Predicting Missing Regions in Charged Particle Tracks Using a Sparse 3D Convolutional Neural Network

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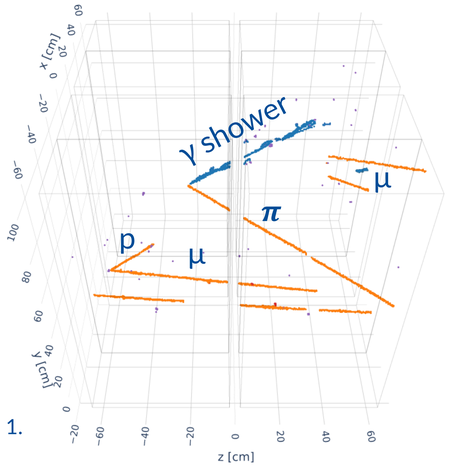
The 2x2 Demonstrator

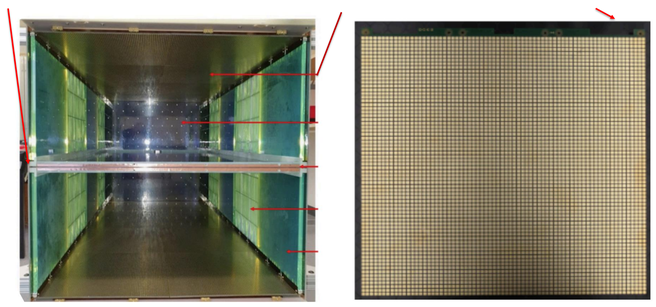
- The 2x2 Demonstrator serves as a prototype for DUNE's Near Detector and shares a modular Liquid Argon Time Projection Chamber (LArTPC) design with the Near Detector. These detectors have gaps—inactive regions—in-between detector modules boundaries where there is reduced or no sensitivity to charge deposition and light signals arising from charged particle interactions with liquid argon.

DUNE: 2x2 Demonstrator Simulation



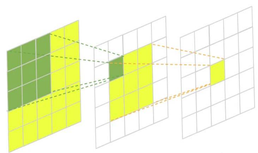
1.

- The 2x2 has self-triggering pixel read out planes along the anodes (sides) of each module, where drifted charge depositions are read out, allowing for 3D tracking of charged particles.

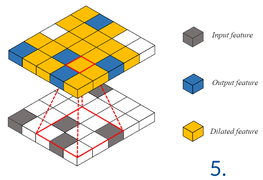


3.

Sparse Convolutional Neural Networks



4. Convolution Kernel

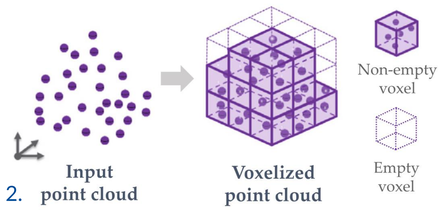


5. Sparse (3D) Convolution Kernel

- Convolutional operations, feature extraction, and subsequent downsampling and upsampling are applied only to non-zero elements and their neighbors.

Method

- Hits corresponding to energy depositions are voxelized into a three-dimensional (3D) grid for each track.
- Inactive regions within the tracks are replaced with a dense, rectangular 3D grid of voxels, ensuring consistent step sizes in X, Y, and Z directions.
- Voxels in these dense regions are initialized with an energy value of -1, indicating nonphysical energy or charge and a learnable parameter.
- A Sparse 3D Convolutional Neural Network is trained to predict which voxels in the dense rectangular region should activate as part of each track and which voxels should not.



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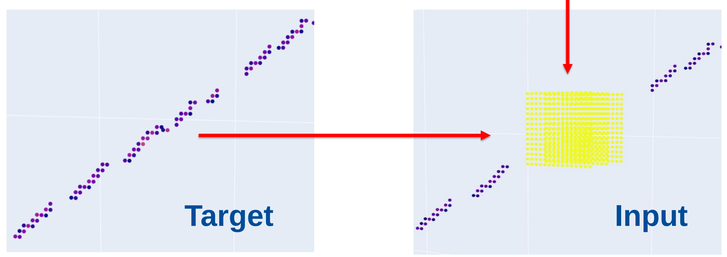
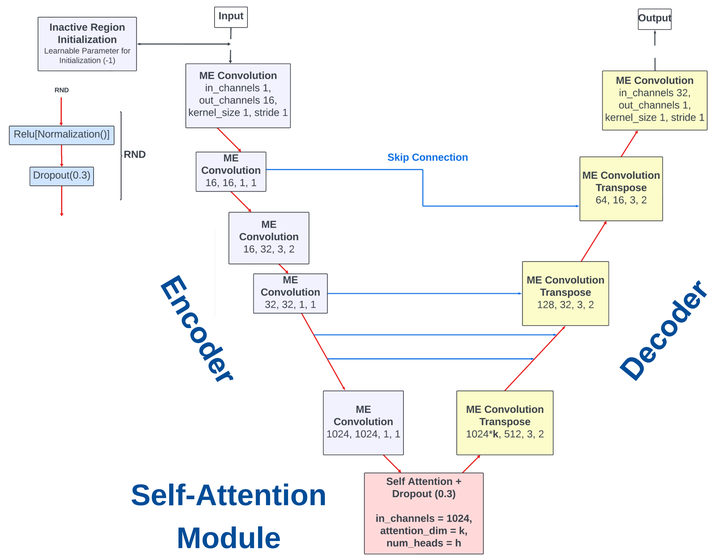
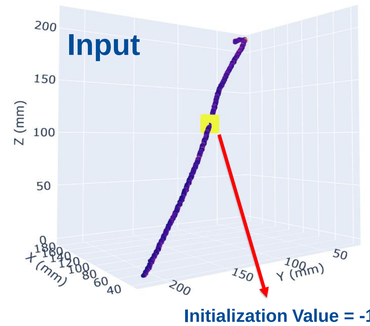


Different particle types

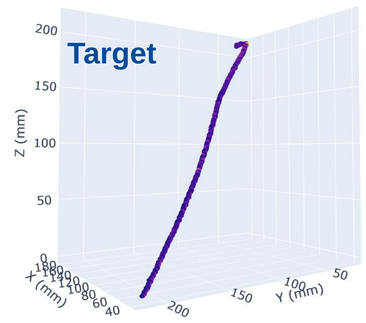
CNN Model & Results

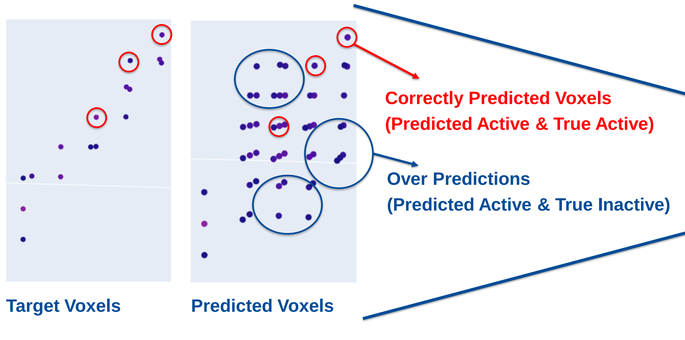


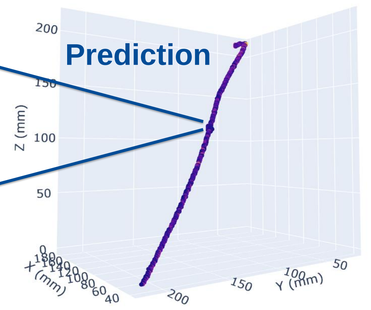
Self-Attention Module



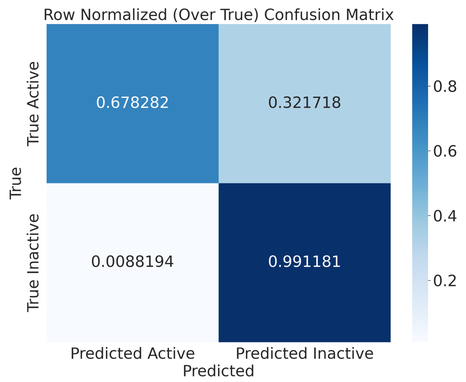
Initialization Value = -1







Dense Region Voxel Activation Confusion Matrix



References

1. "ML-Based Reconstruction Chain: MiniRun3 Status Update", F. Drielsma (SLAC); ND Prototypes Analysis Meeting June 2023
2. "PCSCNet: Fast 3D semantic segmentation of LiDAR point cloud for autonomous car using point convolution and sparse convolution network", J, Park et al.
3. "The 2x2 Demonstrator: A DUNE ND-LAr Prototype", R. Mandujano
4. "How to Calculate Receptive Field Size in CNN", baeldung (https://www.baeldung.com/cs/cnn-receptive-field-size)
5. "Spatial Pruned Sparse Convolution for Efficient 3D Object Detection", J. Liu

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- This work used the resources of the SLAC Shared Science Data Facility (S3DF) at SLAC National Accelerator Laboratory.
- Minkowski Engine: 4D Spatio-Temporal ConvNets: Minkowski Convolutional Neural Networks, C. Choy, et al.