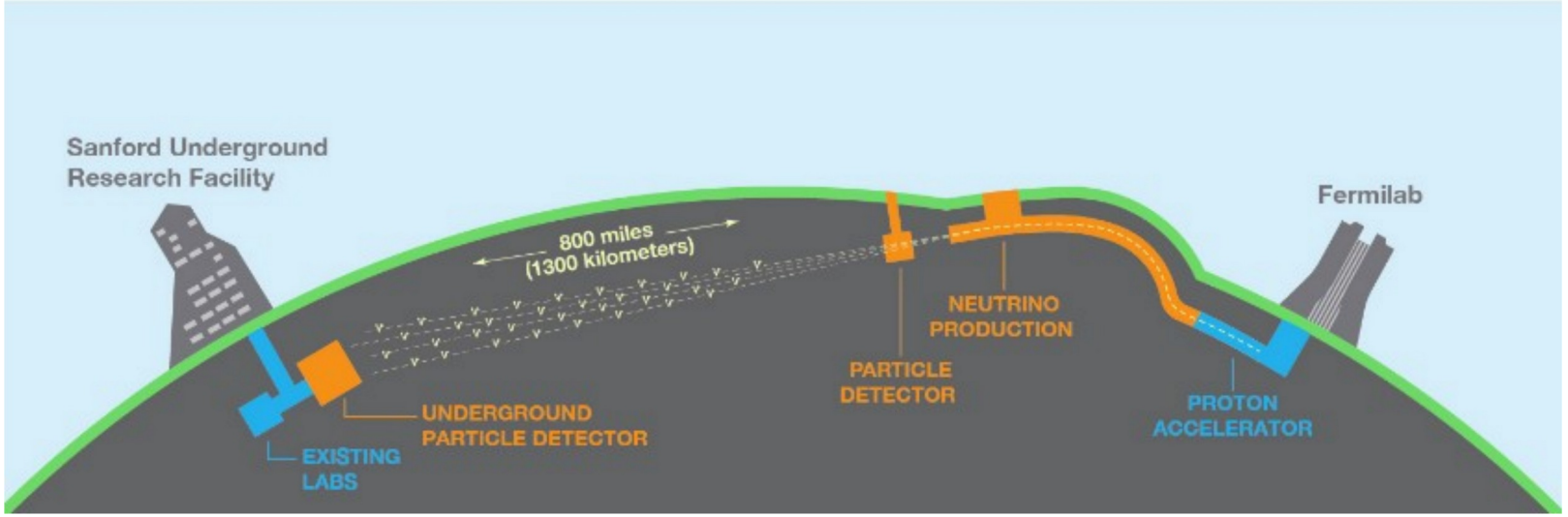
Deep Learning strategies for ProtoDUNE raw data denoising

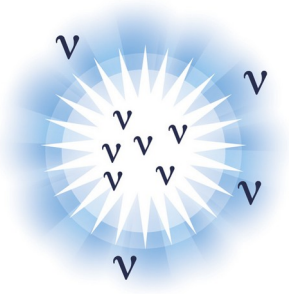
Marco Rossi

Sofia Vallecorsa

DUNE

Deep Underground Neutrino Experiment, Fermilab (US), from 2026





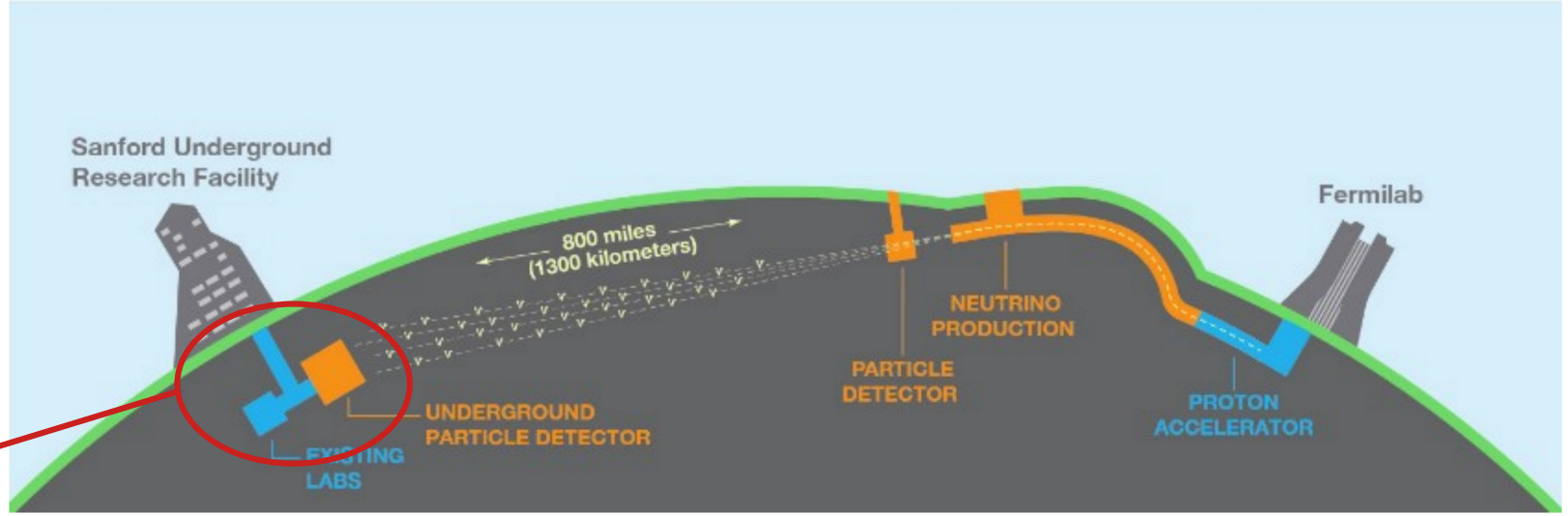
Matter vs Anti-Matter

Unification of Forces

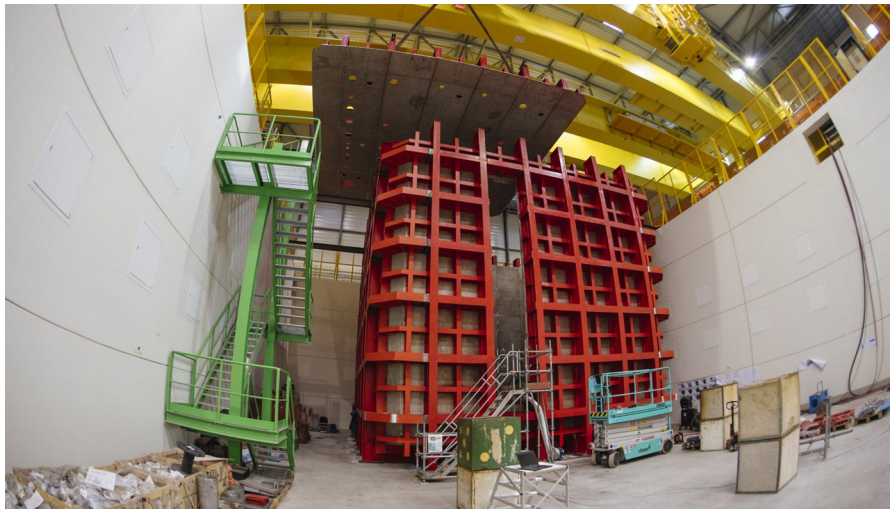
Black Hole Formation

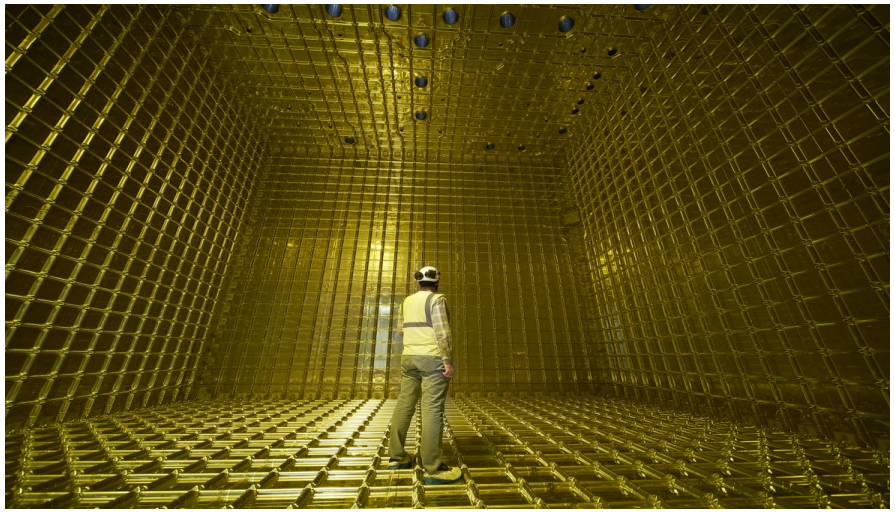
DUNE

Deep Underground Neutrino Experiment, Fermilab (US), from 2026



ProtoDUNE, CERN (CH),
From 2017





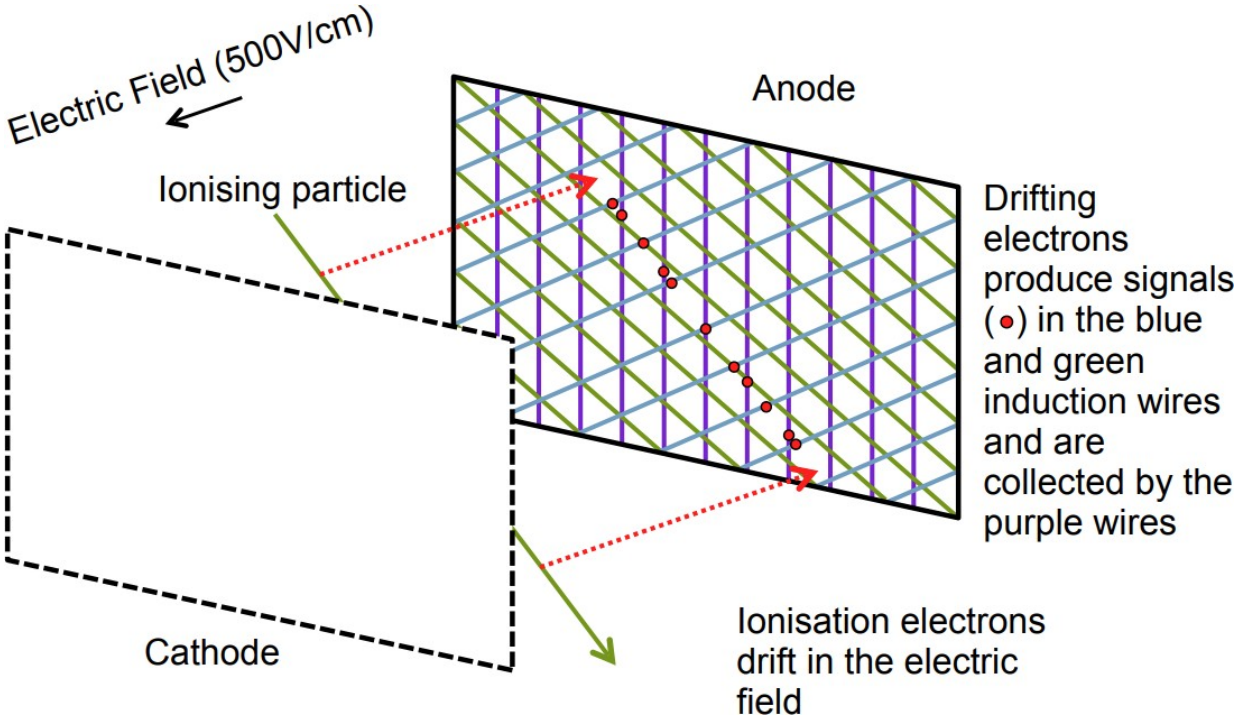
Detector - LArTPC

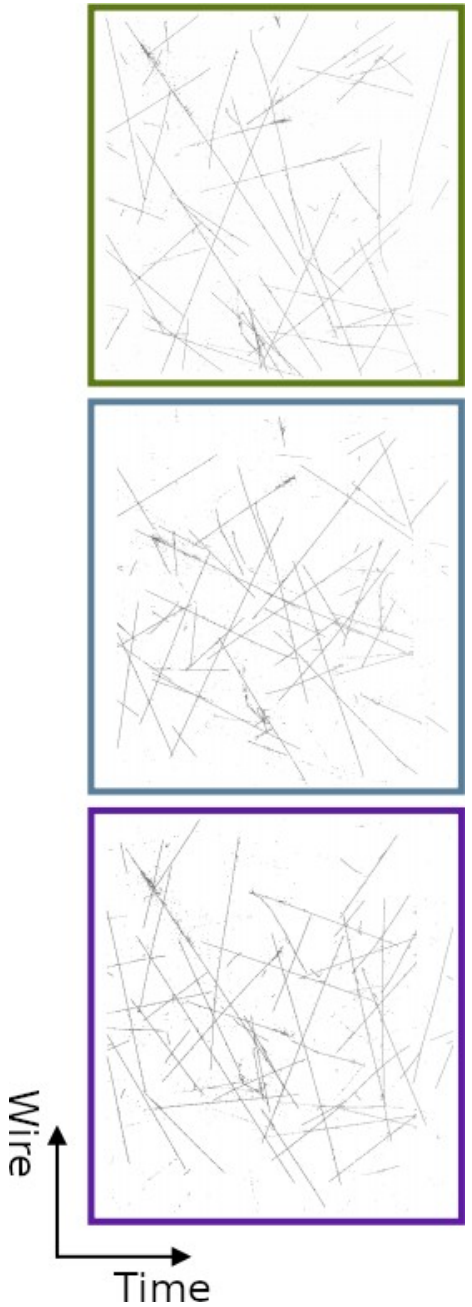
Liquid Argon Time Projection Chamber

Big box filled with liquid Argon (Ar)

Electronics shapes electron induced current

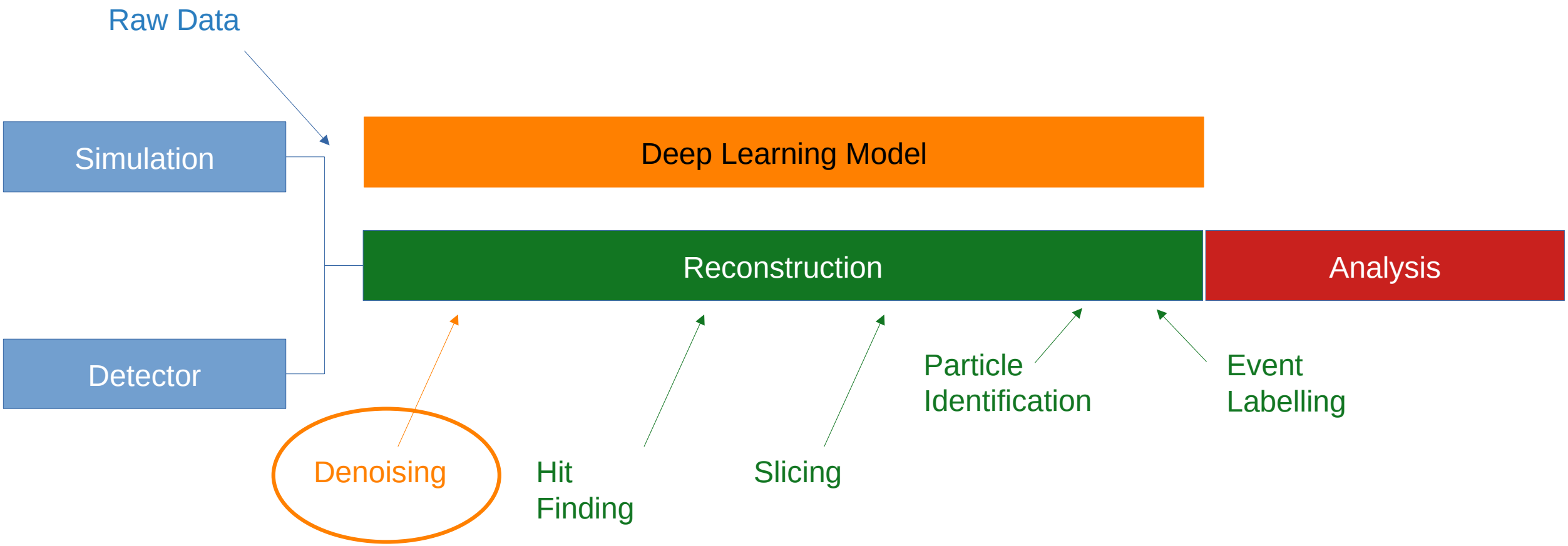
Plot Raw Digits as images (ADC counts on Time vs Wire)





Offline Data Processing

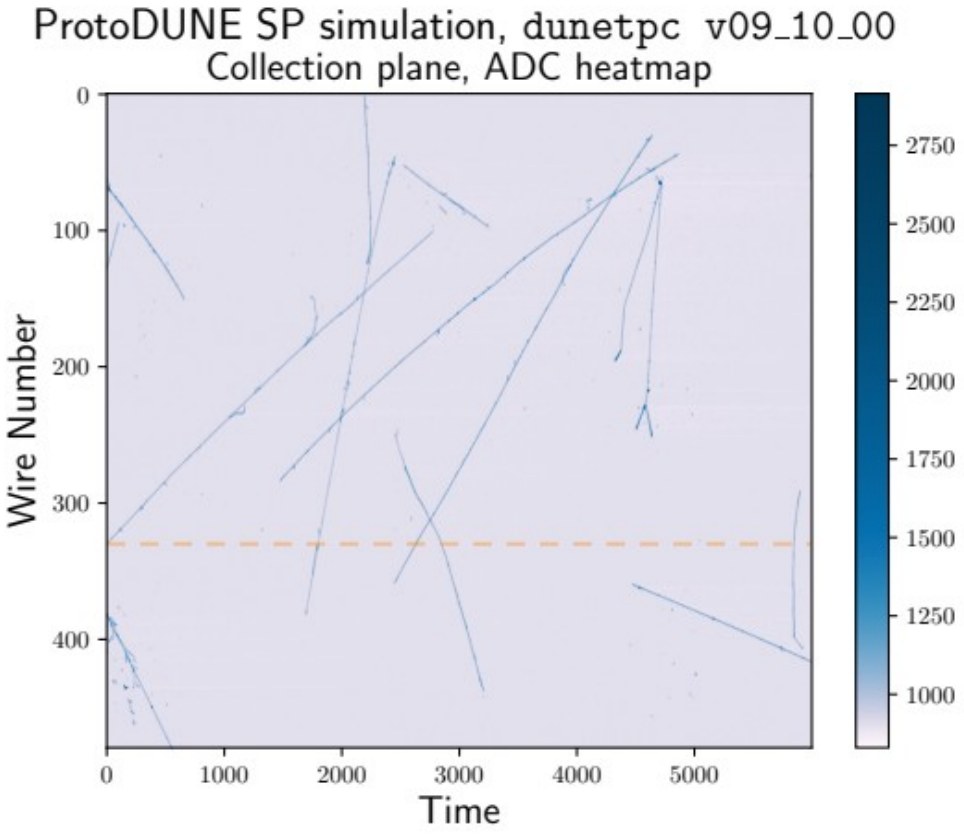
Proposed Workflow



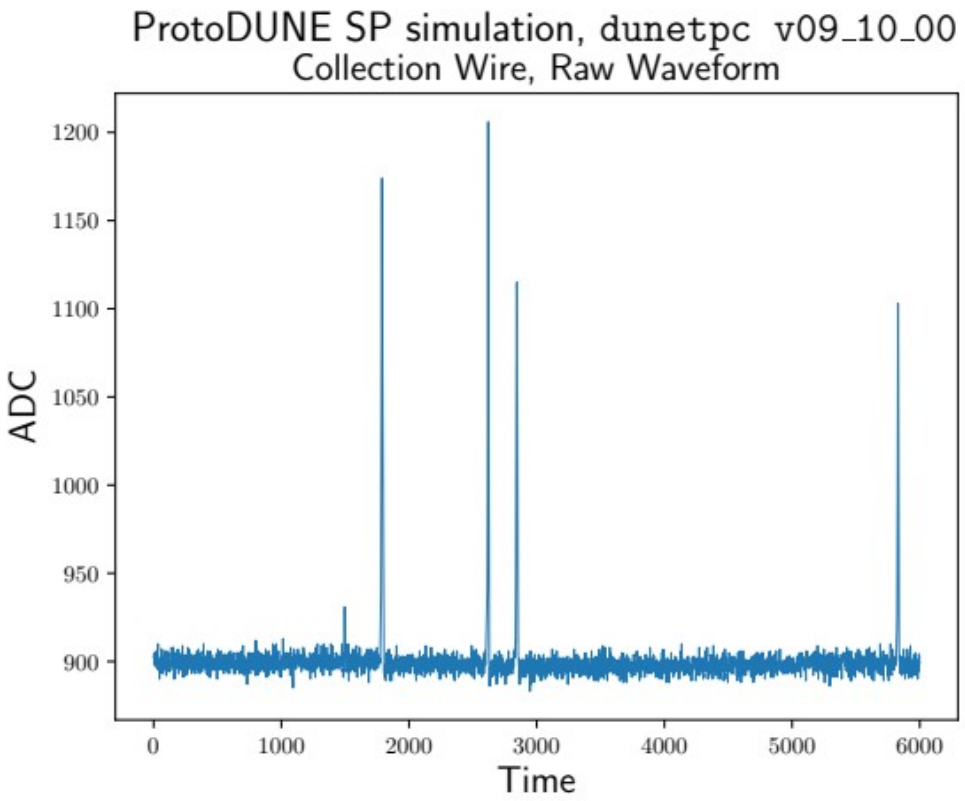
ProtoDUNE – Raw Data

- High resolution
- Sparse features

2D Array



Noisy Waveform



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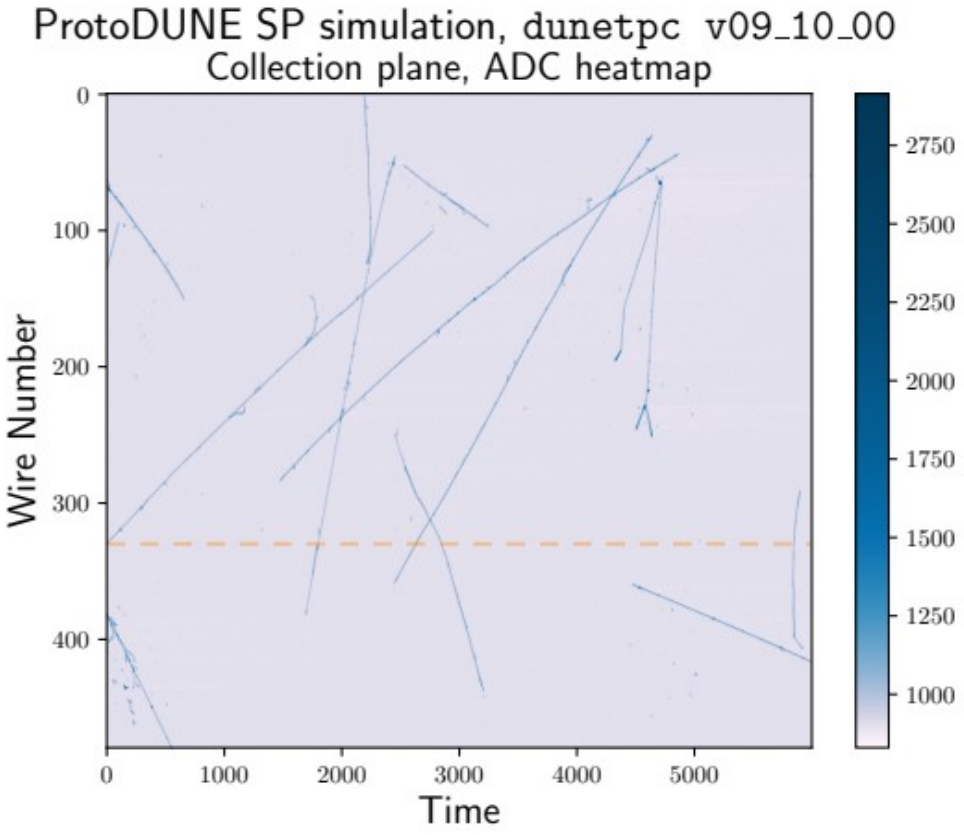
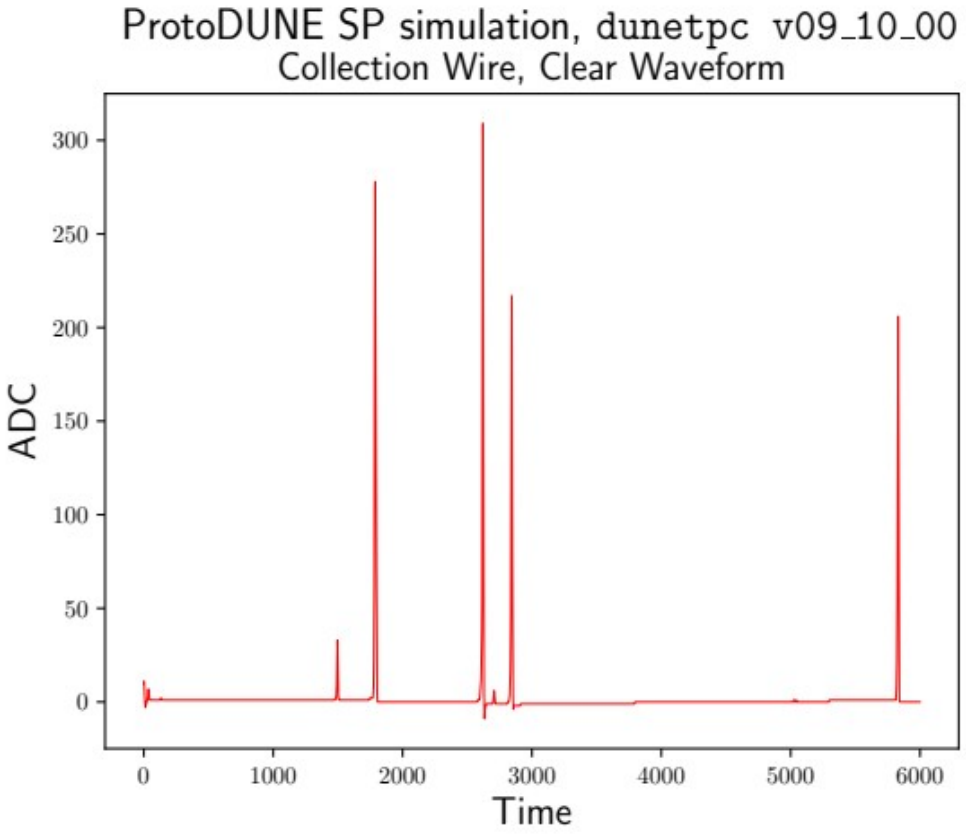


Clear Waveform

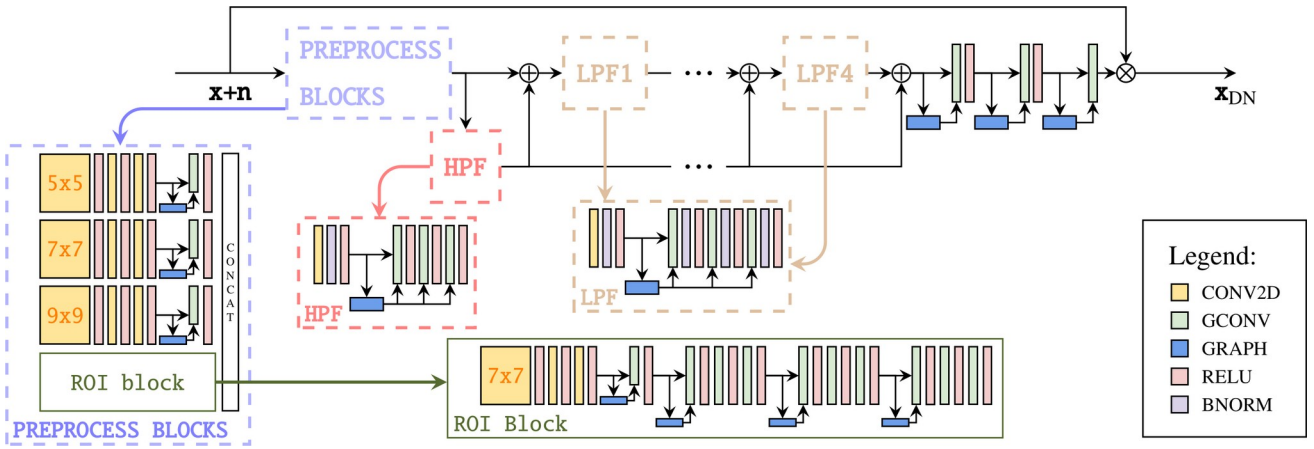


Model Overview

Reference: https://arxiv.org/abs/2103.01596

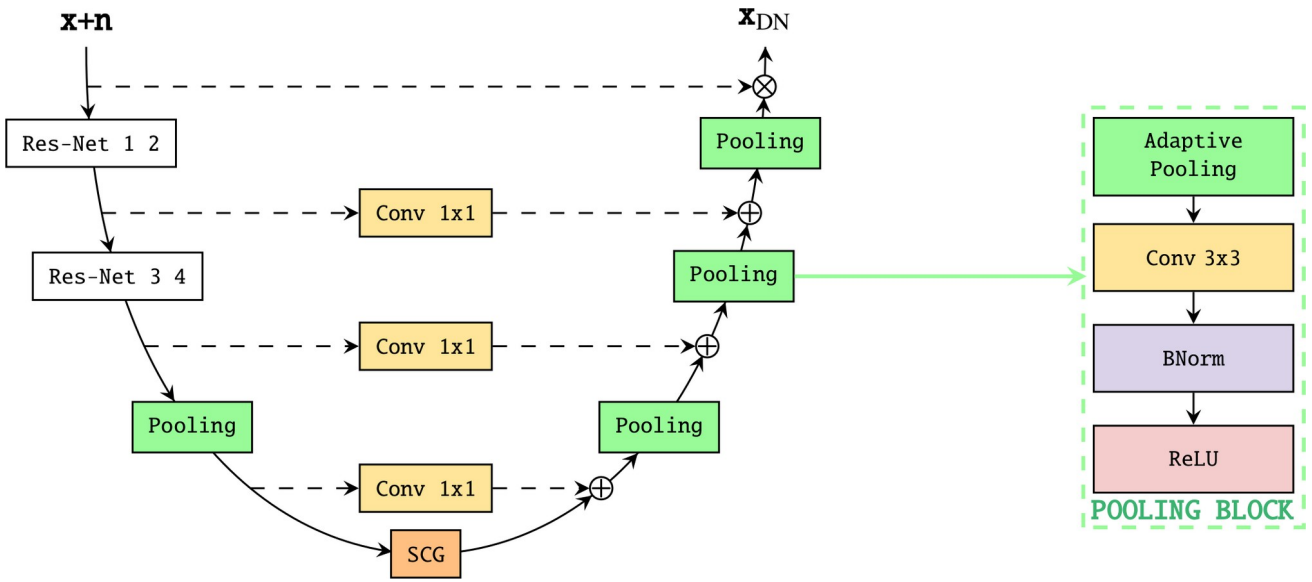
- Graph Convolutional Neural Network (GCNN)

  Exploit Non-Local features
  Data Parallel approach
  Distributed Training (time scaling ?)



- U-Shape Self Constructing Graph Network (USCG-Net)

  Downsampling – Upsampling branches
  Process entire images (long range features)
  Faster inference



GCNN Layer

From GCNN Network

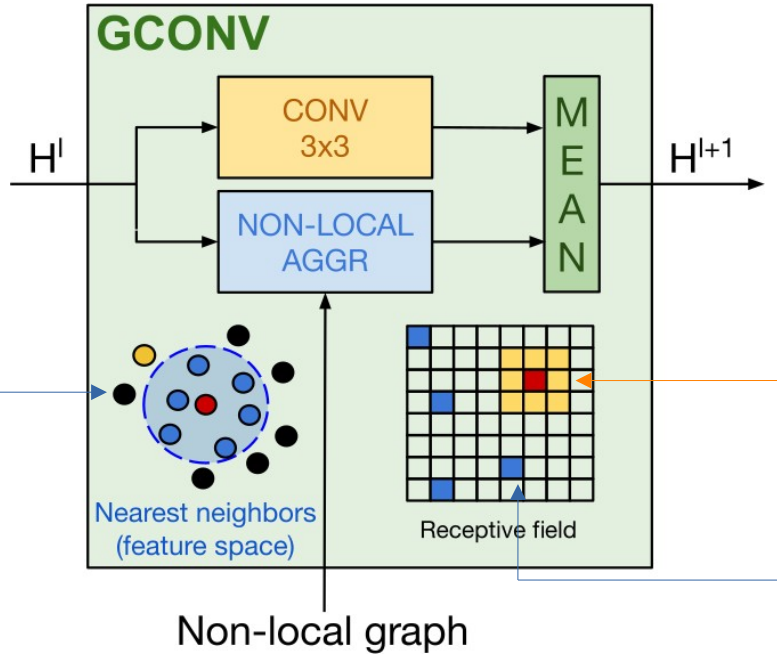
Reference: https://arxiv.org/abs/1907.08448

Non local graph:

Exploit long distance correlations

k = 8

Warning: Complexity order $O(n^2)$



Convolutional Filter (local)

Non local aggregator

Increased complexity within layers

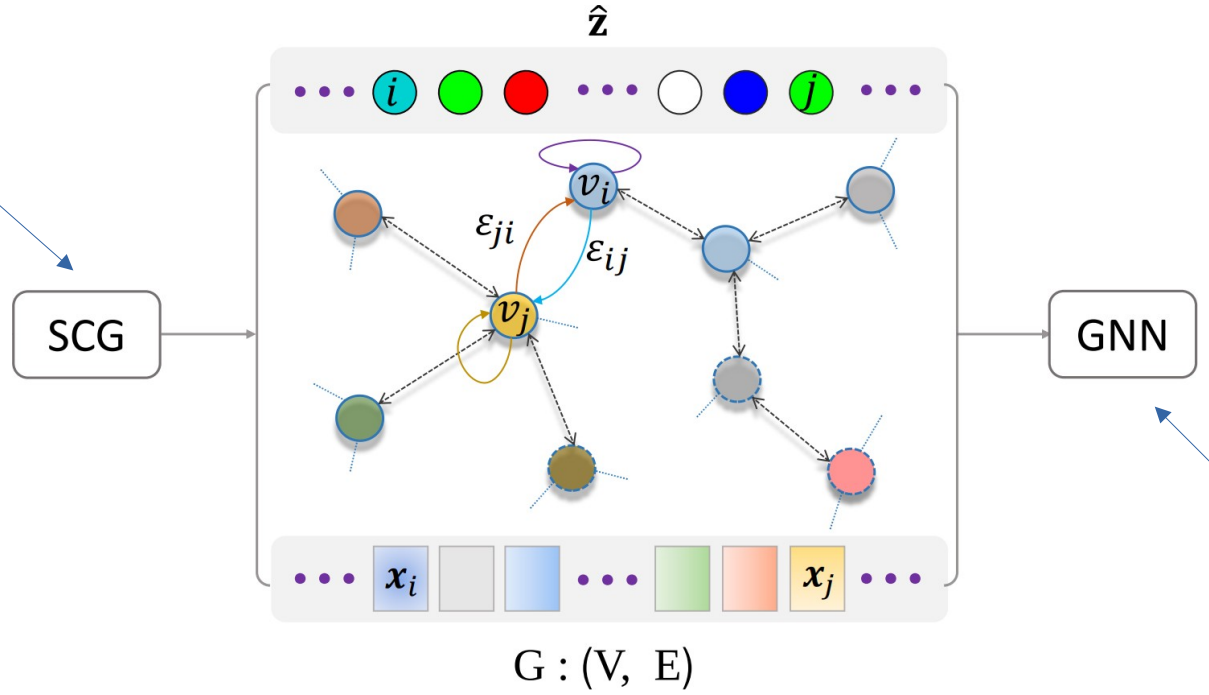
SCG Layer

From USCG-Net

Reference: https://arxiv.org/abs/2009.01599

Learns:

- graph G: (V,E)
- node feature vector $\hat{z}$

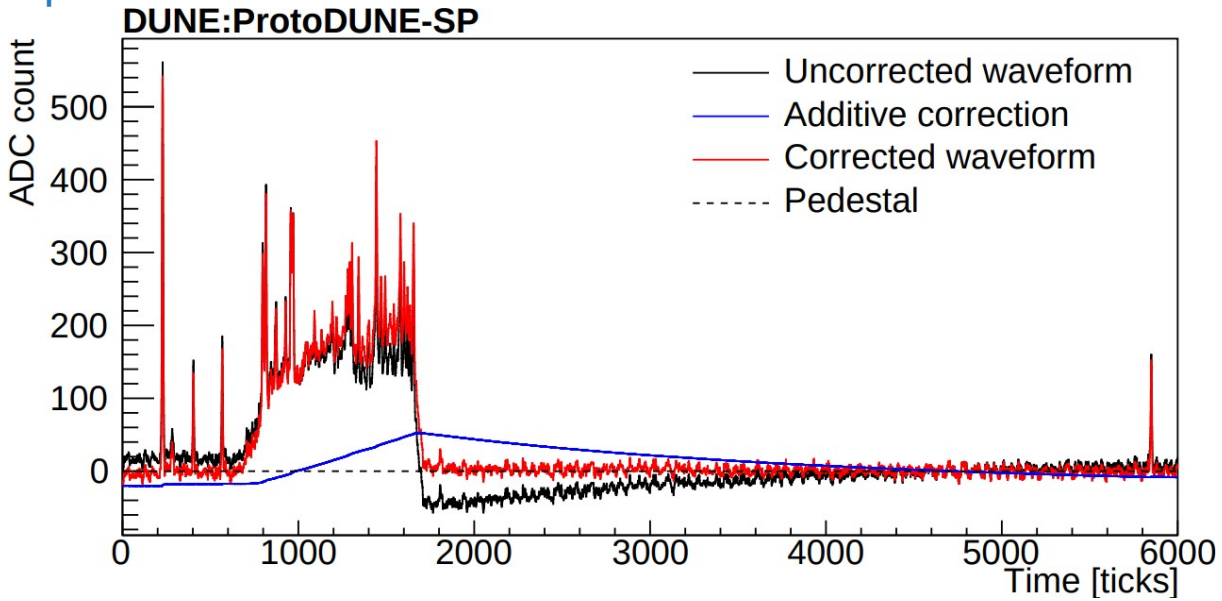


Graph Neural Network to analyze node features

Key point: Computational Efficiency
Before building the graph, downscale the image to low size

Dataset

- Generate two dataset with LarSoft dunetpc software (versions v08_24_00, v09_10_00)
- v08_24_00: 10 events with beam energy 2 GeV
- v09_10_00: 10 events per beam energy (0.3 GeV, 0.5 GeV, 1 GeV, 2 GeV, 3 GeV, 6 GeV, 7GeV), total 80
- v09 dataset is richer and contains more complex signal features to detect (negative tails)
- Split datasets in train/validation/test sets as 80/10/10 %

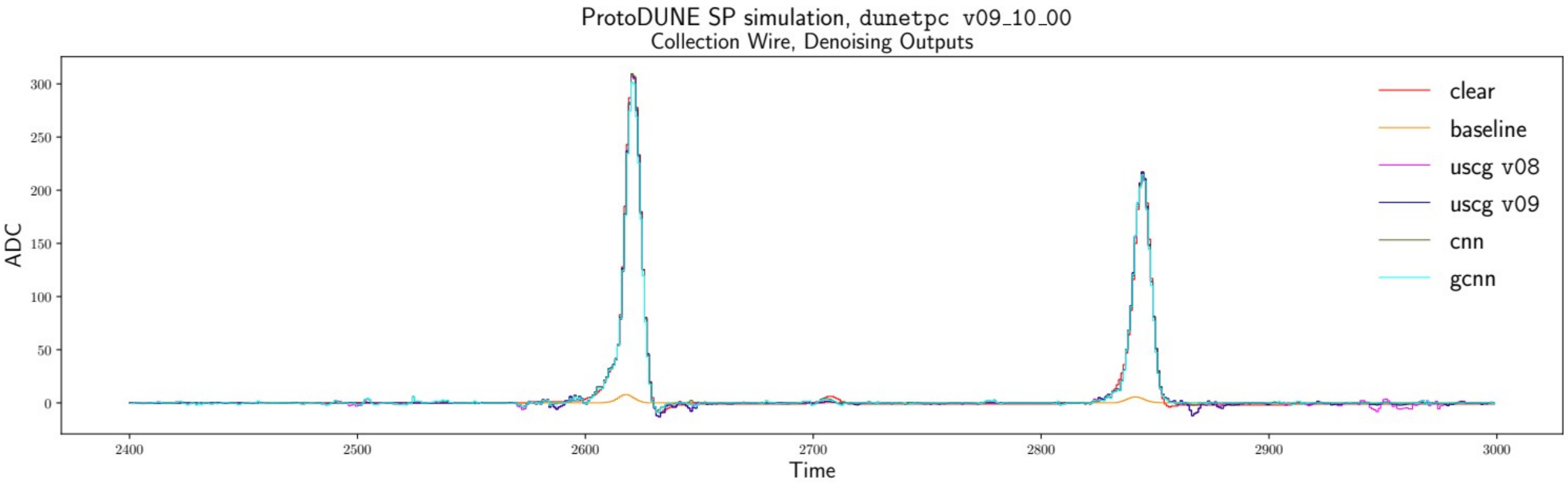


Negative tail example. This feature is present in v09 only.

Reference: https://arxiv.org/pdf/2007.06722.pdf

Results

Reference: https://arxiv.org/abs/2103.01596



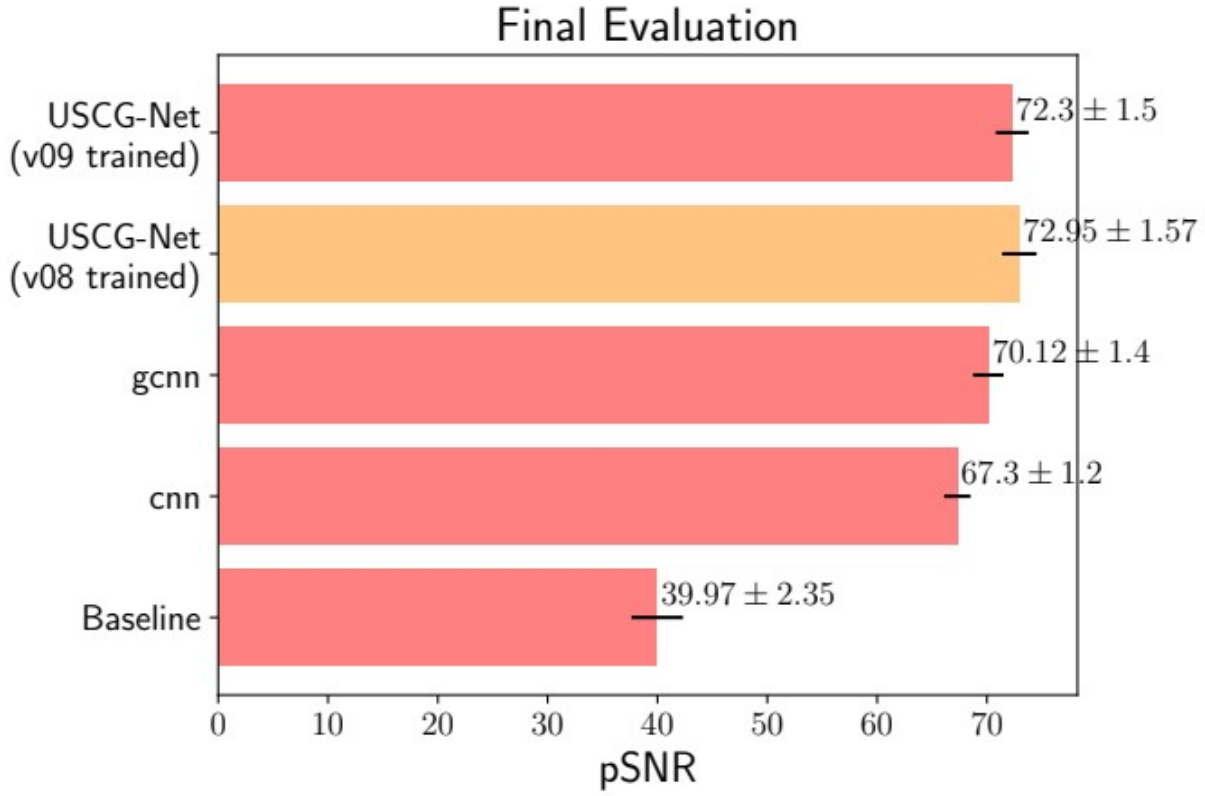
- All networks are trained with Mean Squared Error loss
- Neural networks learn to shape exactly the clear waveform
- The traditional tool filters the waveform in Fourier space not preserving amplitudes

Results

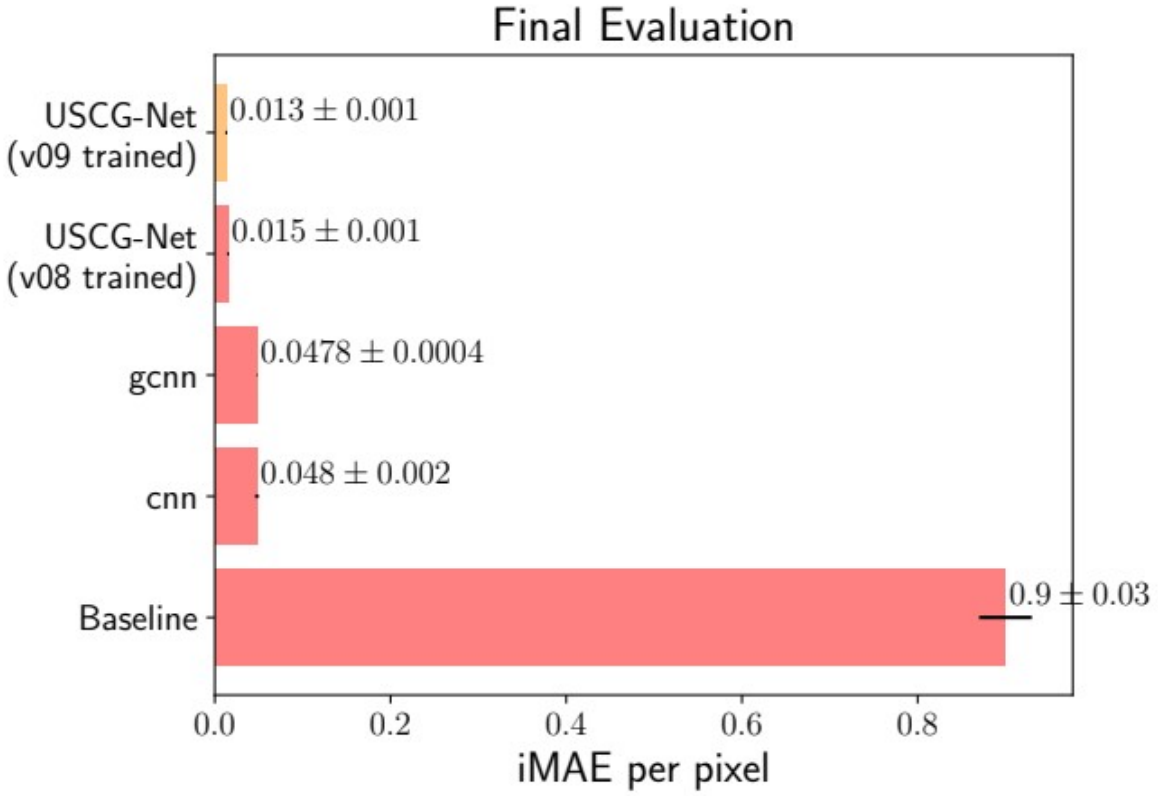
Reference: https://arxiv.org/abs/2103.01596

On v08_24_00 dataset

Metrics measuring the precision of reconstructed (denoised) objects



The higher, the better !



The lower, the better !

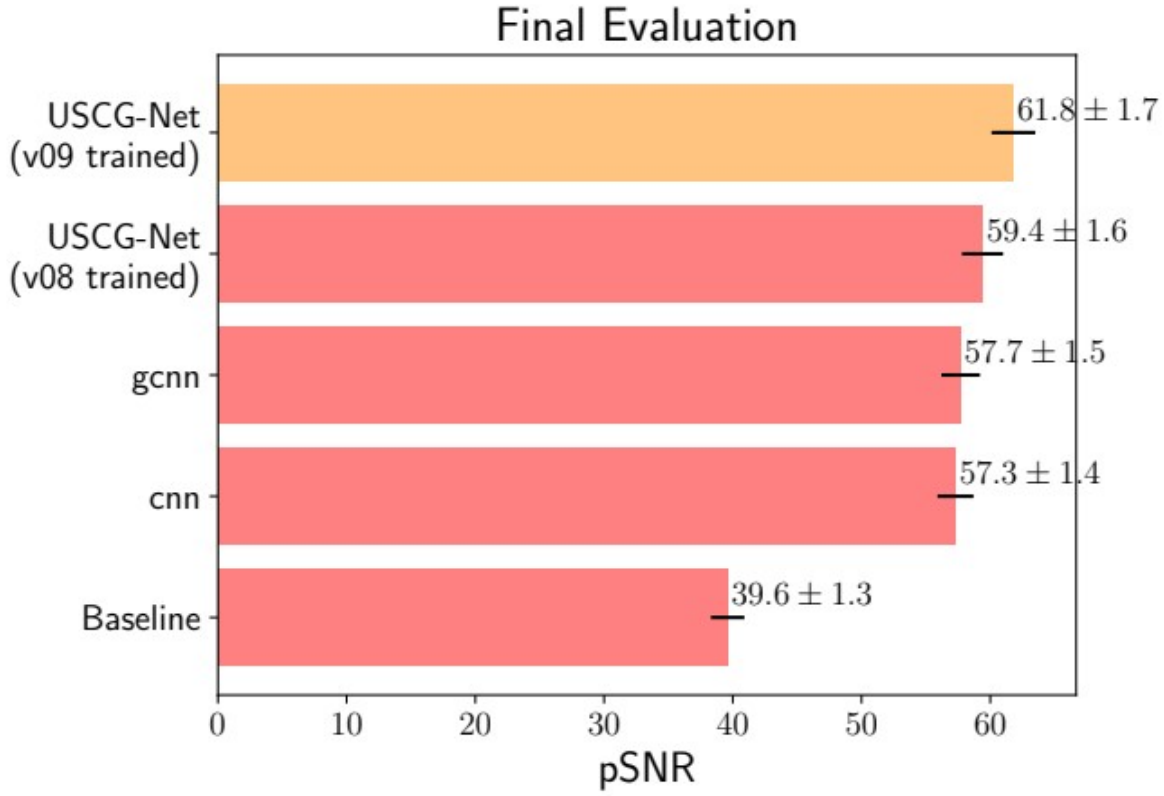
Networks outperform traditional baseline tool

Results

Reference: https://arxiv.org/abs/2103.01596

On v09_10_00 dataset

Metrics measuring the precision of reconstructed (denoised) objects



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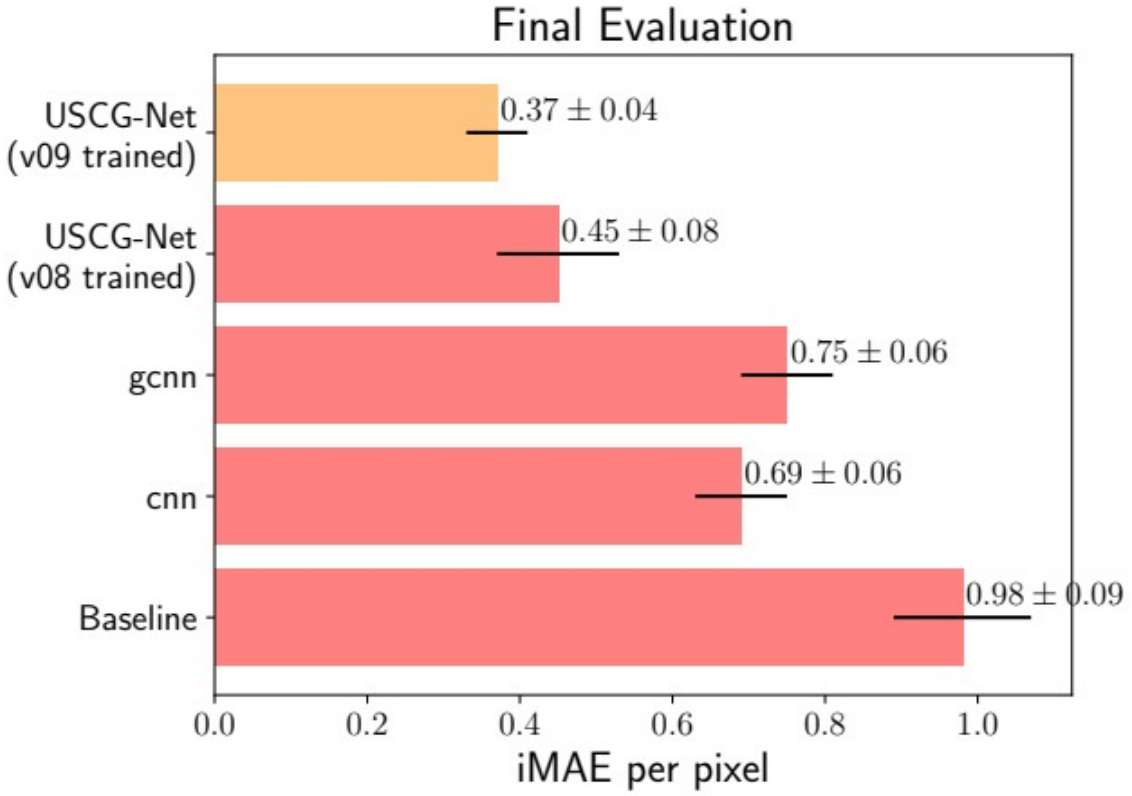


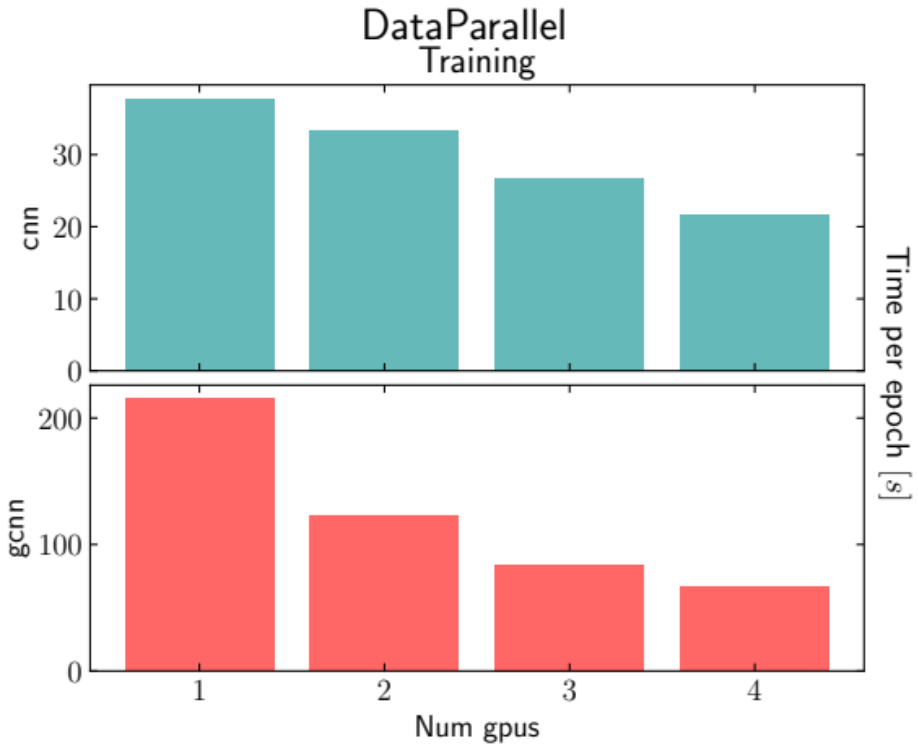
The lower, the better !

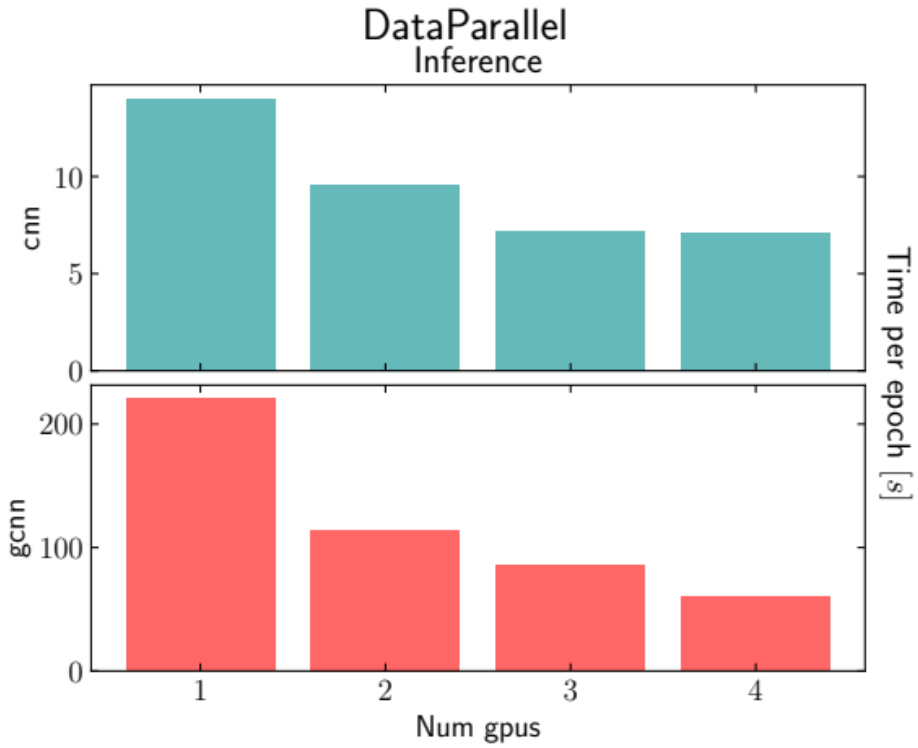
USCG-Net shows good generalization power

Layer Performance

IBM Minsky Power8 Cluster with WMLA

Multi GPU – Single Node - Single Process setup





Algorithm splits the workload on the desired number of GPUs
Good scaling for both networks

Layer Performance

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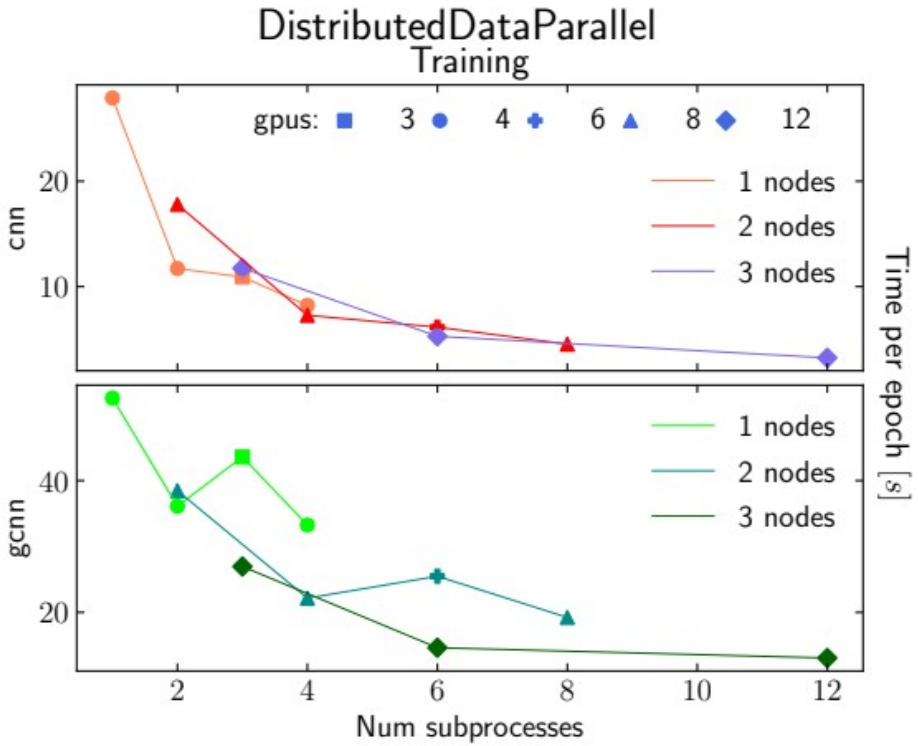
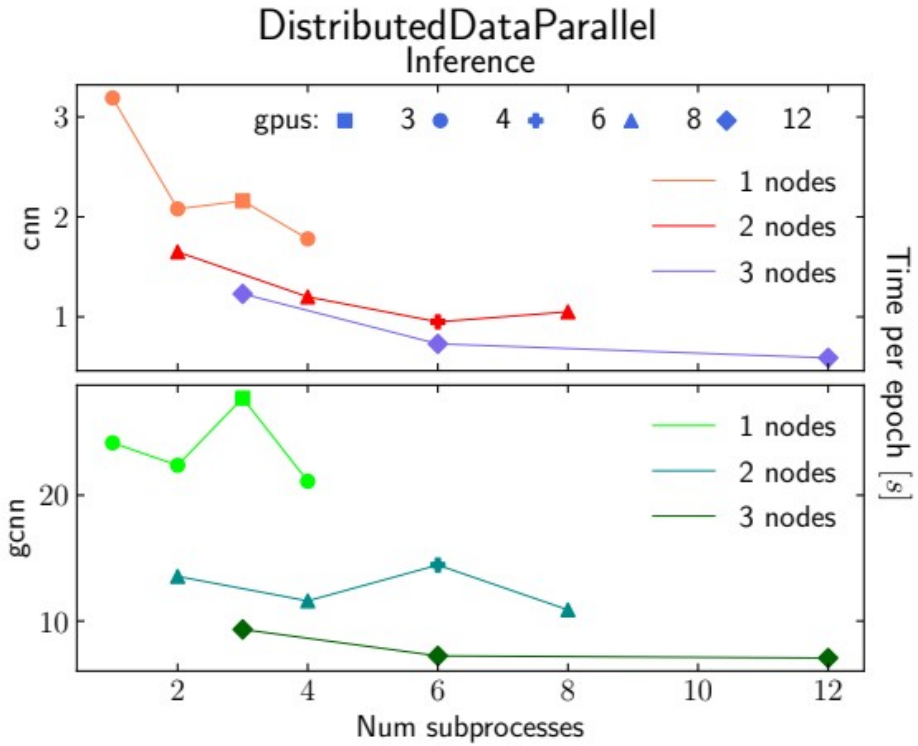
Multi GPU – Multi Node - Multi Process setup





Ordering scheme rule of thumb →

The more available GPUs, the better
The more subprocesses, the better

Summary

- Main goal: replace DUNE reconstruction algorithm with Deep Learning
- Test models on ProtoDUNE Simulation data
- Implemented raw data denoising with multiple DL approaches
- Outperformed baseline algorithm with good generalization power

THANK YOU !

QUESTIONS?

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Sofia Vallecorsa, sofia.vallecorsa@cern.ch

References

Cited Material:

[1] Deep Learning Strategies for ProtoDUNE raw data denoising - https://arxiv.org/pdf/1509.02971.pdf

[2] LarSoft software webpage - https://larsoft.org/

[3] First results on ProtoDUNE-SP liquid argon time projection chamber performance from a beam test at the CERN Neutrino Platform - https://arxiv.org/pdf/2007.06722.pdf

[4] Deep Graph-Convolutional image Denoising - https://arxiv.org/abs/1907.08448

[5] SCG-Net: Self Constructing Graph Neural Networks for Semantic Segmentation - https://arxiv.org/pdf/2009.01599.pdf

Extra Readings:

[1] Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume I: Introduction to DUNE - https://arxiv.org/abs/2002.02967

[2] Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume II: DUNE Physics - https://arxiv.org/abs/2002.03005

[3] Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume III: DUNE Far Detector Technical Coordination - https://arxiv.org/abs/2002.03008

[4] Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume IV: Far Detector Single-phase Technology - https://arxiv.org/abs/2002.03010