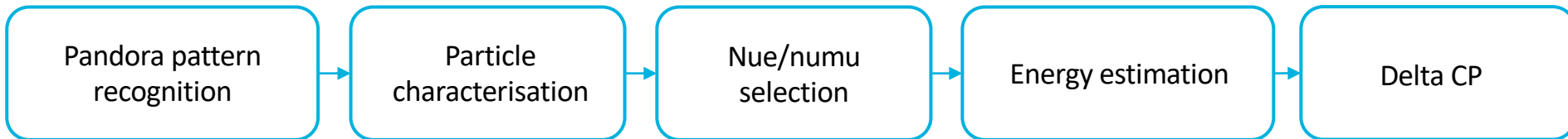


A DeltaCP Sensitivity Motivated Shower Refinement Algorithm within Pandora

Reconstruction → Analysis



CM Sept 2021 LBL Session

https://indico.fnal.gov/event/46504/contributions/223982/attachments/147395/188851/CM_LBL_21_08_21.pdf

CM Sept 2021 DUNE FD Sim/Reco Session

https://indico.fnal.gov/event/46504/contributions/224069/attachments/147572/189113/CM_SR_23_09_21.pdf

LBL WG Meeting Nov 2021

https://indico.fnal.gov/event/51697/contributions/227258/attachments/148827/191354/LBL_01_11_21.pdf

CM Jan 2022 LBL Session

https://indico.fnal.gov/event/50215/contributions/232787/attachments/151288/195431/CM_LBL_26_01_22.pdf

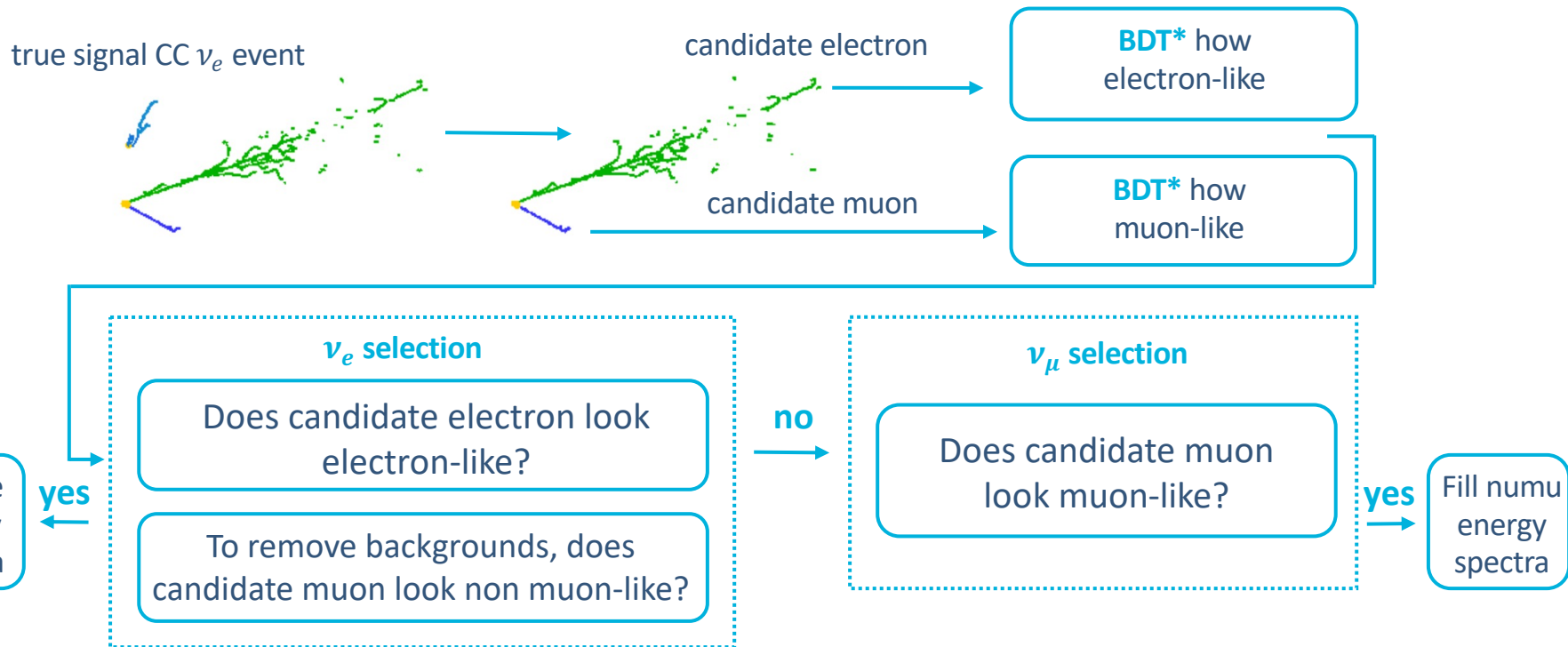
SR WG Meeting Mar 2022

https://indico.fnal.gov/event/53593/contributions/236665/attachments/152966/198362/SR_WG_14_03_22.pdf

nue/numu Selection

- Events are selected as a result of the determined identity of the candidate leading leptons in the event (should they exist)

* Credit to **Dom Brailsford** for initial development and continued support



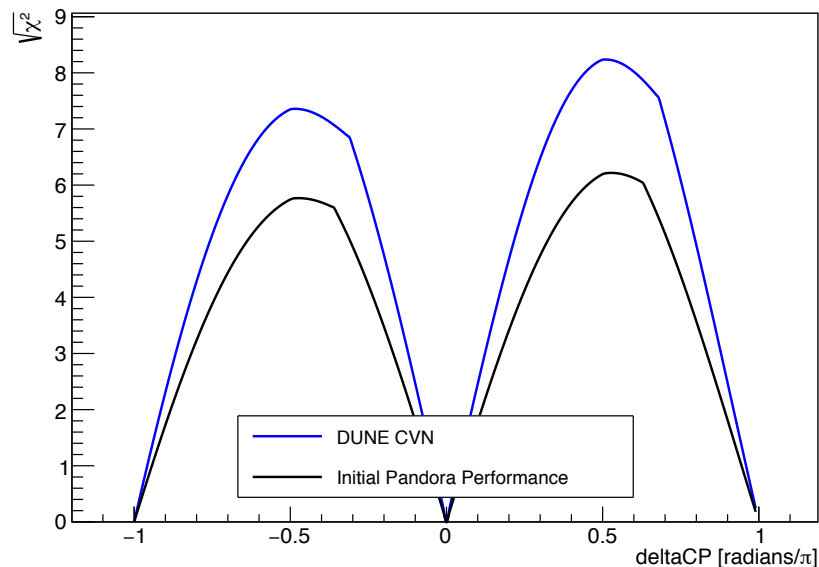
Initial Performance

	Nue Efficiency	Nue Purity	Nue BG Rejection	Numu Efficiency	Numu Purity	Numu BG Rejection
Pandora	60.0%	67.1%	98.6%	88.3%	87.2%	94.4%

- The numu selection is very good, but the **nue selection dominates the sensitivity** and must be improved
- The Pandora **multi-algorithm** approach allows hypothesised improvements to be investigated in an **iterative** manner allowing a **specific** problem to be identified

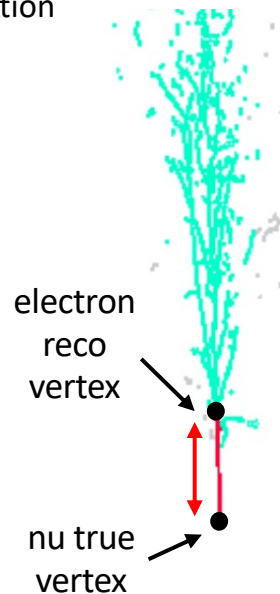
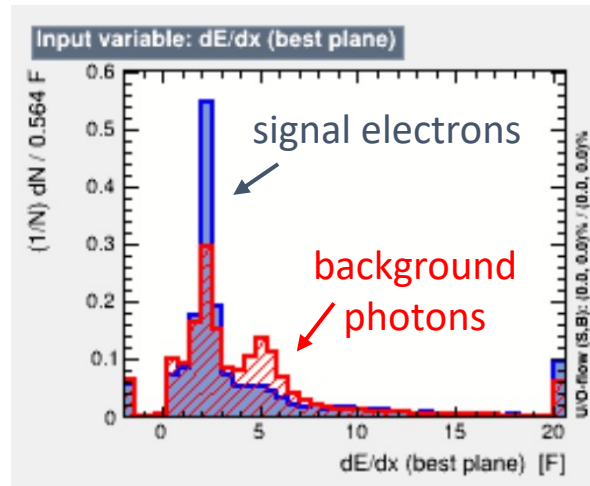
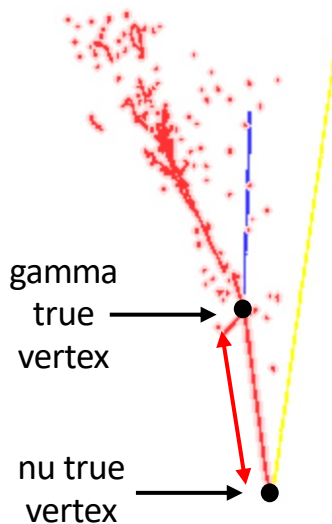
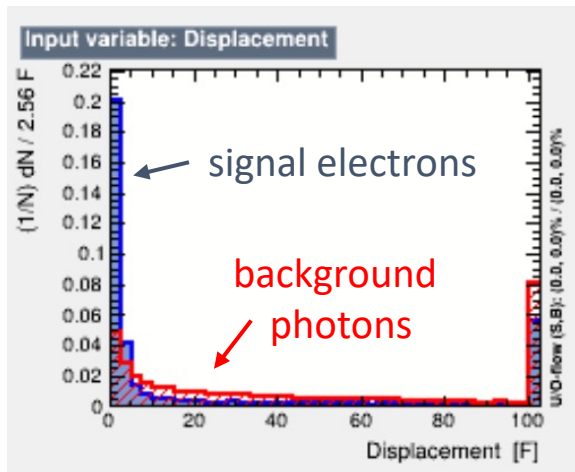
i.e. would a more **accurate neutrino vertex** placement result in a better sensitivity? If so, in what events? for which topologies? etc...

Pandora CP Violation Sensitivity (no stats/systematics)



Leading Reconstruction Failure

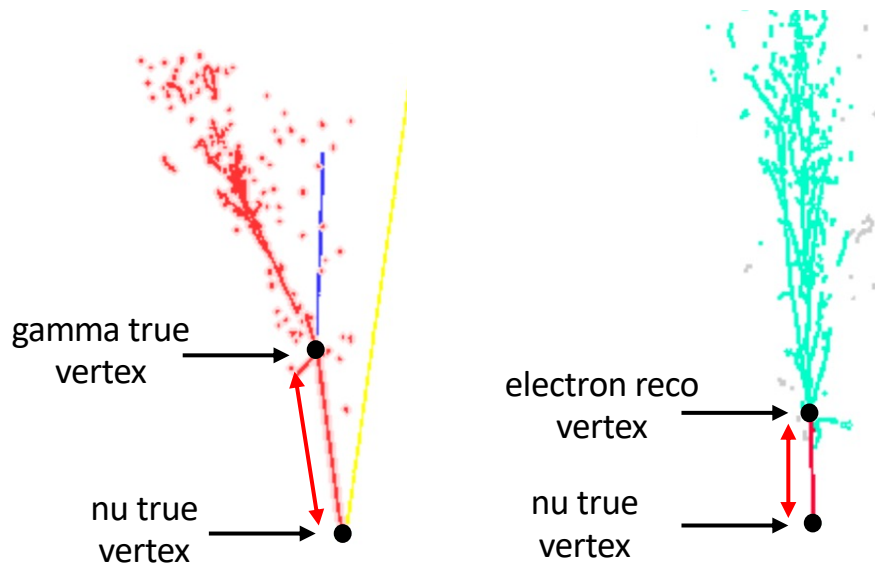
- We know that the **nue selection dominates the sensitivity**, we know that our nue selection relies on our electron-like BDT being accurate, and we know that the main inaccuracy is the **BDT confusing electrons with photons**
- The **initial dE/dx of the shower** and the **nu-shower start displacement** is used to aid electron/photon separation



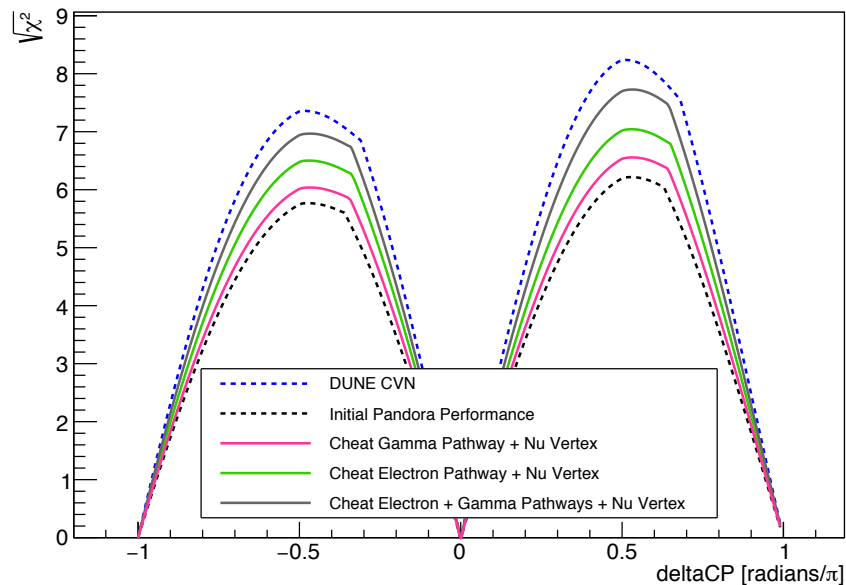
- Perhaps if the reconstruction of the initial shower region is improved, the separation in these BDT variables will increase resulting in gains to the sensitivity...

Cheating the Initial Shower Region

- To investigate this further let's create some cheating algorithms that, in the final stages of Pandora:
 - truncate** gamma pfos by removing all non-gamma hits in the gamma true vertex \rightarrow true nu vertex region
 - extend** electron pfos by bringing in all true hits in the reco \rightarrow true electron vertex region
- Also cheat the neutrino vertex but allow the rest of the reconstruction to **continue as normal**

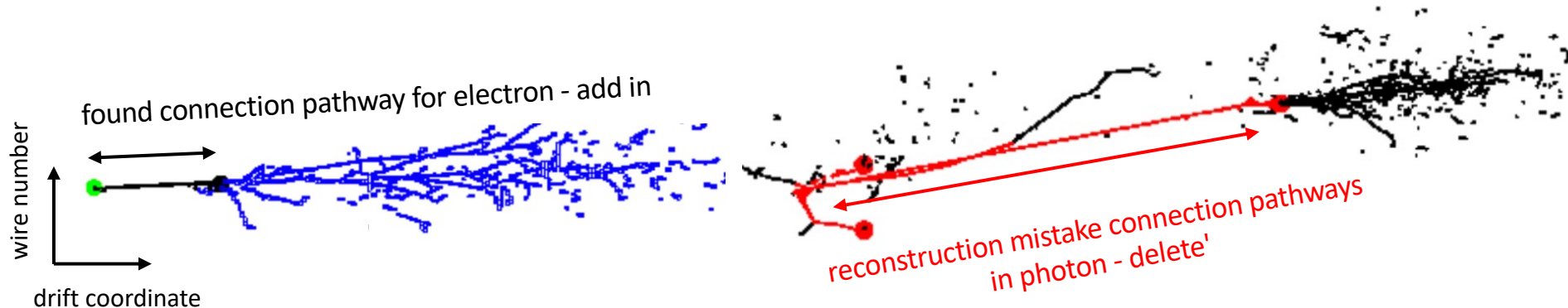


Pandora CP Violation Sensitivity (no stats/systematics)



Creating an Algorithm

- The Pandora multi-algorithm approach allows us to create a **specifically designed algorithm** to fix this reconstruction failure and achieve those tantalising sensitivity improvements
- In this algorithm we
 - Find the **connection pathways** that the electron (photon) should have (has) followed to get back to the neutrino vertex

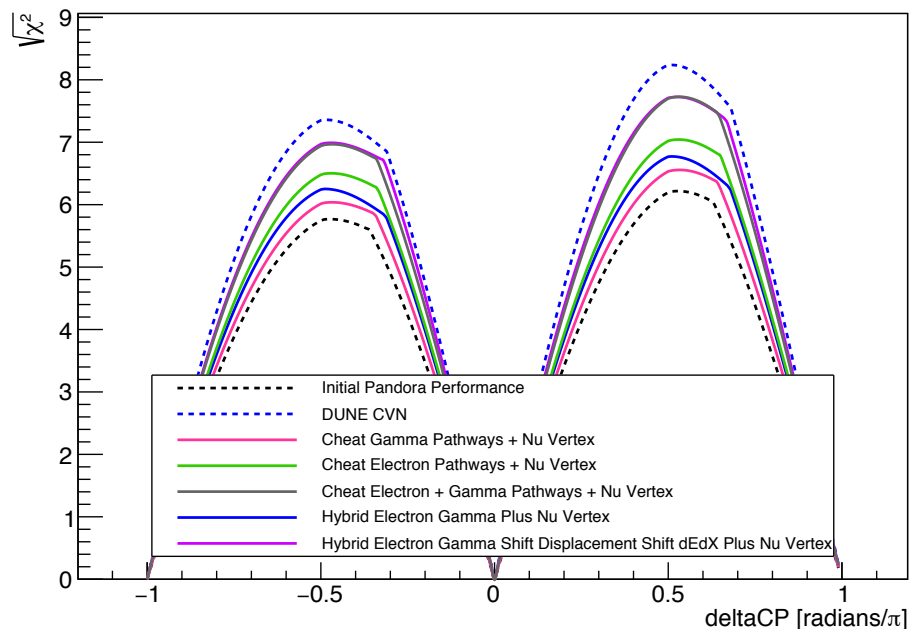


- Decide** whether the connection should be there or not (as a first version **cheat** by using the shower's true identity)
- Add or remove** the connection pathway

Hybrid Algorithm Performance

- In the first version of this algorithm the **connection pathway decision** and the **neutrino vertex placement are cheated**, so let's call this a 'hybrid' configuration

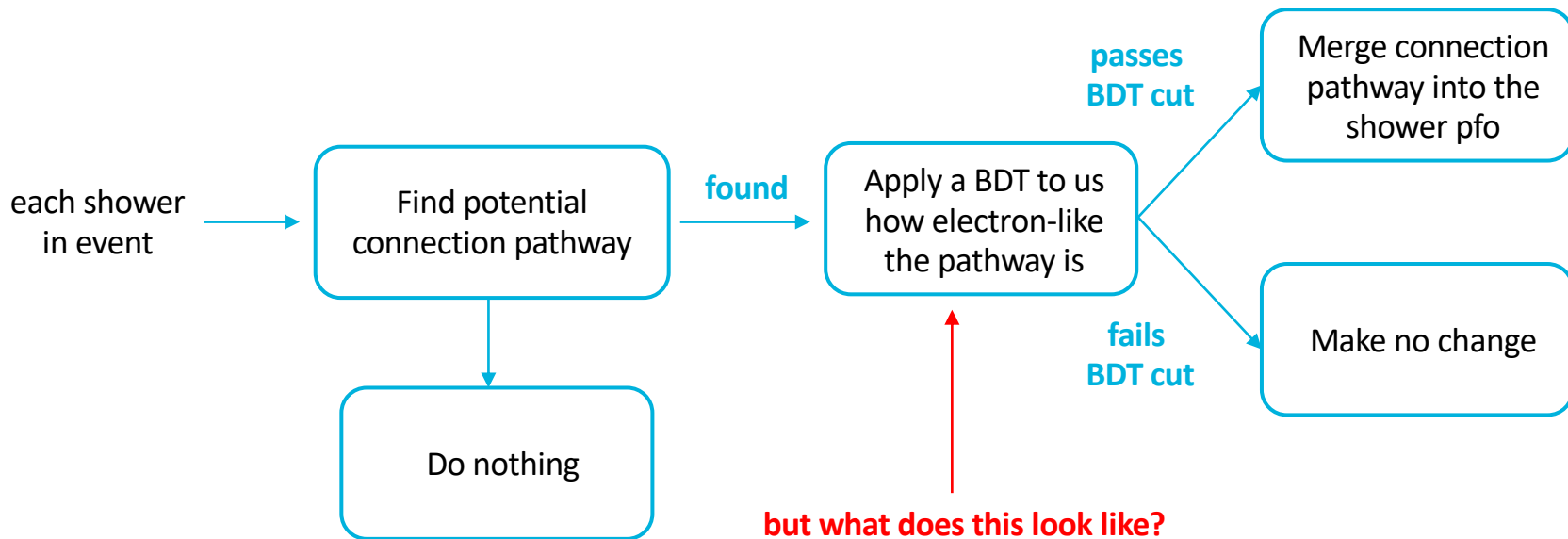
Pandora CP Violation Sensitivity (no stats/systematics)



- I think that, in the hybrid algorithms, we're not managing to achieve the separation in the dedx/displacement variables to the **extent required**
- Why don't we manually set the dedx to an electron-like value and the displacement to 0 for showers that the electron extension algorithm thought to be electrons
- We see giant gains...

Full Reconstruction Algorithm

- To make this a full reconstruction algorithm, a BDT has been created to identify the nature of the connection pathways
- Let's see how this works for the electron extension tool, as reminder the general process is:



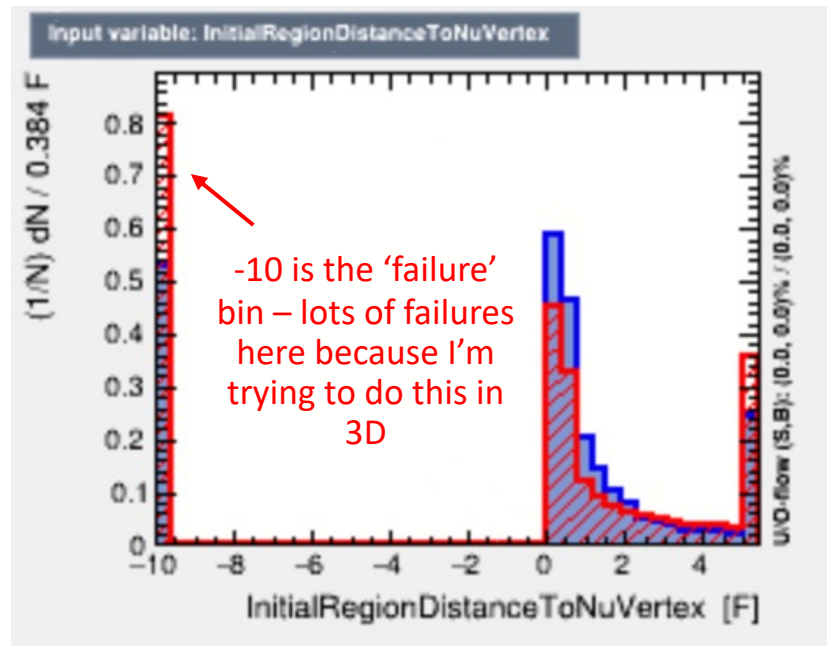
Connection Pathway BDT

- I think, for a shower, there are four areas we consider when trying to determine whether the connection pathway belongs to an electron or not



1) The Initial Region

- This is the region at the very start of the connection pathway
- I expect electrons to have quite clean pathways back to the neutrino vertex and so have quite a small distance between the nu vertex and the closest 3D hit
- I expect photon connecting pathways to be an amalgamation of other particle hits and thus quite gappy and hence have a larger distance between the nu vertex and closest 3D hit

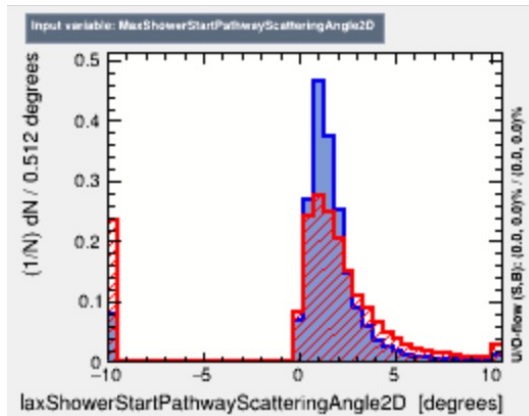
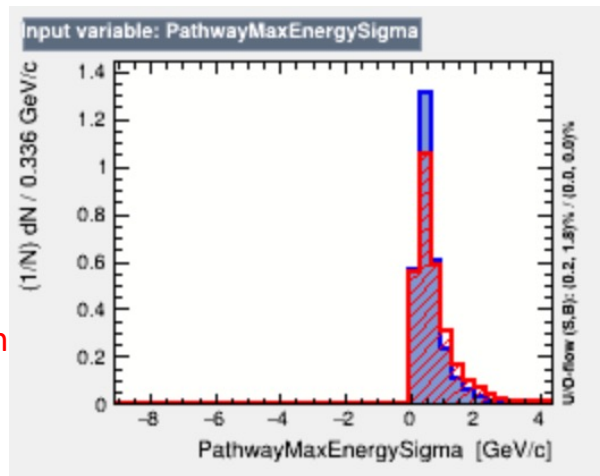
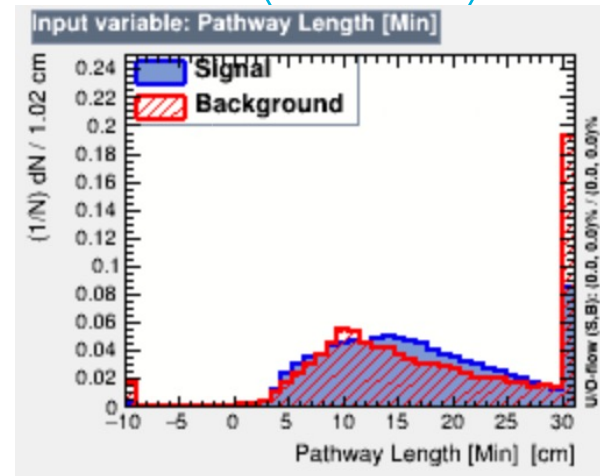


2) Connection Pathway

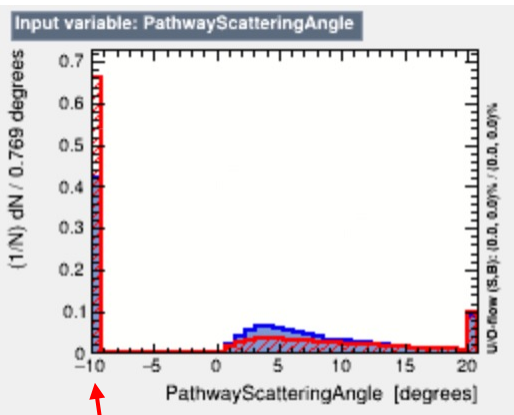
- This is the region between the neutrino vertex and shower start point

I expect the pathways photons have mistakenly taken back to the neutrino vertex to be quite long

and to have kinks in them (in both 2D and 3D)



If the mistaken gamma pathways are often an amalgamation of other particle hits I expect them to have quite a spread in energy

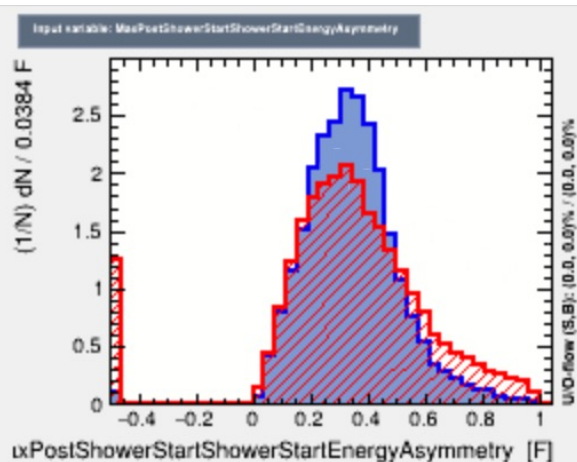
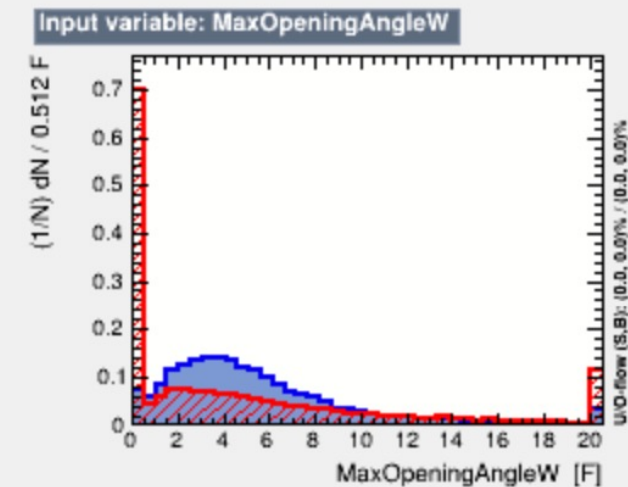
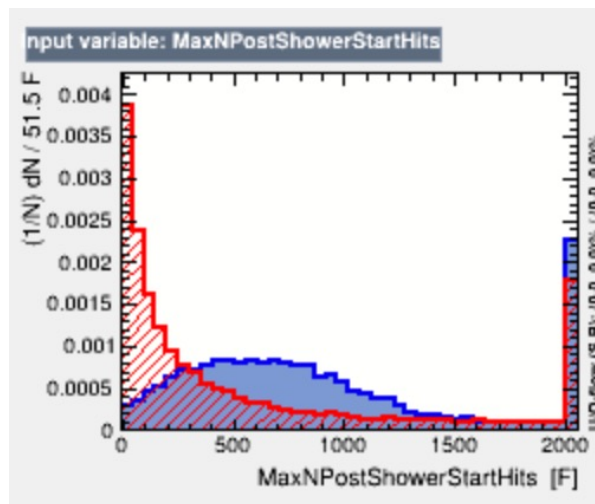


it seems that the separation here is coming from failures in the 3D matching process utilised in this estimator

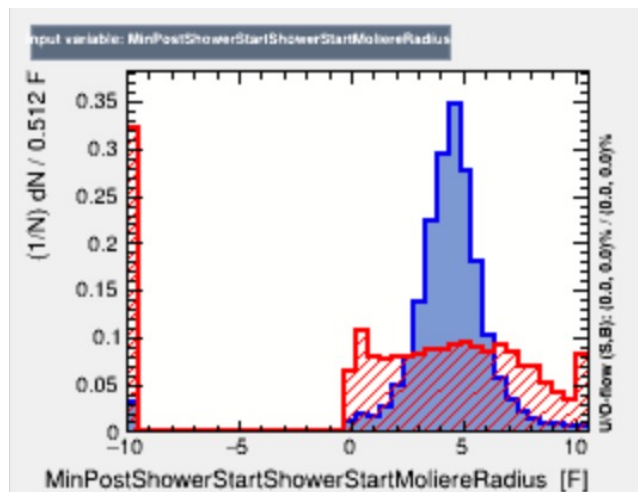
3) Shower Region

- Electrons should resemble showers...

The energy deposition of the shower should be symmetric about the shower axis (originating from the shower start vertex)



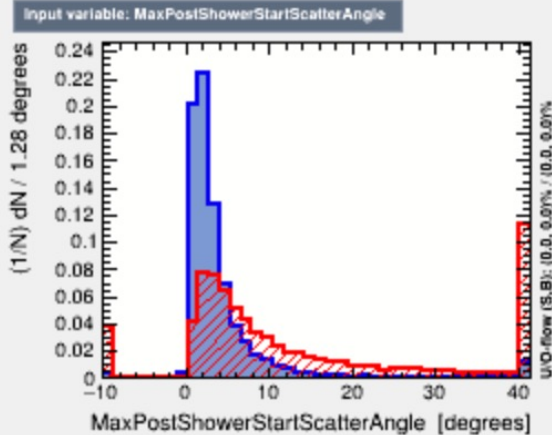
90% of their energy should be within a well defined region



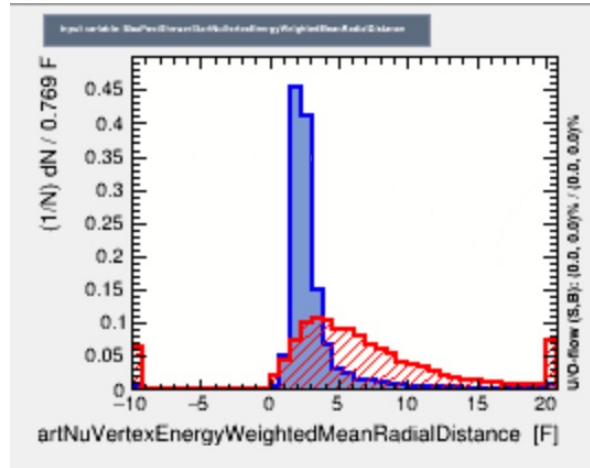
3) Shower Region

- Electrons should look as though they're coming out of the neutrino vertex

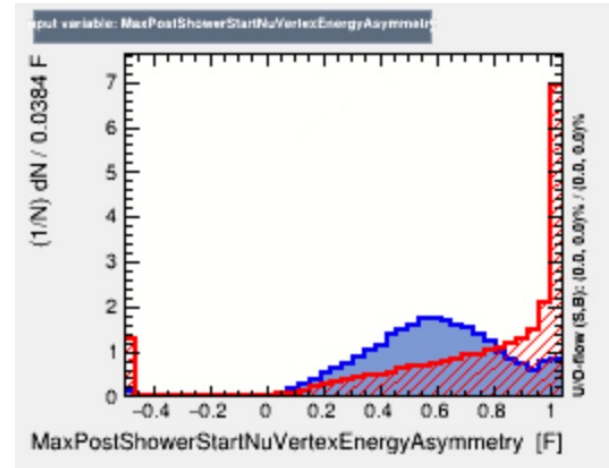
The shower direction should coincide with the connection pathway direction



The core of the shower's energy should be fairly close to the connection pathway direction (originating from the neutrino vertex)

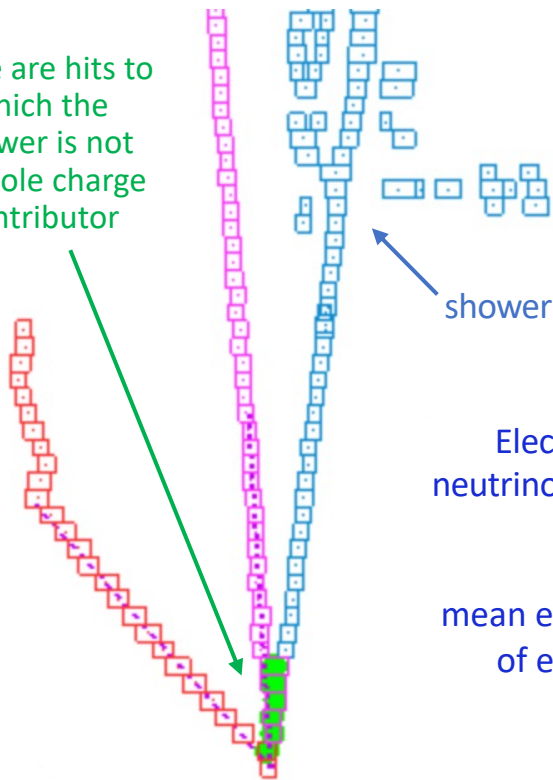


The shower's energy should be symmetrically distributed around connection pathway direction (originating from the neutrino vertex)



4) The Ambiguous Region

these are hits to which the shower is not the sole charge contributor



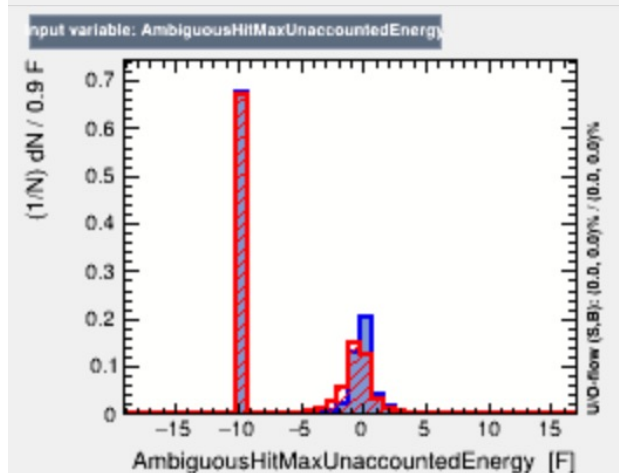
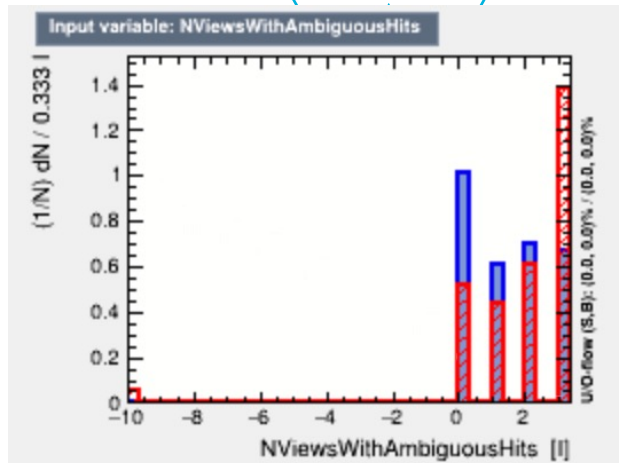
To get back to the neutrino vertex photons have to use hits that obviously belong to other particles

Electrons may, in few views overlap with other particles but they mostly have clean routes back

Electrons should deposit energy from the neutrino vertex so will contribute to the energy of the ambiguous hits, therefore:

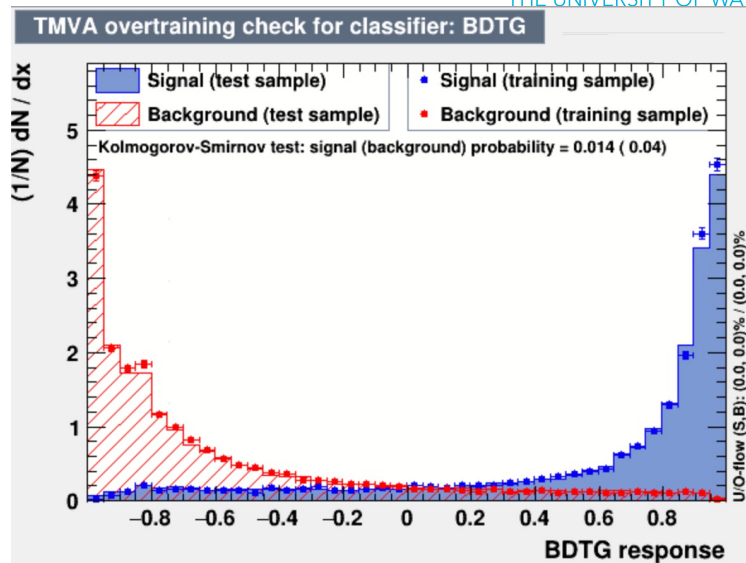
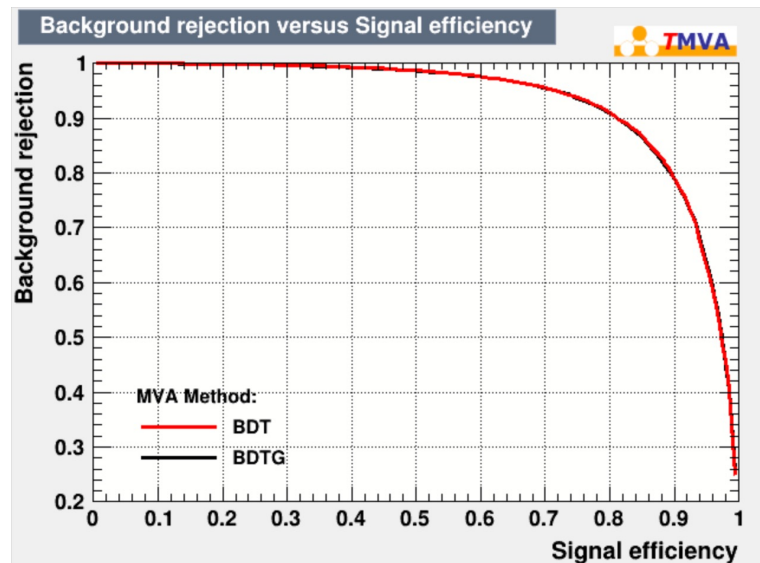
mean energy of ambiguous hits – mean energy of each track owner – energy of shower

should be zero



Performance

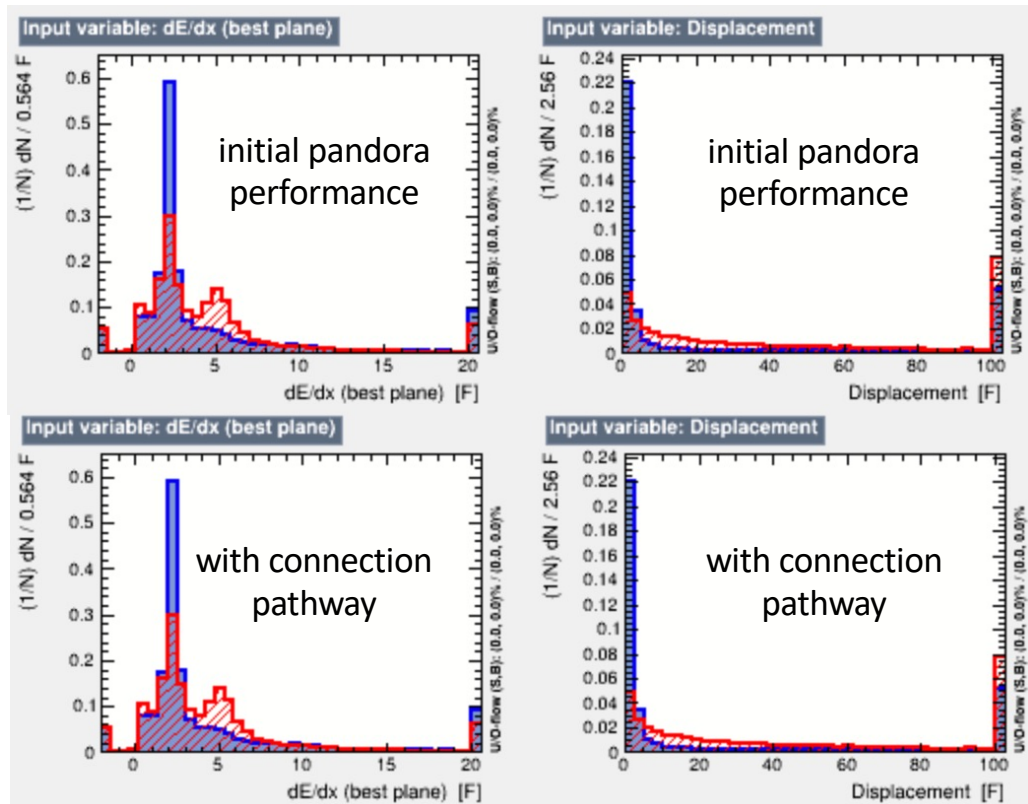
- Considered in isolation the performance is **looking really good!**



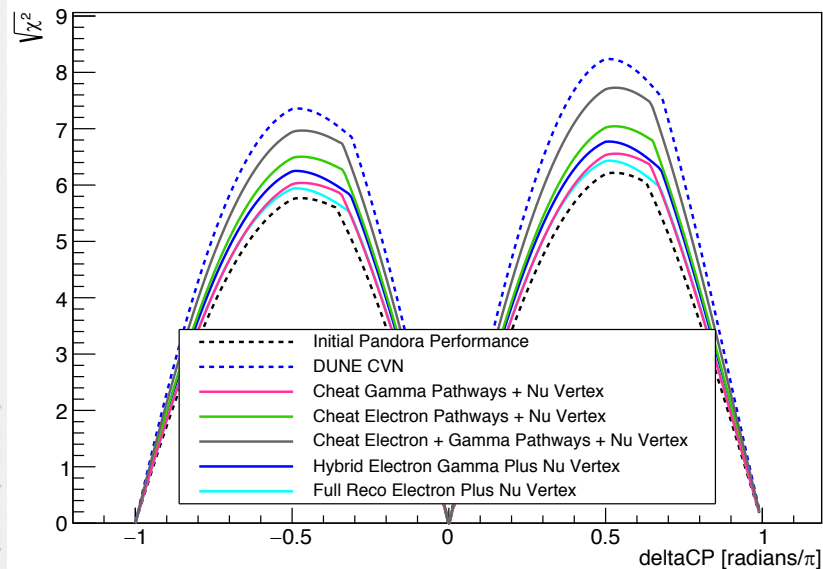
- But of course we really care about what this does for our **sensitivity**
- We have to pick a cut above which connection pathways will be decided to be electron-like and will be added to the shower
- This is **really** difficult to optimise so, for now, let's go with the efficiency*purity optimised BDT cut of -0.1

'Vanilla' Electron-like BDT

- Without any changes to the electron-BDT we see these improvements:

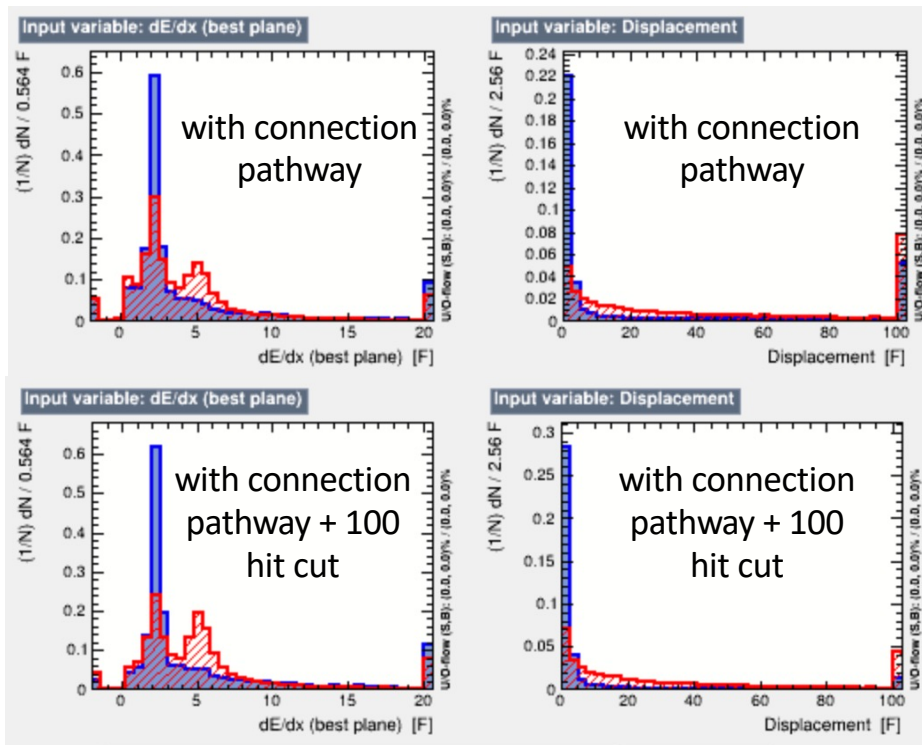


Pandora CP Violation Sensitivity (no stats/systematics)

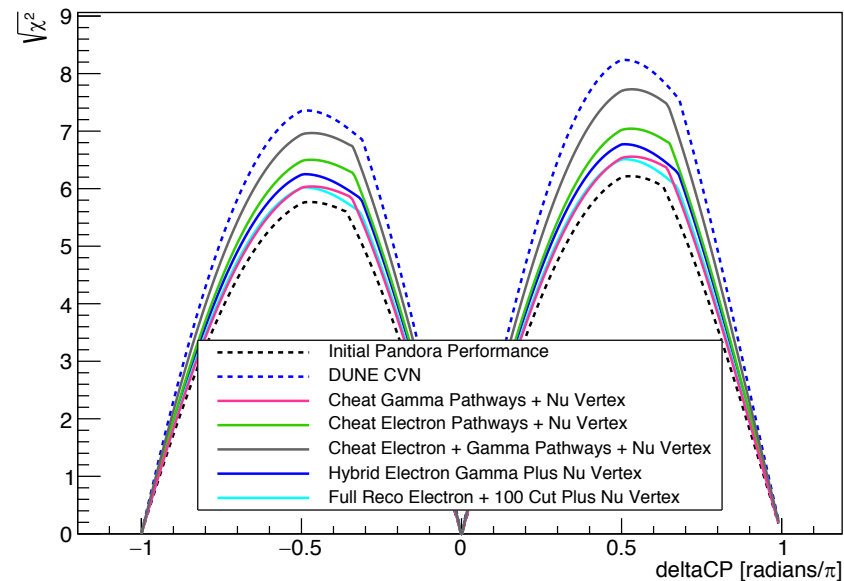


Electron-like BDT + 100 Hit Cut

- It seems that small pfos are actually washing away our distributions
- So let's apply this cut to the training and selection



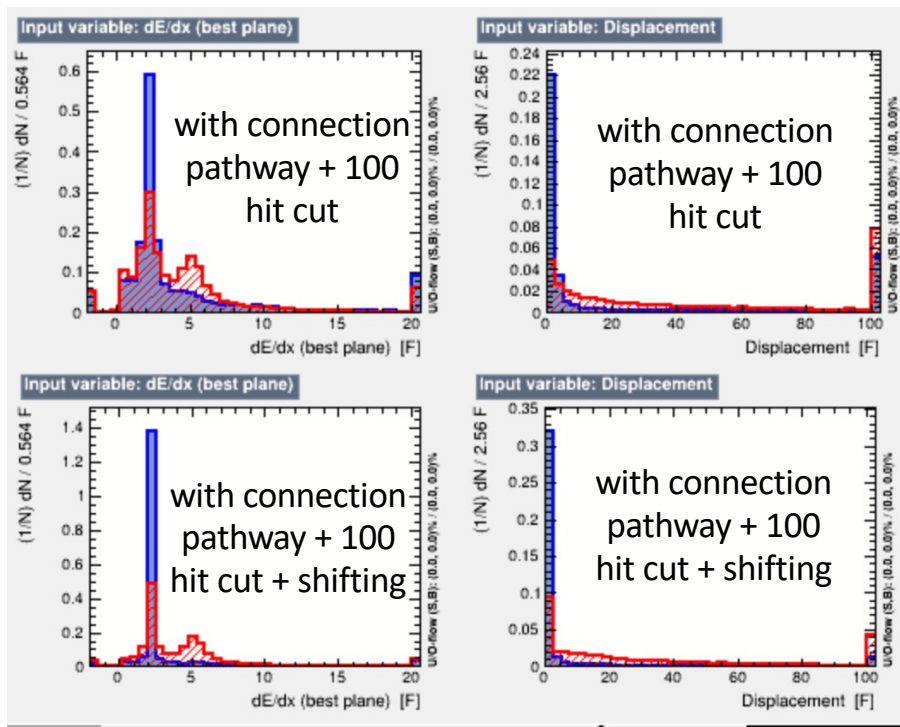
Pandora CP Violation Sensitivity (no stats/systematics)



Electron-like BDT + 100 Hit Cut + Shift BDT Variables

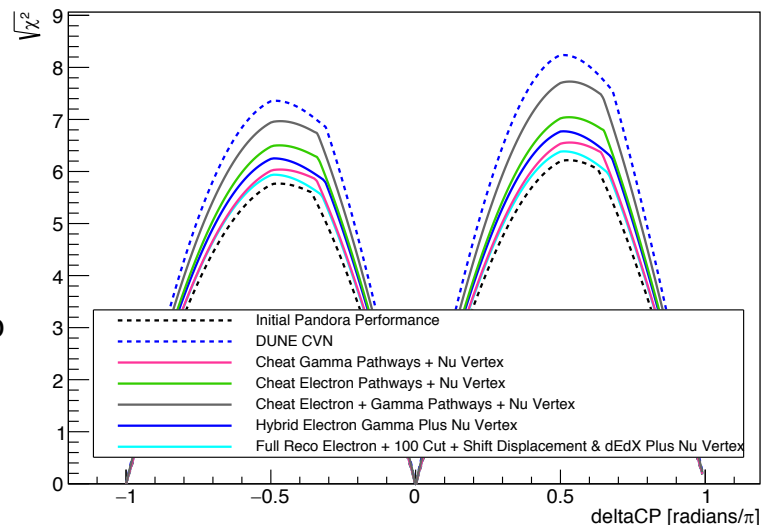
17

- And what if we say 'if the connection pathway was deemed to be electron in origin lets set its dedx to an electron-like value and its displacement from the neutrino vertex to be zero
- Apply this in selection and training (this has been understood to give potentially giant gains)



I think this
doesn't work
too well
because the
BDT cut is too
low

Pandora CP Violation Sensitivity (no stats/systematics)

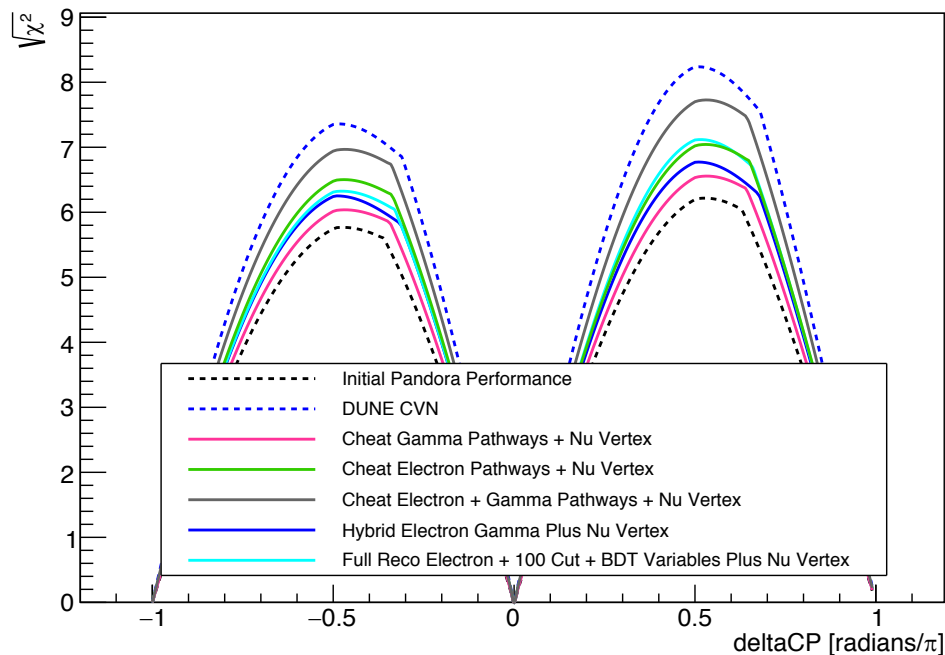


this does demonstrate just how much the algorithm is
doing, so if we can get the tuning right...

Electron-like BDT + 100 Hit Cut + Pathway BDT Variables

- What if we merge the two BDTs?

Pandora CP Violation Sensitivity (no stats/systematics)



This is very, very, very good!!!

I think if we can tune the connection pathway BDT well then we can drag out even further improvements!

Conclusion



- Shown how a CP violation analysis can motivate the reconstruction
- A shower refinement algorithm has been presented as a full cheated algorithm, hybrid reconstruction algorithm and full reconstruction algorithm
- Achieved sensitivity improvements have been demonstrated with lots of options explored
- Now I need to work on tuning the connection pathway BDT and settle on how it should be utilised to achieve the best improvements

Conclusion

- Still a lot of work to do!

BACKUP

Is this a nue event?

Pandizzle → muons
Pandrizzle → electrons

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Reject if the **reconstructed** neutrino vertex is outside the DUNE fiducial volume



Assign all showers **pandrizzle** scores, choosing the **pandrizzliest** shower to be the electron candidate



Reject event if the candidate electron pandrizzle score falls **below** a cut value

To increase purity, remove numu background

Assign all tracks **pandizzle** scores, choosing the **pandizzliest** track to be the muon candidate



Reject event if the candidate muon pandizzle score falls **above** a cut value

Tune pandrizzle cuts such that the **deltaCP sensitivity coverage** is optimised

Is this a numu event?

Reject if the **reconstructed** neutrino vertex is outside the DUNE fiducial volume



Assign all tracks **pandizzle** scores, choosing the **pandizzliest** track to be the muon candidate

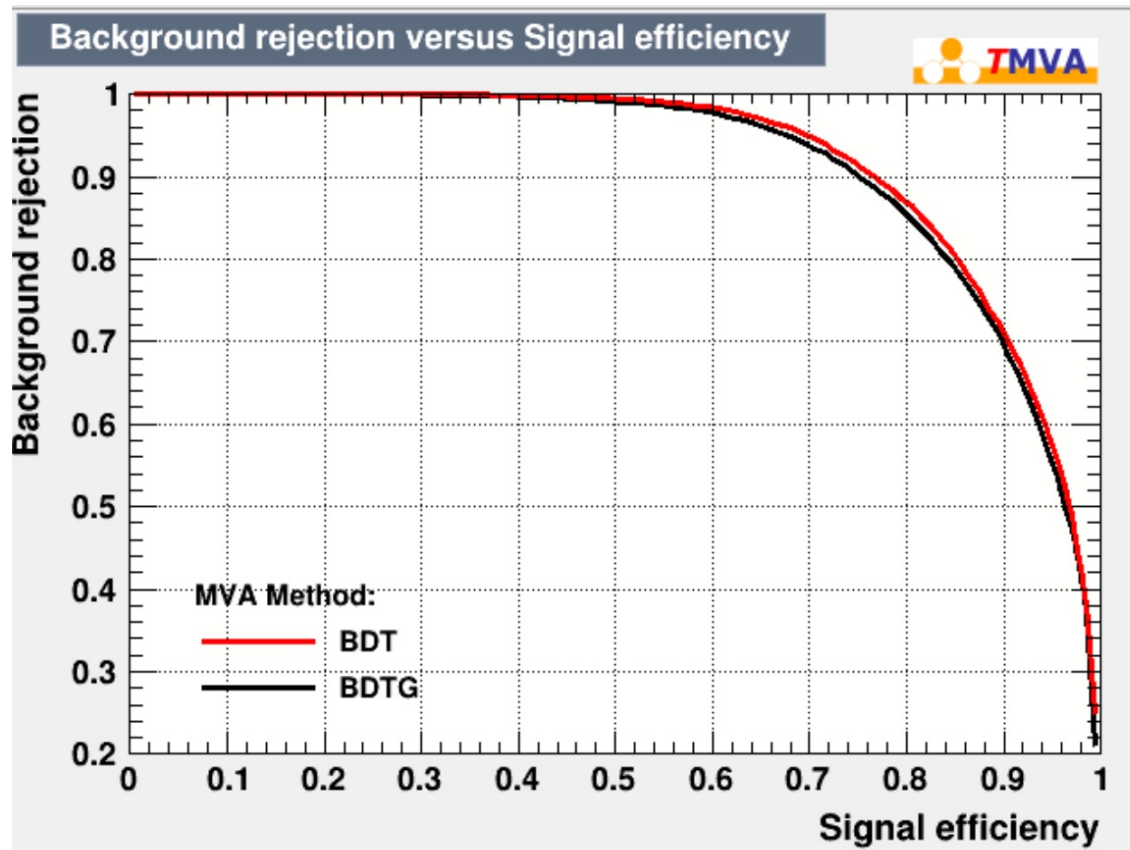


Reject event if the candidate muon pandizzle score falls **below** a cut value

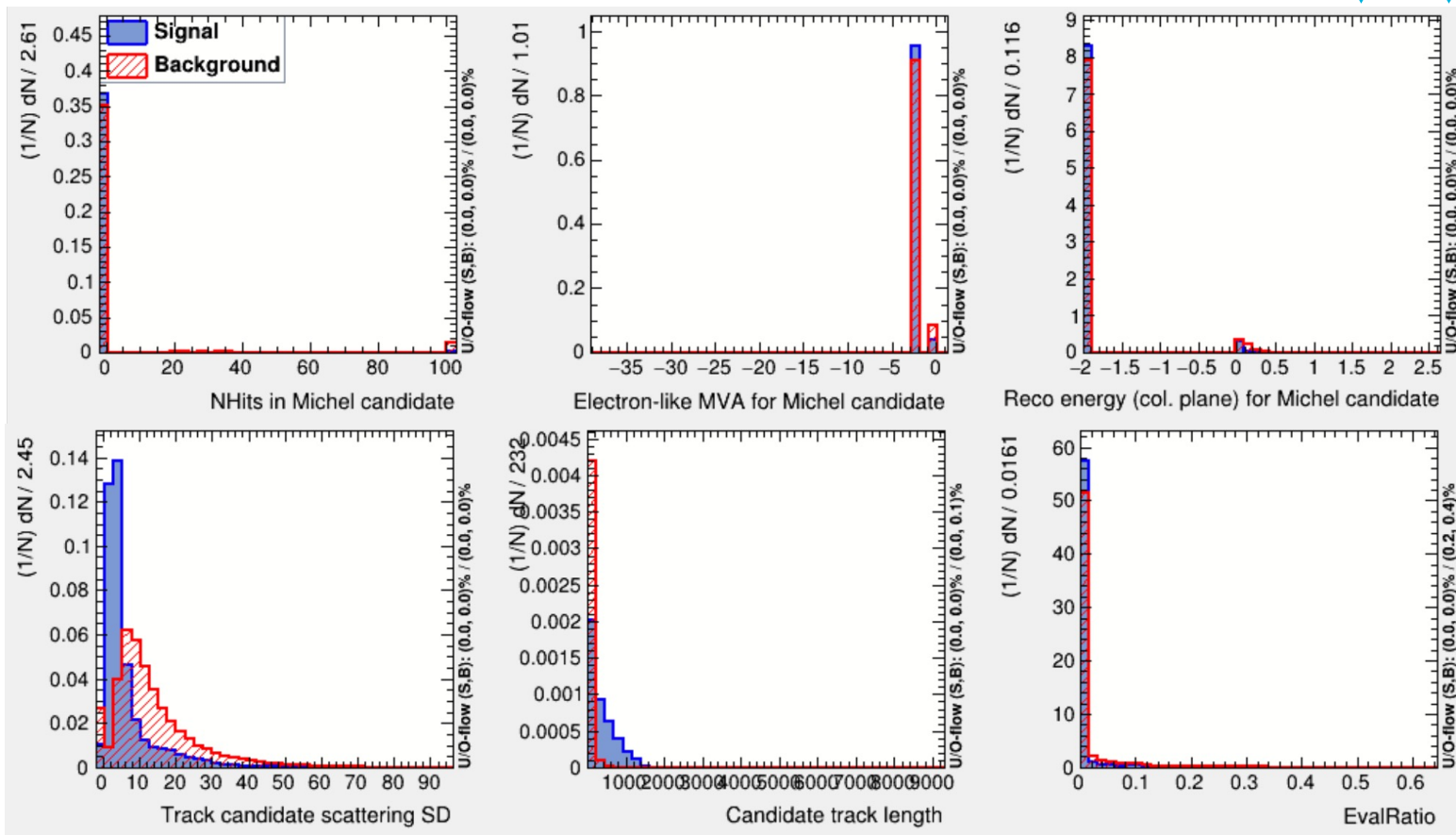
Pandizzle → **muons**
Pandrizzle → **electrons**

Tune cuts such that the selection **efficiency** * **purity** is optimised

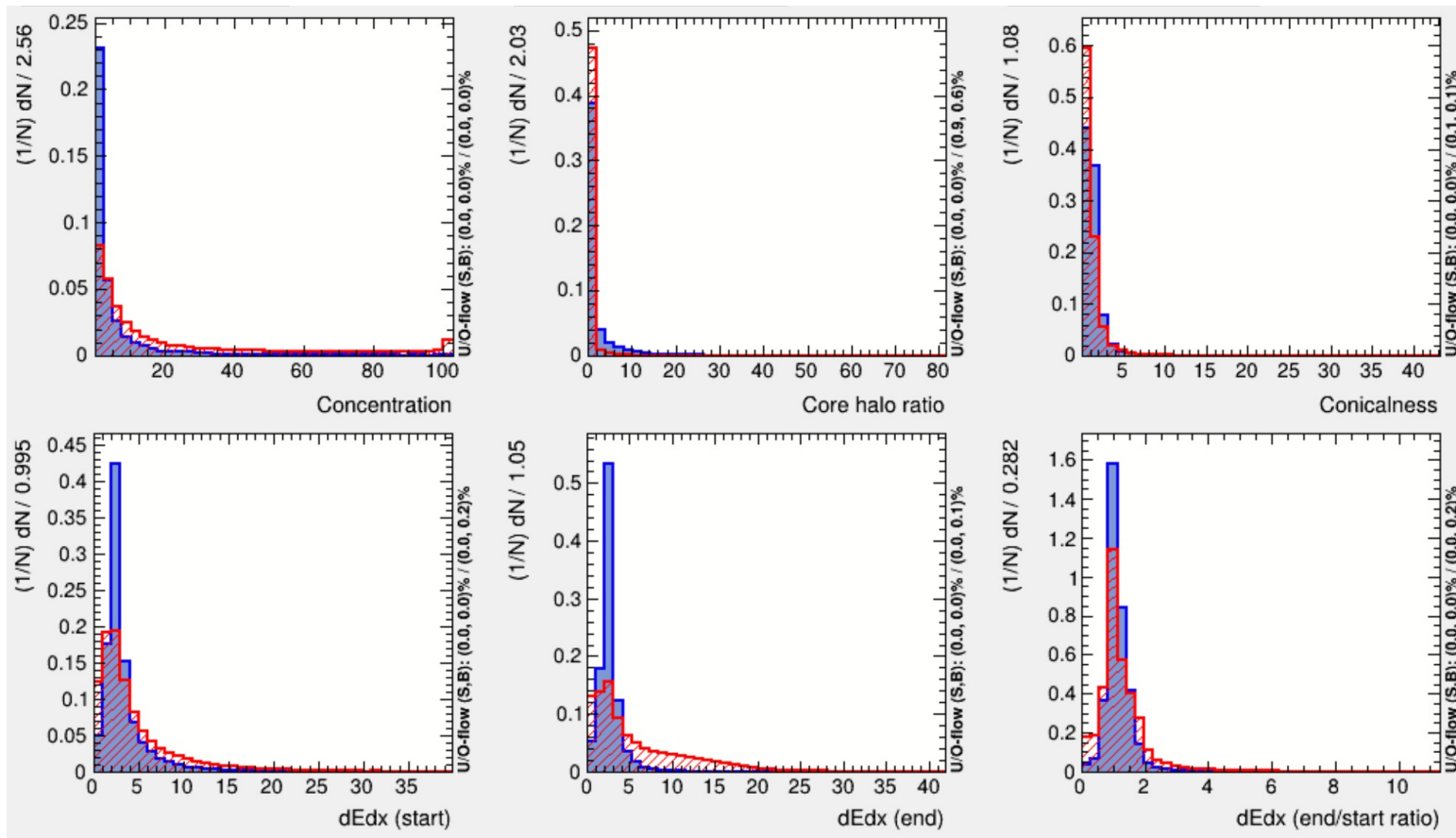
Pandizzle: ROC Curve



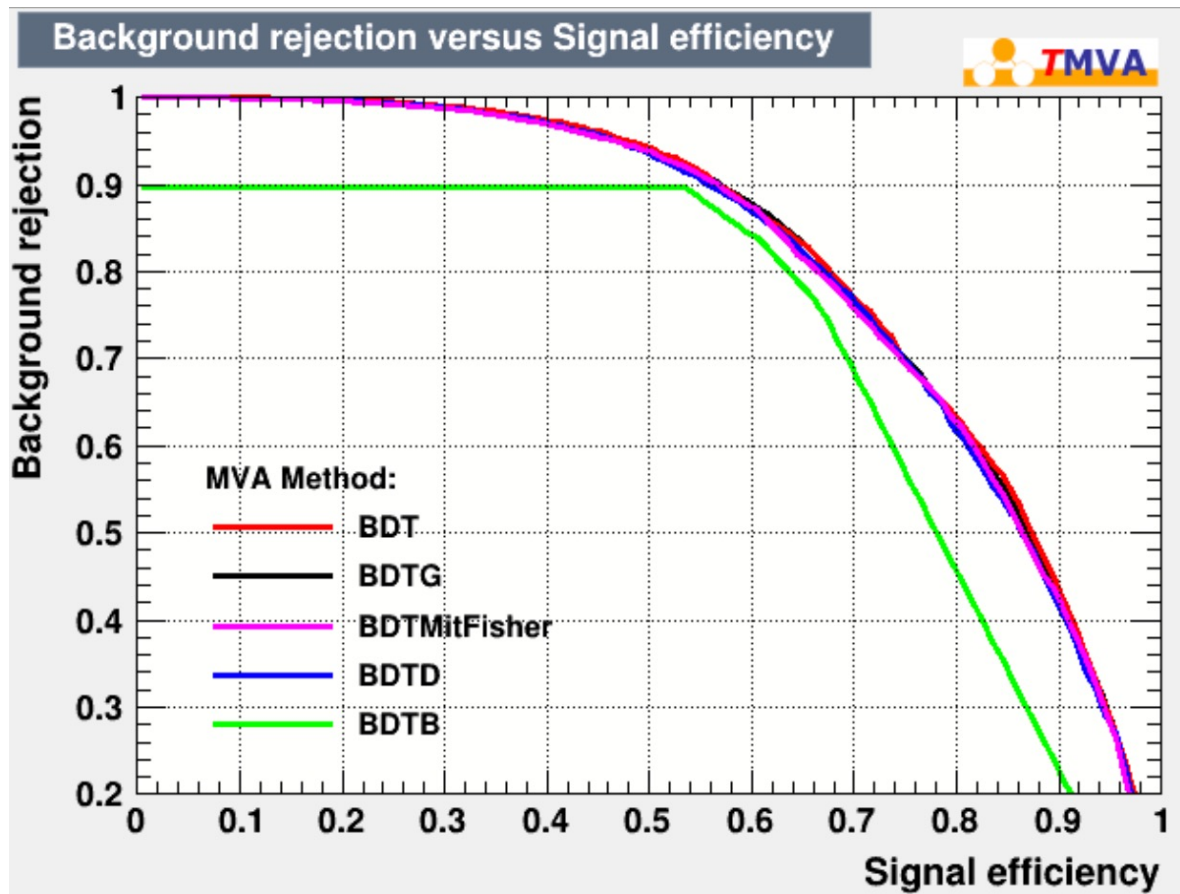
Pandizzle: Input Variables (1)



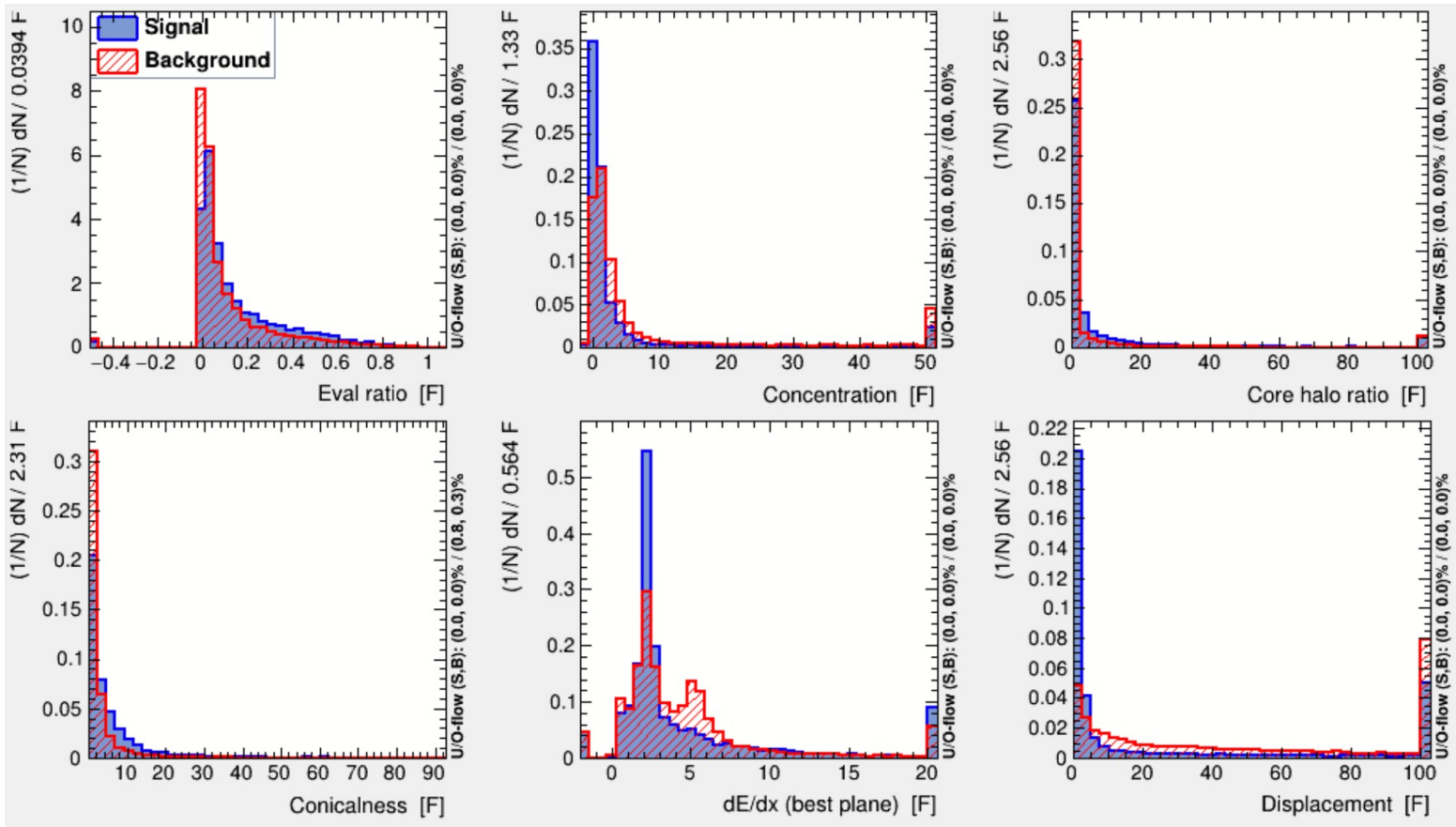
Pandizzle: Input Variables (2)



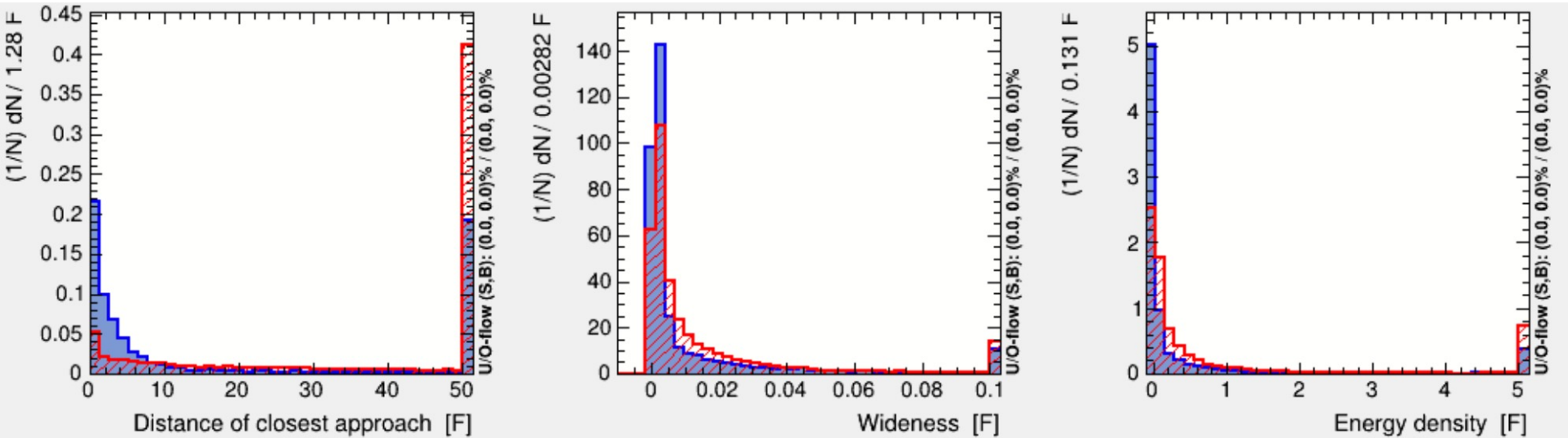
Pandrizzle: ROC Curve



Pandrizzle: Input Variables (1)

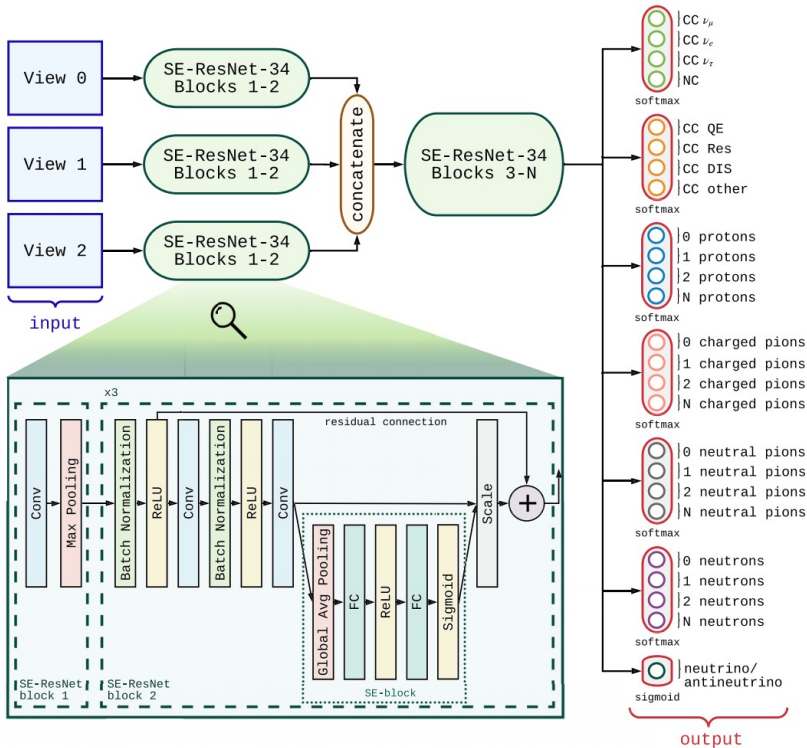


Pandrizzle: Input Variables (2)



DUNE CVN

- Details documented in <https://journals.aps.org/prd/pdf/10.1103/PhysRevD.102.092003>



- The DUNE CVN is a **convolutional neural network**
- Has access to the **whole** image
- For (a)nue selection: $P(\text{nue}) > 0.85$
- For (a)numu selection: $P(\text{numu}) > 0.5$

Tuning the nue cuts

- A 2D histogram is filled with the pandizzle and pandrizzle scores of all events with a reconstructed inside the DUNE fiducial volume
- Apply a test pandizzle and pandrizzle cut position to obtain the selection sample at all deltaCP values and consequently the corresponding deltaCP sensitivity plot
- Investigate the entire pandizzle-pandrizzle phase space, choosing the cuts that optimise the **deltaCP sensitivity coverage**

