Analysis-Driven Reconstruction Optimisation: CPV Searches

DEEP UNDERGROUND NEUTRINO EXPERIMENT

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A Pandora CP-violation Analysis

My thesis analysis:

Optimisation of the Search for CP-symmetry Violation at the Deep Underground Neutrino Experiment

- Completed at the **University of Warwick**
  (with John Marshall, Andy Chappell and Maria Brigida Brunetti)

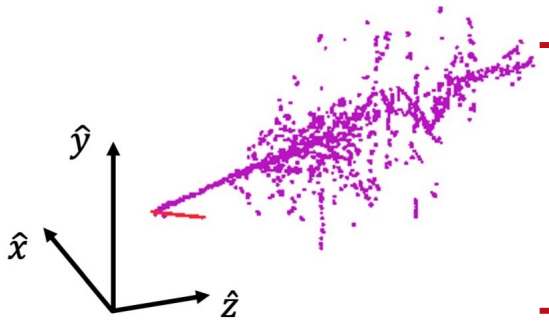
- Example of the broader **reconstruction → analysis continuum** approach taken by the Pandora team

Reconstruction ⟷ **Analysis**

- Helps us to identify (and make) the reconstruction improvements that **matter** to physics analyses

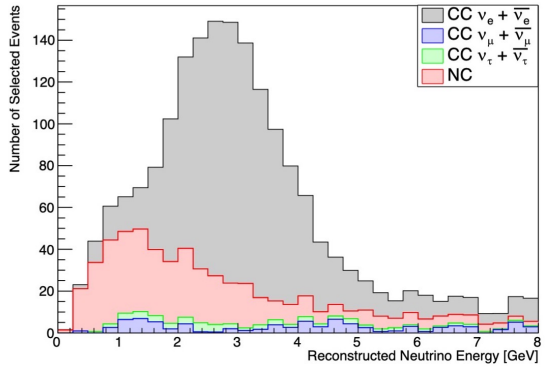
A Pandora CP-violation Analysis

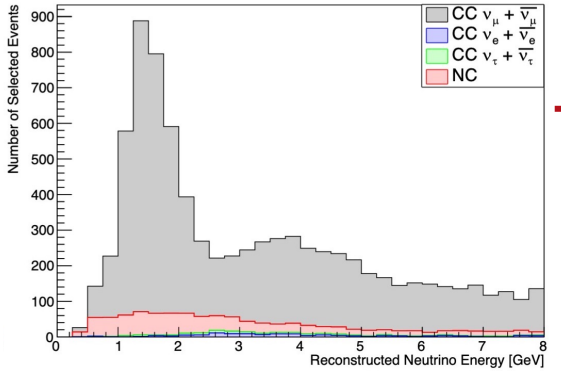
Pandora Pattern Recognition → Particle Characterisation → ν_e/ν_μ Selection → Neutrino Energy Estimation → CP-Violation Sensitivities

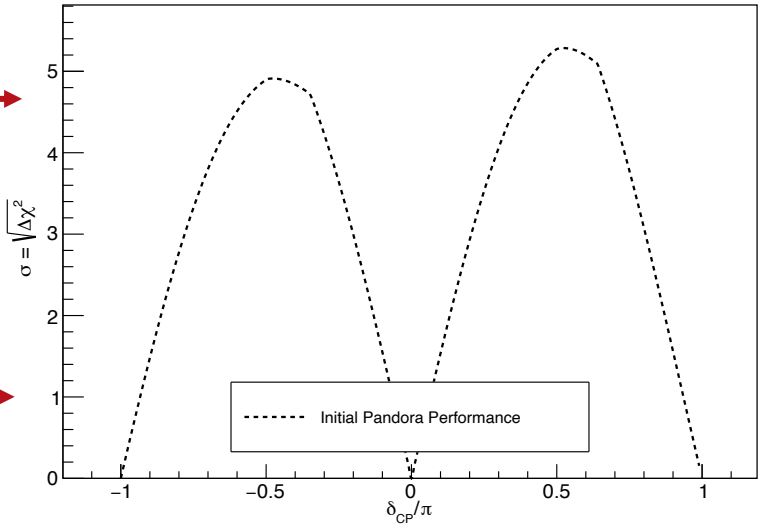


Is ν_e selected?

Is ν_μ selected?



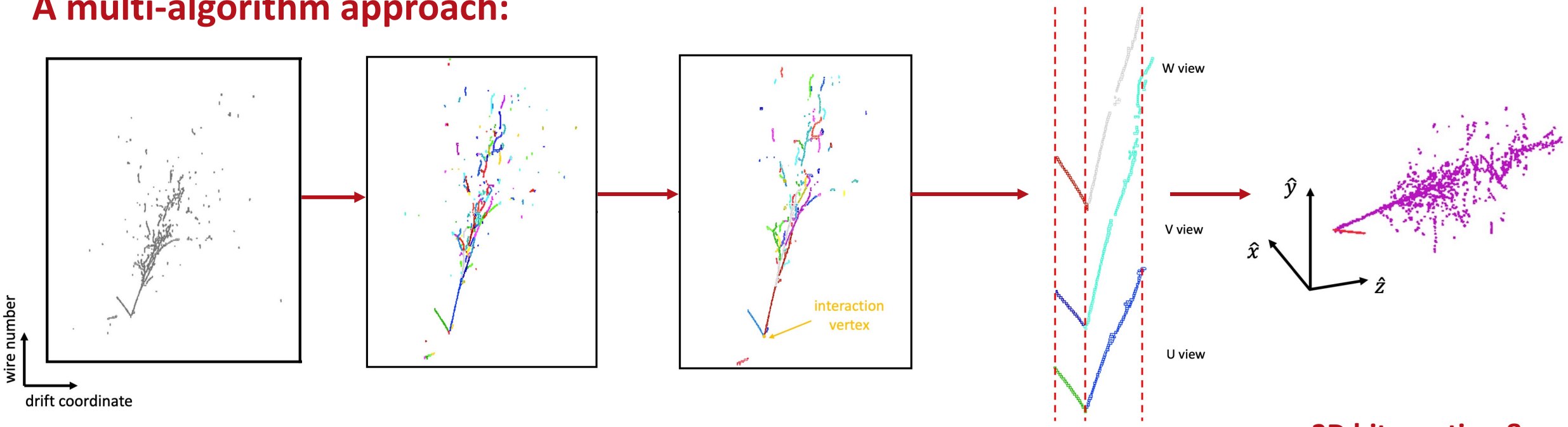




Pandora

Pandora Pattern Recognition → Particle Characterisation → ν_e/ν_μ Selection → Neutrino Energy Estimation → CP-Violation Sensitivities

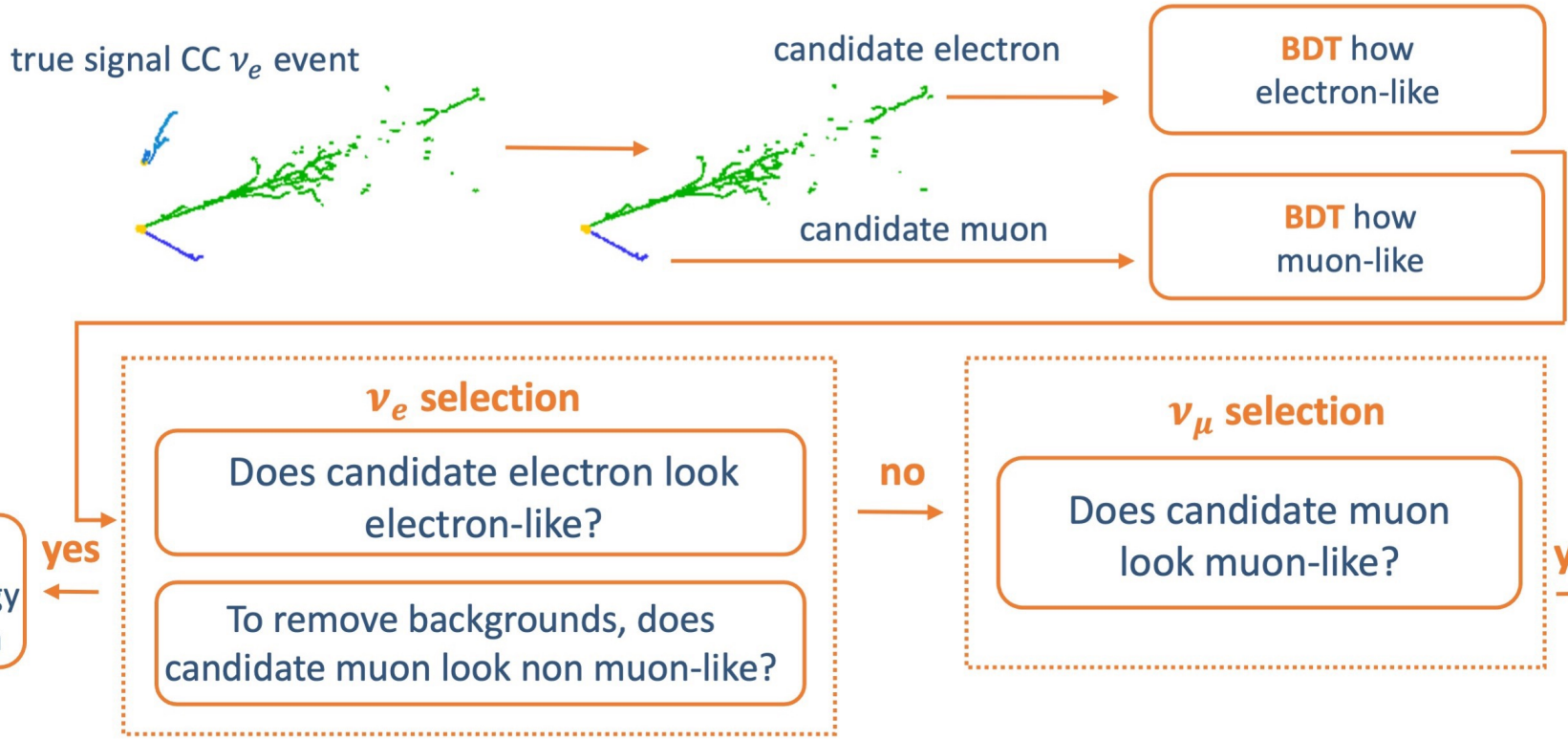
A multi-algorithm approach:



input 2D hits → 2D clustering → neutrino vertexing → 2D → 3D matching → 3D hit creation & hierarchy building

The ν_e/ν_μ Selection

Pandora Pattern Recognition → Particle Characterisation → **ν_e/ν_μ Selection** → Neutrino Energy Estimation → CP-Violation Sensitivities



Estimating DUNE's Sensitivity to CP-Violation

Pandora Pattern Recognition → Particle Characterisation → ν_e/ν_μ Selection → Neutrino Energy Estimation → **CP-Violation Sensitivities**

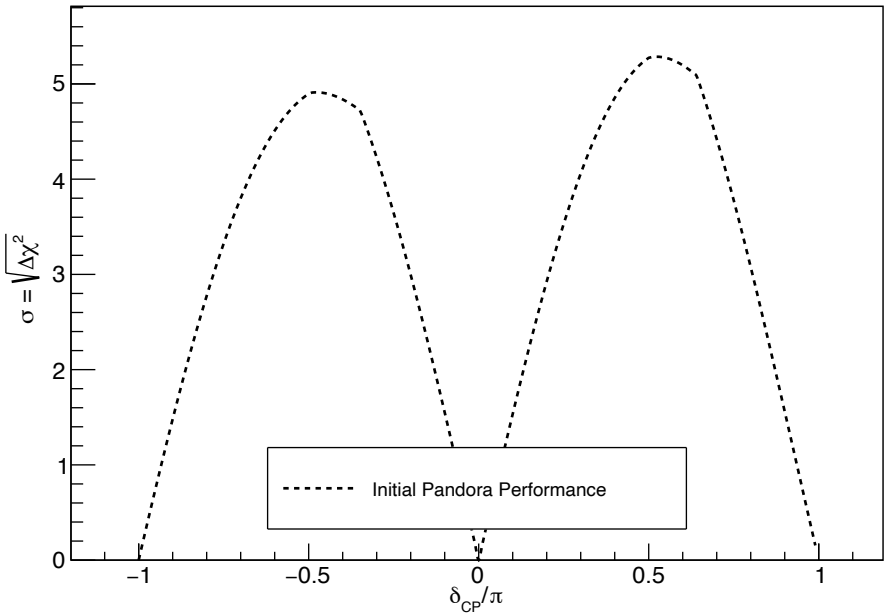
To **estimate** our sensitivity to CP-violation if $\delta_{CP} = x$:

1) **Simulate** the neutrino interactions that DUNE would see for $\delta_{CP} = x$

2) **Select** $\nu_e, \nu_\mu, \bar{\nu}_e, \bar{\nu}_\mu$ interactions and create **reconstructed energy spectra**

3) **Compare** to what we would **expect** if $\delta_{CP} = 0, \pi$ (CP-conservation)

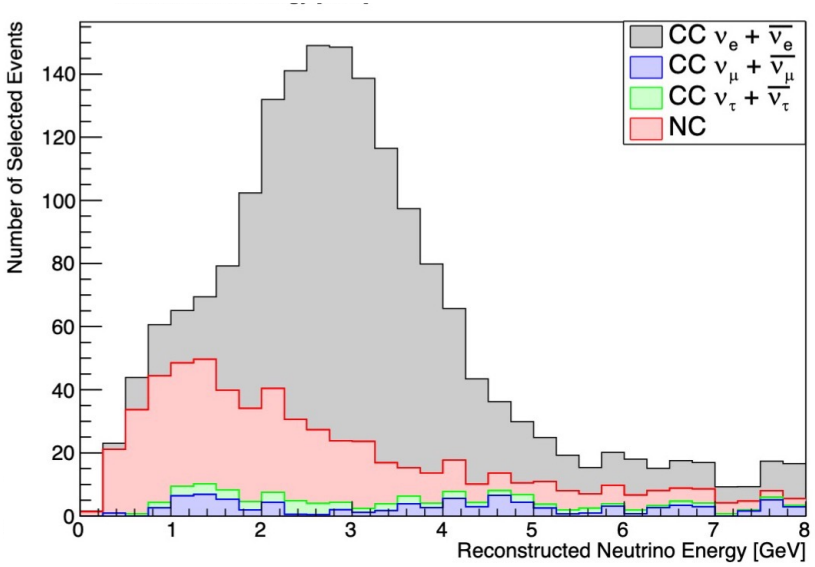
4) Compute the **confidence** to which CP-conservation can be rejected

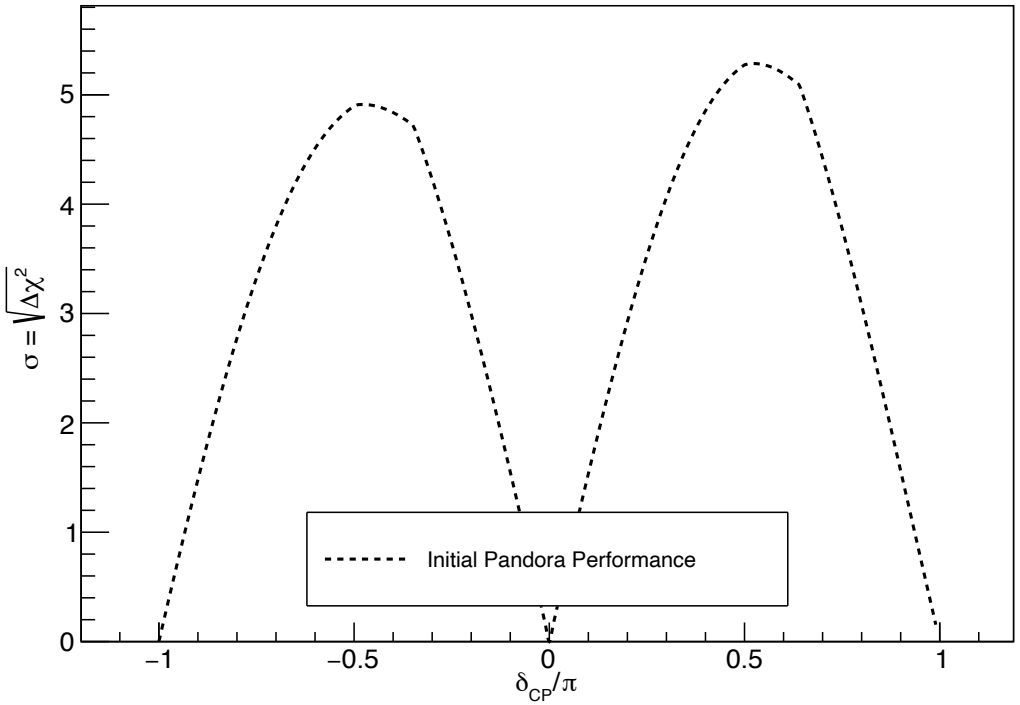


Initial Performance

ν_e Efficiency	ν_e Purity	Background Rejection
60.0%	67.1%	98.6%

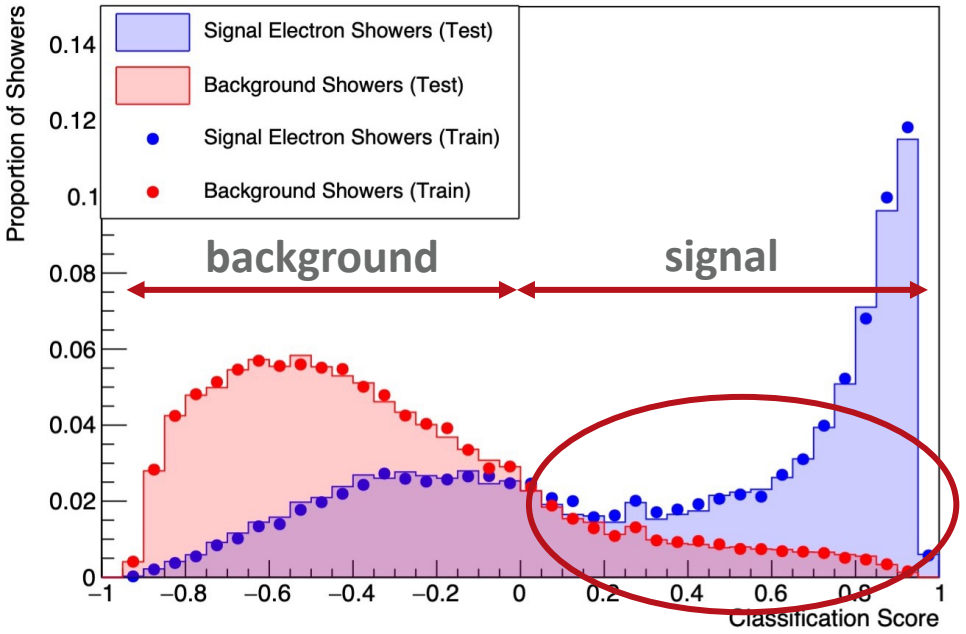
ν_μ Efficiency	ν_μ Purity	Background Rejection
88.3%	87.2%	94.4%

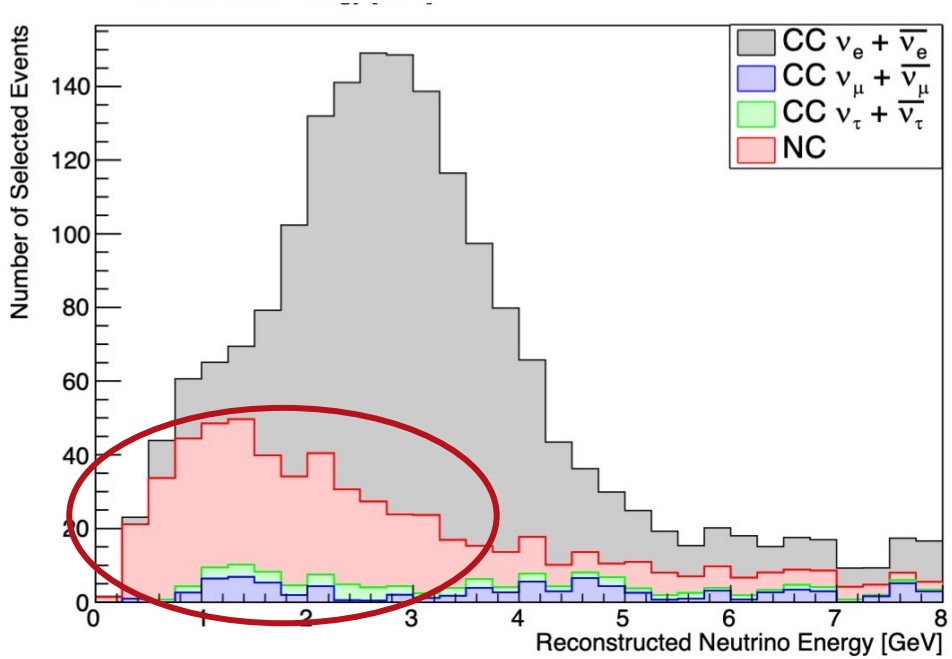




How can we improve this?

What's Limiting the Performance?

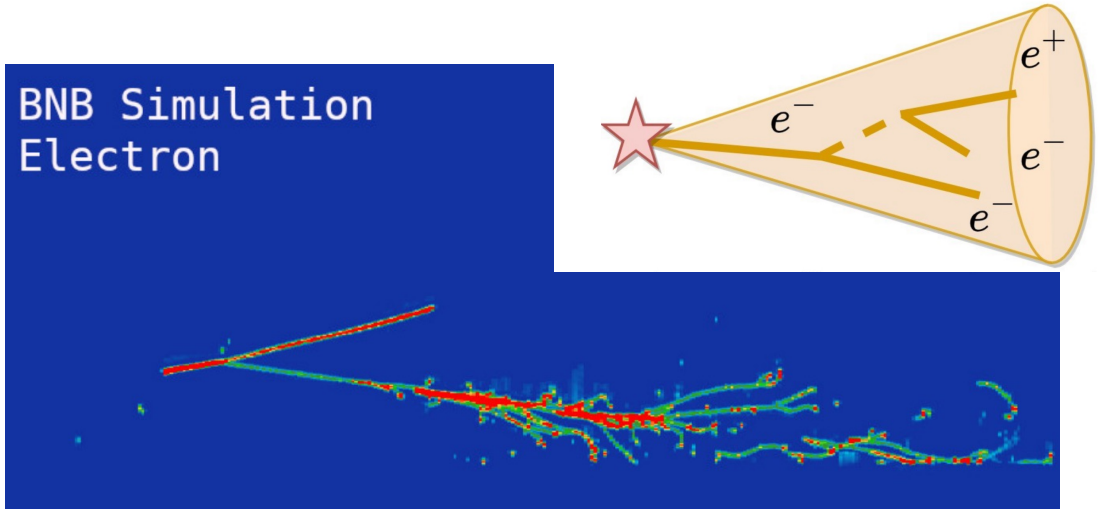


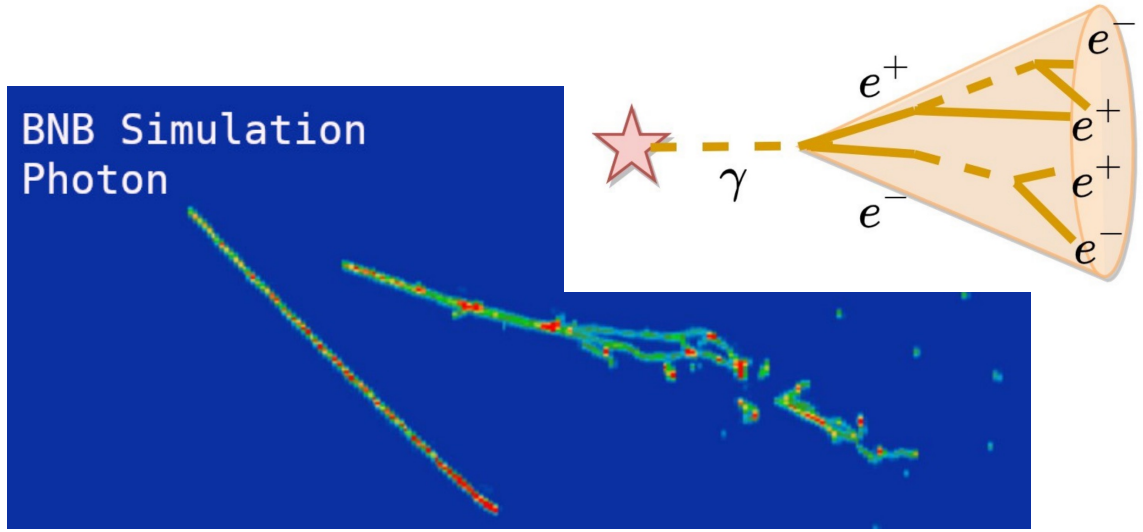


- **Electron/photon separation** in the electron-like BDT isn't the best…
- Broad signal classification distribution ⟹ limits **efficiency**
- Background contamination ⟹ NC events reduce significance of deviations

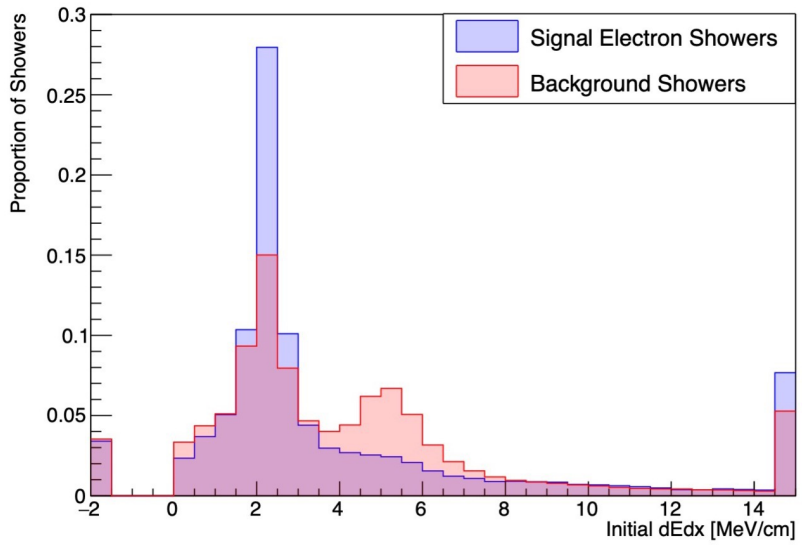
  ⟹ limits sensitivity

Electrons and Photons in LArTPCs





- Electron and photon-induced showers **look similar in LArTPCs**
- There are **two main differences:**
  - Photons are neutral ⟹ we will **see a gap**
  - Photon showers begin with a electron-positron pair ⟹ will have **twice the dE/dx** of an electron



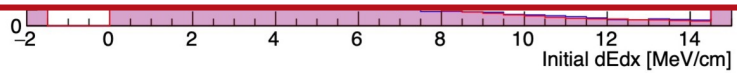
Electrons and Photons in LArTPCs

Thinking back to the reconstruction → analysis continuum…

Reconstruction ⟷ **Analysis**

To get the ‘gap’ and correct initial *dE*/*dx*…

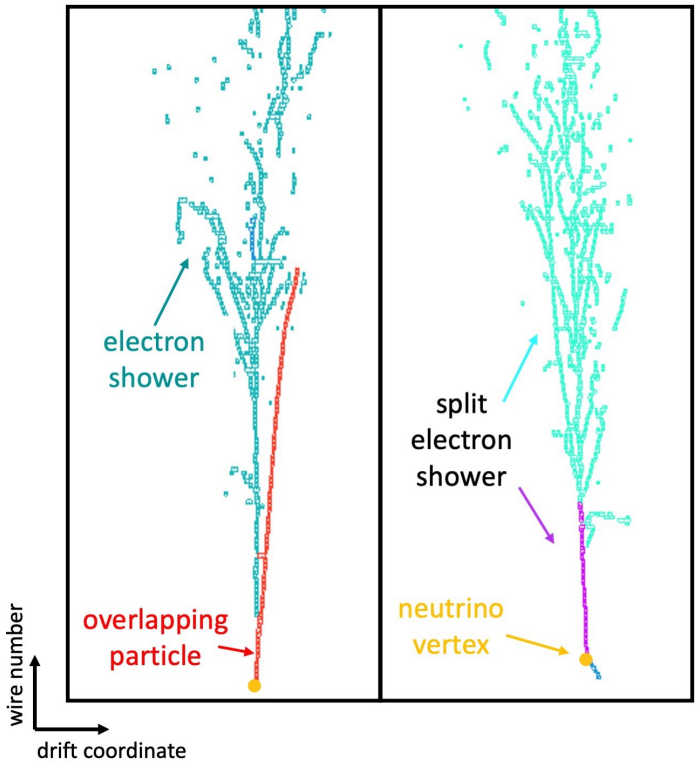
We need to be reconstructing the initial shower region correctly!



What's going wrong?

Electrons

1) Can overlap with other particles
2) **Can split at the point where the shower begins**

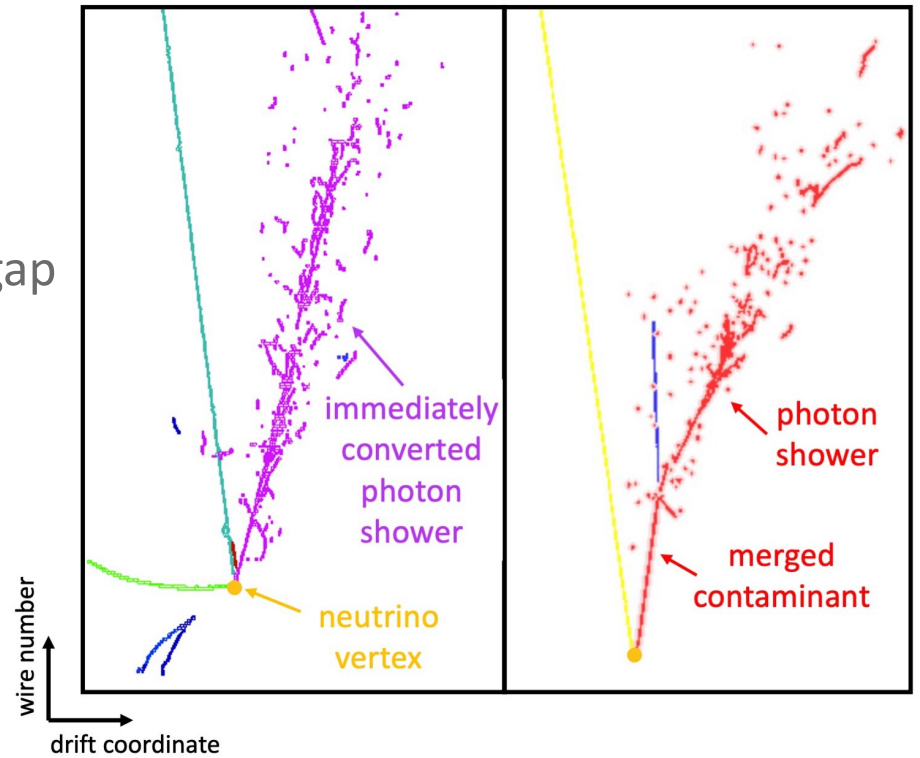


⟹ photon-like gap

⟹ high dE/dx

Photons

1) Can immediately convert
2) **Can merge in contaminants**

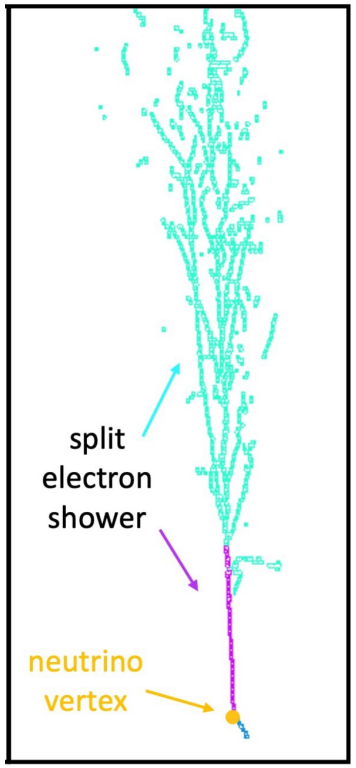


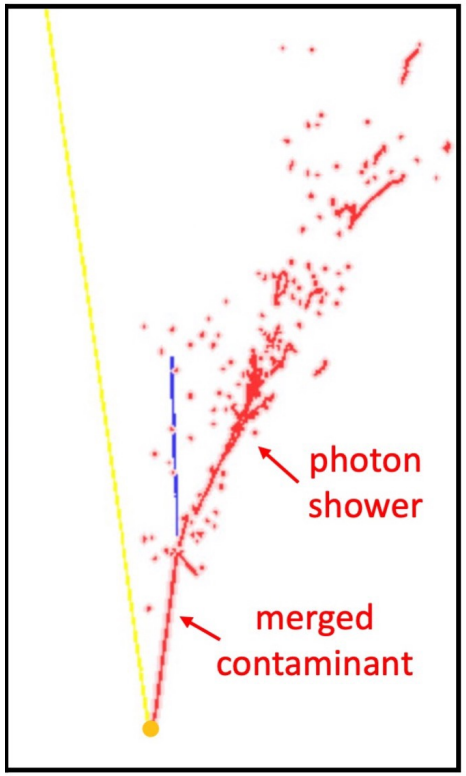
⟹ electron-like gap

⟹ incorrect dE/dx

Let’s fix it!

- The multi-algorithm approach allows one to develop **tailored algorithms** to solve specific problems





- I created an algorithm with the workflow:

Find the **connecting pathway** of the shower to the neutrino vertex

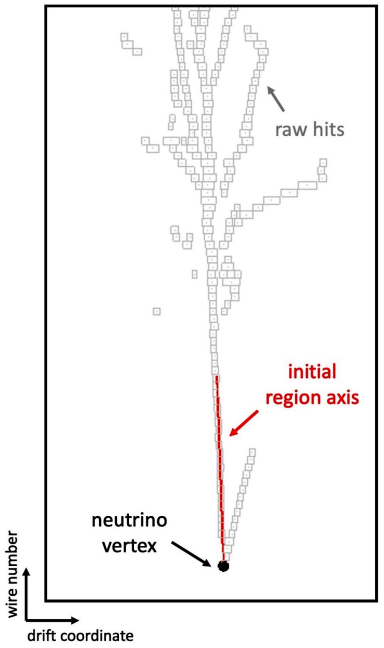
→ Decide whether the pathway belongs to the shower and is **electron-like**

yes → **Merge** the pathway

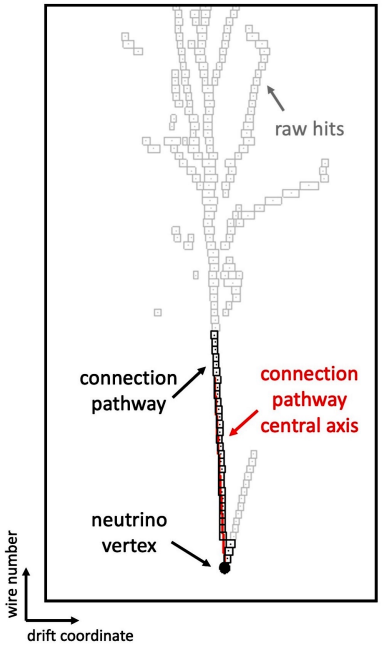
no → **Remove** the pathway

The Connection Pathway BDT

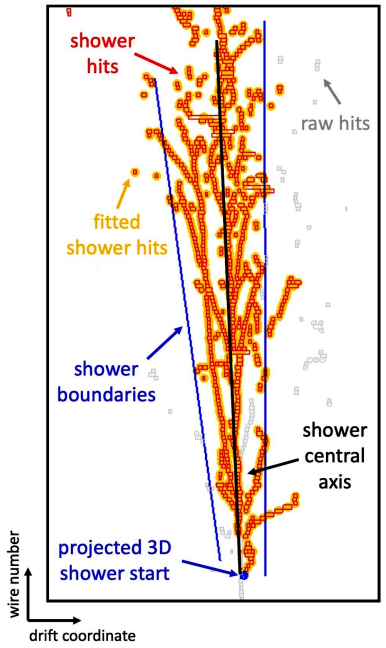
- Does a given connection pathway **'belong to the shower and is electron-like'?**



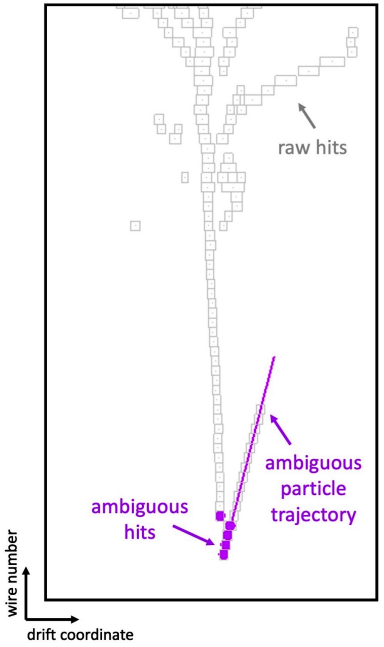
Initial region:
- Is there a gap?



Pathway region:
- Is it straight?
- Is it short?



Shower region:
- Does it look sensible?
- Does it look to come from the vertex?



Ambiguous region:
- Does the shower contribute to the energy of shared hits?

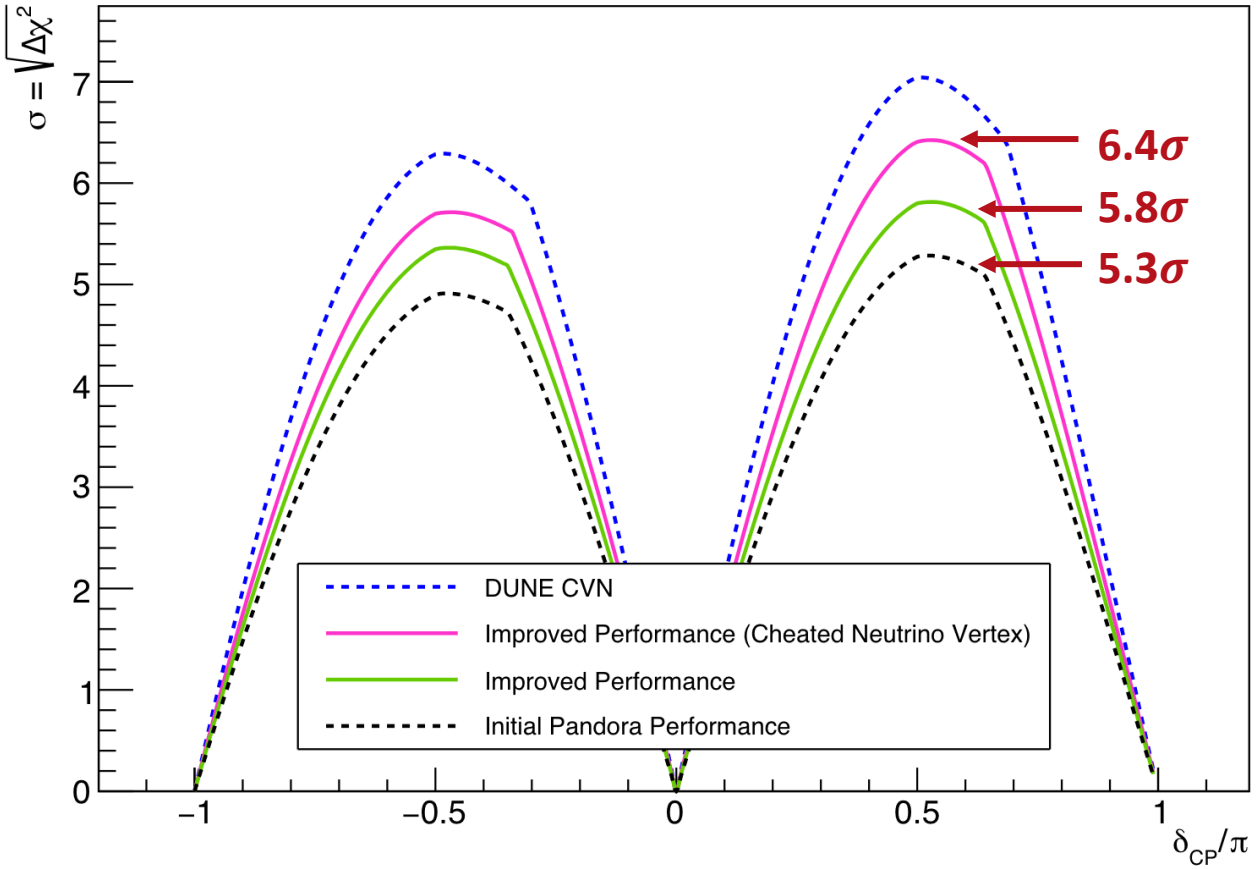
Results

- The **connection pathway BDT** gives us lots of information on whether the shower is an electron

  ⟹ add the connection pathway BDT variables to the electron-like BDT

- With the improved reconstruction and electron-like BDT we saw **substantial gains!!**

- Which can be furthered with a **better neutrino vertex placement**



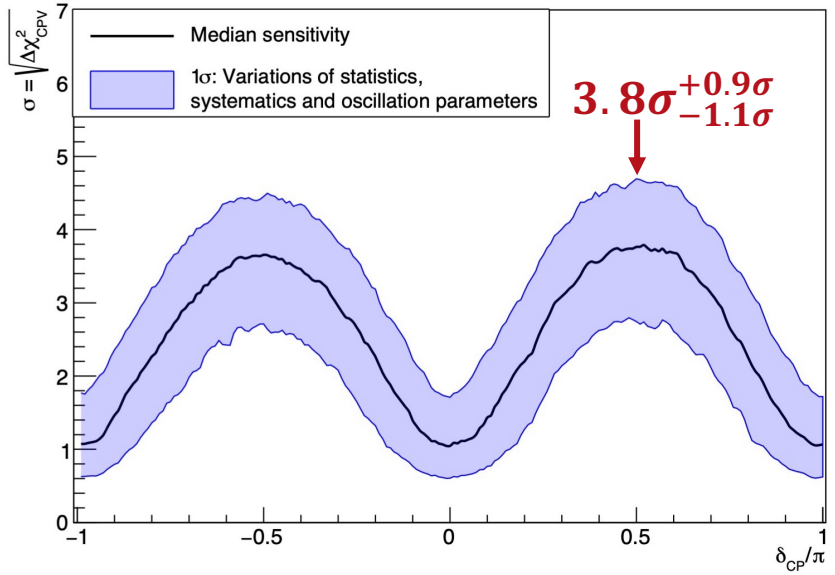
But wait... systematics?

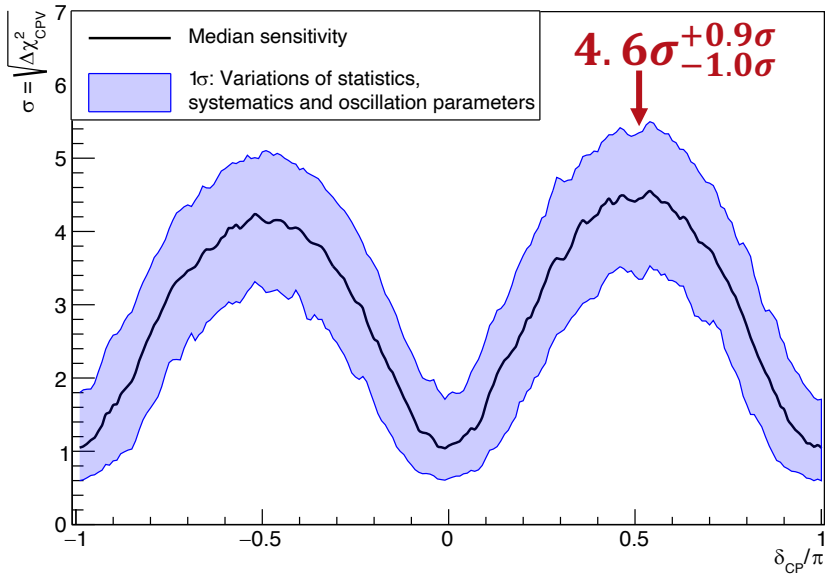
- Our sensitivity plots have used the MC simulation... but **what if it's wrong?** (it definitely is)
- **Flux, cross section and detector systematics** were implemented into our simulated data predictions and energy spectra fitting

  ⟹ Spread of universes result in a sensitivity band

  ⟹ Degenaracies reduce our sensitivity

- **My improvements survived!**





Conclusions and Future Work

- Determining **whether neutrino oscillations violate CP** is one of the future aims of neutrino physics
- I have created a **Pandora-based CP-violation analysis** at DUNE
- Have illustrated how we can **optimise the Pandora reconstruction** with respect to such an analysis
- Am now continuing this work (as a postdoc at Lancaster) with **Maria Brigida Brunetti (Warwick)**
  - Currently looking at the sensitivity gains achieved with recent Pandora developments
  - Plans to develop Maria Brigida's shower reclustering algorithm to the CPV analysis
  - Plans to overhaul the selection procedure i.e. machine-learning, including more event info etc..
  - More reconstruction developments…

Thank you for listening!