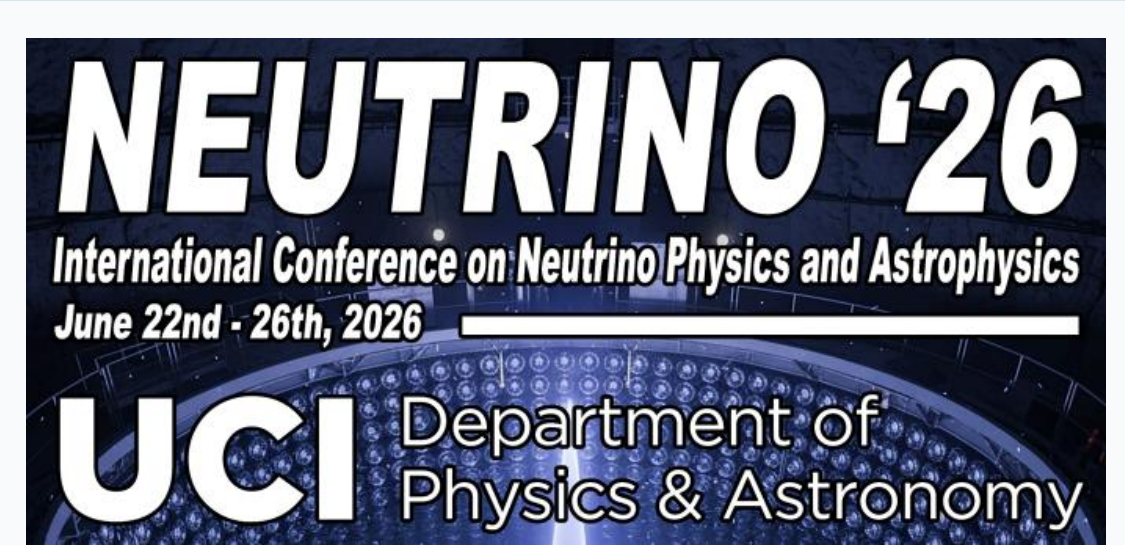


# Online Event Classification in JUNO

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## Introduction and Motivation

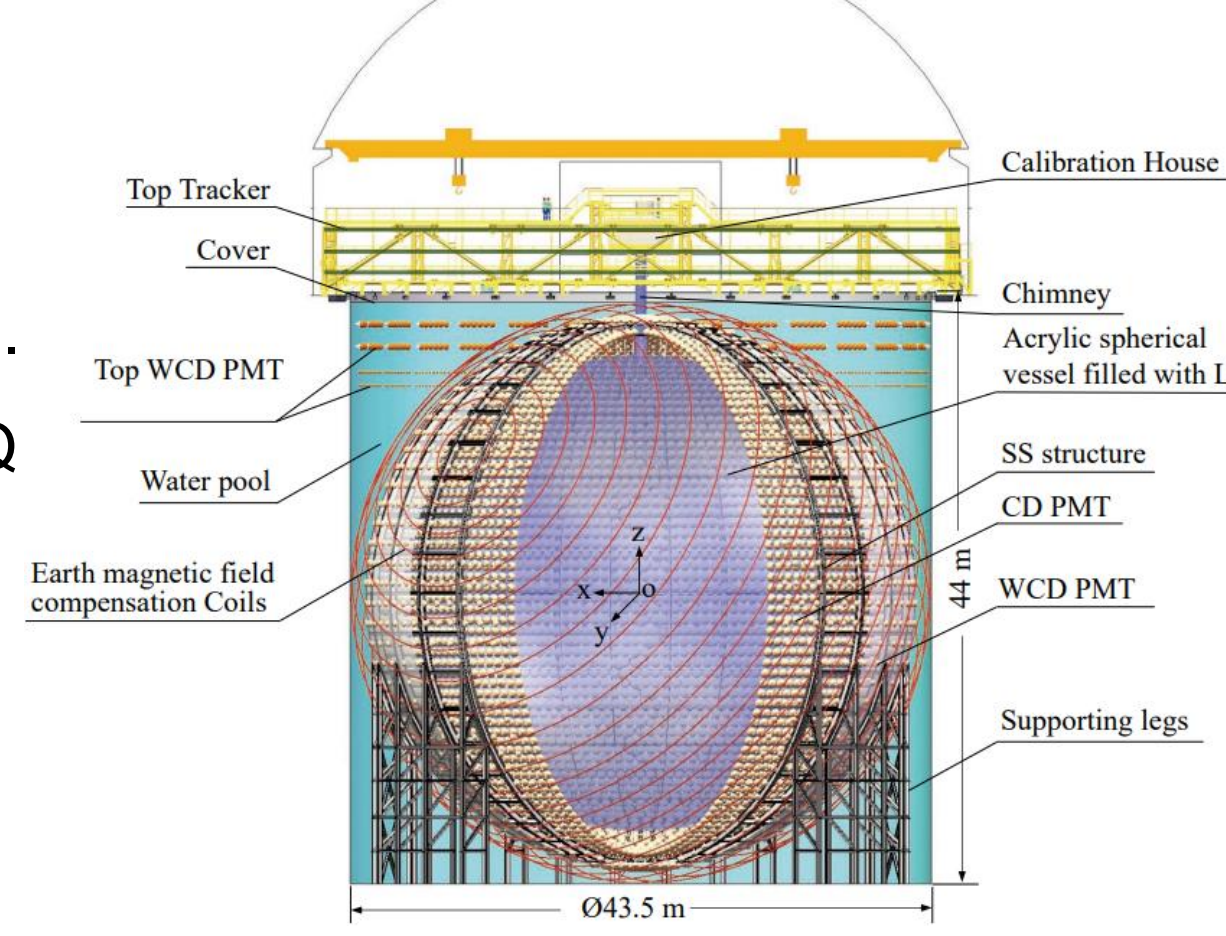
- **Challenge:** JUNO raw data ~40 GB/s @ 1 kHz → impossible to save all data.
- **Solution:** Online Event Classification (OEC) reduces the data volume to ~60 MB/s.

### Why OEC is critical:

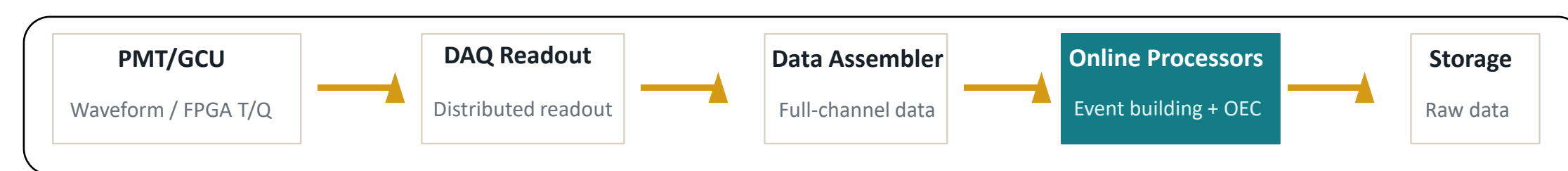
- World's largest LS detector: ~20,000 20-inch PMTs [1].
- Front-end electronics with real-time reconstruction T/Q and waveform output [2].
- Waveforms are needed for fine offline reconstruction.
- Storage limit: only selected events (IBD, neutrons, muons and others) save waveforms/features

### Outcome of OEC:

- Reconstructed PMT T/Q is stored for every event.
- Waveforms/features are saved only for selected events.
- OEC enables both manageable data volume and offline reconstruction precision.



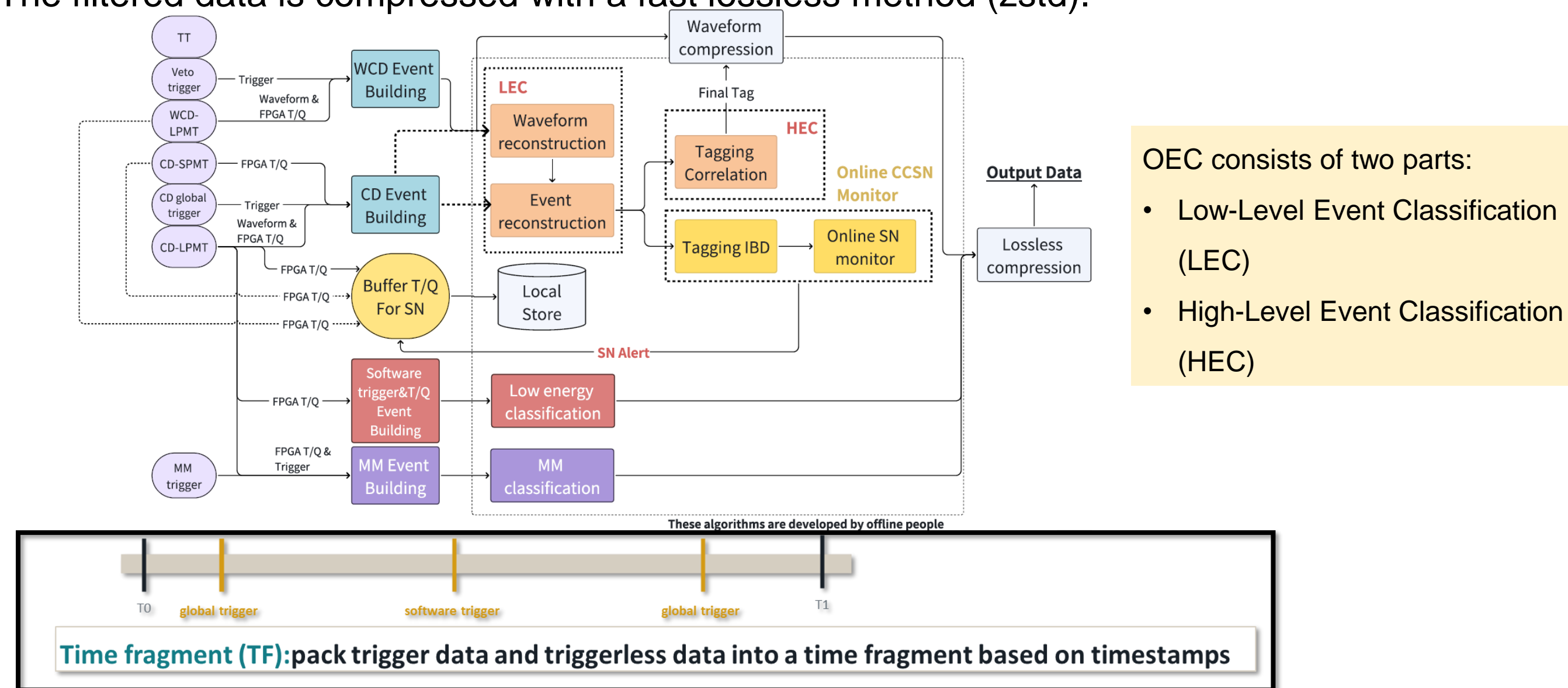
| data type                 | data size | channel num | rate  | data throughput |
|---------------------------|-----------|-------------|-------|-----------------|
| CD 20-inch PMTs Waveform  | 2048 B    | 17596       | 1kHz  | ~36GB/s         |
| WCD 20-inch PMTs Waveform | 2048 B    | 2752        | 200Hz | ~1GB/s          |
| CD 20-inch PMTs FPGA T/Q  | 16 B      | 17596       | 30kHz | ~8GB/s          |
| WCD 20-inch PMTs FPGA T/Q | 16 B      | 2752        | 30kHz | ~1GB/s          |
| CD 3-inch PMTs FPGA T/Q   | -         | 25587       | 500Hz | ~400MB/s        |



## OEC Online Framework

### Two steps are used to reduce the data volume:

- 1) OEC uses the fast classification to select waveforms for saving.
- 2) The filtered data is compressed with a fast lossless method (zstd).



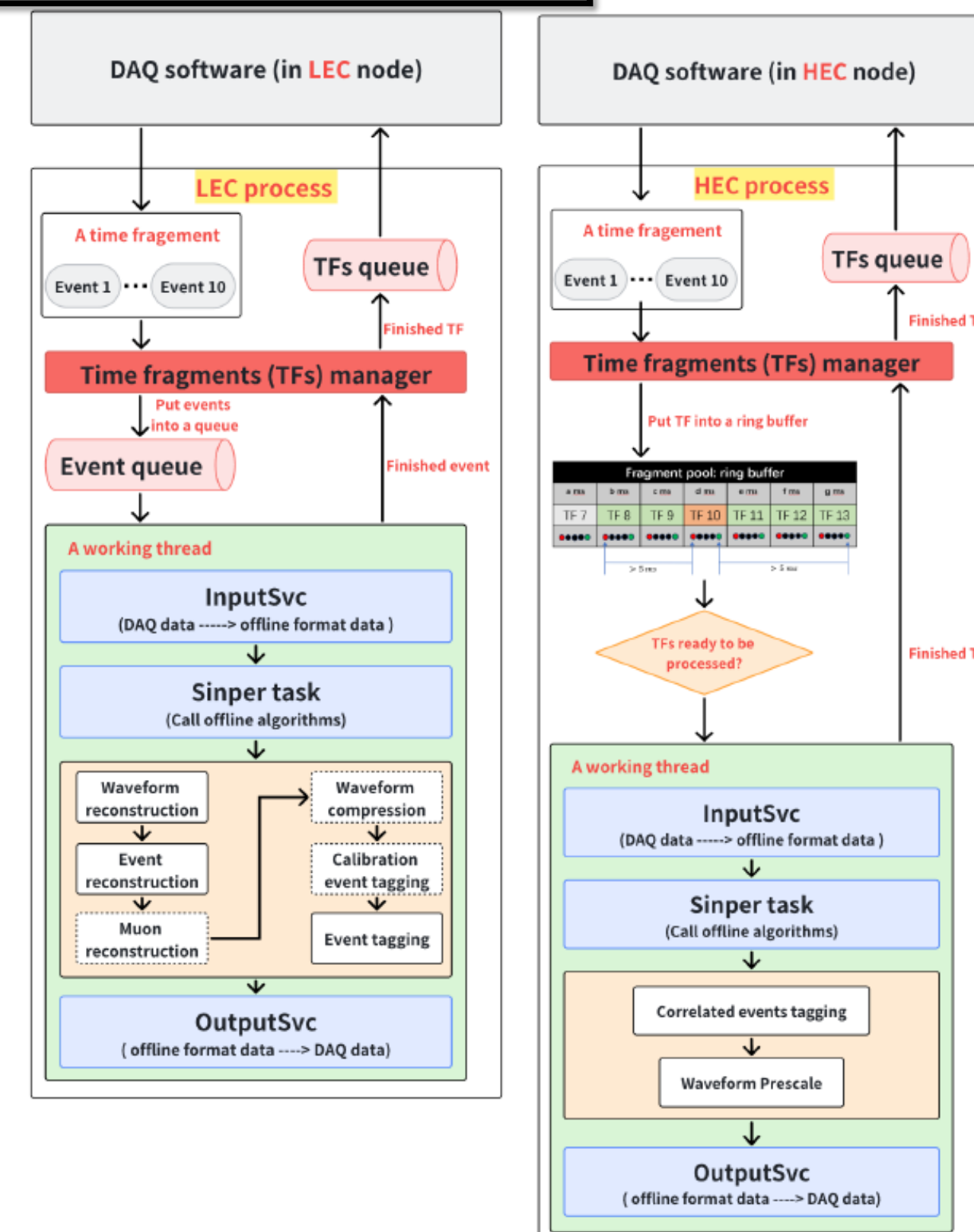
- LEC: multithreading and distributed nodes.
- LEC middleware handles calibration info.

### Calibration system -> DAQ -> LEC

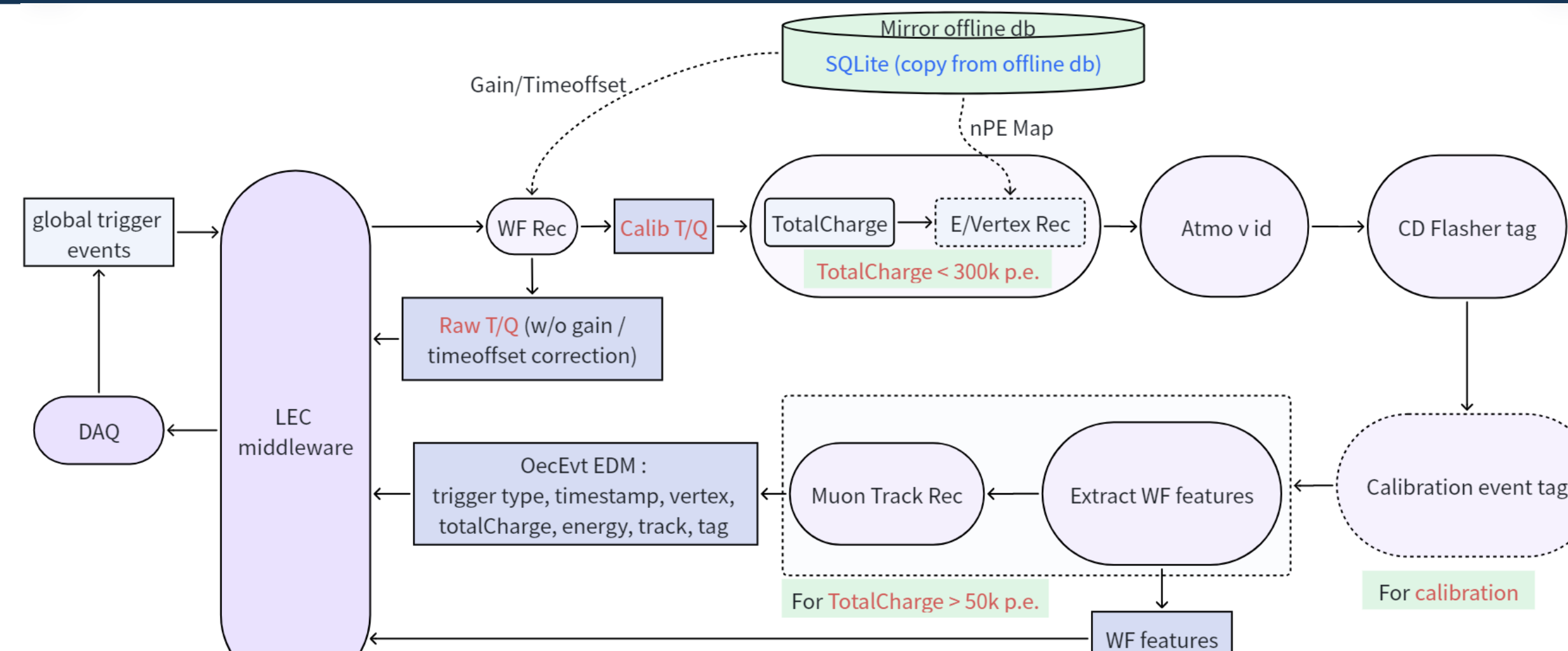
- To reduce HEC latency, each TF received from DAQ is checked to determine whether buffered TFs are ready for processing.

- HEC runs on a single node and uses a ring buffer to manage TFs:

- ✓ insert TFs into the buffer -> find processable TFs -> clean the buffer
- ✓ handle timeout TFs.



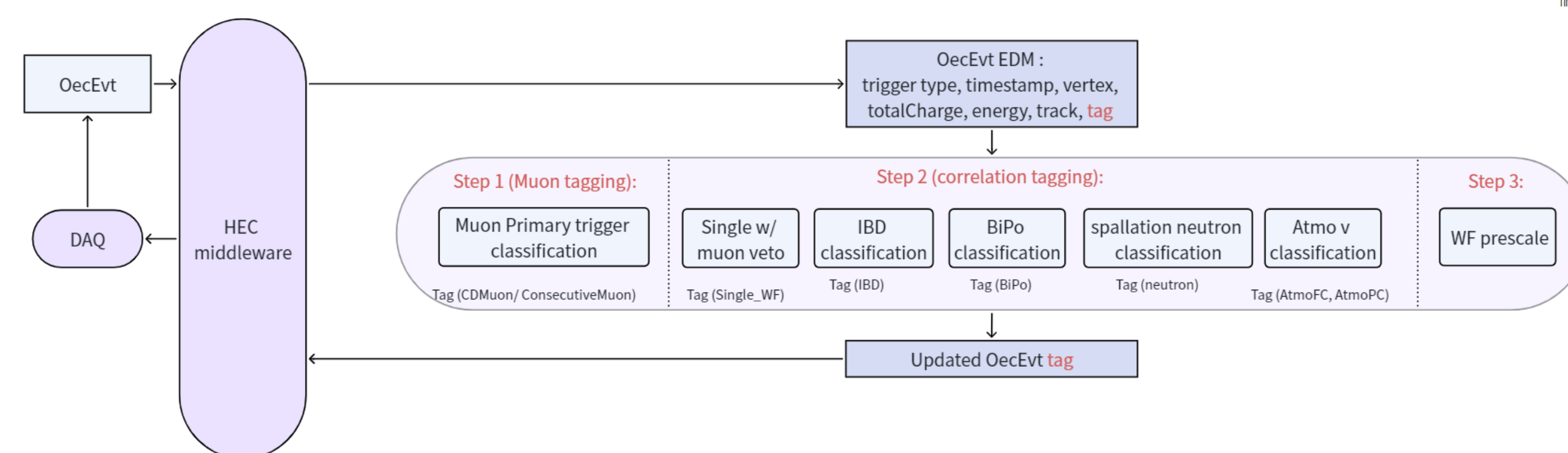
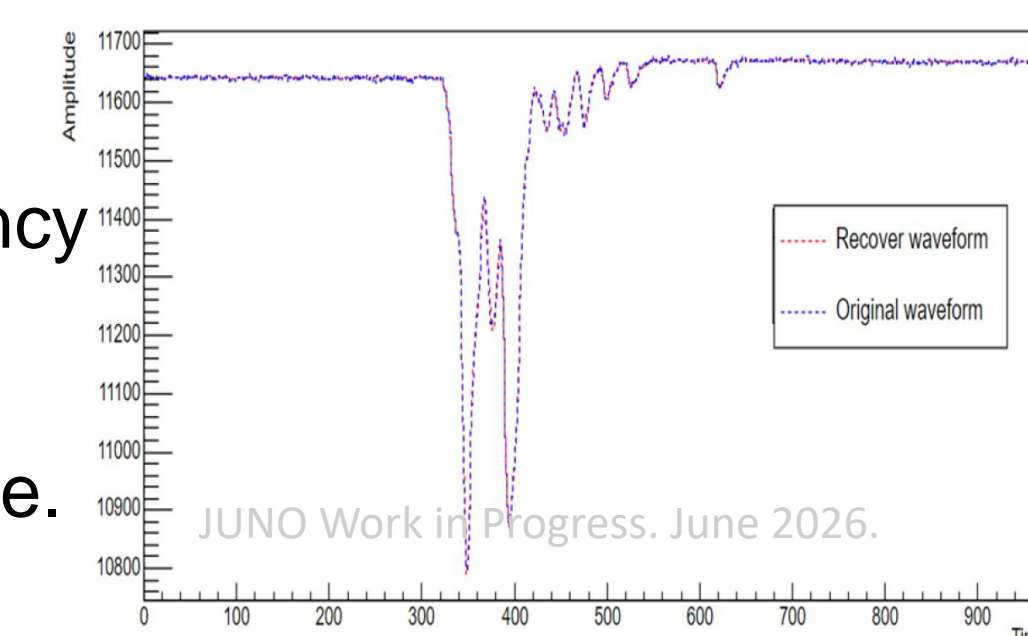
## OEC Software



- Waveform (WF) reconstruction extracts time (T) and charge (Q).
- OecEvt EDM object holds reconstruction outputs and tag.

### Extract WF features

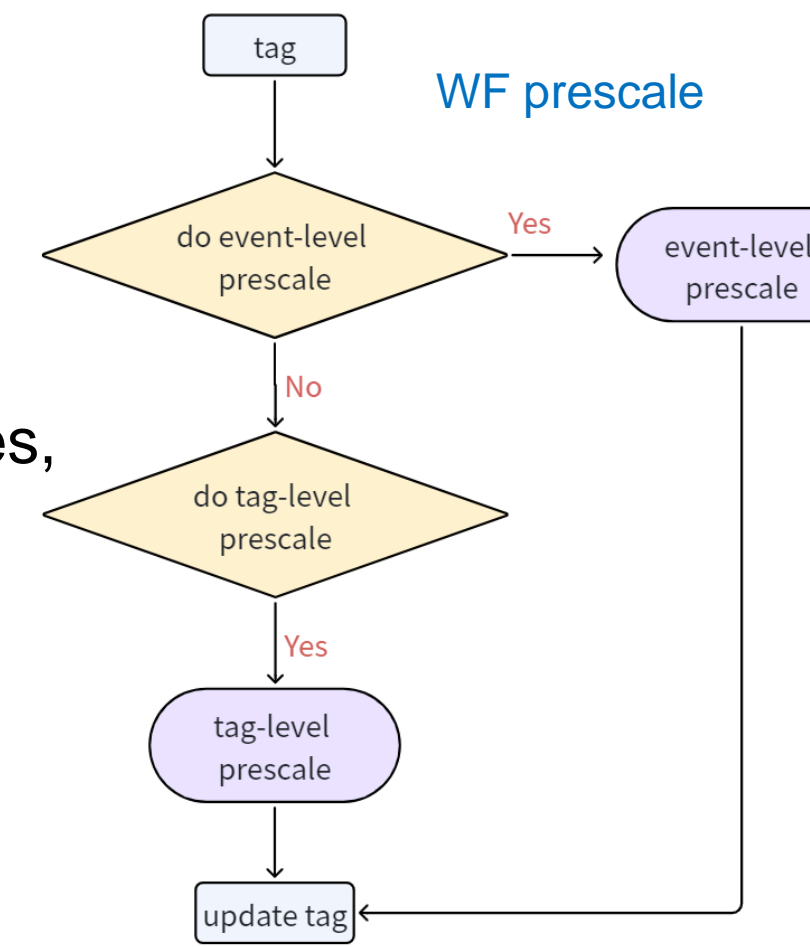
- Fast Fourier Transform (FFT) extracts low-frequency components as WF features.
- The WF can be approximately reconstructed offline.



- Classification algorithms can access the events within a  $\pm 3$  ms time window.

### Waveform prescale method:

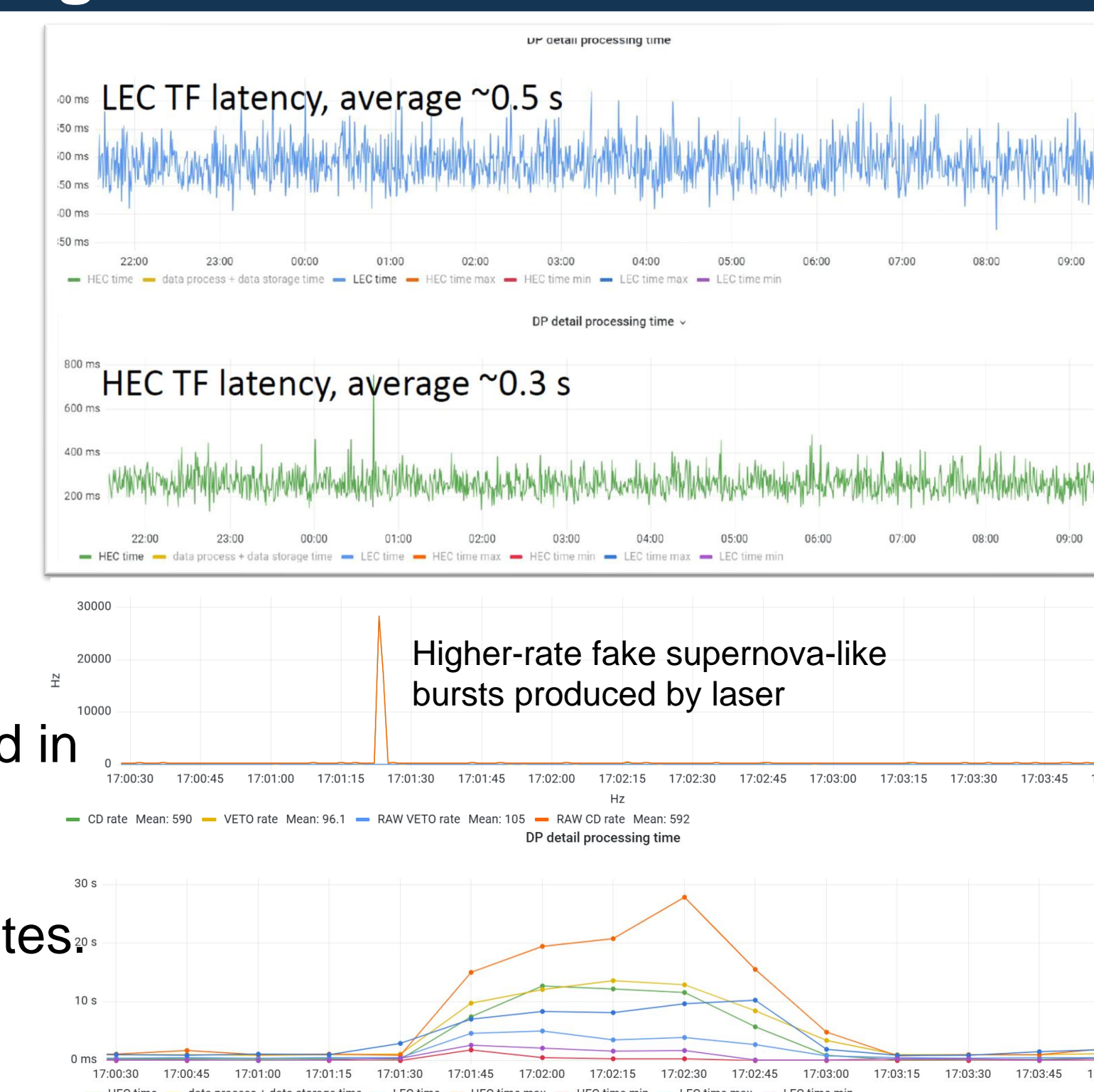
- Event-level: detector type, trigger type, energy and vertex. E.g., 0.4% periodic-trigger events save full waveforms.
- Tag-level: based on OEC tags. E.g., muon: 99% fired-PMT features, 1% fired-PMT waveforms.



## Data-Taking Performance

### Data taking remains stable.

- OEC can handle high-trigger-rate cases (e.g., supernova-like bursts, PMT flashers).
- Accelerates HEC processing by skipping correlated event searches when event count exceeds threshold in 6 ms window.
- Latency recovers within a few minutes.

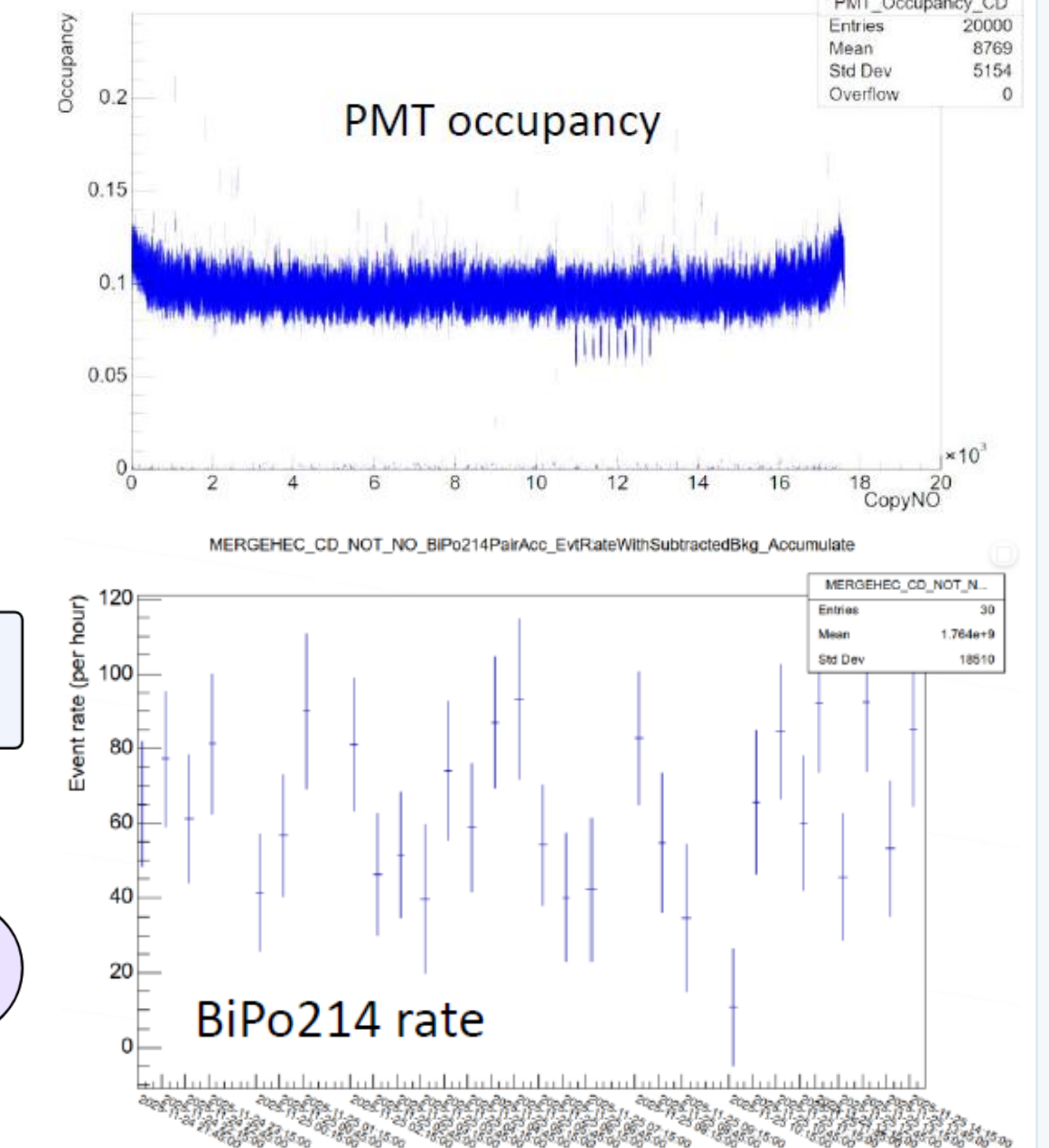
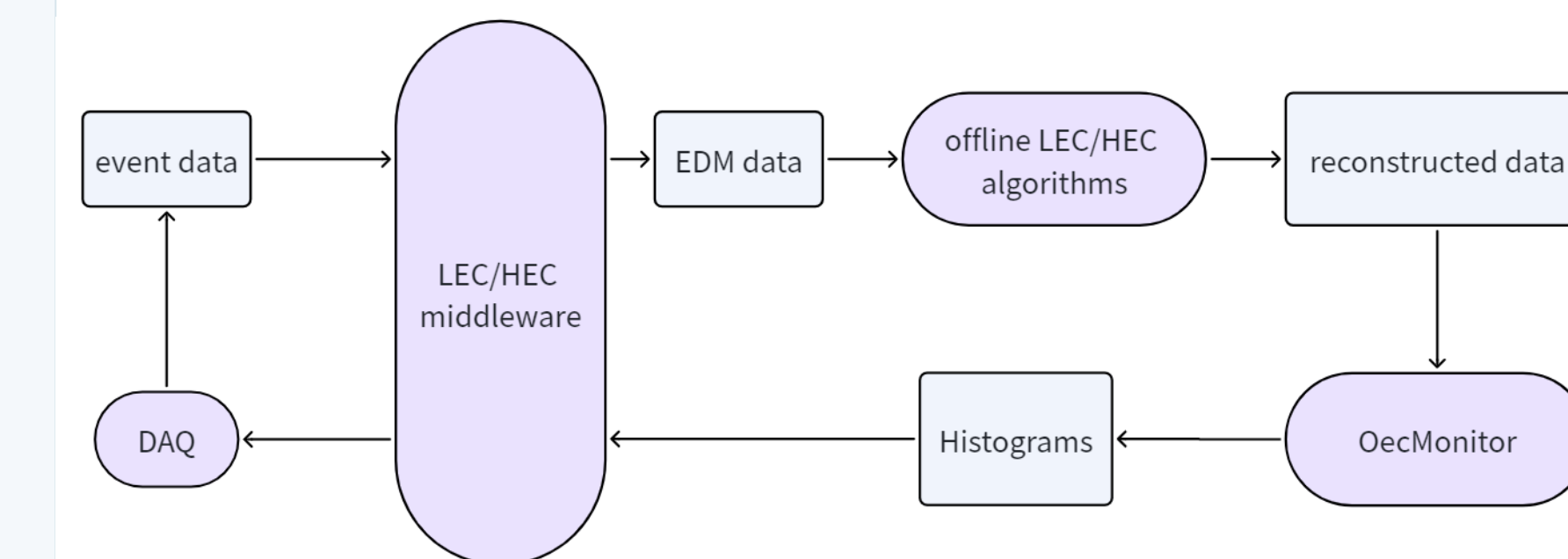


## Prompt Data Quality (OEC Monitor)

- Tracks detector performance & data quality in real time
- Processes channel-level and event-level data into configurable metrics and histograms.

### Monitored Items:

- Rn leakage
- PMT status
- Commissioning tests
- Calibration monitoring



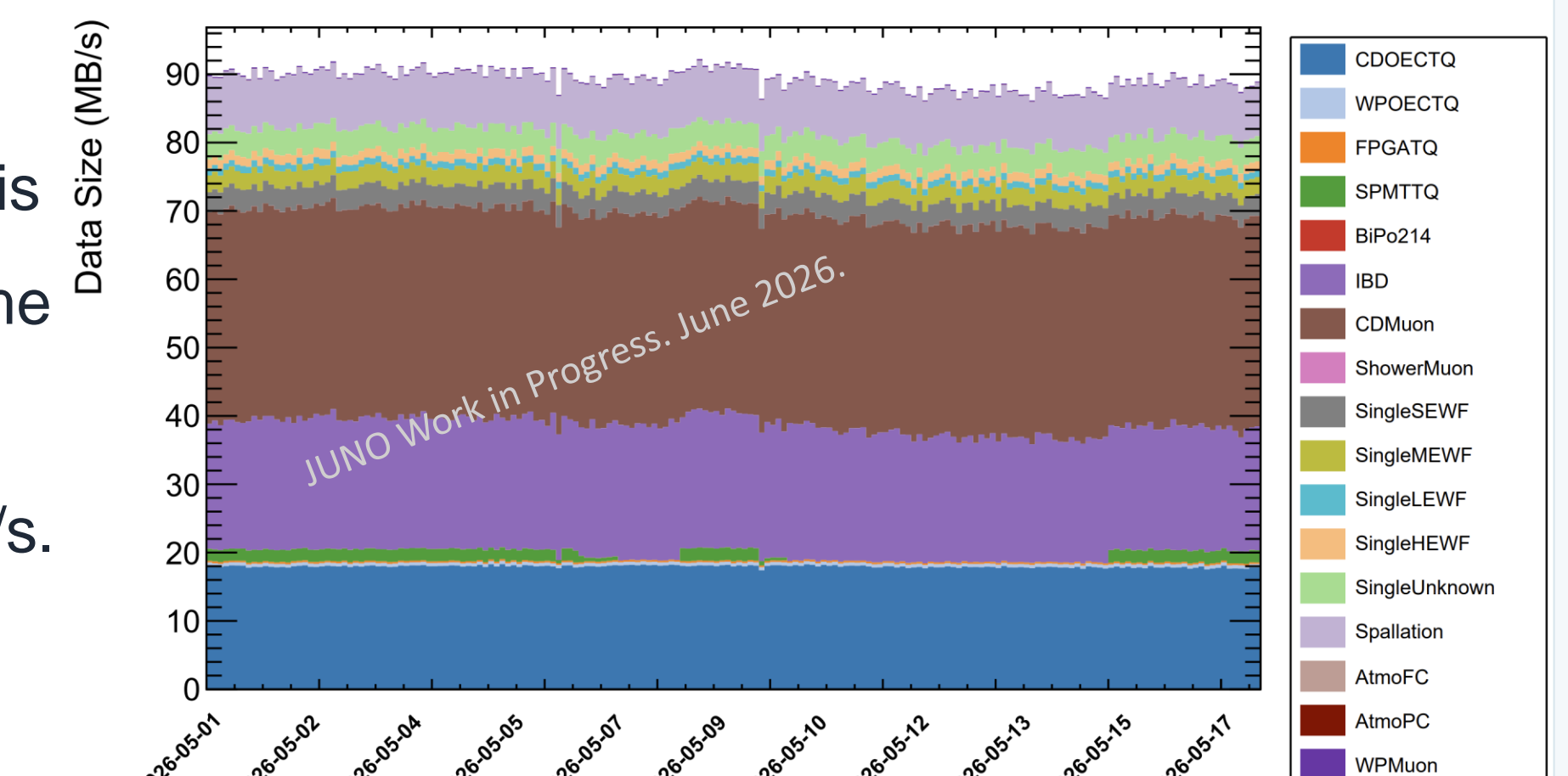
- OEC Monitor reads LEC/HEC streams and produces histograms displayed with JSROOT.

- Shifters assess detector status in real time.

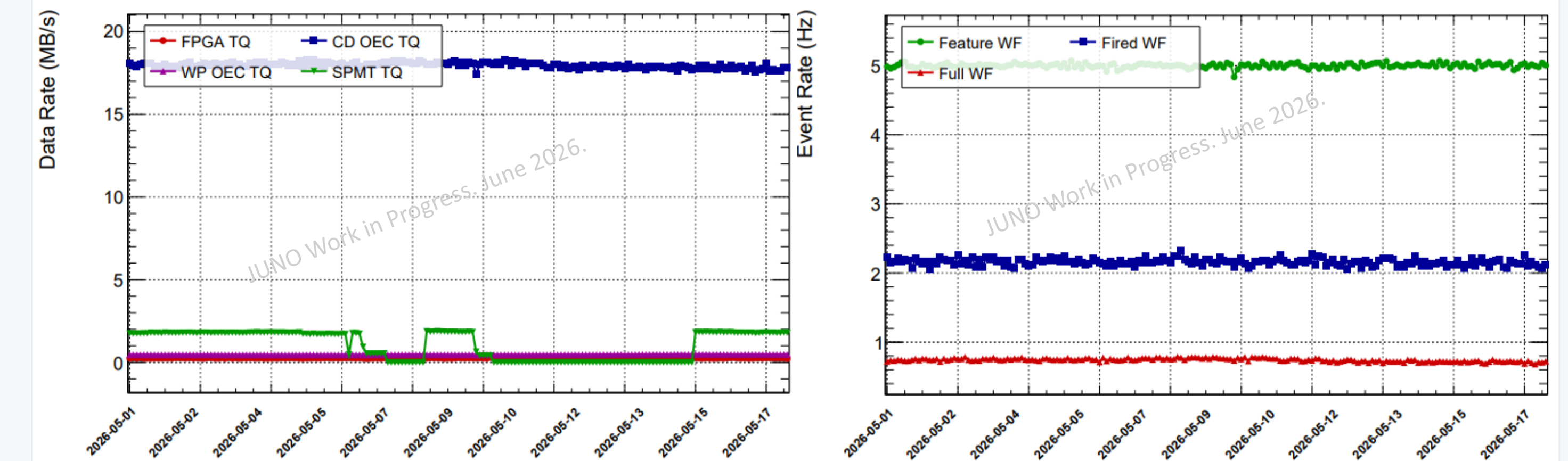
## Data Volume

### Data Volume Composition

- After lossless compression is applied, the total data volume written to disk meets the design bandwidth of 60 MB/s.



### Waveform Event Rates by Strategy



## Summary

- OEC is essential for JUNO data taking and meets the physics requirements.
- The OEC framework has been formally deployed in daily JUNO operations, reducing the raw data bandwidth to approximately 60 MB/s.
- As part of OEC, the online monitor provides prompt data-quality monitoring.

### References:

- [1] JUNO Collaboration, "Initial Performance Results of the JUNO Detector," arXiv:2511.14590, 2025.
- [2] Xu Zhang et al., "JUNO Online Data Processing Software," IEEE TNS-00346-2026.