Applying Deep Learning Techniques for LArTPC Data Reconstruction

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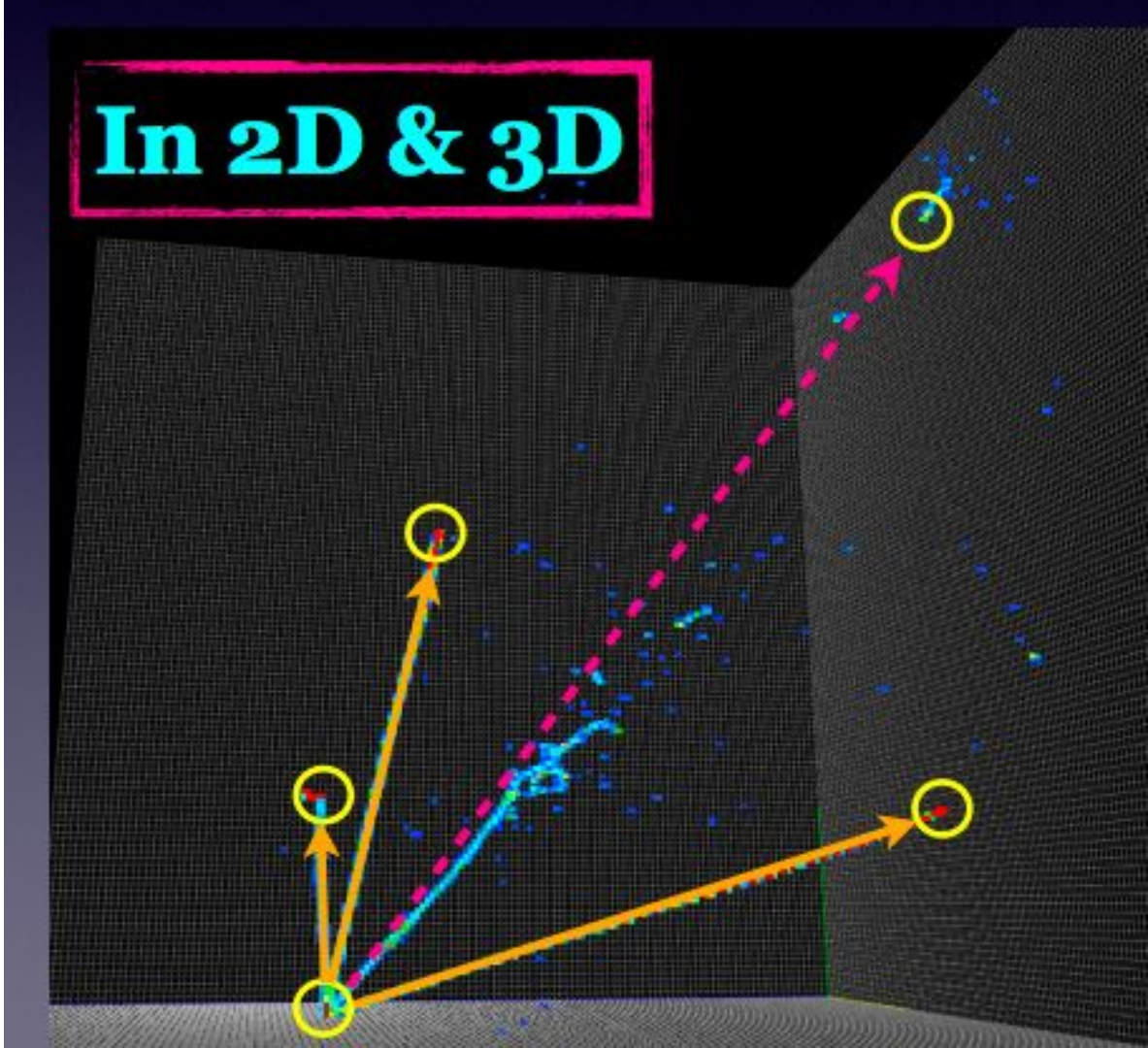
Plan

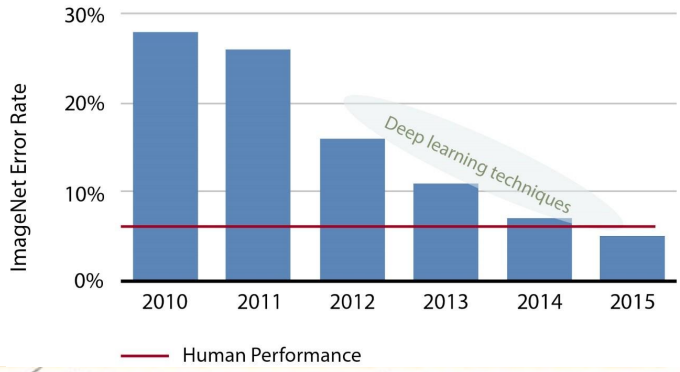
1. Deep Learning & LArTPCs
2. Task 1: Semantic Segmentation
3. Task 2: Point Finding

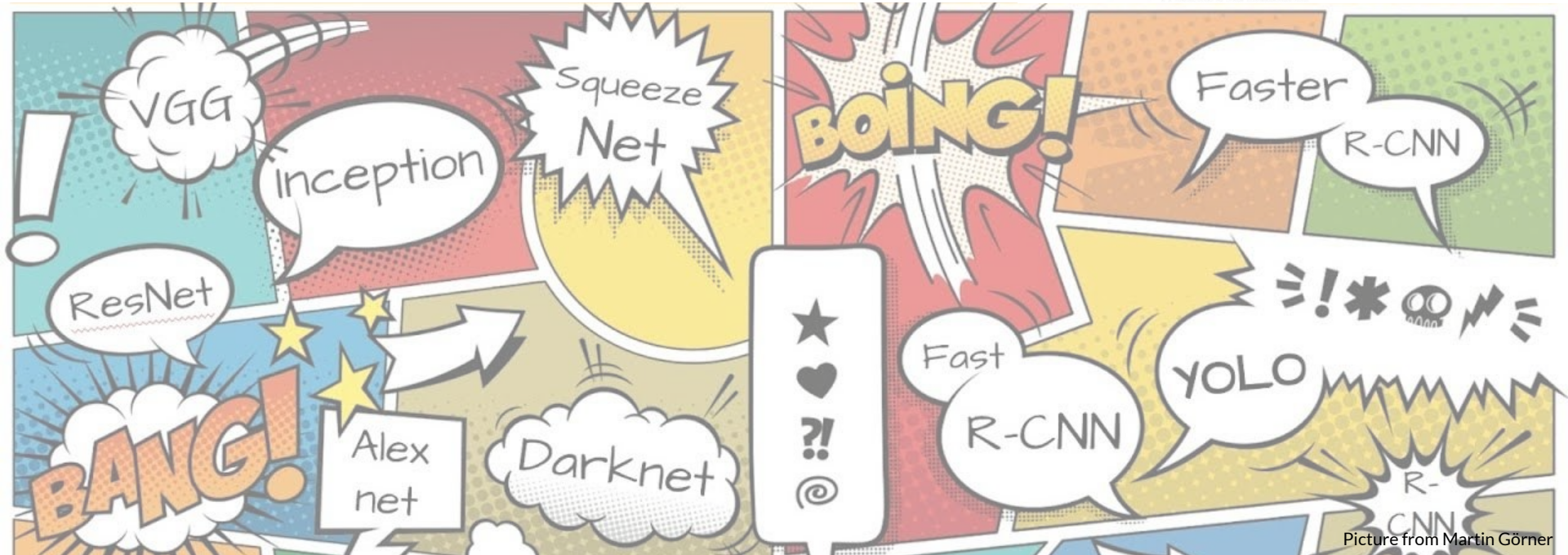
Deep Learning & LArTPCs



What is Deep Learning?

Artificial intelligence > Machine Learning > Deep Learning



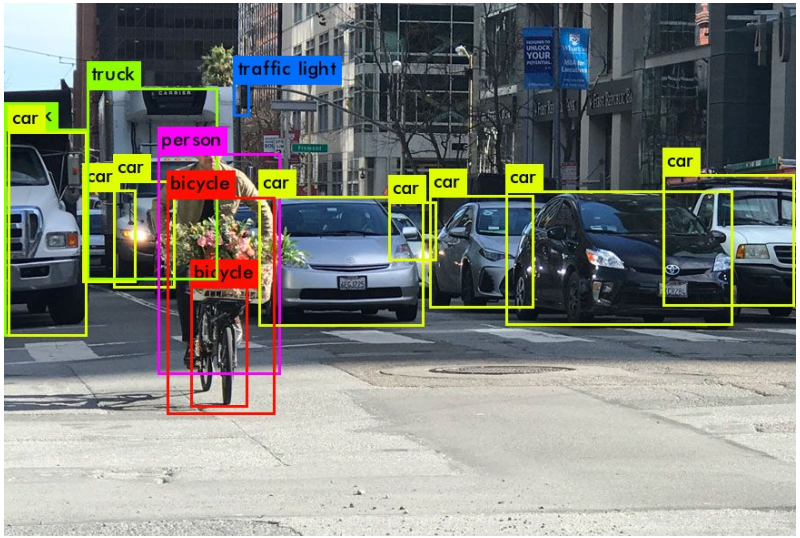


Picture from Martin Görner

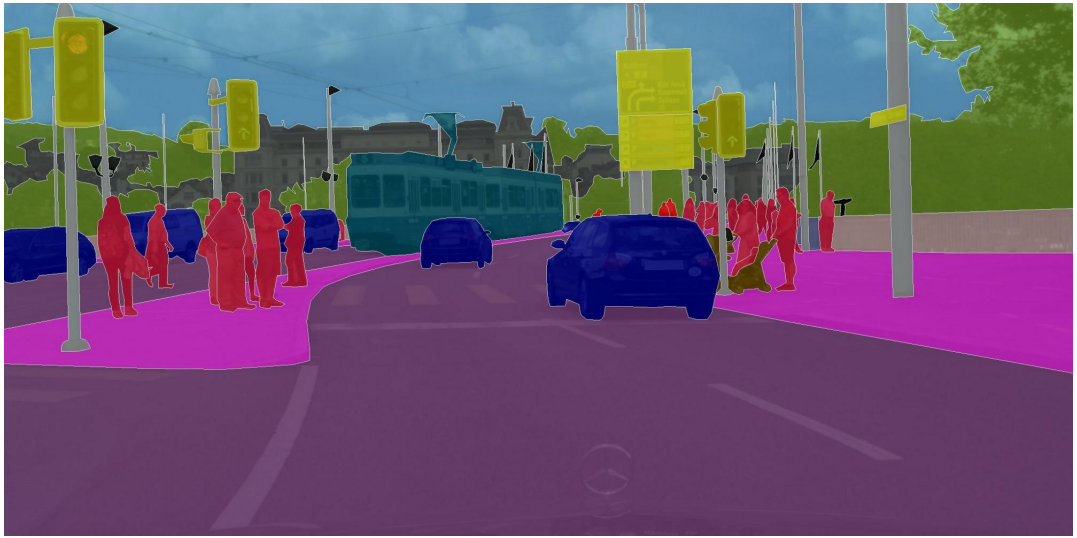
Common tasks in Computer Vision...

... for which the state-of-the-art technique is **Convolutional Neural Networks** (CNNs).

Object detection & classification

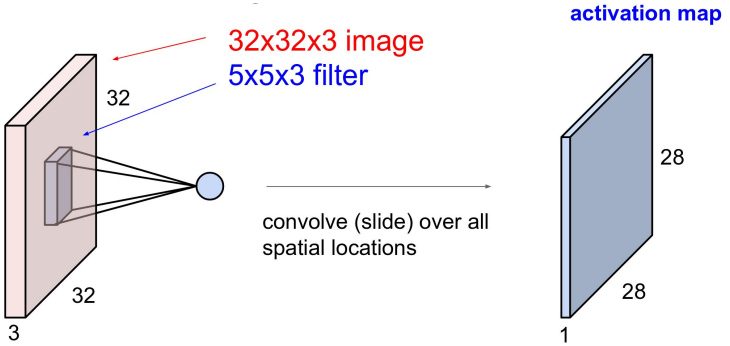


Semantic segmentation

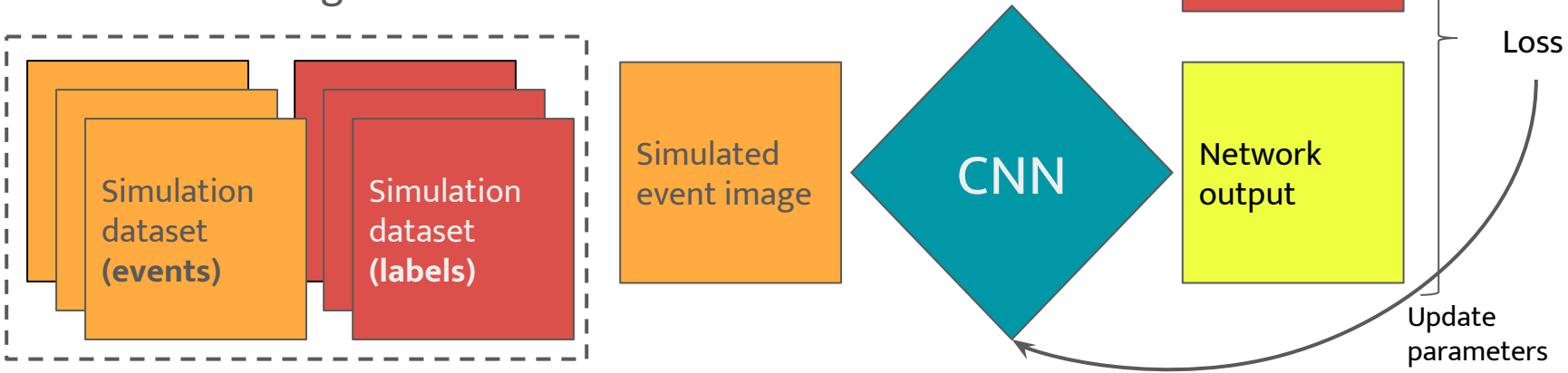


Convolutional Neural Networks (CNNs)

Convolution layer



Network training scheme



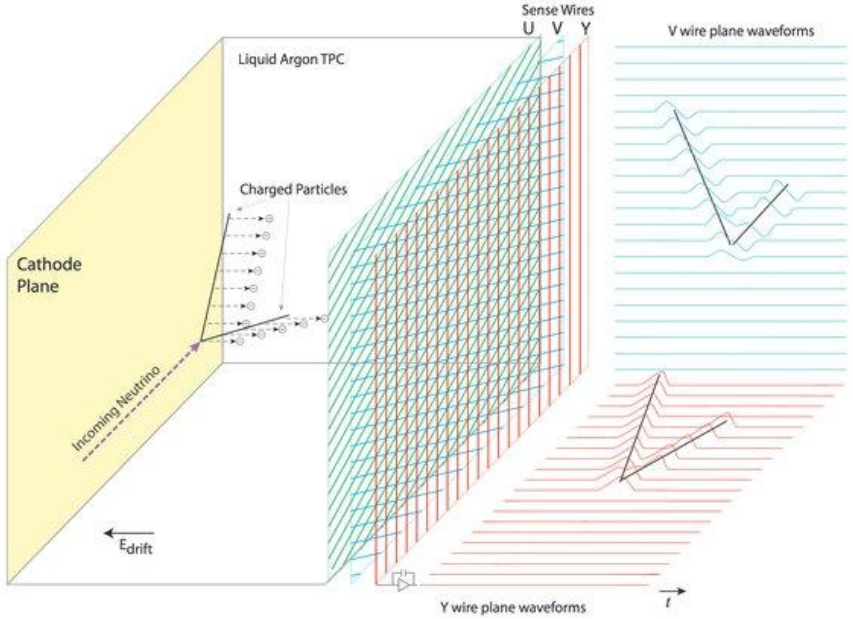
Liquid Argon Time Projection Chambers (LArTPCs)

Particle imaging detectors

Record trajectory of charged particles

Ex: MicroBooNE @ Fermilab (150 tons LAr)

Bigger and bigger! (DUNE: 68,000 tons LAr)

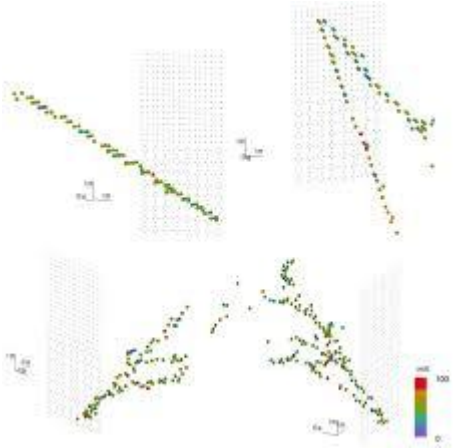


Design of MicroBooNE TPC (arXiv:1612.05824)

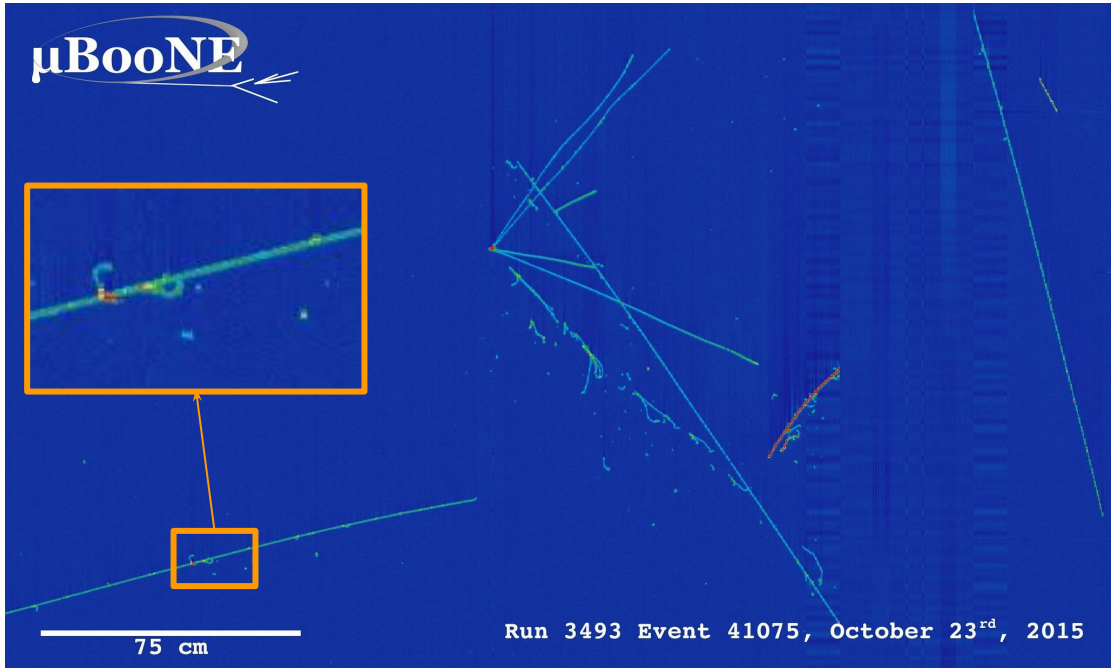
How can deep learning be useful for LArTPC?

LArTPC data = 2D or 3D image

Huge image & many fine details



Cosmic rays in a 3D LArTPC charge readout (arxiv:1808.02969)

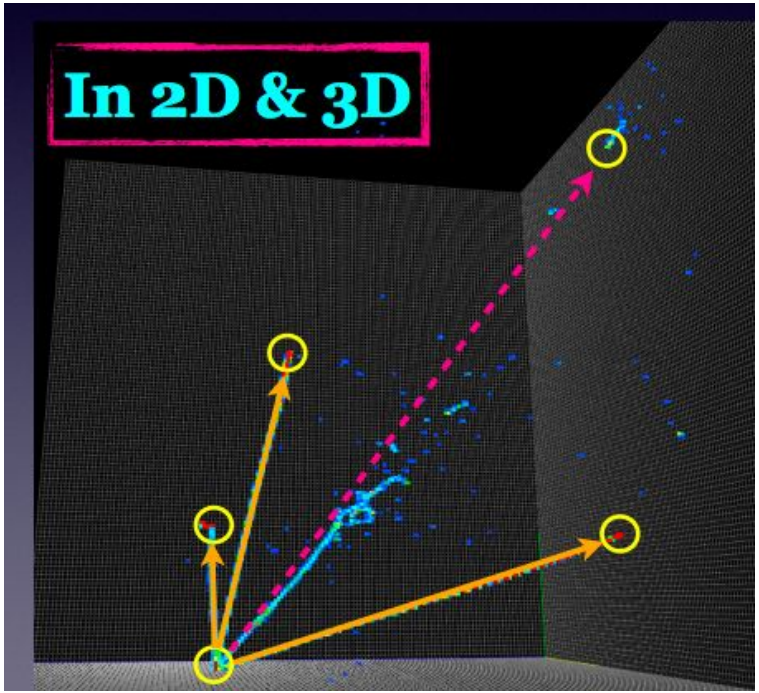


Towards a full reconstruction chain with DL

Current status: a lot of hand-crafted, heuristic algorithms. Start over from scratch for each new experiment...

Goal: replace with a set of DL algorithms which will ideally

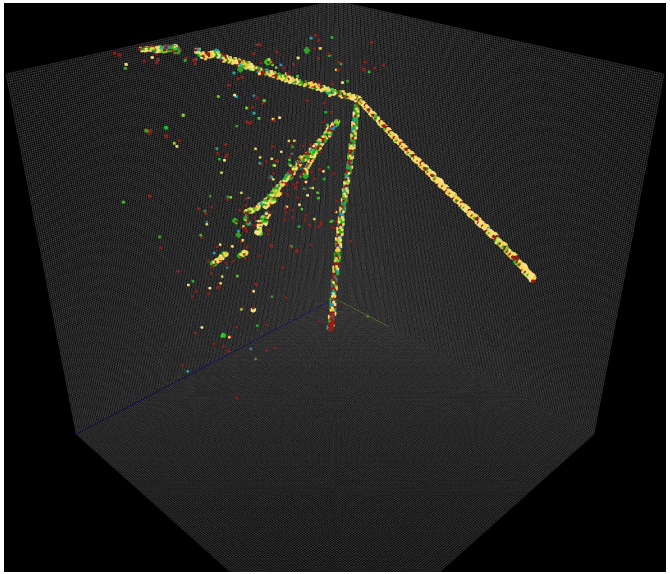
- Be faster
- Be more accurate



Towards a full reconstruction chain with DL

Steps:

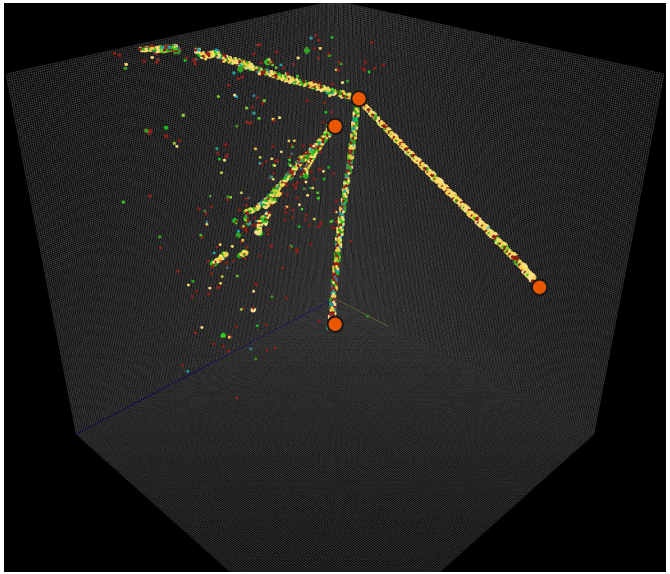
1. **Point detection (track edge)**



Towards a full reconstruction chain with DL

Steps:

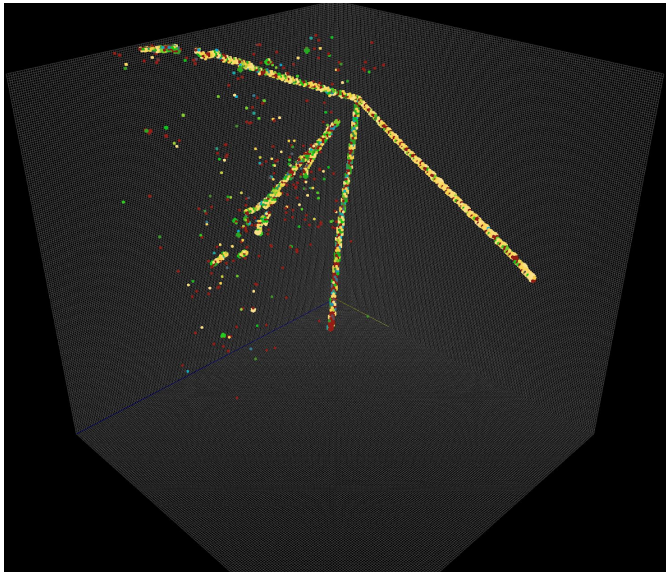
1. ~~**Point detection (track edge)**~~
   PPN



Towards a full reconstruction chain with DL

Steps:

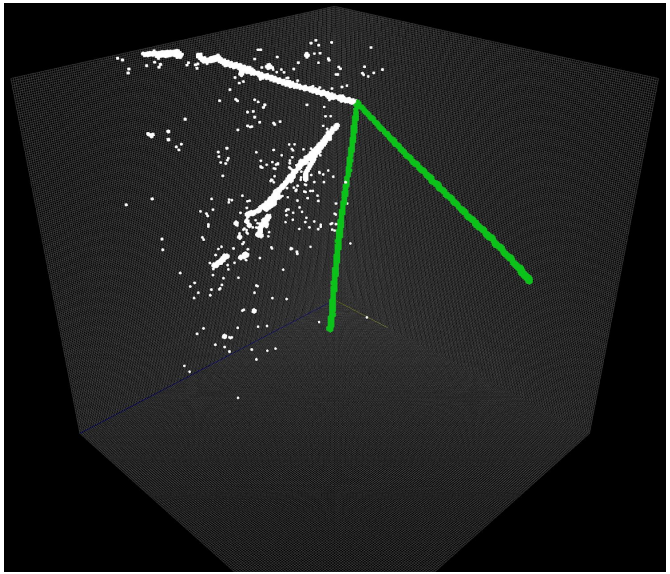
1. ~~**Point detection (track edge)**~~
   PPN
2. **Pixel-wise labeling (particle track vs electromagnetic shower)**



Towards a full reconstruction chain with DL

Steps:

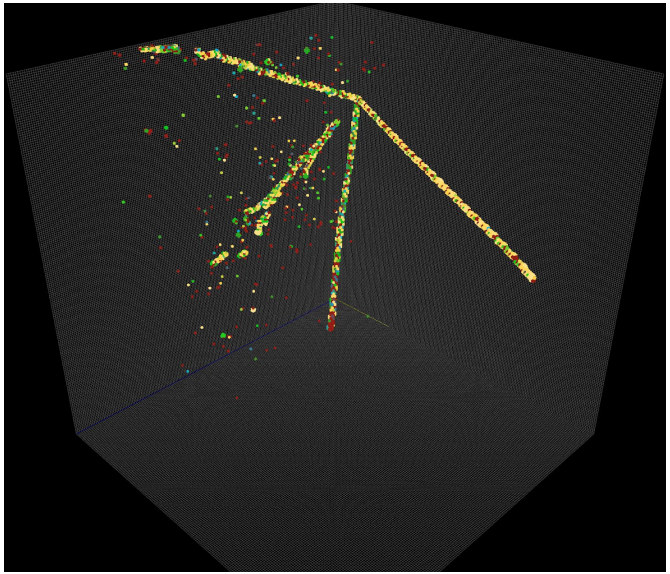
1. ~~Point detection (track edge)~~
   PPN
2. ~~Pixel-wise labeling (particle track vs electromagnetic shower)~~
   UResNet



Towards a full reconstruction chain with DL

Steps:

1. ~~Point detection (track edge)~~
   PPN
2. ~~Pixel-wise labeling (particle track vs electromagnetic shower)~~
   UResNet
3. **Clustering of energy deposits and instance segmentation**



Towards a full reconstruction chain with DL

Steps:

1. ~~Point detection (track edge)~~
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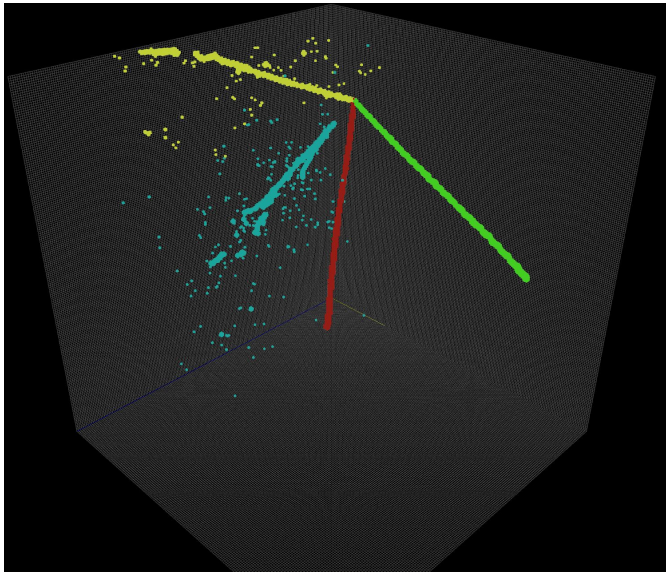
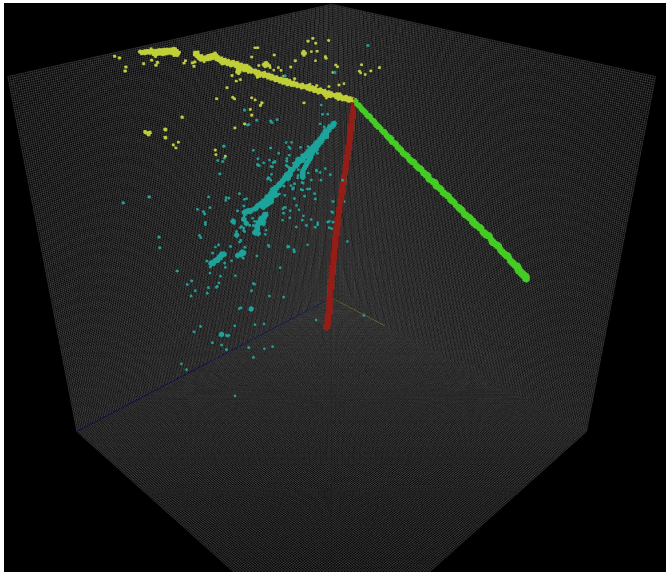
   UResNet
3. **Clustering of energy deposits and instance segmentation**
   Work in progress!



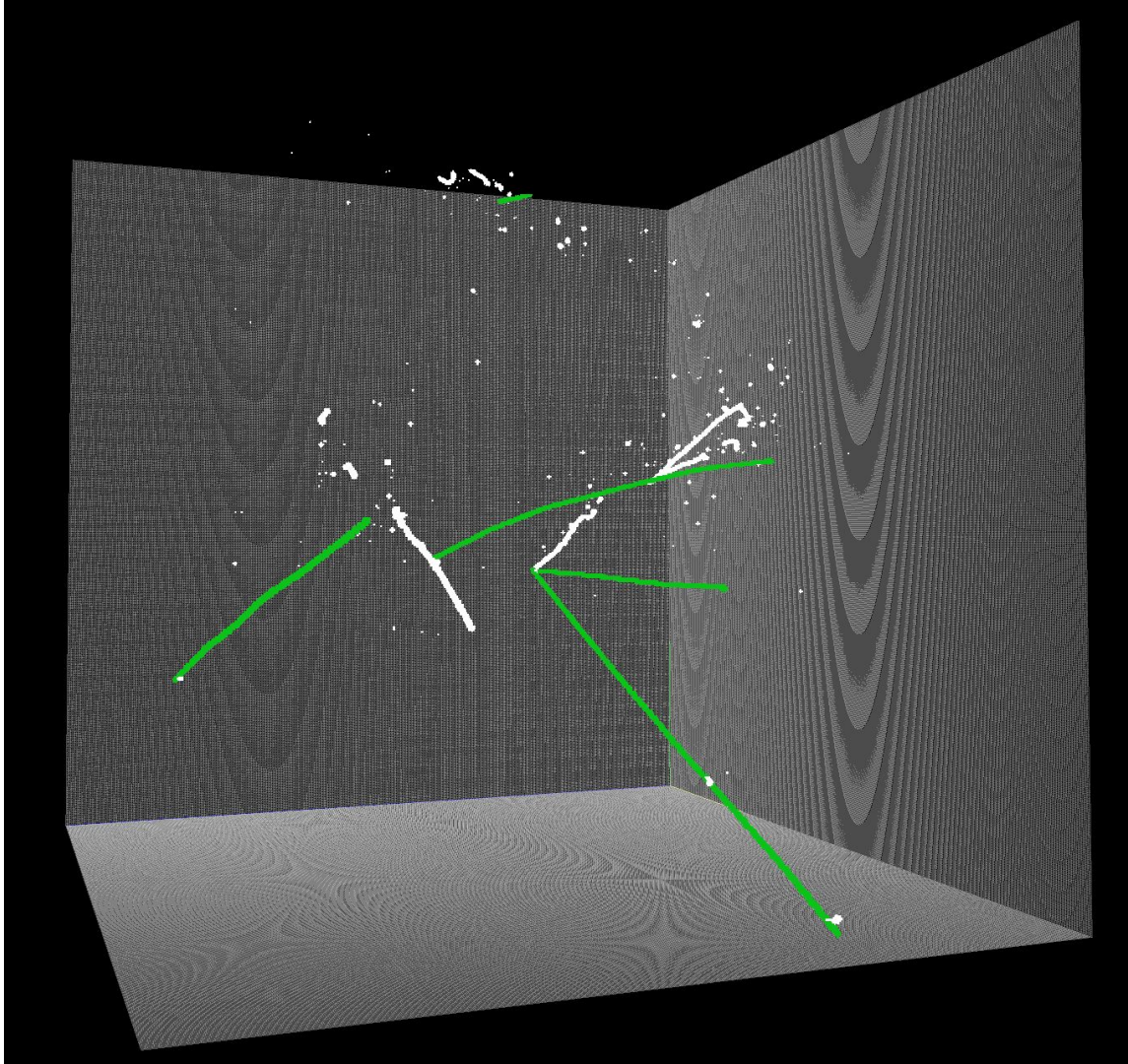
Towards a full reconstruction chain with DL

Steps:

1. ~~**Point detection (track edge)**~~
   PPN
2. ~~**Pixel-wise labeling (particle track vs electromagnetic shower)**~~
   UResNet
3. **Clustering of energy deposits and instance segmentation**
   Work in progress!
4. *Particle identification and energy estimate*
5. *Hierarchy reconstruction*



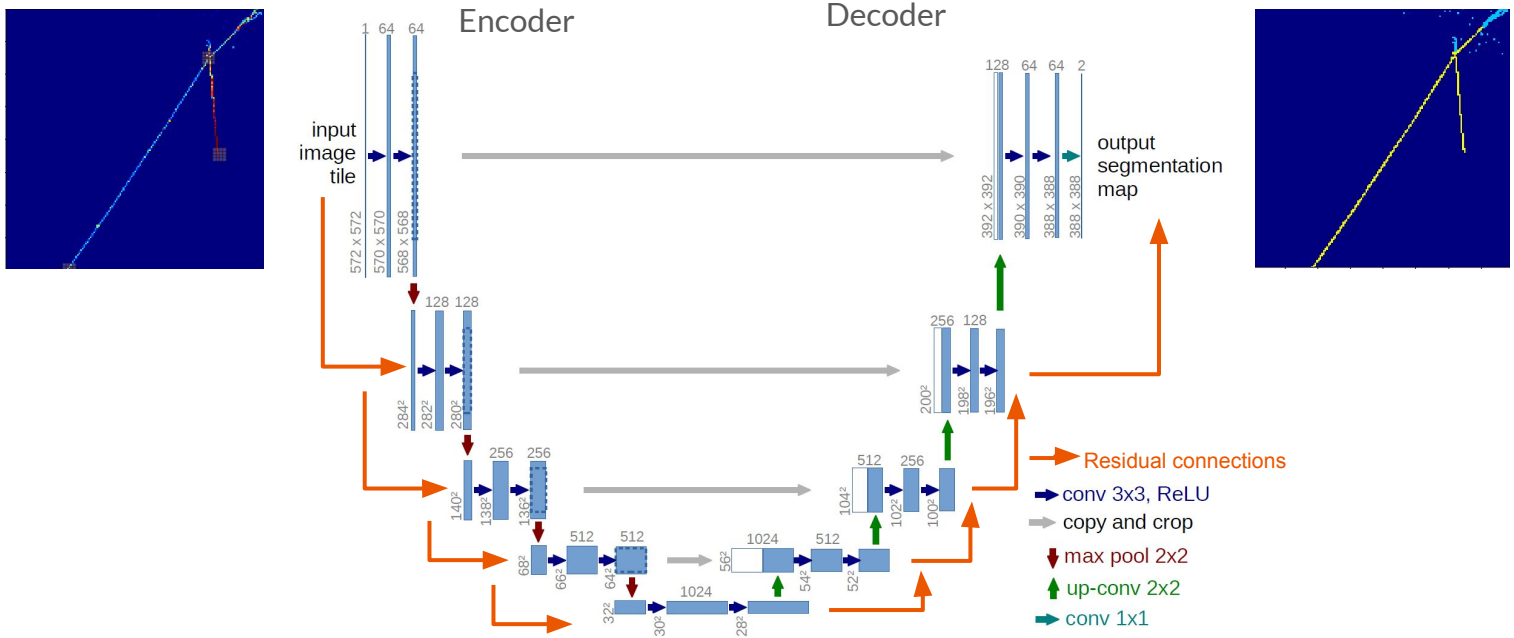
Task 1: Semantic Segmentation



What is semantic segmentation?

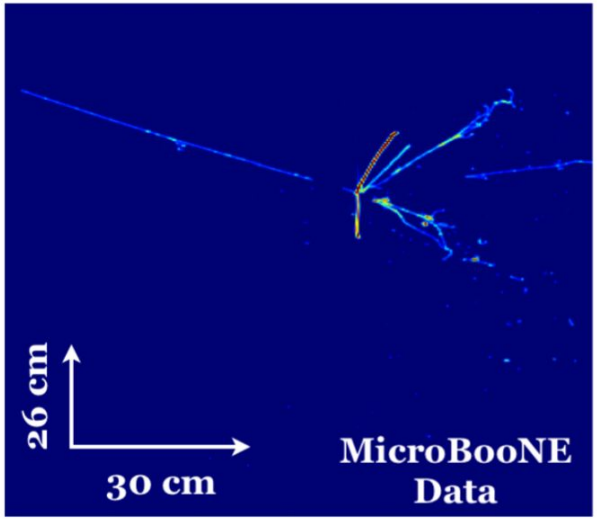
Semantic Segmentation with UResNet

UResNet = U-Net + ResNet (residual connections)

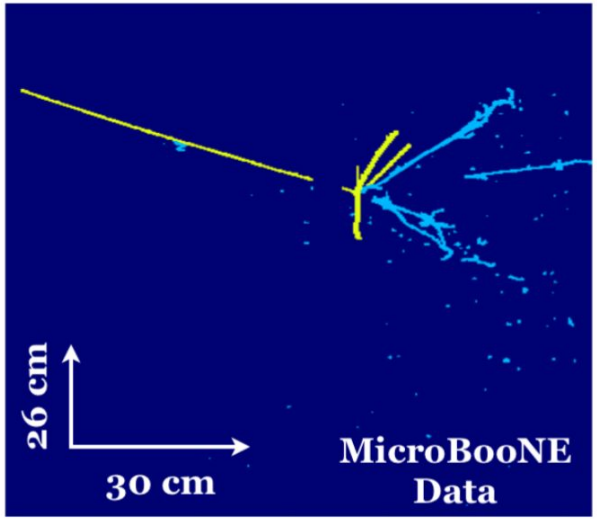


UResNet performance on MicroBooNE data

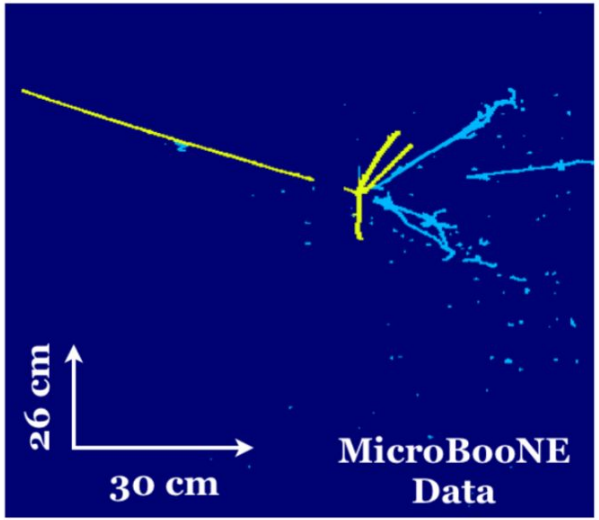
Data



Physicist's label

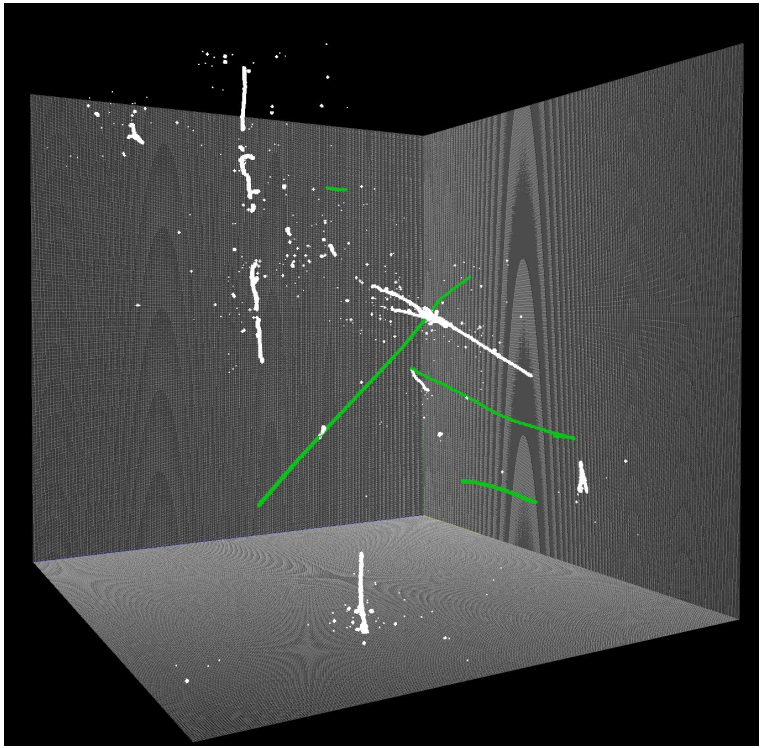


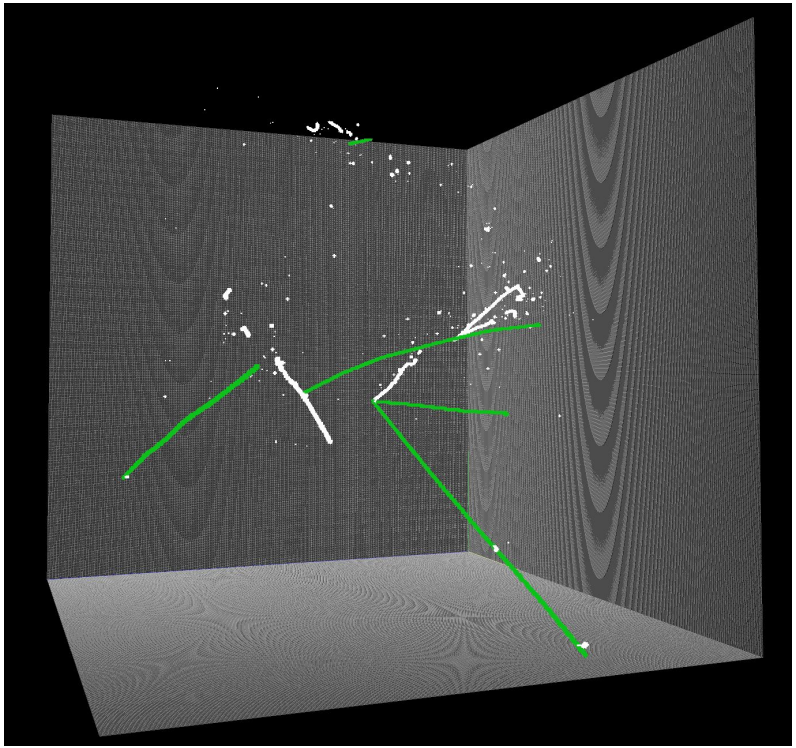
Network's output



A Deep Neural Network for Pixel-Level Electromagnetic Particle Identification in the MicroBooNE Liquid Argon Time Projection Chamber.
https://arxiv.org/abs/1808.07269

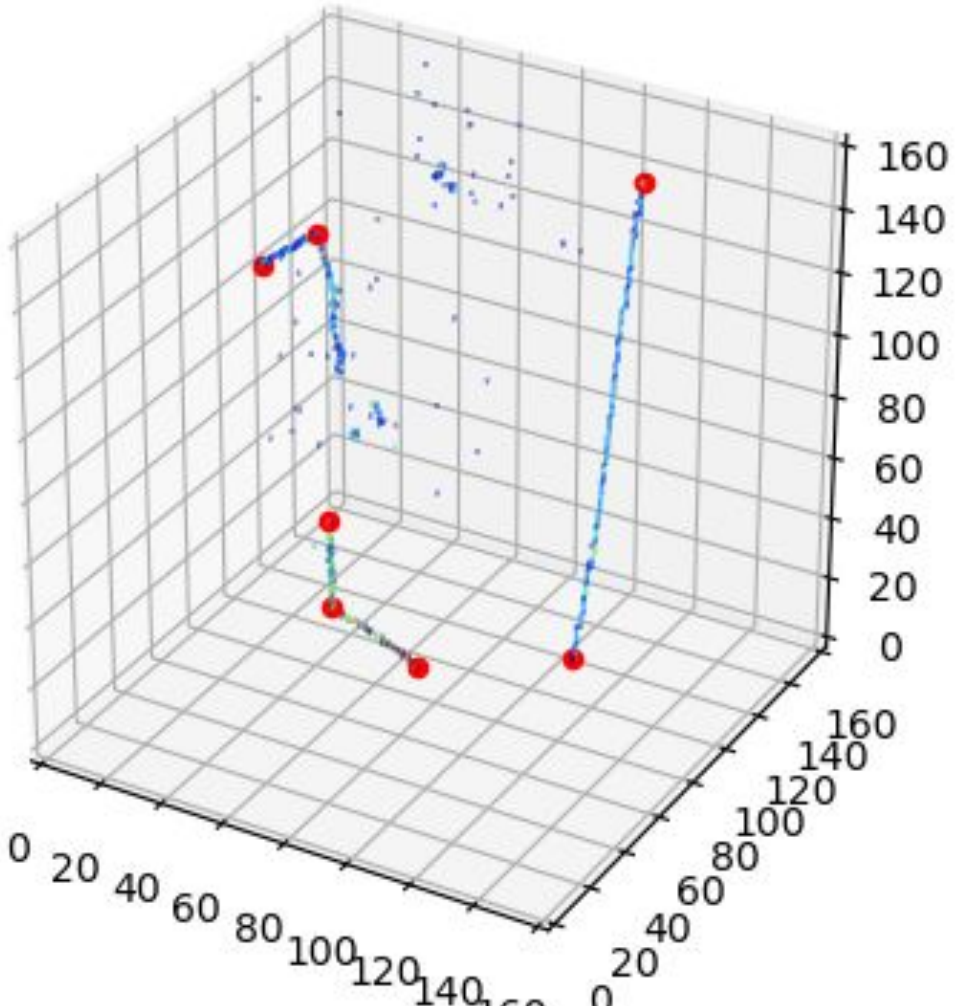
UResNet performance with sparse techniques (WIP)





99.9% accuracy on non-zero voxels... smaller than labeling error!

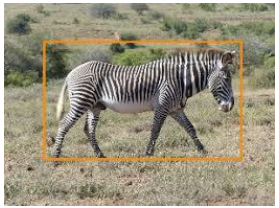
Task 2: Point finding

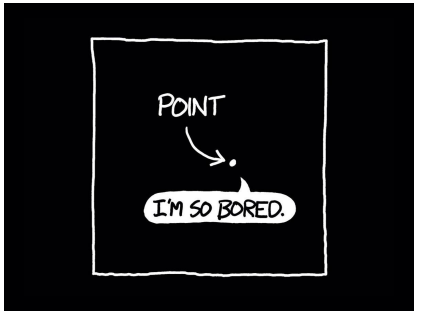


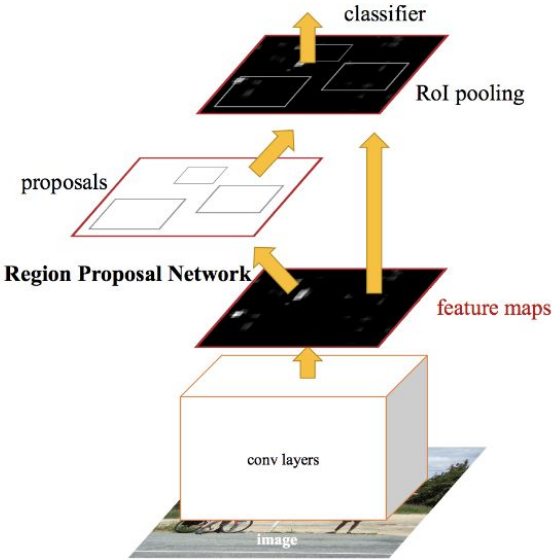
Point Finding with Pixel Proposal Network (PPN)

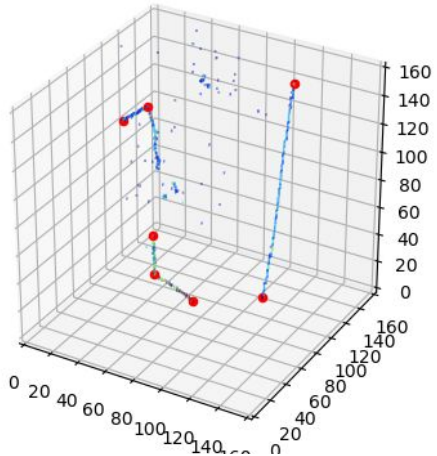
Inspired by **Faster-RCNN** architecture

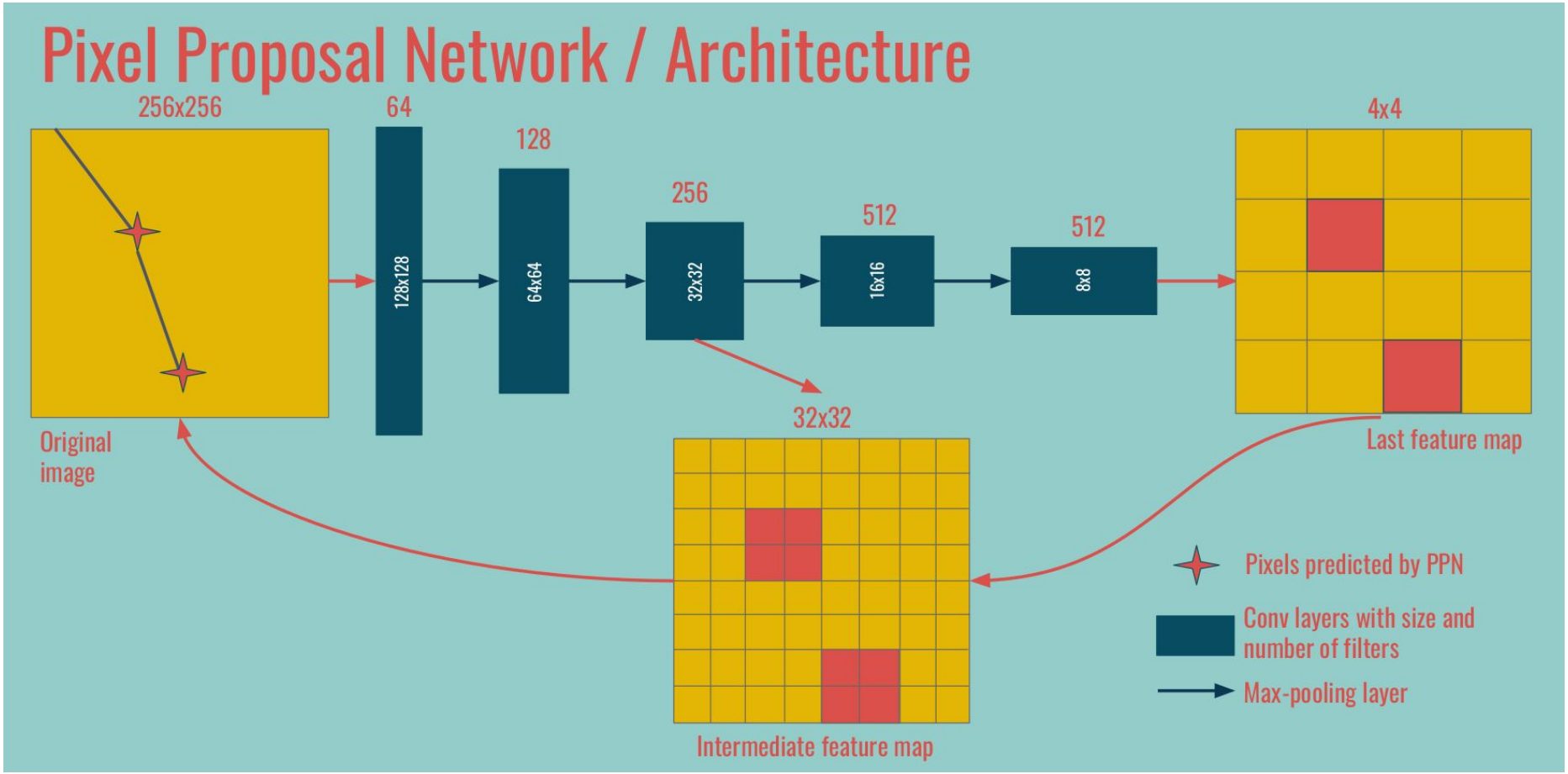
- Region Proposal Network detects regions of interest
- Replace regions with points = **Pixel Proposal Network (PPN)**



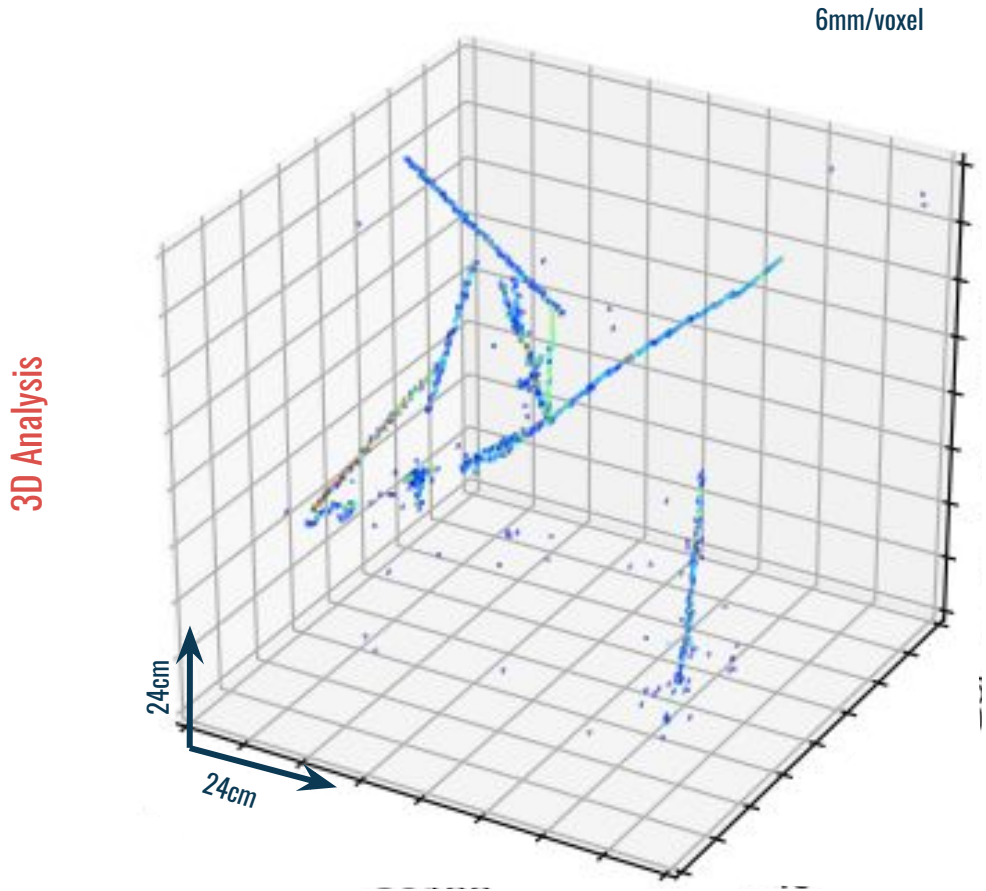




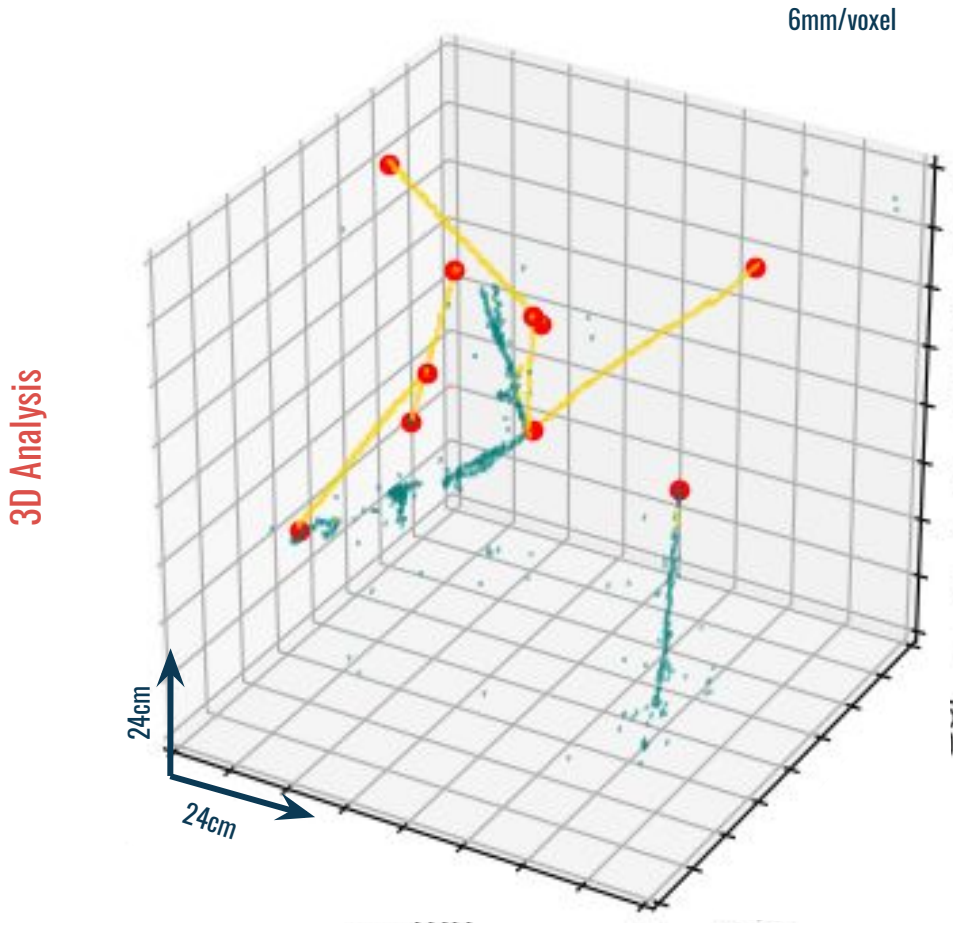



Pixel Proposal Network / Architecture
256x256
64
128
256
512
512
4x4
128x128
64x64
32x32
16x16
8x8
Original image
32x32
Last feature map
Intermediate feature map
Pixels predicted by PPN
Conv layers with size and number of filters
Max-pooling layer

Output of PPN + UResNet



Output of PPN + UResNet



What is next?

Currently WIP:

- Sparse techniques
- Clustering and instance segmentation

Join DeepLearnPhysics group!

- *Technical discussion on ML applied to experimental physics data*
- *Data + code sharing for reproducibility*