Laser-Plasma interactions: The light and dark sides

44th Annual Anomalous Absorption Meeting
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Collaborators

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Lawrence Livermore National Laboratory, Livermore, CA
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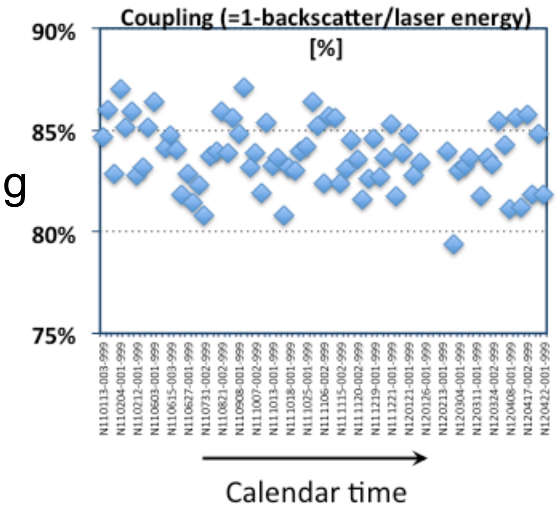
This talk will cover 4 topics

1) Update on NIF backscatter

Coupling



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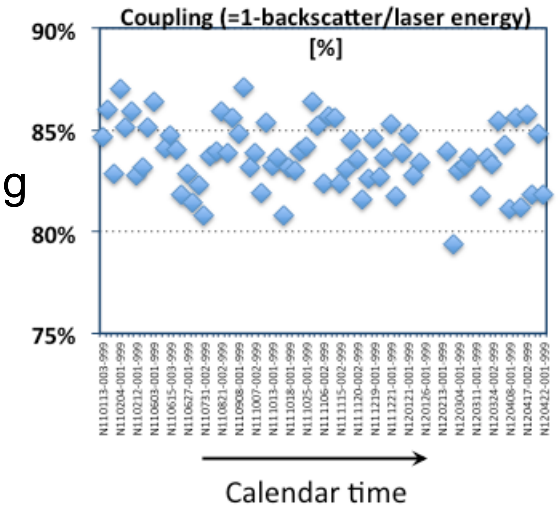

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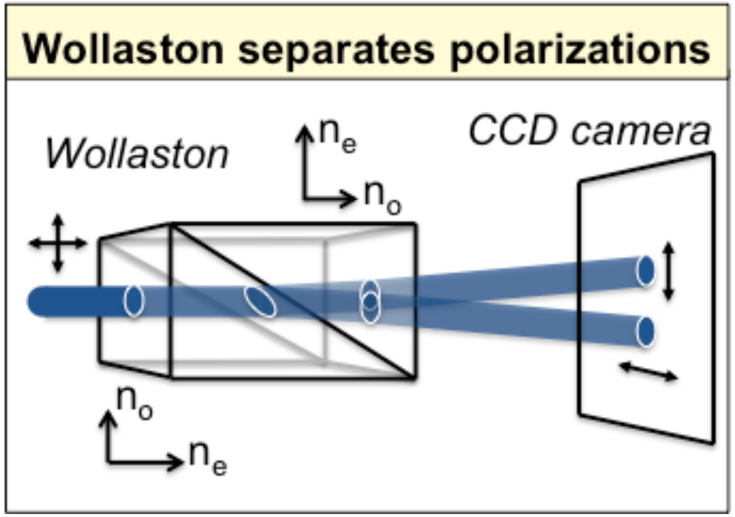

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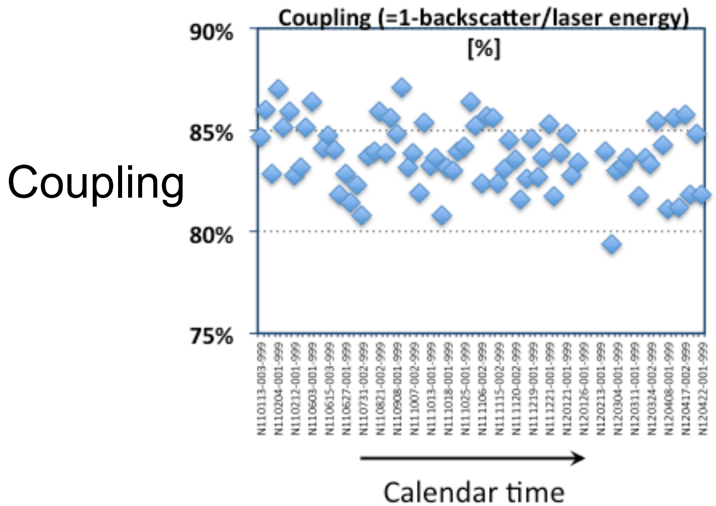

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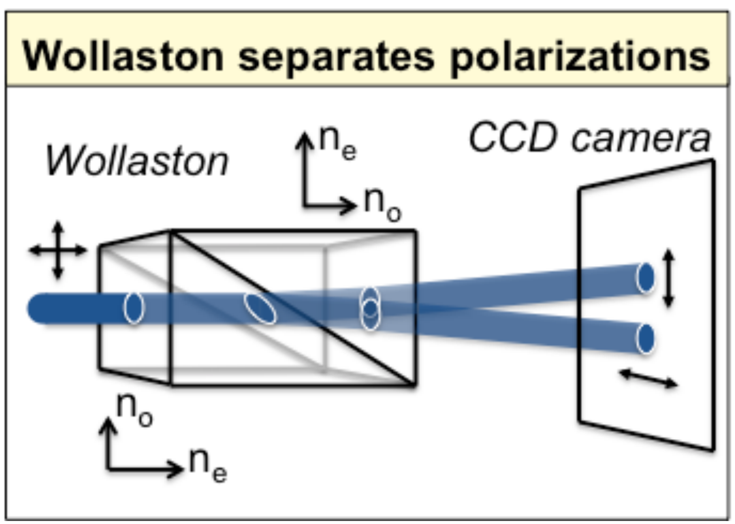

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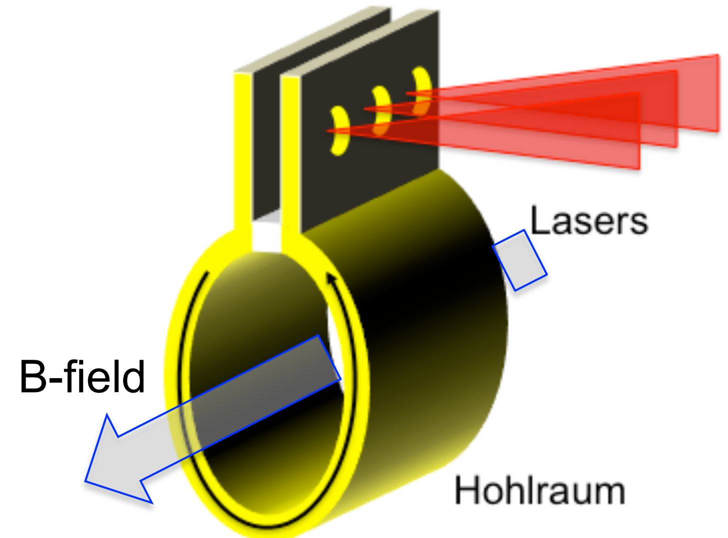

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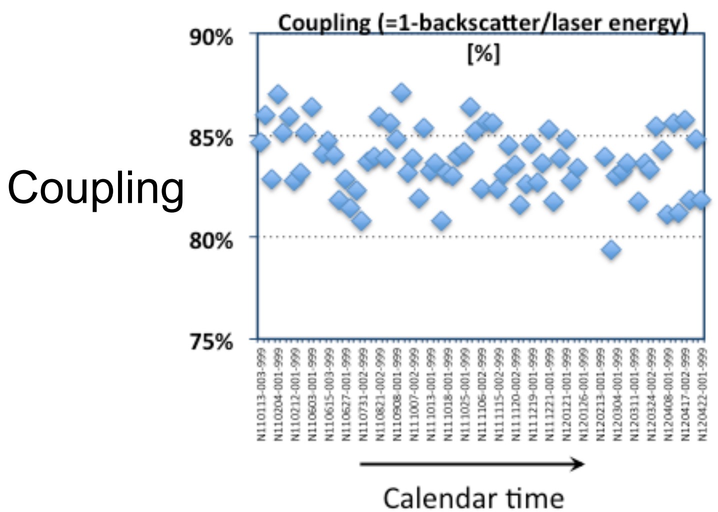

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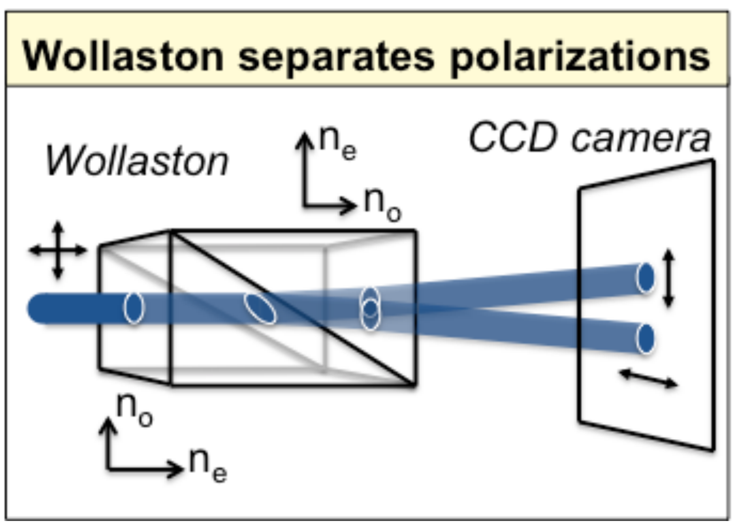

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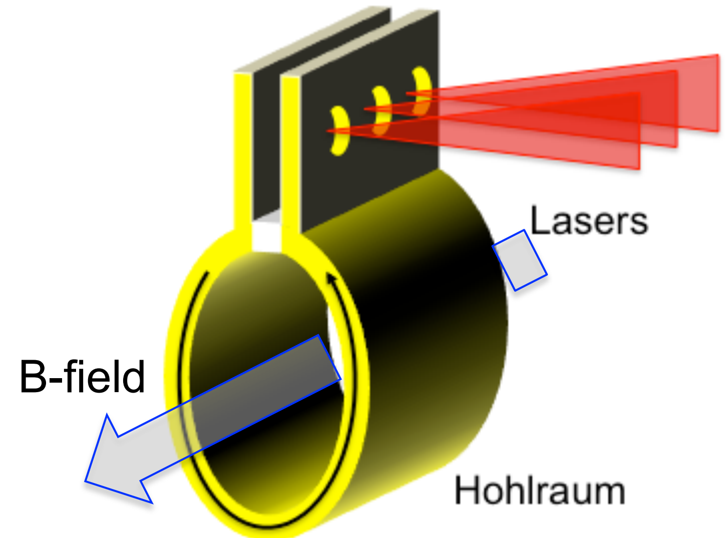

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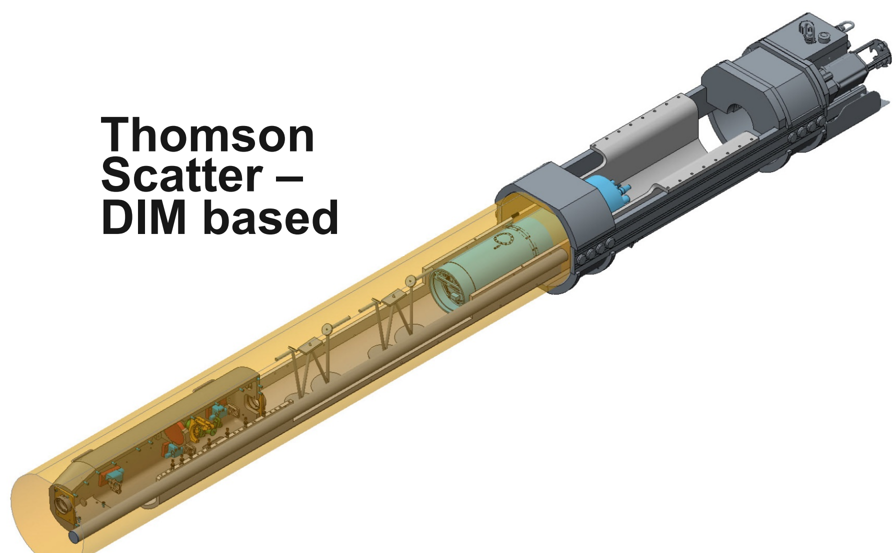
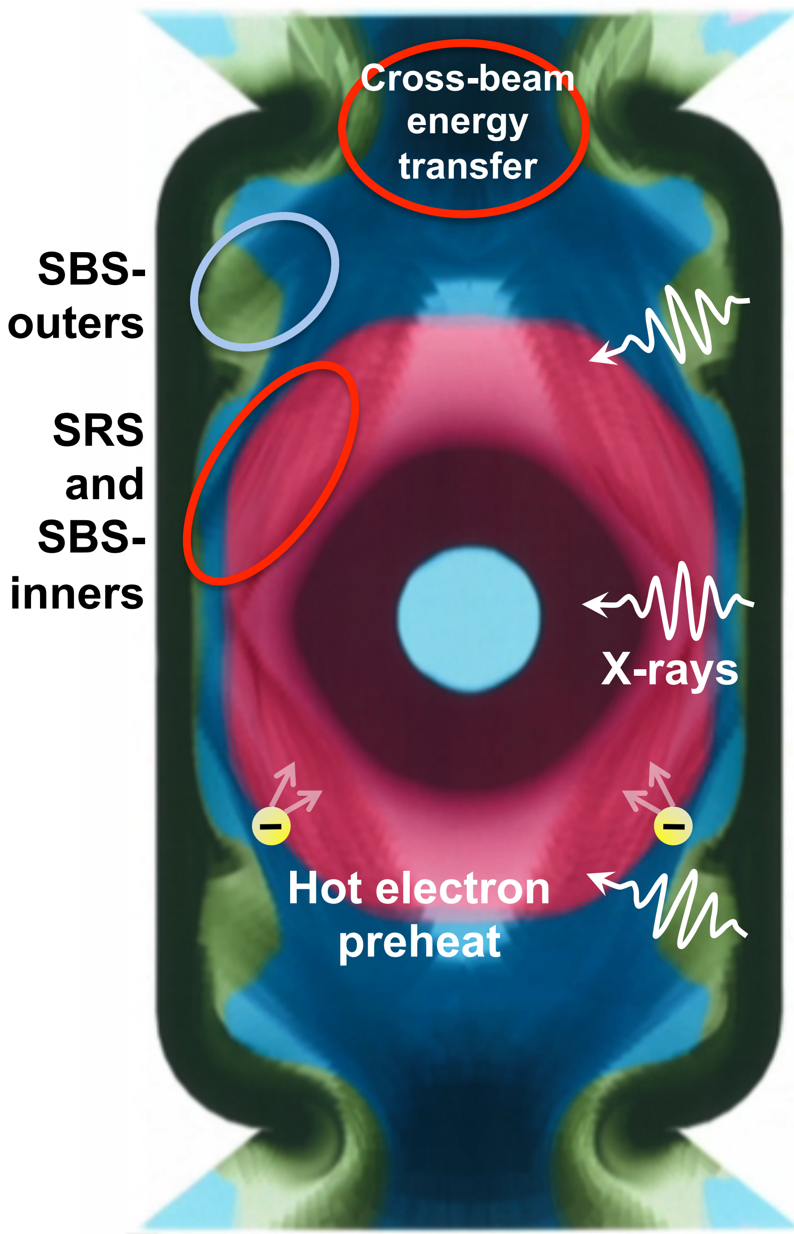
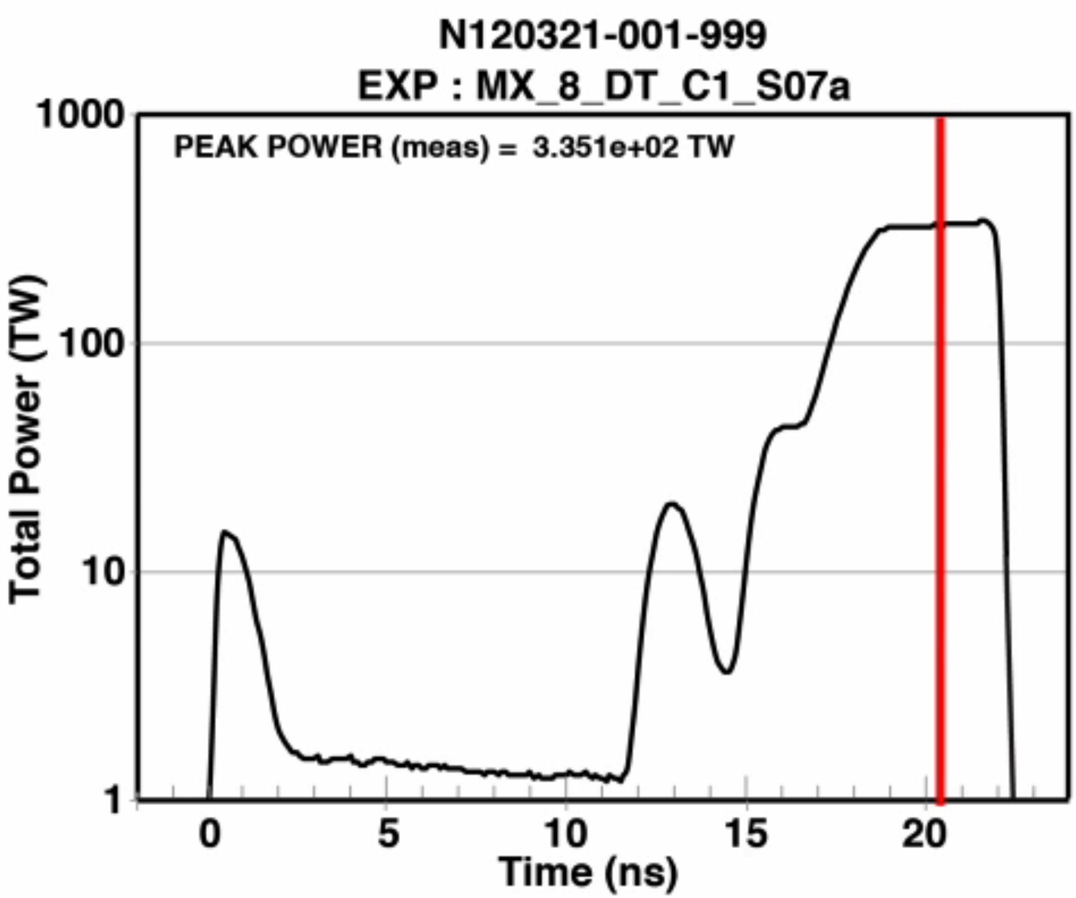


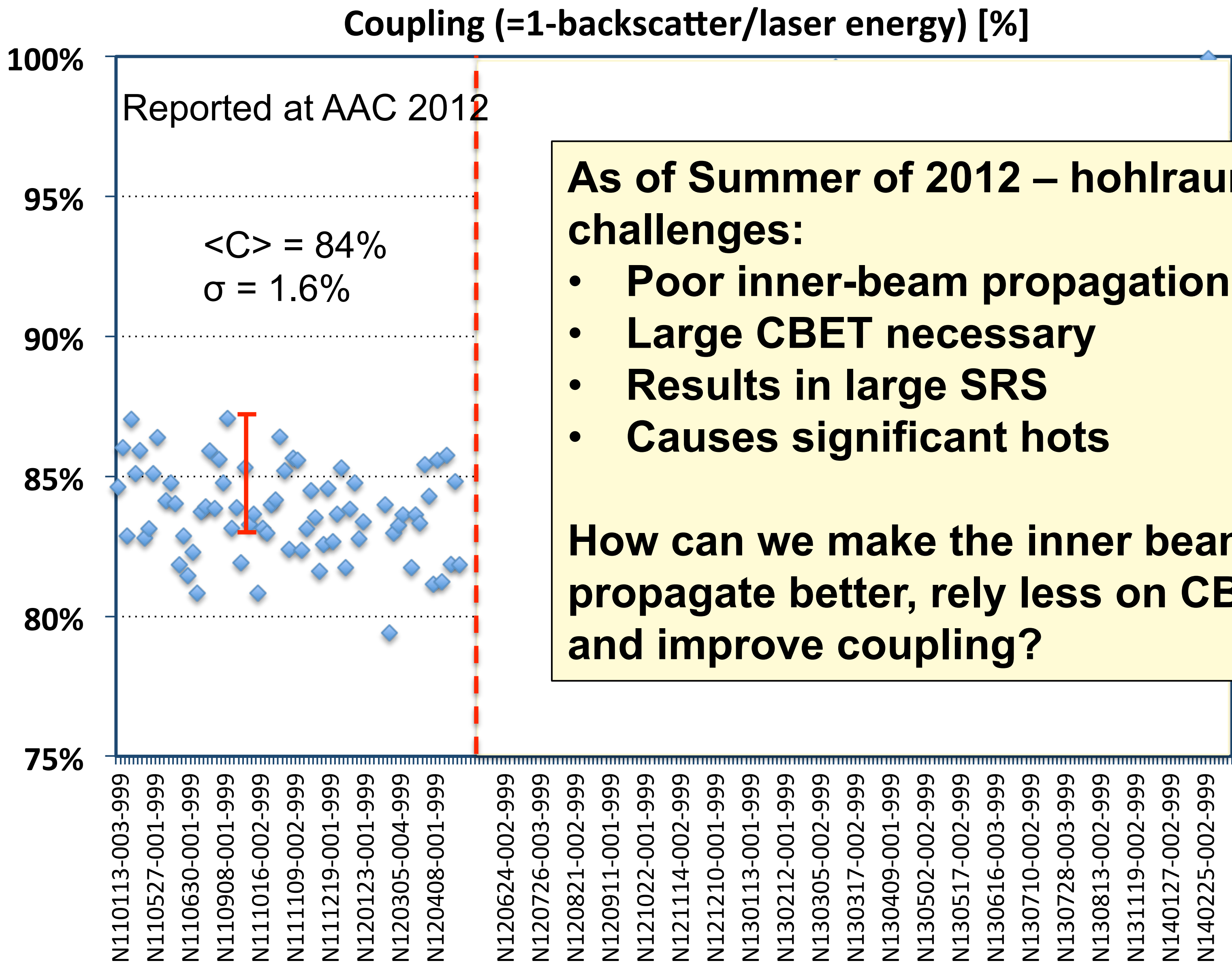
Late-time backscatter can affect symmetry, convergence, hot e-, and capsule speed





How can we make the inner beams propagate better?

Summary of NIF backscatter from 1/2011 to present



As of Summer of 2012 – hohlraum challenges:

- **Poor inner-beam propagation**
- **Large CBET necessary**
- **Results in large SRS**
- **Causes significant hots**

How can we make the inner beams propagate better, rely less on CBET, and improve coupling?

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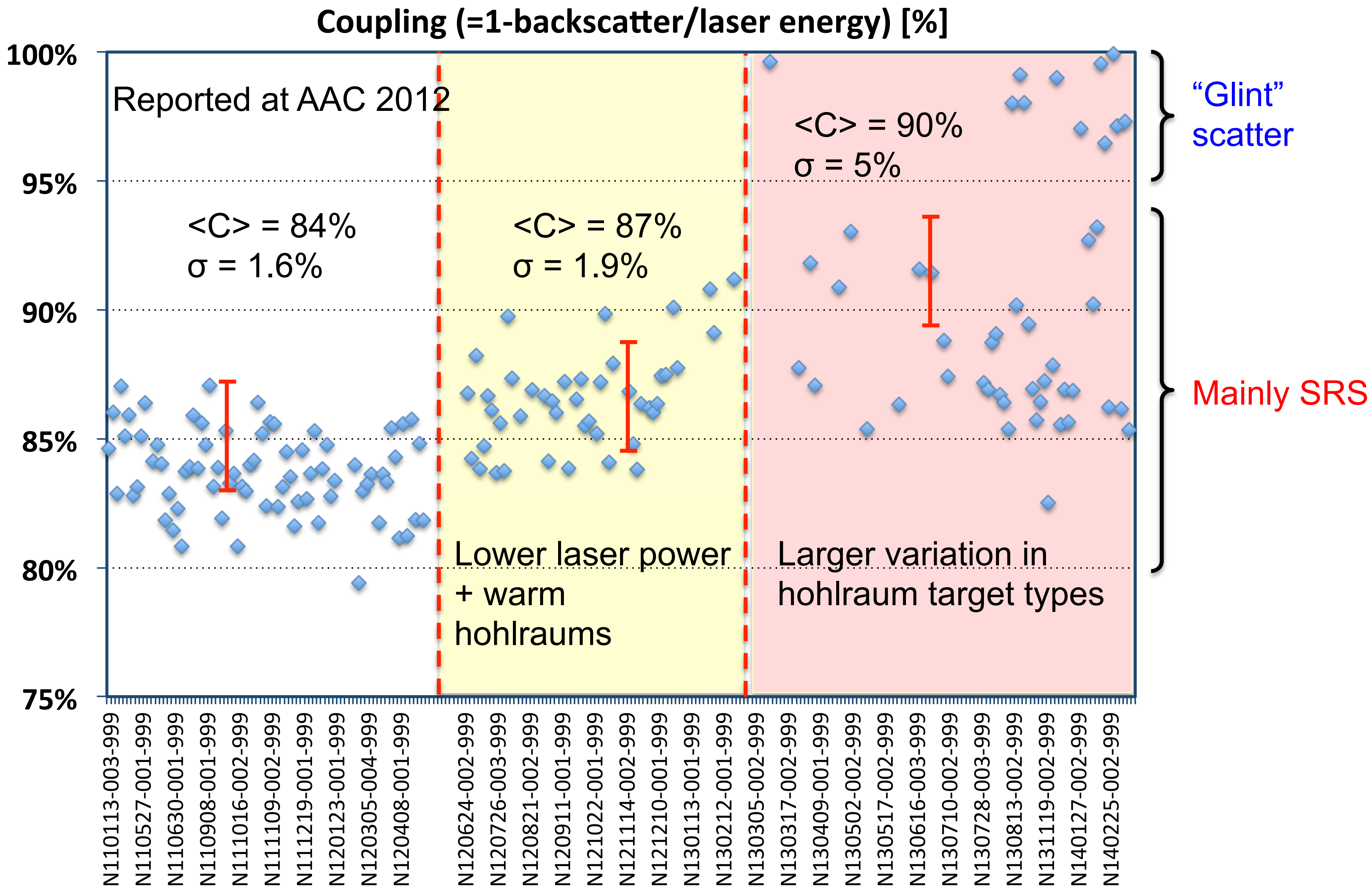

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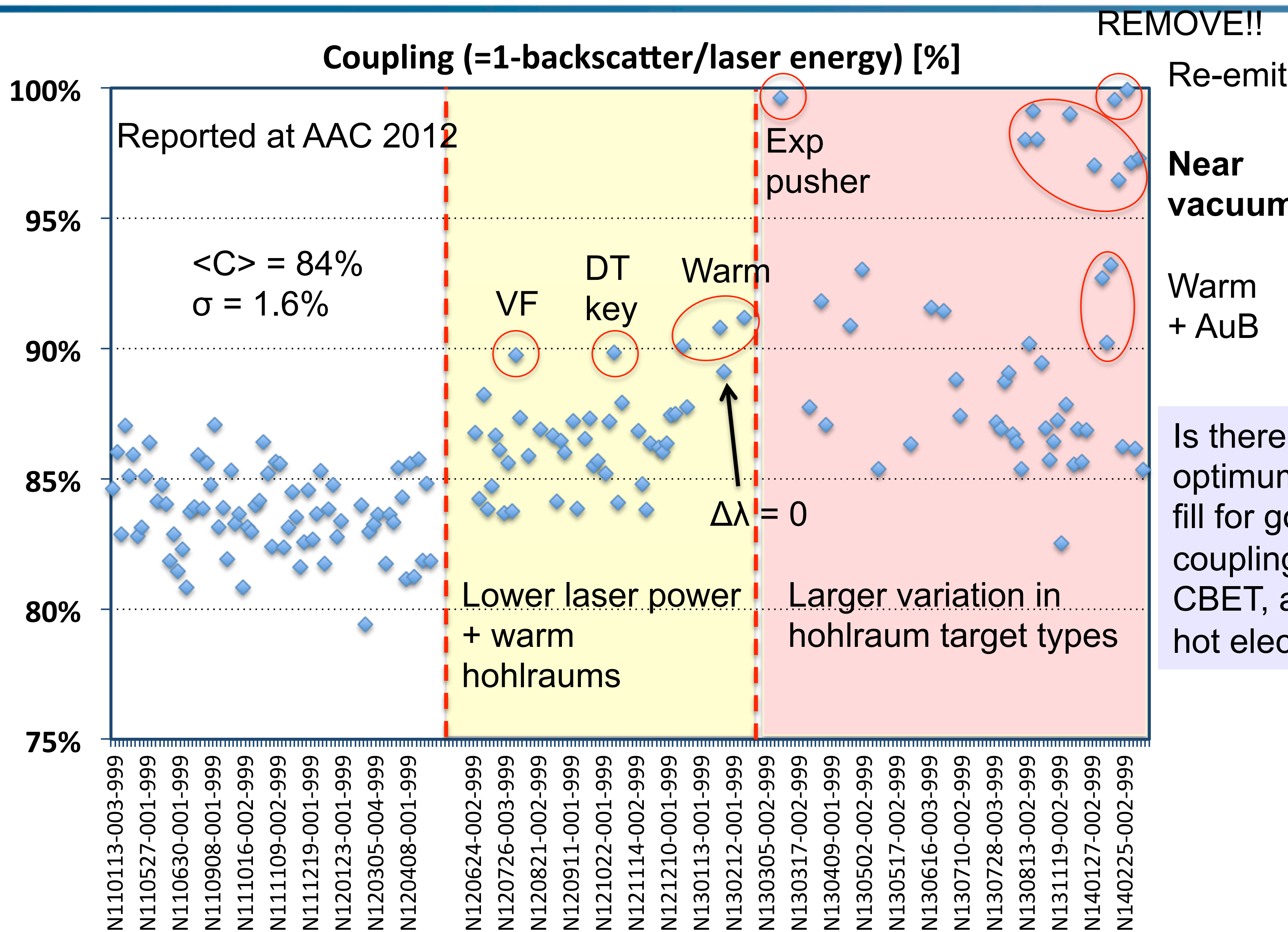
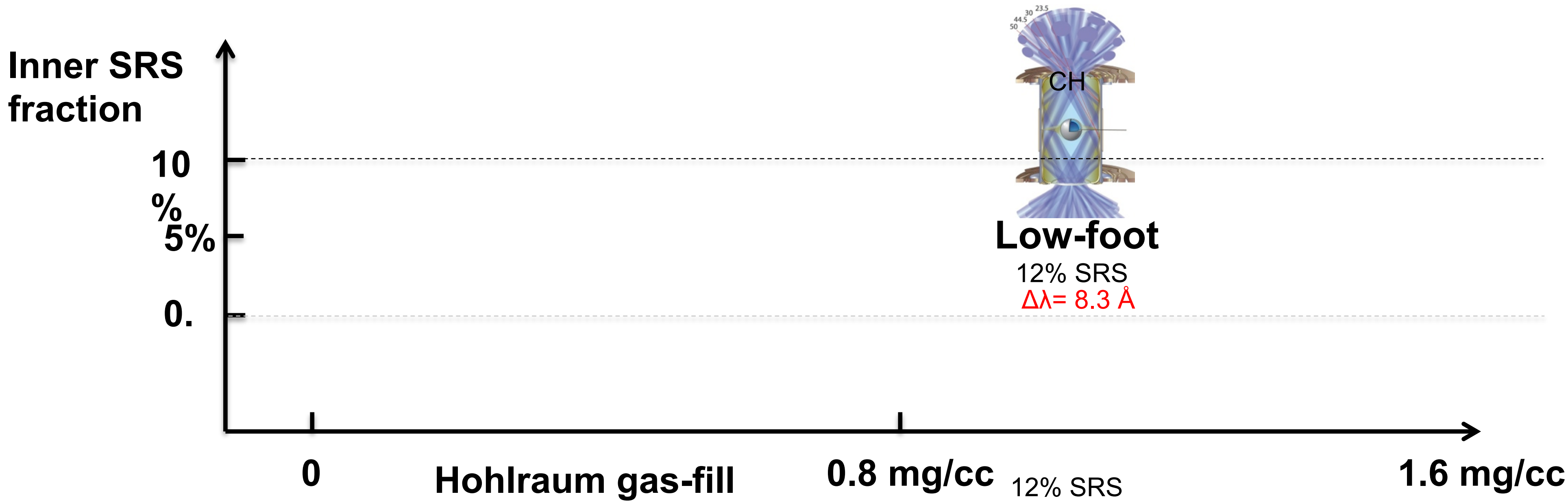
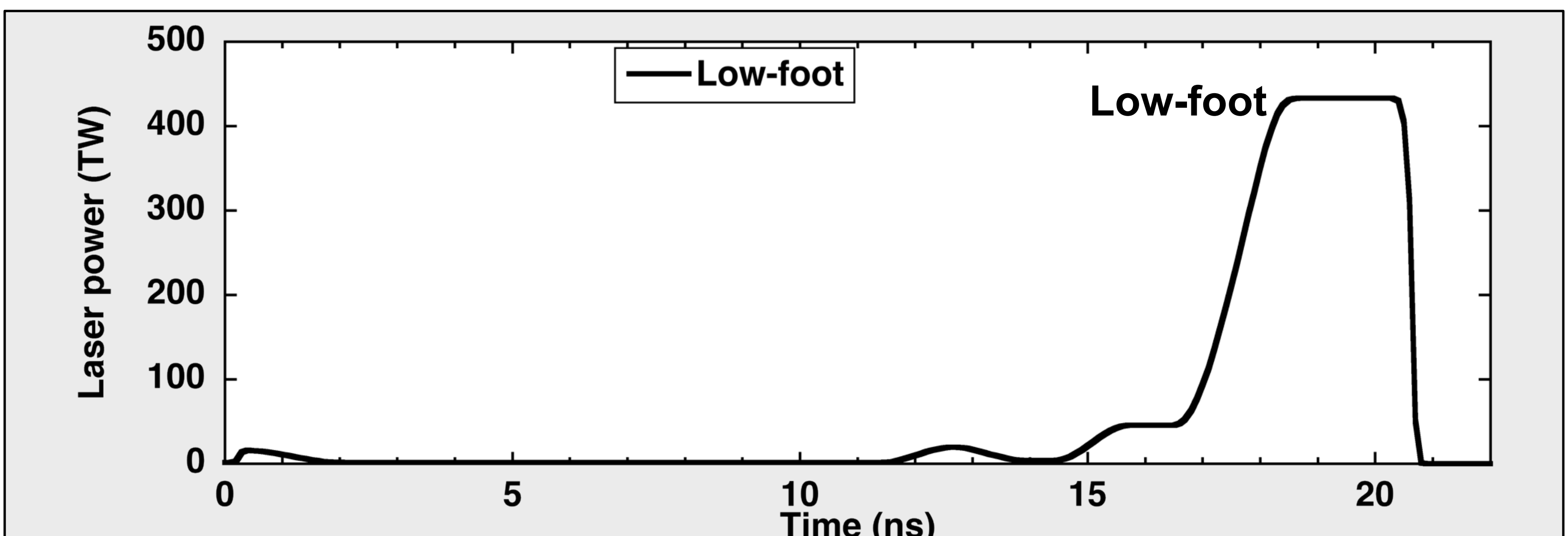


Is there an optimum gas-fill for good coupling, low CBET, and low hot electrons?

Current hohlraum experiments are exploring a broad range of parameters





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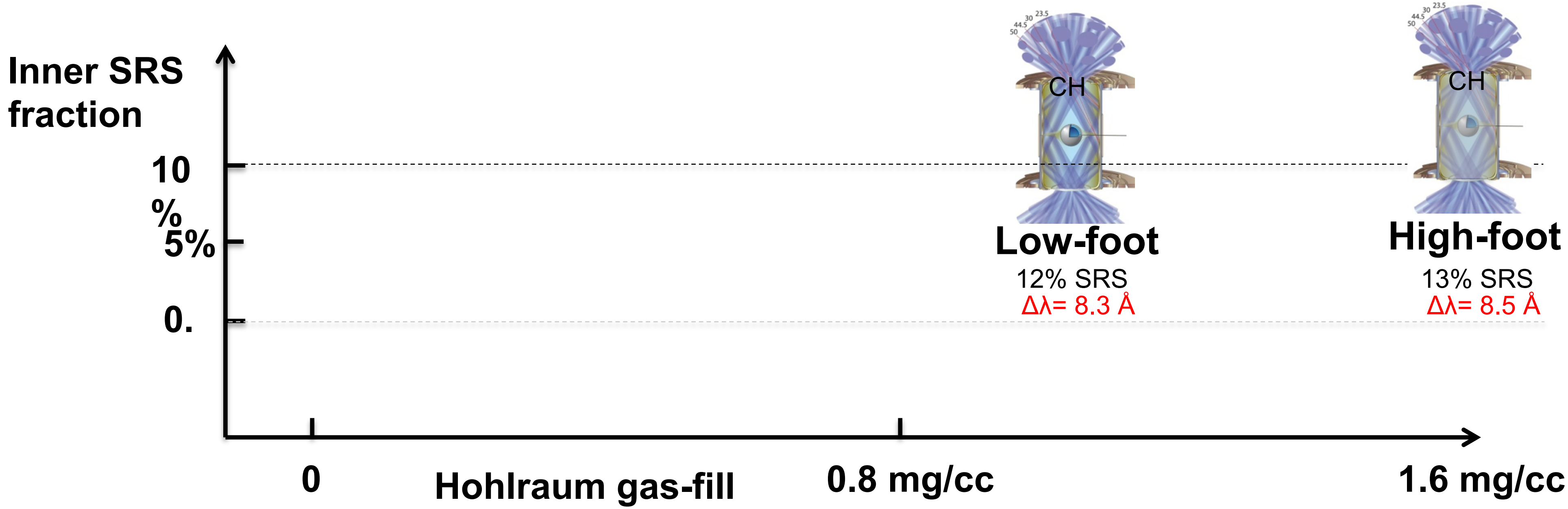

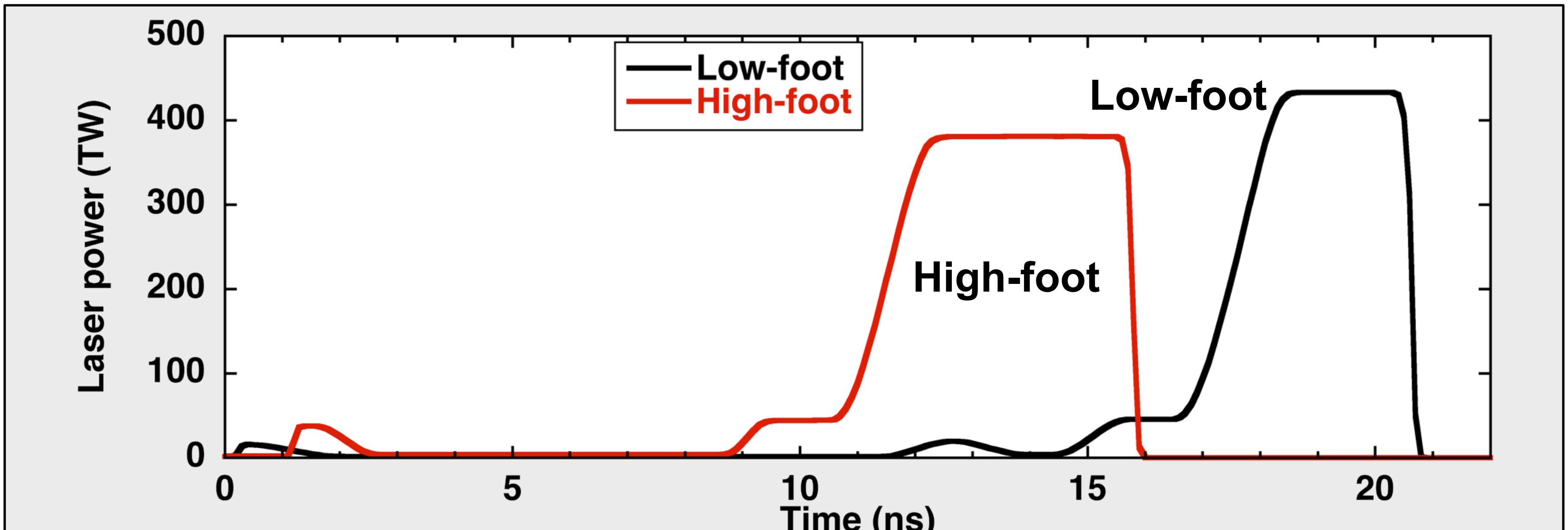

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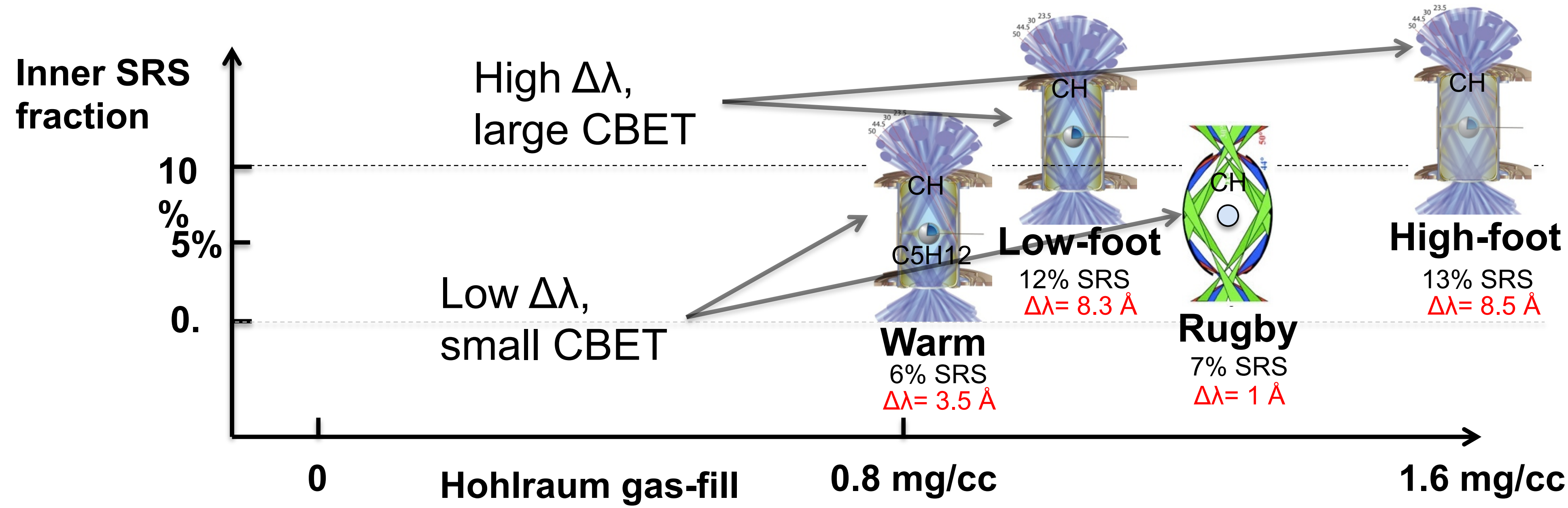

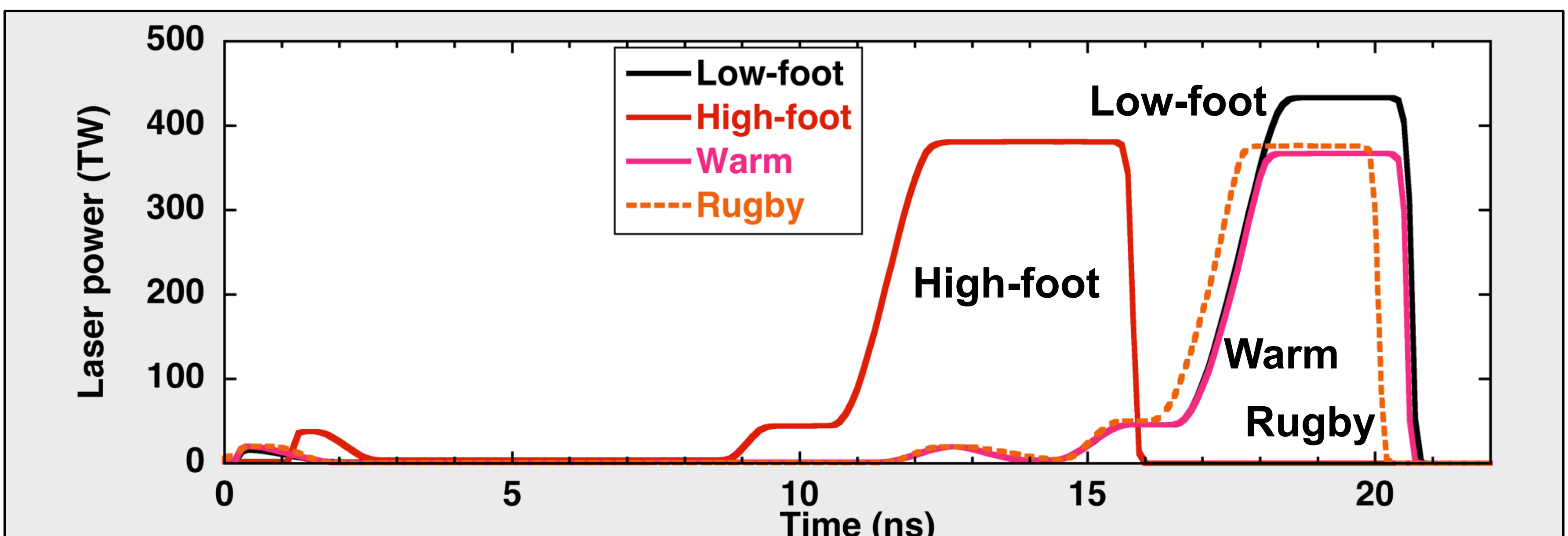

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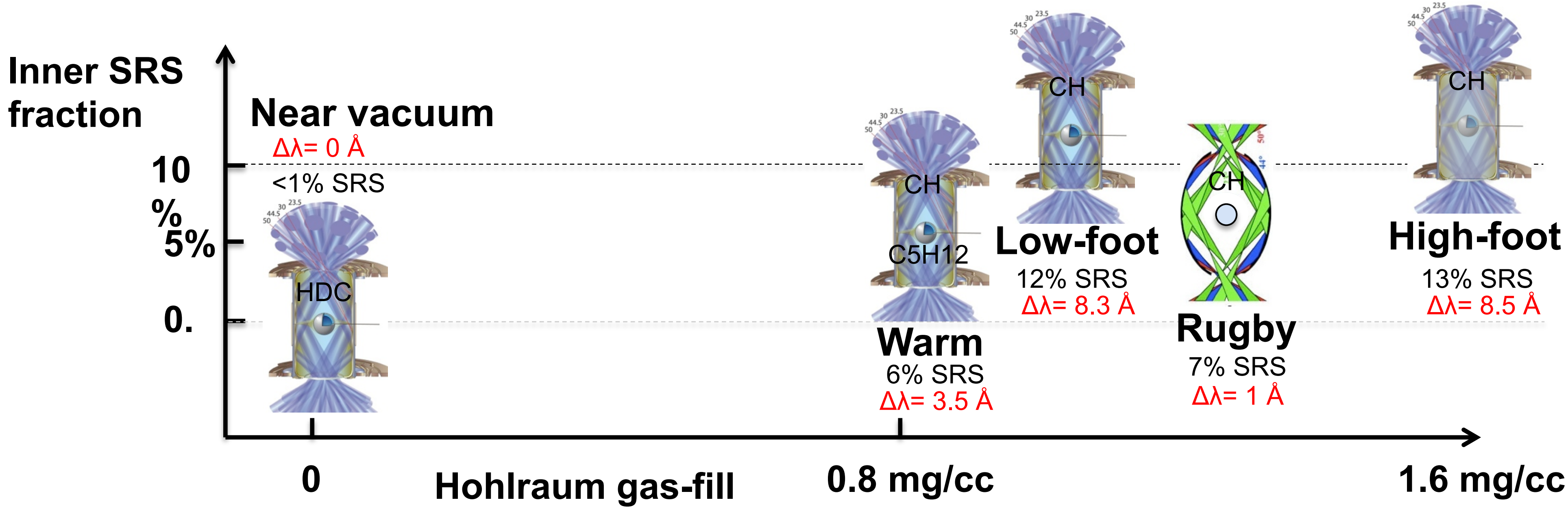

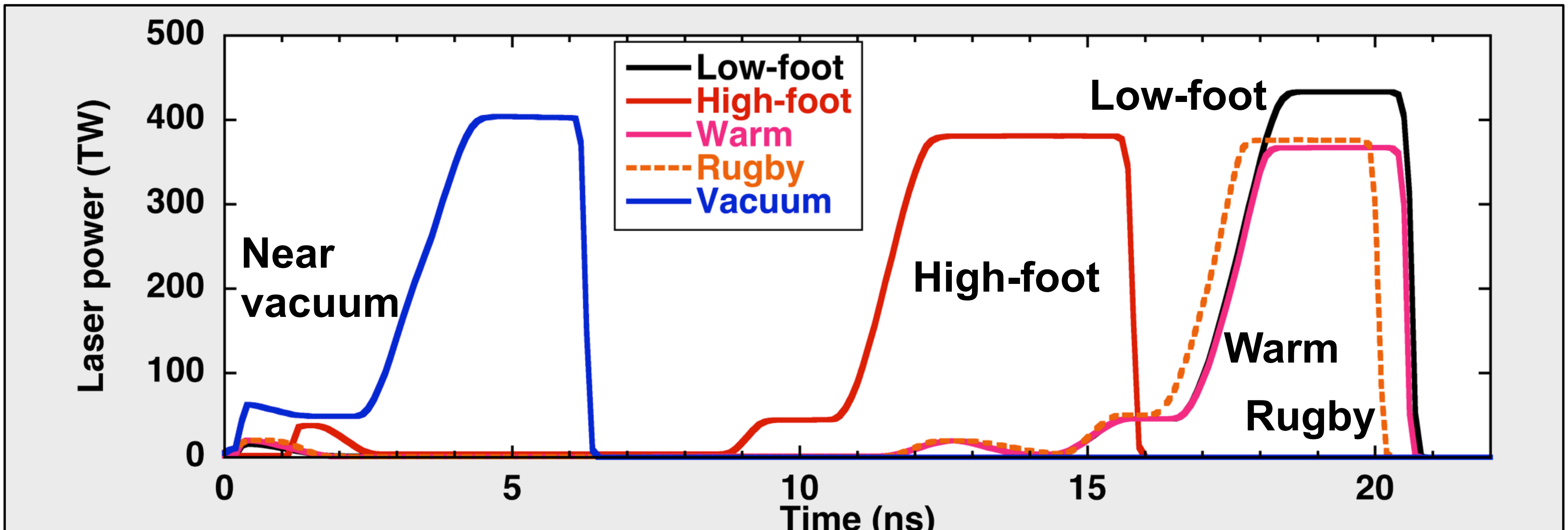

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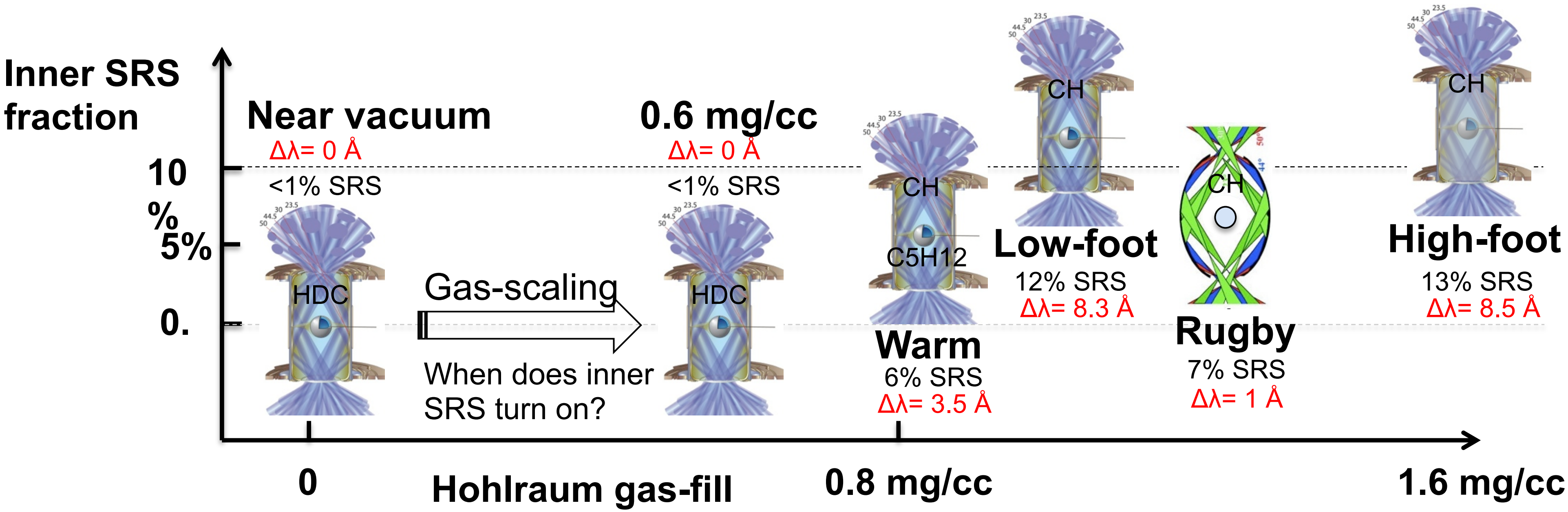

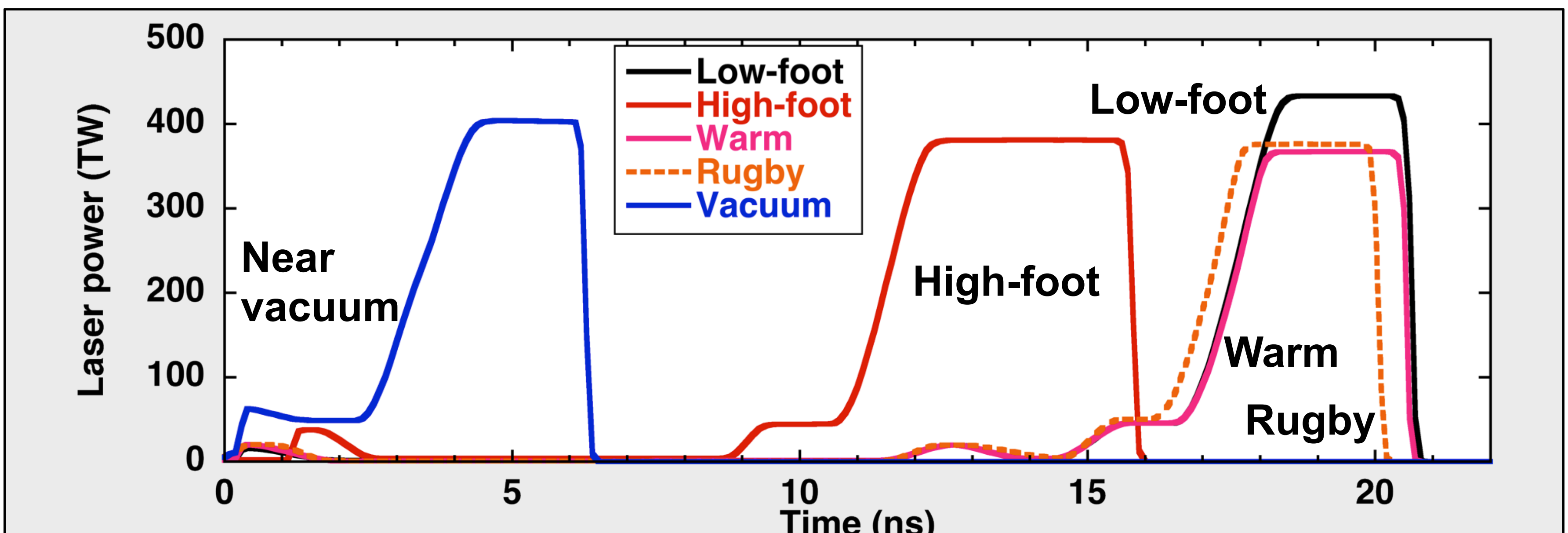

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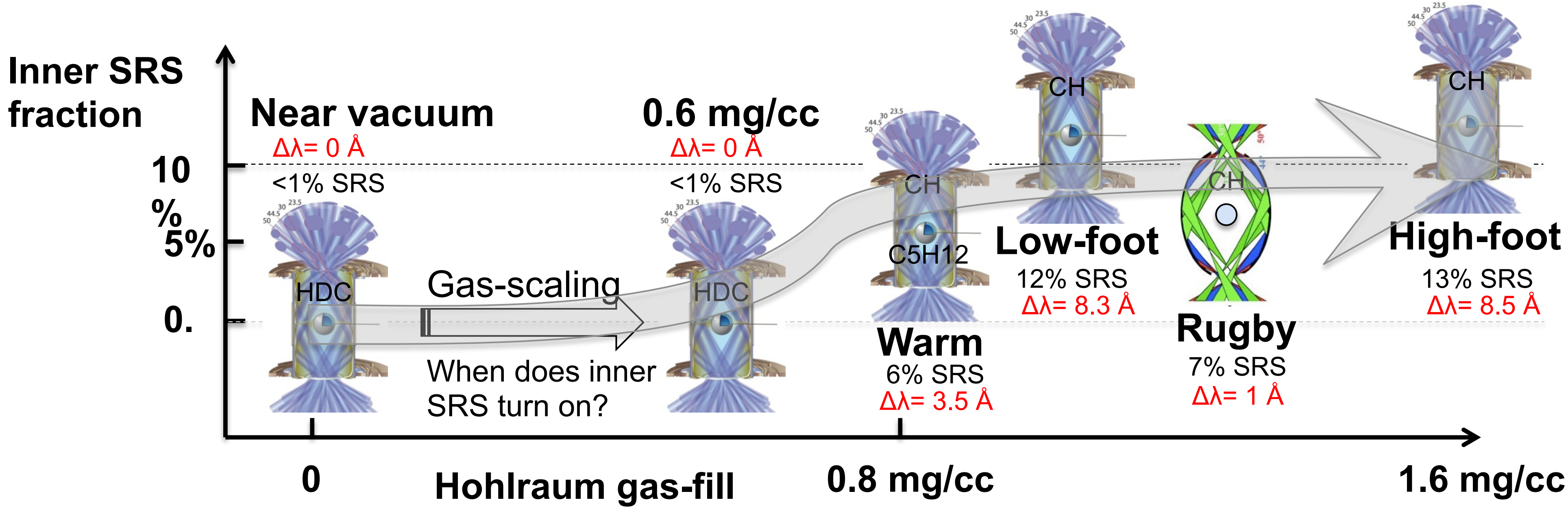
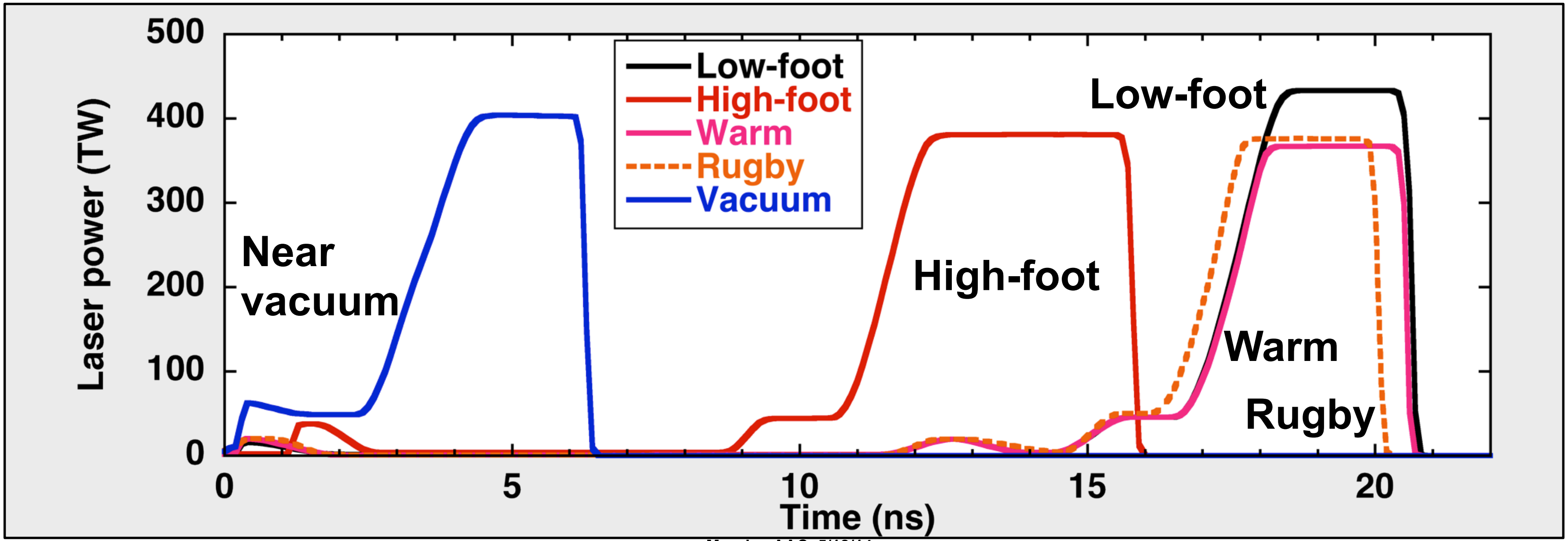
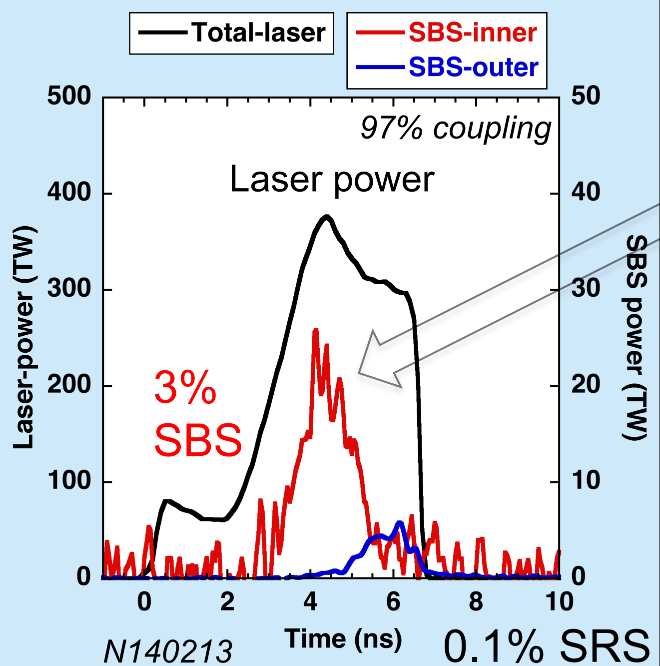




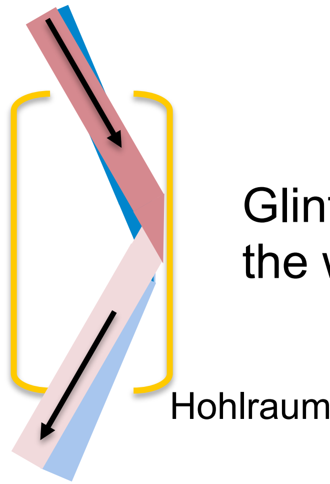
Near-vacuum hohlraum shows "glint" scatter

Only plotting SBS; SRS not shown

0.03 mg/cc He fill density

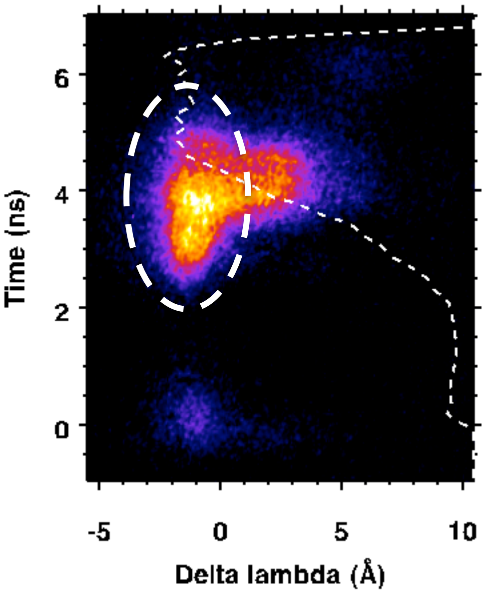


Scatter from the inners at 4 ns is "glint"; no significant hots



Glint – Beams reflect off the wall of the hohlraum

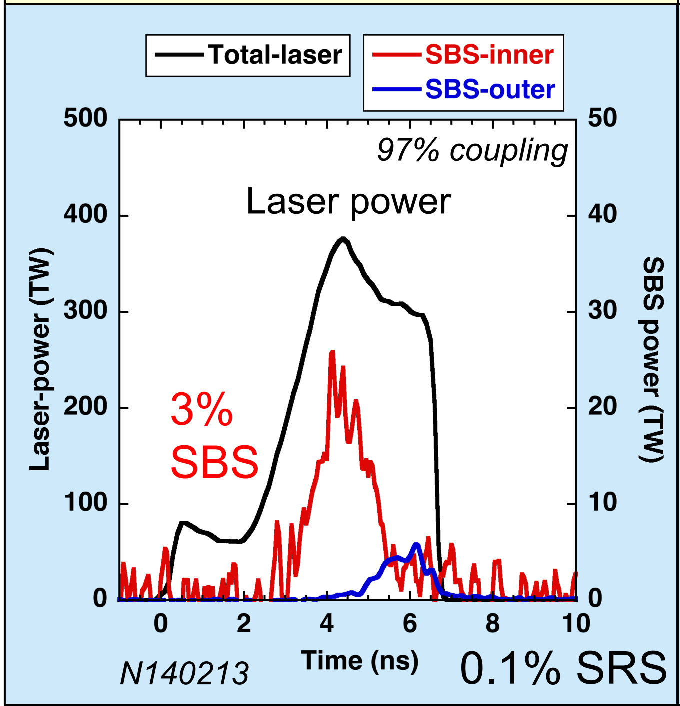
Spectrally blue-shifted; specific near-field pattern



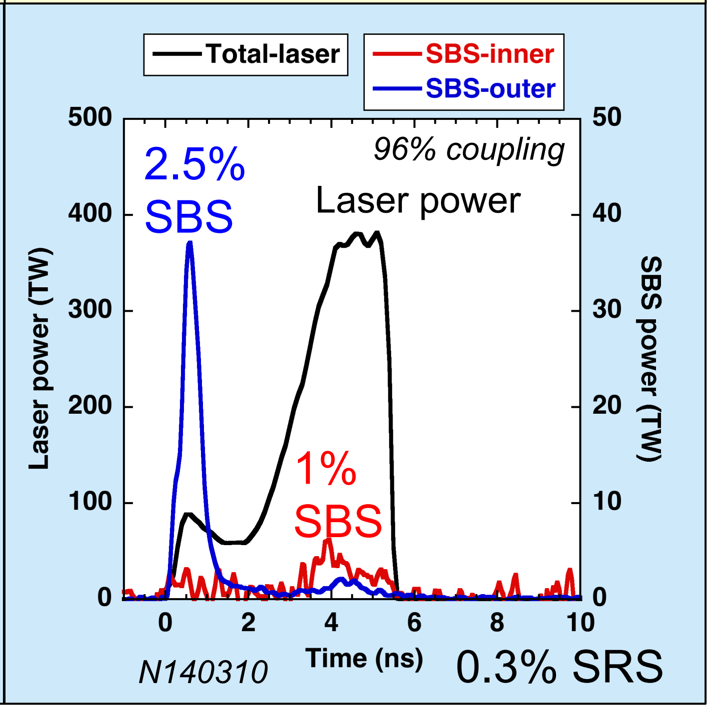
Increasing gas-fill in a 2-shock system reduces "glint" scatter and doesn't increase SRS

Only plotting SBS; SRS not shown

0.03 mg/cc He fill density



0.6 mg/cc He fill density



Scatter from the inners at 4 ns is "glint"; no significant hots

Early window SBS on outers; 4 ns "glint" scatter down; no significant hots

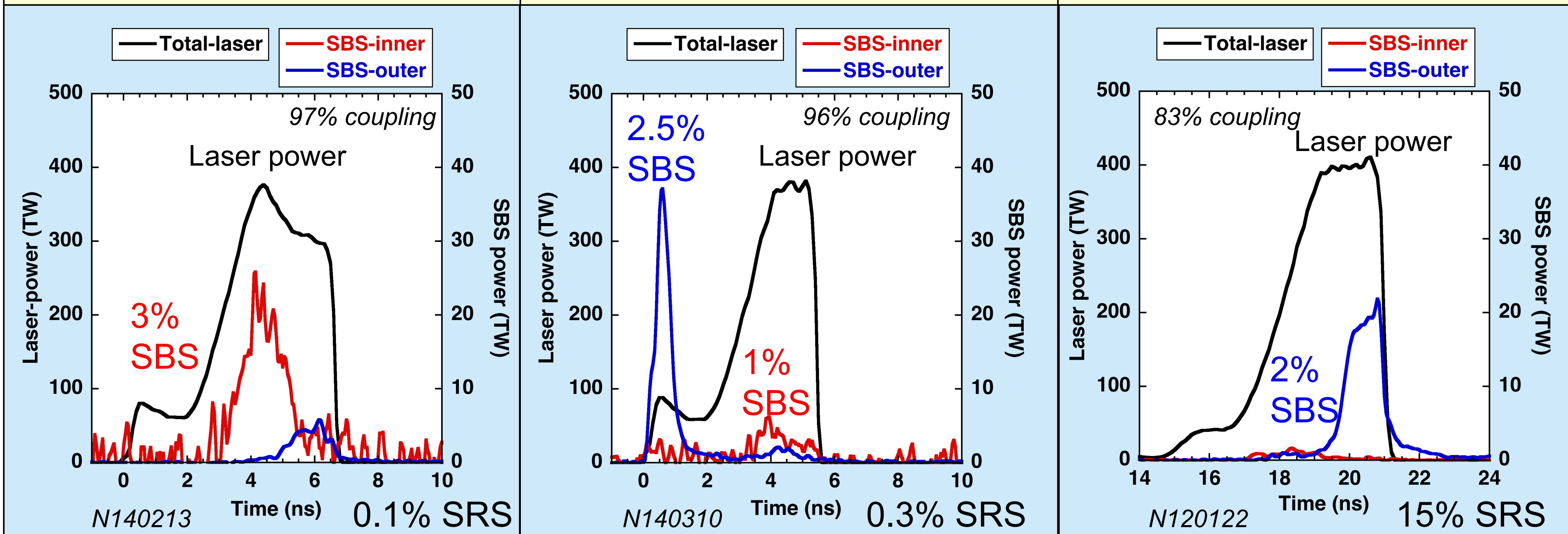
Add some gas-fill: glint nearly gone but early time flash from the outers is observed

Fix legend??

Experiments are testing for an optimum gas-fill

Only plotting SBS; SRS not shown

0.03 mg/cc He fill density	0.6 mg/cc He fill density	0.96 mg/cc He fill density



Scatter from the inners at 4 ns is "glint"; no significant hots

Early window SBS on outers; 4 ns "glint" scatter down; no significant hots

Large SRS inner; outer SBS comes up at end; hots come up during high laser intensity

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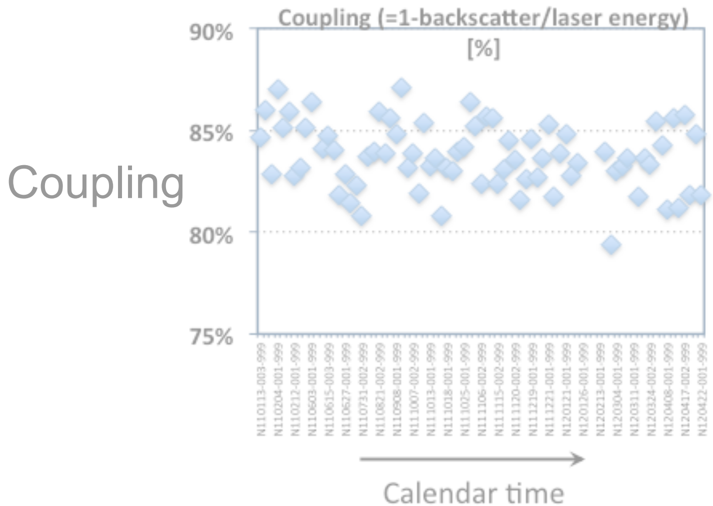

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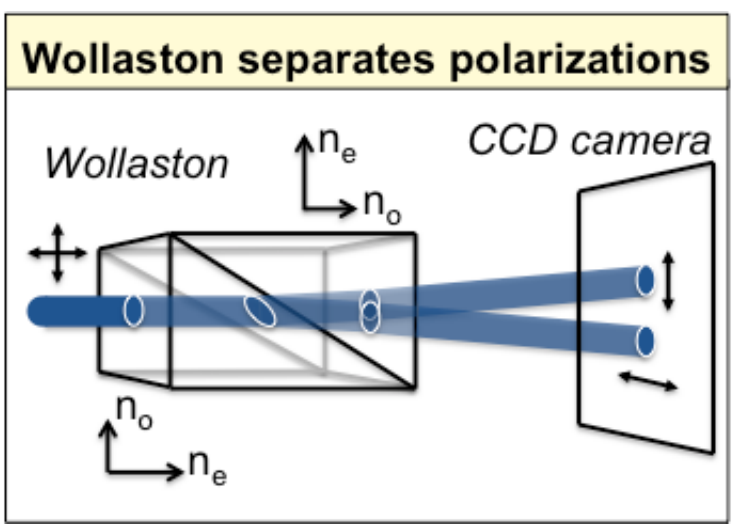

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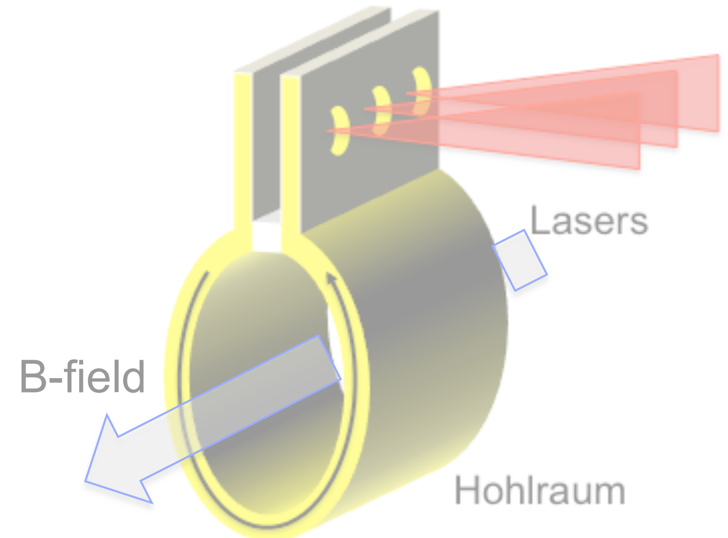

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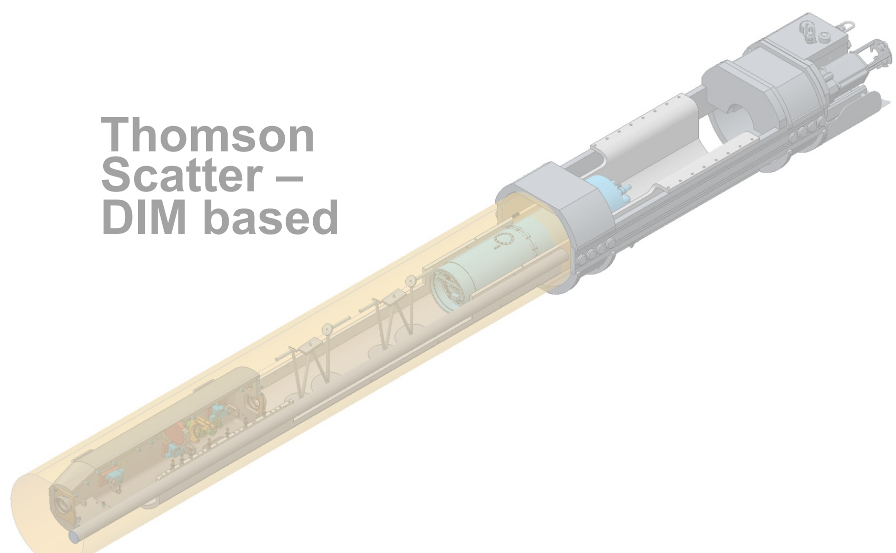
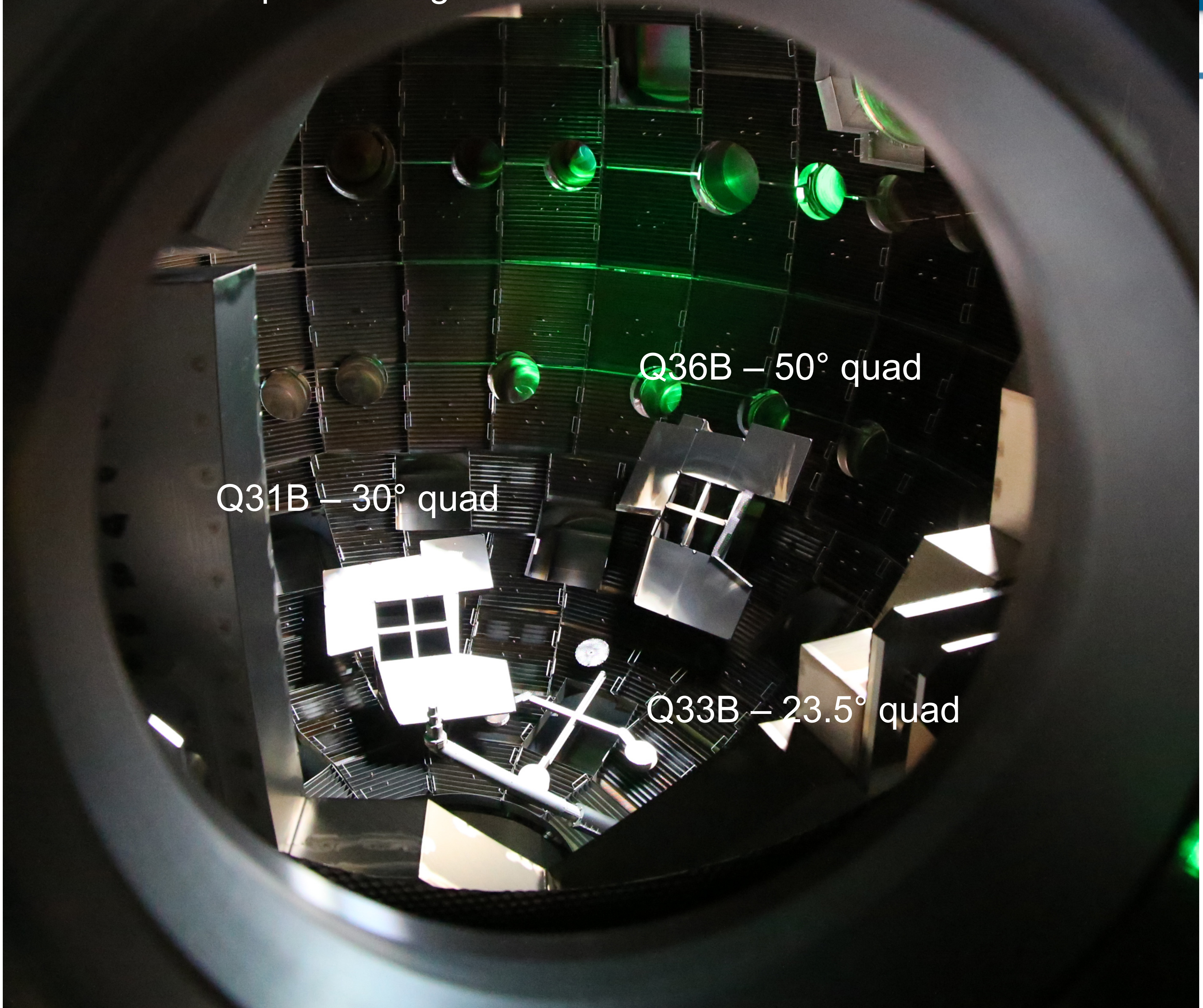
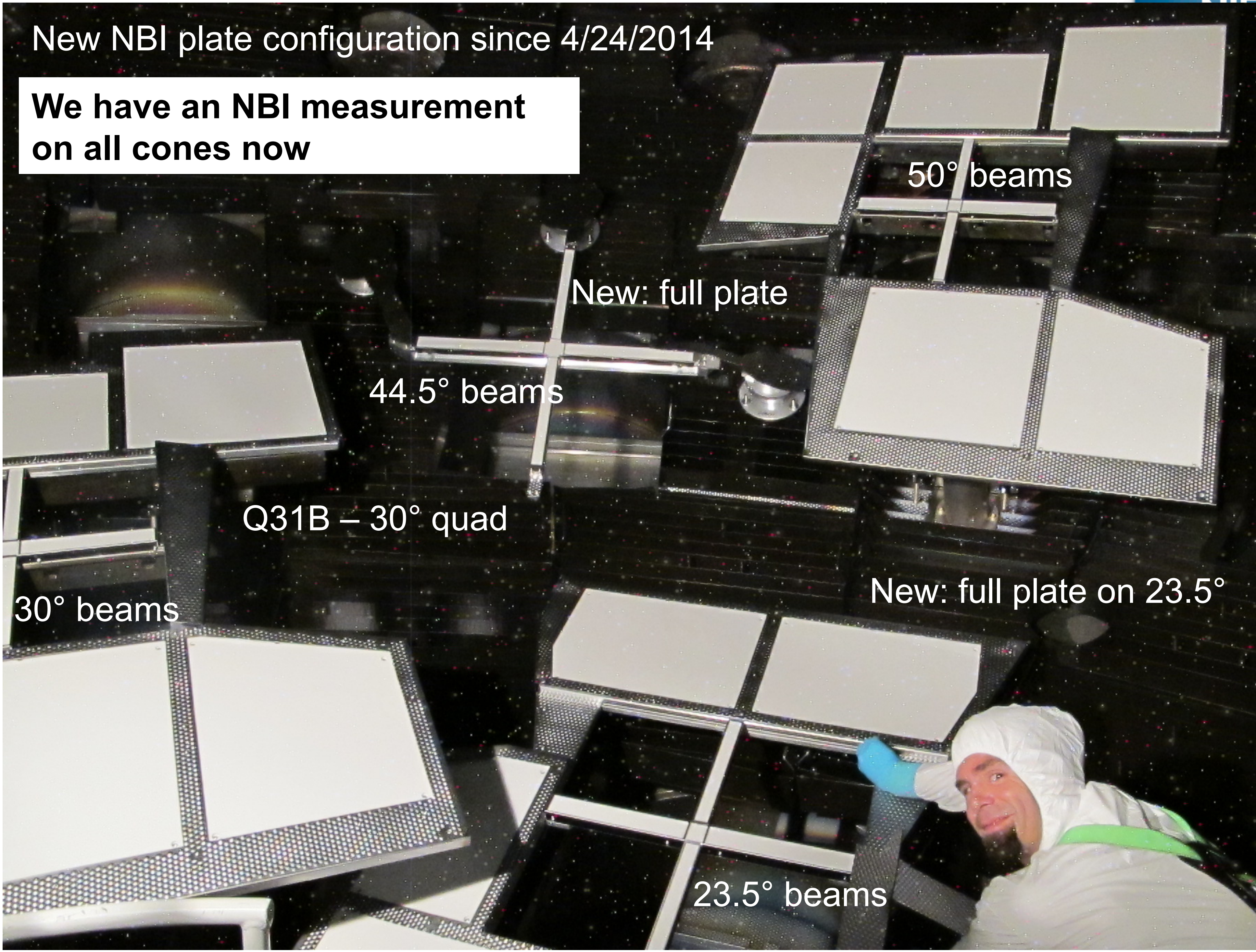
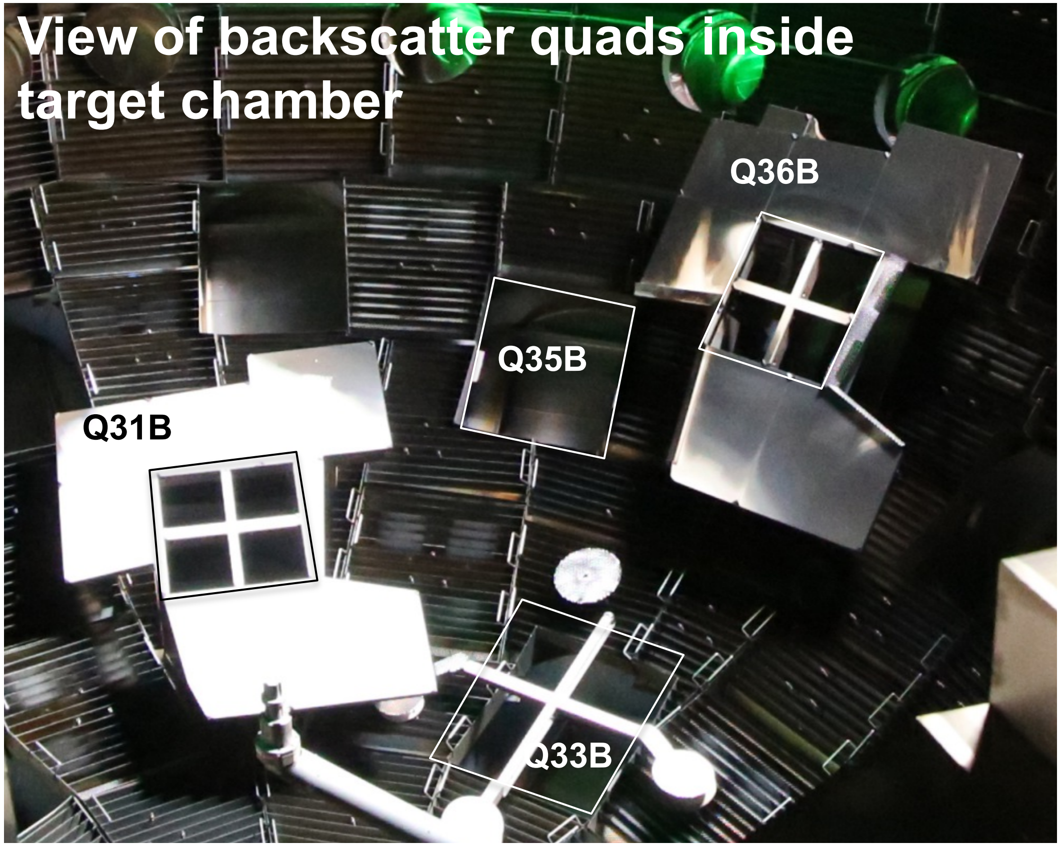


NBI plate configuration from 9/29/2010 to 4/20/2014




New NBI plate configuration since 4/24/2014
We have an NBI measurement on all cones now
50° beams
New: full plate
44.5° beams
Q31B – 30° quad
New: full plate on 23.5°
30° beams
23.5° beams

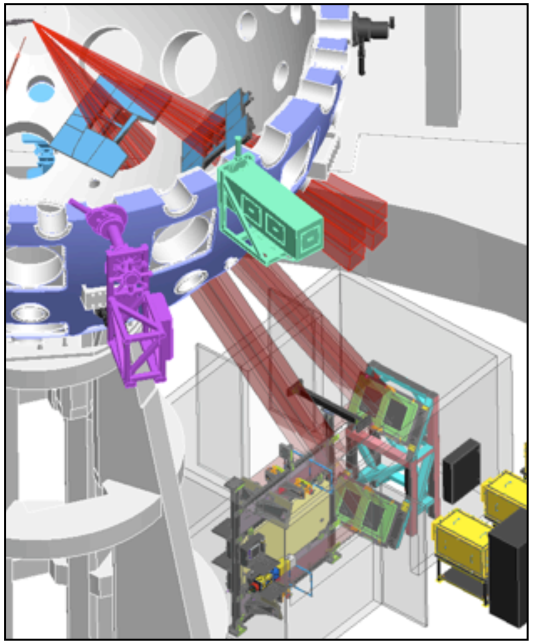
The ability to measure polarization has been added to the Q31B FABS diagnostic

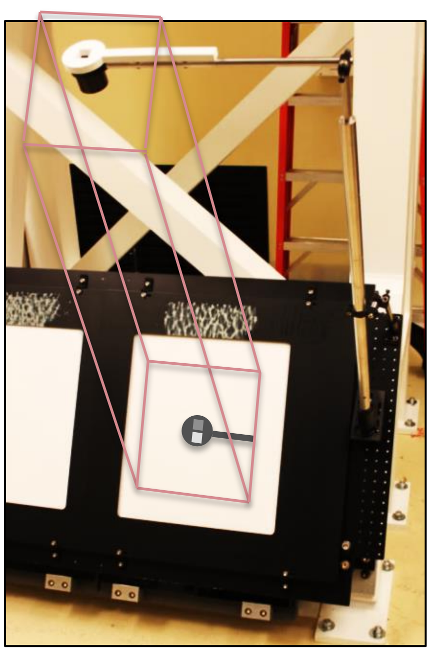


Physics reasons why "backscatter" polarization could be different:

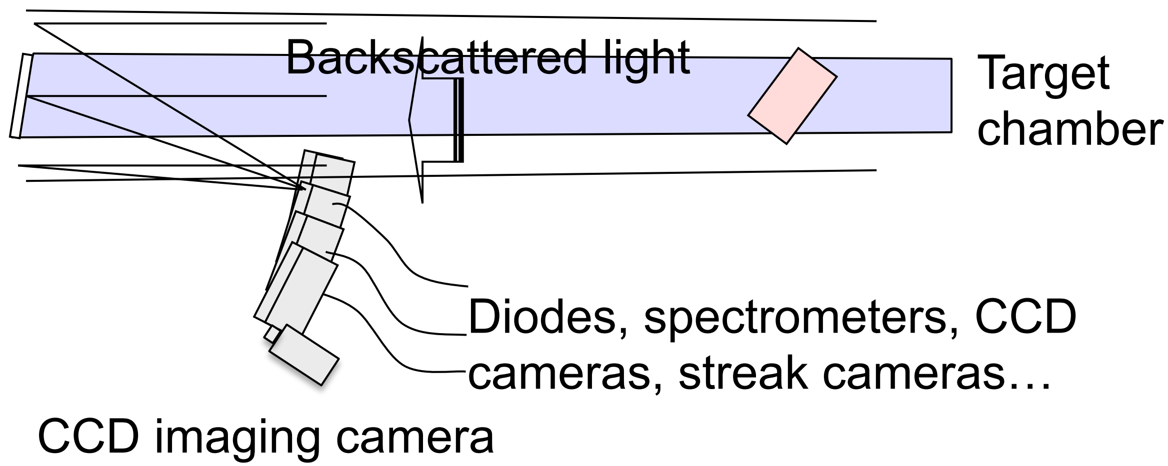
1) Collection of divergent backscatter or sidescatter from other beams
2) Energy transfer between beams with differing polarizations
3) Collection of "glint" from beams in opposite hemisphere
4) Faraday rotation due to magnetic fields in plasma

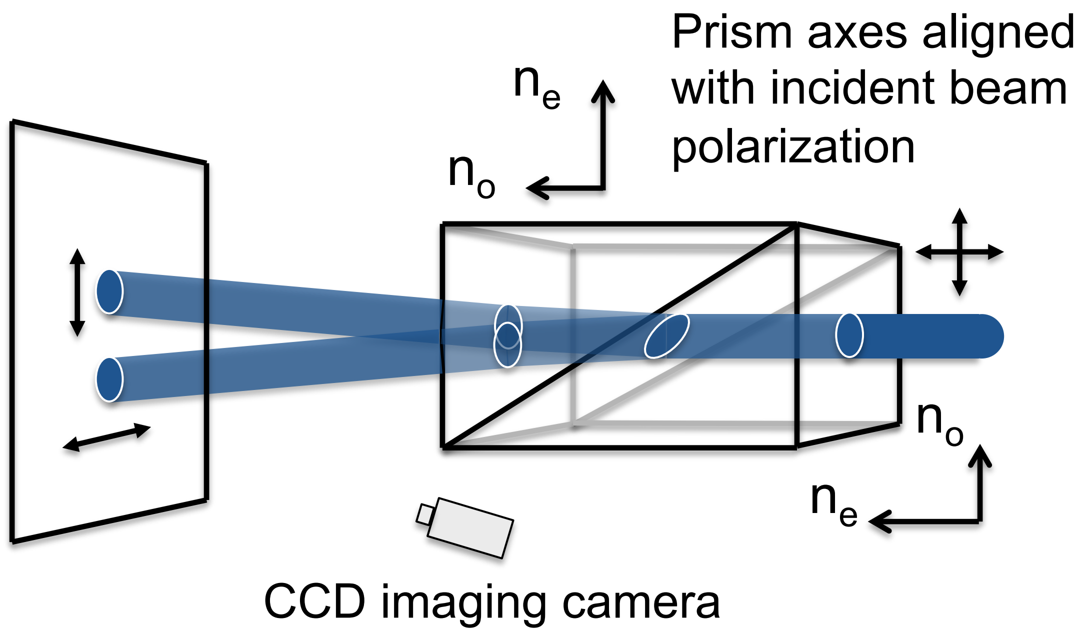
Wollaston prisms were added to backscatter paths prior to scatter plate





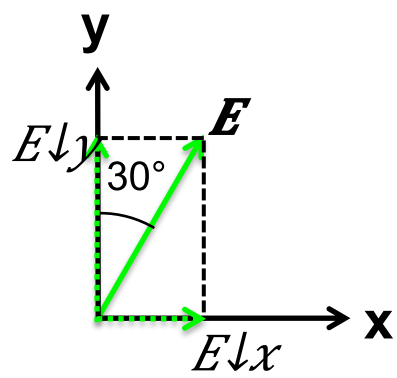
FABS architecture





Output is time-integrated balance of vertical and horizontal light (in quad's reference frame)

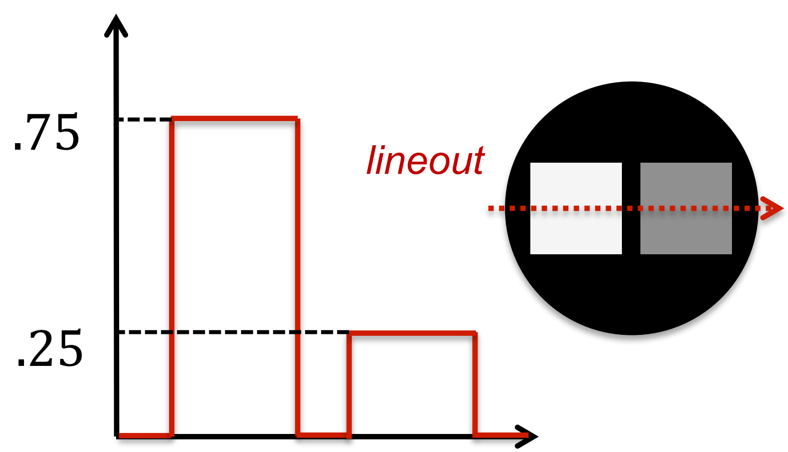
e.g. linearly polarized ($\varphi=0$) light 30° off vertical with no time dependence:



Normalized values:

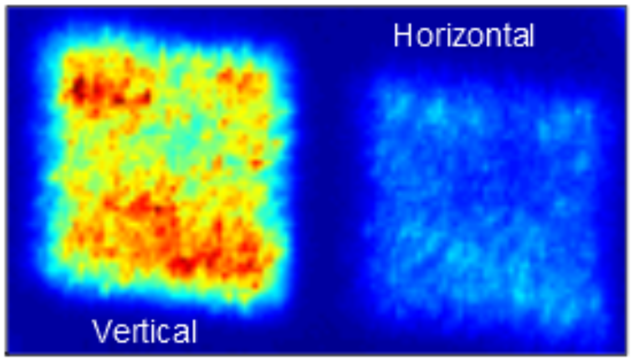
$$\int_0^{t_{end}} E_y(t)^2\, dt = E^2 \cos^2(30)/E$$

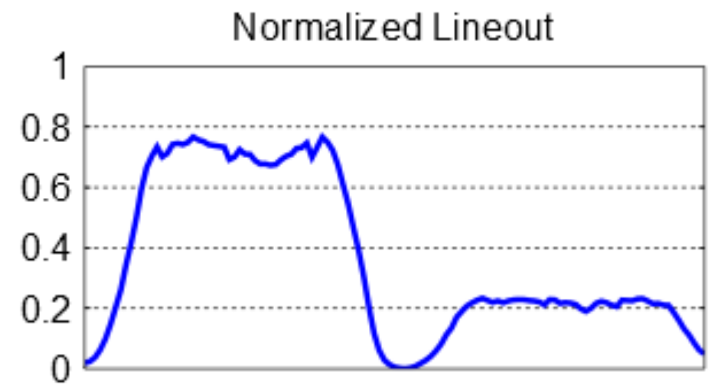
$$\int_0^{t_{end}} E_X(t)^2\, dt = E^2 \sin^2(30)/E$$



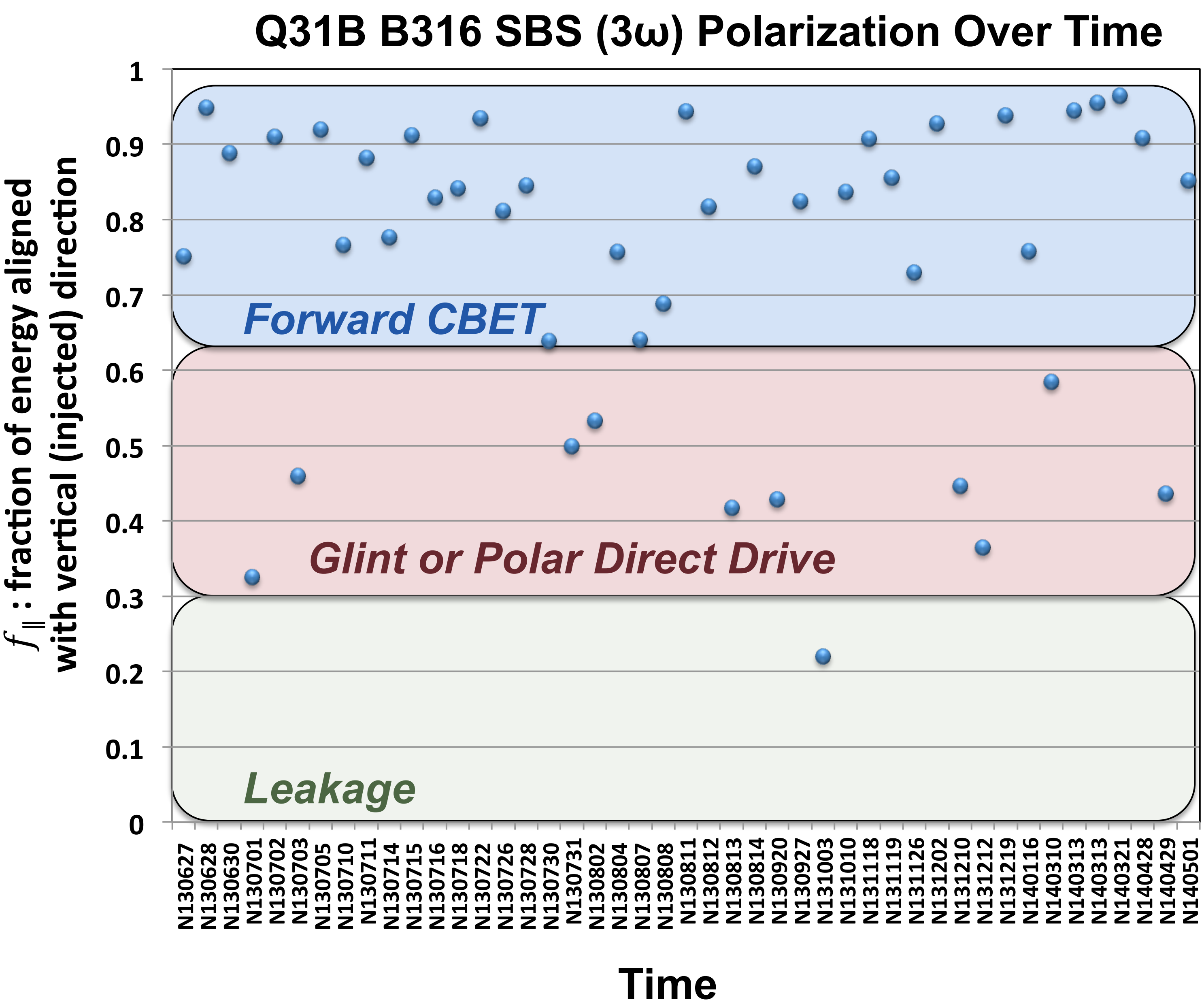
Normalized lineout

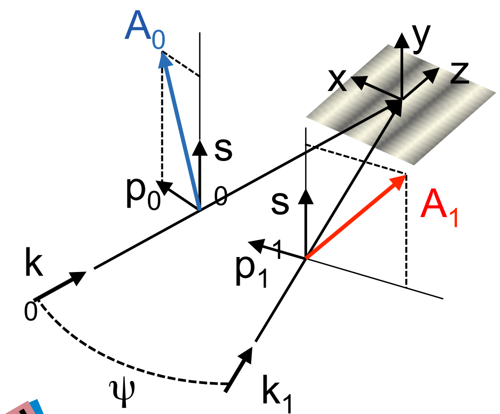
Ex. N130627

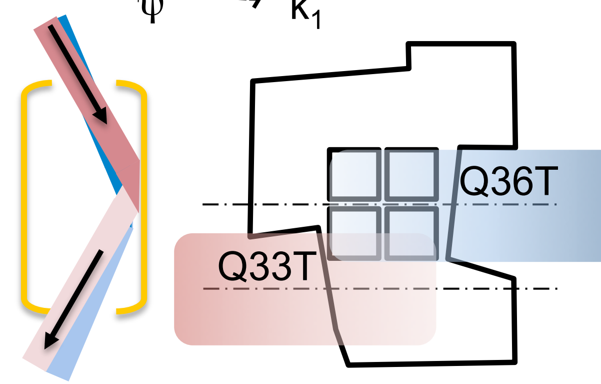


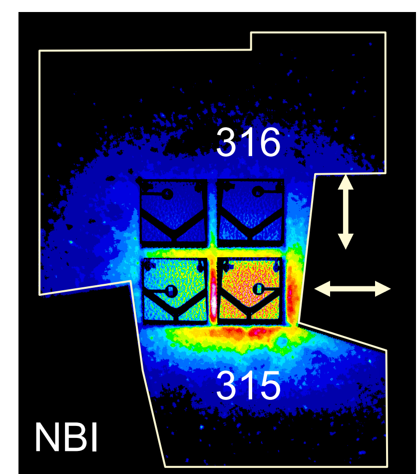


High level survey of results –
They can be broadly classified into three categories









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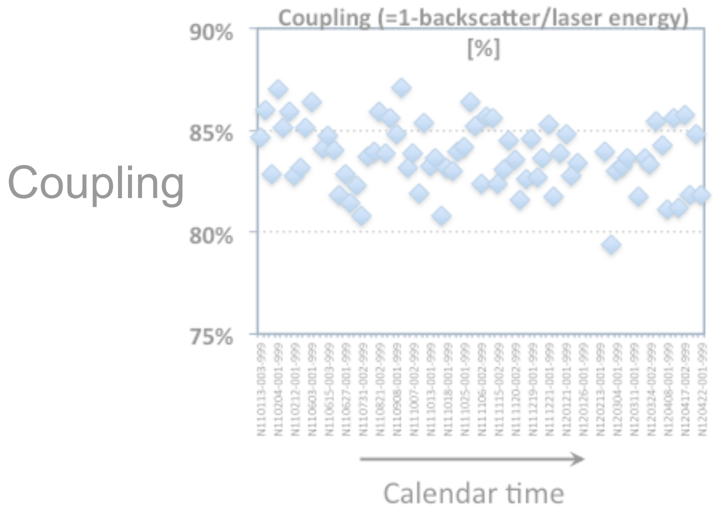

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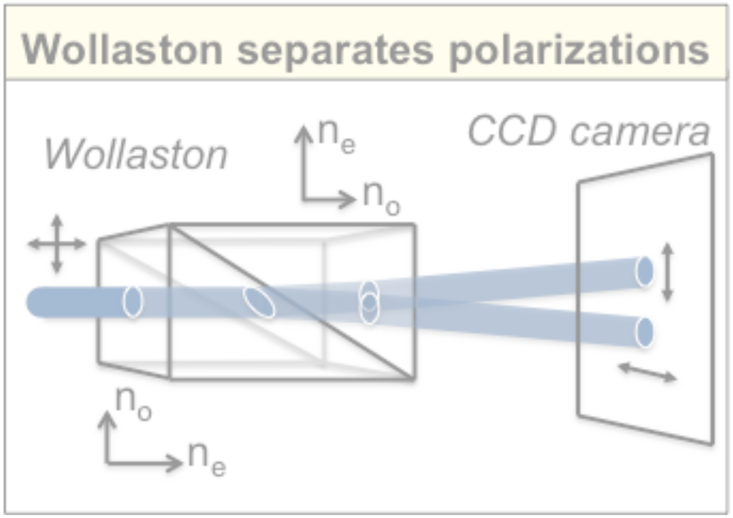

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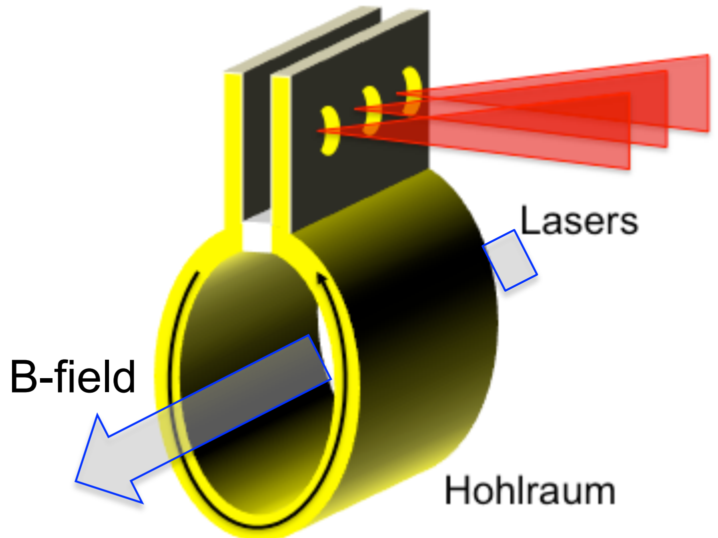

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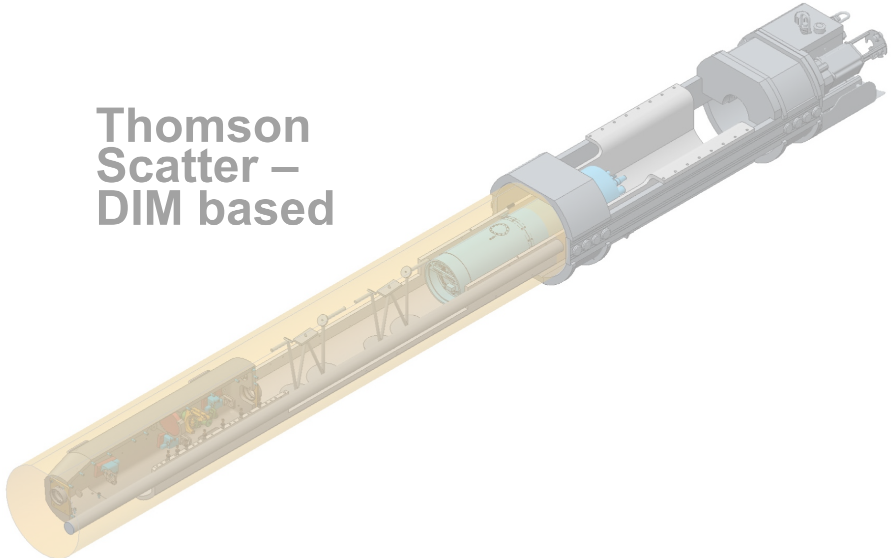
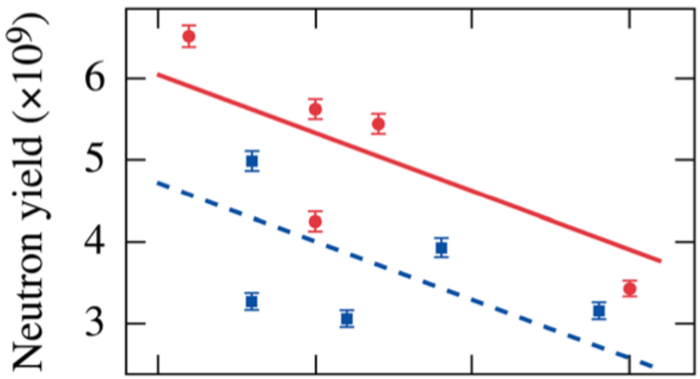
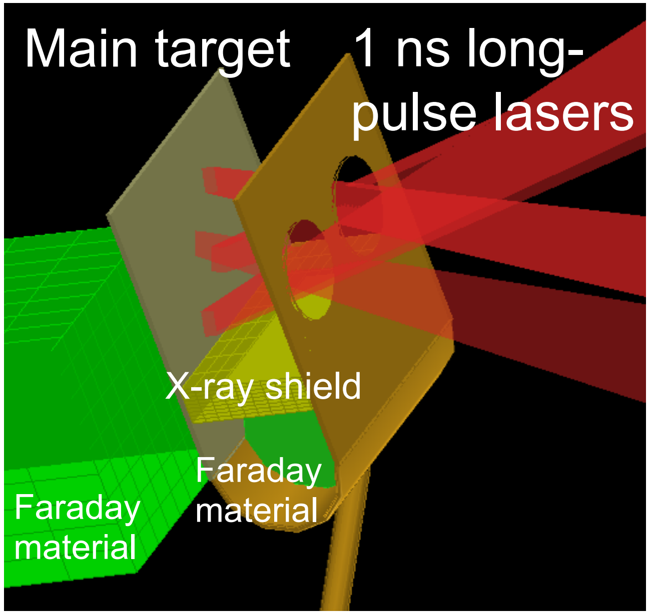


High magnetic fields are of interest for magnetized inertial fusion

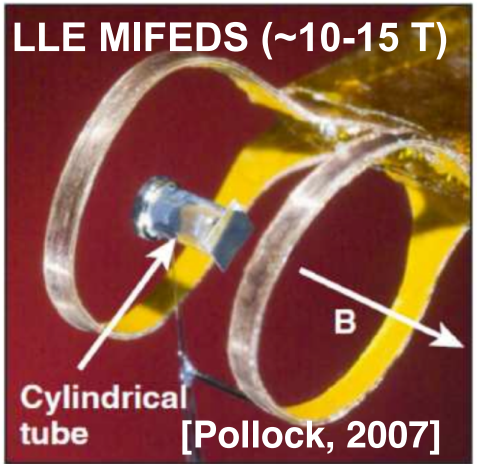
B-fields have improved direct-drive capsule performance



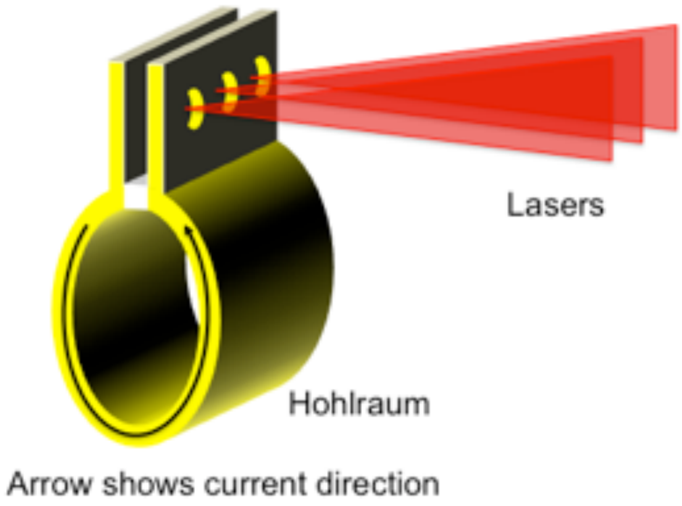
[Chang et al, PRL, 2011]



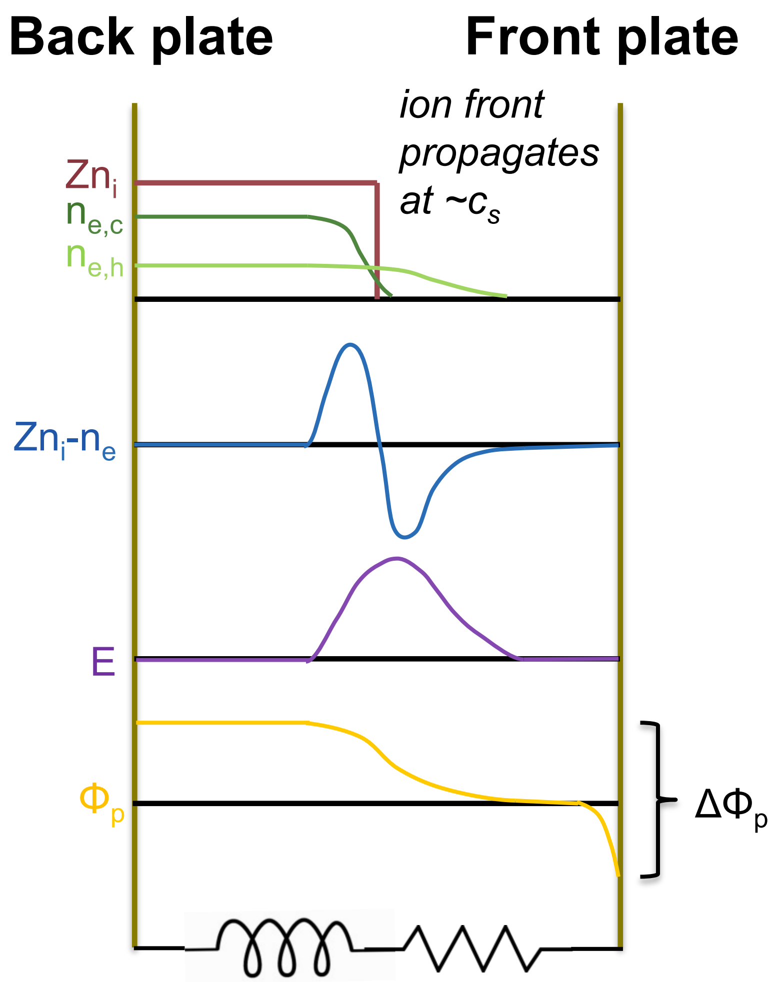
Pulsed power

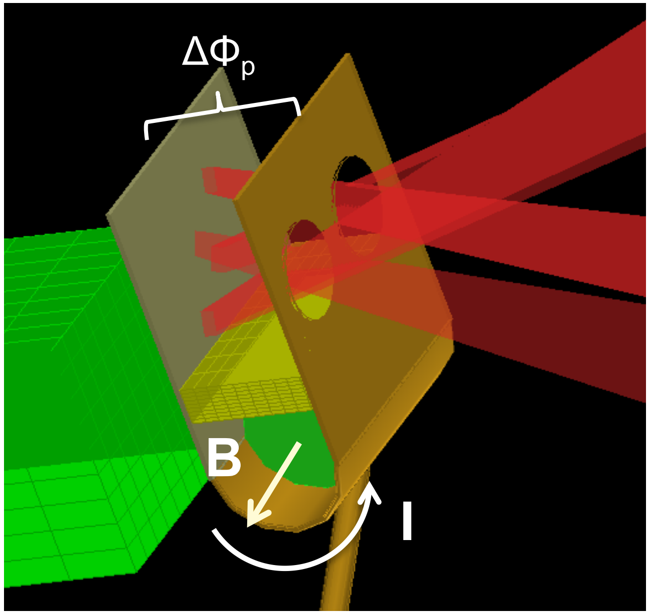


Laser-driven



Proposed simple model for laser-driven fields

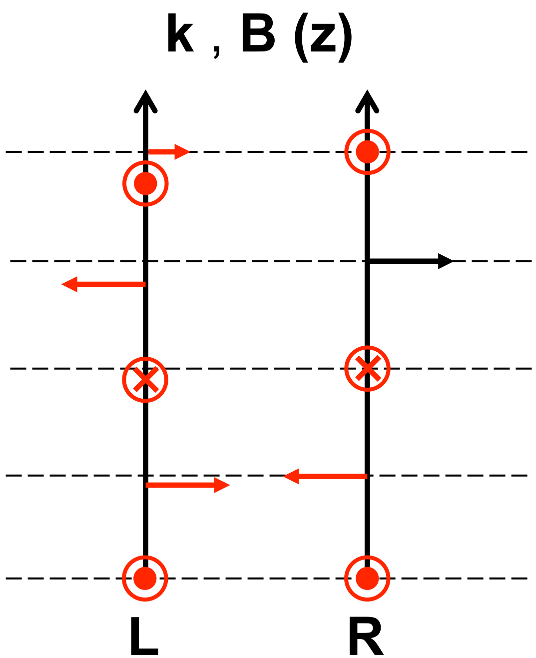


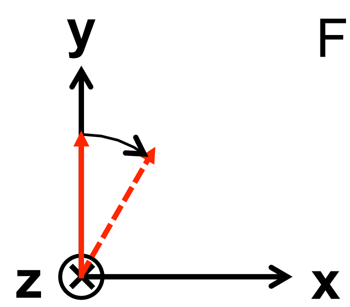


Previous work by Daido, Fujioka, Woolsey and others suggested that B fields of 10s to 100s of Tesla were possible

Polarimetry can also be used to measure magnetic fields in plasma and other materials

B fields are extracted from measurements of the Faraday rotation undergone by a beam propagating parallel to a magnetic field





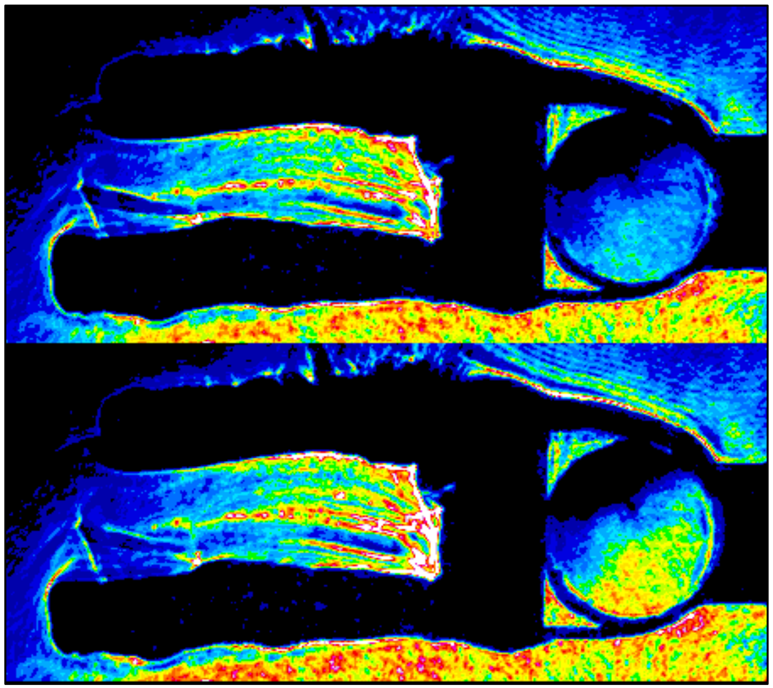
Rotates clockwise (riding with the beam) propagating along B

From D.R.: $n_{L,R} = ck/\omega \approx 1 - 1/2\ \omega_p^2 /\omega$

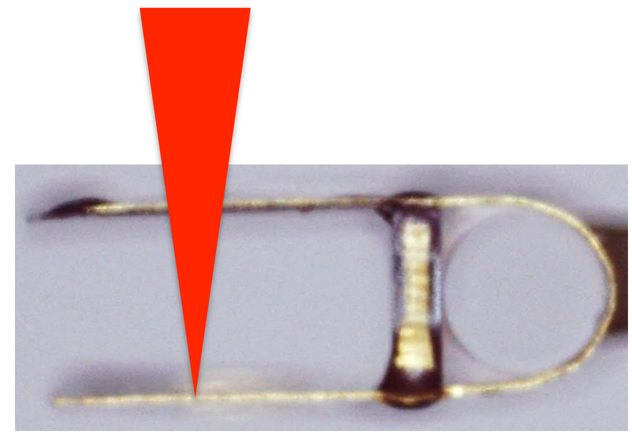
$$\Delta\psi \approx \frac{e}{2m_e c}\frac{n_e}{n_c} BL$$

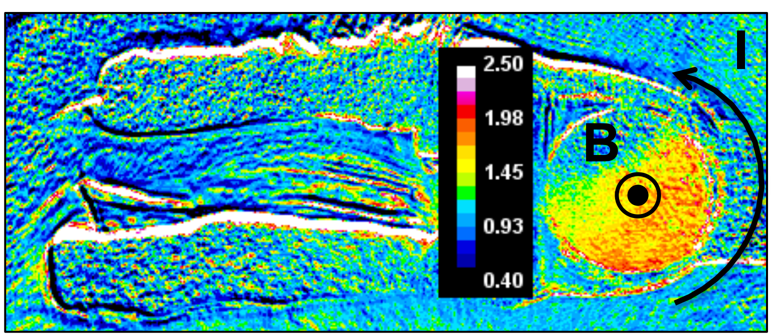
Effectively the plasma Verdet constant V

Example #1 from EP:
100J drive laser energy, 1.5ns 4ω probe timing



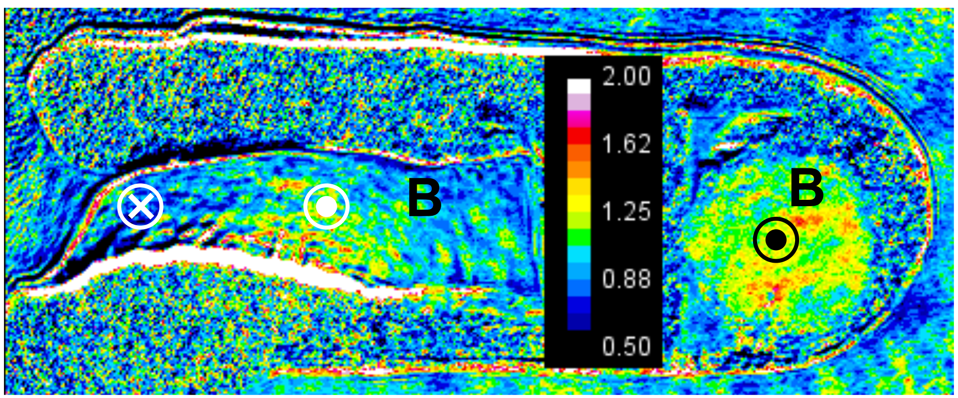
$4.6\pm0.3T$





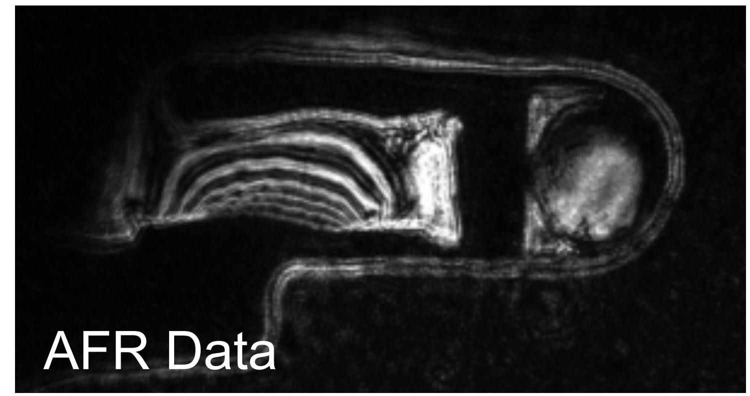
Bottom ÷ top

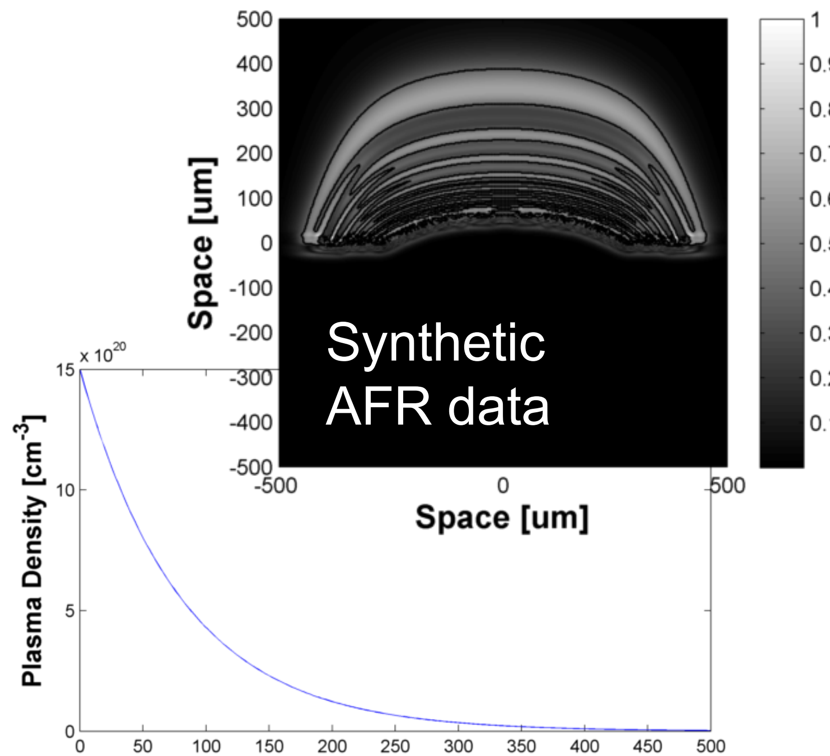
Example #2 from EP:
100J drive laser energy, 1.0ns 4ω probe timing



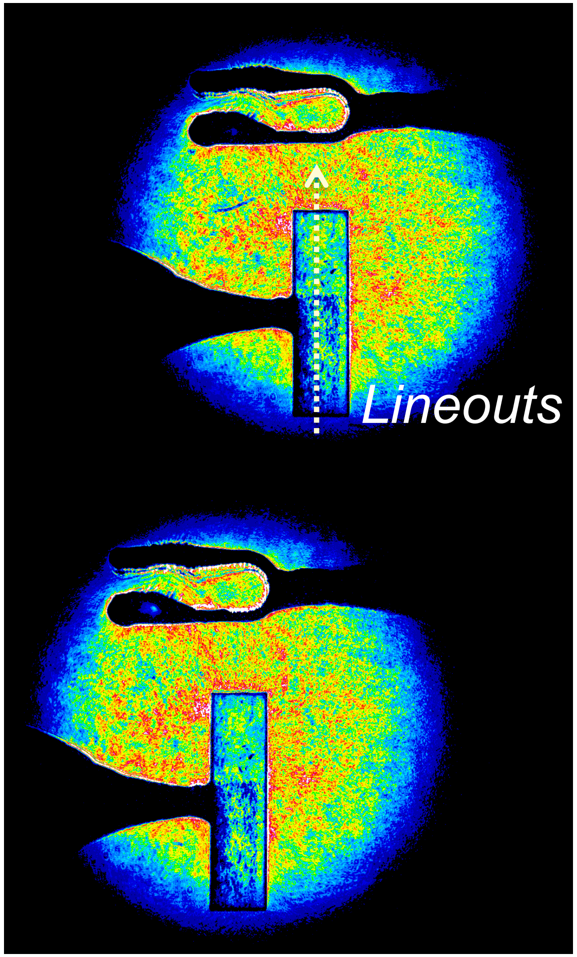
$B \approx 20\ (+20/-10)\ T$ $B \approx 2.1 \pm 0.3 T$

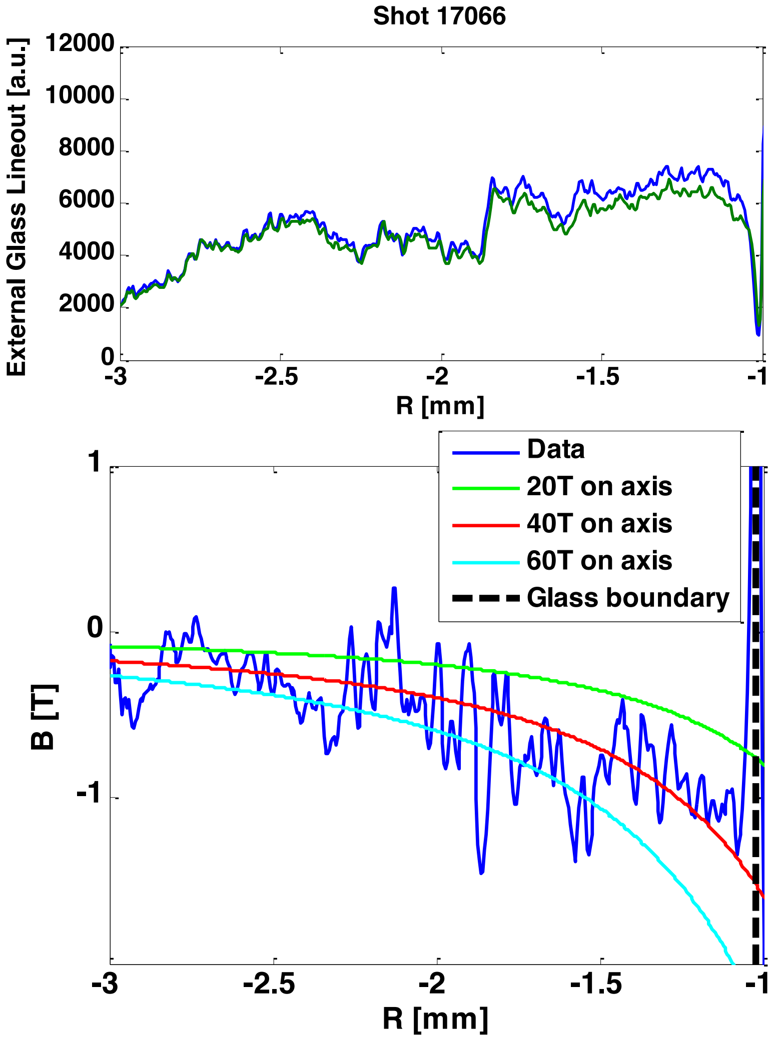
Presence of Biermann battery fields, but we expect they are distinct fields

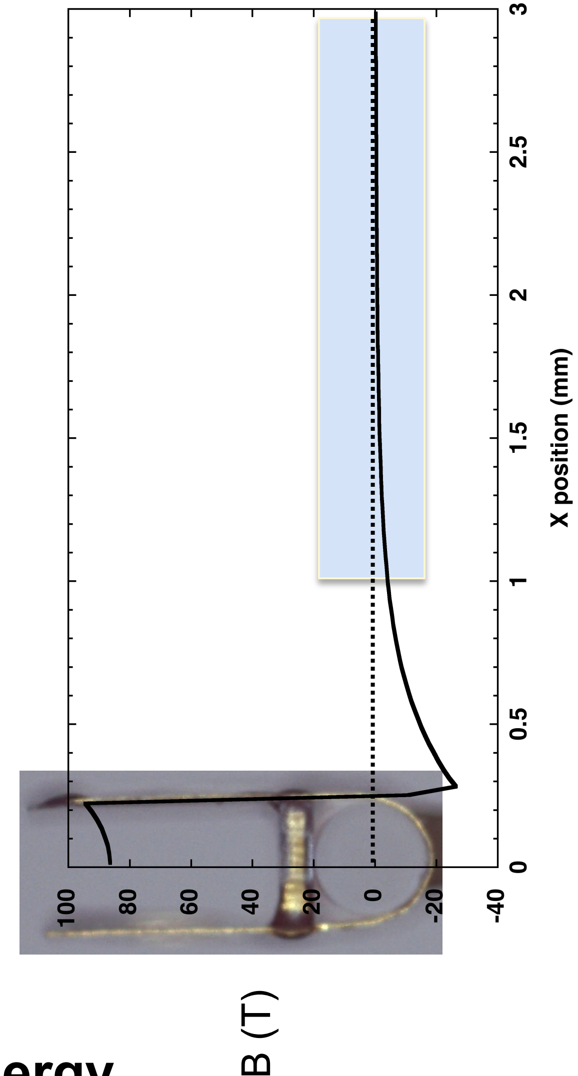




Example #3 from EP:
1000J drive laser energy, 0.5ns 4ω probe timing



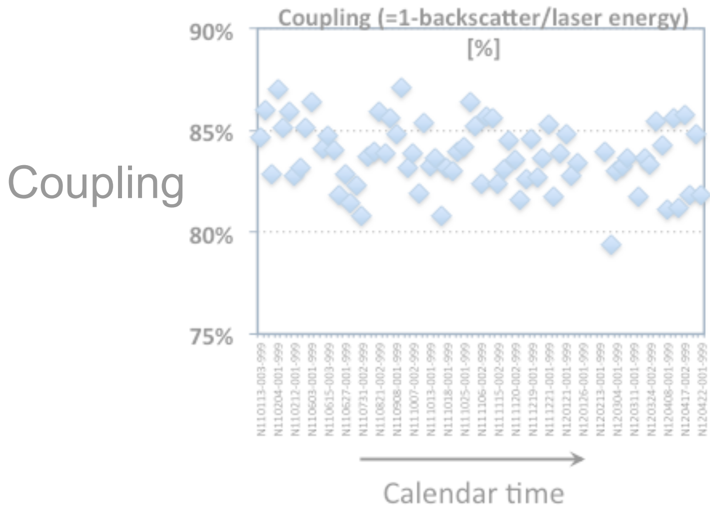




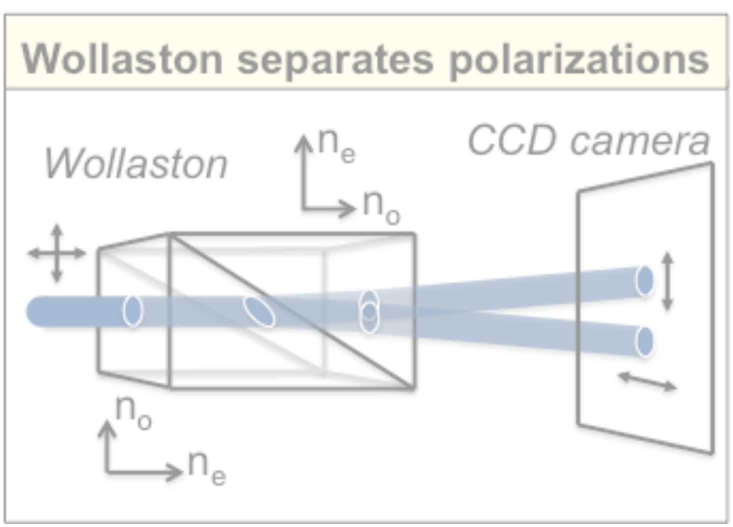
B field seems to approximately scale with laser energy

This talk will cover 4 topics

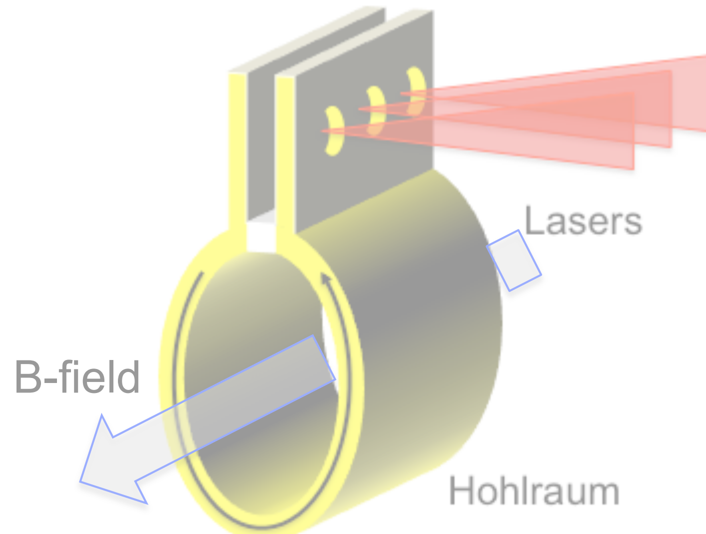
1) Update on NIF backscatter



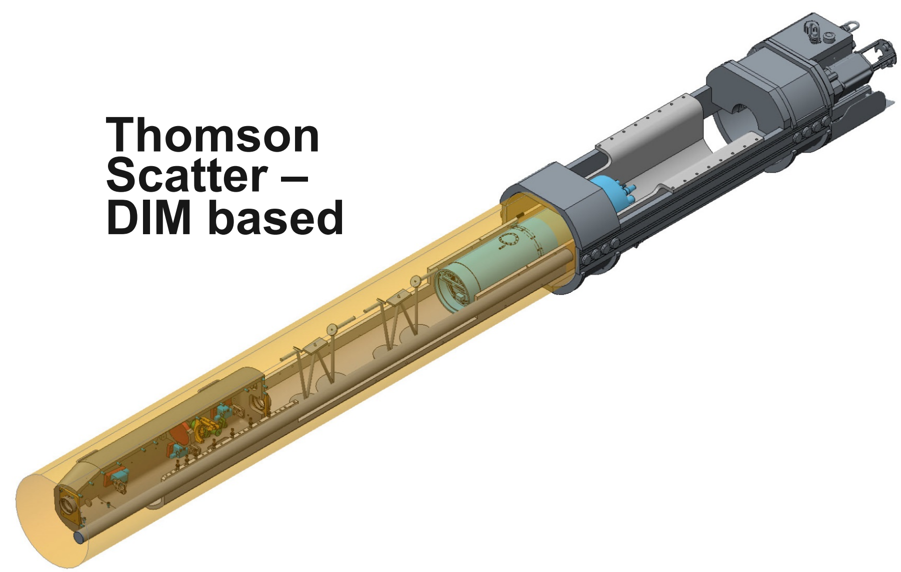
2) Backscatter instrument mods



3) Using LPI to generate B-fields

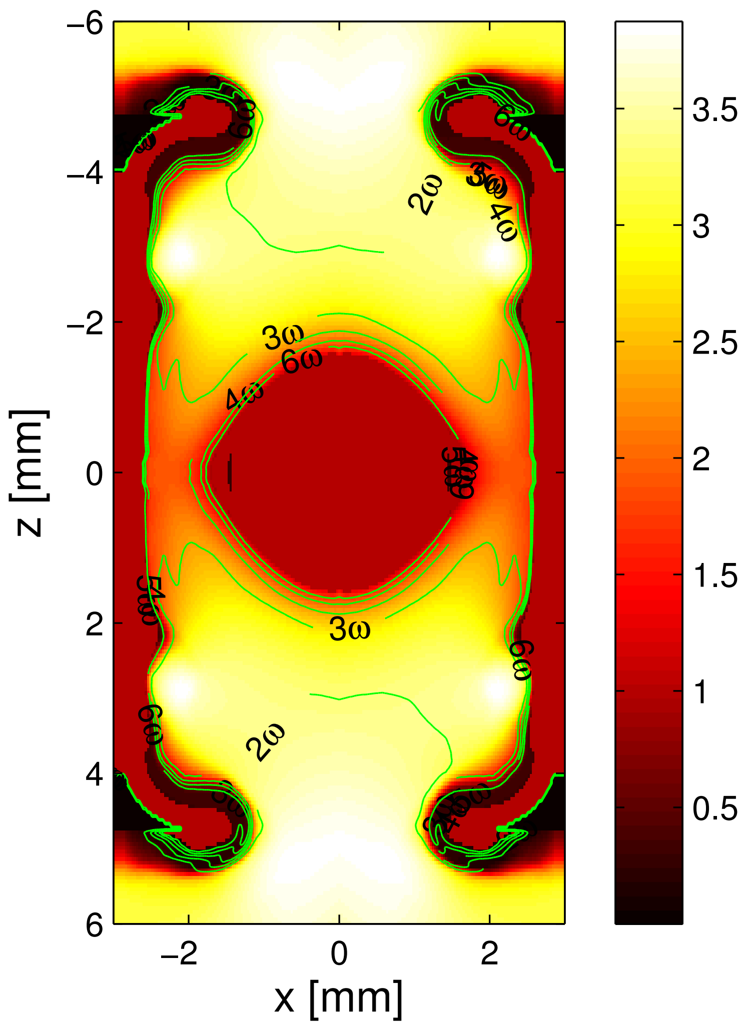


4) LPI and Plasma characterization

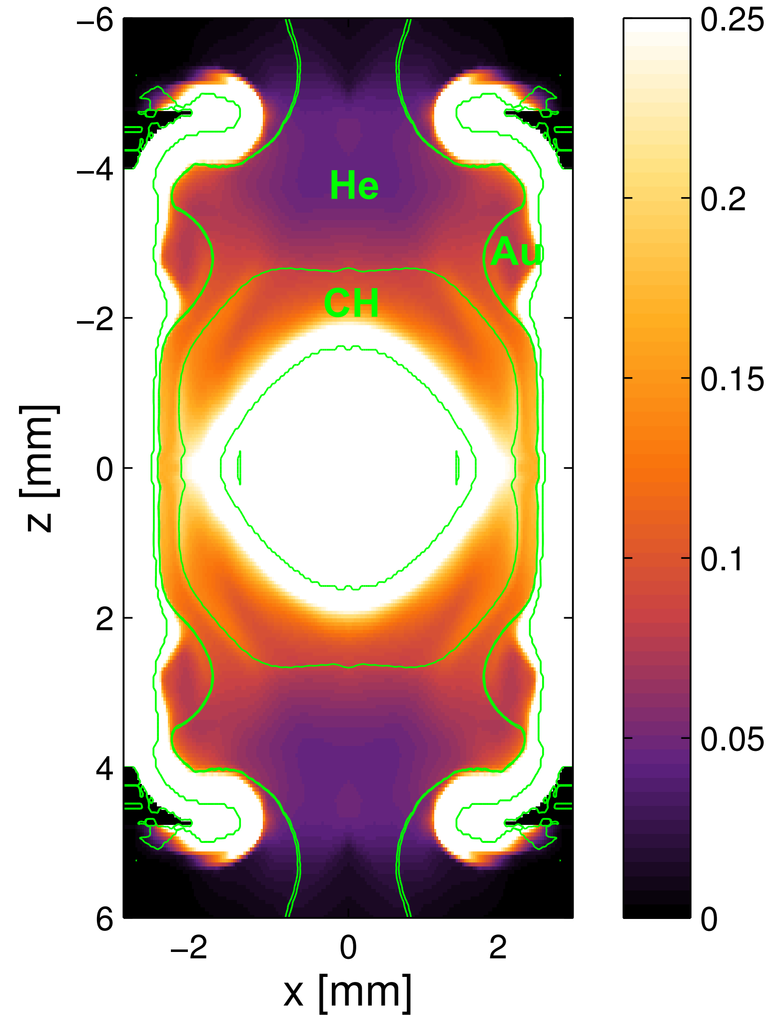


Plasma characterization of a NIF Hohlraum is important for benchmarking hydrodynamic simulations

Te [keV] & 0.15n_c contours



n_e/n_c [@3ω_0] & material contours

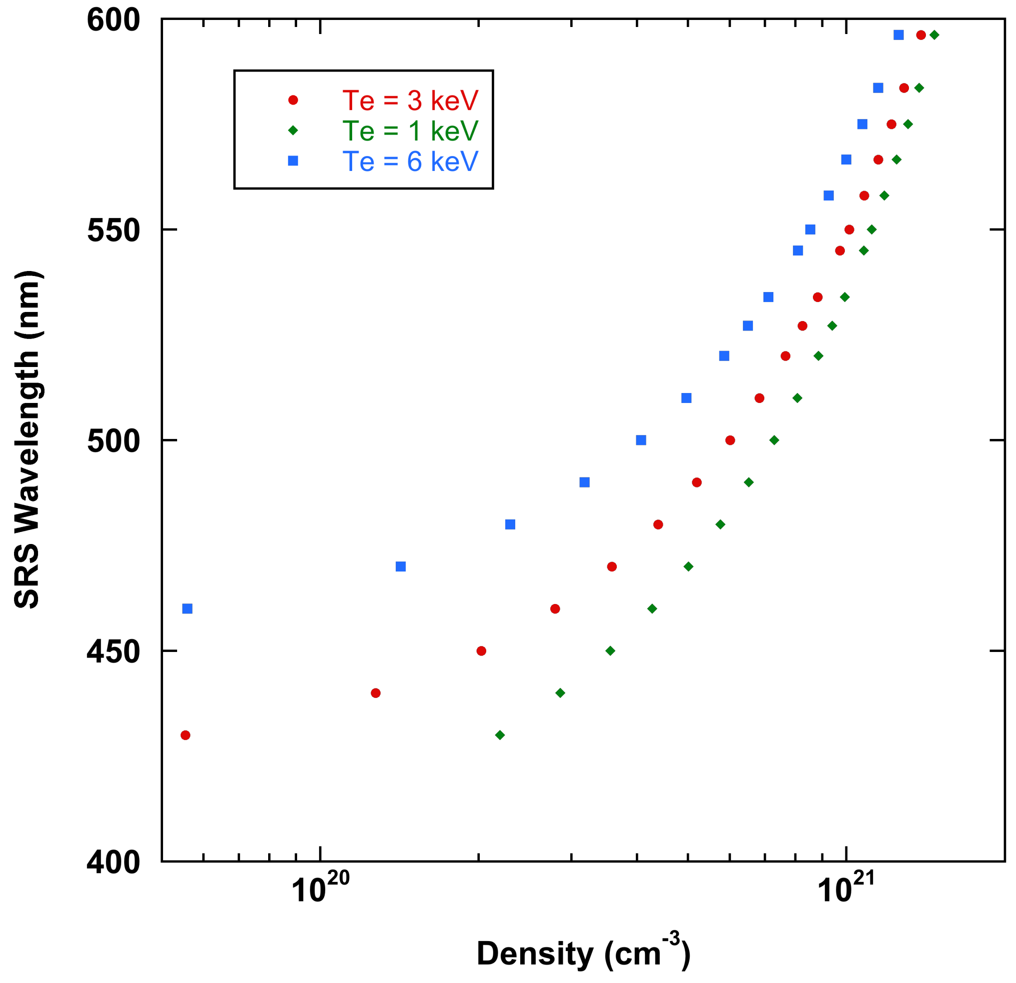


Shot N110807, LASNEX, R. Town

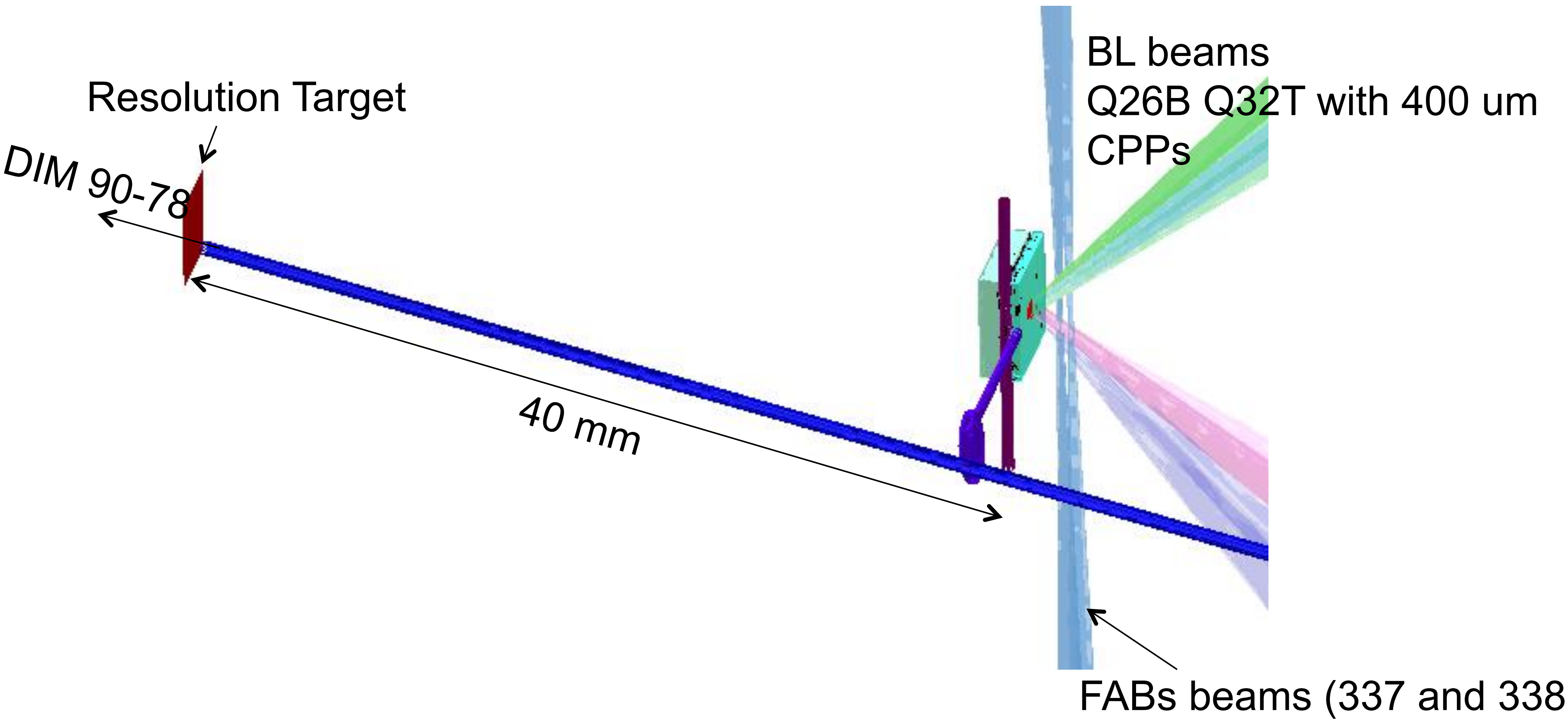
Backscattered stimulated Raman scattering can be used to measure local plasma density

Potential Issues:
- Large beam spots
- Long path lengths
- Steep density gradients

Solutions:
- Remove the phase plates
- Change the target
- Use a “probe” beam



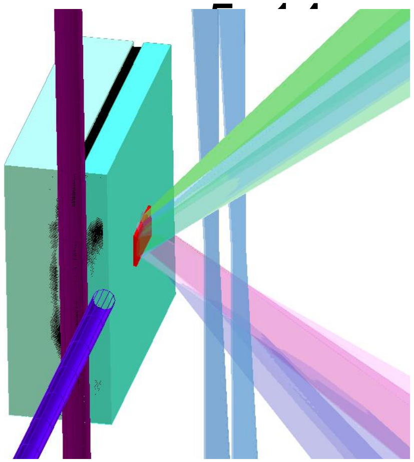
The scattering experiment is a "ride-along" on a backlighter experiment

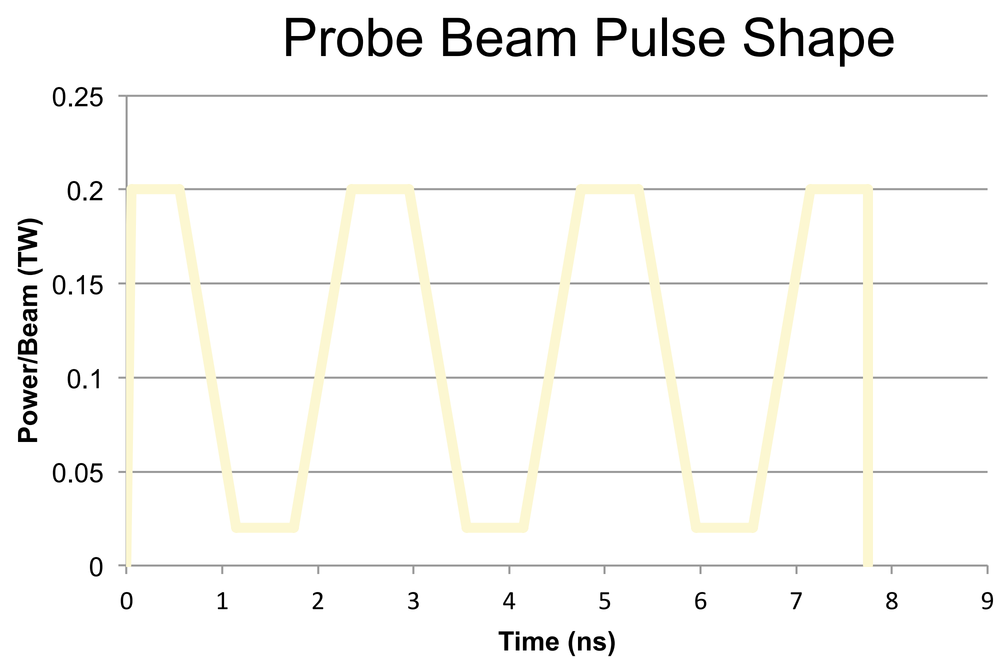


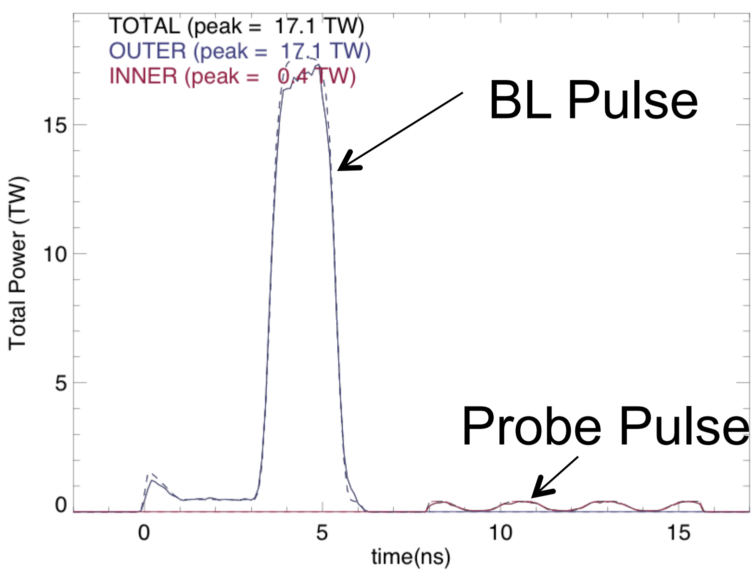
Two beams are pointed 1.0 and 1.5 mm from the face of the target and used as probe beams

The "probe" beams are designed to cause backscatter without significantly perturbing the plasma

The pulse shape was designed for a peak intensity of

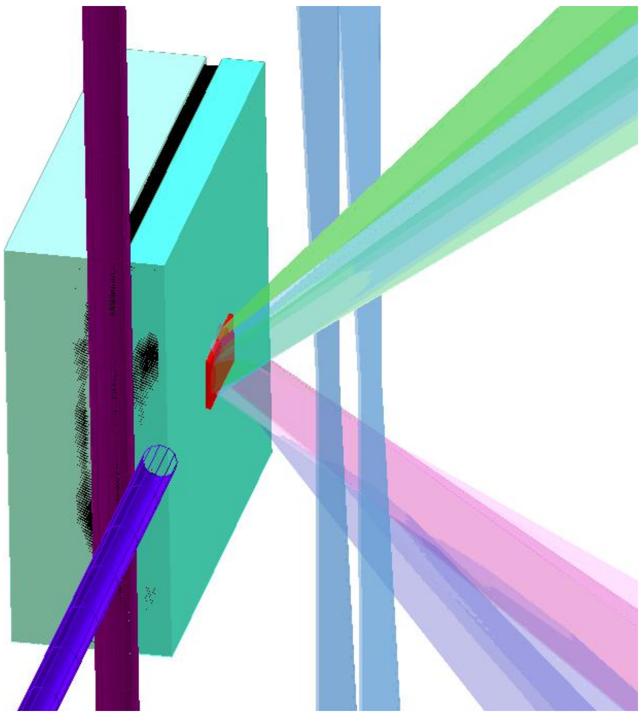


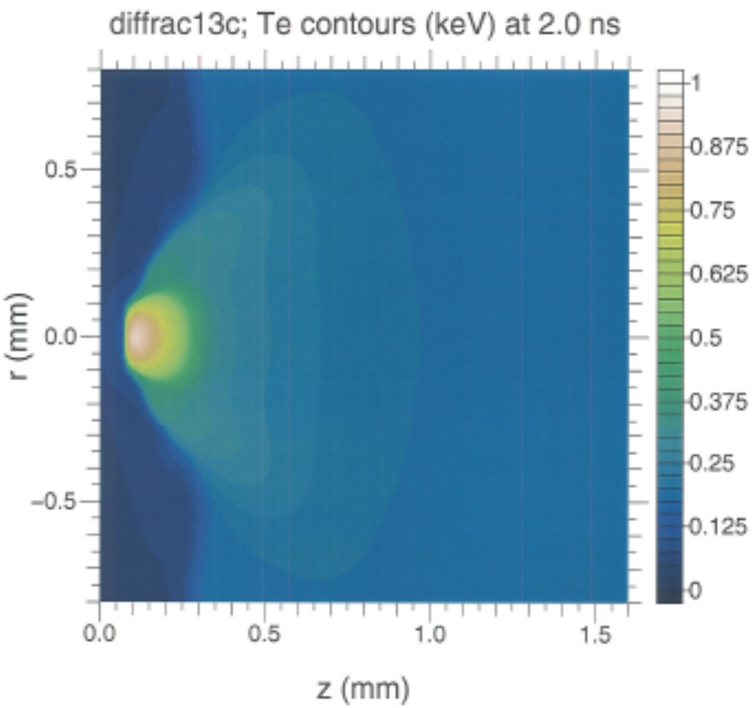




The Probe beam was delayed 2 ns relative to the end of the backlighter drive beams.

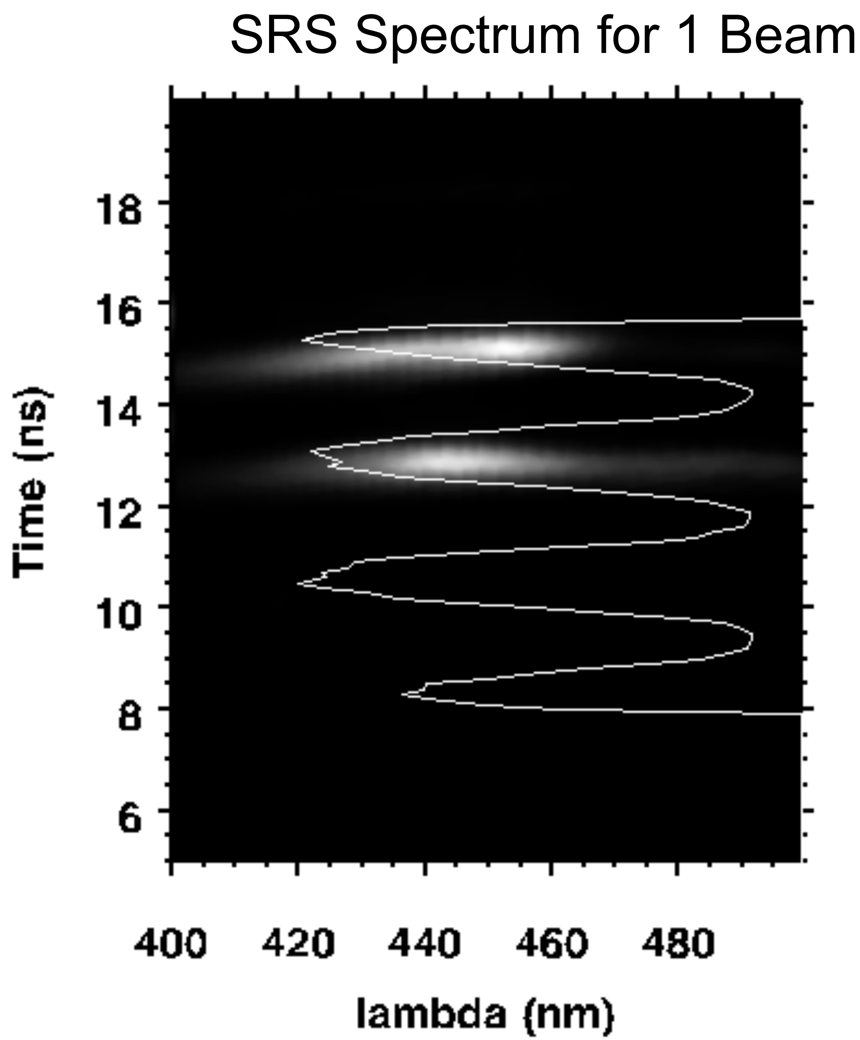
Beam pointing is used to probe different distances from the target surface



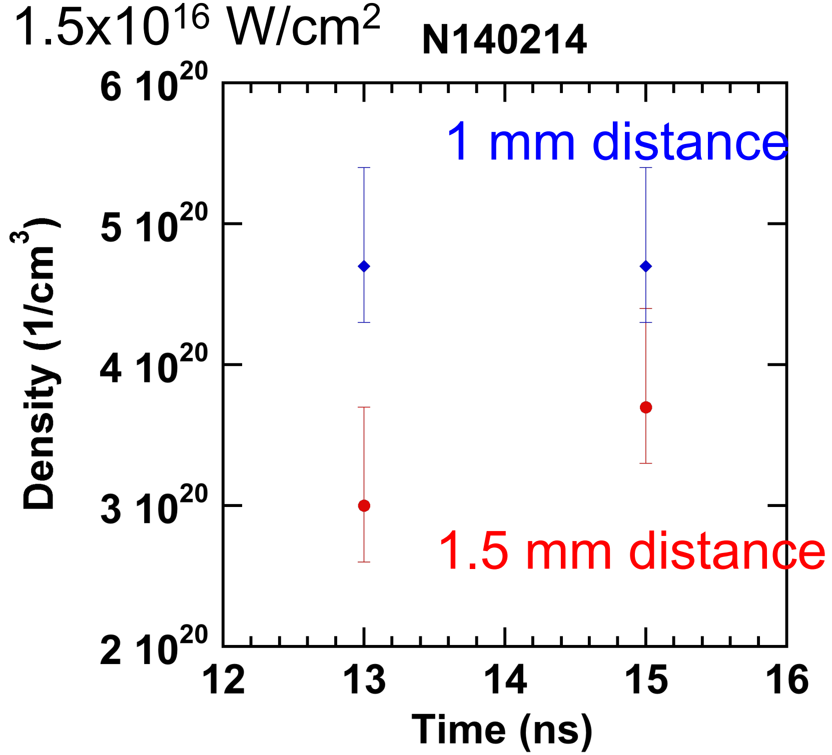


Two beams were pointed 1.0 and 1.5 mm from the face of the target and used as probe beams

The density is measured at 1.0 mm and 1.5 mm from the surface of a Niobium foil



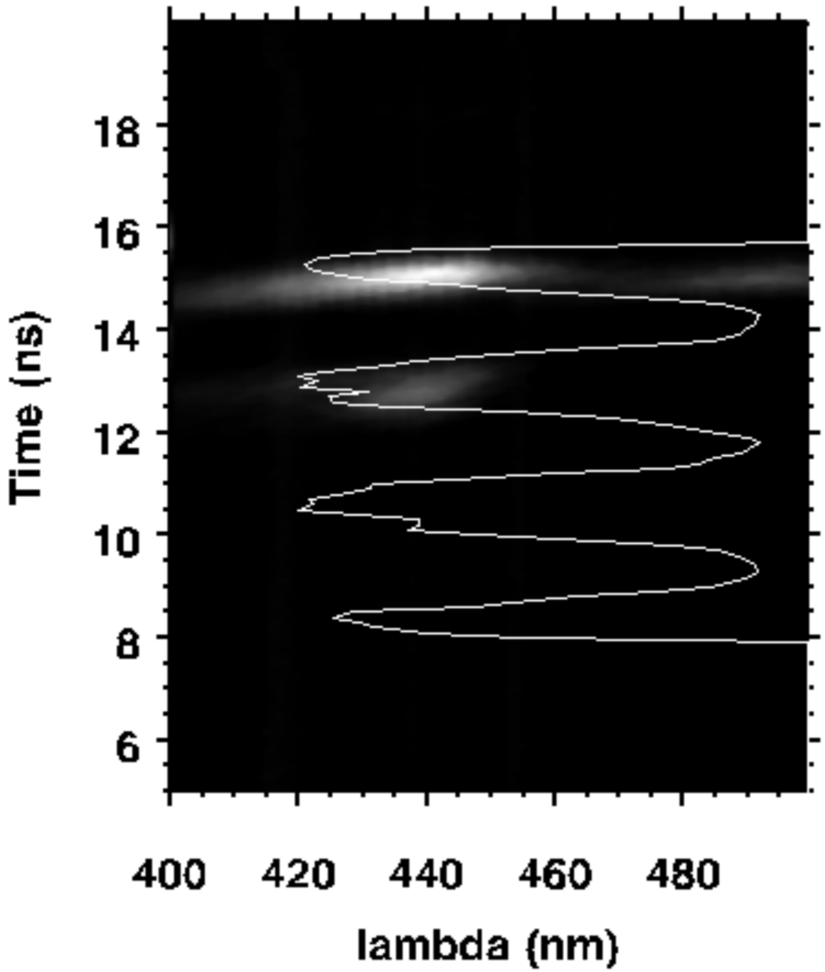
Backlighter beams did not have phase plates for a total intensity of 1.5×10^{16} W/cm^2



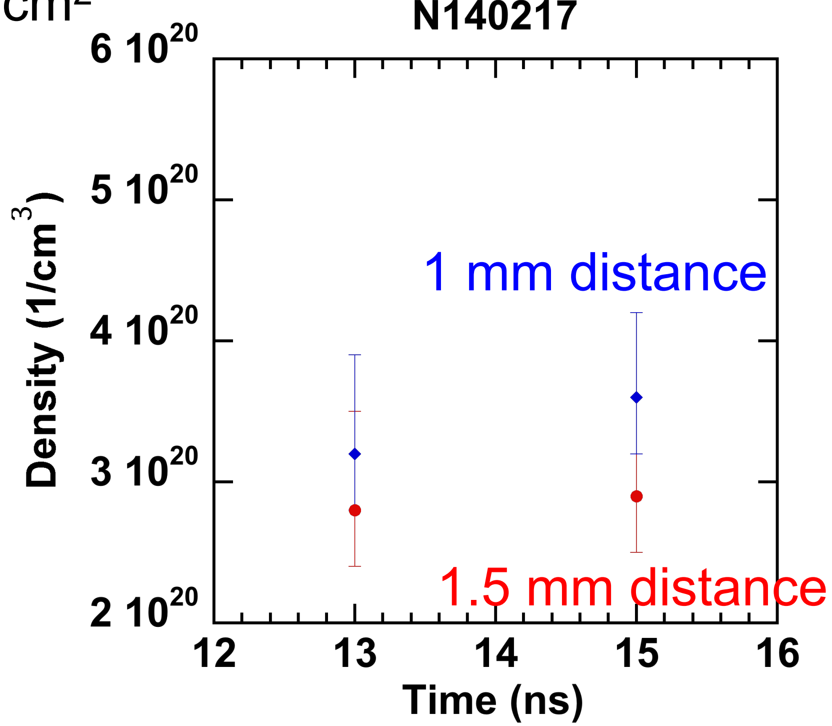
The densities are measured from peak emission assuming an electron temperature of 1 keV. Error bars are generated by assuming 100 eV and 1.5 keV.

A slightly lower density is measured from the Niobium foil when the drive beams have phase plates

SRS Spectrum for 1 Beam



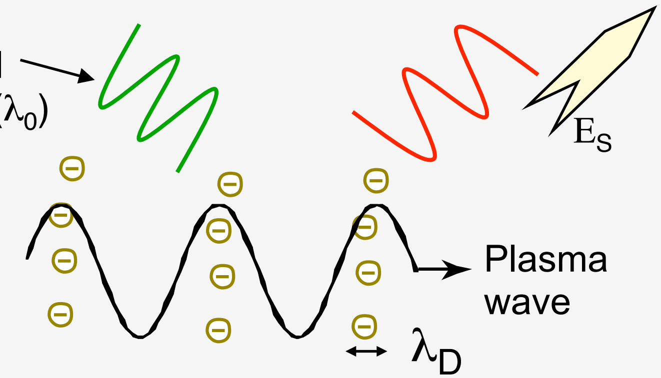
Backlighter beams used 400 μm phase plates with a total intensity of 9×10^{15} W/cm^2



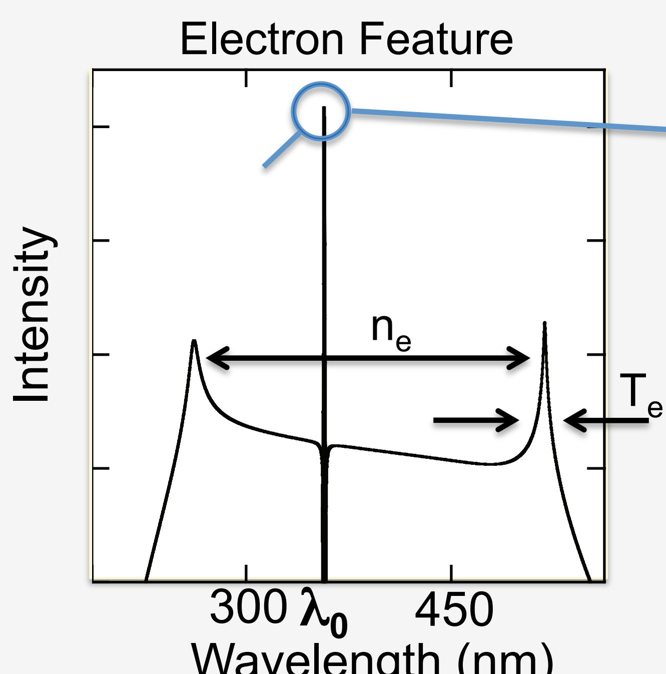
The densities are measured from peak emission assuming an electron temperature of 1 keV. Error bars are generated by assuming 100 eV and 1.5 keV.

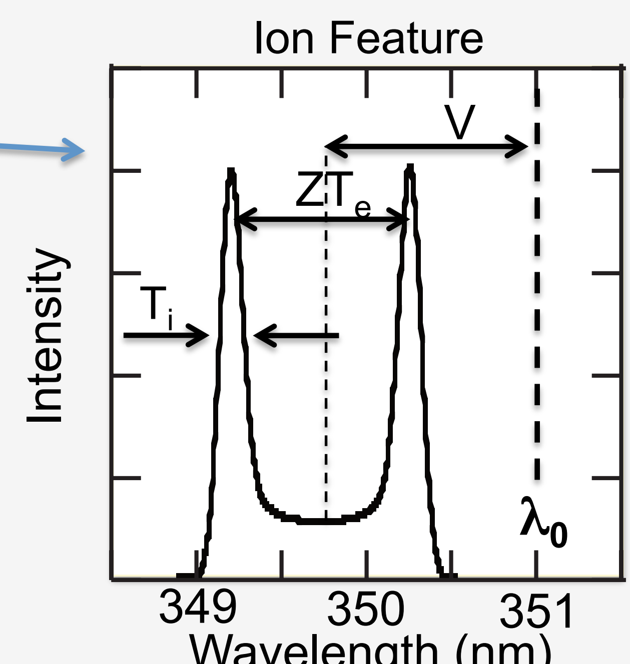
Thomson scattering provides a local measurement of the plasma conditions with high accuracy

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

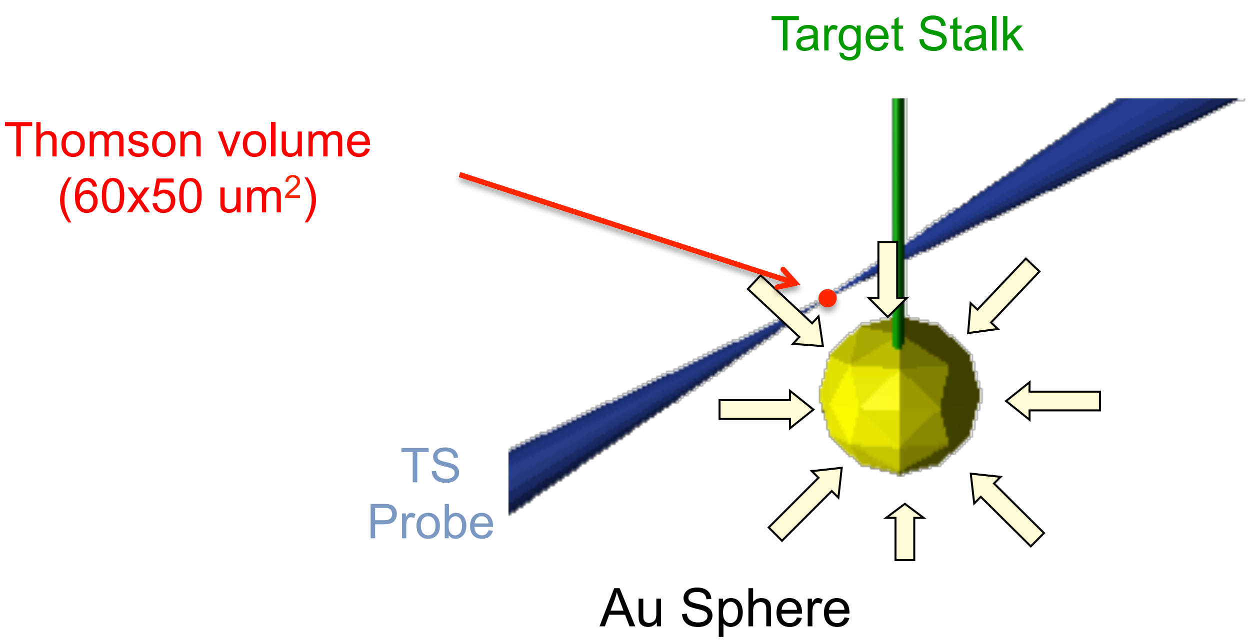


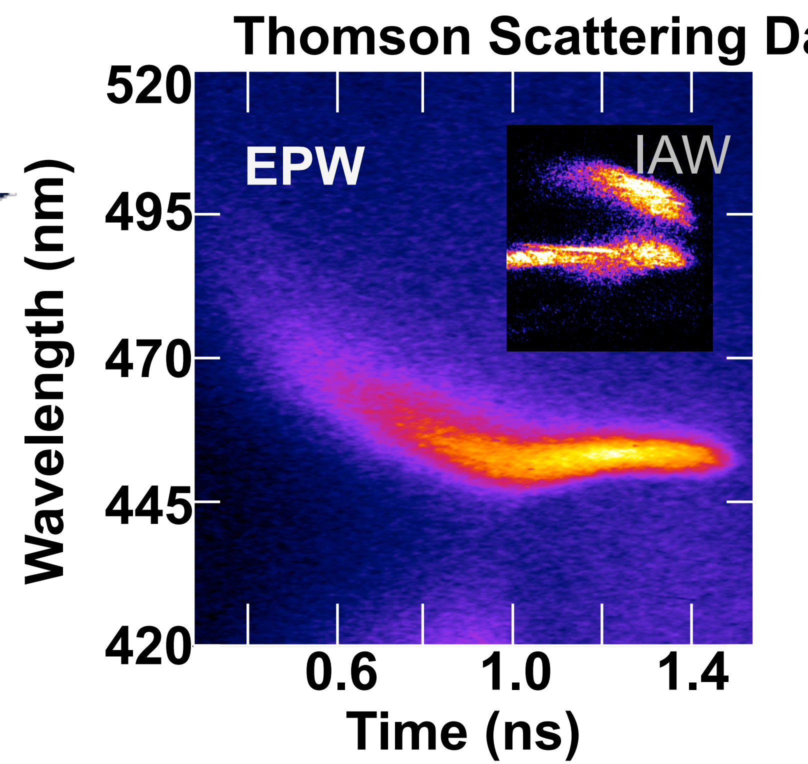
$$S(\mathrm{k},\omega)=\frac{2\pi}{k}\left|1-\frac{\chi_e}{\varepsilon}\right|^2 f_e\left(\frac{\omega}{k}\right)+\frac{2\pi Z}{k}\left|\frac{\chi_e}{\varepsilon}\right|^2 f_i\left(\frac{\omega}{k}\right)$$





Thomson scattering has been used to characterize NIF relevant plasma at Omega

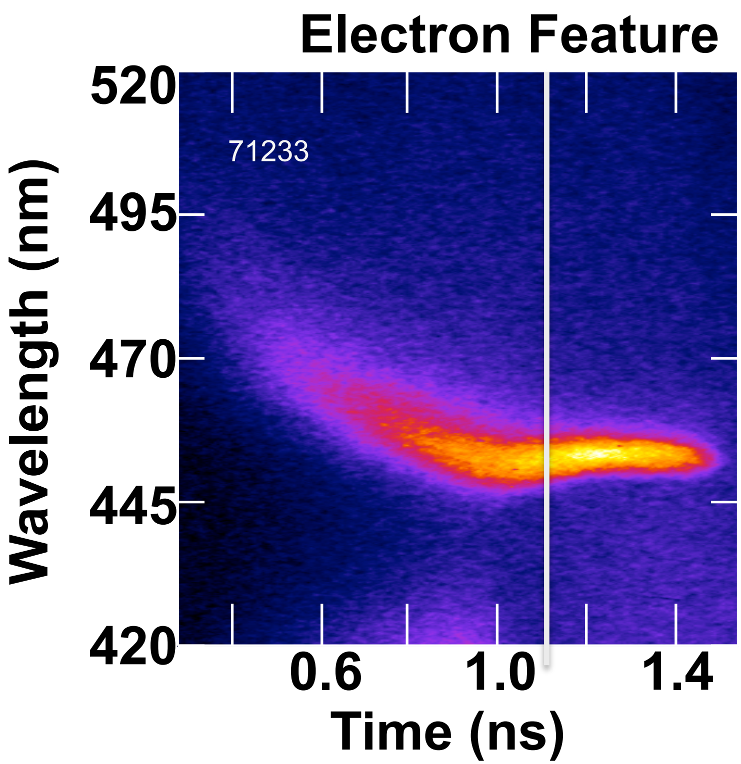


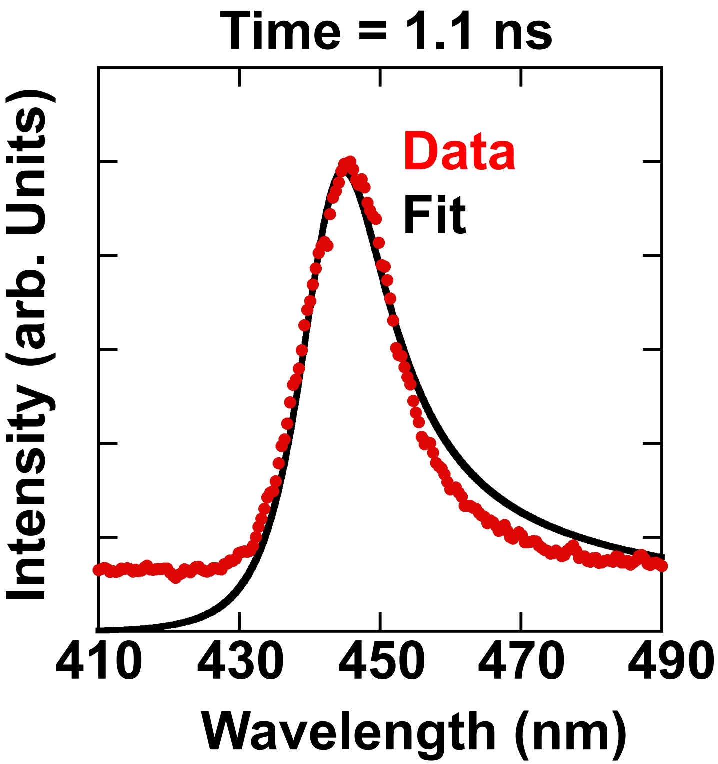


- The Au Sphere is a 1D surrogate for the NIF hohlraum wall
- 59 laser beams produce intensities ranging from 10^{14} to 10^{15} W/cm^2
- Drive beams heat from 0 to 1 ns
- Thomson scattering probe is delayed 0.4 ns relative to the drive

The electron density and temperature and determined by fitting the TS form factor to the measured data

The Thomson scattering form factor is fit to the experimental data

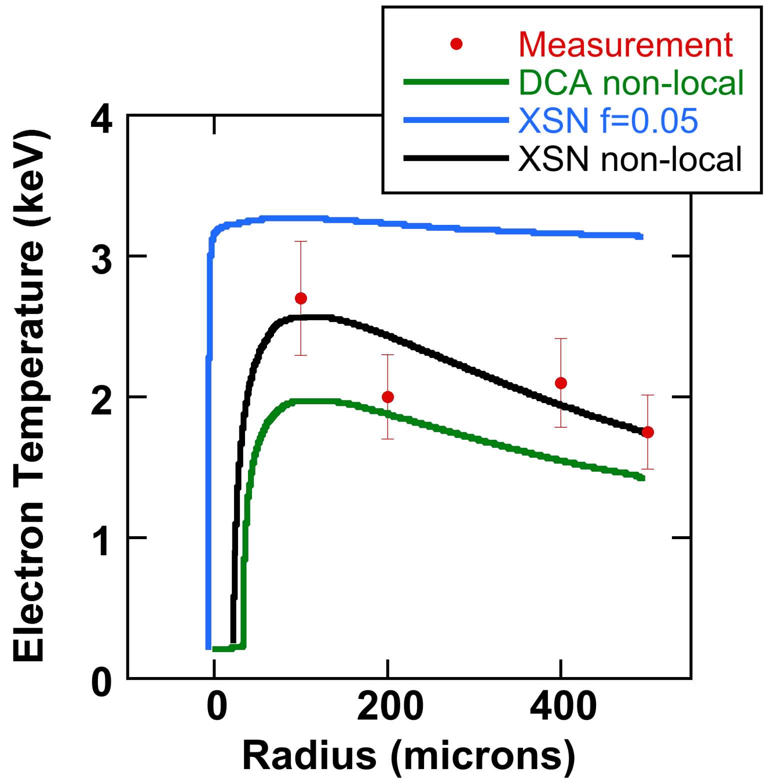


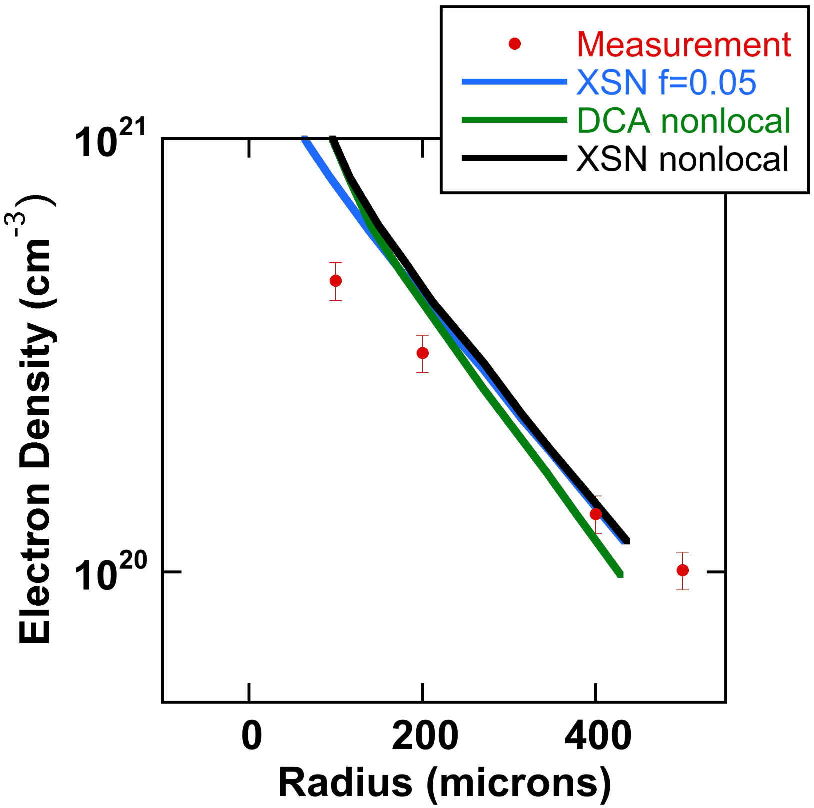


Fit Parameters:
Te = 1.2 keV
Ne = 7.1 x 10^{19}

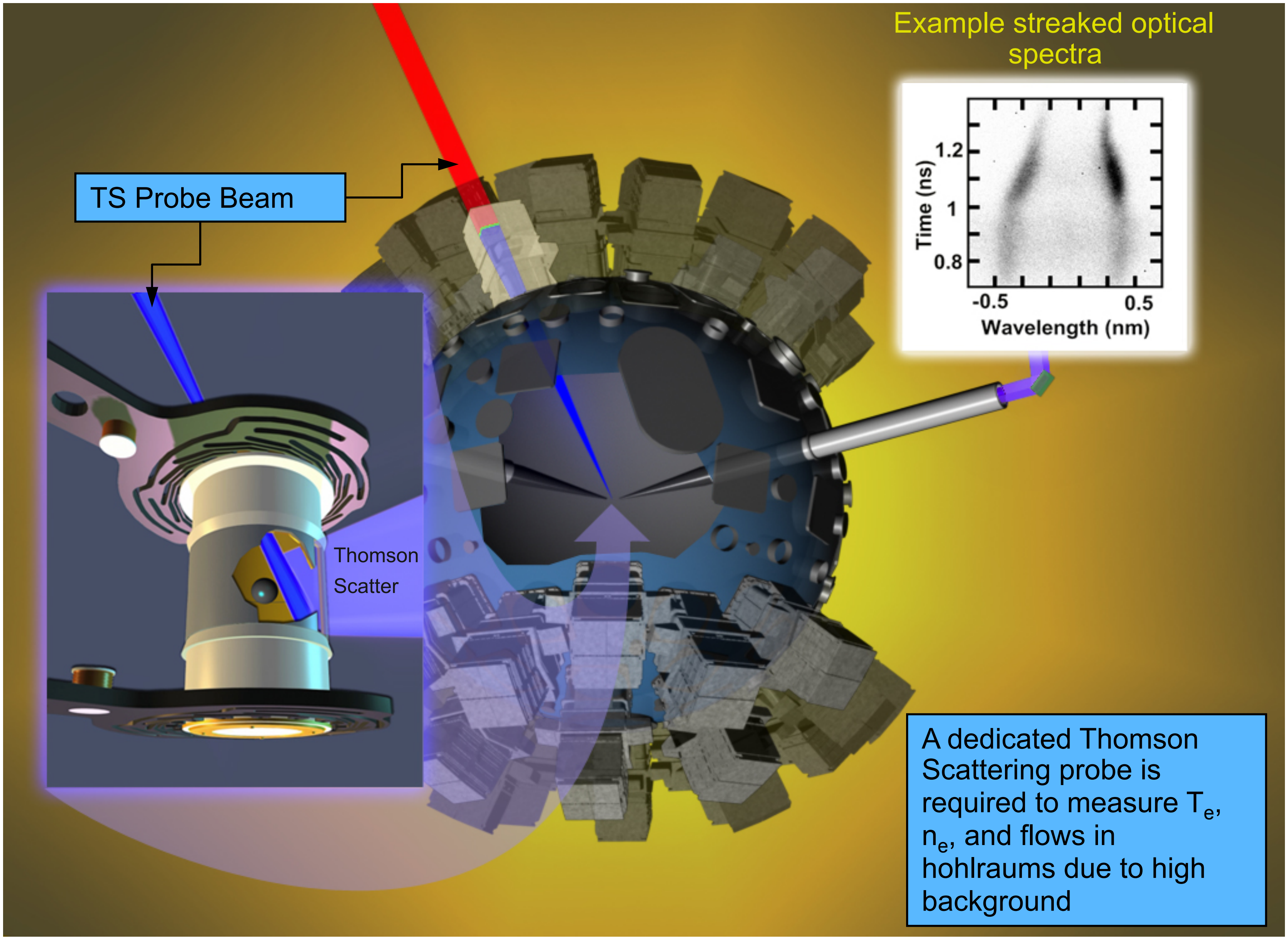
The Thomson scattering measurements are used to benchmark hydrodynamic simulations using different models

Data and simulations are shown for a Au target at a drive intensity of 5x10^14

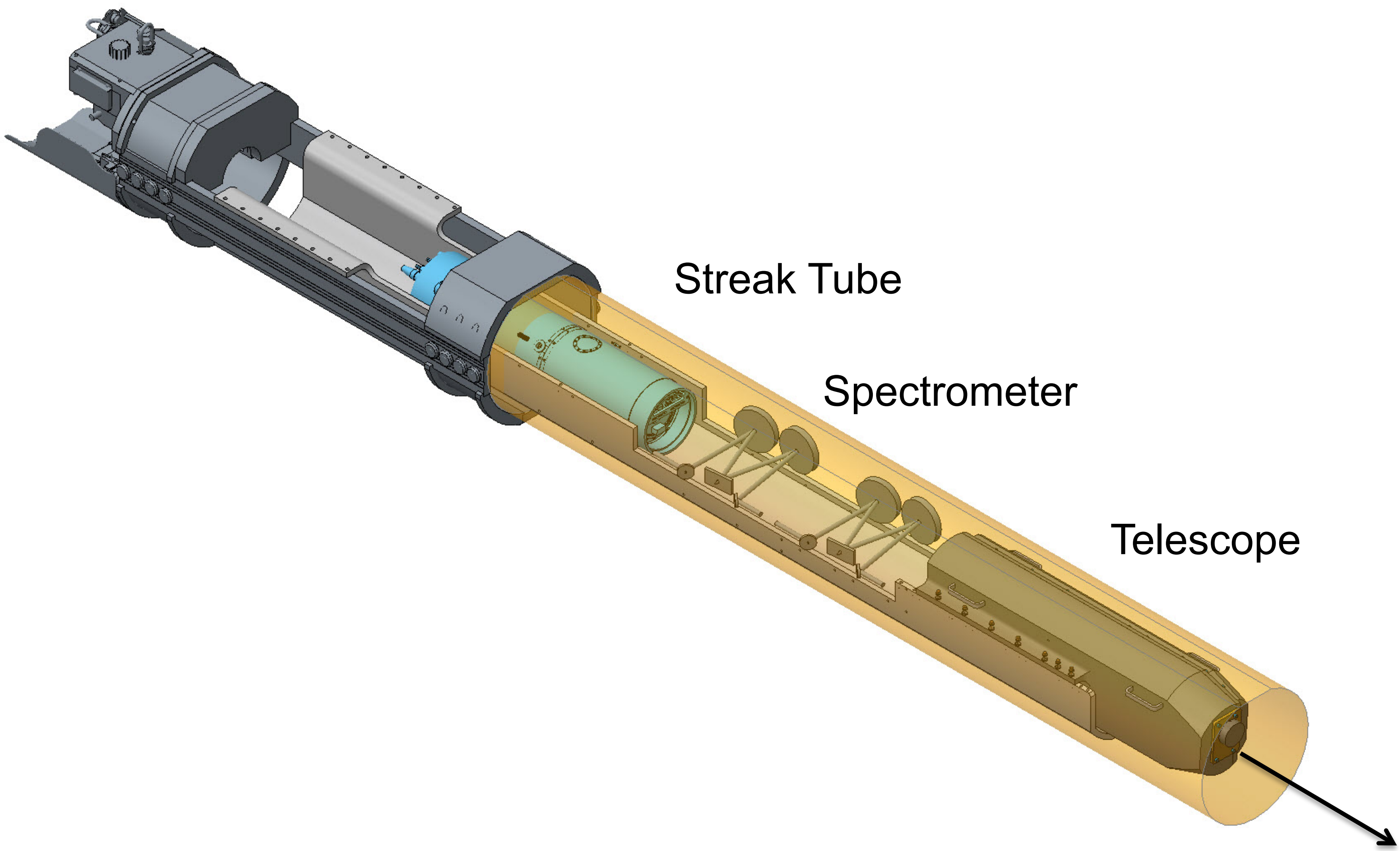




Thomson scattering could be implemented on the NIF using a DIM based collection system



A DIM based system would include the collection optics, a spectrometer, and a streak camera



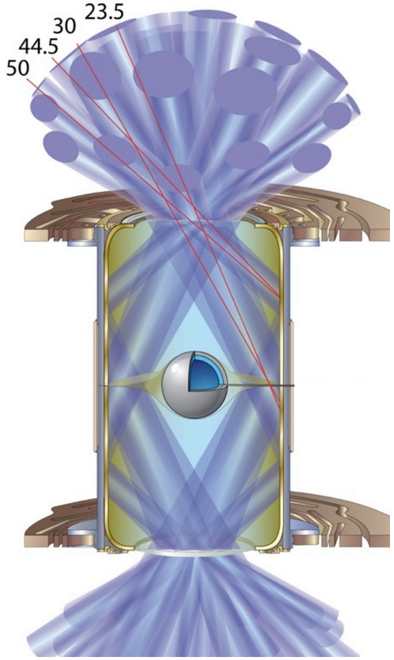
A 2 phase approached is proposed for implementing Thomson Scattering on the NIF

- Phase I
  - Design and field an optical collection system
    - Start with Ion Feature and/or Electron Feature
  - Alignment to ~100 microns (similar to VISAR style)
  - Utilize existing NIF beams for the probe
  - Assess background levels around potential probe wavelengths for different target types (5ω probe maybe at 213 nm)

- Phase II
  - Using the background measurements from Phase I determine the probe beam requirements
  - Design and field a dedicated Thomson scattering probe beam
  - Design an alignment system for the probe beam

Future plans

Hohlraum experiments	Experiment	Physics
	Increase gas-fill from near-vacuum	Gas-fill scaling: NLTE, LPI
	Develop Rugby implosions	No CBET and better symmetry control
	Quartraum*: CBET effects	How does CBET affect laser-spot spatial profile?
	Explore hots mitigations	Can we mitigate hot e- and control preheat?
	X-ray spectrum control	Control hohlraum x-ray spectra
	Thomson scattering	Plasma characterization
	Magnetized hohlraum	Improve coupling, increase T_e, confine hots, trap alphas



*D. Hinkel


NIF