Dependence of Confinement and Transport on Triangularity in ASDEX Upgrade

J. Stober, O. Gruber, V. Mertens, F. Ryter, W. Suttrop, W. Treutterer
and the ASDEX Upgrade Team

*Max-Planck-Institut für Plasma-Physik, EURATOM-Association,
D-85748 Garching, Germany*

Introduction

One possible reason for the scatter of the energy confinement times τ_E with respect to the ITER scalings might be, that the shape of the plasma enters the scalings only via the elongation κ and higher moments such as the triangularity δ are ignored. In the previous campaigns of ASDEX Upgrade operation, δ was significantly lower than in other tokamaks such as JET and DIII-D, which have a strong weight in the ITER confinement database. If ideal ballooning plays a role at the plasma edge, δ is expected to have a strong influence on edge pressure gradients and via stiff profiles also on confinement. Recent modifications of the in-vessel components of ASDEX Upgrade now allow δ to be increased up to 0.35 instead of 0.18 which was possible before. Here and in the following, we define δ as the mean of the upper and lower triangularity of the separatrix. The analysis of the influence of δ is one of the key topics of the current campaign. The results concerning confinement are presented here, further aspects are treated in [2,6].

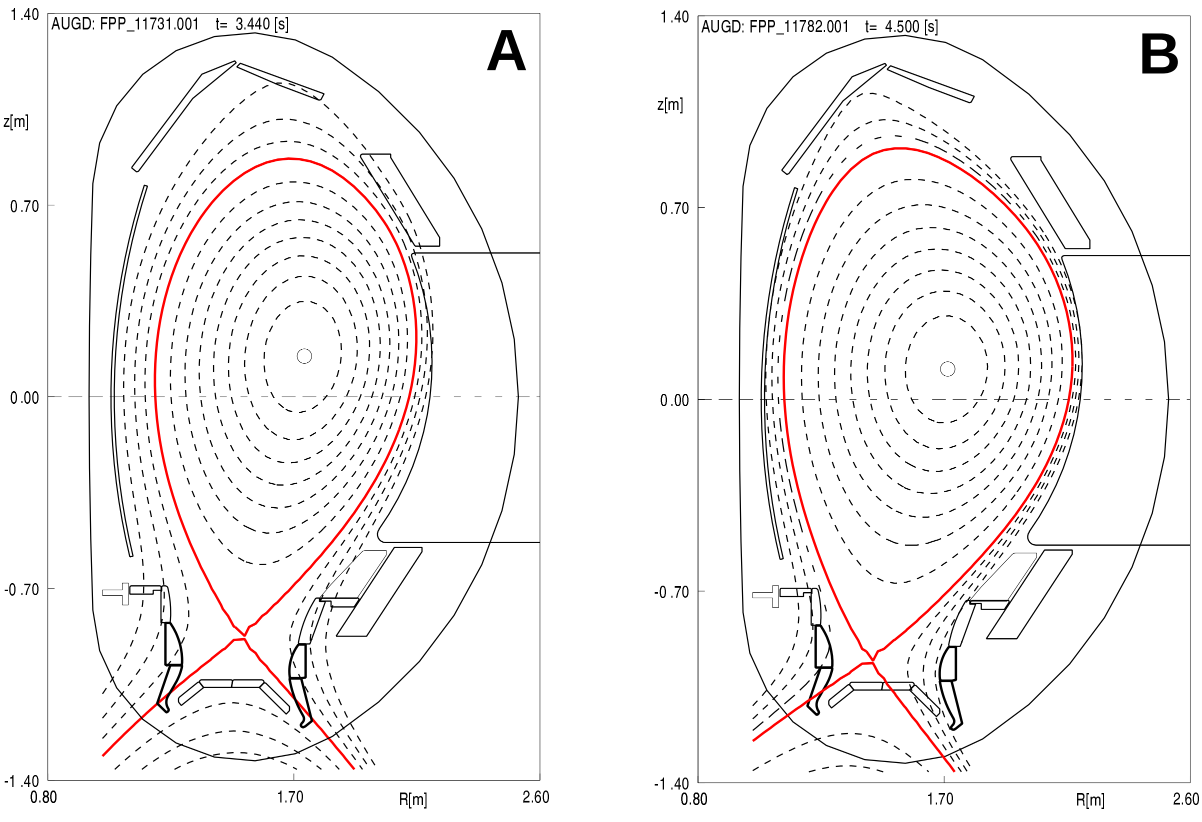

Figure 1: Equilibria for low triangularity (A: $\delta \approx 0.18$) and medium triangularity (B: $\delta \approx 0.30$).

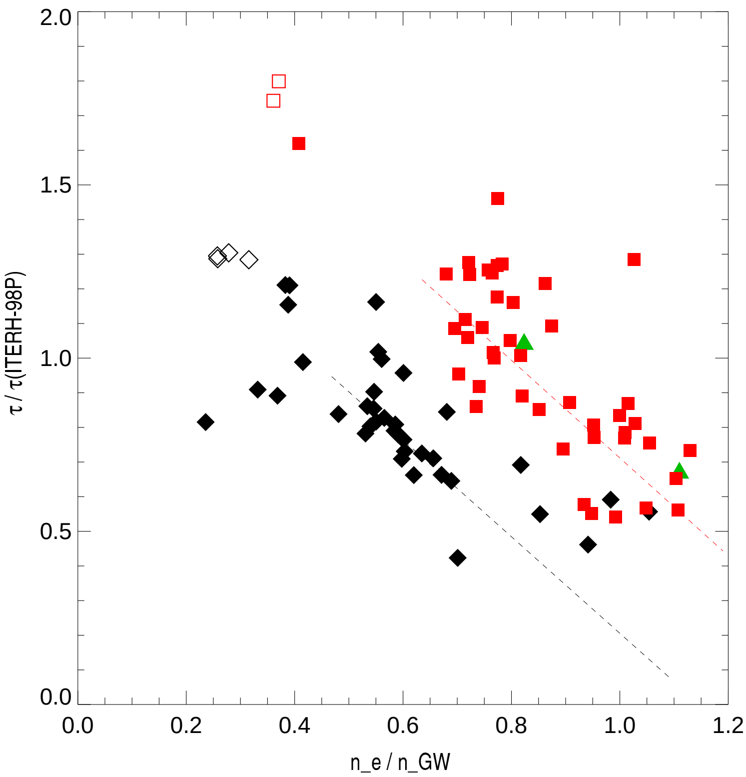

Figure 2: H-factor relative to the ITERH-98P scaling as function of $\bar{n}_e$ divided by the Greenwald density. Black diamonds correspond to $\delta \approx 0.18$, red squares to $\delta \approx 0.30$, green triangles to $\delta \approx 0.35$. Open symbols mean that an internal transport barrier exists.

Plasma shape and pumping

Fig. 1 shows the two equilibria which will be discussed in the following. Unfortunately, the medium triangularity plasma does not fit into the outer divertor. Since pumping is only possible through the bottom opening of the divertor, it is strongly reduced for $\delta = 0.30$, leading to a high natural density in this case. The major radius R and κ have been kept constant within a few percent, but the minor radius a is about 10 % larger for the higher δ. The plasmas with a high δ of 0.35 have not been studied systematically yet, due to limited experimental time.

Energy confinement

As reported earlier [1] increasing density in general reduces confinement at ASDEX Upgrade. An ordering parameter to describe the detoriation with respect to the ITER scalings is the ratio of $\bar{n}_e/n_{GW}$ where n_{GW} is the Greenwald density. Fig. 2 shows the confinement data of both triangularities versus the ratio of $\bar{n}_e/n_{GW}$. Data were taken only from stationary phases or weak density ramps with NBI heating up to 15 MW. For a given density, the confinement is better if δ is higher. Nevertheless, the confinement degrades as well with increasing density and the H-mode is lost close to the Greenwald density though this H-mode density limit is systematically slightly increased (see [2] for details). The data base had well overlapping parameters for both values of δ. q95 is centered in both cases around 4, varying mainly between 3 and 6, so that there is also an overlap in B_t. The most frequent current is 1 MA (additionally 0.8 MA and 1.2 MA for $\delta = 0.18$ and 0.6 MA for $\delta = 0.30$). It turned out, that δ does not modify the transport by changing the Type-I ELM behavior: We find a broad band of ELM frequencies for increased δ, but the product of ELM frequency and energy per ELM, i.e. the average heat flow due to ELM activity remains constant at the value of the low δ discharges [6]. The dashed lines indicating the confinement reduction with density are not the result of

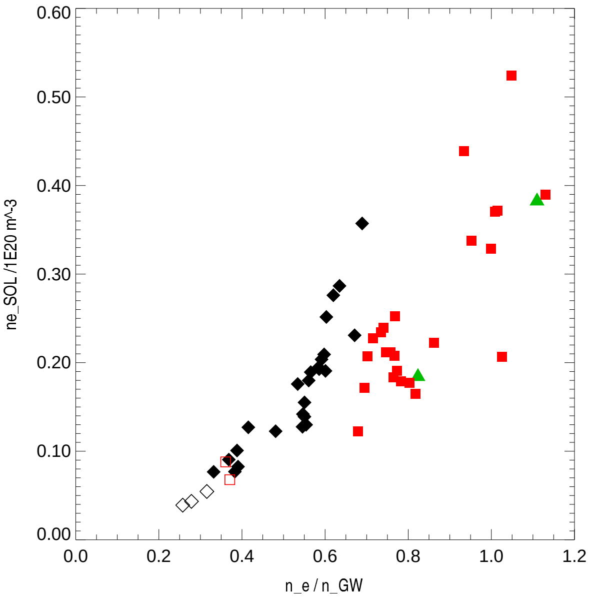

Figure 3: $n_e(SOL)$ as function of $\bar{n}_e/n_{GW}$. Meaning of colors and symbols as in fig. 2, data set reduced to points where $n_e(SOL)$ is available

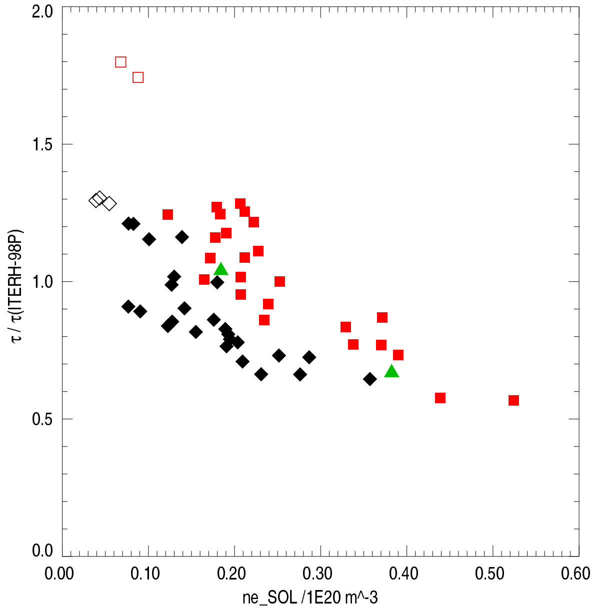

Figure 4: H-factor relative to the ITERH-98P scaling as function of $n_e(SOL)$. Meaning of colors and symbols as in fig. 2, data set reduced to points where $n_e(SOL)$ is available

a regression analysis, but are introduced by eye to compare to results from JET [3]. The slopes of the confinement degradation are very similar, but the absolute values of the H-factors for the high δ case in JET ($\delta = 0.38$) lie slightly below the $\delta = 0.30$ data of ASDEX Upgrade (the consistent definition of δ has been checked). On the other hand our two $\delta = 0.35$ data points do lie well within the the $\delta = 0.30$ points, which might be an indication that the beneficial effect of increasing δ saturates above this level. Further experiments with the high delta configuration will be performed soon to check this assumption on a statistically significant number of events.

Influence of gas puffing

It was checked that the scatter observed within the $\delta = 0.30$ data of fig. 2 is not due to variations in q95, B_t, or I. It has its origin in strong variations of the neutral gas flux outside the plasma which is closely related to the density in the scrape-off layer $n_e(SOL)$ averaged over 6 cm at low field side midplane. These variations are especially strong for the increased δ cases since the density feed-back loop was not adapted to the longer time constants for density control due to the reduced pumping. Fig. 3 shows how $n_e(SOL)$ varies for fixed $\bar{n}_e/n_{GW}$, but nevertheless these quantities are closely correlated. Using $n_e(SOL)$ instead of $\bar{n}_e/n_{GW}$, fig. 2 changes to fig. 4. This reduces the scatter of the data by almost a factor of 2. A detailed analysis of the influence of $n_e(SOL)$ on τ_E is presented in [4].

Transport

For the low-δ plasmas, transport in ELMy H-mode is governed by stiff temperature profiles, so that edge pressure gradient, pedestal width and density peaking mainly determine the energy content of the plasma [5]. The interesting question is if this stiffness will be broken at higher pedestal temperatures [7]. Unfortunately, this cannot be an-

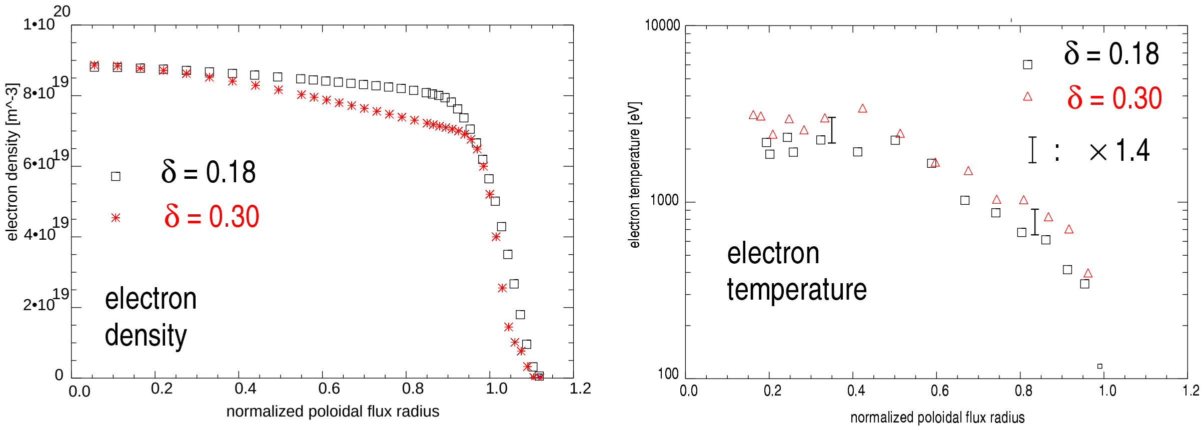

Figure 5: Comparison of electron density profiles (linear) and temperature profiles (logarithmic) of the ASDEX Upgrade discharges with $\delta = 0.18$ (#11746, 3.75 s) and $\delta = 0.30$ (#11783, 4.22 s). The bar in the T_e plot corresponds in the log-plot to a constant ratio of 1.4 as determined from the $W_m hd$ ratio.

swered yet although we obtained up to 50 % higher pedestal pressures for a given current [6] in accordance with ballooning limited edge pressure gradients, but since the natural density was high due to the reduced pumping this does not increase the temperature to values higher than those we achieved with low δ and good pumping. In the accessible density range the transport is also governed by stiff temperature profiles, as shown in fig. 5. Here we compare two shots with different δ but comparable density profiles (the one corresponding to the higher δ is slightly more peaked). The temperature profiles are self similar as can be seen by a roughly constant shift on the logarithmic plot. The factor corresponding to this shift is well in agreement with the ratio of the stored energies which is 1.41 corresponding to the vertical bars in the figure.

Conclusions

The triangularity of a fusion plasma seems to be a good engineering parameter to increase the confinement at densities close to the Greenwald density up to a level predicted by the ITER scalings. Nevertheless, the Greenwald density can not be overcome significantly and has therefore to be taken into account for future fusion devices. There is an preliminary indication, that the beneficial effect of increasing δ saturates above $\delta \approx 0.3$.

References

[1] Gruber, O. et al., Plasma Phys. Control. Fusion, 39, B19, (1997)
[2] Mertens, V. et al., this conference
[3] Saibene, G. et al., Europhys. Conf. Abstr., 22C, 341 (1998)
[4] Kallenbach, A. et al., this conference, invited paper
[5] Suttrop W. et al., Plasma Phys. Control. Fusion, 39, 2051, (1997)
[6] Suttrop, W. et al., this conference
[7] Janeschitz, G. et al., this conference