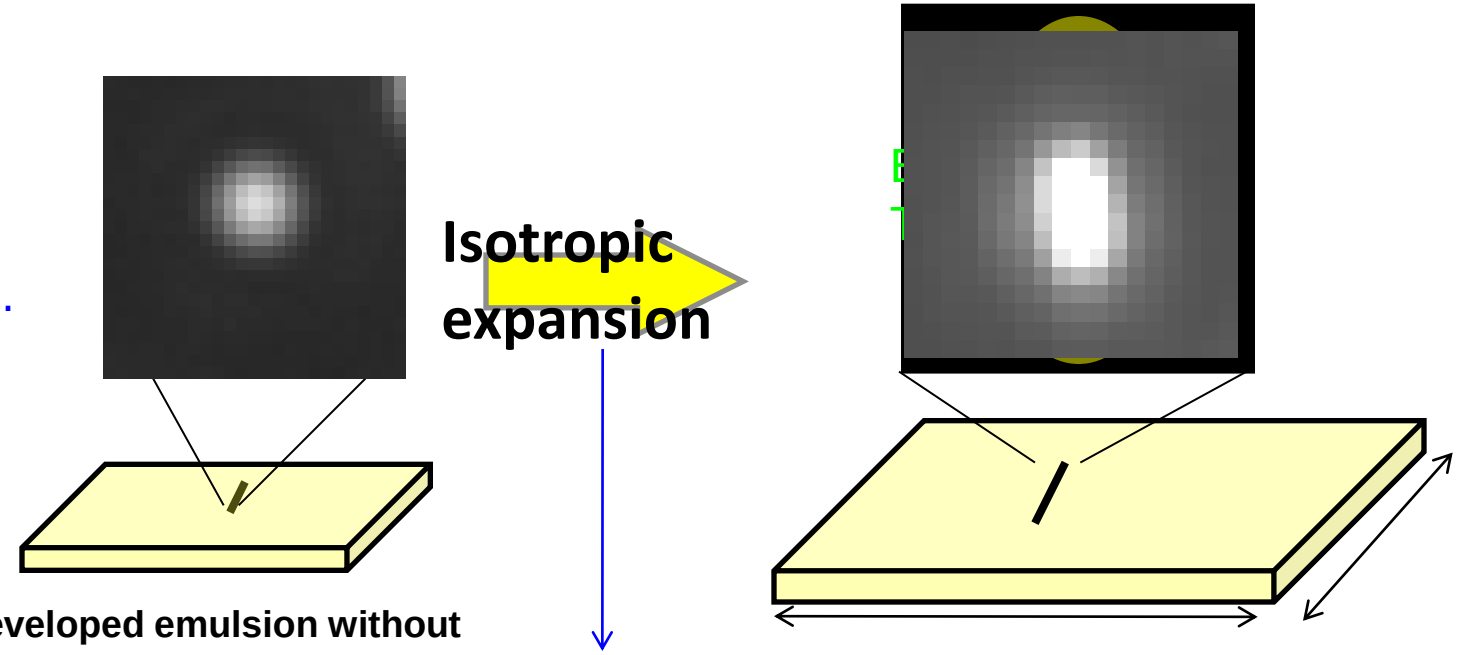
-Gelatin → PVA
- finer grain emulsion (PVA has good characteristic for production of the finer grain emulsion)
-Low background

Preliminary check has done , and it is not difficult to produce it. Now we progress the R&D.

Readout concept and method of nuclear recoil tracks

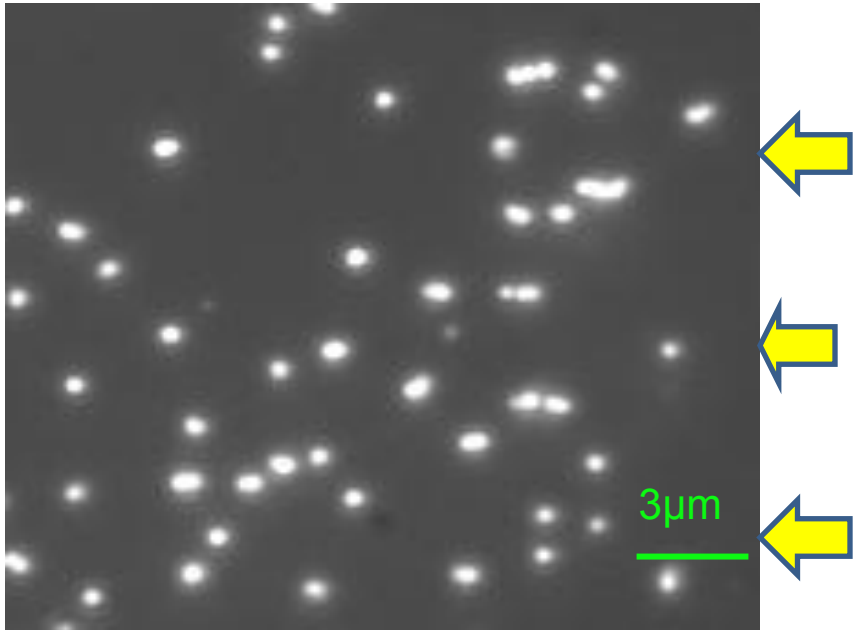
We should recognize the signals as tracks with optical microscope, not electron microscope.

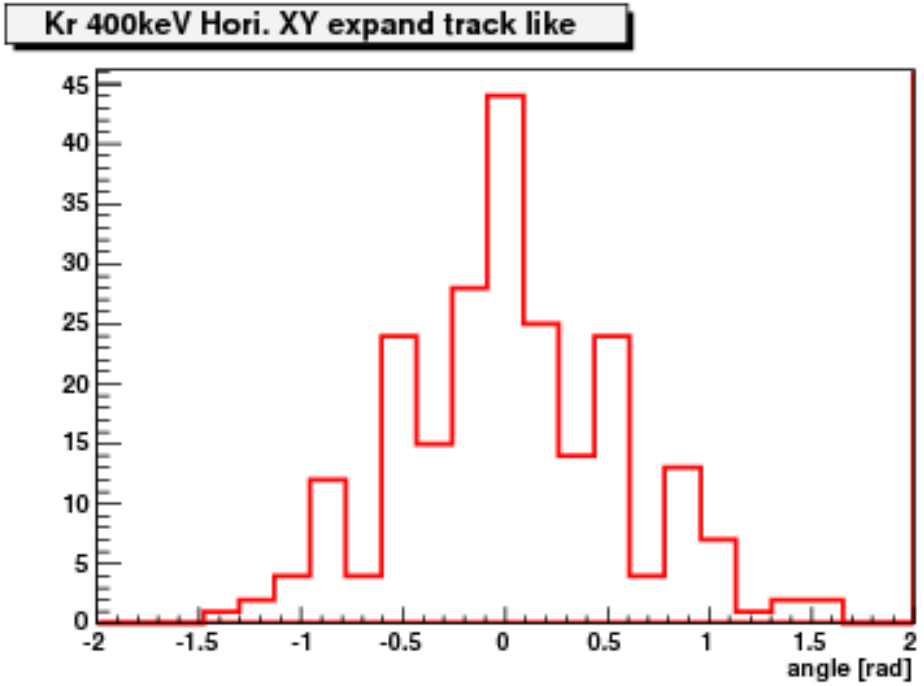
Direction can't be recognized.



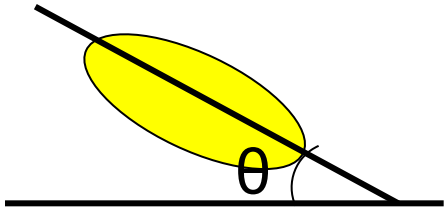
Using the swell characteristic of gelatin and poly-achrilamide(PAA).

Demonstration using low velocity Kr ion tracks





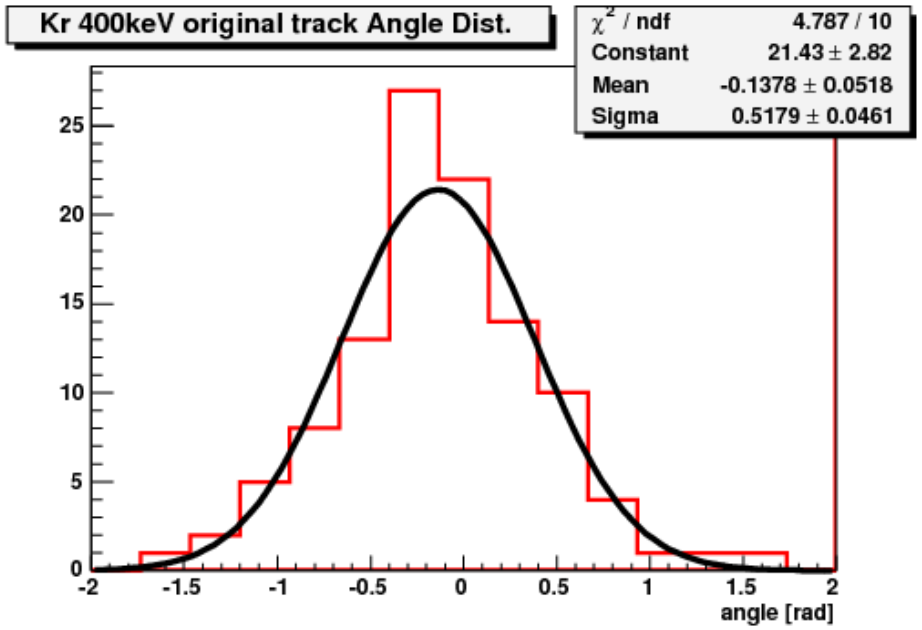
Angle [rad]



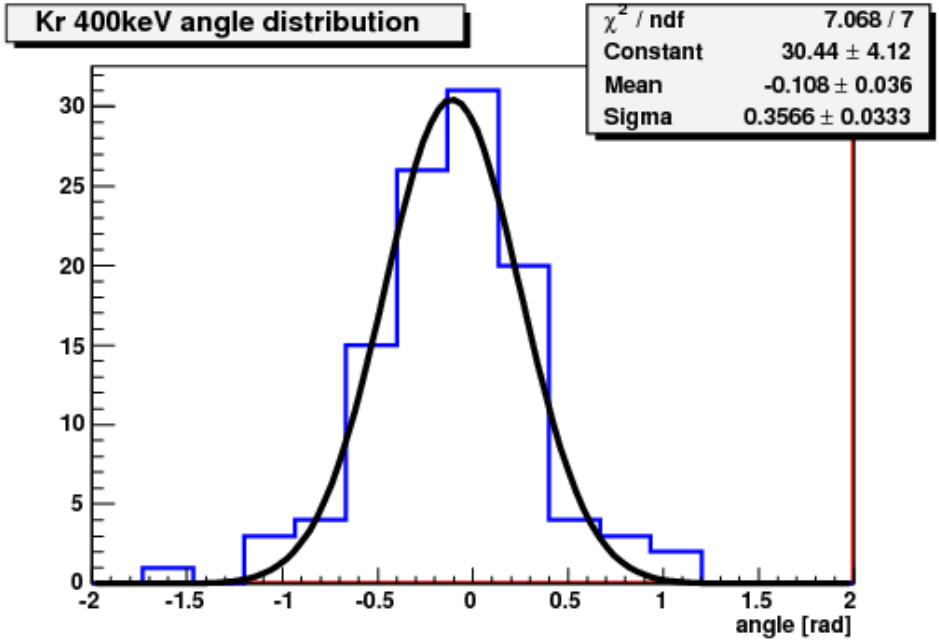
Recognize of direction is possible.

Angular distribution of Kr ion tracks by SEM

Before expansion



After expansion



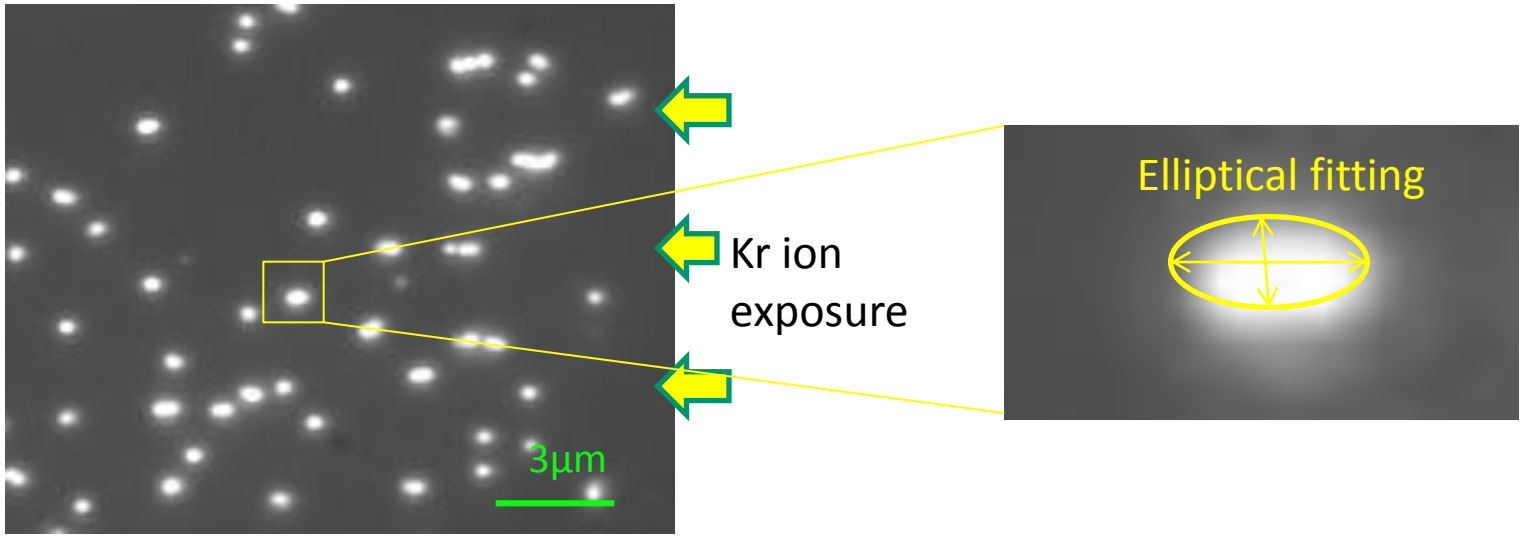
	Original condition	expanded condition
σθ[rad]	0.52+-0.05	0.36+-0.03

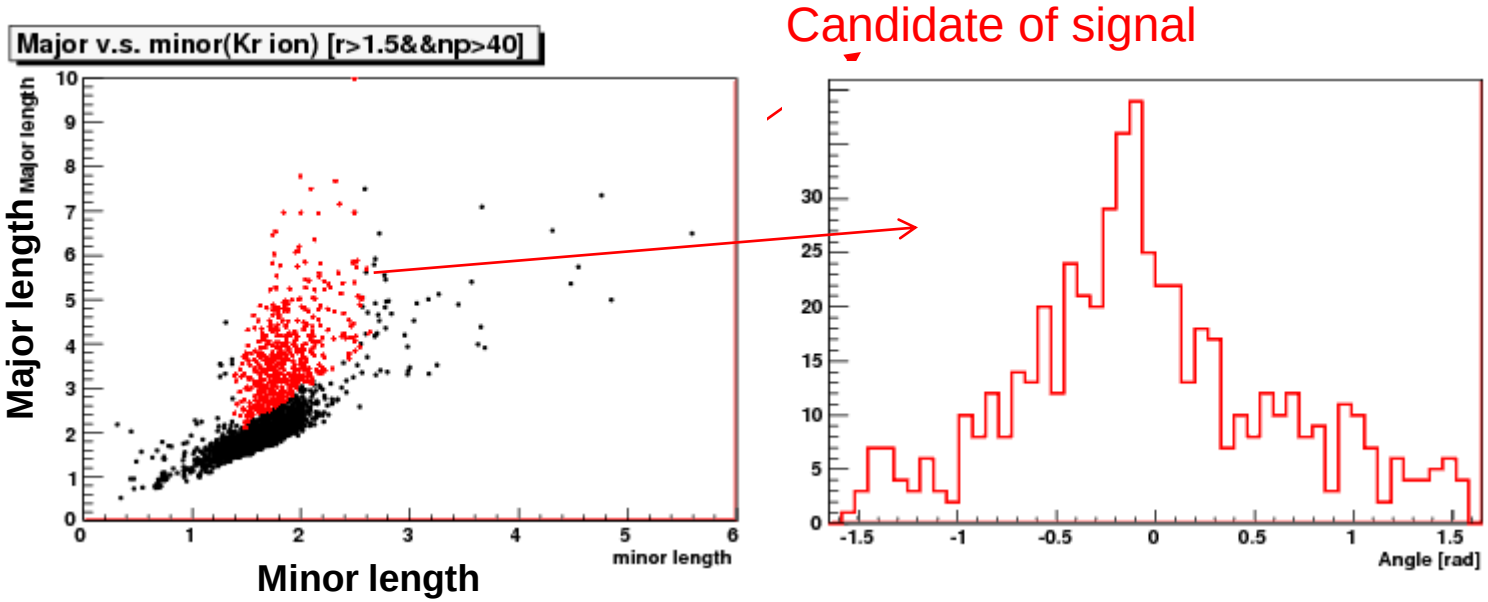
$\sigma_{expansion} < 0.09$rad(5deg.)

[$\sigma_{scatter}$=0.31rad@MC]

Expansion is very isotropic.

Automatic selection by image processing

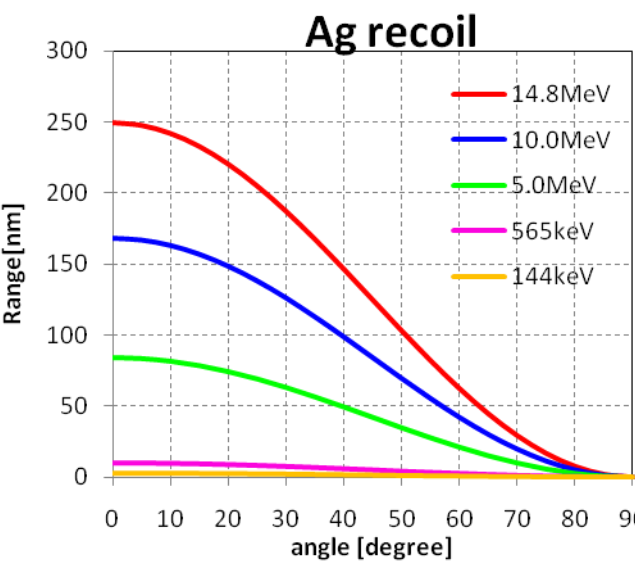


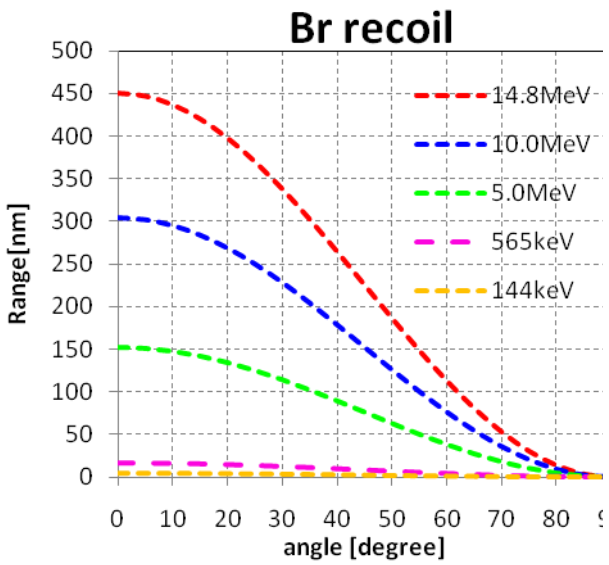


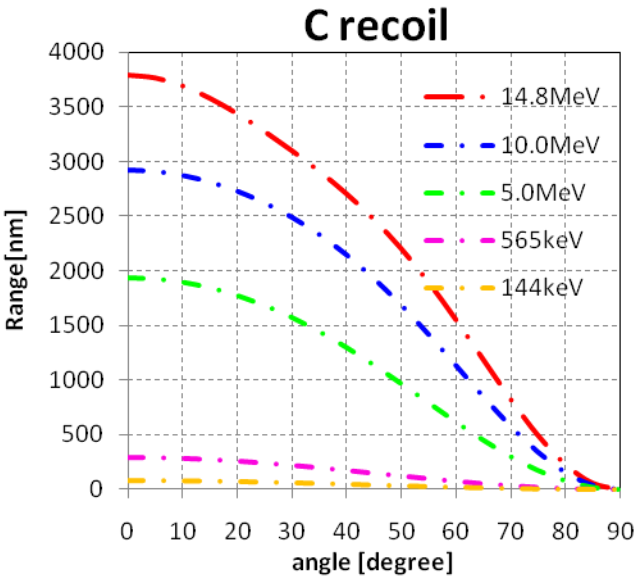
Neutron Study

Selection of neutron energy

$$E_{recoil} = \frac{4M_T m_n}{(M_T + m_n)^2} E_n \cos^2\theta$$







En>10MeV is needed to make 100nm order recoiled tracks by heavy targets (Ag, Br or CNO)

Neutron Source

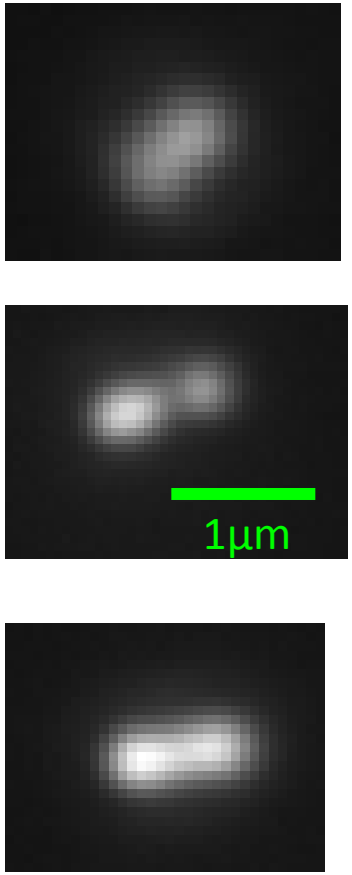
@National Institute of Advanced Indutrial Science and Technology

14.8MeV neutron source by nuclear fission

$$^{2}D + {}^{3}T \rightarrow {}^{4}He + n$$

→ 14.8MeV neutron

Comparison of submicron event density between observed and simulation data



Observed data

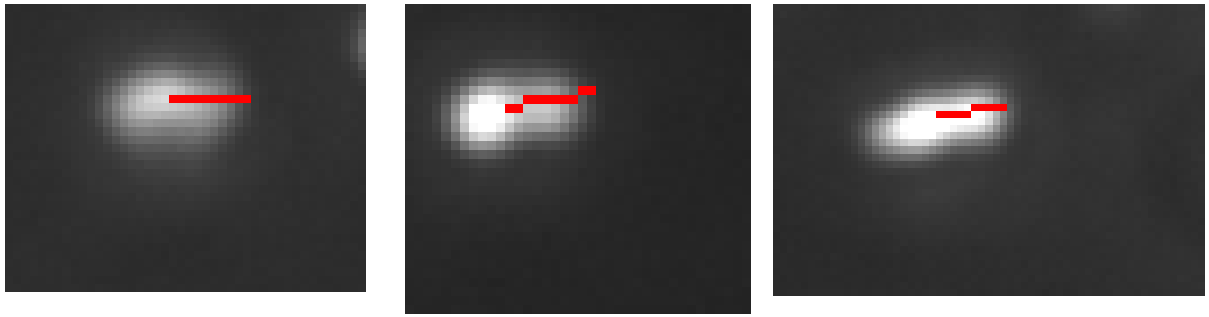
	elliptical event density[/view]
Signal	0.69+-0.18

Predicted event density by Geant4 simulation

	R>0.1μm	R>0.15μm	R>0.2μm
Event density[/view]	**0.69**	**0.60**	**0.53**

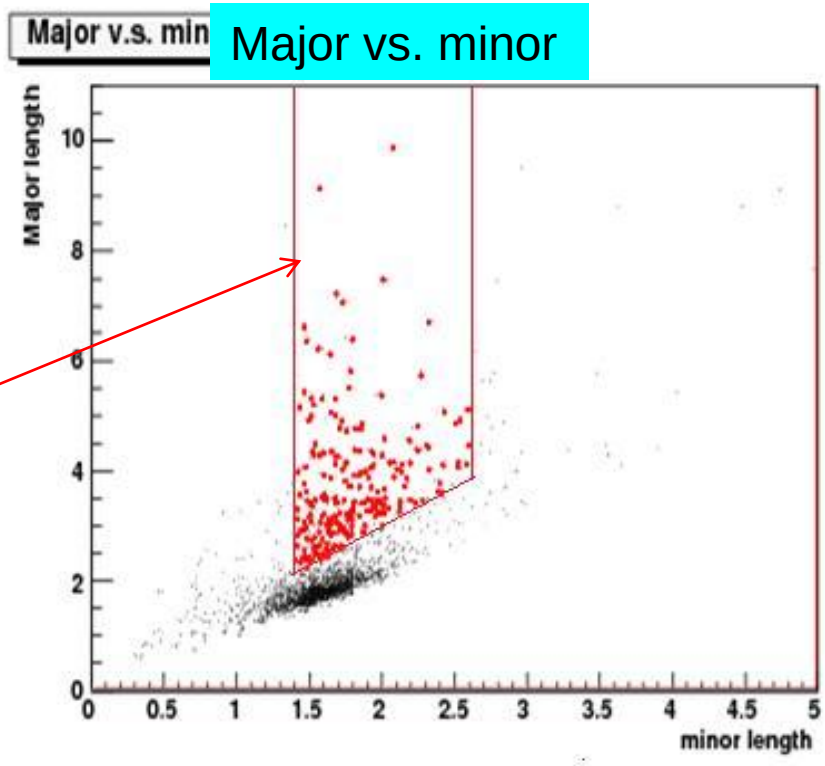
Range threshold of detection does not decide by optical resolution. Higher resolution tool is needed.
⇒X-ray microscope (3 slide later)

Automatic scanning study

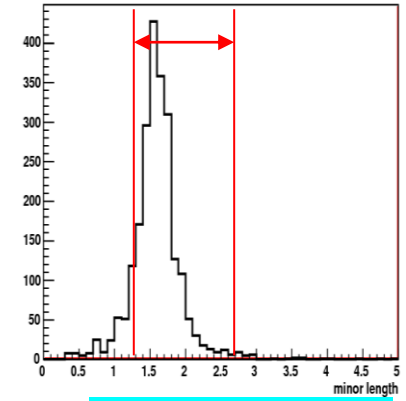


Automatic selection by image processing

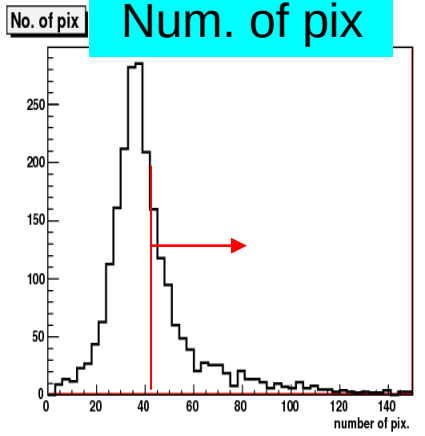
Major vs. minor



minor dist.



Num. of pix



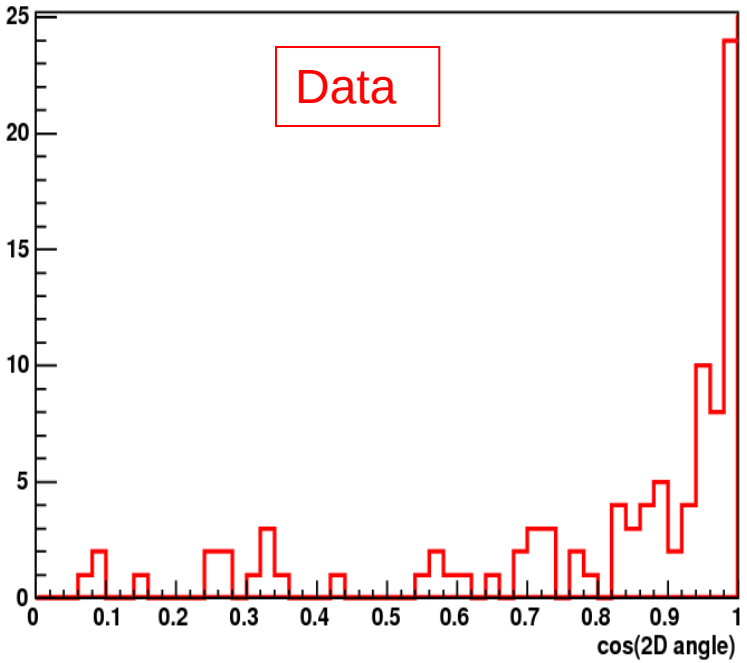
Selection condition

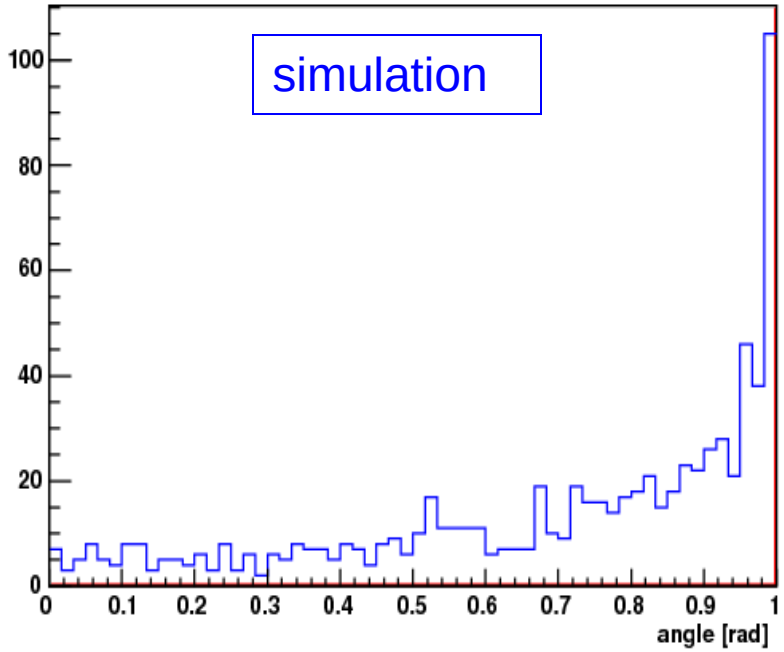
Major/minor>1.5

1.4<minor length<2.6

Number of pix>40

Angular distribution of submicron recoil track



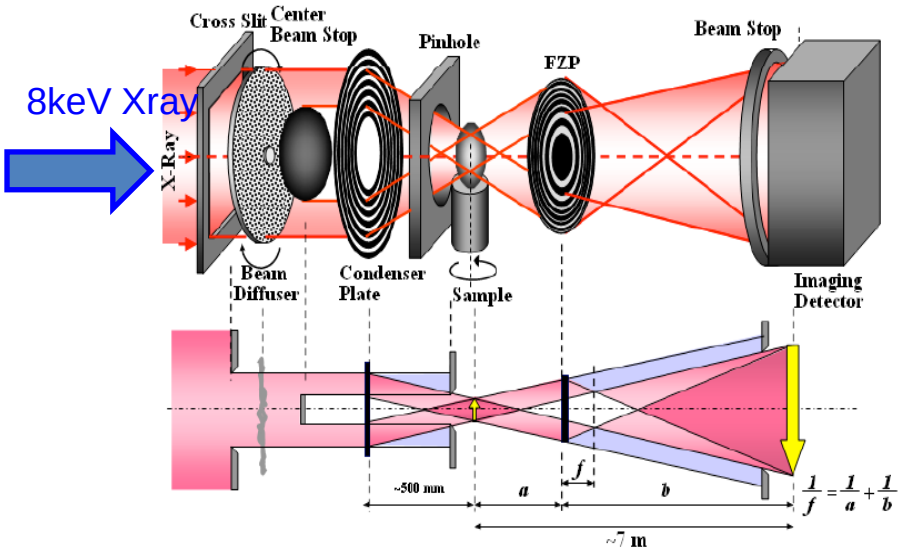


	$\sigma_{observe}$	$\sigma_{simulation}$ ($\angle\theta$=30deg.)
angle of submicron track	0.82+-0.18	0.95+-0.03

Finally, we'd like to check by higher resolution tool.

Development of detail analysis system with X-ray microscope

[Collaborate with Spring-8, BL47XU]

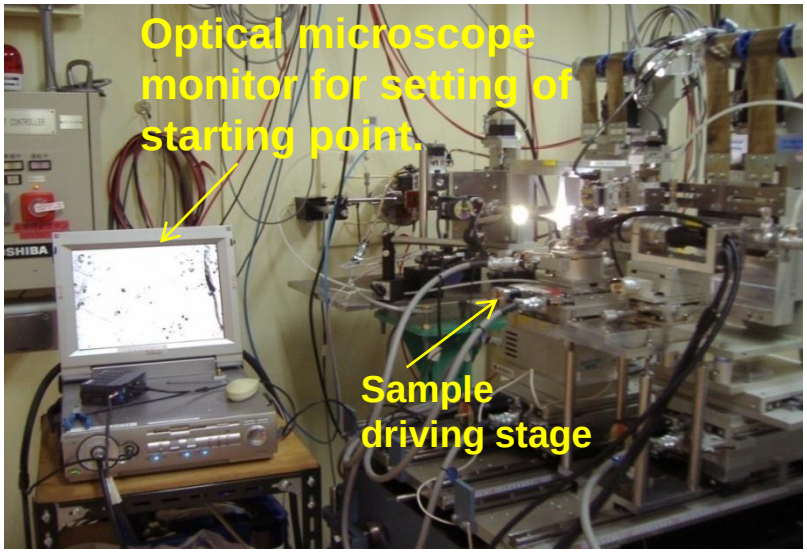


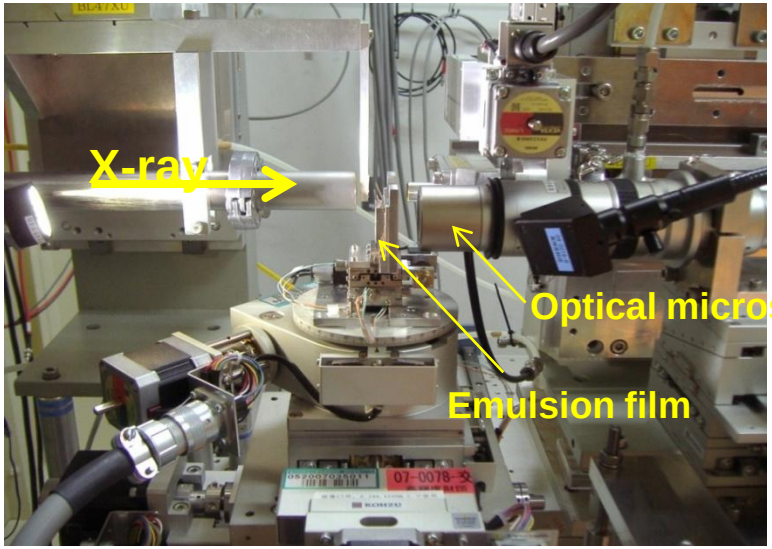
Feature

-Effective resolution : 50-100nm ⇒higher resolution than optical microscope

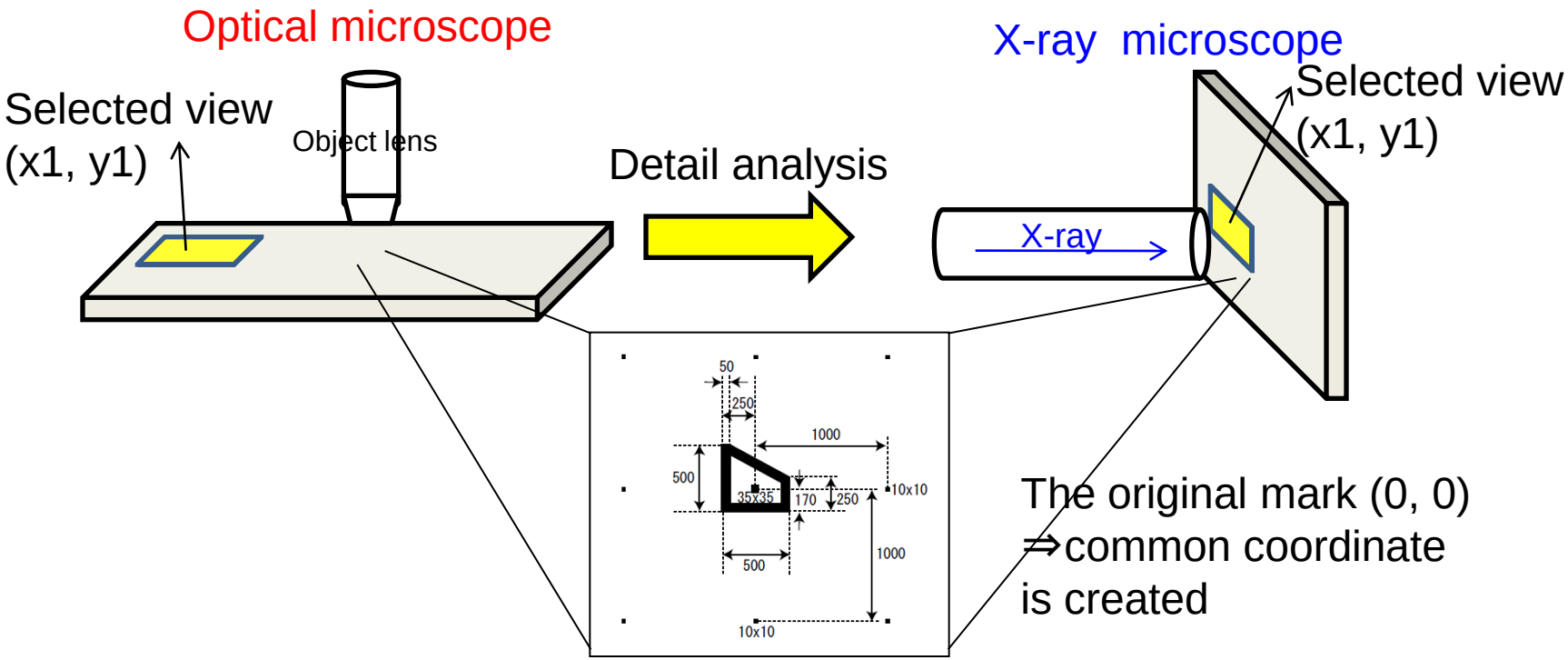
-To observe the 100μm thickness is possible⇒ non-destructive analysis

- large focus depth (70μm) ⇒ short scanning time

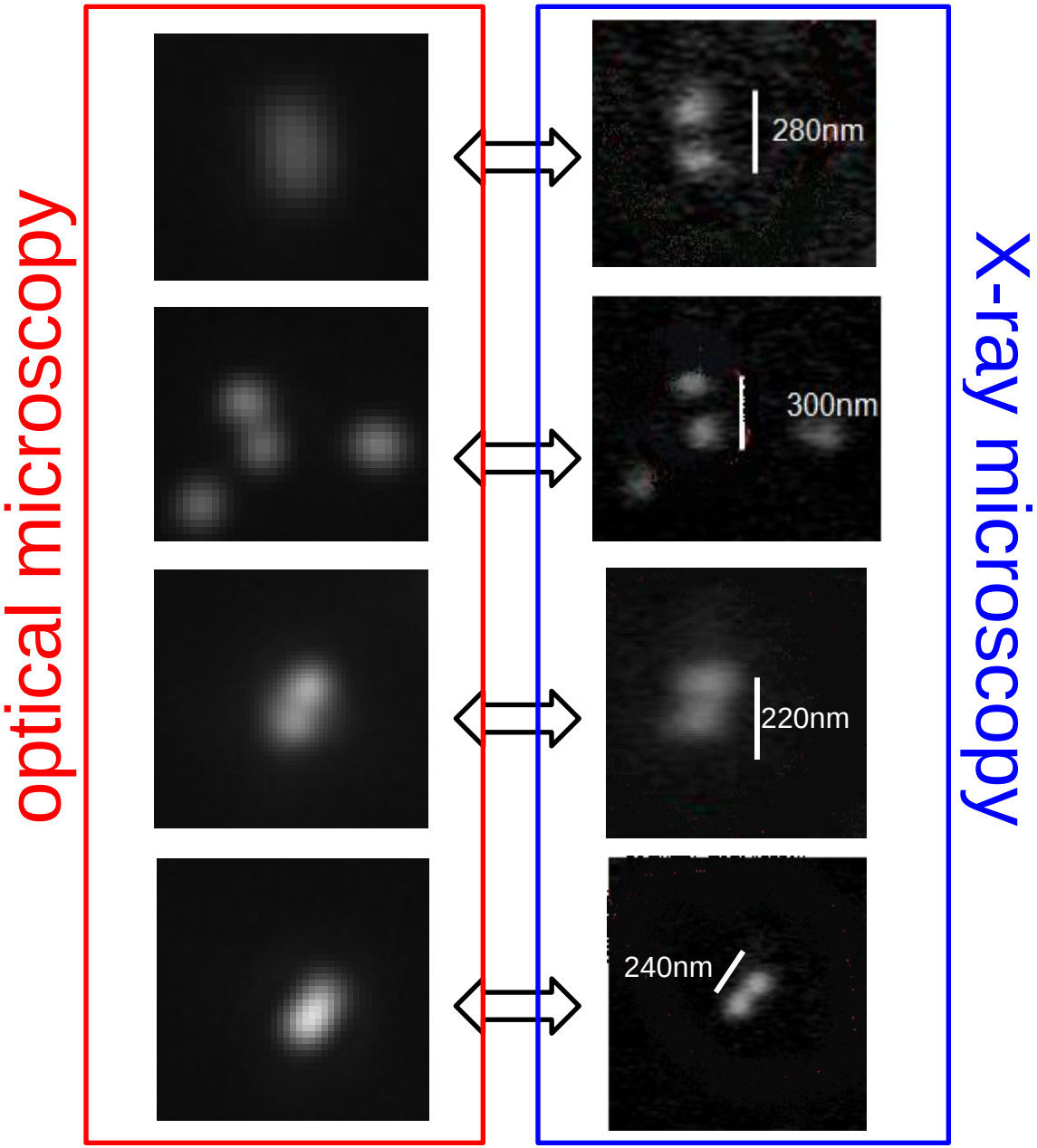




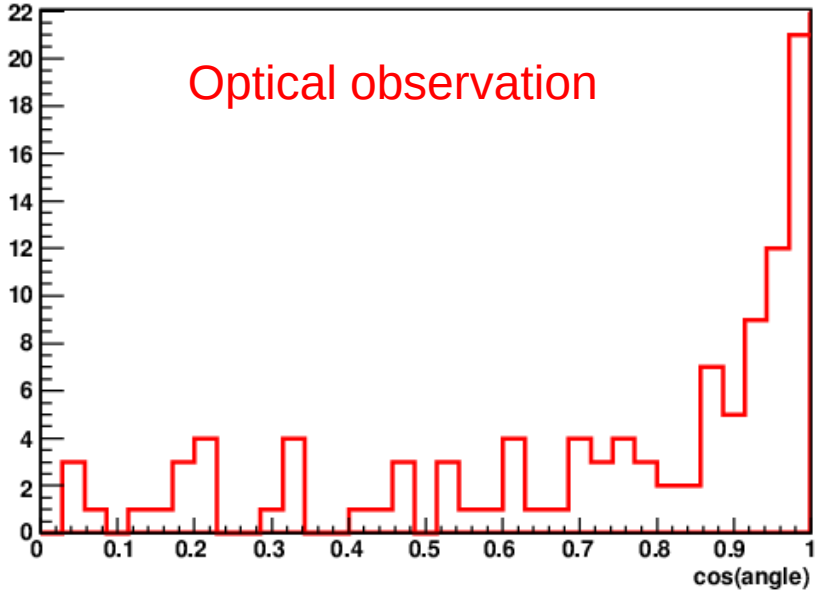
Concept of using the X-ray microscope.

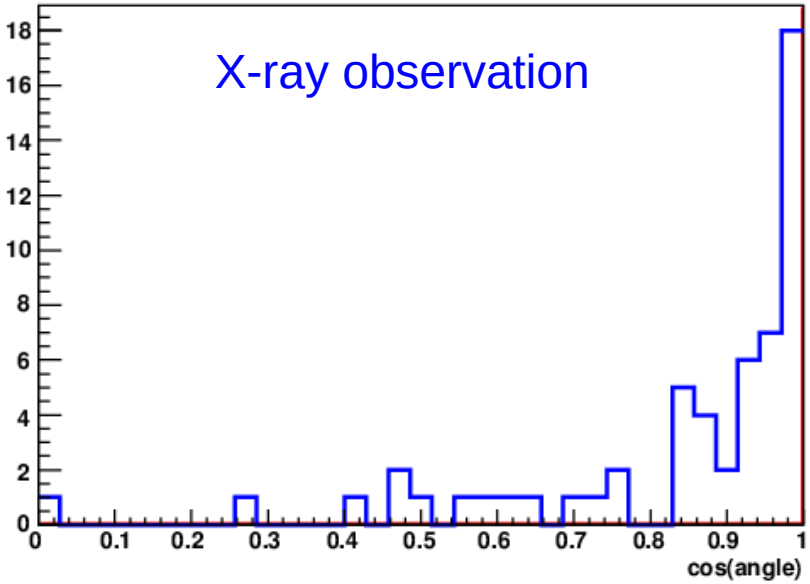


Matching of neutron recoil tracks between optical and X-ray microscopy



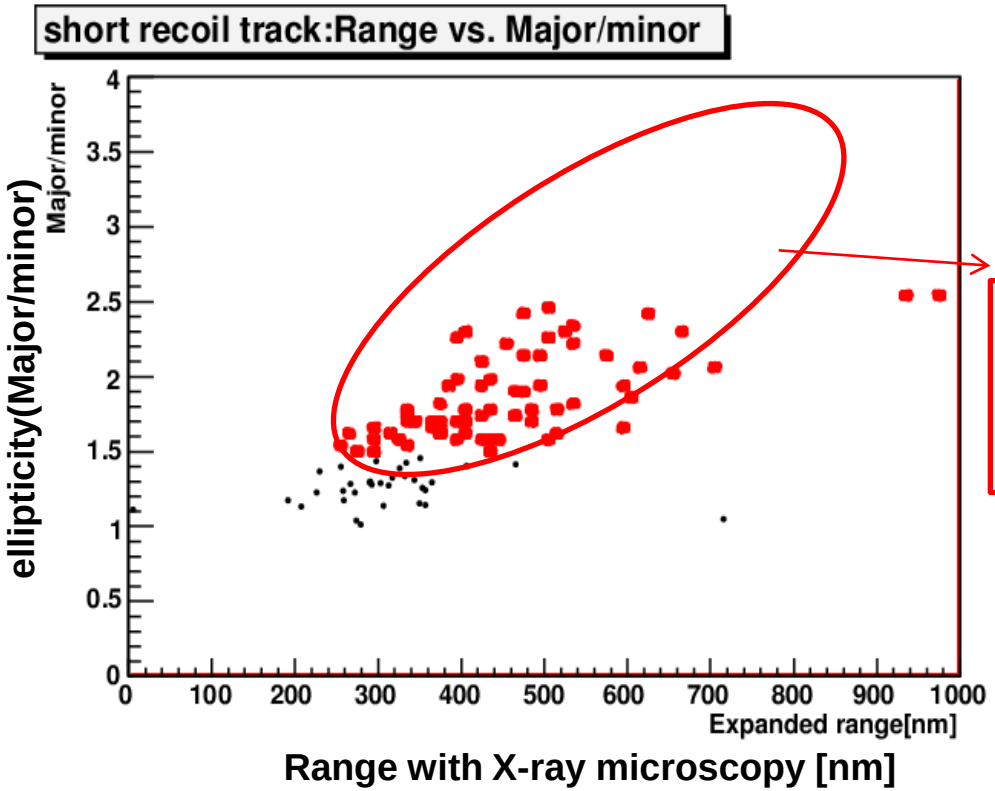
Angular distribution and resolution with X-ray microscope





	angular resolution [degree]	
optical microscope	31.4 +- 4.7 degree	@original range: 150-250nm
X-ray microscope	16.8+-2.9 degree	@original range: 150-250nm

Preliminary



Temporary signal cut region for neutro

-Detection efficiency～70%
- effective range threshold~300nm
⇒correspond to 150nm real range

Analysis of detail becomes possible with event by event.

Near future plan

-Grain size control
-Optical condition
- automatic scanning stage

We will decide the optimum condition for automatic readout system.

Near future planning

Constructing of prototype scanning stage for dark matter search.

-10-100g target scanning system
- Epi-illuminate optical system
- data taking by GPGPU

Analysis and decision of best system condition by large statistics data.

Finding the best quality and sensitivity of emulsion

- Development treatment ⇒ low background and high S/N, (head-tail discrimination)

- PVA emulsion ⇒ low background and finer grain emulsion (low threshold)

We started the collaboration with Italian group, and we aim to start test running with prototype detector.

Test Run at LNGS

- LNGS is good field for starting the new emulsion experiment .

Ex) CS barrack is good candidate.

-A barrack for emulsion handling already exist.

-Develop treatment is possible at underground..

- same background condition to DAMA experiment

The cost of prototype detector is cheap,
so we can put the some background field.

Summery

- We became possible to produce the fine grain nuclear emulsion with the quality equivalent to Fuji Film
- We understood synthetic polymer (PVA) is essential for fine grain emulsion for dark matter search.
- By expansion technique, we became possible to readout the nuclear recoil tracks automatically .
- By using X-ray microscope, we can observe the candidate event in detail.
- We are constructing the new scanning stage and finding the optimum condition of emulsion with aim of starting of test running.