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Edge transport barrier characteristics of improved H-modes in ASDEX Upgrade

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The improved H-mode is a candidate improved confinement scenario for ITER. It is characterised by a flat q profile with $q \geq 1$, no or small sawteeth, $1 < H_{98}(y,2) < 1.5$, $2.5 \leq \beta_N \leq 3$ (limited by the occurrence of 2,1 NTM's) and is achieved over a broad range of ν^*. Recently much interest is being shown in the study of the edge pedestal in improved confinement scenarios, since there are indications that part of the confinement improvement indeed originates from the edge transport barrier (ETB) region [1,2].

In order to investigate the structure of the H-mode pedestal in ASDEX Upgrade (AUG), experiments have been carried out in improved H-modes discharges in which the power was increased stepwise during the pulse. All discharges were carried out at 1 MA, 2.3 T and with the same magnetic configuration (LSN, δ~0.25, κ~1.8, q_{95}~4.7). Discharges with different wall conditions are compared as are discharges with different timing of the additional heating. Edge electron profiles were obtained combining high-resolution measurements from the Thomson scattering system and the ECE heterodyne diagnostic. The edge profiles are then fit by a modified hyperbolic tangent function [3].

As the power is increased, it is observed that: i) the width of the density barrier stays roughly constant or perhaps decreases (Fig. 1); ii) the temperature barrier broadens with power (Fig. 2); iii) the width of the electron density barrier, Δ_{ne}, is narrower than that of the electron temperature: Δ_{ne}~ 1 cm and $2 < \Delta_{Te} < 3$ cm; iv) the pedestal-top density tends to increase with power (in the absence of gas fuelling), due to a combination of steepening of the density gradient in the ETB and of increasing density in the scrape off layer, which raises the base level of the density barrier (Fig. 3); and, as a result, v) the pressure at the pedestal top $pe^{PED} = ne^{PED} * Te^{PED}$ increases with power.

The observation that the density ETB is narrower than the temperature ETB is in contrast to previous analysis on (higher density) conventional H-modes [4]. The present data suggest that fuelling effects may be playing a more important role in determining the edge density profile, as is observed in DIII-D [5]. Detailed modelling of the kind reported in

[4], which is necessary to separate fuelling and particle transport effects, remains to be done for these discharges.

Improved H-modes performed just after a boronisation are characterised by lower pedestal densities, but since the pedestal temperature tends to be higher than in the non-boronised counterpart the overall difference in the pedestal stored energy in the two cases is small.

Typically, in AUG, the flat q profile required for the improved H-mode is created by applying neutral beam heating early in the discharge in order to freeze the current profile before it has fully penetrated to the plasma core as well as to drive off-axis current. In a dedicated experiment to measure the ETB structure with late heating, it is observed that: i) the width of the electron density and temperature barriers are similar to those measured with early heating, both in absolute magnitude and in variation with input power; ii) the pedestal-top density and temperature are typically higher, especially at low power; iii) the pedestal-top temperature increases with power while the density remains roughly constant, so that; iv) the ETB confinement increases with input power and is actually better in the discharges with late heating.

The importance of the edge in setting the global confinement is shown in Fig. 4 where the total plasma thermal stored energy is plotted versus the pedestal stored energy. As input power is increased, the ETB energy increases, leading to increased core energy. Indeed, the main difference in the early and late heating cases is that the pedestal energy of the late heating case is higher, particularly at low input power.

Different mechanisms have been suggested for a dependence of ETB confinement on input power. Here, we consider a model of ion temperature gradient (ITG) turbulence stabilisation due to edge rotational shear [6]. In this model, the growth rate of the ITG turbulence is assumed to decrease with the square of the magnetic shear as the edge is approached. Since the ExB flow shear also increases in this region, there is a crossing point where the turbulence is stabilised, thus defining the size of the ETB.

In order to study the influence of edge shear, high precision equilibria are generated, constrained by magnetics measurements, the new edge profile measurements, measurements of the poloidal current flowing in the SOL, calculations of the separatrix electron temperature based on a SOL power balance model [7], and the assumption that flux surface-averaged toroidal current flowing in the edge plasma is due to Ohmic plus bootstrap current.

The ITG stabilisation model predicts that the ETB width should scale as the product of the toroidal Larmor radius and a power of the edge magnetic shear, taken as two in [6]. In Fig. 5, the measured electron temperature ETB width is plotted versus this scaling factor. There is no obvious trend, although it must be said that the variations in edge shear induced by the power scan are rather small. The measured widths do increase with increasing toroidal Larmor radius (Fig. 6). Given that broader ETBs naturally lead to higher pedestal-top temperatures, it is not clear which is cause and which is effect. In any case, a dedicated experiment, varying the edge shear over a substantial range, is required in order clarify the validity of the proposed scaling.

It is clear that the edge plays an important role in the power dependence of confinement in these improved H-mode discharges. At least three factors are important:

- Broadening of the electron temperature barrier;
- Narrowing and steepening of the edge density barrier, at least at the lowest densities;
- In the early heating discharges, an increase of the separatrix pressure (density) with increasing input power.

Improved confinement due to filling of the SOL, thus increasing the separatrix pressure will saturate as the divertor detachment limits are reached. This may be the explanation why improved H-modes in AUG are observed to have a more favourable power scaling than conventional, higher density H-modes.

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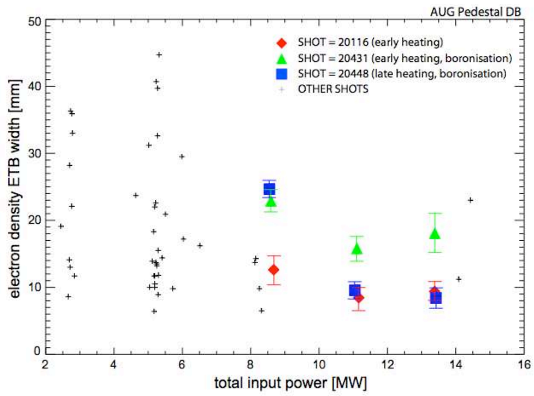

Fig. 1: Measured electron density ETB width for the three power-scan discharges analysed in this paper. Data from the AUG topical database are shown for comparison.

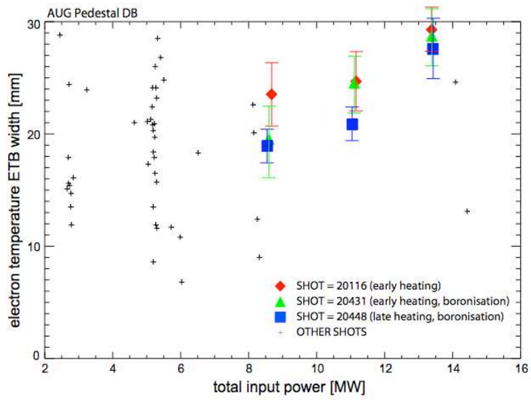

Fig. 2: Measured electron temperature ETB width for the three power-scan discharges analysed in this paper. Data from the AUG topical database are shown for comparison.

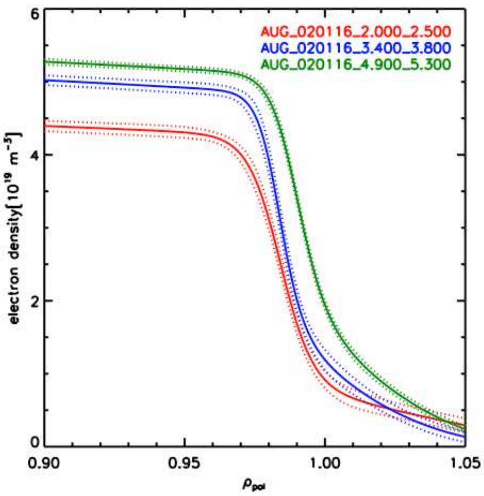

Fig. 3: Fitted edge density profiles for a power scan in an improved H-mode discharge with early heating.

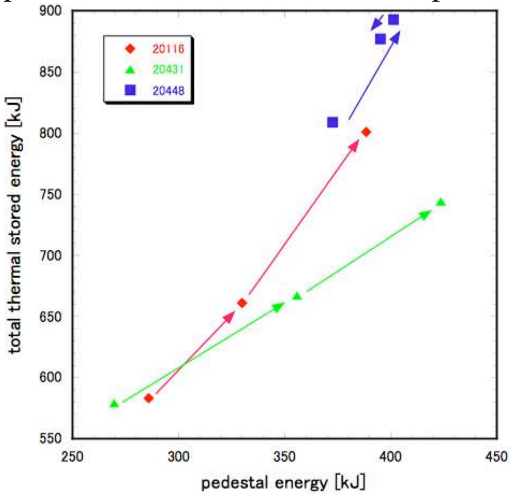

Fig. 4: Plasma thermal stored energy versus pedestal energy for the three power-scan discharges.

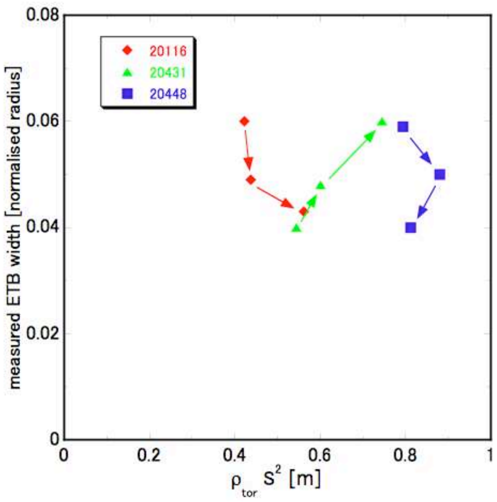

Fig. 5: Measured electron temperature ETB width versus a scaling based on ITG turbulence suppression (see text).

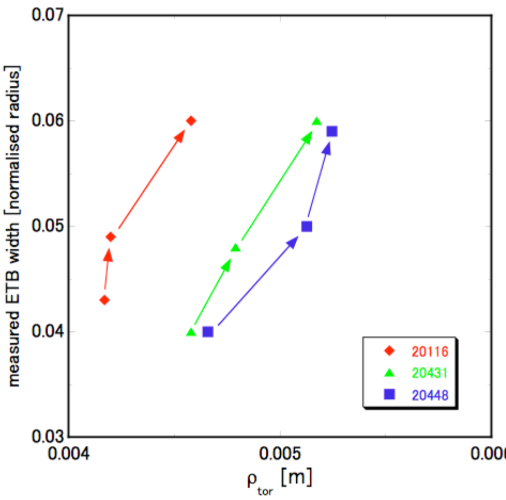

Fig. 6: Measured electron temperature ETB width versus toroidal Larmor radius.