# Finding Neutrinos: The Design of the NOvA Timing and Synchronization System

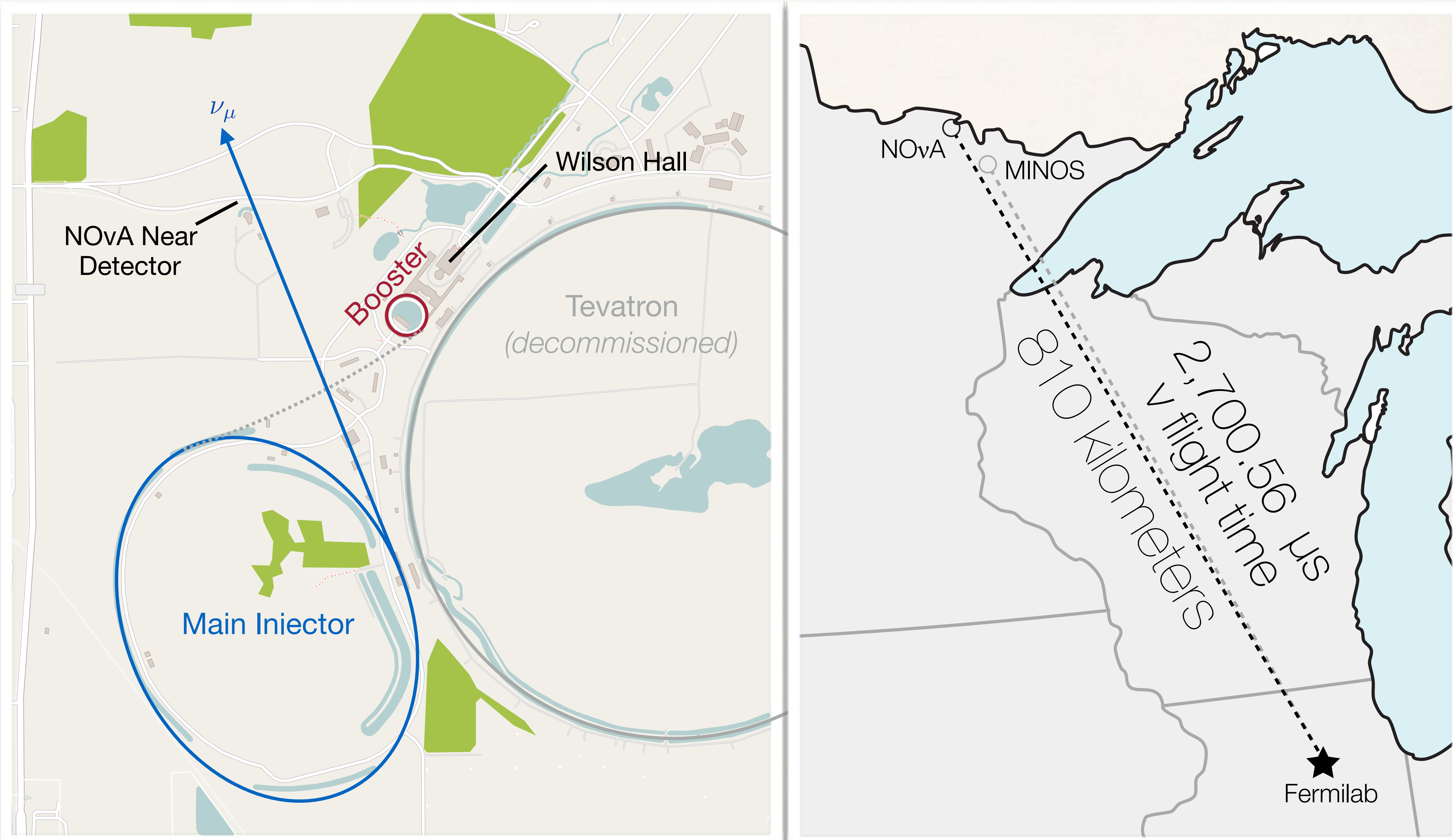
*Justin Vasel /// Indiana University /// New Perspectives 2016 /// 13 June 2016*

# NuMI Beamline

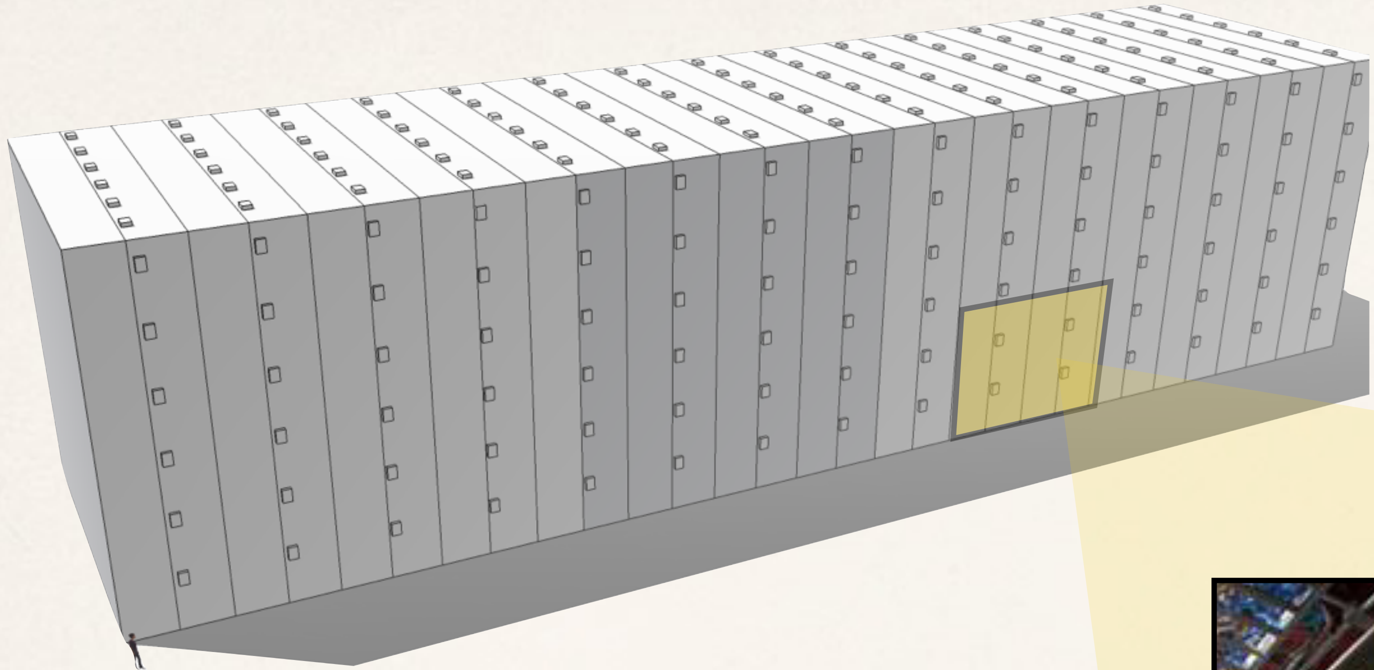
NuMI *Neutrinos at the Main Injector*

1 “spill” of neutrinos every ~1.3 sec.

A pulsed beam 10μs long.



# Far Detector Overview



The Far Detector

10,749 individual sets of readout electronics.

*All of these must be synchronized with one another and with beam spill events happening 810 km away at Fermilab to within 10 ns.*

161 km of copper cabling

*Time it takes for signals to propagate through detector must be taken into account.*

# Timing Requirements

1. All readout components of each detector must be synchronized with one another to within 10 ns.

   *This ensures proper reconstruction and spatial separation of events in the 10,749-channel Far Detector and reduces event pileup in the 631-channel Near Detector.*

2. Detectors must be synchronized to an absolute “wall clock” to know when the pulsed neutrino beam arrives.

   *Far Detector is on surface and sees cosmic rate of 120 kHz.*
   *Can’t use an activity trigger to differentiate beam from background.*
   *Must know when to expect the beam!*

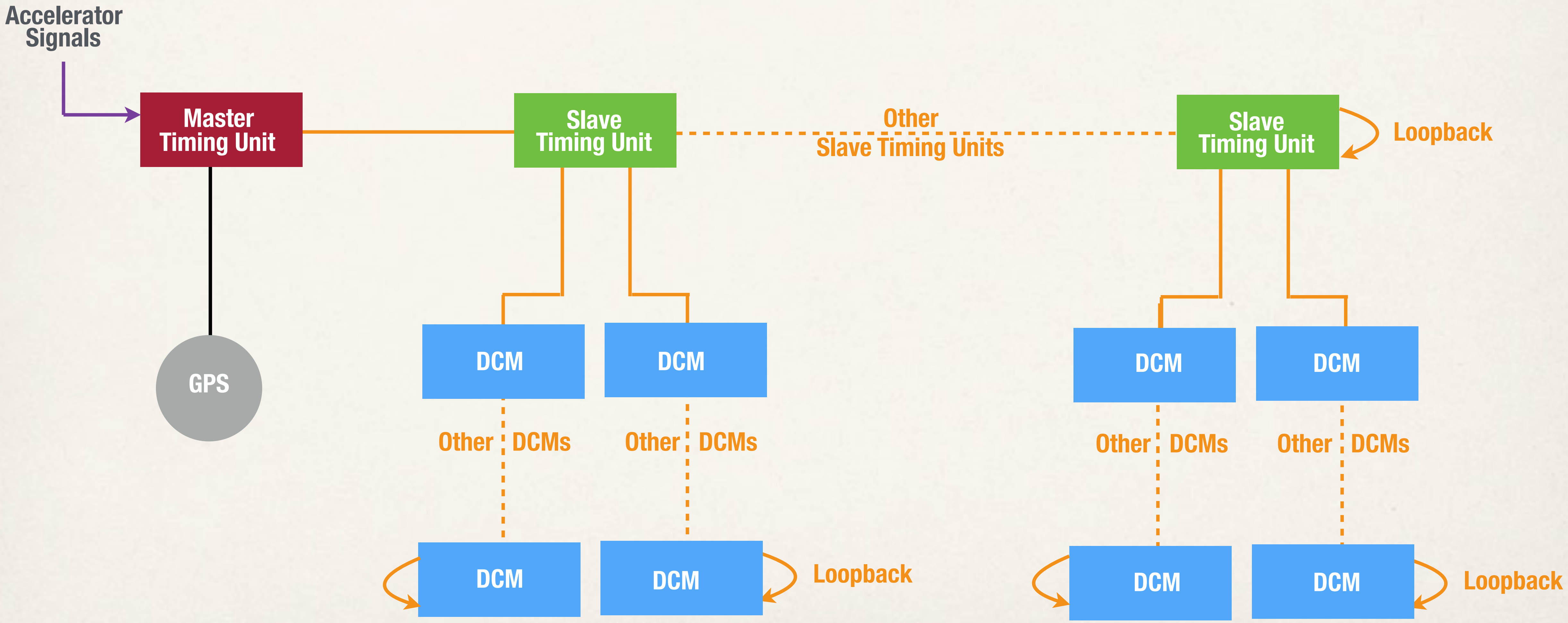
# The NOvA Timing Chain

NOvA uses a distributed approach to synchronizing its detectors.

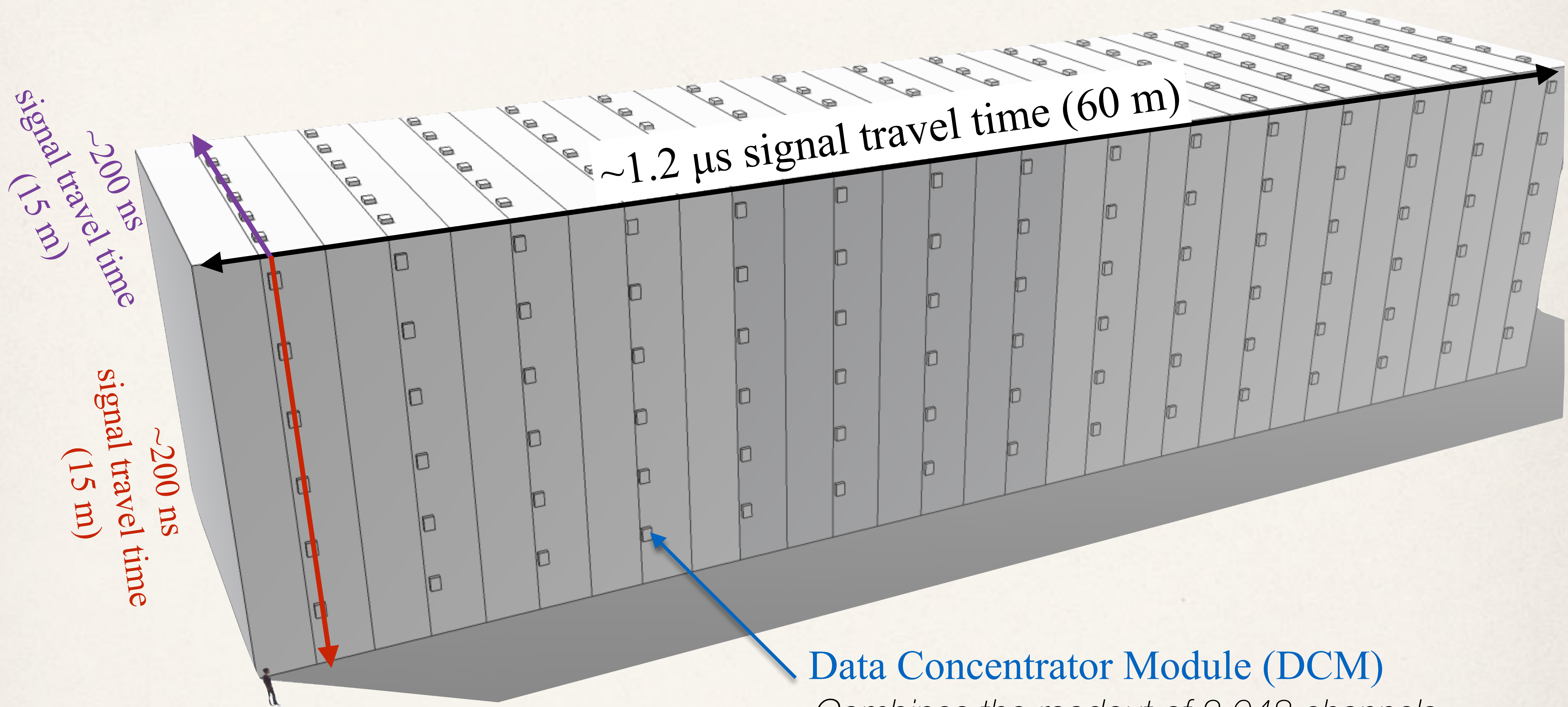
The top-level structure is called a “timing chain”.

*Each detector utilizes two redundant timing chains: one as the primary, and the other as a hot spare.*

*Redundancy also exists for the GPS receivers.*



# Far Detector Overview

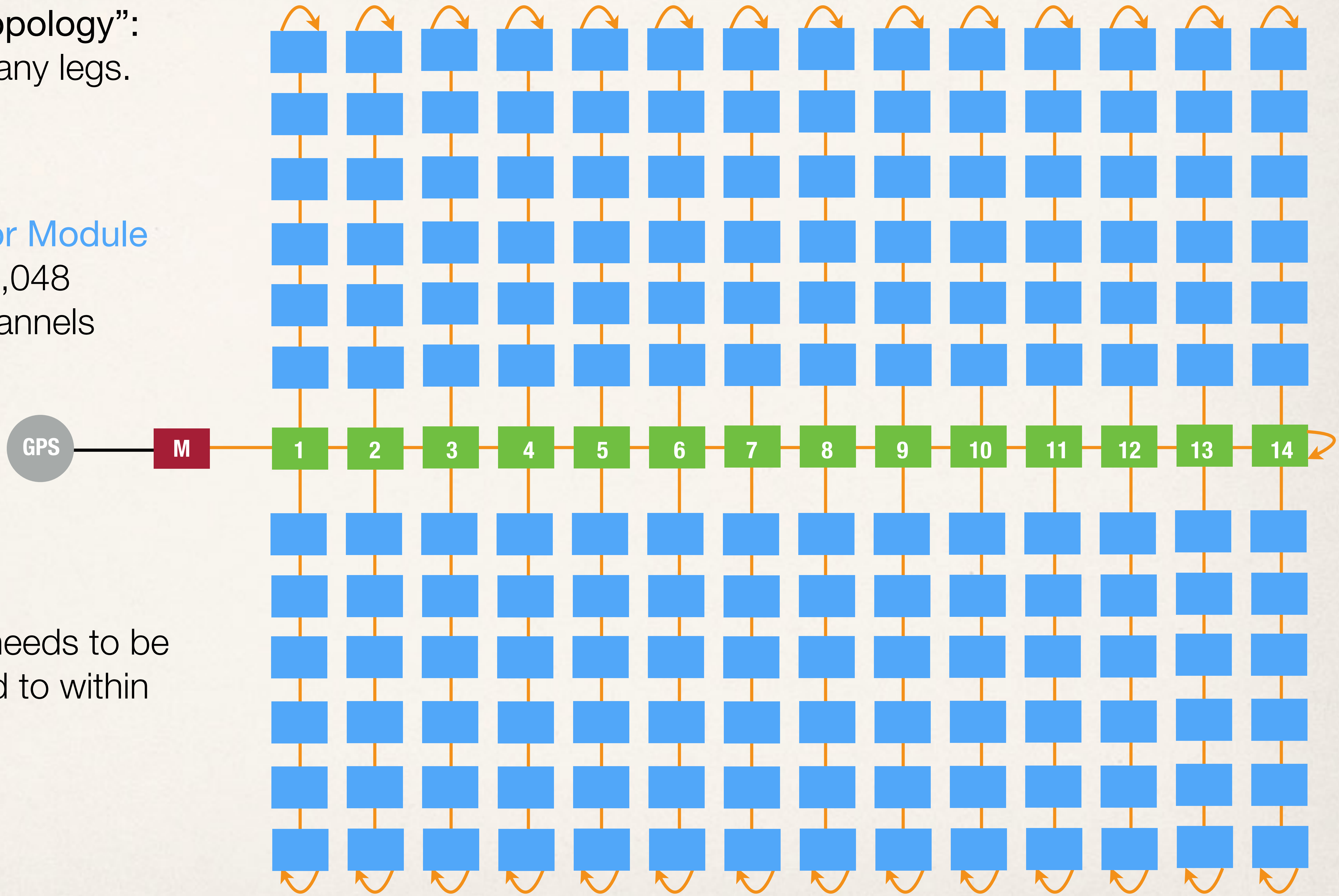


# The NOvA Timing Chain

**“Millipede topology”:** long, with many legs.

Each Data Concentrator Module fans out to 2,048 individual channels *(not shown)*.

**Everything** needs to be synchronized to within 10 ns.



# The NOvA Timing Chain: Timing Distribution Units (TDUs)


Timing distribution units.

## The Master Timing Unit…

### keeps time for the detectors.

*Interface with GPS receiver which supplies a 10 MHz reference clock.*

*A 64 MHz clock is derived from the 10 MHz reference clock.*
*Its purpose is to drive a timestamp register on each detector component.*

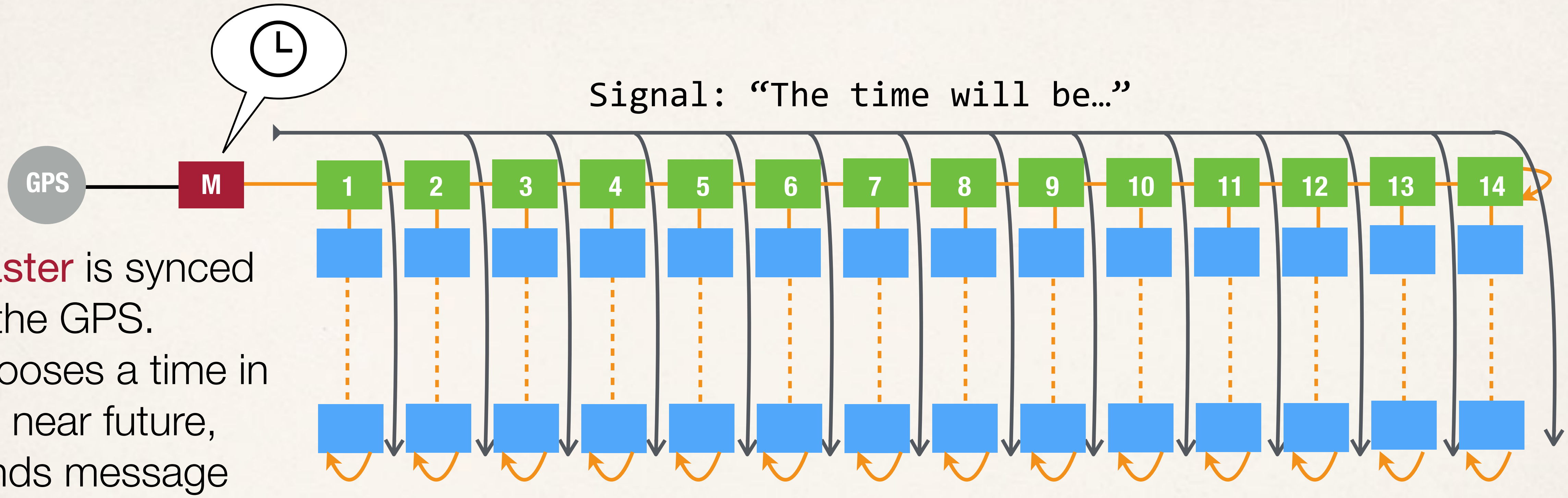
### relays timing commands to rest of the timing chain.

*Signals to synchronize, calculate signal propagation delays, etc.*

# Timing Chain Synchronization

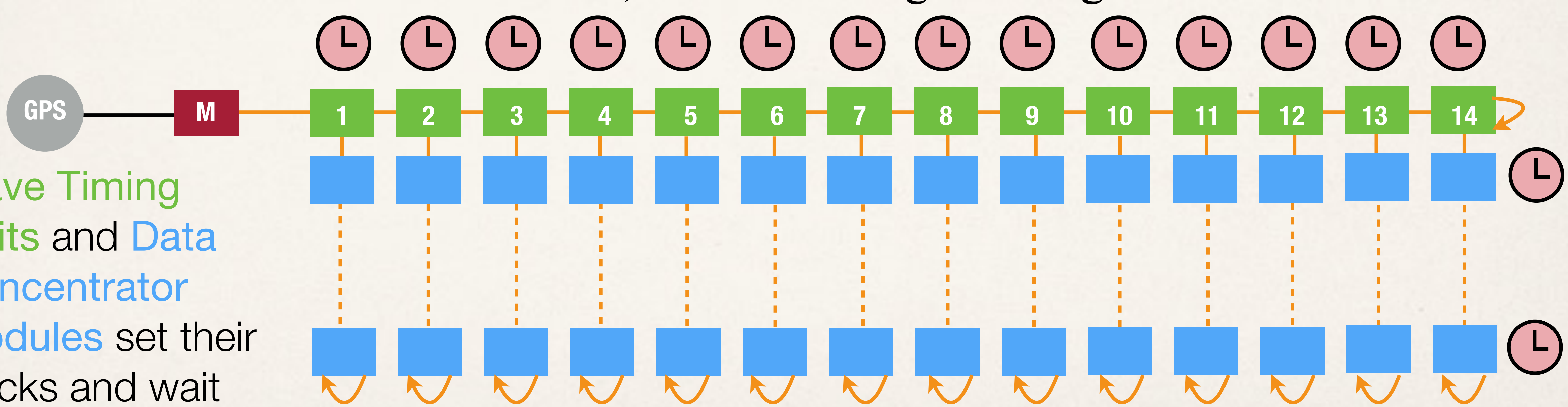
NOvA's synchronization model: *"at the tone, the time will be…"*

# Synchronization: “The time will be…”



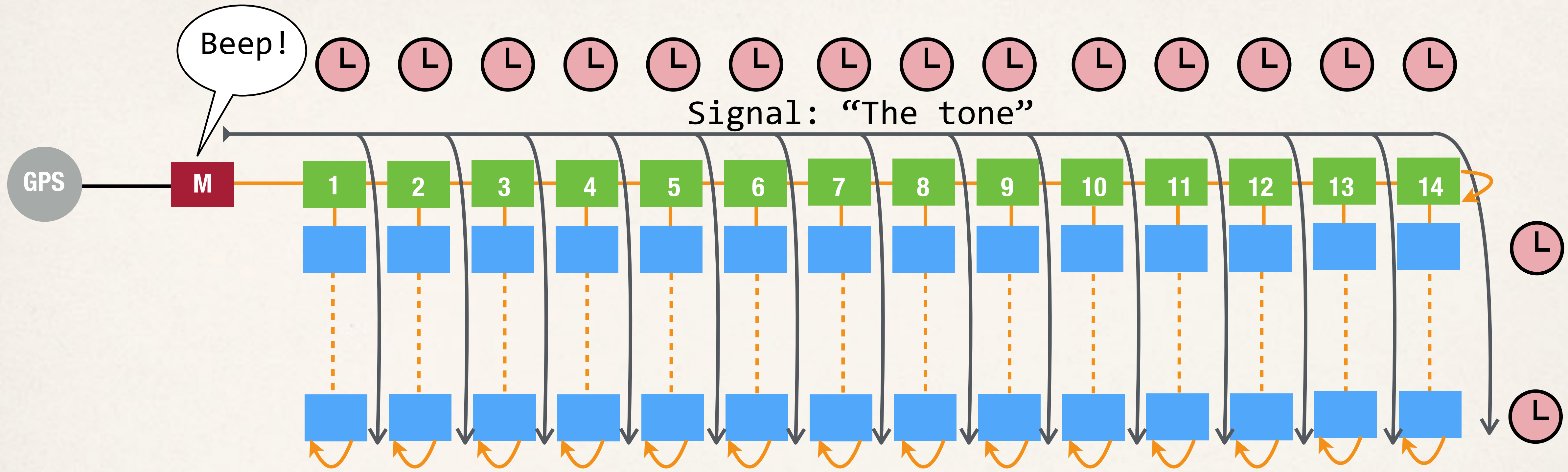

Master is synced to the GPS. Chooses a time in the near future, sends message down the chain.

Clocks are set, but not ticking. Waiting to for “the tone”.

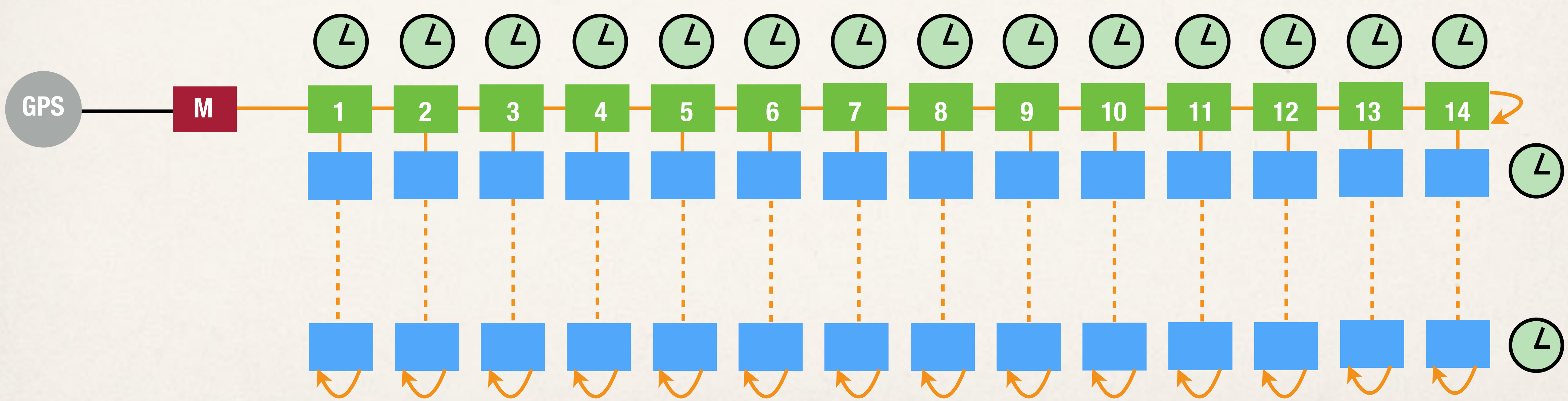



Slave Timing Units and Data Concentrator Modules set their clocks and wait for tone.

# Synchronization: "At the tone…"




Once "the tone" has reached the farthest component, they all start their clocks simultaneously.



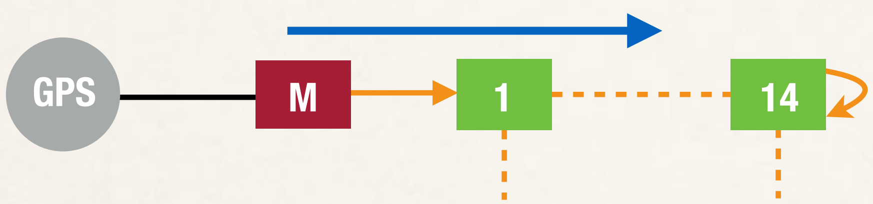
# Delay Calibration

Q. But how do all the components know how long to wait before starting their clocks?

A. Before synchronizing, the timing chain "learns" these delay values.

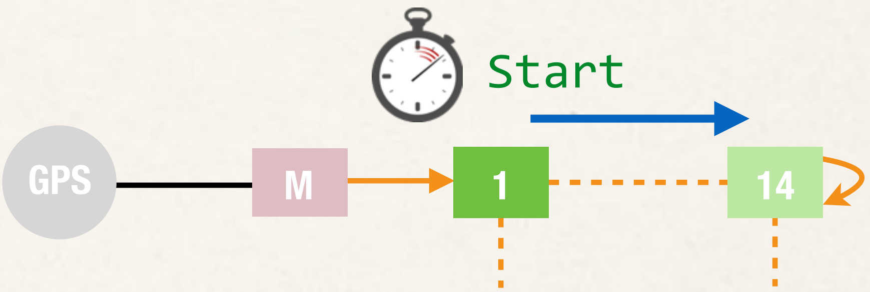
**STEP 1**

A special sync signal is sent from the Master Timing Unit.



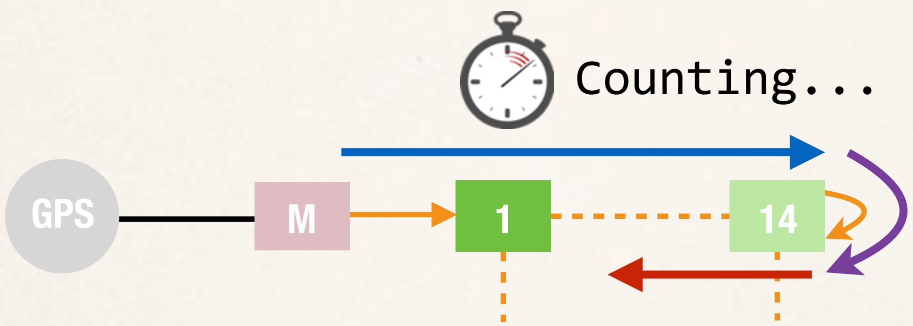

**STEP 2**

When an Slave Timing Unit (STDU) receives this signal, it starts a counter.

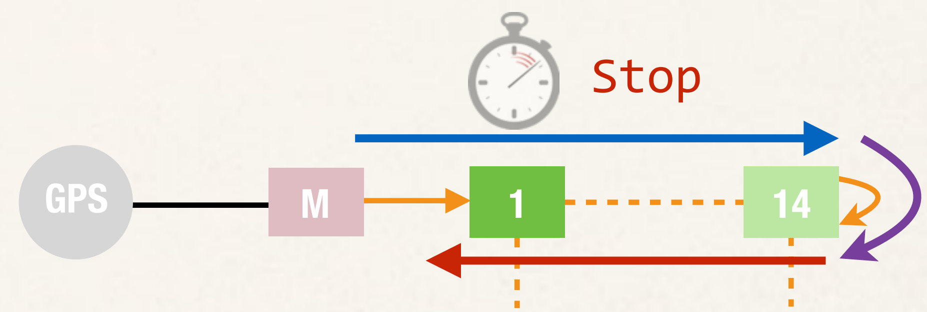


# Delay Calibration (2)

STEP 3
The signal loops back around at the end of the chain.




STEP 4
The STDU receives the signal again, and stops its counter.




Now each STDU knows how far away in time it is from the component at the end of the chain.

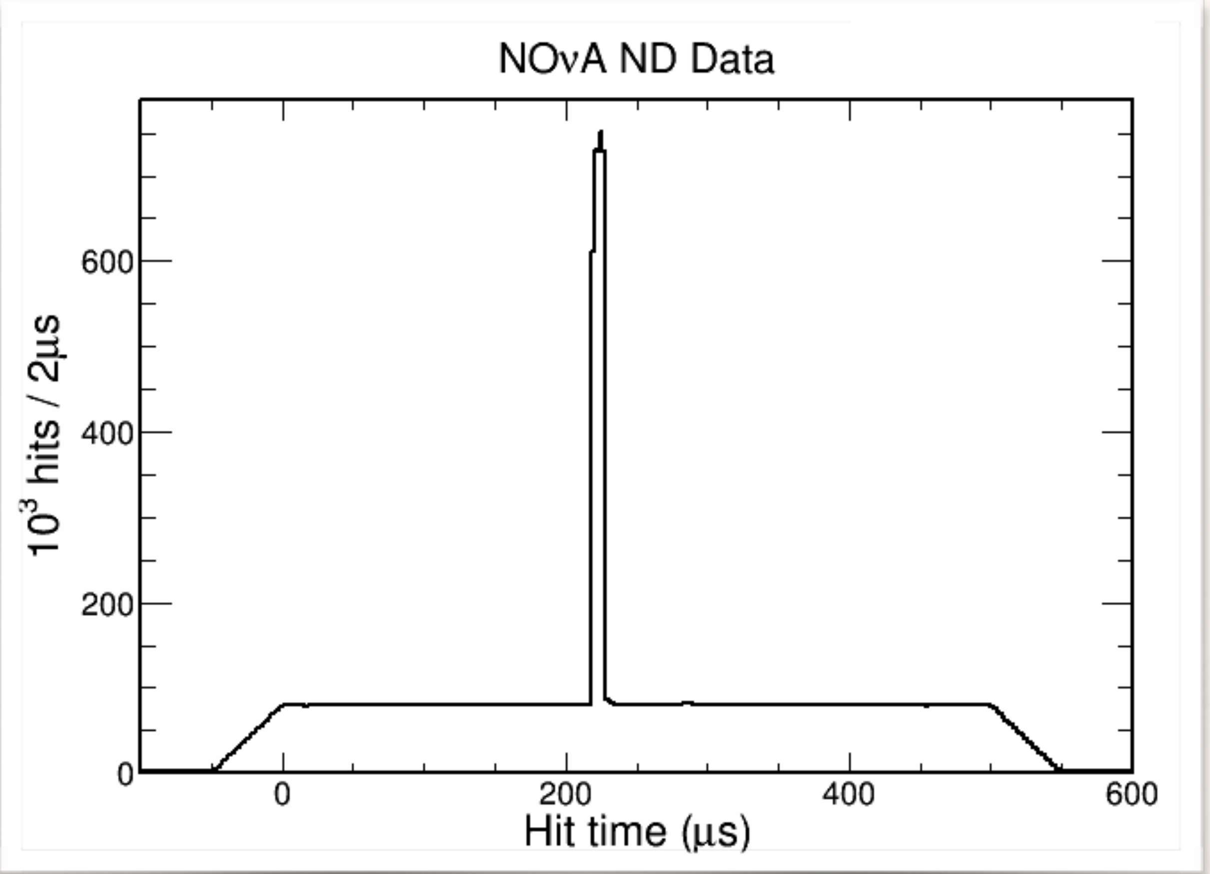
It knows how long to wait after hearing "the tone" to start its clock.

This allows all 10,749 channels to start their clocks simultaneously.

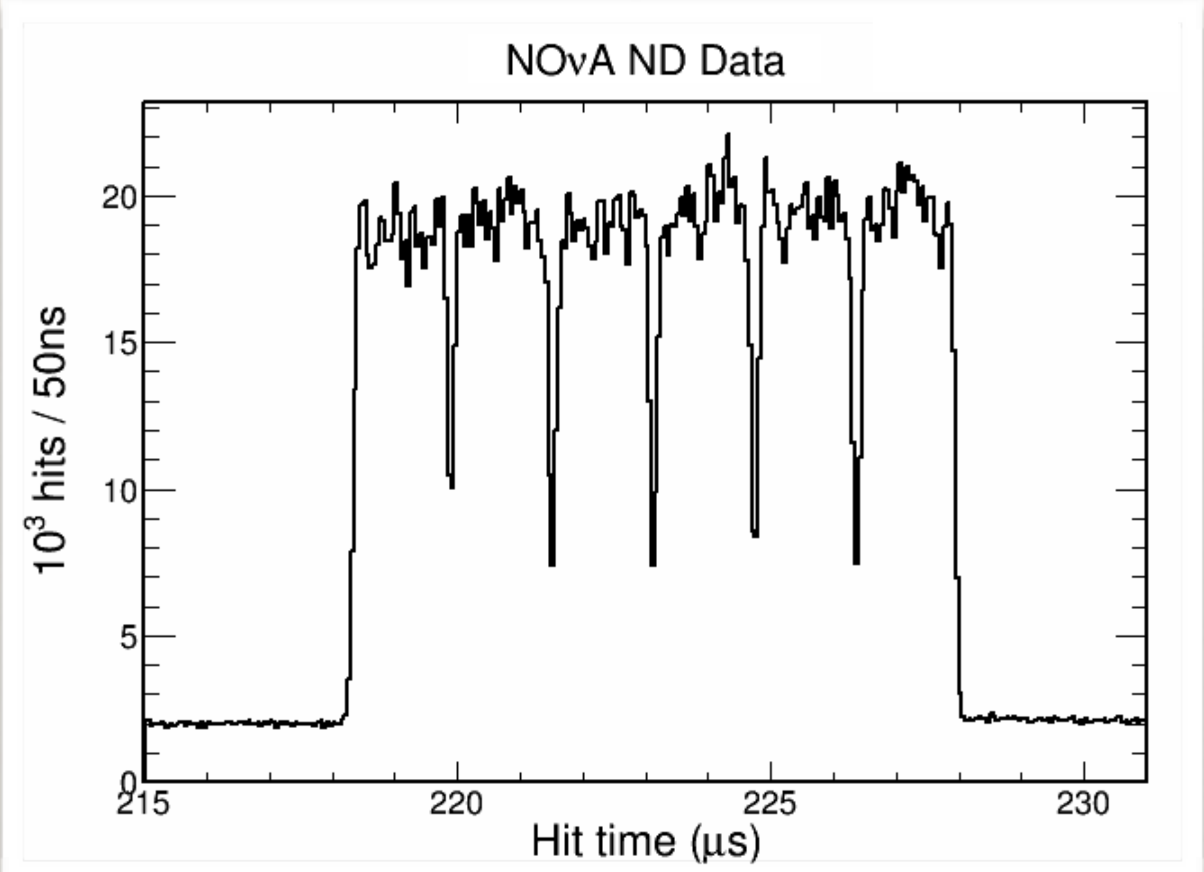
# How do we know it's working?

We monitor our data as it's coming in.

At the Near Detector, we can see the beam peak right away.




We can also see the beam's pulsed structure.

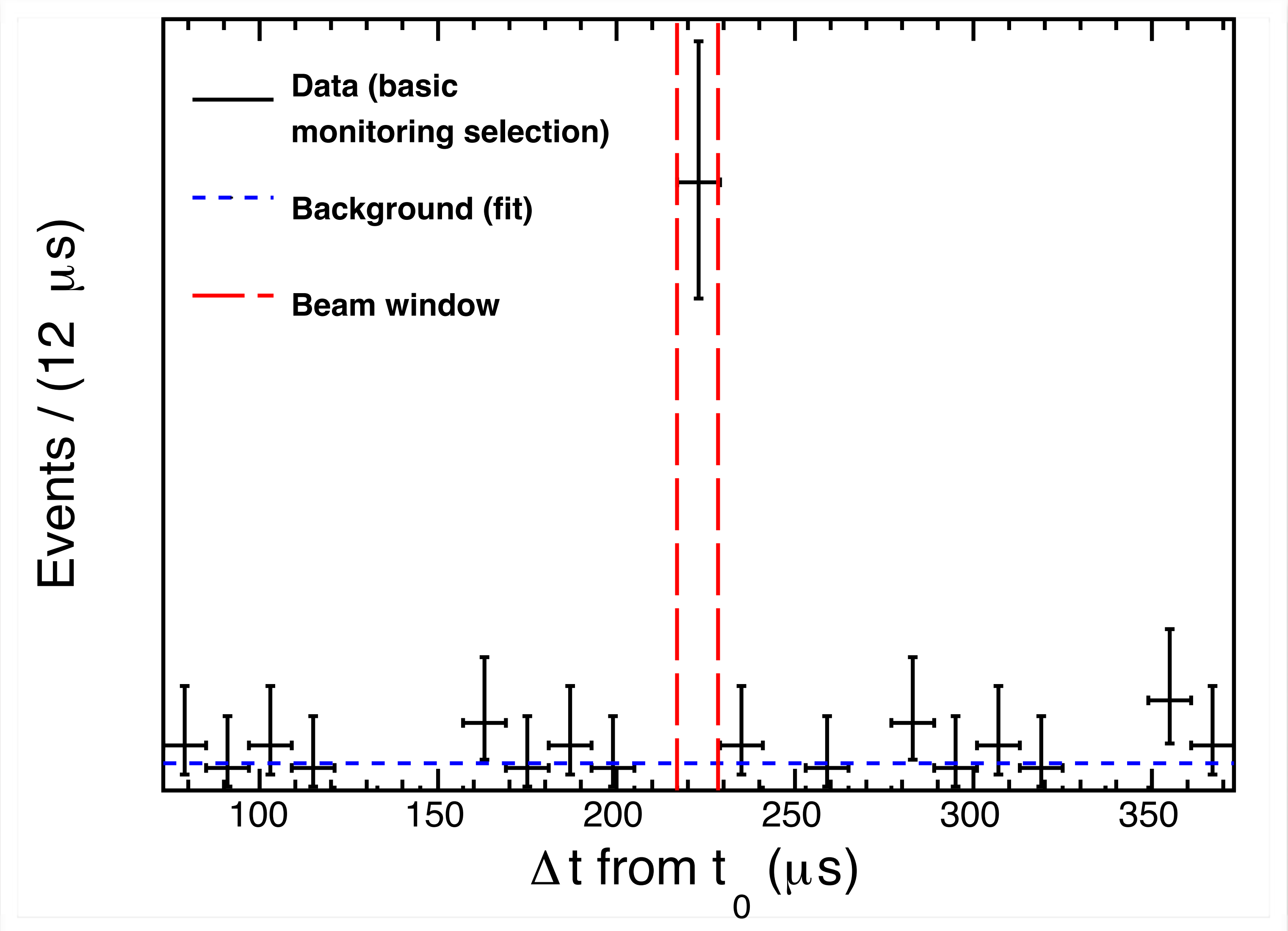



Rate ~10,000 ν events per day

# Monitoring: Far Detector Timing Peak

The Far Detector, on the other hand, is swamped with cosmic rays. The timing peak is not immediately visible.

Applying a basic set of selection cuts allows us to reduce the background enough to see the timing peak.




Issues with the timing system at the Far Detector will manifest themselves in this plot.

Rate < 1 ν events per day

# Monitoring: TCR Monitor

Need to ensure the times to which the Master Timing Units are synced is accurate.

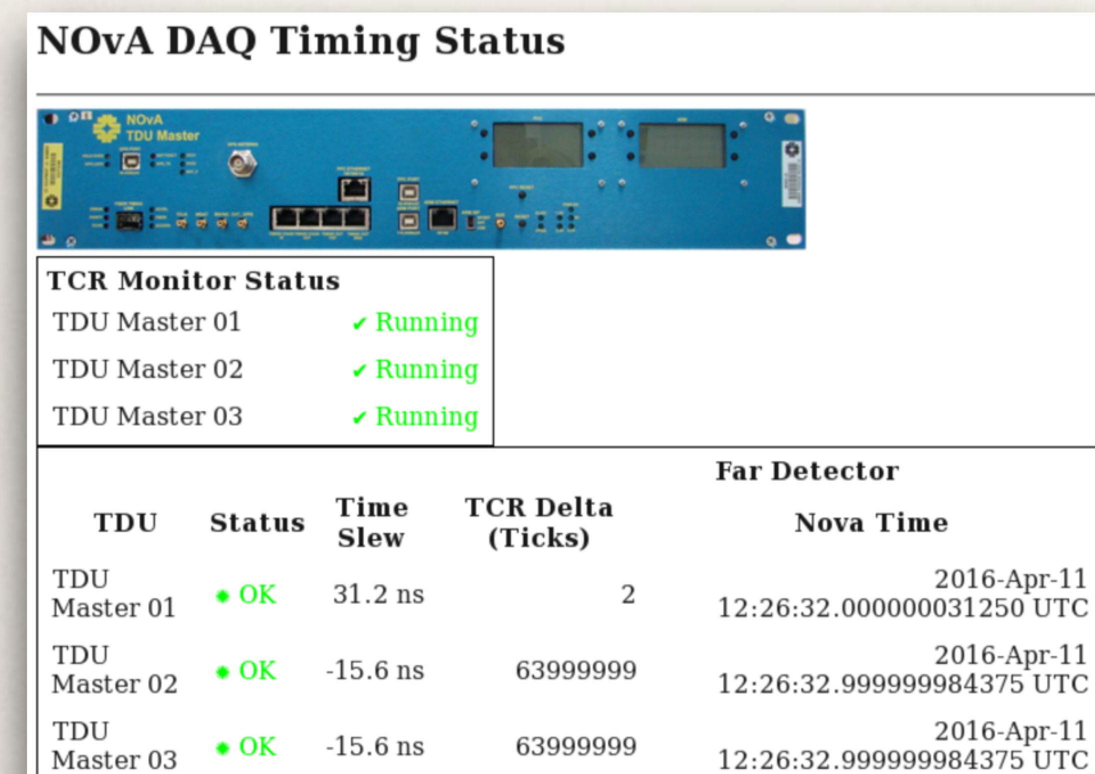
*Inaccuracies could arrive from glitches during the synchronization process or clock drift, for example.*

## Timing Calibration Reference (TCR)

*Independent GPS antenna and receiver that produces a reliable 1 Hz pulse.*

*Each Master Timing Unit compares their clock phase to that of the TCR.*

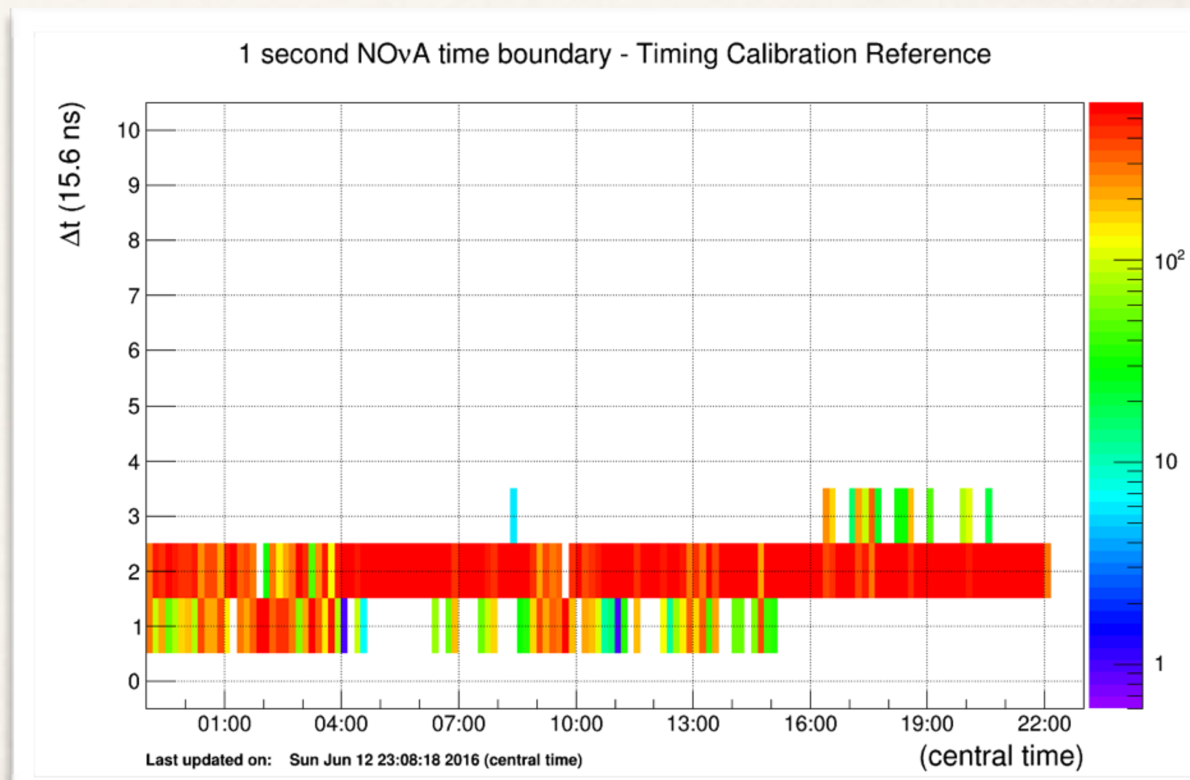
*A web interface (left) showcases this information to shifters to ensure that errors are caught quickly and corrected.*



**NOvA DAQ Timing Status**

| TCR Monitor Status | |
|---|---|
| TDU Master 01 | ✔ Running |
| TDU Master 02 | ✔ Running |
| TDU Master 03 | ✔ Running |

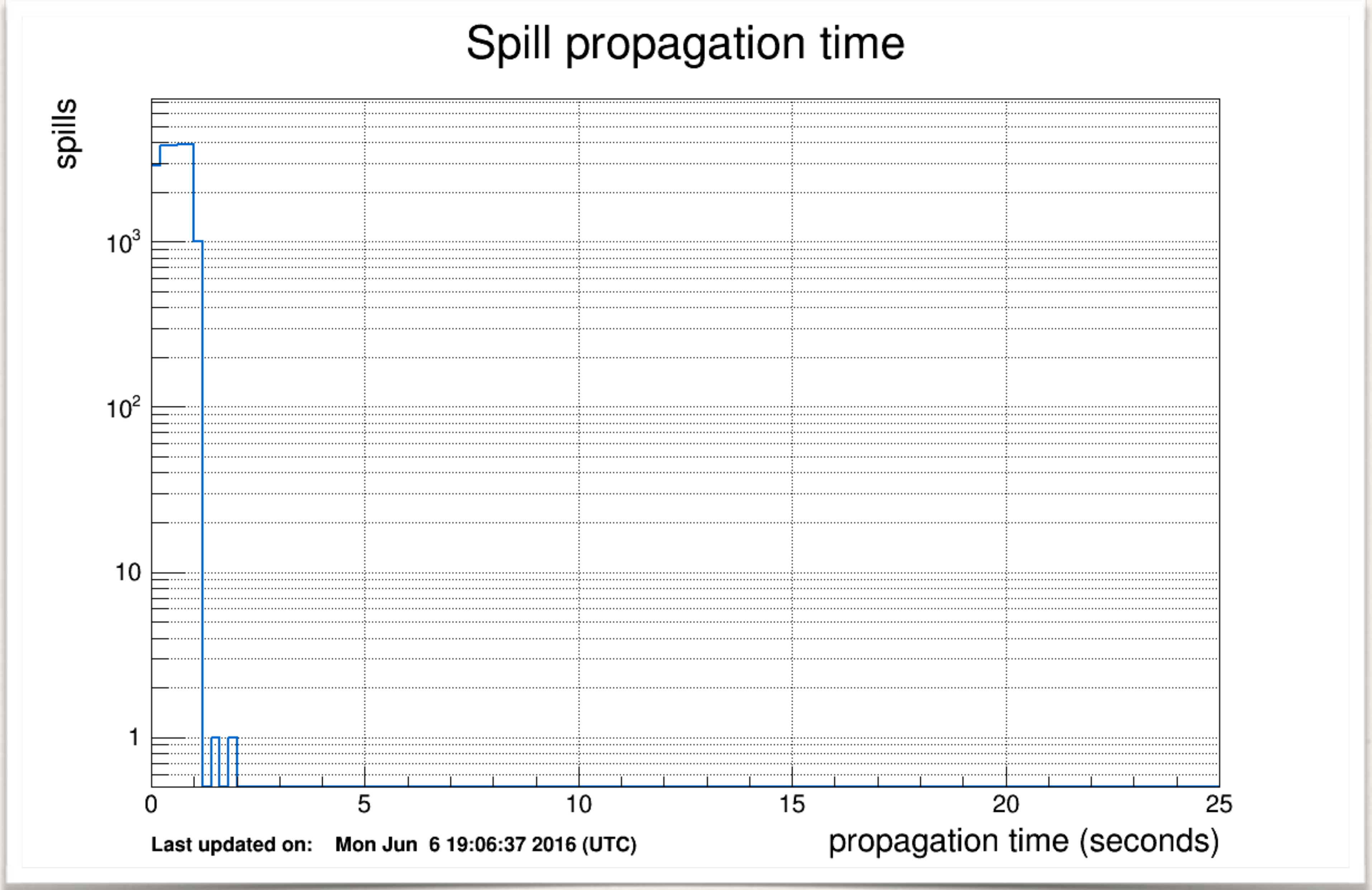
| TDU | Status | Time Slew | TCR Delta (Ticks) | Far Detector Nova Time |
|---|---|---|---|---|
| TDU Master 01 | OK | 31.2 ns | 2 | 2016-Apr-11 12:26:32.000000031250 UTC |
| TDU Master 02 | OK | -15.6 ns | 63999999 | 2016-Apr-11 12:26:32.999999984375 UTC |
| TDU Master 03 | OK | -15.6 ns | 63999999 | 2016-Apr-11 12:26:32.999999984375 UTC |



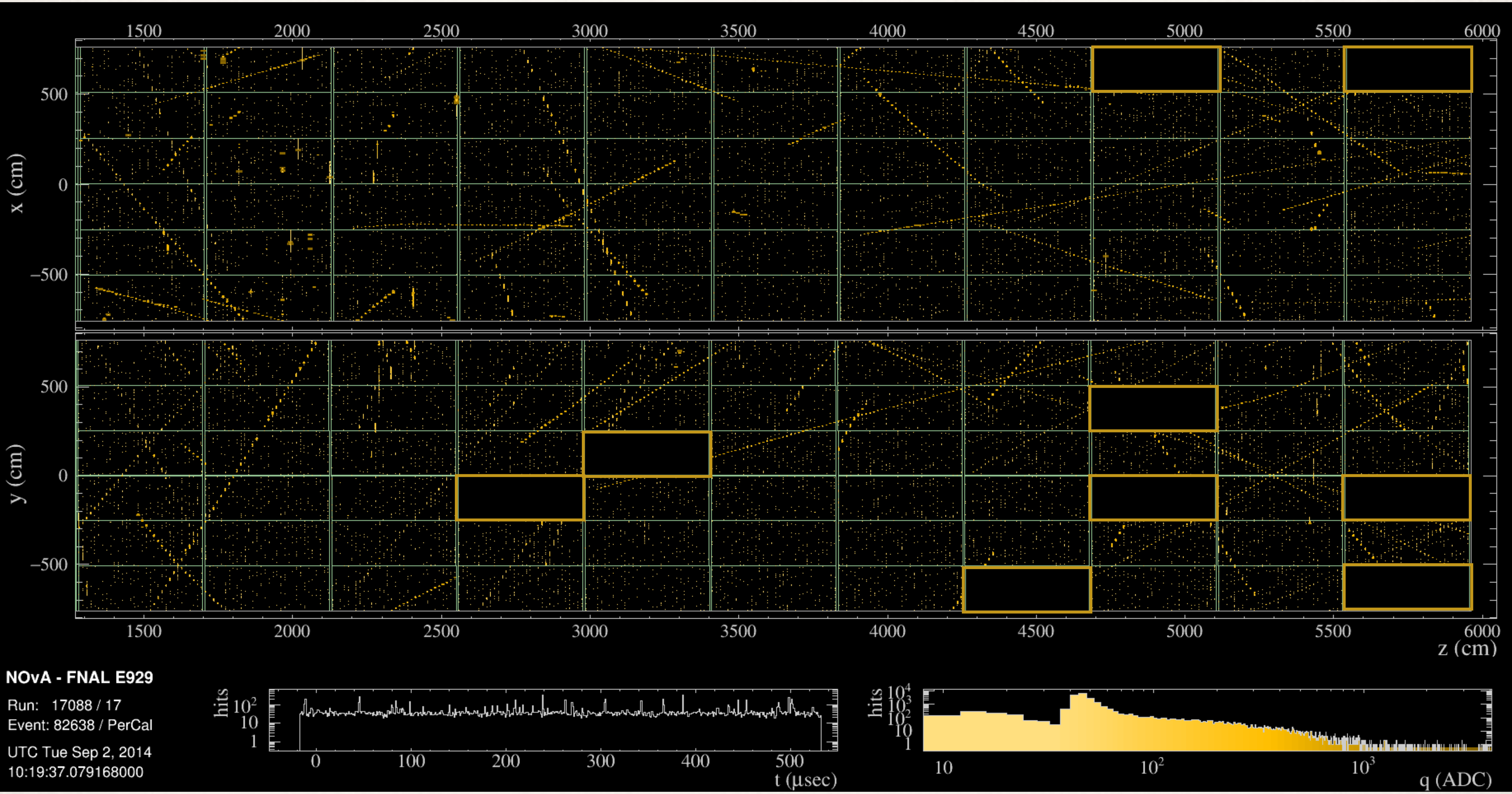
# How do we know it's working?

We can measure how long it takes a trigger to be received at the Far Detector.

Our DAQ provides continuous streaming, unsurpassed readout; all data is buffered for ~20 minutes.



# Monitoring: Long tracks in the event display



# Summary


NOvA's timing system allows us to synchronize more than 10,749 detector elements to within 10 ns of one another.

Without this precision, it becomes difficult to reconstruct neutrino events, and leads to event-pileup in the Near Detector.

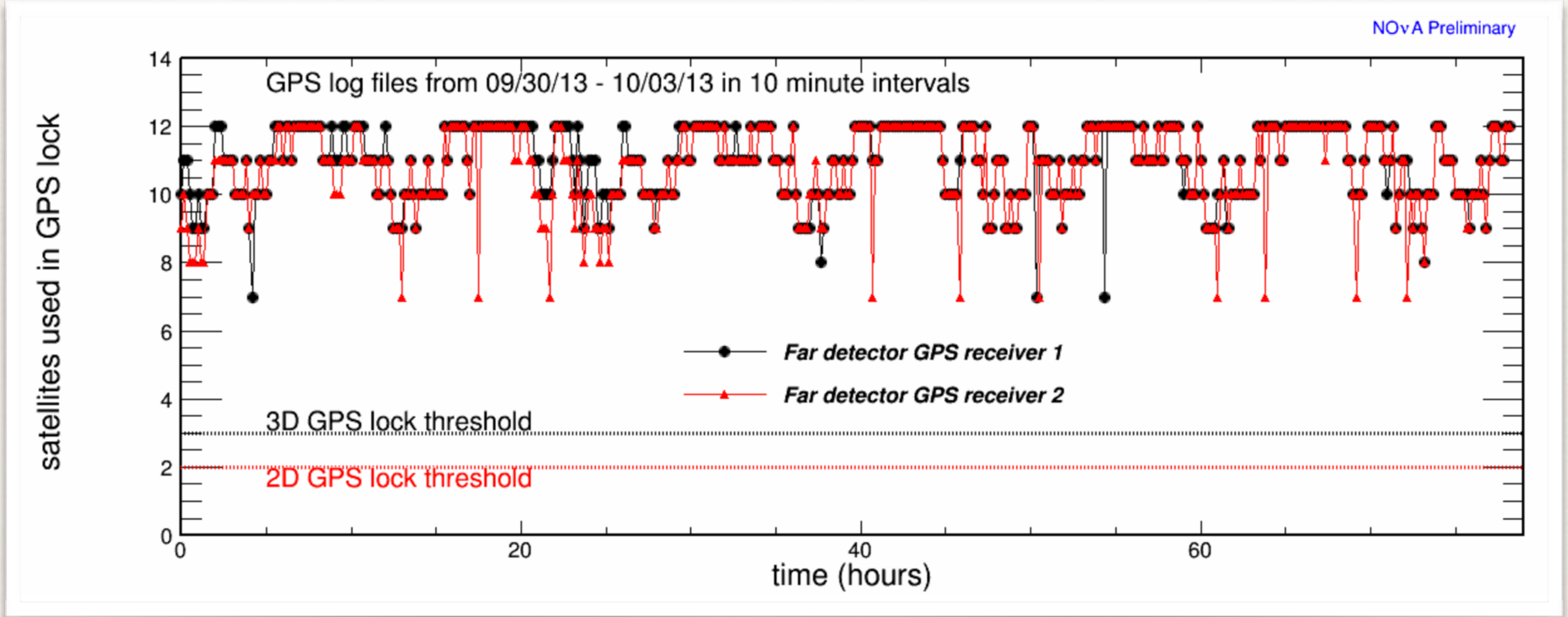
A suite of monitoring tools aids us in understanding when there is an timing system issue that needs to be addressed to ensure good data quality.

# BACKUP

# Backup: GPS

Each detector connected to a commercial GPS antenna and receiver

*Typically locked on to 7 to 12 GPS satellites.*




Variation of number of GPS satellites locked on over time. If a satellite lock is lost, the 10 MHz reference clock will drift from that of the GPS at a rate of 2 parts per billion (~173 μs) per day.