National Ignition Facility

Automatic Alignment System for the National Ignition Facility

Karl C. Wilhelmsen
Lawrence Livermore National Laboratory, USA

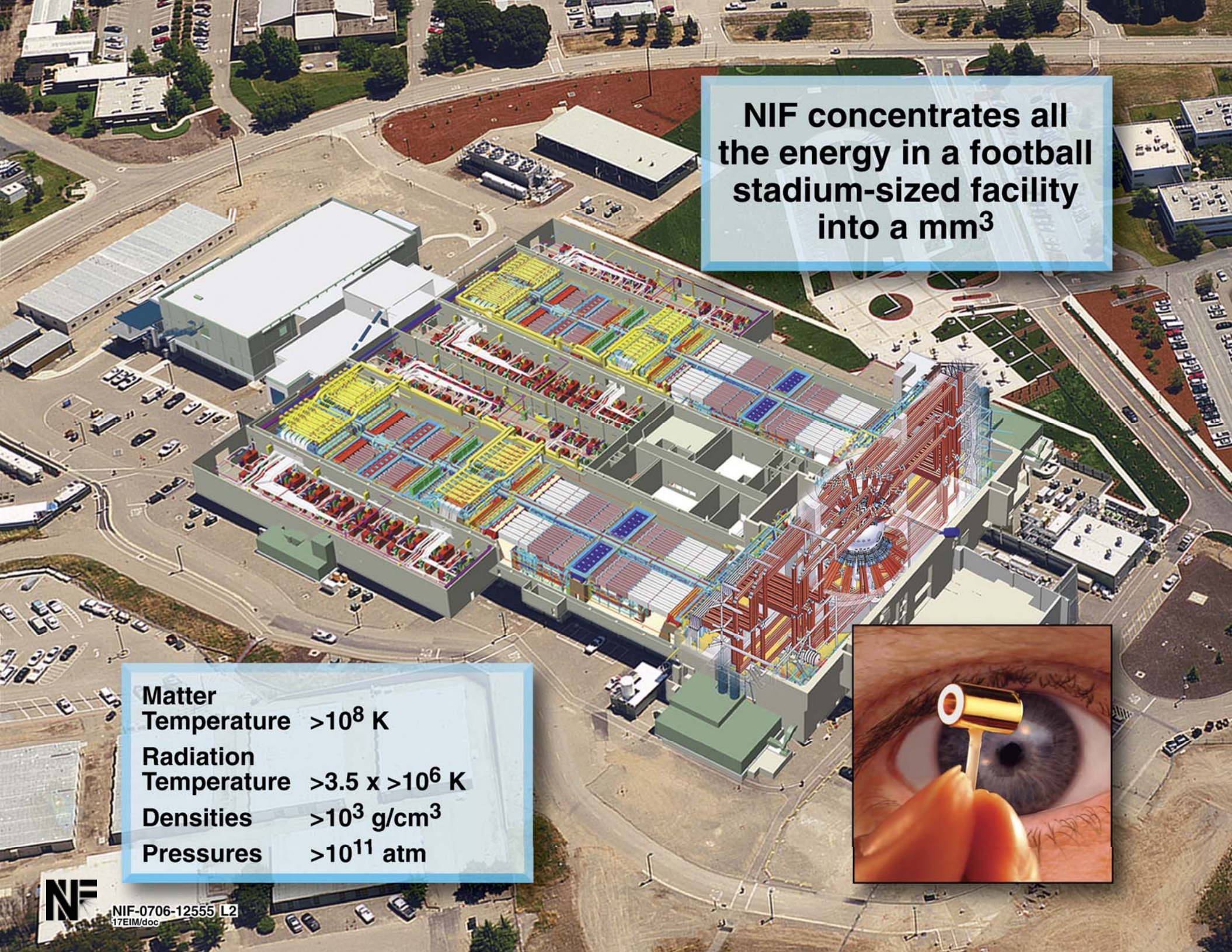
2007 International Conference on Accelerators and Large Experimental Physics Control Systems
Knoxville, Tennessee October 14, 2007

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

Agenda

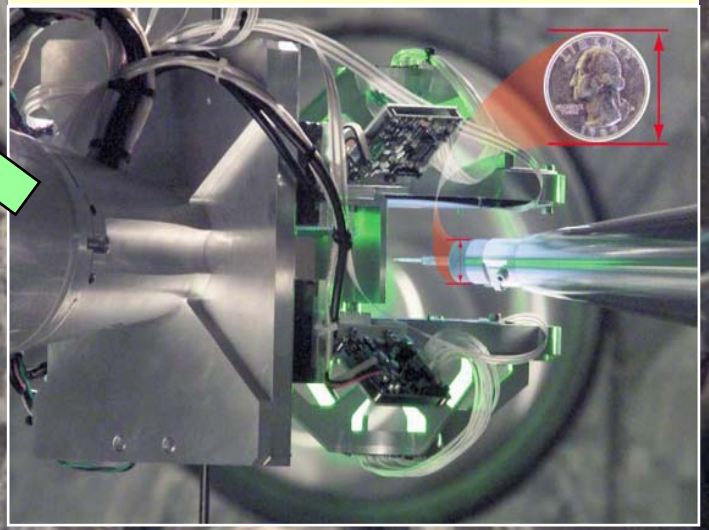
The National Ignition Facility

- Introduction to NIF and automatic alignment
- Control system architecture
- Coordination and scaling
  - 3,800 closed loop adjustments using 12,000 devices
  - Management of shared laser components
- Image processing
  - Algorithm robustness in a laser environment
  - Subpixel accuracy
  - Reliability and off-normal image detection


NIF concentrates all the energy in a football stadium-sized facility into a mm3
Matter Temperature >10^8 K
Radiation Temperature >3.5 x >10^6 K
Densities >10^3 g/cm^3
Pressures >10^11 atm
NIF-0706-12555 L2
17EIM/doc

Beams are aligned along NIF's 500-meter path to focus on the mm-size target within 10 microns

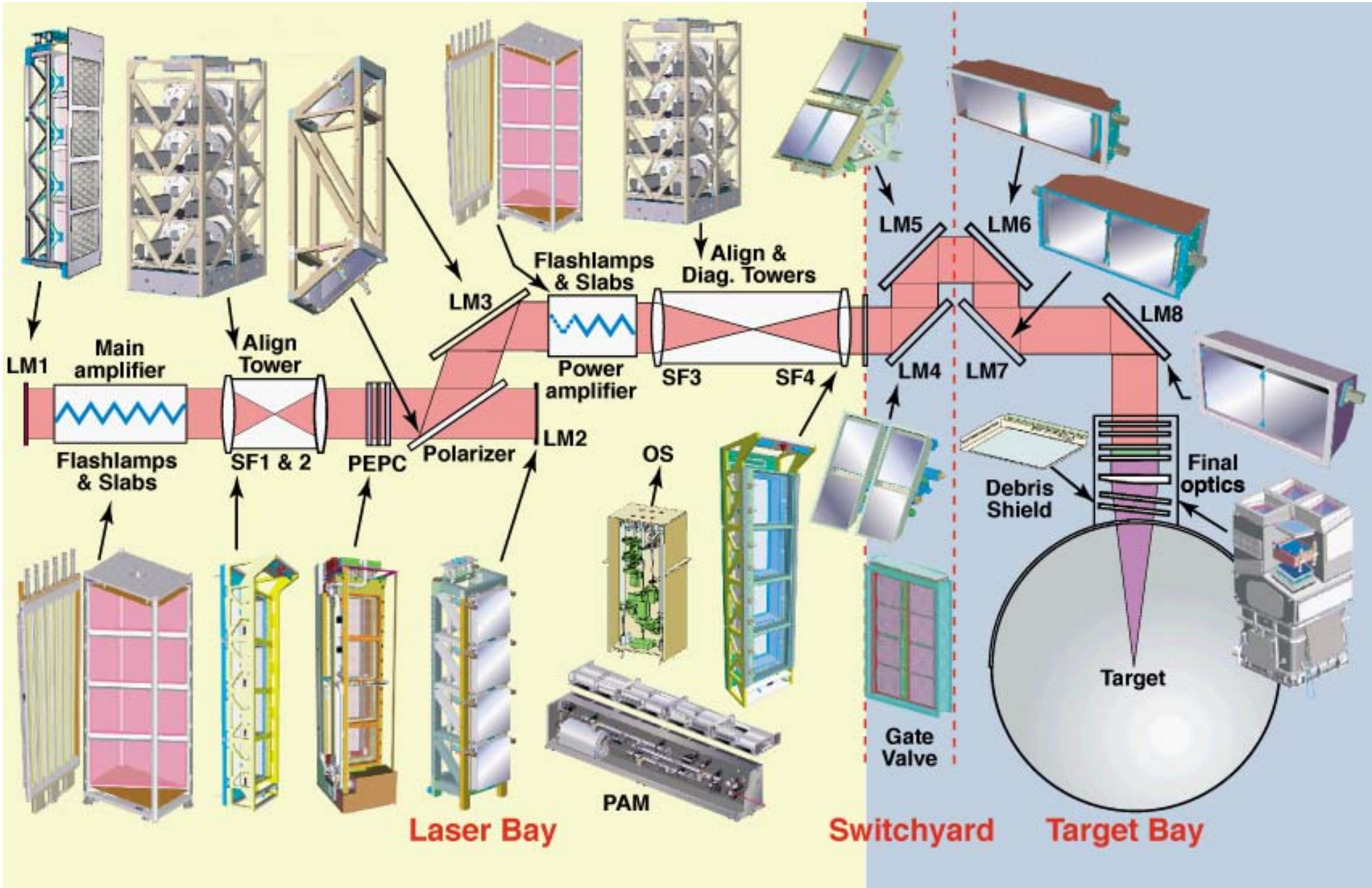
Target Alignment Sensor



In an analogy to baseball, this requirement is like hitting the strike zone with a pitch thrown from 350 miles away

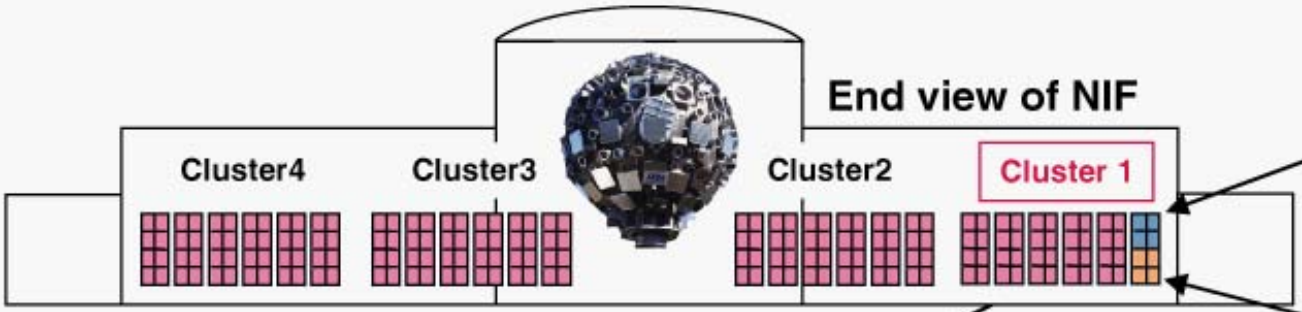
Alignment uses sensors and actuators within Line Replaceable Units

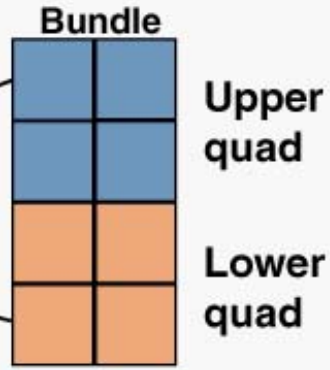
The National Ignition Facility

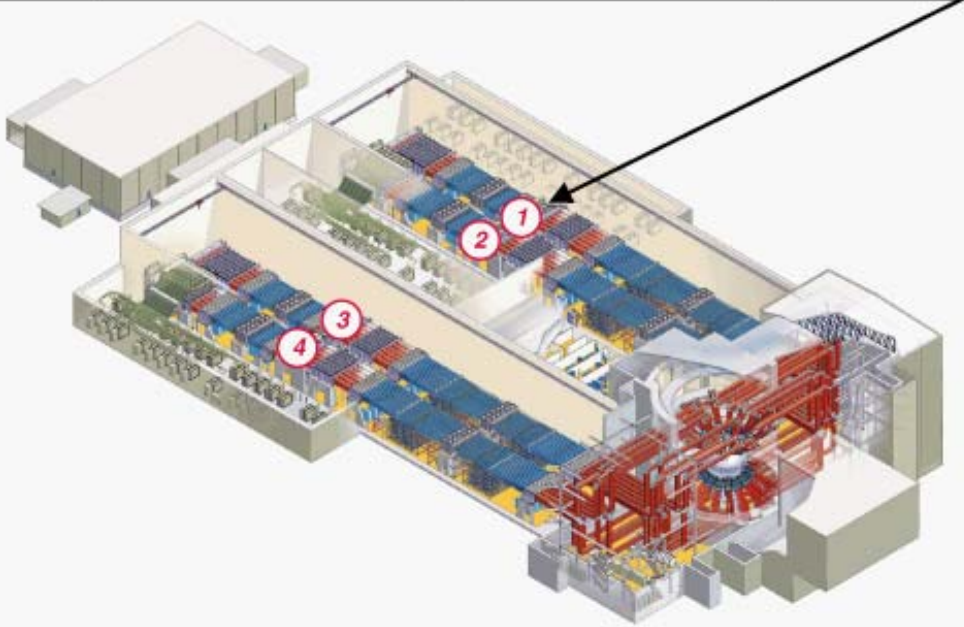


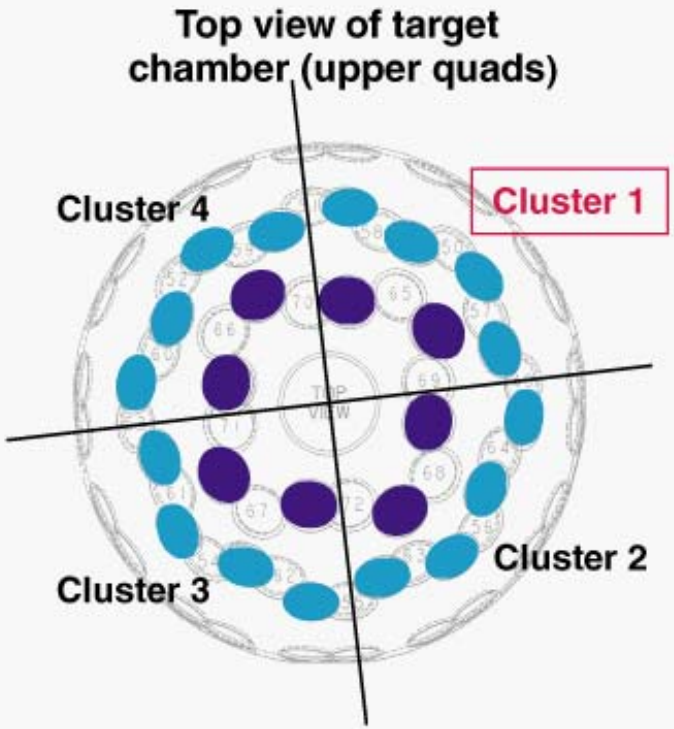
NIF is a 192 beam laser organized into "clusters", "bundles", and "quads"

National Ignition Facility





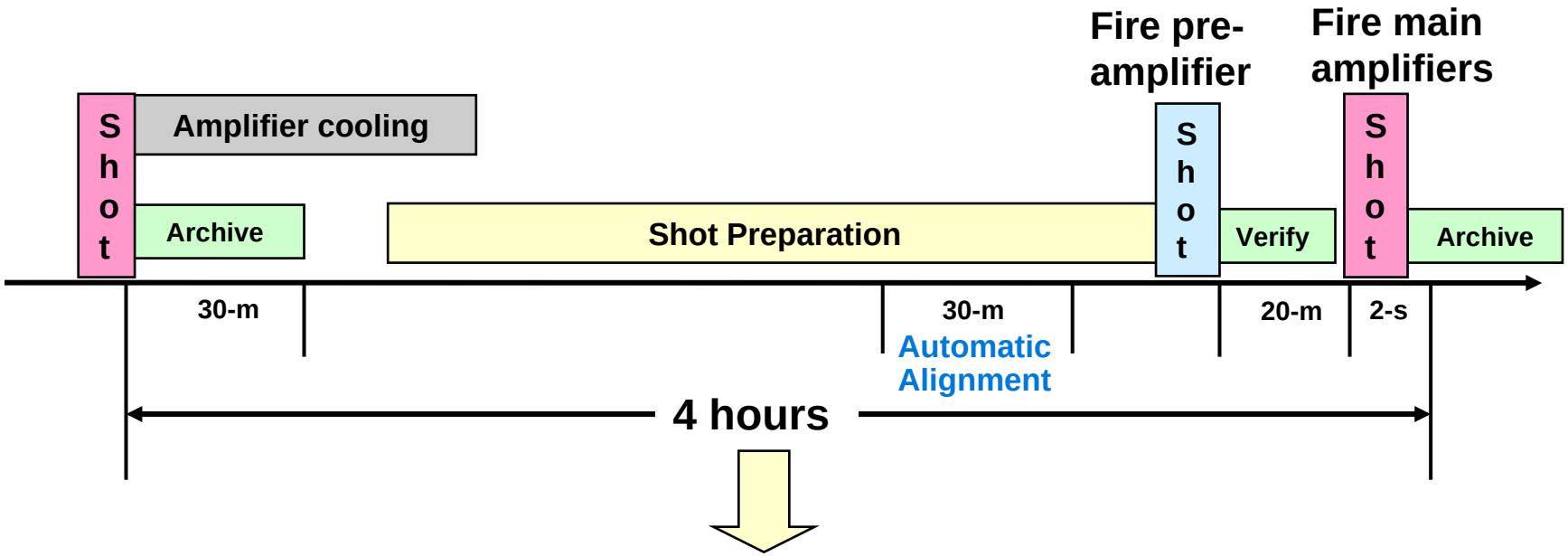




"Quads" are the basic building blocks of a NIF experiment, 4 beams with the same pulse shape and time delay

ICCS shot cycle automatically aligns, fires and diagnoses laser shots every 4 hours

The National Ignition Facility

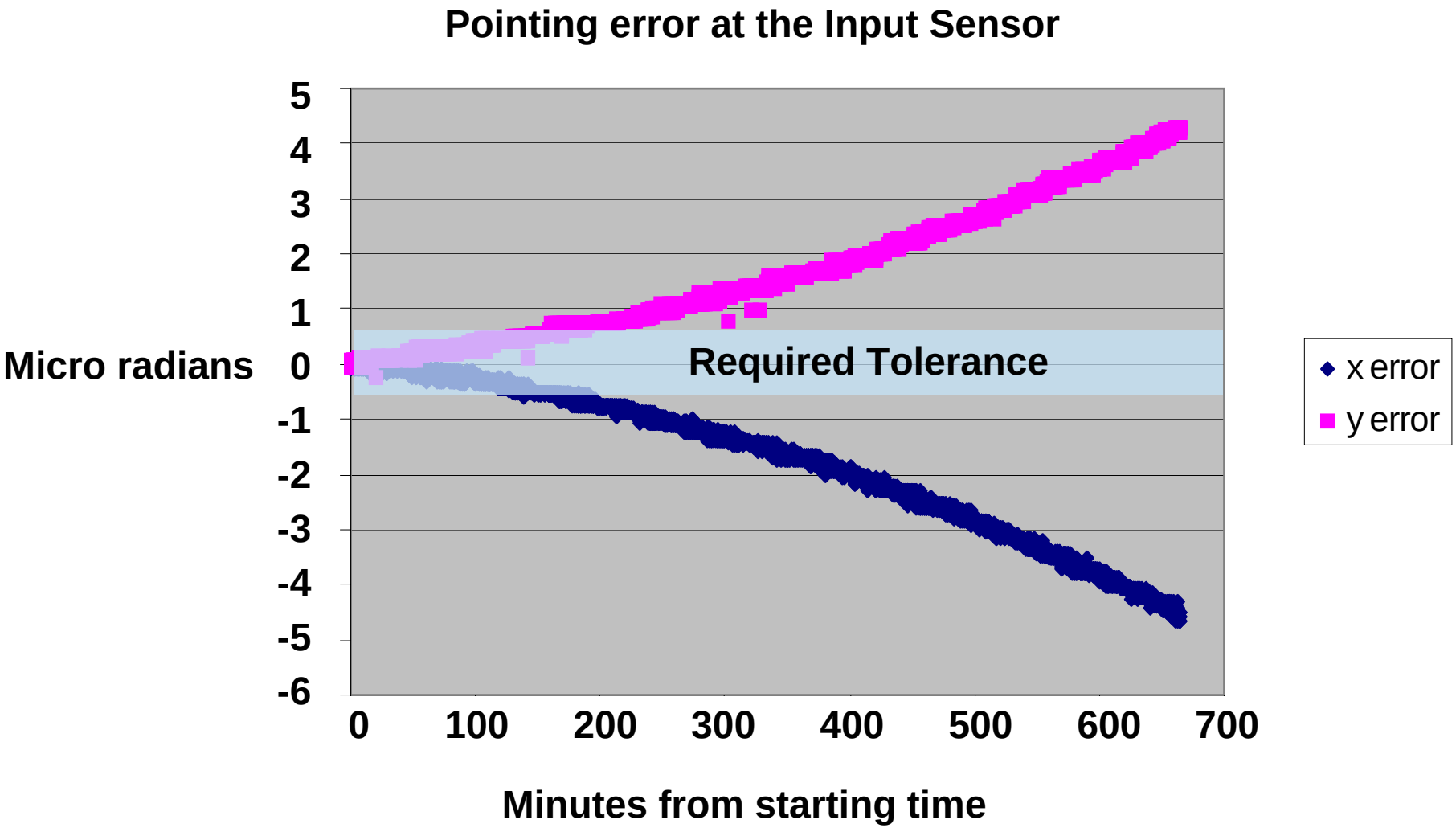


Automated Shot Cycle

- Input shot goals from laser physics model
- Perform automatic alignment
- Configure diagnostics and laser settings
- Conduct countdown (SW: 4-m, HW: 2-s)
- Assess shot outcome and archive data

The automatic alignment system compensates for optical system drift

The National Ignition Facility



Requirements led to significant technical challenges

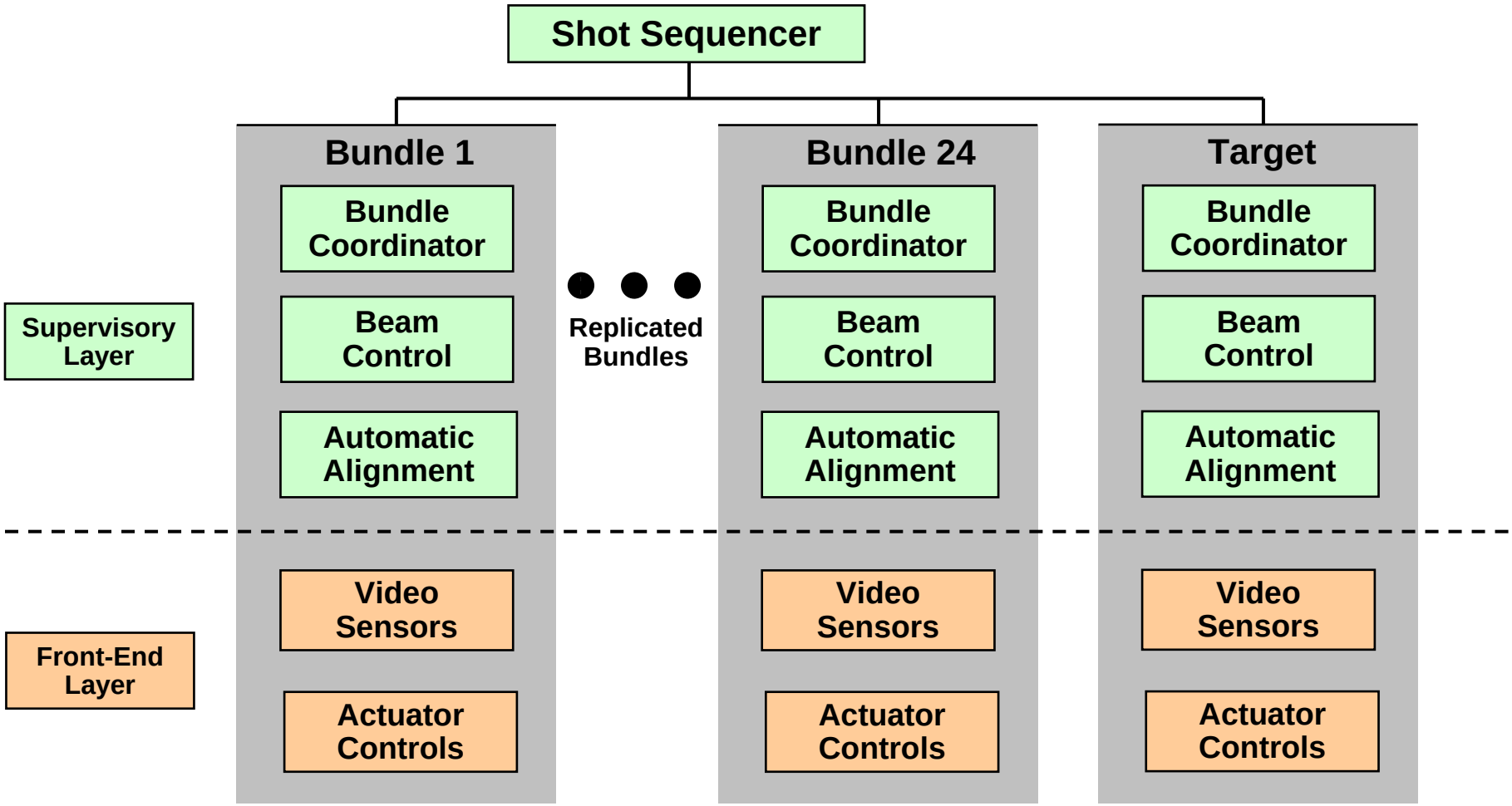
The National Ignition Facility

- Minimize operator effort
  - Situational awareness
  - Manual controls
- Deliver subpixel accuracies
- Algorithms tolerant to
  - Varying light levels
  - Laser diffraction effects
  - Equipment anomalies
- Reject off-normal images
- Rapidly align 192 beams
  - Parallel operation
  - Computational resources
  - Many devices are shared

Single operator oversees Beam Control

The bundle architecture assures full-scale performance of the alignment control system

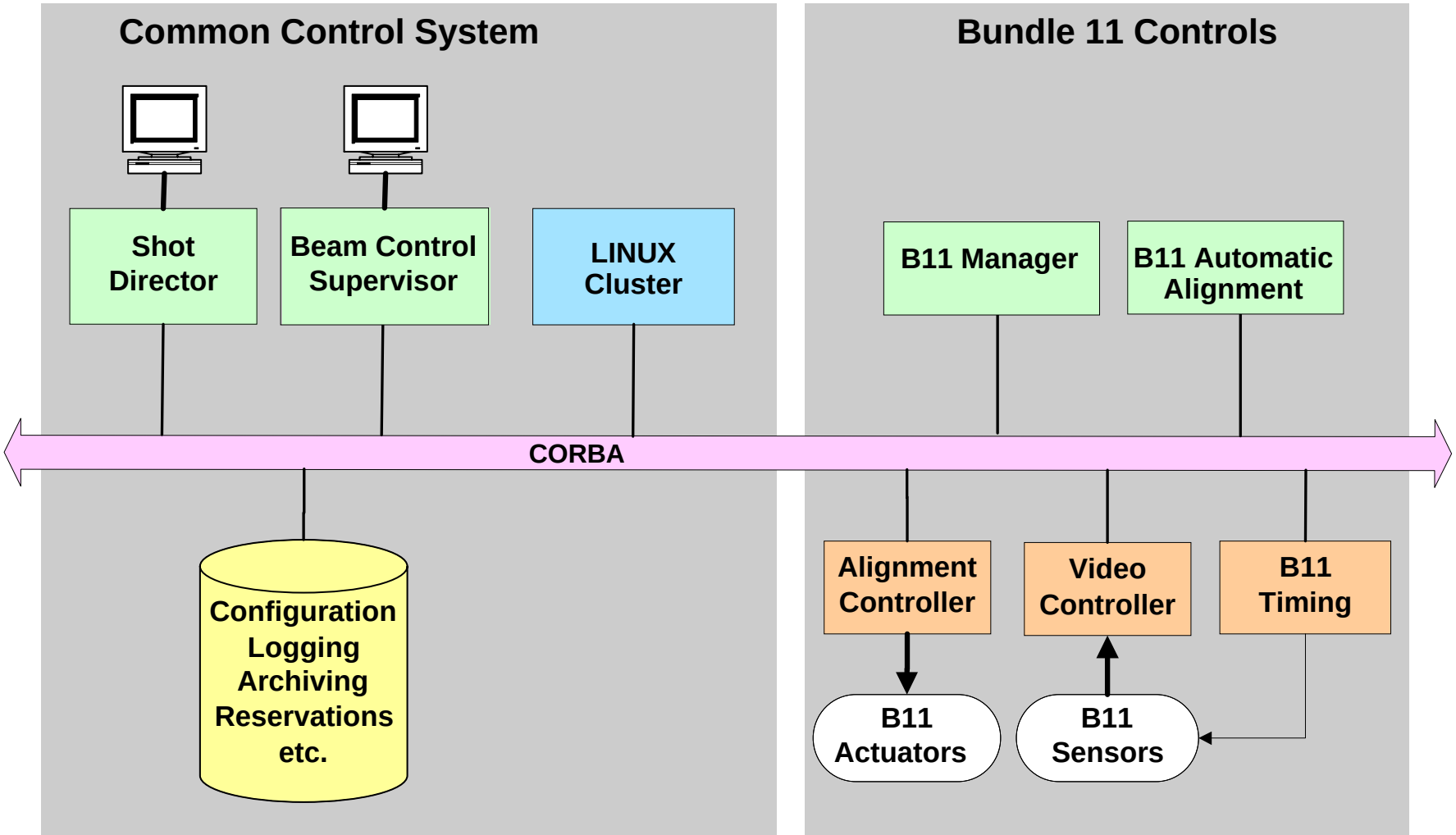
The National Ignition Facility



Replicated bundles are activated by starting new processes in the database

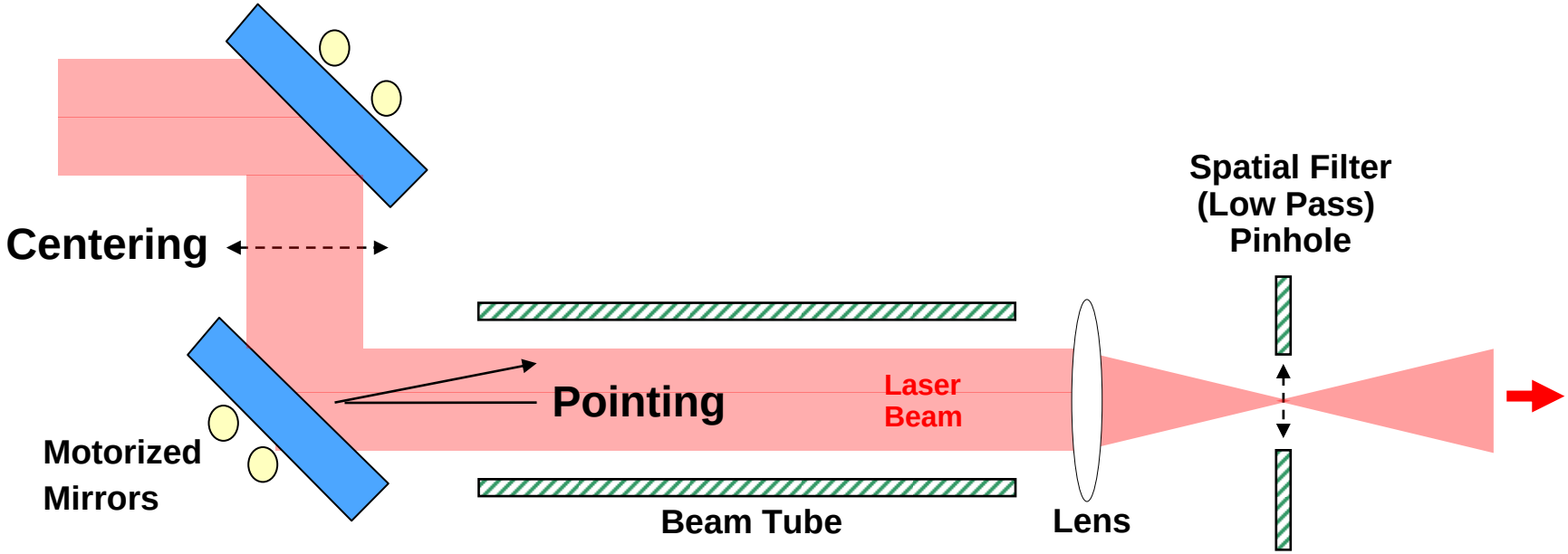
Process distribution example for beam control

The National Ignition Facility



The alignment system maintains the beam within the optical clear aperture

The National Ignition Facility



Centering definition

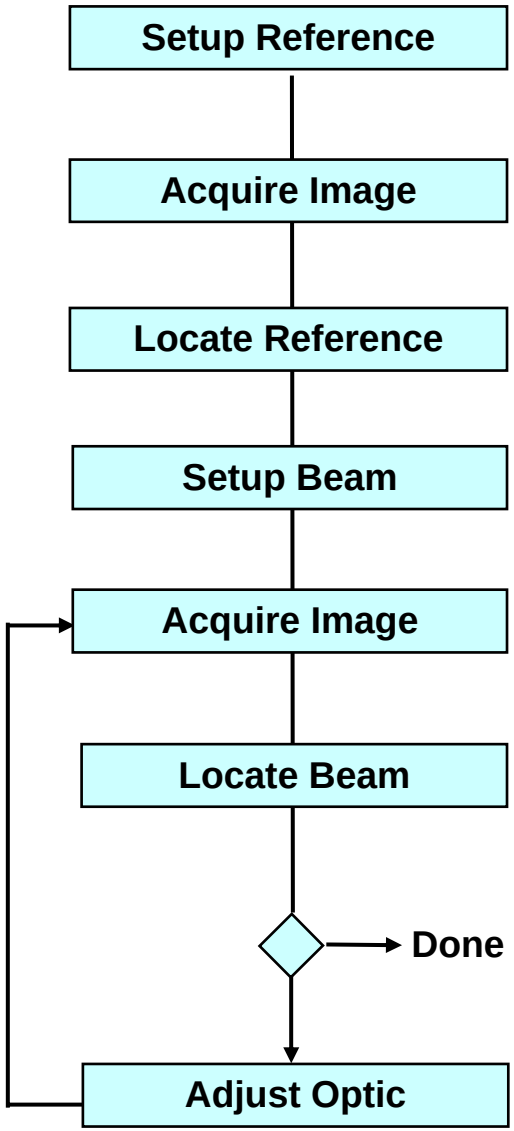
- Translates beam position without affecting pointing
- Sensor configured to near-field mode

Pointing definition

- Adjusts angle of propagation without affecting centering
- Sensor configured to far-field mode

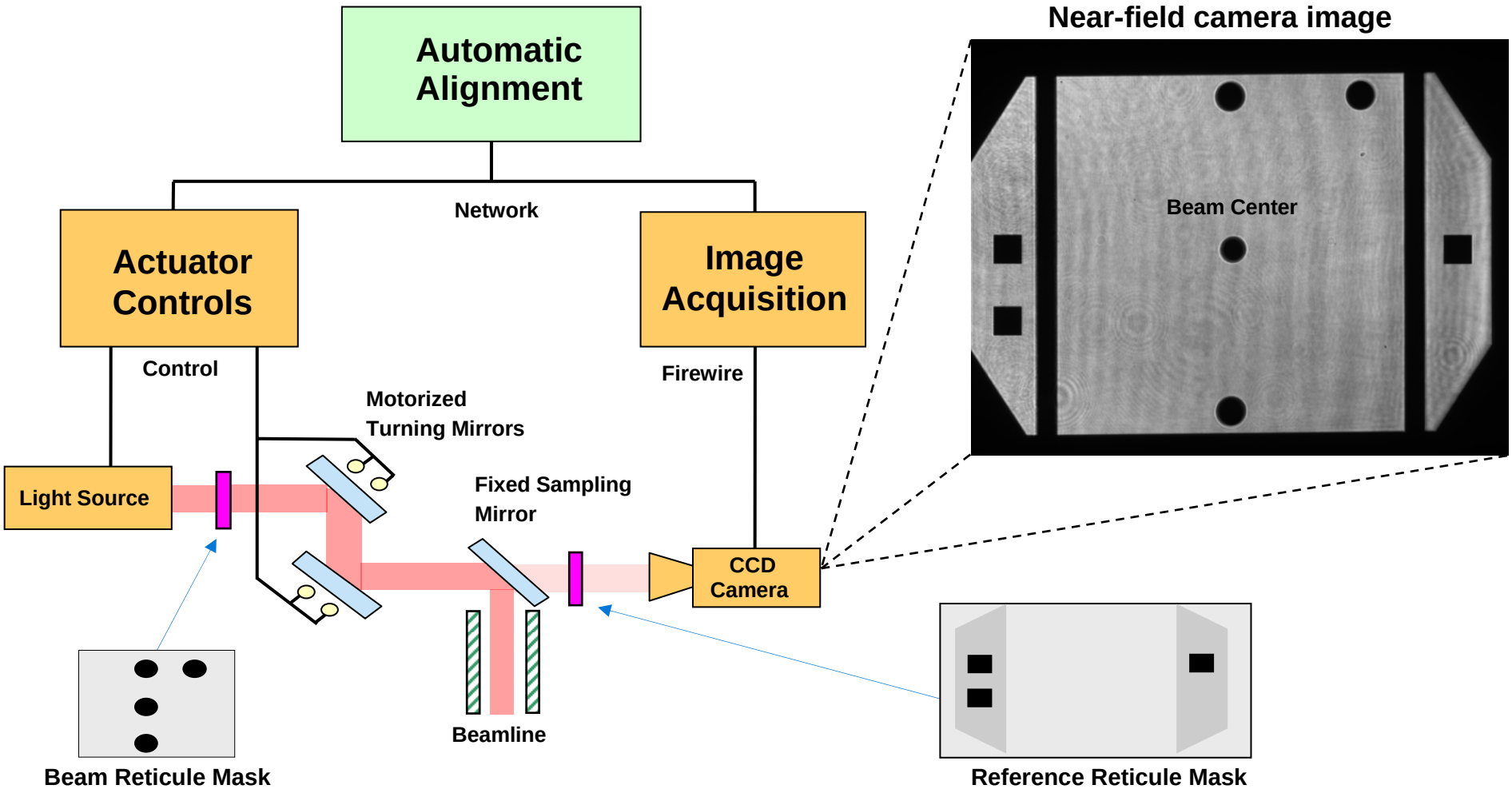
Generic control loop flow diagram

The National Ignition Facility



Centering Alignment Principle

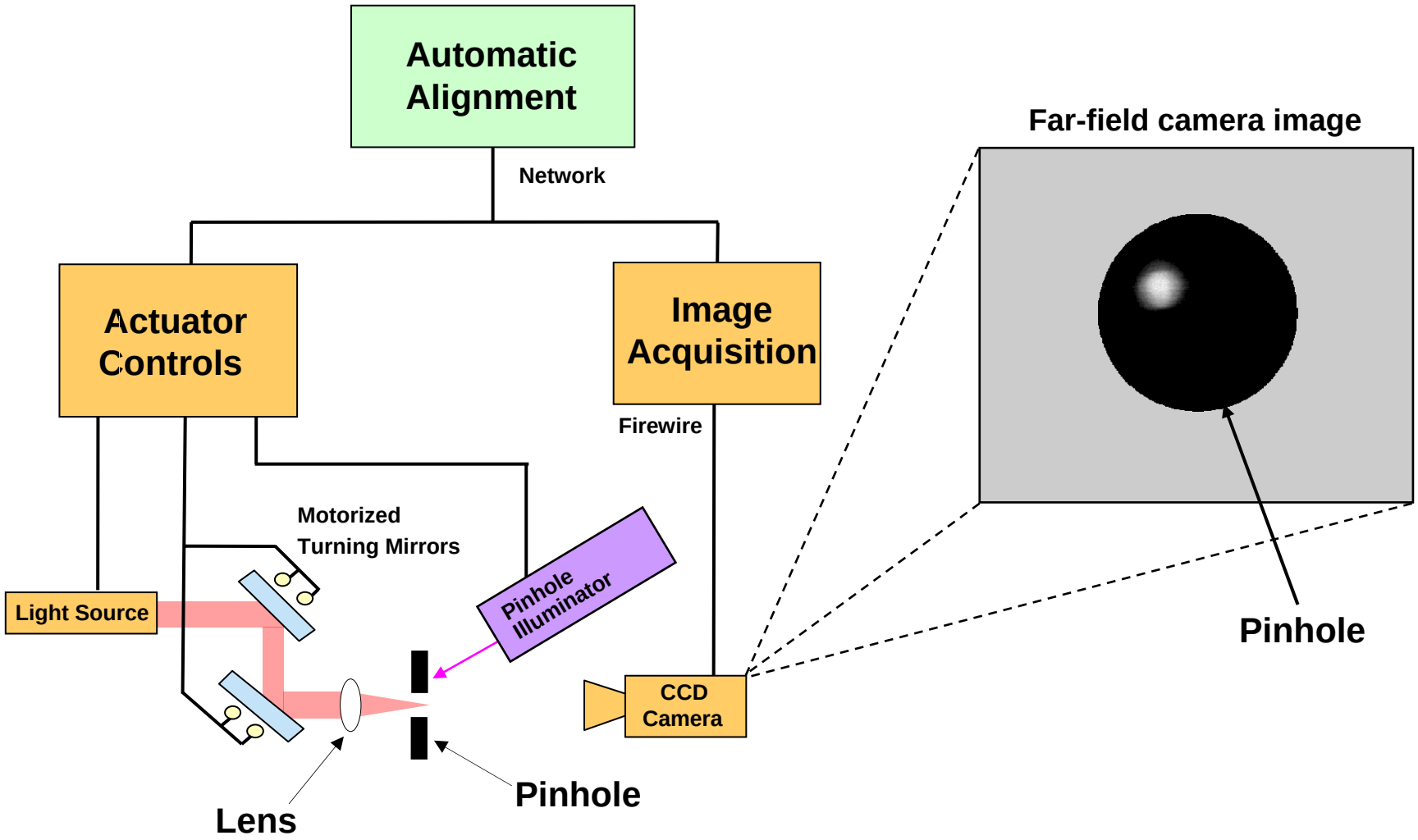
The National Ignition Facility



The image of the beam reticule (circle) is adjusted to the midpoint between the reference reticules (squares)

Pointing Alignment Principle

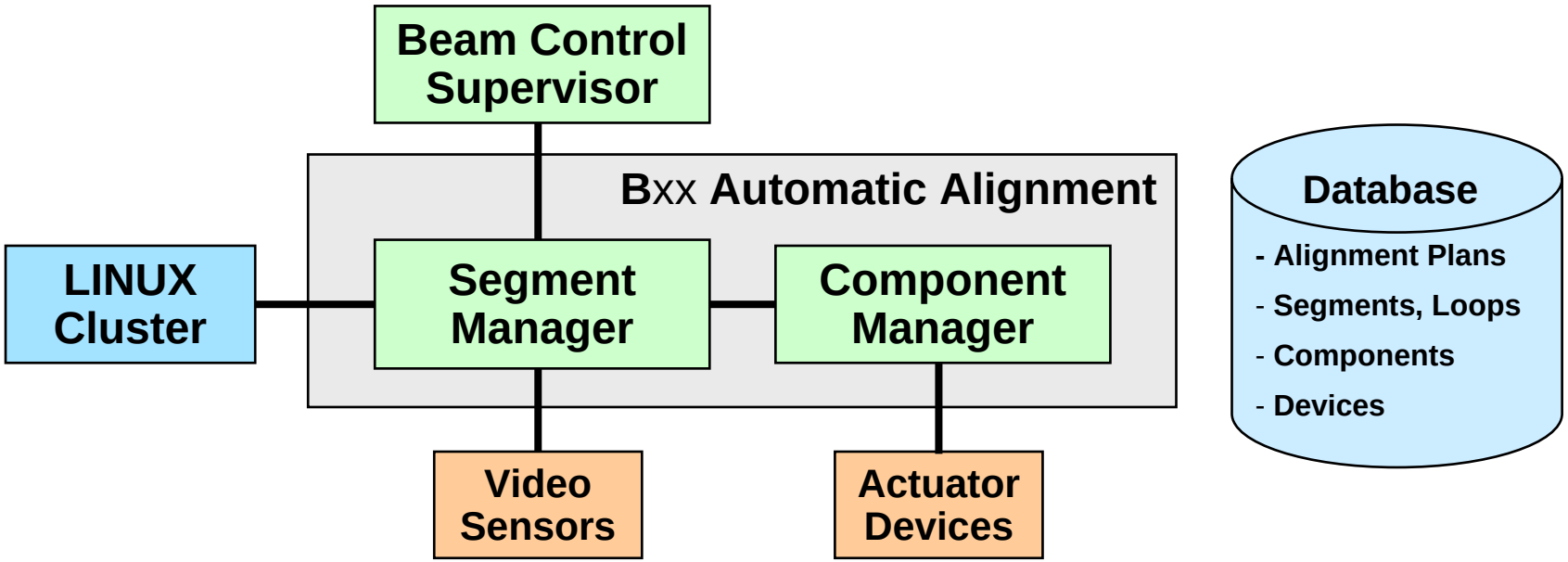
The National Ignition Facility



The source sub-image is aligned to the center of the pinhole shadow

Managers coordinate resources and activities

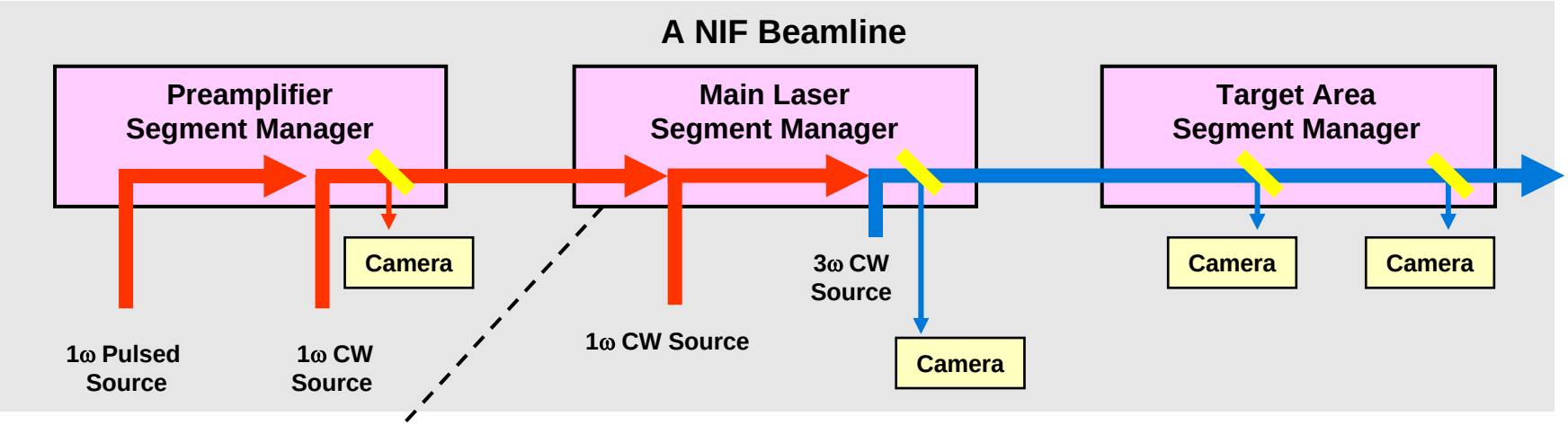
The National Ignition Facility

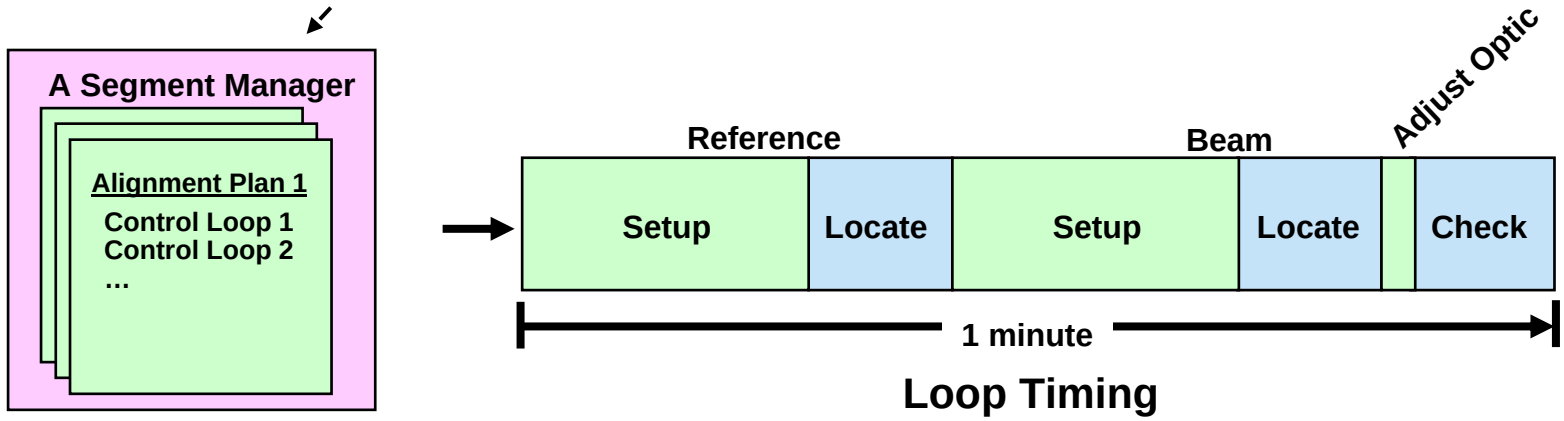


- Supervisor
  - Manual controls
  - Status
- LINUX Cluster
  - Image processing
  - Self-leveling
- Segment Manager
  - Alignment plans
  - Loop definitions
  - Sequence control
- Component Manager
  - Device sharing
  - Throughput optimization

NIF's beamline architecture was designed to permit alignment of segments in parallel

The National Ignition Facility





The Segment Manager executes alignment plans efficiently to achieve the required performance

The Component Manager optimizes task processing throughput

The National Ignition Facility

- Component Managers
  - Orchestrate setting up laser configurations
  - Contain multiple device grouping called mediated components
- Mediated components
  - Manages device positions
  - Can include other mediated components
  - Reservations lock the configuration
- Task queues
  - Requests wait until devices become available
  - Deadlocks eliminated by enforcing priority
  - Queue optimization actively minimizes required movements

The main laser sensor is a mediated component

One out of every four devices in the alignment system are shared

Image processing must always be reliable

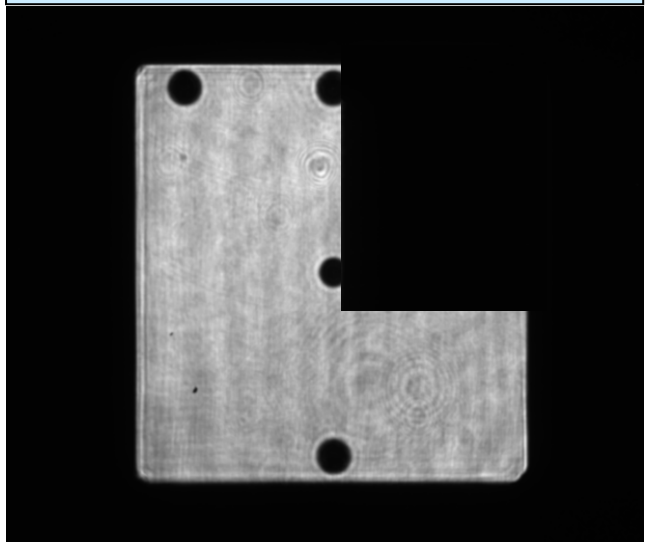
The National Ignition Facility

- **Precision and accuracy required to 0.3 pixels**

- **Robustness is challenged by**
  - **Gradient illumination**
  - **Noise**
  - **Diffraction effects**
  - **Defocus**
  - **Magnification**

- **Discard off-normal images**
  - **Extraneous blobs**
  - **Saturation**
  - **Clipping**

Example of a Clipped Image



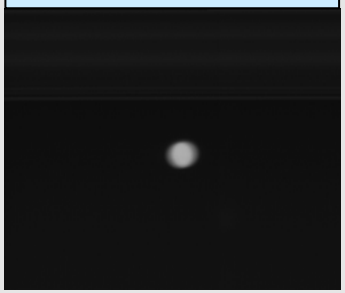
… while still being robust to varying laser conditions !

Many processing algorithms are used …

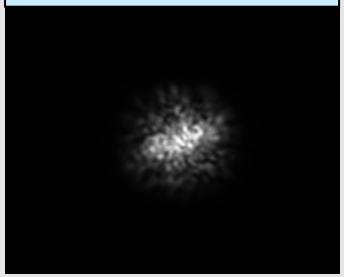
The National Ignition Facility

Weighted Centroid

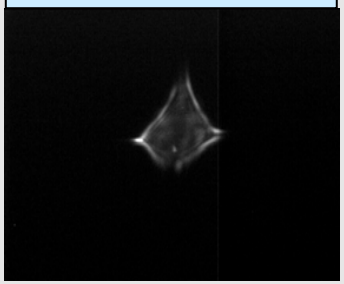
Gaussian Beam



Fiber Source

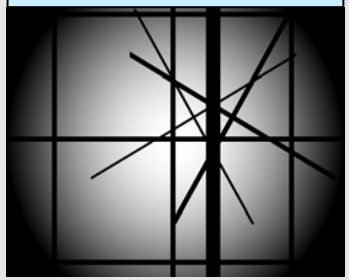


Crystal reflection

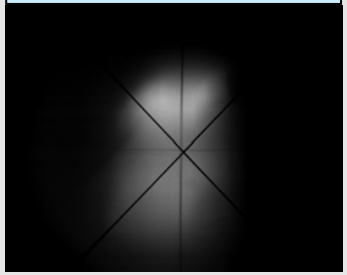


Hough Transform

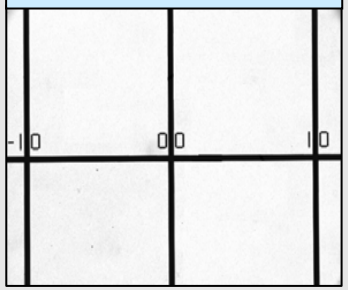
Crosshair Grid



Crosshair Grid

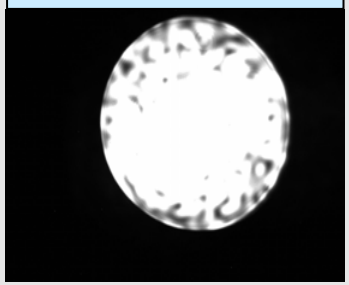


Glass Grid

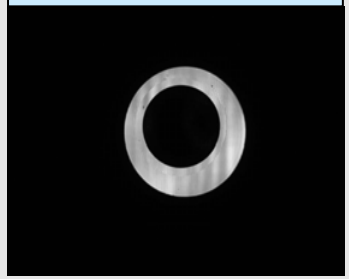


Template Match

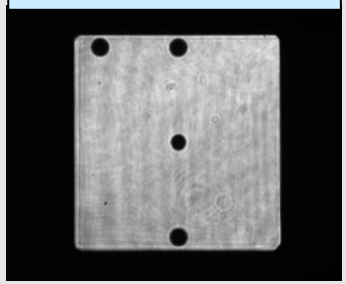
Pinhole



Dark Stop

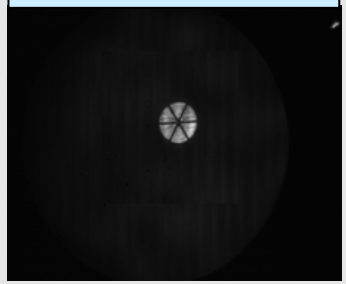


Reticule



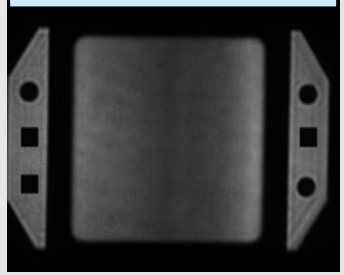
Spiral Search

Corner Cube



Matched filter

Shot Mask



Images undergo three processing steps

The National Ignition Facility

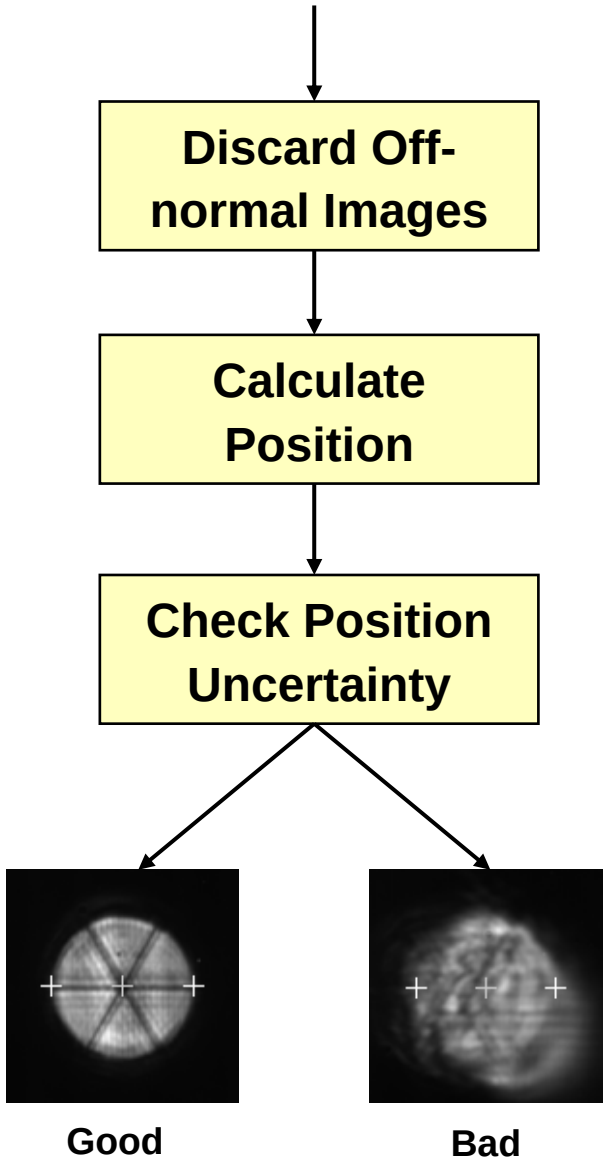


Image quality is measured by estimating algorithm uncertainty

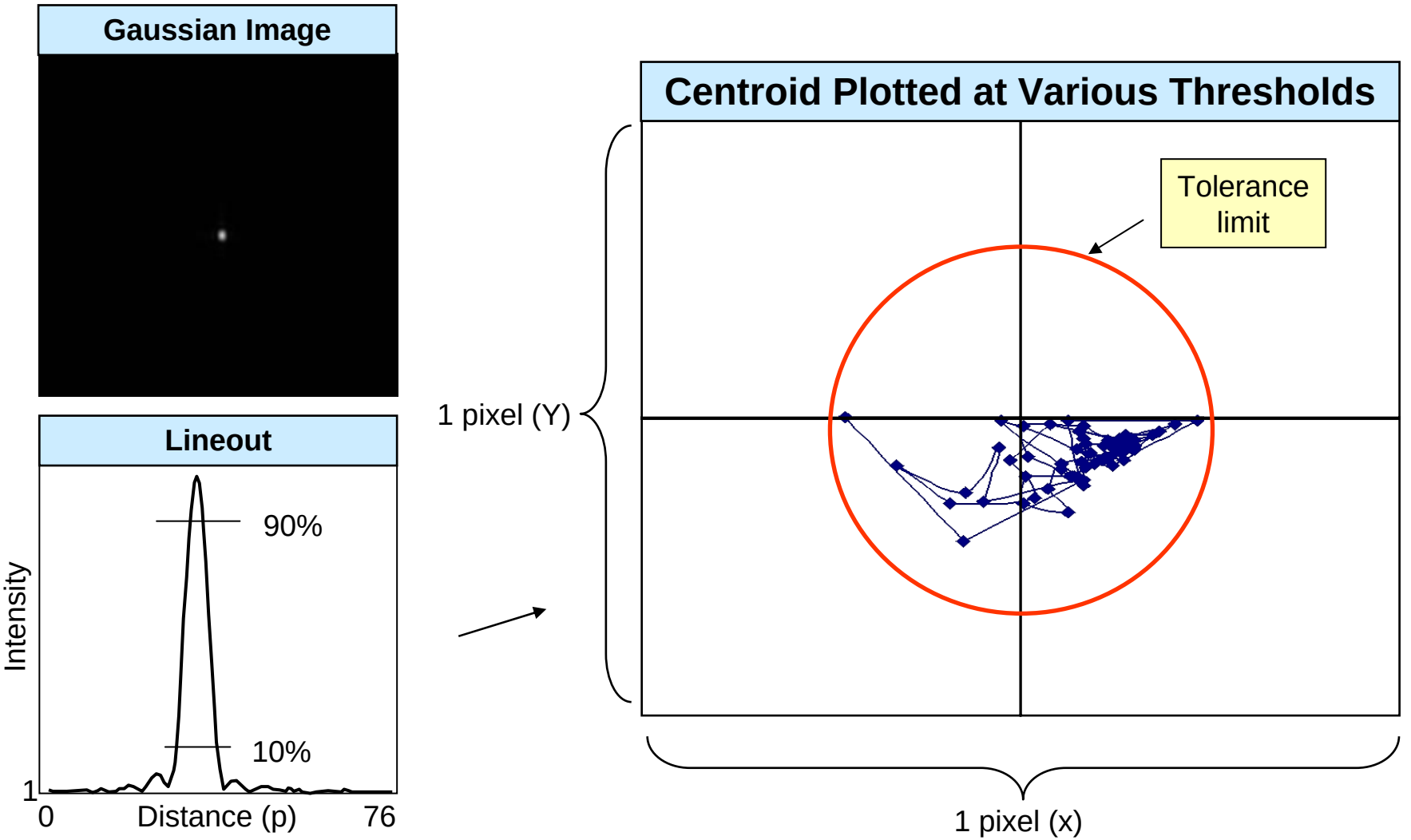
The National Ignition Facility

- Uncertainty Definition
  - Instability in the position determination
  - Obtained by varying either thresholds or noise
- Threshold-based method (e.g. weighted centroid)
  - Image processed with thresholds at 10 different levels
  - Delivers subpixel accuracy as a byproduct
  - Uncertainty: variability of the position estimates
- Noise-based method (e.g. matched filter)
  - Monte Carlo model of known uncertainty is constructed for the image using prescribed amounts of noise
  - Uncertainty: estimated from the model based on noise present in the input image

Low uncertainty confirms a high quality input image, with confidence that algorithm results can be trusted

Example of sub-pixel position estimation confirms accuracy is within tolerance

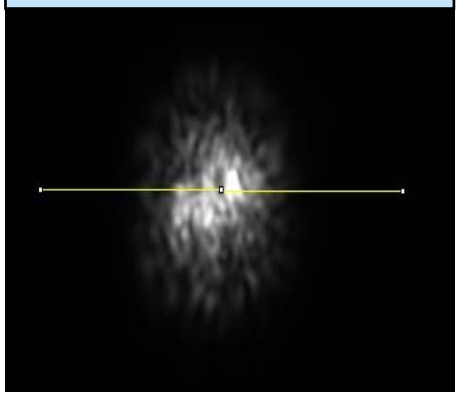
The National Ignition Facility



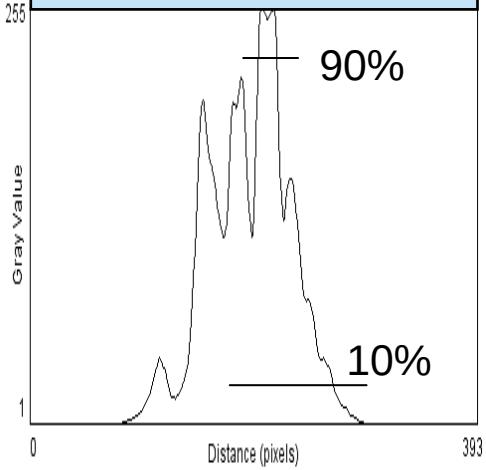
Poor laser wavefront prohibits a successful alignment outcome in this uncertainty example

The National Ignition Facility

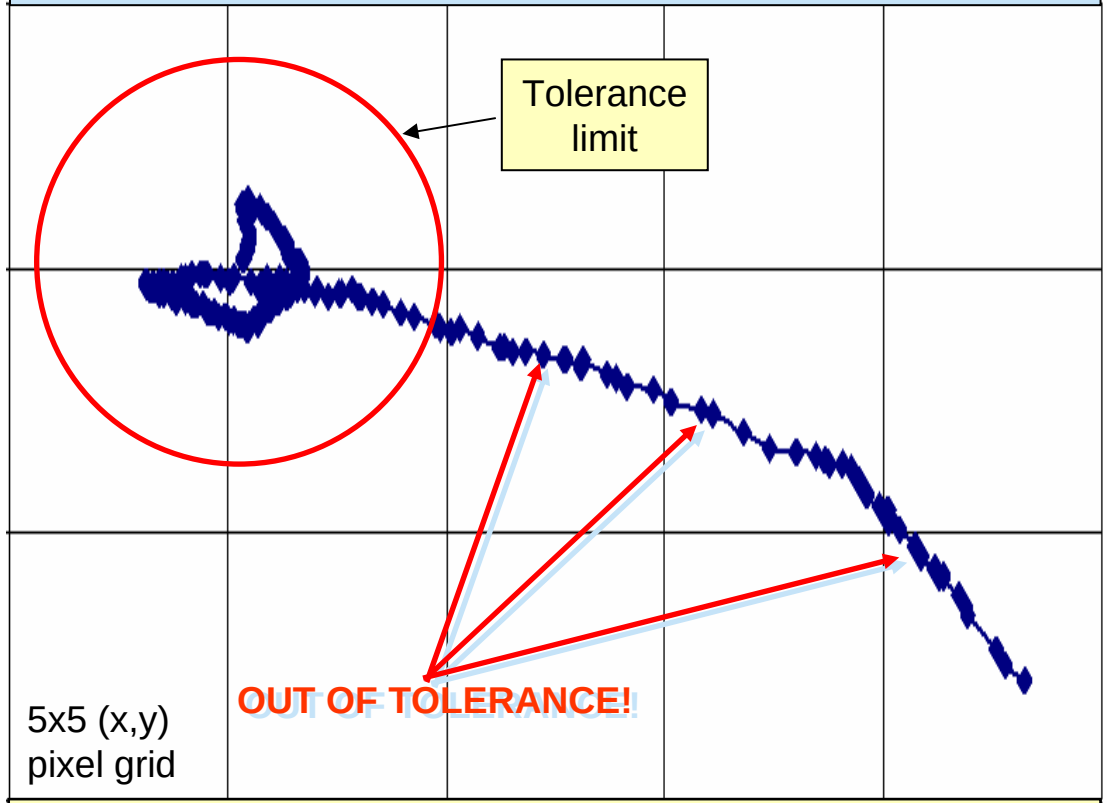
Defocused Gaussian Image



Lineout



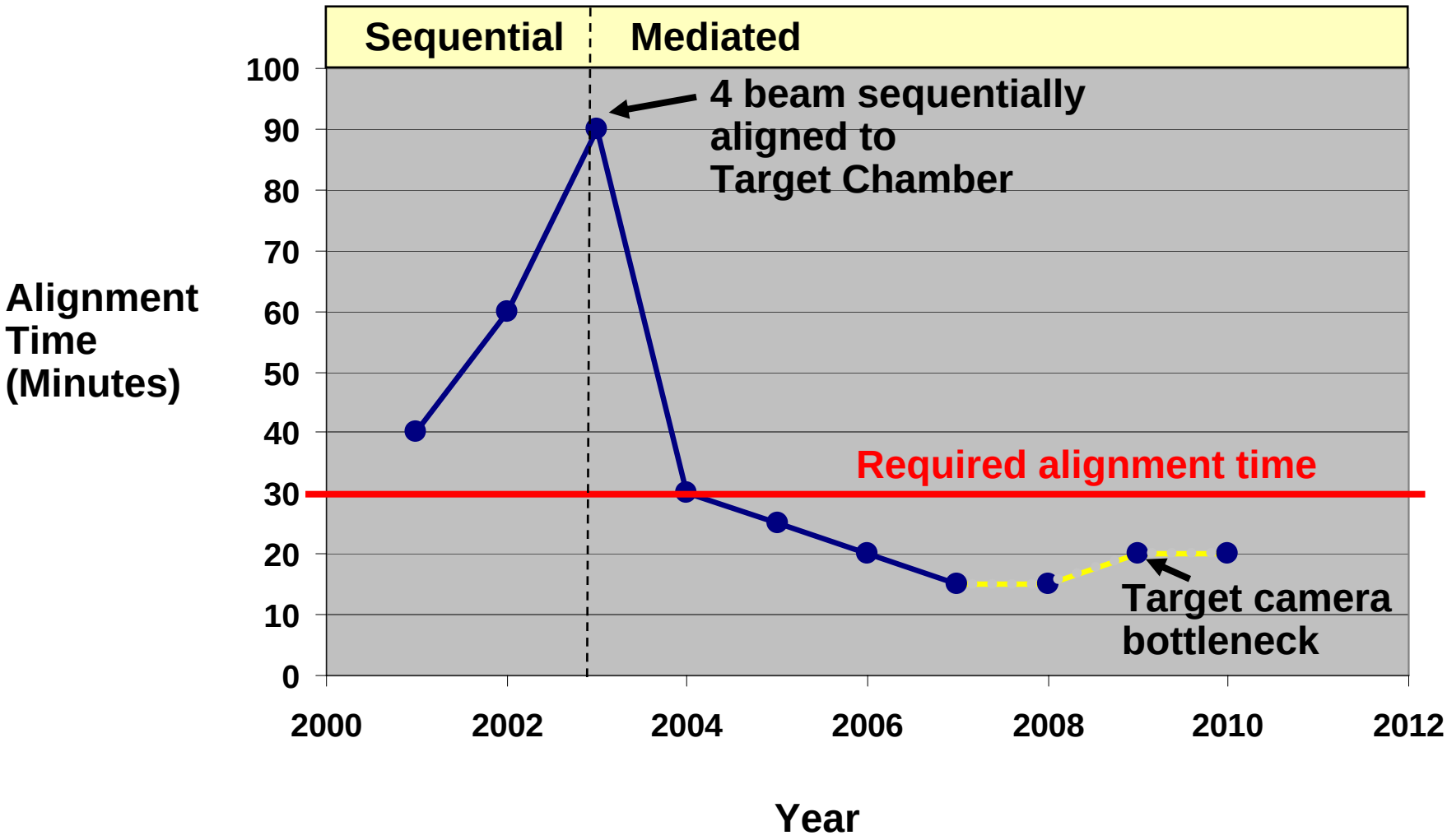
Centroid Plotted at Various Thresholds



High uncertainty halts the automatic alignment process

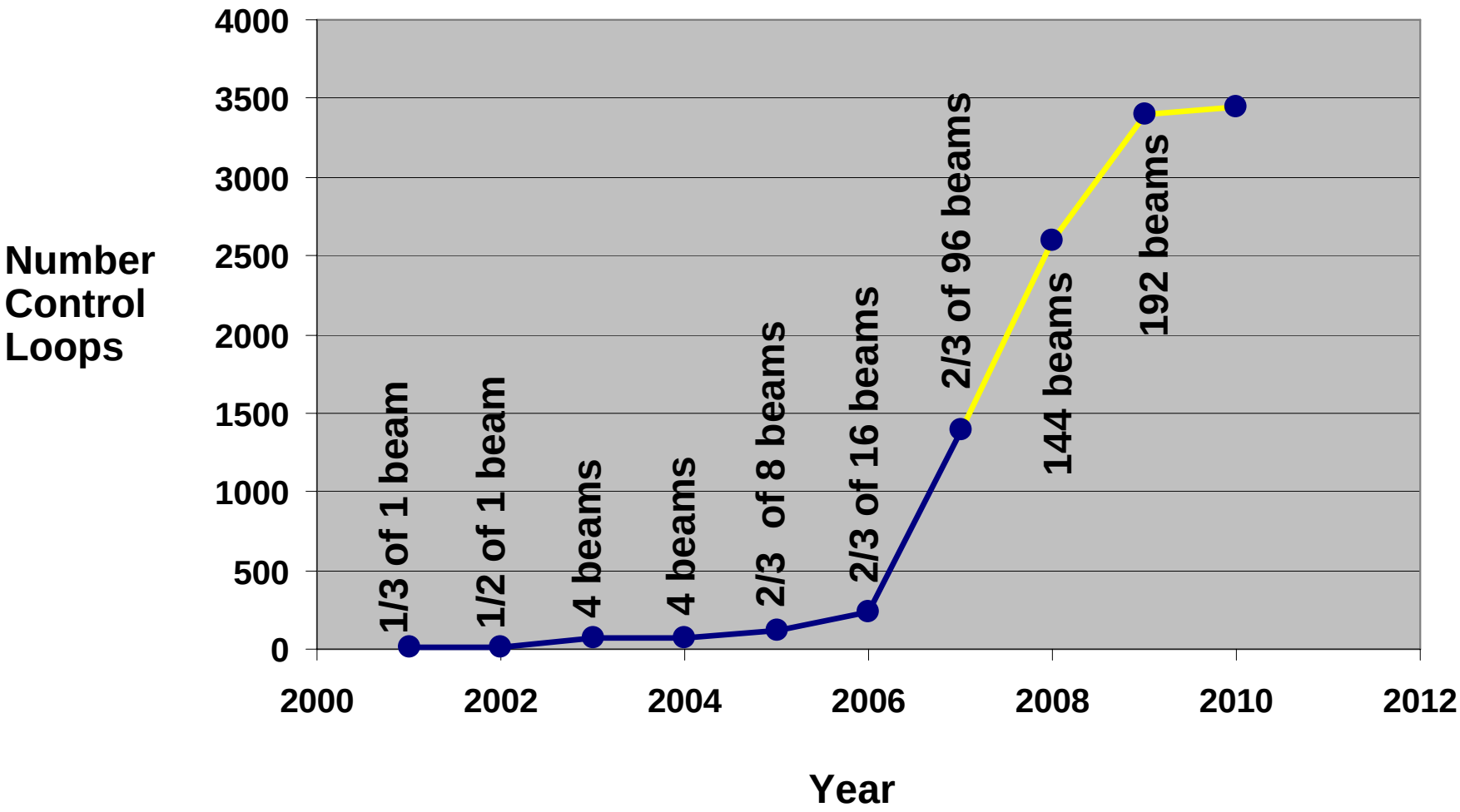
Architectural enhancements achieved the required performance

The National Ignition Facility



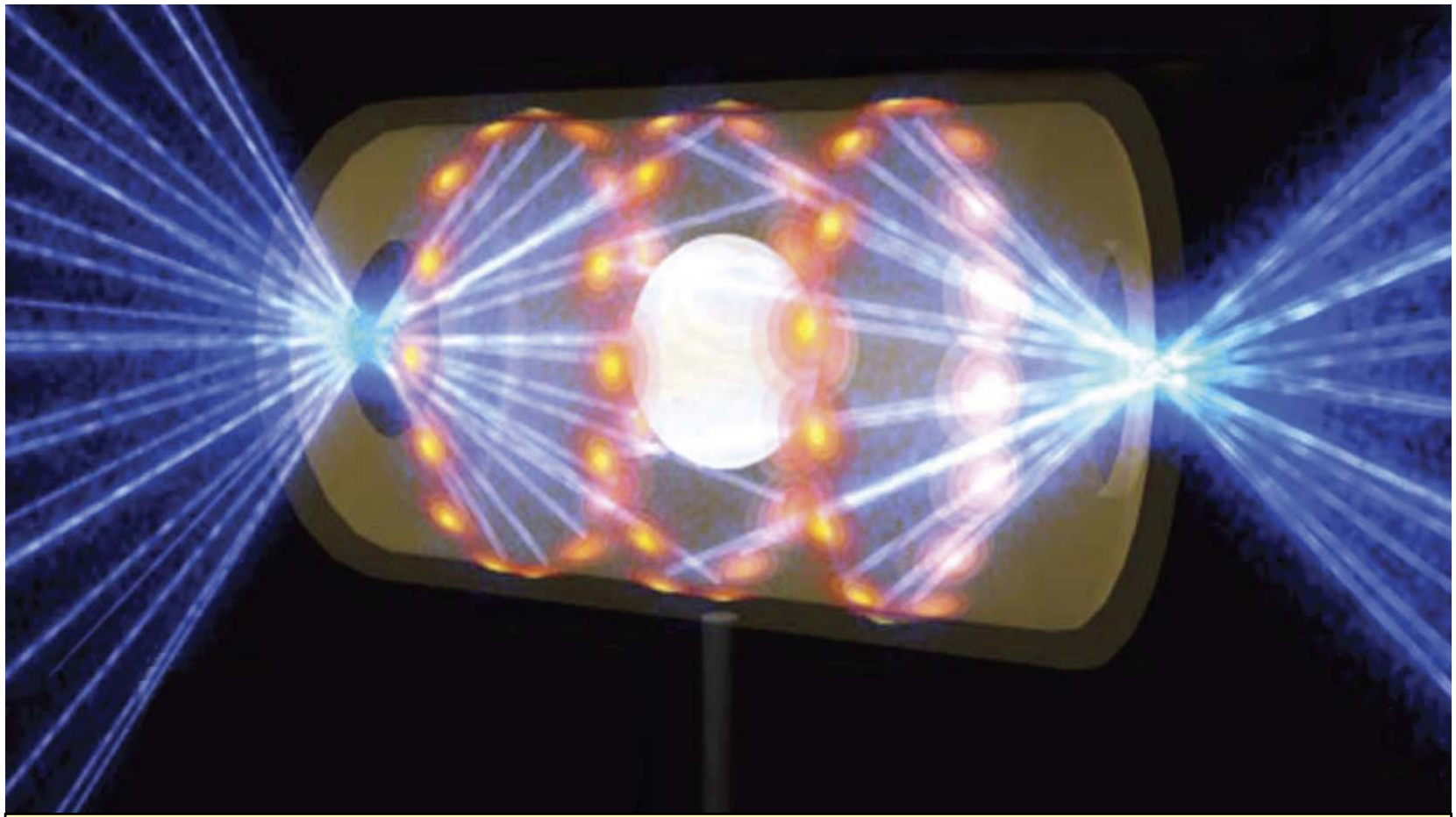
Full automation of all 192 beams is moving rapidly toward completion

The National Ignition Facility



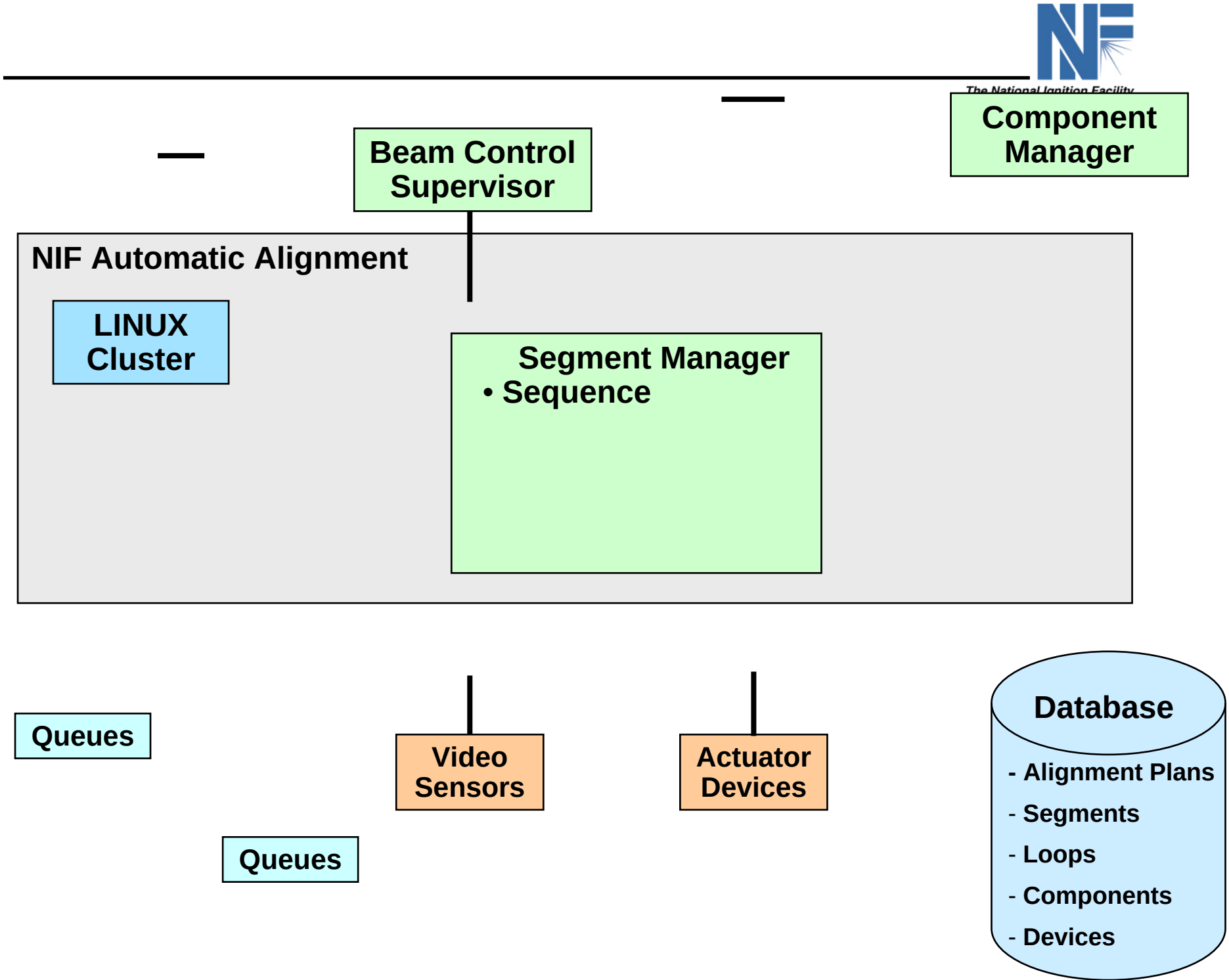
We've exceeded performance goals with a automatic system that is robust and reliable

The National Ignition Facility



Remaining work extends automation of all 192 beams to the target for ignition experiments beginning in 2010

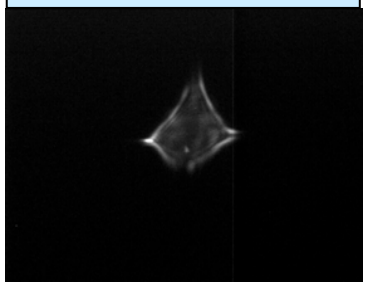

NATIONAL
IGNITION
FACILITY


Component Manager
Beam Control Supervisor
NIF Automatic Alignment
LINUX Cluster
Segment Manager
• Sequence
Queues
Video Sensors
Actuator Devices
Database
- Alignment Plans
- Segments
- Loops
- Components
- Devices
Queues

Many processing algorithms are used …

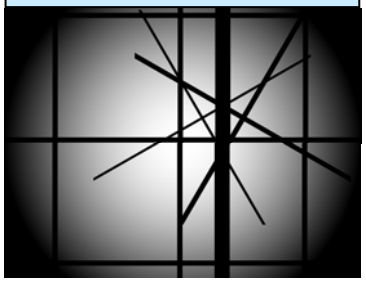
The National Ignition Facility

Crystal Reflection



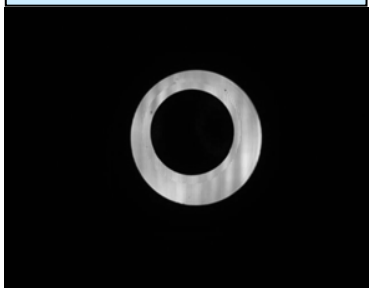
a) Weighted Centroid

Crosshair Grid



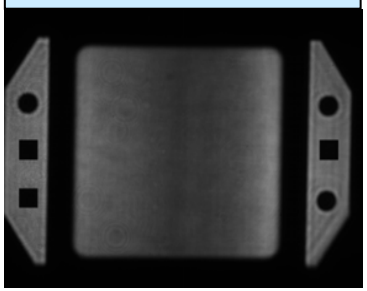
b) Hough Transform

Dark Stop

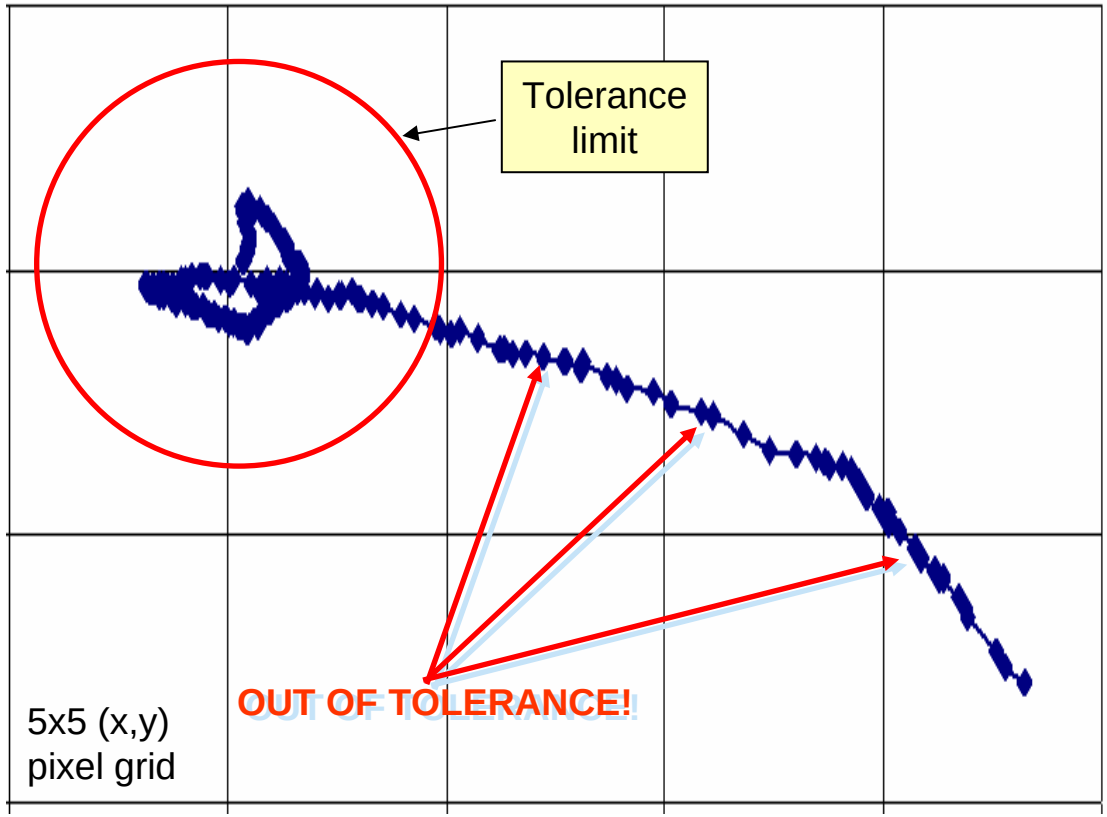


c) Template Match

Shot Mask



d) Matched Filter


Tolerance limit
OUT OF TOLERANCE!
5x5 (x,y) pixel grid