A Deep Learning Selection of Dark Tridents in MicroBooNE

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1.- Introduction

- Dark trident [1] is a proposed novel interaction channel of dark matter in regular matter.
- The dark trident interaction allows exploration of a dark sector composed of a massive dark photon A' and a dark fermion χ.
- Dark matter particles can be produced by neutral meson decay in neutrino beams such as the Neutrino at the Main Injector (NuMI) beam at Fermilab.
- In this work we present the development of a deep learning algorithm to assist in the search for dark tridents in the MicroBooNE experiment.

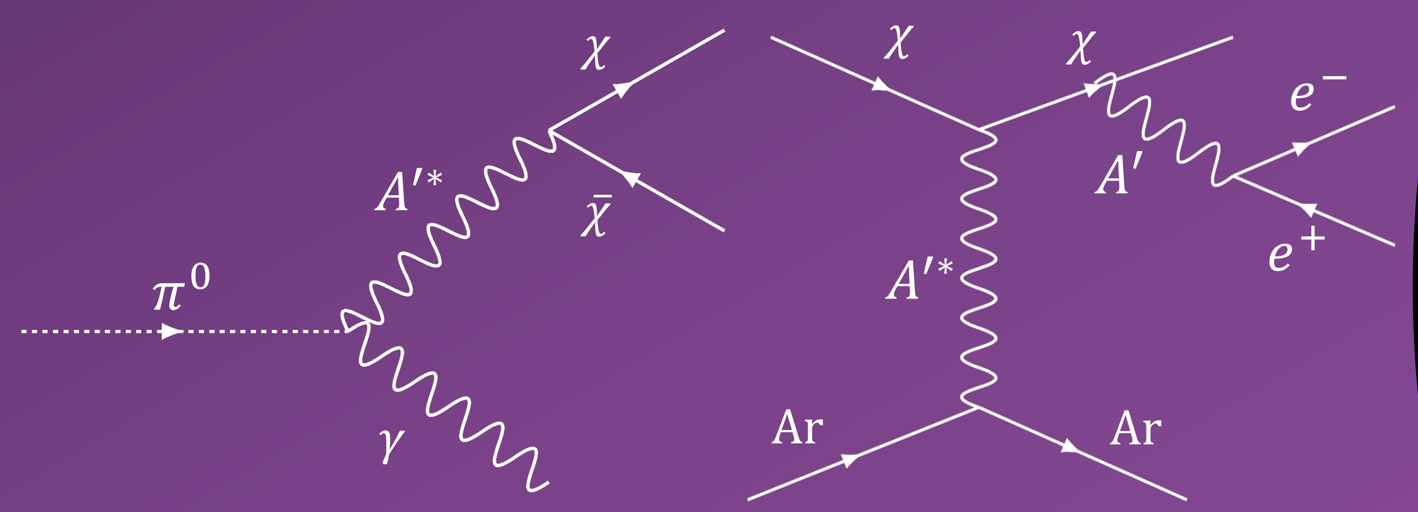


Fig 1. On the left, production of dark matter particles from neutral pion decay. On the right, the dark trident interaction where a dark matter particle scatters with an argon nucleus.

2.- The MicroBooNE Experiment

- The MicroBooNE detector [2] is a liquid argon time projection chamber with 85 tonnes of liquid argon active mass. It is located at 640 m from the NuMI beam, the meson source on the Fermilab campus.
- The detector uses three wire planes that capture the ionized electrons produced by particles travelling through the liquid argon. It also uses photo multiplier tubes for triggering and cosmic ray rejection.
- It has great a calorimetric capacity and mm spatial resolution. 2D high resolution images are produced from the signal recorded by each wire plane.

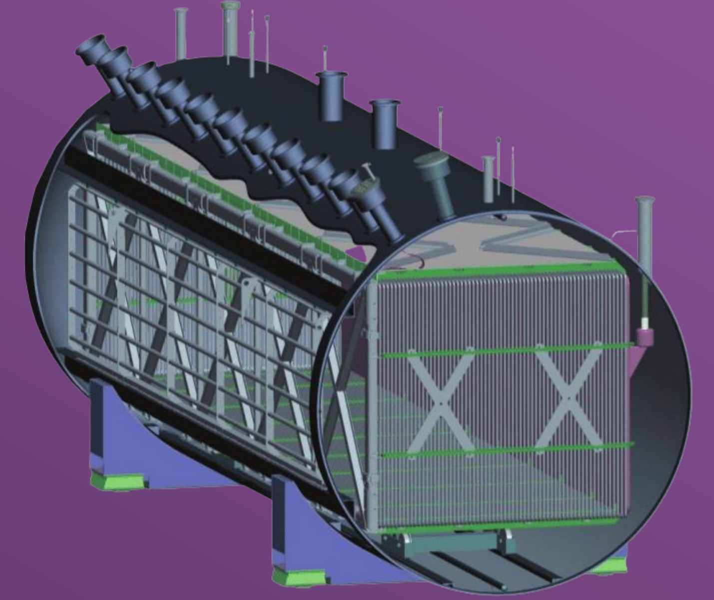


Fig 2. 3D view of the MicroBooNE detector.

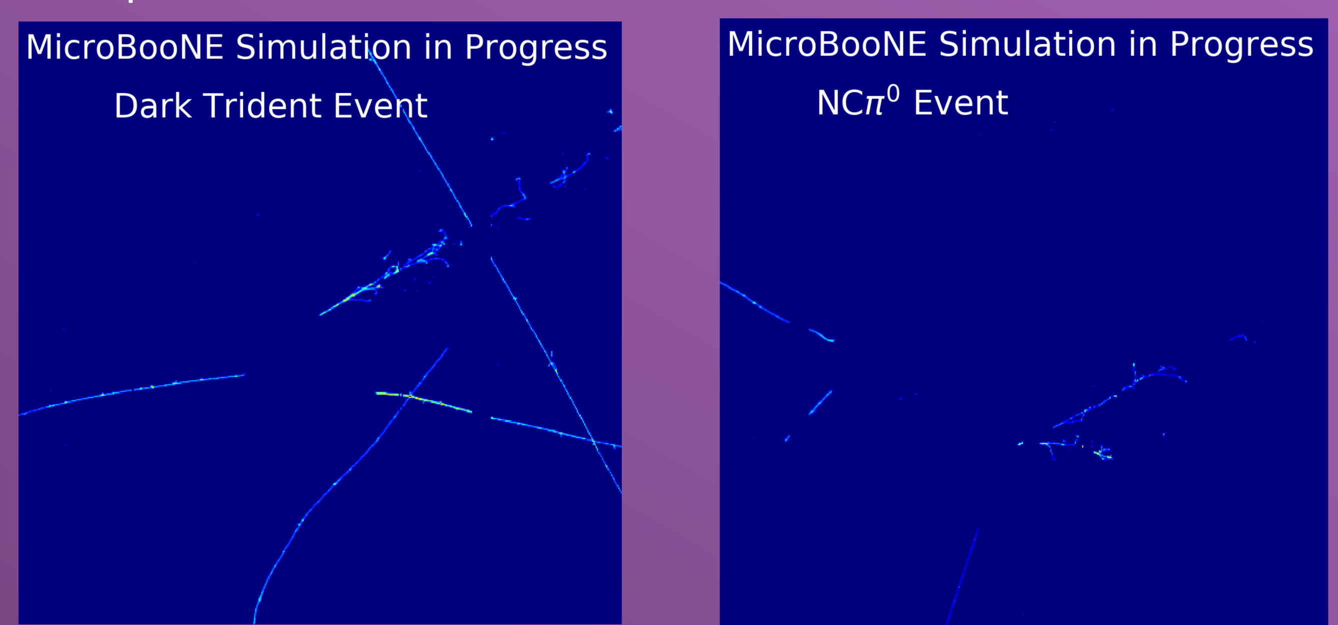
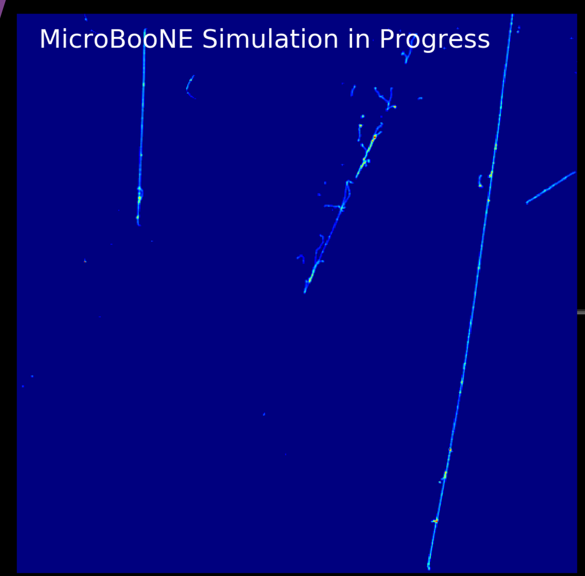
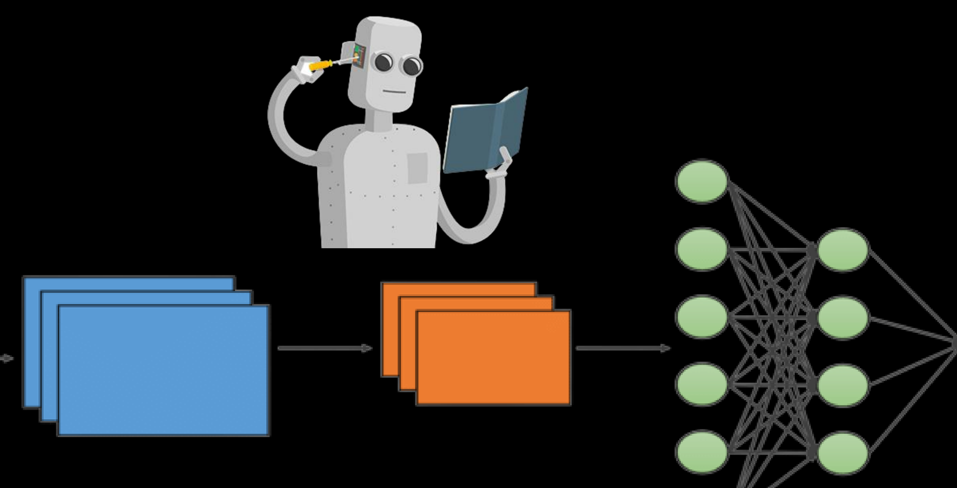


Fig 3. Event displays of a simulated dark trident interaction (left) and a neutrino interaction with neutral pion emission (right). Both images also contain cosmic ray activity that has been overlaid from data.

3.- Convolutional Neural Networks

- A Convolutional Neural Network (CNN) is a deep learning algorithm commonly used in computer vision, face recognition, autonomous driving, and other applications.
- We trained a CNN which tells us the probability of an input image being a dark trident signal or a neutrino neutral current π^0 emission background.





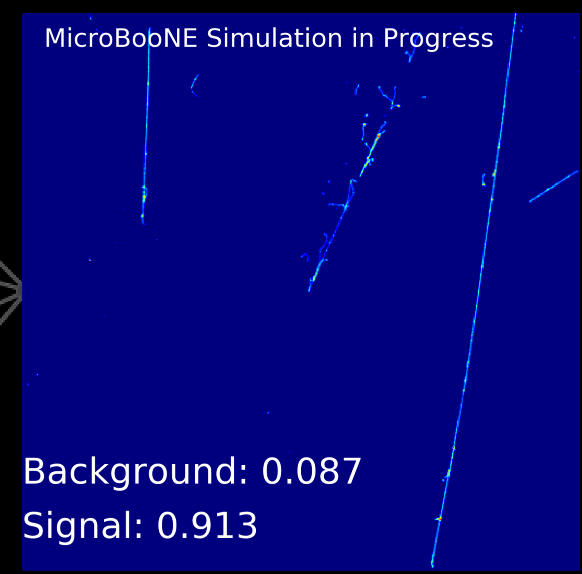


Fig 4. Schematic representation of a CNN architecture to process 2D images.

- To train this model, we used Monte Carlo simulations of the dark trident interaction and background neutrino interaction. For a realistic training set we superimpose onto this cosmic ray activity simulated using CORSIKA [3].
- To measure the performance of the model, we used the accuracy as a metric. The accuracy is defined as the number of correctly classified images over the number of total processed images.
- The accuracy reached by our deep learning algorithm is 95% over the test set which consists of data not used during the training of the algorithm.

4.- CNN Performance

- The CNN has an accuracy of ~95% processing dark trident events simulated using different dark photon masses (top).
- The algorithm is also able to discriminate signal from other backgrounds such as neutral current η and γ emission with an accuracy of 95% (bottom).
- These different checks show that the CNN does not need to be retrained for every different background or different dark photon masses.

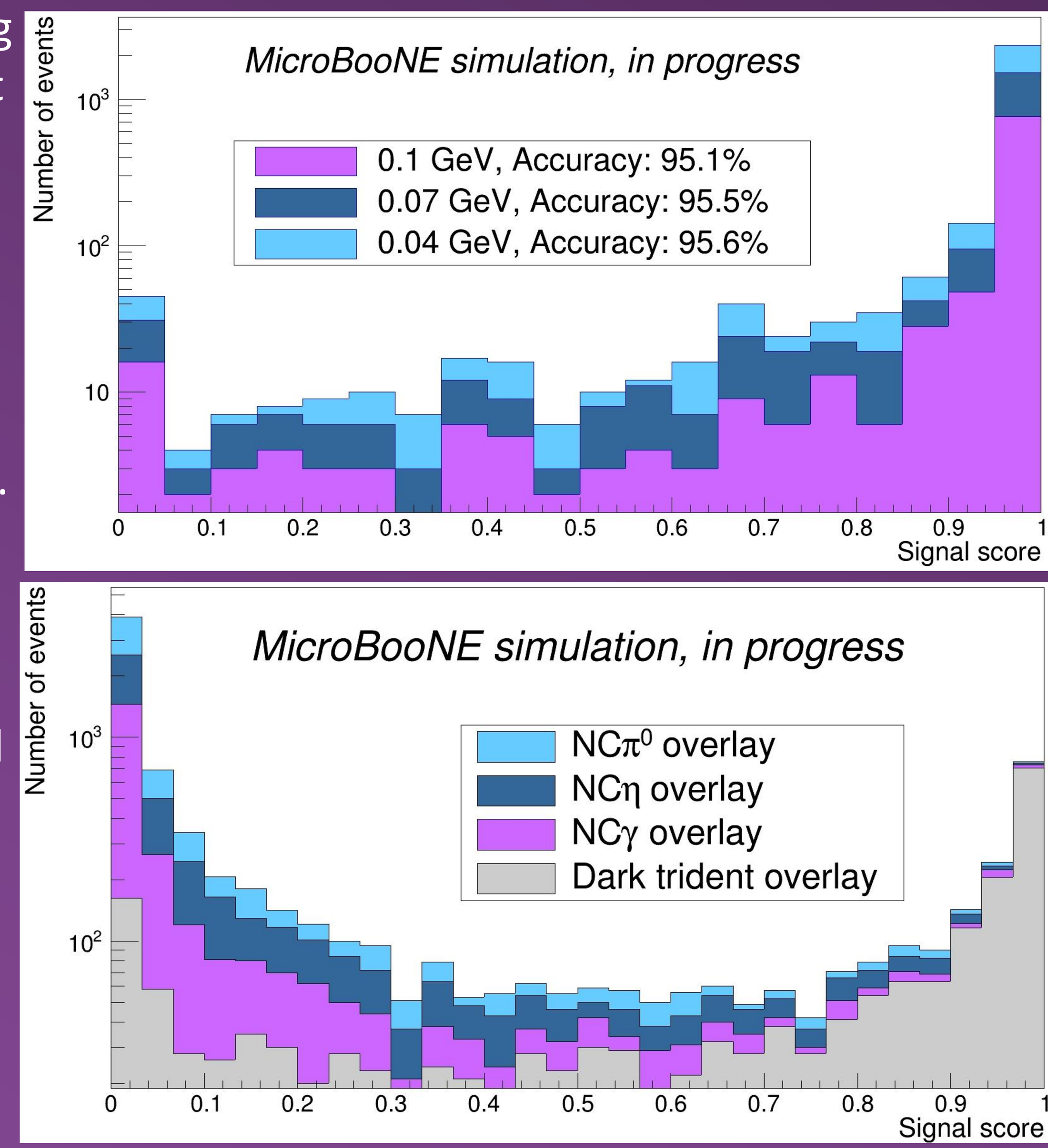


Fig 4. CNN score distributions for datasets with different dark photon masses (top) and different classes of backgrounds (bottom).

5.- CNN Score as a Selection Criterion

- Reconstruction of the events detected by MicroBooNE can be done using Pandora [4]. This framework handles vertex finding, and track and shower identification among other high-level reconstruction variables.
- The CNN score can be used to place a selection requirements and it can be combined with the reconstructed variables obtained by Pandora to perform an event selection.
- Placing a strong requirement on the CNN score, reduces the number of background events considerably, thereby showing the promise of this technique to enhance the event selection of dark tridents.

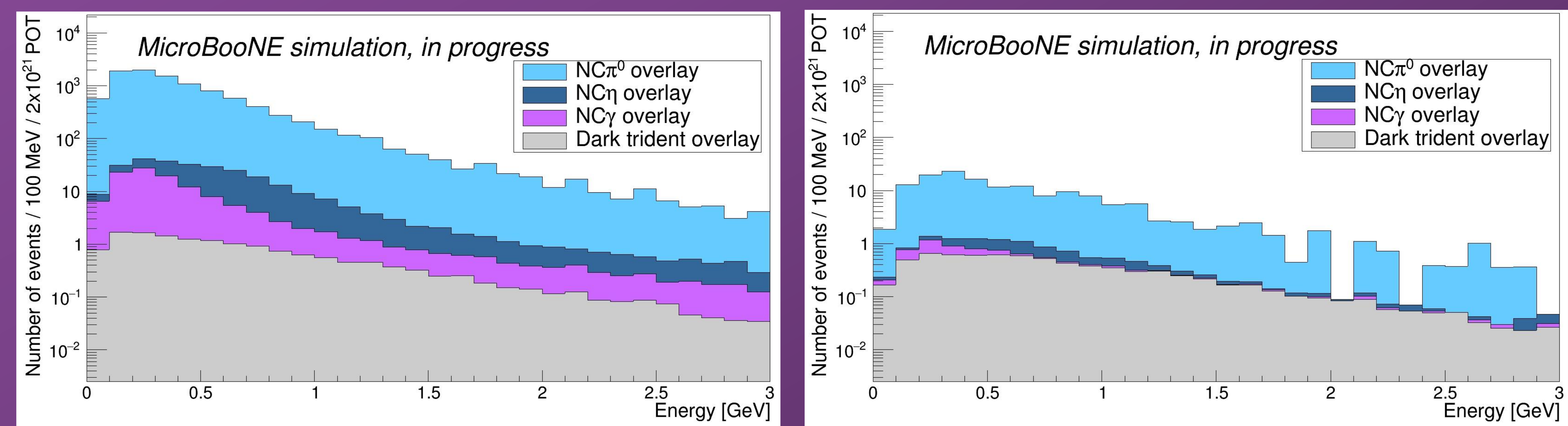


Fig 5. Reconstructed energy distributions of dark trident events and neutrino background events before (left) and after implementing a CNN signal score cut of 0.9 (right). Both energy distributions are normalised to 2×10^{21} protons on target (POT).

[1] André de Gouvêa, Patrick J. Fox, Roni Harnik, Kevin J. Kelly, and Yue Zhang, JHEP 2019, 1 (2019)
[2] R. Acciarri, C. Adams, R. An, et al, JINST 12, P02017 (2017)
[3] D. Heck, J. Knapp, J. Capdevielle, G. Schatz and T. Thouw, KIT 1998, FZKA-6019 (1998).
[4] J. S. Marshall and M. A. Thomson, Eur. Phys. J. C 75, no. 9, 439 (2015)