Electron Neutrino Reconstruction in MicroBooNE Using Deep Learning Technique

New Perspectives
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on behalf of the MicroBooNE Collaboration

Overview

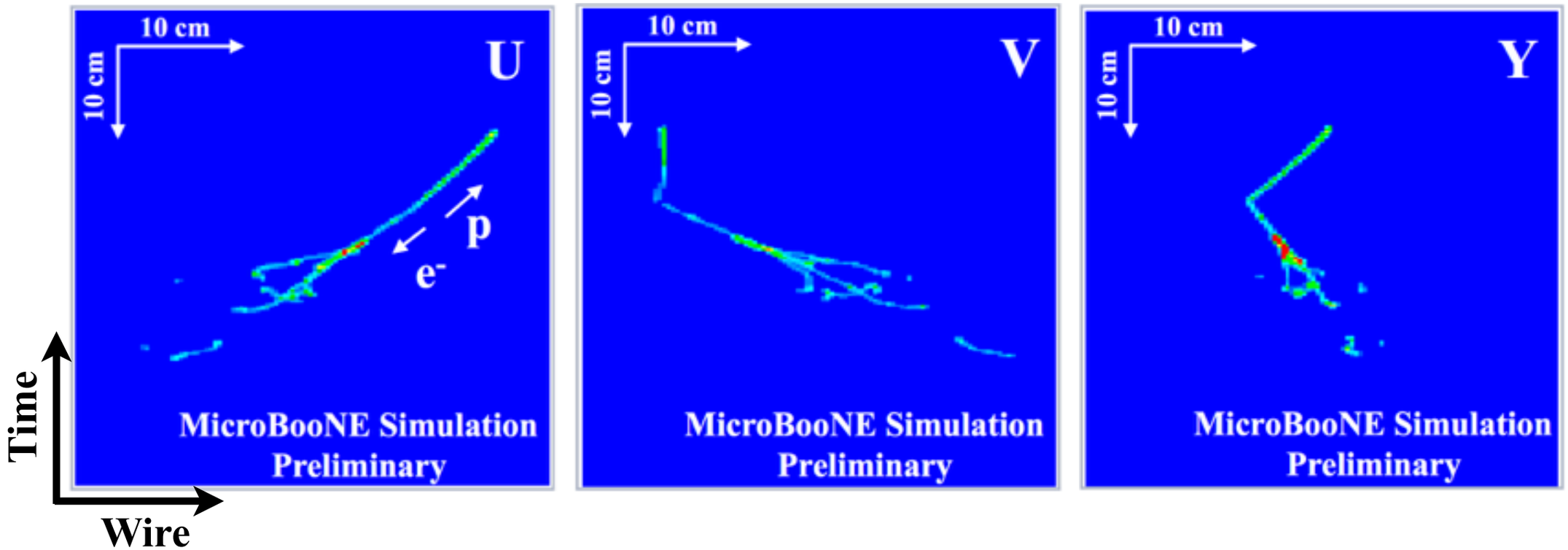
1. MicroBooNE LArTPC images
2. Selecting neutrino images
3. Neutrino interaction reconstruction
4. Reconstructed Events

LArTPC Image

LArTPC Image

Process this event display using image analysis

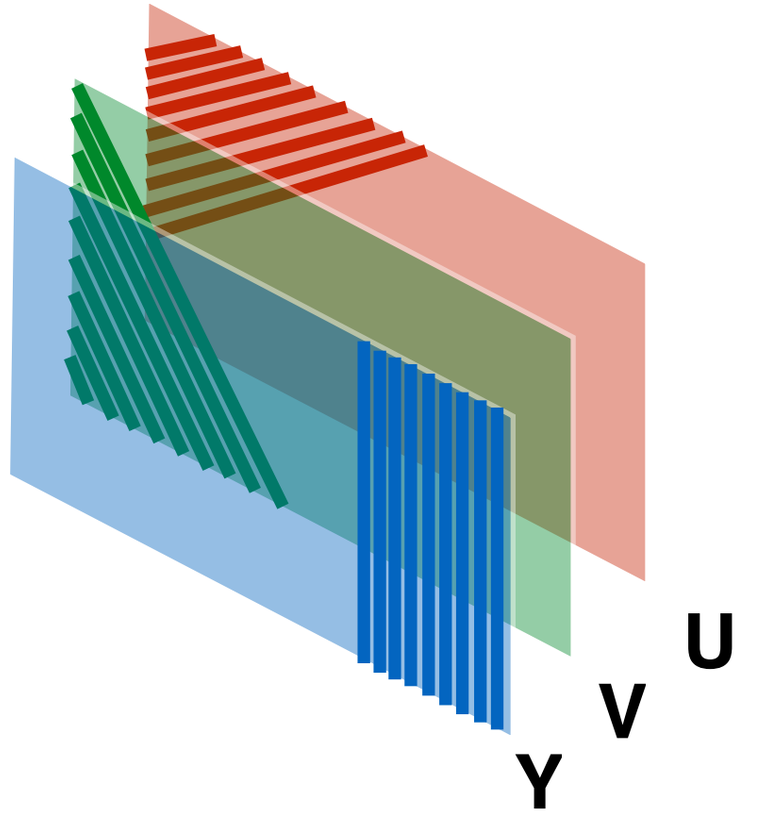
Electron Neutrino LArTPC Image



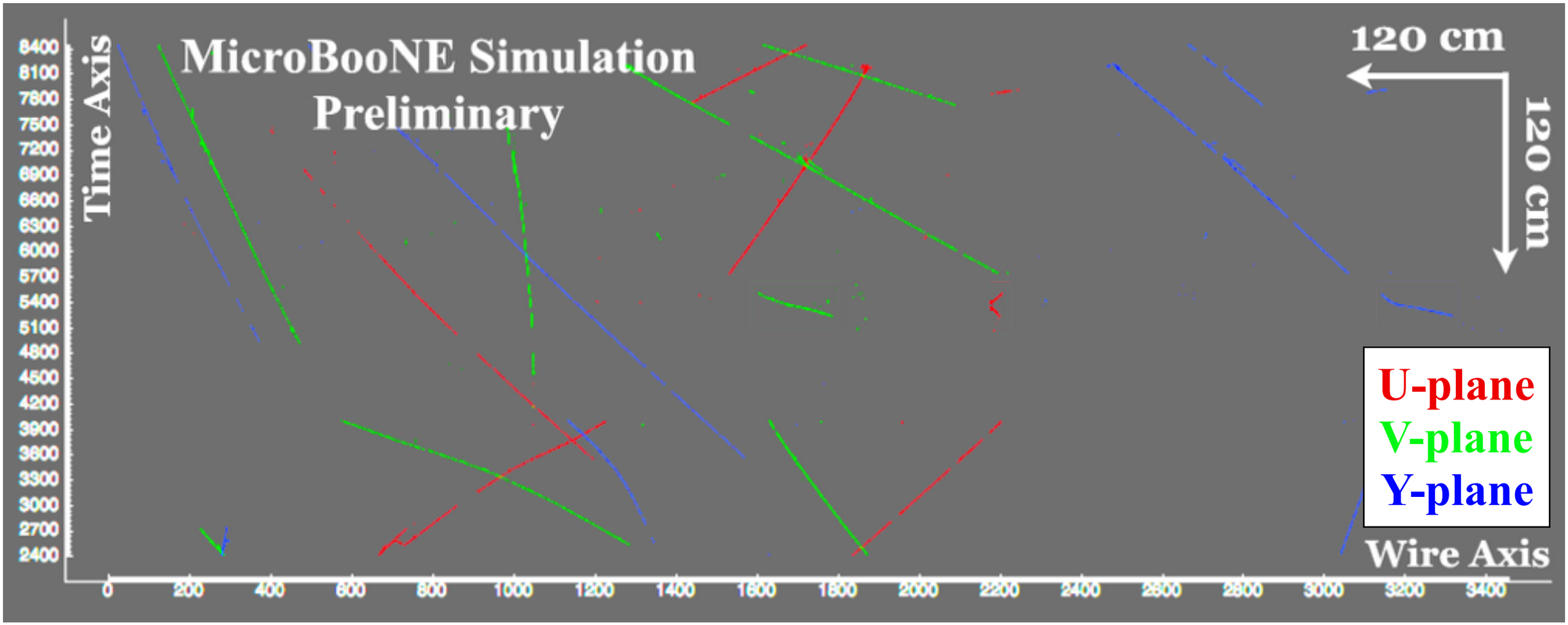
- **Focus on simple 2 prong interaction**
  - 1 proton and 1 electron topology
  - Charged Current Quasi-Elastic (CCQE) events
  - **Motivation**: Low Energy Excess

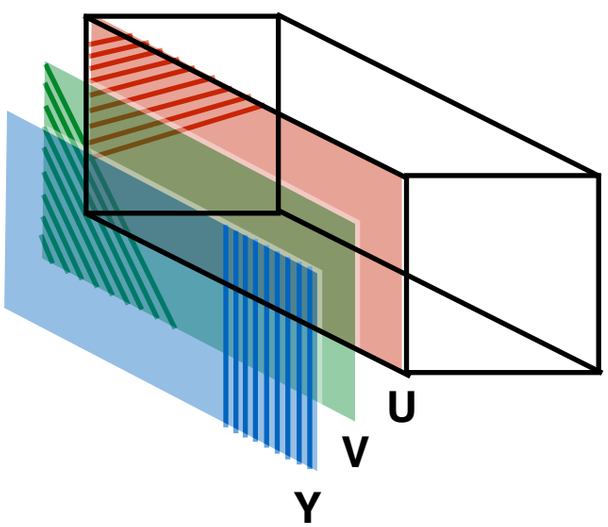
Finding this neutrino interaction is easy for physicists, we've had lots of training. Lets follow our eyes…

Look for a shower on edge of a track



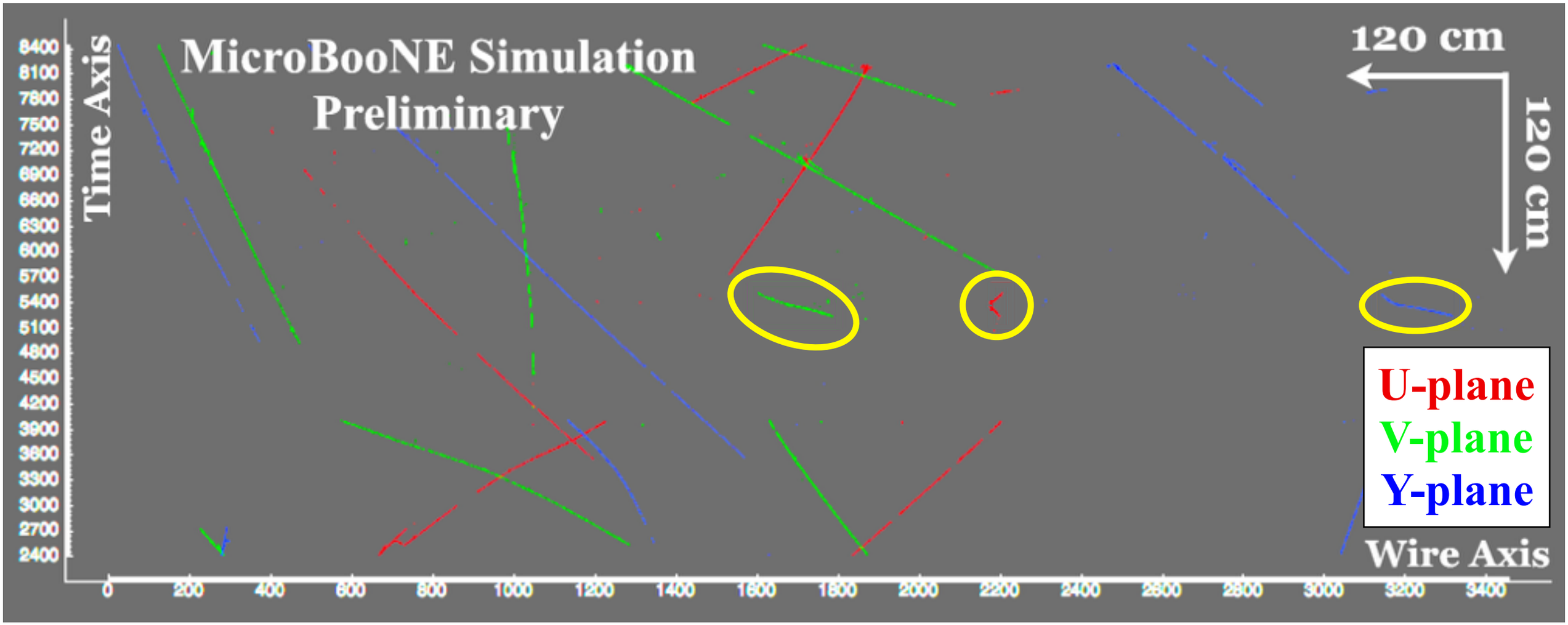
LArTPC Image with ν_e

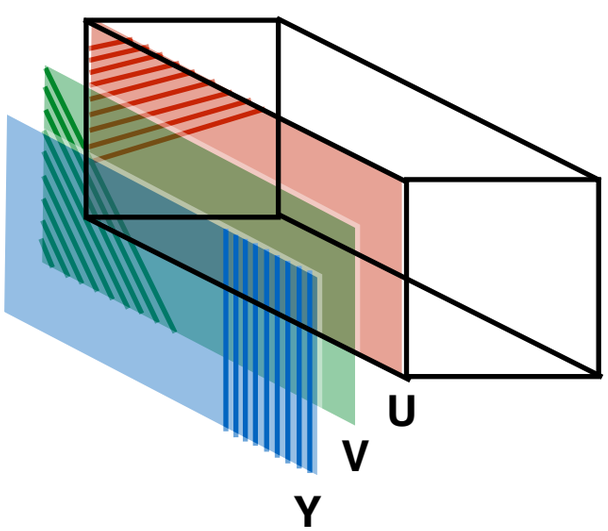




- One color per wire plane
- Time on the Y-axis
- Tracks appear on all three planes
- Can **you** find the neutrino?

LArTPC Image with ν_e

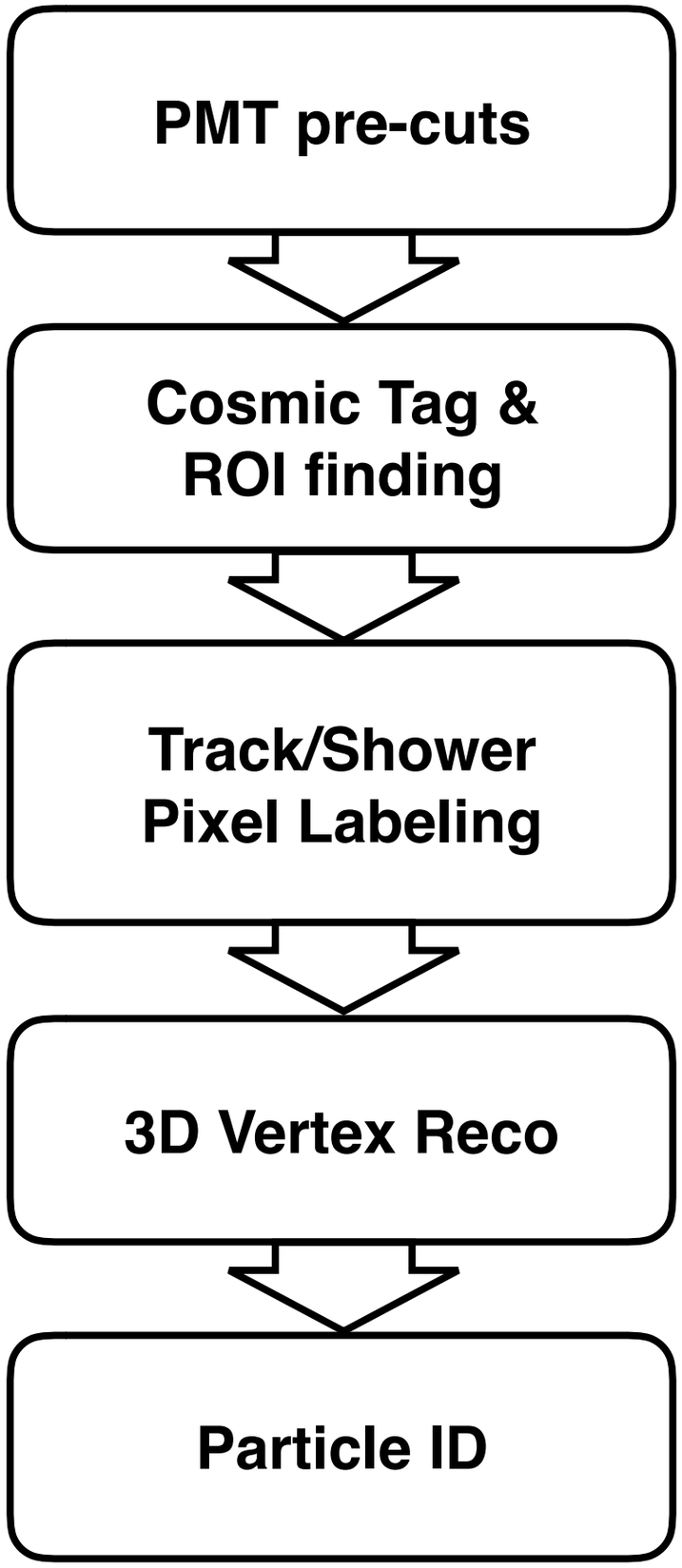




- One color per wire plane
- Time on the Y-axis
- Tracks appear on all three planes
- Can **you** find the neutrino? 😮

Goal: sort through cosmic rays and reconstruct ν_e

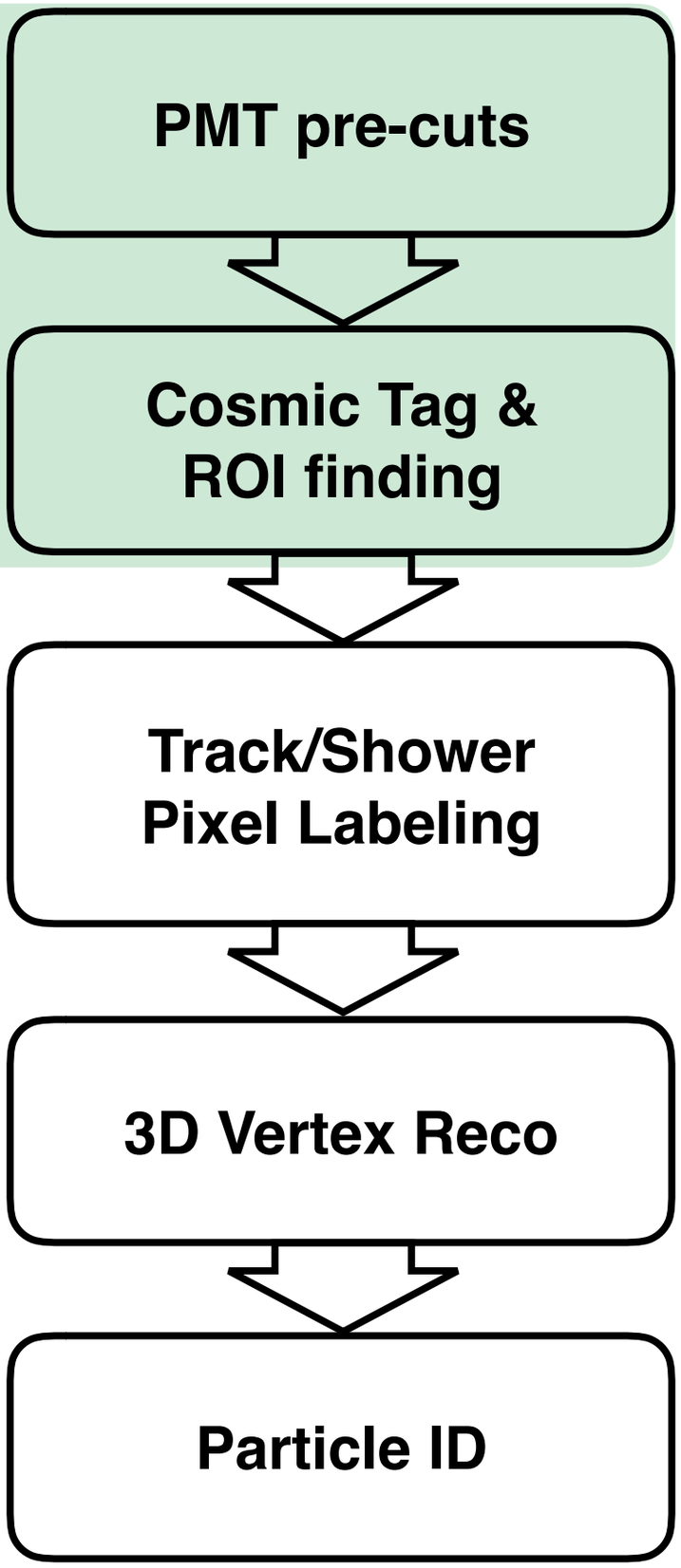
Reconstruction Chain Overview



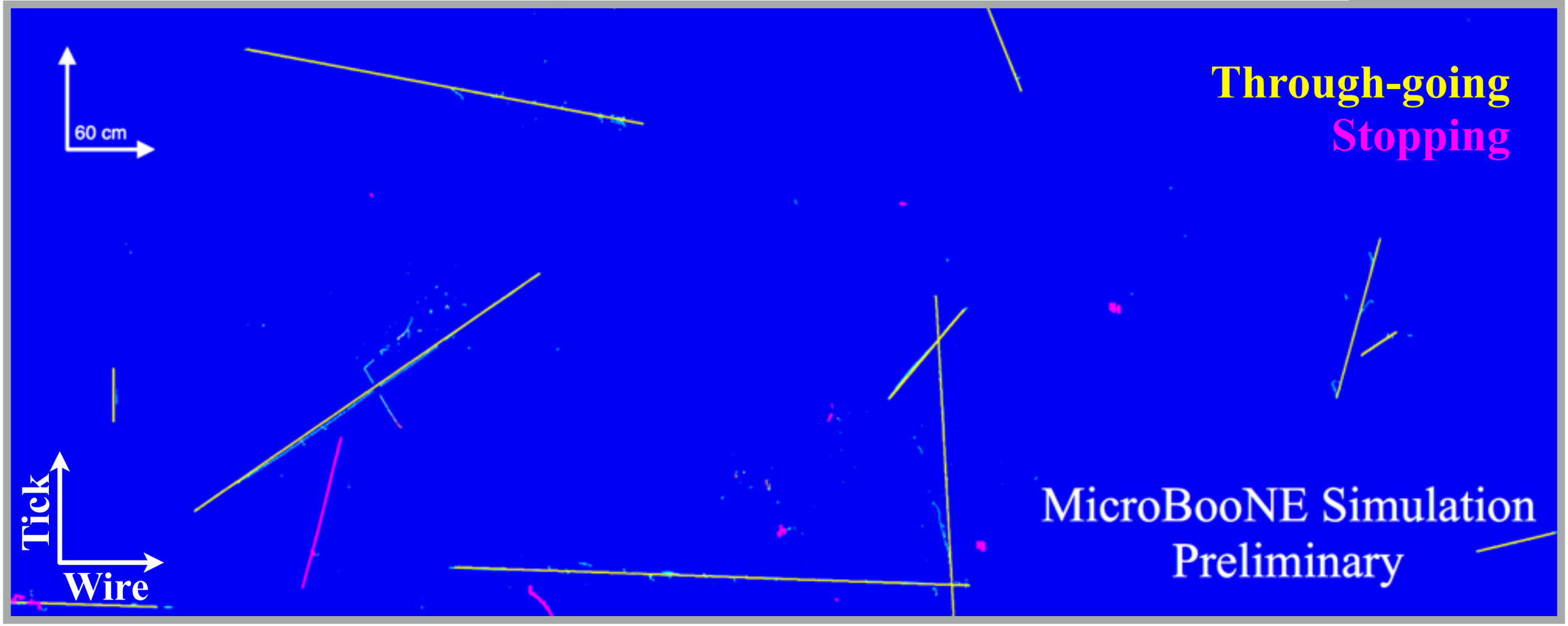
Reconstruction Chain Overview

Event Selection

- Reject cosmic only images
- Identify cosmic rays
- Localize neutrino candidates

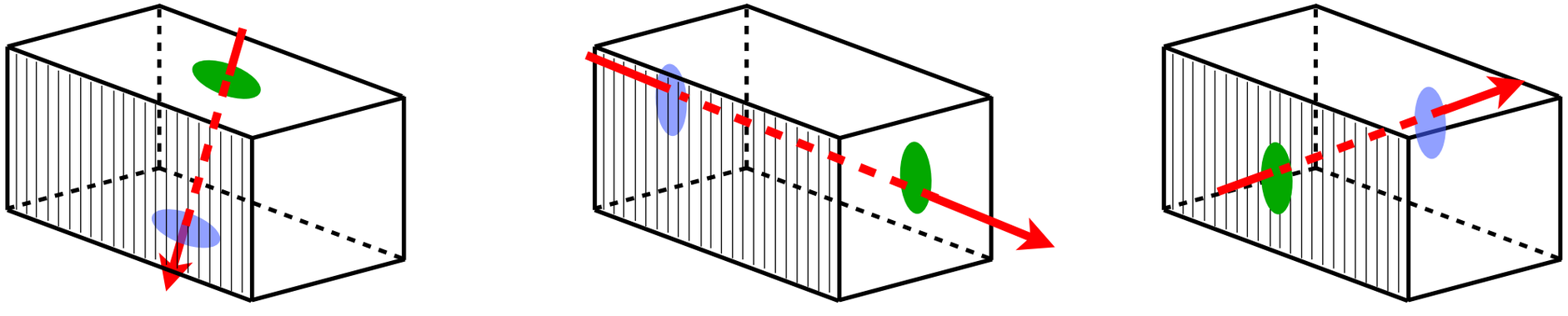


Cosmic Pixel Tagging

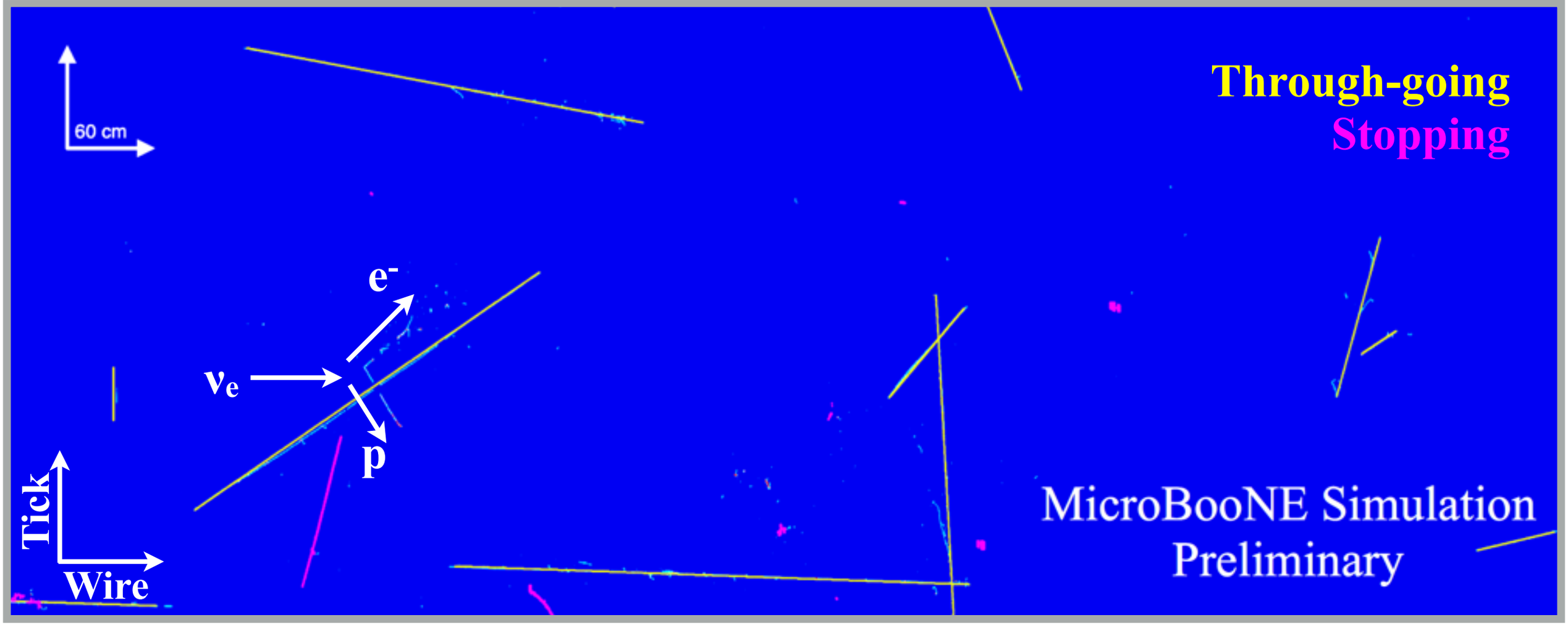


Procedure

- Identify edge-crossing tracks
- Connect end-points by following charge with a 3D path finding algorithm



Cosmic Pixel Tagging



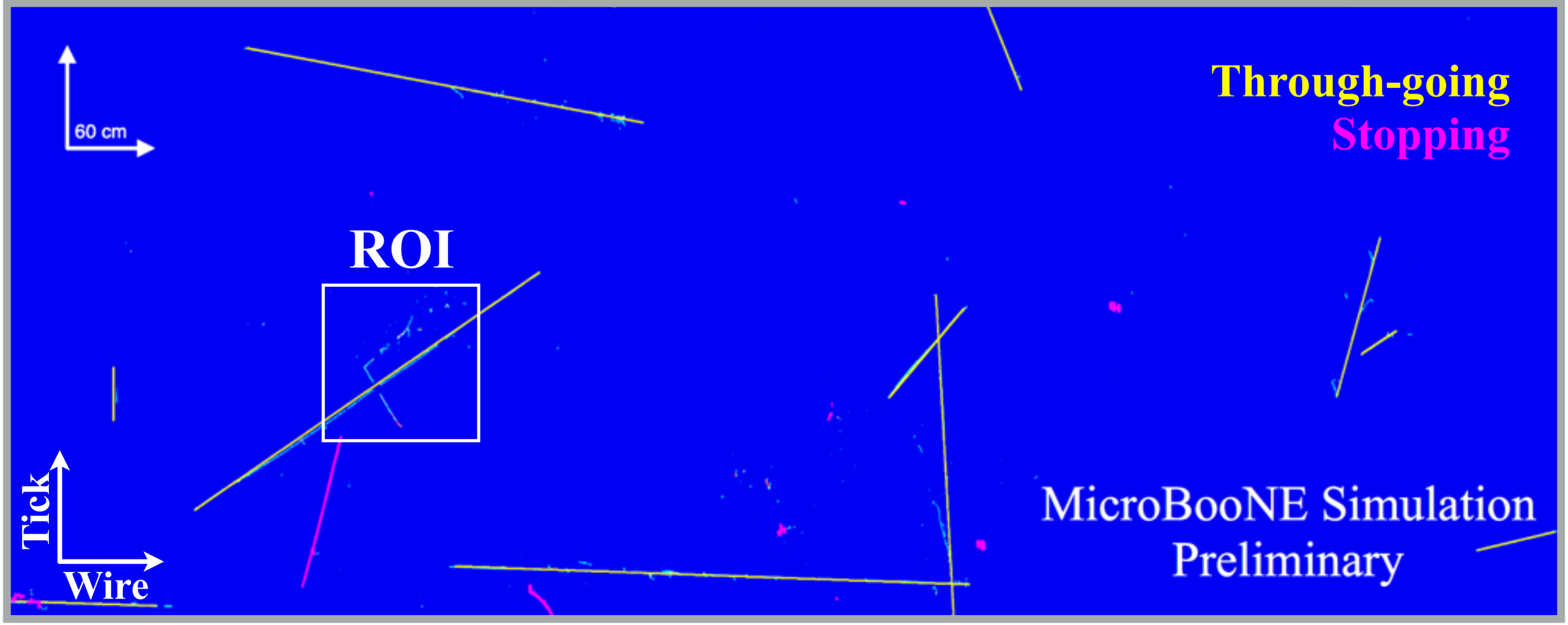
Procedure

- Identify edge-crossing tracks
- Connect end-points by following charge with a 3D path finding algorithm

Result

- Un-tagged pixels: contained tracks, like our neutrino topology

Cosmic Pixel Tagging



Procedure

- Identify edge-crossing tracks
- Connect end-points by following charge with a 3D path finding algorithm

Result

- Un-tagged pixels: contained tracks, like our neutrino topology
- Draw 3D Region of Interest (ROI) around untagged pixels, match with a flash

Reconstruction Chain Overview

Event Selection

- Reject cosmic only images
- Identify cosmic rays
- Localize neutrino candidates

Neutrino interaction reconstruction

- Identify track and shower pixels
- Reconstruct 3D interaction vertex
- Identify particle type

Reconstruction Chain Overview

Event Selection

- Reject cosmic only images
- Identify cosmic rays
- Localize neutrino candidates

Neutrino interaction reconstruction

- Identify track and shower pixels
- Reconstruct 3D interaction vertex
- Identify particle type

PMT pre-cuts

Cosmic Tag & ROI finding

Track/Shower Pixel Labeling

3D Vertex Reco

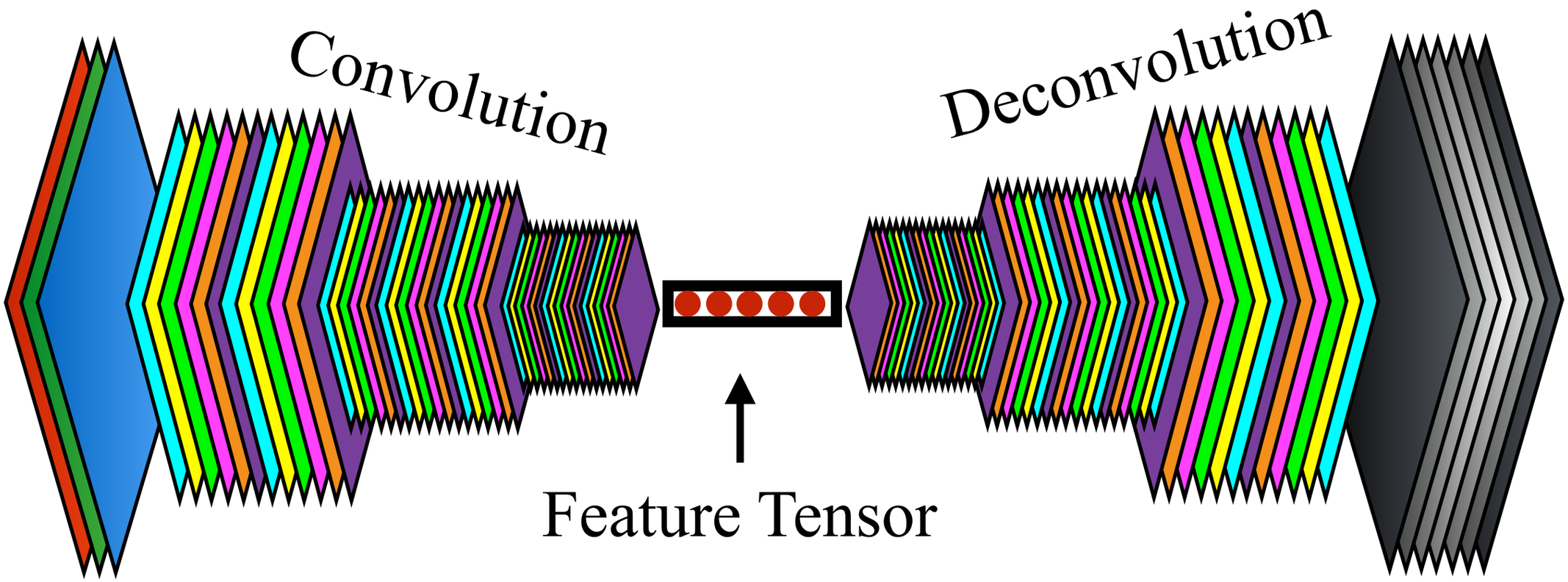
Particle ID

Deep Learning

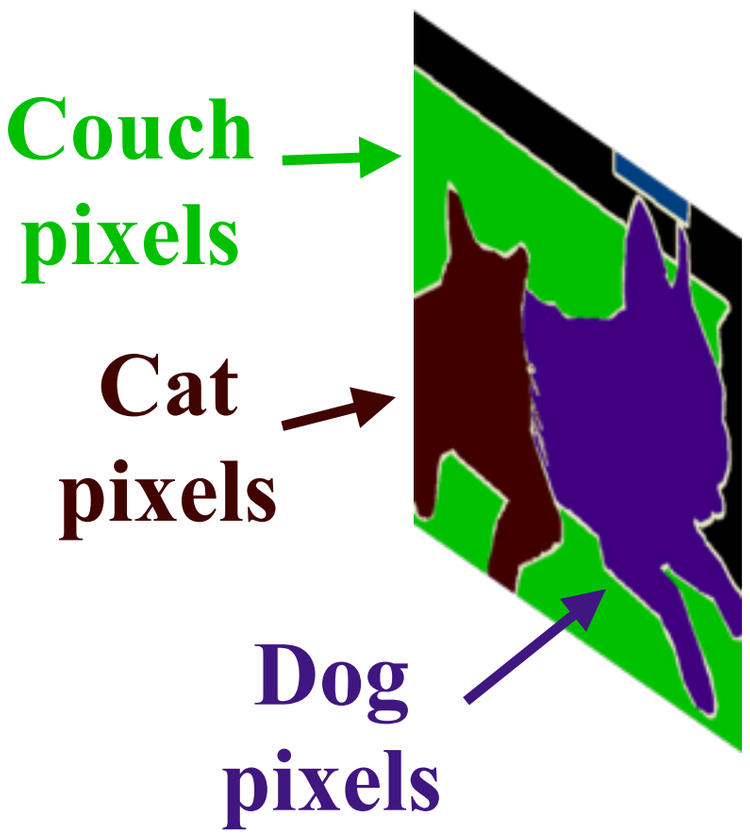
- Convolutional neural networks (CNNs) for feature finding in LArTPC images

Semantic Segmentation

Deep Learning

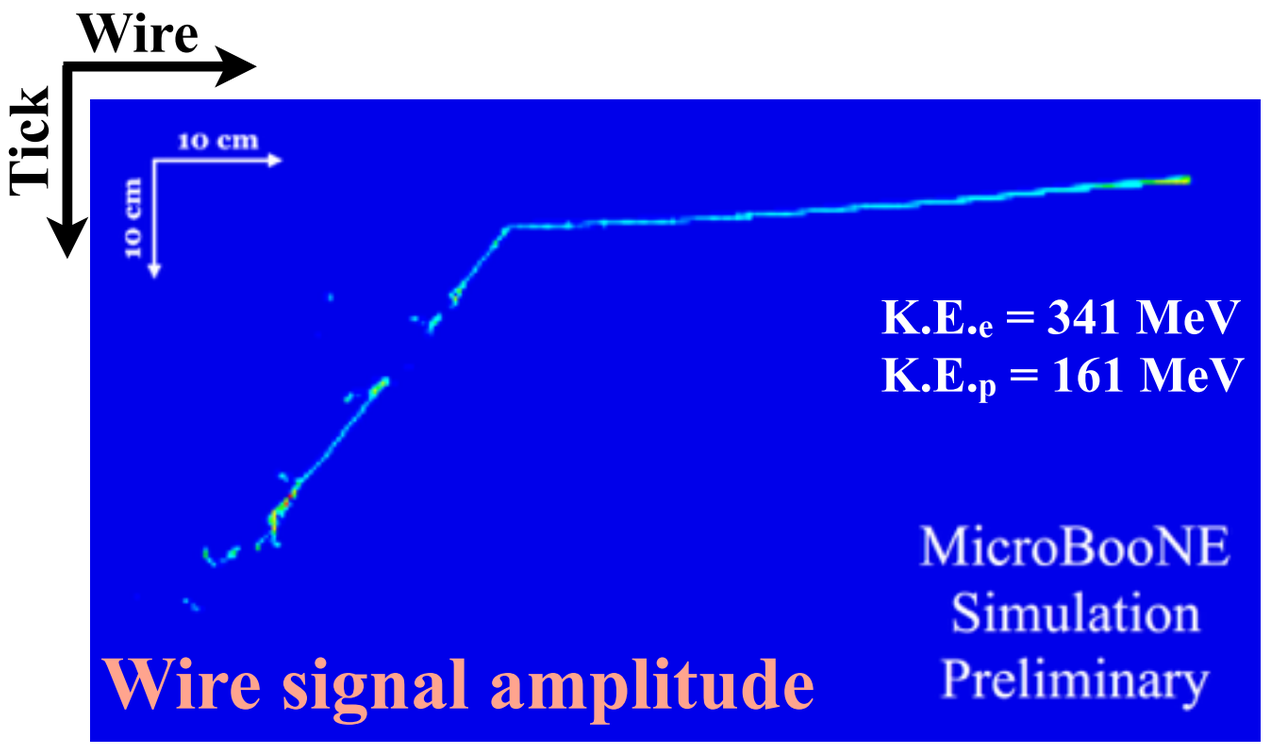


- CNN for pixel-wise classification
- Feature tensor is interpolated back into original image by up-sampling and deconvolution operations

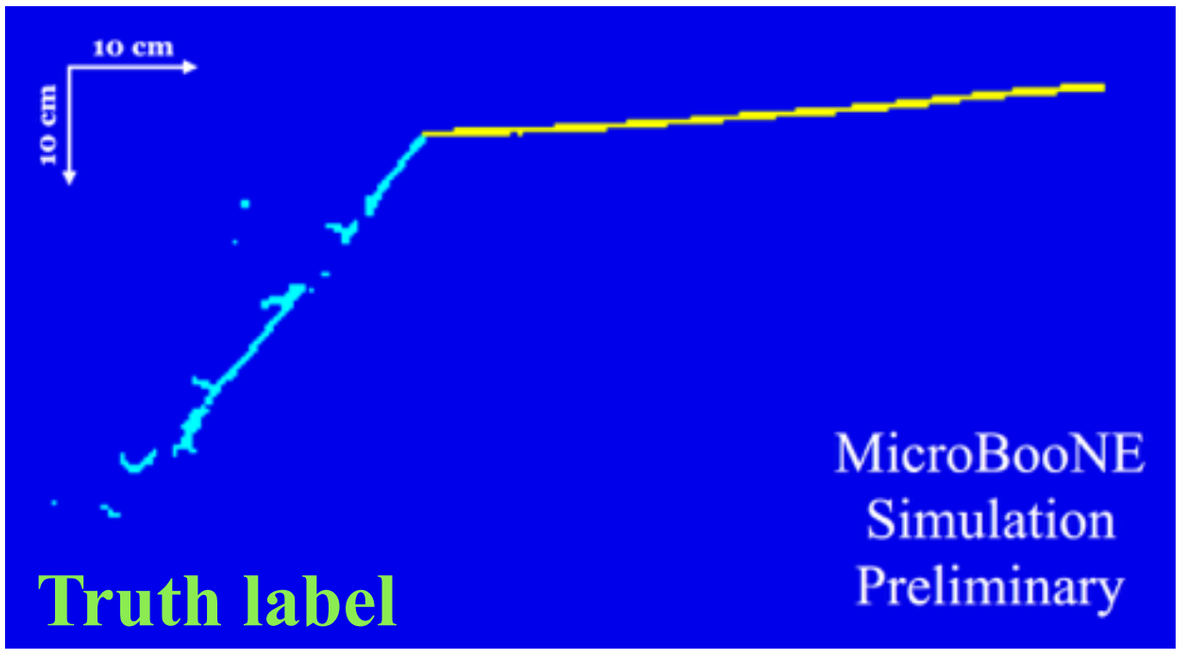


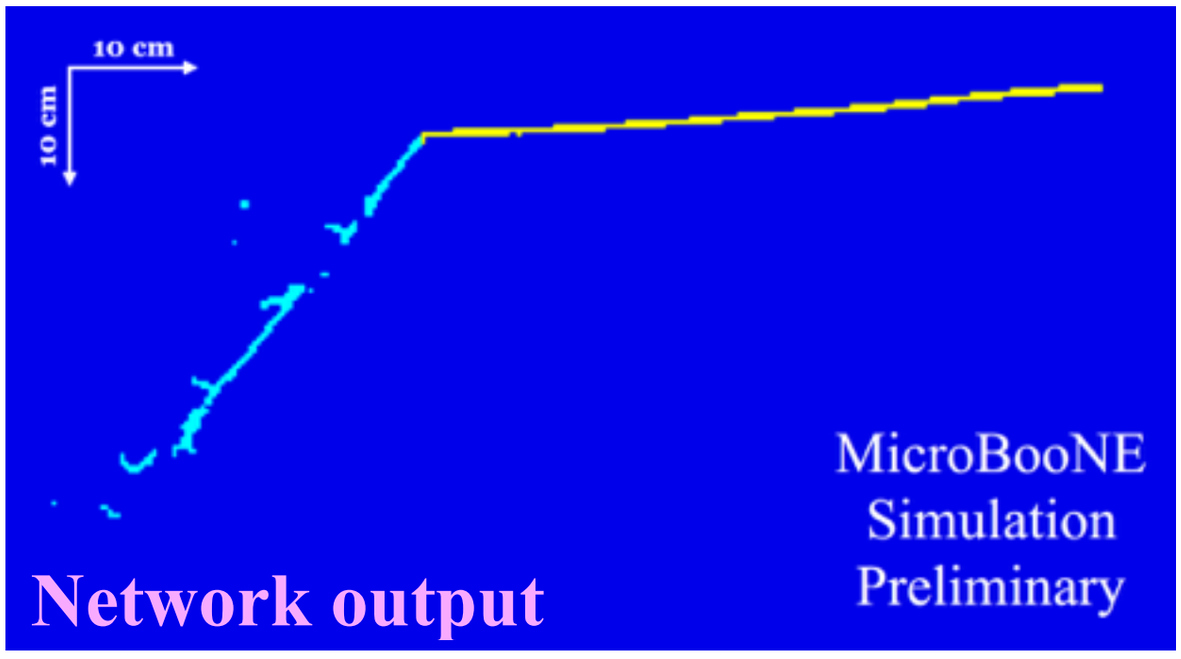
Semantic Segmentation for Track/Shower

Deep Learning



- **Goal**: separate track and shower to assist 3D vertex reconstruction
- Use neural network to label pixels as "background", "track", or "shower"

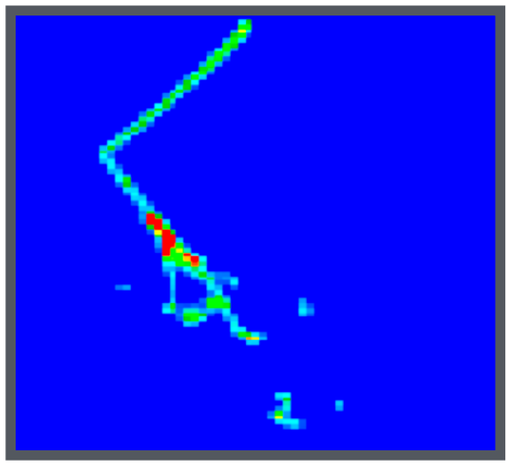




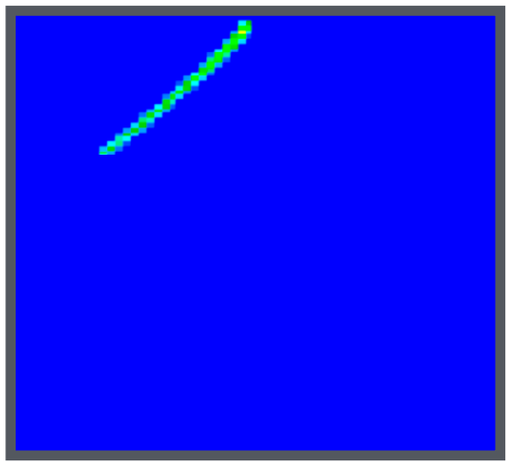
Yellow = Track Cyan = Shower

3D Vertex Reconstruction

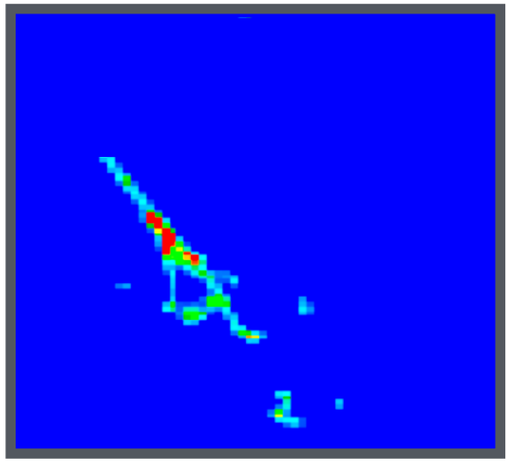
ADC Image



Track Image



Shower Image

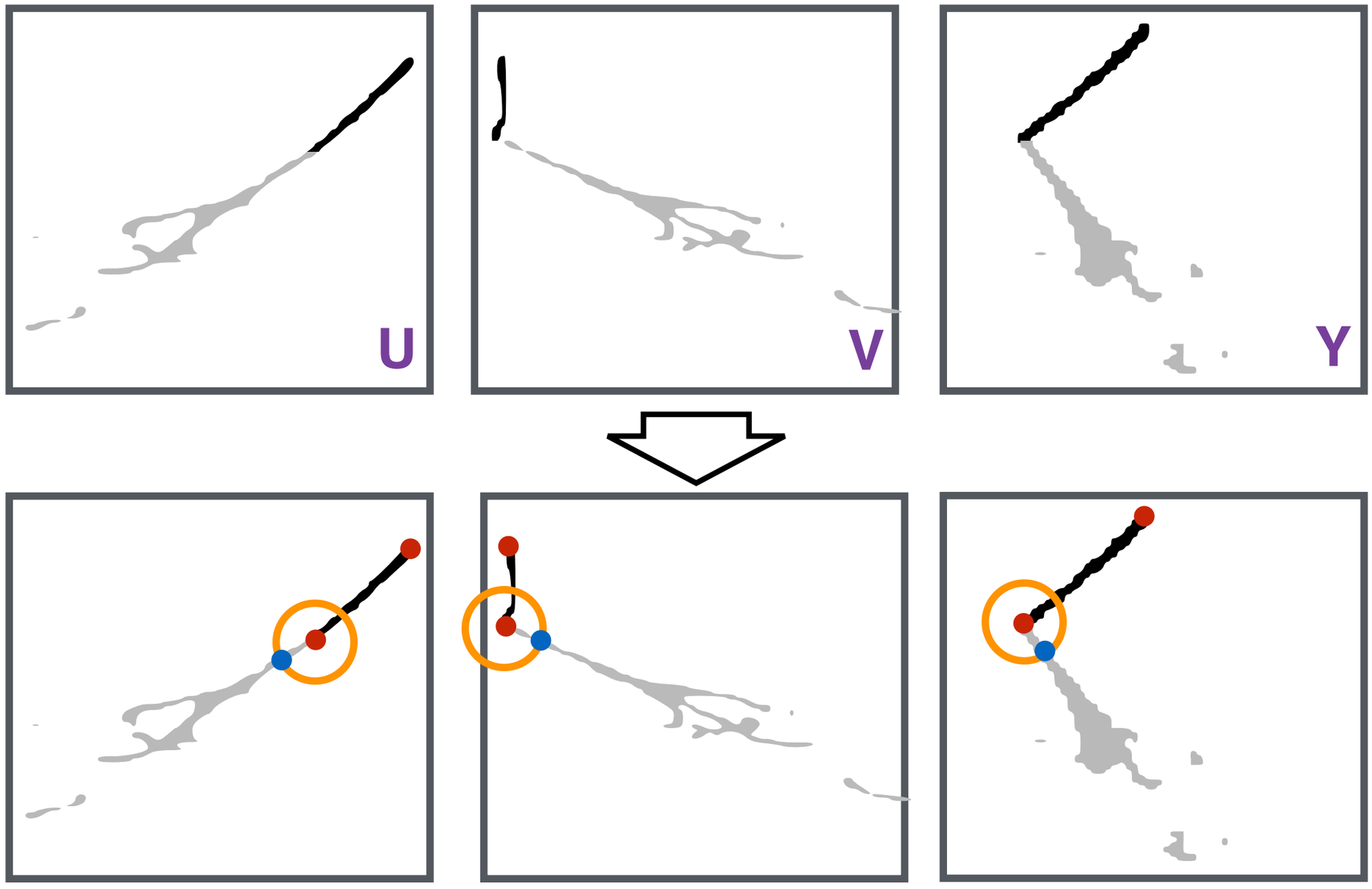


Goal: find 3D vertex using track and shower features

- Find potential vertex candidate in **track+shower image**
  - finding **1 proton** + **1 electron**

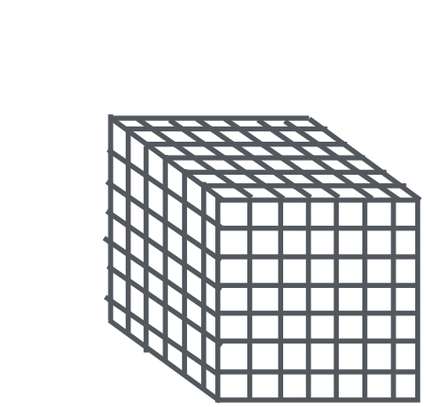
3D Vertex Reconstruction for ν_e

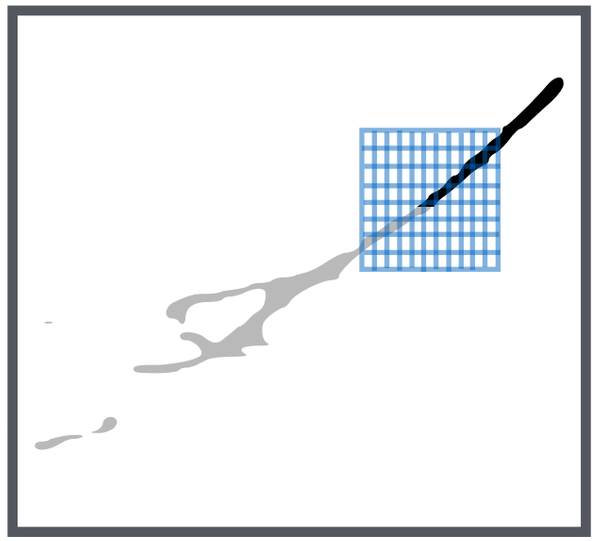
Track Pixels
Shower Pixels

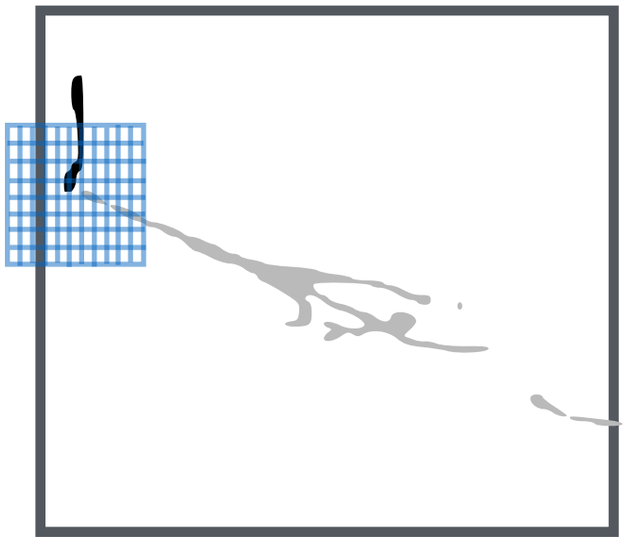


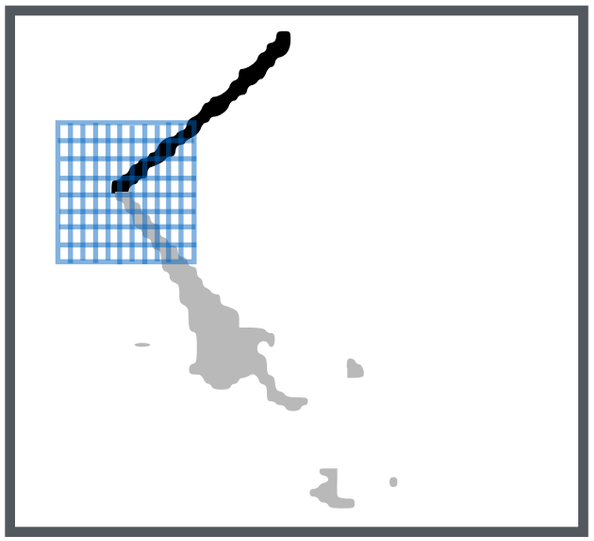
- Find edge of track with shower attached
- Correlate edges across planes and identify coincident 3D region

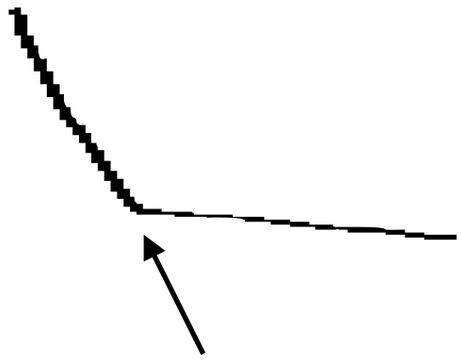
3D Vertex Reconstruction for ν_e



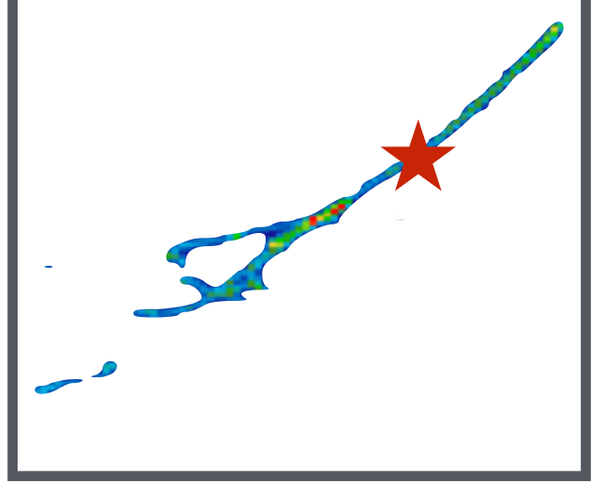


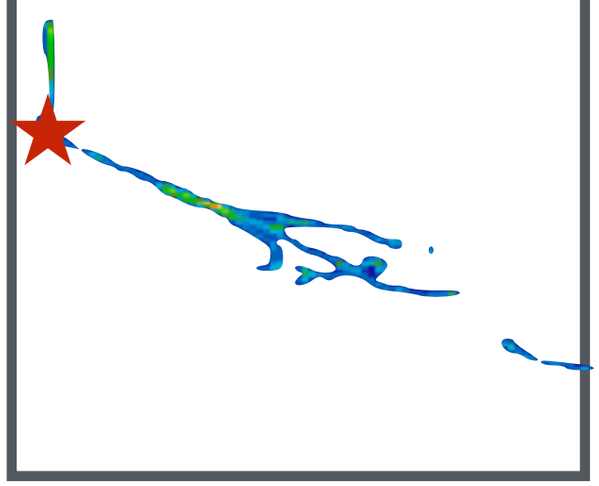


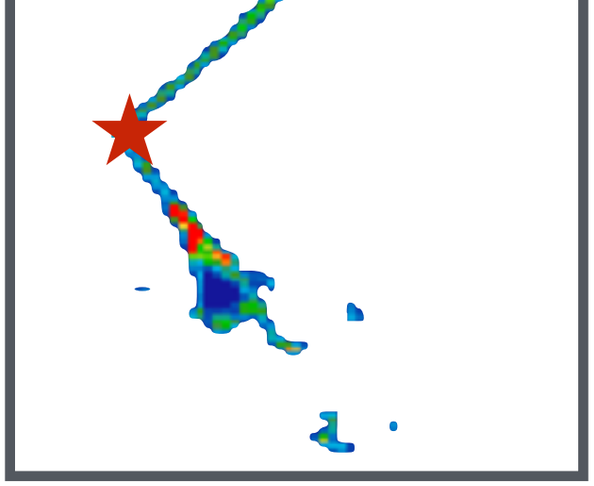




Estimate best coincident location of a kink





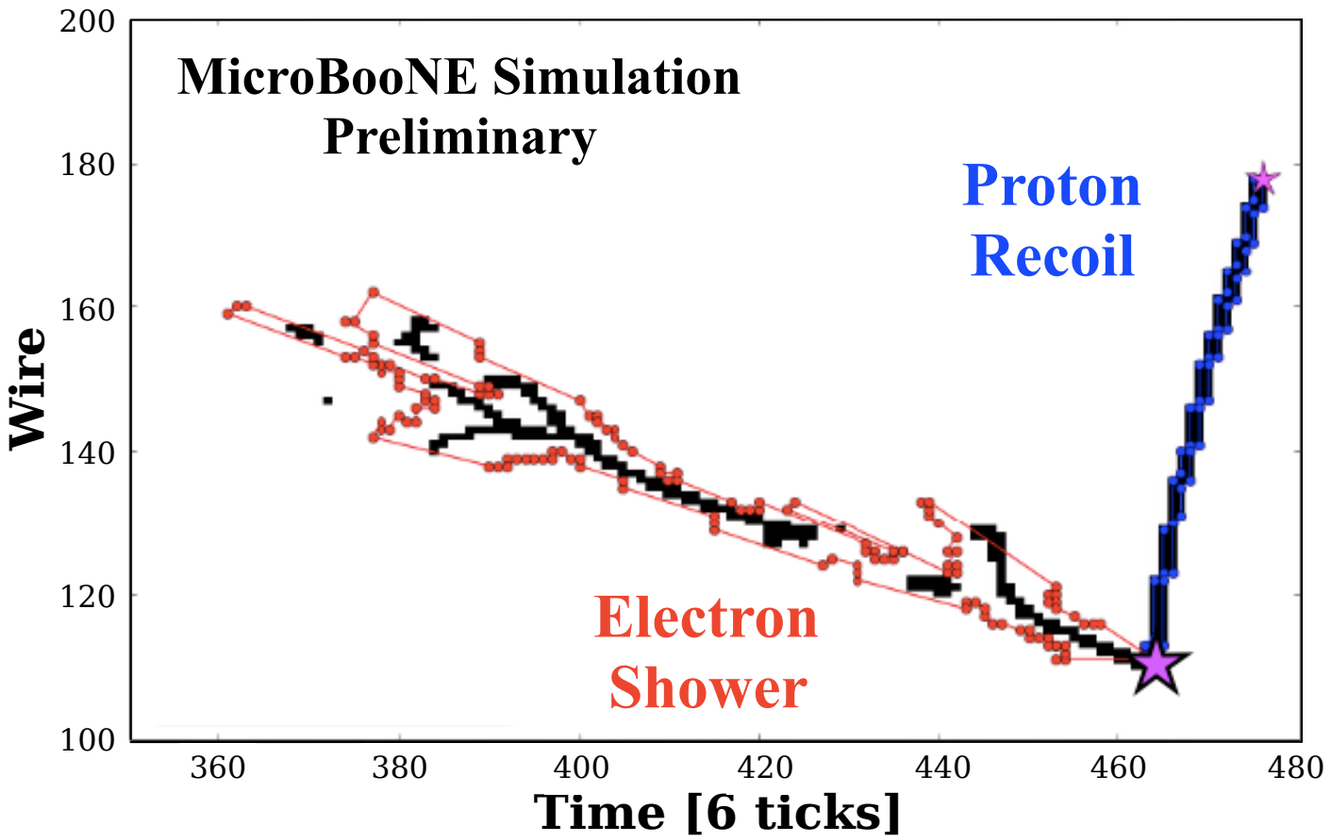


3D Vertex

- X = drift velocity * time coordinate
- Y, Z = wire coincidence

Particle ID

Deep Learning



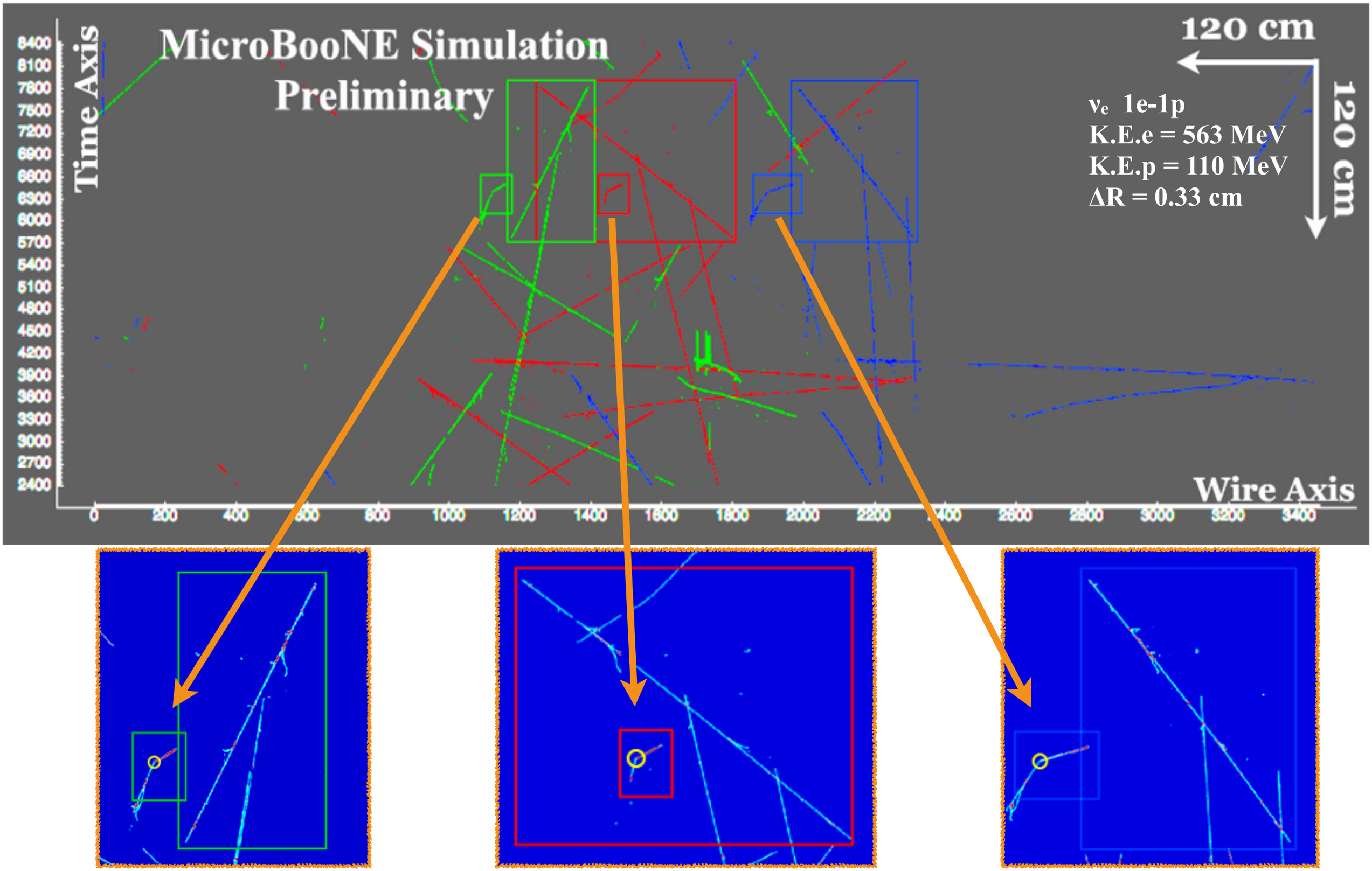
Particle	Correct ID (%)
e^-	77.8 ± 0.7 %
γ	83.4 ± 0.6 %
μ^-	89.7 ± 0.5 %
π^-	71.0 ± 0.7 %
p	91.2 ± 0.5 %

Goal: cluster particles and classify particle type

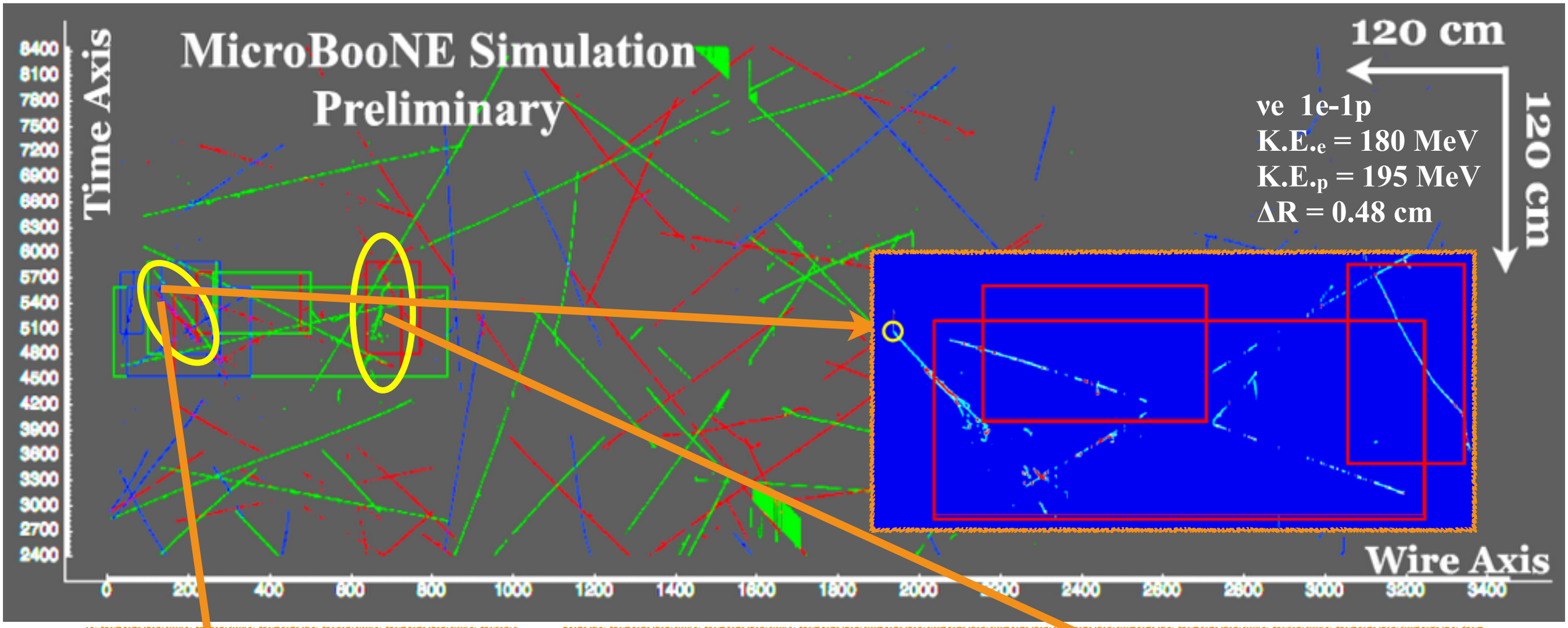
- Feed individual particle cluster to a CNN-based particle ID network
- Based on MicroBooNE 1st publication! JINST 12, P03011 (2017)

Results

Reconstructed Events



Reconstructed Events



Summary

- **Fully automated reconstruction chain** for
  1 proton + 1 electron events using image analysis

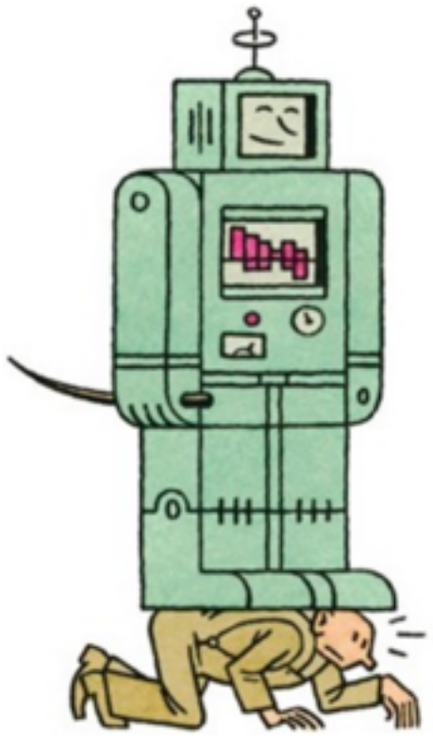
  - Target CCQE topology for Low Energy Excess search

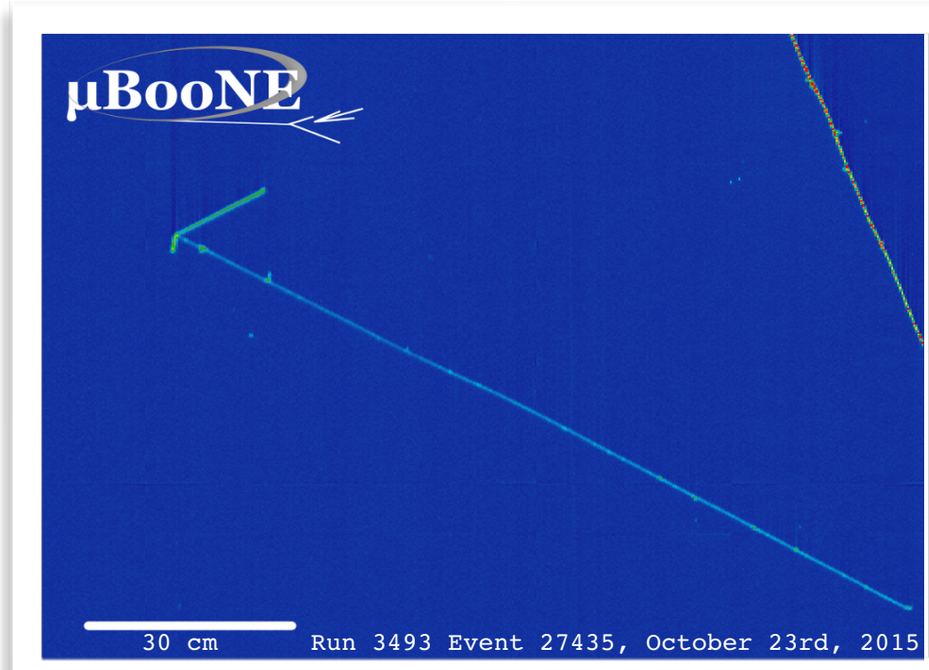
  - Methods for cosmic background ID & rejection

  - CNN Networks to aid reconstruction
    - Semantic segmentation for track/shower labelling
    - Particle ID

  - Reconstruct 3D vertex and can find ν_e in Monte Carlo!

Thanks for your attention!





Backup

MicroBooNE

- **Short Baseline Neutrino Oscillation Experiment @ Fermilab**
  - Oscillation mode:

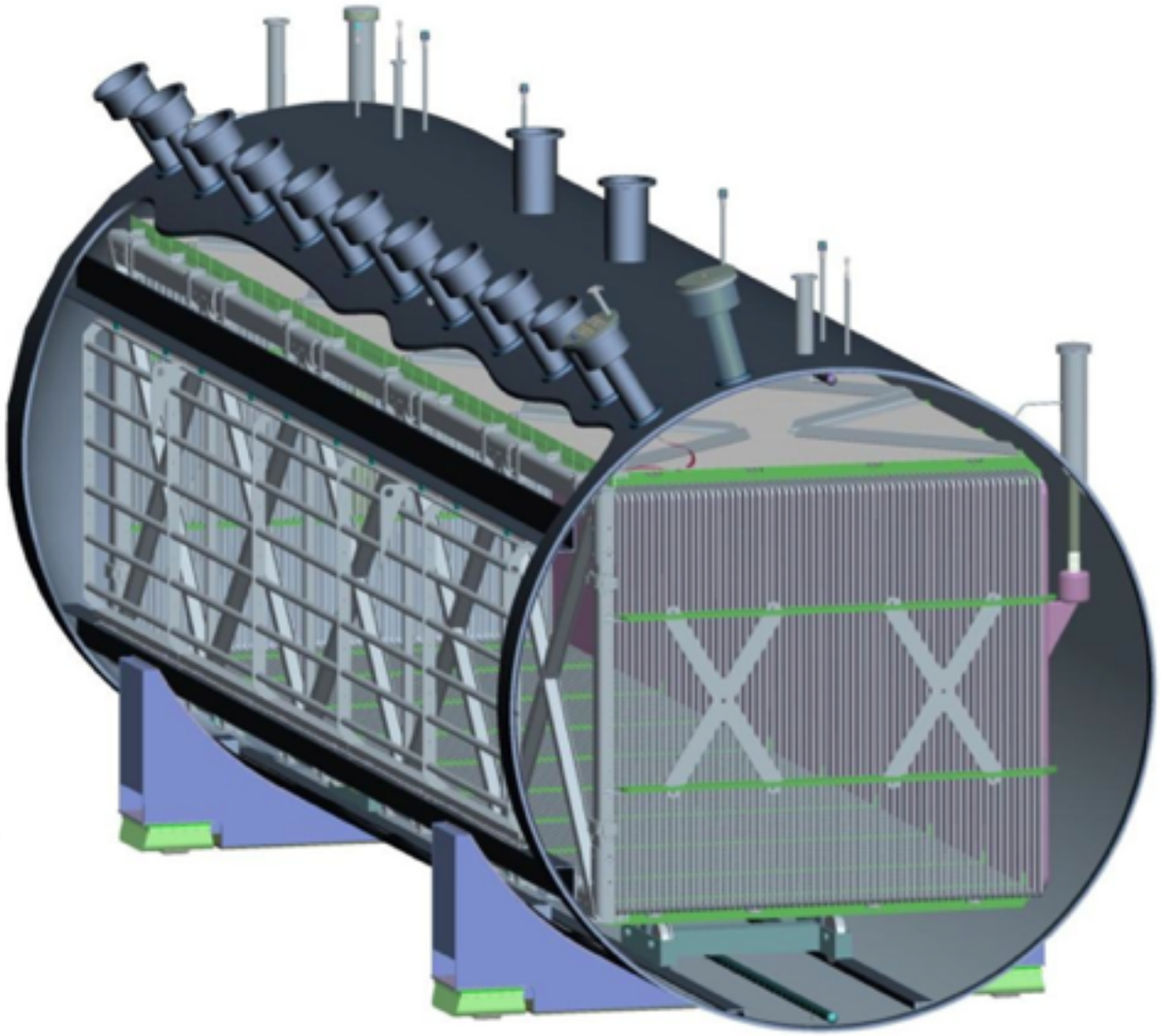
    $\nu_\mu \Rightarrow \nu_e$ … **L/E ≈ *o* (1 m/MeV)**

- **Neutrino source**
  - Booster Neutrino Beam (BNB)
    - Accelerator @ Fermilab

- **Detector (nu-target)**
  1. **Liquid Argon (LAr) Cryostat**
  2. **Time Projection Chamber (TPC)**
  3. **Optical Detector**

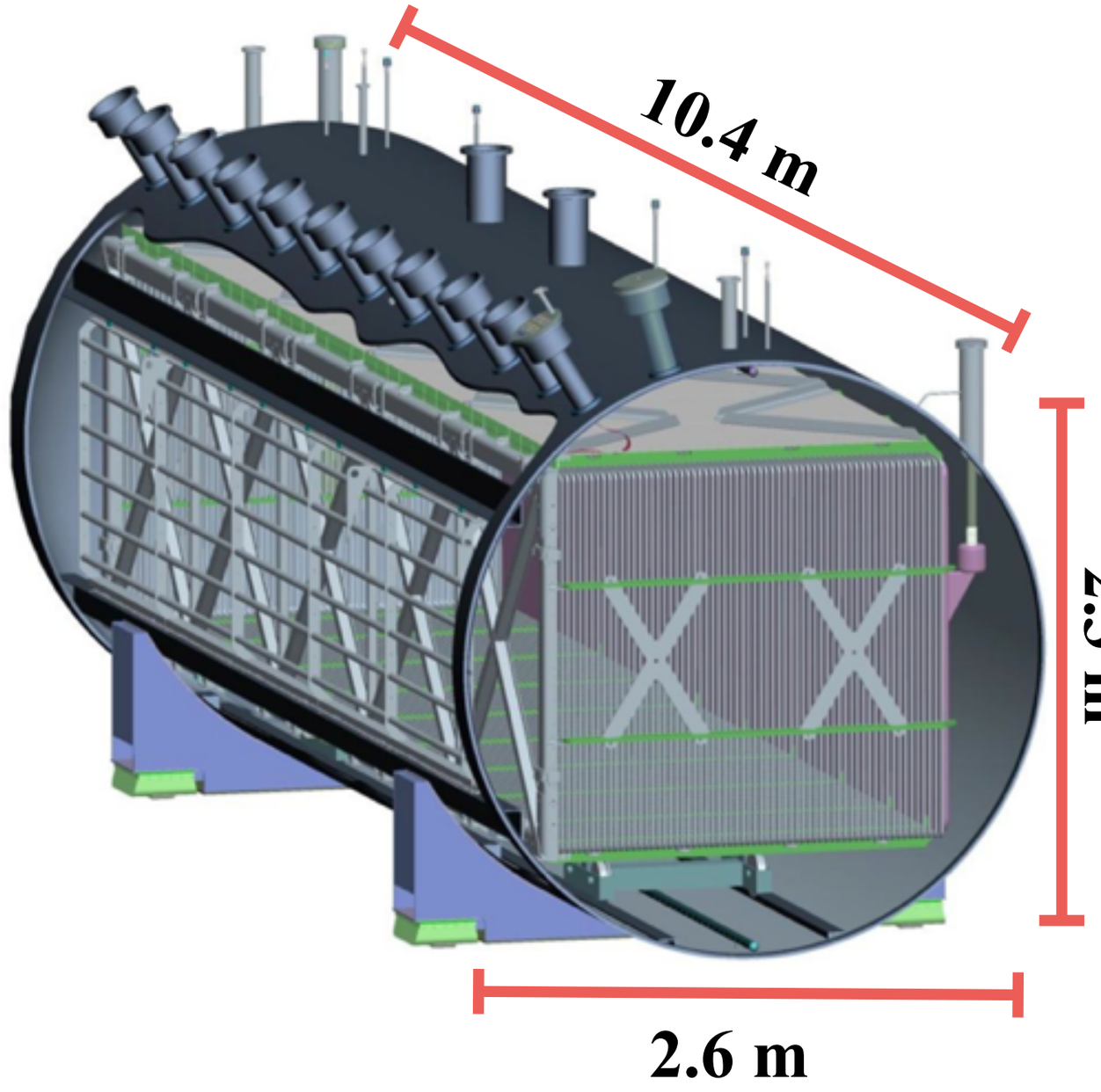
Three Objectives

1. **MiniBooNE low E excess**
2. **Low E ν-Ar cross-section**
3. **LArTPC R&D**



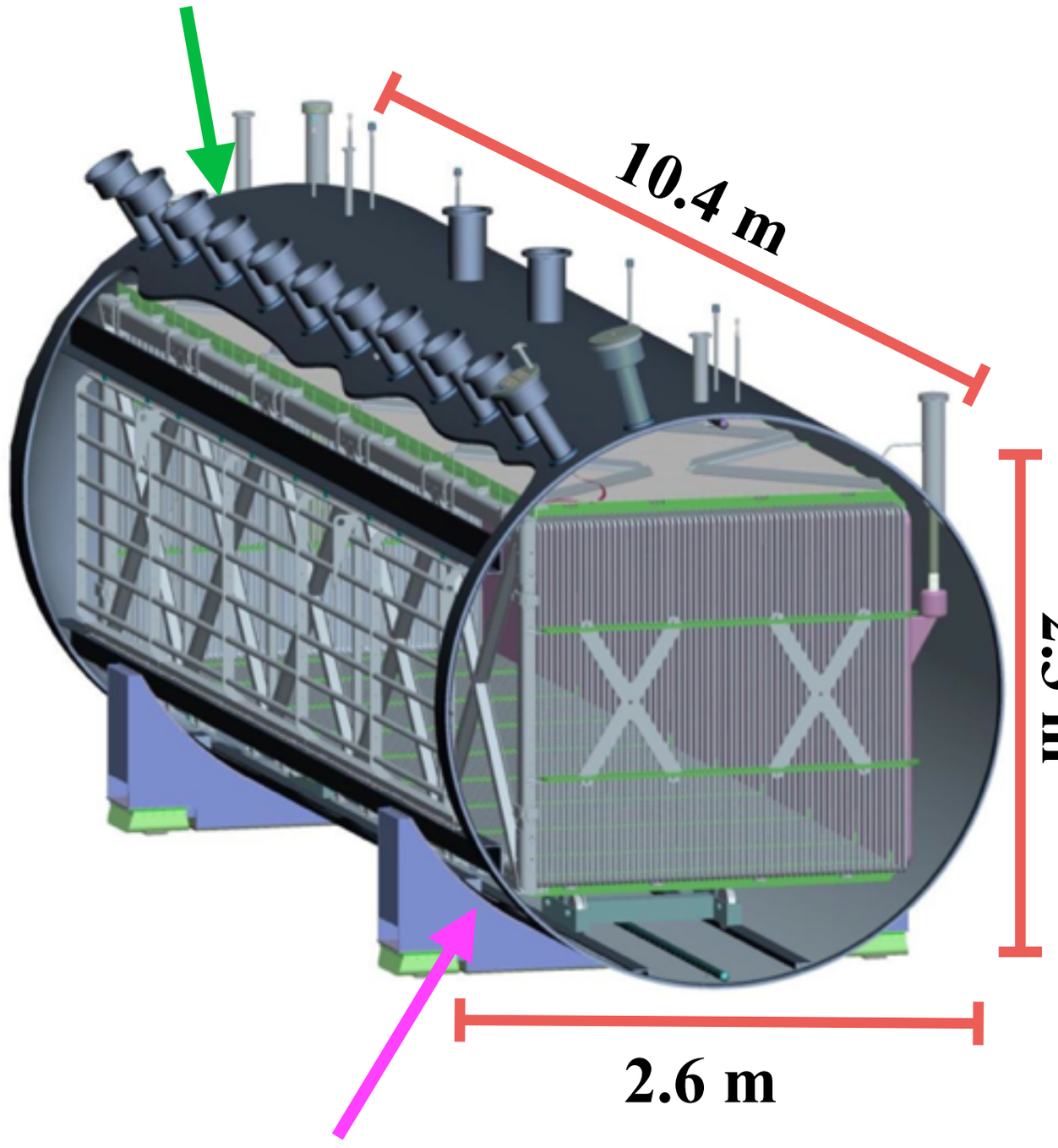
MicroBooNE schematic

MicroBooNE



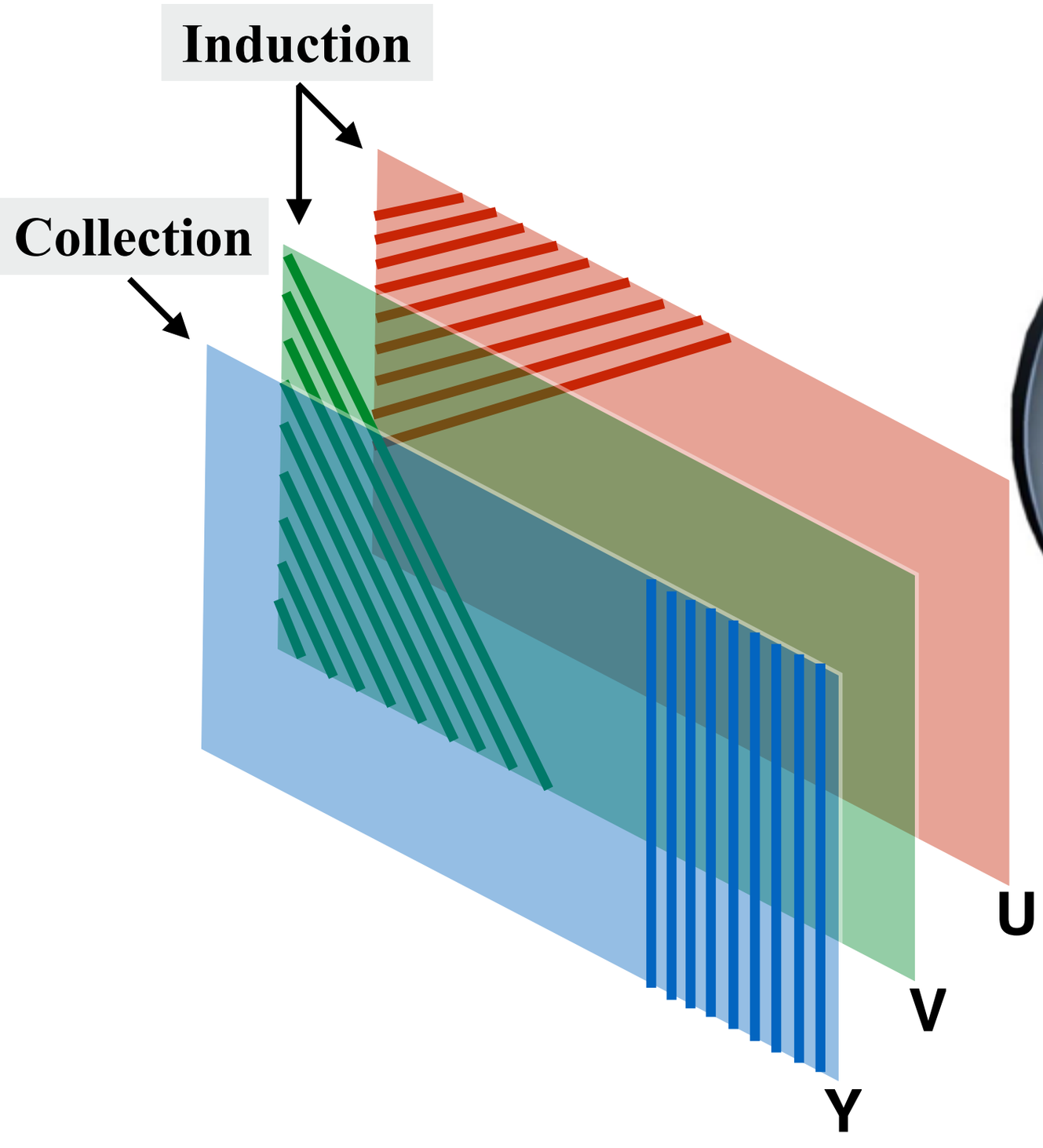
MicroBooNE

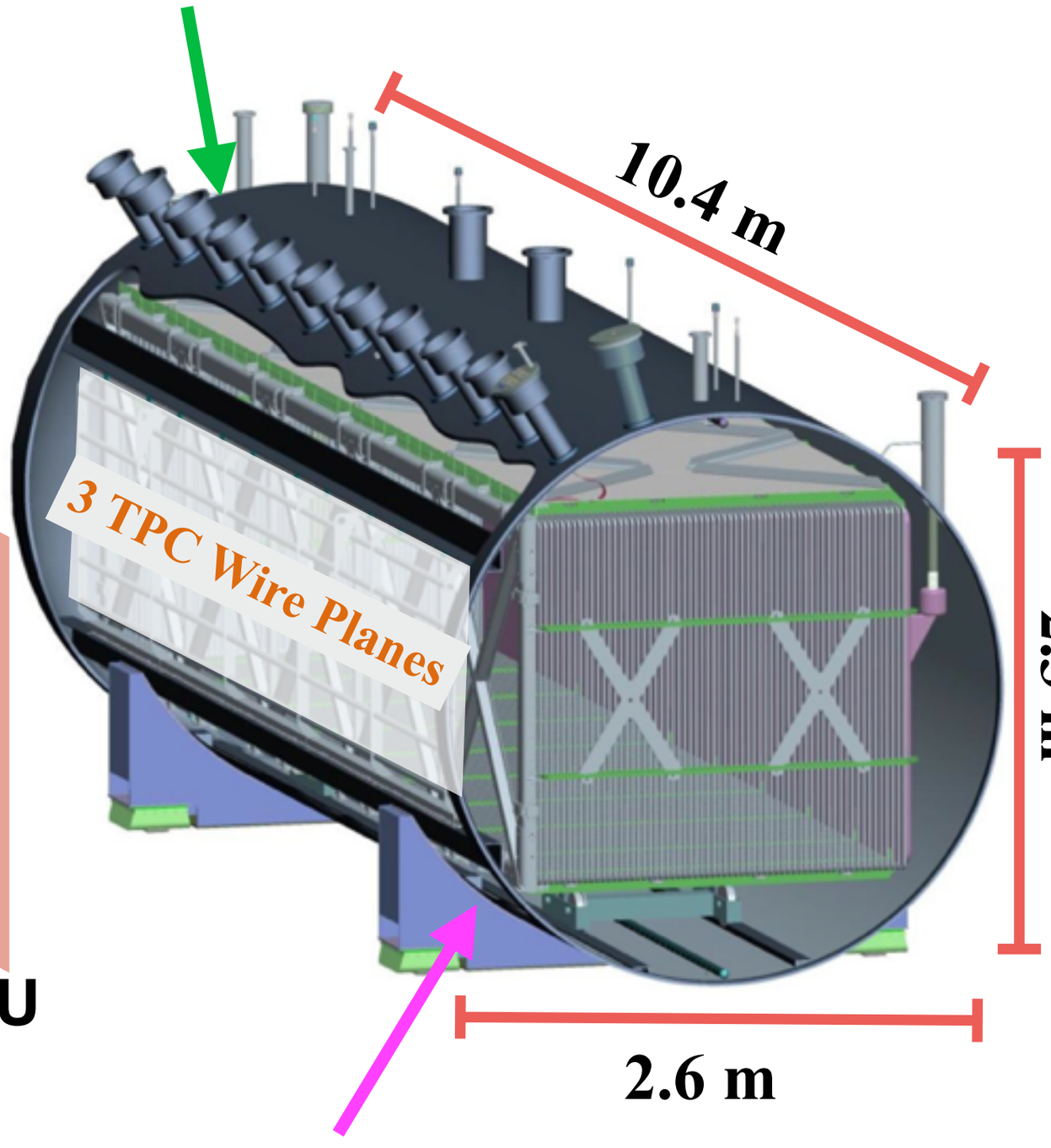
Cryostat
Total LAr mass 170 tons



Field Cage with TPC
Active LAr volume 90 tons

MicroBooNE

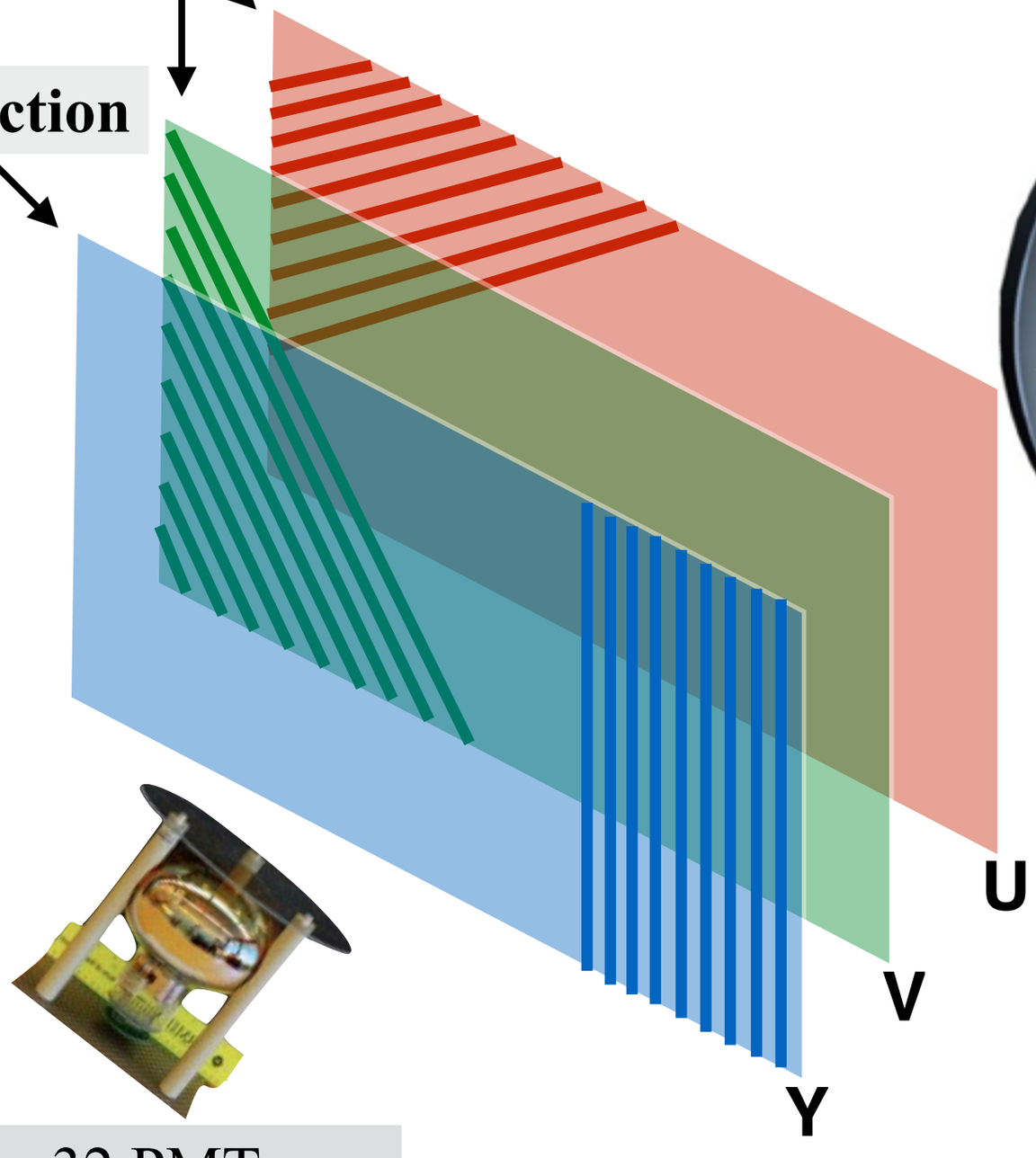

Induction
Collection
U
V
Y


Cryostat
Total LAr mass 170 tons
10.4 m
3 TPC Wire Planes
2.3 m
2.6 m
Field Cage with TPC
Active LAr volume 90 tons

MicroBooNE

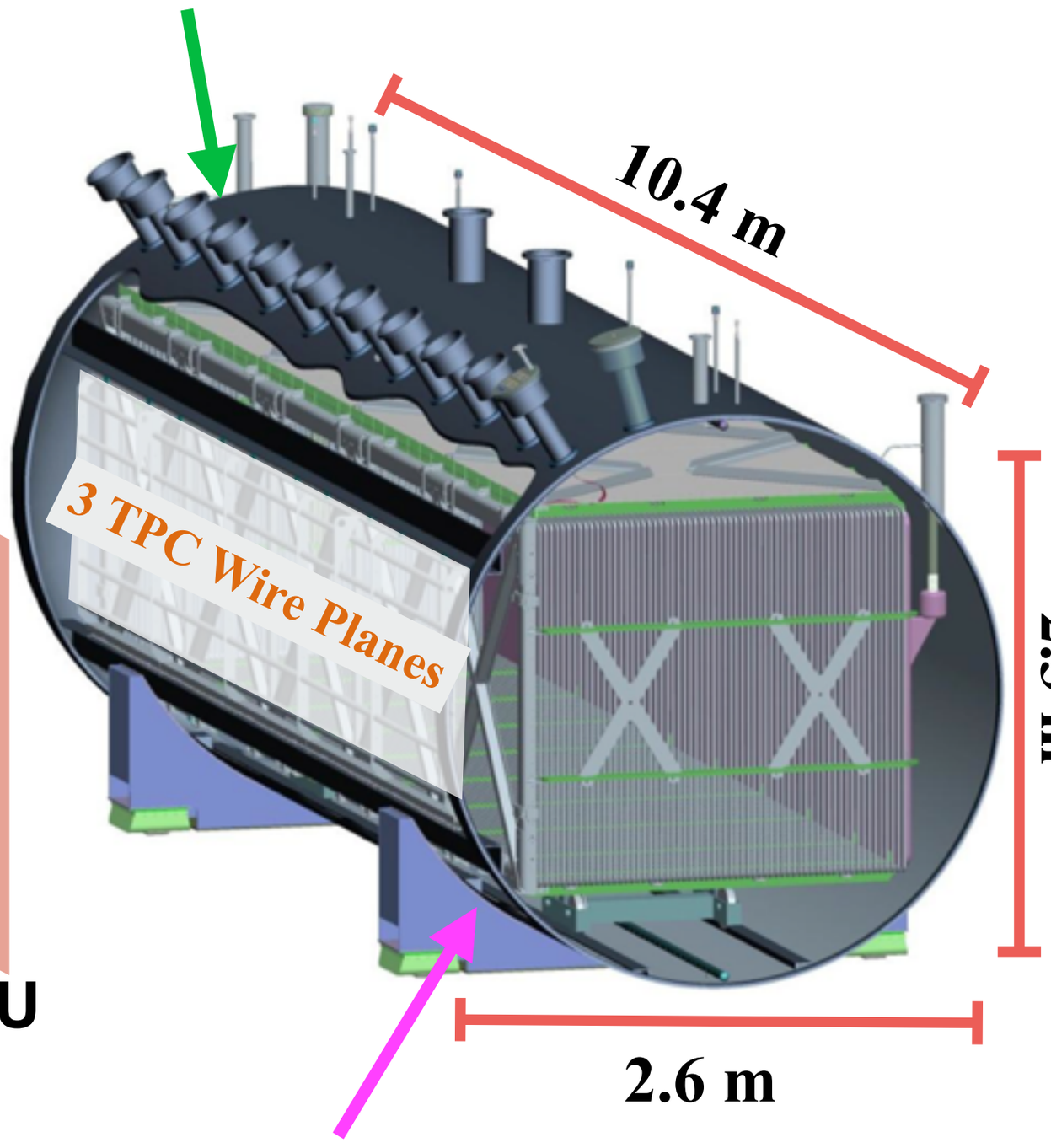
Induction

Collection



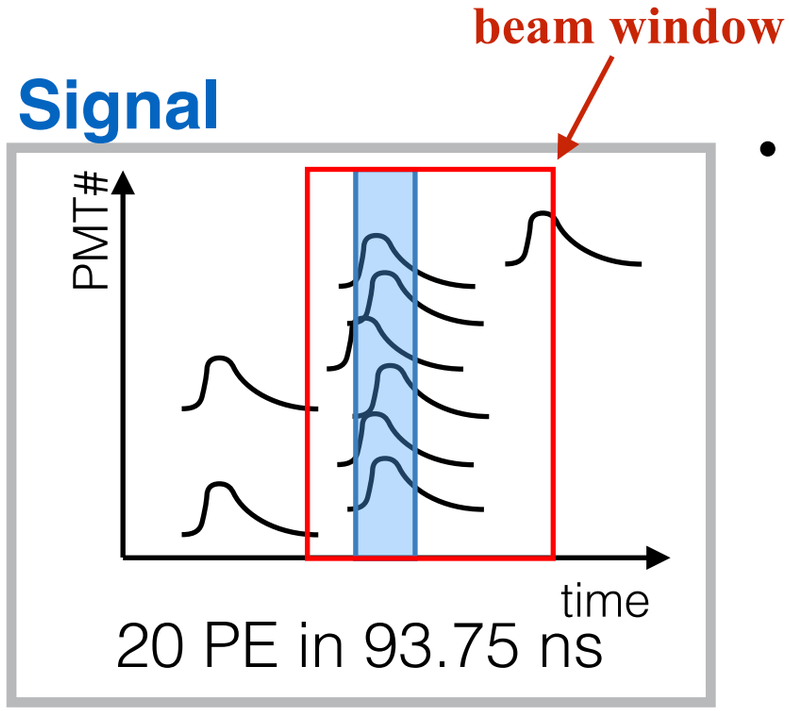
32 PMT
Optical Detector

Cryostat
Total LAr mass 170 tons



Field Cage with TPC
Active LAr volume 90 tons

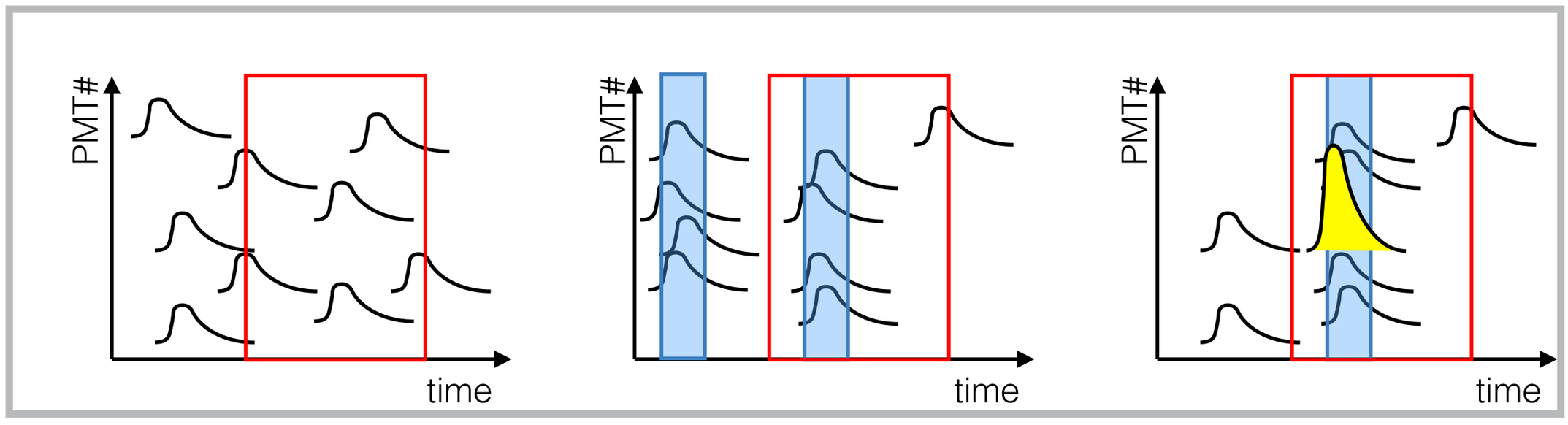
PMT Pre-Cuts



- **Goal**: reduce reconstruction load by selecting events with a neutrino light flash

Efficiency > 96%
Background rejection > 75%

Background



Random single PE noise

No signal 2 μs before beam, reject Michels

Max single PMT light <60% total light, avoid PMT based noise