

Status and analysis system of directional dark matter search with nuclear emulsion.

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Abstract. We have been doing research and development for direct dark matter search by nuclear emulsion which is a solid state detector. This experiment enable directional detection of dark matter with the large mass target and model independent. Until now, we constructed a base of fully automatic analysis system and nuclear emulsion which can detect sub-micron tracks. We have demonstrated that it is possible to detect recoiled tracks of 100 nm or more by neutron irradiation. This track length is correspond to 37 keV in C(N,O) target. Additionally, we evaluated the angular resolution of the energy basis by using an ion implant system, and obtained 25 degrees or better resolution in 80 keV carbon ions. The fully automatic analysis system which can analyze very short tracks lead the experiment to next phase, we will do a quantitative study of the background toward gram scale test experiment at the Gran Sasso underground laboratory.

1. Introduction

We are aiming to detect dark matter around galaxy with the nuclear emulsion detector (emulsion). Then, dark matter signals are nuclei which is recoiled by dark matter in the emulsion, and the emulsion can detect them together with directional information. Because, emulsion has extremely high spatial resolution and solid-state detector (3.2 g/cm^3). So, this experiment enable directional dark matter search with the large mass target and model independent. On the other hand, the emulsion don't have time resolution. So, we will control the direction of the emulsion to Cygnus by mounting on the equatorial telescope. First, we aim to conclude about parameter region (dark matter-nucleon cross section of $10^{-40} \sim 10^{-41} \text{ cm}^2$ and dark matter mass of $10 \text{ GeV}/c^2$) with direction information which is claimed dark matter signals by preceding experiments (DAMA [1], CoGeNT [2] and CRESST [3]).

2. Detector

The emulsion is a kind of photographic film which made from silver halide crystals and polymer as a binder (Table 1). When a charged particle penetrates some crystals, track is detected as a line of silver grains by a process of chemical development. Now, emulsion is able to be produced in Nagoya university Japan and, various types of emulsions can be produced and studied by this facility. In the case of dark matter search, it is necessary to detect the sub-micron scale



tracks. Then, small crystal size is very essential to realize lower threshold of detectable range (energy). New type emulsion detector with fine-grained crystals (40 nm) was already confirmed to be able to detect tracks of more than 100 nm (Figure 2) by using low velocity ions due to ion implantation system like a recoiled nuclei (Figure 1).

Table 1. Parameter of the emulsion.

Atom	Mass ratio [%]
Ag	46
Br	34
C (N, O)	19
Total mass density	3.2 g/cm ³

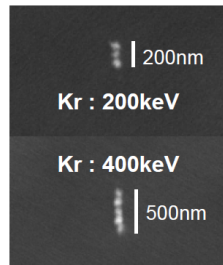


Figure 1. Sub-micron track images by using Kr ion with electron microscope.

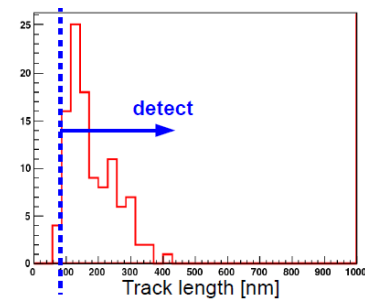


Figure 2. Detectable track lengths are 100 nm or longer by measurements in the electron microscope.

3. Readout system

Analysis is divided into two main phases. In the first scan, we use the optical microscope for selection of candidate. Because, the optical microscope can analyze large volume. In the second scan, candidates are confirmed whether a track or not by using higher spatial resolution microscopy (e.g. X-ray microscope, electron microscope, and super-resolution technique with optical microscope).

3.1. Readout technique of sub-micron tracks

First, the development of readout system to parameterize the quality of track as an Ellipticity (Major/Minor) have been done by constructing the prototype optical microscope called "PTS" for R&D. By this shape recognition system, sub-micron tracks with two or more silver grains can be selected in the emulsion, because main noises are one silver grain and looks like sphere with optical microscope.

The performance of the emulsion sample exposed to neutrons (14.8 MeV by D-T reaction) was evaluated, because recoiled nuclei tracks due to neutron are similar to that of scattered by dark matter. By using the PTS, we have examined the ellipticity distribution of events which have already been confirmed as tracks or noises by X-ray microscopy analysis collaborated with Spring-8 in Japan [4]. So, we constructed X-ray microscope for second scan, and which is good tool to confirm the candidates. Because, X-ray microscope has higher spatial resolution and non destructive observation is possible. And, we could match the events between optical and X-ray microscope like Figure 3. Then, matching efficiency was achieved more than 99 %, and the plot of major vs. minor was obtained like Figure 4 which show signal region by the ellipticity. As the result, the PTS has about 70 % readout efficiency by the method of ellipse fit about 200 nm tracks compared to the X-ray microscope, and 320 nm or longer tracks are 100 % that was shown in Figure 5. And, the angular distribution of tracks in signal region indicated the direction of neutron (Figure 6).

In addition, the best focus selection system for the shape recognition was also developed. So, a base of analysis system was complete. Emulsion can be analyzed fully automatic with optical microscope. Here, current maximum readout speed is about 1 g/10day.

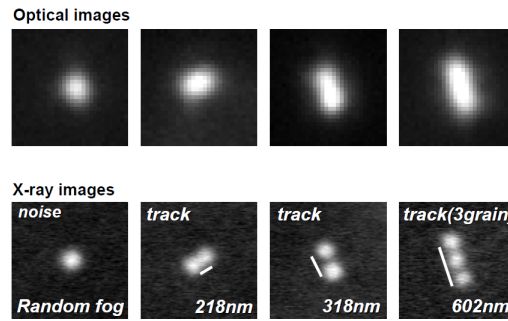


Figure 3. The pinpoint checking of events and noise between optical and X-ray microscope. Above: optical microscope images. Below: X-ray microscope images.

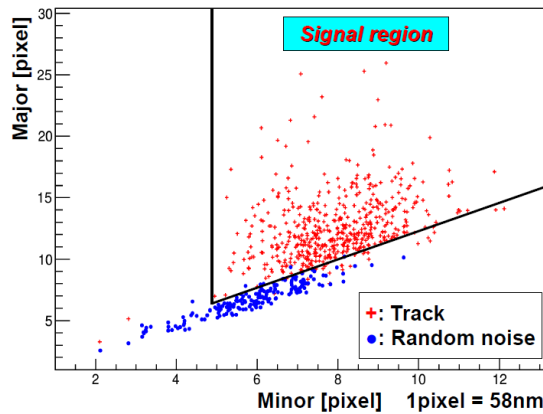


Figure 4. The data is optical readout result of events already confirmed as tracks and noises by X-ray microscope. Signal region that is determined by the Ellipticity (Major/Minor). + dots (red dots in online version) are result of tracks due to neutrons, and • dots (blue dots in online version) are noise events.

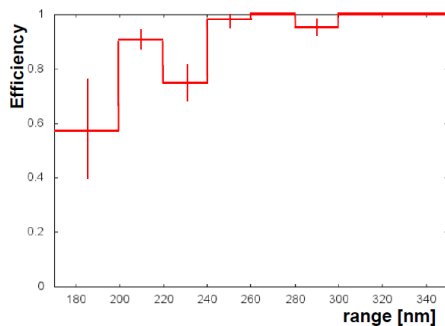


Figure 5. Readout efficiency with optical microscope compared to X-ray microscope. This data was obtained by result of Figure 4, and still preliminary.

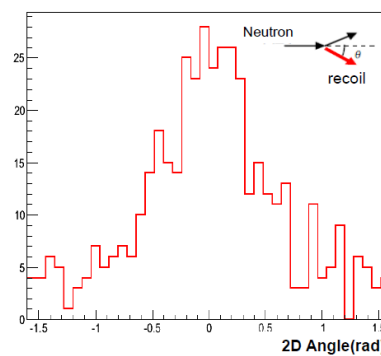


Figure 6. Angular distribution of recoiled tracks in signal region by image processing with optical microscope. This result is consistent with the incident direction of neutrons.

3.2. Angular resolution with optical microscopy

We confirmed angular resolution of optical readout by using ion-implantation system. Ion-implantation system can be used as a demonstration of monochromatic energy nuclei recoiled. In this time, carbon ions are used, and the angular resolution was obtained by compared to the Gaussian distribution of the Monte Carlo simulation (SRIM) [5] smeared by addition of the angular resolution from ideal incident angular distribution of the carbon ions. Angular resolution with optical microscope is better than about 25 degree for 80 keV carbon recoiled tracks like Figure 7.

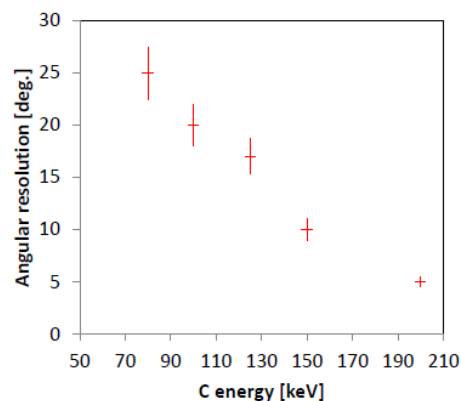


Figure 7. Angular resolution of carbon ions due to ion implantation system, and energy of carbon ions can be selected. This data is still preliminary, because there is a possibility to change depending on improvement of the emulsion and chemical development.

3.3. Techniques to improve the readout efficiency

We have expansion technique to improve the energy threshold with optical microscope [6]. By expansion of emulsion, tracks are elongated. It is possible to expand up to two times by chemical treatment. Therefore, more than 100 nm tracks can be selected. Then, distortion of angle is 0.41 degree after expansion and this is small enough compared to angular resolution.

4. Summary and near future plan

Emulsion have been developed for dark matter search which can detect the tracks of 100 nm or more, and a base of fully automatic analysis system was also completed. The tracks of 100 nm are correspond to about 37 keV C(NO) recoils. As the next step, we will start to study about background (β -rays, γ -rays, and neutrons), and preparing of the measurement about radio activity in the our material was already started. In addition, the rejection efficiency about background with current emulsion will be obtained by the PTS, and we will do R&D of the emulsion about background and low velocity ions sensitivity. In parallel, we are aiming to improve the readout efficiency by changing the conditions of the microscope in order to construct the next optical microscope with higher spatial resolution and readout speed, and to start first test experiment with gram scale emulsion in Gran Sasso national laboratory (LNGS, Italy).

References

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