Parameter dependence of small Edge Localized Modes

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Introduction

H-mode is the most promising candidate for the operation of future fusion devices. Its improved confinement comes along with periodically occurring edge localized modes (ELMs) which crash the edge transport barrier, degrade the pedestal and cause high stress on the divertor and the plasma facing components [1]. Control, mitigation or suppression of ELMs is therefore a widely researched topic. This work focuses on a special type of these instabilities called small ELMs, which occur at high density, highly shaped, close to double null plasmas [2, 3, references therein]. They cause less strain on the plasma facing components and could, therefore, be a possible scenario for ITER and DEMO.

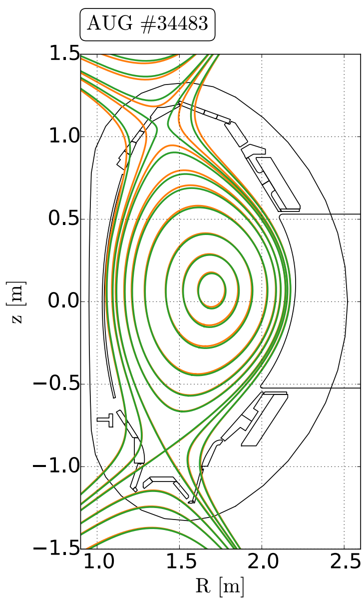

Figure 1: *Close to double null equilibrium of ASDEX Upgrade (orange) and z-shifted downwards (green).*

The z - shift

At ASDEX Upgrade, the standard recipe to achieve a plasma with small ELMs at high density consists of a start-up with a high deuterium gas puff followed by an upward shift of the plasma close to a double-null shape. Figure 1 shows the magnetic equilibrium of such a shape close to double null (orange) with radial distance between the separatrix and the secondary separatrix (of the upper x point) of $\Delta r_{\text{sep}} = 12\,\text{mm}$.

Previous experiments on ASDEX Upgrade suggest that closeness to double null is crucial for small ELMs to occur while simultaneously keeping a good confinement [3]. To further examine this dependence, a set of experiments was conducted with a constant gas puff, shifting the plasma slowly downwards, away from the double-null configuration. Figure 2 shows time traces of a discharge (#34483, $B_{\text{T}} = -2.5\,\text{T}$, $I_{\text{P}} = 1\text{MA}$) where a small ELM phase is achieved with a

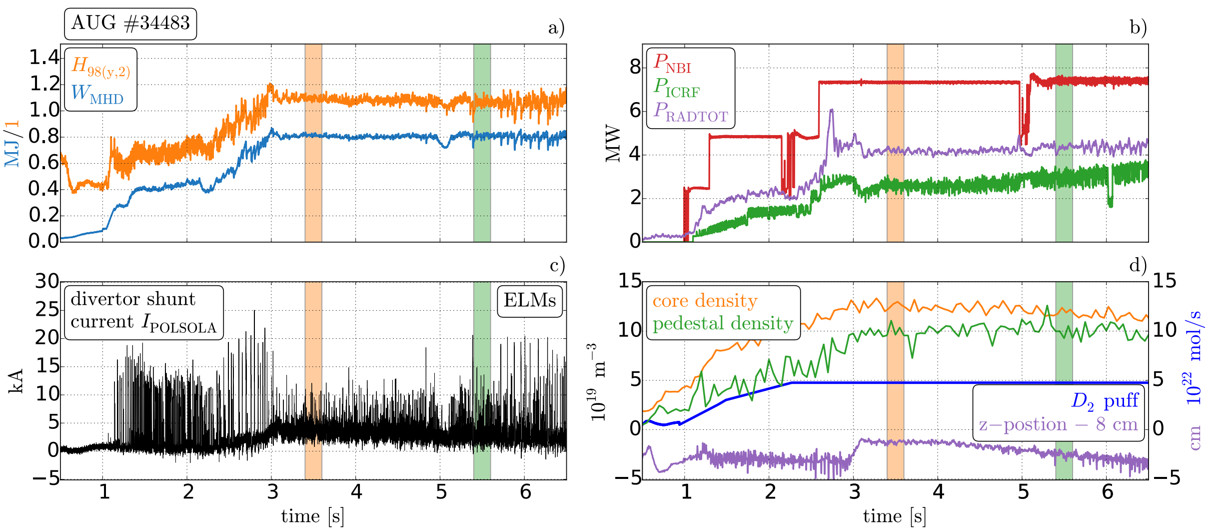

Figure 2: *Time traces of a) stored energy (W_{MHD}) and H-factor ($H_{98(y,2)}$), b) heating power of neutral beams (P_{NBI}) and wave heating (P_{ICRF}) as well as radiated power (P_{RAD}), c) outer divertor shunt current as ELM indicator and d) core (green) and pedestal electron density (orange) measured by the Thomson scattering diagnostic, Deuterium gas puff (dark blue) and the z position of the magnetic axis shifted by* ~ 1.5 cm *(purple).*

high gas puff and an upwards shift of the plasma to create a close to double null shape at 3.0 s which is later (at 4.0 s) reduced by shifting the plasma back down again. The confined energy W_{MHD} stays constant at 0.8 MJ (figure 2 a, blue) while the ITER confinement time scaling factor $H_{98(y,2)}$ is around 1.1 (figure 2 a, orange).

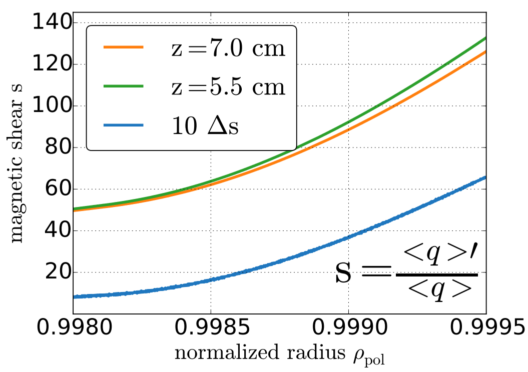

Figure 3: *Global magnetic shear of the two different time points defined in figure 2.*

The NBI and ICRF heating power (figure 2 b, red and green) was kept constant. The outer divertor current shows the ELM behaviour in figure 2 c. The gas puffing rate (figure 2 d in dark blue) is not changed after 3.0 s and also the plasma density stays constant. The purple time trace in figure 2 d shows the vertical (z) position of the magnetic axis being shifted downwards from 4.0 s onward. This changes the ELM characteristics with a gradual reappearance of larger ELMs. Figure 1 shows the plasma shapes of the two time windows indicated in figure 2. As the magnetic axis is shifted downwards by 1.5 cm, the top of the plasma changes significantly while the lower x-point remains in the same position. The aim of the downward shift was to reduce the plasma shape's closeness to a double null configuration. This is apparent in the difference of the two separatrices, which goes from $\Delta r_{sep} = 12$ mm to 17 mm, representing a

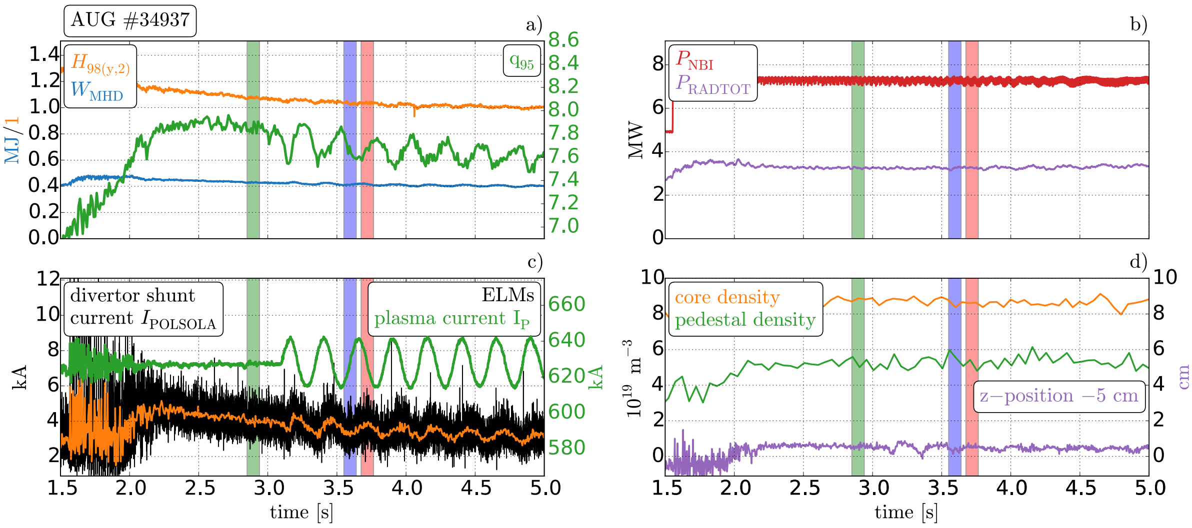

Figure 4: *Time traces of a) stored energy (W_{MHD}), H-factor ($H_{98(y,2)}$) and safety factor (q_{95}) b) heating power of neutral beams (P_{NBI}) as well as radiated power (P_{RAD}), c) outer divertor shunt current as ELM indicator (black) and plasma current with modulation (green) d) core (green) and pedestal (orange) electron density measured by the Thomson scattering diagnostic, and the z position of the magnetic axis shifted by* $\sim 5\,\mathrm{mm}$ *(purple).*

shift of the second separatrix from $\rho_{pol} = 1.011$ to $\rho_{pol} = 1.019$. Figure 3 shows, that the z-shift also changes the magnetic shear very close to the separatrix, which could explain the changing ELM behaviour i.e. the small ELMs becoming smaller when the shear at the seperatrix is higher while at the same time the large ELM amplitudes grow.

Modulation of the plasma current

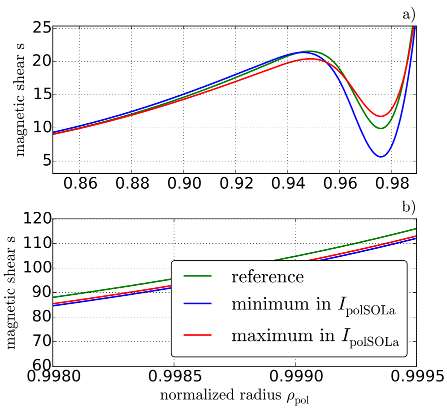

Figure 5: *Global magnetic shear of the three different time points in figure 4 pedestal region a) and close to the separatrix b).*

The analysis of the z-shift discharge points to a dependence of the size of the small ELMs on the magnetic shear. To further examine this dependence an additional plasma discharge (#34937, $B_T = -2.5\,\mathrm{T}$, $I_P = 0.6\,\mathrm{MA}$) was performed on ASDEX Upgrade where the plasma current was modulated in order to change the edge magnetic shear. Figure 4 shows time traces of such a discharge where a small ELM phase is again achieved with a high gas puff and an upwards shift of the plasma to create a close to double null shape at 2.0 s. W_{MHD} stays constant at 0.4 MJ (figure 4 a, blue) while the ITER confinement time scaling factor $H_{98(y,2)}$ is around 1.0 (figure 4 a, orange) and the safety factor at 95% flux (figure 4 a, green) is between 7.5 and 8 after 2.0 s. The NBI heating power (figure 4 b, red) was kept constant. The outer divertor current shows the ELM behaviour in figure 4 c. Figure 4 c also shows the plasma current with the planned 4 Hz $\pm$12.5 kA modulation on top of the constant 625 kA starting at 3.1 s. The plasma density (see figure 4 d) edge/green and core/orange) as well as the vertical (z) position of the magnetic axis (shown as the purple time trace in figure 4 d stay constant from 2.0 s onward. The plasma current modulation changes the divertor current signal, modulating it with 4 Hz but with a phase shift. A minimum I_{polSOLa} can be found at the rising flank of I_{P} (blue) and a maximum at the falling flank (red). A third time-point is marked in green before the current modulation for reference. The 4 Hz modulation can also be seen in the safety factor q_{95} being in antiphase (+180°) with I_{P}. Figure 5 shows, that the plasma current modulation affects the magnetic shear further inward than the z-shift (around the pedestal top) with neither a big change in the kinetic profiles nor the amplitude of the small ELMs. This could be due to the fact that, in this high q discharge the critical ballooning parameter $\alpha_{\mathrm{crit}} \propto \frac{q^2}{B^2}\nabla p$ (described in [3]) is already reached at a lower pressure gradient ∇p and the plasma is already far in the small ELM regime. As the modulation of the plasma current affects many quantities, further work is needed to decorrelate the different plasma parameters. The change of the shear suggests, that the modulation technique is a promising way to investigate the $s-\alpha$ parameter space of small ELMs.

Acknowledgement

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