High-Precision Timing of Gated X-Ray Imagers at the National Ignition Facility

Presentation to

14th International Conference on Accelerator & Large Experimental Physics Control Systems (ICALEPCS)

October 6-11, 2013

S. Glenn, P.M. Bell, L. R. Benedetti, M. W. Bowers, D. K. Bradley, B. Golick, J.P. Holder, D. H. Kalantar, S. F. Khan, N. Simanovskaia

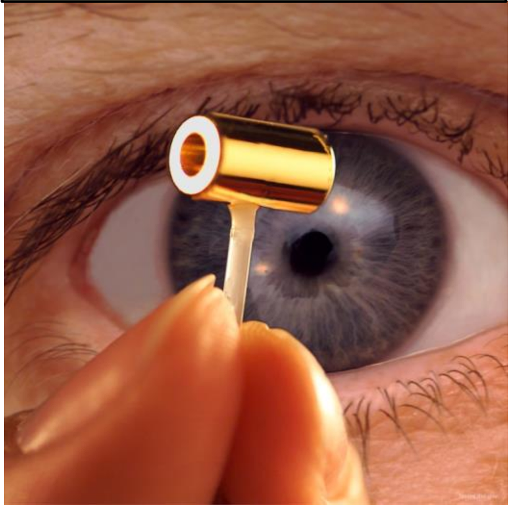
LLNL

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

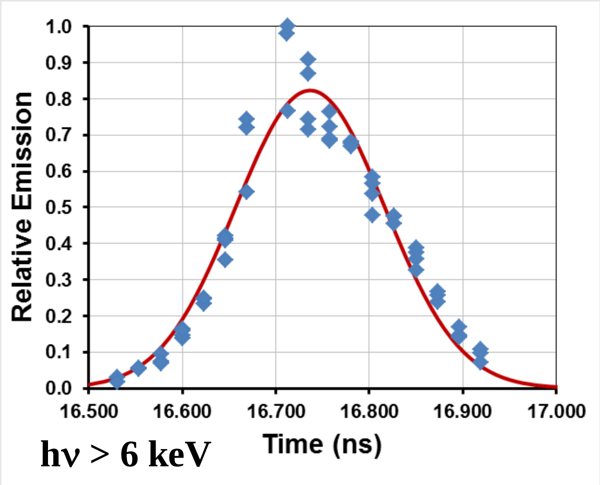
The National Ignition Facility is used for inertial confinement and high energy density laser research.

The NIF is a large facility

Targets are cm-scale



Most x-rays from implosion are emitted within a 100ps window.



- **Accurate timing control and measurement is crucial to execute experiments and interpret results.**
- **Beams are delivered synchronously to target within 30ps (RMS) of request.**
- **Diagnostic instruments trigger within 25ps (RMS) of request.**
- **Many experiments require timing measurement precision of 20ps or less.**

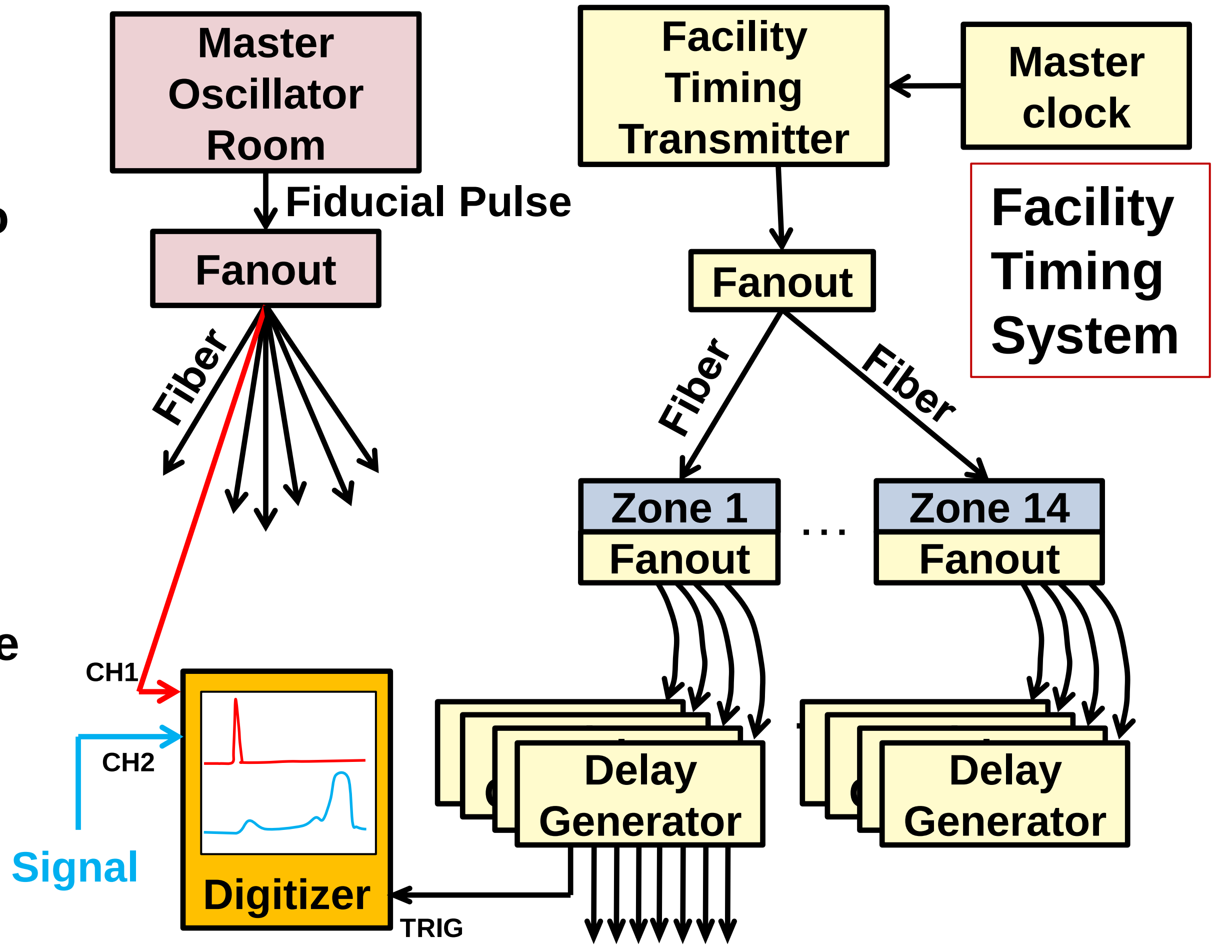
High precision over large scales makes cross-timing the laser and target diagnostics challenging.

Outline

- The NIF Timing System
- Laser Timing Measurements
- Gated X-ray Detectors (GXD's) for target imaging
- GXD gate timing measurement techniques
- GXD timing experiment design and analysis
- GXD timing results and stability relative to NIF beams

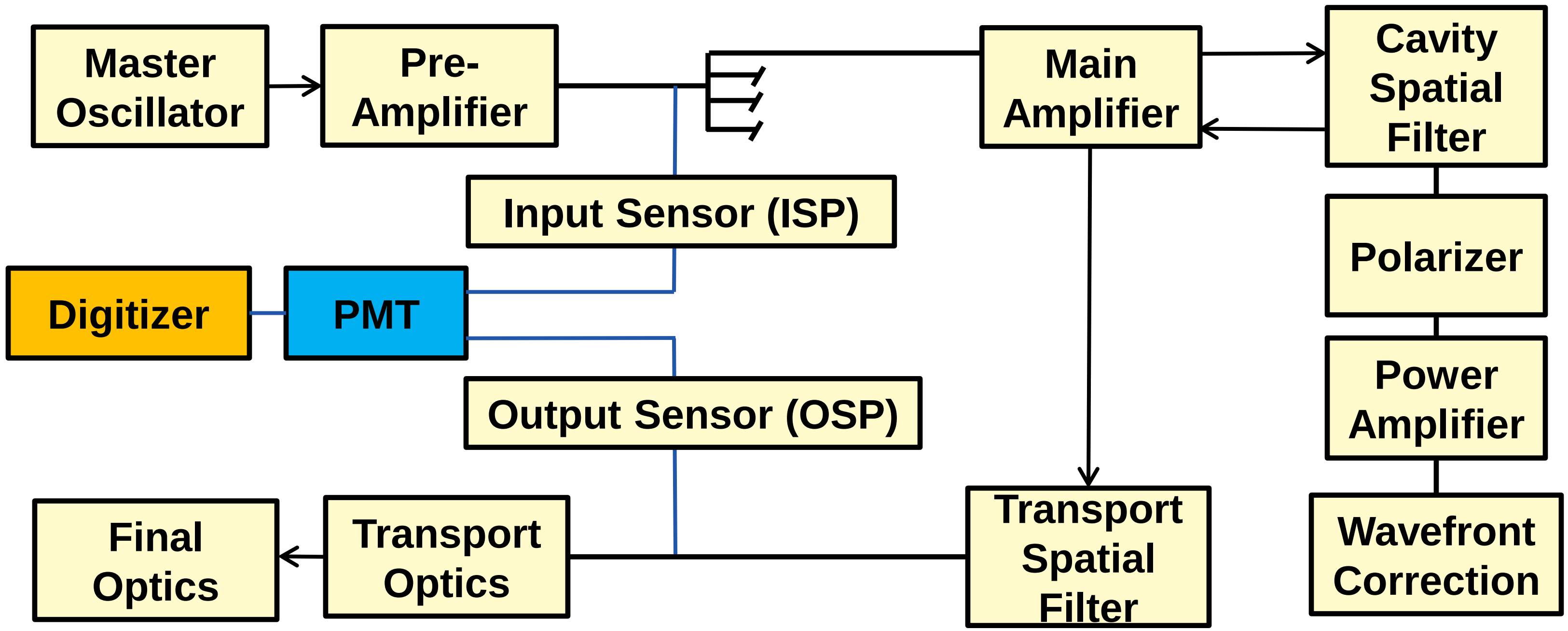
Timing is controlled by the NIF Integrated Timing System (ITS). A fiducial signal is provided for reference.

- A Master Clock drives the Facility Timing Transmitter that produces a serial data stream that is distributed to 14 zones within NIF, up to 500m away.
- Within each zone, the data stream is distributed to as many as 32 local 8-channel delay generators.
- An optical fiducial reference pulse is generated in the MOR, split, and distributed throughout the facility by fixed fiber lengths.



The ITS controls hundreds of devices, and the fiducial provides a precise, stable reference for timing measurements.

Laser pulses are sampled before and after the main amplifiers and monitored for timing.



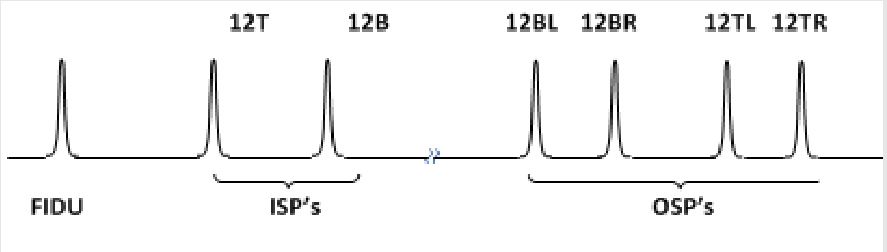
- Each Input Sensor Package (ISP) samples the pulse for a quad before the 4-way split into beams, Output Sensor Package (OSP) samples 2 beamlines in the quad after amplification and before the target chamber
- Beams are initially timed to Target Chamber Center (TCC) individually relative to the fiducial using the Pulse-Synch target
- A reference time is established for pulse arrival on the ISP relative to the fiducial

The 48 ISP signals are the primary laser timing measurements for each shot. The OSP timing measurements confirm these.

Laser timing on a shot is derived from power traces recorded on the Input and Output Sensor Packages

- **For each quad, reference times are established during PulseSync measurements.**
- **Jitter in the scope is removed using the fiducial.**
- **Since the path lengths are fixed, the arrival time for beams in a quad is given by**
  $t = (t_{shot}-t_{ref}) - (fidu_{shot}-fidu_{ref})$
- **Pulse times are measured using a midpoint technique developed by Lerche et al. for symmetric pulses (impulses).**
- **For asymmetric/shaped pulses, timing is derived from 50% of the first rise.**

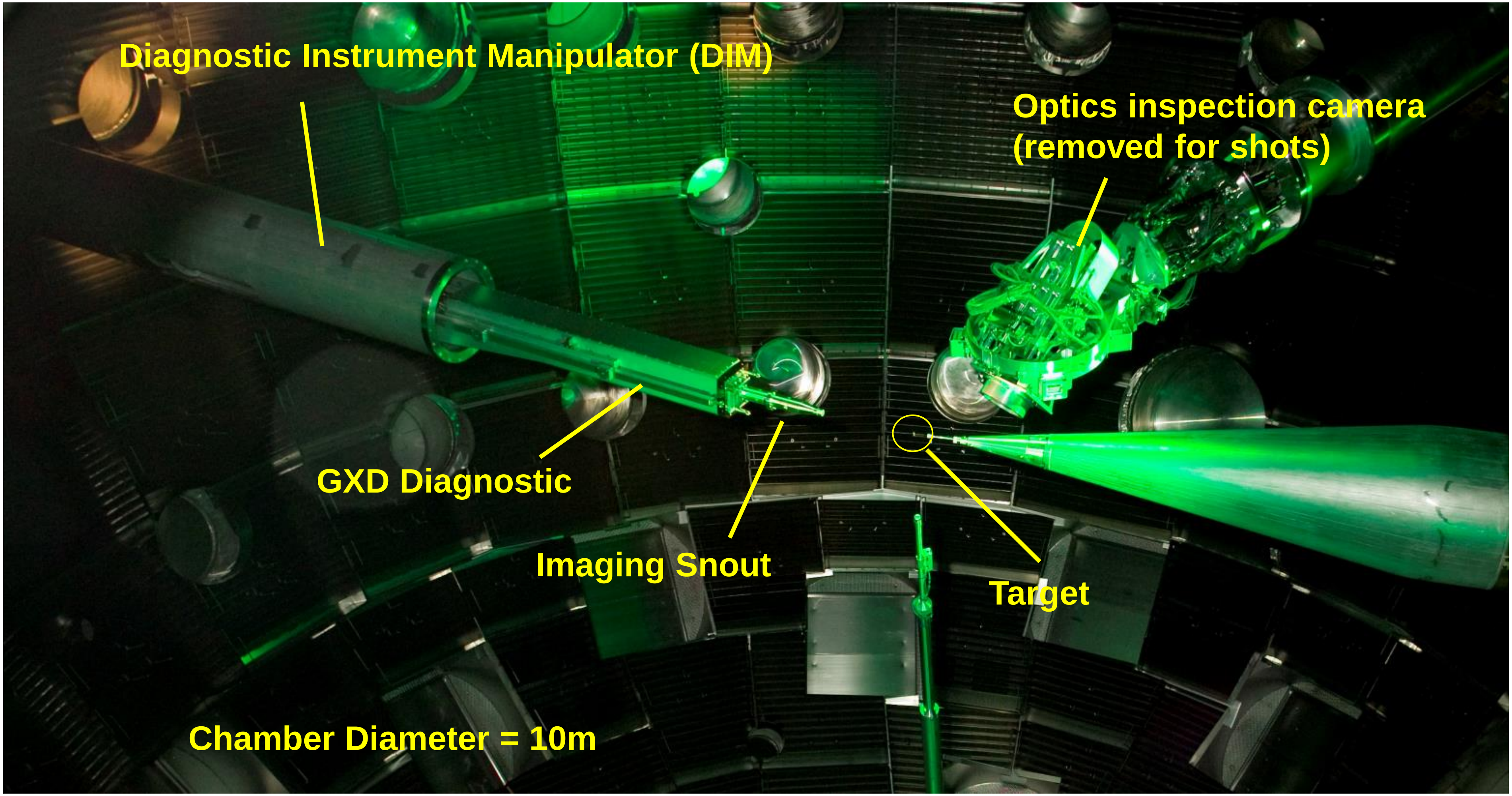
Power Sensor Data for Bundle 12



A single trace contains time-multiplexed data for both quads (input) and half of the beams (output) in an 8-beam bundle.

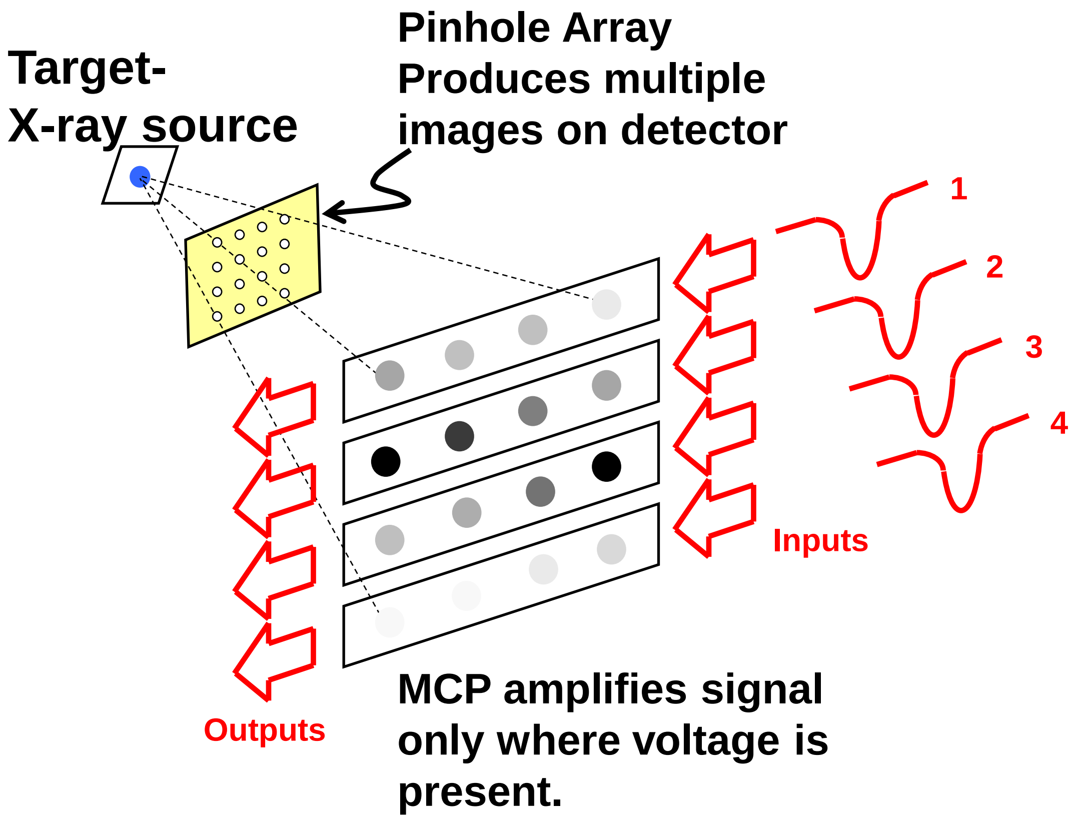
These timing data are needed to establish timing for instruments that image the result of interactions between the laser and target.

X-ray imaging diagnostics are inserted into the NIF target chamber close to the target.



Long cables are needed for control and monitoring.

Gated x-ray detectors (GXD's) are used at the NIF to image transient phenomena.



Gating Pulses

~220 ps transit across strip
~100 ps FWHM
200ps stagger (typical)

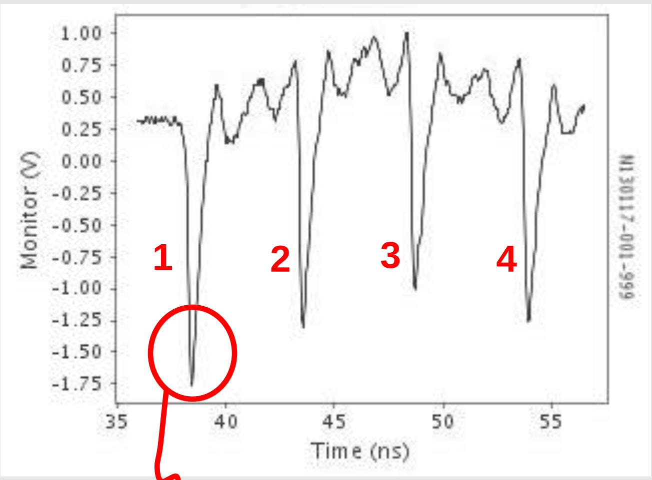
There are a variety of gated x-ray detectors in use at the NIF. Results here are for CCD-based GXD's, but other diagnostics perform similarly.

The electrical gate pulse from the GXD is recorded relative to the fiducial to verify the trigger time.

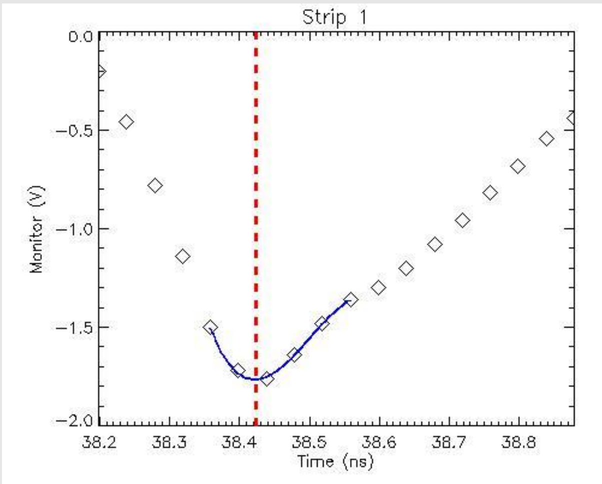
- **Typically, gated x-ray imagers have 25ps RMS trigger jitter.**
- **The gate pulses are time-multiplexed at the output and recorded with a digitizer with 40ps sampling.**
- **The actual GXD trigger time is derived from the first peak using cubic interpolation to achieve 10-12 ps (RMS) resolution.**
- **The timing is referenced to the fiducial signal that is recorded on a separate channel of the digitizer.**
- **Dedicated timing shots are used to establish reference times. The following slides show an example.**

The monitor signal connects the image to the time it was recorded.

GXD Monitor Trace

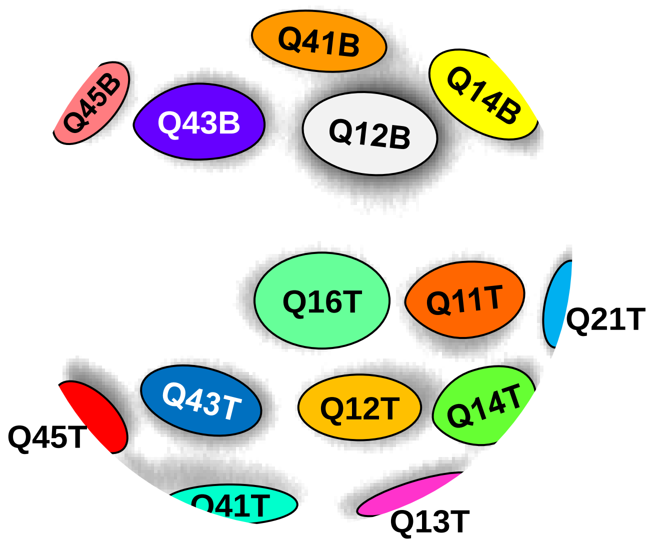


First Peak



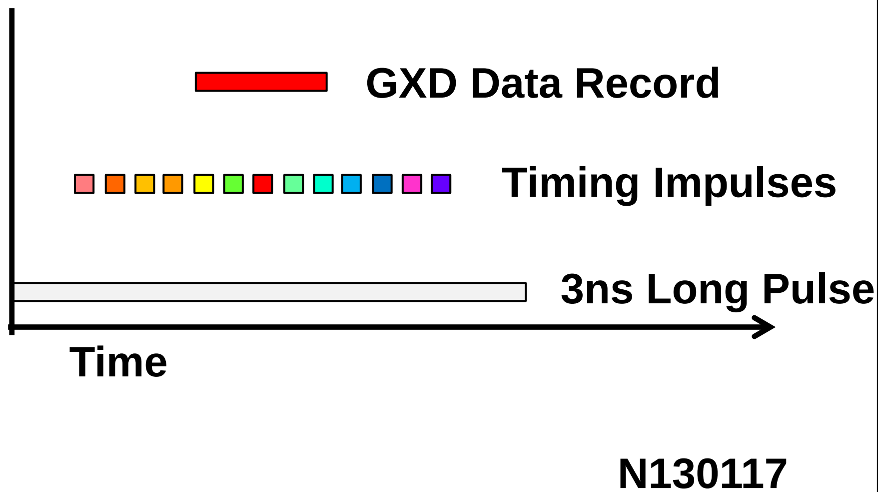
The beam spots form distinct patterns in space and time that facilitate analysis.

Beam pointing on Target



All 4 beams in each quad are overlapped in space & time.

Beam timing



The detector is timed to capture the center of the impulse sequence.

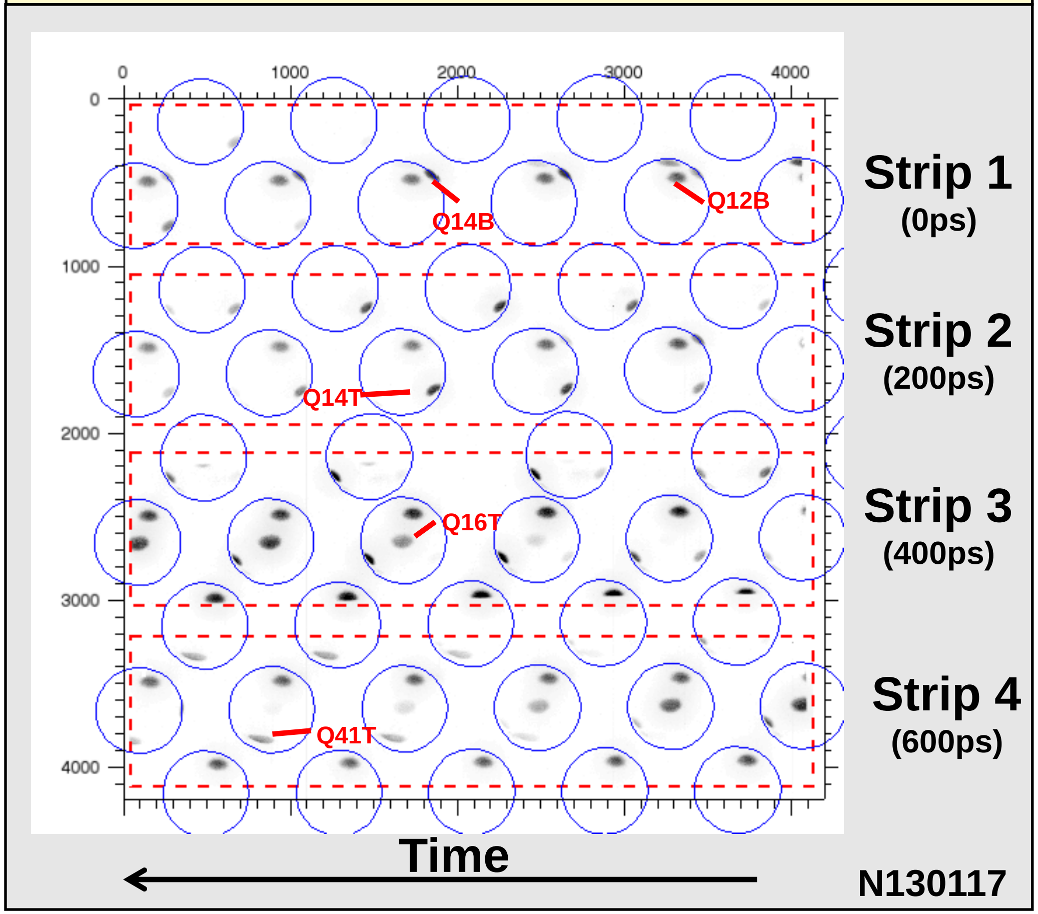
- Quad pointing and timing is arranged for optimal spatial separation and temporal coverage. (100ps impulses)
- Long flat-in-time pulse (3ns) aids pattern recognition and provides in-situ flat-field measurement.

Spots are separated in space and time to provide unambiguous time information.

After the shot, the first analysis task is to associate image features with beams.

- **Strip boundaries are established during pre-installation testing.**
- **Pinhole image spacing gives a measurement of magnification (inferred pinhole distance from target).**
- **The long pulse provides positive identification of pinhole images since it is visible throughout the entire sequence.**
- **Signals due to impulses produced by other quads are identified by their relative positions and intensity histories.**

Sample GXD Image

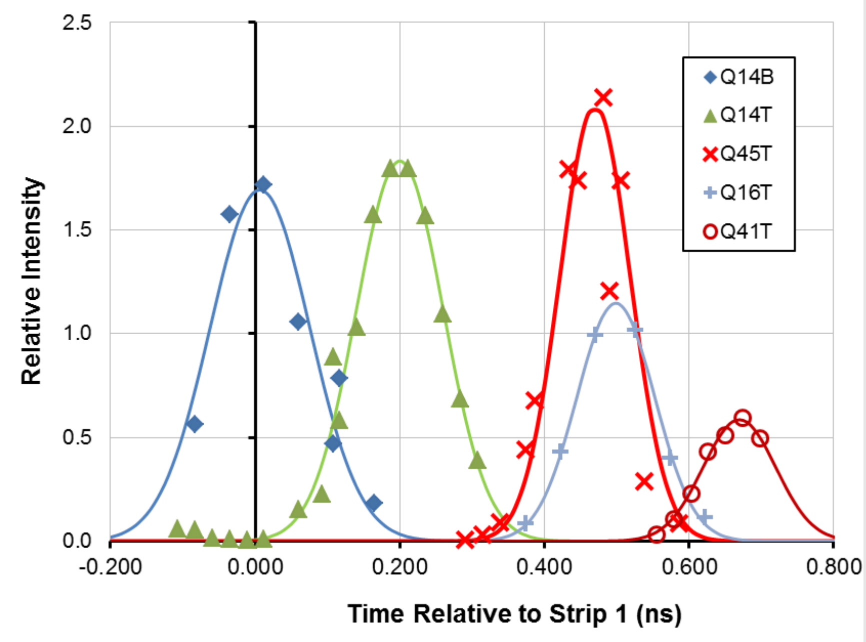


The experiment has been designed to facilitate image interpretation.

The exposure of the beam spots are analyzed to more accurately determine the x-ray pulse timing.

- The relative time associated with each spot is determined by:
  - — Horizontal Location (distance from center /gate velocity)
  - — Strip Gate delay
- Mean intensity is normalized by the flat-top spot intensity within the same image to minimize effects of gain variation along the strips.
- Intensity profiles are fit with Gaussians to determine peak times.
- Assumption: x-rays follow laser power on target.

Spot Intensity History



The relative peak times for the x-ray pulses are typically measured with a precision of better than 10ps.

The GXD results are combined with laser timing measurements to obtain a monitor reference time.

- The monitor reference time defines the position on the monitor scope record corresponding to a beam at the target chamber center at t=0, relative to the fiducial.
- Several data are used in the reference calculation:
  - Timing of brightest GXD image.
  - Inferred distance from source.
  - GXD monitor and fidu arrival times.
  - Measured quad arrival times.
  - Path length correction due to target diameter.
- Results from several quads are averaged to reduce the overall uncertainty.
- Error propagation estimates overall uncertainty of 25ps for each individual measurement, or about 12ps by averaging results from of 4 quads.
- The reference time is used to obtain timing for subsequent shots:

$$t_{GXD} = (Mon - Mon_{Ref}) - (Fidu - Fidu_{Ref}) + distance/c$$

Example

Description	Q14B Value
Impulse at TCC (ns)	3.258
Path correction (ns)	0.011
Inferred MCP distance (mm)	1288
Time of Brightest Image	0.007
Monitor time (ns)	38.423
Monitor reference (ns)	30.887
Fidu time (ns)	-529.243
Monitor-fidu reference (ns)	560.130

Timing accuracy depends on reference accuracy and system stability.

Results from repeated timing shots show excellent reproducibility.

- NIF shots are valuable, so repeats are infrequent.
- GXD's occasionally participate while other diagnostics are timed, providing duplicate measurements.
- Path lengths, fiducial distribution, laser diagnostics, and target diagnostics are all very stable.
- Long path lengths involved:
  - Cables from diagnostics.
  - Fiducial distribution fibers.
  - Beamlines.
- The GXD's were removed/installed several times over the period studied.

Instrument		Reference change (ns)	Elapsed Days
GXD1	Pole	0.007	363
GXD3	Equator	0.002	45
GXD3	Equator	0.006	3

Shot	GXD1 Mon-fidu reference (ns)	GXD3 Mon-fidu reference (ns)
N120105	632.243	-
N120302	-	560.168
N130103	632.250	-
N130114	-	560.170
N130117	-	560.176

The highly repeatable GXD reference values are a reflection of overall system stability over several months to a year.

Summary

- The NIF Integrated Timing System provides both accurate timing control and a precise fiducial timing reference for laser and target diagnostics.
- Laser timing is monitored using power sensors.
- Target diagnostic timing is synchronized with the NIF main laser using dedicated shots.
- We have designed experiments that provide robust and accurate timing for x-ray imagers. This study focused on GXD’s.
- Timing reference measurements for GXD’s show high degree of reproducibility and no evidence of drift over periods up to one year.


NIF