Integration of IceCube Upgrade Strings into the ICNO DAQ

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NSF Mid-Term Review
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IceCube
South Pole Neutrino Observatory

NSF

Presenter Background

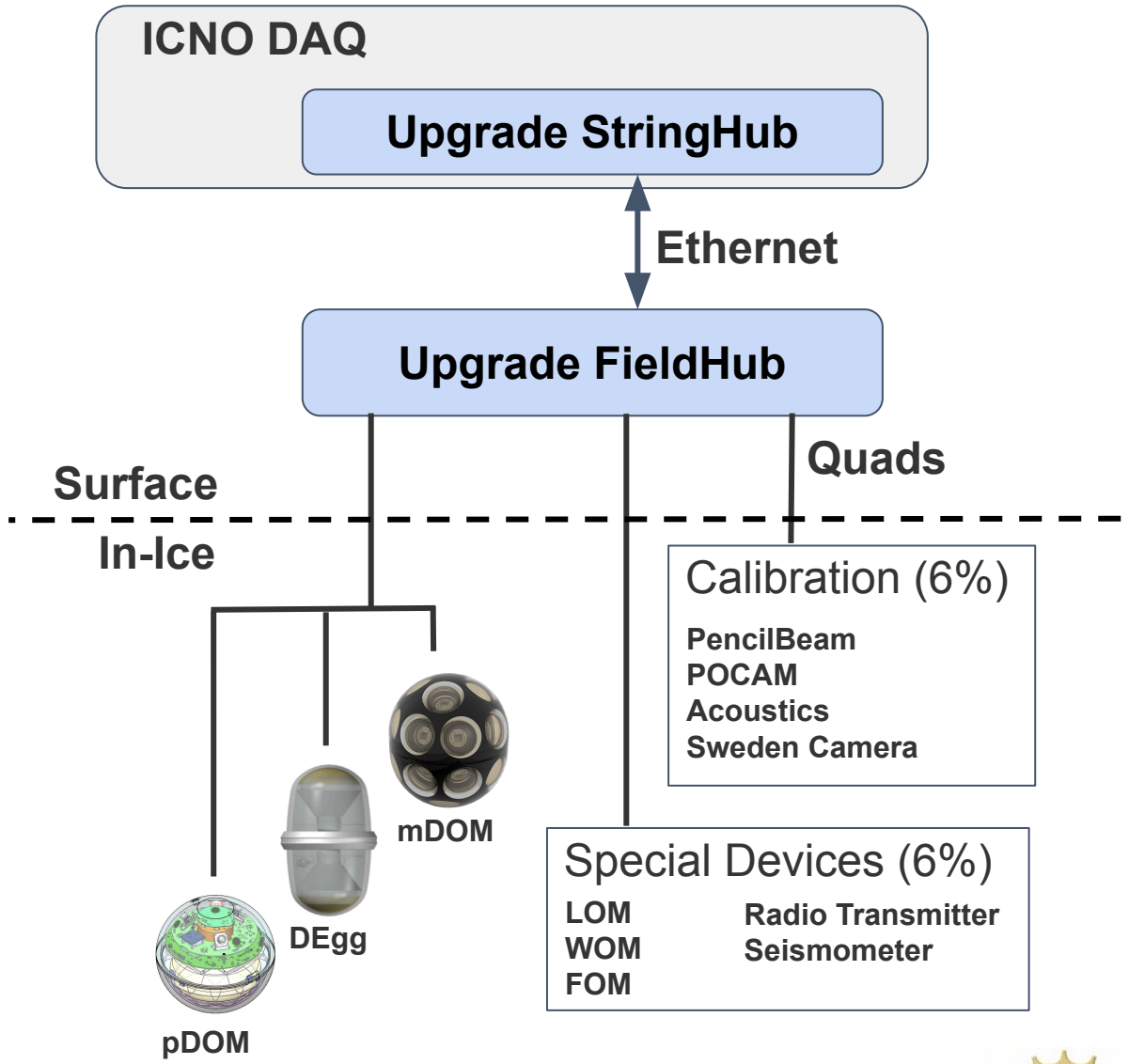
- Research scientist at WIPAC
- IceCube DAQ software manager
- L3 lead for Upgrade DAQ software
- Active in IceCube 2003–2010; 2013–present
- AMANDA/IceCube PhD 2009

Outline

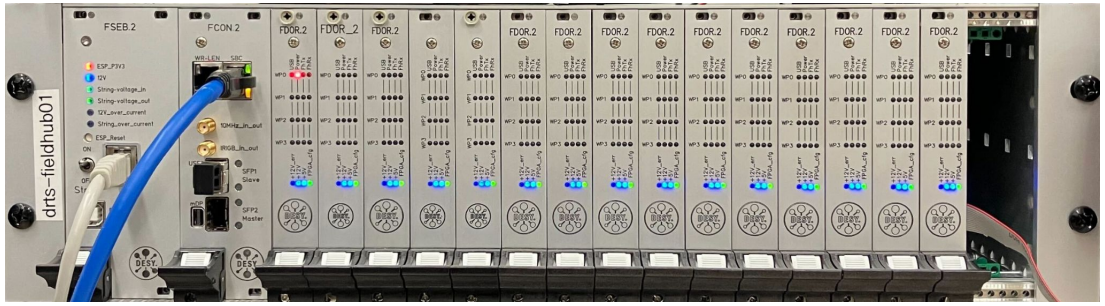
- Overview of Upgrade String DAQ
- Upgrade FieldHub
- In-device Upgrade DAQ software
- Review of ICNO DAQ
- Integration of Upgrade into the ICNO DAQ
- Personnel and schedules
- Key challenges

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



- Provides communications, power, and timing for an entire Upgrade string
  - 21 quads (42 wire pairs)
- Three main components:
  - FDOR (x12): FPGA handles low-level communications/control of two quads (four wire pairs)
  - FSEB: DC power supplies and monitoring single-board computer (SBC)
  - FCON: UTC/White Rabbit timing module and control SBC
- 1.5 Mbps total bandwidth per wire pair, typically shared by three devices
- RAPCal calibrates each Upgrade device clock to within ~1 ns of UTC
- **fh_server** software runs on FieldHub FCON control SBC:
  - Data ports: TCP/IP data socket for each connected Upgrade device
  - Control port: 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

- WIPAC personnel deliver:
  - MCU software framework
  - Core/common MCU software
  - All software for for Upgrade OMs
  - Data-taking application (xDOMApp)

- Calibration/special devices contain unique/diverse hardware
  - Device developers write custom device software within WIPAC software framework

Upgrade In-Device DAQ Application

- ICNO DAQ communicates directly with in-device software through Upgrade FieldHub data socket
- **xDOMApp**: common MCU binary application used on all devices
  - Provides common application interface for all devices
  - Simplifies code maintenance and deployment operations
- Significant in-module data processing required due to wire pair bandwidth
  - Typical Upgrade wire pair: mDOM + mDOM + DEgg

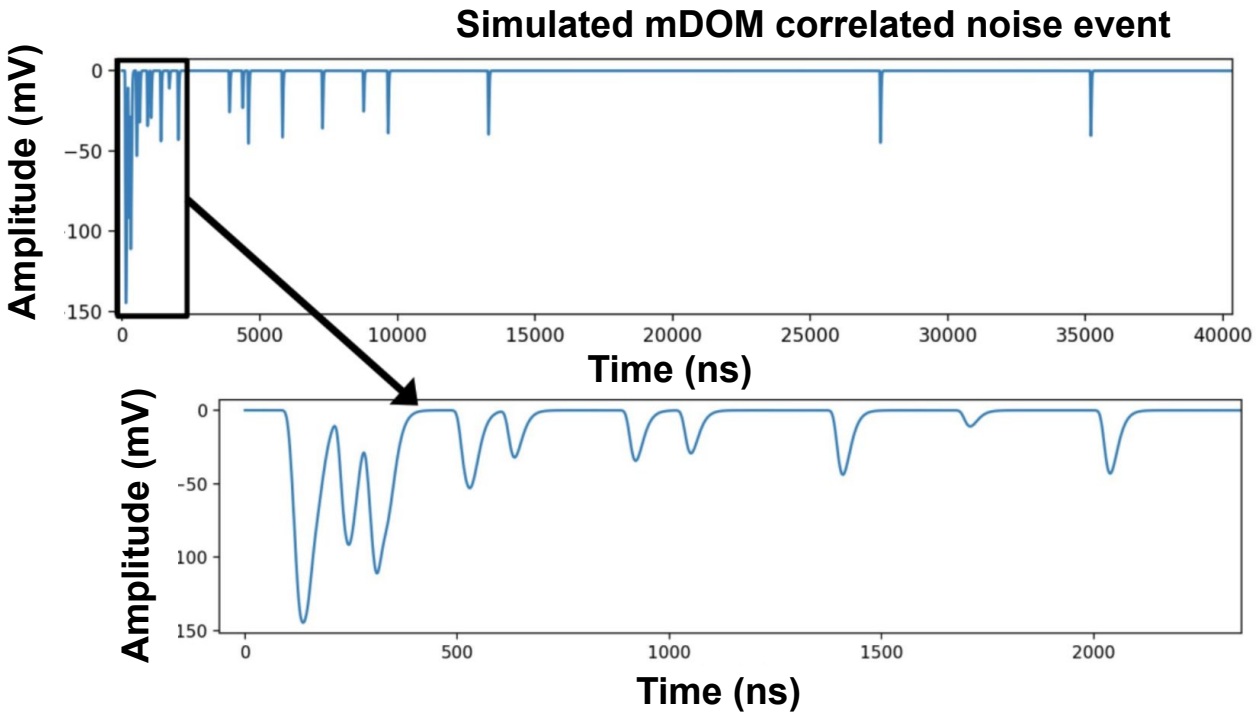
    → ~40 kHz total PMT hit rate
  - Compare to Gen1: ~1 kHz per wire pair, same bandwidth
  - 1.5 Mbps / 40 kHz → ~4.5 bytes per PMT hit can be sent to the surface

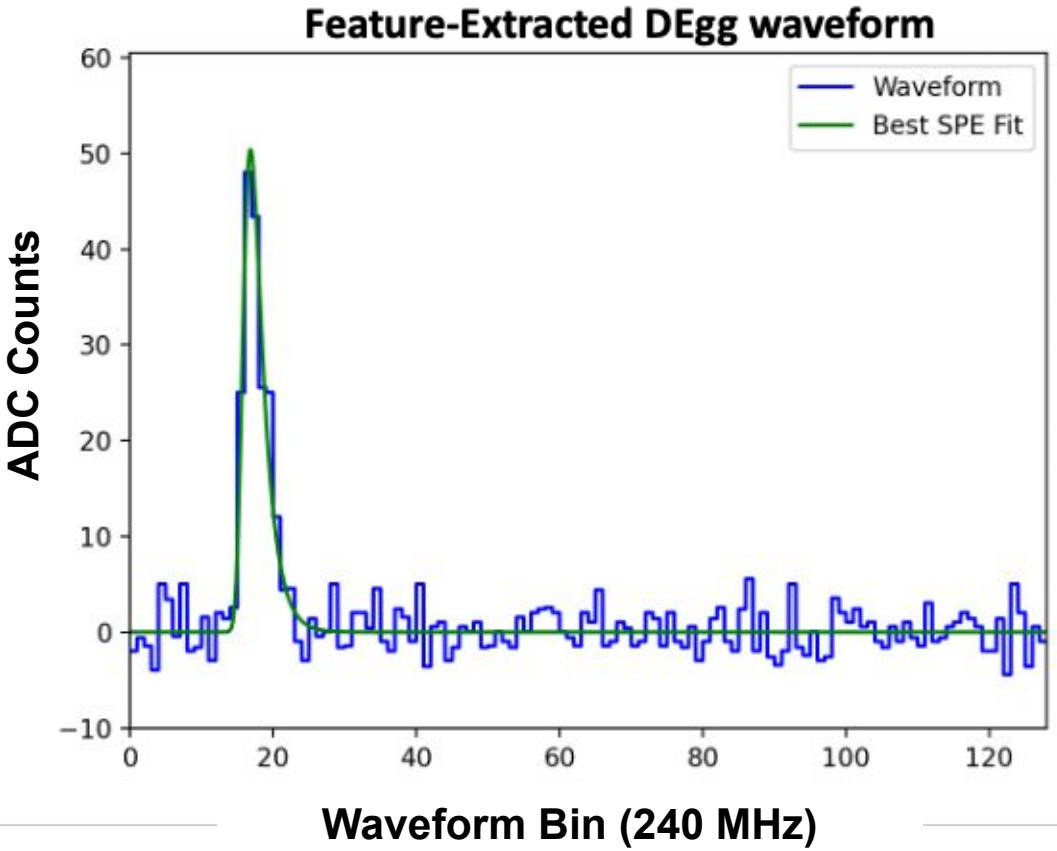
Upgrade In-Device Data Processing

- Waveforms are feature-extracted in-module:

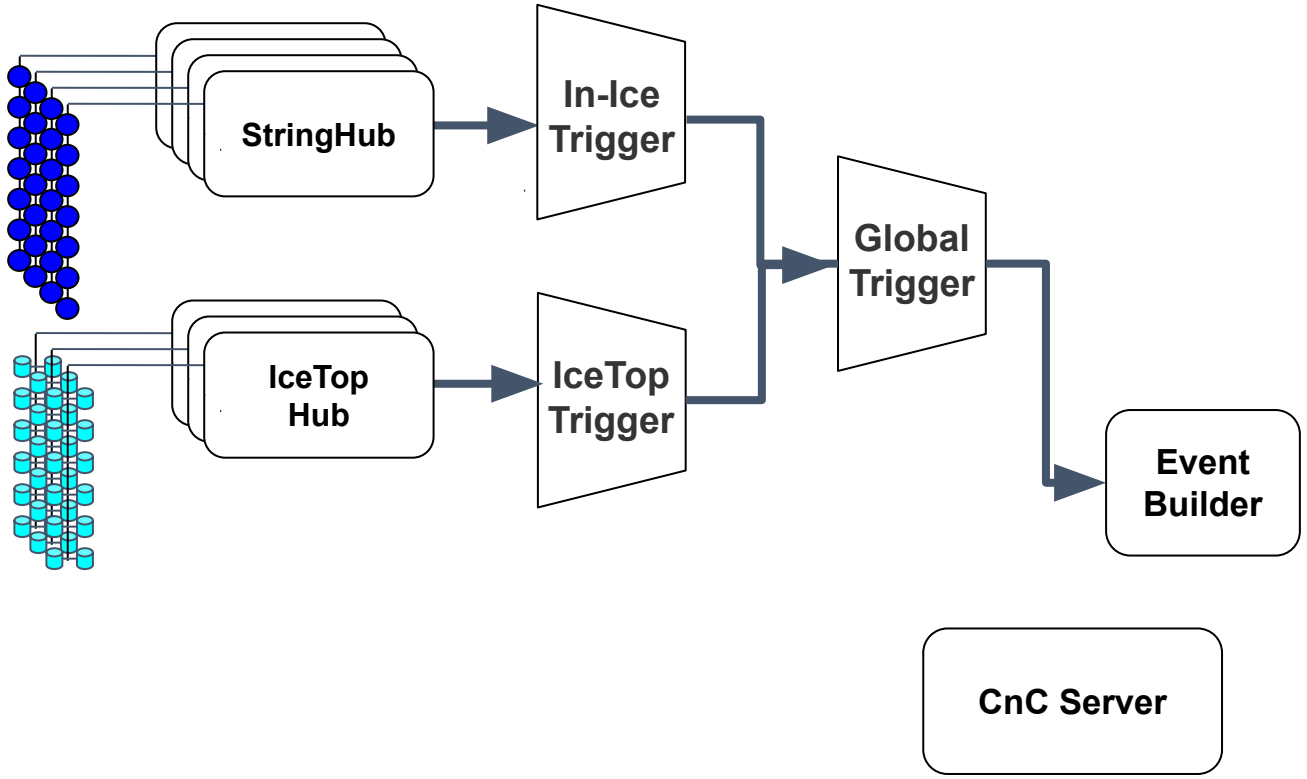
  ADC waveform → (PMT channel, charge, time)

- Noise events due to correlated light from radioactive decay are identified in mDOM data and compressed



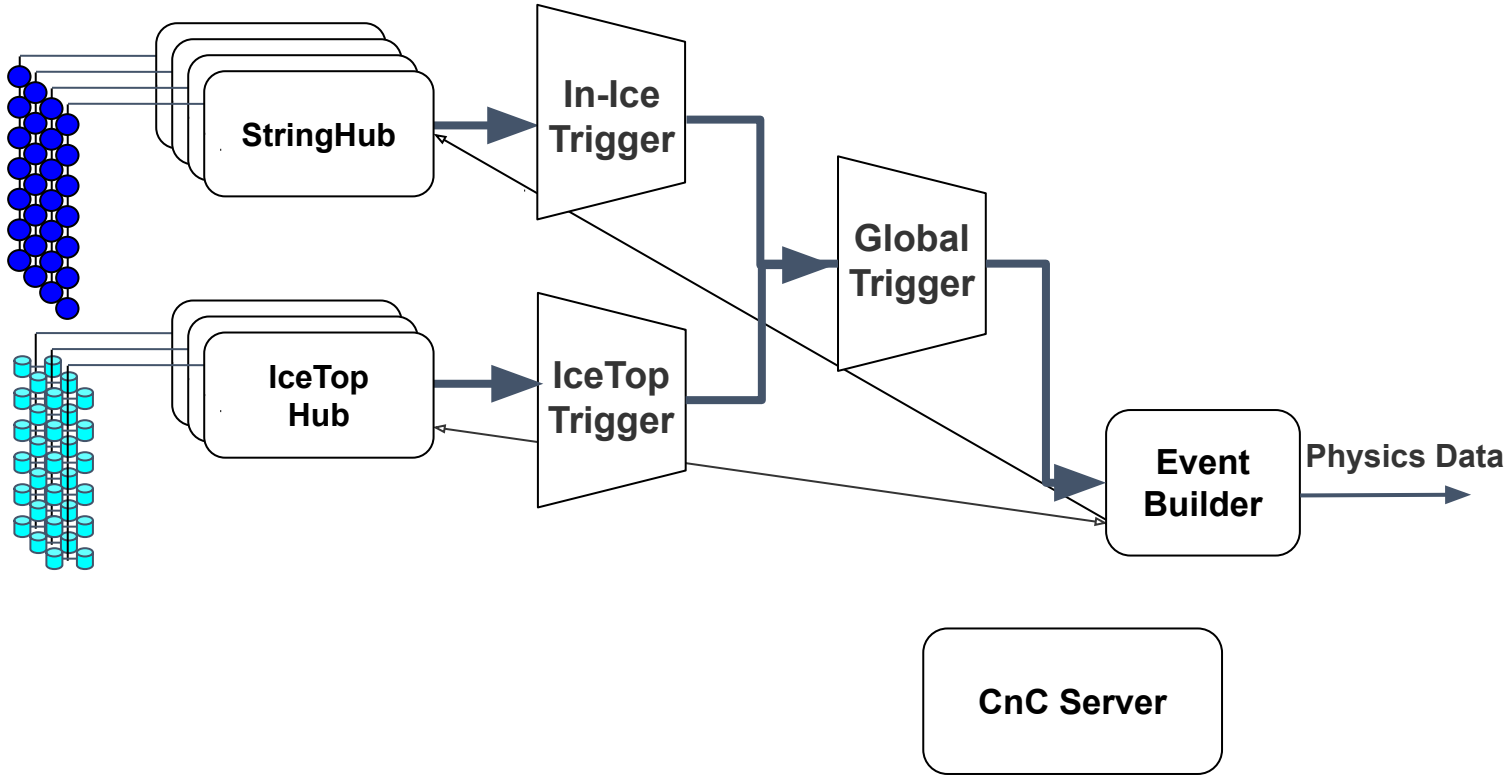


Review of ICNO DAQ



- Hit data read out by StringHub/IceTop Hub
- Fraction of hits passed to trigger algorithms
- Triggers merged by Global Trigger

Review of ICNO DAQ



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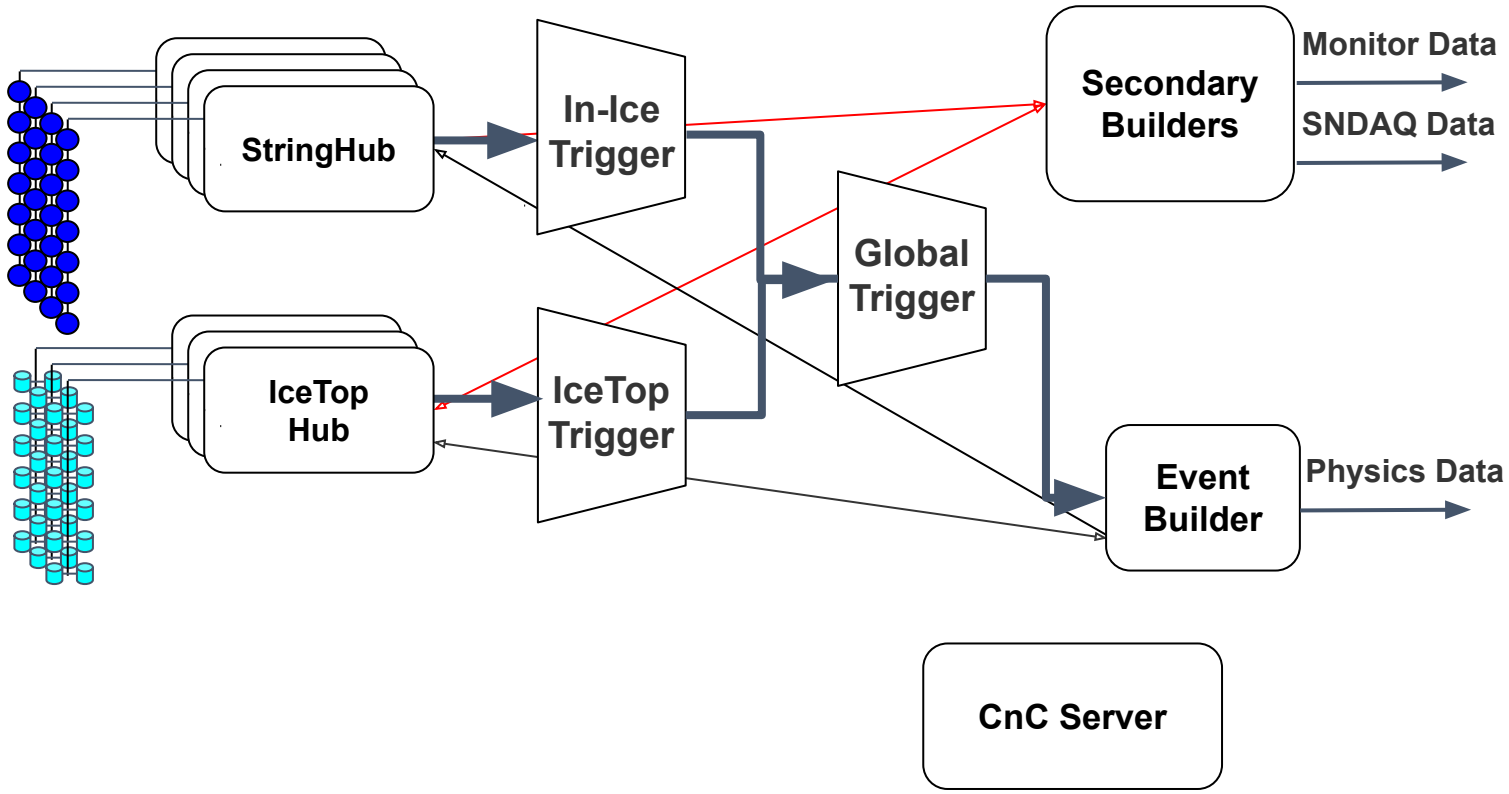
Review of ICNO DAQ



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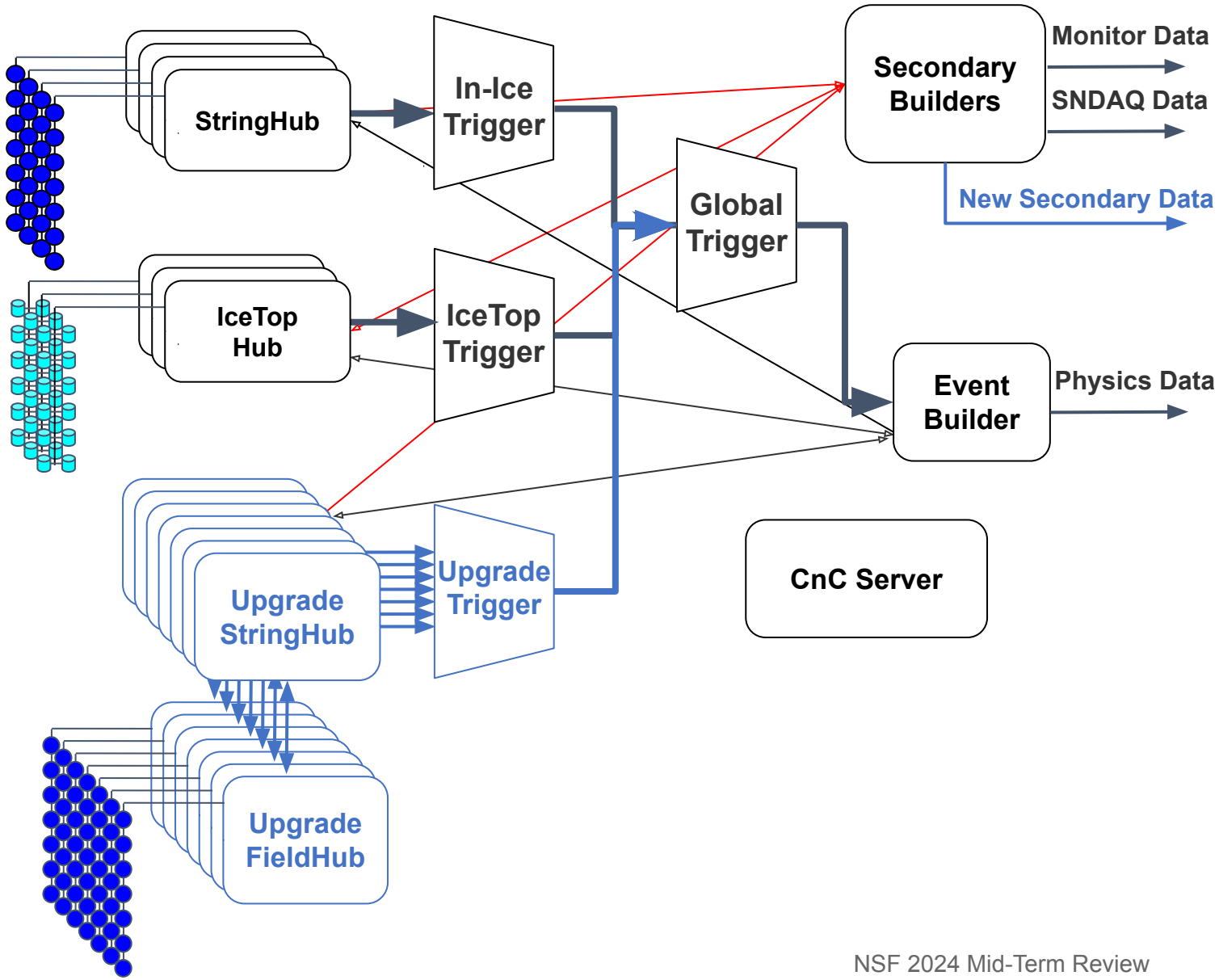
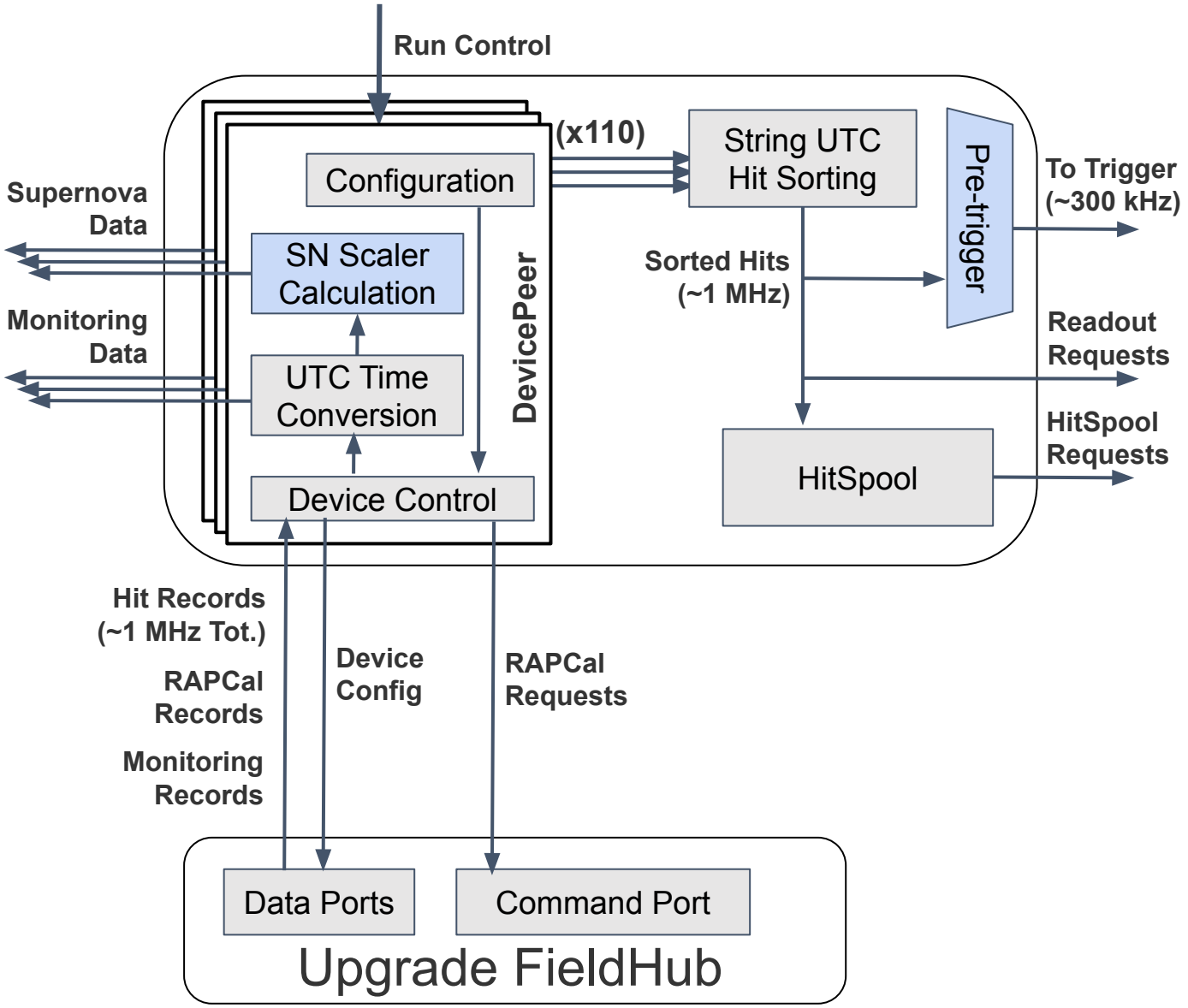
- Fraction of hits passed to trigger algorithms
- Triggers merged by Global Trigger
- Event Builder requests hit data readout for all hits corresponding to triggers; writes physics data files
- Monitoring and SNDAQ “secondary” data written to separate files

Integration of Upgrade Strings Into ICNO DAQ



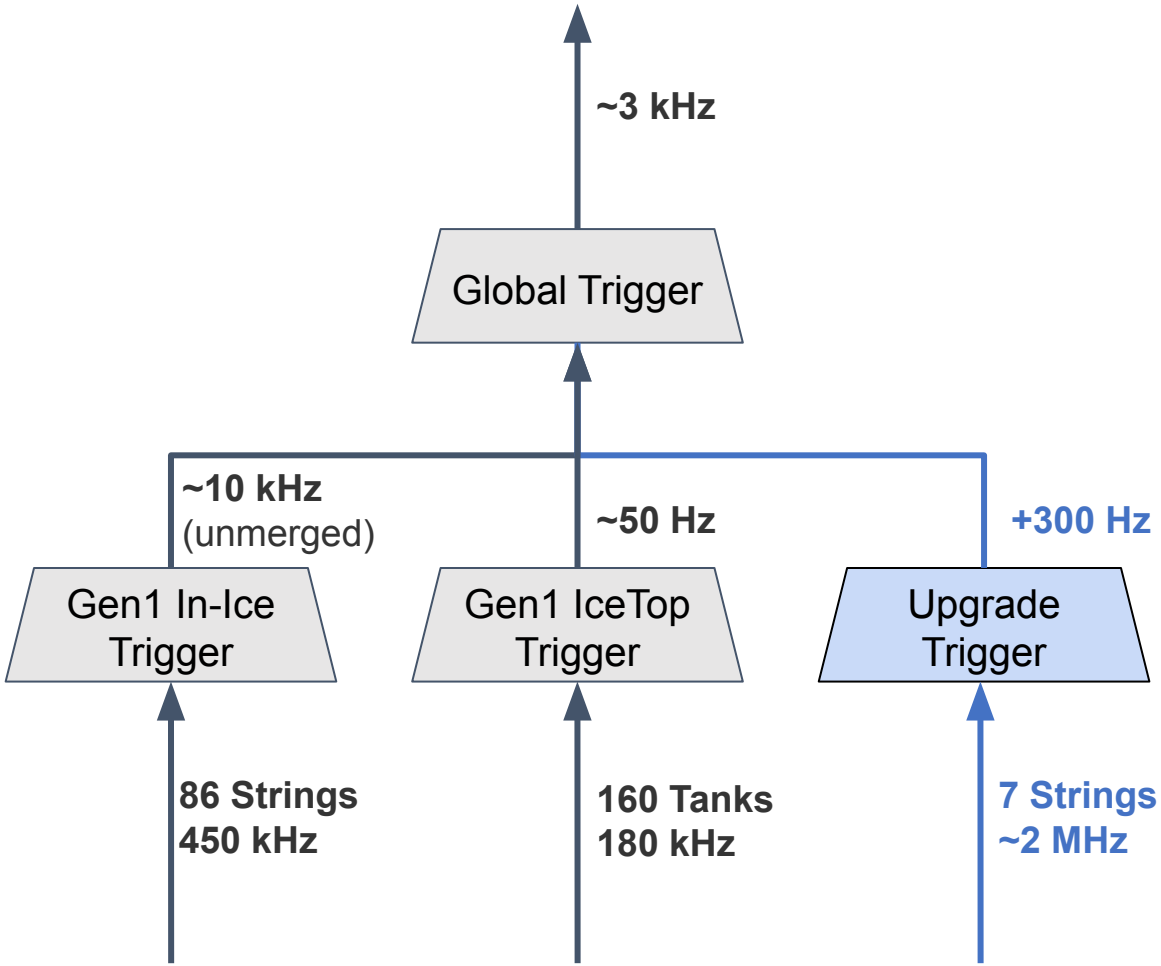
- Add new Upgrade components within ICNO DAQ architecture
- Existing interfaces stay mostly the same
- New components:
  - Upgrade StringHub
  - Upgrade Trigger
- New secondary data streams
  - Camera images
  - Acoustic waveforms
  - POCAM/PencilBeam flash intensity monitoring, etc.
- Identification/refactoring of Gen1-specific code

Upgrade StringHub



- Runs on standard Linux server
- One instance per FieldHub
- Design analogous to Gen1 StringHub
- One **DevicePeer** instance per device (~110 devices/string)
  - Custom for each device type
  - Isolates device-specific interface
  - Initializes/configures/reads out device
  - Requests RAPCal time calibration
  - Converts hit timestamp to UTC
  - New: Calculates SNDAQ scaler data
- Sorts all string hits by UTC time for triggering/HitSpool
- New: Pre-trigger

Upgrade Trigger



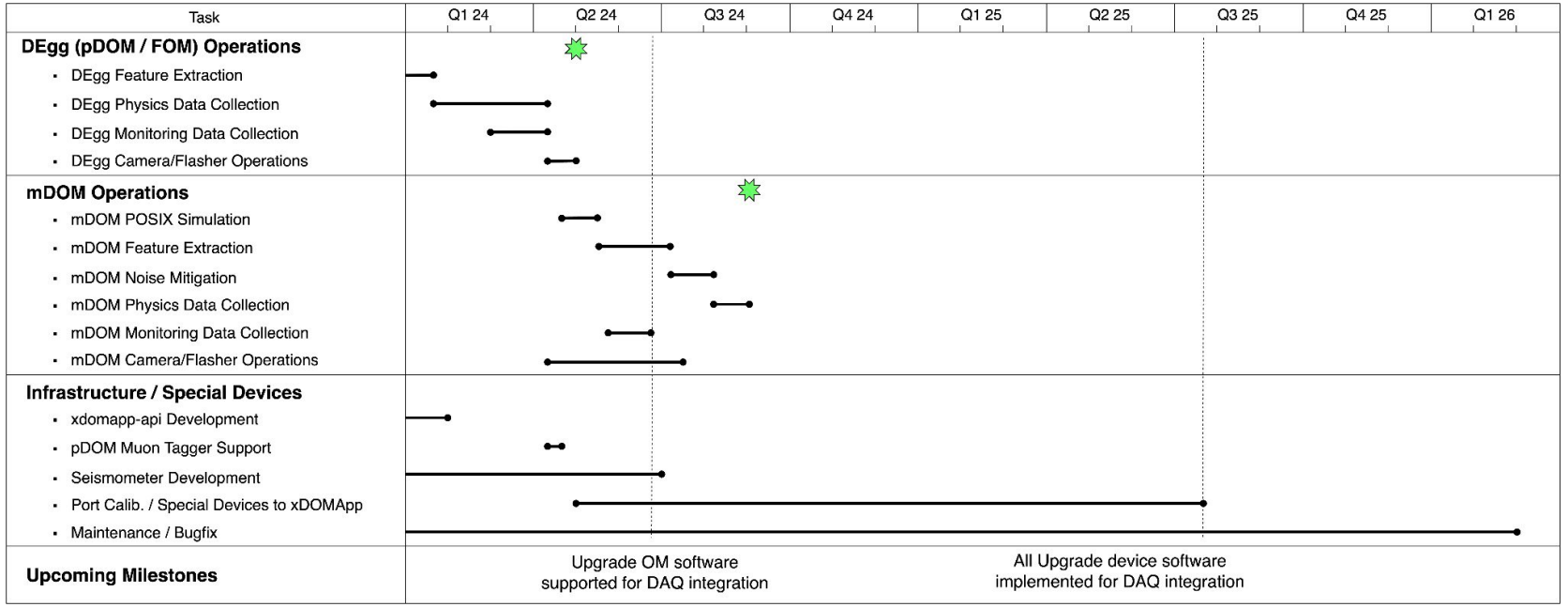
- Include a much larger fraction of hits relative to Gen1
- Total expected Upgrade hit rate of ~8 MHz found to be too large
  - Upgrade StringHub pre-trigger will reduce hit rate to trigger to ~2 MHz
- Target Upgrade-only additional trigger rate: **~300 Hz**
- Gen1 trigger algorithms supported in Upgrade Trigger
- Gen1/Upgrade both read out with any trigger
- Cross-triggering with Gen1 not required/supported

Personnel

- Jim Braun: ICNO DAQ Software Manager / L3 for Upgrade DAQ Software
- ICNO DAQ: (~1.5 FTE)
  - Tim Bendfelt
  - Mirko Kugelmeier
- FieldHub software (0.1 – 0.2 FTE):
  - 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

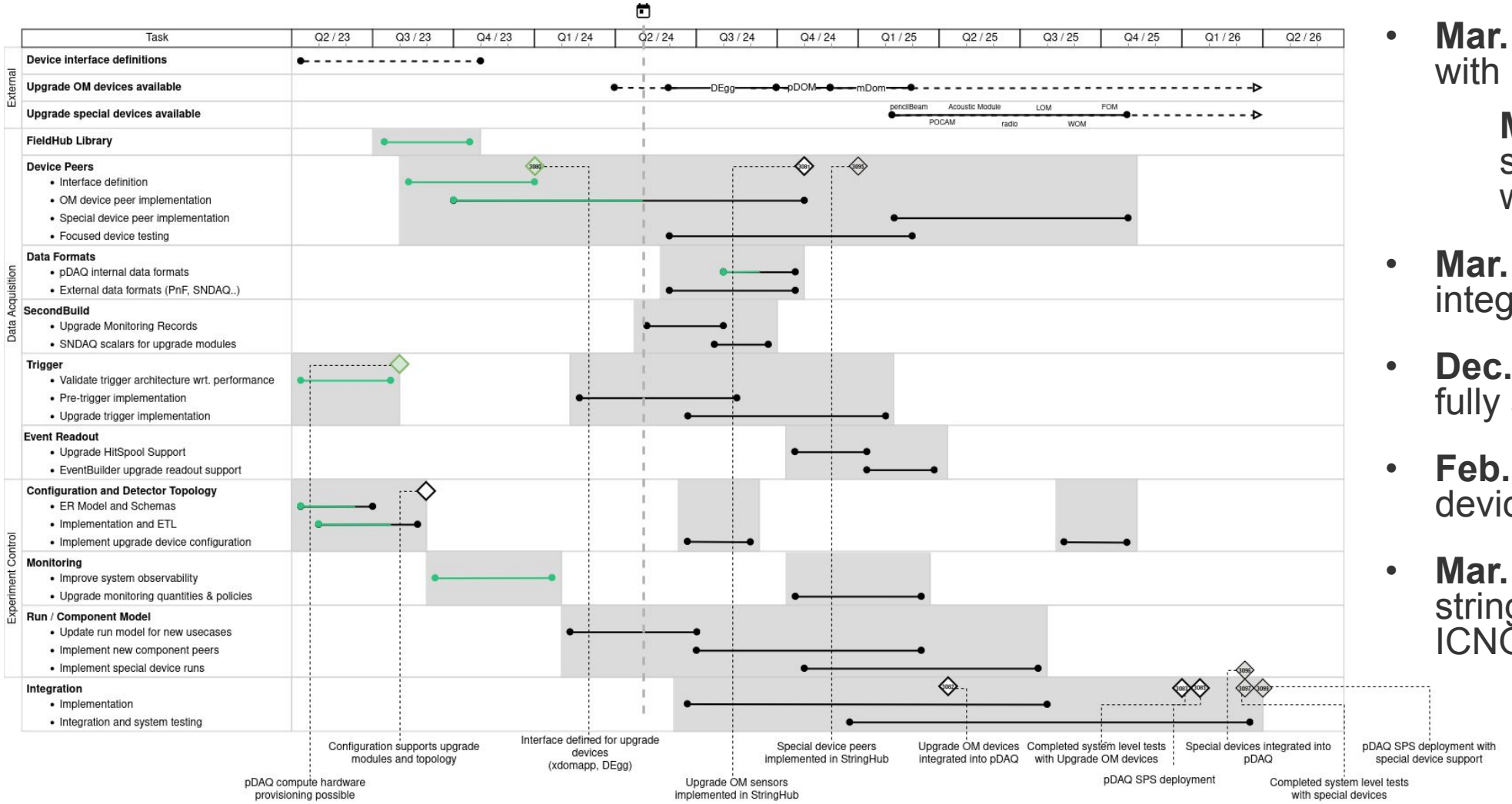
Upgrade in-device MCU software schedule



- 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
- **July 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. 15, 2024**: First successful DEgg run with ICNO DAQ
- **Mar. 2025**: Upgrade OMs integrated into ICNO DAQ
- **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 ensure 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

   → Prioritization order: [Upgrade OMs → calibration devices → special devices] to minimize risk

Summary

- Software support for Upgrade FieldHub and Upgrade OMs nearly complete
- Plan and design for Upgrade ICNO DAQ integration 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