# WP1: Reconstruction
# An overview of Pandora

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DUNE **DEEP UNDERGROUND NEUTRINO EXPERIMENT**

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# Work Package 1

- WP1 is the component of the UK project tasked with delivering neutrino interaction reconstruction and cosmic-ray calibration for the DUNE Far Detector

Core Reconstruction Algorithms

| WP1.2.1 Pattern Recognition | WP1.2.2 Deep Learning | WP1.2.3 High-level Reconstruction |
|---|---|---|

Event types

| Accelerator v |
|---|
| WP1.2.4 Atmospherics, Cosmics, Proton Decay |

Technologies

| Horizontal Drift |
|---|
| WP1.2.5 Vertical Drift |

Benchmarking & Calibration

| WP1.2.6 ProtoDUNEs |
|---|
| WP1.4.1 Calibration |

Ongoing ND efforts fit alongside the work package activities

# Pandora

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- The core of the UK software effort is the Pandora software suite

Pandora Software Suite

| PandoraSDK | LArContent* | LArPandora | PandoraMonitoring |

- Pandora performs pattern recognition to move from raw hit information to high-level objects representing the particles emerging from an event and their relationships

- **No pattern recognition, no physics**

*also known as larpandoracontent in the context of LArSoft

# PandoraSDK

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Pandora Software Suite

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- Software Development Kit (SDK)
  - Almost all pattern-recognition problems can be broken down into a core set of operations
    Cluster hits
    Refine clusters by merging and splitting
    Relate clusters into particles and hierarchies of particles
  - The **SDK provides core operations, runs pattern recognition** algorithms and handles the book-keeping associated with all pattern recognition objects
  - Operations should be **agnostic** to the interaction medium, the detector, the source of incident particles
  - The SDK is **stable**, changes are rare

# LArContent

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Pandora Software Suite

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- LArContent
  - This is where the pattern-recognition happens
  - While the SDK manages which algorithms run and when, those **algorithms are defined** here
  - The Pandora development team spends most of its time working on this component of Pandora
  - Algorithms are now **targeted to the liquid argon interaction medium** (LCContent exists for pattern recognition in linear colliders), but remain **agnostic to the experimental context**
  - Within DUNE, LArContent algorithms support both horizontal and vertical drift far detectors and the vertical drift coldbox, ProtoDUNE single phase, dual phase and ProtoDUNE-HD
  - Outside of DUNE, LArContent algorithms support MicroBooNE, SBND and ICARUS
  - We must be able to handle **neutrinos** from any source, **test beam** particles and **cosmic rays**

# LArContent

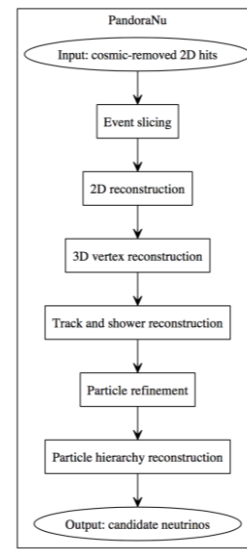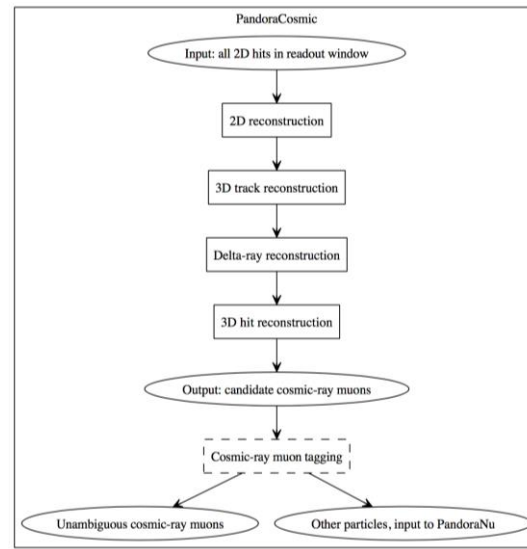- The core of the UK software effort is the Pandora software suite

**Pandora Software Suite**

| PandoraSDK | LArContent | LArPandora | PandoraMonitoring |
|---|---|---|---|

- Reconstruction chain
  - Two chains of algorithms for LArTPC reconstruction with much in common
  - PandoraCosmic: **track-oriented**; **showers assumed delta rays**, added as children of primary muons; **muon vertices at track high-y coordinate**
  - PandoraNu: finds **neutrino interaction vertex** and protects all particles emerging from vertex position; careful treatment to address track/shower tensions



PandoraCosmic:
Input: all 2D hits in readout window → 2D reconstruction → 3D track reconstruction → Delta-ray reconstruction → 3D hit reconstruction → Output: candidate cosmic-ray muons → Cosmic-ray muon tagging → Unambiguous cosmic-ray muons / Other particles, input to PandoraNu

PandoraNu:
Input: cosmic-removed 2D hits → Event slicing → 2D reconstruction → 3D vertex reconstruction → Track and shower reconstruction → Particle refinement → Particle hierarchy reconstruction → Output: candidate neutrinos

# LArPandora

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- The core of the UK software effort is the Pandora software suite

Pandora Software Suite

| PandoraSDK | LArContent | LArPandora | PandoraMonitoring |

- LArPandora
  - This is the **interface with LArSoft** (the core DUNE software stack)
  - We take raw hit information (signal processing happens before Pandora runs), detector geometry information and, where appropriate monte carlo truth information from LArSoft's ArtROOT format and convert it to Pandora's internal format
  - This information is then passed to the SDK, which runs the pattern recognition
  - Pandora's internal format is then converted back to ArtROOT and passed back to LArSoft to continue with high-level analysis tasks

# PandoraMonitoring

- The core of the UK software effort is the Pandora software suite

Pandora Software Suite

| | | | |
|---|---|---|---|
| PandoraSDK | LArContent | LArPandora | PandoraMonitoring |

- PandoraMonitoring
  - This is a package that Pandora uses to **record and report on pattern recognition status**
  - It's turned **off by default** in the LArSoft context, but can be **switched on in XML**
  - This can provide detailed debugging information, ROOT outputs and **access to Pandora's internal TEve-based event display** (distinct from the LArSoft event display you'll typically use)
  - Unless you're a Pandora dev, you probably won't interact with this package much, but useful to know it's there, as it can provide a lot of information about almost any stage of the pattern recognition

# Pandora's multi-algorithm approach
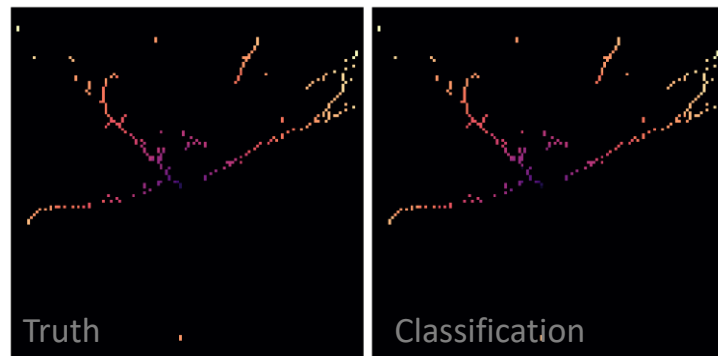
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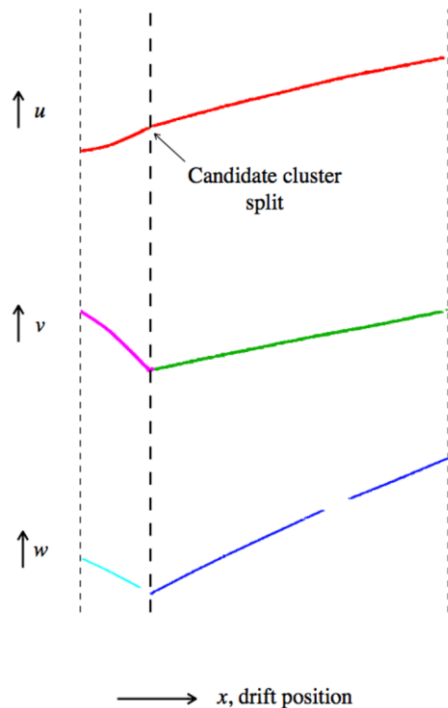
Detector-physics



- Build up event in stages
- Use underlying physics and detector knowledge alongside 'traditional' pattern recognition and machine learning
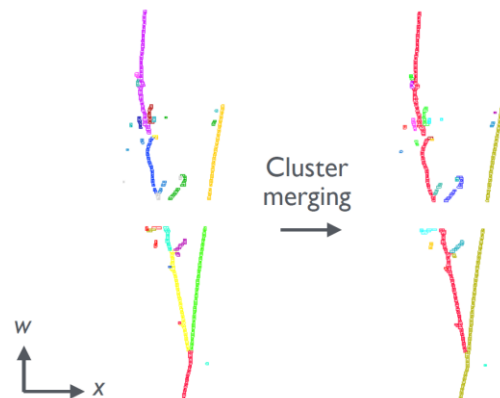


Traditional pattern recognition

Deep learning

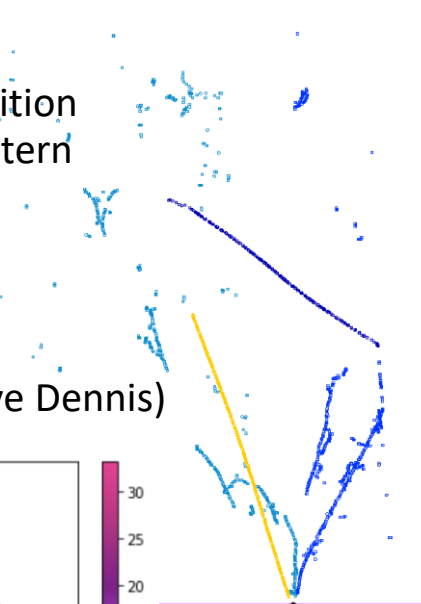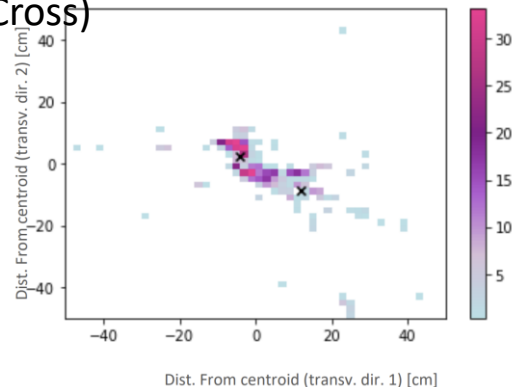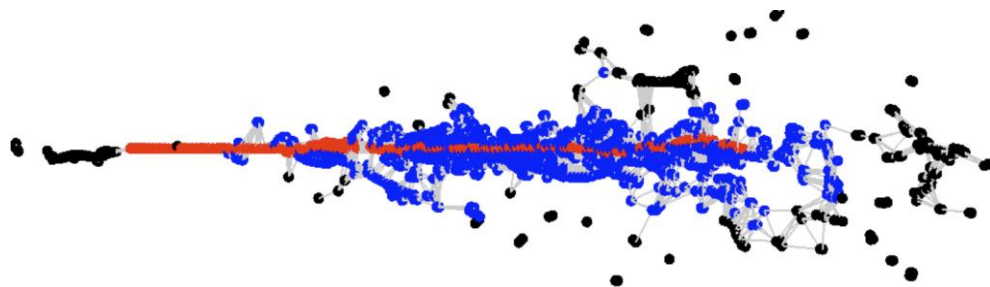# Pandora activities

- Reconstruction in DUNE is not a solved problem yet

- Many algorithms (> 100) already exist to solve specific pattern recognition problems, but new algorithms are in development to improve the pattern recognition

- Interaction vertex finding via semantic segmentation (Andy Chappell)

- Merged shower splitting (Maria Brigida Brunetti)

- Track and shower focused reconstruction streams in ProtoDUNE (Steve Dennis)

- 3D shower growing with graph networks (Ryan Cross)

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# Pandora activities

- e/γ separation for improved CP sensitivity  (Isobel Mawby)

- Refinement of reconstruction in vertical drift detector (Dom Brailsford, Maria Brigida Brunetti)

- Particle characterisation (Andy Chappell)

- Slicing refinement and preparations for ProtoDUNE-HD (Leigh Whitehead)

- Calorimetric matching algorithms (Dom Brailsford)
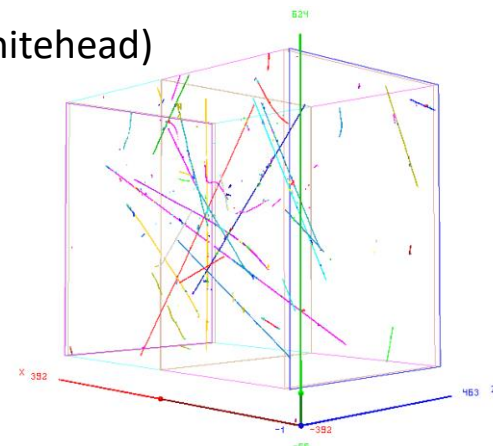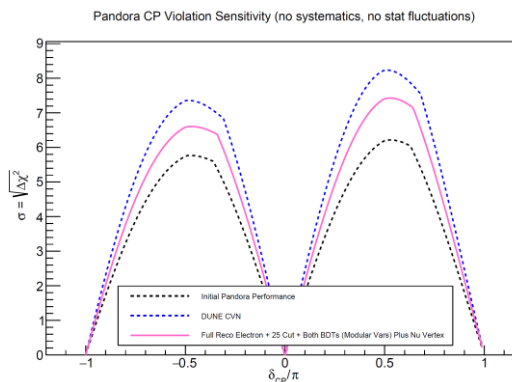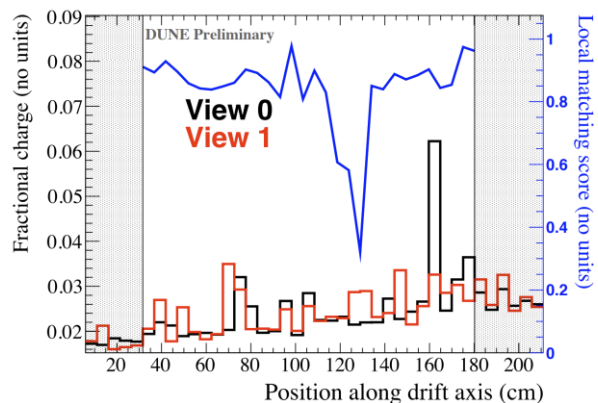
# Summary

- Reconstruction is a crucial prerequisite to achieving DUNE's physics goals

- Pandora provides many pattern recognition algorithms to support these goals

- Active development work to enhance the algorithms and support newer detector geometries

- If you have questions, reconstruction requests or would like to work on reconstruction, please get in touch!
  - DUNE Pandora slack