Temperature Measurements of SPECTOR Plasmas

generalfusion

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EPR 2017 Conference Vancouver, Canada August 1-4, 2017 **P2.005**

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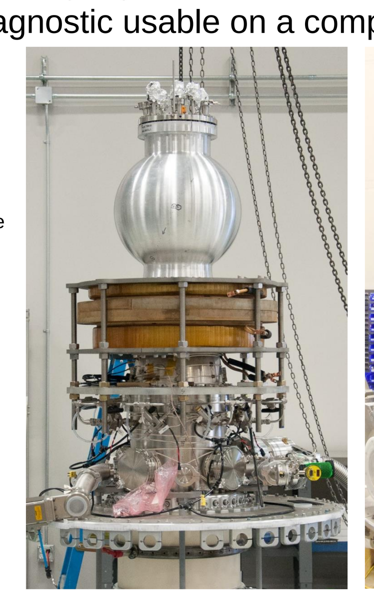
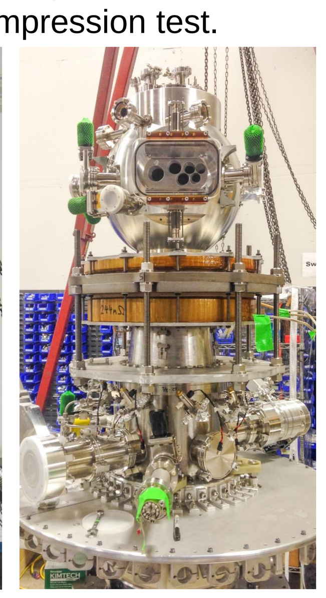
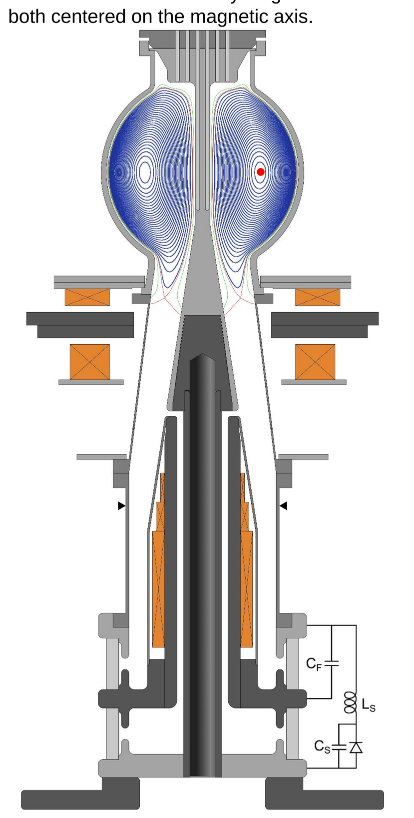
INTRODUCTION

Here we report details of electron temperature diagnostics at General Fusion for the SPECTOR (SPhErical Compact TORoid) device. SPECTOR is the latest reduced-scale plasma injector at General Fusion designed to enable more spherical, self-similar compressions of candidate plasma targets for our MTF program. Two versions of SPECTOR have been built: an uncompressed laboratory version for diagnosing the pre-compressed plasmas, and a version compatible with compression (PCS) tests. A six-point Thomson scattering diagnostic is installed only on the laboratory version only, while a two filter soft x-ray diagnostic is installed on both versions. One of the major goals of the uncompressed machine is to validate a temperature diagnostic usable on a compression test.

Near Right: Compression version of SPECTOR during assembly
Far Right: Instrumented, lab version during assembly
Below: Cross-section showing equilibrium magnetic field lines and the magnetic axis (red dot). The Thomson laser beam and the view of the lab version of soft x-ray diagnostic chords are both centered on the magnetic axis.

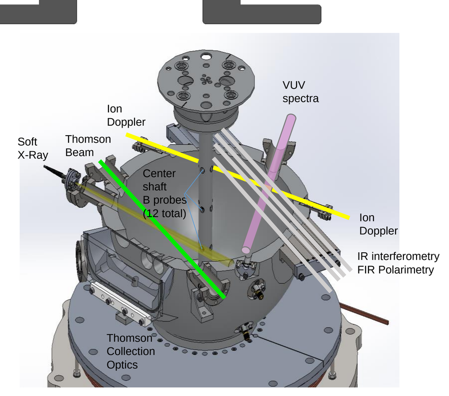


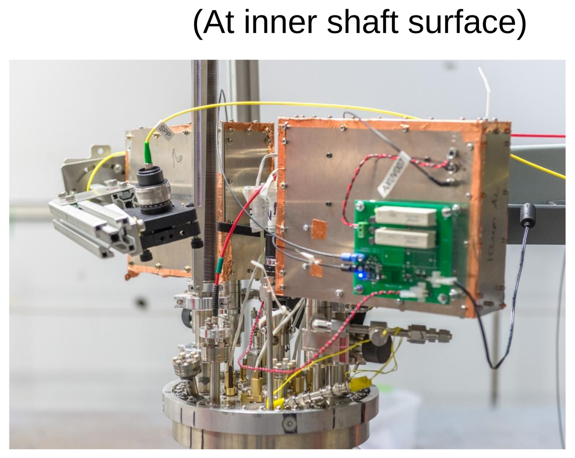




Typical Plasma Conditions

Lifetime:	1-2 ms
Species:	Deuterium
Inner Radius:	19 cm
Density:	0.2-1.5x10^{20} m^{-3}
T_e:	100-400 eV
Magnetic Field:	1 T Poloidal, 10 T Toroidal (At inner shaft surface)





Above Left: The arrangement of midplane diagnostics on the uncompressed SPECTOR
Above Right: In contrast, the compression SPECTOR has nearly all of the diagnostics in the very top.

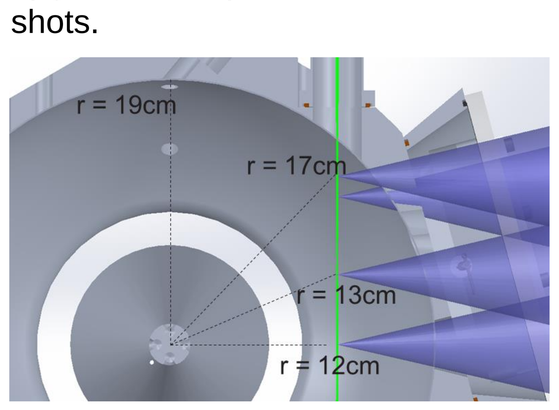
SPECTOR Diagnostics

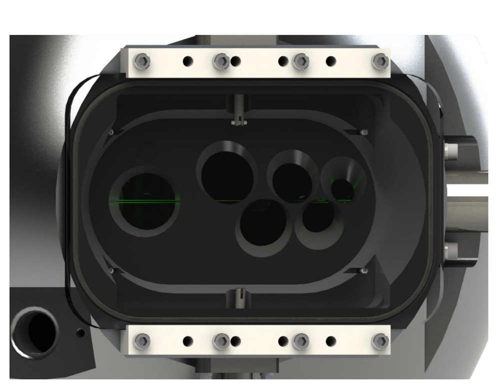
- Magnetic pick-up probes
- NIR Interferometers
- Visible light spectroscopy
- Visible light photodiodes
- X-ray photodiodes
- Scintillators
- X-ray phosphor camera
- Two filter X-ray spectroscopy
- Ion Doppler Spectroscopy
- VUV Spectroscopy*
- Multi-point Thomson Scattering*
- Multi-chord FIR Polarimeter & Interferometer*

(*Lab only diagnostics in red)

THOMSON SCATTERING OPTICS

The diagnostic uses a frequency double Nd:YAG laser, with 1.3-1.8 J pulse energy at 532 nm. The laser operates at 10 Hz, with a single, asynchronous pulse per plasma shot for measurements. A recently upgraded computer controlled beamline maintains laser position between shots.

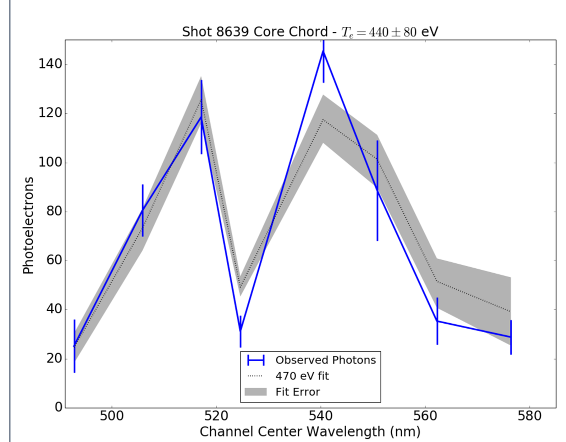


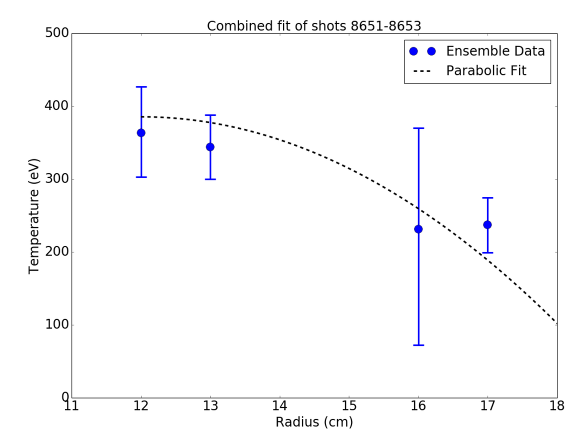


There are six Thomson scattering viewports at 1 cm radial spacing and 90 degree scattering angle. These range from the vacuum magnetic axis at r=12cm to r=17cm, 2 cm within the vacuum vessel inner radius.

Five of the viewports are staggered vertical (external side view: above, right), to maximize collection without using a single, large hole in the conducting vessel. All viewports are cones of the same angle and appear to have different sizes due to the angled, exterior face.

THOMSON SCATTERING RESULTS

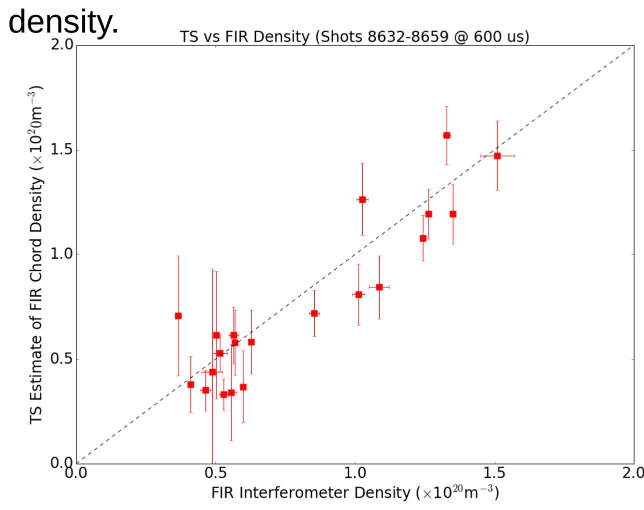




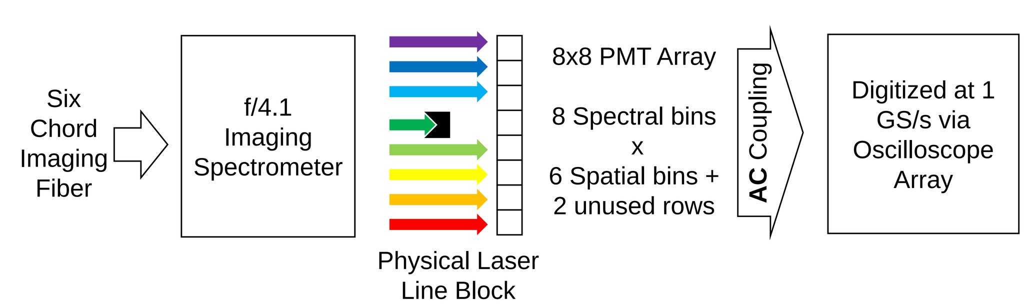
A typical, high temperature spectral profile is shown above left. The central channel is lower because it contains the laser line block, but allows some non-laser light (see spectral response in Detectors section).

With current signal levels, radial profiles are difficult to resolve on a single shot, but ensembling similar shots together does resolve some profile, and is in agreement with a parabolic profile (ensemble of 10 shots shown above right).

The Thomson scattering diagnostic has been calibrated for density, and is compared against the FIR interferometer density below. The TS data uses a weighted average that matches the geometry of FIR's chord averaging of density.



DETECTORS

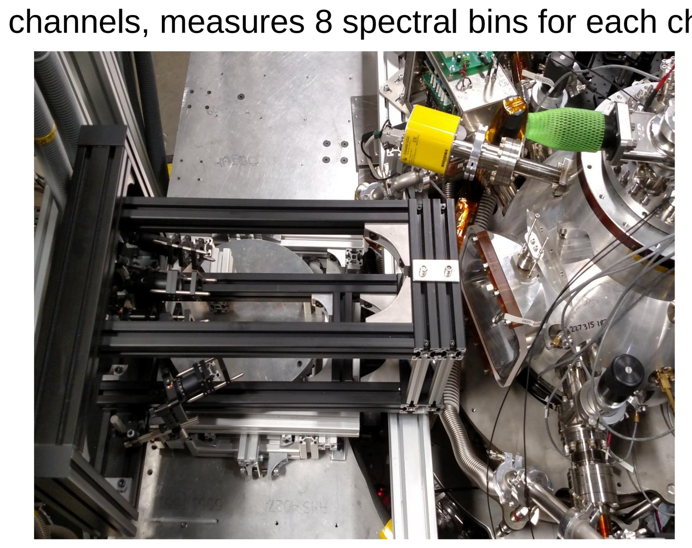


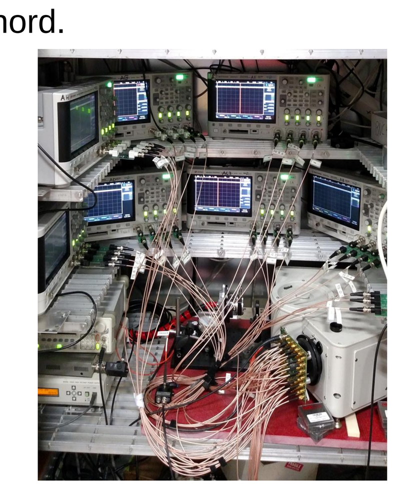
A spectrometer and PMT based system provides spectral measurement of scattered light (outlined in above diagram and photo shown to right).

The numerical aperture of the fibers is matched to the spectrometer. The spectrometer, a Horiba iHR320 f/4.1 imaging spectrometer, is the ultimate etendue bottleneck of the system.

A physical block is used to remove the laser line from the spectrum. This block can scatter light within the spectrometer, so plasma-free reference shots are taken to subtract out the scattered light. However, with current stray light reduction, typically only a couple photons of stray laser light bypass the block.

A Hamamatsu H7546A-20 photomultiplier tube array, with 8x8 channels, measures 8 spectral bins for each chord.

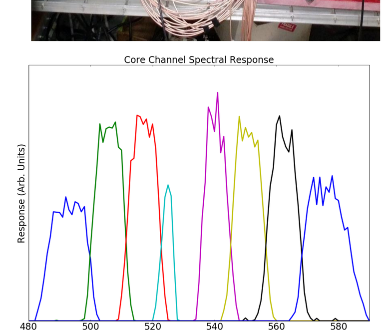




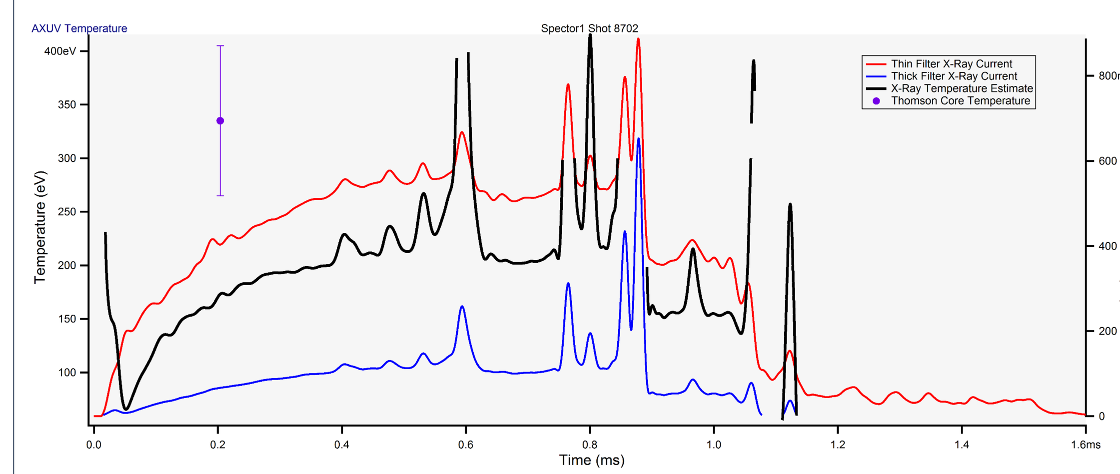
Above: A photo of the collection optics. The laser goes upward from the lower right corner . Fibers off the left edge of the image gather light from the collection optics in the black frame.

Above Right: A photo of the Thomson scattering detector setup, all located within a shielded box.

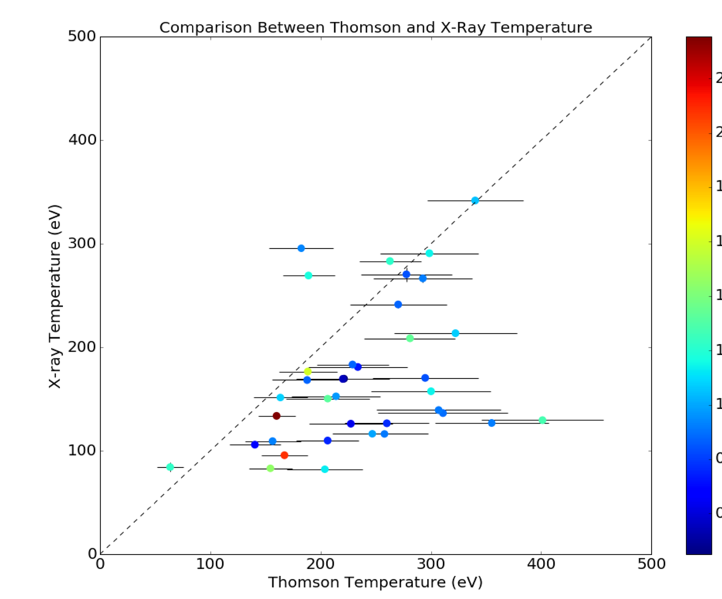
Below Right: The spectral response of the eight PMT channels is shown for one Thomson spatial point.



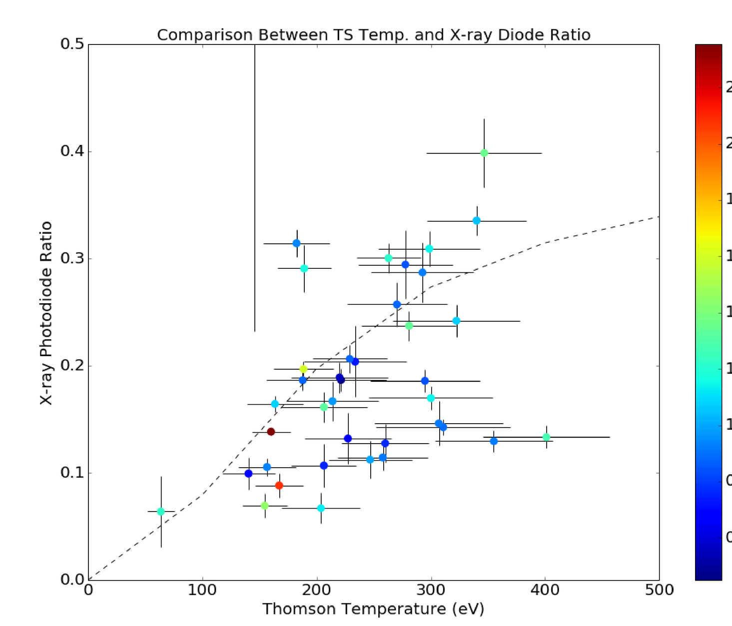
SOFT X-RAY RESULTS



A typical soft x-ray time trace for a single shot is shown above, with a Thomson temperature measurement at a single time point.



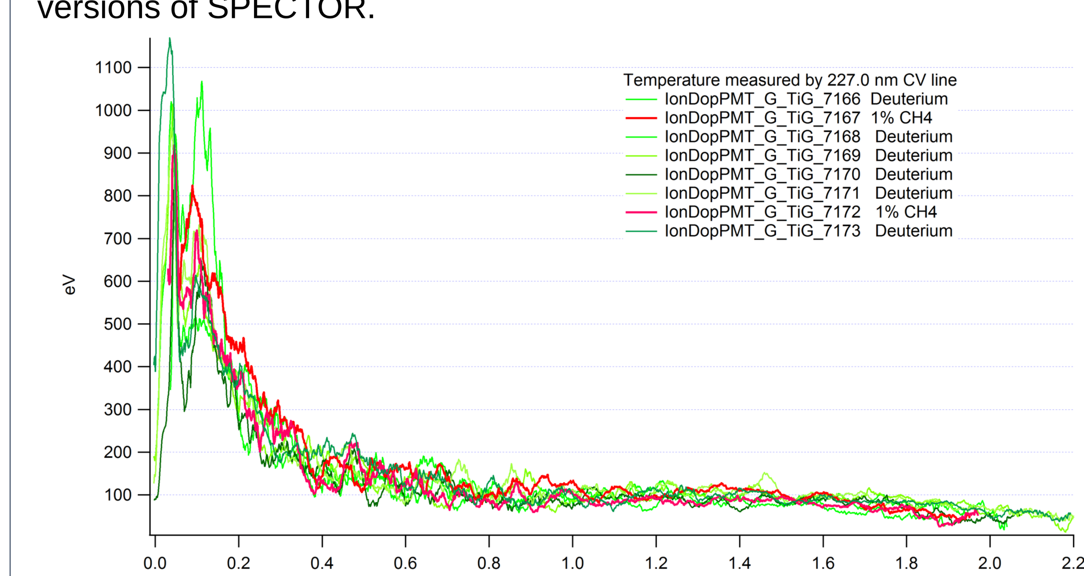
A comparison between soft x-ray and Thomson scattering temperatures is shown above, illustrating that soft x-ray provides a lower bound on temperature.



A comparison between the two-filter ratio and Thomson scattering temperature is plotted above using the same data, along with an expected calibration curve (see right column).

ION DOPPLER SPECTROSCOPY

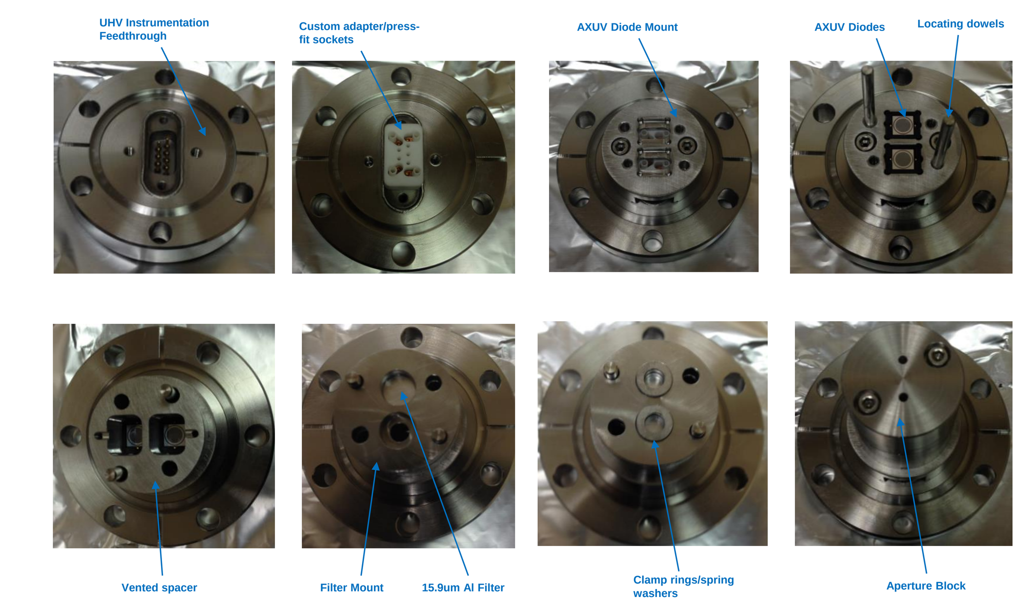
Ion Doppler spectroscopy can be performed on a variety of impurity lines using a Horiba spectrometer and PMT array (similar to TS setup to left). This diagnostic is available on both compressed and uncompressed versions of SPECTOR.



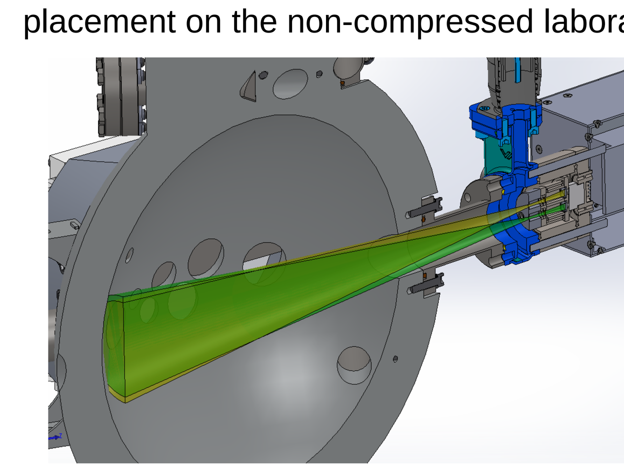
Ion Doppler temperatures are preliminary, with on going work to compare with electron temperature and between ion species.

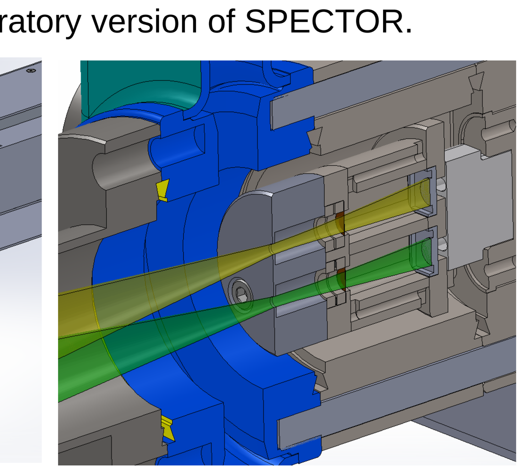
SOFT X-RAY DESIGN AND CALIBRATION

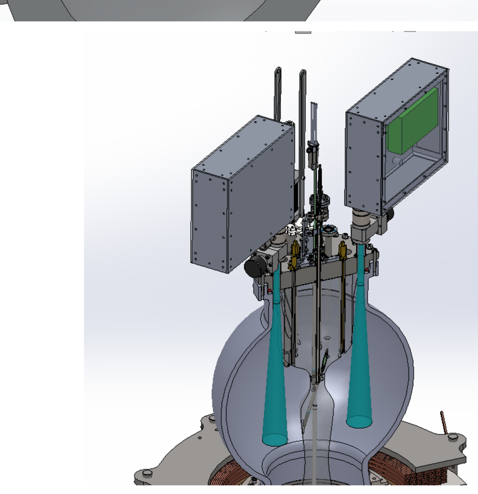
The soft x-ray diagnostic consists of a pair of x-ray photodiodes and filters within a vacuum-side, stacked assembly outlined below.

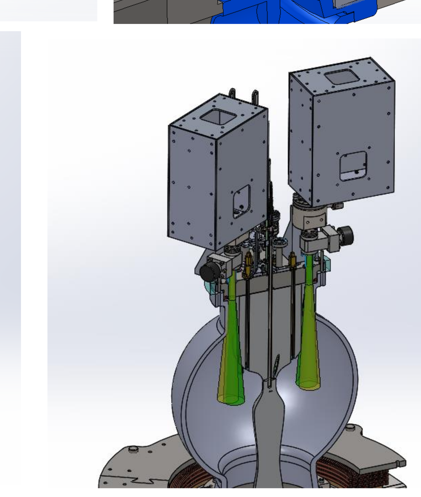


Side-by-side placement of the diodes results in a large overlap between the views of the two different filtered diodes, as shown below for their placement on the non-compressed laboratory version of SPECTOR.



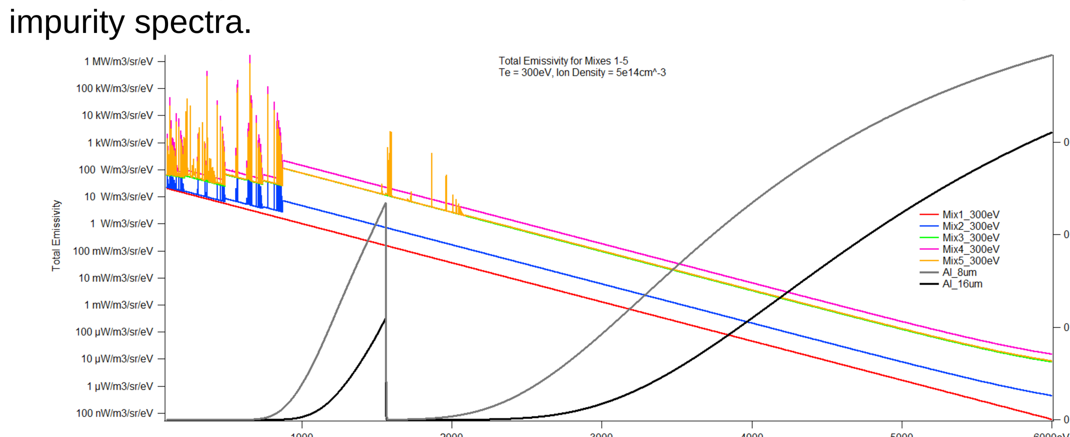




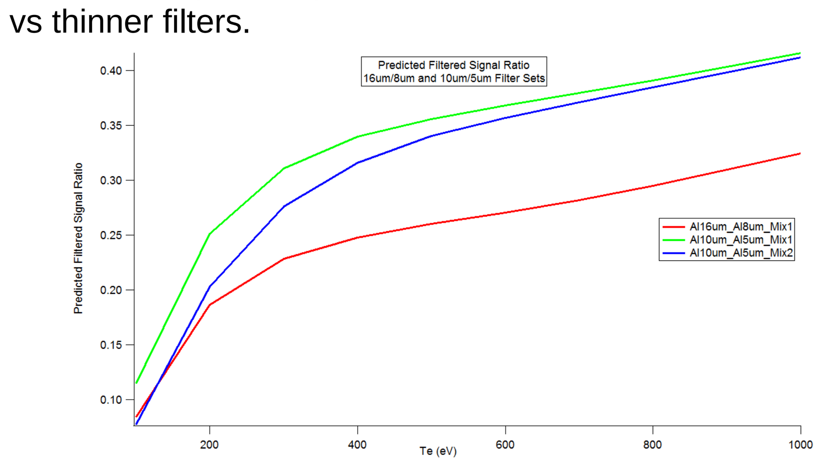


On an earlier compressed experiment, the two diodes did not share the same location due to space constraints (above left). The next experiment will use two pairs (above right.

Filter selection and response modeling is done by using FLYCHK to model spectra from different possible impurity mixes. An example filter response for 8 and 16 μm aluminum filters are shown below with example low Z impurity spectra.



Temperatures can be estimated by using the ratios of signals from above models, with example temperature calibration curves shown below for thicker vs thinner filters.



ACKNOWLEDGEMENTS

Funding provided in part by the Natural Sciences and Engineering Research Council of Canada.