

DUNE trigger and data acquisition (TDAQ) system

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On behalf of the DUNE Collaboration

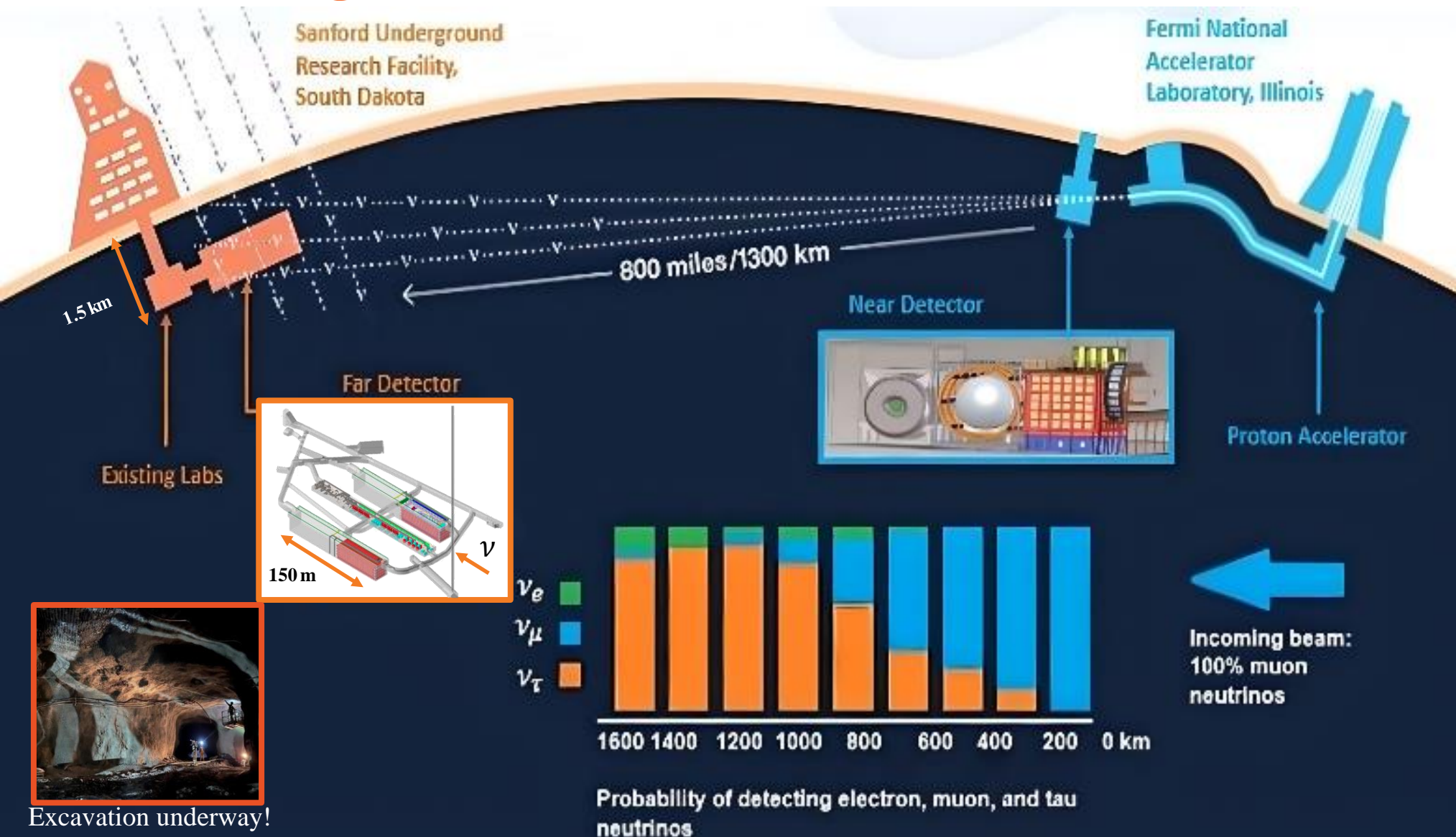
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Inside ProtoDUNE

DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT



- Next-generation international neutrino & underground science experiment hosted in the United States (37 countries + CERN).
- High-intensity neutrino beam, near detector complex at Fermilab.
- Large, deep underground Liquid Argon Time Projection Chamber (LArTPC) far detectors at SURF.
- Precision neutrino oscillation measurements, MeV-scale neutrino physics broad program of physics searches beyond the Standard Model.

ProtoDUNE

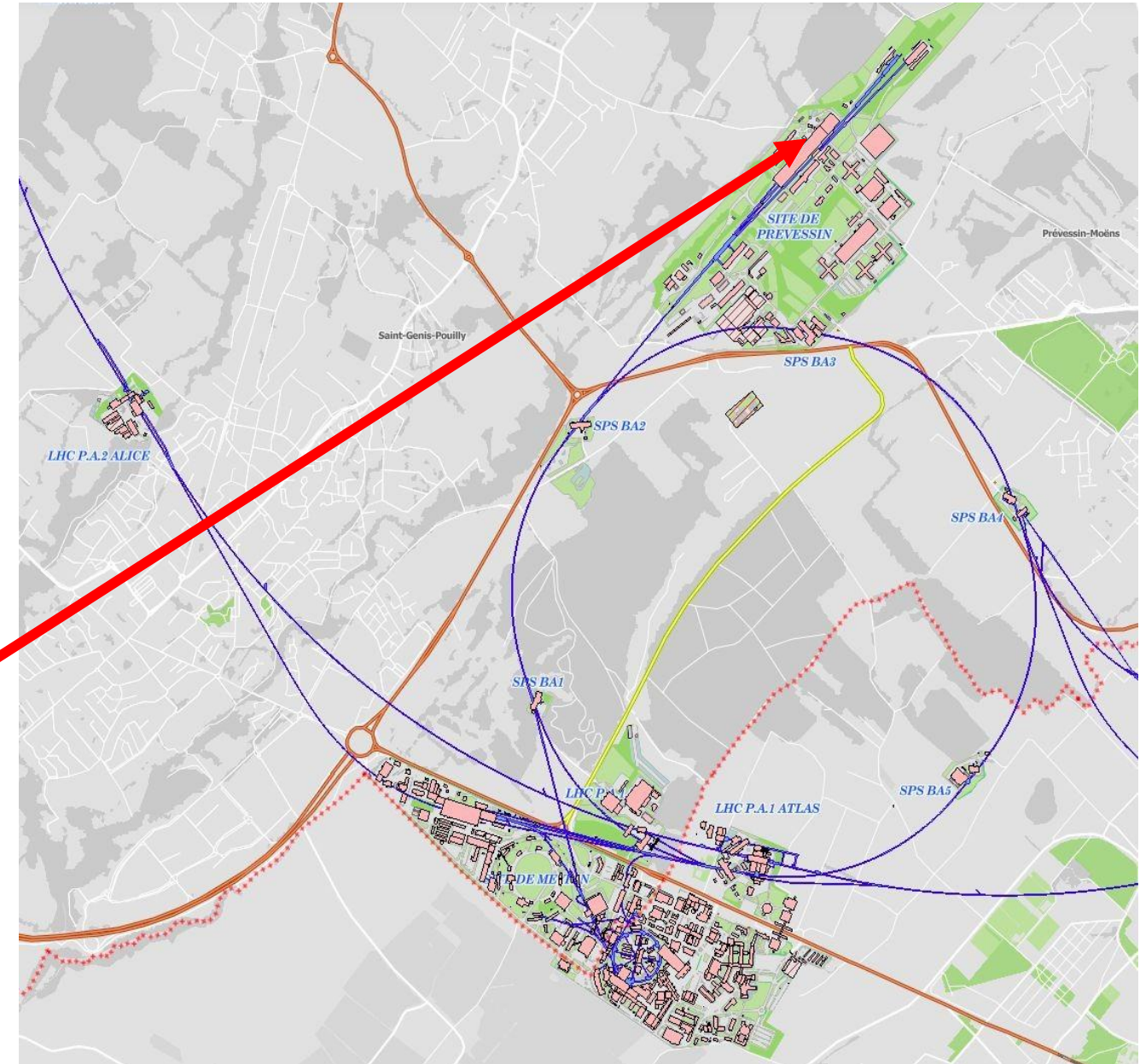
Two LArTPC designs:

- Horizontal drift (HD) → DUNE FD Module 1
- Vertical drift (VD) → DUNE FD Module 2
- For reference, ProtoDUNE Horizontal drift is an 800t active mass TPC, making it the largest LArTPC constructed.
- ProtoDUNE successfully operated in 2018 and will operate soon (2023/2024) with a completely new TDAQ system.

Figure: Neutrino Platform.



Figure: CERN.



The TDAQ system

The TDAQ system has various critical functions to ensure smooth data acquisition and analysis:

- Provides timing and synchronization to the detector electronics and calibration devices.
- Configure, control, and monitor the data-taking process.
- Receives and buffers data streaming from the TPC and the PDs (Photon Detectors).
- Extracts information from the data at a local level to subsequently form Trigger Decisions.
- Builds trigger records, defined as a collection from selected detector space-time volumes corresponding to a Trigger Decision.
- Carries out additional data reduction and compression if needed.
- Relays trigger records to permanent storage.

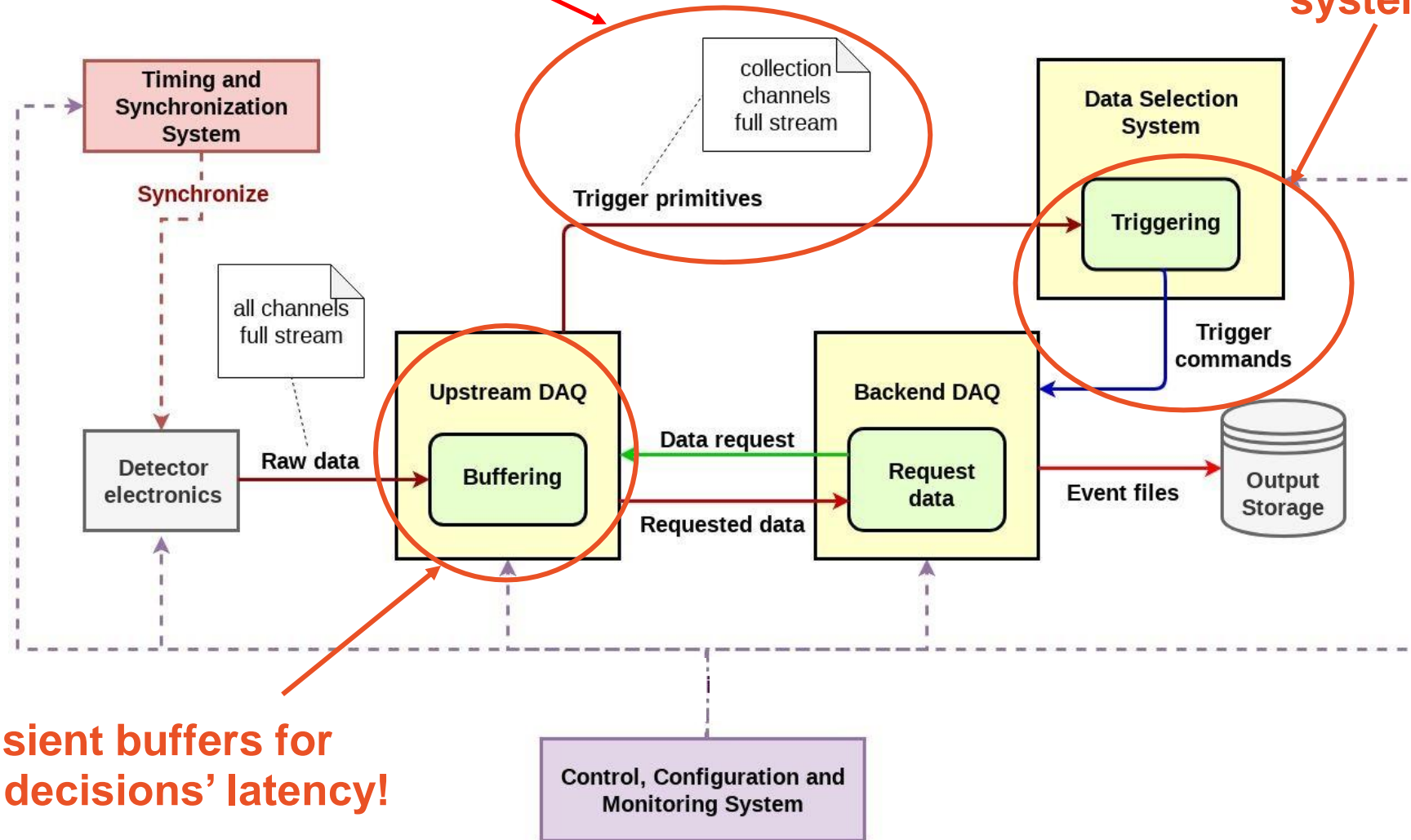
The main challenges:

- Development of effective, resilient software.
- Optimize the performance of the hardware resources used.
- Manage a high volume of data from both the TPC and the PDS (≈ 30 PB/year for all FD modules).
- Trigger and process events with different energies (high \rightarrow tau neutrinos and low \rightarrow supernova neutrinos).
- Difficult access (underground servers).

Trigger system

Real-time processed datastream!

Self-triggered system!



O(10 s) transient buffers for data request decisions' latency!

<https://indico.phy.ornl.gov/event/112/contributions/561/>

Trigger system: Data-taking scenarios

Interaction triggers (interesting localized activity somewhere in the detector)

- Examples: beam triggers, cosmic rays, and photon detection.

Supernova Neutrino Burst (SNB) triggers (sufficient activity in the detector to suggest a SNB)

- $\sim 10^{58}$ of ~ 10 MeV supernova neutrinos emitted for few seconds.
- All data is stored for 100 sec window including $O(10\text{ s})$ before the trigger signal.
- Needs special handling due to the volume of data (~ 140 to 180 TB).
- Both the copying of the data to the 100-sec buffer and the transfer of the data from Readout to Dataflow go on in parallel with the processing of any Interaction Triggers.
- The Trigger will send messages to the External Trigger Interface (ETI) on occurrence of a SNB trigger, to eventually prepare a message for the SuperNova Early Warning System (SNEWS).

Limited-bandwidth streaming data

- Examples: trigger primitive stream, calibration, and electronics debugging data

Readout system

The readout system:

- receives and buffers the raw data from detector electronics,
- generates Trigger Primitives by processing the incoming data in quasi-real time,
- streams the generated Trigger Primitives to Trigger and Dataflow,
- responds to readout requests from Dataflow and Data Quality Monitoring (DQM).

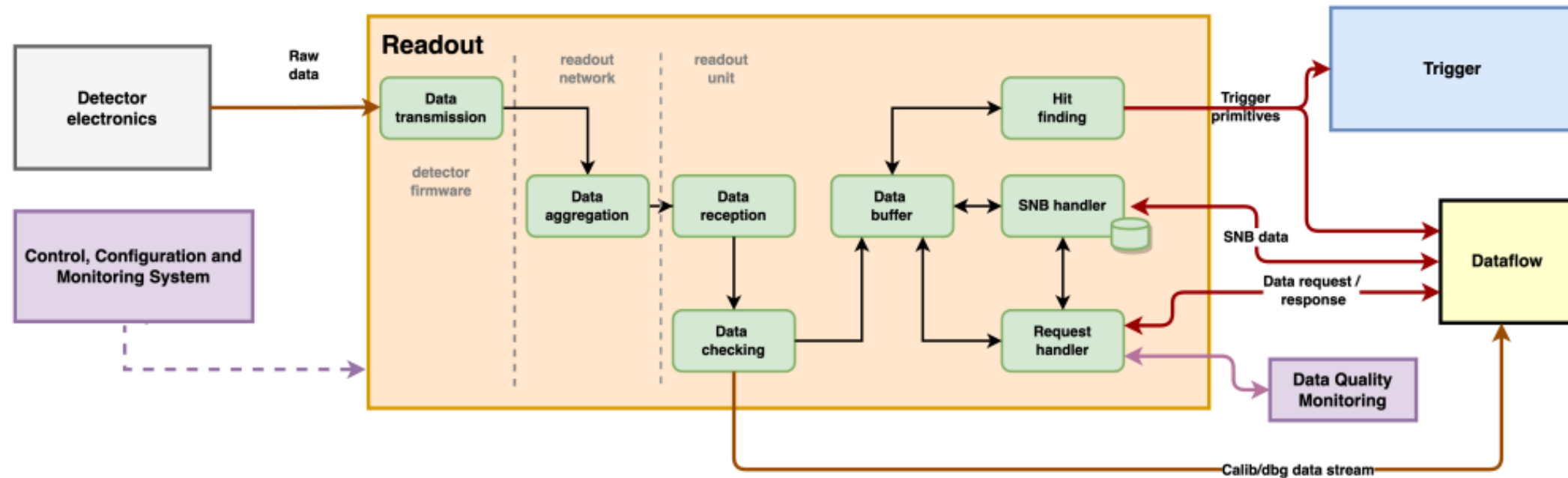


Figure: Interfaces of Readout components with other TDAQ sub-systems.

Readout system

Challenges:

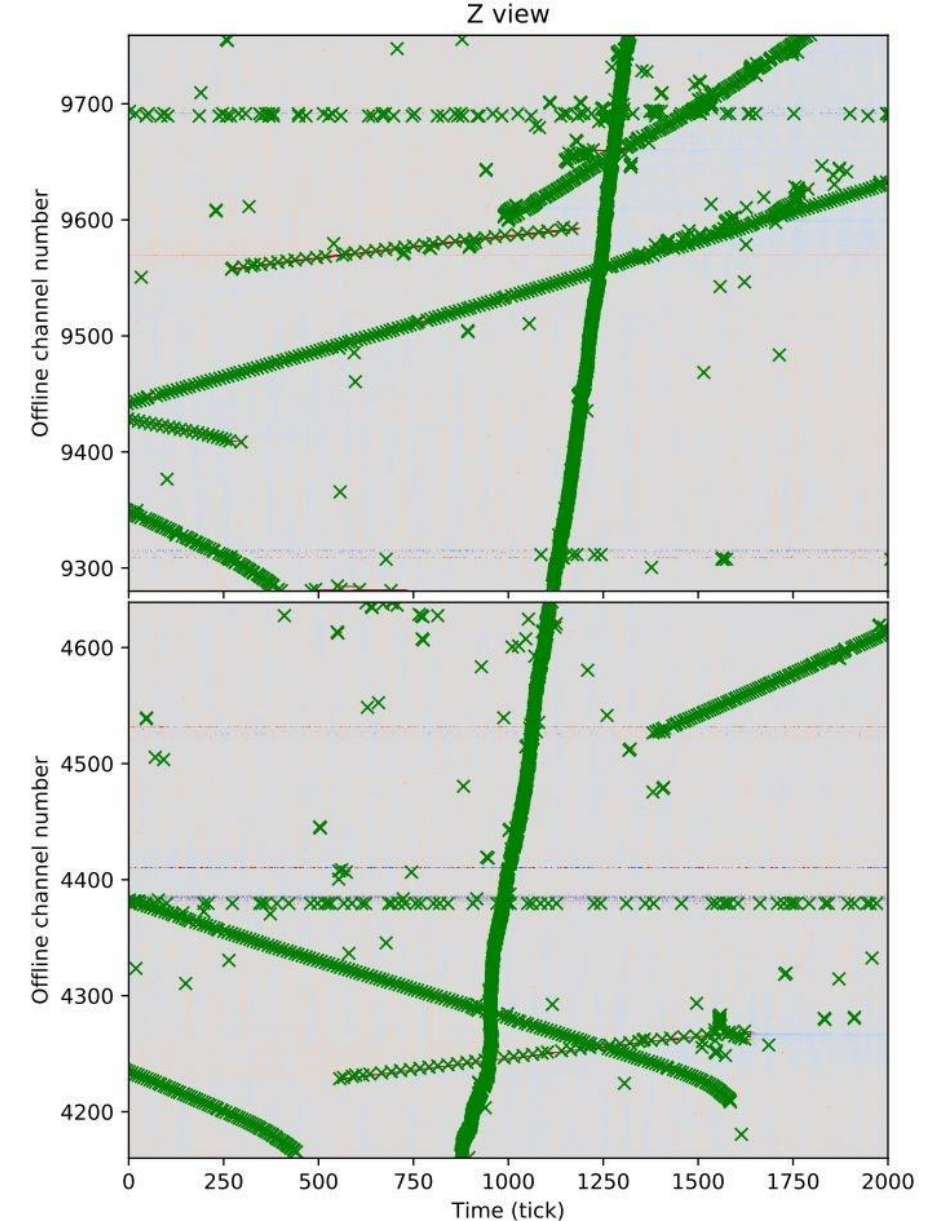
- **Support all possible front-end types:** be agnostic about data rate and payload size.
- **Buffer received data** for a specified/maximum amount of time.
- **Respond to data requests** with time-windows of $O(\mu\text{s})$ to $O(\text{s})$
- **In-flight data processing:** Error and consistency checks with custom algorithms (e.g.: hit-finding) are also supported.

Feature extraction - “Hit” finding:

Real-time processing and streaming of interesting data regions for trigger decisions.

- Extracts collection channel.
- Does pedestal subtraction, low level filter, and hit-finding.
- **Operational in ProtoDUNE: With a full self-triggering chain!**

1 time tick = 16 ns



<https://indico.phy.ornl.gov/event/112/contributions/561/>

Data flow system

The Dataflow system include the following:

- It handles triggered data as well as streaming data of constrained bandwidth.
- It delivers data to Data Filter and DQM systems, and it is responsible for preparing the data for transfer to offline storage.
- It will be used in all the TDAQ sub-systems of the Near and Far detectors (ND and FD).

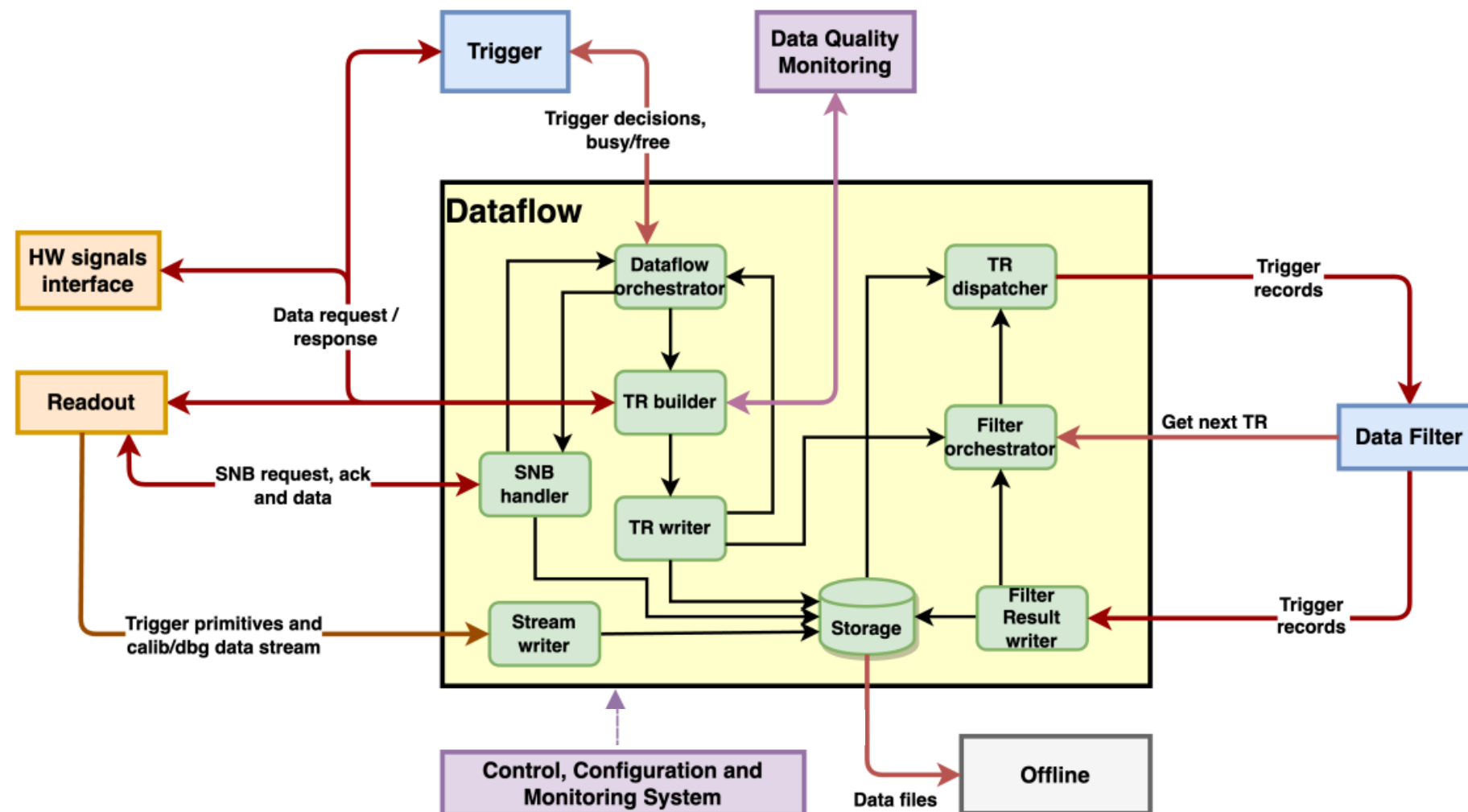


Figure: Interfaces of Dataflow components with other TDAQ sub-systems.

The expected maximum input rate to the Dataflow servers and the TDAQ storage system within each FD TDAQ will be 30 GB/s and the maximum output rate will be 7 GB/s.

Control, configuration, and monitoring system

The CCM system is a centralized framework that enables operators to manage and oversee the experiment.

- It provides a single interface for controlling the TDAQ system:
 - Allowing operators to initiate and stop data acquisition,
 - Adjust trigger thresholds,
 - Configure data storage parameters.
 - Remote operation of the experiment.

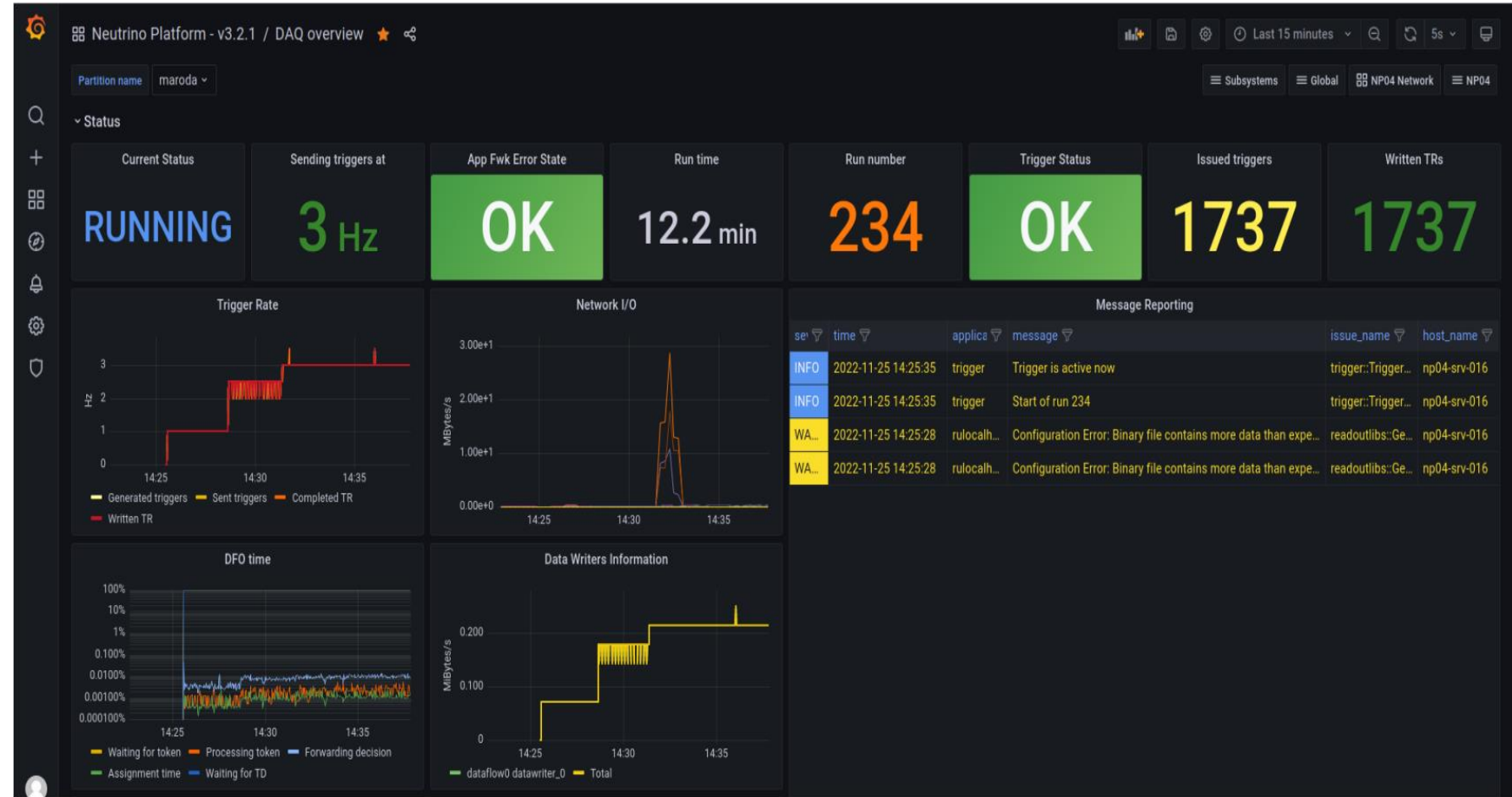


Figure: CCM system dashboard entry point.

- at the top left is the panel for the selection of the DAQ session;
- at the top right the navigation links that point to all the other dashboards;
- the table in the right part of the dashboard is devoted to logging (Error Reporting Service (ERS)) messages.

Summary

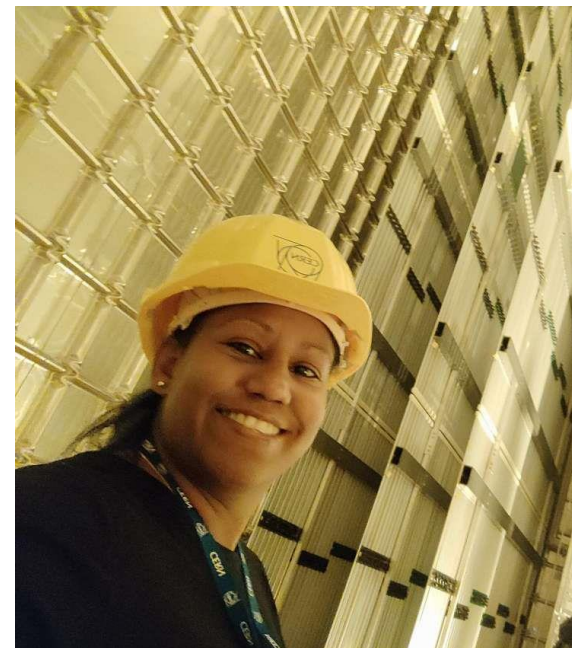
- DUNE represents a significant scientific endeavor with the potential for groundbreaking discoveries.
- The trigger system plays a pivotal role in identifying and selecting relevant events from the continuous stream of data.
- The DAQ system complements the trigger system by managing the efficient transfer, processing, and storage of the captured data.
- The TDAQ system has a variable size readout window, from few μs (calibration) to 100 s (SNB).
- The TDAQ system is being optimize for low energy physics such Supernova & Boron 8 neutrinos.
- A high-performance Ethernet network interconnects all the elements and allows them to operate as a single, distributed system.
- ProtoDUNE demonstrated steady storage at ~ 40 Gb/s for a storage volume of 700 TB.
- ProtoDUNE detectors will soon run again, and they will be the basis for validating the detector design, technologies, and TDAQ system.

END

Thanks for your time!!!

References

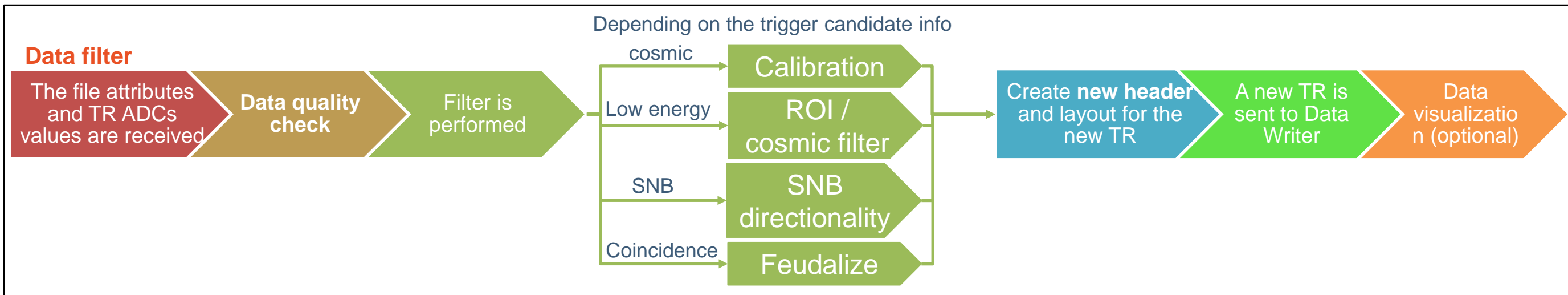
- FDR
<https://edms.cern.ch/ui/#!/master/navigator/document?D:101190518:101190518:subDocs>
- Trigger and Data Acquisition Overview <https://indico.fnal.gov/event/57752/contributions/260312/>
- The readout system of the DUNE experiment:
<https://indico.phy.ornl.gov/event/112/contributions/561/>
- The DAQ for the single-phase DUNE Prototype at CERN:
<https://indico.cern.ch/event/543031/contributions/2921456/>
- Kubernetes for DUNE DAQ <https://indico.jlab.org/event/459/contributions/11389/>



Data Filter system

The Data Filter has several possible roles:

- **Additional reduction** (beyond Trigger) of data volume to disk to fit within DUNE's 30 PB/year storage allocation.
- **Removal of instrumentally generated “garbage” events** (eg. high-voltage ‘streamers’).
- **ROI filtering** to optimizing DAQ for low energy physics such Supernova & Boron 8 neutrinos.
- **Filtering of event classes used for calibration monitoring** (e.g., 39 Ar events) after some processing is done.
- **Other high-level processing tasks** that can help filter the data.



Data Quality Monitoring (DQM) system

The DQM system provides a framework to:

- Perform sampling of data from each detector subsystem as it is being collected.
- Perform analysis of the sampled data to assess its quality, generating alerts when chosen metrics go outside meaningful bounds.
- Publish data quality summary information using the operational monitoring subsystem, such that it can be consumed by the CCM supervisor.
- Preserve a record of historical data quality metrics over the run history of the detector(s).

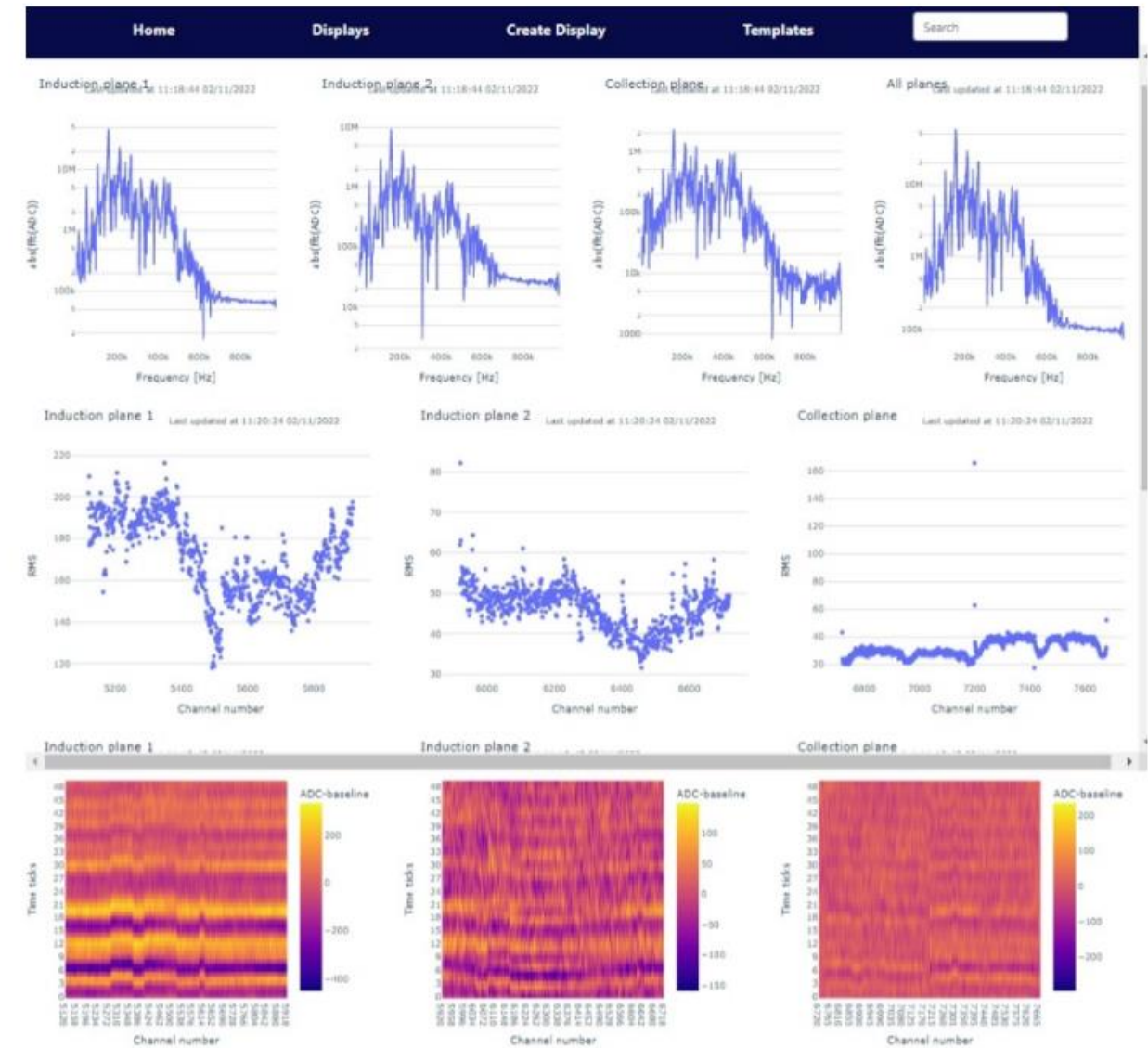
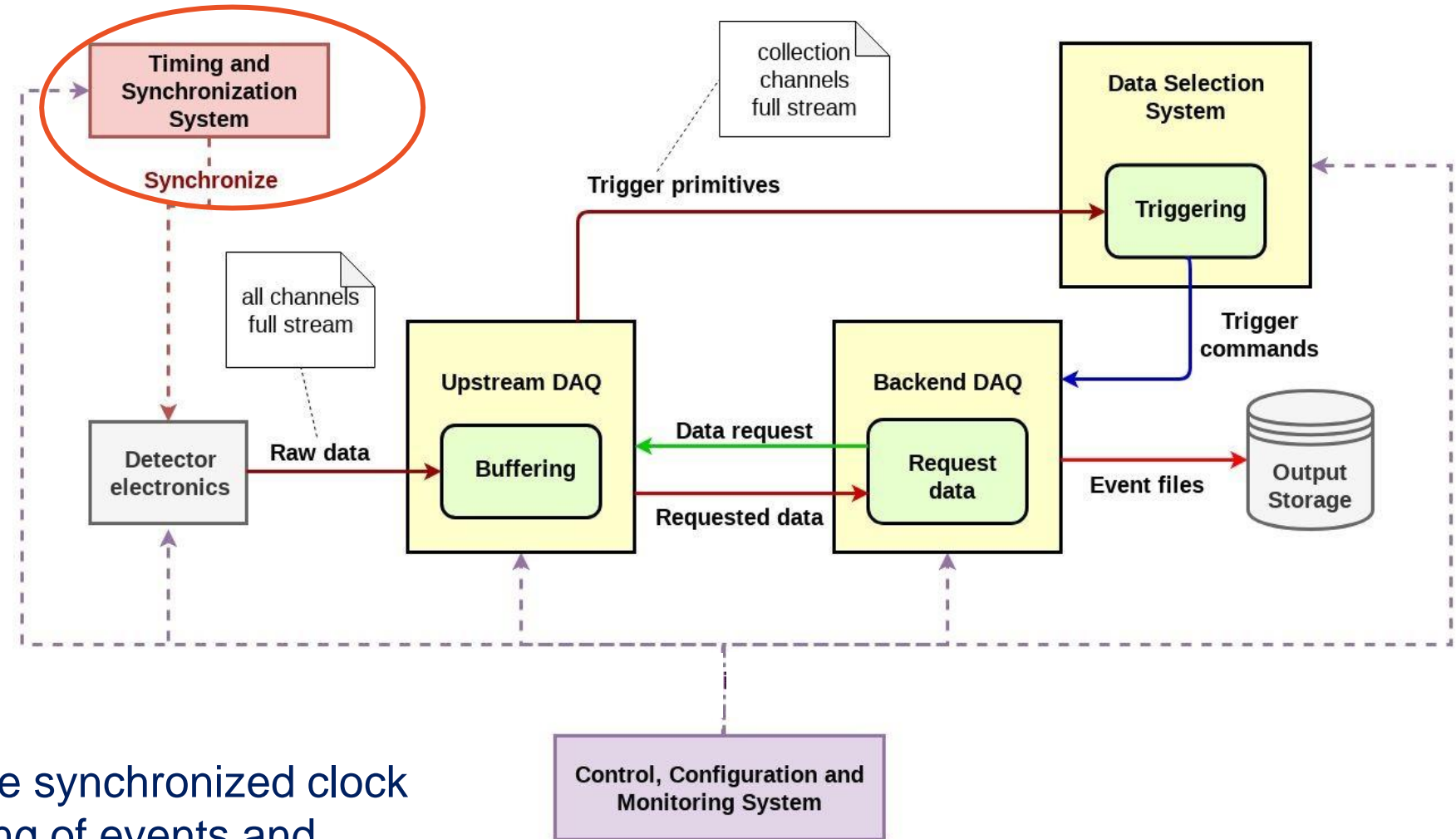


Figure: DQM system dashboard entry point.

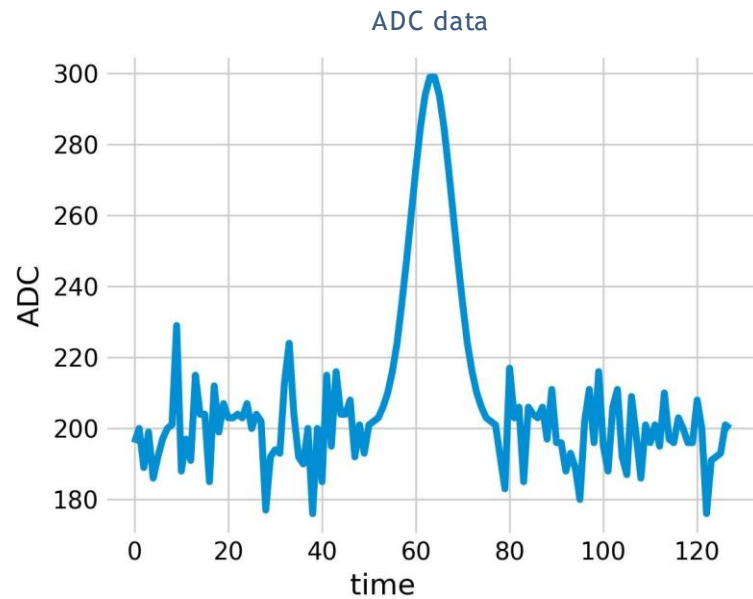
Timing system

- Provides the core clock to all endpoints
- Features:
 - Timestamping
 - Trigger distribution
 - Internal triggers
 - Trigger veto
 - Partitioning
 - Synchronisation
- Interfaces to readout boards necessarily vary

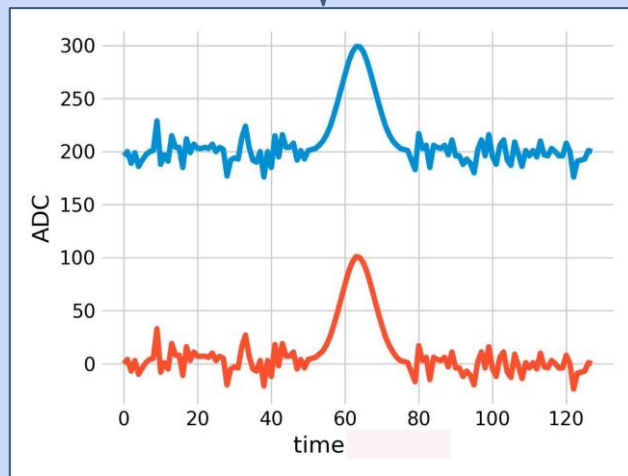


The endpoint devices utilize the synchronized clock signal for accurate timestamping of events and triggering data acquisition processes.

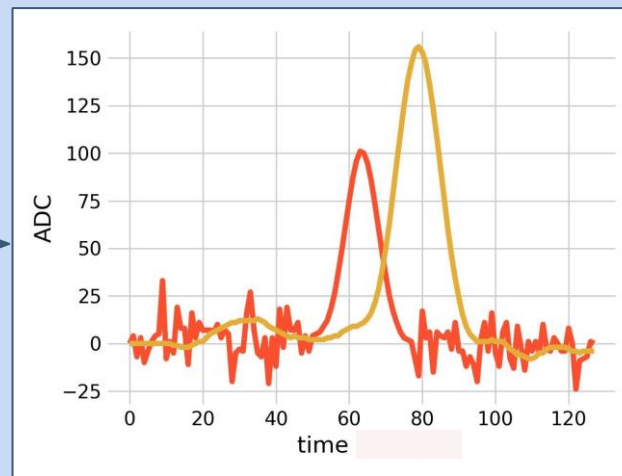
Trigger system: Trigger Primitive Generation (TPG)



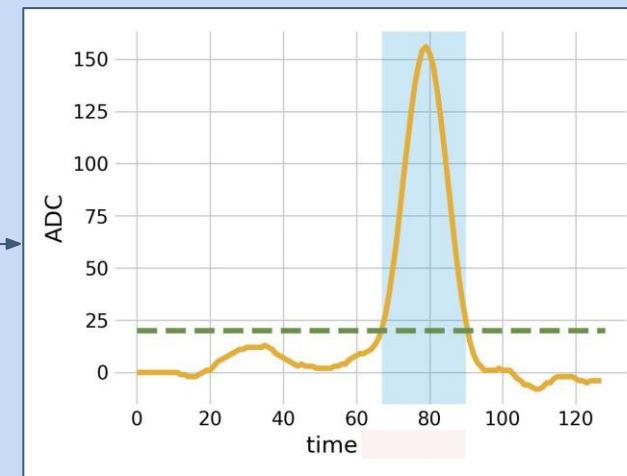
- TPG from the readout board uses the Field Programmable Gate Array (FPGA) for processing Analog-to-Digital Converter (ADC) data.
- TP information contains start time, end time, peak time, sum ADC and peak ADC.



Pedestal subtraction (high pass filter)



FIR filter (low pass filter)



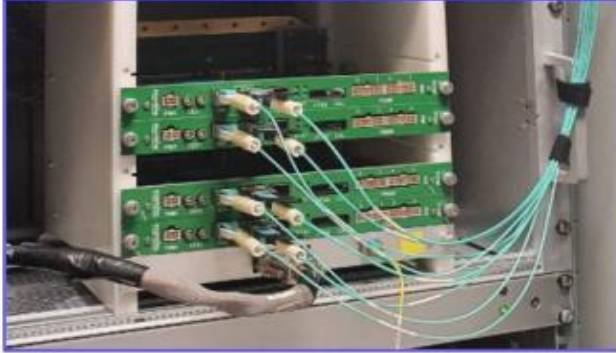
Hit finding

Trigger
Primitive

made with [fast hit emu](#)

Readout system: Front-end electronics

Time Projection Chamber (TPC) readout



Silicon Photomultiplier (SiPM) readout



Commercial Off-The-Shelf (COTS) servers



different rates and
payload sizes

Network Interface Controller (NIC)



Control, configuration, and monitoring system

