Pandora-based Sensitivity Studies

Isobel Mawby LBL WG Meeting 31/10/22

A Pandora CP-violation Analysis

The application of a Pandora-based nue/numu selection procedure to study CP-violation at DUNE

Pandora pattern recognition → Particle characterisation → Nue/numu selection → Neutrino energy estimation → CP-violation metrics

nue/numu Selection

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

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

true signal CC ν_e event

candidate electron

candidate muon

BDT* how electron-like

BDT* how muon-like

ν_e selection

Does candidate electron look electron-like?

To remove backgrounds, does candidate muon look non muon-like?

yes

Fill nue energy spectra

no

ν_μ selection

Does candidate muon look muon-like?

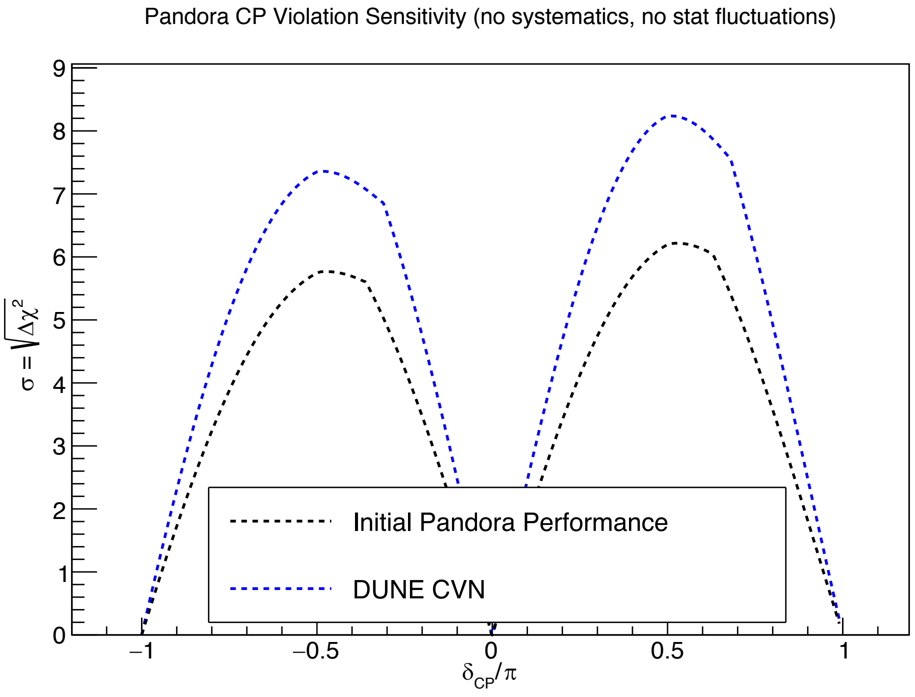
yes

Fill numu energy spectra

Initial Performance

Nue Efficiency	Nue Purity	Nue BG Rejection
60.0%	67.1%	98.6%

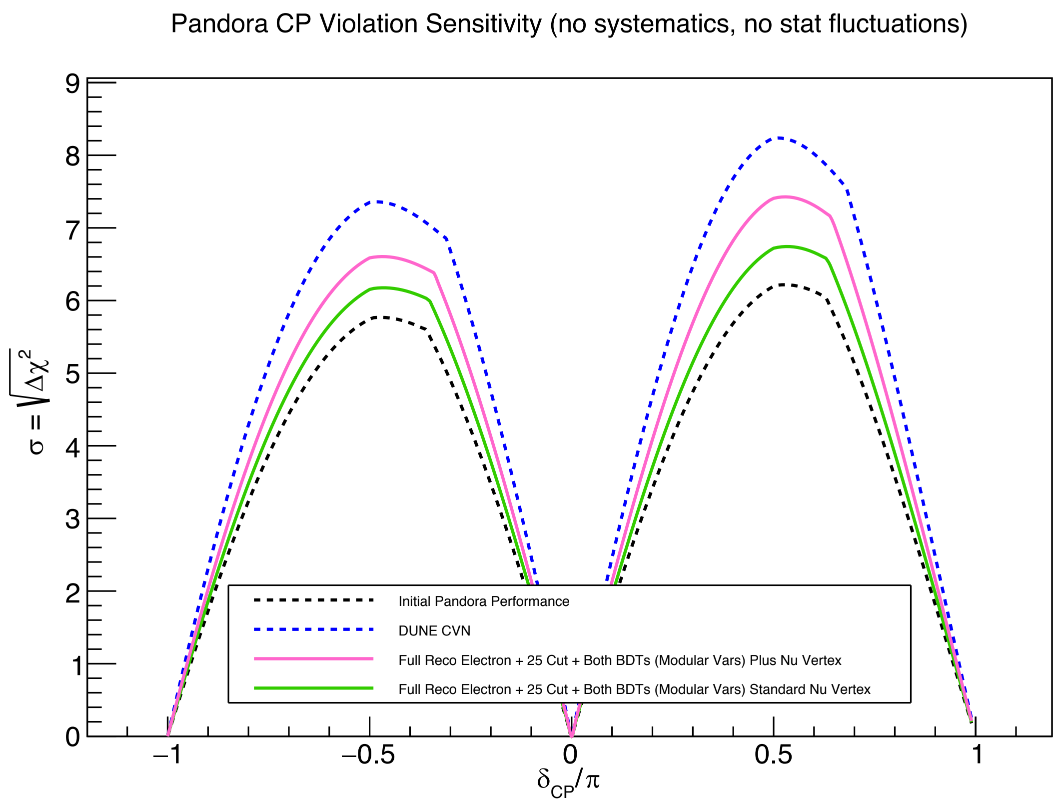
Numu Efficiency	Numu Purity	Numu BG Rejection
88.3%	87.2%	94.4%



Improved Performance

- I developed the Pandora reconstruction and the Pandora-based CP-violation analysis to improve **electron-photon separation**

- These improvements resulted in **substantial sensitivity gains!**



Validating Results

There are several limitations to these results:

1. The sensitivity is only understood in one ‘universe’, which assumes that there are **no oscillation parameter or systematic uncertainties**

   → This doesn’t tell you how the sensitivity might look if our MC model is wrong

2. Degeneracies are ignored

   → Not allowing any parameter variations so will always be able to assign a CP-violating signal to the CP-violating phase

NEED TO INCORPORATE OSCILLATION PARAMETER AND SYSTEMATIC UNCERTAINTIES!

Including Systematics

Three types of systematics to consider:

Detector/Energy	Cross Section	Flux

How does each systematic mimic CP-violation, if at all?

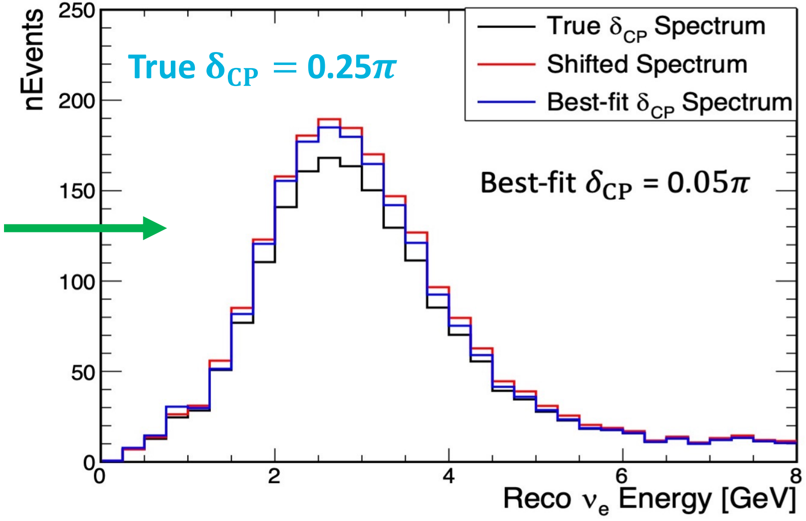
1. Create our 'special throw' fake data and then apply a thrown systematic shift
2. Investigate how well a fit, **that only allows δ_{CP} to vary,** can find the true CP-violating phase
3. Repeat
4. Do this for each value of the true CP-violating phase

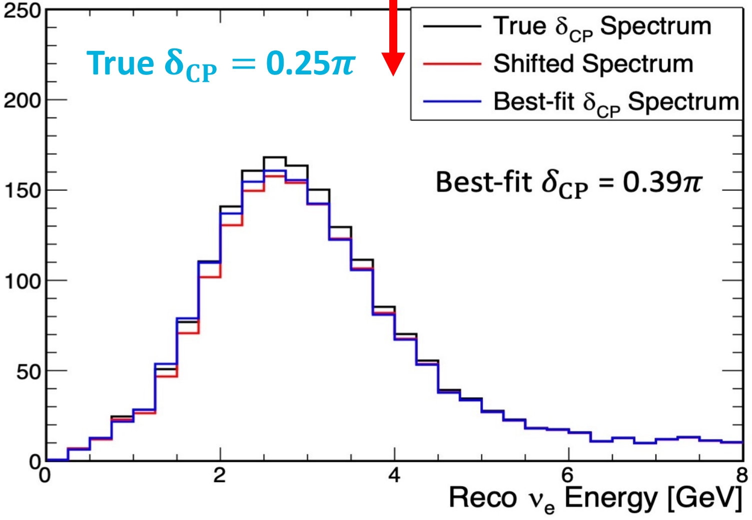
Flux Systematics

Focus on the **dominant** contributor to the sensitivity FHC ν_e:

negative shifts decrease the spectrum

positive shifts increase the spectrum



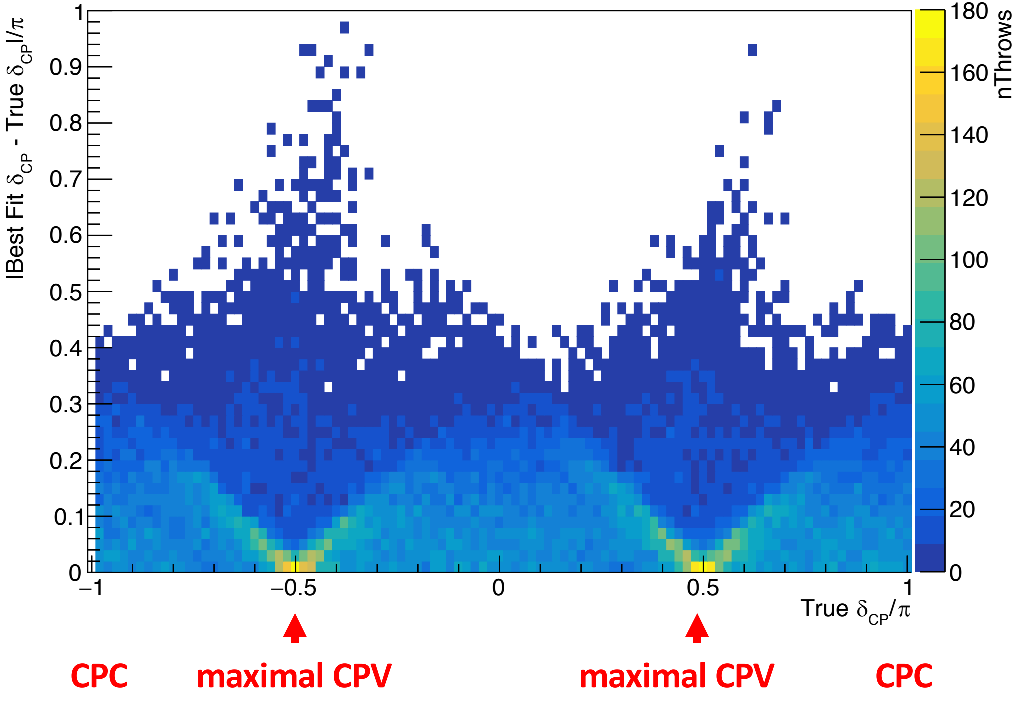


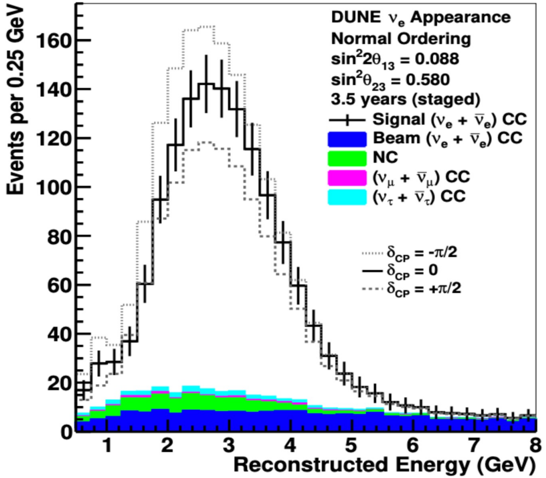
A **positive shift** pushes the best fit CP phase value closer to -$\pi/2$

A **negative shift** pushes the best fit CP phase closer to $\pi/2$

Results of Throws

But, the CPV spectra are bounded and this can result in interesting features in the accuracy plot…



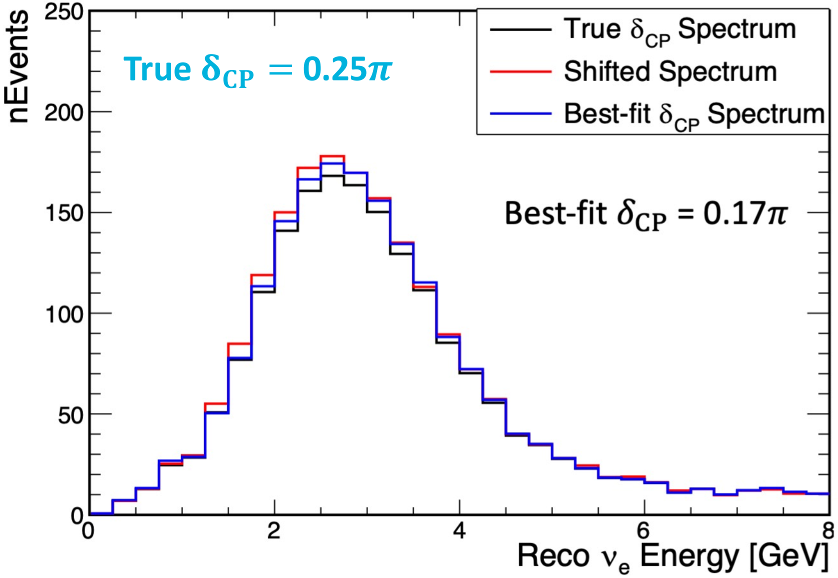


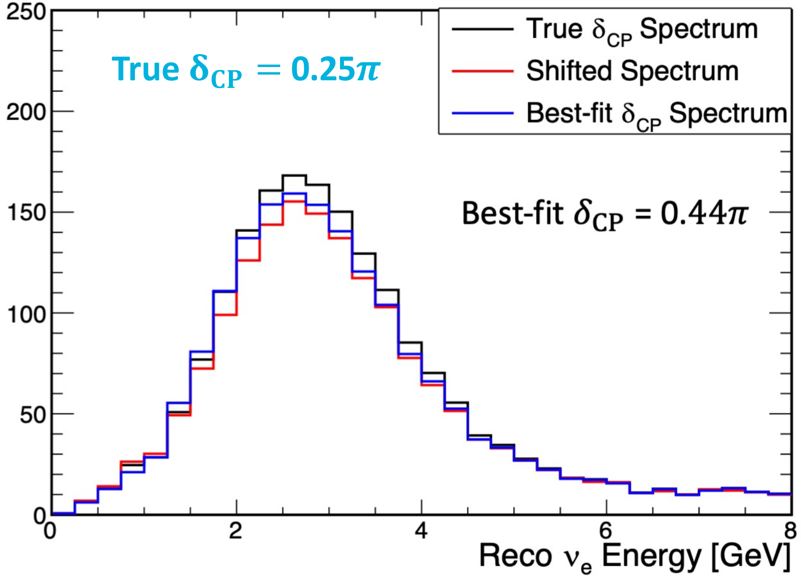
- For each CPV phase, systematic shifts will eventually push the spectra past the true CPV spectra bounds
- The resulting best fit points will be at the CPV maxima and the chi2 will be poor
- This is most prominent at maximal CPV

XSec Systematics

positive shifts increase the spectrum

negative shifts decrease the spectrum



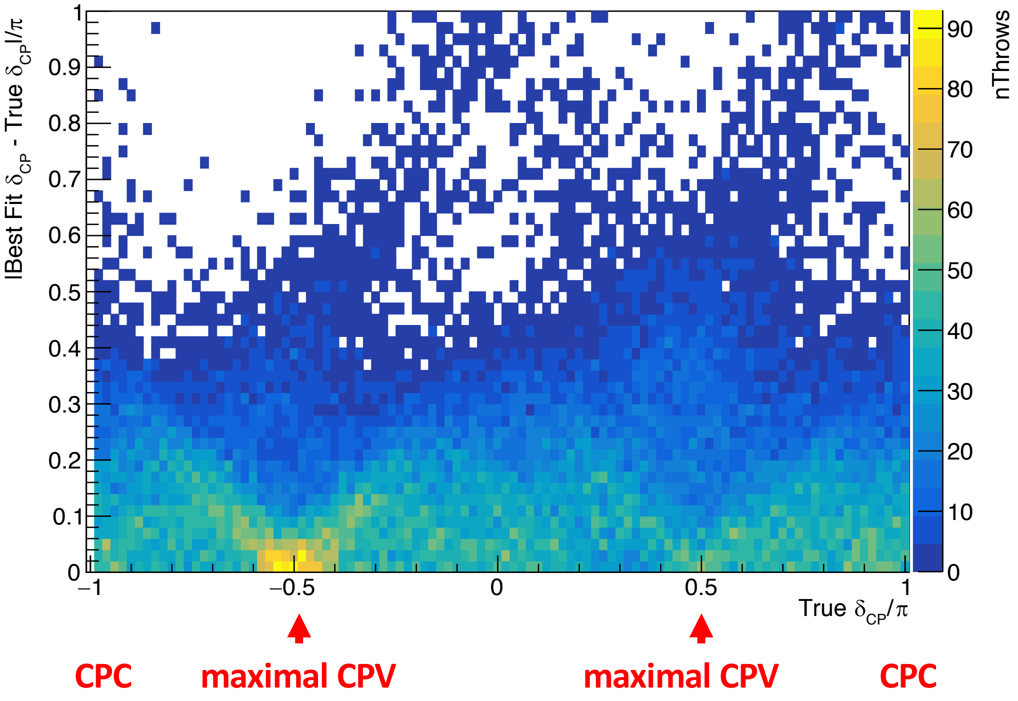


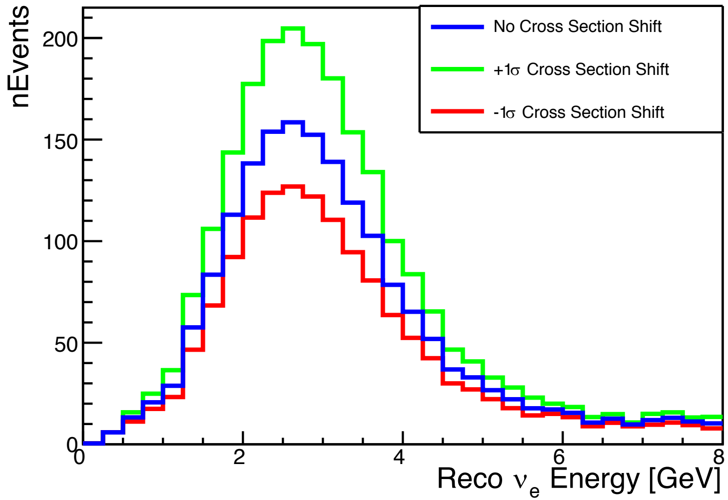
A **positive shift** pushes the best fit CP phase value closer to -$\pi/2$

A **negative shift** pushes the best fit CP phase closer to $\pi/2$

Results of Throws

Same behaviour as seen for the flux systematics…



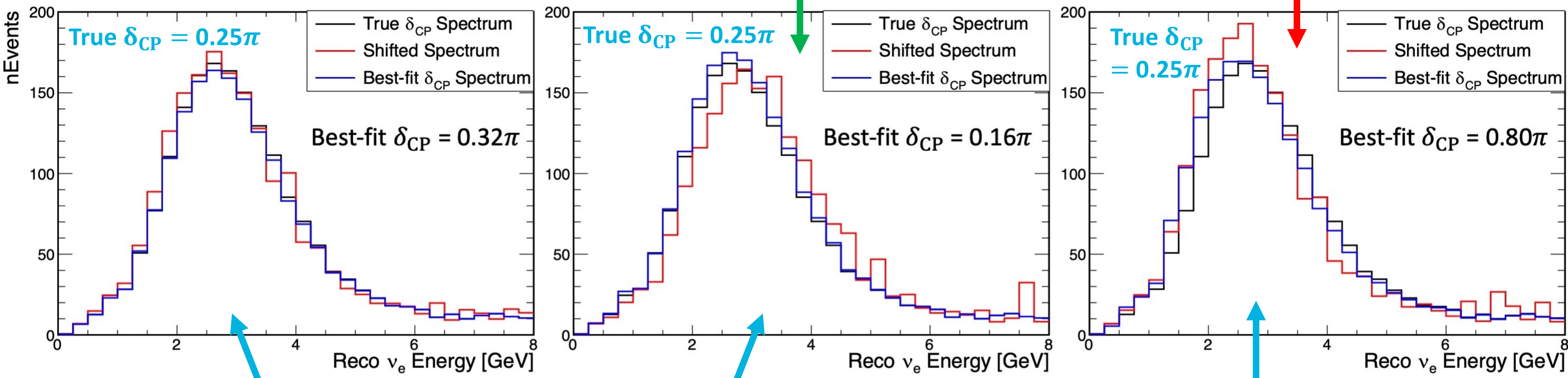


- Spread is **larger** than for flux shifts
- Boundary effect **only** seen at $-\pi/2$
- This is because the magnitude of the **positive shifts are larger** than those of the negative shifts

Energy Systematics

positive shifts move events to higher energies

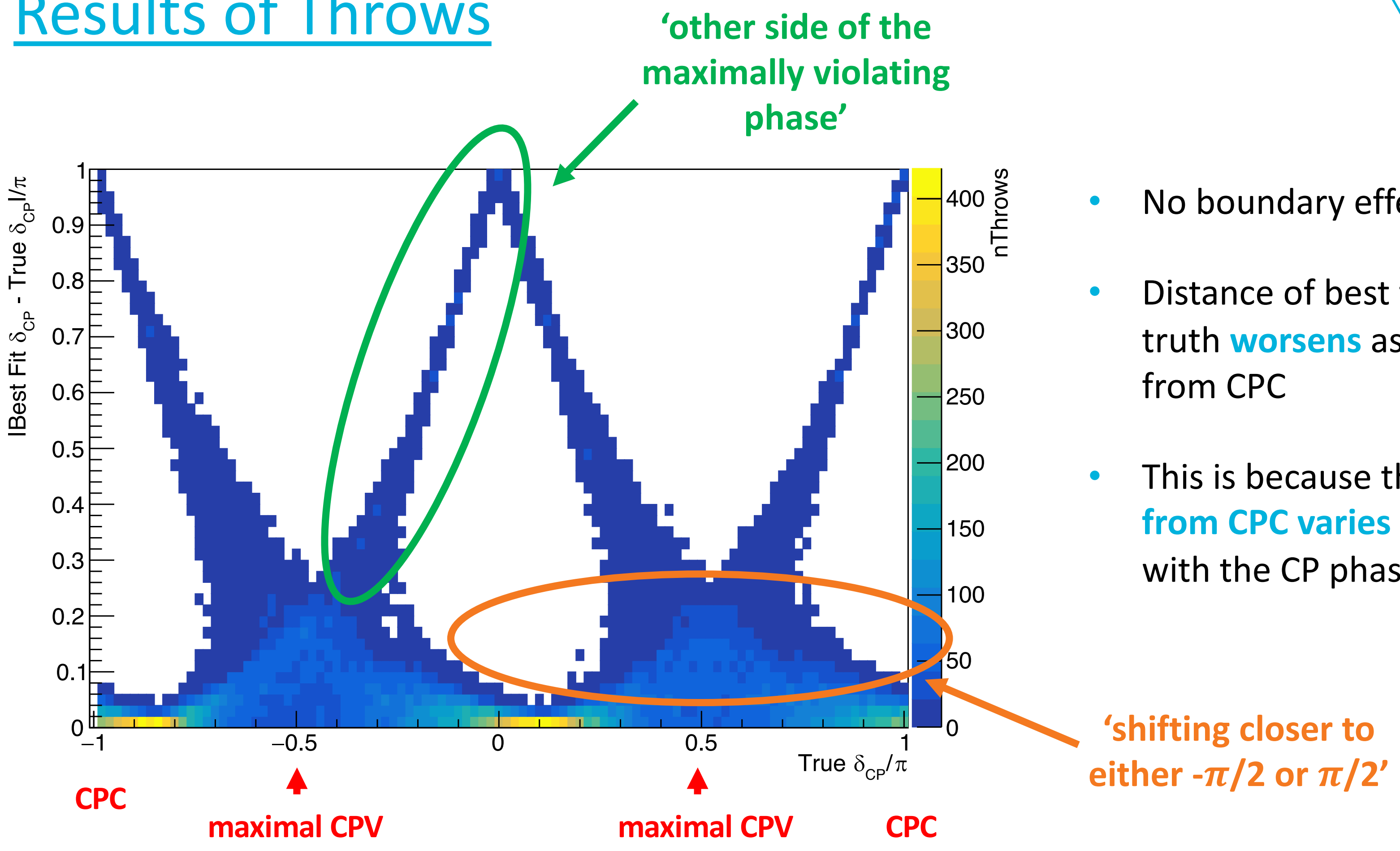
negative shifts move events to lower energies



Depending on the **side of the spectrum** that minimises the χ^2, a best fit CP phase value is found that is **either** closer -$\pi/2$ or $\pi/2$

For large shifts, a **degenerate** solution on the **other side** of the maximally violating peak can be found

Results of Throws



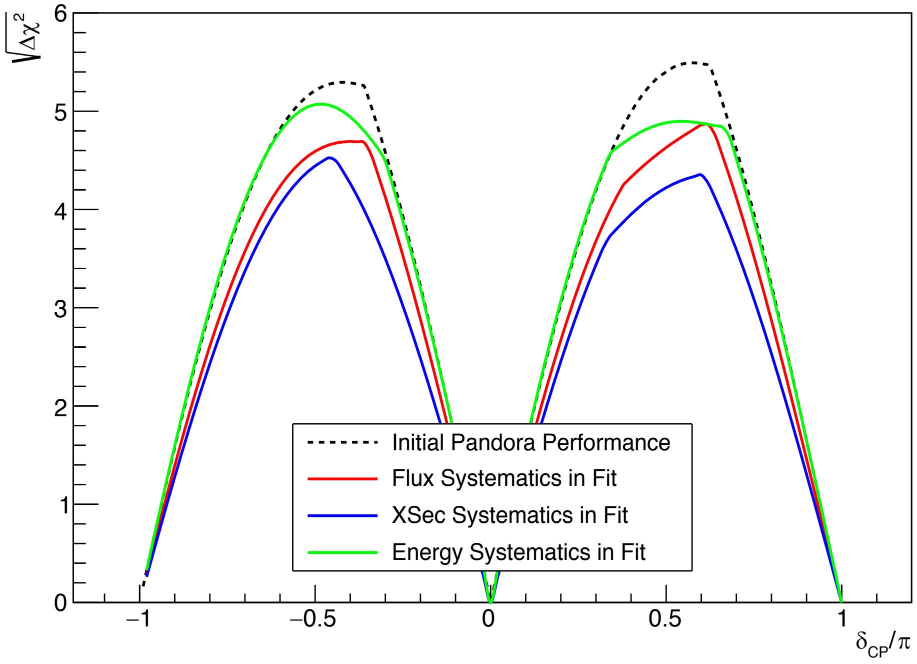
- No boundary effect seen
- Distance of best fit CP phase to truth **worsens** as we move **away** from CPC
- This is because the **deviation from CPC varies sinusoidally** with the CP phase

Affect of Systematics

We can make the following predictions:

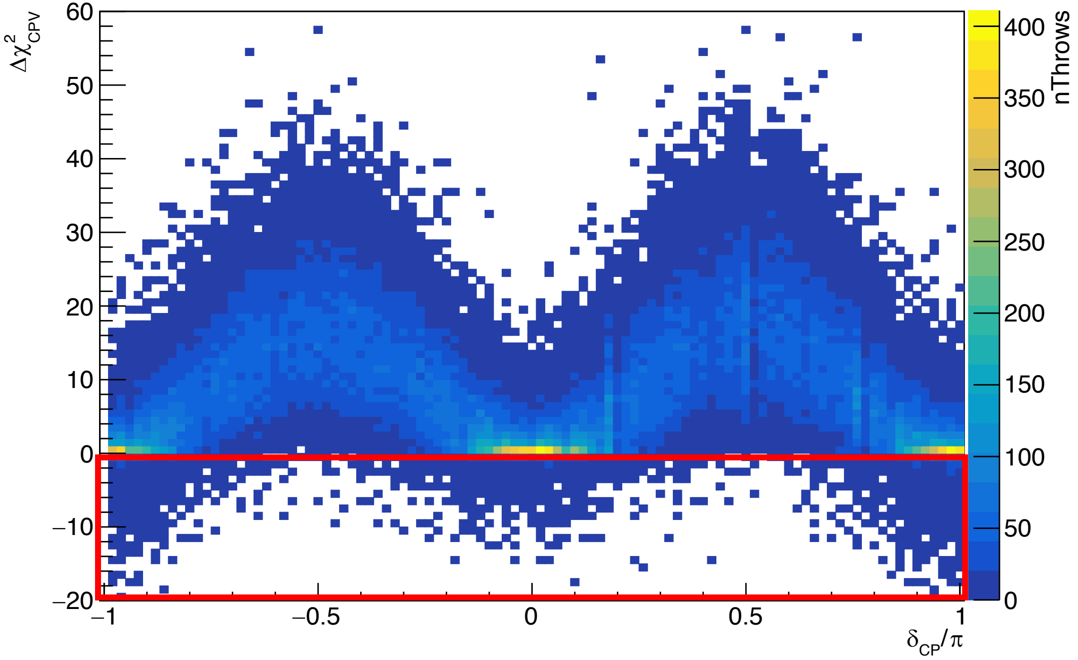
- All systematics allow a CP-conserving hypothesis to better fit a CP-violating observation
  - Order of significance: xsec → flux → energy
- The impact of the energy systematics will be most significant at the maximally violating phases
- The degenerate solutions will have little impact on the sensitivity

‘Central values’ fake data, allow oscillation parameters and systematics to vary



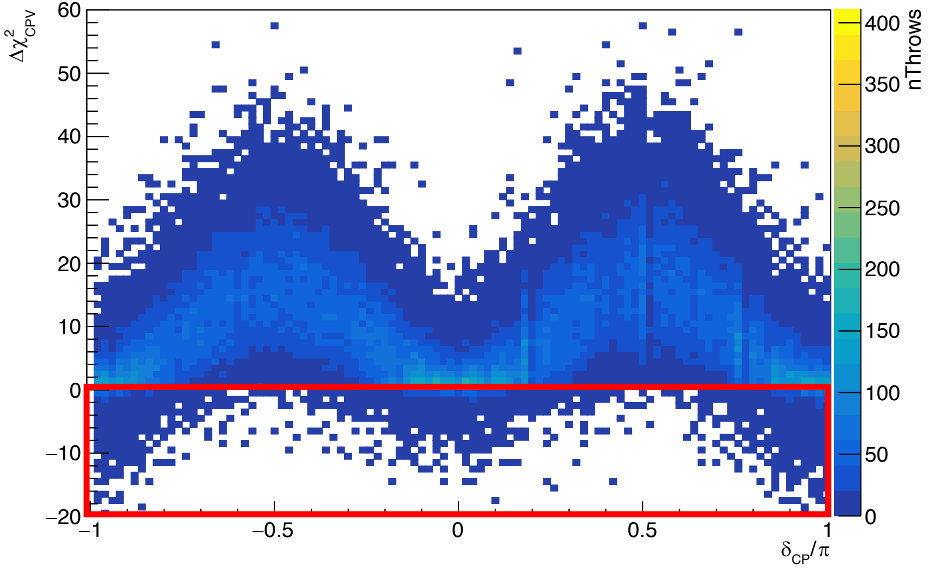
Bringing it all together

- Create a fake data throw
  - Throw the oscillation parameters and systematics
  - Apply a poisson fluctuation
- Perform fit where
  - Allow oscillation parameters to vary within their constraints
  - Add in all dominant systematics
- Repeat



But we get negative values…

Negatives?

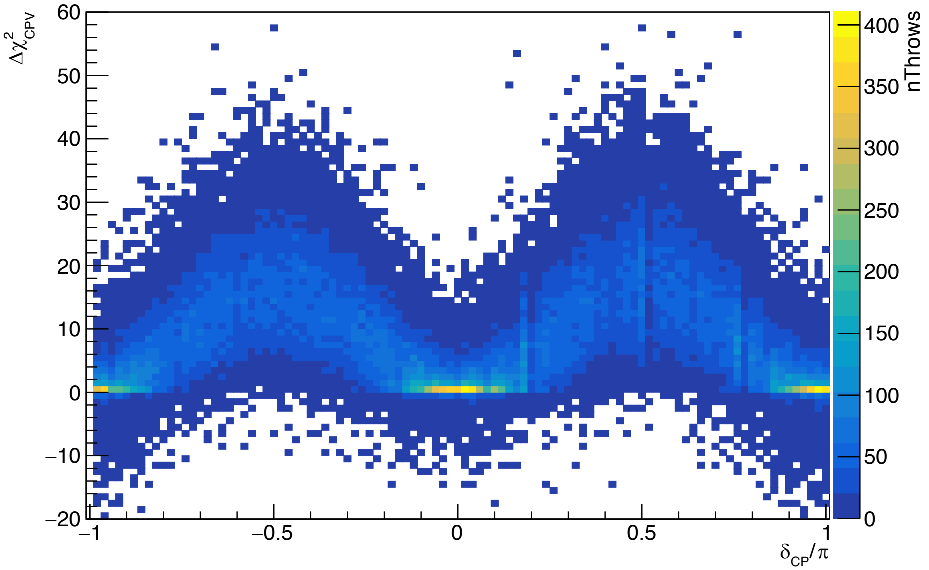


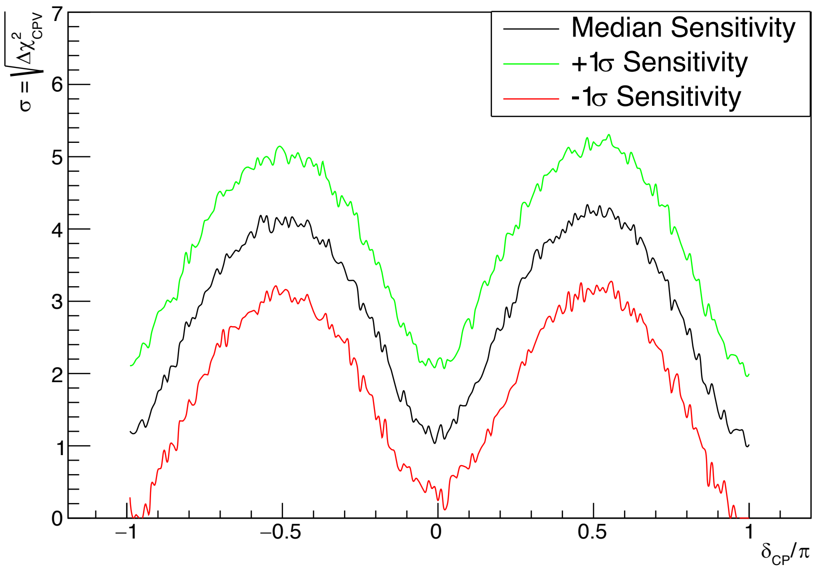
$$\sqrt{\Delta\chi^2_{\mathrm{CPV}}} = \sqrt{\min\{\chi^2_{\delta_{\mathrm{CP}}=0}, \chi^2_{\delta_{\mathrm{CP}}=\pm\pi}\} - \chi^2_{\mathrm{CPV}}}$$

CP-conserving fit **CP-violating fit**

- Despite many seeds, the CP-violating fit sometimes finds a worse minima than the CP-conserving fit
- Fixed by seeding the CP-violating fit at the best fit position of the CP-conserving fit (jobs still running)

±68% of Throws





- The sensitivity distribution at a given CP phase is rarely Gaussian
- Median and 68% boundaries found by computing quantiles using ROOT's GetQuantiles() function

Conclusions

1. Illustrated the use of the Pandora-based selection procedure to study CP-violation at DUNE

2. Significant gains to the nue selection performance and sensitivity have been achieved

3. The behaviour of the systematics on the spectra and on the sensitivity have been discussed

4. Sensitivity estimate with systematic and oscillation parameter uncertainties has been presented

TODO: Work is now focused on repeating for the ‘improved’ Pandora so that a final comparison can be made