DEEP UNDERGROUND NEUTRINO EXPERIMENT

How LArTPC Geometry Affects the Pandora Reconstruction

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Introduction

- Pandora is used for the reconstruction in a number of different LArTPC experiments with different detector geometries; the wire angles (to the vertical) for those experiments are:

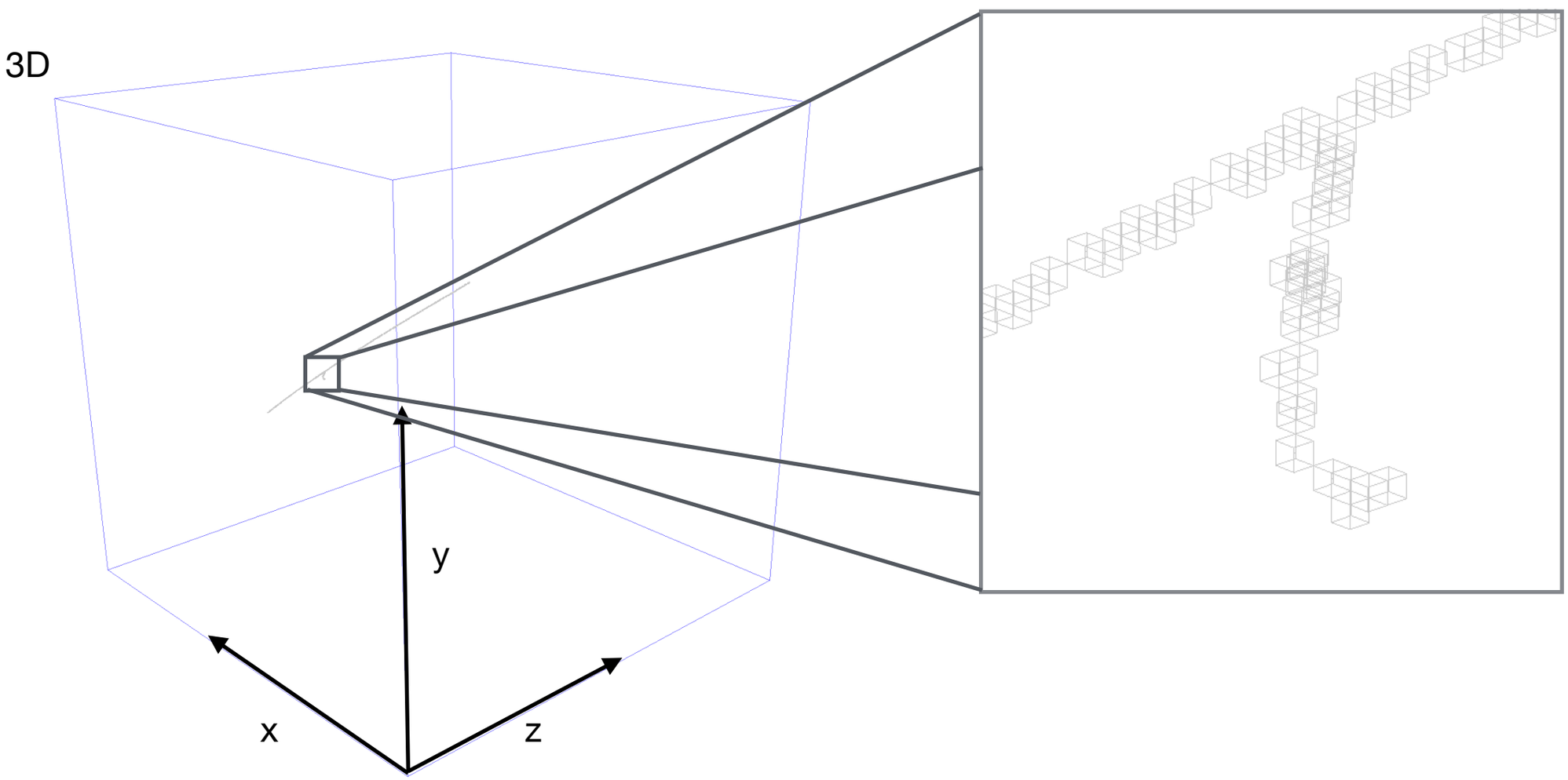
	θ_u	θ_v	θ_w
ProtoDUNE-SP	36 (π/5)	-36 (-π/5)	0
ProtoDUNE-DP	90 (π/2)	-	0
MicroBooNE	60 (π/3)	-60 (-π/3)	0
SBND	60 (π/3)	-60 (-π/3)	0
ICARUS	30 (π/6)	-30 (-π/6)	90 (π/2)
DUNEFD-SP	36 (π/5)	-36 (-π/5)	0

- We want to find out, which is ultimately the best geometry to use.
- In order to do this, we need to extract ourselves from all experiment specific software frameworks so that we can compare exactly the same event for different detector geometries.
- To do this, we have built a “Pseudo-LArTPC” that only *depends only upon Geant4*.

Introduction

Concept:

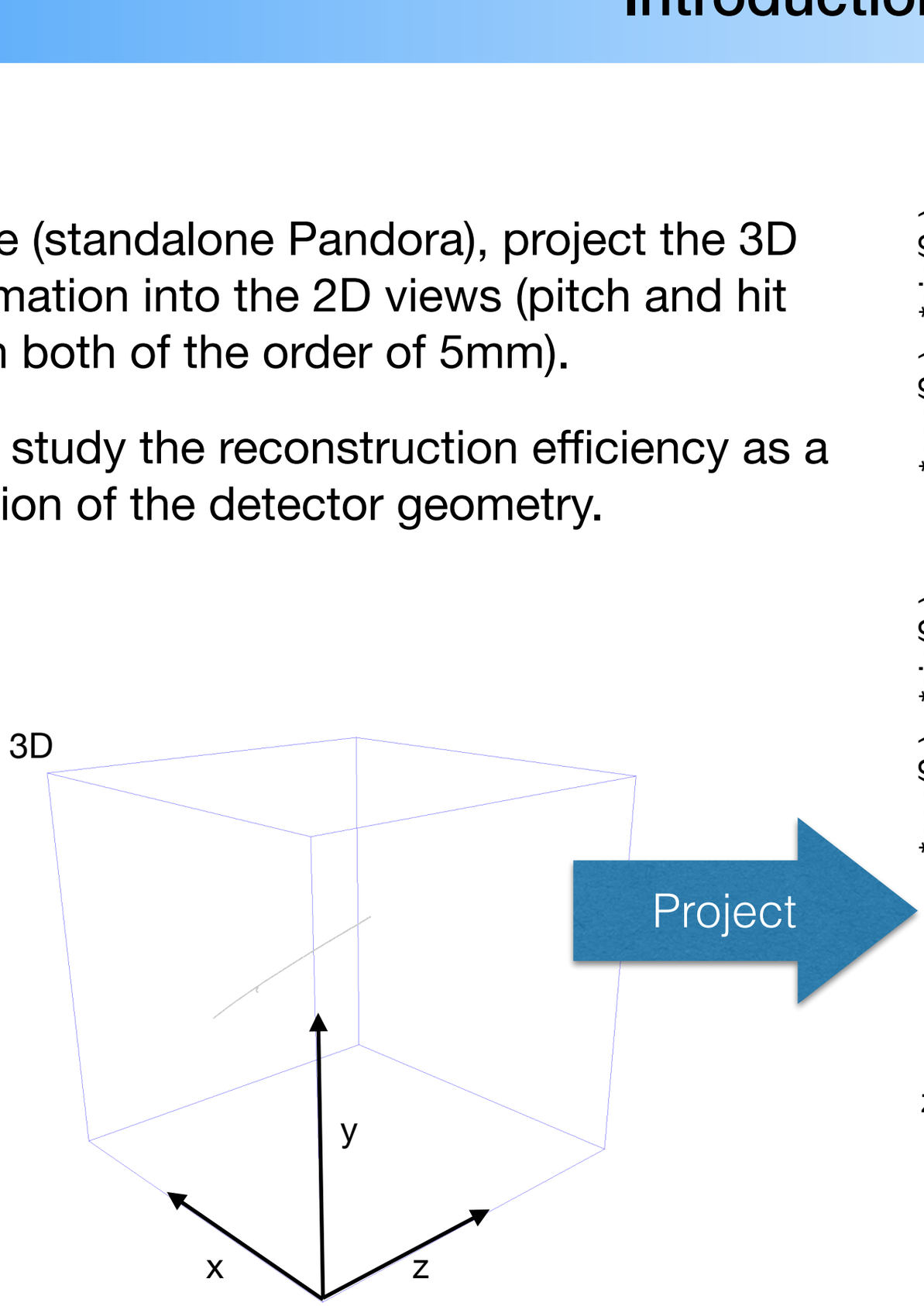
- Get Geant4 to write out the full 3D information in fine detail (1mm cube bins).
- The “charge” for these hits is the true energy loss in the detector, which isn’t realistic to use in analyses, but we don’t use calorimetry in the reconstruction.



Introduction

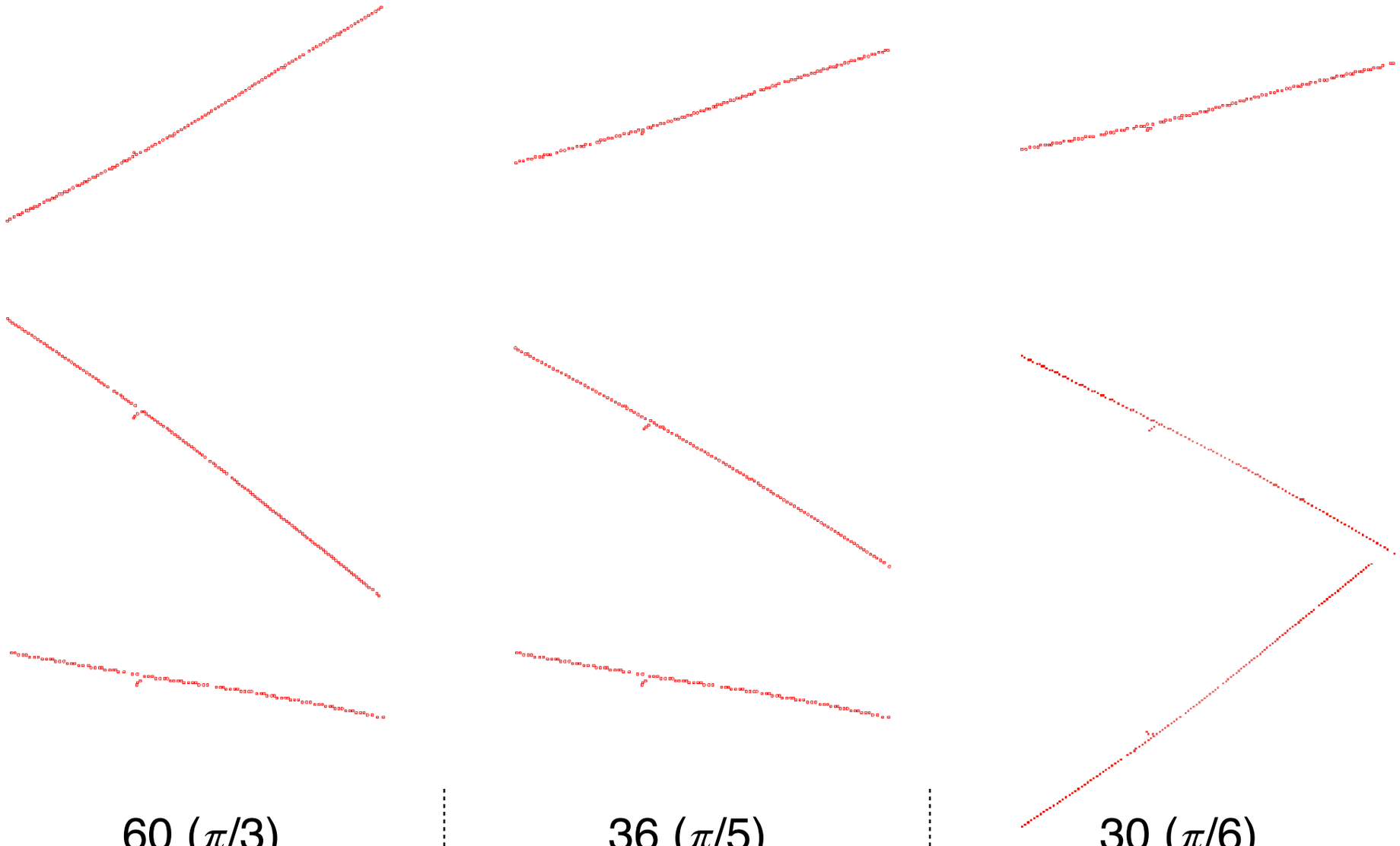
- Inside (standalone Pandora), project the 3D information into the 2D views (pitch and hit width both of the order of 5mm).
- Then study the reconstruction efficiency as a function of the detector geometry.

These functions are the inverse of what is used inside Pandora to build 3D points from the 2D images



Example

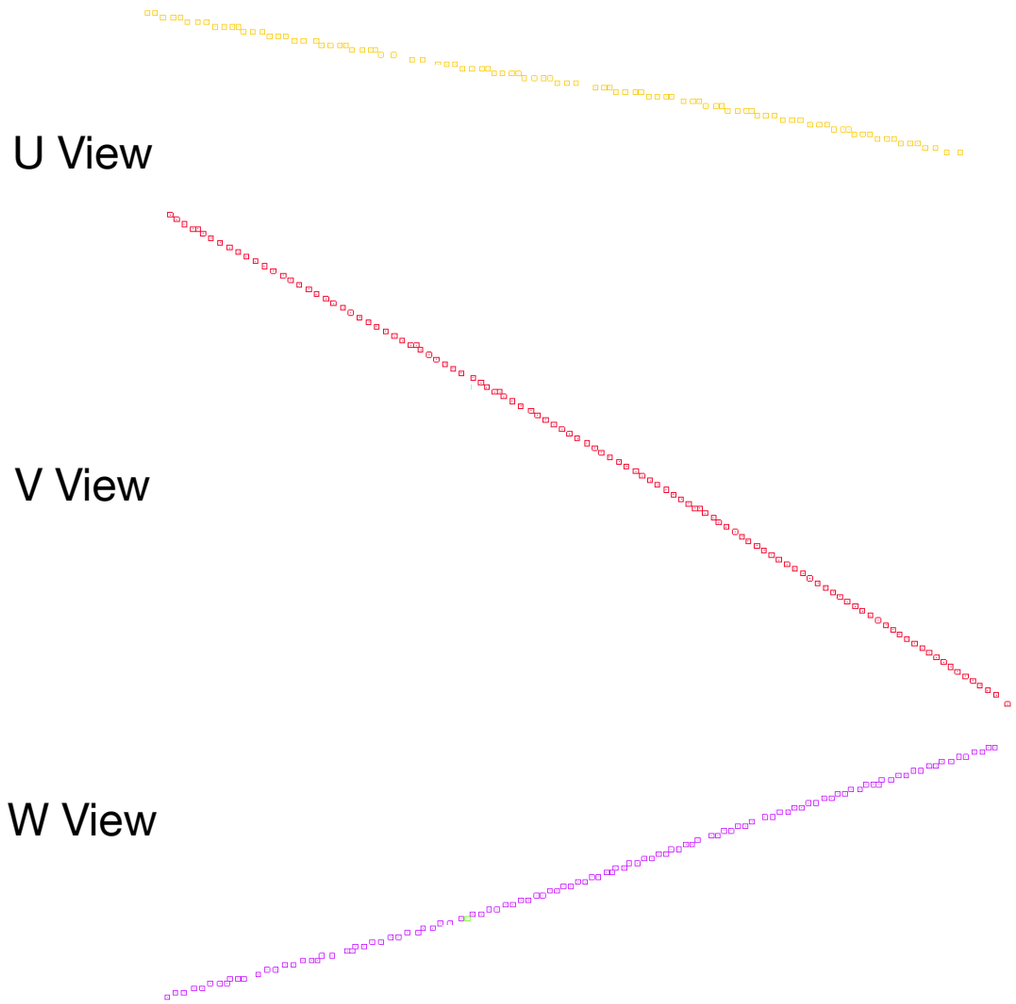
The Pandora reconstruction was initially developed for MicroBooNE →

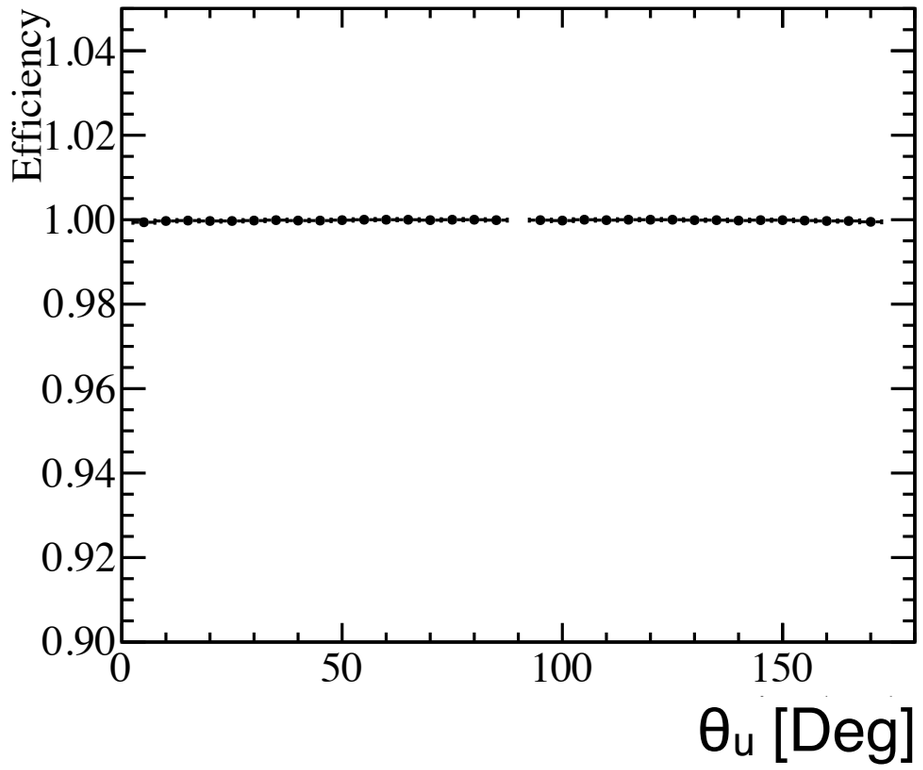


	MicroBooNE-Like	ProtoDUNE-SP-Like	ICARUS-Like
θ_u [Deg]	60 (π/3)	36 (π/5)	30 (π/6)
θ_v [Deg]	-60 (-π/3)	-36 (-π/5)	-30 (-π/6)
θ_w [Deg]	0	0	90 (π/2)

Reconstruction Metric

- Initially we looked at the reconstruction efficiency for events containing a single 1GeV μ^- track in a ProtoDUNE-SP-like detector; all daughter particle hits were removed.
- In this (and all other studies presented here) 10,000 isotropic events were considered.
- The Pandora reconstruction efficiency was almost 100% for all detector geometries considered because Pandora could clearly reconstruct single ionisation tracks.

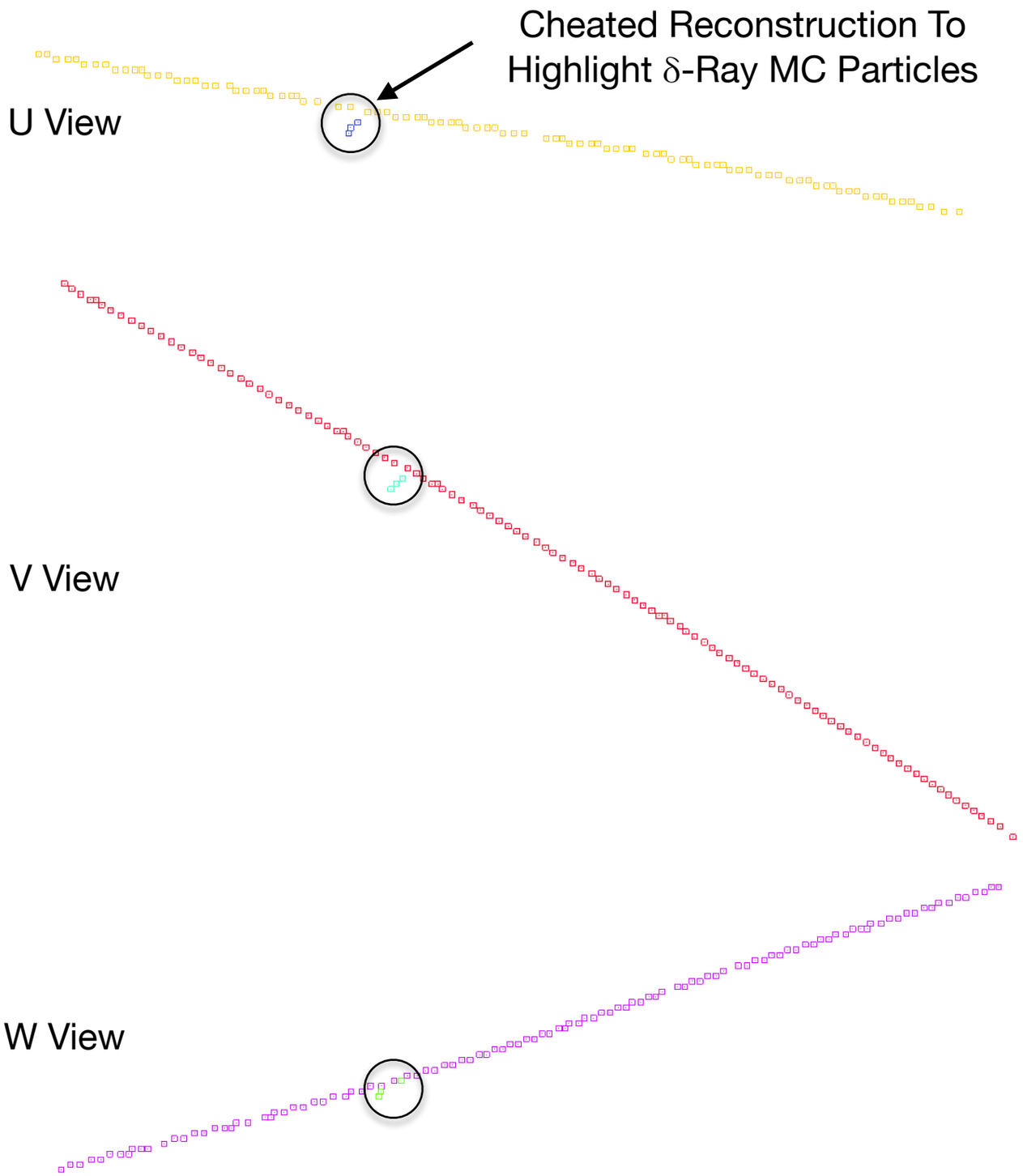




θ_u	Varied
θ_v	$-\theta_u$
θ_w	0
Pitch U	4.7mm
Pitch V	4.7mm
Pitch W	4.8mm

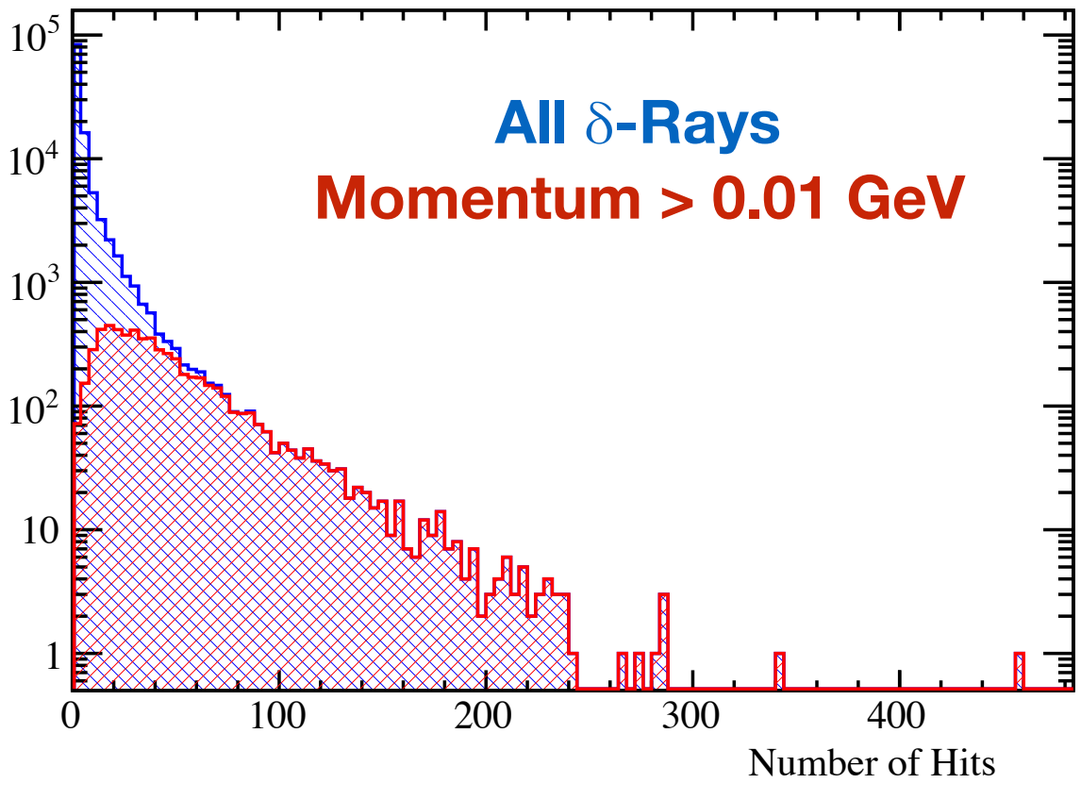
Reconstruction Metric

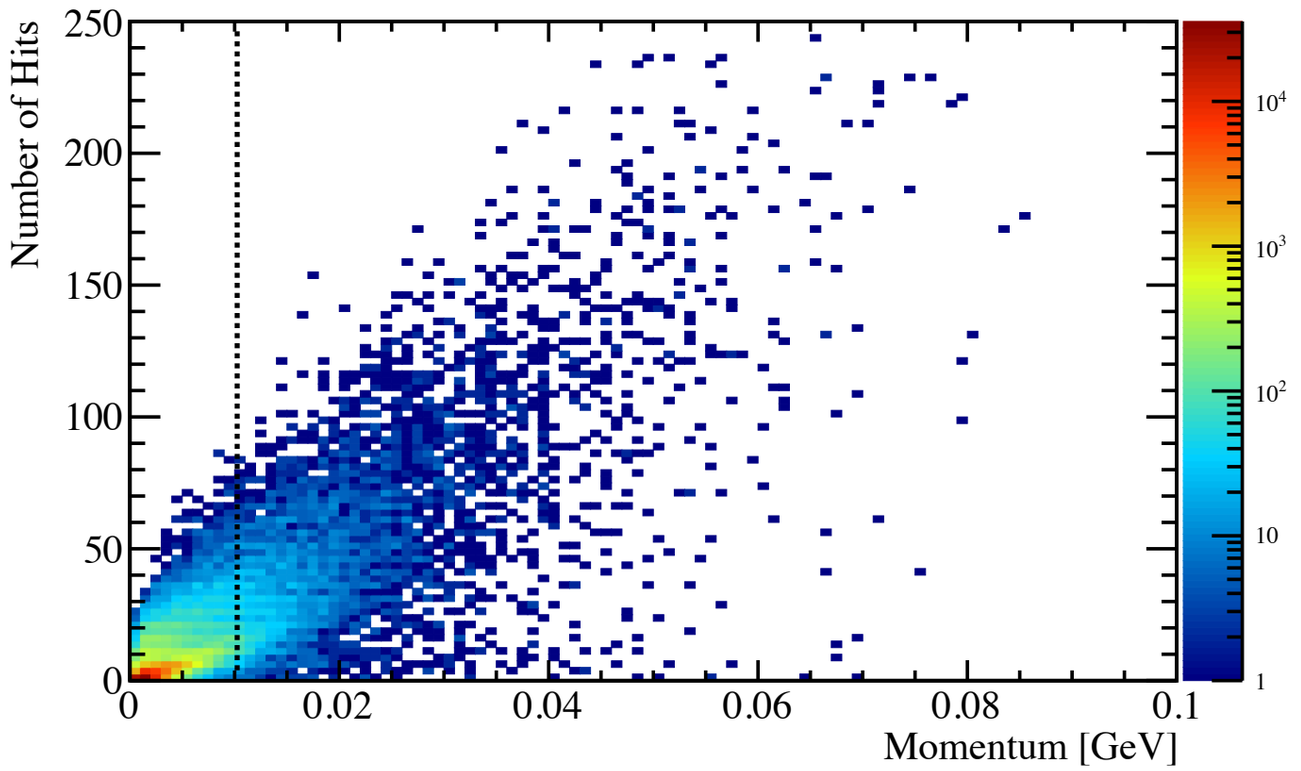
- Instead we consider the full particle hierarchy.
- In the LArG4 step for the majority of active experiments, the option to suppress electromagnetic shower daughters is active so no MC particles for δ-rays appear.
- However, for these studies we disable that to get the full MC particle hierarchy.
- Correctly reconstructed event: Unique reconstructed particle match to all MC particles in the event including the daughter δ-rays.



Reconstruction Metric

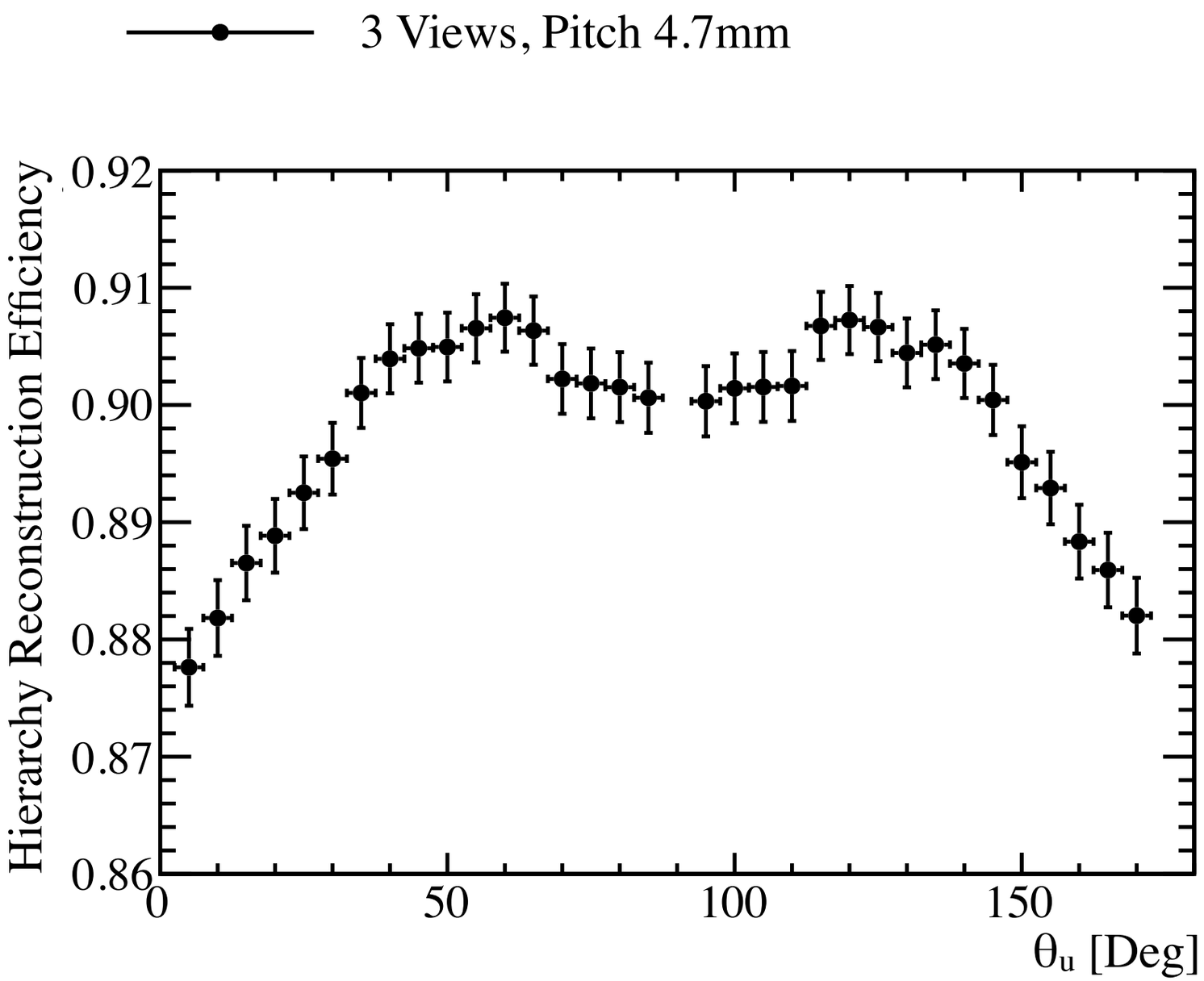
- Some δ-rays deposit next to no hits in the detector; usually we would not consider these in the Pandora reconstruction metrics.
- However, as later we want to compare detectors with 2 and 3 views, we don't want to cut on the number of hits because the 3 view detectors will inherently have more than 2 view detectors.
- Instead, we cut on the momentum of the δ-rays: Require δ-ray momentum > 0.01 GeV for us to consider it.





Results

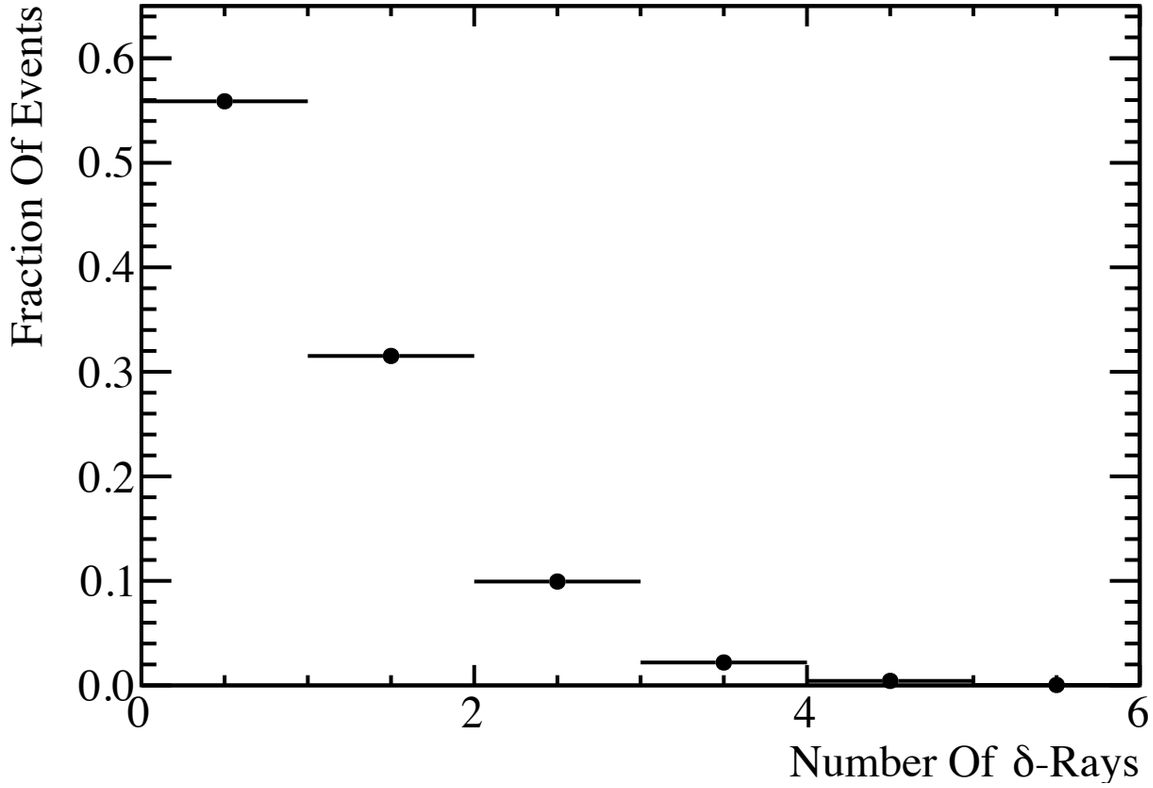
- Hierarchy reconstruction efficiency averages around 90% for all wire angles.
- Efficiency peaks at θ_u=60 and θ_u=120 degrees, where the three wire planes are maximally separated.
- There is a dip in efficiency at θ_u=0 and θ_u=180 occur at these points the U, V and W planes look identical.
- There is a smaller dip in efficiency at θ_u=90 where the U and V planes looks identical (but W still distinct).

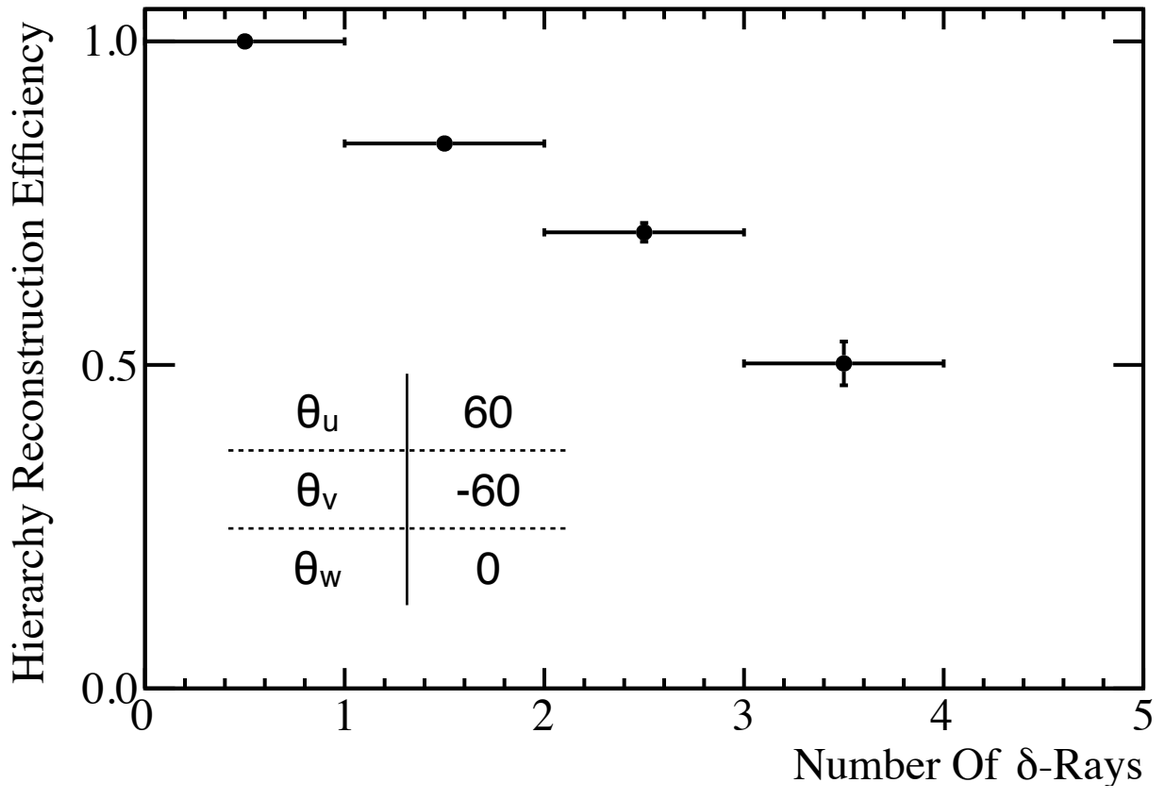


θ_u	Varied	Pitch U	4.7mm
θ_v	$-\theta_u$	Pitch V	4.7mm
θ_w	0	Pitch W	4.8mm

Results

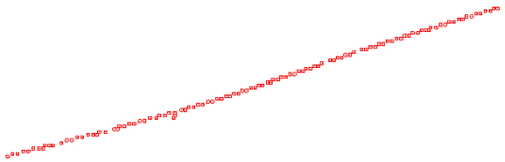
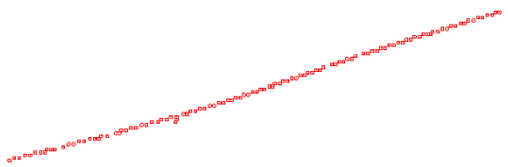
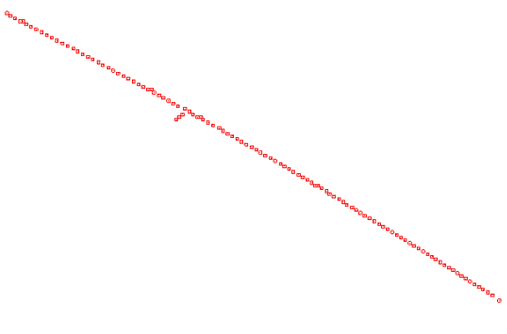
- The majority, ~55%, of events have no high momentum δ-ray, but the remainder do have at leat one.
- As the number of δ-rays in the event increases, the reconstruction efficiency decreases as it becomes harder to resolve each individual δ-ray.
- However, even for complex events (up to 3 δ-rays) we have a good reconstruction efficiency (~50%).





2 View LArTPC

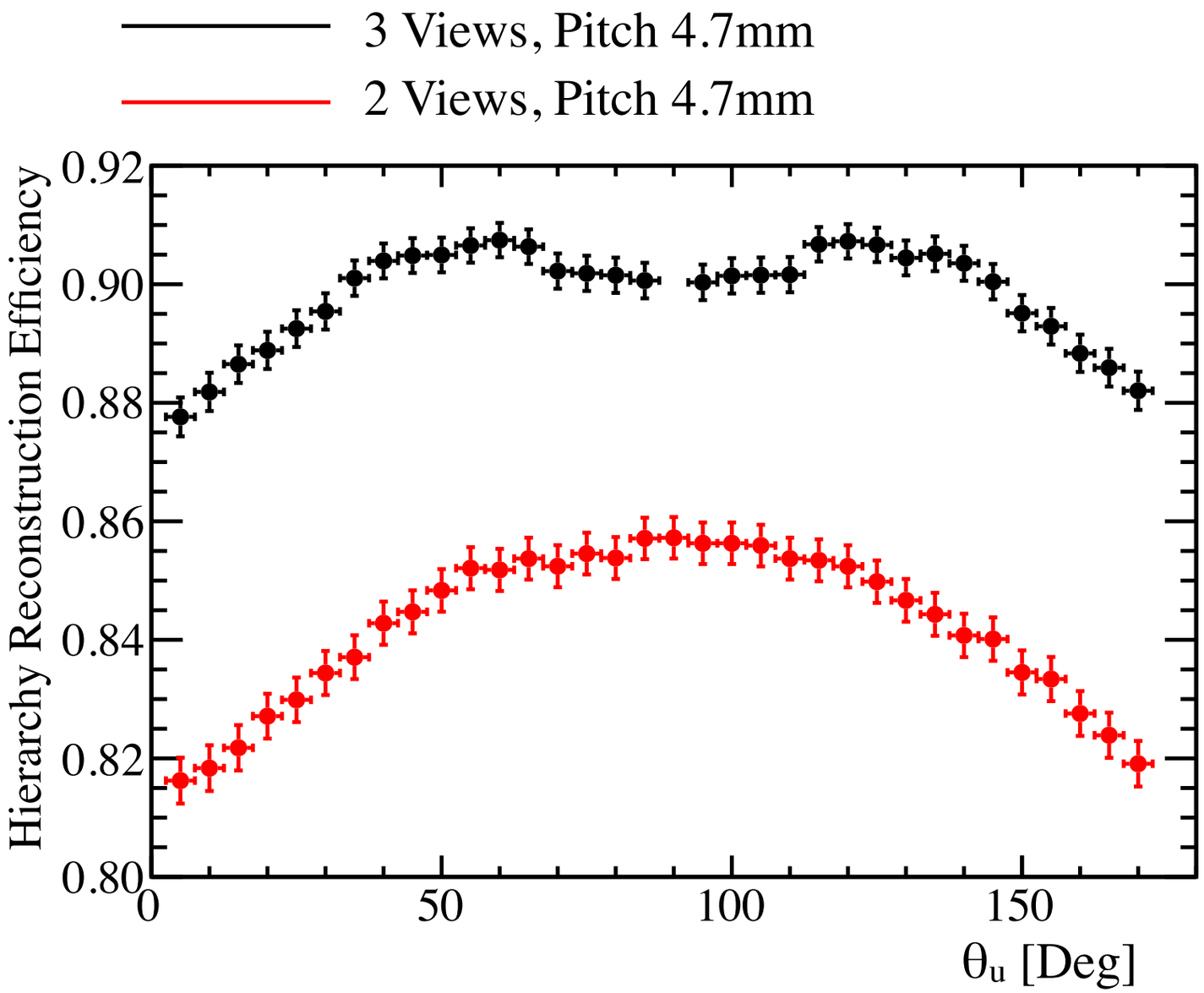
- The Pandora LArTPC reconstruction was initially developed for a 3 view LArTPC.
- Now we want to compare the reconstruction performance for a 3 view and 2 view LArTPC.
- To do this we remove the V view from the reconstruction*.
- Repeat the same study as before…

	3 Views	2 Views
U View		
V View		**N/A**
W View		

***Note: This is <u>not a direct comparison between single and dual phase</u> detector geometries as the dual phase has a better signal to noise ratio and a different pitch, but we will attempt to address some of these issues later.**

2 View LArTPC

- The 2 view LArTPC configuration has a lower average reconstruction efficiency by ~6% as a function of wire angle.
- The 2 view LArTPC reconstruction is most efficiency when θ_u=90 and the wires are maximally separated.
- The efficiency drops at θ_u=0 and θ_u=180 when the two views begin to look similar.

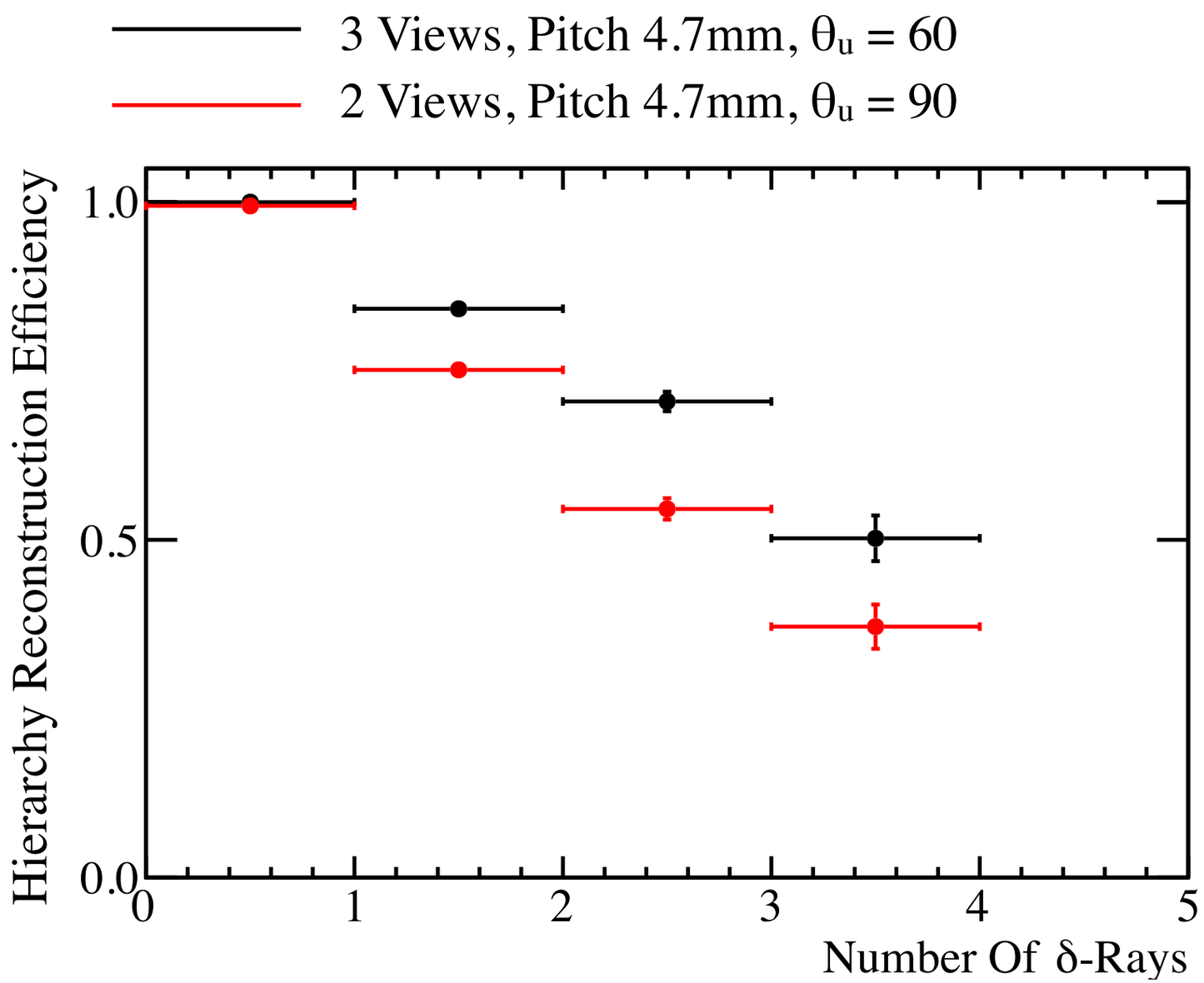


3 view LArTPC	
θ_u	Varied
θ_v	$-\theta_u$
θ_w	0

2 view LArTPC	
θ_u	Varied
θ_v	-
θ_w	0

2 View LArTPC

- Hierarchy reconstruction efficiency as a function of the number of delta rays is comparable to 3 view LArTPC in shape, but lower in magnitude.
- Now let's attempt to account for the other differences between single and dual phase LArTPCs, namely:
  - Pitch - In ProtoDUNE single phase pitch ~4.7mm, but dual phase is ~3mm.
  - Signal to noise ratio - Dual phase aim is to have a gain roughly 10 times better than single phase.



3 view LArTPC		2 view LArTPC	
θ_u	60	θ_u	90
θ_v	-60	θ_v	-
θ_w	0	θ_w	0

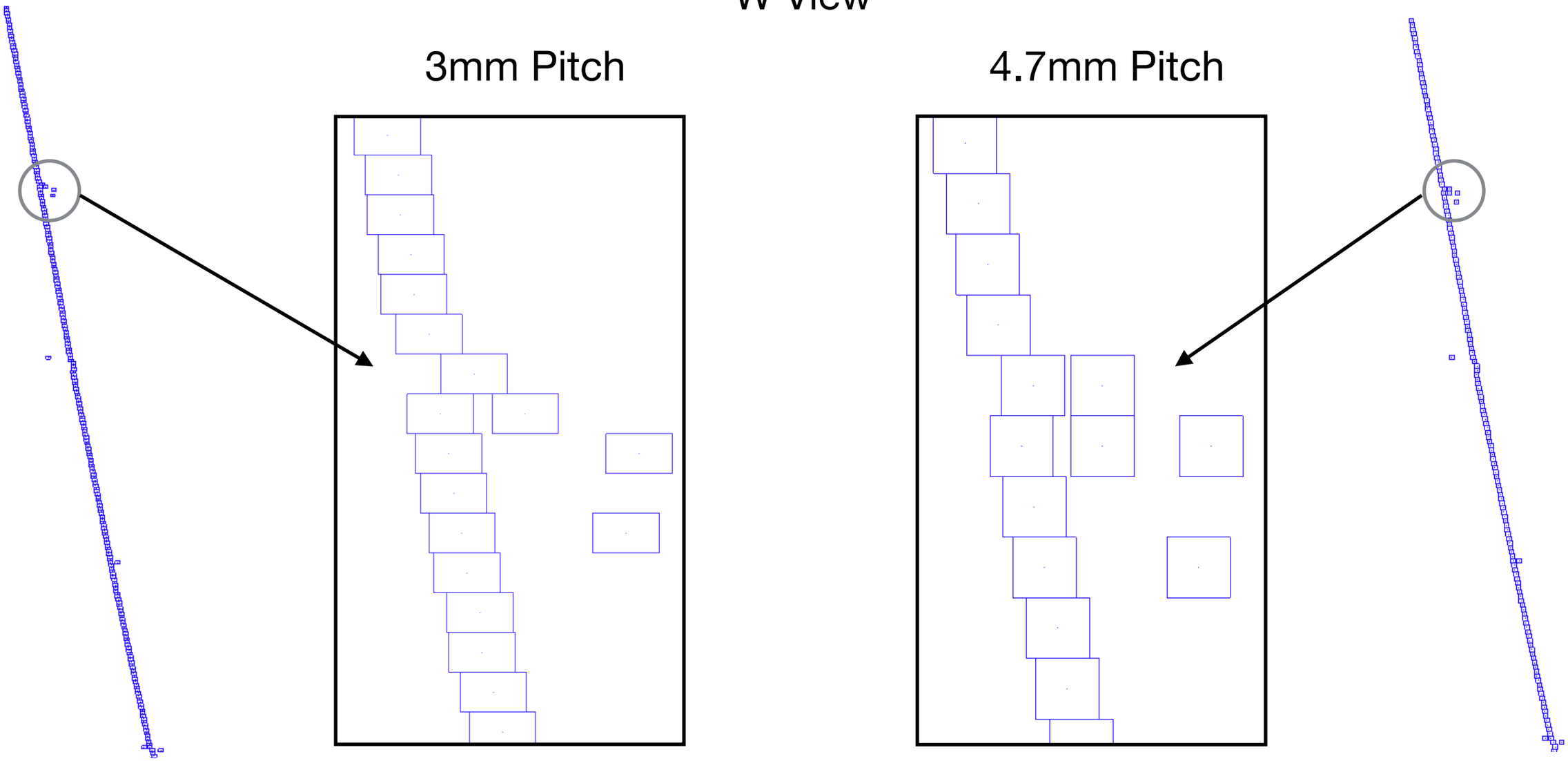
Example

- Example of the same event with different simulated pitches.
- For illustrative purposes only look at W view here, but same binning is applied to U and V views also.

W View

3mm Pitch

4.7mm Pitch

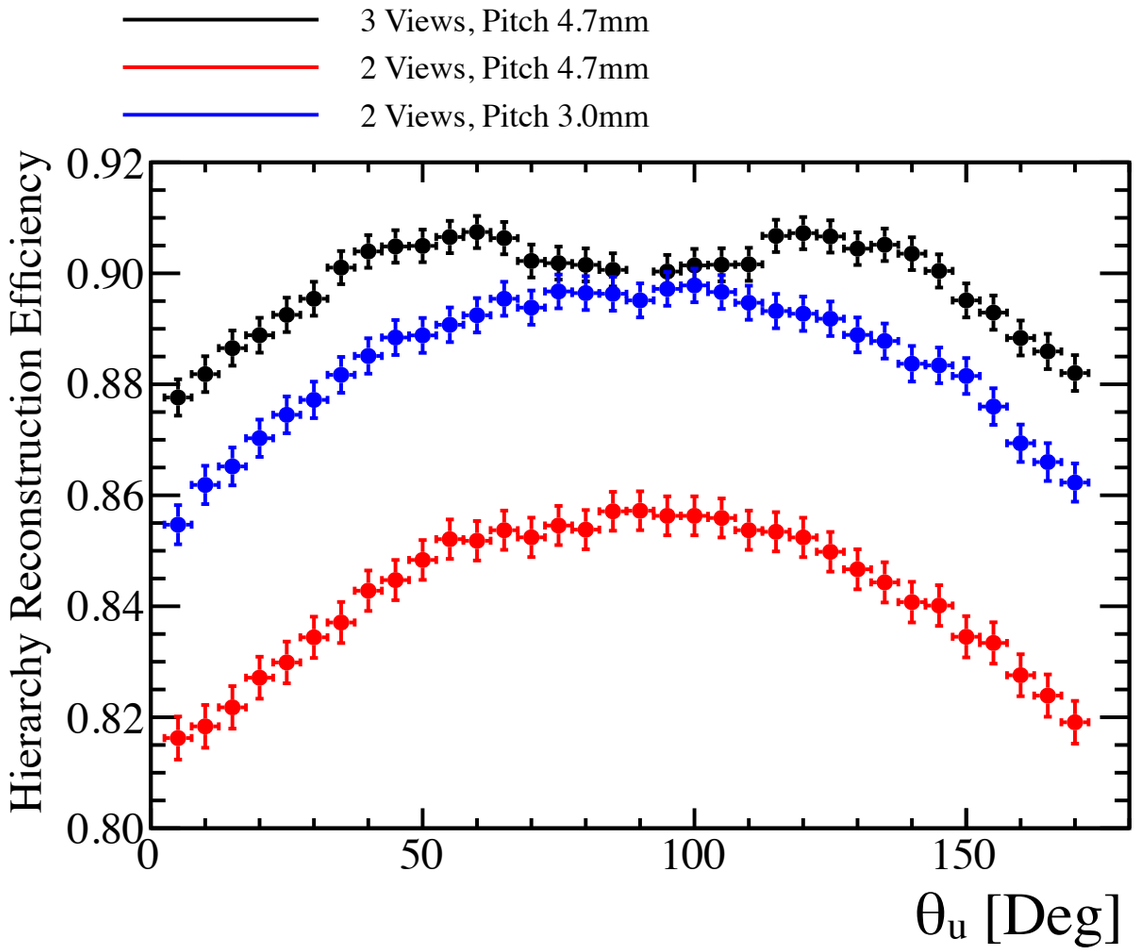


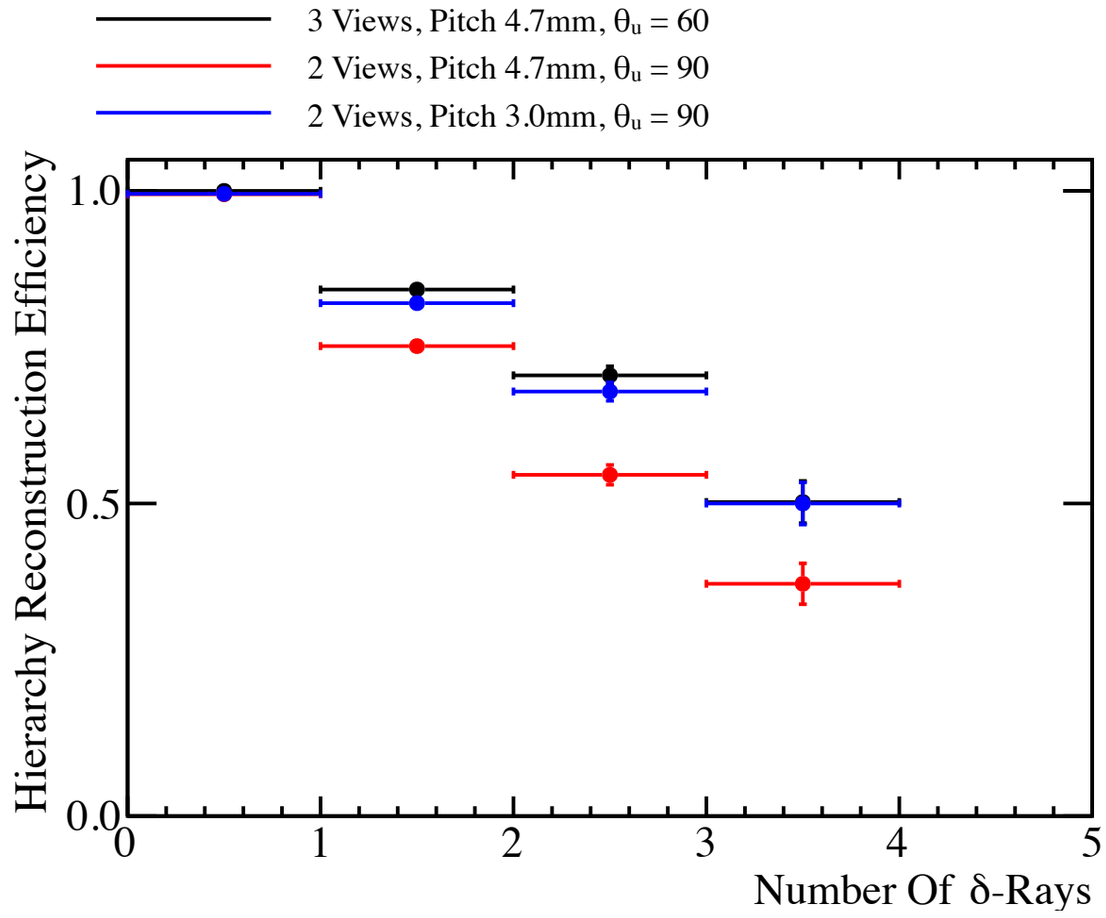
2 View LArTPC

- Moving the pitch from 4.7mm to 3mm increases the reconstruction efficiency significantly, ~4%, for the 2 view LArTPC model.
- Similar gain observed in reconstruction efficiency as a function of number of δ-rays.
- Shape of distributions broadly similar to larger pitch model.

3 view LArTPC	
θ_u	Varied
θ_v	$-\theta_u$
θ_w	0

2 view LArTPC	
θ_u	Varied
θ_v	-
θ_w	0

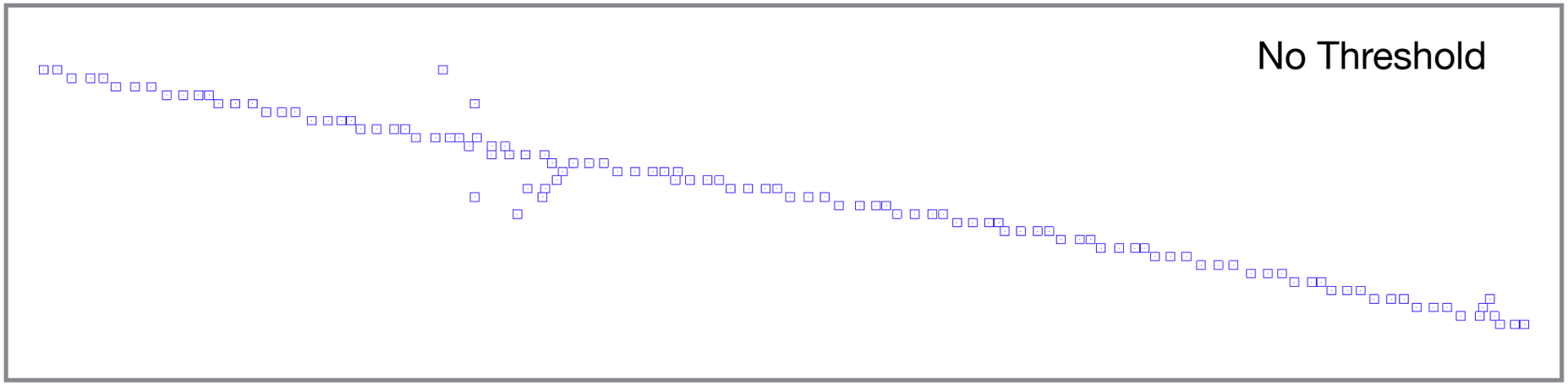


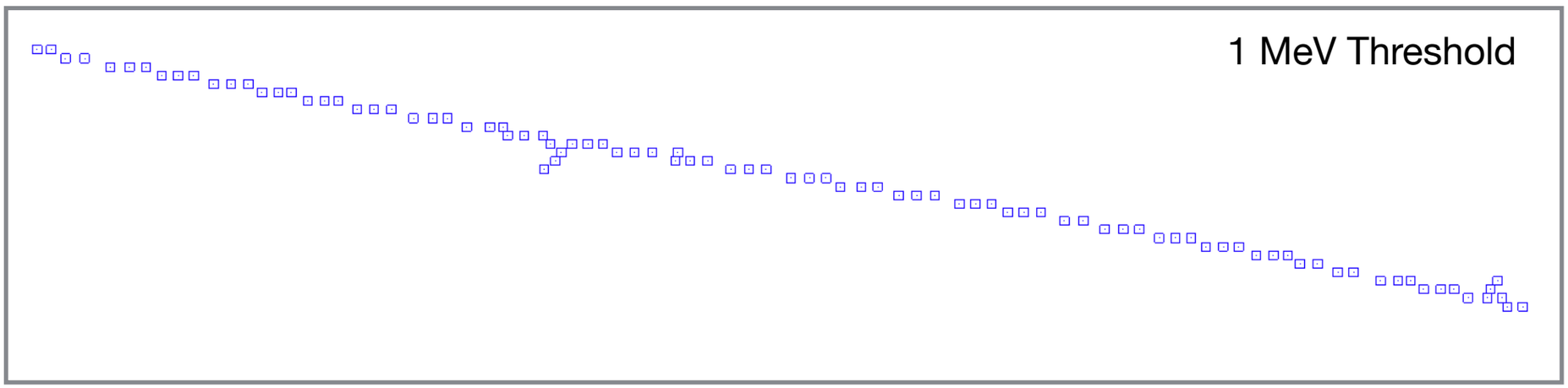


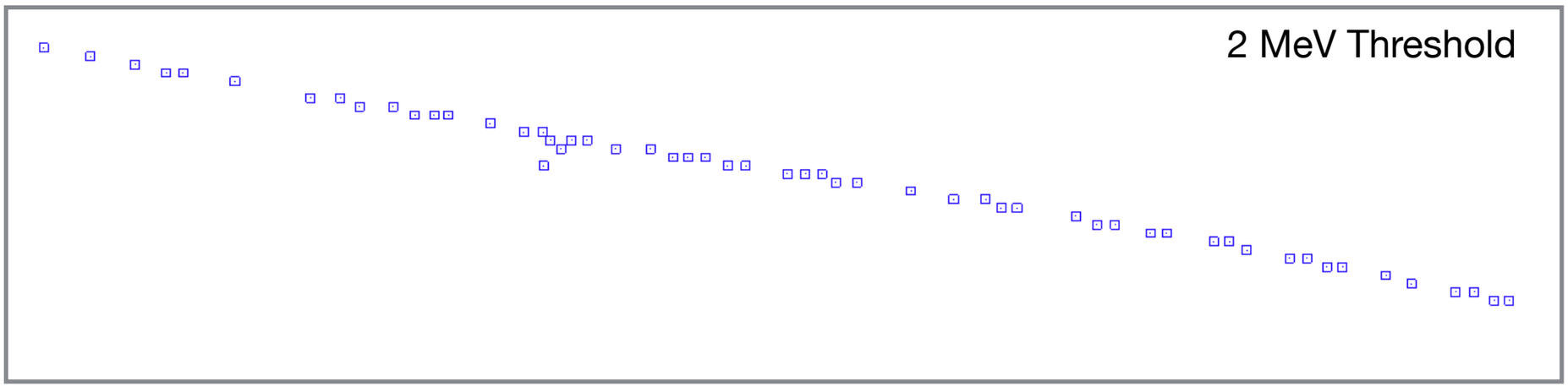
Hit Threshold

- In order to mimic a better signal to noise ratio we will place a threshold on the hit energy.
- This is a rough model as it only affects the signal quality and not the background noise level (i.e. fake hits).
- This threshold is applied to raw energy deposit in the detector and will be lower for the 2 view LArTPC than the 3 view LArTPC.

Example : W View Hits

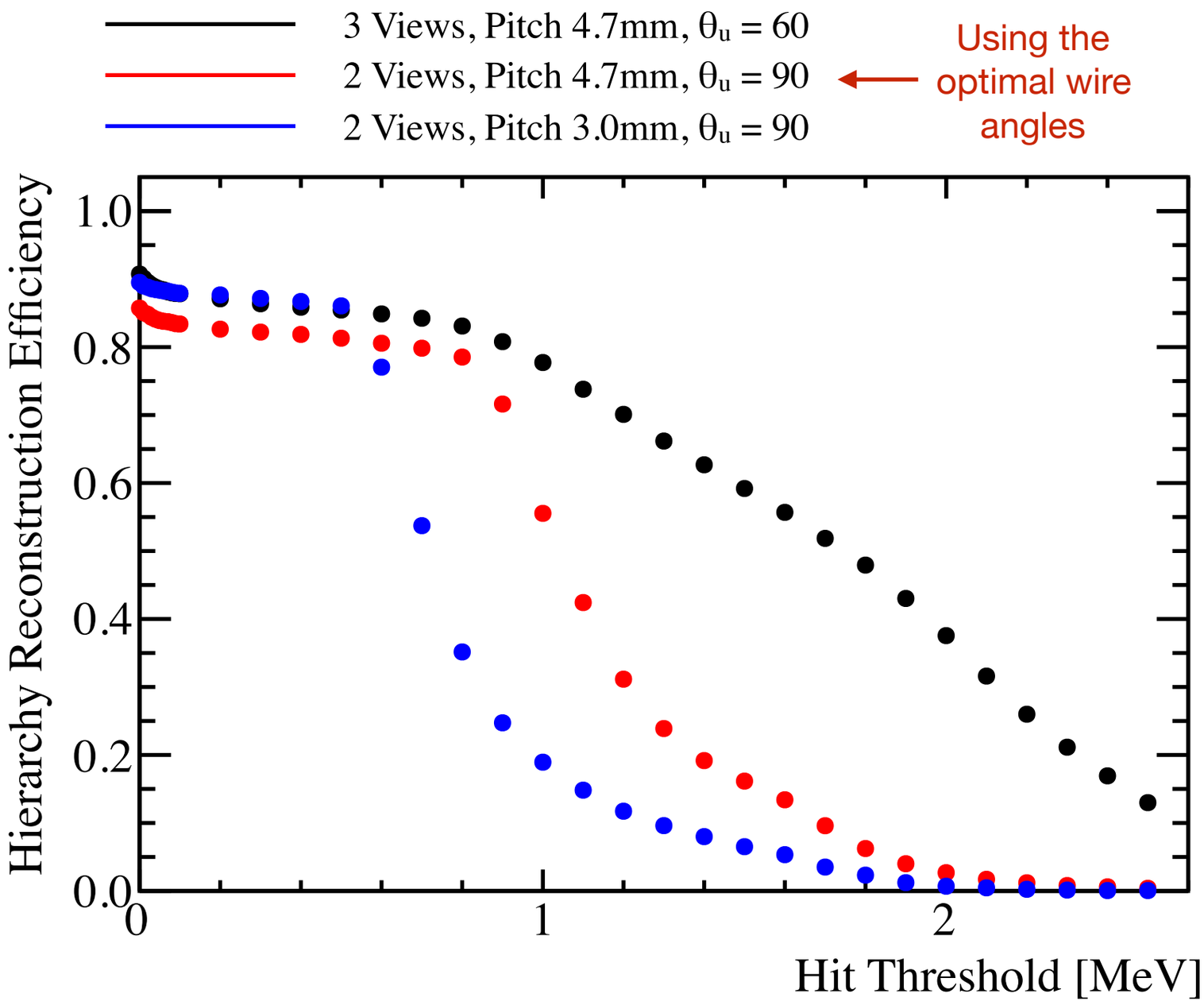






2 View LArTPC

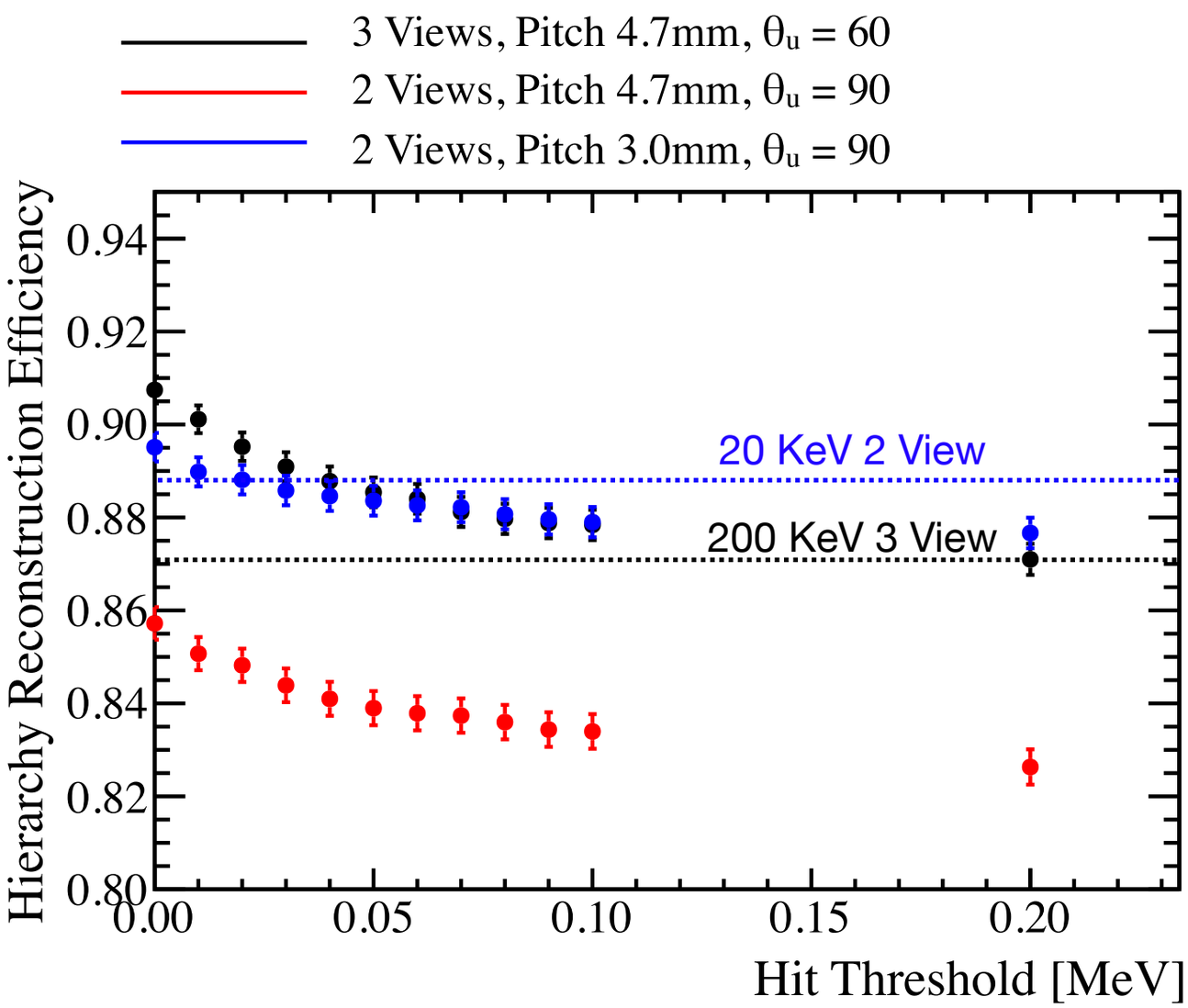
- As the threshold increases the hierarchy reconstruction efficiency drops as fewer hits appear in the detector.
- The 3 view LArTPC is more resilient to large hit thresholds, as the additional view allows Pandora to compensate for information lacking in a single view.
- Significant drop off in 2 view LArTPC reconstruction efficiency around a threshold of 0.6 MeV.



2 View LArTPC

- After discussion with TPC calorimeter experts we found that a hit threshold of ~200 KeV is appropriate for single phase and ~20 KeV* for dual phase.
- Using these thresholds the hierarchy reconstruction efficiencies are very similar; the 2 view, 3mm pitch LArTPC is marginally better than the 3 view, 4.7mm pitch LArTPC by ~1.5%.
- A similar trend also appears when the energy of the muon increased.
- These results rely on the hit threshold assumptions, which should always be kept in mind!

***These numbers are very speculative because they approximate a huge number of effects. Do not assume they are 100% accurate!**

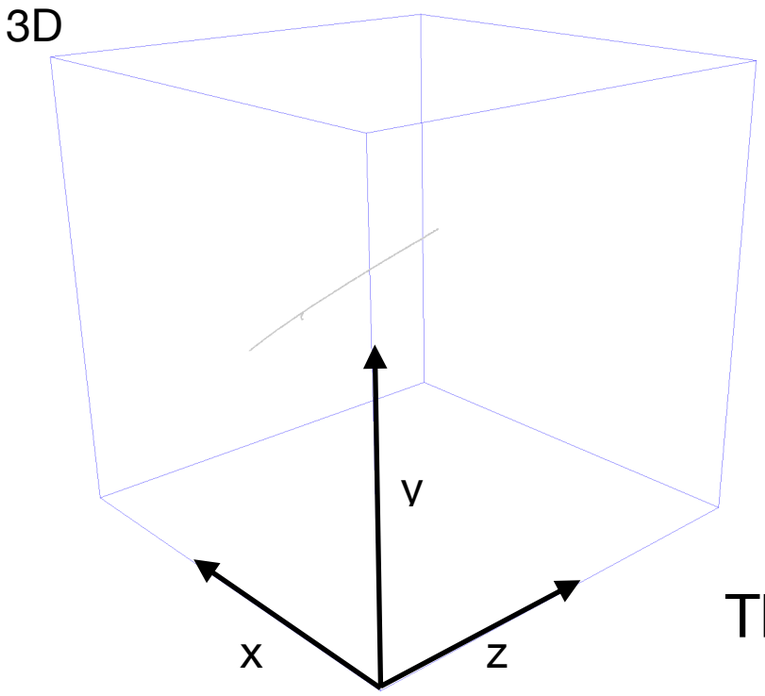


Using Thresholds*

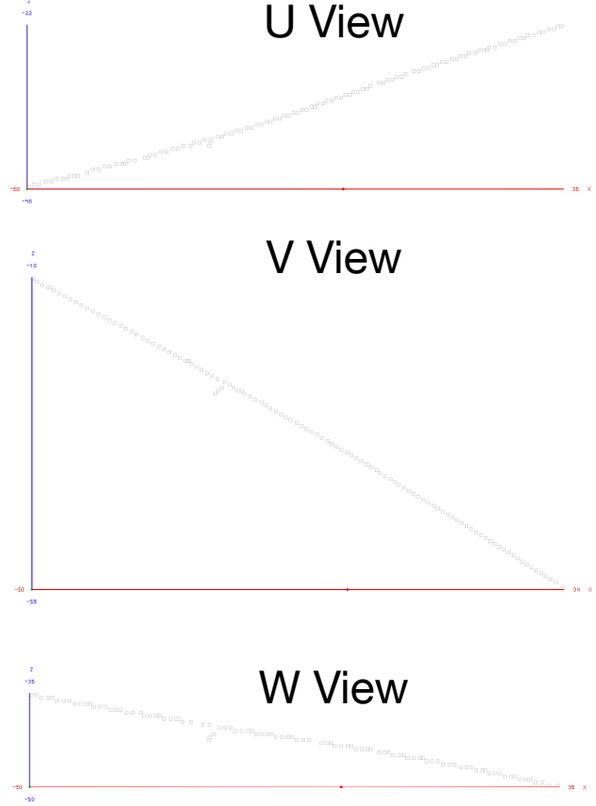
Reconstruction Efficiency	3 Views 4.7mm Pitch	2 Views 4.7mm Pitch	2 Views 3mm Pitch
1GeV μ^-	0.871±0.003	0.848±0.004	0.888±0.003
3GeV μ^-	0.829±0.004	0.800±0.004	0.850±0.004
5GeV μ^-	0.821±0.004	0.787±0.004	0.840±0.003

Conclusions

- We have studies the effect on the Pandora cosmic-ray muon reconstruction of varying the detector geometry for 3 and 2 view LArTPCs in a toy simulated detector.
- Both detector technologies yield very similar hierarchy reconstruction efficiencies once the pitch and hit energy thresholds have been accounted for.
- More work is needed to compare how the geometry changes affect the remaining reconstruction algorithm chains (test beam/neutrino) and the accuracy of the 3D reconstruction.



Project



Thank you for your attention!

Questions?

Pandora Pattern Recognition

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.

Pandora SDK Development	John Marshall (John.Marshall@warwick.ac.uk) Mark Thomson (thomson@hep.phy.cam.ac.uk)
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https://github.com/PandoraPFA

https://pandorapfa.slack.com

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