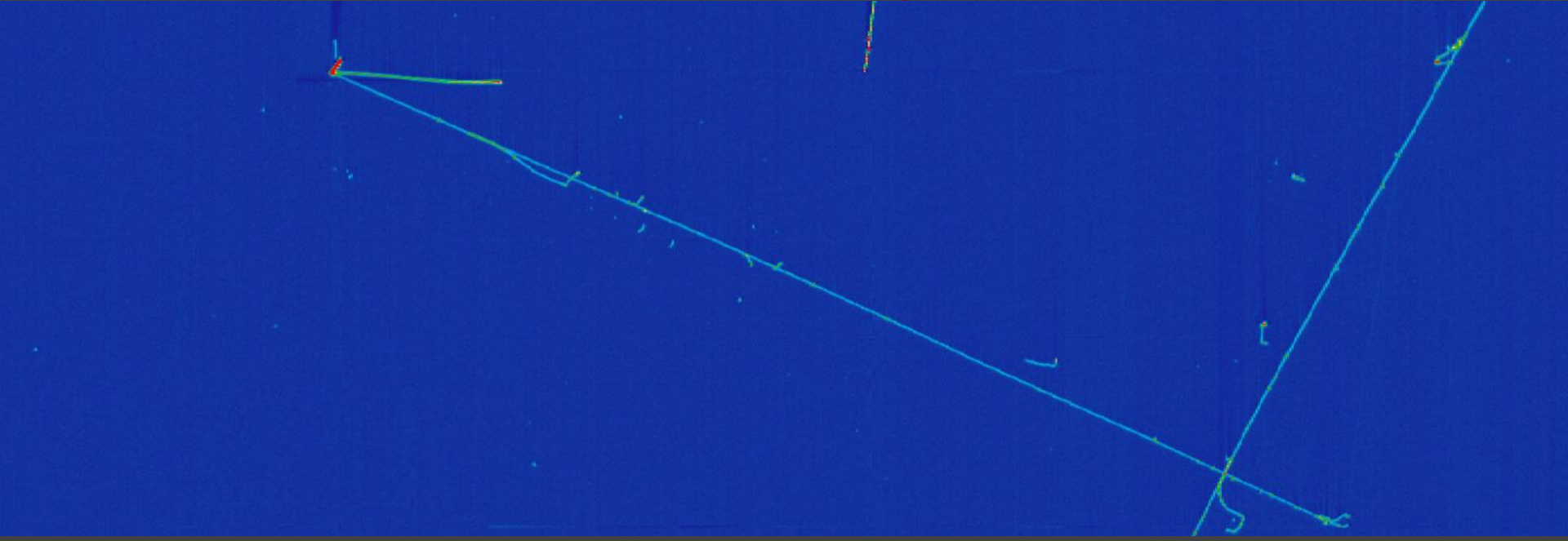


Simulation/Reconstruction Development Status

Kazuhiro Terao on behalf of many others
SLAC National Accelerator Lab.
DUNE-ND Workshop @ FNAL (25-27 May 2019)

U.S. DEPARTMENT OF ENERGY
Office of Science

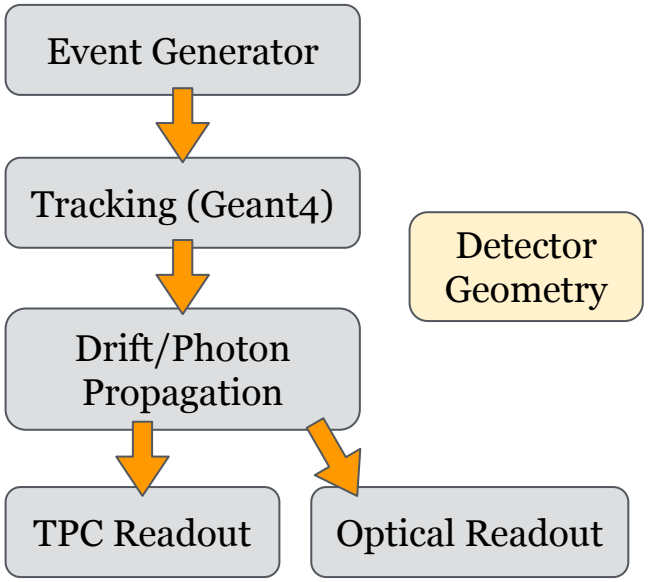
SLAC NATIONAL ACCELERATOR LABORATORY

Pixel Detector Simulation

DUNE Near Detector
Simulation Software Development

SLAC

Simulation Chain



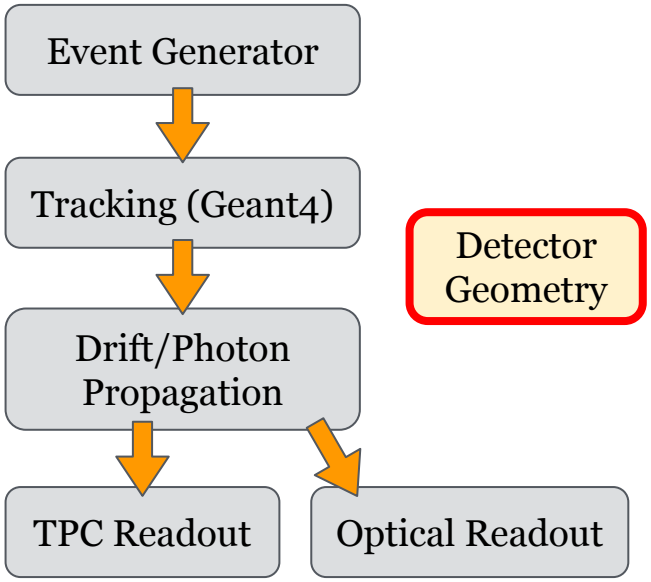
Goal: a full chain inside/outside LArSoft

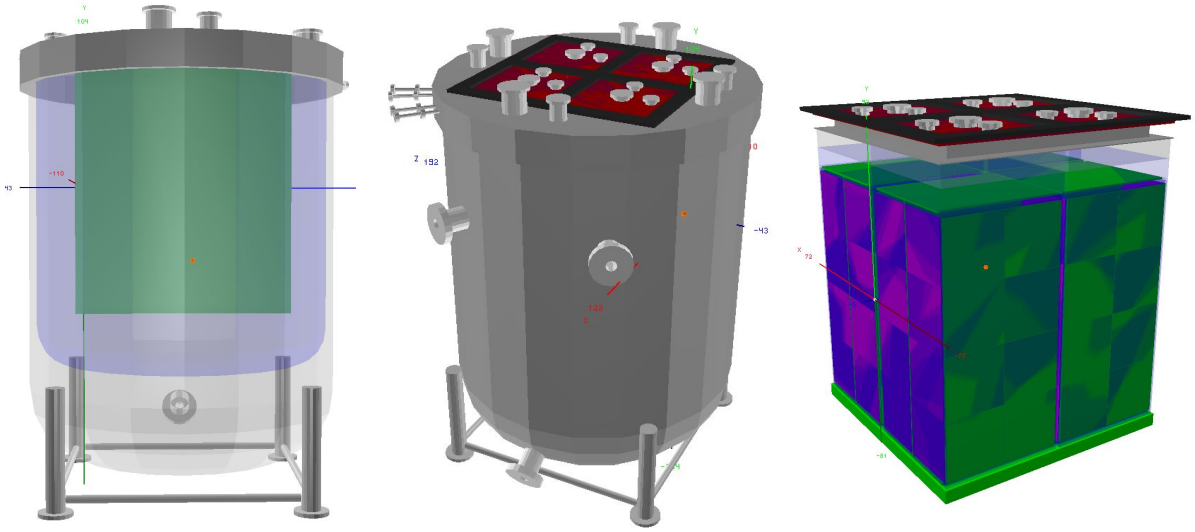
1. Develop detector geometry GDML
2. Make LArSoft work with a pixel geometry
   - Allows running Geant4 inside LArSoft
3. Develop TPC E-field response for drift
4. Develop photon propagation (photon lib?)
5. Implement TPC/Optical readout

DUNE Near Detector
Simulation Software Development

SLAC

Simulation Chain





Images courtesy of Hunter Sullivan @ UTA

Geometry (GDML)

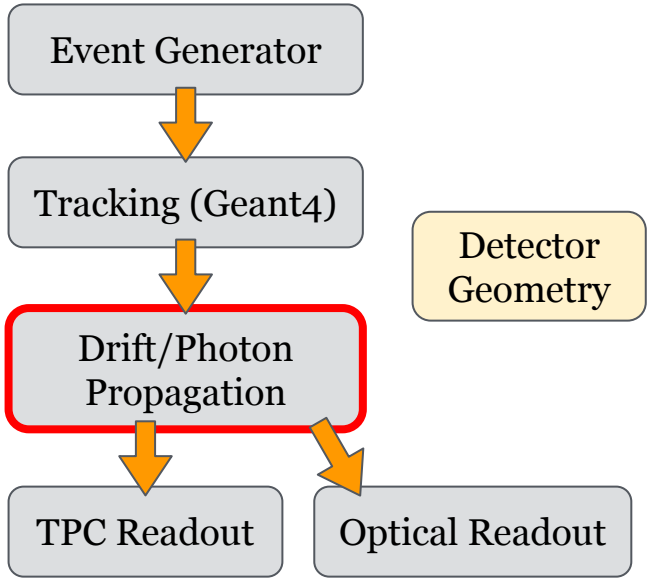
Use GeGeDe-ND toolkit for develop & maintenance of GDML files

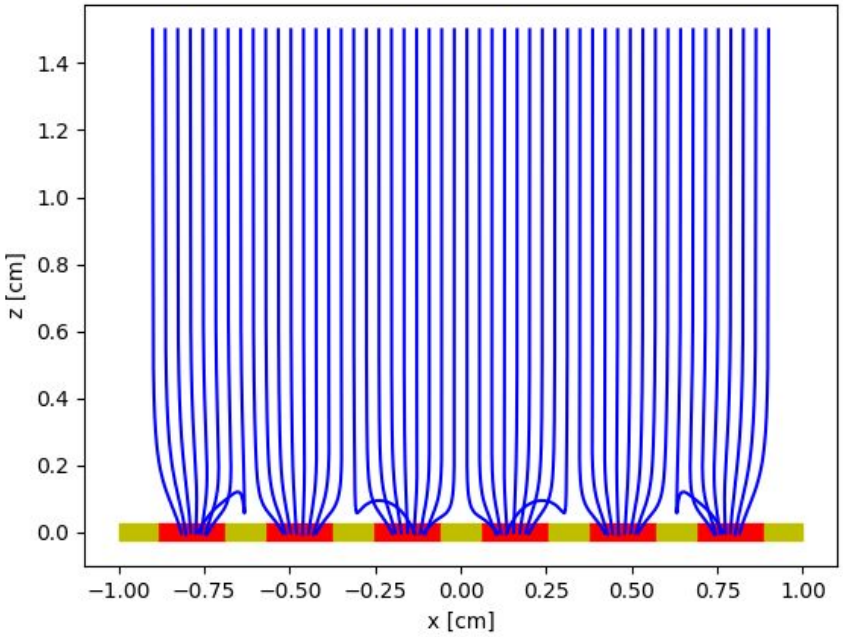
- DUNE-ND preliminary GDML file to be made work in LArSoft
- New GDML file for ArgonCUBE 2x2 module for Fermilab run
  - Implementation by **Patrick** (Bern) & **Hunter** (UTA) including the cryostat, TPC module, and optical modules.

DUNE Near Detector
Simulation Software Development

SLAC

Simulation Chain





Electric field response

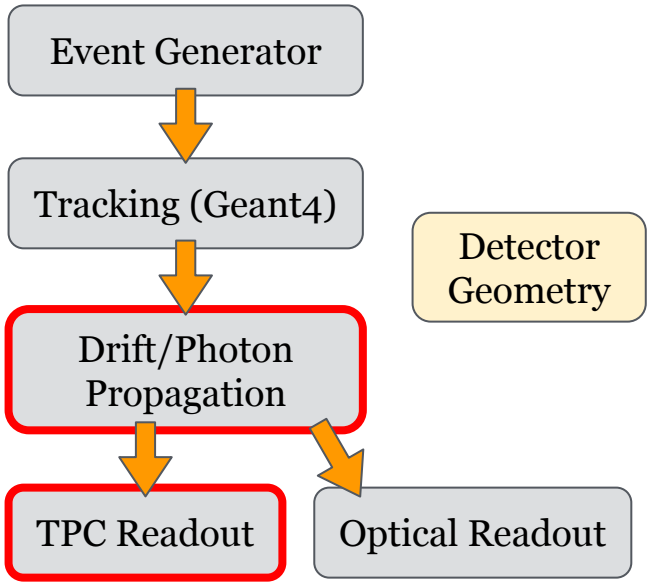
Evolving closely with the detector design updates (kapton wall, pixel geometry, etc.), lead by **Dan Douglas** (MSU)

- Using now 2.5 x 2.5mm pixel + 3.88 mm pitch (from **Knut** @ SLAC)
- Non-uniformity of Kapton surface resistivity
- Dielectric materials

DUNE Near Detector
Simulation Software Development

SLAC

Simulation Chain



TPC Readout

Digitized waveform for electronics response

- "Vectorized code" written by **Dan Dwyer** (LBNL), ready(?) to be integrated with drift/E-field simulation.
- Seek for ways to integrate vectorization scheme made available(?) in LArSoft

Photon Propagation

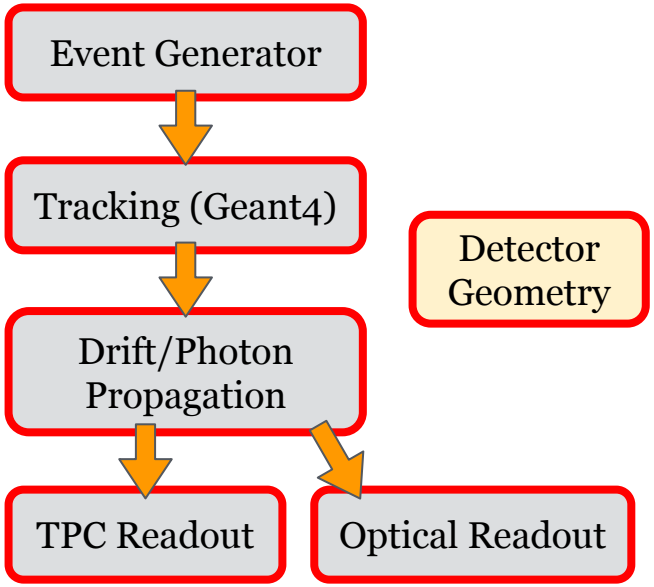
Individual photon ray tracing is time consuming. Study a solution using a photon library for ArgonCUBE 2x2 prototype.

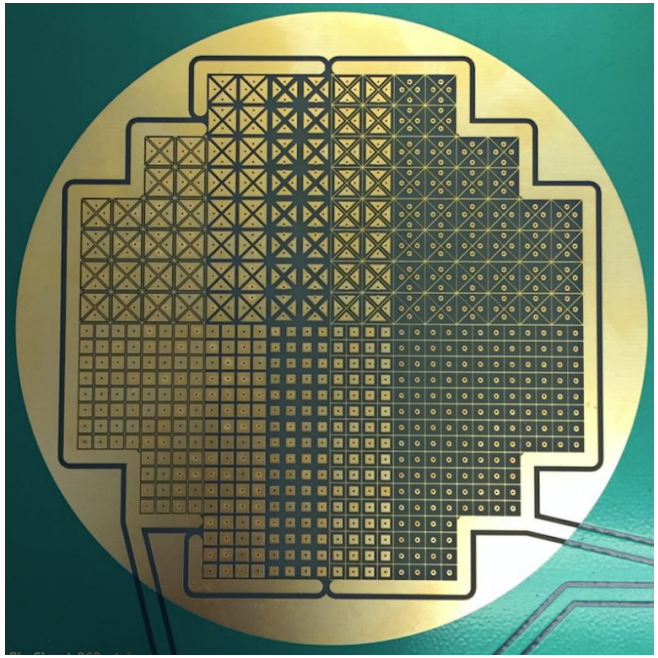
- LArSoft: a "photon library" (look-up table) for photon collection efficiency and timing estimates at different detector locations.
- Need to run a full simulation to build the library

DUNE Near Detector
Simulation Software Development

SLAC

Simulation Chain





Pixel Geometry in LArSoft

LArSoft assumes "wire" in the core of Geometry design & APIs to query geometry information (PlaneGeo/WireGeo). Needs to be changed.

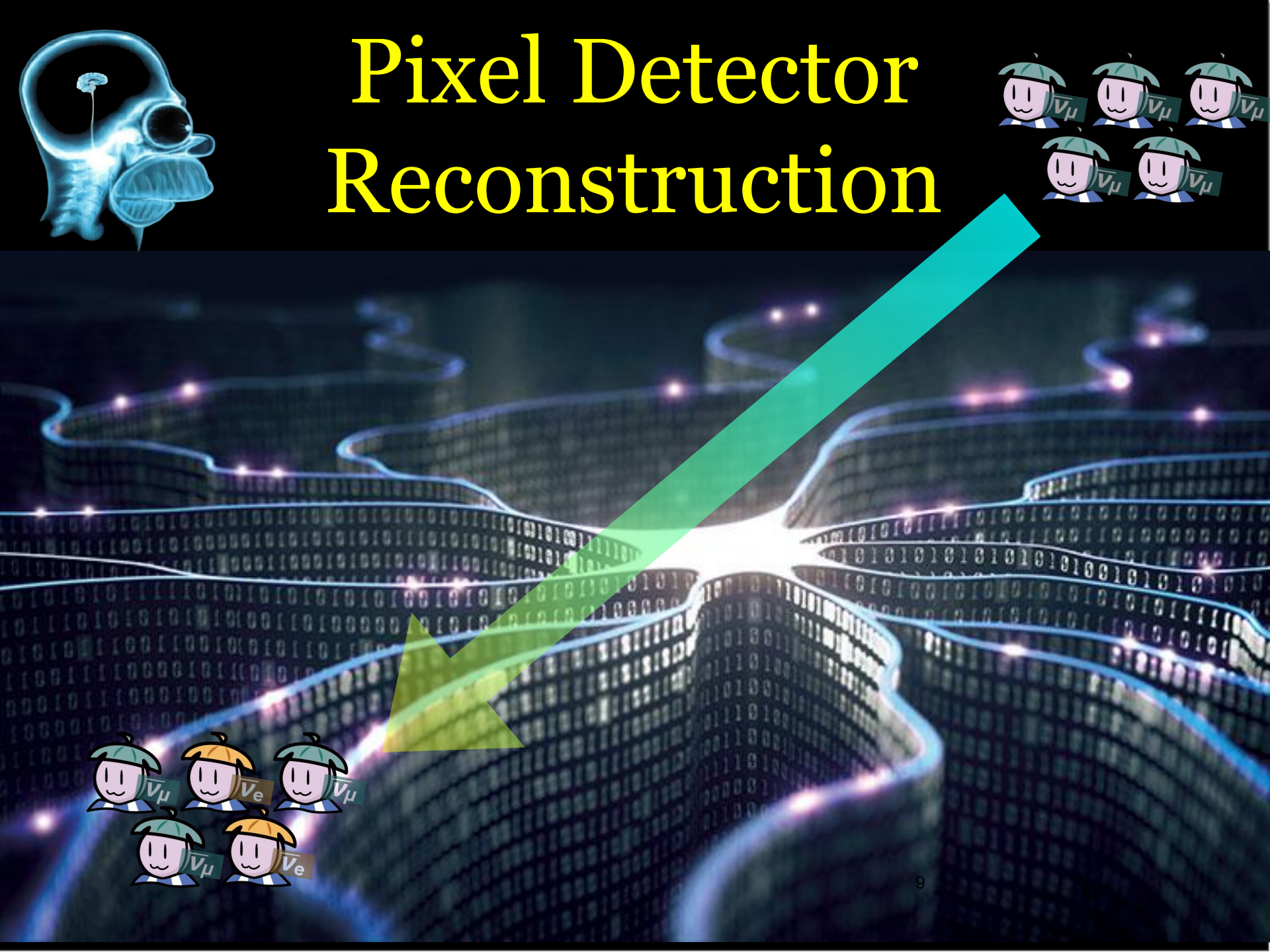
- Designed a generic "charge-sensitive element" to replace the current implementation in non-distruptive manner (by **Gianluca** @ SLAC)
- Now in testing stage: goal is to run largeant for wire & pixel geometry

DUNE Near Detector
Plan for LArSoft Integration (Simulation)

SLAC

Simulation

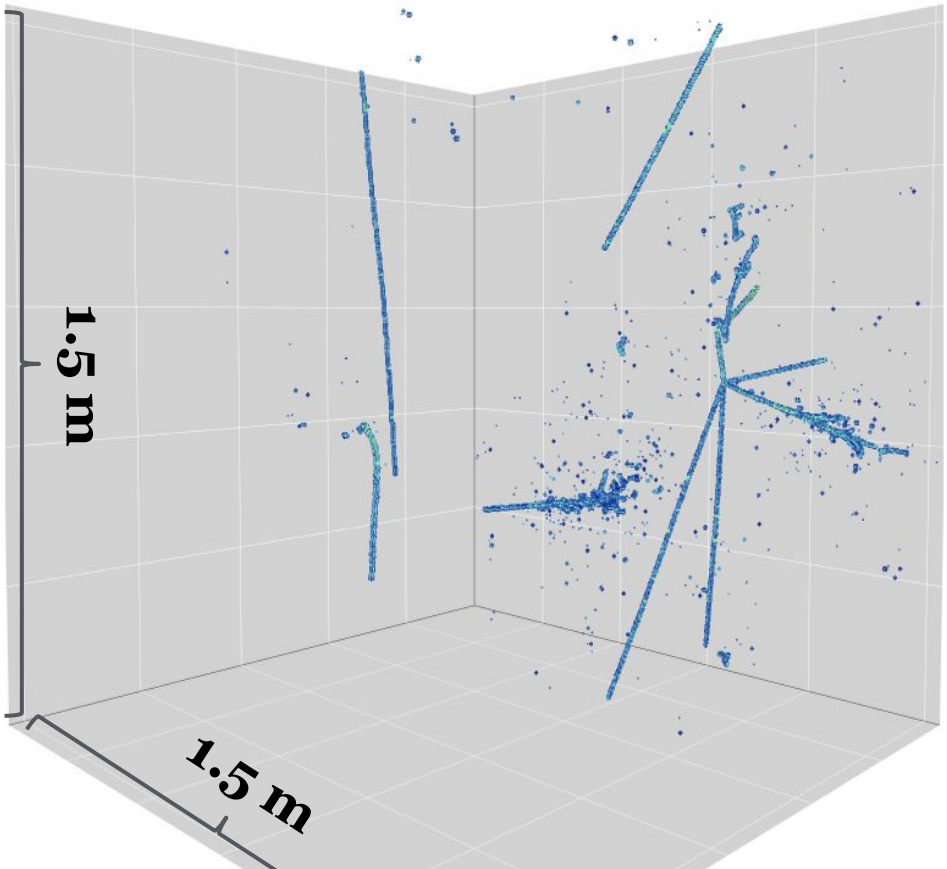
1. Debug the pixel geometry implementation
   - **Goal**: run largeant for wire & pixel geometry
2. Generate photon library
   - **Goal**: photon library within TPC active volume
3. Implement E-field response into LArSoft
   - **Goal**: run drift simulation for wire & pixel geometry
4. Implement pixel readout response into LArSoft
   - **Goal**: run the whole readout chain for pixel (no wire)
5. Keep working till we are happy


Pixel Detector
Reconstruction

DUNE Near Detector
Data Reconstruction Development

SLAC

Goal: describe all observables

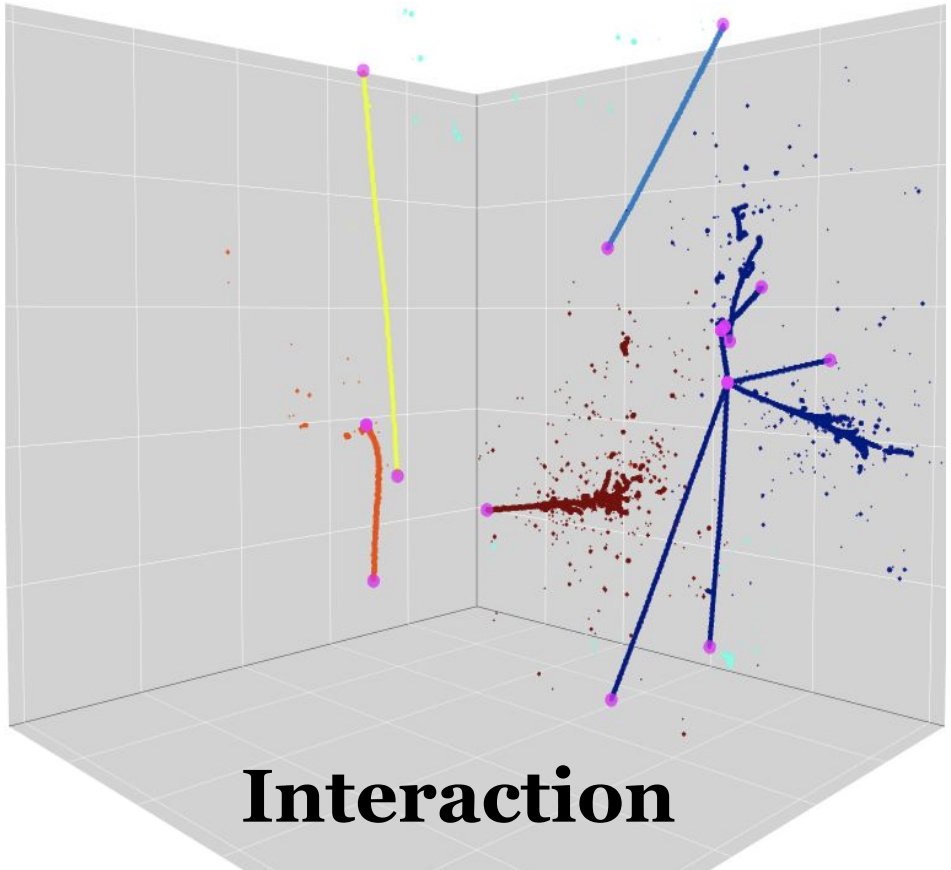


DUNE Near Detector
Data Reconstruction Development

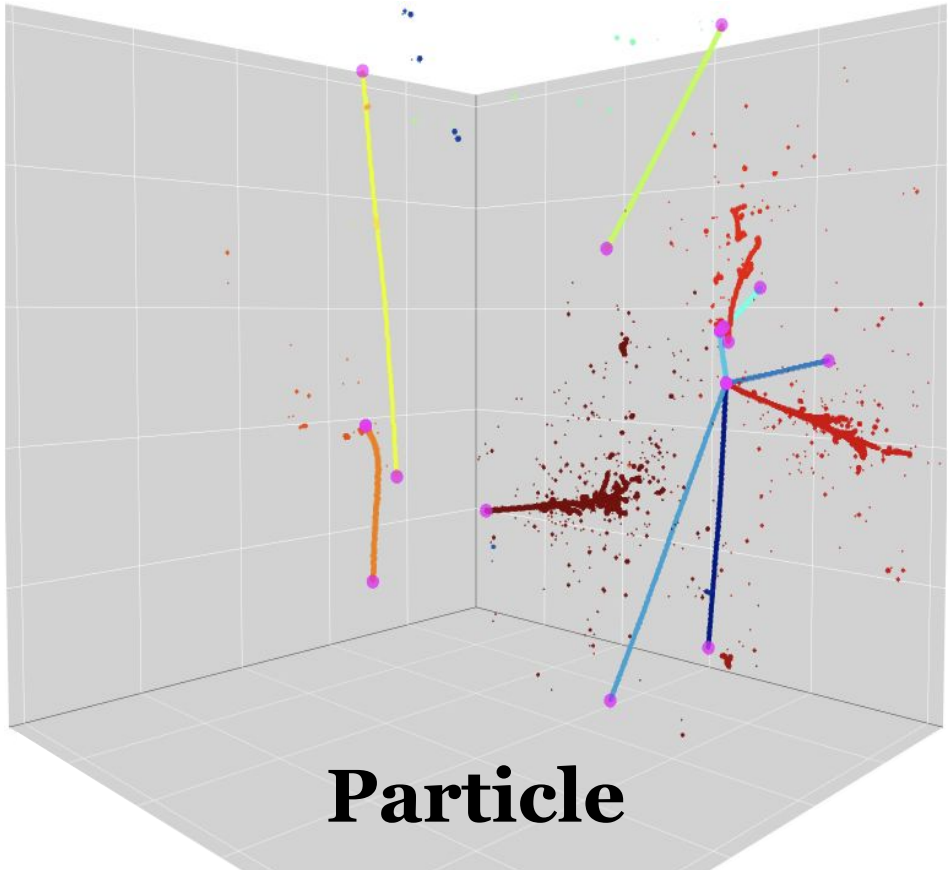
SLAC

Goal: describe all observables

- identify (cluster) individual interaction, vertex, individual particle and type/geometry/kinematics



Interaction

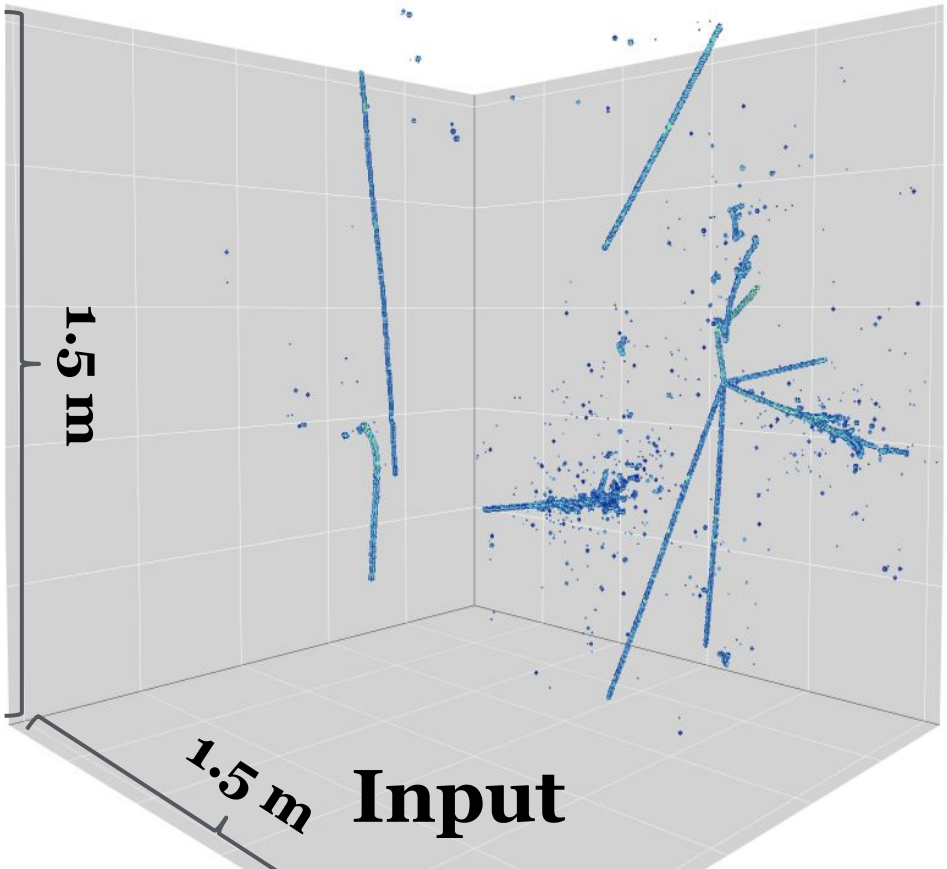


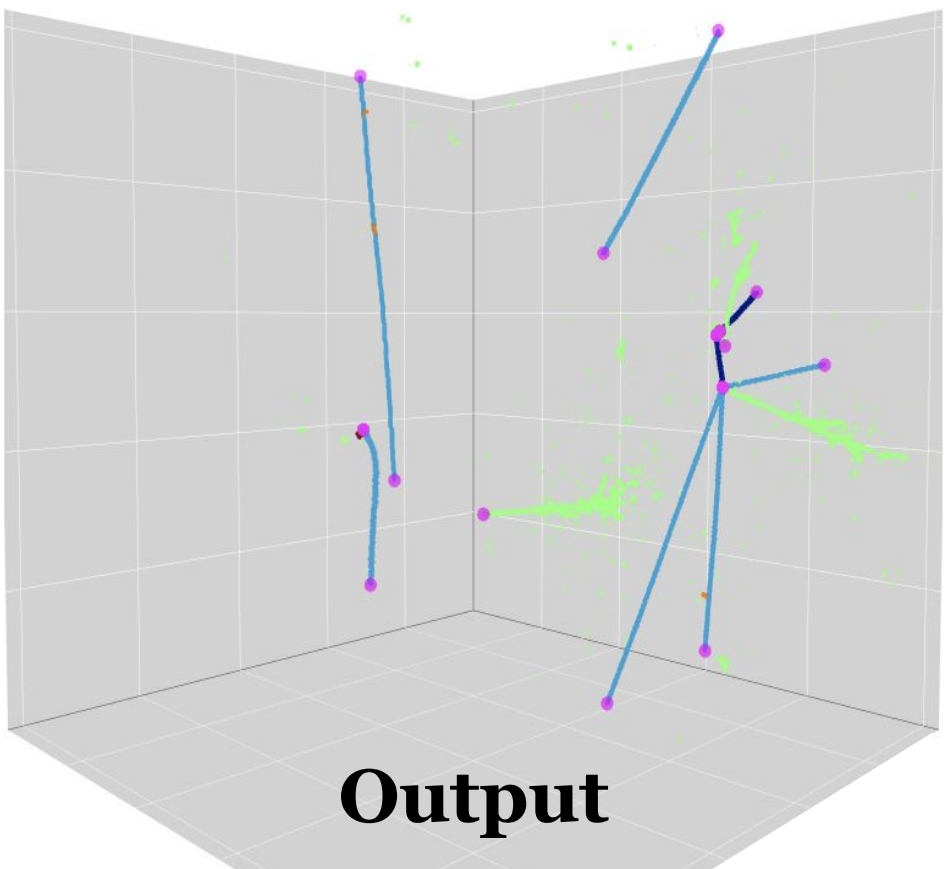
Particle

DUNE Near Detector
Data Reconstruction Development

SLAC

Status: a chain for pixel segmentation + “feature point” identification, “end-to-end” optimization





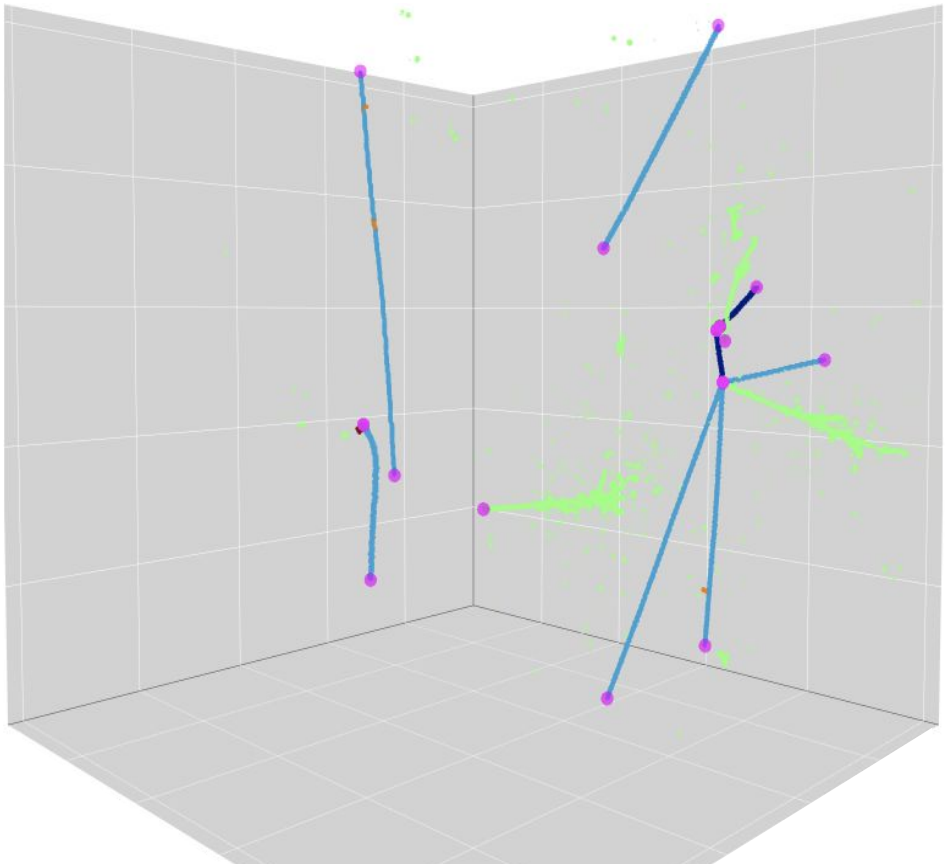
DUNE Near Detector
Data Reconstruction Development

SLAC

Status: a chain for pixel segmentation + "feature point" identification, "end-to-end" optimization

Sparse Submanifold Convolution

- <1/500 mem., 1/30< time
- Improved accuracy
- Better scalability
  - By # of non-zero pixels
  - Fit the whole detector
  - Good enough w/ CPU



Computer Science > Computer Vision and Pattern Recognition

Scalable Deep Convolutional Neural Networks for Sparse, Locally Dense Liquid Argon Time Projection Chamber Data

Laura Dominé, Kazuhiro Terao

(Submitted on 13 Mar 2019 (v1), last revised 15 Mar 2019 (this version, v2))

Deep convolutional neural networks (CNNs) show strong promise for analyzing scientific data in many domains including particle imaging detectors such as a liquid argon time projection chamber (LArTPC). Yet the high sparsity of LArTPC data challenges traditional CNNs which were designed for dense data such as photographs. A naive application of CNNs on LArTPC data results in

DUNE Near Detector
Data Reconstruction Development

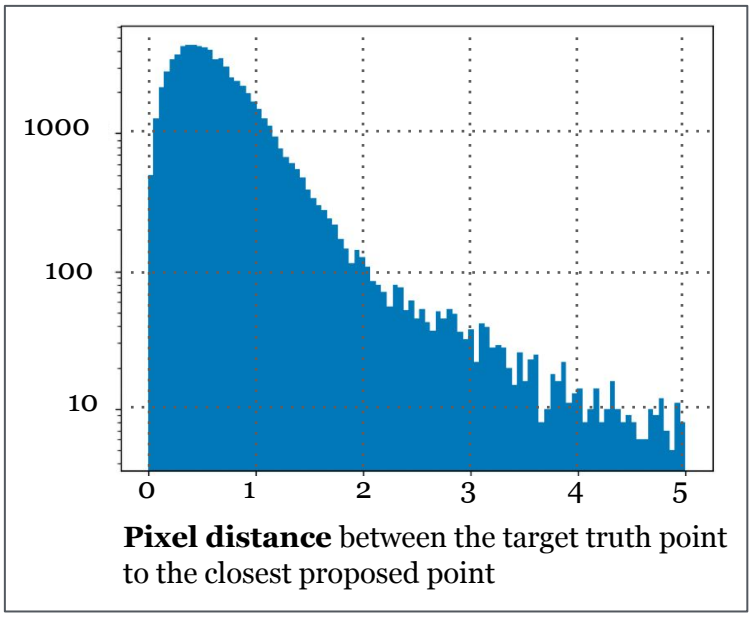
SLAC

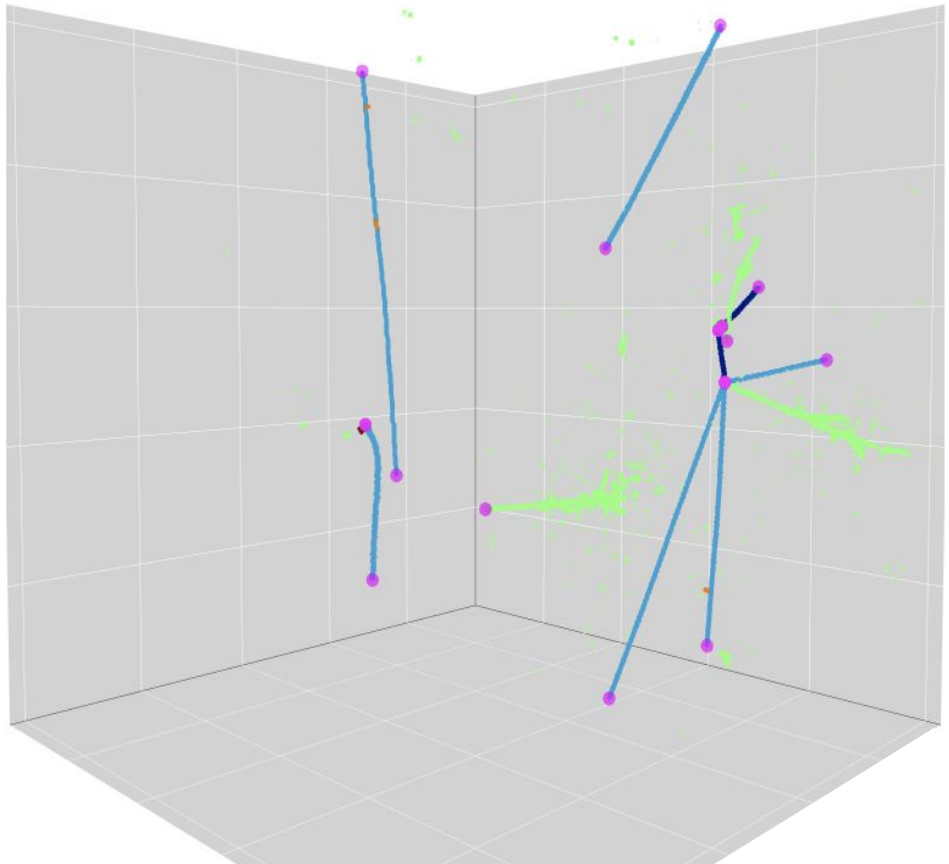
Status: a chain for pixel segmentation + “feature point” identification, “end-to-end” optimization

Segmentation Accuracy

Type	Track	Shower	Delta	Michel
Acc.	0.99	0.99	0.97	0.96

Feature Point Accuracy





DUNE Near Detector
Data Reconstruction Development

SLAC

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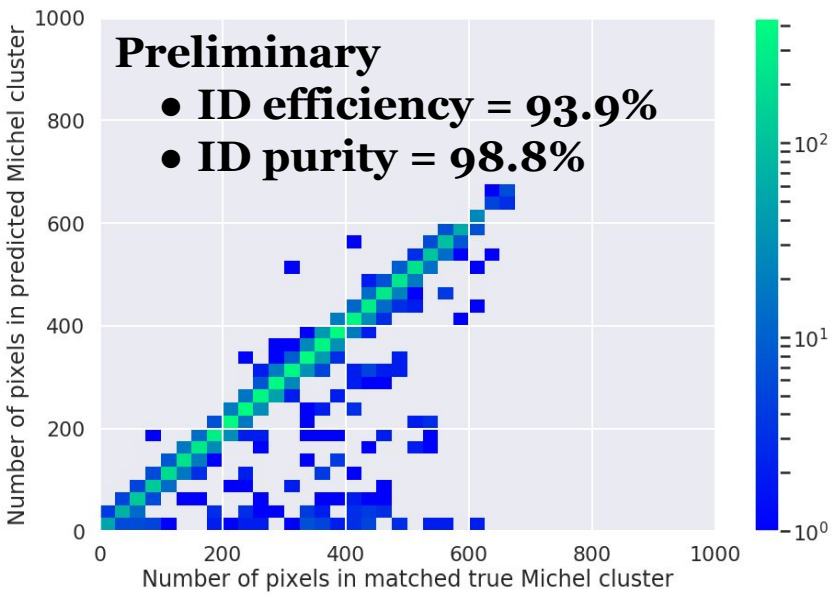
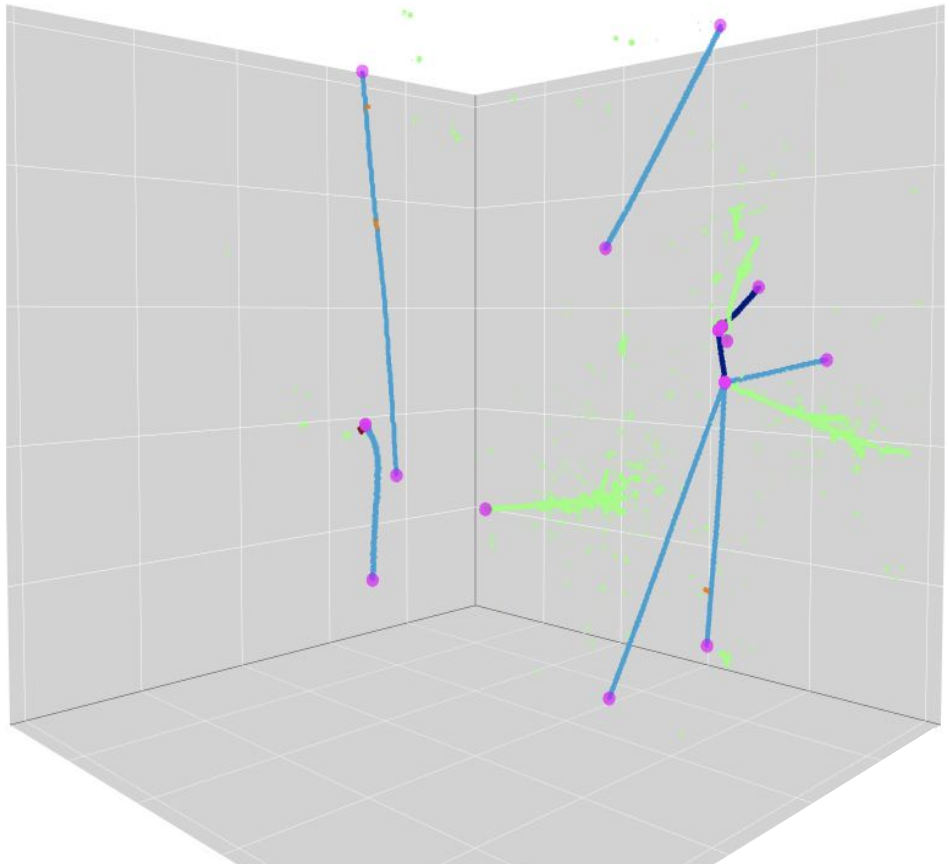
Michel Electron Demo





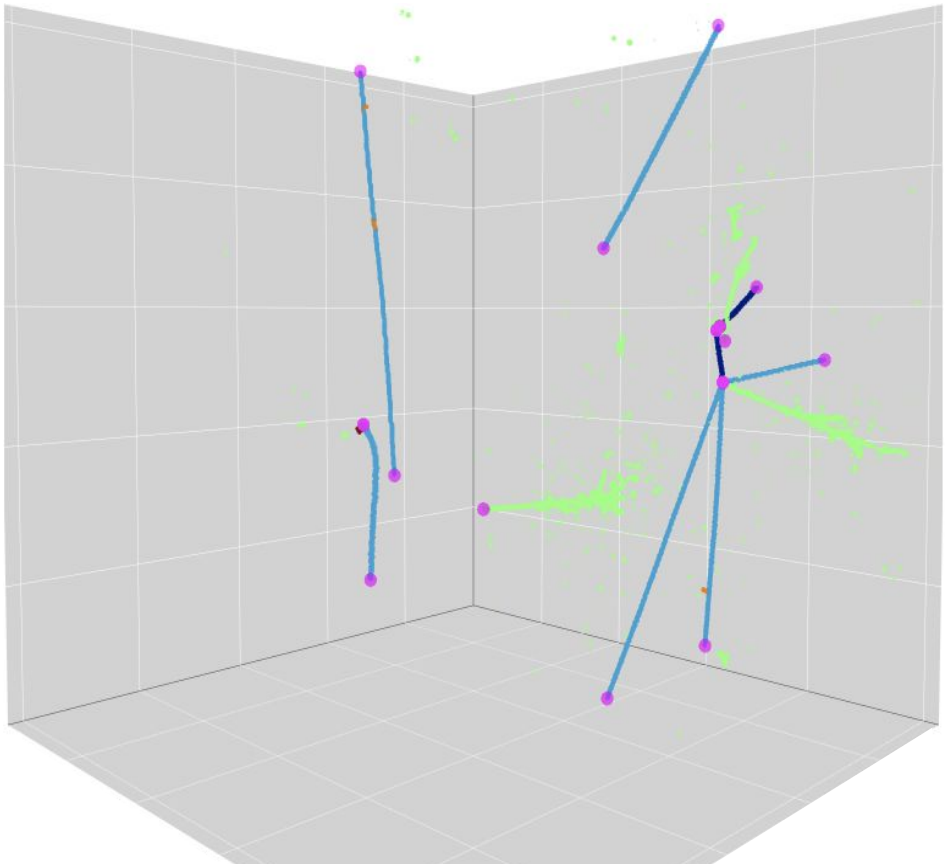
DUNE Near Detector
Data Reconstruction Development

SLAC

Next: generic clustering algorithm development (initial focus on particle clustering in particular)

Track-like particles

- DBScan + Break



DUNE Near Detector
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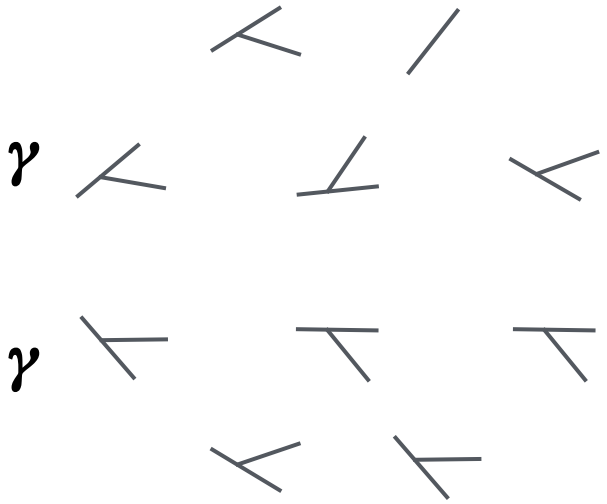

DUNE Near Detector
Data Reconstruction Development

SLAC

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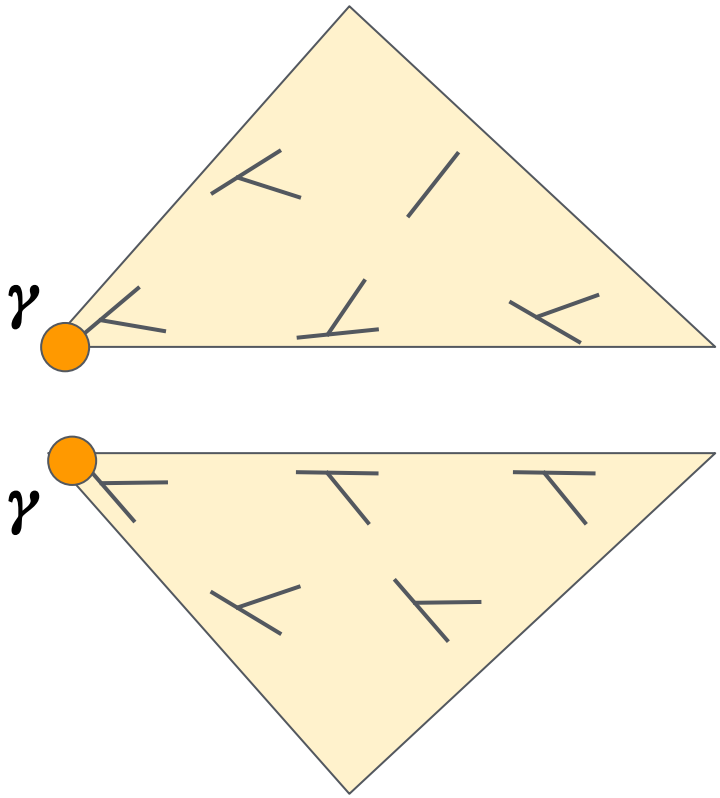
Delta/Michel/Shower particles

- **Approach 1**: classic method
  - Start point + direction + “cone”



DUNE Near Detector
Data Reconstruction Development

SLAC

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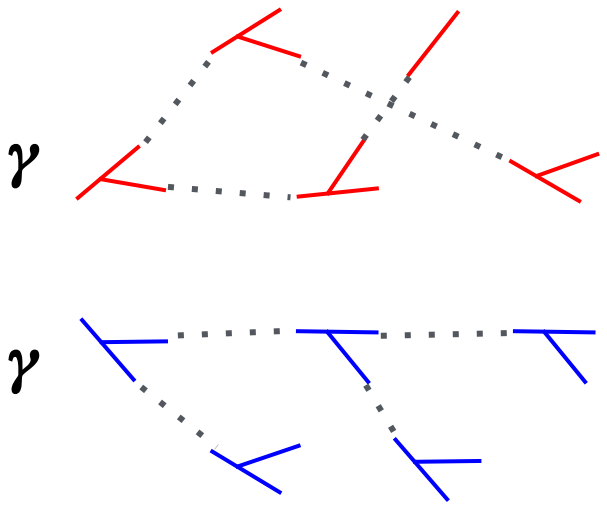
- **Approach 1**: classic method
  - Start point + direction + "cone"
- **Approach 2**: pattern recognition



DUNE Near Detector
Data Reconstruction Development

SLAC

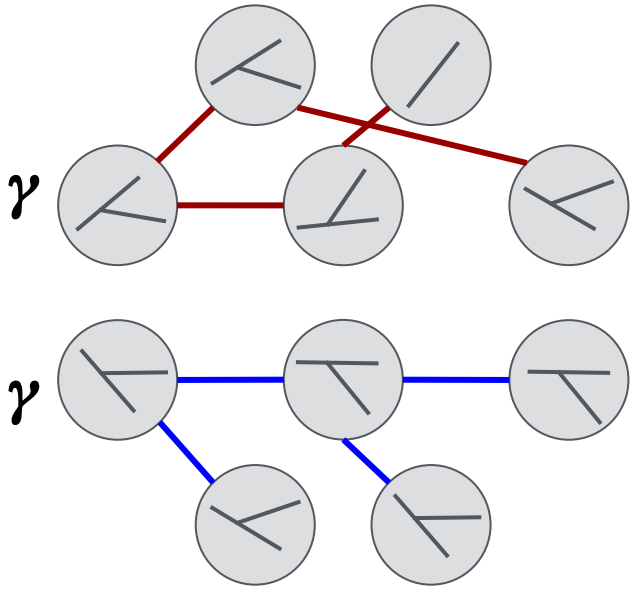
Next: generic clustering algorithm development (initial focus on particle clustering in particular)

Track-like particles

- DBScan + Break

Delta/Michel/Shower particles

- **Approach 1**: classic method
  - Start point + direction + "cone"
- **Approach 2**: pattern recognition
  - Represent the targets as "nodes", evaluate "edges" (relationship)
  - On-going: machine learning approach
  - **Exa Trk Collaboration** … SLAC/FNAL/LBNL/CalTech funded for DUNE/HL-LHC development (postdoc per institution)

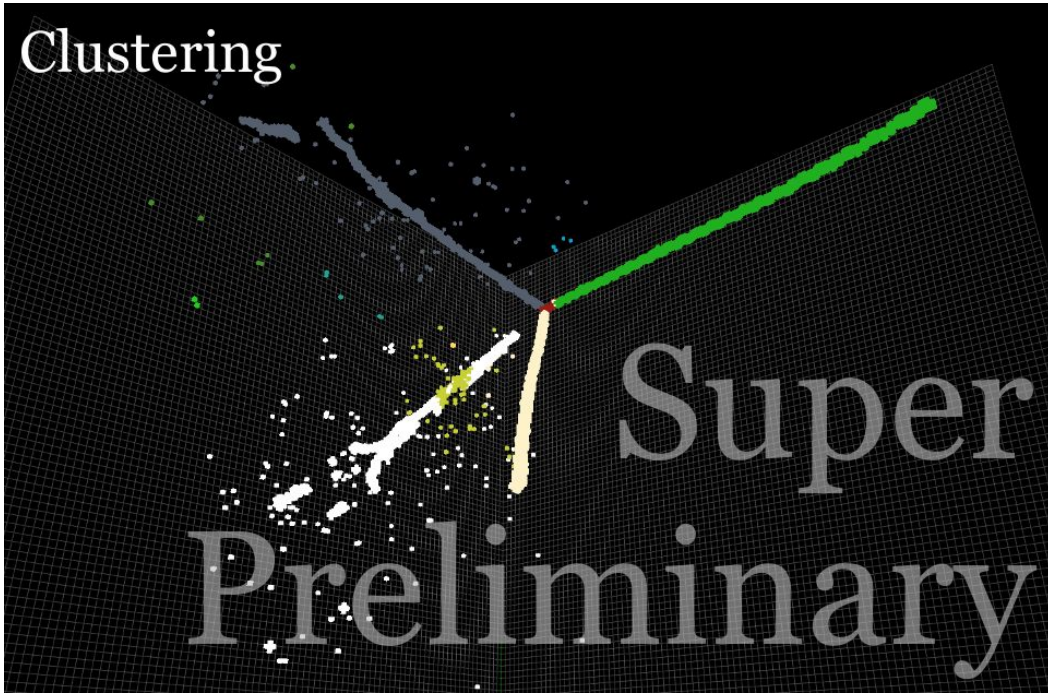


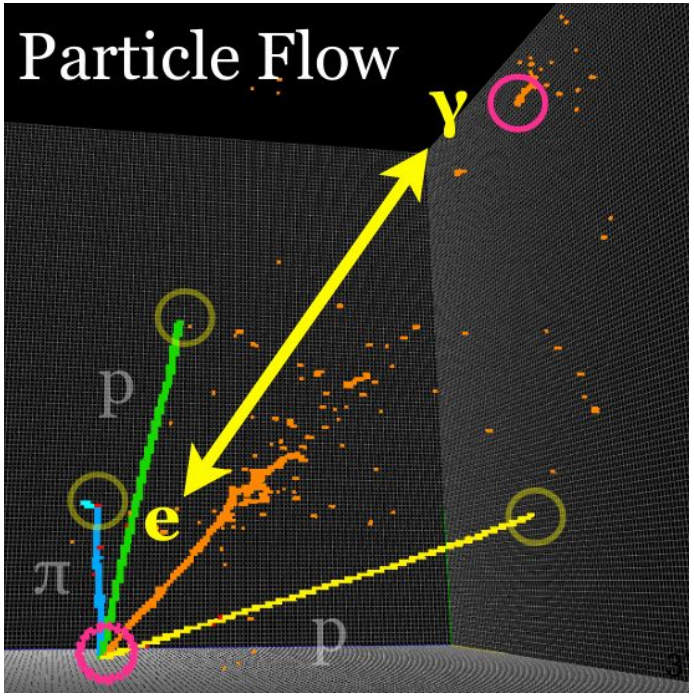
DUNE Near Detector
Data Reconstruction Development

SLAC

Next: generic clustering algorithm development

- Clustering pixels into a particle
- Clustering pixels/particle into individual interaction
- "Flash" reconstruction (PE clustering)
- Matching PMT+TPC signals





DUNE Near Detector
Data Reconstruction Development

SLAC

Analysis Target

- Neutral pion reconstruction
  - Proto-DUNE / ICARUS / ArgonCUBE 2x2
- Michel reconstruction
  - ICARUS
- Neutrino reconstruction
  - All experiments :)
  - Individual neutrino reco @ DUNE-ND

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Data Reconstruction Development

SLAC

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  - All experiments :)
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Common denominator = lots of interest … CSU, SLAC, LBNL, and more. Analysis can be developed NOW (no need to wait for clustering ML algorithms) using naive clustering methods. Join meetings + workshops!

DUNE Near Detector
Data Reconstruction Development

SLAC

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  - Proto-DUNE / ICARUS / ArgonCUBE 2x2
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  - All experiments :)
  - Individual neutrino reco @ DUNE-ND

LArSoft Integration Plan

- Build pytorch+LArSoft with MAGMA+CUDA backend
- Implement driver code and C++ APIs

DUNE Near Detector
Data Reconstruction Development

SLAC

Thanks to your attention!

Appreciate your patience
... for food
... for drink

DUNE Near Detector
Data Reconstruction Development

SLAC

Thanks to your attention!

Appreciate your patience
... for food
... for drink
... of our family back home

Questions?

Backup: SCN

ML-based LArTPC Data Reconstruction Chain

Scalability for larger, hi-resolution 3D data

SLAC

"Applying CNN in 3D" is simple, but **is it scalable?**

LArTPC data is generally sparse, but locally dense

CNN applies **dense matrix operations**

In photographs, **all pixels are meaningful**

ML-based LArTPC Data Reconstruction Chain

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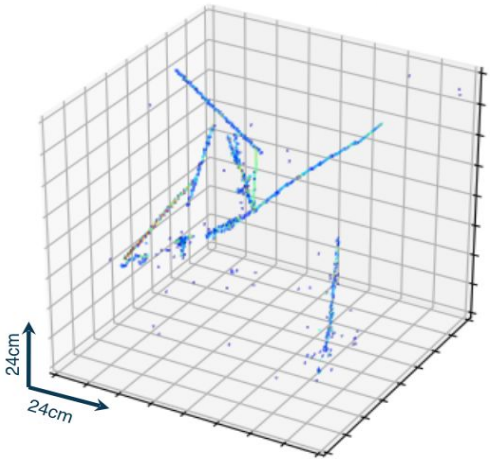

<1% of pixels are non-zero in LArTPC data

Zero pixels are meaningless!

ML-based LArTPC Data Reconstruction Chain

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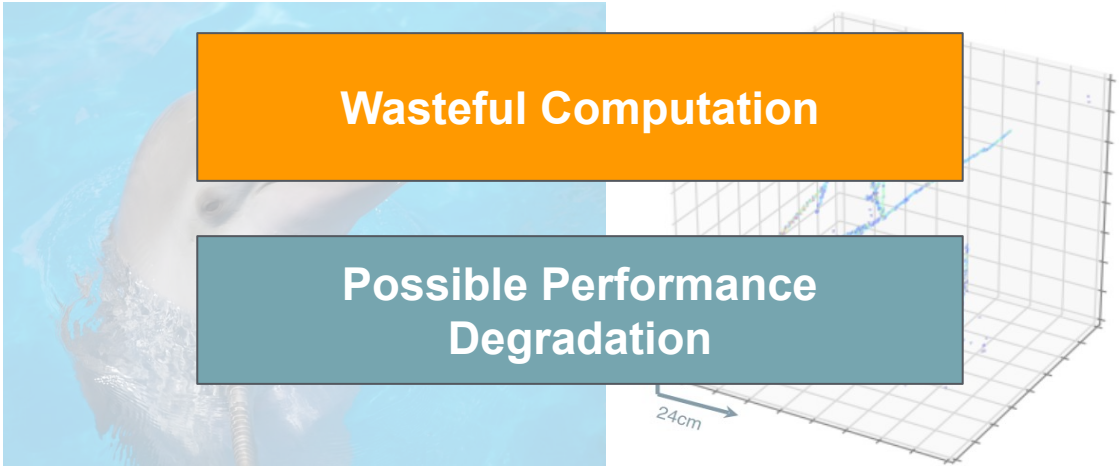


<1% of pixels are non-zero in LArTPC data

Zero pixels are meaningless!

- **Scalability for larger detectors**
  - Computation cost increases linearly with the volume
  - But the number of non-zero pixles does not
    - e.g.) A straight muon in cubes with the side 1m and 2m will yield 1m and 2m long tracks respectively … while total pixel counts increase by x8.

Submanifold Sparse Convolutional Network (SSCN)

Many variants exist for "*sparse convolution*", a few are great…

Submanifold Sparse Convolutions (arXiv:1711.10275, CVPR2018)
… by FAIR (https://github.com/facebookresearch/SparseConvNet)

State-of-the-art for ShapeNet challenge (3D part segmentation)

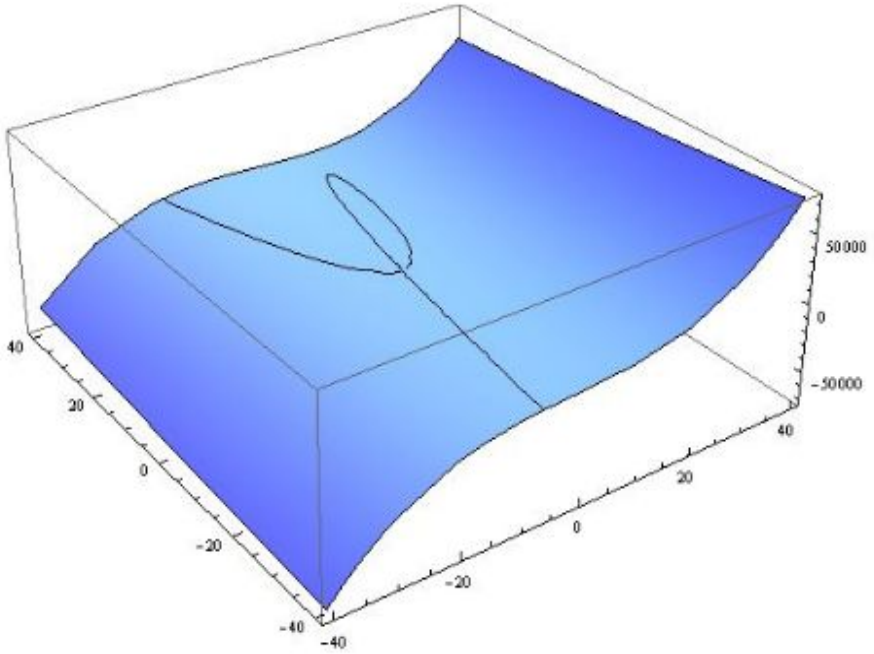
ML-based LArTPC Data Reconstruction Chain

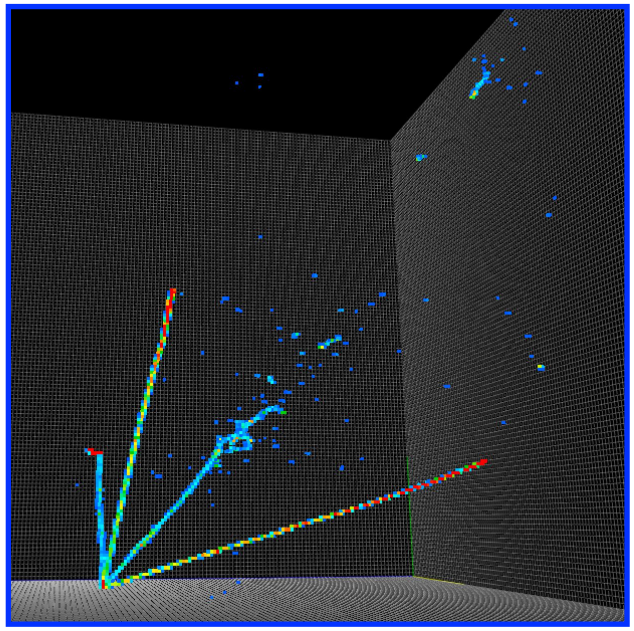
Scalability for larger, hi-resolution 3D data

SLAC

Submanifold = *"features in lower effective dimension than the space in which it lives"*

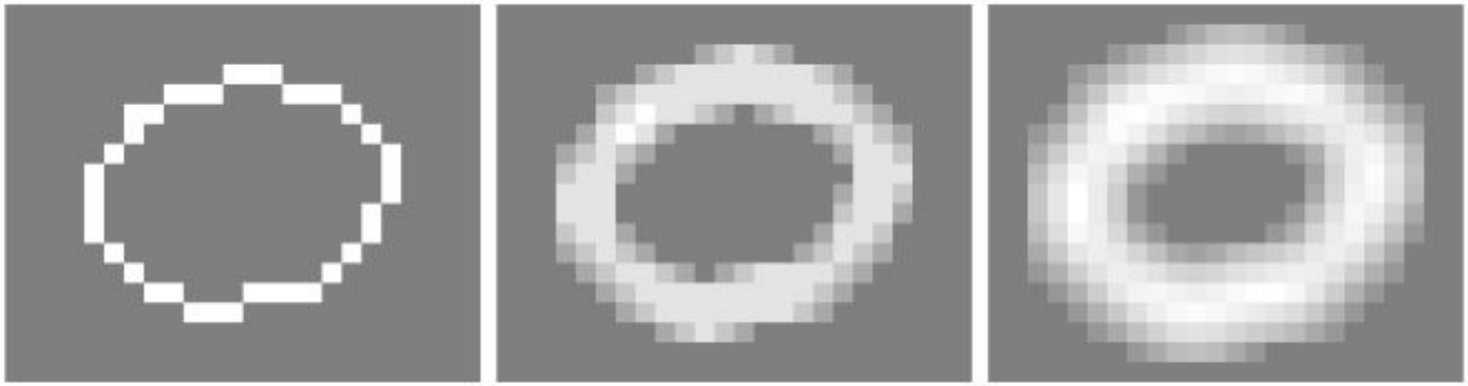
- 2D surface in 3D volume
- 1D line/curve in 2D image or 3D volume





SSCN addresses our challenges

- **Only acts on non-zero pixels**
  - No resource waste by null pixels
  - Computation resource usage scales by non-zero pixel counts
- **No dilation problem** that degrades the network performance
  - "Blurring" effect caused by a standard convolution on sparse data



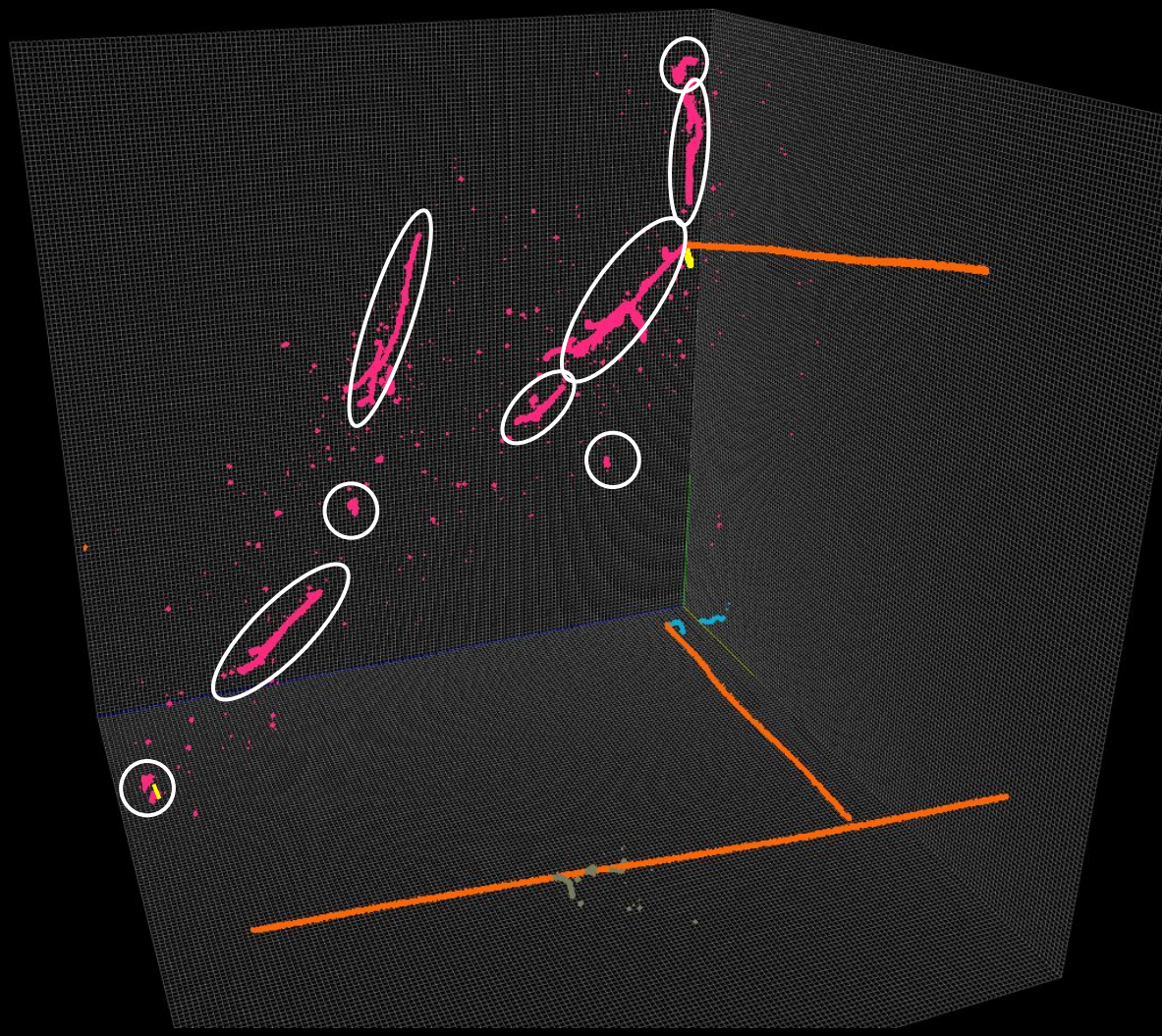
Input | Dilation (after 1st Convolution) | More dilation (after 2nd Convolution)

Backup: Misc

DUNE Near Detector
ML-based Data Reconstruction Development

SLAC

Next step: clustering



DUNE Near Detector
ML-based Data Reconstruction Development

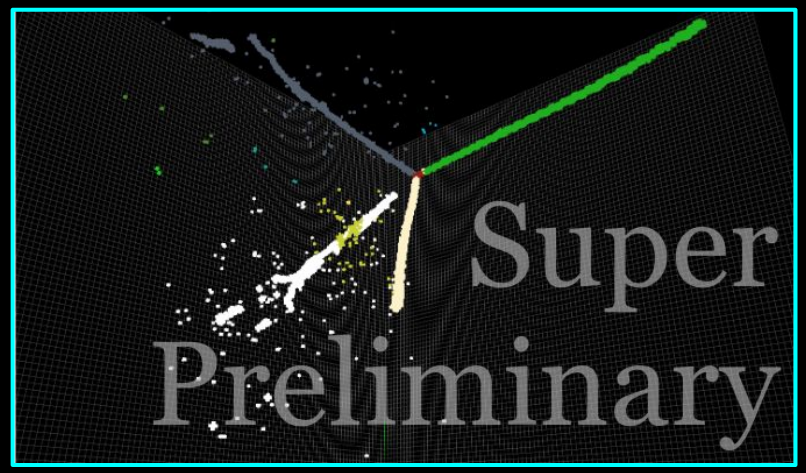
SLAC

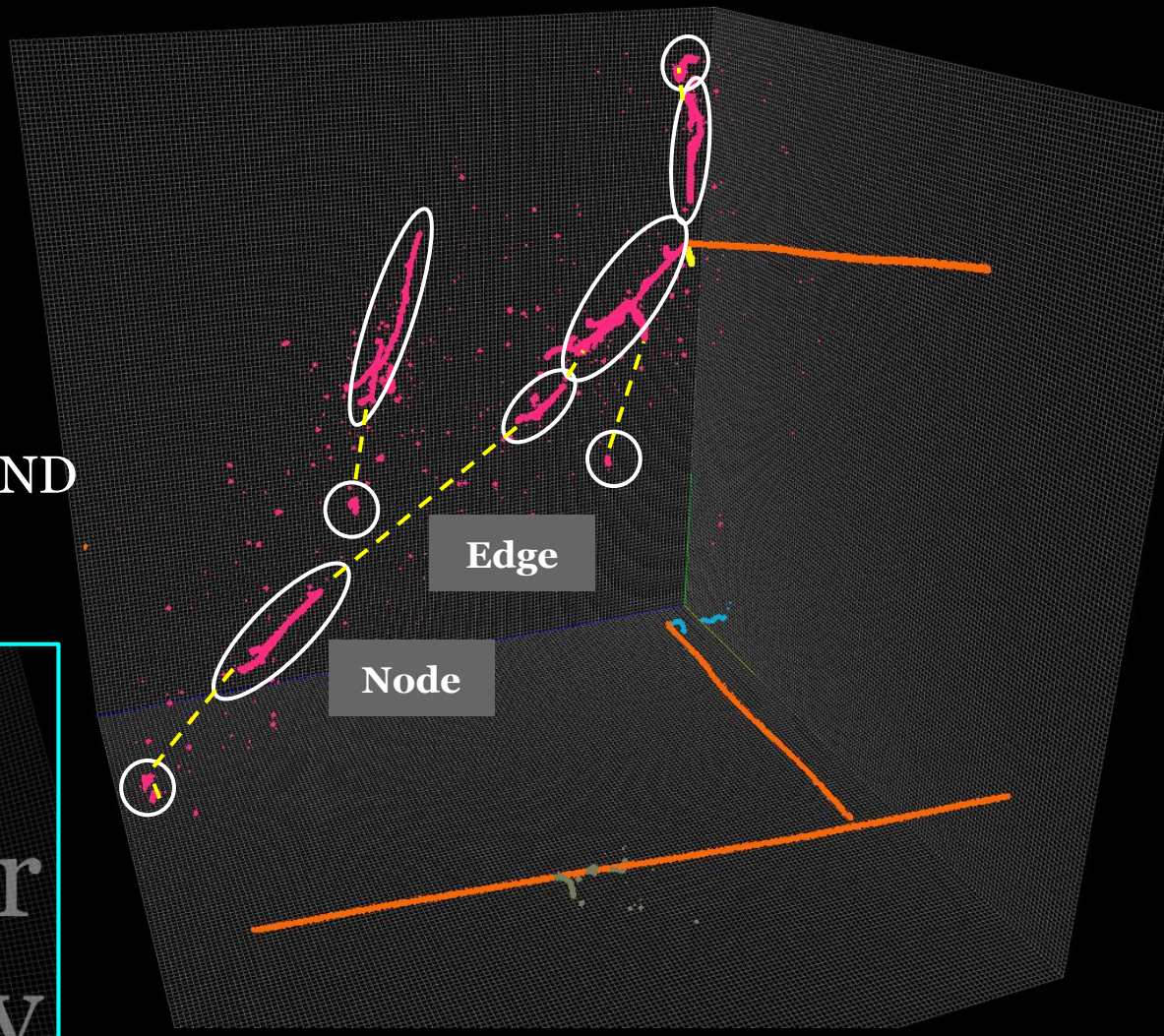
Next step: clustering

Approach: GNN for a generic object-to-object correlation analysis

- Particle clustering

A post-doc funded for DUNE-ND under ATLAS-DUNE joint ML-for-Tracking proposal





DUNE Near Detector
ML-based Data Reconstruction Development

SLAC

Next step: clustering

Approach: GNN for a generic object-to-object correlation analysis

- Particle clustering
- Interaction clustering
- PMT-TPC matching