

Integration of IceCube Upgrade Strings into the ICNO DAQ

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Presenter Background

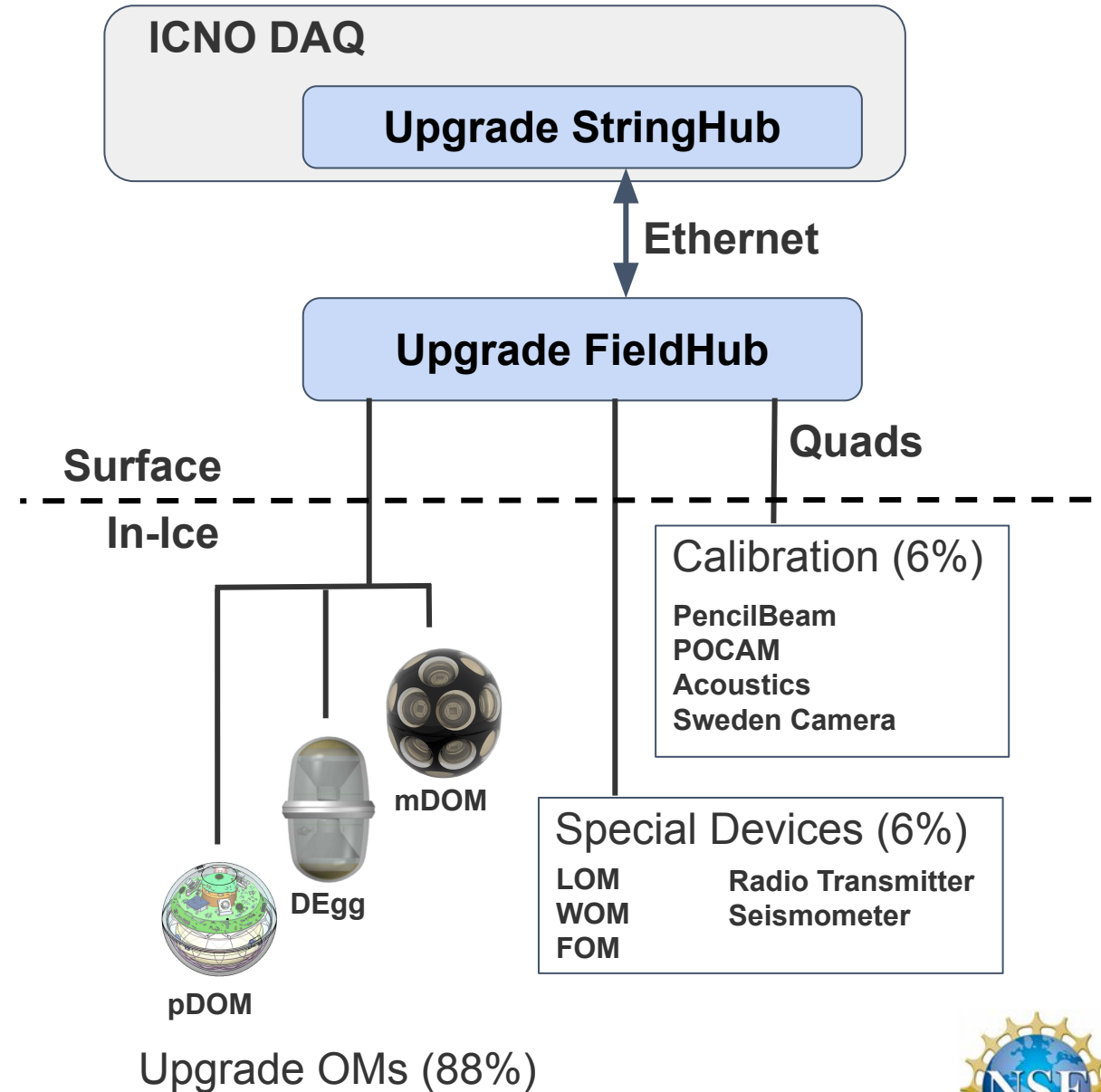
- Research scientist at WIPAC
- IceCube DAQ software manager
- L3 lead for Upgrade DAQ software
- Active in IceCube 2003–2010; 2013–present
- AMANDA/IceCube Ph.D 2009

Outline

- Overview of Upgrade String DAQ
- FieldHub and in-device DAQ components
- Integration of Upgrade into the ICNO DAQ
- Personnel and schedules
- Key challenges

Upgrade String Overview

- Most in-ice devices deployed by Upgrade are optical modules (OMs)
 - mDOM
 - DEgg
 - pDOM
- Four calibration devices and five special devices also deployed
- Upgrade FieldHub provides power, low-level communications, and timing for all Upgrade devices
- All Upgrade devices configured/read out by ICNO DAQ (exception: Sweden Camera, Seismometer)



Upgrade FieldHub

- Supports communications, power, and timing for an entire Upgrade string
 - 21 quads (42 wire pairs)
- Three main components:
 - FDOR: FPGA handles low-level control of each wire pair
 - FCON: UTC/White Rabbit timing module
 - FSEB: Single-board computer that implements user interface
- 1.5 Mbps total bandwidth per wire pair shared by typically three devices
- RAPCal calibrates each Upgrade device clock to within ~ 1 ns of UTC
- **fh_server** software runs on FieldHub FSEB SBC:
 - Provides a TCP/IP data socket for each connected Upgrade device
 - Provides access to control functions, e.g. enabling wire pair DC power



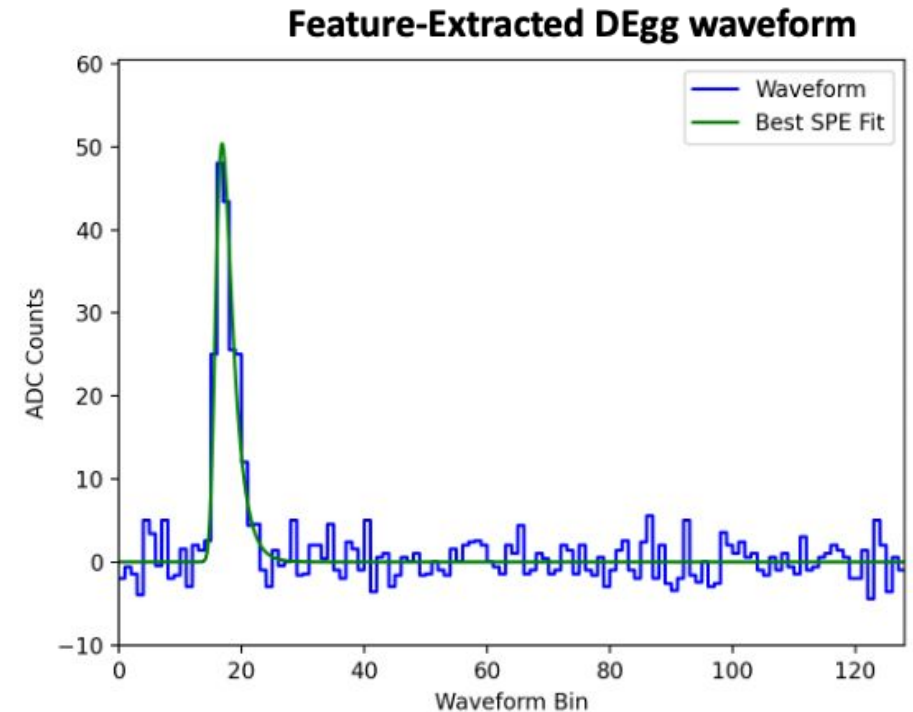
Upgrade In-Device Software

- All Upgrade devices controlled by STM32H743 microcontroller (MCU)
- **STM32Workspace**: Common software framework in GitHub allowed collaborative development of Upgrade MCU software
 - ~100,000 lines of Upgrade MCU code;
~3800 commits
- Core/common MCU software and support for Upgrade OMs delivered by WIPAC personnel
- Support for special devices largely delivered by device developers

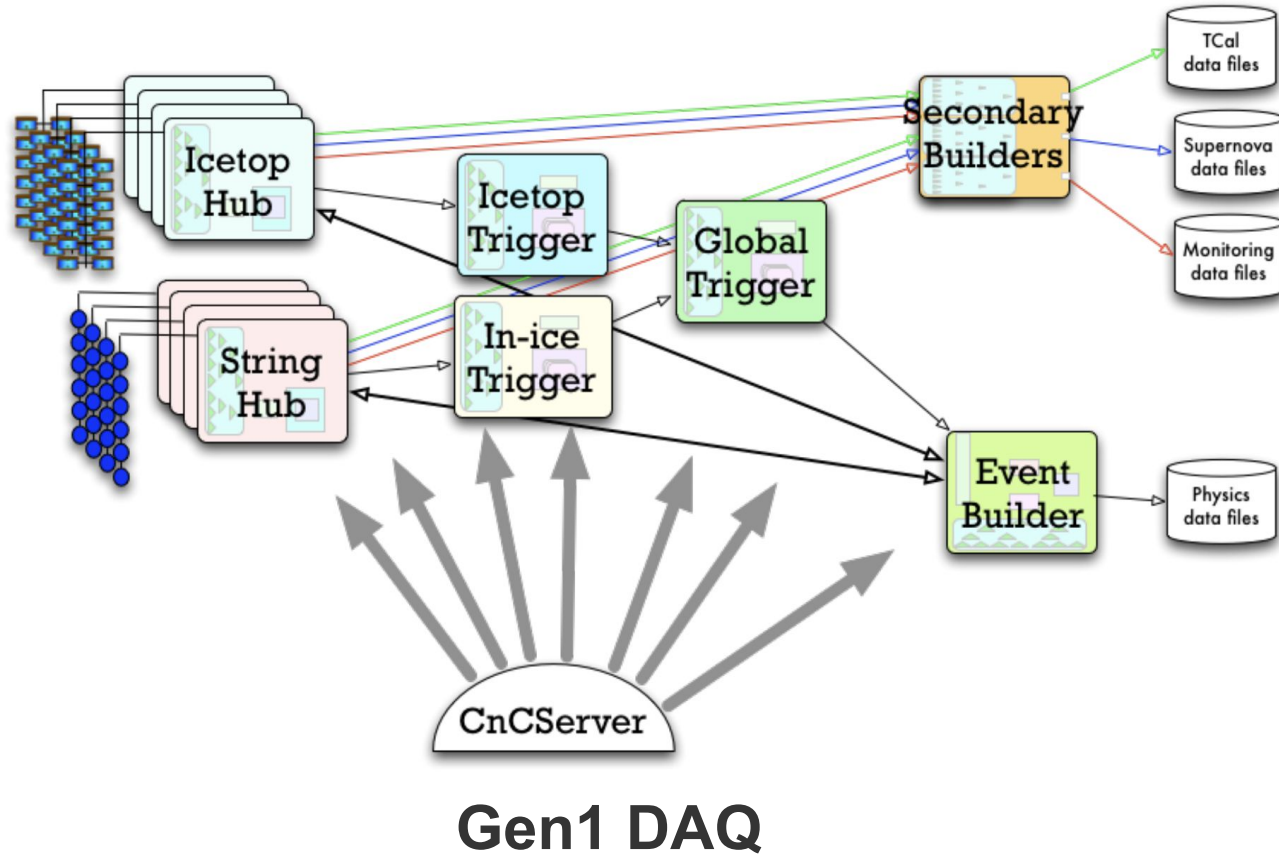


Upgrade In-Device DAQ Application

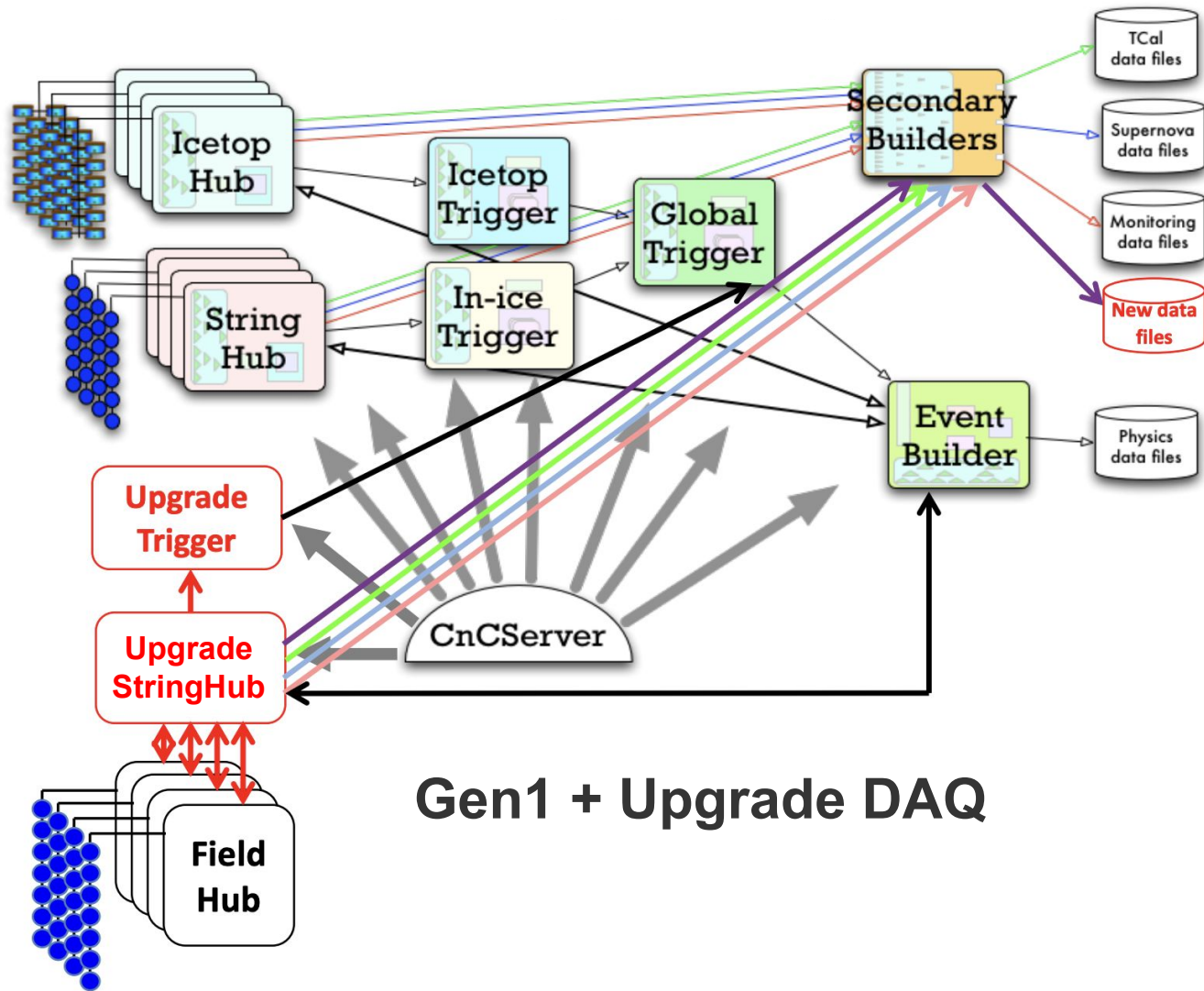
- ICNO DAQ communicates directly with in-device software
- **xDOMApp**: common MCU binary application used on all devices
 - Provides common application interface
 - Simplifies code maintenance and deployment operations
- Significant in-module data processing required
 - mDOM + mDOM + DEgg: ~40 kHz total PMT hit rate
 - 1.5 Mbps / 40 kHz → ~4.5 bytes per PMT hit can be sent to the surface
- Waveforms feature-extracted in-module
- Noise events from scintillation light cleaned/removed



Integration of Upgrade Strings Into ICNO DAQ



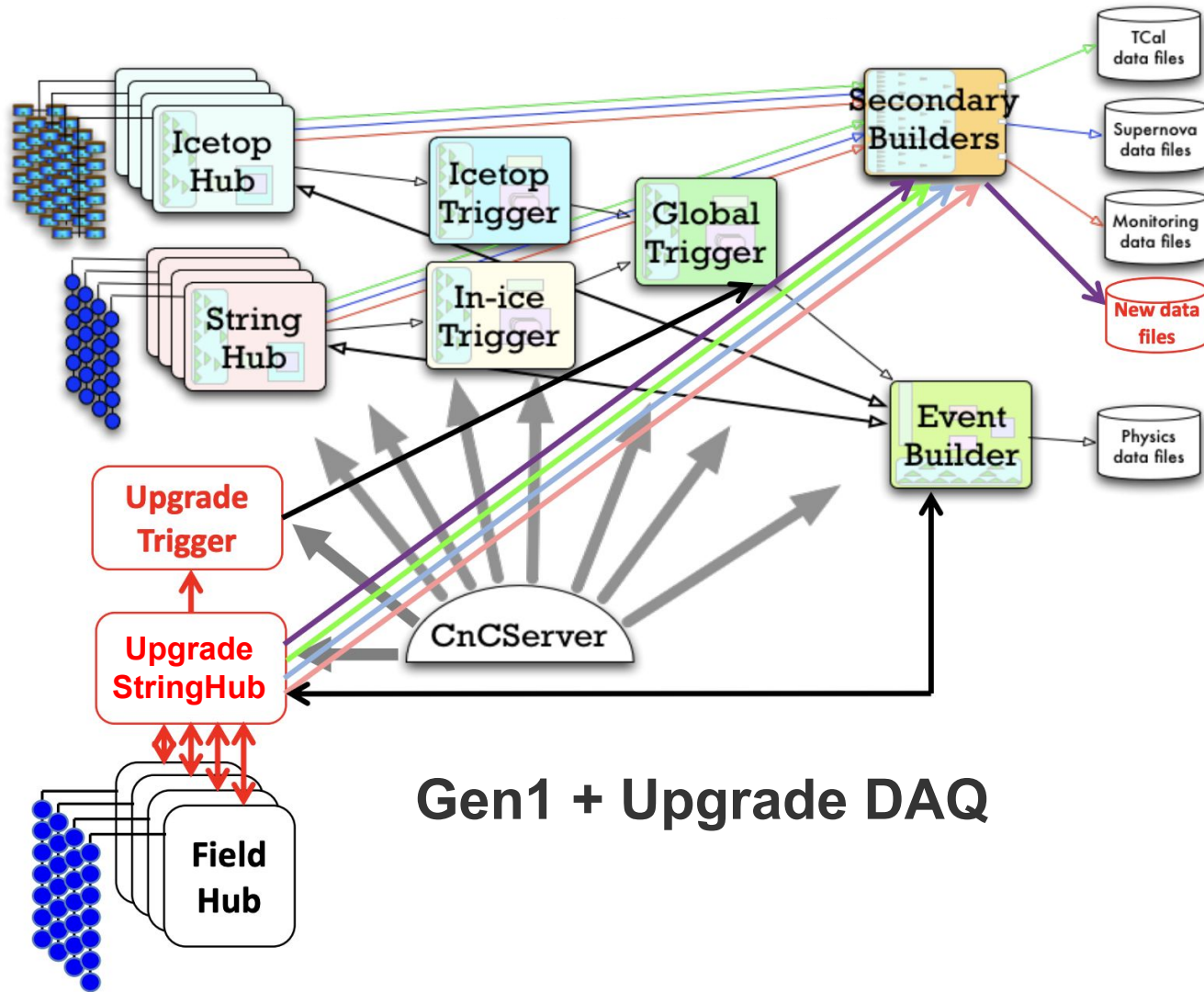
Integration of Upgrade Strings Into ICNO DAQ



Gen1 + Upgrade DAQ

- Support Upgrade within existing ICNO DAQ architecture
- Existing interfaces stay mostly the same
 - Data taken in runs/subruns
 - Combined Upgrade/Gen1 Physics event readout
- New components:
 - Upgrade StringHub
 - Upgrade Trigger
 - New output data streams supporting calibration/special devices

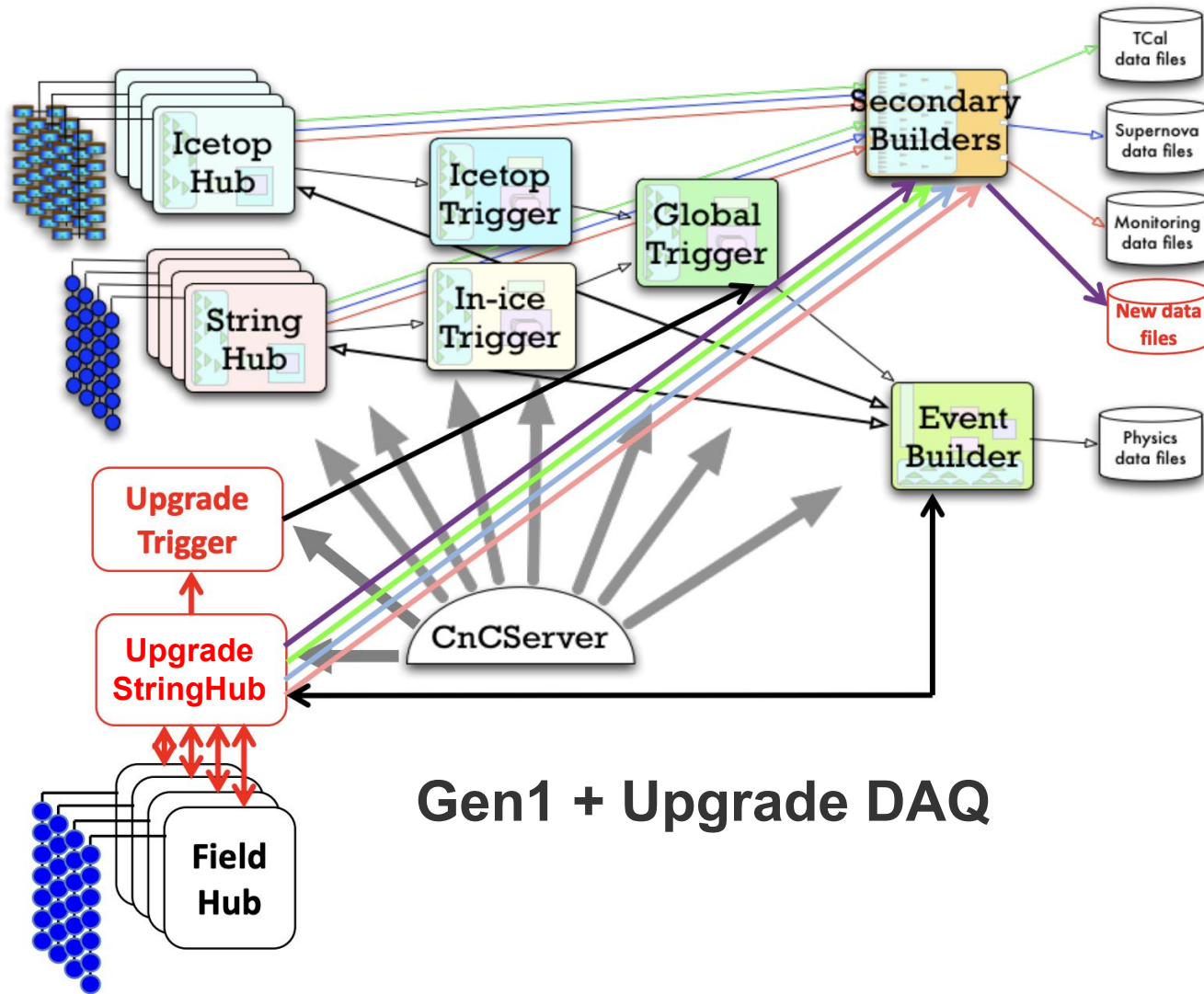
Upgrade StringHub



Gen1 + Upgrade DAQ

- One instance per FieldHub
 - Handles communications with xDOMApp running on each Upgrade device
 - Requests time calibration from FieldHub
- Runs on standard Linux server box
- Performs many of the same functions as Gen1 StringHub:
 - Conversion of device timestamp to UTC time
 - Time-sorting of data
 - HitSpool
- New functions
 - Generates supernova DAQ input data directly from hit data
 - Pre-trigger

Upgrade Trigger



Gen1 + Upgrade DAQ

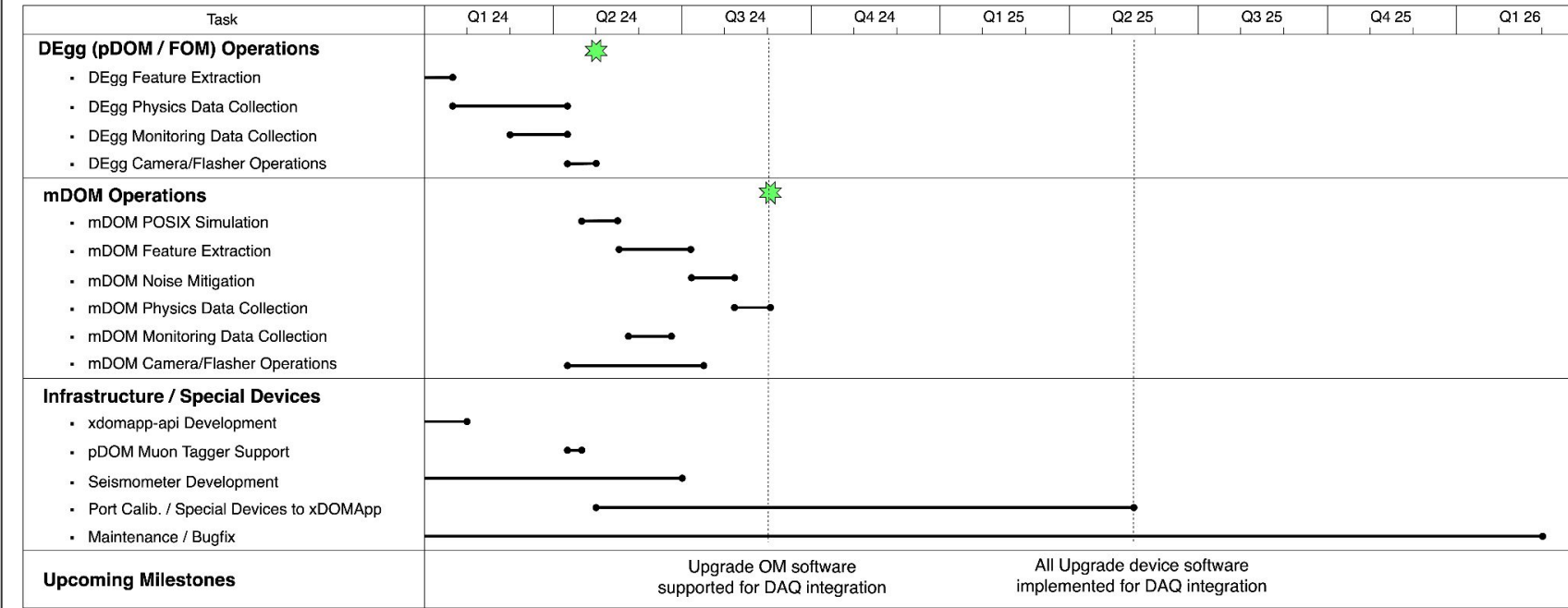
- Support Gen1 trigger algorithms
- Cross-triggering with Gen1 not required/supported
- Gen1 in-ice trigger uses only a fraction of hits (~450 kHz)
- Upgrade trigger will include many more hits, but total expected Upgrade hit rate of 8 MHz found to be too large
 - Upgrade StringHub pre-trigger will reduce hit rate to trigger to ~3 MHz

Personnel

- Jim Braun: ICNO DAQ Software Manager / L3 for Upgrade DAQ Software
- ICNO DAQ: (~1.5 FTE)
 - Tim Bendfelt
 - Mirko Kugelmeier
- FieldHub software:
 - John Kelley
- In-ice device software (~1 FTE+):
 - John Jacobsen
 - Jim Braun
 - Jeff Weber
 - Software controlling unique hardware on calibration/special devices contributed by device developers

Device/FieldHub Software Schedule

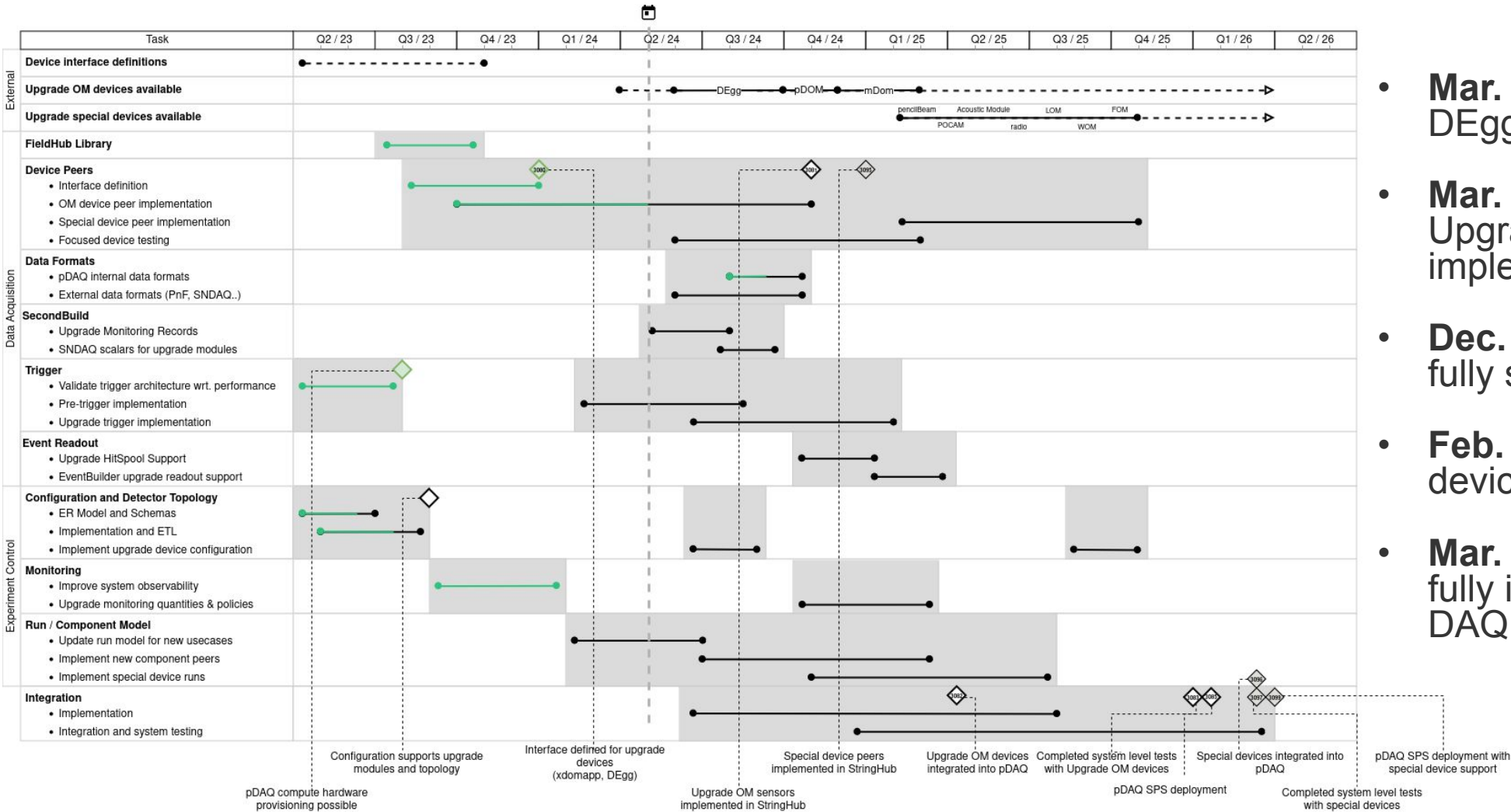
Upgrade in-device MCU software schedule



- Bulk of device software already written in support of device testing
- Current work focusing on DAQ integration
- **May 2024:** DEgg fully supported
- **Sep. 2024:** Upgrade OMs fully supported
- **May 2025:** All Upgrade devices fully supported

- Upgrade FieldHub software largely complete in support of device testing
- **Nov 2024:** FieldHub software fully supports DAQ operations

ICNO DAQ Upgrade Software Schedule



- **Mar. 2024:** Integration with DEgg began
- **Mar. 2025:** Readout of Upgrade OMs fully implemented
- **Dec. 2025:** Upgrade OMs fully supported
- **Feb. 2026:** All Upgrade devices fully supported
- **Mar. 2026:** Upgrade strings fully integrated into ICNO DAQ



Addressing Key Challenges

- 1. Cable bandwidth:** 1.5 Mbps wire pair bandwidth shared by three devices
 - Requires feature extraction / cleaning of raw data before transmission to surface
 - Assigned additional effort to Upgrade OM in-device software
- 2. Support of diverse Upgrade in-ice hardware**
 - Each device type requires unique in-module software to support device-specific hardware
 - Most devices require unique ICNO DAQ configuration, operations, and data handling
 - Common software framework/single in-device application simplifies development and M&O
 - Early reviews of device operations has ensured compatibility with ICNO DAQ plans
- 3. Effort:** Most personnel also involved in day-to-day ICNO M&O
 - Gen1 experience has been key in developing Upgrade software
 - Prioritize Upgrade OMs, then calibration devices to minimize risk

Summary

- Software support for Upgrade FieldHub and Upgrade OMs nearly complete
- Design of Upgrade DAQ components is complete, and effort to support Upgrade strings in the ICNO DAQ is well-underway
- We are on-schedule to support integration of Upgrade strings by March 2026