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Particle Transport and Density Profile Behaviour in TCV

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The observation of peaked density profiles in tokamak plasmas, which are dominated by turbulent transport, is still eluding a satisfactory theoretical description. The aim of this paper is to present and temptatively interpret density profile behaviour in a wide range of conditions in the TCV tokamak in the framework of two potential turbulent particle transport mechanisms, Turbulent Equipartition (TEP) and Turbulent Thermodiffusion (TTD).

Electron temperature and pressure profiles, as well as sawtooth inversion radii in L-mode tokamak discharges are known to scale with $1/q_a$ in plasmas with circular cross sections [1]. This generalises to a scaling with $\langle j\rangle/(q_0 j_0)$ in shaped plasmas [2,3] such as exemplified in fig.1. This parameter is easily evaluated with an equilibrium code, or alternatively, can be accurately approximated from global plasma parameters, even for extremely shaped plasma cross sections [2].

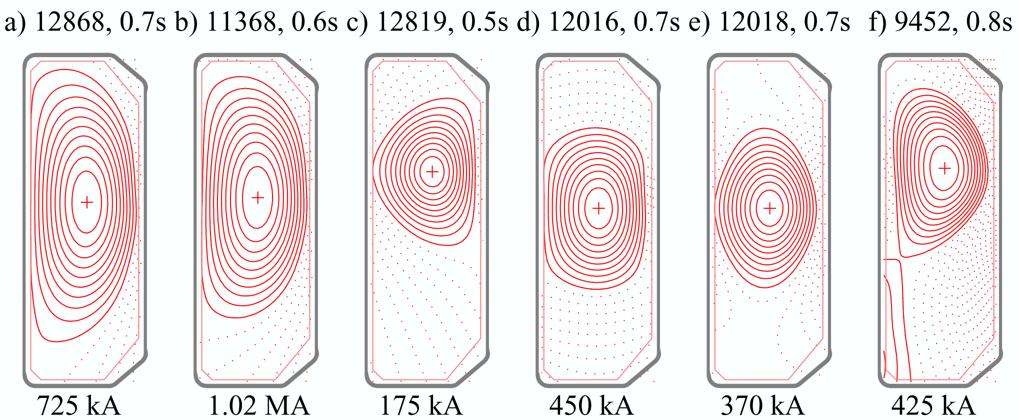

Fig. 1 Examples of discharge cross sections in the dataset under investigation

A scaling with $j\rangle/(q_0 j_0)$ is also observed for the electron density profile peaking in TCV, implying the existence of an inward particle pinch and a dependence of particle transport coefficients on this scaling parameter. Fig.2 shows typical density and temperature profiles in

Ohmic L-mode plasmas as a function of $\rho_{vol} = \sqrt{V/V_{LCFS}}$, where V is the volume enclosed

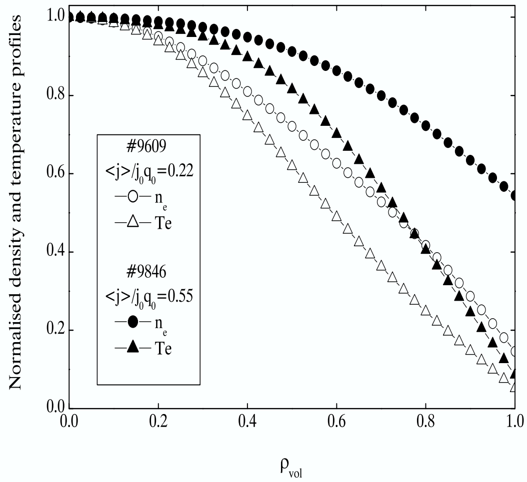

Fig. 2 Examples of electron density and temperature profiles at different values of $\langle j\rangle/(q_0 j_0)$ in Ohmic L-modes.

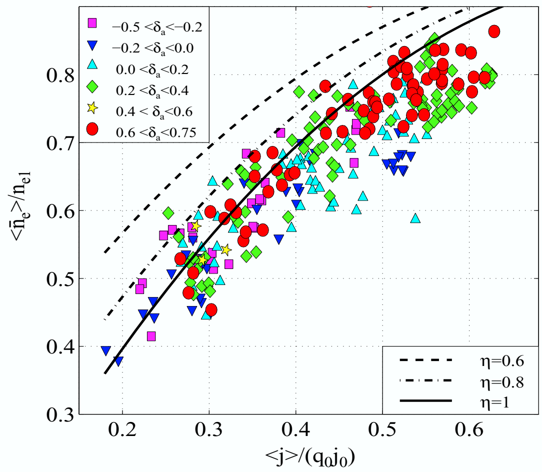

Fig. 3 Density profile widhts from experiment- for Ohmic L-mode discharges and expected for $n_e \propto 1/(q d\Phi/dV)^{\eta}$

by the flux surface. The data were taken using a repetitively pulsed Thomson Scattering system and mapped to ρ_{vol} as smooth functions. The scaling of the widths (inverse peaking factors) $\langle n_e\rangle/n_{e1}$ of the density profiles is shown in fig.3 for a wide variety of discharge conditions in TCV: $1 < \kappa_a < 2.6$, $0.5 < \delta_a < 0.7$, $2 < q_{95} < 7$, $1.2 \cdot 10^{19} m^{-3} < n_e < 12 \cdot 10^{19} m^{-3}$, $0.1 < \nu^*_{75} < 10$, where κ_a and δ_a are the elongation and the triangularity at the LCFS and ν^*_{75} is the electron collisionality at 75% of the poloidal flux.. The normalisation is made with respect to the density n_{e1} at the sawtooth inversion radius, $\rho_{inv} \approx \langle j\rangle/j_0 q_0$, rather than at the magnetic axis, in order to make it independent of the moment at which the sample was taken during the sawtooth cycle.

This result can be interpreted as being due to Turbulent Equipartition (TEP), which assumes conservation of the magnetic moment and the longitudinal invariant J during transport. According to TEP, particles spread evenly over the poloidal flux, i.e. $\partial N/\partial\Psi \approx const$, where N is the total number of particles within a given flux surface. Fig.4 shows, for each subplot, a superposition of about 130 normalised total particle number profiles as a function of poloidal flux, calculated from an equilibrium code, establishing that N increases roughly linearly with Ψ, irrespective of other discharge parameters.

TEP is expected to lead to density profiles roughly proportional to $(1/q)^{\eta}$ with $0.3 \le \eta \le 1$, depending on the relative contributions of trapped and passing particles to transport [4]. TEP implies a scaling of inverse peaking factors with $\langle j\rangle/(q_0 j_0)$ in shaped plasmas, in rough agreement with observations for $\eta \sim 1$ (lines in fig.3). Note that for many cases values of η larger than unity would be required in order to account for the peaking. These are unphysical from the TEP point of view. Density profiles also depart from TEP predictions in the case of ECH heating in the confinement zone (off-axis power deposition) and in all cases in the vicinity of the LCFS, where fuelling is likely to be important. Possible reasons are the non conservation of the above mentioned invariants in the presence of intense sources of heat and the influence of electrostatic potentials, which enter in the definition of J, but are not considered in the derivation of TEP predictions. Particle expulsion from the plasma core ('pumpout'), as observed with strong central ECH in the presence of a (1,1) island, is also at odds with TEP expectations, presumably because the low levels of turbulent particle diffusivity in the central region allow neoclassical effects to compete [5].

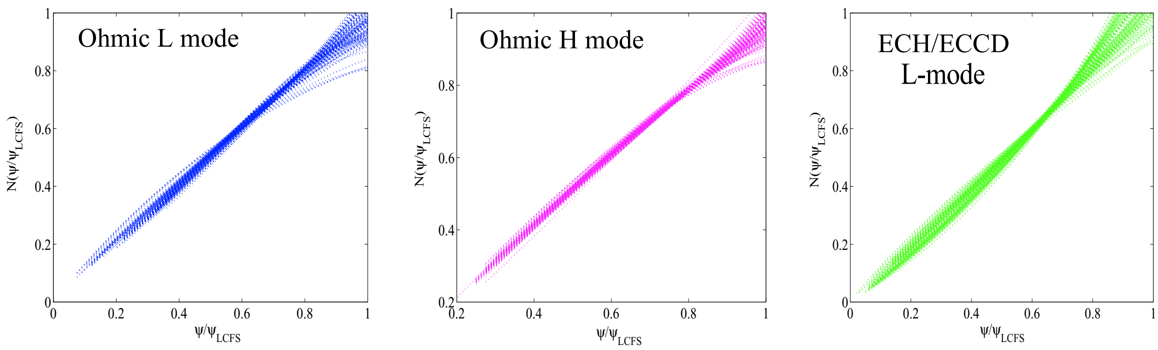

Fig. 4 Integrated, normalised particle content versus normalised poloidal flux in OH-Lmode, OH H-mode and ECH/ECCD L-mode datasets. Each line corresponds to a density profile. Only the portion corresponding to the confinement zone is shown

An alternative explanation of the observed density profile behaviour is offered by turbulent thermodiffusion by (TTD). This process is based on an energy dependent phase space diffusivity of the particles or more precisely decrease of the diffusion coefficient with velocity within the velocity distribution. Such diffusion behaviour is expected to lead to steady-state density gradients, which, in source-free regions and in the absence of other pinch mechanisms, are proportional to the temperature gradients, such that $\nabla n/n = \alpha_T \nabla T/T$ [6], with $\alpha_T < 0.5$ [6]. Fig. 5 shows the normalized density gradient as a function of normalised temperature gradient in the region 0.2<ρ<0.75 for Ohmic L-modes with three different values of $\langle j \rangle/(q_0 j_0)$. No convincing comparison with thermodiffusion has so far been obtained in ECH plasmas, possibly owing to the poor signal to noise ratio of Thomson Scattering at the low densities necessary for ECH in TCV. For most of the confinement zone in Ohmic L- and H-modes, a single value of α_T provides a satisfactory fit of the density profile, when the temperature profile is known. The value of however varies as a function of $\langle j \rangle/(q_0 j_0)$ from around 0.8 to around 0.4 over the database range and exhibits considerable scatter, not accounted for by measurement errors (fig.6).

Assuming a single value of α_T does not allow to account for the observed scaling of density peaking with $<j>/(q_0 j_0)$. In addition, the degree of peaking appears to exceed TTD expectations in many cases, making it unlikely that TTD alone can account for the observations.

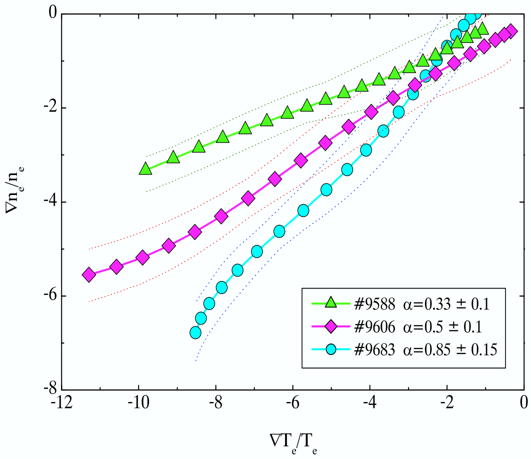

Fig. 5 Relation between electron density and temperature gradients in three different Ohmic L-modes in the region 0.2<ρ<0.75.

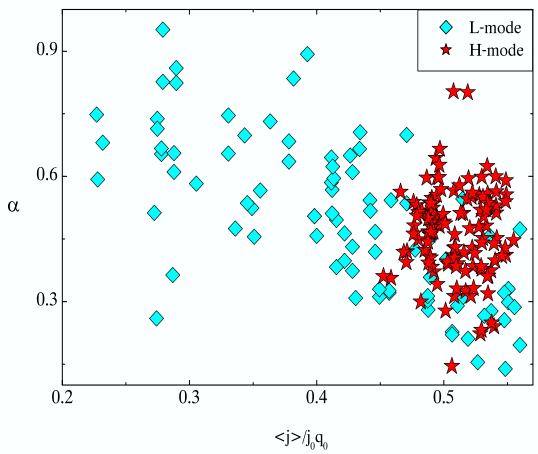

Fig. 6 Ratio of density to temperature gradient lengths versus $<j>/(q_0 j_0)$ in Ohmic L- and H-modes.

In principle density peaking can also result from a combination of TEP and TTD. Since botht-emperature profiles and poloidal flux profiles are strongly correlated (being parameterised by$<j>/(q_0 j_0)$ in normal magnetic shear discharges*)*, it is however difficult to seperate the two effects on the basis on the available dataset. Since at least part of the density profiles are more peaked than predicted by TEP and TTD, additional pinch effects, such as the Ware pinch, may have to be considered.

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