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Performance of the NOνA Data Acquisition and Data Driven Trigger Systems for the full 14 kT Far Detector

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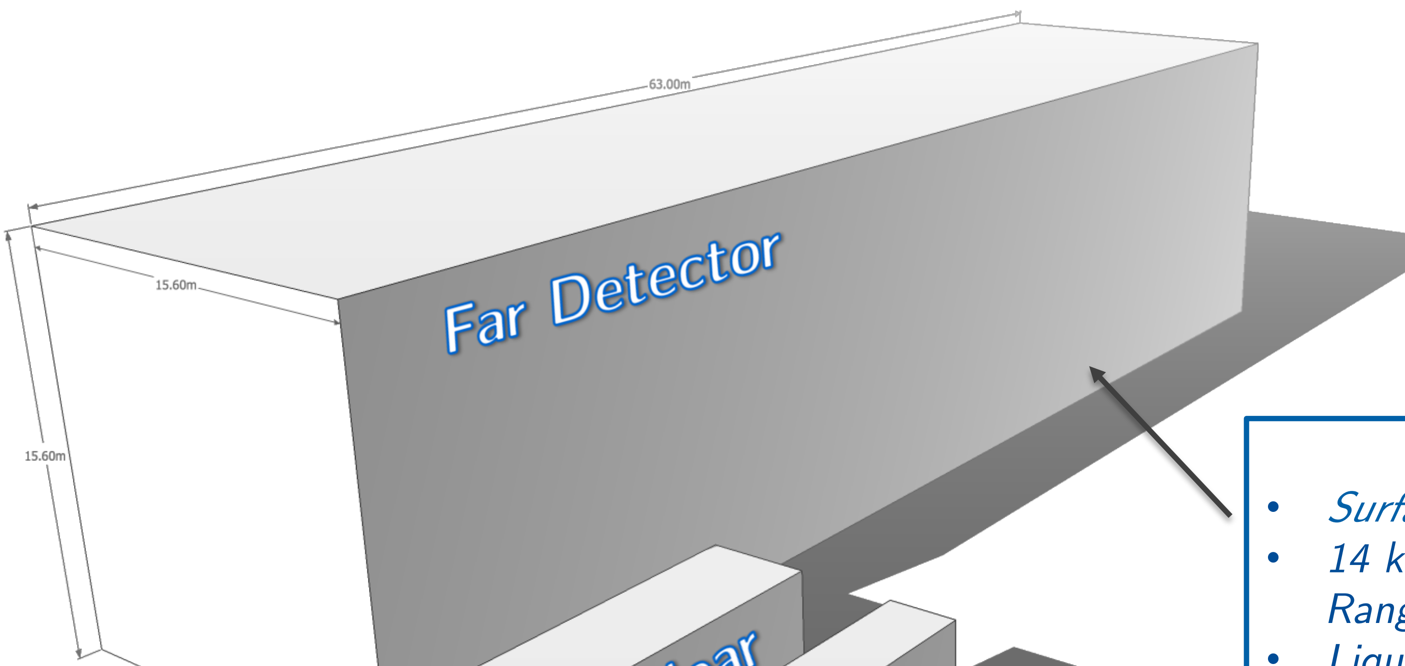
for the NOνA collaboration

NOvA Detectors



Near Detector

Underground Detector
Identical to far detector
Optimized for NuMI cavern rates
-- 4x sampling rate electronics
Completed April 2014

Far Detector

- *Surface Detector*
- *14 kt "Totally Active", Low Z, Range Stack/Calorimeter*
- *Liquid Scintillator filled PVC*
- *896 alternating X-Y planes*
- *Optimized for EM shower reconstruction & muon tracking, $X_0 \approx 40cm$, $R_m \approx 11cm$*
- *Dims: 53x53x180 ft*
- *"Largest Plastic Structure built by man"*
- *Started Operations May 2013*
- *First Beam Aug 2013*
- *Completed April 2014*

Introduction

NOνA is a unique challenge for Trigger & DAQ

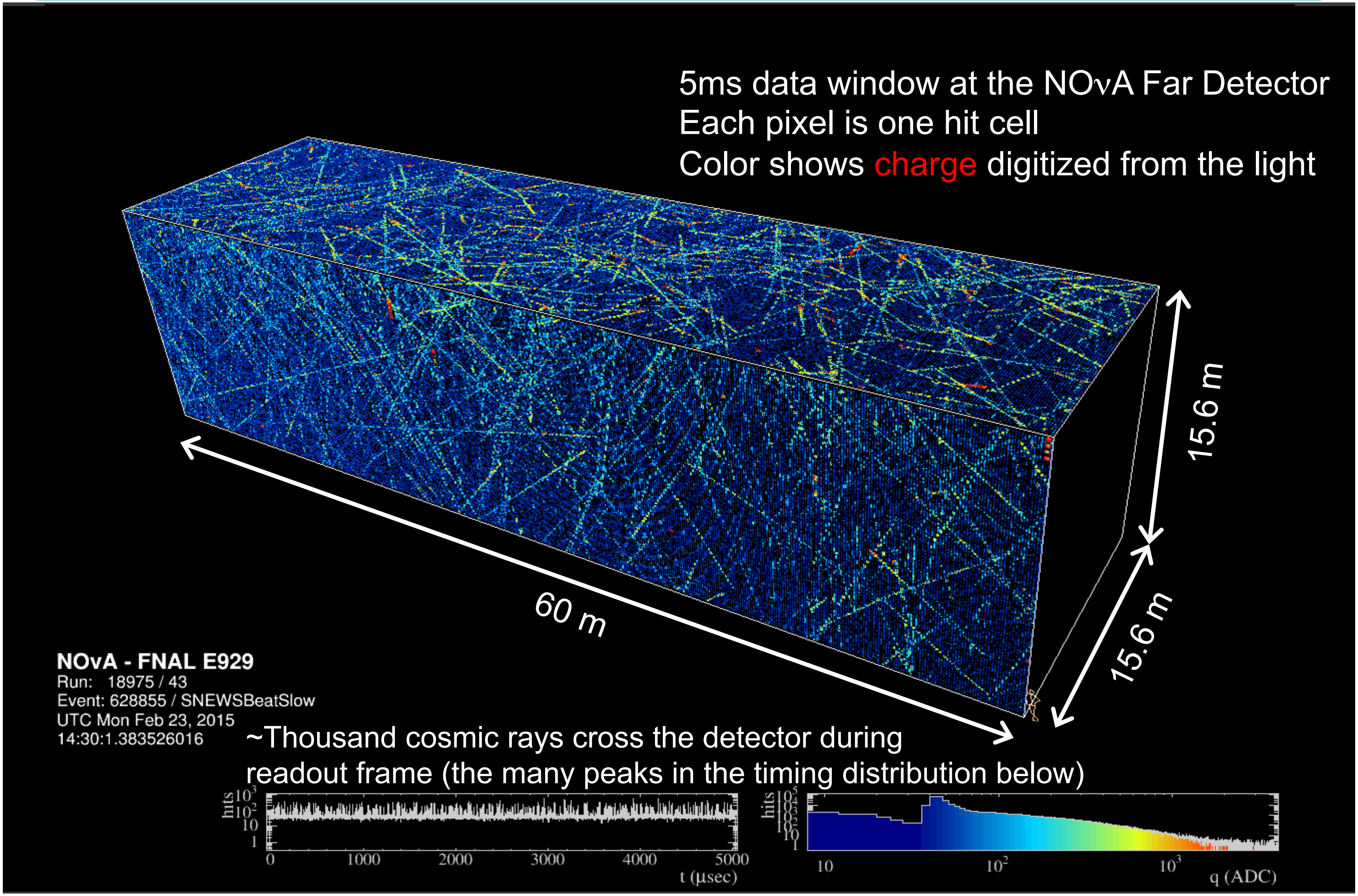
At one level it's very simple

- There is only one detector technology

But…

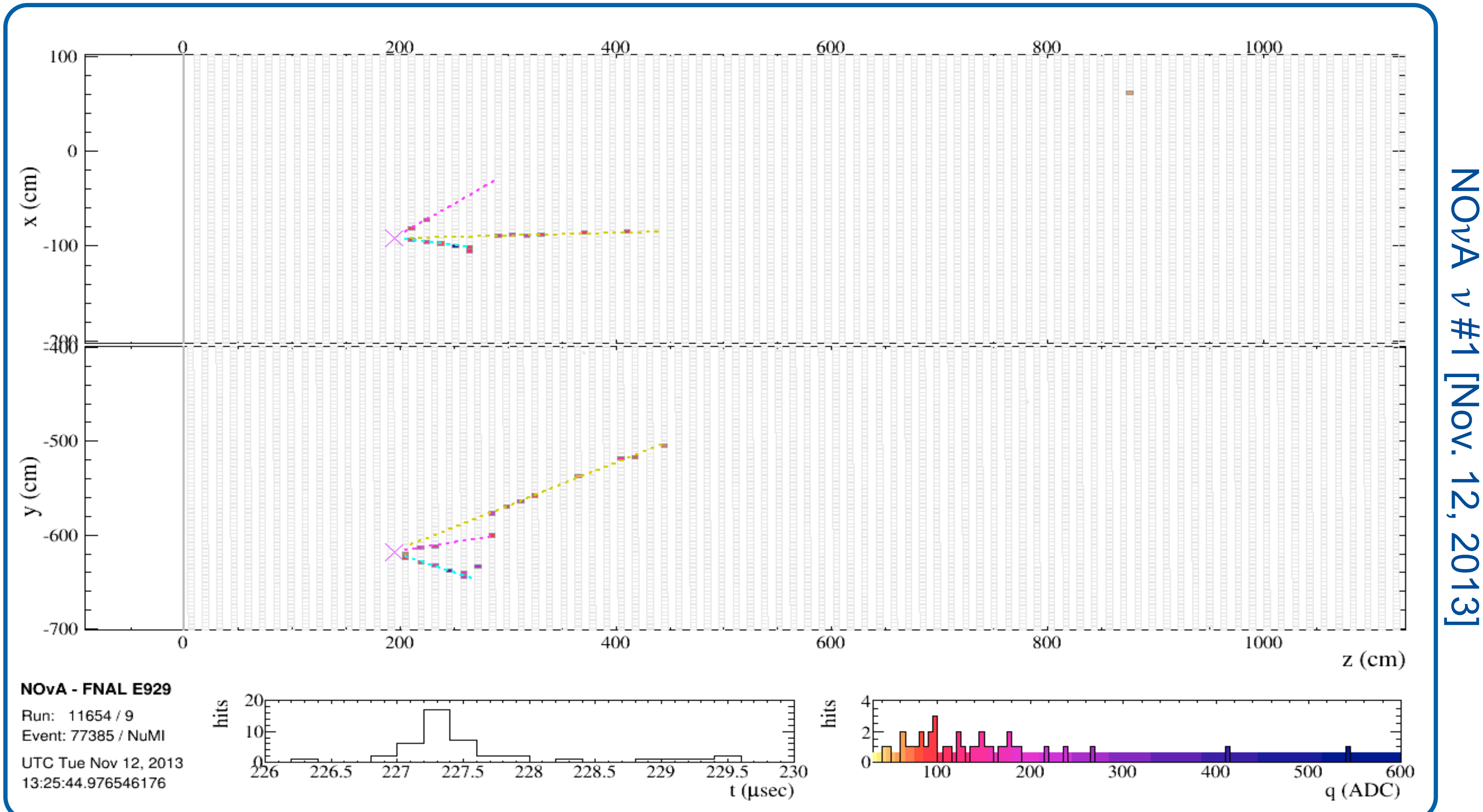
- That element is repeated 344064 times
- All of these are precisely synchronized to each other and to their counter parts 810 km away
- Elements are ALL in free running continuous waveform readout
- 180 kHz of cosmic rays are constantly lighting up the detector

Job of the trigger is to examine….

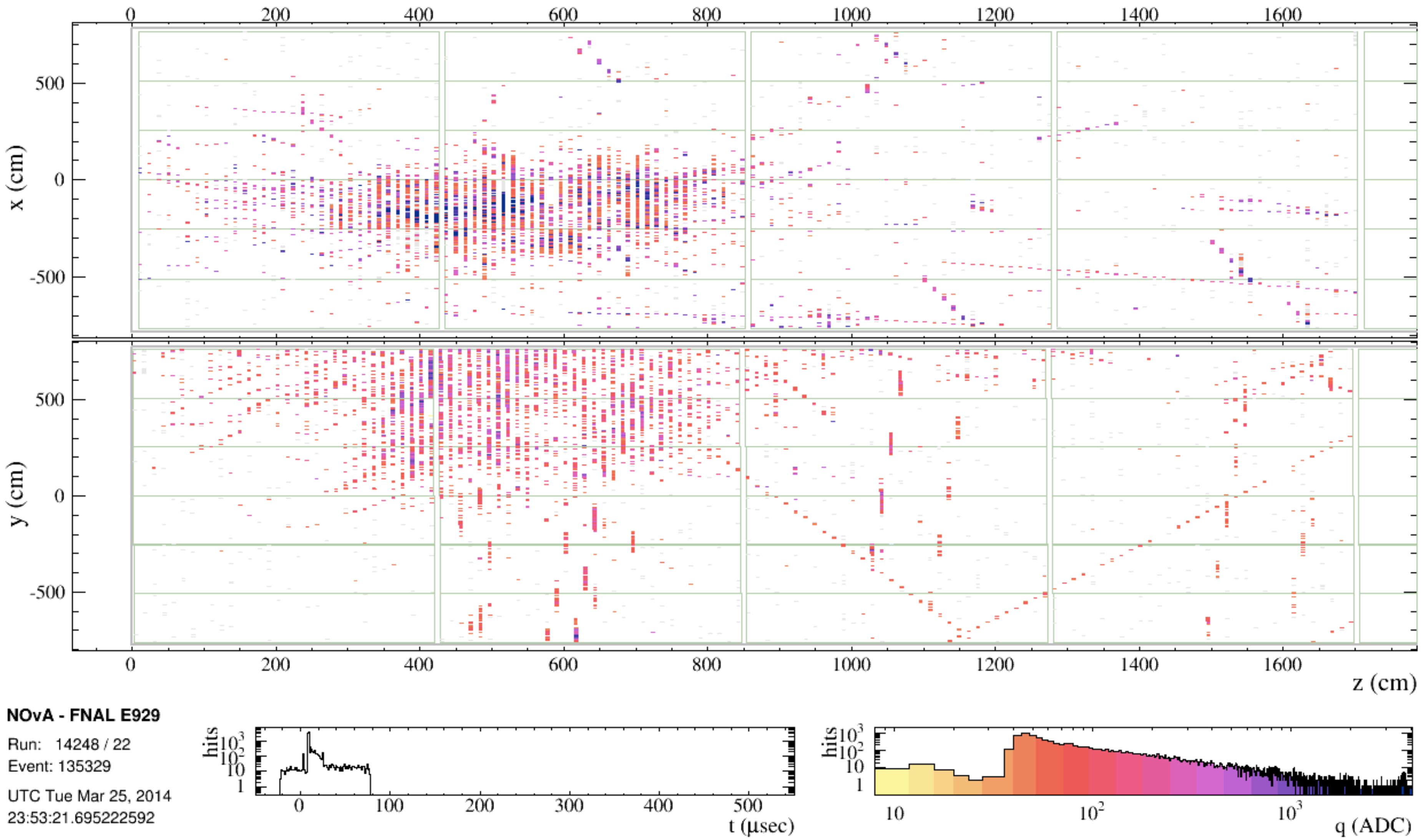


Trigger

- To find ultra rare topologies like this:



Or this….



x (cm)
y (cm)
z (cm)
NOvA - FNAL E929
Run: 14248 / 22
Event: 135329
UTC Tue Mar 25, 2014
23:53:21.695222592
hits
t (µsec)
q (ADC)

DAQ/Trigger Configuration 2014-2015

- Fully instrumented/operational 14 kt far detector

  344,064 detection cells, 10,752 front end board,
  168 data concentrators, 45 data buffer/L3 trigger nodes, 5 data logging/ arrays, 30 timing distributions units, 4 GPS clock systems

Top view of completed NOνA far detector

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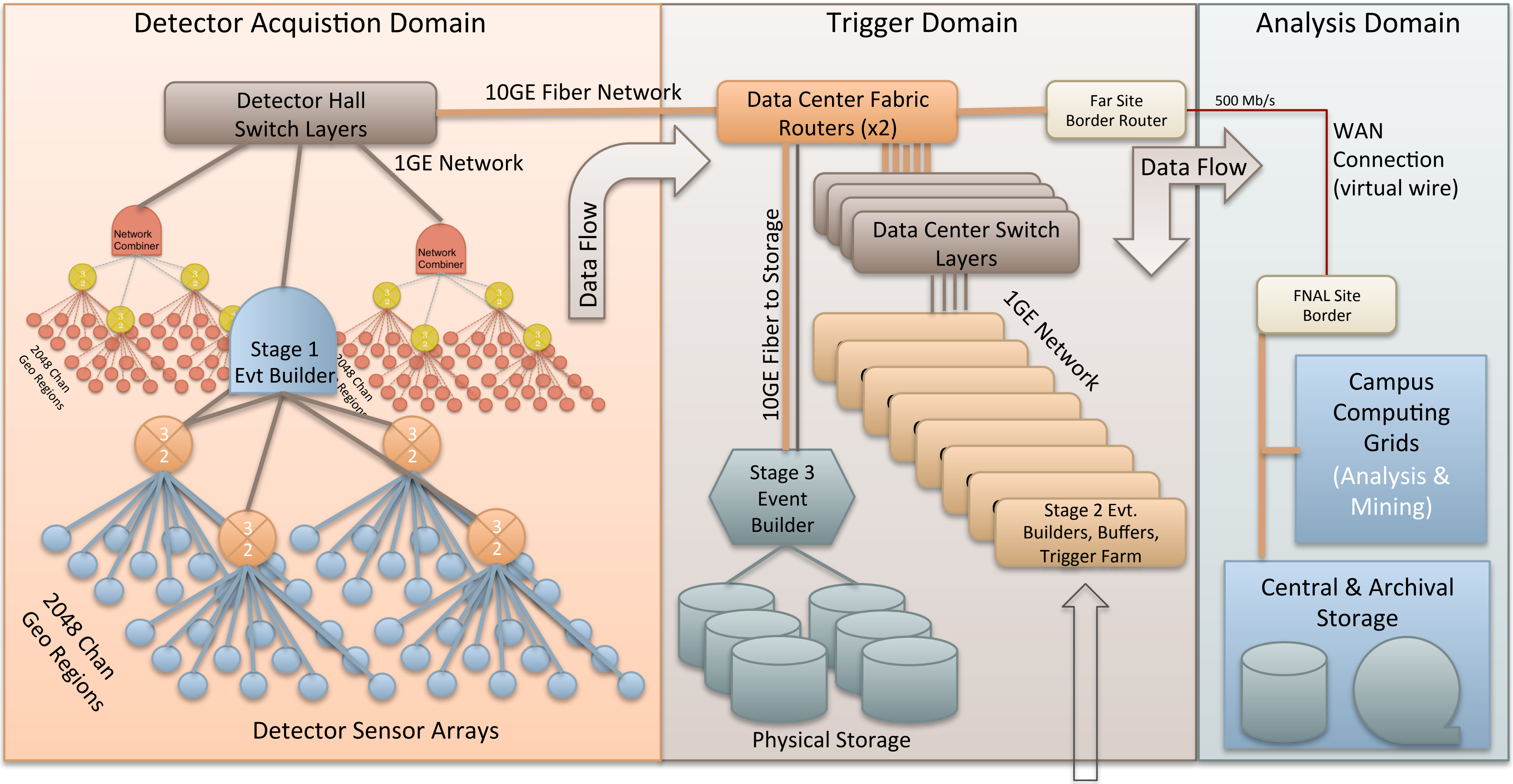
  arrays, 30 timing distributions units, 4 GPS clock systems

Front End Boards & Data Concentrators
(Stage 1 Event Builders) mounted directly
on the detector

Top view of completed NOνA far detector

NOνA DAQ & Trigger Topology



Continuous Flood of data into Trigger & Buffer Farm at peak of ~4.2 GB/s corresponding to 100% total live readout

Readout Data Structure

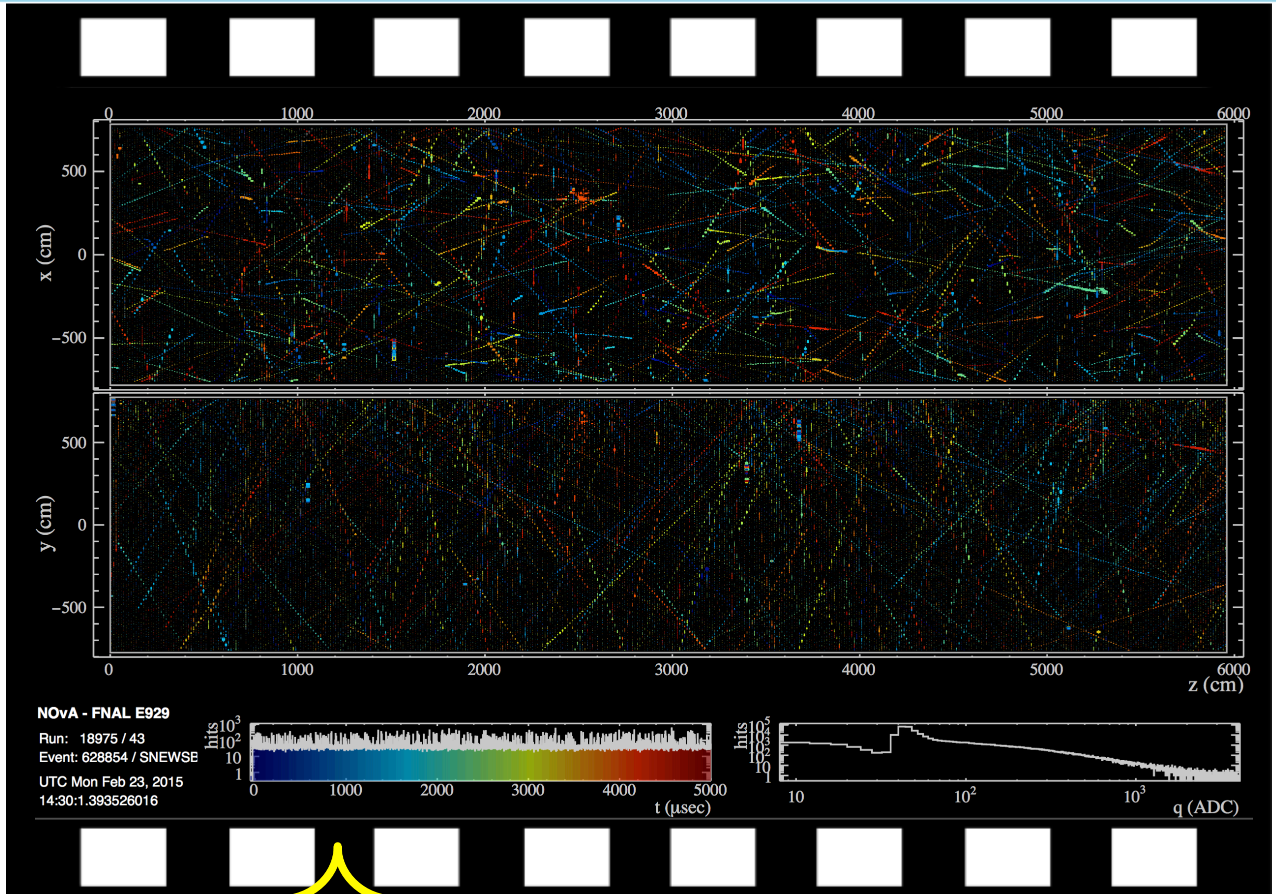
Data Readout is continuous series of 5ms readout frames

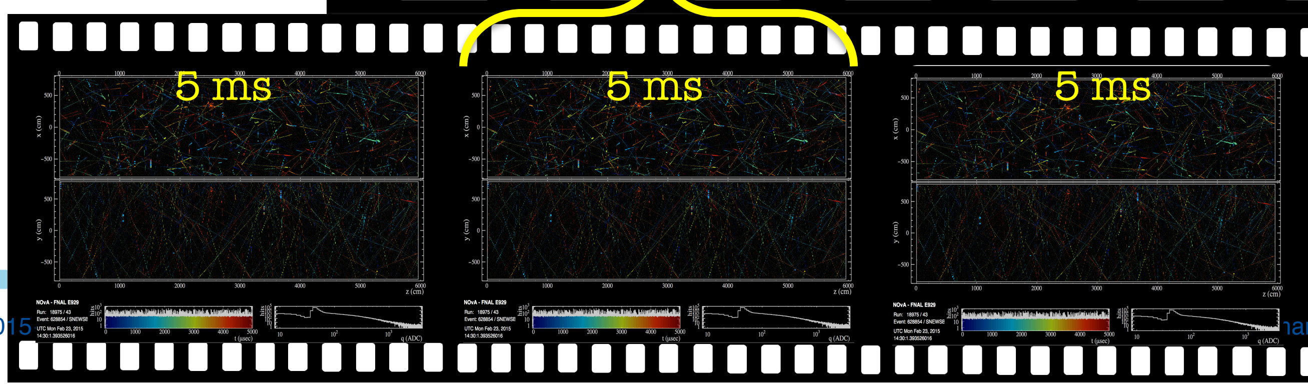
"Movie of the Detector"

Minimal data suppression
(~6 MeV single hit threshold)

There are no gaps between frames

Each frame is routed to a separate buffer/trigger nodes for processing

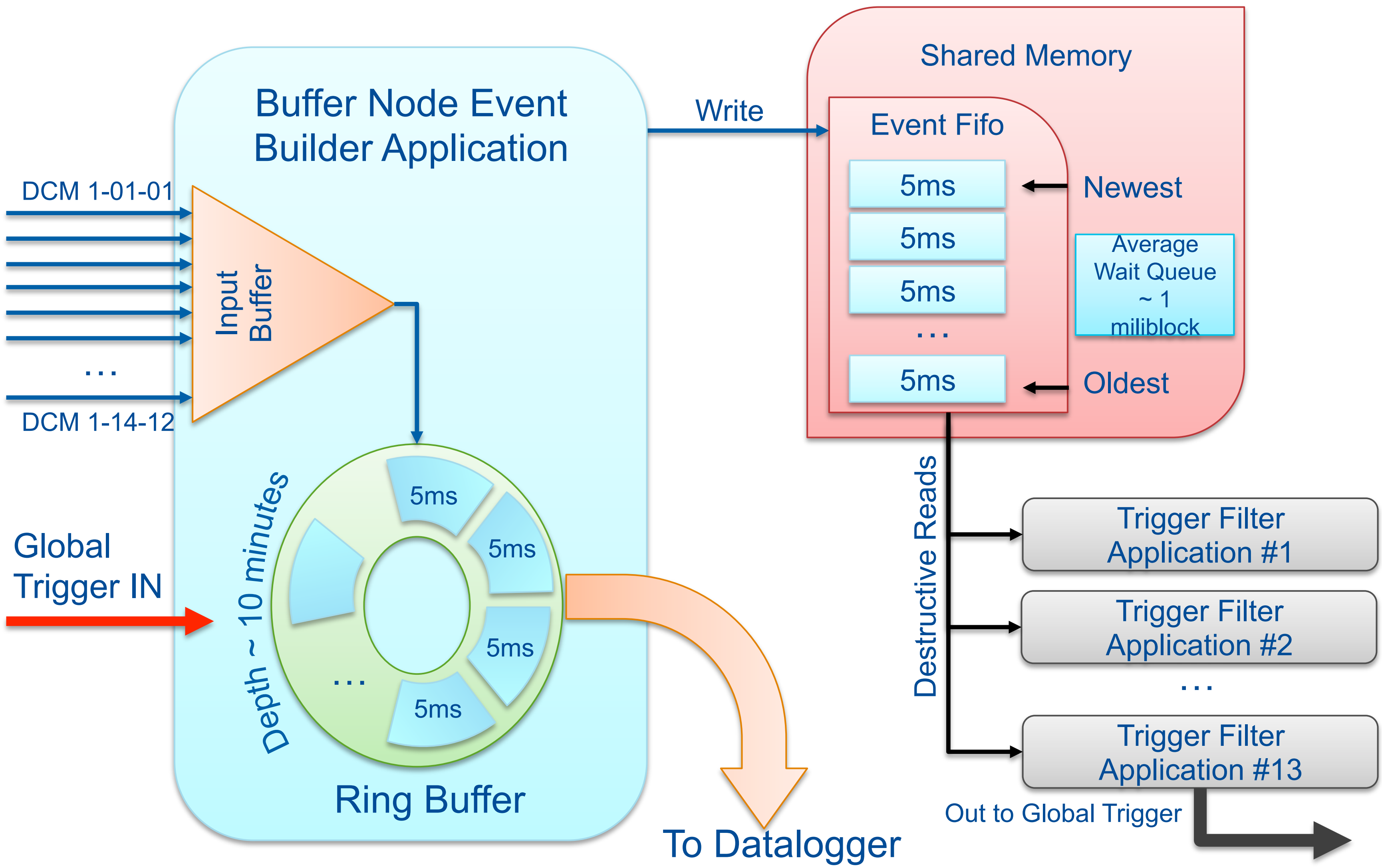




EventBuilder/Buffer to Data Driven Trigger Interface

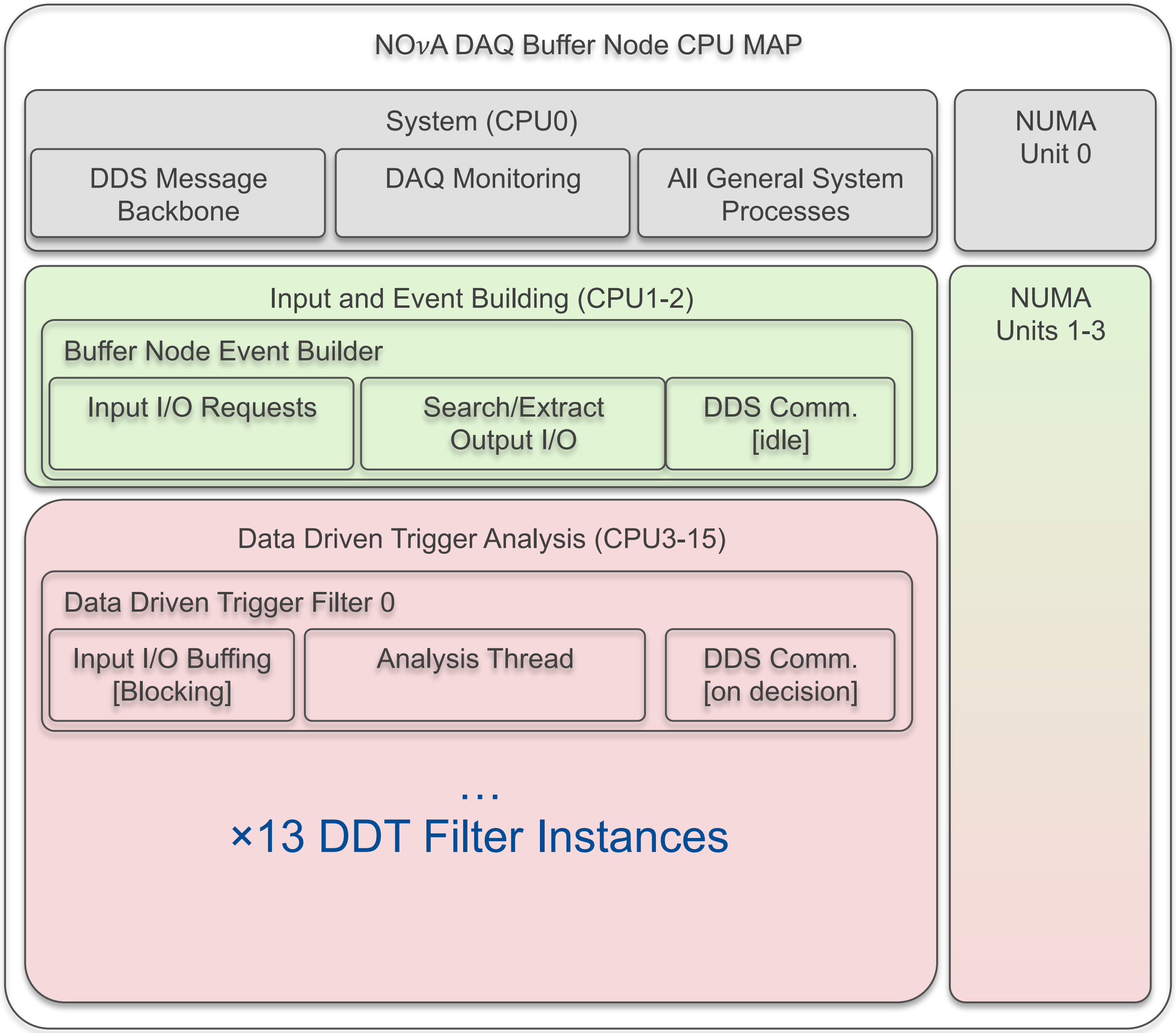
- Primary event builders assemble 5ms snap shots of full detector
  - 5 ms Data blocks need to be passed to software trigger chain
  - Desire for isolation between DAQ and Trigger
    - e.g. bad trigger algorithm should not affect event building
- Use Sys V IPC shared memory as isolation layer
- Single writer, multiple reader design
  - Implemented as circular buffer for writer
  - Presented as fixed length fifo w/ destructive read for readers

Buffer Node to Data Driven Trigger Interface



CPU Resource Mapping and Affinity

- 16 CPU cores on each buffer node are task assigned based on a shield/set model
- Three affinity sets:
  System, DAQ, Trigger
- Enforce resource allocations
- Impose subsystem separation
- Balances I/O, Proc and Comm. loads
- Operational Loads: [Idle, 6-8%, 99%]



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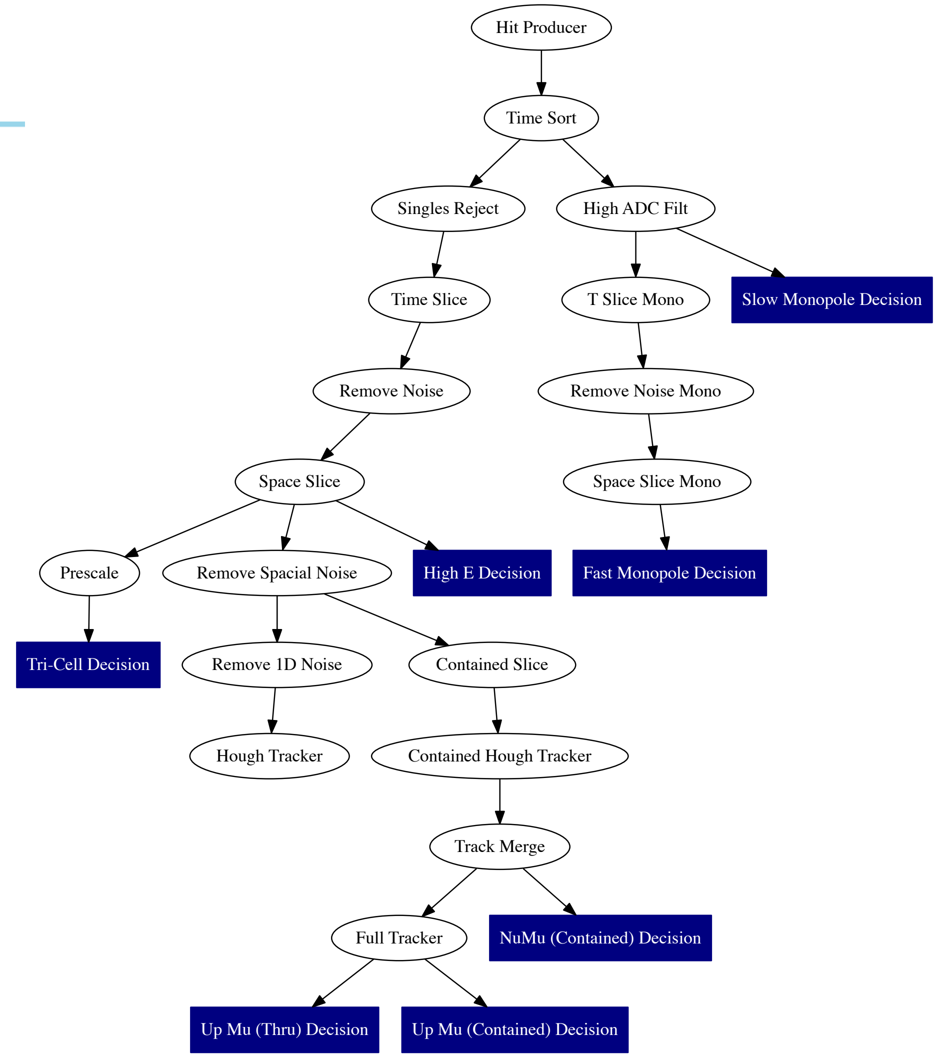
Cascading Trigger Algorithms

- Trigger is designed to take advantage of modularity
  - Each trigger is a series of "paths" through different common algorithm modules
- Builds complex triggers from smaller units of work
- Paths are conditionally cascaded to run each module at most <u>once</u>
  - Entire branches can be aborted
- Each final decision is independent,
  - Out of order and minimized time to decision for each trigger path

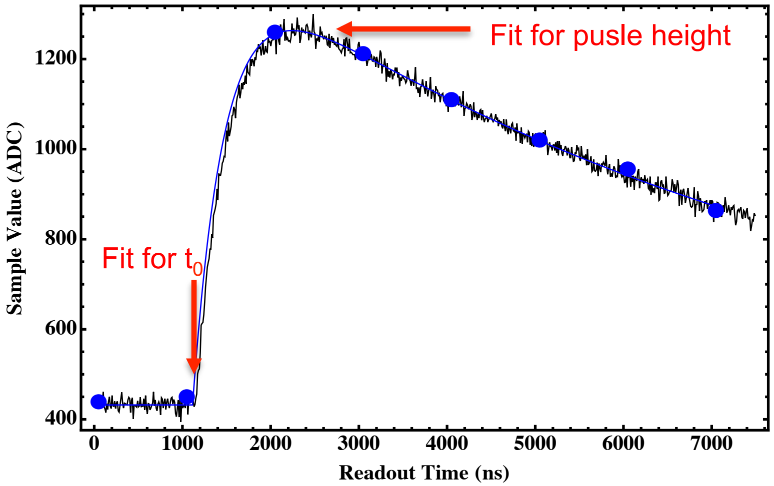


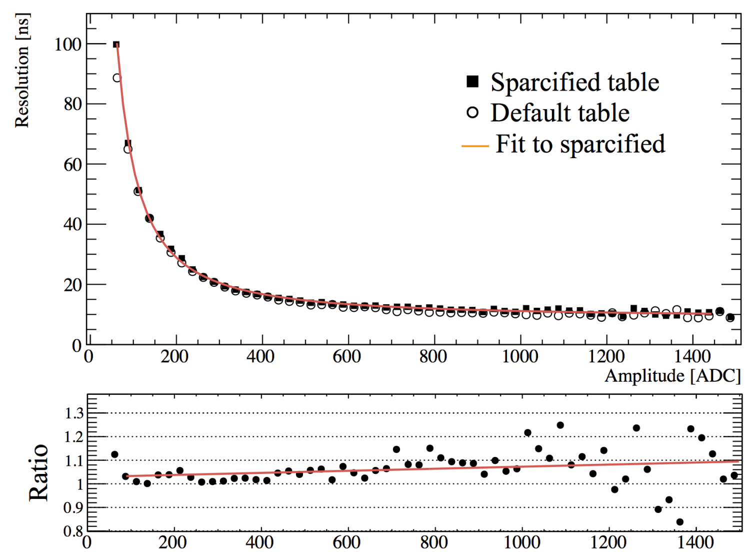
Cascade of trigger/reconstruction modules for upward going muon, magnetic monopoles, calibration and high energy deposition triggers. Trigger decision points shown in blue

Trigger Timing Resolution

- NOνA Front End boards now run in multi-point "waveform readout"
  - Spare sampling of APD input
- Fit for t_0 performed at data unpack for trigger over full dynamic range
  - Improves timing resolution by 7x over raw readout
  - Uses 12 bit (Int) → 9 bit (FP) encoding and lookup table scheme
  - Shared 44 MB lookup table covers > 68 B fit solutions at < 1.2% induced error on t_0
  - 15% impact on data unpack
- Single channel time resolution ~10 ns
- Make possible high resolution timing on track fits → Upward going μ detection

NOνA multi-point readout scheme





Trigger Time to Decision

Time to decision for each 5 ms data block is driven by the total number of buffer nodes N_{Buff} that are used in a round robin pattern and the number of filters per node M_{filt} that are analyzing the data

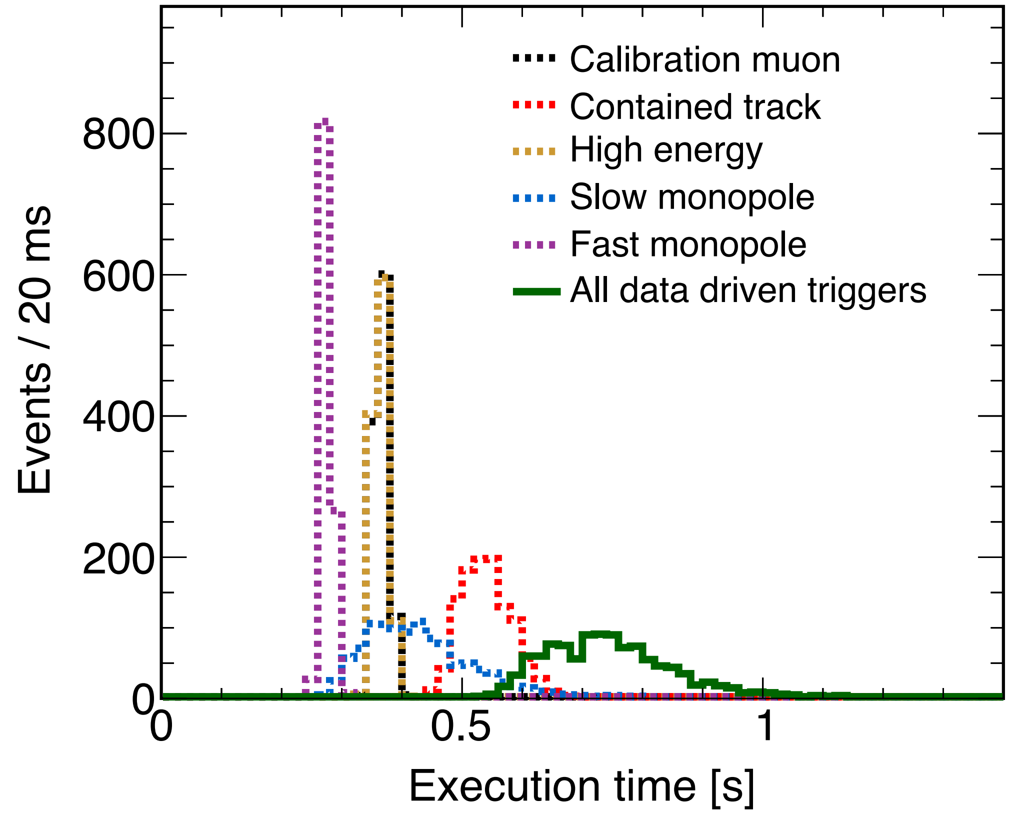
$$\langle \Delta t_{dec} \rangle = N_{buff} M_{filt} * 5 \text{ ms}$$

Current configuration runs:

- 45 buffer nodes
- 13 filters per node

$$\langle \Delta t_{dec} \rangle = 2.925 \ s$$

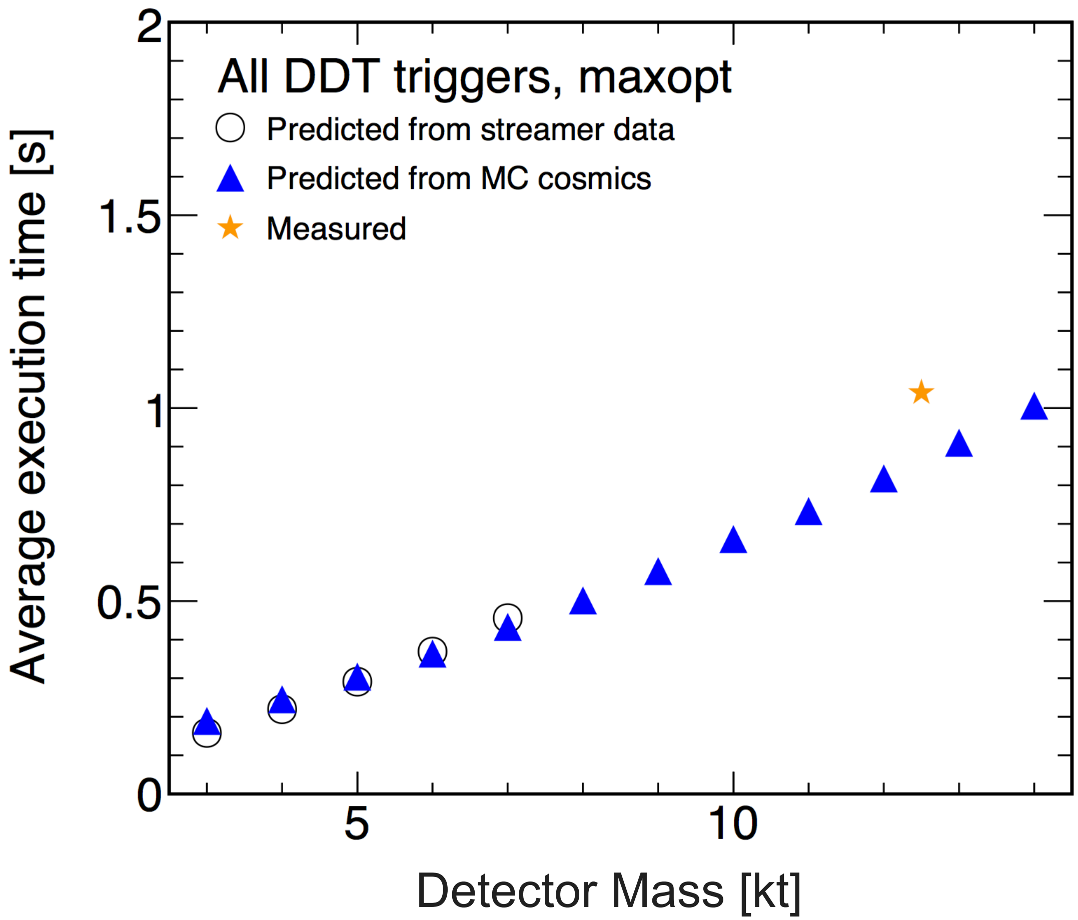
NOνA Preliminary



NOνA trigger execution time for leading trigger processes. Total average time to decision < 1 s.

Trigger Time to Decision

- Trigger is fully integrated with offline analysis framework
- Allows complete characterization of new triggers performance
- Use combination of Zero bias readout data & Monte Carlo simulation to determine scaling prior to new trigger deployment



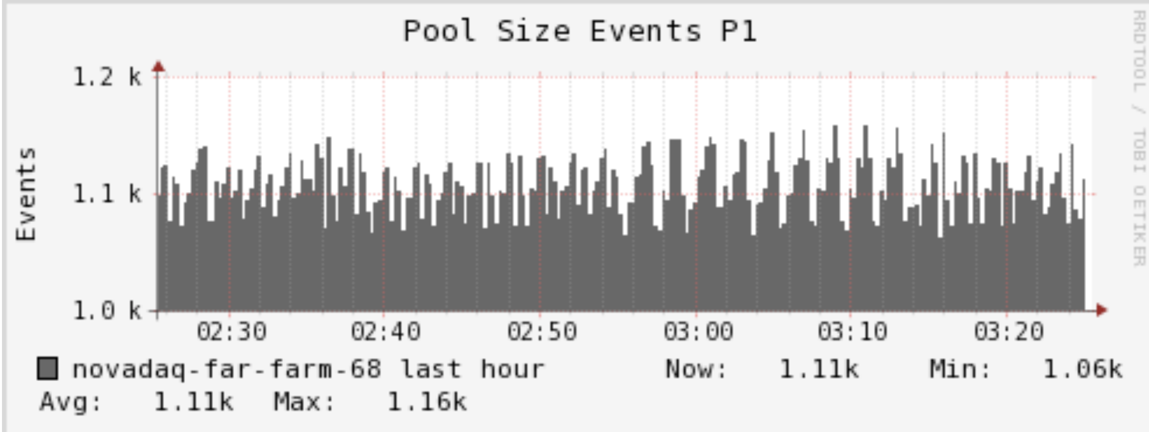
Scaling of trigger decision time with detector readout mass. Triggers are characterized based on zero bias readout of current detector configuration

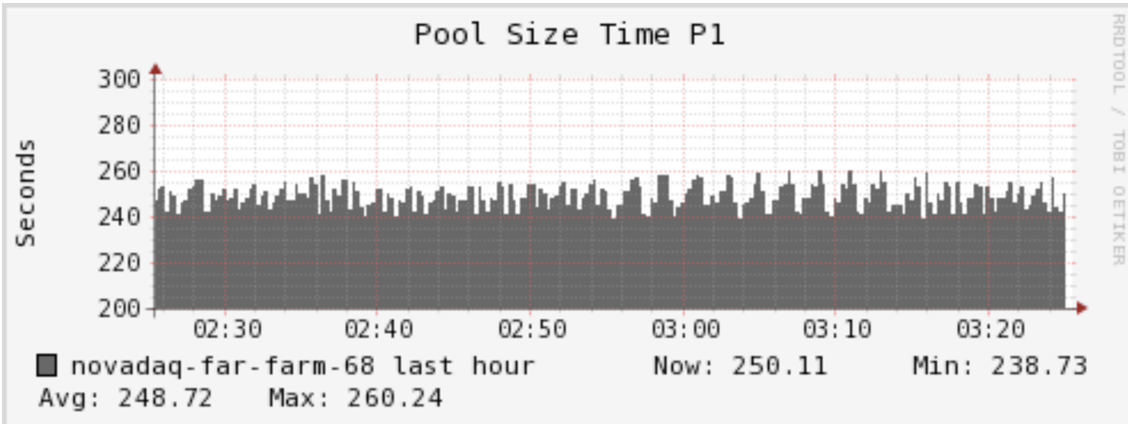
Maximum Time to Decision

Maximum time to decision is based on the total data volume buffered across the DAQ farm.

Each buffer nodes is configured with a 5 GB memory segment dedicated to live data storage.

- Each buffer holds ≈ 5.5 s of full detector data
- Aggregated ≈ 4 min look back





Look back buffer is aggregated across buffer node pool. Gives a maximum 240 s of latency to trigger decisions

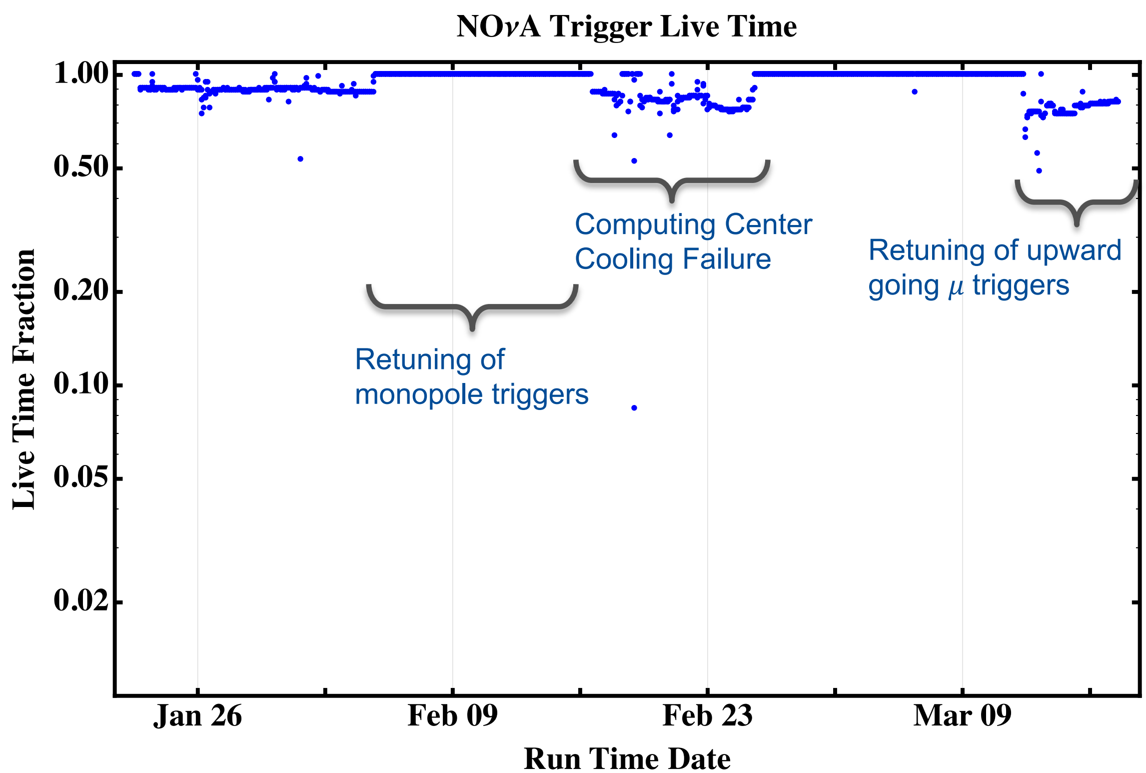
Trigger Live Time

DAQ Readout is 100% live in streaming mode

Trigger operates on the stream with live time determined from the number of dropped 5 ms data frames which are NOT examined by the trigger

Total trigger live time is balanced against physics sensitivity for current trigger suite

Average live time > 0.9



NOνA trigger live time corresponds to the absolute wall time that the trigger was able to process to decision across all paths.

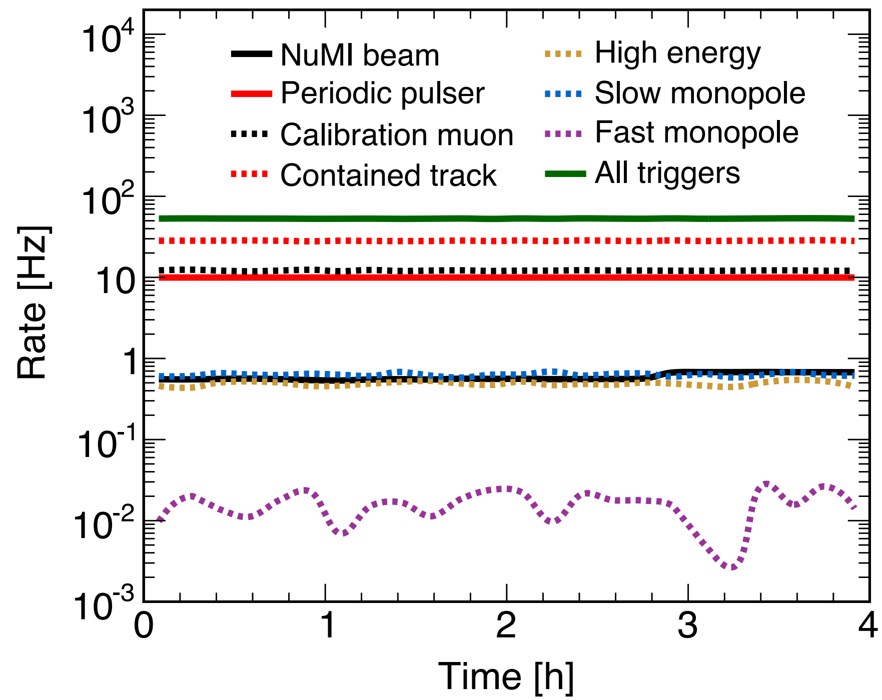
NOνA Global Trigger Design

- Global Trigger aggregations multiple trigger sources through prioritized queue structure

- Permits independent trigger and trigger group based
  - Prioritization
  - Prescaling
  - Throttling

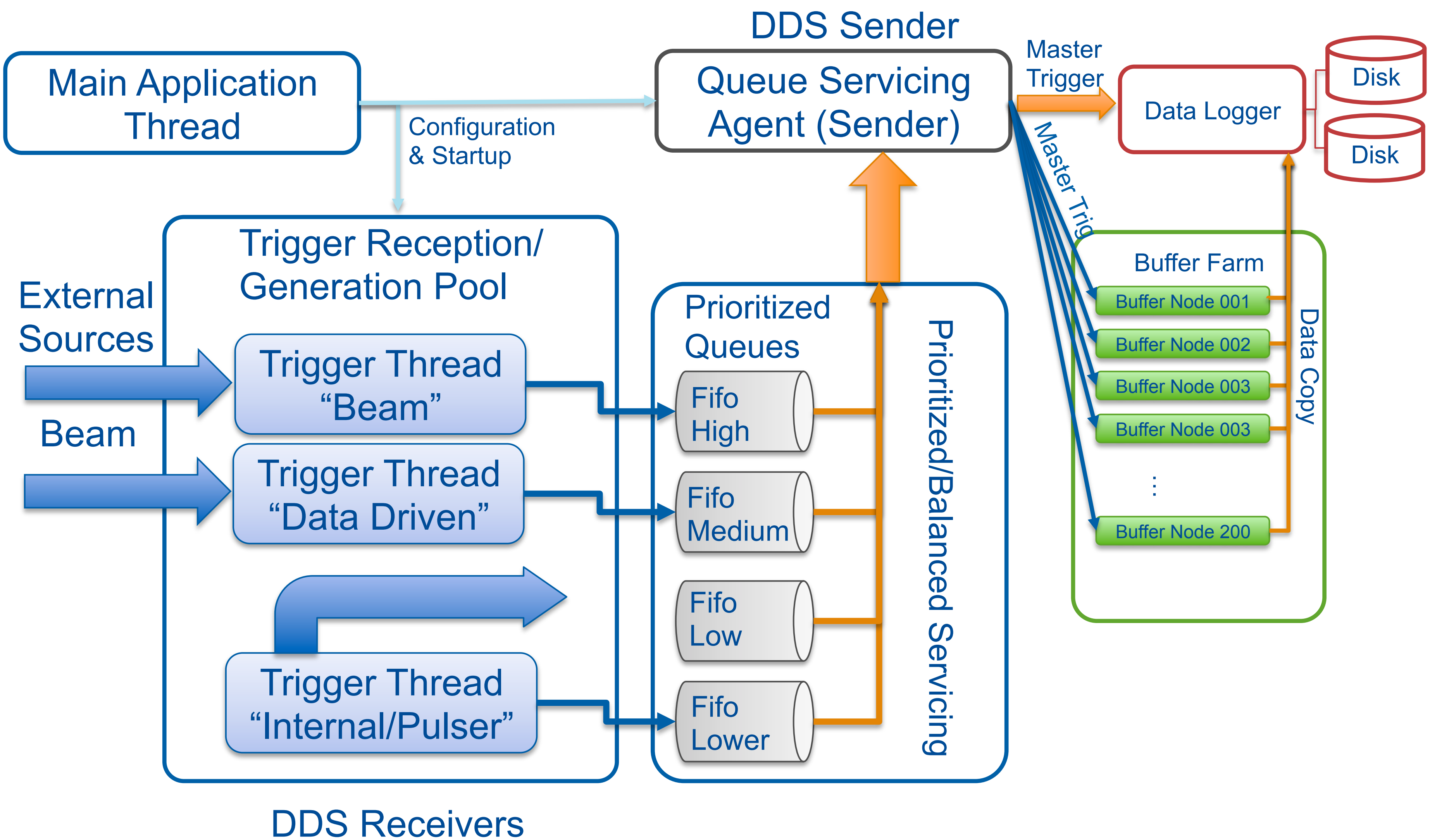
- Allows for balancing
  - High Level software DDTs
  - External Beam triggers
  - Pulsers (hardware/software)
  - Readouts 50 μs – 60 s

NOνA Preliminary

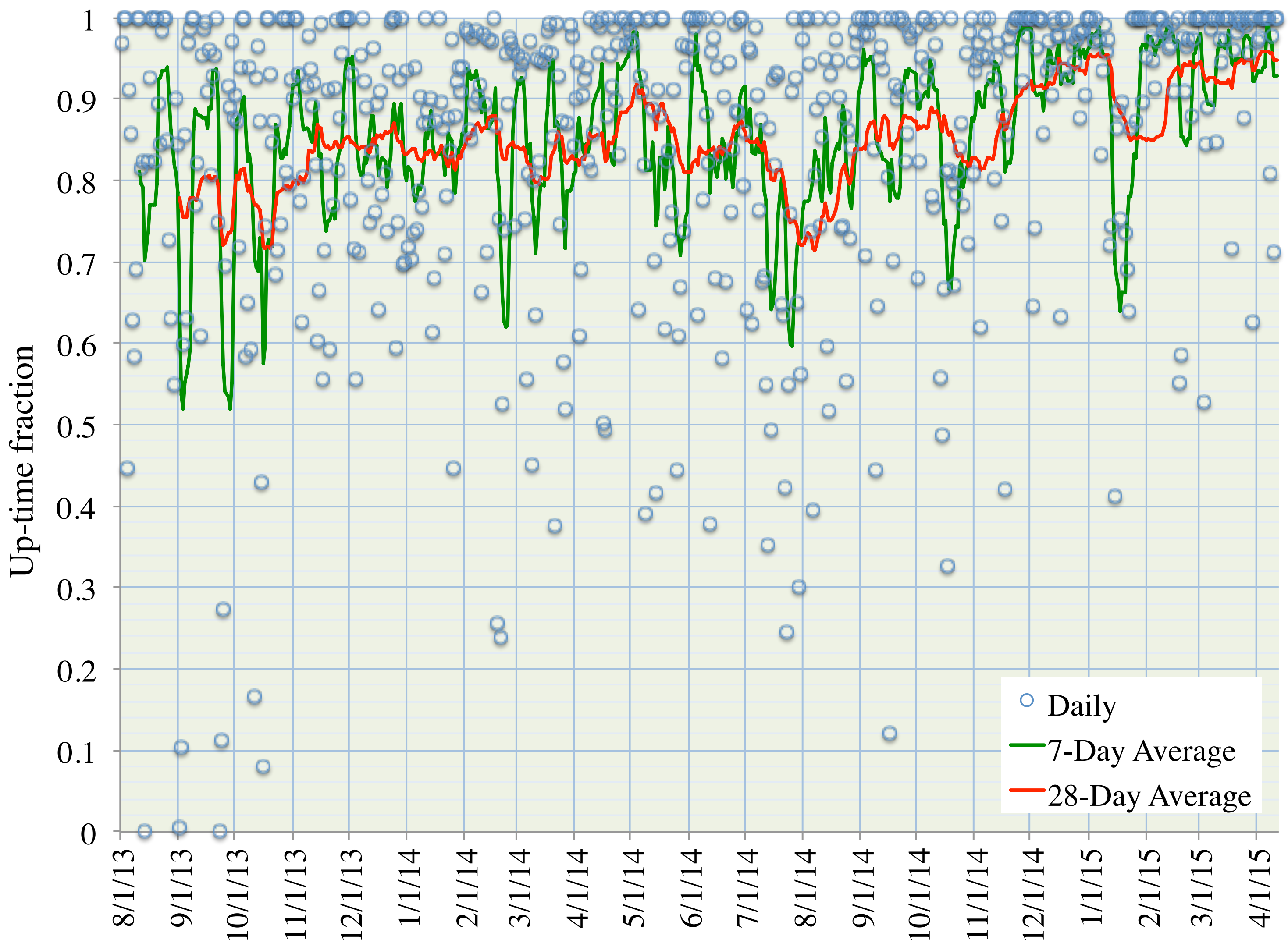


NOνA trigger rate balancing and stability for select trigger groups

NOνA Global Trigger Design

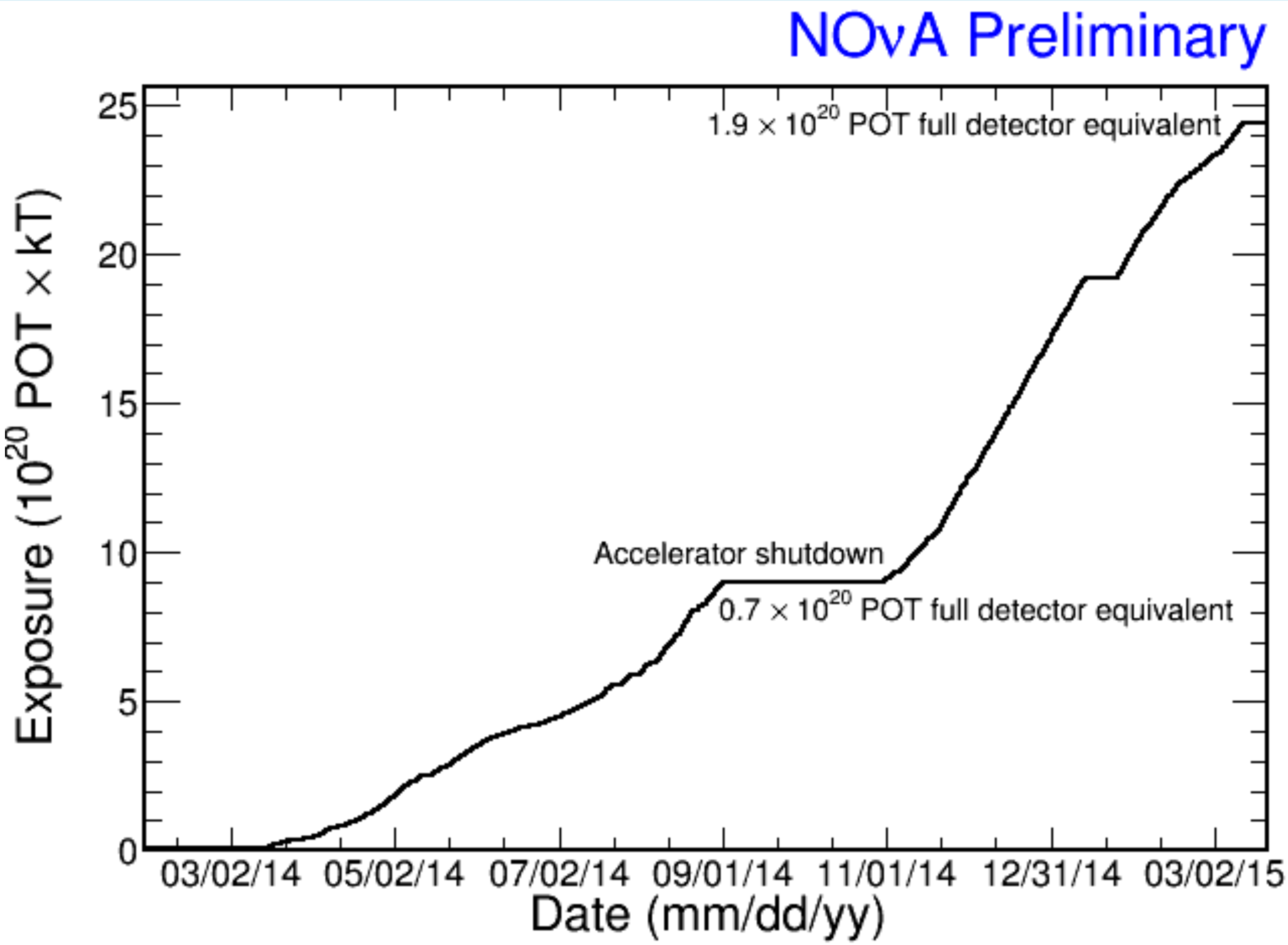


DAQ Uptime



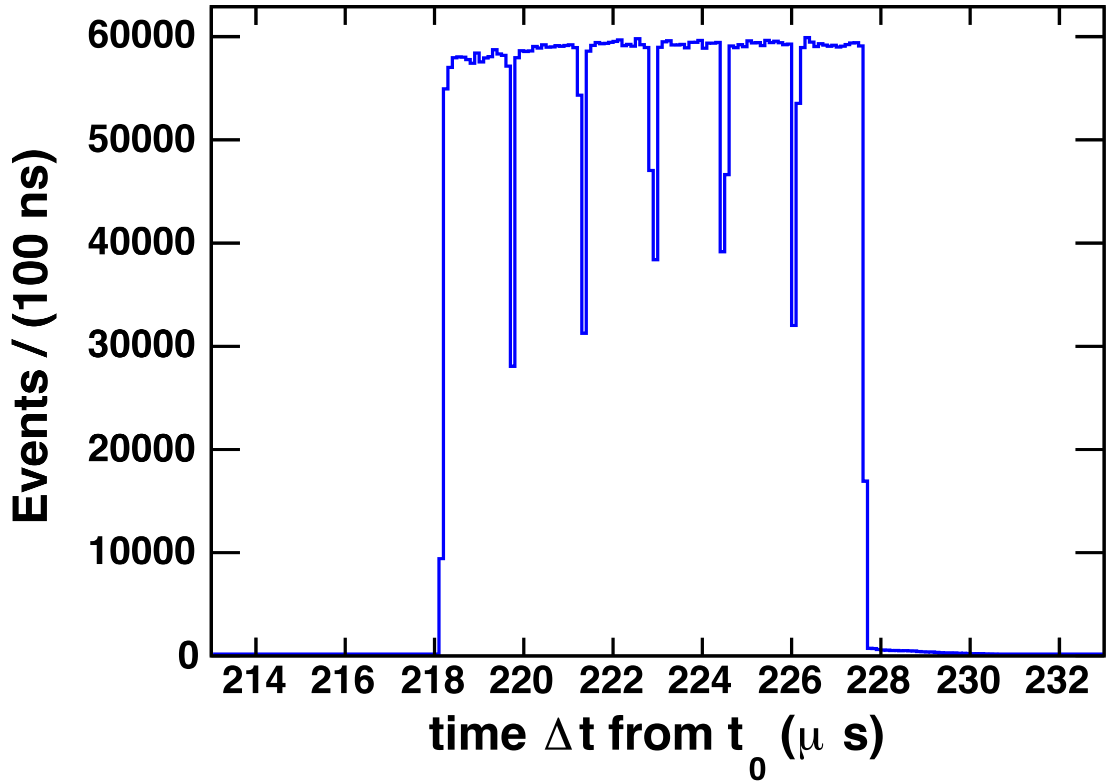
Up-time fraction
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
8/1/13
9/1/13
10/1/13
11/1/13
12/1/13
1/1/14
2/1/14
3/1/14
4/1/14
5/1/14
6/1/14
7/1/14
8/1/14
9/1/14
10/1/14
11/1/14
12/1/14
1/1/15
2/1/15
3/1/15
4/1/15
Daily
7-Day Average
28-Day Average

DAQ Uptime



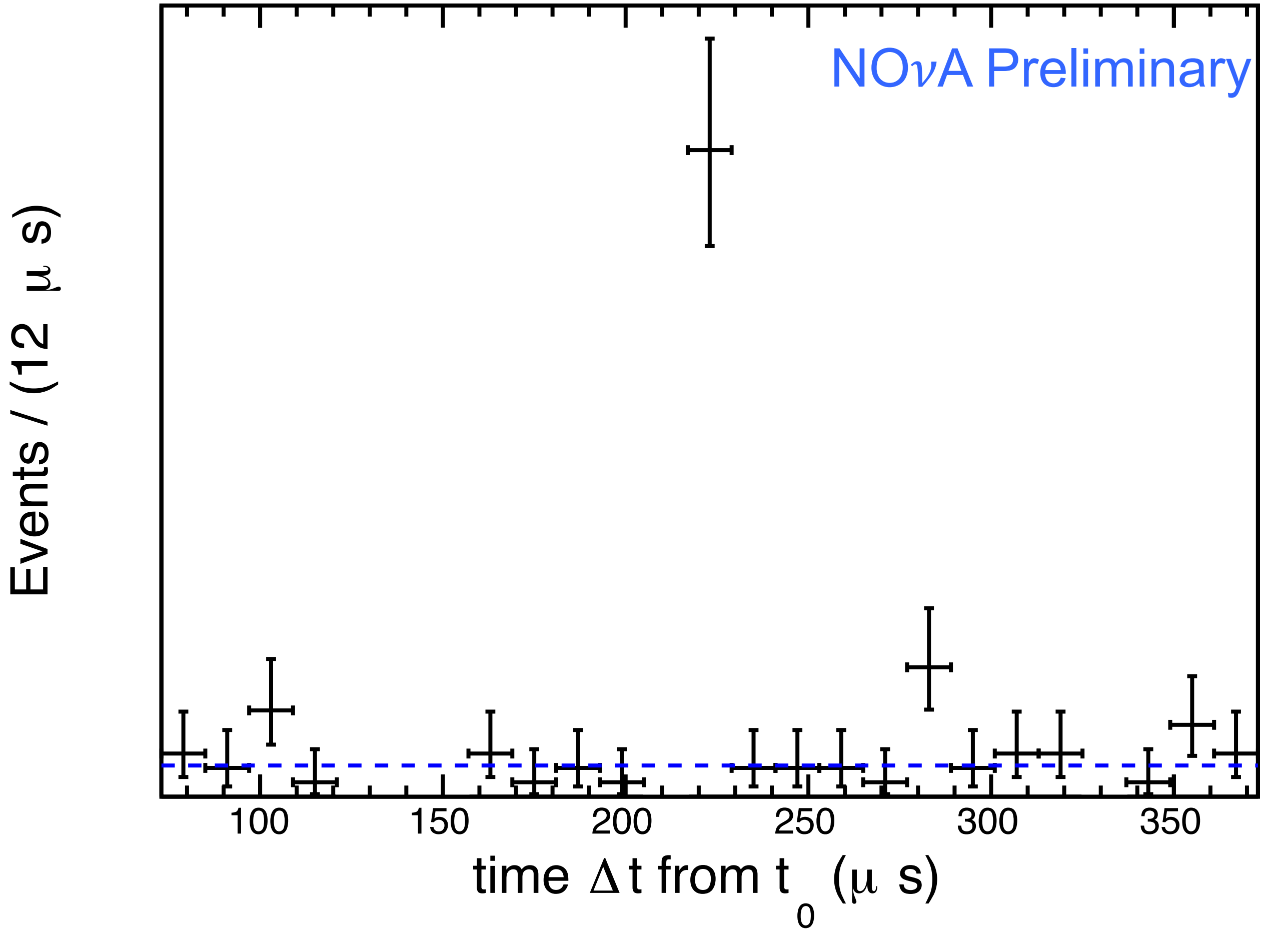
Acquired far detector neutrino exposure
for first 12 months of physics running

Beam Timing and Sync



NOνA Near Detector beam profile as a function of the time **Δ**t between the trigger time t_0 and the time of the observed hits in the detector. Beam crossing was computed to occur 217.6 μs after the trigger time t_0. The 6 batch structure of the extracted NuMI beam is evident.

Far Detector ν Observation



Observed time profile of candidate neutrino events observed at the NOνA Far detector from March 2014-March 2015. The excess seen in the spectrum corresponds to the time interval, corrected for ν flight times, electronic and signal propagation delays, of the predicted far detector beam crossing.

Summary

- The NOνA experiment has successfully created, commissioned and is operating, a continuous, free running, dead-timeless DAQ system that is able to scale to readout the full 14 kt NOνA far detector.

- The experiment has also successfully created a high level "data driven trigger" system that is capable of analyzing the full, unfiltered NOνA data stream and readout triggers windows from 50 μs to 1 minute in length.

- These combined systems have currently collected over 5.7 billion events which are currently under analysis.