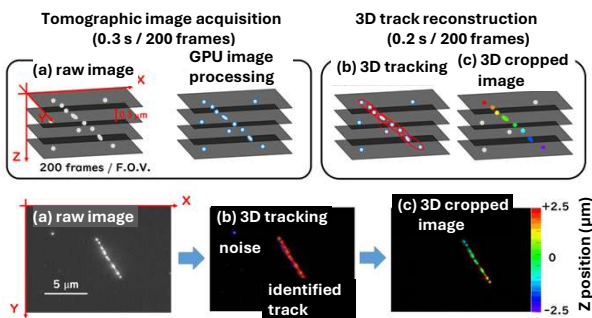


Neutron Track Identification with a 3D Convolutional Neural Network (3D-CNN)

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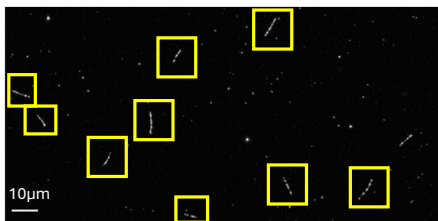
1. Introduction

Dark matter (DM) is thought to account for most of the matter in the universe. Direct detection experiments search for nuclear recoils induced by DM particles. The NEWSdm experiment uses nuclear emulsion films as both target and tracking detector; optical microscopy provides 3D images from which the recoil energy and direction are reconstructed.



2. Challenges and Objectives

- Higher sensitivity requires a larger emulsion target mass, which increases both the image data volume and the background rate. Neutron-induced recoils are indistinguishable from DM-induced ones, and are used here as a proxy for the DM signal.
- In the image data, it is difficult to distinguish single recoil tracks from point-like noise, making manual inspection impractical (figure below).
- In our dataset, noise outnumbers signal by $\sim 30:1$. We aim to identify neutron tracks from this imbalanced dataset rapidly and accurately.

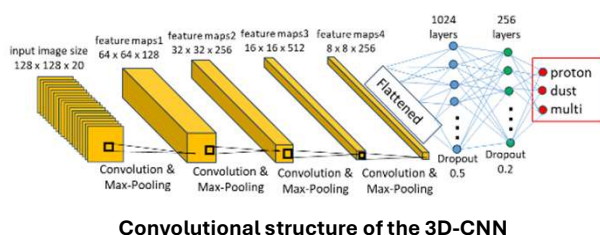


signal: Neutron events obtained by beamline irradiation.

noise: Non-neutron events obtained in an underground environment.

3. Methods

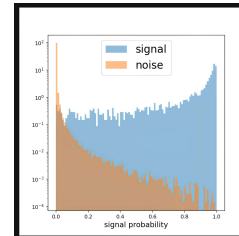
- A 3D-CNN was used to automatically classify tracks into signal and noise, based on the shape and position of each track in the 3D image data (figure below).
- During training, the trainable parameters were updated to minimize the loss. A class weight of approximately 30 was assigned to the signal class to account for the class imbalance. Early stopping was also used to prevent overfitting.



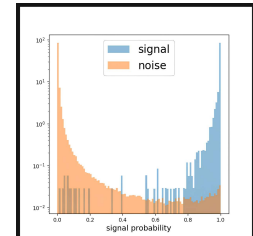
Convolutional structure of the 3D-CNN

4. Results: Effects of Class Weighting

① Signal probability



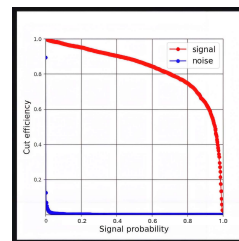
Without weighting



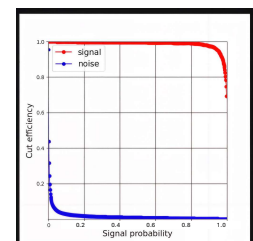
With weighting

With weighting, noise is concentrated below 0.2 and signal above 0.8.

② Cut efficiency



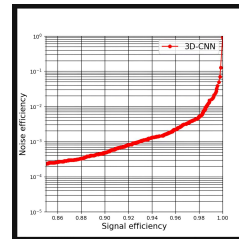
Without weighting



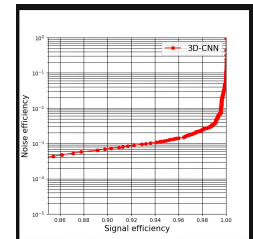
With weighting

Without weighting, signal efficiency begins to decline around a cut value of 0.7. With weighting, it stays above 0.95 until around a cut value of 0.9.

③ SN curve (ROC curve)



Without weighting



With weighting

At a signal efficiency of 0.95, noise efficiency decreased from $\sim 2 \times 10^{-3}$ without weighting to $\sim 1 \times 10^{-3}$ with weighting, a reduction by only a factor of about 2.

5. Summary and Future Prospects

- The proposed 3D-CNN-based identification method is a step toward automating and streamlining data processing for larger-mass nuclear emulsion detectors.
- Class weighting kept signal efficiency above 0.95 up to a cut value of around 0.9. At a signal efficiency of 0.95, noise efficiency was reduced by only a factor of about 2, from $\sim 2 \times 10^{-3}$ to $\sim 1 \times 10^{-3}$.
- We aim to further reduce noise by exploring approaches beyond the 3D-CNN.

Appendix: Details of the Graphs

- Signal probability:** a measure of how likely a track is to be a neutron event. Tracks with a signal probability above the cut value are selected as signal.
- Cut efficiency:** the fraction of signal and noise events retained as the cut value is varied. The SN curve (ROC curve) plots noise efficiency against signal efficiency.