

Fluorescent Optical Module Prototype Evaluation in the IceCube Upgrade

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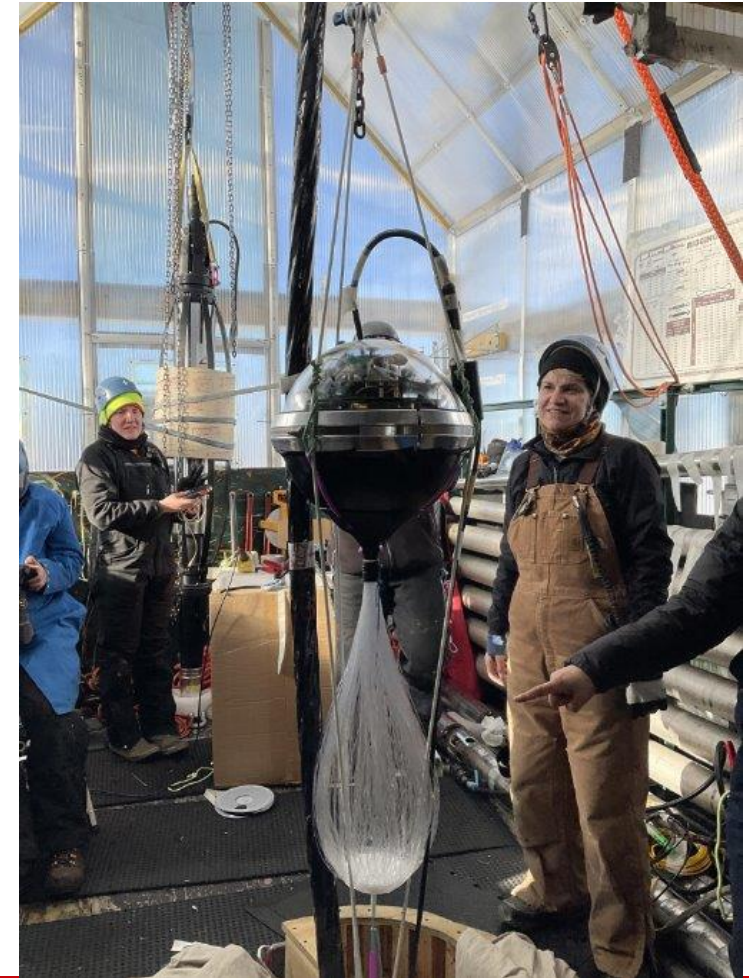
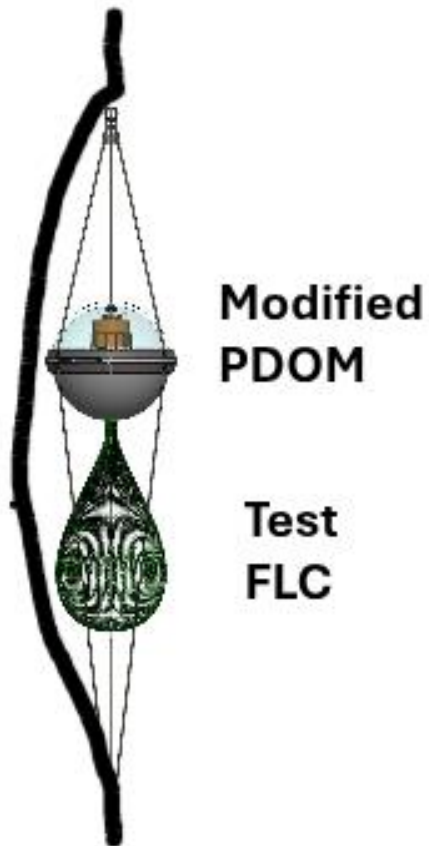


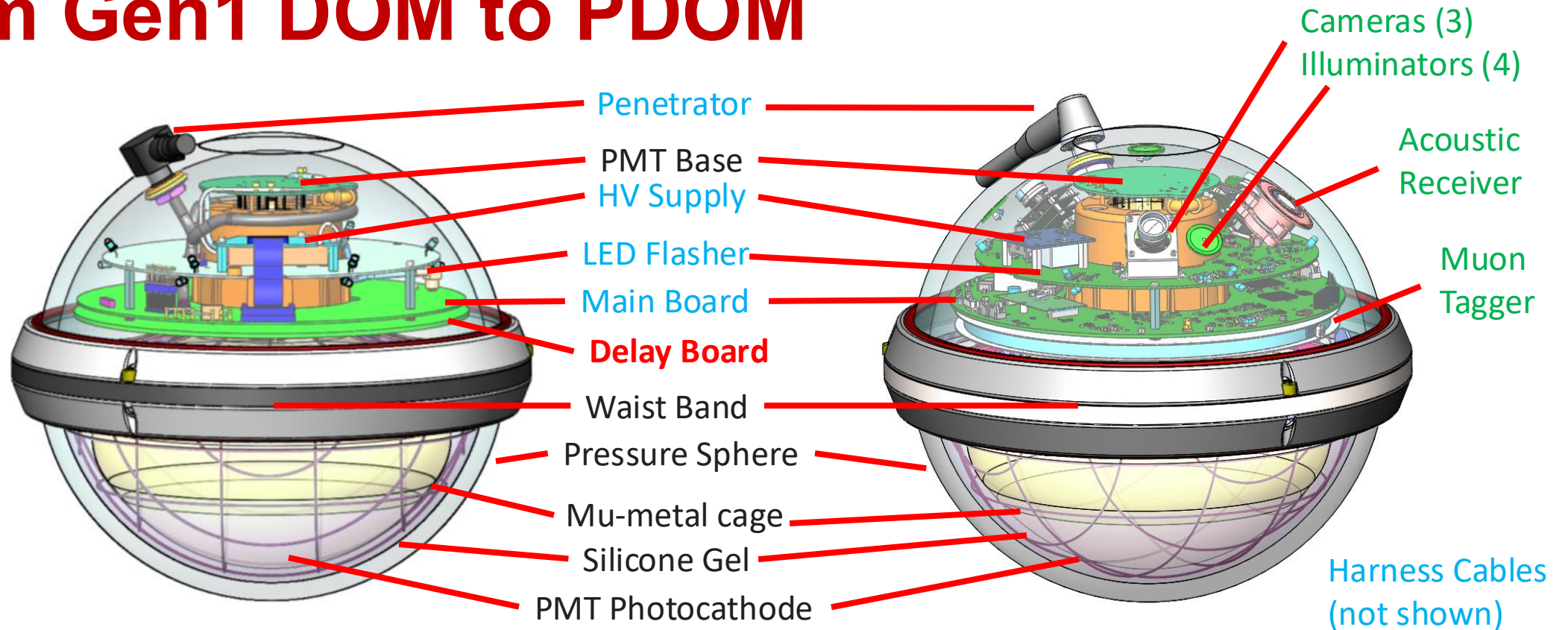
Photo: Yuya Makino

Fluorescent Optical Module (FOM) in Upgrade



- 100% (3/3) of deployed FOMs survived freeze-in and function as expected
- Fluorescent Light Collector (FLC) coupled to modified precision digital optical module (PDOM).
- Upgrade Science Goals of PDOM
 - Cross-calibration of optical signals with Gen1 DOMs
 - Colour imaging of ice and hardware
 - Ice studies with adjustable white-light illuminators
 - Detecting direct muon hits for optical reconstruction checks
 - **Testbed for FOM; FLC is read out by Identical PMT, signal and data paths as PDOM reference sensors**

From Gen1 DOM to PDOM



IceCube Gen1
DOM

KEY:
 Component identical
Component eliminated
Component re-designed
Component added

IceCube Upgrade
PDOM

From PDOMs to FOMs

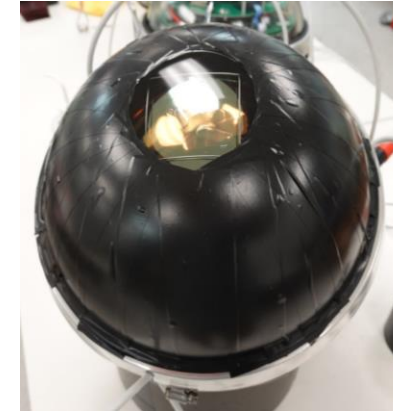
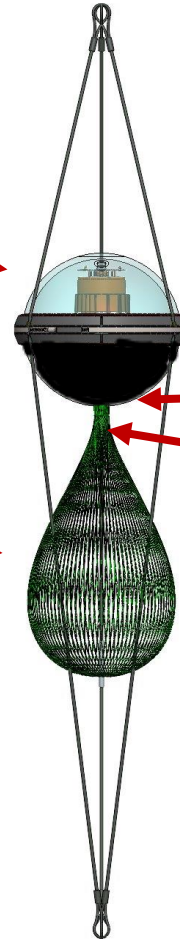
FOM

PDOM

- Modified PDOM used as sensor module
- Taped PMT accepts only FLC output light
- Harness waistband is offset to fit FLC

FLC

- Fluorescent Light Collector
- Held on with rubber bands and twist ties
- FLC output couples through ice into glass
- Overall FLC size is limited by PDOM harness



*Taped PMT
3" aperture*

- Masked PMT with central aperture
- Light-blocking skirt
- FLC output bundle



*Output bundle
with skirt*

FLCs shipped to South Pole - 1



FLCs shipped to South Pole - 2



**UV flashlight
from left side**
(note relatively
uniform
excitation)



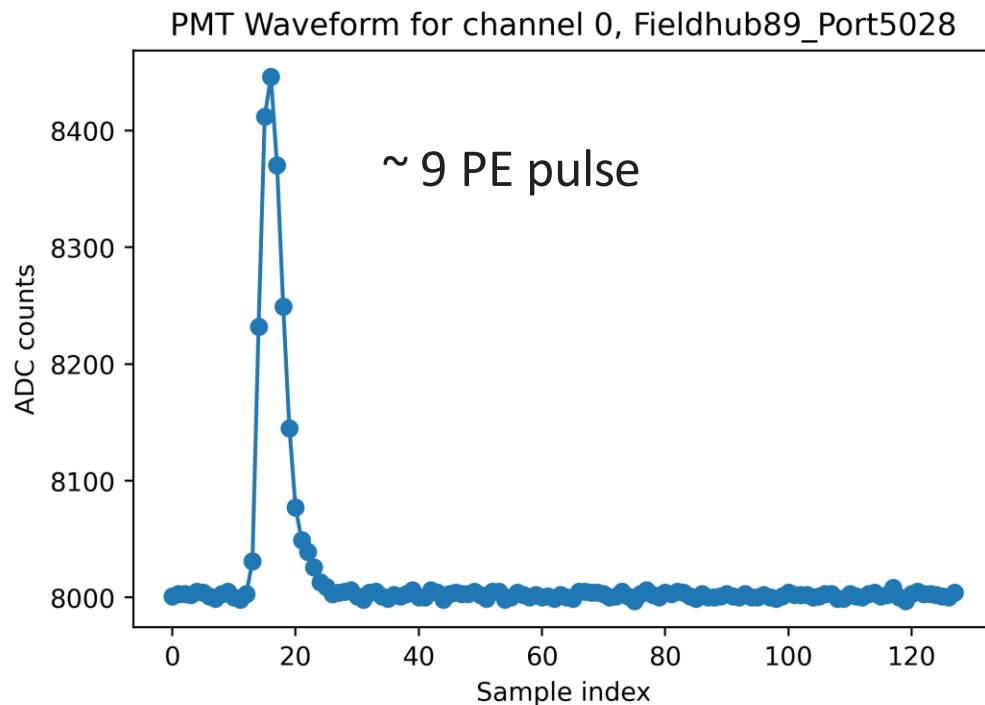


First look at FOM data

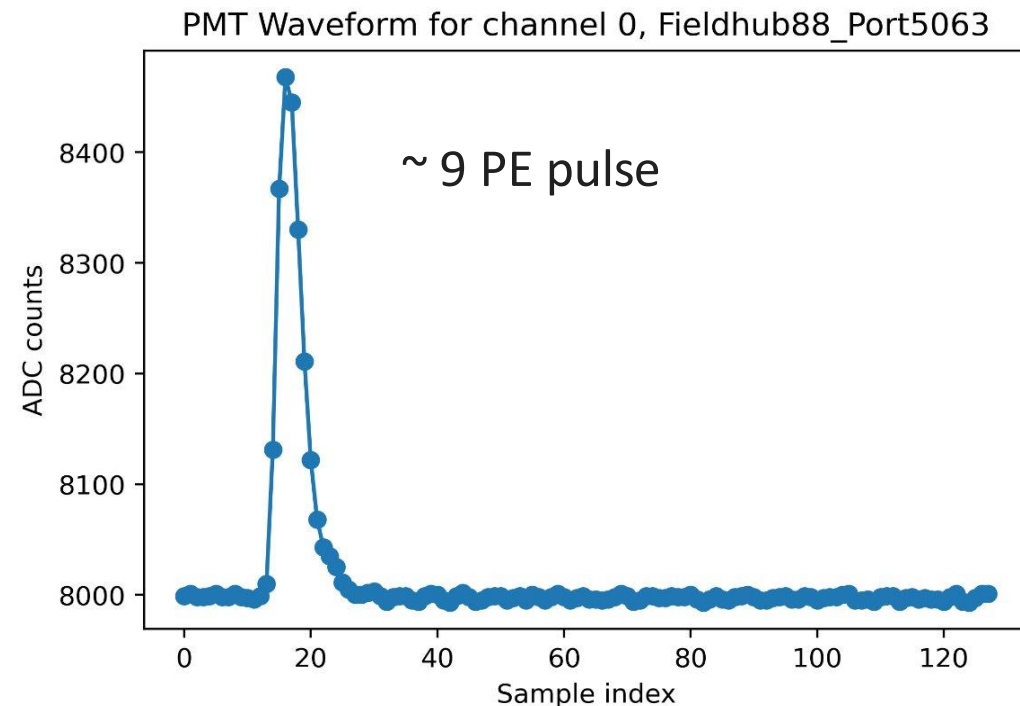
Inspect pulse shapes for time-smearing

- Check for any obvious differences in pulse shapes (large pulses from muons, not noise)
- Pulse shape for same-height examples are similar between FOM and PDOM

FOM (SN D18)

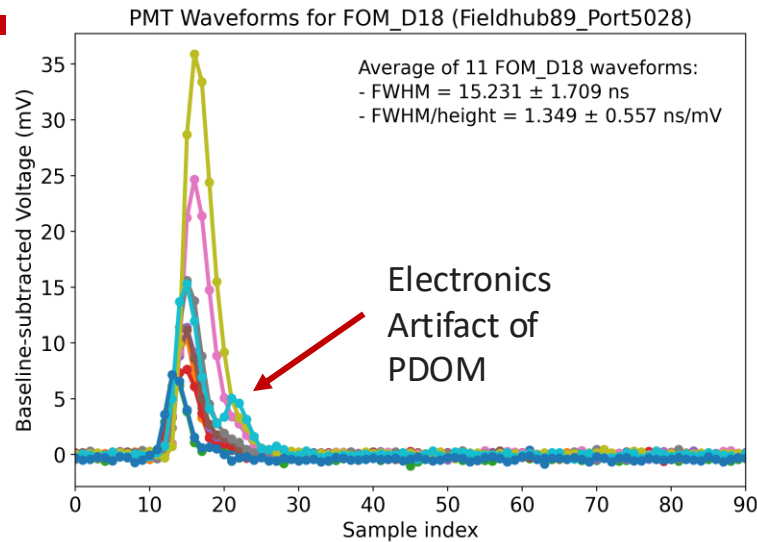


PDOM (SN 244)

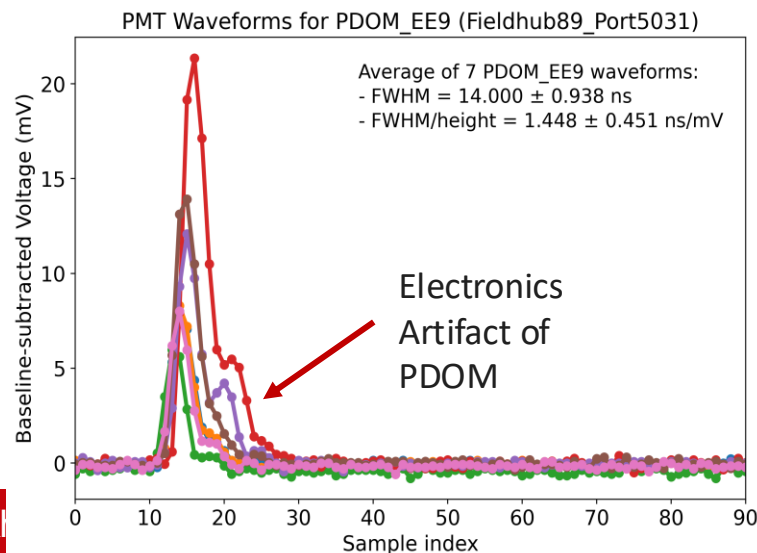


Waveform Studies (2h special run)

FOM



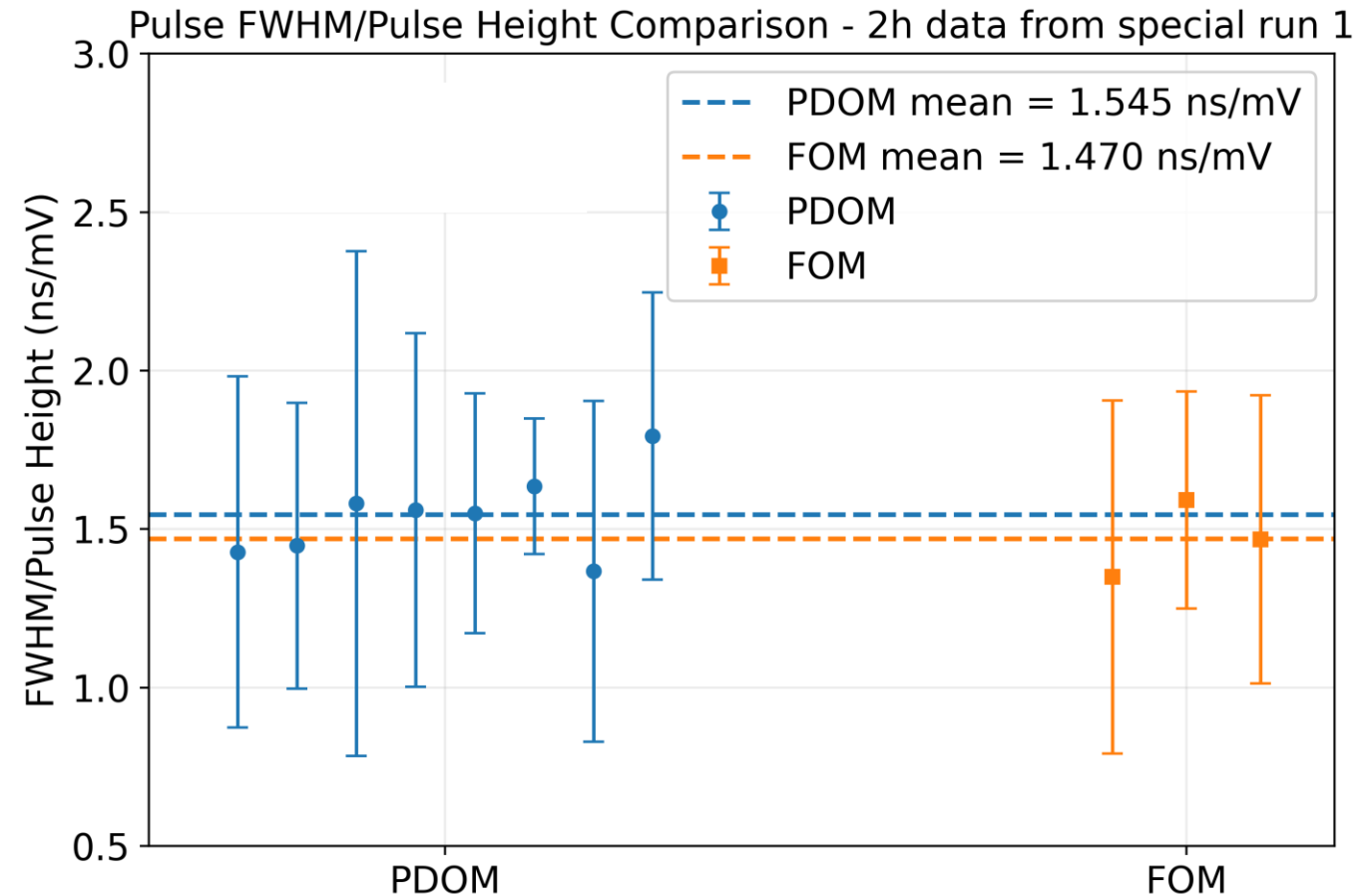
PDOM



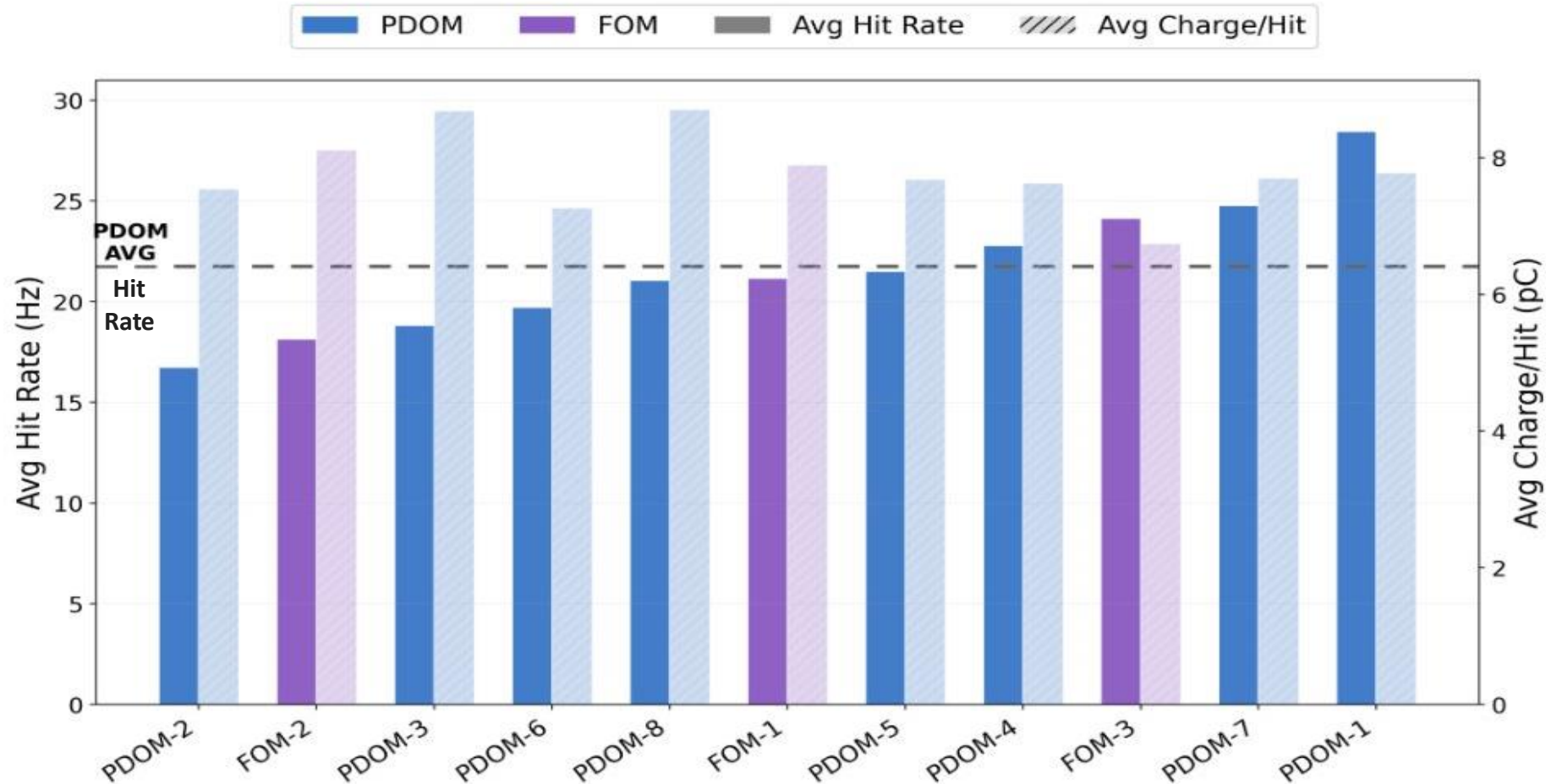
- Does the FLC introduce an additional time smearing?
- Compare signals from PDOMs and FOMs
- Exact same PMT and signal chain in both devices eliminates systematic time response differences
- Collected pulses above 2.5PE from 2hr special run of FOMs and PDOMs
- Only light that goes through FLC is considered

Waveform Studies – FWHM/Height

- Does the FLC introduce an additional time smearing?
- ~1.5 ns/mV width/height ratio for FOM & PDOM
- Likely reflects the intrinsic response of the measurement system more than propagation effects in the 1.5 m FLC.
- The average FWHM contains amplitude and sensitivity differences.
- FWHM/Height helps normalize the width measurement
- **Futurework:**
 - Collect more data to better estimate errors.



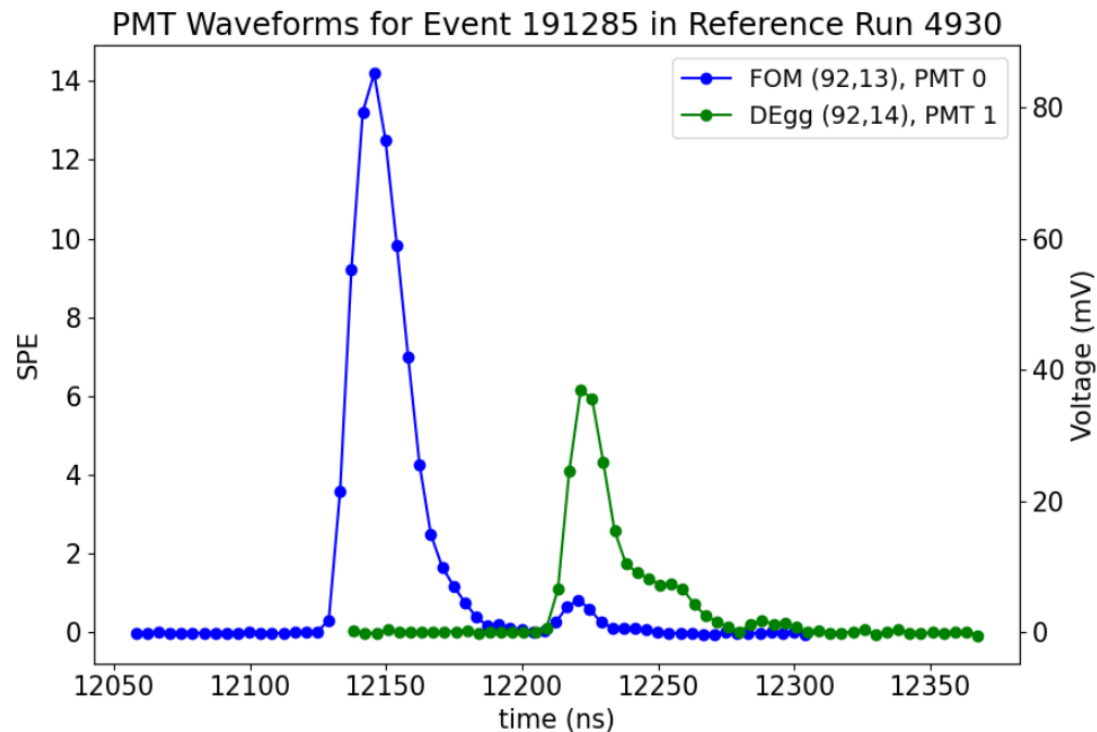
Hit rate and charge/hit comparison (2h special run)



- Solid bars - average hit rate
- Shaded bars - average charge per hit
- FOMs exhibit hit rates and charge-per-hit values similar to those of the pDOMs.

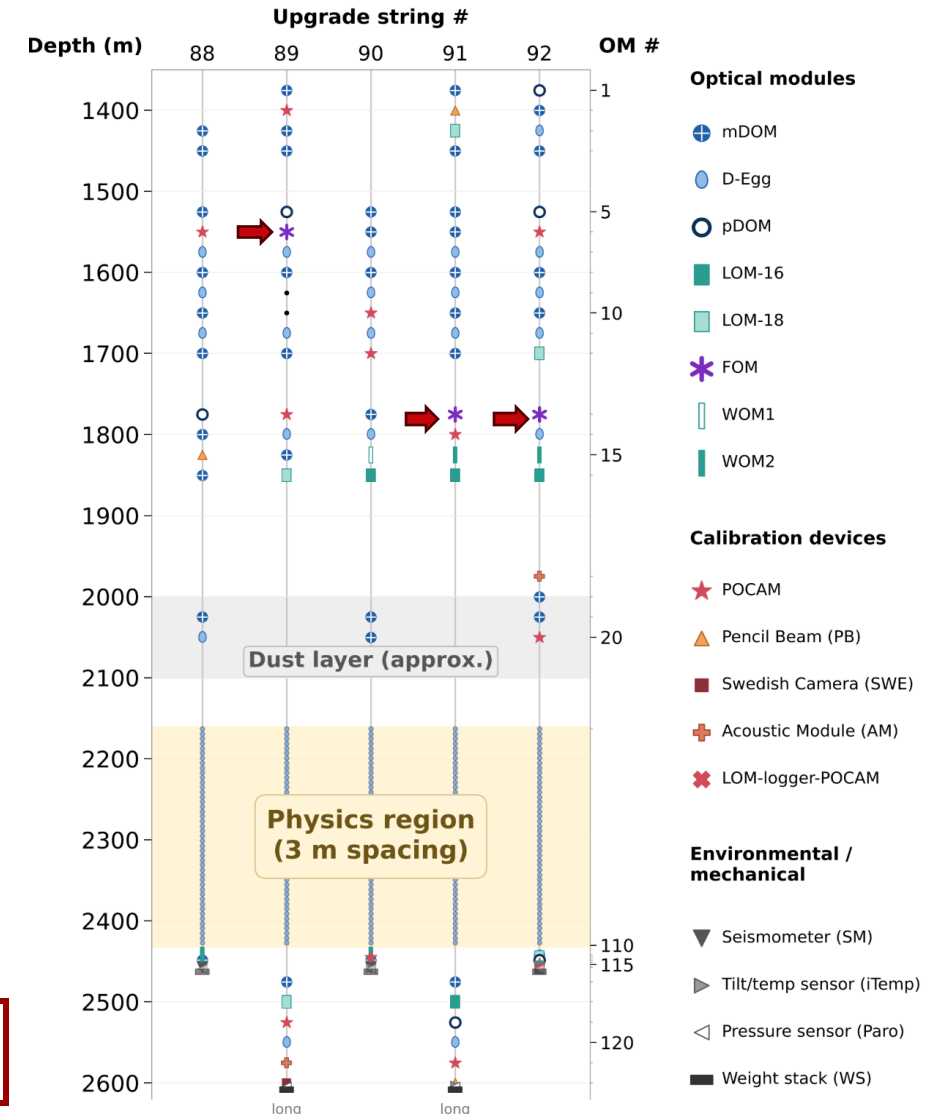
Correlations with Triggered Events (10 mins)

- FOMs located near top of detector in "shallow region"
- Not included in "physics region" trigger formation
- FOM & neighboring xDOMs witnessed triggered events



Work in Progress

92	distance to next sensor
pDOM	25
mDOM	25
DEgg	25
mDOM	75
pDOM	25
POCAM	25
DEgg	25
mDOM	25
DEgg	25
mDOM	25
DEgg	25
LOM-18	75
FOM	25
DEgg	25
WOM2	25

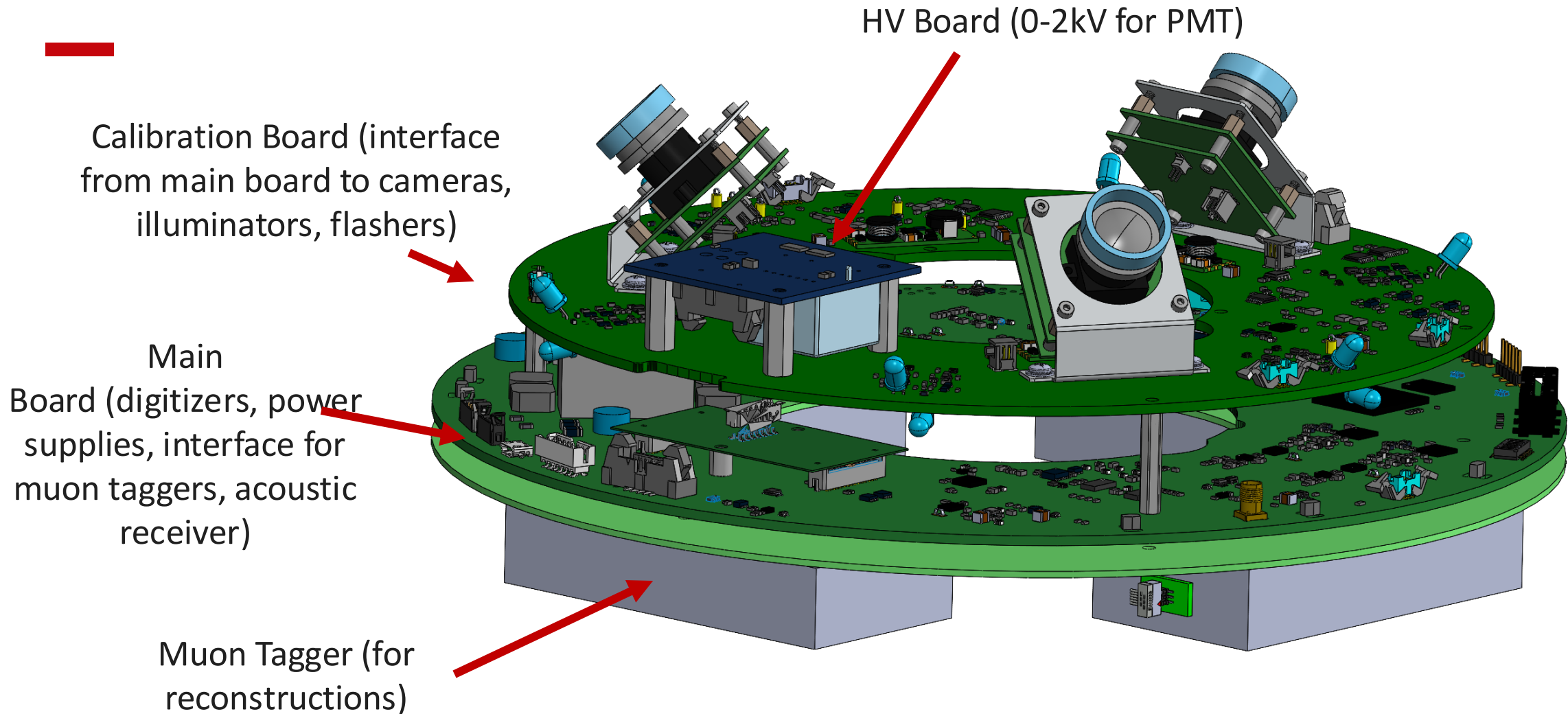


Future Work

- More in-ice data collection - Threshold scalar scans, waveform studies, sensitivity comparisons to Gen1 and upgrade DOMs
- Measure effective area of FOM FLC in the ice with physics signals
- Electronics and pressure vessel development
- Water tank testing of improved FLC designs at Arguelles lab @ Harvard
- Geant4 simulations of FLC designs
 - Directional response for various FLC shapes
 - Scalability of FLC size
 - Timing impacts with larger FLCs
 - Coupling between FLC and PMT

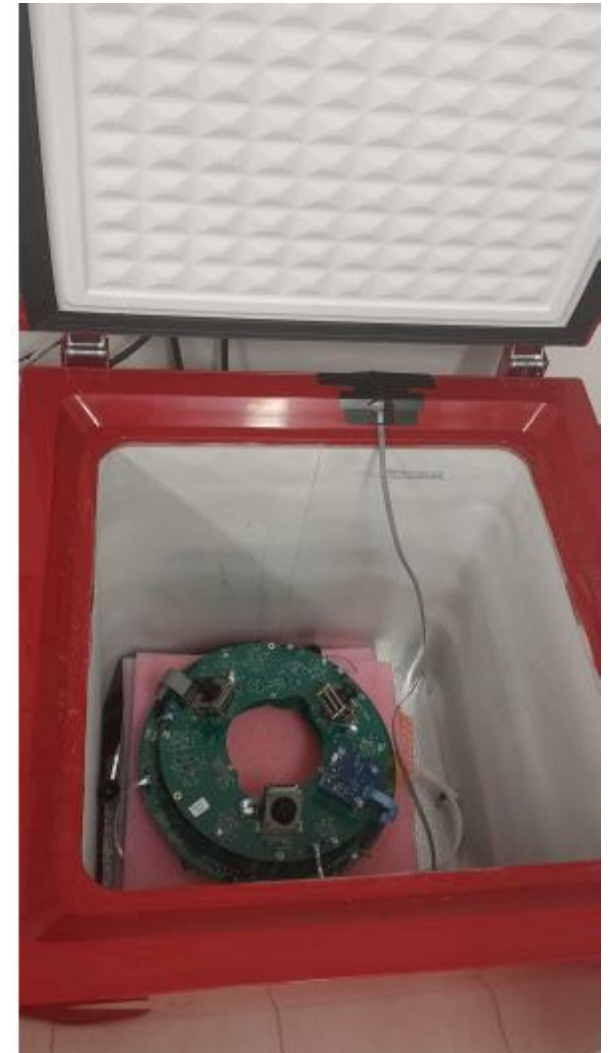


PDOM Boardstack



Board Stack testing

- Batch testing of 6 boards per test cycle
- STF (mainboard & cal electronics)
- Muon tagger functionality
- Design verification and trouble shooting at -30C

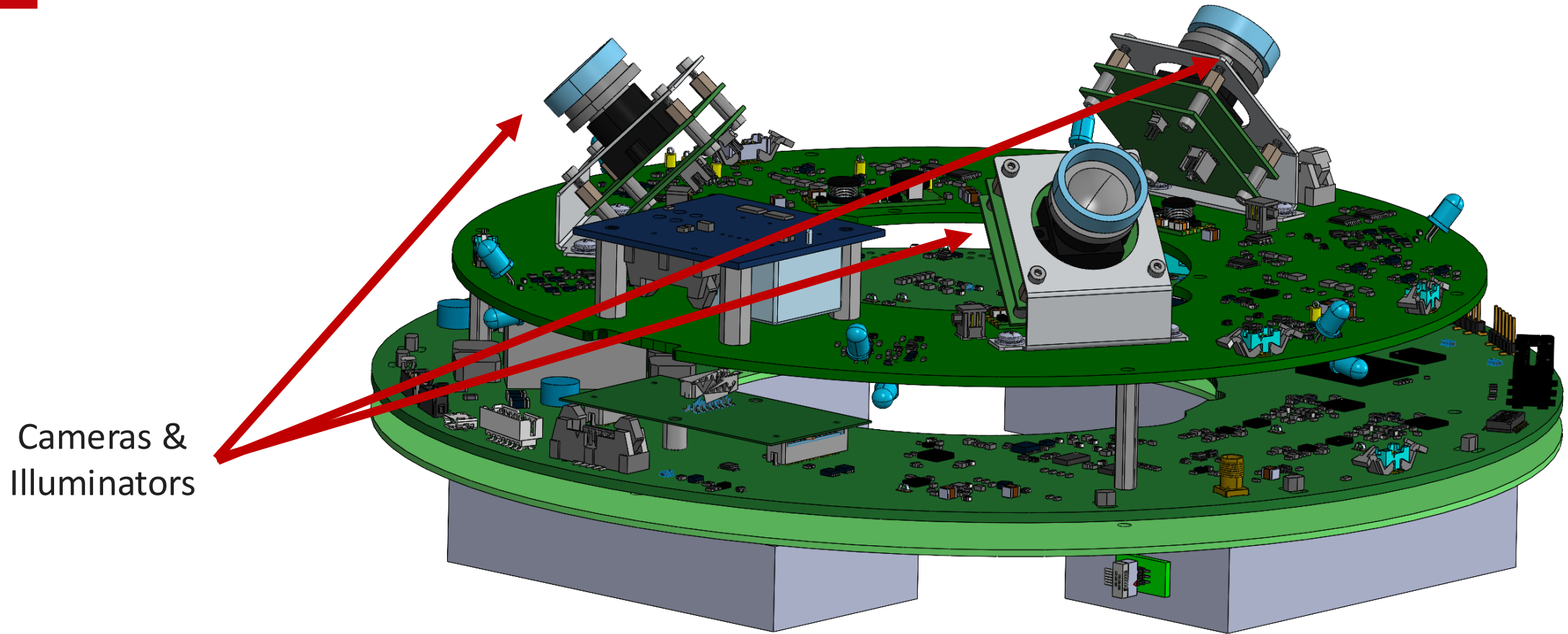


Simple Test Framework for FAT testing

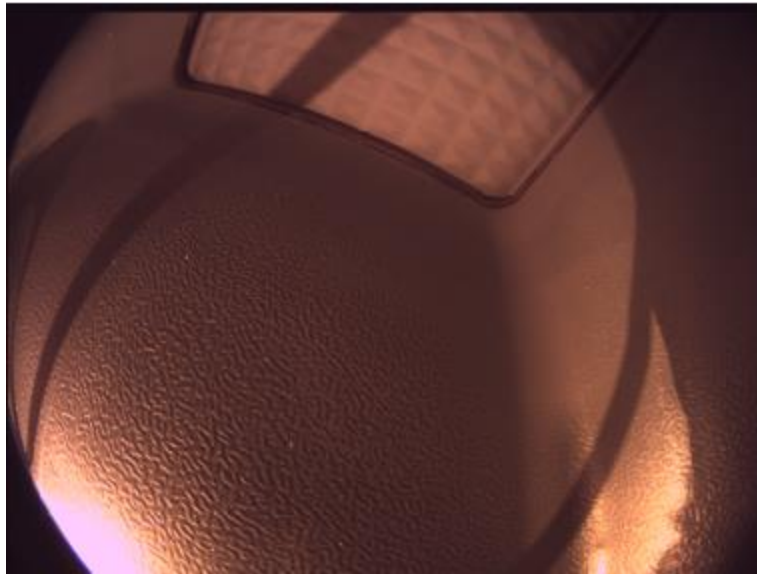
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PASS results/pDOM-FAT-01/2025.08.06_153343/pdom-a40000007f926442/ADCComms-channel-0-v1.0_pdom-a40000007f926442.json
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Summary: processed 50 files, outcome counts: {'FAIL': 1, 'PASS': 49}
```

- ADC Comms/Noise Level/Noise Spectrum/Test Patterns
- Acoustic Module
- Baseline stability
- Camera Communications
- FE Pulser Charge, Height, Linearity, Width
- Sensors – Light, Temperature, Pressure, Magnetometer
- HV Monitor & Stability
- Other FAT testing:
 - Camera testing
 - Gain curve

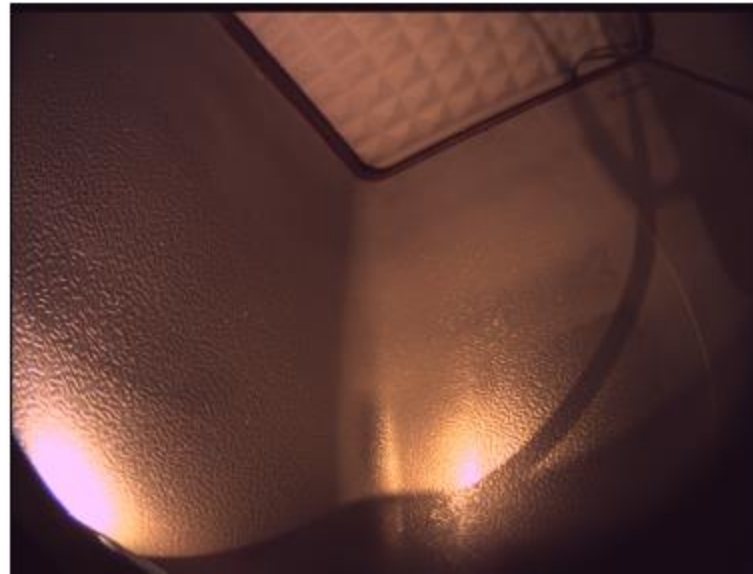
pDOM Camera & Illuminator tests



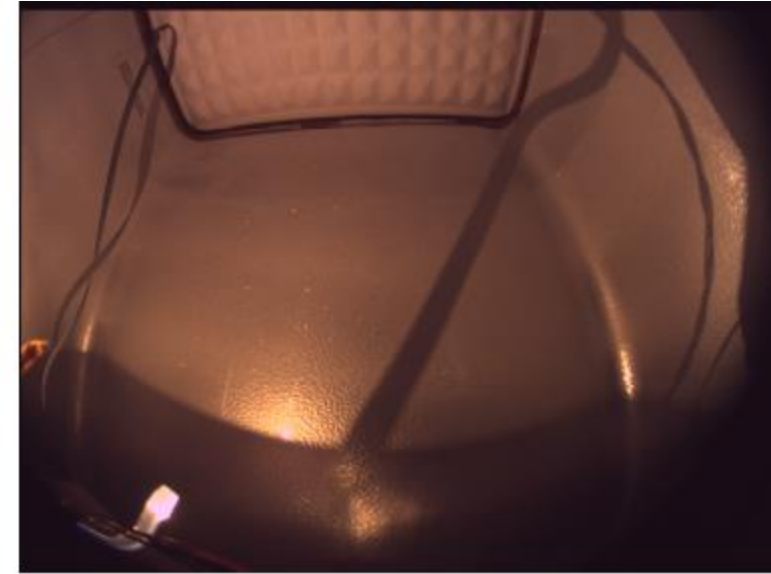
Camera & Illuminator DVTs at -30C



Camera 1



Camera 2



Camera 3

Gain = 2, exposure time = 30 ms, cross talk eliminated by additional series resistance in MOSI line

Camera & Illuminator FATs



Camera 1



Camera 2

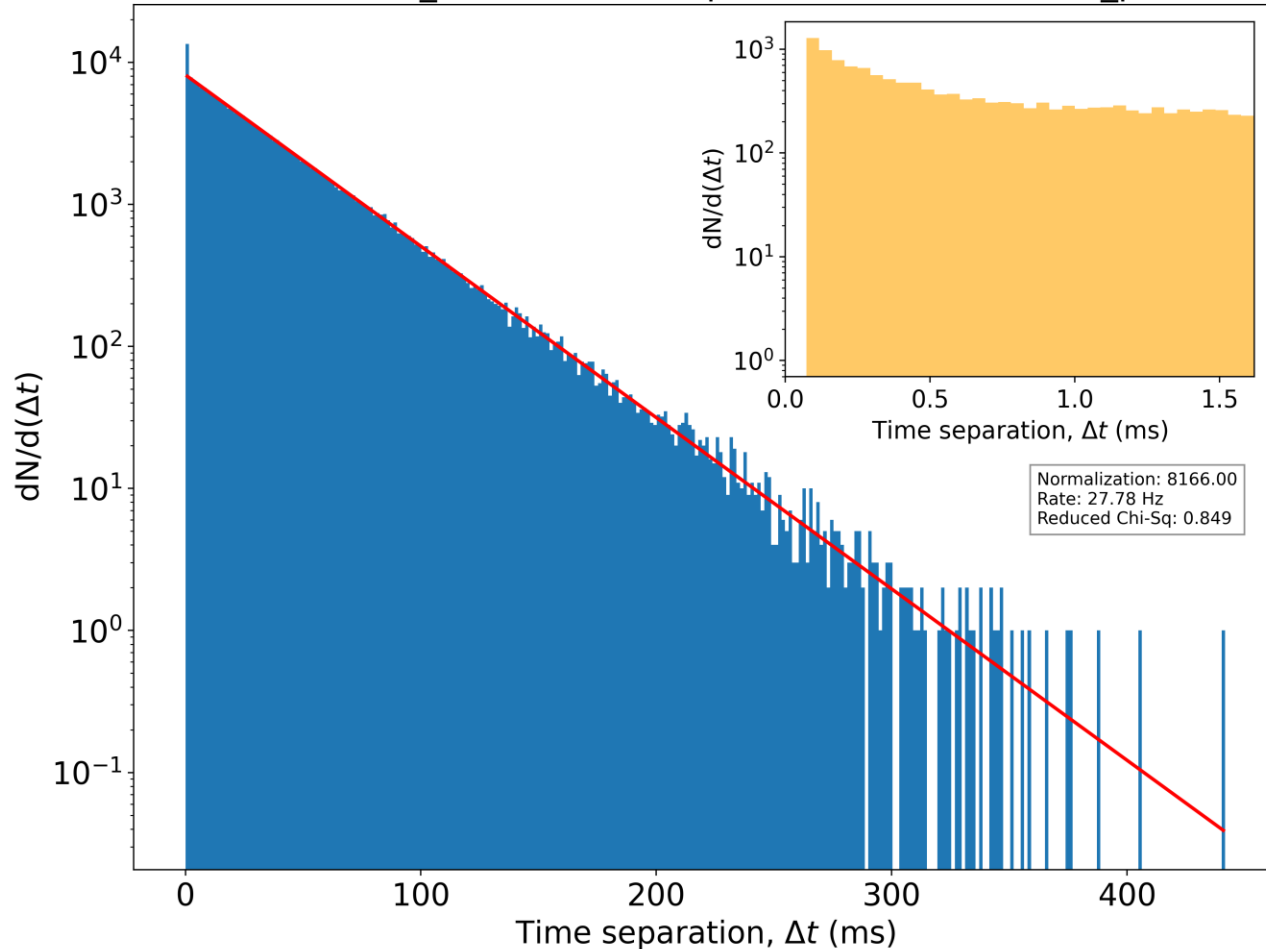


Camera 3

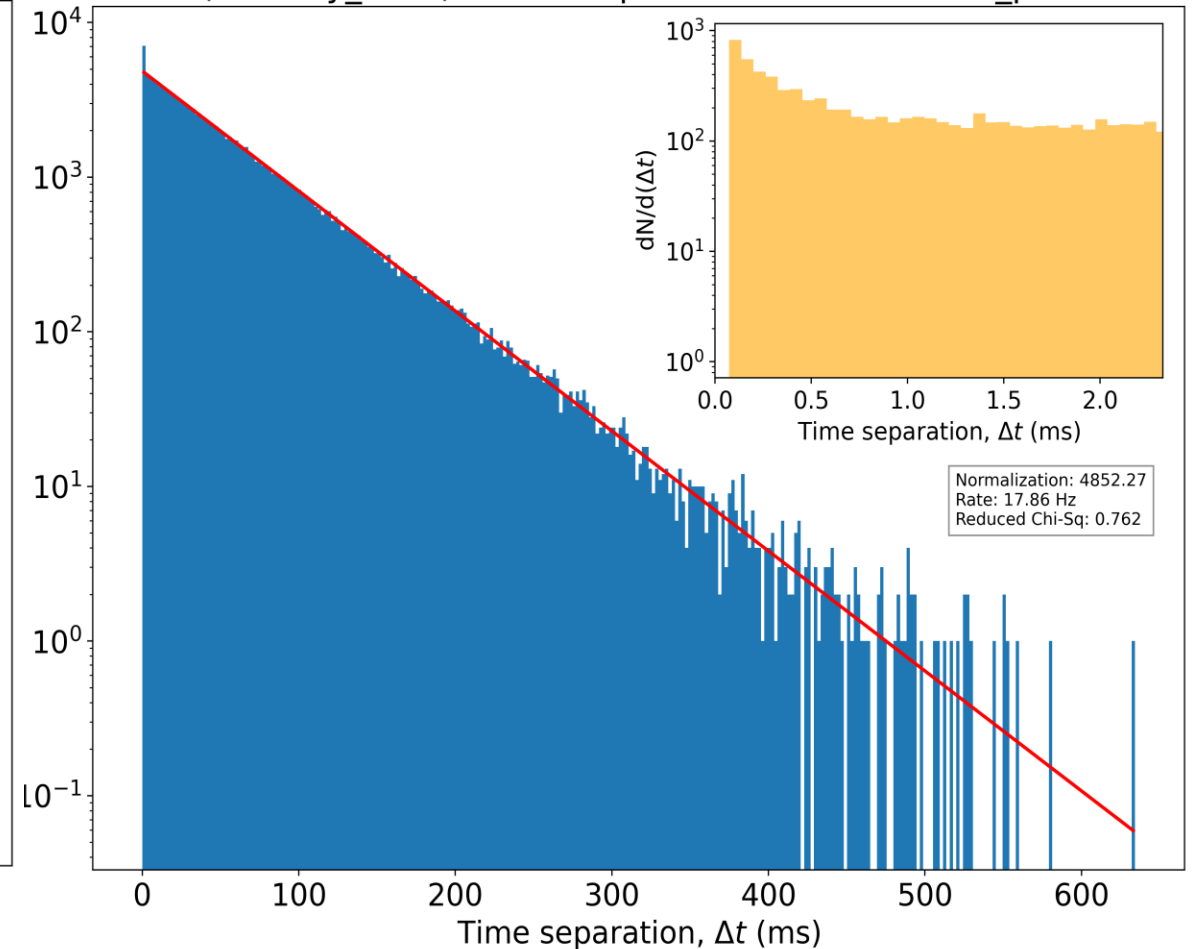
Gain = 2, exposure time = 30 ms (pictures from inside the black ESD bag – light sealed)

PDOM vs FOM – hit rate comparisons

PDOM (Precision_DOM): PMT Δt Spectrum for fieldhub89_port5031



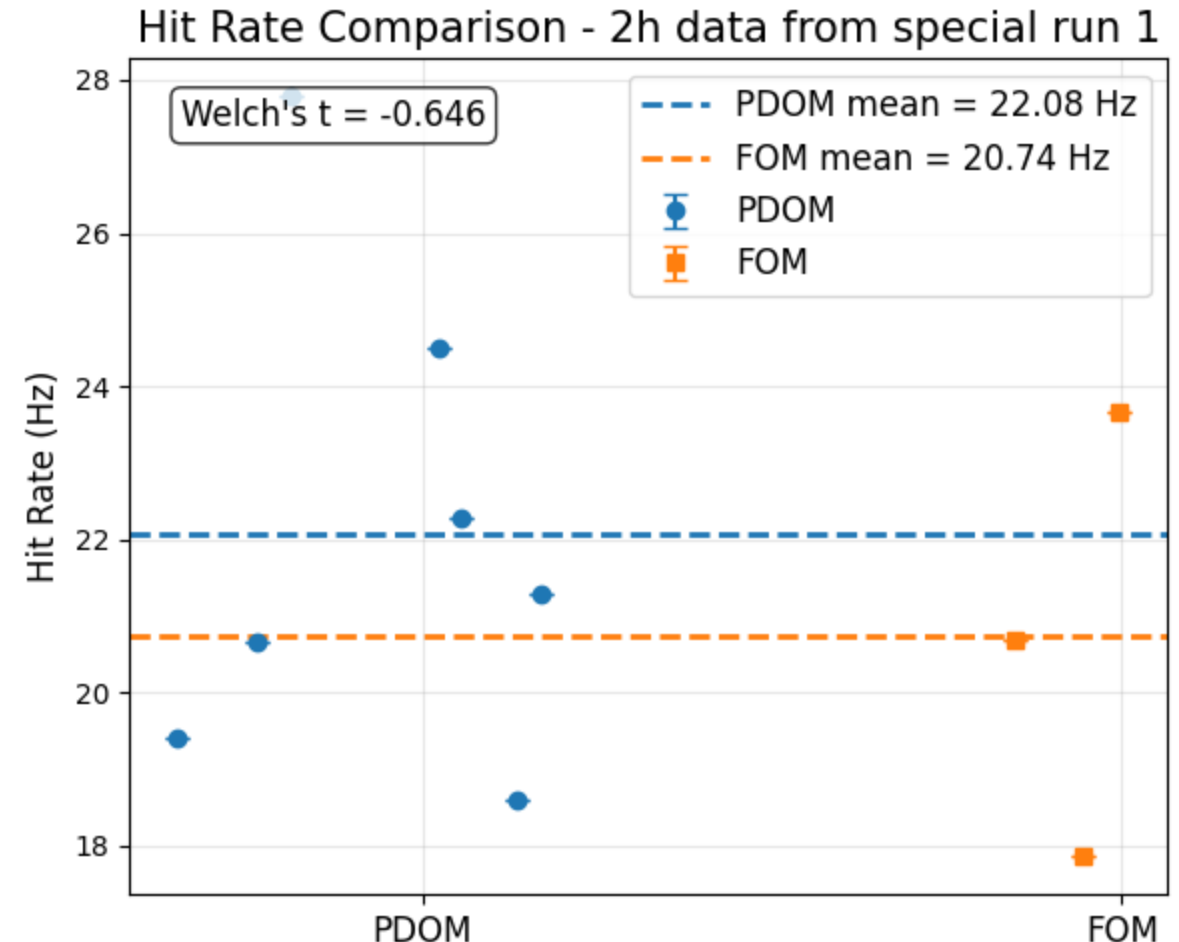
FOM (Faraday_DOM): PMT Δt Spectrum for fieldhub89_port5028



PMT Hit-Rates

- Does the FLC affect observed hit-rate statistics & pulse arrival process?

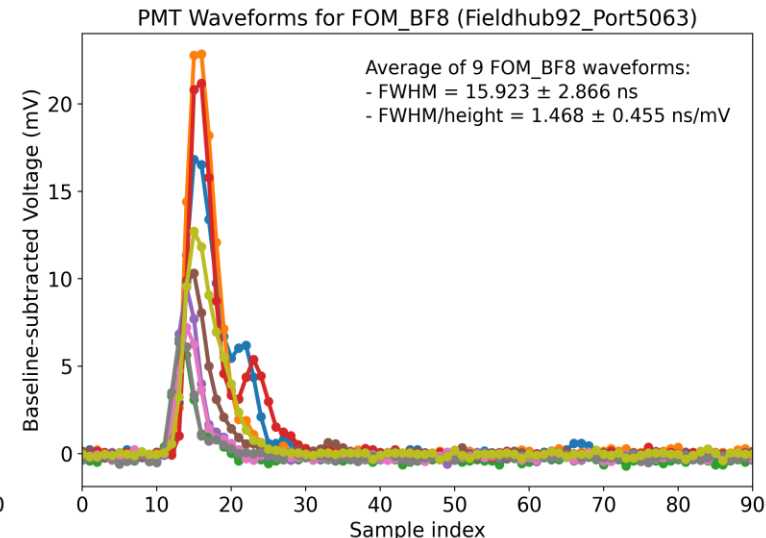
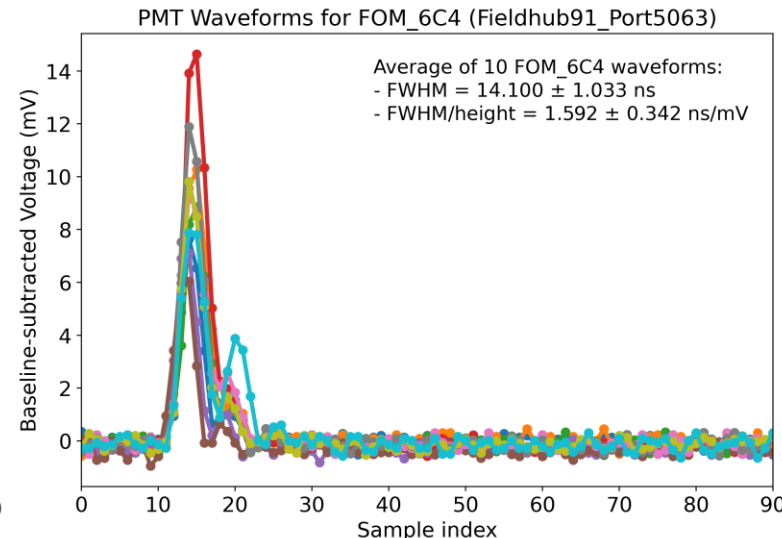
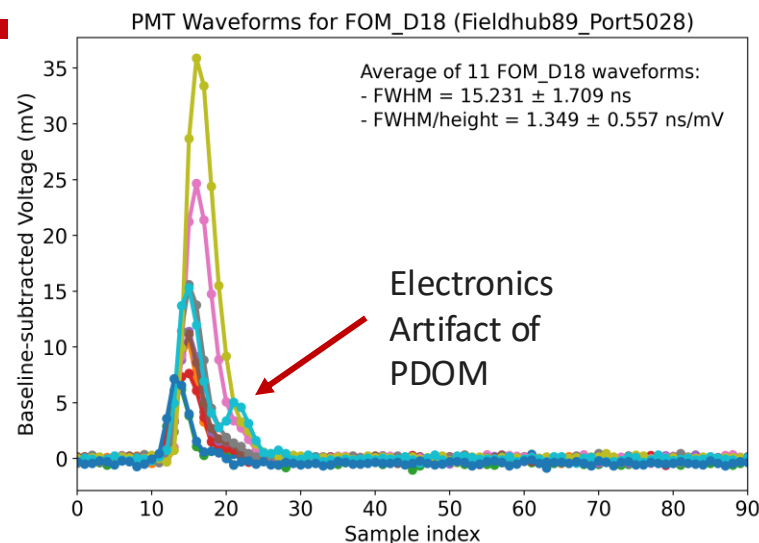
- $\langle \text{RFOM} \rangle \approx 20.74 \text{ Hz}$
- $\langle \text{RPDOM} \rangle \approx 22.08 \text{ Hz}$
- Δt spectra fit well by a single exponential
- Reduced $\chi^2 \approx 0.7\text{-}0.9$ for all DOMs
- The FLC does not noticeably alter PMT hit-rate statistics.
 - No obvious excess delayed component
 - No deviation from Poisson arrival statistics



Waveform Studies

Does the FLC introduce any additional time smearing?

FOM



PDOM

