UV Thomson Scattering on the NIF

National ICF Diagnostics Working Group Meeting
October 6 - 8, 2015

James Steven Ross

October 6th, 2015

LLNL-PRES-XXXXXX
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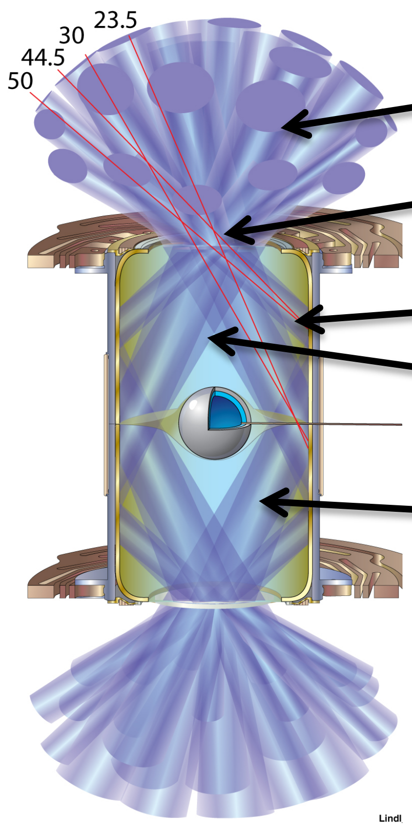
Optical Thomson Scattering (OTS) team

- OTS Working Group
  - LLNL: J. S. Ross, J. Moody, L. Divol, P. Michel, D. Turnbull, O. Landen, B. Pollock, G. Swadling, C. Goyon, O. Jones, J. Milovich
  - GA: J. Kilkenny
  - LLE: D. Froula, J. Zuegal, J. Bromage
  - LANL: D. Montgomery, J. Kline
  - SLAC: S. Glenzer
  - NRL: J. Weaver
  - SNL: A. Sefkow
  - AWE: D. Chapman
  - U. Alberta: W. Rozmus
- OTS Design Team (LLNL)
  - Target Diagnostic Lead – Joe Kilkenny
  - Optical Diagnostic Lead – John Moody
  - Responsible Scientist – Steven Ross
  - Responsible Individual – Philip Datte
  - Mechanical Design – Justin Galbraith/ Michael Vitalich
  - Electrical Design – Ben Hatch/Warren Massey/Gene Vergel de Dios/Ray Iaea
  - Optical Design – Stacie Manuel/Bill Molander
  - Software – Kelly Burns/Barry Fishler
  - Additional Support – Steven Yang/Mike Rayce

Outline

- TS Physics Motivation
  - Hohlraum plasma conditions
- NIF Diagnostic requirements
- NIF Diagnostic design
- Point Design measurements
  - Hohlraum LEH
  - PDD
  - MagLIF
  - Collisionless Shocks
- Technical challenges
- Schedule

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

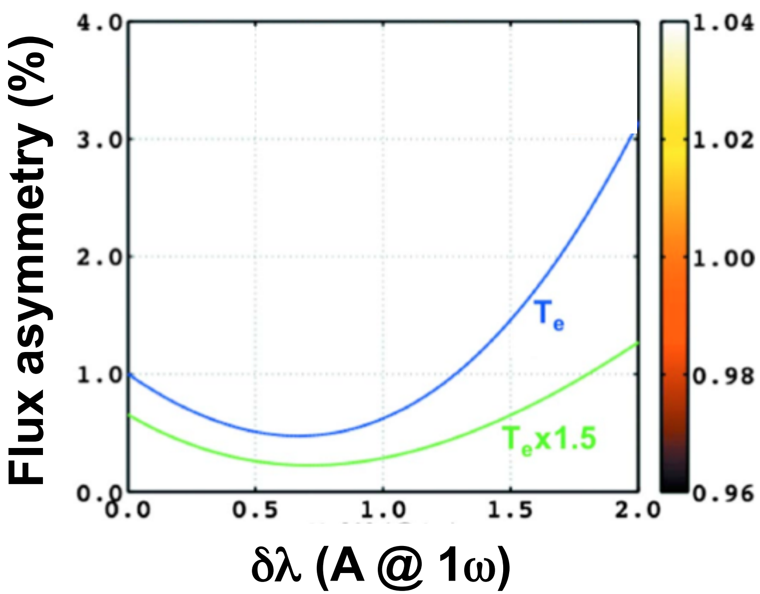


Additional physics: X-ray conversion, wall losses, wall-gas mix, hot-electron preheat, glint, re-amplification…

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

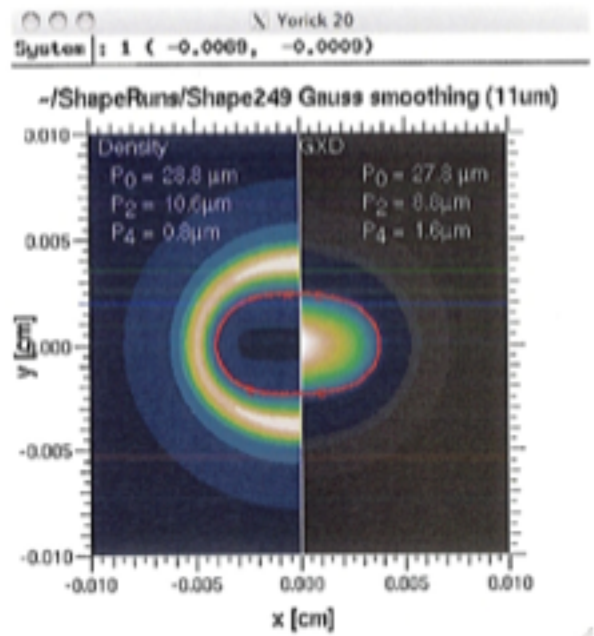
Gas-filled hohlraums rely on CBET to control shape

Our ability to predict CBET and implosion shape is highly dependent on our understanding of plasma conditions



P. Michel et. al. PoP 2009

-1% P2 Flux



Calculation by A. Kritcher

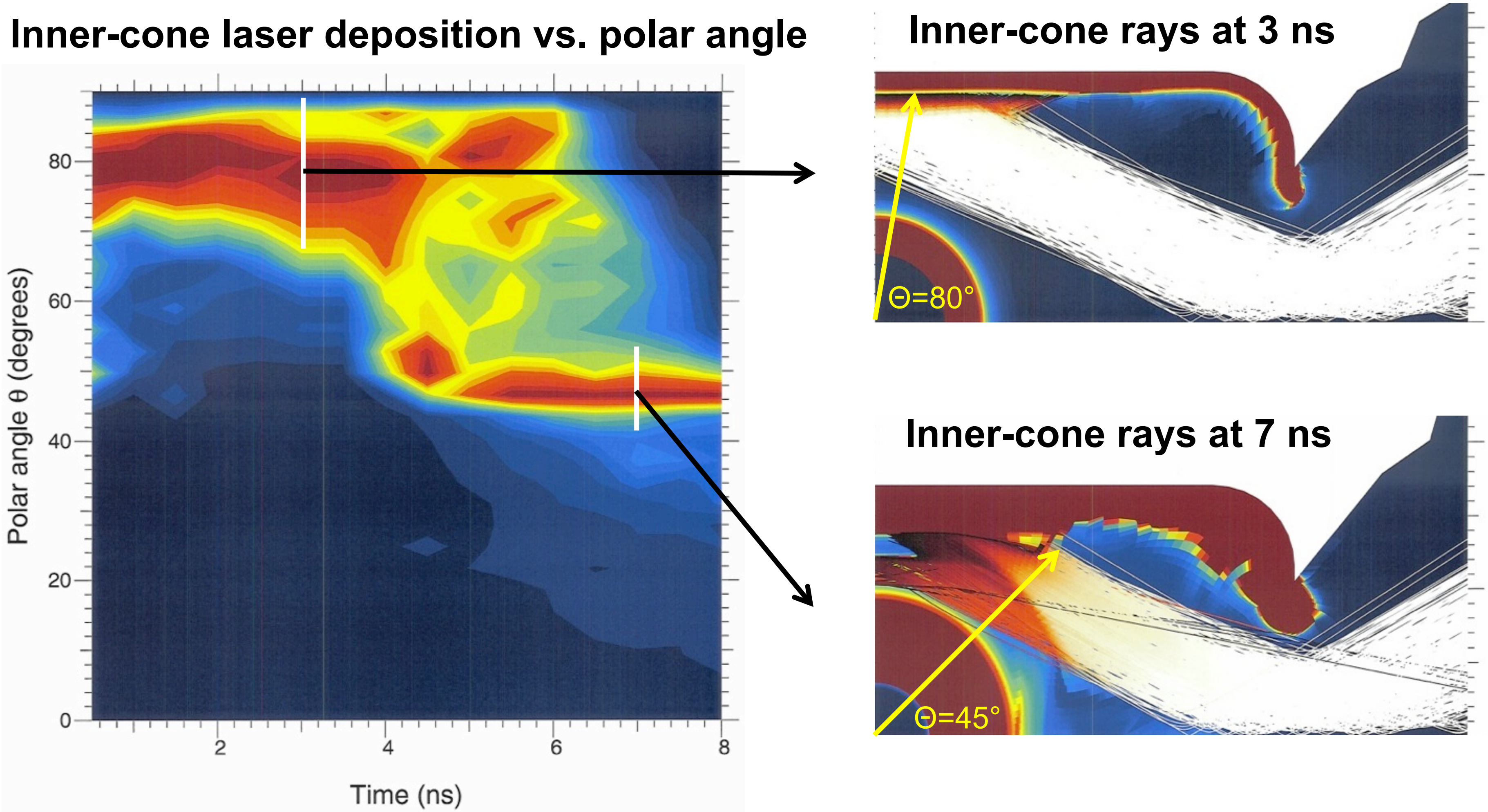
A 1% flux asymmetry in the peak of the laser pulse can result in unacceptable (>30% P2/P0) shape

Shape control in vacuum hohlraums is a challenge due to wall motion

Inner-cone laser deposition vs. polar angle

Inner-cone rays at 3 ns

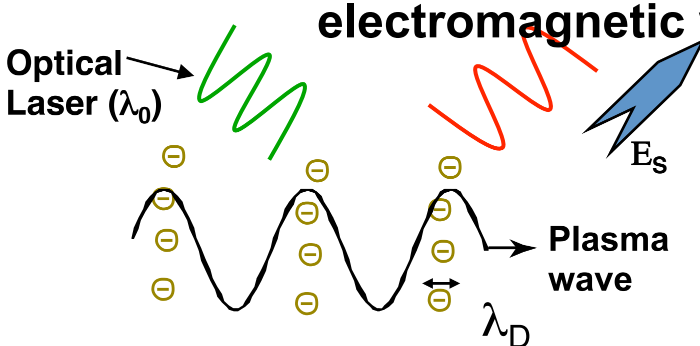
Inner-cone rays at 7 ns



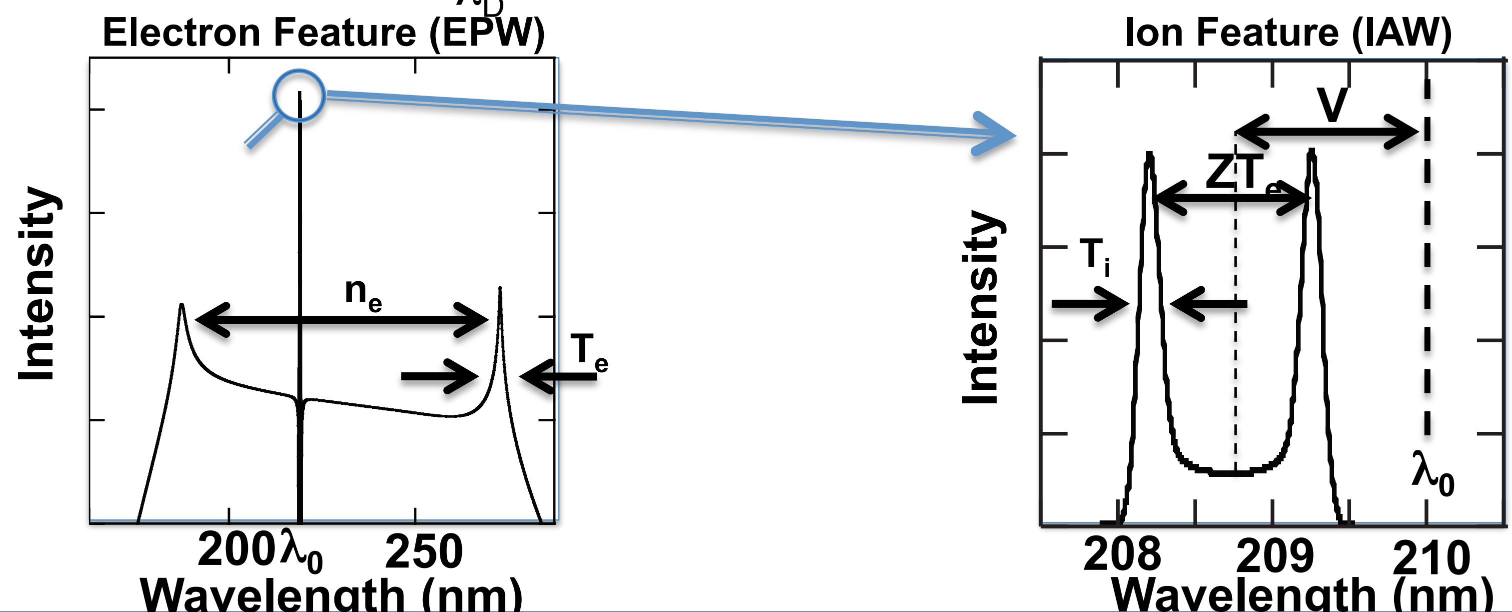
Calculation by N. Meezan

Optical Thomson provides a local measurement of the plasma conditions

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

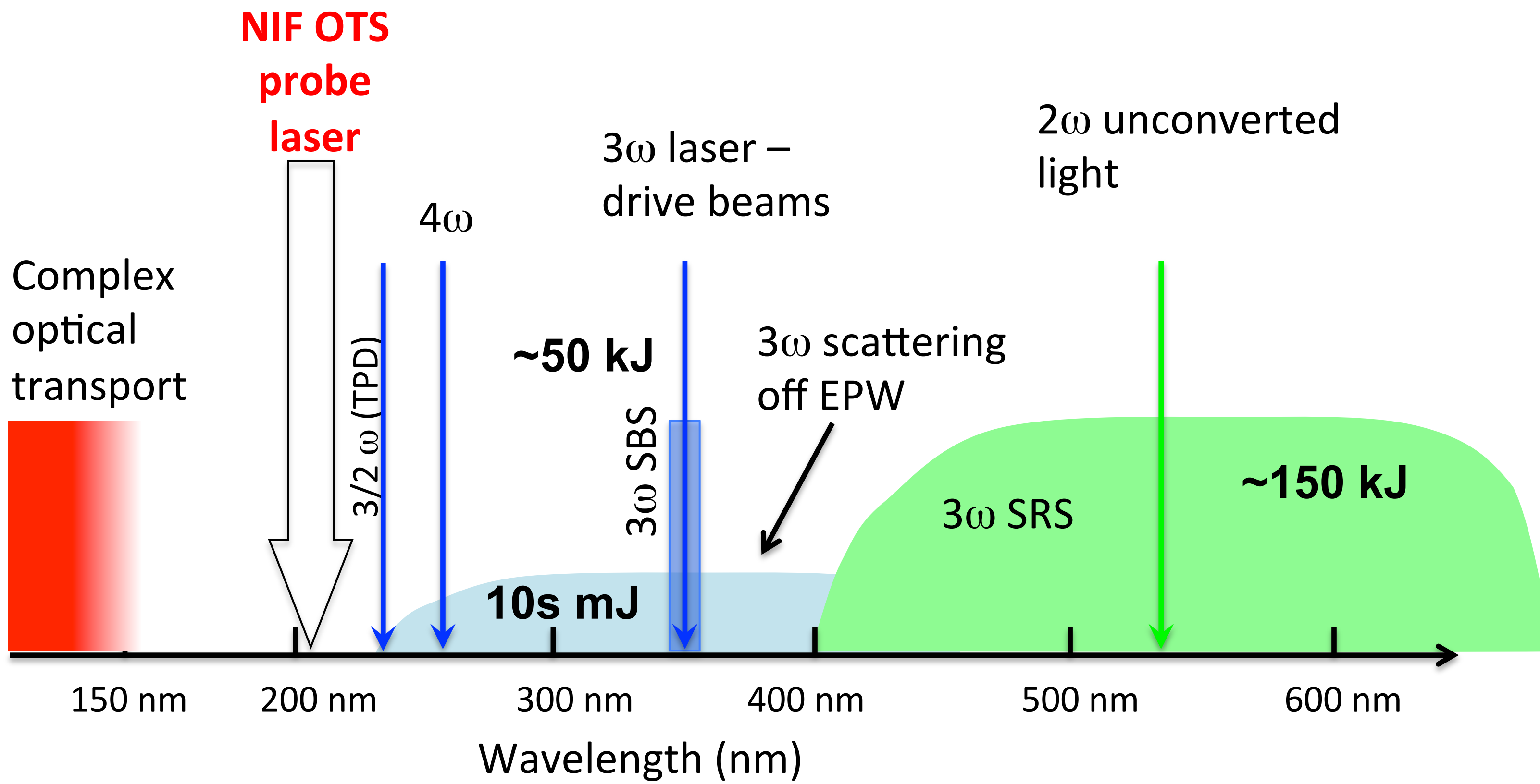


$$S(\mathrm{k},\omega)=\frac{2\pi}{k}\left|1-\frac{\chi_e}{\varepsilon}\right|^2 f_e\left(\frac{\omega}{k}\right)+\frac{2\pi Z}{k}\left|\frac{\chi_e}{\varepsilon}\right|^2 f_i\left(\frac{\omega}{k}\right)$$



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

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

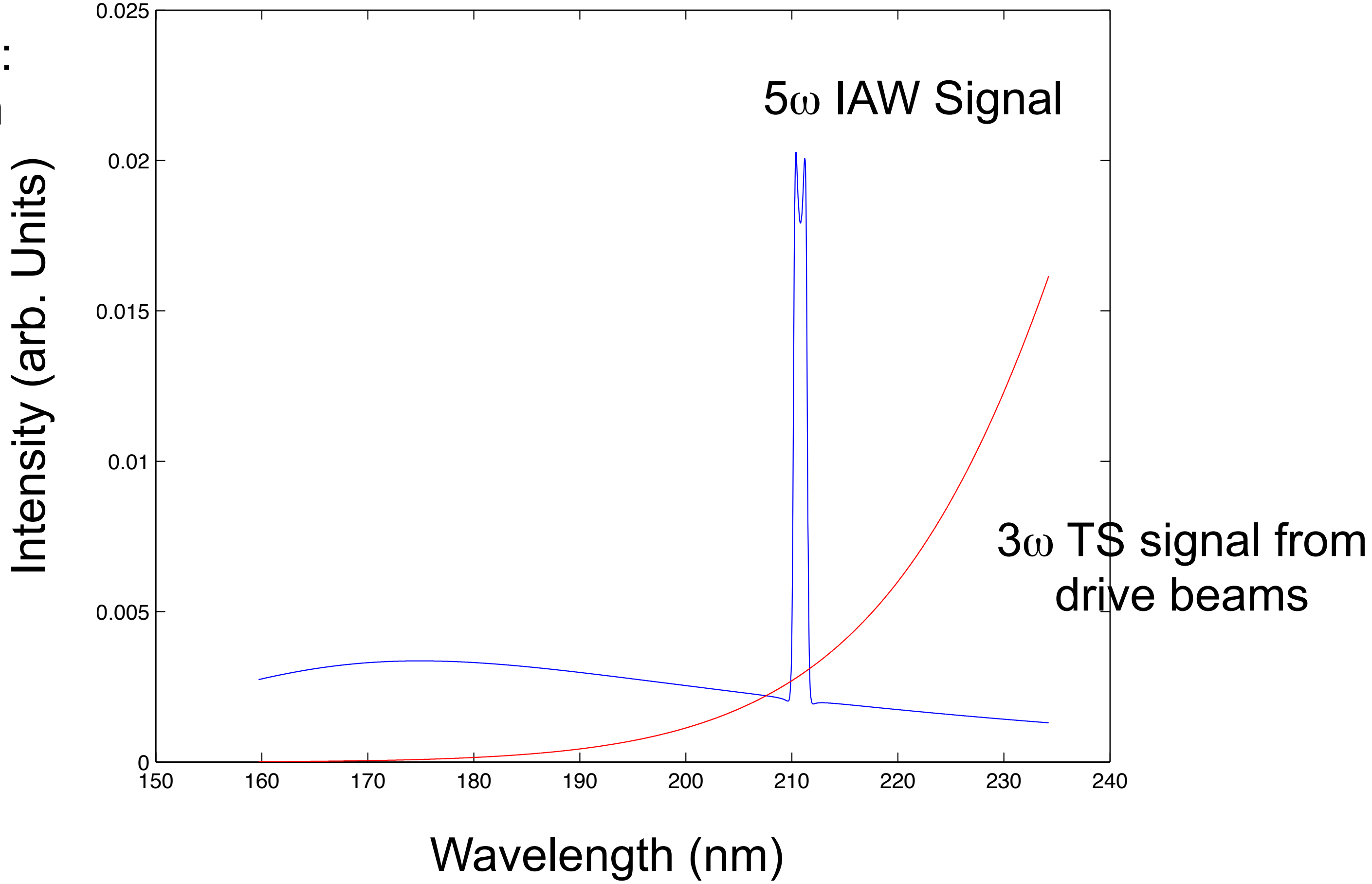


Expected TS signal is a few μJ

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

The 5ω probe wavelength is critical to avoid scattering background from the 3ω drive beams

Pointing:
Z=5 mm



G. Swadling will talk about this calculation in detail this afternoon.

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 ~200 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**

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

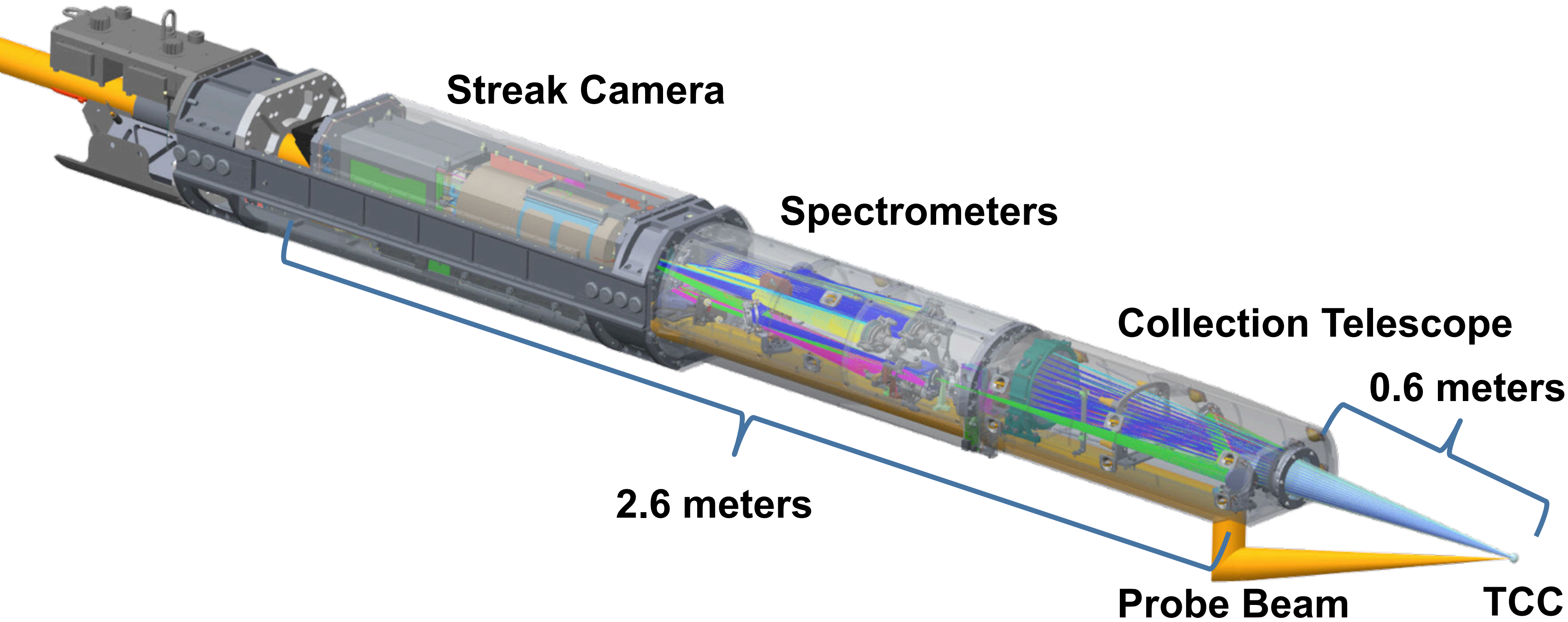
Probe laser

- 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)

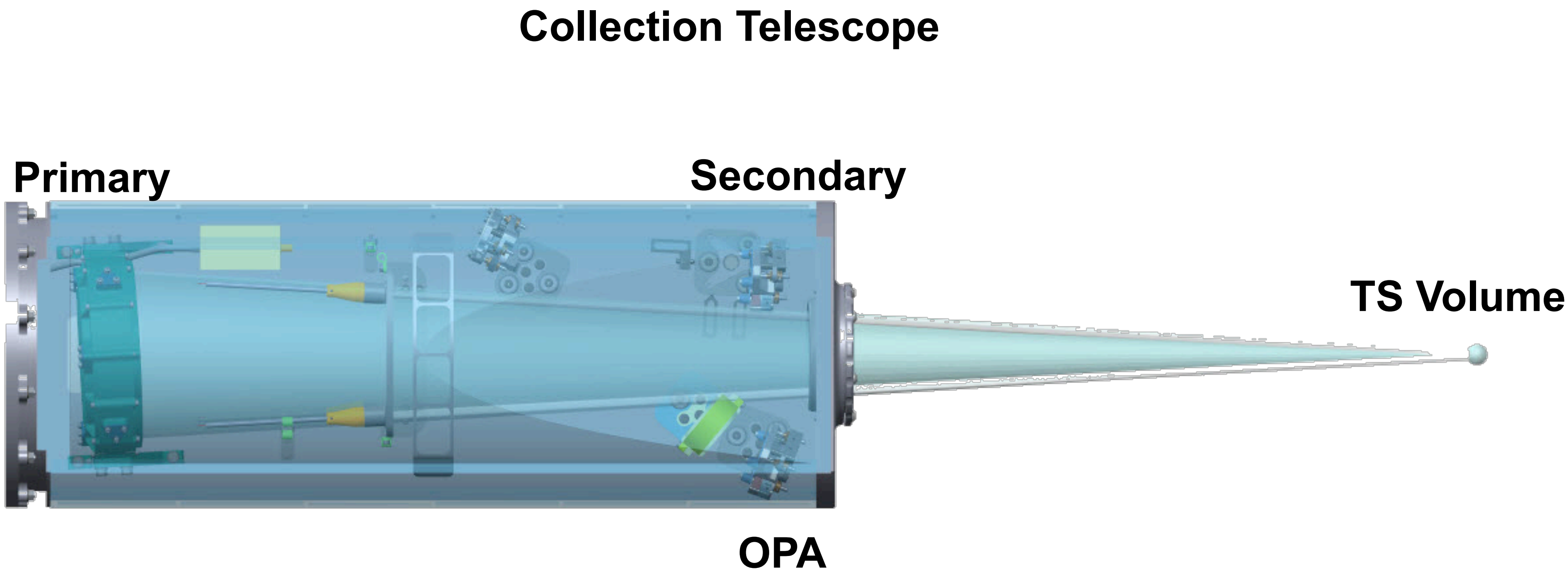
- Probe to collection alignment ±50 μm
- Collection to target alignment ±250 μm
- Collection angle ~18 degrees

A DIM based OTS system is currently being designed

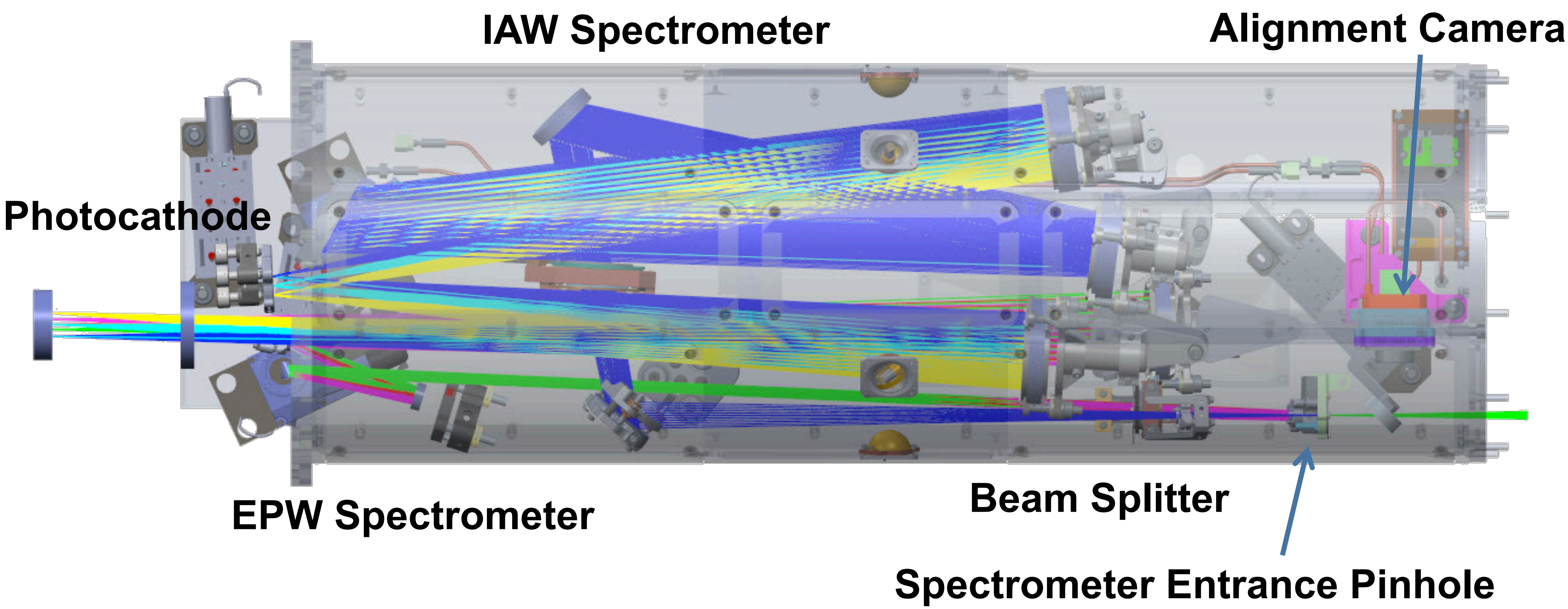


P. Datte will provide details in his talk this afternoon

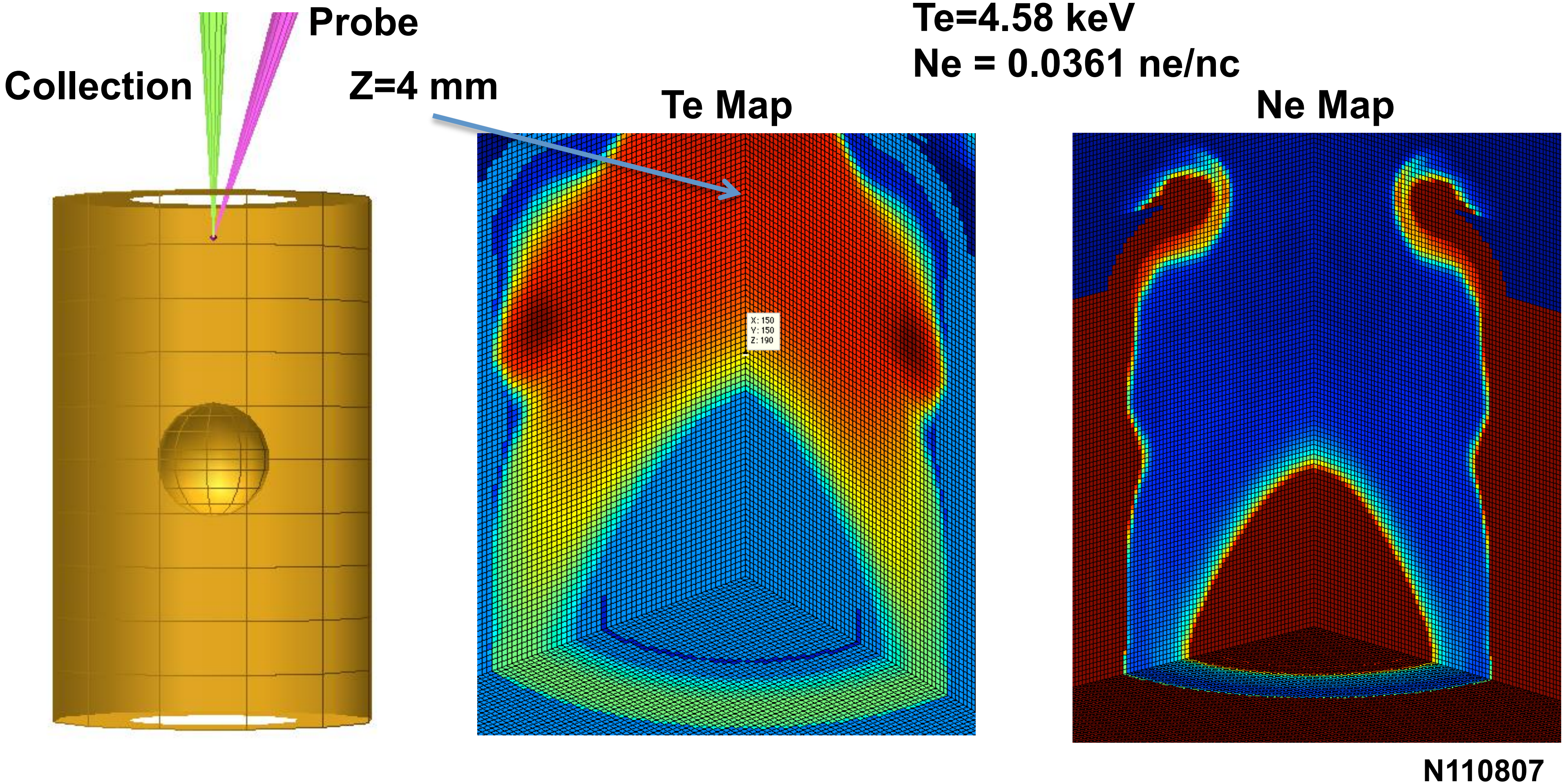
An f/8.3 Schwarzschild telescope is used to collected scattered light from the TS volume



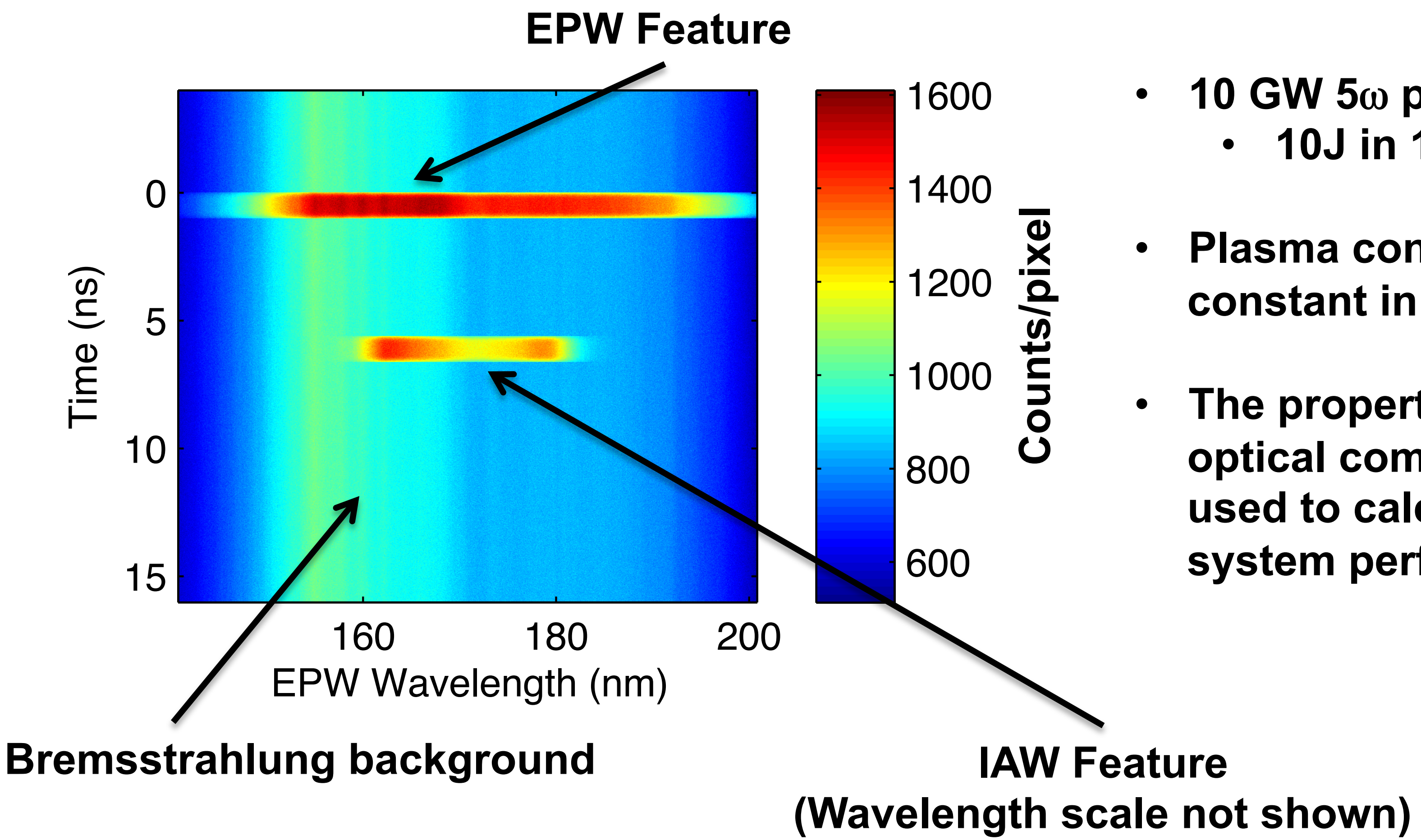
A pair of spectrometers are used to disperse the collected light



Initial OTS experiments will focus on measuring plasma conditions in the hohlraum LEH region

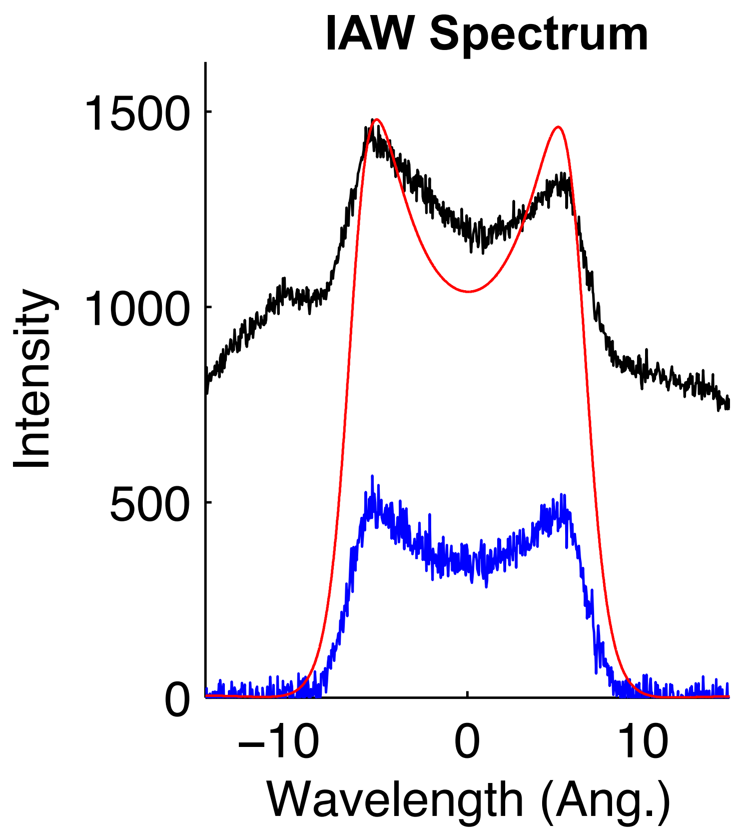


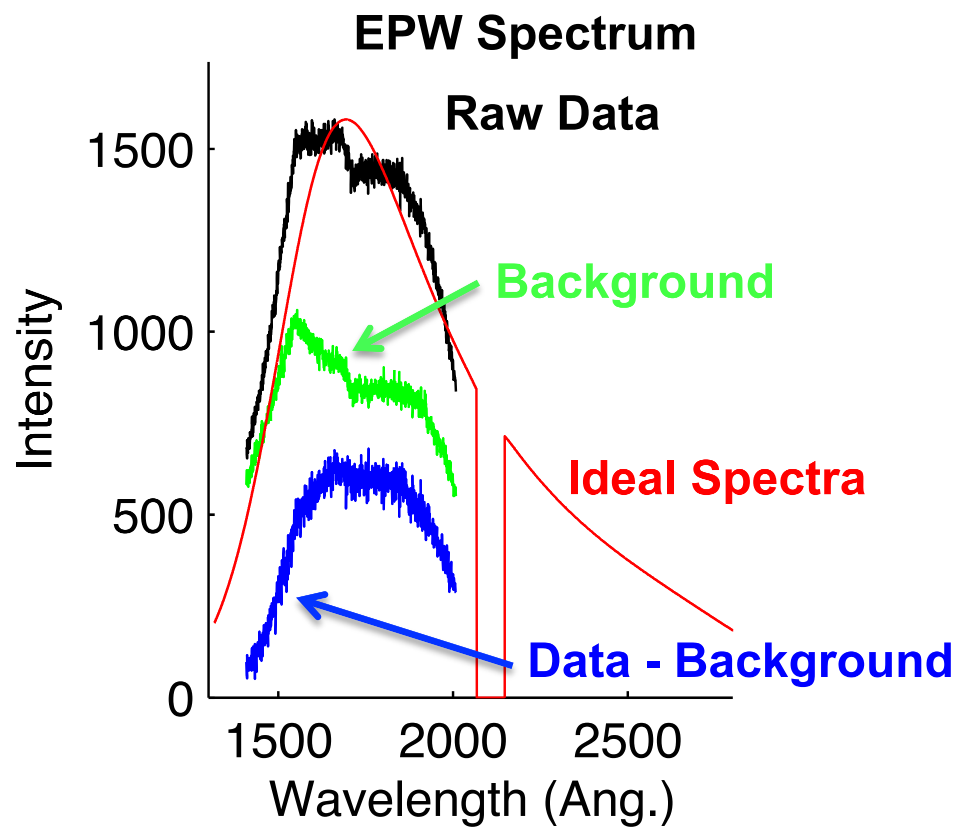
Synthetic data is generated using the expected system throughput, quantum efficiency and background



- 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

A signal to background of ~0.8 is expected for these experimental conditions using a 10J probe



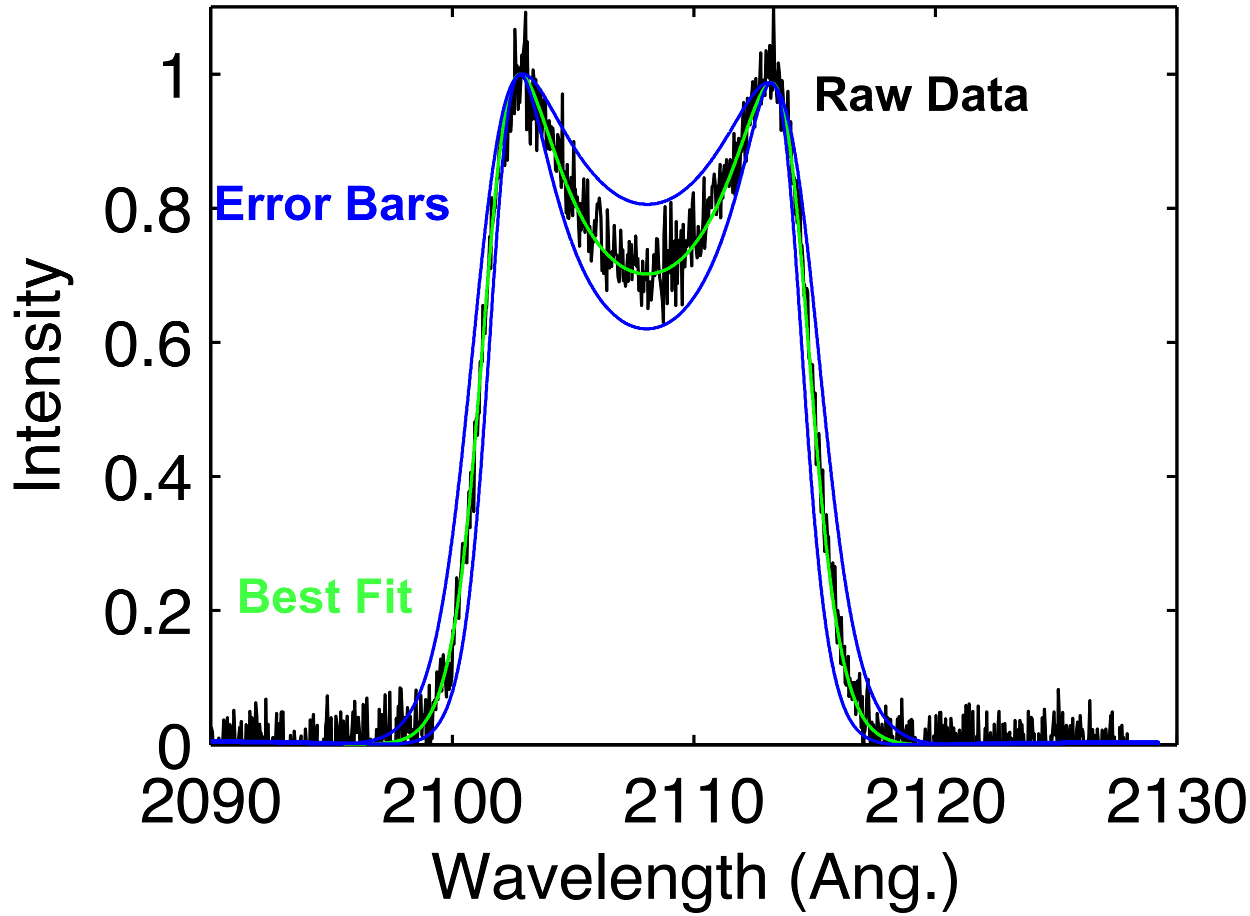


IAW background is dominated by the EPW background due to time multiplexing.

The Thomson scattering ion feature will be used to determine ZTe and Ti

Alpha ($1/k\lambda_D$) = 0.8

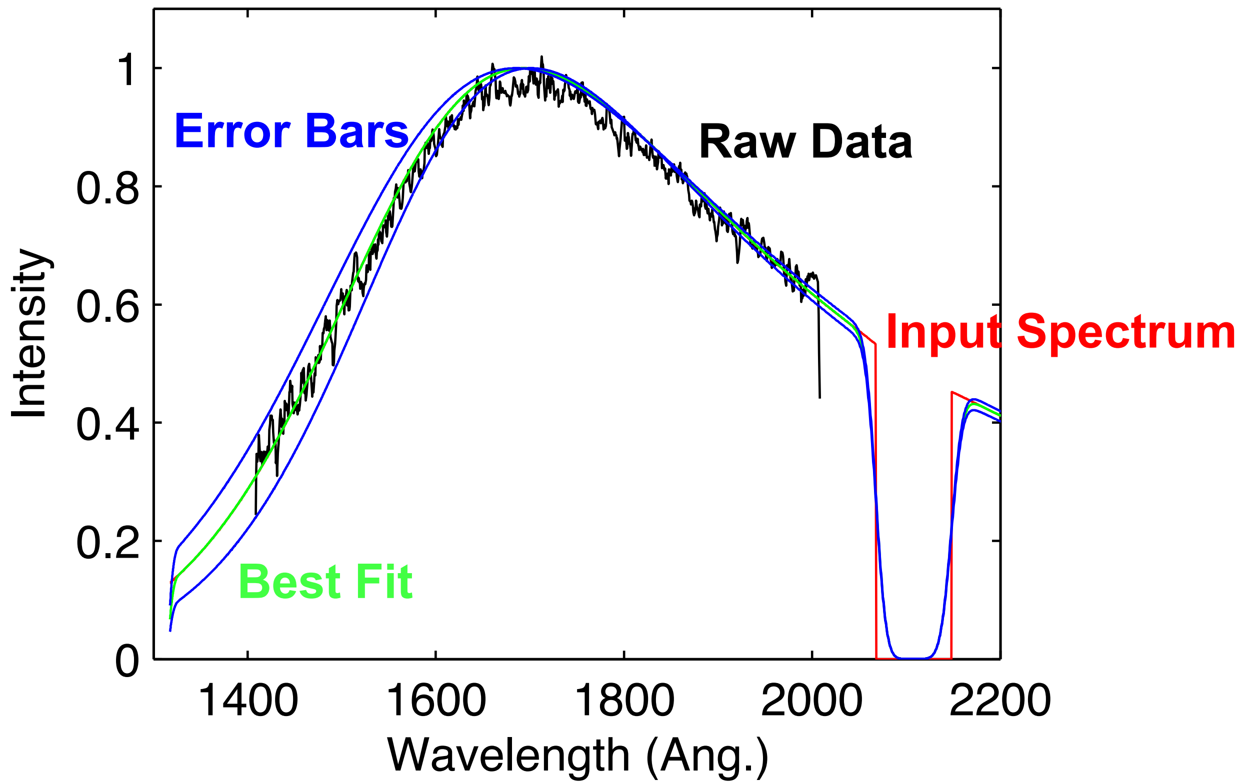
+/- 20% in Ti
+/- 30% in ZTe
(assuming no EPW measurement)



The electron feature will be used to measure Te and Ne

Alpha = 0.8

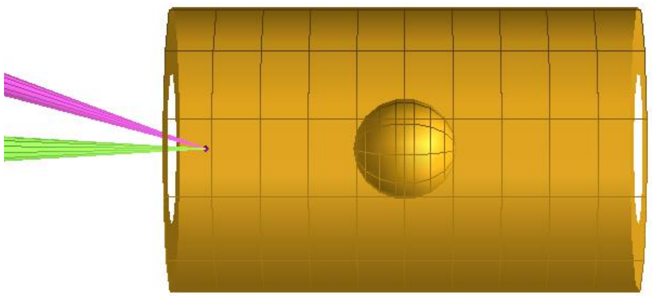
+/- 20% in Te
+/- 25% in ne



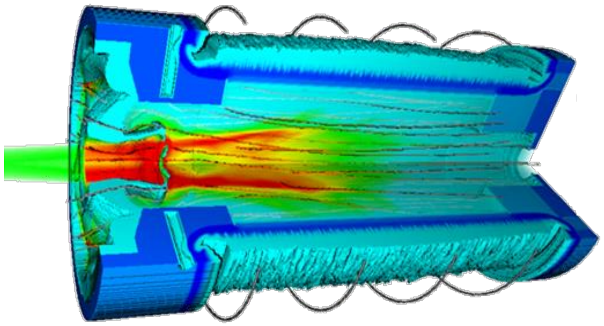
An accurate measurement of the system response and the hohlraum background is critical to making a useful electron feature measurement when alpha is low.

Thomson scattering will provide valuable data for a range of experimental platforms

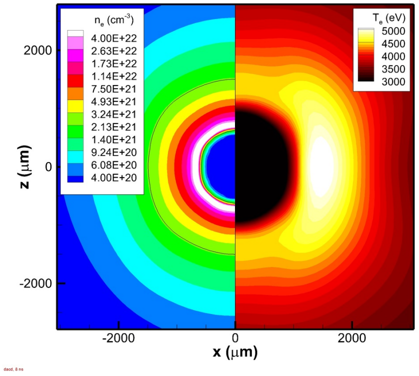
Indirect Drive ICF



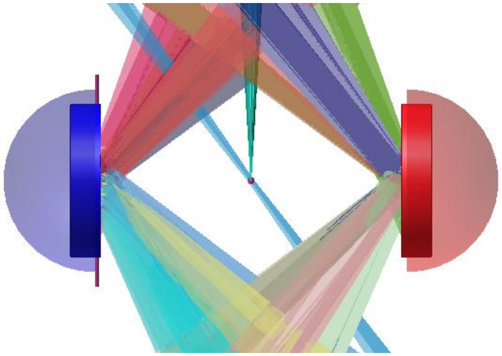
MagLIF



Direct Drive ICF

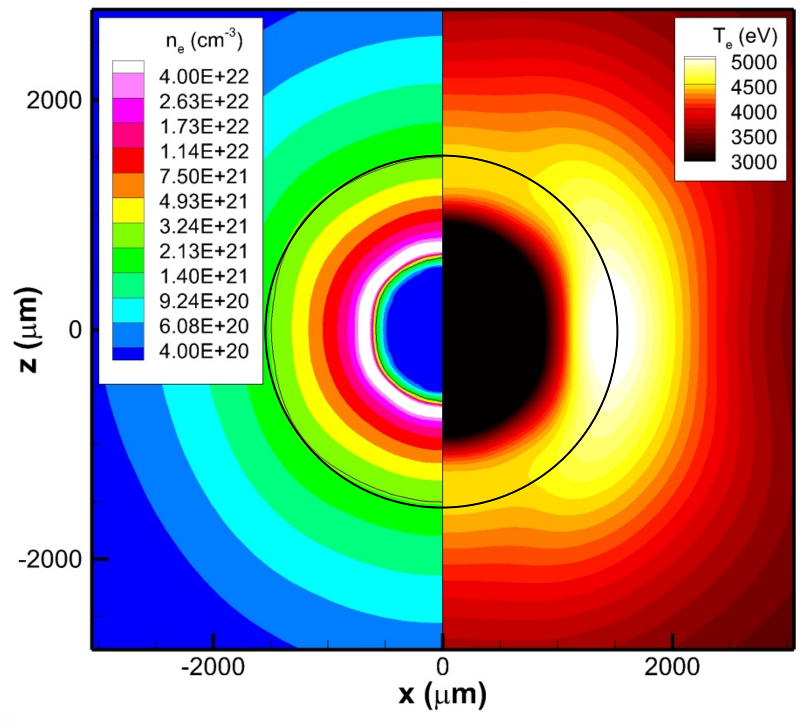


Discovery Science

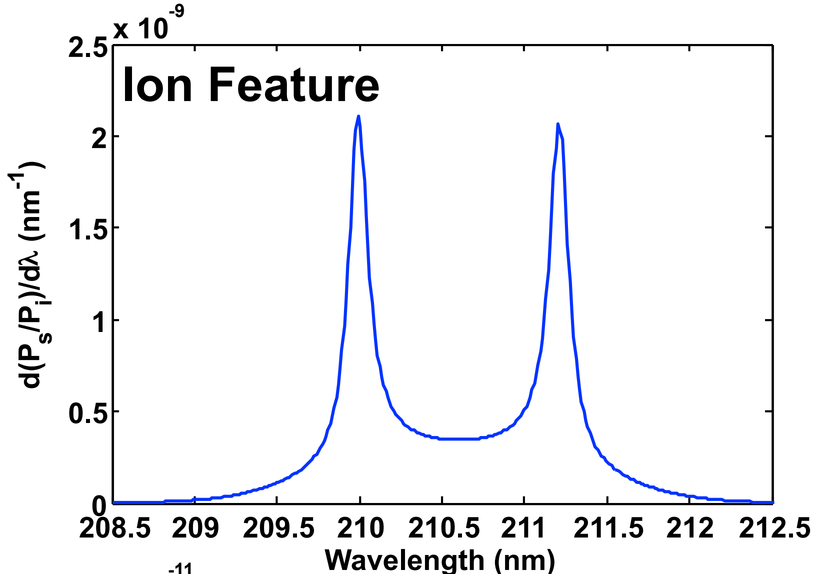


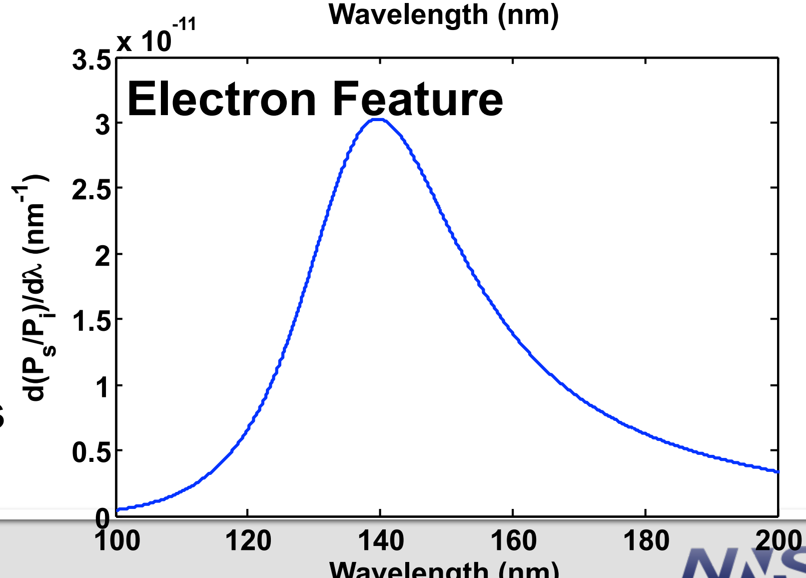
5ω Thomson scattering will provide access to quarter critical plasma conditions in polar direct drive experiments

LLE led experiments



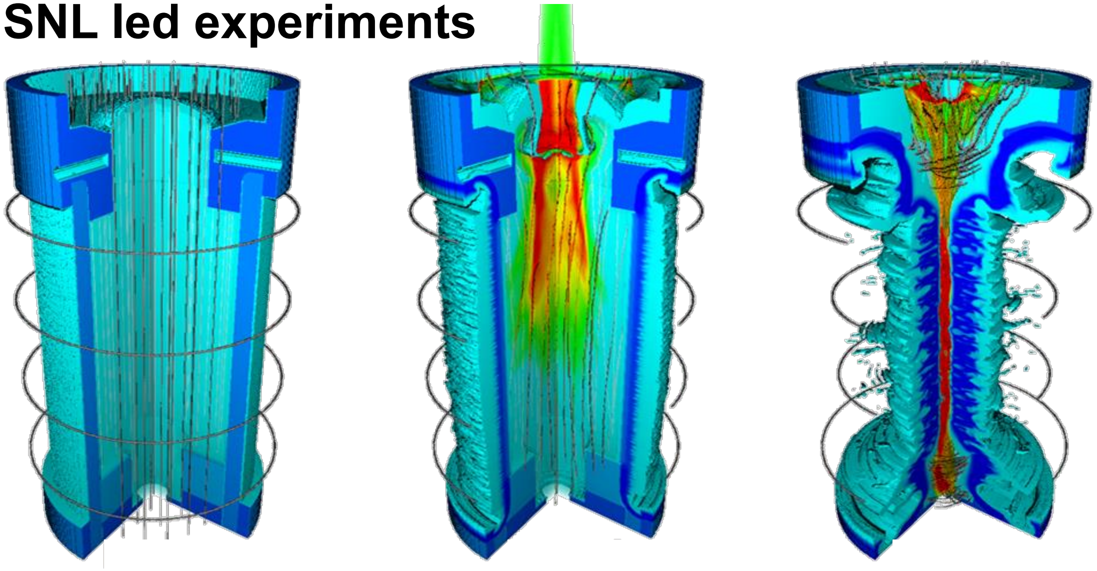
Thomson scattering will characterize the significant angular temperature gradients predicted by hydrodynamic simulations





Magnetized Liner Inertial Fusion experiments will use OTS to characterize plasma conditions

SNL led experiments



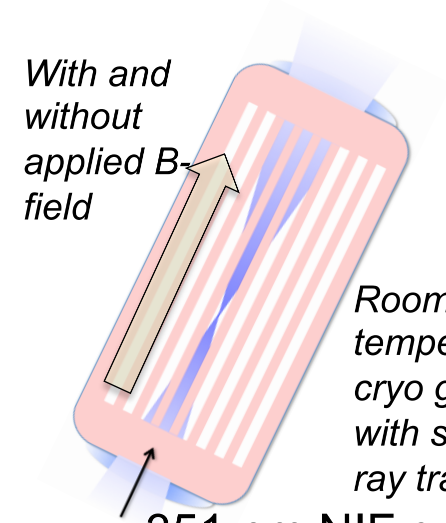
Magnetization with external B-Field (10-30T)

Laser heating with Z-Beamlet (2-6kJ @ 2-6ns)

Compression with ‘Z’

S. Slutz et al, Phys. Plasmas **17**, 056303 (2010)
M. R. Gomez et al, Phys. Rev. Lett. **113**, 155003 (2014)

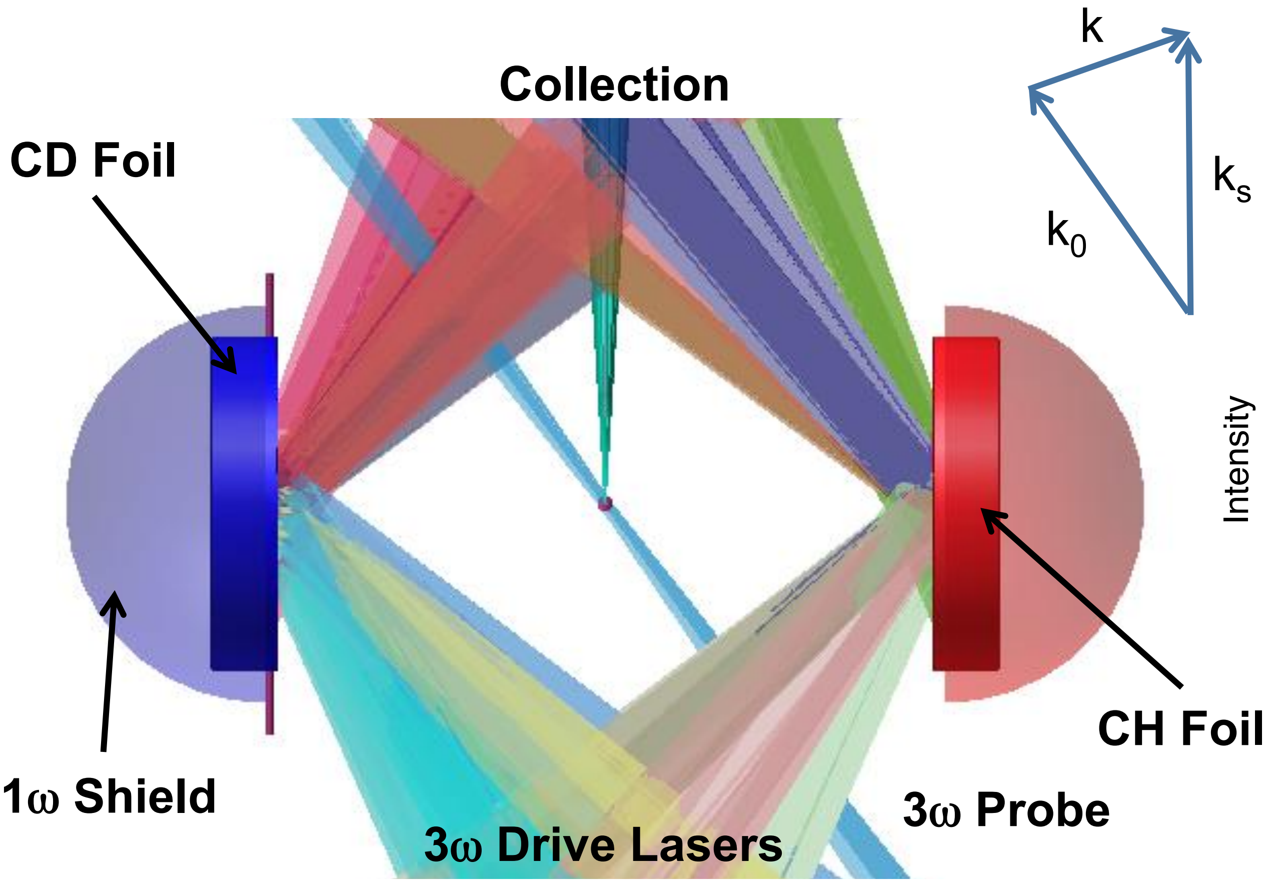
The NIF gas-pipe will study laser heating and wall-mix physics

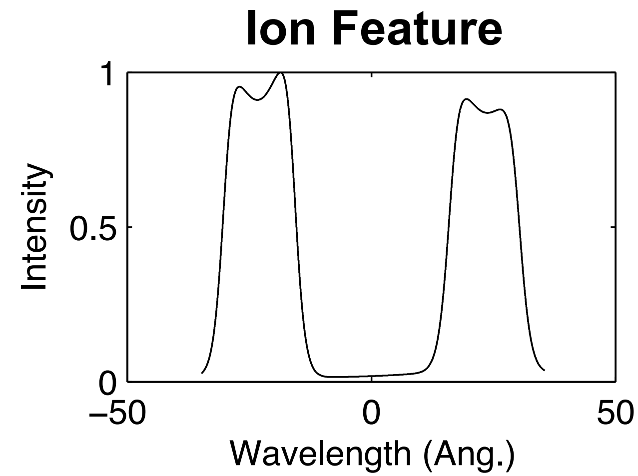


- Measure laser propagation and wall mix along gas-pipe axis with and without B-field
- Measure x-ray emission from mid-Z materials and use results to improve rad-hydro models

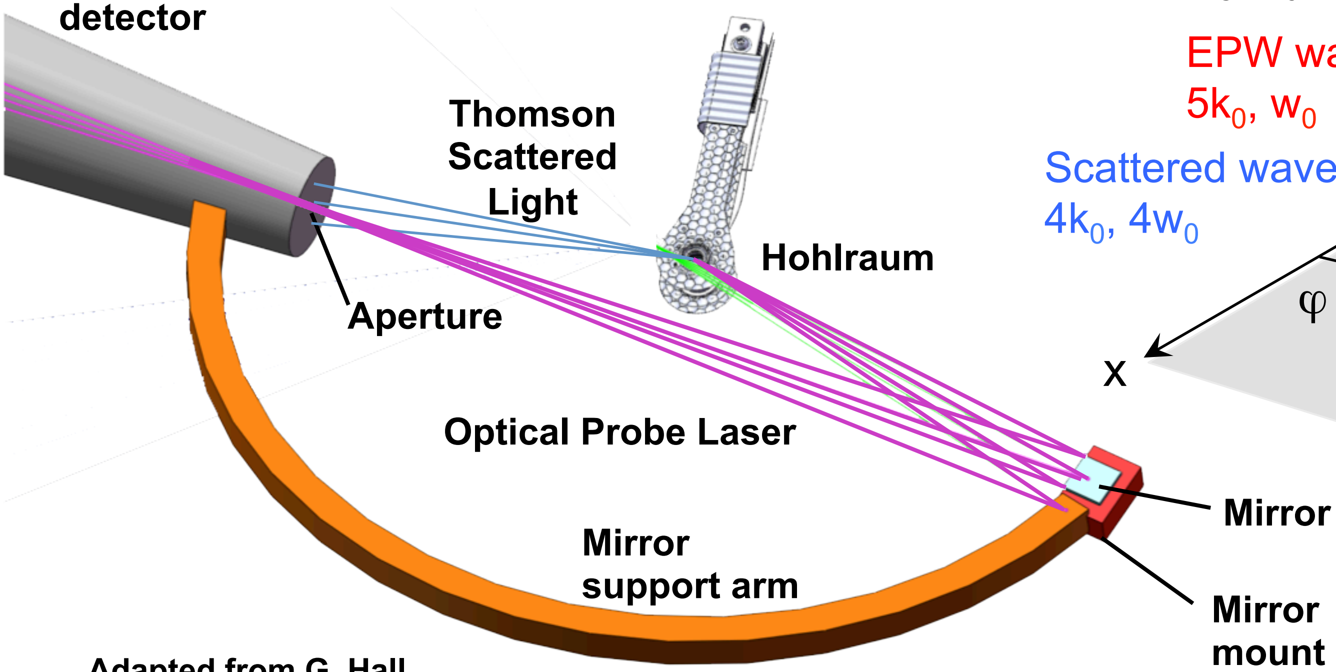
Collision-less Shock experiments are an ideal platform for 3ω Thomson scattering

Osaka/LLNL led experiments

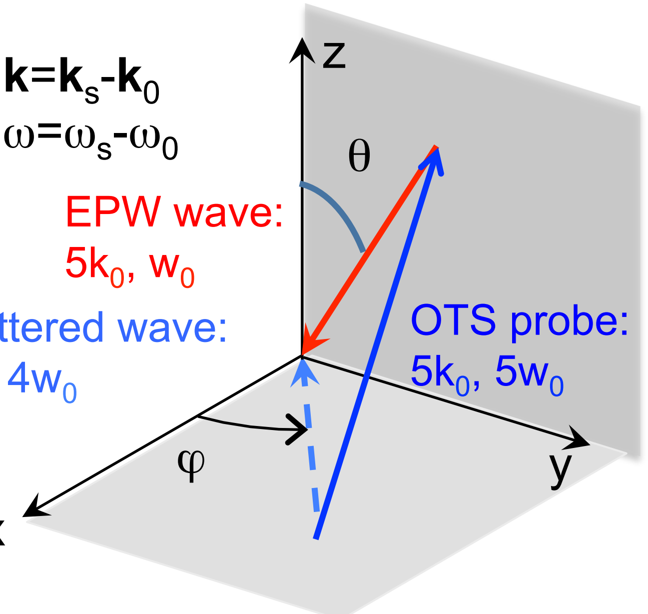




A mirror can be used to change the scattering angle and k-match driven waves



Adapted from G. Hall



This arm would need to be rotated out of the equatorial plane to k-match SRS driven waves

Technical challenges

- There are a number of target physics and laser concerns that are currently being investigated via experiments, analytic calculations and simulations

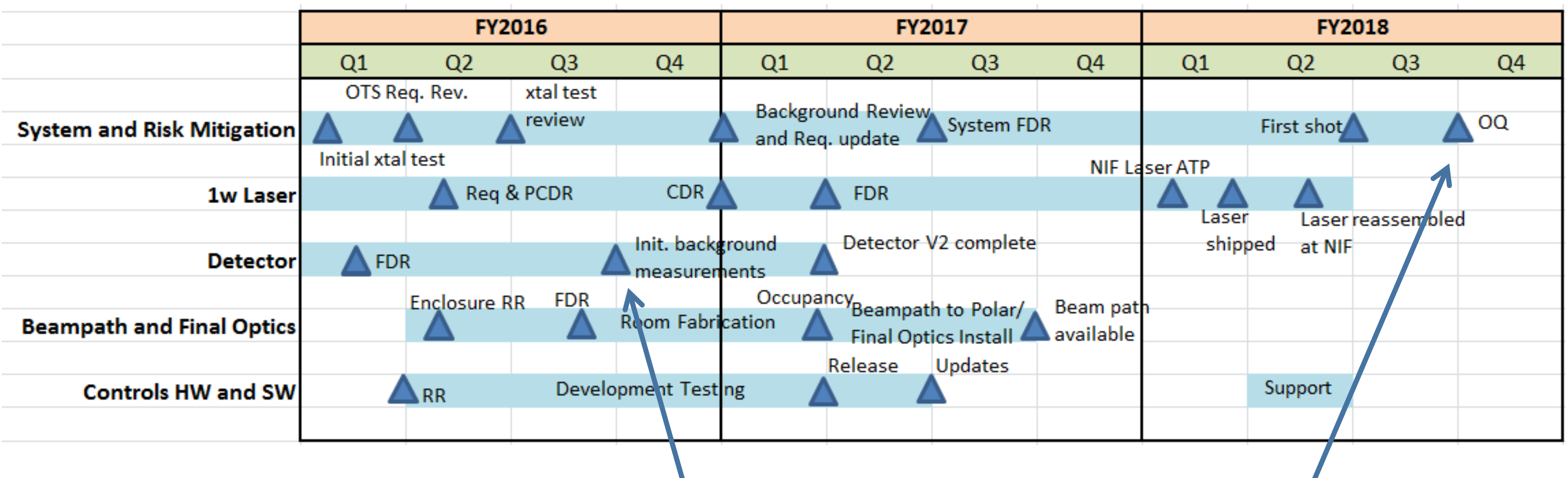
- 5ω Laser Development (DCS laser development talk this afternoon)
    - An joint effort with LLE is currently underway to develop a 5ω probe laser
    - Initial 5ω crystal testing is scheduled for later this year on MTW (LLE)

- X-ray blanking of the blast shield
    - High x-ray fluence has the potential to excite electrons in the blast shield making it opaque to the Thomson scattered light

- Bremsstrahlung background
    - A series of analytic calculations have been used to estimate the bremsstrahlung
    - The goal of Phase 1 is to measure the Bremsstrahlung level for a series of target configurations

G. Swadling will talk about these challenges in detail this afternoon

High level OTS schedule



System ready for 3ω TS measurements

System ready for 5ω TS measurements

Conclusions

- **An OTS DIM based collection and laser delivery system is being designed to satisfy requirements for a range of experimental platforms (Indirect drive, direct drive, MagLIF, Discovery Science)**
- **The harsh hohlraum environment requires an innovative approach (210 nm Thomson scattering probe)**
- **A collaborative laser development effort is underway with LLE**
- **3ω Thomson scattering and background measurements will begin late in FY16 and 5ω operations will begin in late FY18**

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