The NOνA Data Acquisition system with the full 14 kt far detector

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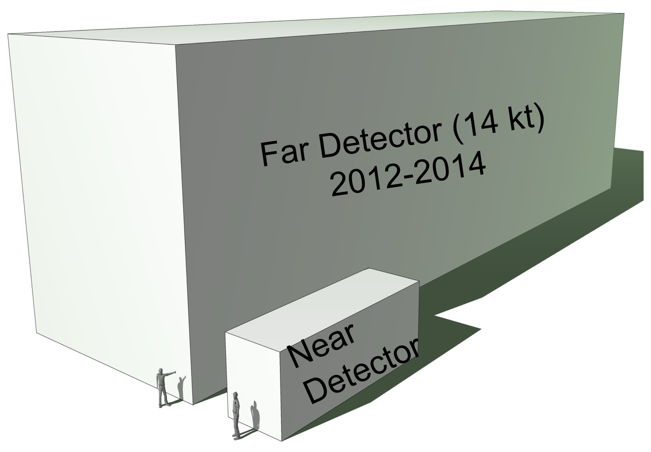
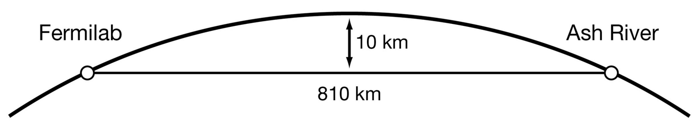
NOνA experiment

The NOνA experiment is a long baseline neutrino oscillation experiment designed to measure both ν_e appearance and ν_μ disappearance in order to determine the neutrino mass hierarchy, improve knowledge of the neutrino mixing structure and investigate the CP violating phase δ_{CP}.





The experiment uses a multi detector design where each of the NOνA detector uses a functionally identical design and differ only in the their size and locations.

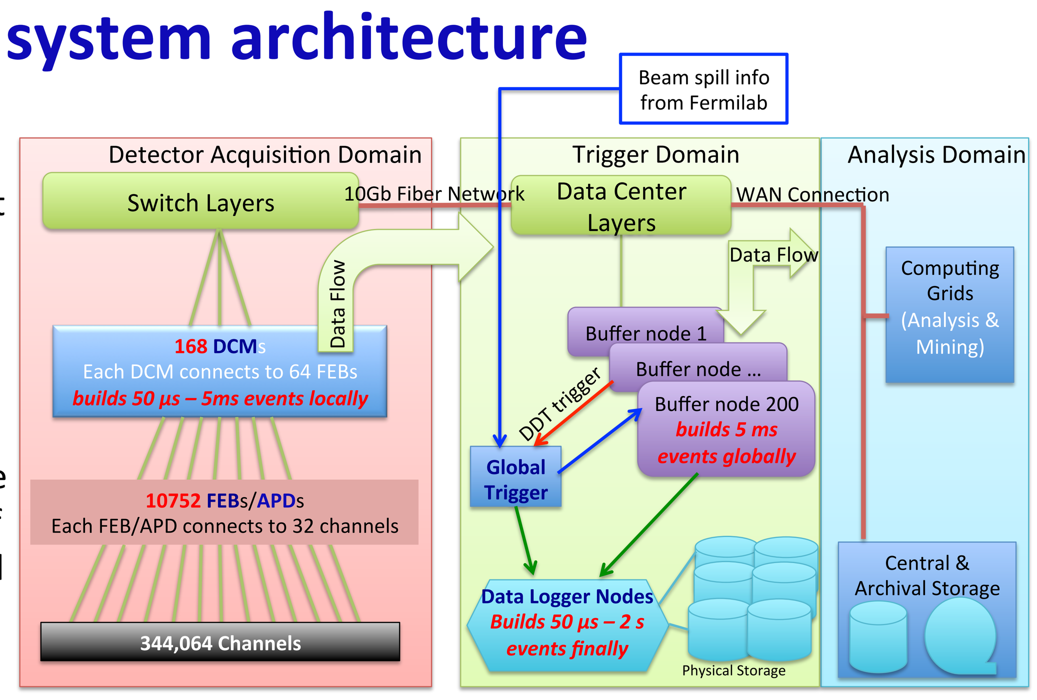
The experiment features:

- A 300 t underground near detector is located at approximately 1 km from the primary target station and 14 mrad off the beam;
- A massive 14 kt far detector is located in Ash River Minnesota, at 810 km from the primary target station and 14 mrad off-axis;
- The detectors are exposed to the neutrino beam from the 120 GeV NuMI beamline.

The DAQ system architecture

NOνA uses a novel data acquisition system based on a continuous deadtime-less readout of the front-end electronics, extended buffering of the data stream and asynchronous software triggering.

Neutrino interactions in the detectors are detected as light pulses in the scintillator. The NOνA detectors, both far and near, consist of scintillation particles suspended in mineral oil within a PVC tube. A wavelength shifting optical fiber is routed inside the PVC tube to collect the light, and an **Avalanche Photo Diode (APD)** attached to the fiber converts the light pulse into electrical signals.



A schematic overview of the data acquisition system.

The **Front End Board (FEB)** will discriminate and time tag the signals from 32 readout channels.

A **timing system** (more details in a separate poster) will synchronize and provide the time base to all the DAQ electronics modules. This system both internally and site-to-site synchronizes the more than 12,000 custom FEBs to within 16 ns of each other.

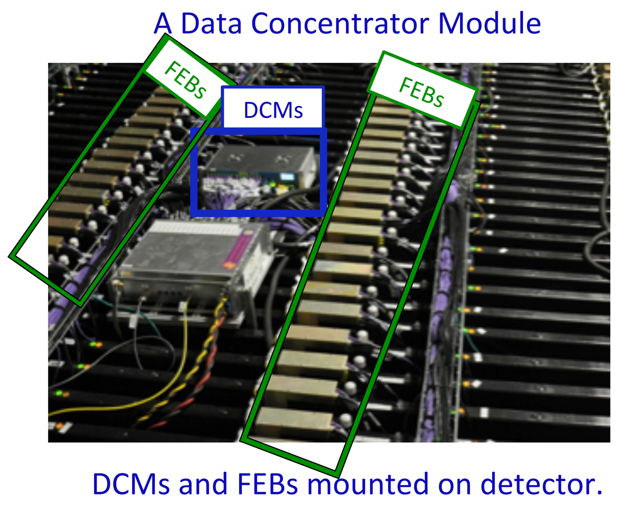
FEBs will transmit the over-threshold signals to the **Data Concentrator Module (DCM)**. The DCM will collect data from up to 64 FEBs and transmit packets of data onto the **DAQ network**.

A farm of ~200 computers (**buffer nodes**) will buffer the data, build requested events based on the time tags, do real time analysis by the **"data driven trigger" system (DDT)** and archive that data. The selected data will be transmitted to the data processing center at Fermilab for storage and offline analysis.

Readout Module

DCMs are detector mounted devices with an embedded CPU running Linux. The CPU pulls data from a buffer implemented in an FPGA. This buffer is continuously filled with serial data collected from up to 64 FEB modules via a custom serial and timing interface protocol over the CAT5e front end link cable. The link deserializers, first stage buffers, and data concatenation logic are also implemented in the FPGA. DCMs receive timing and control information from the NOνA timing system over a dedicated link. This information is transmitted to the FEBs over the remaining three pairs of wires in the cable. DCMs are connected to the Giga-bit Ethernet DAQ network, and are positioned on the detector as necessary to keep the FEB data cable lengths manageable.

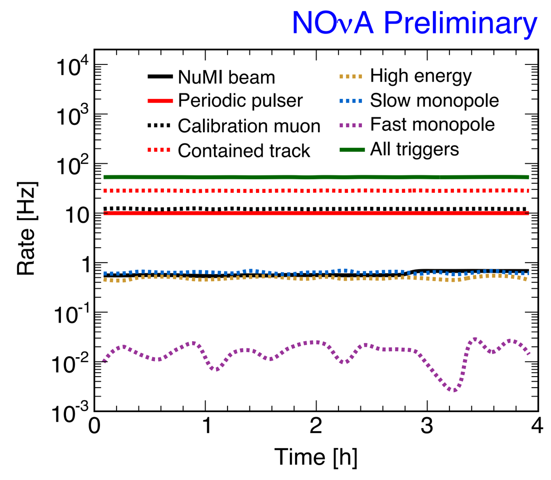
A Data Concentrator Module



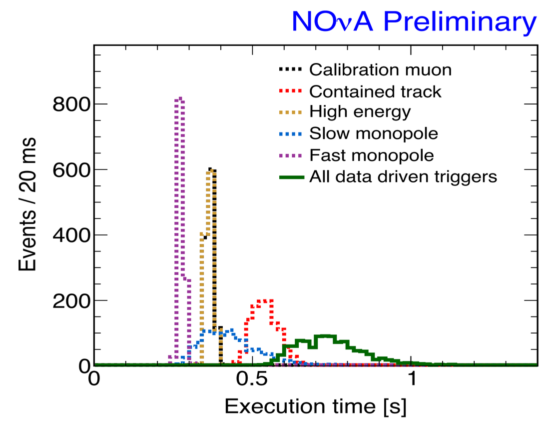
DCMs and FEBs mounted on detector.

Data Driven Trigger

The DDT analyzes all the data collected by the NOvA detectors in real time using hundreds of parallel instances of highly optimised analysis software running within the ARTDAQ framework. It has been in operation continuously as part of both the prototype near detector and the FD for several months and has exhibited well understood, stable, rates as well as algorithm execution times that fit within the stringent criteria needed to operate in real time.



The rates of all triggers.



Execution time for various DDT algorithms.

The current selection of triggers includes algorithms designed to identify muon tracks useful for calibration, contained tracks collinear with the beam line, and high energy deposits, as well as both fast and slow monopoles. It is trivially extendable to support many more signatures.

The modular software design means common components are only executed once, making optimum use of the computing resources.

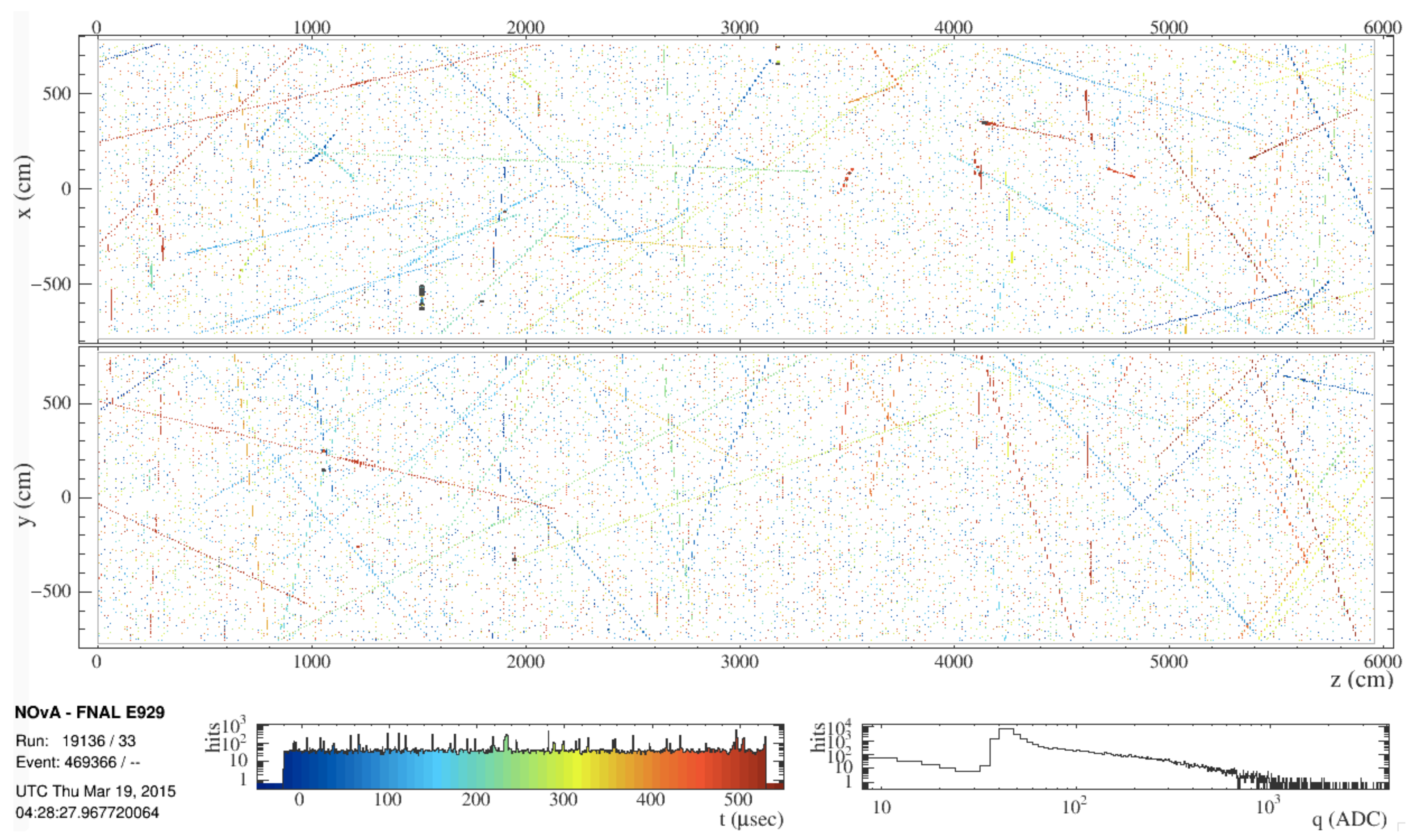
Buffer nodes

The DAQ system contains a large collection, of over 200 compute nodes running Scientific Linux Fermi, which serves as a memory buffer for data. The farm is designed to buffer data for a minimum of 20 seconds. They are designed to be one large circular buffer. Data on each DCM is accumulated for 5 milliseconds and then routed over TCP/IP to a buffer node. Data from all DCMs collected during that same time period will also be sent to the same node. The buffer farm also allows for monitoring and triggering algorithms to run over the buffered data. The Global Trigger receives trigger messages from the DDT trigger processes and remotely generated beam spill triggers, and generates trigger messages in the form of time windows to the buffer nodes. Upon receiving a trigger window the buffer farm nodes will search their data buffers for matching data and route it to a data logger process on a separate node. The data buffers inside each buffer farm node are treated as circular memory.

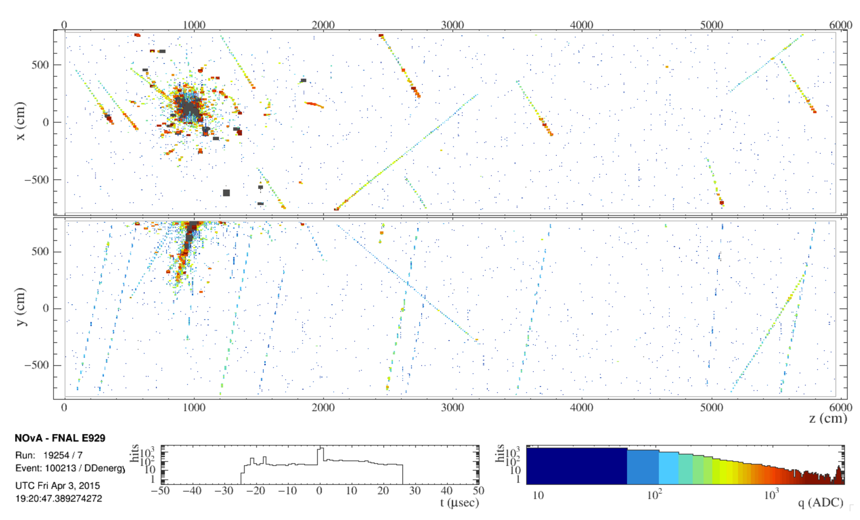
Networking

The DAQ network is based on commercially available gigabit Ethernet hardware. These interconnect over 10 GB uplinks to fabric routers to connect the front end readout and aggregation (Detector Hall) with the trigger, buffer farm and final event builders (Datacenter). The system is capable of bursting the full readout data from the detector into individual buffer nodes for further processing and triggering. The system is capable of writing 2.2 GB/s to disk.

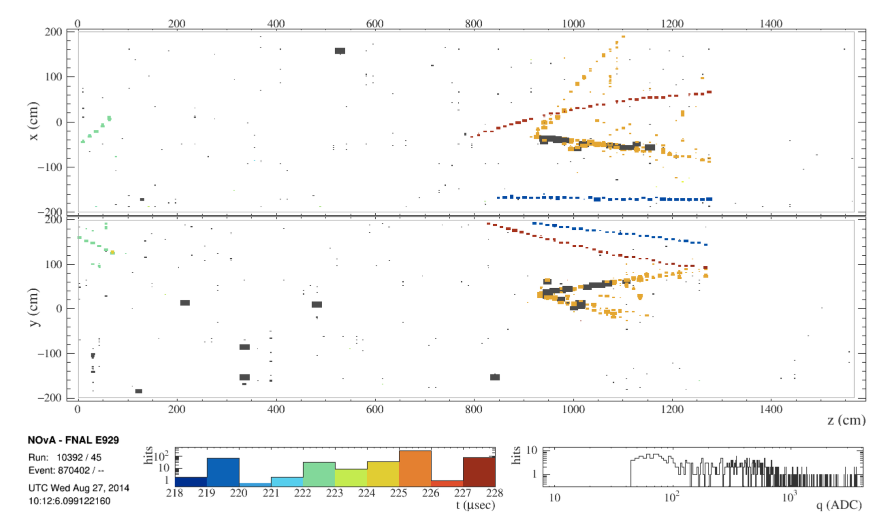
Event Display



An event of 550 µs readout in the far detector.



An event with high energy showers in Far Detector



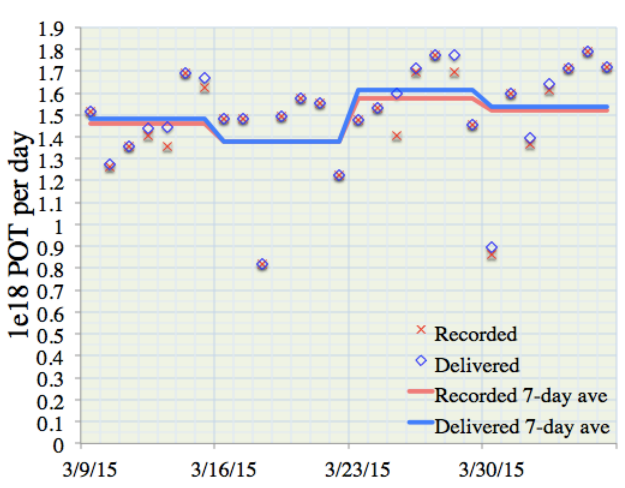
A neutrino interaction at the vertex of two showers coincident with cosmic rays in the near detector.

The DAQ system performance

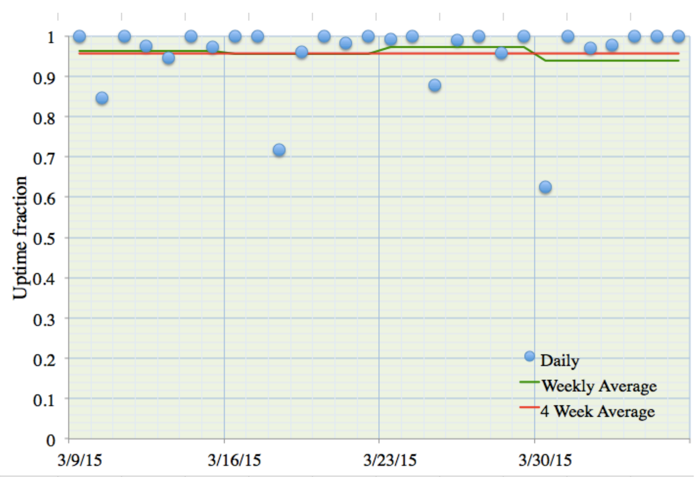
The system has been performing with an average of over 90% DAQ system live time.

A total of ~332 TB data, consisting 14,308,325 NuMI beam spill and 231,210,960 cosmic ray minimum bias events, have been recorded by the DAQ system in the last 12 months.

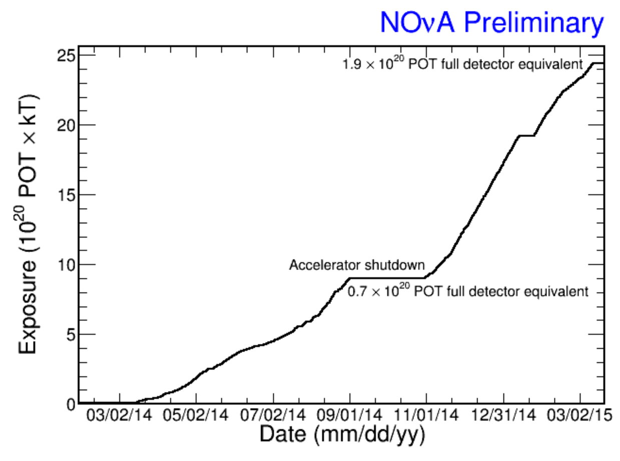
This represents 1.9 x 10^{20} POT equivalent exposure for the full 14 kt detector.



Daily Protons-On-Target (POT).



DAQ live time fraction.



Accumulated exposure to NuMI beam.

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