DUNE trigger and data acquisition (TDAQ) system

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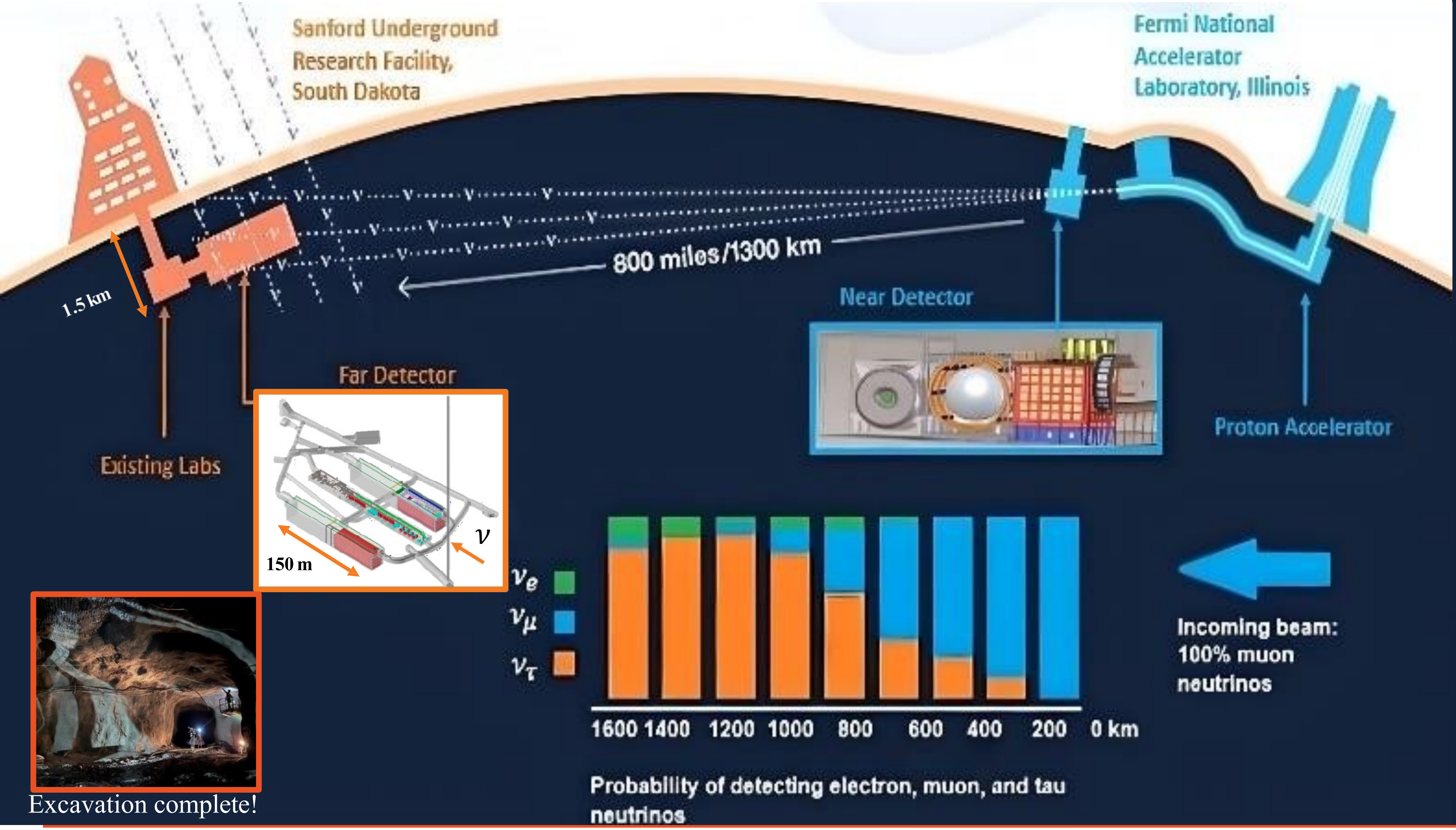
DEEP UNDERGROUND NEUTRINO EXPERIMENT



- Next-generation neutrino experiment hosted in the United States.
- High-intensity neutrino beam, near detector complex at Fermilab.
- Underground Liquid Argon Time Projection Chamber (LArTPC) far detectors at SURF.
- Broad program of physics: precision neutrino oscillation measurements, MeV-scale neutrino physics, searches beyond the Standard Model.

ProtoDUNE

Prototypes of 2 DUNE far detector (FD) modules, located at CERN

Two LArTPC designs:

- Horizontal drift (HD) technology
- Vertical drift (VD) technology

- ProtoDUNE Horizontal drift is an 800t active mass TPC, making it the largest LArTPC constructed.
- ProtoDUNE successfully operated in 2018 and is preparing for its second run now

Figure: CERN Neutrino Platform.

Figure: CERN.

Why do we need a trigger anyway?

https://indico.fnal.gov/event/57752/contributions/260312/

Untriggered, the FD VD module has a data volume of ≈1.8 TB/s (FD HD ≈1.4 TB/s).

DUNE's storage limit is ≈30 PB/year for all FD modules.

So DAQ is responsible for data reduction on the order 10^4.

This is where the trigger comes in.

Triggering on beam events in not a problem.

The challenge is capturing a wide range of physics at varying energies and rates without being swamped by background, for example:

- Low energy solar boron-8 neutrinos at few MeV scale
- High energy atmospheric neutrinos at >GeV scale
- See backup slide "Data selection constraints" for low energy background rates

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 a from both the TPC and the PDS (≈30 PB/year for all FD modules).
- Trigger and process events with different energies and rates.
- Difficult access (underground servers).

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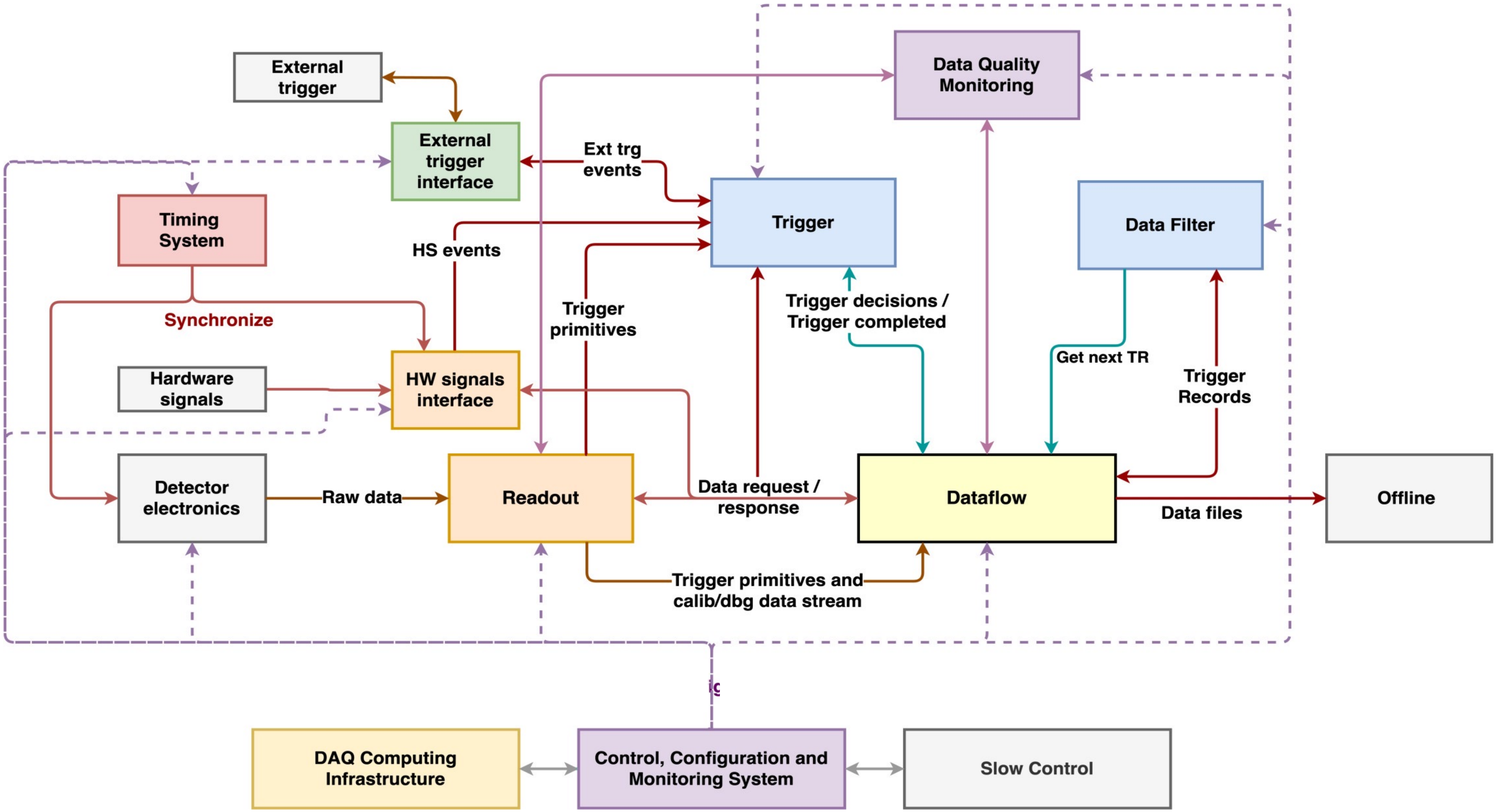
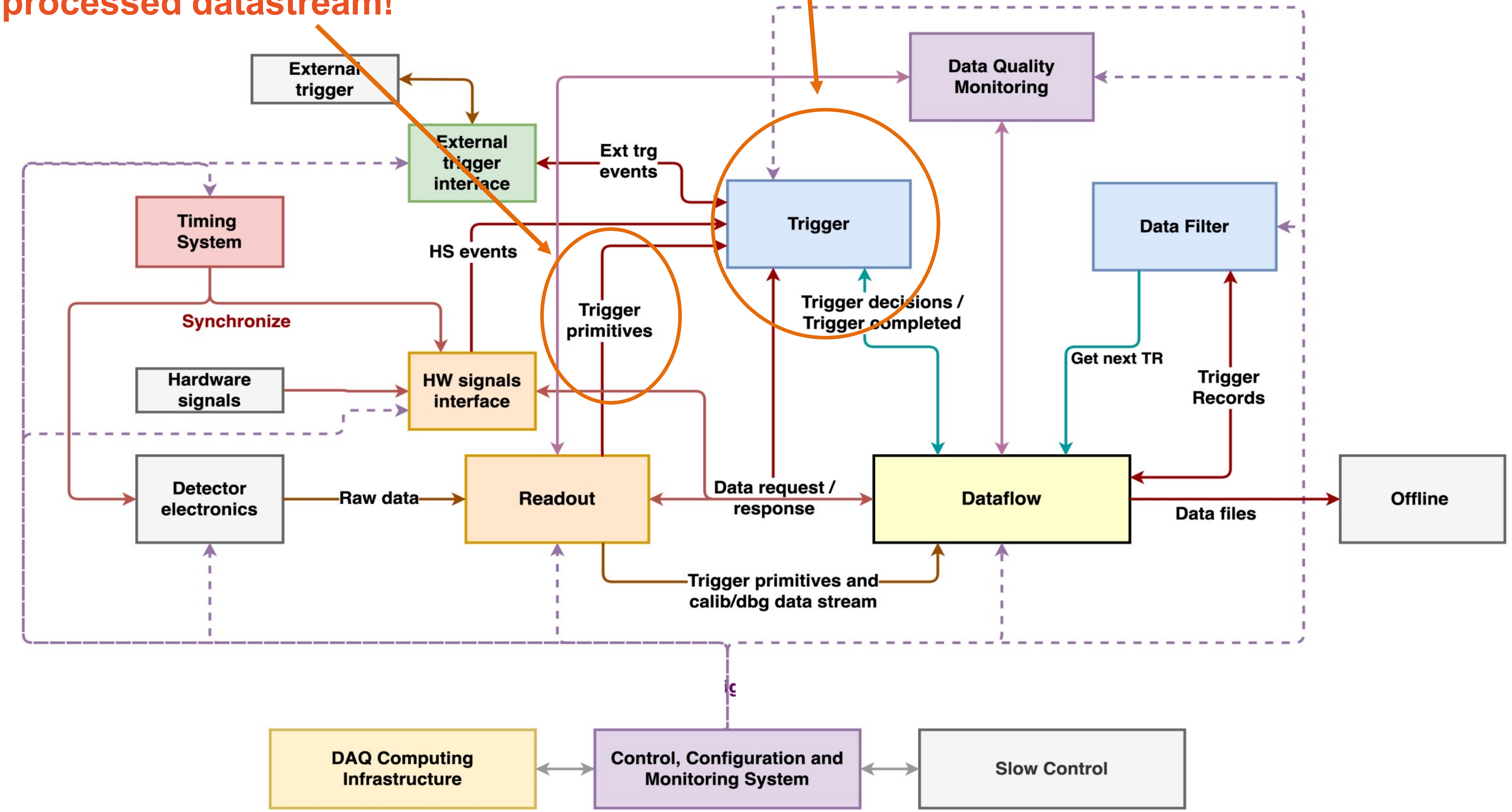
The TDAQ system



The Trigger system

Self-triggered system!

Real-time processed datastream!



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)

- ~ 10^{58} of ~ 10 MeV supernova neutrinos emitted for few seconds.
- All data is stored for 100 sec window including O(10 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

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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).

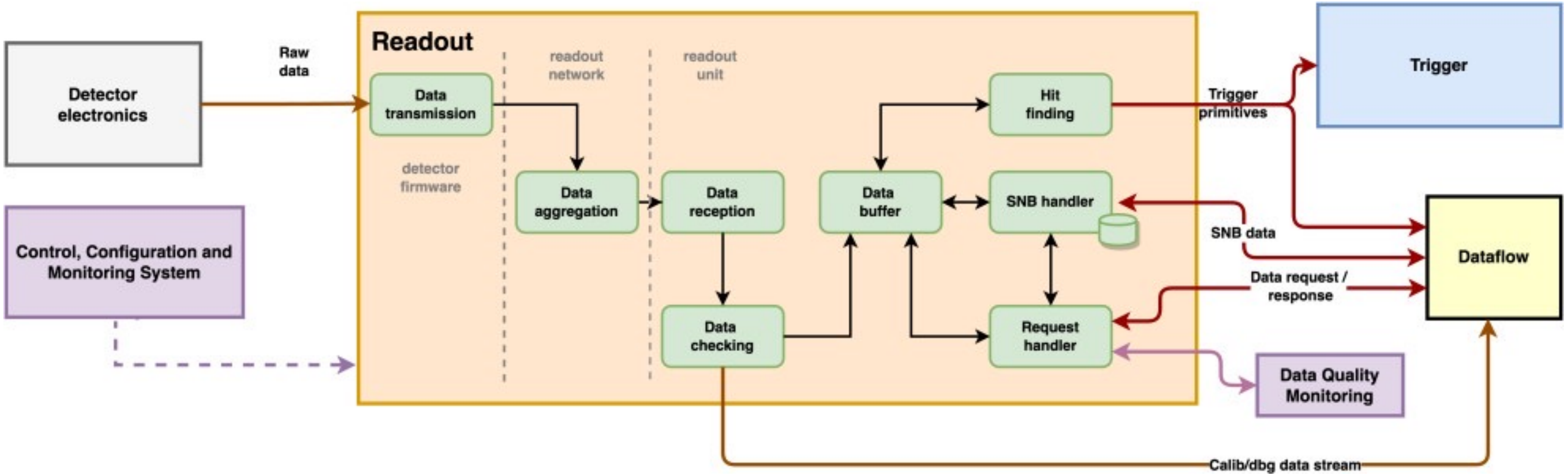


Figure: Interfaces of Readout components with other TDAQ sub-systems.

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

Readout system

Challenges:

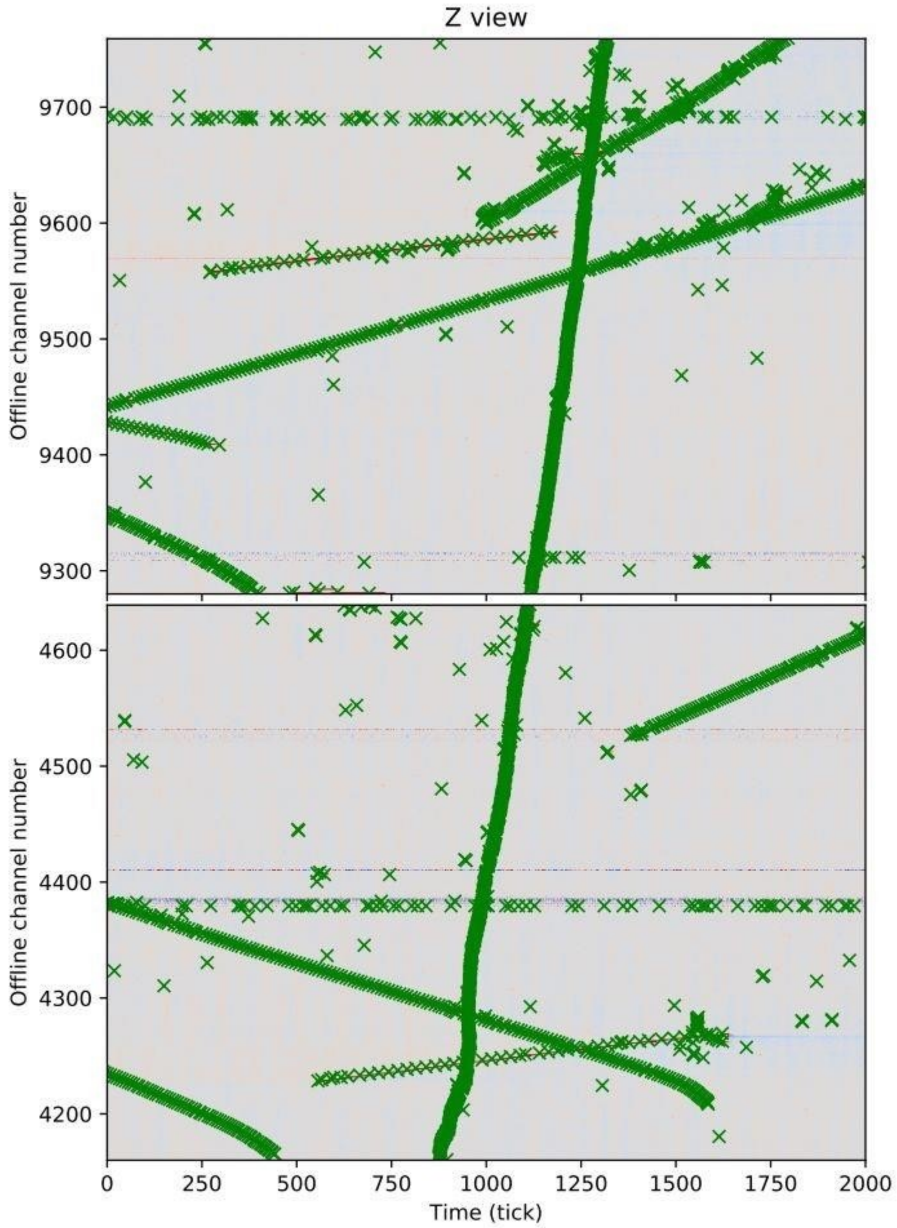
- Support all possible front-end types: be agnostic about data rate and payload size.
- Buffer received data for a specified/maximum amount of time.
- Respond to data requests with time-windows of O(μs) to O(s)
- In-flight data processing: Error and consistency checks with custom algorithms (e.g.: hit-finding)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

Feature extraction - "Hit" finding:

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

- Several algorithms implemented, to extracts hits from all channels, or collection plane only.
- Does pedestal subtraction, low level filter, and hit-finding.
- **Operational in ProtoDUNE: With a full self-triggering chain!**

1 time tick = 16 ns



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Data flow system

The Dataflow system includes 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).

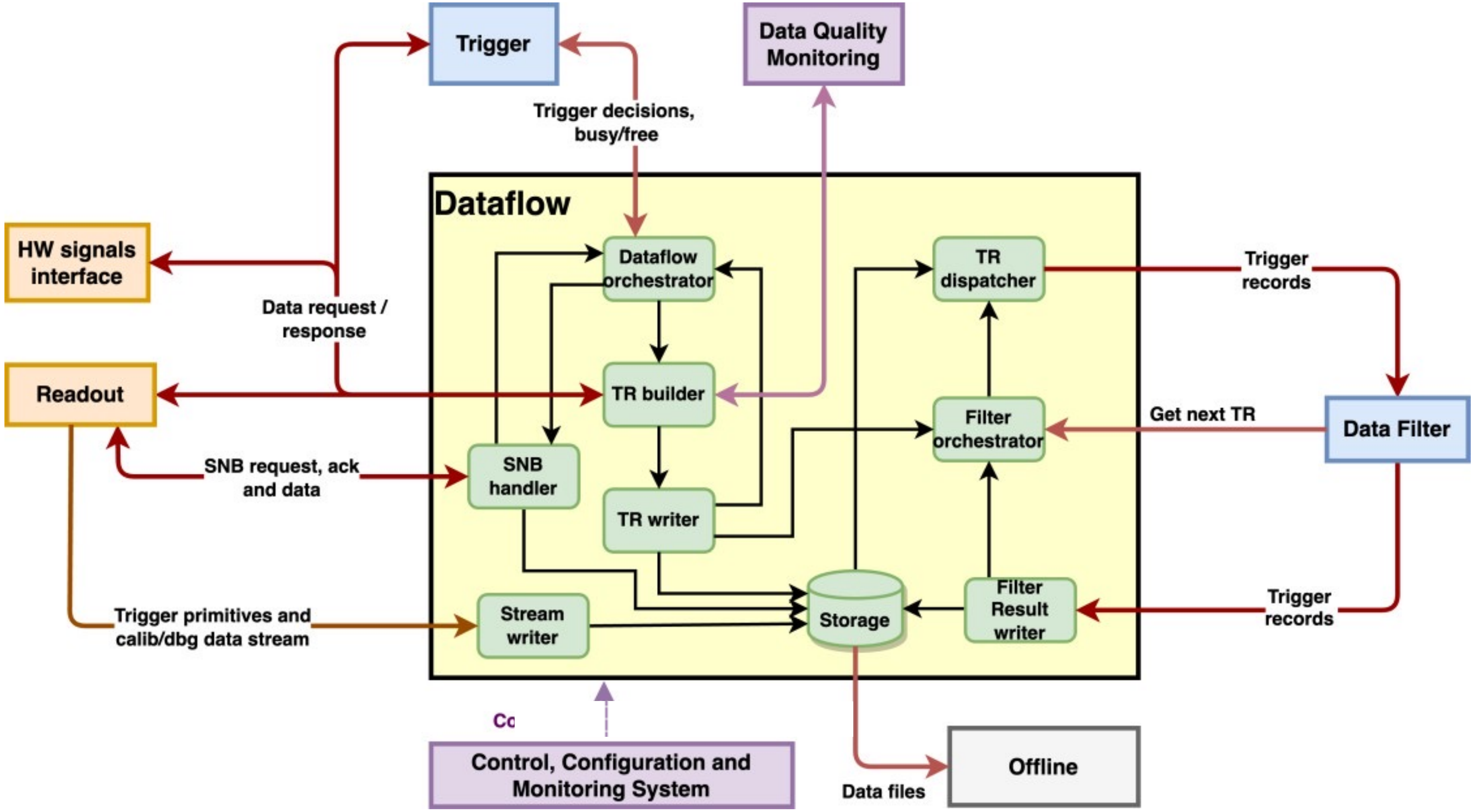

Figure: Interfaces of Dataflow components with other TDAQ sub-systems.

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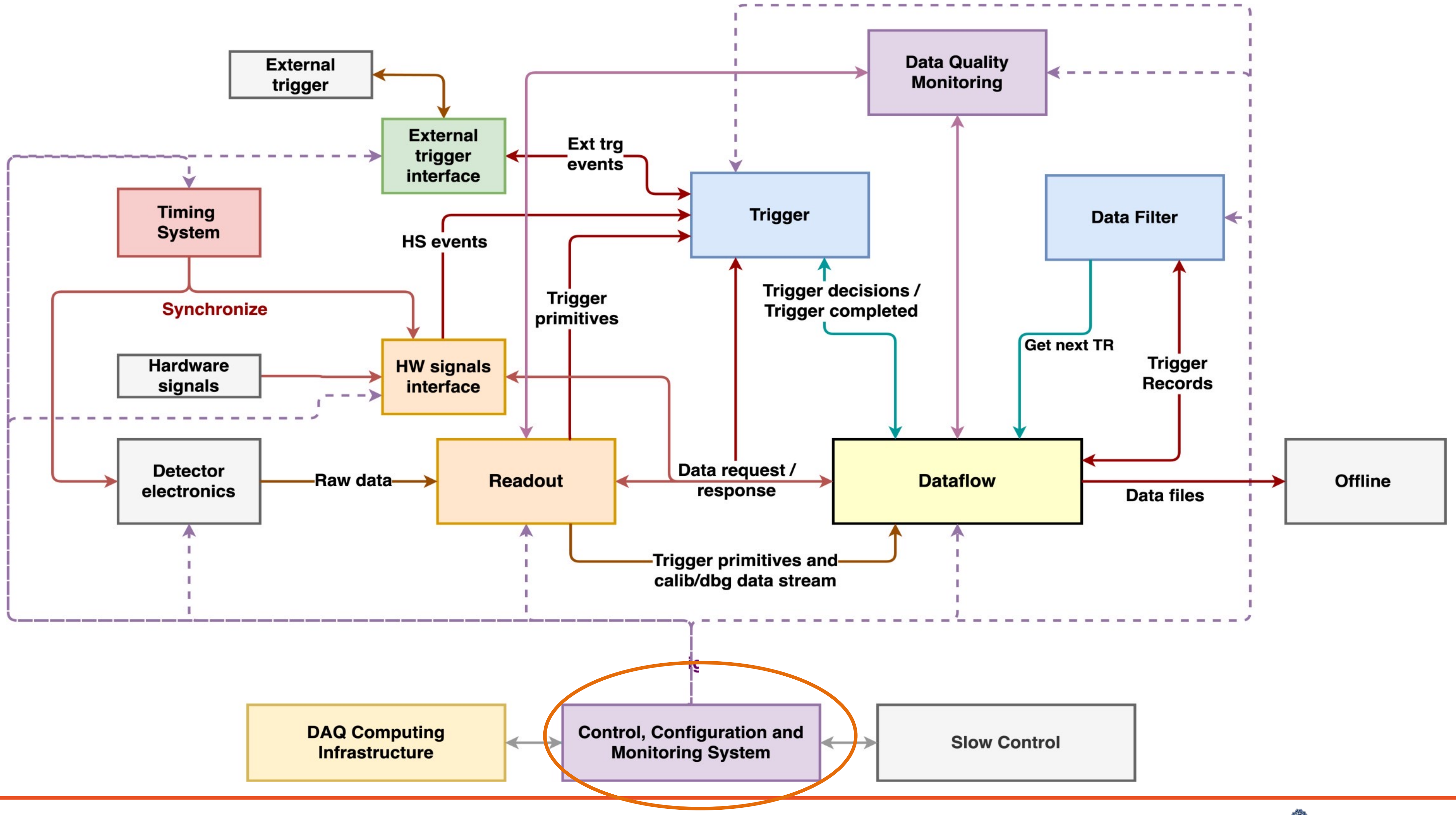
The expected maximum input rate to the Dataflow servers and the TDAQ storage system within each FD TDAQ will be 30 GB/s and the maximum output rate will be 7 GB/s.

Control, configuration, and monitoring system



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.

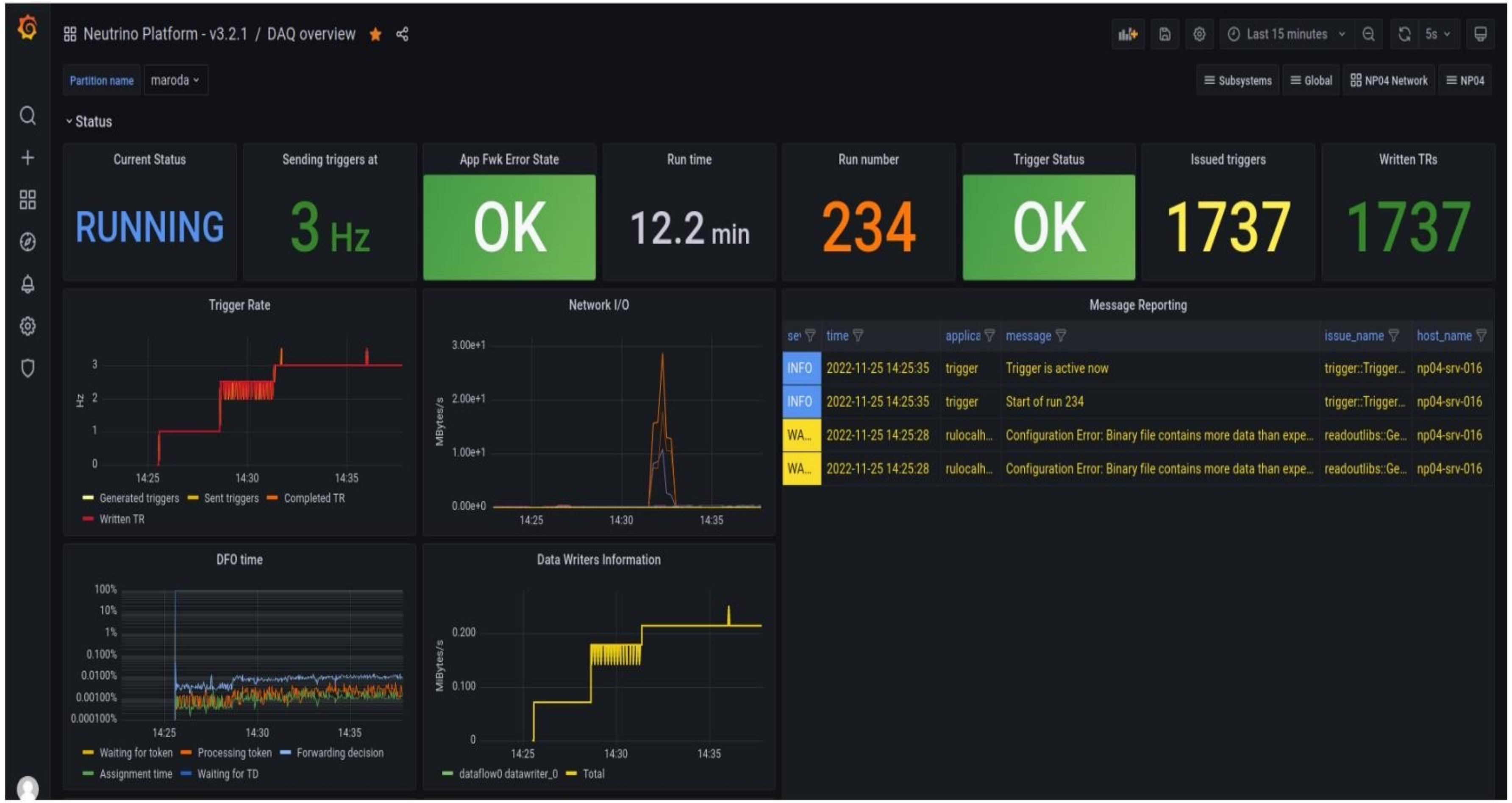


Figure: CCM system dashboard entry point.

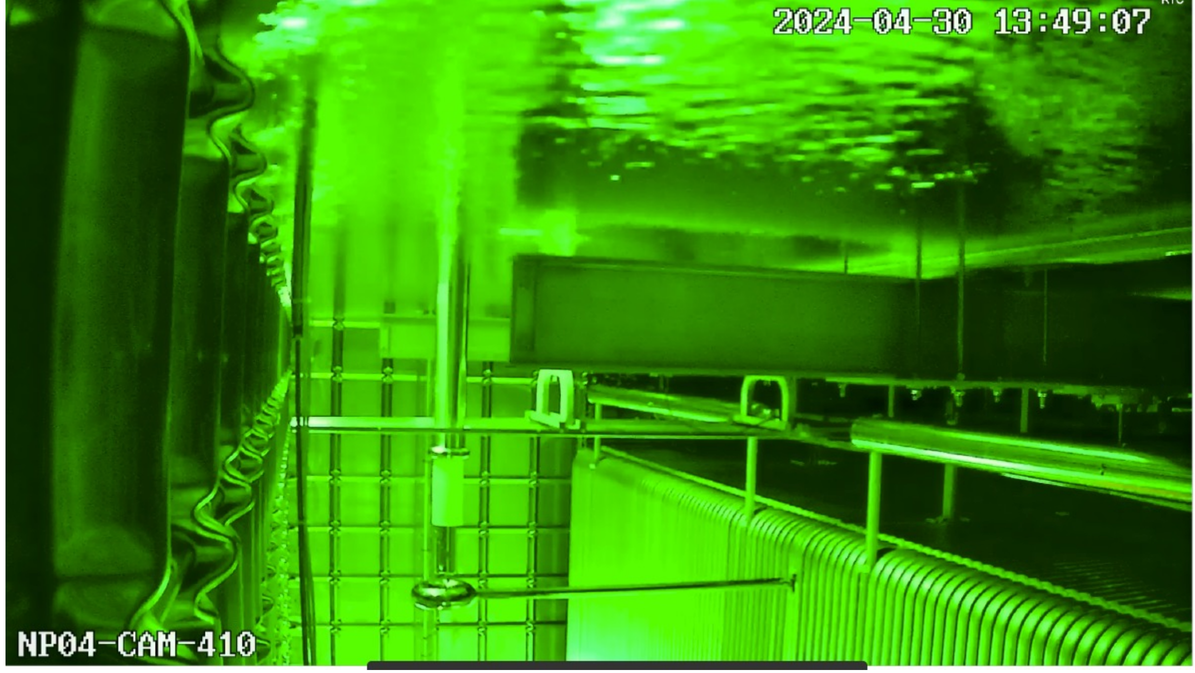
- at the top left is the panel for the selection of the DAQ session;
- at the top right the navigation links that point to all the other dashboards;
- the table in the right part of the dashboard is devoted to logging (Error Reporting Service (ERS)) messages.

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 data acquisition system complements the trigger system by managing the efficient transfer, processing, and storage of the captured data.
- 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.
- The TDAQ system is being optimized for low energy physics such as Supernova & Boron 8 neutrinos.
- The TDAQ system has a variable size readout window, from few μs (calibration) to 100 s (SNB).
- ProtoDUNE detectors will run again this year, and they will be the basis for validating the detector design, technologies, and TDAQ system.

END

Thanks for your time!!!



ProtoDUNE HD filled and being purified!

References

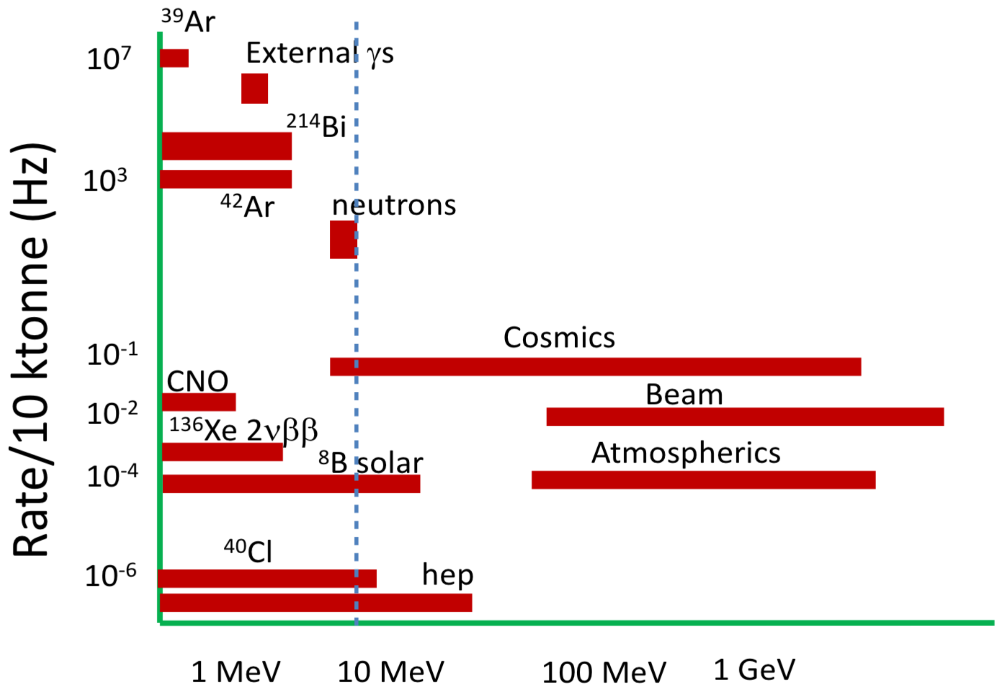
- FDR https://edms.cern.ch/ui/#!master/navigator/document?D:101190518:101190518:subDocs
- Trigger and Data AcQuisition Overview https://indico.fnal.gov/event/57752/contributions/260312/
- The readout system of the DUNE experiment: https://indico.phy.ornl.gov/event/112/contributions/561/
- The DAQ for 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 selection constraints

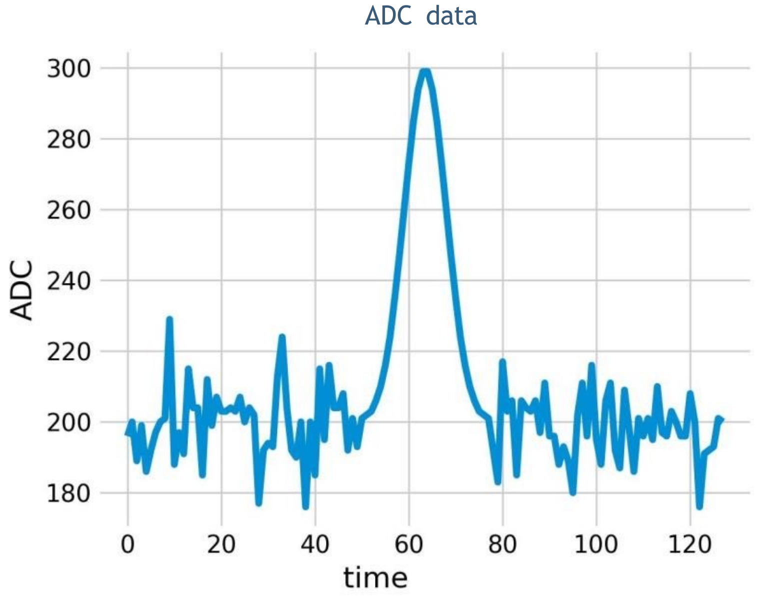
- Activity below ~10 MeV dominated by background, by orders of magnitude

- Large fraction of Ar39 expected to be identified as hits

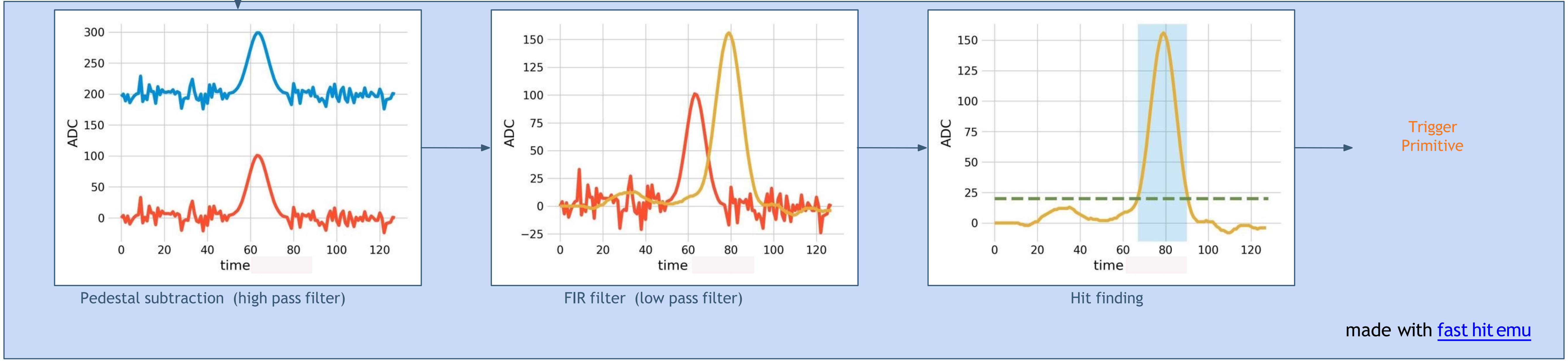
- Data volume must be reduced by > 10^4
    - Cut on energy and/or
    - Region-of-Interest readout



Trigger system: Trigger Primitive Generation (TPG)

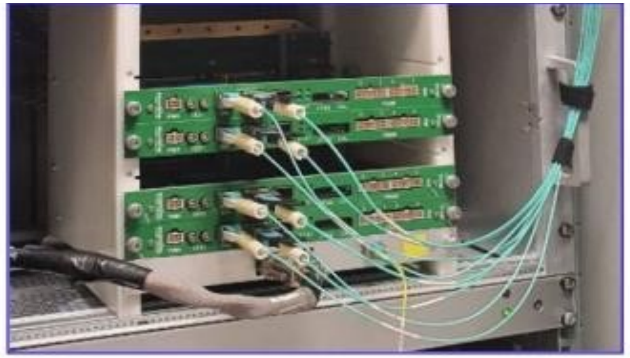


- TPG from the readout board uses the Field Programmable Gate Array (FPGA) for processing Analog-to-Digital Converter (ADC) data.
- TP information contains start time, end time, peak time, sum ADC and peak ADC.



Readout system: Front-end electronics

Time Projection Chamber (TPC) readout



Silicon Photomultiplier (SiPM) readout

raw data

different rates and payload sizes

Commercial Off-The-Shelf (COTS) servers

Network Interface Controller (NIC)

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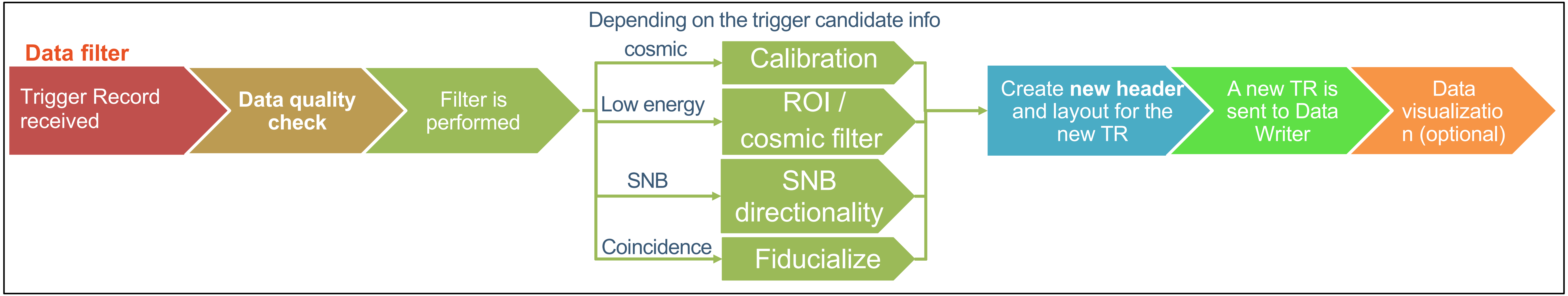
Data Filter

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 as 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.

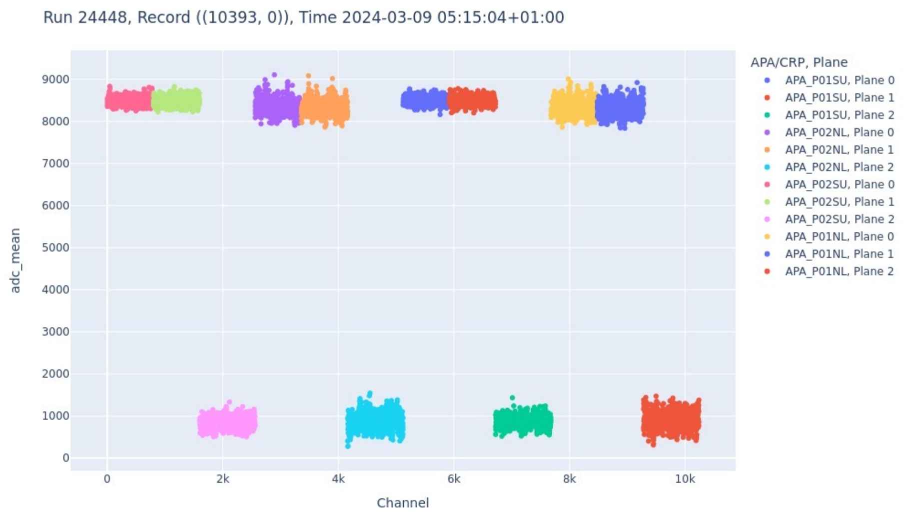


Data Quality Monitoring (DQM) system

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).

Mean ADC



RMS ADC

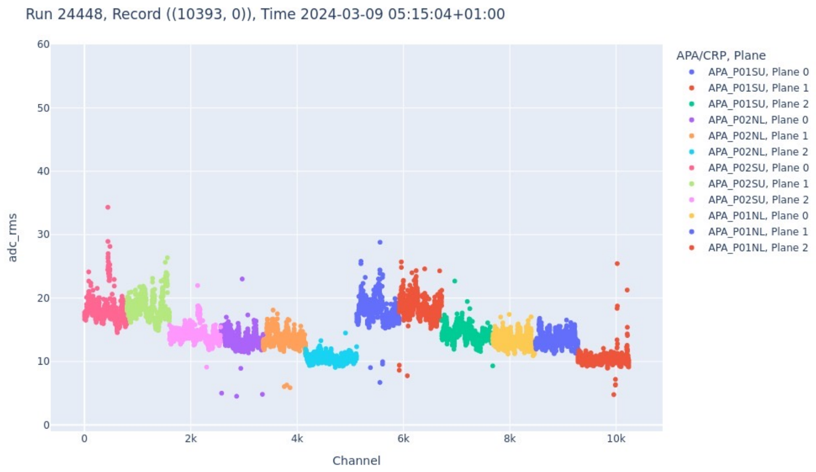
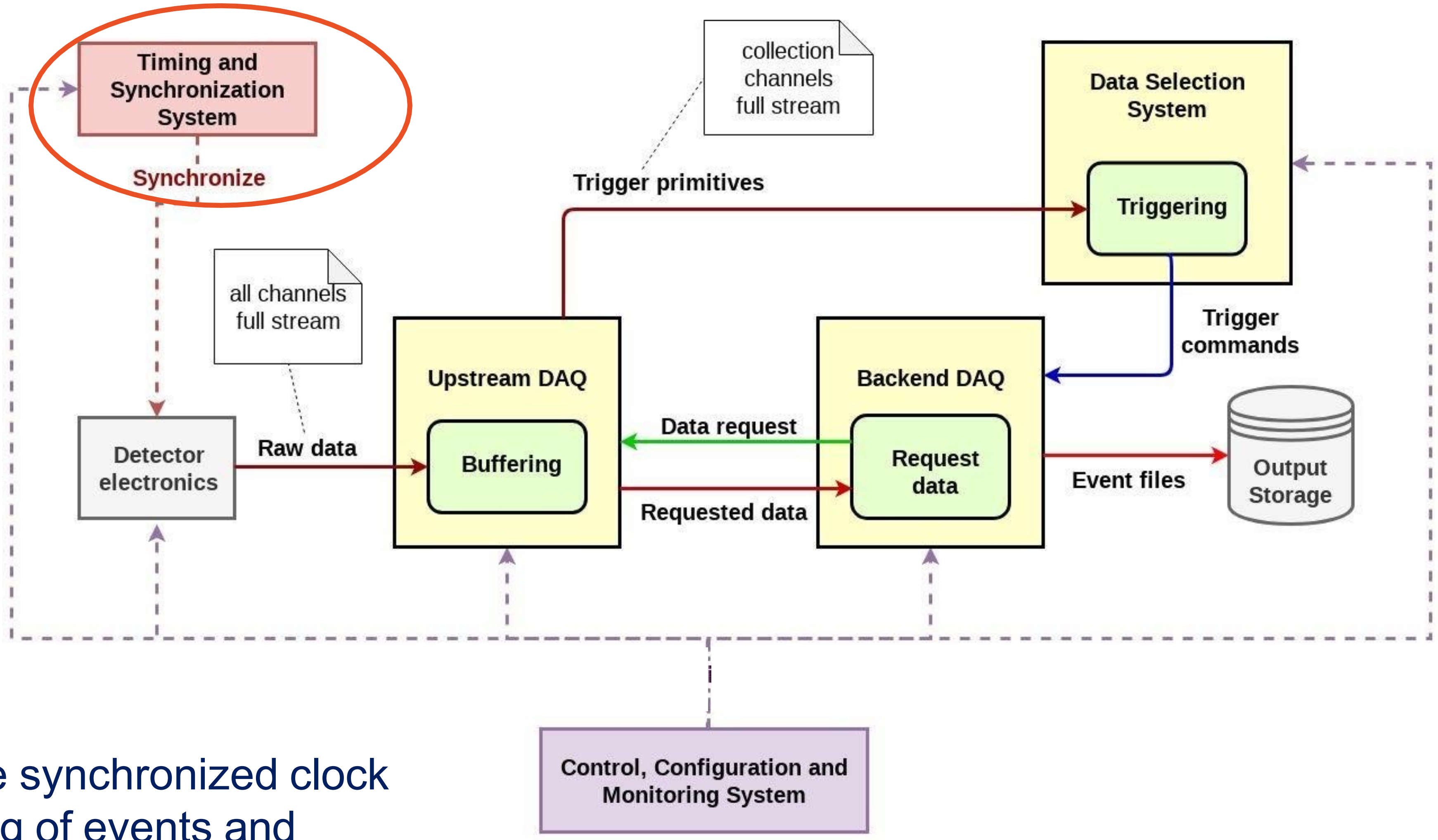


Figure: DQM system metrics

DUNE TDAQ: 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.

https://indico.cern.ch/event/543031/contributions/2921456/