DEEP UNDERGROUND
NEUTRINO EXPERIMENT

The University Of Sheffield.

Shower Reconstruction in LAr for the Detection of π^0s in the DUNE Far Detector

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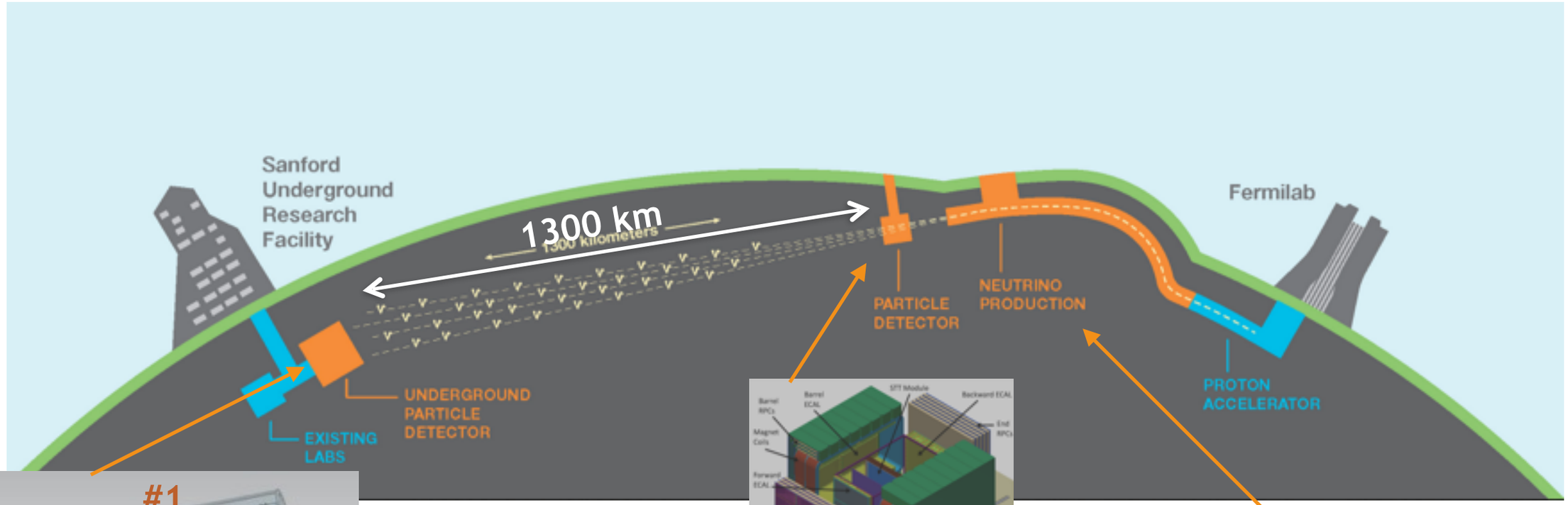
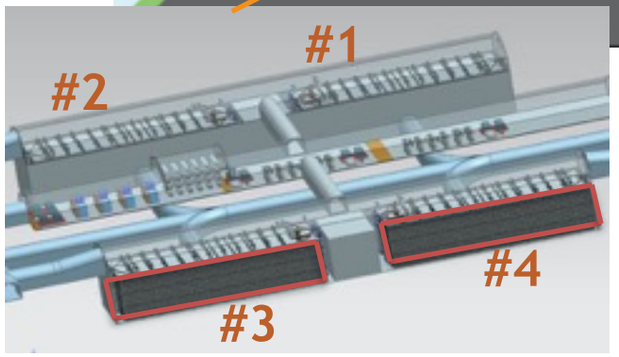
IOP HEPP&APP Conference, University of Sussex, Brighton
22nd March 2016

Overview

- DUNE
- LArTPCs
- Reconstruction in LArTPCs
- BlurredCluster
- EMShower
- Performance of Shower Reconstruction
- 35t Prototype Shower
- Summary

DUNE Experiment





Four identical cryostats deep underground; staged approach to four independent 10kton LAr detector modules

High precision near detector at 574 m

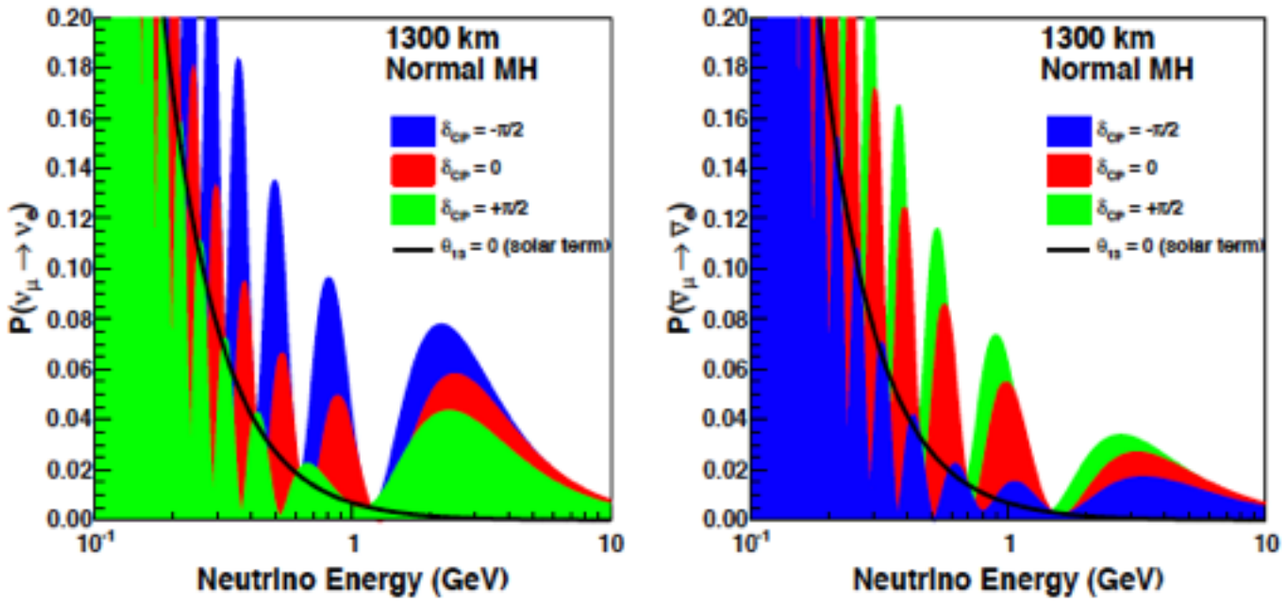
Wide band, high purity beam with peak flux at 2.5 GeV operating at ~1.2 MW and upgradable

- Future long-baseline neutrino oscillation experiment with a rich program in neutrino physics, nucleon decay and astrophysical physics.
- Also precision measurements of neutrino interactions in near detector.
- Utilises LAr TPC technology to make highly sensitive physics measurements.

DUNE Oscillation Signal

- Detect oscillation appearance of ν_e in a ν_μ beam.

$P(\nu_\mu \to \nu_e)$



$P(\bar{\nu}_\mu \to \bar{\nu}_e)$

DUNE CDR "physics volume"
arXiv:1512.06148v2

- In order to distinguish between

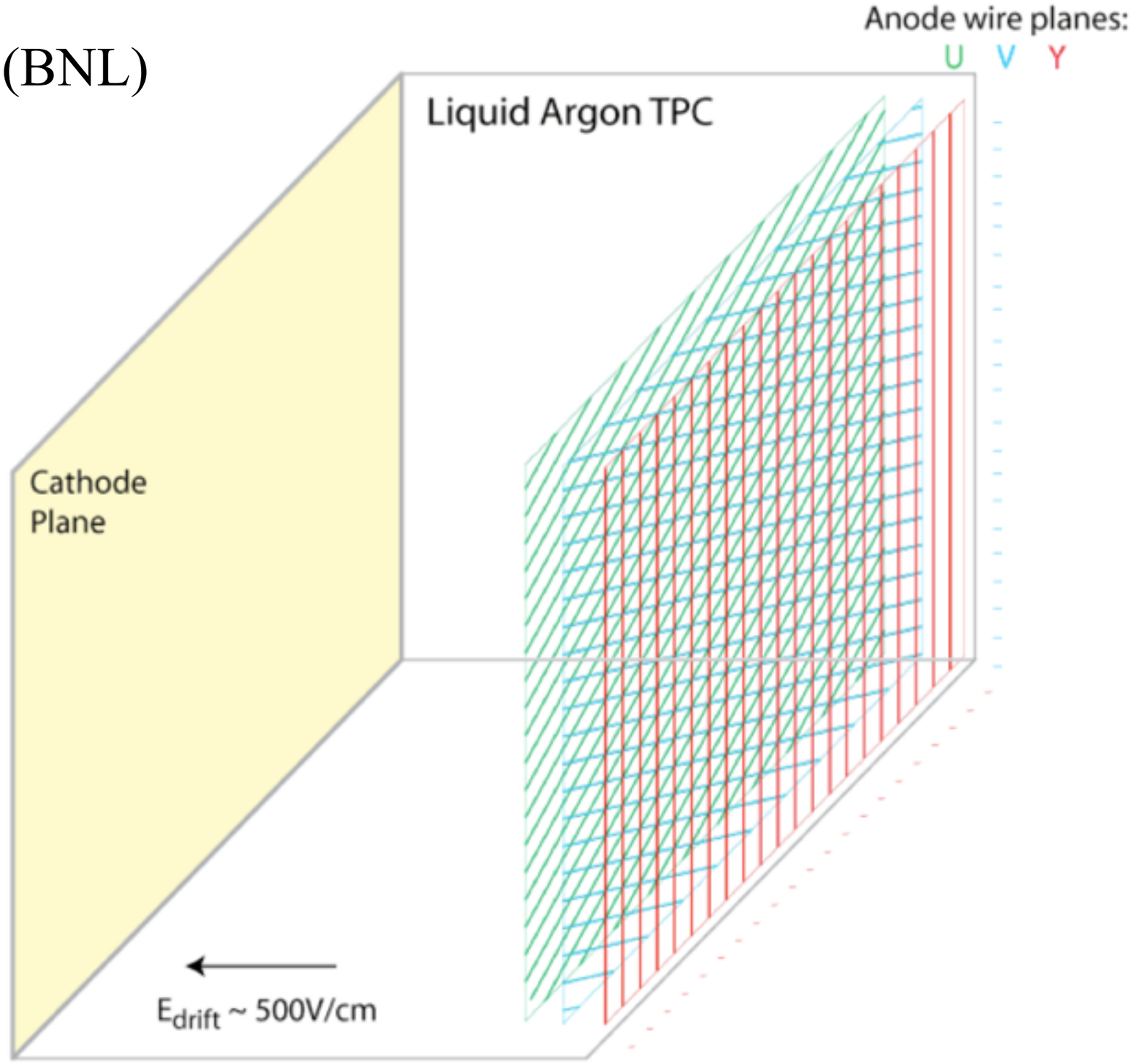
$$\nu_e + n \to e^- + p \qquad \text{and} \qquad \nu_\mu + n \to \nu_\mu + \pi^0 + hadrons$$

need to distinguish between the electron and the π^0 decay photons.

- Both photons and electrons initiate electromagnetic showers in LAr so excellent shower reconstruction is required to achieve DUNE physics goals.

LArTPC Concept

Bo Yu (BNL)



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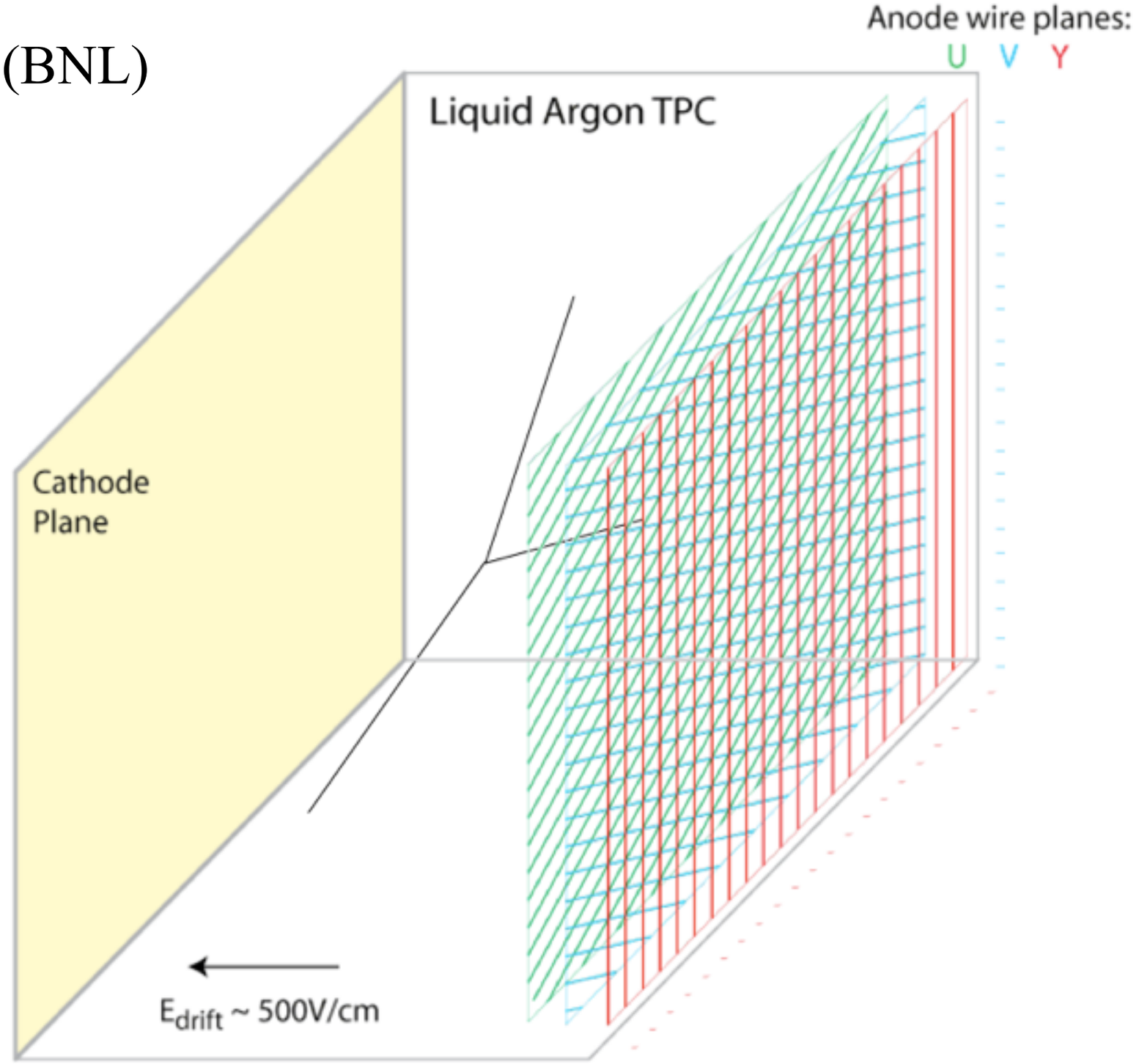

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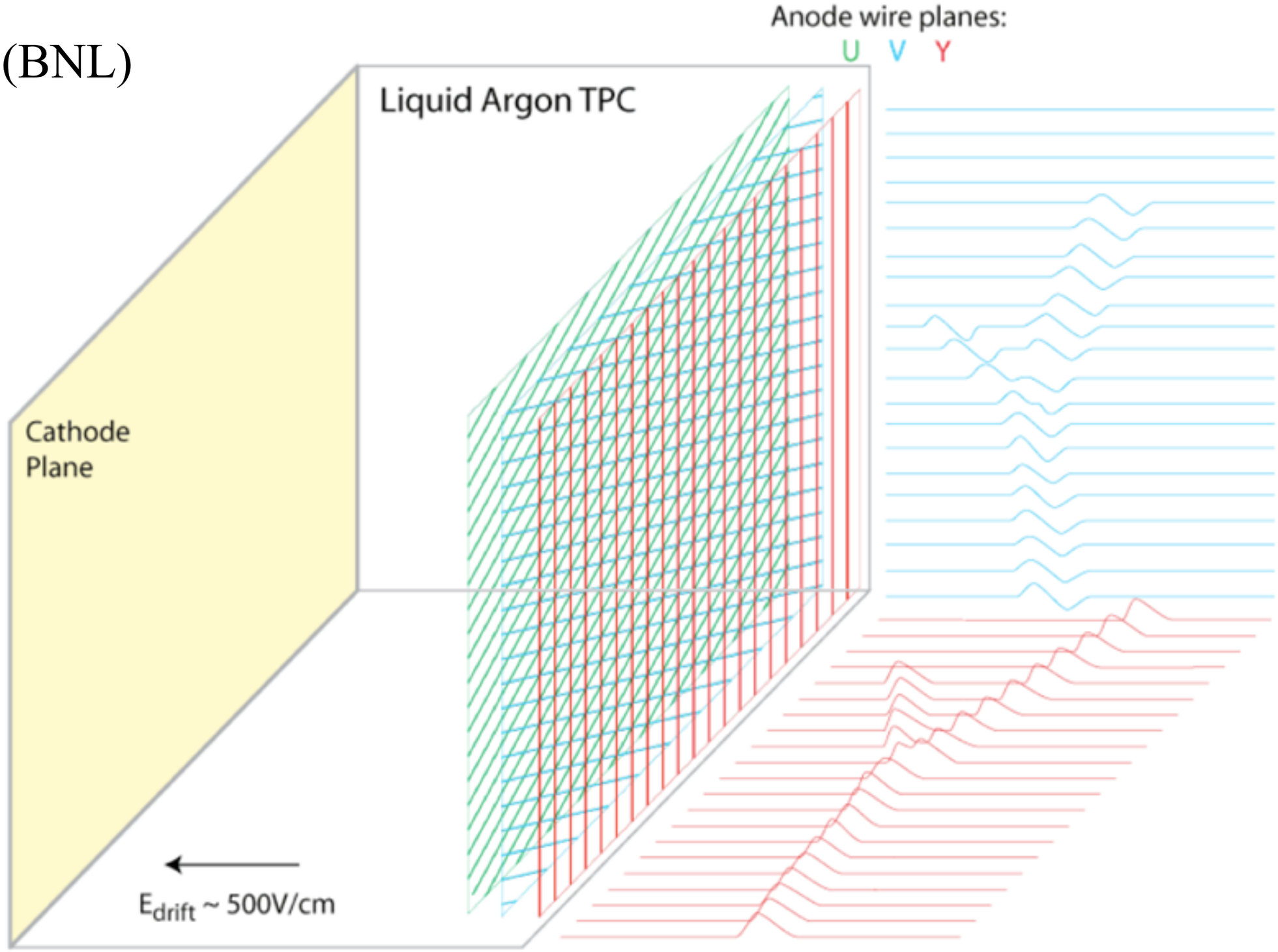

LArTPC Concept

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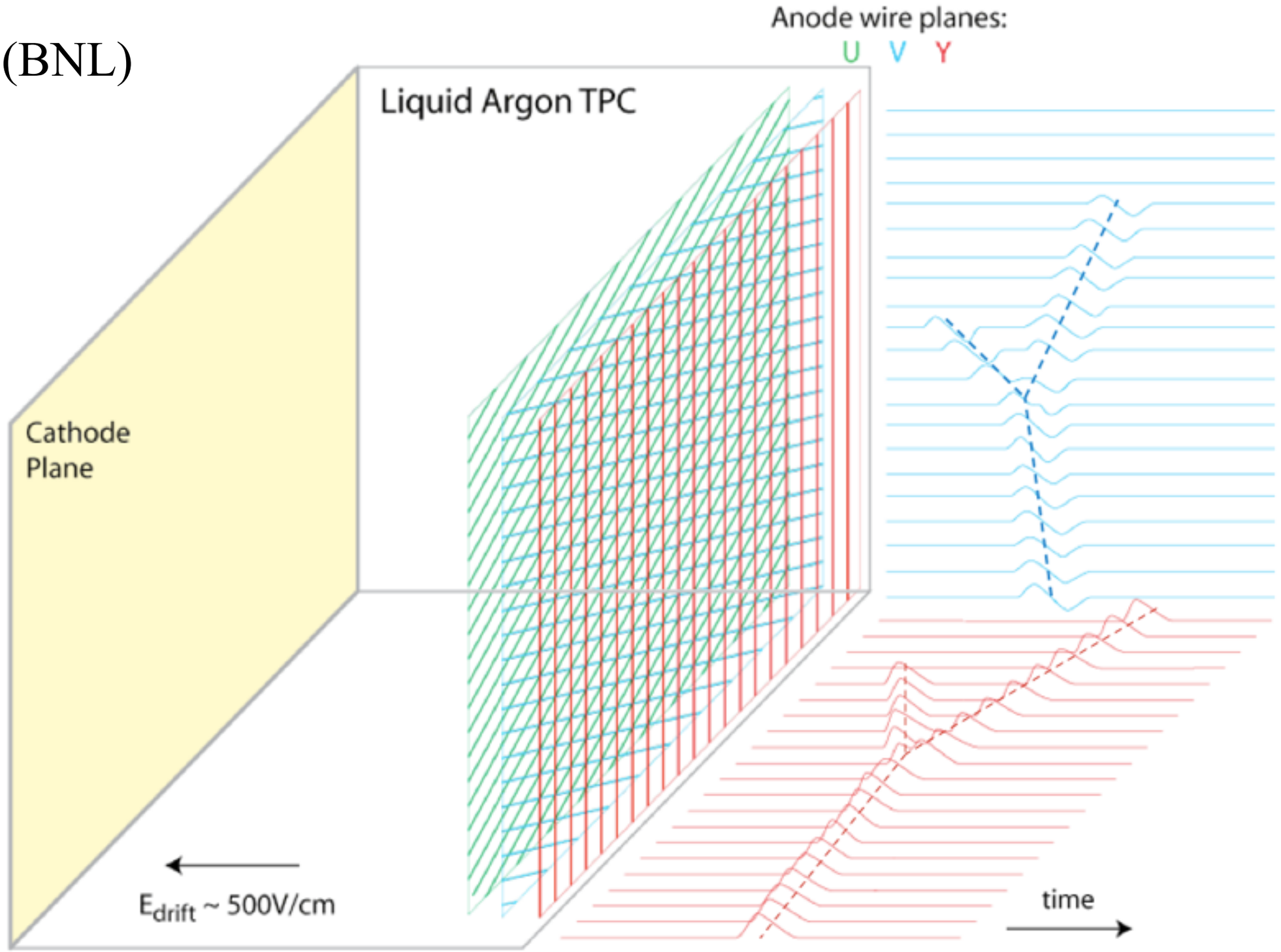
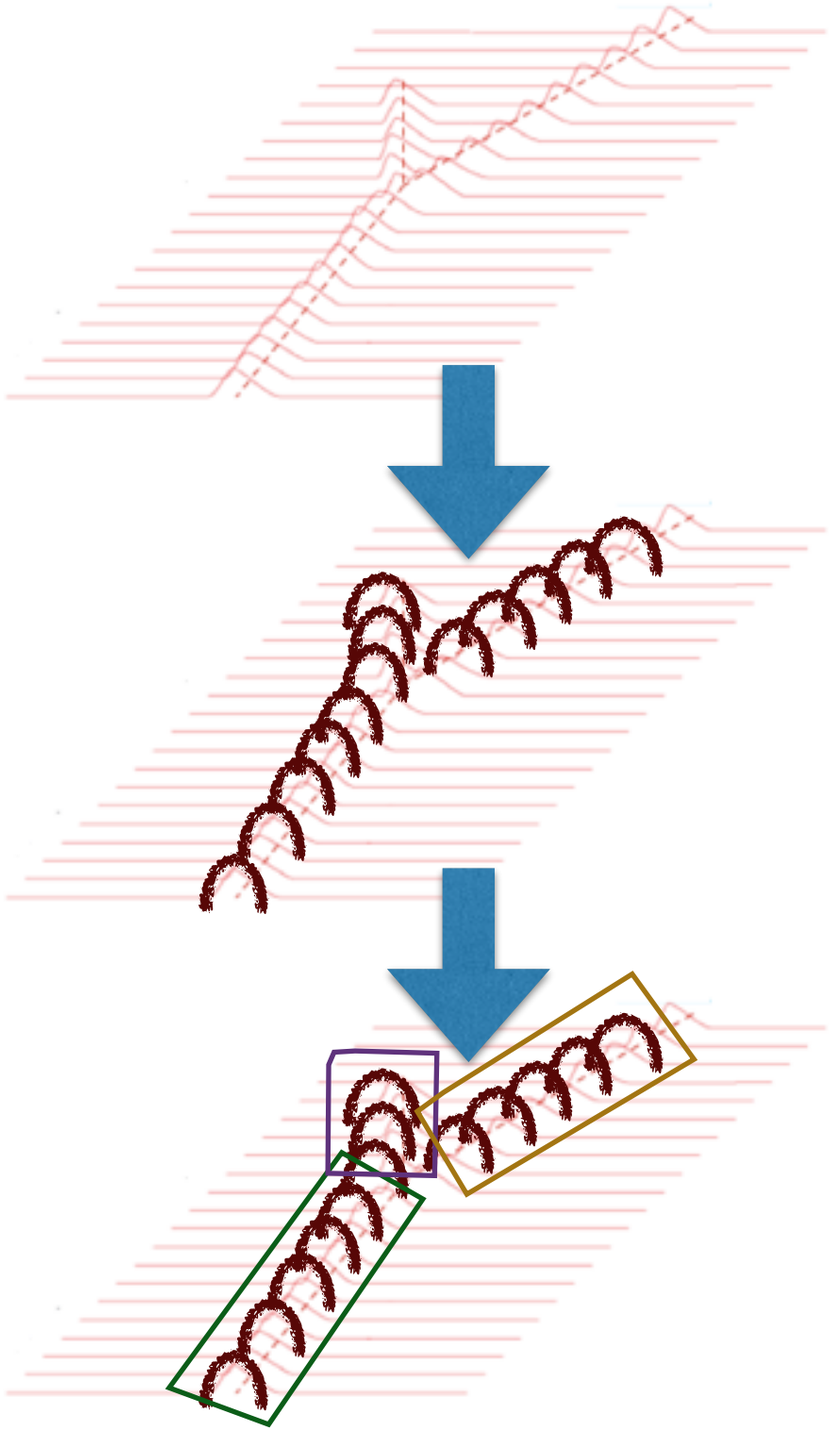


LArTPC Reconstruction

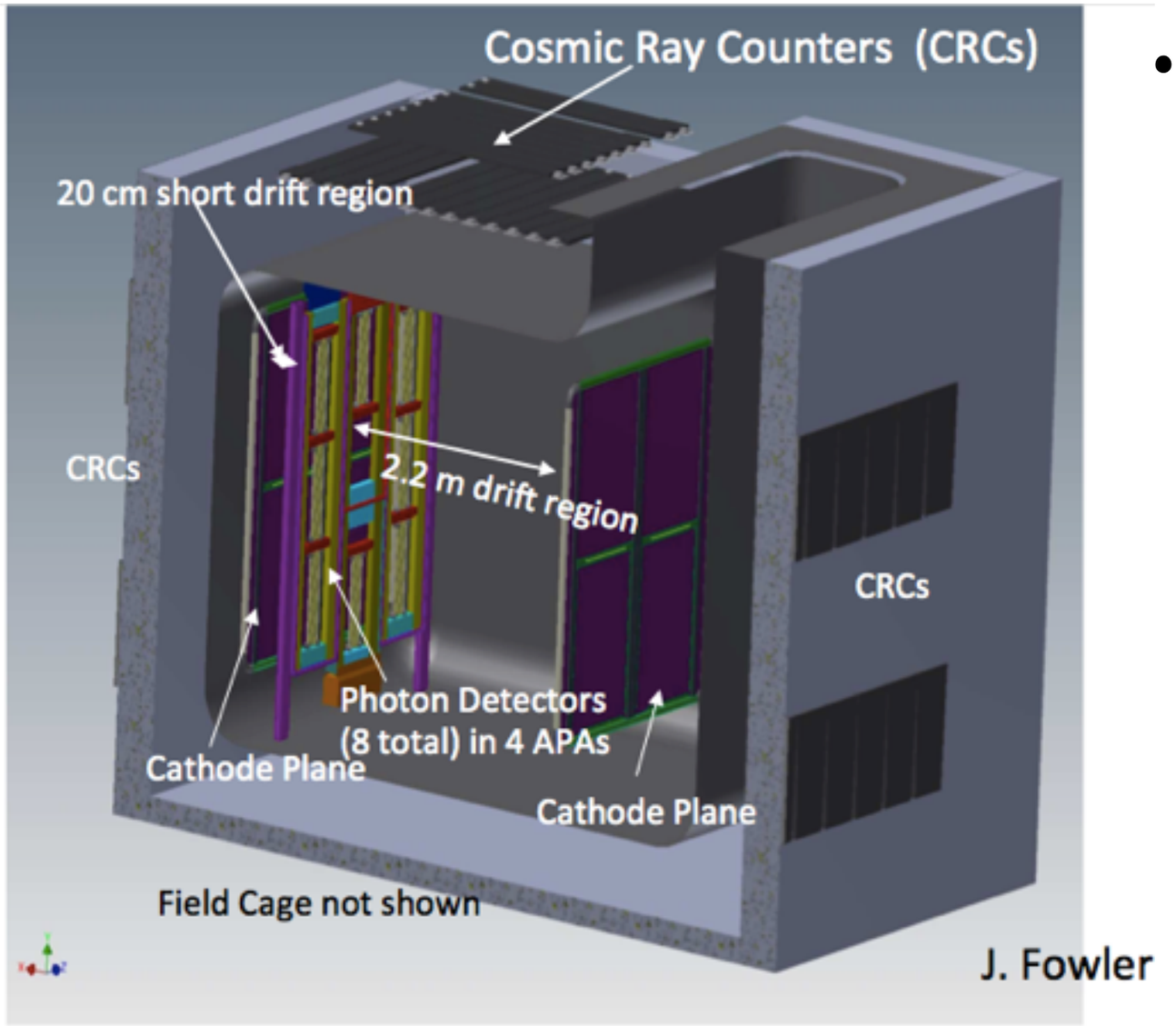
- Raw signal is a pulse on a wire.
- Hit finding looks for peaks in charge which correspond to a through-going ionisation electron.
- Hits can be grouped together in a 2D view (single wire plane) to form ‘clusters’.
- 3D objects (tracks and showers) are found by matching views together — combining these 2D clusters from different wire planes.



LArTPC Reconstruction

- Require:
  - High drift field (typically ~500 V/cm) to drift the ionisation electrons.
  - Good LAr purity in order to increase the ‘electron lifetime’, a measure of the time an electron typically drifts before recombination.
  - Good signal/noise ratio on the wires to facilitate reconstruction.
  - Sophisticated reconstruction algorithms to interpret the signals.
- Before the full DUNE 40kt far detector:
  - 35ton DUNE prototype (Fermilab)
  - ProtoDUNE (CERN)

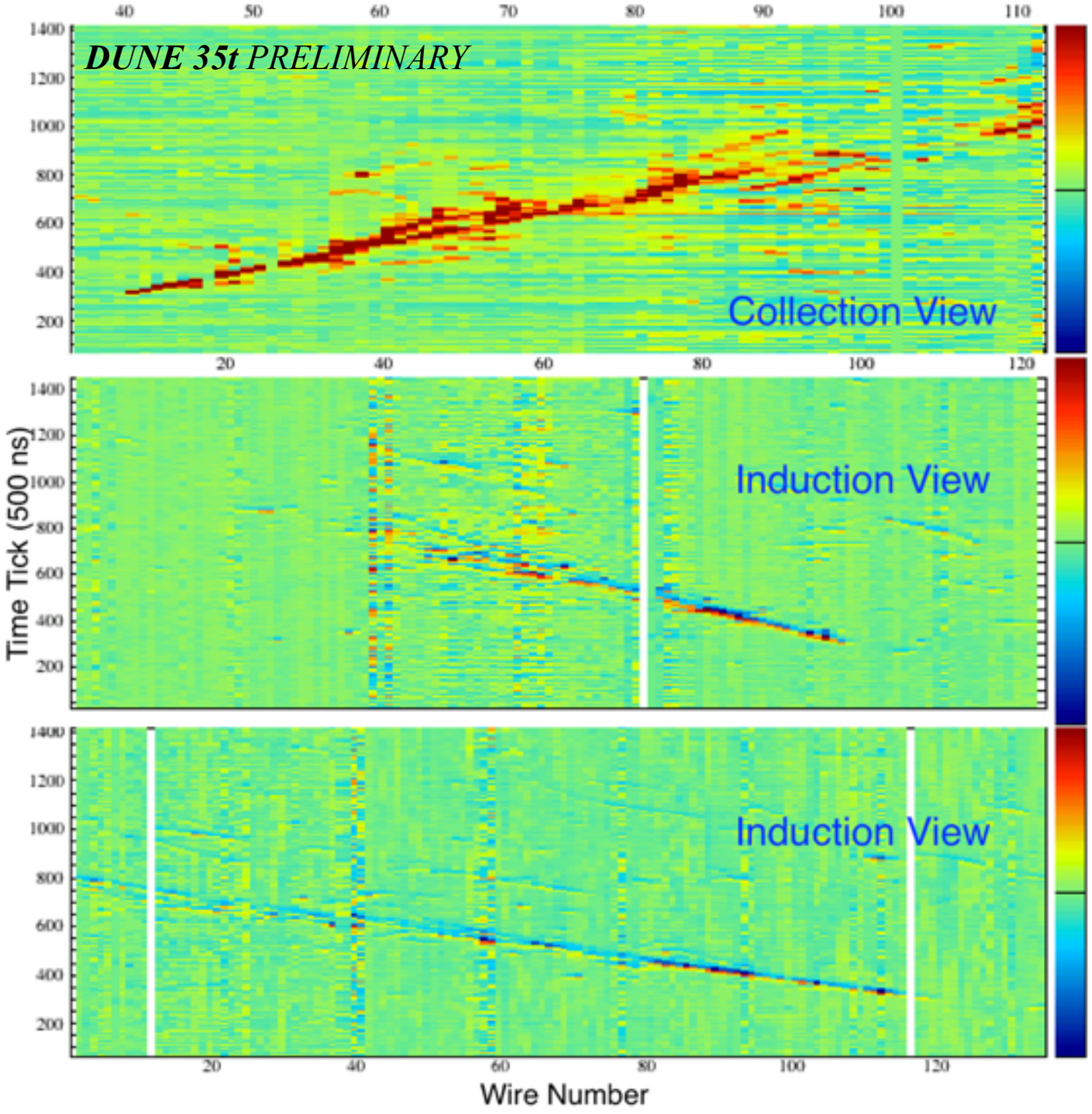
35ton DUNE Prototype



- Prototype many of the design features of the DUNE far detector.

- Run 1 (Jan-Mar 2014) successfully achieved good LAr purity within the membrane cryostat (no detector).
- Run 2 (now!) includes small-scale detector (field cage, TPC, photon detectors, external counters).

Observed 35t Shower!



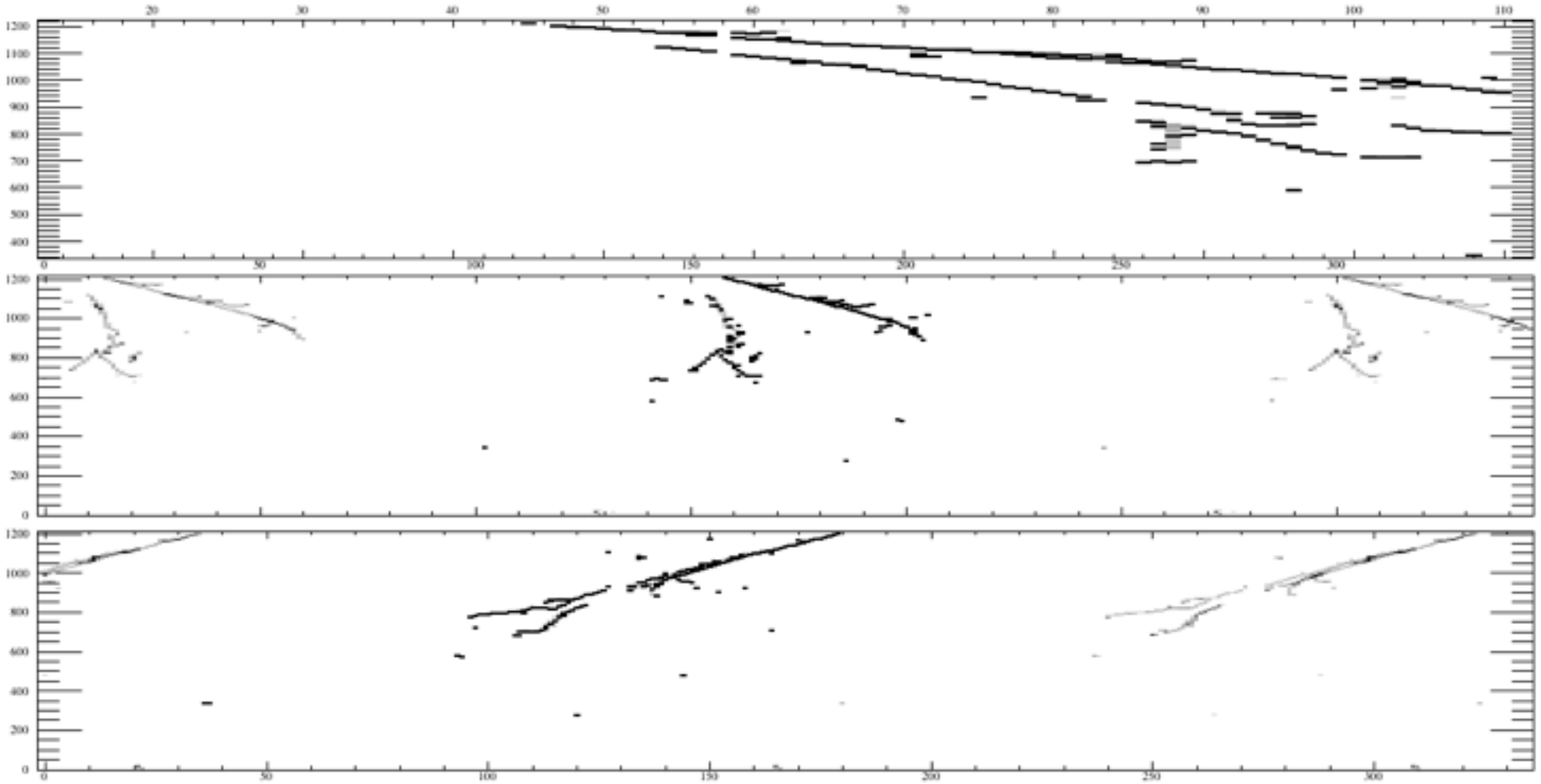
Event display:
wire vs time

Two induction wire planes, one collection

This is what we want to reconstruct!

BlurredCluster Algorithm

- 2D reconstruction algorithm specialising in shower reconstruction.
- Developed with the aim of being able to reconstruct π^0s in DUNE:



Showers right next to each other!

Collection view

'Shadow showers' are an artefact of the wrapped-wire readout planes

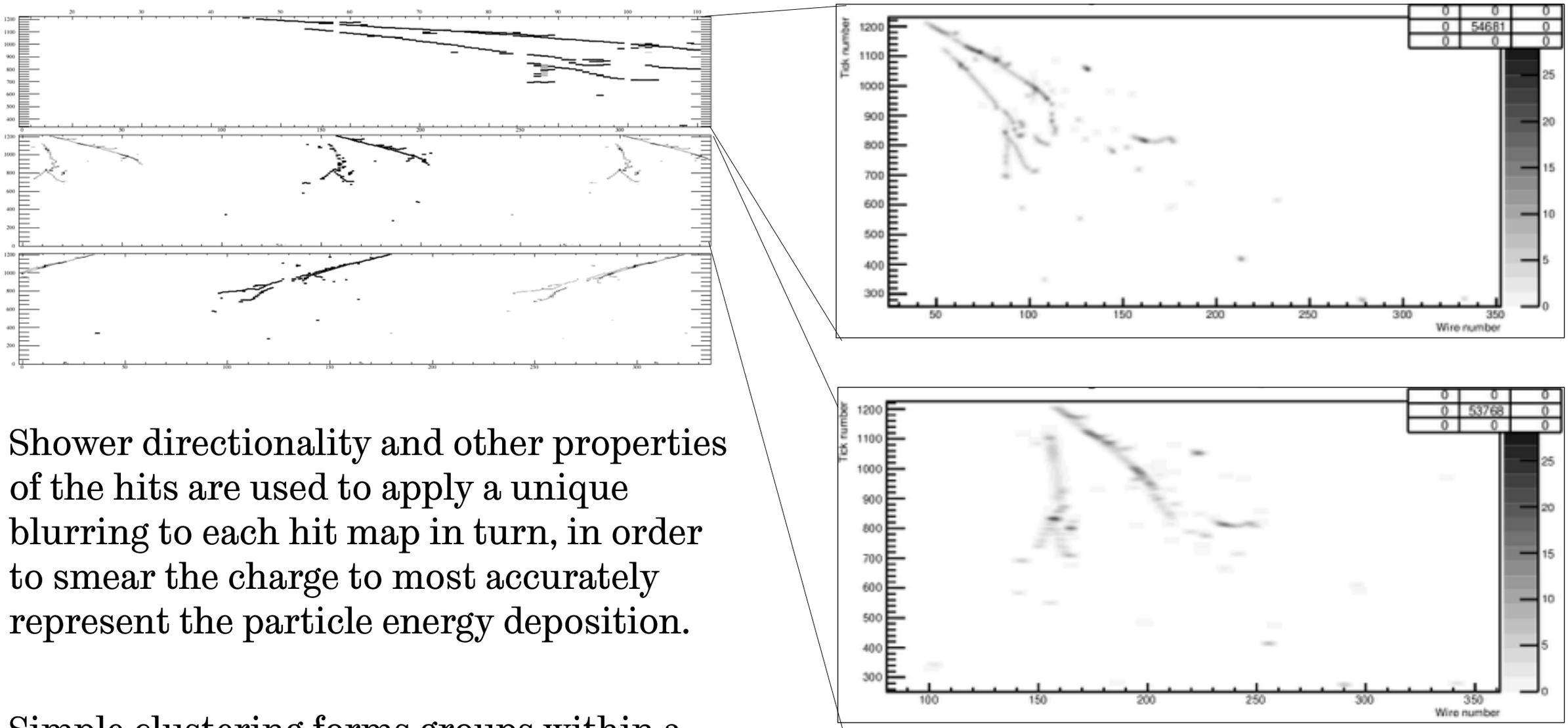
Induction view

DUNE 35t π^0 particle gun event

Induction view

BlurredCluster Algorithm

- Applies a Gaussian smearing to the 2D hit map in order to more isotropically spread the distributed charge and create more complete clusters:

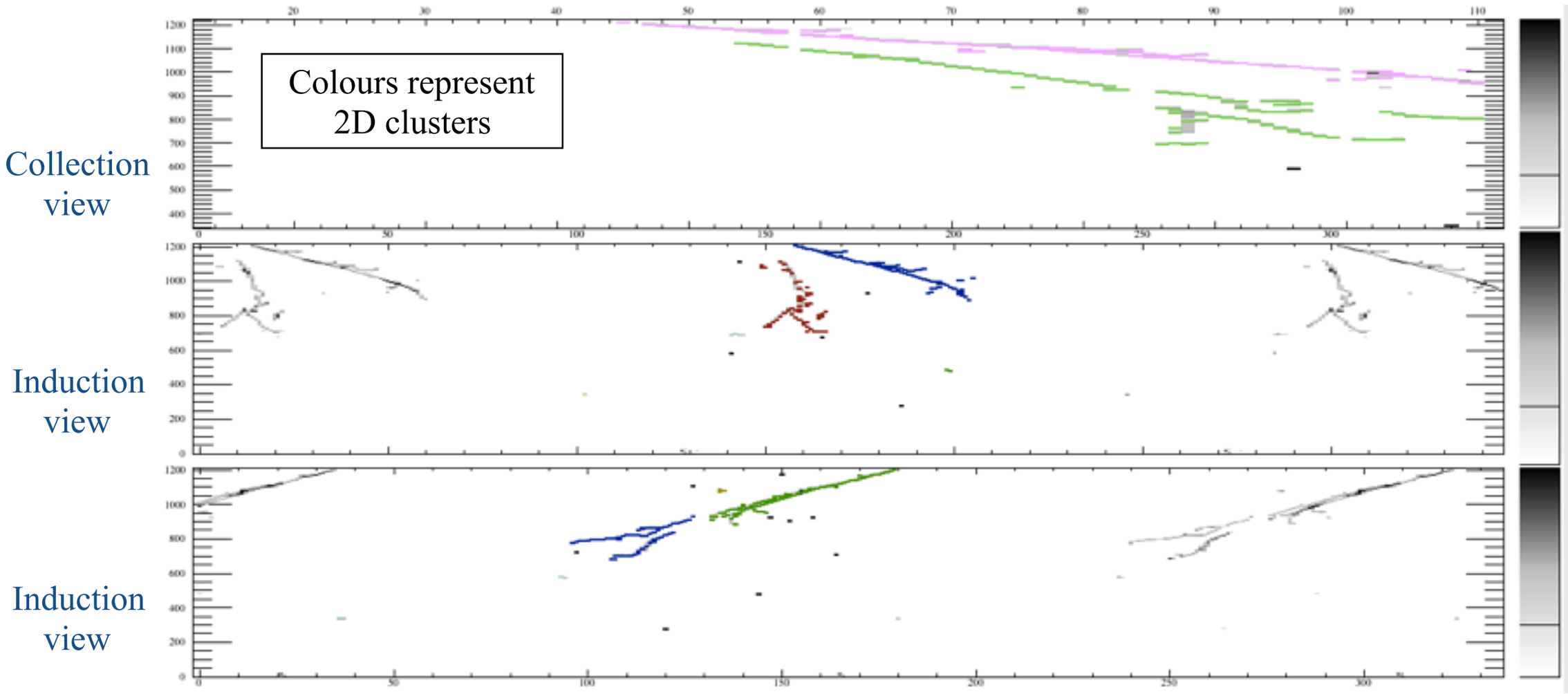


- Shower directionality and other properties of the hits are used to apply a unique blurring to each hit map in turn, in order to smear the charge to most accurately represent the particle energy deposition.

- Simple clustering forms groups within a blurred region.

BlurredCluster Algorithm

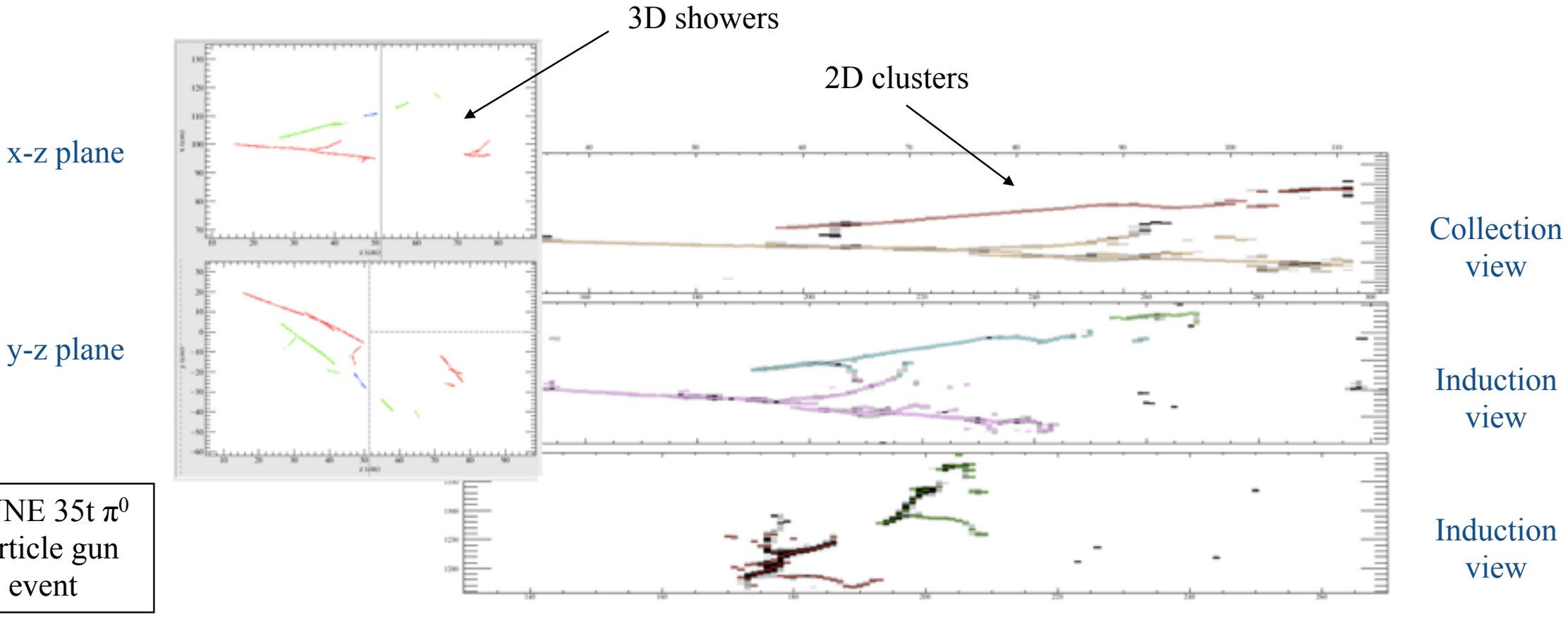
- Final output 2D clusters:



- Impressive shower separation is achieved, which in turn leads to more complete and accurate showers.

EMShower Algorithm

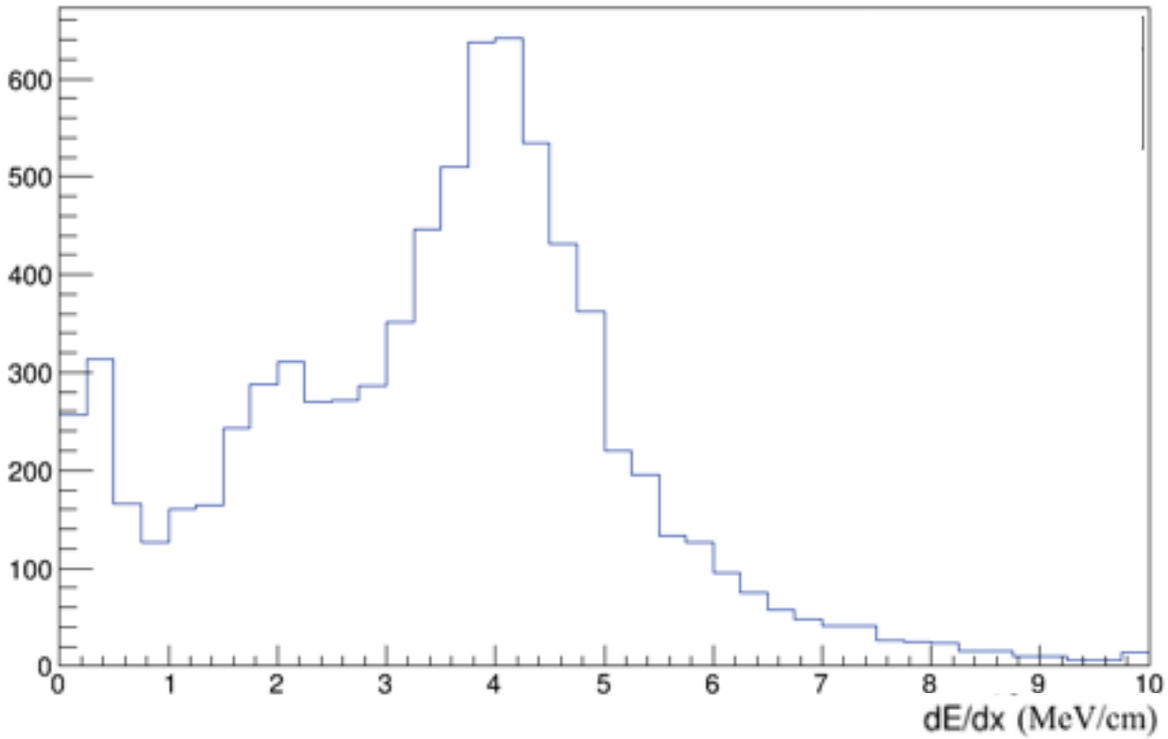
- 3D shower reconstruction algorithm; uses Blurred Clusters as input and creates complete shower objects.
- The algorithm simply matches 2D clusters between the different detector planes, using 3D tracking information, to form 3D objects:

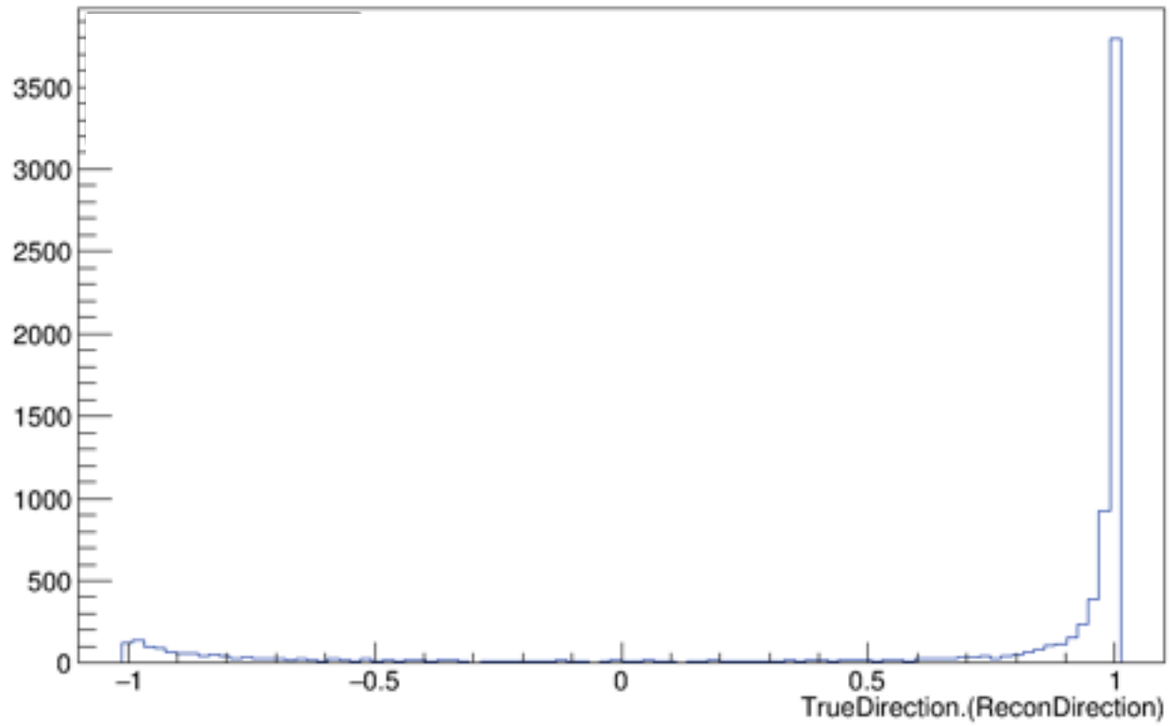


- Further algorithms determine shower properties: shower starting position, shower direction, total energy, dE/dx (rate of energy deposit in the first few cm) etc.

Shower Properties

- Properties of the showers when applied to a 35t π^0 sample:

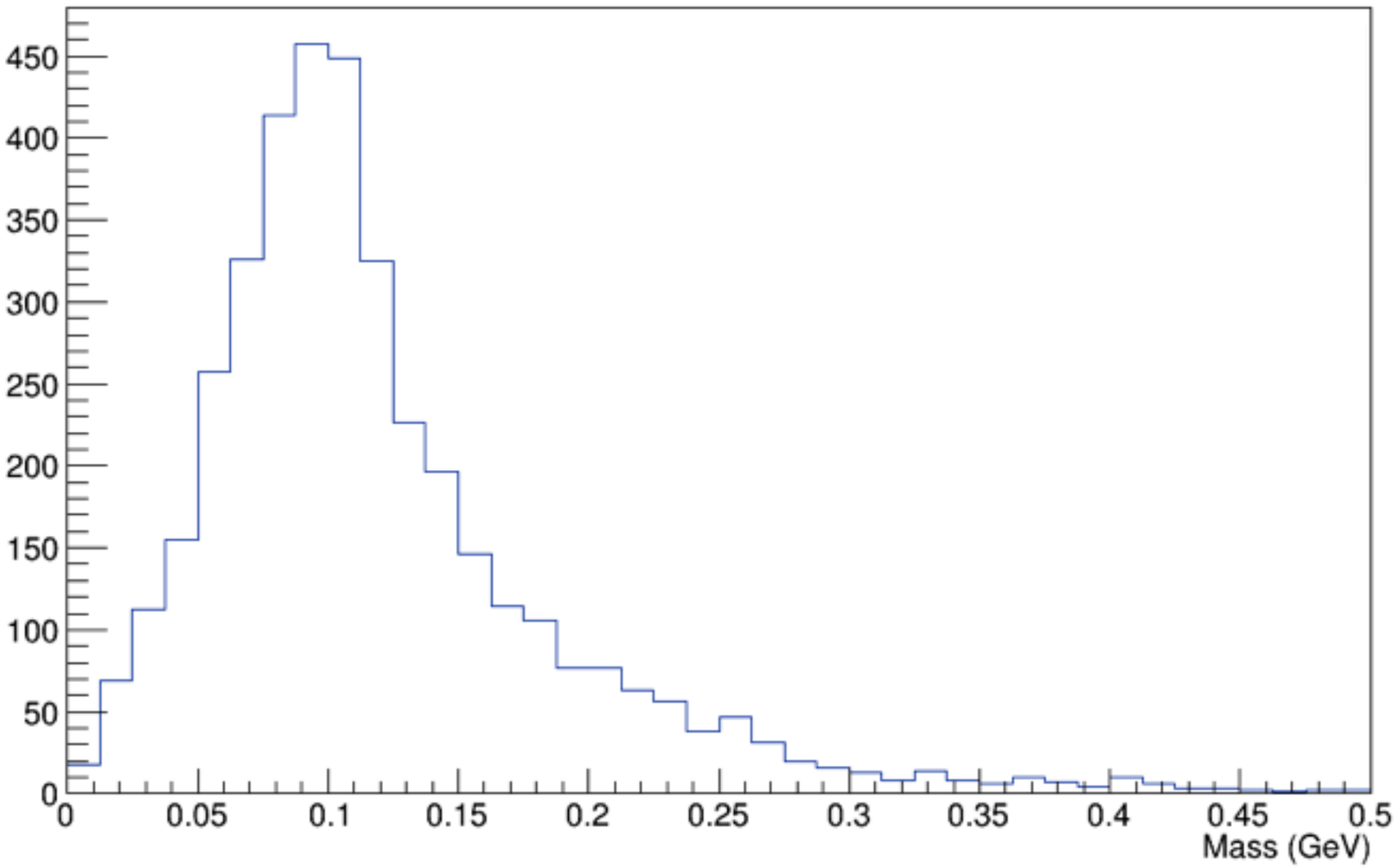




- Left: dE/dx — looks about right for photon-induced showers.
- Right: true (GEANT4 sim)/recon direction comparison — looks good.

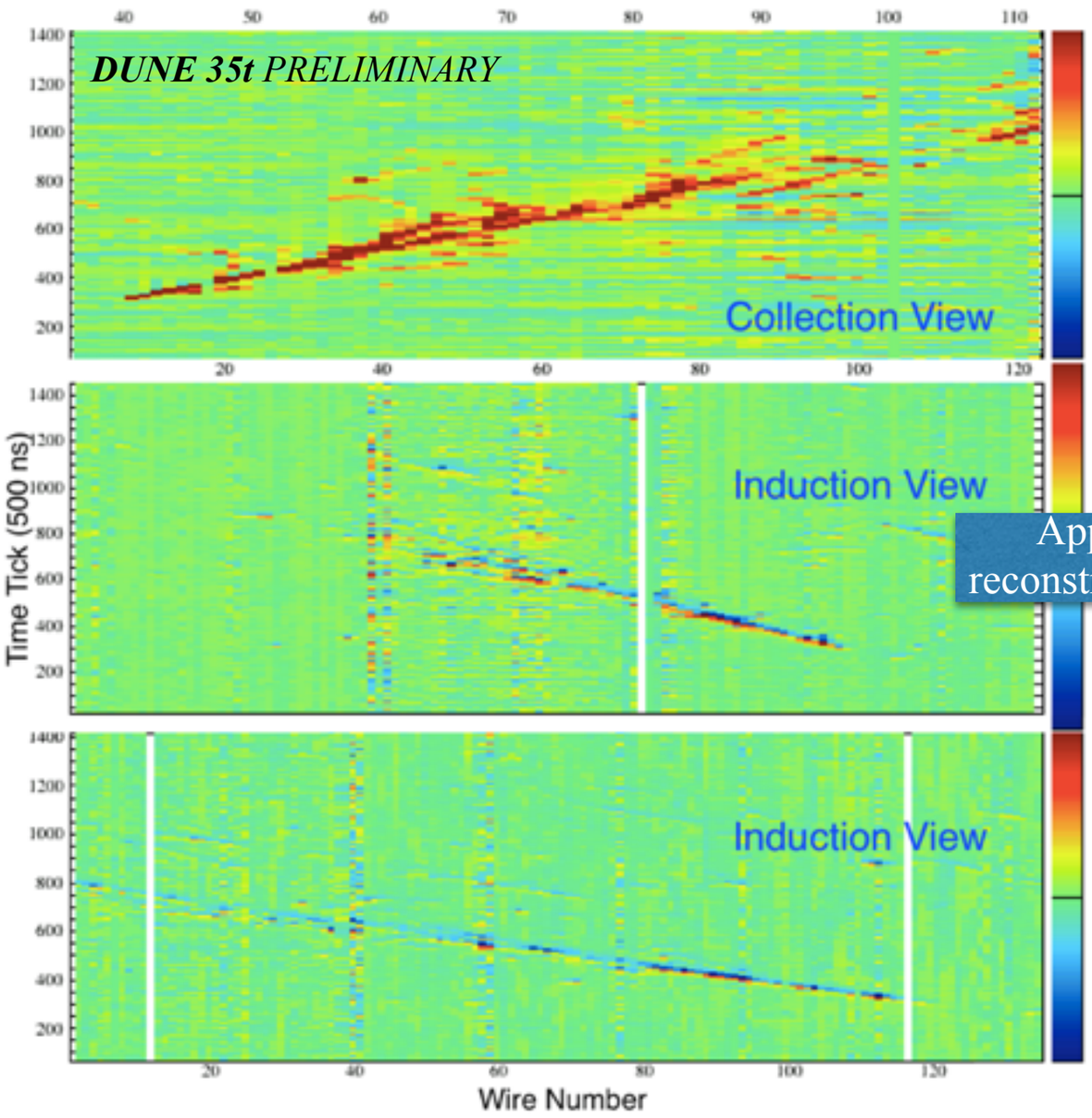
35t π^0 Mass Peak

- Eventual aim of reconstructing π^0s is the invariant mass peak:

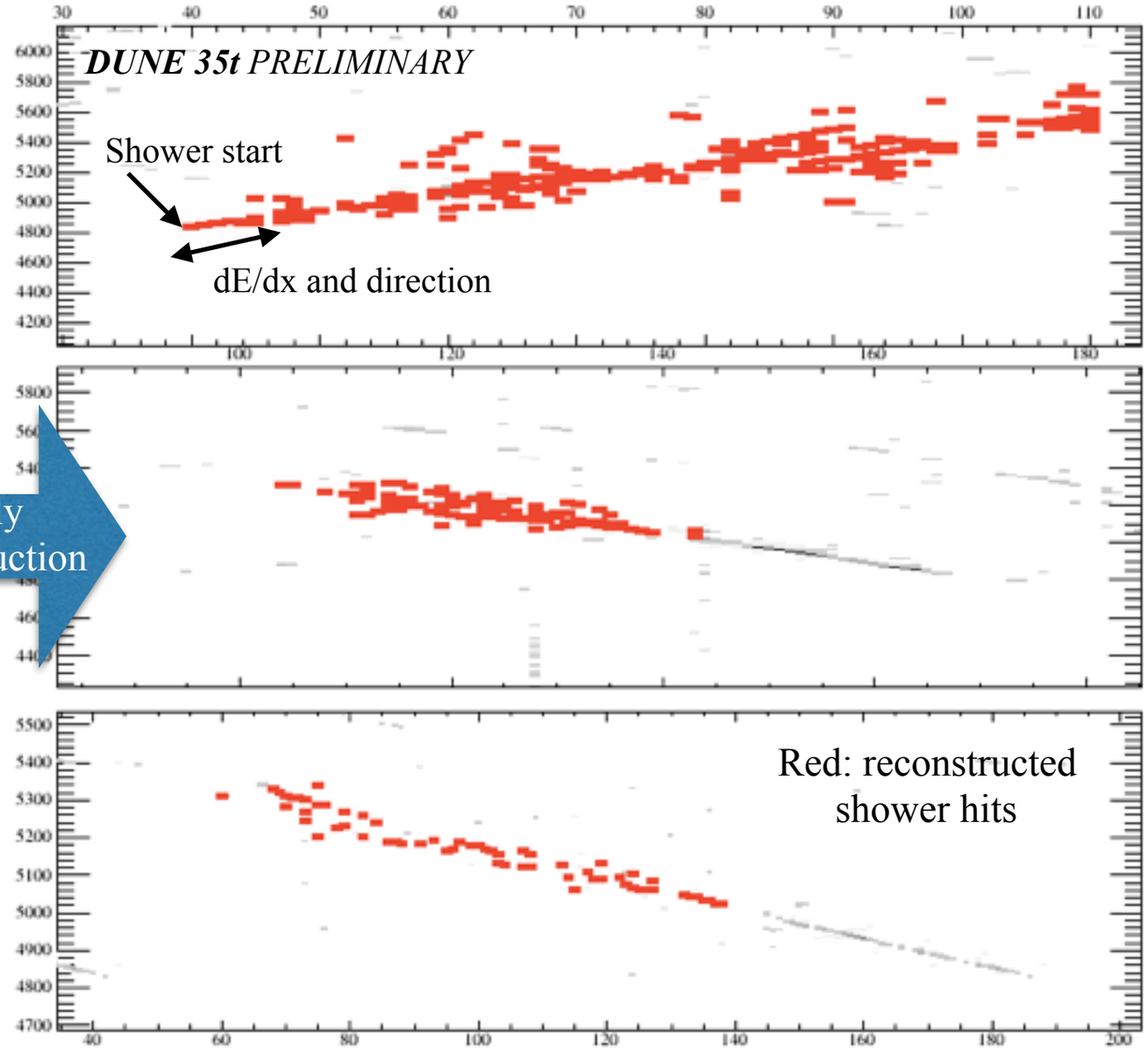


- Filled only with reconstructed quantities. Used truth information from simulation to select the correct showers.

35t Shower Revisited



Apply reconstruction



Reconstructed shower from 35t data!
VERY preliminary — work in progress.

Summary

- Shower reconstruction is paramount to DUNE's science goals.
  - It is also very, very challenging in LAr!
- Well-developed shower reconstruction method presented:
  - Shows great promise with LArTPC reconstruction;
  - Within LArSoft (shared LAr software framework); used by DUNE and LArIAT, has been used by MicroBooNE.
- Still have plenty of development ongoing so anticipate even better reconstruction.
- Will be used in a 35t π^0 analysis after the 35t prototype data collection has finished.

Backup

Blurred Cluster: Algorithm Details

- Gaussian kernel:

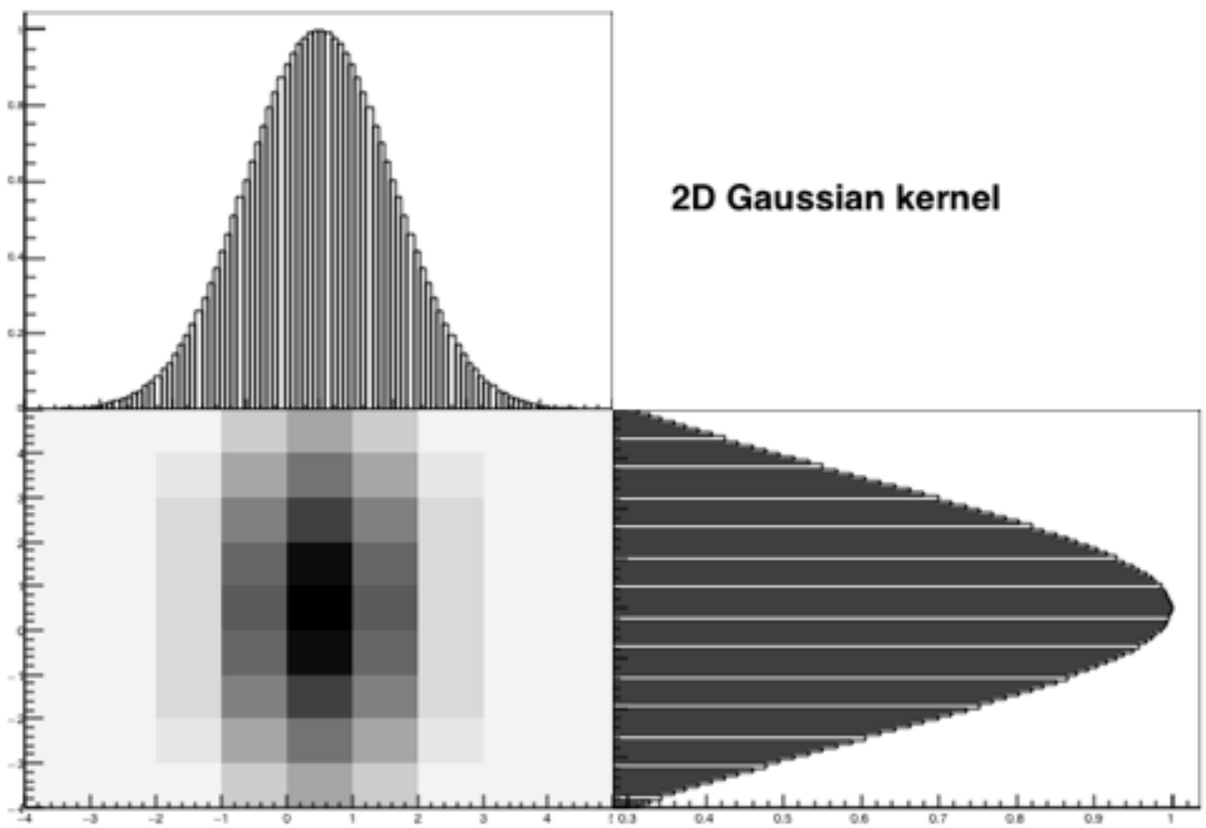
$$\frac{1}{\sqrt{2\pi}\sigma_{wire}}\frac{1}{\sqrt{2\pi}\sigma_{tick}}e^{-\frac{r_{wire}^2}{2\sigma_{wire}^2}}e^{-\frac{r_{tick}^2}{2\sigma_{tick}^2}}$$

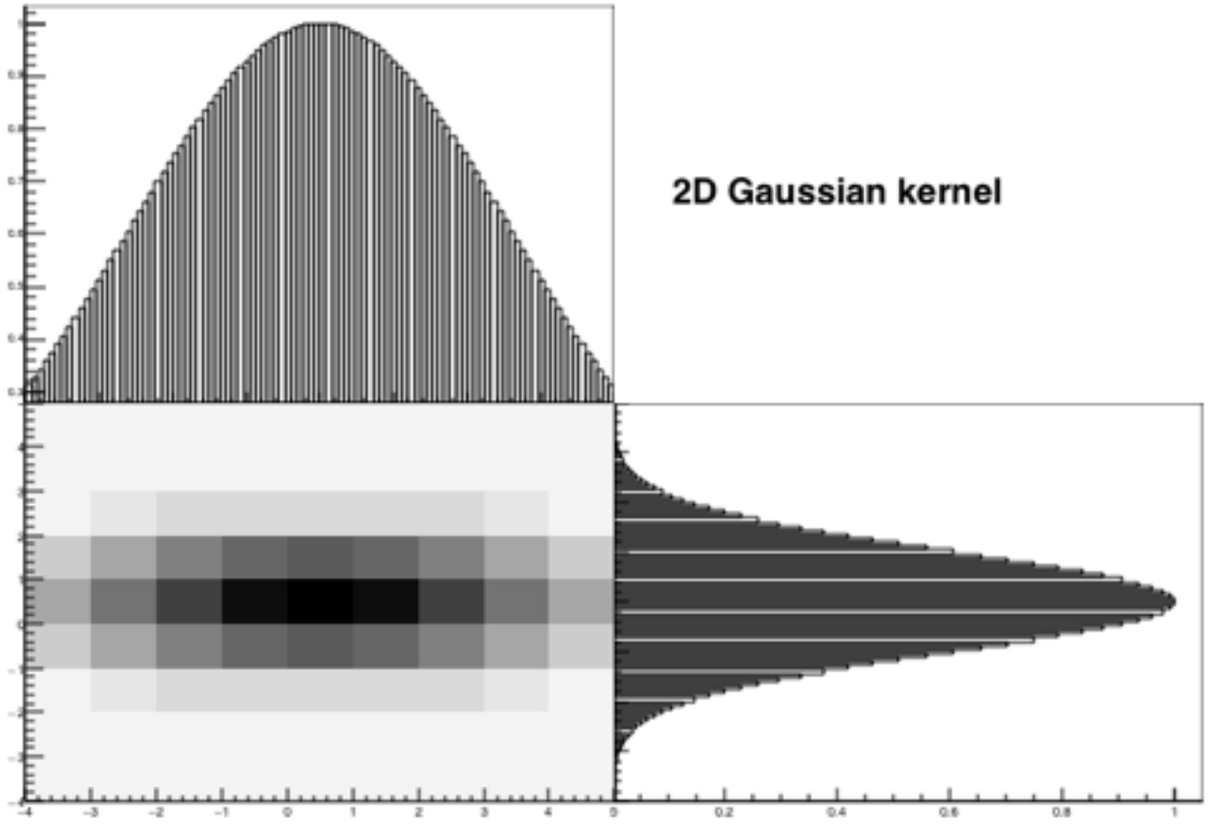
- Parameters to fix are the **blur radius** (r) and the **Gaussian sigma**.

- Other defining parameters are the **clustering distance** (how far from a seed to cluster) and the **charge threshold**.

- The clustering runs in each drift volume separately but doesn't yet have a method to stitch between the two.

Blurred Cluster: Gaussian Kernel

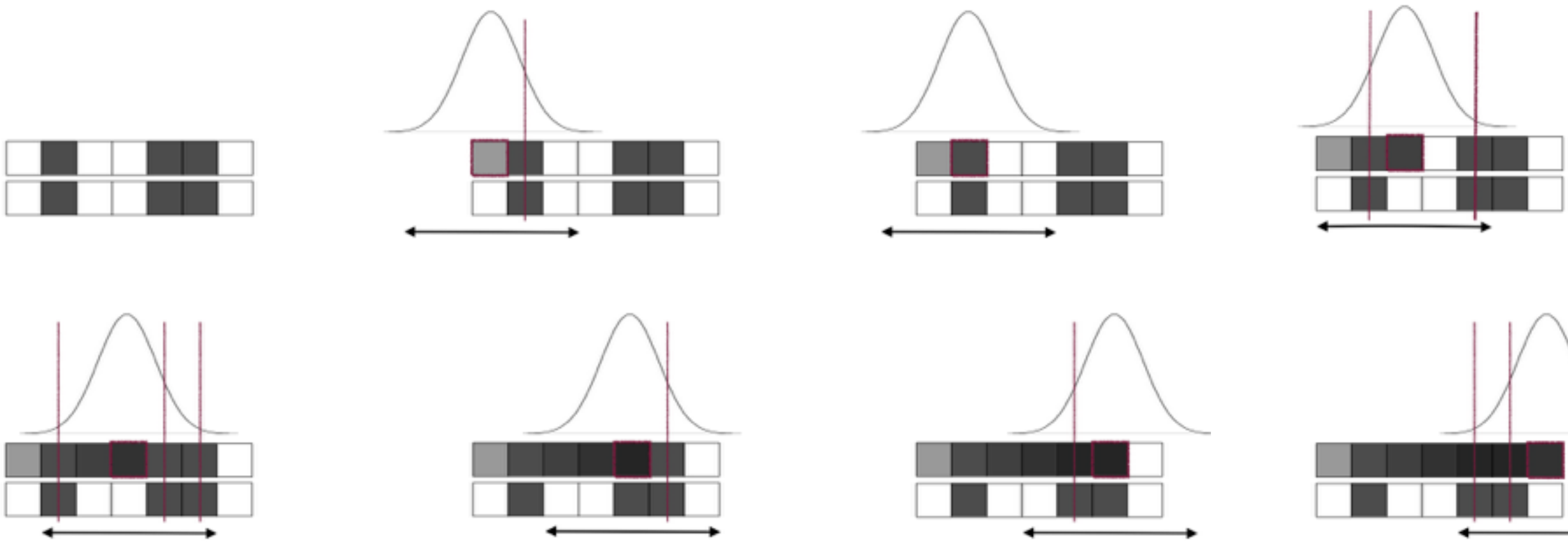




- Left: more effect in tick direction (sigmax = 1, sigmay = 2.6)
- Right more effect in wire direction (sigmax = 2.6, sigmay = 1)

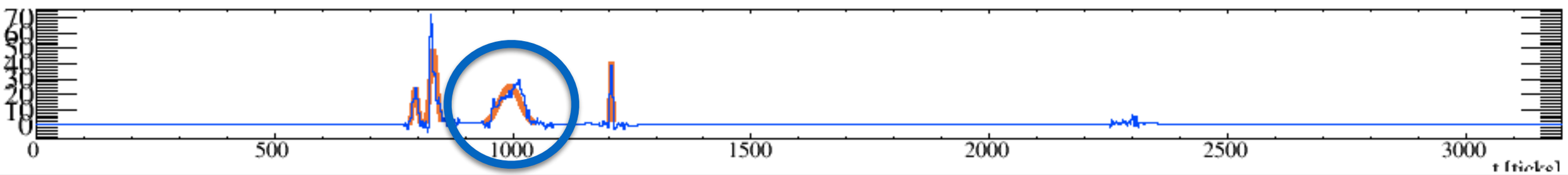
Blurred Cluster: Blur Radius

- How far to blur in each particular direction (demo in 1D with blur radius of 2):

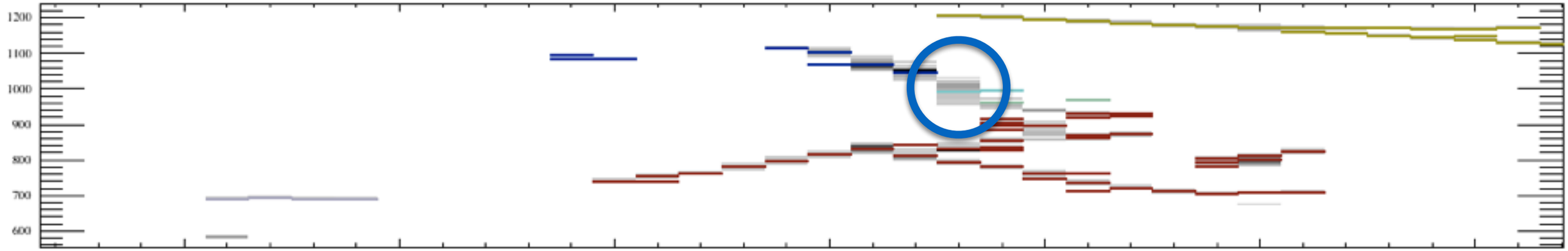


- Output is blurred version of our initial 1D hit map.

BlurredCluster Problem



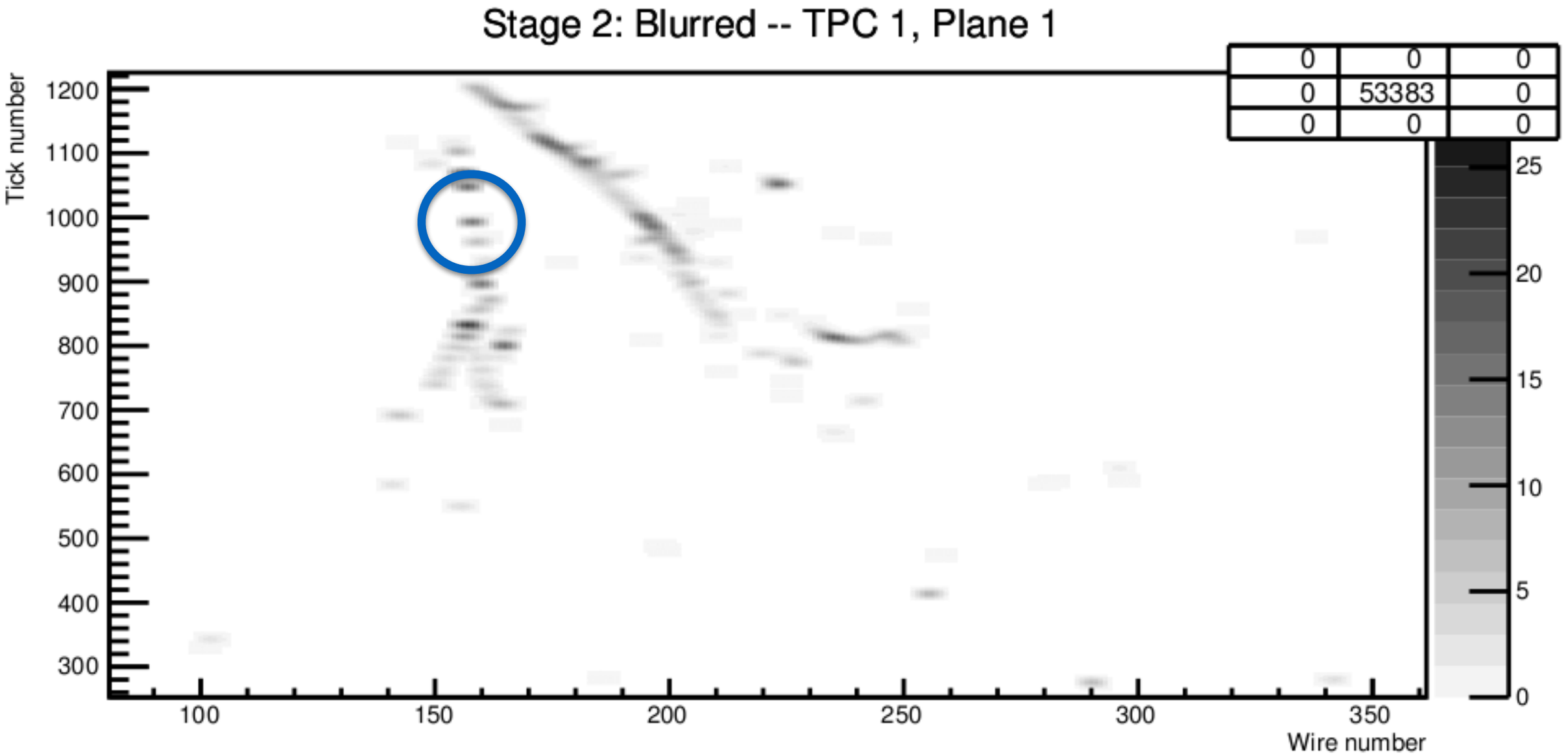
The width of the hit demonstrates how spread in time the charge is.



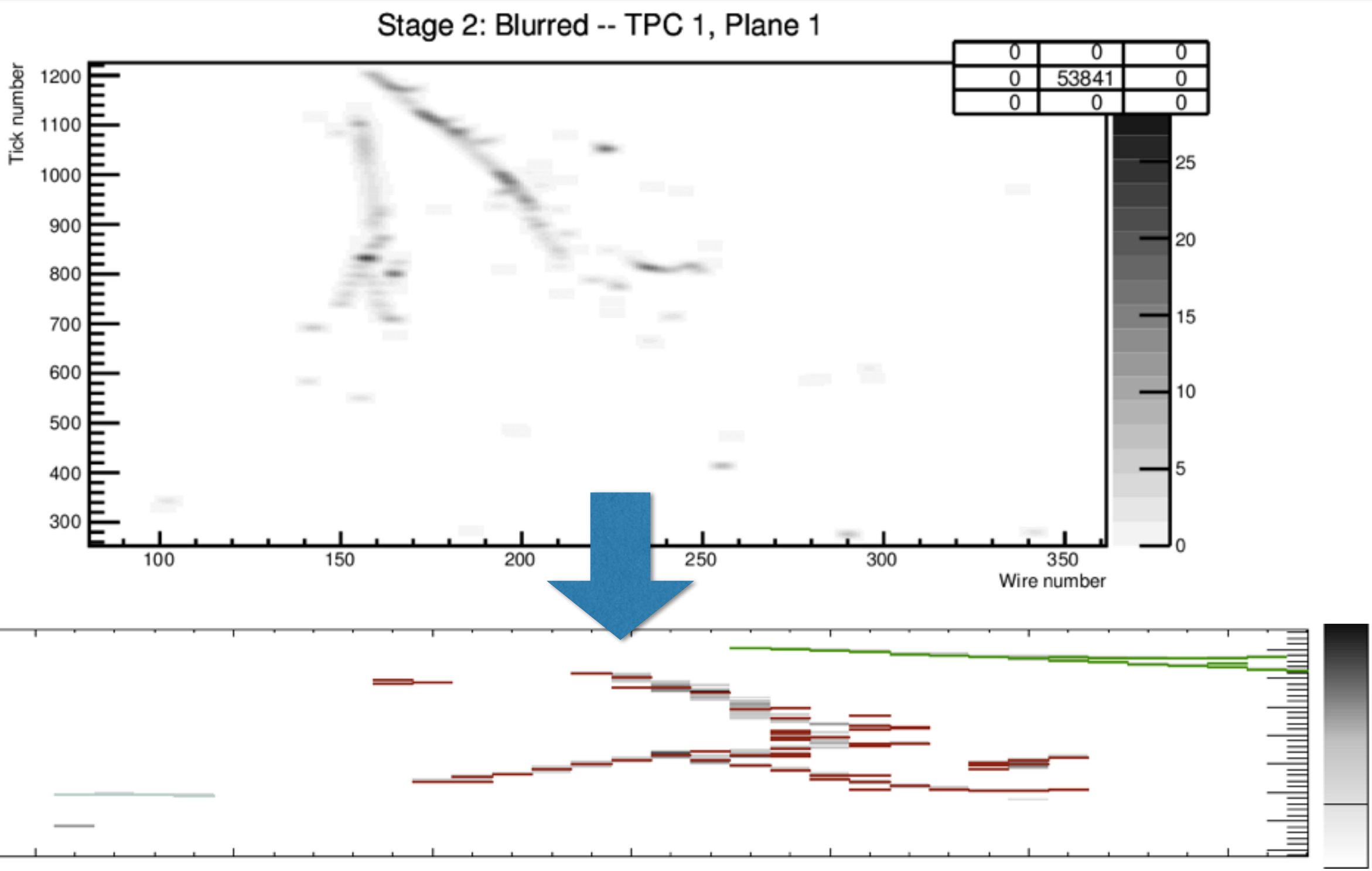
- Previously, the clustering was just modelling this as a hit at a single tick.
- This doesn't take into account all the hit information and means that clusters like the one above are broken.

Blurred Cluster: Natural Reconstruction

- First step of the clustering algorithm is to apply the Gaussian blur…



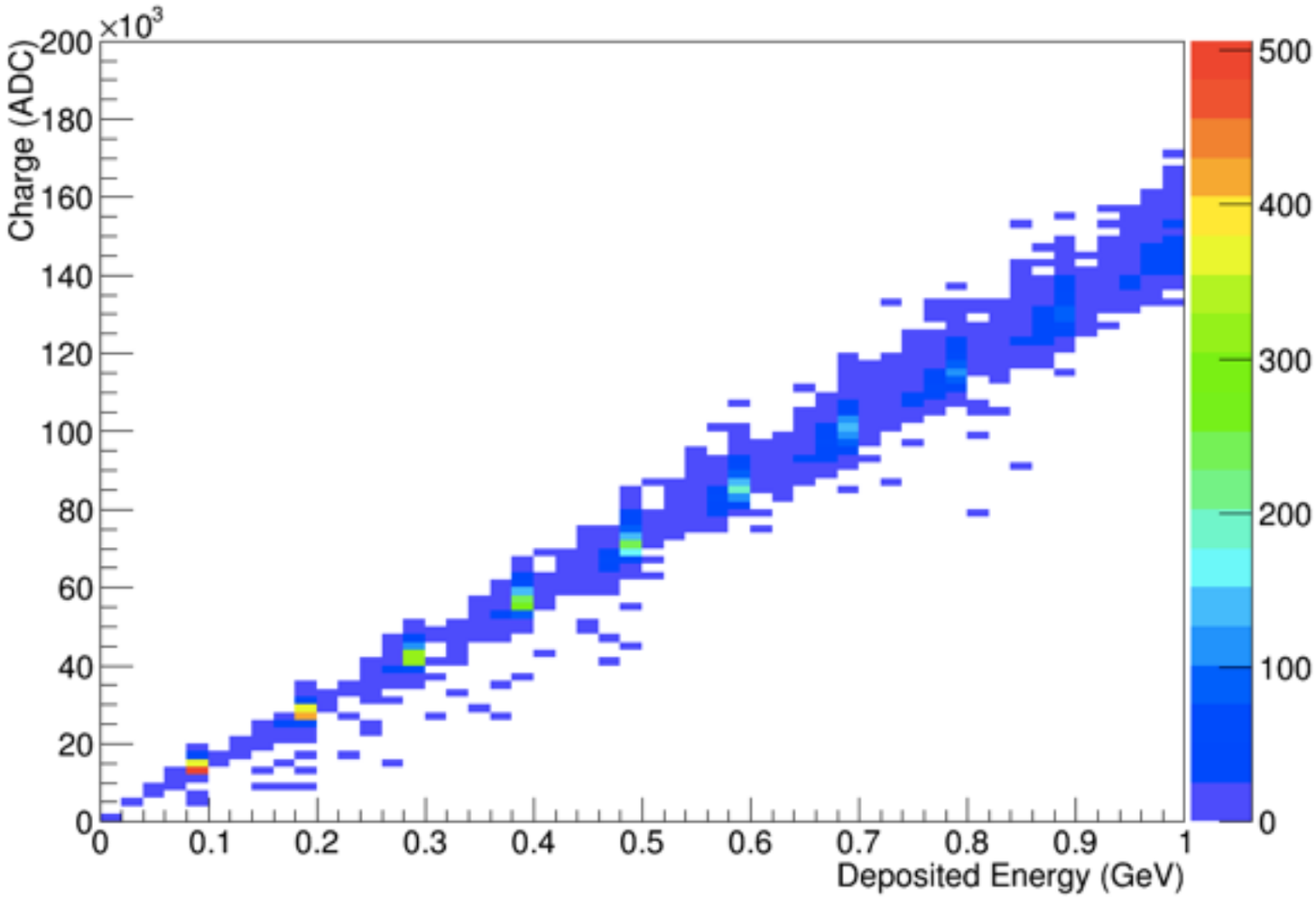
Blurred Cluster: Natural Reconstruction



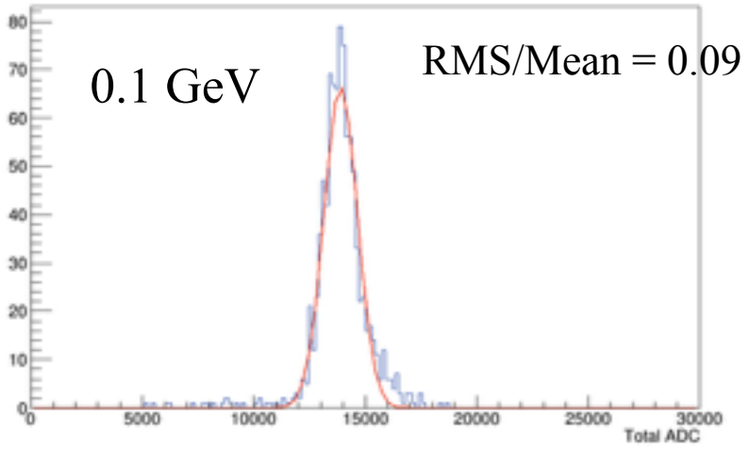
Energy Reconstruction

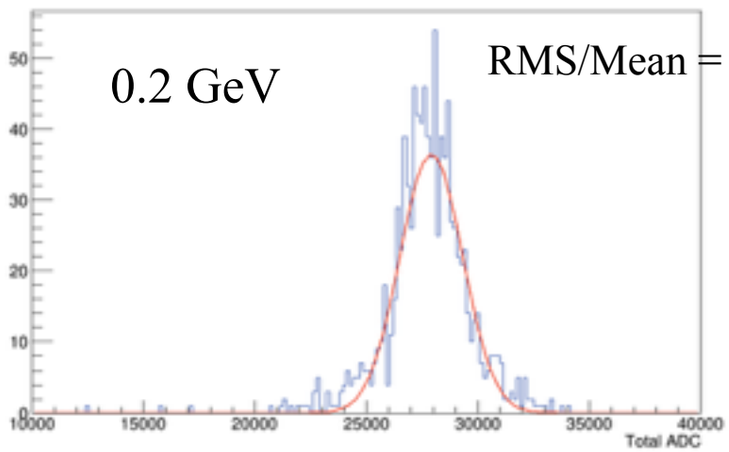
- To reconstruct the particle energy, need to convert from the charge deposited on each plane.

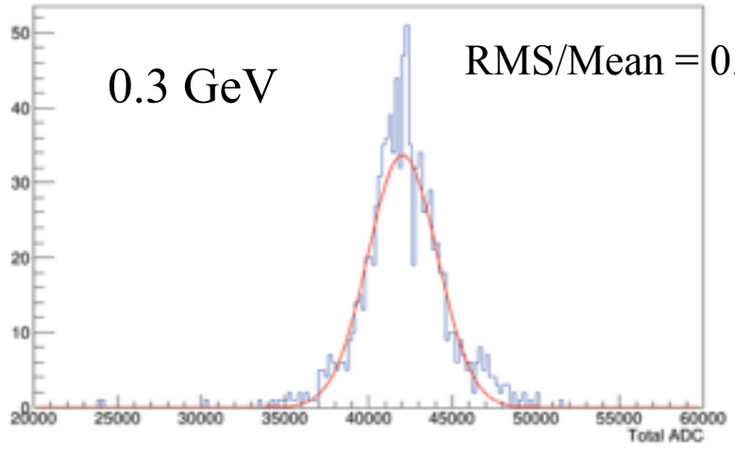
- Nice correlation between these quantities (e.g. U plane):

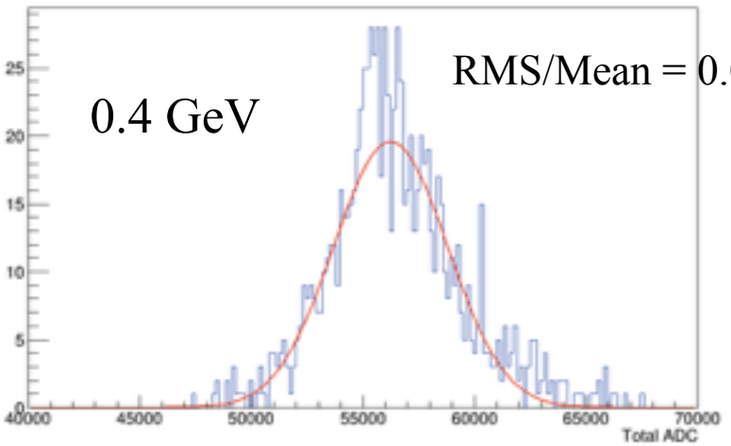


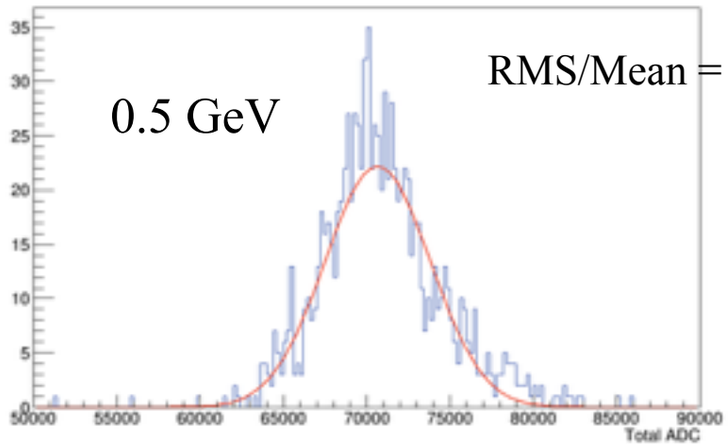
Charge Resolution

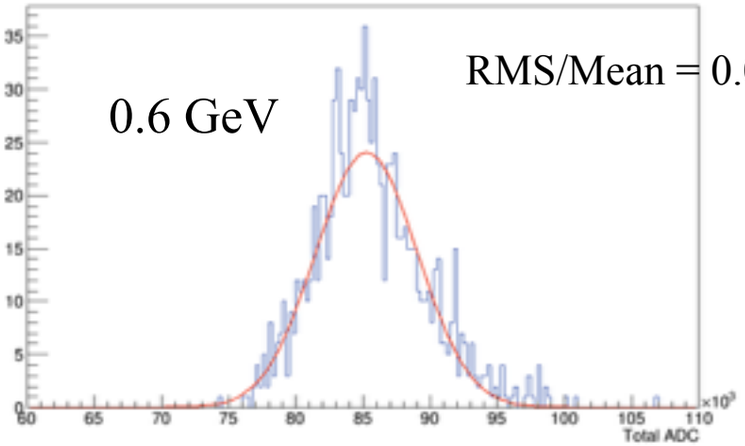


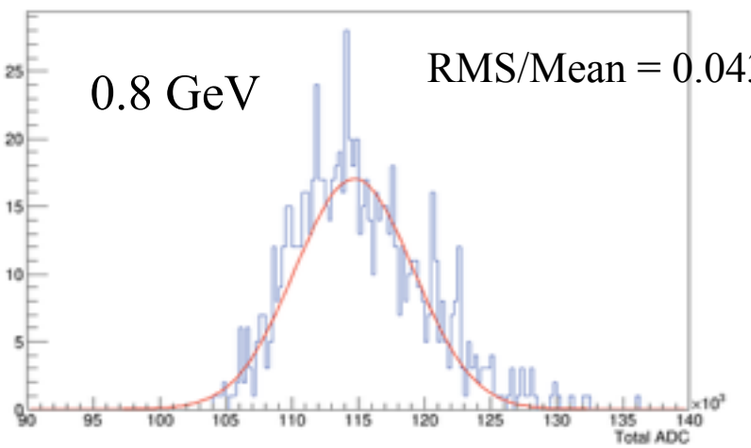


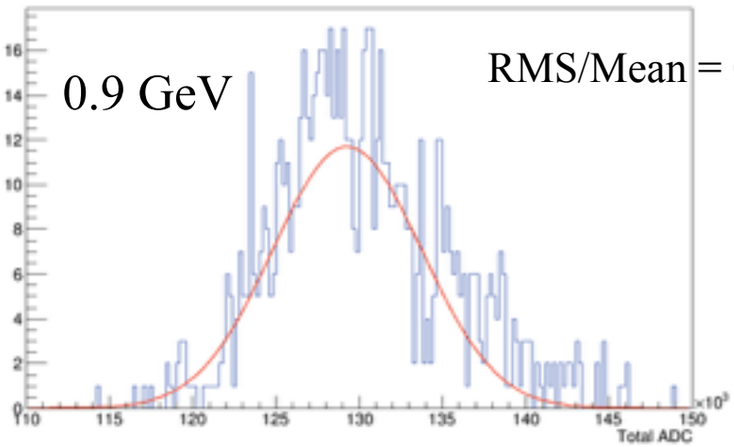


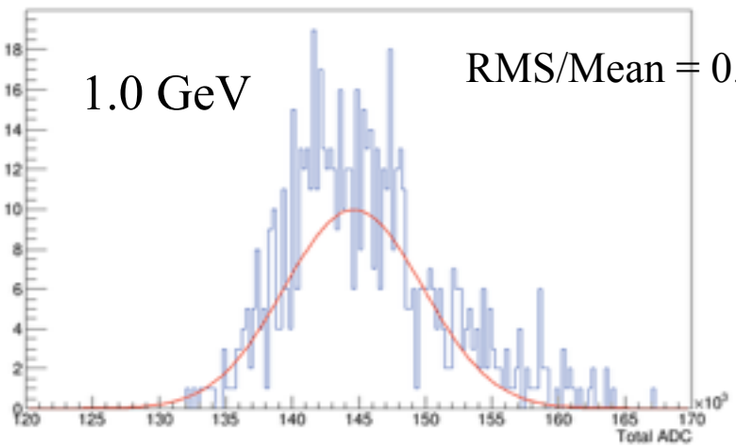






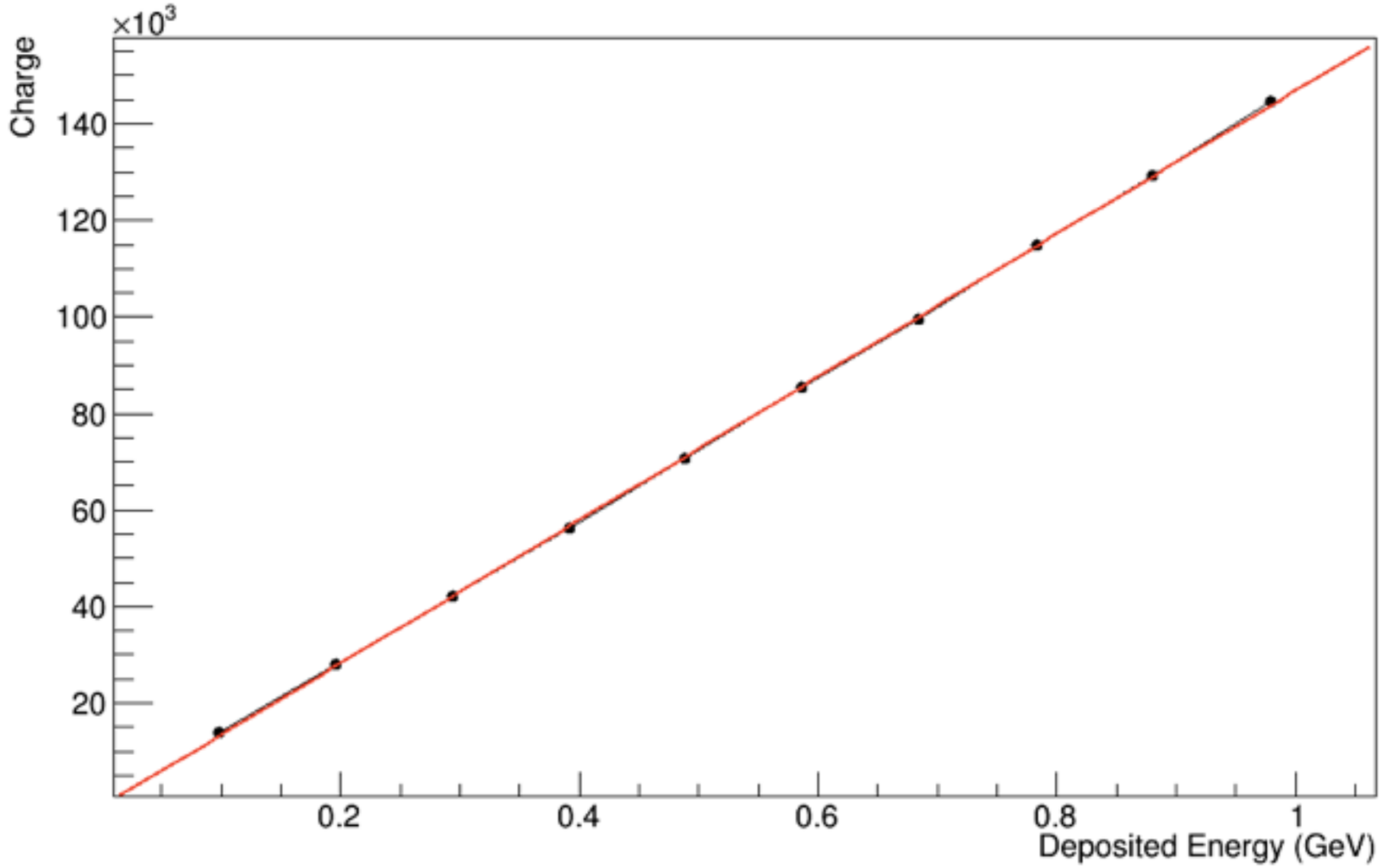






Energy-Charge Correlation

- The mean of these Gaussians and the mean of the energies:

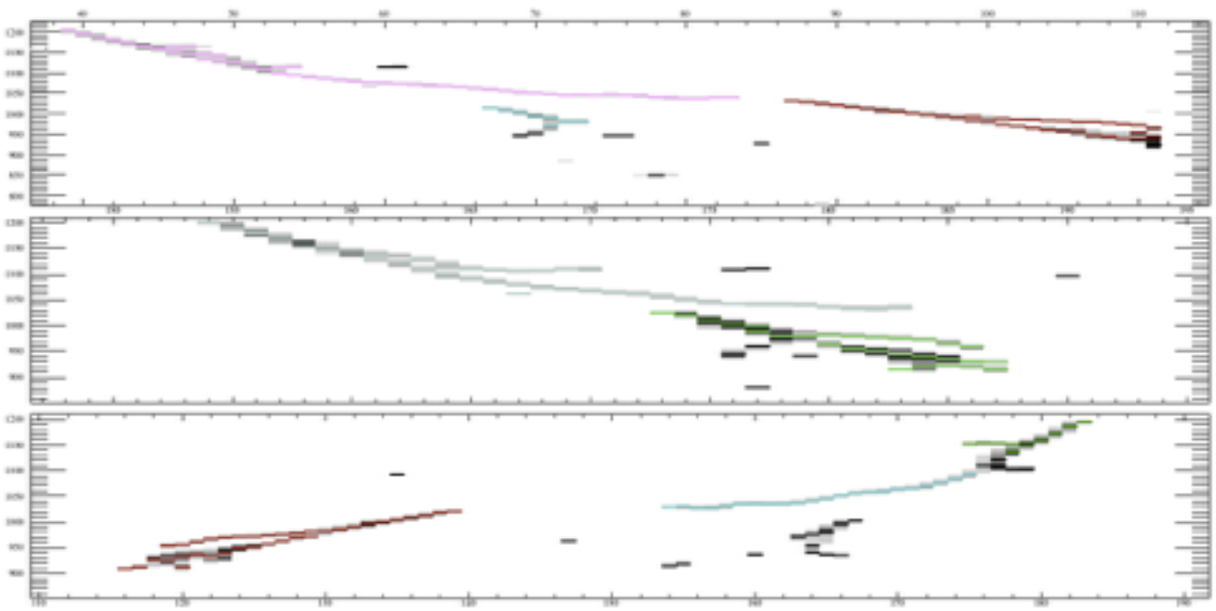


- Nice linear correlation between the charge read out on a plane and the energy deposited in the detector.

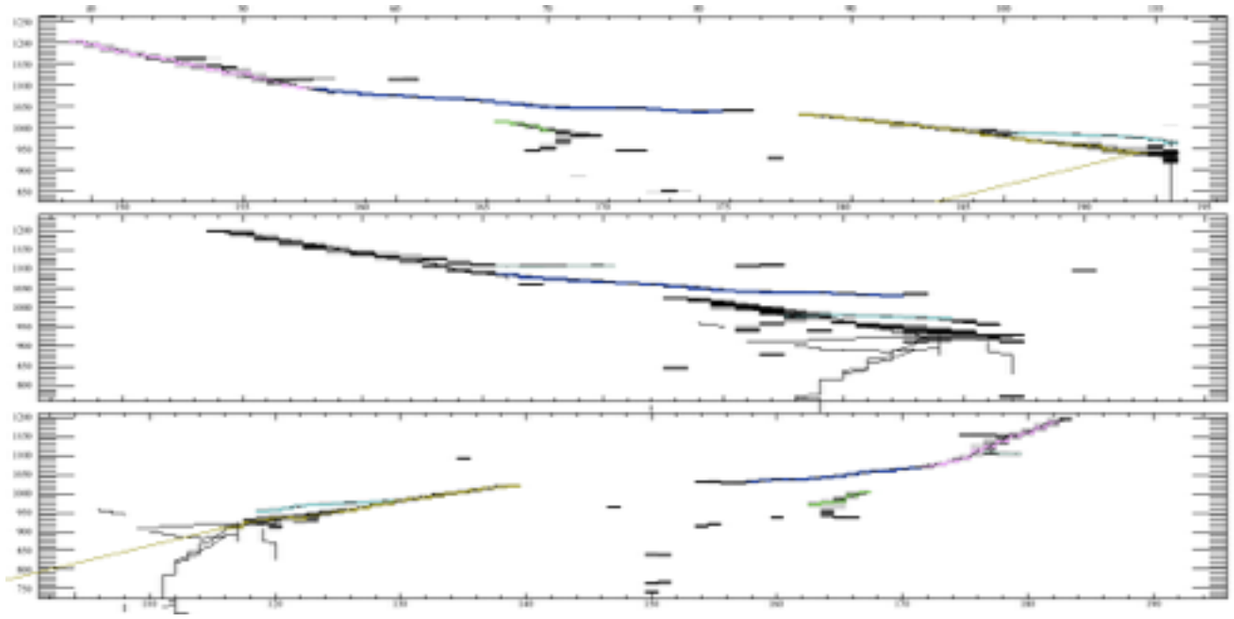
EMShower: Algorithm Details

- The shower reconstruction runs on the output of clustering and tracking on the events.

- Each cluster is associated with a track and, by using the 3D nature of tracks, means that clusters across multiple views can be matched to forms showers:



BlurredCluster



PMTrack

Example 35t pi0 event

EMShower: Algorithm Details

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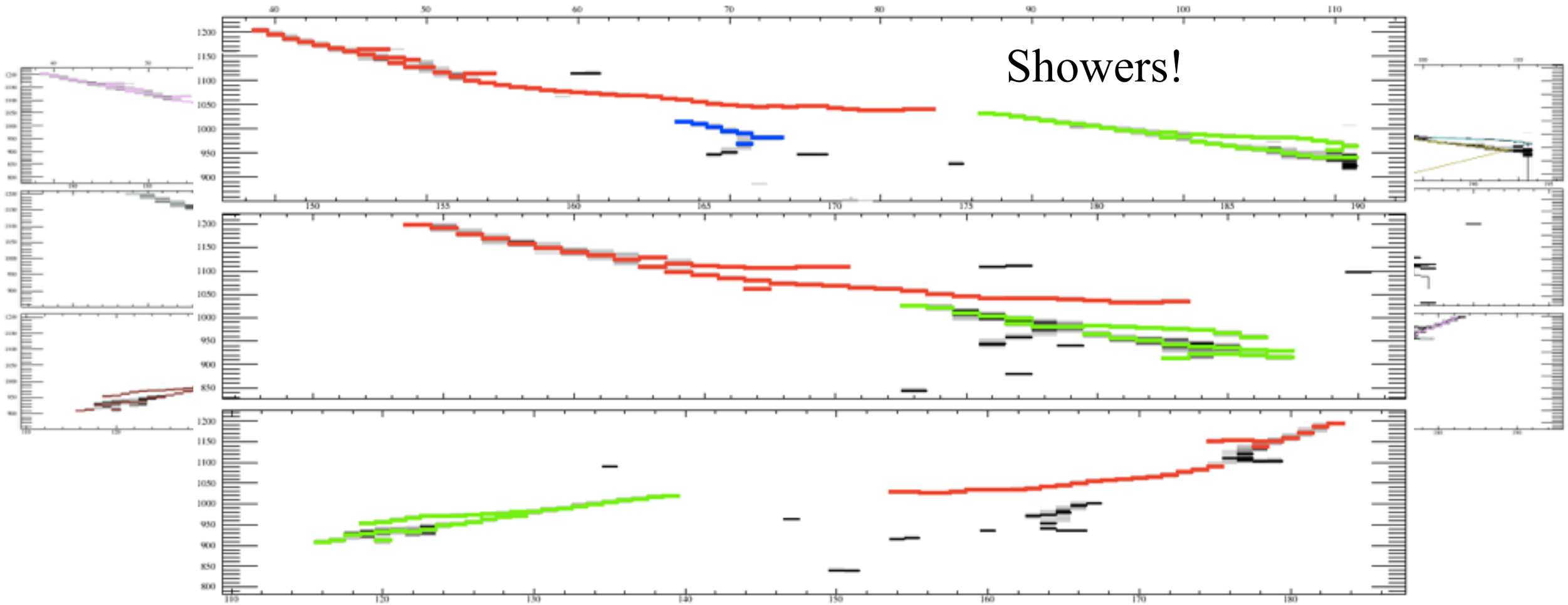
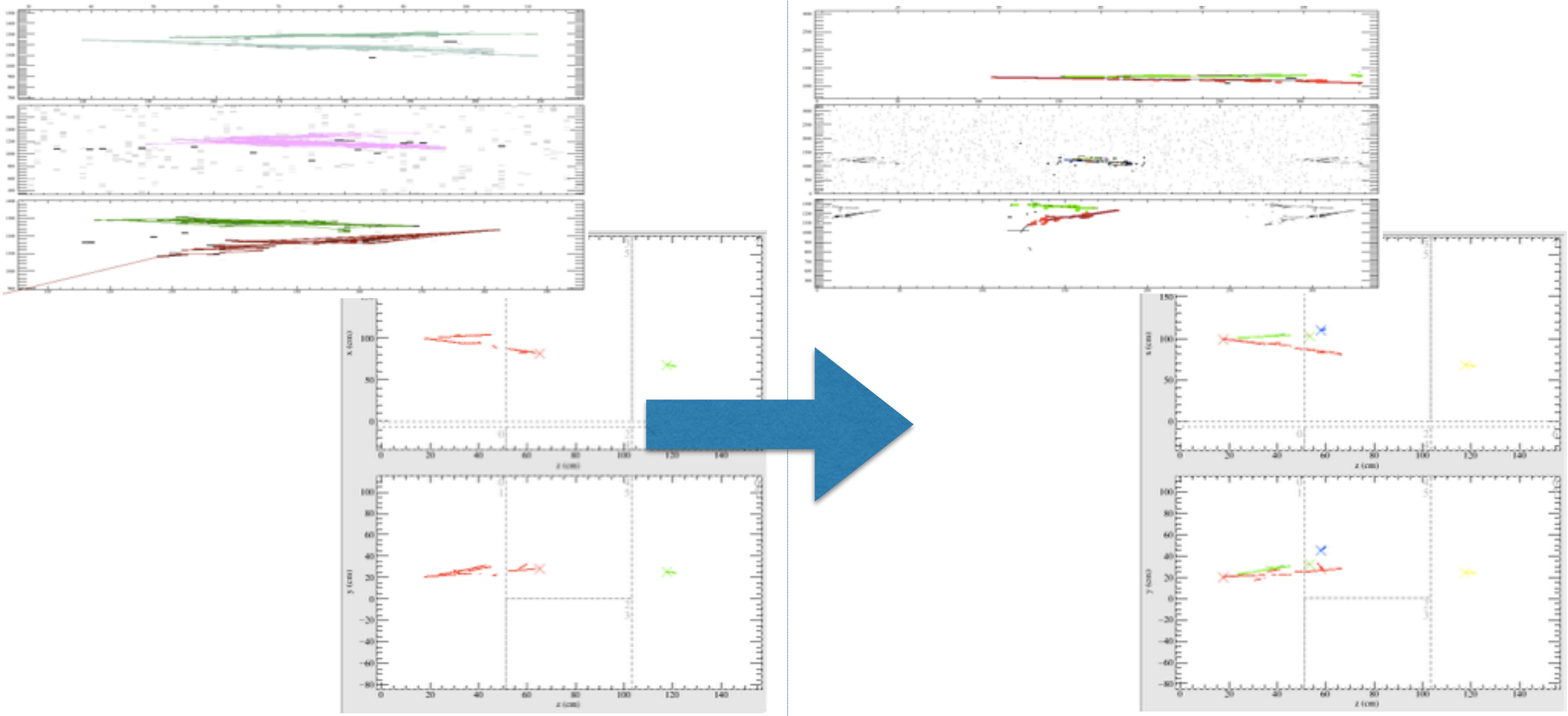
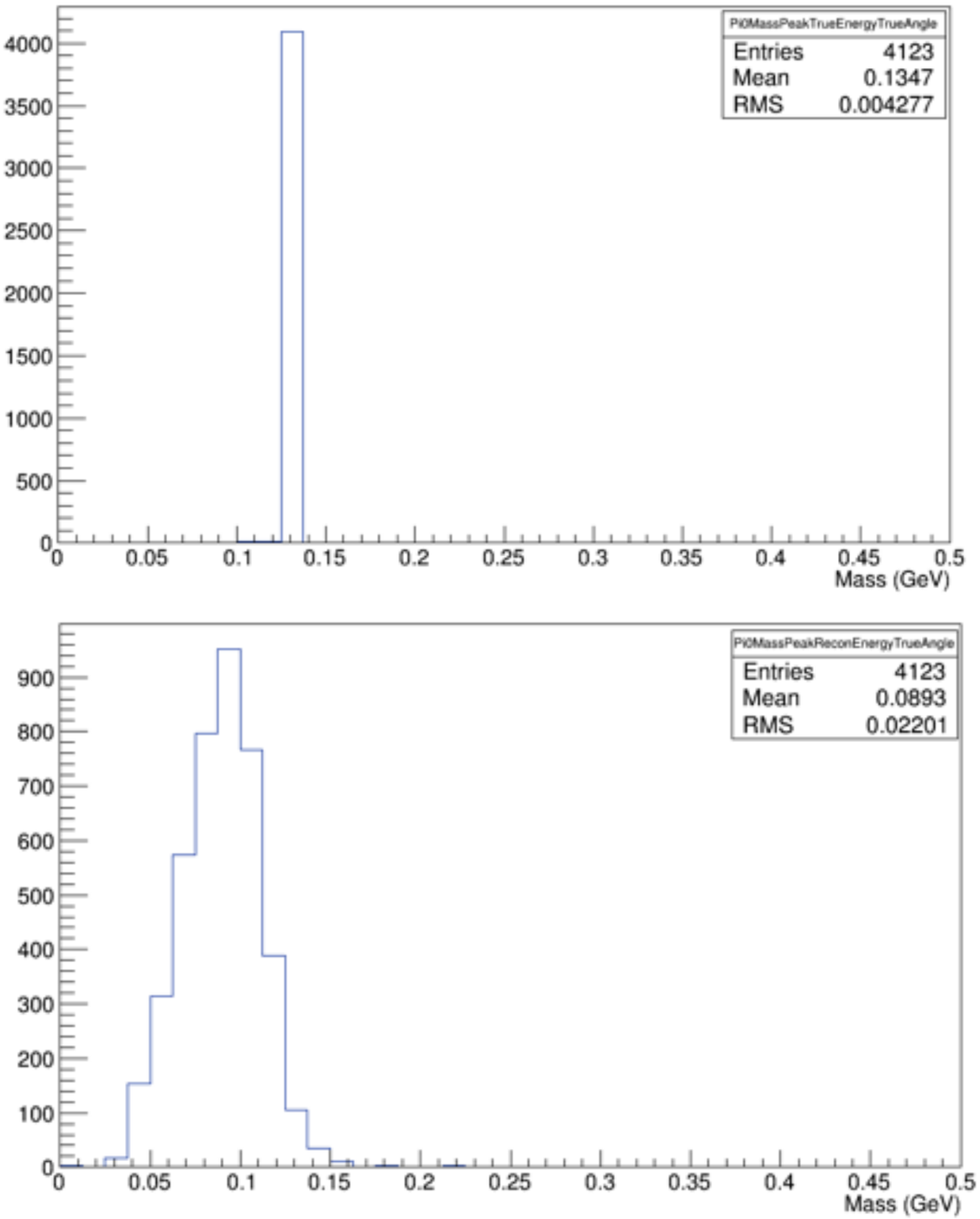


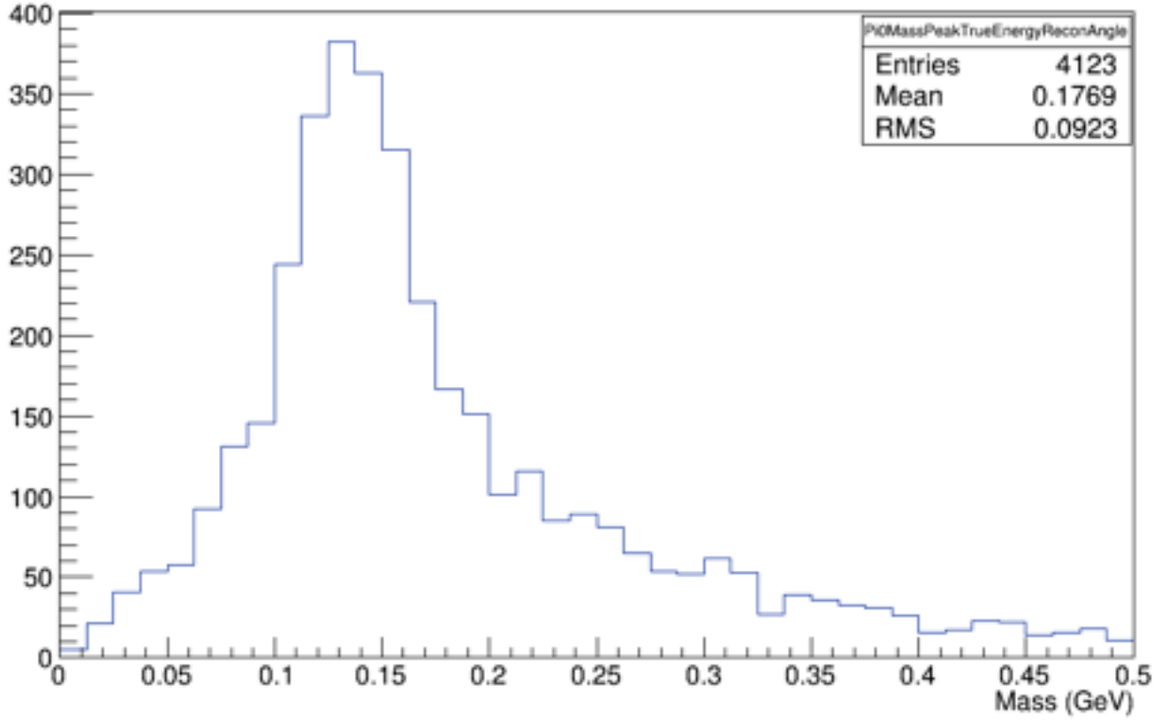
EMShower: Bad Views

- Have functionality to check if a single poorly reconstructed view is ruining the full event, and ignoring it if so.



35t π^0 Mass Peak: The Truth





- Top left: true energy, true direction.
- Top right: true energy, recon angle.
- Bottom left: recon energy, true angle.