# THOMSON SCATTERING IN THE JET EDGE PLASMA

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## 1. INTRODUCTION

The behavior of the plasma edge temperature and density in H-mode plasmas with type I ELMs has been successfully described by the so-called edge operational diagram [1]. The edge diagram shows a clear boundary for the upper limit to the edge pressure. It is often assumed that the mechanism for this limitation is the ballooning instability which has a critical edge pressure gradient. We have not in the past experimentally been able to fully test this hypothesis at JET because the spatial resolution of our measurements was not sufficient. Scaling experiments suggest that the scale length is determined by the ion poloidal Larmor radius of the fast ions in neutral beam heated plasmas, making the scale length ~ 3 cm or less. A new attempt at determining edge density and temperature gradients using a LIDAR Thomson scattering system [2] is presented.

## 2. DIAGNOSTIC

To achieve the required spatial resolution the backward scattered signal is collected along a chord that passes through the plasma just over the X-point, Figure 1. The maximum equivalent mid-plane penetration of this path is between 5 and 10 cm depending on the position of the X-point and the alignment of the diagnostic. The effective F# of the collection system seen from the scattering volume is ~20. The subtended F# is ~14.

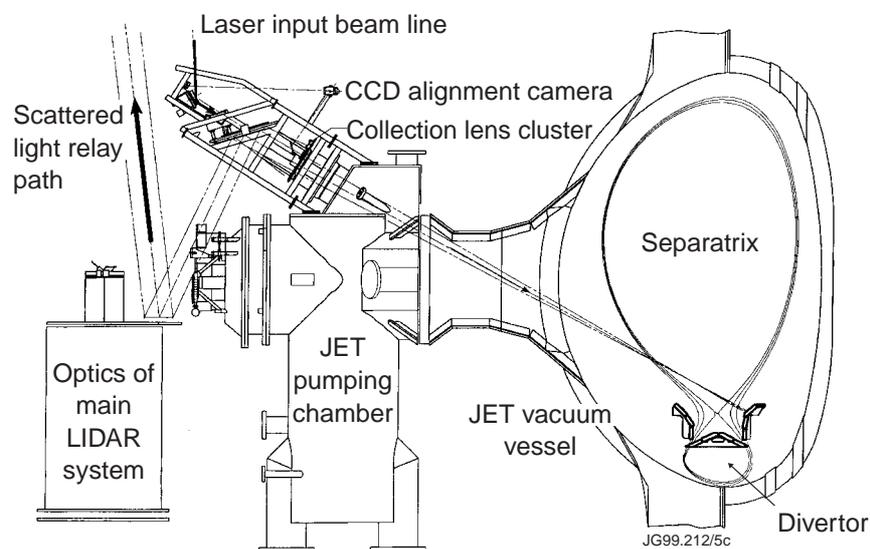The system uses a 1 Hz repetition rate,



*Figure 1 General layout of LIDAR Thomson scattering system used for edge measurements. The laser beam and the collected light are both passing through a penetration in the Torus Hall biological shield and a window cluster on top of the pumping box. Alignment is achieved by looking at the image on the divertor tile of a 633 nm alignment beam using a CCD camera inside the spectrometer*

a 1 Hz repetition rate, 300 ps, 2 joule ruby laser, fast gated MCP photomultipliers and a 1 GHz analog bandwidth, 4 channel HP-Infinium oscilloscope. The current set of ITT photomultipliers have a response

time of 600 ps yielding an overall spatial resolution of ~13 cm along the laser path, resulting in an equivalent mid-plane resolution of better than 2 cm.

The scattered spectrum is measured by a four channel filter spectrometer, Figure 2. The optical path length is the same to all detectors. Cable lengths from the detectors to the oscilloscope are also kept the same, ensuring synchronization of the recorded signals of the four channels. A time marker is introduced optically from the laser on channel 1 to determine the absolute position of the scattered signal.

In a LIDAR Thomson scattering system the image is not fixed and the solid angle of collection varies with scattering position. In a complex system as on JET vignetting from apertures in the relay system can further complicate this. We have chosen to image the detector at the center of the scattering path, making sure that this image is not vignetted by the relay optics. The solid angle of collection for all scattering volumes is then determined by this central image (40 mm diam.) and by the windows on the vacuum vessel. The laser beam size at the center of scattering is ~5 mm. The étendue of the system resulting from this choice is sufficient to make the effect of vignetting insignificant in the outer half of the path.
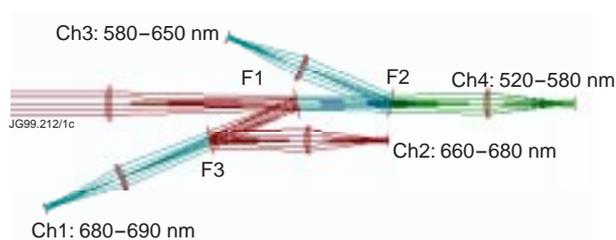


*Figure 2 Four channel filter spectrometer. Input lens is at image of collection window. A lens in front of each detector images this lens onto each detector. Optical path lengths to detectors are the same. Shown are three filters at 12 degree incidence (F1 – F3) a fourth filter limits the channel nearest the laser line.*

**The scattering volume**

The angle of the laser beam with respect to the LCFS at the outboard side is ~ 30 degrees which together with the flux expansion gives a midplane equivalent spatial resolution ~4 times better than the physical resolution. The flux expansion near the X-point is even greater but unfortunately we are not able to use the signal in this region due to the stray signal resulting from the leading edge of the laser pulse impinging on the divertor tiles. Better spatial resolution can be achieved by lowering the laser beam path nearer to the X-point. However this is achieved at the cost of smaller penetration into the plasma. Figure 3 shows the difference in spatial resolution resulting from lowering the scattering line by approximately 5 cm.
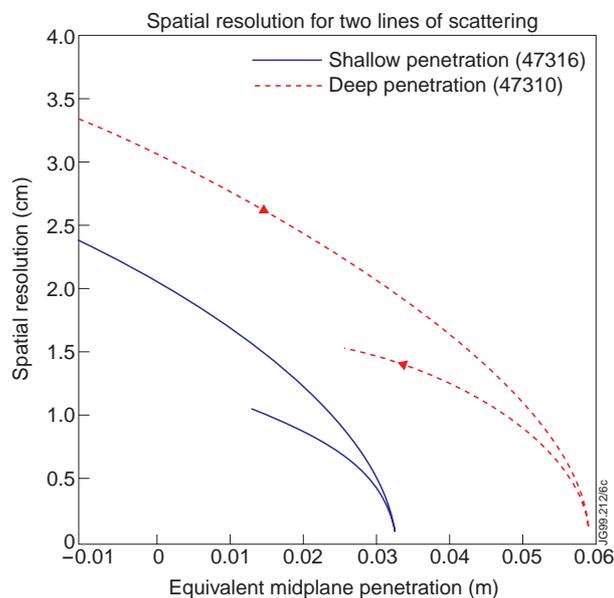


*Figure 3 The spatial resolution vs. equivalent midplane position for a given discharge. The two curves demonstrate the effect of varying the path of the scattering system. The arrows show the direction of the laser beam as it enters from the outside.*

## 3. EXPERIMENTS TO MEASURE GRADIENT SCALE LENGTHS

### The discharges

To study the evolution of the H-mode pressure gradient two discharges at constant q were developed. The discharges were designed to have long ELM free periods, with some ELM free periods longer than one second. The discharges have good reproducibility. The two discharges were at 1T/1MA and 2.5T/2.5MA respectively. Figure 4 shows the D-alpha signal for one of each type of discharge. Also shown are the measured electron temperature and density at the point of deepest penetration. By adjusting the timing of the 1 Hz laser pulses it is in principle possible to follow the profile evolution up to the time of the ELM.



*Figure 4* *The D-alpha signals showing the ELM frequency for the 2.5T/2.5MA (a) and the 1T/1MA discharges (b). The temperature (c) and density (d) at the point of deepest penetration are shown for the two discharges*

### Results

Figure 5 shows the raw data for the last laser pulse in 47310, t = 23.8 s. The timing of this pulse is immediately before an ELM, thus providing a good measure of the limiting pressure gradient.
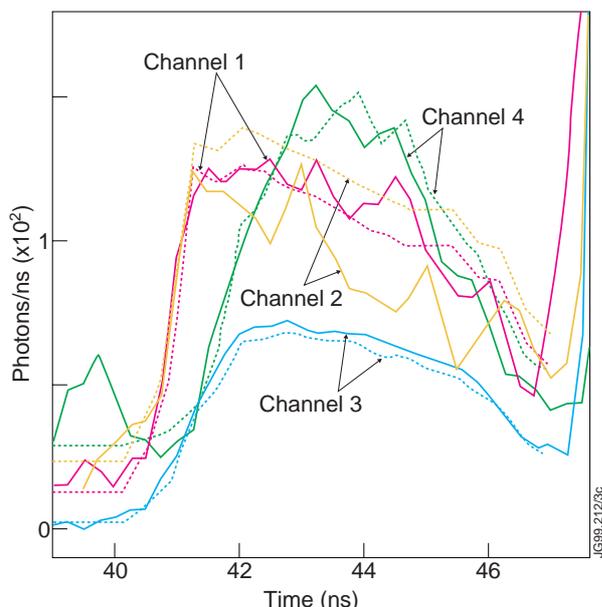


*Figure 5* *Raw data for 47310, t = 23.8 s. The solid curves are the raw data of the four channels and the dashed curves show the expected signal for the fitted temperature and density profile.*
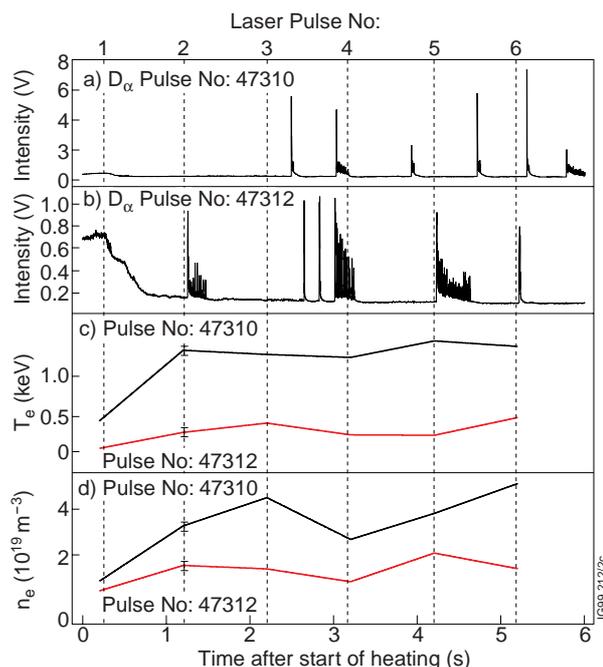
Analysing the pulses in this series of measurements we find general good agreement with the main LIDAR system and with the ECE measurement at the high field. At the lower field ECE cannot be used.

In order to test whether the measured scale length is instrument limited the pulses were repeated with the scattering system aligned for shallower penetration (see Figure 3).

The temperature and density profiles for deep and shallow penetration are shown for the two discharge types in Figure 6. The data show good consistency between deep and shallow penetration.

The measurements often show scale lengths smaller than the instrument resolution putting only an upper limit on the scale length. The raw signals of the individual spectral channels are in these cases not consistent with a single temperature within a

scattering volume. A new parametric analysis routine allowing for this has been developed which effectively improves the spatial resolution.

**Pressure gradients and scale lengths**

It is difficult to tell if the scale length is related to the poloidal ion Larmor radius based on this limited data set. The scale length in the high field case is ~ 5 cm on the temperature gradient. The density scale length shown in the figure is much shorter. However, we believe that the fall in density may be insignificant at the plasma boundary. The apparent sharp drop is a result of the temperature dropping below the minimum detectable temperature of the current spectrometer.

Assuming that the pressure gradient is entirely due to the temperature profile we obtain the following electron pressure gradients:

$$p_e = 160 \text{ kPa/m @ 2.5T/2.5MA}$$

and

$$p_e = 20 \text{ kPa/m @ 1T/1MA}$$

**4. CONCLUSIONS**

A new LIDAR Thomson scattering system has been developed which is capable of resolving the edge pressure gradients of most of the JET plasmas. The scaling of the measured pressure gradients are to within measurement accuracy proportional to magnetic field pressure, consistent with a ballooning mode limit. More measurements at different probing depths and more field values are required to make definite conclusions particularly with respect to the scale length. Data from the reciprocating Langmuir probe are required to resolve the conjecture that the density does not change before the LCFS.
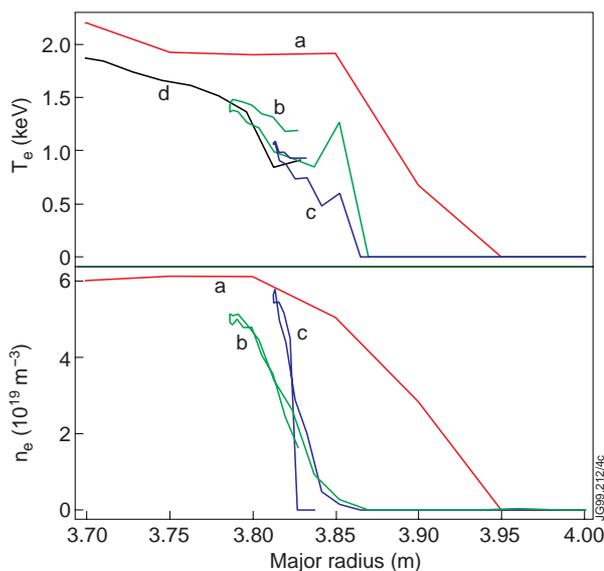


*Figure 6* *Temperature (top figure) and density (bottom figure) profiles for 2.5T/2.5MA. Profile data from the main LIDAR system (a) and the heterodyne ECE system (d) are compared with two edge profiles (b) and (c) in each figure from the new Divertor LIDAR system which correspond to two different levels of penetration into the plasma. The temperature profiles show good agreement however the density profiles reveal some apparent spatial resolution limitations*

**References**

[1] M Kaufmann et al., 16<sup>th</sup> IAEA  Conf. on Plasma Phys. and Contr. Nucl. Fus. Research, Montreal, 1996 F1-CN-64/01-05.
[2] H Salzmann et al., Rev. Sci.  Instrum. 59,1451 (1988)