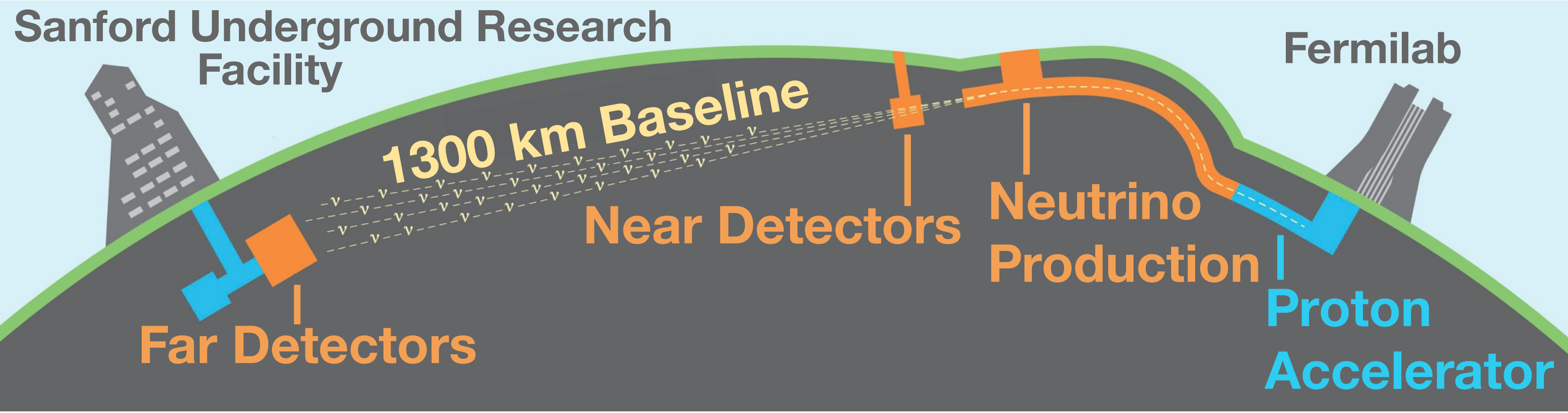
DUNE Long Baseline Oscillations

Lake Louise
Winter Institute 2022
2022/02/23

Luke Pickering
for DUNE Collaboration

ROYAL HOLLOWAY UNIVERSITY OF LONDON

The Deep Underground Neutrino Experiment



The Deep Underground Neutrino Experiment

The People

- 1100+ Collaborators
- 35+ Countries

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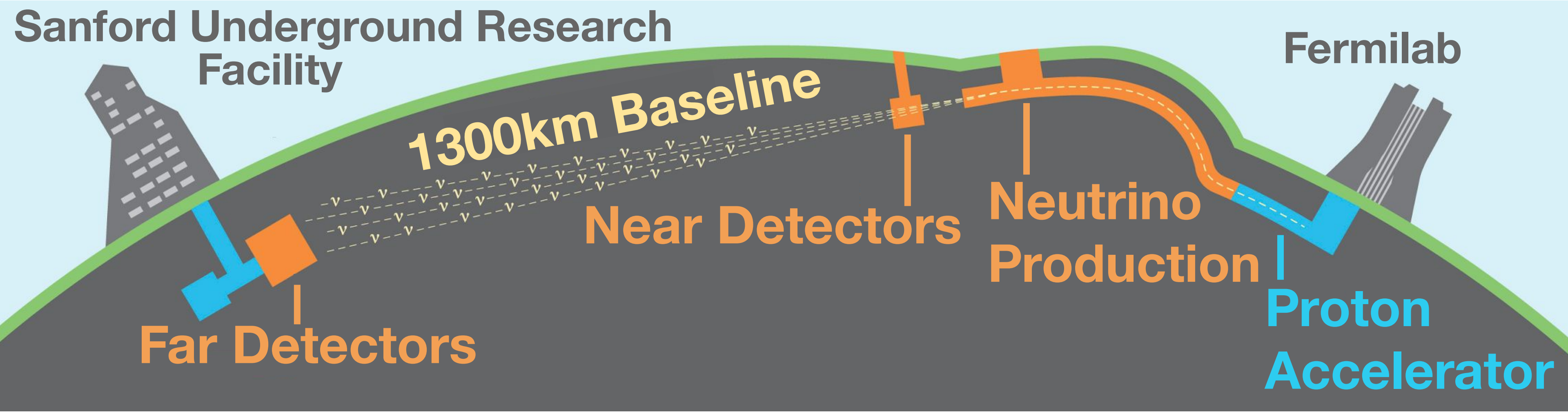

The People

- 1100+ Collaborators
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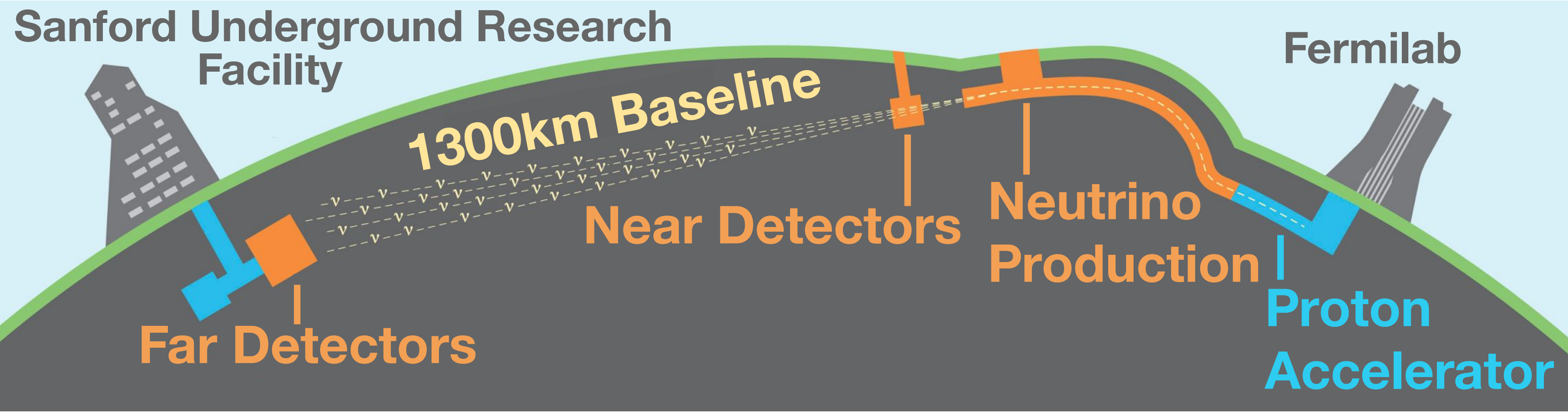
PMNS Oscillations

- Unprecedented precision
- Strong δ_{CP} and MO Sensitivity

The Deep Underground Neutrino Experiment



The People

- 1100+ Collaborators
- 35+ Countries

PMNS Oscillations

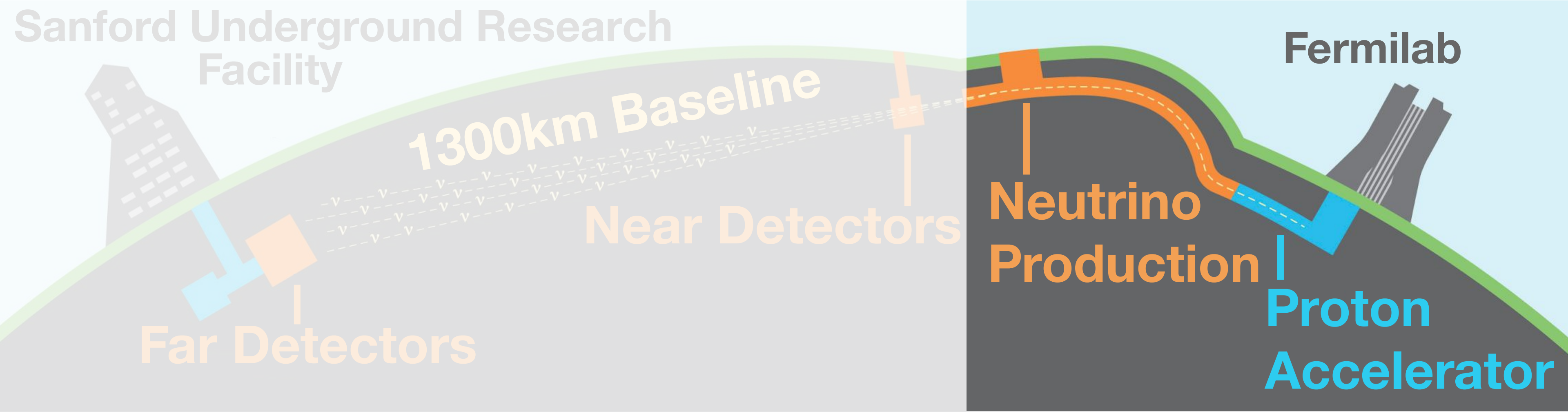
- Unprecedented precision
- Strong δ_{CP} and MO Sensitivity

Rich Physics Program

- Sterile ν's
- Weak nuclear probe
- Solar ν's
- Geo ν's
- SN ν's

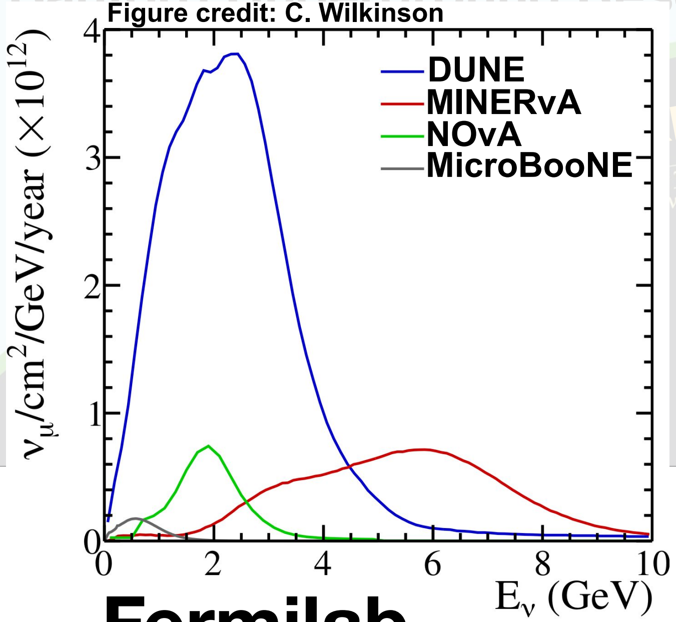
DUNE Components

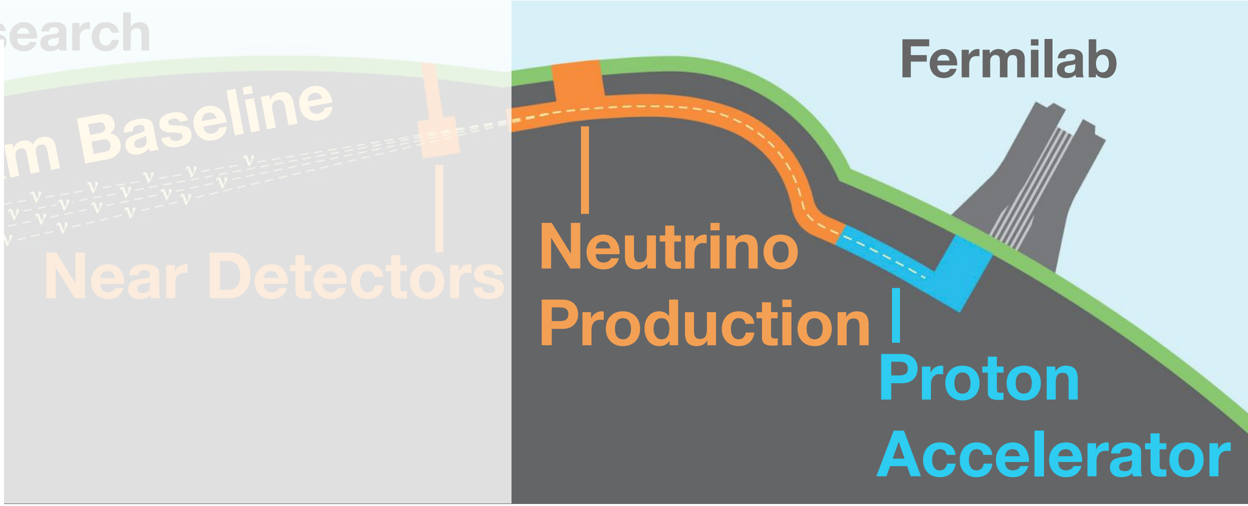
Measuring Neutrino Oscillations



The DUNE Neutrino Beam

Measuring Neutrino Oscillations



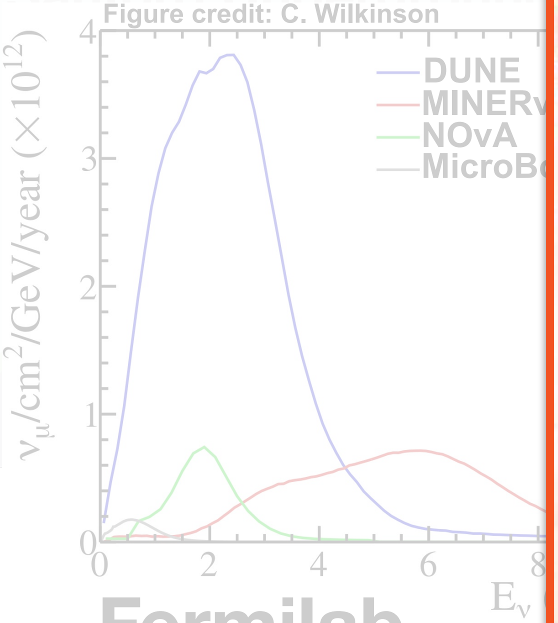


Fermilab neutrino fluxes

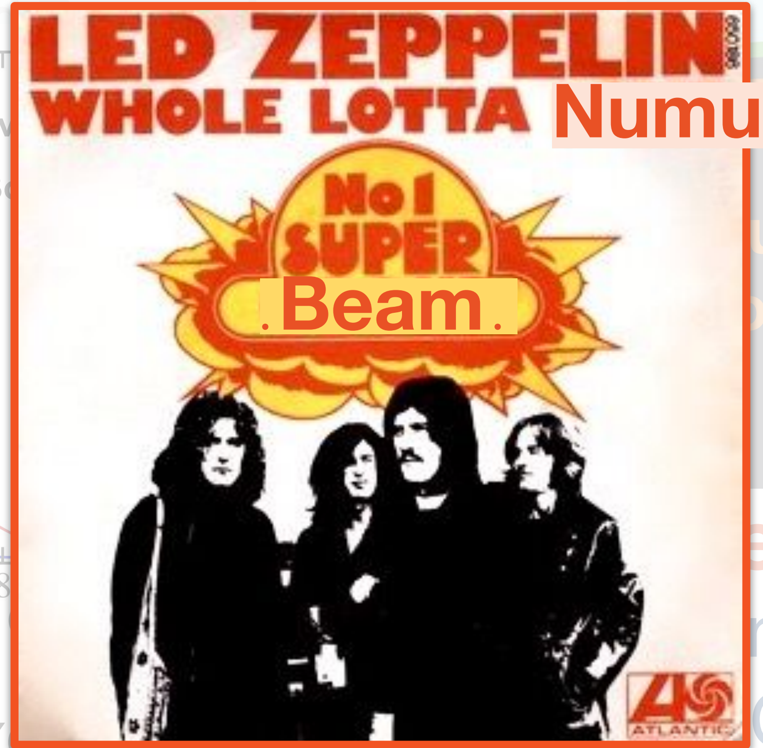
The DUNE Neutrino Beam

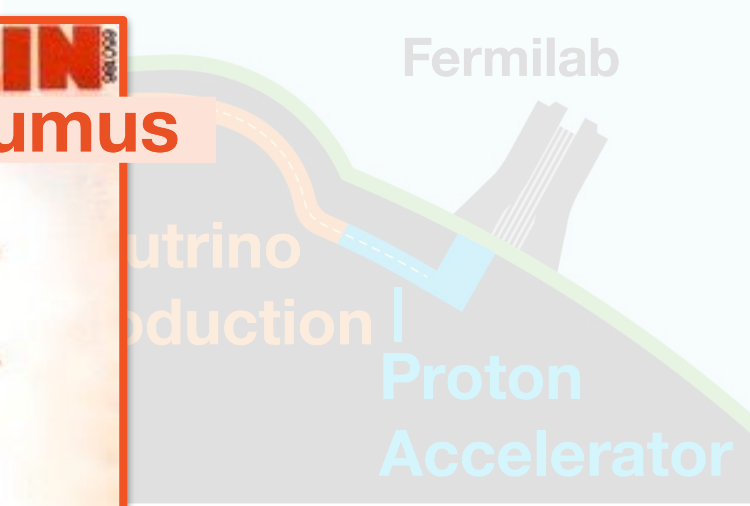
- 1.2 MW neutrino beam
- Optimized for CPV sensitivity

Measuring Neutrino Oscillations



Fermilab
neutrino flux



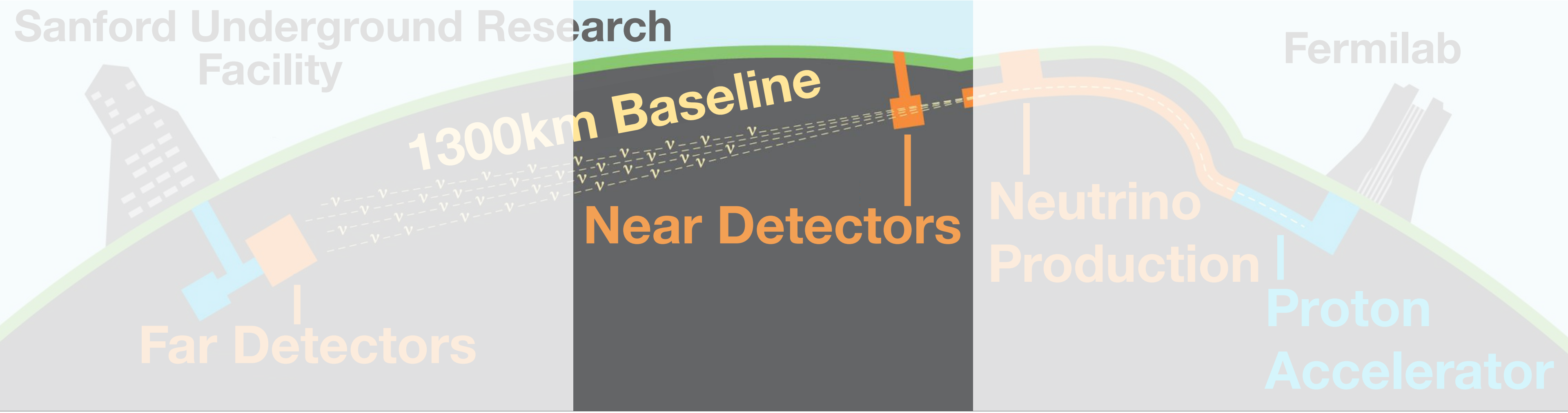


eutrino Beam

no beam

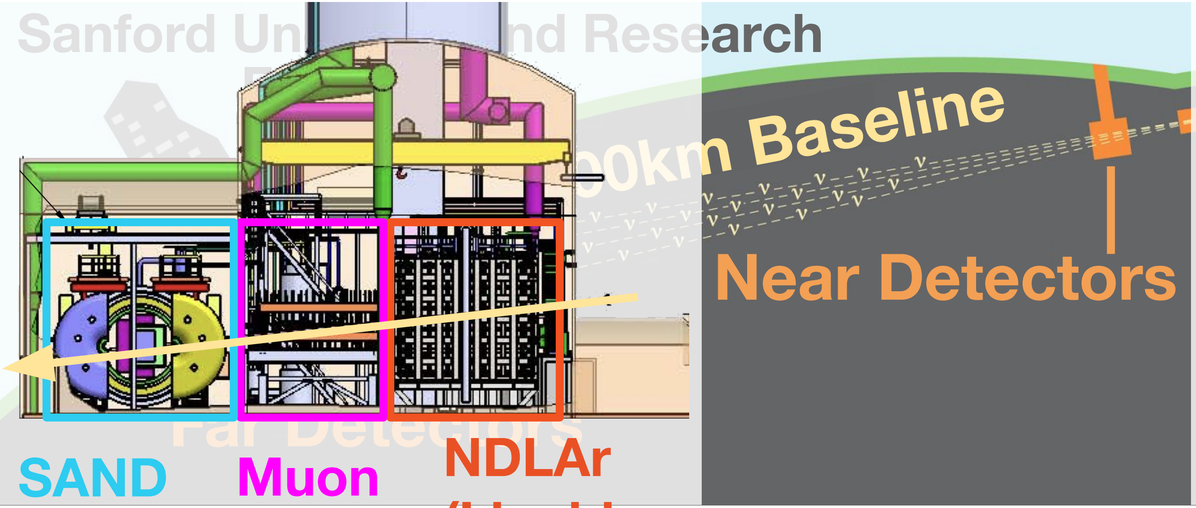
CPV sensitivity

Measuring Neutrino Oscillations



Near Detector Suite

Measuring Neutrino Oscillations

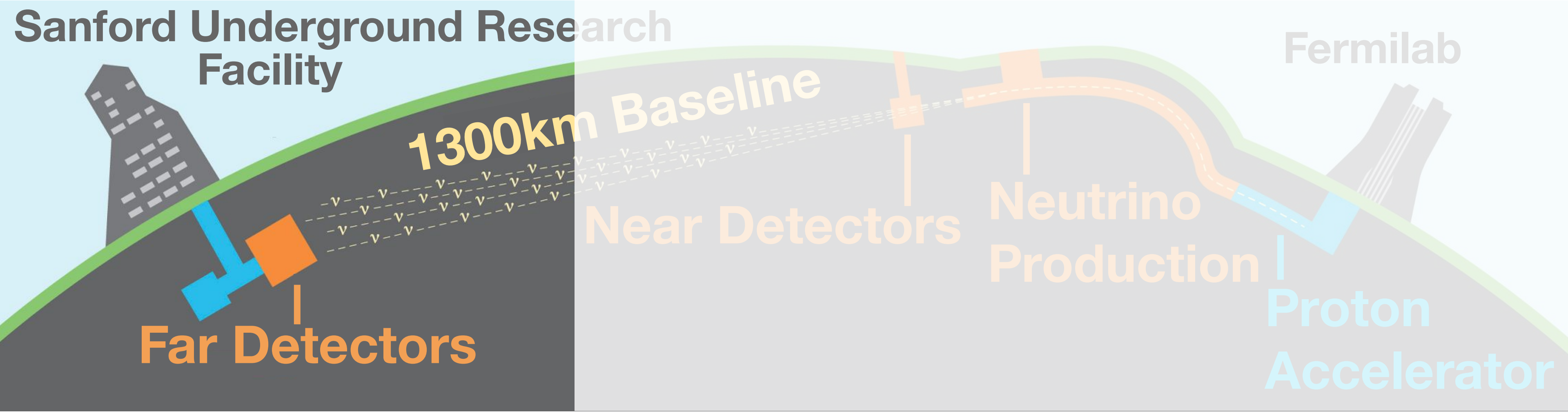


NDLAr	All int.	
Run duration	$N_{\nu_\mu CC}$	N_{Sel}
½ beam-yr	21.6M	10.1M

Near Detector Suite

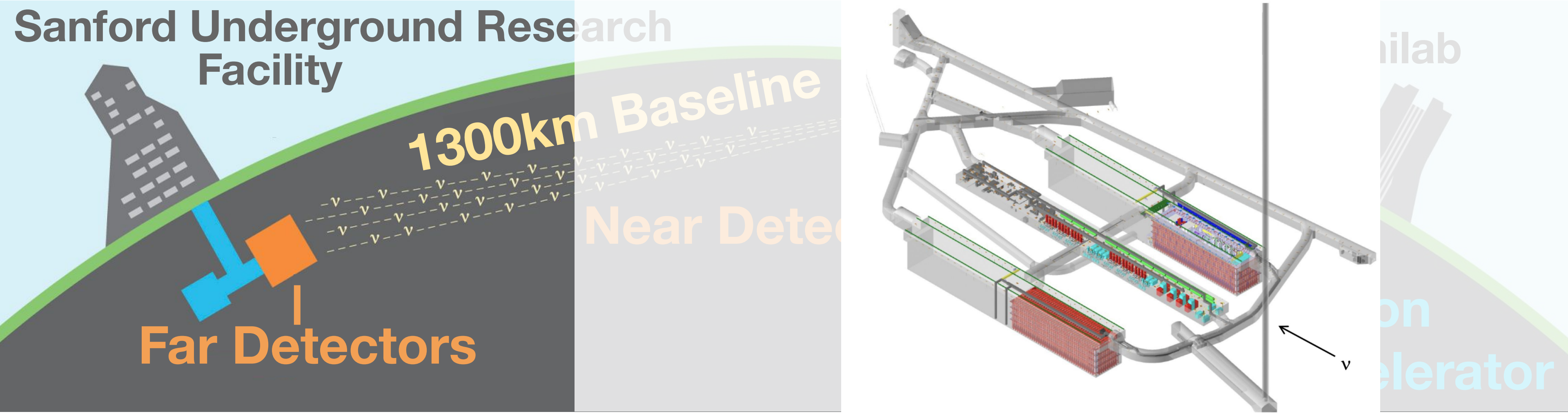
- See D. Cherdack talk, up next

Measuring Neutrino Oscillations



The Far Detectors

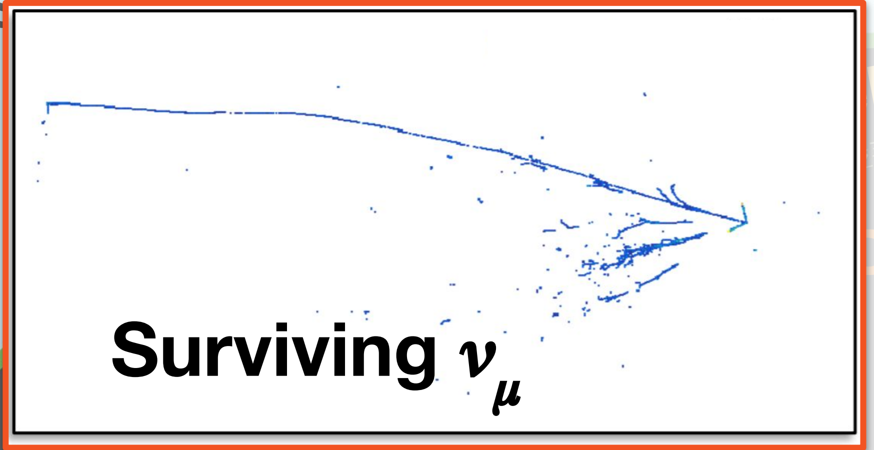
Measuring Neutrino Oscillations

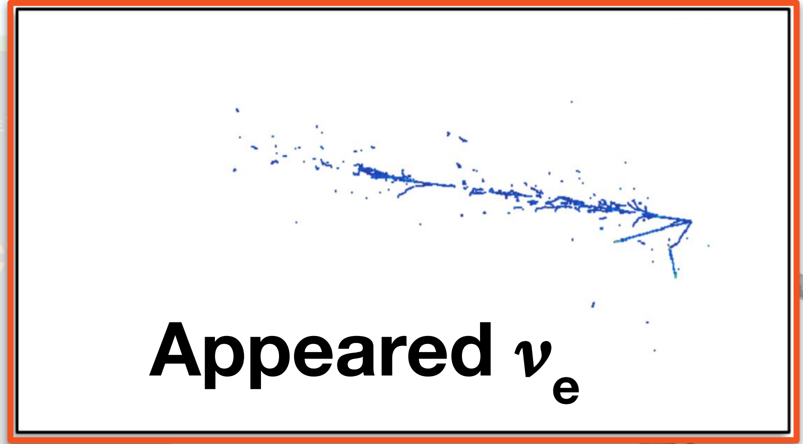


The Far Detectors

- Four modules: each 17 kT

Measuring Neutrino Oscillations

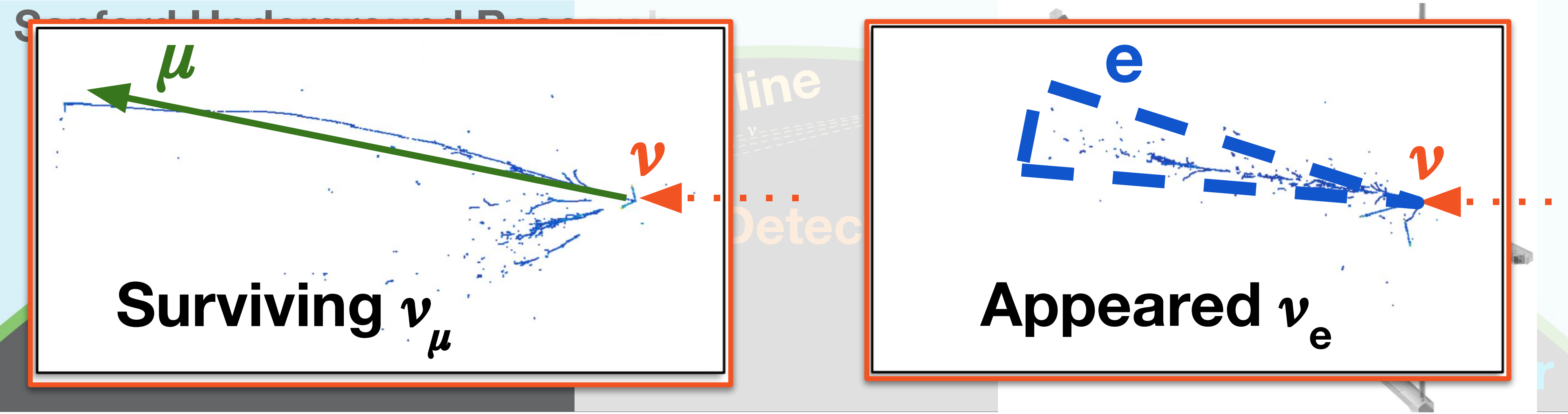




The Far Detectors

- Four modules: each 17 kT
- Uniquely fine-grained for far detectors

Measuring Neutrino Oscillations



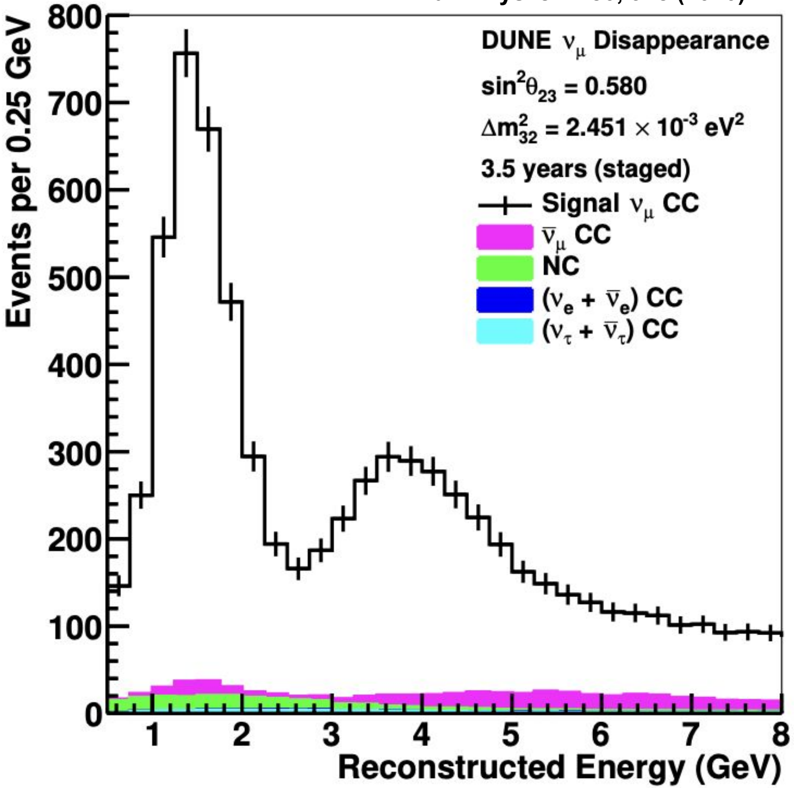
The Far Detectors

- Four modules: each 17 kT
- Uniquely fine-grained for far detectors

PMNS Oscillation Sensitivities

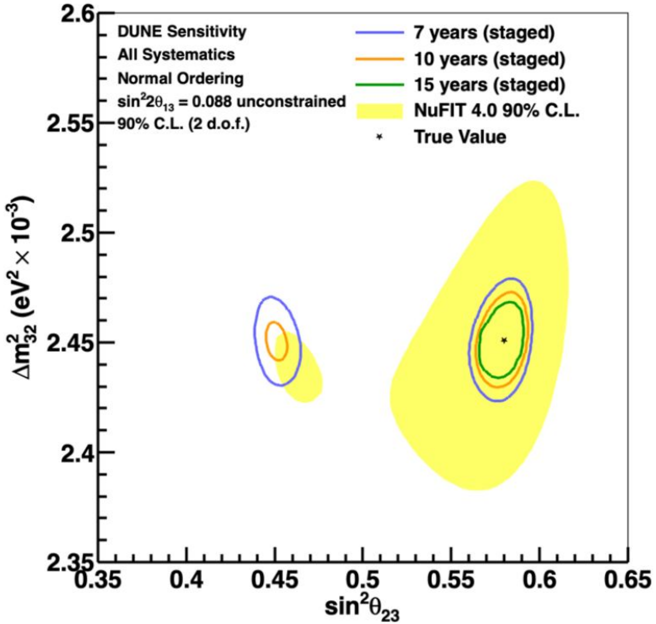
Disappearance Sensitivity

Eur. Phys. J. C 80, 978 (2020)



- Excellent energy resolution
- Massive far detector event rate

Disappearance Sensitivity



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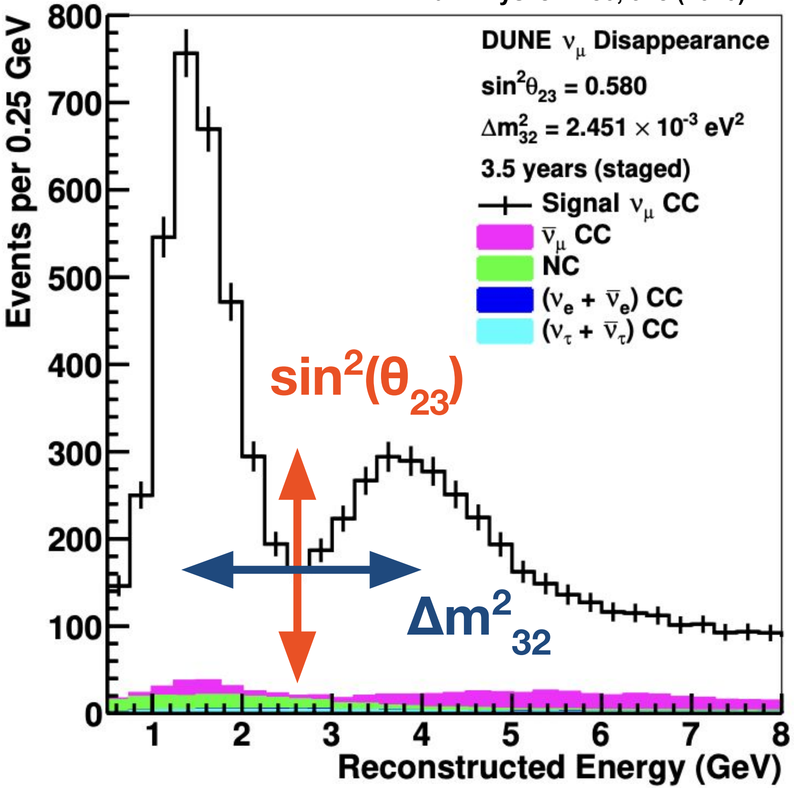
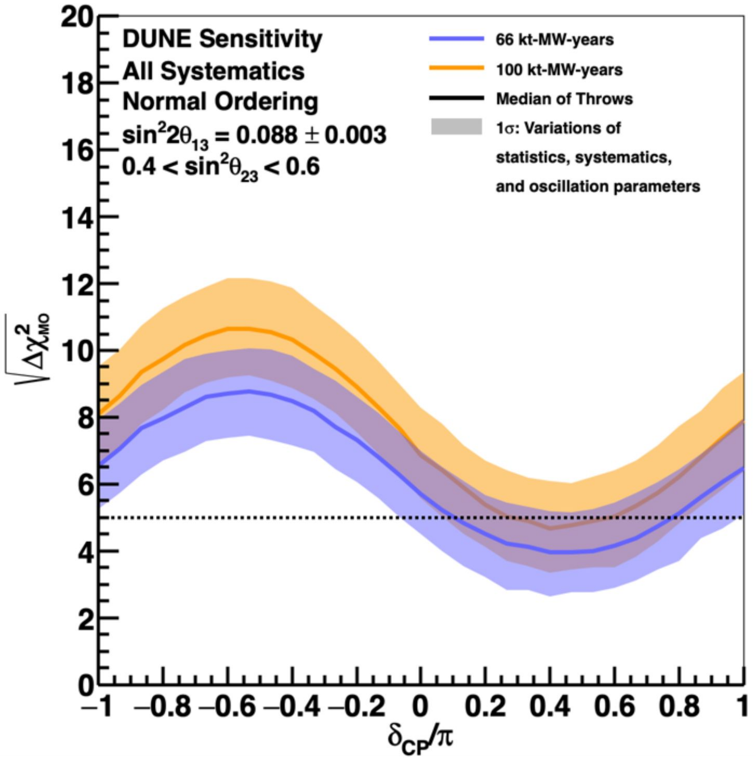
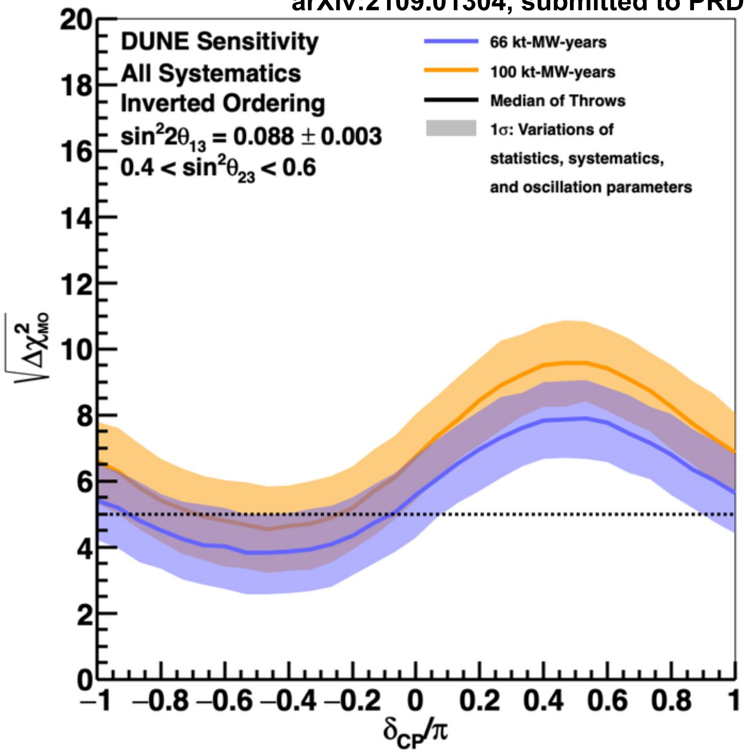


- Excellent energy resolution
- Massive far detector event rate
- Unprecedented oscillation parameter sensitivity

Low Exposure Mass Ordering Sensitivity

arXiv:2109.01304, submitted to PRD

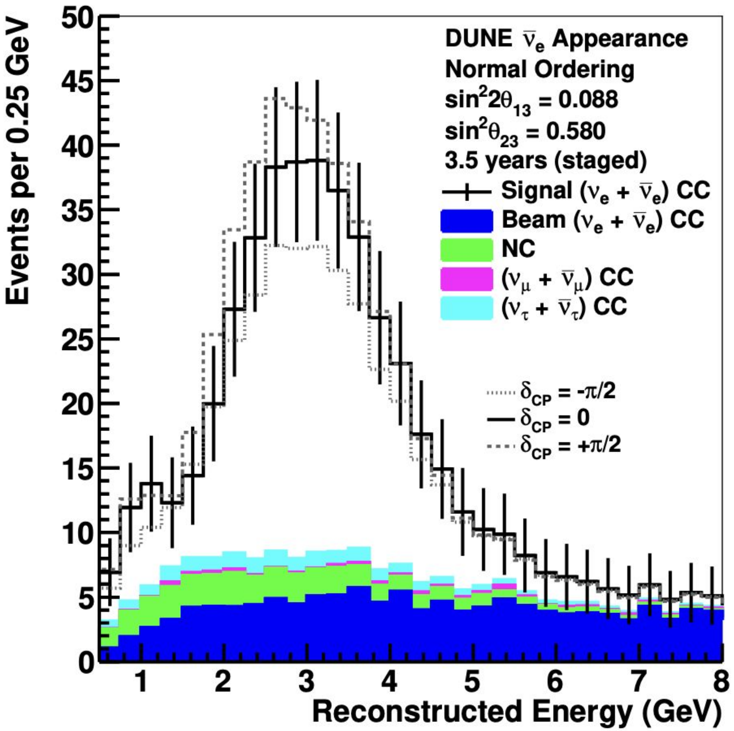


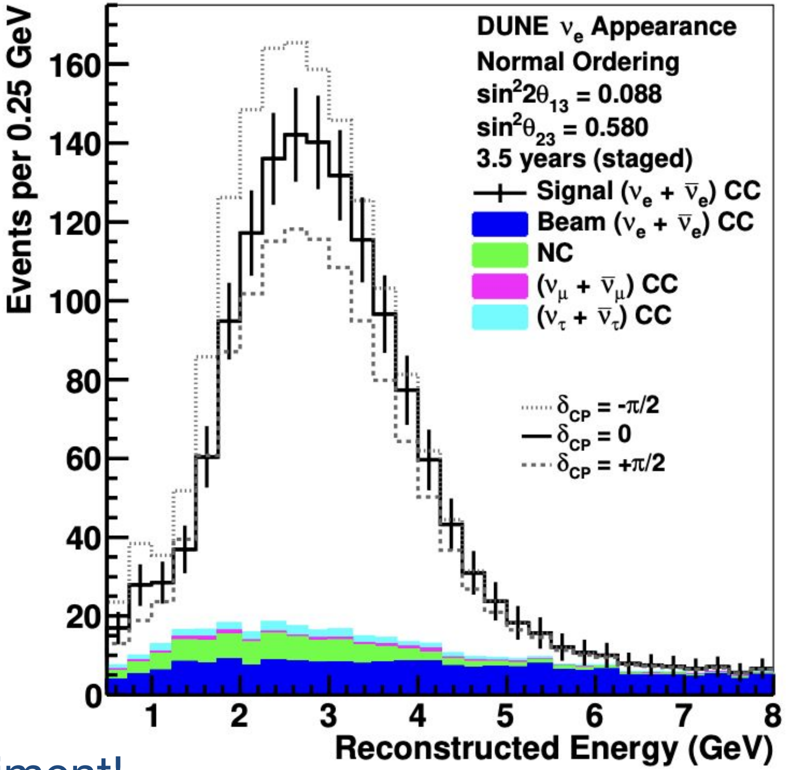


- Unambiguous Mass Ordering determination early in the physics programme

Appearance Sensitivity

Eur. Phys. J. C 80, 978 (2020)





- Unique access to MO + CPV in one experiment!

Appearance Sensitivity

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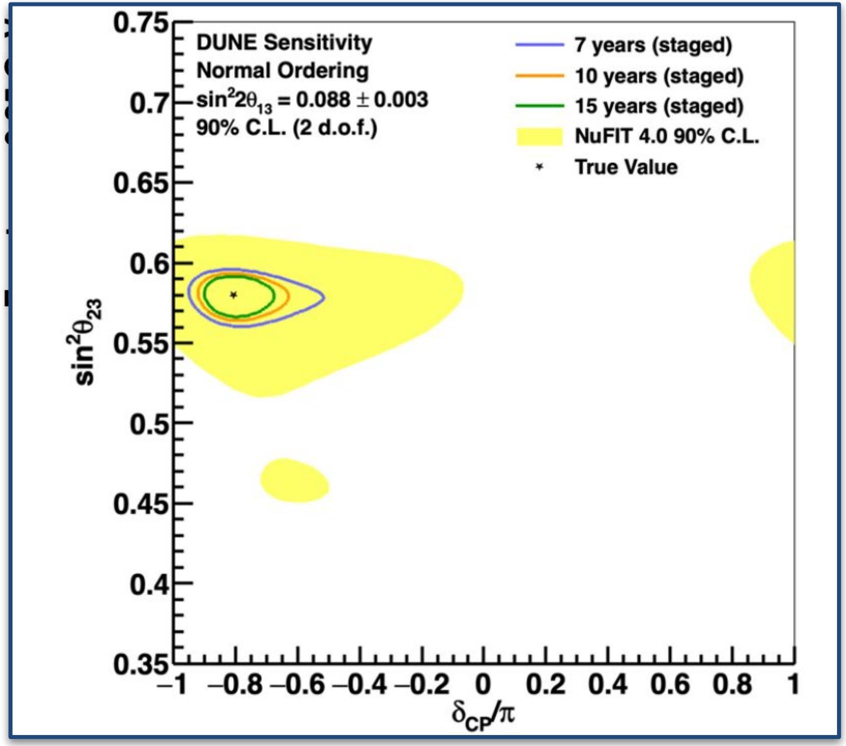

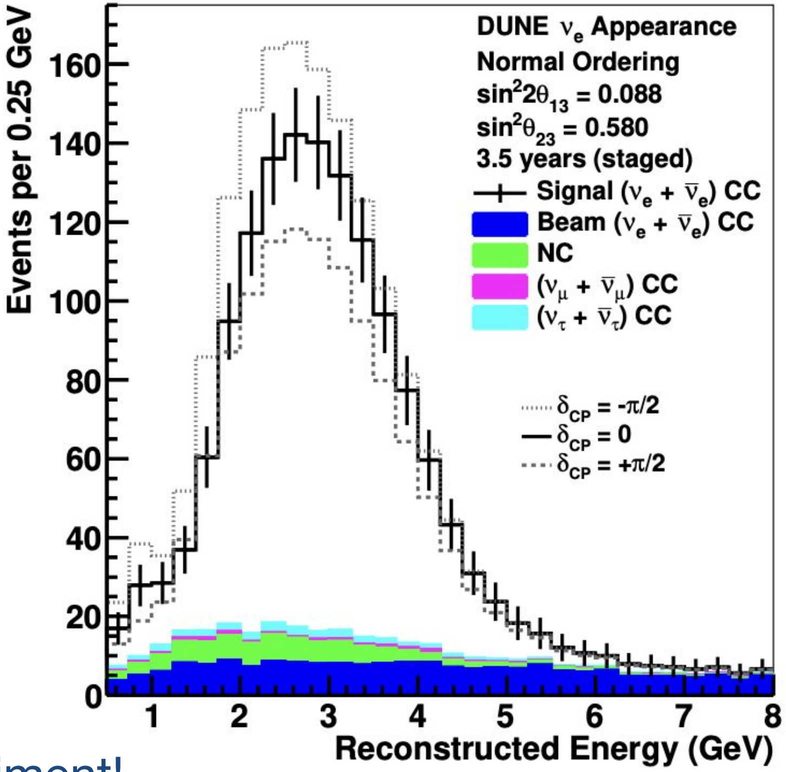

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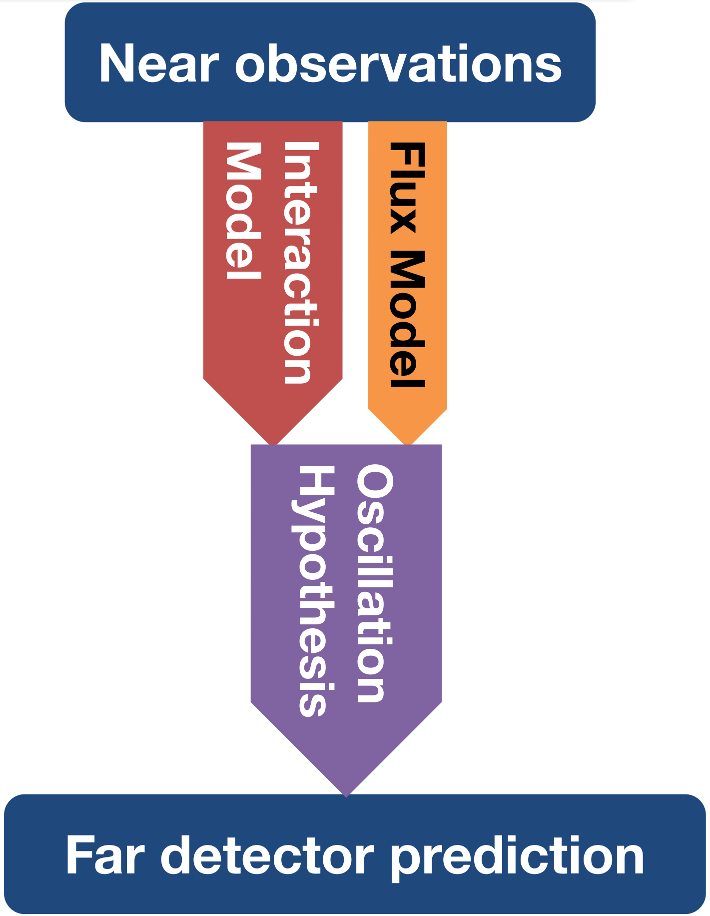
Moving Beyond Sensitivities

- Traditionally:
  - Use models to 'unfold' near detector observations.
  - Apply oscillation hypothesis
  - Compare to far detector observations



Moving Beyond Sensitivities

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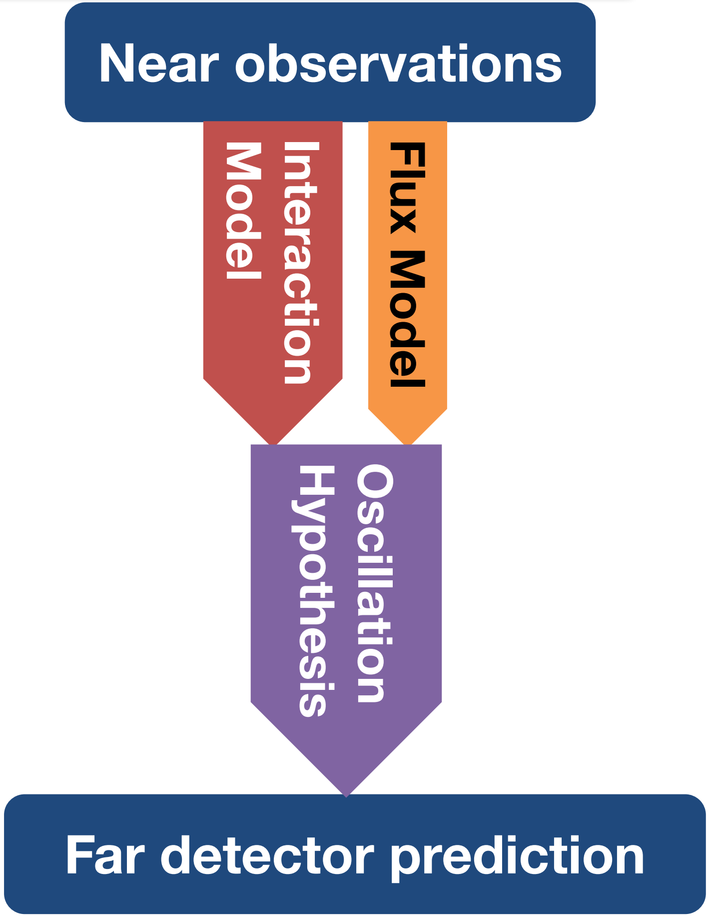
- What happens if the model is wrong?
  - Inflate errors → degrade sensitivity
  - Bias measurements



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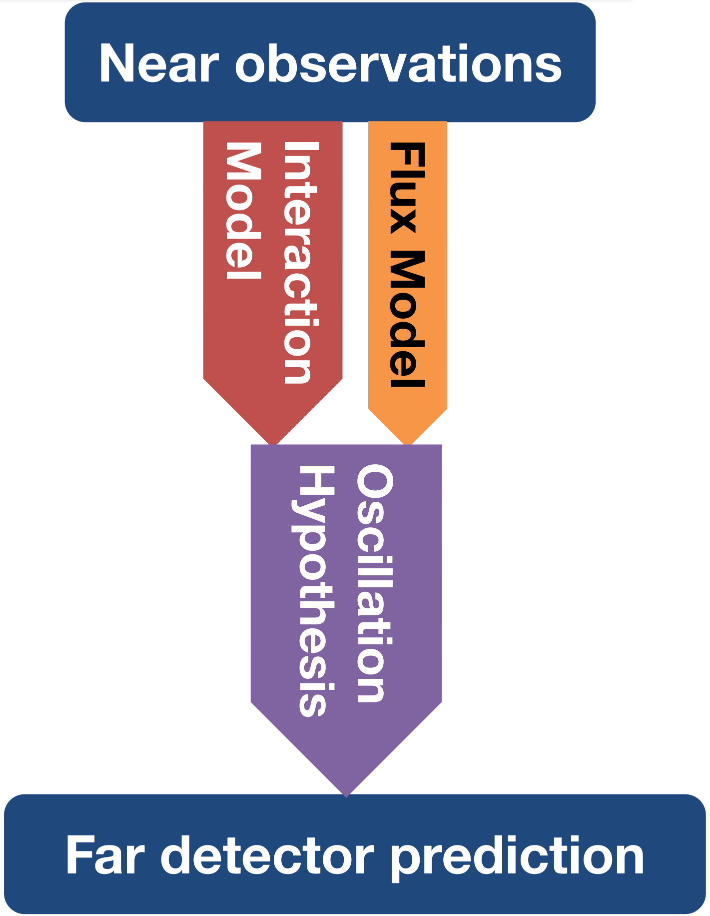
- **Case study:** What if we mis-model neutrino energy fraction to protons but don't notice at the near detector?



Moving Beyond Sensitivities

Near observations

- Traditionally:
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  - Compare to far detector observations
- What happens if the model is wrong?
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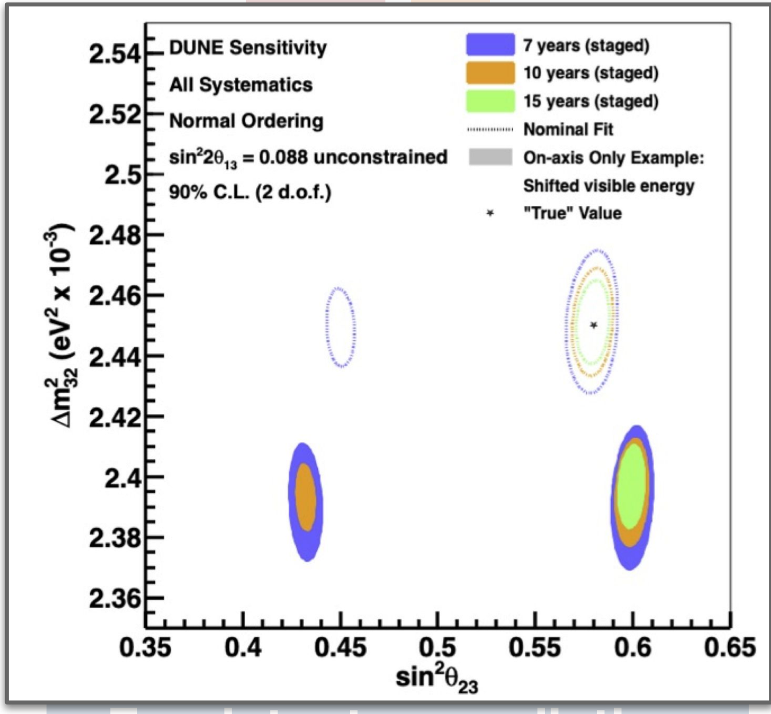
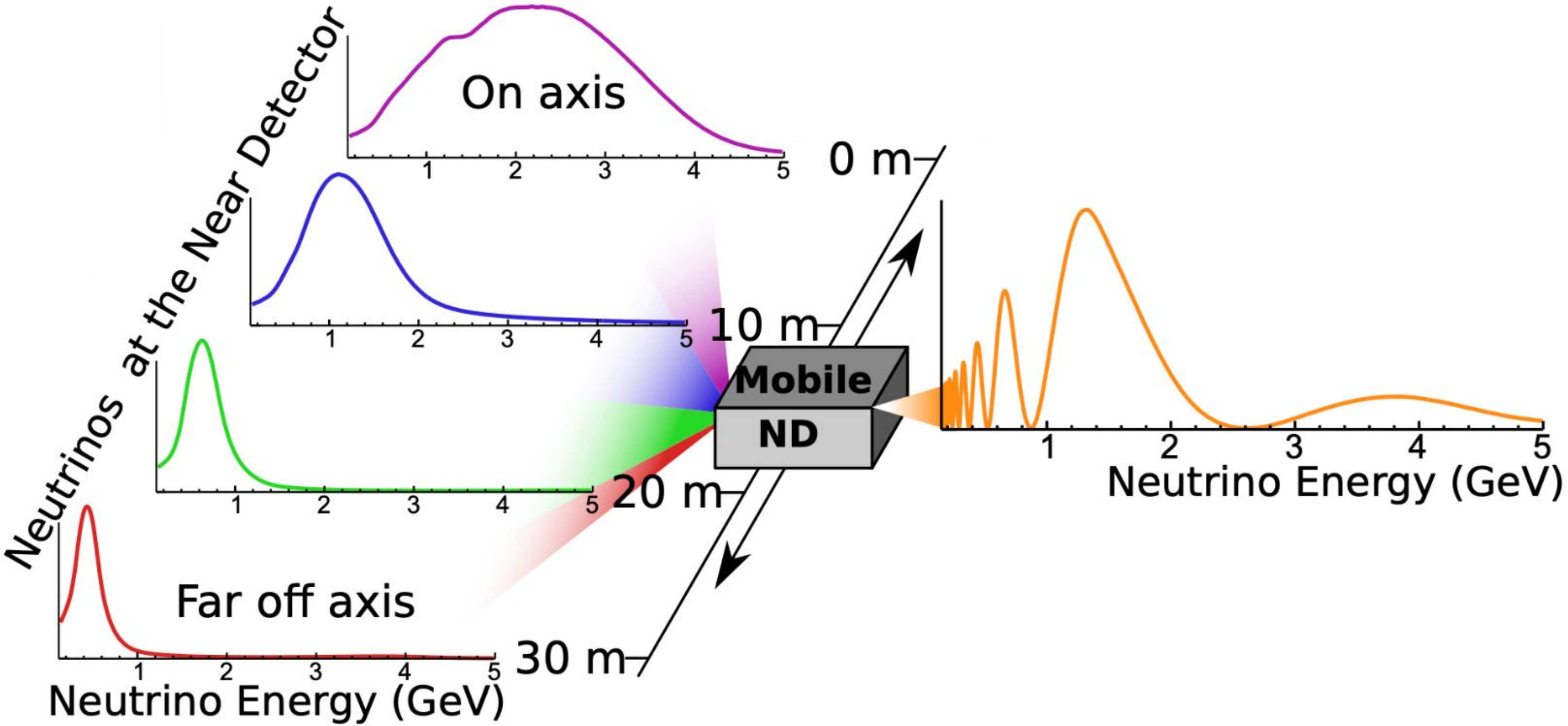
  - Bias measurements
- **Case study:** What if we mis-model neutrino energy fraction to protons but don't notice at the near detector?



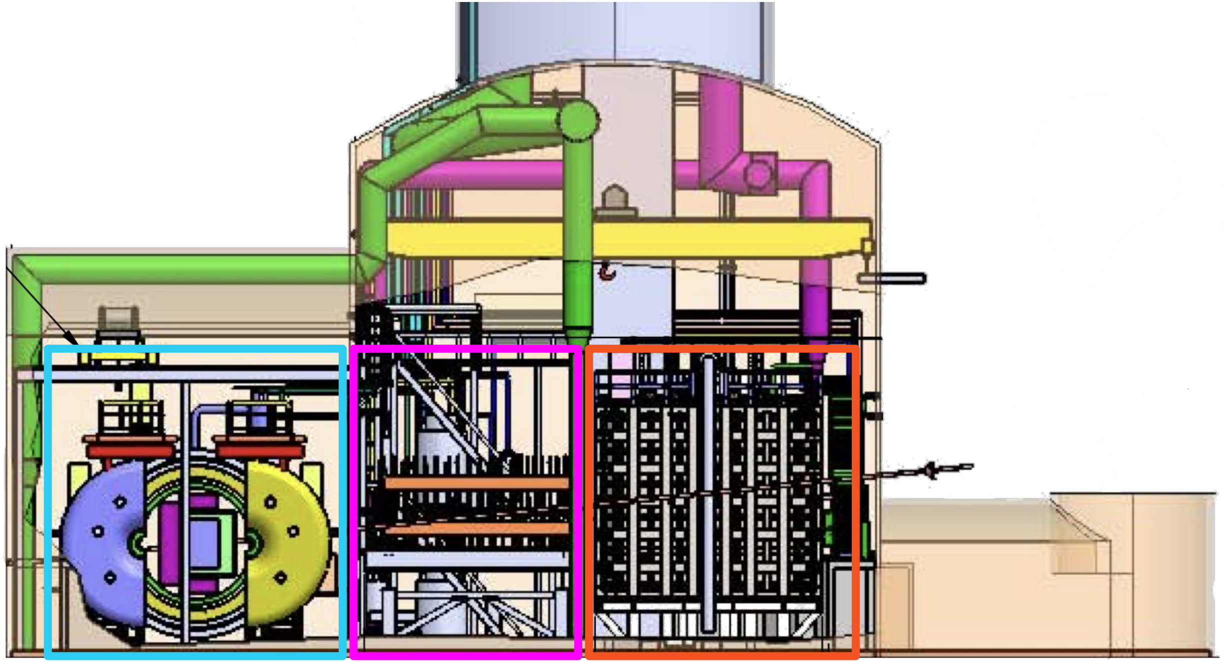
Far detector prediction

DUNE PRISM

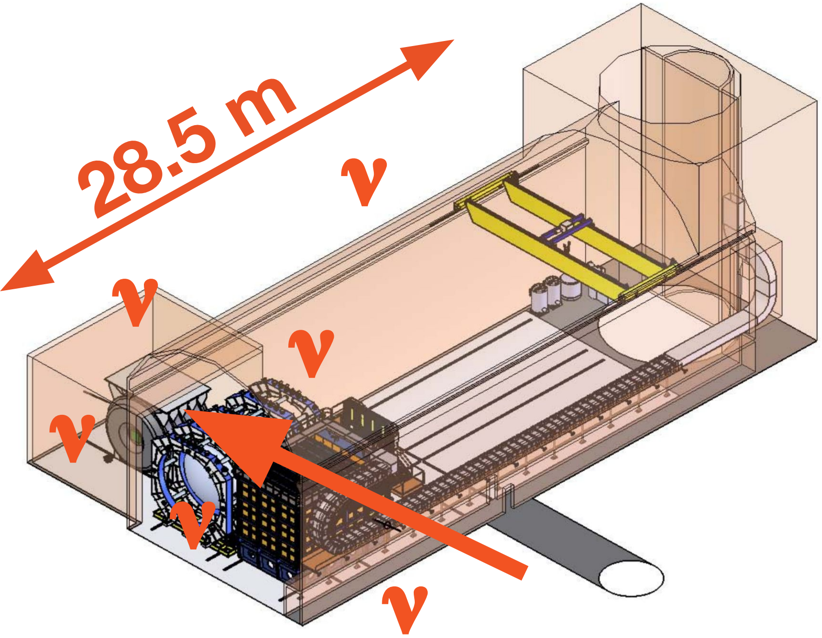
Precision Reaction-Independent Spectrum Measurement


Neutrinos at the Near Detector
On axis
Far off axis
Neutrino Energy (GeV)
1 2 3 4 5
0 m
10 m
20 m
30 m
Mobile
ND
Neutrino Energy (GeV)

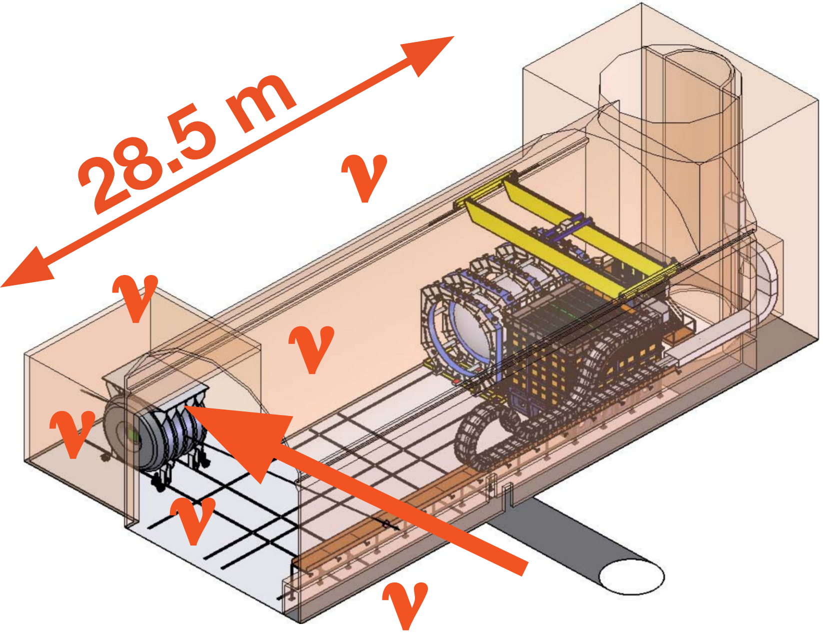
DUNE-PRISM Near Detector



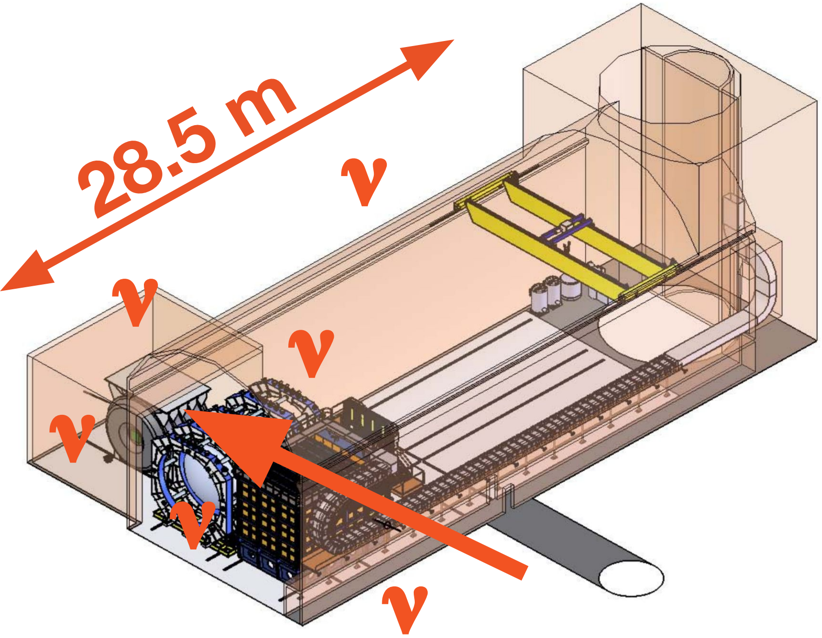
DUNE-PRISM Near Detector

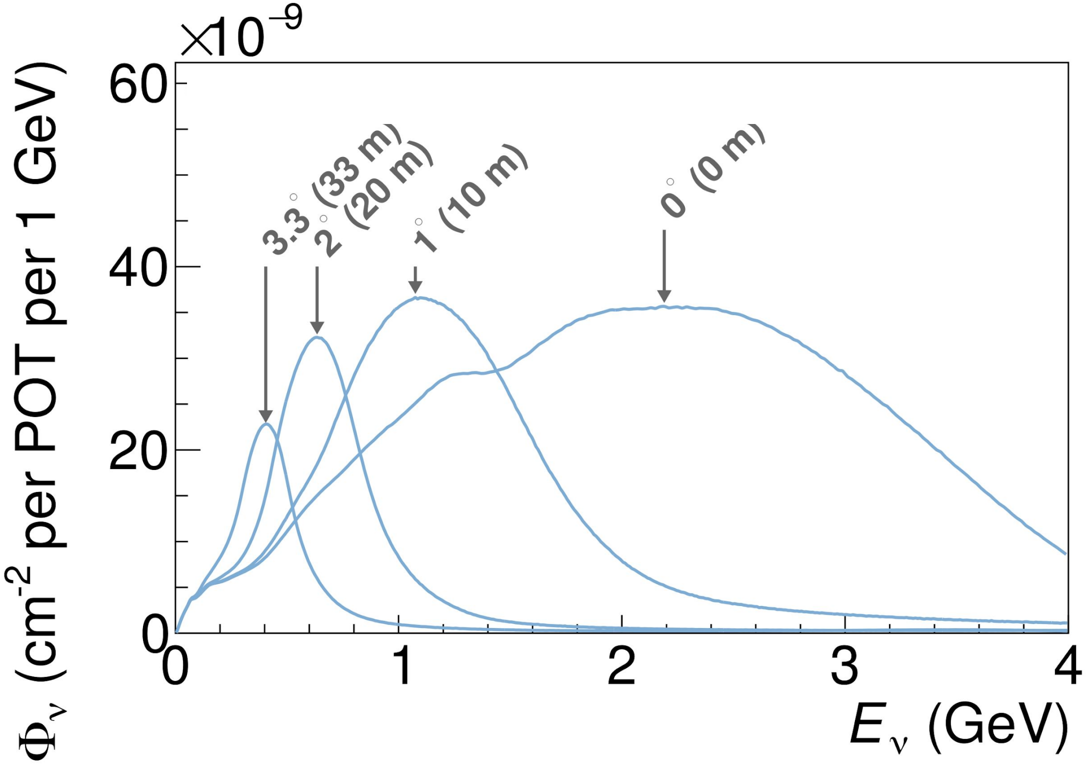


DUNE-PRISM Near Detector



Off Axis at the Near Detector





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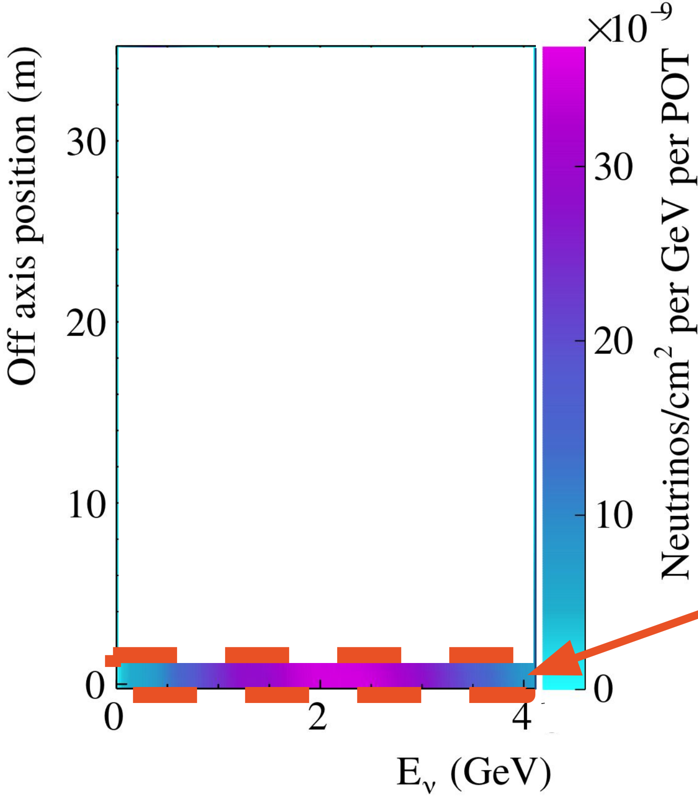

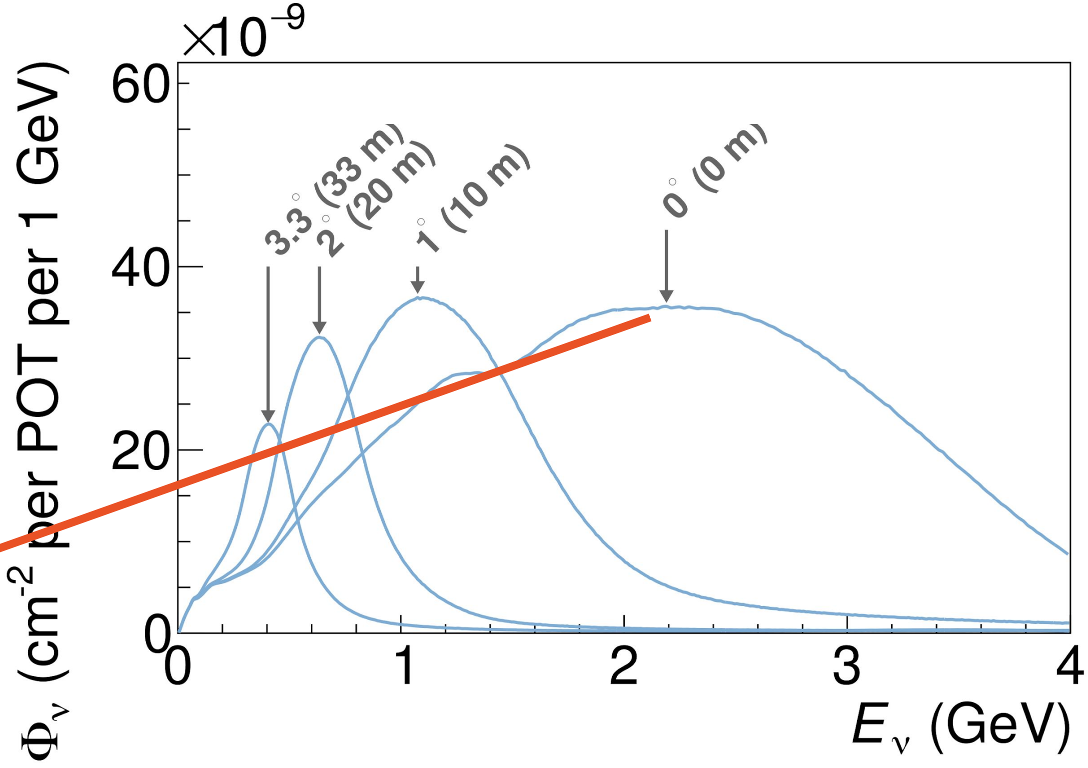

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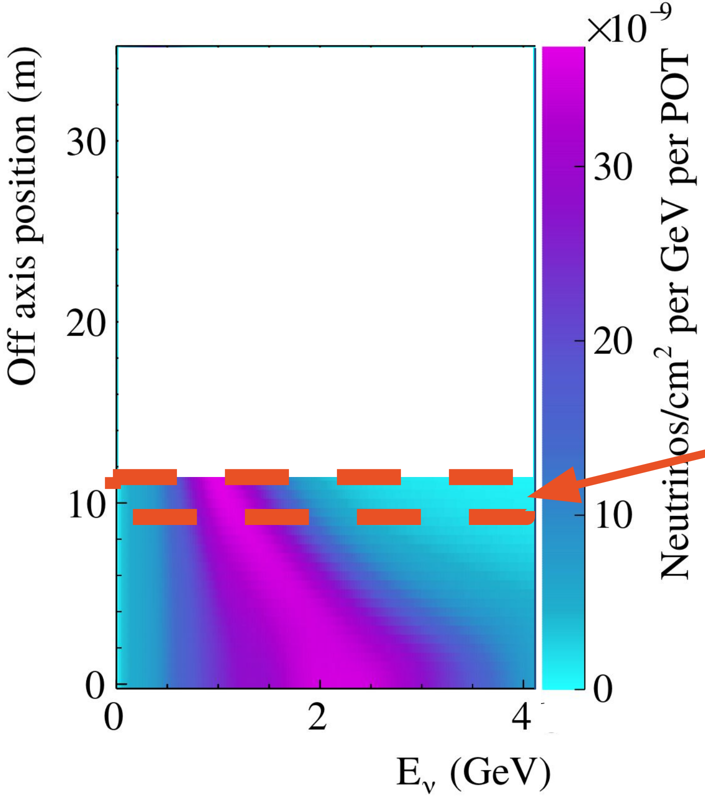

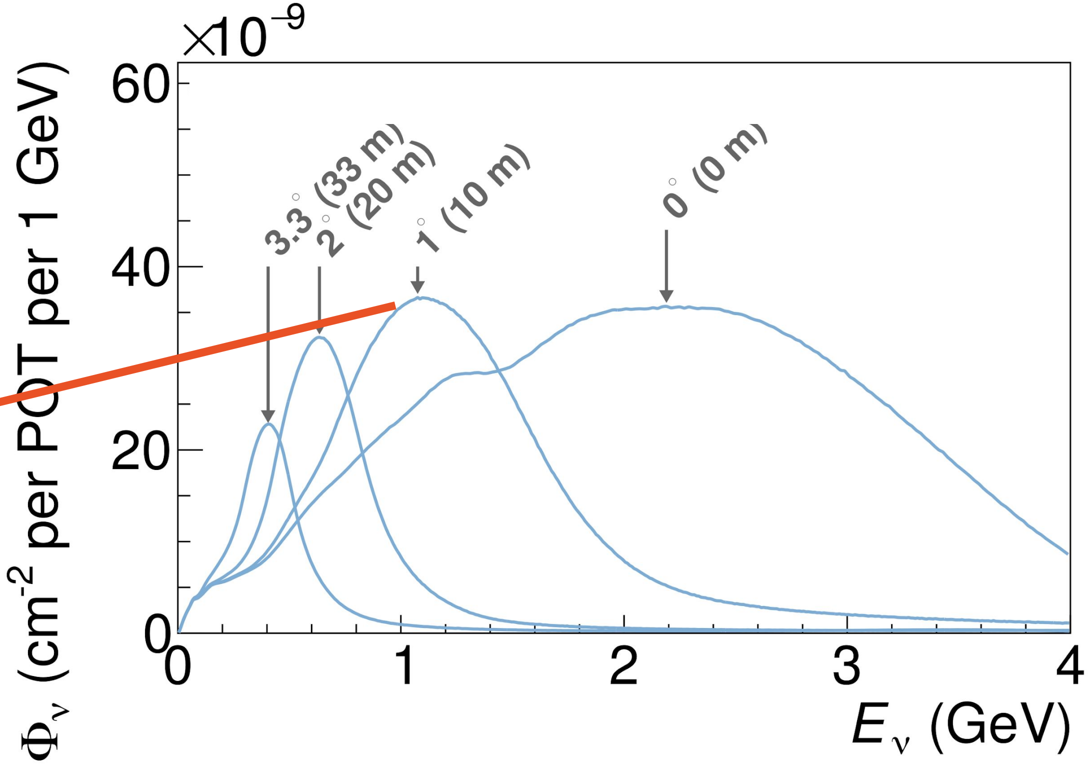

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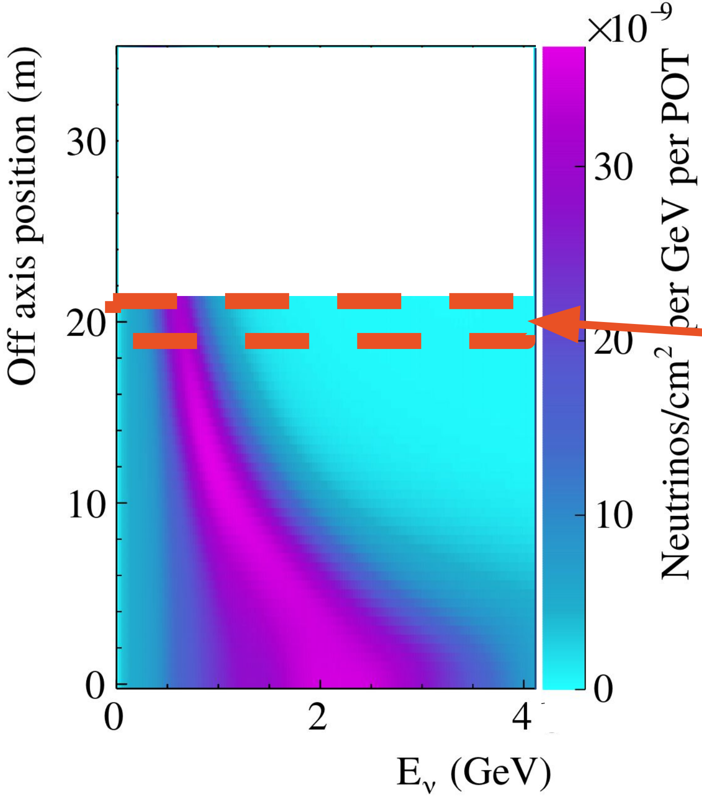

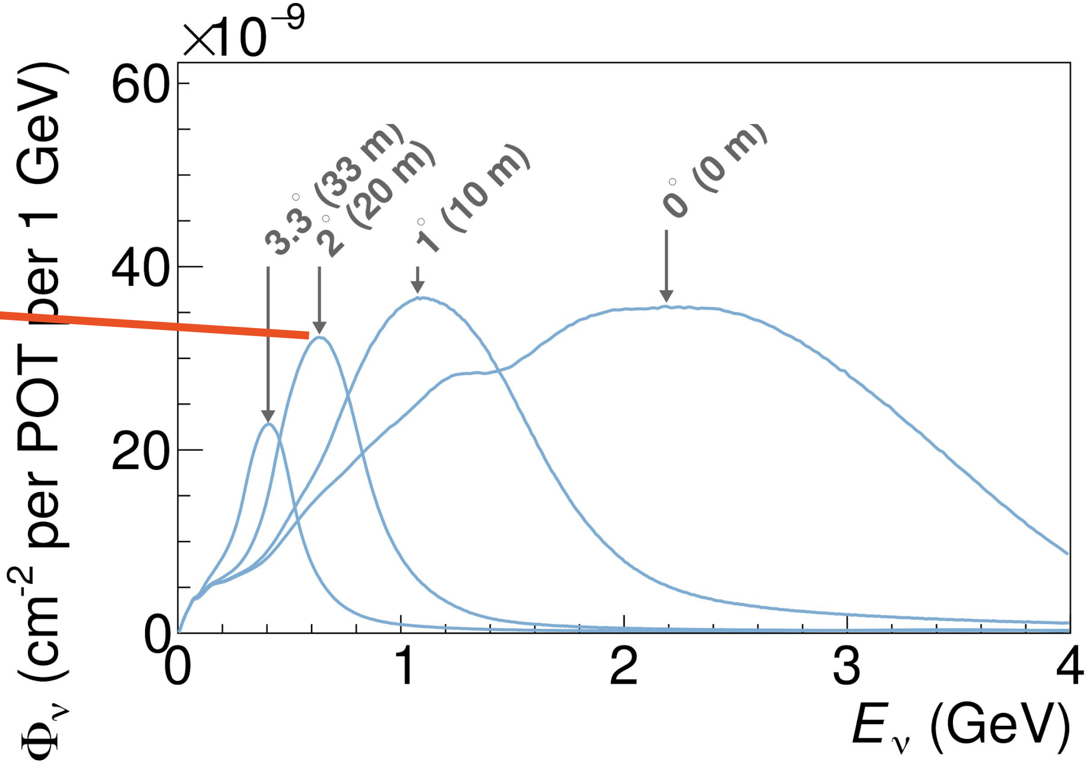

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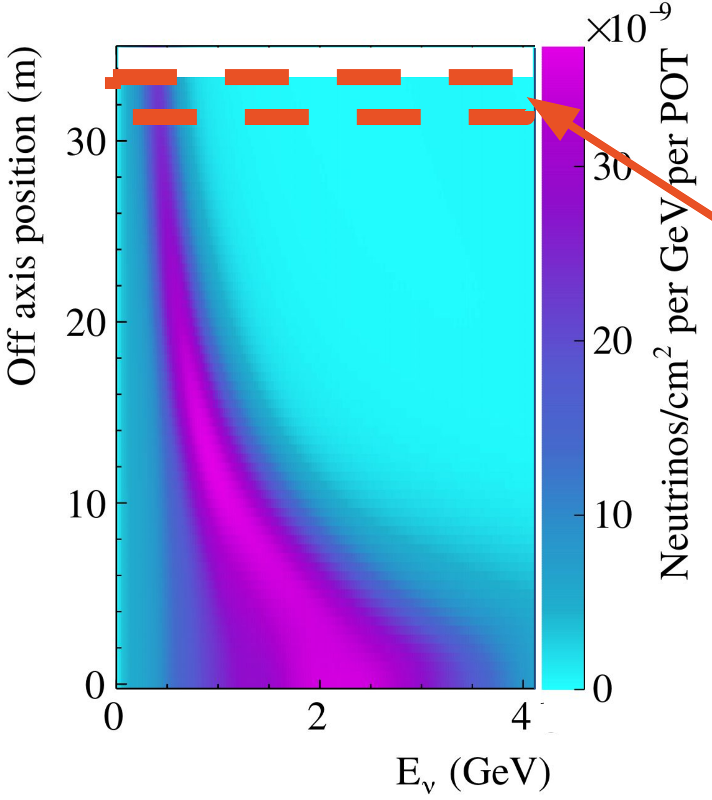
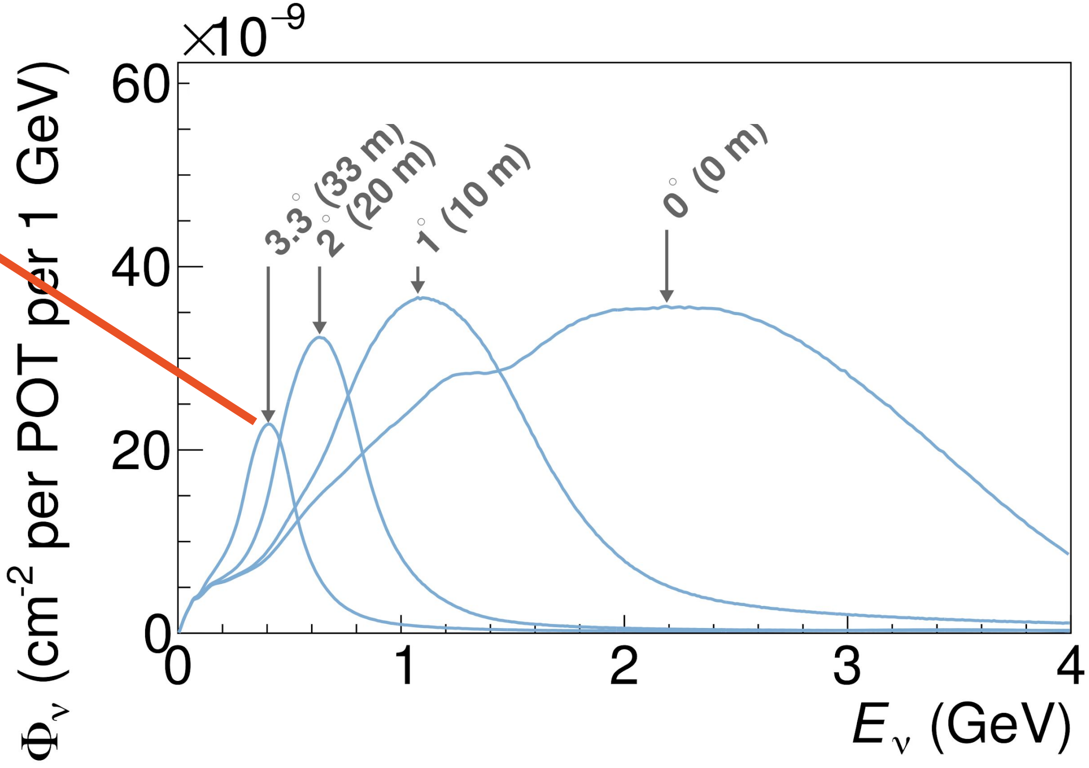
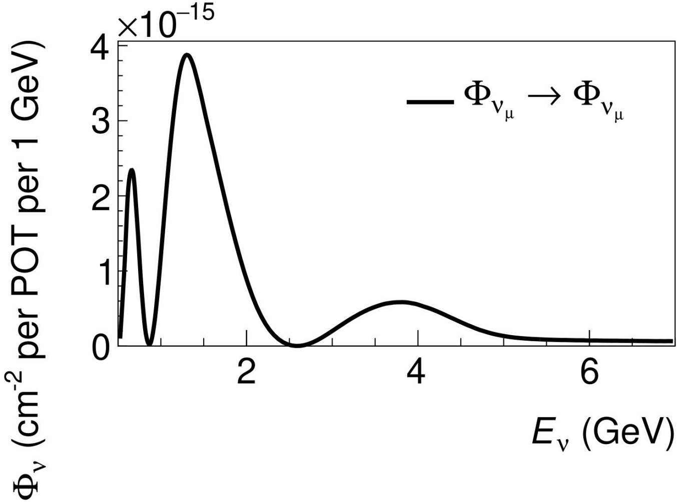




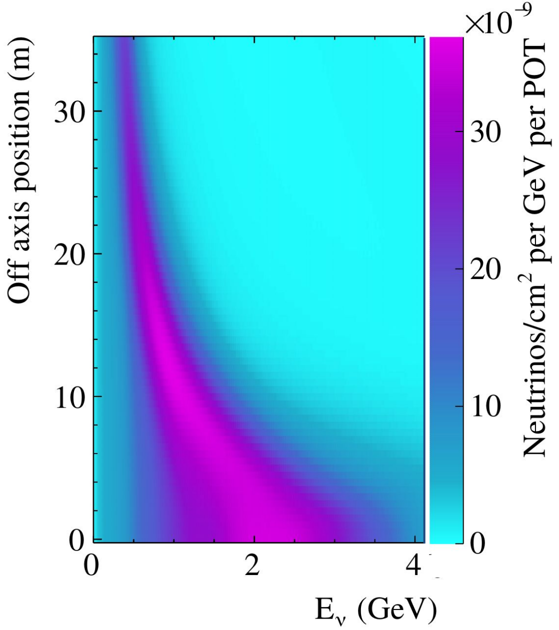
Predicting Oscillations with the Near Detector

$$\Phi^{\nu}_{\mathrm{Far}} \cdot P^{\mathcal{H}}_{\mathrm{Osc}}$$

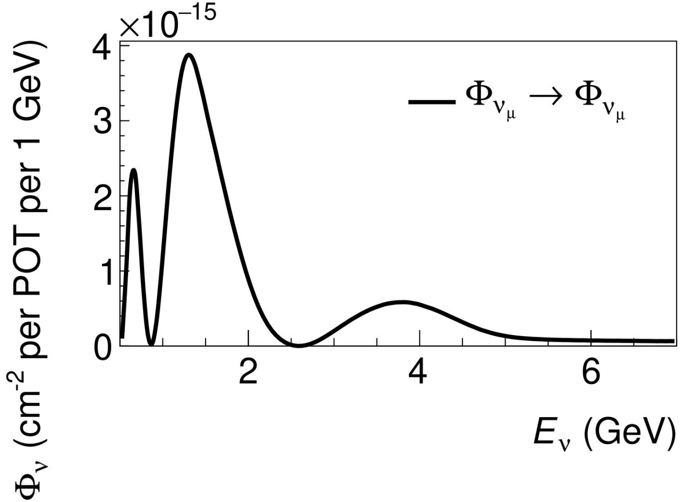


Predicting Oscillations with the Near Detector

$$\Phi^{\nu}_{\mathrm{Near}}$$

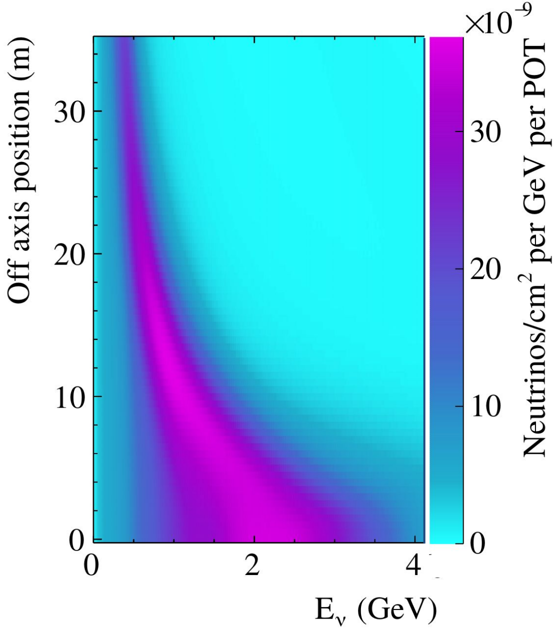


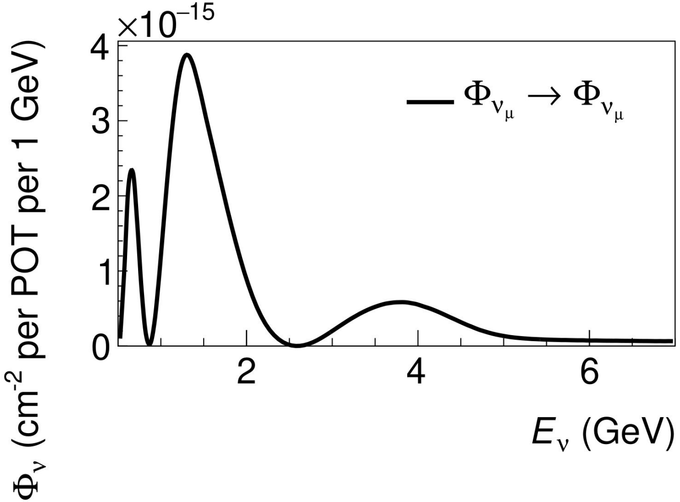
$$\Phi^{\nu}_{\mathrm{Far}} \cdot P^{\mathcal{H}}_{\mathrm{Osc}}$$



Predicting Oscillations with the Near Detector

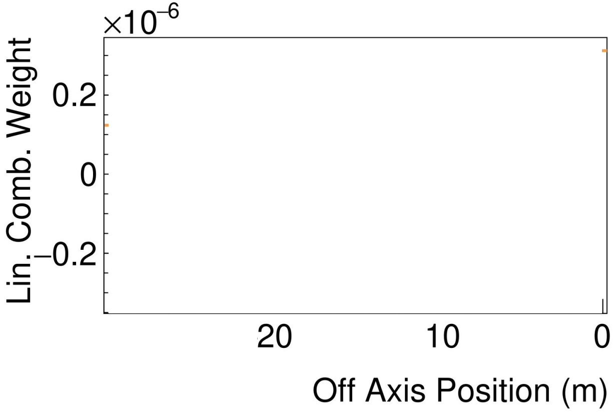
$$\Phi^{\nu}_{\mathrm{Near}} \qquad \vec{\Phi}^{\nu}_{\mathrm{Far}} \cdot P^{\mathcal{H}}_{\mathrm{Osc}}$$

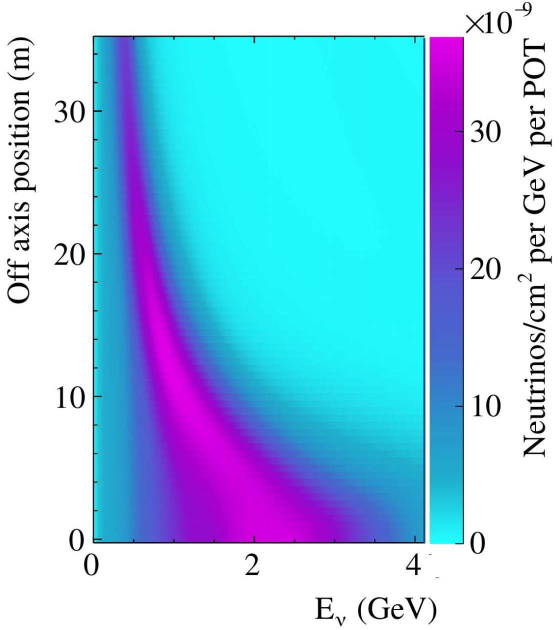


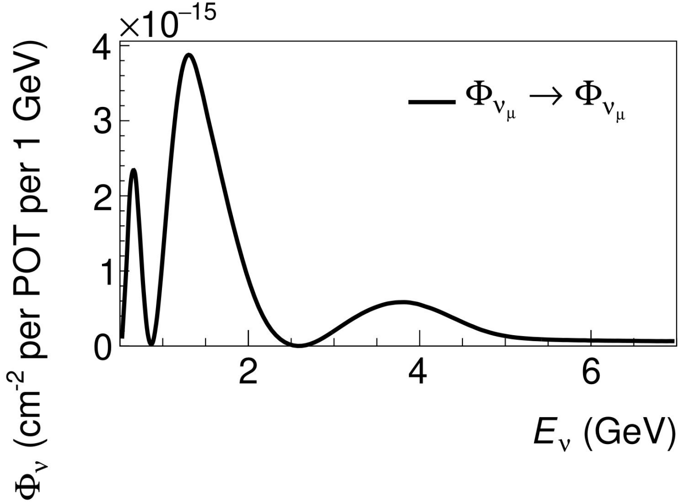


Predicting Oscillations with the Near Detector

$$\vec{\mathcal{C}} \cdot \Phi^{\nu}_{\mathrm{Near}} = \vec{\Phi}^{\nu}_{\mathrm{Far}} \cdot P^{\mathcal{H}}_{\mathrm{Osc}}$$

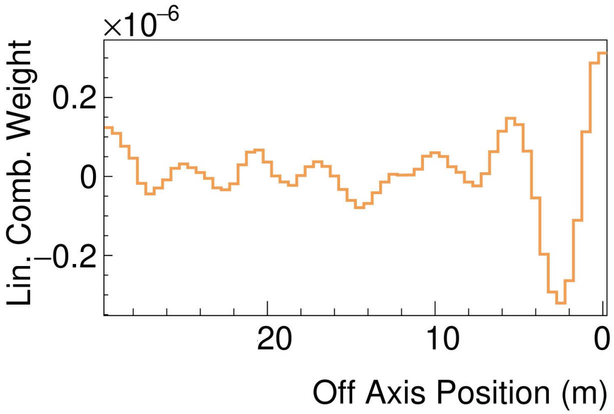


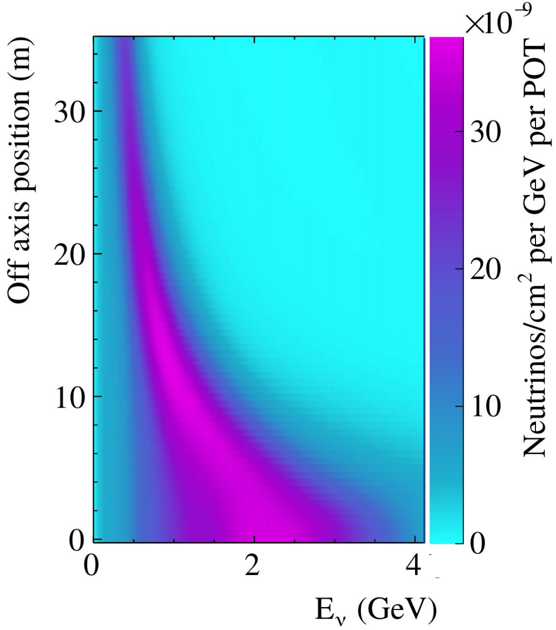


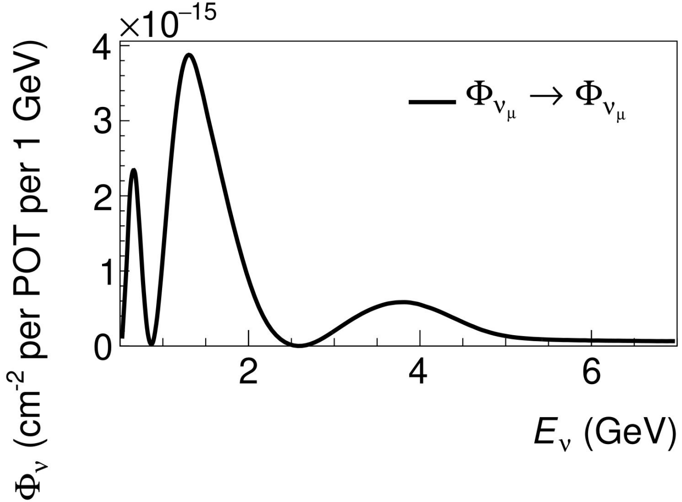


Predicting Oscillations with the Near Detector

$$\vec{\mathcal{C}} \cdot \Phi^{\nu}_{\mathrm{Near}} = \vec{\Phi}^{\nu}_{\mathrm{Far}} \cdot P^{\mathcal{H}}_{\mathrm{Osc}}$$

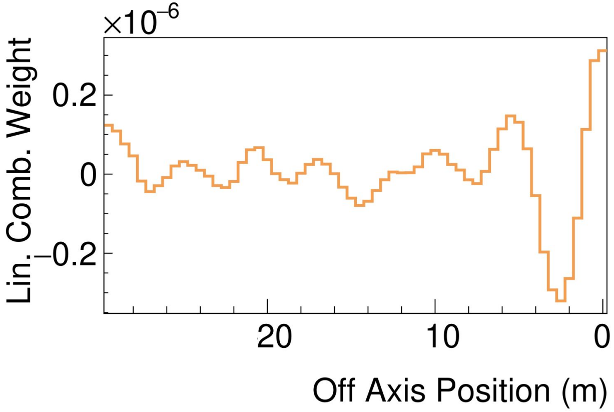


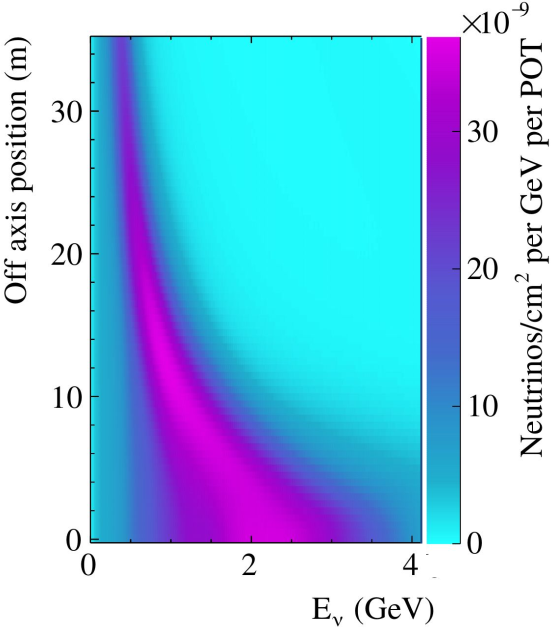


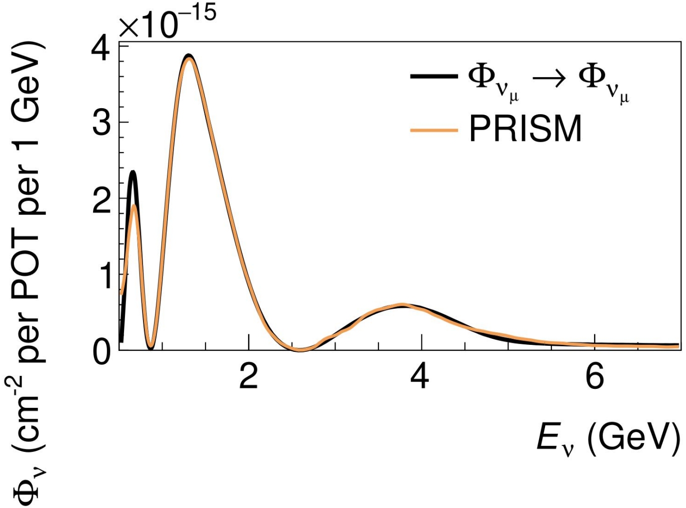


Predicting Oscillations with the Near Detector

$$\vec{\mathcal{C}} \cdot \Phi^{\nu}_{\mathrm{Near}} = \vec{\Phi}^{\nu}_{\mathrm{Far}} \cdot P^{\mathcal{H}}_{\mathrm{Osc}}$$

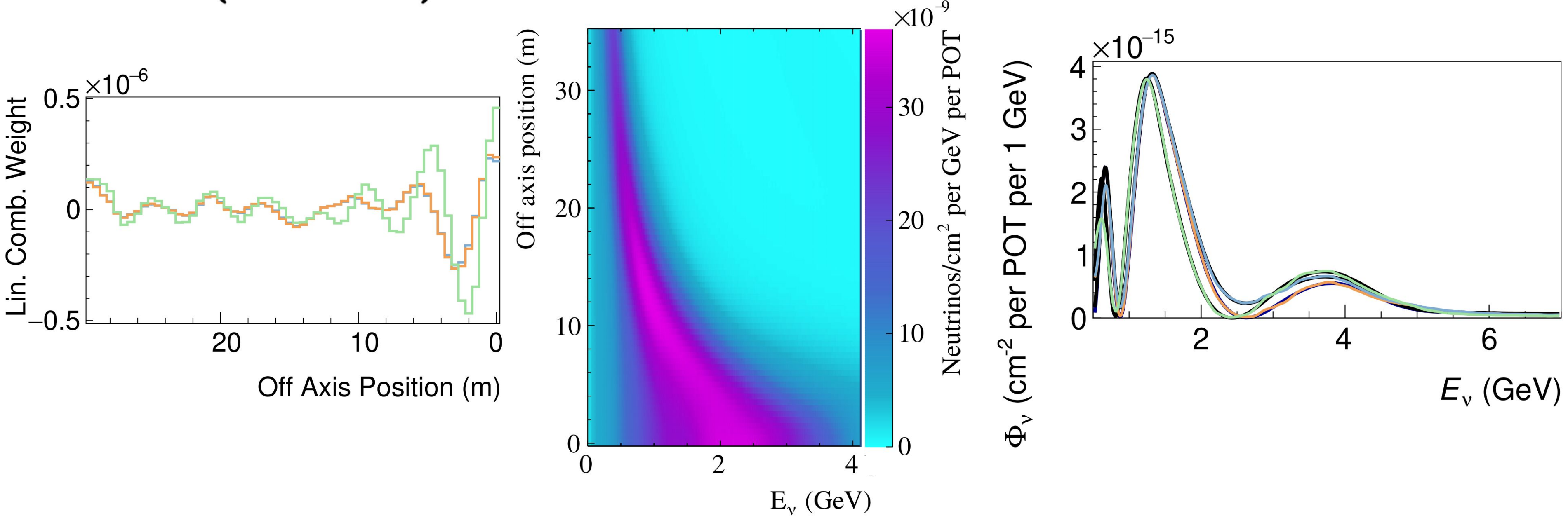






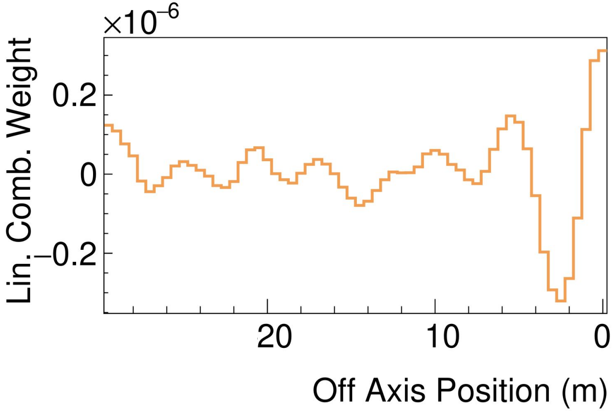
Predicting Oscillations with the Near Detector

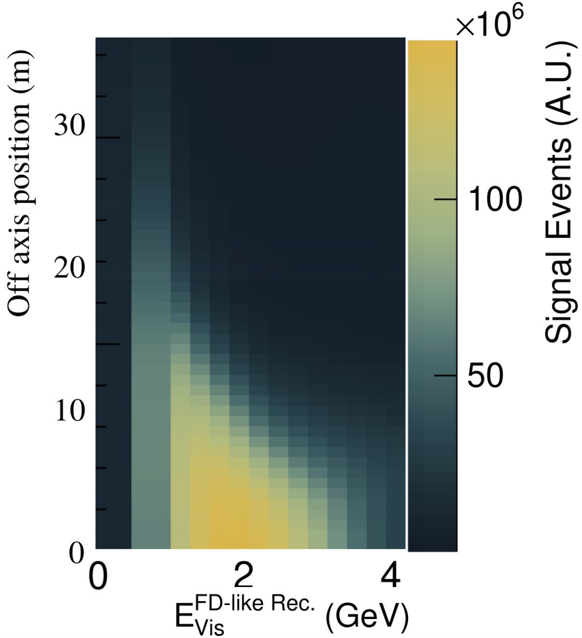
$$\vec{\mathcal{C}}\left(P^{\mathcal{H}}_{\mathrm{Osc}}\right) \cdot \mathbf{\Phi}^{\nu}_{\mathrm{Near}} = \vec{\Phi}^{\nu}_{\mathrm{Far}} \cdot P^{\mathcal{H}}_{\mathrm{Osc}}$$

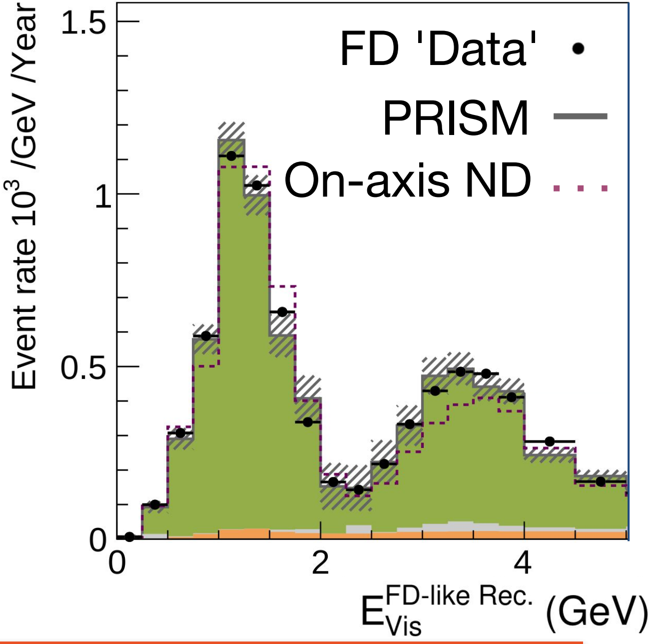


Predicting Oscillations with the Near Detector

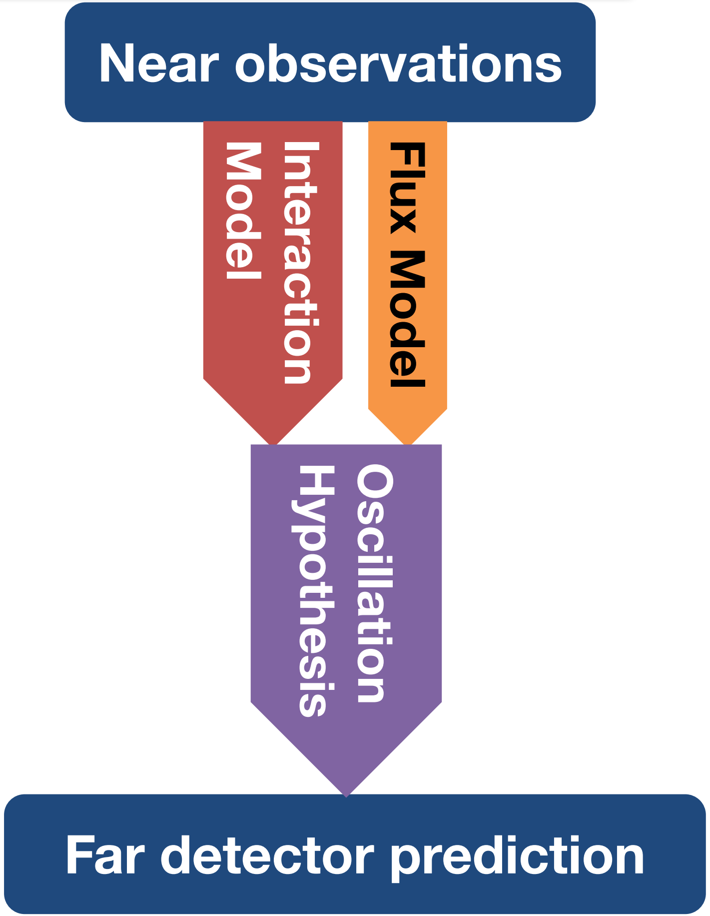
$$\vec{\mathcal{C}}\left(P^{\mathcal{H}}_{\mathrm{Osc}}\right) \cdot \mathbf{R}^{\nu}_{\mathrm{Near}} \left(= \mathbf{\Phi}^{\nu}_{\mathrm{Near}} \cdot \sigma^{\nu}\right) = \vec{\mathrm{R}}^{\nu}_{\mathrm{Far}} \left(= \vec{\Phi}^{\nu}_{\mathrm{Far}} \cdot P^{\mathcal{H}}_{\mathrm{Osc}} \cdot \sigma^{\nu}\right)$$



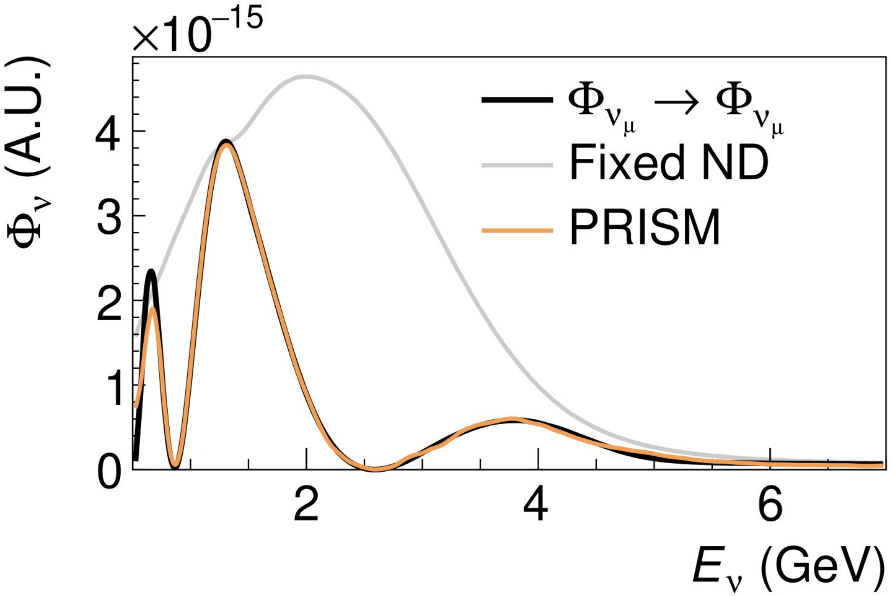




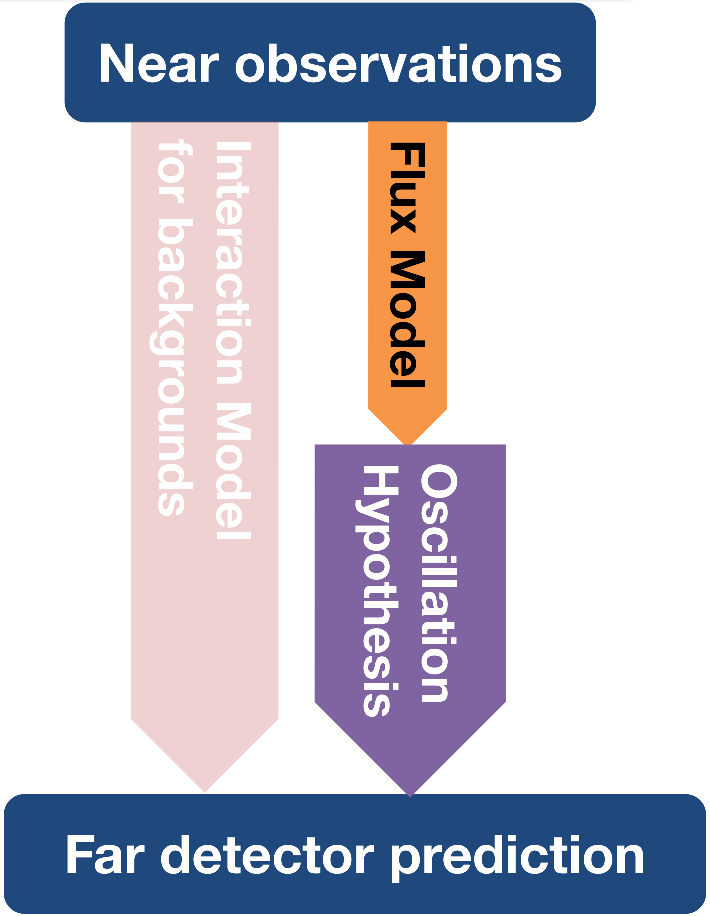
Why PRISM?


Near observations
Interaction Model
Flux Model
Oscillation Hypothesis
Far detector prediction

Why PRISM?



- Direct extrapolation of ND constraint
- Resilient to unknown unknowns in signal modelling

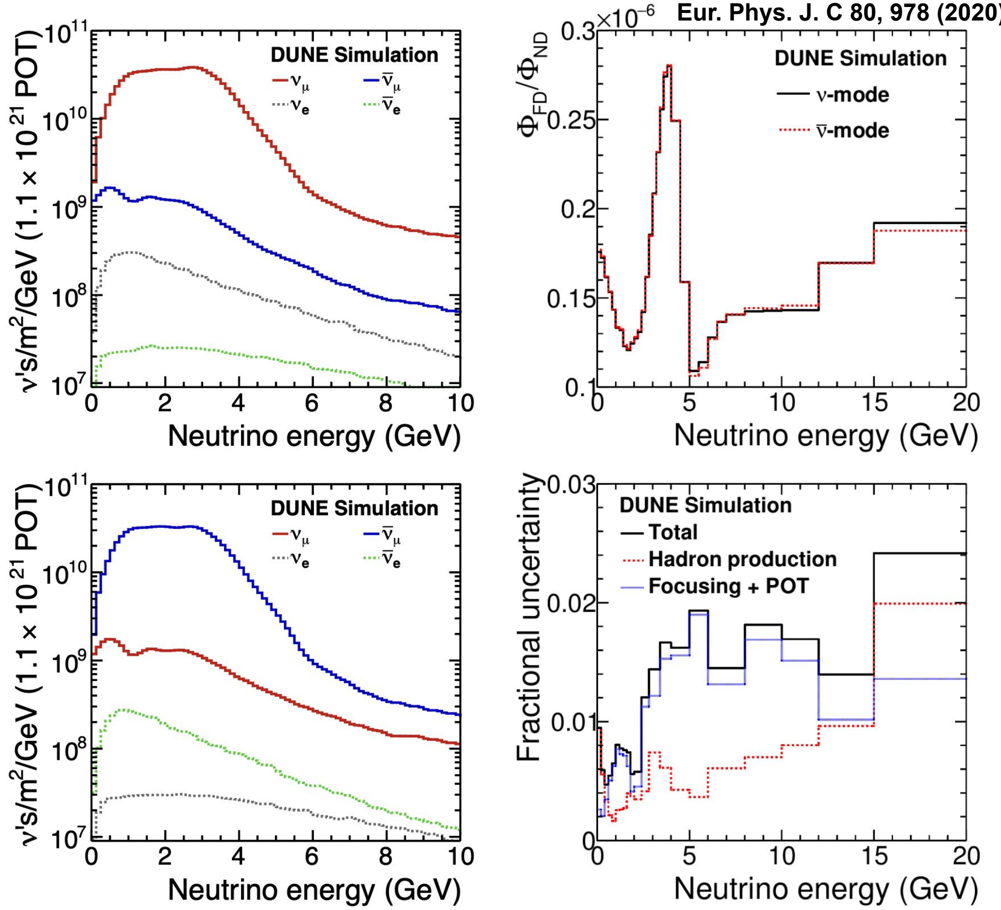


Summary

- Unprecedented sensitivity to PMNS oscillations
  - PRISM insures against poor interaction modelling
  - CPV and Mass Ordering in one experiment
- Wide physics programme beyond standard oscillations

Backups

DUNE Fluxes



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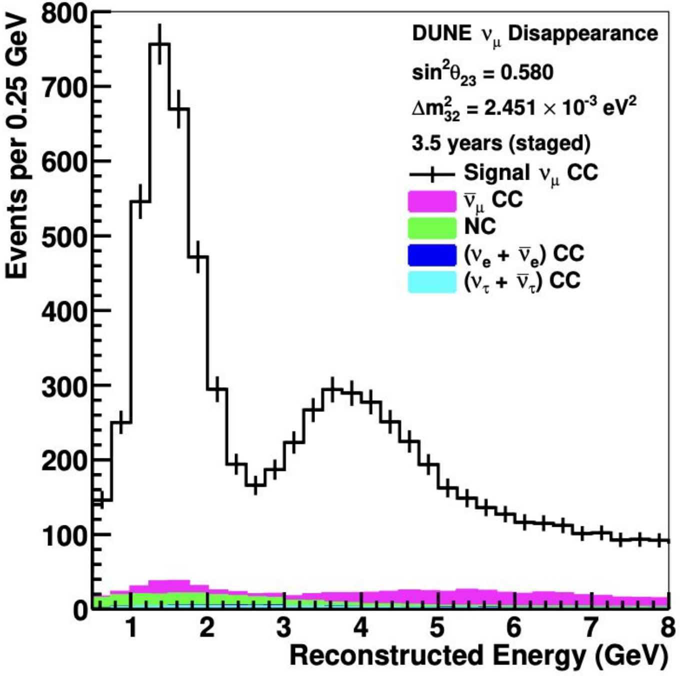
Disp Samples



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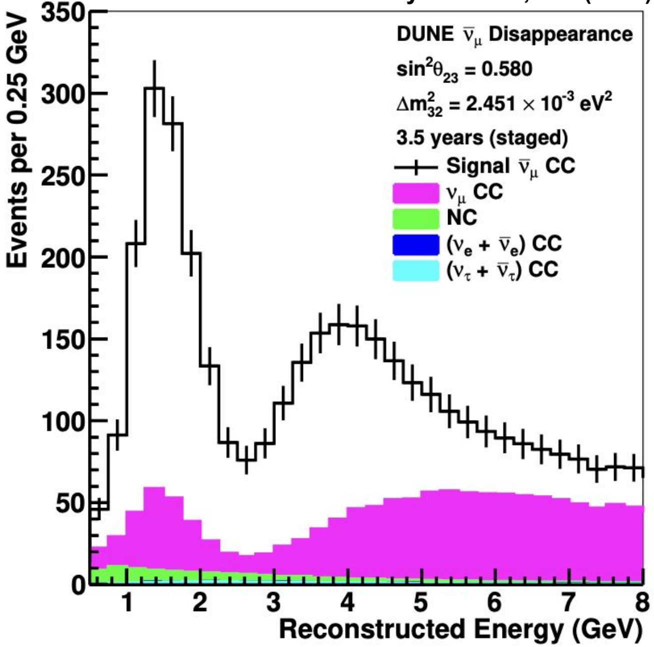

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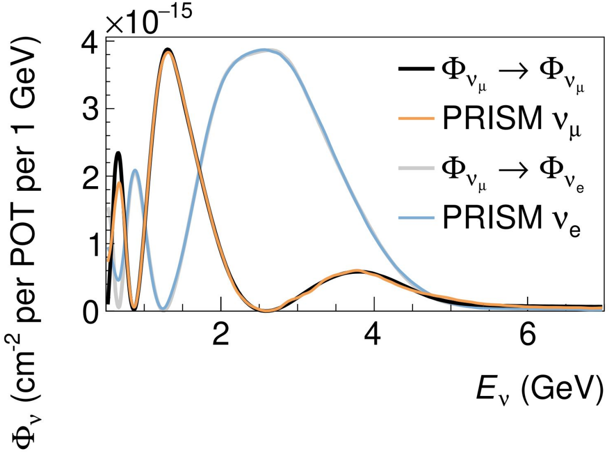
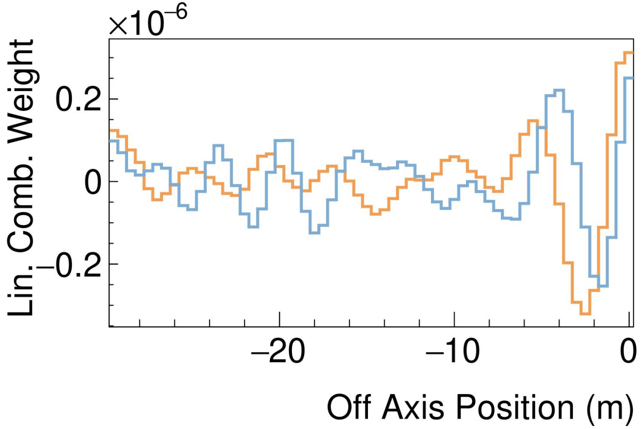
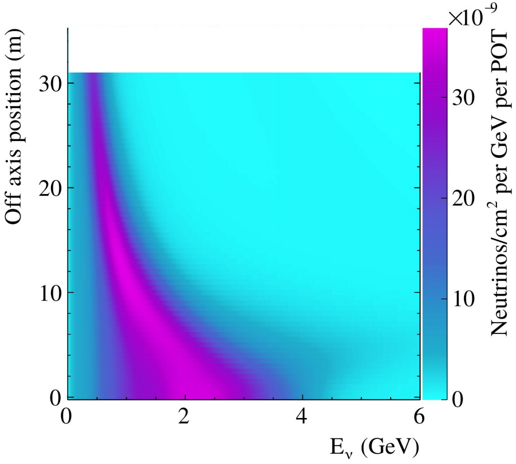
PRISM Appearance







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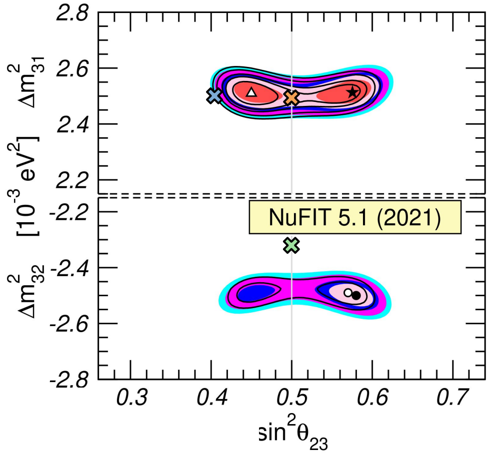
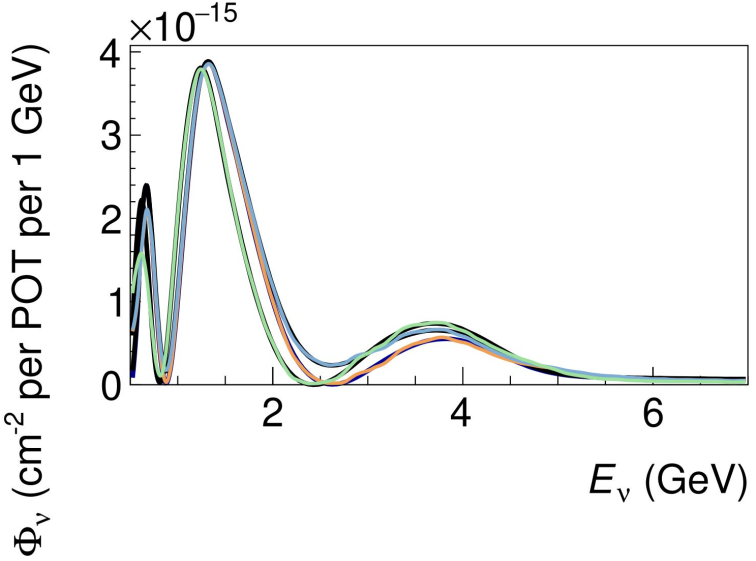
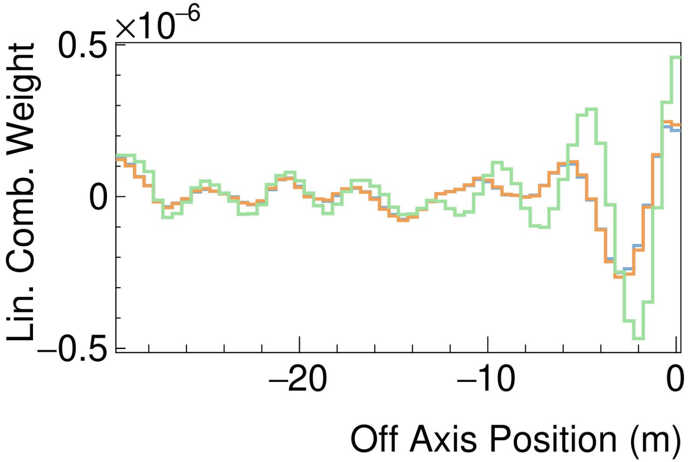
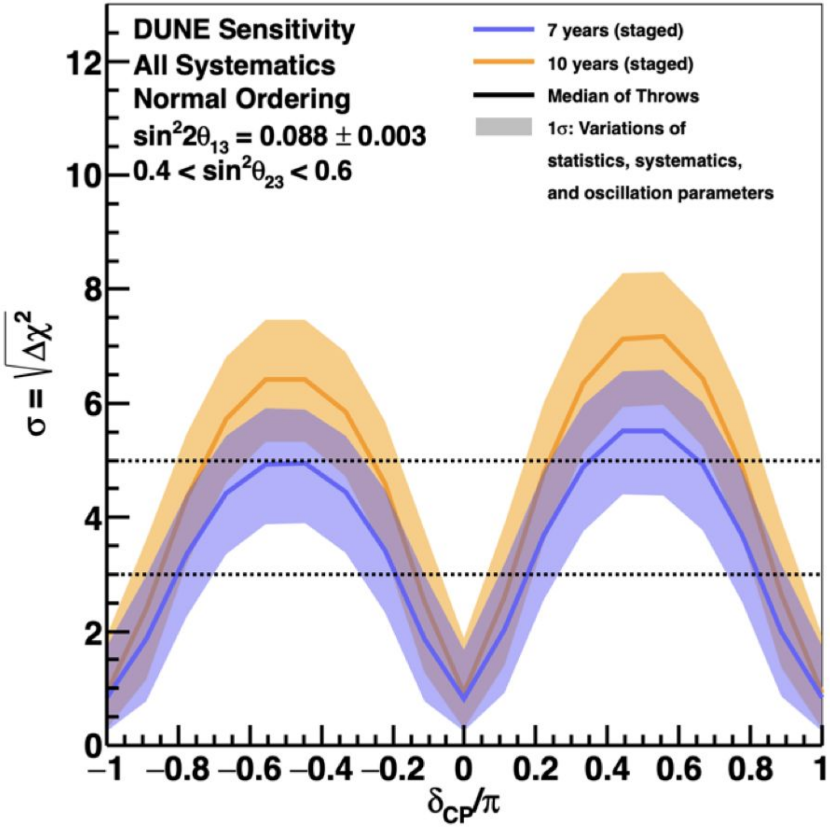
Disappearance Hypotheses

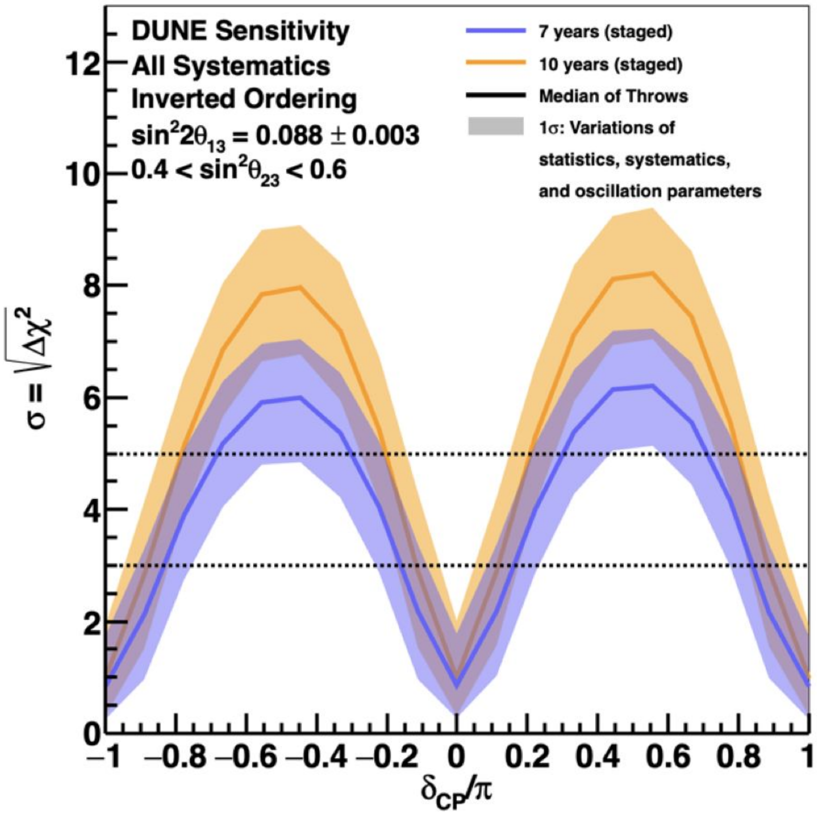




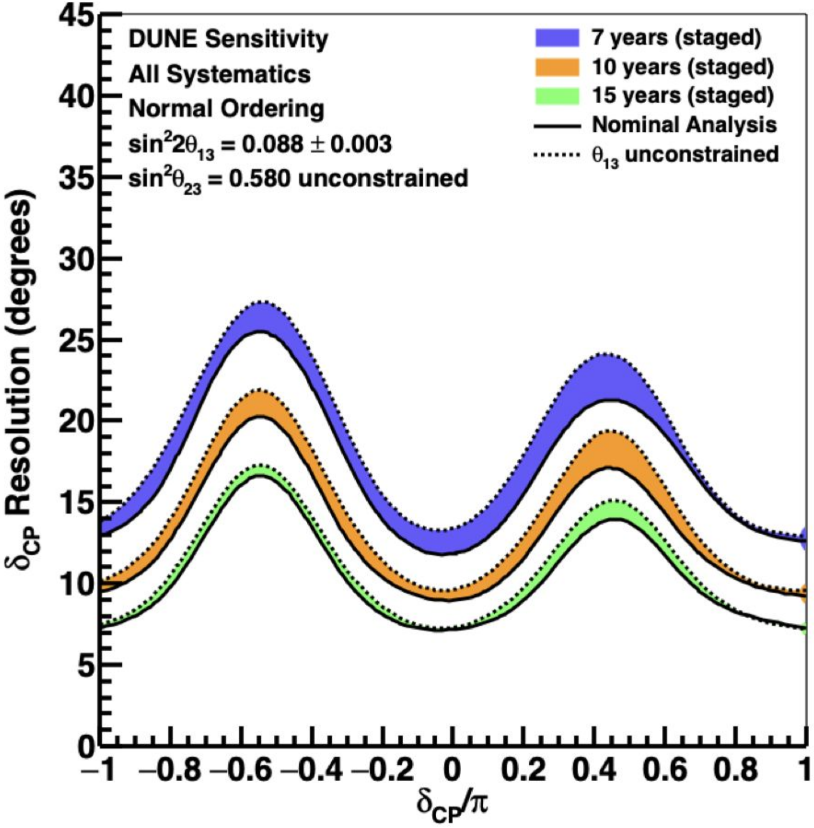


Macdonald's Plots

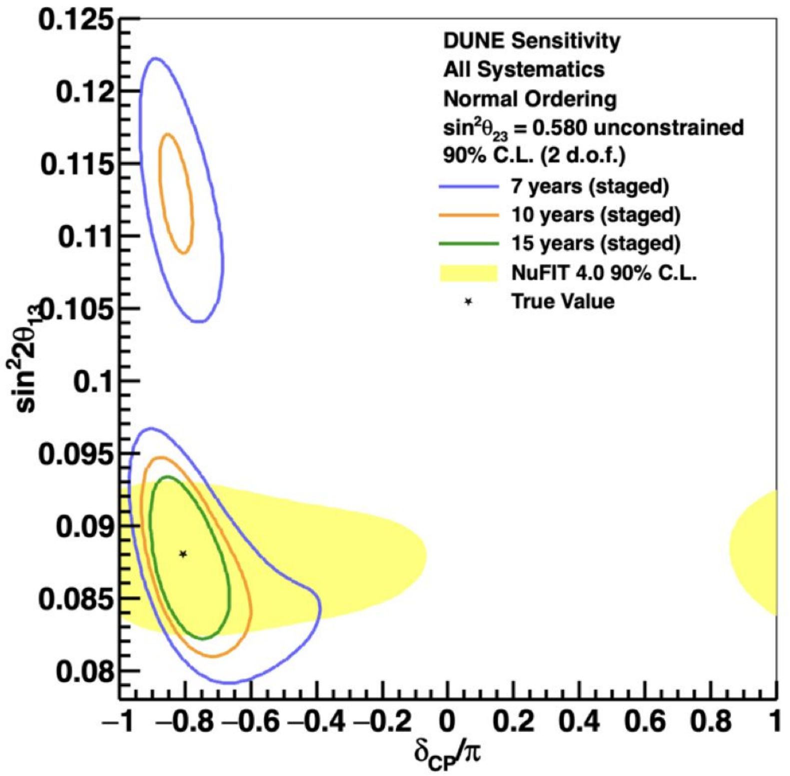




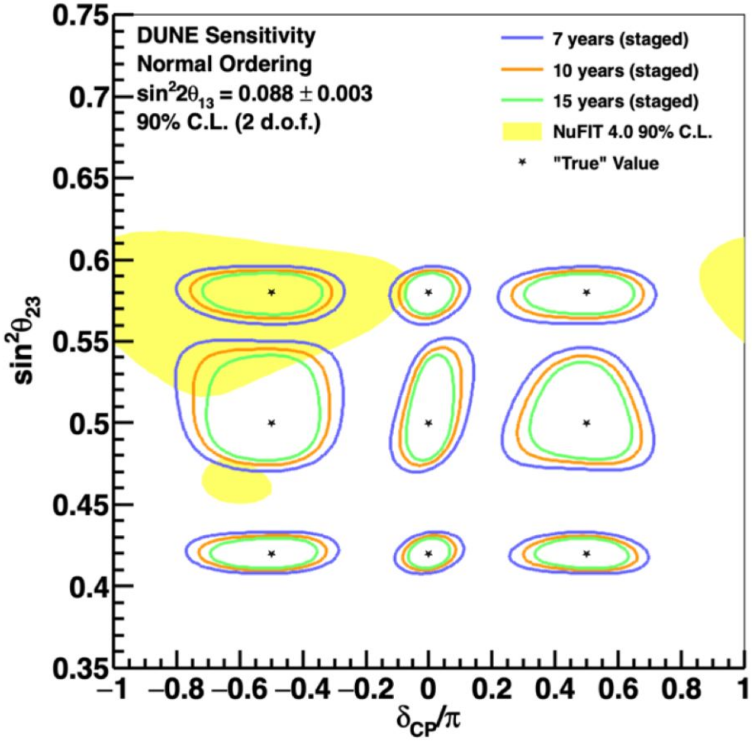
δ_{CP} Resolution

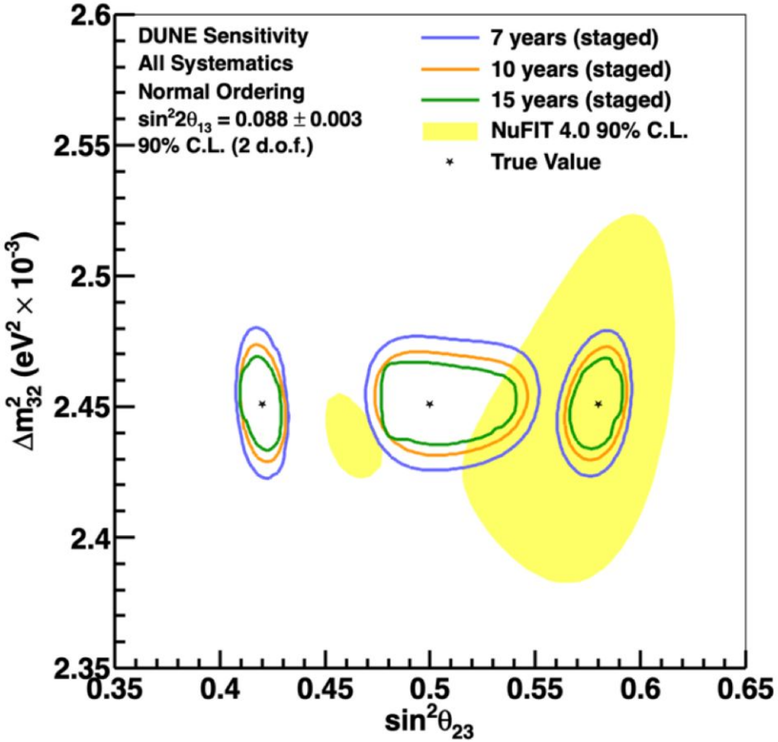


δ_{CP} and θ_{13}

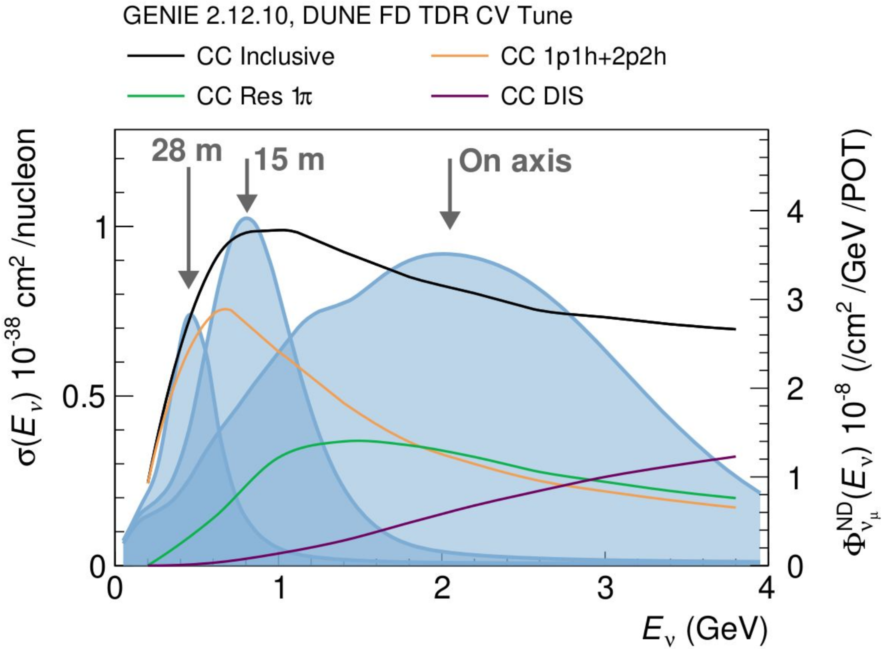


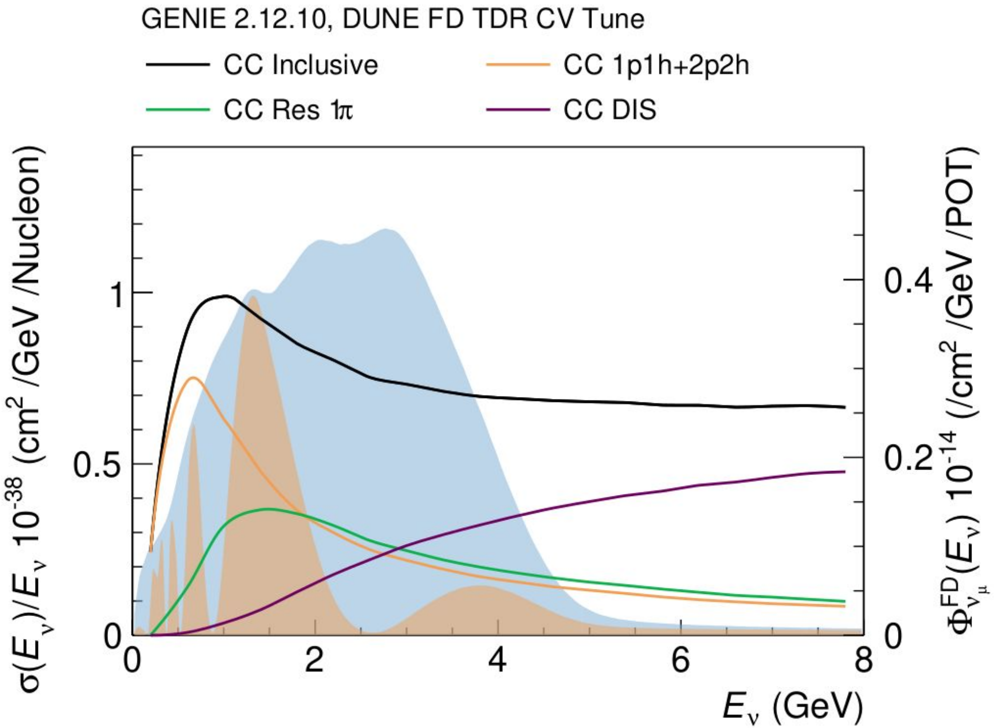
Sensitivities for different scenarios





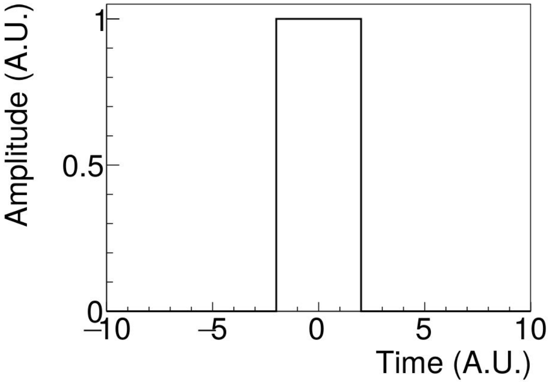
Cross-sections





Discrete Fourier Transforms

- Approximate function as a linear sum of sines and cosines



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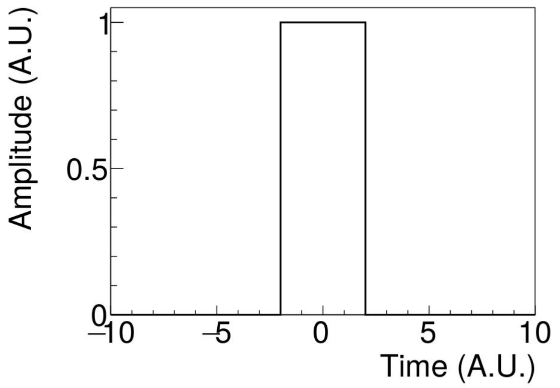

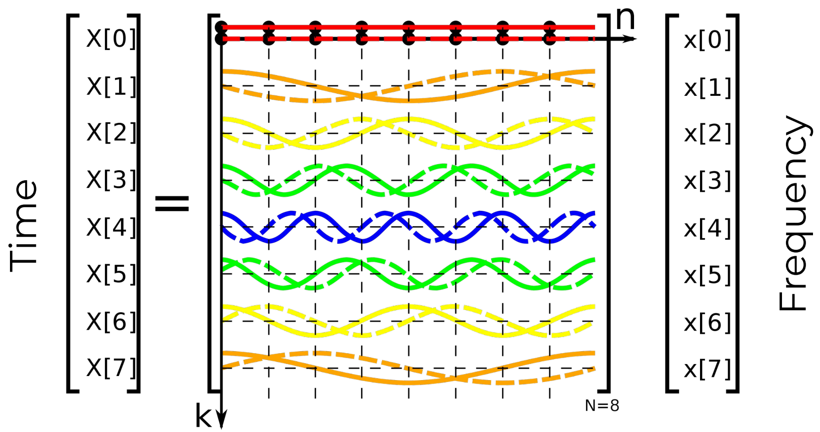

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Discrete Fourier Transforms

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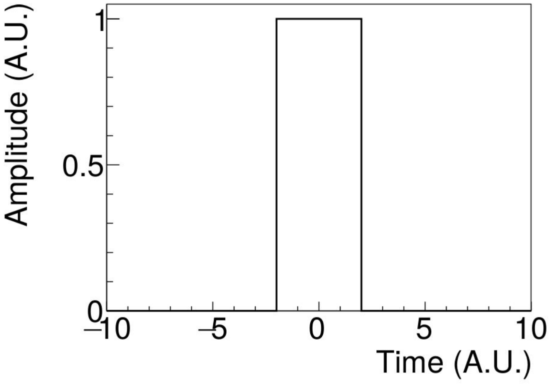

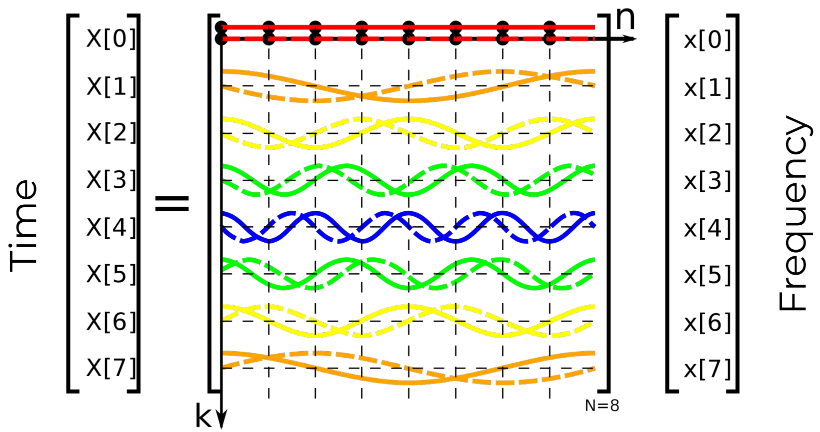

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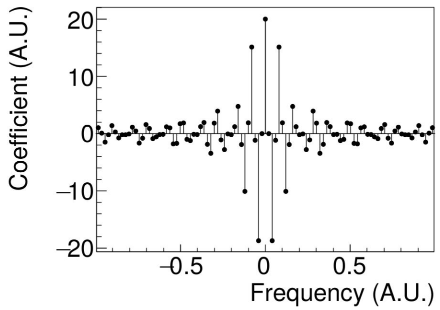

Discrete Fourier Transforms

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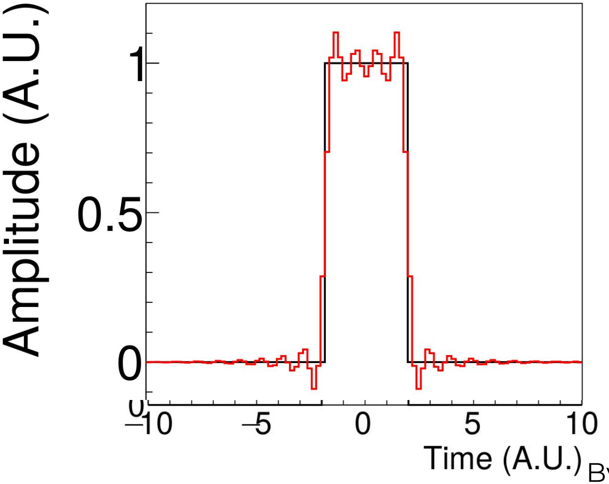

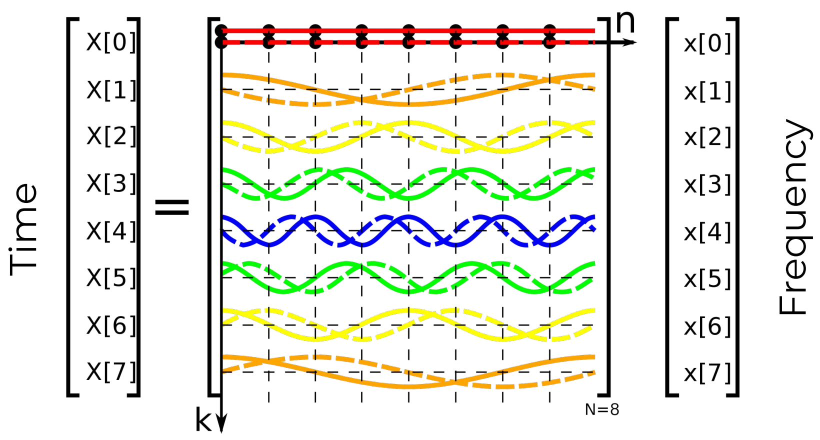

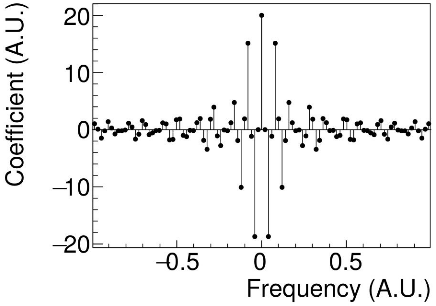

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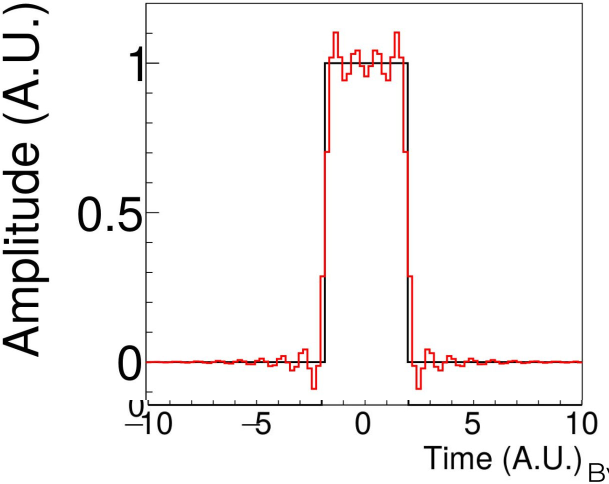

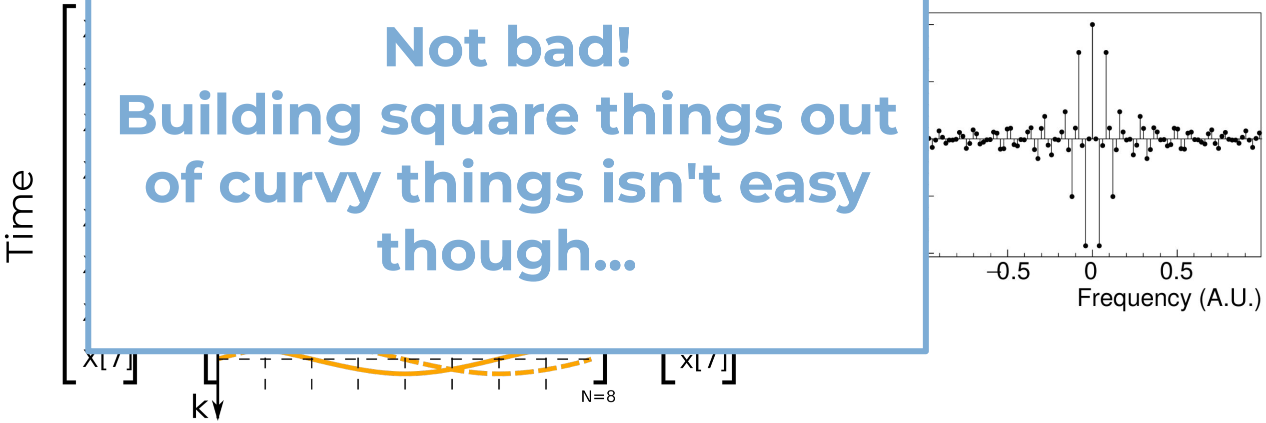

Not bad!
Building square things out of curvy things isn't easy though...

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DUNE PRISM