First look at supernova neutrino reconstruction with Pandora

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16/01/23

DEEP UNDERGROUND NEUTRINO EXPERIMENT

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Personal introduction

- New first year PhD student at University of Warwick (Started my undergrad there in 2018)
- Working as part of the DUNE group at Warwick under **John Marshall**
  - In cooperation with
    - Andy Chappell (PDRA)
    - Maria Brigida Brunetti (PDRA)
    - Isobel Mawby (Soon to be a PDRA at Lancaster)
- Working alongside the Low Energy working group convened by Dan Pershey and Clara Cuesta

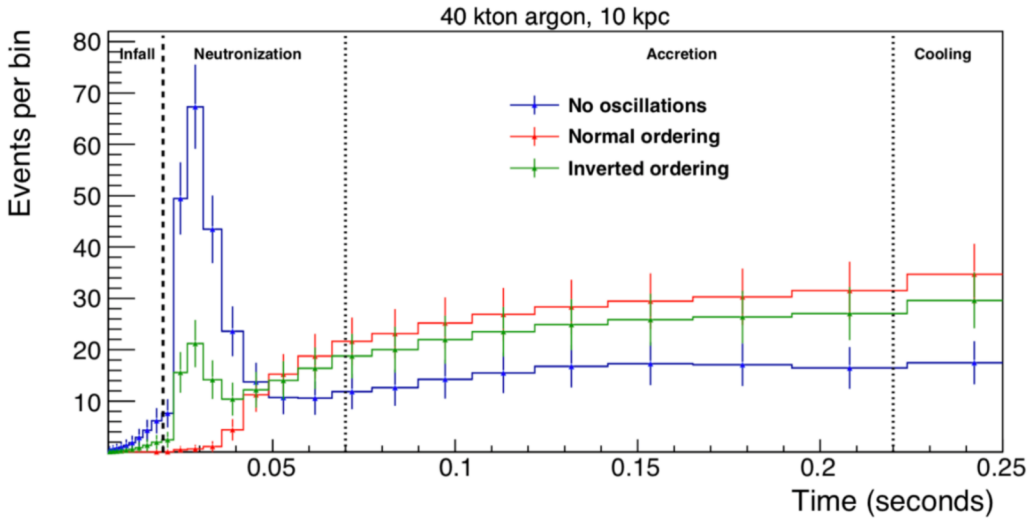
Current supernova theory

Detection and measurement of the electron neutrino flux from a core-collapse supernova within our galaxy.

- Core-collapse supernova - large flux of neutrinos released, carry 99% of the energy.
- Estimated with 40kt fiducial mass of DUNE's far detector – will record 3350 neutrinos (according to the "GKVM" model from a supernova 10kpc away from Earth)
- Signal dominated by electron neutrinos and detected in the process:

$$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$$

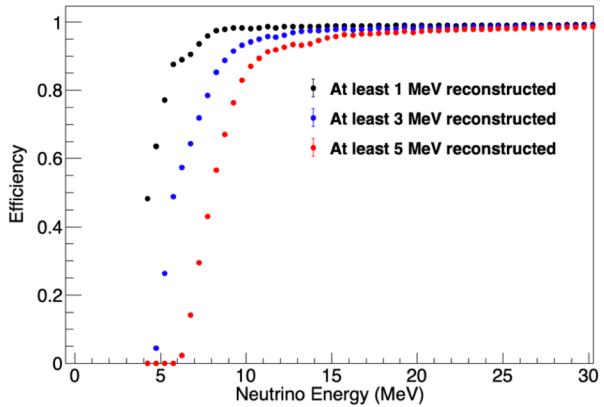
- Neutrino 'telescopes' and early warning systems
- Would be looking at neutrinos order ~10 MeV

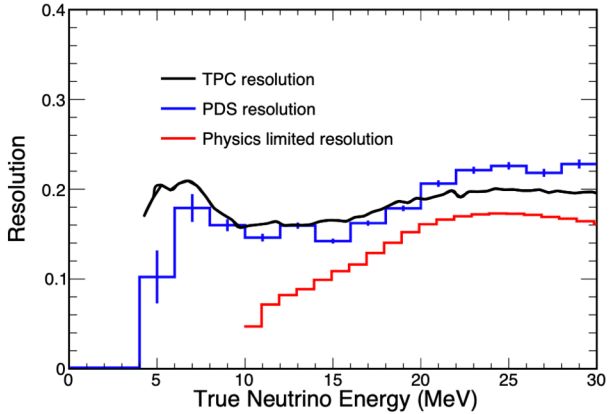


DUNE far detector TDR - https://cds.cern.ch/record/2709273/files/fermilab-pub-20-025-nd.pdf

Differences in Pandora pattern recognition

- Topologies are very different to samples which were previously reconstructed with Pandora
- Interaction of ~ **10 MeV** compared to beam neutrinos ~ **1 GeV**
- Small number of hits - order of **10s of hits** per event
- Arrival direction of neutrinos is unknown
- Close to threshold for reconstruction and current pattern recognition.
- **Specific thresholds and development required**!





DUNE far detector TDR - https://cds.cern.ch/record/2709273/files/fermilab-pub-20-025-nd.pdf

What are the reconstruction processes?

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- **Signal processing**
- **Hit finding** – identifying hits by fitting Gaussians to the signal processing output
- **Pattern recognition**
  - Cluster creation, splitting and merging in 2D, then a 3D clustering process

  (Changes to threshold criteria for reconstruction and new clustering algorithms required!)

  - PFO (Particle Flow Object) creation
  - Hierarchy, ID and shower/track tagging
- **Higher level reconstruction**
  - Estimating energies and direction, dE/dx and momentum of reconstructed PFOs.

Generated sample information

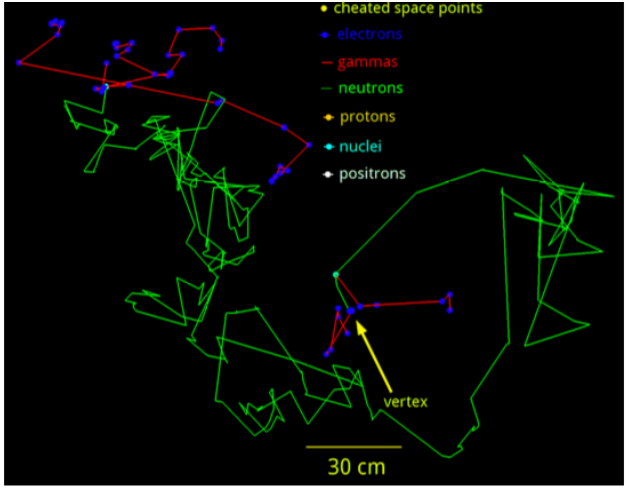
- Files generated by **MARLEY**

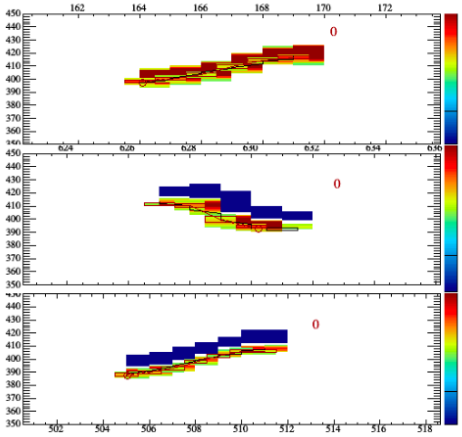
  (Model of Argon Reaction Low Energy Yields)
- Designed for interactions of ~ **10 MeV**
- Using the 1x8x14 30 degree vertical drift geometry
- Files **excluding** cosmological backgrounds at 5 – 30

  MeV containing 5000 events

Thanks to Laura Paulucci for samples

Figure 7.4: Visualization of an example MARLEY-simulated ν_e CC event, showing the trajectories and energy deposition points of the interaction products.

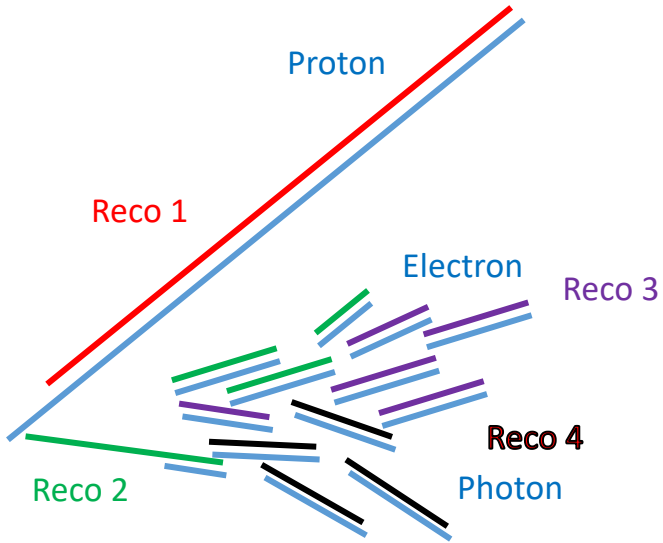




An intuition for the reconstruction – a single event

MC truth

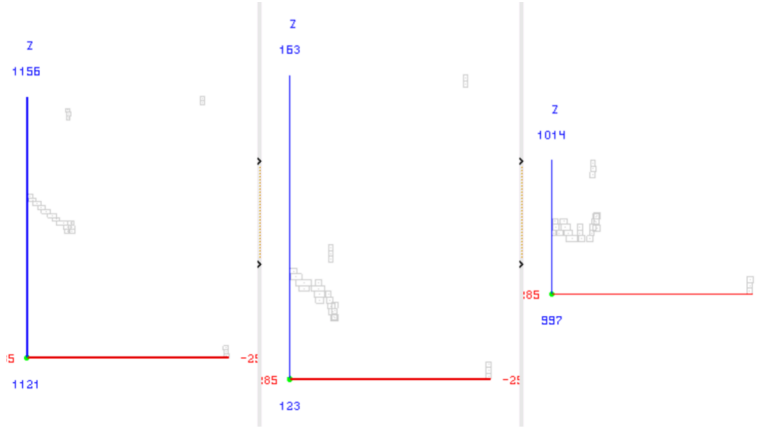
Reconstruction



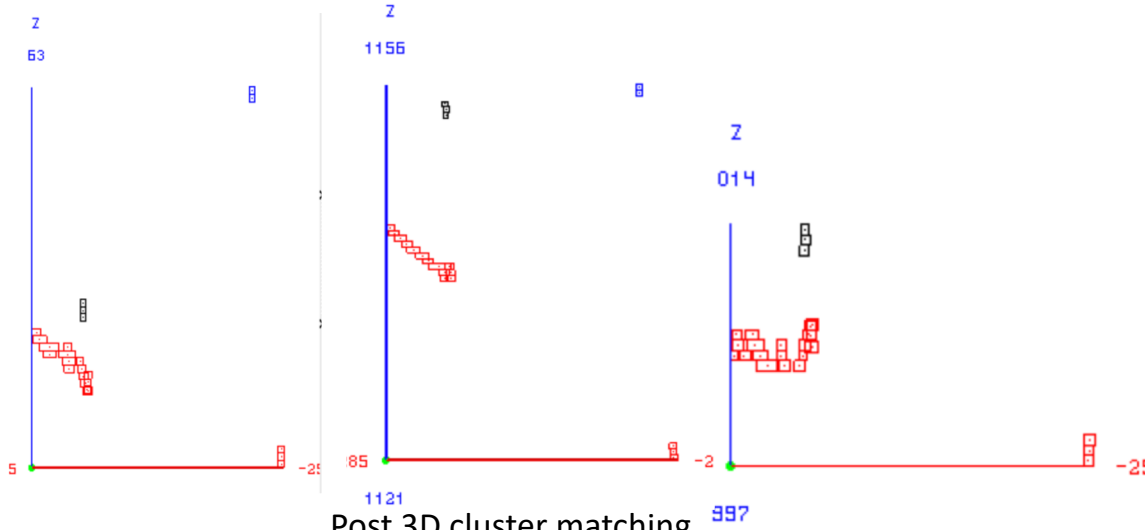
	MC Truth	Reconstruction	Comments
Proton	100 hits	99 hits	99% complete 100% pure - Reconstructed
Electron	100 hits	51 hits	50 % complete 98% pure - Poor reconstruction
		30 hits	-
		20 hits	-
Photon	5 hits	-	- Not reconstruction

Pandora event display

An event display in Pandora from a 30 MeV file



Input hits before Pandora pattern recognition



Post 3D cluster matching

Something to work on

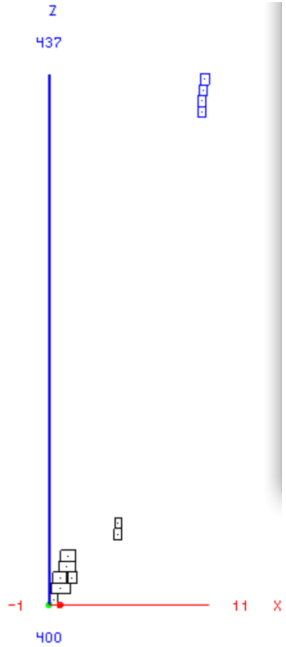
The issues:

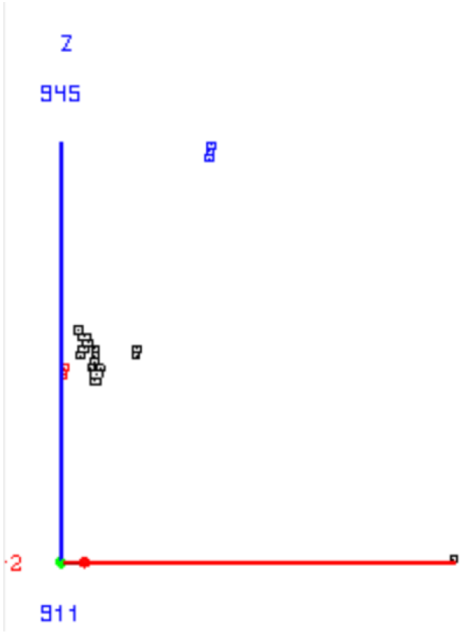
- MC ID 3 skipped
- First MC particle split into three

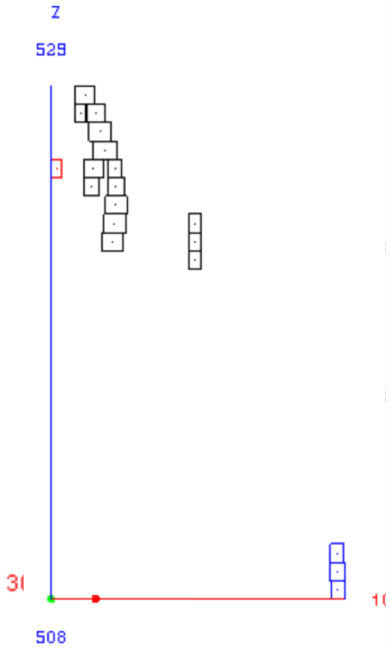
```
Original Event: ( 6 )
MC ID 1
  MC:  38
  reco [17 16  8]

Original Event: ( 6 )
MC ID 2
  MC:  10
  reco []

Original Event: ( 6 )
MC ID 4
  MC:  3
  reco []
```

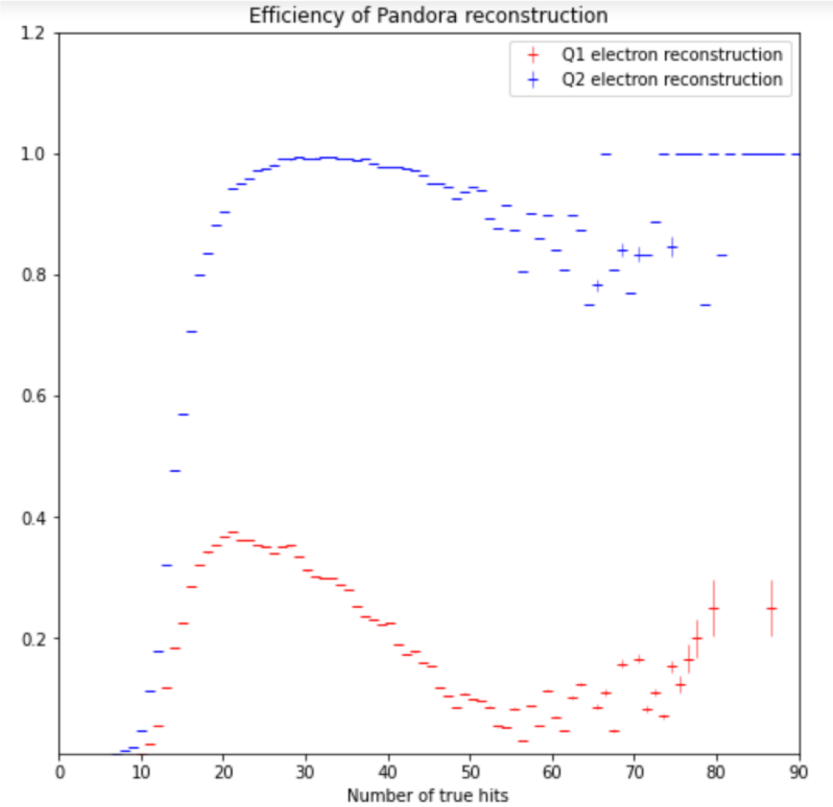






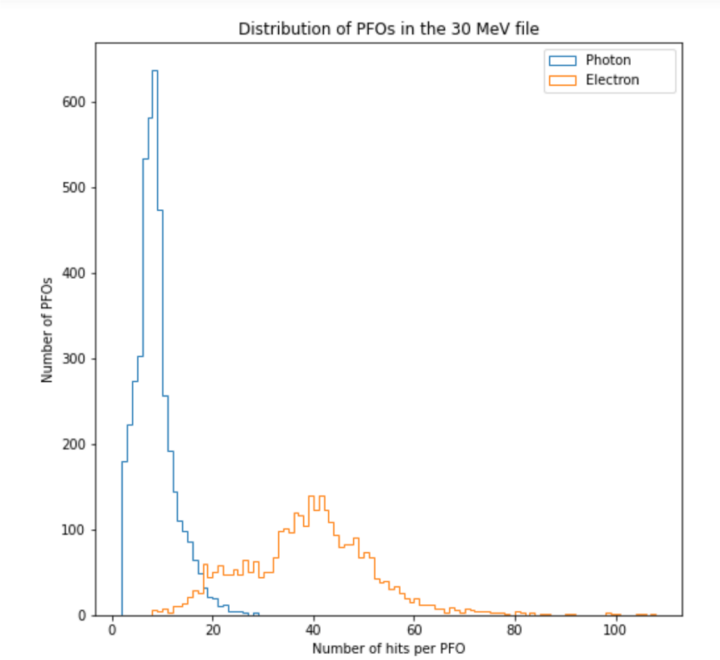
Metrics - Efficiency

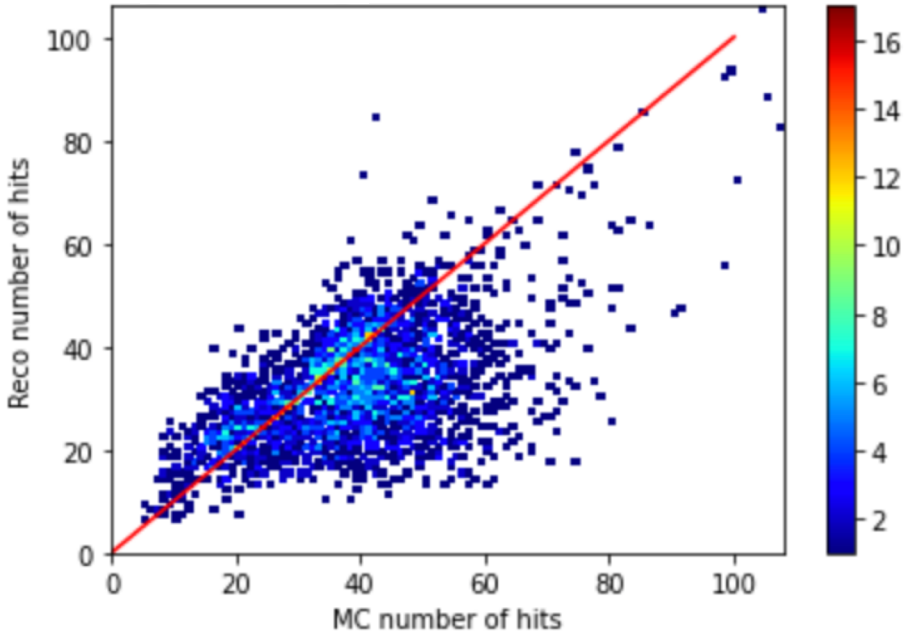
- Q1 - the number of hit in the reconstructed is within 5 hits of the number of hits in MC true particle
- Q2 - a reconstructed PFO has been created and meets a 50% completeness and 80% purity threshold



Metrics – hit numbers

We can use plots like these to benchmark our progress with improvements to the reconstructions in conjunction with the DUNE Low Energy Working group





Want to improve algorithm metrics:

- Efficiency
- Purity and Completeness

Pandora for MicroBooNE - https://link.springer.com/content/pdf/10.1140/epjc/s10052-017-5481-6.pdf?pdf=button%20sticky

First steps for improvement

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- Need to set **new thresholds for reconstruction (for the performance metrics/evaluation)**
- Currently, to be deemed reconstructable, Pandora requires:
  - Minimum of 15 hits per event total
  - Minimum of 5 hits per 2D plane to be deemed a ‘good’ view
  - Minimum of 2 ‘good’ views required.
- This is fine for beam neutrinos since files have many hundreds of hits
- However, for the supernovae event files, these **are** majority of events
- Want to remove the thresholds and **examine exactly how these low hit events are reconstructed**
- How does Pandora perform for these low information events?

Future plans and timeline

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- Implement cheated vertexing and cheated vertex selection and examine the change in metric plots to to see which aspects of the reconstruction could provide the largest gains after targeted development **– In Progress**
- Make changes to the regular algorithms with an hand firmly on the underlying physics as guidance – **To do**
- Iterations of cheating for different algorithms and adjustment to reconstruction thresholds and to further develop algorithms – **To do**
- Provide LArContent/LArReco GitHub branches with the new developments and the corresponding XML settings file for testing and wider use – **To do**

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Will be keeping the Low Energy and FD Sim/Reco working groups up to date and will produce some results in the coming weeks

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Back up slides

Vertical drift info

- Some information on detector geometry…

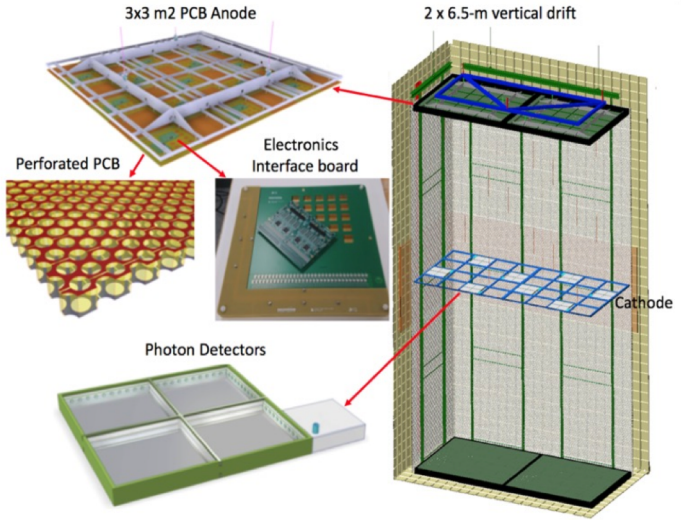

Figure 1: A cross-section of a single vertical drift module.

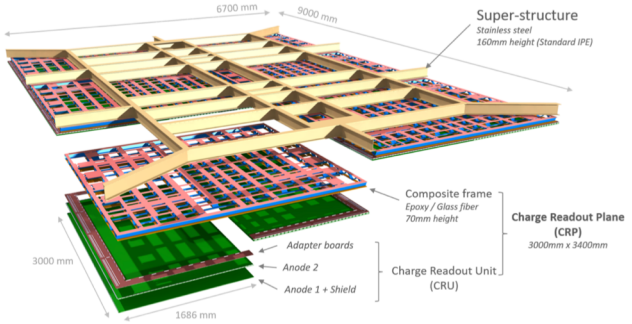

Figure 2: A schematic of a far detector CRP, attached to a mechanical support structure.

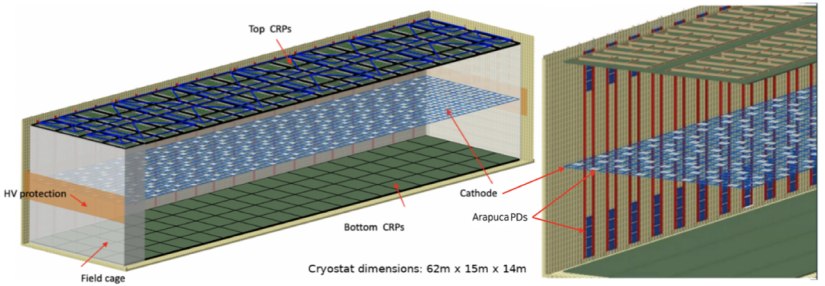

Figure 4: The layout of the Vertical Drift FD module.

First insights and areas to tackle

```
Original Event: ( 5 )
MC ID 1
  MC:  39
  reco [39]

Original Event: ( 5 )
MC ID 2
  MC:  13
  reco [14]

Original Event: ( 5 )
MC ID 3
  MC:  10
  reco []
```

Third MC Particle doesn't appear in terminal

```
Original Event: ( 6 )
MC ID 1
  MC:  38
  reco [17 16  8]

Original Event: ( 6 )
MC ID 2
  MC:  10
  reco []

Original Event: ( 6 )
MC ID 4
  MC:  3
  reco []
```

MC ID 3 skipped and first MC particle split in three

```
Original Event: ( 17 )
MC ID 1
  MC:  41
  reco [47]

Original Event: ( 17 )
MC ID 2
  MC:  8
  reco []

Original Event: ( 17 )
MC ID 4
  MC:  5
  reco []
```

MC ID 3 skipped and all three MC particles added to single reconstructed PFO