E61: Reducing Neutrino Interaction Model Dependence for Oscillation Experiments

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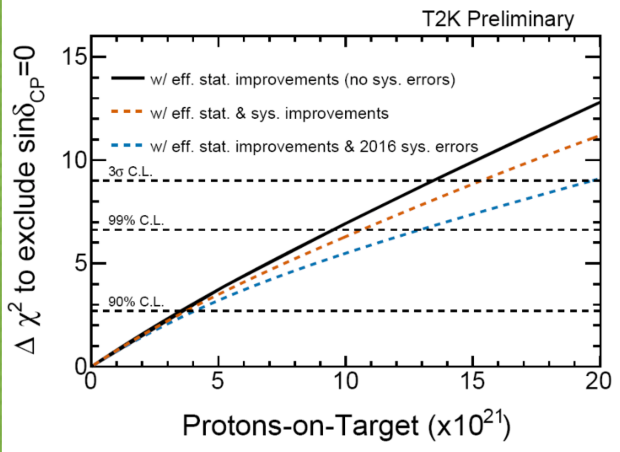
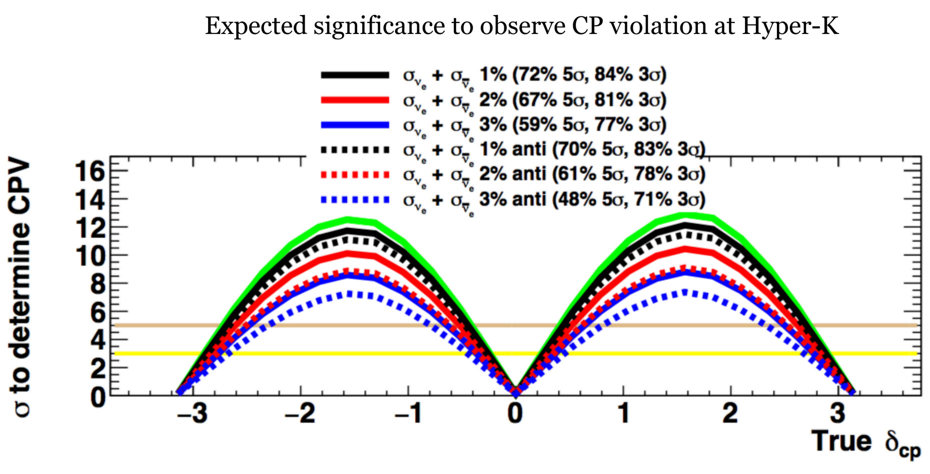
Motivation for E61

- T2K-II sensitive to maximal CP violation at the 3σ level. arXiv:1805.04163
- Hyper-K will be sensitive to δ_{CP} at 5σ over a range of values.
- Systematic errors result in diminishing returns as POT increases.
- Future long baseline experiments limited by systematic rather than statistical uncertainty.
- Major uncertainties from neutrino cross-section model, flux constraint, and ν_e to ν_μ cross-section ratio measurements.
- Necessary to improve cross-section modelling and reduce model dependence.

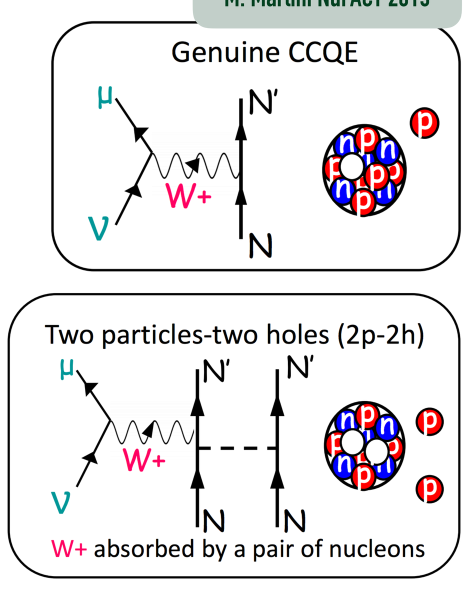


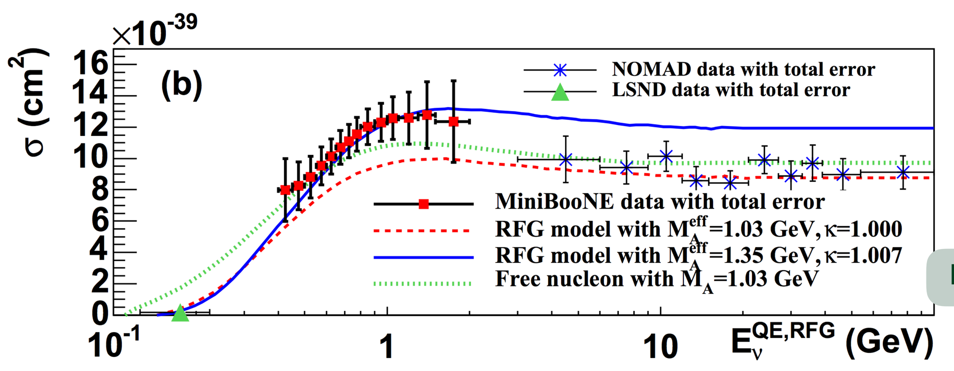


Problems measuring neutrino energy

- Nuclear models are hard to constrain with a typical near detector.
- Can only measure outgoing particles to determine neutrino energy.
- Hadronic state not well reconstructed.
- Can not distinguish between CCQE and multi-nucleon interactions.
- Multi-nucleon interactions may explain conflicting cross-section results.
- Many different models and energy loss different for neutrinos and anti-neutrinos.

M. Martini NuFACT 2015





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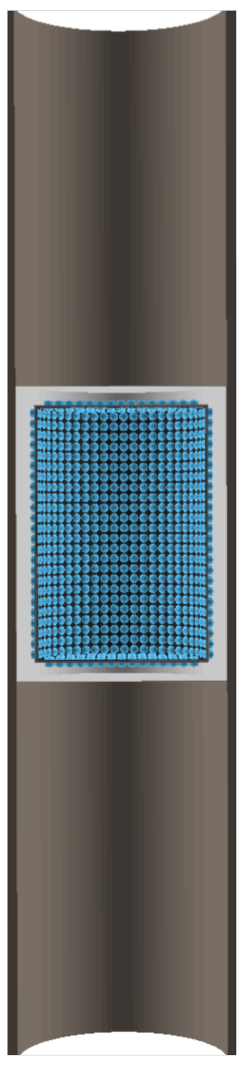
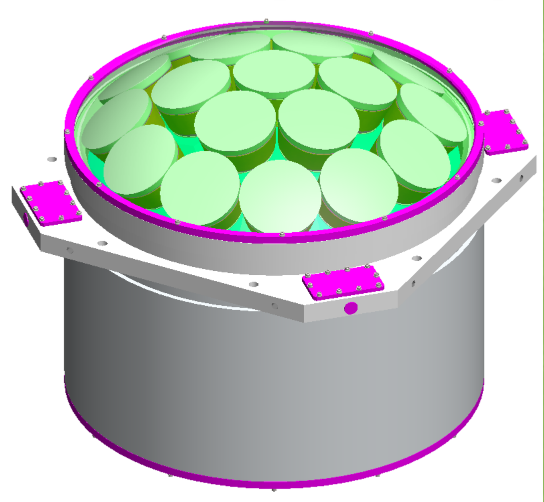
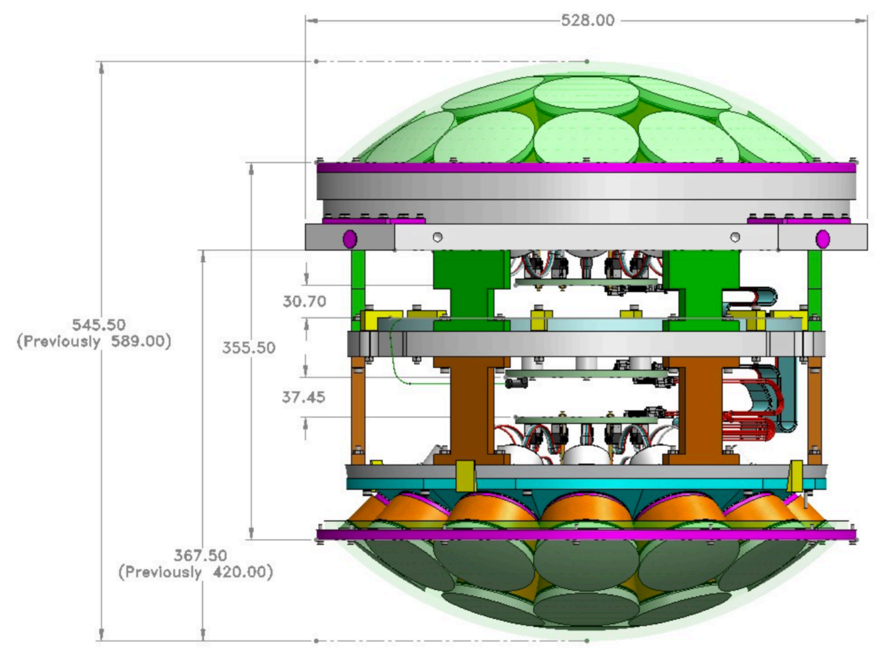
E61 detector

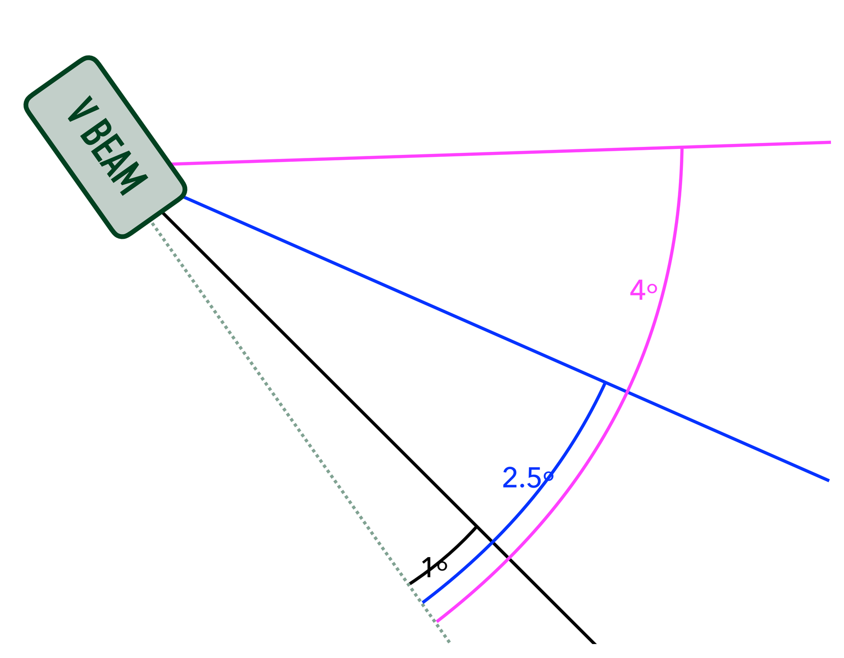
- An Intermediate Water Cherenkov Detector. arXiv:1412.3086
- Same nuclear target as the far detector.
- Smaller near to far extrapolation systematic.
- 50 m tall shaft located ~1 km downstream of neutrino beam.
- Instrumented portion of detector moves up and down through the shaft.
- Spans 1-4 degrees from neutrino beam axis.
- Inner detector: 8 m diameter.
- Optically separated outer detector: 10 m diameter.
- Detector height: 8-12 m, optimised for distance from target. arXiv:1601.07459
- Tank lined with multi-PMT modules that monitor inner and outer volumes (see poster by T. Lindner).
- Probes neutrino energy vs final state kinematics.
- Gd loading to measure neutron multiplicities in neutrino-nucleus interactions.
- Neutrino energies span 0.4-1 GeV.
- Measures ν_e ($\overline{\nu}_e$) cross section with intrinsic ν_e ($\overline{\nu}_e$) beam component.
- Purity increases at higher off-axis angle.
- Measure ν_e ($\overline{\nu}_e$) and NC background rates with near identical flux to far detector.
- Broad physics program: oscillation measurement, sterile neutrinos, cross section measurements, reactor neutrinos.

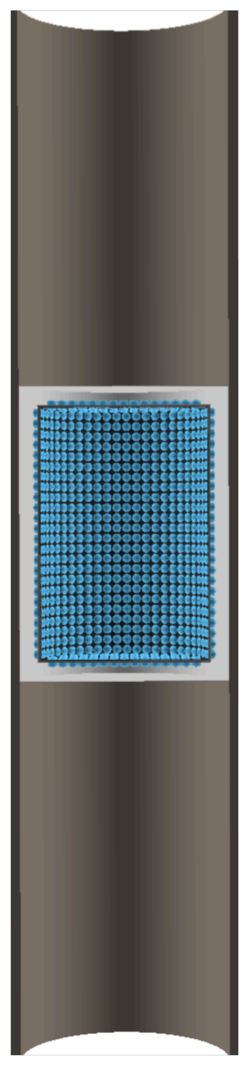




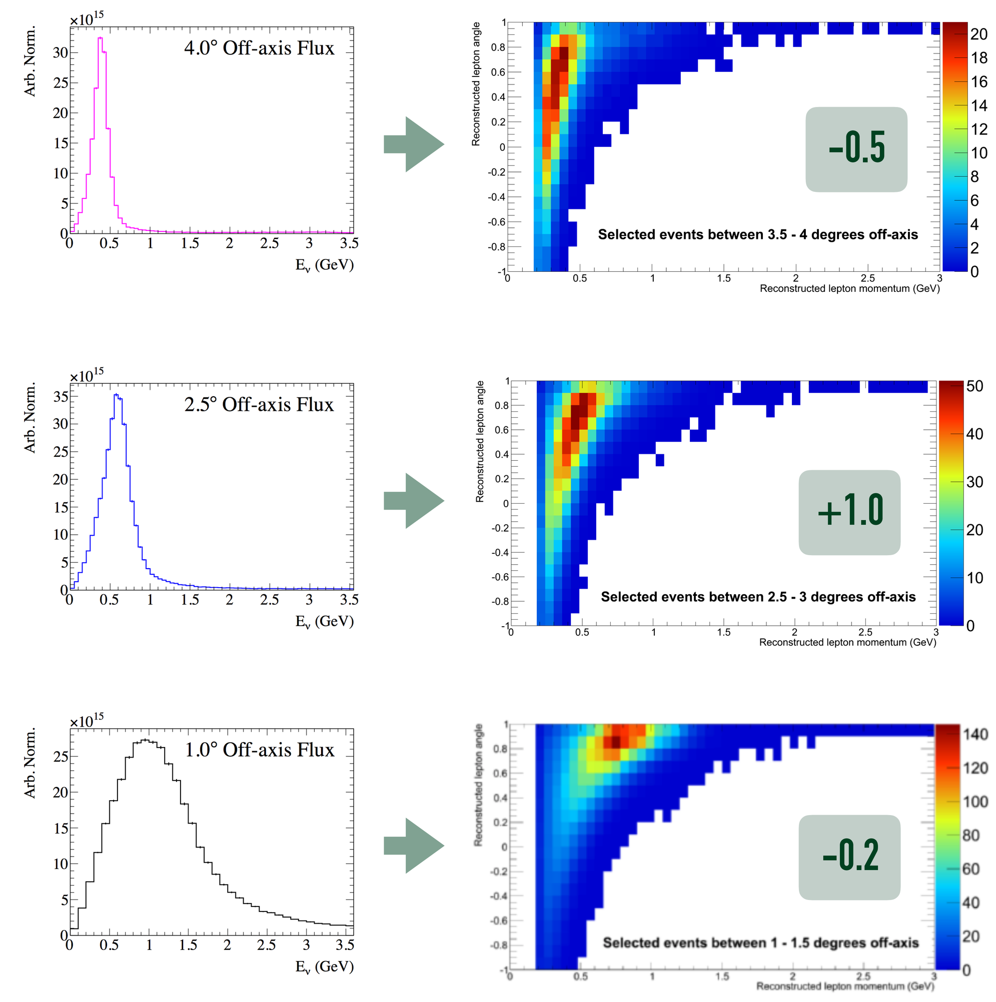


E61 concept



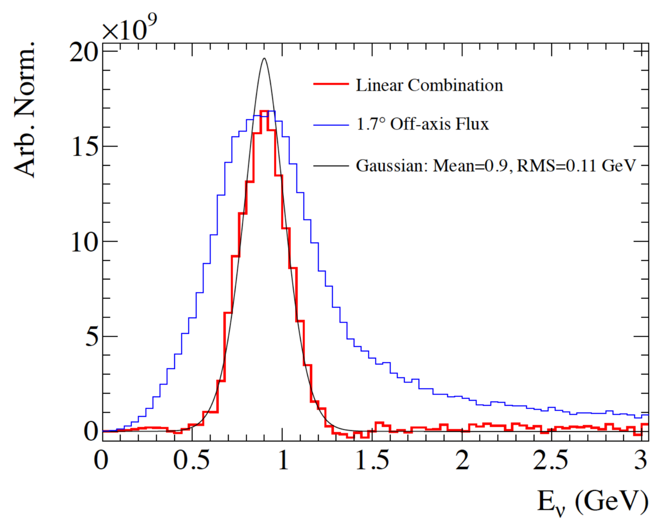


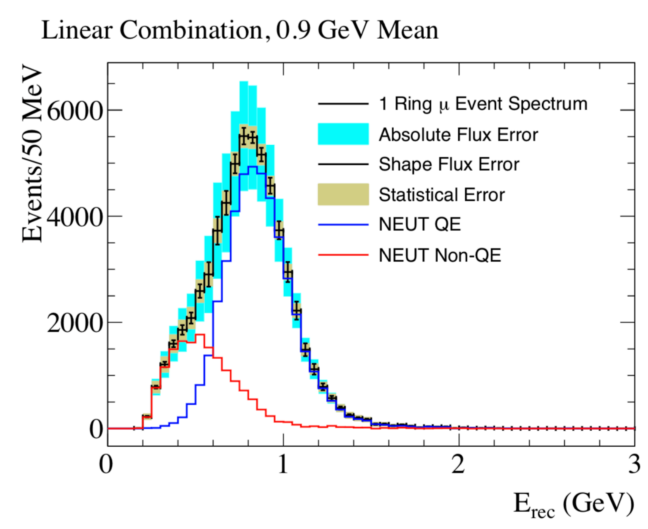
- Take linear combinations of different off-axis slices.
- Create neutrino flux of interest e.g. Gaussian to constrain neutrino cross-section models, or reproduce the oscillated far detector flux.



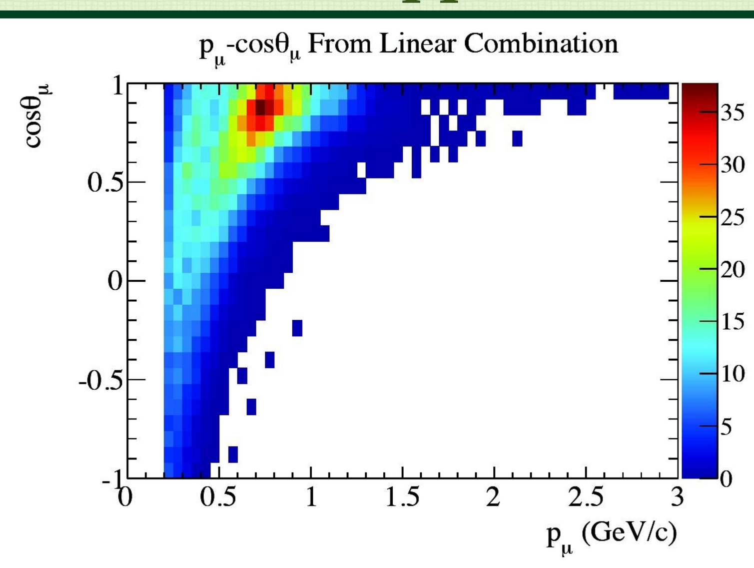
Pseudo-monochromatic beams

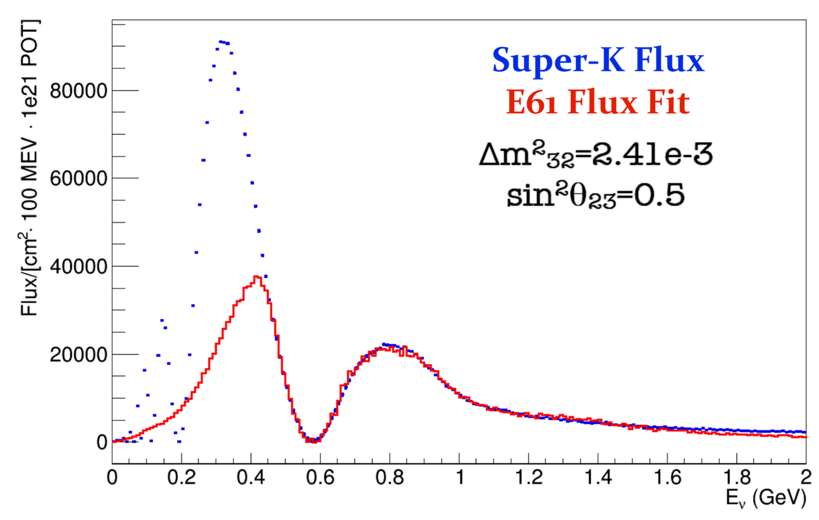
- Linear combination technique can subtract off low and high energy flux tails.
- Separation of QE and non-QE (including multi-nucleon) scatters in reconstructed variables.
- Directly predict the effect of non-QE scatters in oscillation measurements and provide a unique constraint on nuclear models.
- Can measure cross sections as a function of true neutrino energy.





Muon neutrino disappearance

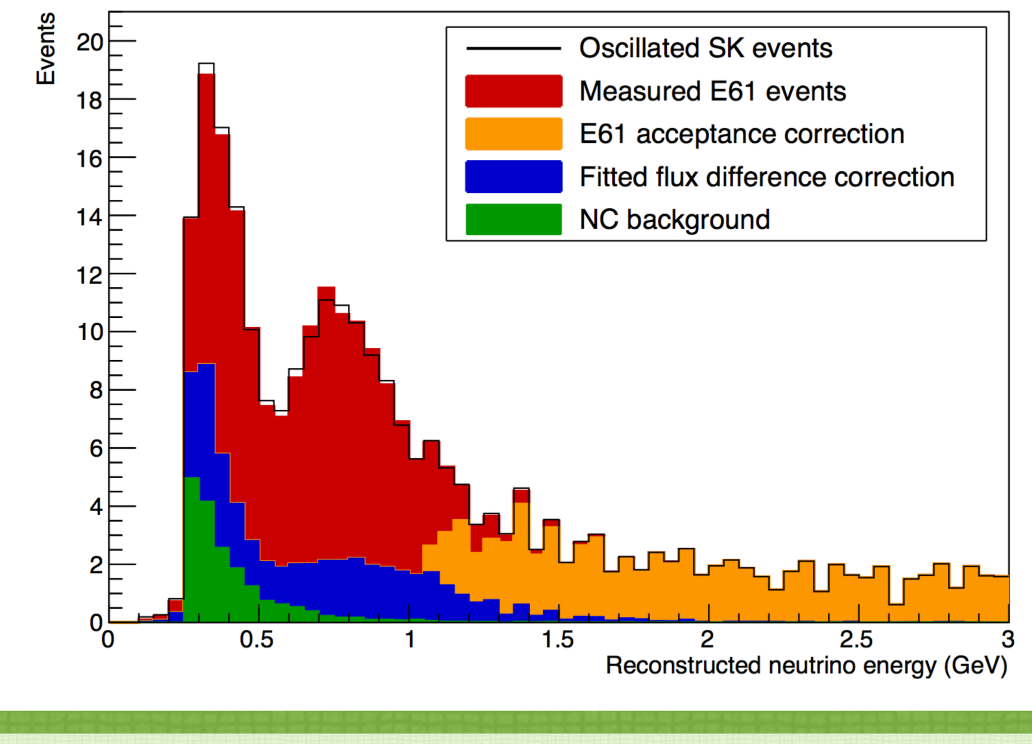




- For each oscillation hypothesis we want to test, we find a linear combination of the E61 off-axis fluxes to give the oscillated spectrum.
- With matched fluxes E61 event rate the same as oscillated SK event rate.
- E61 and SK have the same interaction material - same interaction cross-section.
- No cross-section model, no effect from wrong model choice.
- Directly compare E61 muon p-θ prediction to observed SK events to obtain oscillation parameters.

Applying method to simulated events

- **Red:** Use coefficients with E61 events to predict SK oscillated spectrum for muons with momentum less than 1 GeV.
- **Yellow:** Use selected SK events for muons above 1 GeV.
- **Blue:** Add on flux difference between fitted E61 flux and oscillated SK flux.
- SK detector efficiency is applied to the measured E61 events.
- **Green:** NC background subtracted from E61 and re-added from SK.
- Good agreement between measured E61 events and SK selected events.



Project Status

- Pursuing a phased experimental approach with an initial prototype detector in a test beam.
- Prove that 1% level calibration can be achieved.
- Measure physics processes, such as Cherenkov light profile and pion scattering.
- Assembly of mPMT modules scheduled for 2019, the prototype detector for 2020, and operation to begin in 2021.