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Directional Direct Detection with Nuclear Emulsion

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Abstract

We propose nuclear emulsion as new directional dark matter detector. Nuclear emulsion is possible to be large mass detector because density ~3g/cm3.

Track length of nuclear recoil is expected 10-100nm order in the emulsion. So we developed high resolution emulsion (NIT), and confirmed to be able to detect 100nm order track. To read out by optical microscope, we developed the technique to expand track. By expanding track, we could recognize 100nm order track by optical microscope and read out high efficiency(more than 80%) by track selector.

By controlling sensitivity of NIT, we confirmed that electron background rejection power is 10E-5. After making progressed further R&D, we will ready 1kg test running.

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[1] Speaker

1. Introduction

Directional detection of WIMP is very important for high reliability and knowledge of distribution of WIMP in dark halo.

For direct detection of WIMP, status of detectors that having directional sensitivity are almost gas (TPC, drift chamber). Gas detector have fatal defect that is difficult to be large mass detector.

We propose nuclear emulsion as new dark matter detector having directional sensitivity. Nuclear emulsion has extreme high resolution in all of detector and is possible to do large mass experiment because it is the solid detector (density~3g/cm^3).

2. Nuclear Emulsion

Nuclear emulsion is a kind of photographic film and 3D tracking detector (not 2D). It has constitution that AgBr crystal dispersing in the gelatin. When charged particle penetrates AgBr crystal, latent image is generated. Ag filament develops until visible size(50nm-1 μ m) by making latent image seed in the process of development.

Then, possibility of generation of latent image depends on energy deposit (dE/dx) of charged particle. And resolution of nuclear emulsion depends on size and number density of AgBr.

3. High resolution nuclear emulsion

Length of nuclear recoil track is expected as 10-100nm order in nuclear emulsion by SRIM simulation.

The case of normal emulsion is impossible to recognize 100nm order track because the line density of AgBr penetrated by particle is 2.3grains/μm (Fig1 left)[1]. So we developed high resolution emulsion (Nano Imaging Tracker:NIT) with Fuji Film[2]. AgBr size of NIT is 40nm and line density is about 11AgBr/μm (Fig1 right). NIT has high resolution that can recognize 100nm order track.

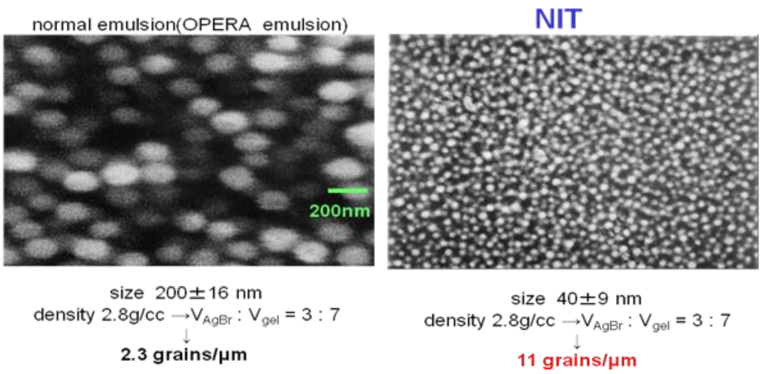


Fig1. SEM image of normal emulsion(left) and NIT(right) before development. White ball is AgBr crystal.

4. Tracking of nuclear recoil

We tested whether NIT can detect the recoil track. Here low velocity Kr ion by Ion Implanter Machine was used instead of nuclear recoil. After development treatment, we could confirm some 100nm tracks formed in NIT by using Scanning Electron Microscope (SEM) (Fig2)[2].

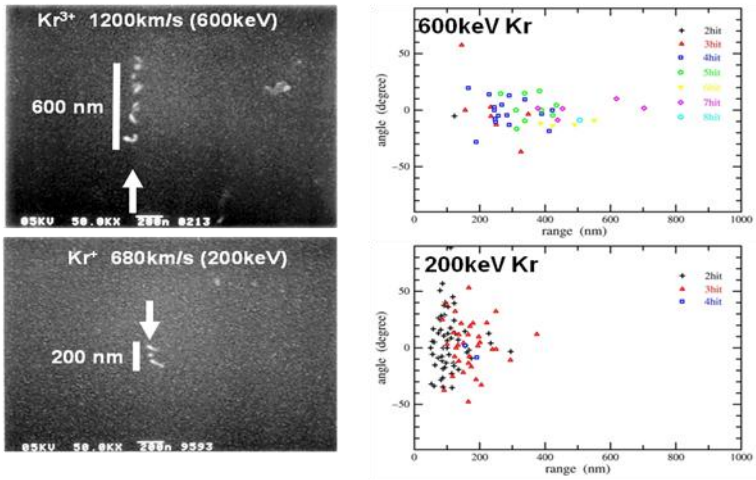


Fig2. Kr track image by SEM(left) and observed track data(right) [2]

5. Recognition of recoil track by optical microscope.

Now, data taking of track in nuclear emulsion are all automatic by track selector that based on optical microscope [3].

Optical microscope can't distinguish 100nm track from noise (random fog: look like 1 grain signal) because optical resolution is μm order. However it is important to recognize as track by optical microscope for large volume scanning.

To solve this problem, we considered expanding short length tracks by swell of gelatin. By this technique, optical microscope must be able to recognize it as track if grains constituting track are separated and track length become μm order.

First I exposed low velocity Kr NIT vertically (Z direction) and treated to swell larger after development, because it swells Z direction especially for the usual apply way for thick emulsion. Here, we used NaOH and glycerin solution for making swell larger. And we observed cross section of sample sliced 1mm thickness by optical microscope [4]. I confirmed to be able to recognize 100nm order tracks as track by optical microscope (Fig3).

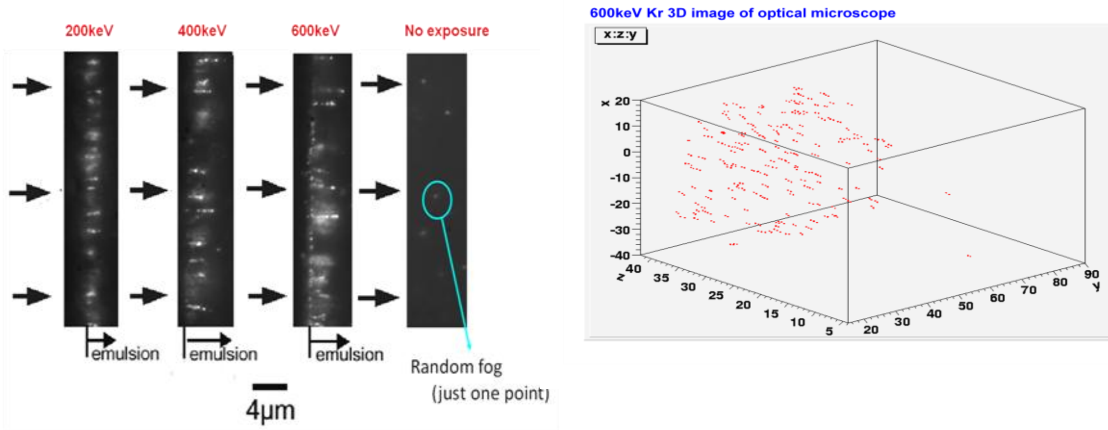
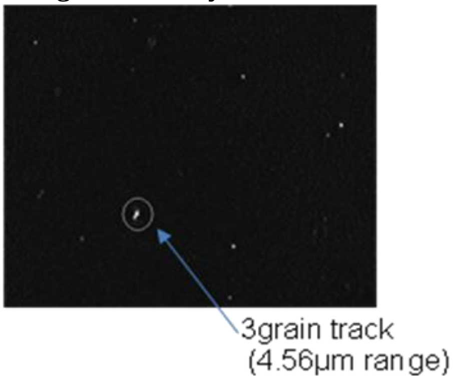


Fig3. Expanded Kr track image by optical microscope (left) and image data of expanded 600keV Kr track (right).

6. Status R&D of automatic scanning

We tested whether short length tracks expanded could be detected by track selector [3]. Here we used the tracks that recoiled from neutron. Neutron source is DD reaction neutron (2.5MeV). Almost tracks were recoil proton that had about 15μm length. However 2~5grains tracks (track length <1μm, may be C,N,O) are object of this study.

Efficiency was estimated by manual check tracking data every 5 view scanning. The results of efficiency are 86% in the case of ph>9 and 81% in the case of ph>10. (ph is strength of signal). We confirmed track selector could detect the short length track in high efficiency.



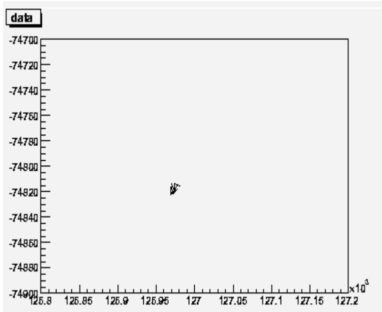


Fig4. Recoil track image by neutron (left) and detected track data (right).

7. Background rejection

The backgrounds for WIMP search using nuclear emulsion are β・γ ray from ^{14}C, ^{40}K, Th・U including in gelatin. Here we considered to reject background by own sensitivity control of nuclear emulsion because deference of dE/dx between nuclear recoil and low energy electron have from 10 to 100 times. .

The factors deciding nuclear emulsion sensitivity are size of AgBr crystal and chemical sensitized treatment. So we tried to control sensitivity of NIT by using chemical sensitized treatment.

Normal NIT has no sensitivity MIP. However we comprehended that it has sensitivity 20% of total for stopping electron, and background track was 1% of total electron by analysis using expanded technique and manual scanning.

Sensitivity of NIT not sensitized is too low for low velocity Kr ion (tracking efficiency is less than 20%). So we controlled sensitivity by "halogen acceptor sensitized treatment" [5]. NIT sensitized by this treatment (HA-NIT) has 1/3 sensitivity of normal NIT for αray . We confirmed the sensitivity of HA-NIT for Kr ion is about equal to normal NIT in tracking efficiency. And signal of stopping electron reduced to 0.25% of total electron. Background track was 0 consistent for the manual scanning volume in this time. Ultimately rejection power of HA-NIT for electron is more than 5 figures.

8.Prospect

Selection of candidate track may be possible by deference of light scatter intensity. For example, response from polarized light scatter is expected to be deference between one silver (fog) and more than 2 silver grains line (track). Deference of these configuration should affect resonance wavelength by deference of dipole moment. This method has possibility to be able to distinguish the candidate tracks from random fog without expansion and lead to faster scanning speed.

It is possible to control sensitivity by development treatment. Then redox potential of latent image depends on dE/dx of penetrated particle. This means that latent images are deference between nuclear recoil and background signal. By control of Fermi level of developer, it may be possible that only nuclear recoil signal is developed and background signal is not.

9.Summery

We are doing R&D of directional search of WIMP using nuclear emulsion. We developed high resolution nuclear emulsion (NIT) for WIMP search, and confirmed it can detect nuclear recoil track by using low velocity Kr ion and SEM. For large volume analysis by optical microscope, we developed the technique to expand short length track until μm order. By this technique, we could recognize short length track as track by optical microscope and confirmed track selector could detect expanded tracks with more than 80% efficiency.

By sensitivity control of NIT, background rejection for electron is 10E-5.

We will progress further on these R&D and start 1kg test running.

Reference

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