The P-ONE Optical Module

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Overview

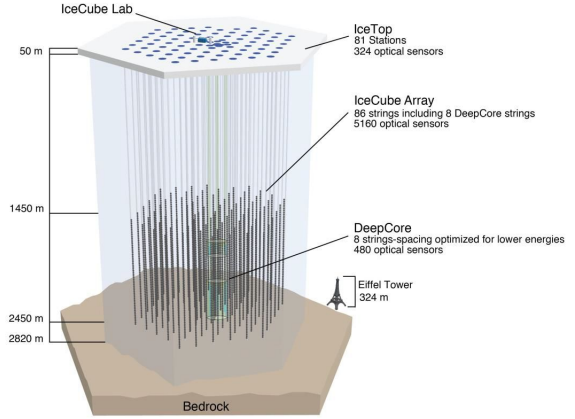
- Neutrino astrophysics and its challenges
- P-ONE
- Module components
- Module design
- Timeline
- Summary

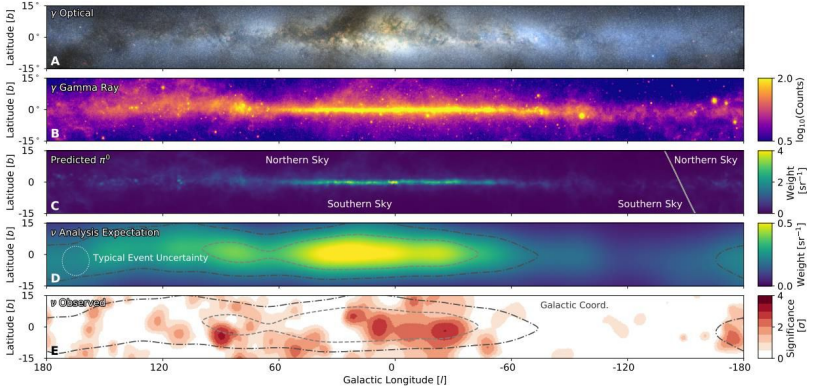
Neutrino Astrophysics and Detection

- Neutrinos produced in astrophysical processes
  - Nuclear reactions in stars
  - Supernovae
  - Blazars
- Neutrinos are neutrally charged
  - Path from origin to Earth is a straight line
  - Cannot be directly detected
- Indirectly detectable through Cherenkov radiation from neutrino conversion into charged leptons (e, μ, τ)

Neutrino Astrophysics Challenges

- IceCube: Current state of the art astrophysical neutrino detector located at South Pole
- IceCube has detected many high energy neutrino events, but unable to assign vast majority to specific sources
- To identify more point sources of neutrinos, better angular resolution is required
  - IceCube's angular resolution is ~0.4 degrees for muon neutrinos





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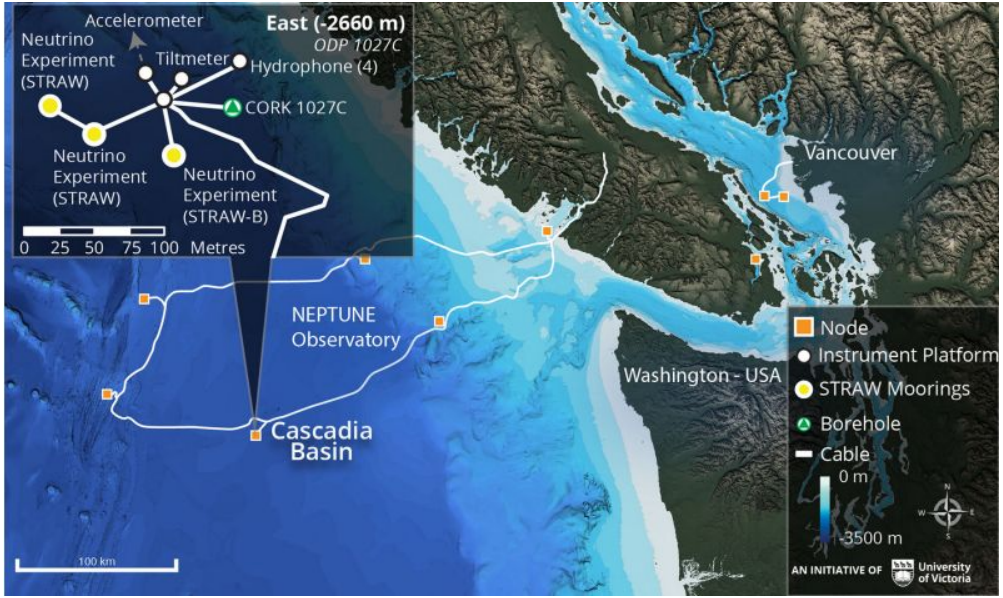
IceCube Collaboration

P-ONE

- Pacific Ocean Neutrino Experiment
- Cubic-kilometer neutrino observatory
- Will be located off the coast of Vancouver, CA in Cascadia Basin
- Partnering with Ocean Networks Canada, which operates the NEPTUNE observatory
- Goal: detect high energy neutrinos from astrophysical sources



ONC

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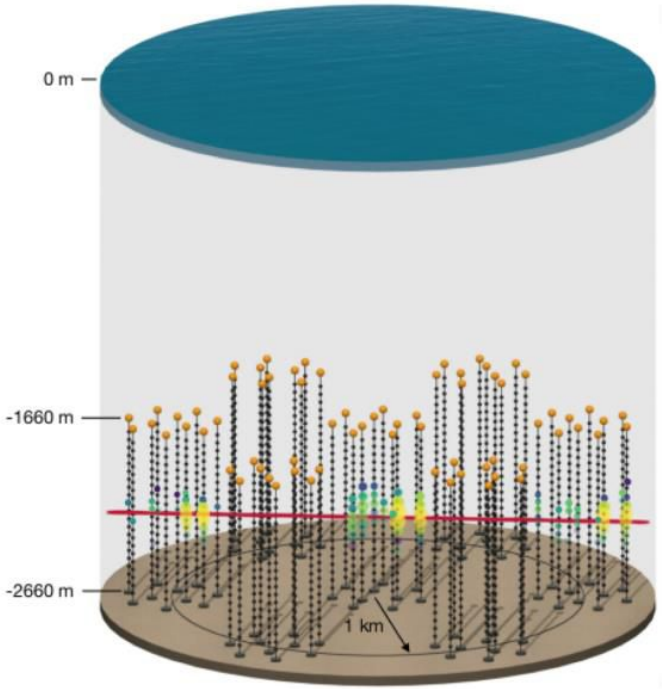
Principle of Operation

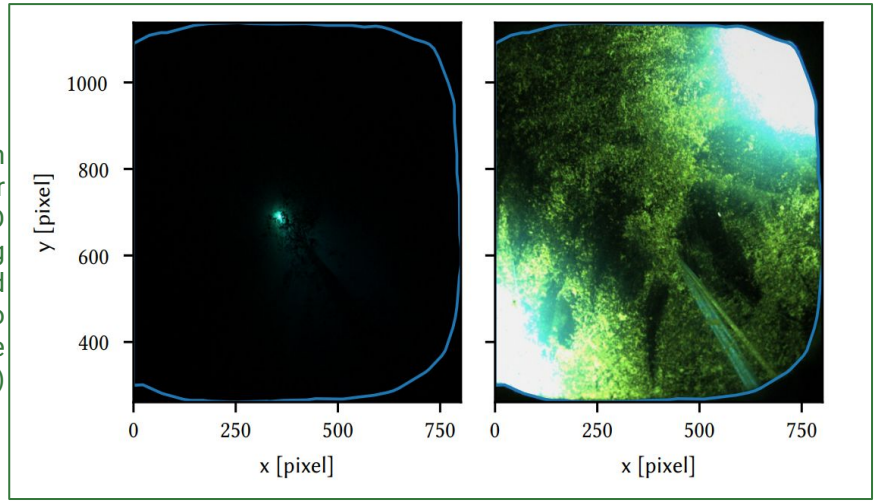
- Neutrinos enter detector, interact to create charged leptons
- Lepton interacts with water, produces Cherenkov light
- Light detected by PMTs as particle moves through water
- Path of travel can be reconstructed by determining which PMTs on which modules were hit at what time



The P-ONE Collaboration

Key Detector Features

Images from P-ONE pathfinder (STRAW). LED from neighboring module (left) and LED next to camera on same module (right)



K. Holzapfel

- Water as a medium- provides low scattering for Cherenkov light, resulting in improved angular resolution than ice
- 16 PMTs/module- higher angular resolution due to better directional accuracy per module
- Modules will be on flexible 1 km cables- will require positional calibration with moving ocean currents

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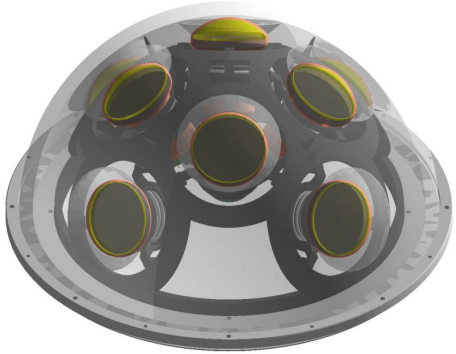
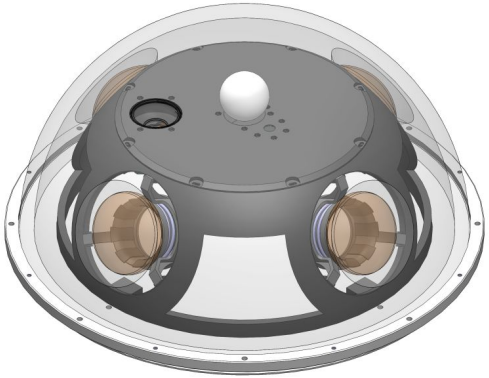
P-ONE Modules

- Optical modules (P-OMs):
  - 16 PMTs and high voltage bases
  - Mainboard/digitization electronics
  - Majority of modules will be P-OMs
- Calibration modules (P-CALs):
  - Up to 3/string
  - Contain fewer PMTs than P-OMs and have same mainboard electronics
  - Powerful LEDs that flash into detector volume to calibrate position



P-OM hemisphere



P-CAL hemisphere

PoS(ICRC2023)1219

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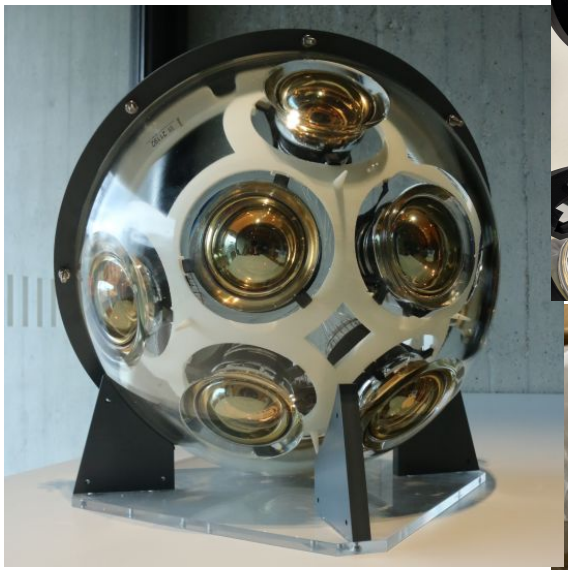
PMTs

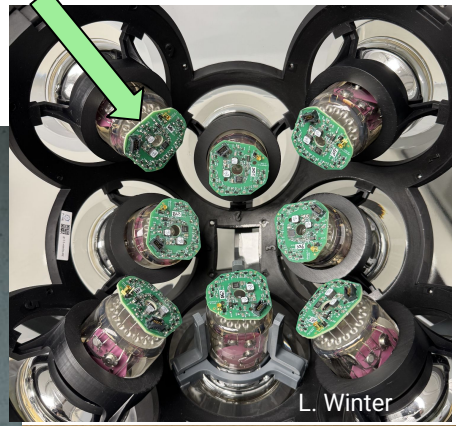
- Cherenkov light detected using 3” Hamamatsu PMTs
  - 8 per module hemisphere
- High voltage distributed to PMTs using microbases originally designed for IceCube

P-OM hemisphere with 8 PMTs



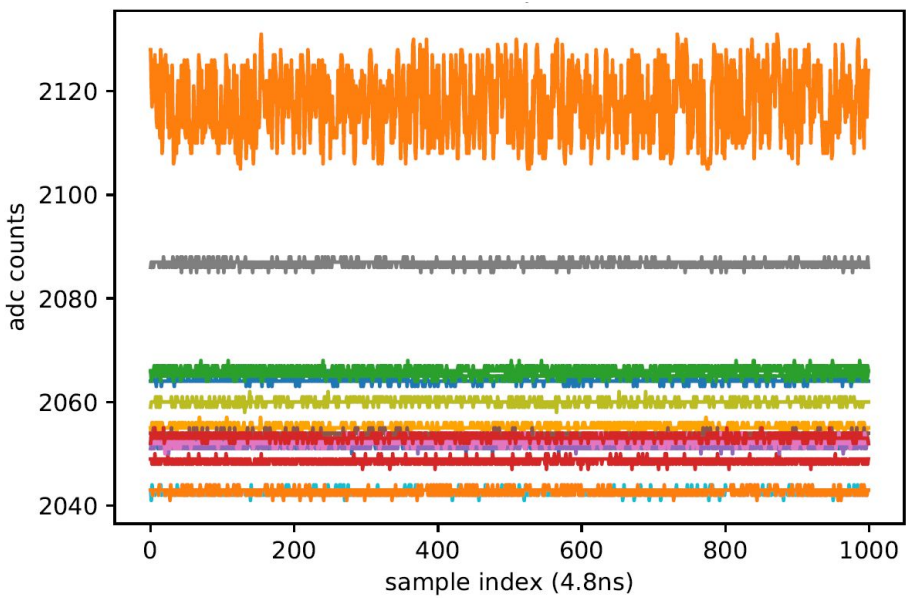
C. Spannfellner (PoS(ICRC2023)1219)

MicroBase



ADC

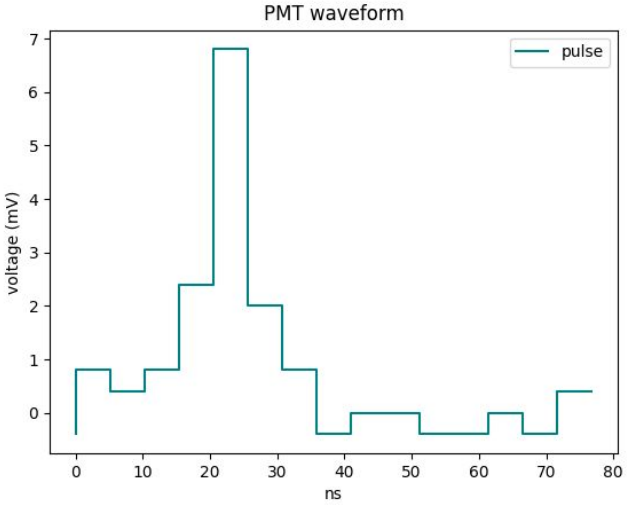
- Waveforms collected by continuously sampling ADC
- 12-bit, 16 channel
- ADC digitizes all data immediately
- Sample rate 210 MHz (4.8ns/sample)
- Preliminary studies show ~2.5 counts/mV
- Typical digitizer noise ~0.6 counts

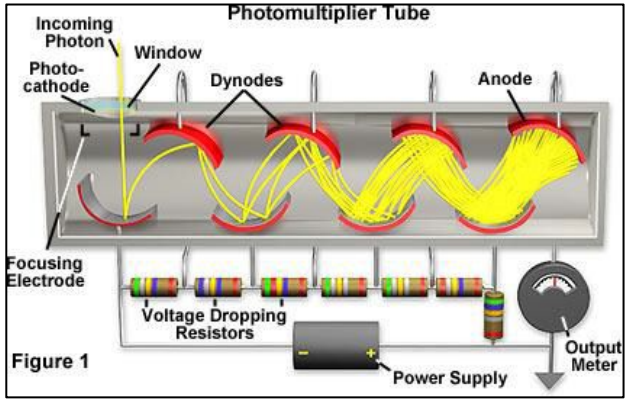


Digital noise baselines for ADC eval board in lab

PMT Waveforms

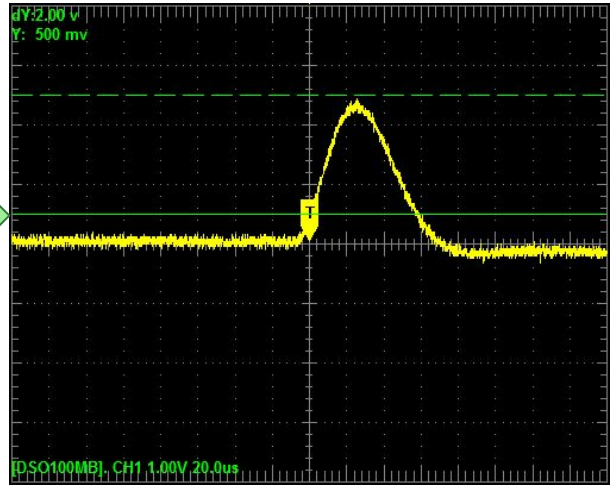
- Shape of waveforms using this DAQ electronics setup has been extensively characterized
- Reconstruction and simulation of these waveforms in progress





Hamamatsu

Charge collected at anode creates PMT waveform



PhysicsOpenLab

PMT waveform digitized by P-ONE DAQ electronics

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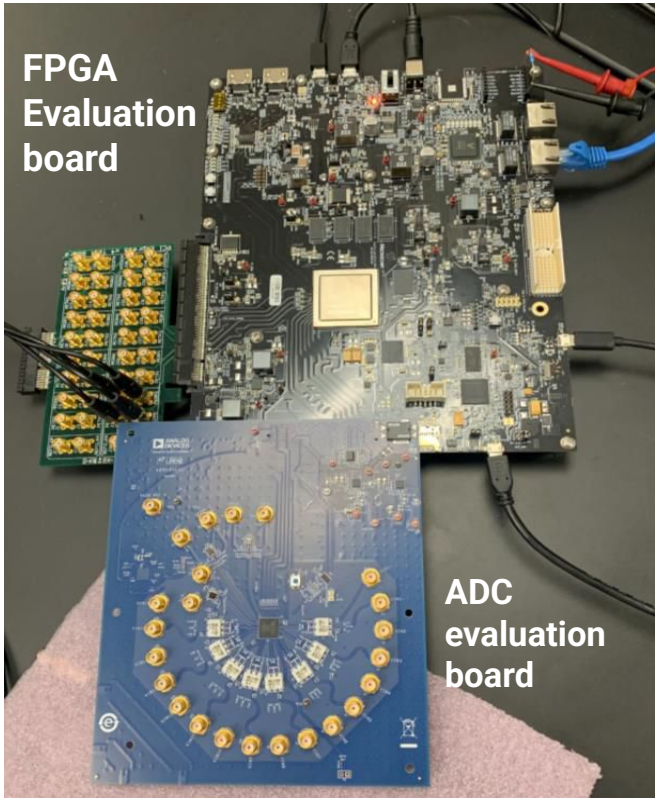
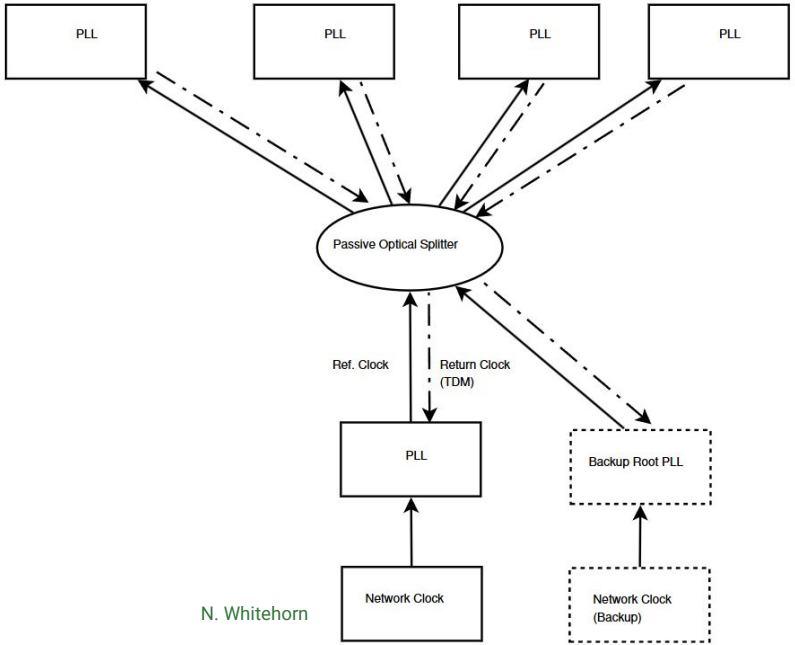
Mainboard

- Custom PCB including ADC, FPGA, CPU
- Digital, not analog, trigger
  - Novel trigger setup, cuts down on latency
  - Digital trigger logic contained in FPGA firmware
- PMT data stored in a 4GB ring buffer on CPU
  - Ring buffer fills up in ~0.8s
- Also included:
  - Acoustic ADC
  - Timing chip
  - Environmental sensors (pTH, magnetometer, accelerometer)



Mainboard+ADC prototype boards

Precision Timing



N. Whitehorn

- Sub-ns timing required to achieve desired angular resolution
- Timing chips on each mainboard are used to a create phase-locked loop (PLL), which accurately measures delay time between modules
  - Single “start” pulse is sent, gets to modules at same time, and then clock frequencies are locked together
- Signals between modules travel over fiber, increasing reliability and minimizing electrical noise on timing cables

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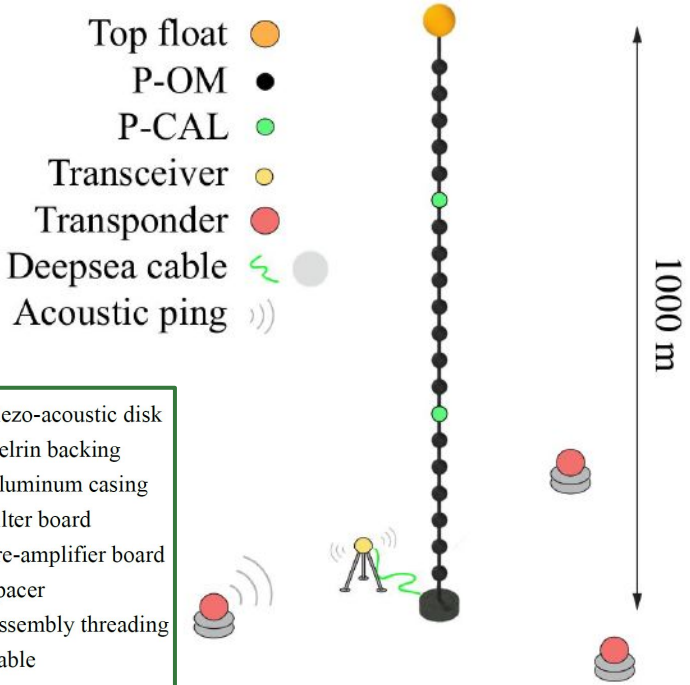
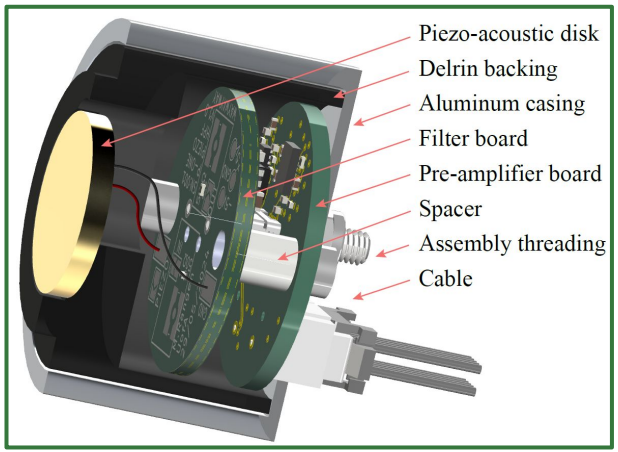
Fiber optic timing distribution system for P-ONE

Acoustic Sensors

- Acoustic receivers on P-OMs used to determine location of P-OMs in real time
- 4 channel acoustic ADC on mainboard used to digitize acoustic data
  - Data available to CPU as memory map



D. Ghuman



D. Ghuman

Hemisphere Assembly

- P-OM hemispheres assembled at the Technical University of Munich
- 17” glass hemispheres
- Each hemisphere contains 8 PMTs mounted in a frame
- Gel pads are installed on the PMTs to optically couple PMTs to the glass and increase photocathode area

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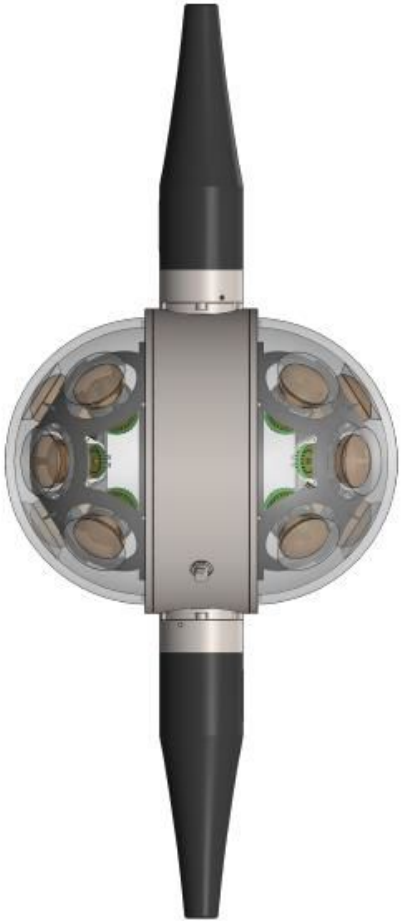
Cable Design

- Module hemispheres will be connected to a titanium cylinder
- Fiber and copper connections between modules fan out inside cylinder
- P-OMs will not have penetrator cables, eliminating another mode of failure
- Design also does not impede field of view for any PMTs
- Developed in collaboration with MacArtney Subsea Engineering and Nautilus Marine Service GmbH



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P-ONE Timeline

Year	2025	2026	2027	2028
P-ONE-1 Integration				
P-ONE-1 deployment	September!! 			
5-9 more strings deployed				
Module production				
Data collection				

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Summary

- P-ONE will be a next generation neutrino observatory to further the study of particle astrophysics
- P-OMs contain 16 PMTs and various calibration and environmental sensors
- P-OM designed with improved angular resolution, precision timing, precision calibration in mind
- P-OM design, testing, and production is mature

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