Deep Learning Based Reconstruction for DUNE

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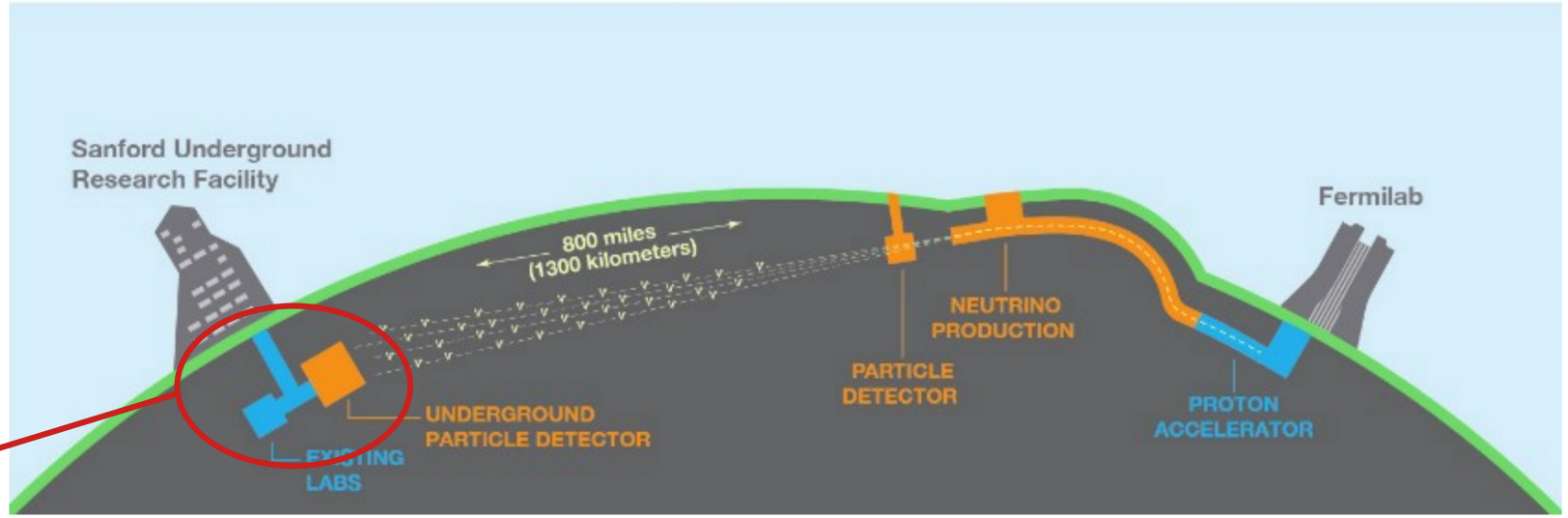
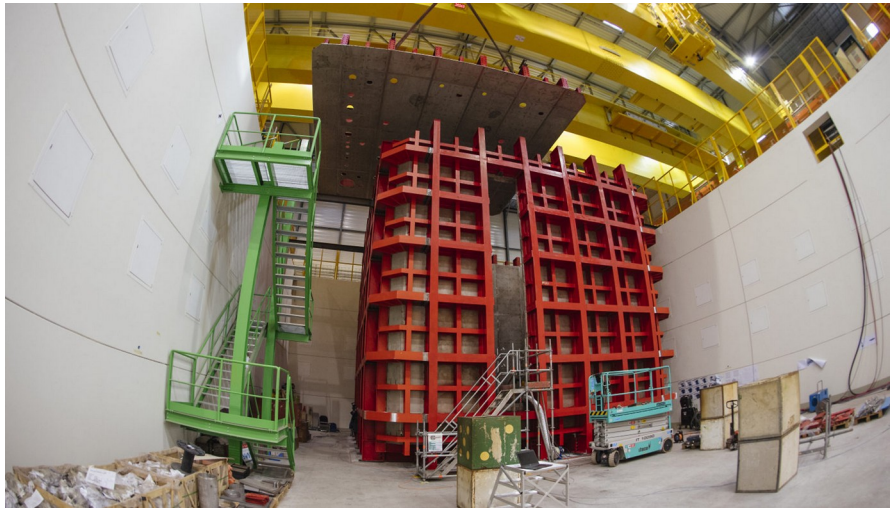
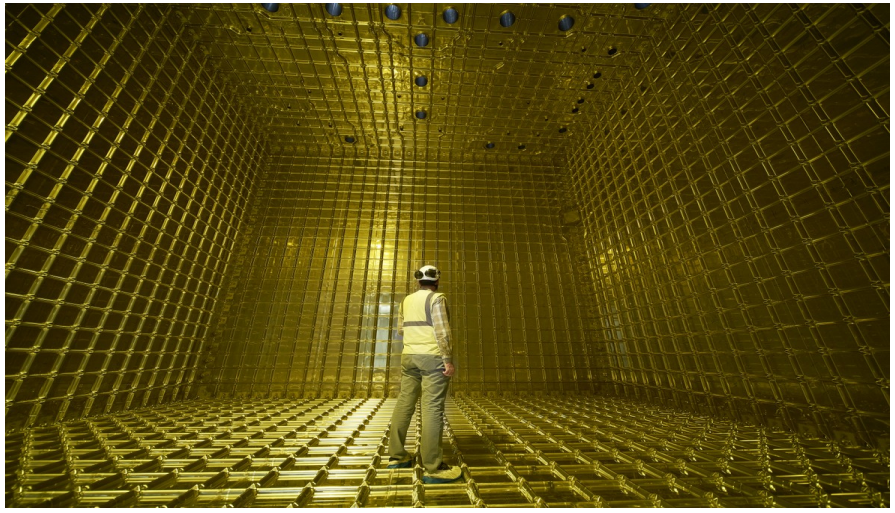
DUNE

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



ProtoDUNE, CERN (CH),
From 2017



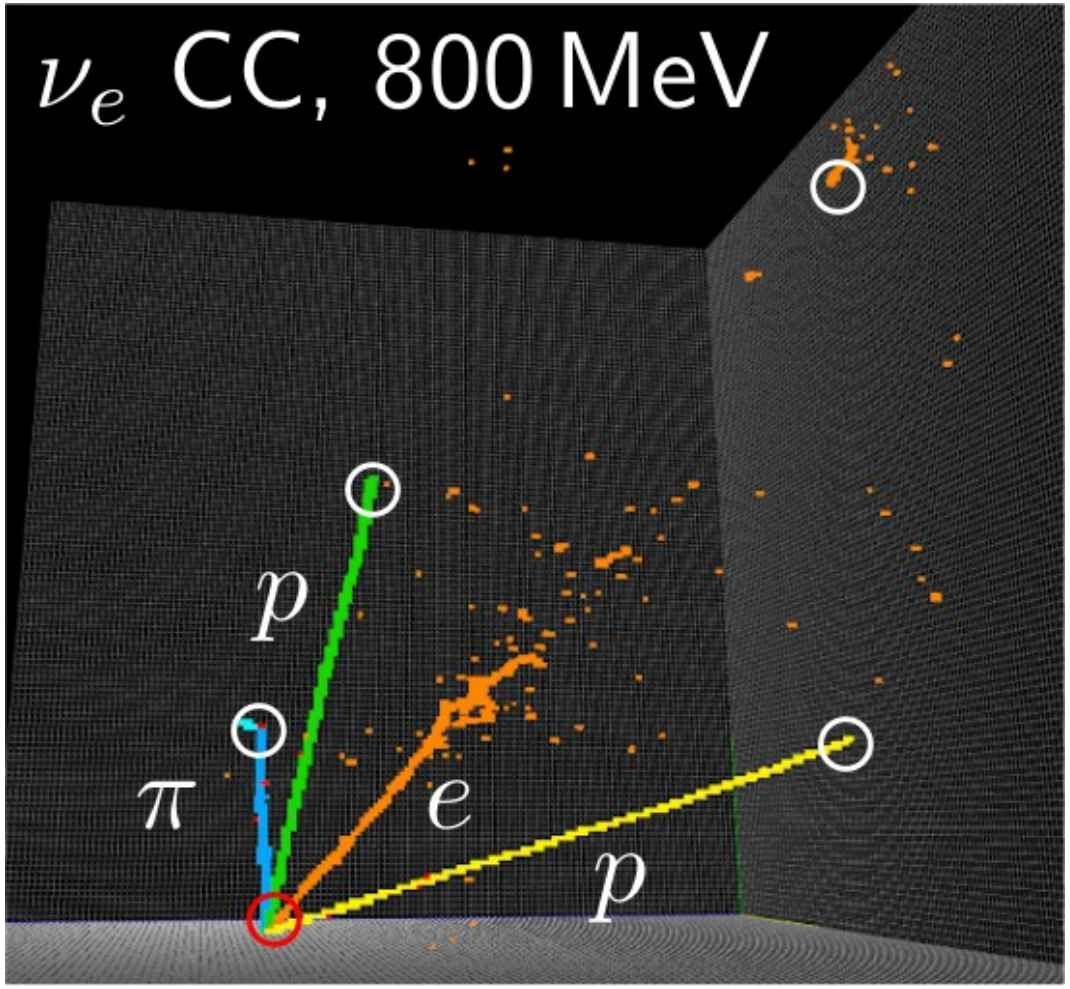


Reconstruction

RAW DATA → EVENT STRUCTURES

Easy for human brain !

Not so easy for automated software !



Computer vision

- Image denoising
- Image segmentation
- Object detection
- Clustering techniques
- Image classification

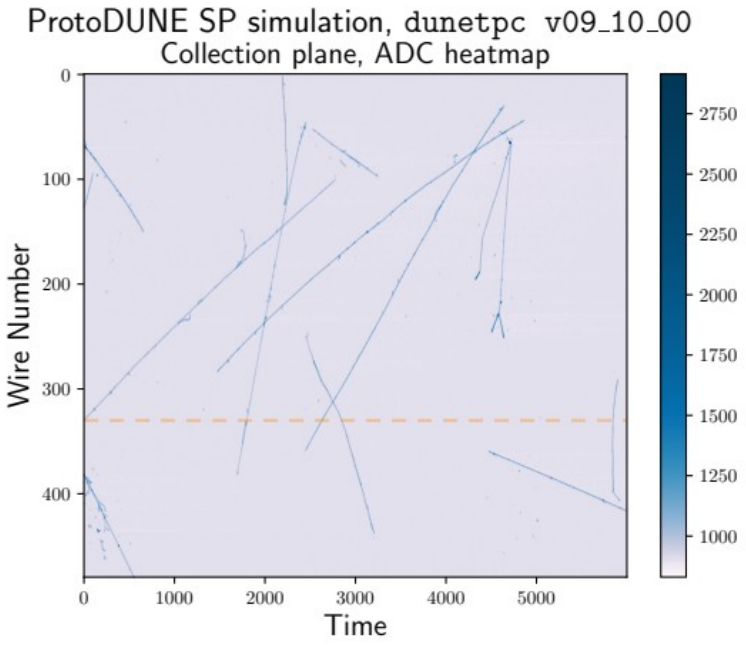
Physics reconstruction

- Denoising raw data
- Region of Interest selection
- Vertex finding
- Slicing
- Event labelling

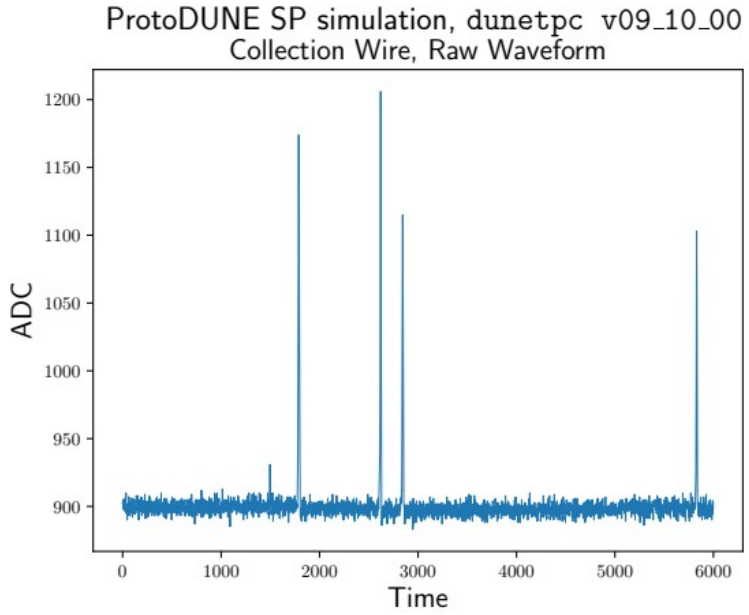
References: Springer, arXiv:2103.01956

ProtoDUNE – Denoising Raw Data

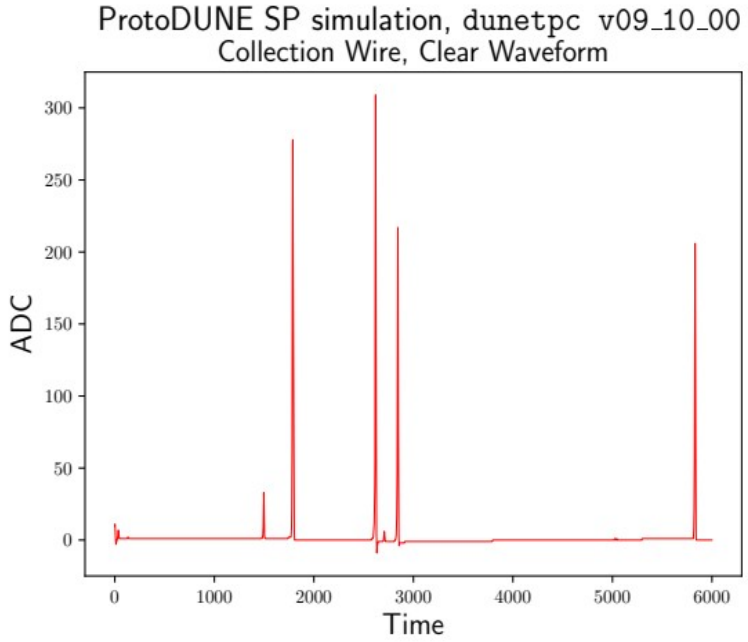
Input image sample



Noisy Waveform



Clear Waveform



Inputs main properties:

- High resolution (6000x480)
- Sparse features

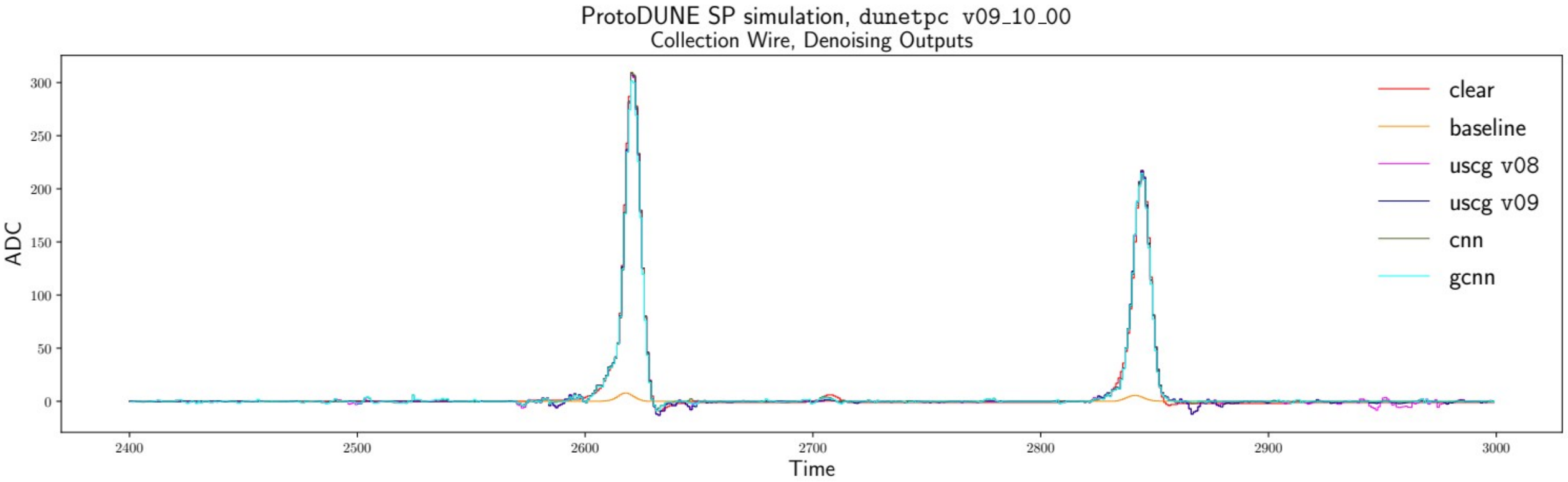
A 1D slice of the inputs:

- Big spikes
- Noisy background

The desired output

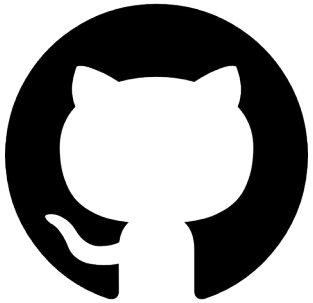
Denoising Results

- Convolutional and graph neural networks learn to shape exactly the clear waveform
- The traditional tool filters the waveform in Fourier space not preserving amplitudes (orange line)
- Quantitative evaluation available in the online article



Future work directions

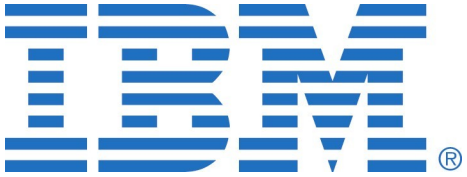
- The software is public and available on GitHub



- Next goal: architecture agnostic code, run on multiple platforms

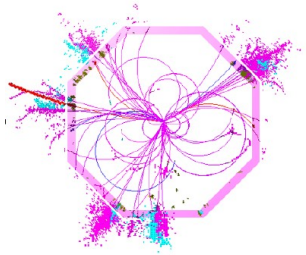
  export models to ONNX form, run with ONNX Runtime

  run on IBM POWER 10 machines (AI optimized)



Slicing

References:
[1] Pandora: article, GitHub
[2] ACAT2021 Talk



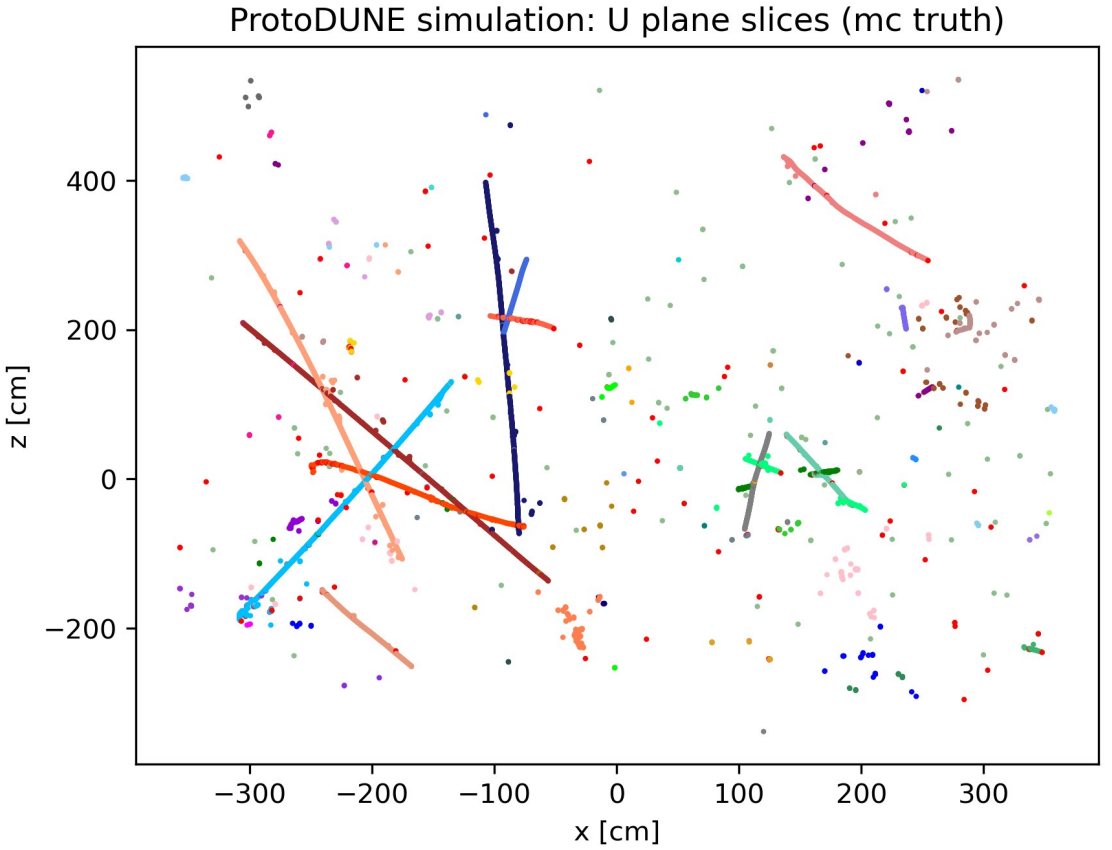
- Cooperate with Pandora UK team: Multi Experiment Reconstruction Toolkit, [1]

- Slicing problem [2]:
  cluster detector hits based on the main primary interacting particle

- Number of cluster is unknown a priori

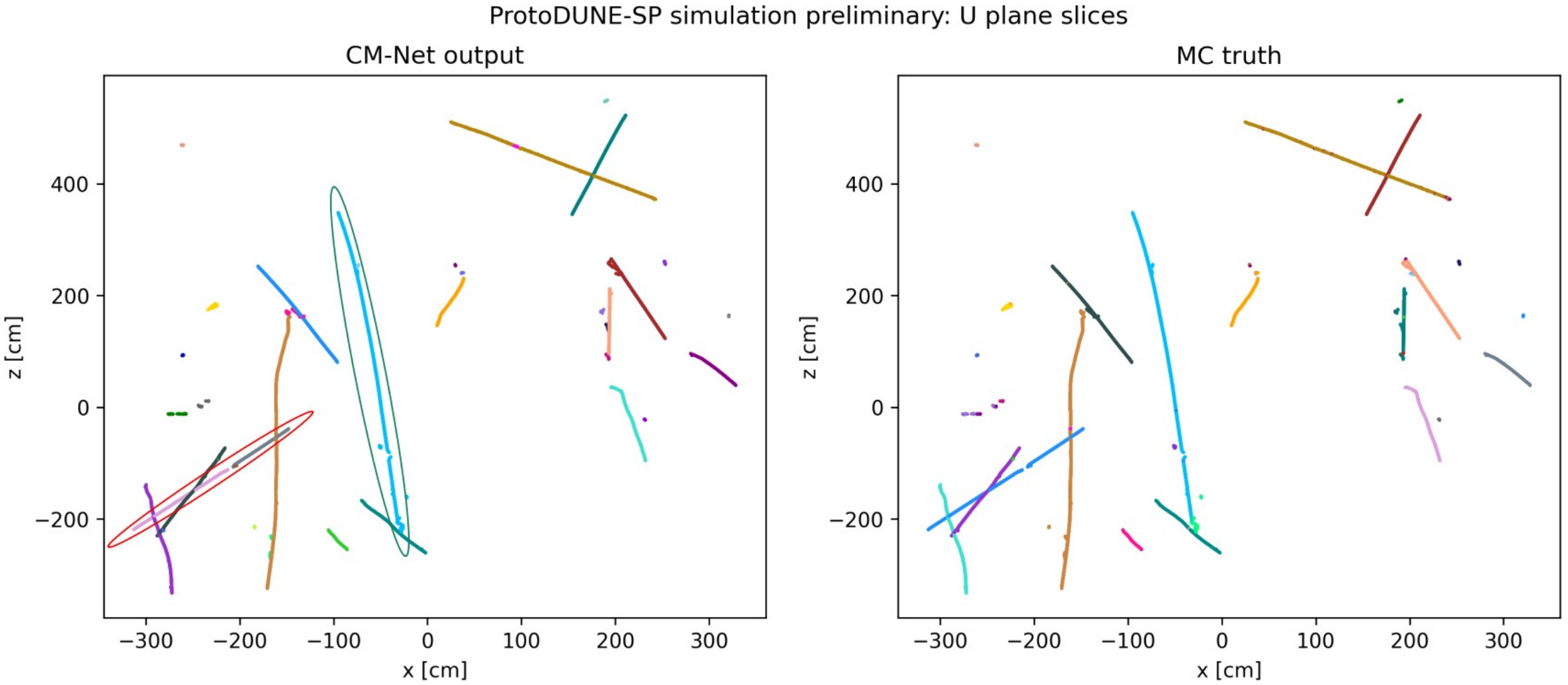
- Right plot: same color equals to same slice

- Train a neural network to gather detector hits into slice sets



Slicing Results

Visual example – technical details at this [poster]



Conclusions

- Achievements:

  DUNE experiment reconstruction with deep learning: denoising, slicing

- Next:

  Platform agnostic models through ONNX port

- Further developments (not covered in this talk):

  Investigate architectures at the frontier of DL research: attention networks, visual tranformers

THANK YOU !

QUESTIONS?

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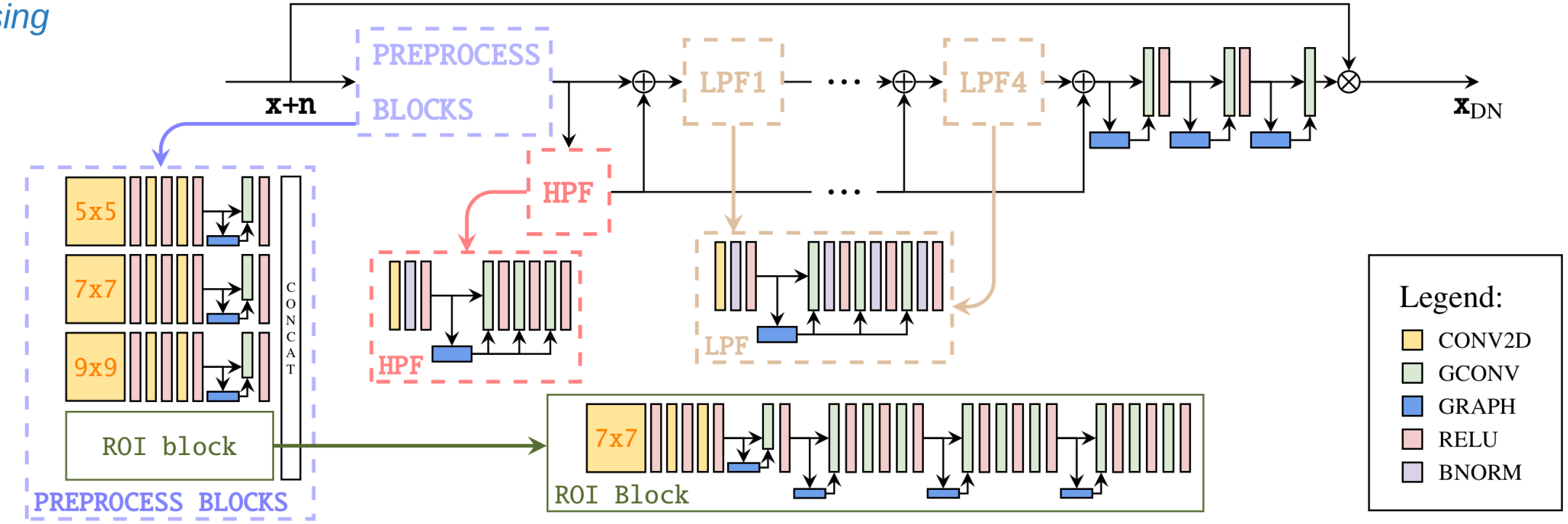
Backup slides

Graph Convolutional Neural Network

Denoising



- Graph – GCONV – operation to exploit non-local pixel features
- Complex architecture acting independently on image crops – 32x32 pixels
- Each event contains more than 5k crops
- Speed up training and inference with a distributed environment – multi-GPU

Graph Convolutional Layer

Denoising

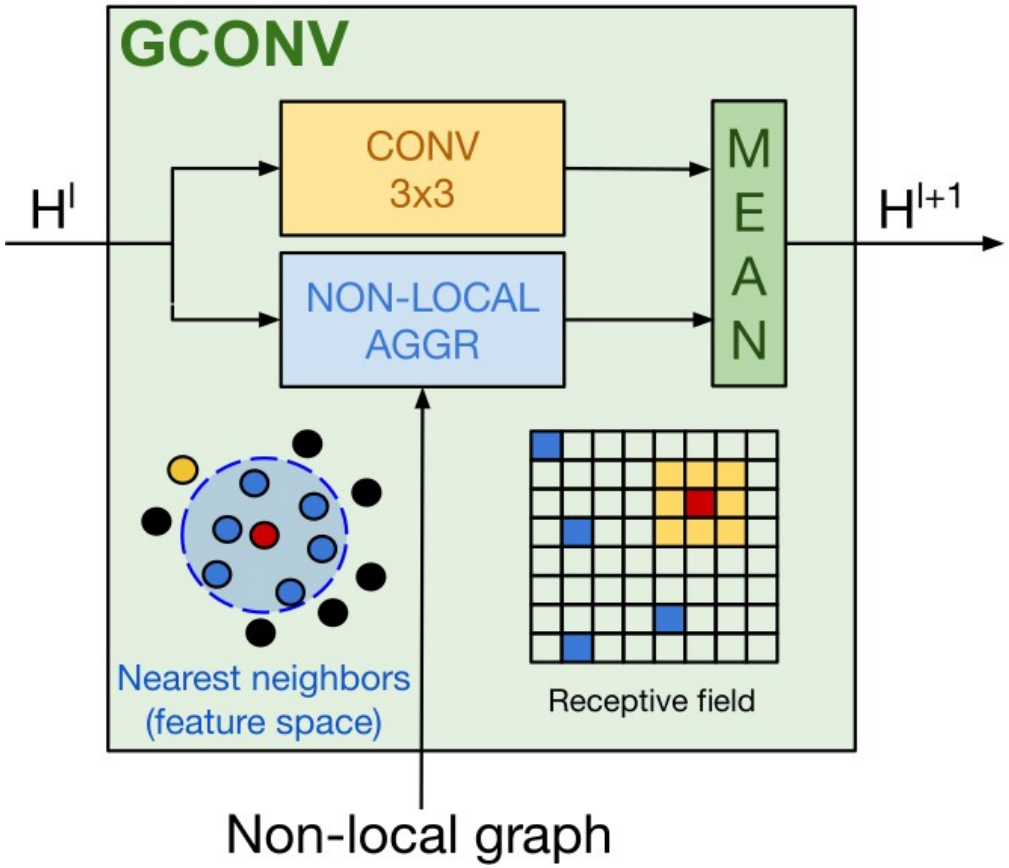
Reference: https://arxiv.org/abs/1907.08448

Input: rank 3 input image array (H,W,C_{in})

Output: rank 3 output array (H,W,C_{out}), average of convolution and non local aggregation NLA operations

Non local aggregation for each pixel:

- takes the K closest points in feature space – K=8
- mixes their features like a sparse convolution
- passes the output through a non linear function
- stores the result as the pixel feature vector



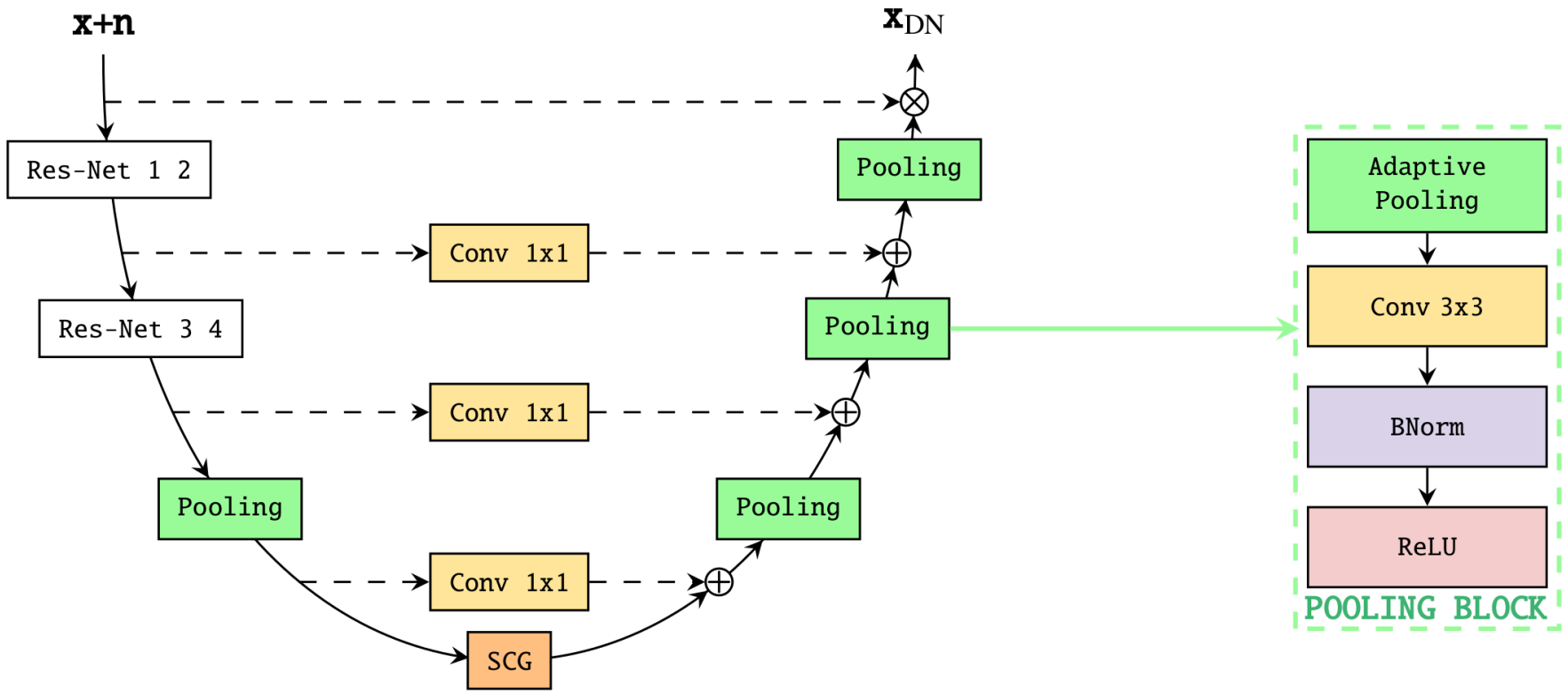
! NLA is $O(n^2)$ in the input number of pixels !

! Memory expensive operation !

CONV is local, NLA is non-local

U-shape Self Constructing Graph Network

Denoising



- Downsampling – upsampling branches to process entire images: no cropping
- SCG layer at the bottom, to exploit extremely long distance correlations
- Fast inference and low GPU memory consumption: only one GPU per image needed

Cluster Merging Network

Slicing

- *Approach*: rely on previous reconstruction products (sub-clusters)

Decide to merge or not two sub-clusters !

- *Input*: sub-clusters pair features (fixed size vector)
- *Output*: binary output (merge?)

- *Difficulties*:
  - variable number of clusters
  - variable number of hits inside cluster

- *Network*:
  - feed forward neural network