EUROFUSION WPJET1-PR(16) 15606

A Wynn et al.

Scrape-Off Layer density shoulder formation & evolution in JET

Preprint of Paper to be submitted for publication in
43rd European Physical Society Conference on Plasma Physics (EPS)

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Scrape-Off Layer density shoulder formation & evolution in JET

A. Wynn[1], B. Lipschultz[1], G. Matthews[2], B.Tal[3], F. Militello[2], N. Walkden[2] C. Guillemaut[4], J. Harrison[2] A. Huber[5], U. Kruezi[2], M. Brix[2] , A. Nielsen[6], S. Wiesen[5], E. Joffrin[7], D. Frigione[8] and JET contributors*

*EUROfusion Consortium, JET, Abingdon, UK,[1] York Plasma Institute, York, UK, [2]Culham Centre for Fusion Energy, Abingdon, UK [3]Wigner Research Centre for Physics, Budapest, Hungary [4]Instituto de Plasmas e Fusao Nuclear, Lisboa, Portugal [5]Forschungszentrum Jülich Gmbh, Institut für Energie- und Klimaforschung – Plasmaphysik, Jülich, Germany [6]Association Euratom DTU, Roskilde, Denmark, [7]Association EURATOM-CEA, Cadarache, France, [8]Associazione EURATOM-ENEA sulla Fusione, Rome, Italy *Appendix of F. Romanelli et al., Proc. of the 25th IAEA FEC 2014, St Petersburg, Russia*

The plasma flux to the main chamber has significant influence on impurity sources, first-wall lifetimes and through recycling, core confinement[1]. The appearance of shoulders and the subsequent broadening of the scrape-off layer (SOL) density profile indicates radial transport is non-diffusive[2,3]. Indeed convective, filamentary structures, observed on many machines [4], likely dominate the radial transport at the first wall and may lead to shoulder formation

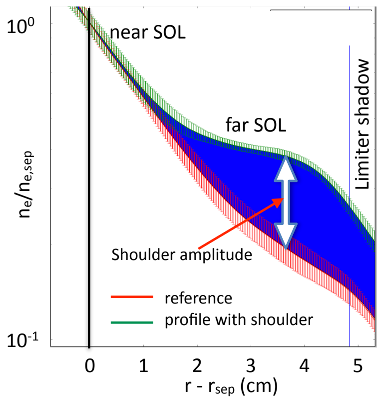

Figure 1:Example and definition of the shoulder

The density shoulder is quantified here as the maximum difference of a given density profile, normalised to the separatrix density, compared to a reference, low density profile where the divertor is in the sheath-limited regime. This quantity will be referred to as the shoulder amplitude (figure 1).

There are several potential mechanisms which may control shoulder formation. Mechanisms in the main chamber SOL, or upstream, include firstly the ionisation of neutrals, locally fuelling the SOL and secondly, the change to filament properties based on core plasma parameters, (e.g. core density $<n_e>$, plasma current I_p or others). Mechanisms in the divertor region, or downstream, include firstly increasing electrical resistance, expressed as a collisionality at the divertor target, $\mathbf{\Lambda}_{div}$, influencing filament properties. Secondly, neutral processes in the divertor region could affect the upstream SOL indirectly.

Recent analysis of L-mode ASDEX and JET plasmas concluded $\mathbf{\Lambda}_{div}$ is a control parameter for shoulder formation[5]. The results here suggest $\mathbf{\Lambda}_{div}>1$ may be a necessary condition, but it is not sufficient; another mechanism is responsible. Additionally, upstream neutral ionisation is not responsible.

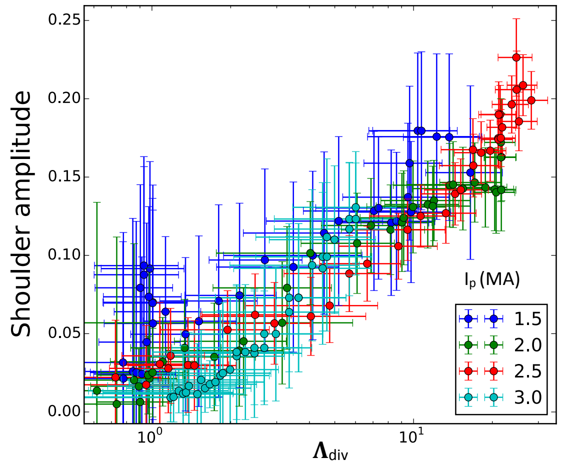

Figure 2: Shoulder amplitude as a function of divertor collisionality, $\mathbf{\Lambda}_{div}$ .For all I_p the shoulder forms at $\mathbf{\Lambda}_{div}$=1-3.

To study the potential mechanisms which lead shoulder formation, our experimental pulses varied <n_e>, I_p, divertor configuration and input and seeding gases.

As a first step, a set of Ohmic density ramps were performed, with varying I_p =(1.5,2.0,2.5,3.0)MA, at fixed q_{95} = 3.1, in horizontal target configuration (outer strike point on Tile 5). The discharge was fuelled via D injection into the private flux region (PFR) and the divertor low field side (LFS) SOL. The divertor conditions ranged from sheath-limited to detached at all I_p. The upstream SOL n_e profile was measured using the Li beam diagnostic [6]. Figure 2 shows the shoulder amplitude as a function of $\mathbf{\Lambda}_{div}$ = $3.4\text{x}10^{-15}L_{//}n_{e,div}/T_{e,div}^2$, for all I_p, calculated using divertor Langmuir probes. $L_{//}$ ~60m is the field line length from mid plane to Divertor, $n_{e,div}$ and $T_{e,div}$ are the electron density and temperature at the divertor target respectively. $\mathbf{\Lambda}_{div}$ was calculated using divertor Langmuir probe data lying in flux surfaces between 0-1cm outside the mid-plane separatrix. Note that the shoulder forms 2-3cm from the separatrix referenced to the mid-plane (figure 1) where there were no corresponding divertor target Langmuir probe data. Nevertheless, the data of figure 2 shows that shoulder forms at values of $\mathbf{\Lambda}_{div}$ = 1-3 inline with previous results from ASDEX and JET [5] which used λ_n to characterise the shoulder and calculated $\mathbf{\Lambda}_{div}$ at points corresponding to r-r_{sep}=1.5cm at the mid-plane. The results of Fig. 2 are particularly strong in that the study was done over a wide range of plasma currents and densities. In terms of divertor condition, shoulder formation occurred at the transition from sheath-limited to high-recycling transport regimes, not at divertor detachment [5].

When changing the outer strike point to the vertical divertor target (outer strike point on Tile 7), for the same range of <n_e>, core T_e and mid-plane pressures as the horizontal target, with I_p = 2.5MA, the shoulder is not present, as shown in figure 3(a). Given that the same mid-plane pressures are achieved as a function of <n_e> in both horizontal and vertical targets, the absence of shoulders with vertical target suggests ionisation of neutrals in the SOL is not playing a significant role in shoulder formation, in line with observations of density shoulders on MAST [7]. Such a general equivalence of the upstream conditions for the two divertor configurations, together with

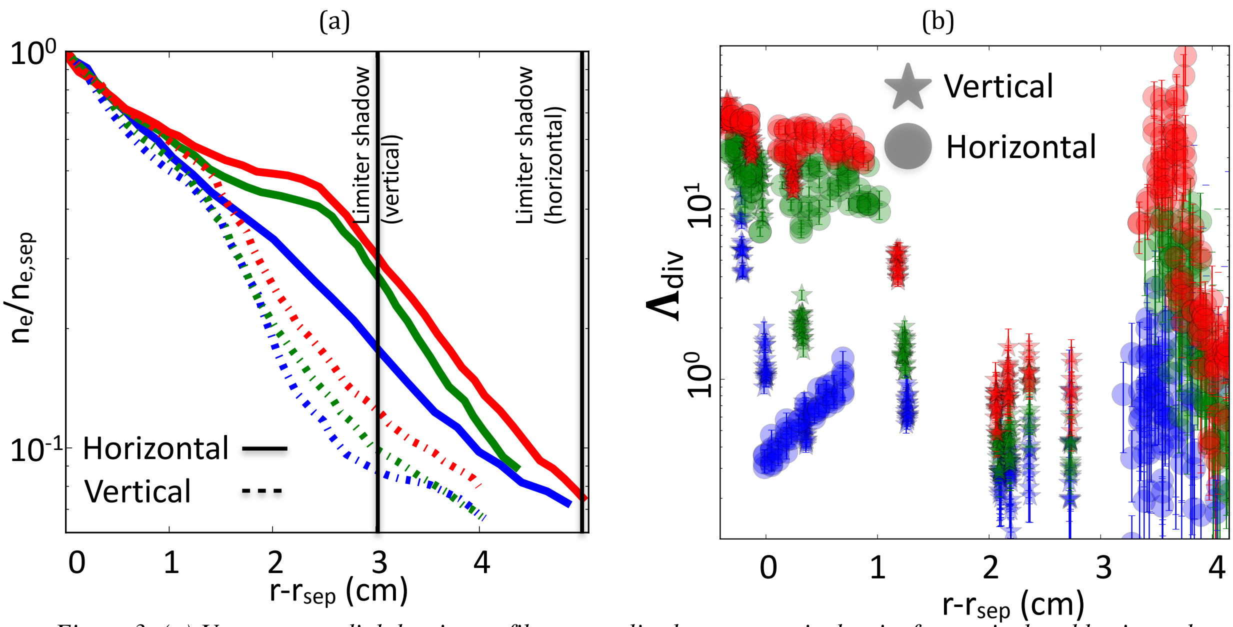

Figure 3: (a) Upstream radial density profiles normalised to separatrix density for vertical and horizontal divertor configurations. (b) Corresponding radial profile of divertor collisionality $\boldsymbol{\Lambda}_{div}$*, mapped upstream.*

the lack of shoulder formation in vertical configuration indicates that the mechanism dominating shoulder formation is in the divertor region. Regarding the role of $\boldsymbol{\Lambda}_{div}$, its value is comparable near the separatrix in both configurations, but low (~1) for the vertical target in regions where the shoulder should form ($r\text{-}r_{sep}$=2-3cm). However, given the lack of data there for the horizontal target we cannot make a proper comparison.

As another test of the role of upstream vs downstream effects, N injection was used to increase $\boldsymbol{\Lambda}_{div}$ whilst keeping upstream conditions approximately constant. Due to its sticking property, N levels built up in the machine during successive N seeded pulses. The N injection rate into the LFS SOL, with horizontal divertor configuration, was ramped from 0-1.5e22e/s over 10s. In the period prior to N injection in the first pulse (D_2 fuelling only), a low amplitude shoulder formed at $\boldsymbol{\Lambda}_{div}$=5, consistent with the data of figure 2. During the subsequent N injection in the same pulse, $\boldsymbol{\Lambda}_{div}$ increased to 50 with no further increase of shoulder amplitude. After multiple N seeded pulses, the N remaining in the machine, along with a standard D_2 fuelling, led to shoulders forming at $\boldsymbol{\Lambda}_{div}$=20 (see figure 4), indicating $\boldsymbol{\Lambda}_{div}$>1 is not a sufficient general condition to induce shoulder formation, although it may be a necessary condition. Based on the effect of N injection on shoulder formation we cannot rule out that changes in $\boldsymbol{\Lambda}_{div}$ are a consequence of shoulder formation and not a controller of it.

The studies presented explore the proposed mechanisms for shoulder formation. Upstream D ionisation will locally fuel the SOL, but the absence of the shoulder formation in vertical target

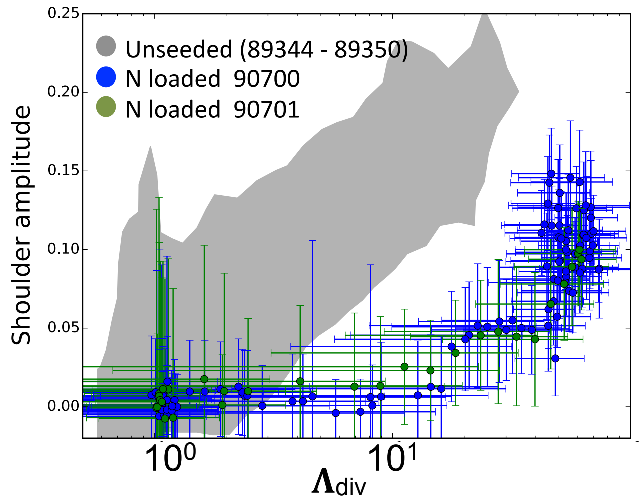

Figure 4: Shoulder amplitude as a function of divertor collisionality, Λ_{div}, for N seeded and unseeded pulses. The grated area is the same data as figure 1.

indicates it is insufficient to cause the shoulder formation. The general equivalence of the upstream conditions, in vertical and horizontal target, localises the mechanism responsible for shoulder formation to the divertor region. Furthermore, N injection into the LFS SOL decoupled $\mathbf{\Lambda}_{div}$ and the formation of the shoulder, indicating $\mathbf{\Lambda}_{div}$ is not the general control parameter, nor $\mathbf{\Lambda}_{div}>1$ the sufficient and necessary condition. Therefore another mechanism must be responsible and it appears to be some aspect of divertor condition. Progressing towards the identification of the control mechanism, the results presented here indicate that one or more neutral processes in the divertor are responsible. The lack of effect of N upon the shoulder in comparison to D provides direction for further investigation. With regard to implications for future devices, the results here suggest that modifying the downstream conditions via N does not contribute to the shoulder formation.

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. This work was also part-funded by the RCUK Energy Programme under grant EP/I501045. The views and opinions expressed may not reflect those of the European Commission. This work was supported by the Engineering and Physical Sciences Research Council [EP/K504178/1]

[1]Challis C et al, *Nucl Fusion* 55 (2015) 053031
[2]McCormick K, et al, *J. Nucl. Mat* 196-198 (1992) 264
[3]LaBombard B et al., *Nucl. Fusion* 40 (2000) 2041
[4]D'Ippolito DA et al, *Phys. Plasmas* 18 (2011) 060501
[5]Carralero D et al, *Phys. Rev. Lett.* 115 (2015) 215002
[6]Brix M et al, *Rev. Sci. Instrum.* 83 (2012) 10D533.
[7]Militello, F et al, *Nucl. Fusion* 56 (2015) 016006
[8]Stangeby PC, *The Plasma Boundary of Magnetic Fusion Devices,* IoP Publishing
[9]Militello F et al, *Nucl. Fusion Letters* submitted