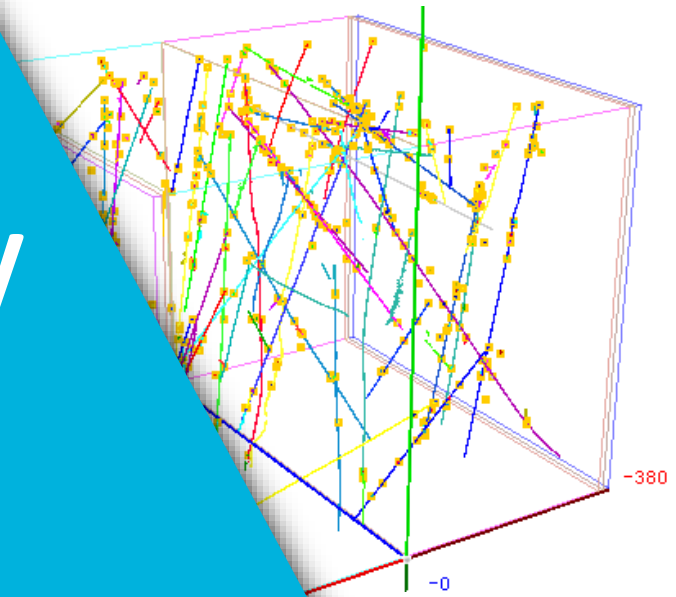
Pandora event display

Part 2: Visualizing the algorithms

(Exercise)

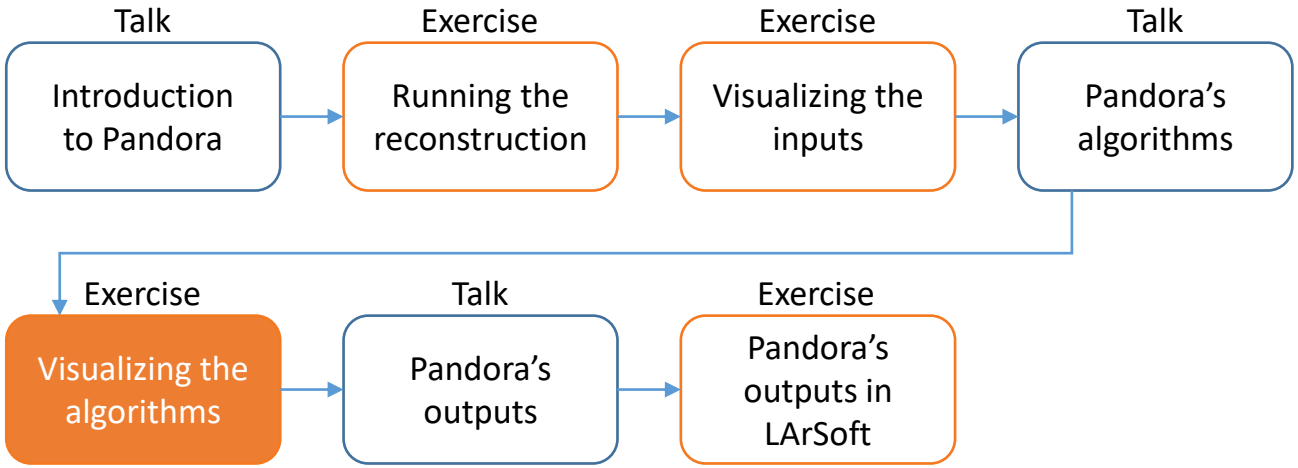


Isobel Mawby and Steve Dennis for the Pandora team

09/11/2022

7th UK LArTPC Software and Analysis Workshop

Reconstruction session



Credit: These slides are based on previous LArSoft workshop slides by Andrew Smith

Key references:
Pandora ProtoDUNE paper
Pandora MicroBooNE paper

Goals

- This session scheduled for 45 minutes
- Main goal - Visualize the status of the pattern-recognition after each main stage
  - Add the visual monitoring algorithm to the Pandora configuration XML file after running the:
    - 2D reconstruction
    - 3D vertex reconstruction
    - Track & Shower reconstruction & particle refinement
    - 3D hit reconstruction
    - Neutrino hierarchy reconstruction
- Please don’t worry if you don’t get through all of the steps
  - This session is just for you to get some intuition for what Pandora’s algorithms do

Main goal

Visualize the algorithms

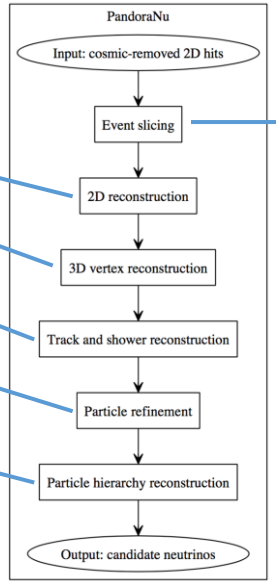
The neutrino algorithm chain

- Go to our config directory and make a copy of the Pandora neutrino XML settings file

```
$ cd $MRB_TOP/reco/config
$ cp $LARPANDORA_DIR/scripts/PandoraSettings_Neutrino_Standard.xml MyPandoraSettings_Neutrino_Standard.xml
$ vim MyPandoraSettings_Neutrino_Standard.xml
```

- Look through the file for the sections listed below:

```
<!-- TwoDReconstruction -->
<!-- VertexAlgorithms -->
<!-- ThreeDTrackAlgorithms -->
<!-- ThreeDShowerAlgorithms -->
<!-- Repeat ThreeDTrackAlgorithms -->
<!-- ThreeDRecoveryAlgorithms -->
<!-- TwoDMopUpAlgorithms -->
<!-- ThreeDHitAlgorithms -->
<!-- ThreeDMopUpAlgorithms -->
<!-- NeutrinoAlgorithms -->
<!-- Track and shower building -->
```



We're not running the event slicing because we don't have cosmics to deal with

Point to our neutrino settings file

- Modify MyPandoraSettings_Master_Standard.xml and point it to our new neutrino settings file
- Remove the visual monitoring algorithms that we've been using so far

```
+ MyPandoraSettings_Master_Standard.xml
<pandora>
    <!-- GLOBAL SETTINGS -->
    <IsMonitoringEnabled>true</IsMonitoringEnabled>
    <ShouldDisplayAlgorithmInfo>true</ShouldDisplayAlgorithmInfo>
    <SingleHitTypeClusteringMode>true</SingleHitTypeClusteringMode>

    <!-- ALGORITHM SETTINGS -->
    <algorithm type = "LArPreProcessing">
        <OutputCaloHitListNameU>CaloHitListU</OutputCaloHitListNameU>
        <OutputCaloHitListNameV>CaloHitListV</OutputCaloHitListNameV>
        <OutputCaloHitListNameW>CaloHitListW</OutputCaloHitListNameW>
        <FilteredCaloHitListName>CaloHitList2D</FilteredCaloHitListName>
        <CurrentCaloHitListReplacement>CaloHitList2D</CurrentCaloHitListReplacement>
    </algorithm>

    <algorithm type = "LArVisualMonitoring">
        <CaloHitListNames>CaloHitListU CaloHitListV CaloHitListW</CaloHitListNames>
        <ShowDetector>true</ShowDetector>
    </algorithm>

    <algorithm type = "LArMaster">
        <CRSettingsFile>PandoraSettings_Cosmic_Standard.xml</CRSettingsFile>
        <NuSettingsFile>MyPandoraSettings_Neutrino_Standard.xml</NuSettingsFile>
        <SlicingSettingsFile>PandoraSettings_Slicing_Standard.xml</SlicingSettingsFile>


  ... more settings ...


    <algorithm type = "LArVisualMonitoring">
        <ShowCurrentPfos>true</ShowCurrentPfos>
        <ShowDetector>true</ShowDetector>
    </algorithm>
</pandora>_
```

Remove this algorithm block

Change this line to point to MyPandoraSettings_Neutrino_Standard.xml

Remove this algorithm block

2D reconstruction

Add in some visualizations

- Add to MyPandoraSettings_Neutrino_Standard.xml at the end of the TwoDReconstruction section

../c/MyPandoraSettings_Neutrino_Standard.xml

```
<pandora>
    <!-- Output list management -->
    <!-- GLOBAL SETTINGS -->
    <IsMonitoringEnabled>true</IsMonitoringEnabled>
    <ShouldDisplayAlgorithmInfo>true</ShouldDisplayAlgorithmInfo>
    <SingleHitTypeClusteringMode>true</SingleHitTypeClusteringMode>

  ... more settings ...

    <algorithm type = "LArKinkSplitting"/>
    <algorithm type = "LArTrackConsolidation">
        <algorithm type = "LArSimpleClusterCreation" description = "ClusterRebuilding"/>
    </algorithm>

    <algorithm type = "LArVisualMonitoring">
        <CaloHitListNames>CaloHitListU</CaloHitListNames>
        <ClusterListNames>ClustersU</ClusterListNames>
        <ShowDetector>true</ShowDetector>
    </algorithm>

    <algorithm type = "LArVisualMonitoring">
        <CaloHitListNames>CaloHitListV</CaloHitListNames>
        <ClusterListNames>ClustersV</ClusterListNames>
        <ShowDetector>true</ShowDetector>
    </algorithm>

    <algorithm type = "LArVisualMonitoring">
        <CaloHitListNames>CaloHitListW</CaloHitListNames>
        <ClusterListNames>ClustersW</ClusterListNames>
        <ShowDetector>true</ShowDetector>
    </algorithm>
    <!-- VertexAlgorithms -->
    <algorithm type = "LArCandidateVertexCreation">
        <InputClusterListNames>ClustersU ClustersV ClustersW</InputClusterListNames>
        <OutputVertexListName>CandidateVertices3D</OutputVertexListName>
        <ReplaceCurrentVertexList>true</ReplaceCurrentVertexList>
```

Set this to true - this will print to the terminal all of the algorithms we are running

Modify the **Neutrino** file not the **Master** settings file

Add these visual monitoring blocks. When we run, this will make 3 event displays - each showing the hits and clusters in the U, V and W views respectively

Add the above lines just before the VertexAlgorithms section

Visualizing the initial 2D reconstruction

```
$ cd $MRB_TOP/reco/work
$ lar -c event_display_driver.fcl -s reco_events.root -n 1
```

Let's just look at 1 event for now!

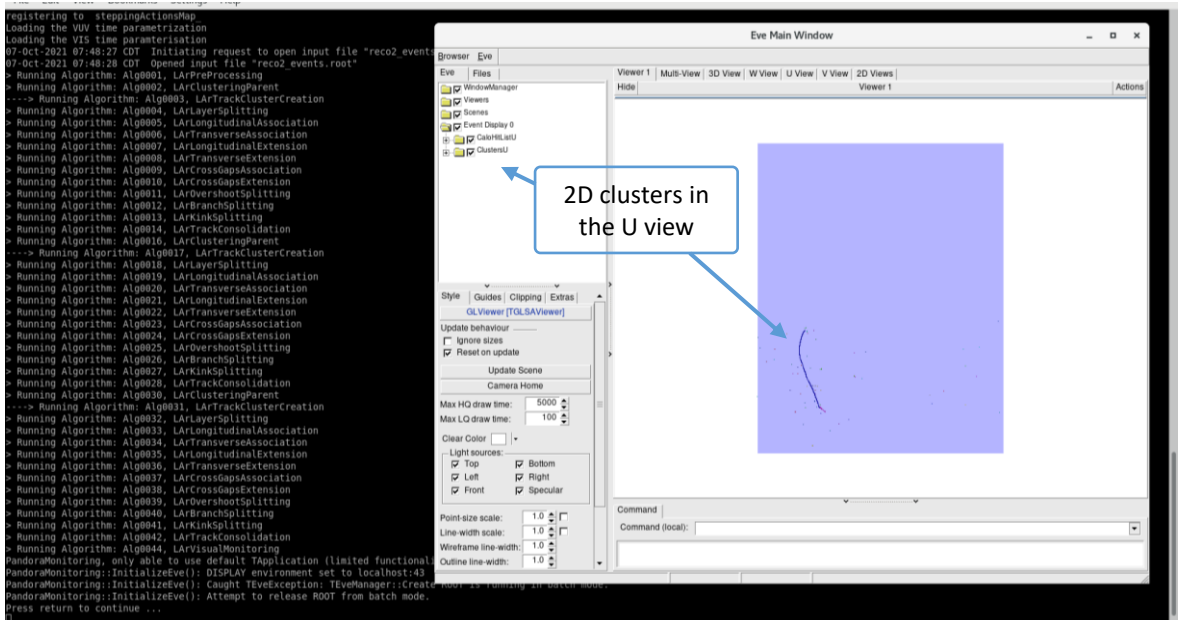
Can also run on pre-made reco file in /home/share/november2022/reconstruction/

2D clustering algorithms in the U-view

2D clustering algorithms in the V-view

2D clustering algorithms in the U-view

First visualization



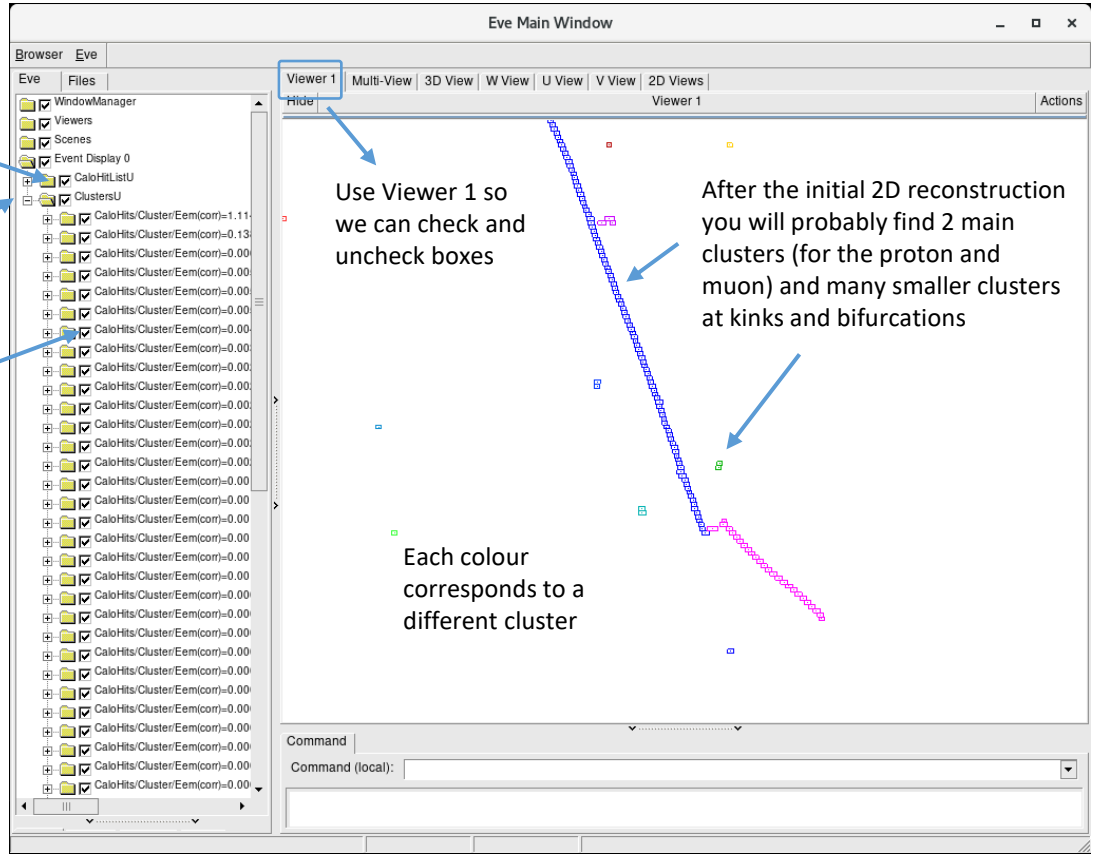
Looking at the reconstructed particles – 3D View

Turn off the hits, we've included them so you can always refer back to the inputs if you like

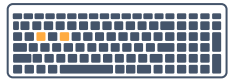
Expand the list of clusters

Try turning on and off some of the clusters so you can see what they correspond to in the viewer

Clusters are ordered by the total energy deposited



Wheel up - zoom out
Wheel down - zoom in
Wheel press + drag - pan viewport

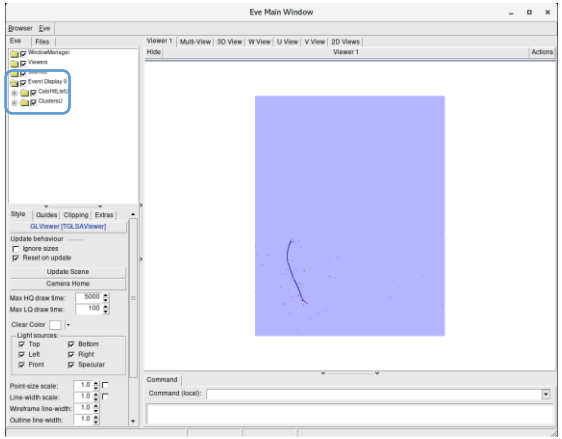


W - wireframe mode
R - return from wireframe mode

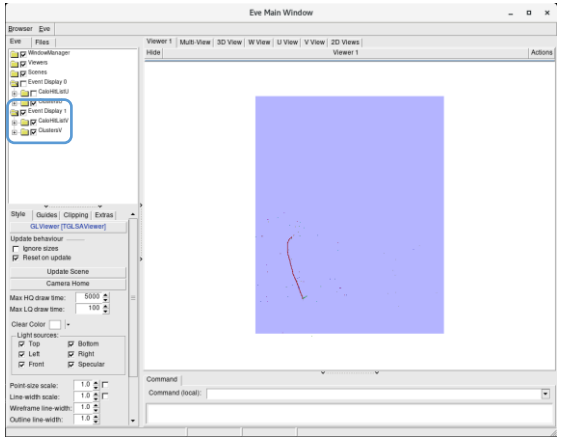
Looking at the other views

Click in the terminal window and press Return ↵ to visualize the other views

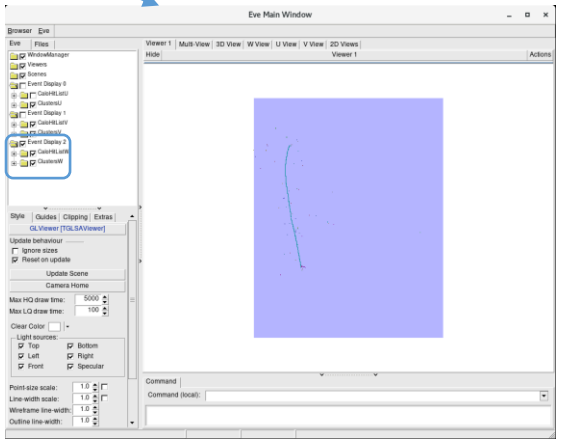
```
<algorithm type = "LArVisualMonitoring">
    <CaloHitListNames>CaloHitListU</CaloHitListNames>
    <ClusterListNames>ClustersU</ClusterListNames>
    <ShowDetector>true</ShowDetector>
</algorithm>                                    Return ↵

<algorithm type = "LArVisualMonitoring">
    <CaloHitListNames>CaloHitListV</CaloHitListNames>
    <ClusterListNames>ClustersV</ClusterListNames>
    <ShowDetector>true</ShowDetector>
</algorithm>                                    Return ↵

<algorithm type = "LArVisualMonitoring">
    <CaloHitListNames>CaloHitListW</CaloHitListNames>
    <ClusterListNames>ClustersW</ClusterListNames>
    <ShowDetector>true</ShowDetector>
</algorithm>                                    Return ↵
```



U view clusters



V view clusters



W view clusters

3D vertex reconstruction

Add in some more visualizations

- Add to MyPandoraSettings_Neutrino_Standard.xml at the end of the VertexAlgorithms section

```
<!-- VertexAlgorithms -->
<algorithm type = "LArCandidateVertexCreation">
    <InputClusterListNames>ClustersU ClustersV ClustersW</InputClusterListNames>
    <OutputVertexListName>CandidateVertices3D</OutputVertexListName>
    <ReplaceCurrentVertexList>true</ReplaceCurrentVertexList>
    <EnableCrossingCandidates>false</EnableCrossingCandidates>
</algorithm>
<algorithm type = "LArEnergyKickVertexSelection">
    <InputCaloHitListNames>CaloHitListU CaloHitListV CaloHitListW</InputCaloHitListNames>
    <InputClusterListNames>ClustersU ClustersV ClustersW</InputClusterListNames>
    <OutputVertexListName>NeutrinoVertices3D</OutputVertexListName>
    <ReplaceCurrentVertexList>true</ReplaceCurrentVertexList>
    <FeatureTools>
        <tool type = "LArEnergyKickFeature"/>
        <tool type = "LArLocalAsymmetryFeature"/>
    </FeatureTools>
</algorithm>
<algorithm type = "LArVertexSplitting">
    <InputClusterListNames>ClustersU ClustersV ClustersW</InputClusterListNames>
</algorithm>

<algorithm type = "LArVisualMonitoring">
    <ClusterListNames>ClustersV</ClusterListNames>
    <VertexListNames>CandidateVertices3D</VertexListNames>
    <ShowDetector>true</ShowDetector>
</algorithm>

<algorithm type = "LArVisualMonitoring">
    <ClusterListNames>ClustersW</ClusterListNames>
    <VertexListNames>NeutrinoVertices3D</VertexListNames>
    <ShowDetector>true</ShowDetector>
</algorithm>

<!-- ThreeDTrackAlgorithms -->
<algorithm type = "LArThreeDTransverseTracks">
    <InputClusterListNameU>ClustersU</InputClusterListNameU>
    <InputClusterListNameV>ClustersV</InputClusterListNameV>
    <InputClusterListNameW>ClustersW</InputClusterListNameW>
```

The LArCandidateVertexCreation algorithm creates a list of 3D candidate vertices at positions that project onto the ends of the existing 2D clusters

The LArEnergyKickVertexSelection algorithm selects the neutrino vertex from the candidates

Visualize the 3D candidate vertices along with the W-view clusters for comparison

Visualize the selected neutrino vertex along with the W-view clusters for comparison

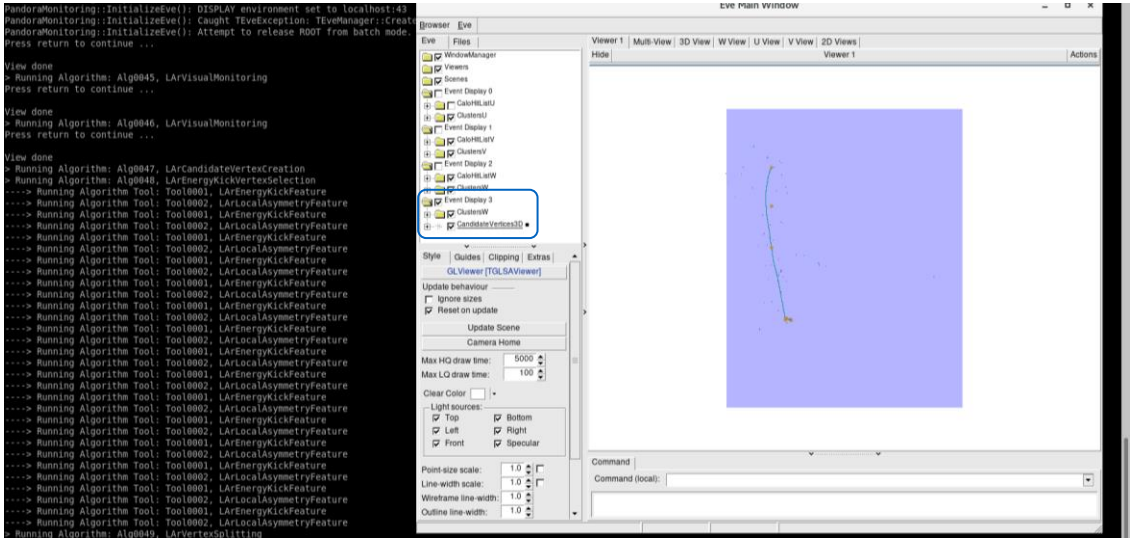
Add the above lines just before the ThreeDTrackAlgorithms section

Run Pandora again!

- Run our FHiCl file again

```
$ cd $MRB_TOP/reco/work
$ lar -c event_display_driver.fcl -s reco_events.root -n 1
```

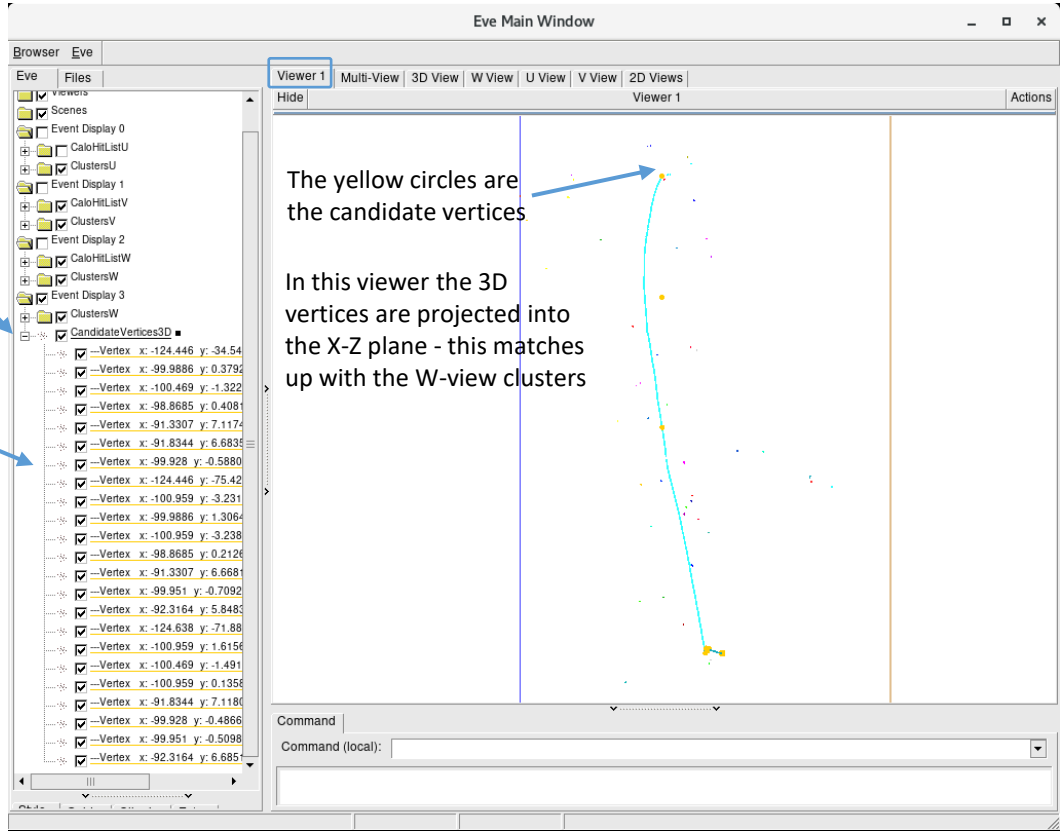
- After the event display has loaded press Return ↵ three times, to skip through our visualizations from part 1



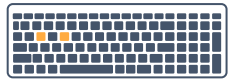
Candidate 3D vertices vs W-view clusters

Expand the list of candidate vertices - there will be many!

Each vertex here is displayed as a yellow circle in the viewer



Wheel up - zoom out
Wheel down - zoom in
Wheel press + drag - pan viewport



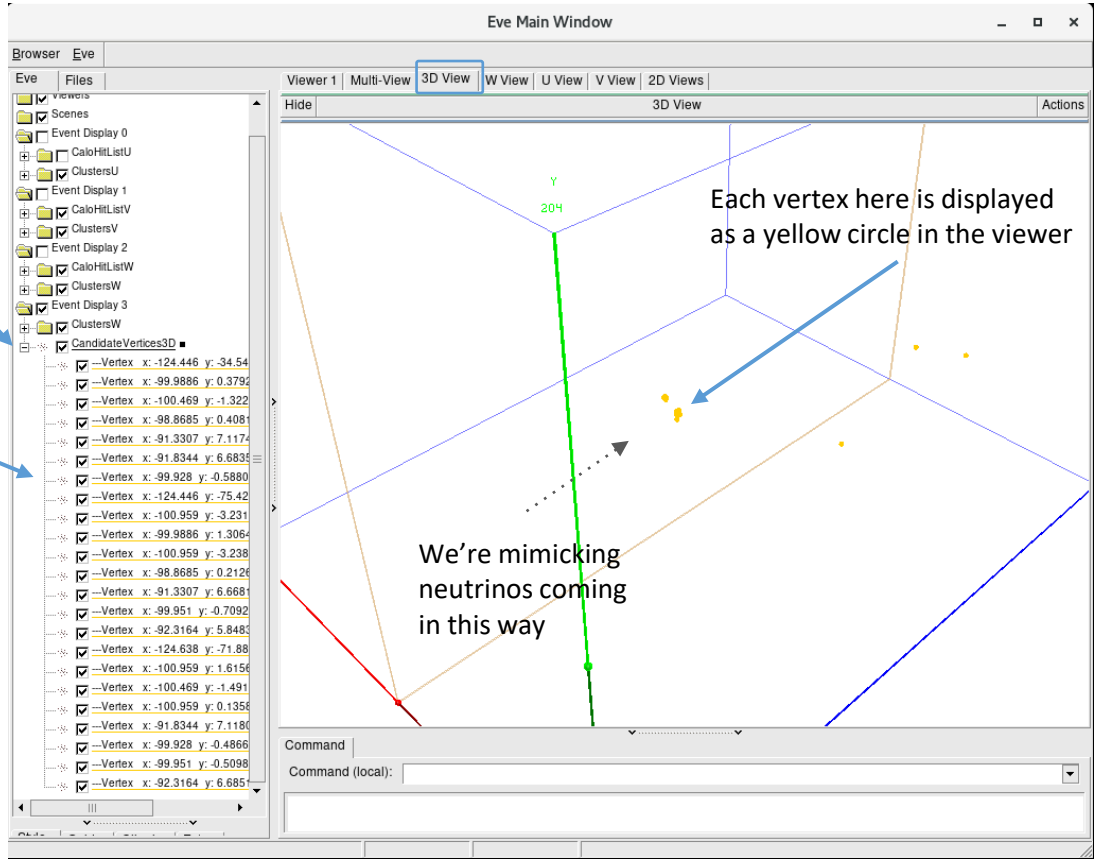
W - wireframe mode
R - return from wireframe mode

Candidate 3D vertices vs W-view clusters

Expand the list of candidate vertices - there will be many!

Each vertex here is displayed as a yellow circle in the viewer

When you are finished, press Return ↵ to move to the next display



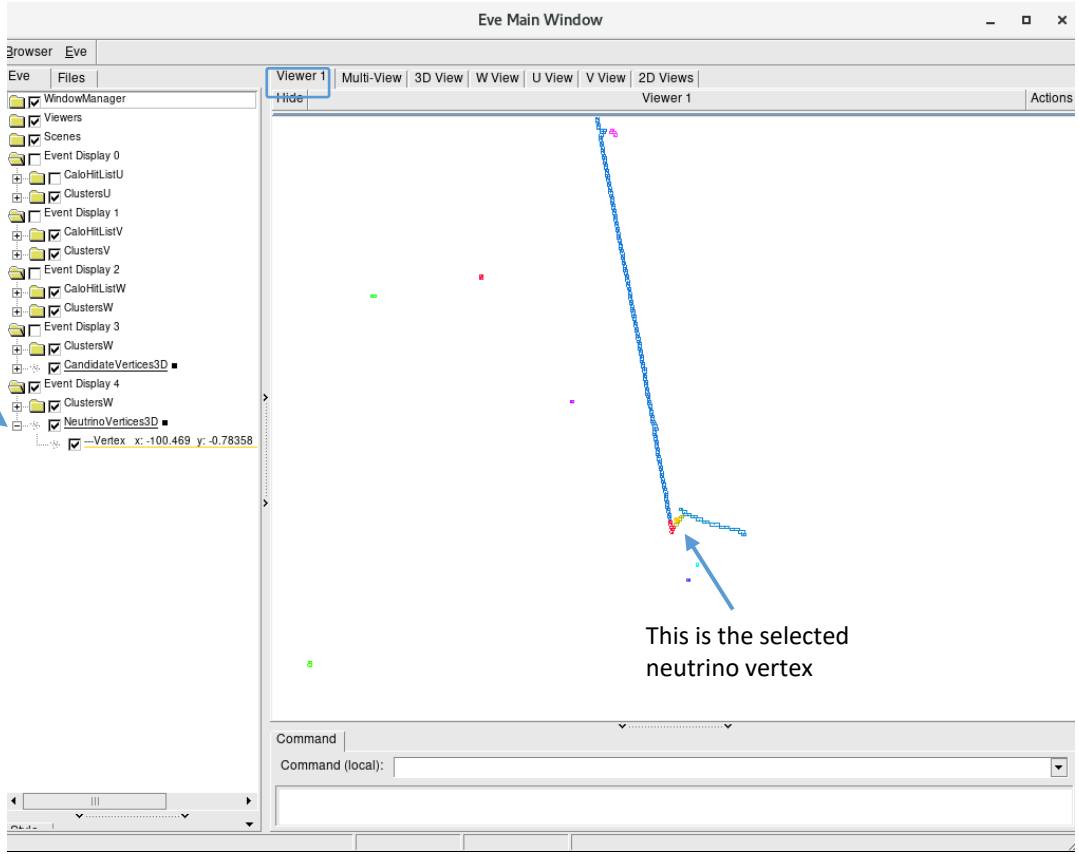
Wheel up - zoom out
Wheel down - zoom in
Wheel press + drag - pan viewport

Left press + drag - rotate 3D view

W - wireframe mode
R - return from wireframe mode

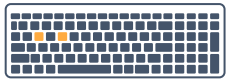
Selected neutrino vertex vs W-view clusters

Expand the list of selected neutrino vertices - there should only be one



When you are finished, press Return ↵ to move to the next display

Wheel up - zoom out
Wheel down - zoom in
Wheel press + drag - pan viewport



W - wireframe mode
R - return from wireframe mode

3D track & shower reconstruction

Add in some more visualizations

- Add to MyPandoraSettings_Neutrino_Standard.xml at the end of the TwoDMopUpAlgorithms section

```
<!-- TwoDMopUpAlgorithms -->
<algorithm type = "LArBoundedClusterMopUp">
    <PfoListNames>ShowerParticles3D</PfoListNames>
    <DaughterListNames>ClustersU ClustersV ClustersW</DaughterListNames>
</algorithm>
<algorithm type = "LArConeClusterMopUp">
    <PfoListNames>ShowerParticles3D</PfoListNames>
    <DaughterListNames>ClustersU ClustersV ClustersW</DaughterListNames>
</algorithm>
<algorithm type = "LArNearbyClusterMopUp">
    <PfoListNames>ShowerParticles3D</PfoListNames>
    <DaughterListNames>ClustersU ClustersV ClustersW</DaughterListNames>
</algorithm>

<algorithm type = "LArVisualMonitoring">
    <PfoListNames>TrackParticles3D ShowerParticles3D</PfoListNames>
    <ShowDetector>true</ShowDetector>
</algorithm>

<!-- ThreeDHitAlgorithms -->
<algorithm type = "LArCutPfoCharacterisation">
    <TrackPfoListName>TrackParticles3D</TrackPfoListName>
    <ShowerPfoListName>ShowerParticles3D</ShowerPfoListName>
    <PostBranchAddition>true</PostBranchAddition>
    <UseThreeDInformation>false</UseThreeDInformation>
</algorithm>
```

Visualize the track-like and shower-like reconstructed particles

Add the above lines just before the ThreeDHitAlgorithms section

Run Pandora once again!

```
$ cd $MRB_TOP/reco/work
$ lar -c event_display_driver.fcl -s reco_events.root -n 1
```

- After the event display has loaded press Return ↵ five times, to skip through our visualizations from parts 1-2

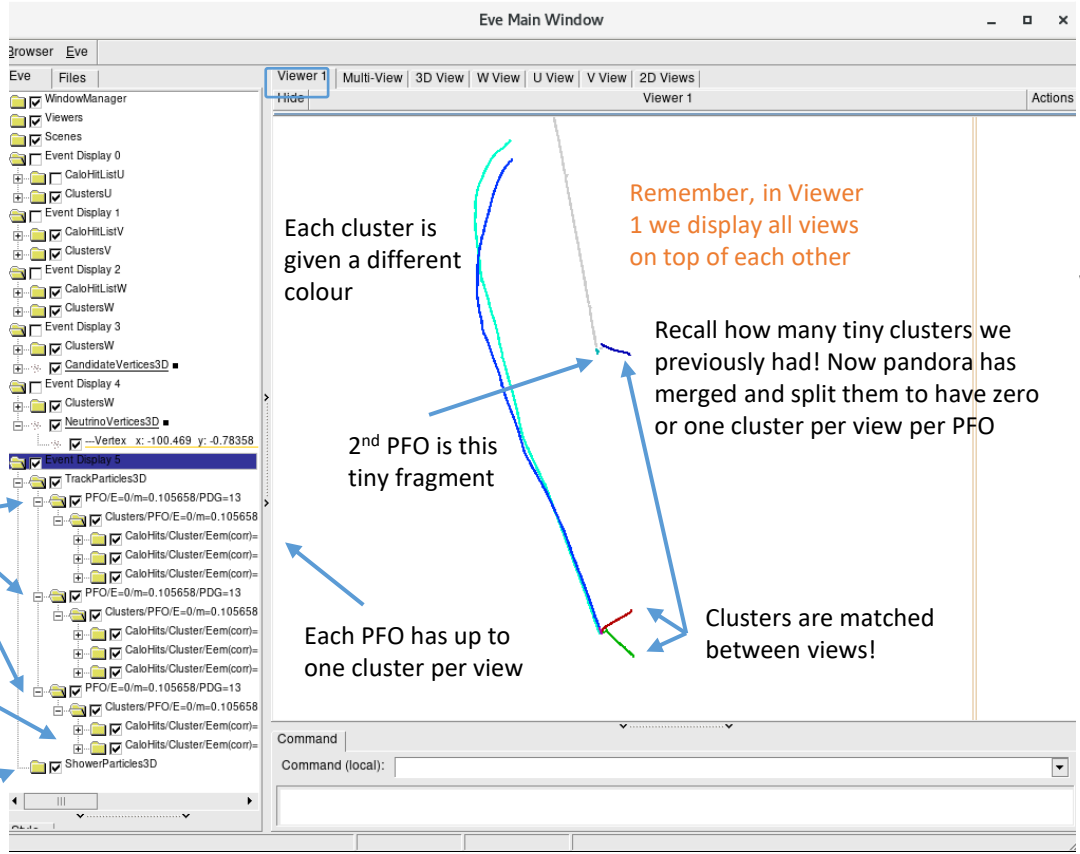
Reconstructed track & shower-like particles

Expand all of the menus to see the clusters at this point and how they have been matched together into reconstructed particles (PFOs)

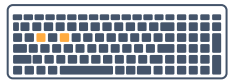
Here there are 3 track-like PFOs reconstructed

Hover over a cluster to see which view it belongs to - in this case it's the W view

In this event there are no shower-like particles to see



Wheel up - zoom out
Wheel down - zoom in
Wheel press + drag - pan viewport



W - wireframe mode
R - return from wireframe mode

When you are finished, press Return ↵ to move to the next display

3D hit reconstruction

Add in some more visualizations

- Add to MyPandoraSettings_Neutrino_Standard.xml at the end of the ThreeDHitAlgorithms section

```
        <tool type = "LArMultiValuedTransverseTrackHits"><MinViews>3</MinViews></tool>
        <tool type = "LArClearTransverseTrackHits"><MinViews>2</MinViews></tool>
        <tool type = "LArClearLongitudinalTrackHits"><MinViews>2</MinViews></tool>
        <tool type = "LArMultiValuedLongitudinalTrackHits"><MinViews>2</MinViews></tool>
    </HitCreationTools>
</algorithm>
<algorithm type = "LArThreeDHitCreation">
    <InputPfoListName>ShowerParticles3D</InputPfoListName>
    <OutputCaloHitListName>ShowerCaloHits3D</OutputCaloHitListName>
    <OutputClusterListName>ShowerClusters3D</OutputClusterListName>
    <HitCreationTools>
        <tool type = "LArThreeViewShowerHits"/>
        <tool type = "LArTwoViewShowerHits"/>
        <tool type = "LArDeltaRayShowerHits"/>
    </HitCreationTools>
</algorithm>

<algorithm type = "LArVisualMonitoring">
    <PfoListNames>TrackParticles3D ShowerParticles3D</PfoListNames>
    <ShowDetector>true</ShowDetector>
</algorithm>

<!-- ThreeDMopUpAlgorithms -->
<algorithm type = "LArSlidingConePfoMopUp">
    <InputPfoListNames>TrackParticles3D ShowerParticles3D</InputPfoListNames>
    <DaughterListNames>ClustersU ClustersV ClustersW TrackClusters3D ShowerClusters3D</Daugh
```

Visualize the reconstructed particles again

Add the above lines just before the ThreeDMopUpAlgorithms section

Run Pandora once again!

```
$ cd $MRB_TOP/reco/work
$ lar -c event_display_driver.fcl -s reco_events.root -n 1
```

- After the event display has loaded press Return ↵ six times, to skip through our visualizations from parts 1-3

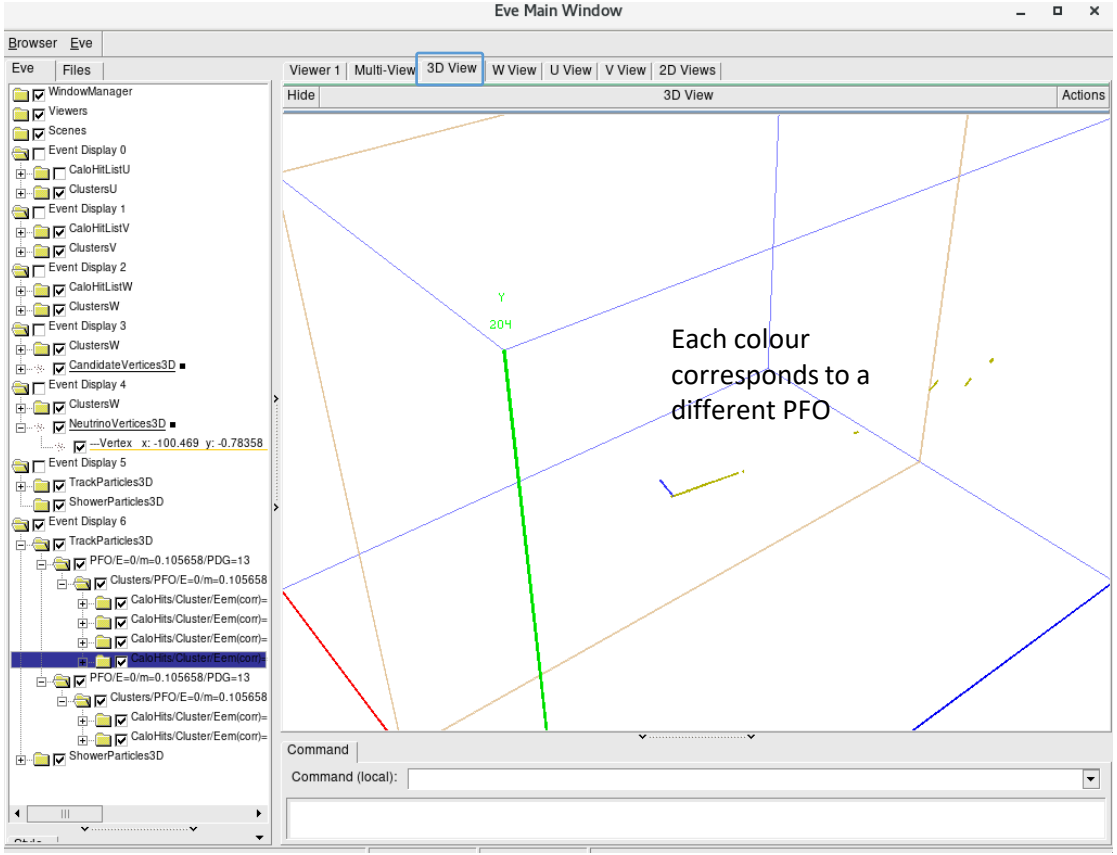
3D hits

When you are finished, press Return ↵ to close the event display

Expand the list of candidate vertices - there will be many!

Our PFOs now have a new cluster of 3D hits that we have just created

Since the last step, one of the particles has been classified as shower like - we use different 3D hit creation algorithms depending on the PFOs track-shower classification



Wheel up - zoom out
Wheel down - zoom in
Wheel press + drag - pan viewport

Left press + drag - rotate 3D view

W - wireframe mode
R - return from wireframe mode

Neutrino hierarchy reconstruction

Add in some more visualizations

- Add to MyPandoraSettings_Neutrino_Standard.xml at the end of the file

```
        <OutputVertexListName>DaughterVertices3D</OutputVertexListName>
    </algorithm>
    <algorithm type = "LArNeutrinoProperties">
        <NeutrinoPfoListName>NeutrinoParticles3D</NeutrinoPfoListName>
    </algorithm>

    <!-- Track and shower building -->
    <algorithm type = "LArTrackParticleBuilding">
        <PfoListName>TrackParticles3D</PfoListName>
        <VertexListName>DaughterVertices3D</VertexListName>
    </algorithm>

    <!-- Output list management -->
    <algorithm type = "LArPostProcessing">
        <PfoListNames>NeutrinoParticles3D TrackParticles3D ShowerParticles3D</PfoListNames>
        <VertexListNames>NeutrinoVertices3D DaughterVertices3D CandidateVertices3D</VertexListNames>
        <ClusterListNames>ClustersU ClustersV ClustersW TrackClusters3D ShowerClusters3D</ClusterListNames>
        <CaloHitListNames>CaloHitListU CaloHitListV CaloHitListW CaloHitList2D</CaloHitListNames>
        <CurrentPfoListReplacement>NeutrinoParticles3D</CurrentPfoListReplacement>
    </algorithm>

    <algorithm type = "LArVisualMonitoring">
        <ShowCurrentPfos>true</ShowCurrentPfos>
        <ShowDetector>true</ShowDetector>
    </algorithm>

</pandora>
```

Visualize the final reconstructed particles

Run Pandora once again!

```
$ cd $MRB_TOP/reco/work
$ lar -c event_display_driver.fcl -s reco_events.root -n 1
```

- After the event display has loaded press Return ↵ seven times, to skip through parts 1-4

The final outcome

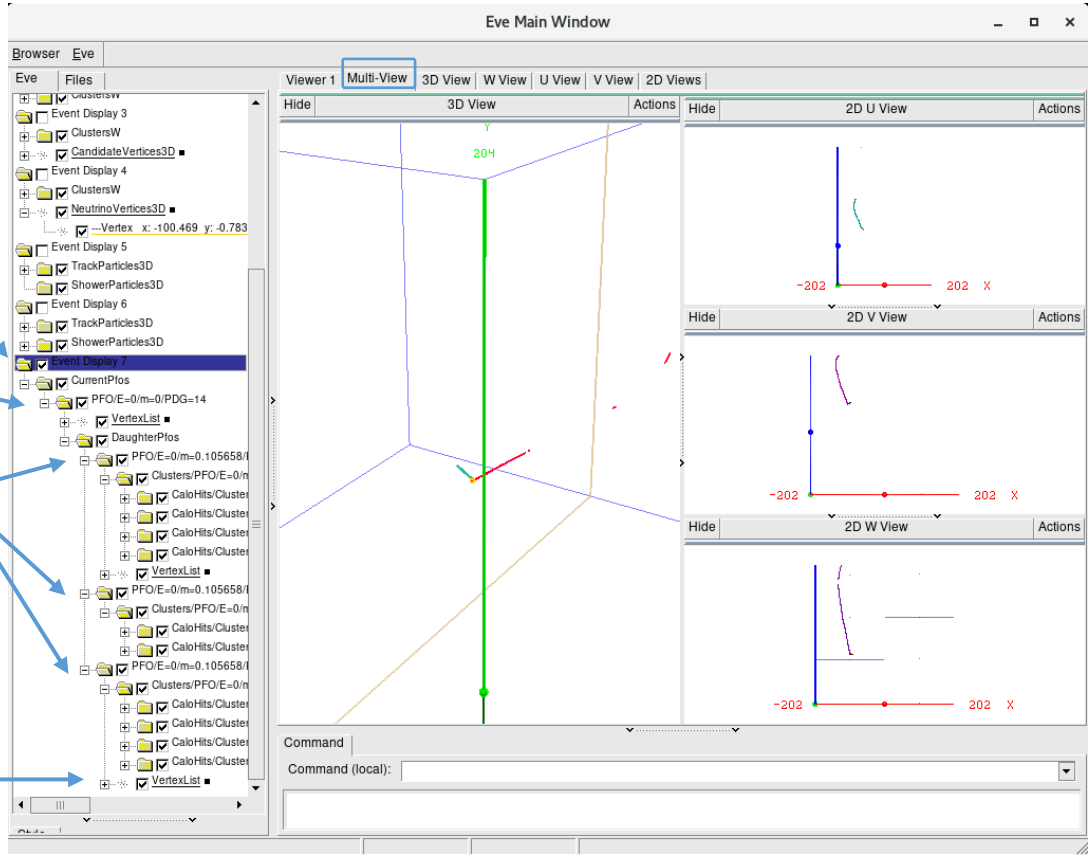
Expand all of the menus again to see what we now have

The PFOs are now arranged in a hierarchy! The top-level PFO has PDG code = 14 ⇒ $\nu\mu$

The neutrino PFO has 3 daughter PFOs which each have clusters of 2D & 3D hits

The PFOs have been classified once more as track-like (assigned PDG 13) or shower-like (assigned PDG 11)

Every PFO has a vertex this is the reconstructed start position

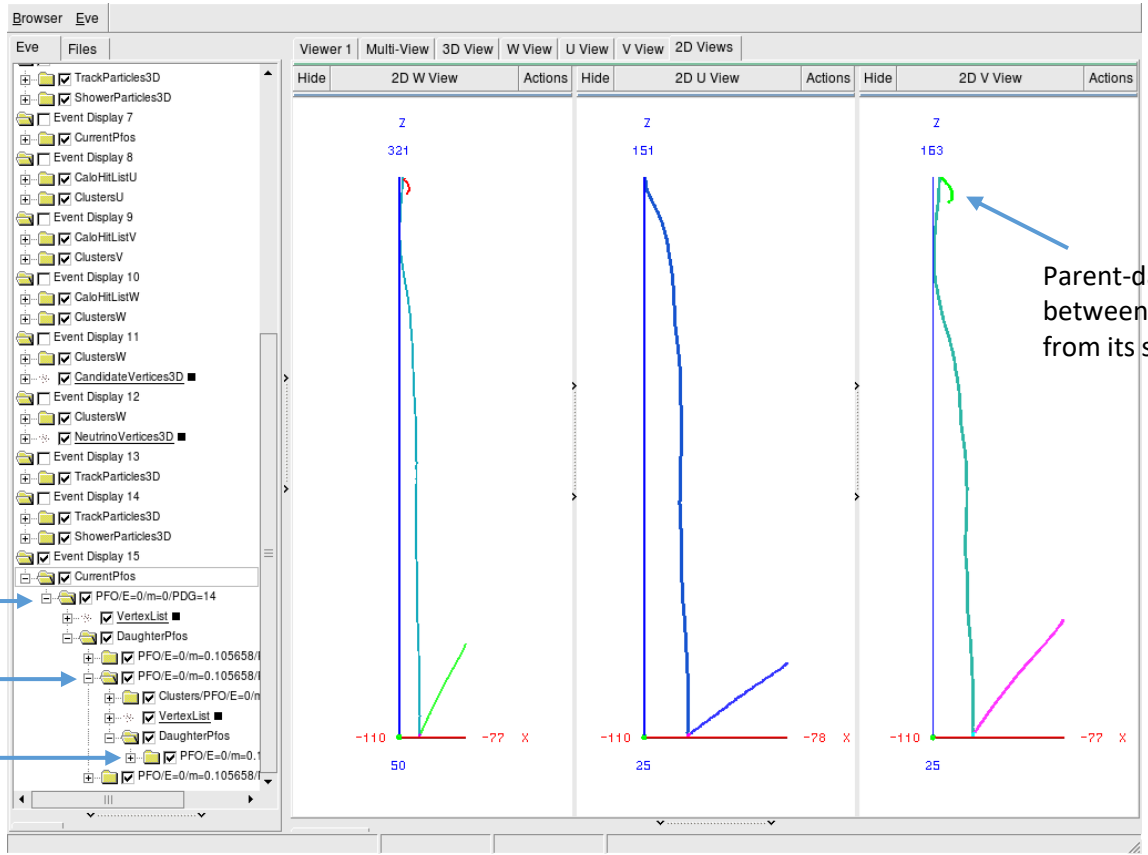


When you are finished, press Return ↵ to close the event display

Secondary particles - a different event

Please note, this is now the final outcome of a different event

In this event, the muon undergoes a secondary interaction
In this event, the muon undergoes a secondary interaction



Neutrino PFO

Muon PFO
(Daughter of neutrino)

Electron PFO
(Daughter of muon)

Parent-daughter link is made between muon and the particle from its secondary interaction

Got spare time?

Run your FHiCL file again over multiple events
Do you understand what Pandora is doing in each of the steps?