# Impact of 3-D fields on divertor detachment in NSTX and DIII-D

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The increasing input power and plasma current in the present and future tokamak machines naturally lead to more serious divertor and first wall heat flux problem. This is true for both the steady state and the transient ELM heat deposition. Therefore, the ELM control using the 3-D fields and the peak heat flux reduction technique with the divertor detachment must be compatible with each other. Partial divertor detachment both on the inboard and outboard sides has been demonstrated in the high performance H-mode plasmas in NSTX [1]. Results from NSTX have shown that partially detached divertor plasma can be re-attached by applying 3-D fields (n=3). However, this can be avoided when the detachment is enhanced by puffing sufficient gas into the divertor region [2].

A large amount of deuterium ($D_2$) gas is puffed into the lower divertor area through the 'CHI gap' between the inner and outer divertor plates in NSTX, for naturally ELMy H-mode plasmas to produce partially detached divertor condition, *i.e.* detachment only occurs near the strike point. A small amount of lithium (50 mg for the inter-shot evaporation, compared to ~300 mg necessary for the full ELM suppression) was used to condition the PFC surface. 0.2kA of n=3 error field correction field is applied first and then the n=3 perturbation field is superimposed for the 2$^{nd}$ half of the gas puff period. The amplitude of 3-D coil current ($I_{3\text{-}D}$ = −0.5 kA) is below the ELM triggering threshold that was confirmed from the ELM triggering experiment in the lithium enhanced ELM-free plasma. Plots in figure 1 are the calculated heat flux profile onto the divertor surface during the inter-ELM period, based on the dual band IR camera data [3]. Two levels of gas amount for the divertor puff were tested. Plot 1(a) is for the low gas puff (2000 Torr of pressure, estimated to be ~7x10$^{21}$ D/sec of particle flow rate) and 1(b) is for the high gas puff (3000 Torr of pressure, estimated to be ~11x10$^{21}$ D/sec of flow rate) case. Heat flux profiles in red are before the gas puff and are peaked near the strike point at r~38 cm in both cases, which indicates that the divertor plasma is attached. The blue profiles are obtained

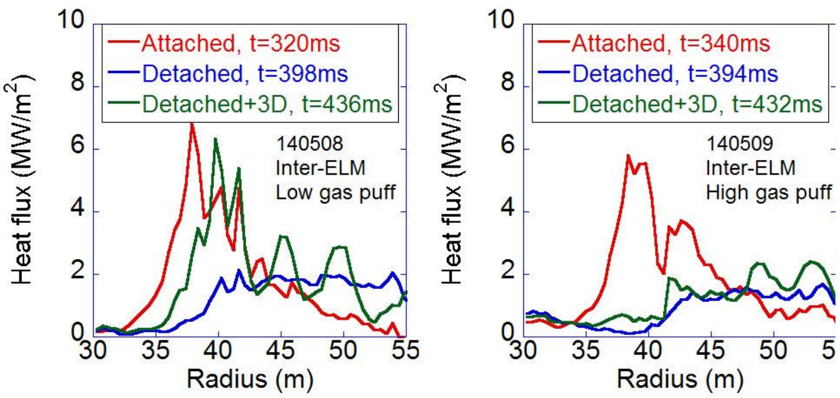

Figure 1 Measured heat flux profiles for discharges with divertor detachment in NSTX by (a) low and (b) high divertor gas puff ($D_2$). Each profile is color coded; red is before gas puff, blue is after gas puff, green is after gas puff plus 3-D field application.

after the detachment onset (by gas puff) but before the 3-D field application. The peak heat flux is reduced by ~70 % compared to those in the attached regime before the gas puff. It is also seen that the heat flux profile after the detachment onset is slightly higher for the low gas puff case. This is interpreted as a “weaker” detachment compared to the high gas puff case. The green profiles are after the 3-D field was applied to the detachment. It is clearly seen that the heat flux profile becomes peaked again in the low gas puff case; the divertor plasma re-attaches. However, it remains flat in the high gas puff case, which indicates that the plasma remains detached. Therefore, the 3-D fields can re-attach weakly detached plasma but this can be avoided by enhancing detachment with higher gas puff.

The evidence of detachment by divertor gas puff and re-attachment induced by the applied 3-D fields is also provided by spectroscopic data. High-n Balmer line emission, for example Balmer-10, provided by DIMS diagnostic [4] is a good indicative of volume recombination and is only present in the condition of low $T_e$ (< 5 eV) and high density. We thus use this signal as an indicator of divertor plasma condition. The radial distribution of line integrated Balmer-10 line emission intensity for the high and low gas puff cases shows that intensities near the outer strike point rapidly increases with the divertor gas puff, leading to the broadening of the emission profile. This continues to grow after the application of 3-D fields in the high gas puff case, but with the onset of re-attachment by 3-D fields in the low gas puff case, the process begins to reverse. This observation is consistent with the temporal evolution of surface heat flux profiles shown in figure 1.

A similar experiment was carried out at DIII-D to investigate the impact of n=3 3-D fields by I-coils on divertor detachment, which was established by upstream $D_2$ gas puff. 4 kA of coil current was applied with both even and odd parities. It was found that the plasma did not respond to the applied 3-D fields, *i.e.* there was no striation observed either in the heat or particle flux profile. Figure 2 shows contour plot of connection lengths ($L_c$) calculated by TRIP3D-MAFOT field line tracing code for an n=3 even parity case. While the vacuum approximation, figure 2(a), predicts a clear striation pattern, inclusion of linear, resistive plasma response from M3D-C[1] in the field line tracing shows reduction of striation, see figure 2(b). Work is in progress to model field line tracing for cases of clear striation with 3-D fields in order to check consistency with the experimental trend, and ultimately for comparison with results from a 3-D boundary transport code such as EMC3-Eirene using the B-field model with plasma response included.

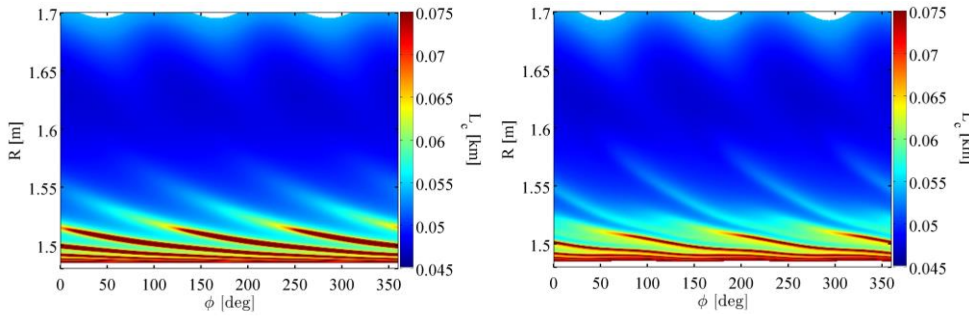


Figure 2 Calculated connection lengths ($L_c$) at the outer divertor surface from TRIP3D-MAFOT for the n=3 even parity I-coil application at DIII-D. The left plot is without plasma response and the right is with plasma response (from M3D-C[1] calculation) included in the field line tracing.

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## Reference

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