NOνA Data Acquisition System
TIPP 2011

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for the NOνA DAQ Group:

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and the NOνA Collaboration

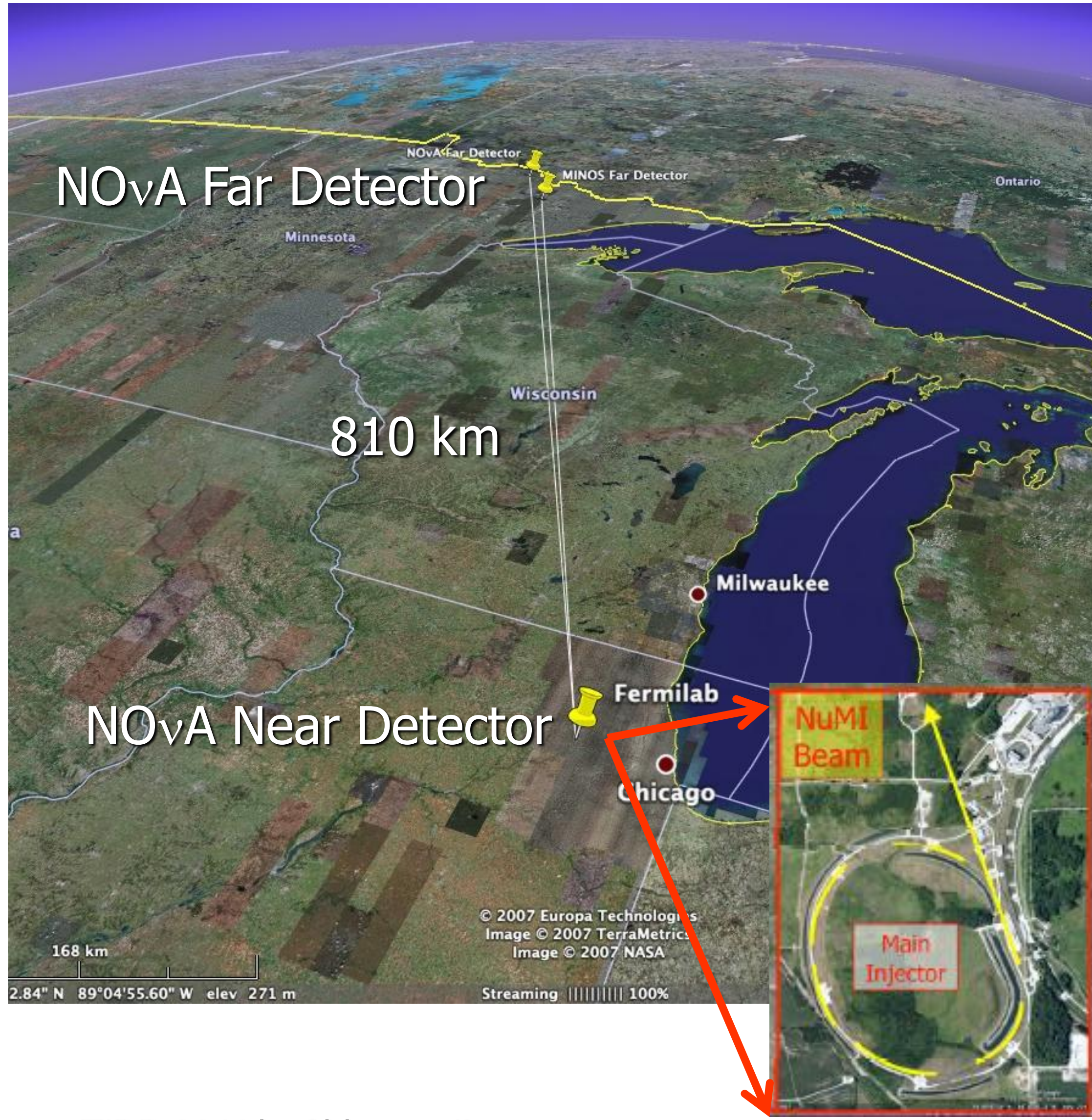
The NOvA Collaboration

140 Collaborators in 26 Institutions from 4 Countries

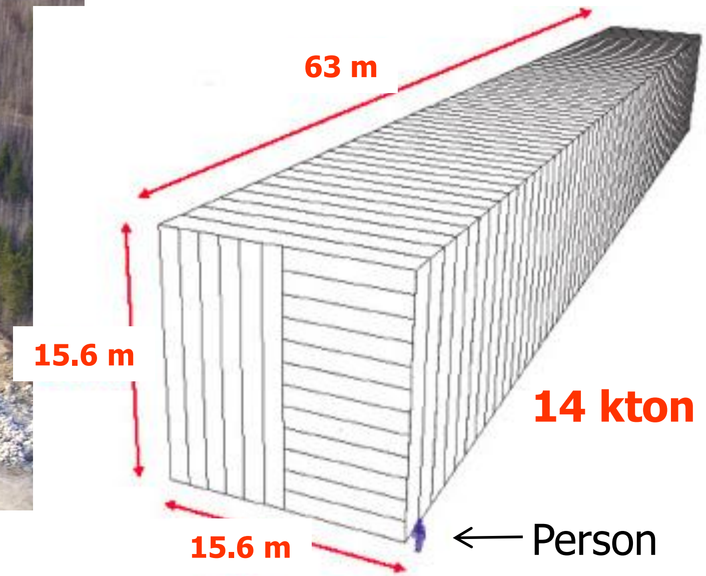
Argonne, Athens, Caltech, Charles, CTU Prague, Fermilab, FZU, Harvard, Indiana, Lebedev Physical Institute, Michigan State, Minnesota-Twin Cities, Minnesota-Duluth, INR Moscow, Iowa State, South Carolina, SMU, Stanford, Tennessee, Texas-Austin,Texas-Dallas, Tufts, Virginia, Wichita State, William & Mary

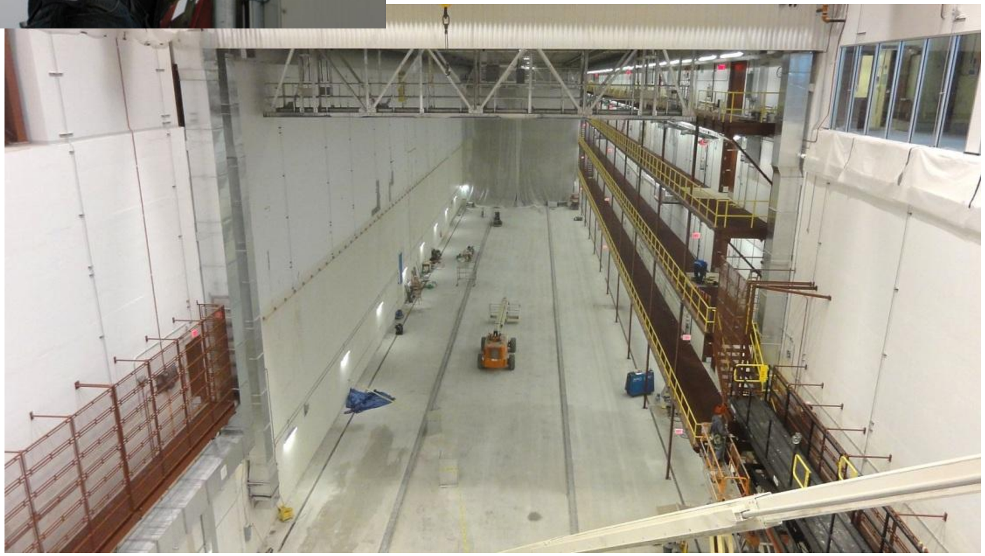
NuMI Off-Axis ν_e Appearance

- NOνA is a second generation neutrino oscillation experiment in the NuMI beam
- Near and Far Detectors placed 14 mrad off the beam axis
- Optimized for the detection of $\nu_\mu \rightarrow \nu_e$ and $\overline{\nu_\mu} \rightarrow \overline{\nu_e}$ oscillations
  - Narrow band neutrino beam. L/E ~ 400 km/GeV
  - Primary goals: Measure θ_{13}, mass hierarchy, δ_{CP}
- DAQ systems for both detectors are functionally equivalent



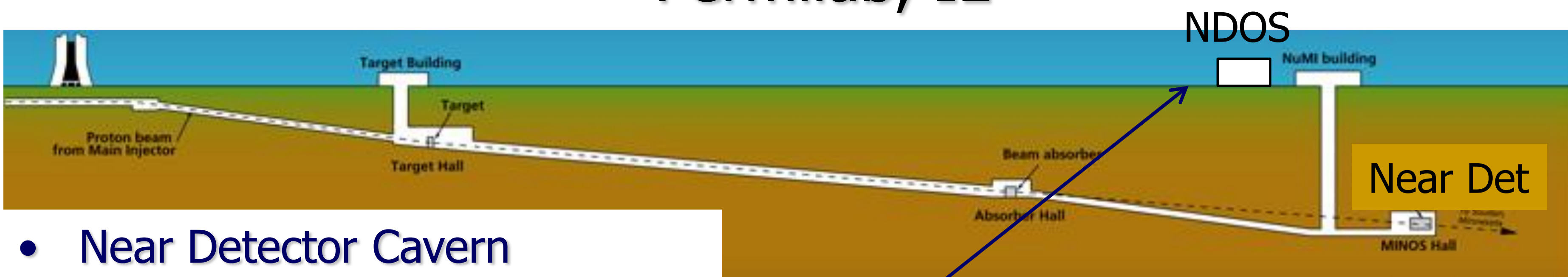
NOνA Far Detector
Ash River, MN



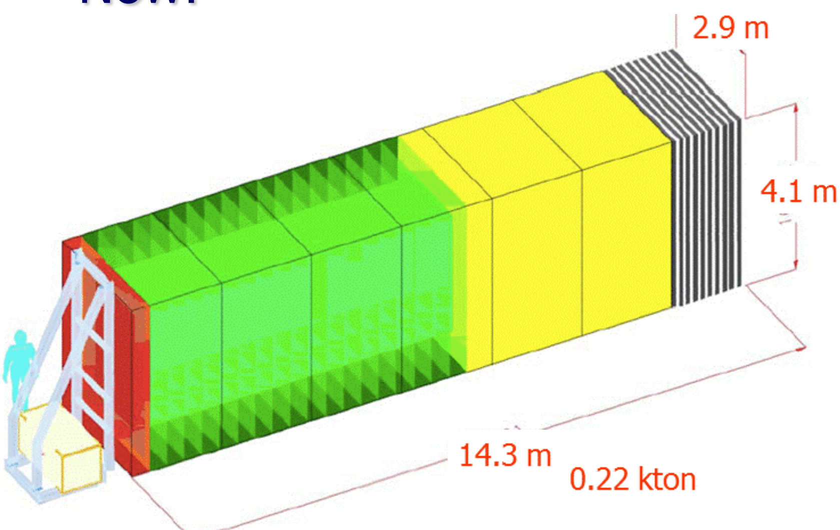


- Beneficial Occupancy of Far Detector Building – Apr, 2011
- Readout of First Detector Block ~ Early 2012
- Completion of Detector Assembly ~Early 2014

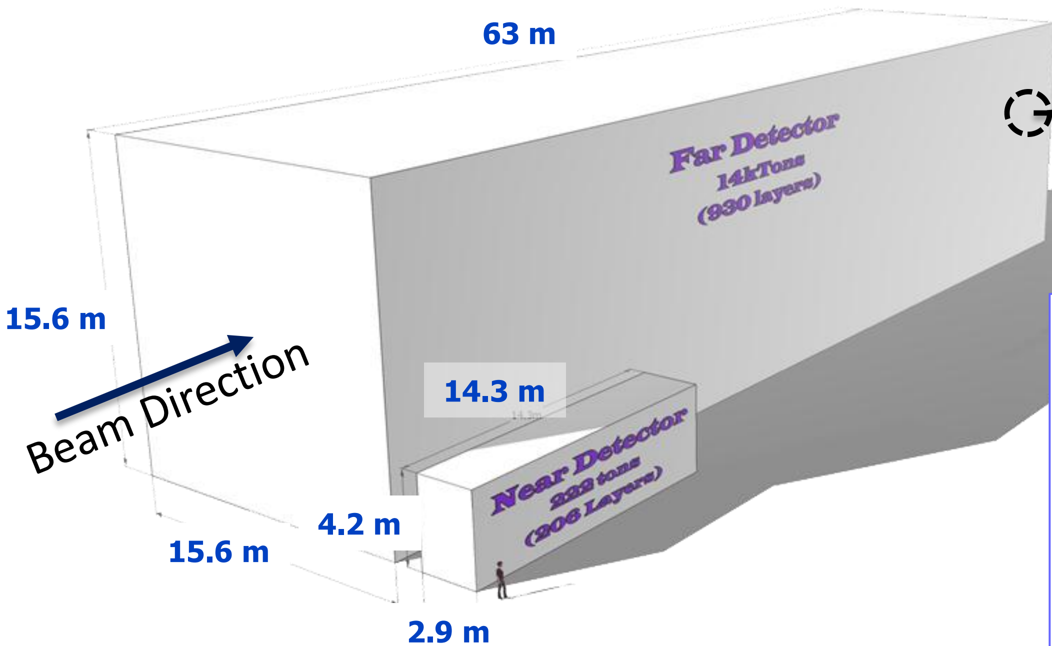
NOνA Near Detector
Fermilab, IL

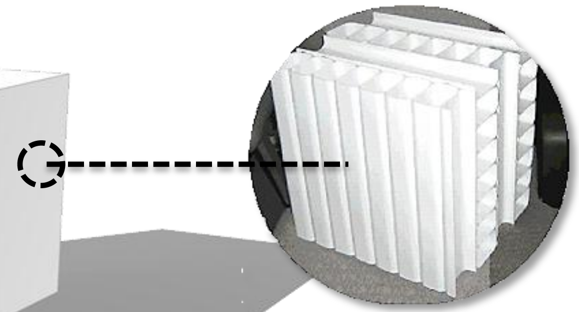


- Near Detector Cavern Excavation Begins Mar, 2012
- 100 m below the surface
- Prototype **N**ear **D**etector **o**n **S**urface (NDOS) – Taking Data Now!



NOνA Detectors Side-by-Side





Far Detector

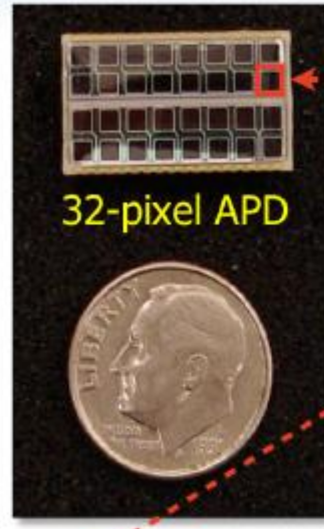
- 930 Planes (15.6 m x 15.6 m)
- 360000 cells
- Cosmic Ray Muon Rate:
  - ~200 kHz (2-3 m overburden)
  - Avg Hits/muon ~200
  - Hit Rate/detector = 40 MHz
  - Hit Rate/cell = 110 Hz

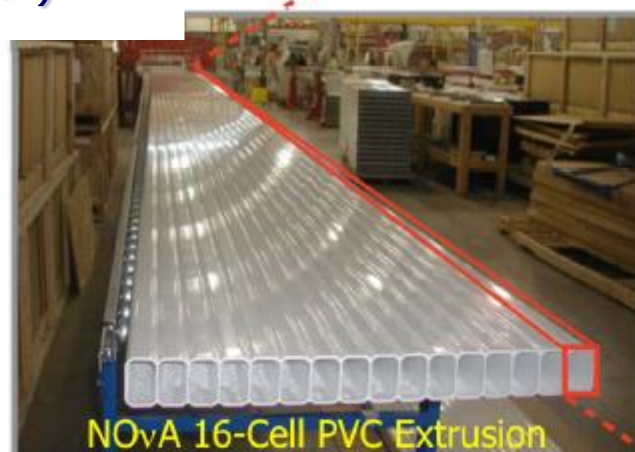
Near Detector

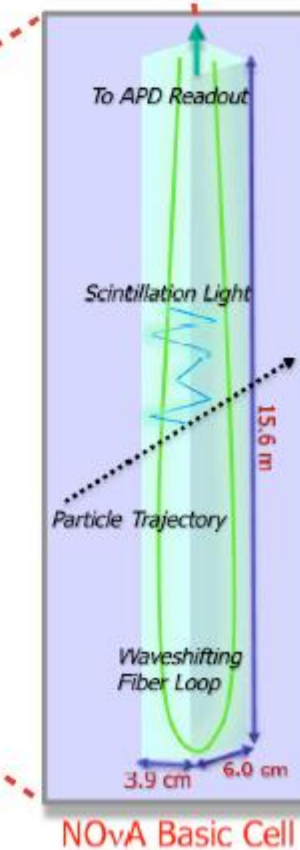
- 196 Planes (3m x 4m) + 10 Steel/Scint Plane Pairs ("Muon Catcher")
- 16000 cells
- Cosmic Ray Muon Rate:
  - ~50 Hz (105 m overburden)
  - Avg Hits/muon ~50
  - Hit Rate/detector = 2.5 kHz
  - Hit Rate/cell = 0.2 Hz
- In-Spill Rate:
  - 10 μs duration every 1.33 s
  - 30 neutrino events/spill
    - 100 hits/event
  - Hit Rate/cell = 20 kHz (Instantaneous)

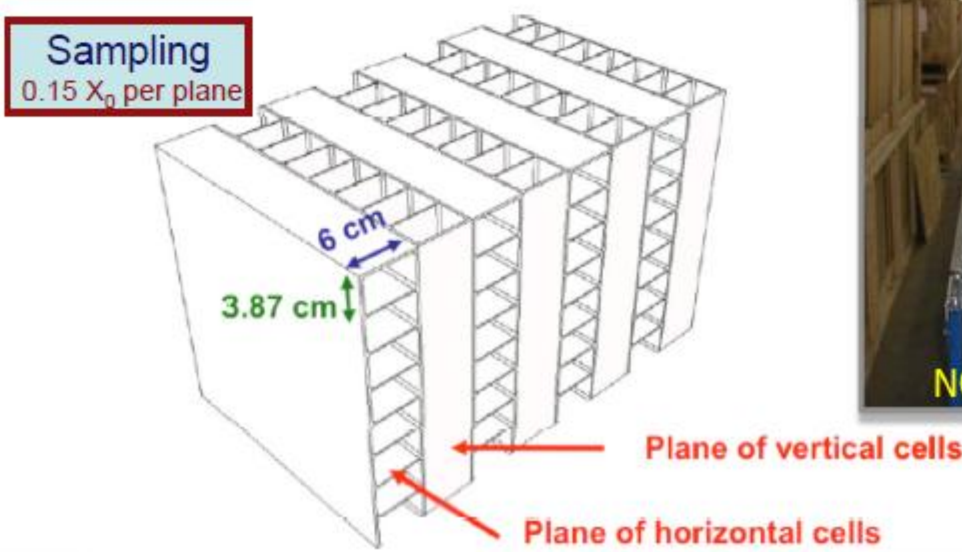
Detector Technology

- Detectors composed of highly reflective PVC extrusions
- Filled with liquid scintillator (mineral oil + 5% pseudocumene)
- Each cell readout by a wavelength shifting fiber onto one pixel of a 32-pixel avalanche photodiode (APD)
  - 30 PE from far end of cell into APD for MIP
- Num cells: 360000 (Far), 16000 (Near)









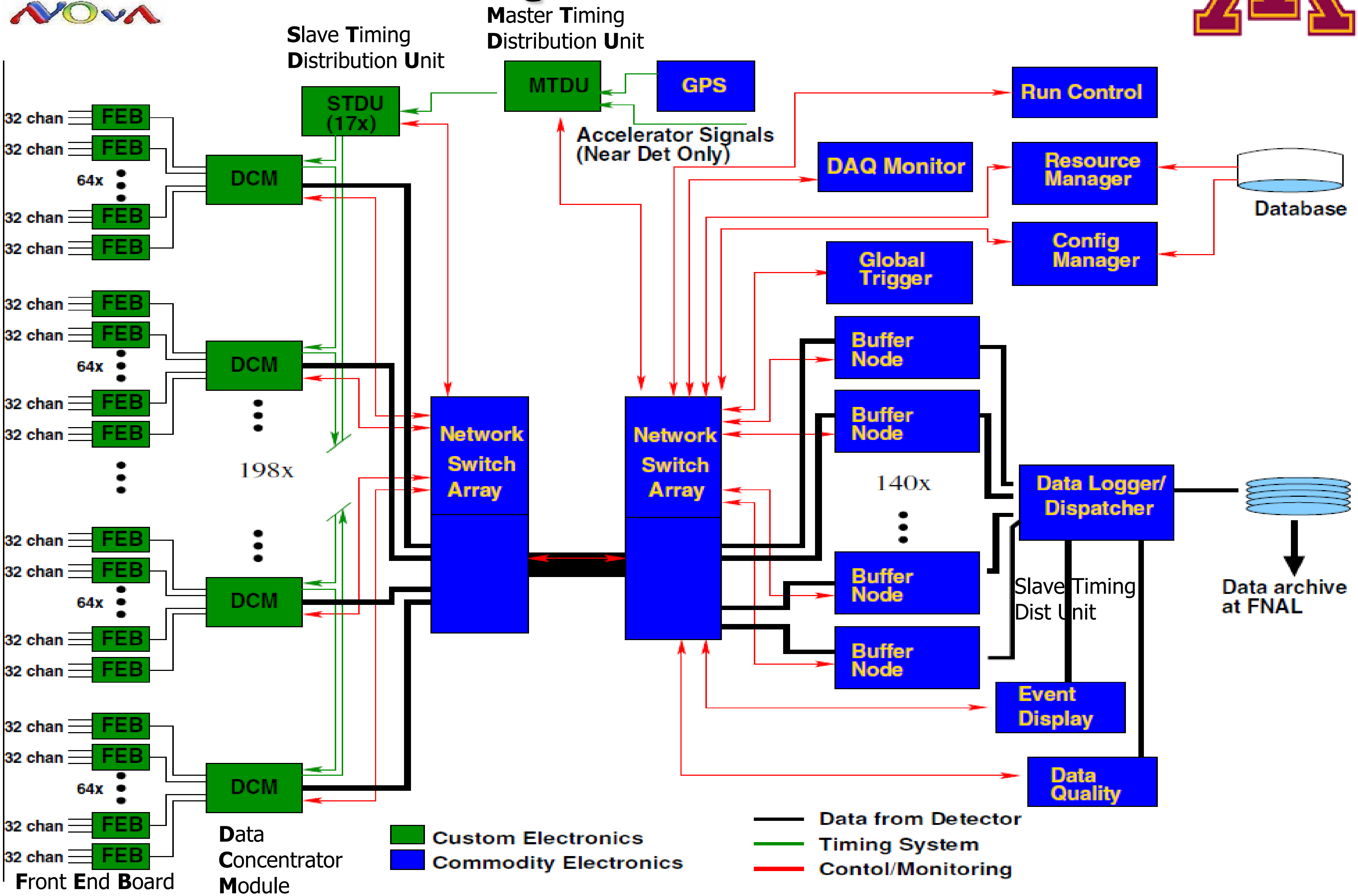
NOνA DAQ Introduction

- Design of DAQ driven by goals of experiment:
  - Beam Neutrino Events:
    - 10 μs beam spill => 30 μs trigger window for each spill
    - Period ~1.3 s
    - Beam Spill signal:
      - Near Det: Spill signal sent via ACNET ~200 μs before Neutrino Beam
      - Far Det: 90-95% of Spill signals received within 1 s, ~100% within 10 s via Internet
  - Calibration Events (Cosmic Rays):
    - 100x Beam Spill trigger window, randomly sampled
  - Other Physics Events (not primary goal of experiment):
    - Supernova, Magnetic Monopoles, High Energy ν's, ?, …
    - SN Explosion at 10 kpc (33000 light years) results in thousands of ν's within $\mathcal{O}(10)$ seconds in Far Detector

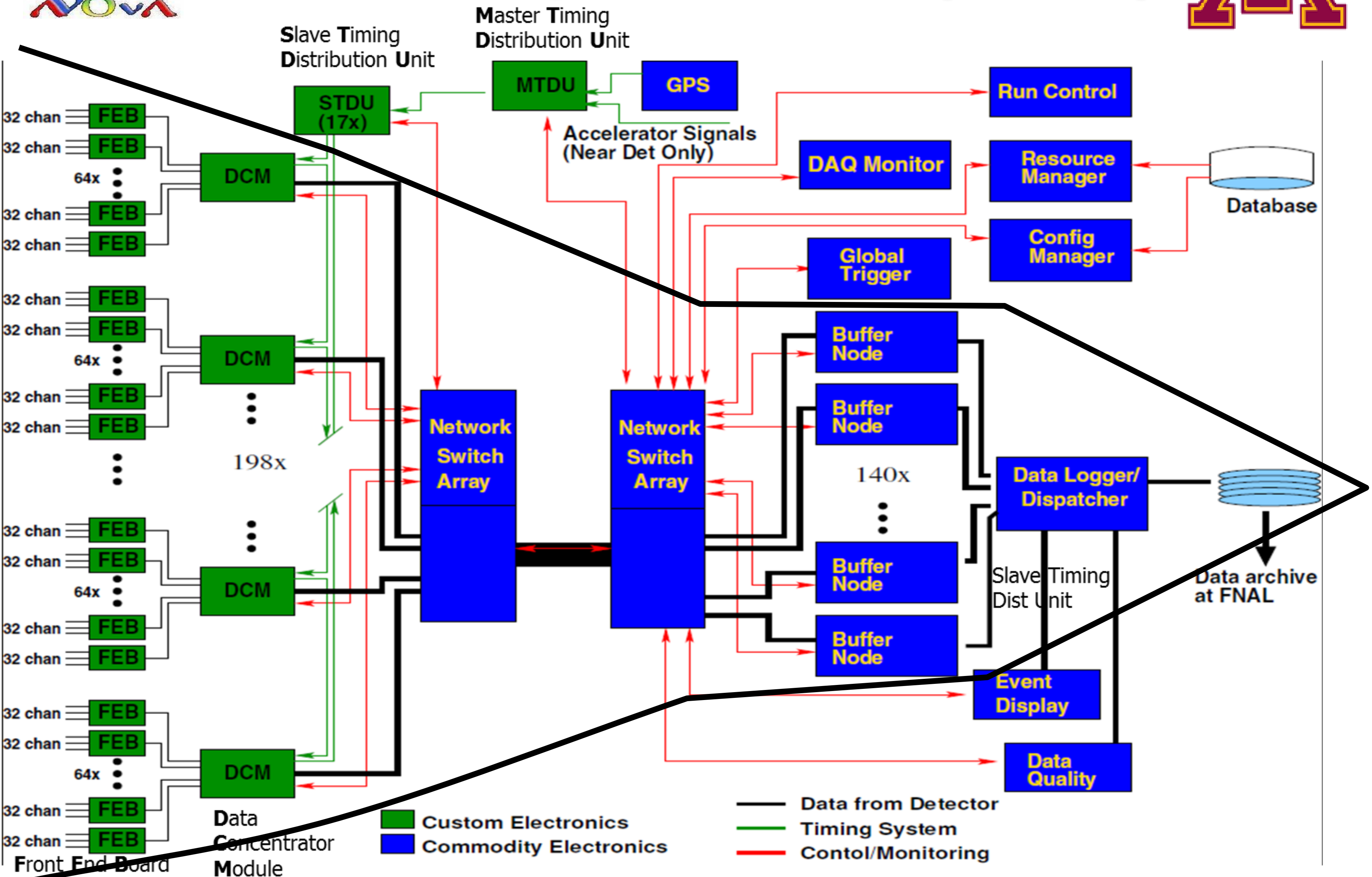
NOνA DAQ Introduction

- Design goals met with a DAQ system which has:
  - Front End Electronics which read out continuously with no dead time
    - This allows selection of events to be made downstream in the DAQ Buffer Farm with software applied triggers
  - A Buffer Farm in which data can be stored for 20 seconds or more while waiting for:
    - A remote spill trigger (sent from Fermilab to the Far Detector site)
    - A decision regarding whether or not an interesting physics event has occurred (e.g. Supernova)
  - A Timing System with compensation for the large geographic area covered by the Far Detector
- DAQ Systems for both detectors are functionally equivalent
  - In the following slides, the numbers of components refer to the Far Detector =>

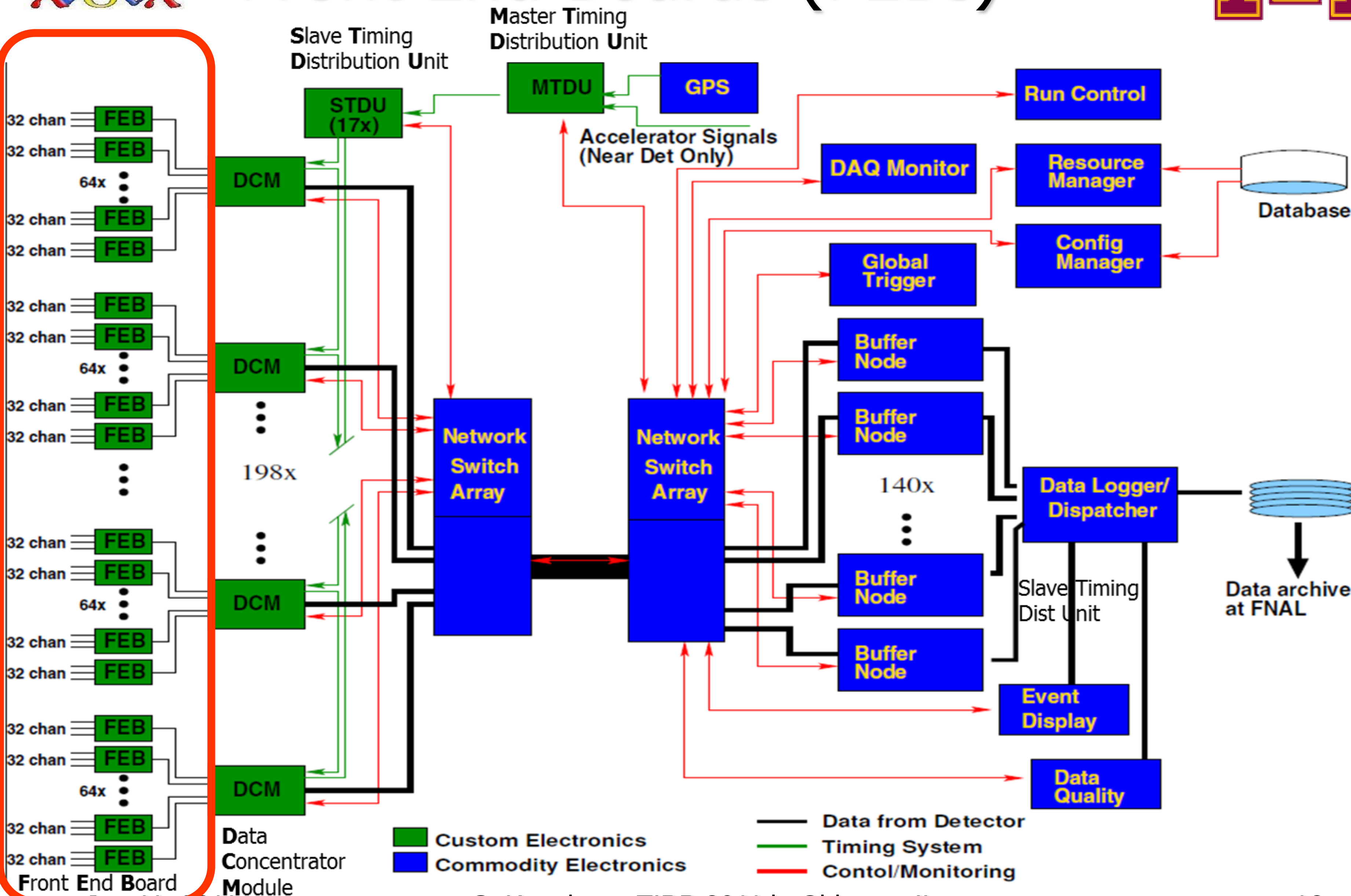
NOνA DAQ - Overview



NOνA DAQ–Data Flow (L to R)

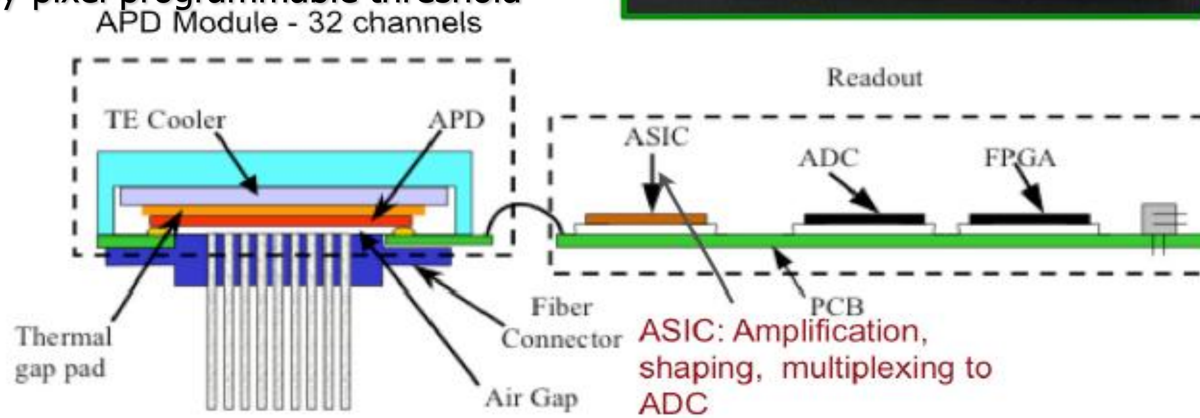


Front End Boards (FEBs)



Front End Boards (FEBs)

- APD pixels sampled at 2 MHz by Front End Boards at Far Det, 8 MHz at Near Det
  - Higher detector activity during beam spill at Near Det requires higher time resolution
- FEB operated in triggerless, continuous readout mode with no dead time
- Signal recognition/zero suppression done in real time by FPGA
  - Data compared to a pixel-by-pixel programmable threshold



Avalanche Photo Diodes:
- 85% Quantum Efficiency
- Gain~100
- cooled to -15C for 2PE dark noise

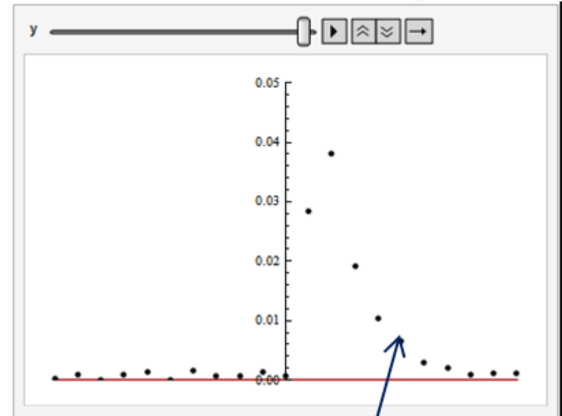
Response :

- ~30 photo-electrons from MIP at far end of cell (10-12 MeV of deposition in the scint)
- 4 PE in total noise => Light yield gives a minimum Sig/Noise 10:1 (far end)

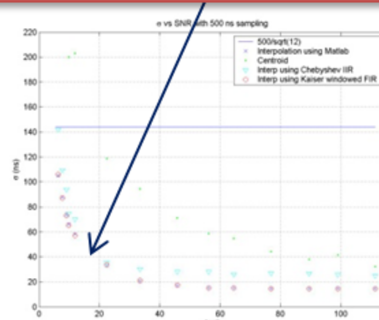
Front End Boards (FEBs)

- FEB FPGA uses Digital Signal Processing (DSP) to extract pulse height and timing edge
- Timing resolution better than digitization rate using fit of signal to ideal response to interpolate true pulse leading edge
  - Both "Matched Filtering" and "Dual Correlated Sampling" DSP algorithms have been explored.
    - Dual Correlated Sampling in use at Prototype Near Detector

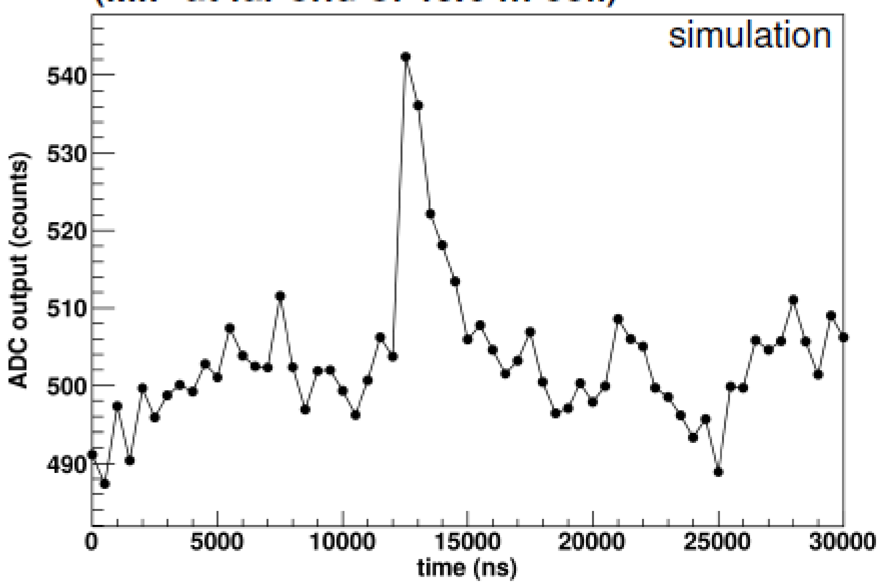
Matched Filtering



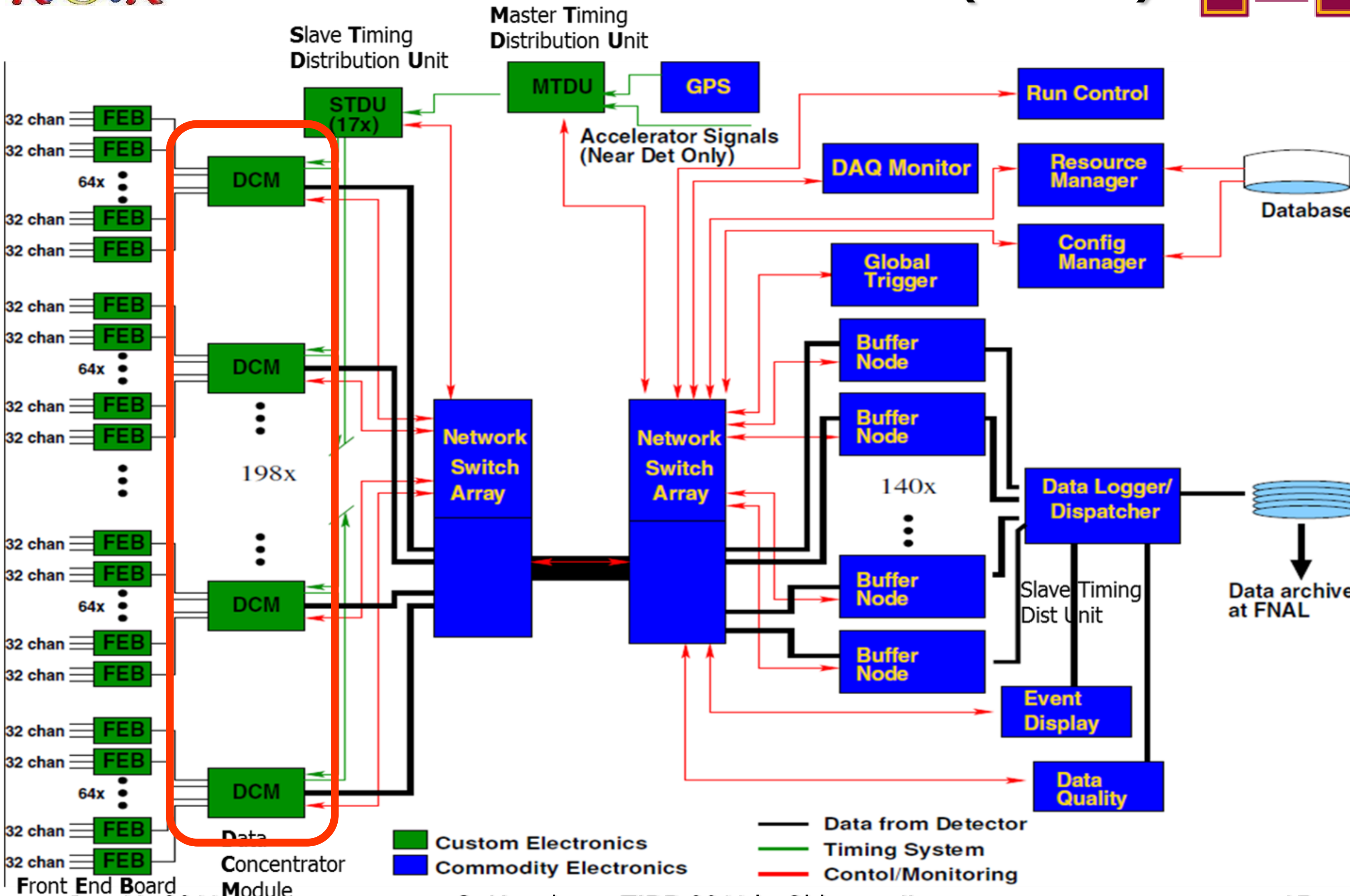
Raw data is matched to ideal response function in the FPGA, to extract pulse height and timing edge.
Timing resolution is a function of Sig/Noise (10:1 min) giving a timing resolution of < 30ns



Approx. smallest signal of interest (MIP at far end of 15.6 m cell)



Data Concentrator Modules (DCMs)

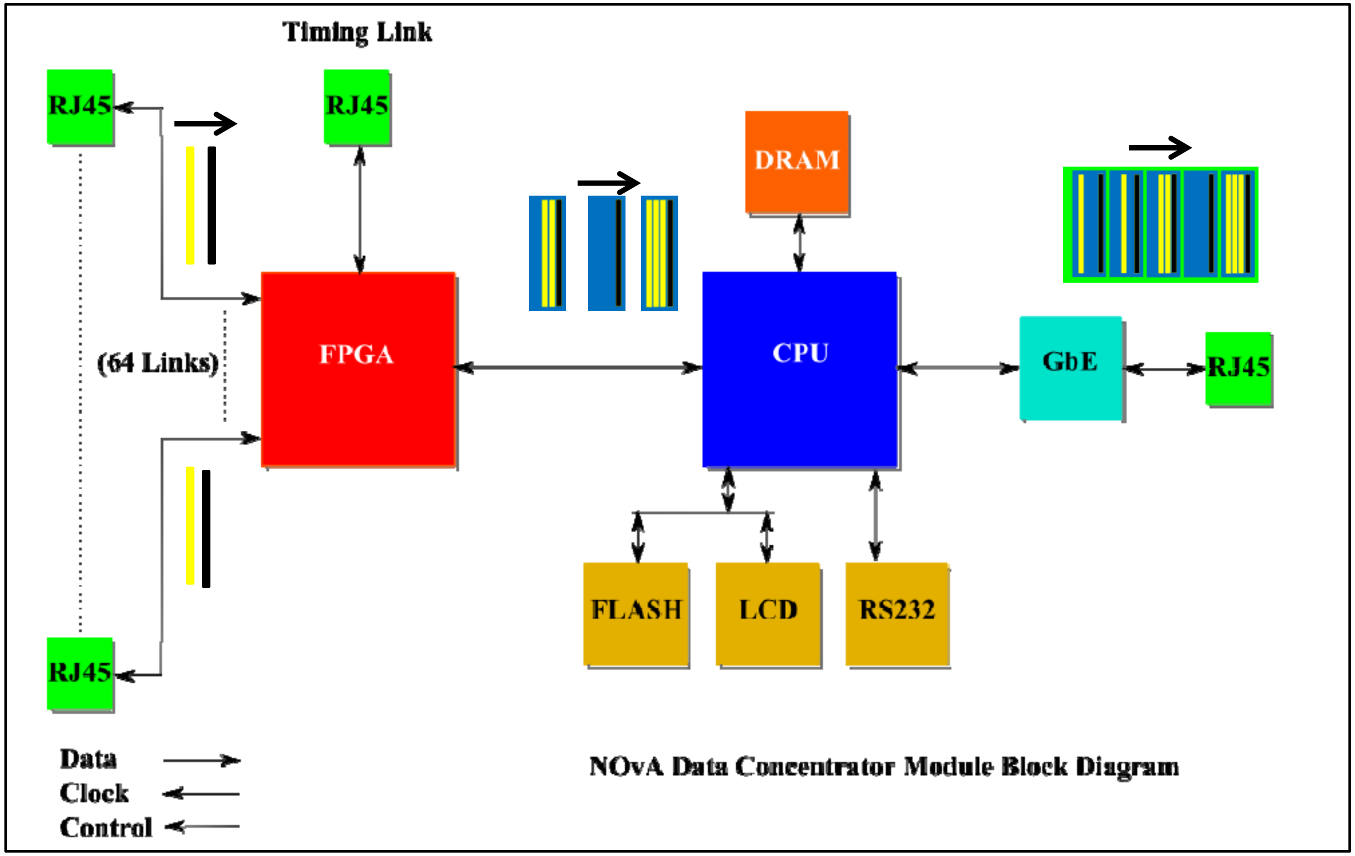


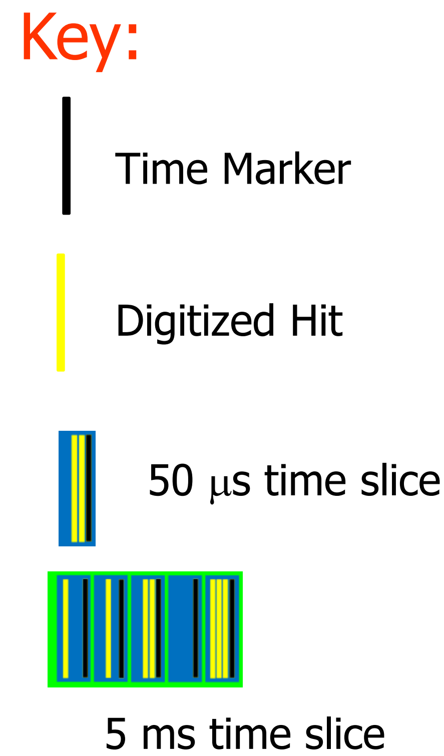
Data Concentrator Modules (DCMs)

- DCMs attach to racks on sides and top of detector
- One DCM reads out up to 64 FEBs; each of which reads out 32 APD pixels
- Purpose:
  - Consolidate hit data from FEBs into 5 ms time slice optimal for data transfer to downstream Buffer Nodes
  - Program, configure, and monitor FEBs
  - Pass Timing System clock, sync to FEBs

*PDB=Power Distribution Box

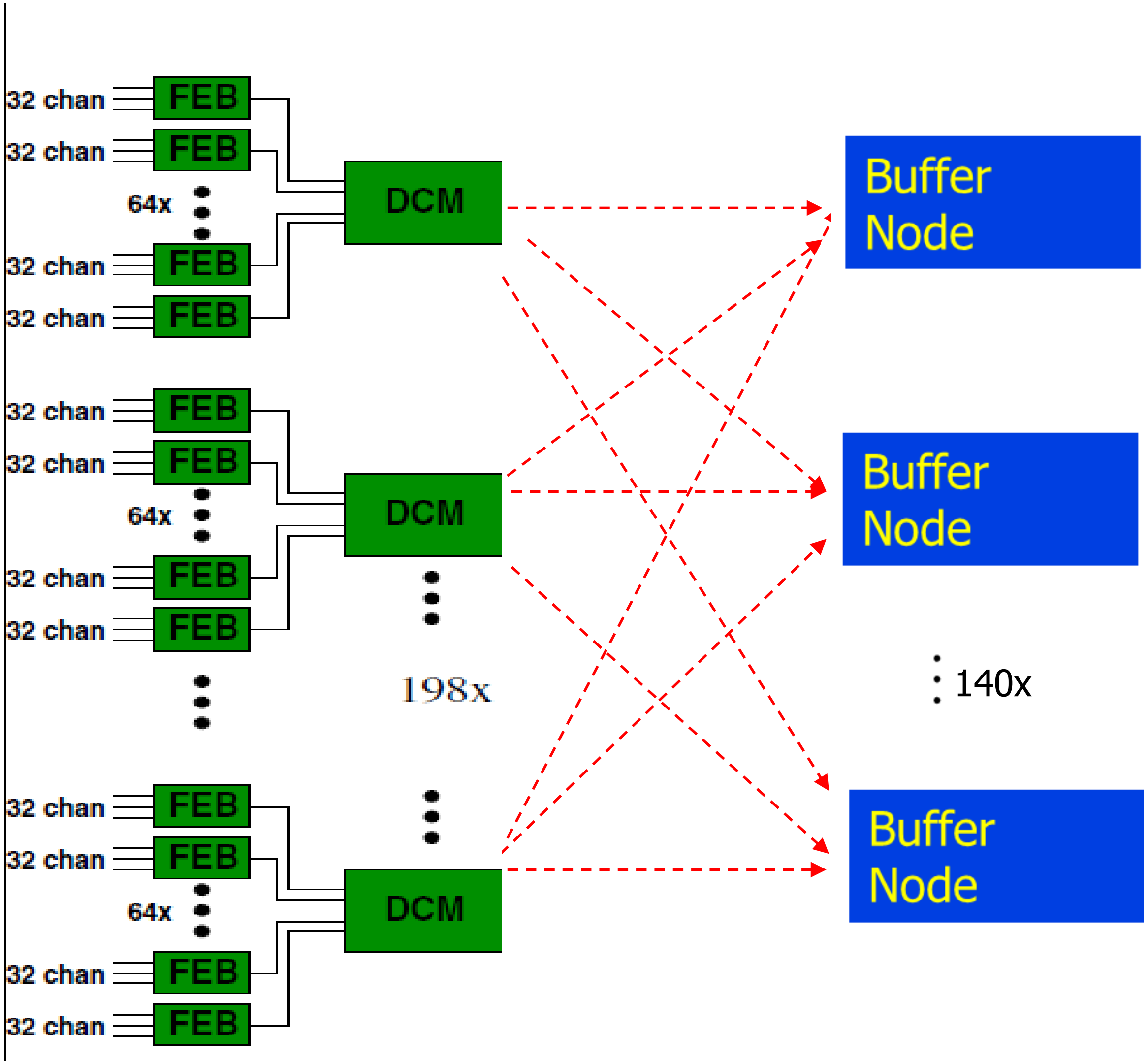
Data Concentrator Modules (DCM)





- Data Flow is left to right
  - FEB FPGA produces timing markers at periodic intervals (50 μs) interspersed with digitized hits
  - The digitized hits are consolidated by the DCM FPGA to 50 μs time slices containing data from all 64 FEBs
  - An application running on the DCM PowerPC CPU consolidates this data further to a longer time slice (5 ms) and routes this time slice to downstream buffer node for further processing.

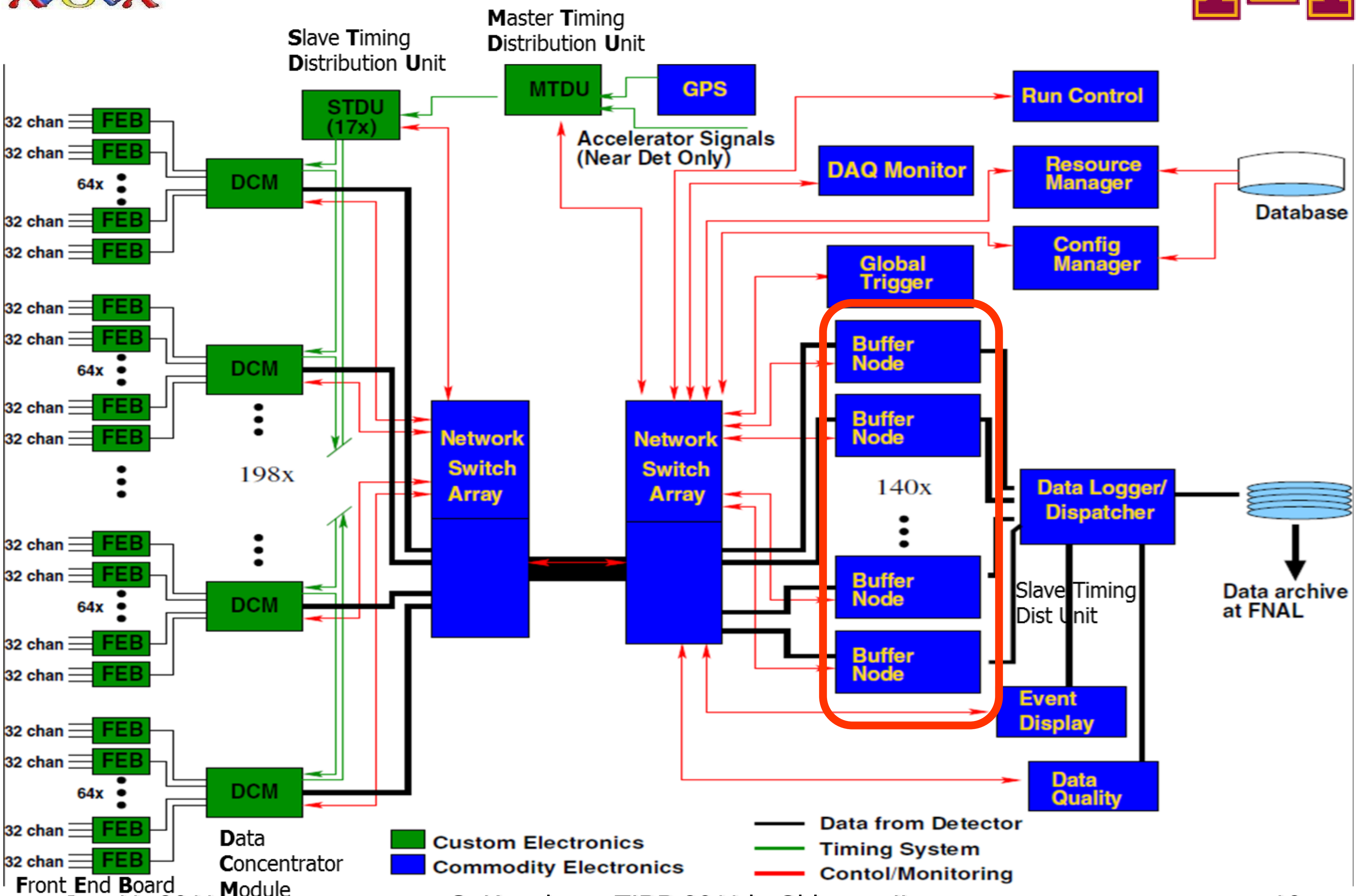
Data Concentrator Modules (DCMs)



- 5 ms time slices of data are routed by the DCM to downstream Buffer Nodes in Round Robin fashion
- All hit data from throughout the detector corresponding to one 5 ms time slice is routed to the same Buffer Node.
- The Buffer Node will select data from this time slice corresponding to a Trigger.

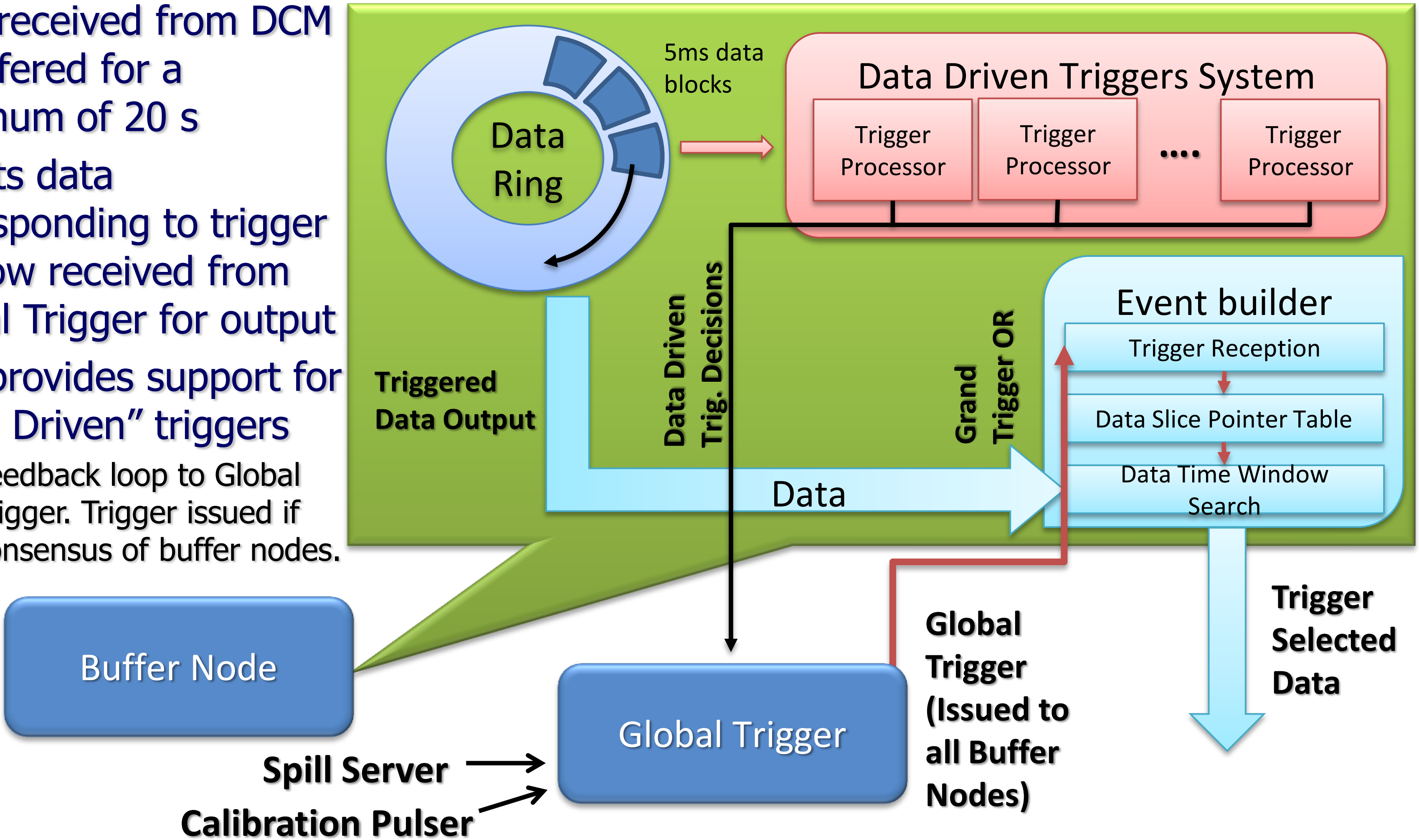
(Animation is idealized – network packet buffering will cause slices to be staggered in their arrival at buffer nodes)

Buffer Nodes

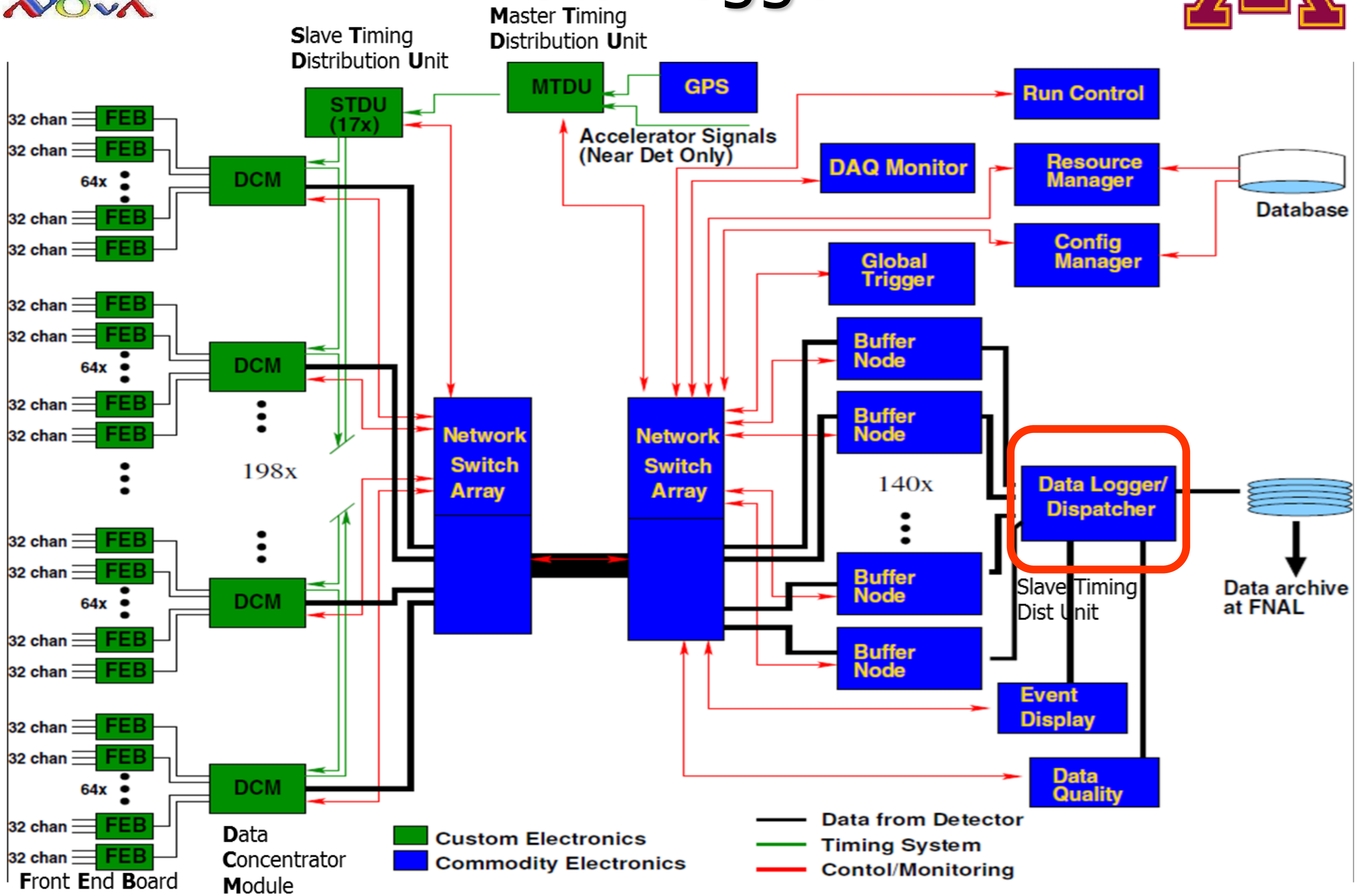


Buffer Nodes & Trigger

- A Buffer Node is a commodity server
- Data received from DCM is buffered for a minimum of 20 s
- Selects data corresponding to trigger window received from Global Trigger for output
- Also provides support for "Data Driven" triggers
  - Feedback loop to Global Trigger. Trigger issued if consensus of buffer nodes.

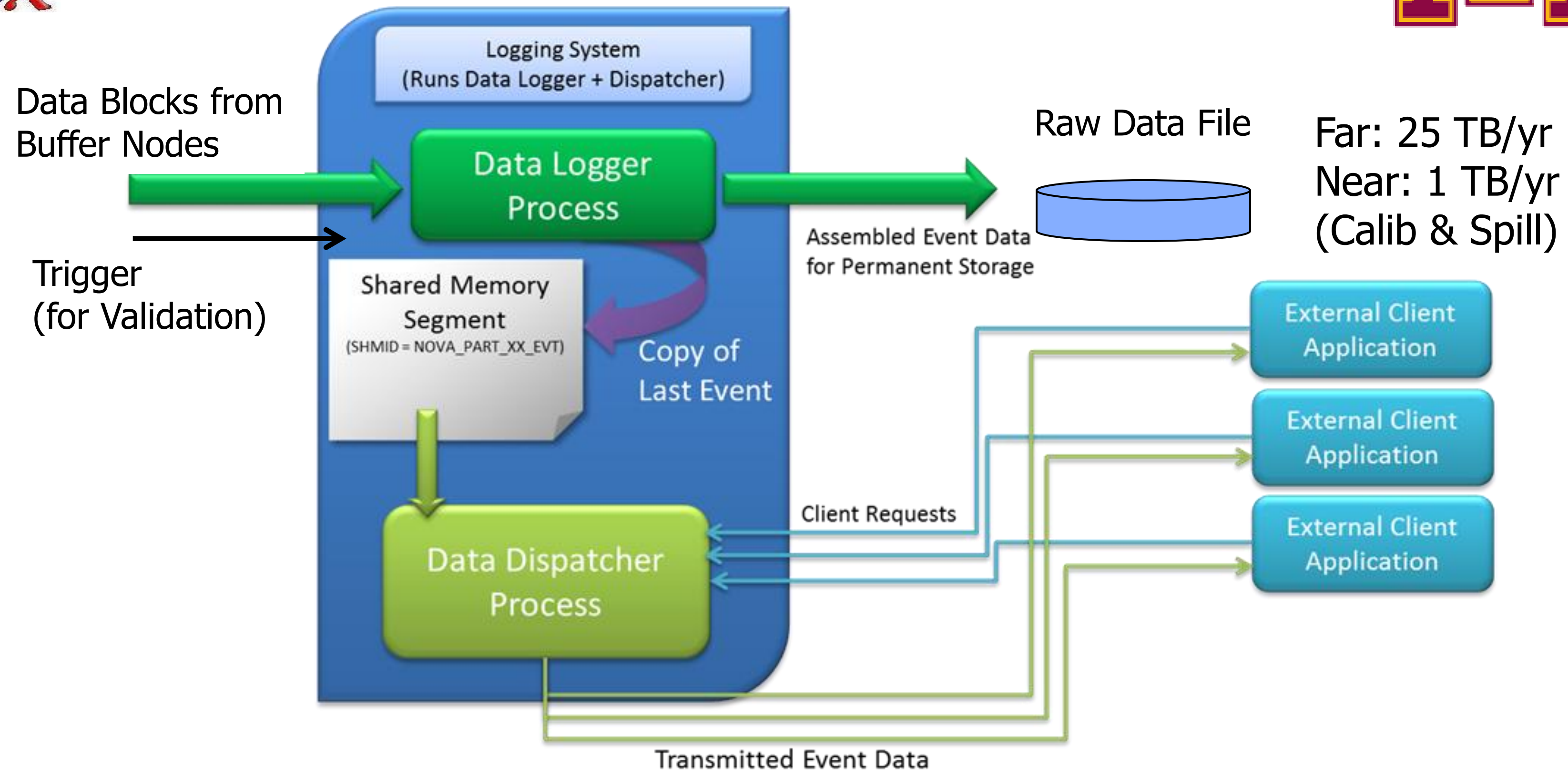


Data Logger



Slave Timing Distribution Unit
Master Timing Distribution Unit
STDU (17x)
MTDU
GPS
Accelerator Signals (Near Det Only)
Run Control
DAQ Monitor
Resource Manager
Config Manager
Database
Global Trigger
32 chan
FEB
64x
DCM
198x
Network Switch Array
Network Switch Array
Buffer Node
140x
Data Logger/ Dispatcher
Slave Timing Dist Unit
Data archive at FNAL
Event Display
Data Quality
Front End Board
Data Concentrator Module
Custom Electronics
Commodity Electronics
Data from Detector
Timing System
Contol/Monitoring

Data Logger



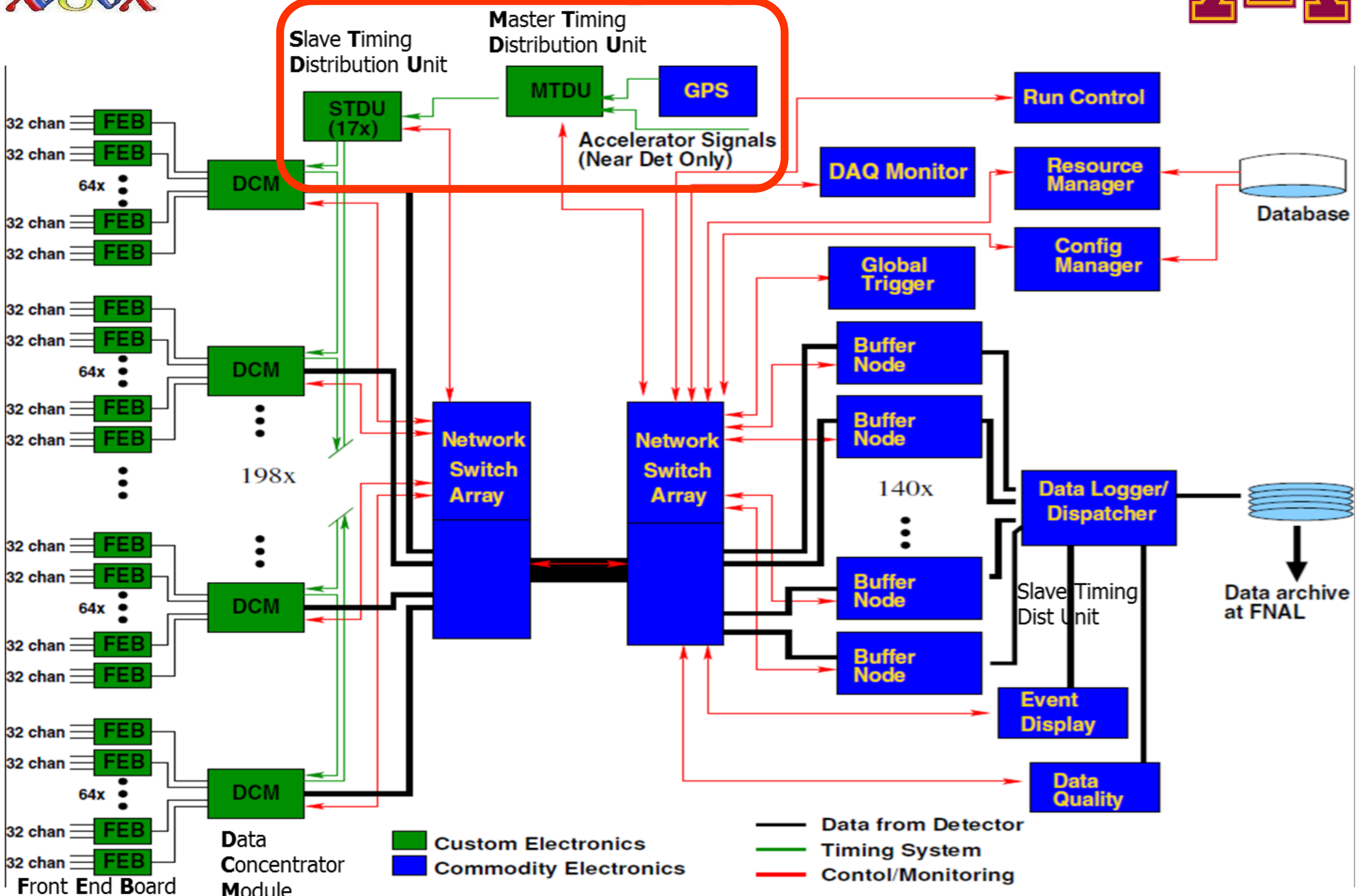
- Single Data Logger is a commodity server
- Data Blocks received from Buffer Nodes are merged to form Event
- Events written to file. Archived to FNAL mass storage via separate File Transfer system.
- Events also written to shared memory for Dispatch to quasi-online consumers such as Online Monitoring and Online Event Display.

Expected Data Rates

	Near		Far	
	Data Rate/ Component (kB/s)	Number	Data Rate/ Component (kB/s)	Number
FEB	120	500	160	11250
DCM	250	9	3000	180
Buffer Node In/ Out*	300/ 4	8	3800/ 8	140
Data Logger	30	1	1100	1

*Buffer Node Output rates consider Beam Spill + Calibration Triggers only

Timing System

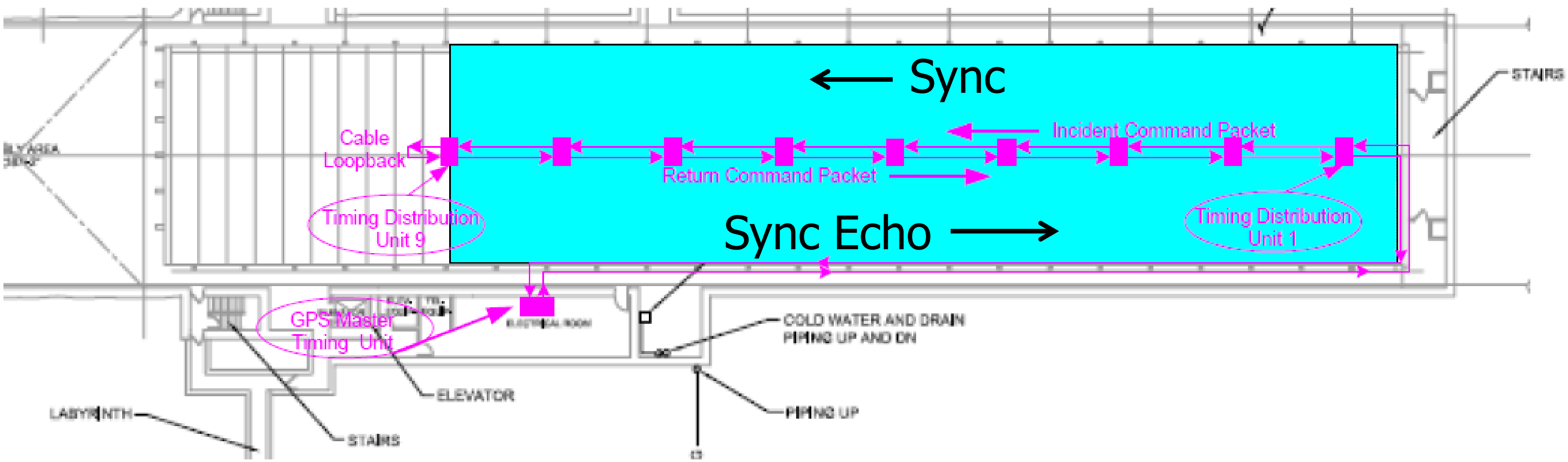


Timing System

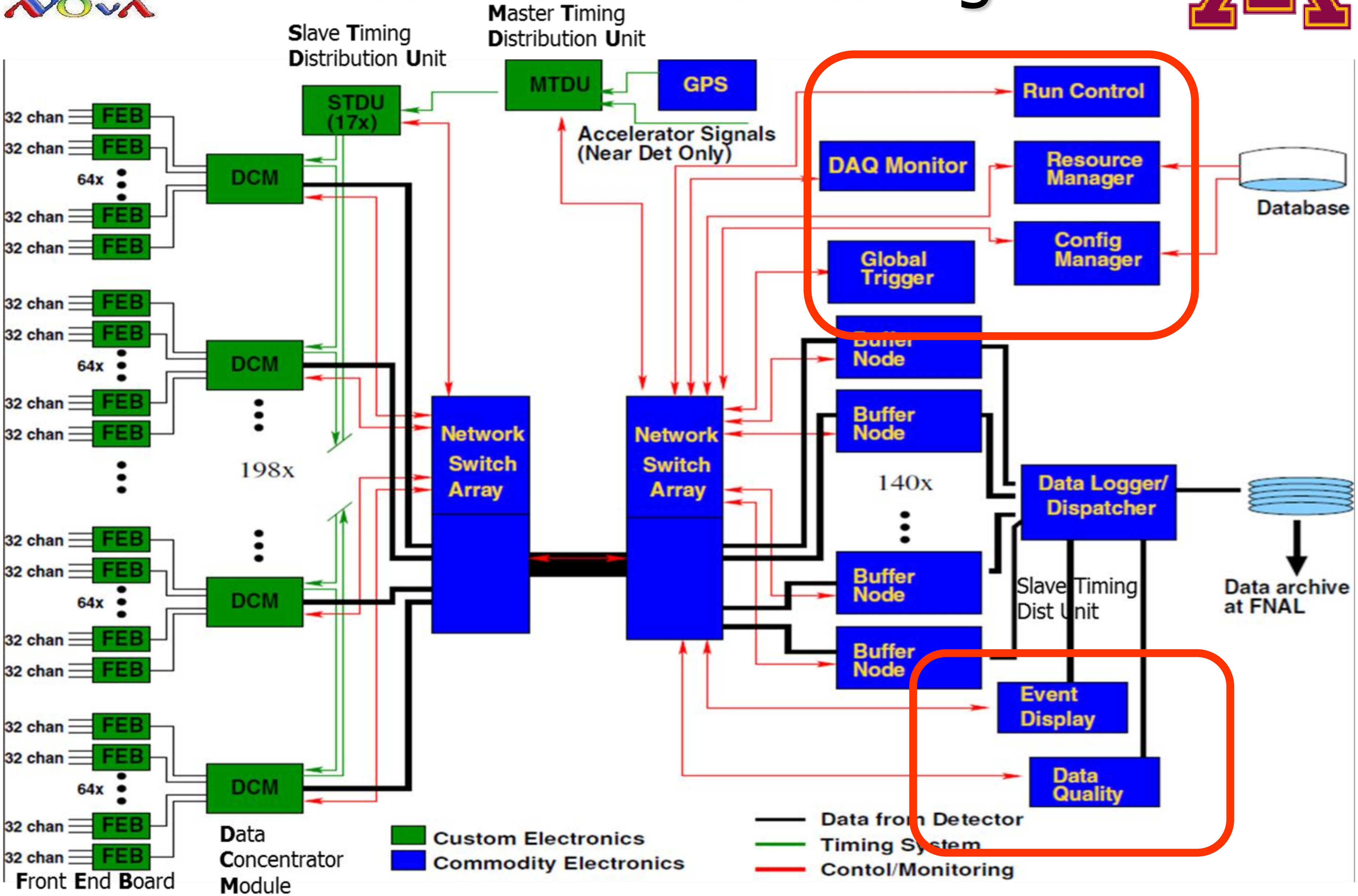
- All FEBs/DCMs are sync'ed to a common high precision 16 MHz clock reference
- Clock distributed to DCMs by Slave Timing Distribution Units (STDUs) daisy-chained along backbone of detector
  - Two outputs per STDU supply clocks to two groups of 6 daisy-chained DCMs
- Master Timing Distribution Unit (MTDU) derives clock from GPS, distributes to first STDU in chain
  - Signal regenerated at each step in chain.

Timing System

- TDUs have 4 differential pairs for communication: Sync, Command, Clock, and Sync Echo
- STDUs have "Delay Learn" feature to compensate for cable length propagation delays using TOF/2 method
  - When in Learn mode, each STDU will start a timer on next Sync that will run until it receives a Sync Echo
  - This time can be used to self-correct for propagation delays => synchronization within +/- ½ clock cycle

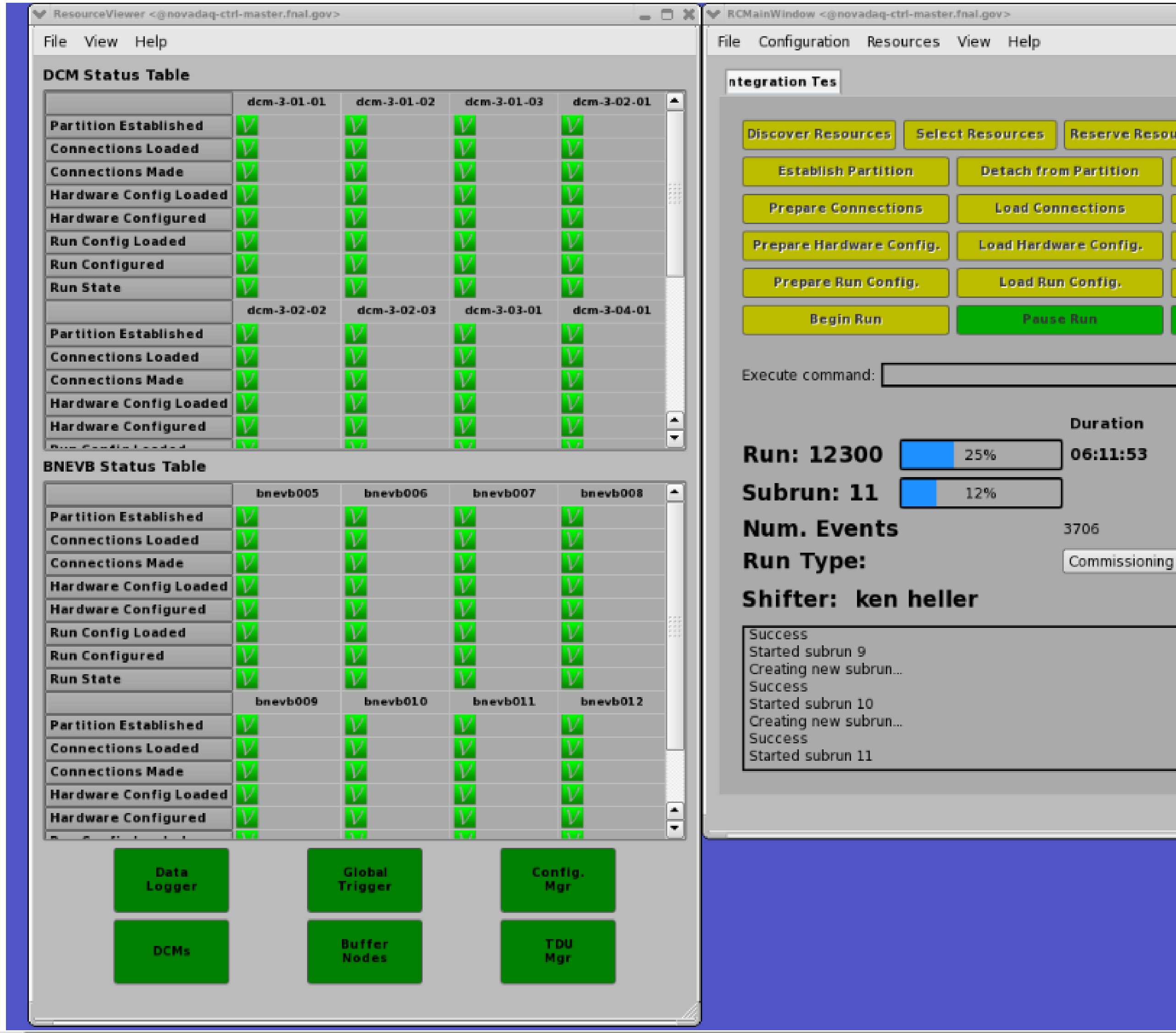


Control & Monitoring

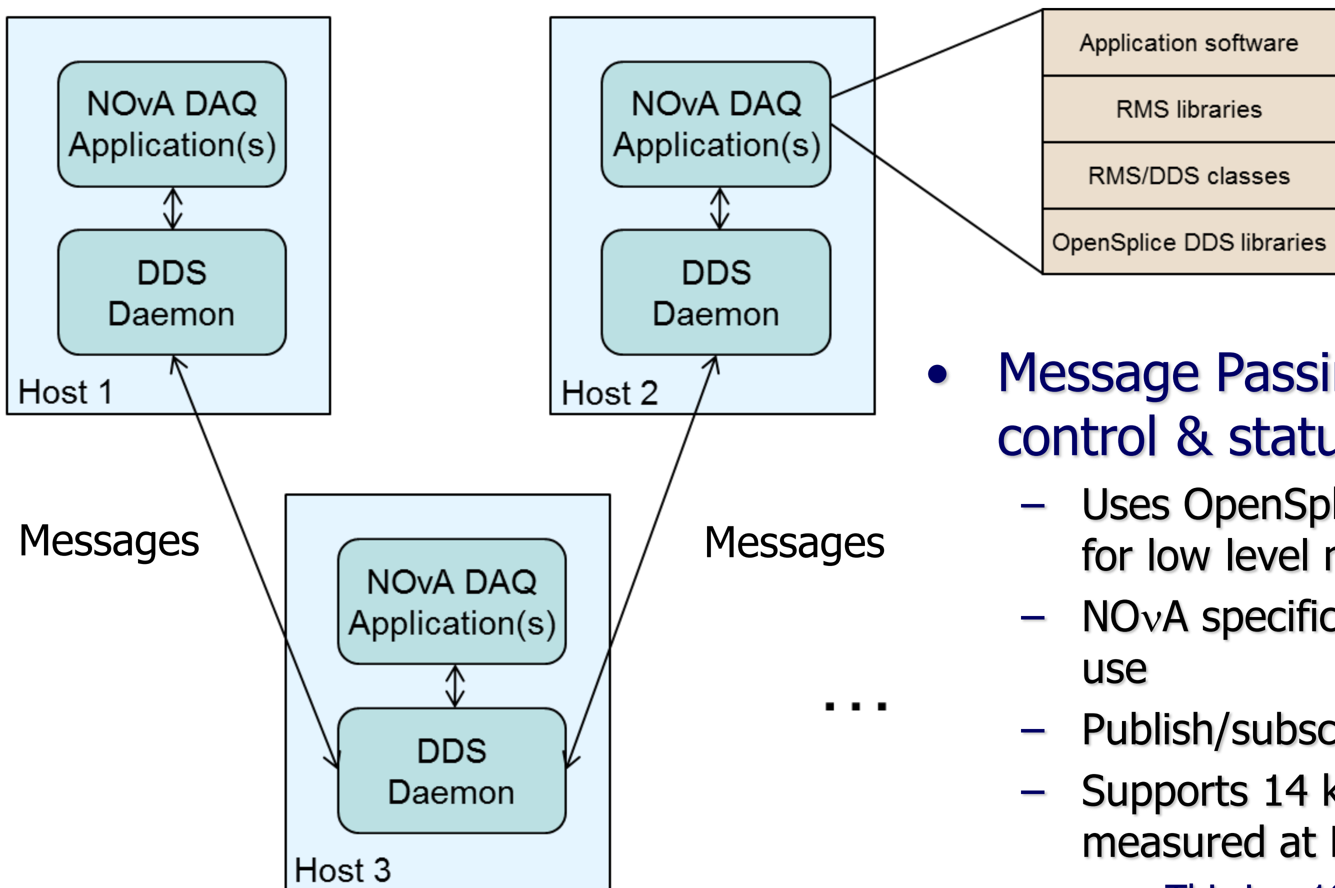


Run Control

- 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 tools to implement GUI



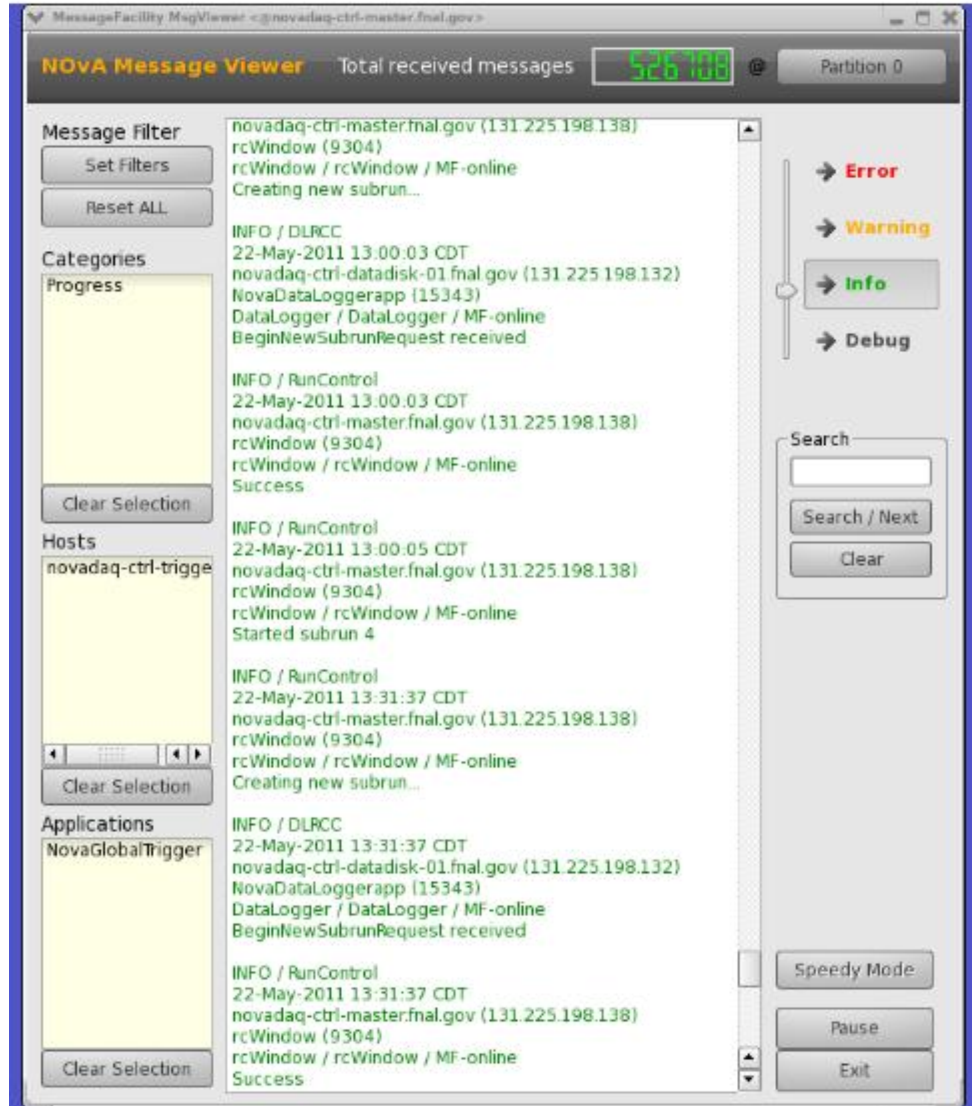
DAQ Messaging



- Message Passing System handles control & status messages
  - Uses OpenSplice DDS from Prism Tech for low level message transmission
  - NOνA specific layers provide ease-of-use
  - Publish/subscribe methodology
  - Supports 14 kHz message rate as measured at NDOS Prototype Detector
    - This is ~10x that needed for Near Detector
    - Will optimize towards preferred goal of ~2x faster for Far Detector

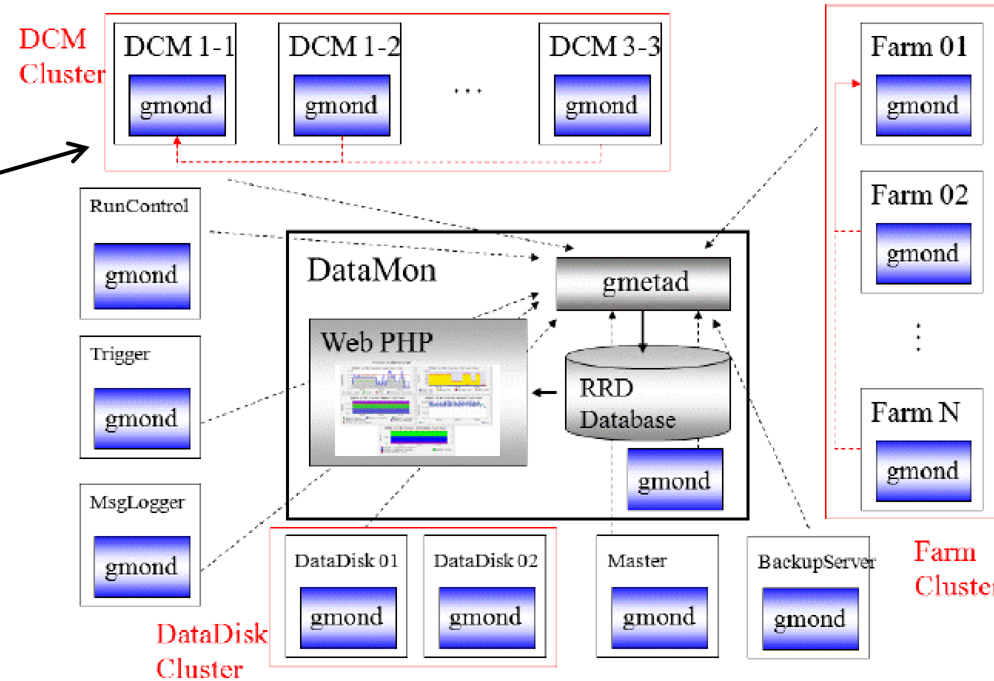
Message Facility

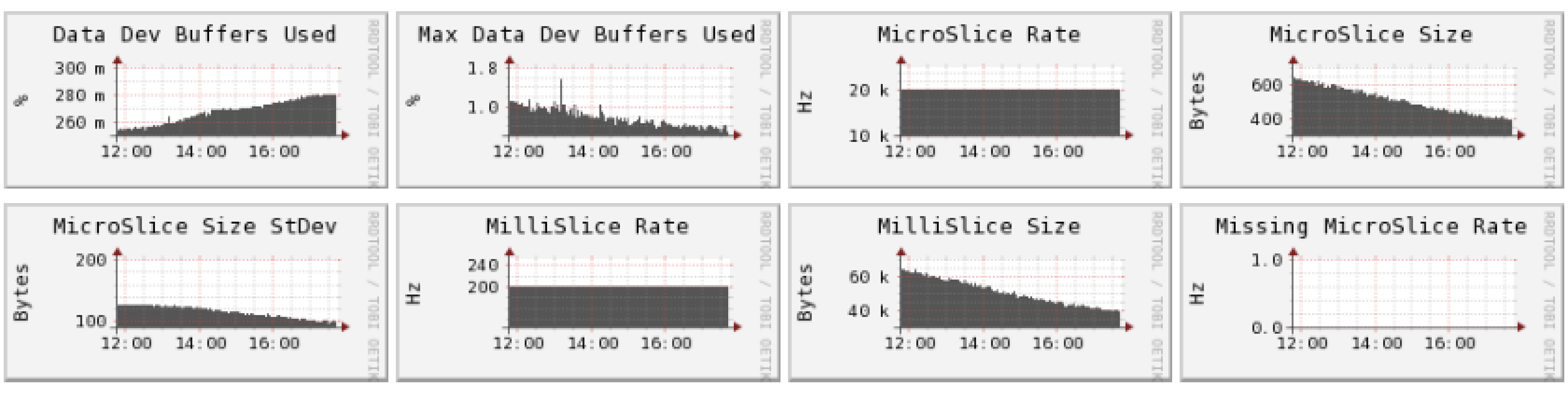
- Message Facility for logging Messages
  - Based on CMS Message Logger
- Capable of logging messages to multiple destinations
  - std out, file and/or msg server
  - Uses DDS for sending client messages to msg server
- GUI display for server
  - Allows server-side filtering
  - Used in control room
- Additional package “Message Analyzer” monitors messages to gauge overall detector health
  - Prototype version implemented at NDOS



DAQ Monitor

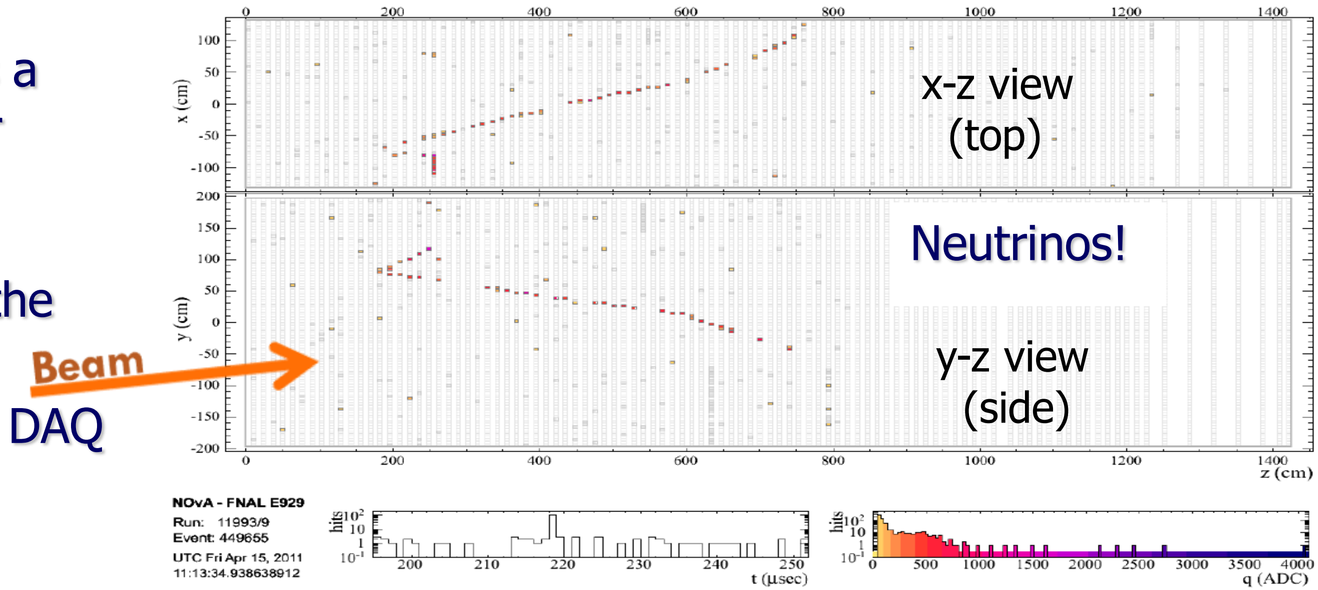
- Uses Ganglia Monitoring System at its base
  - Ganglia daemons gmetad and gmond collect and distribute metrics
- NOνA specific classes allow client applications to submit custom metrics

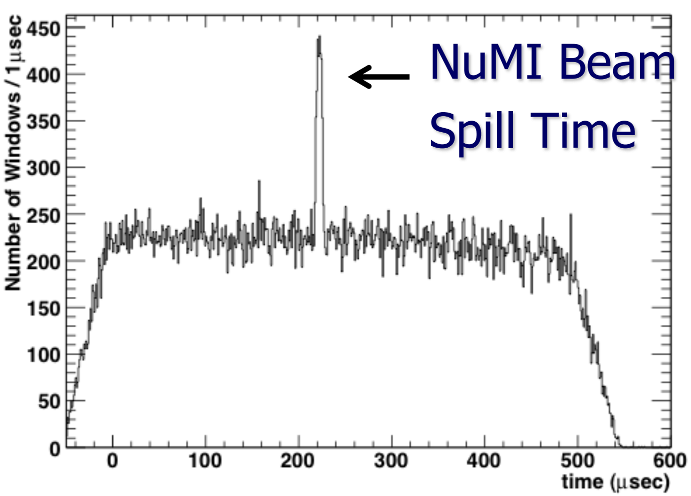


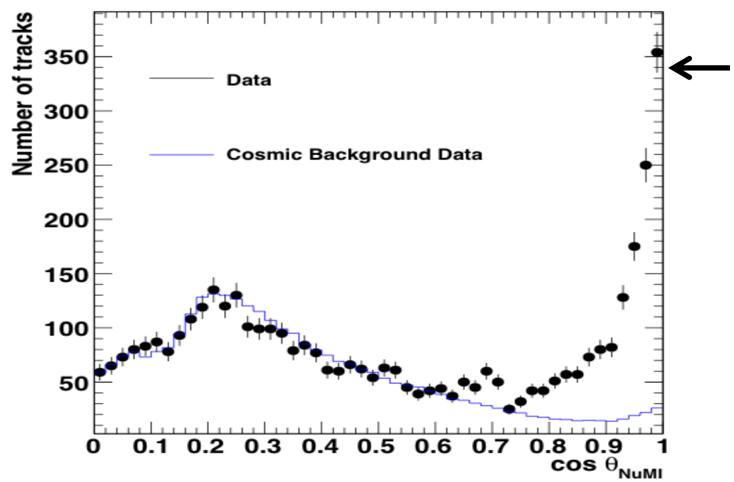


NDOS Prototype Detector
Performance

- NDOS has served as a valuable test bed for commissioning all aspects of detector operation including the DAQ
- Core functionality of DAQ system is working…





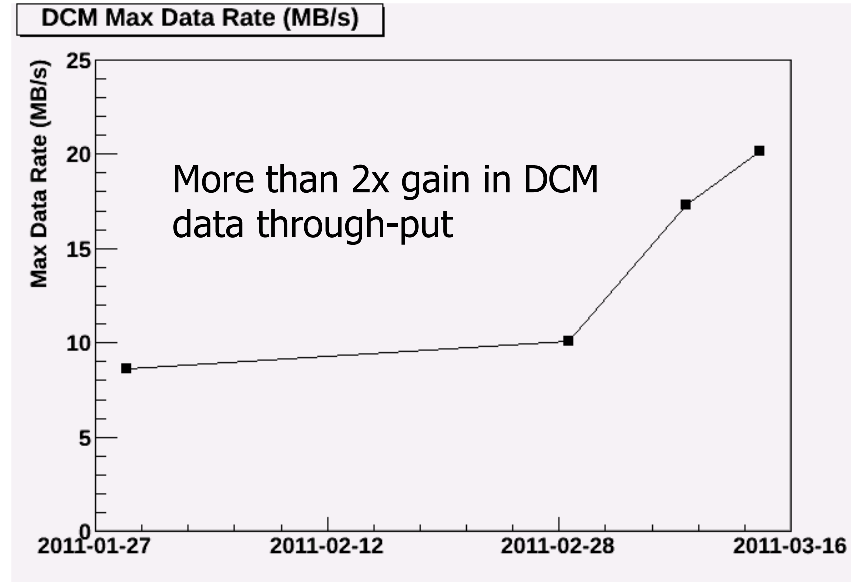


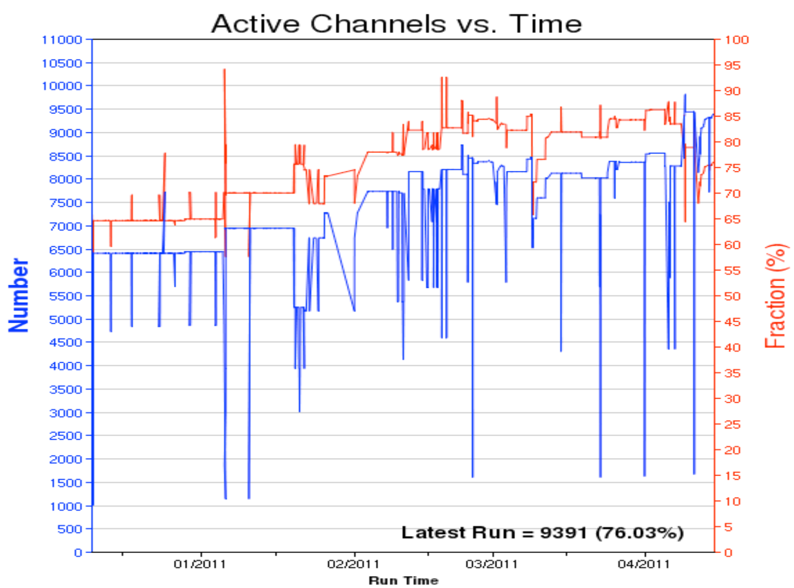
Peak in direction of beam

$\cos\theta_{NUMI} = 1$ is in direction of off-axis beam

NDOS Prototype Detector
Performance

- Many performance gains and fixes of bugs have been made as a result of commissioning the Prototype Near Detector
  - This plot shows the through-put gain of the DCM as a result of optimizing software & network usage





- Number of active channels, live time, quality of data continue to improve over time
  - Number: instrumented channels
  - Fraction: fraction of instrumented channels enabled

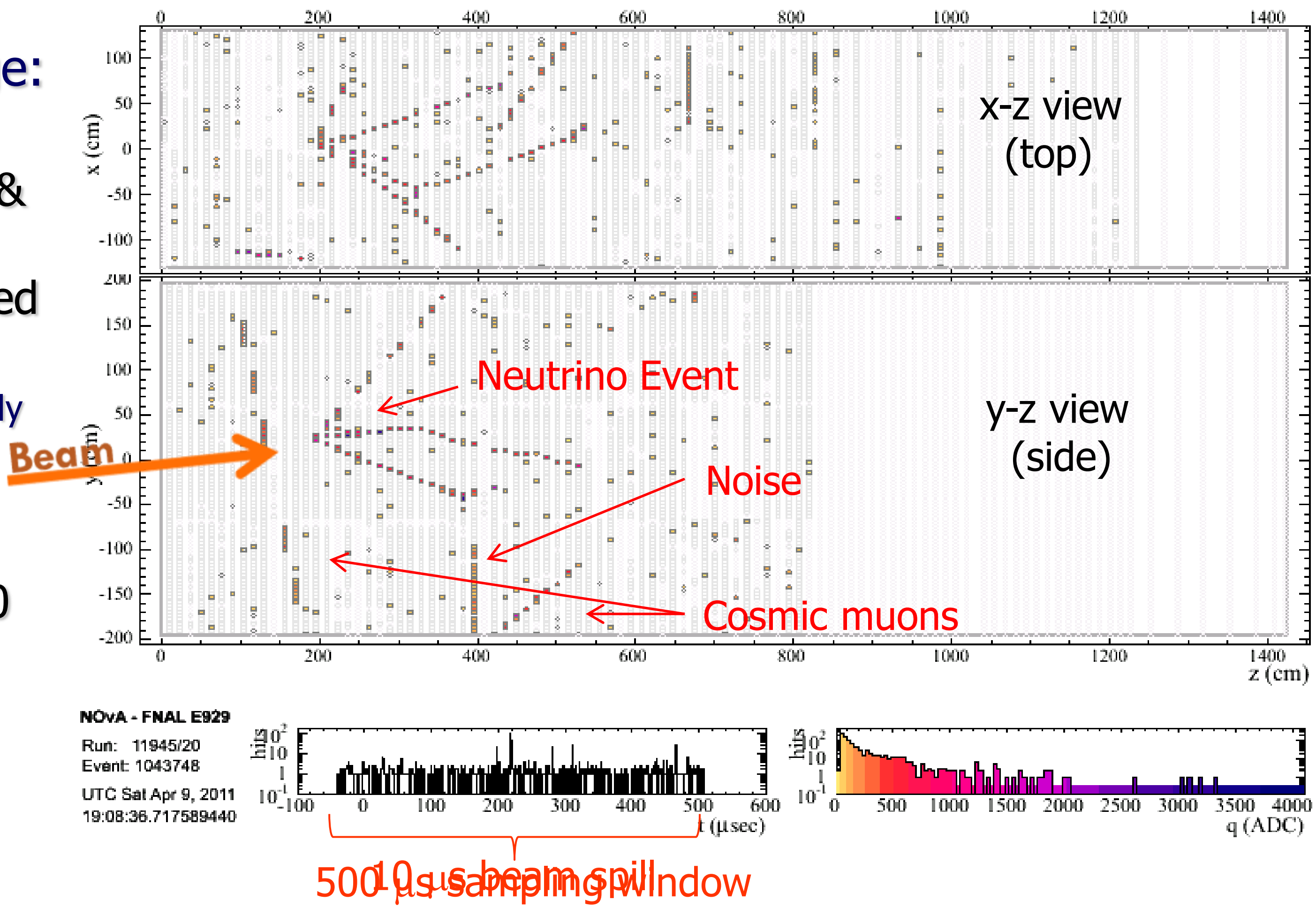
Summary

- Much of the DAQ system has been implemented and deployed to the NOνA prototype detector (NDOS)
- Now shifting effort towards work to do before deploying at NOνA Far Detector:
  - Automatic Error Recovery
  - Scaling GUIs/Displays for larger number of nodes
  - Stress testing system for Rate capacity (underway)
  - Partition support (operate different sections of detector in different run modes)
  - Learn Delay mechanism of Timing System
  - Data Driven Trigger Support in Buffer Node
  - , etc..
- Thank you for your time!

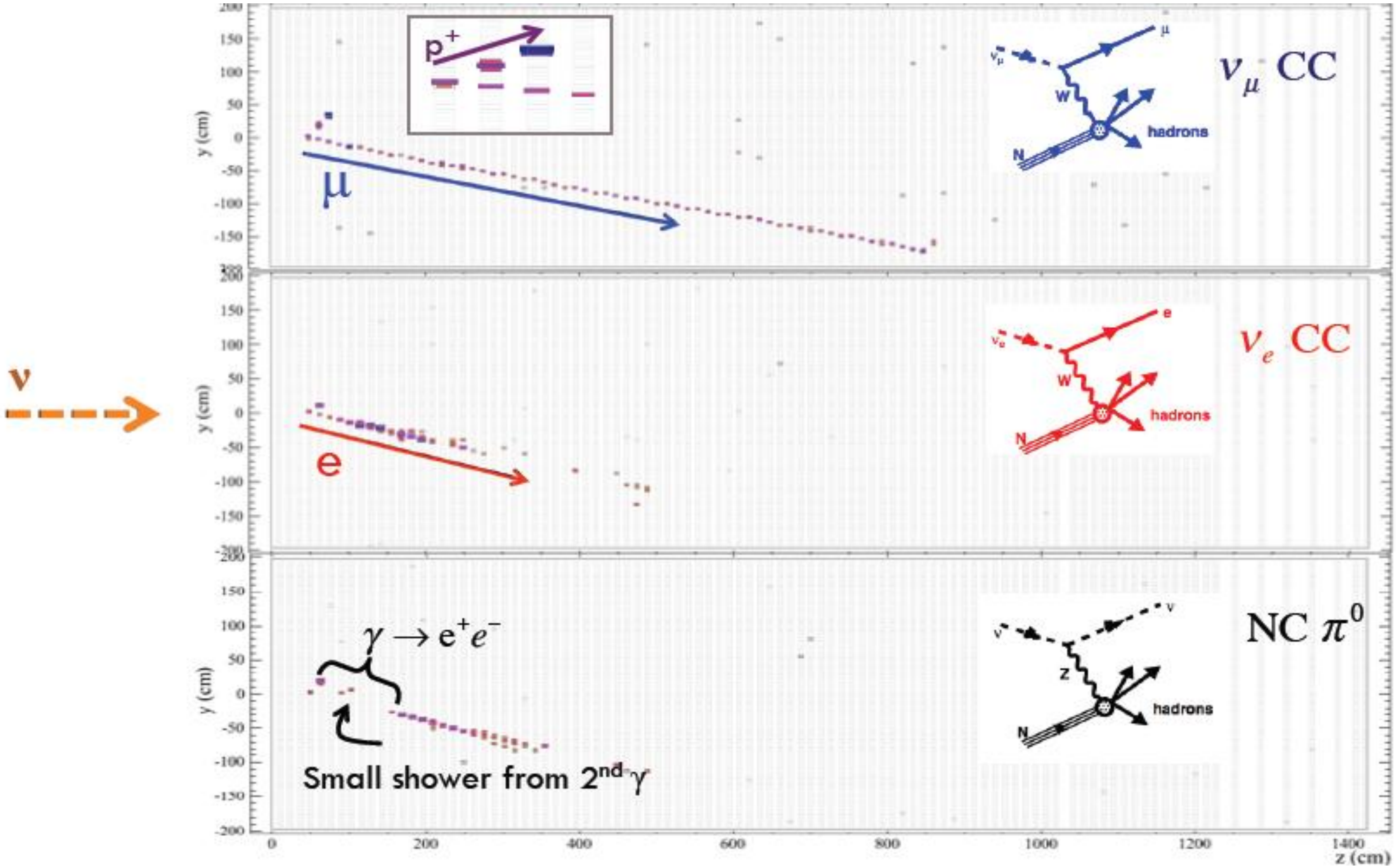
Backup Slides

NDOS Prototype Detector Data

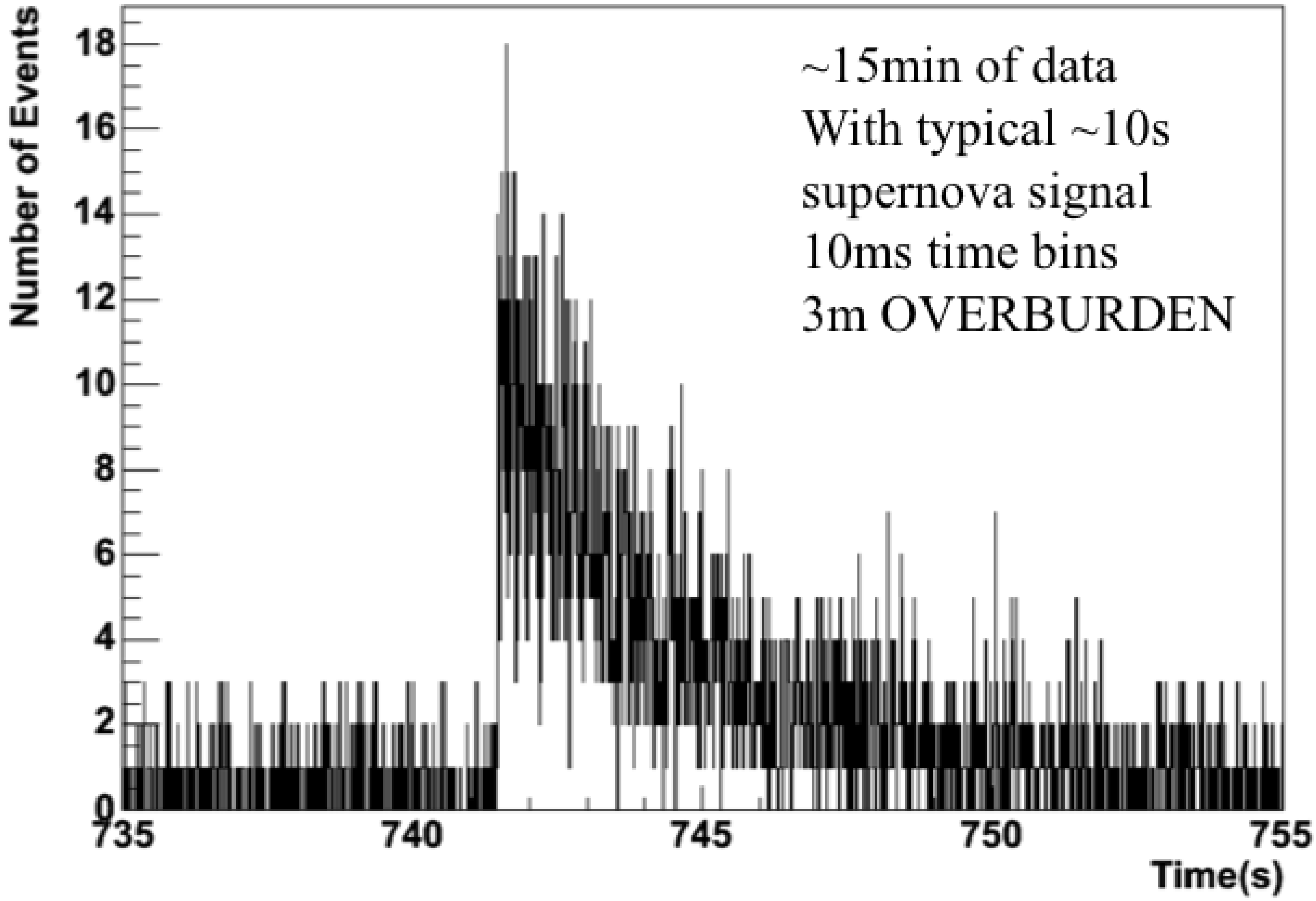
- NDOS Trigger Windows are large:
  - 500 μs window for both Beam & Calibration Triggers sampled at about 15 Hz
    - Beam spills only ~10 μs long
    - Click to see Animation =>
  - Will use only 30 μs window at Near and Far Detectors
  - Time slicing distinguishes events



Neutrino Events in NOνA
Simulated



Galactic Supernova Signal



NOνA would see burst of 5000 events for a supernova at the center of the galaxy