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Formation Criterion and Position of Internal Transport Barriers in ASDEX Upgrade

E.D. Quigley[1], P.J. Mc Carthy[1], A.G. Peeters[2], J. Hobirk[2]
and the ASDEX Upgrade Team[2]

[1]*Physics Dept., University College Cork, Association EURATOM-DCU, Cork, Ireland*
[2]*Max-Planck-Institut für Plasmaphysik, EURATOM Assoziation, D-85748 Garching*

1. Introduction

This paper details the present status of ongoing research at ASDEX Upgrade on the formation criterion and position of internal transport barriers. Formation criterion (section 2) were investigated by studying the differences between similarly run discharges which did or did not exhibit an ITB. Study of the position of the ITB (section 3) involved determining the safety factor (q) profile for ITB discharges and comparing the shape of the q profile, and hence the shear, with the position of the ITB.

2. Global formation criterion for ITBs

Correlations between ITB formation and plasma parameters, just before formation, have been investigated, this involved making comparisons between similarly run discharges which did or did not exhibit an ITB. The ITB discharges chosen were that of the 1999 campaign, in which approximately 5MW NBI power was turned on at around 0.3s, while I_p is ramped up at a rate of approximately 1MAs^{-1} up to a maximum of 0.8MA or 1MA, and with the plasma in an inner limiter or upper single null plasma configuration. This original ITB scenario is unreliable in the production of ITBs and an aim of this work was to identify an experimental setup which would allow ITBs to be readily produced.

It was found that barriers form only at low density. From the figure 1(a) it can be seen that at the time points where the ITBs typically form, 0.45s-0.75s, the density for the ITB discharges is lower than for the non-ITB discharges. It seems that for the non-ITB discharges when otherwise conditions would facilitate ITB formation, the density is too high and thus an ITB does not form. This hypothesis is supported by evidence from the 2002 campaign ITB discharges, in both upper and lower single null plasmas, where heating during the current ramp was delayed until 0.7 seconds (figure 1(b)). This delayed heating prevents the neutral beam fuelling from generating higher density before ITB formation. Here, very reproducible strong ITBs are seen to form very soon after the NBI power is switched on, at around 0.71 seconds, when other conditions are favourable for ITB formation and the plasma density is even lower than that of the ITB discharges from the 1999 campaign. Also in the 1999 campaign, a clear correlation of barrier formation with the time since boronisation was found, with barriers forming only in discharges just after boronisation. This is expected to be linked to the need for lower density since just after boronisation the impurity density would be low. No clear correlation with ECE radiation temperature, gas puff, radiation power or l_i could be established.

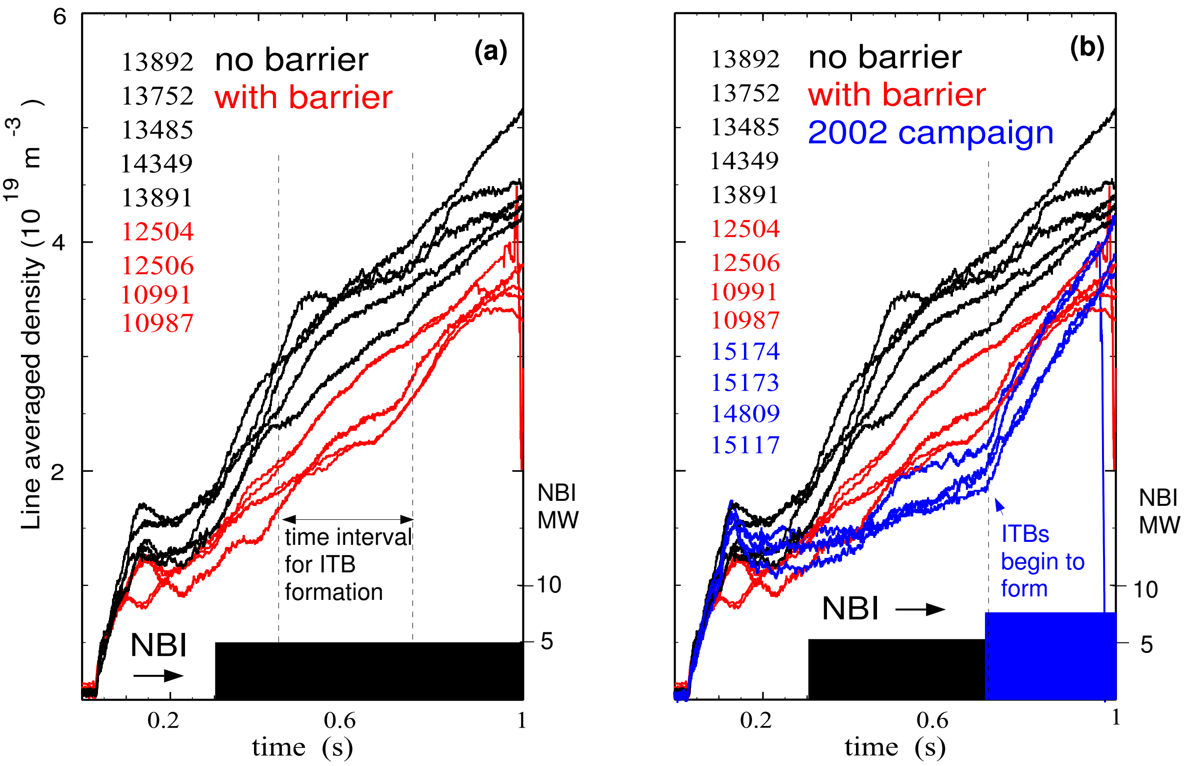

Figure 1: Comparison of density evolution for (a) ITB and non-ITB discharges and (b) 2002 campaign discharges

3. Relationship between the barrier position and the q profile

The relationship between the ITB structure and q profile have been investigated for a limited number of discharges. The q profiles and their error estimates were found using the CLISTE equilibrium code [1], constrained with MSE data. In order to achieve this the curvature penalties in the code were relaxed until the closest possible fit to the MSE and magnetic measurements was found. The error bars for the q profile were estimated by increasing the curvature penalties until the fit to the MSE data was just within acceptable MSE error bars of 0.28 degrees. Figure 2 shows a q profile with calculated error bars. Note that the error on the q profile increase dramatically towards the center of the plasma. Unfortunately the discharges used to investigate the global formation criterion did not have MSE data available, hence another set of discharges were analysed, these had 5 MW or 7.5 MW NBI power, I_p ramped up at a rate of approximately 1MAs^{-1} up to a maximum of 0.8MA or 1MA, and with the plasma in an inner limiter or upper single null plasma configuration. The position of the foot and the top (i.e. top of the steep gradient region) of the barriers were found manually by approximating the best fit to the ion temperature profile data and the errors on these positions were estimated by finding the worst fit to the data.

On comparison of the position of the foot of the barrier with q_{min}, see figure 3, we find that $\rho_{pol,foot}$ increases with decreasing q_{min} value, i.e. the barrier becomes broader as q_{min} decreases. However, all the broadest ITBs are at later time-points, which is in agreement with DIII-D and JT-60U results [2] which found that ITBs become broader with time.

Therefore it can not be determined what leads to the broader barrier: the value of q_{min} or the longer time, which is needed to arrive at lower q_{min} values via current diffusion.

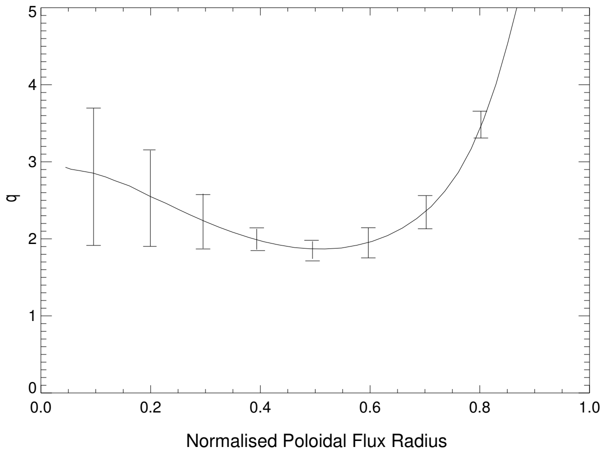

Figure 2: q profile for discharge 13149 and error bars

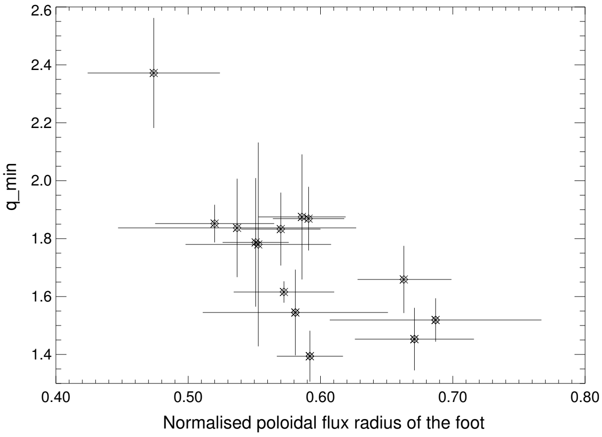

Figure 3: Normalised poloidal flux radius of the barrier foot plotted against the minimum value of q

From figure 4(a) it can be seen that all of the ITBs are positioned with their foot in the positive shear region and their top in the negative shear region, thus the ITBs encompass all of the negative and some of the positive shear region up to $\hat{s} \approx 1$. Also this plot shows that the shear and the position of the barrier foot are linearly related, i.e. the broader the barrier the higher the shear at the foot (or vice versa). This is related to the plot in figure 4(b) which shows that all of the ITBs are located with their foot at a larger radial position than q_{min} and the broadest ITBs lie with their foot further outside the $\rho_{pol,qmin}$ position (i.e. their shear is larger). On the DIII-D experiment it has been found that ITBs are not limited to the negative shear region [2], in fact with low power (5MW) the ITB is confined to the core of the plasma and with increased power (7.5MW) it moves farther out possibly into the positive shear region [3]. Research at JET also shows that ITBs can develop that encompass both the negative and positive shear regions, but that shear is always less than 1 inside the barrier [4].

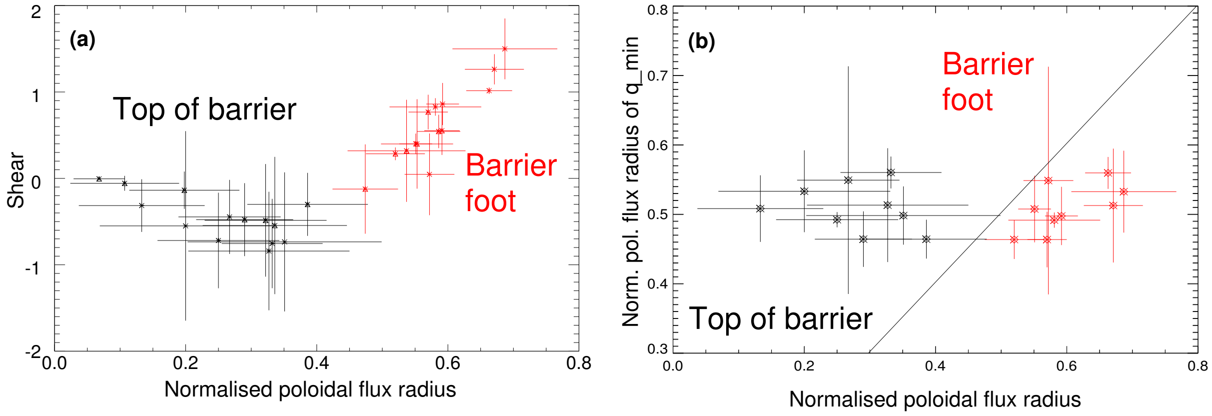

Figure 4: Comparison of (a) $\rho_{pol,foot}$ and $\rho_{pol,top}$ with $\hat{s}$ and (b) $\rho_{pol,foot}$ and $\rho_{pol,top}$ with $\rho_{pol,q_{min}}$ for ITB discharges

4. Conclusions

ITBs on ASDEX Upgrade form only at low densities. Broad barriers are facilitated by low q_{min} or later time or a relationship between the two. Also the broadest ITBs have $\rho_{pol,foot}$ lying further outside the $\rho_{pol,q_{min}}$ position. ITBs on ASDEX Upgrade can encompass some of the positive shear region , up to $s \approx 1$, as well all of the negative shear region.

References

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