Fine Grained Nuclear Emulsion as High Resolution Tracking Detector

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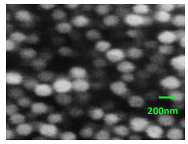
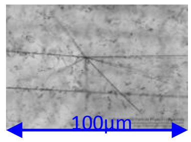
1. Introduction

1.1 Nuclear emulsion

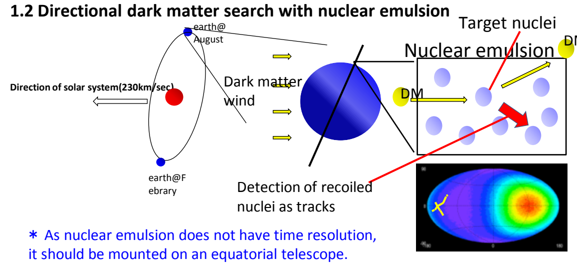
Nuclear emulsion is a type of photographic film, and 3D tracking detector for charged particles. Nuclear emulsion has extreme high spatial resolution. In recent experiments, very large nuclear emulsion detector was used because automatic high speed readout with optical microscope became possible.

Recently, we developed the fine grained nuclear emulsion, it can achieved higher spatial resolution. This make possible to search a physics of new energy region. Here, we propose a directional dark matter search with nuclear emulsion.





1.2 Directional dark matter search with nuclear emulsion

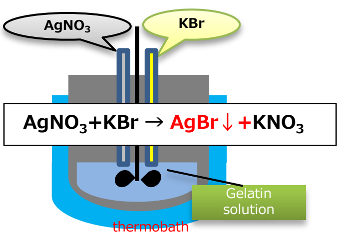


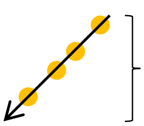
* As nuclear emulsion does not have time resolution, it should be mounted on an equatorial telescope.

2. Production facility of fine grained nuclear Emulsion

2.1 Nuclear emulsion production by ourselves

Now, we can produce the nuclear emulsion by ourselves in Nagoya university, Japan. By this technology, various type of emulsion can be produced.

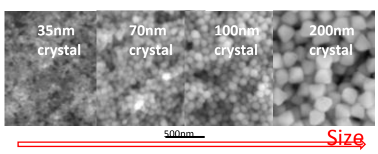




Spatial resolution depends on crystal size and density

Fine grain is essential for higher spatial resolution.

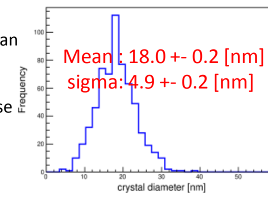
Silver halide crystals are generated via reaction between $AgNO_3$ and KBr. Here, temperature, rotation speed and addition speed is essential factor to define the crystal size.



2.2 Status silver halide crystal size

Small crystal size is very important because it can lower detectable range threshold (i.e., energy threshold). However, to produce stable fine grained nuclear emulsion is very difficult because condensation of crystals is easy to occur.

We resolved this problem by using Polyvinyl Alchol (PVA). By combining PVA with gelatin, condensation and crystal growth are supressed, stable fine grain can be generated.



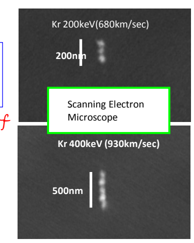
Usual binder	→	New binder
Gelatin		Gelatin (85 %) + PVA (15 %)

Very important for suppression of crystal condensation

2.3 Low-velocity ion tracking

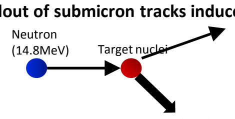
Low velocity ion is good demonstration for submicron tracking test and directional dark matter detection.

It can be dosed by ion implant system. By using this, we confirmed our fine grained nuclear emulsion can detect the signal as track of more than 100 nm.

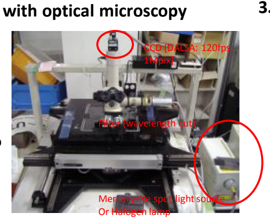


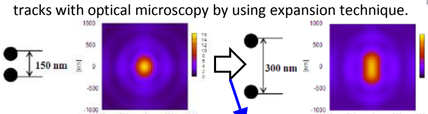
3. Readout technique of submicron tracks

3.1 Readout of submicron tracks induced by neutron with optical microscopy

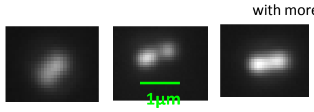


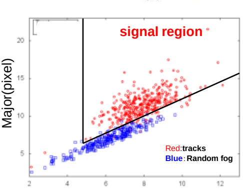
Neutron is good simulation of dark matter detection. Here, to produce the submicron tracks of heavy target nuclei (e.g., Ag or Br), 14.8 MeV neutrons due to D-T reaction were exposed to emulsion film. And, we detected the submicron tracks with optical microscopy by using expansion technique.





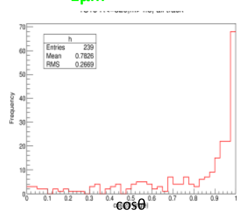
By treatment of mechanical expansion of emulsion film, tracks are elongated, and they are distinguished by optical resolution. Here, expansion factor is 2 times.





Elongated signals can be read out by optical microscopy using image processing. Here, by applying the elliptical fitting, signal region can be defined in high ellipticity.

By this system, we could observe the angular distribution of recoil tracks induced by neutron. This result is consistent with simulation.

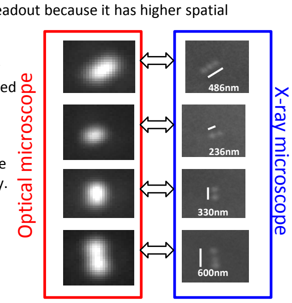


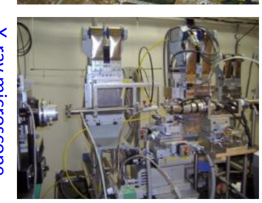
3.2 Detailed confirmation with pin-point by X-ray microscopy.

X-ray microscope is available for final check to confirm the selected candidated tracks by optical readout because it has higher spatial resolution and non-distractive observation is possible.

Here, we developed the X-ray microscope system collaborated with Spring-8.

We achieved the pinpoint checking of candidate tracks selected by optical microscope with more than 99 % efficiency.





Matching efficiency > 99%

Readout efficiency

90-100nm : 60 %
100- 110 nm : 80 %
110- 120 nm : 90 %
>120nm : > 95%

	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

4. Future planning of underground facility in Gran Sasso

4.1 Construction of underground facility for R&D in Gran Sasso

We started to construct an underground facility in Gran Sasso laboratory (LNGS). As this facility had been using in OPERA experiment which big experiment using nuclear emulsion, we can start the test production and R&D study quickly. First, we will start neutron flux measurement with nuclear emulsion. After that, we will start background run with fine grained nuclear emulsion for directional dark matter search.

4.2 Sensitivity for dark matter search

Our first aim is to search the region of DAMA or other experiments which have positive results. Right figure shows the ideal sensitivity of nuclear emulsion for dark matter search for dark matter mass vs. dark matter-ncleon cross section with 1000 kg・year exposure and 90 %CL.

Target nuclei for nuclear emulsion are divided on light target (C,N,O) and heavy targets(Ag, Br). By optimization of sensitivity which can detect recoilled light target nuclei induced by dark matter, we will be able to search in wide dark matter mass region with high sensitivity. For search of heavy dark matter, only Ag and Br targets are available. In this situation, background rejection is easier because recoiled nuclei of heavy targets have large dE/dx, we can use lower sensitivity detector.