Thomson scattering beamline installation on the Compact Toroidal Hybrid Experiment

P.J. Traverso
D.A. Maurer, D.A. Ennis, G.J. Hartwell
Auburn University, Auburn, AL

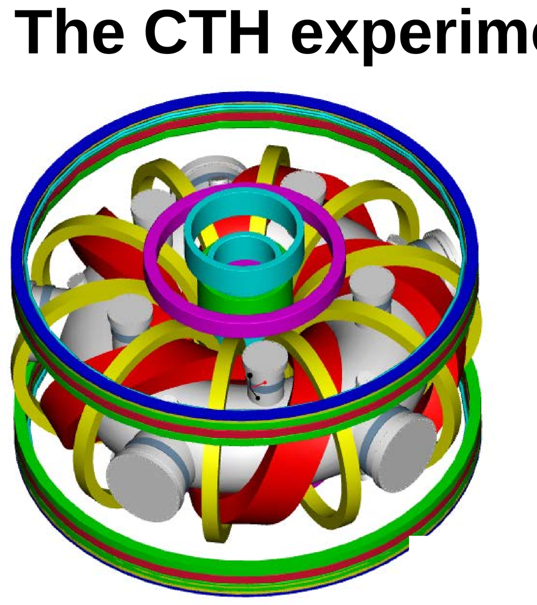
The CTH experiment

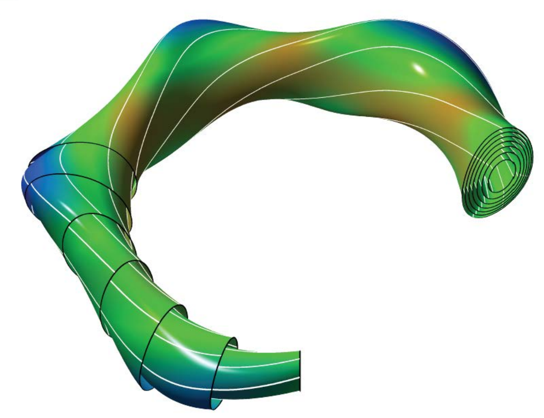
CTH* is a five field-period torsatron investigating the avoidance of disruptions over a wide range of plasma parameters.

Plasmas are created by launching an ECRH pulse to ionize Hydrogen gas, after which a plasma current is ohmically driven in this pre-established plasma providing further heating to reach higher temperatures and densities.

CTH has the unique feature of operating with different ratios of vacuum to plasma transform. This allows CTH to control the magnetic topology from tokamak-like to stellarator-like.

*Supported by US DOE Grant DE-FG-02-00ER54610





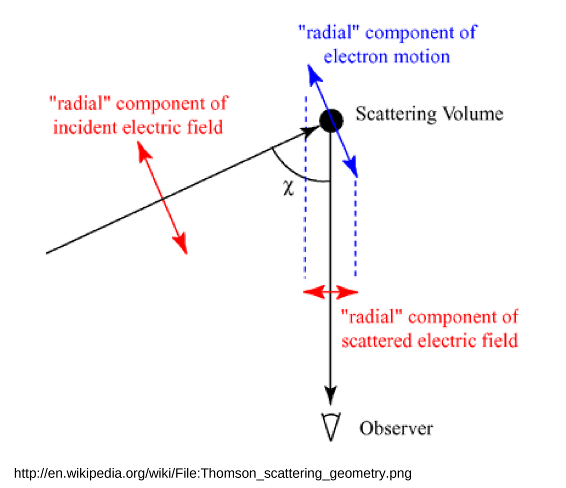
CTH parameters:

- Aspect ratio $A \approx 3 - 4$
- $R = 0.75\ m\,,\ < a > = 0.2\ m$
- $|B| \leq 0.7\ T$ on axis
- $0.02 \leq \iota_{vac} \leq 0.32$
- $I_{plasma} \leq 80\ kA$
- $n_e \leq\ 5 \times 10^{19}\ m^{-3}$
- $T_e \leq\ 200\ eV$
- $P_{input}\ \leq 30\ kW$ of ECRH
- $P_{input}\ \approx 200\ kW$ of Ohmic drive

Thomson Scattering as a Plasma Diagnostic

Advantages of Thomson Scattering

- Non-invasive
- Non-perturbing
- Internal and local measurement



$$I_{scattered} \propto \sqrt{\frac{m_e}{2\pi T_e}}\, n_e \exp\left(\frac{m_e \omega^2}{2k^2 T_e}\right)$$

$$\frac{P_{scattered}}{P_{input}} \approx r_e^{\,2}\, n_e\, L\, d\Omega$$

$$\frac{P_{scattered}}{P_{input}} \approx 2.94 \times 10^{-14}$$

$$P_{scattered} \approx \frac{2\,J}{7\times10^{-9}s}(2.94 \times 10^{-14})$$

$$P_{scattered}\ \approx 8\ \mu W$$

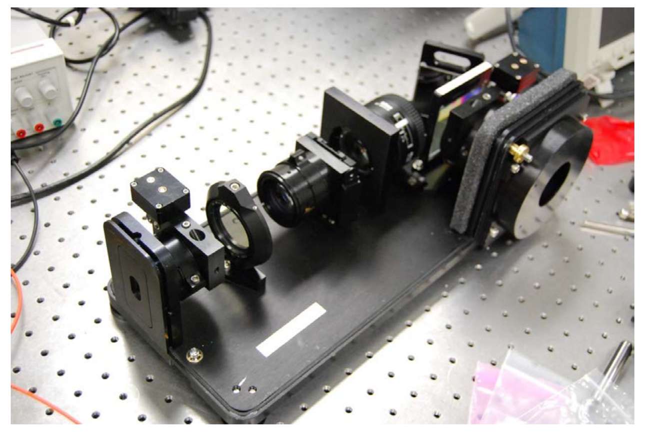
Addressing the Challenges of Thomson Scattering

- Low number of scattered photons
  - High Power laser
  - Large Viewing solid angle
- Necessary stray light mitigation
  - Geometrically confine stray light
  - Actively filter and spectrally isolate desired wavelengths
- Complex system components
  - High throughput spectrometer, CCD, and laser are all commercially available

System Components and Signal Estimates

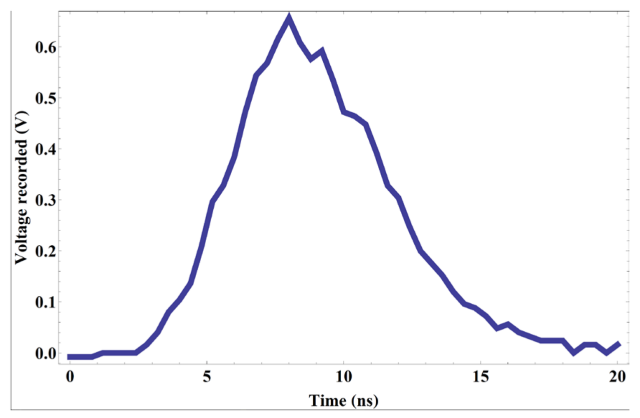
HoloSpec Imaging Spectrograph

- f/1.8 allows for large throughput of light
- Option of Interference filter that rejects laser line
- Volume-phase holographic transmission grating
- 532 nm laser light not focused onto imaging device



High Energy Nd:YAG Laser

- 4 J at 1064 nm and 2 J at 532 nm
- Pulse width of 6-10 ns (FWHM)
- Rep rate of 10 Hz
- $M^2 \approx 7$
- Gaussian beam with beam waste of 12 mm

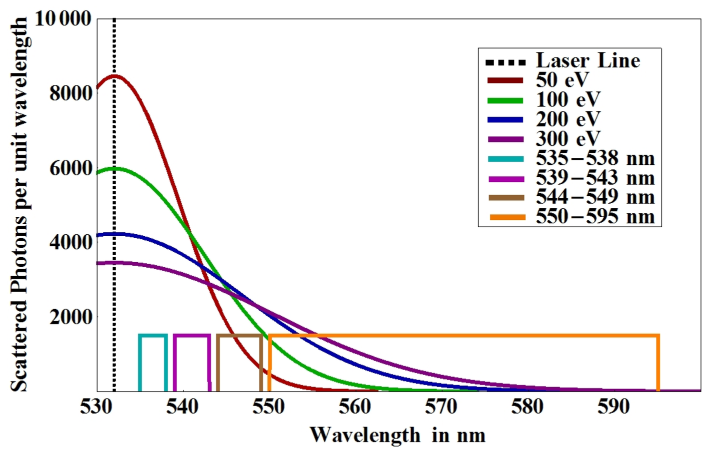


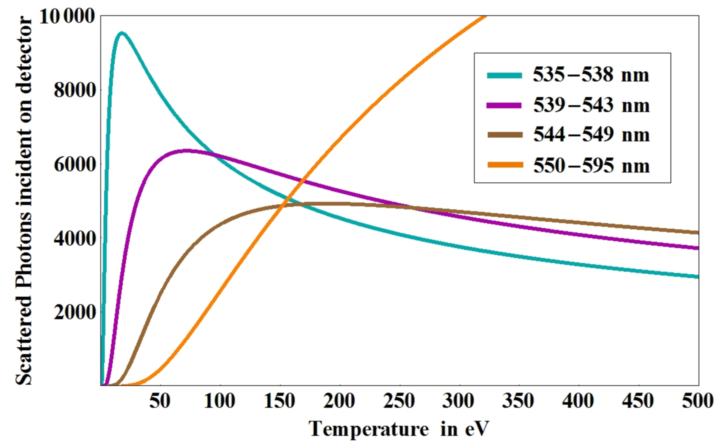
System is based upon one recently developed for the Pegasus tokamak [1] [2]

Andor iStar ICCD

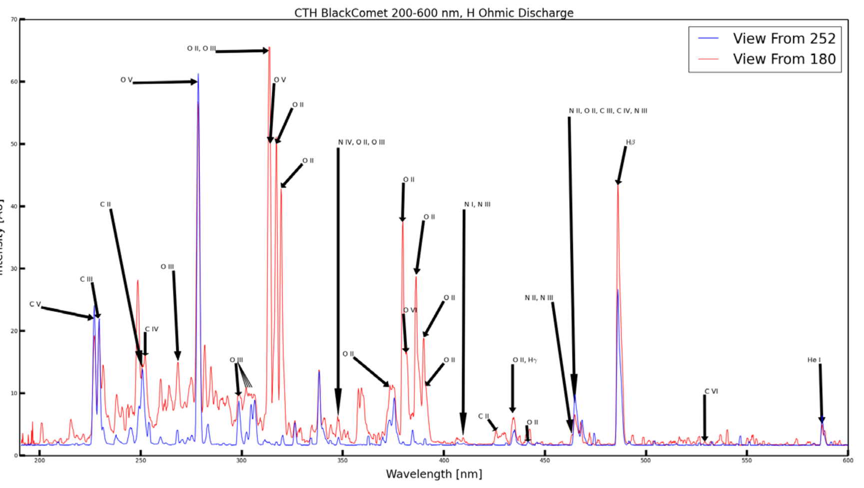
- DH740-18U-C3
- 1330 by 512 active pixel array
- Quantum Efficiency ~0.19

Simulated Thomson signals



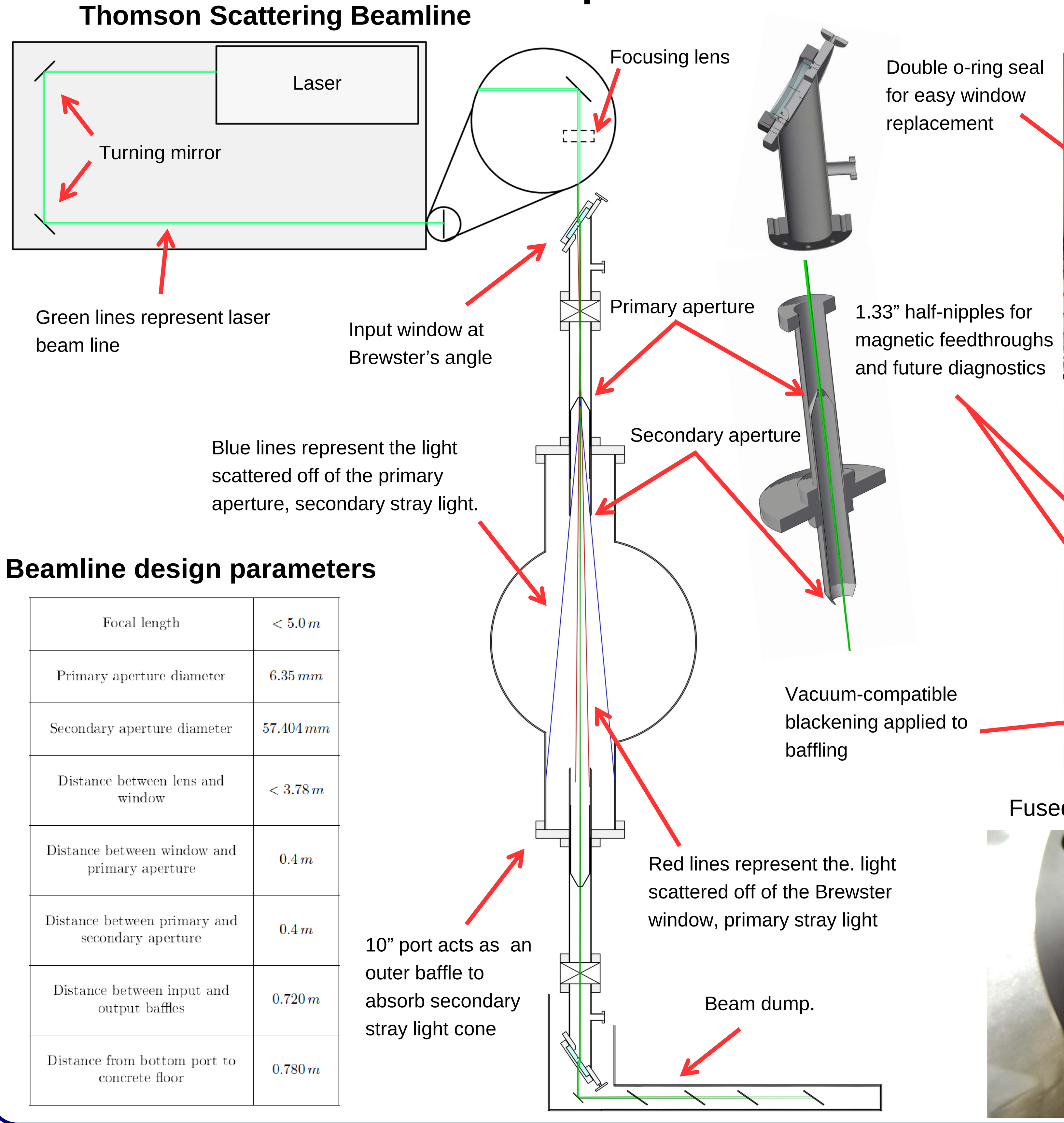


CTH Visible Spectra



Proposed Beamline Geometry

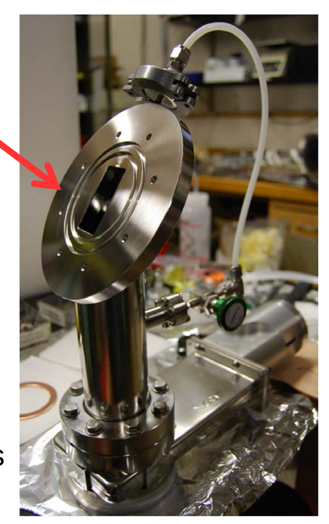
Thomson Scattering Beamline

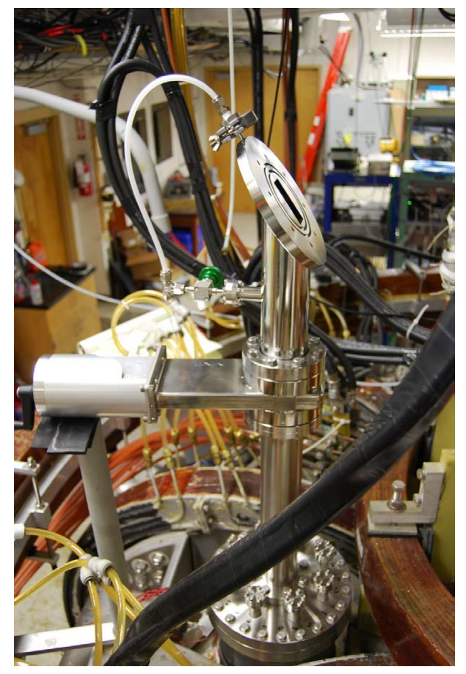


Beamline design parameters

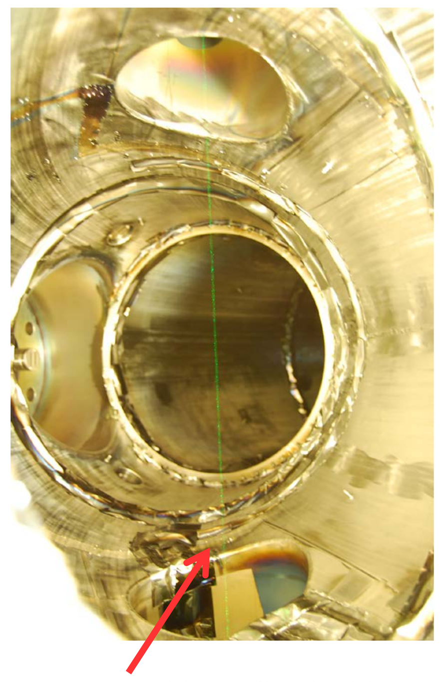
Focal length	$< 5.0\,m$
Primary aperture diameter	$6.35\,mm$
Secondary aperture diameter	$57.404\,mm$
Distance between lens and window	$< 3.78\,m$
Distance between window and primary aperture	$0.4\,m$
Distance between primary and secondary aperture	$0.4\,m$
Distance between input and output baffles	$0.720\,m$
Distance from bottom port to concrete floor	$0.780\,m$

Installation of Beamline





View from 18" collection port

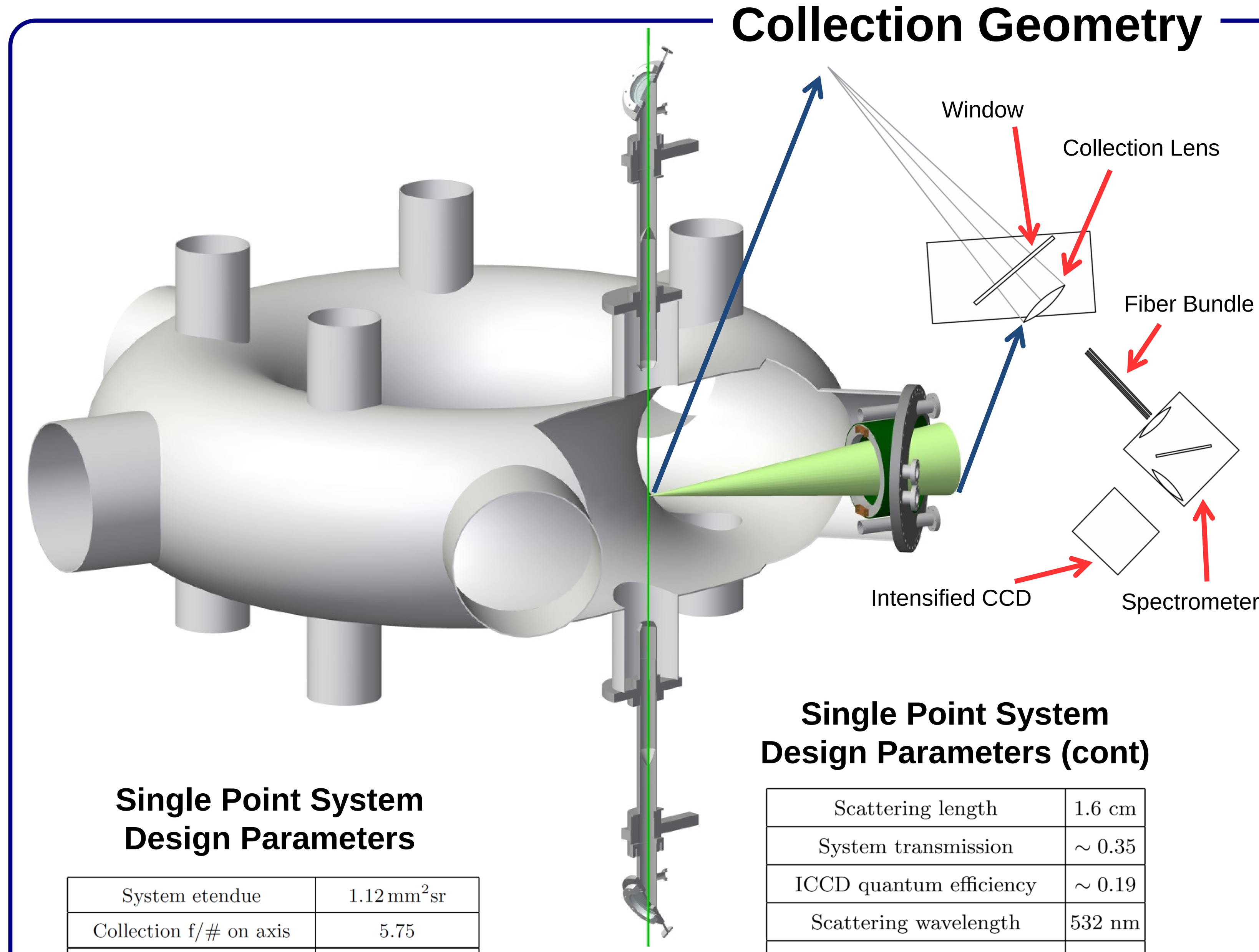


Focused beamline inside vacuum vessel

Fused silica window

Beam damage from 5 m focal length lens

Collection Geometry



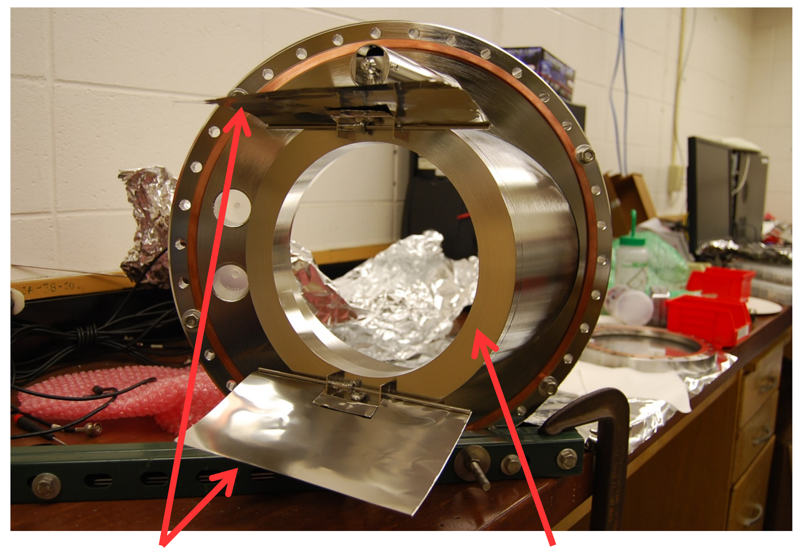
Single Point System Design Parameters

System etendue	$1.12\,\mathrm{mm}^2\mathrm{sr}$
Collection f/# on axis	5.75
Collection lens f/#	~ 1
Collection lens focal length	13.3 mm
Detector Size	18 mm by 6.9 mm

Single Point System Design Parameters (cont)

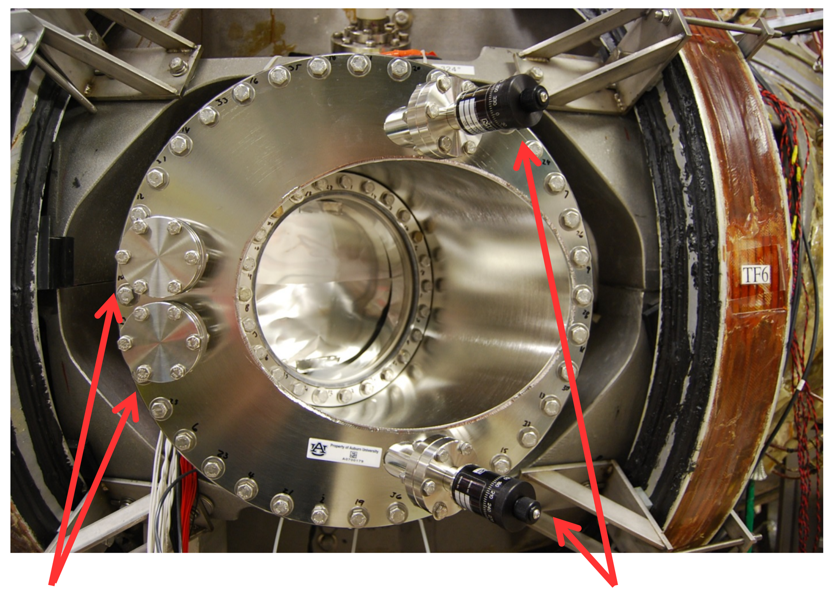
Scattering length	1.6 cm
System transmission	~ 0.35
ICCD quantum efficiency	~ 0.19
Scattering wavelength	532 nm
Laser energy	~ 2 J
$\frac{\text{Total photo−electrons}}{10^{19}\ \text{plasma e−}}$	$\sim 10^4$
$\frac{\text{Total electrons collected per channel}}{10^{19}\ \text{plasma e−}}$	$\sim 10^3$
S/N ratio per channel	~ 32

Installation of Collection Port



Shuttering

19.7 cm of clear aperture



Extra 2.75" half-nipples

Manual shutter control

Future Work

- Determine longest focal length lens for consistent beam width in plasma without damaging Brewster windows
- Decide upon single-point versus multi-point collection optics and fiber bundles
- Implement full design and calibrate the system including data comparisons to soft x-ray and interferometer measurements

References

[1]Schlossberg et al., Rev. Sci. Instrum 83, 10E335 (2012).

[2]Schoenbeck et al., Rev. Sci. Instrum 83, 10E330 (2012).

[3] Sheffield, John. "Noncollective Scattering." *Plasma Scattering of Electromagnetic Radiation: Theory and Measurement Techniques*. Amsterdam: Elsevier, 2011. 69-90. Print.