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 resulting in a higher temperature and density.

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.

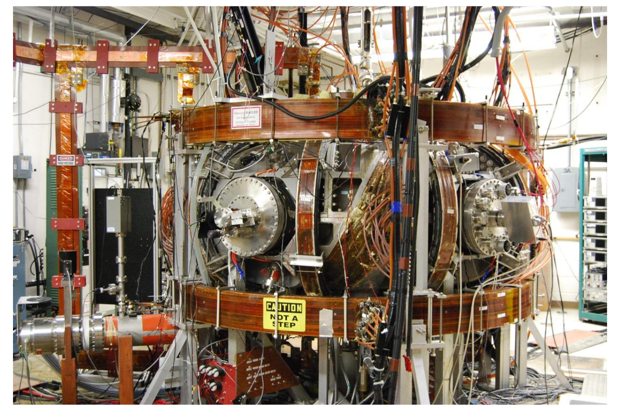
*Supported by US DOE Grant DE-FG-02-00ER54610

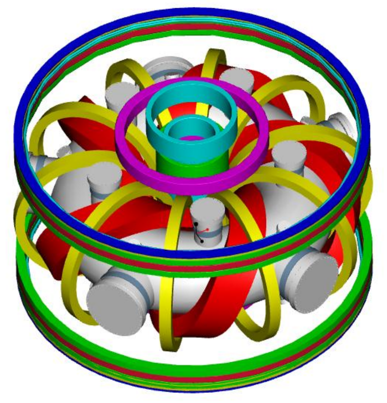
CTH parameters:

- 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
- Vacuum pressure $\approx 1\times 10^{-8}\ Torr$

Motivation for Thomson Scattering:

- Measurement of density and temperature profiles
- Improved Equilibrium Reconstructions with V3FIT especially for pressure profiles
- Better characterize CTH plasmas to understand disruptions and MHD activity





Thomson Scattering as a Plasma Diagnostic

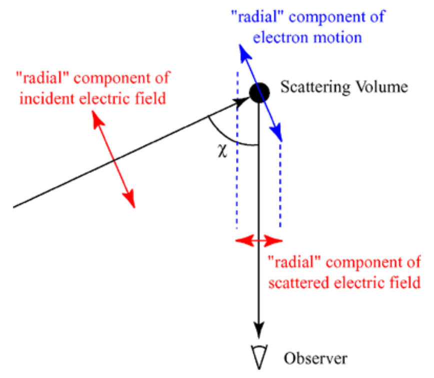
Thomson Scattering Basics

- Elastic scattering of electromagnetic radiation from free charged particles
- Electrons accelerate in electric field of the radiation causing the electrons to reradiate.
- Scattered Intensity is proportional to the electron density and temperature

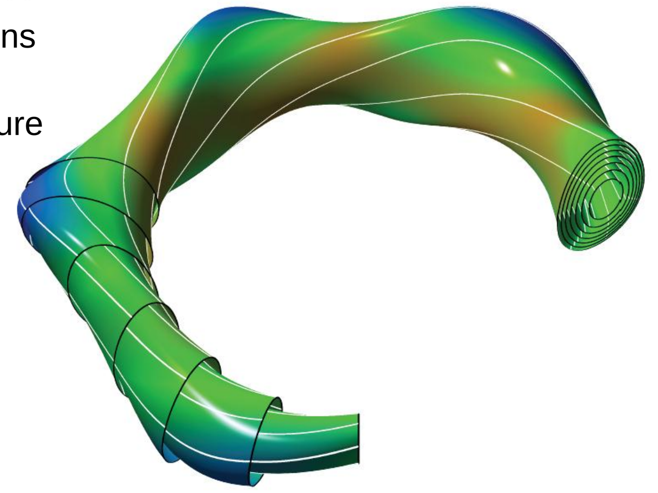
$$I_{scattered} \propto \sqrt{\frac{m_e}{2\pi T_e}}\, n_e \exp\left(\frac{m_e\omega^2}{2k^2T_e}\right)$$

Advantages of Thomson Scattering

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



http://en.wikipedia.org/wiki/File:Thomson_scattering_geometry.png



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

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

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

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

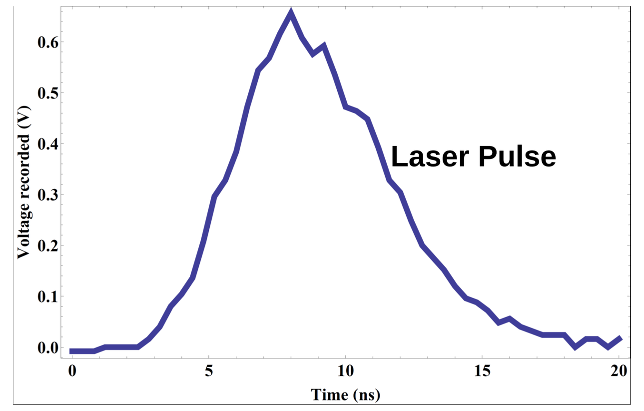
Addressing the Challenges of Thomson Scattering

- 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

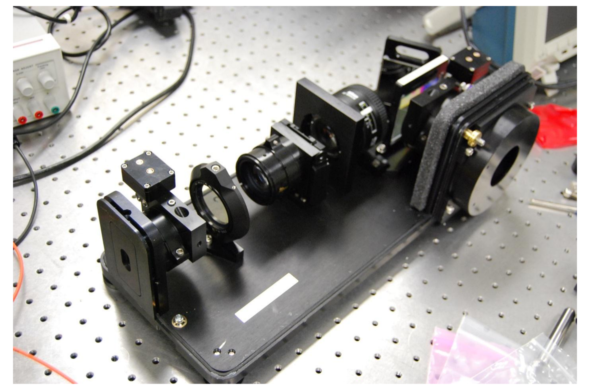
High Energy Nd:YAG Laser

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



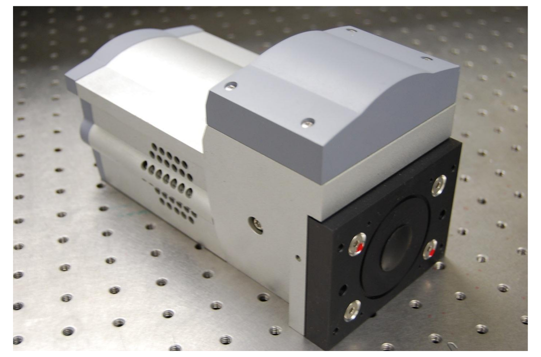
HoloSpec Imaging Spectrograph

- 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

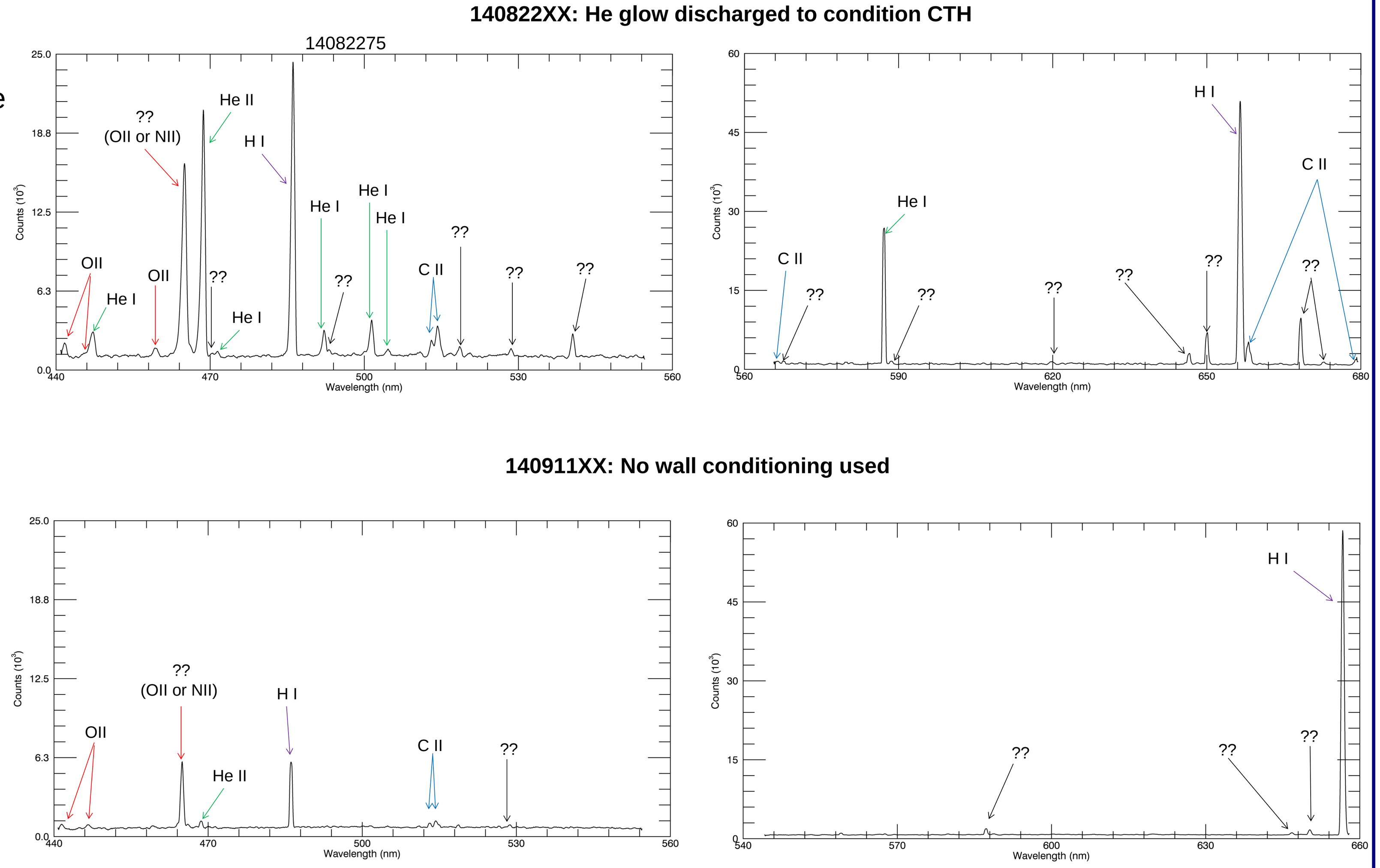


Andor iStar ICCD

- DH740-18U-C3
- 2048 by 512 pixel array
- Quantum Efficiency ~0.19



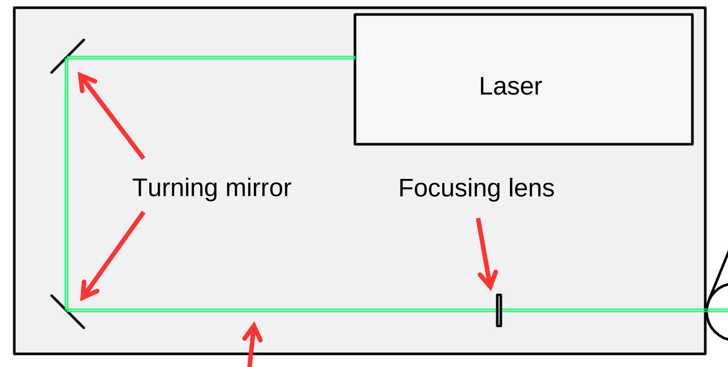
CTH Visible Spectra $(\sim 430\ \mathrm{nm\ to\ }680\ \mathrm{nm})$

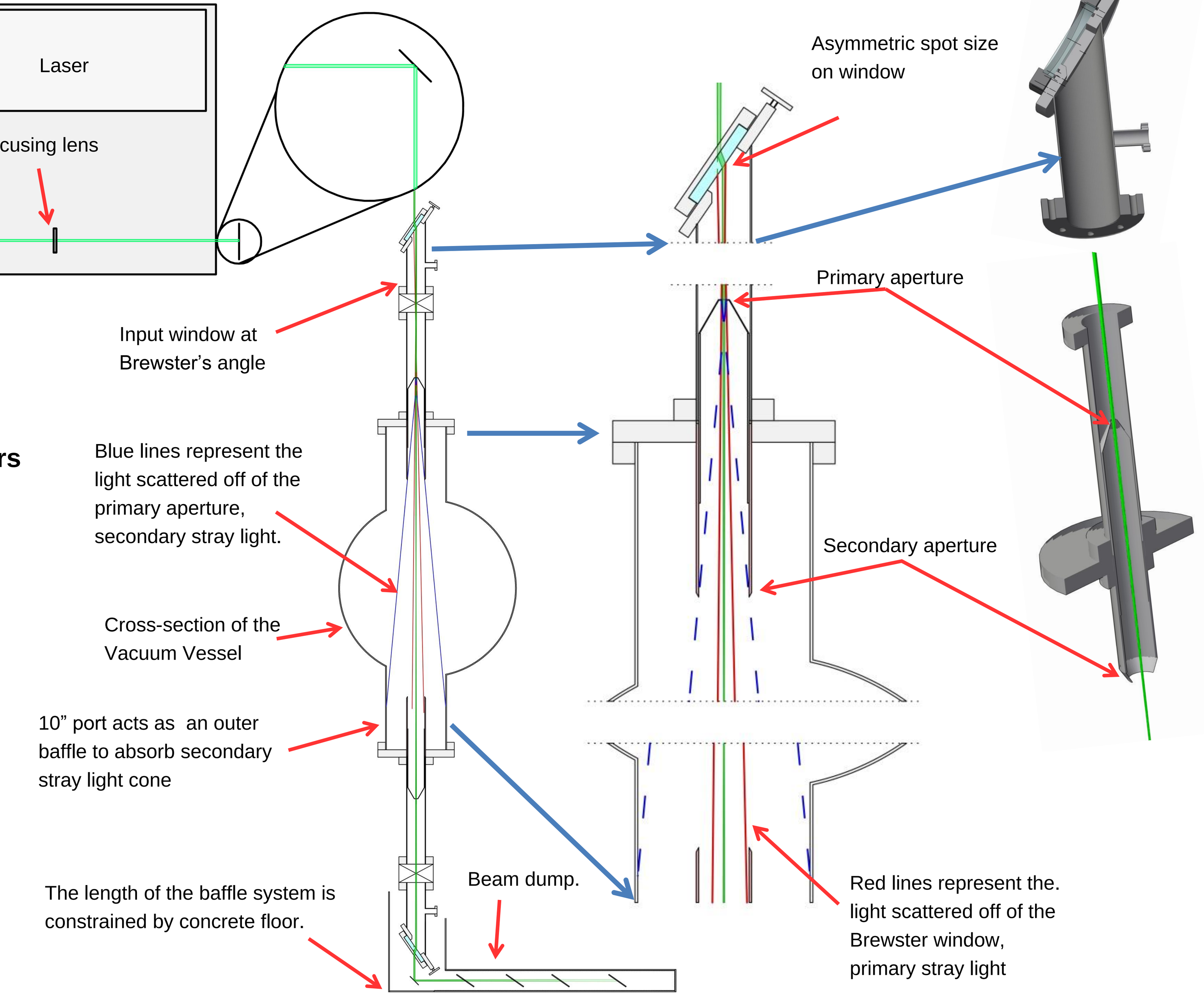


System is based upon one recently developed for the Pegasus tokamak [1] [2]

Proposed Beamline Geometry

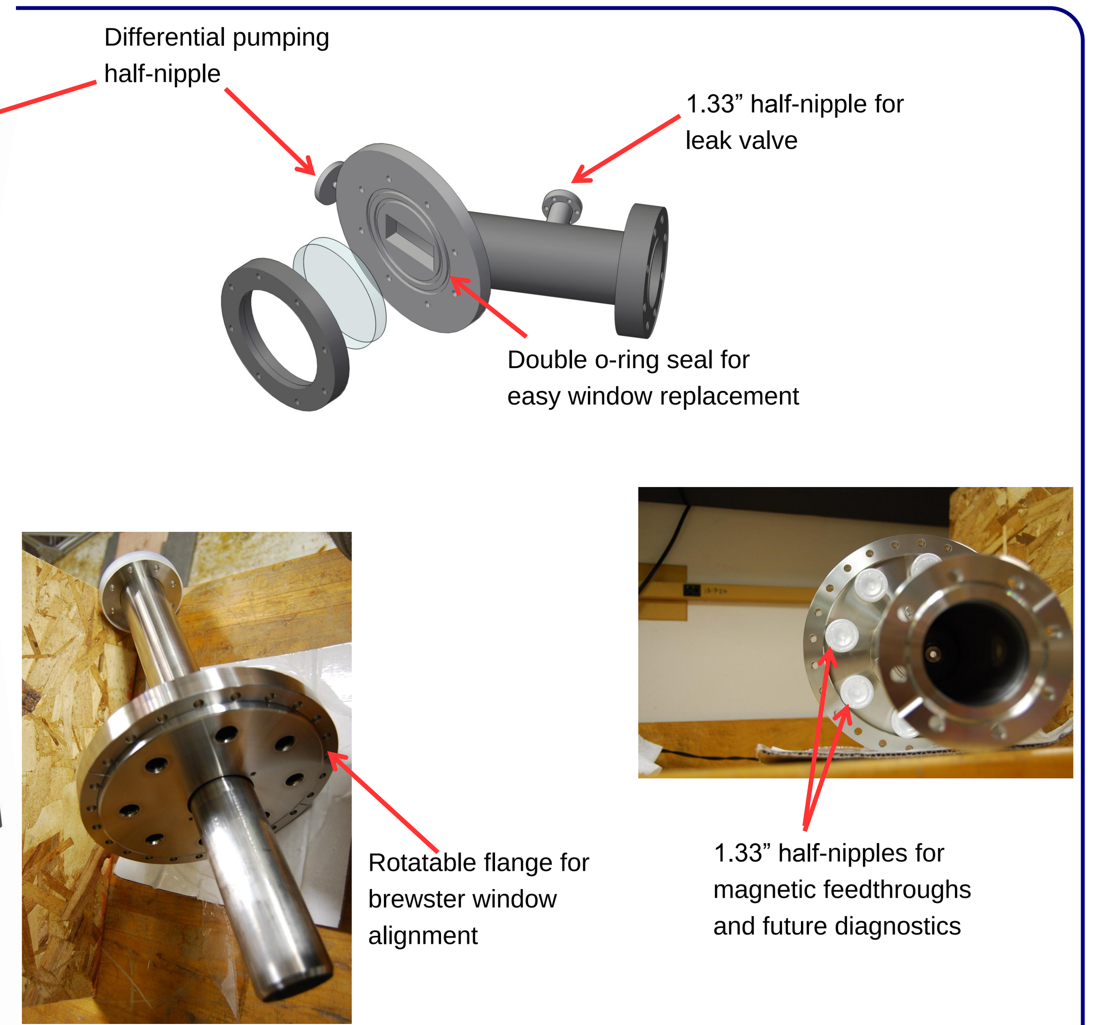
Thomson Scattering Beamline





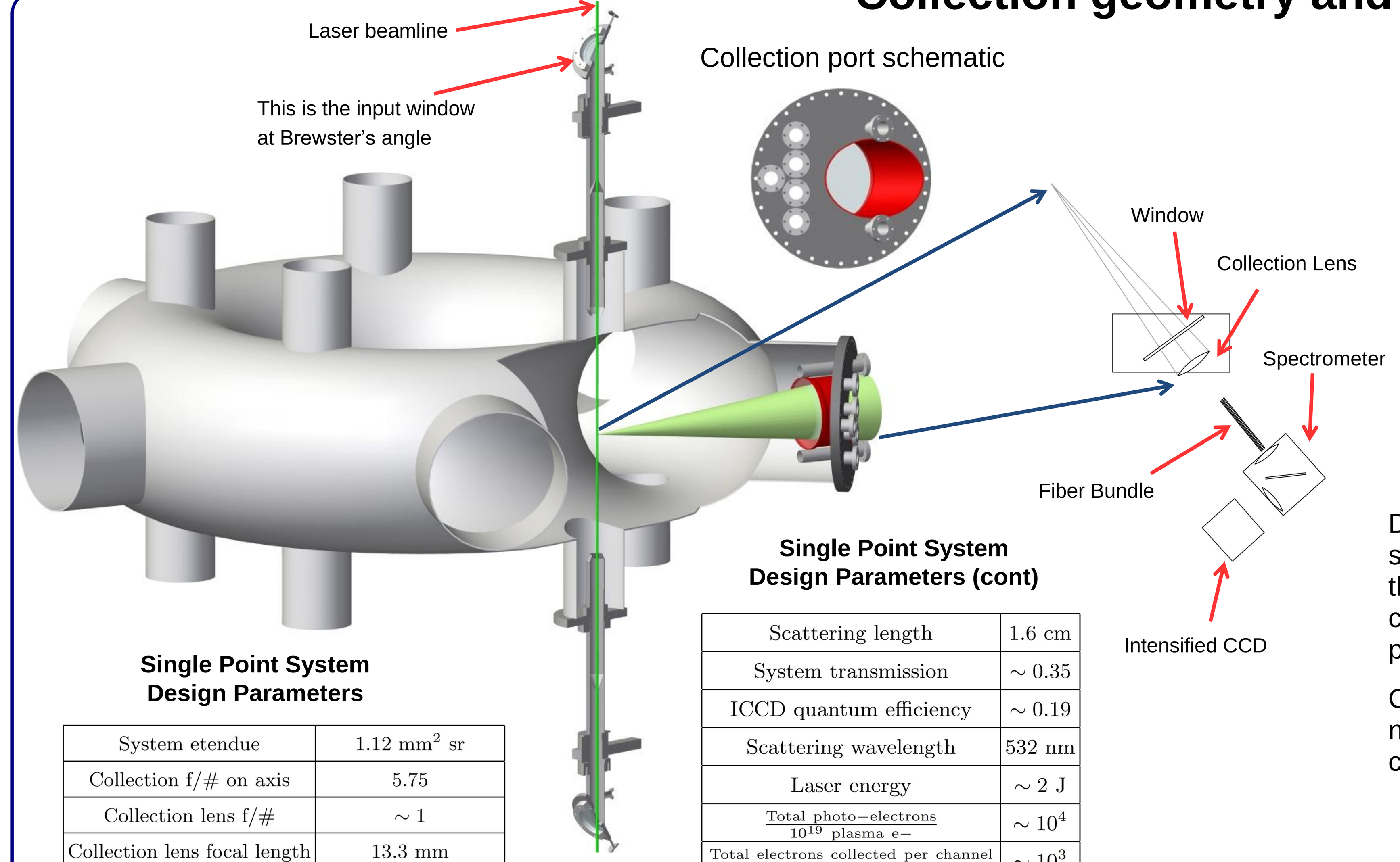
Beam line design parameters

Focal length	6.0 m
Primary aperture diameter	6.35 mm
Secondary aperture diameter	57.404 mm
Distance between lens and window	4.66 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



Pictures of modular baffling

Collection geometry and Signal estimates



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	27.6 mm by 6.9 mm

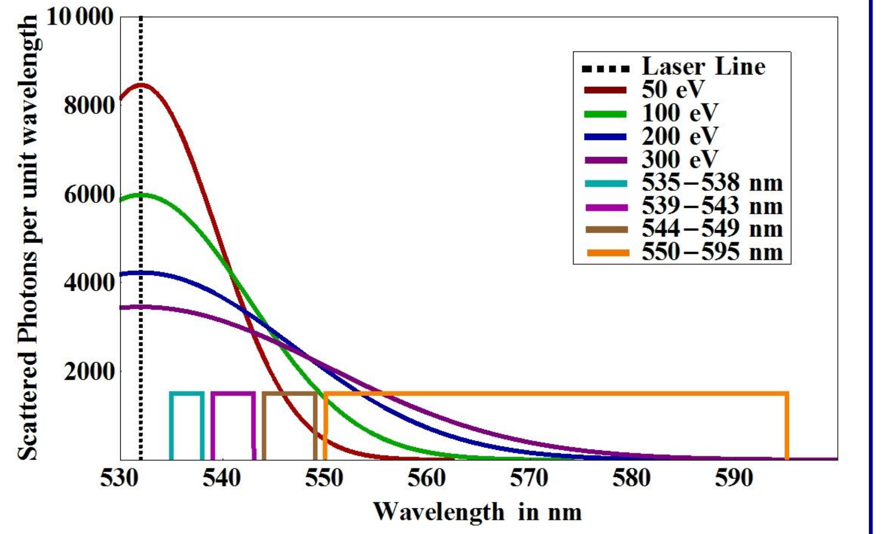
Single Point System Design Parameters (cont)

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

Depicts the number of scattered photons as a function of wavelength at various plasma temperatures overlaid with four spectral channels.

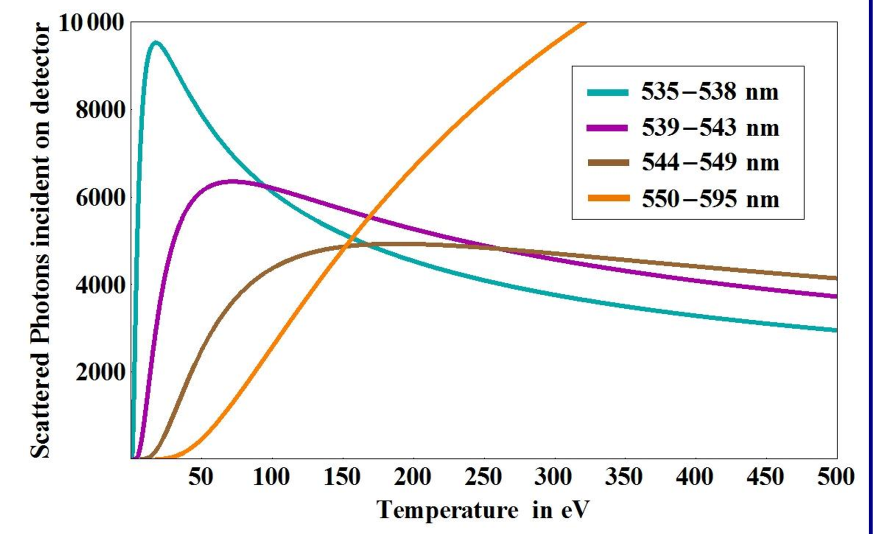
Inputs to Calculation

- Scattering geometry
- Laser input Power
- Typical CTH plasma density



Depicts the number of scattered photons incident on the CCD for each respective channel as a function of plasma temperature.

Optimized to yield the same number of photons per channel at 150 eV plasmas



Future work

- Finish background spectroscopic work to determine real noise floor within $(532\pm 60)\ nm$
- Planned installation early 2015
- Finish bench testing of specific components (e.g. laser, spectrometer, fiber bundle,etc)
- Implement full design and calibrate the system including data comparisons to soft x-ray and interferometer measurements
- Use Thomson scattering data as internal conditions for the V3FIT code for improved equilibrium reconstructions

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.