Measuring the Absorption Length of the Deep Pacific Ocean

Results from STRAW, a Pathfinder Mission for the Proposed P-ONE Neutrino Telescope

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12/02/2021

Neutrino telescopes

- Detect Cherenkov light of secondary particles created in neutrino interactions
- Large grid of optical modules (photomultiplier tubes) placed in transparent medium
- Good telescope site is characterized by long optical attenuation length

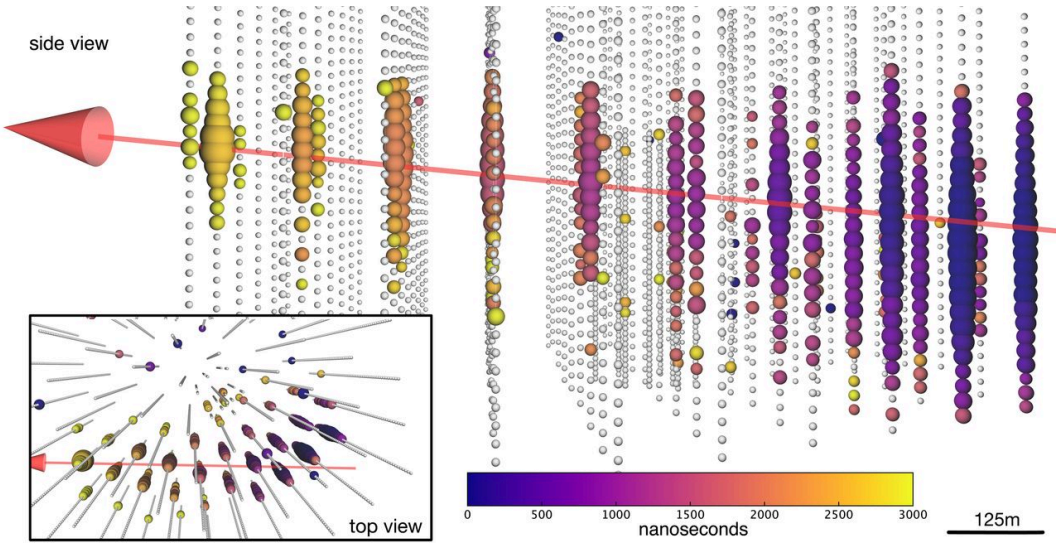

Image: IceCube Collaboration

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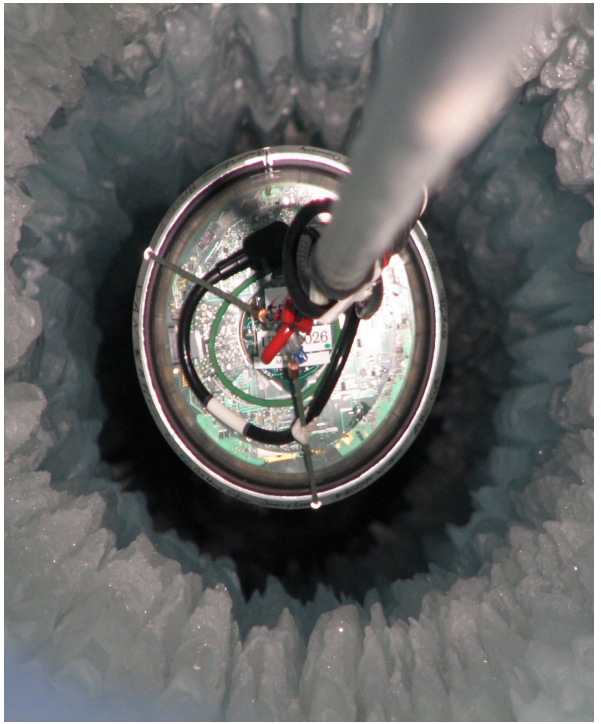
Neutrino telescopes

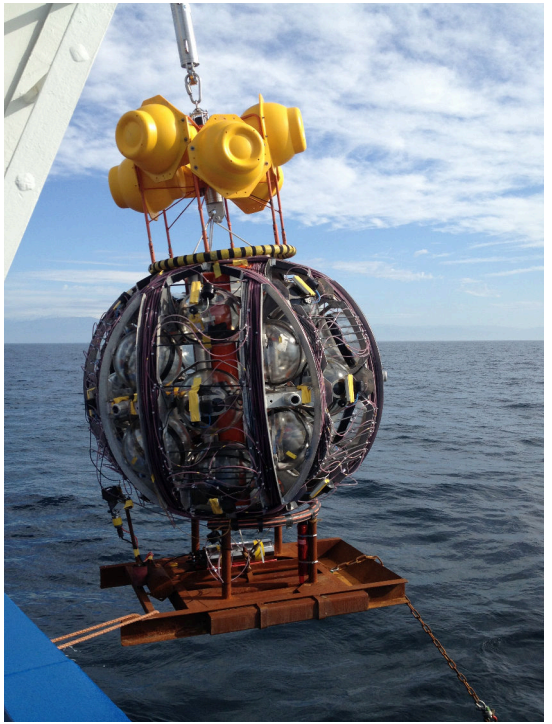
Natural sources of transparent Cherenkov medium

- Fresh water (Gigaton Volume Detector, Lake Baikal)
- Ice (IceCube, Antarctica)
- Sea water (KM3Net, Mediterranean)

- Each medium has different challenges is detector construction and infrastructure



IceCube string being lowered into a borehole
Image: Mark Krasberg, IceCube/NSF



KM3Net mooring line before deployment
Image: KM3NeT

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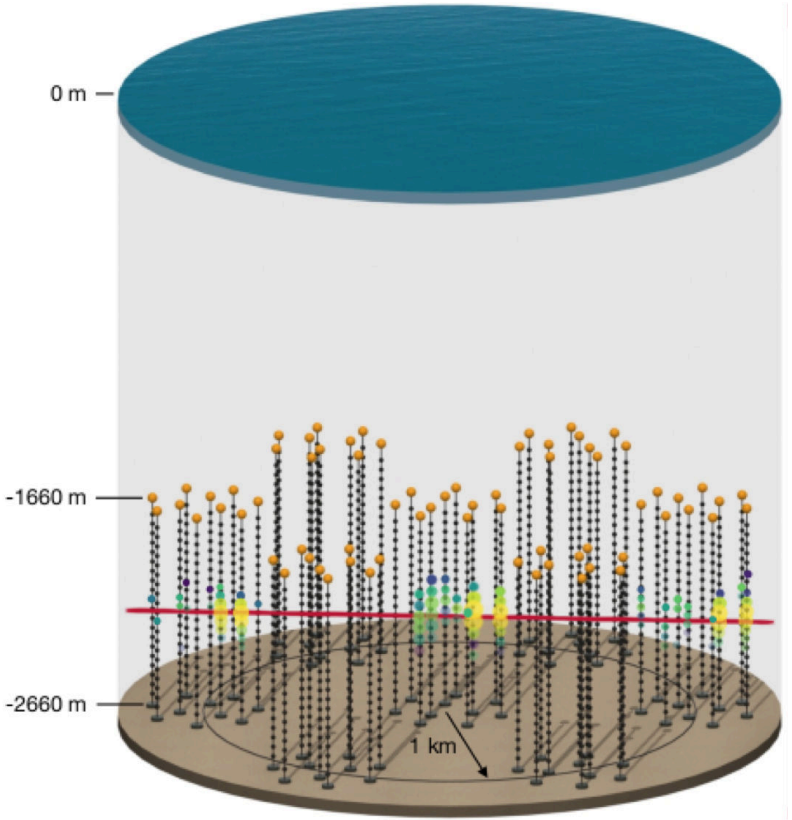
Pacific Ocean Neutrino Experiment

- Proposed new neutrino telescope near Vancouver Island
- Cubic kilometer detector, optimized for 10TeV-12PeV
- Complementary sky coverage to other neutrino telescopes
- Uses existing ONC infrastructure



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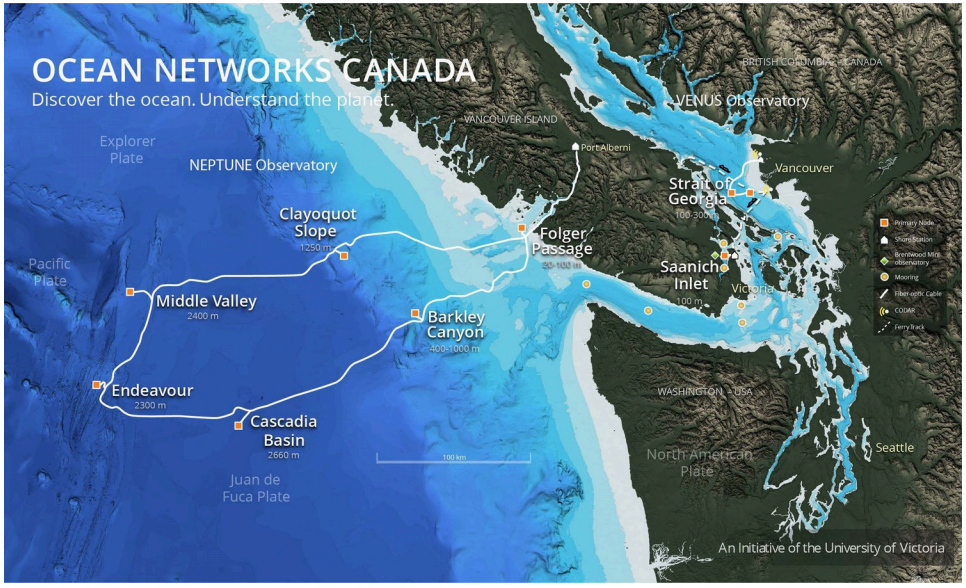
Ocean Networks Canada (ONC)

- Main challenge of marine neutrino telescopes: infrastructure
- Ocean Networks Canada provides infrastructure for various scientific disciplines in Pacific, Atlantic and Artic Sea
- “Plug and play” power and network connection
- Neptune observatory: 800km underwater cable loop with several nodes
- Cascadia Basin node
  - 2600m deep abyssal plain
  - 2°C year-round
  - Low currents (0.1m/s)

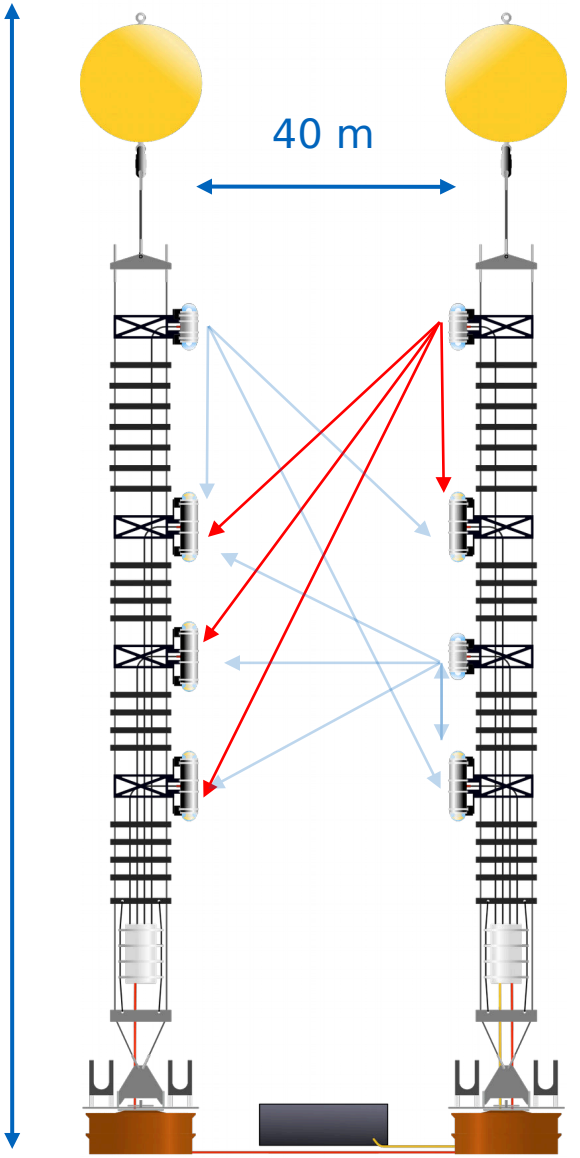


Images: Ocean Networks Canada

Pathfinder mission - STRAW

„Test optical properties and infrastructure of the site by mimicking a neutrino detector“

- Two strings (130m, 4 modules each)
- SDOMs (STRAW digital optical modules) for background (radioactivity, (bio-)luminescence) measurement
- POCAMs emit calibrated light pulses that can be used for absorption length and scattering measurements at 4 different wavelengths



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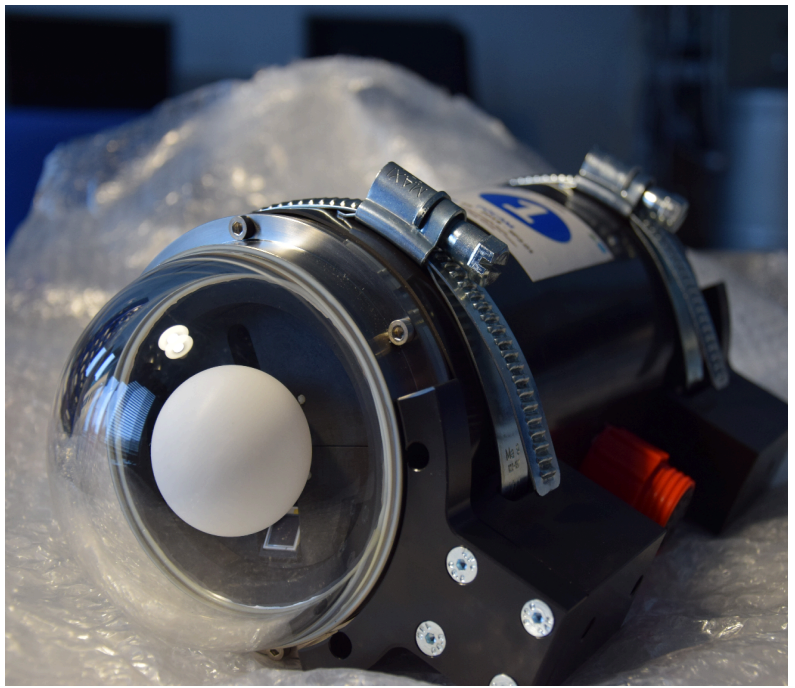
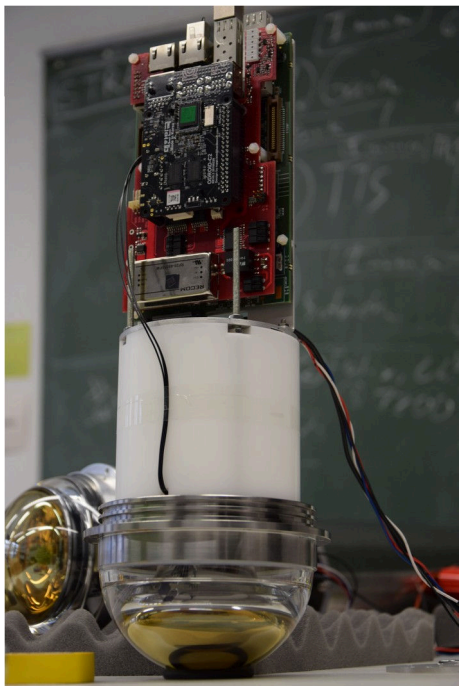
Hardware



POCAM module showing the hollow PTFE sphere used for creating isotropic light pulses



SDOM electronics and one of the two PMTs

One of the two STRAW strings spooled onto the deployment winch

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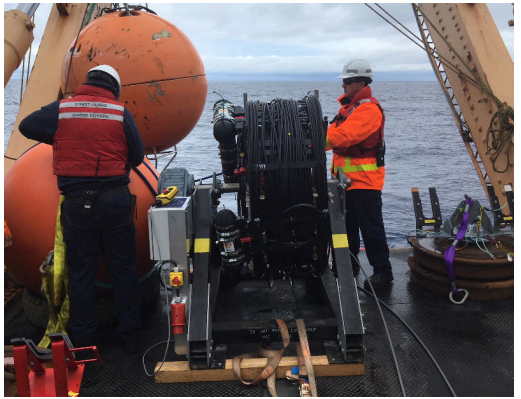
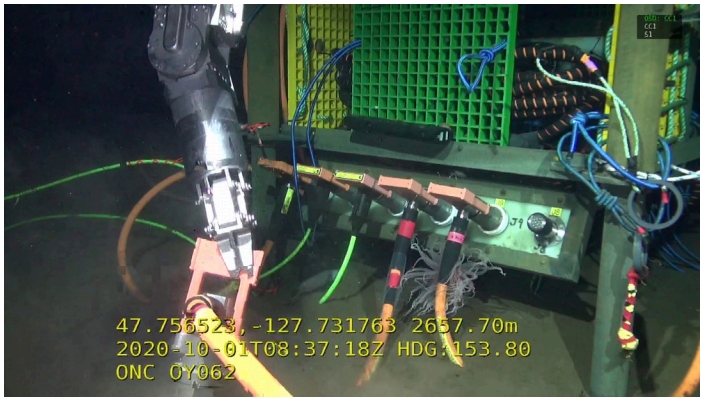
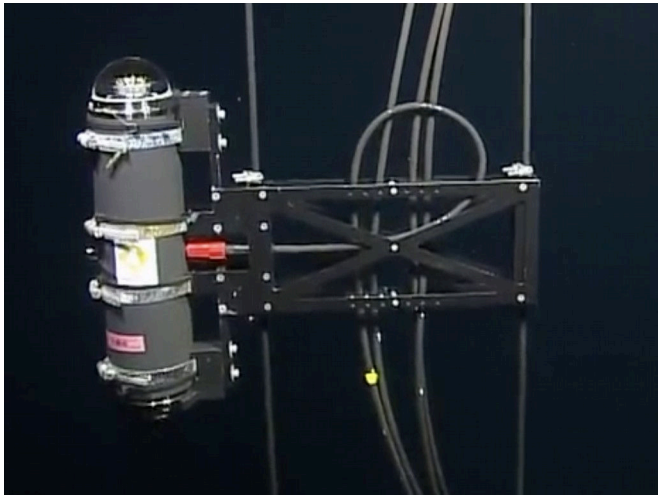
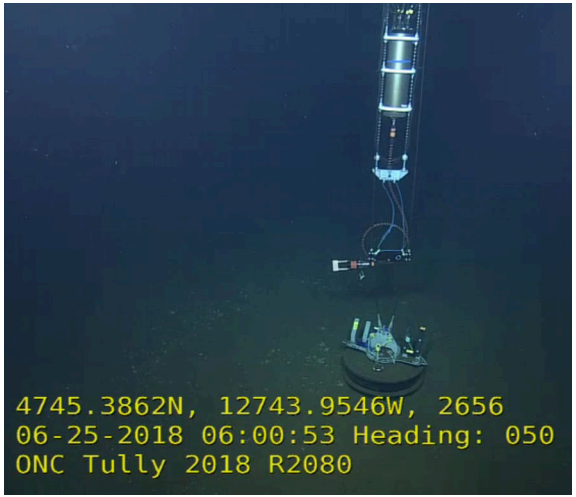
Deployment

- built within 8 months by Ocean Networks Canada and Technical University of Munich
- Construction of instruments and main structure in Munich
- Interface, anchoring and deployment operation by Ocean Networks Canada
- Deployed in June 2018
- Continuously taking data since March 2019









Images: Ocean Networks Canada

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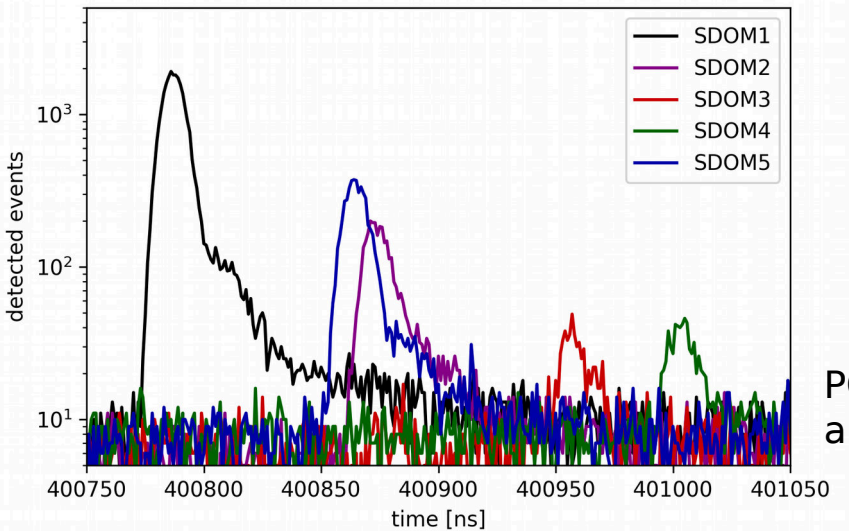
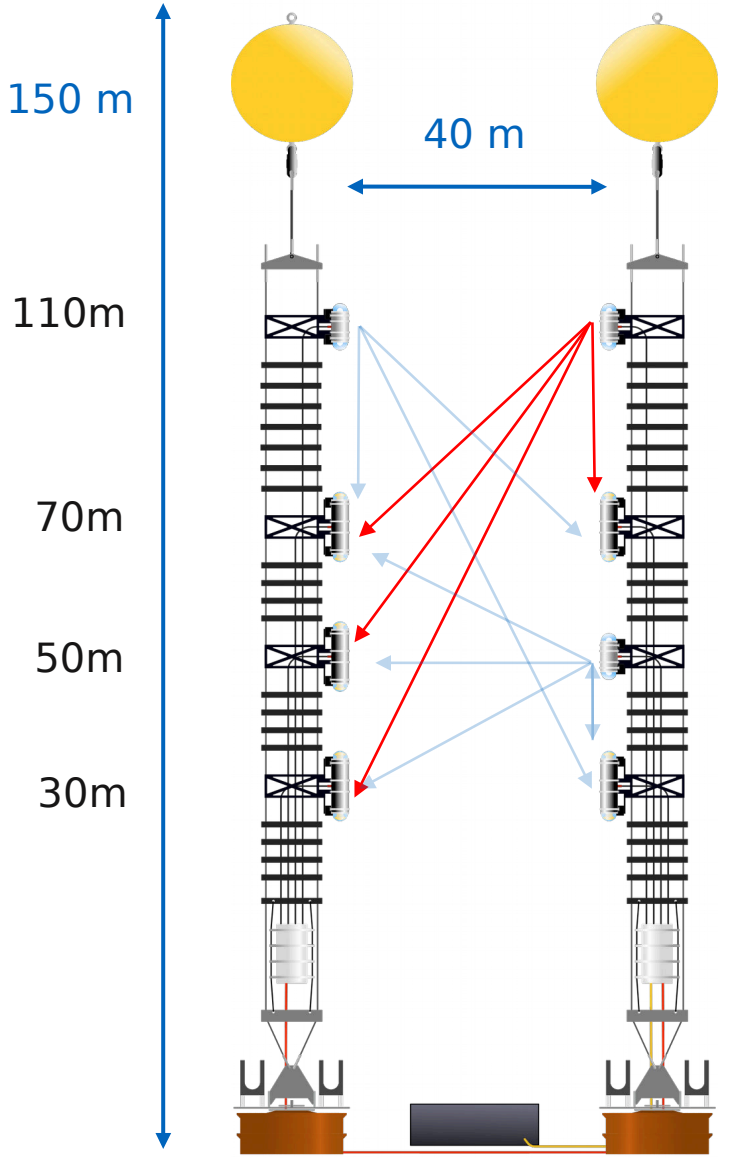
A look at the data

- POCAM pulses are detected by SDOMs
- Signal can be used to fit attenuation length
- Signal has to be extracted from strong bioluminescence background



POCAM pulses as seen in all five SDOM detectors



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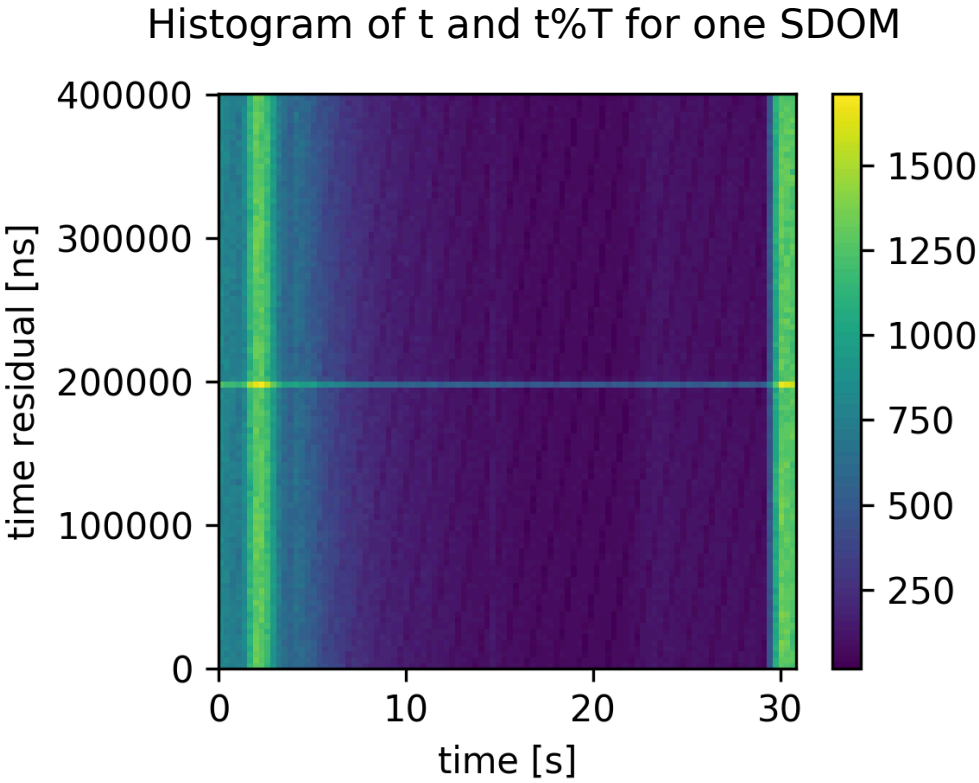
Extracting the signal

- Two background components
  - Constant background caused by radioactivity, PMT noise, …
  - Highly variable background caused by bioluminescence
- Search for repeating signal with period T
- Use SDOMs with strong signal as timing reference for other SDOMs
- Use multiple flasher intensities to get a signal on single-photon level for each SDOM



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Fitting the attenuation length

$$I(r) = I_0 / 4\pi r^2 \cdot \exp(-r/l_{att})$$

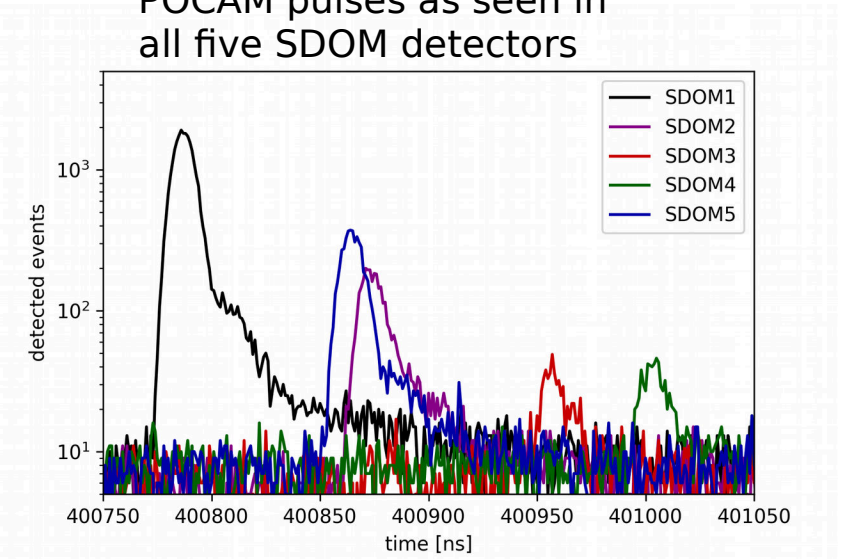
Important input parameters

- Angular profile of SDOM and POCAM
- Position of modules on string
- Lab calibration of each module

Fit parameters

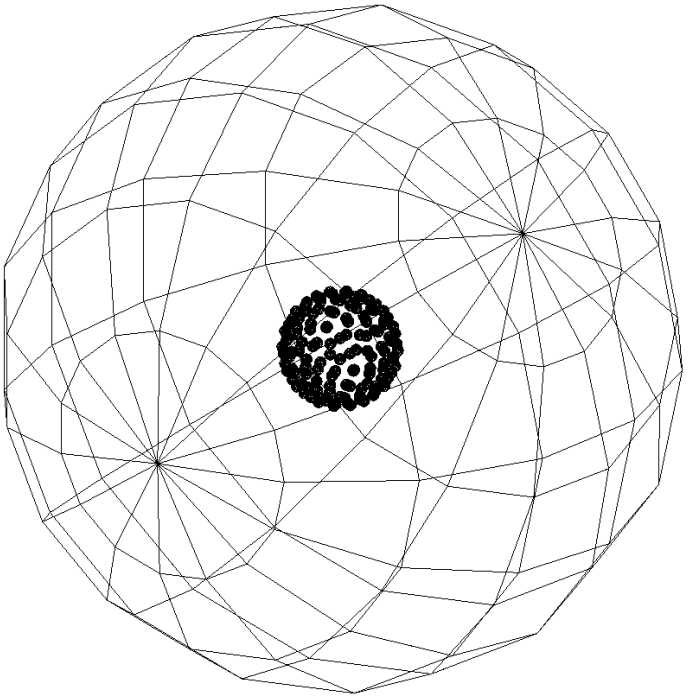
- Distance between strings (+-1m Gaussian prior)
- Module calibration uncertainties (quantum efficiency, trigger efficiency, angular profile,…) (Gaussian prior)
- Attenuation length (no prior)

POCAM pulses as seen in all five SDOM detectors



Cross checks

- Distance between strings (+-1m Gaussian prior)
  - Cross-check with timing information
- Module calibration uncertainties (quantum efficiency, trigger efficiency, angular profile,...) (Gaussian prior)
  - Cross-check with background rates
- Perform two independent fits, one using exponential formula and one using Geant4 simulation
- Measure repeatedly over several days to check if parameters are stable



Sketch of the Geant4 simulation with hundreds of simulated detectors for improved statistics

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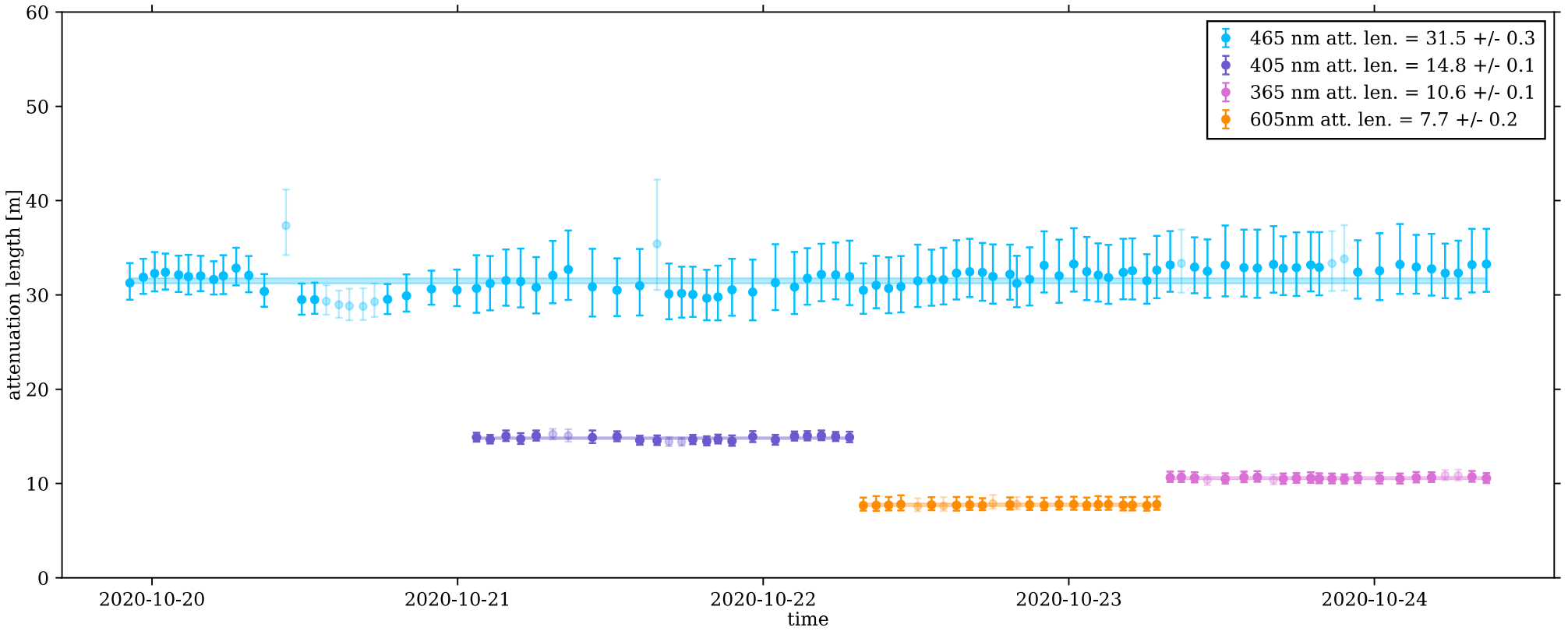
Results



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Publications

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

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