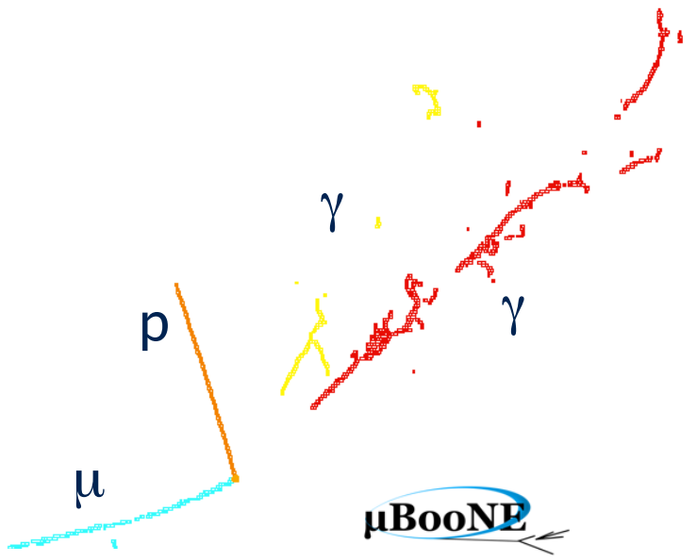


Pandora Pattern Recognition Update

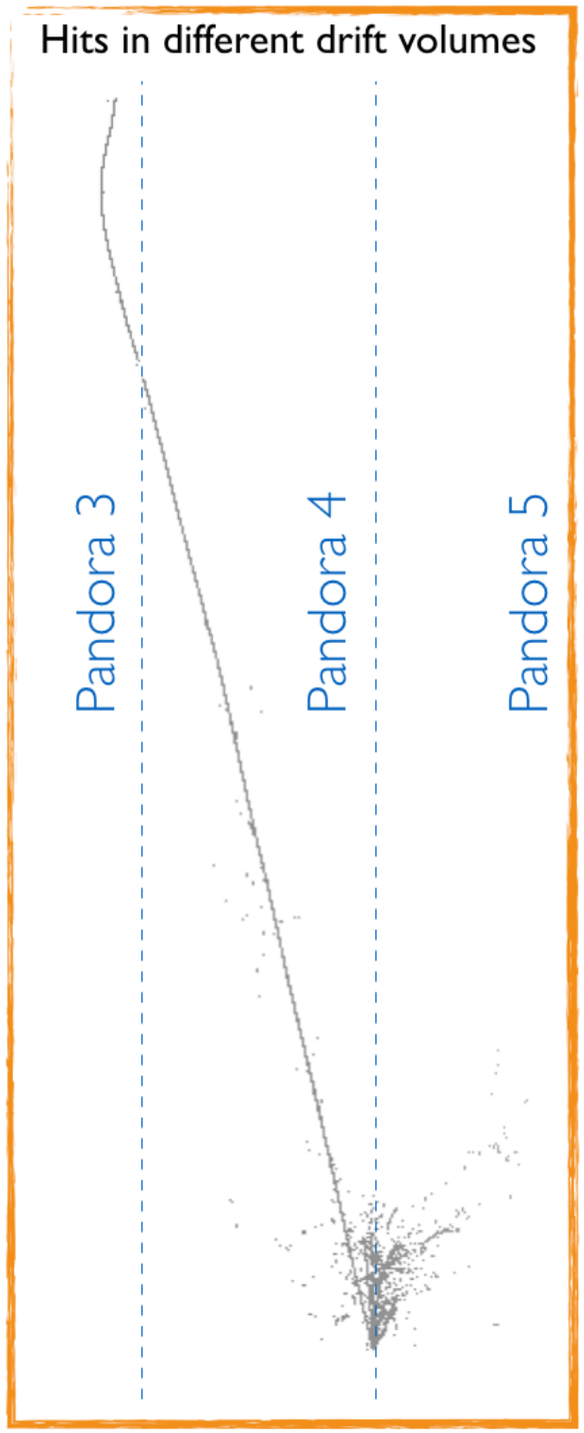
L. Escudero for the Pandora Team

DUNE Sim/Reco and LBL meeting

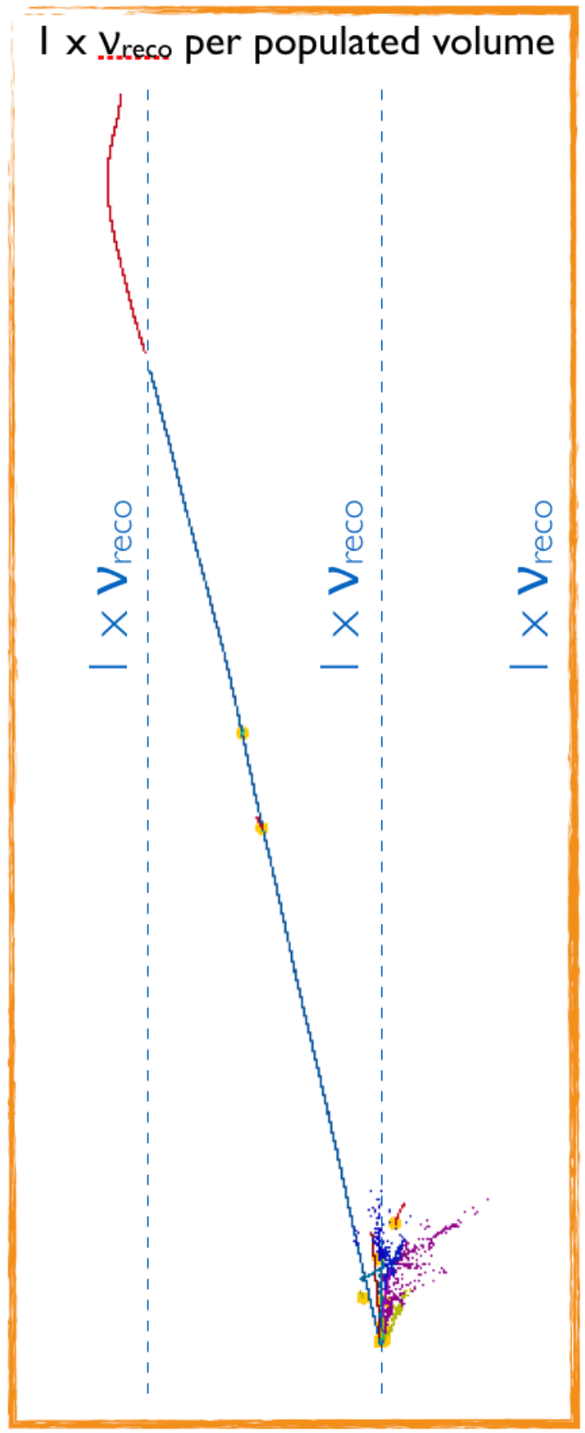
March 20, 2017

Particle "Stitching"

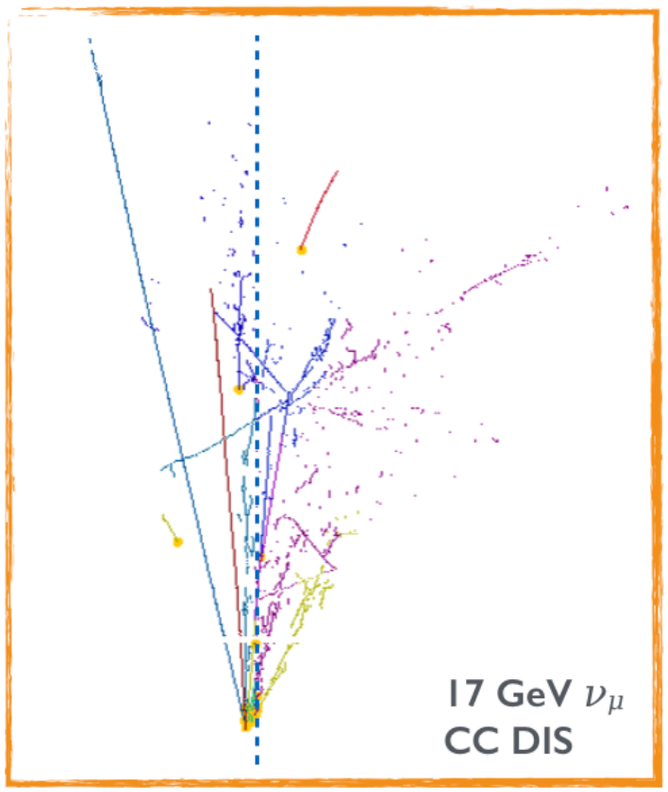
circa January Collaboration Meeting



n x uboone pattern recognition →



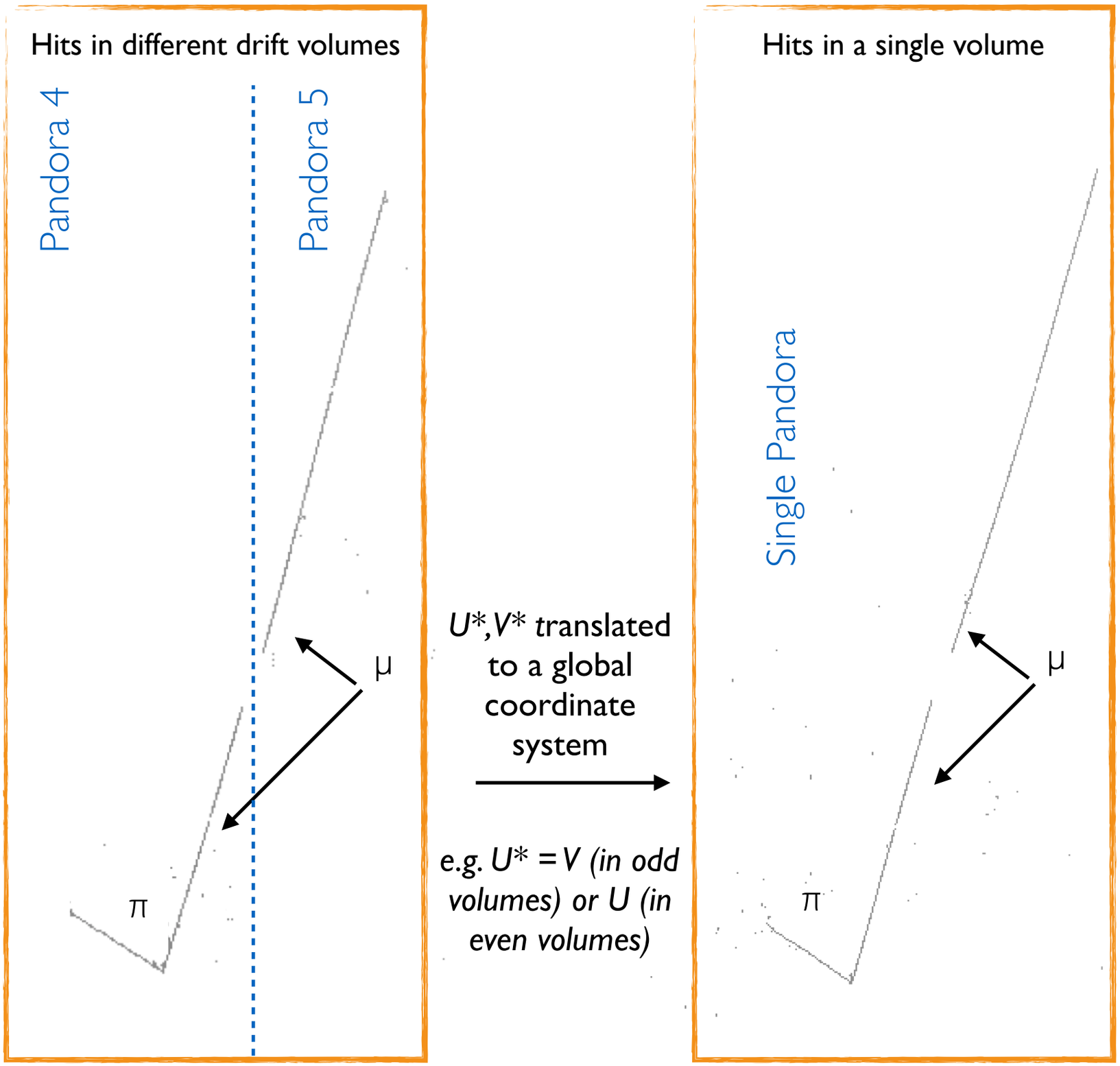
Zoom in to reco particles →



One Pandora per "drift volume": Region with common drift direction, wire pitches and angles.

- Stitching Pandora instance then reads output from each Pandora and merges particles, as req'd.
- Stitching is difficult for neutrinos - how are others handling this?

Single Instance



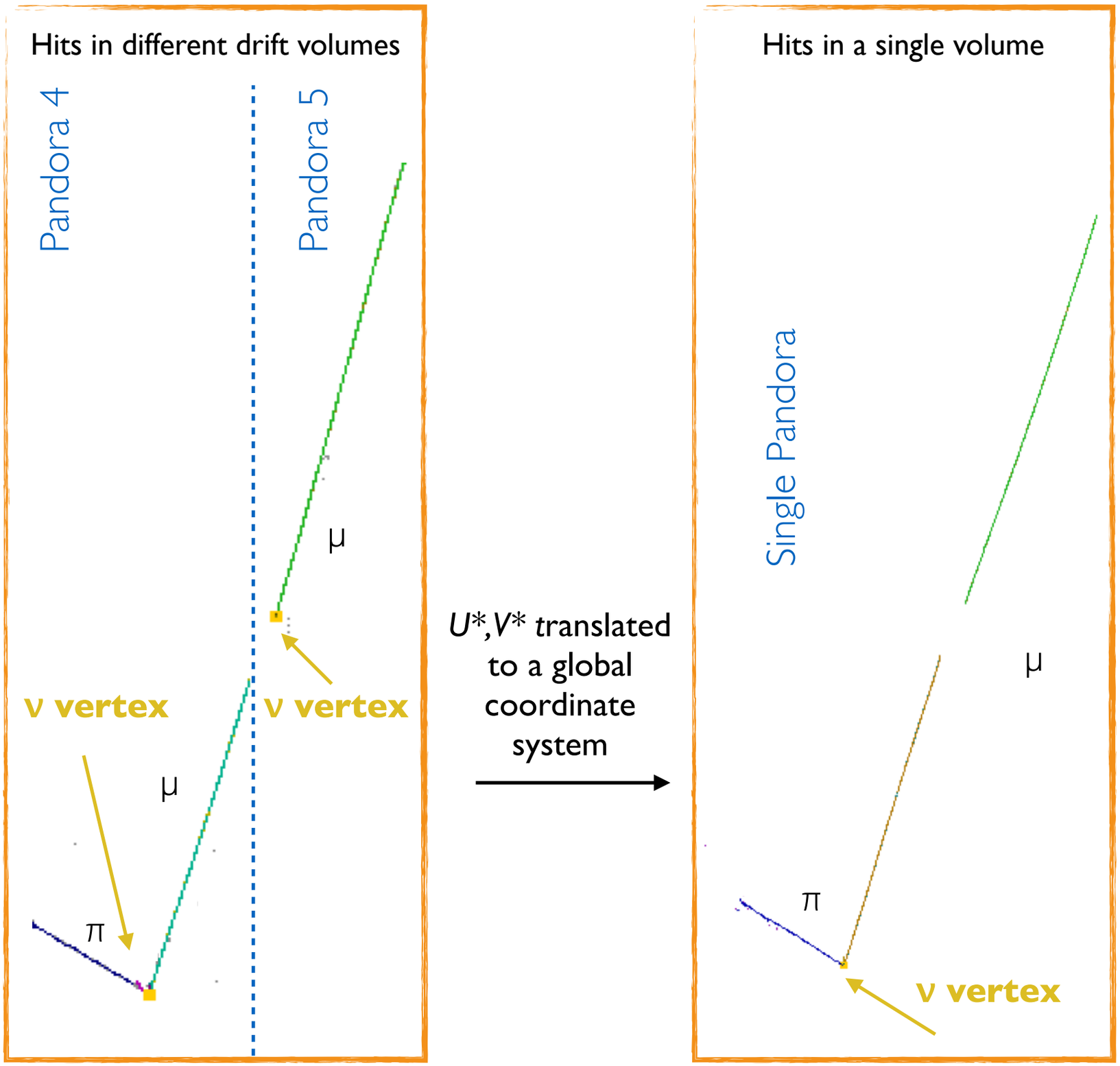
Using a single instance

John and Andy put together a translation per drift volume to have a global coordinate system (using that they are parallel, and wires have the same angles)

This makes have a single MicroBooNE-like instance

This is at the moment under development in a feature branch

Single Instance



Using a single instance

With a single instance of Pandora we will have a single neutrino interaction reconstructed (single neutrino vertex) and no need for stitching of PFOs from different volumes afterwards

This is at the moment under development in a feature branch

“Correct” Event Fractions

Interaction type

Final state particles

Using a single instance

CCQE	μ	μ+p	NCQE p
NEvents	9339	12603	2378
Correct [%]	81.0	72.8	73.8
CCRES	μ	μ+p	NCRES p
NEvents	792	2452	1090
Correct [%]	82.3	71.0	78.8
CCRES	$\mu+2\pi^C$	$\mu+\pi^C+p$	NCRES π^0
NEvents	167	7814	2492
Correct [%]	44.3	58.4	33.1
CCRES	$\mu+\pi^0$	$\mu+\pi^0+p$	NCRES π^0+p
NEvents	1362	3373	1795
Correct [%]	36.6	30.3	33.5
CCDIS	μ	μ+p	NCDIS π^C
NEvents	397	1054	1287
Correct [%]	83.4	62.8	40.5
CCDIS	$\mu+\pi^C$	$\mu+\pi^C+p$	NCDIS π^C+p
NEvents	9484	3946	2773
Correct [%]	50.8	42.3	37.3
CCDIS	$\mu+2\pi^C$	$\mu+2\pi^C+p$	NCDIS π^0
NEvents	2148	3214	1358
Correct [%]	35.5	27.9	31.0
CCDIS	$\mu+\pi^0$	$\mu+\pi^0+p$	NCDIS π^0+p
NEvents	828	4882	915
Correct [%]	31.3	22.8	25.7

← Correct fraction

← nEvents, for context

A selection of exclusive final states

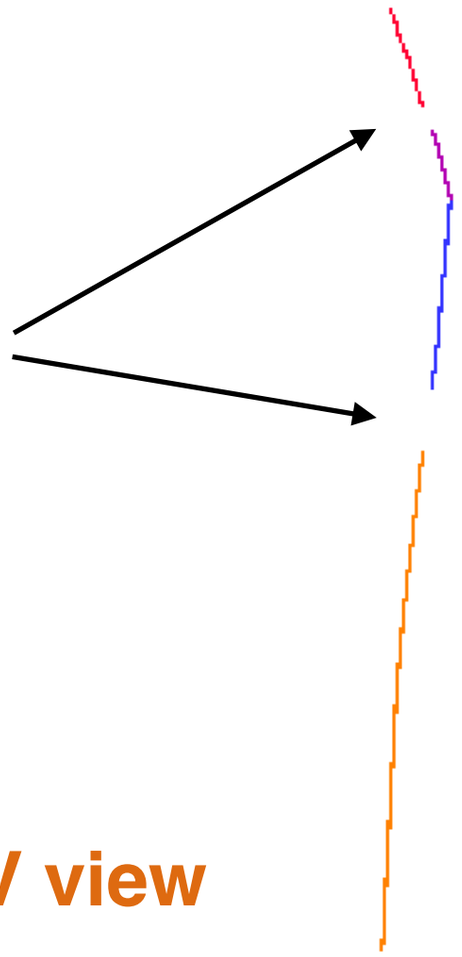
Across different volumes

```
---PROCESSED-MATCHING-OUTPUT-------------------------------------------------------------
MinPrimaryGoodHits 15, MinHitsForGoodView 5, MinPrimaryGoodViews 2
UseSmallPrimaries 1, MinSharedHits 5, MinCompleteness 0.1, MinPurity 0.5

Primary 0, PDG 13, nMCHits 4785 (1108, 1897, 1780), [nGood 4783 (1108, 1896, 1779)]
-MatchedPfo 0, PDG 13, nMatchedHits 2767 (612, 1122, 1033), nPfoHits 2767 (612, 1122, 1033)
-MatchedPfo 1, PDG 13, nMatchedHits 1051 (255, 398, 398), nPfoHits 1051 (255, 398, 398)
-MatchedPfo 2, PDG 13, nMatchedHits 518 (112, 212, 194), nPfoHits 518 (112, 212, 194)
-(Below threshold) MatchedPfo 3, PDG 11, nMatchedHits 383 (94, 147, 142), nPfoHits 383 (94, 147, 142)

Is correct? 0
```

Regions of "dead material" crossing from one drift volume to another



V view

Particles (specially long muons) often cross different volumes. By adding the information of the dead material between different volumes we can avoid splitting them

We do have the tools in Pandora to deal with registered gaps for MicroBooNE, needs retuning for DUNE

Very strict metrics

Example of Pandora MC-reco matching output

```
---PROCESSED-MATCHING-OUTPUT-------------------------------------------------------------
MinPrimaryGoodHits 15, MinHitsForGoodView 5, MinPrimaryGoodViews 2
UseSmallPrimaries 1, MinSharedHits 5, MinCompleteness 0.1, MinPurity 0.5

Primary 0, PDG 13, nMCHits 13105 (3870, 4366, 4869), [nGood 13068 (3859, 4356, 4853)]
-MatchedPfo 0, PDG 13, nMatchedHits 11860 (3454, 3973, 4433), nPfoHits 11900 (3462, 3991, 4447)
-(Below threshold) MatchedPfo 3, PDG 11, nMatchedHits 452 (133, 153, 166), nPfoHits 452 (133, 153, 166)
-(Below threshold) MatchedPfo 4, PDG 11, nMatchedHits 435 (139, 140, 156), nPfoHits 435 (139, 140, 156)
-(Below threshold) MatchedPfo 9, PDG 11, nMatchedHits 54 (31, 11, 12), nPfoHits 54 (31, 11, 12)
-(Below threshold) MatchedPfo 12, PDG 11, nMatchedHits 37 (10, 13, 14), nPfoHits 37 (10, 13, 14)
-(Below threshold) MatchedPfo 13, PDG 11, nMatchedHits 30 (12, 12, 6), nPfoHits 30 (12, 12, 6)

Primary 1, PDG 211, nMCHits 1953 (651, 583, 719), [nGood 1940 (650, 579, 711)]
-MatchedPfo 1, PDG 13, nMatchedHits 1781 (651, 492, 638), nPfoHits 1847 (653, 539, 655)
-(Below threshold) MatchedPfo 5, PDG 11, nMatchedHits 8 (0, 8, 0), nPfoHits 8 (0, 8, 0)

Primary 2, PDG 211, nMCHits 434 (138, 131, 165), [nGood 422 (136, 126, 160)]
-MatchedPfo 2, PDG 13, nMatchedHits 375 (126, 105, 144), nPfoHits 376 (126, 106, 144)
-(Below threshold) MatchedPfo 11, PDG 11, nMatchedHits 32 (10, 9, 13), nPfoHits 36 (10, 13, 13)

Primary 3, PDG 22, nMCHits 394 (141, 128, 125), [nGood 387 (140, 126, 121)]
-MatchedPfo 10, PDG 11, nMatchedHits 80 (31, 17, 32), nPfoHits 80 (31, 17, 32)

Primary 4, PDG 22, nMCHits 185 (66, 74, 45), [nGood 178 (65, 72, 41)]

Primary 5, PDG 2212, nMCHits 36 (5, 18, 13), [nGood 25 (4, 10, 11)]

(Non target) Primary 6, PDG 2212, nMCHits 18 (9, 3, 6), [nGood 14 (7, 1, 6)]
-(Below threshold) MatchedPfo 14, PDG 11, nMatchedHits 9 (0, 3, 6), nPfoHits 26 (0, 6, 20)

(Non target) Primary 7, PDG 2212, nMCHits 11 (4, 3, 4), [nGood 9 (4, 2, 3)]
-MatchedPfo 15, PDG 11, nMatchedHits 6 (0, 3, 3), nPfoHits 6 (0, 3, 3)

Is correct? 0
```

Event deemed incorrect

Example: correct up to here

Missing only small particles which are only a small fraction of the event

Algorithm Flow

Basic flow of PandoraNu reconstruction, skipping over some subtleties:

1. Track-oriented 2D clustering
2. 2D topological association
3. 3D track matching
4. Track vs. shower id *
5. 2D shower growing *
6. 3D shower matching
7. Shower refinement
8. Particle recovery
9. 3D hit creation *
10. Event building, characterisation

Track oriented

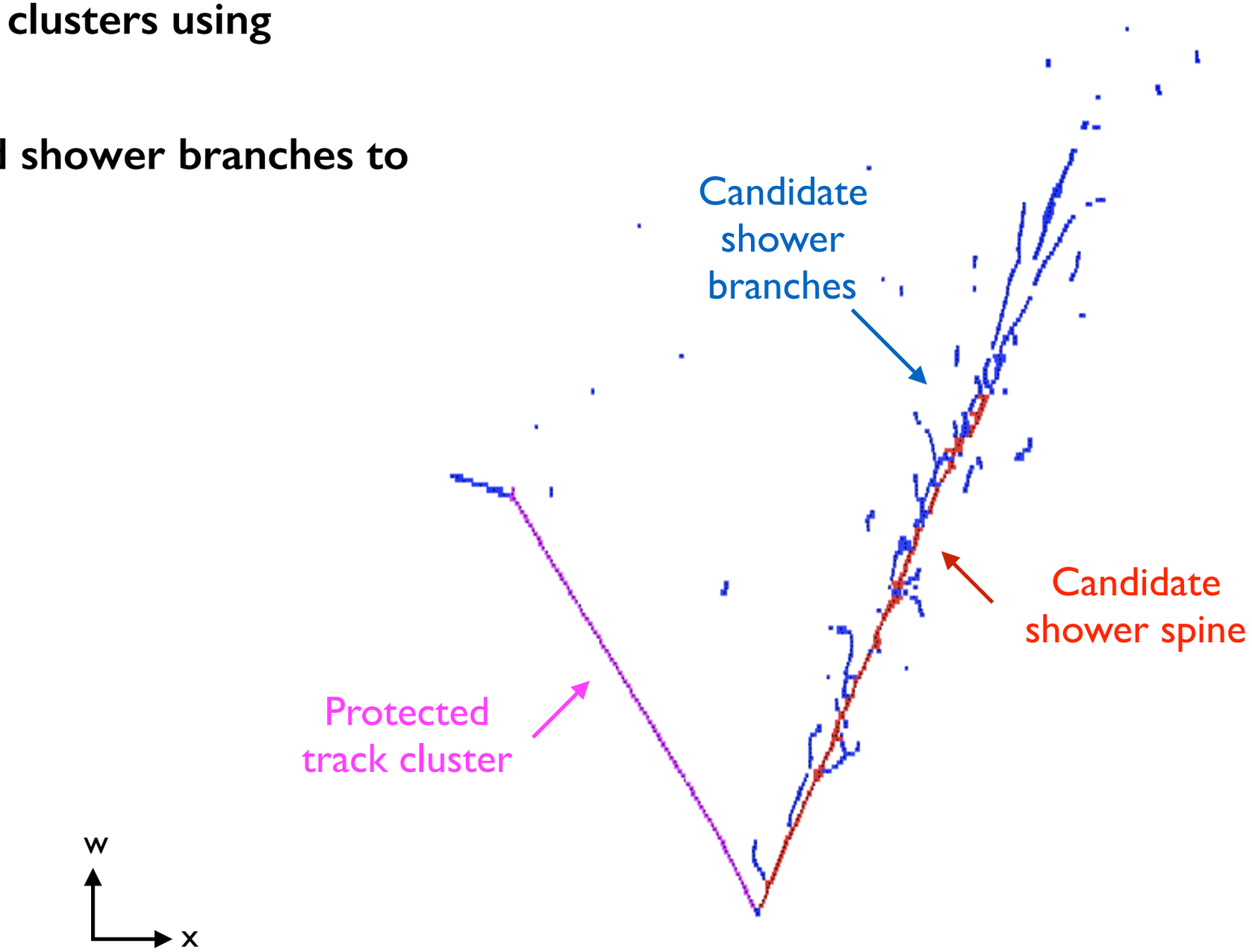
Try to address track vs. shower "tension"

Shower oriented

Places where the track/shower ID is used

Track/Shower Id

- Aim: Classify 2D clusters using following labels
- Use labels to add shower branches to shower spines

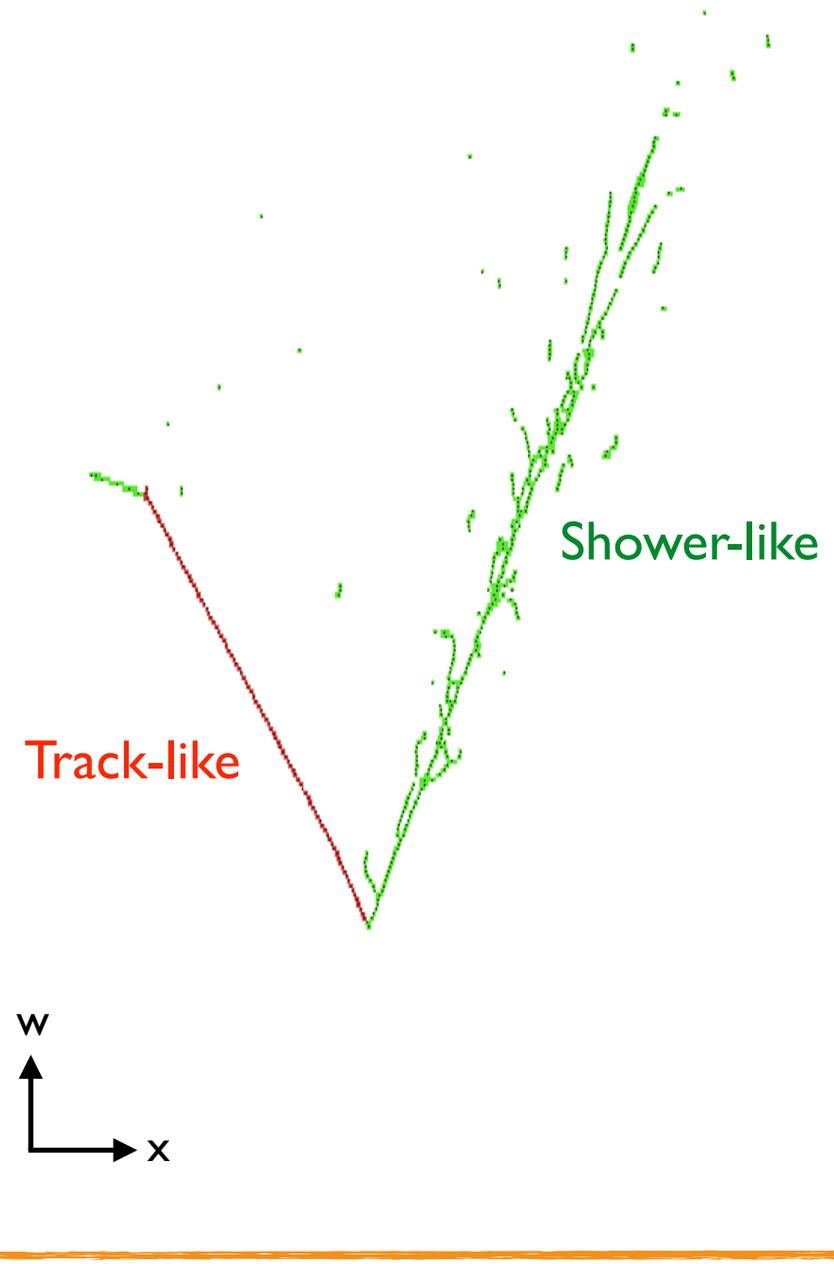


Track/Shower Id

- **Firstly, after the initial track-oriented reconstruction, clusters forming a PFO (Particle Flow Object) are analysed to check whether they are more likely to be a track or a shower spine**

- **Helps address tension between PatRec for tracks and showers afterwards:**
- Can be careful adding branches near tracks.
- Can be generous adding branches to showers.

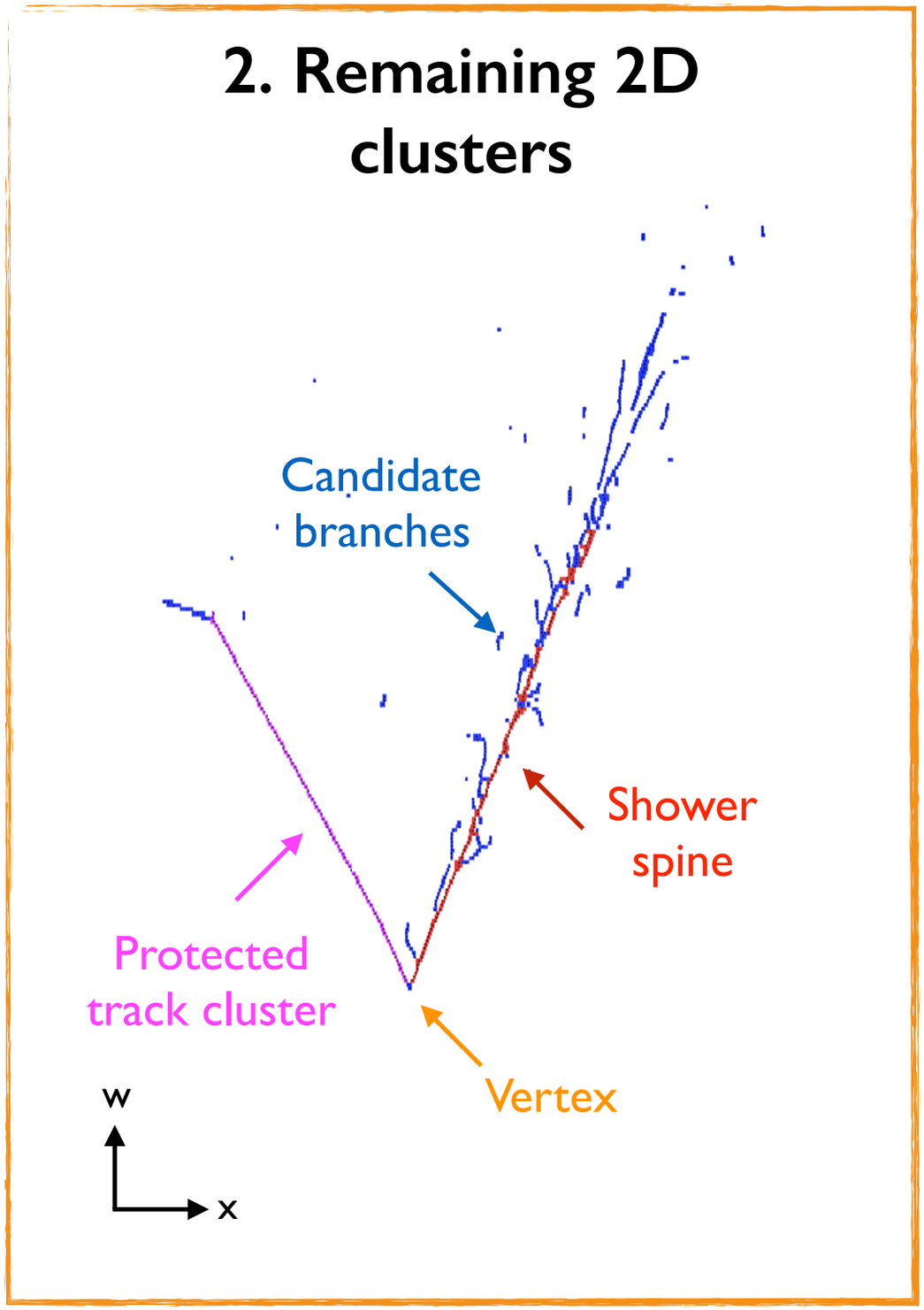
1. Output of track cluster-matching



Track/Shower Id

- **Then, the track/shower characterisation is also used in the 2D shower growing**

- **Three key steps required for 2D shower growing:**
- Characterise 2D clusters as track-like or shower-like.
- Identify long (often vertex-associated), shower-like 2D clusters that represent shower spines.
- Add branches to the list of spines: work recursively, finding branches for top-level spine, then branches on branches, etc. For every branch, record strength of association to each spine.



Track/Shower Id

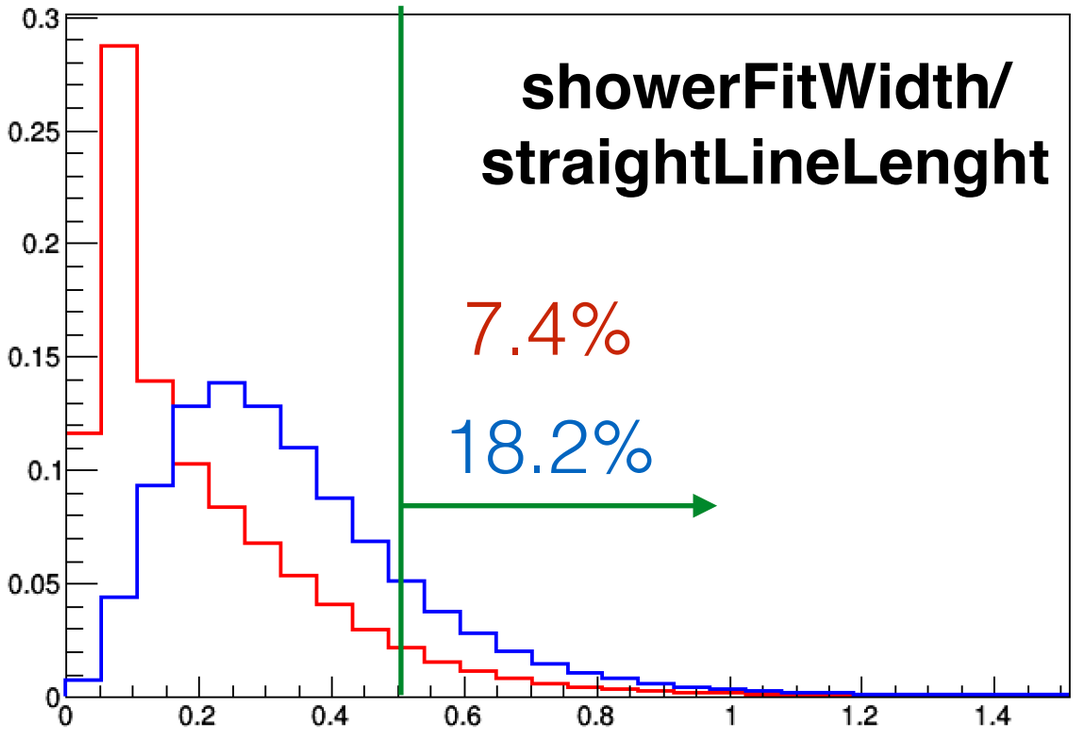
- **At the 3D level (once we have particles with branches added) we check again to characterise the final output particle**

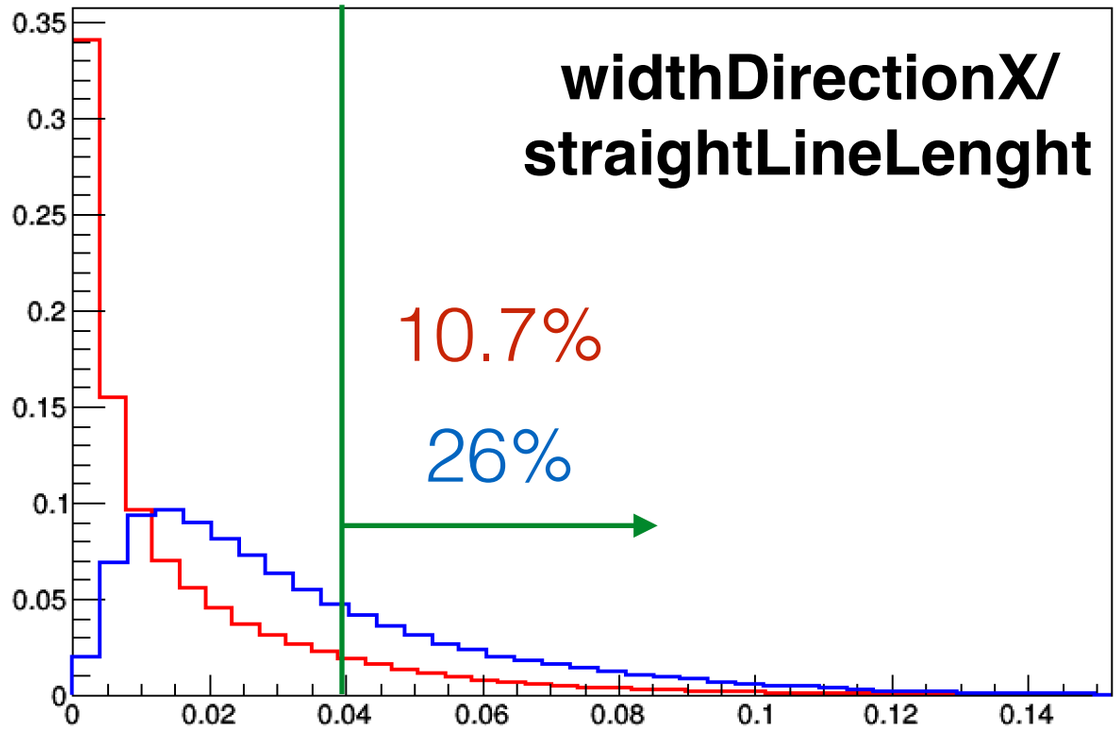
- Track/Shower ID separation is based on broad topological properties, no calorimetric information yet
- It uses simple cuts for the moment
- Track/Shower ID cuts developed for MicroBooNE were added to LArPandoraContent v03_01_00
- Started retuning these cuts for DUNE now. At the first stage for the moment (step 1, after track-like reconstruction, before branches are added)

3. Final Output/ Particle ID

Track/Shower Id

Looking at different topological variables in DUNE. Examples (at the first stage in W view)





showerFitWidth:
measurement of the width of the 2D sliding shower fit to the cluster (~envelope width)

widthDirectionX:
the spread of the direction vector in the X coordinate along the sliding linear fit of the cluster

True track

True shower

In general: normalised to total length, to have common cuts for any cluster

Track vs. Shower Id: MicroBooNE case

	True track	True shower
Reco track	36.1 %	3.2 %
Reco Shower	63.9 %	96.8 %

Using MicroBooNE cuts

Very preliminary test on DUNE specific cuts (at the first stage)

	True track	True shower
Reco track	63.0 %	23.9 %
Reco Shower	37.0 %	76.1 %

Effect in "correct" Event Fractions

Interaction type → Final state particles

CCQE NEvents Correct [%]	μ 9339 81,0 (81,0)	μ+p 12603 74,3 (72,8)	NCQE p 2378 74,1 (73,8)
CCRES NEvents Correct [%]	μ 792 82,8 (82,3)	μ+p 2452 71,3 (71,0)	NCRES p 1090 80,2 (78,8)
CCRES NEvents Correct [%]	$\mu+2\pi^C$ 167 41,9 (44,3)	$\mu+\pi^C+p$ 7814 59,1 (58,4)	NCRES π^0 2492 32,2 (33,1)
CCRES NEvents Correct [%]	$\mu+\pi^0$ 1362 34,4 (36,6)	$\mu+\pi^0+p$ 3373 26,7 (30,3)	NCRES π^0+p 1795 29,4 (33,5)
CCDIS NEvents Correct [%]	μ 397 83,9 (83,4)	μ+p 1054 64,4 (62,8)	NCDIS π^C 1287 40,9 (40,5)
CCDIS NEvents Correct [%]	$\mu+\pi^C$ 9484 56,5 (50,8)	$\mu+\pi^C+p$ 3946 47,2 (42,3)	NCDIS π^C+p 2773 42,1 (37,3)
CCDIS NEvents Correct [%]	$\mu+2\pi^C$ 2148 40,0 (35,5)	$\mu+2\pi^C+p$ 3214 28,3 (27,9)	NCDIS π^0 1358 29,0 (31,0)
CCDIS NEvents Correct [%]	$\mu+\pi^0$ 828 29,3 (31,3)	$\mu+\pi^0+p$ 4882 20,5 (22,8)	NCDIS π^0+p 915 23,1 (25,7)

Preliminary test on DUNE specific cuts

Not surprisingly, with the tested cuts (as previous slide), tracky channels improve but showery ones are slightly worse

work in progress!

Summary

- Moved from several drift volumes to one single instance - in a feature branch for the moment, under development
- Track/Shower ID studies using single instance in progress
- Track/Shower ID: would it be possible to incorporate track-like shower-like characterisation per hit as input to Pandora?
- Some pathologies already identified, tools to address them are present, needs specific DUNE retuning

Thanks for your attention!

Contact details overleaf…

Pandora LAr TPC Reconstruction

Pandora is an open project and new contributors would be extremely welcome.
We'd love to hear from you and we will always try to answer your questions!

Contact details:

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Please visit https://github.com/PandoraPFA

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