The Acoustic Module for the IceCube Upgrade

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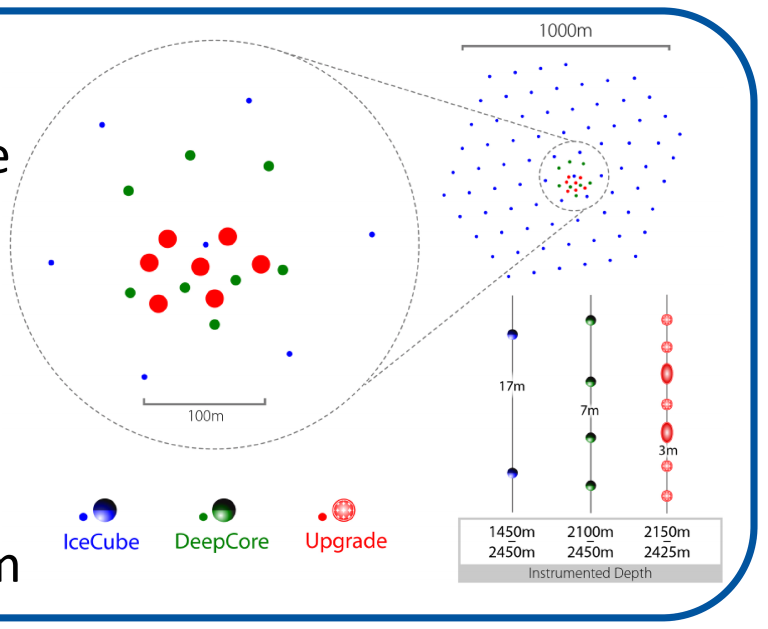
The IceCube Upgrade [1]

- 7 new strings will be deployed in the center of the IceCube array
- 700 more digital optical modules (DOMs) plus calibration devices will be deployed
- Horizontal string spacing: 30 m
- Module spacing along the string: 3 m



The Acoustic Calibration System

Objectives:

- Precise geometrical calibration of the DOMs by trilateration
- Measure the sound attenuation and speed in ice
- Measure acoustic signals in coincidence with high-energy neutrino events
- Proof of concept for the upcoming IceCube-Gen2 detector

Overall System:

- Based on experience from the EnEx-RANGE [2] system
- 10 emitting and receiving Acoustic Modules (AMs) distributed on Upgrade strings
- 7 in the physics volume between 2140 m and 2440 m depth
- 3 outside the physics volume (1 at 1550 m depth)
- Distances between AMs up to 1000 m
- Acoustical sensors integrated into some of the optical modules

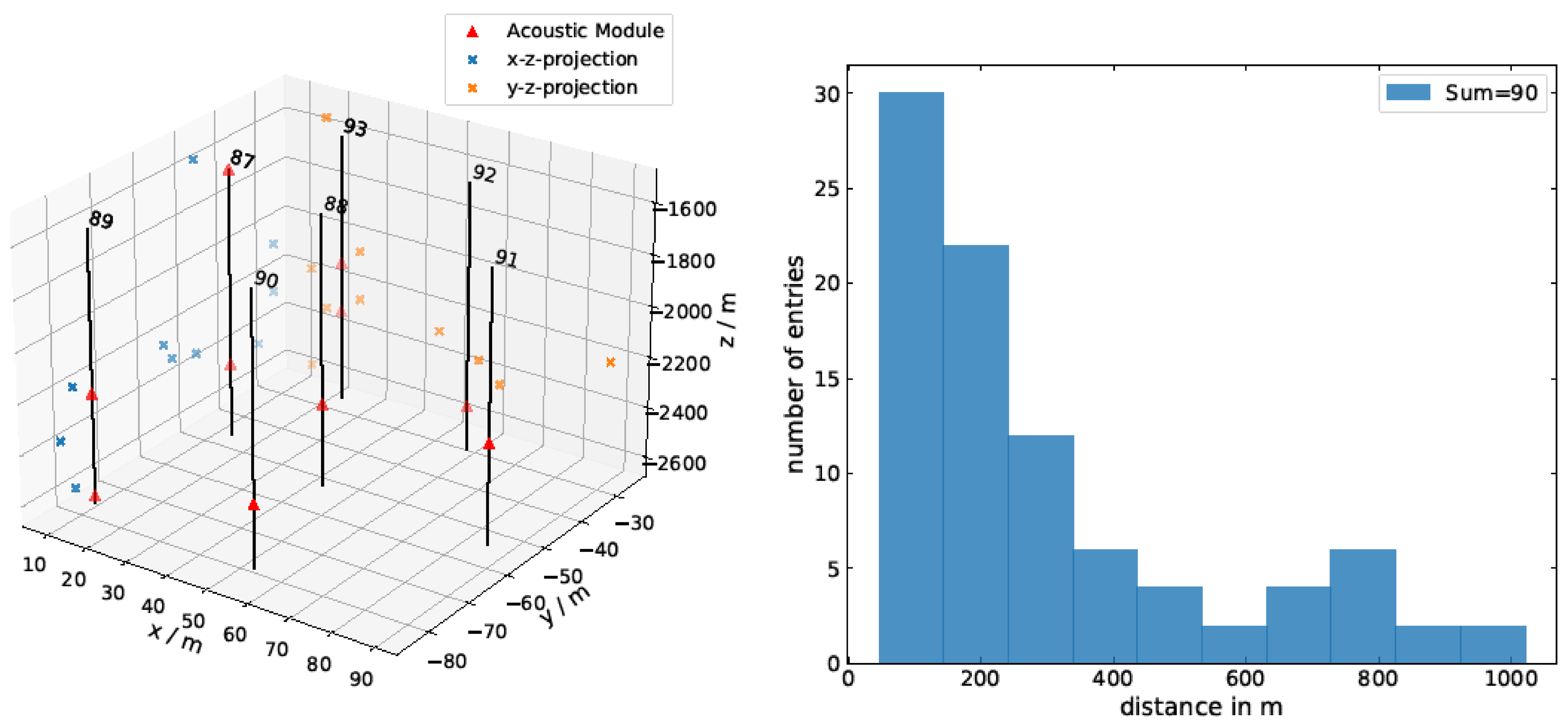


Figure 1: (Left) 3D view of the positions of the acoustic modules on the upgrade strings. (Right) Distribution of distances between Ams (both directions).

Technical Design of the Acoustic Module

The acoustic module is a standalone device that functions as a high-power acoustic emitter or receiver.

Components and their functions:

- Pressure Housing
  - Steel cylinder designed for pressures up to 700 Mpa
- Mini-Mainboard
  - Power supply and control
  - Used by many devices in the upgrade, developed in Aachen
- Ice-Comms Module
  - Common device for communication and synchronization
- Pinger Driver Board
  - Generates signals to drive the piezo transducer
  - 320 V output DC/DC converter
  - Full-bridge driver with up to 1 MSps
- Capacitor Bank
  - Stores energy for acoustic pulses, C ~400 µF
- Acoustic Receiver Board
  - Variable gain
  - 100 kHz Sampling rate
- Acoustic Transducer (Tonpilz design)
  - 16 piezo discs pre-stressed in between head and tail mass

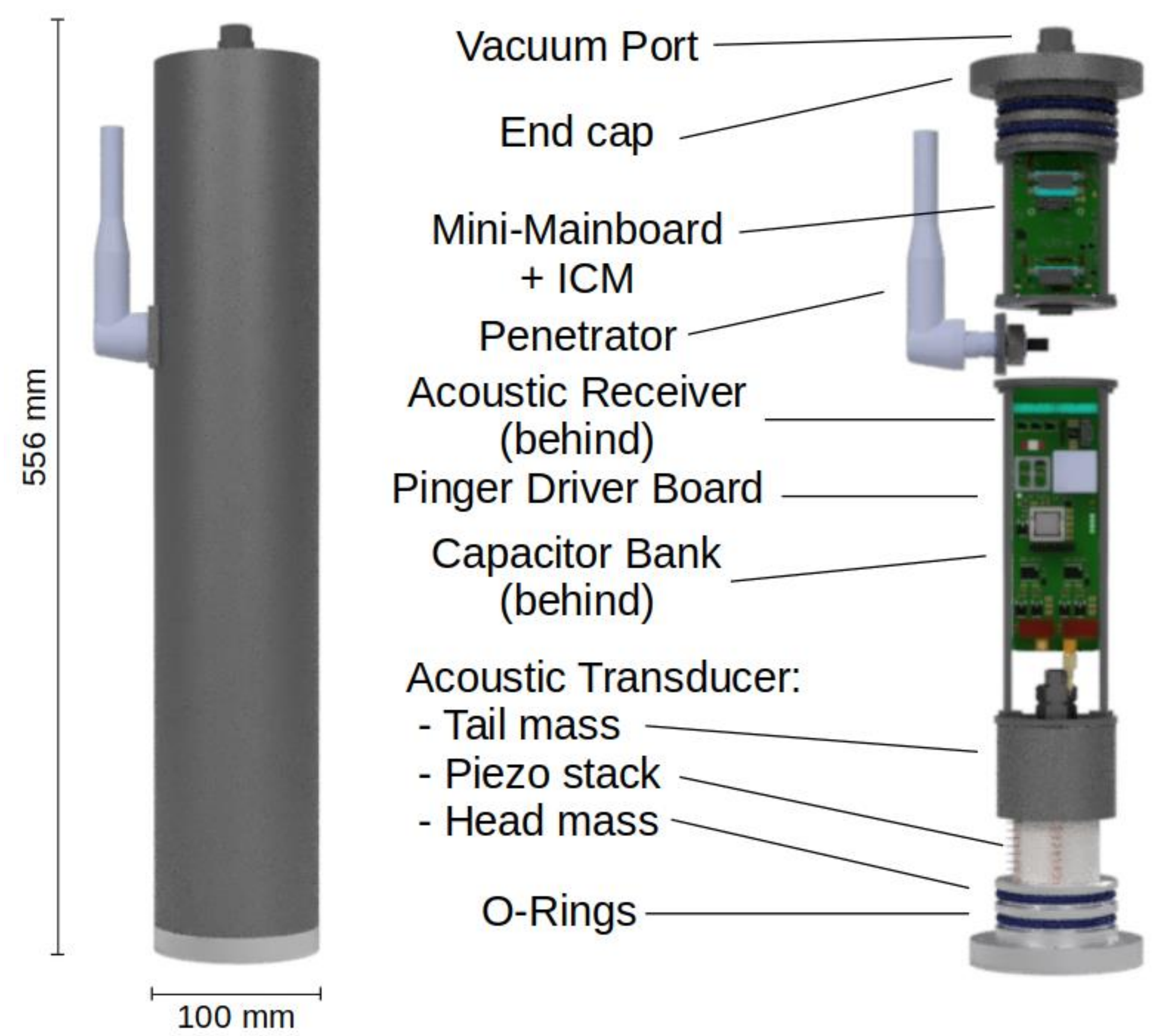


Figure 2: Illustration of the acoustic module and its internal components.

Simulation of the Array Performance

- Investigate the precision of distance measurement
- Uncertainties arise from digitization, synchronization, pinger size and distance dependent signal-to-noise ratio
- Different attenuation length and output powers have been assumed (λ=300 m default)
- Average uncertainty for AMs in the physics volume: 12 cm
- Solitary AM has a larger uncertainty due to larger distance smaller angular lever arm

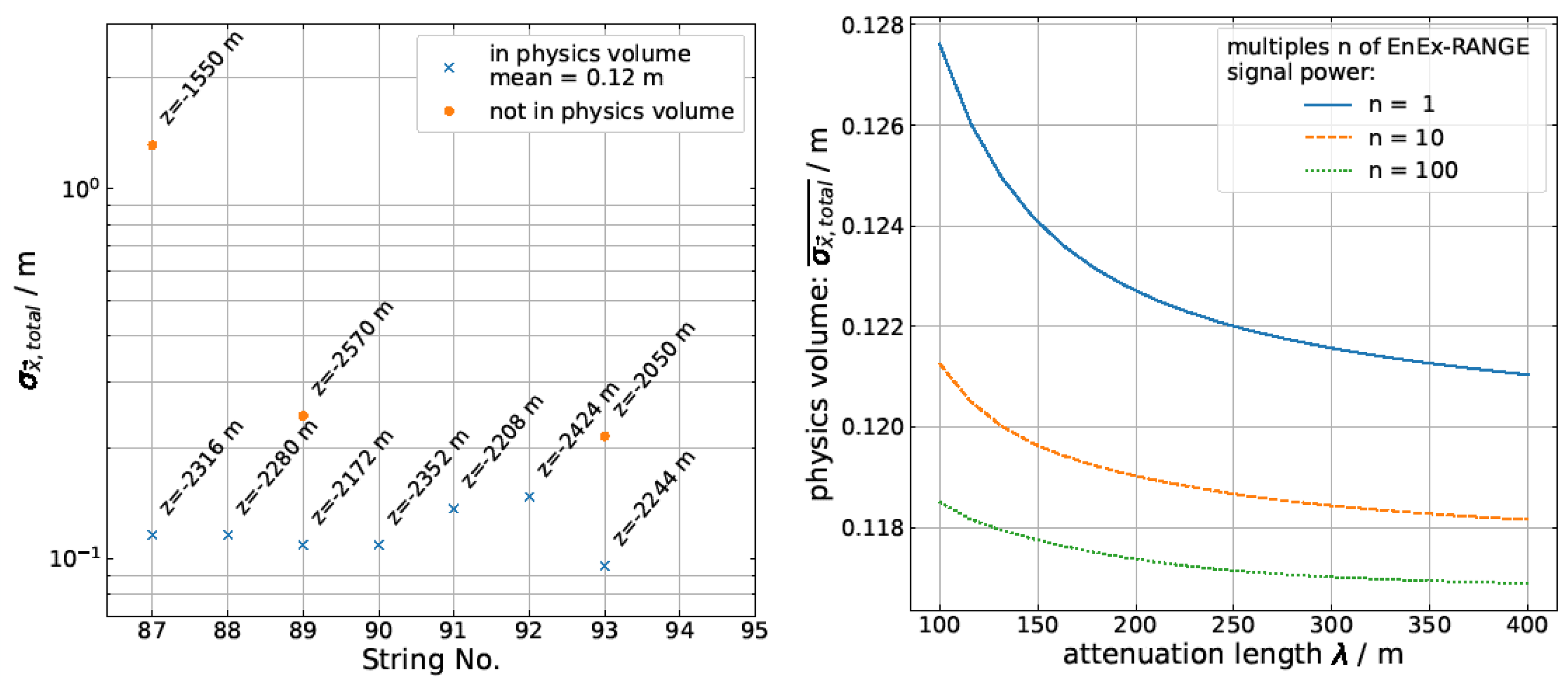


Figure 3: (Left) uncertainties of individual AMs. (Right) mean uncertainty for different input assumptions.

Phase Response Method

- Propagation time measurement of acoustic signals in ice
- New method that analyses the signals in frequency domain, information is found as group delay
- Measurement chain consists of three subsystems: acoustic emitter - medium (ice) - acoustic receiver
- Medium ice is modelled as a delay time element, where its delay τ is the signal propagation time between emitter and receiver
- Bode gain phase relation [3] is used to calculate group delay τ from measured input signal (sine sweep) and receiver output
- Method is more robust and precise than regular threshold method

Conclusion

- Acoustic modules are a promising candidate for the geometrical calibration of the IceCube detector as predicted by simulations
- The long range and high precision makes the system interesting for the upcoming Gen2 detector with string spacings of ~240 m

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References:
[1] IceCubeCollaboration, A. Ishihara PoSICRC2019 (2019) 1031.
[2] L. S. Weinstock et al. Annals of Glaciology(2020) 1–10.
[3] W. Bode, Relations between Attenuation and Phase in feedback Amplifier Design. American Telephone and Telegraph Company, New York, 1940.

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