The NOvA Far Detector Data Acquisition System

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for the NOvA Collaboration

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Fermilab

The NOνA Experiment

Goals:

- **Measure $\nu_\mu \rightarrow \nu_e$ oscillations:**
  - Measure θ_{13}
  - Determine the mass hierarchy
  - Constrain δ_{CP}
  - Determine the θ_{23} octant
  - Measure ν_μ disappearance.
  - Precision measurement of $|\Delta m^2_{32}|$, $\sin^2 2\theta_{23}$
- **Other physics:**
  - Near Detector neutrino cross-sections
  - Sterile neutrinos
  - Supernova search
  - Monopole search
  - Dark matter searches

A long-baseline neutrino oscillation experiment

Ash River - Far Det

810 km
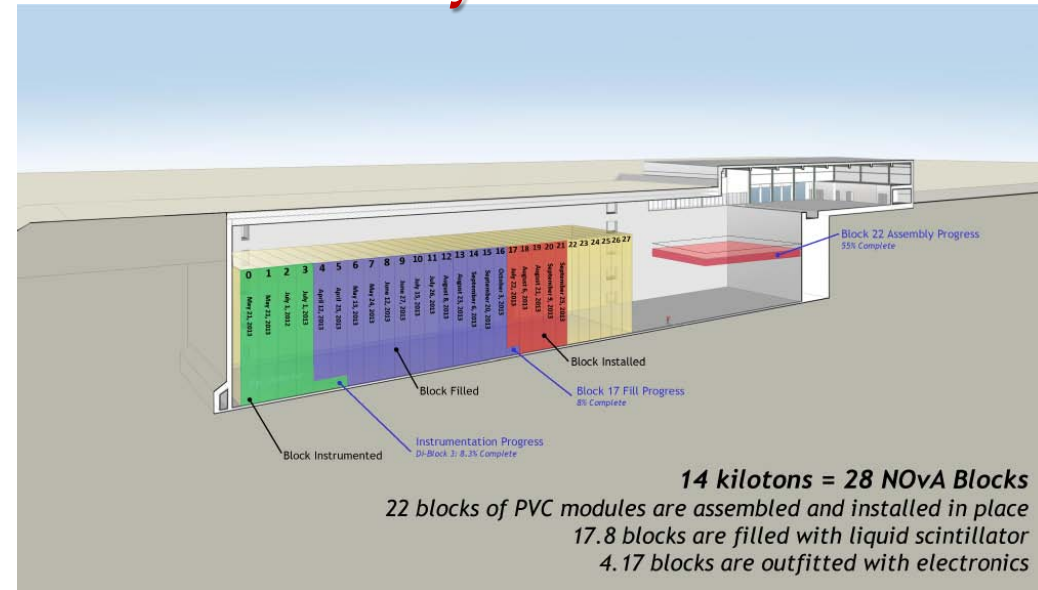
Fermilab - Near Det

The NOνA Detectors

Far Detector:

- Surface Detector
- 14 kton
- 60 x 15.6 x 15.6 m^3
- 896 alternating X-Y planes
- 334 064 cells
- "Totally Active" Calorimeter
- 3D - tracking
- Liquid Scintillator filled PVC
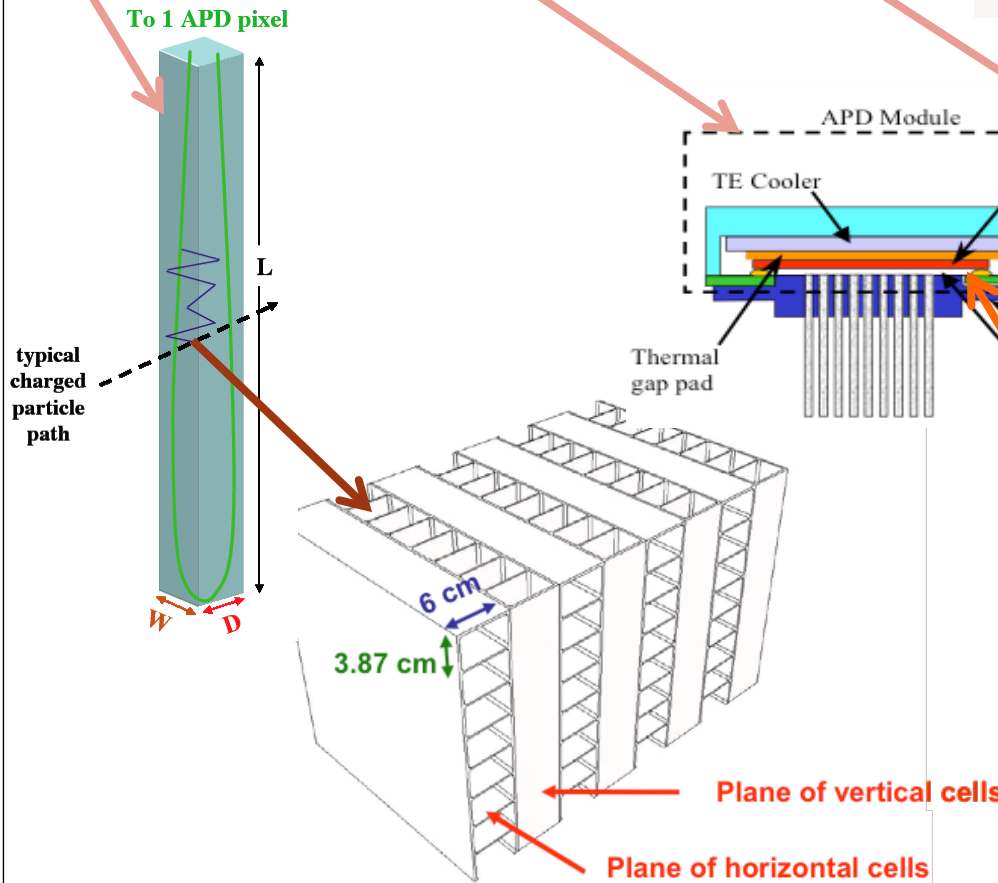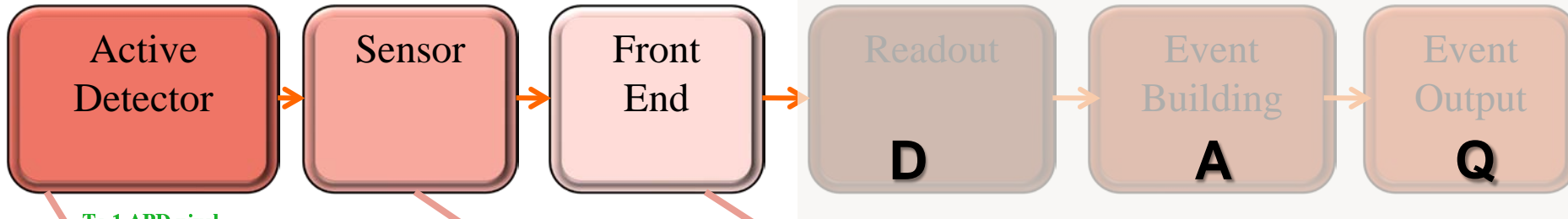- Optimized for EM shower reconstruction & muon tracking

Near Detector:

- Identical to Far detector
- Underground Detector
- 1:4 scale size
- Optimized for NuMI cavern rates - 4x sampling rate electronics
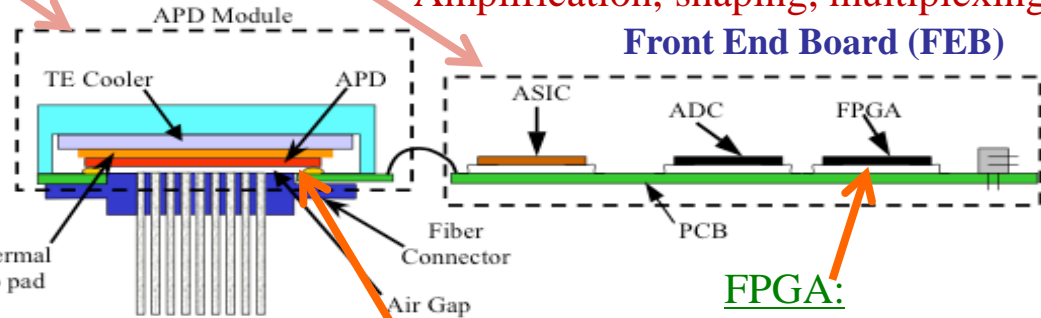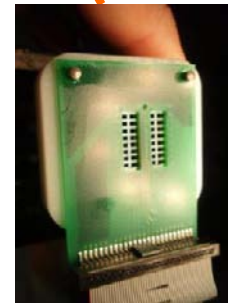- Construction just began

FarDet: Assembly status 7Oct2013

14 kilotons = 28 NOvA Blocks
22 blocks of PVC modules are assembled and installed in place
17.8 blocks are filled with liquid scintillator
4.17 blocks are outfitted with electronics

NOvA Sensor and Front End

Active Detector → Sensor → Front End →

To 1 APD pixel

L

W   D

typical charged particle path

ASIC:
Amplification, shaping, multiplexing to ADC

Front End Board (FEB)

APD Module

TE Cooler   APD

ASIC   ADC   FPGA

Thermal gap pad

Fiber Connector

PCB

Air Gap

FPGA:
Digital signal processing

6 cm

3.87 cm

Plane of vertical cells

Plane of horizontal cells

Avalanche Photo Diodes (APD):
- 32 channels
- 85% Quantum Efficiency
- Gain ~100
- Cooled to -15C for 2PE dark noise

FEB Signal Processing

Sampled waveform

ASIC Output Pulse Shaping (FarDet)

- 380 ns rise time, 7 μs fall time
- Sample each channel every 500 ns
- Actual clock runs at 62.5 ns,
- Four 8:1 multiplexors

Near Detector

- 60ns rise time, 500ns fall time
- Sample each channel every 125 ns
- Same base clock, but 2:1 multiplexing

DCS Mode

- Dual Correlated Sampling
- Output data when V_i-V_{i-2} exceeds configured threshold
- Data: pulse height = V_i-V_{i-2}, timestamp=T_i

DSO Mode

- Digital Sampling Oscilloscope
- Take (1000) contiguous samples
- Use to measure noise level and set appropriate DCS threshold

Fast Timing

Two pulses with identical DCS output Pulseheight and Time

ND readout (Rise = 60 ns / Fall = 500 ns / Digit interval = 125 ns)
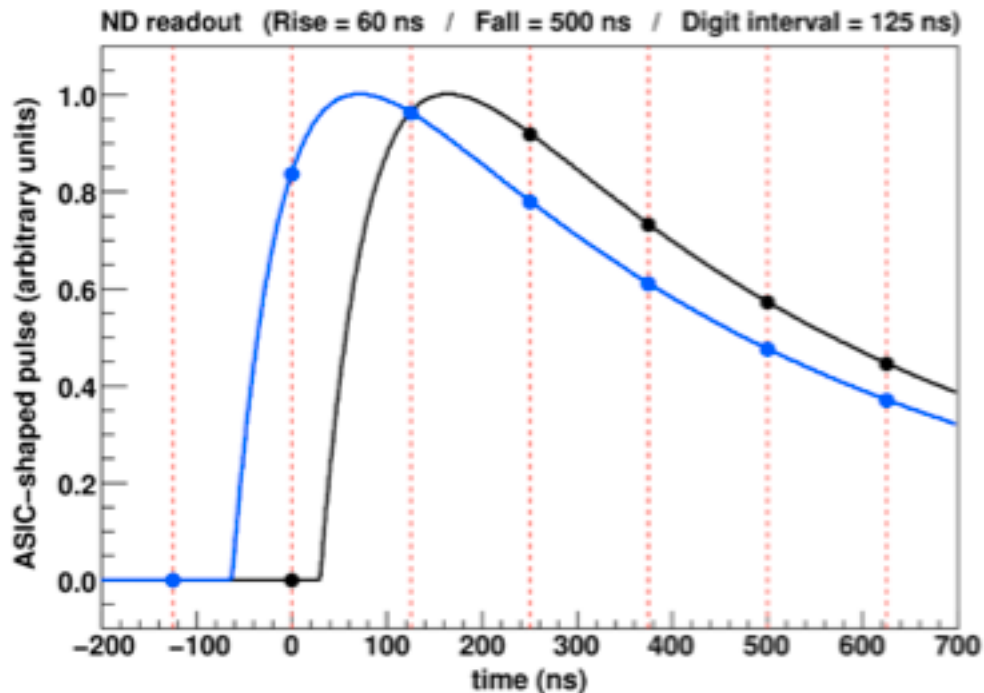
Multi-point sampling

- Apply DCS-threshold, but read out multiple contiguous samples
- With compression, can read out up to 12 samples with only 2 addition data words
- Apply matched filtering to improve timing resolution substantially
- Factor of 3 improvement demonstrated in Data with 4 points

Benefits

- Reduce Near Detector Pile-up
- FarDet: track direction from timing

DAQ Requirements

❑ Record beam spills in a window of at least 30 µs, with no dead time

  ➢ Every 1.33 seconds

❑ Record ~100 times as many periodic cosmic spills with no dead time

❑ Cosmic rays (200 kHz!) and noise add up to a hit rate of about 52 MHz, or 620 MB/sec

  ➢ Process 620 MB/sec readout with no dead time
  ➢ Write out 1.4 MB/sec saved events.

NOνA DAQ Layout

24MB/s
Data stream

Timing In

Timing Out
To next DCM

DCM (Data Concentrator Module)

- Designed to aggregate the continuous data stream 64 front end boards (2048 detector cells) into partially time sorted data block
- Combines a large FPGA with a single board computer to build 5ms
- Run custom embedded linux with support for NOνA firmware
- 168 DCMs for the Far Detetor
- 620 MB/sec readout, ~4 MB/sec/DCM

Hit data at
Max 3.2MB/s

64 FEBs
Per DCM

32 Chan APD
Per FEB

32 Detector Cell
Readout Fibers Per APD

Data flow
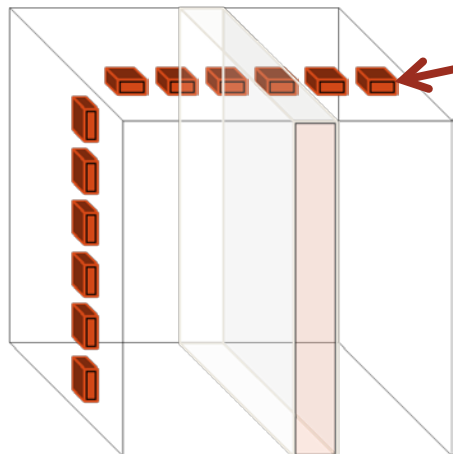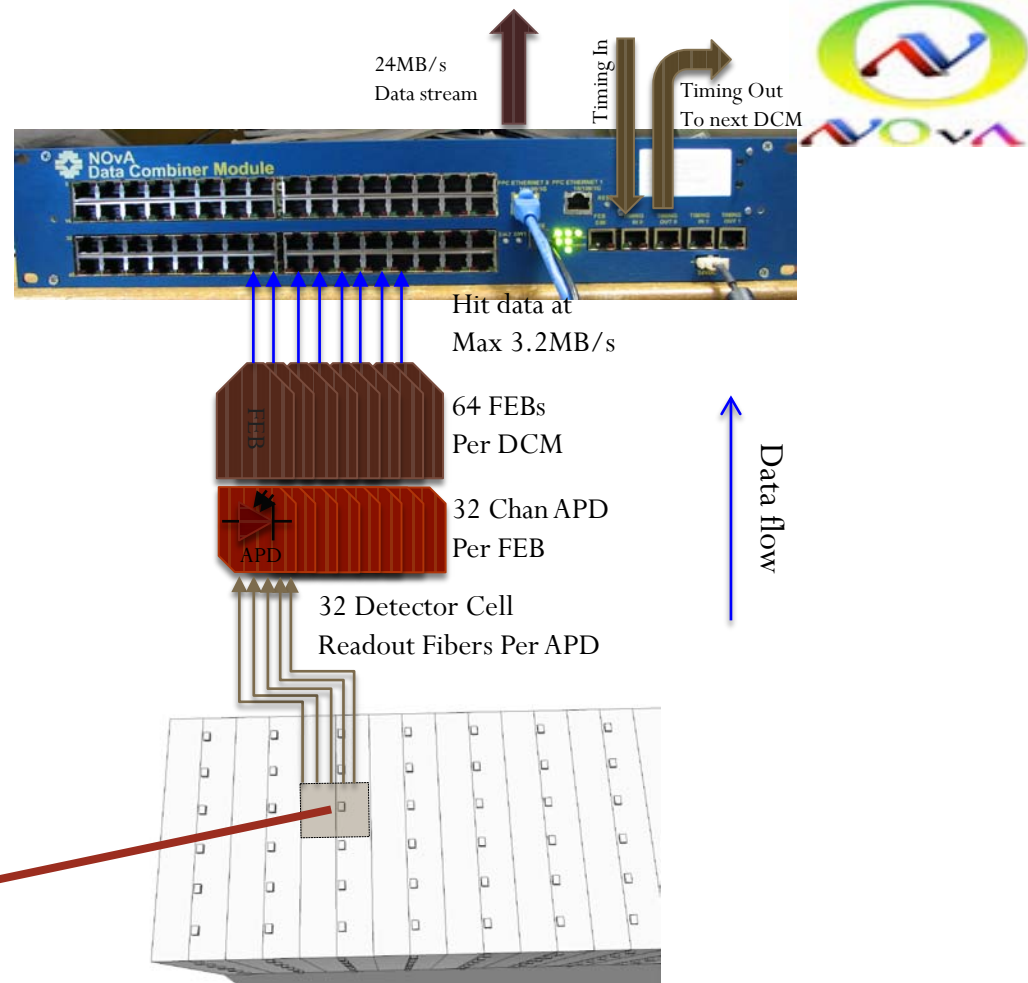
1 Diblock:

- 12 DCMs mounted on detector
- 6 per view
- Each DCM reads out a 2-module-wide slice

DAQ Cluster (Buffer Farm and Control Nodes)

- Ash River – Computing center in Detector building
- Fermilab – Lattice Computing Center

NOνA DAQ Architecture

10 gigabit Ethernet switch

Data Logger – Event Output
- Like Buffer Nodes, with
- 22 Terabyte of RAID array

DCM Readout
- PowerPC-based custom computers
- Read out 64 Front End Boards each
- Sends all hits over threshold to Buffer Nodes

Buffer Farm – Event Buffering and Building
- O(100) Commodity Linux nodes
- 16 cores, 2.66 GHz,
- 2 GB RAM/core
- < $1000 node
- Stores every hit above zero suppression threshold for more than 20 seconds
- Collates data from DCMs
- Sends triggered data to Data Logger

NOνA Trigger Architecture

Trigger Inputs
- Neutrino beam spills times
- Random/Periodic gates
- Data-driven triggers

10 gigabit Ethernet switch

Global Trigger

Data Logger
- Receives trigger as cross-check on data from Buffer Farm

Buffer Farm
- All Data touching trigger window is sent to Data Logger
- Data-driven trigger:
  - Desirable cosmic events
  - Neutrinos
  - Supernovae
  - Exotic signatures

Trigger Outputs
- $(T_0, T_0+\Delta T)$ trigger window
- Sent as software message to Buffer Farm and Data Logger
- No Hardware trigger in NOνA!

NOvA Timing System
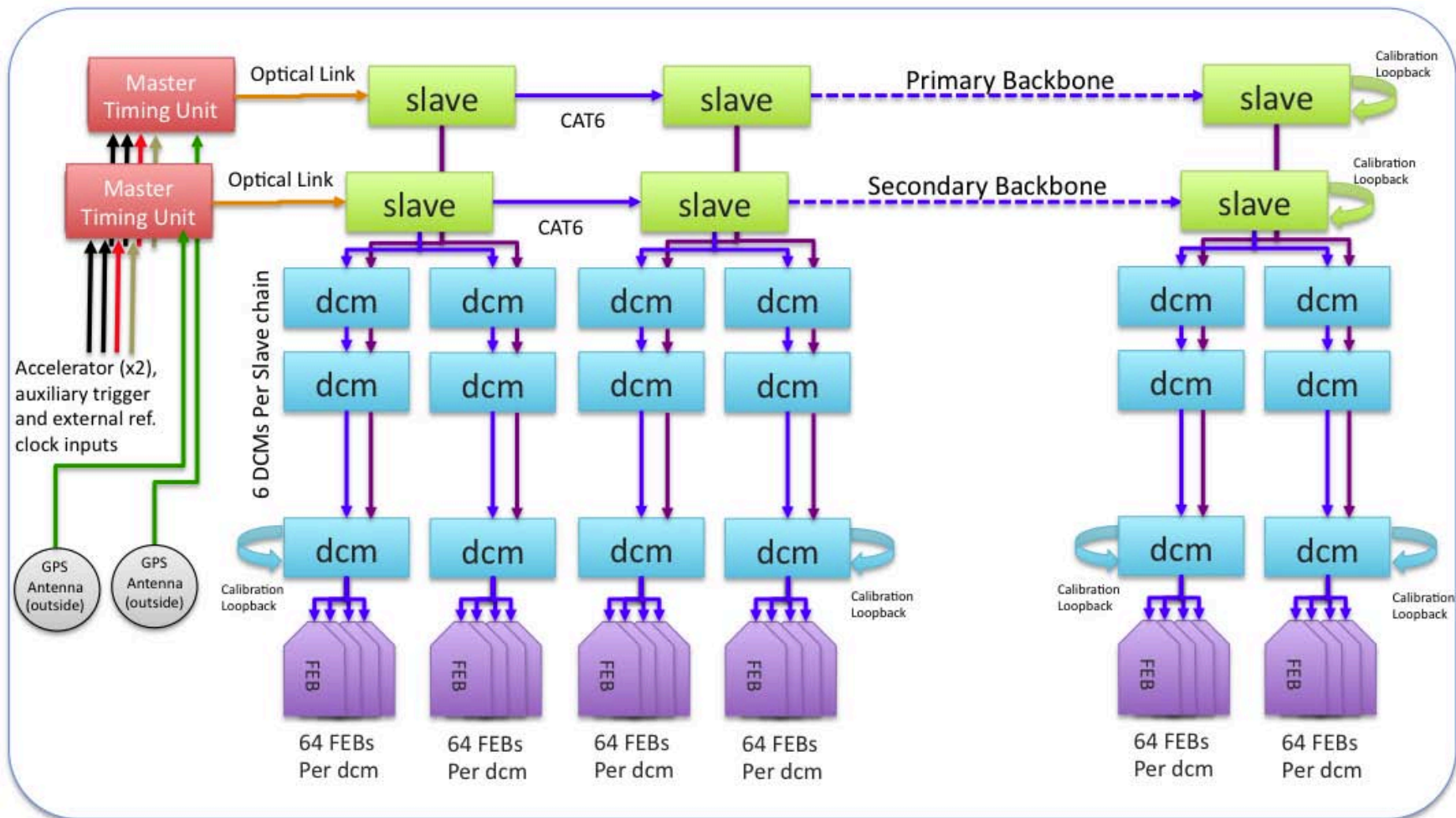
NOvA Clock:
- 64 MHz clock represented in 56 bits (24+32), covers 36+ year span with 15.625 ns ticks
- All FEB/DCM/TDUs are synchronized via GPS clock

DDT Design Overview

11520 FEBs
(368,4600 det. channels)

FEB   FEB
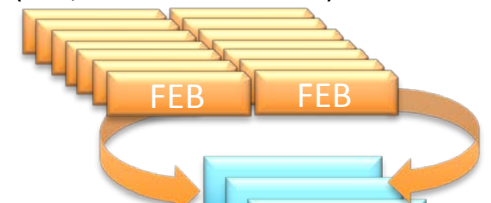
Zero Suppressed
at $\frac{1}{2} - \frac{2}{3} MIP$
(6-8MeV/cell)

DCMs

Minimum Bias
0.75GB/S Stream

COtS Ethernet 1Gb/s

Shared Memory
DDT event stack

Data
Buffer

5ms data
blocks

Data Driven Triggers System

Trigger Processor   Trigger Processor   ....   Trigger Processor

Event builder

Trigger Reception

Data Slice Pointer Table

Data Time Window Search

Data Driven
Trig. Decisions

Grand
Trigger OR

Triggered
Data Output

Data

Data

200 Buffer Nodes
(3200+ Compute Cores)

Buffer Nodes

Trigger Broadcast

Data Logger

Beam Spill Indicator
(Async from FNAL @ .5-.9Hz)

Calib. Pulser (50-91Hz)

Global Trigger Processor
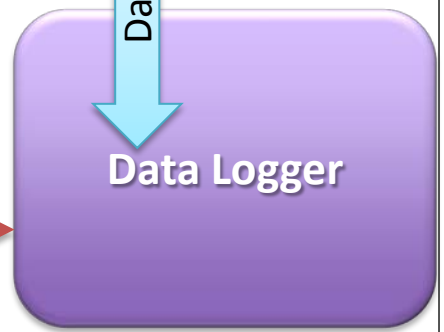
Data Concentrator Module

"Kernel module"
Serves FPGA data to CPU as device driver
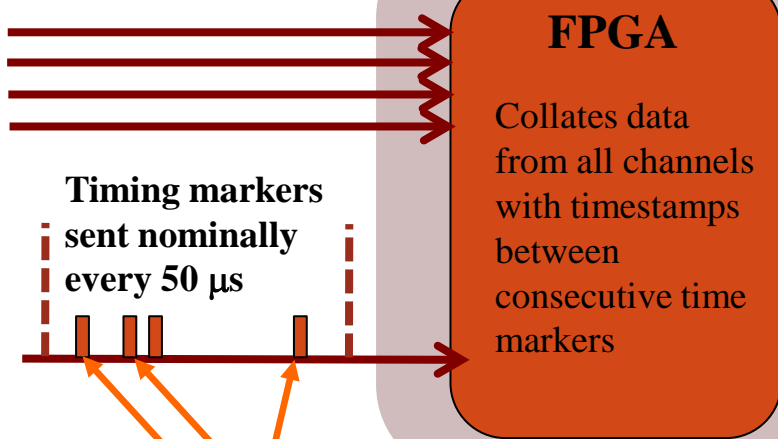
56-bit 64 MHz time marker
Roll over every 36+ years

64 FEBs / DCM

FPGA

Collates data from all channels with timestamps between consecutive time markers

CPU

Timing markers sent nominally every 50 μs

Microslice Header
Time Marker Low
Time Marker High
Nanoslice 0 FEB 0
Nanoslice 1 FEB 0
Nanoslice 0 FEB 2
Nanoslice 0 FEB 2
Nanoslice 0 FEB 3

Hit data: Nanoslice (500 ns)

Serial FEB-DCM link limit:
~ 15 hits/FEB/50 μs

31	29 28	26 25	21 20	16 15	9 8	3	2	1	0
DFT	SEQ	Version	Pixel Adr	FEB Status	FEB ID		DM	DP	LS

Nanoslice Header
Timestamp counter

	Pulse Height	Reserved

DCM Application
- DAQ system interface for control of DCM and FEB settings
- Monitors data quality
- Produces "Microslices" – data between consecutive time markers
- Builds Millislice for transfer to buffer node: collection of all Microslices within 5 ms

Buffer Nodes / Data Logger

Round-robin input

- All DCMs send to the same Buffer Node for a give 5ms period (sequence number)
- With 100 buffer nodes, this means a buffer node is used twice each second

MilliBlock

- 1st Millislice seen in a sequence causes creation of new Milliblock
- Complete when last DCM with sequence number is seen

Trigger data search:

- Create a DataBlock for output to DataLogger
- Check all MilliBlocks in buffer
- Does MilliBlock time overlap with trigger time? Check MicroBlocks:
- Copy all MicroBlocks touching Trigger Window into DataBlock

MilliBlock

Copy to shared memory for analysis by data-driven trigger

DataBlock

Pointer written to MillBlock pool for buffering
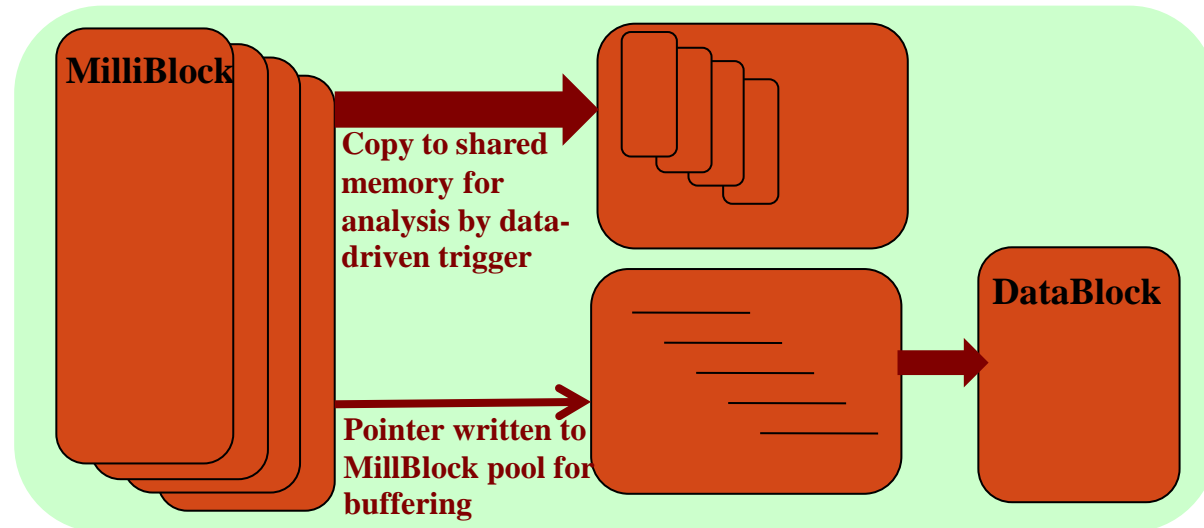
Event ("Data Atom" until complete)

- Receipt of Trigger or DataBlock with event no
- Header, Trigger Info, DataBlocks, Tail
- Complete when data received from Trigger and all Buffer Node**s**
- Note: The trigger, not the hit data, defines the event. The same data can appear in multiple events.

Output

- Send data to configurable set of streams (files on disk) based on trigger ID

Data Monitoring / Applications

Data Logger → Shared Memory Segment → Event Dispatcher

Data Logger Node:
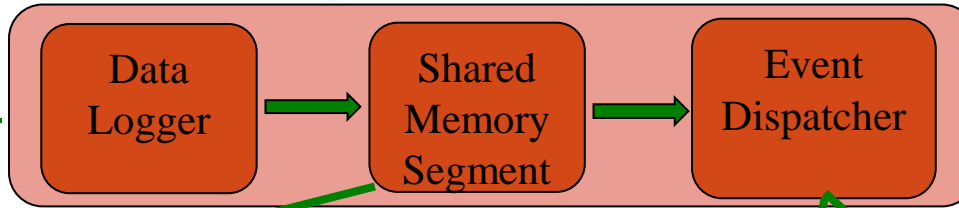
Event Dispatcher: servers data to monitoring applications
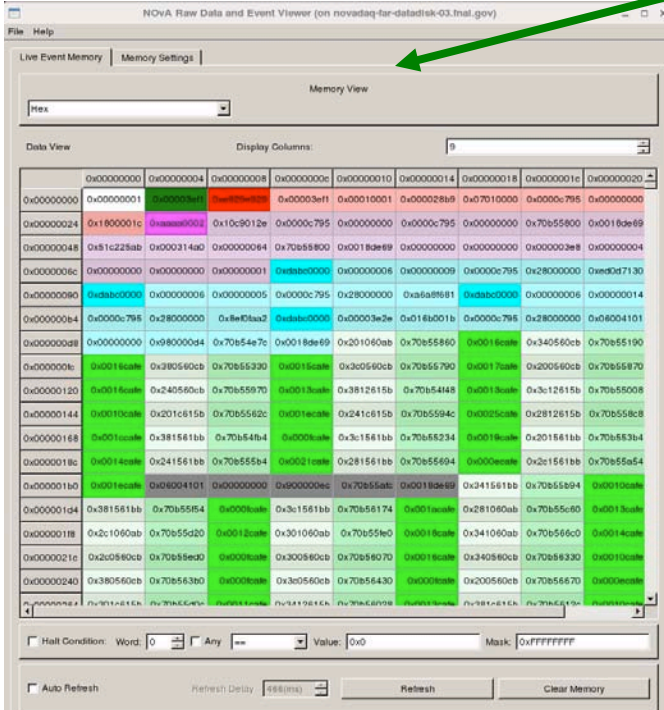
Online monitorig: histogram producer/viewer
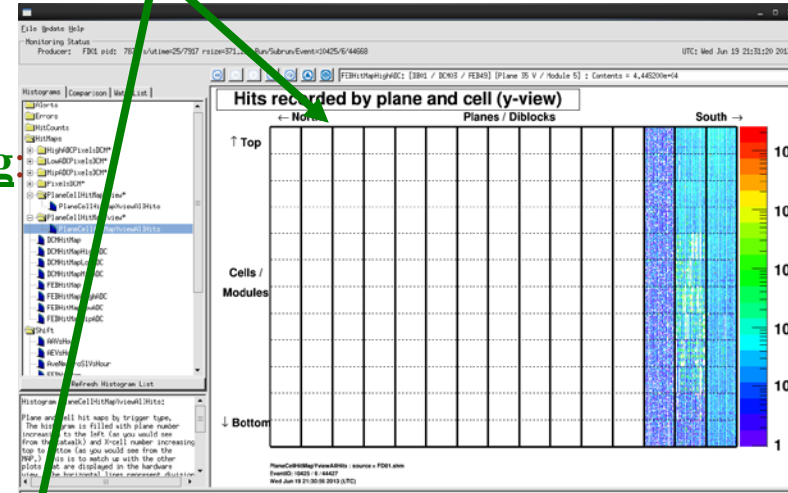
Event Display:
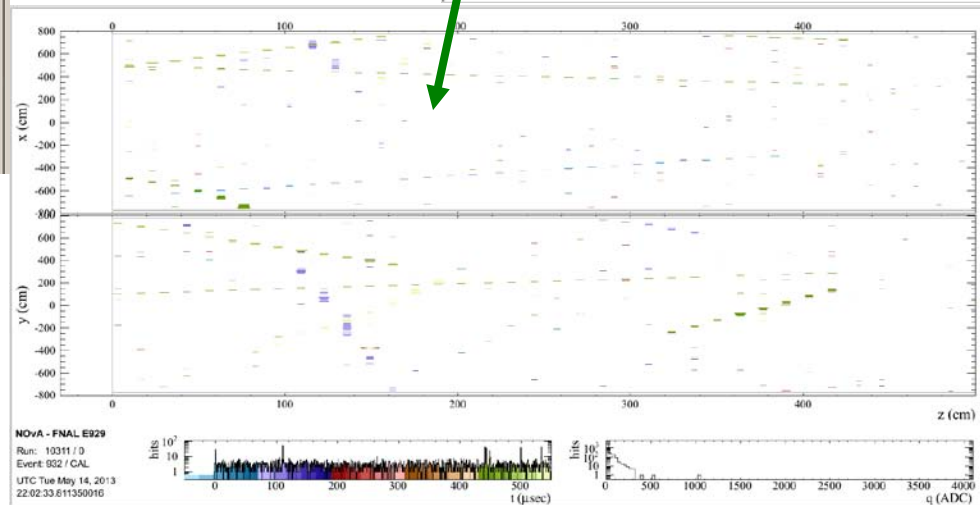
Memory Viewer:
- Displays raw data with highlighting to indicate data block type

DAQ Control & Monitor Systems

Database

Configuration

Run Control

Resource Management

DAQ Subsystem

Message Passing System DDS (open spliced)

Application Manager

DAQ Health Monitor

DAQ Subsystem

Message Logger
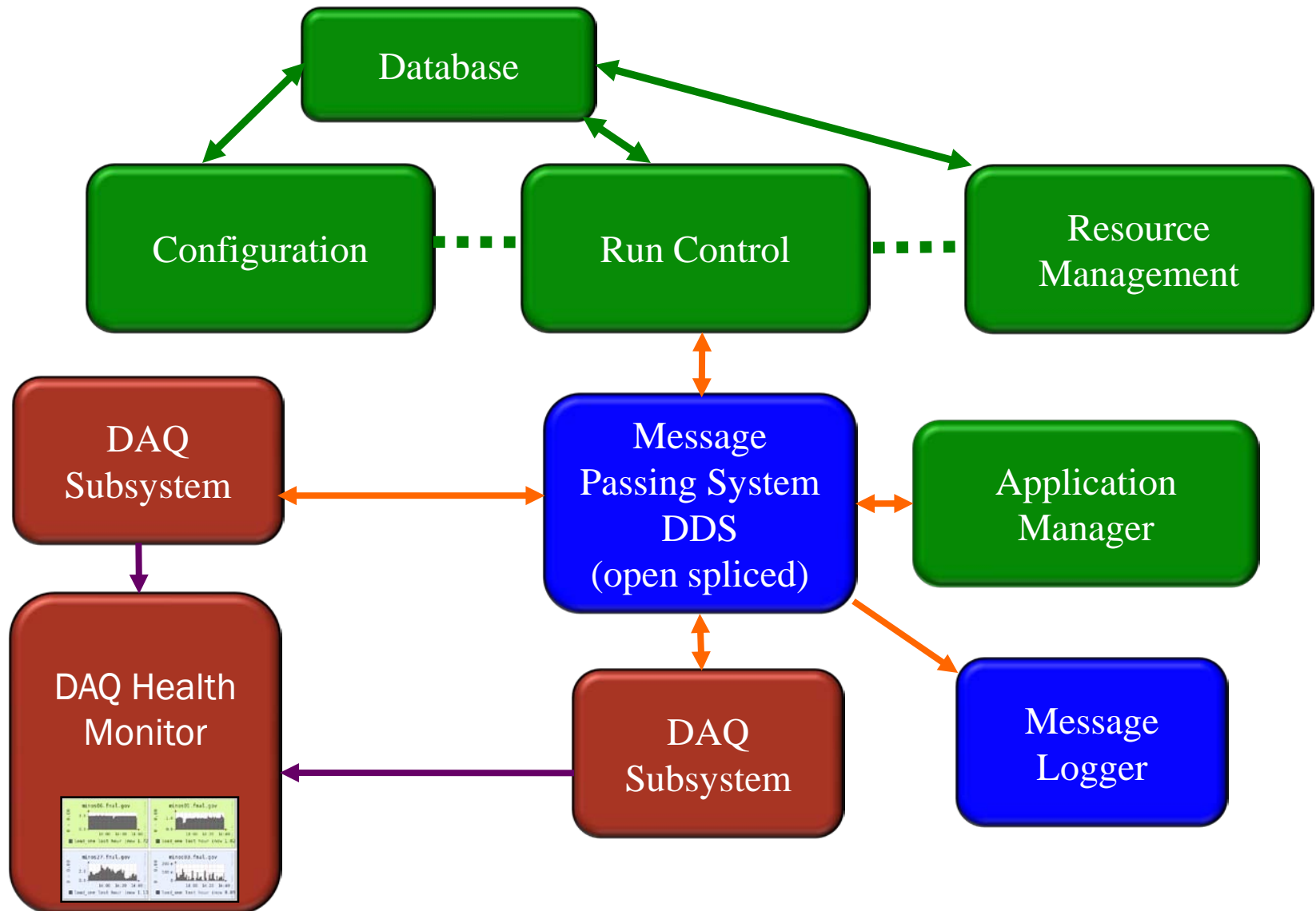
Summary

- ❑ **Far Detector commissioning is in progress and Near detector construction has begun.**

- ❑ **NOvA is achieving its DAQ design goals with a commodity online buffer farm and commodity network.**

- ❑ **We have built the foundation for a unique free-running DAQ system**

- ❑ **We understand how to perform continuous readout and buffering**

- ❑ **We have solved the problem of correlation and synchronization → see talk by Evan Niner**

- ❑ **We are exploring the power and opportunities of Data Driven Triggering → see poster by Zukai Wang**

BackUp

Resource Management

Resource Manager

- Keeps track of which resources are in use
- Resource ~ a DCM or other node

Partition

- A totally independent DAQ system
- One partition can be used for taking physics data on an established part of the detector, while another is used for checkout and commissioning

Run Control

- User selects resources for partition via Run Control
- Once applications are started, Run Control is used to execute configuration steps, and start/stop run

Application Management
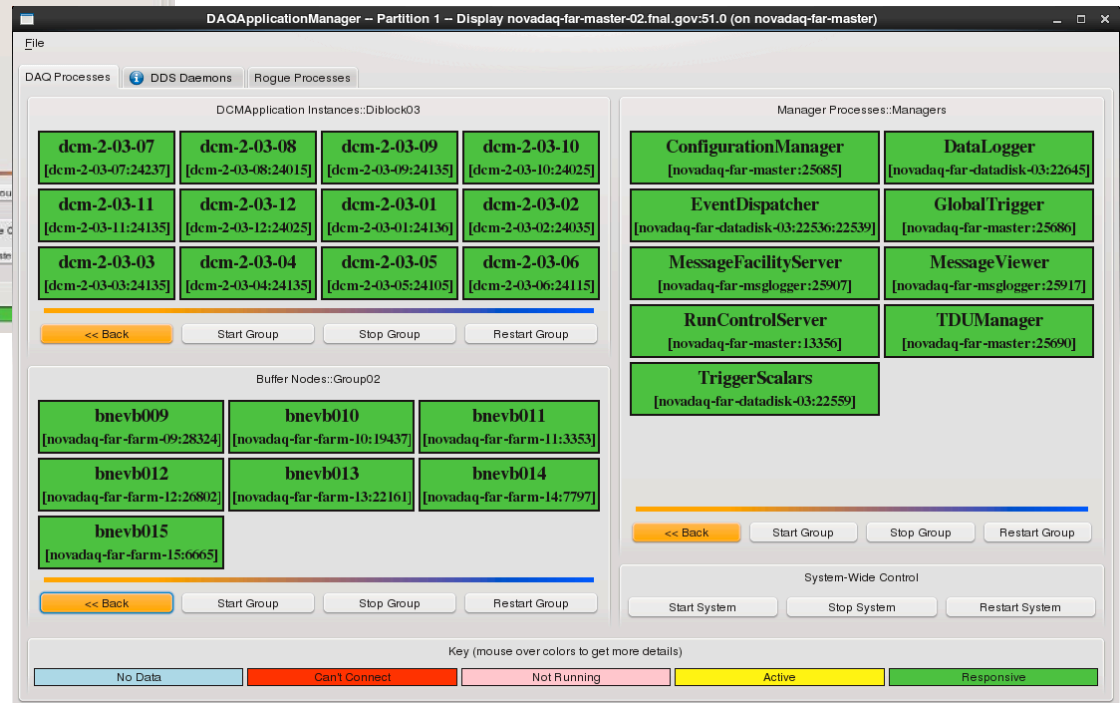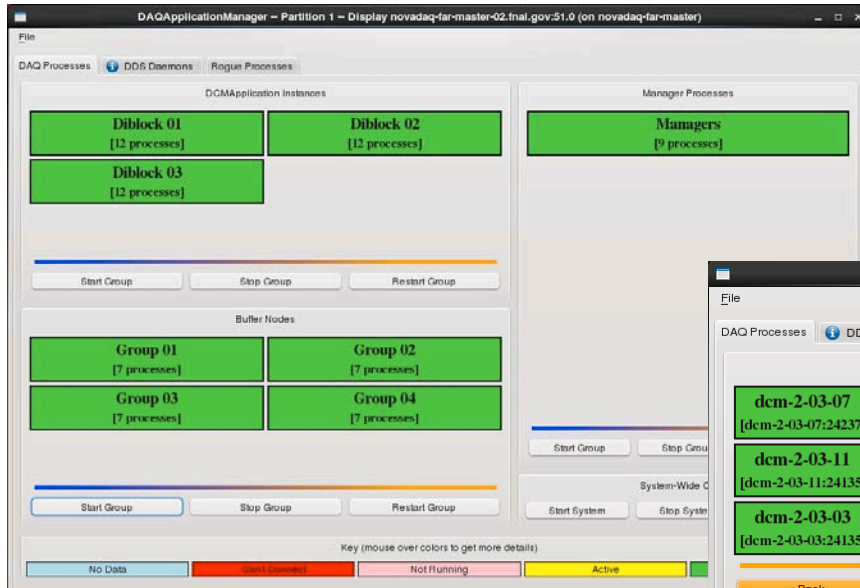
Application Manager:
- starts/stops/monitors applications and Message Service Daemons

Message Facility

Message Facility – Log Messages:
- Used in offline ART framework
- For Online, has Server destination using DDS backbone
- Message rate throttling is run-time-configurable

Message Analyzer:
- Configured to recognize patterns of errors, e.g., many DCMs complain about the same buffer node
- Integration to Automatic Error Recovery actions

NOνA DAQ Monitoring

Ganglia:
- Widely-used open-source cluster monitoring package
- Daemon on each host sends to central server
- Web-based display of plots of metrics vs. time for "Grid", "Cluster", and nodes
- Default metrics: CPU use, free memory, etc.
- Extensible to custom metrics

Nova DAQ Monitor
- System for generating warnings and alarms when metrics vary outside configured limits