Optical Thomson Scattering on NIF

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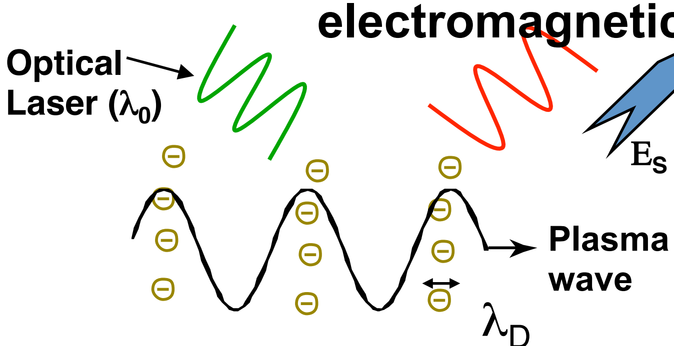
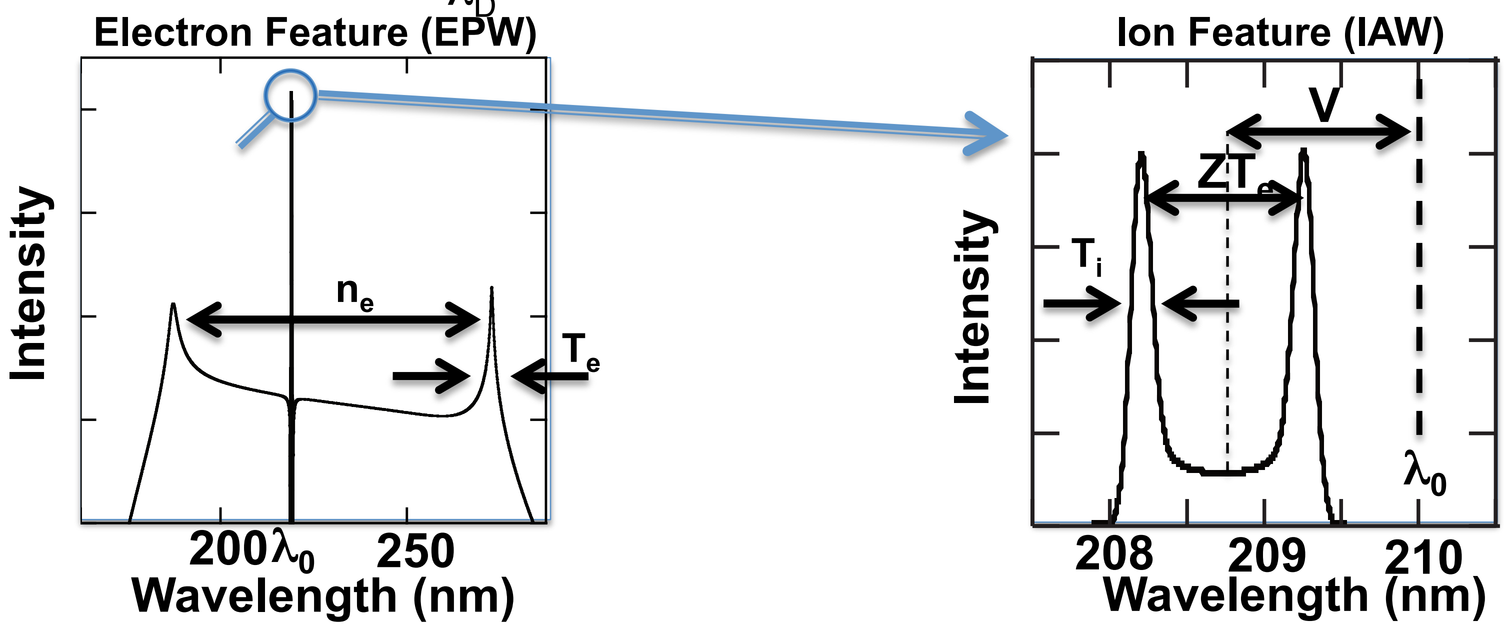
Optical Thomson provides a local measurement of the plasma conditions

Thomson scattering is the scattering of an electromagnetic wave by free electrons.

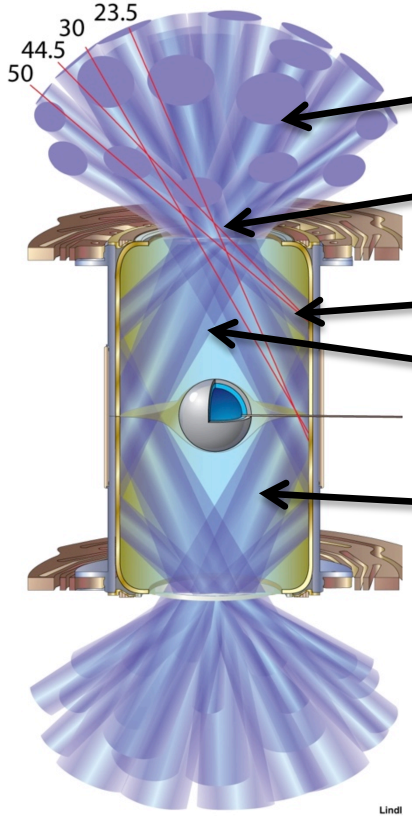


$$S(\mathrm{k},\omega) = \frac{2\pi}{k}\left|1-\frac{\chi_e}{\varepsilon}\right|^2 f_e\left(\frac{\omega}{k}\right) + \frac{2\pi Z}{k}\left|\frac{\chi_e}{\varepsilon}\right|^2 f_i\left(\frac{\omega}{k}\right)$$



TS cross section is 6.65×10^{-29} m^2 (very small), for a typical experiment you hope to collect 10^{-9} of the probe beam energy

Improving our physics based hohlraum understanding and predictive capability is a major program focus



Backscatter

CBET

Wall blow-in

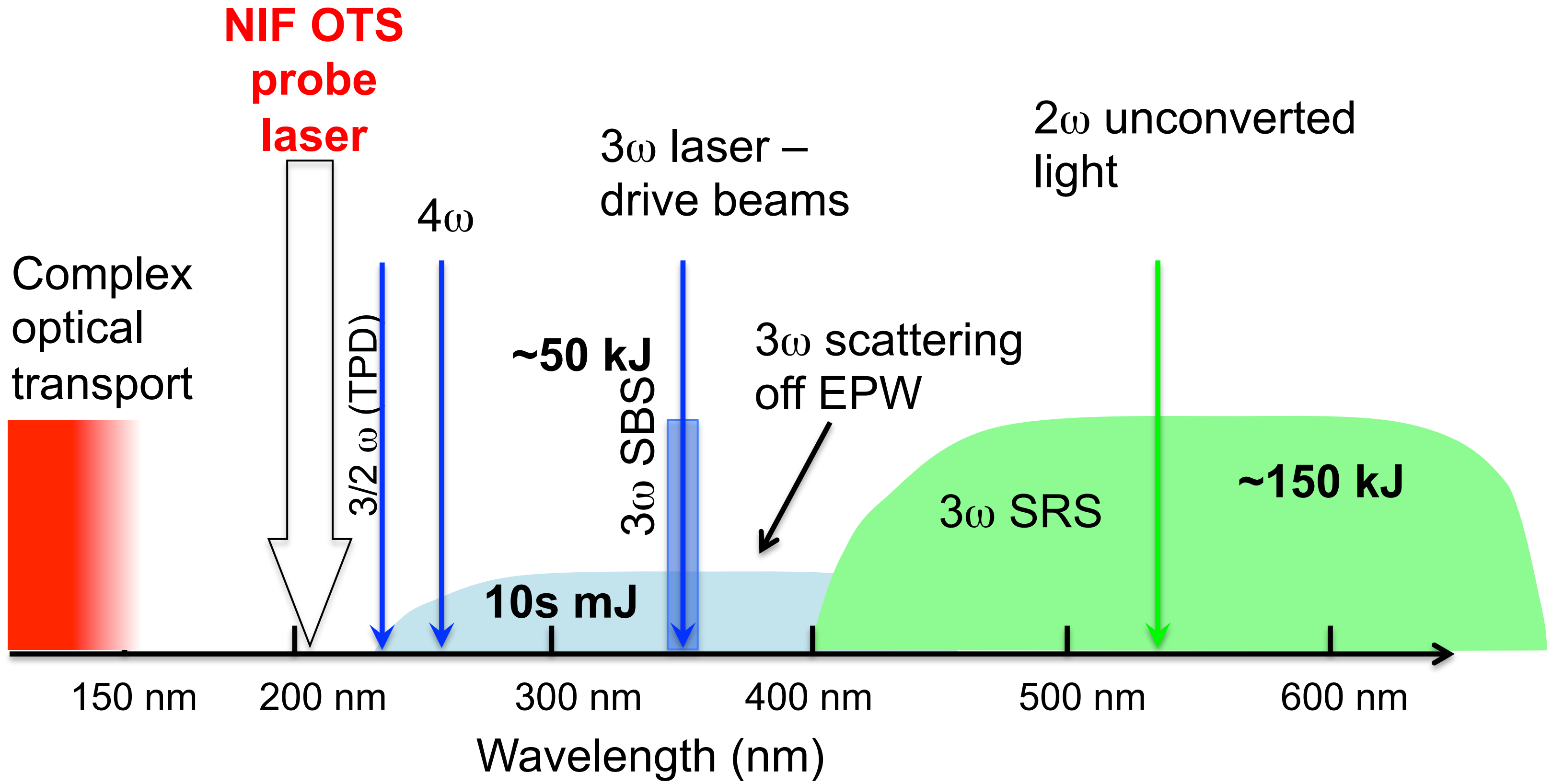
Plasma temperature, density, and flow

Beam propagation

Additional physics: X-ray conversion, wall losses, wall-gas mix, hot-electron preheat, glint, re-amplification…

Thomson scattering has the ability to enhance our understanding of a majority of these issues

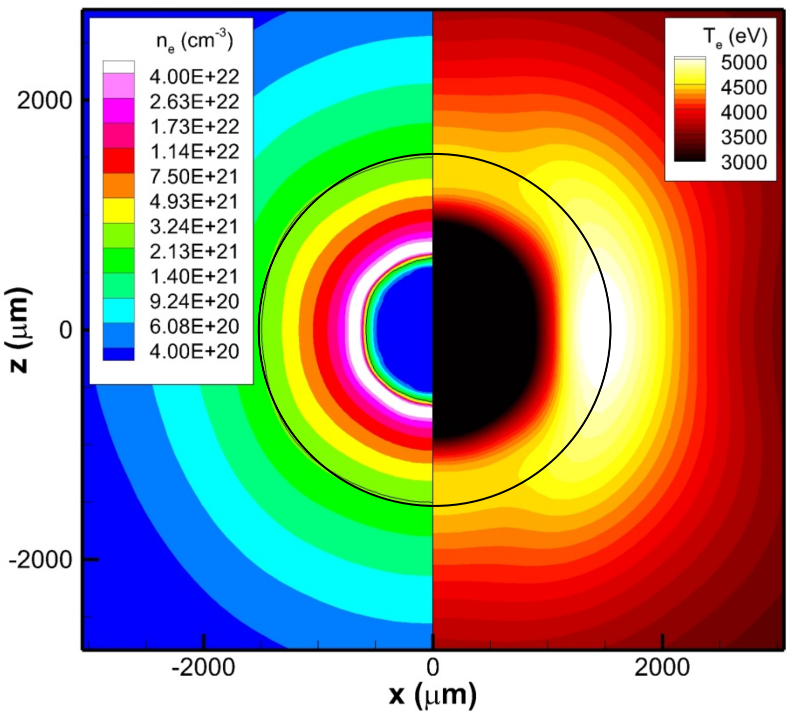
Thomson scattering from a deep-UV probe beam will overcome the harsh environment that challenges optical measurements in a hohlraum

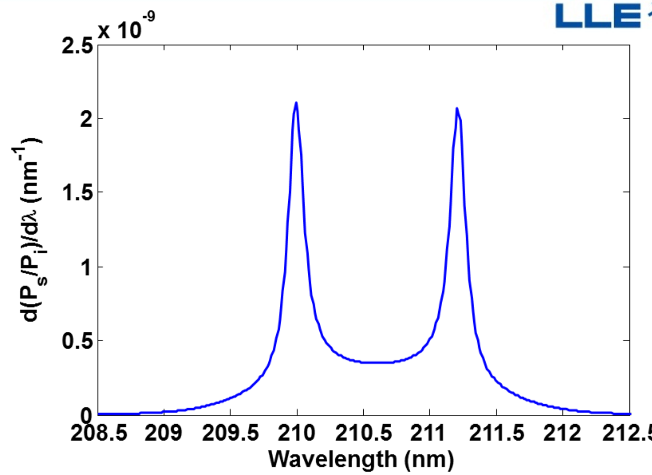


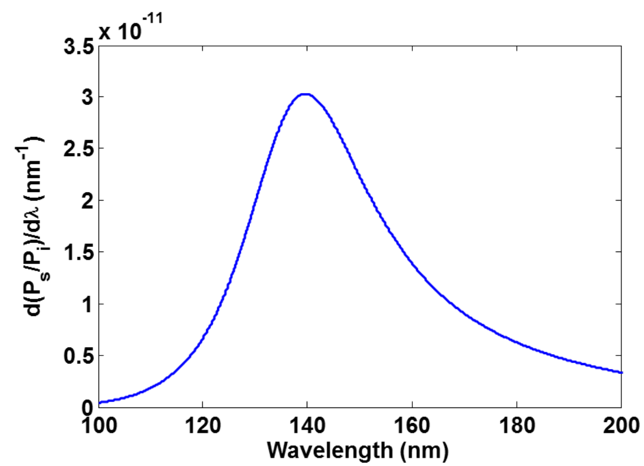
Expected TS signal is a few μJ

The deep-UV NIF OTS will be a pioneering diagnostic in Thomson scattering research

5ω Thomson scattering will also provide access to quarter critical plasma conditions in polar direct drive experiments







- **5ω operations will enable:**
  - **Access to $n_{cr}/4$ plasma conditions (T_e, T_i, N_e, V_{flow})**
  - **The direct measurement of the amplitude of ion-acoustic waves driven by cross-beam energy transfer**

Slide courtesy of D. Froula

A phased approach to Optical Thomson Scattering (OTS) will mitigate the risk presented by background levels

Based on the recommendation of two diagnostic workshops we have developed a phased approach

- **Phase I**
  - **Assess background levels around potential probe wavelengths**
    - **Design and field an optical collection system**
      - **Supporting Electron Feature not to preclude Ion Feature**
    - **Alignment to +/-250 microns for different target types**
    - **Utilize existing NIF beams for the probe on "simple" experiments (Quartraums, Collisionless Shocks, etc.)**

- **Phase II**
  - **Using the background measurements from Phase I validate the probe beam requirements**
  - **Design and field a Thomson scattering system with a dedicated probe beam to allow measurements on all platforms**

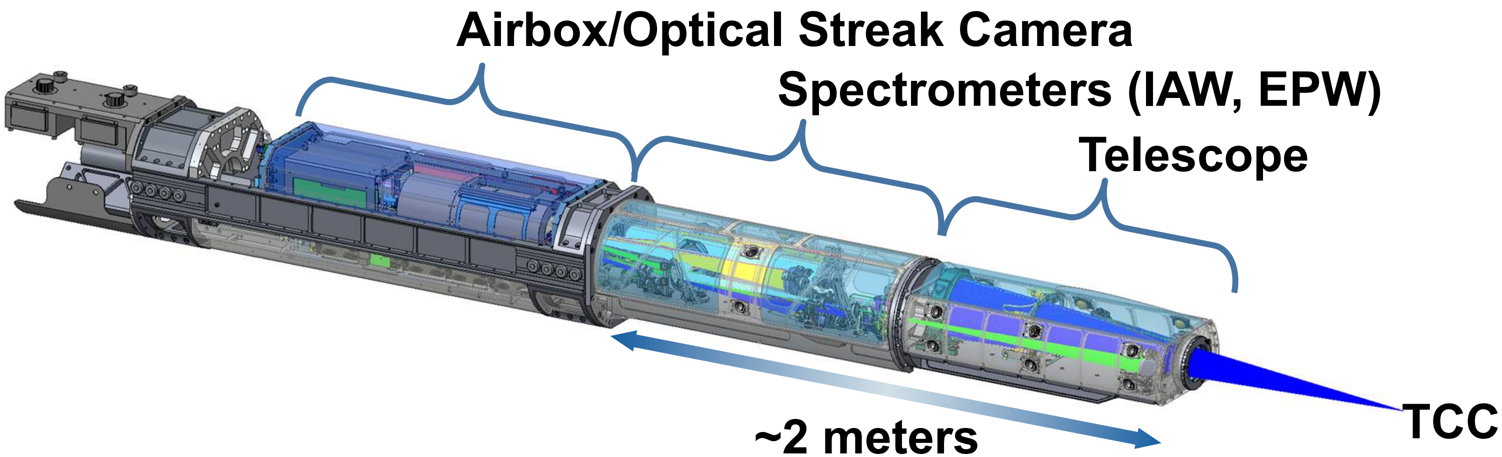
OTS Phase I is currently in progress

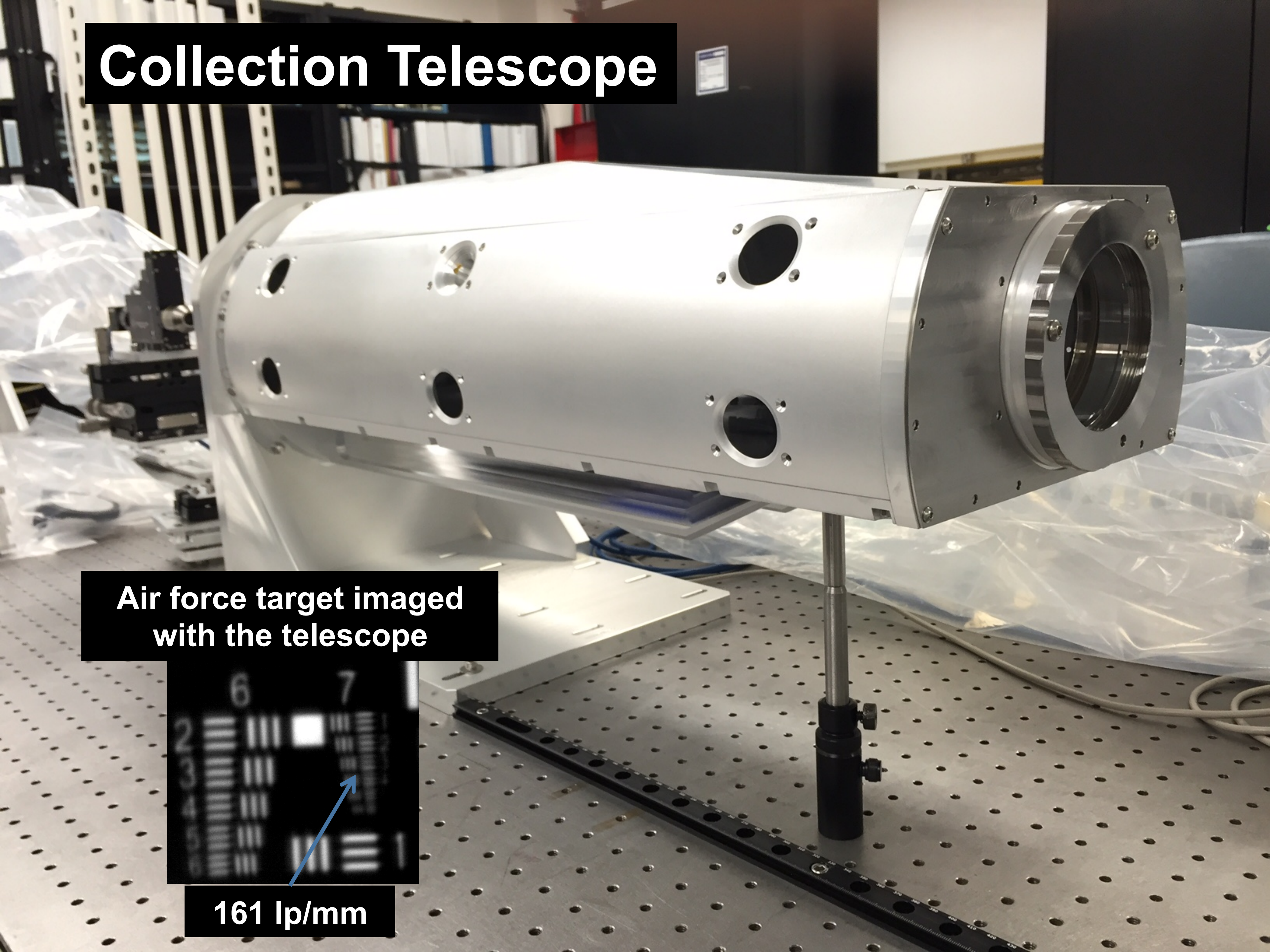
- Optical Thomson Scattering, Phase I
  - ✓ — Requirements Review (RR) – 11/21/14
  - ✓ — Conceptual Design Review (CDR) – 3/19/15
  - ✓ — Optical System Review – 11/5/15
  - ✓ — Final Design Review (FDR) – 12/7/15

  - Installation/Operational Qualification – Q4FY16
  - 1st Qualification shot scheduled – 10/2016
  - A series of qualification shots are planned for FY17
  - Once the diagnostic is qualified it will be made available to users

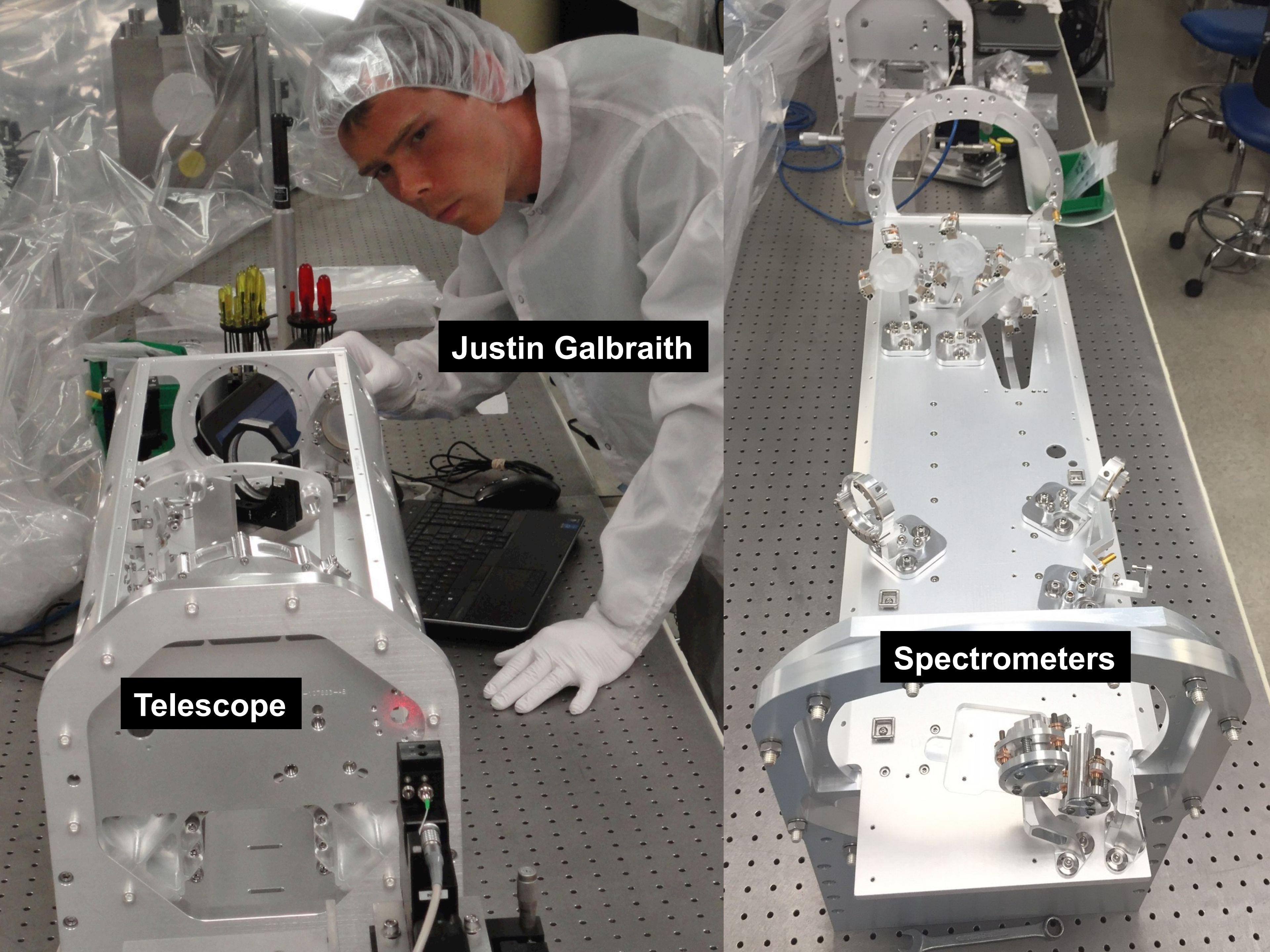
Optical Thomson Scattering is a DIM based diagnostic platform

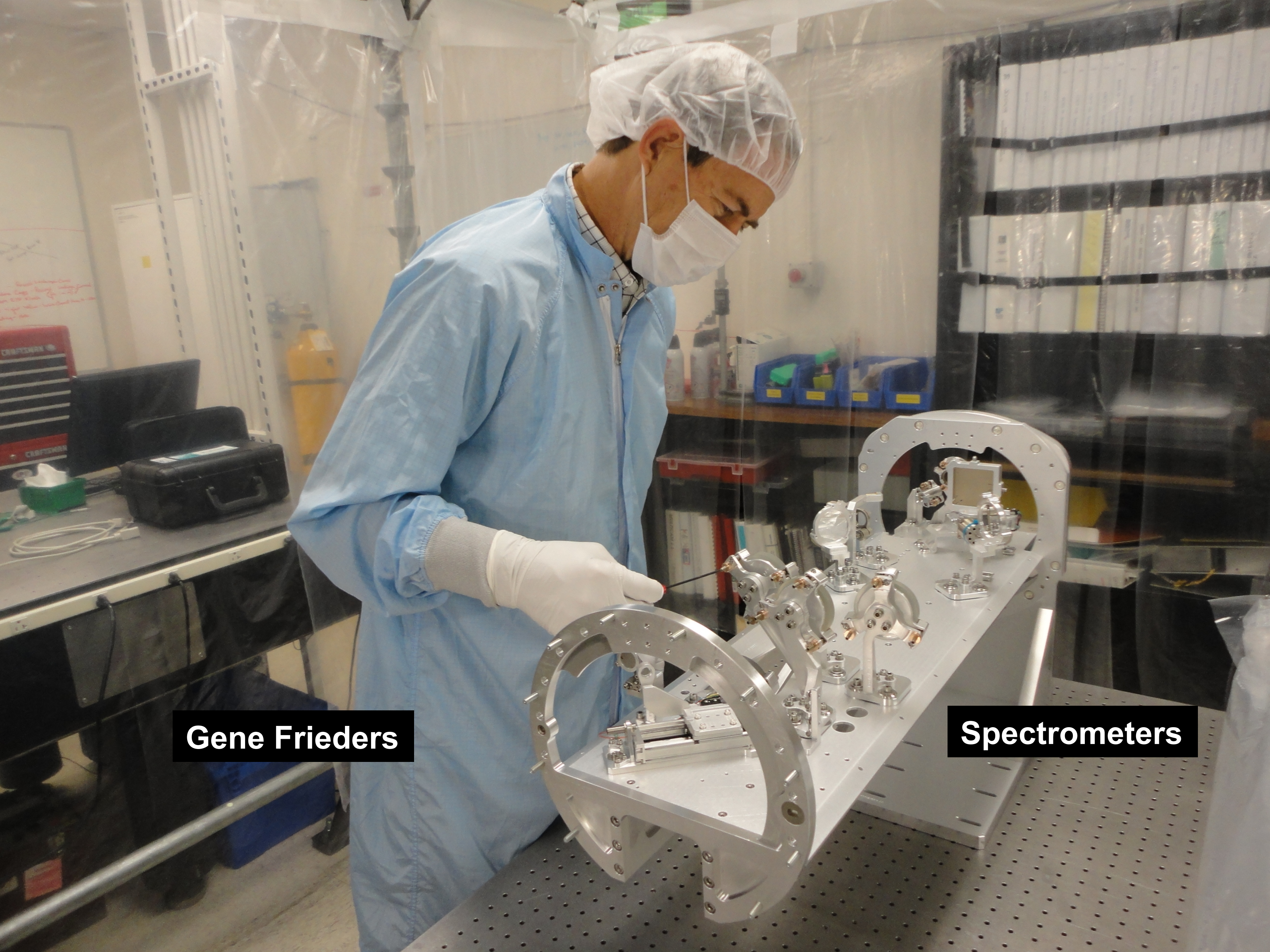
- Optical components include
  - Blast window
  - Unobscured collection telescope
  - Transport optics, including off-axis parabola for focusing to pinhole
  - Separate Czerny-Turner spectrometers for ion-wave & electron-wave band
- Streak camera records time-multiplexed spectrums from two spectrometers:
  - the electron plasma wave spectrometer (low resolution ~0.15m)
  - the ion acoustical wave spectrometer (high resolution ~0.6m)

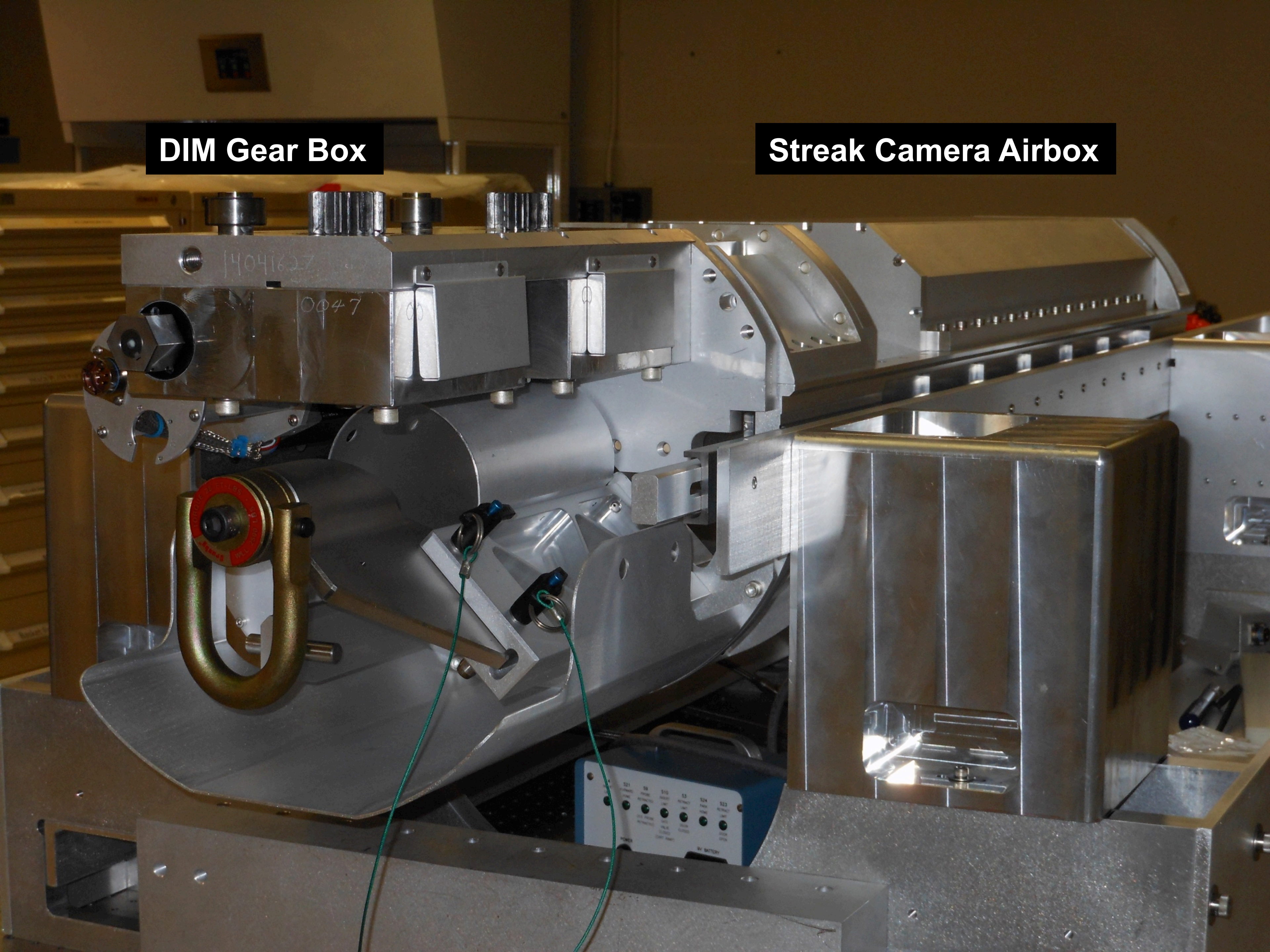



Collection Telescope
Air force target imaged
with the telescope
161 lp/mm

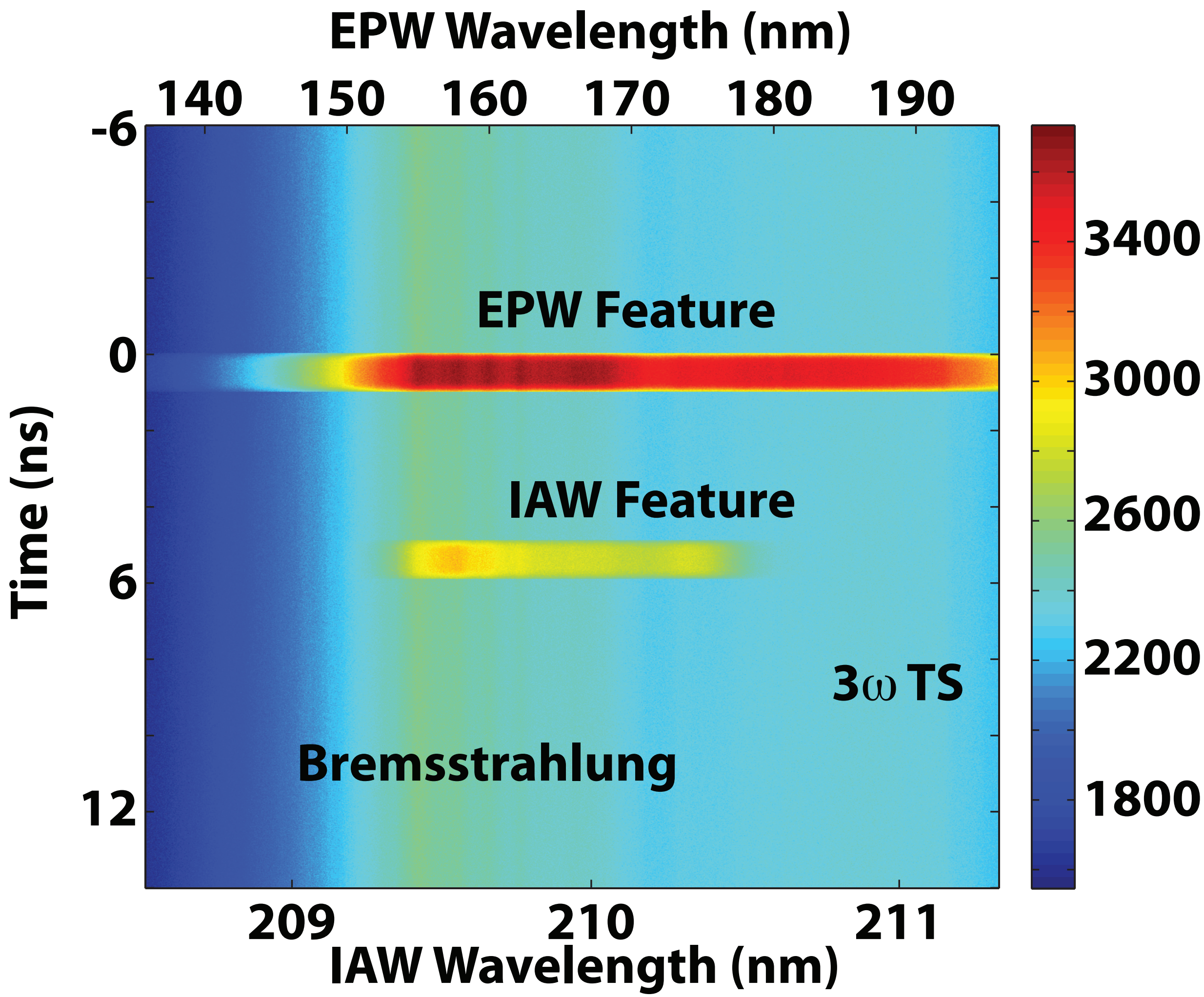

Tom Mccarville


Justin Galbraith
Telescope
Spectrometers


Gene Frieders
Spectrometers


DIM Gear Box
Streak Camera Airbox

Synthetic data is generated using the expected system throughput, quantum efficiency and background



- 10 GW 5ω pulse
  - 10J in 1ns
- Plasma conditions are constant in time
- The properties of each optical component are used to calculate the system performance

The OTS system is also designed for 3ω operations

With minimal component changes the system can be used with a 3ω probe
Magnifications, Size of Thomson volume, time resolution are all unchanged
Assumption: use same gratings, IAW now in 1st order

	IAW	EPW
Reciprocal linear dispersion at exit slit (nm/mm)	0.6313	5.620
Reciprocal linear dispersion at photocathode (nm/mm)	0.4858	4.369
Desired bandwidth (nm)	4	50
Bandwidth for 20mm photocathode width (nm)*	9.2	71.4
Size of desired band at photocathode (mm)	17.4	11.3
Resolution specification (δλ/λ)	0.0001	0.01
Achieved resolution (given dispersion, pinhole size)	0.000113	0.00335
Theoretical resolution (based on illuminated grooves)	0.000004	0.000095

* Accounts for clipping at EPW mask plane mirror

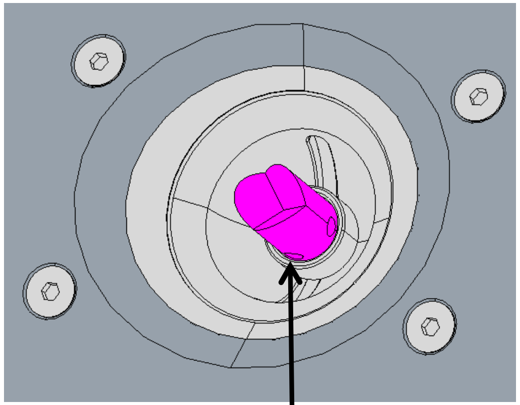
Concept of operations for OTS during shot cycle

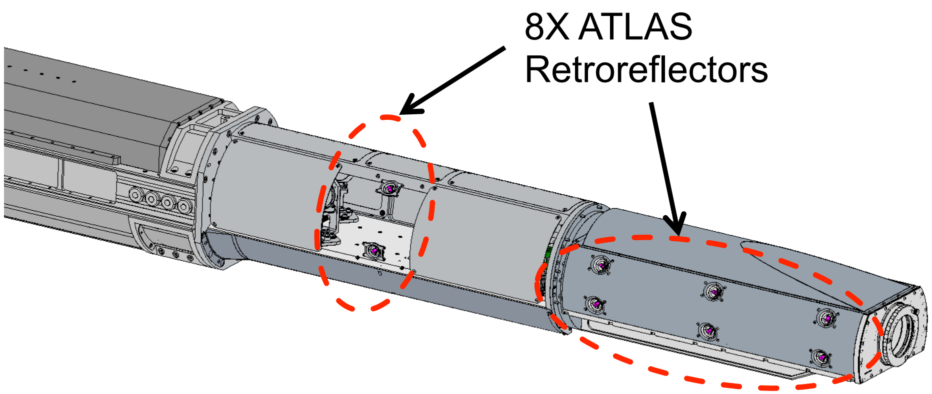
- DIM based installation
- Streak camera control
  - Pre shot dry runs
  - Comb and FIDU recording
- ATLAS Alignment
  - Video internal alignment
  - Illumination control
- Iris adjustments
- Grating adjustments
- Mask adjustments

- OTS currently does **not** support classified operations.
- If required to operate in classified mode simple changes to the video camera controls could be implemented.

The OTS diagnostic can be aligned with an internal alignment camera or ATLAS

- Initial Alignment within NIF
  - Align target to TCC using TAS
    - ATLAS measures TAS to locate TCC
  - Pick off mirror is inserted to direct light from the telescope to PixeLINK 957G camera
  - Telescope views target and image is relayed to camera
    - Adjust telescope position until image overlays pinhole location
  - ATLAS measures OTS DLP of retroreflecting targets (8)
    - Defines relationship between target location and OTS LOS





16 ATLAS retroreflecting targets are included within the telescope and spectrometer modules (8 viewable by DIM 0-0 and 8 viewable by DIM 90-315)

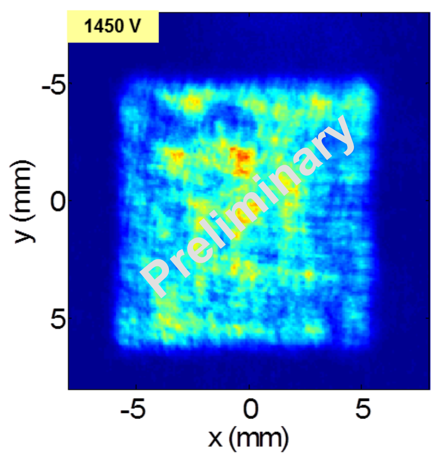
OTS Phase II laser system evaluation in progress

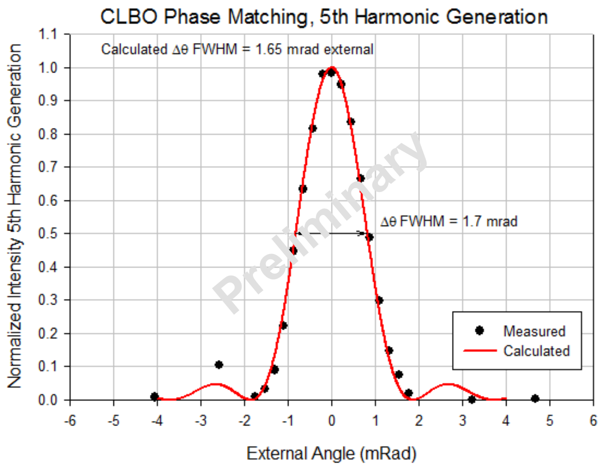
- Develop a laser plan for OTS Phase II
- Evaluate a 5th harmonic generator
  - Conversion efficiency
  - Damage threshold
  - Estimate crystal aperture
- Determine the required energy for NIF OTS – Phase I measurements
- Establish facility configuration options – Switch yard 1, 40ft level
- Evaluate laser sources that can meet performance

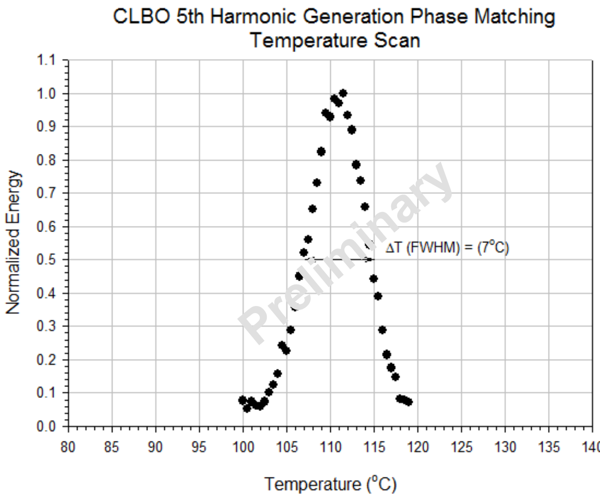
Laser system is required for Phase II operation, several areas require investigation

CLBO 5th harmonic generation evaluation summary

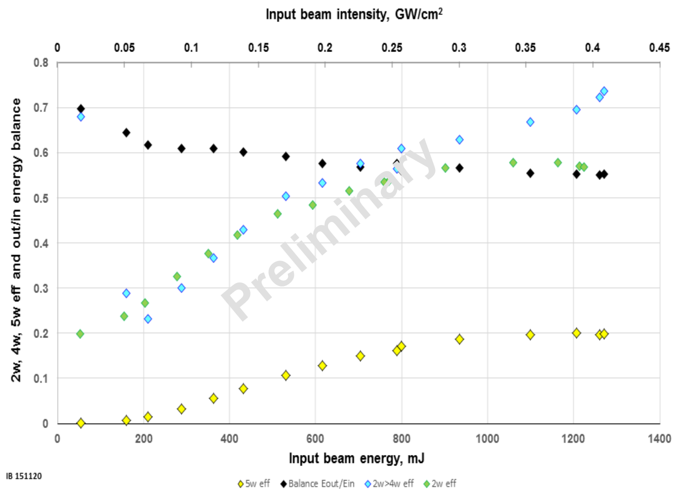
- Measurement Include
  - Phase matching
  - Temperature sensitivity
  - Image at crystal plane
  - Conversion efficiency
  - Max operating power

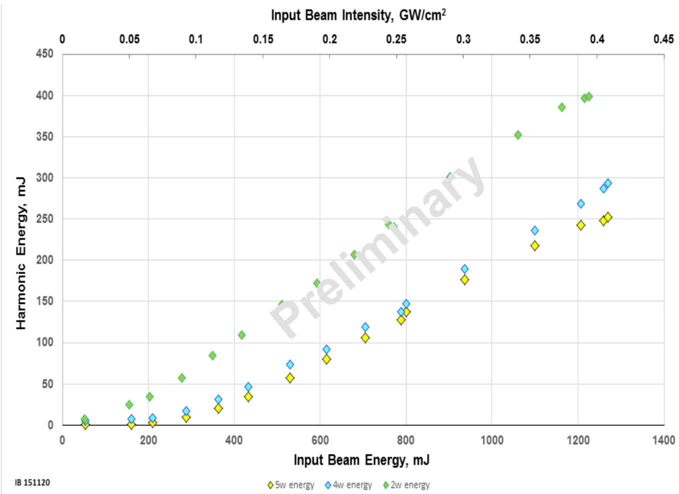






CLBO 5th harmonic generation evaluation summary - Continued





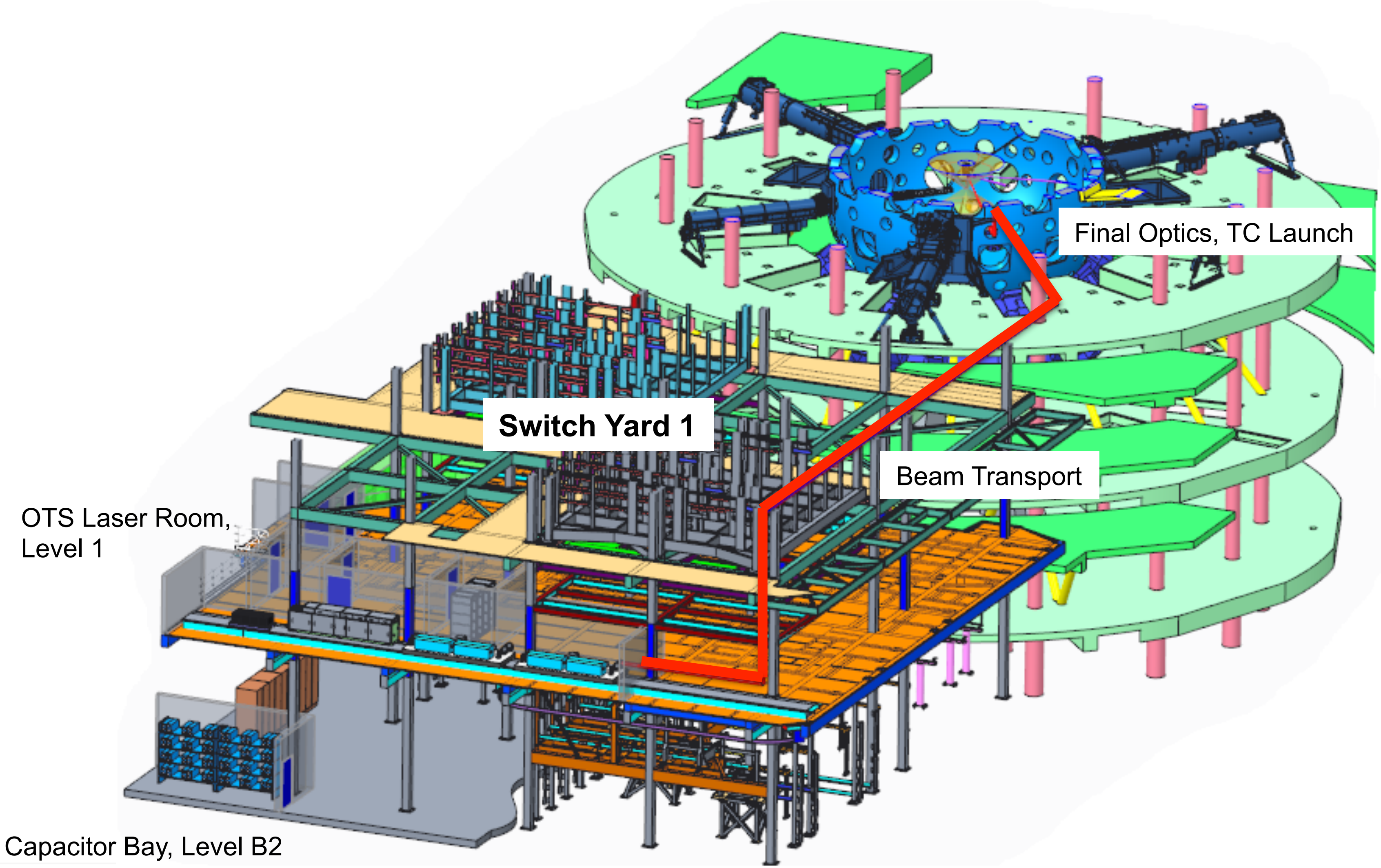
Preliminary results show:

- Phase matching angle (FWHM): 1.7 mRad
- Temperature sensitivity(FWHM): 7 °C
- Conversion efficiency: ~20% @ 2.8ns pulse width
- Operation power (GW/cm^2): ~ 0.4

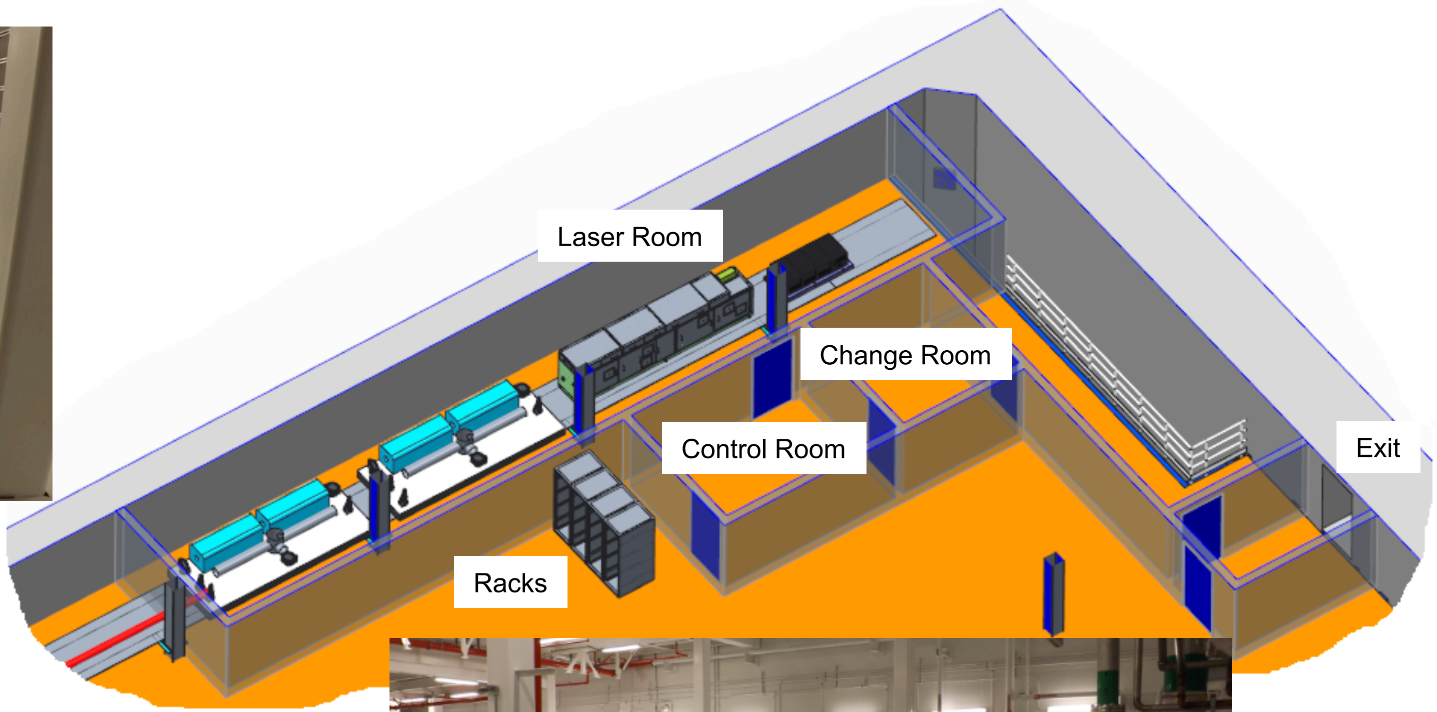
Data Acknowledgement:

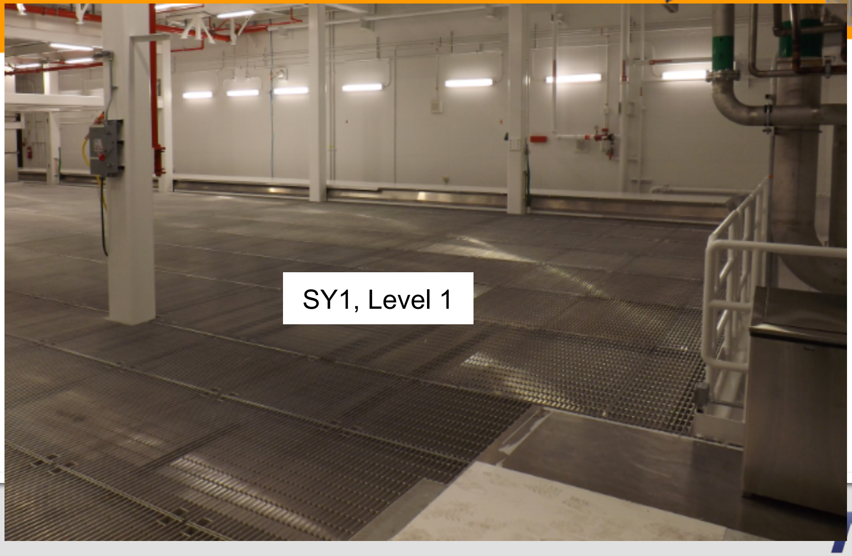
- Special thanks to LLE for working with LLNL to complete these important and encouraging measurements!

Conceptual Laser System Overview



OTS Laser Room





SIS CCB5 Feedback, 5/17/16:

- Area will be swept for all shots
- No occupancy allowed during CAT C or precision shots
- Consider laser curtain, local HEPA change room
- Consider NTOF Pit for Cap Bay
- Need laser safety assessment

OTS Laser concept

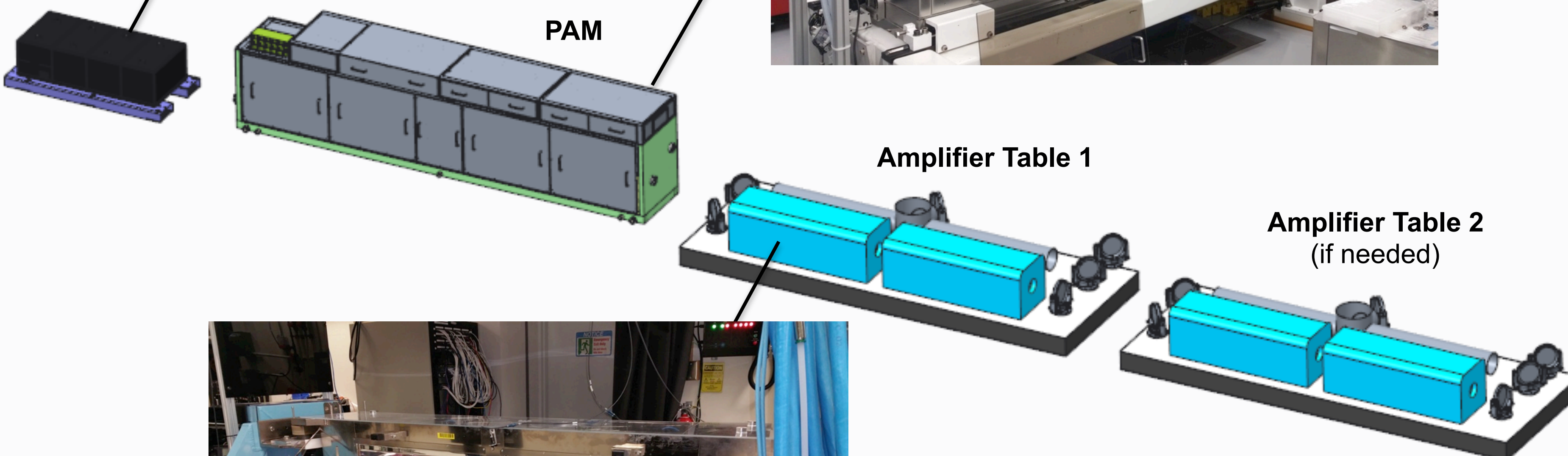
LLE PAM

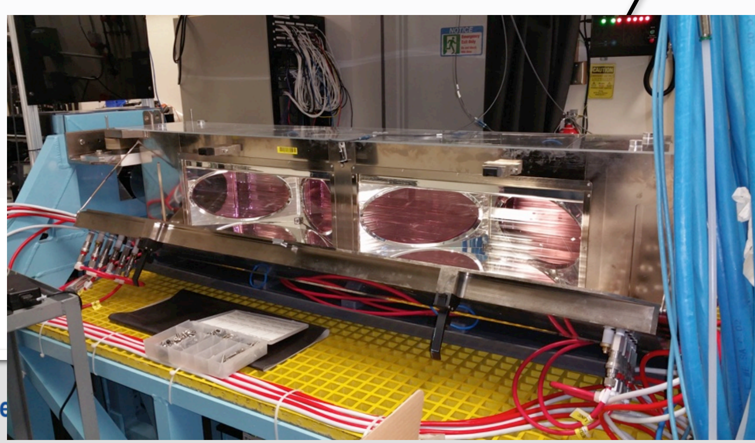
PCU

PAM

Amplifier Table 1

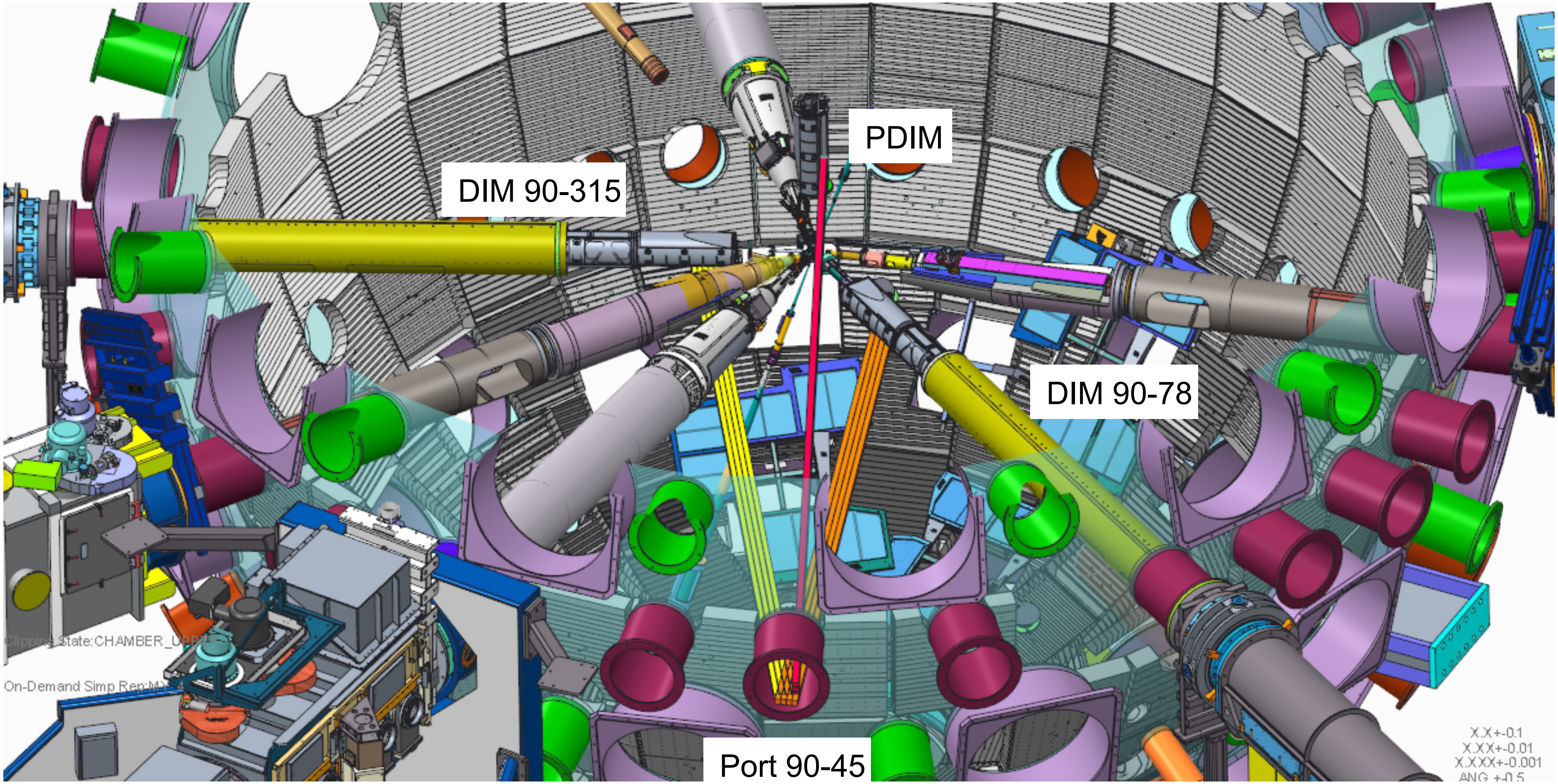
Amplifier Table 2
(if needed)



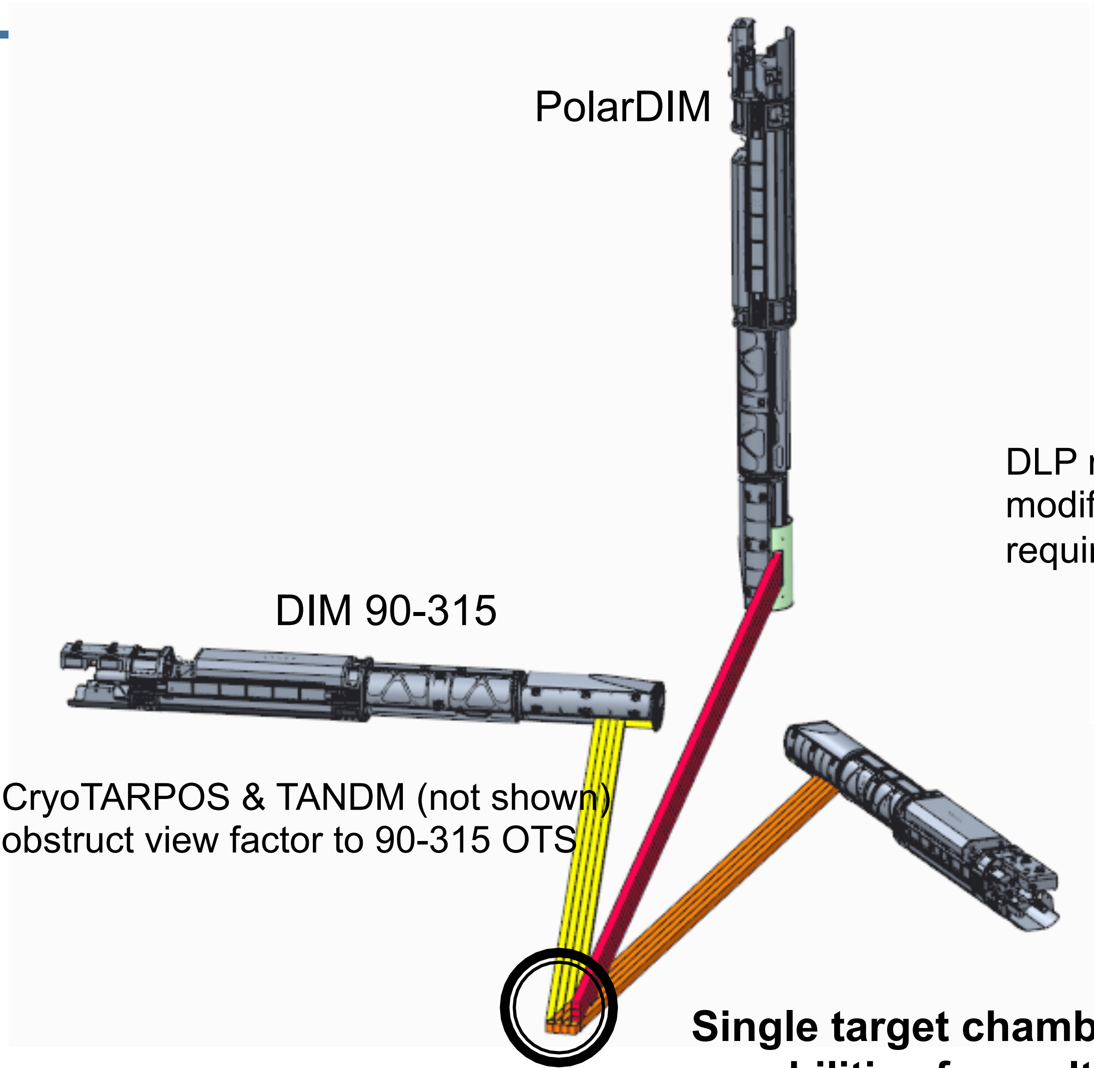


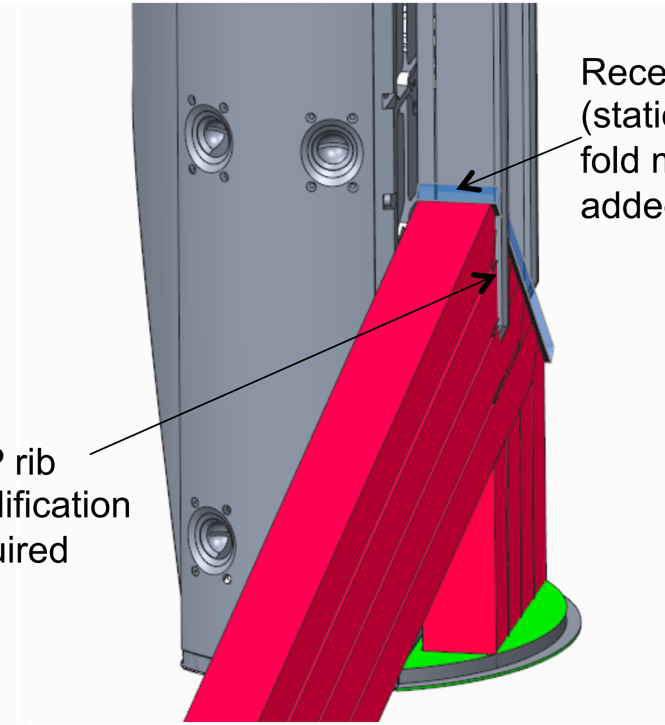
15cm LLE Disc Amplifier

Concept for beam delivery to target chamber center



The laser is pointed to the DIM due to alignment constraints





Single target chamber port sought for OTSL launch capabilities for multiple DIM orientations

Current OTS laser status

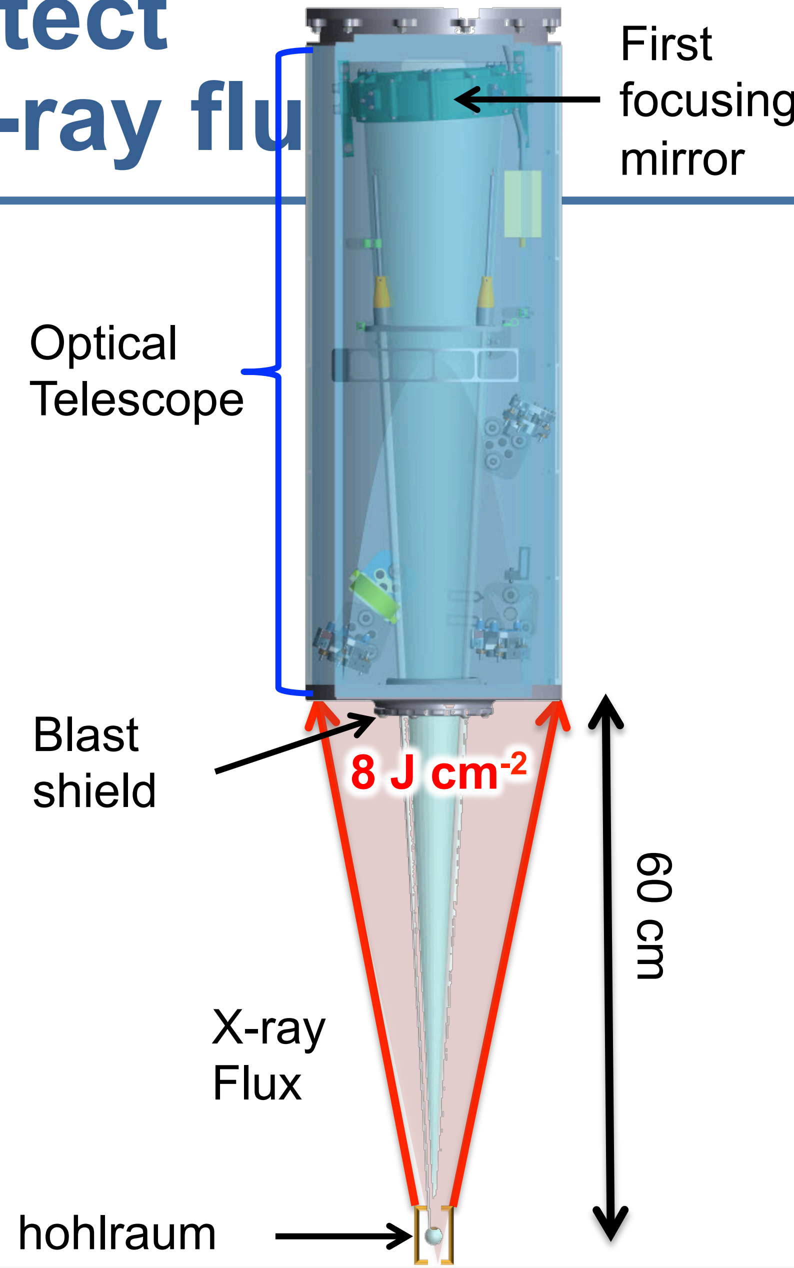
- Crystal evaluation demonstrates that CLBO is a very encouraging candidate, more data will be collected over the next few months.
- Location has been identified in switchyard 1
- Laser energy limits will be established with Phase 1 measurements (Q1FY17).
- Laser development requires "custom" designs that are not off the shelf.

OTS Summary

- OTS is a DIM based collection system designed for wavelengths from 150nm to >600nm
- The system will operate in either the polar and equatorial location
- OTS Phase I fabrication is in progress with installation planned for 4Q FY16
- OTS Phase I (including 3w Thomson Scattering) qualification begins in FY17
- Once the diagnostic is qualified it will be made available to users
- A dedicated 5th harmonic probe beam is being developed in collaboration with LLE

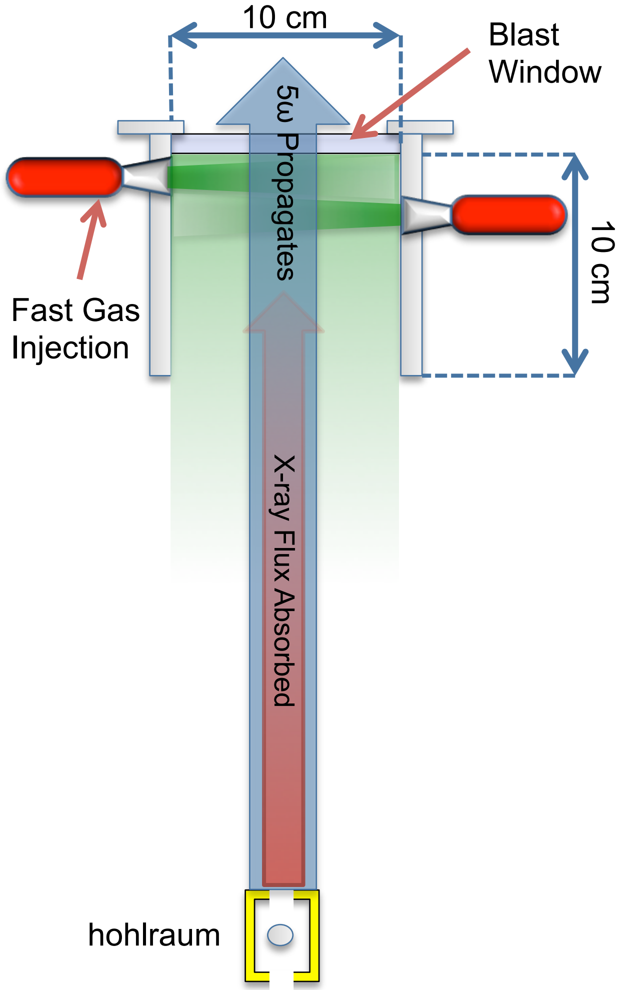
Motivation: Need to Protect optics from hohlraum x-ray flu

- Optical diagnostics require **blast shields** to protect optics
- Blast shield subjected to hohlraum x-ray flux
- X-rays cause **"blanking"** – radiation induced opacity of glass
    - Looked at during development of Near Backscatter Imager (NBI):
        - London et. al., Blanking @ **300 mJ cm^{-2}**
    - Thomson scattering blast shield is 60cm from TCC
    - experimental evidence and theory both suggest that at this distance **blast shield will blank** rapidly without protection

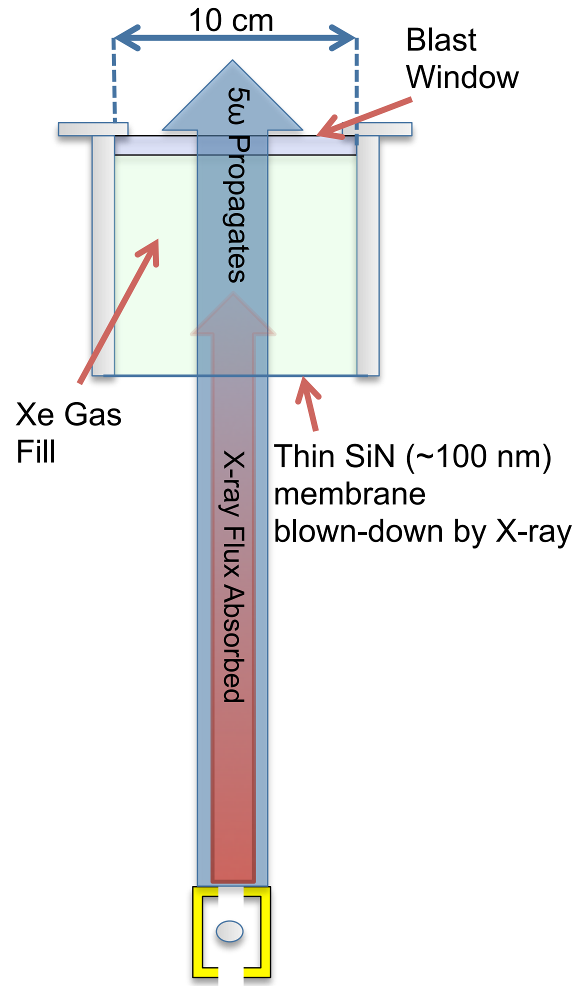


Concept – Currently considering two designs of gas x-ray shield for the NIF

Dynamic gas jet



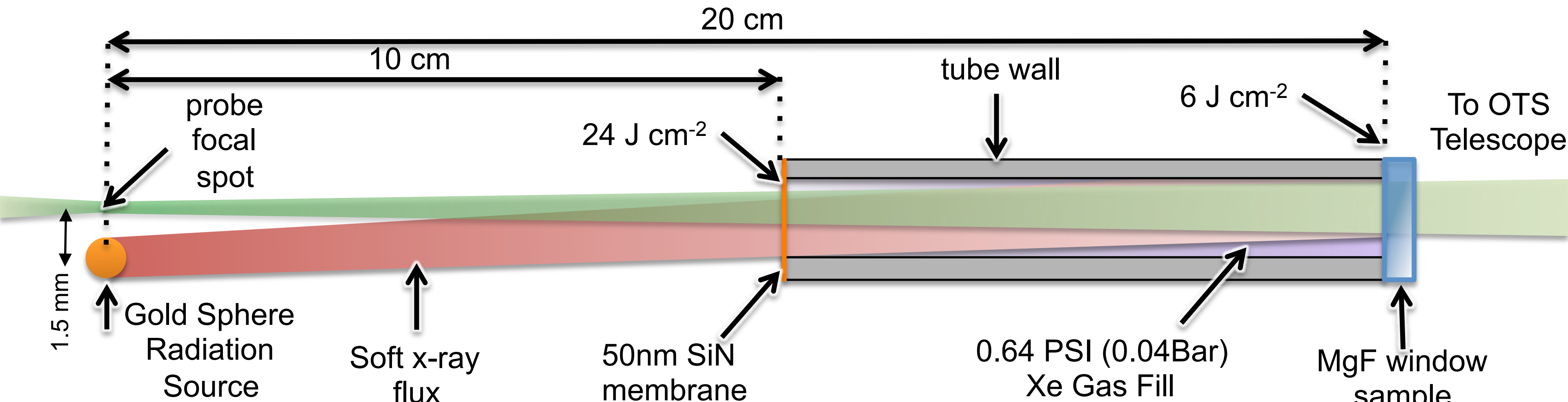
Static gas cell



- X-rays **absorbed** in Xe gas
  - similar to concept developed for LIFE program
- **Xe** is **photo-ionized** by x-rays
- Xe density tailored such that **max(n_e) << n_c**
  - $n_c(5\omega) = 2.5\times10^{22}$ cm^{-3}
- **UV** signal is **transmitted** through photo-ionized plasma

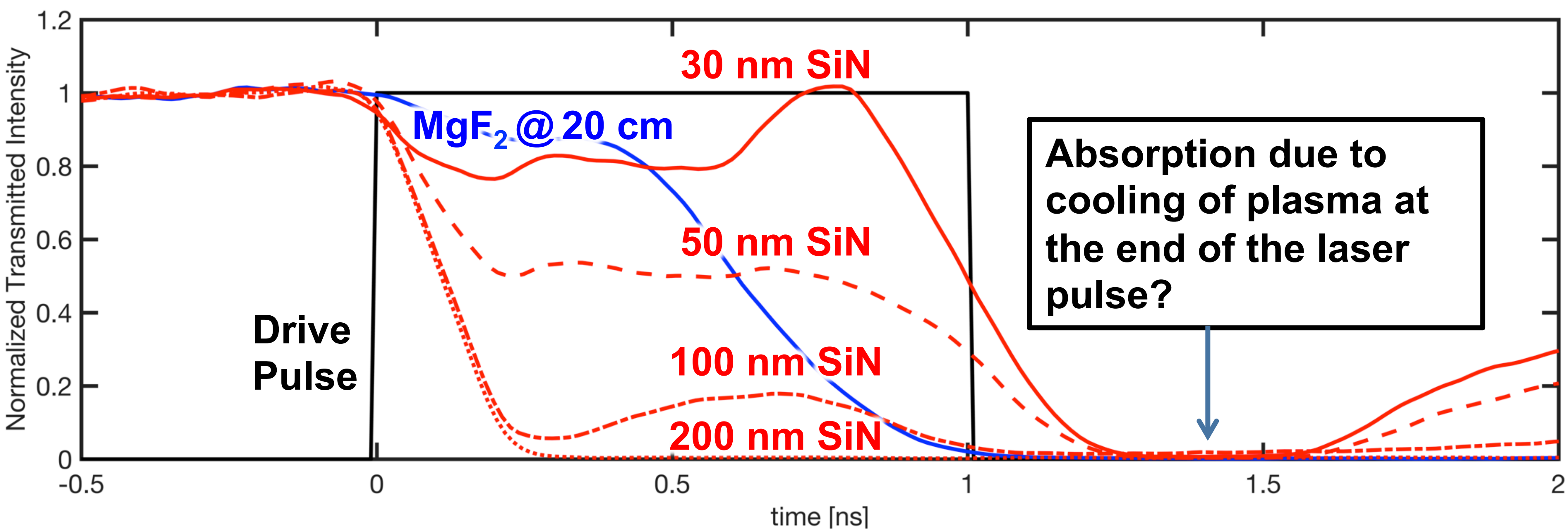
OMEGA results provide a path to a blanking mitigation scheme for NIF OTS

- Shot day was April 26th – currently <u>only **preliminary** analysis is available</u>.
- High quality data was captured in a total of 11 target shots.
  - 4 Shots measured onset of blanking in Fused Silica and Magnesium Fluoride at 10 and 20cm distances
  - 2 Shots tested statically filled gas x-ray shields with 500 nm & 200 nm membranes
  - 4 Shots tested in-situ filled gas x-ray shields 100 nm, 50 nm and 30 nm
  - 1 Control Shots:
    - 50 nm membrane **<u>only</u>**



Xe gas shield appears to mitigate x-ray blanking of MgF_2 samples

- Xe gas shield with SiN membrane is capable of mitigating x-ray blanking
- Thickness of SiN membrane is critical – 30 and 50nm membranes show improvement over bare MgF_2



The high level technical requirements for the NIF OTS system were developed to allow plasma characterization in NIF hohlraums

Spectrometers

- Ion feature band ($\Delta\lambda$ ±4 nm)
  - Ion feature resolution – ($\delta\lambda/\lambda$) = 0.0001
- Electron feature band (150-300 nm)
  - Electron features – ($\delta\lambda/\lambda$) = 0.01
- Time window 5-35 ns

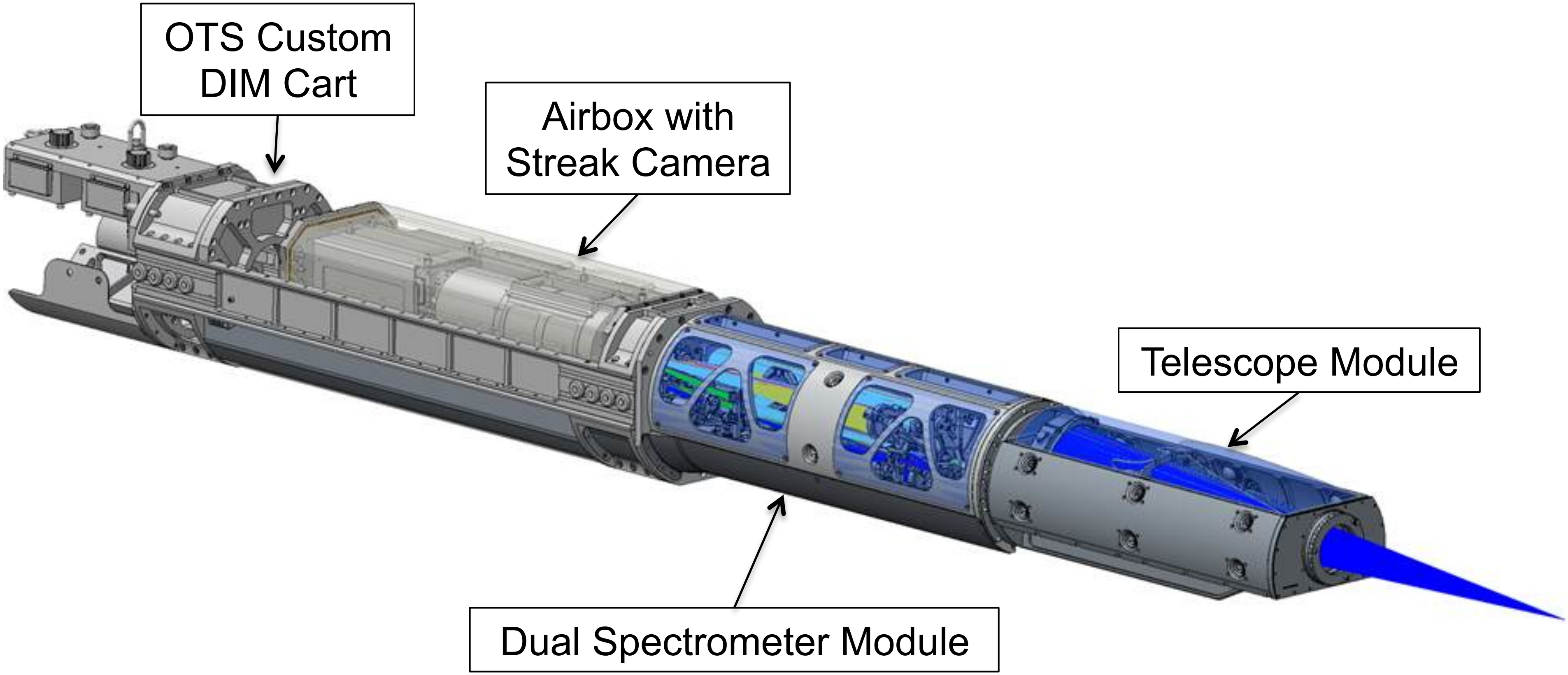
Probe laser

- Wavelength , λ_0– between 185-215 nm
- Power – 10 GW
- Energy – 10J
- Pulse width – 1 ns, flat-top

Probe laser and collection port location – (0-0 notional)

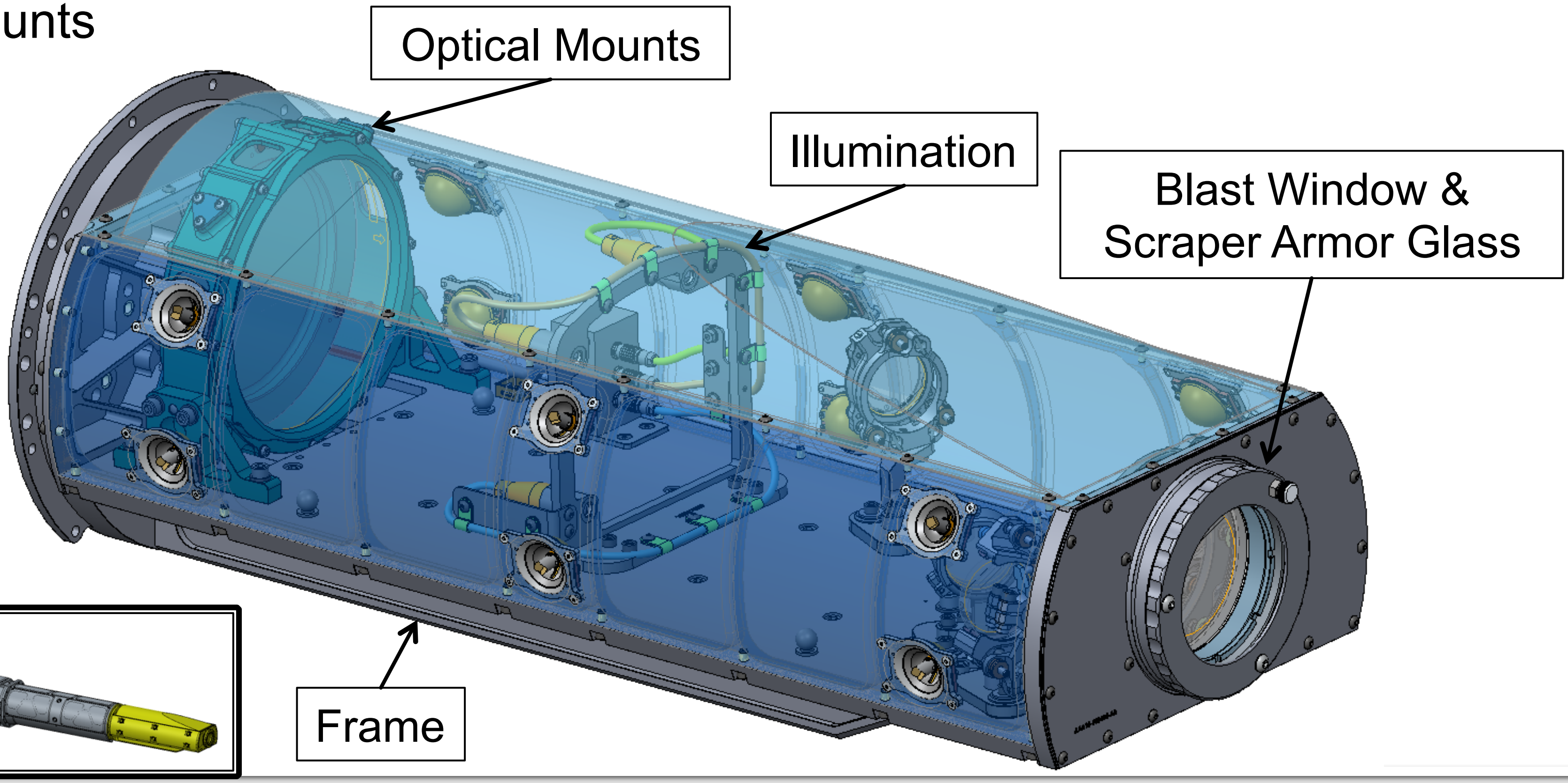
- Collection to target alignment ±250 μm
- Probe to collection alignment ±50 μm
- Collection angle ~18 degrees

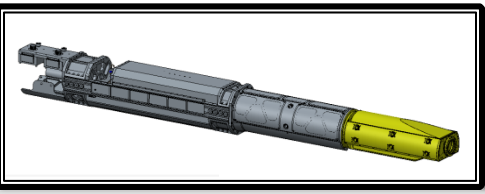
The mechanical design consists of four major subsystems



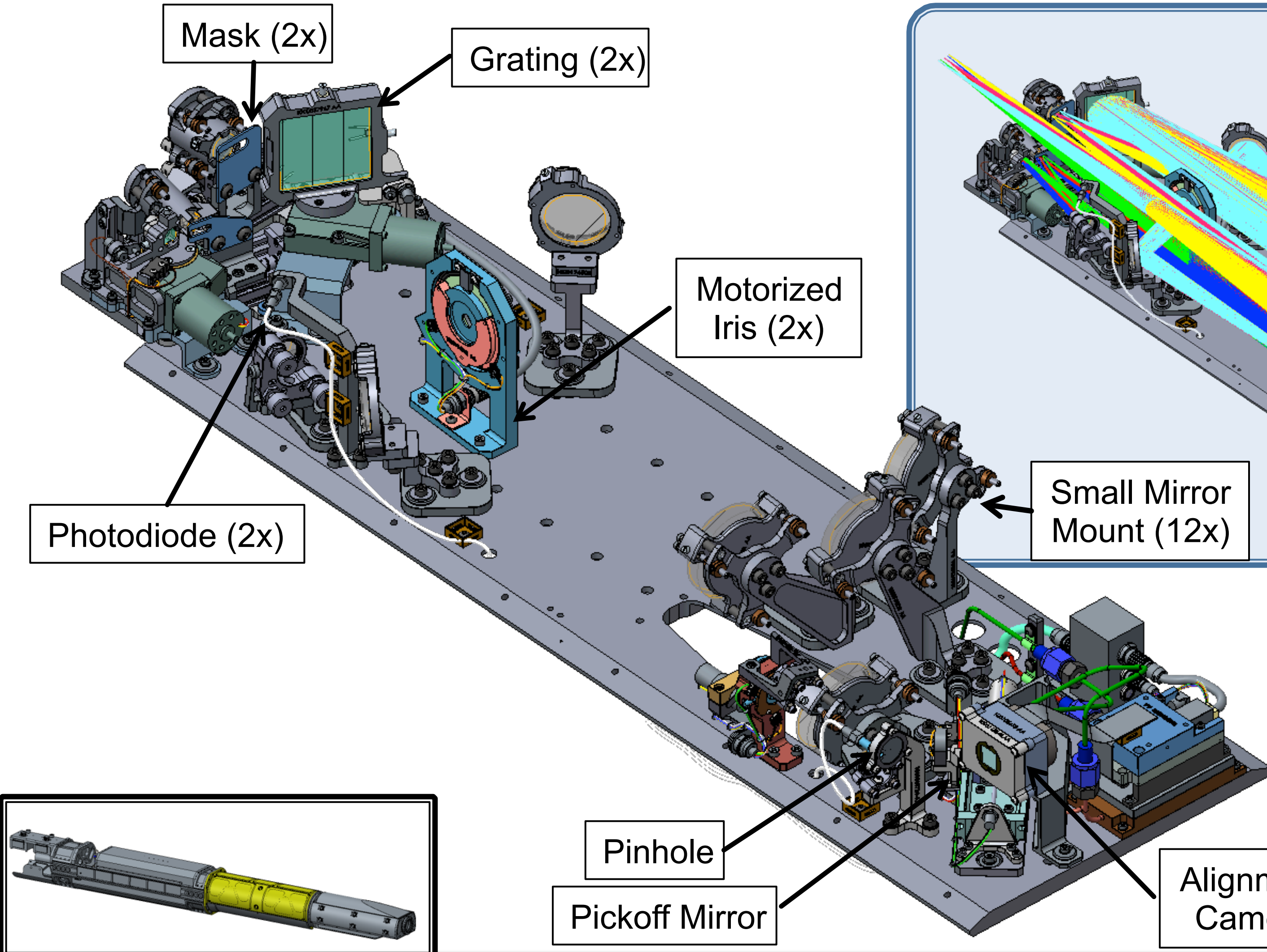
OTS telescope module

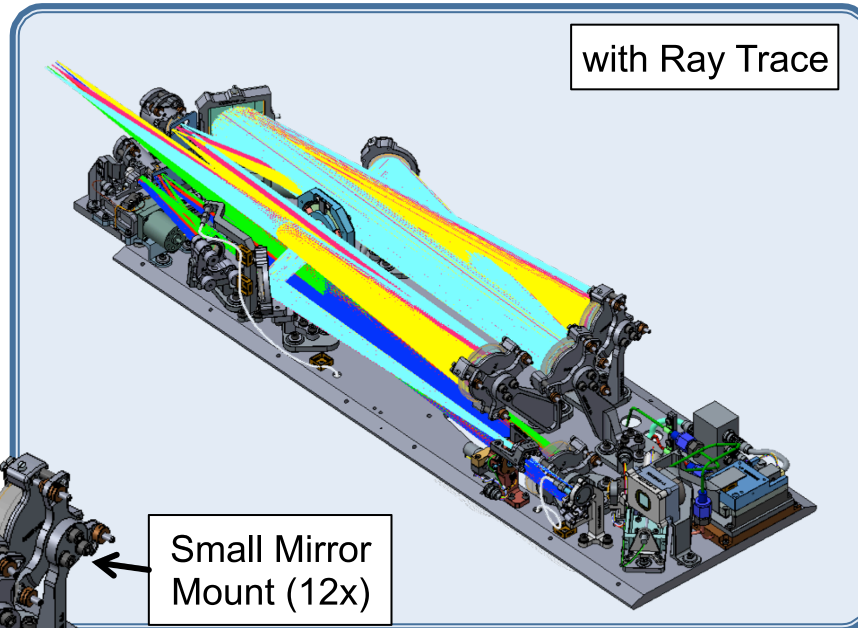
- Self contained
- Mounts to Spectrometer Module with fasteners and precision pins
- Subsystems include: Frame, Blast Window, Illumination, and Optical Mounts



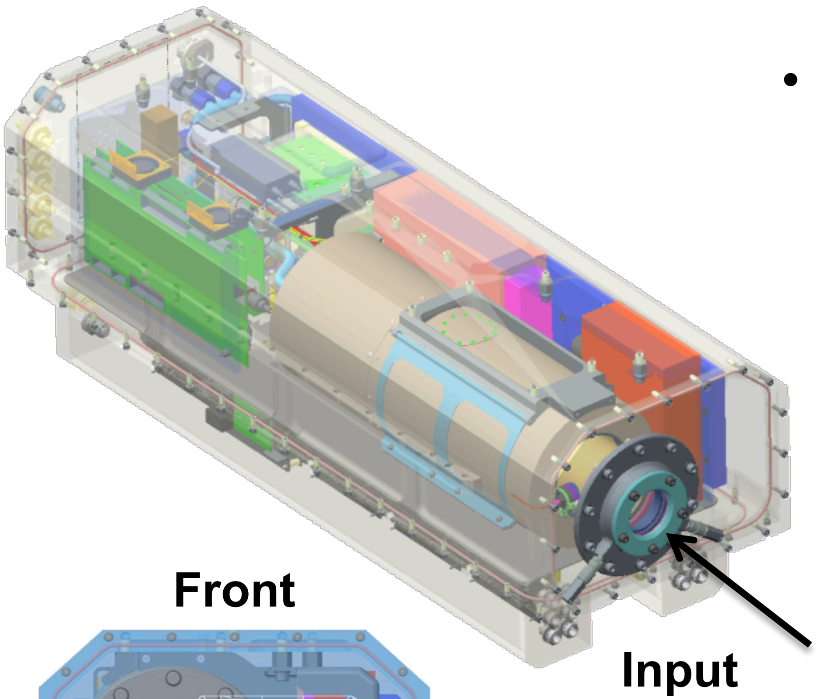


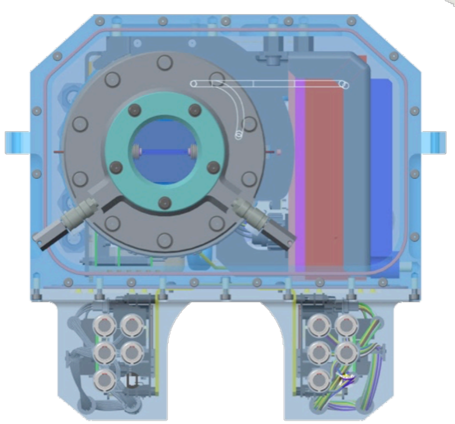
OTS spectrometer module – hardware layout





The OTS streak camera is housed in an airbox





- Optical streak camera configuration
  - S-20 Streak tube
  - 21 mm spatial region for IAW & EWP spectrum
  - Resolution element ~100 um
  - FIDU and Comb imprinted on data image
  - Gated cathode operation
  - 4 selectable sweep window (5,10,15,35) ns
  - CaF_2 Airbox vacuum window
  - CaF_2 photo-cathode window
  - N_2 beam path from window to optical path