Detector developing for directional dark matter search with nuclear emulsion

Takashi Asada

Flab, Nagoya University

JSPS Research Fellow

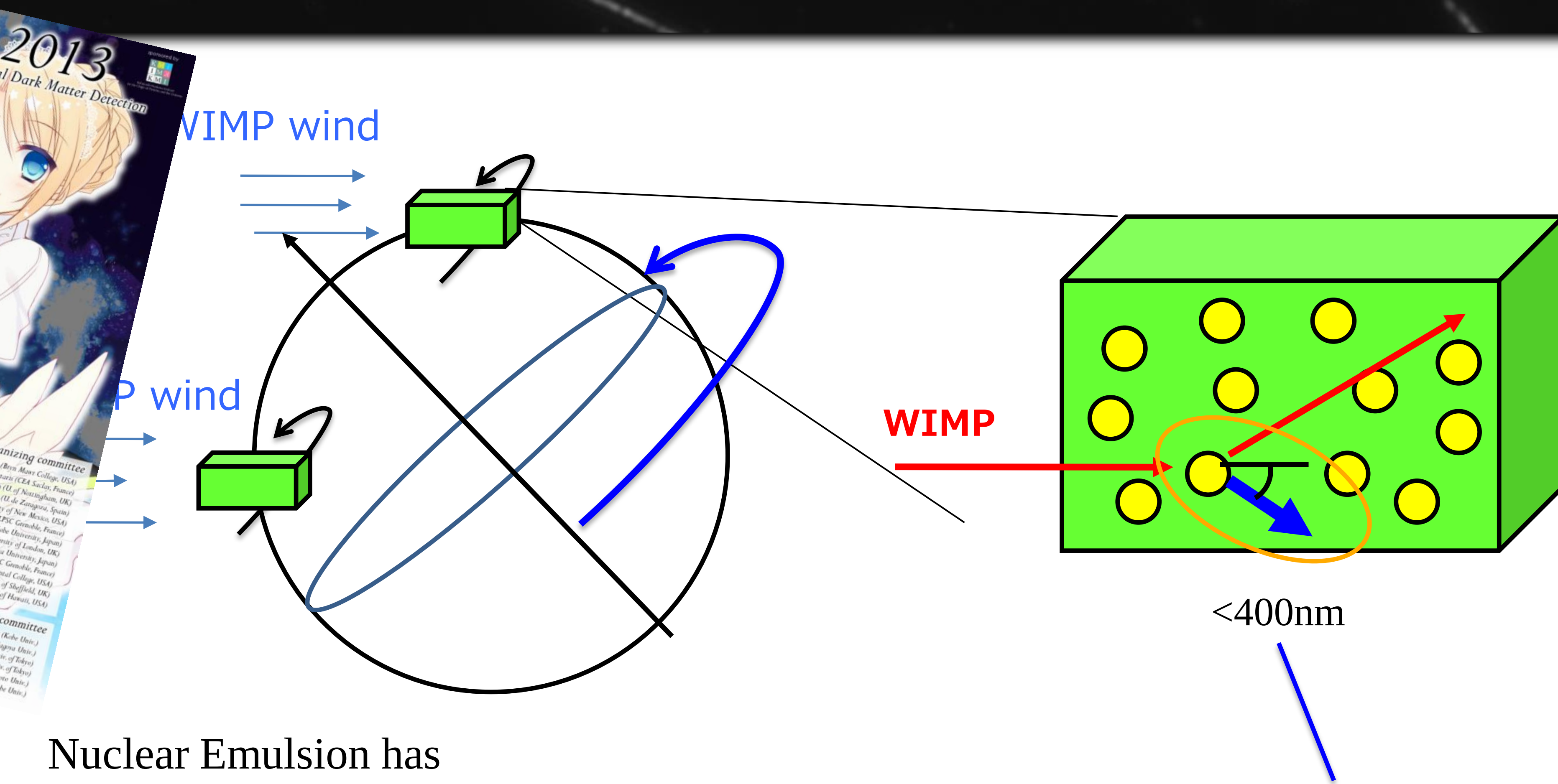
CYGNUS 2013

Outlines

- About Nuclear Emulsion
- Production of Emulsion
- High sensitivity Emulsion
- Noise
- Micronized Emulsion
- Sensitivity control
- Summary

Nuclear Emulsion

Directional Dark Matter Search with Nuclear Emulsion

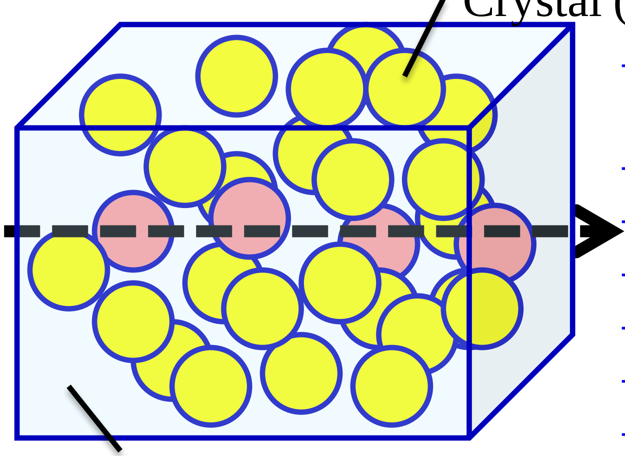


Nuclear Emulsion has

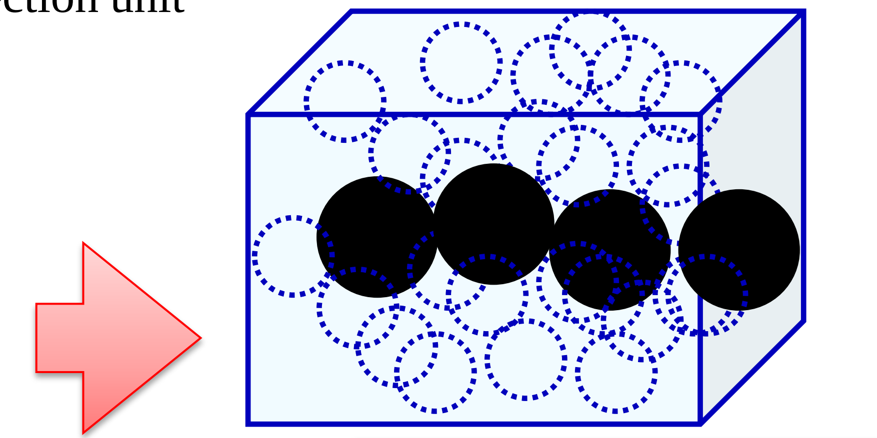
- no time resolution
  →equatorial telescope
- good spatial resolution
- potential for large mass experiment

The key is how detect very short tracks

Nuclear Emulsion Mechanism



3.2g/cc	mass %
Ag	46.3
Br	33.9
I	1.1
C	7.2
O	7.2
N	2.8



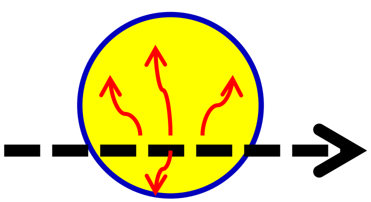
silver grain tracks

particles passing

developing

ionization

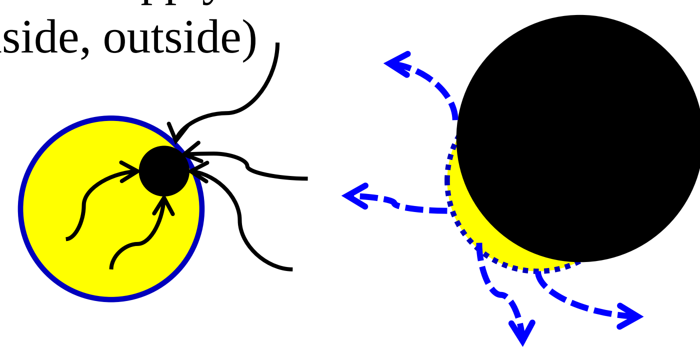
electron capture



little silver speck is generated
(latent image speck)

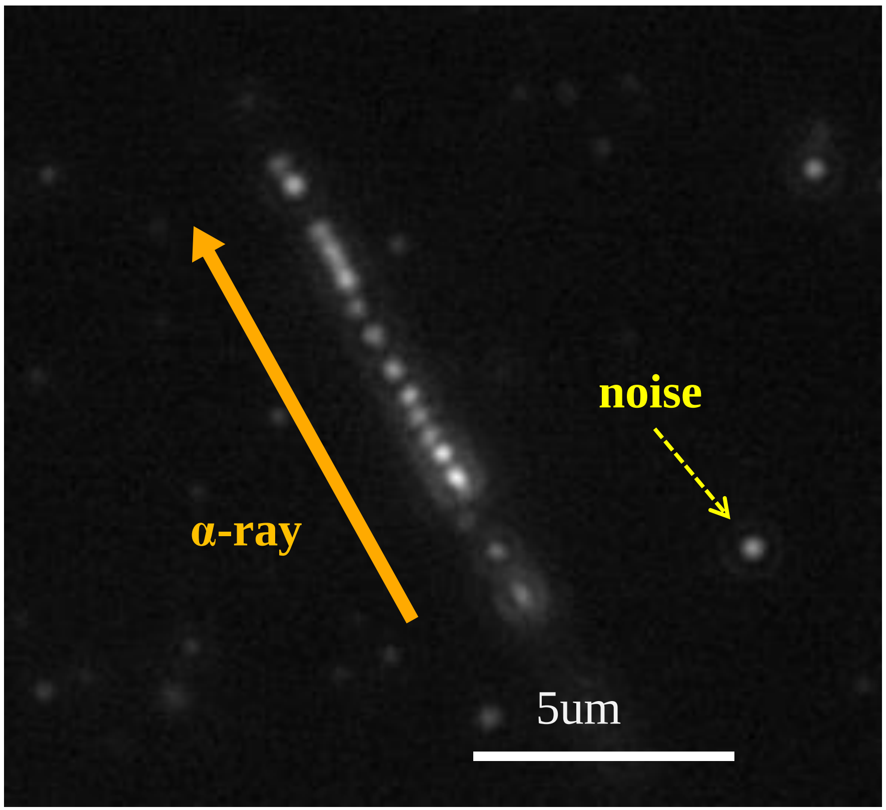
silver supply
(inside, outside)

visible silver grain

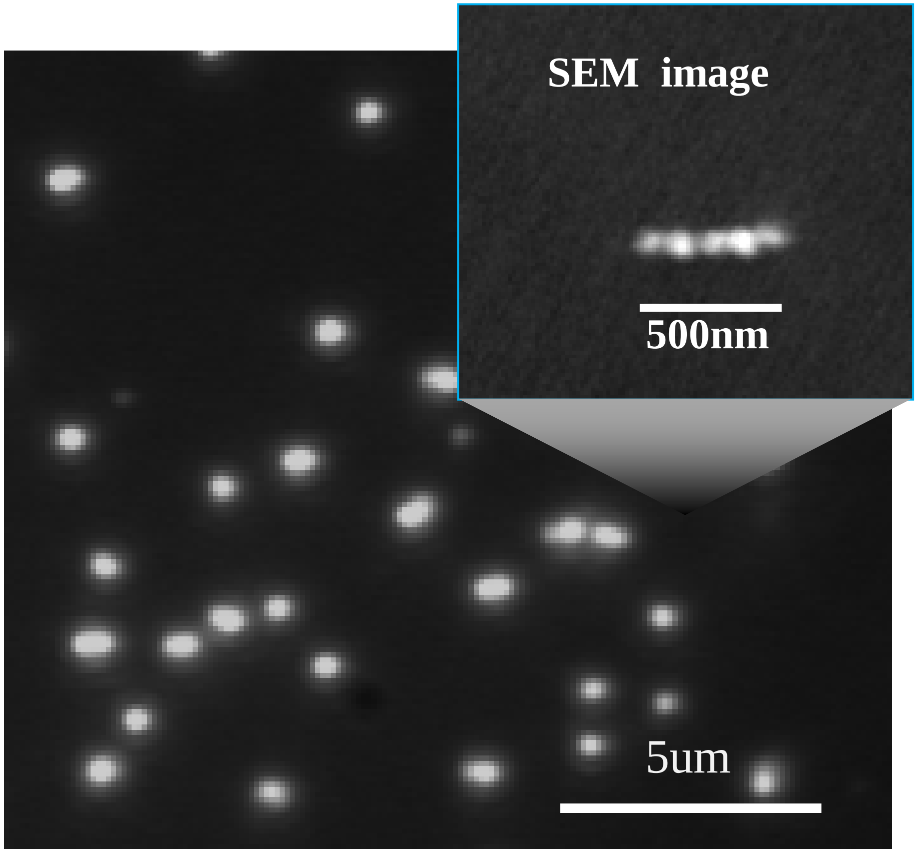


Crystal dissolve

Optical image of Real Events



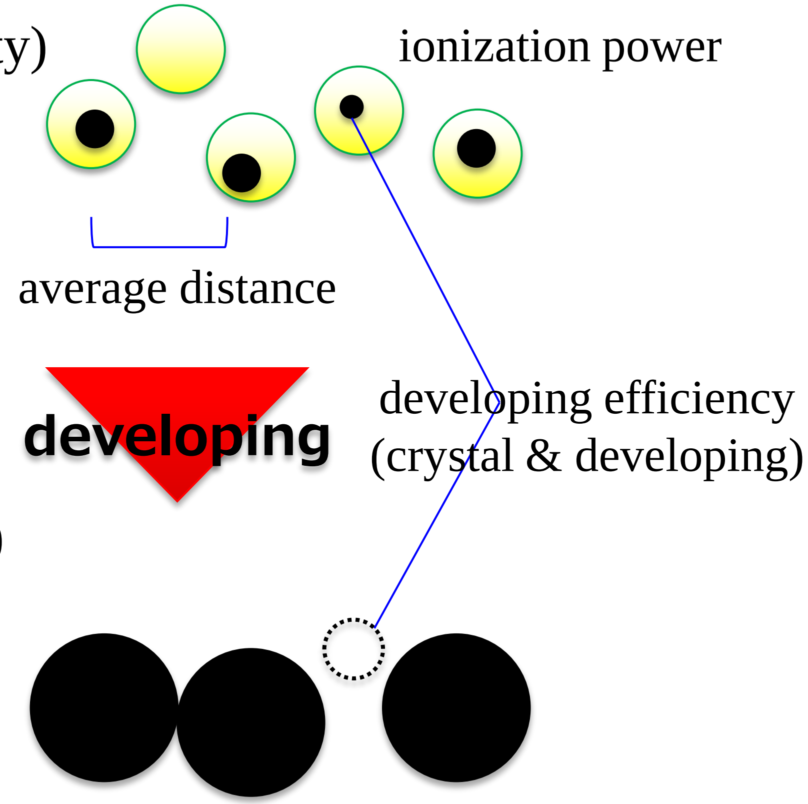
^{241}Am alpha-ray



400keV Kr ion
double expanded by chemical treatment

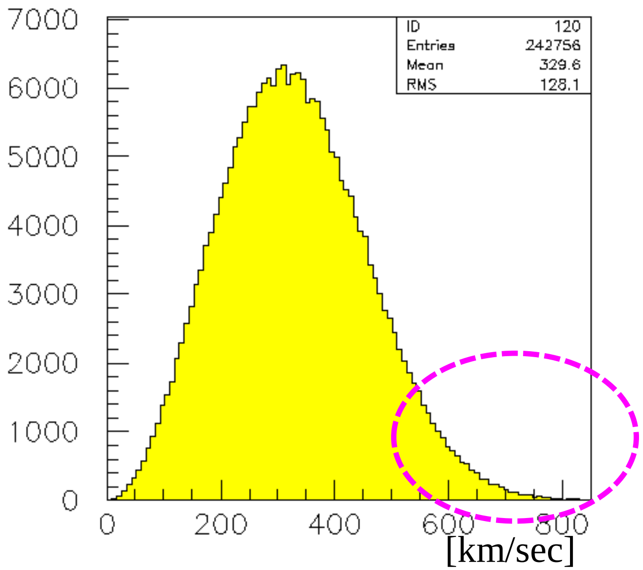
Emulsion Feature

- resolution
  - Crystal distance (depend on size & density)
  - Microscope resolution
- Sensitivity
  - Kind of particles (ionization power)
  - Crystal (size & chemical treatment)
  - Developing (latent image speck growing)
  - Analysis (track detection efficiency)
- background
  - Emulsion original background (random developing grain)
  - Electron and low energy proton hit

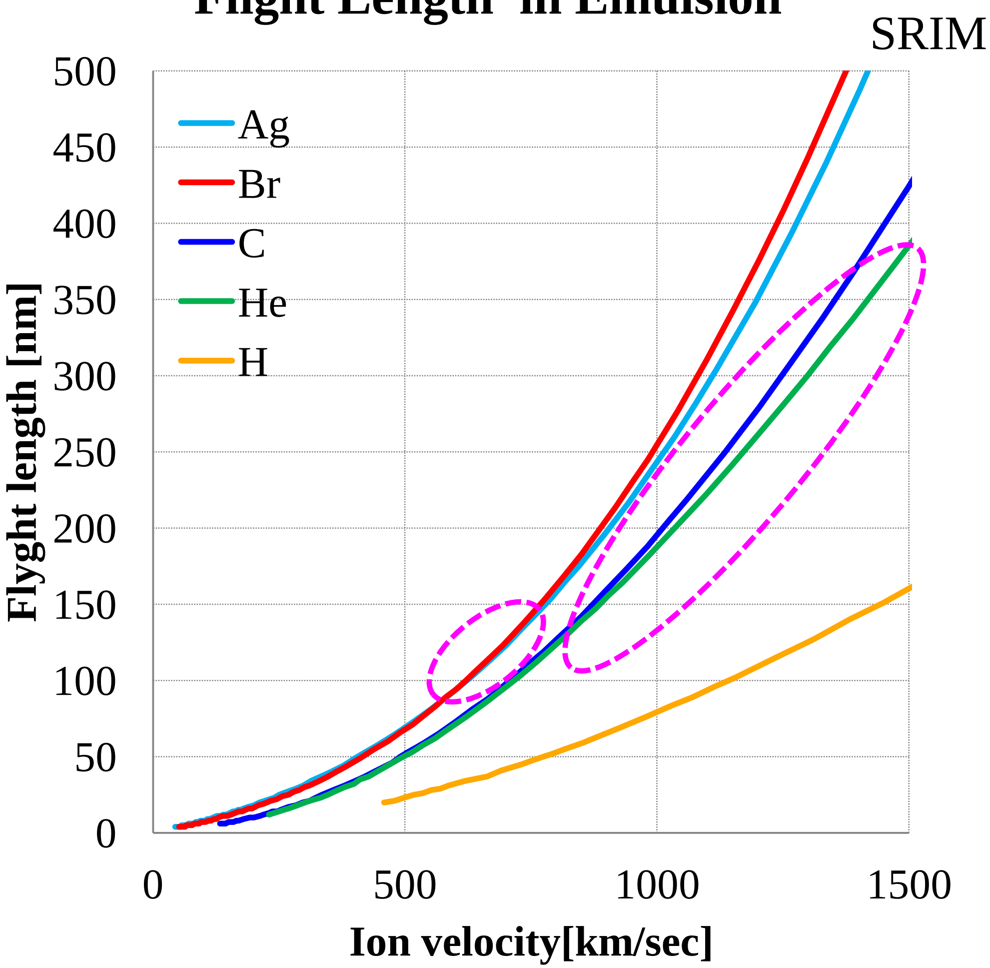


Signal Track Range

WIMP velocity on the Earth

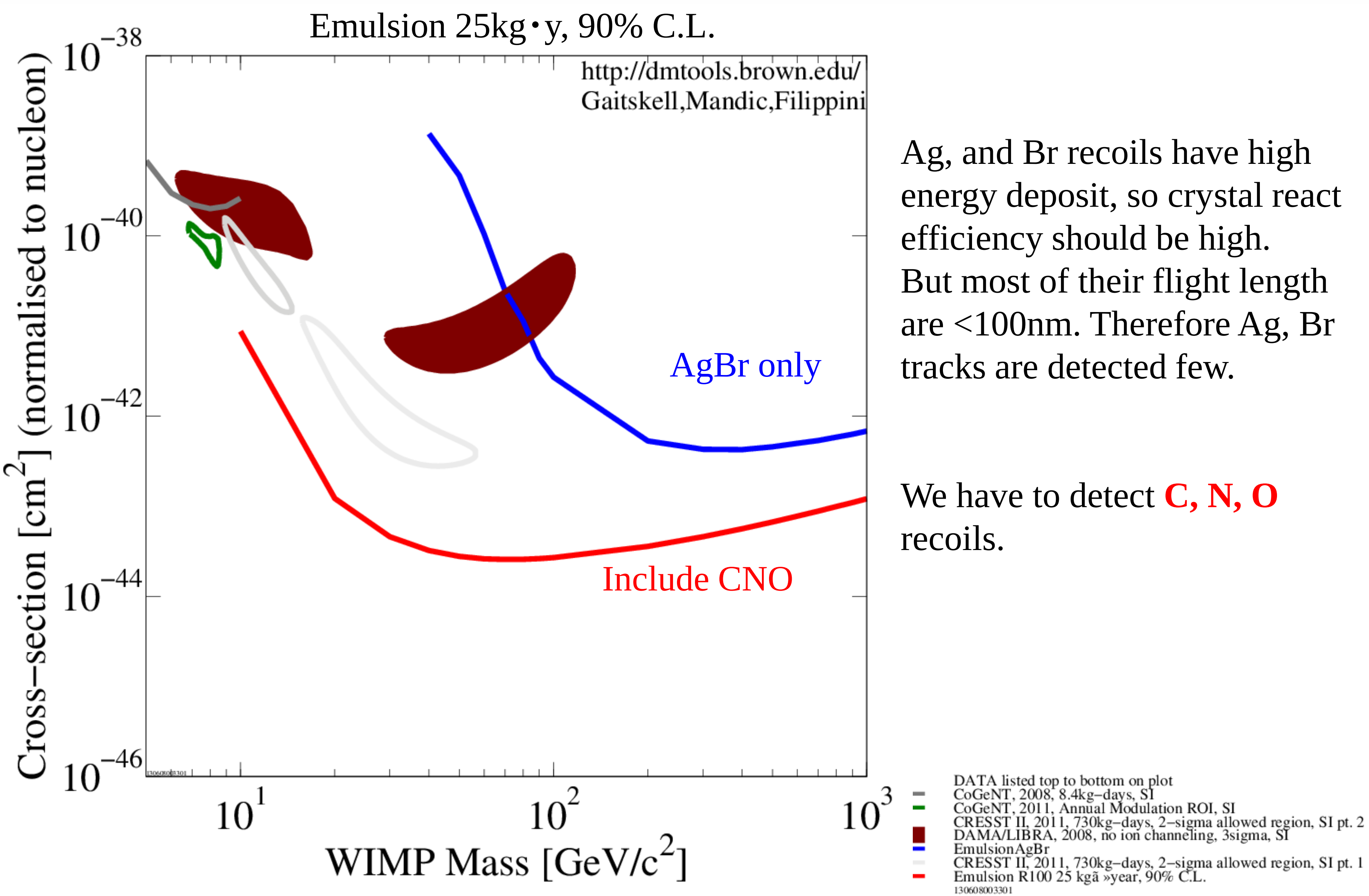


Flight Length in Emulsion



It is important how detect tracks **under 400nm** for WIMP directional search.

Cross Section for Ag Br and CNO



Ag, and Br recoils have high energy deposit, so crystal react efficiency should be high.
But most of their flight length are <100nm. Therefore Ag, Br tracks are detected few.

We have to detect **C, N, O** recoils.

Production of Emulsion

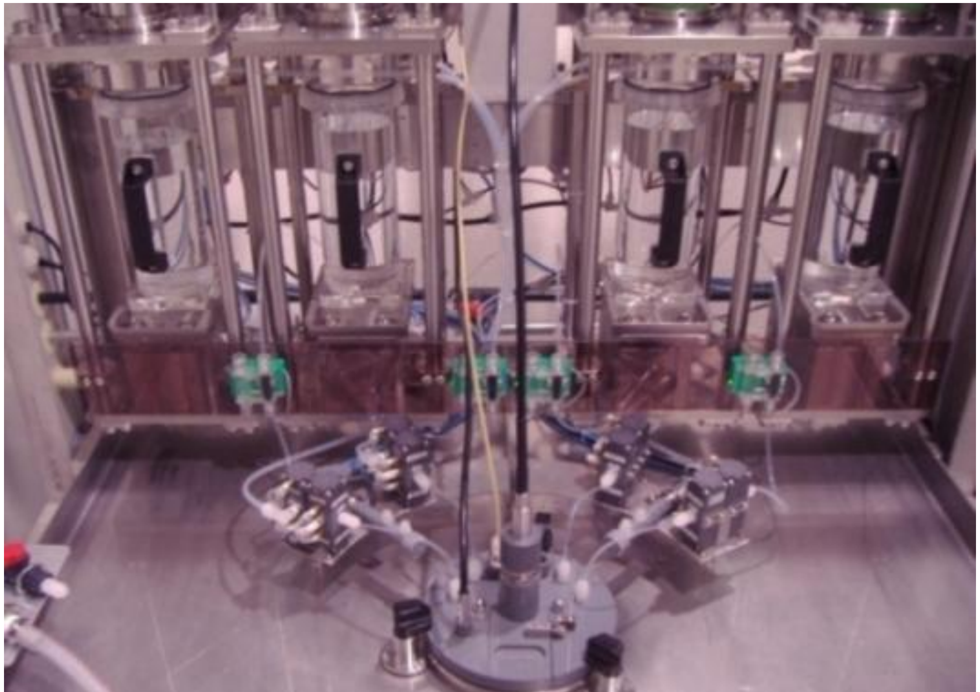
Demands for Emulsion

Ideal emulsion for carbon tracks is that

- each crystal certainly react to carbon ion
- crystal distance is enough shorter than carbon tracks

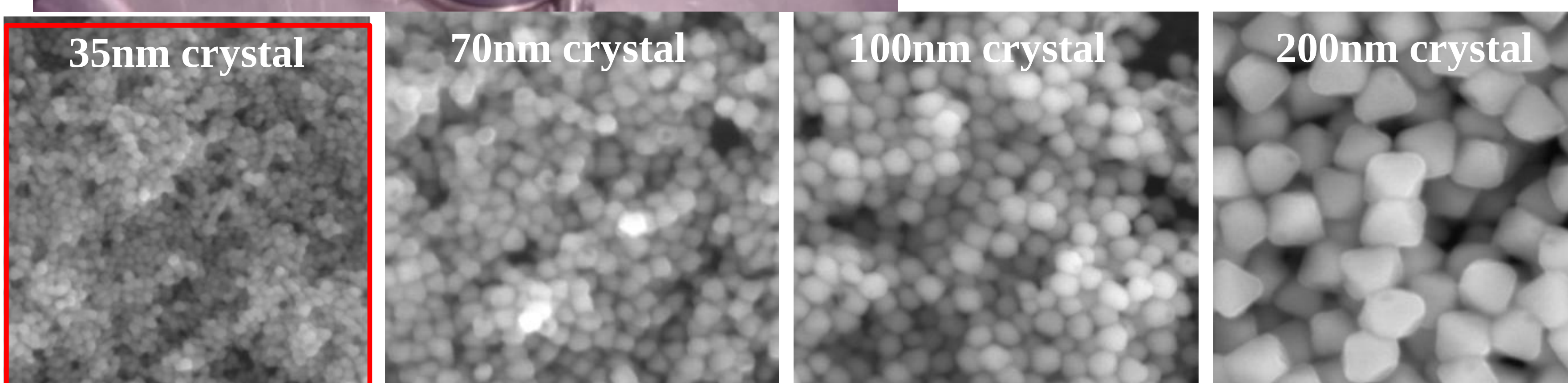
To make such emulsion, first, we developed small and stable crystal, and then studied sensitivity control

Production of Emulsion in Nagoya (2010~)



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

We are planning 3 times volume machine
→20kg/month
~100kg experiment is possible



SEM Image without Gelatin

For dark matter (low velocity ion)

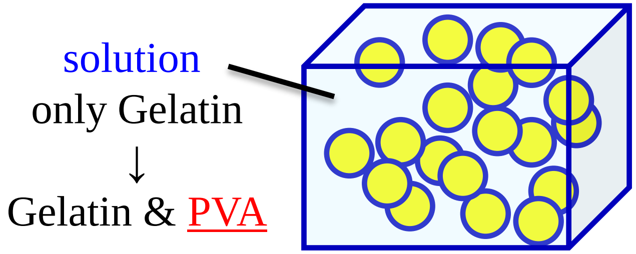
For proton

500nm

For MIP

Fine Crystal Emulsion production with PVA

- Fine crystal only with gelatin is succeeded, but the size isn't stable

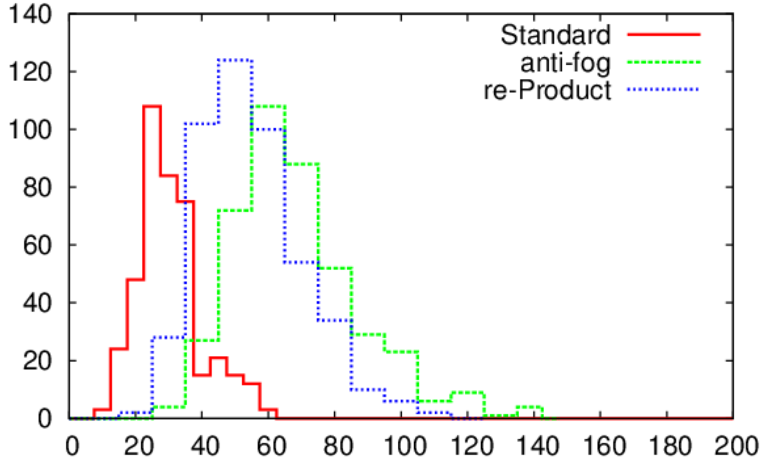


- We try new method to product with **polyvinyl alcohol (PVA)** , which strongly covers crystals surface and suppresses their growing.

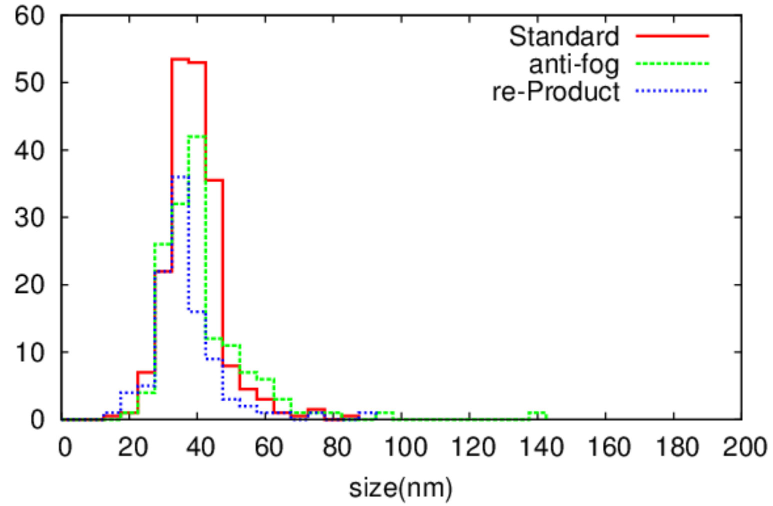
  Production with PVA solution make crystals size very stable.

  We could start studying about crystal sensitivity.

only gelatin type crystal size



PVA mixed type crystal size



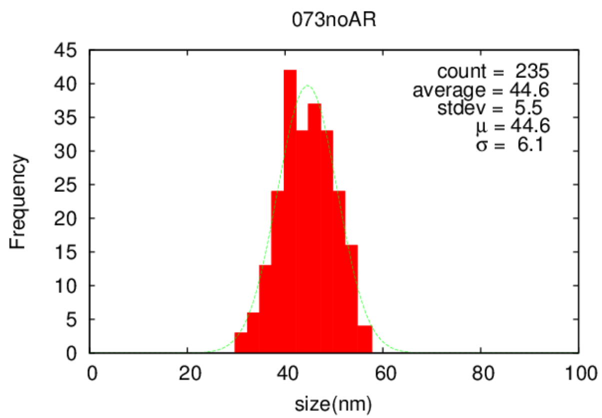
High sensitivity Emulsion

New emulsion in Nagoya

Concept

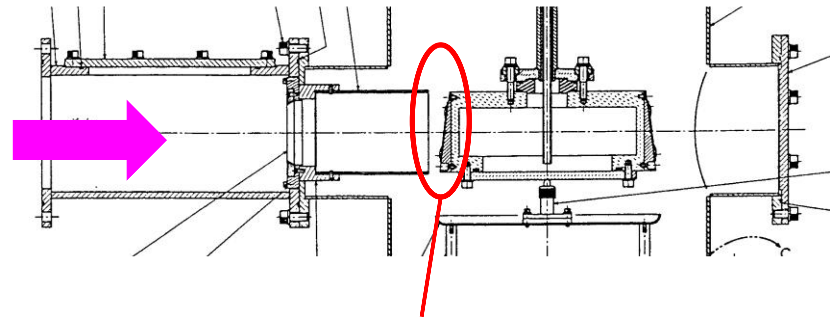
- crystal size～40nm (to keep crystal sensitivity)
- Theoretical resolution is ~100nm
  - cf. Optical analysis threshold is about 100nm now.
- Strong chemical treatment with PVA method.

crystal size	45nm
crystal distance	85nm
crystal sensitivity for alpha-ray	>20% (not sensitized)



+ chemical treatment

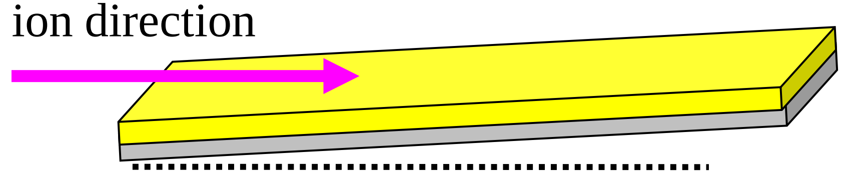
Sensitivity Check with the low velocity ion.



Low velocity ion which is created by "ion implantation system"

gas source : Kr, Ar+CO_2, BF_4 etc

Acceleration voltage : 30-200keV



Direct ion implantation to emulsion film, and check with optical and Electron microscope.

C ion detection

We started to measure C ion efficiency.

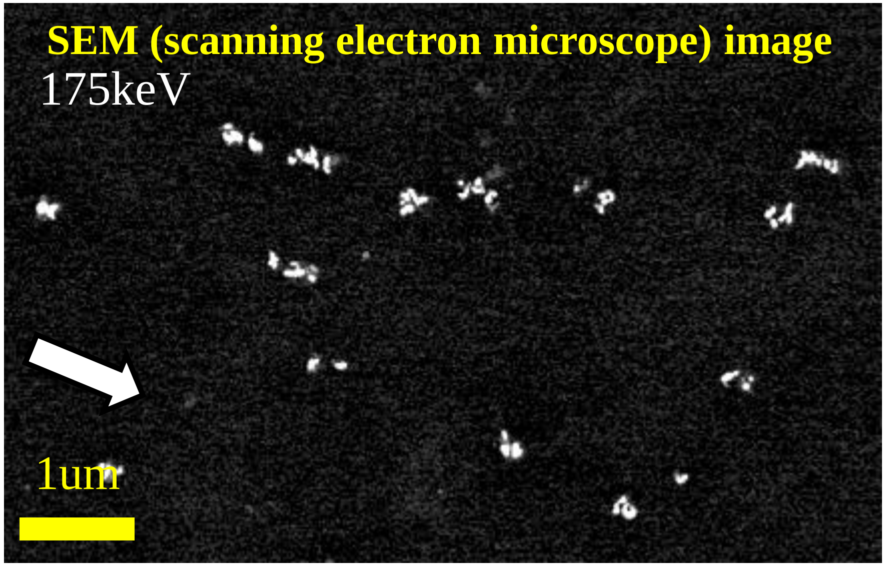
preliminary

track detection efficiency

175keV (520nm expected): 80%

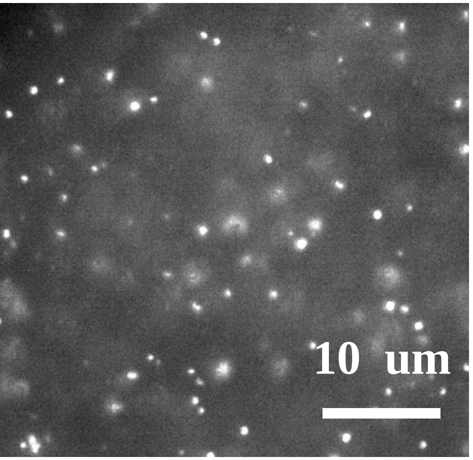
80keV (250nm expected) : 50%

<u>Crystal sensitivity is about 50%</u>



Noise

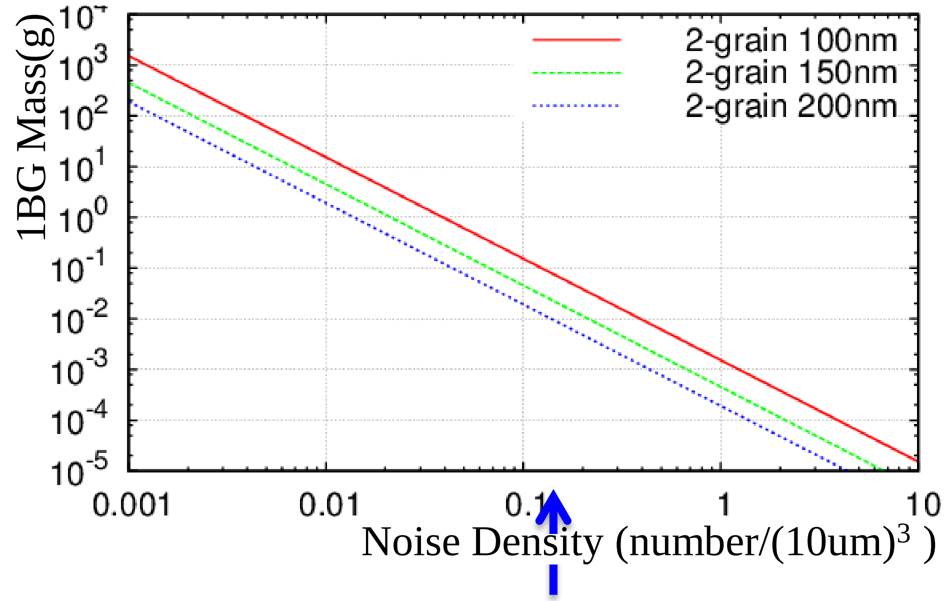
Accidental background



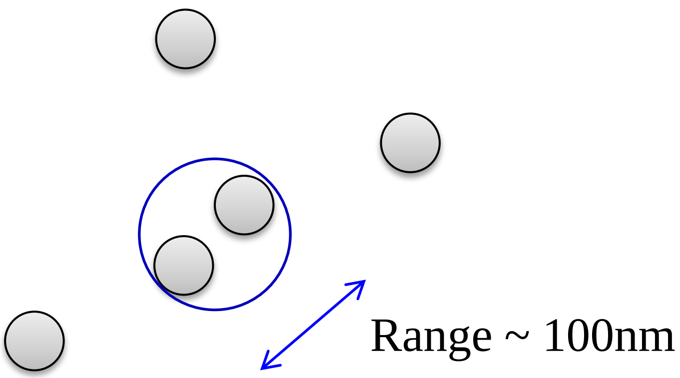
With developing, unexpected silver grains are generated at random.

If they are generated too close, they become noise tracks.

Noise Density and Mass which generate 1BG



~lowest BG

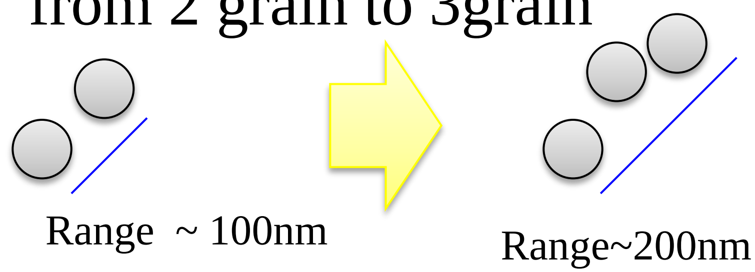


Signal range threshold : **r**, Noise Density : $\mathbf{d_{Fd}}$
volume :V
→Expected number of BG is $n_E \sim \frac{2}{3}\pi r^3 d_{FD}{}^2 V$

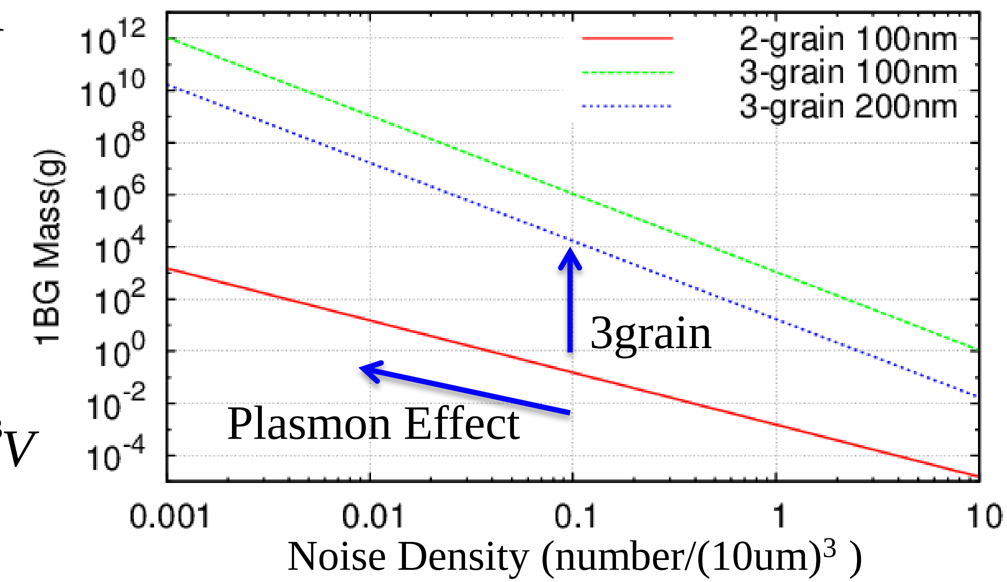
We can only do 0.1g mass experiment without BG

Background Reduction

- Change requirement for signal from 2 grain to 3grain



$$n_E \sim \frac{2}{3}\pi r^3 d_{FD}{}^2 V \qquad n_E \sim \frac{8}{27}\pi^2 r^6 d_{FD}{}^3 V$$

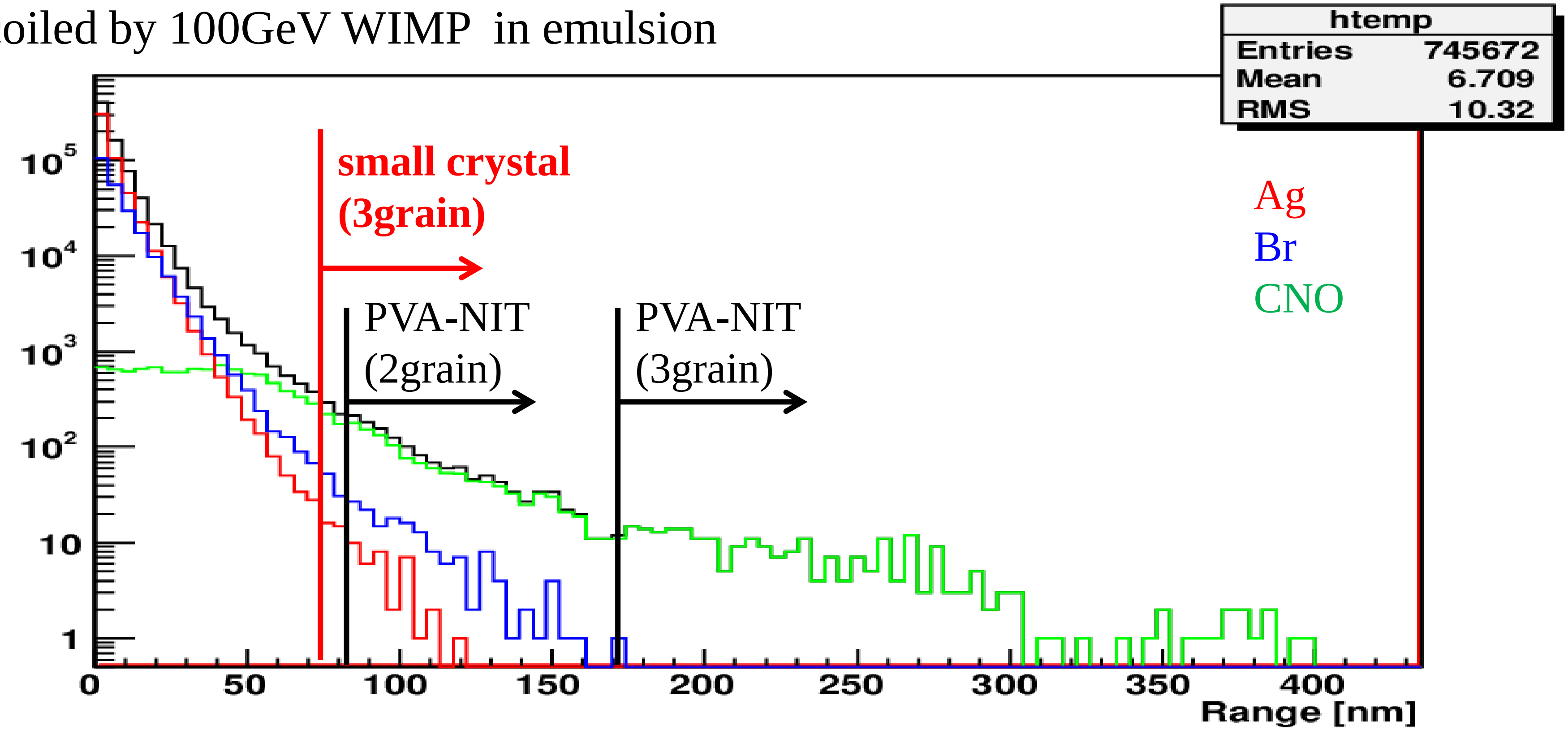


Range threshold become worse,
but <u>chance coincidence of noise was greatly reduced</u>.
If noise density is 0.1 and range threshold is 200nm,
we can do 1kg mass experiments without background.

Silver grains of noise have another generating mechanism from signal's one.
We are studying <u>Plasmon Effect</u>, which show non-liner behavior of signal grains.
It is expected to <u>distinguish noise track from signal.</u>
It can reduce noise amount directly.

Flight Length of Atoms in Emulsion

recoiled by 100GeV WIMP in emulsion



Crystal Size and Mean distance (g/cm^3 normalized)

	Crystal size	mean crystal distance
PVA-NIT	45 nm	85nm at 2grain
		170nm at 3grain
small crystal (ideal)	**20 nm**	**76nm at 3grain**

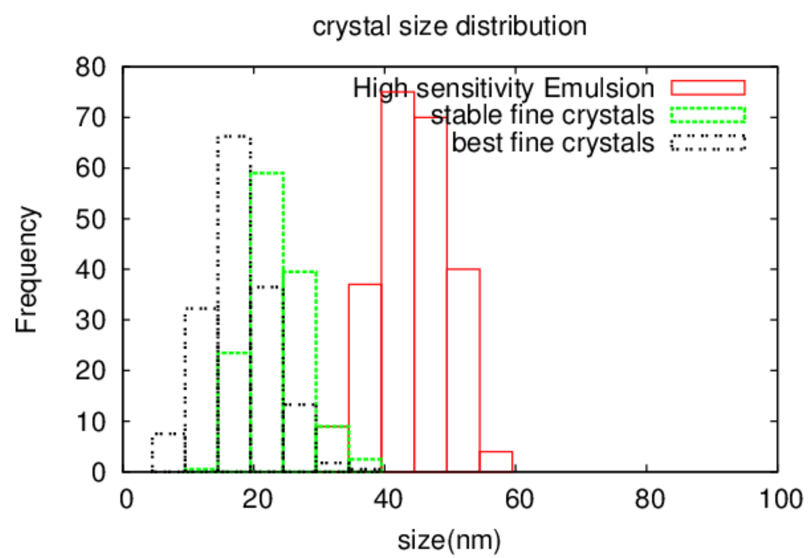
With 3 grain tracking, bad range threshold seriously effects event detection amount

Micronized Emulsion

micronization

3 grain detection require more micronized crystals.

Additionally, optical analysis resolution improvement also requires emulsion resolution improvement (<100nm) in the future.



	Micronized Emulsion	High sensitivity Emulsion
crystal size	25nm	45nm
crystal distance	48nm (3grain:96nm)	85nm (3grain:170nm)
crystal sensitivity for alpha-ray	10%	>20%

With PVA treatment and carefully tuning of parameters of production, the size becomes stable at 25nm,
and best score is 18nm.

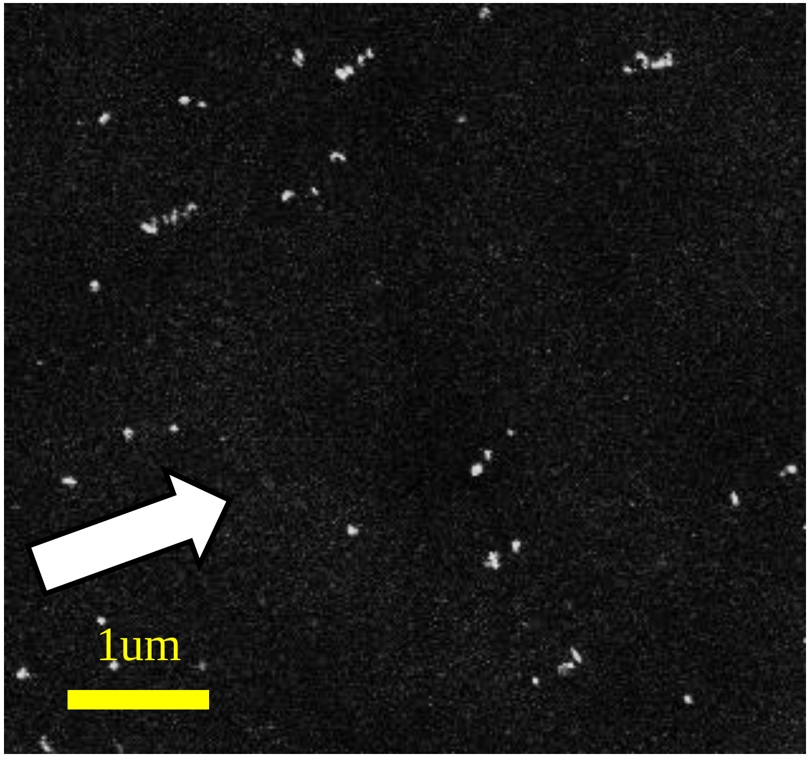
Sensitivity

- Small crystal size seriously effect its sensitivity.

- Each crystal efficiency for alpha-ray is about 10%
  It's not enough to detect low energy carbon.

preliminary

- High energy (200keV) carbon was detected (590nm expected)
- Now we are tuning conditions and sensitizing crystals.



Sensitivity control

Desensitizing reason and aim

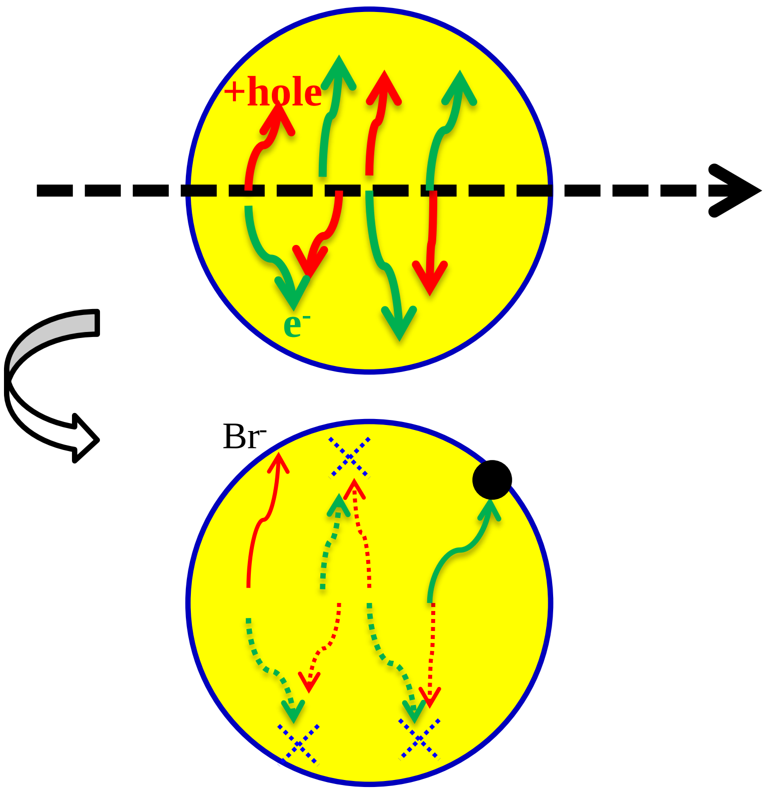
Track detection for carbon has not be perfect yet.

This reason considered

- recombine of electron and hole.
- silver speck dispersion.

Desensitization Effect of Crystal

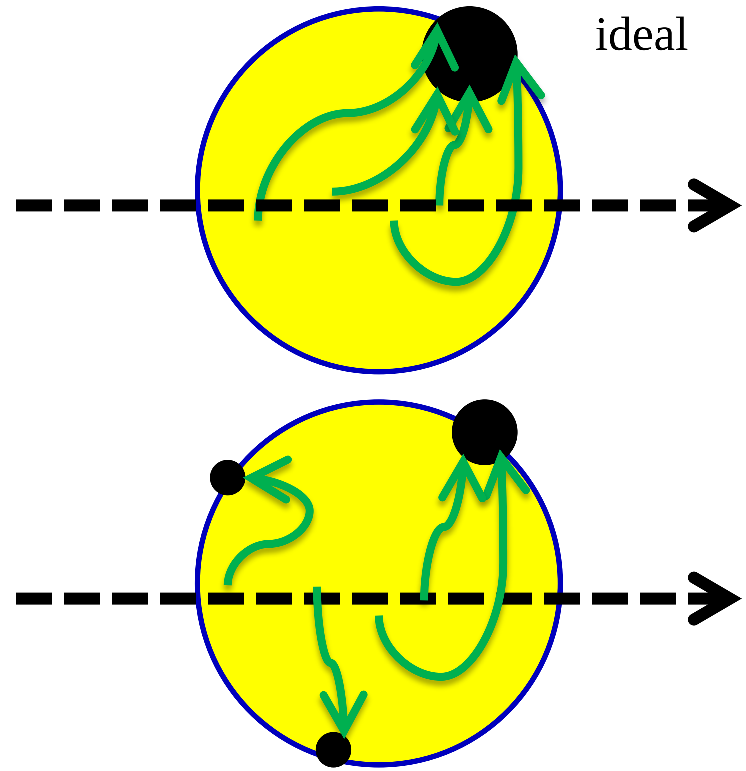
recombine of electron and hole



most of elected electron are disappeared

Making capture spot for hole is effective.
We'll try "**Reduction Sensitization**"

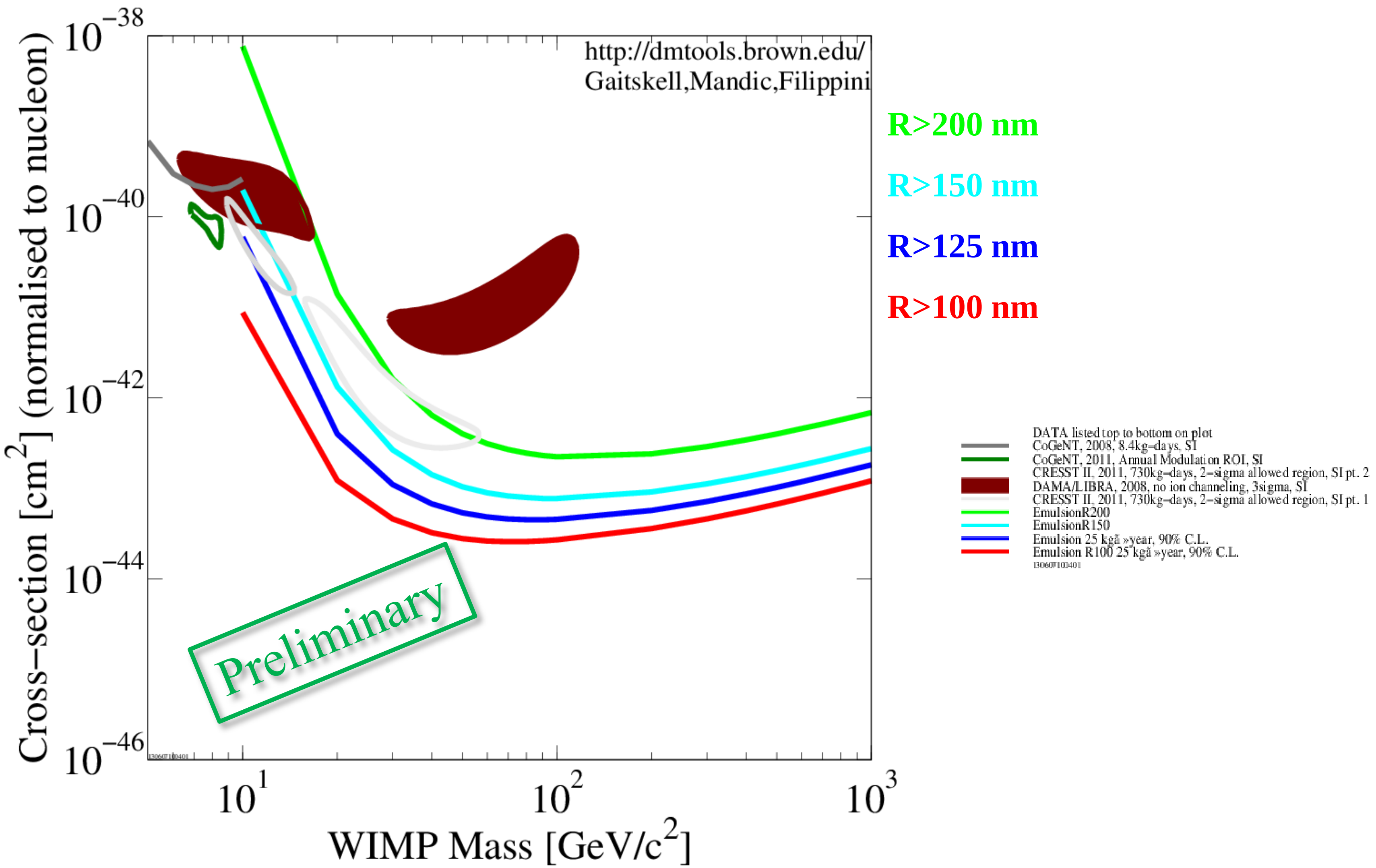
silver speck dispersion



small spec is low active for developing

Recently this effect have been observed.
We are searching more effective way of gathering electrons to one silver speck.

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



Summary

- Detecting recoil atom of C,N,O is essential.

- We have gotten emulsion whose crystal size was very stable, thanks to PVA mixing method.

  Then we start study about crystal sensitivity.

- Developing back ground is serious, but there are some way of reduction.

- When background is enough rejected and range threshold becomes 100nm, we will reach very interesting cross section area.