# NO$\nu$A Data Acquisition System

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# Outline

NO$\nu$A DAQ Basics

NO$\nu$A DAQ Subsystems

NO$\nu$A DAQ erformance

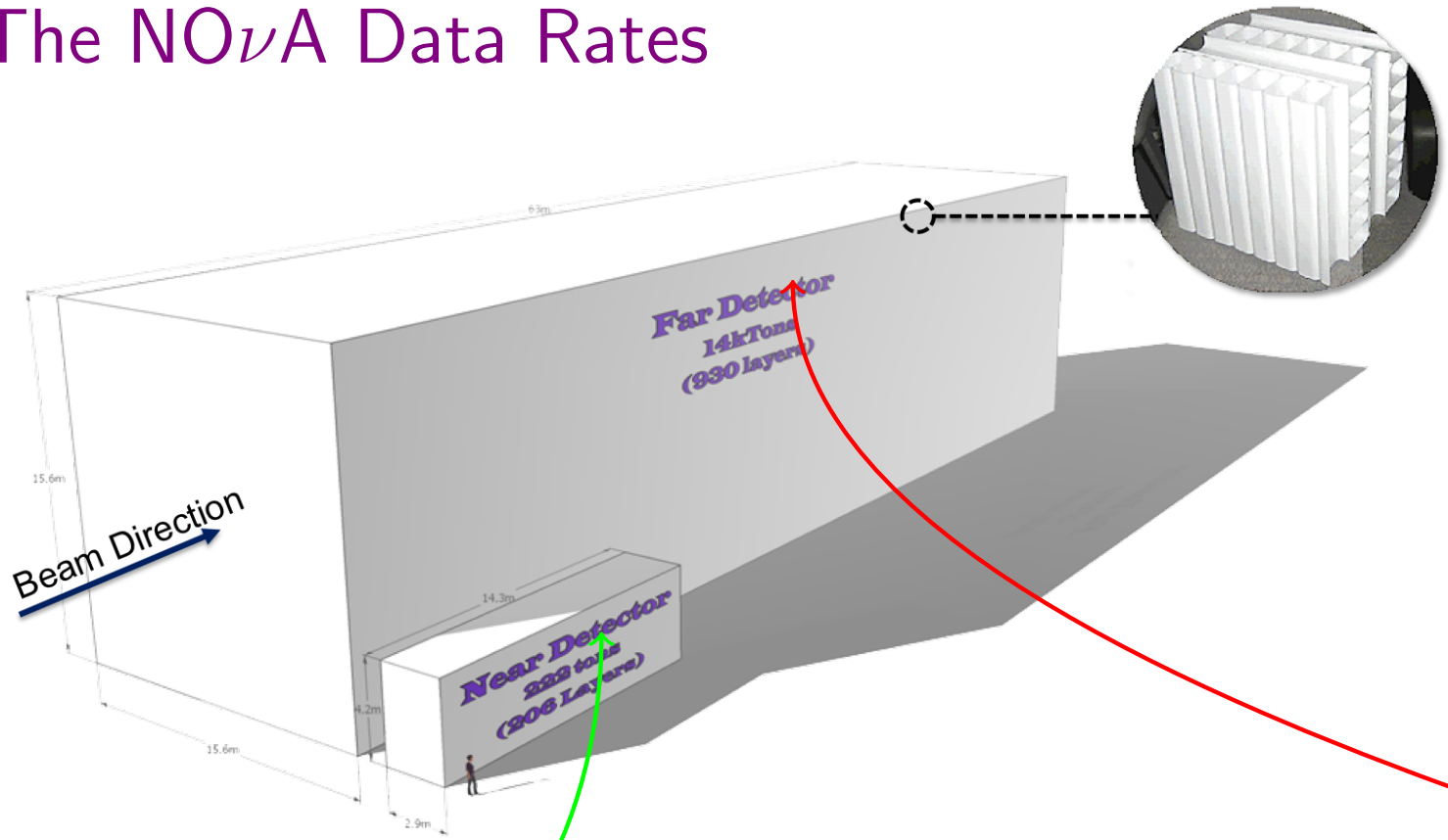
Summary

# DAQ Design Driven by NO$\nu$A Physics Goals

- NO$\nu$A Physics Goals - $\theta_{13}$, $\delta_{CP}$, mass hierarchy, $\theta_{23} \stackrel{?}{=} 45^\circ$ [1]
  - Need to record data from both the near and far detectors that are correlated with the beam spills
- Beam Neutrino Events
  - 10$\mu$s beam spill every 2.2 s moving to every 1.3 s after accelerator upgrade
  - Beam spill is time stamped by a GPS based timing system at FNAL
  - The beam spill information is transmitted over open internet to the far detector
  - Data corresponding to the timestamp of the beam is extracted from the far detector buffers
  - Maximum end to end latency is planned at 20s (extendable via deeper buffers)
- Calibration Events (Cosmic Muon Rays)
  - Zero bias calibration data are taken to give 100$\times$ spill data
- Other Physics Events
  - Supernova, Supernova explosion at 10 kpc results in thousands of $\nu$'s within $\mathcal{O}(10)$ seconds in Far Detector
  - High Energy neutrinos, *etc.*

[1] See Gavin Davis's talk for details

# The NO$\nu$A Data Rates




- 222 tones, 209 layers, 16,000 cells
- Event Rates
  - Cosmic Ray Muon Rate: $\sim$ 50 Hz (105 m overburden)
  - In-Spill Rate: 24 neutrino events/spill
  - Data Rates: 75 TB/year through DAQ system, 1 TB/year written to disk

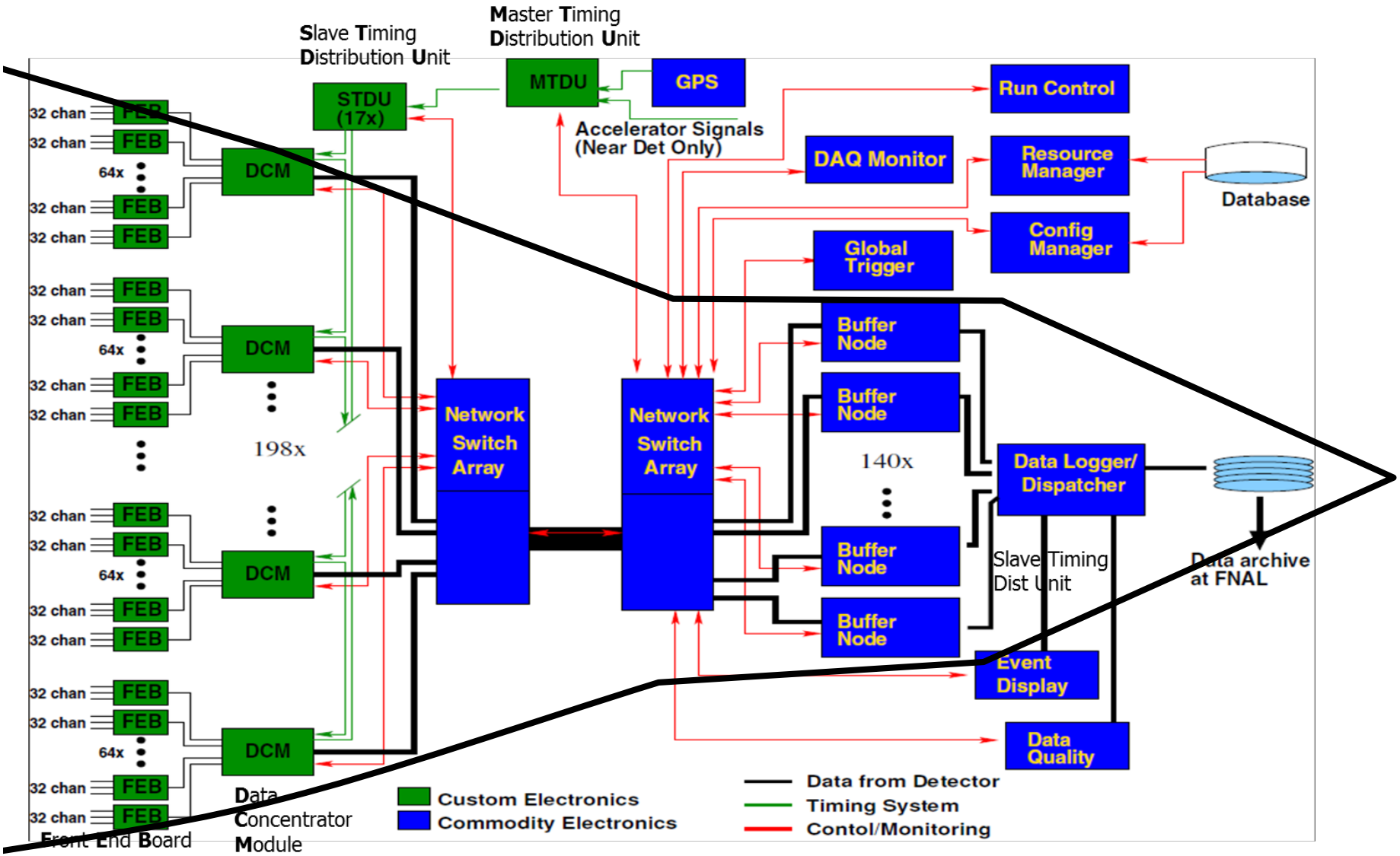
- 14 ktons, 960 layers, 360,000 cells
- Event Rates
  - Cosmic Ray Muon Rate: $\sim$ 200 kHz (3 m earth equivalent overburden)
  - Data Rates: 12,000 TB/year through DAQ system, 25 TB/year written to disk

# NO$\nu$A DAQ Basics

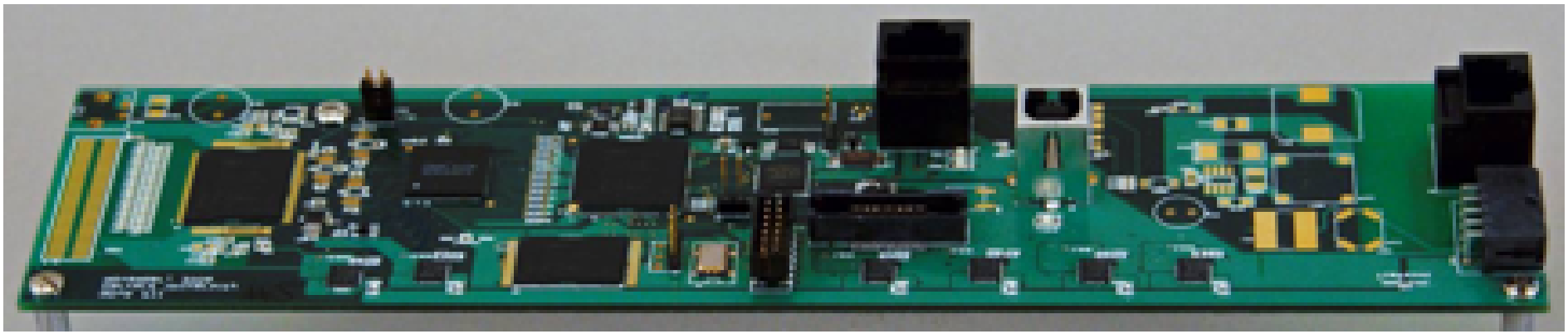
- FEBs continuously digitized on 16MHz (64MHz near detector) clock and perform zero suppression and digital signal processing (DSP) algorithms via an onboard FPGA. Data from 32 detectors cells are streams out from the FEBs and stored in the buffer nodes
- A large buffer farm 200+ nodes, (1600+ cpu cores) buffers all the detector data grouped into time slices. The buffer farm waits for a trigger decision, then writes the appropriate information out to storage via a datalogging system
- Baseline buffering for the far detector is 20 s of data (extendable via deeper buffers on each node)
- DAQ systems for both Near and Far Detectors are functionally equivalent

# NO$\nu$A DAQ Subsystems

# Data Acquisition System



# Front End Boards (FEBs)

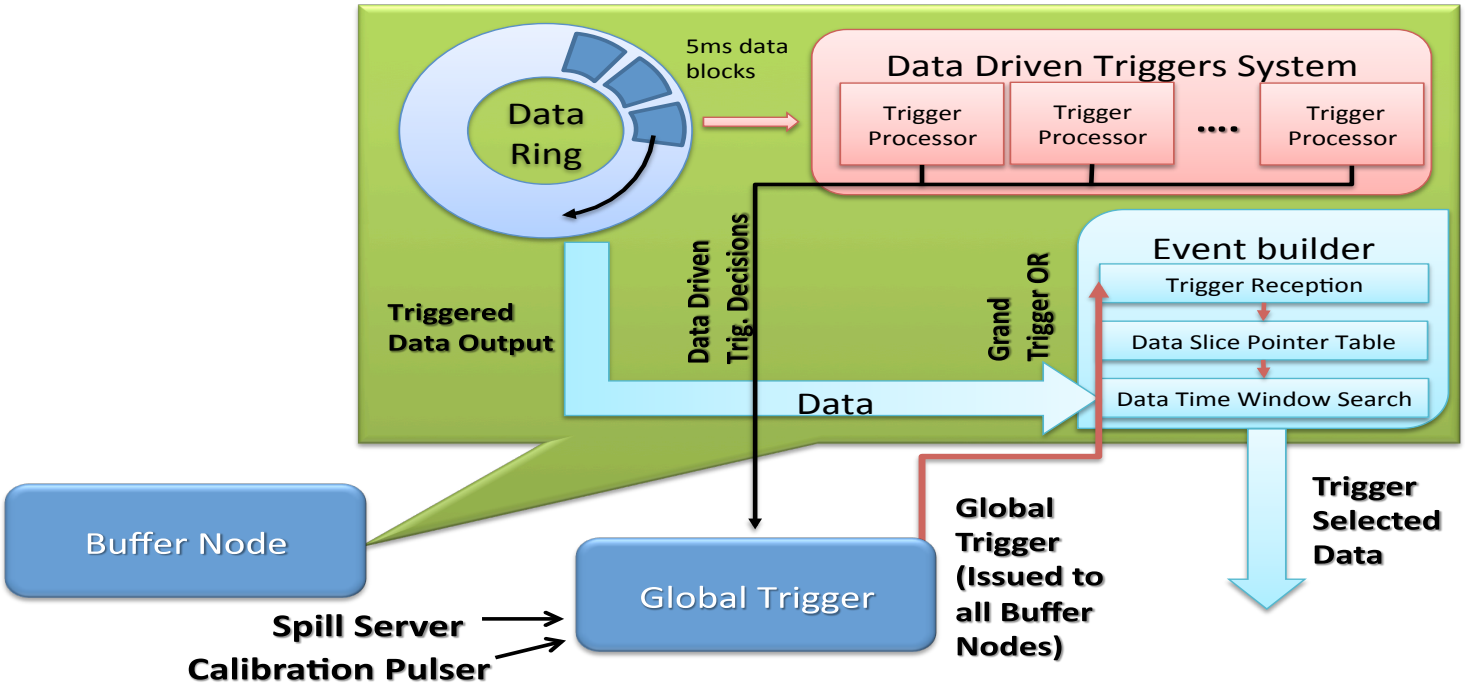


- FEB operated in trigger-less, continuous readout mode with no dead time
  - Data is zero suppressed based on DSP algorithms
- Each FEB readouts 32 channels (32 APD pixels)
  - 1 APD $=>$ 1 FEB
- APD pixels sampled at 2 MHz by FEBs at FD, 8 MHz at ND
  - Higher detector activity during beam spill at ND requires higher time resolution
- Capable of limited waveform digitization and waveform readout

# Data Concentrator Modules (DCMs)

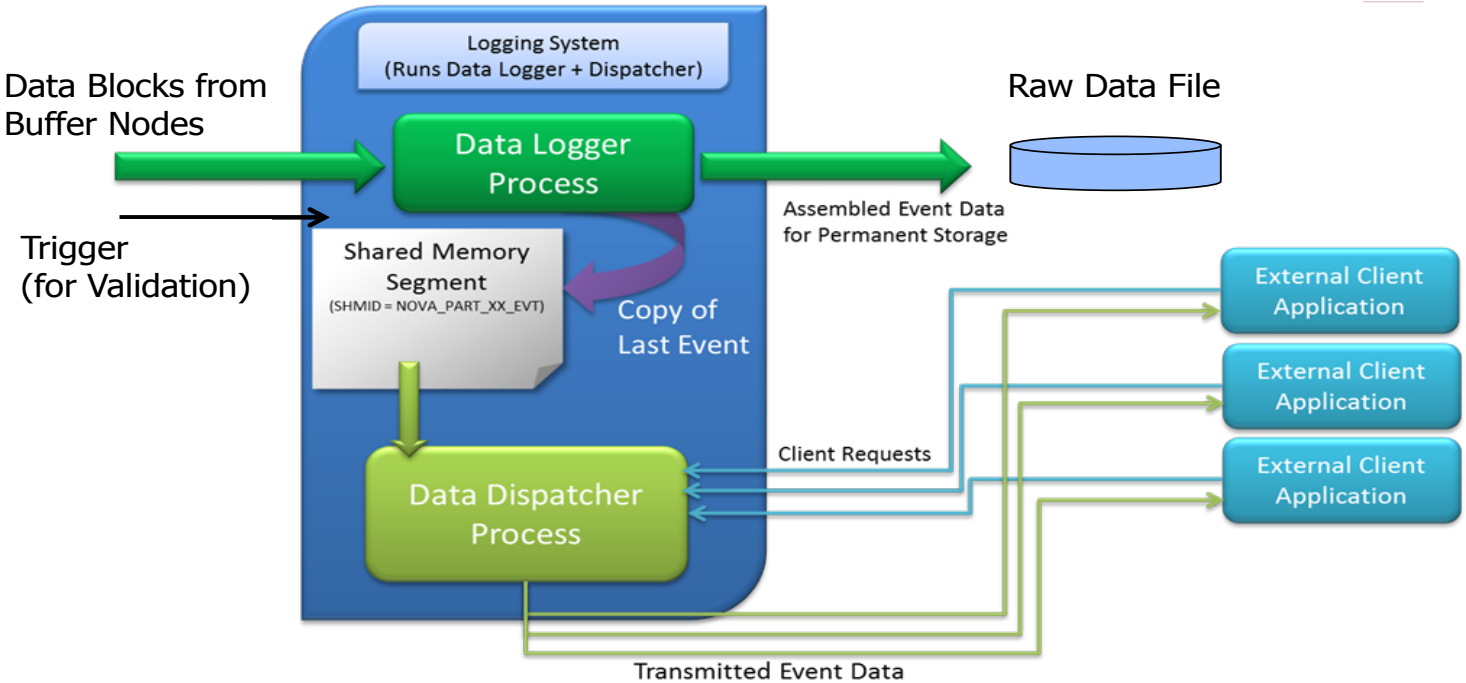
- Groups of 64 FEBs are readout by a DCM
- The DCM consolidates the FEB data into 50 $\mu$s time slices
- Then further consolidates the data 50 $\mu$s slices into 5 ms time slices
- Pass a single common timing clock to all FEBs to maintain a sync to common time better than $\pm$1 64MHz tick detector wide

# Buffer Nodes




- Buffer Nodes for buffering/triggering
- 5 ms time slices of data are routed by the DCM to downstream Buffer Nodes in Round Robin fashion
- The Buffer holds raw hit data from the entire detector
- Data received from DCM is buffered for a minimum of 20 s

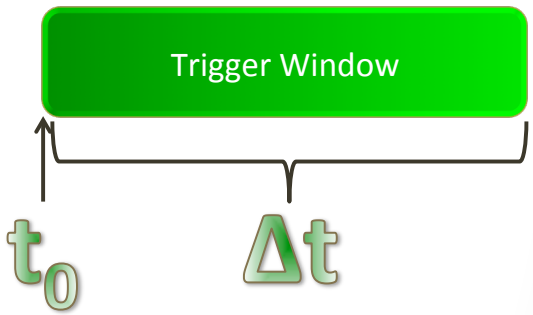
# Data Logger




- Data Blocks from Buffer Nodes are merged to form Event
- Uses a "mailbox" scheme to manage collection of data from Buffer Nodes.
- Events written to file for storage or shared memory for monitoring (Online Monitoring and Online EventDisplay)

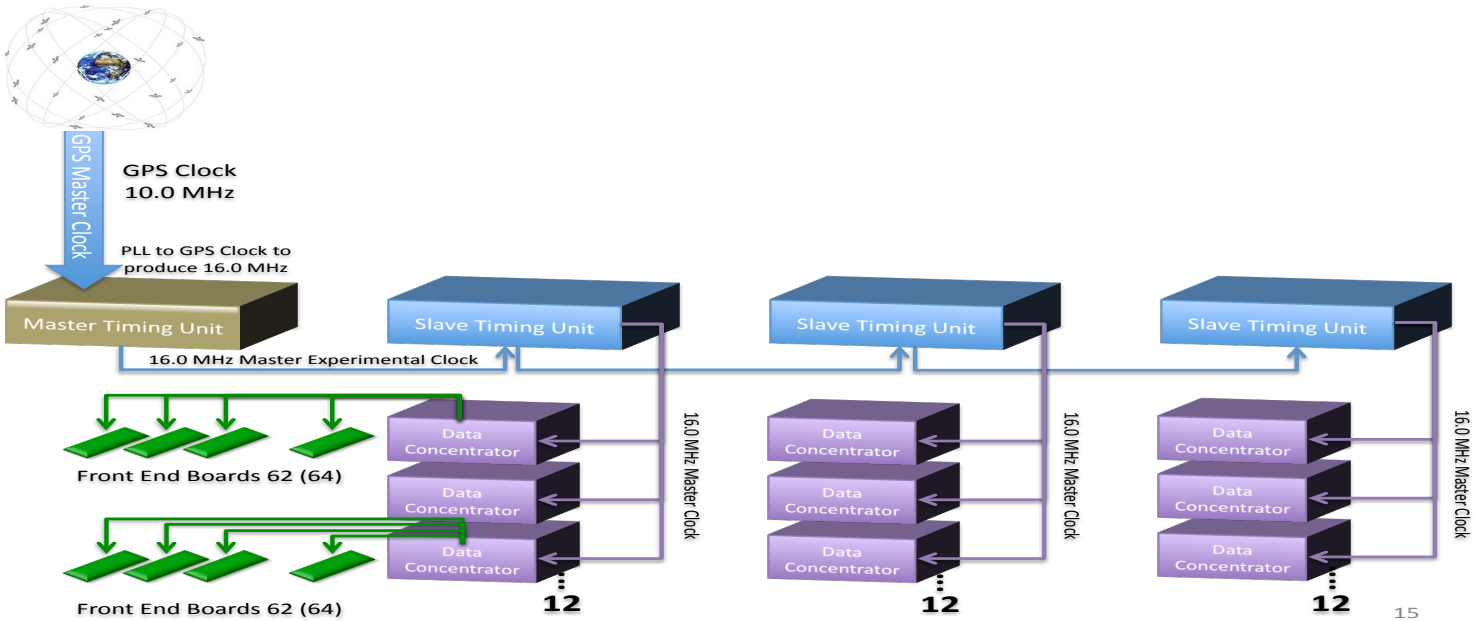
# Trigger

- Triggers are generated completely asynchronous to the readout (and independent of)
  - Time base window of interest
  - Start time $= t_0$
  - Duration $= \Delta t$
  - $\Delta t$ are adjustable from 10's of $\mu$s up to seconds



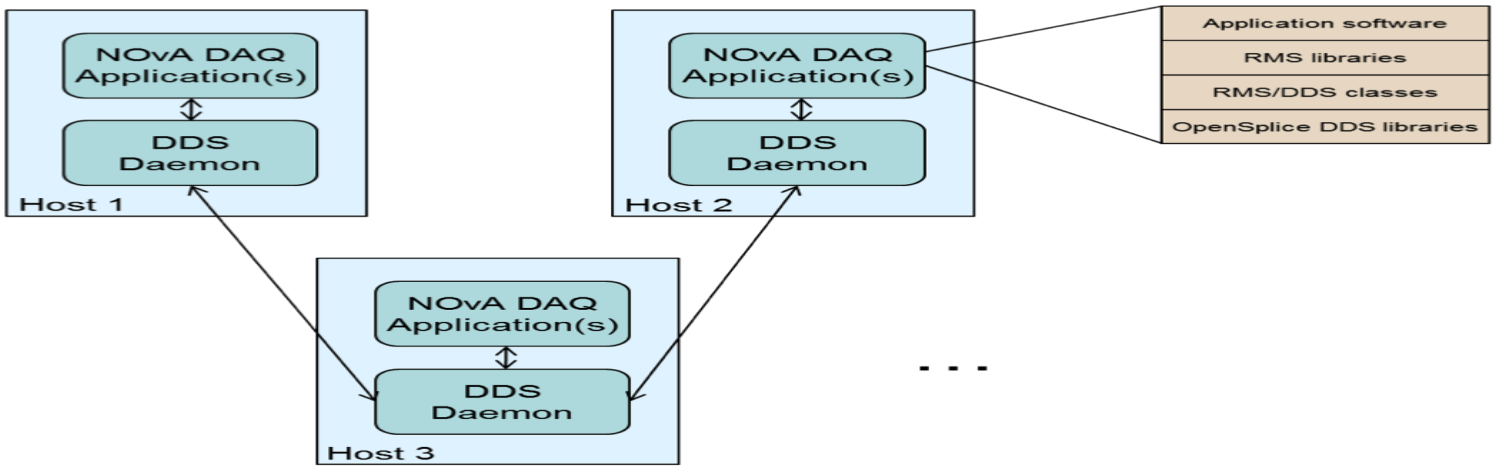

- Selects data corresponding to a trigger window received from Global Trigger for output
  - NuMI beam Trigger - window centered on GPS time of NuMI spill at FNAL
  - Booster Beam Trigger
  - Periodic "Calibration" Pulser Trigger - Random sampling of time windows at 100$\times$ beam period
- Also provides support for "Data Driven" triggers
  - Feedback loop to Global Trigger. Trigger issued if consensus of buffer nodes

# Timing System




- All FEBs/DCMs are synchronized to a common high precision 16 MHz clock reference
- Correct for all cable/transmission delays between units (timing units and data concentrators)
- Master Timing Distribution Unit (MTDU) derives clock from GPS, distributes to first Slave Timing Distribution Unit (STDU) in chain
- Clock distributed to DCMs by STDU

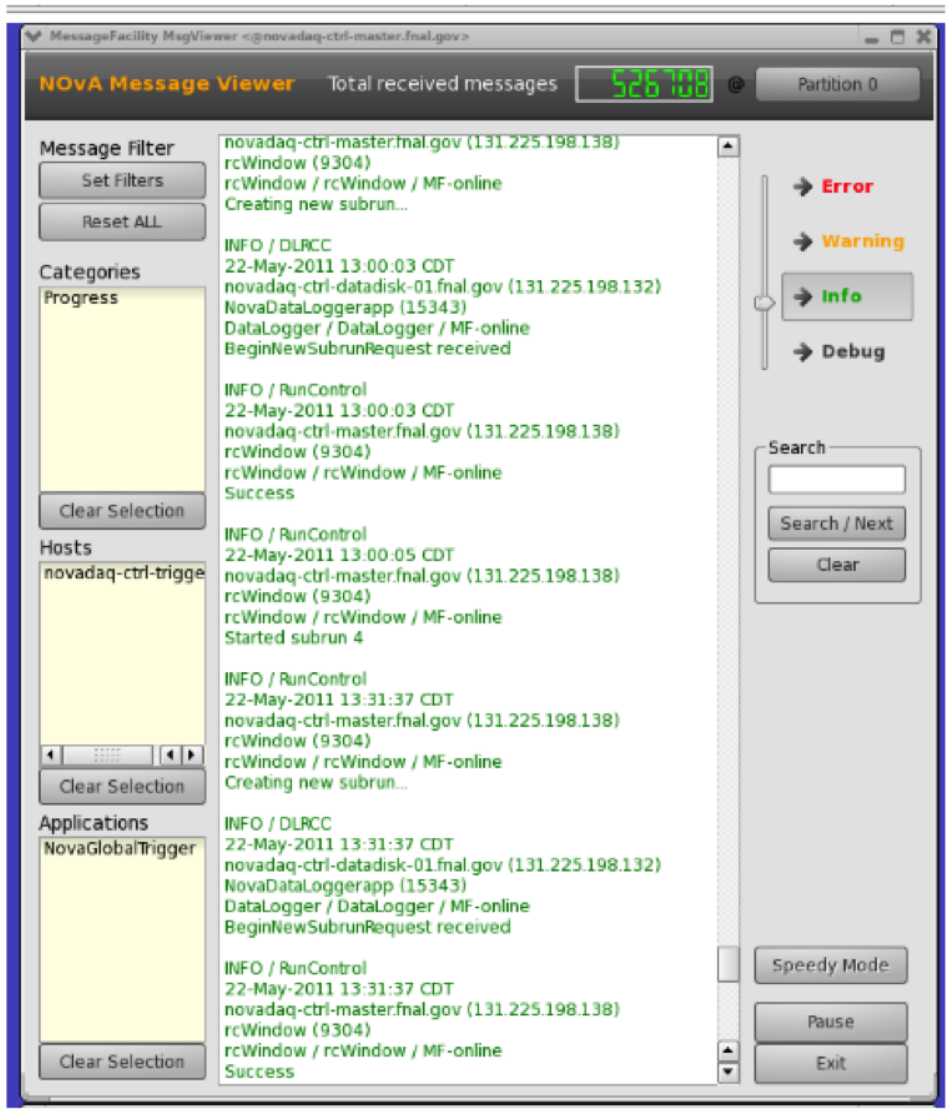
# Message Passing



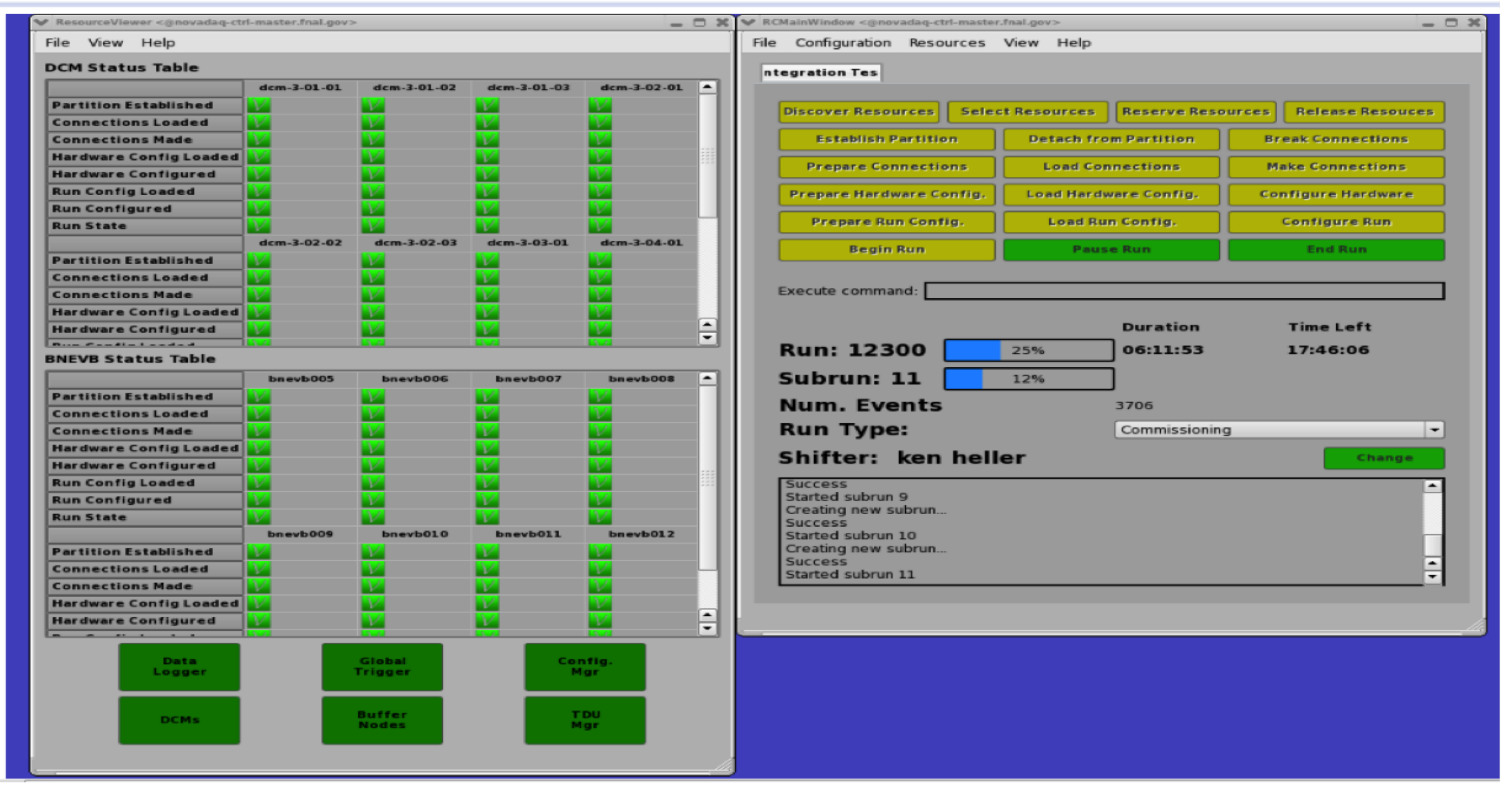

- Message Passing System handles control and status messages
- General Message Passing is handled using the FNAL "Responsive Message System (RMS)"
  - Uses OpenSplice DDS from Prism Tech for low level message transmission
    - Publish/Subscribe messaging system model
    - Provides guaranteed message delivery
    - Provides serialization/de-serialization based on schema
  - NO$\nu$A specific layers provide ease-of-use
- Capable of high message bandwidth (kHz+)

# Message Facility

- Message Facility for logging Messages
  - Based on CMS Message Logger
- Capable of logging messages to multiple destinations
  - std out, file and/or message server
  - Uses DDS for sending client messages to message server
- GUI display for server
  - Allows server-side filtering
  - Used in control room
- Additional package "Message Analyzer" monitors messages to gauge overall detector health
  - Package under development



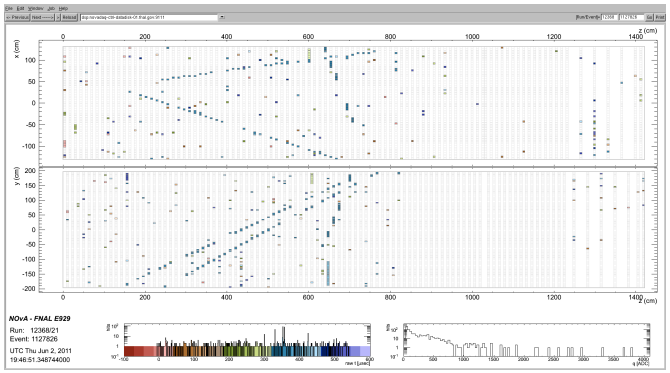
# Run Control



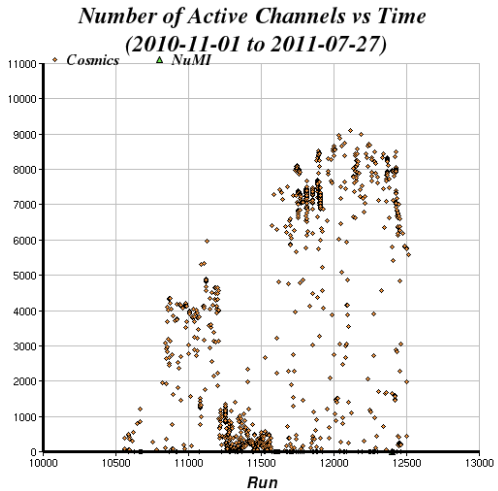

- Provides overall control of the DAQ system
- All DAQ components implement a well defined state model and, under the command of Run Control, make transitions between states
  - Implemented as client/server model
  - Written in C++ using QT to implement GUI, signal/slot

# Monitoring[2]

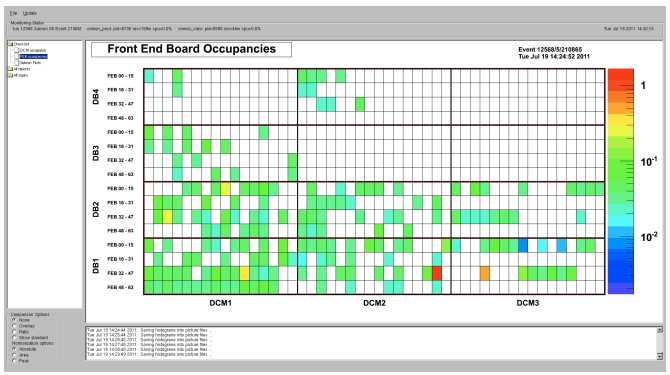
Online EventDisplay



Data Check

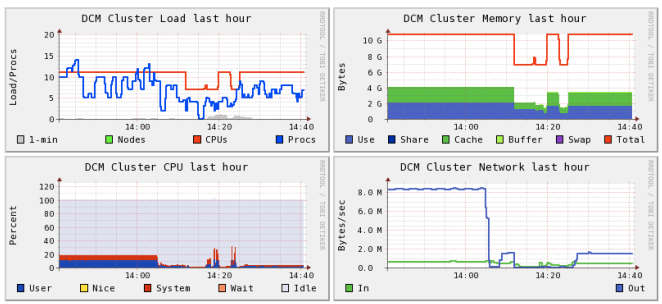



Online Monitoring



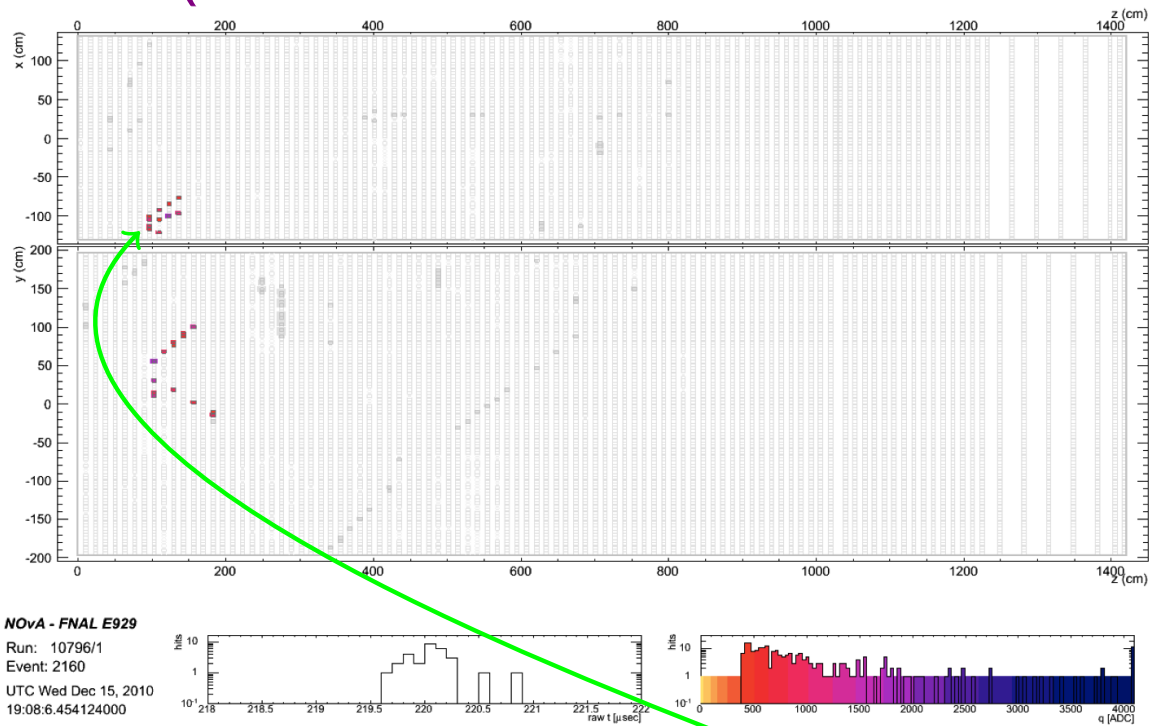

Memory View

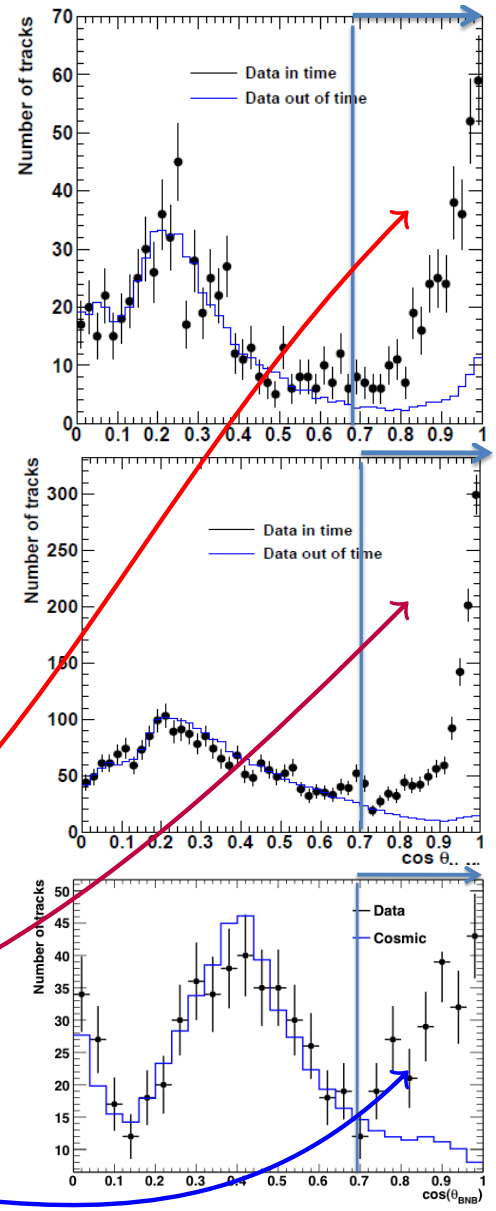
DAQ Monitoring




[2]Please refer to Susan Lein's " Data quality and performance" talk for details

# NDOS (Near Detector On the Surface) performance[3]

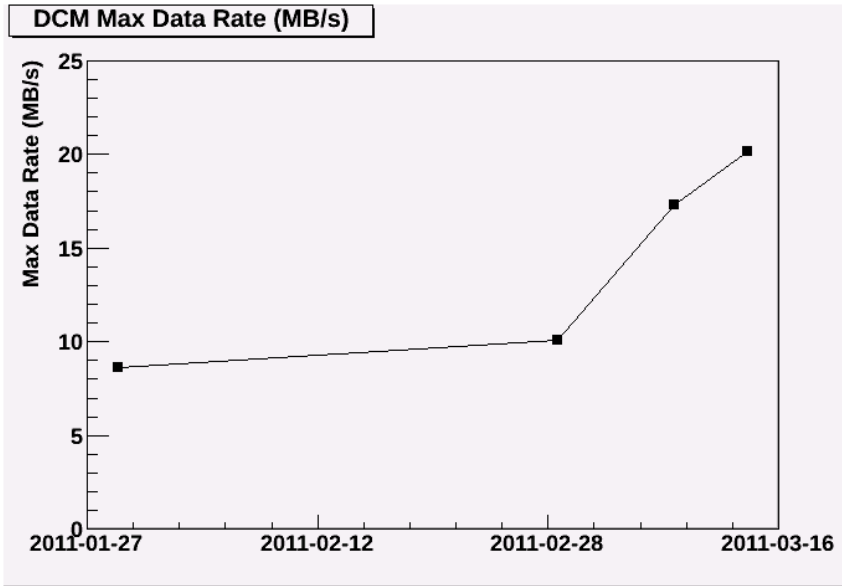


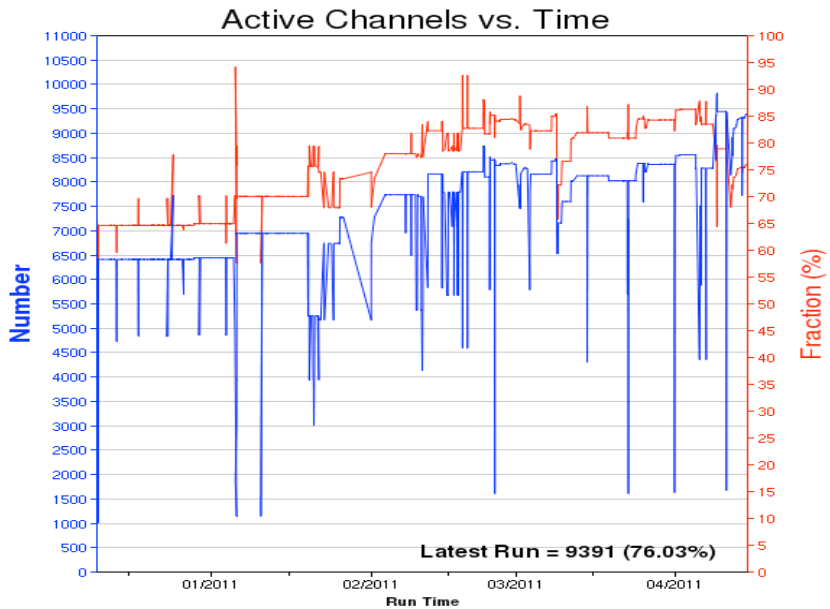




- DAQ system has been up and running from last year
  - 1$^{\text{st}}$ $\nu$ candidate was observed on 12/15/2010.
  - 8.4$\times 10^{18}$ POTs of NuMI $\nu$
  - 5.6$\times 10^{18}$ POTs of NuMI $\bar{\nu}$
  - 3.0$\times 10^{19}$ POTs in Booster $\bar{\nu}$

[3]Please refer to Minerba Betancourt's talks for more information

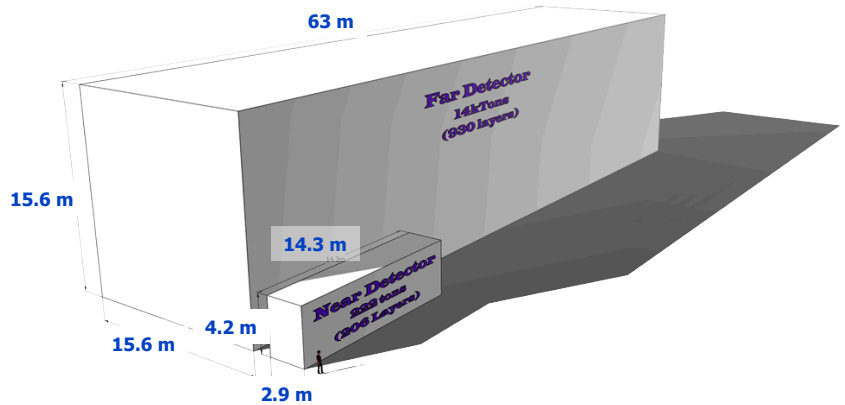
# NDOS (Near Detector On the Surface) performance




- Many DAQ performance gains and fixes of bugs have resulted from NDOS commissioning and running
  - More than 2$\times$ gain in DCM data through-put as a result of optimizing software and network
- Number of active channels, live time, quality of data continue to improve over time

# From NDOS to Ash Rive




- Construction starting Jan. 2012, expect to read out first di-block early next year
- Move effort on the Far Detector DAQ system
  - Automatic error recovery
  - Stress testing system for rate capacity
  - Data Driven Trigger support in Buffer Node
  - Partition support (operate different sections of detector in different run modes)
  - Scaling GUIs/Displays for larger number of nodes
  - Learn Delay mechanism of Timing System
  - *etc.*

# Summary

- The DAQ is robust enough that can run the readout for the NDOS at near 100% live readout to disk
- Much of the DAQ system has been designed, implemented and deployed to the NO$\nu$A prototype detector (NDOS)
  - The DAQ system on NDOS is extremely stable
  - Many performance gains and fixes of bugs have been made as a result of commissioning the Prototype Detector
- NO$\nu$A DAQ is extremely stable and the system is ready for the rate conditions that will see at FD this fall

# Backup Slides

# Expected Data Rates

| | ND | | FD | |
|---|---|---|---|---|
| FEB | 120 | 500 | 160 | 11250 |
| DCM | 250 | 9 | 3000 | 180 |
| Buffer Node In/Out[1] | 300/4 | 8 | 3800/8 | 140 |
| Data Logger | 30 | 1 | 1100 | 1 |

[1] Buffer Node Output rates consider Beam Spill + Calibration Triggers only.