Peaked Density Profiles in Low Collisionality H-modes in JET, ASDEX Upgrade and TCV

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Synopsis. Results from an extensive database analysis of JET and AUG density profiles in H-mode, show that the density peaking factor $n_{e0}/\langle n_e\rangle$ increases to above 1.5 as the effective collisionality defined as $\nu_{eff} \propto R_0 n_e/T_e^2$ drops to near 0.1, as expected for ITER (fig.1). On any single device density peaking is also strongly correlated with the Greenwald number N_G and the particle outward flux Γ from the neutral beam source.

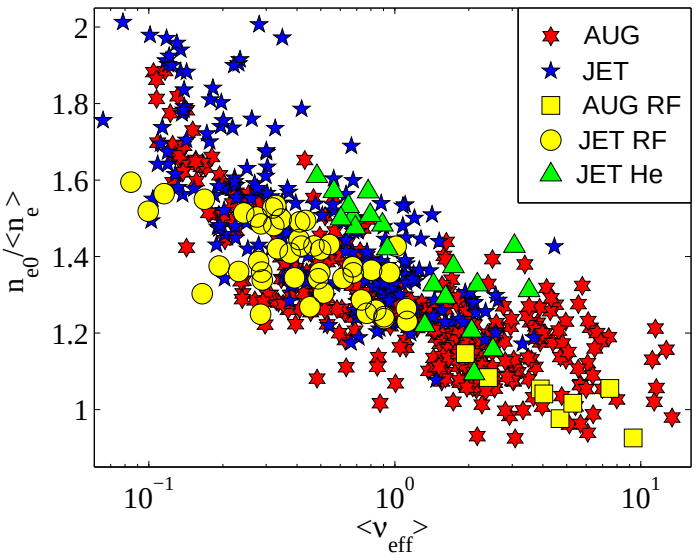

Figure 1. Peaking factor versus collisionality.

The recent combination of the JET and AUG databases has allowed to lift colinearities between ν_{eff}, N_G and the particle source, identifying ν_{eff} as the statistically most relevant parameter for density peaking. Correlations with l_i, q_{95}, β_N, ρ^*, L_{Te}, L_{Ti} , the toroidal Mach number and its shear are weak. H-modes heated only by ICRH (yellow squares and dots on fig.1) are on average only slightly less peaked than H-modes dominated by NBI, demonstrating that neutral beam fuelling can only explain a modest part (<20%) of the peaking. The contribution of the Ware pinch to peaking is only a few percent and decreases towards low ν_{eff}. Calculations of neutral penetration in D plasmas using the DOUBLE Monte Carlo code show that the peaking is too strong to be accounted for only by the edge source and diffusive transport. This is confirmed in discharges using He as a working gas. These plasmas are not less peaked than D plasmas (fig.1) with otherwise identical plasma parameters, experimentally demonstrating, due to the low cross-section for double charge

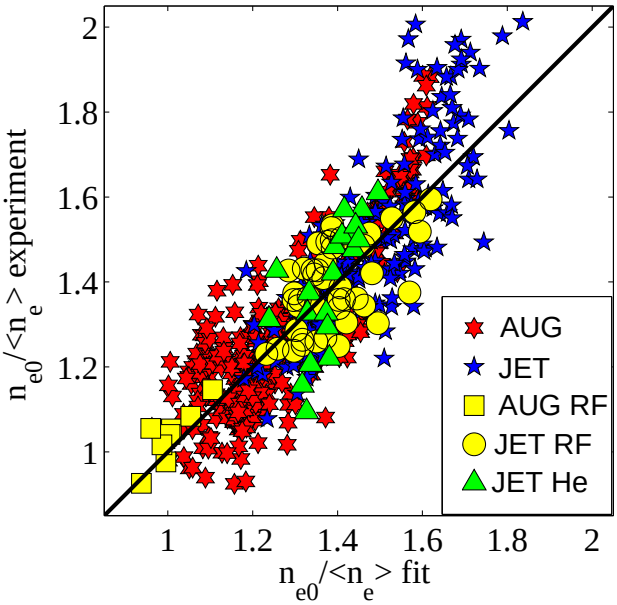

Figure 2. Example of combined scaling using JET and AUG databases: $n_{e0}/\langle n_e\rangle_{fit}=1.02\,\nu_{eff}^{-0.11}q_{95}^{-0.1}\beta^{-0.04}\delta^{-0.04}\rho^{*-0.063}\Gamma^{*0.02}$ *, where* Γ^* *is a dimensionless NBI source term*

exchange (CX), that density peaking is not explained by edge neutrals penetrating by successive CX reactions. Scaling expressions using the combined database (fig.2) yield a prediction of $n_{e0}/<n_e>$ ~1.5 in ITER, providing a boost of fusion power of 30% for fixed β and N_G with respect to the usual assumption of a flat density profile.

Since neither the Ware pinch, nor the core particle source are sufficient to explain the peaked density profiles, we conclude that they must be due to an anomalous pinch. A collisionality dependence of the anomalous pinch, which is qualitatively consistent with observations in H-mode, is predicted by gyrofluid drift wave turbulence models. The gyrokinetic code GS2 however only provides a significant pinch at collisionalities well below those achieved in the experiments. The lack of dependences of peaking on magnetic shear and L_{Te}, which would be consistent with a curvature pinch and anomalous thermodiffusion, is also at odds with theory. The fact that density profiles tend to be flatter at low values of T_i/T_e is however in qualitative agreement with predictions. A theoretical expectation for a reactor is that the large core electron heating by slowing-down alpha particles may strongly destabilise TEM's. TEM's drive a thermodiffusive outward flux, which may lead to partial or complete flattening of the density profile and a reduction of the associated benefit. This cannot be tested at JET yet because purely ICRH heated H-modes in JET only have β_N~1, due to a lack of available power. However purely electron heated H-modes with $\beta_N\cong2$ and $T_e/T_i\cong2$, recently obtained in TCV using ECH, show that flattening is only partial and significantly peaked density profiles ($n_{e0}/<n_e>$~1.6 in TCV) persist in electron heated regimes at reactor relevant values of β_N.

Peaked density profiles may have important consequences for a reactor, such as an increased susceptibility to NTM's due to the larger bootstrap current and a proneness to heavy impurity accumulation. On the positive side, peaked density profiles provide a boost in fusion performance which may in part preempt the negative consequences of a lower than expected density limit [1].

[1] K. BORRASS et al., Nuclear Fusion **44** (2004) 752