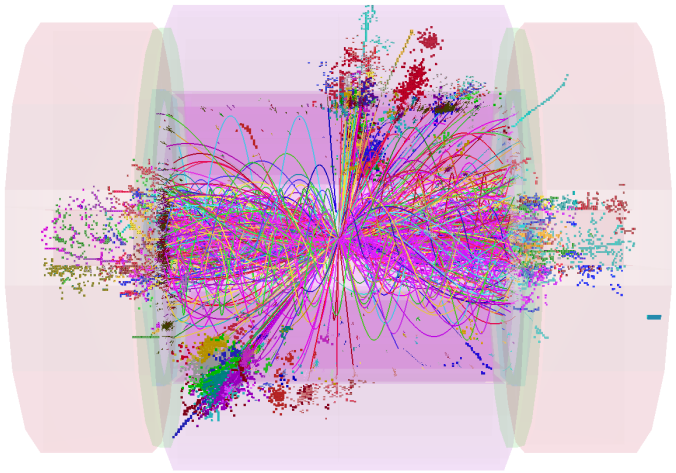
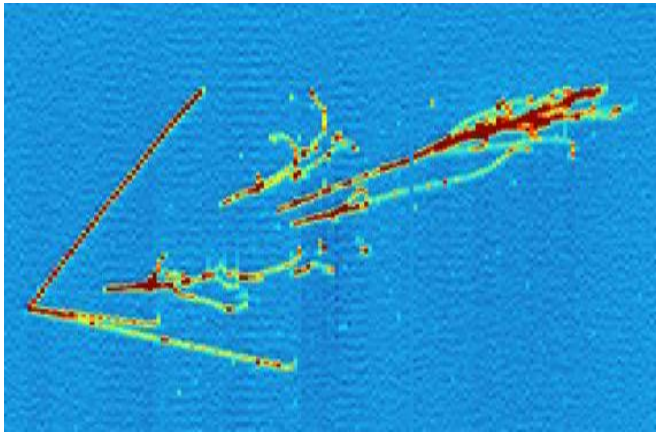




Introduction

Mark Thomson

Pandora MicroBooNE Workshop, 11th July 2017

UNIVERSITY OF CAMBRIDGE

μBooNE

Firstly…

- ★ **Welcome to the MicroBooNE Pandora Workshop!**
- ★ **We hope this workshop will provide a valuable introduction to Pandora**
  - Particular thanks to John for putting together a lot of the the material/exercises
- ★ **Aims:**
  - Provide a hands-on overview of working inside Pandora
  - Expand team developing Pandora-based LArTPC reconstruction
  - Hopefully have fun in the process…

Secondly…

- ★ **Welcome to Cambridge !**
- ★ **Some logistics:**
  - Dinner tonight starts with drinks at 1900

  - Lunches – two options:
    - i) Cavendish cafeteria (for the brave)
    - ii) Hauser Forum Cafe (a 5 minute walk)

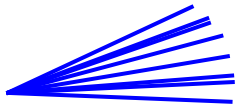
1. Pandora Origins

- **PandoraPFA was developed as a proof-of-principle for high-granularity particle flow calorimetry**
  - New paradigm for future collider detectors
    - ILC, CLIC and now the CMS endcap upgrade
  - Effectiveness relies on complex pattern recognition software
    - Validating concept required advanced reconstruction software many years ahead of time

Particle Flow Calorimetry

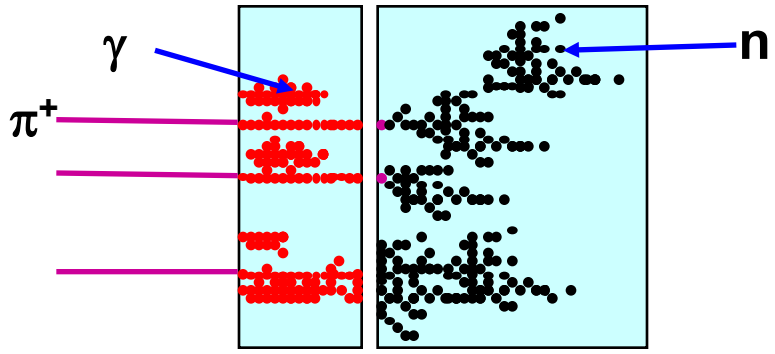
★ In a typical jet :

- 60 % of jet energy in charged hadrons
- 30 % in photons (mainly from $\pi^0 \rightarrow \gamma\gamma$)
- 10 % in neutral hadrons (mainly n and K_L)



★ Traditional calorimetric approach:

- Measure all components of jet energy in ECAL/HCAL !
- ~70 % of energy measured in HCAL: $\sigma_E/E \approx 60\%/\sqrt{E(GeV)}$
- Intrinsically "poor" HCAL resolution limits jet energy resolution

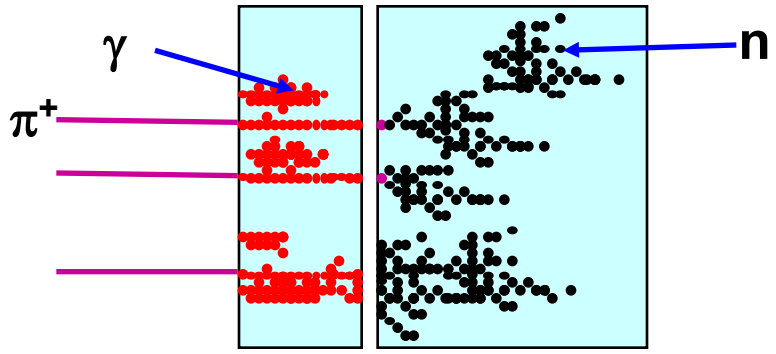


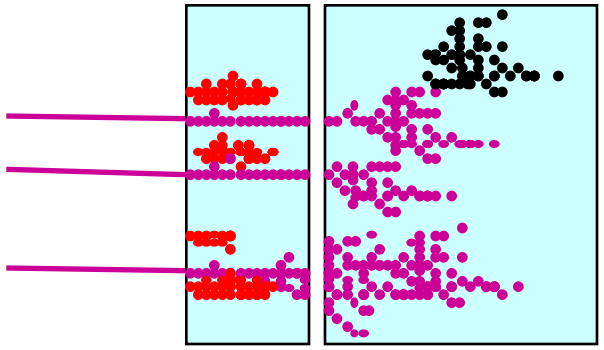
$E_{JET} = E_{ECAL} + E_{HCAL}$

Particle Flow Calorimetry

★ **Particle flow approach:**
- Try and measure energies of individual particles
- Reduce dependence on intrinsically "poor" HCAL resolution

★ **Idealised Particle Flow Calorimetry paradigm:**
- charged particles measured in tracker (essentially perfectly)
- Photons in ECAL:
- Neutral hadrons (ONLY) in HCAL
- Only 10 % of jet energy from HCAL ⇨ improved jet energy res.





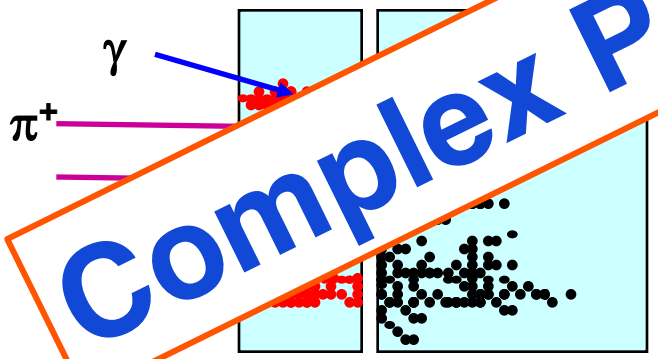
$E_{JET} = E_{ECAL} + E_{HCAL}$ ⇨ $E_{JET} = E_{TRACK} + E_{\gamma} + E_{n}$

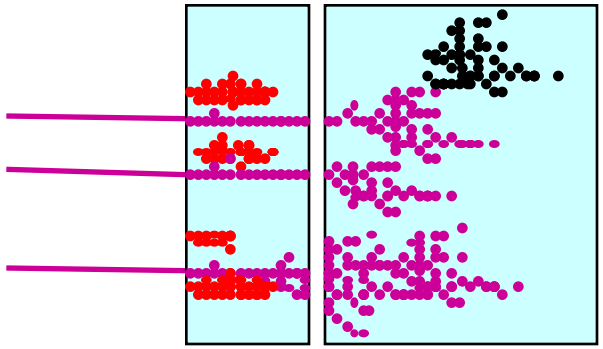
Particle Flow Calorimetry

★ **Particle flow approach:**
- Try and measure energies of individual particles
- Reduce dependence on intrinsically "poor" HCAL res

★ **Idealised Particle Flow Calorimetry paradigm:**
- charged particles measured in tracker (not ECAL) (perfectly)
- Photons in ECAL:
- Neutral hadrons (ONLY) in H
- Only 10 % of jet energy → improved jet energy res.

Complex Pattern Recognition

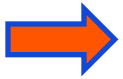




$E_{JET} = E_{ECAL} + E_{HCAL}$ ⇒ $E_{JET} = E_{TRACK} + E_{\gamma} + E_{n}$

Pandora Origins

- **PandoraPFA was developed as a proof-of-principle for high-granularity particle flow calorimetry**
  - New paradigm for future collider detectors
    - ILC, CLIC and now the CMS endcap upgrade
- **In principle, Particle Flow Calorimetry can deliver factors of two–to–three better performance**
  - Proof-of-principle relied on pattern recognition software
  - Initially typical applications were based on a “core” clustering approach
  - Very limited success…

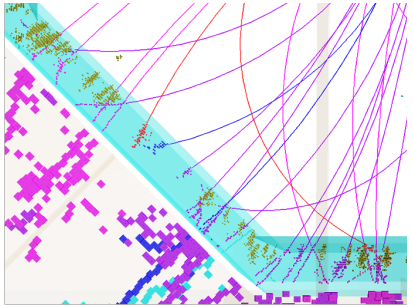


Different Approach

- **PandoraPFA**
  - Address problem with many “small” algorithms

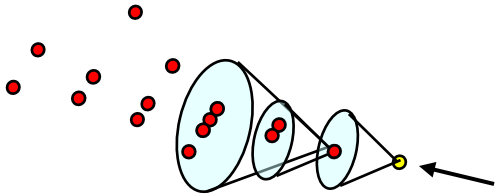
3. Pandora "Philosophy"

- **Single clustering approach is unlikely to work in a complex topology**
  - mix of track-like and shower-like clusters



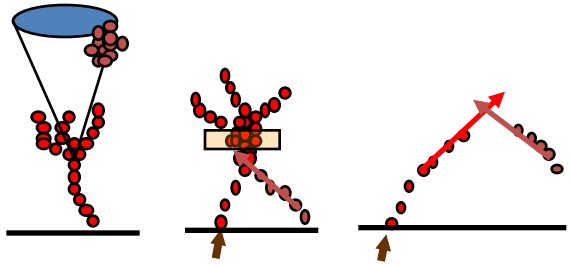
- **Replace with multi-algorithm approach**
  - Build up event gradually
  - Each step is incremental - aim not to make mistakes
    - Undoing mistakes is hard…
  - Build in physics knowledge in algorithms
    - e.g. knowledge of depth in calorimeters (radiation length in front)
    - e.g. properties of EM and Hadronic showers
  - Deploy more sophisticated algorithms as picture of event is developed

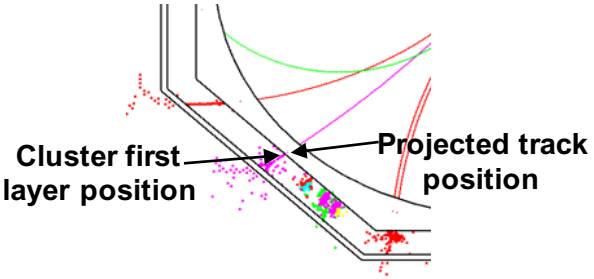
Pandora for the ILC/CLIC



ConeClustering Algorithm

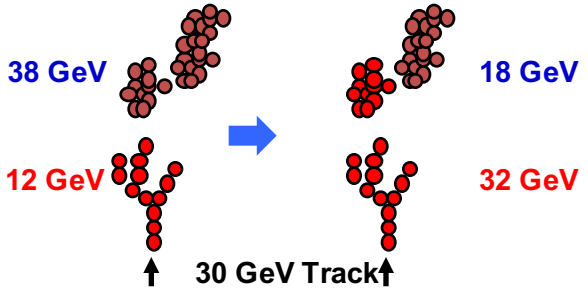
Topological Association Algorithms

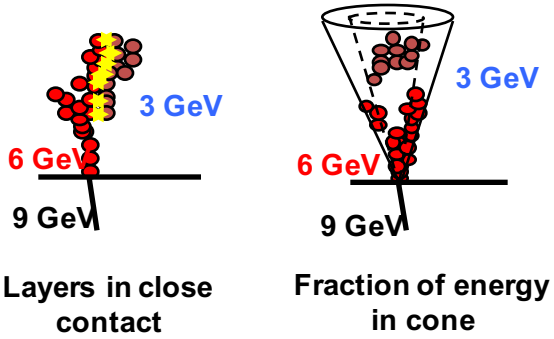




Track-Cluster Association Algorithms

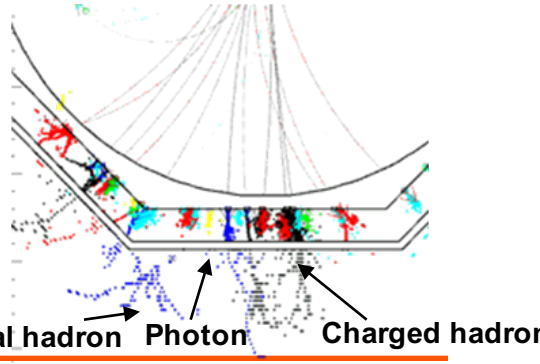
Reclustering Algorithms





Fragment Removal Algorithms

PFO Construction Algorithms



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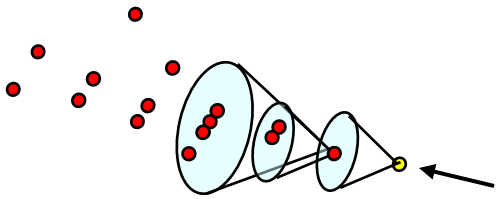
Pandora for the ILC/CLIC



ConeClustering Algorithm

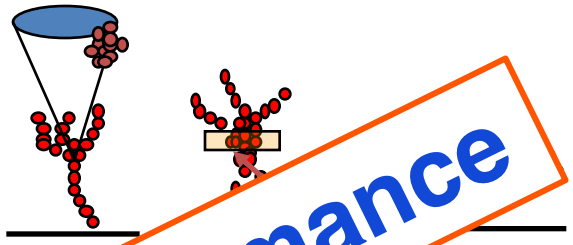
Topological Association Algorithms

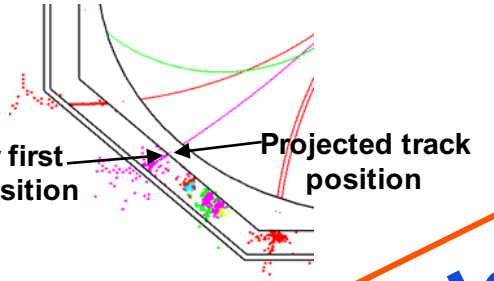
Track-Clu… Ass…

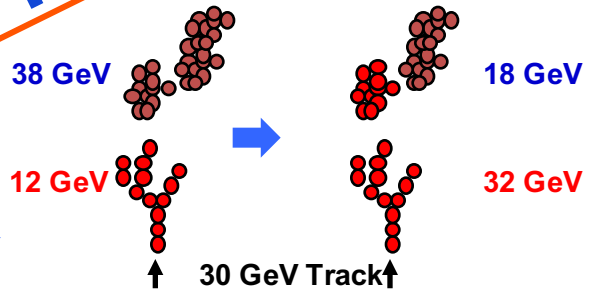
…clustering Algorithms

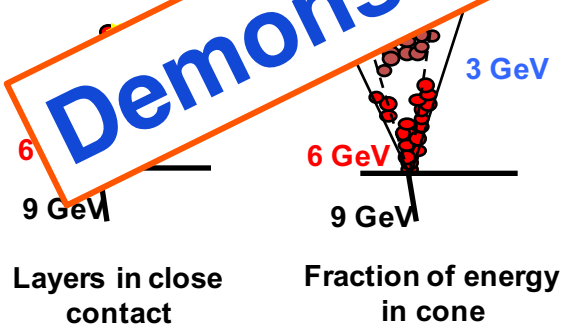
Fragment Removal Algorithms

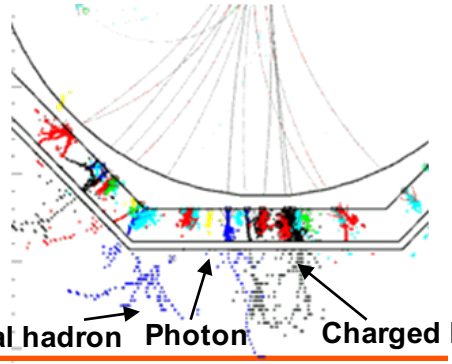
PFO Construction Algorithms











Demonstration of required performance

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Pandora for the ILC/CLIC

- **Some very powerful ideas: e.g. reclustering**
  - Effectively branch reconstruction within a "parent algorithm"
  - Choose "best" outcome at end of the parent algorithm
- **Reclustering**
  - If track momentum and cluster energy inconsistent: RECLUSTER

e.g.

Change clustering parameters/algs. until cluster splits and get sensible track-cluster match

4. Pandora Evolution

★ **Pandora Software**

- Originally written in "physicist C++"
- Then thrown away….

★ **Pandora Software Development Kit**

- 6 – 12 months of **careful design**
- Robust, fast, optimized container choices, etc.
- Professional implementation (thanks to John)
- Generalization of functionality

⇒ Enabled LAr-TPC reconstruction

~

Pandora for LAr-TPCs

- **Reconstruction challenges similar to those for high-granularity particle flow calorimetry**
  - Mix of n track-like objects and m shower-like objects
  - Single algorithm approach unlikely to fit all event types
    - e.g. trivial to develop an algorithm to cluster a single shower, but a priori do not know individual event topology
- **Potential advantages of Pandora approach**
  - Provides the software infrastructure to manage a complex algorithm chain
  - Multi-algorithm approach enables parallel development
  - Powerful built-in visualization tools for development
  - Supports complex (and potentially very powerful) algorithm structures, e.g. reclustering

Pandora for LAr-TPCs

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  - Multi-alg ach enables parallel development
  - Po in visualization tools for development
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Full potential – not yet exploited

5. Summary

- **Pandora provides a powerful and robust pattern recognition toolkit**

- **Powerful multi-algorithm approach**
  - A number of potential advantages for complex/diverse event topologies
  - Opportunities for parallel developments/developers

- **Development in Pandora is (relatively) easy**
  - As will (hopefully) be demonstrated in this workshop

5. Summary

- **Pandora provides a powerful and robust pattern recognition toolkit**

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  - Opportunities for parallel developments/developers

- **Development in Pandora is (relatively) easy**
  - As will (hopefully) be demonstrated in this workshop

New collaborators on Pandora LAr-TPC project for MicroBooNE and elsewehre would be very welcome

Questions?