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GENERAL ATOMICS

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Initial results of the high resolution edge Thomson Scattering upgrade at DIII-D[a)]

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Abstract. Validation of models of pedestal structure is an important part of predicting pedestal height and performance in future tokamaks. The Thomson scattering diagnostic at DIII-D has been upgraded in support of validating these models. Spatial and temporal resolution, as well as signal to noise ratio, have all been specifically enhanced in the pedestal region. This region is now diagnosed by 20 view-chords with a spacing of 6 mm and a scattering length of just under 5 mm sampled at a nominal rate of 250 Hz. When mapped to the outboard midplane, this corresponds to ~3 mm spacing. These measurements are being used to test critical gradient models, in which pedestal gradients increase in time until a threshold is reached. This paper will describe the specifications of the upgrade and present initial results of the system.

I. INTRODUCTION

The ability to predict the performance in the core of a fusion plasma is essential to planning future devices. Current models use the height of the H-mode pedestal as an important input[1]. Height in turn depends on the width of the pedestal[2]. The DIII-D Thomson scattering system[3] has been upgraded with the primary goal of providing accurate measurements of the pedestal width. Thus, models for pedestal structure may be tested and reliable boundary conditions for core transport models can eventually be provided.

II. BACKGROUND

This diagnostic has always measured the pedestal region of plasma where a vertical laser path crosses the separatrix near the top of the machine, as seen in Fig. 1. The main advantage of this strategy is that flux surfaces are less closely packed here than at the machine midplane, effectively doubling passive spatial resolution.

Scattered light is collected through a wide angle achromatic lens and is projected onto the ends of many fiber optic bundles (see Fig. 2). The fibers terminate in polychromators[4] equipped with sets of optical band pass filters and avalanche photo diode based detectors.

Previous to the upgrade, a key weakness of the system was that too few points fell within the steep gradient region and their scattering lengths were too long compared to the expected width of the pedestal. The pedestal width along the vertical laser is typically about 20 to 30 mm. The old spot spacing of 12 mm was not enough to allow confidence in measurements of pedestal width. Further, the signal was averaged across the entire 9 mm scattering length. This is too great a fraction of the pedestal width to provide good detail. The main goal of the spatial resolution upgrade was to solve these problems.

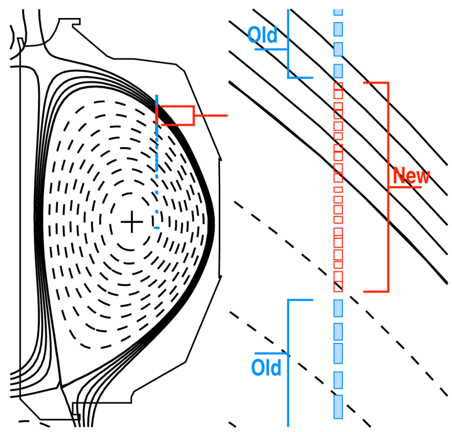

FIG. 1. Position of high resolution channels in DIII-D. High resolution chords shown in red (open) and standard chords shown in blue (filled).

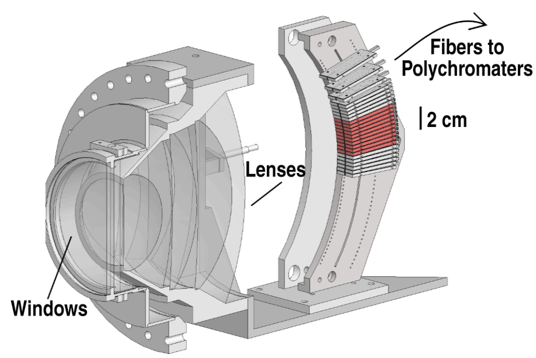

FIG. 2. Configuration of DIII-D Thomson scattering collection optics. The windows and flange on the left are attached to the vacuum vessel. The lenses and fiber mount on the right are supported by a separate structure so that they do not vibrate relative to the laser. The high-resolution fibers terminate in cartridges which have been marked in red (darker).

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III. UPGRADE PARAMETERS

Planning the upgrade was a matter of finding the optimal balance between shortening the scattering length and increasing the resolution on one hand, and preserving temperature accuracy on the other. Reductions in scattering length run into diminishing returns when the length is comparable to the laser diameter because of the angle at which the laser crosses flux surfaces (typically ≈45°, see Fig. 3).

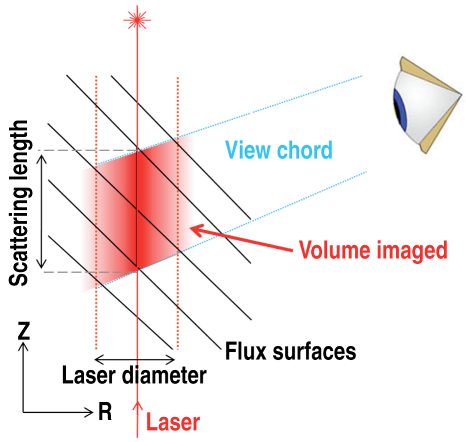

FIG. 3. Geometry of a typical scattering volume. When the scattering length (controlled by fiber size) becomes small, the laser beam's diameter determines the spot's span across flux surfaces. Scattering lengths are ≈5 mm for the upgraded channels and ≈9 mm for standard channels near the lens axis. Most of the laser's energy is contained within a 3 mm diameter.

The new fiber size selection was based on the results of simulations that showed that halving the fiber bundle height decreased the minimum measurable pedestal width from 15mm to 10mm, as seen in Fig. 4. The same simulation showed that further reductions in fiber size yielded almost no benefit, as the laser's width spans flux surfaces.

The spatial resolution upgrade consisted of replacing ten standard optical fiber bundles with twenty high-resolution bundles which image the same range of positions (hardware shown in Fig. 5). This improved resolution from ≈12 mm to ≈6 mm and reduced scattering length from ≈9 mm to ≈5 mm. New detection equipment was constructed to serve the additional measurement points. The high-resolution zone spans 120 mm vertically. When mapped along flux surfaces to the machine midplane, the separation between points is roughly 3 mm center to center (compare to DIII-D major, minor radius = 1.69 m, minor radius = 0.60 m).

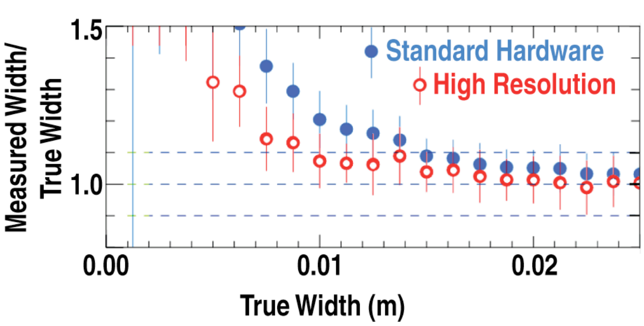

FIG. 4. Simulations using hyperbolic tangent profiles show minimum resolvable pedestal width with standard and upgraded hardware.

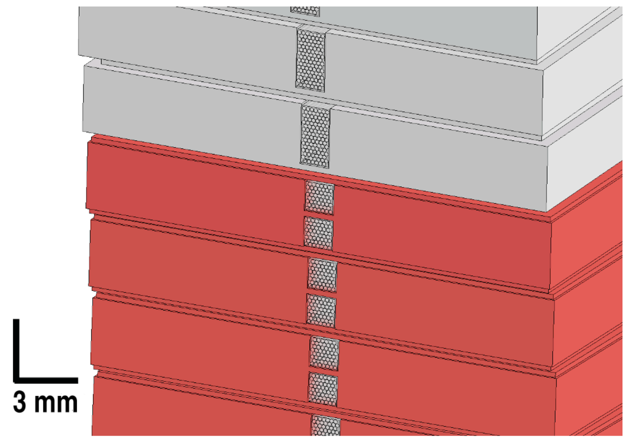

FIG. 5. Close up model of fiber bundles in their mounting hardware. New fibers are held by the red (darker) cartridges. Fig. 2 shows relation to other components of the collection optics.

The new polychromators have a new set of optical band pass filters which is optimized for the pedestal and allows good temperature fits up to at least 2 keV. A full simulation was performed to test proposed modifications to the filter set. The chosen set retains most of the longer wavelength filters used for low temperatures, but the two shortest wavelength (high temperature relevant) filters are combined. The transmission curves for the new filters are plotted in Fig. 6.

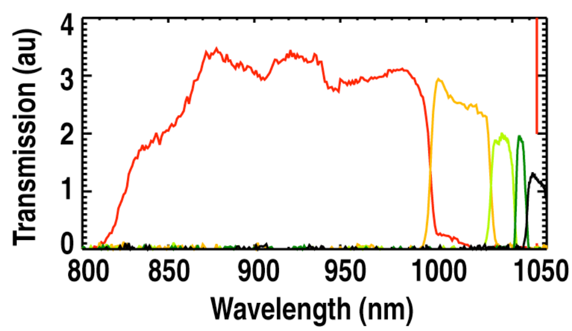

FIG. 6. Typical spectral transmission functions for the new filter sets, convoluted with detector gain and quantum efficiency.

Despite the smaller cross sectional area of the high resolution fiber bundles, signal to noise ratio was not significantly changed because the new fibers transmit light more efficiently than do the old fibers. Damage due to ≈20 years of neutron exposure is a possible explanation for the lower transmission efficiency of the old fibers. Typical random error in temperature, calculated based on noise due to background light and detector dark noise is ≈10% in the steep gradient region and ≈5-10% at the top of the pedestal. Random density errors are typically ≈5% at the top of the pedestal and ≈5-10% in the steep gradient region. Good temperature measurements (≤10% error) generally require densities higher than 2×10^{19} m^{-3}, although useful performance is possible at lower density.

The upgrade to temporal resolution consisted of adding a group of 50 Hz Nd:YAG lasers to the existing set of 20 Hz lasers.

This increased the nominal performance of the core laser group from 80 Hz to 250 Hz. Maximum achieved repetition rate is 230 Hz from 7 out of 8 lasers. Pulse energy is typically 1 J and pulse length is 8 ns.

IV. RESULTS

The Thomson Scattering System on DIII-D can now resolve the pedestal in a single laser pulse with good reliability. Having more, smaller scattering volumes (see Fig. 7b-c) in the pedestal has allowed direct measurements of pedestal width where previously only an upper bound could be stated with confidence.

Another benefit of the increased resolution is that small features such as ELM filaments and magnetic islands might now be captured by more measurement points and thus be clearly distinguished from random errors. The system has returned profiles that clearly show features in density outside of the separatrix which are correlated in time with spikes in D_α (i.e. ELMS).

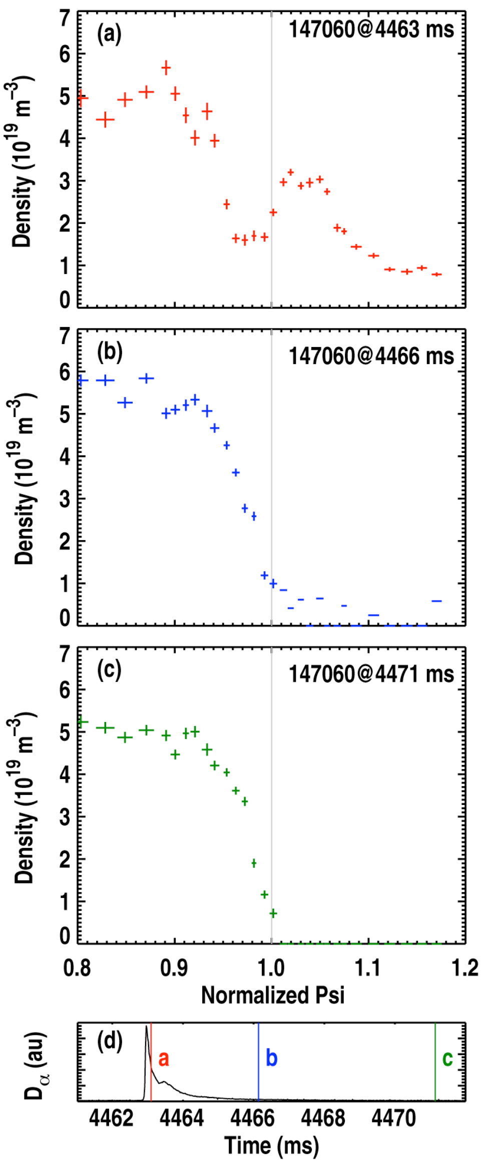

FIG. 7. (a) An ELM is visible as a bump in density at $\psi_N \approx 1.05$. (b-c): Recovery following the ELM. (d): Timing of laser pulses in relation to spike in D_α light. In all plots, the horizontal error bars represent the scattering lengths and the vertical error bars are uncertainty due to random errors from measured noise sources.

V. ACKNOWLEDGEMENTS

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