P-ONE

— The Pacific Ocean Neutrino Explorer —

TRIUMF 5y planning

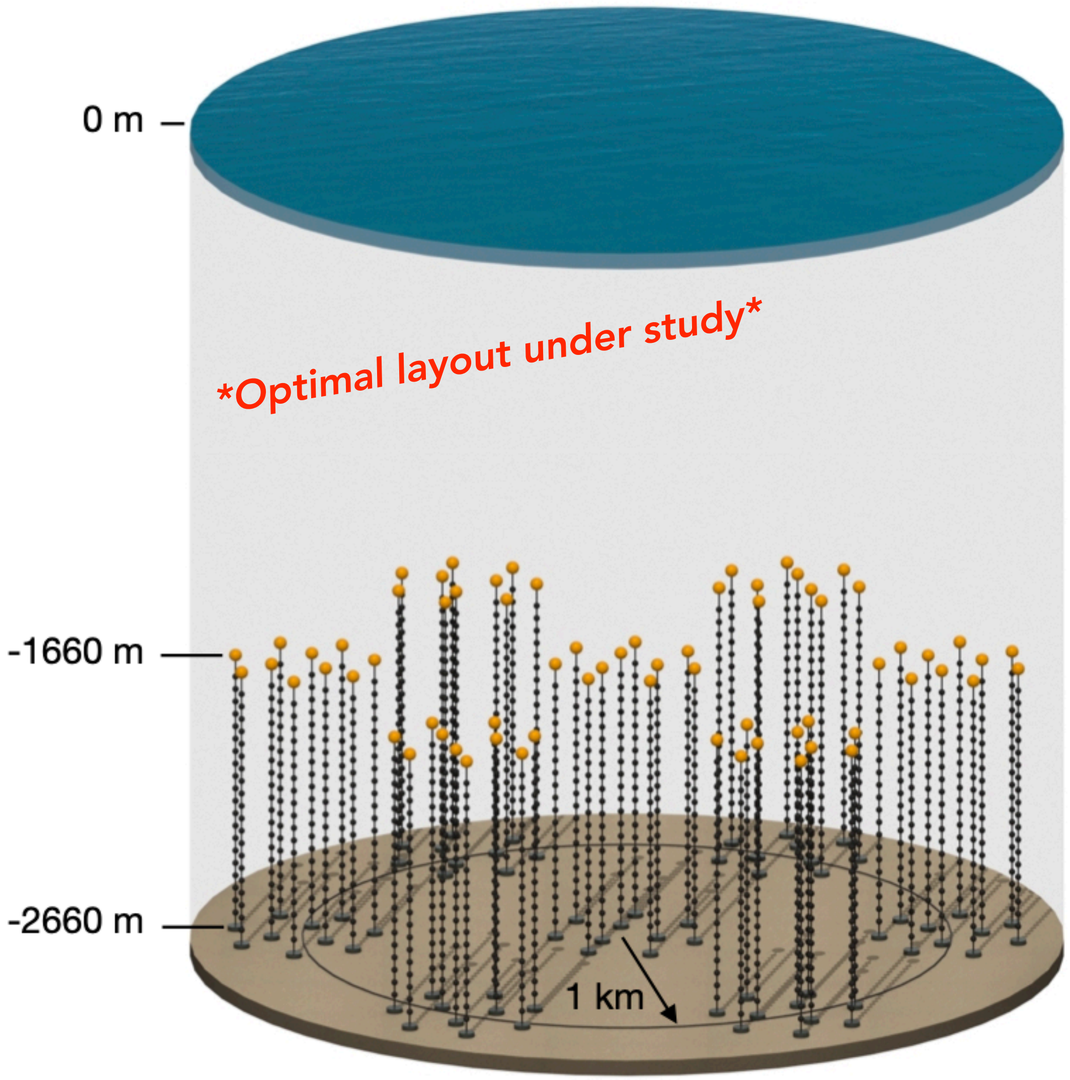
Matthias Danninger

SFU

SIMON FRASER UNIVERSITY

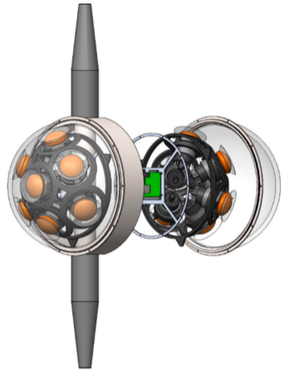
P-ONE — The current vision

P-ONE Collaboration, Nature Astronomy (2020)



Design inspired by existing experiments:

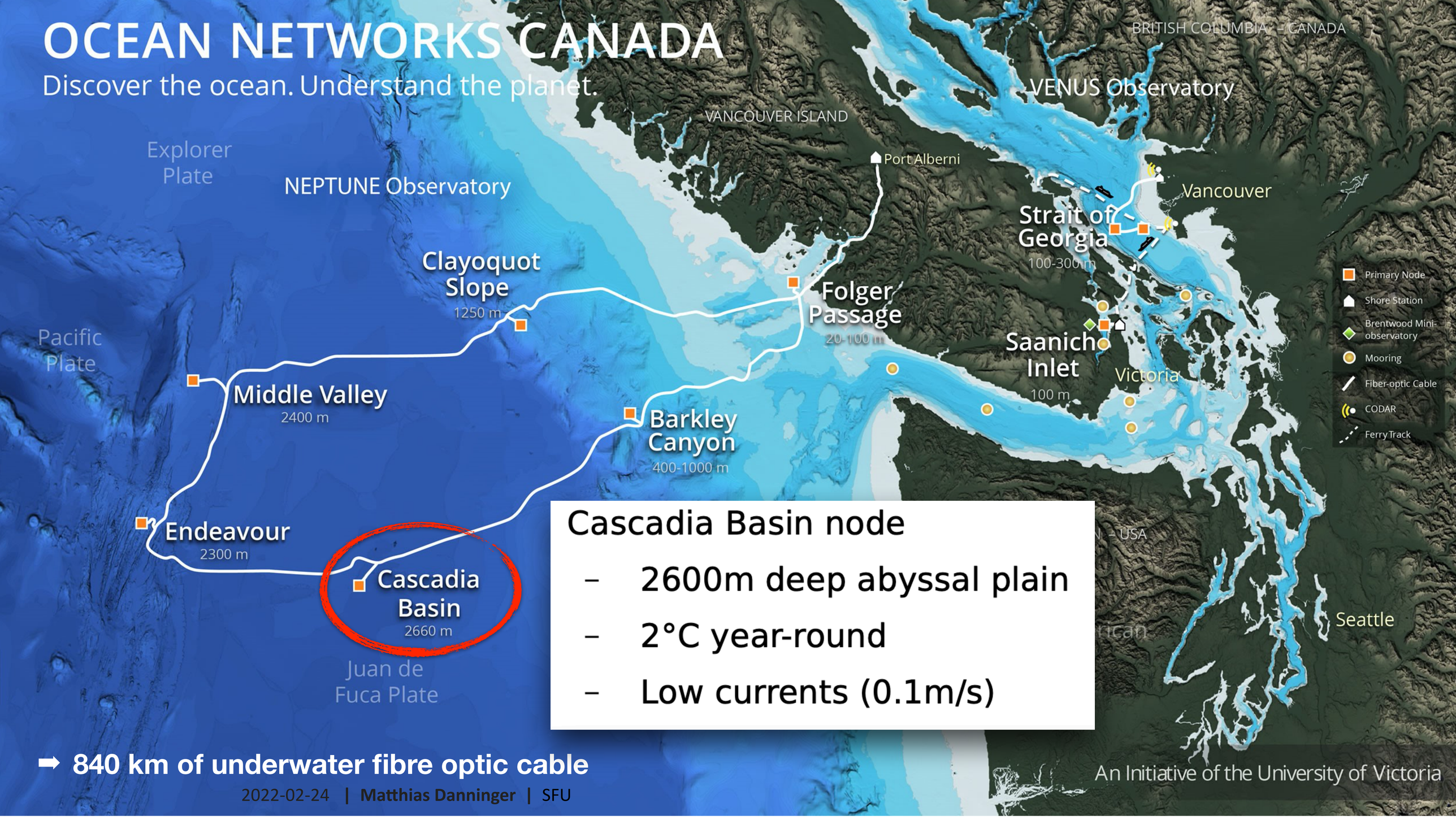
- Array of instrumented vertical lines (IceCube)
- Multi PMT optical sensors (KM3Net)
- Clustered deployment (GVD)



What is different?

First Neutrino Telescope hosted by an existing large scale oceanographic infrastructure:

OCEAN NETWORKS CANADA


OCEAN NETWORKS CANADA
Discover the ocean. Understand the planet.
BRITISH COLUMBIA - CANADA
VENUS Observatory
VANCOUVER ISLAND
Port Alberni
Explorer Plate
NEPTUNE Observatory
Vancouver
Strait of Georgia
100-300 m
Clayoquot Slope
1250 m
Folger Passage
20-100 m
Pacific Plate
Saanich Inlet
100 m
Victoria
Middle Valley
2400 m
Barkley Canyon
400-1000 m
Endeavour
2300 m
Cascadia Basin
2660 m
Juan de Fuca Plate
Seattle
Primary Node
Shore Station
Brentwood Mini-observatory
Mooring
Fiber-optic Cable
CODAR
Ferry Track
Cascadia Basin node
– 2600m deep abyssal plain
– 2°C year-round
– Low currents (0.1m/s)
➡ 840 km of underwater fibre optic cable
2022-02-24 | Matthias Danninger | SFU
An Initiative of the University of Victoria

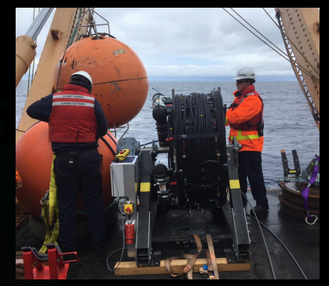
OCEAN NETWORKS CANADA

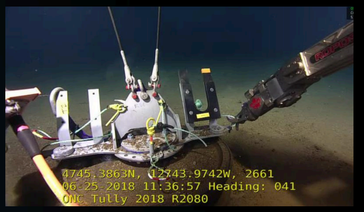
Discover the ocean. Understand the planet.

- One of world's largest and most advanced cabled ocean observatory
- *"A gem in the Canadian research landscape is the infrastructure developed by Ocean Networks"*
- ***NEPTUNE observatory:***
  - completed in 2009
  - 800km loop of fibre optic cable, data flow and power infrastructure
  - designed for long-lived, highly reliable underwater operations
  - high-speed data link (10GB/s)
  - high power (at least 9 kW/node)
  - "plug and play" basis allowing a highly modular deployment and maintenance

➡ **840 km of underwater fibre optic cable**

2 P-ONE pathfinder missions (2018 & 2020)

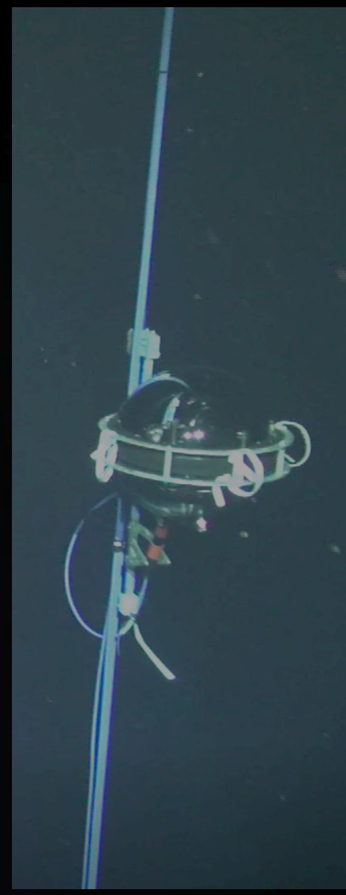




- Interface, anchoring and deployment operation by ONC
  - *JINST 14, P02013 (2019) and EPJC 81, 1071 (2021)*
- Goal — Characterize optical properties
  - Key result 1: Excellent detector lifetime (98%)
  - Key result 2: Optical properties are good (attenuation length)
  - Key result 3: In-situ K40 background is understood
  - Key result 4: Bioluminescence activities as expected and stable

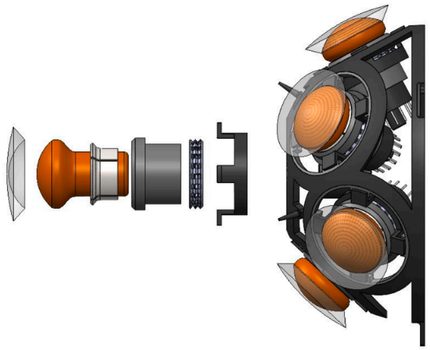
— P-ONE —

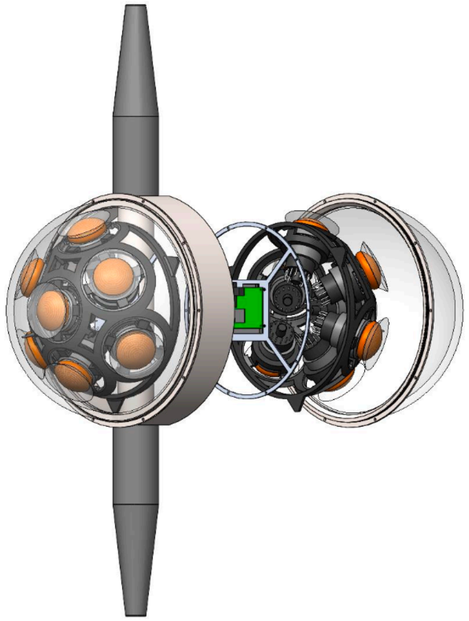
- Next steps towards a neutrino observatory

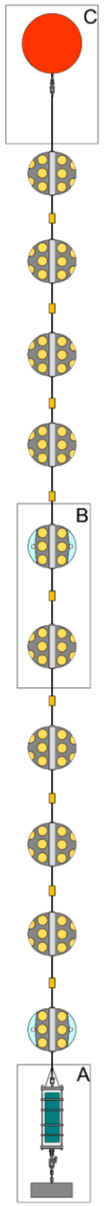


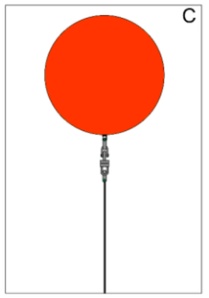
P-ONE — prototype line (2023)

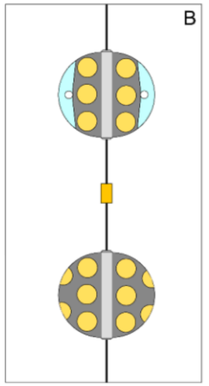
- Construction and deployment of a complete P-ONE mooring line
- Proof and verification of;
  - detector design
  - deployment techniques
  - positioning calibration (we aim to use optical position system)

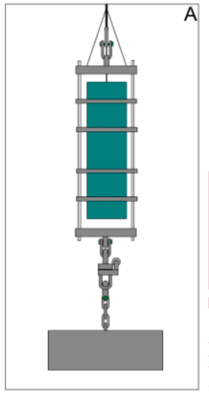












Optical Module | In development | 16 pcs

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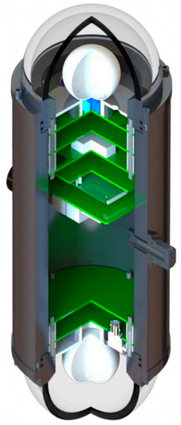
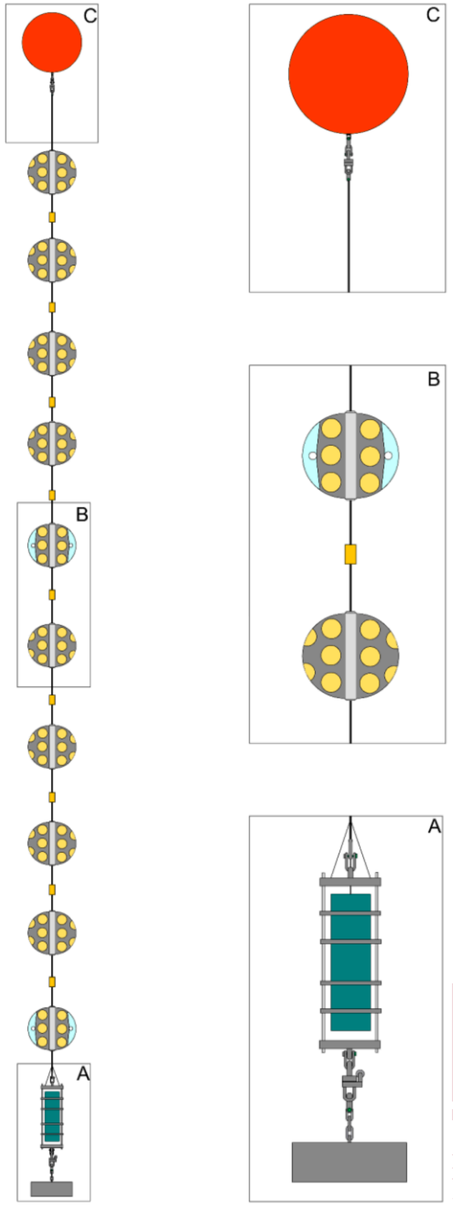


Optical Calibration

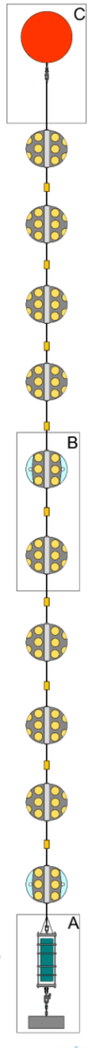
- Understanding ocean water is key to the success
- Synergy with IceCube but also HyperK

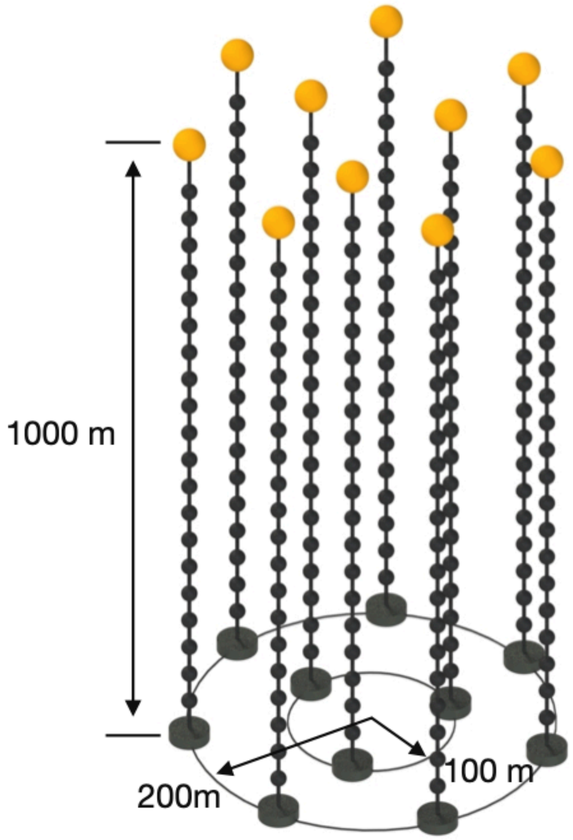


Calibration Module | Adapted POCAM | 4 pcs

P-ONE — up to 10 line “Explorer” (2023 - 2026)

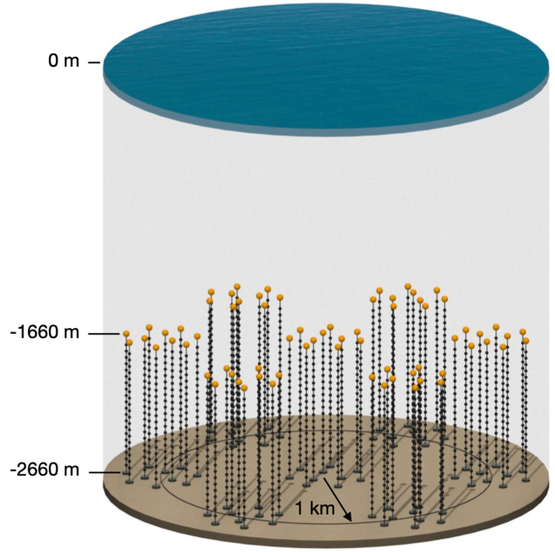
Prototype — 10 string Explorer — Experiment





- up to 10 lines
- 200 modules
- ~100m spacing
- Instrumented Volume ~1/8 km3
- Exploring physics potential for:
  - atm. neutrinos
  - moon shadow
  - ambient background
  - Galactic sources?

2027 and beyond



P-ONE

P-ONE Collaboration, Nature Astron. (2020) e-Print: 2005.09493

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Fast evolving collaboration and funding situation

- Current funding:
  - Prototype + 2 strings (Predominantly Europe + SFU JELF)
    —> Huge European funding success thus far (*recent news*)
- Planned funding rounds for 2022 (completes approx. 10 strings):
  - CFI-IF —> key infrastructure components (main junction box, mini JB, + 2 strings) —> will ***enable*** a 10 string detector!
  - US funding for ~3-4 strings (similar timescale as CFI)
- McDonald Inst. followup CFREF lists P-ONE as one of 4 corner stones:
  - Huge opportunity in terms of funding person power for both TRIUMF & SFU (SFU very likely to join this CFREF)

Fast evolving collaboration and funding situation

- Huge interest from new groups in joining the collaboration:
  - Several US IceCube institutes joining the US proposal
    - Hardware interests as IceCube-gen2 might be “delayed”
    - Physics interests in all sky-coverage, i.e. Galactic sources!!
  - Eastern European groups (Slovakia, Czech Republic, Poland) from GvD-Baikal are in discussions of joining P-ONE
    - Political reasons for this move are of course awful

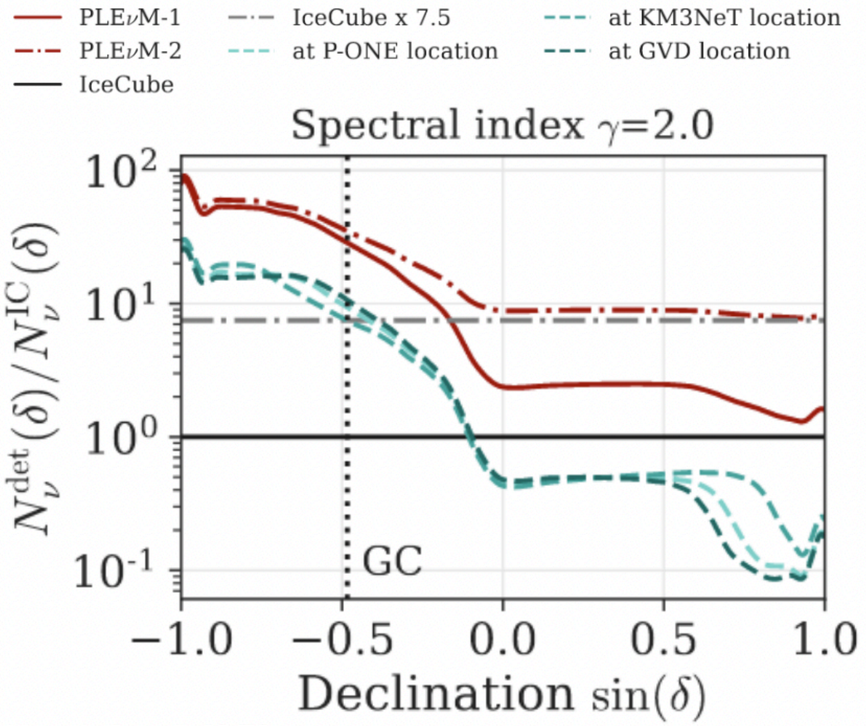
The vision: from a single telescope (IceCube) to a multi network

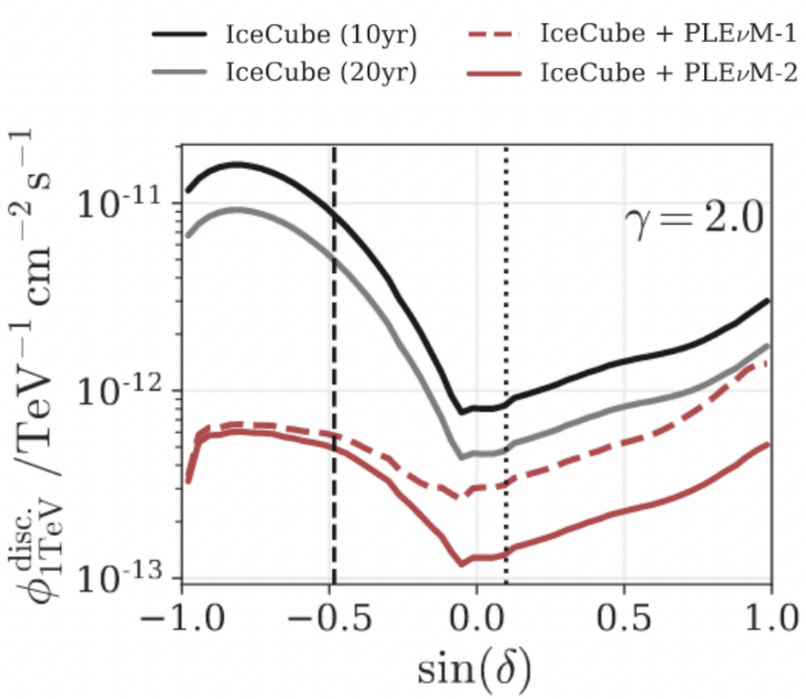
Assumption: IceCube size detector at KM3NeT, GVD, and P-ONE location

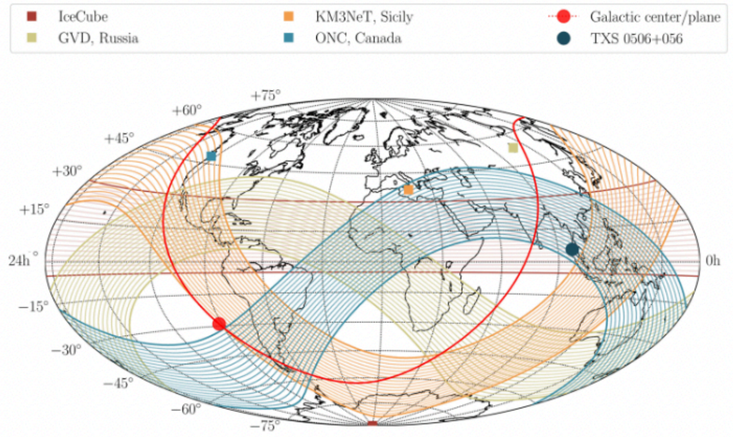
PoS(ICRC2021)1185

Impact:

- P-ONE will boost exposure to the Southern Sky by order of magnitudes
- A global network will achieve excellent full sky coverage for high-E astrophysical neutrinos
- For Galactic sources a 10-string unit could have equivalent sensitivity as IceCube







The Science Case continued

- Astrophysical neutrinos discovered but unstudied
- Multi-messenger astronomy (neutrinos, gamma rays, optical, gravitational waves)
- Neutrino Astronomy! Neutrinos are key to understand Cosmic Ray puzzle and their cosmic and galactic accelerators
- Neutrino physics and particle physics in TeV and PeV range
  - Glashow resonance studies
  - Neutrino all flavour oscillations at high-energies (particle ID possible at P-ONE)
  - Sterile neutrino searches and neutrino properties
- Low energy neutrinos from core collapse Supernovae
- Indirect Dark Matter searches

- Support, interest, funding, and the Science case is growing rapidly in last 2 years
- P-ONE seems on a strong path, but next years will be key!

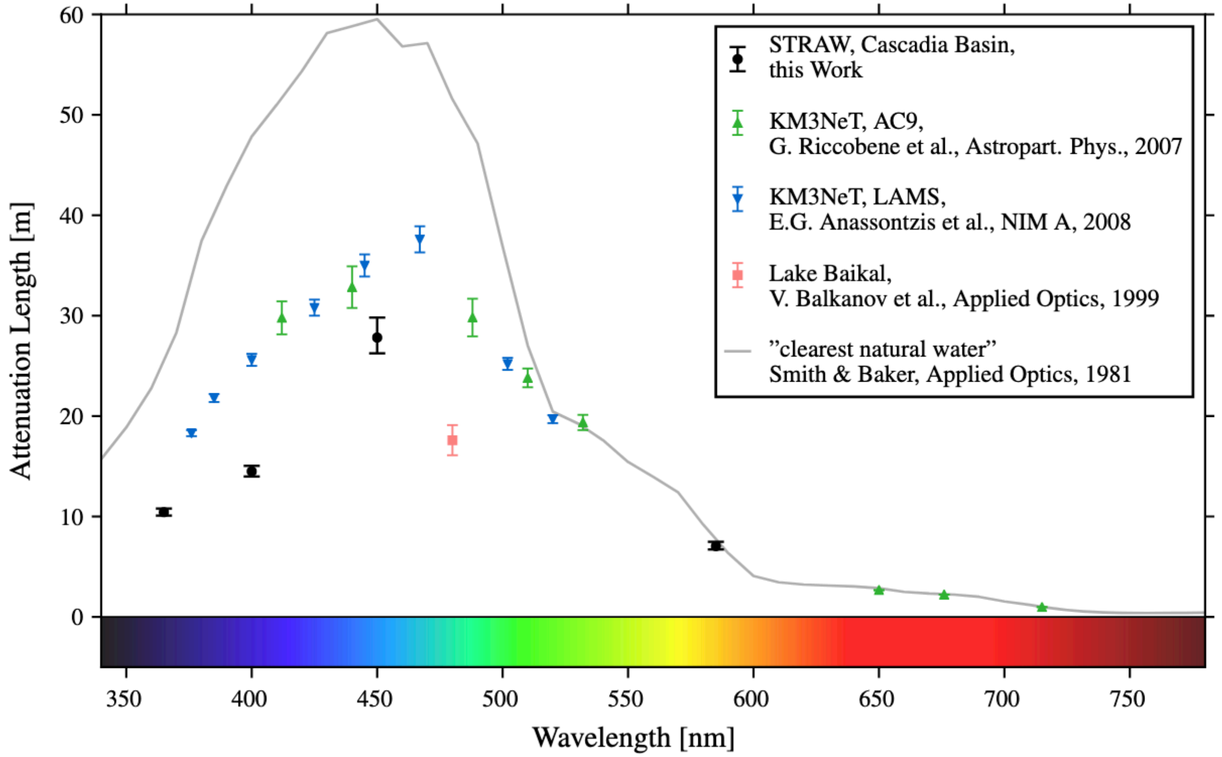
Extras

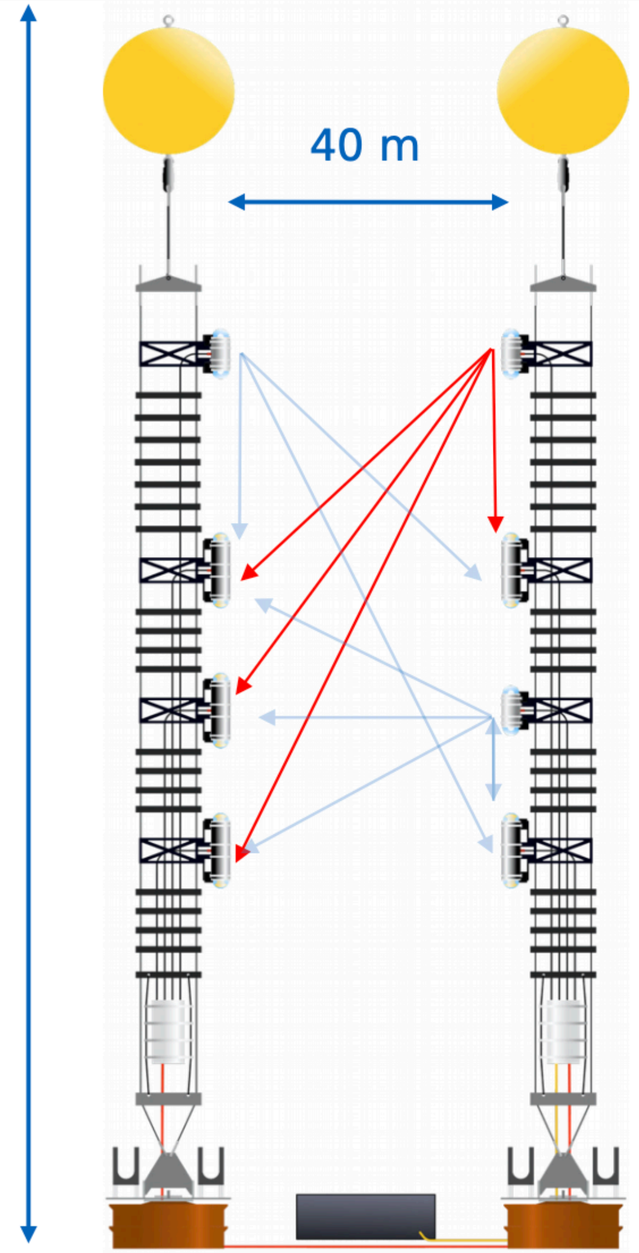
Key result 1: Attenuation length

- Measure Attenuation length in the water
  - For different wavelength
  - Constant over 2 years of measurements
  - **Optical properties are good!**

$$I(r) = \frac{I_0}{r^2} e^{\frac{-r}{\lambda_{att}}}$$

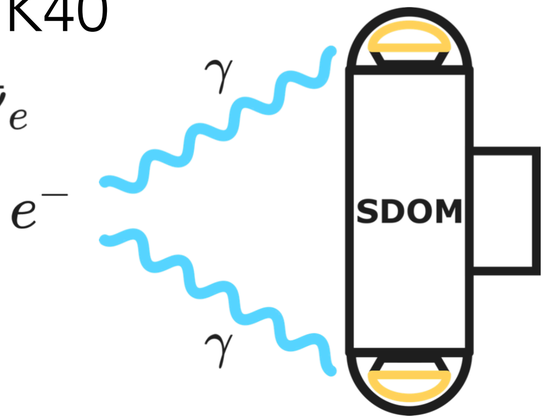
$$\frac{1}{\lambda_{att}} = \frac{1}{\lambda_{sct}} + \frac{1}{\lambda_{abs}}$$

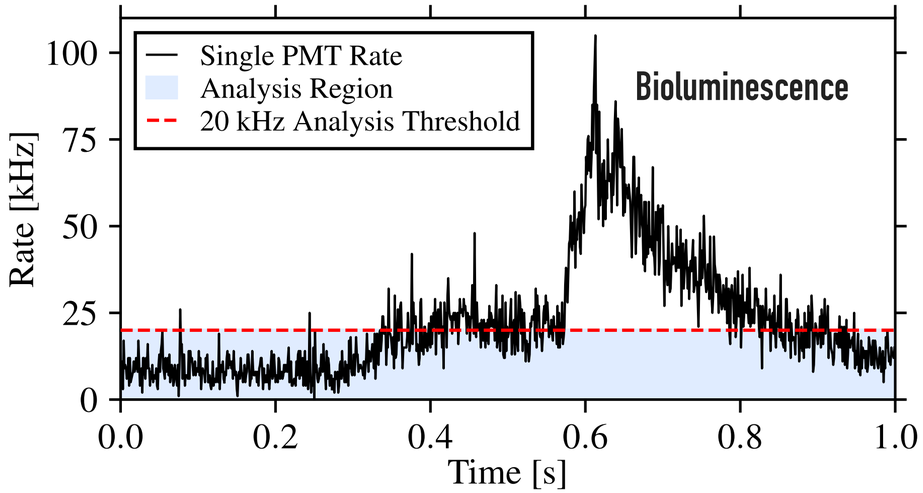




Key result 2: ^{40}K in situ measurement

- Understanding the 40K background
  - Natural in-situ calibration with K40 possible $^{40}\mathrm{K} \rightarrow ^{40}\mathrm{Ca} + e^- + \bar{\nu}_e$
  - Cross-check of λ_{att} results, detector and site model





SDOM PMT housing Geant4 model

Key result 2: ^{40}K in situ measurement

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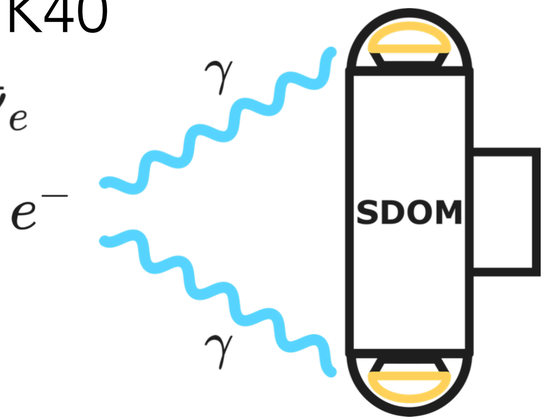
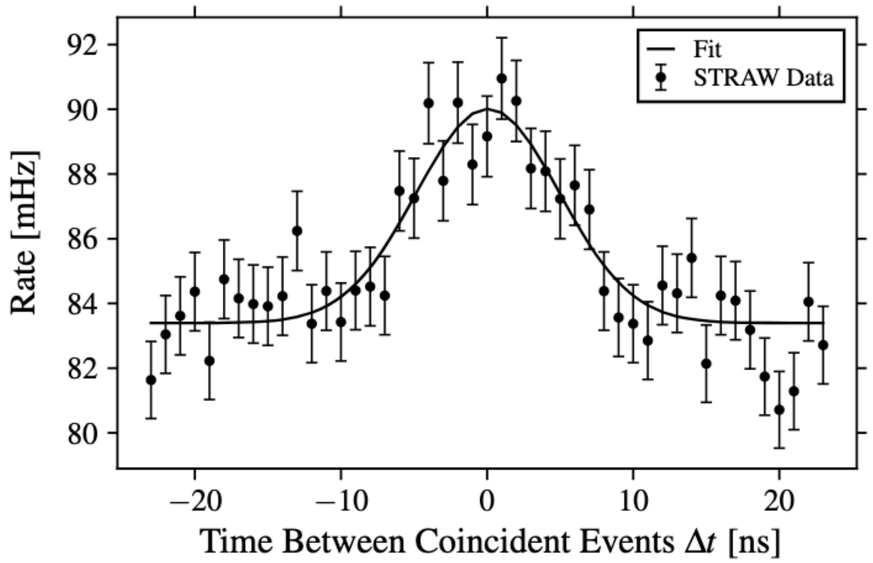
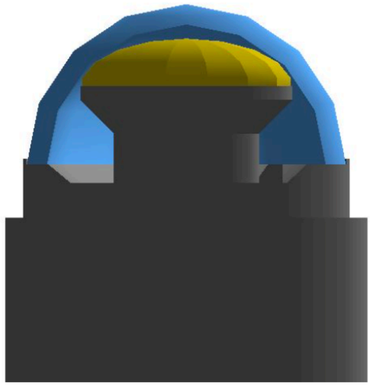
  - Natural in-situ calibration with K40 possible $^{40}\mathrm{K} \rightarrow ^{40}\mathrm{Ca} + e^- + \bar{\nu}_e$
  - Cross-check of λ_{att} results, detector and site model
- **Consistent results!**





Salinity from this work: 2.5±1.4%
Salinity from ONC: 3.482±0.001%
Salinity at ANTARES site: 3.844%



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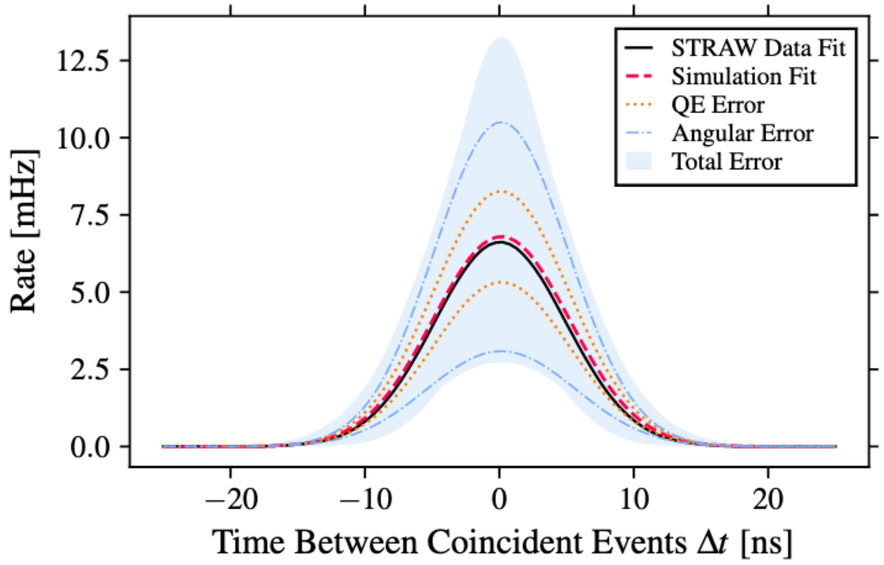
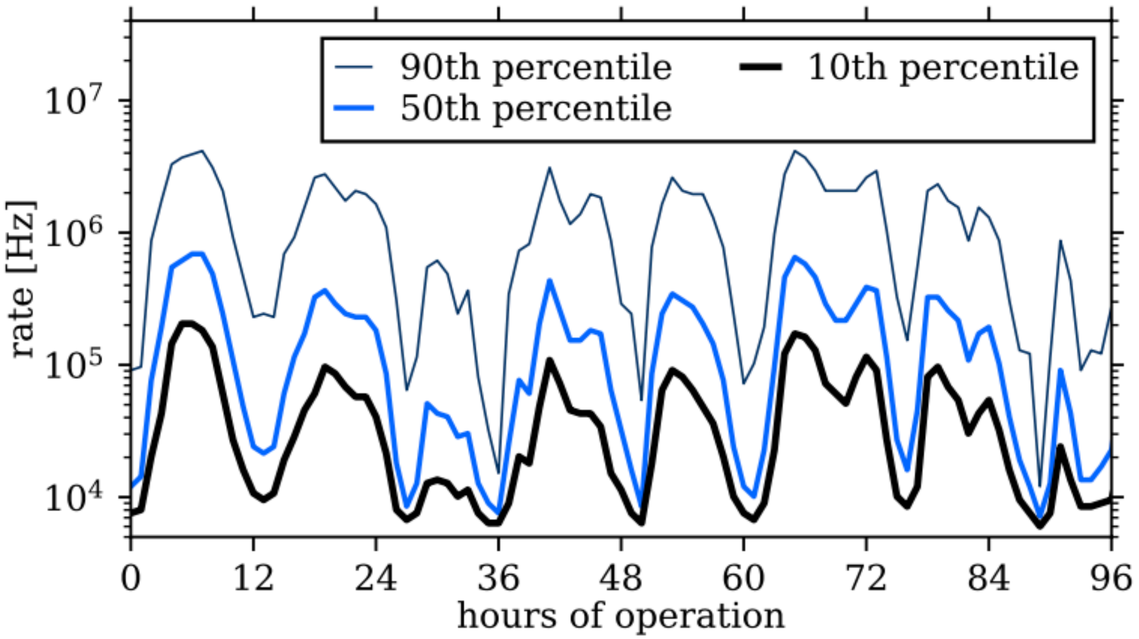
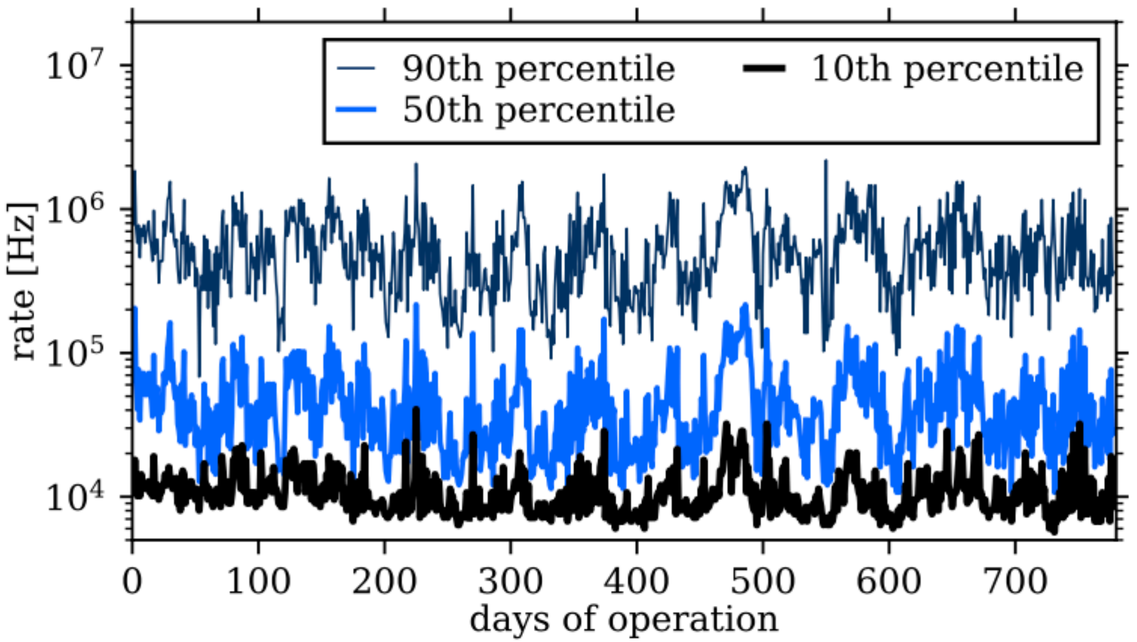


Key result 3: Bioluminescence as expected



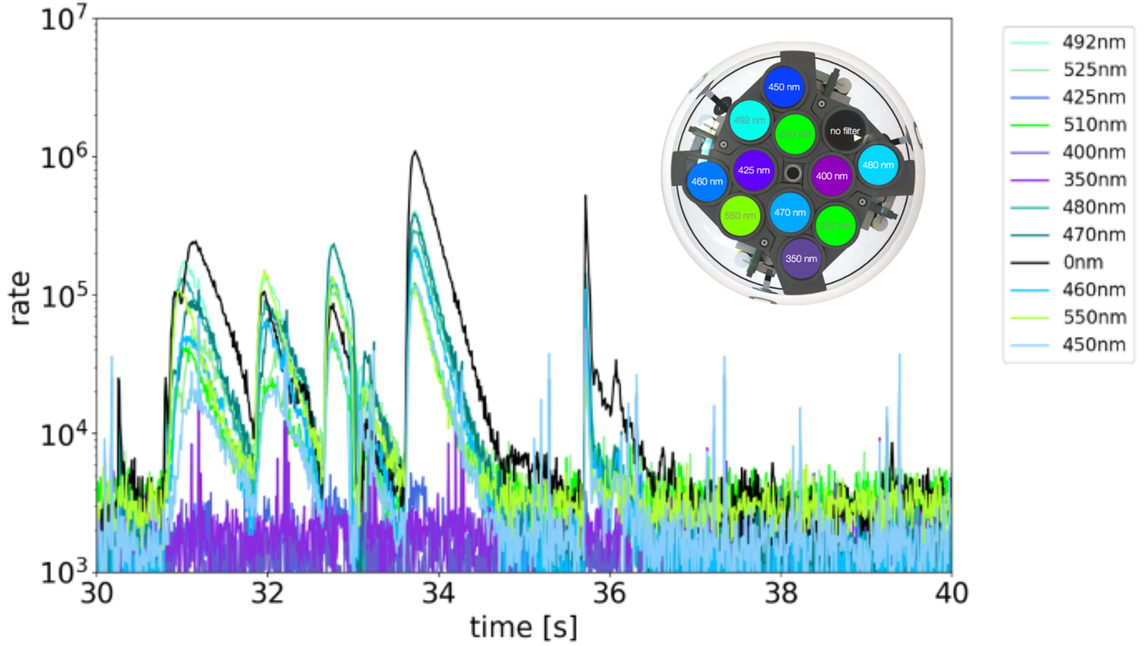


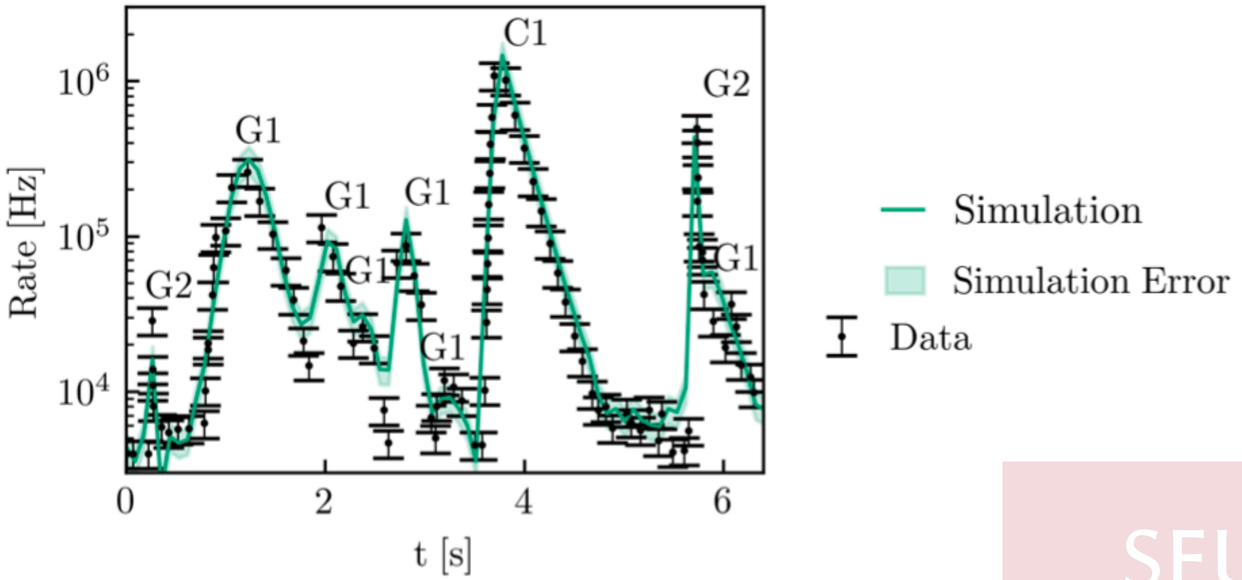
- Bioluminescence is modulated with the tides
- Constant over more than 2 years of operations —> no big bursts

The deep sea site of Cascadia basin is optically qualified to host P-ONE

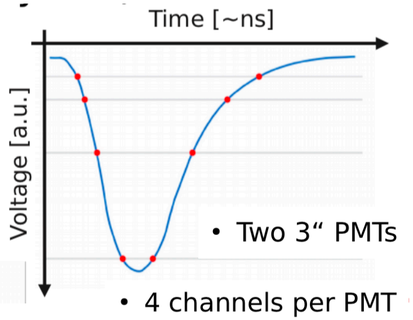
Better characterization of Bioluminescence

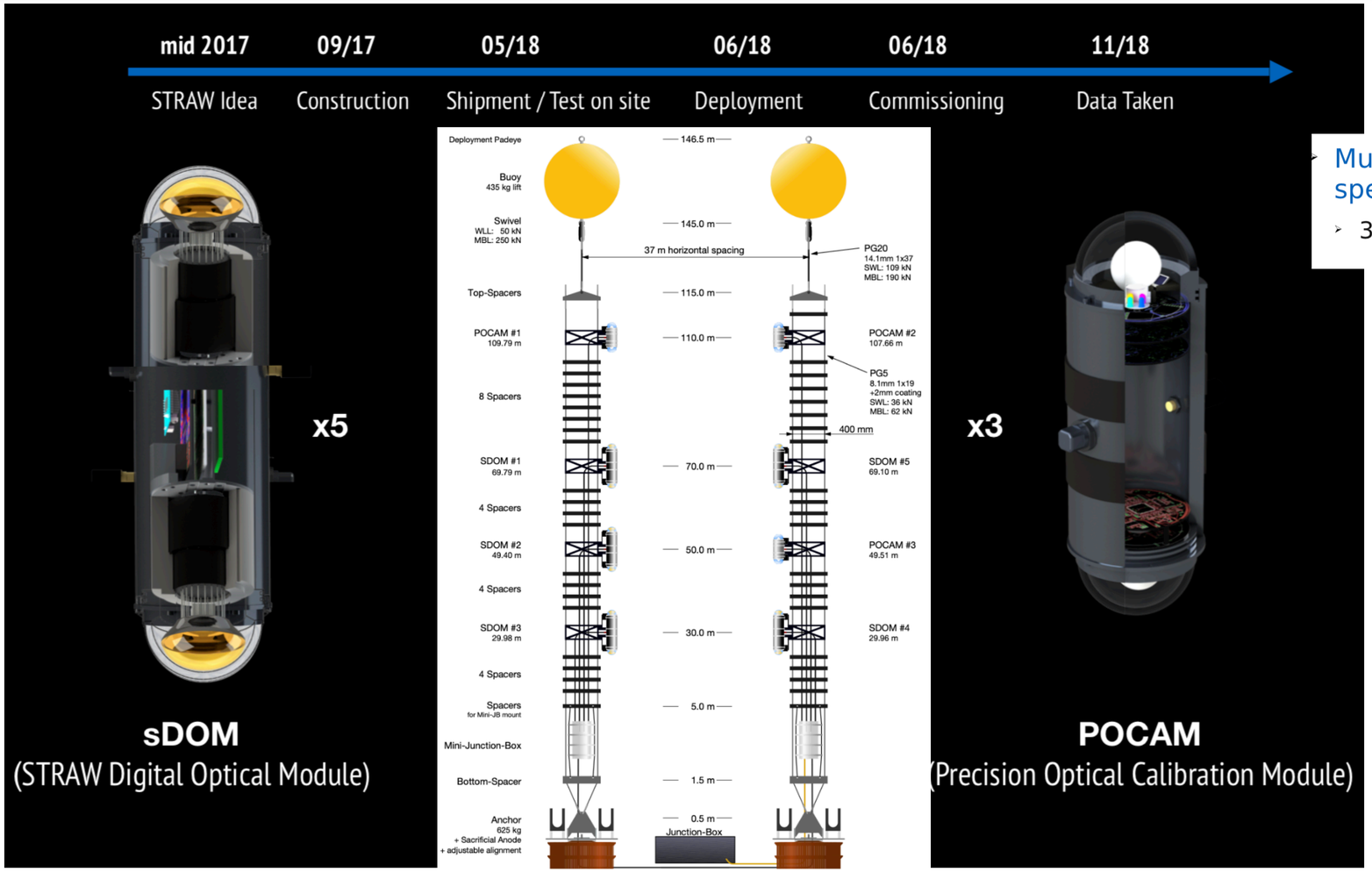
Picture of a bioluminescent animal (1 min exposure)





STRAW — Strings for absorption length in water





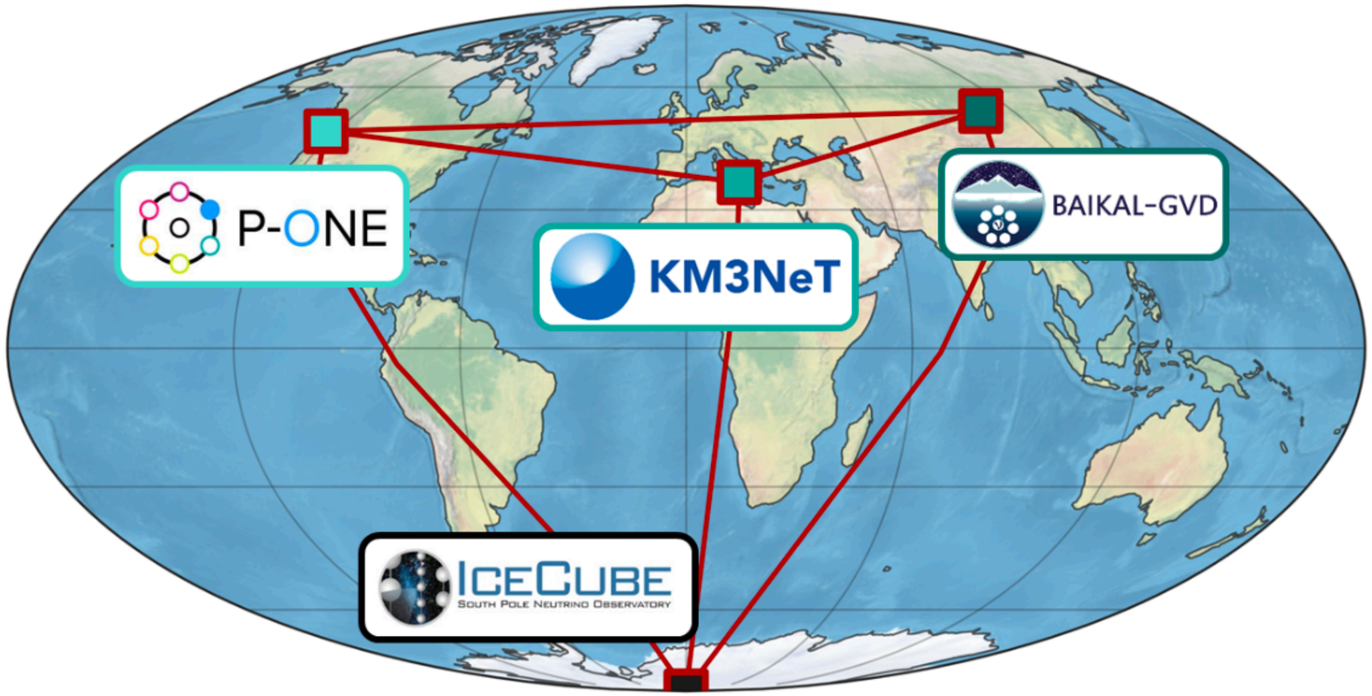
- Multi-wavelength emission for spectral studies
  - 365, 405, 465, 525, 605nm

Deployment was a 100% success!

- M. Boehmer et al JINST 14 P02013 (2019)
- Site characteristics EPJ C 81, 1071 (2021)

Why another neutrino telescope?

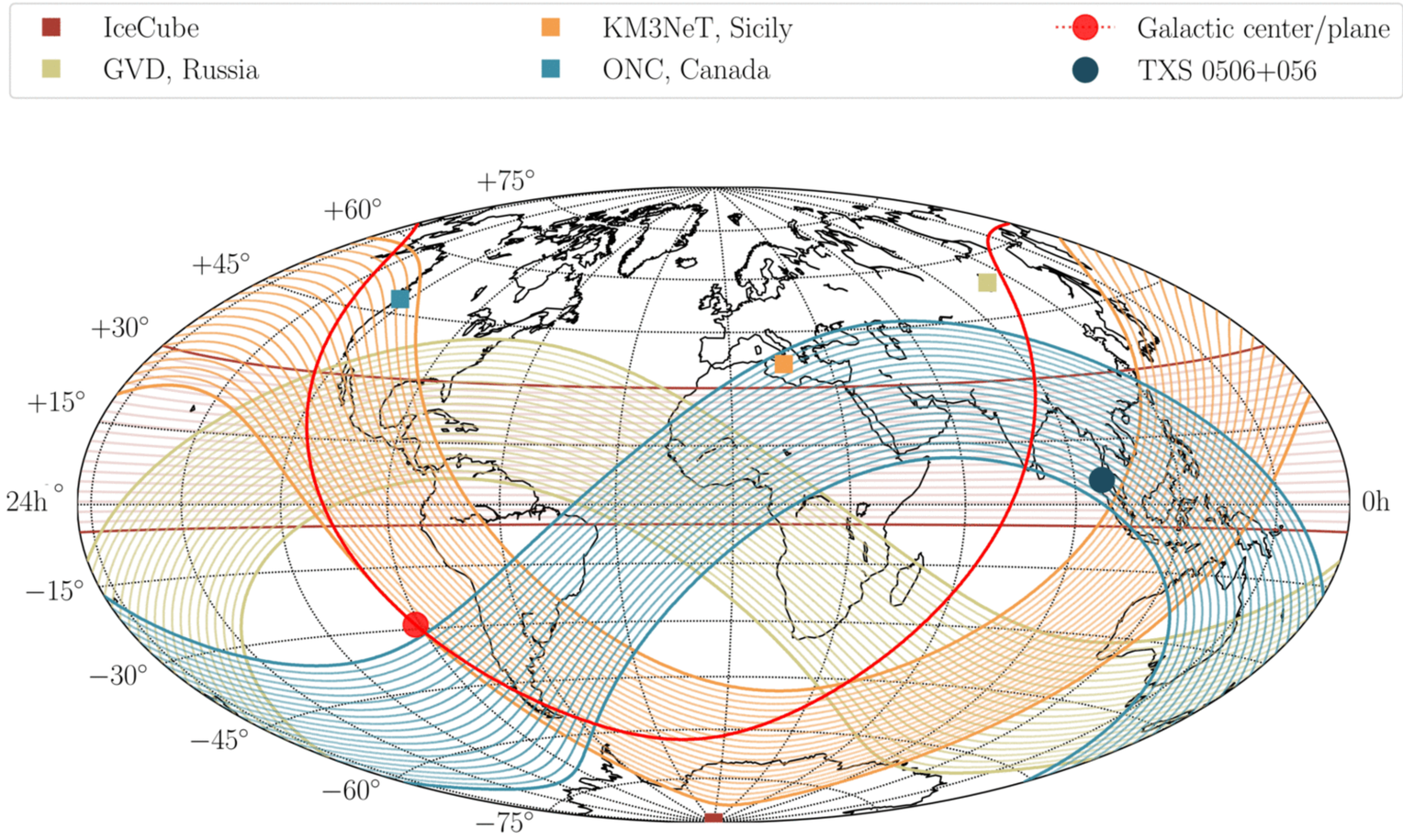
- More neutrinos, better neutrinos!



- P-ONE project has large emphasis on collaboration and complementarity with existing efforts such as IceCube, GvD (Baikal), and KM3NeT —> we welcome collaboration/participation
- We aim for combined cross-calibration efforts to boost precision of all measurements at all neutrino telescope sites worldwide (POCAM, LiDAR, etc..)

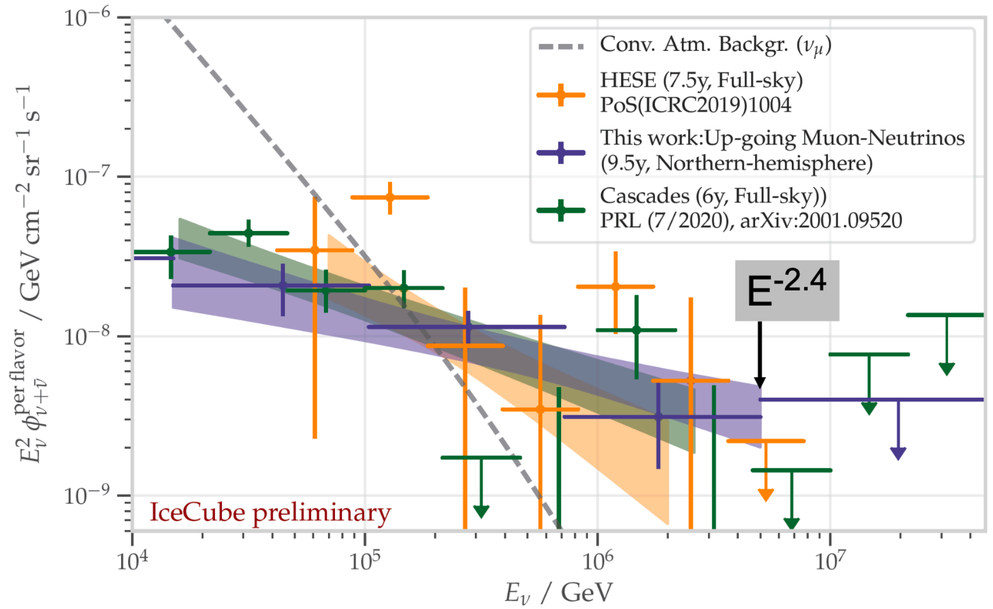
Why another neutrino telescope?

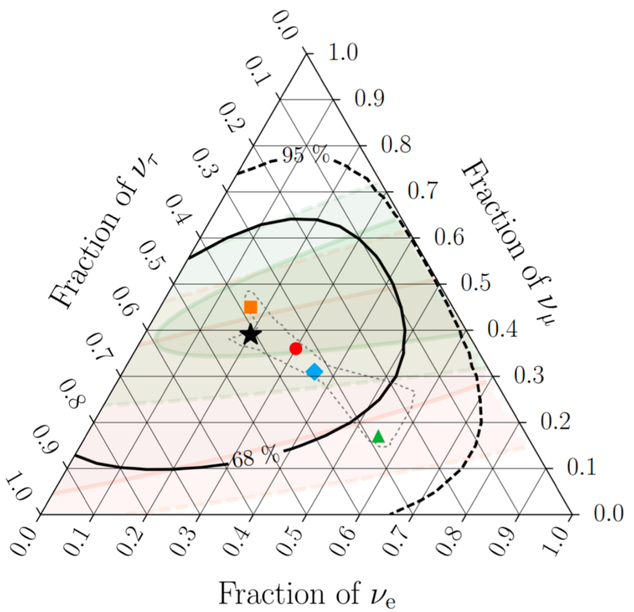
- Horizontal coverage from which HE ν will not be affected by the Earth absorption
- With IceCube +3 neutrino telescopes (similar size), current sensitivity to astrophysical neutrinos would be improved by up two orders of magnitude (gain depends on energy)!

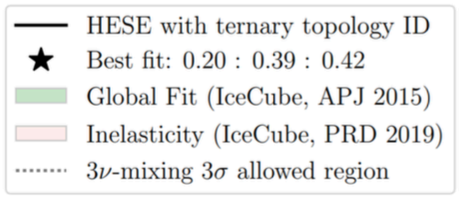


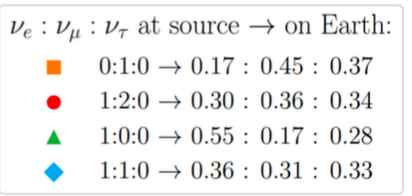
Neutrinos from the Universe

- Since 2013 — Astrophysical neutrinos discovered
- 2018 — Evidence for First source: Neutrino events in a direction of a flaring blazar, TXS 0506+056
- 2019 — Very likely the first Glashow resonance observed
- Neutrino oscillation measurements at PeV scale!
- ….and so much more yet to be discovered









https://arxiv.org/pdf/2011.03561.pdf

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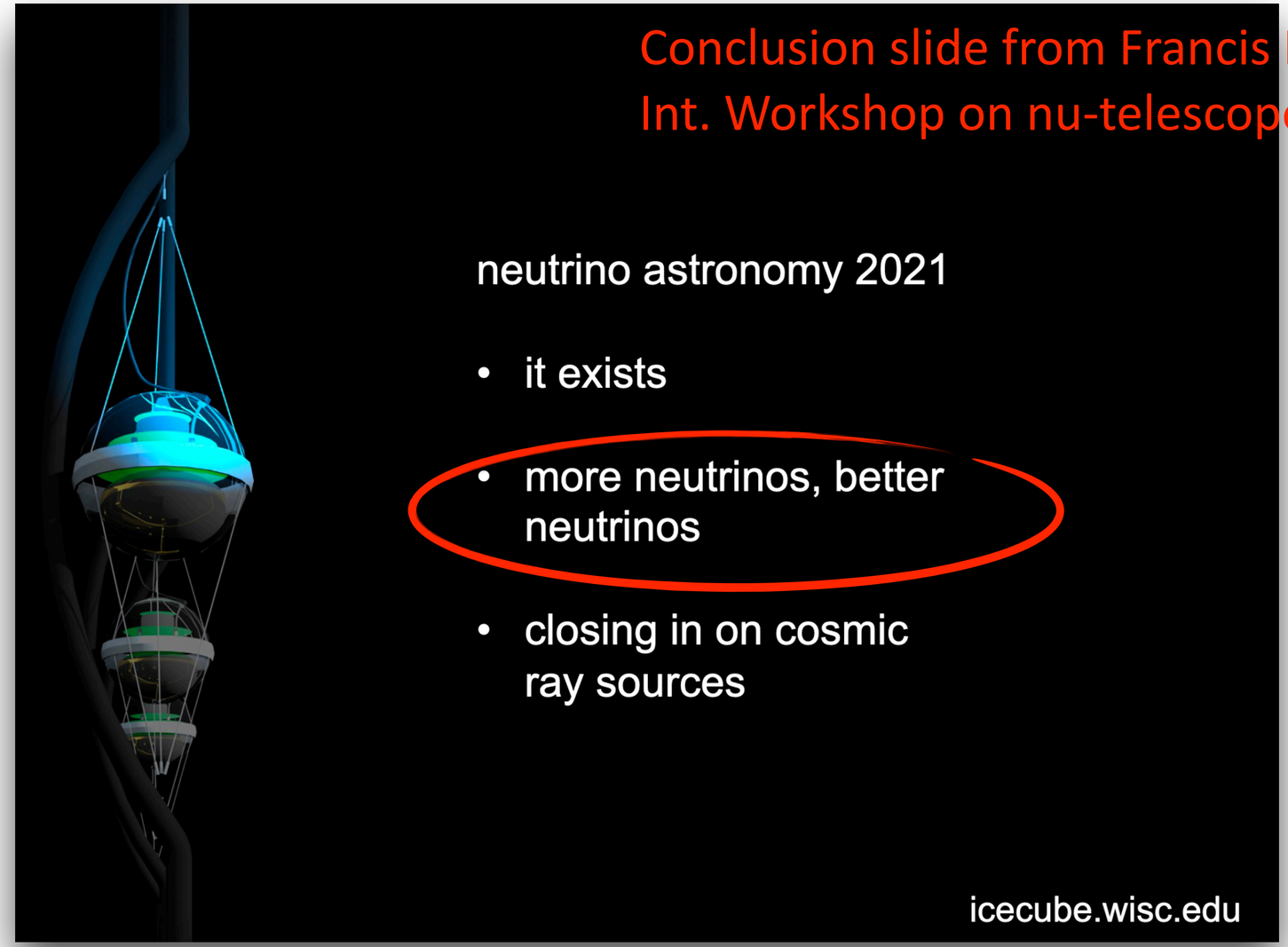
Why another neutrino telescope?

Conclusion slide from Francis Halzen's talk at Int. Workshop on nu-telescopes (Feb 2021)!



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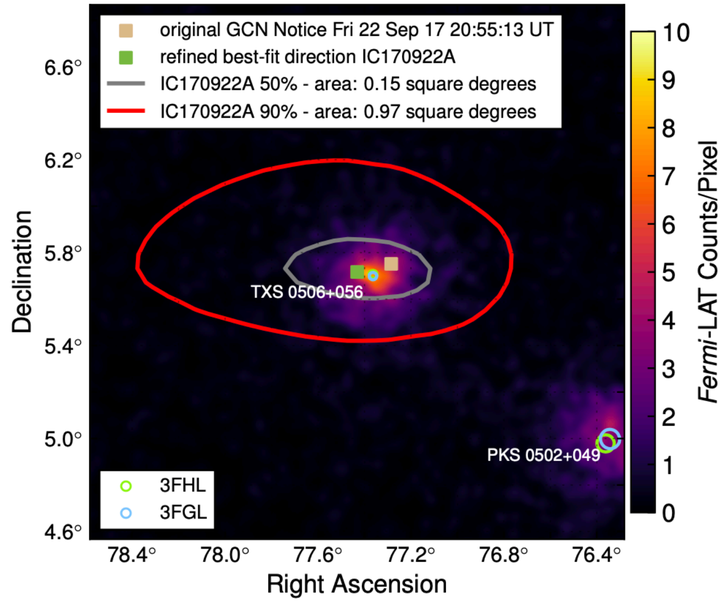

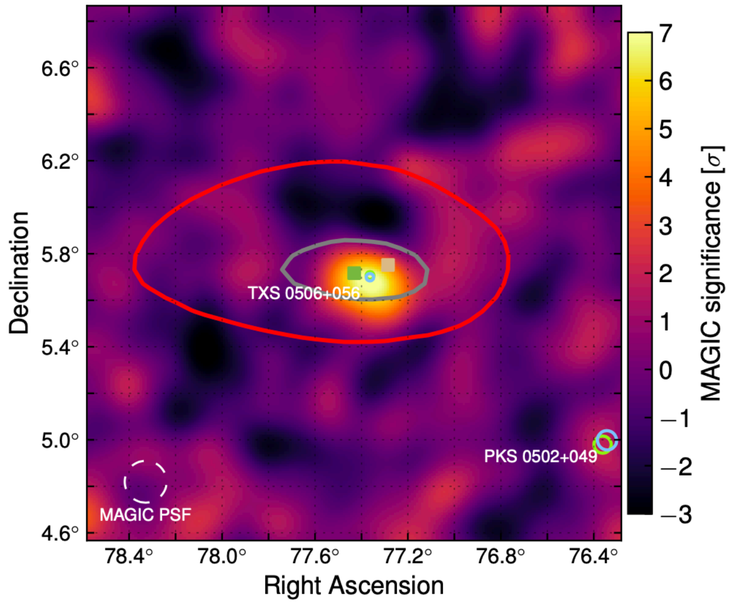

Neutrinos from the Universe

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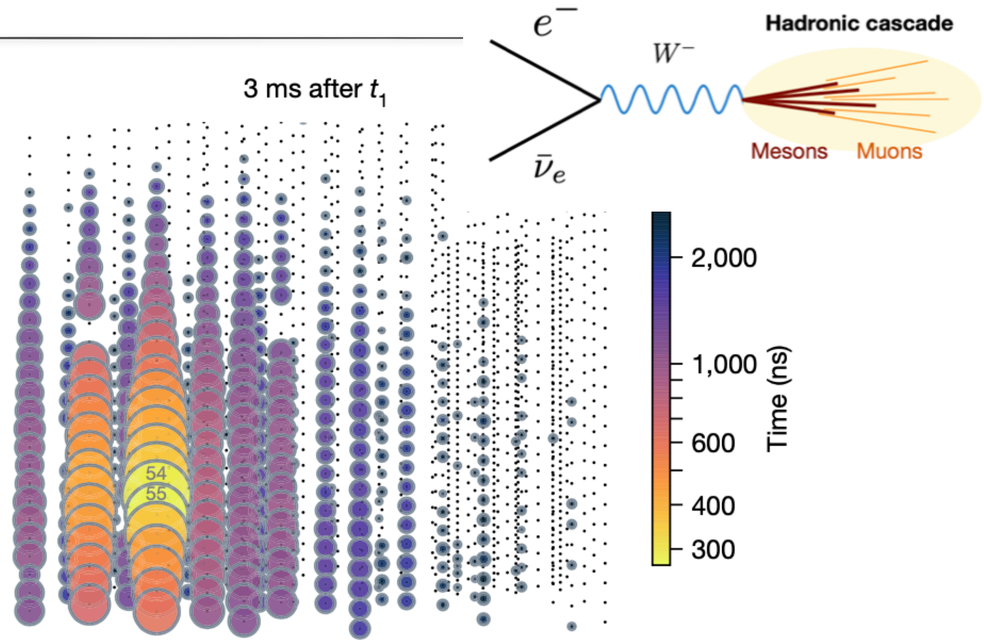
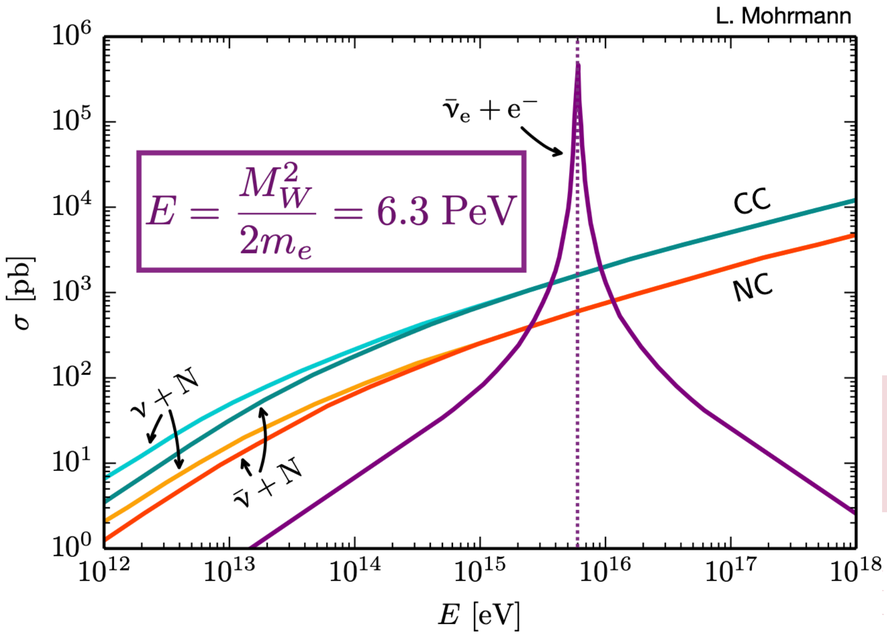
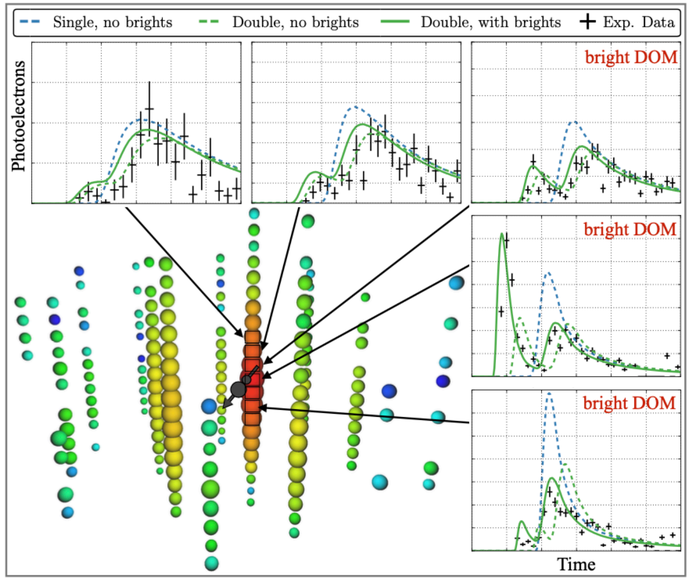
- 2018 — Evidence for First source: Neutrino events in a direction of a flaring blazar, TXS 0506+056
- 2019/20 — Very likely the first event at the Glashow resonance observed

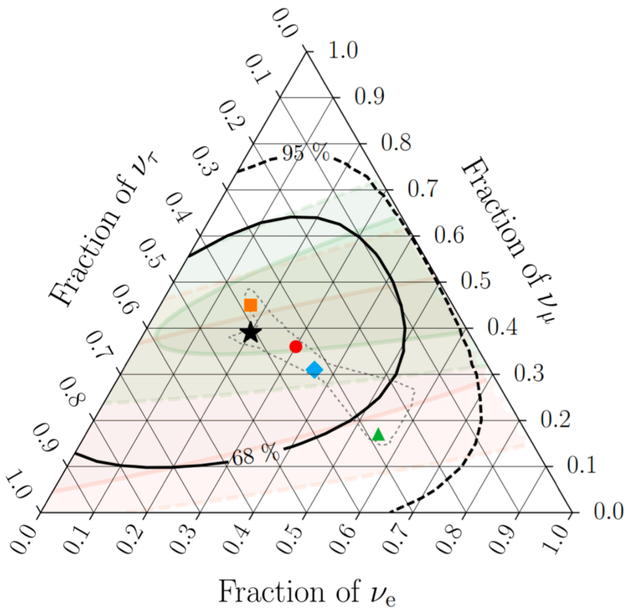


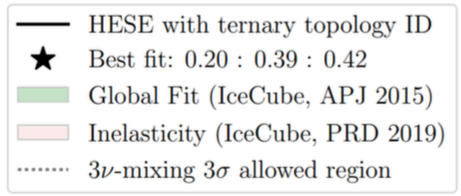


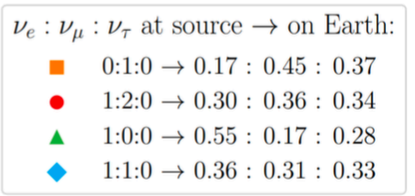
Neutrinos from the Universe

- Since 2013 — Astrophysical neutrinos discovered
- 2018 — Evidence for First source: Neutrino events in a direction of a flaring blazar, TXS 0506+056
- 2019/20 — Very likely the first event at the Glashow resonance observed
- 2020 — Neutrino oscillation measurements at PeV scale!
- ….and so much more yet to be discovered









https://arxiv.org/pdf/2011.03561.pdf

P-ONE

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Why another neutrino telescope?

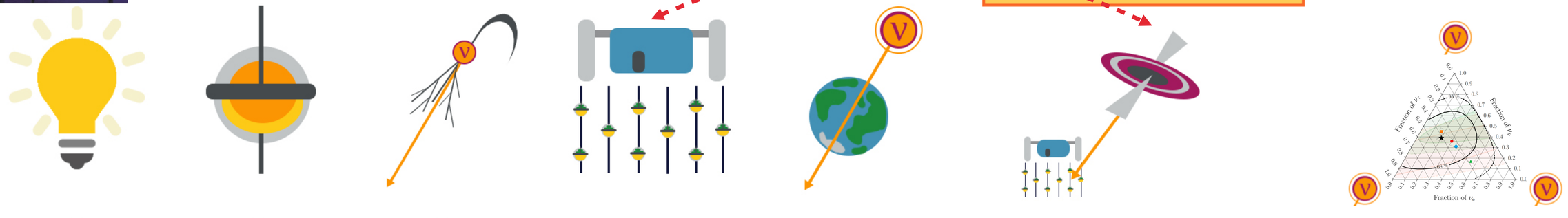

image adapted from Elisa R.

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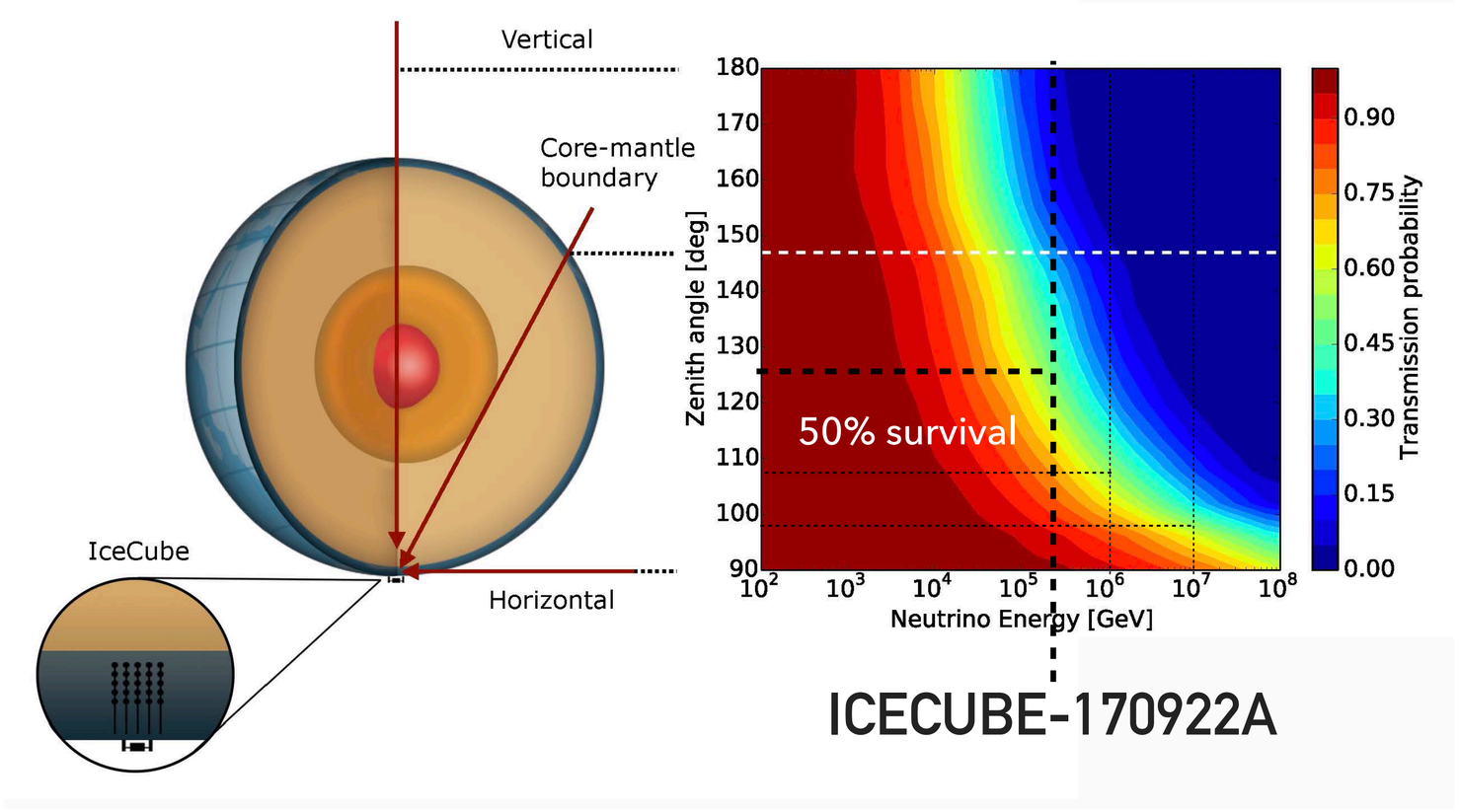
Why another neutrino telescope?

AT HIGH ENERGY THE EARTH IS OPAQUE TO NEUTRINOS

➡️ THE FIELD OF VIEW OF NTs (>50TEV): THE HORIZON



IceCube Collaboration, "Measurement of the multi-TeV neutrino cross section with IceCube using Earth absorption

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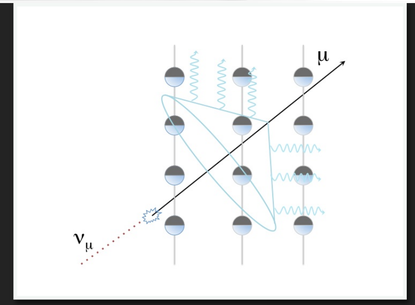
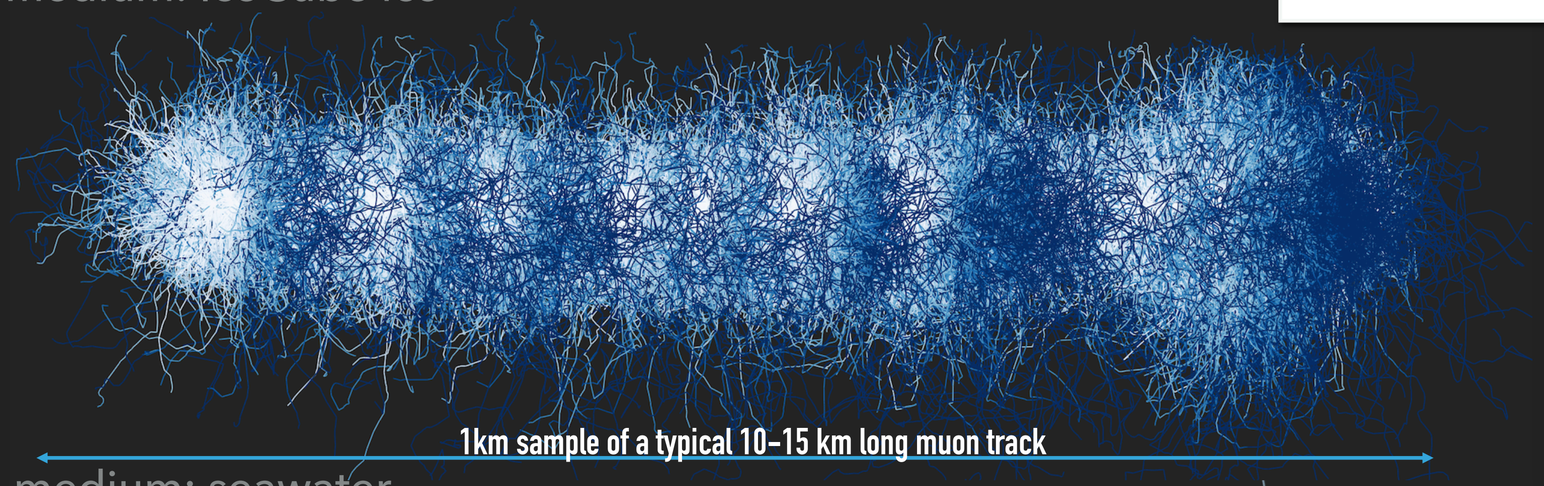
Photons in ice and water

HORIZONTAL HIGH ENERGY MUONS: THE SIGNATURE

1 PeV horizontal muon

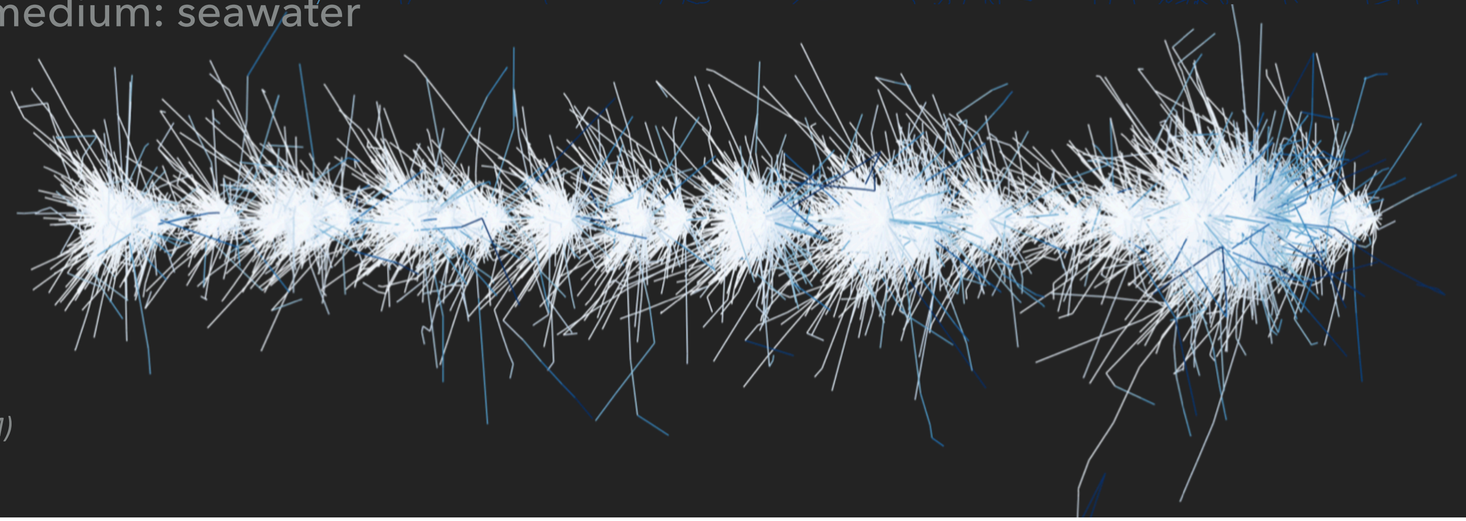


medium: IceCube ice



1km sample of a typical 10–15 km long muon track

medium: seawater



K. Krings (TUM)

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