A next-generation optical sensor for IceCube-Gen2

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Overview

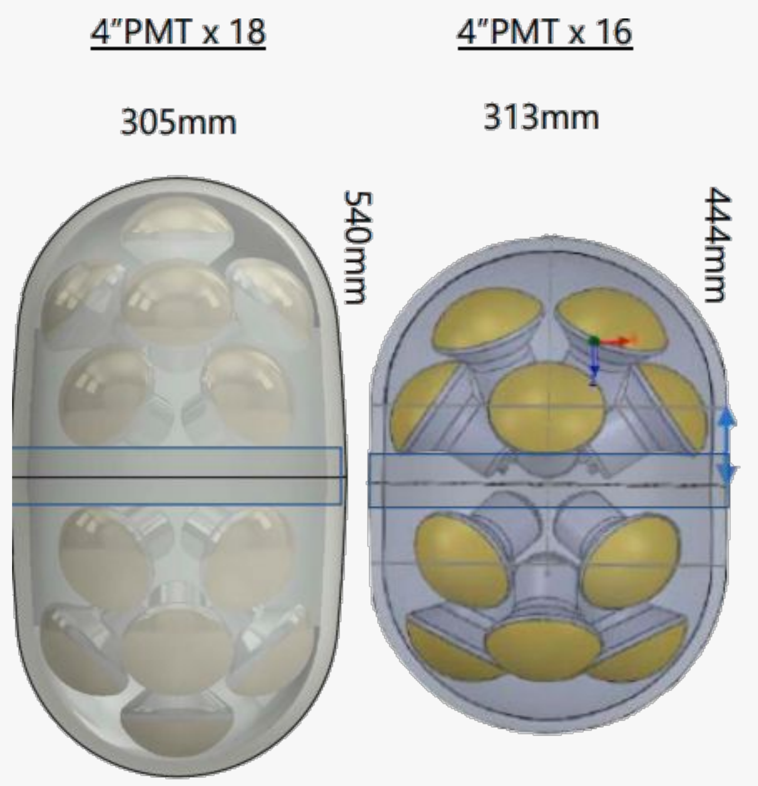
IceCube-Gen2, a planned expansion of the IceCube facility at the South Pole, aims to increase the rate of observed cosmic neutrinos and detect fainter sources [1]. The **IceCube Upgrade**, as a first step, will consist of 693 densely spaced new sensors [2], enhancing sensitivity to GeV neutrinos. A new sensor module is being developed using 4” PMTs in a glass pressure vessel, for installation into holes drilled into ice. Challenges arise from constrained borehole size and PMT close-packing. The electronics have been designed to fit the physical and power requirements.

From Upgrade to Gen2

Upgrade mDOM (24x3”PMTs)

Upgrade D-Egg (2x8”PMTs)

The Long Optical Module (LOM), an evolution of the IceCube Upgrade modules, limits sensor diameter to 12” to save on drilling. Multiple 4” PMTs are fitted to optimize effective area.



The LOM power consumption is limited to 4W, requiring a lower digitisation rate of 60 MSPS, and waveform processing shifted to PMT bases. Due to Gen2’s large string spacing (240m), the lower ADC rate has only a modest effect on reconstructions.

Two designs are under scrutiny, with 18 and 16 PMTs. These will be developed into a single design for Gen2 [3]. In the near term, we aim to deploy 6 modules of each type for Upgrade.

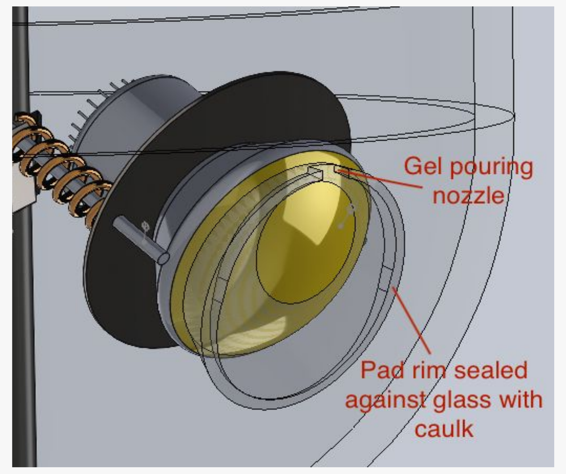
Mechanical Structure Design

The support structure must orient PMTs while accommodating low-temperature shrinkage. The design thus dovetails with the PMT installation procedure

PMT Interfacing Procedure

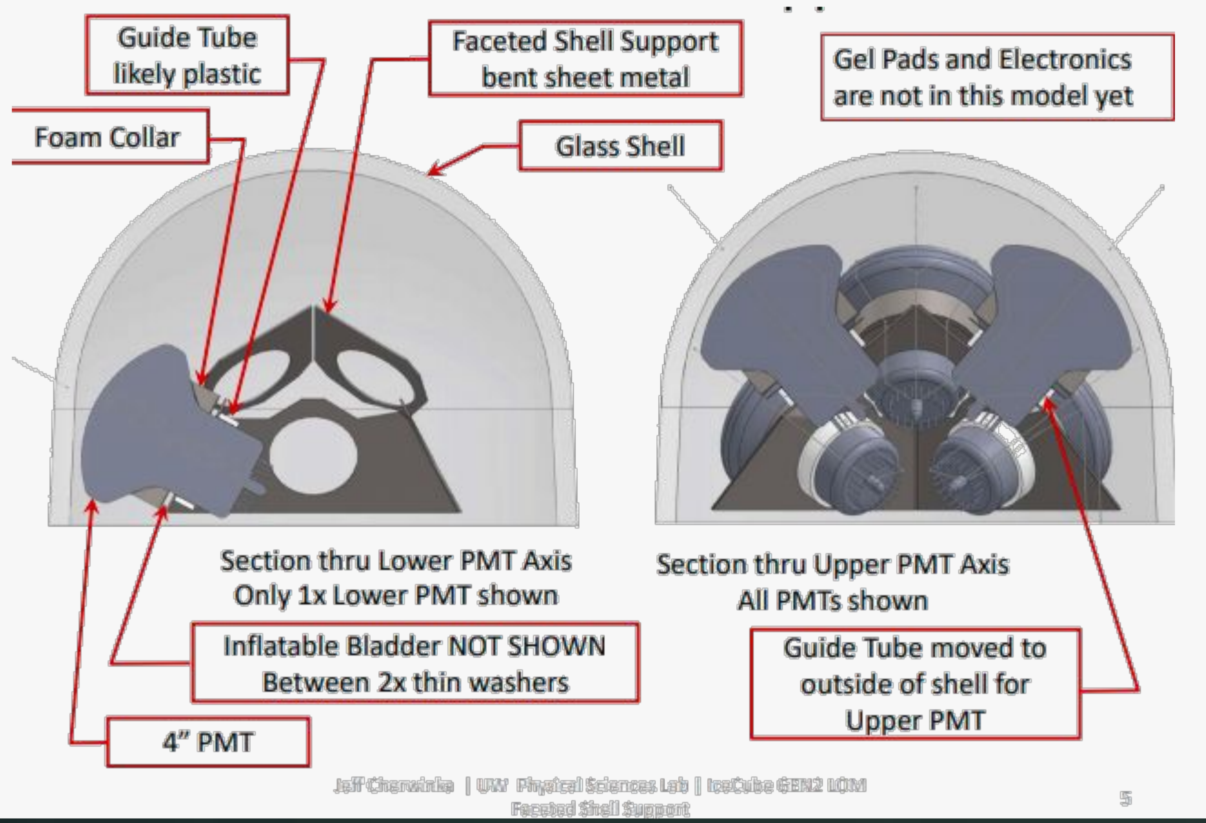
- Use pre-cured silicone **gel pads**, to enhance photon capture rates via total internal reflection.
- Pads are cast onto PMT face; care taken to obviate bubble formation at interface.

- Our approach to interfacing the pads employs a flat pad face, framing a cavity with vessel.
- Pad rim sealed against vessel, and cavity filled with gel to cure.
- Degassing to remove introduced bubbles



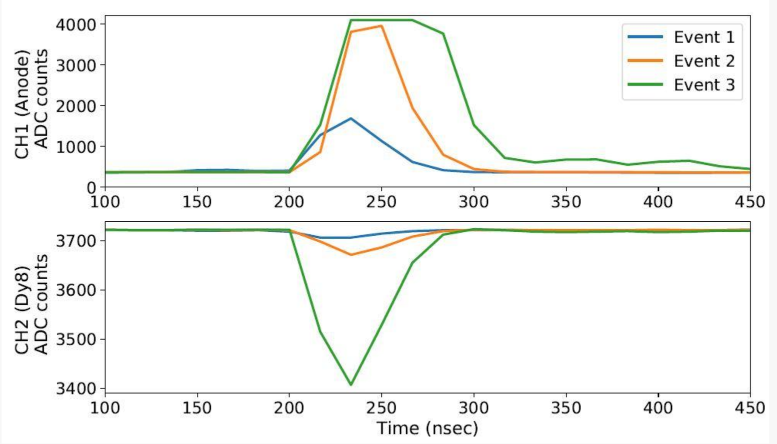
Support Structure

- Support structure constructed of sheet metal.
- PMTs aligned using plastic bearings.An inflatable bladder around the PMT neck exerts outward pressure for gel pad interfacing.
- Features combine to yield a scalable cost-effective solution.

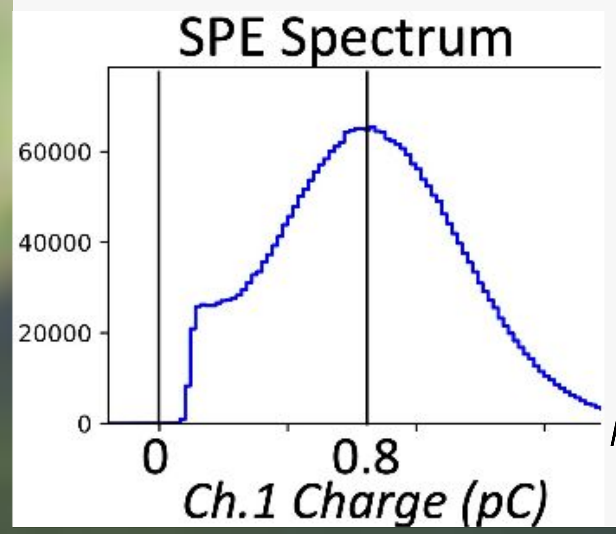


Waveform MicroBase

- Extending the dynamic range for neutrino events of varying photon yield, both the anode and a preceding dynode are digitized, using a 2-channel ADC at 60 MSPS.
- To further improve timing resolution, a delay line module within FPGA records leading edge time with 1ns resolution.



A sample event readout. Event 3 has saturated the anode readout on CH1, but using the readout from dynode 8 on CH2, one is able to retain event information

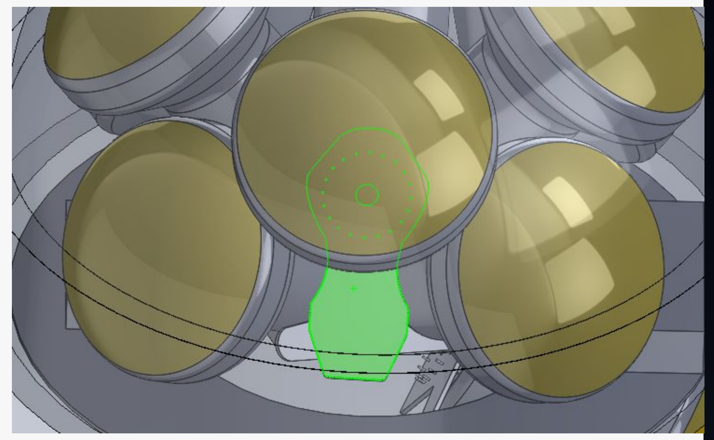


The measured charge distribution for single photoelectrons at a gain of 5x10^6

Electronics Design

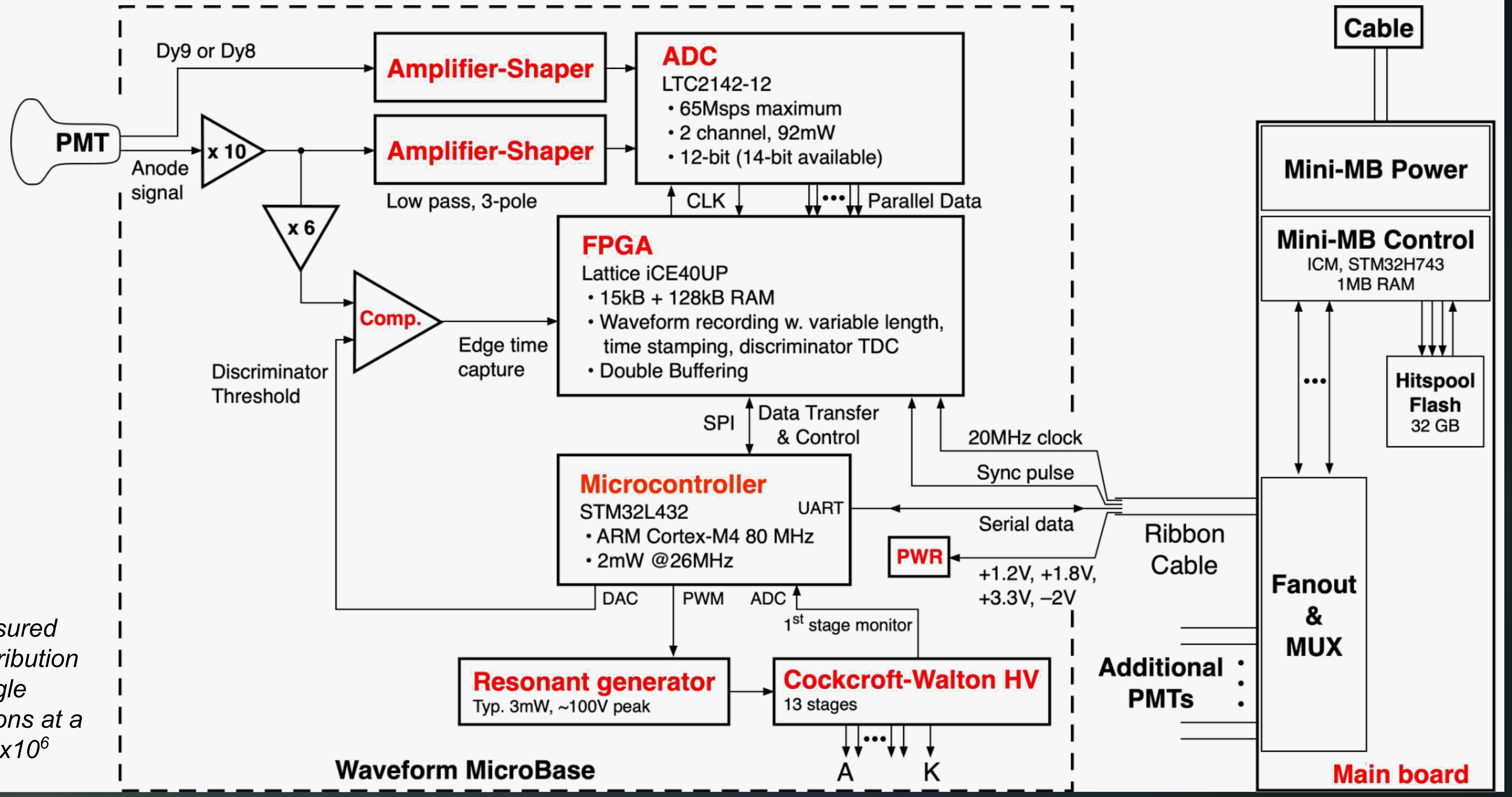
The LOM builds upon the mDOM electronics [3], expanding the MicroBase, which regulates the PMT high voltage (HV) generation, to include data acquisition (DAQ) functionality.

*The new bases, referred to as **Waveform MicroBases**, have shapes optimized for close packing.*



Central Board

- Provides data management and interfaces with the surface computers.
- Contains **IceCube Communications Module** (ICM) for timing and synchronization.
- Waveform MicroBase interfaces are multiplexed over UART connection.
- Data retained in flash memory for 1 week for detector level trigger [4]



Outlook

- Guiding principle: to arrive at an economical, fault-tolerant solution, easily scalable for mass production.
- Support structure evolved to create viable assembly procedure.
- Design and verification of electronics proceeding apace.
- Orders have been placed for first prototypes of components such as new PMTs and pressure vessels.

References

[1] IceCube Collaboration, M. G. Aartsen, et al. JINST 12 no. 03, (2017) P03012.

[2] IceCube Collaboration, L. Classen et al. PoS ICRC2021 (these proceedings) XXX.

[3] IceCube Collaboration, M. G. Aartsen, et al. J. Phys. G 48 no. 6, (2021) 060501.

[4] IceCube Collaboration, J. Kelley JINST VLVnT2021 (2021) XXX.