Ambient Background Modeling and Event Trigger Development for the Pacific Ocean Neutrino Explorer

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June 10, 2021

P-ONE

http://p-one.nu

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Neutrino Telescopes

- Telescopes detect Cherenkov light produced by secondary particles from neutrino interactions using a large volume array of optical modules in a transparent medium
    - Fresh water - Gigaton Volume Detector, Lake Baikal
    - Salt water - ANTARES, KM3NeT, Mediterranean
    - Ice - IceCube, Antarctica

- We need more neutrino telescopes to truly understand what neutrinos, the PeV messengers of our Universe, can tell us about the cosmos

Image: KM3NeT Collaboration [2]

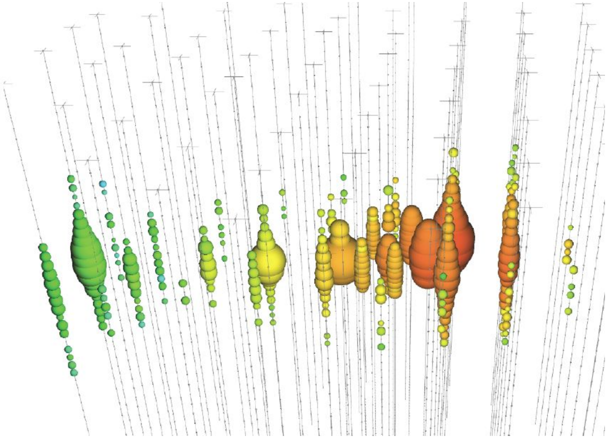


Image: IceCube Collaboration [1]

The Pacific Ocean Neutrino Experiment (P-ONE)

- Proposed cubic-kilometer scale neutrino telescope in the Pacific Ocean off the coast of Vancouver Island
- Make use of existing Ocean Networks Canada (ONC) infrastructure in the Cascadia Basin

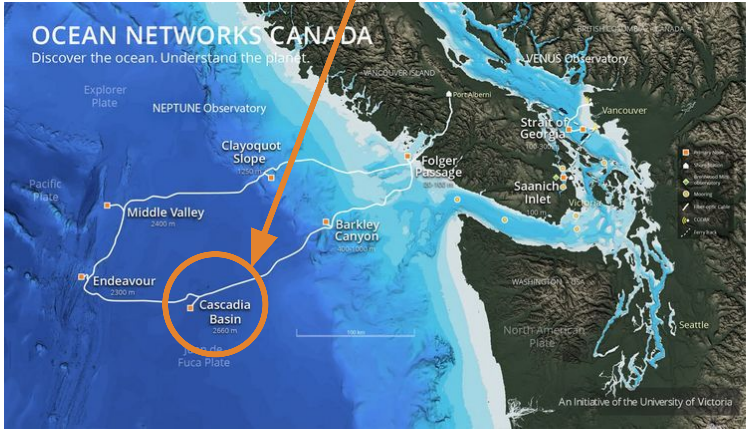
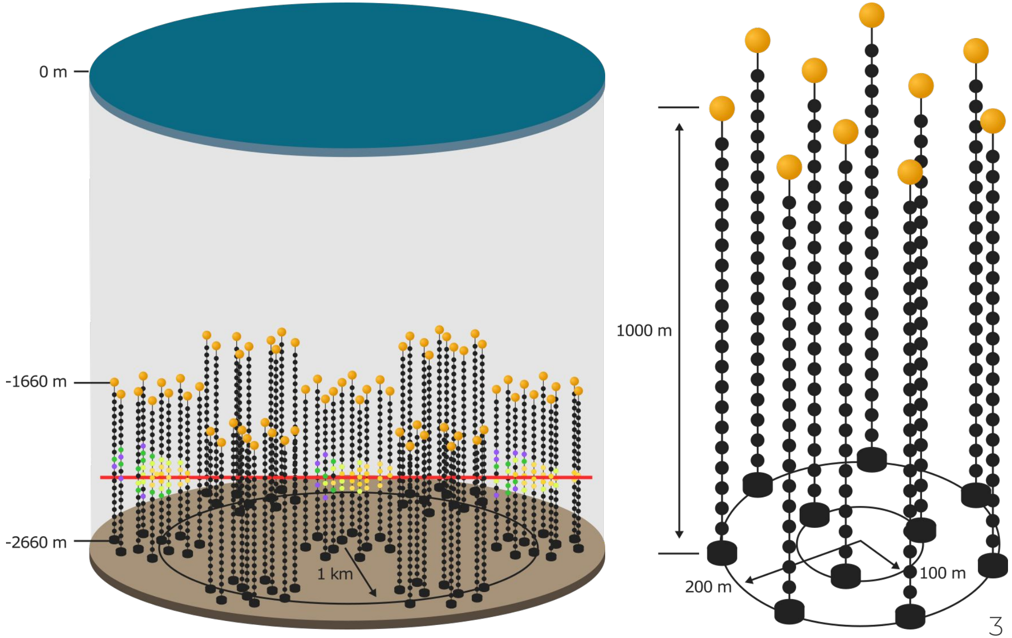


Image: Ocean Networks Canada [3]

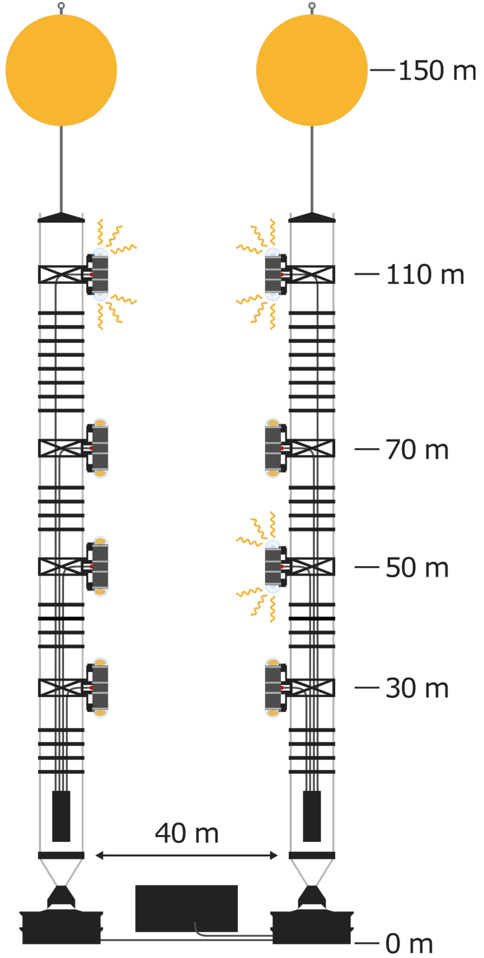


STRings for Absorption length in Water (STRAW)

- Pathfinder deployed in the Cascadia Basin to study site characteristics
  - Scattering length
  - Absorption length
  - Ambient undersea background

- System of two mooring lines equipped with
  - Light flashing modules (POCAM)
  - Light detecting modules (sDOM)

- Understanding background is important for future event trigger development



POCAM: Precision Optical Calibration Module

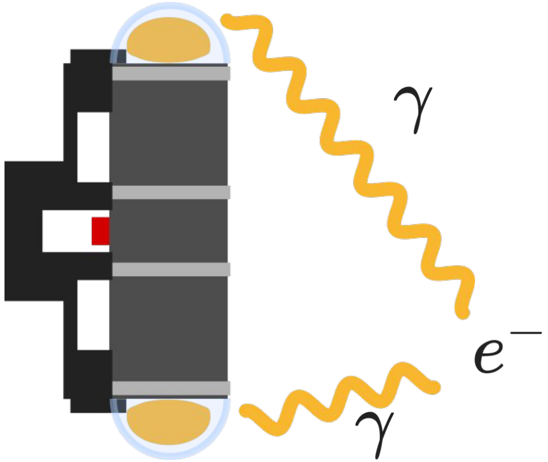
sDOM: STRAW Digital Optical Module

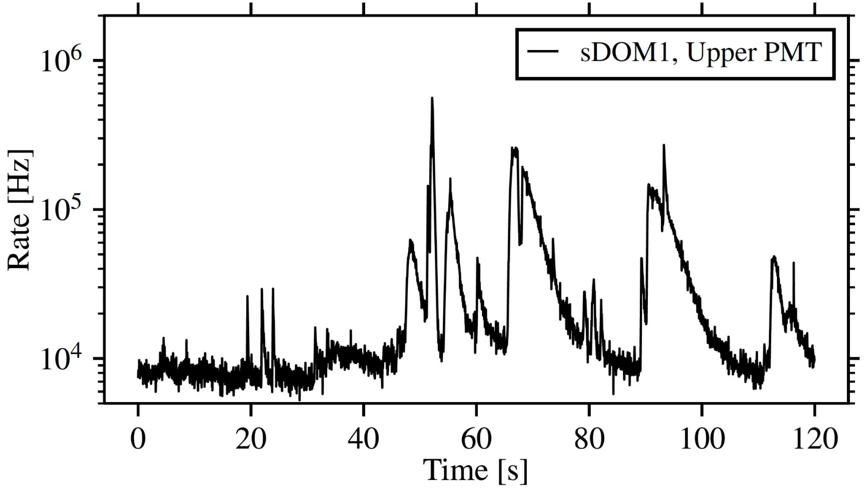
STRAW ^{40}K Background Study

- β^- decay of ^{40}K contributes most significantly to the background baseline

$$^{40}\mathrm{K} \rightarrow ^{40}\mathrm{Ca} + e^- + \bar{\nu}_e$$

- Simulate potassium activity around an sDOM and compare to measured data to verify simulation input parameters

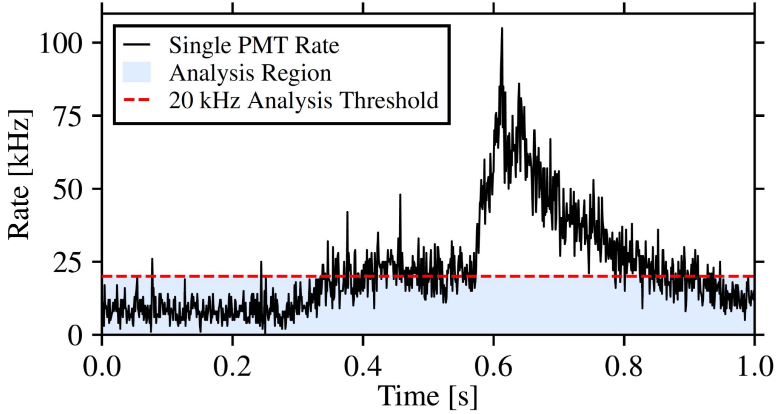




P-ONE Preliminary
Image: A. Gaertner

Extracting ^{40}K from STRAW Data

- Potassium noise contributes to the lowest noise baseline in STRAW data otherwise dominated by stochastic bioluminescent spikes
- Only consider data from low rate times of less than 20 kHz
- 16 hours of filtered data analyzed for coincidences



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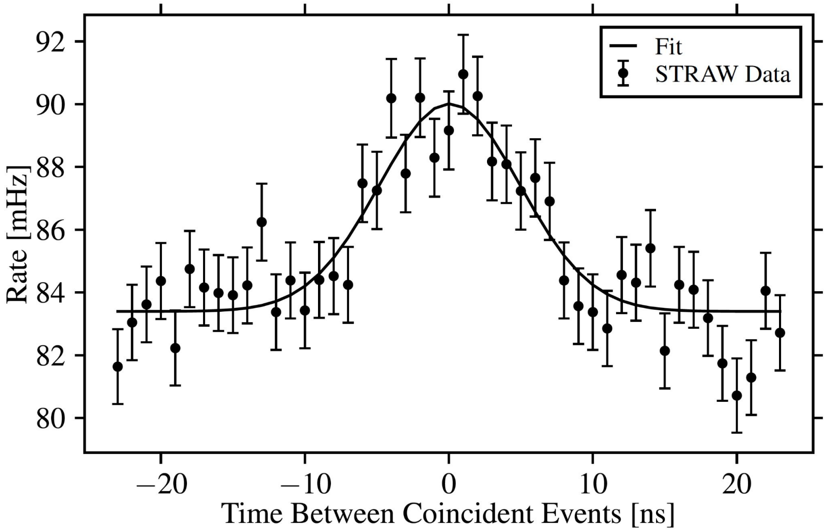

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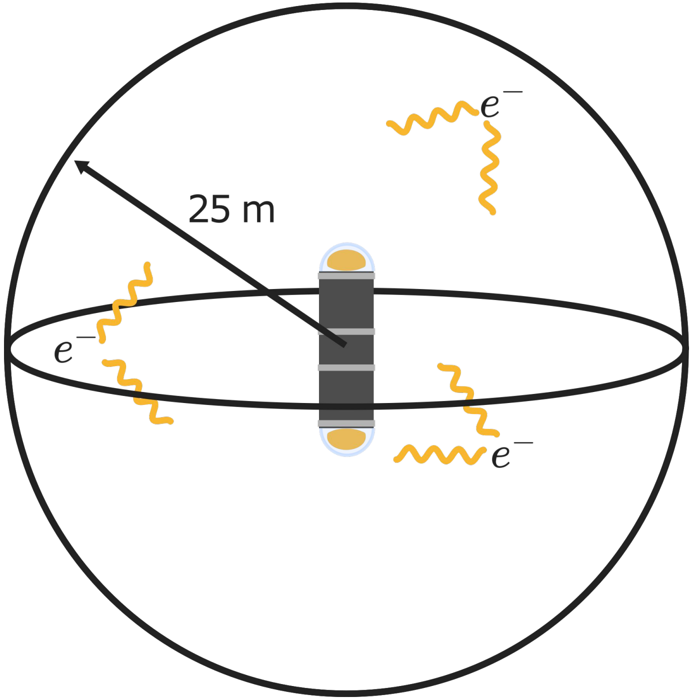
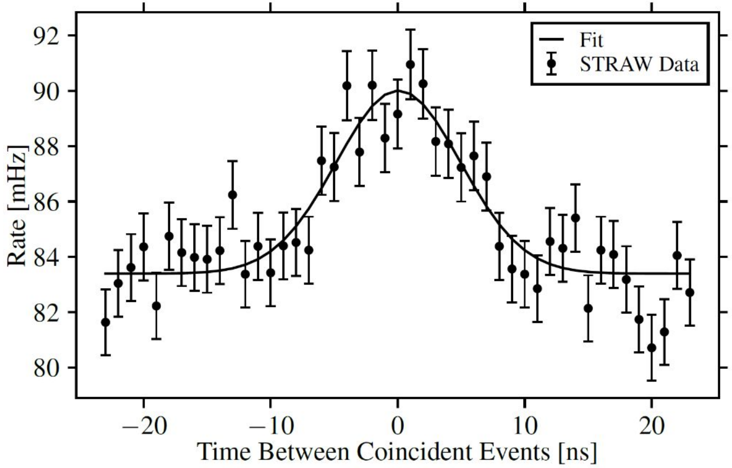
Simulating the ^{40}K Background

- Model an sDOM in Geant4 inside a spherical world of sea water
- Generate electrons uniformly throughout the 25 m radius spherical volume based on the expected ^{40}K decay rate
- Simulation inputs include
  - Absorption length in water
  - Glass and gel transmittance
  - PMT geometry
  - PMT quantum efficiency
  - PMT transit time
  - DAQ trigger efficiency



Analysis Results

- Removing the baseline so that only true coincidences are considered, we can compare the fits
- Systematic errors dominated by limited large angle sDOM characarization
- Using the simulated decay rate, the salinity of the Cascadia Basin is $2.7^{+3.1}_{-0.9}$% which spans over the measured ONC value of 3.482 ± 0.001%



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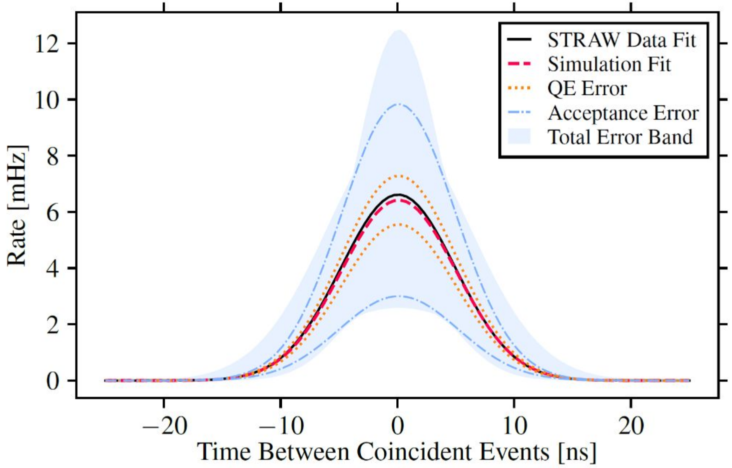

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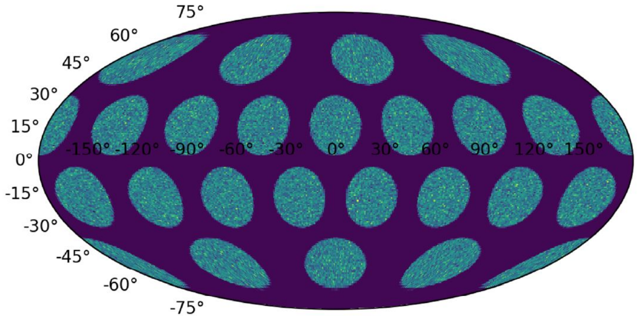
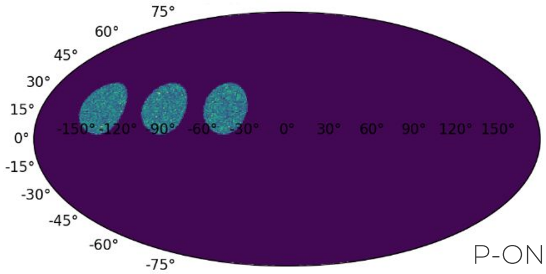
Ongoing Work Towards P-ONE Trigger Development

- Move on to simulating a full detector DOM rather than just an sDOM
- Study coincidences between multiple PMTs and over varying time windows to develop a trigger which minimizes the detection of noise
- Inject interesting events such as muons to test detector sensitivity



Genuine Coincidence



False Coincidence

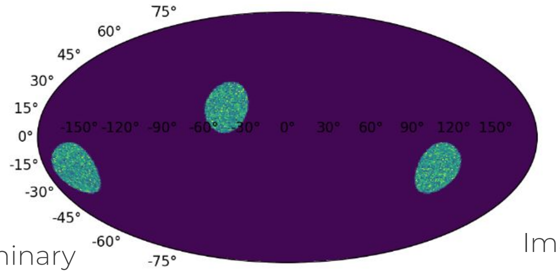


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Image: M. Ens

Summary

- Measured the in situ natural ^{40}K activity rate in the Cascadia Basin
- Successfully displayed that simulations using measured parameter inputs match directly observed site characteristics
- Performed a circle check by extracting ocean salinity from simulated data which covers the in situ measured value used as an input
- Directly confirmed that the optical properties found using STRAW are correct
- Simulation of full detector DOMs for trigger development is underway
- For more information on P-ONE visit http://p-one.nu

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References

[1] IceCube Collaboration, “The detection of neutrinos in icecube,” https://masterclass.icecube.wisc.edu/en/learn/detecting-neutrinos.

[2] KM3NeT Collaboration, “DOM_bottom_view,” https://www.km3net.org/characterisation-of-photomultipliers-for-km3net/dom_bottom_view/.

[3] P-ONE, “Pacific Ocean Neutrino Explorer: Towards a new neutrino telescope in the pacific”. https://www.pacific-neutrino.org/.

[4] M. Agostini et al., “The Pacific Ocean Neutrino Experiment”, https://arxiv.org/pdf/2005.09493.pdf.

[5] M. Boehmer et al., “STRAW (STRings for Absorption length in Water): pathfinder for a neutrino telescope in the deep Pacific Ocean”, DOI: 10.1088/1748-0221/14/02/P02013

[6] Ocean Networks Canada, "Cascadia Basin," 10 Feb 2021. [Online]. Available: https://www.oceannetworks.ca/observatories/pacific/cascadia-basin#SOO-ODP1026.

Questions?

Neutrino Flux

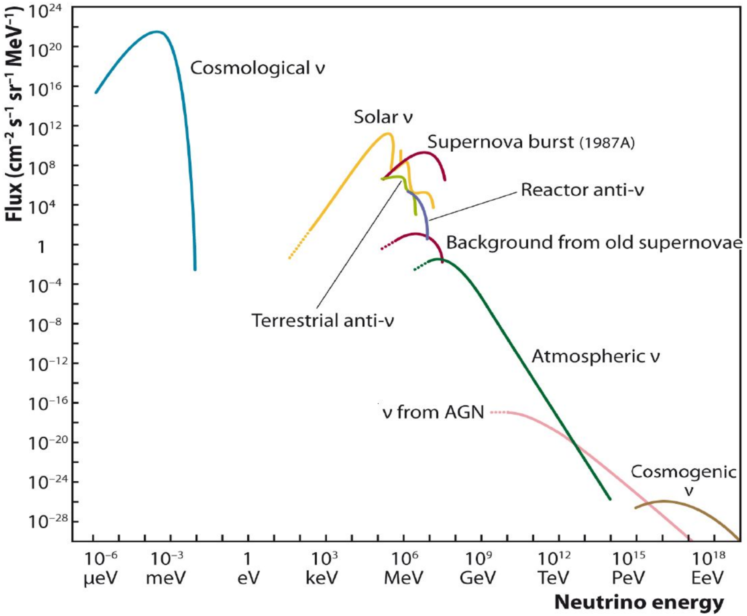
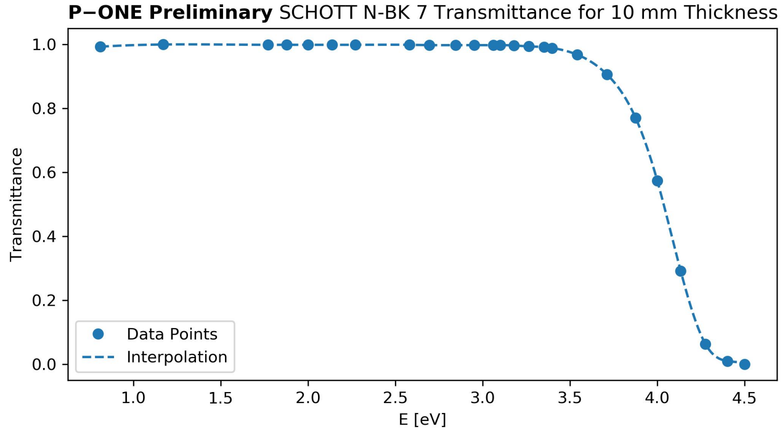
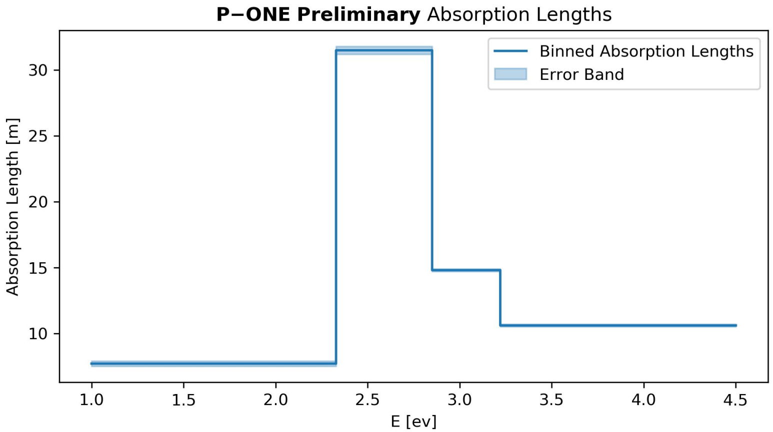


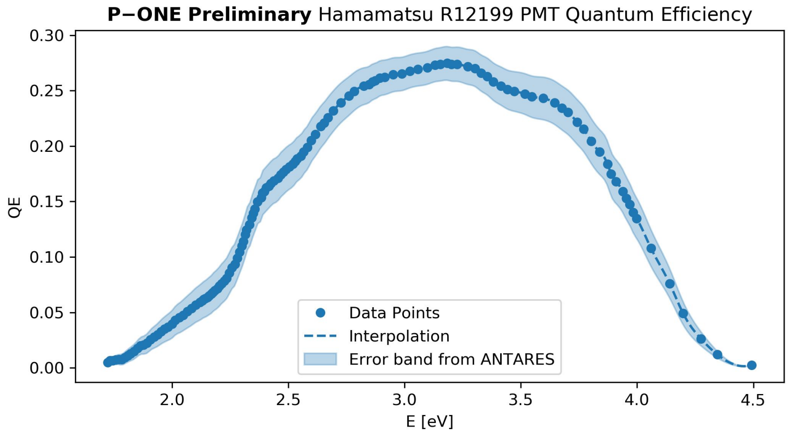
Image: IceCube Collaboration [1]

Simulating the ^{40}K Background - Inputs

- Simulation inputs include
  - Absorption length in water
  - Glass and gel transmittance
  - PMT geometry
  - PMT quantum efficiency
  - PMT transit time ~ 6.5 ± 1 ns
  - DAQ trigger efficiency ~ 85%



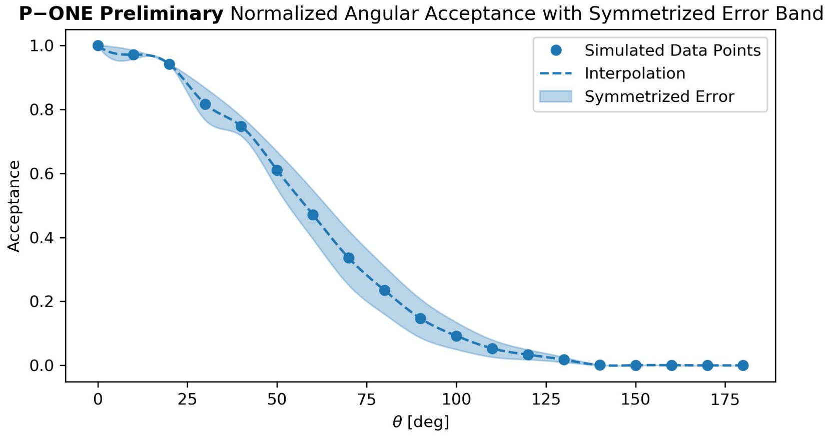


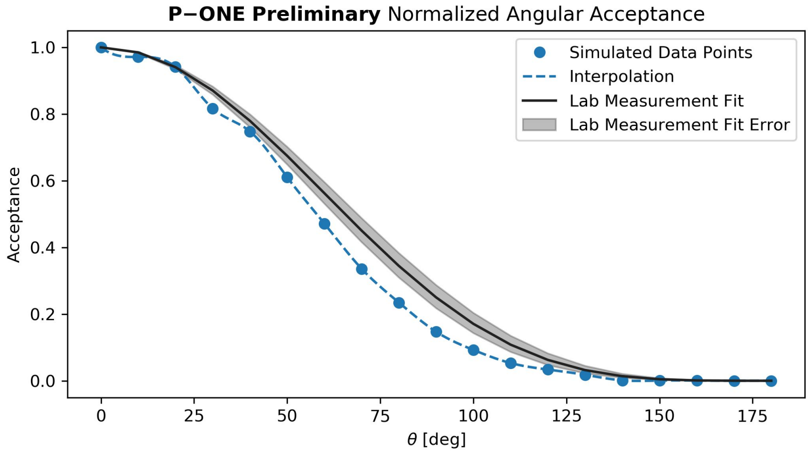


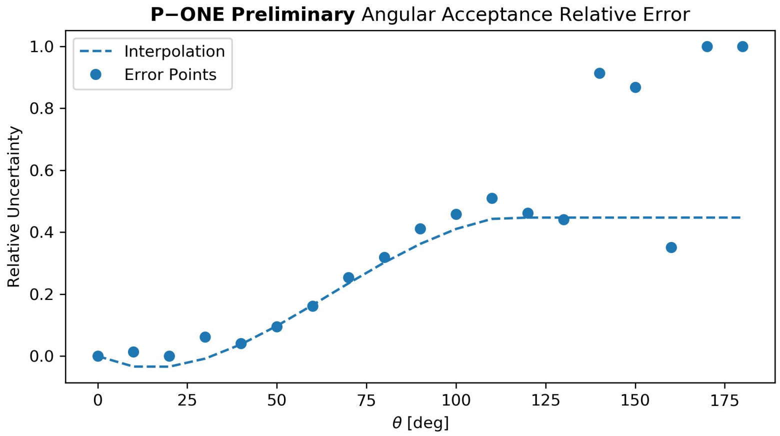
Simulating the ^{40}K Background - Angular Acceptance

- The SDOM geometry is not ideal for making coincident measurements because most coincident photons are going to be arriving at large angles

$$\text{Error} = 1 - \frac{\text{Simulated Fit}}{\text{Measured Fit}}$$







Salinity

- Calculate effective volume

$$V_{\text{eff}} = \frac{n_d}{n_{gen}} V_{gen} = 8.7 \pm 4.7 \text{ cm}^3$$

- Calculate potassium activity rate

$$B_q = \frac{1}{V_{\text{eff}}} \frac{a\sigma\sqrt{2\pi}}{\Delta\tau} = 9.3^{+10.8}_{-3.3} \times 10^3 \,\frac{\text{Decays}}{\text{sm}^3}$$

- Calculate Salinity

$$r_s = \frac{r_K r_I \rho}{B_q} \frac{\ln 2}{\tau_{1/2}} \frac{N_A}{A} = 2.7^{+3.1}_{-0.9}\,\%$$

ONC Cascadia Basin Measurements

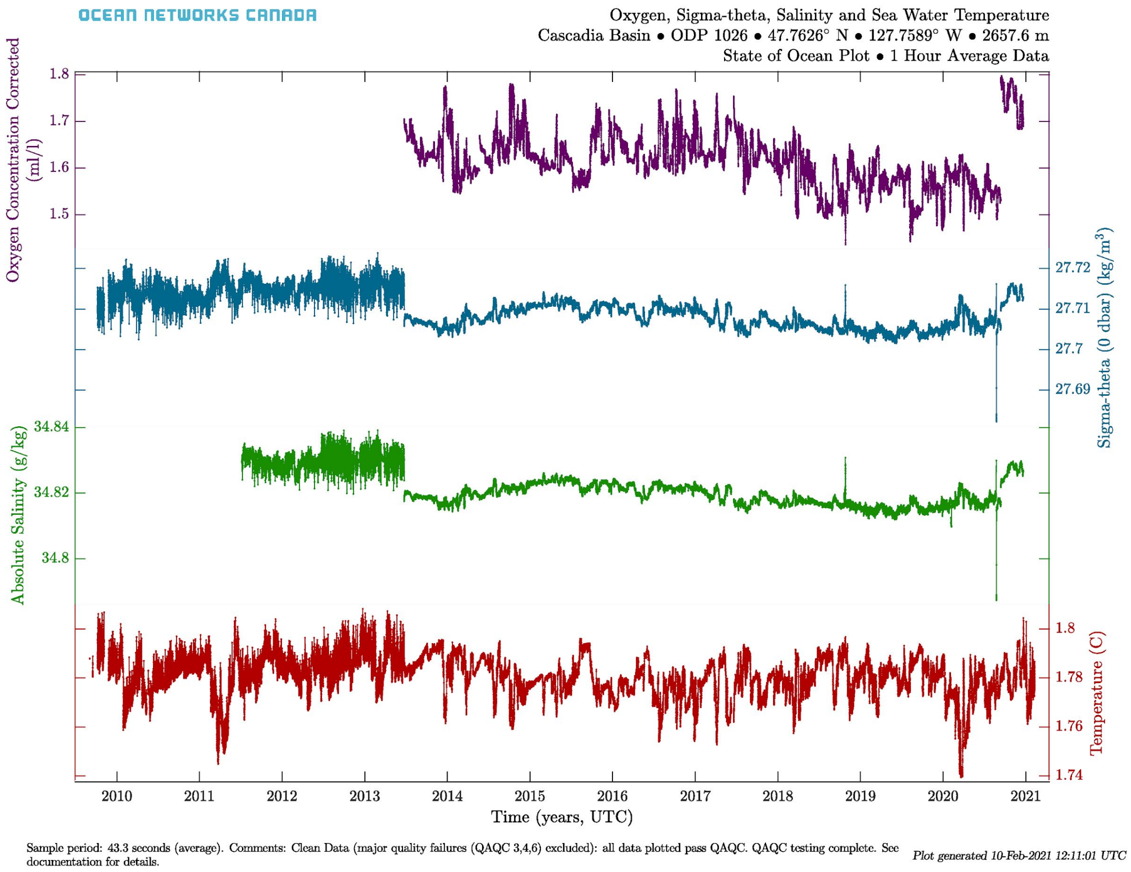


Image: ONC [6]