

# DUNE trigger and data acquisition (TDAQ) system

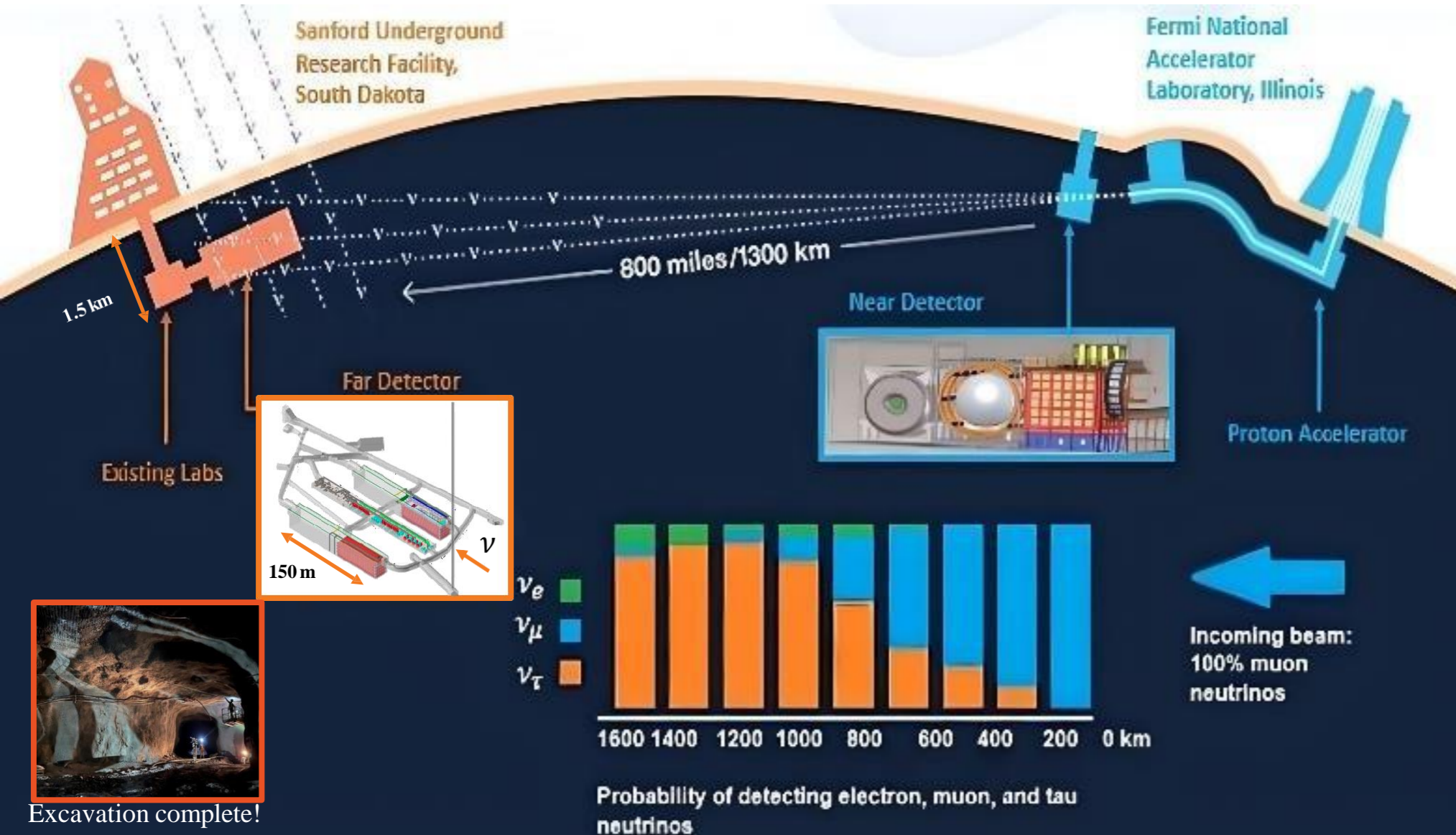
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- Next-generation long baseline neutrino experiment hosted in the United States.
- High-intensity neutrino beam, near detector complex at Fermilab.
- Underground Liquid Argon Time Projection Chamber (LArTPC) far detectors at SURF.
- Broad program of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



Excavation complete!

# 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.
- **We have used this as a test of our TDAQ system and are continuing to improve it during our off beam time.**
- ProtoDUNE successfully operated in 2018 and we are now running again!
- We have taken our first week of beam data from June 19<sup>th</sup> – June 26<sup>th</sup>
- Over this week we collected 250 TB of beam data and over 2M trigger records collected.
- We are taking beam data now again as we speak (since the 10<sup>th</sup>).



Figure: CERN Neutrino Platform



# Why do we need a trigger anyway?

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

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

DUNE’s storage limit is  $\approx 30$  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 is not a problem.

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

# The TDAQ system

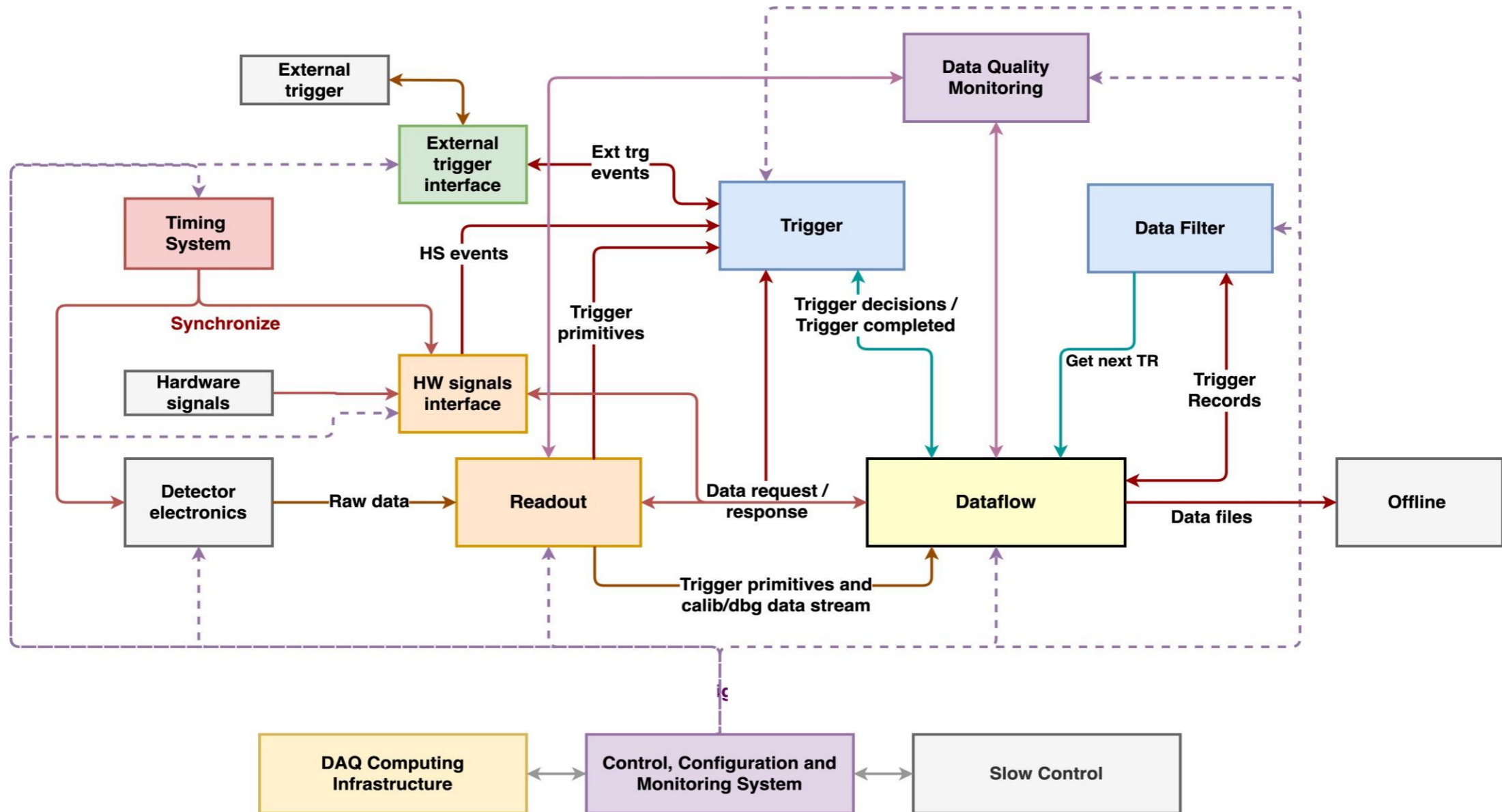
**The TDAQ system has various critical functions to ensure smooth data acquisition and analysis:**

- 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 ( $\approx 30$  PB/year for all FD modules).
- Trigger and process events with different energies and rates.
- Difficult access (underground servers).

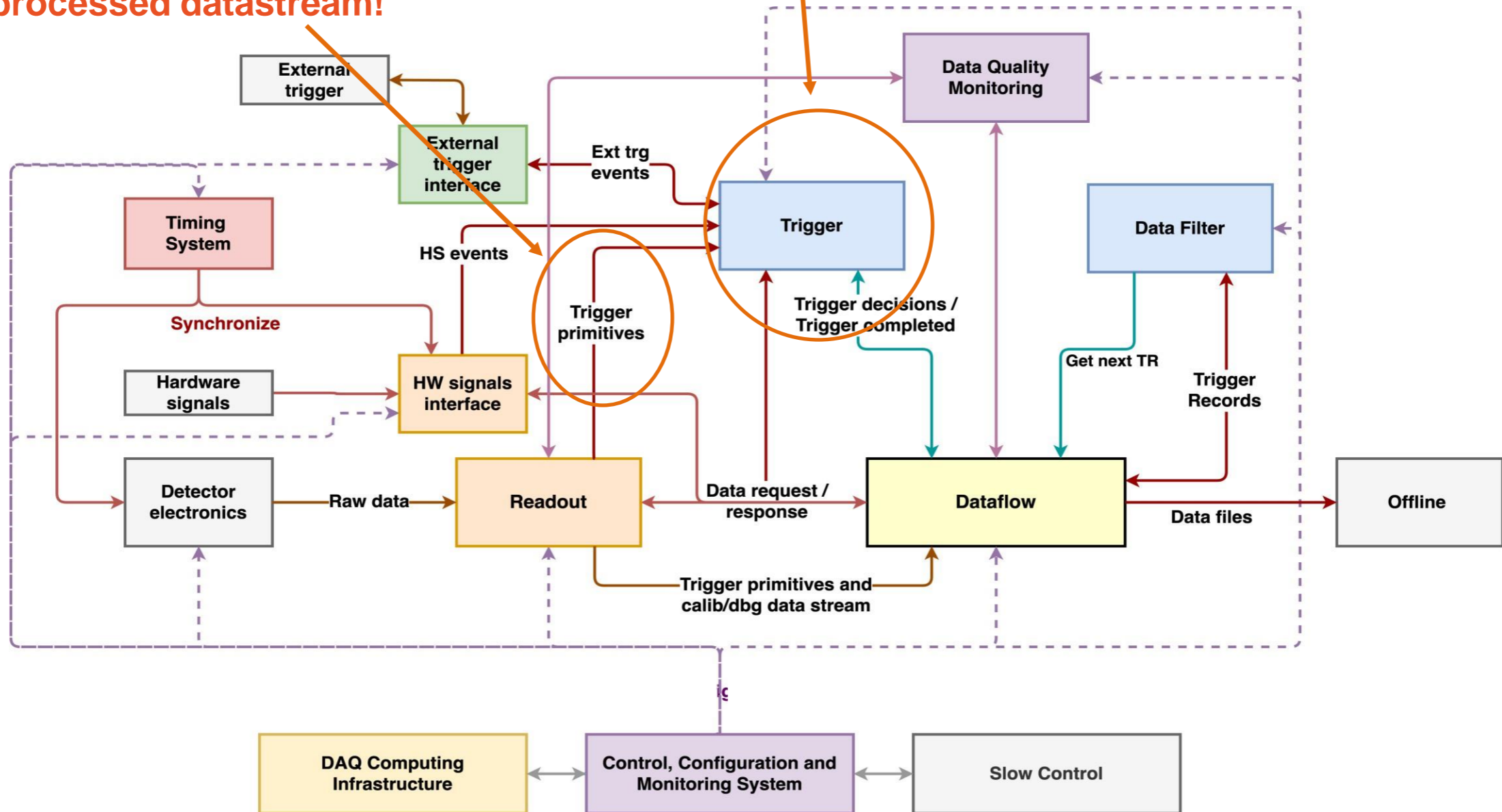
# The TDAQ system



# The Trigger system

Real-time processed datastream!

Self-triggered system!



# 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  $\sim 10$  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 ( $\sim 140$  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).

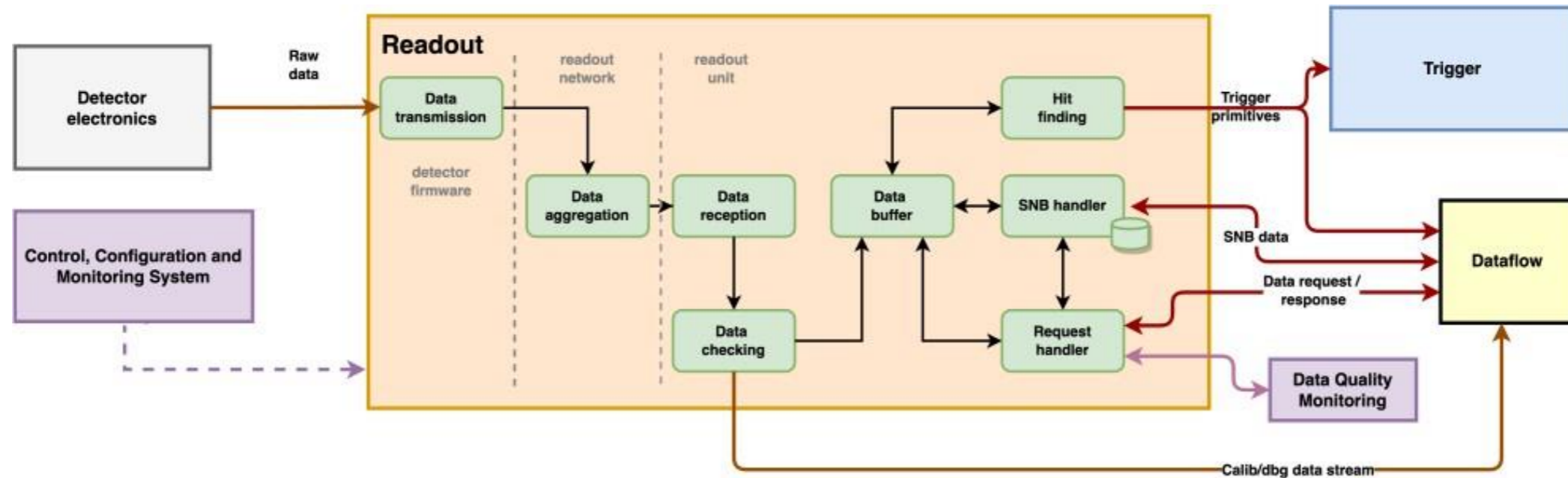


Figure: Interfaces of Readout components with other TDAQ sub-systems.

# Readout system

## Challenges:

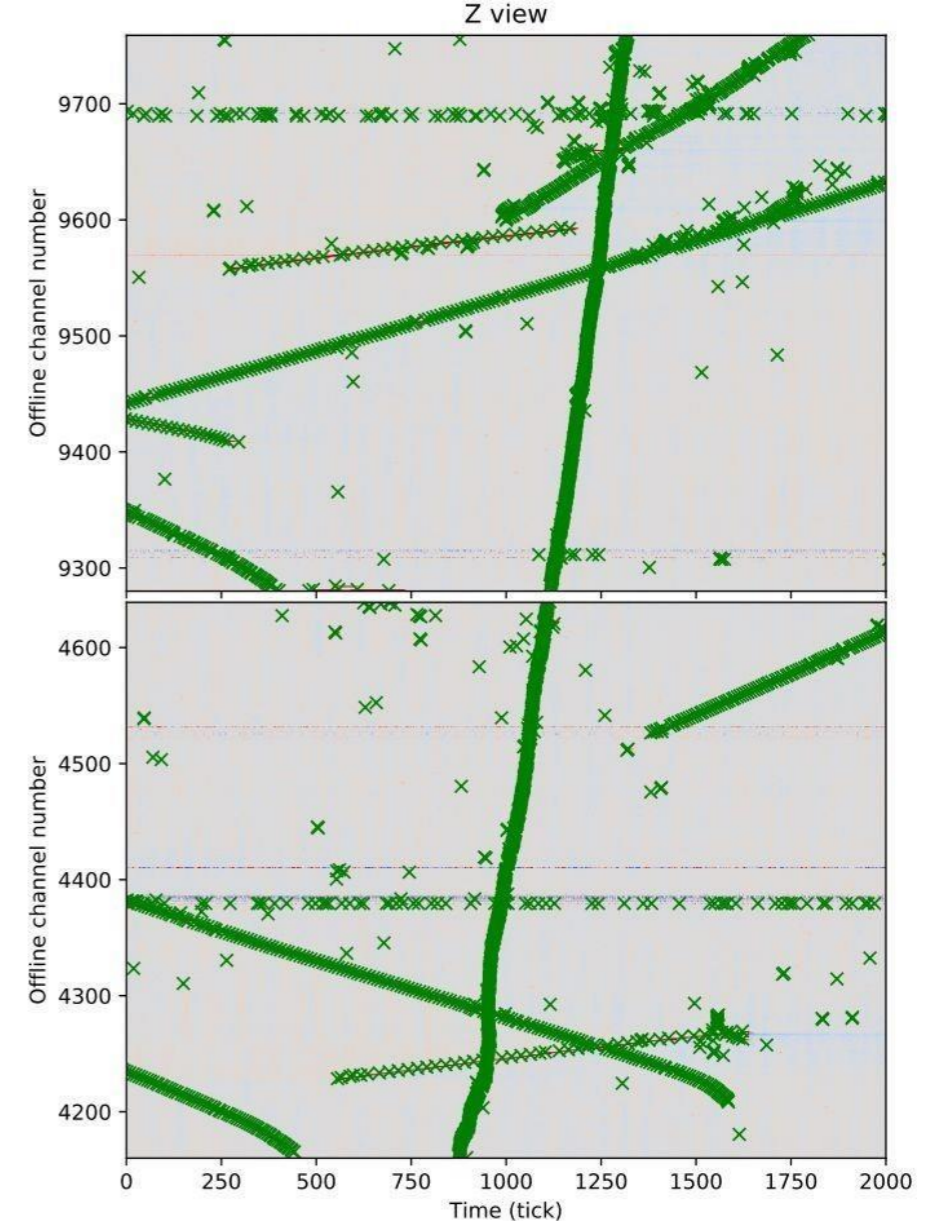
- Support all possible front-end types: be agnostic about data rate and payload size.
- Buffer received data for a specified/maximum amount of time.
- Respond to data requests with time-windows of  $O(\mu\text{s})$  to  $O(\text{s})$
- In-flight data processing: Error and consistency checks with custom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

## Feature extraction - “Hit” finding:

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

- Several algorithms implemented, to extract 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



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

# Dataflow 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).

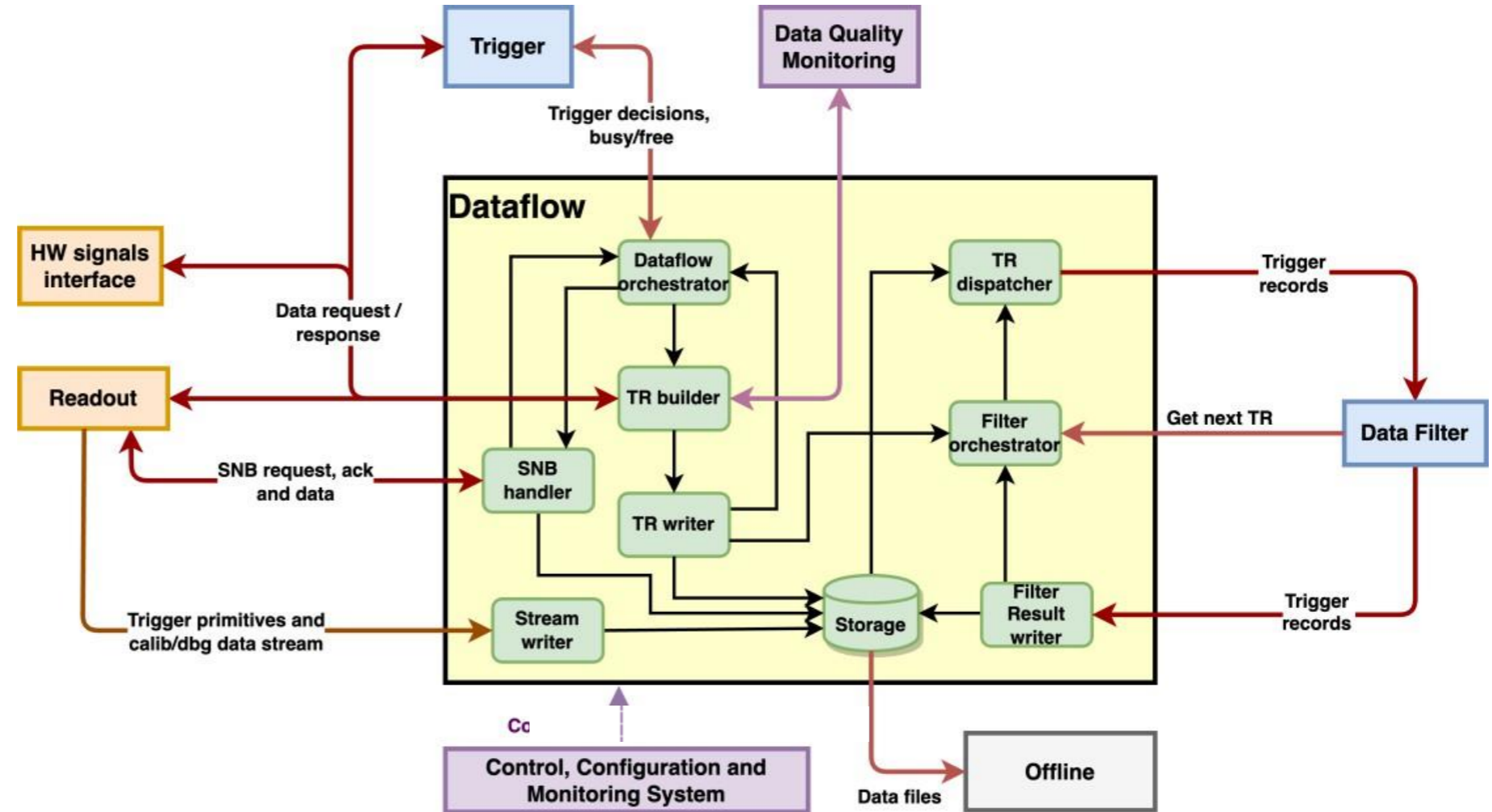
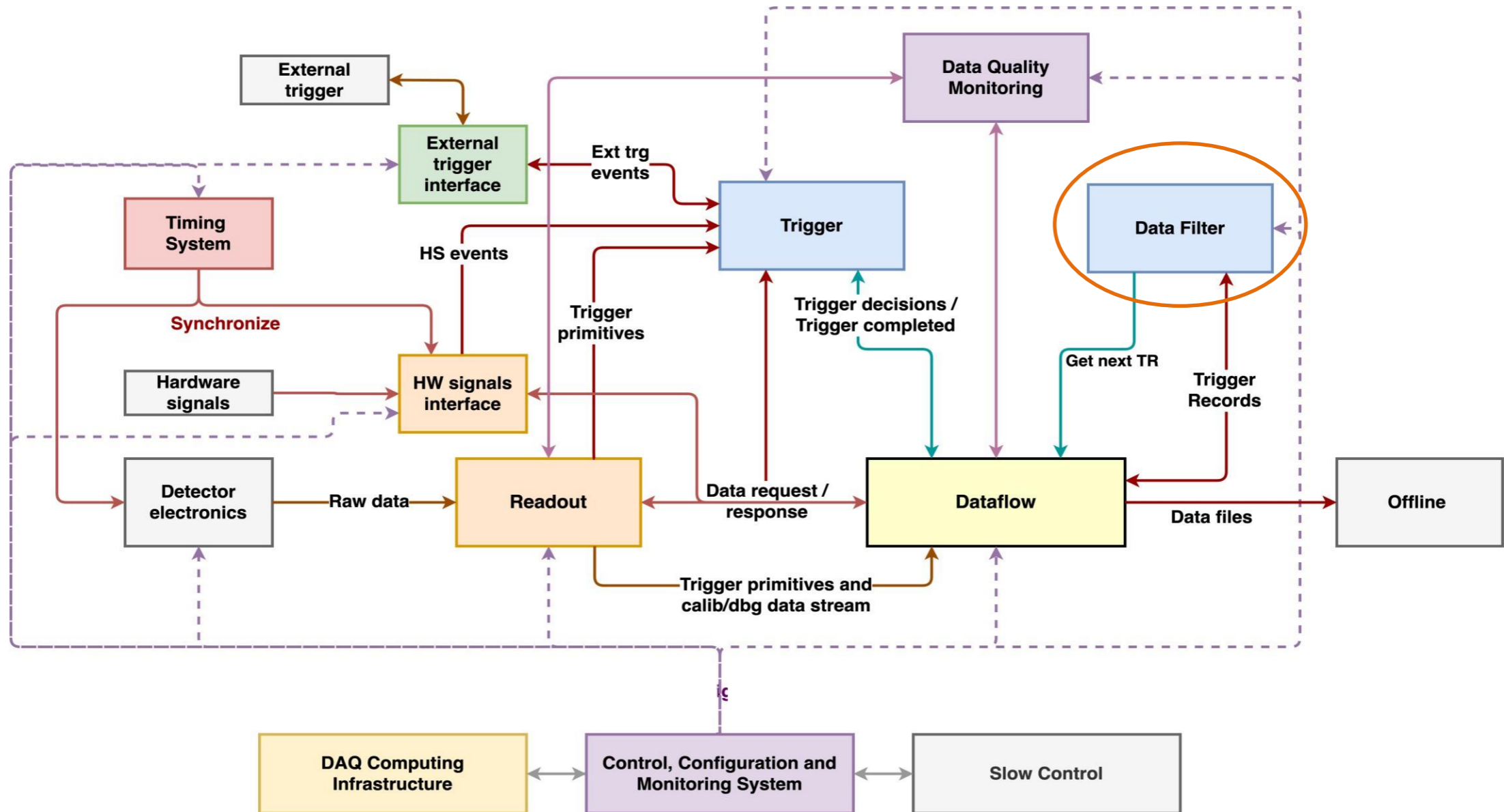


Figure: Interfaces of Dataflow components with other TDAQ sub-systems.

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.

# Data Filter

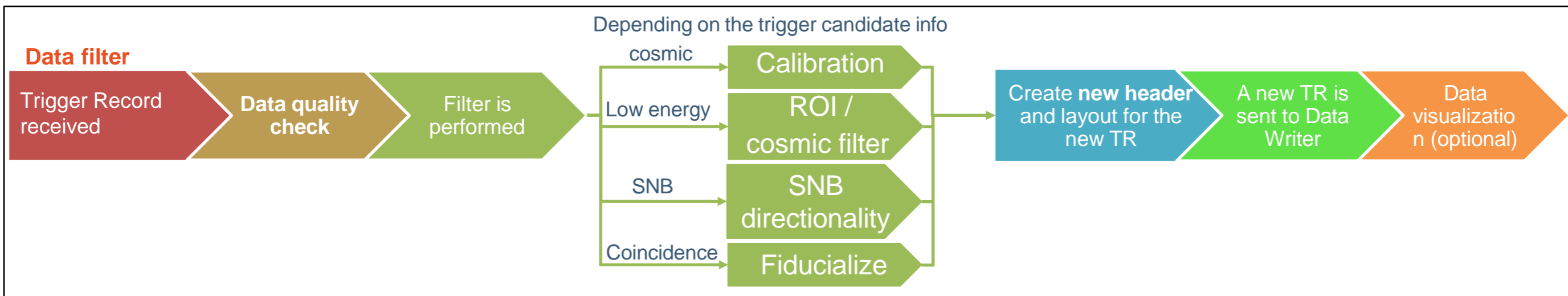




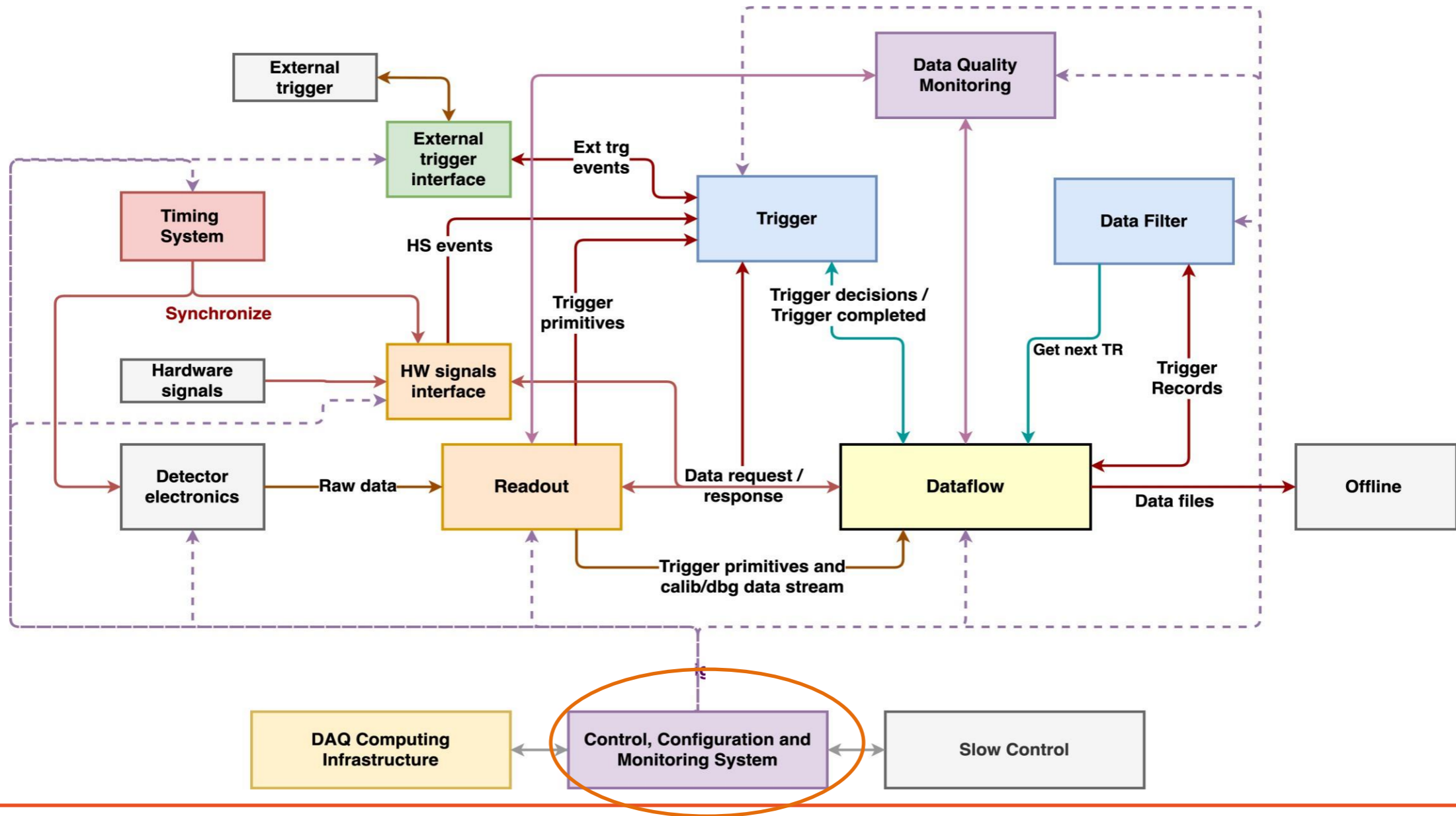
# Data Filter

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.



# Control, configuration, and monitoring system



# Control, configuration, and monitoring system

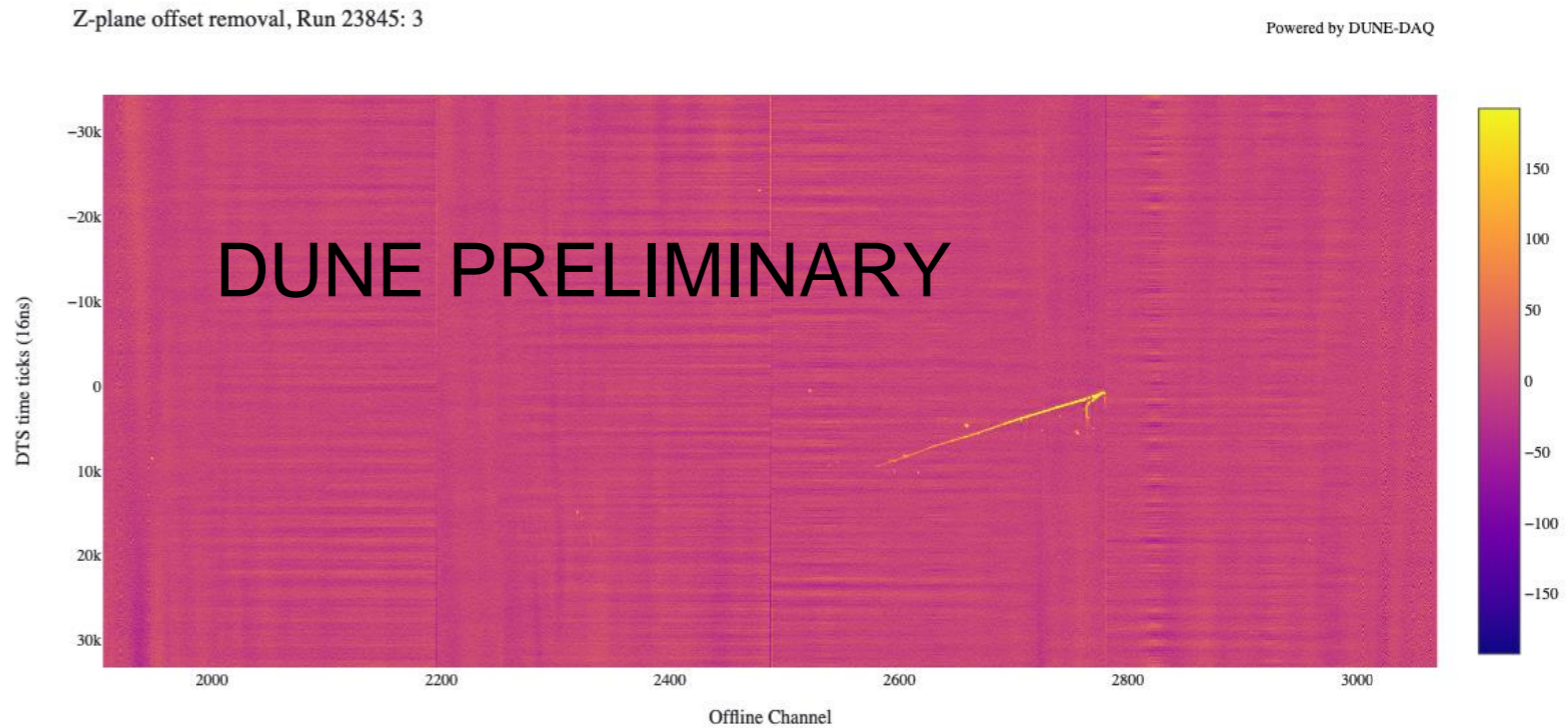
The CCM system is a centralized framework that enables operators to manage and oversee the experiment.

- It provides a single interface for controlling the TDAQ system



# Data Quality Monitoring

- The TDAQ also has developed a variety of data quality monitoring (DQM) tools.
- Used to give quasi real-time information on the quality of the data we are collecting.
- Enables problems to be fixed in a timely fashion and will help with the uptime requirements.
- Have used these effectively in the latest protoDUNE run.
- We have an instance of the DQM running on the CERN network automatically updates event displays, and a checklist for the WIBs and the PDS system





# 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  $\sim 40$  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  $\mu\text{s}$  (calibration) to 100 s (SNB).

# END

## Thanks for your time!!!



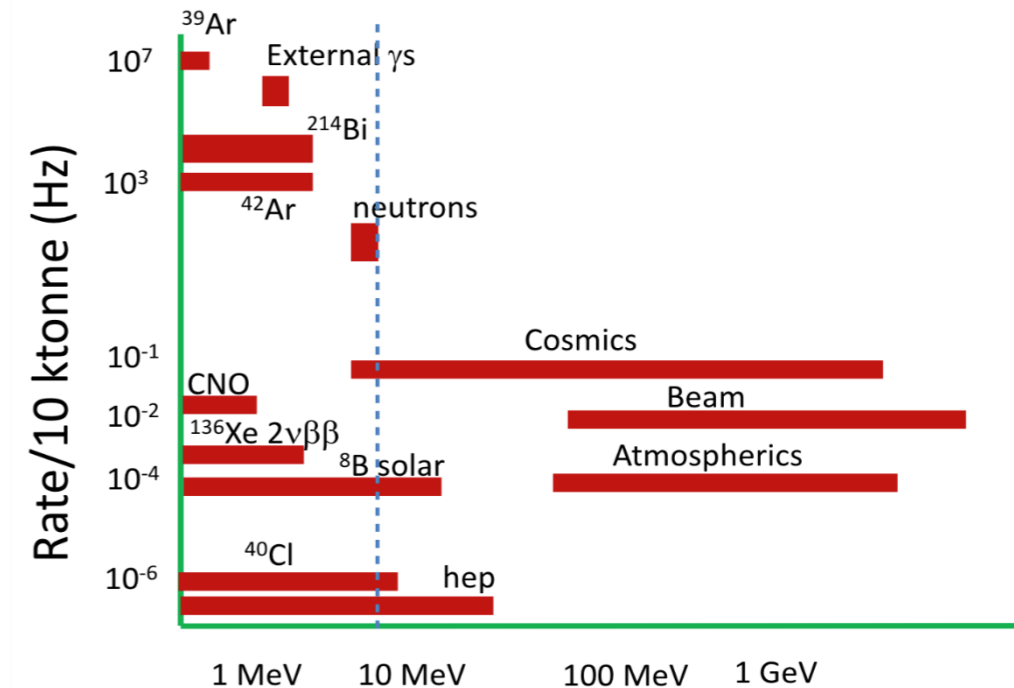
Thanks as well to Matthew Man and Danaïsis Vargas for the content of many of the slides and for their help in preparing for this talk

### References

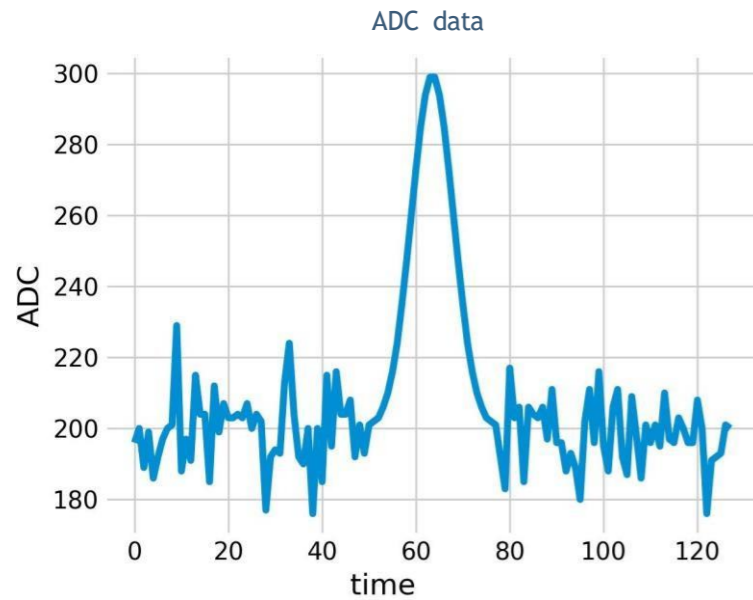
- FDR  
<https://edms.cern.ch/ui/#!/master/navigator/document?D:101190518:101190518:subDocs>
- Trigger and Data Acquisition Overview <https://indico.fnal.gov/event/57752/contributions/260312/>
- The readout system of the DUNE experiment:  
<https://indico.phy.ornl.gov/event/112/contributions/561/>
-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

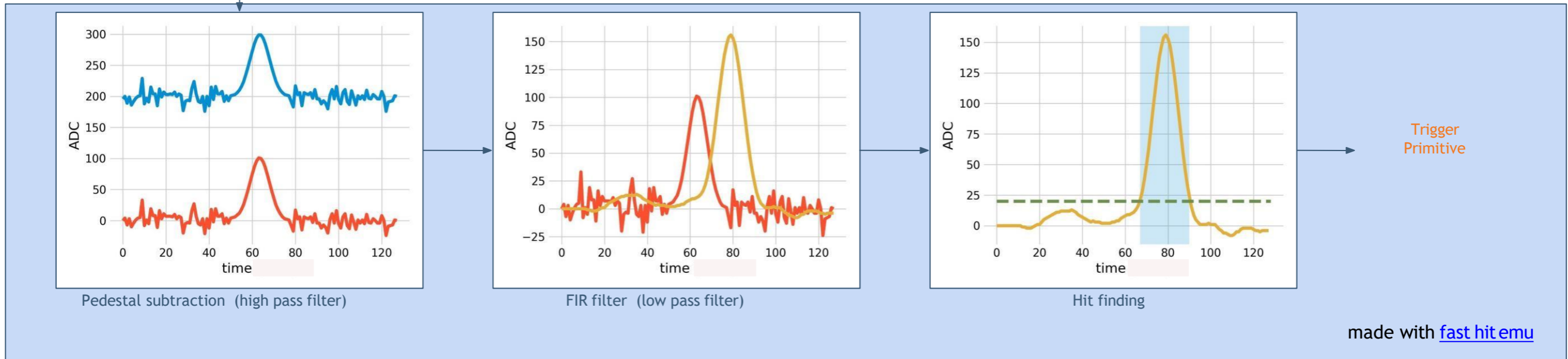
- Activity below  $\sim 10$  MeV dominated by background, by orders of magnitude
- Large fraction of Ar39 expected to be identified as hits
- Data volume must be reduced by  $> 10^4$ 
  - Cut on energy and/or
  - Region-of-Interest readout



# Trigger system: Trigger Primitive Generation (TPG)



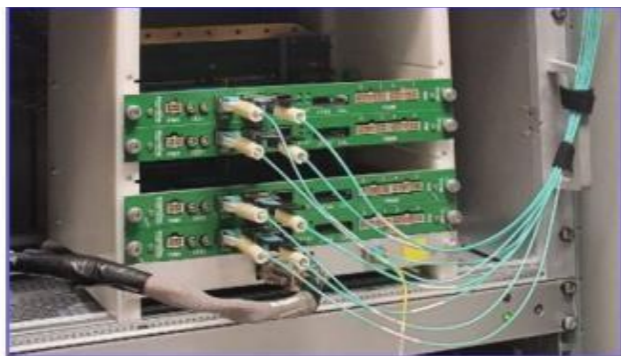
- TPG from the readout board uses the Field Programmable Gate Array (FPGA) for processing Analog-to-Digital Converter (ADC) data.
- TP information contains start time, end time, peak time, sum ADC and peak ADC.





# Readout system: Front-end electronics

Time Projection Chamber (TPC) readout



Silicon Photomultiplier (SiPM) readout



Commercial Off-The-Shelf (COTS) servers



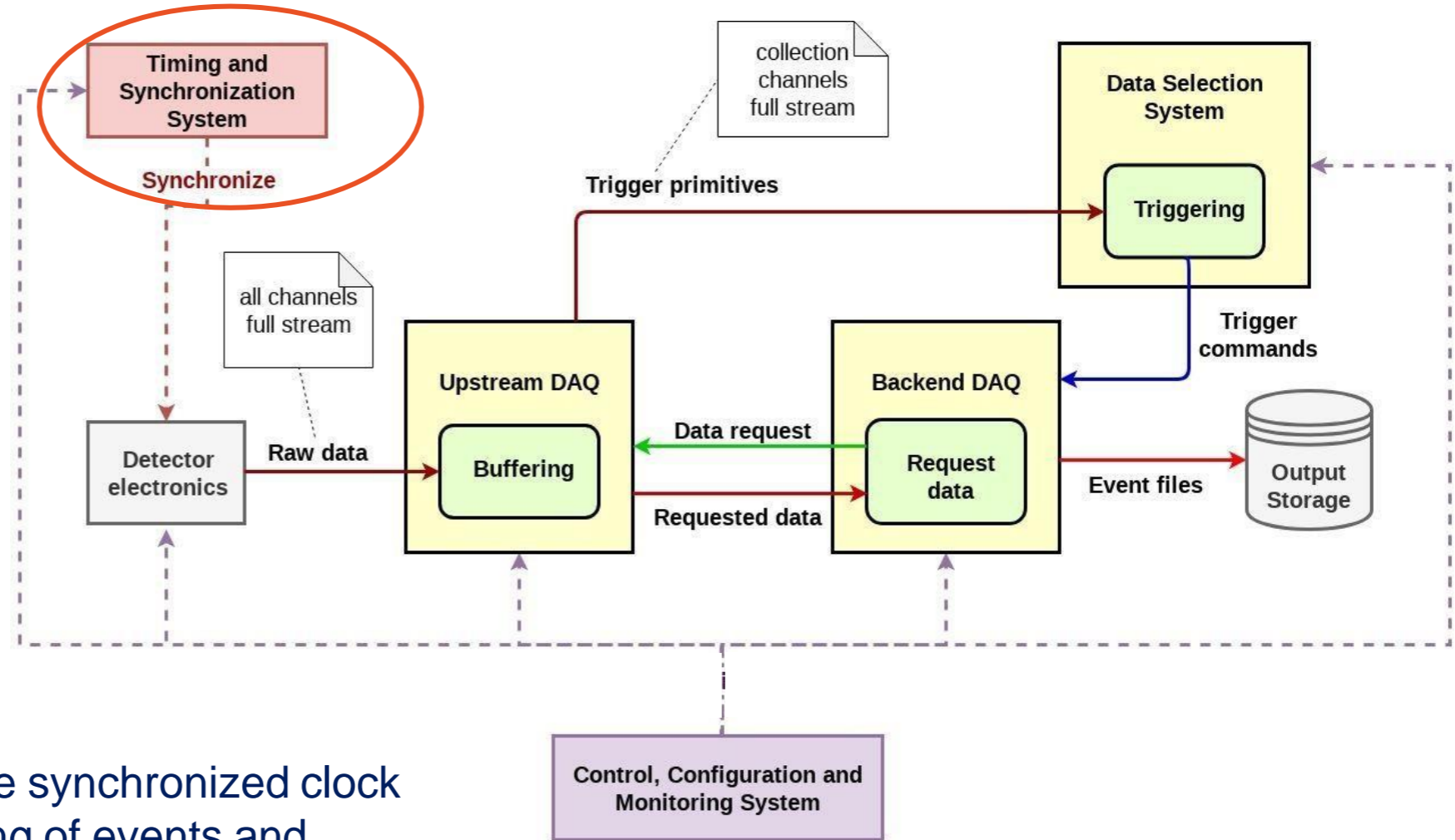
different rates and  
payload sizes

Network Interface Controller (NIC)



# 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.