

## Core versus edge confinement in JET with the ILW compared to the CFC first-wall.

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## INTRODUCTION

The baseline type I ELMy H-mode scenario has been re-established in JET with the new W MKII-HD divertor and Be-main wall (hereafter called ITER-like wall, ILW).

A steady state H-mode profile database has been constructed from high quality kinetic diagnostics. It contains plasmas with low ( $\delta \sim 0.2-0.3$ ) and high ( $\delta \sim 0.38-0.42$ ) triangularity with both the CFC wall and the ILW. For the CFC wall, the database contains both baseline (BL) ELMy H-mode plasmas  $q_{95}=2.8-3.6$  as well as Hybrid H-mode plasmas with  $q_{95}=3.5-4.2$  and plasma current in the range 1-3MA [1,2]. For the ILW plasmas, the database contains baseline ELMy H-mode plasmas at  $q_{95}=2.8-3.6$ ,  $I_p=1.0-2.5$ MA and hybrids plasma at  $q_{95}=3.6-4.3$  with  $I_p \approx 1.5$ MA. The low triangularity ILW hybrids have  $\delta$  larger than the corresponding CFC plasmas ( $\delta \sim 0.3$  for ILW and  $\delta \sim 0.22$  for CFC). The applied heating systems are mainly NBI for all plasmas and some ICRH for the baseline plasmas ( $P_{ICRH}/P_{NBI} < 0-10\%$ ). The electron density and temperature parameters (pedestal heights and profiles) are obtained from the High Resolution Thomson Scattering diagnostic [3].

## CONFINEMENT OVERVIEW

The thermal stored energy  $W_{th}$  for the CFC database and the ILW database is shown in figure 1(a) versus  $W_{98}$ . The thermal energy is calculated from the diamagnetic energy corrected for the fast particle losses while  $W_{98}$  is the thermal energy expected from the IPB98(y,2) scaling:

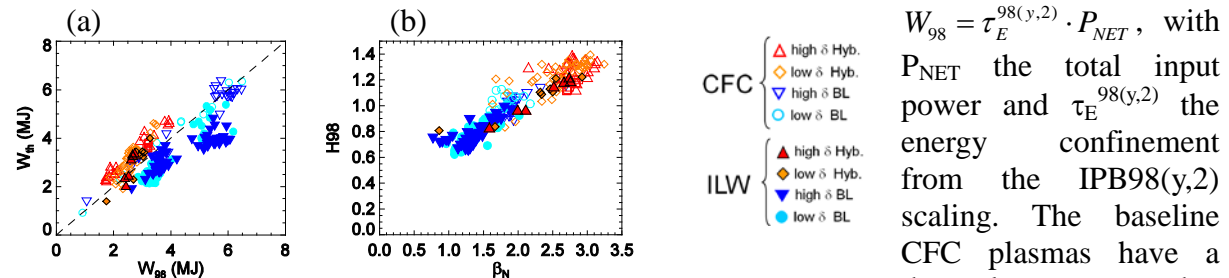


Figure 1. Frame (a): stored thermal energy obtained from the diamagnetic energy corrected for the fast particle energy versus the thermal energy expected by the IPB98(y,2) scaling. Frame (b)  $H_{98}$  versus normalized beta for CFC and ILW plasmas.

baseline ILW shots the thermal energy is lower than the expected  $W_{98}$ . Concerning the hybrid plasmas, the thermal energy is larger than  $W_{98}$  in both CFC and ILW shots. A clear overlap between ILW and CFC hybrids is present. This behaviour is reflected in the  $H_{98}$ , as shown in figure 1(b). In the hybrid scenarios,  $H_{98} > 1$  for both CFC and ILW plasmas. Instead baseline

$W_{98} = \tau_E^{98(y,2)} \cdot P_{NET}$ , with  $P_{NET}$  the total input power and  $\tau_E^{98(y,2)}$  the energy confinement from the IPB98(y,2) scaling. The baseline CFC plasmas have a thermal energy that follows the IPB98(y,2) scaling, while in many

CFC plasmas have  $H_{98} \approx 1$ , while only few baseline ILW shots reach  $H_{98} \approx 1$ . The few ILW hybrids with  $H_{98} < 1$  have low input power and/or high gas fuelling, as later discussed. Note the same trend of  $H_{98}$  versus the normalized beta for both CFC and ILW.

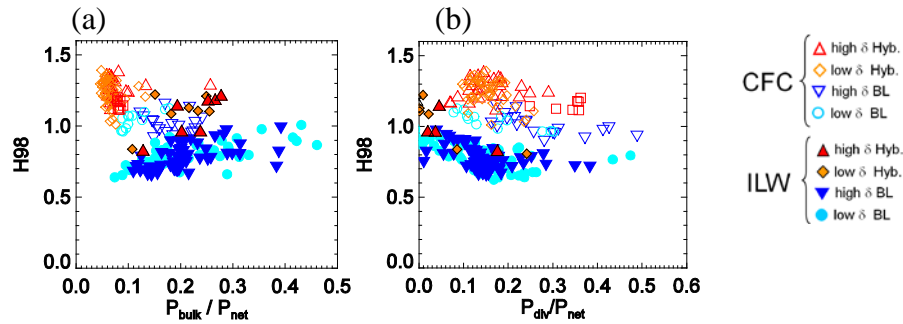


Figure 2. Confinement factor versus the power radiated by the bulk plasma normalized to the total input power (a) and versus the power radiated at the divertor normalized to the total input power.

The correlation of  $H_{98}$  versus the power radiated by the bulk plasma is shown in figure 2(a) and versus the power radiated at the divertor in figure 2(b). For CFC plasmas no clear trend is present within each scenario, even if globally a reduction of  $H_{98}$  with the  $P_{\text{bulk}}$  and  $P_{\text{div}}$  is present. For the baseline ILW plasmas, data might suggest a weak positive correlation between  $H_{98}$  and  $P_{\text{bulk}}/P_{\text{net}}$ . Note that the baseline ILW and CFC plasmas cover similar  $P_{\text{bulk}}/P_{\text{net}}$  ranges (even though ILW shots can reach higher  $P_{\text{bulk}}/P_{\text{net}}$ ). In ILW and CFC hybrids,  $P_{\text{bulk}}/P_{\text{net}}$  is different while the  $H_{98}$  is comparable. Concerning  $P_{\text{div}}$ , a negative trend of  $H_{98}$  vs  $P_{\text{div}}/P_{\text{net}}$  is present. This might be a side effect of the  $H_{98}$  degradation with the gas fuelling, as later discussed (figure 3a). CFC plasmas radiate a similar power from the bulk and at the divertor while in ILW shots  $P_{\text{div}}$  can be significantly lower than  $P_{\text{bulk}}$ . Finally, note that ILW shots with  $P_{\text{bulk}}/P_{\text{net}}$  and/or  $P_{\text{div}}/P_{\text{net}}$  similar to the CFC shots have lower  $H_{98}$ . These observations suggest that the radiated power is likely not the main source of difference between ILW and CFC shots.

Because of possible tungsten accumulation, ILW, a relatively higher gas fuelling is needed with the ILW.

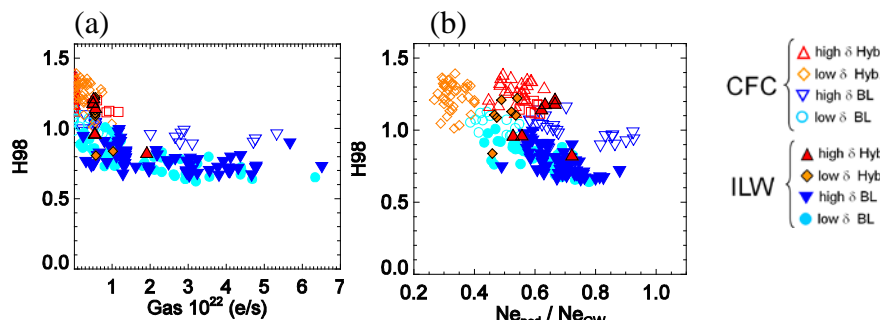


Figure 3. Confinement factor versus gas rate (a) and versus pedestal density normalized to the Greenwald density (b).

Therefore, an important parameter that might affect the confinement is the rate of the injected gas. The correlation between  $H_{98}$  and the gas rate is shown in figure 3(a). Globally a negative trend is present for both the CFC and the ILW shots, suggesting that a better performance can be obtained with lower fuelling. Within each ILW scenario, the trend is clear for the low  $\delta$  baselines, while for the high  $\delta$  baselines the scatter is relatively larger. An analysis over a subset of high  $\delta$  baseline plasmas with same  $I_p$ ,  $P_{\text{net}}$  and  $B_t$  shows a relatively clear trend. A detailed analysis of the pedestal behaviour for this subset shows that the improvement at low gas rate is related to the increase of the electron pedestal pressure due to a strong increase of the pedestal temperature accompanied by a weak reduction of the pedestal density.

Figure 3(b) shows the correlation of  $H_{98}$  with the electron pedestal density normalized to the Greenwald density. As already described in reference [4] for a set of baseline plasmas, a reduction of  $H_{98}$  is observed at high pedestal densities. This reduction is also present in this CFC database, both for baseline and hybrids plasmas. Note that at similar  $N_{e}^{ped}/N_{e}^{GW}$  the highest performances are obtained by the high triangularity discharges. For the ILW plasmas, the low  $\delta$  baselines follow the same trend of the corresponding CFC shots.

Note that ILW and CFC plasmas with the same normalized pedestal density have comparable  $H_{98}$ . The high  $\delta$  baseline ILW shots also have a negative trend, but their  $H_{98}$  is clearly similar to the low  $\delta$  ILW baselines. At the similar pedestal density, the high  $\delta$  ILW baseline clearly underperform if compared to their corresponding CFC shots, as if in ILW the shape affects less the confinement. From a quantitative point of view,  $H_{98}$  is in the range 0.9-1.1 for high  $\delta$  CFC BLs and 0.7-1.0 for high  $\delta$  ILW BLs.

The ILW hybrids are instead comparable to their corresponding CFC shots. The difference in the pedestal density between ILW and CFC low  $\delta$  hybrids is likely related to the fact that their shapes are not perfectly matching.

### GLOBAL AND PEDESTAL CONFINEMENT.

To investigate the origin of the low confinement in high  $\delta$  ILW baseline shots, figure 4(a) shows the energy confinement versus the input power. To avoid the spread of the data due to the fact that shots with different currents and fields are considered,  $\tau_E$  is normalized using the trend expected by the IPB98(y,2) scaling. Moreover, only the shots with  $I_p \approx 2.5$  MA are shown. The dashed lines represent constant  $H_{98}$  curves.

High  $\delta$  ILW shots have a power degradation that clearly follows the trend expected by IPB98(y,2) scaling. Note that at the same input power, ILW shots have normalized  $\tau_E$  lower than the corresponding CFCs. This lower confinement is clearly related to the pedestal temperature, as described in figure 4(b), where the normalized  $T_e^{ped}$  versus the normalized  $N_{e}^{ped}$  is shown. The dashed lines highlight the constant  $\beta_0^{ped}$  curves. The ILW and CFC plasmas have similar  $N_{e}^{ped}$ , but  $T_e^{ped}$  is  $\approx 30$ -50% lower in the ILW shots. As a consequence, the pedestal beta is approximately  $\beta_0^{ped} \approx 0.1$ -0.2 in ILW and  $\approx 0.2$ -0.3 in CFC.

The comparison of the global confinement for the low  $\delta$  baseline scenarios is shown in figure

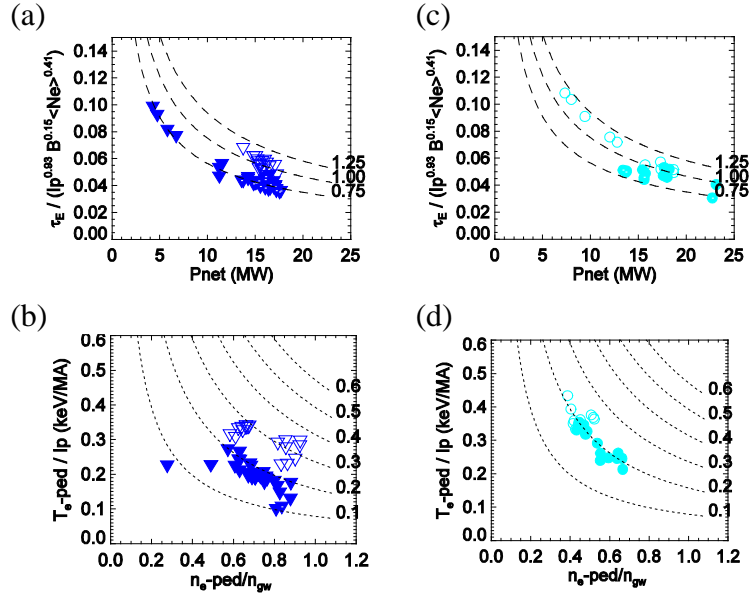


Figure 4. Baseline plasmas. Normalized energy confinement versus input power (a) and (c). Normalized pedestal temperature versus normalized pedestal density, frames (b) and (d). Symbol definition as in figure 1.

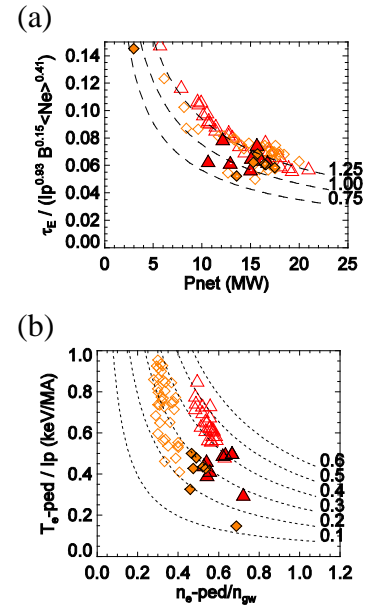


Figure 5. Hybrid plasma. Normalized energy confinement versus input power (a). Normalized pedestal temperature versus normalized pedestal density, (b). Symbol definition as in figure 1.

4(c). For this scenario the normalized  $\tau_E$  is comparable between ILW and CFC shots with similar input power. This is due to the fact that the pedestal parameters can be relatively similar, as shown in figure 4(d). On average, the ILW shots have higher pedestal density and lower pedestal temperature than the corresponding CFC shots, but they both lie on the same constant beta curve, at  $\beta_{\theta}^{\text{ped}} \approx 0.2$ . Note that the low  $\delta$  ILW shots with pedestal density similar to the CFC shots have also similar pedestal temperature.

The hybrids shots are described in figure 5. Excluding the ILW shots with low input power and/or high gas fuelling, the normalized  $\tau_E$  is comparable between ILW and CFC plasmas, figure 5(a). ILW hybrids can reach a pedestal density similar or slightly higher than the CFC shots, while the pedestal temperature is comparable or slightly lower. This is again related to the fact that the pedestal confinement is relatively similar, being  $\beta_{\theta}^{\text{ped}}$  up to 0.4 and 0.3 for the ILW high and low  $\delta$  shots respectively and  $\beta_{\theta}^{\text{ped}}$  up to 0.4-0.5 and 0.2-0.4 for the CFC high and low  $\delta$  shots respectively.

### PROFILE PEAKING

To investigate more in detail the role of the electron temperature and density profile in the confinement, in figure 6(a) the temperature and density gradient length,  $R/L_{Te}$  and  $R/L_{Ne}$ , calculated at  $\rho_{\text{tor}} \approx 0.6$  are shown versus the collisionality. As described in references [1,2,5], a negative trend in  $R/L_{Ne}$  is present for the CFC plasmas. The ILW shots have higher collisionality, but follow the same trend. Instead, for  $R/L_{Te}$  a positive trend is present for the CFC shots while no trend or a slightly negative trend is present for the ILW shots. In particular, at  $v_{\text{eff}} = 0.9$  the temperature gradient length are clearly different for ILW and CFC shots. These behaviours are shown in figures 6(b) and 6(c), where the normalized density and temperature profiles are shown. The profiles correspond to two high  $\delta$  baseline shots with  $v_{\text{eff}} = 0.9$ . While the density profiles are similar, the ILW shot (blue) is clearly more peaked in the core. This behaviour is consistent with the fact that the lower confinement in high  $\delta$  ILW baseline shots is mainly correlated to a reduced pedestal confinement.

### CONCLUSIONS

In conclusion, high  $\delta$  BL plasmas seem to underperform with the ILW compared to CFC wall mainly because of the lower pedestal  $T_e$ . Even if not shown in this work, preliminary results suggest that the  $N_2$  seeding in high  $\delta$  BLs increases the pedestal height, the stored energy and the confinement to values comparable to the CFC plasma. For low  $\delta$  BL plasmas the confinement is similar in ILW and CFC shots, provided a low gas rate. At high input power, ILW Hybrids plasmas have confinement relatively similar to the corresponding CFC plasmas. ILW hybrids with low confinement are related to low pedestal  $T_e$  due to low input power and/or high gas fuelling.

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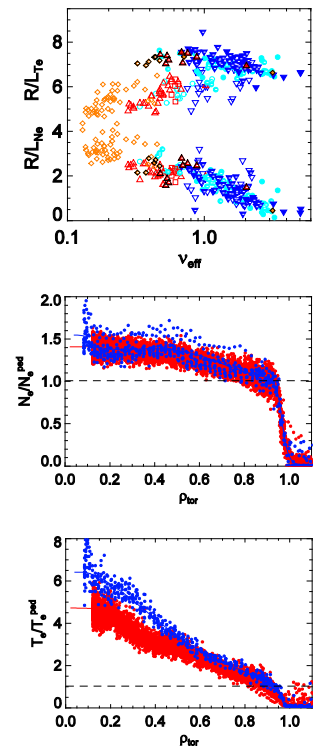


Figure 6. Gradient length at  $\rho_{\text{tor}} = 0.6$  (a). Normalized  $N_e$  and  $T_e$  profile for a ILW (blue) and a CFC (red) shot with  $v_{\text{eff}} = 0.9$  (both high  $\delta$  BL plasmas).