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1. INTRODUCTION

The removal of Helium in future fusion devices with significant alpha particle production is essential. The removal of the "ash" has to be effcient enough to provide a "clean" core plasma and to prevent from high throughput of the fuelling gas in the pumping system. We concentrate in this paper on the transport in the plasma edge, i.e. scrape-off layer and divertor. For an overview of the work on this topic done so far, the reader is referred to [1] and references therein. The exhaust studies in reversed B aimed on the understanding of the Helium and Deuterium edge transport towards the divertor by comparing the reversed and the forward B configuration.

The strike point position with respect to the pumping slot has a strong impact on the pumping efficiency (c.f. [1; 2]). This is mainly due to geometrical effects. This fact can be exploited for the analysis of particle transport in the scrape-off layer. We consider four different strike point positions as shown in figure 1. If e.g. a directed flow in the SOL exists, we would expect to see this in a change of the particle compression into the divertor when switching between the two asymmetric strike point configurations.

QUANTITATIVE DESCRIPTION OF THE PARTICLE EXHAUST

A sufficient helium pumping is achieved, if the helium pressure in the pumping chamber of the divertor is maximized. Additionally it is favorable to have a high helium concentration in the pumping chamber in order to keep the amount of fuel cycling in the pumping system as low as possible. To quantify these demands the particle compression into the divertor and the helium enrichment have been defined as figures of merit. The first quantity is defined as (e.g. [1]) the ratio between the neutral density in the subdivertor $n^{0}{}_{sdiv}$ and the ion density in the plasma $n^{+}{}_{plasma}$:

$$C_p = n^0_{sdiv} / n^+_{plasma} \tag{1}$$

The second quantity is the ratio between the helium concentration in the divertor and the plasma core:

$$\eta = C_p^{He} / C_p^D \tag{2}$$

Figure 2 shows the time traces of these parameters for the four strike point configurations. The discharges were heated with 5MW NBI power, the line averaged density is at about 2.5×10^{19} m^{-3}, plasma current is 2.4MA and the toroidal field is 2.5T. A flat-top phase (indicated by the blue regions) establishes after each injection of helium gas. The helium concentration ranges from 10% to 40%. It is usually measured by CXRS, however, for the forward field reference pulses this diagnostic was not available. We therefore estimated the core concentration for these cases from the divertor values. The neutral pressure of Deuterium and Helium in the pumping chamber of the divertor was measured by penning gauge spectroscopy [1]. The discharges compared here differ unfortunately in confinement: the discharges in forward B switch to H-mode with small dithering

ELM's if at least one strike point is place in the divertor corner, whereas the discharges in reversed B stay in L-mode for all configurations. However, this difference should not affect the analysis performed here. From the left figure we see, that the compression for both species drops in forward and reversed B configuration significantly when the two strike points are shifted upwards onto the vertical target plates away from the pumping slot. The right figure shows the cases with the asymmetric strike point positions. We find for the forward B case, that the compression for deuterium is higher if the outer strike point is placed in the corner. For the reversed B case it is higher if the inner strike point is placed into the corner. The same is true for helium although not that pronounced for forward B. This suggests that for forward B the inner divertor has a higher pumping ability compared to the outer divertor and vice versa for reversed B.

For the further analysis, we will now have a closer look onto the definition of the particle compression. We take for the ion density the volume averaged value and get for the particle compression $C_p = V_{plasma} N_{sdiv}/V_{sdiv} N_{plasma}$. The compression can be written in terms of the particle con¯nement time τ_p, the e±ciency for the divertor pumping ε_{pump}, the wall pumping ε_{wall} and the divertor screening ε_{screen} like

$$C_p = \frac{V_{plasma}}{V_{sdiv}} \frac{\tau_{pump}}{\tau_p} \frac{(1 - \varepsilon_{wall})\,\varepsilon_{pump}}{1 - (1 - \varepsilon_{wall})\,\varepsilon_{screen}} \tag{3}$$

This representation allows to separate the core transport from the edge and divertor effects. The compression is a function of the particle confinement time τ_p, but it depends also on the divertor properties: good screening abilities and a maximized pumping effciency results in a high C_p. The divertor pumping effciency is defined as the ratio of the ion flux arriving at the target plates $\Gamma_{||}$ and the neutral flux being pumped by the divertor pump

$$\varepsilon_{pump} = \frac{N_{sdiv} / \tau_{pump}}{\Gamma_{||}} \tag{4}$$

The divertor cryogenic pump is - if no argon frost is applied - only capable of pumping the deuterium but not the helium. A characteristic pumping time τ_{pump} of 22ms results from the pumping speed of about $110 m^3 s^{-1}$ and the volume of the subdivertor of about $2.5 m^3$. The ion flux to the divertor is measured by spectroscopic means observing the Dα light and a HeI line at 668nm. The particle fluxes are deduced using conversion factors of 20 ionizations per photon for deuterium and 110 for helium. The measured pumping e±ciencies are in the range of a few percent and we write C_p in the limit $\tau_{pump} \rightarrow 0$:

$$C_p = \frac{V_{plasma}}{V_{sdiv}} \frac{(1 - \varepsilon_{wall})}{\tau_p (1 - \varepsilon_{screen})} \tau_{pump}\, \varepsilon_{pump} + O(\varepsilon_{pump}^2) \tag{5}$$

Figure 3 shows the helium and deuterium compression as a function of the pumping effciency times the pumping time in order to give the values independently from the pumping speed. The particle compression is within the error margin linear in the pumping effciency. The effective confinement time $\tau_p^{eff} = \tau_p (1 - \varepsilon_{screen}) = (1 - \varepsilon_{wall})$ (c.f. equation 5) is about 15ms (forward B) to 20ms (reversed B) for deuterium and 50ms (forward B) to 60ms (reversed B) for helium. The shaded area indicates the deviation from these values by 25%. The C_p values for the *vv* configuration in forward field are higher because of the confinement degradation when switching to L-mode. The wall pumping can be assumed to be zero for Helium. Thus it follows, that either the core transport is faster for deuterium than for helium and/or the screeningeffciency is higher for deuterium. The latter is plausible since the ionization energy is higher for helium.

Since the particle compression is linear in the pumping effciency, changes in the overall divertor screening or the core confinement can be excluded when switching between the different strike point positions. The pumping efficiency itself depends mainly on the geometry. Thus if the particles preferentially flow to the inner divertor (forward B) or the outer divertor (reversed B) the pumping efficiency will be highest in the case of asymmetric strike point positions if the inner or, respectively, the outer strike point is placed into the corner. Such flows are indicated by Mach probe measurements [3]. However, the same is true if the screening efficiency is different in the inner and the outer divertor, which would also result in asymmetric particle fluxes to the divertor target. Nevertheless, to obtain asymmetric screening effciencies it needs a driving force to built up asymmetric plasma parameters in the divertor. Both mechanism - particle flow in the SOL and/or asymmetries in the divertor plasma - result in a higher particle flux in the inner divertor for forward B and in the outer for reversed B, which is confirmed by the ion saturation current measured by the target probes. The existence of such asymmetries has been for example reported in [4].

The maximum pumping effciency for deuterium achieved with the *cc* configuration is about 4%. The *vv* configuration results in less than 1% pumping effciency. The helium enrichment is around $0.4 - 0.7$ for forward B and $0.8 - 1.1$ for reversed B, where a higher pumping efficiency for helium is achieved. The lower enrichment for forward B might result from an over estimation of the helium core concentration. However, the enrichment factor is not representative without applying helium pumping, which will reduce the enrichment significantly.

CONCLUSIONS

It is the inner divertor which makes a larger contribution to particle pumping for forward B and it is the outer divertor in the case of reversed B. This results in a higher pumping effciency and a higher particle compression for deuterium and helium if the inner (forward B) or outer (reversed B) strike point is positioned close to the pumping slot. A particle flow in the scrape-off layer is a good candidate to explain the different pumping abilities of the inner and outer divertor.

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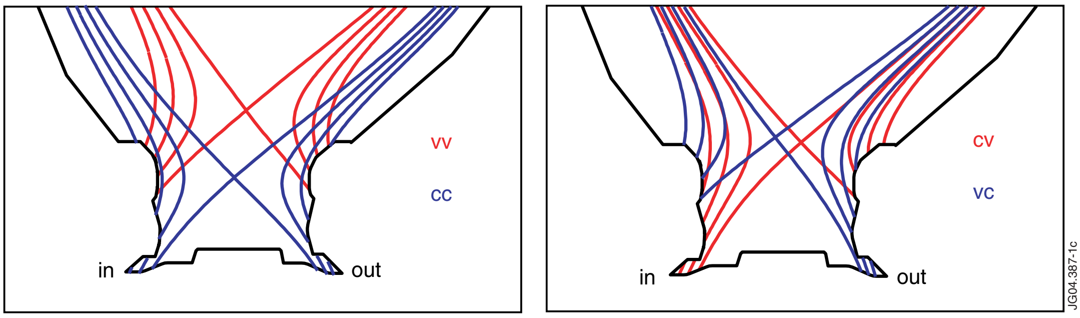

Figure 1: The four configurations of the strike point positions (e.g. vc means inner strike point at the vertical target and outer strike point at the corner position).

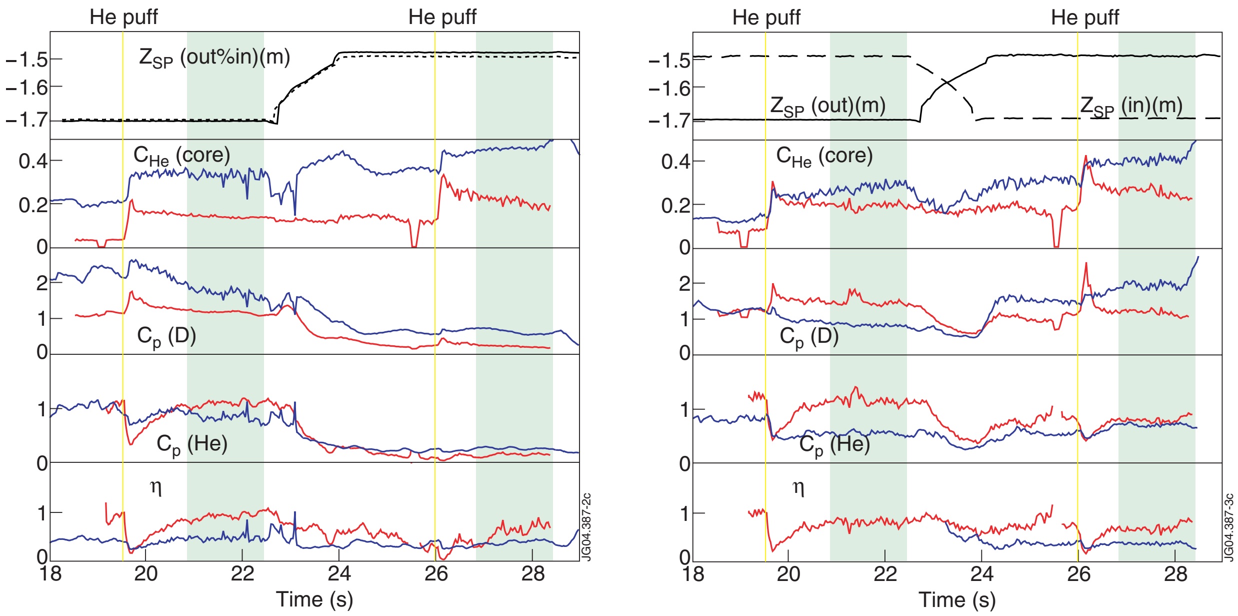

Figure 2: Typical time traces of the strike point position, the helium concentration, the pumping effciency, the compression and the helium enrichment. The left figure shows the symmetric strike point configurations (cc and vv), the right figure shows the asymmetric configurations (vc and cv). The data from reversed B is plotted in red, the forward case is given in blue. The relevant flat-top regions are marked with the blue boxes.

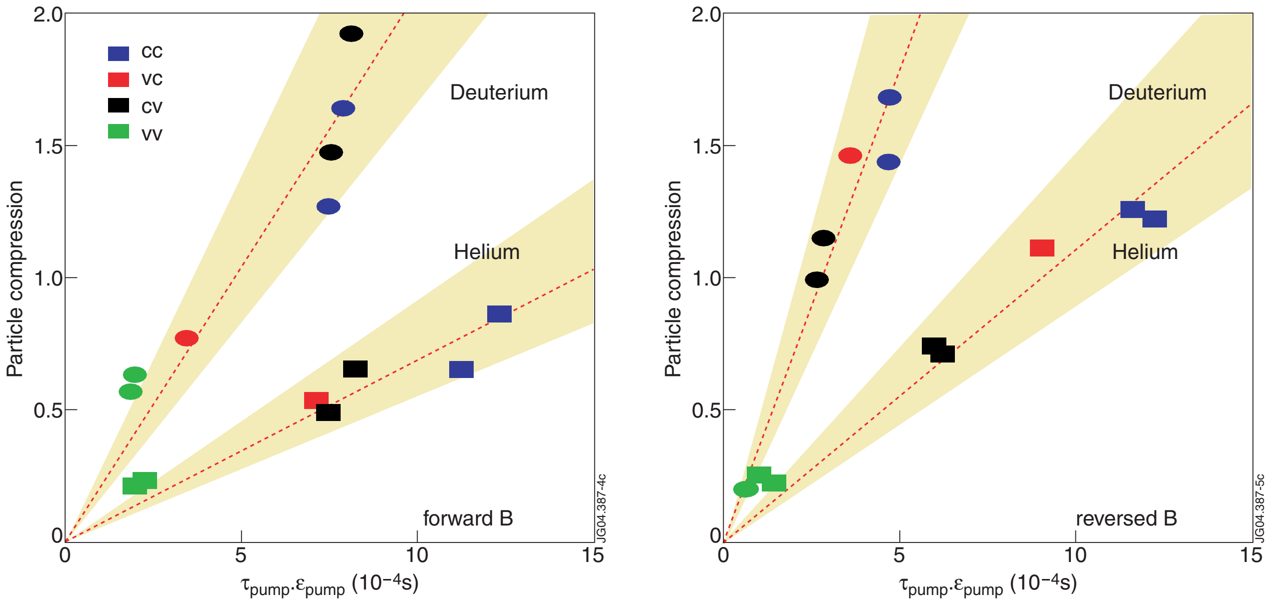

Figure 3: Particle compression for Helium and Deuterium as a function of the pumping effciency times the characteristic pumping time.