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ELM Suppression Characterisation by Plasma Response on ASDEX Upgrade

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Introduction. In ITER and future tokamaks, it is crucial that ELMs be strongly mitigated or entirely suppressed. Experiments on ASDEX Upgrade suggest that a sufficient edge peeling response is one of the necessary conditions for ELM suppression[2], and there are several reasons we may expect systematic differences in the peeling response of ELM suppressed and mitigated phases. Firstly, ELM suppressed phases have systematically lower densities than mitigated, so it is expected that they also will have a lower plasma β_N and hence a lower drive for the peeling response. Conversely, it is observed that immediately following a transition to ELM suppression there is a sudden and sustained increase in the density pump out[2]. A previously observed correlation between the peeling response and RMP induced pump out[3], therefore leads us to expect a larger peeling response in the suppressed phase. In this work the predicted peeling response in suppressed and mitigated phases are compared by conducing a computational survey of the edge peeling response in ELM suppression experiments, and the dependence of the peeling response on pedestal properties is studied using a numerical scan of the edge pedestal pressure gradient.

Peeling Response Survey. Using the magnetically constrained equilibrium reconstructions routinely produced by the CLISTE code[4] after all ASDEX Upgrade discharges, and fitted kinetic profiles of T_e, T_i, n_e and bulk ion impurity toroidal rotation v_T, a database of equilibria and kinetic profiles consisting of 148 timepoints from 22 discharges is assembled from ASDEX Upgrade ELM suppression experiments. Using the linear resistive MHD code MARS-F[5], the plasma response to the

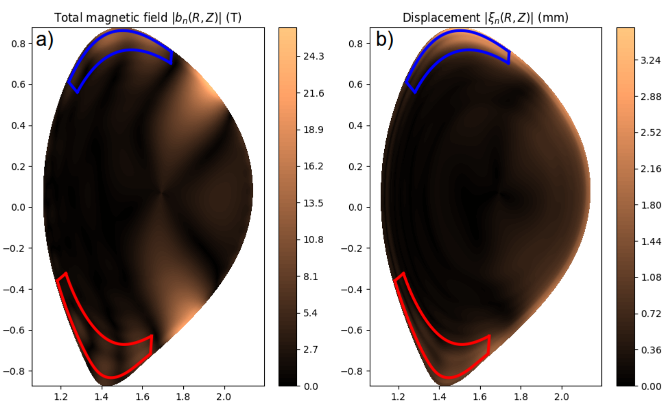

Figure 1: The peeling response typically manifests as a peak in the total field and displacement near the plasma X point and top, where the poloidal field is minimised. Data from 33353 at 2.325s. a) bnT and bnX are the maximum total magnetic field within the blue and red solid lines respectively. b) ξnT and ξnX are the maximum plasma displacement within the blue and red solid lines respectively.

experimentally applied RMP fields is computed for this database. Scalar metrics used to characterise the peeling response in this study are described in Figure 1. Figure 2a) plots the distribution of experimentally applied fields, and Figures 2c-f) plot the parameter space of the resultant plasma response metrics for suppression, and good and poor mitigation. For simplicity, in this work 'poor' and 'good' mitigation is crudely defined as f_{elm}<200Hz and f_{elm}>200Hz respectively. The figure shows that the peeling response is generally lower for poor mitigation than for good mitigation and suppression as expected, which is simply a consequence of the smaller applied field in the poor mitigation cases. The database points are chosen such that the applied fields for the suppression cases and majority of good mitigation cases are similar in PSL corrected amplitude, so any variation in the plasma response between the two sets should result primarily from differences in the plasma equilibria. The figure indicates that there is no discernible systematic difference between the peeling response of the ELM suppressed cases and the 'good' ELM mitigated cases. This finding confounds our expectation of the peeling response in suppression being either systematically larger than in mitigation as suggested by the increased density pump out, or smaller than in mitigation due to the lower β_N values of the suppressed phase.

<u>Pressure Gradient Dependence.</u> Current working theory[2] proposes that increasing the plasma triangularity boosts the edge pressure gradient *p'*, and thereby boosts the peeling

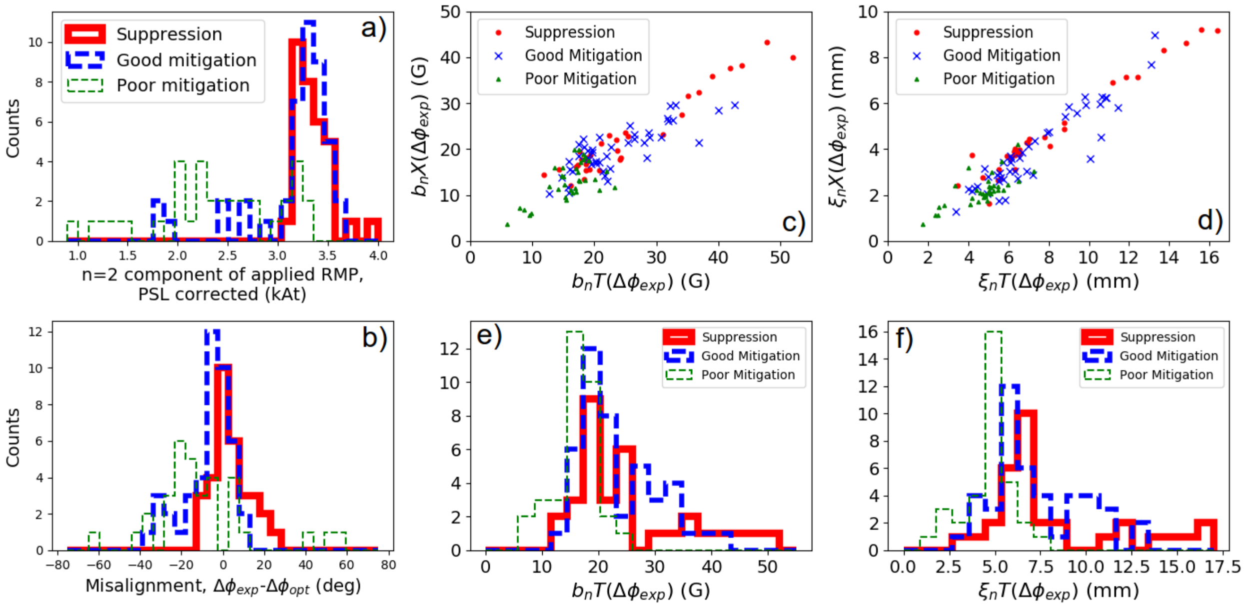

Figure 2: a) Distribution of the experimental RMP fields applied to the equilibria in the dataset, corrected for PSL attenuation. The points are chosen such that the fields applied to suppression and mitigation cases are comparable. b) Comparison of the applied coil phase difference with the optimal phase confirms that the applied phase was very close to optimal for the large majority of points used. Hence, coil phase is a controlled variable in this work. c,d) Plotting the computed plasma response metrics it is possible to map the plasma response 'space' occupied by mitigation and suppression. The plots indicate that the mitigation and suppression spaces overlap, as shown more clearly in histograms of the plasma response metrics, plots e) and f).

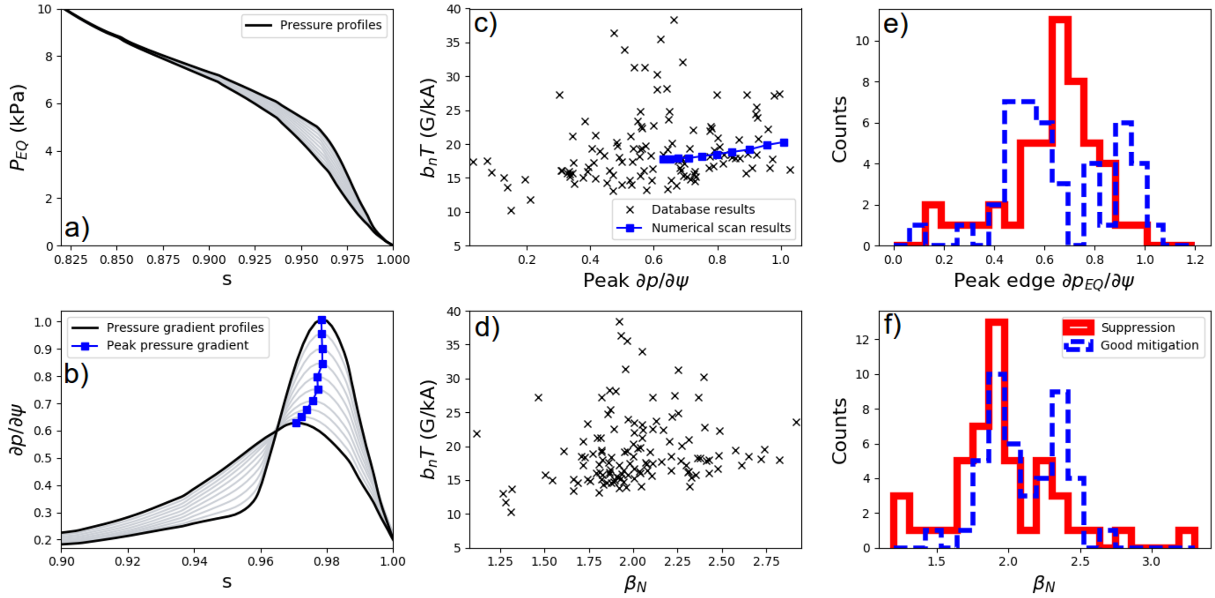

Figure 3: a) Using CLISTE a set of self consistent equilibria were produced which scan the edge pressure gradient. b) The edge pressure gradient was characterised by the peak pressure gradient in the edge region. c) A fixed 5kAt field (1kA current with 5 turns) was applied to the database of equilibria, and the peeling response plotted against the peak pressure gradient of the intershot equilibria (scattered crosses). Overplotted is the result of the numerical CLISTE scan (blue squares). d) The peeling response is plotted against the plasma β_N of the equilibrium database. Plots c) and d) show that the plasma response has a weak dependence on p' and β_N. It is also shown in plots e) and f), that the distributions of p' and β_N of mitigated and suppressed phases in the database contain little or no systematic difference, which is suggested here to be the reason for the prediction of no systematic difference in the peeling response between the suppressed and mitigated phases.

response, allowing easier access to ELM suppression. This theory would be supported by a strong dependence of the peeling response on *p'*, which is investigated numerically in this section. A numerical scan of *p'* was performed using the equilibrium code CLISTE[4], to produce a self consistent set of equilibria and kinetic profiles. Figures 3a) and b) plot the pressure and pressure gradient of the scan, and Figure 3c) plots the resulting peeling response (blue line and squares). Furthermore, the points of the input dataset are re-computed using a fixed 5kAt field, instead of the experimentally applied coil currents as in the previous section. The resulting peeling response is also plotted in Figure 3c) (black crosses). The plot shows an apparent correlation between edge pressure gradient and the peeling response as expected, however in both instances (the scan and the dataset) the sensitivity of the peeling response to *p'* is weak, showing an increase on the order of 20% over the range of pressure gradients. Figures 3e) and 3f) plot the distributions of *p'* and β_N of the equilibrium database, which shows the expected shift in the ELM suppressed phases towards lower β_N, but also shows that the suppressed and mitigated phases do not have systematically different pressure gradients. The intershot equilibria used in this study are constrained only by magnetic measurements. If there is a subtle difference in the edge pressure profiles of suppressed and mitigated cases, then it may be necessary to include kinetic constraints in the equilibrium reconstruction to resolve it. To quantify the uncertainty in the plasma response due to equilibrium uncertainty, a detailed comparison of the intershot equilibria with kinetically constrained equilibria, is ongoing and will be reported in a future work. The lack of systematic difference in edge pressure gradients of the mitigated and suppressed cases, and the weakness of the dependence of the peeling response on β_N and p', is suggested as a likely explanation for the lack of the expected systematic differences in peeling response between mitigated and suppressed phases.

Conclusion. Considering the known correlation between the computed peeling response and observed density pump out[3], the observation of an increase in the density pump out in ELM suppression[2] suggests an enhanced peeling response relative to the mitigated phase. Meanwhile, lower plasma β_N of ELM suppressed phases suggests the opposite. So we may expect the peeling response in suppression to be systematically higher or lower than in mitigation. However, a computational survey of the peeling response in suppressed and mitigated phases, finds no systematic difference in the peeling response between the two. Lack of difference in p', only marginal shift in β_N, and weak dependence of peeling response on p' and β_N, may be sufficient to explain why the peeling response in suppression and mitigation are apparently indistinguishable. This result implies that the additional transport responsible for the enhanced density pump out observed in the suppressed phase, is not correlated with an enhanced peeling response as it is in the mitigated phase. This suggests that the mechanism of enhanced pump out observed in ELM suppression is distinct from, rather than being an extreme case of, the pump out mechanism present in ELM mitigation. While linear computations of the plasma response have been effective for developing predictors of ELM mitigation, this study suggests that this approach may struggle to produce predictors for ELM suppression, the physics of which may be more subtle than a linear single fluid MHD model can resolve.

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