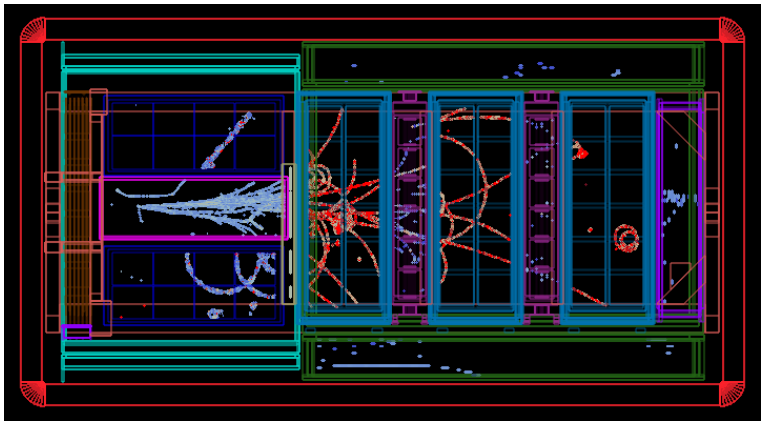


T2K Near Detector Contribution to the Neutrino Oscillations Analysis

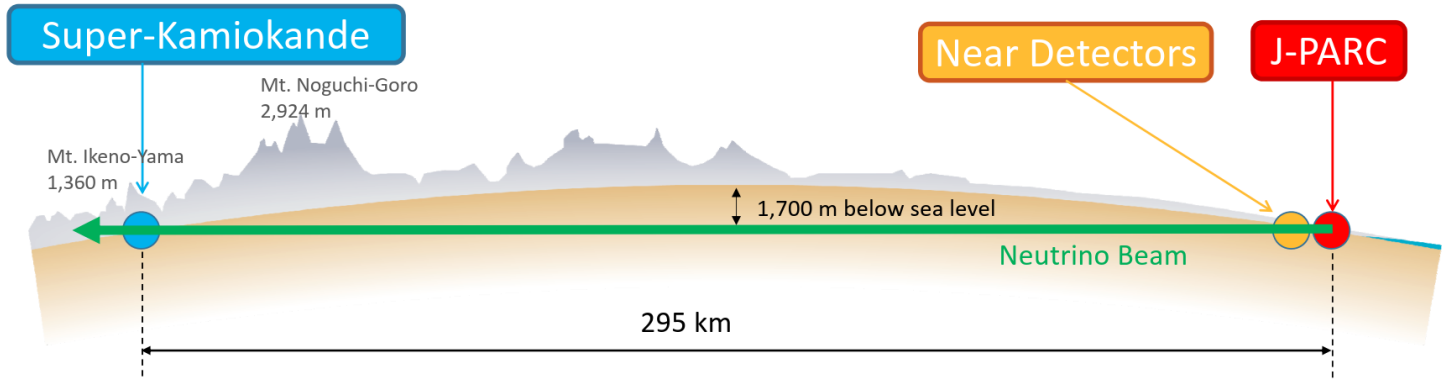
Ewan Miller

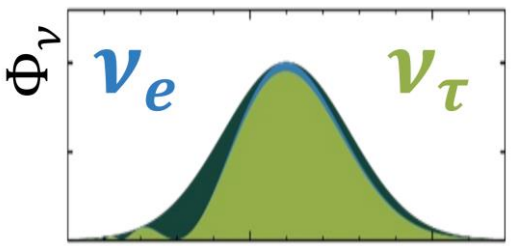
IFAE
17/09/2024

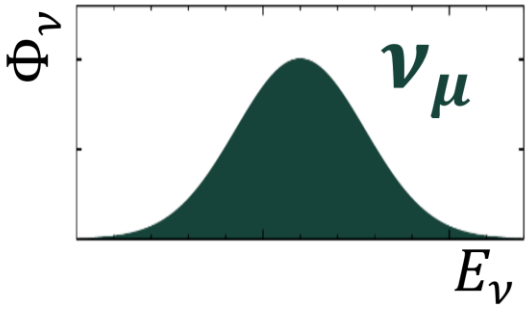
Institut de Física d'Altes Energies

The T2K Experiment

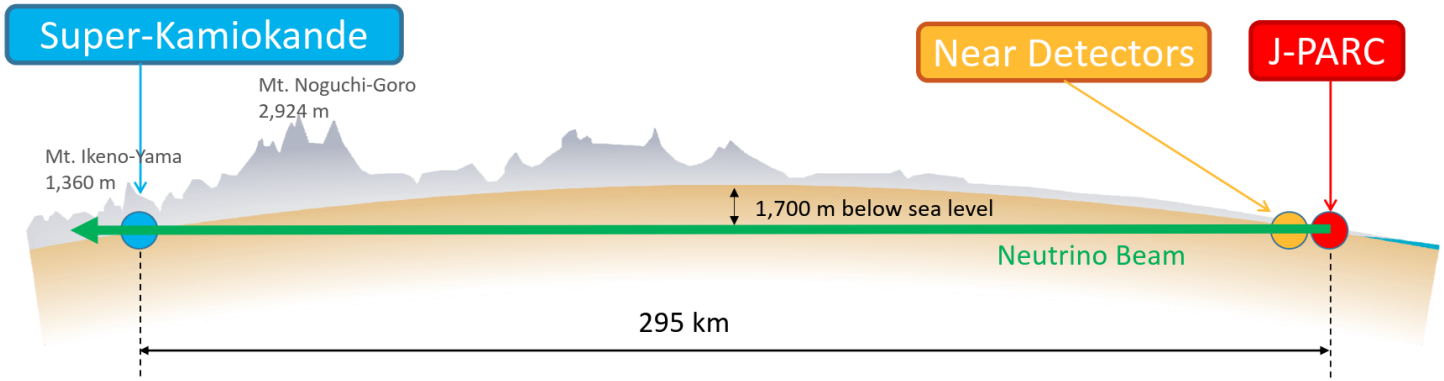
The T2K Experiment

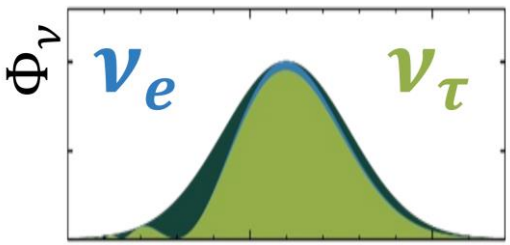






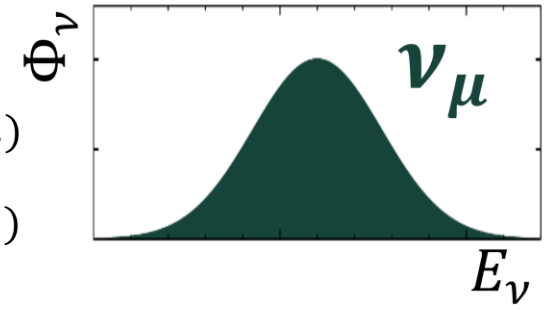
The T2K Experiment



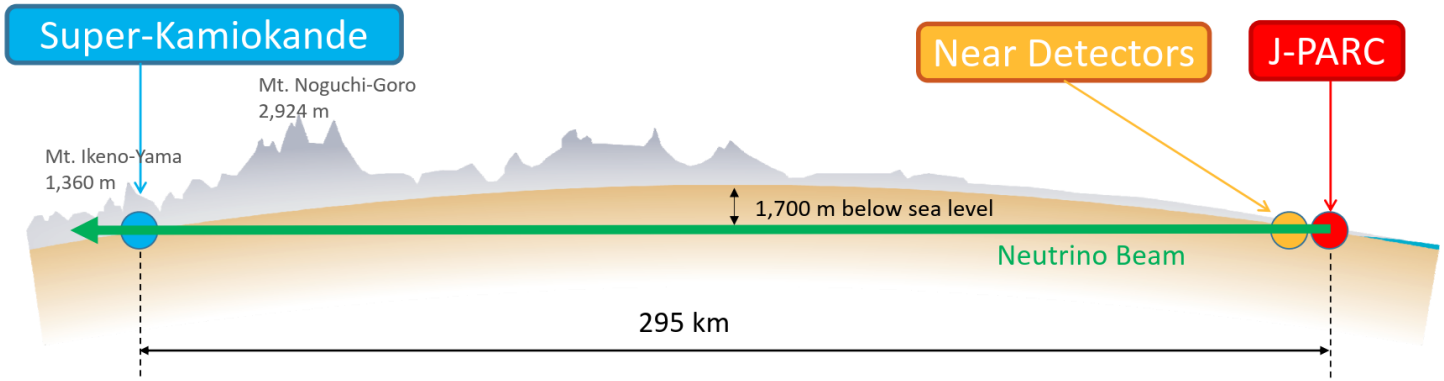


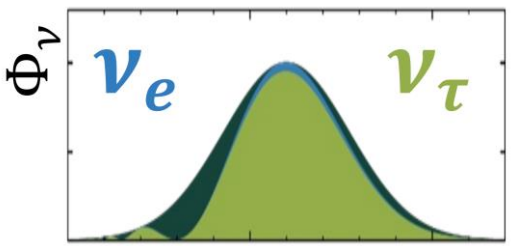
$$N_\mu(E_\mu) = P(\nu_\mu \to \nu_\mu)\ \sigma(E_\nu)\Phi_{\nu_\mu}(E_\nu)\ \delta(E_\nu)$$

$$N_e(E_\mu) = P(\nu_\mu \to \nu_e)\ \sigma(E_\nu)\Phi_{\nu_\mu}(E_\nu)\ \delta(E_\nu)$$



The T2K Experiment





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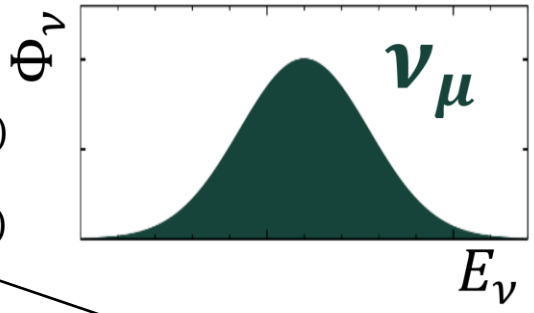


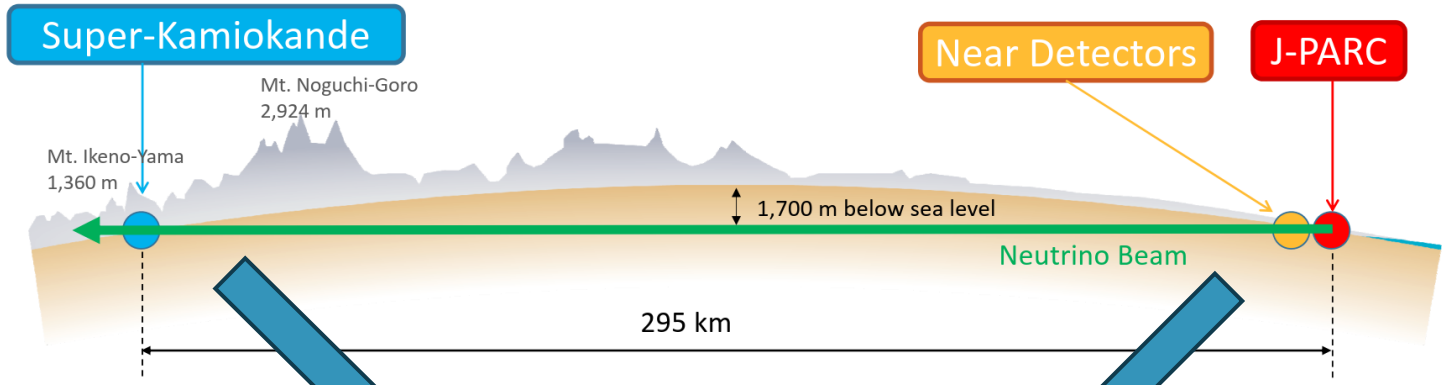
Oscillation probabilities

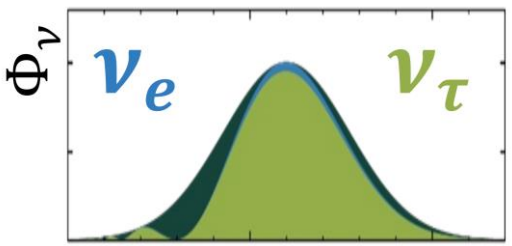
Neutrino interaction cross section

Initial ν_μ Flux

Detector specific effects

The T2K Experiment



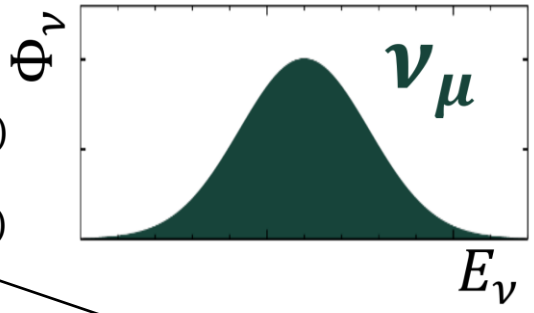


Constrained by FD

Constrained mostly by ND

$$N_\mu(E_\mu) = P(\nu_\mu \to \nu_\mu)\,\sigma(E_\nu)\Phi_{\nu_\mu}(E_\nu)\,\delta(E_\nu)$$

$$N_e(E_\mu) = P(\nu_\mu \to \nu_e)\,\sigma(E_\nu)\Phi_{\nu_\mu}(E_\nu)\,\delta(E_\nu)$$



Oscillation probabilities

Neutrino interaction cross section

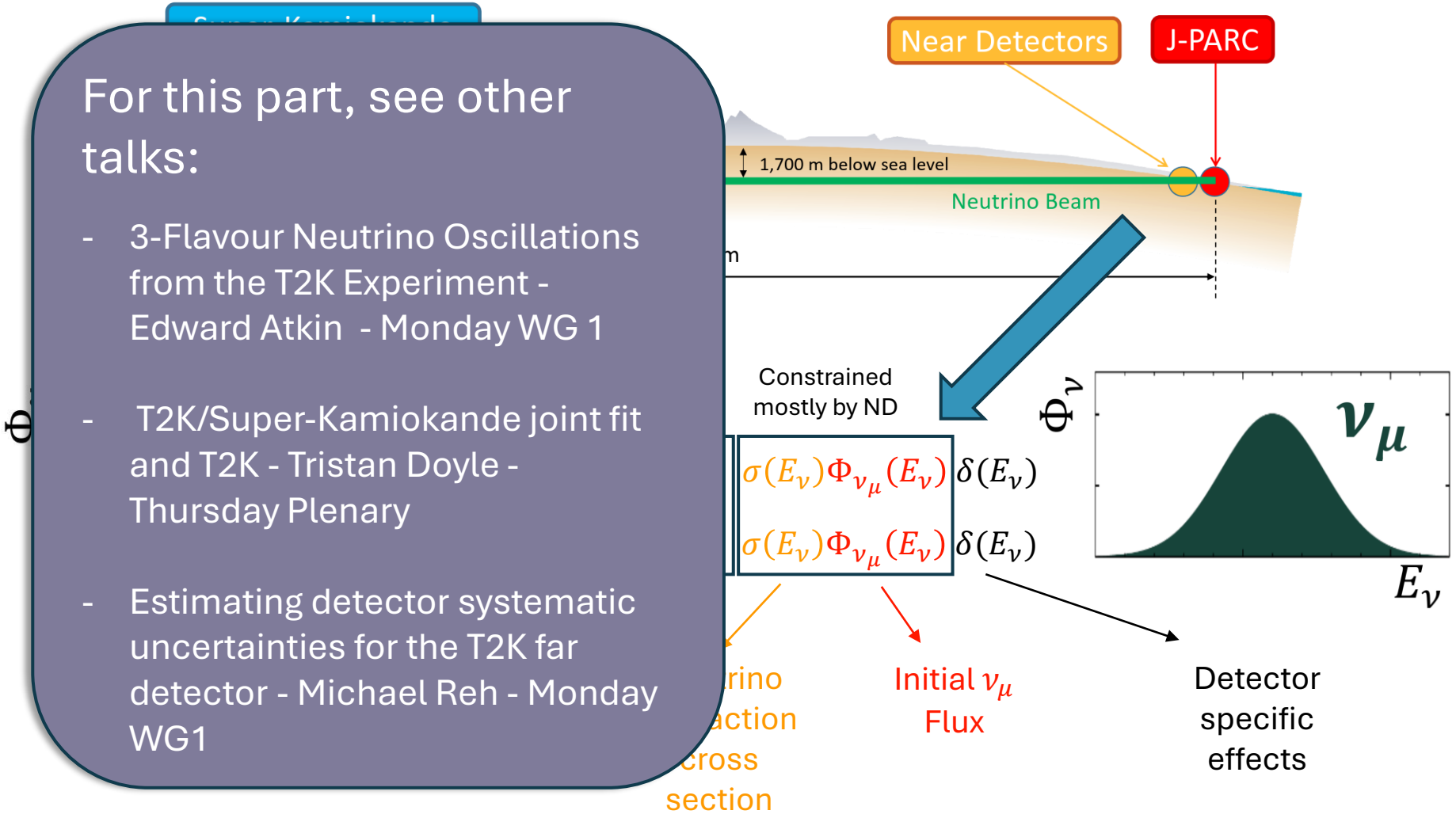
Initial ν_μ Flux

Detector specific effects

The T2K Experiment

For this part, see other talks:

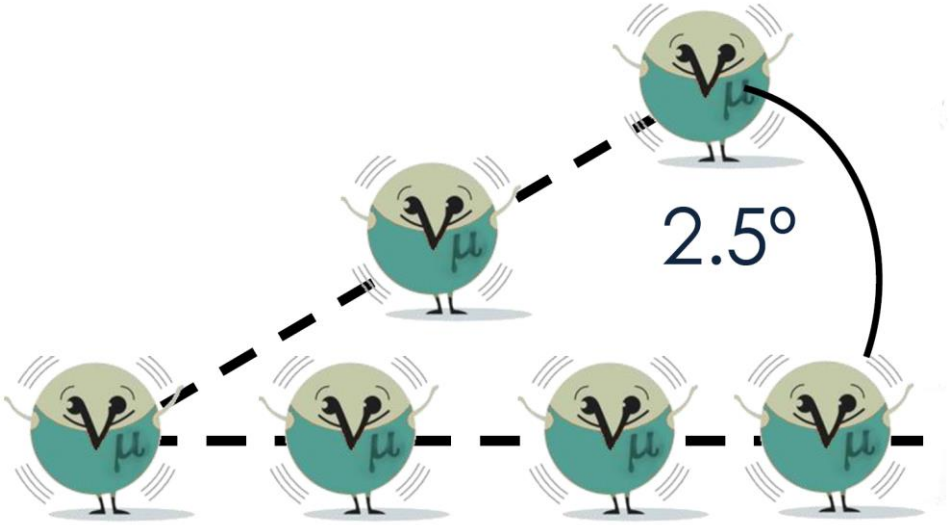
- 3-Flavour Neutrino Oscillations from the T2K Experiment - Edward Atkin - Monday WG 1
- T2K/Super-Kamiokande joint fit and T2K - Tristan Doyle - Thursday Plenary
- Estimating detector systematic uncertainties for the T2K far detector - Michael Reh - Monday WG1

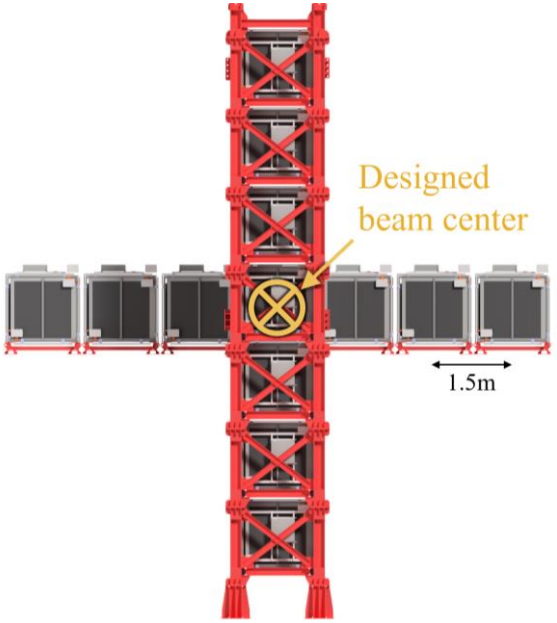


Near Detector Analysis

Near Detectors

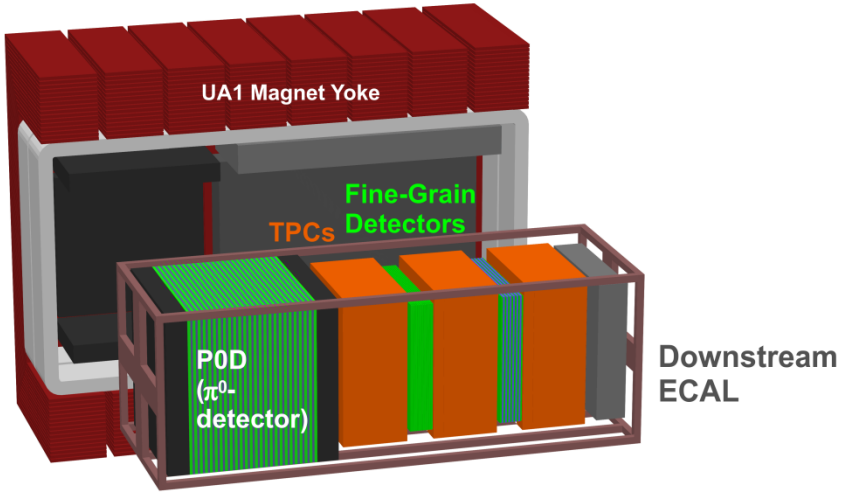
- INGRID: on axis detector
  - Measures beam profile & stability
  - Constrains flux uncertainties

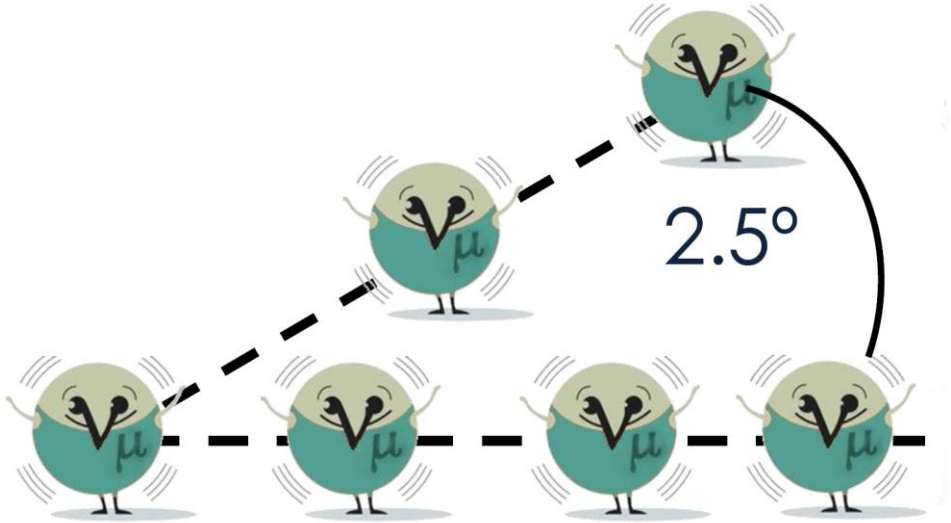


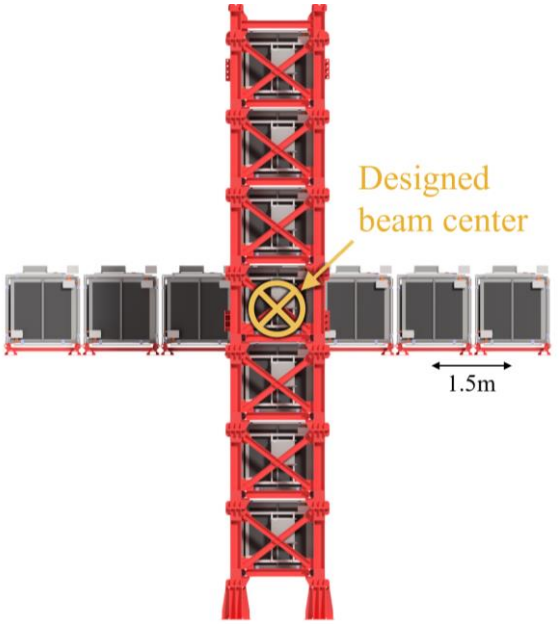


Near Detectors

- ND280: off axis detector
  - Constrains flux and cross section uncertainties

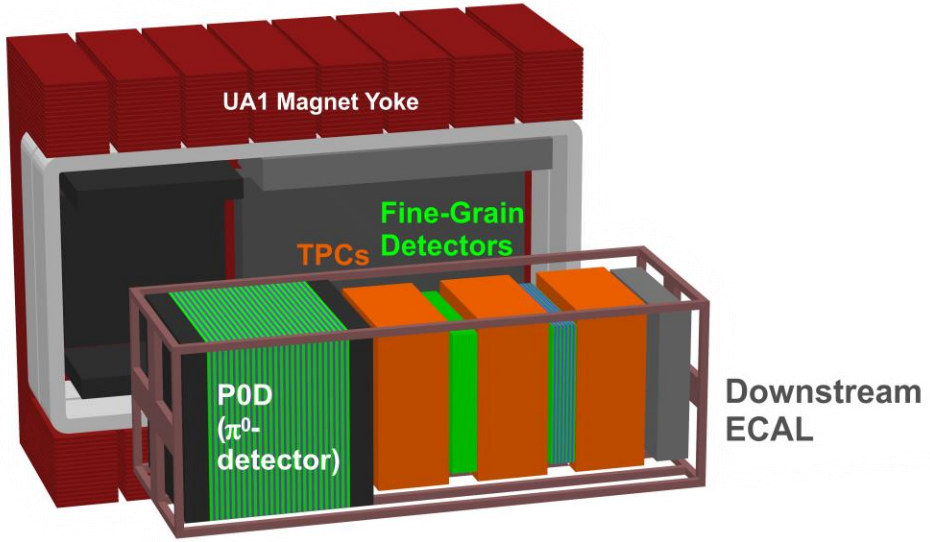


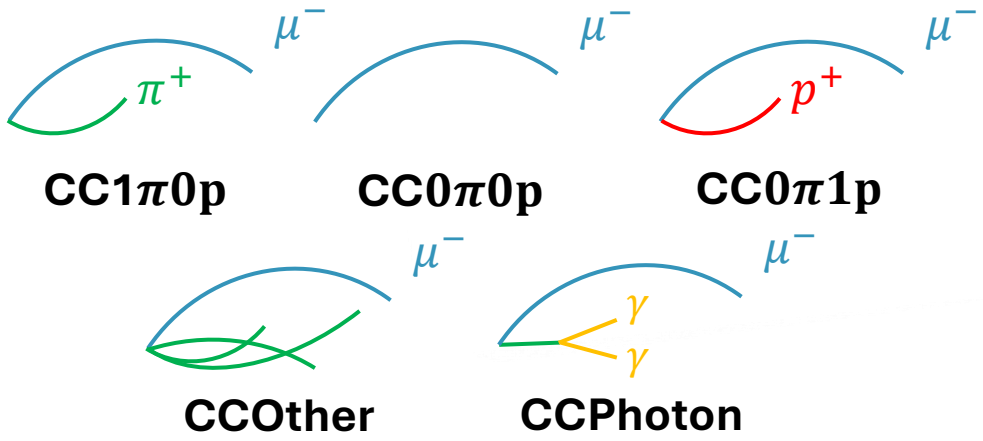




Near Detector Analysis

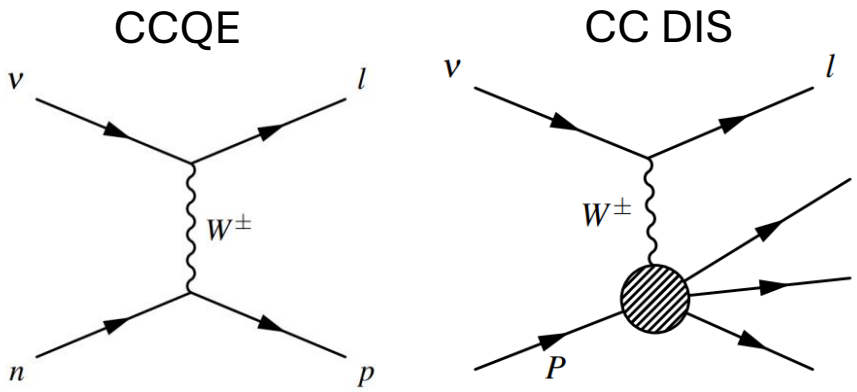
- Split our events based on particle content of their final state

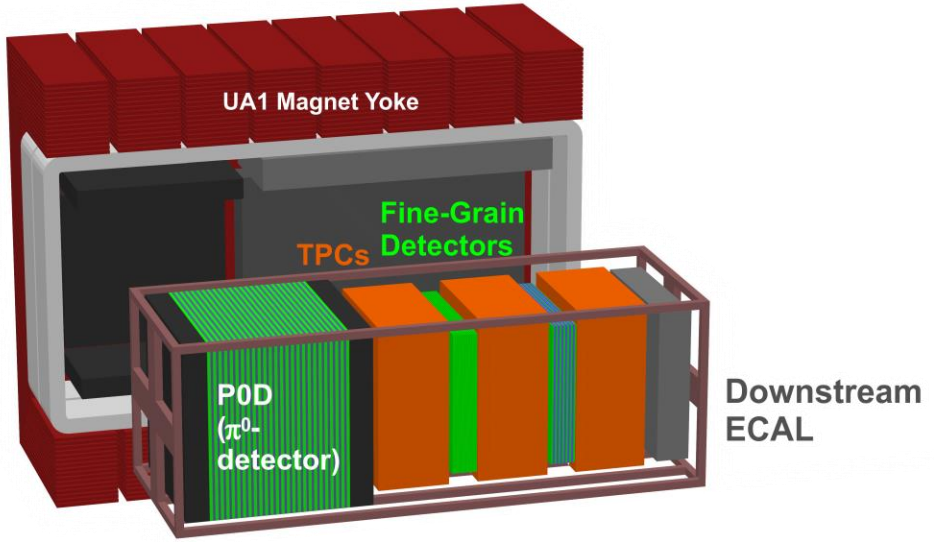


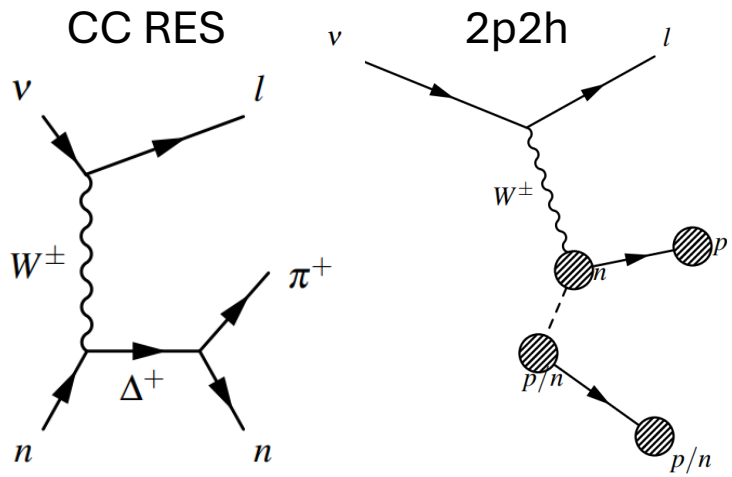


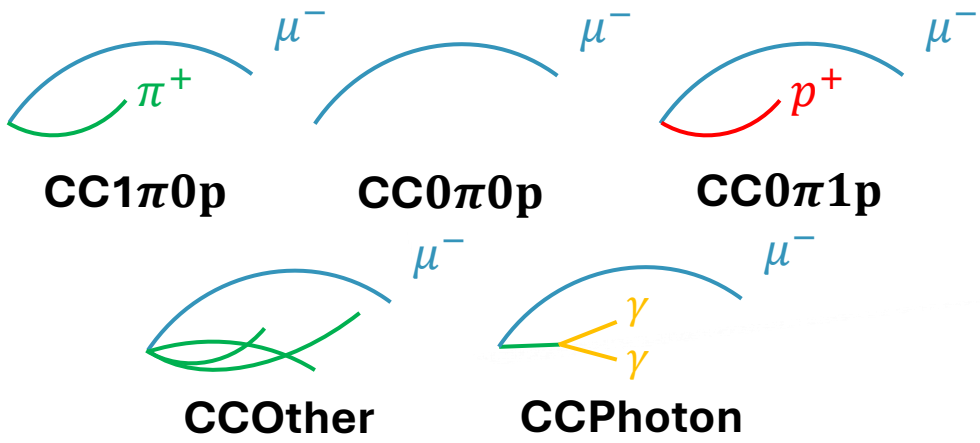
Near Detector Analysis

- Correspond to different interaction modes

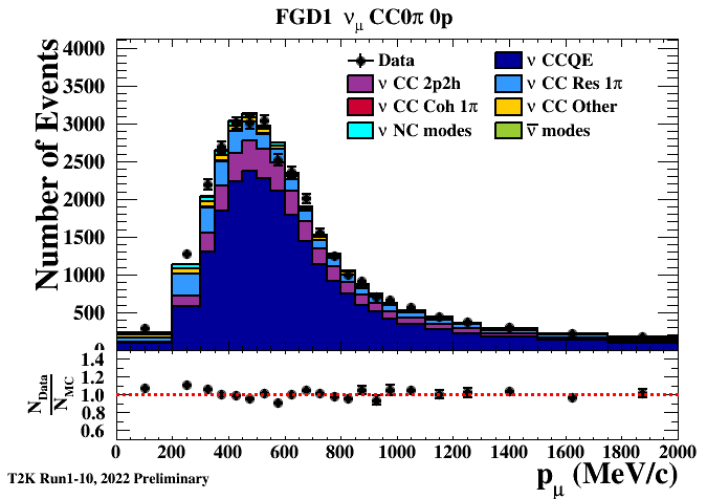


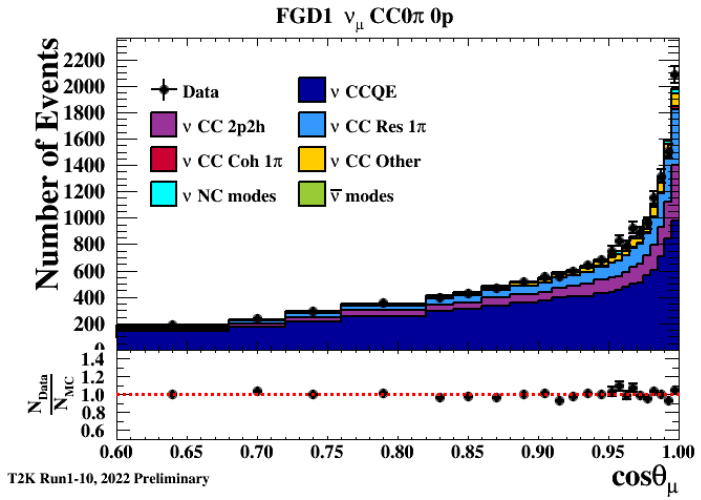


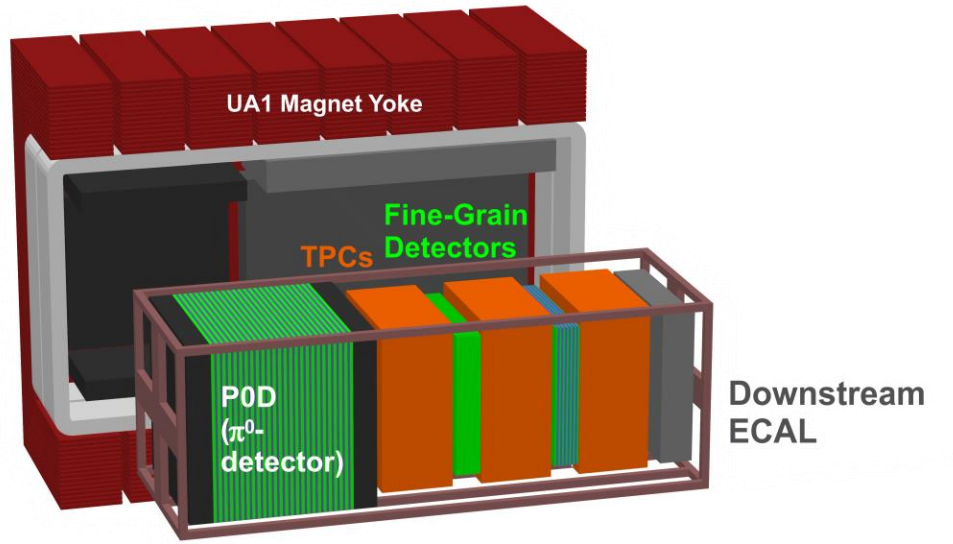


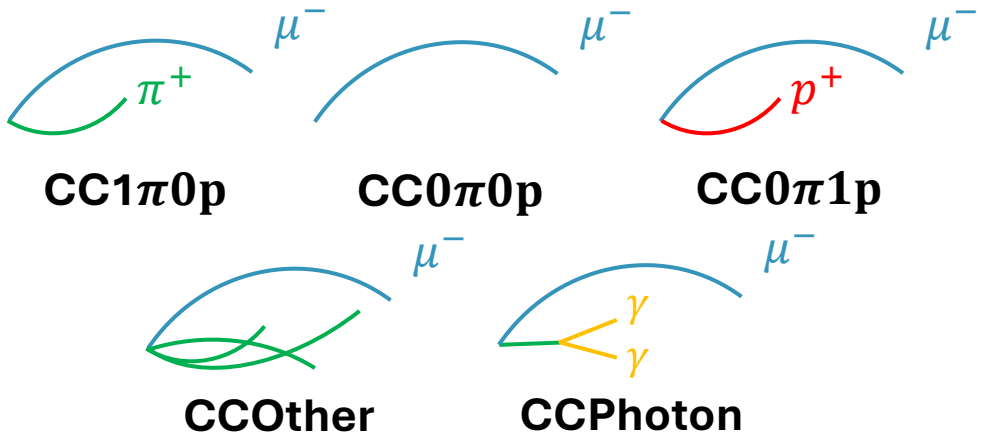


Near Detector Analysis



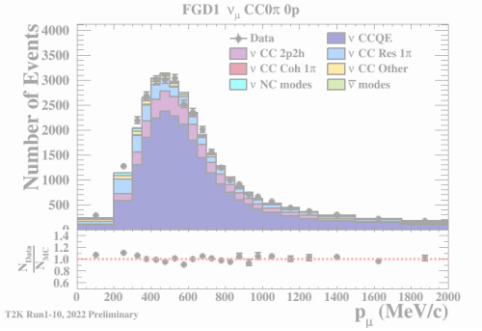


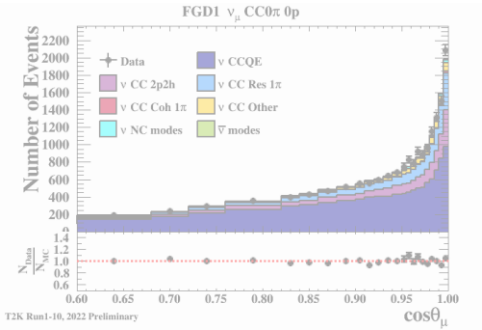


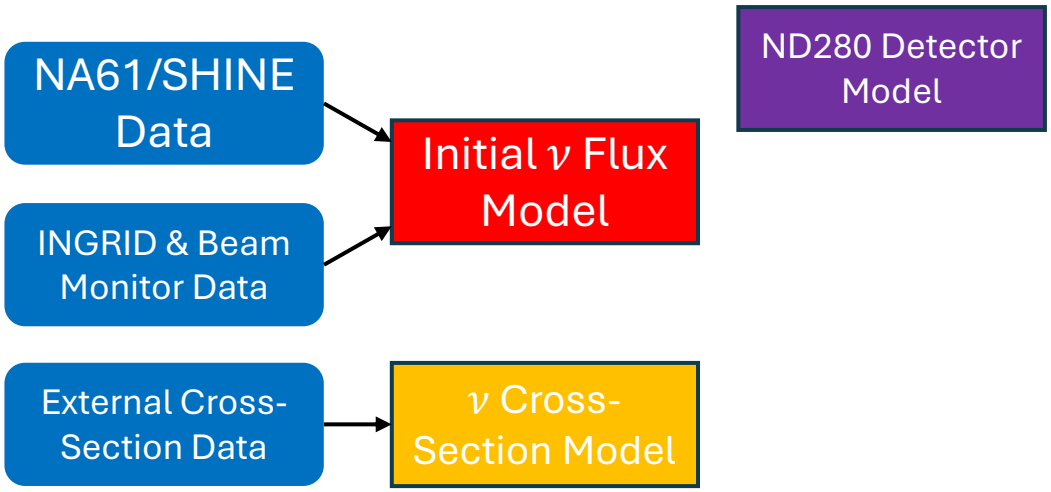


Near Detector Analysis

$$N_\mu(p_\mu, \theta_\mu) = \sigma(E_\nu)\Phi_{\nu_\mu}(E_\nu)\ \delta(p_\mu, \theta_\mu)$$



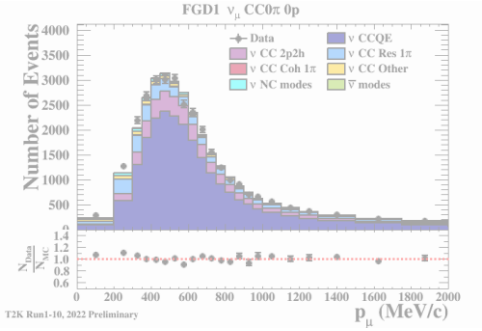


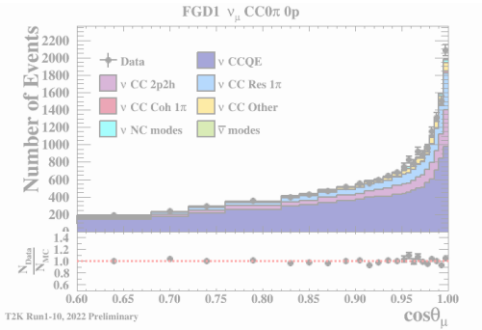


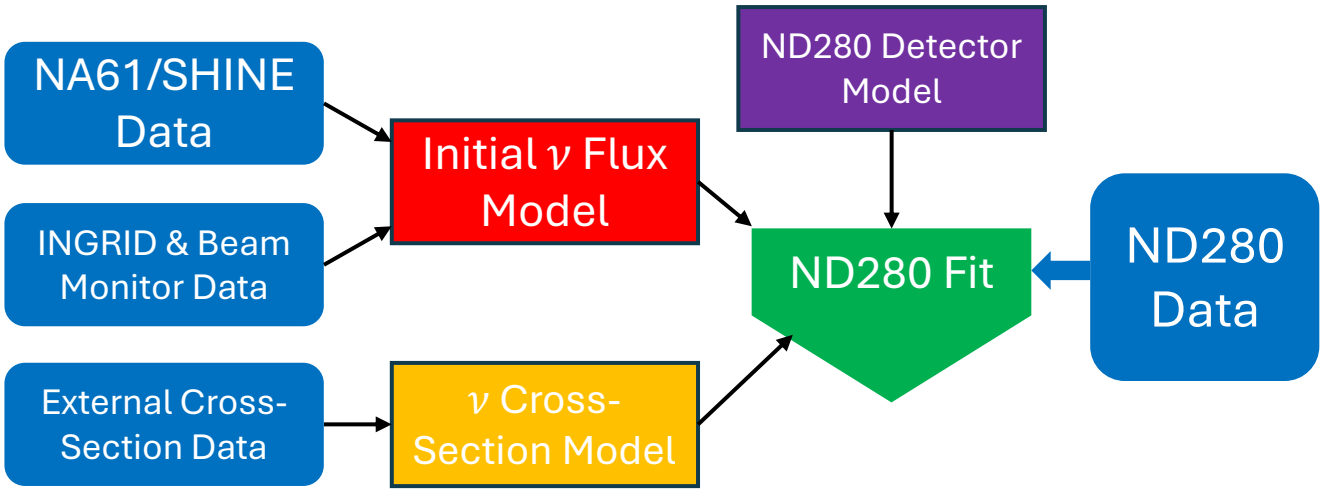
- Construct complex parameterised models using **external data**

Near Detector Analysis

$$N_\mu(p_\mu, \theta_\mu) = \sigma(E_\nu)\Phi_{\nu_\mu}(E_\nu)\ \delta(p_\mu, \theta_\mu)$$



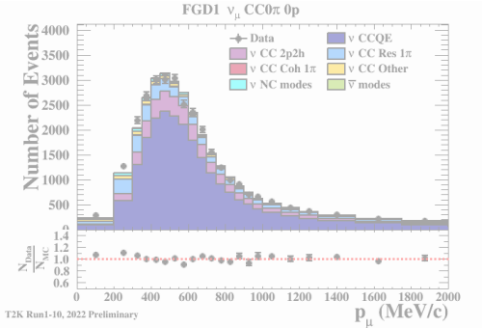


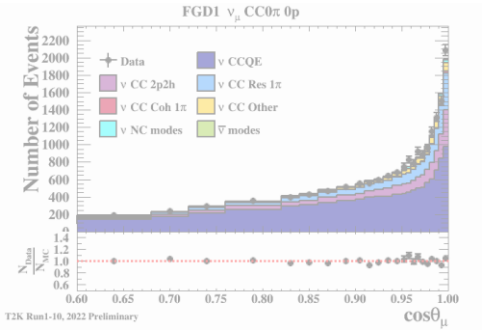


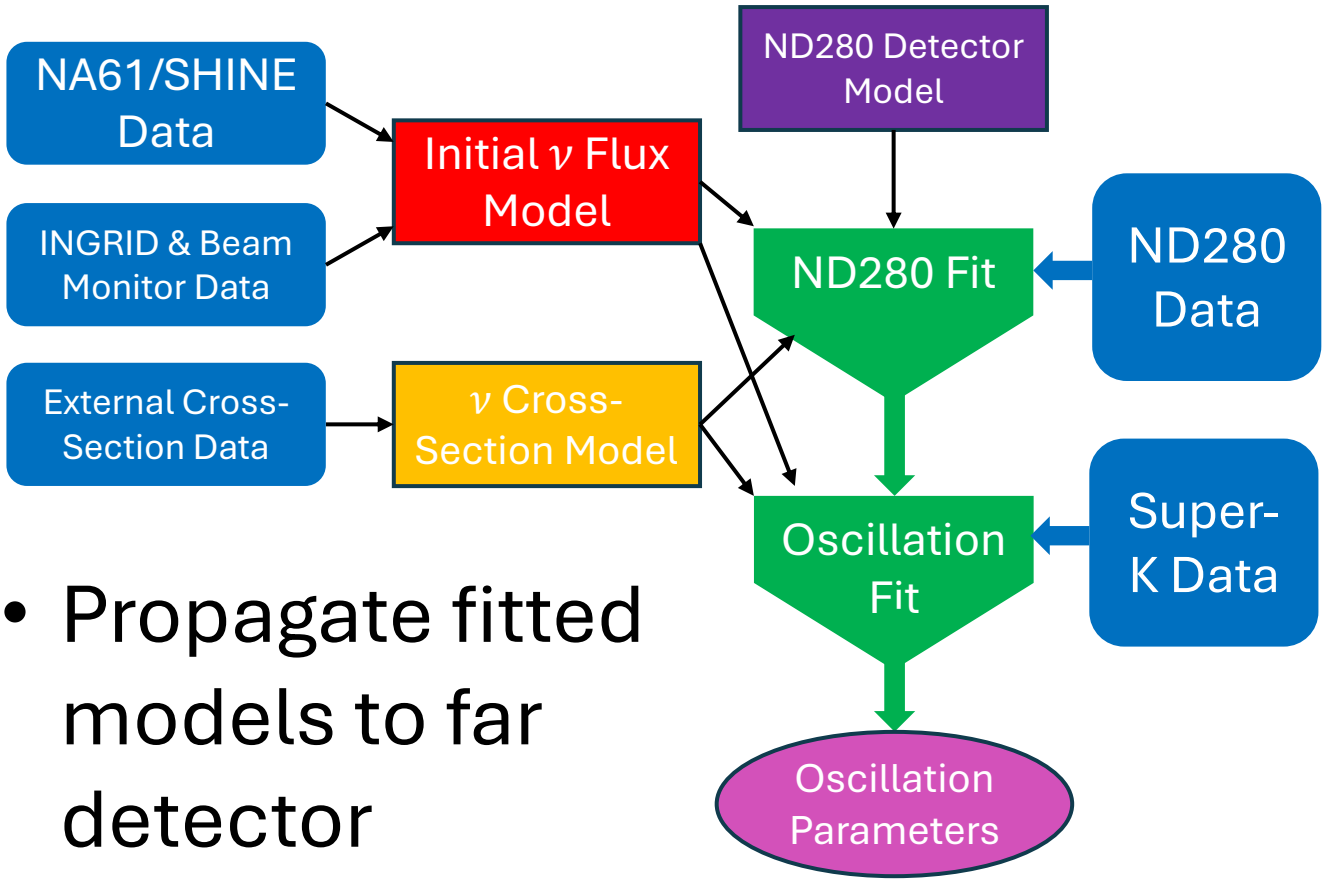
- Fit the model parameters to match the predictions to ND280 data

Near Detector Analysis

$$N_\mu(p_\mu, \theta_\mu) = \sigma(E_\nu)\Phi_{\nu_\mu}(E_\nu)\ \delta(p_\mu, \theta_\mu)$$

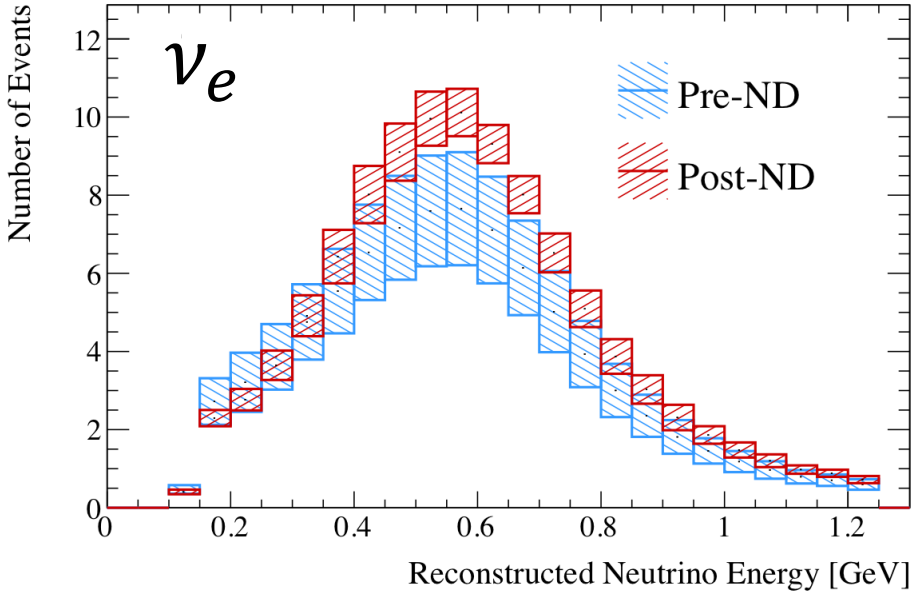


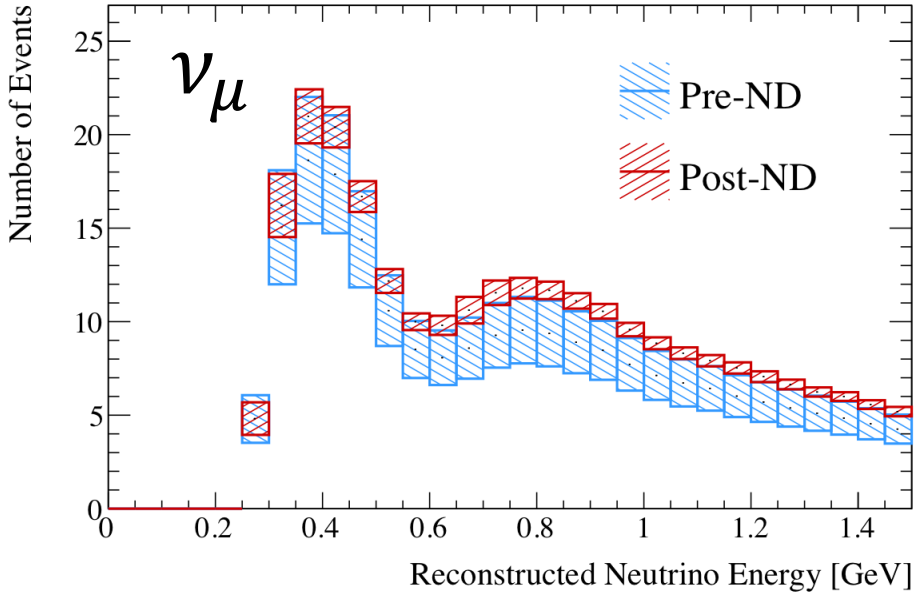




- Propagate fitted models to far detector

Near Detector Analysis

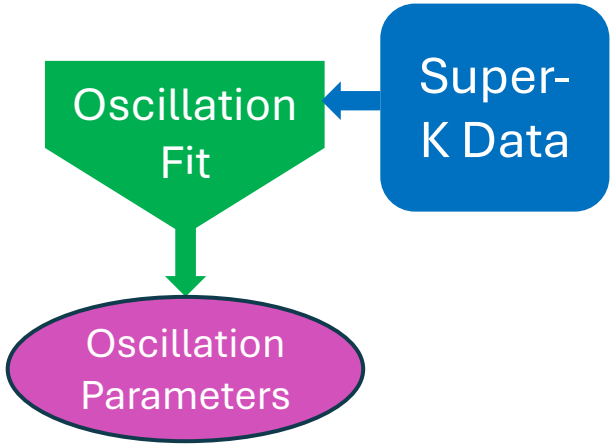




- Greatly reduce uncertainties on event rates at SK:

  ν_μ: ~17% → ~3%

  ν_e: ~17% → ~5%

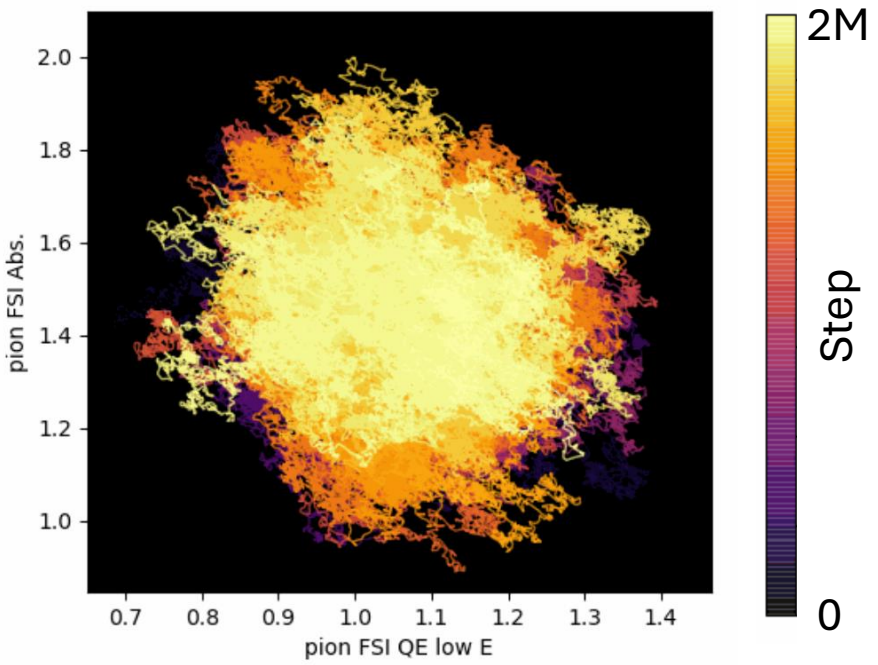


Near Detector Analysis - Fitters

MaCh3

Bayesian MCMC

- Uses Metropolis-Hastings to perform random walk in parameter space
- Step values sample posterior likelihood



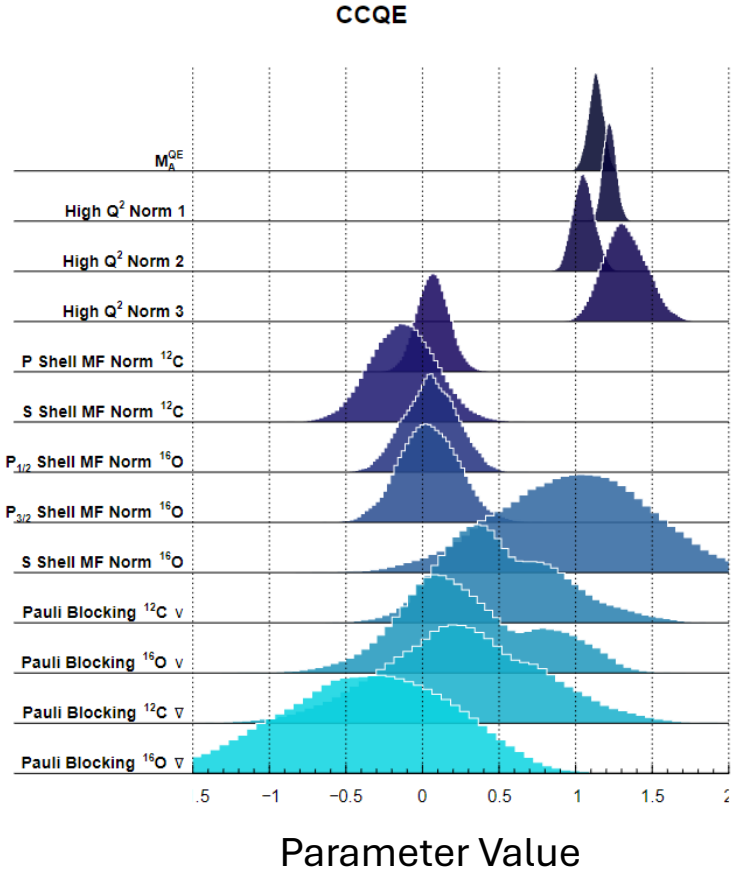
GUNDAM

Likelihood Minimiser

- Uses Gradient descent to find best fit point of parameters
- New to the current oscillation analysis iteration
- Also used extensively in T2K neutrino cross section analyses
- Comparison of results between fitters allows us to validate our fitting frameworks and have confidence in our results

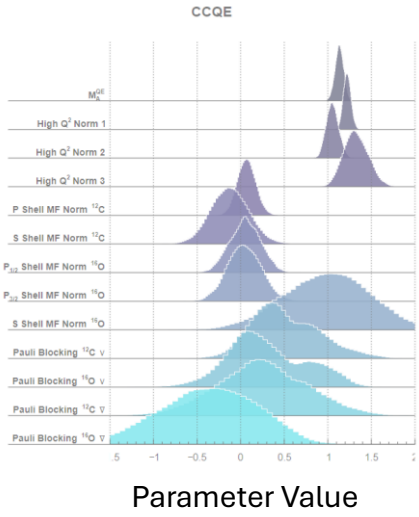
Near Detector Analysis - Fitters

- Posterior Likelihood Distributions:

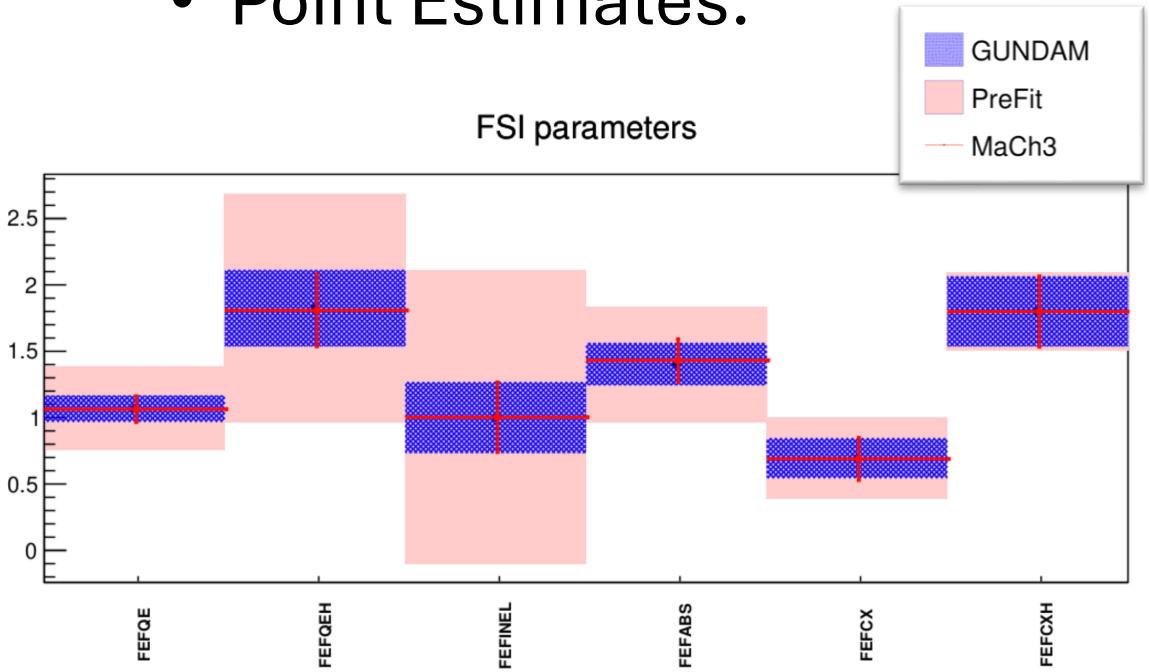


Near Detector Analysis - Fitters

- Posterior Likelihood Distributions:

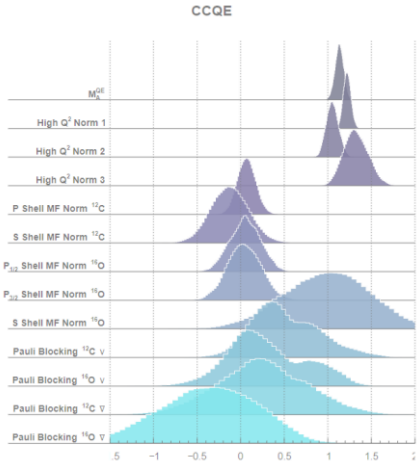


- Point Estimates:

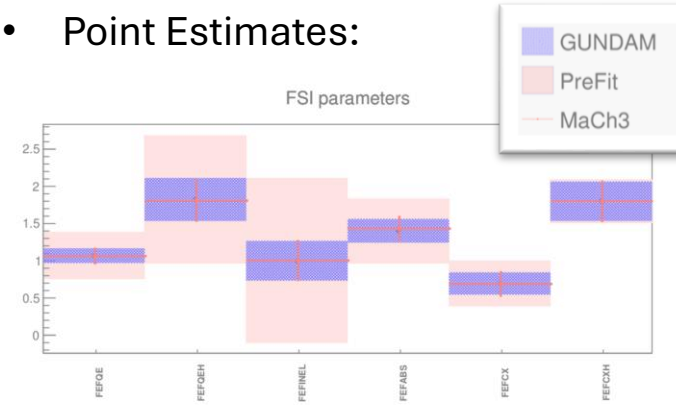


Near Detector Analysis - Fitters

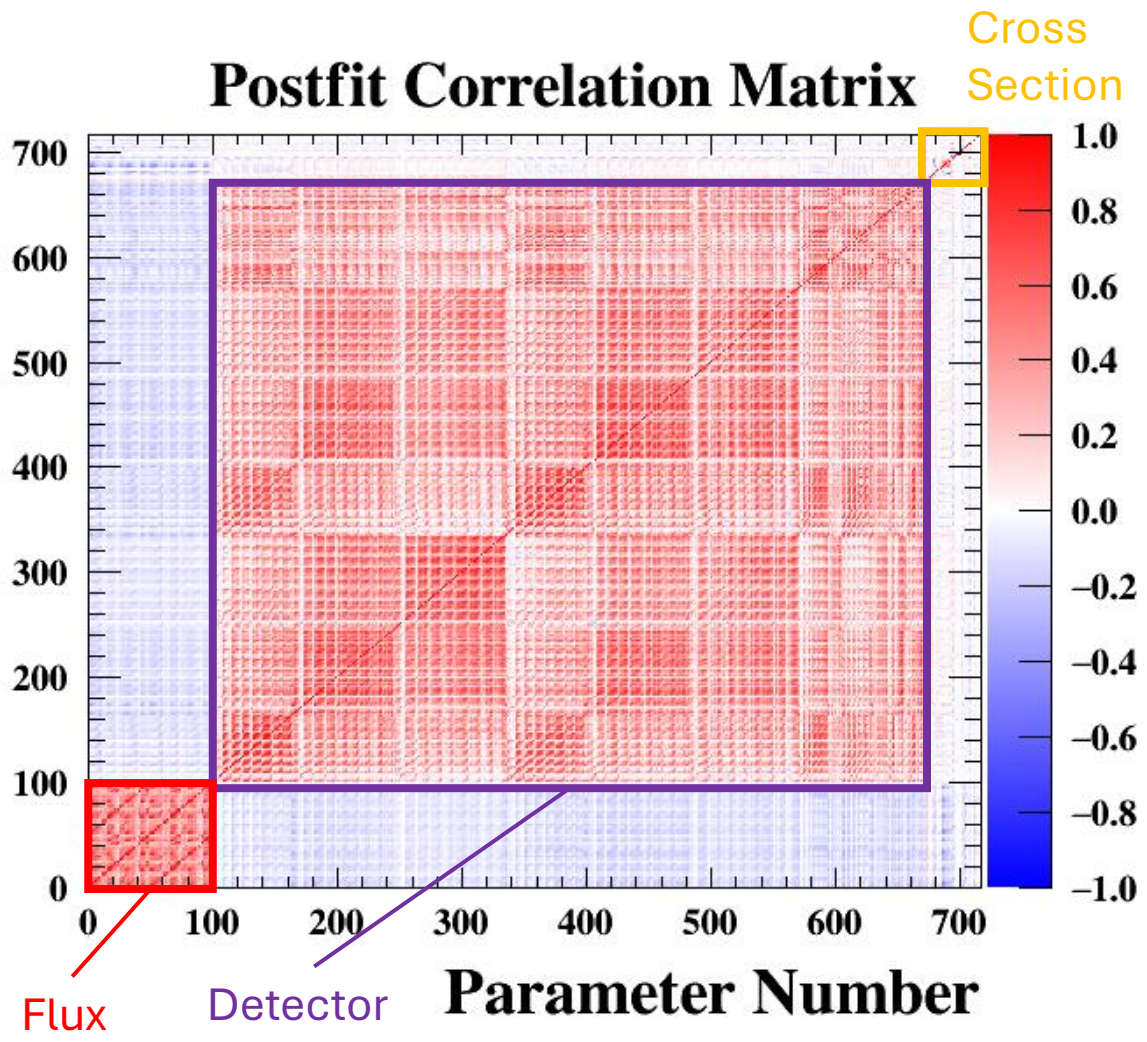
- Posterior Likelihood Distributions:



- Point Estimates:



- Correlations between



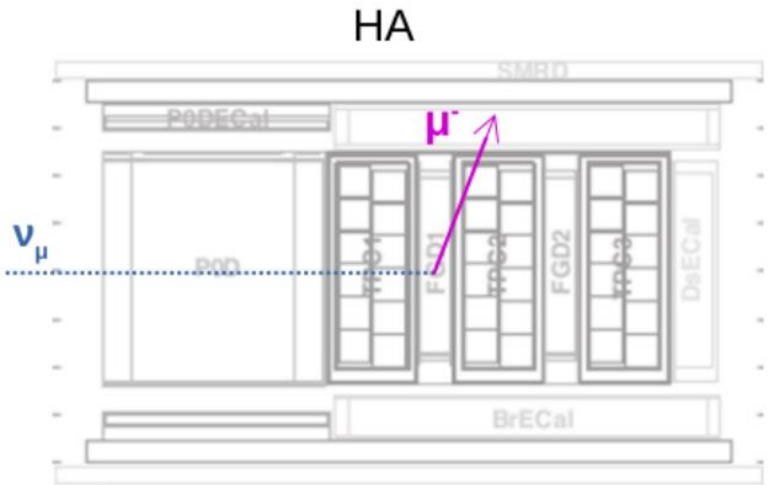
What's New?

New Samples!

- Previous analyses used only events with “Forward” going muons

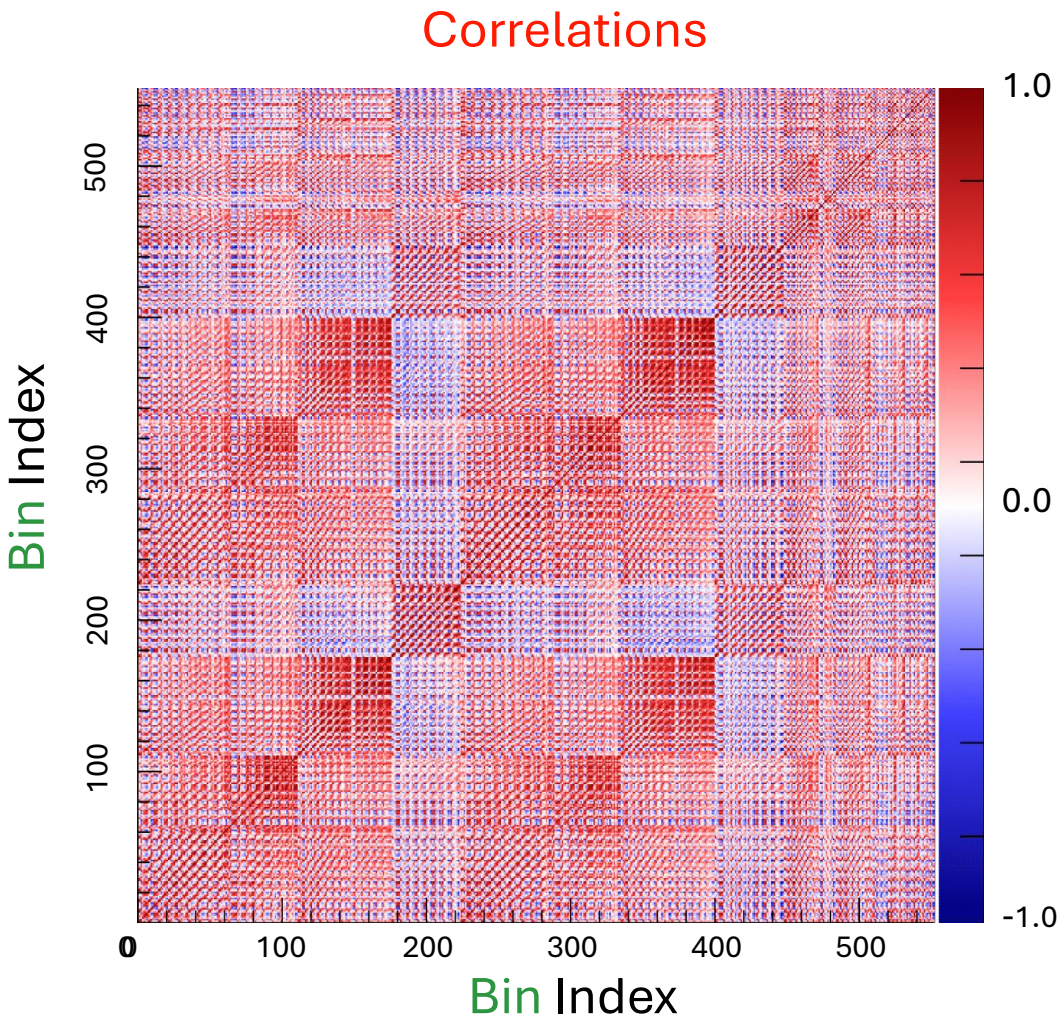
New Samples!

- New “High angle” and “Backward” going muon event samples



- Cover more phase space
- Include higher Q^2 events

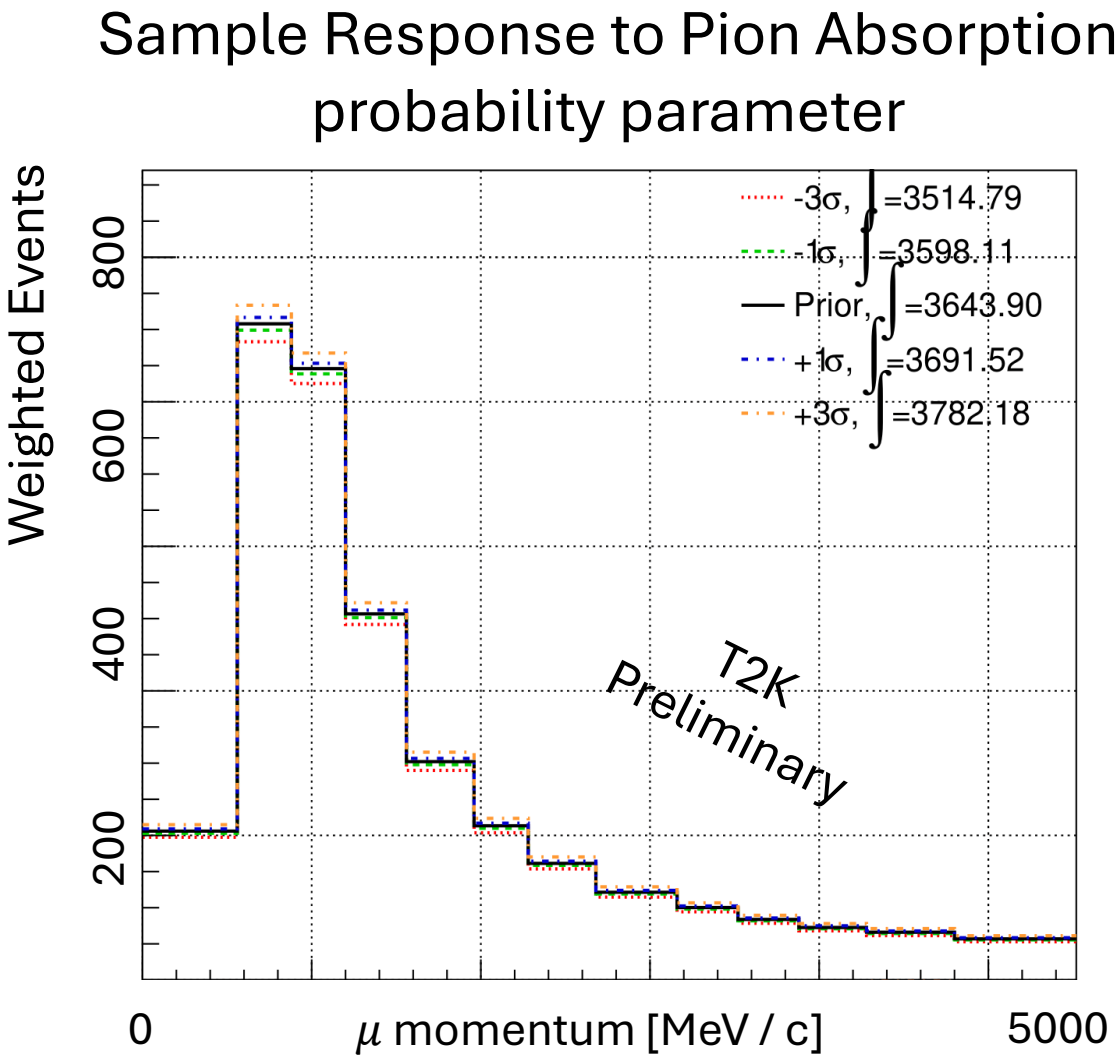
New ND280 Systematic Treatment!



- Previous analyses used effective smearing approach for detector systematics
- Estimate total effect of detector systematics as correlated Gaussian smear of kinematic bins
- Inflates number of fit parameters (need 1 for each bin)

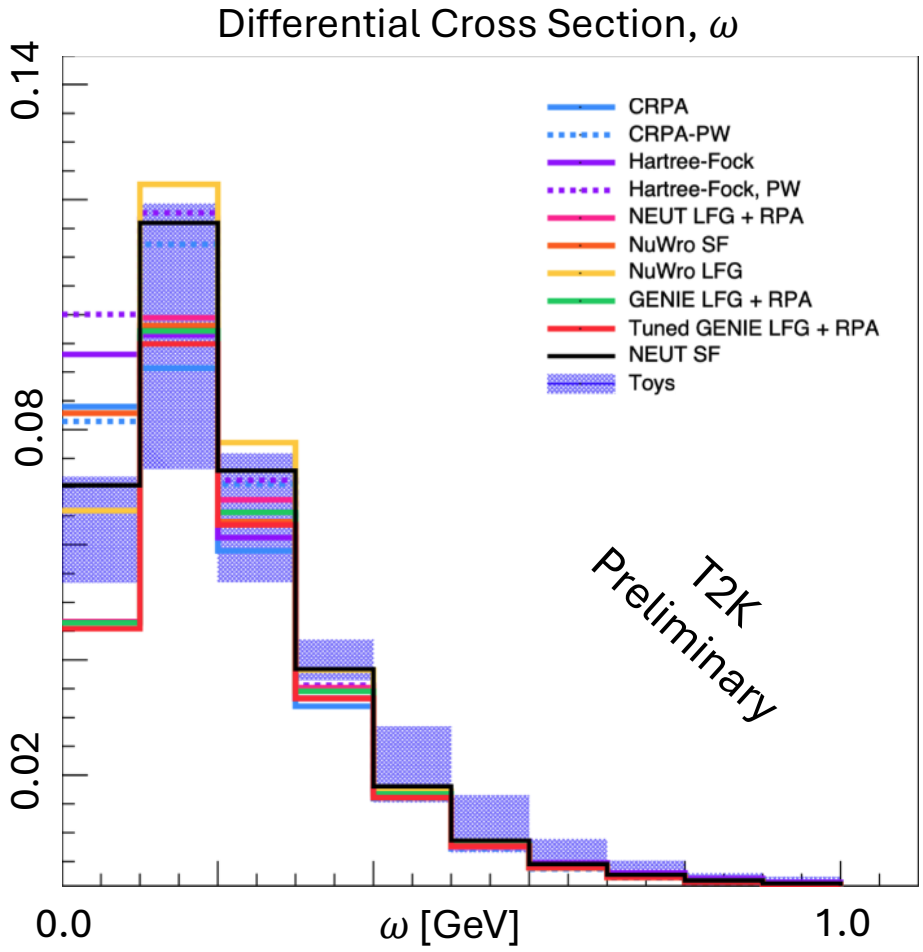
New ND280 Systematic Treatment!

- Now Using event by event reweighting approach
- No longer inflate N parameters
- Directly see effects of individual parameters



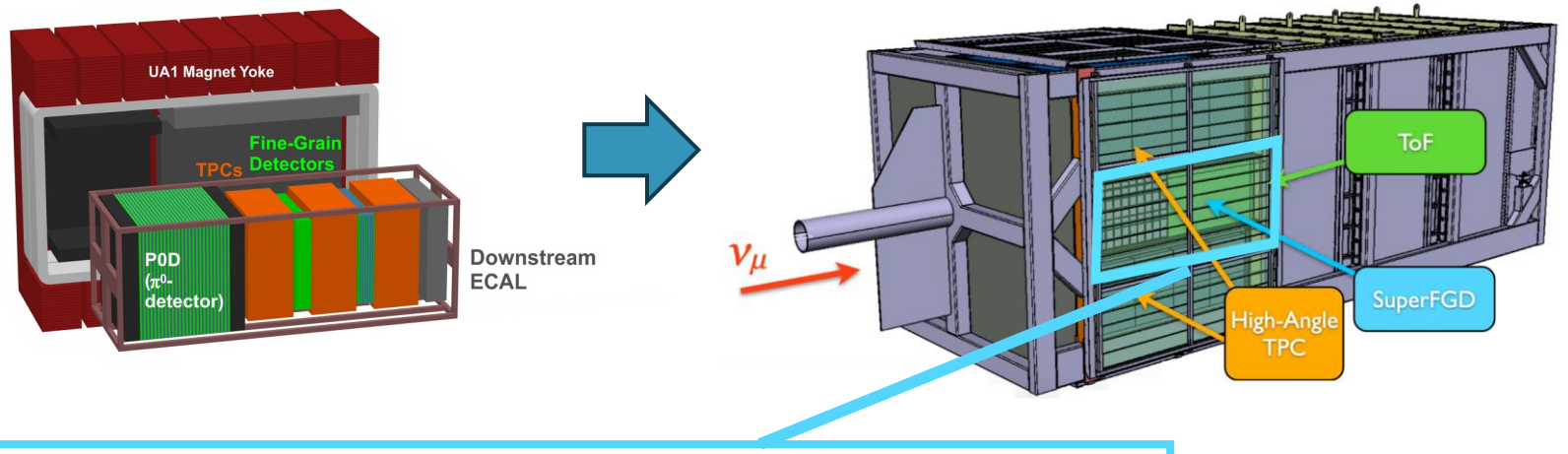
Expanded Cross Section Model!

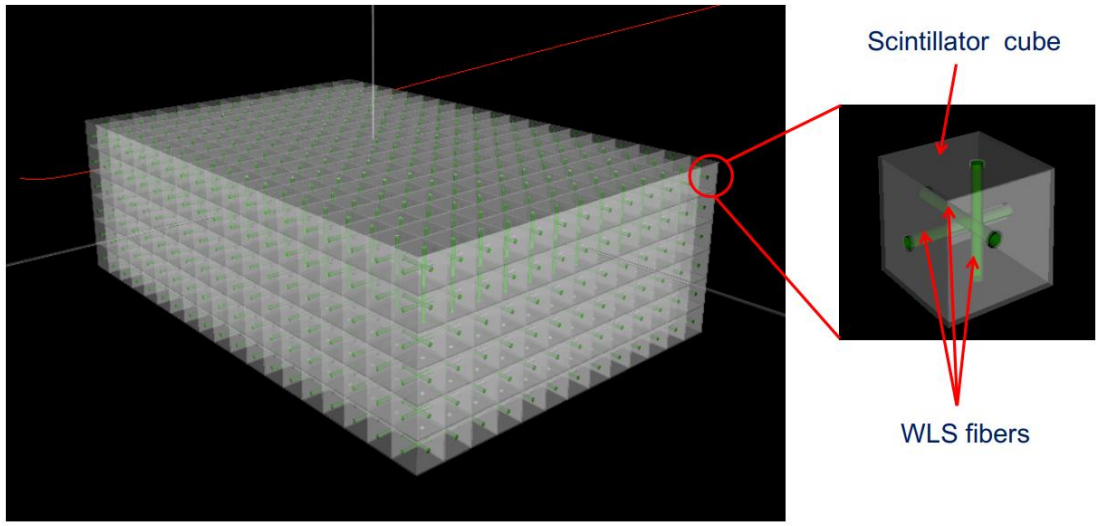
- Massively expanded parameterisation of the neutrino cross section model
- New parameters to cover modelling of low energy transfer events
- Many, many more!



Future Plans

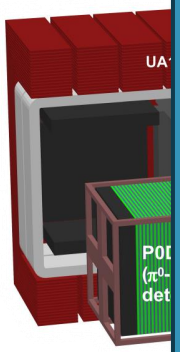
New Detectors!

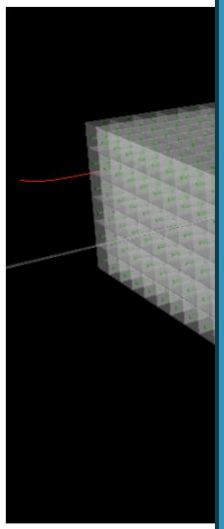




- Upgrade is fully complete and we are now taking data with it!

New Detectors!





See other talks and posters on upgraded ND280 for more information:

- DAQ system and detector response for Super-FGD in the upgraded T2K near detector – Jianru Hu – Monday Poster session
- Particle identification for proton and pion event discrimination using the SuperFGD prototype detector - Diana Leon Silverio – Monday Poster session
- A new near neutrino detector SuperFGD for the T2K experiment – Tristan Doyle – Thursday WG 6
- Technical challenges for the new T2K High Angle TPCs - Samira Hassani – Thursday WG 6

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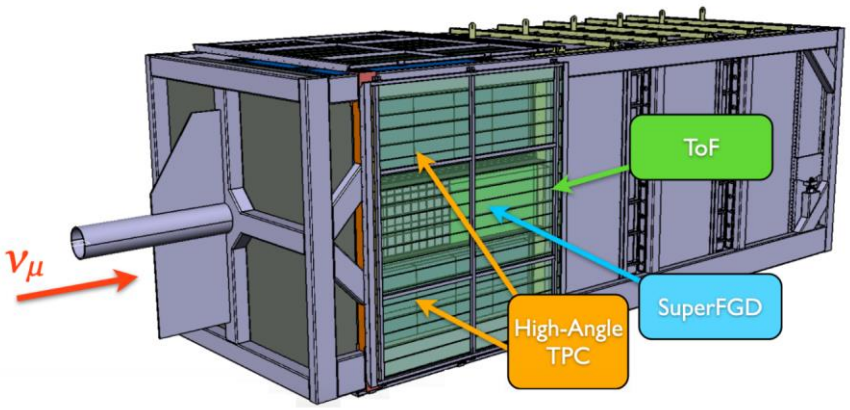
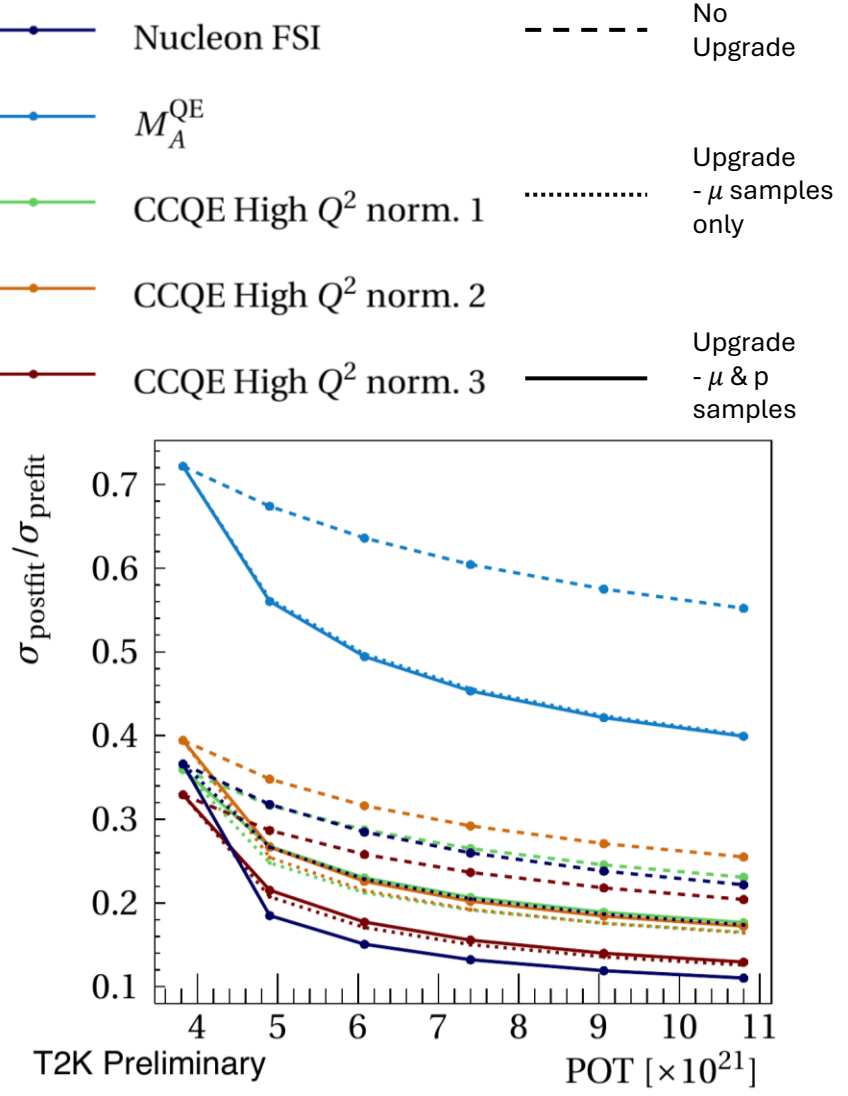
Future Analysis Plans

- Inclusion of ND280 Upgrade samples
  - Lower thresholds
  - Better resolution
  - Possibility to include neutron tagging / kinematics

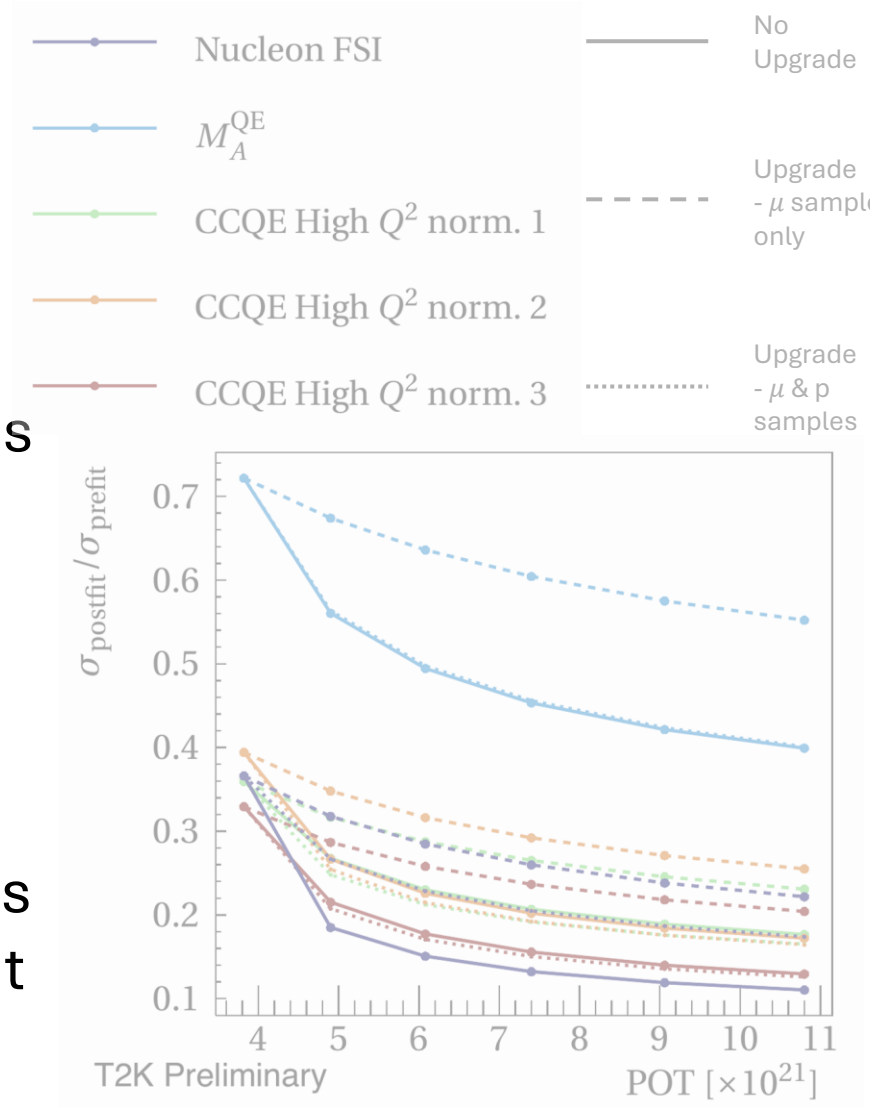




Future Analysis Plans

- Inclusion of ND280 Upgrade samples
  - Lower thresholds
  - Better resolution
  - Possibility to include neutron tagging / kinematics

- Fitting in pion and proton kinematic variables
  - Better separation of interaction types
  - Will require significant cross section model development



Summary

Summary

- ND280 analysis is crucial to constrain the neutrino flux and interaction models
- Ongoing efforts to improve this analysis:
  - New full coverage analysis samples
  - Improved approach to detector systematics
  - Expanded neutrino interaction model
- Plenty of plans to further improve the analysis:
  - Inclusion of the upgraded detectors
  - Inclusion of more kinematic variables in the fit

Other T2K Talks & Posters

- Exploration of the beam profile using the ND280 detector in the T2K experiment - Svetlana Karpova – Monday poster session
- Latest cross section results from T2K - Laura Munteanu - Wednesday WG2

Backup