Day 1 Near Detector physics

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3 February, 2021

UNIVERSITY of ROCHESTER

Document describing D1ND physics sent to LBNC yesterday

- Requested by LBNC ND subcommittee
- Describe our estimated short-term physics sensitivity in more detail
- Written by CM and Hiro Tanaka
- Thanks to Callum Wilkinson, Cris Vilela, Luke Pickering, Seb Jones for contributions
- DocDB-21943

Physics performance of the Day 1 Near Detector

DUNE long-baseline physics working group

1 February 2021

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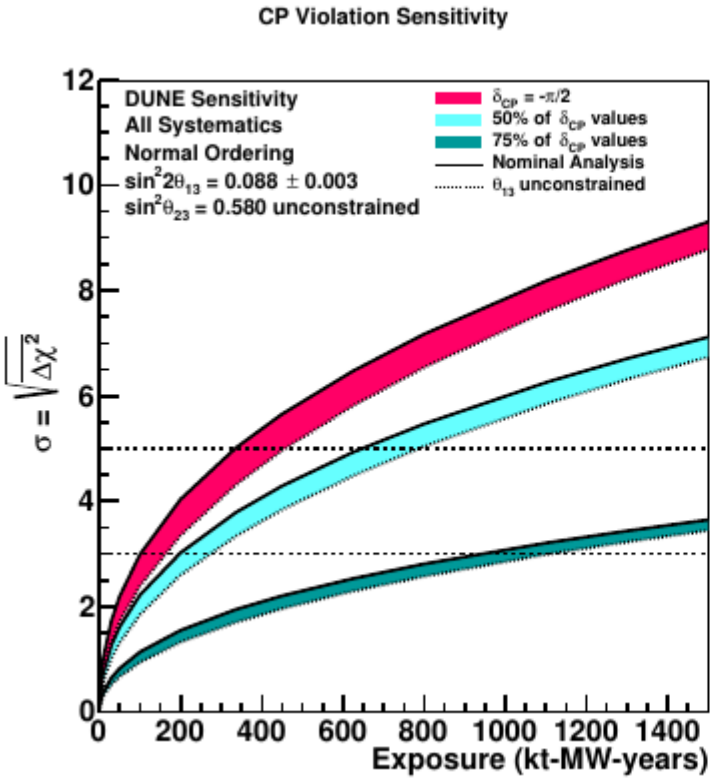
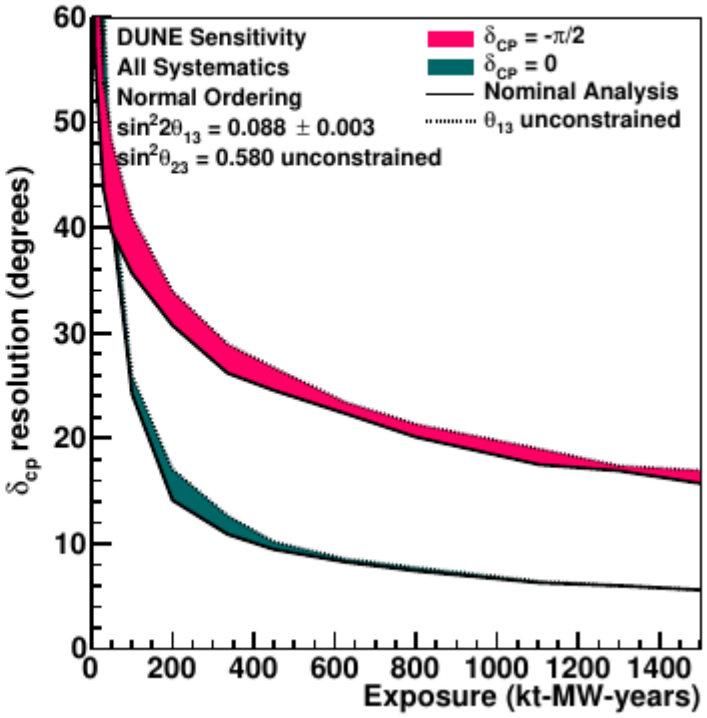
Define metrics for short- and long-term physics goals





- Metric for long-term sensitivity: CPV sensitivity for 50% of δ values
- Metric for short-term sensitivity: CPV for $\delta = -\pi/2$

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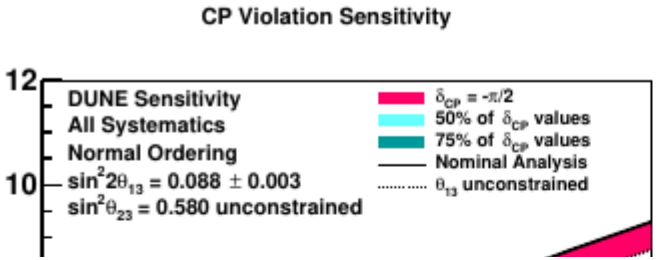
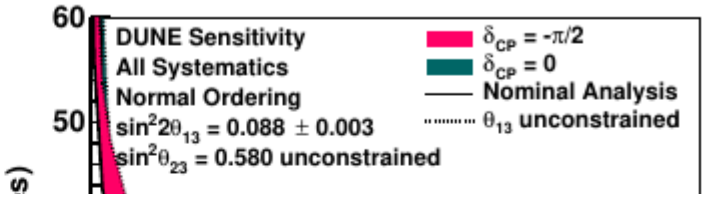
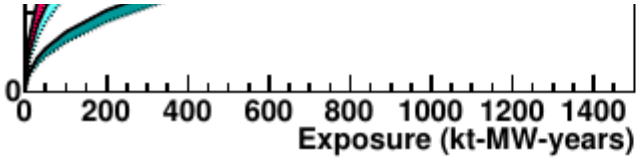
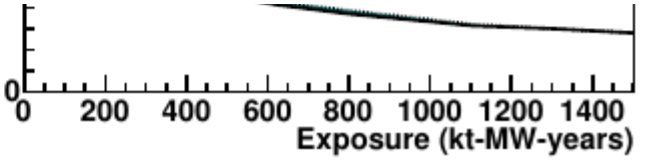
Define metrics for short- and long-term physics goals





Physics Milestone	Exposure (kt-MW-years)	Approx. Staged Years
$5\,\sigma$ mass ordering ($\delta_{CP} = -\pi/2$)	16	1
$5\,\sigma$ mass ordering (100% of δ_{CP} values)	66	2
$3\,\sigma$ CPV sig. ($\delta_{CP} = -\pi/2$)	100	3
$3\,\sigma$ CPV sig. (50% if δ_{CP} values)	197	5
$5\,\sigma$ CPV sig. ($\delta_{CP} = -\pi/2$)	334	7





- Metric for long-term sensitivity: CPV sensitivity for 50% of δ values
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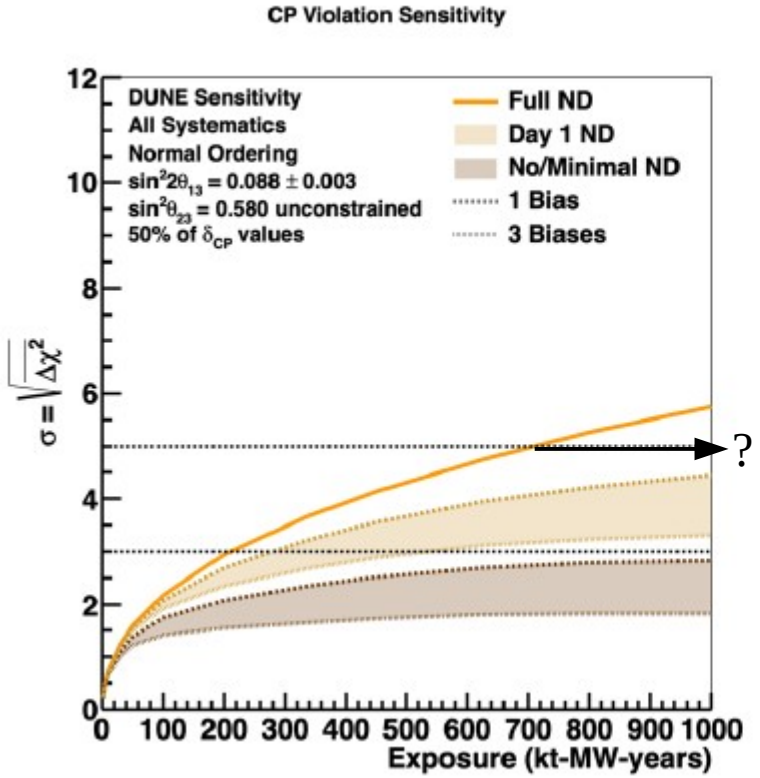
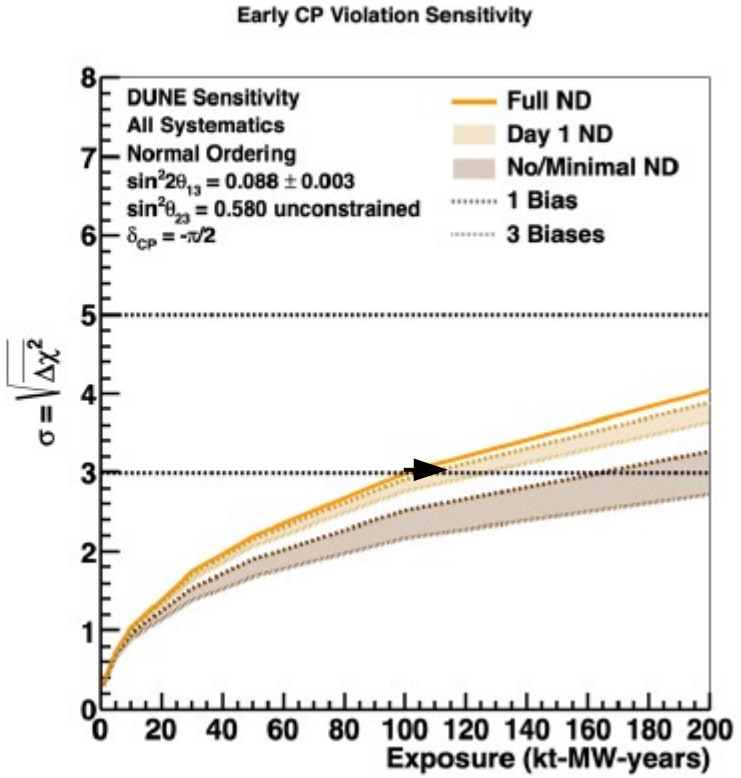
Conclusion:

Reference ND is required for long-term, but D1ND OK for short-term





- By including "out-of-model" effects (NuWro mock data), we show that the additional uncertainty in going from Reference ND to D1ND eliminates long-term goal, but has minimal impact on short-term goal

How we get to that conclusion

- Use “mock data” from alternate generator (NuWro)
- Show that this biases measured δ
- Show that this effect is mitigated by the ND
  - Using D1ND reduces the bias, but does not eliminate it
  - Using Reference ND including ND-GAr largely eliminates it
- In progress: augment this story by including additional alternate models (NEUT, GENIE3 alt tunes)

Producing mock data with event reweighting

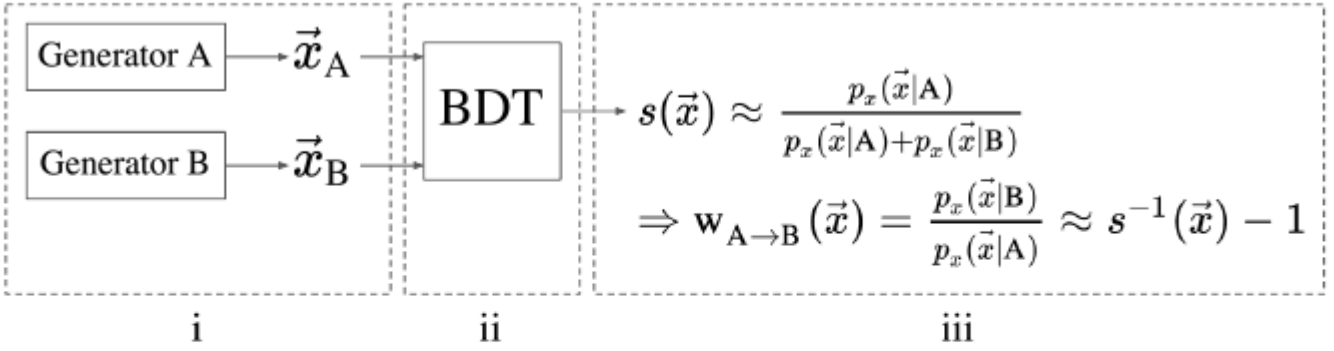
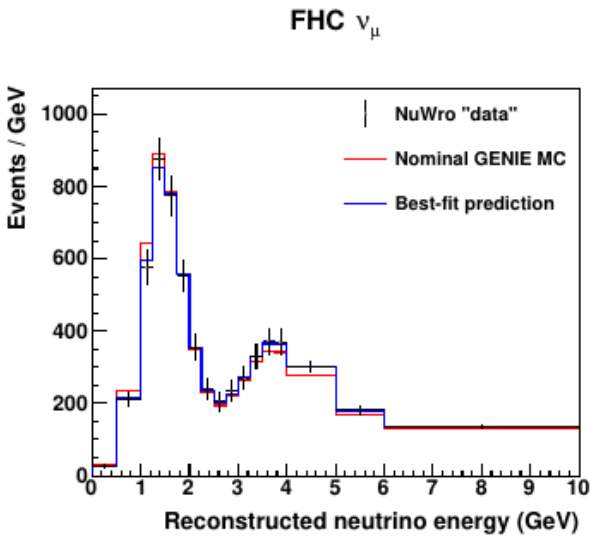
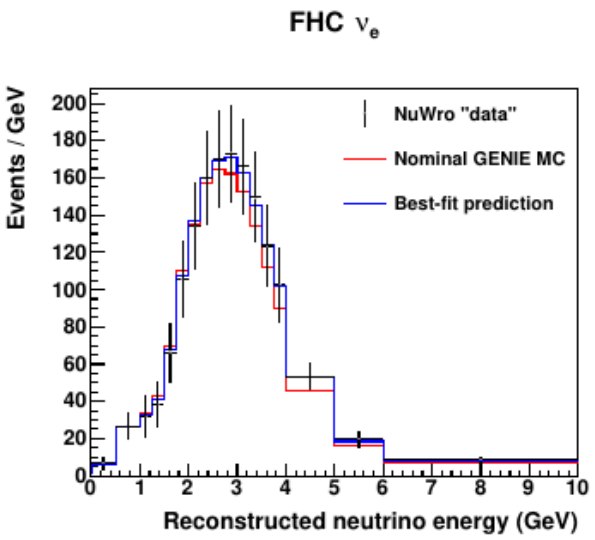


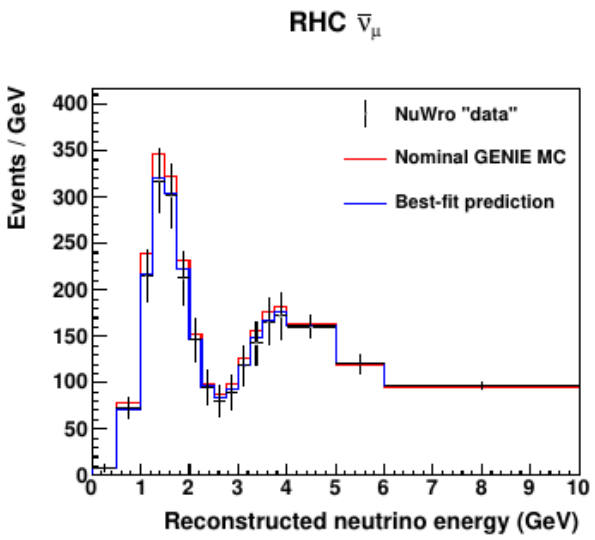
Figure 4: Multidimensional event reweighting with BDTs: (i) event samples are produced using two generators, A and B, and a set of 23 truth-level variables $\vec{x}$ as described in the text is computed for each event generated; (ii) a BDT is trained to discriminate events between generators A and B using the truth-level variables $\vec{x}$; (iii) the resulting discriminant, $s(\vec{x})$, approximates a density ratio which can be recast as a weighting function, $w_{A\to B}(\vec{x})$.

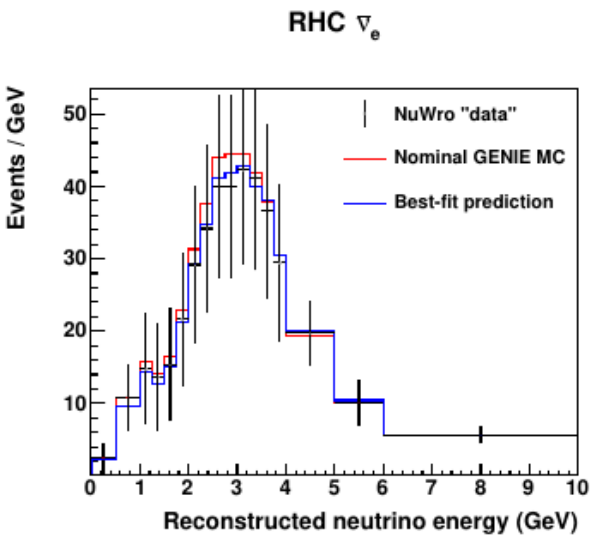
- BDT algorithm trained to distinguish GENIE event from NuWro event based on truth kinematics
- Produces weights that make GENIE look like NuWro in 23-dimensional kinematic space

Fitting mock data at FD



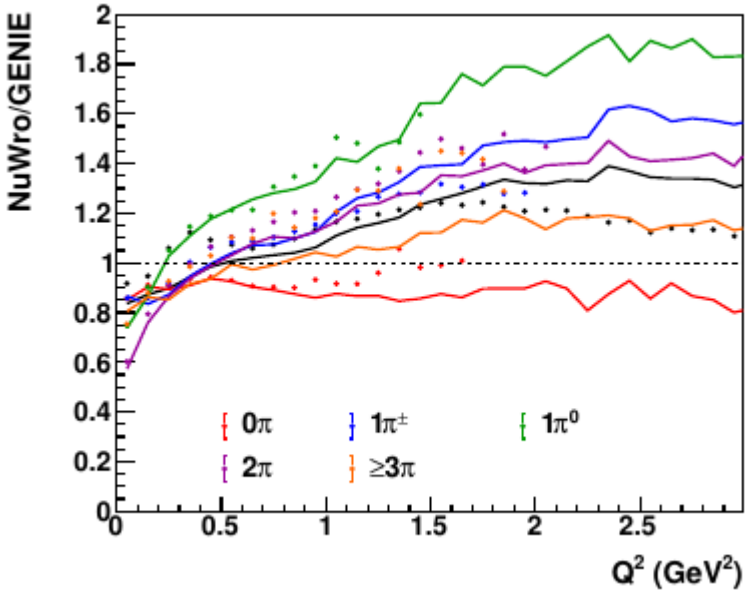


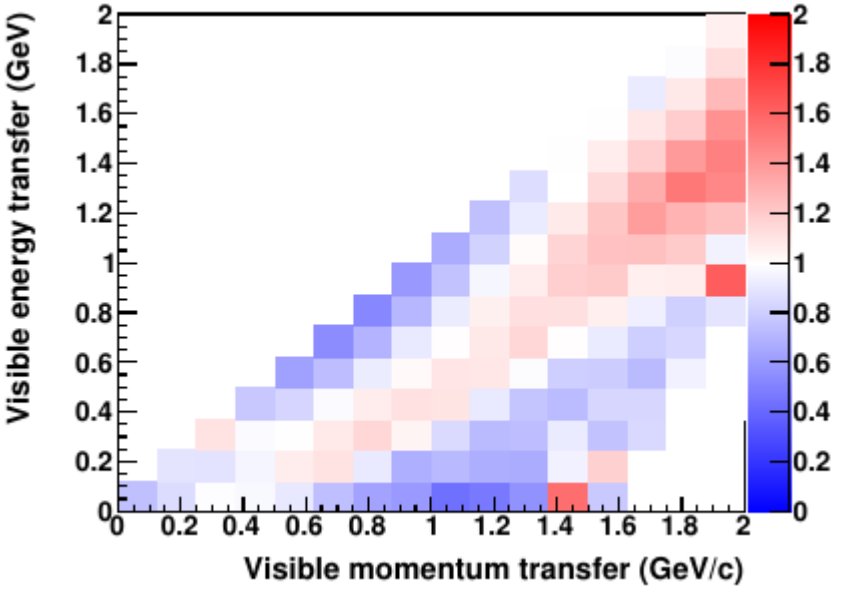




- FD is easily able to fit the mock data, but best-fit gets δ wrong by ~17°
- This is small compared to early resolution (~30-60°), but not small compared to ultimate resolution (7-15°)

Incorporating D1ND





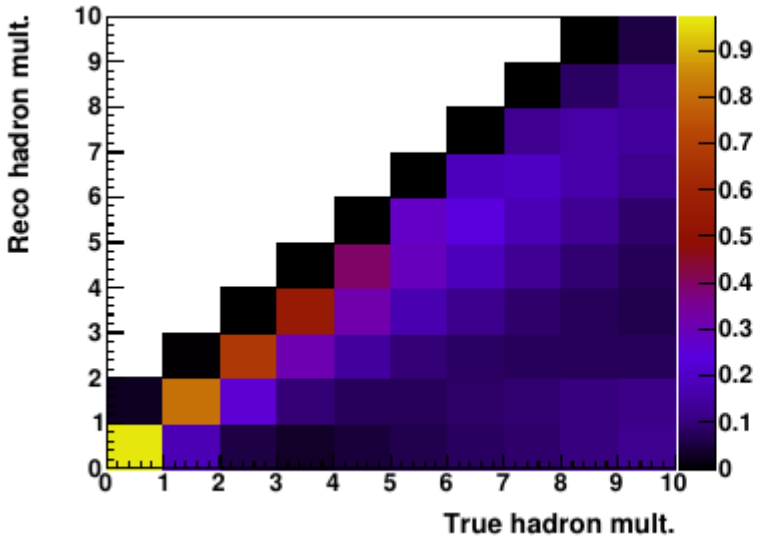
- Use LAr + TMS reconstruction to reweight the MC as a function of “Evis” and “pvis”

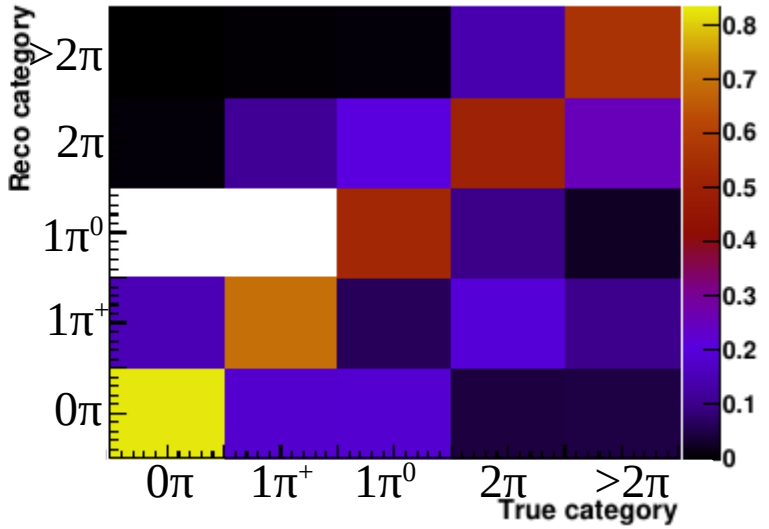
$$E_{vis} = T_p + E_\pi$$

$$Q^2 = 2E_\nu(E_{lep} - p_{lep}\cos\theta_{lep}) - m^2_{lep}$$

$$p_{vis} = \sqrt{Q^2 + E^2_{vis}}$$

Incorporating D1ND

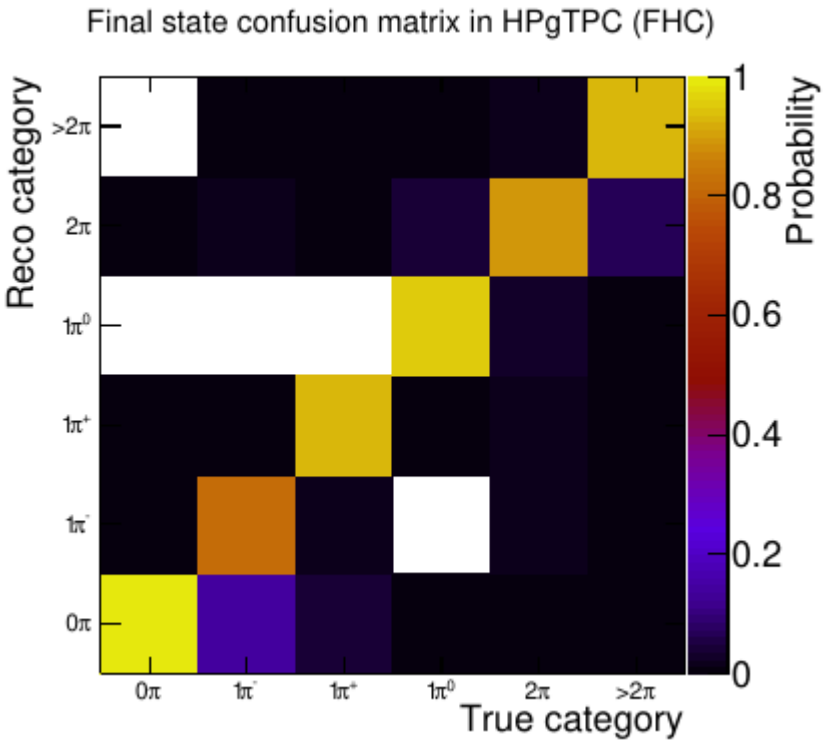




- With D1ND, nothing is gained by splitting the sample up into exclusive channels
  - Large smearing between channels (20-30%)
  - Different channels populate different regions of Evis-pvis space already, so this single CC inclusive sample suffices

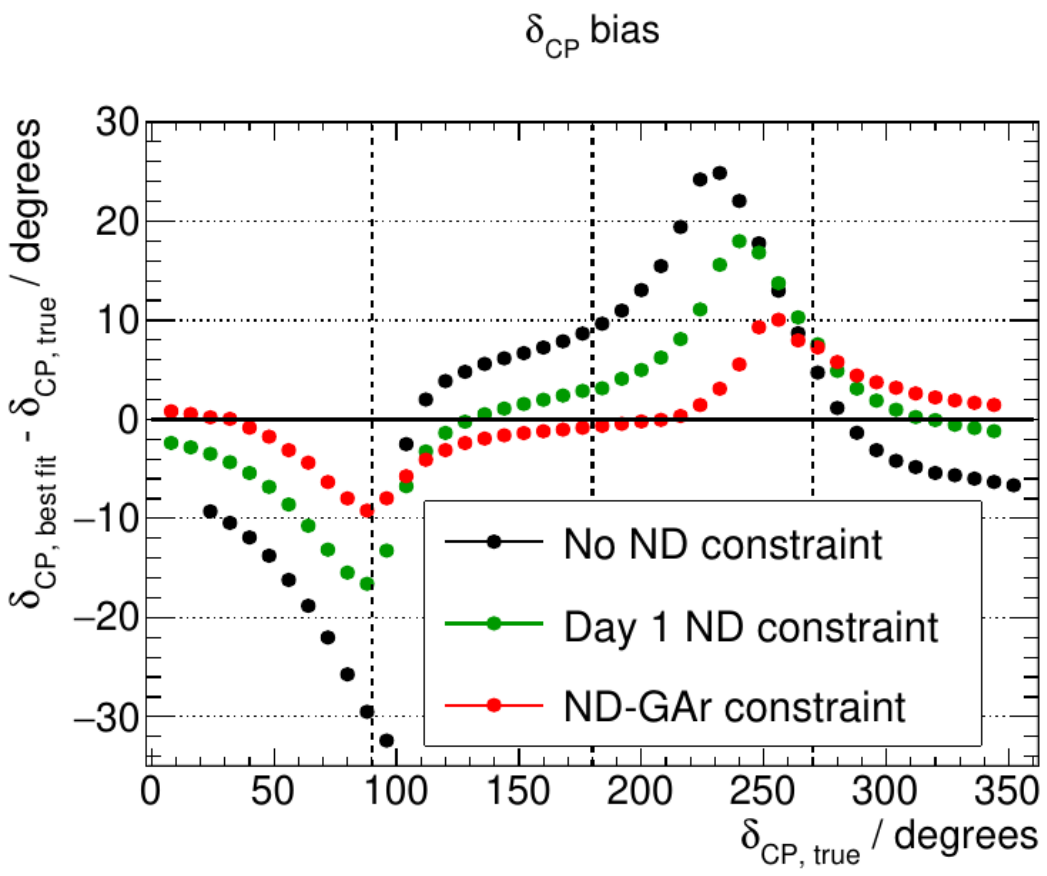
Incorporating D1ND

- ND-GAr measurement of these quantities is superior due to
  - Lack of particle reinteractions
  - Ease of excluding neutrons from Evis definition



- Splitting into exclusive channels offers significant improvement
  - Very little smearing between channels due to superior PID

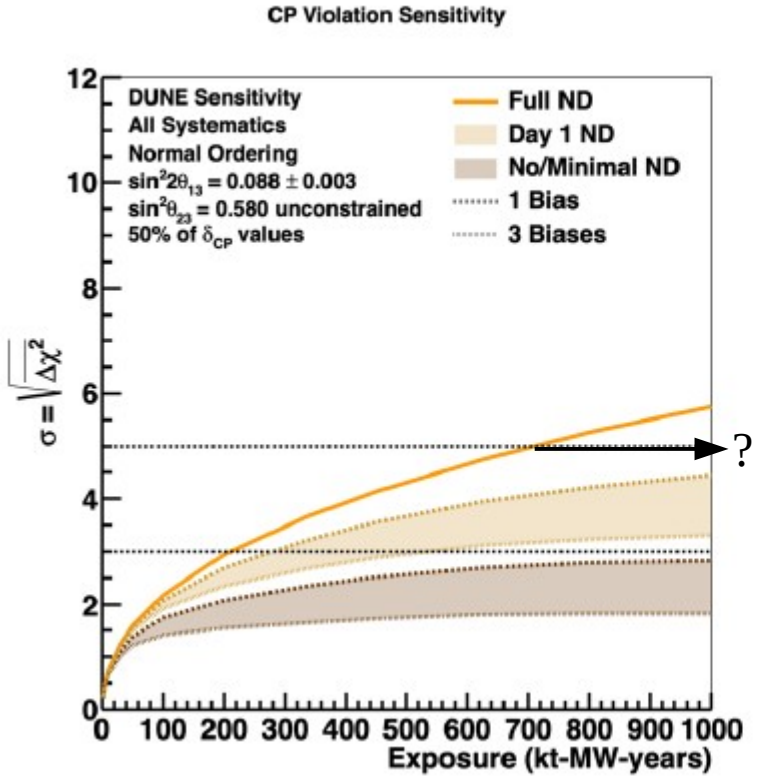
Reduced bias with ND-derived weights to FD prediction

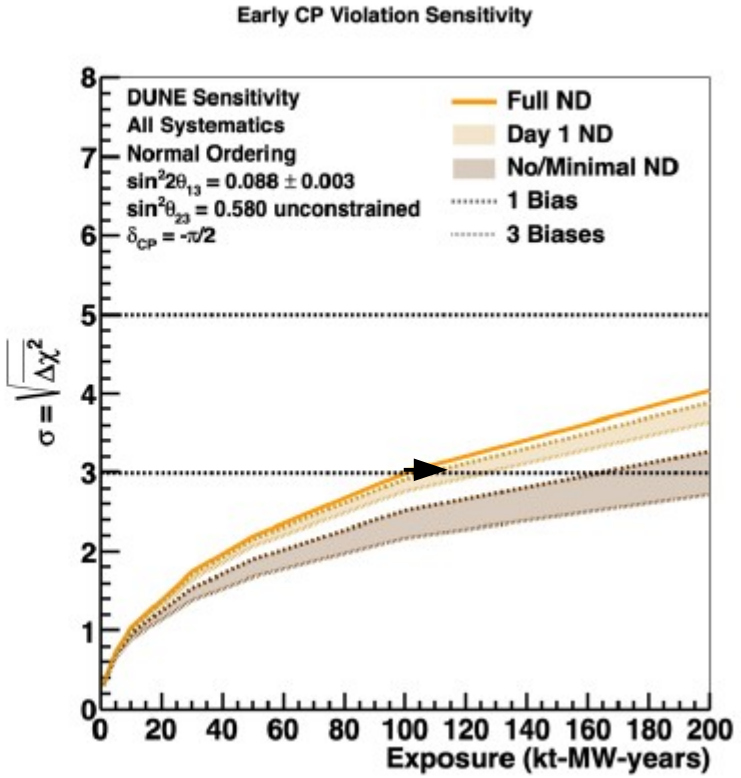


- Use of ND data reduces bias from ~17° to ~9° (D1ND) to <4° (Full ND)
- This bias is treated as an additional systematic added in quadrature to CPV sensitivities

Conclusion:

Reference ND is required for long-term, but D1ND OK for short-term





- By including "out-of-model" effects (NuWro mock data), we show that the additional uncertainty in going from Reference ND to D1ND eliminates long-term goal, but has minimal impact on short-term goal

Work in progress: additional mock data bias studies

- Originally, this study was used to demonstrate a physics case for ND-GAr
- Now, we are trying to use this study to show that D1ND is sufficient for early physics
- Mock data study is “existence proof”; it is easier to prove something is necessary than to prove something is sufficient
- Hope to augment the case by adding 2 or 3 additional biases that lead to the same conclusion

End