Status report on
DNNROI sigproc

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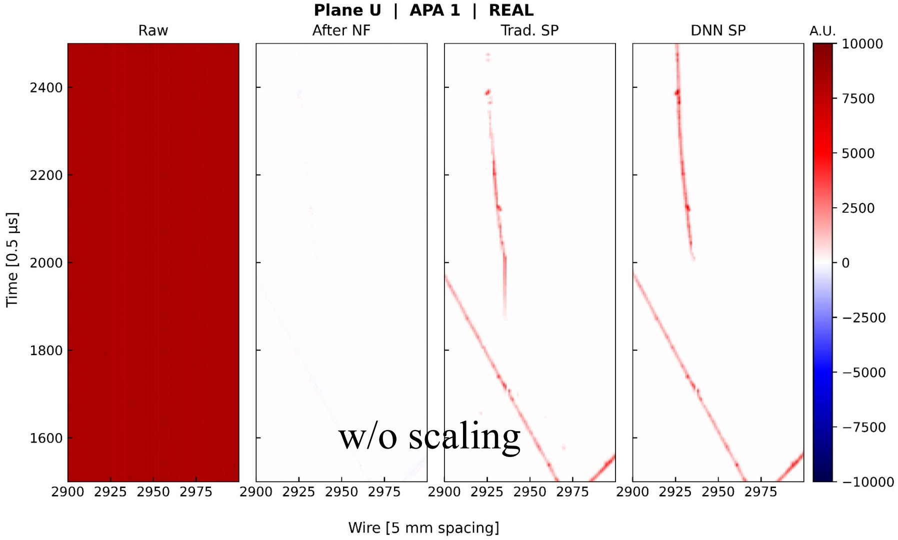
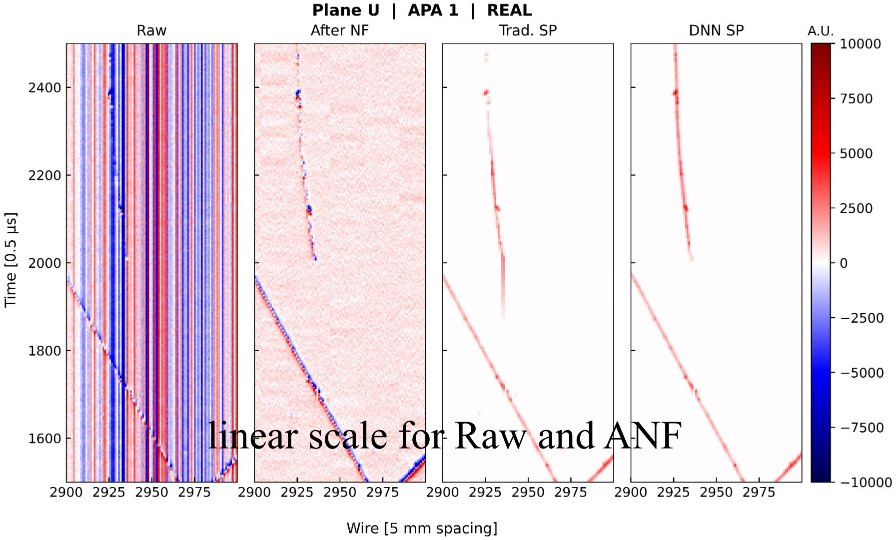
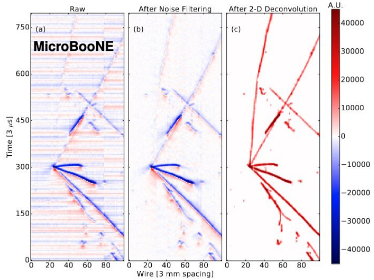
Chung-Ang University

2D Waveform Evolution in SigProc

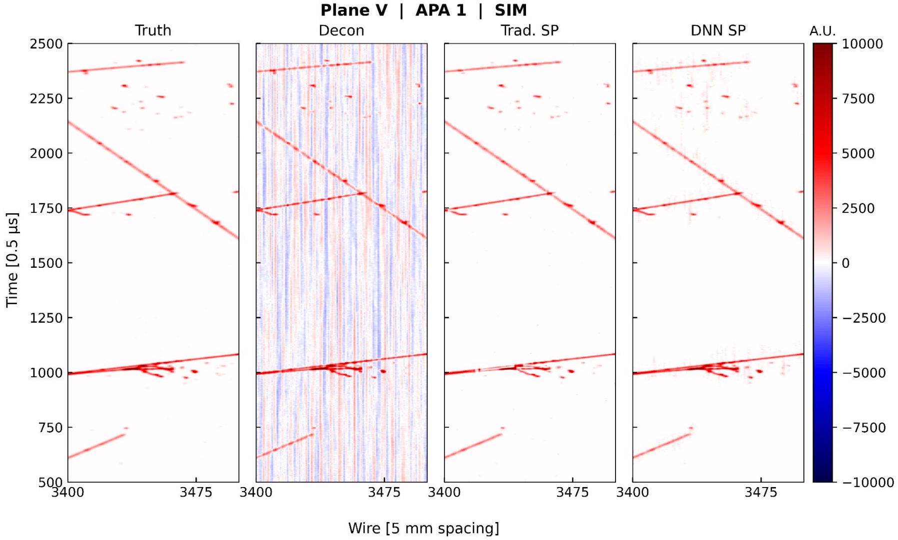




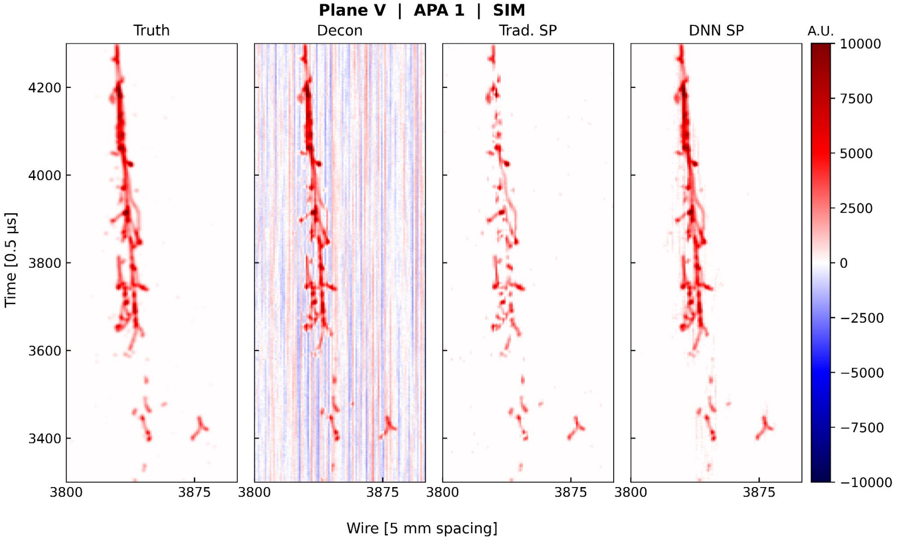
- PD-HD data: 28588-4562
- Wire-Cell version 0.30.2 | LAr version art 3.14.04
- TorchScript:
  - Architecture: MobileU-Net (MobileNetV3 + U-Net)
  - Rebin factor: 10
  - Truth threshold: 10



2D Waveform Evolution in SigProc



❑ Sim: Cosmic-ray

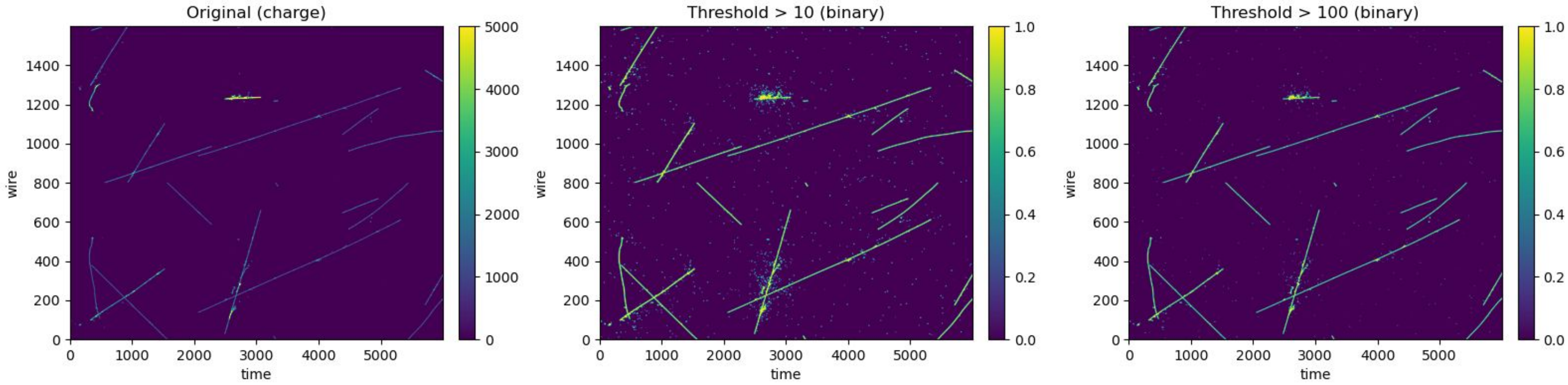


❑ Sim: Single shower (1 GeV)

- Wire-Cell version 0.30.2 | LAr version art 3.14.04
- TorchScript:
  - Architecture: MobileU-Net (MobileNetV3 + U-Net)
  - Rebin factor: 10
  - Truth threshold: 10

- DNN ROI
  - Position resolution ↓
  - Charge reconstruction ↑

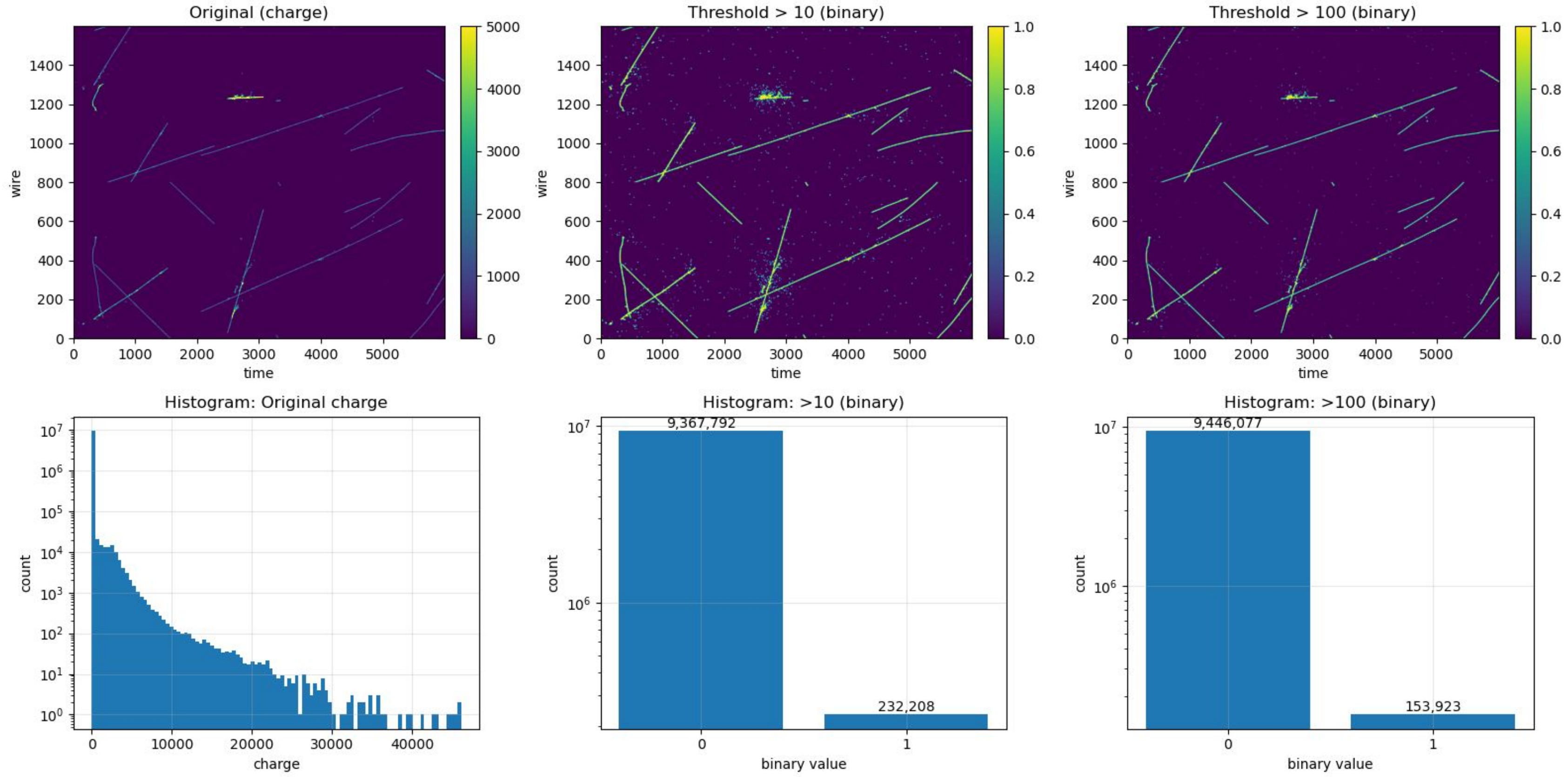
True ROI definition in training script



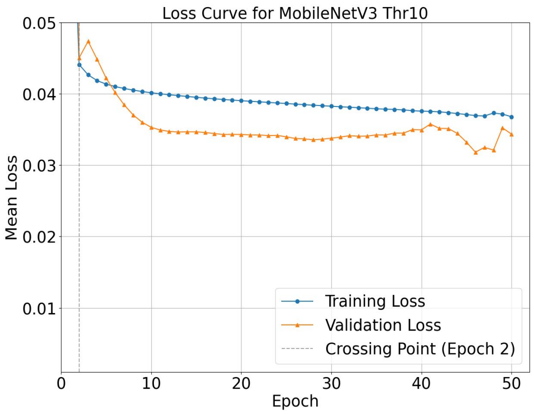
True ROI: Convert continuous charge map into binary mask for training (for BCE loss)

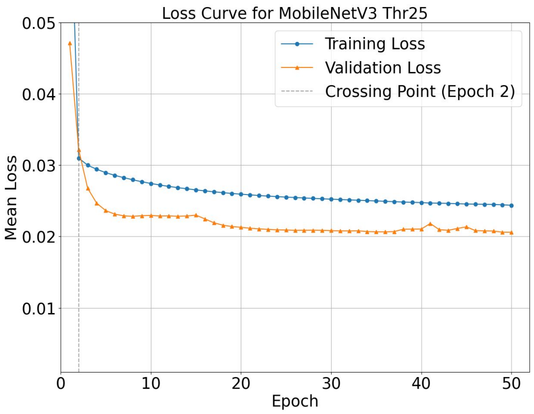
- Raw Truth Data: each pixel = deposited charge at (wire, time)
- Rebin & Crop: downsample in time using rebin factor, and select region for training
- Thresholding over bin content (truth_th in code):
  - If charge > threshold → mask as signal (1)
  - If charge ≤ threshold → background (0)
- Low threshold → more pixels labeled as signal (recall ↑, precision ↓)
- High threshold → fewer pixels labeled as signal (recall ↓, precision ↑)

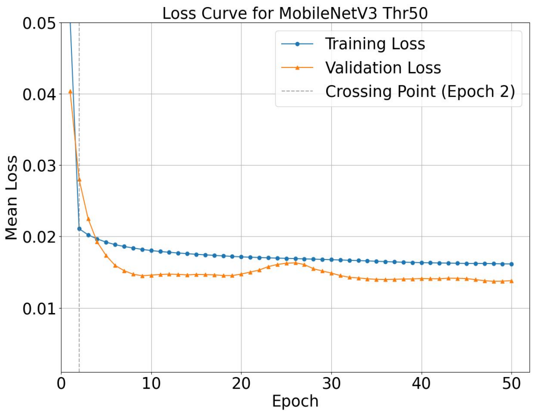
True ROI definition in training script

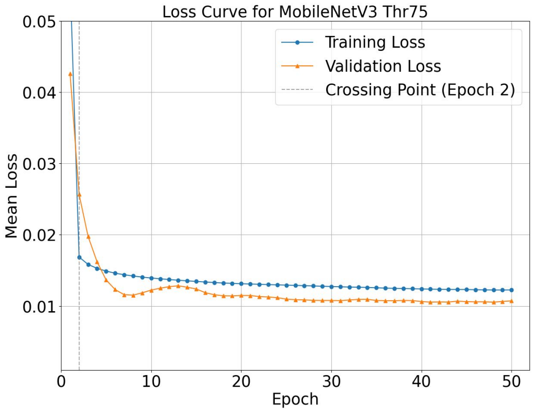


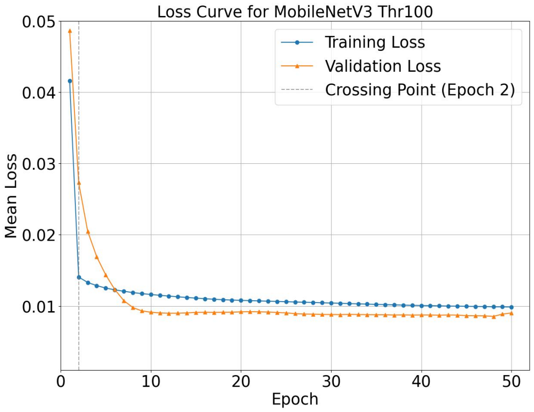
MobileU-Net (V3) - Train vs. Val loss with different truth threshold





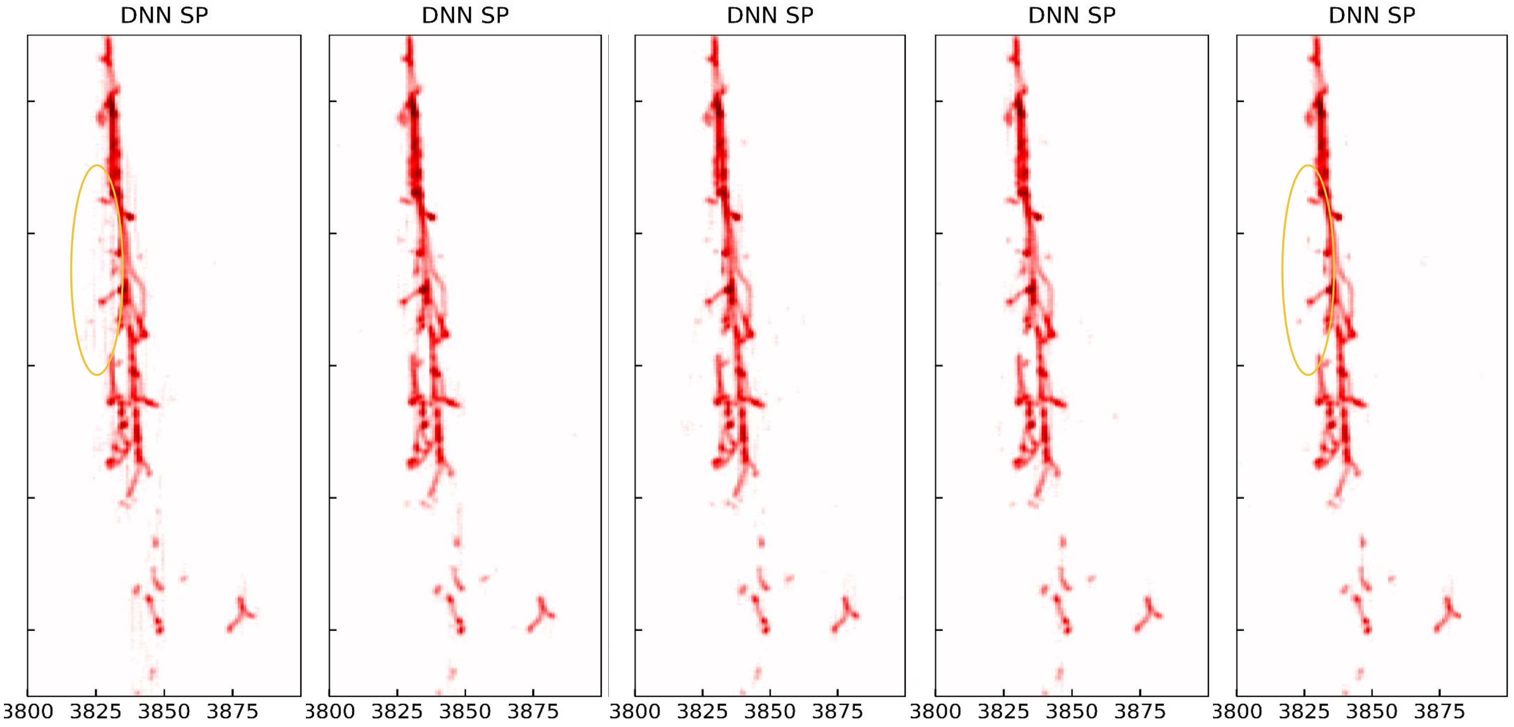






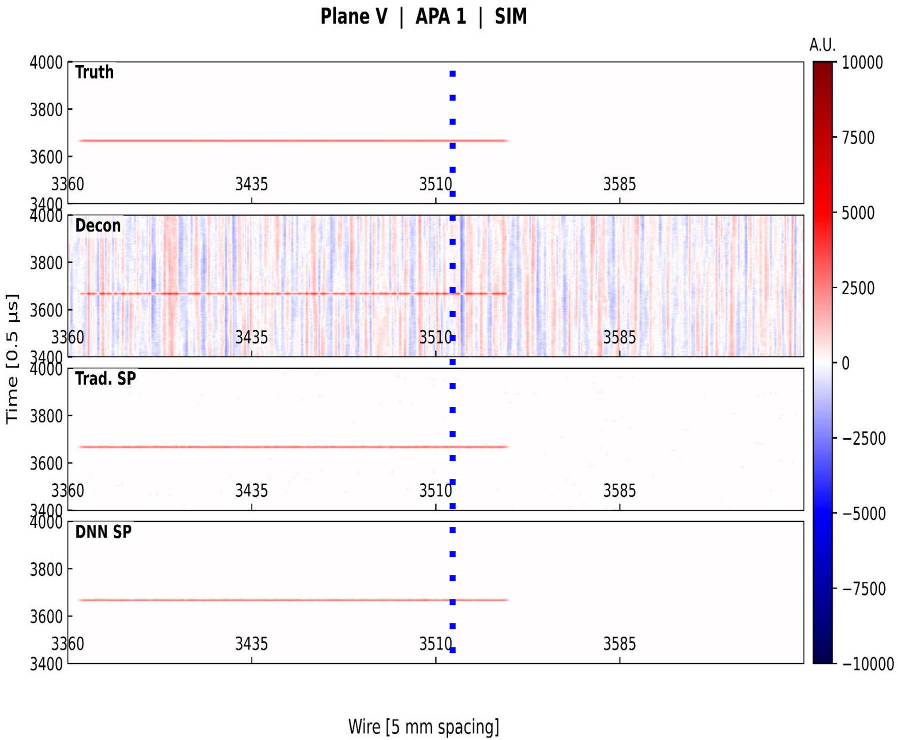
Threshold	Train Loss
10	0.0367
25	0.0243
50	0.0161
75	0.0122
100	0.0098

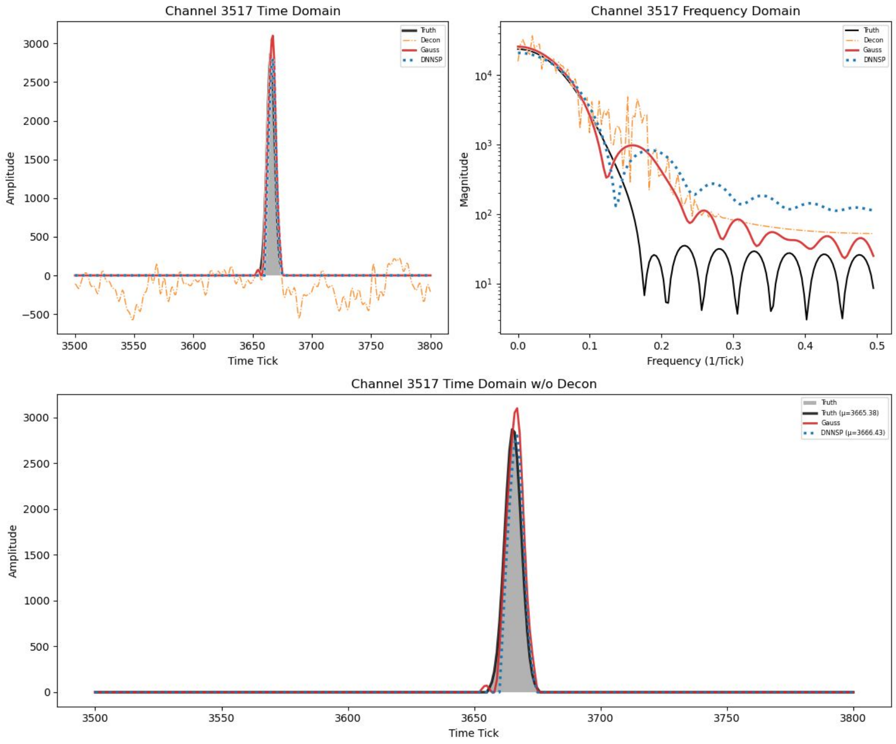
2D Waveform with Different Truth Threshold



- Threshold 10
- Threshold 25
- Threshold 50
- Threshold 75
- Threshold 100

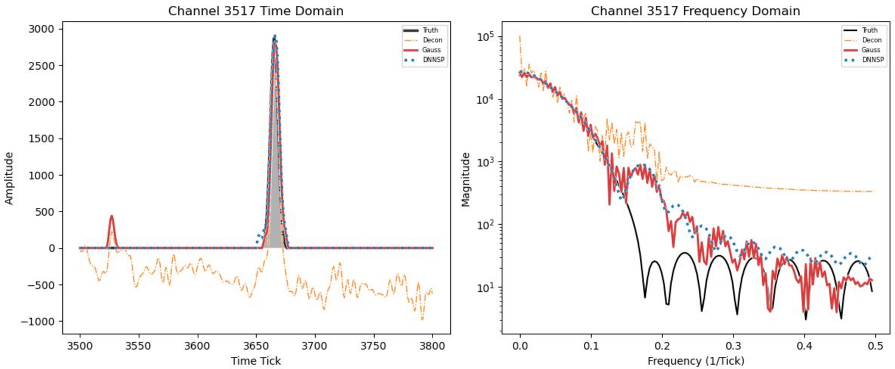
Waveform from Isochronous Track

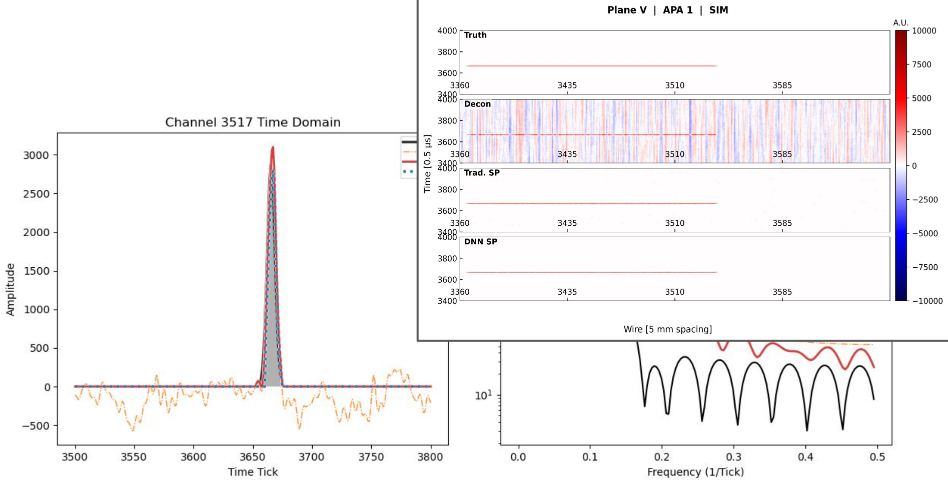


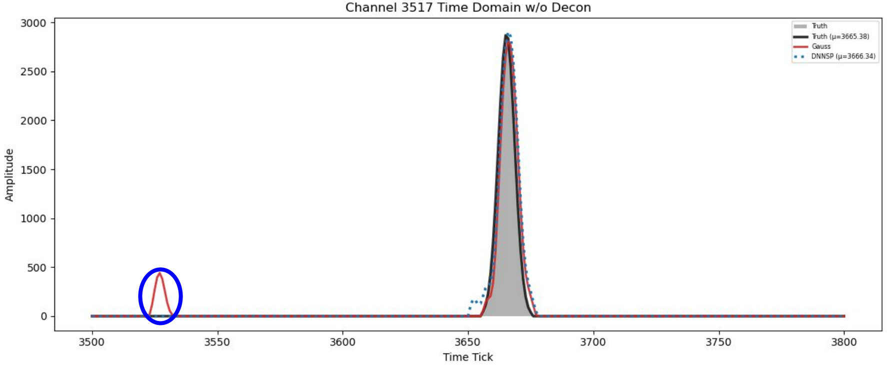


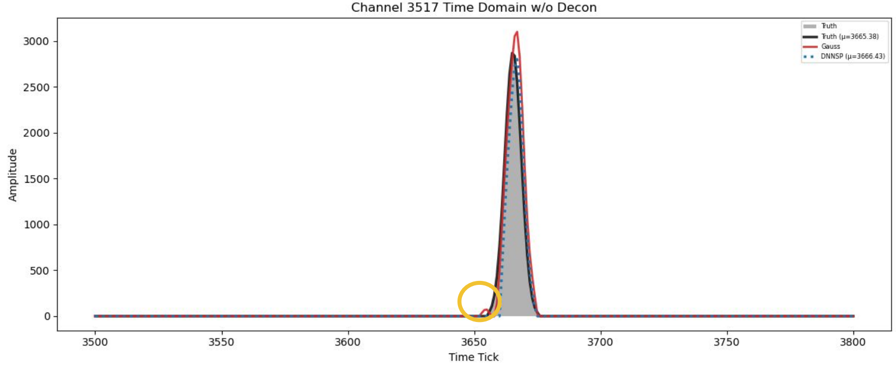
- Both methods demonstrated good charge reconstruction

Waveform from Isochronous Track





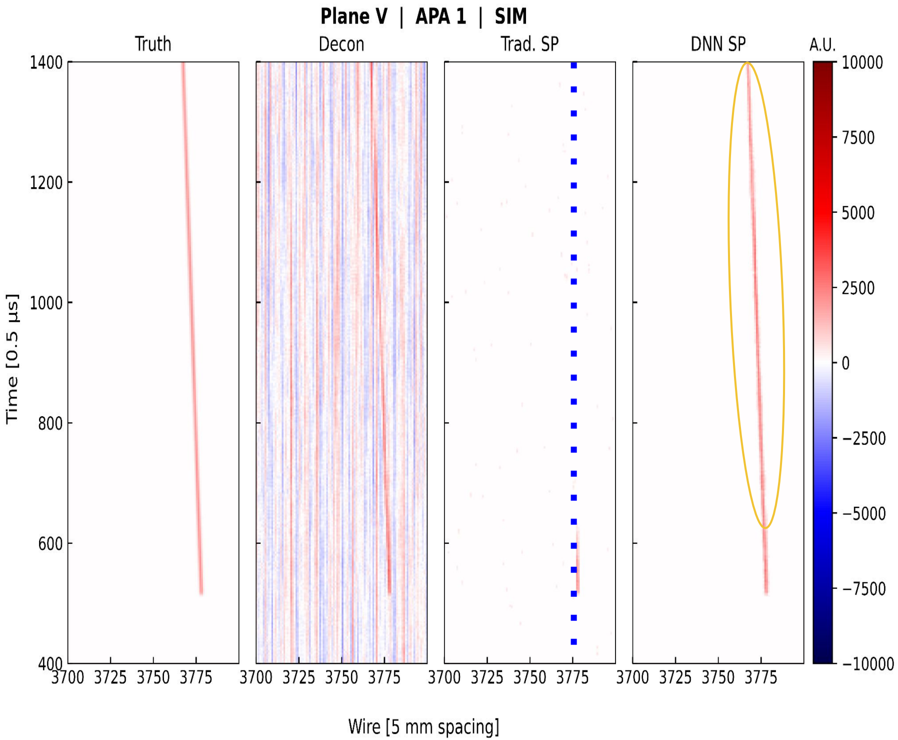


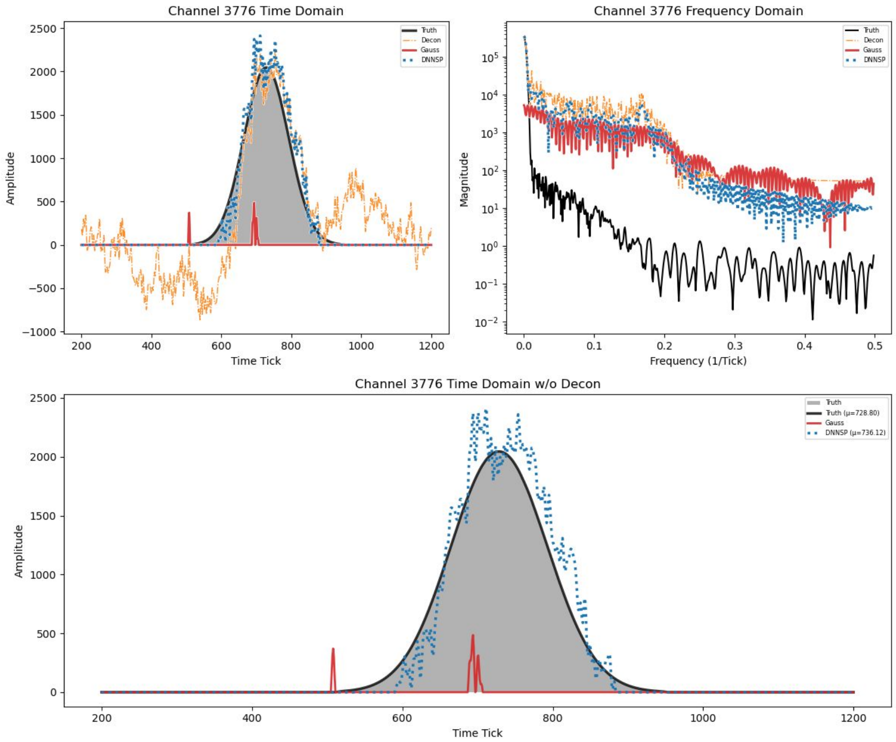


- Threshold 10
- Threshold 100

- Higher truth_th has narrowed ROI window
- Traditional ROI more frequently picks up fake signals at time ticks that have no truth

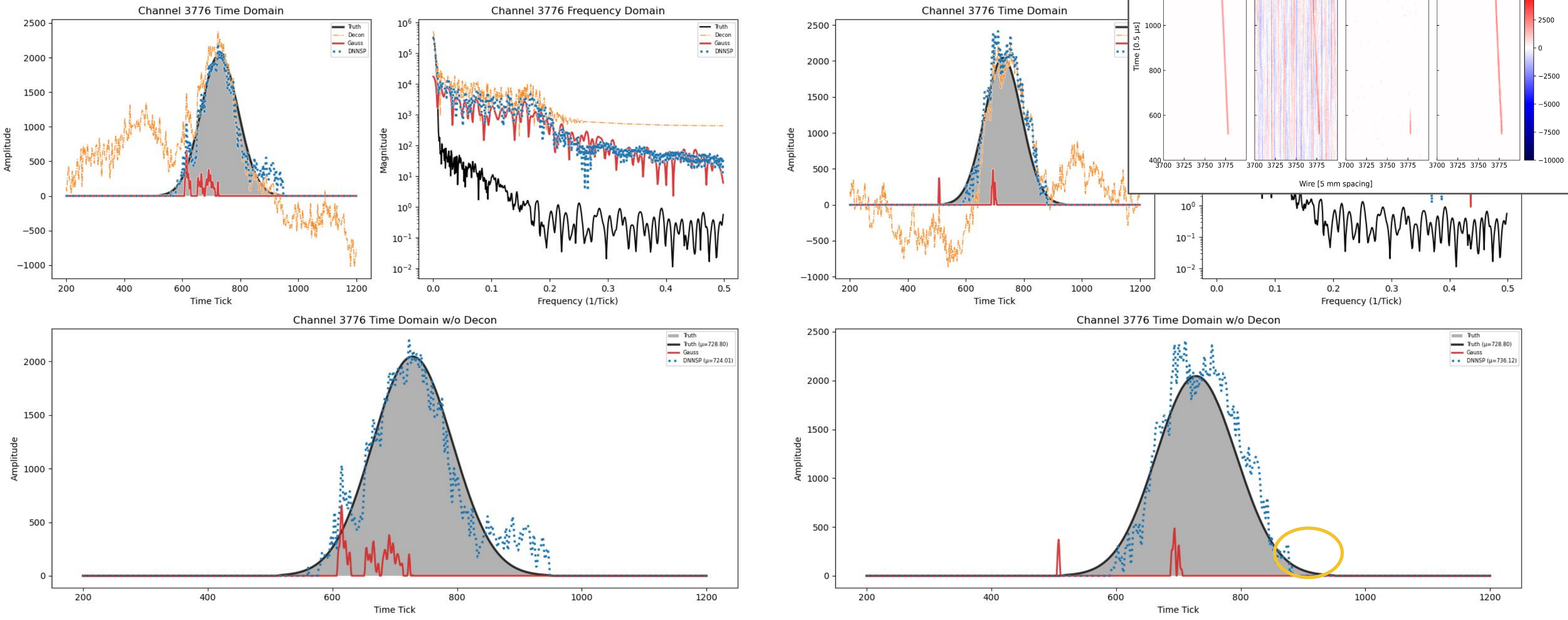
Waveform from Prolonged Track





- In this case, the DNN ROI reconstructed the charge much better

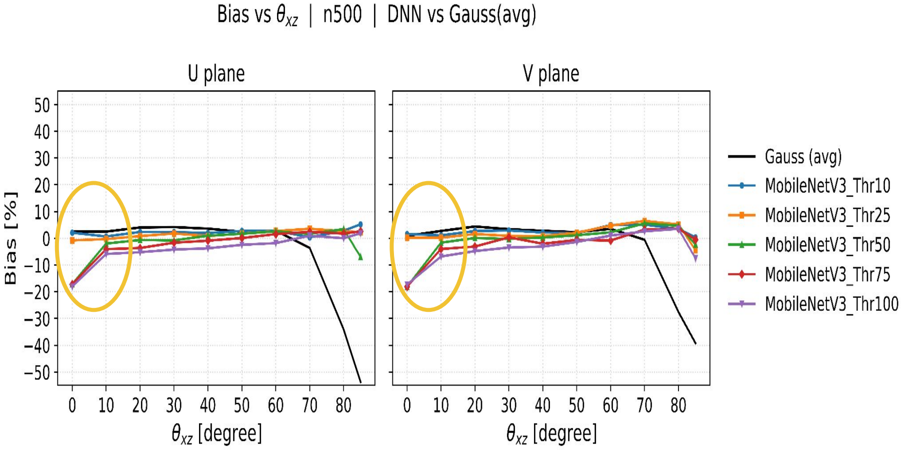
Waveform from Prolonged Track

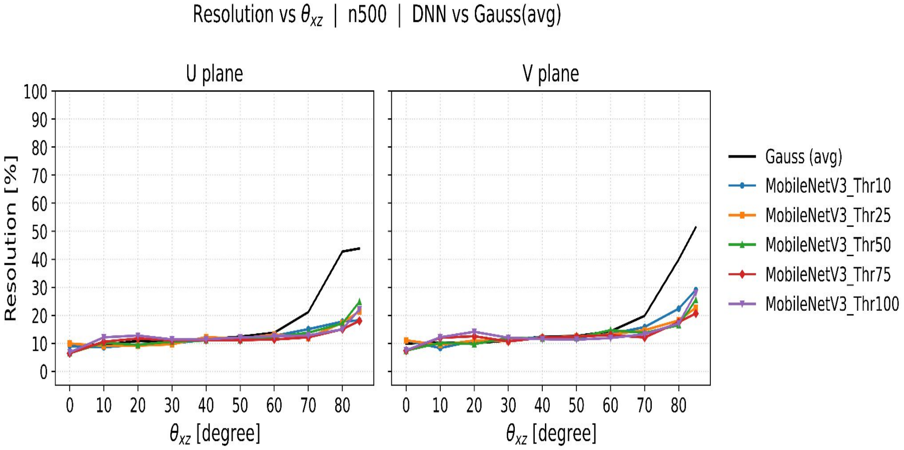


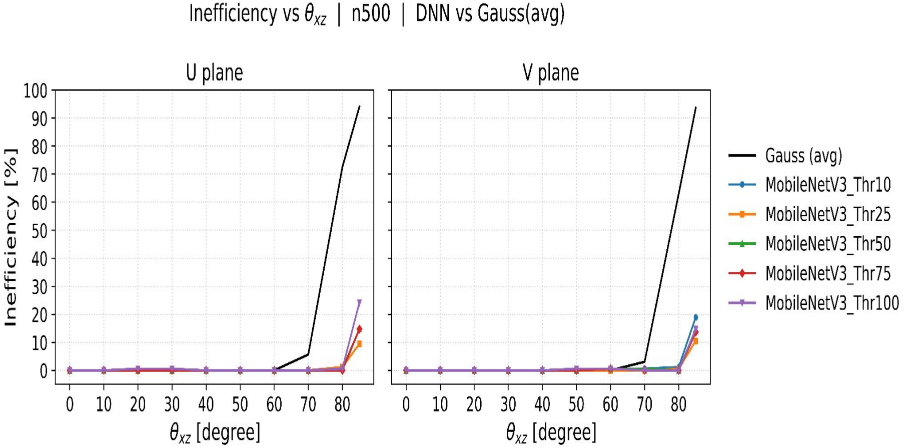
- Threshold 10
- Threshold 100

- For prolonged track, traditional ROI barely reconstruct charge

Single Track Evaluation



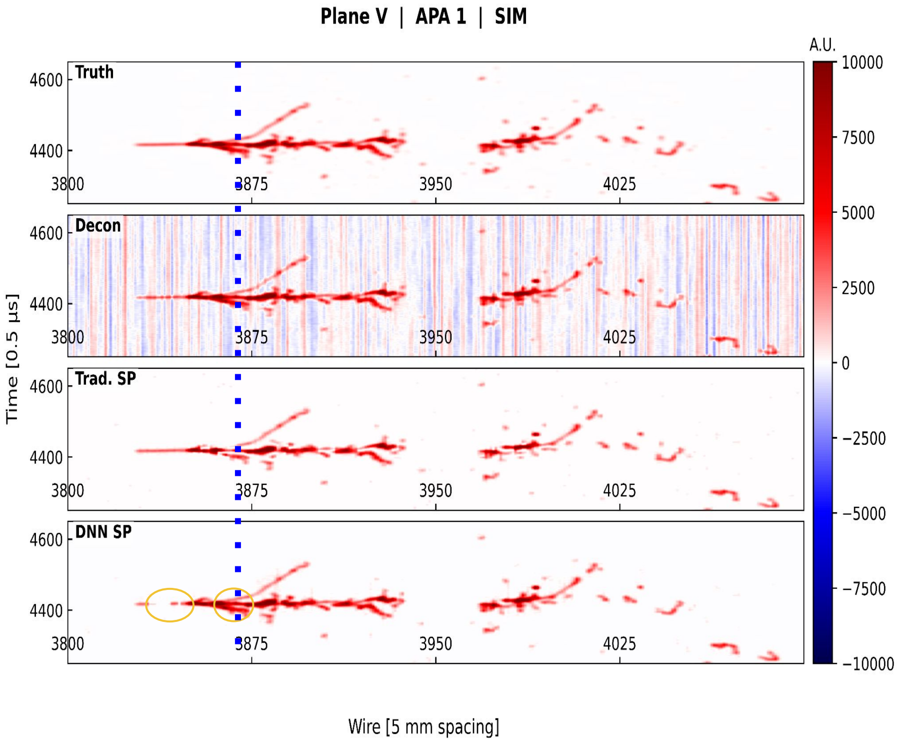


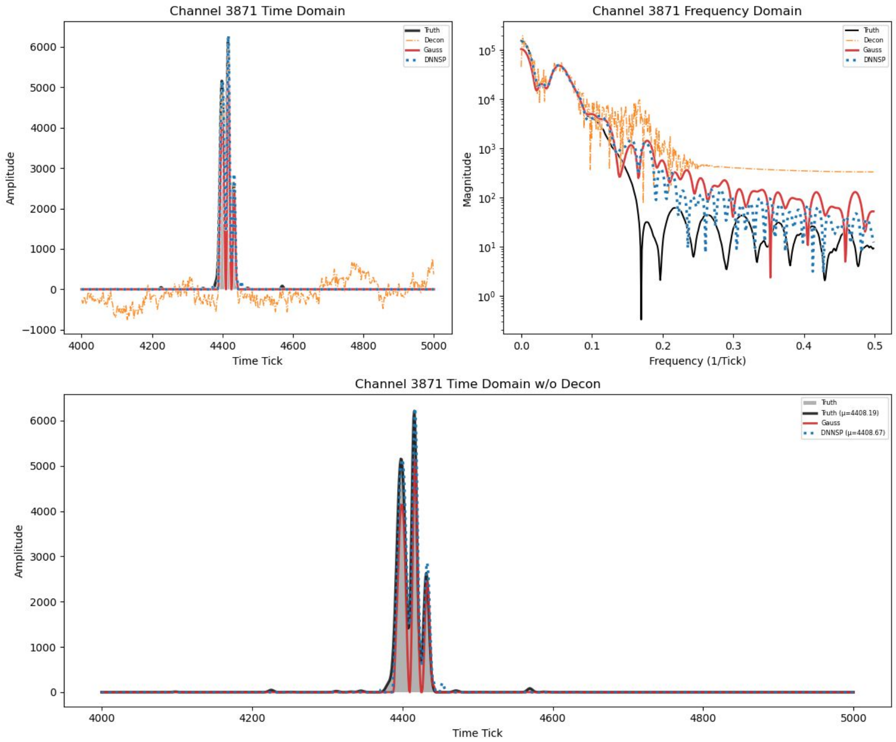


- Models with thruth_th > 50 showed about -20% bias in the low angle region
- Possible causes (from visual inspection of waveforms)
  - **ROI window is slightly smaller** than the truth
  - **Peak charge amplitude is lower** than the truth

(See slide 19 for supporting plots)

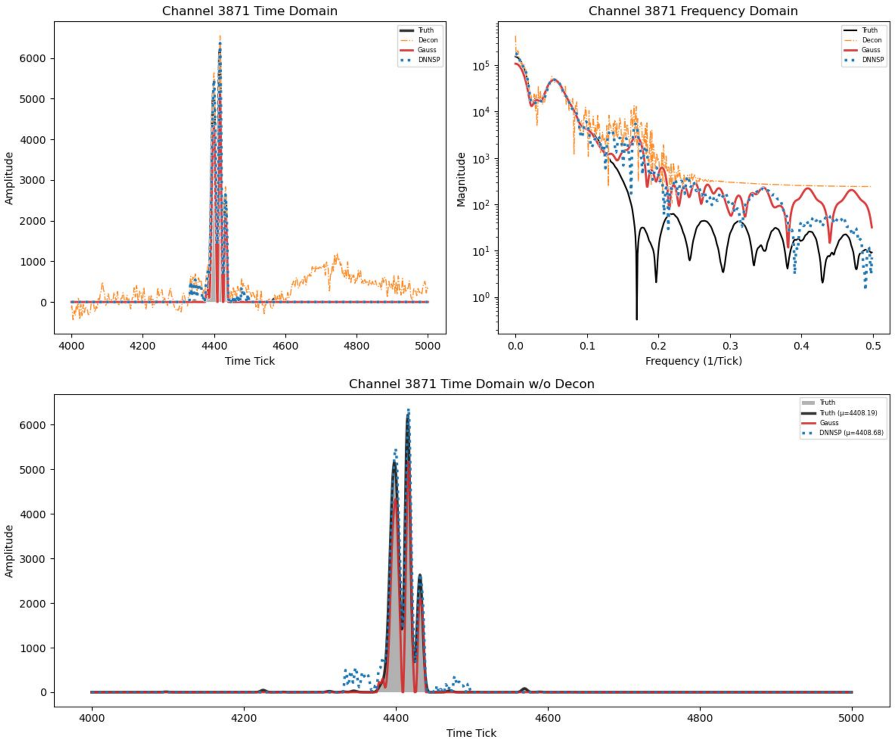
Waveform from Isochronous Shower

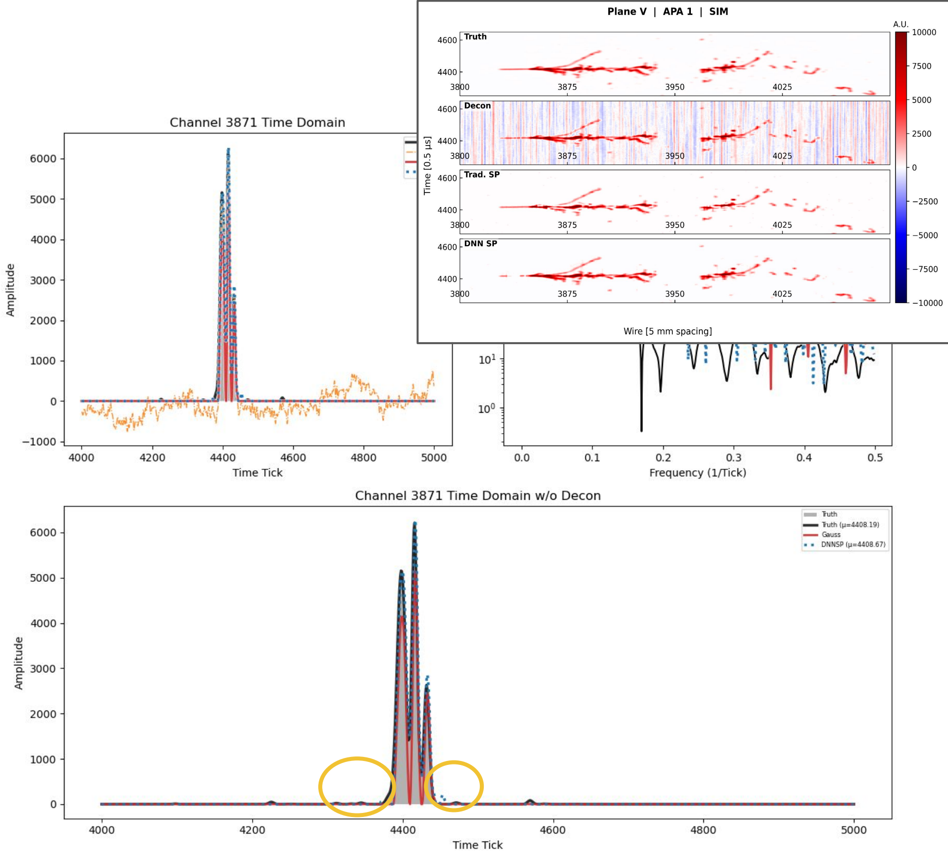




- While the DNN ROI reconstructed the charge effectively in regions with complex waveforms, certain portions were not reconstructed as the truth threshold became higher

Waveform from Isochronous Shower

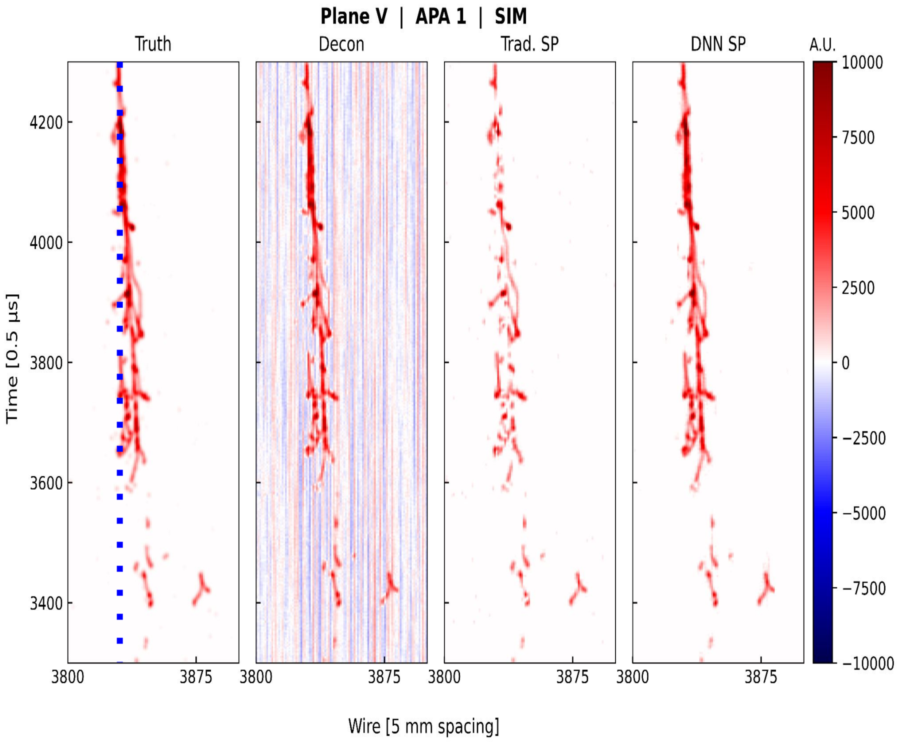


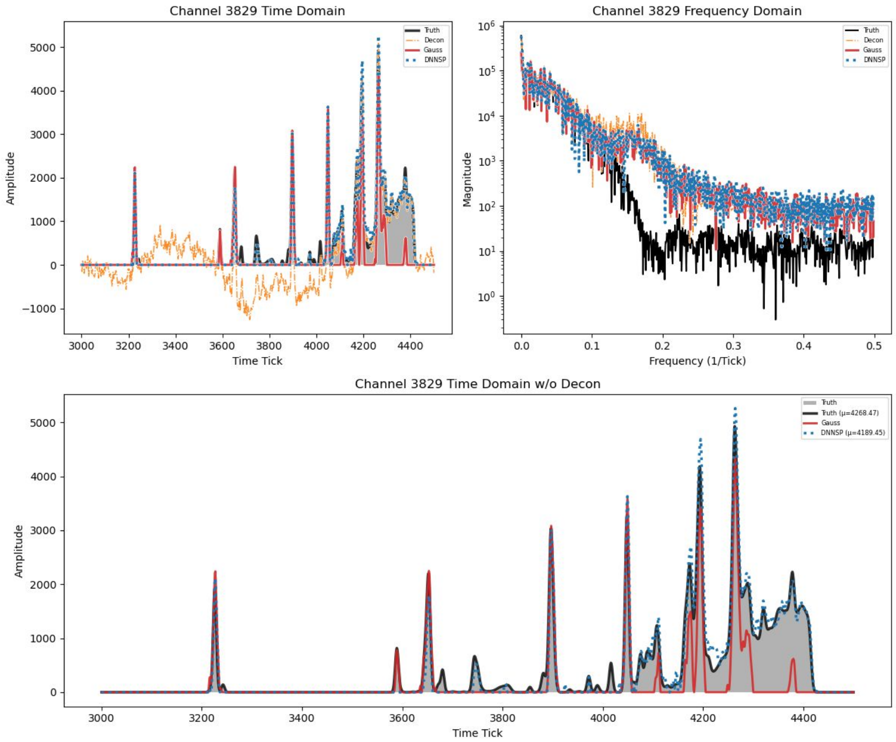


- Threshold 10
- Threshold 100

- For the same g4.root file, the decon result differs (How to have same decon shape?)

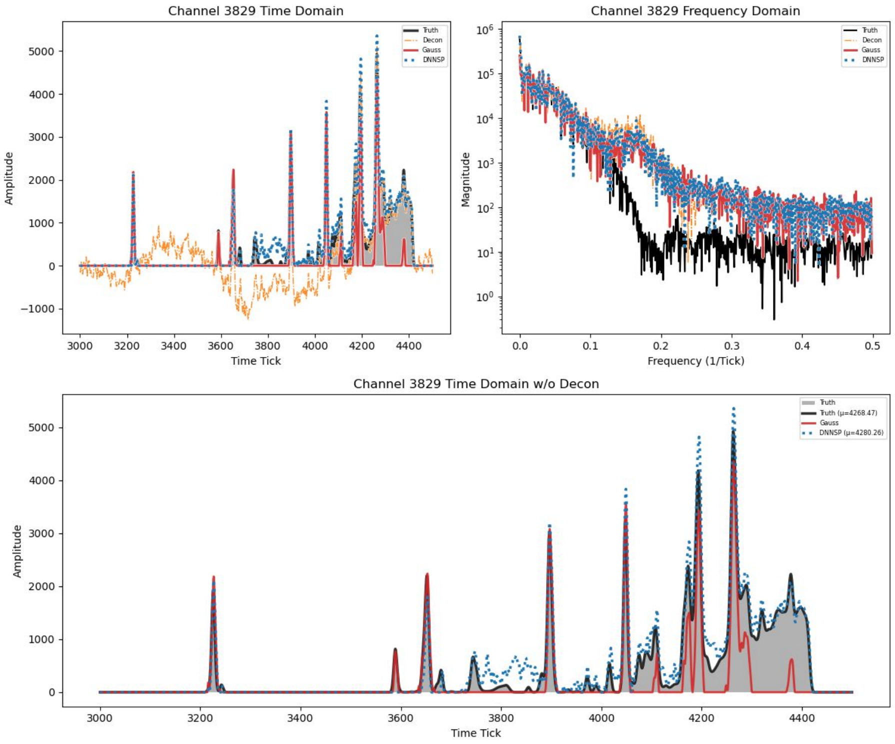
Waveform from Prolonged Shower



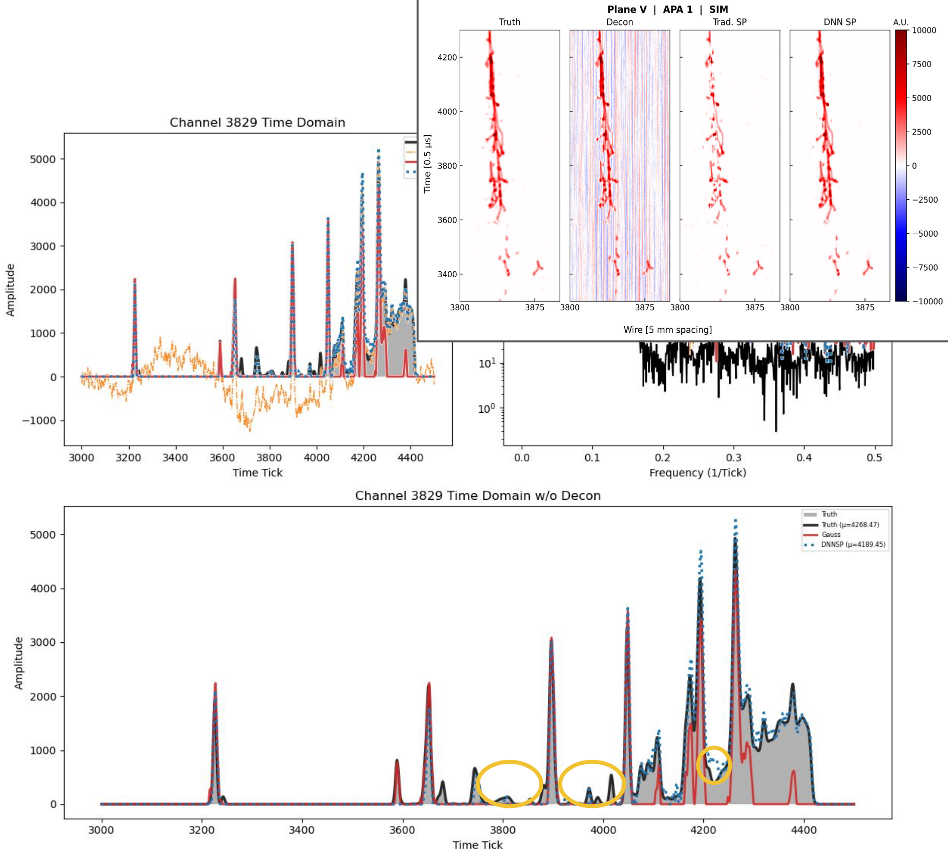


- In this case, the DNN ROI reconstructed the charge much better

Waveform from Prolonged Shower



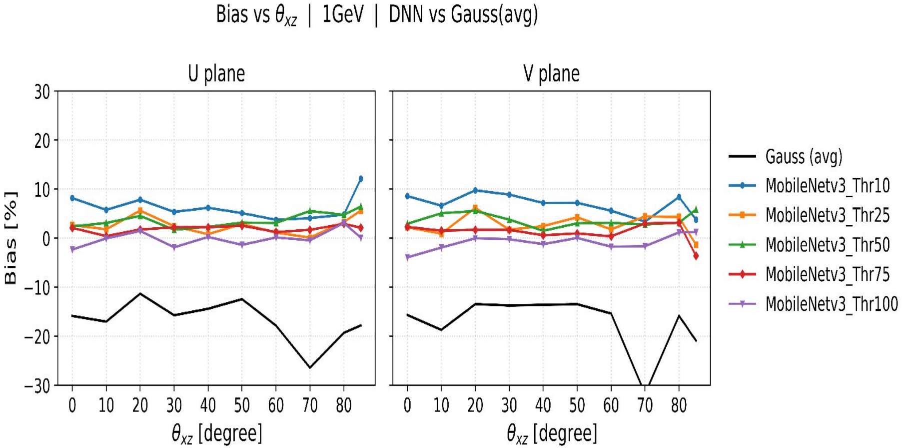
- Threshold 10

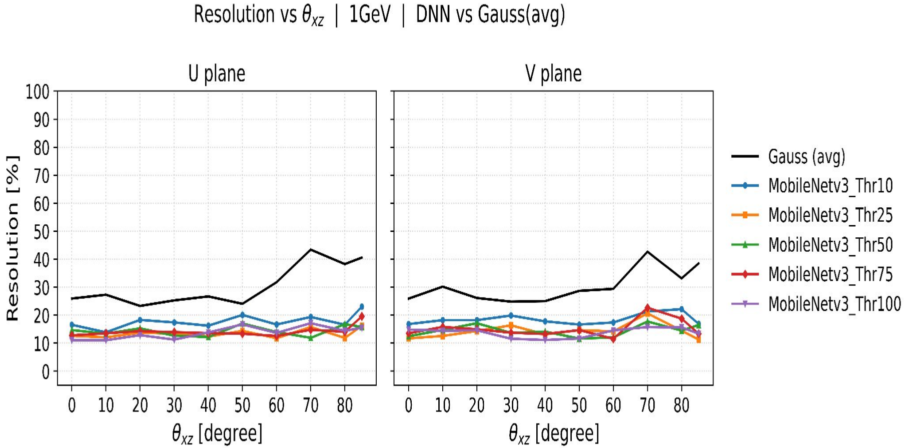


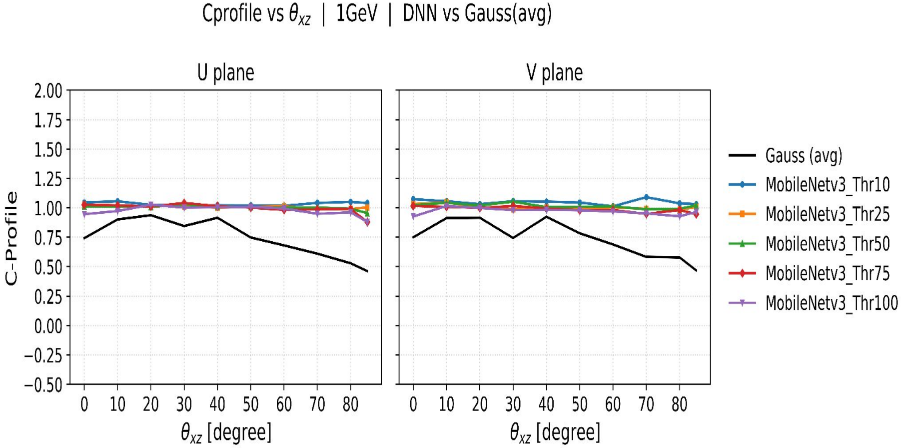
- Threshold 100

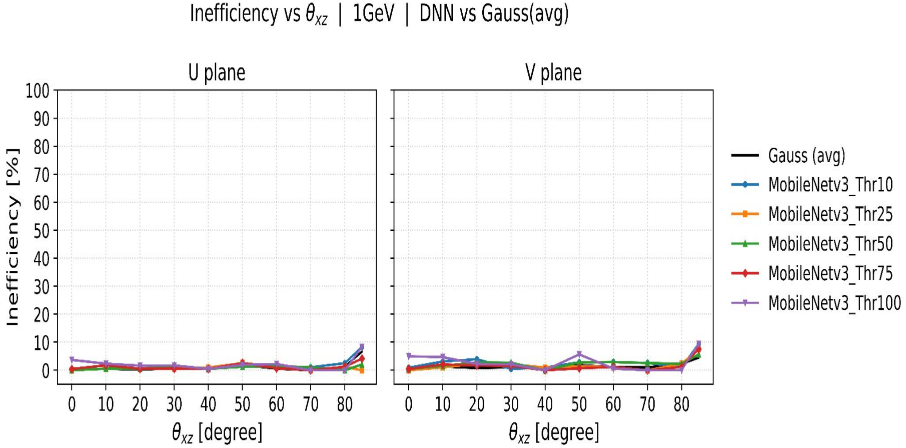
- The decon is almost identical in this case, higher truth_th succeeded to decrease the noise

Single Shower Evaluation (1 GeV)

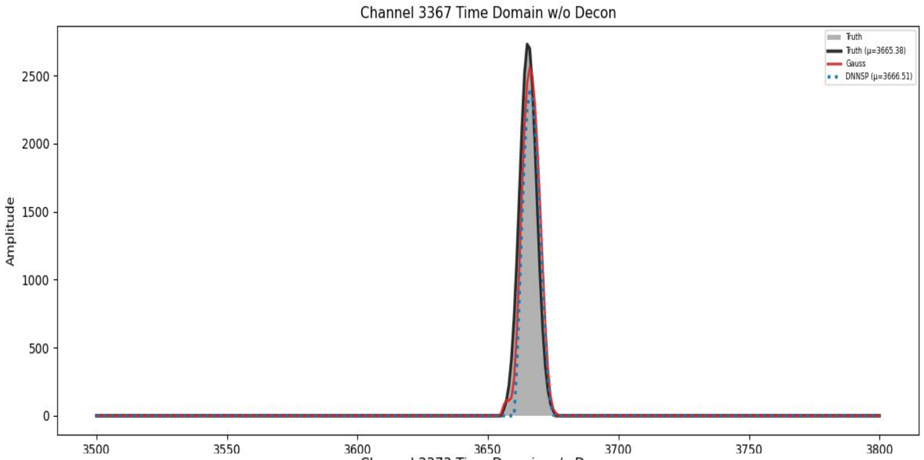


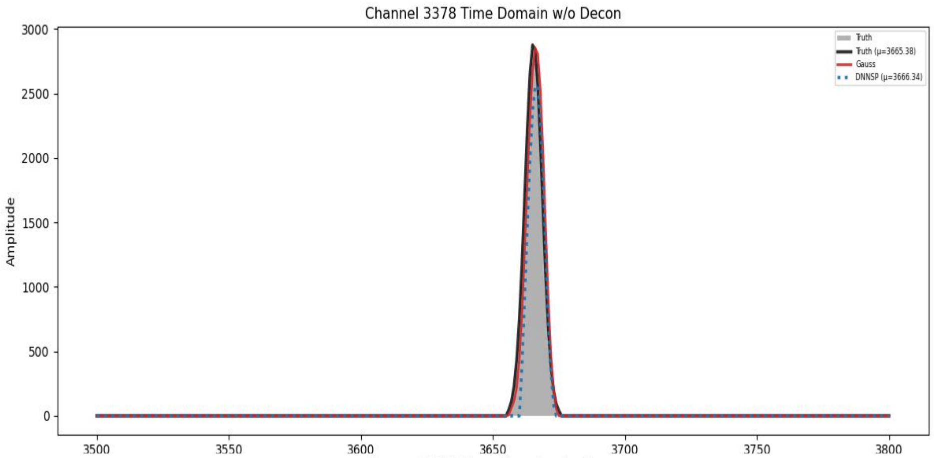


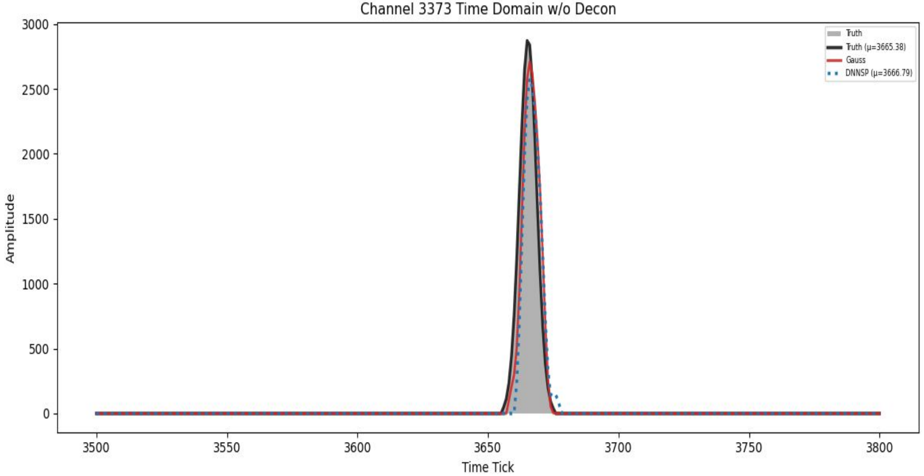


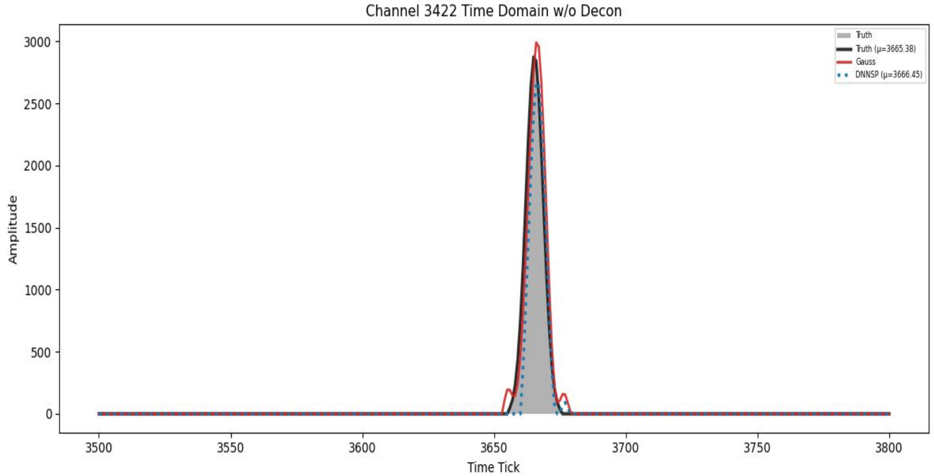


Back Up


Channel 3367 Time Domain w/o Decon
Truth
Truth (μ=3665.38)
Gauss
DNNSP (μ=3666.51)
Amplitude


Channel 3378 Time Domain w/o Decon
Truth
Truth (μ=3665.38)
Gauss
DNNSP (μ=3666.34)
Amplitude


Channel 3373 Time Domain w/o Decon
Truth
Truth (μ=3665.38)
Gauss
DNNSP (μ=3666.79)
Amplitude
Time Tick


Channel 3422 Time Domain w/o Decon
Truth
Truth (μ=3665.38)
Gauss
DNNSP (μ=3666.45)
Amplitude
Time Tick

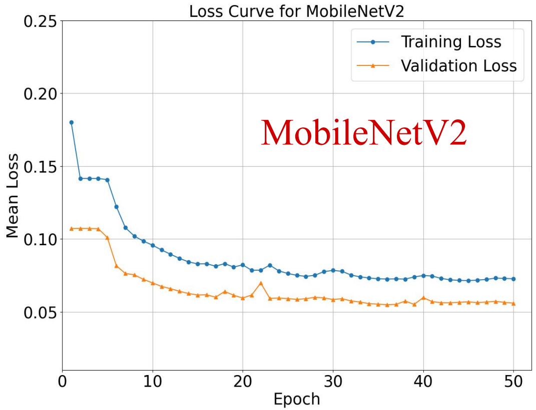
Model Comparison - Network Architectures

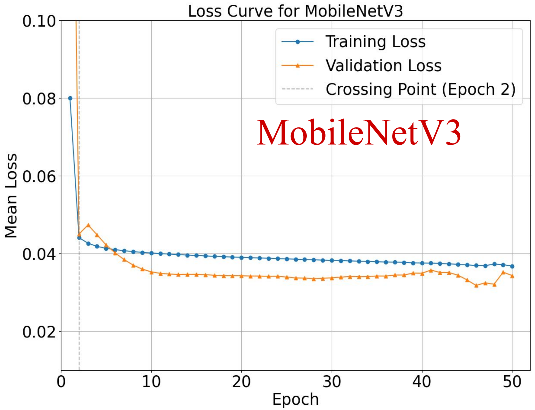
Model	Encoder	Decoder	Skip Connection	Downsampling Depth	Activations	
					Encoder	Decoder
UNet	Convs	4 Convs	Yes	1/16	ReLU	ReLU
MobileNetV2-UNet	Depthwise separable	2 Convs	None	1/32	ReLU6	ReLU
MobileNetV3-UNet	Depthwise separable + SE	4 Convs	Yes	1/32	h-swish + ReLU	ReLU
Transformer-UNet	Convs + Transformer bottleneck	4 Convs	Yes	1/16	ReLU	ReLU
					GELU (transformer)	

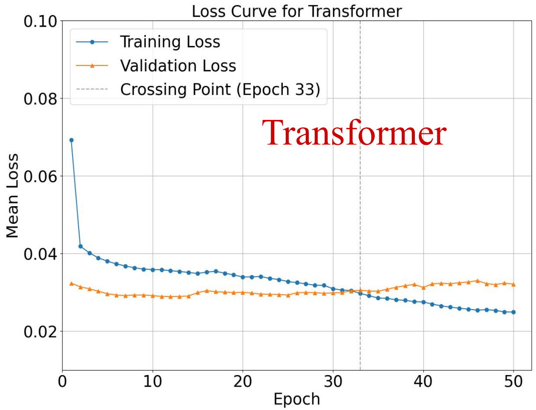
- Training dataset: 590 cosmic-ray events
- Optimizer: SGD (Stochastic Gradient Descent)
- Learning rate: 0.1
- Early stopping: Enabled
- Train/Val split: 0.9/0.1
- Loss: BCELoss (Binary Cross-Entropy Loss)
- Number of epochs : 50
- Output activation function: Sigmoid

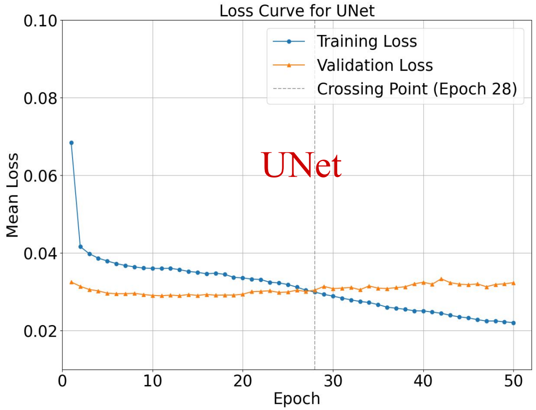
Training was carried out on the WC Cluster using an NVIDIA GeForce RTX 4090 GPU (24 GB)

Model Comparison - Train vs Val loss



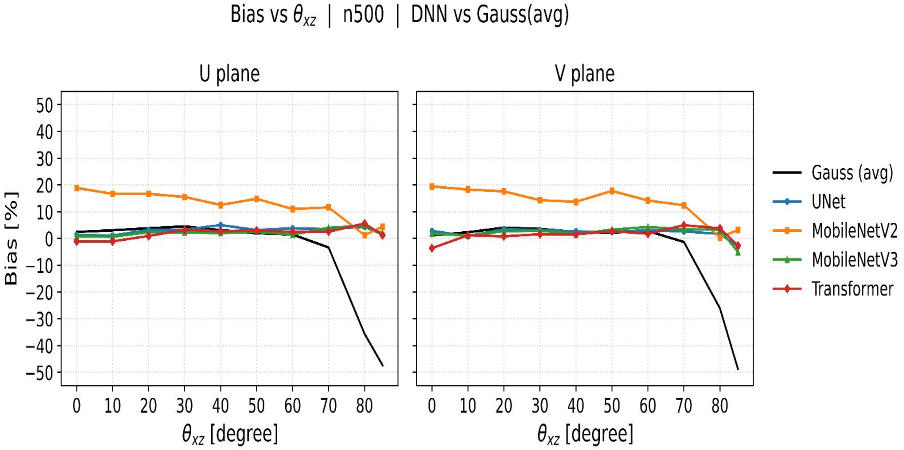


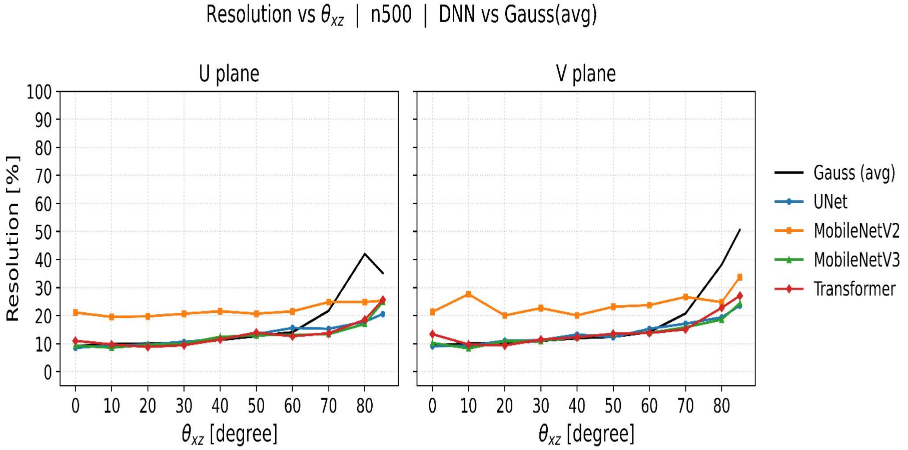


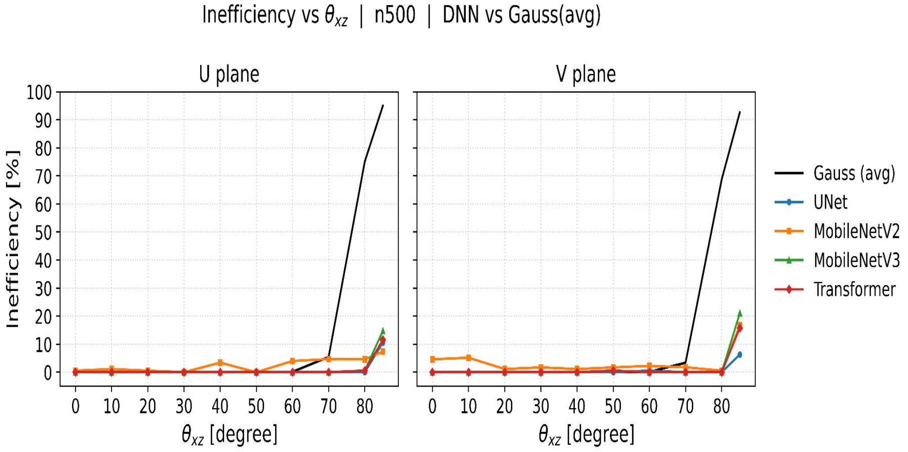


- Rebin factor was set to 10 during training
- Training losses at the selected checkpoints:
  - UNet: 0.029 (Epoch 28)
  - MobileNetV2: 0.072 (Epoch 50)
  - MobileNetV3: 0.044 (Epoch 50)
  - Transformer: 0.029 (Epoch 32)
- Among the models, UNet and Transformer reached the most stable convergence with the lowest final losses

Single Track Evaluation







- Simulations on the normal APA (2nd)
- MobileNetV2 exhibits ~20% bias at low angles
- The lower performance is likely due to:
  - Fewer convolution blocks in the decoder
  - Absence of skip connections
- Other models demonstrate comparable performance

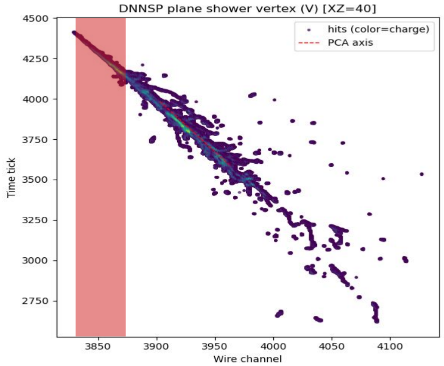
DNN-ROI Performance Evaluation

- For track events, three metrics are used: Bias, Resolution, and Inefficiency

$$Bias = 100 \times \left(\left\langle \frac{Q_{reco}}{Q_{truth}} \right\rangle - 1 \right) \quad Resolution = 100 \times \frac{RMS\left(\frac{Q_{reco}}{Q_{truth}}\right)}{\left\langle \frac{Q_{reco}}{Q_{truth}} \right\rangle} \quad Inefficiency = 100 \times \frac{Number\ of\ bad\ channels}{Number\ of\ valid\ truth\ channels}$$

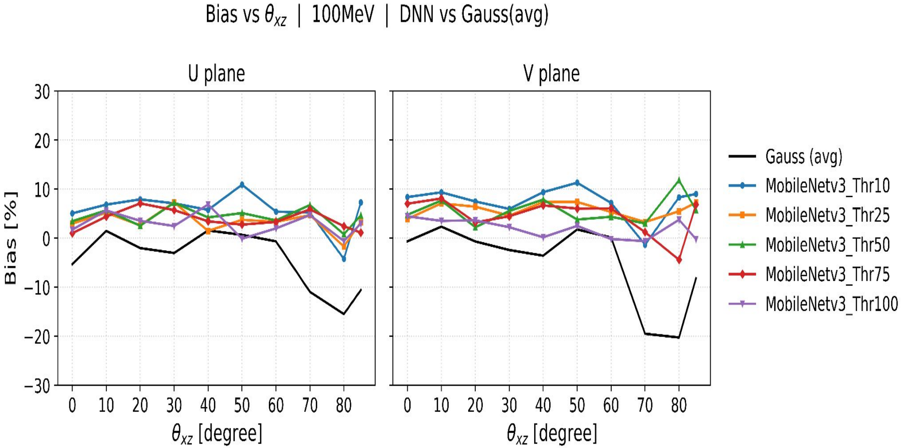
- For shower events, a charge profile based on vertex information was added as the fourth metric:
  - Sum the charge along the shower direction up to 42 wire channels (≈ 1–2 radiation lengths)
  - Compare the reconstructed-to-truth ratio charge ratio

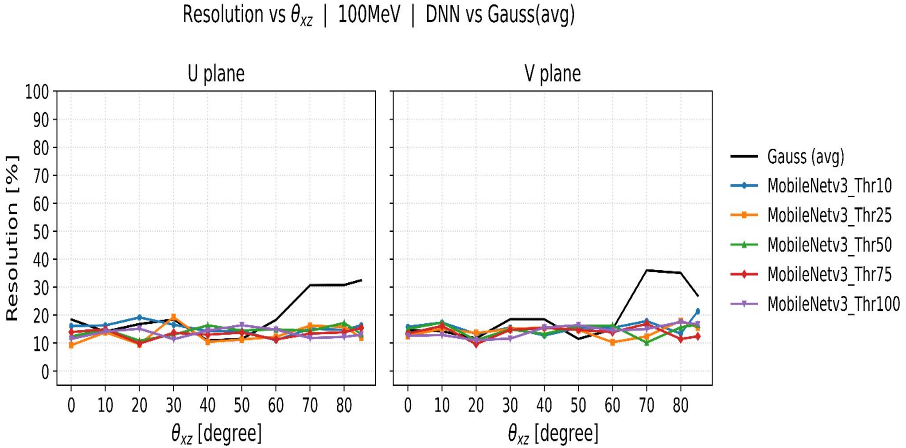
$$Q_{method} = \sum_{w \in W} Q_{method}(w) \qquad R_{cprofile} = \frac{Q_{reco}}{Q_{truth}}$$

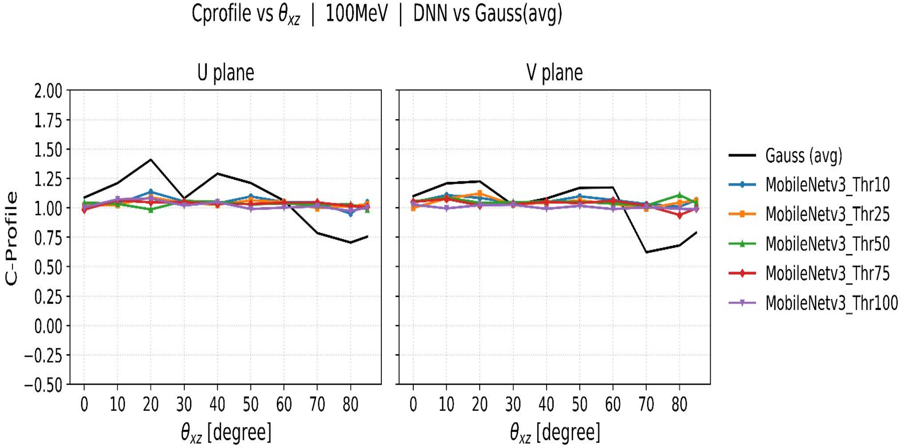


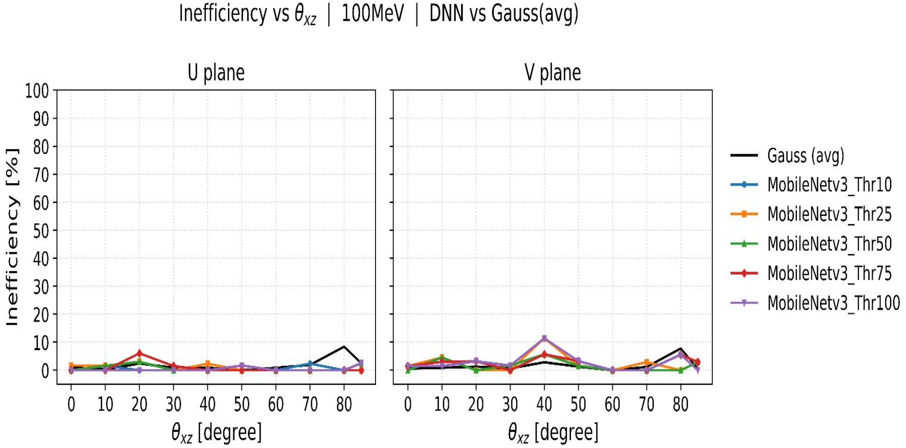
- Samples were generated with
  - Detector configuration: ProtoDUNE - Horizontal Drift (PD-HD)
  - XZ angle: 0°, 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°, 85°
  - Shower energies: 100 MeV, 500 MeV, 1 GeV, 2 GeV, 3 GeV, 5 GeV
  - Software: WCT standalone (Tracks), LAr-WCT (Showers)

Single Shower Evaluation (Thr 100, 100 MeV)

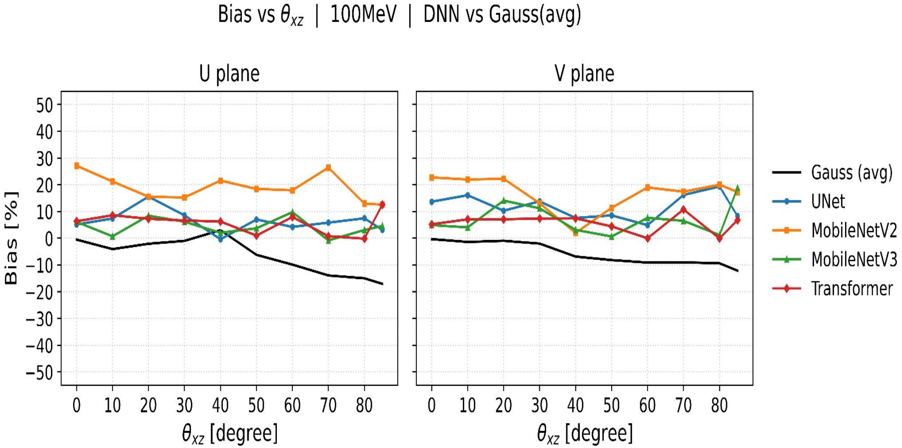


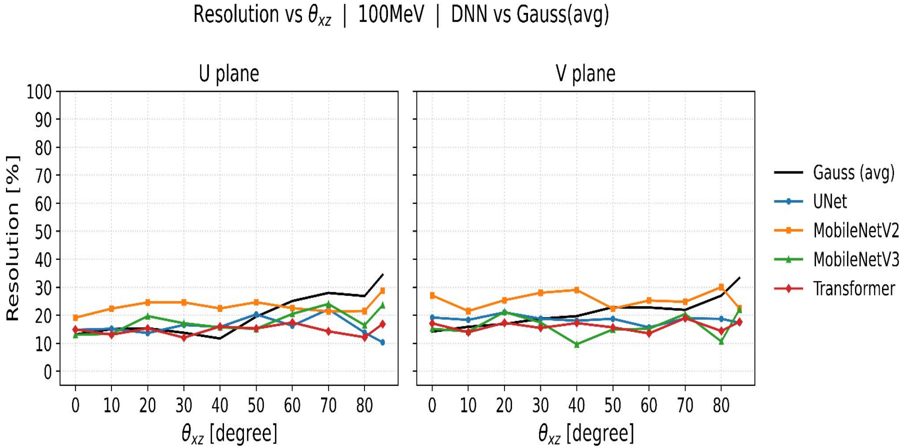


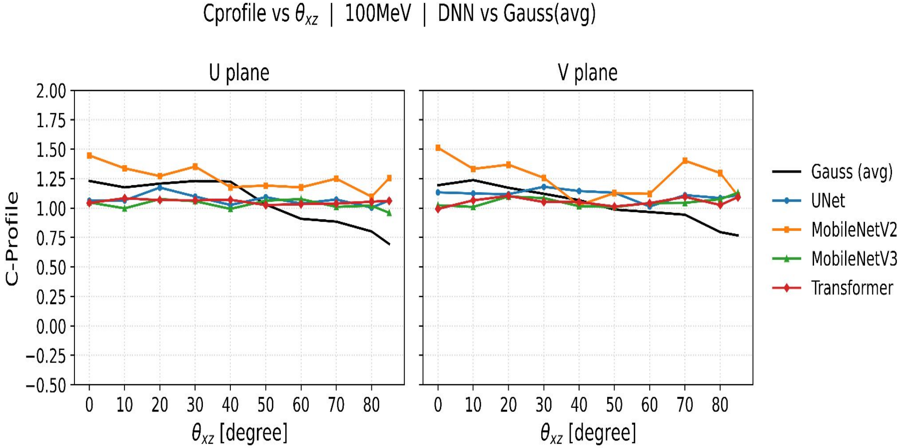


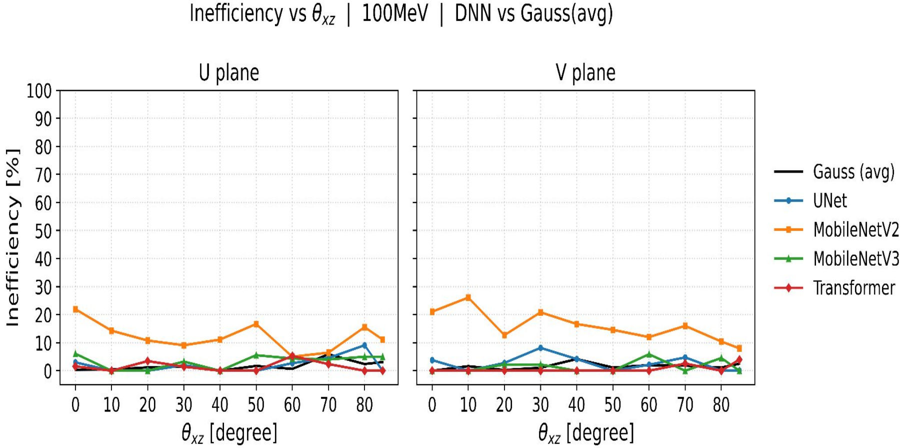


Single Shower Evaluation (Thr 10, 100 MeV)









Single Shower Evaluation (Thr 100, 1 GeV)