Pacific Ocean Neutrino Experiment (P-ONE)

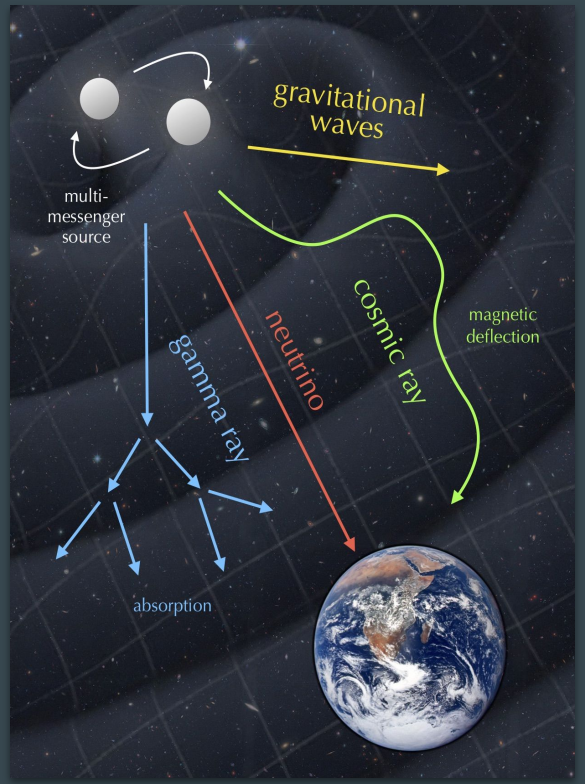
Paweł Malecki

THE HENRYK NIEWODNICZAŃSKI
INSTITUTE OF NUCLEAR PHYSICS
POLISH ACADEMY OF SCIENCES

P-ONE

Neutrino astronomy

Astrophysicist
(noun)
Someone that gets excited about things that no one else cares about.



- While cosmic rays are mostly composed of nuclei, astrophysical neutrinos are also present.
- The universe is transparent to them, no deflection or bending of trajectories happens,
- They can escape very dense environments and provide undistorted picture of their sources.
- Therefore we may speak of *neutrino astronomy* - neutrinos point directly towards their sources!
- Yet the sources are still barely known in detail...

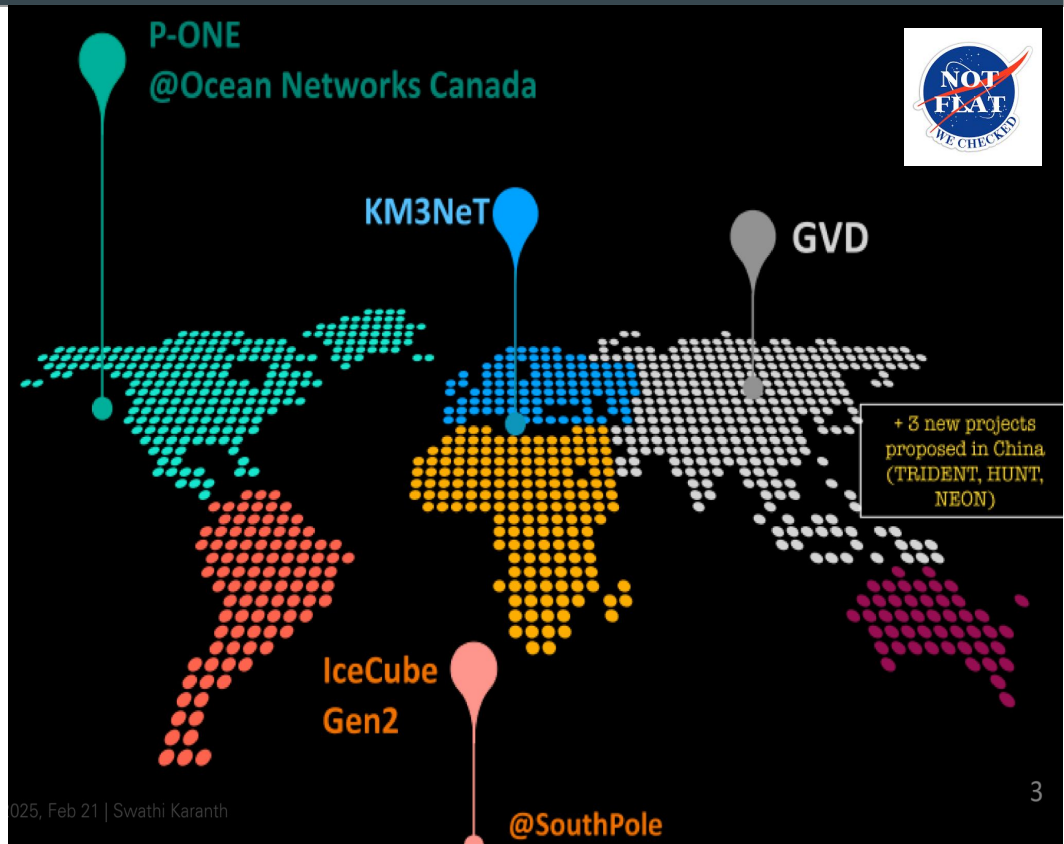
Neutrino telescopes: the current landscape

The leading telescope is **IceCube** in South Pole ($1km^3$ detector, fully operational and mature).

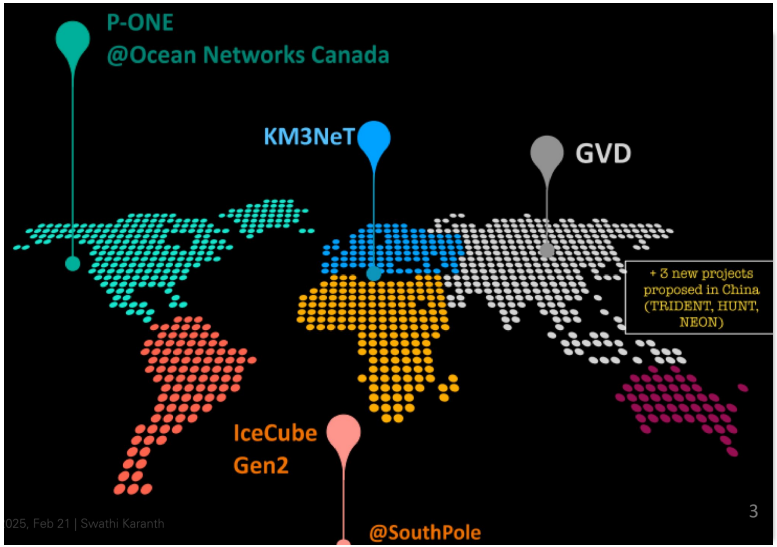
In the Northern Hemisphere there is **Baikal-GVD** (Baikal lake freezes in winter - installation simplified) and KM3NeT.

Several projects developing in South China Sea.

P-ONE will bring a huge increase in sky coverage & statistics due to next-gen design.

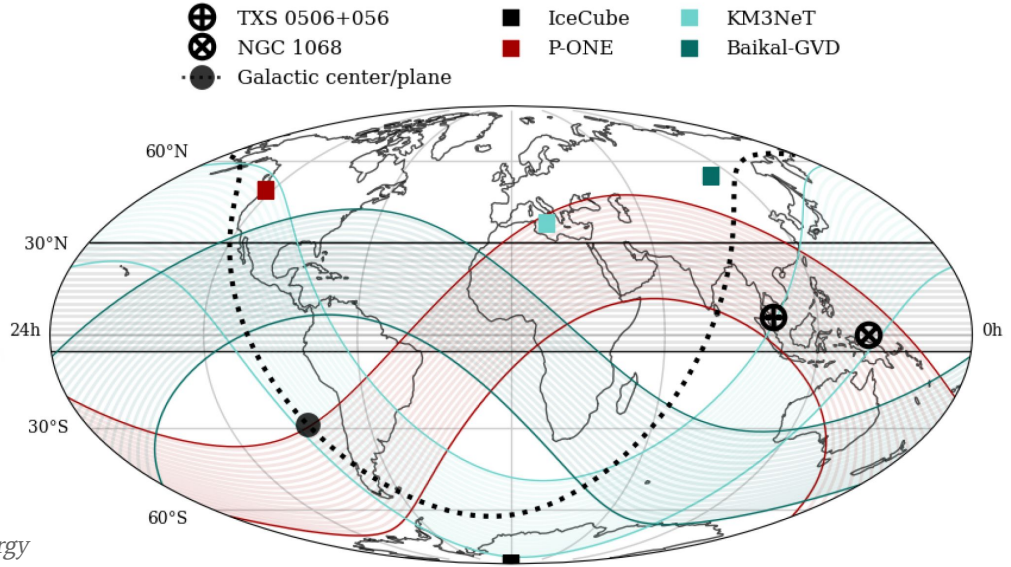


More neutrino telescopes? PLEnuM



Need more telescopes to quickly advance in the field:

- Increased sky coverage,
- Increased rate of data.



L. Schumacher et al., PLEnuM: A global and distributed monitoring system of high-energy astrophysical neutrinos, *ICRC* (2021)

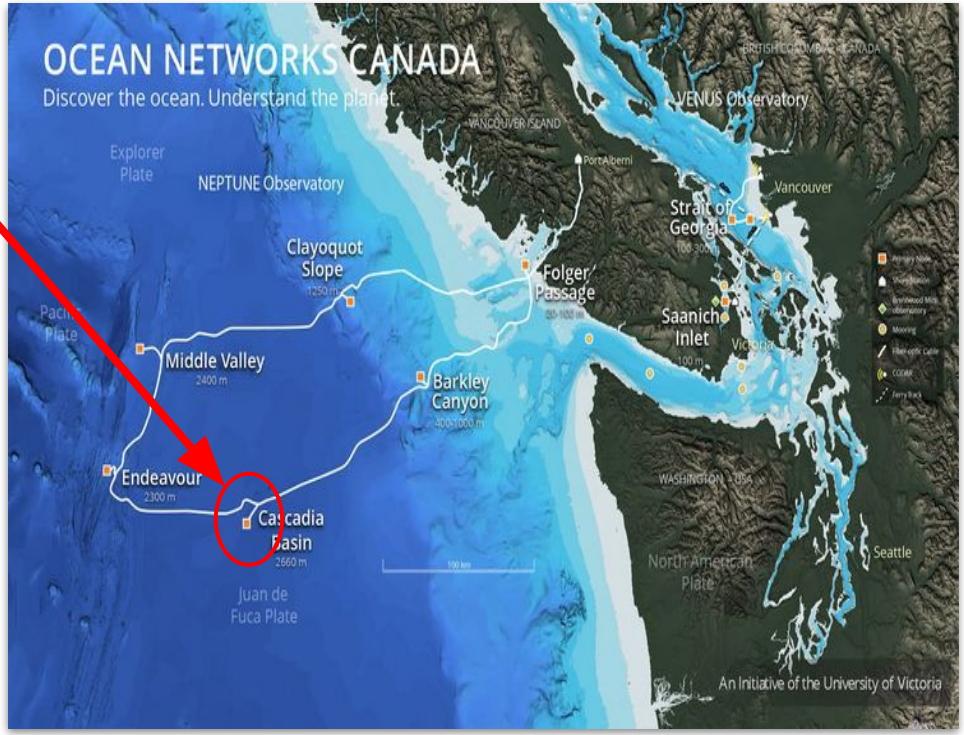
L. Schumacher et al., *Beyond first light: Global monitoring for high-energy neutrino astronomy*, arXiv:2503.07549v2, accepted by PRD

L. Schumacher, F. Oikonomou, PoS(ICRC2023)991

P-ONE: the site

- Site location: Cascadia basin, North-East Pacific, 600-km West from Vancouver.
- NEPTUNE observatory of **Ocean Networks Canada (ONC)** - 800-km loop of power and data cables.
- Depth of ~2660 m,
- Good optical clarity of water (attenuation length ~28 m, similar as in Baikal),
- Low currents (0.1 m/s),
- Stable 2°C temperature,

ONC provides required infrastructure & marine operations support.



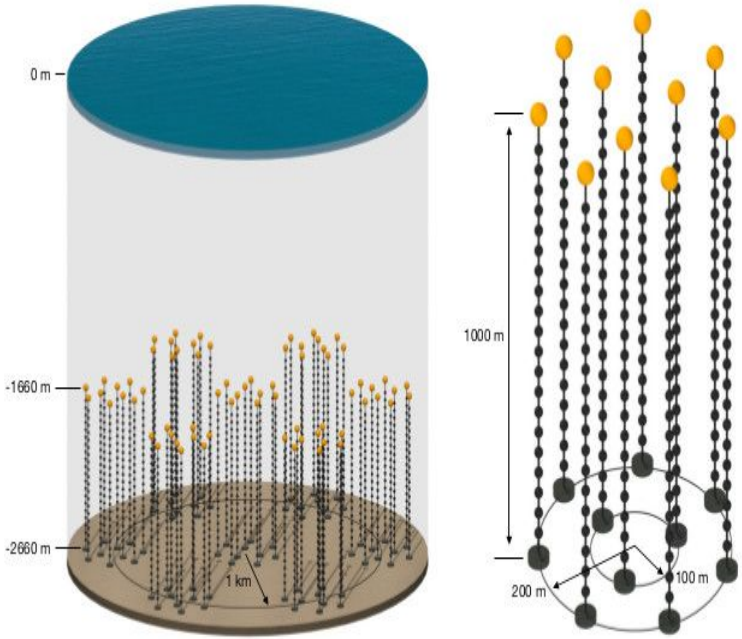
P-ONE: Collaboration

- Georgia Institute of Technology, USA
- Simon Fraser University, Canada
- Michigan State University, USA
- University of Alberta–Edmonton, Canada
- Queen's University, Canada
- University College London, UK
- University of Chicago, USA
- Duke University, USA
- Elmhurst University, USA
- Los Alamos National Laboratory, USA
- Technische Universität München, Ge
- Drexel University, USA
- TRIUMF, Canada
- Ocean Networks Canada, Canada
- IFJPAN

Physics program

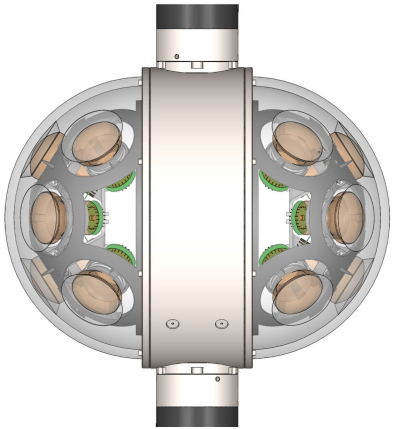
- Search for sources of high-energy phenomena:
  - Extragalactic (50 TeV - 100 PeV): Active Galactic Nuclei (AGN), Gamma-ray bursts (GRB), starburst galaxies, etc.
  - Galactic (up to ~1 PeV): Supernovae, pulsars, the black hole Sgr A*, binary systems, etc...
- Diffuse neutrino flux:
  - Unidentified sources, check energy spectrum, anisotropies, flavor composition...
- Multi-messenger astronomy:
  - Simultaneous observations of the same part of the sky with cosmic rays, neutrinos, photons, gravitational waves...
- Search for dark-matter particles, magnetic monopoles, etc...

P-ONE: planned structure

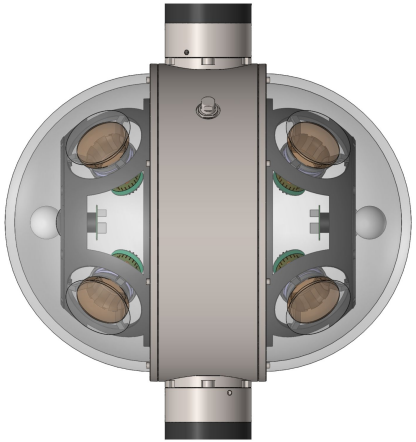


Segmented structure (clusters) to cover 1 km^3 in the first stage.

7 clusters, 10 1-km strings each with 20 optical modules per line.

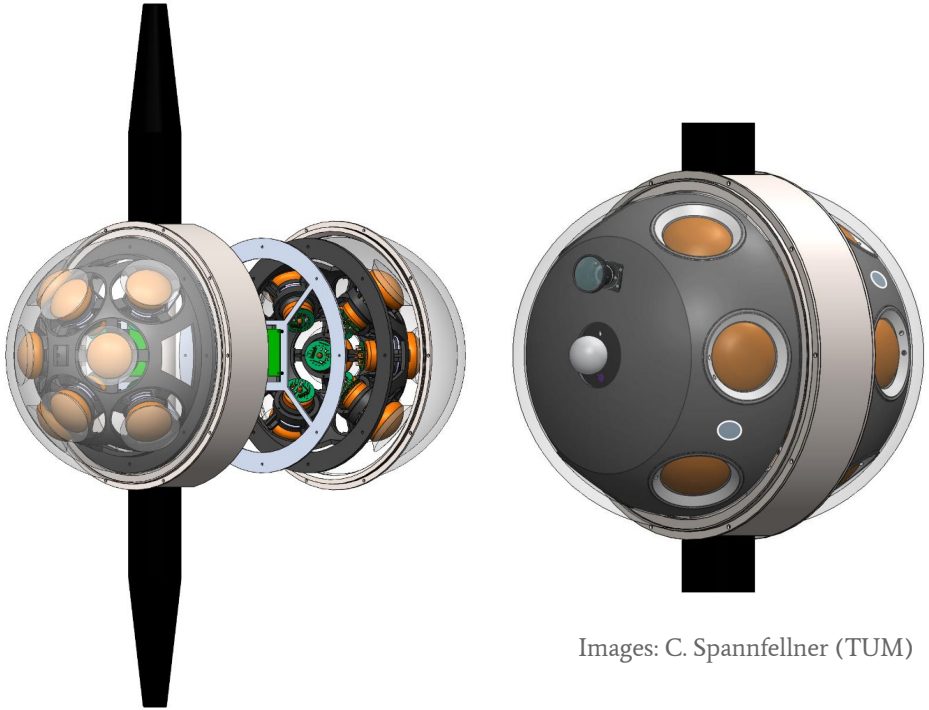


P-ONE Optical Module



P-ONE Calibration Module

P-ONE: planned structure



Images: C. Spannfellner (TUM)

17-inch Multi-PMT Optical Modules (P-OM) containing 16 PMT* for better reduction of biological background and directional resolution.

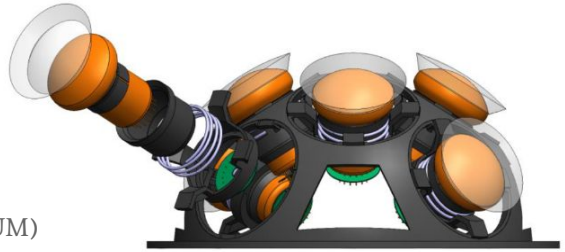
Calibration modules: continuous monitoring of detector operation and geometry. Also containing PMT's (~10) plus additional light sources (LED flashers, laser).

* 3-inch Hamamatsu R14374-10

P-ONE Optical Module

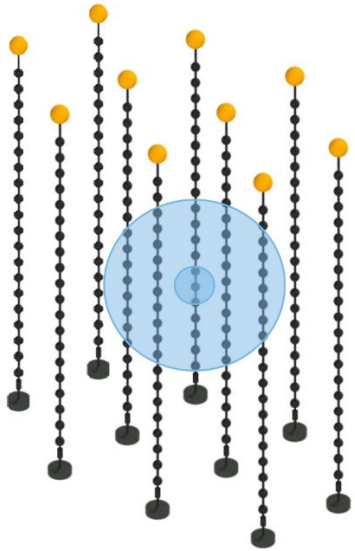
- P-ONE baseline optical module with 16 PMTs
- PMT: Hamamatsu R14374-10
  - Gain: 3x10^6
  - QE at 450 nm: 24.5 %
  - Transit-time-spread (FWHM): 1.5 ns
  - Effective area: 75 mm
  - Dark rate: 350 Hz (12 h in dark)
- Modular, spring loaded mounting structure
- Optical gel reflector pads to increase light yield

Please note: illustrations are preliminary studies!

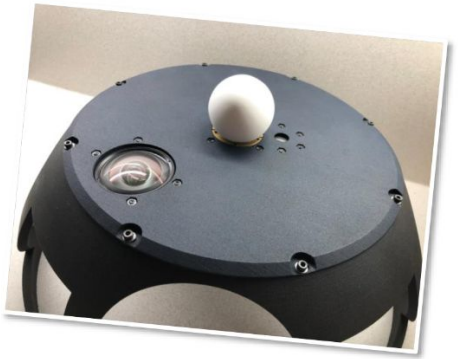


Images: C. Spannfellner (TUM)

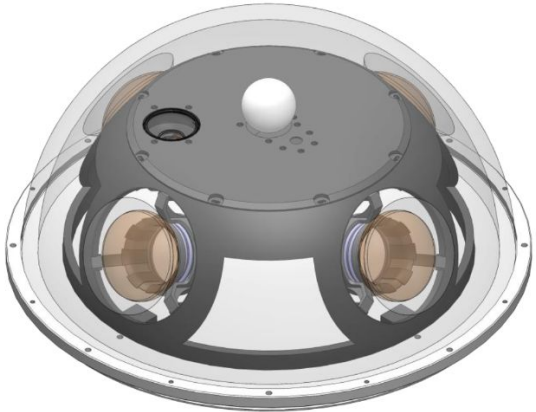
P-ONE calibration



- **P-CAL - Optical calibration**
  - Emission of an sub-ns light pulse into detector regime
  - In-situ monitored by photosensors (PD, SiPM)
  - Relative measurement (if not installed on seabed)



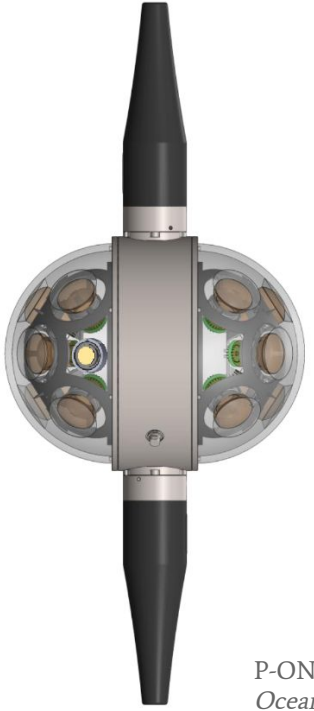
- **PIEZO - Acoustical calibration**
  - Acoustic receivers (piezo-based) installed in modules
  - Beacons on seafloor for triangulation
  - Absolute positioning



F. Henningsen et al., A self-monitoring precision calibration light source for large-volume neutrino telescopes, Journal of Instrumentation 15 (2020)

Images: C. Spannfellner (TUM)

P-ONE calibration



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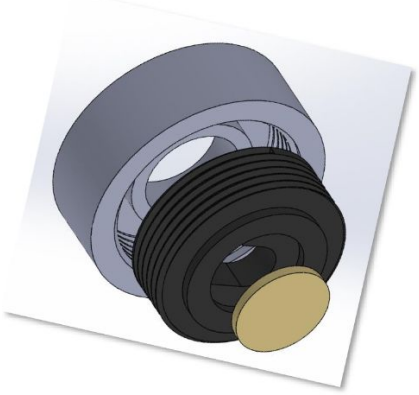

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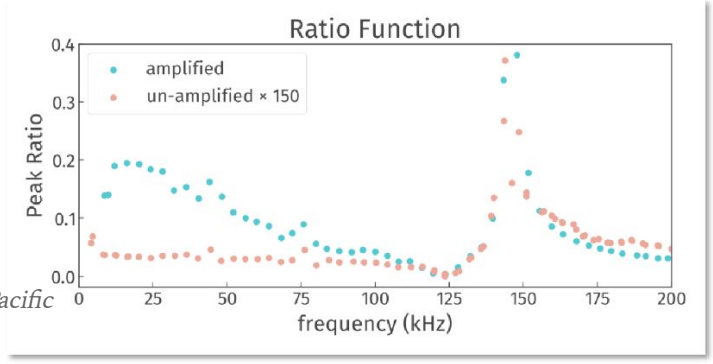
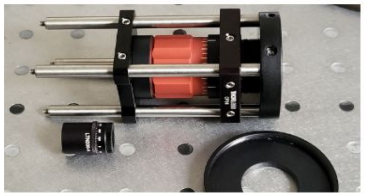


P-ONE Collaboration, *Prototype acoustic positioning system for the Pacific Ocean Neutrino Experiment*, JINST 20 (2025) P07003

P-ONE calibration (again)

Axicone

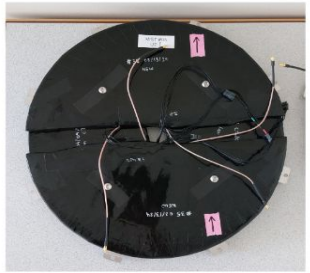


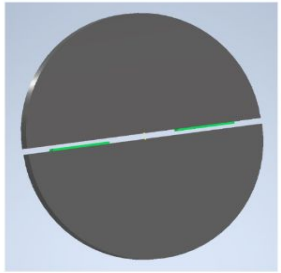
actual beam emission from axicon

water mist projection / axicon geometry graph

- Cone emission at 450 nm
- Measure optical properties of water
- Optical calibration

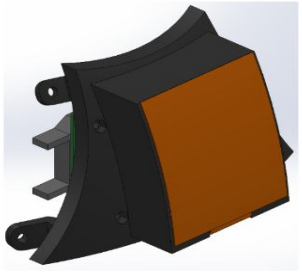
Muon In-Situ Tracker

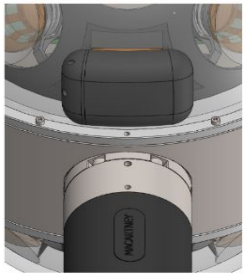




- Scintillator Muon Tracker
- Verify pointing resolution
- 4 scintillators with 90 deg rotation
- SiPM from Onsemi

Oceanographic Sensor Interface

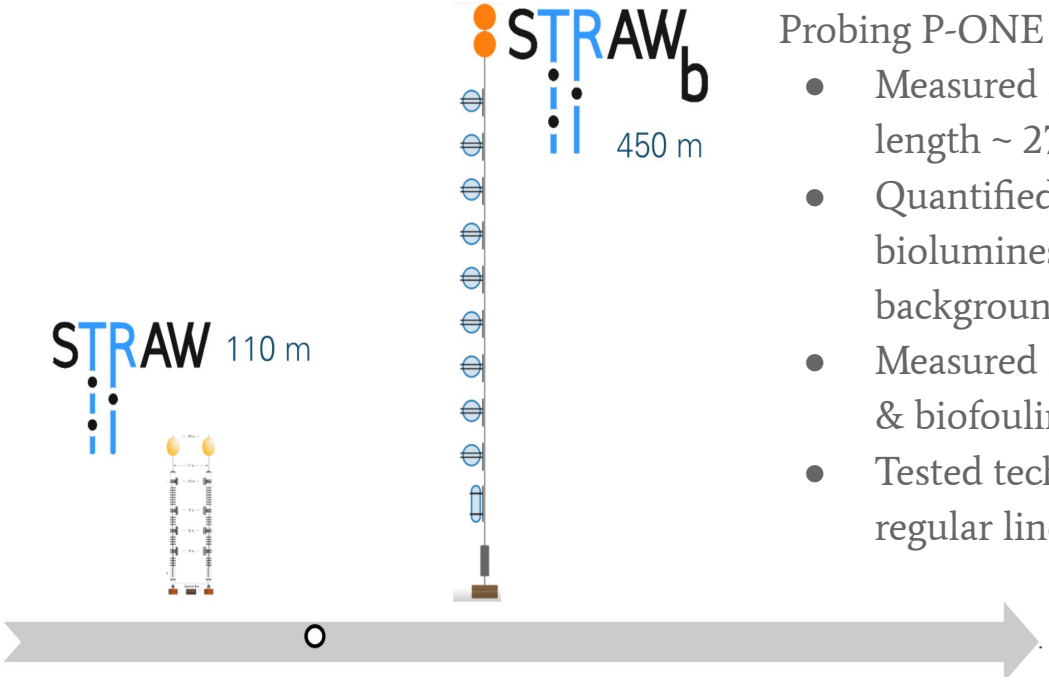




- Multi-purpose interface for oceanography sensors
- Internal and external mounting
- Wireless power and communication transfer

From C. Lagunas Gualda's talk at ICRC2025

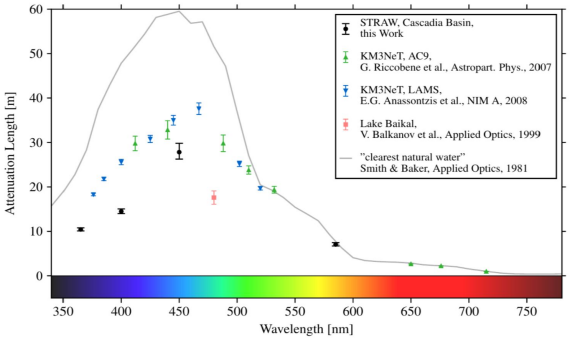
Timeline (so far)

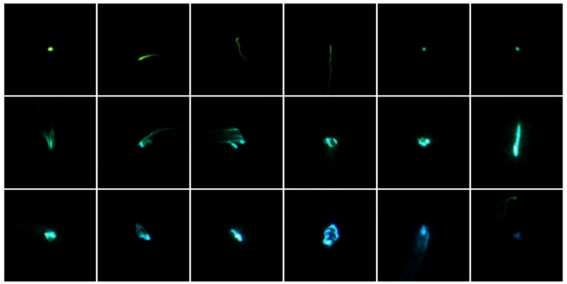


Probing P-ONE site:

- Measured attenuation length ~ 27.7 m,
- Quantified K40 & bioluminescence backgrounds,
- Measured sedimentation & biofouling,
- Tested technology for the regular lines.

Bailly et al., *Eur.Phys.J.C* 81 (2021) 12, 1071

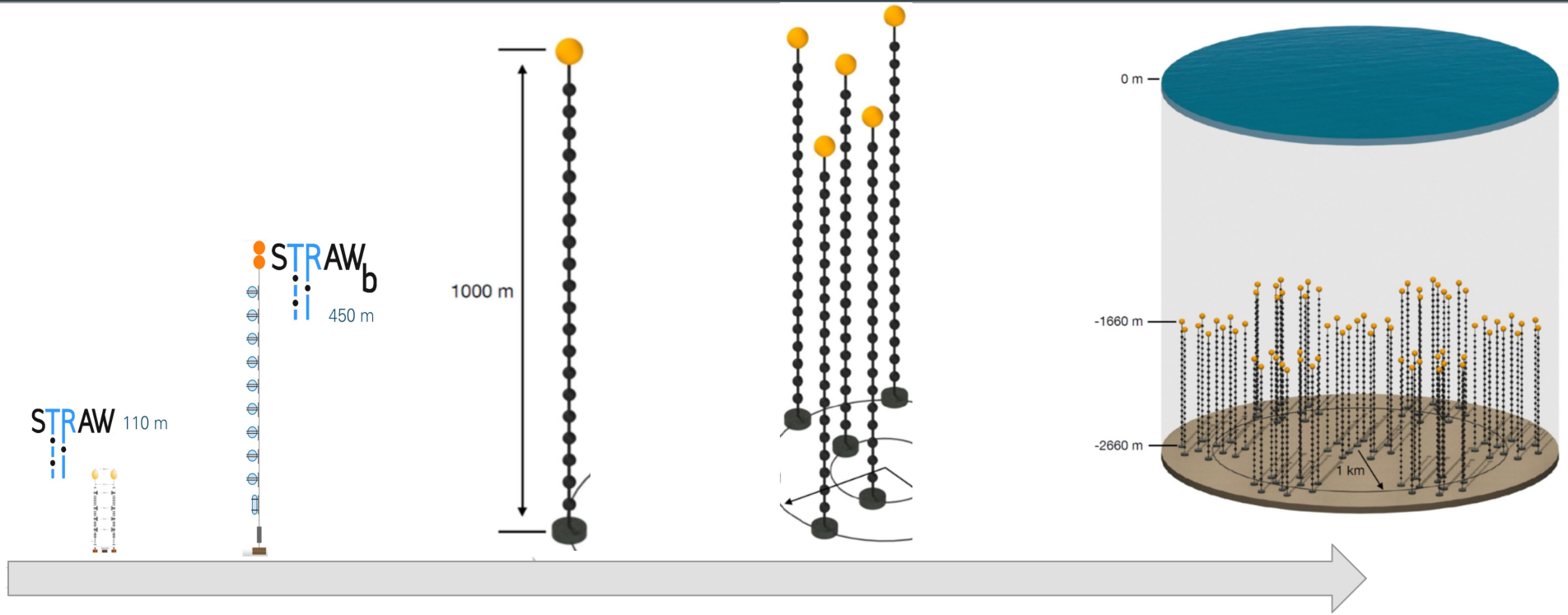




PoS (ICRC2023) 1166

Pathfinders: 2018 - 2023

Timeline (further steps)



Pathfinders:
2018 - 2023

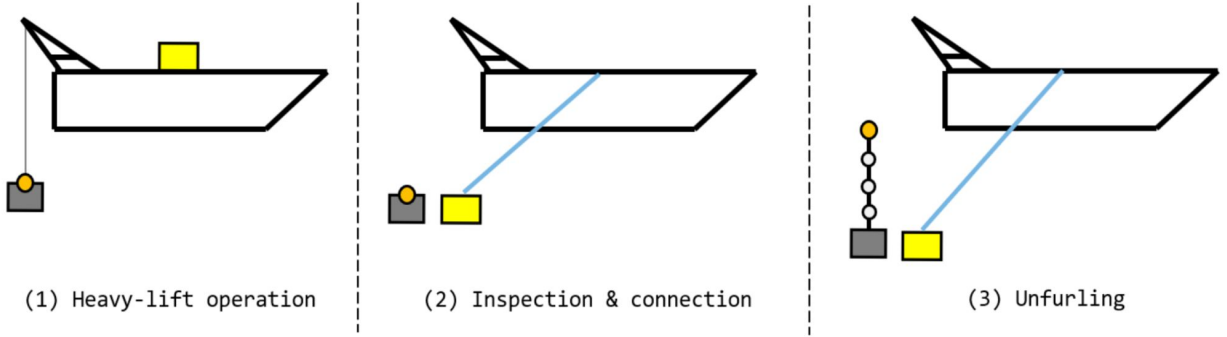
P-ONE-1
2026

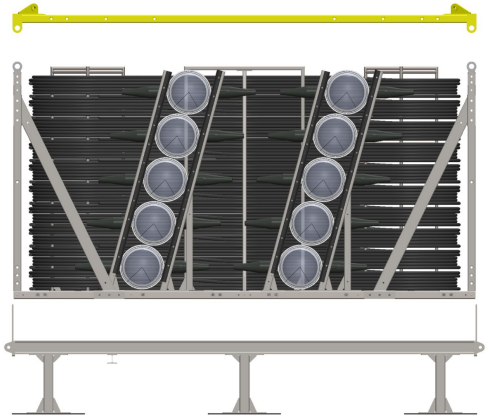
Demonstrator
2028

P-ONE
2030+

P-ONE-1 - first regular measurement line

- Bottom-up approach,
- Deployment frame is the anchor for the line,
- Aims:
  - Proof of concept,
  - Collect as much data as possible,
  - Benchmark for technology in the full P-ONE.

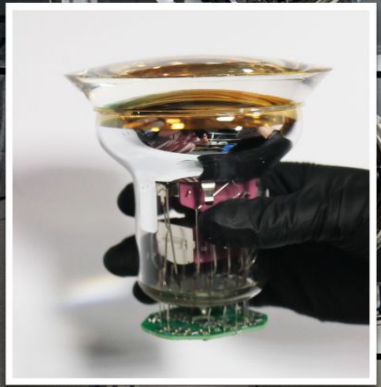


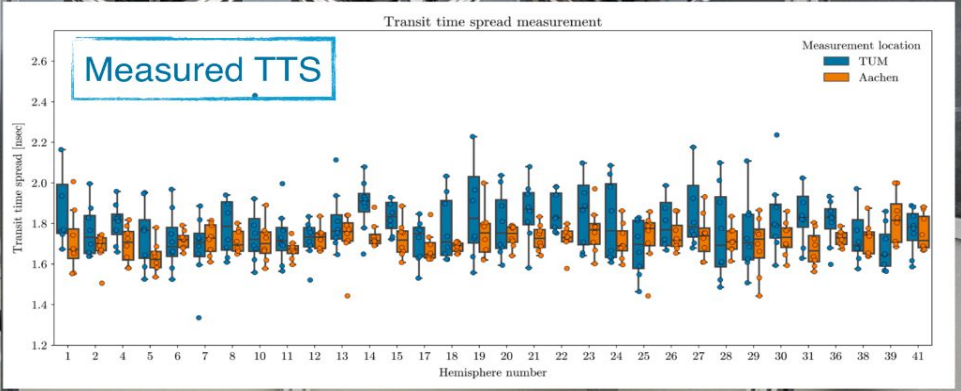


P-ONE-1 - towards deployment

From C. Lagunas Gualda's talk at ICRC2025

P-ONE-1 - towards deployment





~400 gel pads produced

37 hemispheres already produced

All PMTs within the hemispheres already tested and compatible with Hamamatsu specifications

From C. Lagunas Gualda's talk at ICRC2025

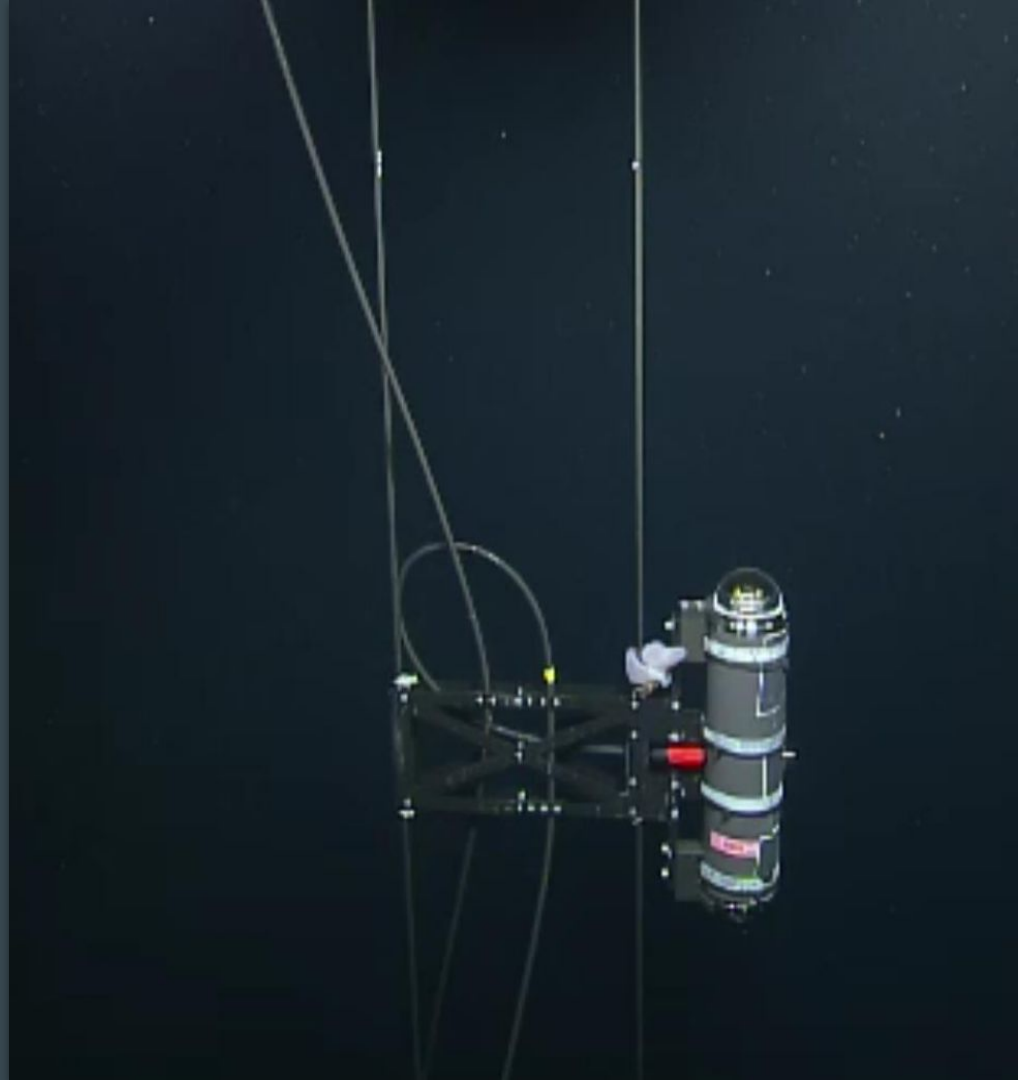
Summary & Outlook

P-ONE is approaching the deployment of first measurement line in 2026,

It provides an exciting potential for new discoveries and observations (improved sky coverage, best angular precision),

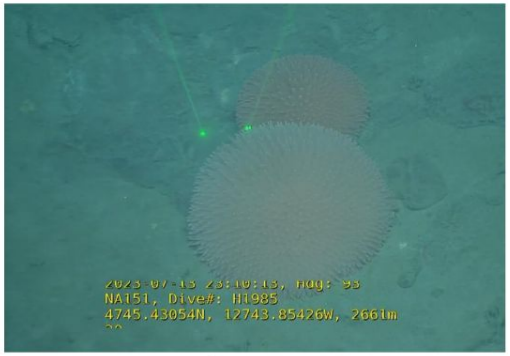
Funding is secured for first 5-10 measurement lines, applied for more,

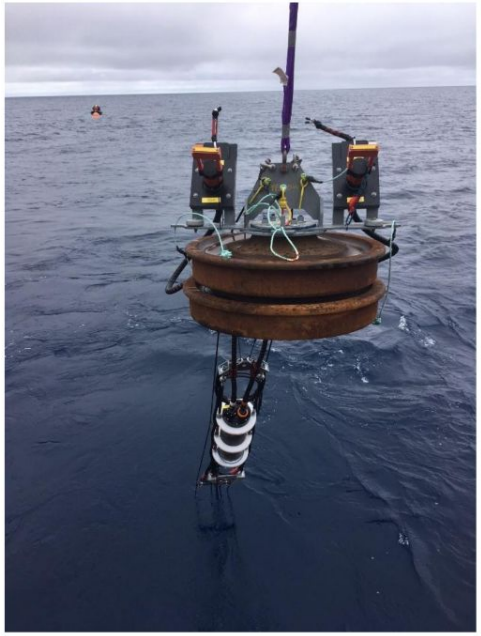
Infrastructure & deployment support from ONC simplifies the development.

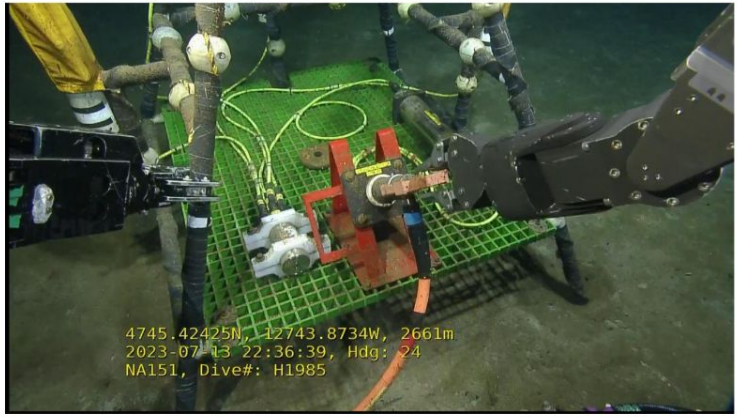


Thank you!

Backup





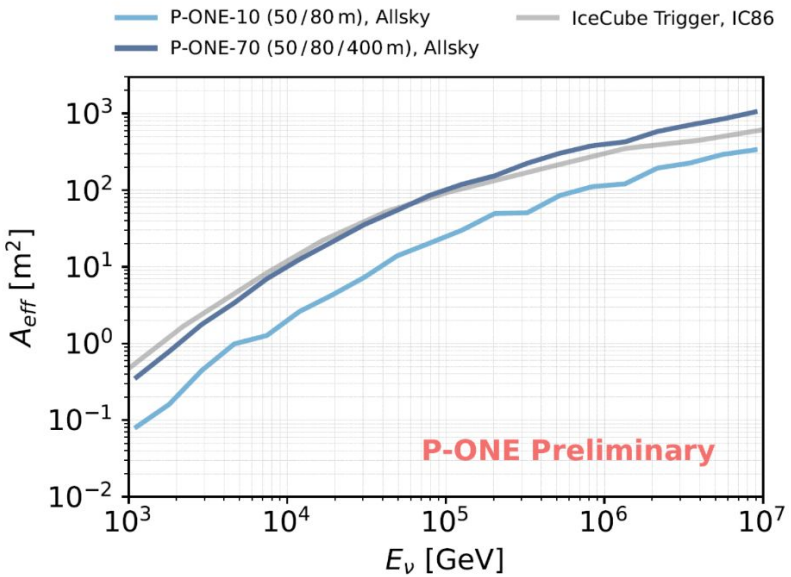


All pictures from ONC

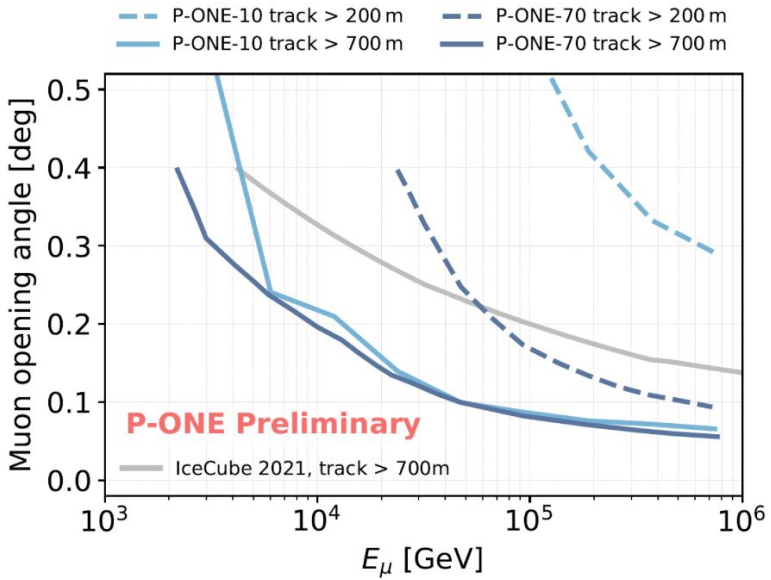
Effective area and resolutions

Effective area

trigger level (3 PMTs in 10ns)

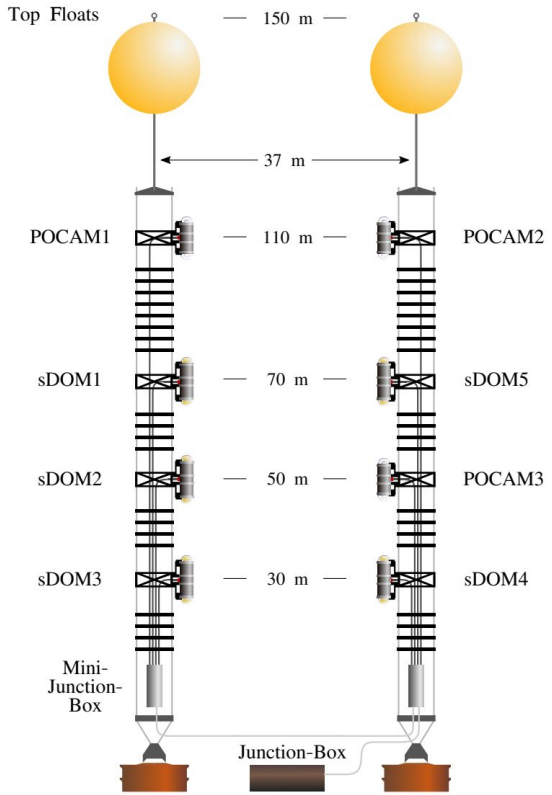


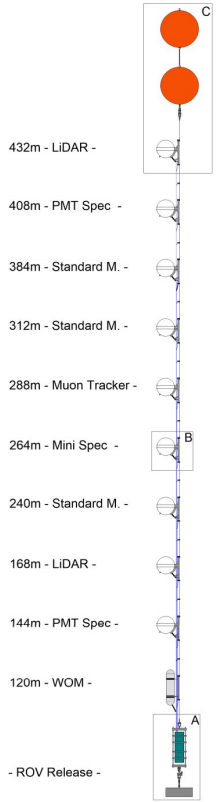
Directional reconstruction



Current status: pathfinder missions

- Deployed 2 pathfinders, STRAW and STRAW-b,
- STRAW (2018, fully operational until 2023):
  - Measure the water attenuation length.
  - Verify the amount of light from ^{40}K decays
  - Estimate rate for bioluminescence.
- STRAW-b (2020-2023) deployed with a variety of modules to better study the site, analysis is ongoing.

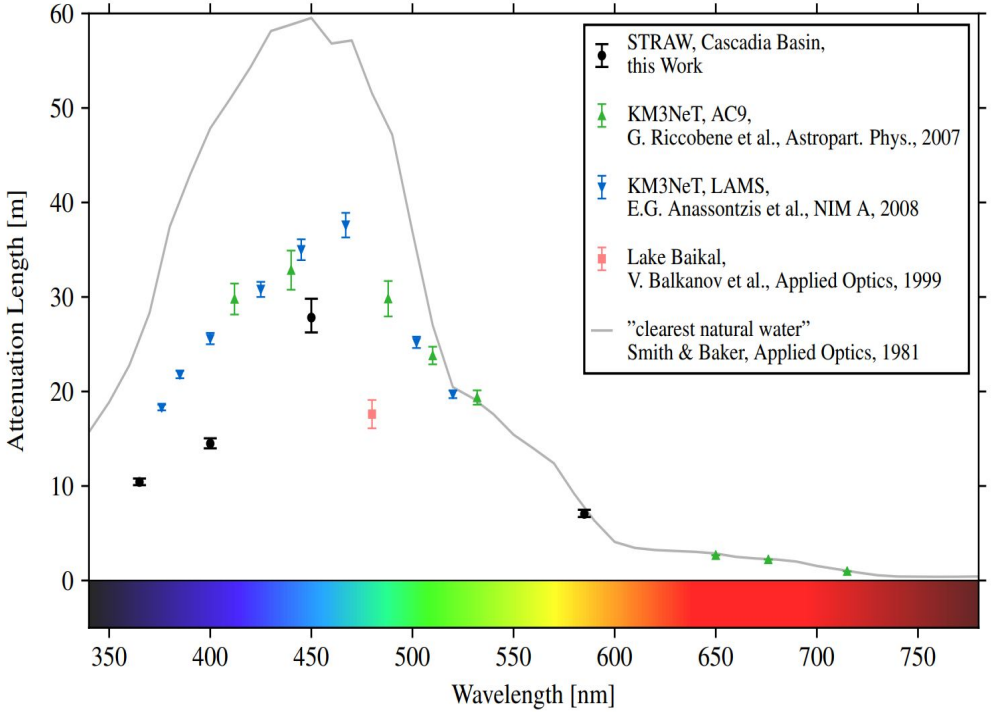




N. Bailly *et al.*, Eur.Phys.J.C 81 (2021) 12, 1071,
I.C. Rea *et al.*, PoS ICRC2021 (2021) 1092, July 2021

Water optical properties

- Using LED flashers at specific wavelengths, the attenuation length was measured at the P-ONE location the Cascadia Basin.
- Water is reasonably clear and suitable for a neutrino telescope.
- Attenuation length peaks at 27.7 ± 1.9 m at 450 nm.



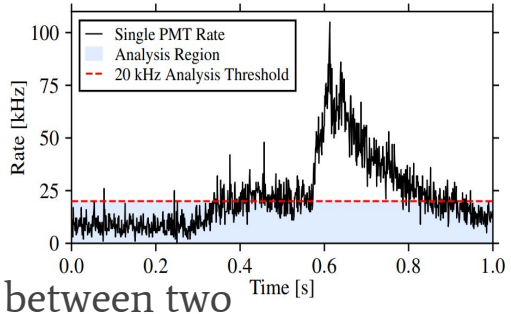
N. Bailly *et al.*, Eur.Phys.J.C 81 (2021) 12, 1071.

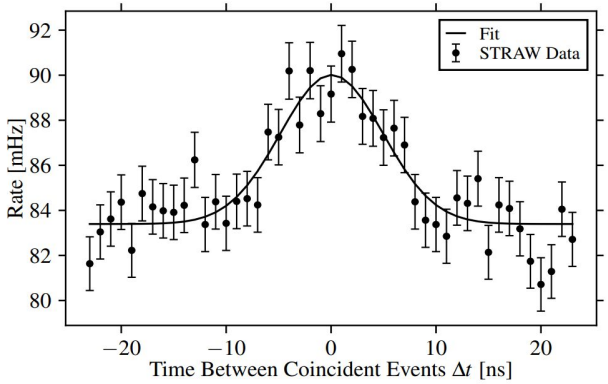
^{40}K decays and salinity

Background from:

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

$^{40}K + e^{-} \rightarrow {}^{40}Ar + \nu_e + \gamma.$



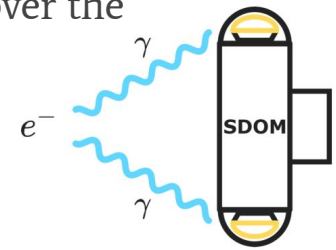


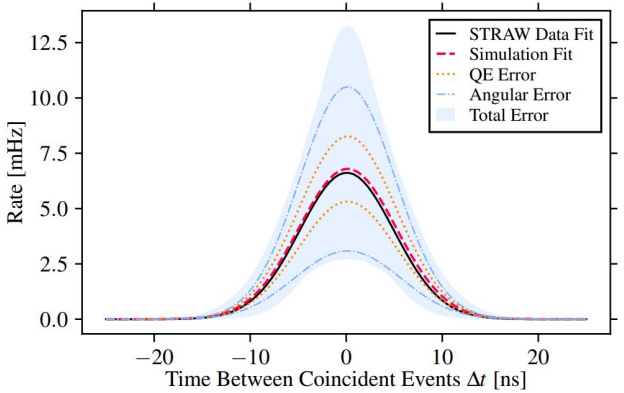
Idea: search for coincidences between two PMTs in the same module at rates < 20 kHz.

Compare with simulations to recover the salinity value:

This work: 2.5 ± 1.4 %,

ONC: 3.482 ± 0.001 %.

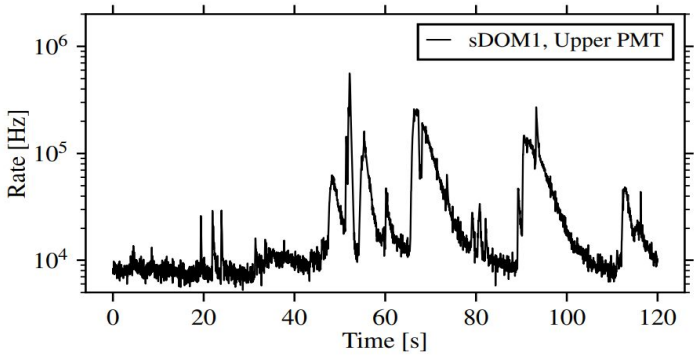




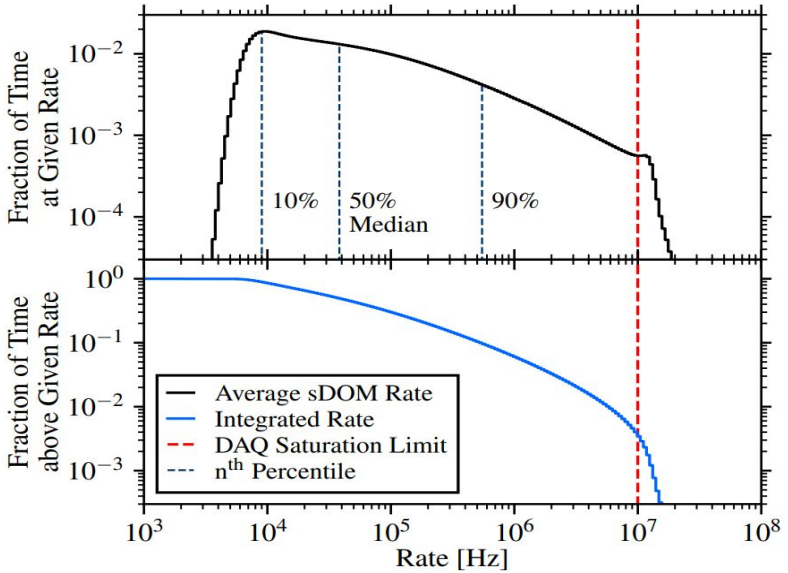
N. Bailly *et al.*, Eur.Phys.J.C 81 (2021) 12, 1071.

Bioluminescence

Emission of light by living organisms, from bacteria to large fish, for finding food, attracting mates, and evading predators.



Usually visible as large *spikes* over ~constant background.

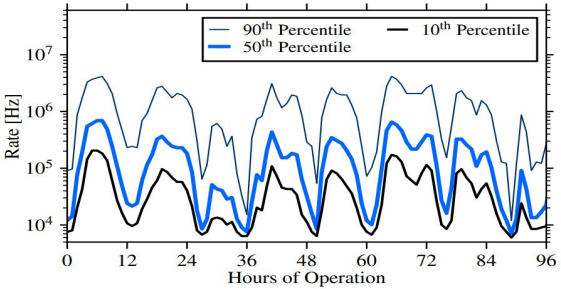


Distribution of single-PMT background rates.
10 kHz is from ^{40}K decays, the values above - from bioluminescence. The DAQ saturation is exceeded only for small fraction of time.

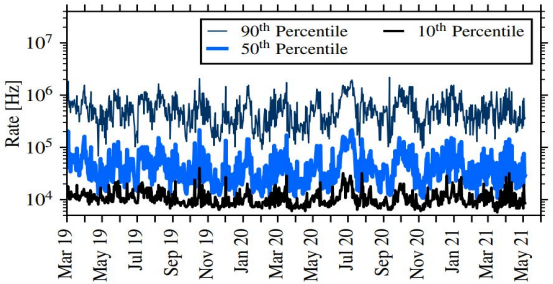
N. Bailly *et al.*, Eur.Phys.J.C 81 (2021) 12, 1071.

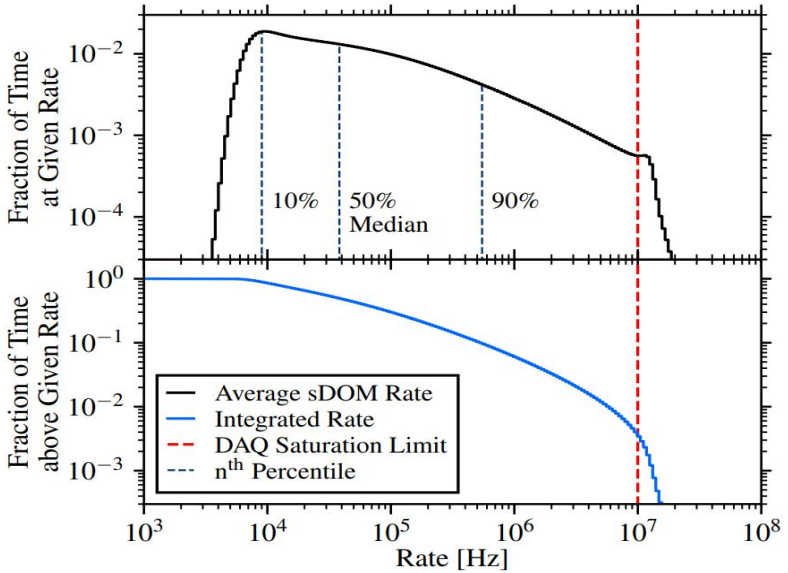
Bioluminescence

Percentile evolution over time reflects the tidal cycle (12.5 hours):



But no seasonal variation:





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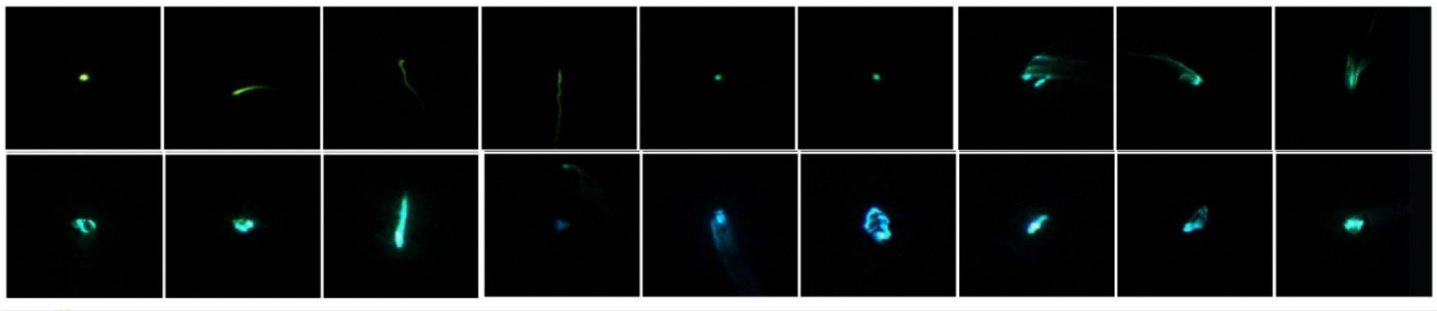
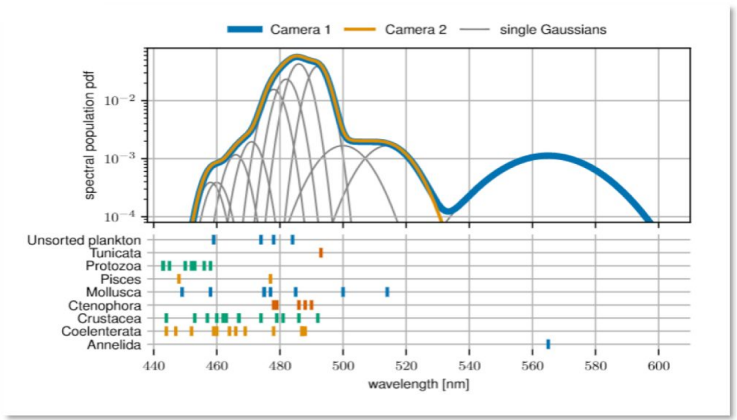




K. Holzapfel, et al., **PoS(ICRC2023)1166**

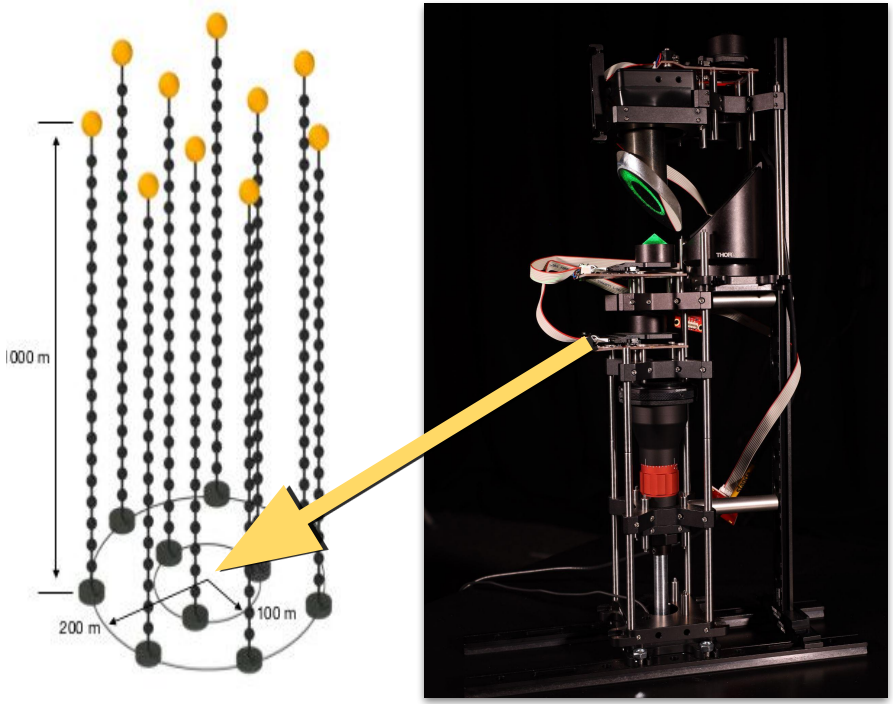
Background at Cascadia Basin

- Baseline component (few kHz)
  - K40 decay
  - Diffuse bioluminescence
- Bioluminescence bursts (MHz)

2nd pathfinder for R&D and further background analysis

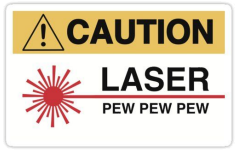
Activities in Kraków

Kraków: from BGVD to P-ONE



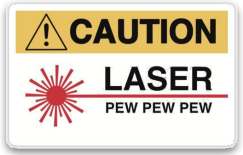
Direct continuation of experience of Kraków group:

- Laser calibration system: prototyped for BGVD, to adapt for P-ONE: done, integration upcoming,
- Fast simulation of photons in water & framework implementation in P-ONE: final stage,
- Experience in analysis of experimental data - working on **STRAW & STRAW-b** data:
  - Understand LIDAR,
  - Attempt absorption & scattering measurement.



Examples of our work: laser calibration system

K. Kopański



DPSS laser

beam expander

Iris diaphragm

motorized slider

Axicon 20º

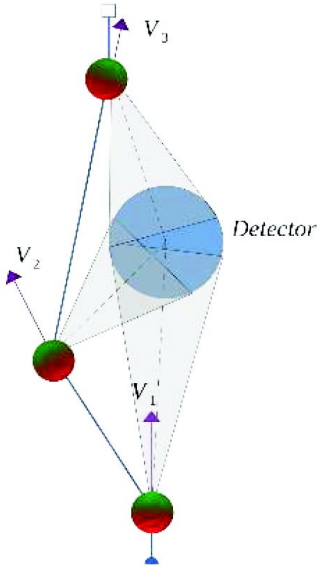
rotor

rotary mirror

static mirror

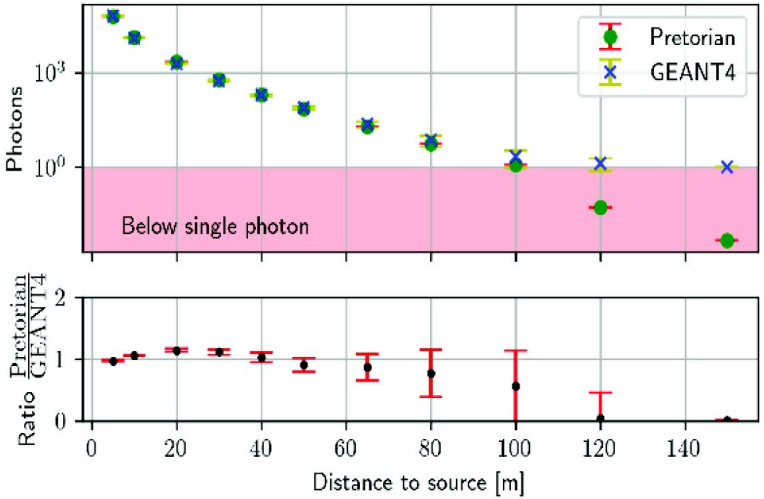
Pretorian & Hybrid Ray Tracing

W. Noga



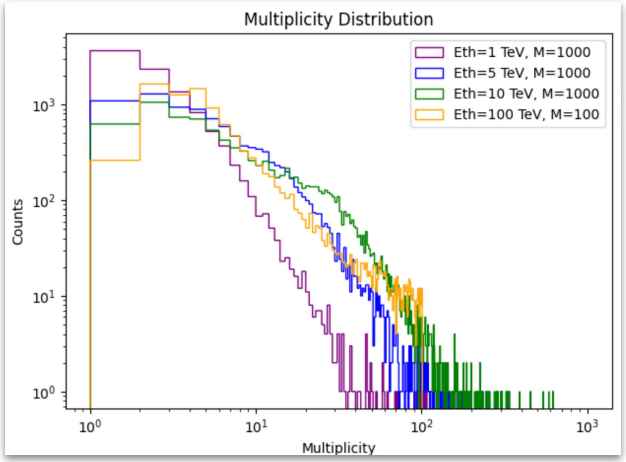
1. Propagate photons by Forward RT and check intersections
2. New light sources at scattering points
3. Calculate number of photons from new light sources

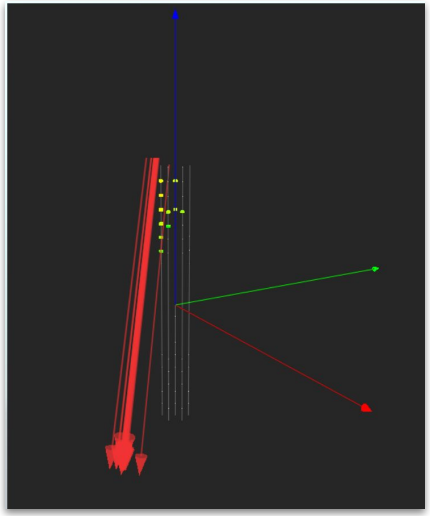
- New light sources are parametrized by scattering function
- To calculate how many photons reached the detector from these sources, use the Backward RT (include propagation effects)



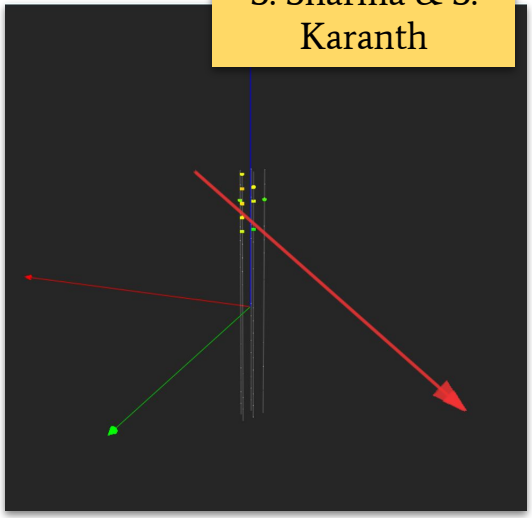
Muon studies for first-data measurements

Simulating muon events with various generators, interfacing with P-ONE software, assessment of measurements feasibility with P-ONE-1 and Demonstrator.





S. Sharma & S. Karanth

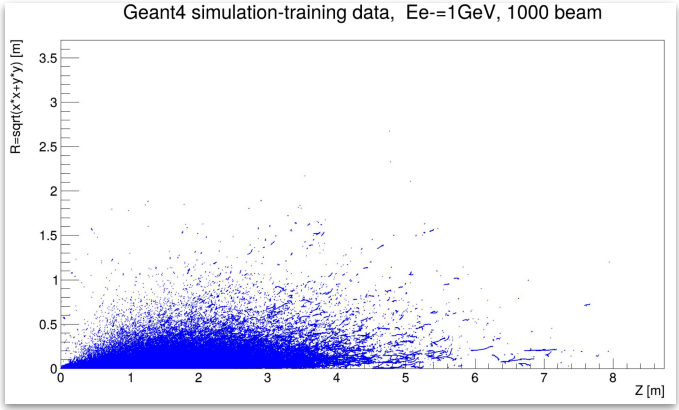


AI-based cascade generator

The *usual* simulations with GEANT4 are very precise but consume a lot of CPU time.

Idea: train a neural network (GAN) on a small sample of G4 data and use it to produce bigger samples.

Time gain: GAN works almost **400 times** faster with GPU vs CPU.



R. Wroński