Pandora updates for Low Energy

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Tuesday 4th July 2023| LBNF/DUNE UK July 2023| University of Warwick

DEEP UNDERGROUND NEUTRINO EXPERIMENT

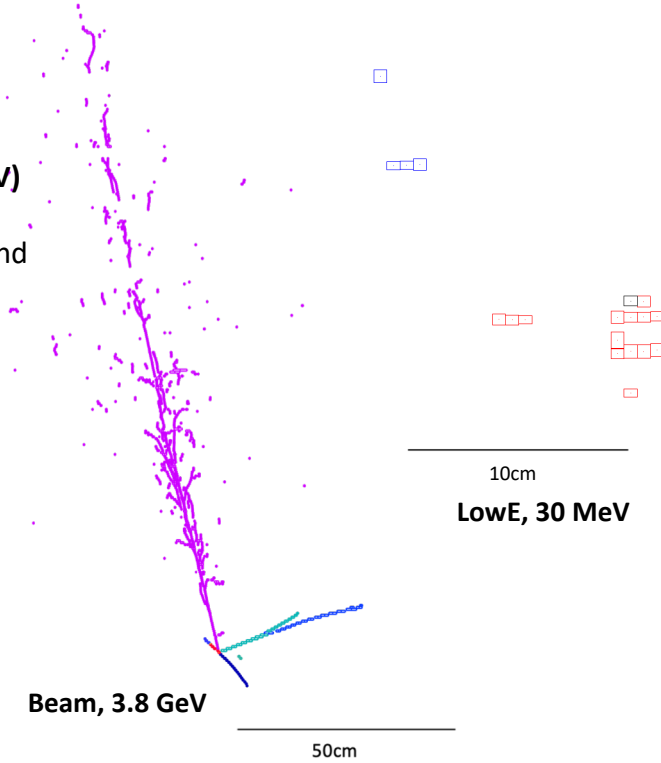
WARWICK

Recent work improvements

- **Implemented updated Hierarchy tools branch for improvements to metrics**

- **Explored training a Deep Learning network on low energy MARLEY samples (5-30 MeV)**
  - A Pass 1 and Pass 2 run show considerable improvements in the 10 – 40 hit region
  - Comparisons show LowE-tuned DL is more performant than the beam-tune BDT and Atmos-tuned DL
  - Some algorithms rely on good vertex position so boosting vertex efficiency boosts particle efficiency

- **Identified the differences between the standard 2D to 3D matching step and Cheated PFO algorithm (ongoing)**
  - Handscanned events and noted error modes and points for improvement
  - Cheating algorithm shows a ceiling for possible performance with current 2D matching and vertexing performance
  - Improvements here will raise the dip in the 50 - 80 hit region



Thanks to John, Maria Brigida and Andy for their support and help

Plan for increasing electron reconstruction efficiency

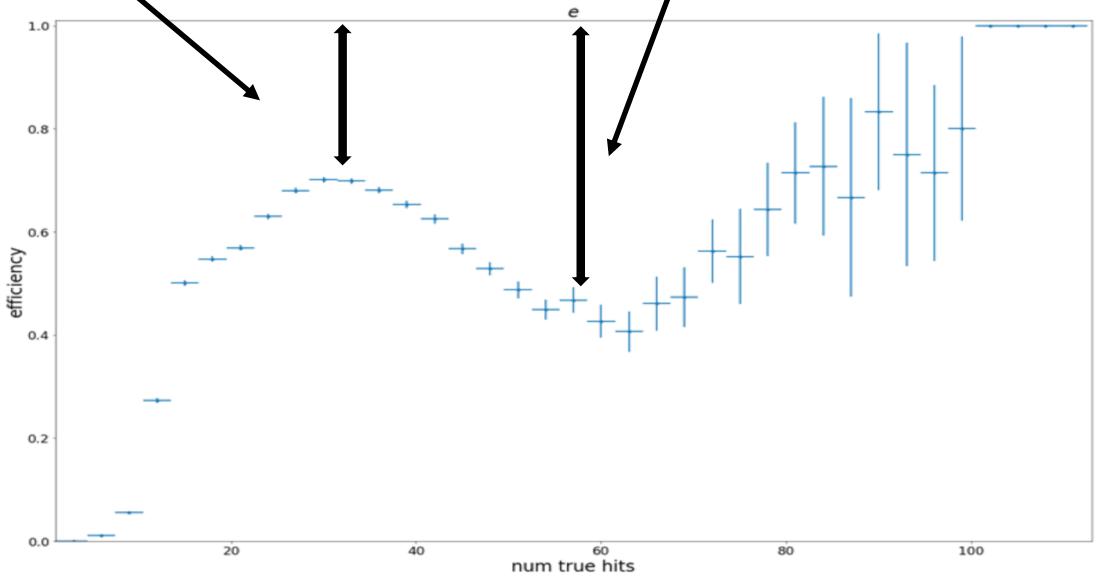
Plot shows efficiency of standard Pandora with no adjustments for low energy MARLEY samples

Low hit region (10 – 40 hits)
No PFO made

Target with:
Train a DL network with low energy samples to locate the vertex
->
activates Pandora algorithms to improve efficiency around vertex region

Middle hit region (50 – 80 hits)
True particle split in to multiple PFOs **->** fragmented, drops below thresholds

Target with:
Dedicated approach to 2D cluster for low energy and adjustments to the 2D to 3D cluster matching algorithms



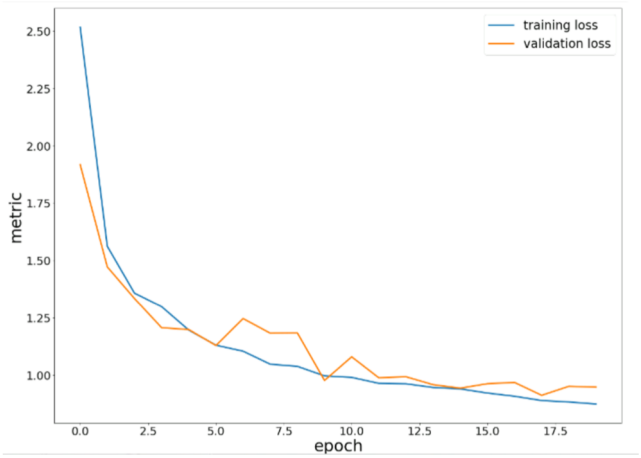
Training a Deep Learning Network, Pass 1

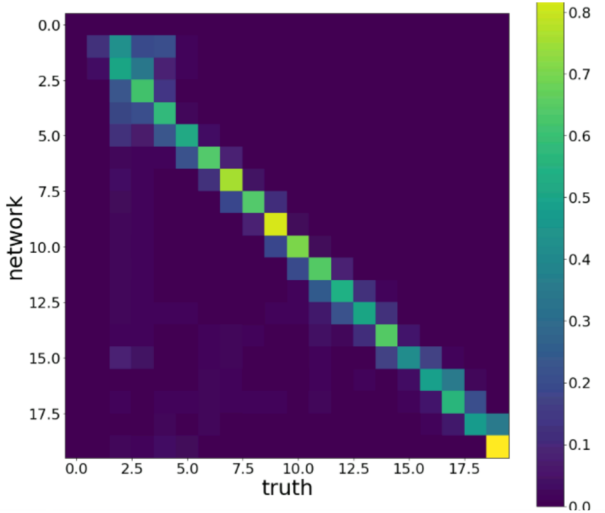
- **Explore training a new Deep Learning network on low energy samples**
  - Generated 50k images equally distributed over the MARLEY monoenergetic files (5 – 30 MeV)
  - Trained the network on the images (25% used for validation) and ran for 20 epochs
  - Outputted a low energy network per view for Pandora
  - Added additional DL xml to run new LowE-tune DL
  - Validated on separate 50k events to explore performance improvements

Thanks to Andy Chappell for his work and help

Loss and Accuracy for Deep Learning U Network, Pass 1

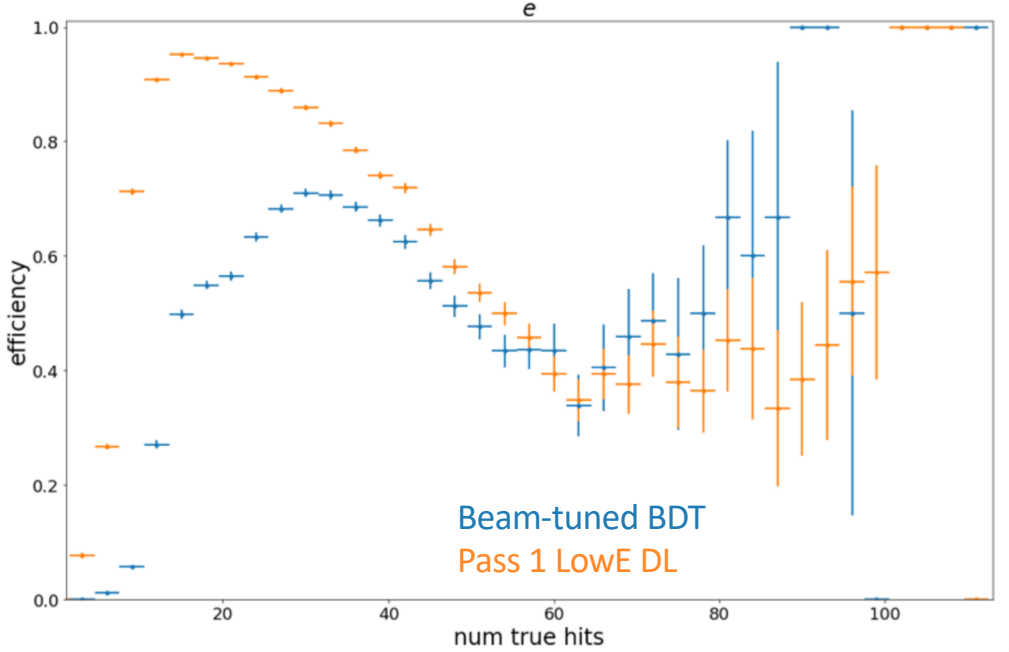
- For the U view, accuracy and loss metrics and confusion matrix
- Training has run fine, no huge jumps or apparent over fitting
- Appears to converge well in 20 epochs
- Fine binning in region closest to vertex has some misclassification





Electron Efficiency comparison for Pass 1 Deep Learning U Network

- **Electron Efficiency with a single pass LowE-tuned DL network for vertexing**
- Great improvements to the low hit regime – training sample has heavier weighting for this region
- Some drop off in performance at higher hits (beyond 50 hits)



Vertexing variants

Standard Pandora running a beam-tuned BDT for vertexing

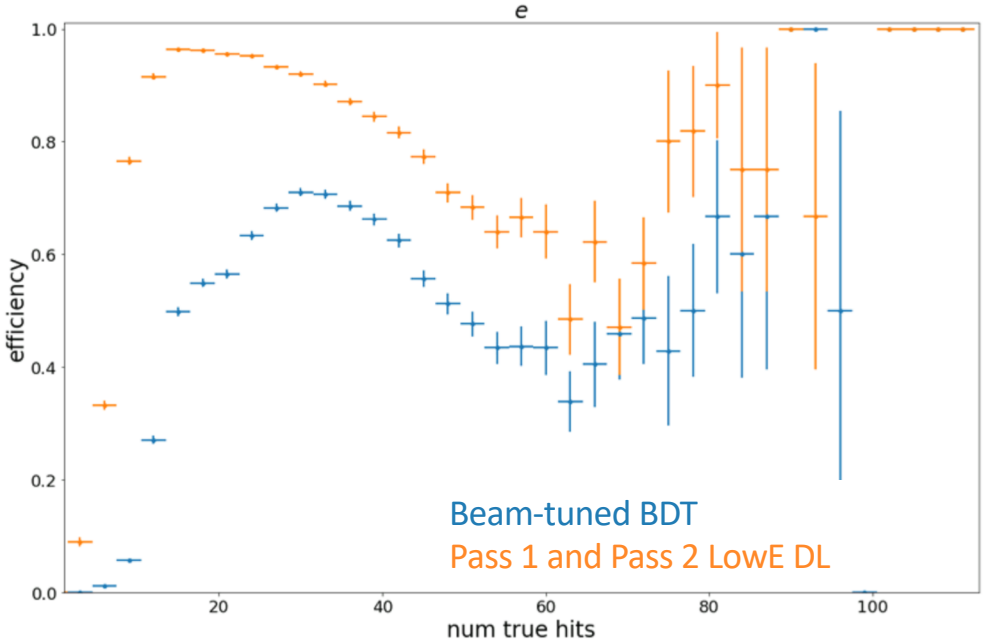
Standard Pandora running a single pass, LowE-tuned DL network for vertexing

Training a Deep Learning Network, Pass 2

- **Explore training a new Deep Learning network on low energy samples**
  - Generated 50k images equally distributed over the MARLEY monoenergetic files (5 – 30 MeV)
  - The Pass 2 uses the Pass 1 vertexing to identify a pixel region to perform zoomed-in Pass 2 (128x128)
  - Trained the network on the images (25% used for validation) and ran for 20 epochs
  - Outputted a low energy network per view for Pandora
  - Added additional DL xml to run new LowE-tune DL
  - Validated on separate 50k events to explore performance improvements

Electron Efficiency comparison for Pass 1 and 2 Deep Learning U Network

- **Electron Efficiency with a Pass 1 and 2 LowE-tuned DL network for vertexing**
- Great improvements to all regions



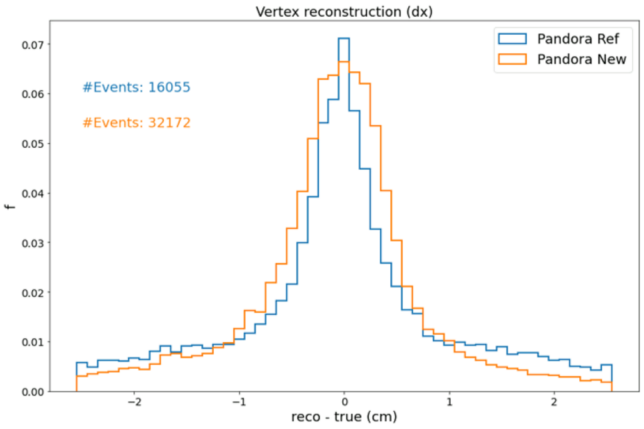
Vertexing variants

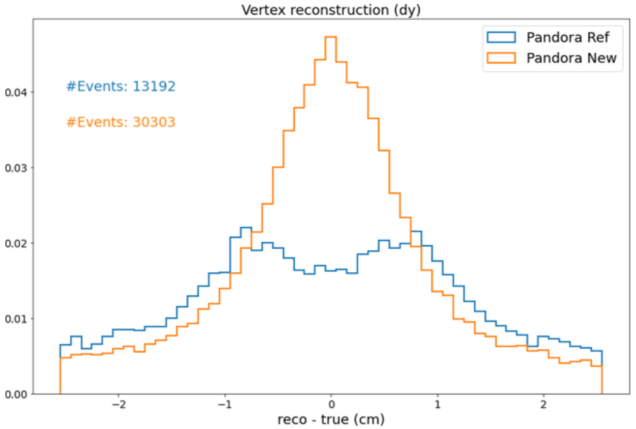
Standard Pandora running a beam-tuned BDT for vertexing

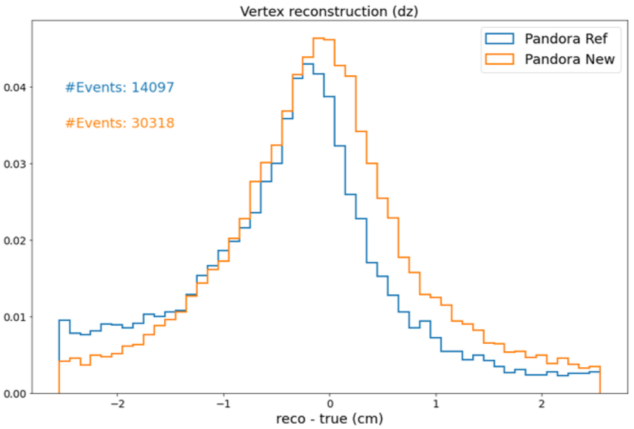
Standard Pandora running a Pass 1 and Pass 2, LowE-tuned DL network for vertexing

Vertexing performance, Beam BDT vs LowE DL

- **Vertexing plot comparisons – for dx, dy and dz position**
- Improvements to tails in each axis direction
- dx wider due to an artefact of the DL vertexing projection across each 2D view – no longer keeping constant x-coordinate like with BDT
- Identifies a vertex in many more events compared to the BDT
- Number of events within plot is twice as many for the DL within these plots

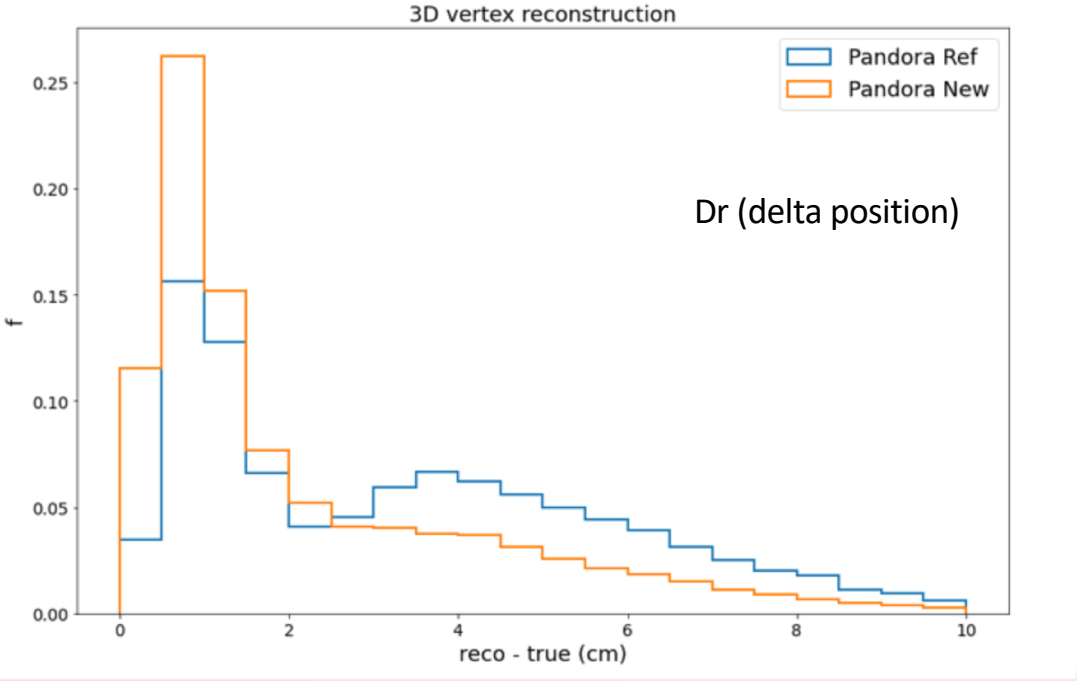






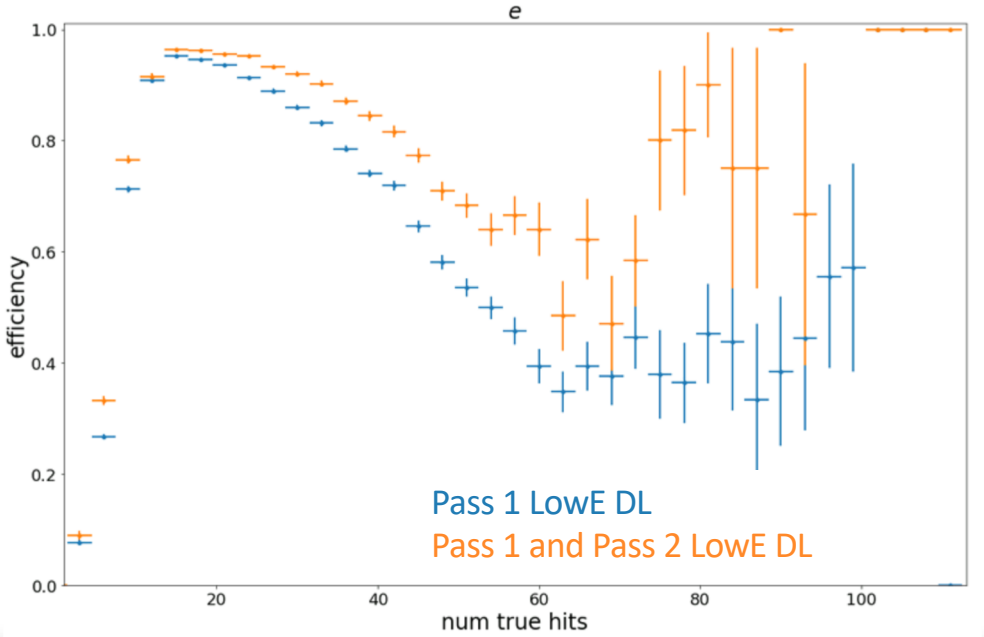
Vertexing performance for delta r, Beam BDT vs LowE DL

- **Vertexing plot comparisons – reco – true (cm)**
- Overall, much more accurate vertexing



Electron Efficiency Comparison for Pass 1 and Pass 2 LowE-tune

- **Pass 1 LowE DL Vertexing vs Pass 1 and Pass 2 LowE DL Vertexing**
- Considerable improvements across entire hit range
- Second pass shows good performance in higher hit region



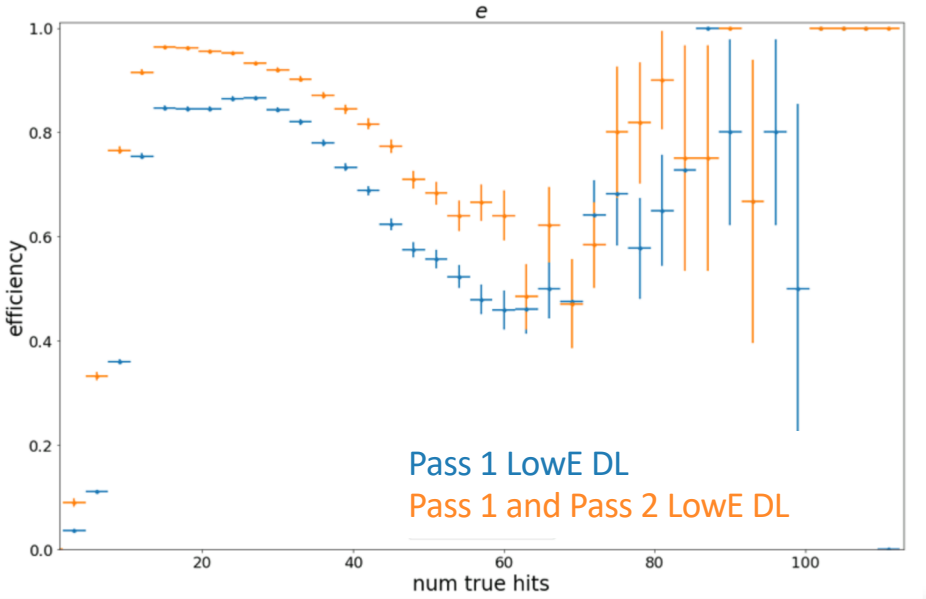
Vertexing variants

Standard Pandora running Pass 1 LowE DL Vertexing

Standard Pandora running Pass 1 and Pass 2 LowE DL Vertexing

Electron Efficiency Comparison for Pass 2 LowE-tune and Pass 2 Atmos-tune

- **Pass 1 and Pass 2 Atmospheric DL Vertexing vs Pass 1 and Pass 2 LowE DL Vertexing**
- DL networks seem to be a useful tool as they bring PFOs in to existence at much lower thresholds than with a BDT
- Don't require 'candidates' to be scored like BDT
- Training on Low energy shows to be beneficial



Vertexing variants

Standard Pandora running Pass 1 and Pass 2 Atmospheric DL Vertexing

Standard Pandora running Pass 1 and Pass 2 LowE DL Vertexing

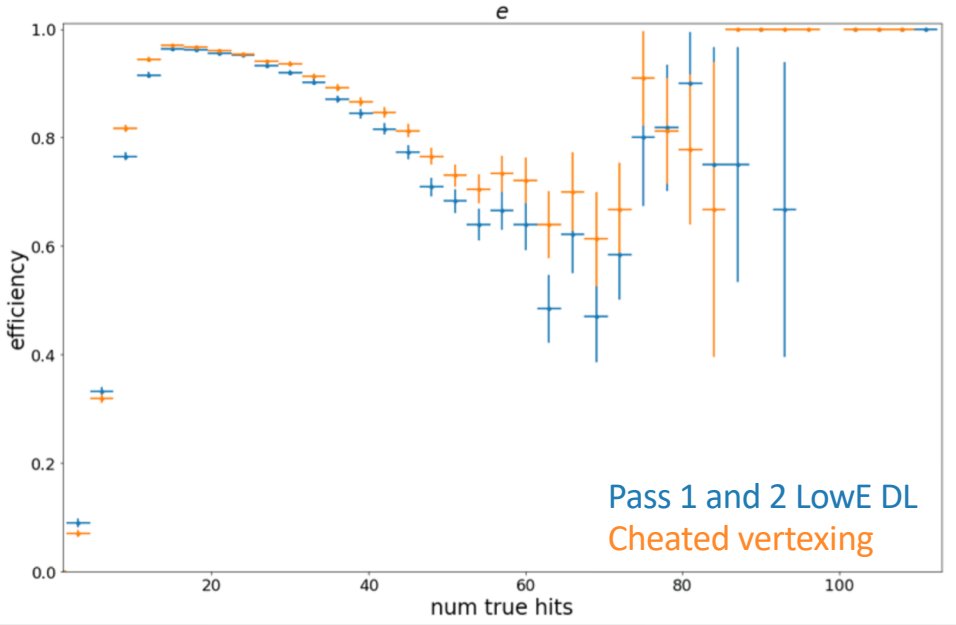
Can we improve the efficiency further with vertexing?

Future Improvements

- **What is the upper bound for vertexing performance?**
  - Will look at Pass 1 and Pass 2 LowE DL Vertexing vs Cheated Vertexing
- **What is the upper bound for particle efficiency considering the current vertexing performance?**
  - Will look at Pass 1 and Pass 2 LowE DL Vertexing vs Pass 1 and Pass 2 LowE DL Vertexing with Cheated PFO creation

Electron Efficiency Comparison for Pass 1 and Pass 2 LowE DL Vertexing vs Cheated Vertexing

- Promising, as getting close to ceiling for improvement with vertexing considering the current state of 2D clustering and 2D to 3D cluster matching
- Low hit region performant



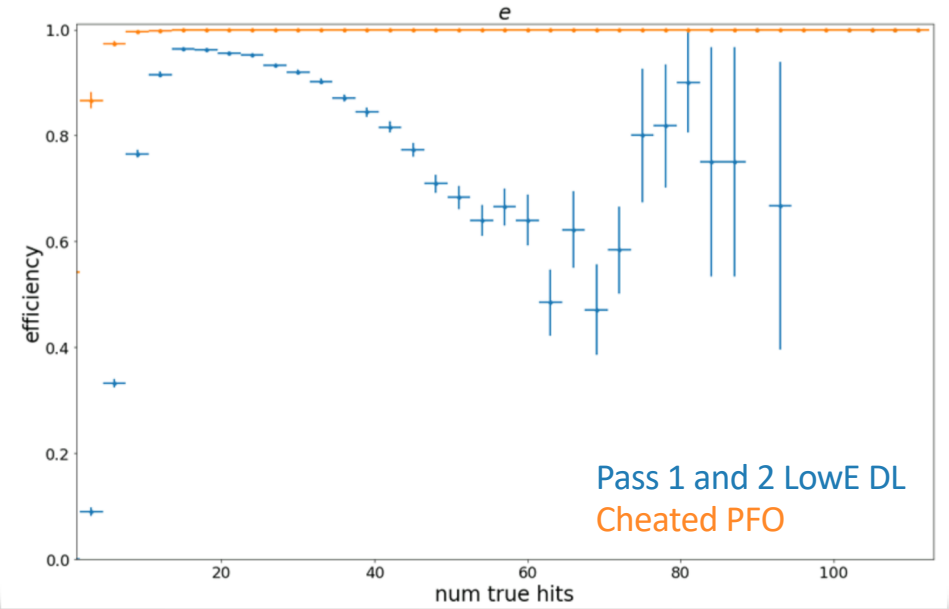
Vertexing variants

Standard Pandora running Pass 1 and Pass 2 LowE DL Vertexing

Standard Pandora running cheated vertexing

Electron Efficiency comparison for Pass 1 and Pass 2 LowE DL Vertexing vs Pass 1 and Pass 2 LowE DL with Cheated PFO creation

- DL network has brought step improvement and boosted the performance in the 10 – 40 hit region
- Work in 2D to 3D cluster matching will bring further improvements in the 50 – 80 hit region



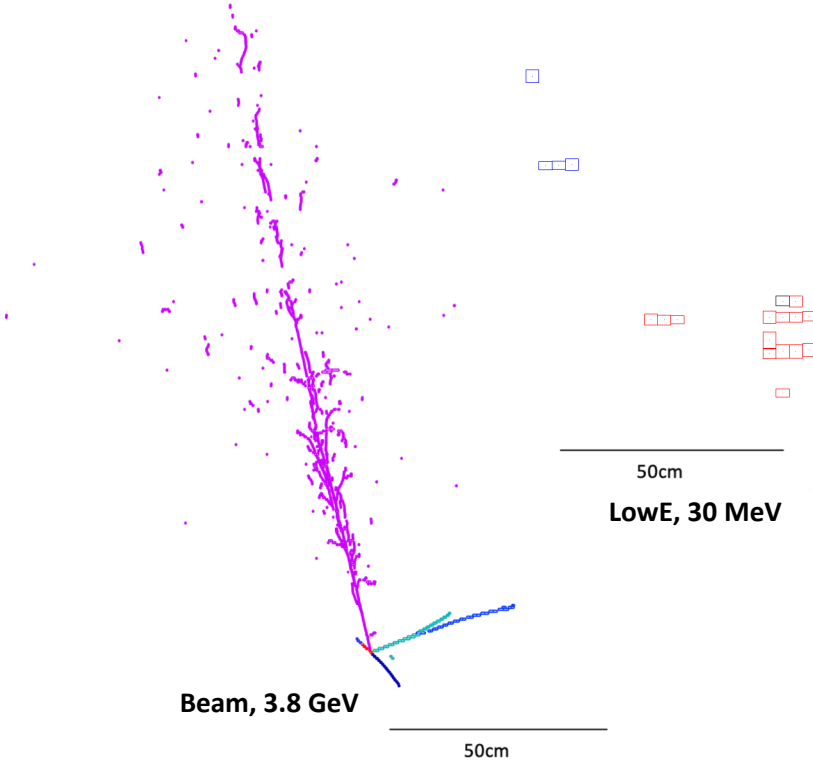
Vertexing variants

Standard Pandora running Pass 1 and Pass 2 LowE DL Vertexing

Standard Pandora running Pass 1 and Pass 2 LowE DL with Cheated PFO creation

Key take away points

- **Implemented updated Hierarchy tools branch for improvements to metrics**
- **Trained a performant 2 Pass DL network on MARLEY samples**
  - A Pass 1 and Pass 2 LowE DL show considerable improvements in the 10 – 40 hit region
  - Comparisons show LowE-tuned DL is more performant than the beam-tune BDT and Atmos-tuned DL
- **Identified areas of work in the 2D to 3D matching step and Cheated PFO algorithm**
  - Improvements here will raise the dip in the 50 - 80 hit region
  - Future work to be described later



Thanks to John, Maria Brigida and Andy for their support and help

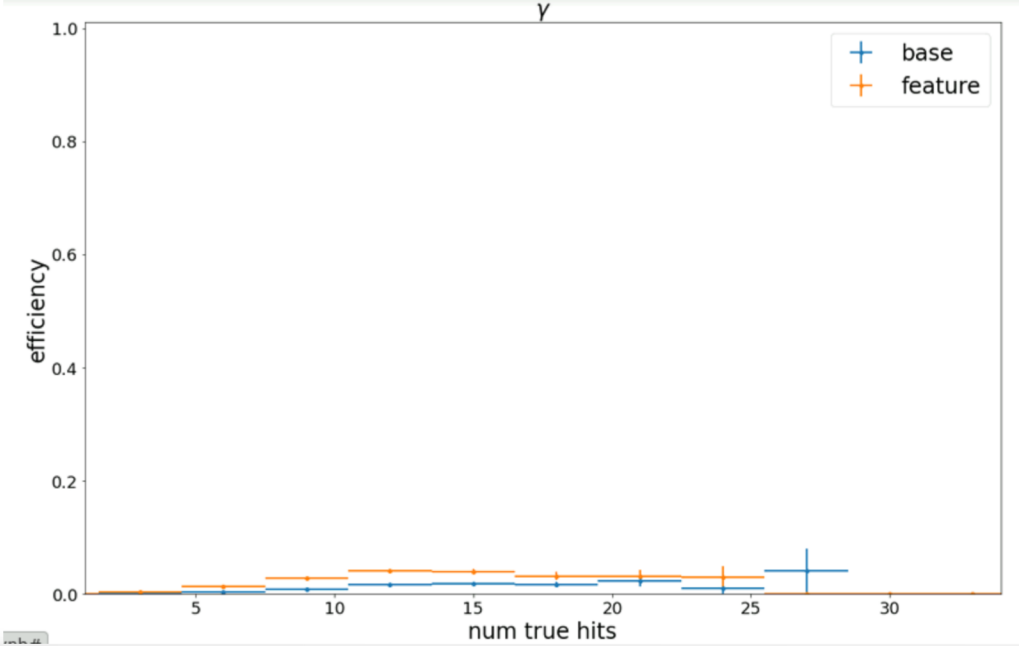
BACK UP

Useful repositories for validation

- **My LArMachineLearningData branch with Low-E Trained .pt files:**
  https://github.com/MattOsbiston/LArMachineLearningData/tree/feature/LowEnergy
- **My LArReco branch with various new xml configurations for Low E DL and various cheating configurations:**
  https://github.com/MattOsbiston/LArReco/tree/feature/hierarchy_update1
- **A repositiory with useful .sh scripts to run validation across the Low E samples:**
  https://github.com/MattOsbiston/UsefulScripts

Deep Learning U Network – Efficiency comparison

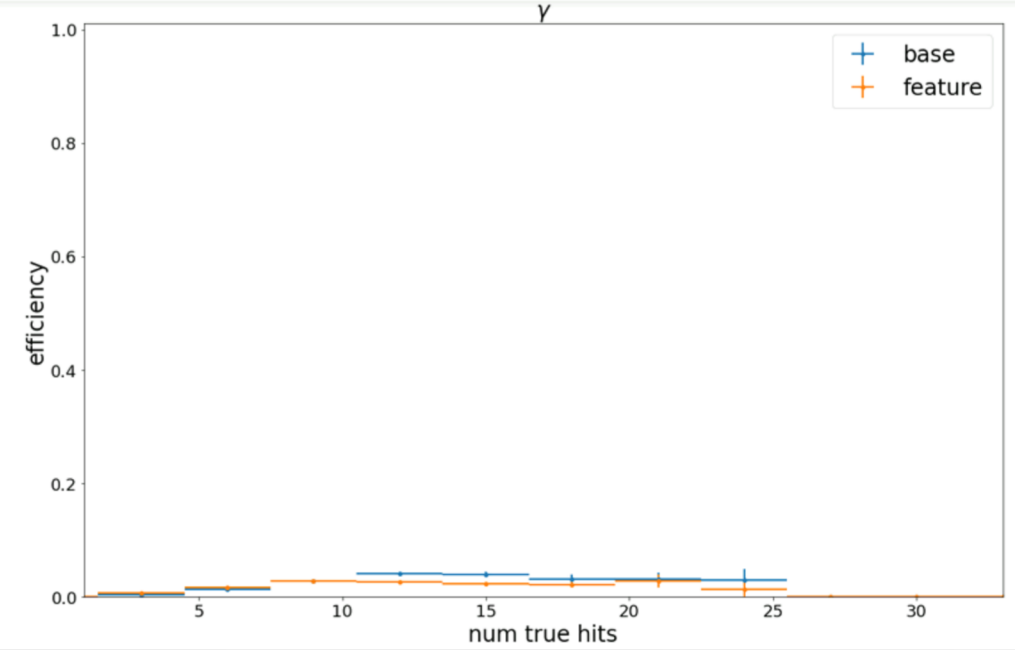
- **With a newly tuned DL network Pass 1 and Pass 2**
- Photon efficiency still low
- May require modified approach for improvement – perhaps from remastered 2D clustering



- **Base** – Standard Pandora running a beam-tuned BDT
- **Feature** – Standard Pandora running a Pass 1 and Pass 2, LowE-tuned DL network for vertexing

Deep Learning U Network – Efficiency comparison

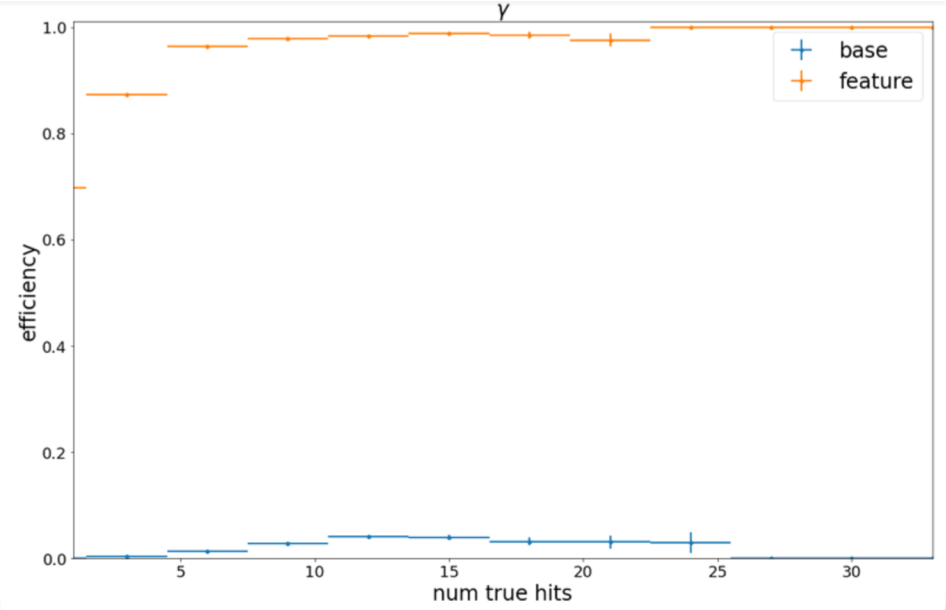
- **Pass 1 and Pass 2 LowE DL Vertexing vs Cheated Vertexing**
- DL appears to have better efficiency than cheated vertexing
- Having the perfect vertex isn't so useful when clusters aren't accurate or we have very sparse hits



- **Base** – Standard Pandora running Pass 1 and Pass 2 LowE DL Vertexing
- **Feature** – Standard Pandora running cheated vertexing

Deep Learning U Network – Efficiency comparison

- **Pass 1 and Pass 2 LowE DL Vertexing vs Pass 1 and Pass 2 LowE DL with Cheated PFO creation**
- Have boosted the performance in the 10 – 40 hit region with vertexing improvements
- Room for some further improvement in the 50 – 80 hit region, 2D to 3D cluster matching refinements
- Will continue to explore alternate approaches to better identify and create photon PFOs



- **Base** – Standard Pandora running Pass 1 and Pass 2 LowE DL Vertexing
- **Feature** – Standard Pandora running Pass 1 and Pass 2 LowE DL with Cheated PFO creation