THE INTERMEDIATE WATER CHERENKOV DETECTOR FOR THE JAPANESE LONG BASELINE PROGRAM

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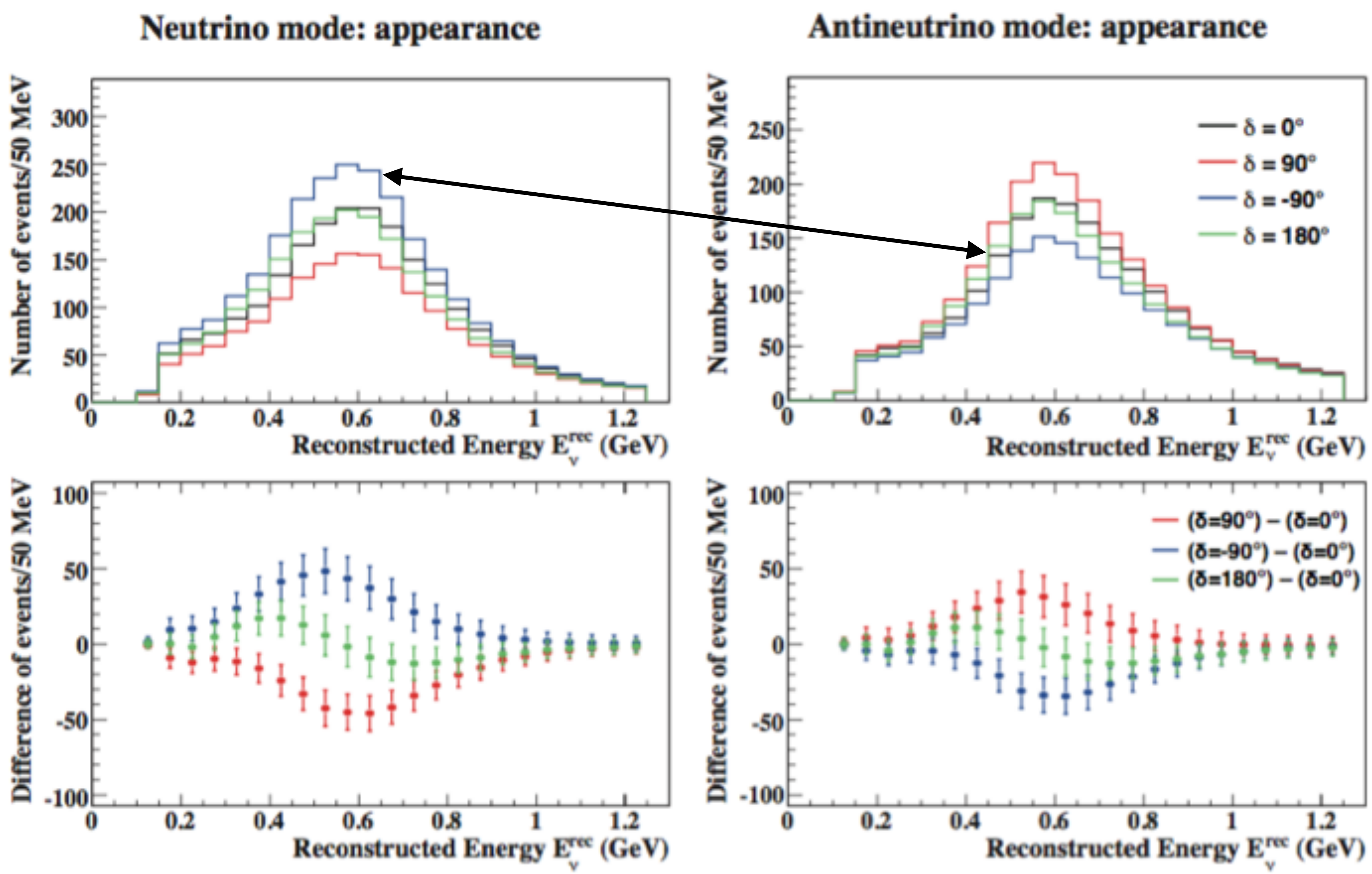
OUTLINE

- Why do we need an intermediate water Cherenkov detector (IWCD)?
- What is the E61 (formerly NuPRISM) proposal?
- Plan to realize the IWCD for the Japanese long baseline neutrino program.

CP VIOLATION MEASUREMENT AT HYPER-K



Search for asymmetry in the rates of electron neutrino and antineutrino candidates

10 years, 1 tank = 2058 electron neutrino and 1906 electron antineutrino candidates

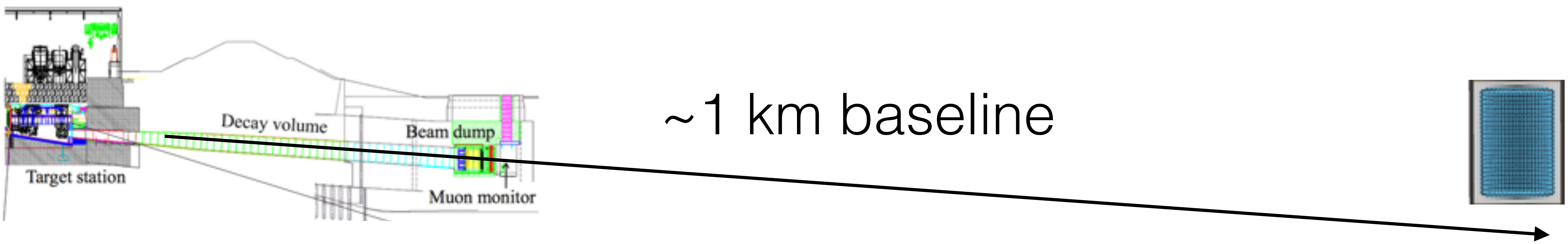
3.2% statistical error on measurement of CP asymmetry

CURRENT SYSTEMATIC ERRORS FROM T2K

- Systematic errors in T2K are 4.8%
- 4.5% of errors related to neutrino and secondary particle interaction modeling
- A program to reduce systematic errors for Hyper-K is necessary
- Requires new measurements at near (intermediate) detectors
- Uncertainties on the shape of the observed spectrum are also important

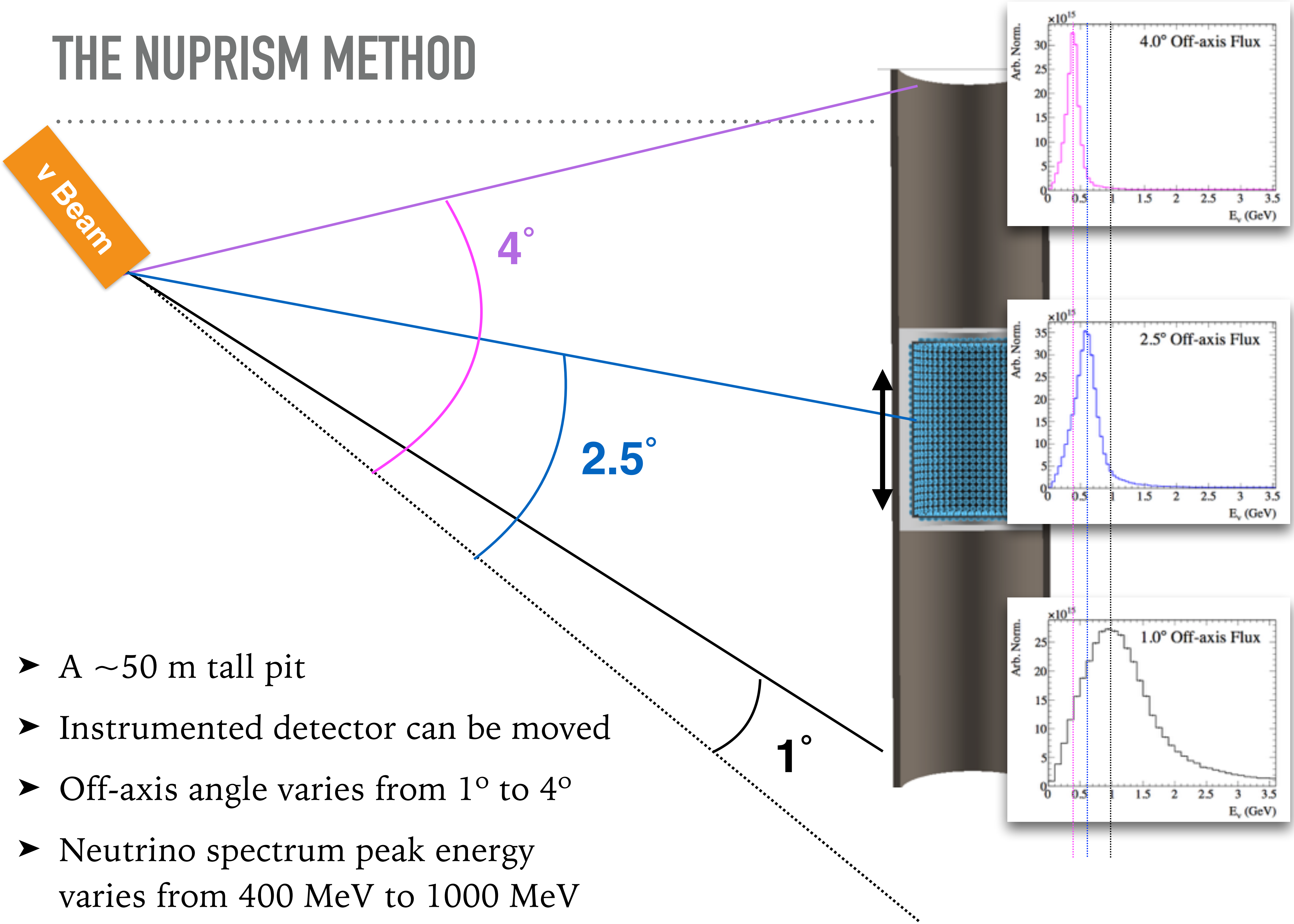
Error Source	% Error on neutrino/ antineutrino rate
Pion Interactions	1.6
Neutral Current Background	1.5
Electron (anti)neutrino cross section	3.0
Extrapolation from near detector	2.5
Far detector modeling	1.6
Total	4.8

AN INTERMEDIATE WATER CHERENKOV DETECTOR



- Intermediate water Cherenkov detector: kiloton scale detector at 1-2 km baseline
- Advantages:
  - Same detector technology as far detector
    - Matching acceptance and efficiency
    - Same nuclear target
  - At 1 km baseline, un-oscillated flux is similar to far detector

THE NUPRISM METHOD



- A ~50 m tall pit
- Instrumented detector can be moved
- Off-axis angle varies from 1° to 4°
- Neutrino spectrum peak energy varies from 400 MeV to 1000 MeV

THE E61 COLLABORATION

- Formed from merger of **NuPRISM** and **TITUS** intermediate water Cherenkov proposals
- E61 is the J-PARC experimental designation - has received Stage-1 status from the J-PARC PAC
- **100 collaborators from 34 institutes in 8 countries**
- Maintain the proposal for an off-axis spanning detector
- Pursue Gd loading in support of SK-Gd and Hyper-K programs

Report from the E61 Experiment, July 2017

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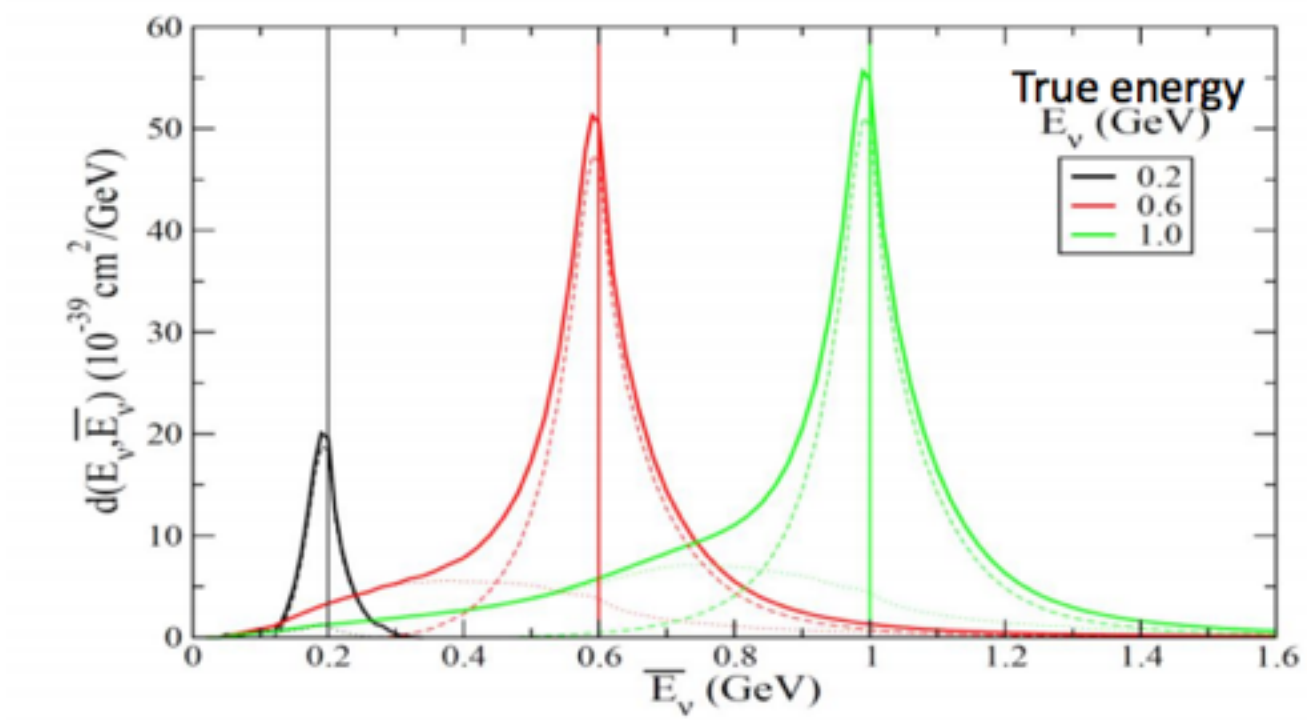
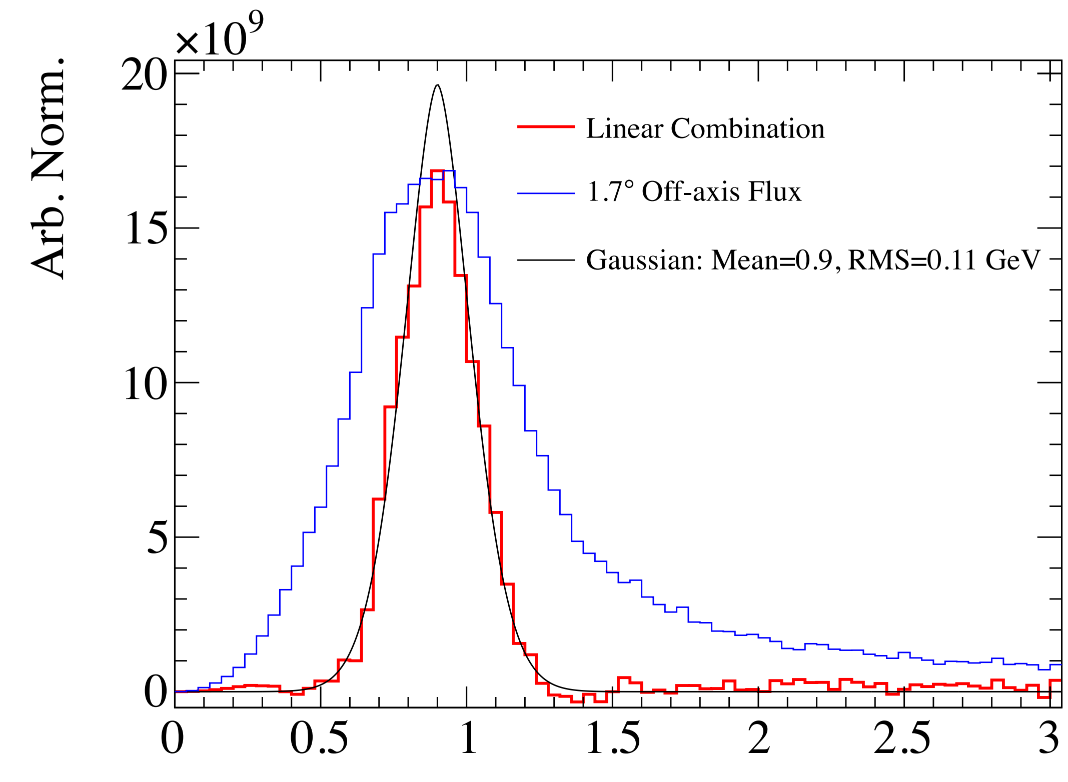
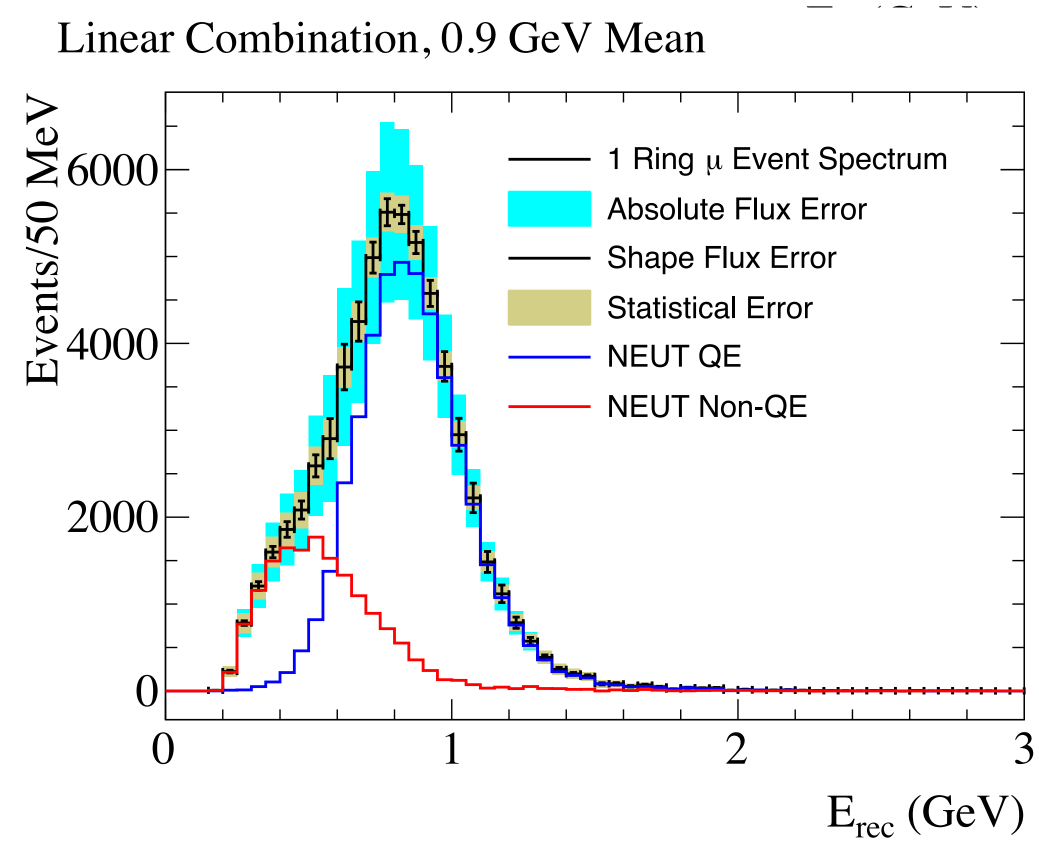
THE PHYSICS OF E61 – NUCLEAR EFFECTS

ν energy distribution



M. Martini, M. Ericson, G. Chanfray,
Phys. Rev. D 85 093012 (2012)

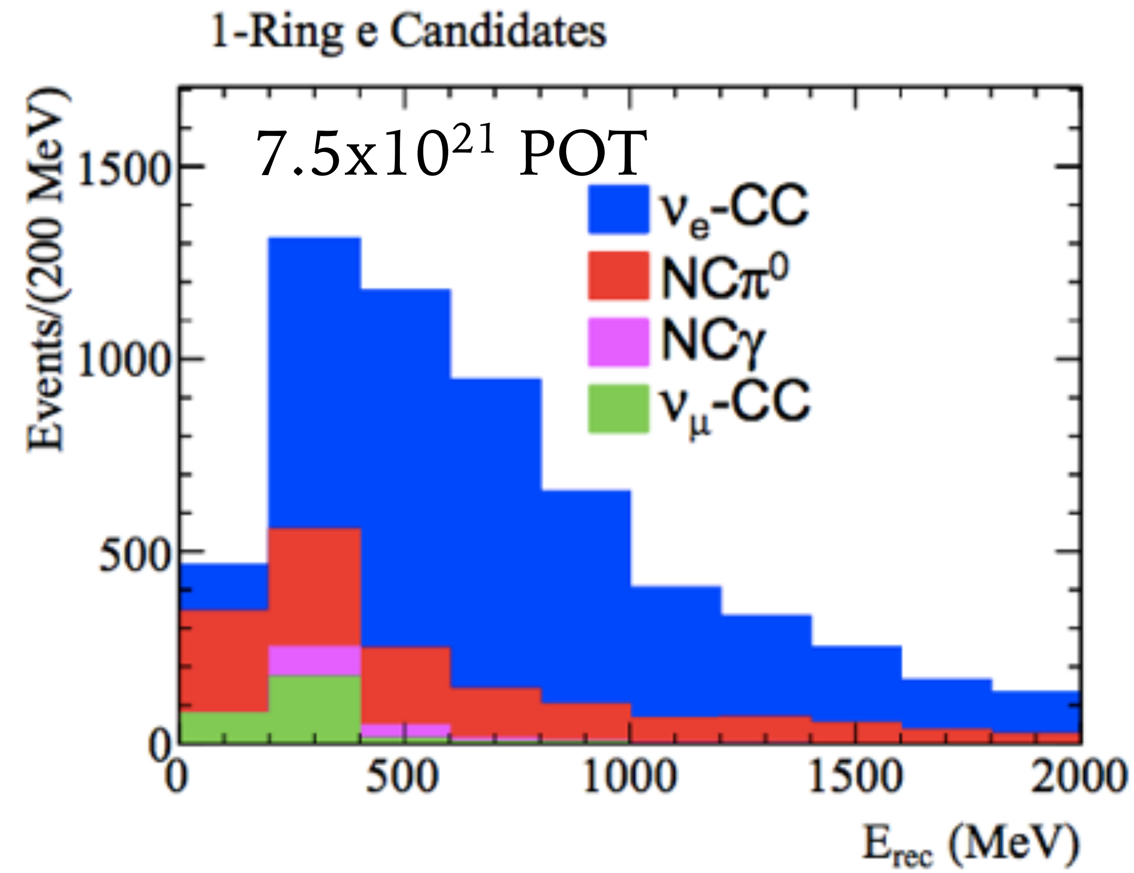




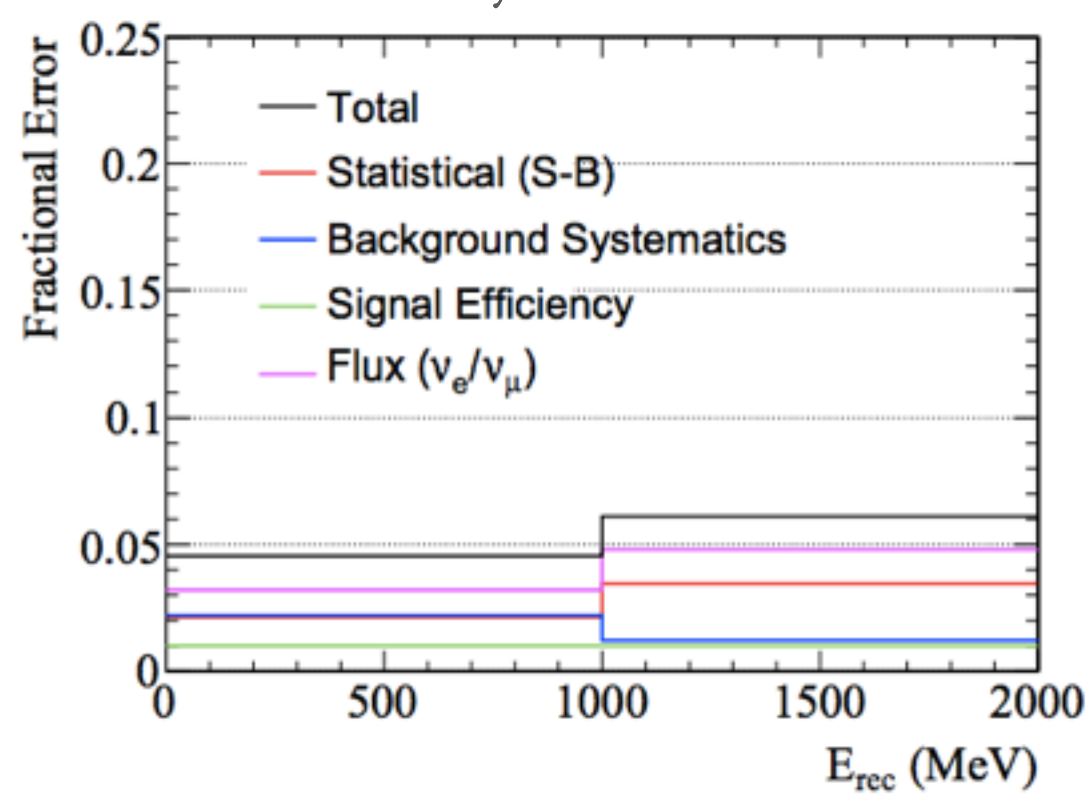
- ➤ Need study of non-QE components of cross section that have a different energy reconstruction distribution
- ➤ Measurements at different off-axis angles used to subtract high and low energy tails of flux - mono-energetic beam
- ➤ Can understand energy mis-reconstruction due to nuclear effects

THE PHYSICS OF E61 – ELECTRON (ANTI)NEUTRINO CROSS SECTION

- Measure the electron (anti)neutrino cross section using the intrinsic component in the beam
- Large detector mass provides sufficient statics - 5000 events for Hyper-K exposure
- Intrinsic electron (anti)neutrino component increases with off-axis angle
- Water Cherenkov detector: active shielding against external photon backgrounds

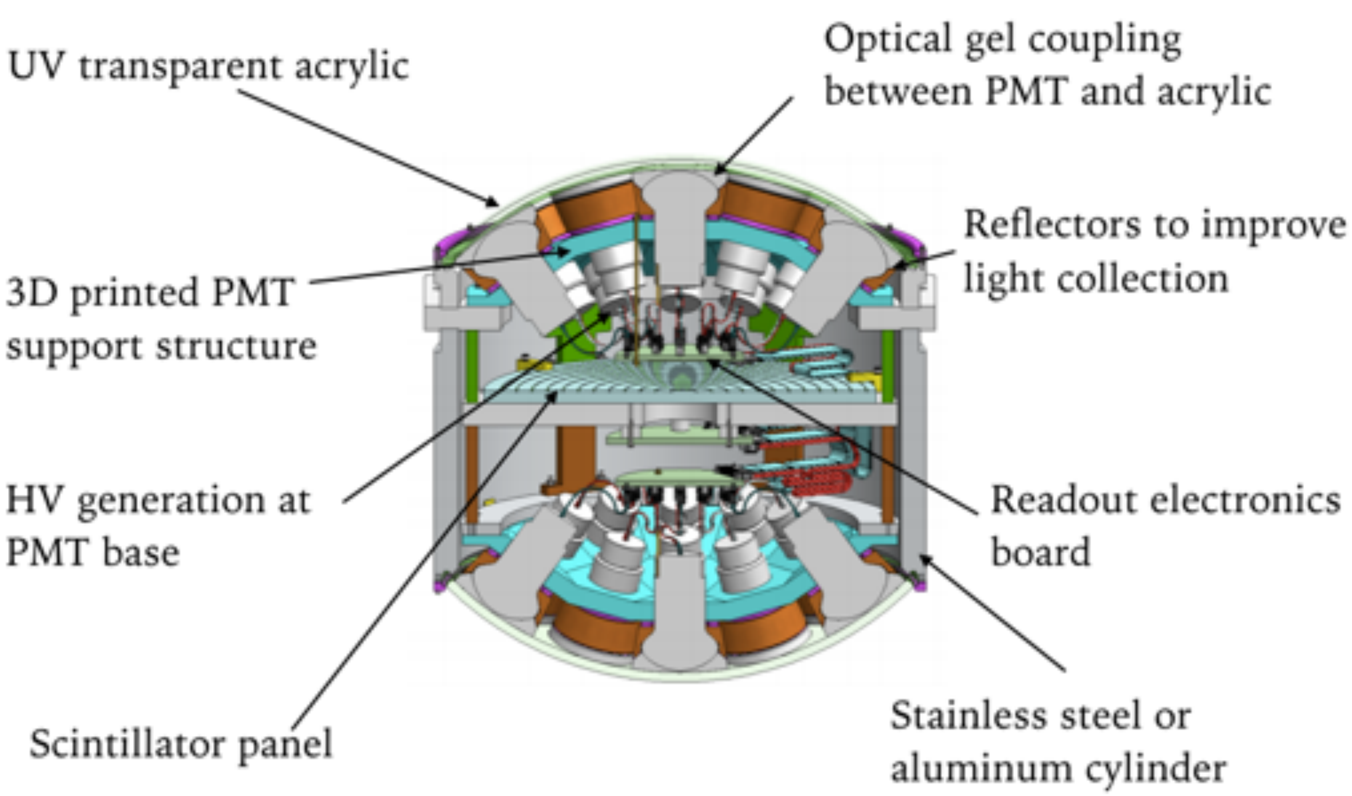


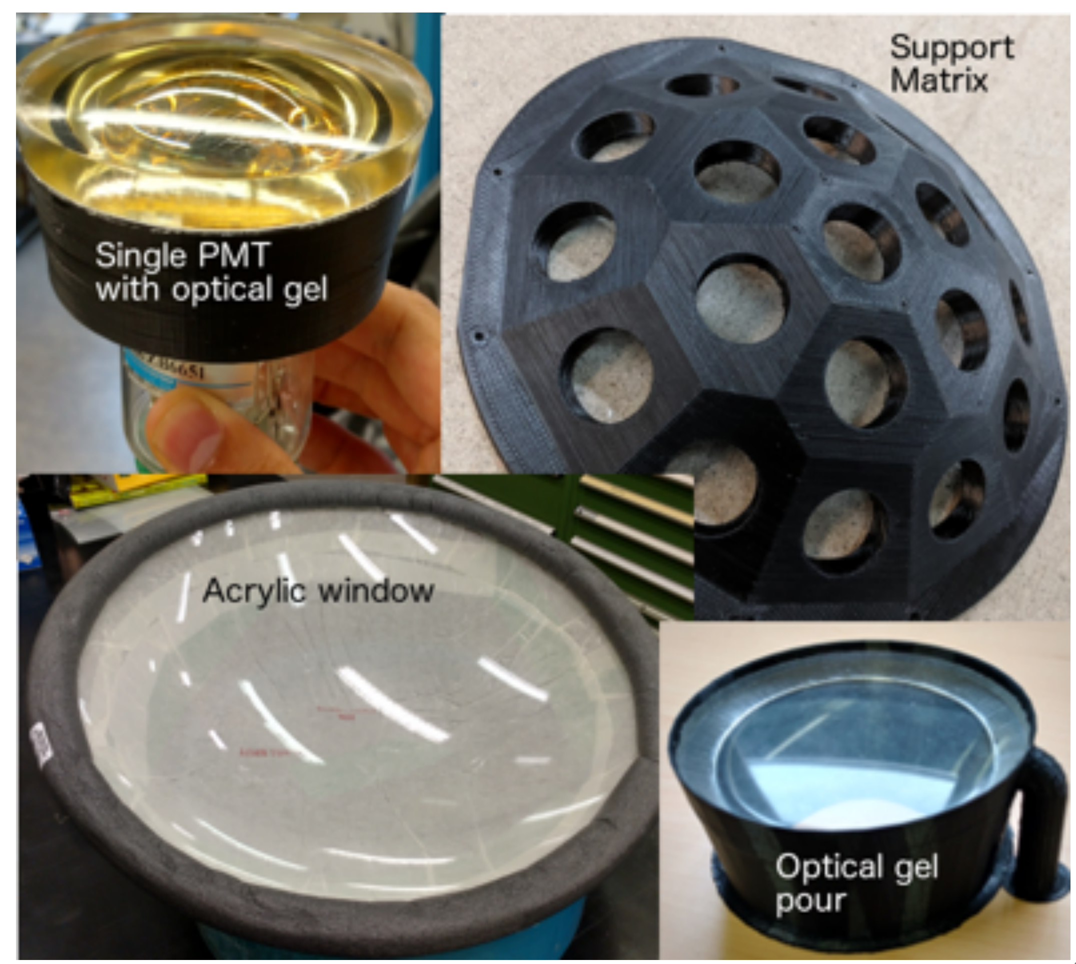
Uncertainty on Measurement



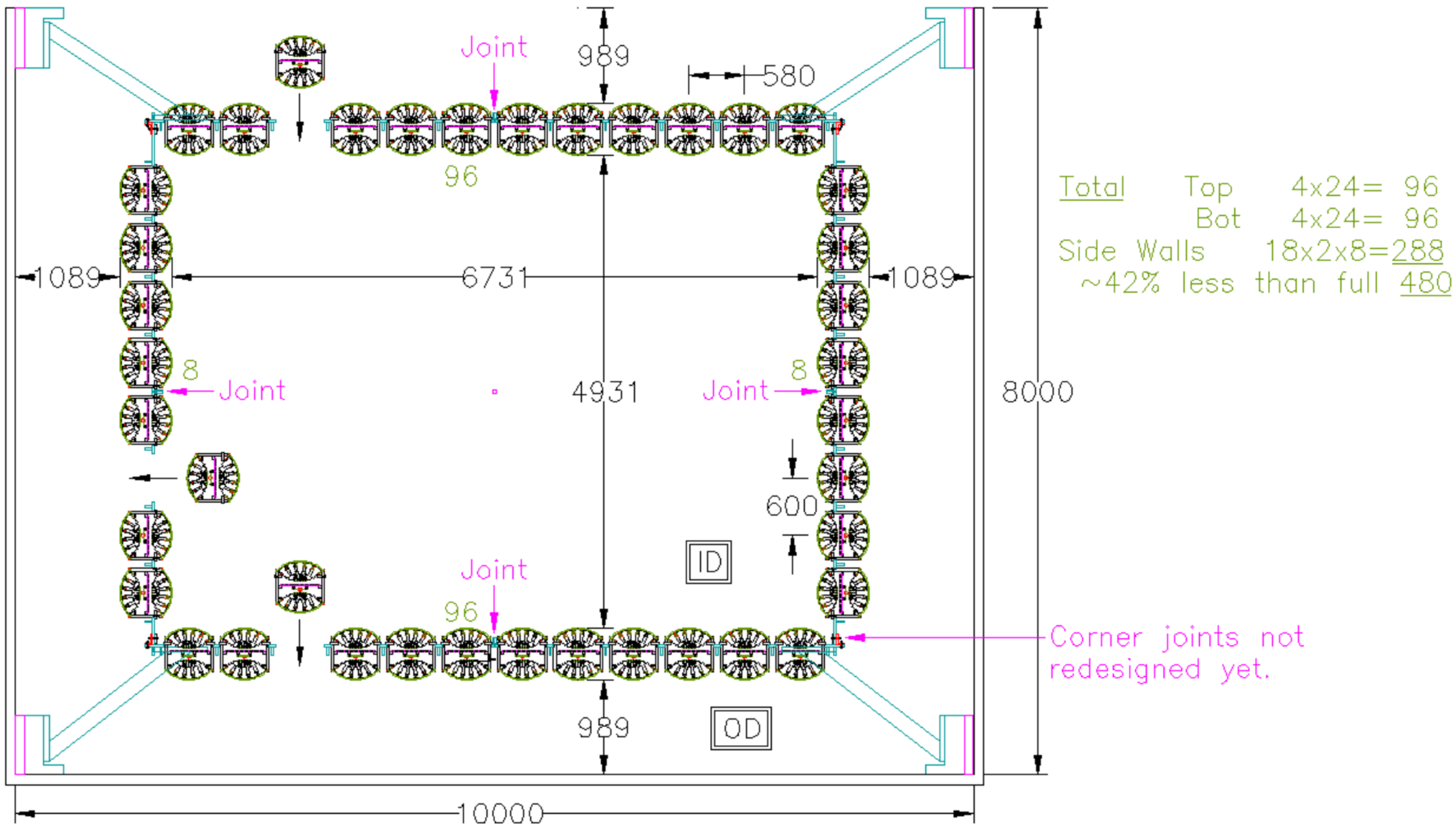
MPMT: NEW PHOTOSENSOR TECHNOLOGY

- Development of a multi-PMT photosensor module will bring improvements in spatial and timing resolution
- TRIUMF is a leading institute in this effort
- New fast 3-inch PMTs developed with Hamamatsu
- Potential applications to Hyper-K and other future particle physics experiments





DETECTOR WITH MULTI-PMTS

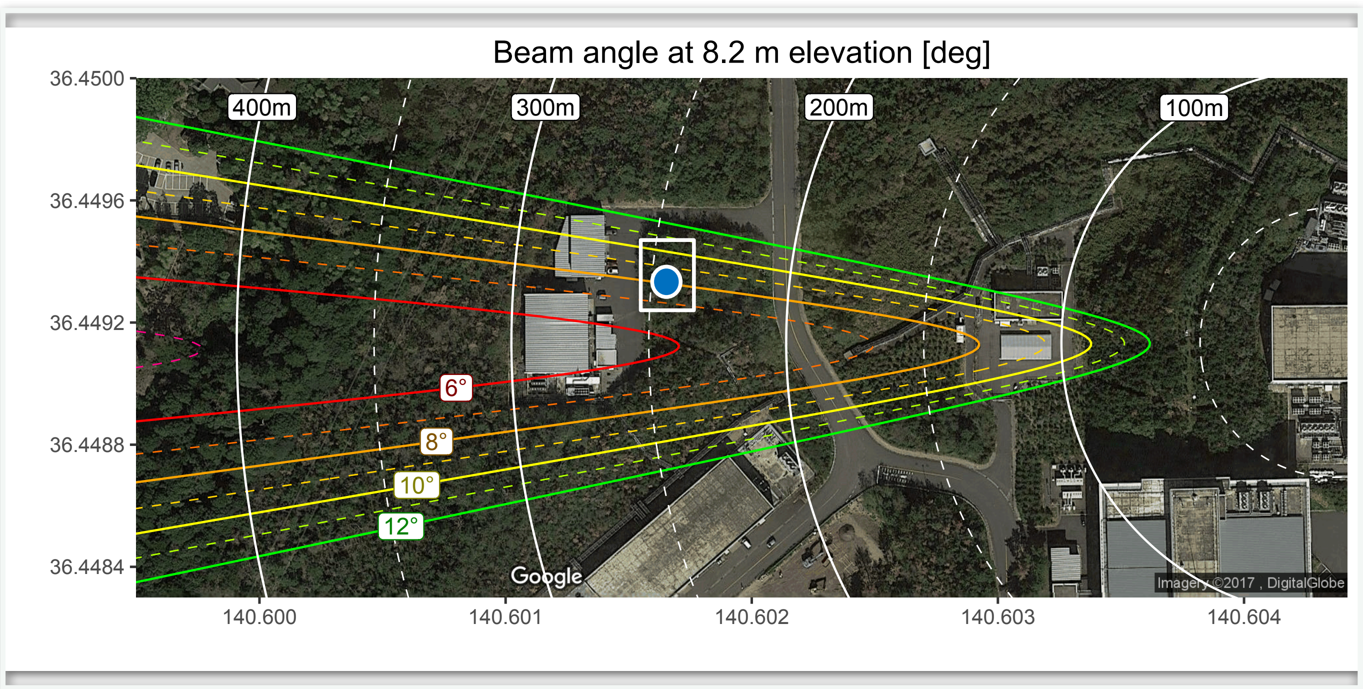


- Example detector configuration with mPMT photosensors
- Height of detector depends on baseline where detector is built
  - "Short" (5 m tall ID) version of the detector design can be used if detector site is 700 m - 1000 m baseline

A PHASED APPROACH FOR E61

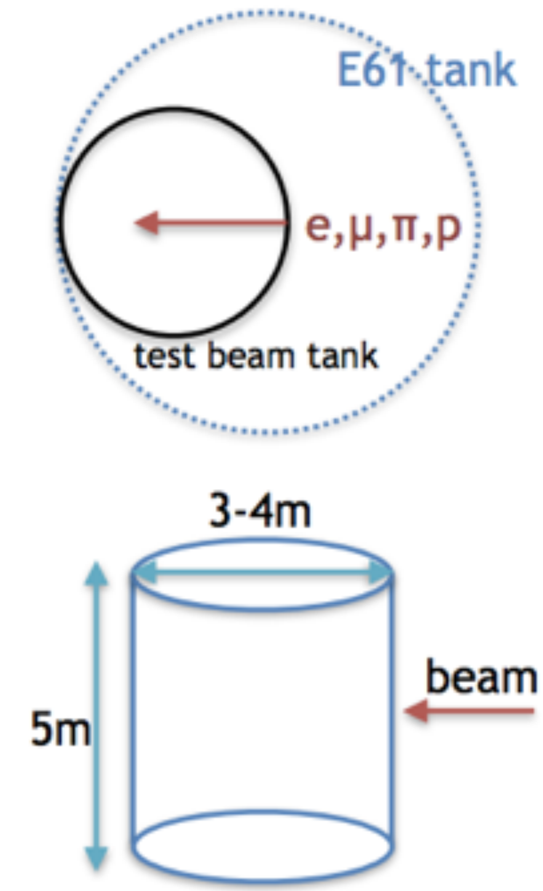
- E61 is pursuing a phased approach of the experiment:
  - Initial phase: reduced cost experiment to gain experience with 1% level calibration
  - Two options being considered:

Surface detector at J-PARC



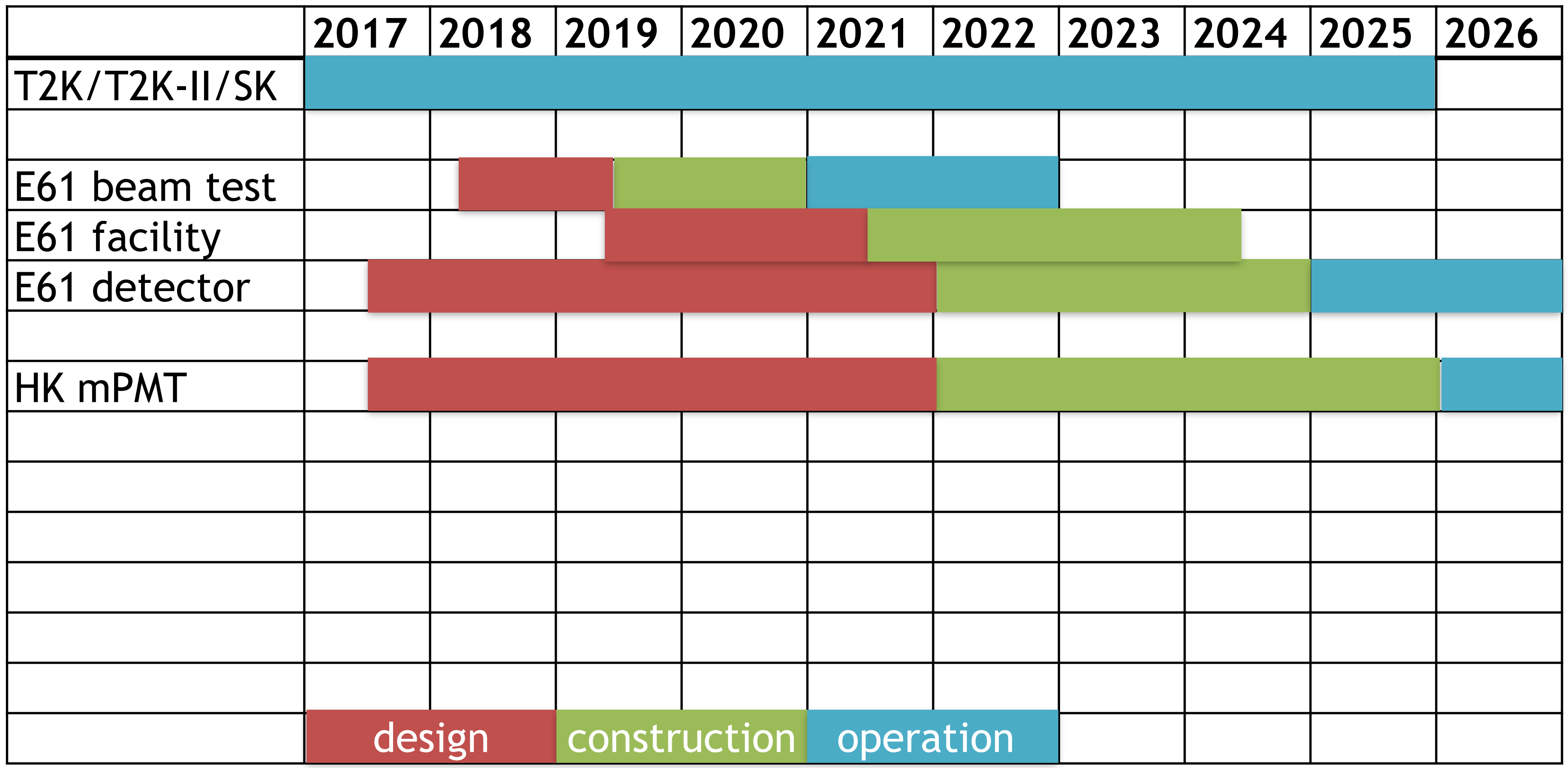
Neutrino interactions at 8 degrees off-axis to study the electron neutrino cross section

Charged particle beam test



Calibrate and study detector response with known particle type, momentum.

E61 TIMELINE (WITH TEST EXPERIMENT)



- Schedule includes test experiment running from 2021
- Facility construction for full detector ramping up in 2021
- Detector construction starts in 2022 and finishes in 2024
  - A fraction of the mPMT modules will be constructed for the test experiment

NEAR DETECTOR SCHEDULE FOR HYPER-K

	JFY 2018	2019	2020	2021	2022	2023	2024	2025
Near Detector system	0	0	0	0.5	2.5	5	2	0
		ND facility (civil construction etc)						
			R&D and production				ND construction	

Near detector conceptual design report

Near detector technical design report

Collaboration technical review

Collaboration approval of conceptual design

Collaboration approval of technical design

TRANSITIONING FROM E61 TO HYPER-K IWCD

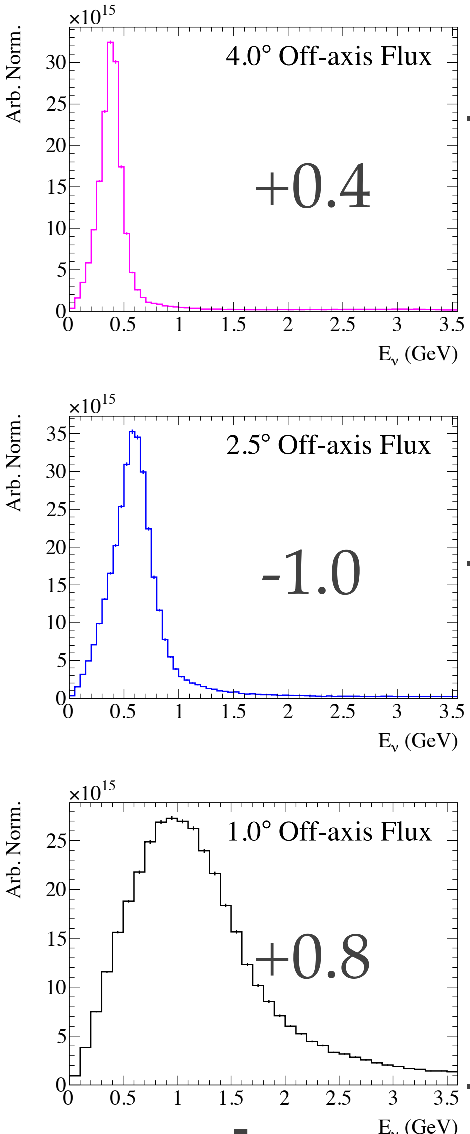
- 2018: Conceptual design for Hyper-K near detectors will be presented to the Hyper-K collaboration
  - Will include the E61 design for the IWCD
- When the collaboration officially approves the intermediate detector, the status of the E61 collaboration needs to be determined
  - Should it remain a separate collaboration or be merged into Hyper-K? Requires discussion between E61 and Hyper-K
- Questions to KEK:
  - Is it practical for E61 to proceed as a separate experiment (assuming Hyper-K approval)
  - If E61 is merged into the Hyper-K project, what is the procedure for KEK approval, facility design support and the facility funding request?

SUMMARY

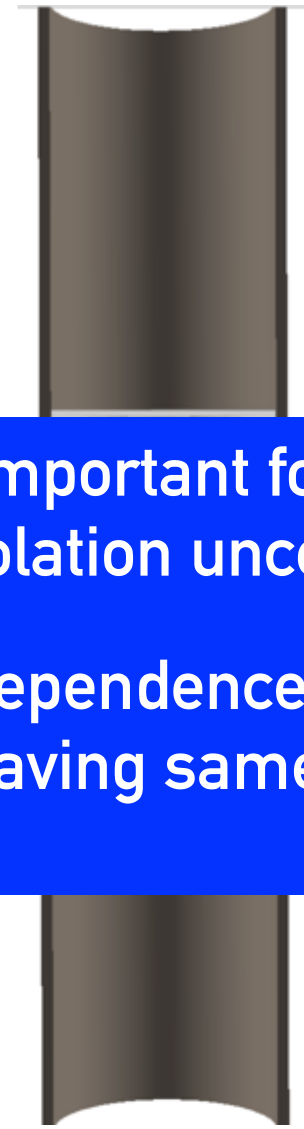
- Long baseline neutrino experiments are entering a precision error where systematic error reduction is critical
- The E61 experiment is proposed to address critical systematic errors in neutrino-nucleus scattering
- Development of a new multi-PMT photosensor for E61 and potentially Hyper-K is ongoing
- Review of near detectors inside the Hyper-K experiment is ongoing with preparation of a CDR
- Need careful coordination between E61, Hyper-K and KEK to develop plan to realize the intermediate water Cherenkov detector for Hyper-K

THANK YOU

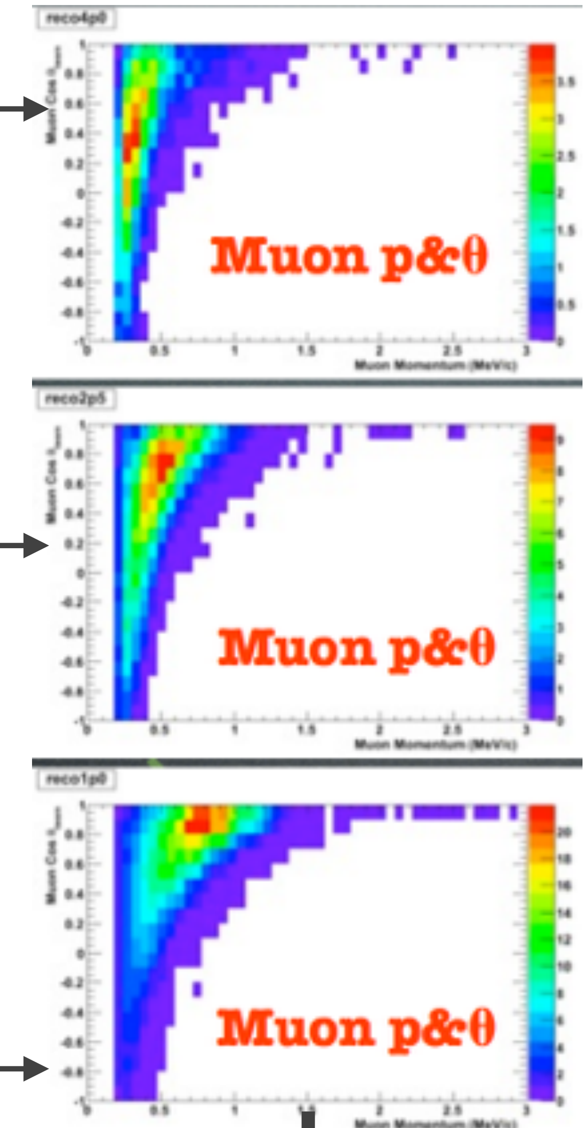
ENERGY RESPONSE MEASUREMENT



Spectra at at each off-axis bin

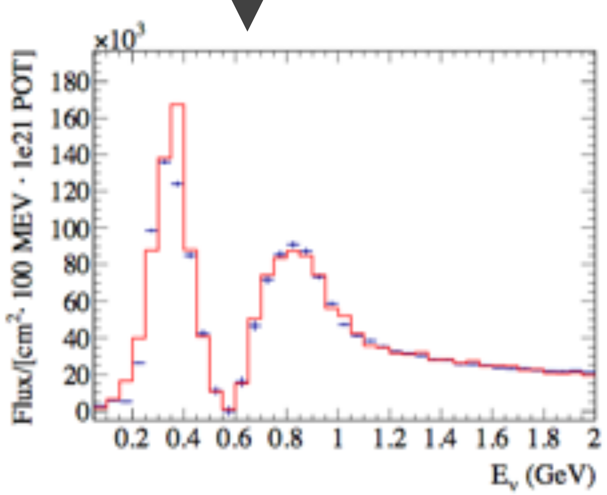


Observed muon kinematic distributions

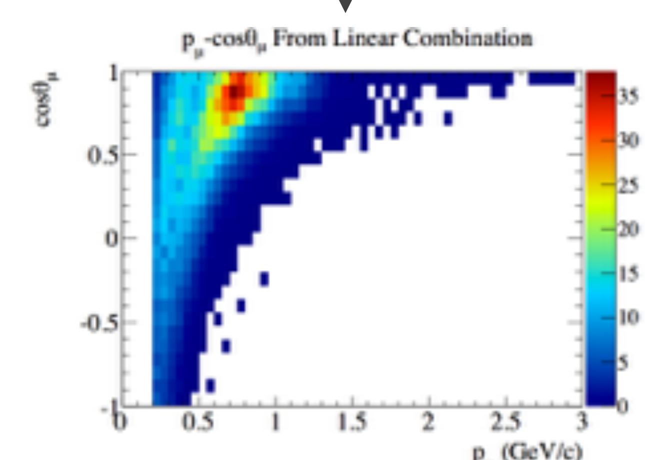


This approach is important for reducing the near to far extrapolation uncertainty.

Minimize model dependence in the extrapolation by having same spectrum in near and far detector.

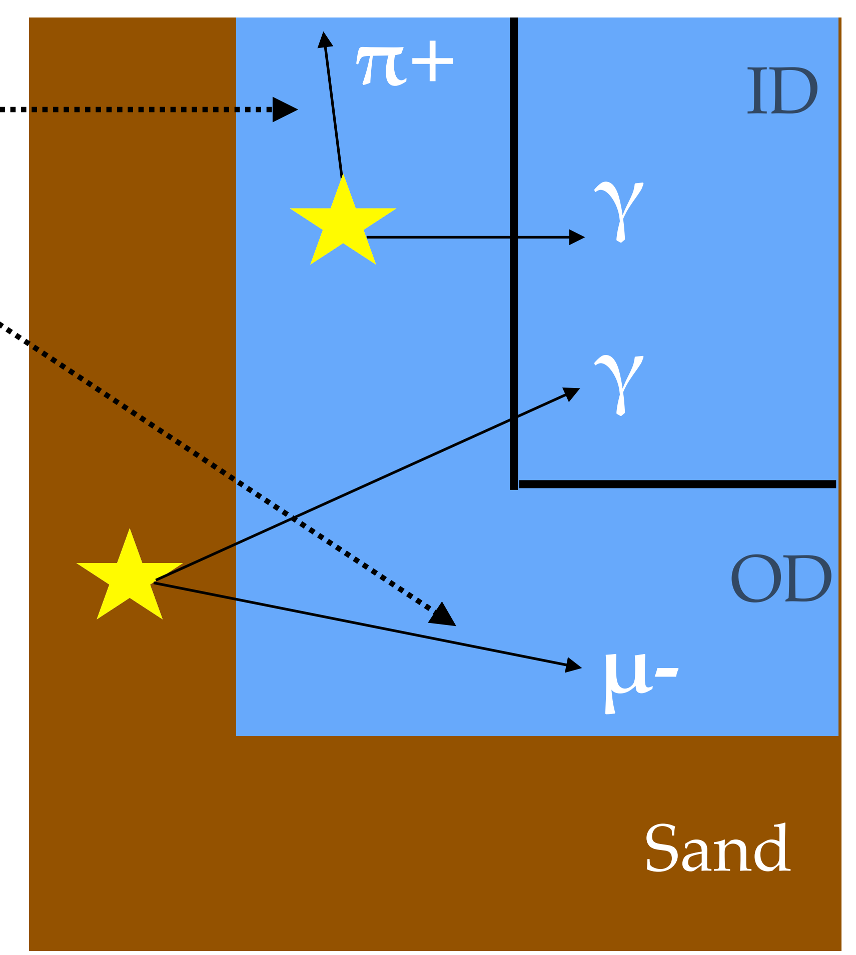


Linear combinations reproduce the oscillated flux, and predict muon kinematic distributions for the oscillated flux



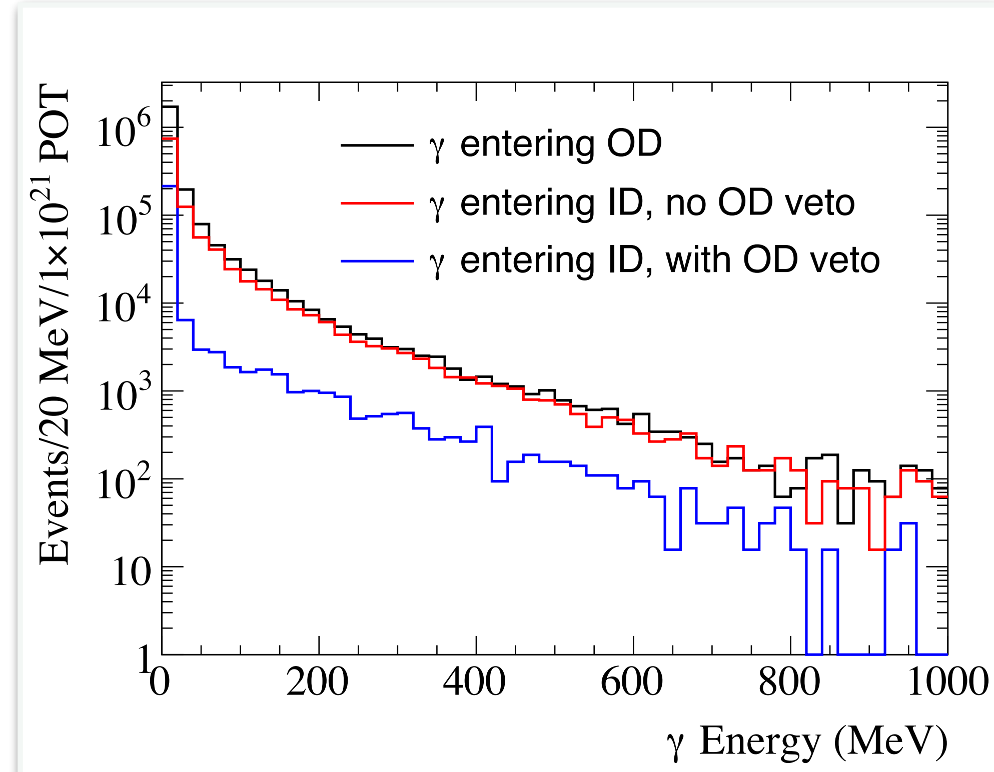
PHASE-0 ENTERING GAMMA STUDY

- External γ are simulated with a full GEANT4 based simulation including neutrino interactions in the surrounding sand and the OD
- Events in the ID and backgrounds entering ID are simulated with WCSim (GEANT4 based) and have fiTQun reconstruction applied
- OD Veto: >50 MeV of energy loss above Cherenkov threshold from charged particles in the OD
- Event Selection:
  - Single contained electron-like ring
  - No Michel electron
  - >100 MeV of visible energy
  - >Vertex 155 cm from the ID wall
    - 130 ton fiducial mass
  - To wall along candidate direction >195 cm

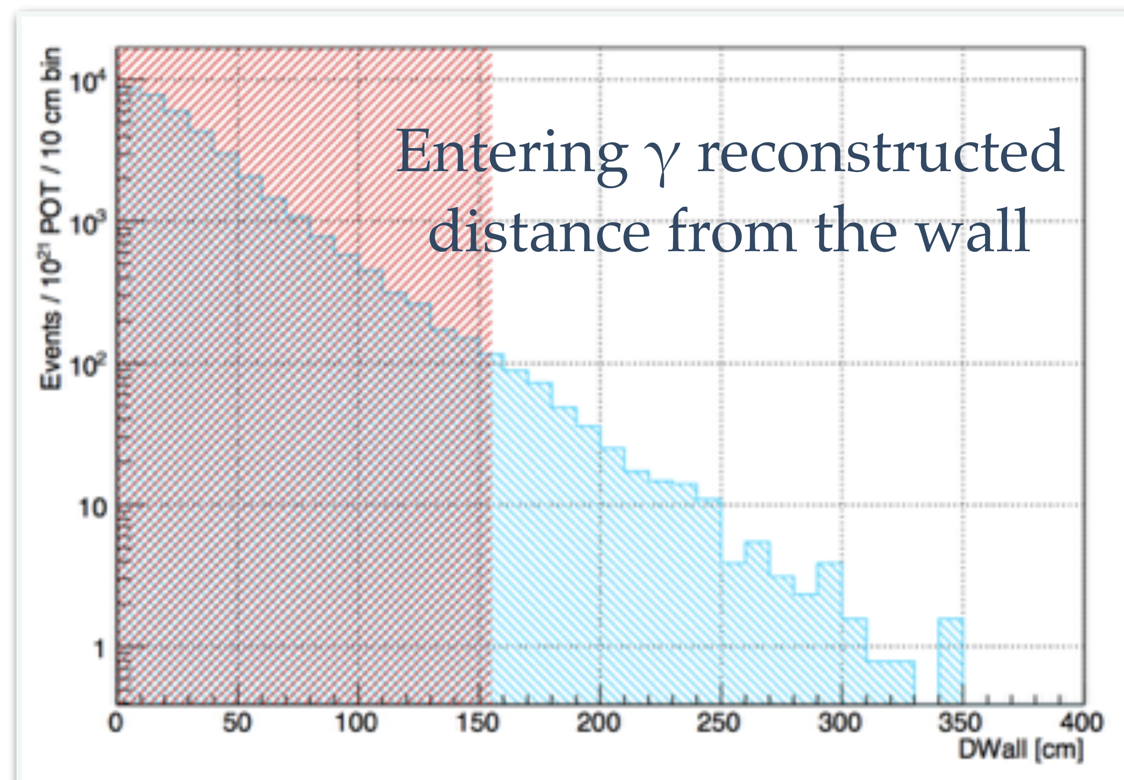


GAMMA REJECTION

- The OD veto reduces the rate of external γs entering the ID by 7
  - Efficiency of 50 MeV of visible energy cut sets a design goal for OD performance



- Additional reduction from the >155 cm from ID wall cut
  - Only 1.1% of external γs pass this cut
  - Remaining background from long conversion lengths



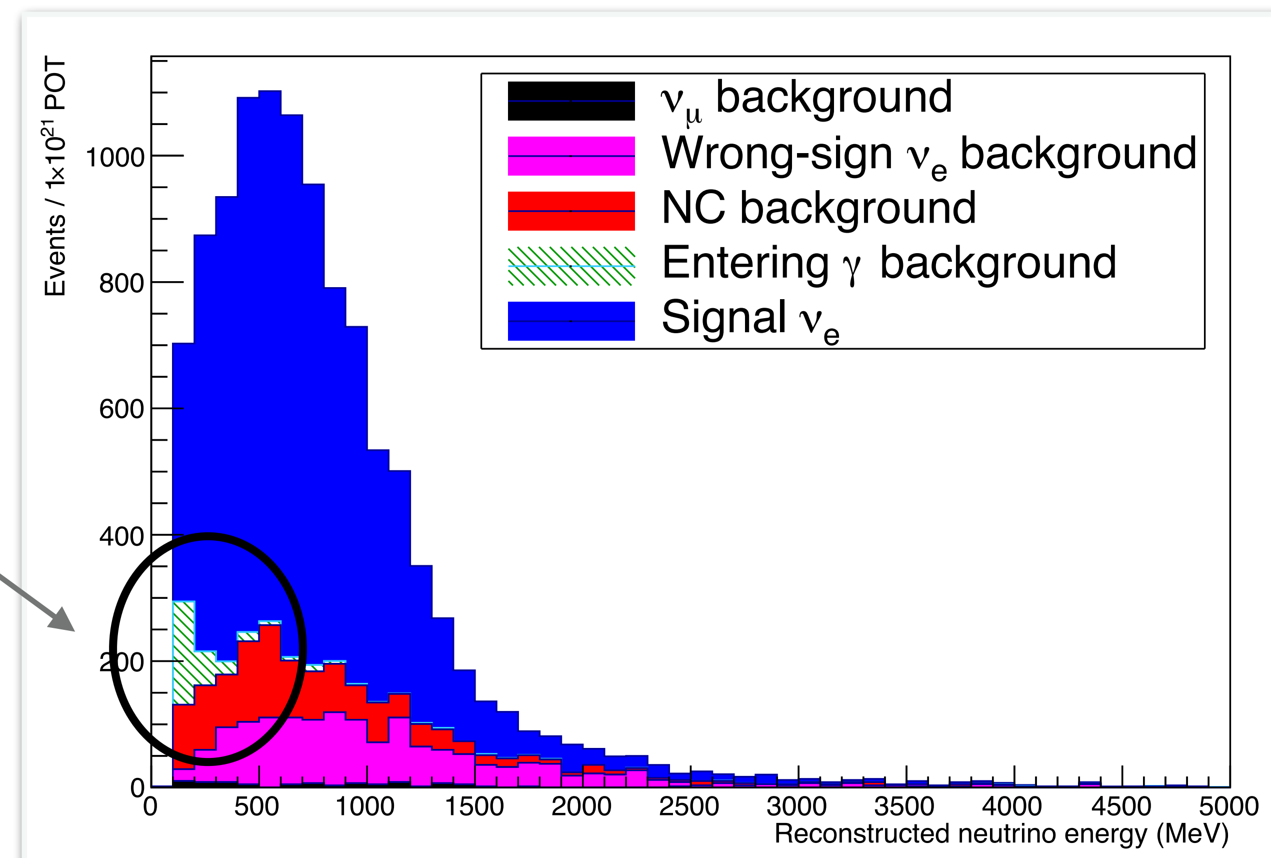
GAMMA BACKGROUND IN PHASE-0

1e21 protons on target (1/2 year at 1.3 MW), Reconstructed energy < 1 GeV:

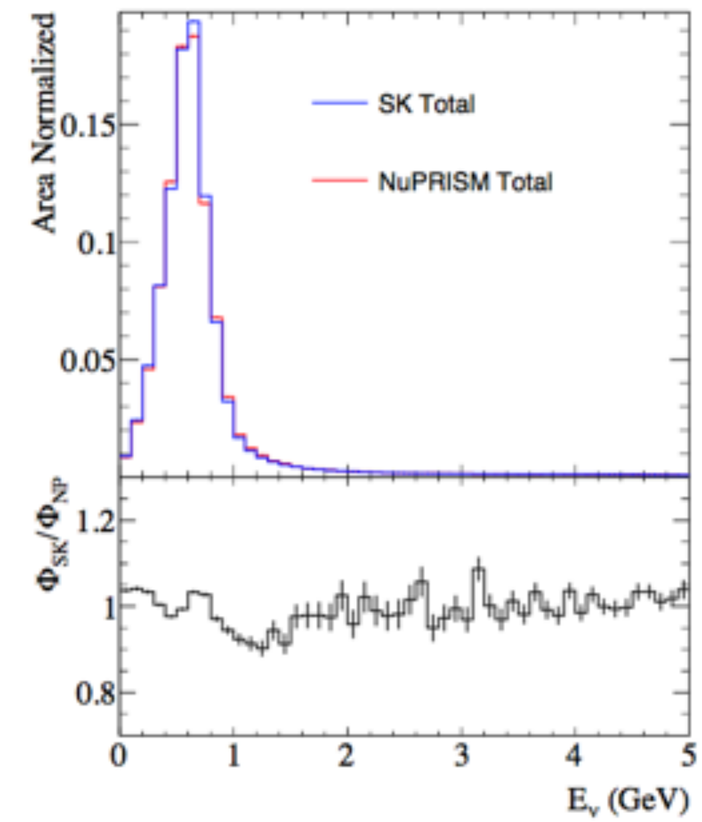
Right Sign Signal	Wrong Sign Signal	NCπ0	NCγ	External γ	Other	Total	Purity
6262	790	768	92	282	55	8247	75.9%

In Phase-0, entering gamma background is well controlled

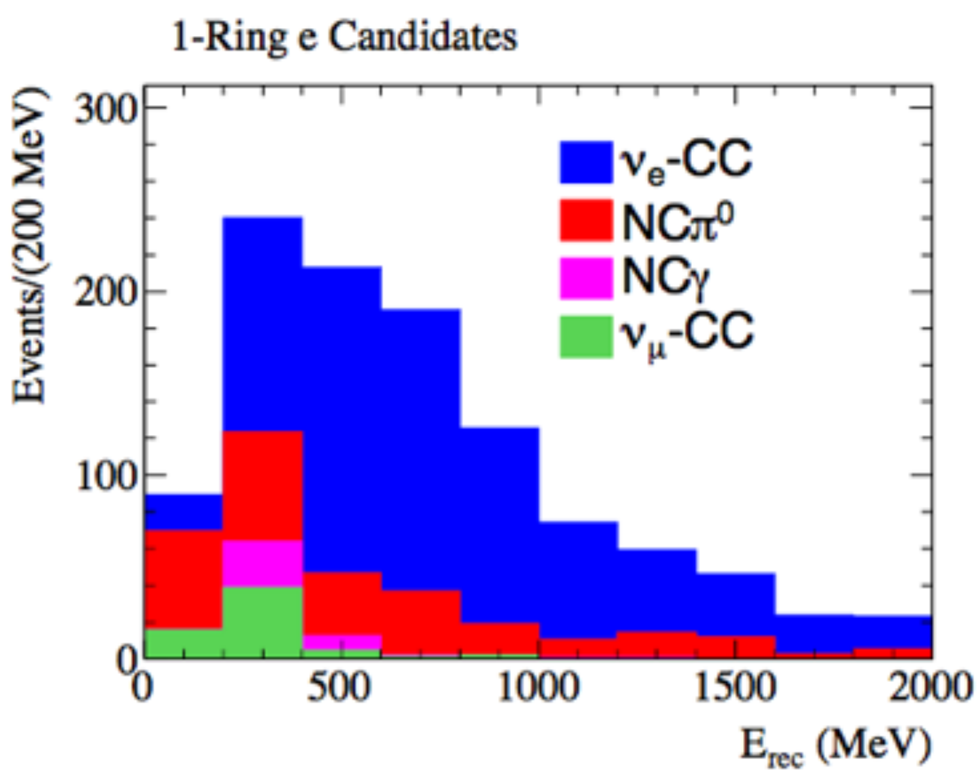
Need to extend the study to Phase-1



INTRINSIC NC AND ELECTRON NEUTRINO BACKGROUND



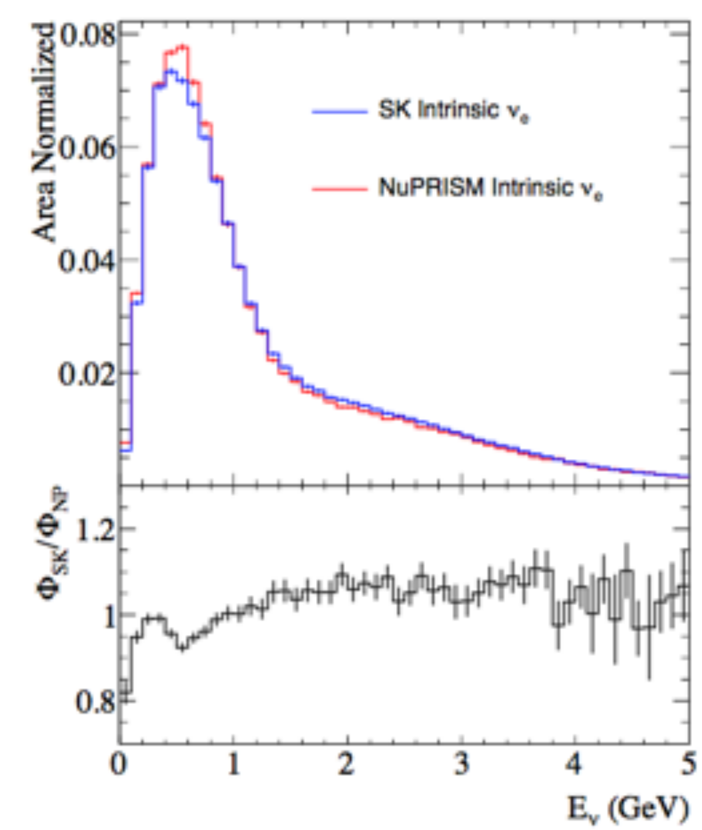
- Total neutrino and intrinsic ν_e and fluxes are nearly identical in the intermediate and far detectors
- Can measure the intrinsic+NC background directly in the intermediate detector



300 ton ID x 1.5e21 POT

3% statistical precision can be achieved

Study of systematic errors is planned



WHY IS E61 SEPARATE FROM HYPER-K?

- NuPRISM was originally proposed inside T2K
- Decision was made to propose as a separate experiment
- A separate proposal for NuPRISM was necessary, eventually leading to E61 collaboration with merger of NuPRISM and TITUS groups
- In the long term, the E61 detector will be used in Hyper-K. Expect a close relationship and possible merger of the collaboration into the Hyper-K collaboration