The Pacific Ocean Neutrino Experiment (P-ONE) Development of the first detector line

Andreas Gaertner for the P-ONE Collaboration
11 September 2023

Neutrino Astronomy

- Classical astronomy: photons only
- Multi-messenger astronomy:
  - Cosmic rays
  - Gravitational waves
  - Neutrinos

- Neutrinos are the only particles that travel unperturbed by matter or magnetic fields

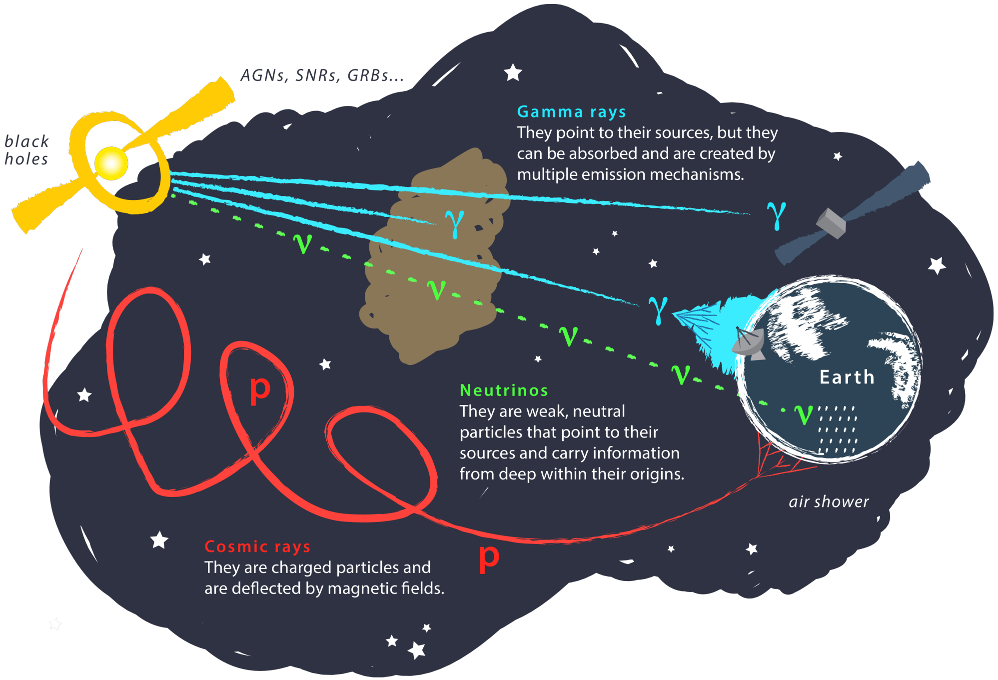
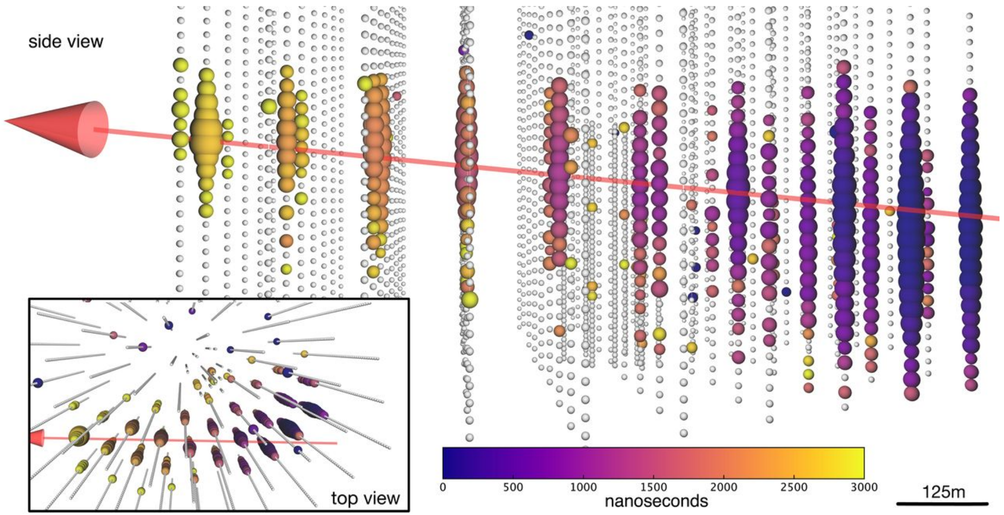


Image: IceCube Collaboration

Neutrino Telescopes

- Neutrinos interact with matter to produce high-energy charged lepton
- Charged lepton produces Cherenkov light

- ➔ Photomultipliers (PMTs) for light detection
- ➔ Large volume of transparent medium (water or ice)



Visualization of a muon track (red) in IceCube. Each dot represents an optical module with a PMT.
Image: IceCube Collaboration

Neutrino Telescopes

IceCube (South Pole)
Operational

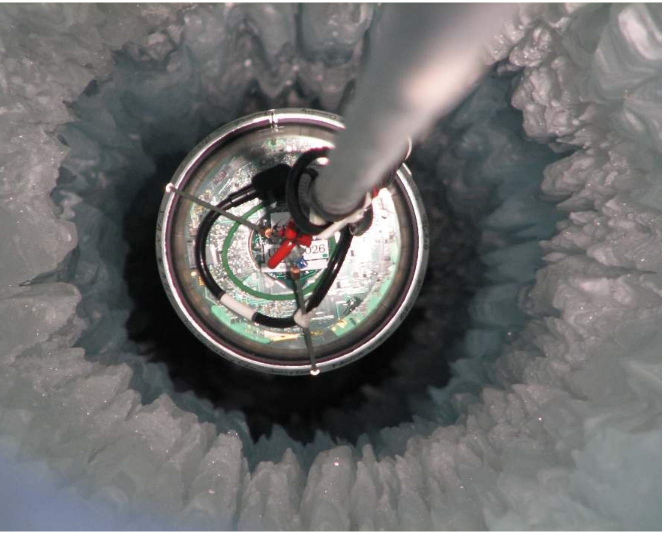


Image: IceCube Collaboration

GVD (Lake Baikal)
Partially operational

Image: F. Henningsen

KM3NeT (Mediterranean)
Partially operational

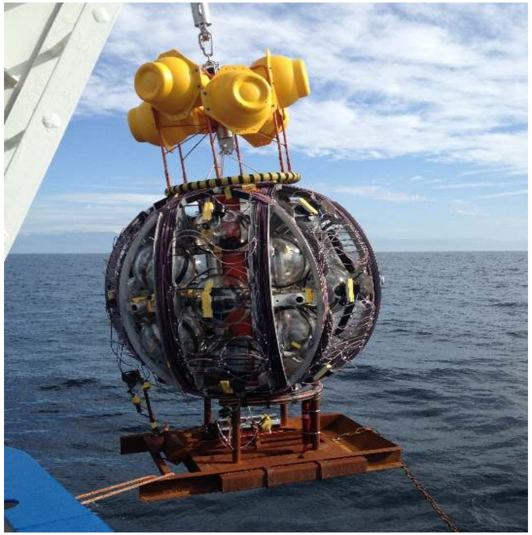
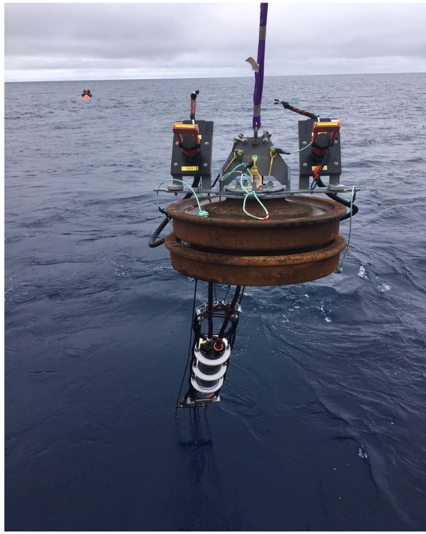


Image: KM3NeT

P-ONE (Pacific)
In preparation



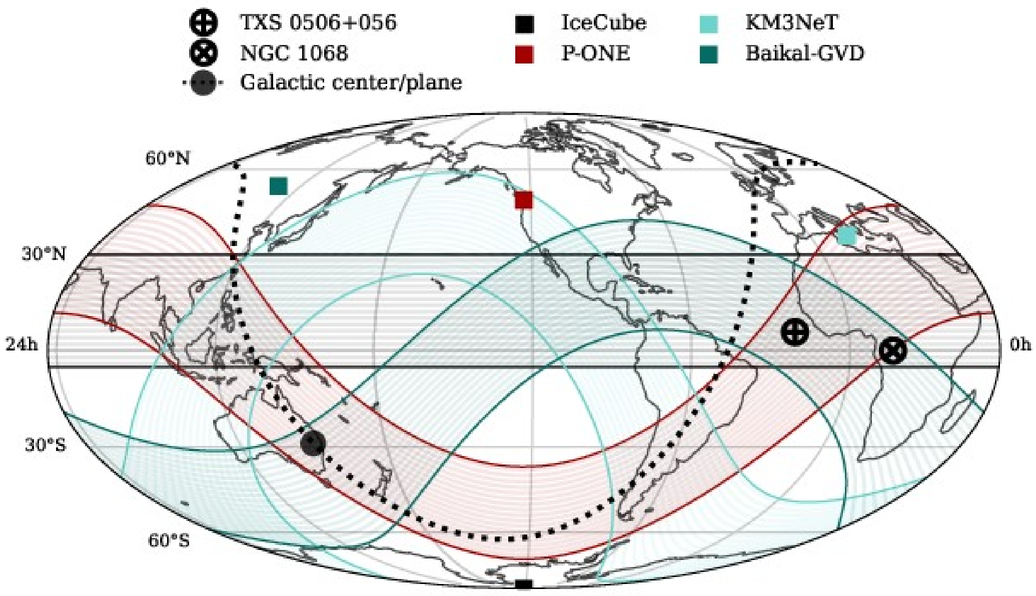
Neutrino Telescopes

Looking up:
- Background from atmospheric muons

Looking down:
- Works for low energies
- At high energies (PeV) earth becomes opaque

→ Small band around horizon

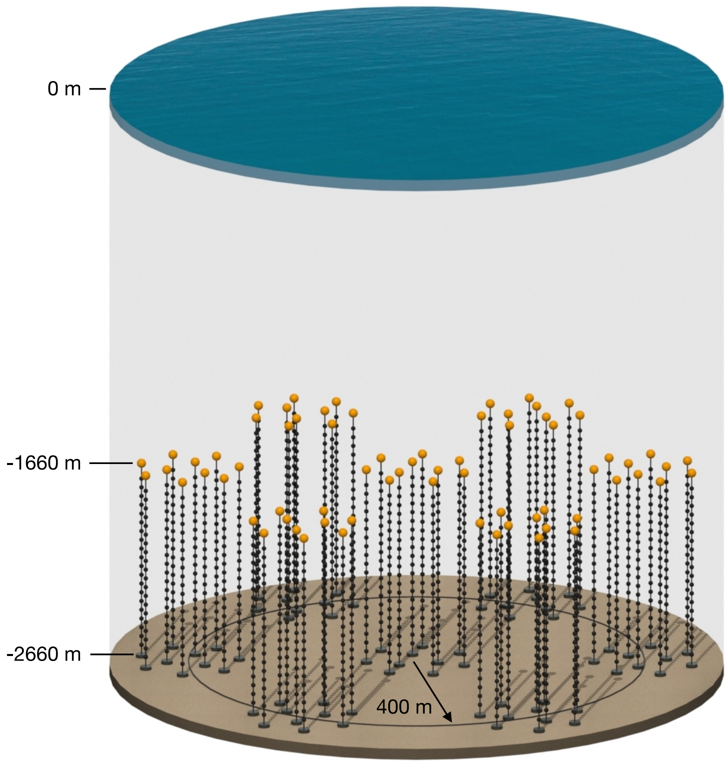
→ Multiple telescopes are needed across the planet



Plot: L. Schumacher

The Pacific Ocean Neutrino Experiment (P-ONE)

- New neutrino telescope in the Pacific Ocean
- >1 km³ instrumented volume
- Aimed at high neutrino energies (TeV-PeV)

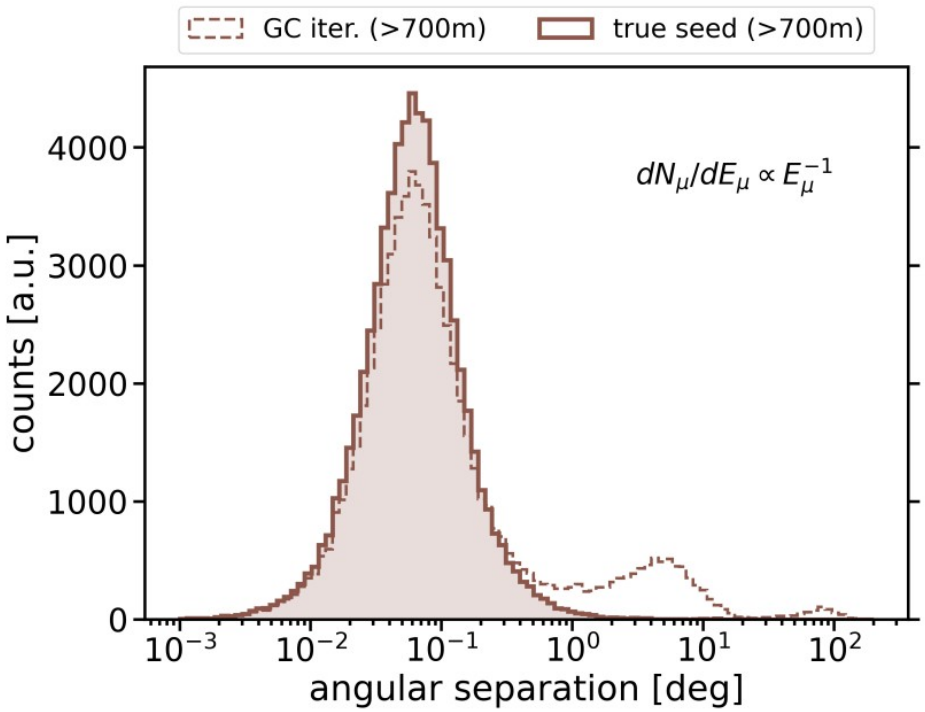


Possible detector geometry

The Pacific Ocean Neutrino Experiment (P-ONE)

- Less scattering in water compared to ice
  - Better angular resolution (0.1 degrees)
- Using existing infrastructure of Ocean Networks Canada
- 2 successful pathfinder missions

➔ Working on first string of P-ONE



Plot: J.P. Twagirayezu

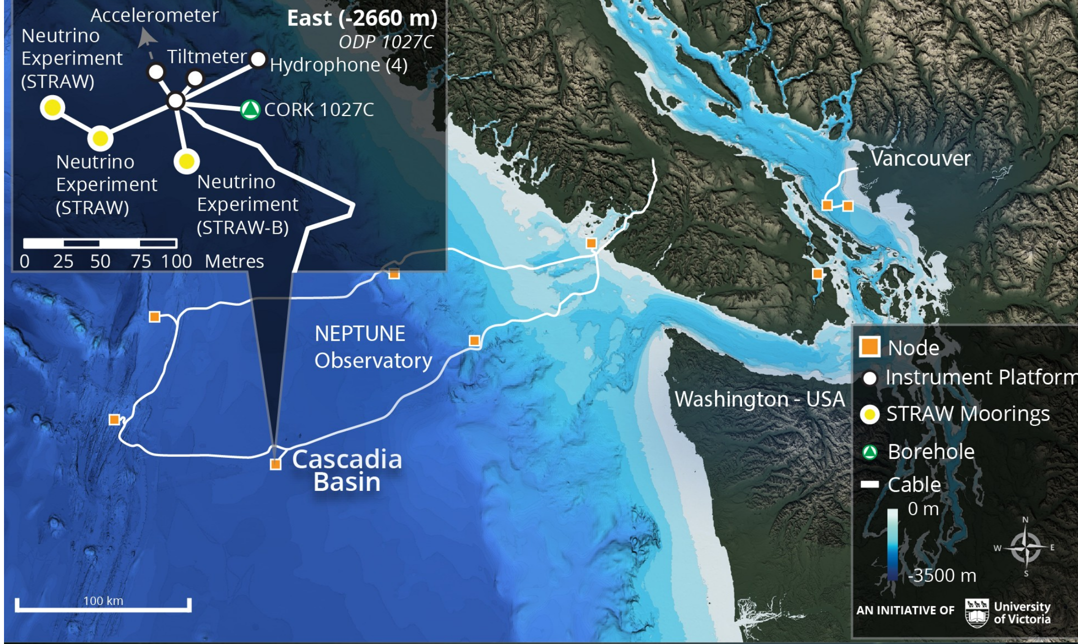
Ocean Networks Canada (ONC)

- Initiative of the University of Victoria
- Provides power and network connections on the sea floor for scientific instruments
- Over 15 years of experience in deploying and maintaining sea floor infrastructure
- Multiple observatories all over Canada

NEPTUNE Observatory

- 800 km cable loop in the Pacific Ocean
- Cascadia Basin
  - Abyssal plain
  - Low currents (0.1 m/s)
  - Low temperature (2°C)
  - Flat sea floor
  - 2.6 km depth

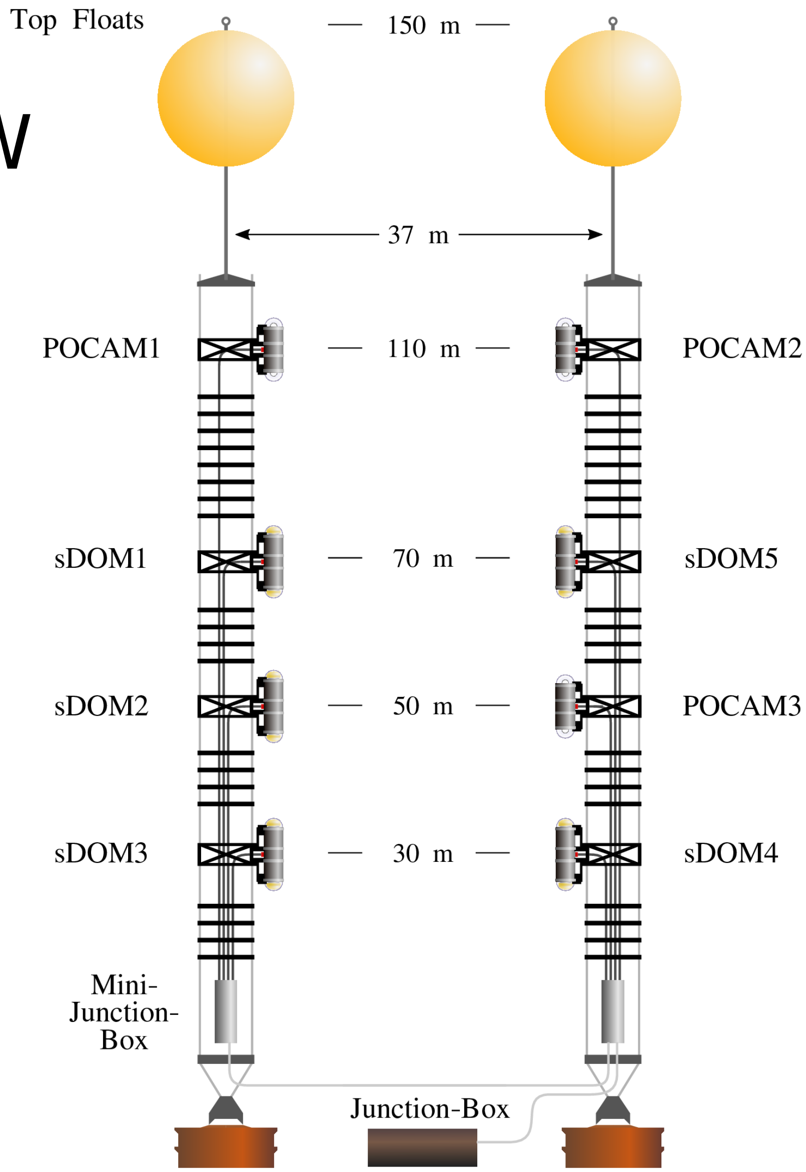
➔ ideal environment for neutrino telescope



First pathfinder mission - STRAW

- Measure optical properties of water (optical attenuation, bioluminescence, radioactivity)
- Two 150m strings with four modules each
  - POCAMs: create isotropic light pulses
  - sDOMs: contain 2 PMTs each, detect POCAM pulses and background light

Deployed 2018, recovered 2023



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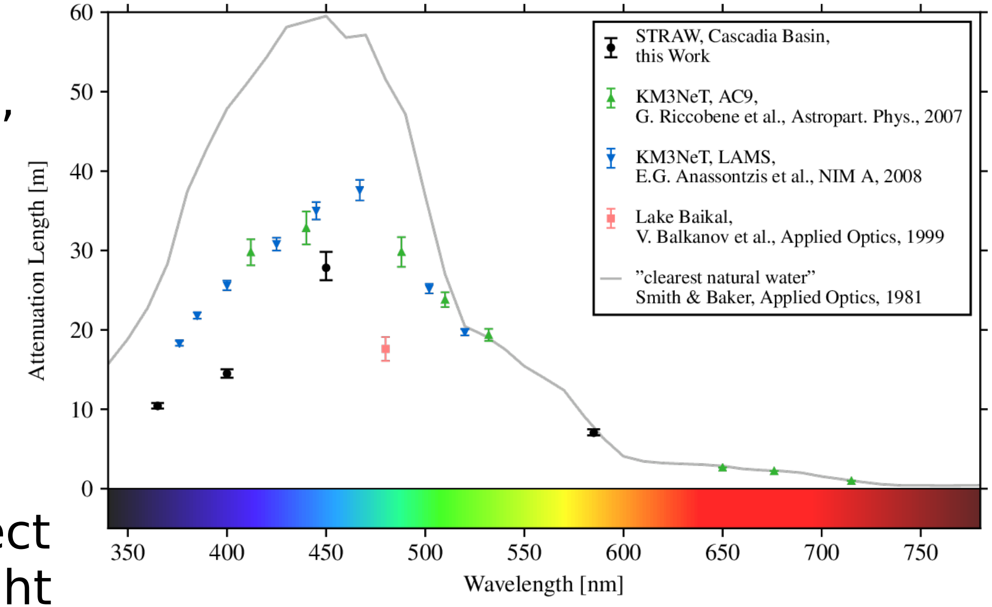


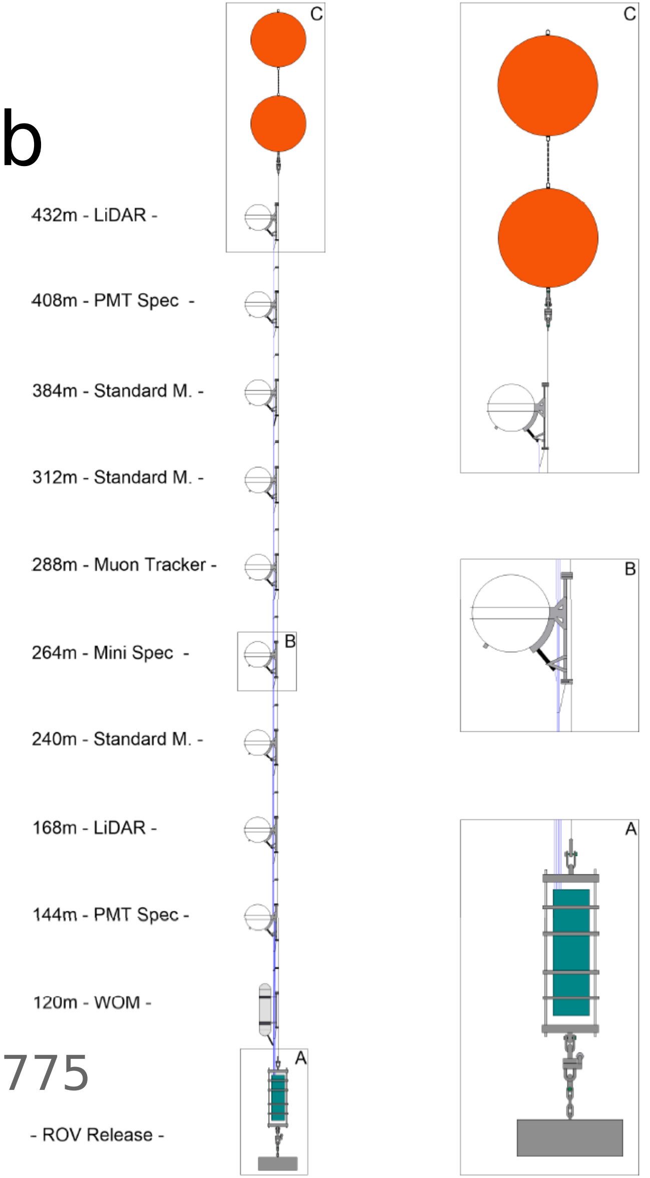
Deployed 2018, recovered 2023

Second pathfinder mission - STRAW-b

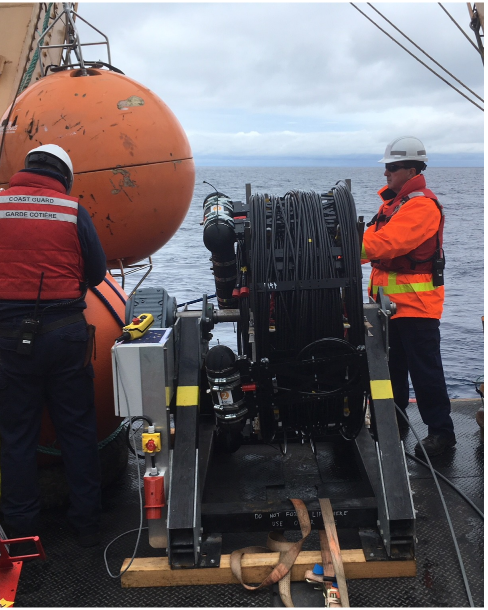
- Complement STRAW measurements
- Single 500 m string with 10 modules
  - Spectrometers
  - LiDARs
  - Cameras
  - ...
- Proof of principle for long string

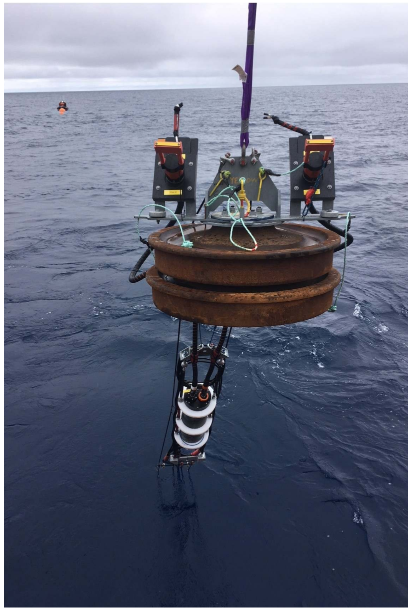
Deployed 2020, recovered 2023

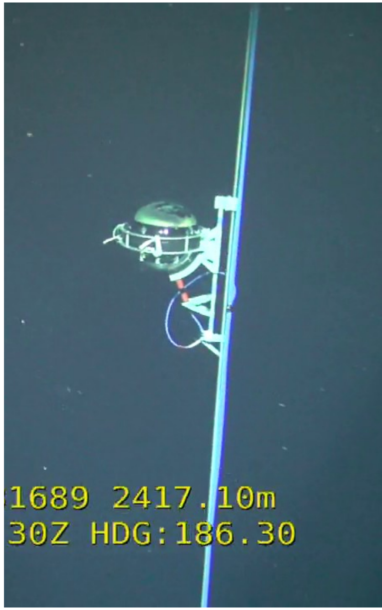
Results presented at TeVPa by Ruohan Li
https://agenda.infn.it/event/33457/contributions/204775



Pathfinder missions - Deployment





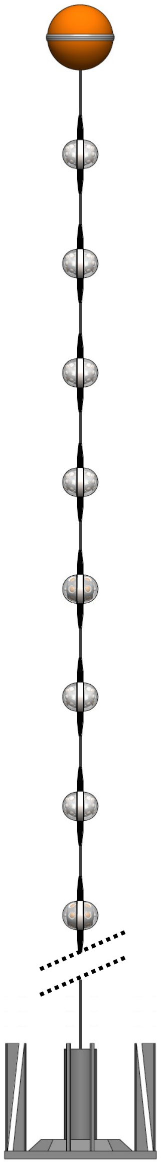


Current work: First P-ONE string

- 20 modules on 1km string
- First of 6-7 financed strings (P-ONE Demonstrator)

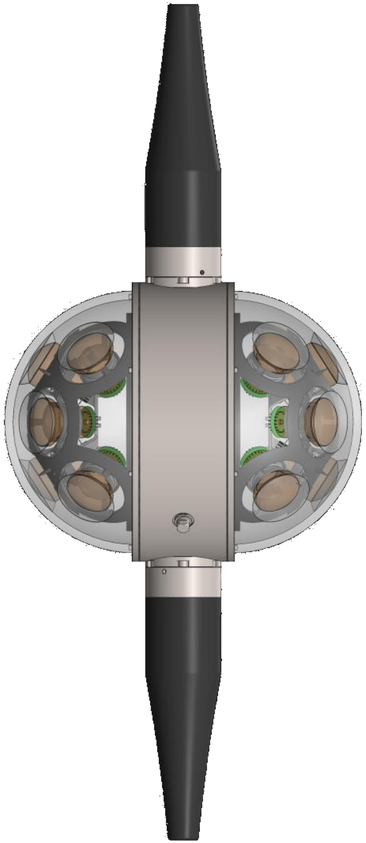
- Proof of concept, no relevant physical measurements with only one string
- Collect background data
- Atmospheric muons
- Test time synchronisation, triggering, …

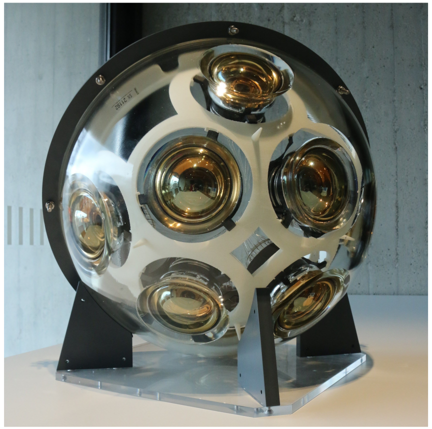
Planned deployment: 2024/2025



P-ONE Optical Module (P-OM)

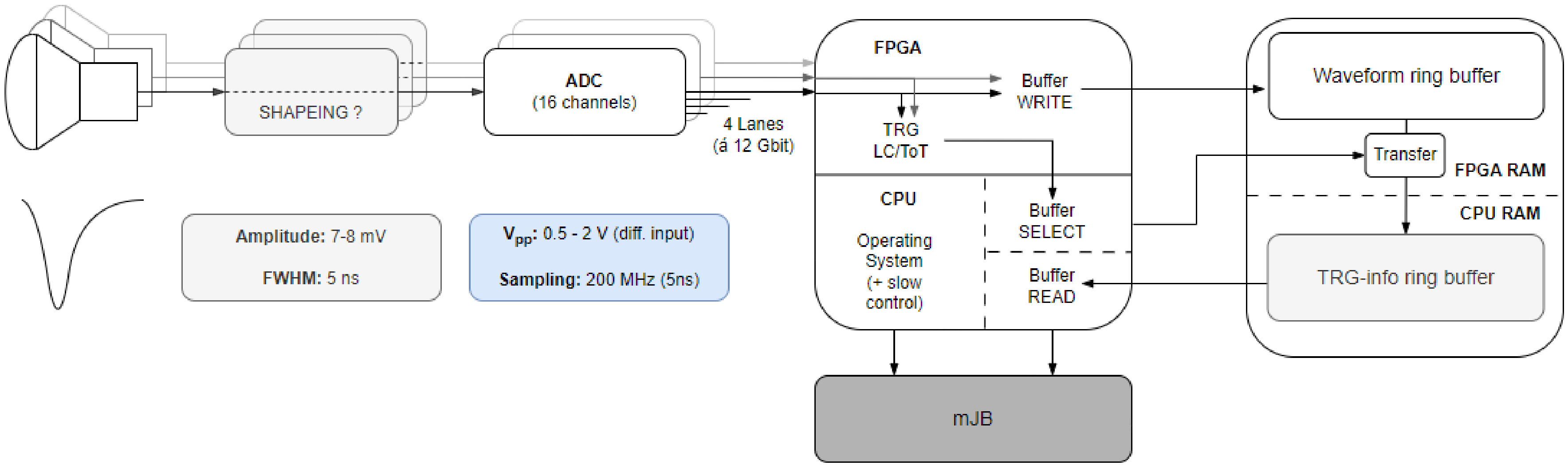
- Multi-PMT module based on KM3NeT OM and IceCube mDOM
- 16 PMTs per module (3” Hamamatsu R14374)
  - measure direction of incident light
- Spring-loaded mounting structure
- Gel pads with reflectors to increase light yield
- Individually adjustable HV





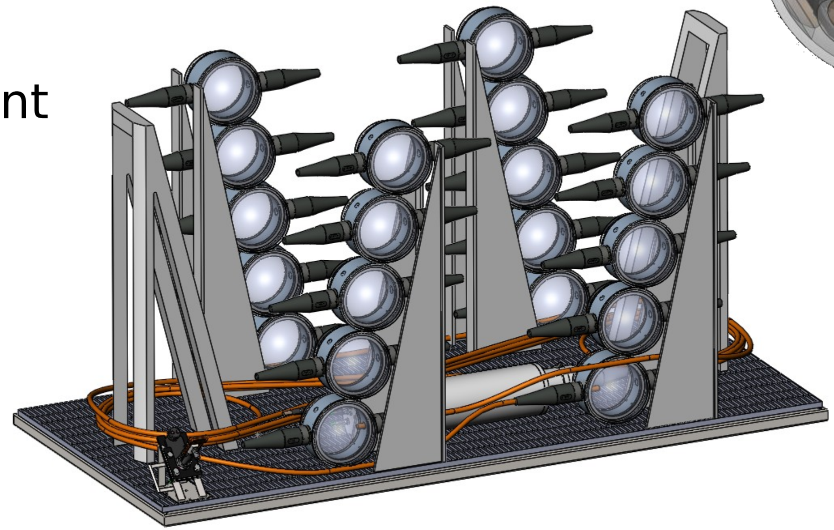
P-OM Electronics

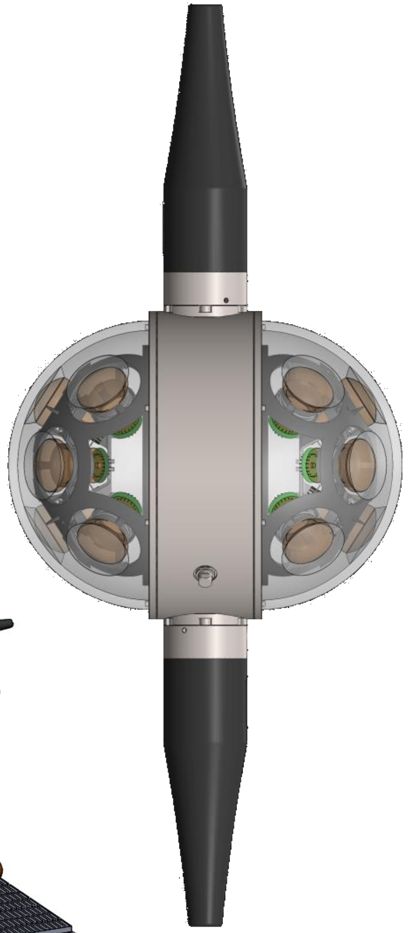
- PMTs read out by 210 MHz 12-bit ADC + FPGA
  - ➔ Full waveform digitization
- Microprocessor, 4GB shared memory with FPGA
  - ➔ Local data buffering, coincidence triggering, communication



Cable and deployment

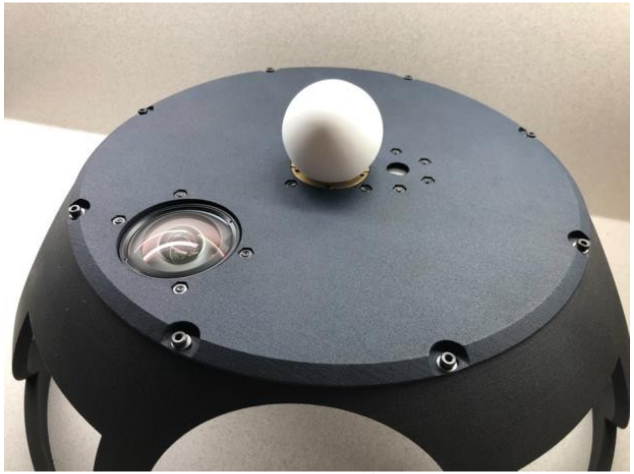
- 1km/20=50m segments
  - Module serves as breakout box
  - ➔ No connectors
- Cable serves as mechanical backbone
  - ➔ Reduced cable shadow
  - ➔ Designed for easy deployment (bottom-up)

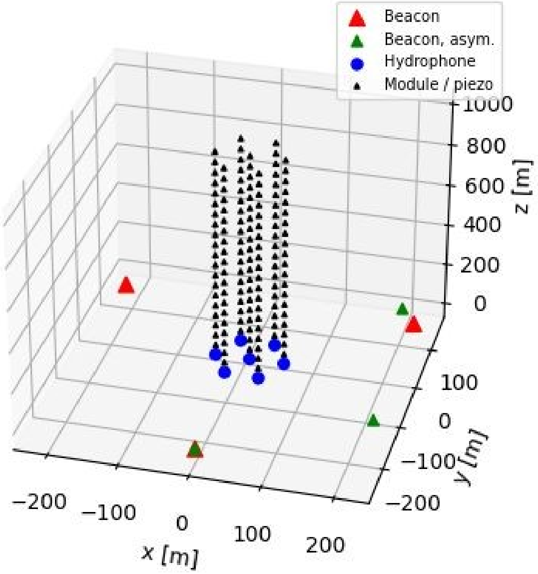




Calibration and timing

- Calibration modules replacing 4 PMTs with hollow PTFE diffuser and flasher matrix producing nanosecond pulses
  - ➔ Monitor water properties
  - ➔ Triangulate module positions
- Cameras in calibration modules
  - ➔ Bioluminescence/biofouling
- Piezo receivers in all modules, acoustic beacons on sea floor
  - ➔ Triangulate module positions (backup to optical triangulation)
- Network: GbE inside TRBnet
  - Sub-ns timing accuracy

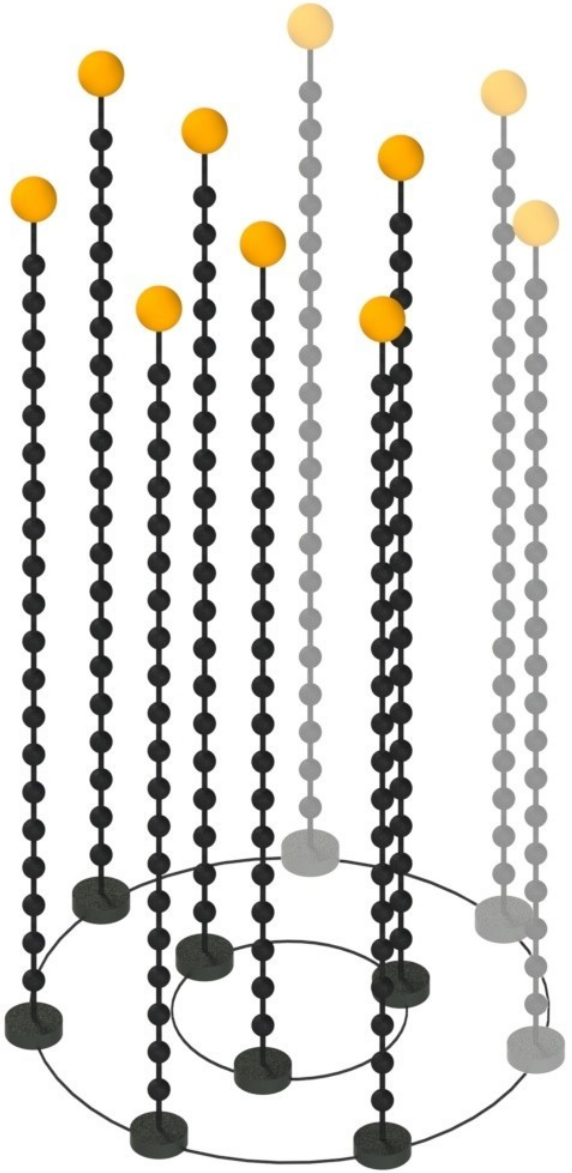




Next step: P-ONE Demonstrator

- 6-7 strings of first 10-string cluster
- Funding secured from European agencies, positive messages from Canadian agencies
- First physics measurements
  - Atmospheric neutrinos
  - Moon shadow
  - Bioluminescence study
  - Trigger algorithm development

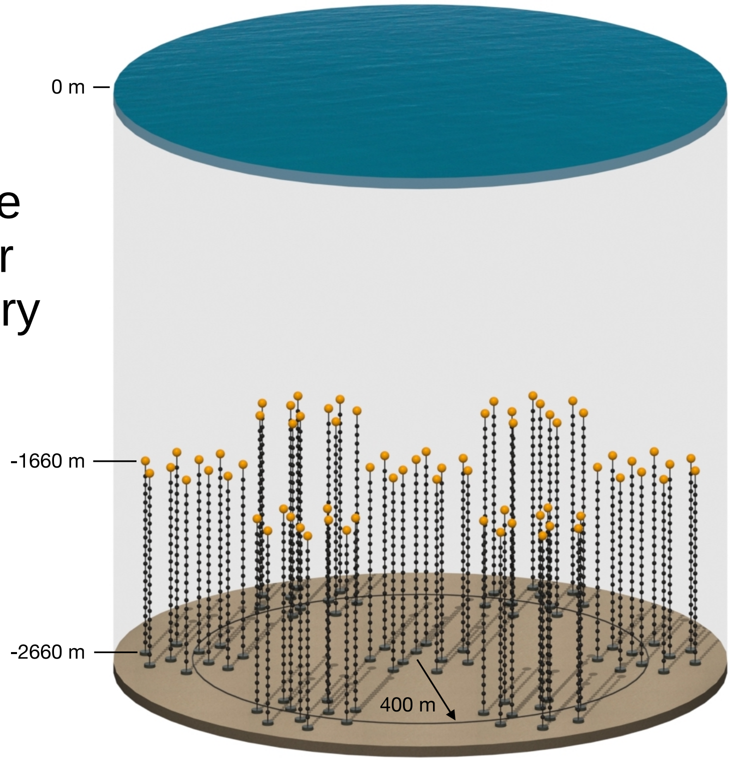
Deployment over next three years

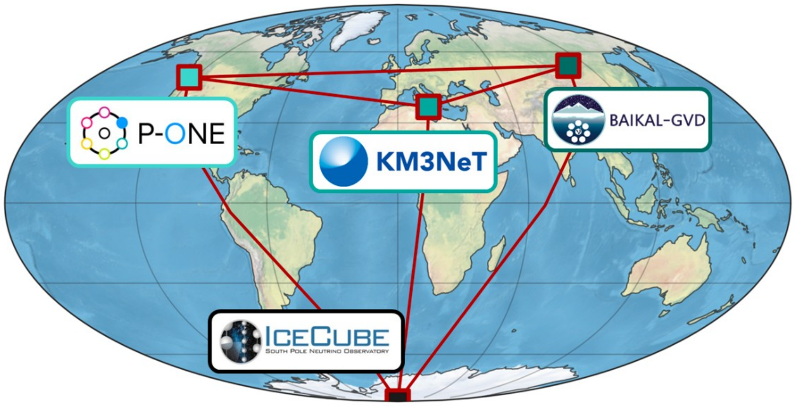


The full detector

- 7 clusters of 10 strings
- >1 km³ instrumented volume
- Built over several years
- First neutrino telescope in the Pacific

Possible detector geometry





Plot: L. Schumacher

Long term goal: planetary neutrino network, using data from all neutrino telescopes

Further reading

M. Agostini et al., Nat. Astron. 4, p913–915 (2020), arXiv:2005.09493

M. Boehmer et al., JINST 14 (2019) 02, P02013, arxiv:1810.13265

N. Bailly et al., Eur. Phys. J. C (2021) 81: 1071, arxiv:2108.04961

www.pacific-neutrino.org

P-ONE collaboration meeting, Spring 2023

P-ONE

UNIVERSITY OF ALBERTA

OCEAN NETWORKS CANADA

Queen's UNIVERSITY

SFU SIMON FRASER UNIVERSITY

TRIUMF

NSERC CRSNG

MICHIGAN STATE UNIVERSITY

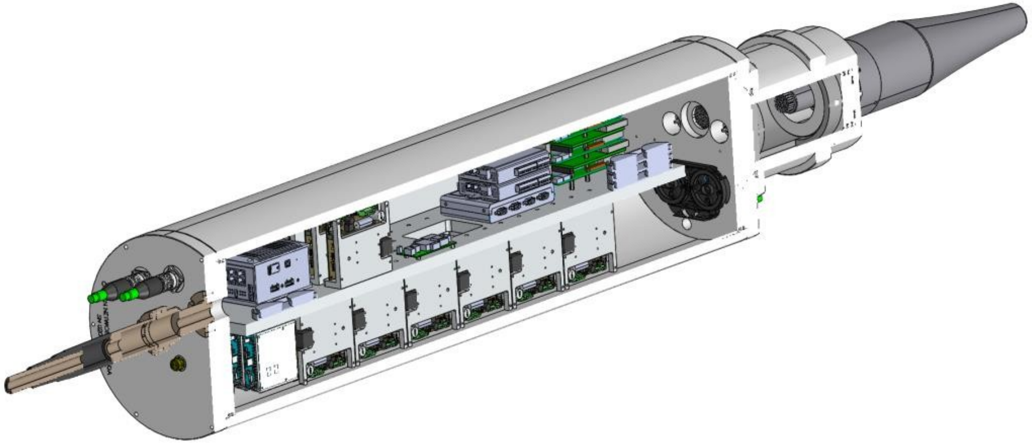
Drexel

TUM

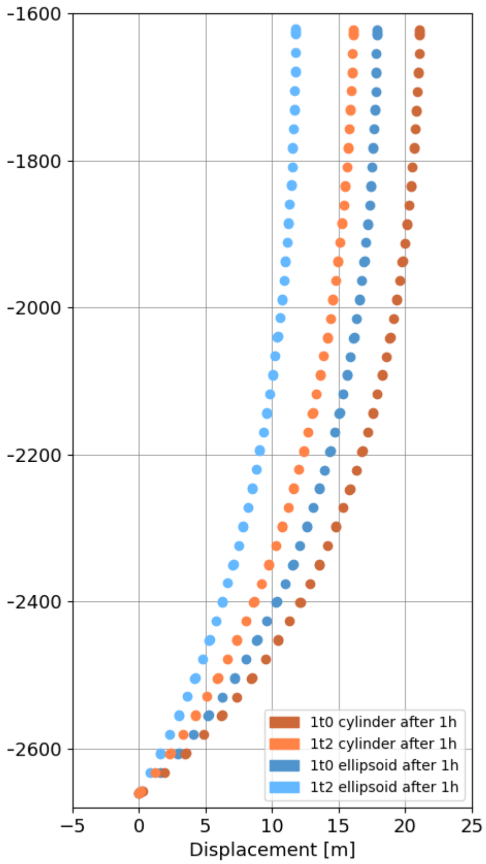
UCL

erc European Research Council

Backup - Cable and deployment



Mooring junction box



Simulations of string tilt in the current

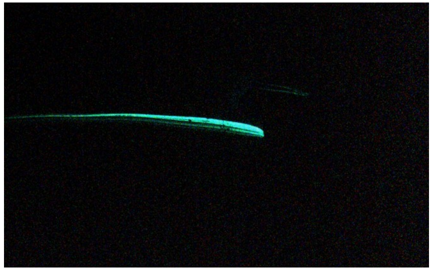
Backup – Bioluminescence

Bioluminescence

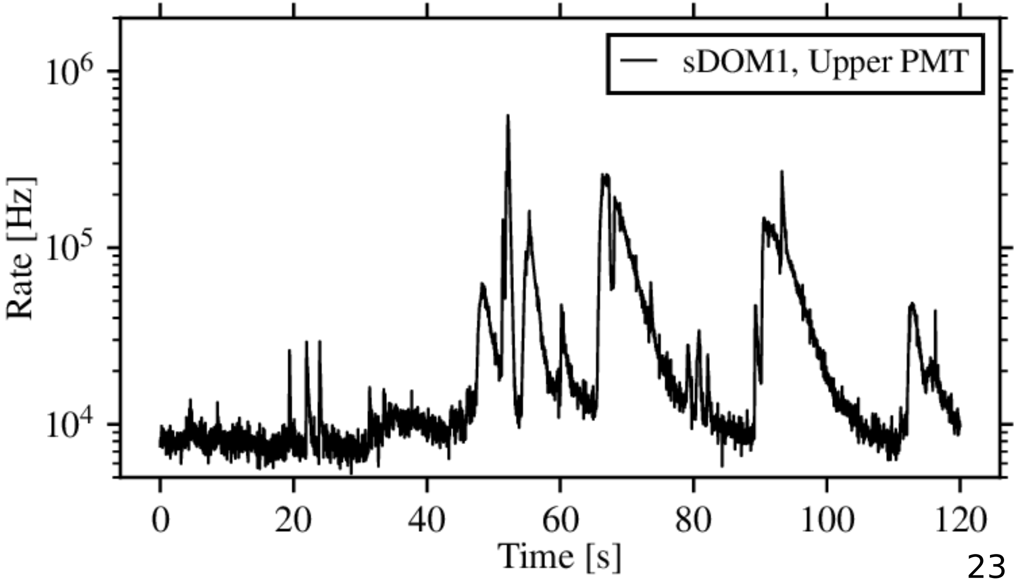
- 10kHz – Mhz background
- Spikes of a few seconds
- Varies with tides and seasons

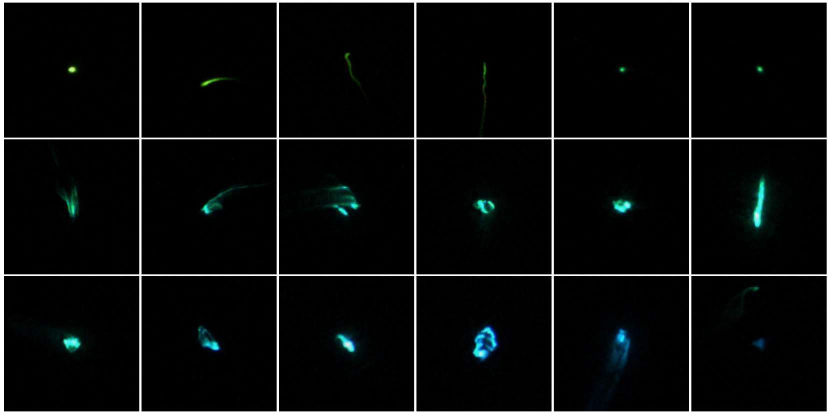
➔ **Need appropriate coincidence trigger**

Paper on bioluminescence forthcoming

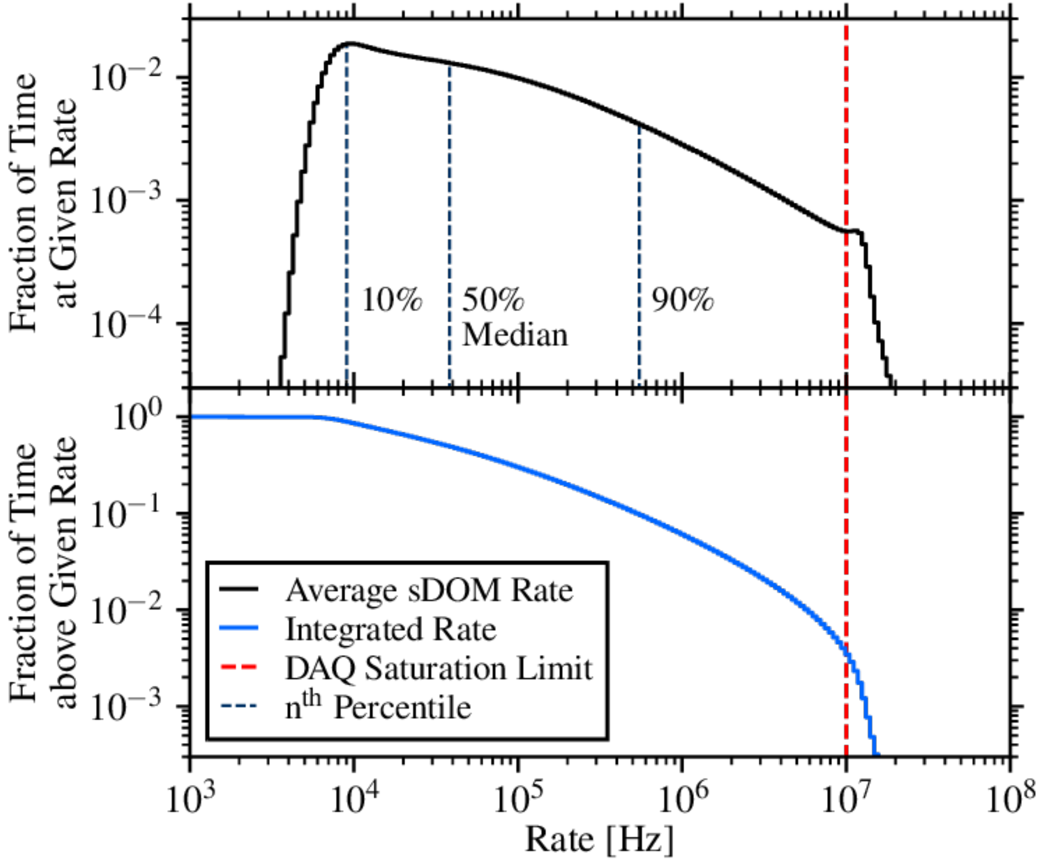


Picture of bioluminescent organism from STRAW-b camera, 60s exposure time





Backup – Bioluminescence



N. Bailly et al., Eur. Phys. J. C (2021) 81: 1071, arxiv:2108.04961

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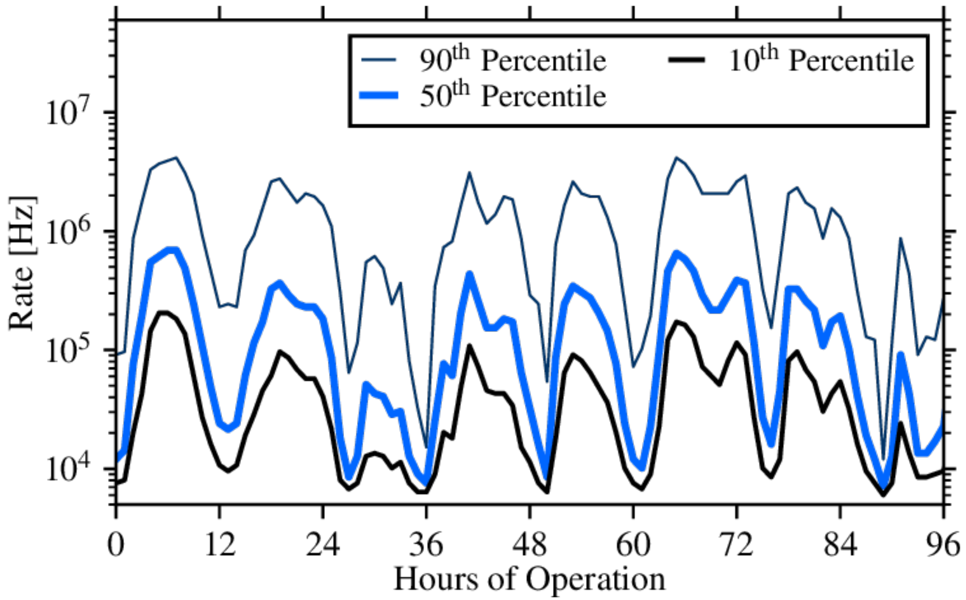

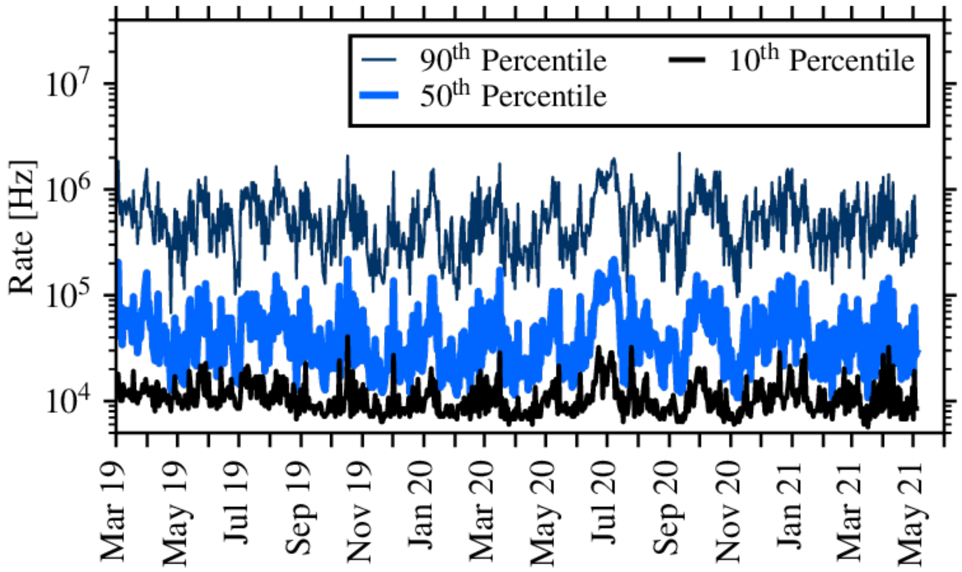

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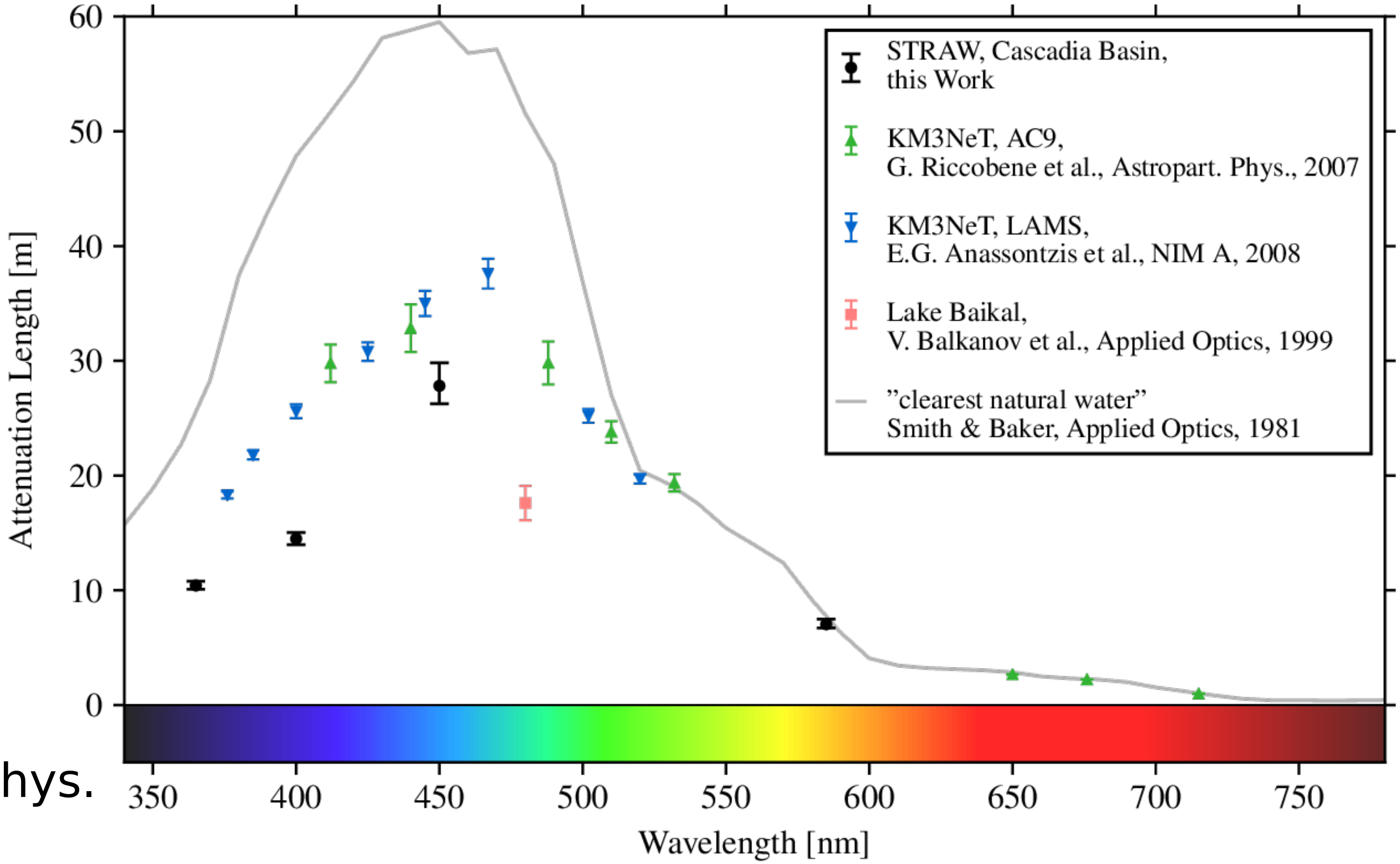
Backup – Attenuation length



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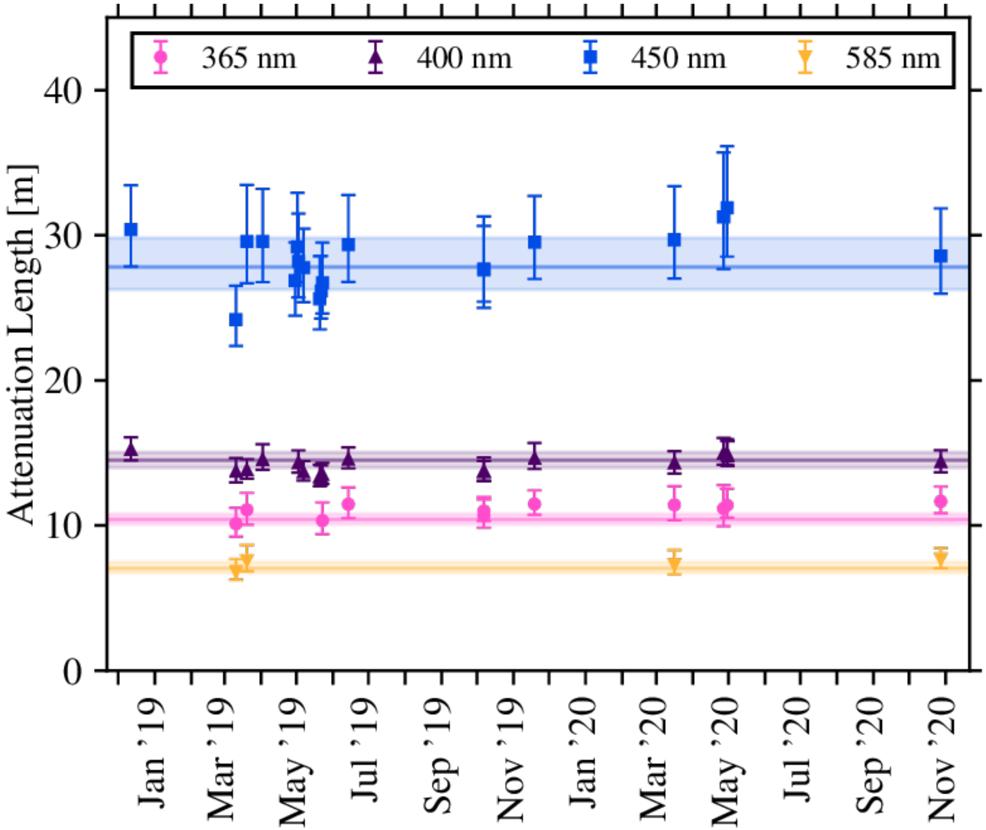
Backup – Attenuation length

Attenuation length

- Determines P-ONE module spacing and energy resolution
- Measured at 28m for 450nm

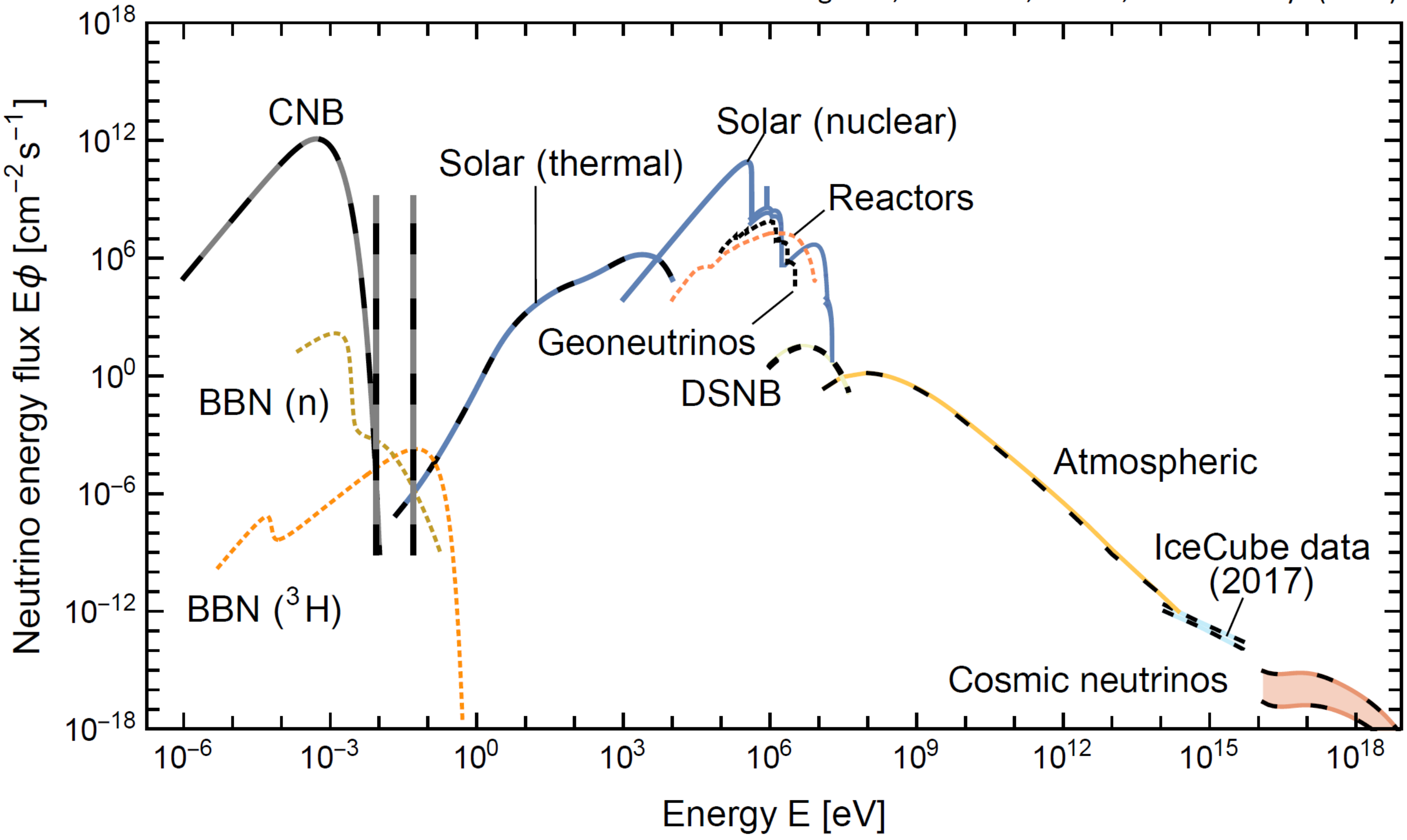
➔ **Site is suitable for neutrino telescope**



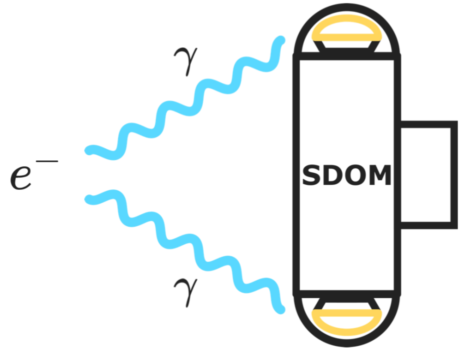
N. Bailly et al., Eur. Phys. J. C (2021) 81: 1071, arxiv:2108.04961

Backup - Neutrino spectrum

Vitagliano, Tamborra, Raffelt, Rev.Mod.Phys (2019)

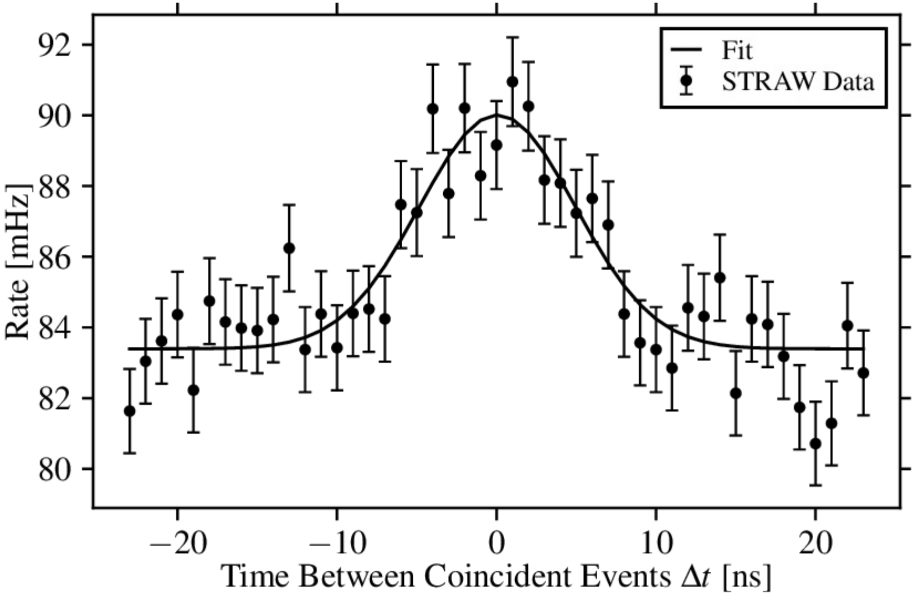


Backup - K40



Potassium-40 decays

- Source of coincident photons
- K-40 measurements agree with predictions



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