CAD Model-Based Visual Control System for the National Ignition Facility Target Area Positioners

12th ICALEPCS conference , Knoxville, Tennessee , USA, Oct 17, 2007

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

NIF is 94% complete, on schedule and budget

NIF concentrates all the energy in a football stadium-sized facility into a mm^3

Matter Temperature	$>10^8$ K
Radiation Temperature	$>3.5 \times >10^6$ K
Densities	$>10^3$ g/cm^3
Pressures	$>10^{11}$ atm

NIF-0706-12555 L2
17EIM/doc

NIF is a 192 beam laser organized into quads, bundles and clusters with a 10m diameter chamber

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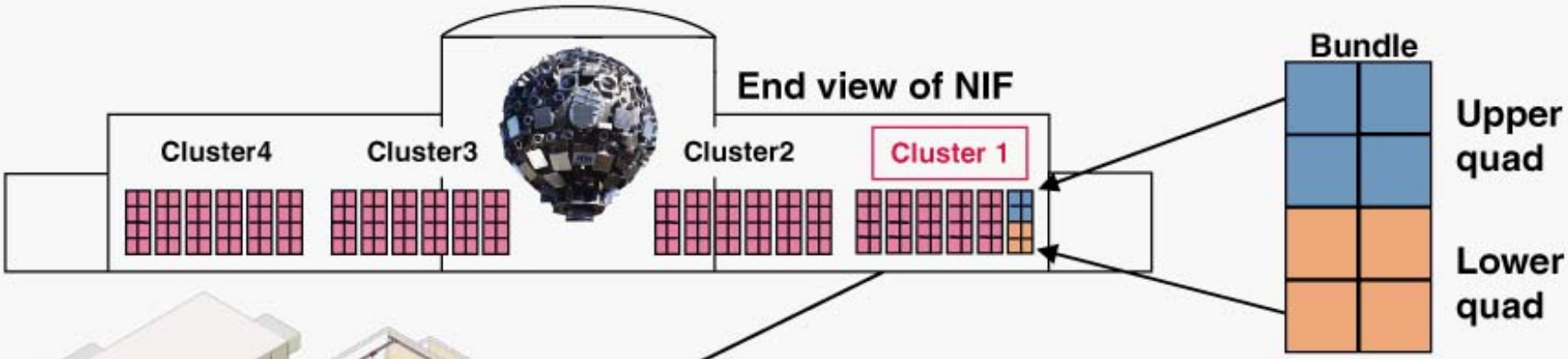

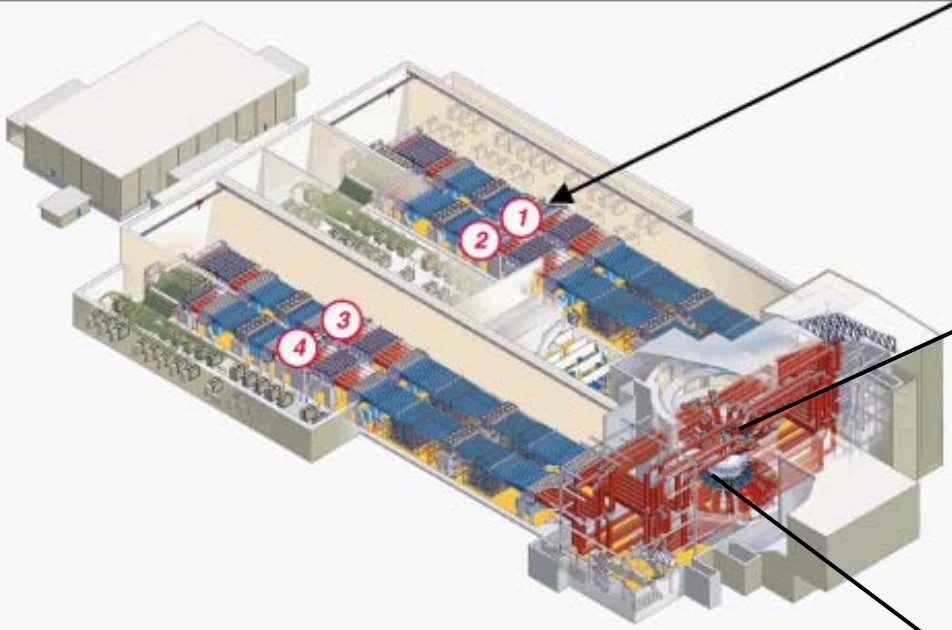

Target Chamber

Quads are the basic building blocks of a NIF experiment, 4 beams with same pulse shape and time delay. Each quad enters the chamber through the final optic assemble.

The Integrated Computer Control System (ICCS) orchestrates complex automated shots

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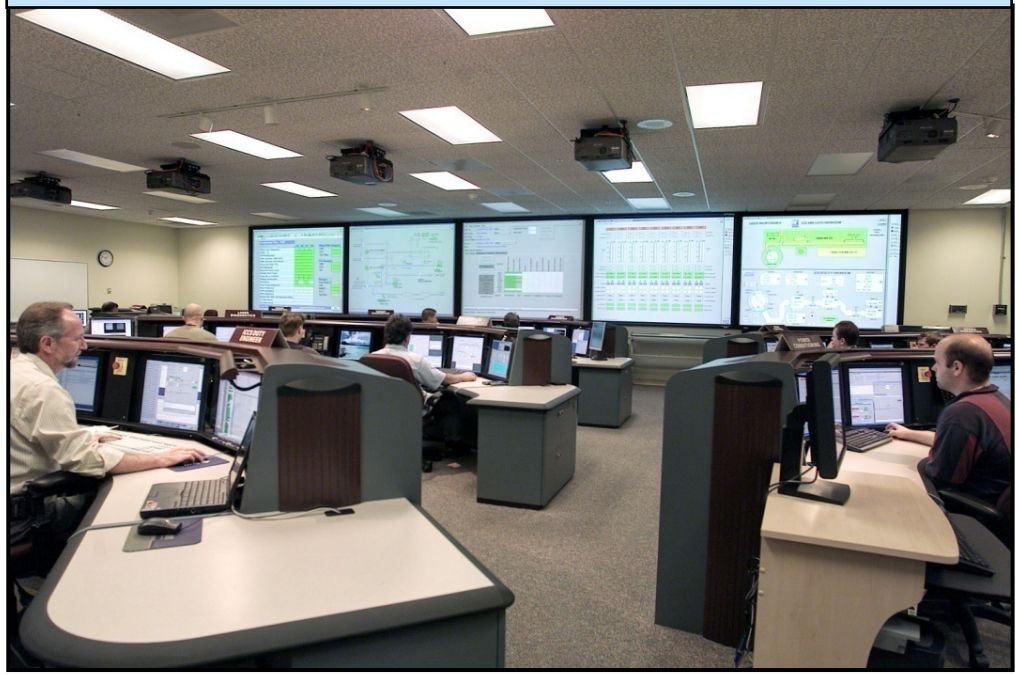
- 60,000 control points are installed in over 6,000 line replaceable units
- ICCS is deployed on 850 front-end processors, servers, and workstations
- A CORBA-based software framework was developed to deliver 1.8M SLOC
- 192 beams precisely aligned on target to 10 microns over a 300-meter optical path

Main Control Room



Shots fired every few hours culminate in a nanosecond laser pulse in lock-step with diagnostics timed to 30 picoseconds

Ten target and diagnostic positioners are precision aligned for each shot

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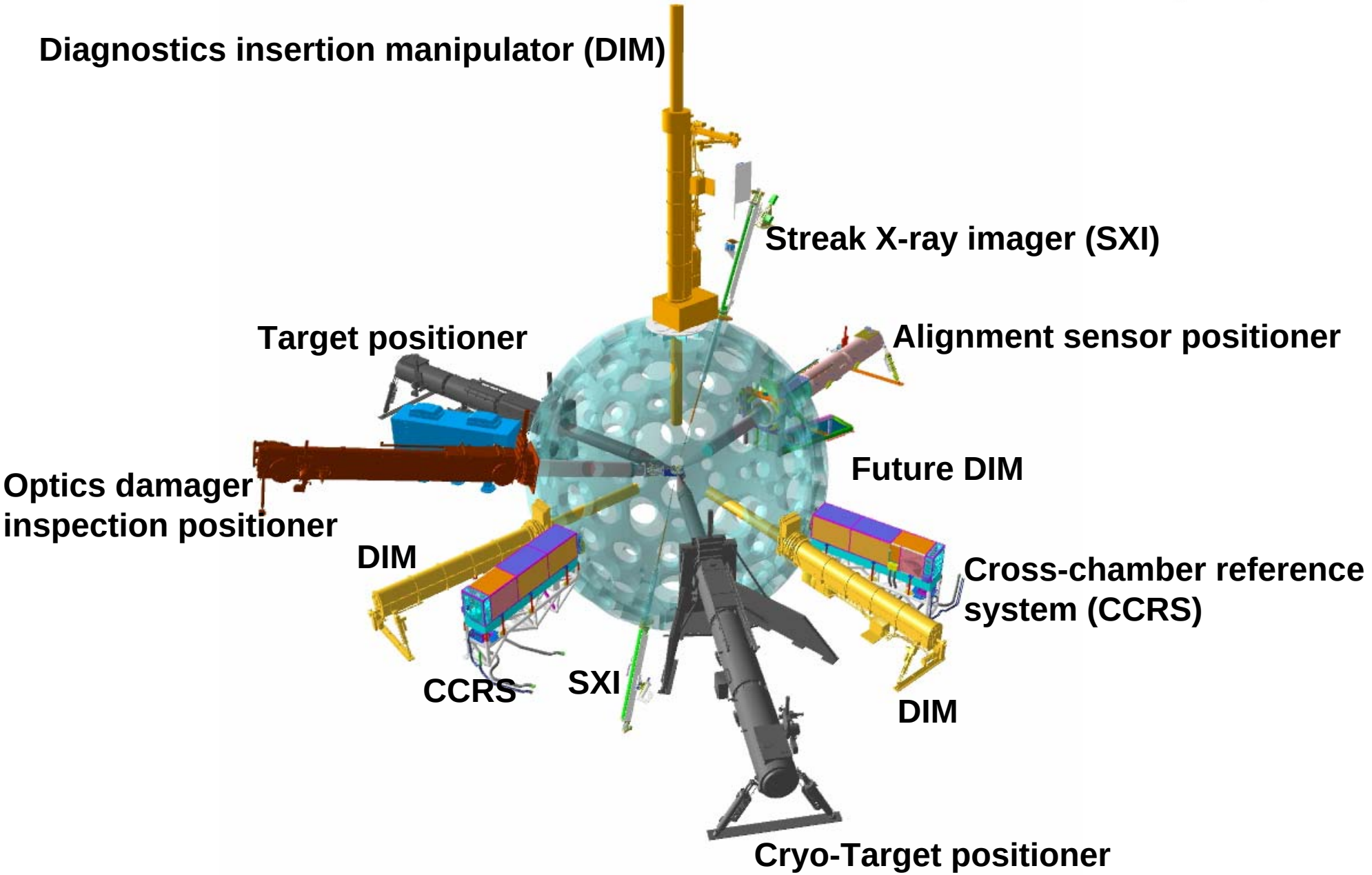
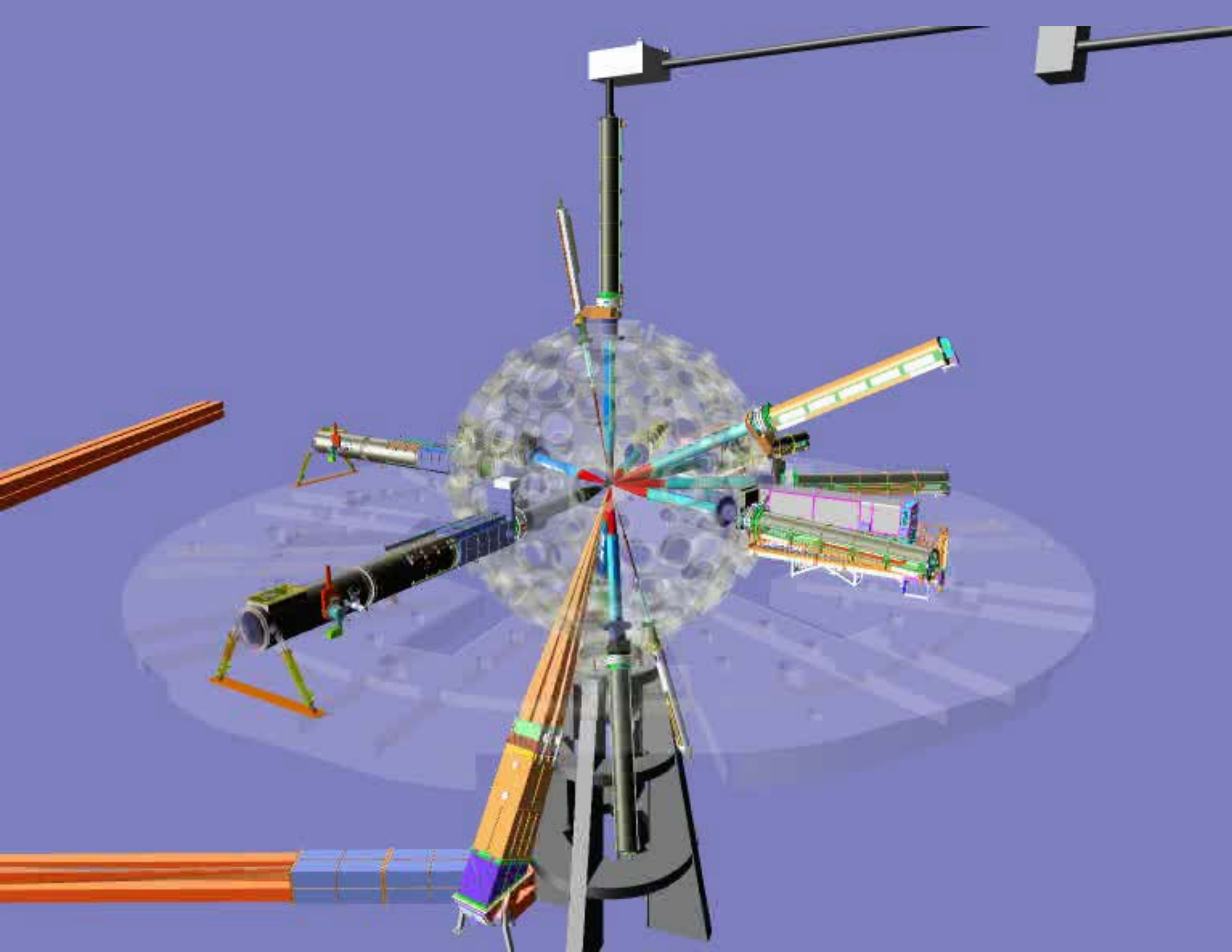
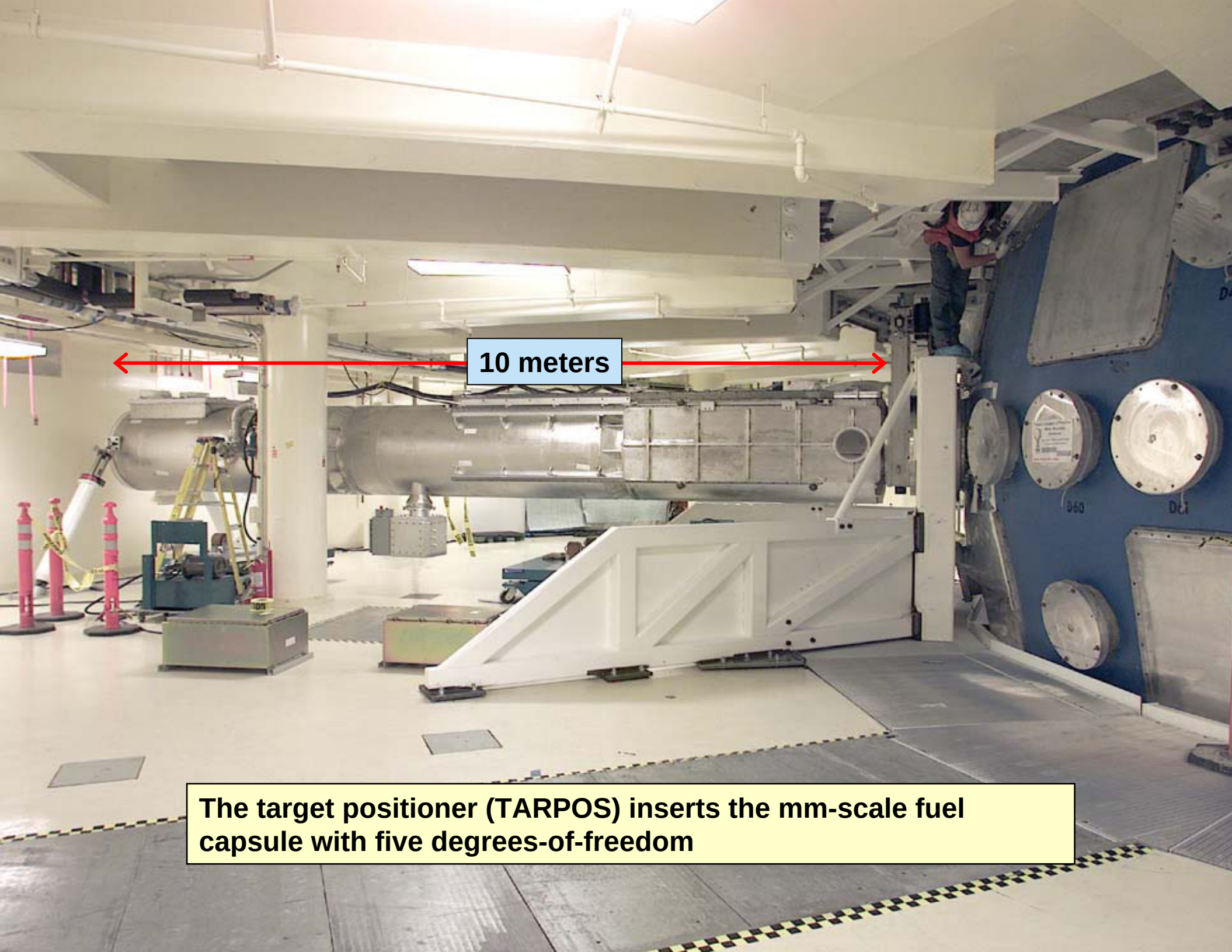
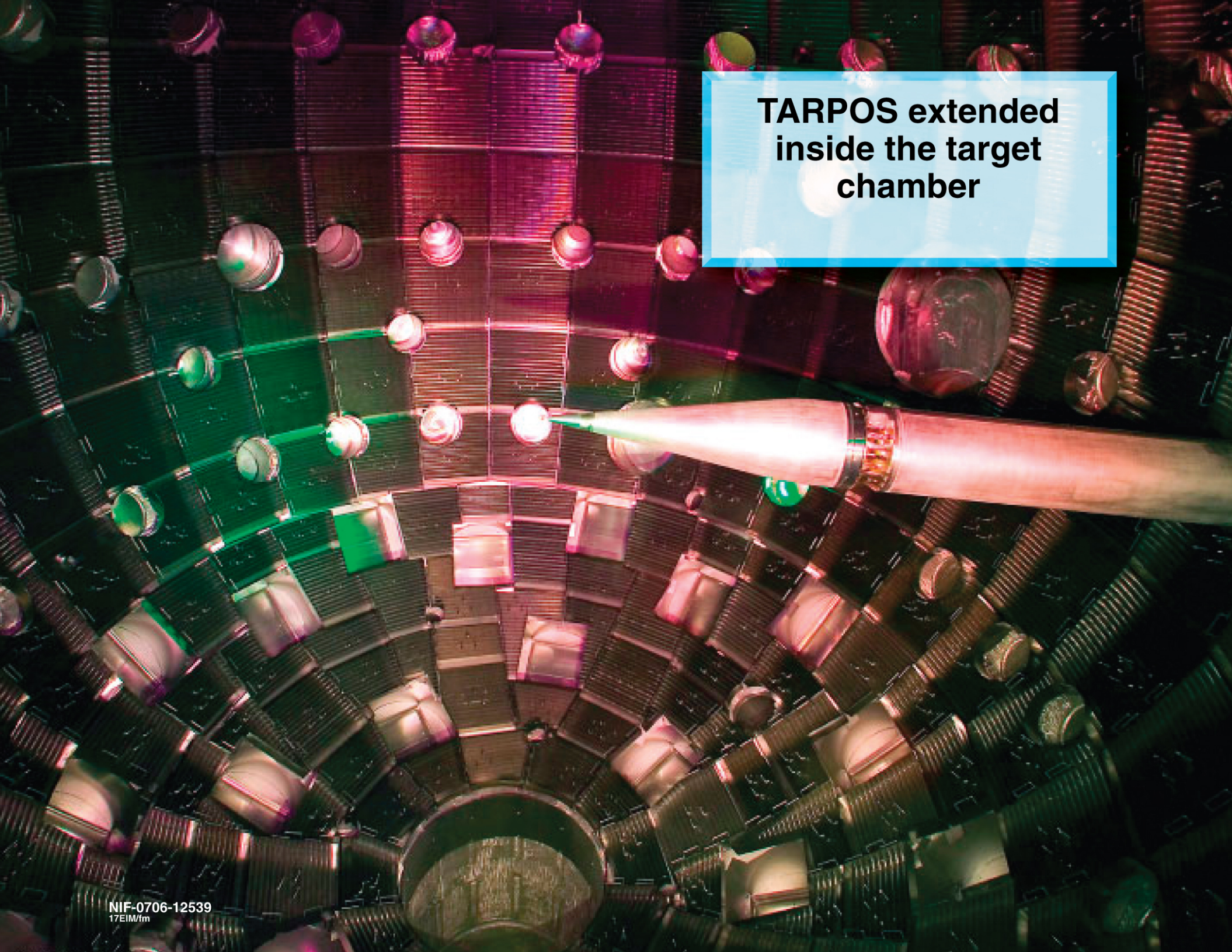






The target positioner (TARPOS) inserts the mm-scale fuel capsule with five degrees-of-freedom


TARPOS extended inside the target chamber
NIF-0706-12539
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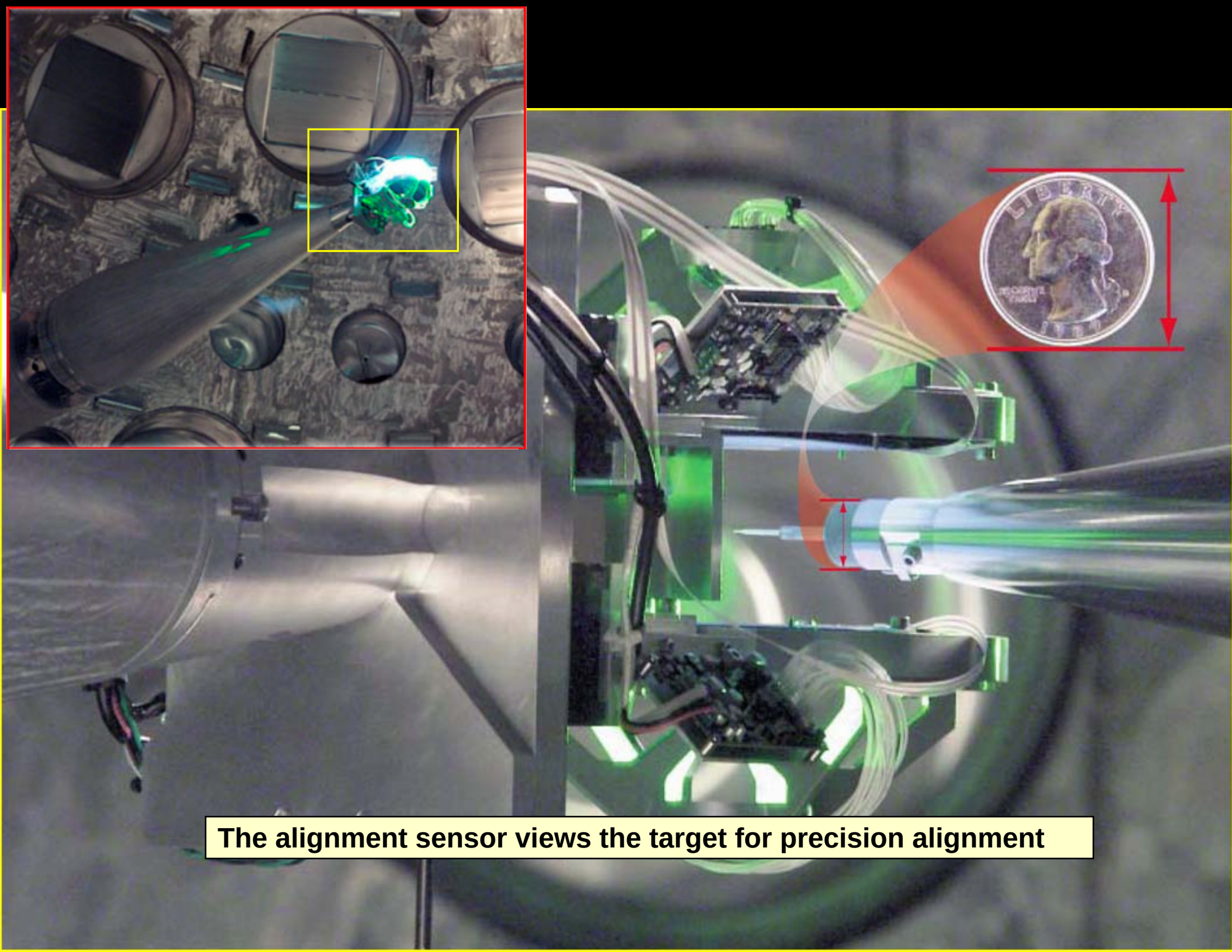

The alignment sensor views the target for precision alignment

Diagnostic instruments manipulators (DIM) position physics packages at chamber center

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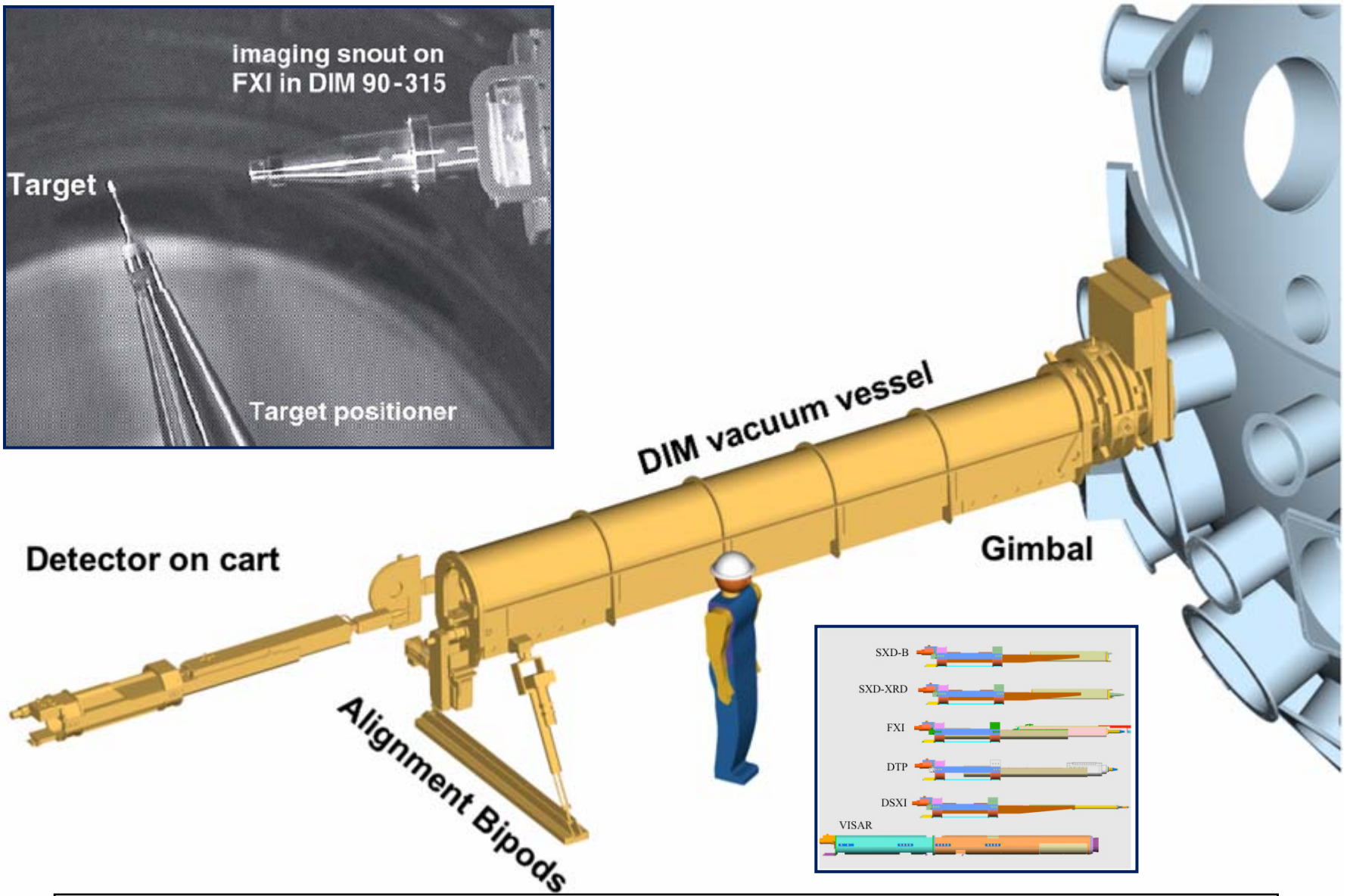

Four DIMs precision align a diverse suite of diagnostic instruments

Target Chamber

Upper Beam Ports

The seven-floor target bay contains the vacuum chamber, final optics system, and target diagnostics

Each experiment requires careful coordination of the motion control system

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- Limited chamber access requires remote control and sensing
- Positions maintained to accuracies of 10 microns
- Varied 3D geometries and alignment scenarios
- Complex motion sequences involving multiple devices
- Absolute encoder and video feedback
- Potential collisions must be avoided

A CAD model-based control system with integrated video feedback meets these requirements

Collision avoidance protects positioners that reach 6 meters into the chamber

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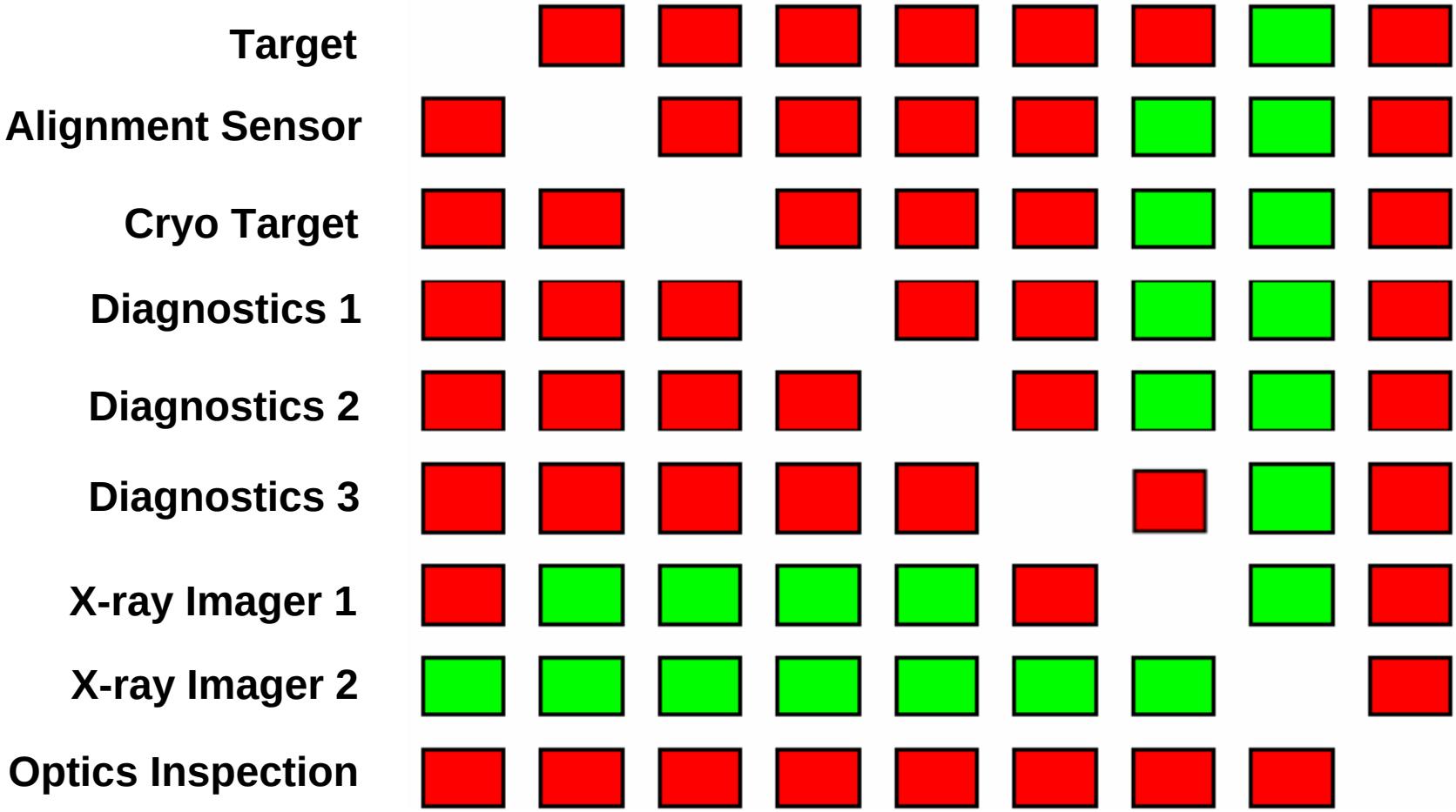
Positioner Interference Matrix



Situational awareness provided by the surveillance cameras is less than ideal

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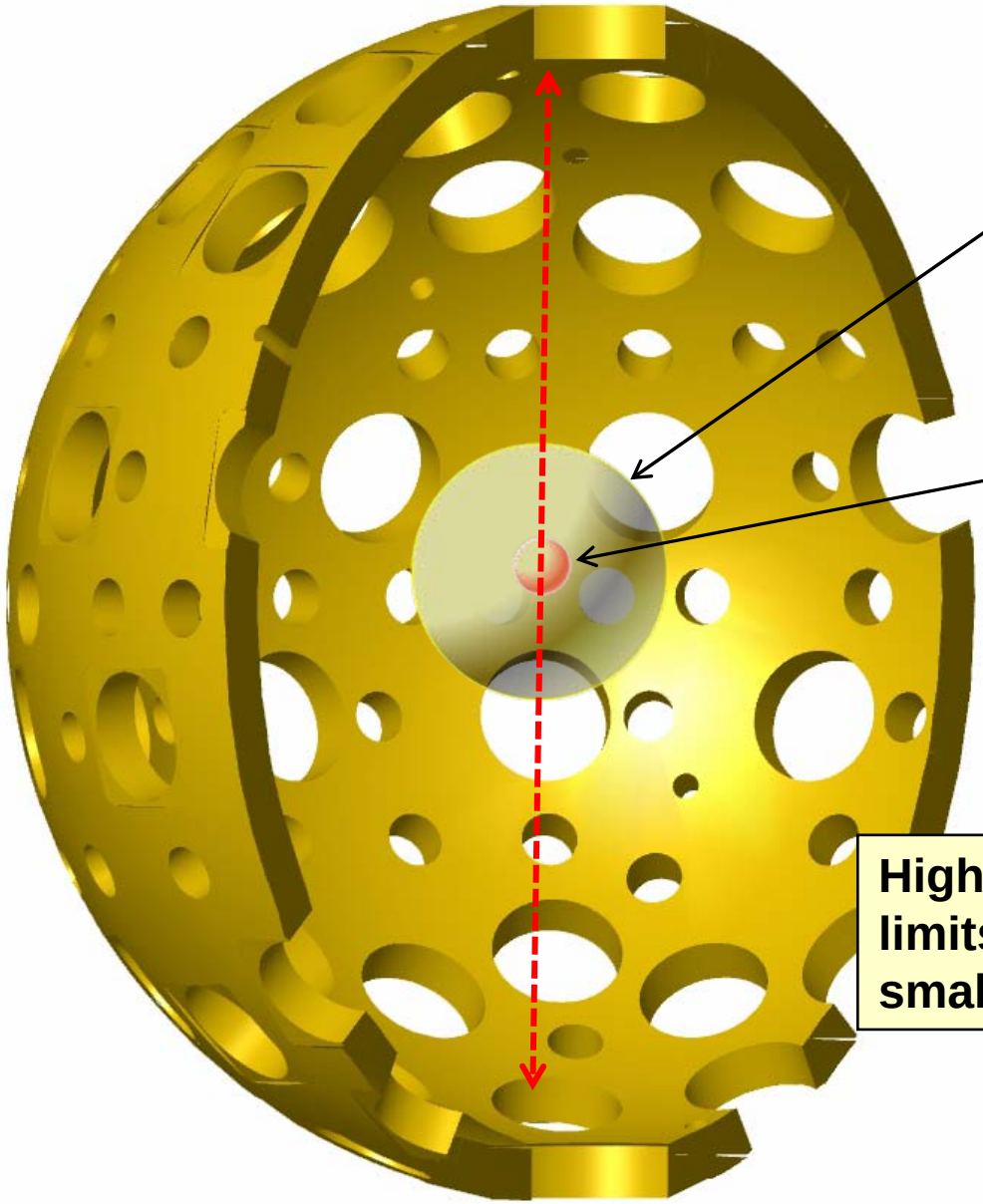

High viewer magnification limits the field-of-view to a small central region

Camera views of the chamber interior

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Wide FOV

Narrow FOV

Collision-free positioner routes are calculated using model-based analysis and tracking tools

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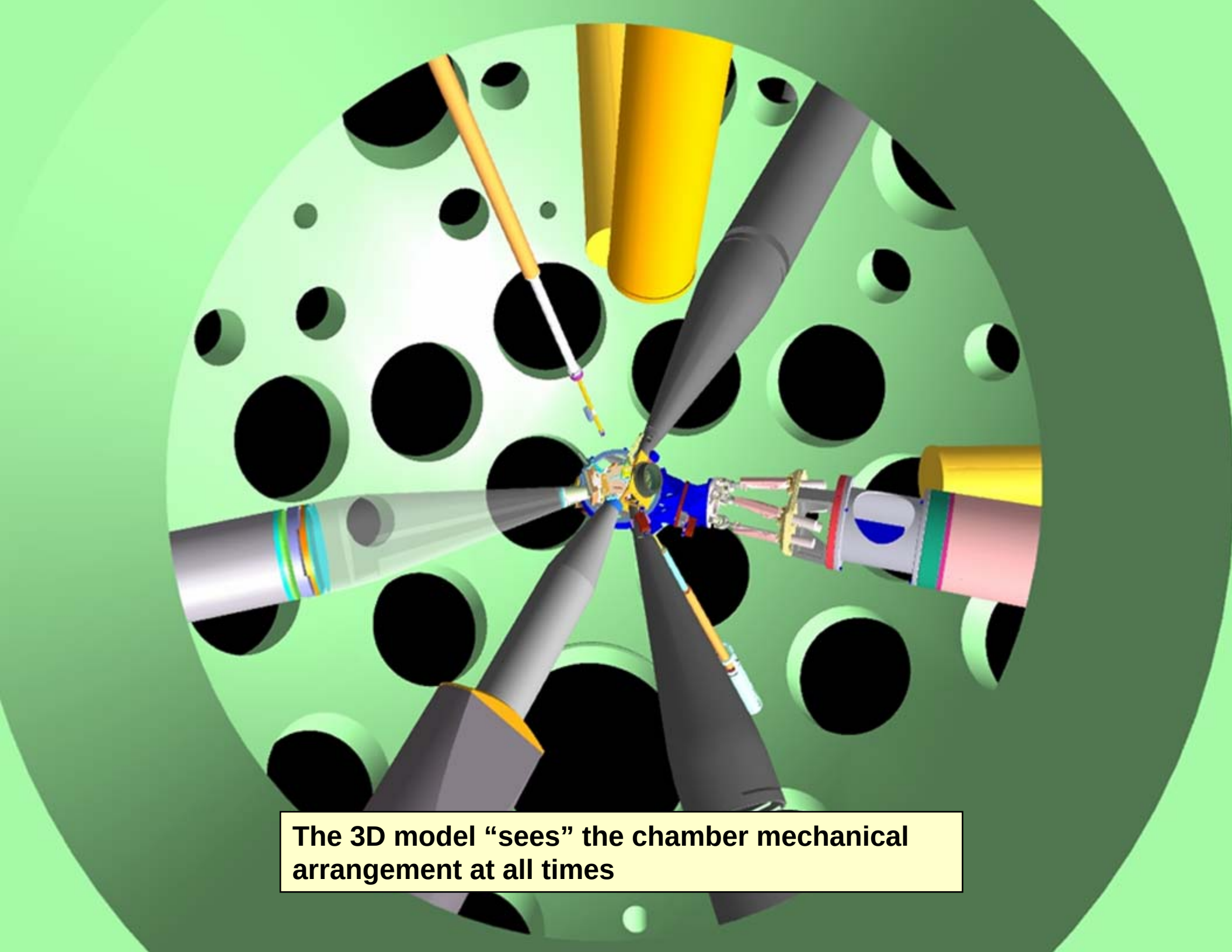
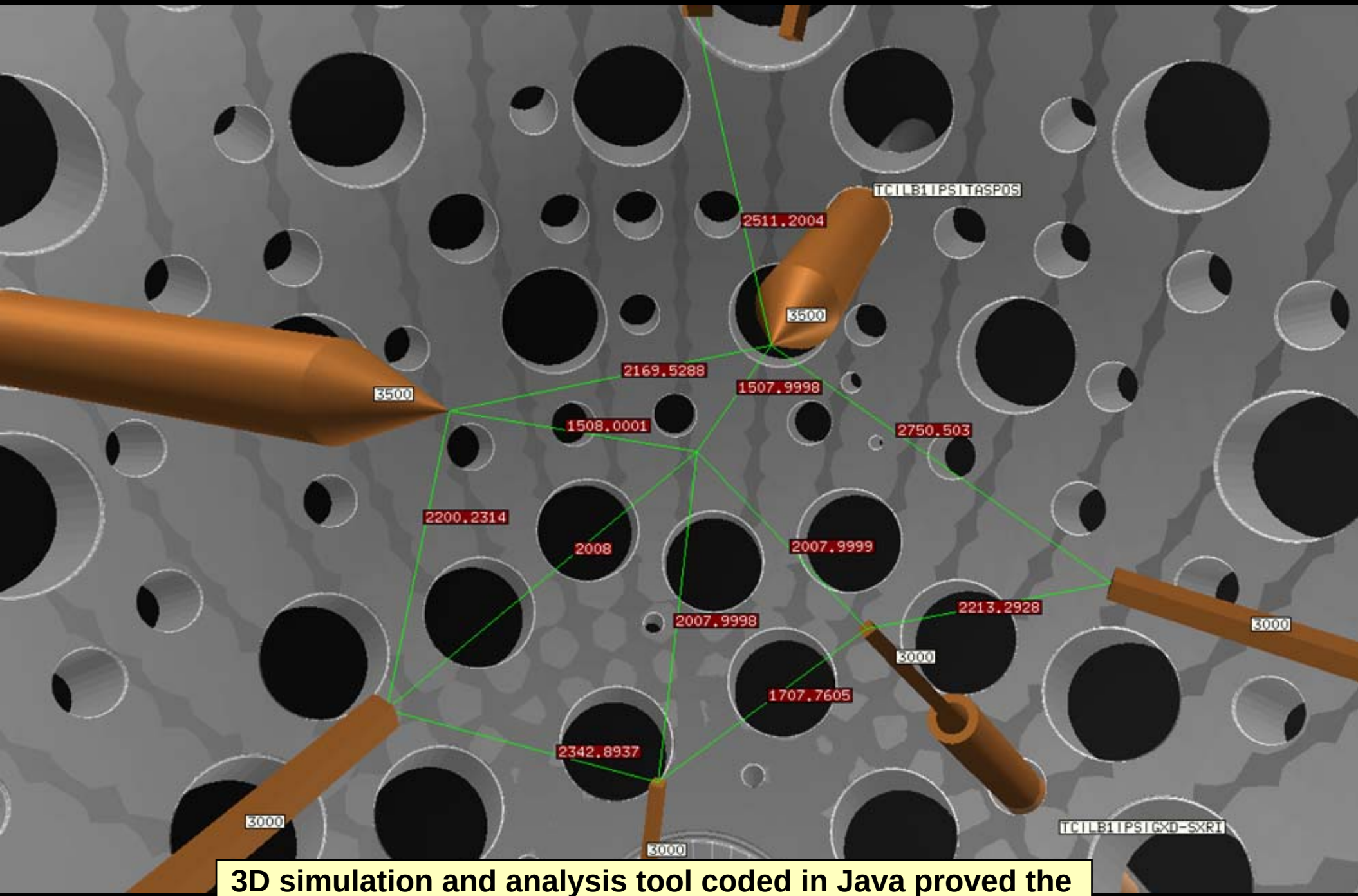
- Pro/ENGINEER*
  - CAD tool used to design NIF's mechanical hardware
  - Leveraged to derive the control system model

- DIVISION MockUp*
  - 3D simulation of the chamber and all positioners
    - Based on experimental set up
    - Used for real-time controls during operations
  - Live visualization of positioner operation
    - Delivers sub-millimeter accuracy
    - High-precision servo motors with encoders provide hardware feedback
  - Determines distances between points or/and positioners
  - Calculates collision free routes
  - Video overlays for manual control



The 3D model “sees” the chamber mechanical arrangement at all times



3D simulation and analysis tool coded in Java proved the model-based concept

Simulation integrity is verified in real-time by comparison to the view generated by MockUp

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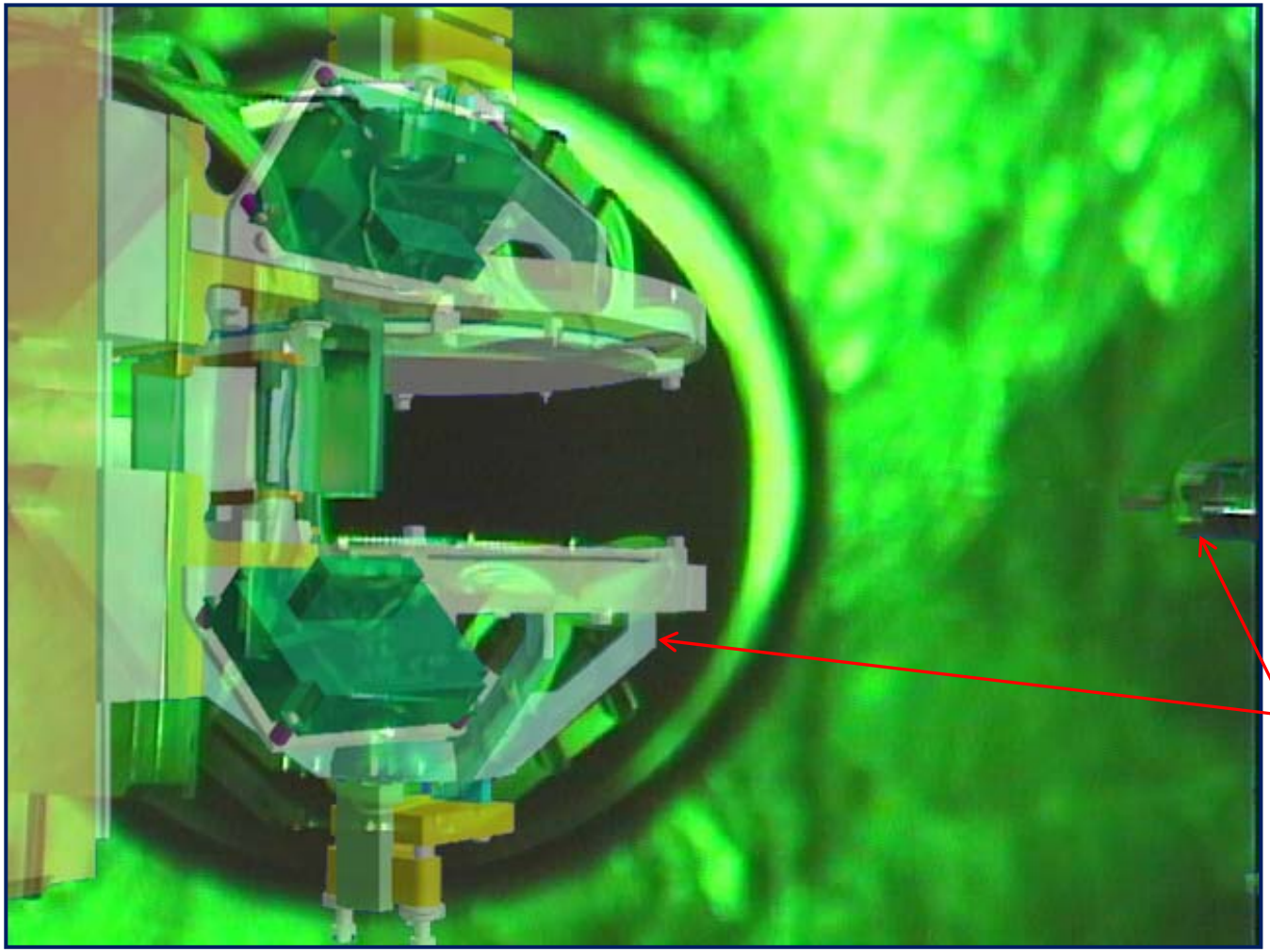

Live-video

Semi-transparent overlay from MockUp

Visual assisted control

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- Calibrated video
  - Virtual 3D axes are defined using cross-coupling matrices
  - Video views are calibrated to these axes
- Video integrated control
  - Calibrated videos provide a live-video integrated control by dragging movement commands on the screen
- Operator aids
  - Live-video overlays
  - Alignment markers
  - Zoom, etc.

Movement commands are “dragged” across the live video display using calibrated views

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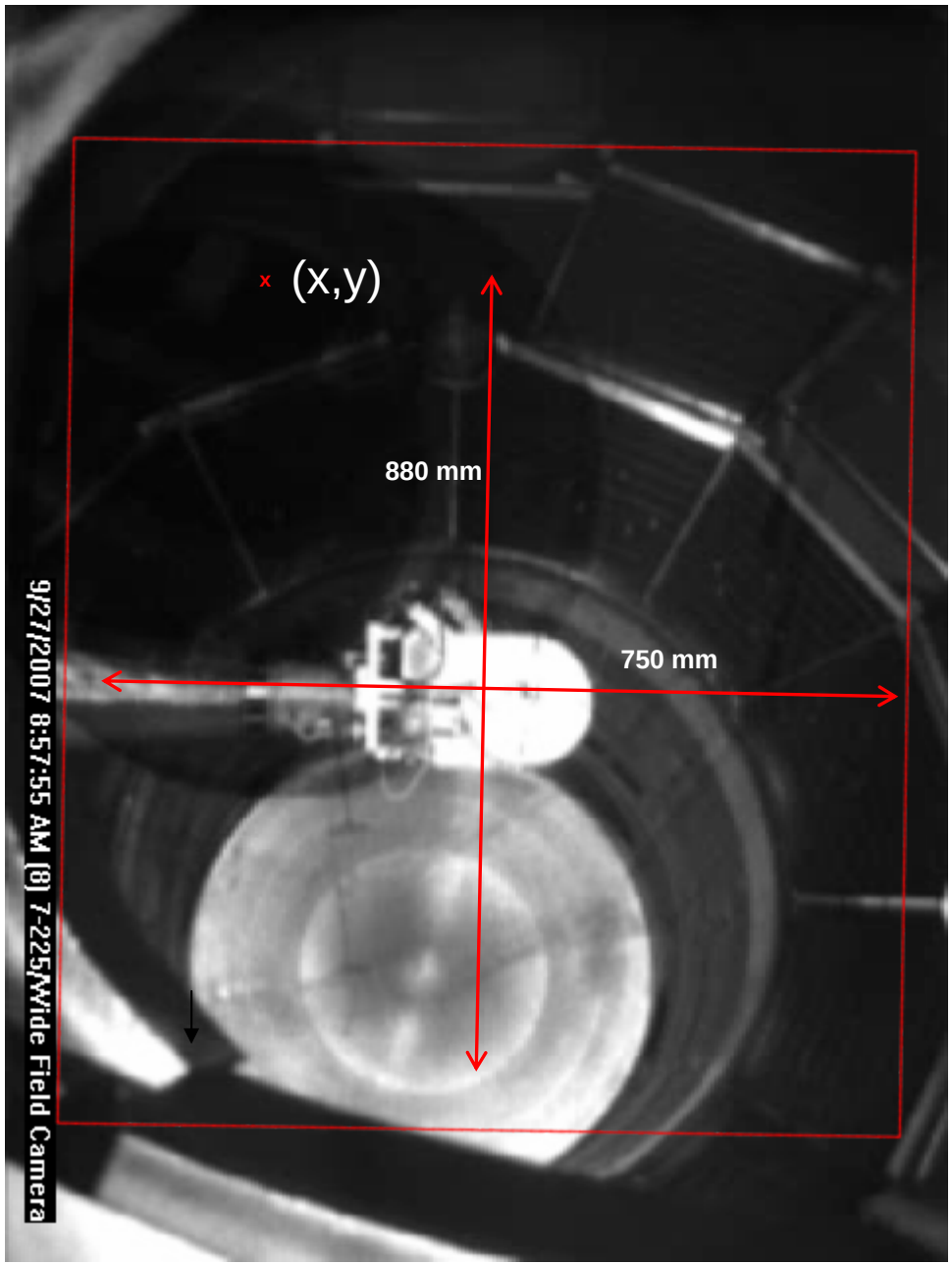

- Reference point and transformation matrix
  - Maps any point (x,y) in the camera coordinate system to (x,y,z) in chamber coordinate system
- Scale and rotation factors
  - Maps video pixels (x,y) to positioner coordinate system
- 3D virtual-axes
  - Defined along camera field-of-view using cross-coupling matrices

Routing is analogous to driving directions given by Google Maps

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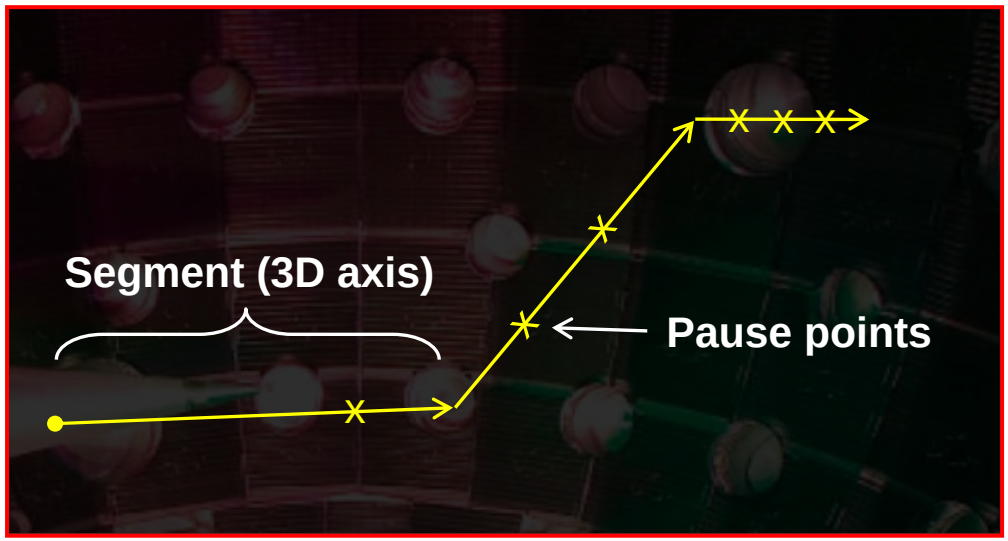
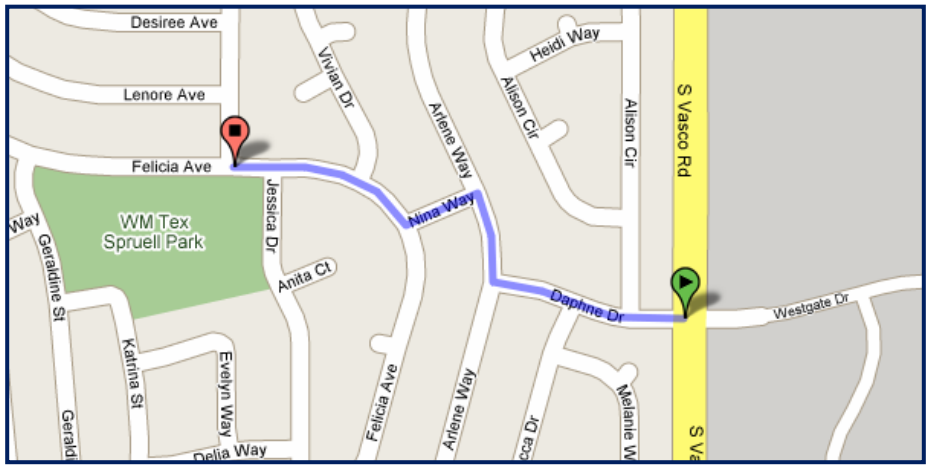


Positioner route finding

Google™ Map

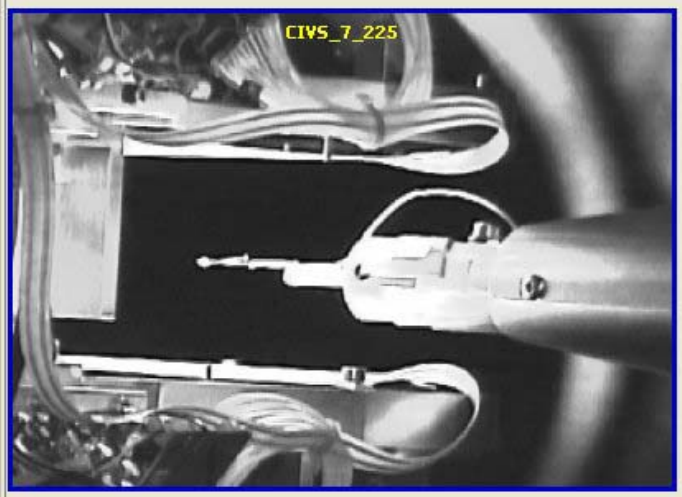


Target Area Overview User: paik6, Role: OBSERVER

File View Services Status Set User Role Help

Target Area Overview

Target Area Broadview | TARPOS | DIM 45 | DIM 315 | Polar DIM | Upper SXI | Lower SXI



Status

TARPOS	4.99 m	----------	Gr, askew, nod+, roll+
DIM 45	5.24 m	----------	Green zone, askew
DIM 315	5.31 m	----------	Retracted, askew
Polar DIM	5.30 m	----------	Green zone, askew
Upper SXI	5.31 m	----------	Retracted, askew
Lower SXI	5.31 m	----------	Retracted, askew

Equator | Polar | Overall Health | Overall Alignment

Sequence Management | Composite Setpoints

ET Sequence

Go To Inhibit Setpoint | Manage Setpoints

0 Test1 | 1 Test2 | 2 ag | 3 New | 4 gsghsh | 5 ETT | 6 Tim | 7 qwerty

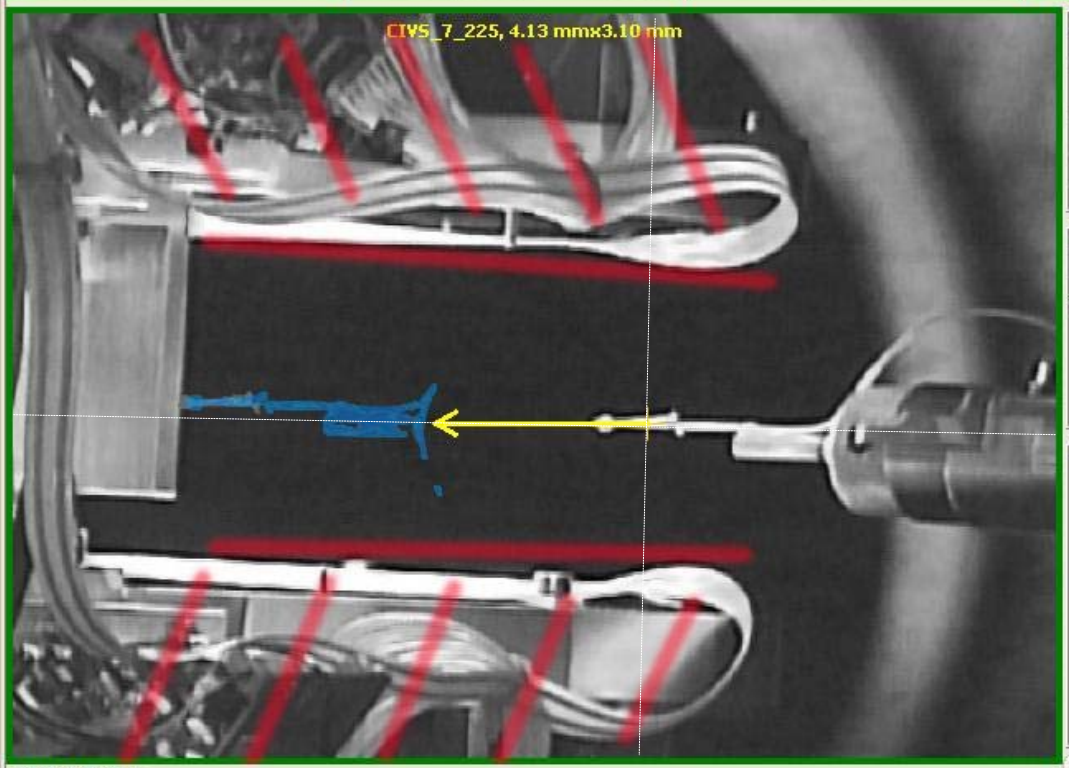
Devices Connected | Automatic Updates | Emulation | v7.0.0

AC | TB | TARPOS | TARPOS User: tekle1 , Role: DEVELOPER

File View Services Status Set User Role Help

AC | TB | TARPOS | TARPOS — User: tekle1, Role: DEVELOPER

Target Area Broadview | TARPOS | DIM 45 | DIM 315 | Polar DIM | Upper SXI | Lower SXI | Video Overview



Movement

Propose Move | Approve Move | Execute Move | Clear Move

STOP

Undo | Redo | Home | Relinquish Control | Become CIVS Operator

Progress

This move will:
Take about 0 seconds
Retract 825.6 µm (-128 pixels)
Go down 0 µm (0 pixels)

Set Aligned | Park | Re-align

Joystick

COARSE-X-JS

LEFT RIGHT 100.0

Maximum Step: 100.0 mm
Maximum Rate: 100%

100%, 0.01 mm/pixel, 0 mm/sec

Chamber Status Panel

TARPOS — Green zone, roll right

DIM 45 — Aligned

DIM 315 — Green zone, askew

Polar DIM — Green zone, askew

Upper SXI — Retracted, askew

Lower SXI — Green zone, askew

Motor Status

2312203 steps	SM-Z-COARSE	418.6 mm
1004851 steps	SM-LB	-6.1 mm
2141253 steps	SM-RB	100 mm
47850 steps	SM-NOD	43.8 mm
249075 steps	SM-ROLL	-19.6 mm

Setpoints | Edit Setpoints | Detailed Values

Current Setpoint

		Name	Left_Bipod	Right_Bipod	Z	Nod	Roll

Create | Copy | Edit | Delete | Goto | Details

15:56:39 User tekle1 is authenticated
15:56:41 Making connections...
15:56:42 Making connections...
15:56:44 Making connections...

Devices Connected | Automatic Updates | Emulation | v6.0.0

The offline test lab integrates special hardware simulators and cameras

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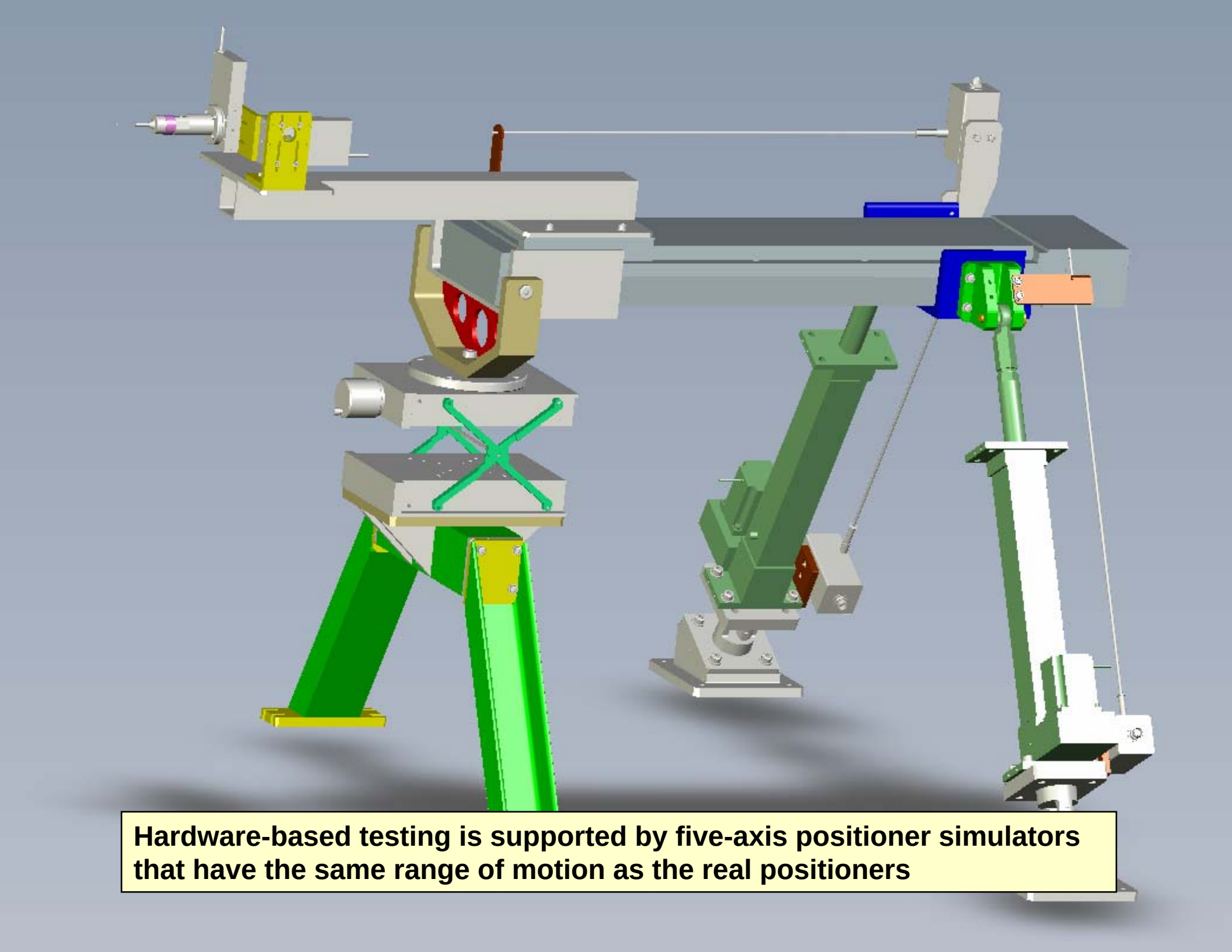
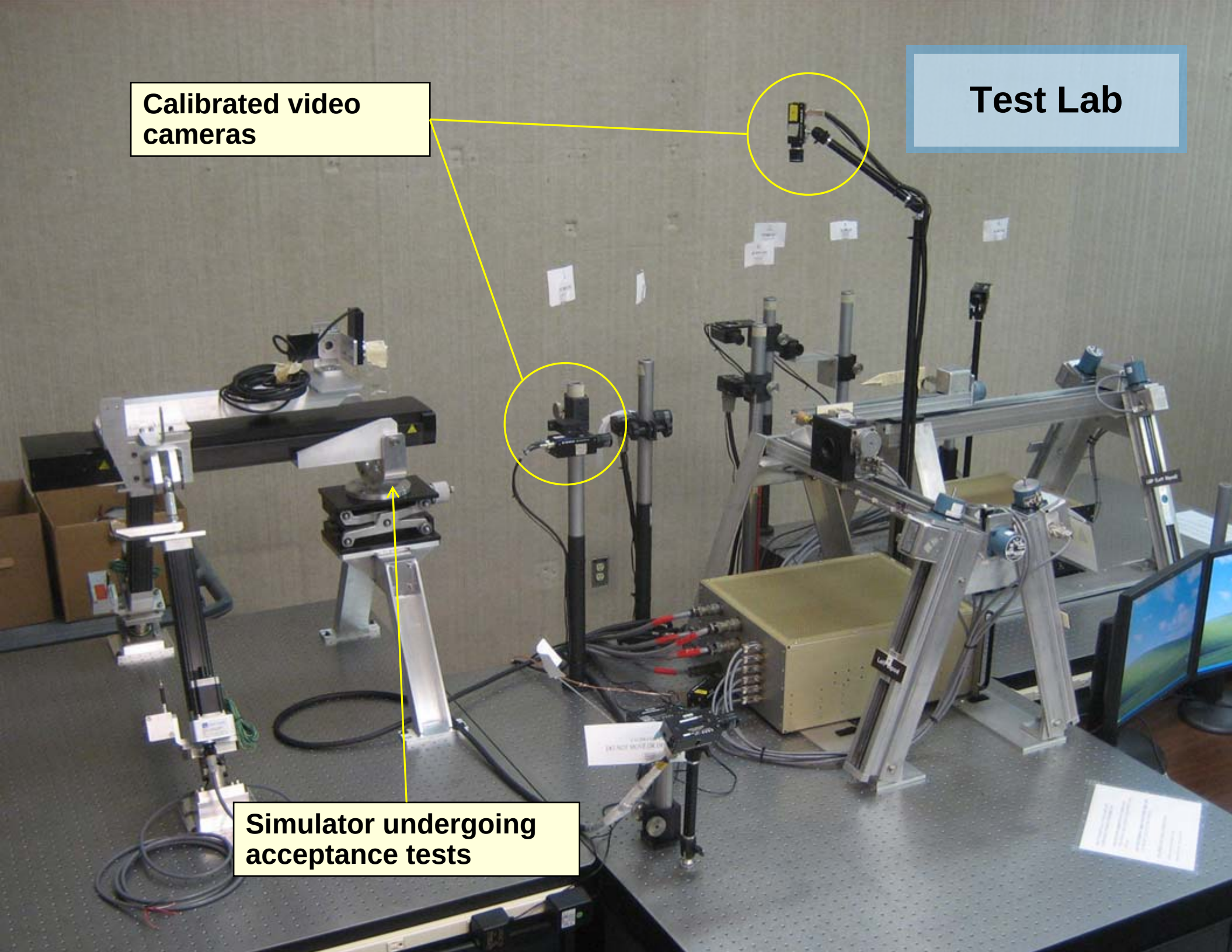
- Hardware-based testing
  - Multi-axis encoded hardware simulators on an optics table
  - Calibrated cameras
  - PLC motor end-of-travel monitoring and shut-down system
  - Configured to mimic the NIF target chamber
- Software-based testing
  - Emulated virtual positioners
  - Provides for multiple concurrent tests

The test lab ensures software quality, assesses usability, and helps train operators



Hardware-based testing is supported by five-axis positioner simulators that have the same range of motion as the real positioners


Test Lab
Calibrated video cameras
Simulator undergoing acceptance tests

Conclusion

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- Enhanced real-time video feedback provides operators with metrology and controls in real physical dimensions
- Model-based visualizations provide a complete control environment in support of complex operations in the limited access chamber
- Model validation assures the system accurately represents reality
- Automated controls ensure interference-free and repeatable coordinated motion sequences
- Status
  - Video-assisted controls are deployed to NIF
  - CAD model-based system is on schedule for delivery next year


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