*32nd EPS Conference on Plasma Phys. Tarragona, 27 June - 1 July 2005 ECA Vol.**29C**, P-5.037 (2005)*

Internal Transport Barrier Simulation in LHD

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Abstract

In order to study the electron heat transport channel and to clarify the electron thermal diffusivity dependence with some plasma parameters in LHD [1] shots with electron internal transport barrier (eITB), some transport models have been added to TOTAL [2] code. These models can be divided into two categories: GyroBohm-like models and drift wave models. A sketch of mixed short and long wavelength models has been derived for this study as a good candidate for the eITB explaining. The effect of anomalous transport reduction by the neoclassical ambipolar electric field shear has been introduced by means of the factor $\left(1+(\tau f_{ExB})^{\gamma}\right)^{-1}$. This factor has been previously checked as a good candidate to drive anomalous transport in tokamak plasmas [3]. Results show that a combination of short wavelength and long wavelength together with the electric field shear can explain the transition between non-eITB and eITB modes.

Experimental set-up

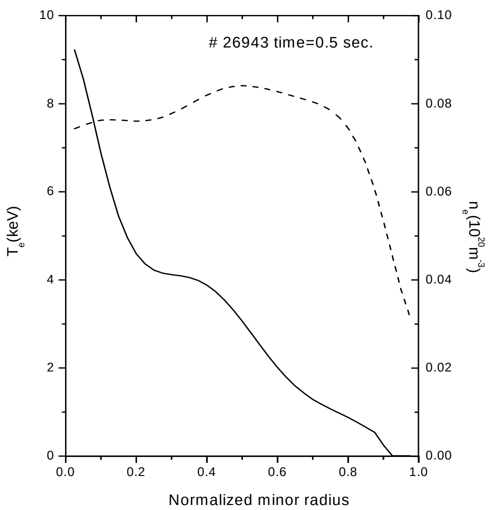

Figure 1 Experimental profiles of electron temperature (solid) and density (dashed) obtained in LHD

The shot analyzed (#26943, figure 1) corresponds to the fifth campaign of the LHD experiment. The high peaked electron temperature profile has been obtained by using 1 MW of Electron Cyclotron Heating (ECH) power [4]. Figure 1 shows the electron temperature and density profile measured by 200-channel YAG Thomson scattering system and 11-channel FIR interferometer. The density profile was obtained by Abel inversion method with 3-dimensional self-consistent equilibrium calculated by using extended radial magnetic coordinates to treat with ergodic regions in the PRE-TOTAL code

Anomalous transport models

The following electron heat transport models have been introduced in the TOTAL code in order to make an eITB transport simulation,

1. GyroBohm-like model (long drift wavelength):

$$\chi_e = \alpha_e^{gB} \chi_{gB}\, , \ \chi_{gB} = (cT_e / eB)(\rho_i / L_{Te})\, , \ \ L_{Te} = \left| \frac{\nabla T_e}{T_e} \right|^{-1}$$

2. Short drift wavelength $\chi_e = C_1 (r/R)^{1/2} \frac{v_{the}}{R} \frac{c^2}{\omega_{pe}^2}$

3. Mixed short wavelength-long wavelength model

$$\chi_e = C_1 (r/R)^{1/2} \frac{v_{the}}{R} \frac{c^2}{\omega_{pe}^2} \theta(\beta_{crit}) + (1-\theta(\beta_{crit}))C_2 (cT_e / eB)(\rho_i / L_{Te})\text{, with}$$

$\beta_{crit} = L_{Te}^2 / q^2 R^2$ and θ the Heaviside function

4. Internal transport barrier model $\chi_{e,shear} = \frac{\chi_e}{1+(\tau f_{ExB})^{\gamma}}$, where $f_{ExB} = \partial_r (E_r / B_\theta)$ with E_r the plasma radial electric field and B_θ the poloidal magnetic field. The following values τ =5.5 s, γ=1.5 have been used throughout this study.

Simulation results

The short wavelength and GyroBohm simulations are shown in figure 2, whereas the mixed model is given in figure 3. As can be seen from the figures, one can see that short wavelength model can reproduce the temperature profile in the plasma core in the range $0 \le \rho < 0.2$. However, outside this range, the plasma profiles are completely wrong, with temperatures quite different from the experimental ones. In the GyroBohm case, the central temperature profile obtained has more parabolic shape compared to the drift wave. However a high gradient (comparable to the ones obtained in the drift wave profiles) is obtained in the region $0.1 \le \rho < 0.2$. The main difference between this simulation and the one studied in the previous case is that outside the plasma core (where the influence of the electric field shear is negligible) the model reproduces with reasonably accuracy the experimental profiles. Taking account these facts a simulation was performed mixing both models. From figure 3, one can see that the simulated profile has a steep gradient at the plasma core and a more flat shape at the edge. Therefore, the simulated profile fits reasonably well the experimental one.

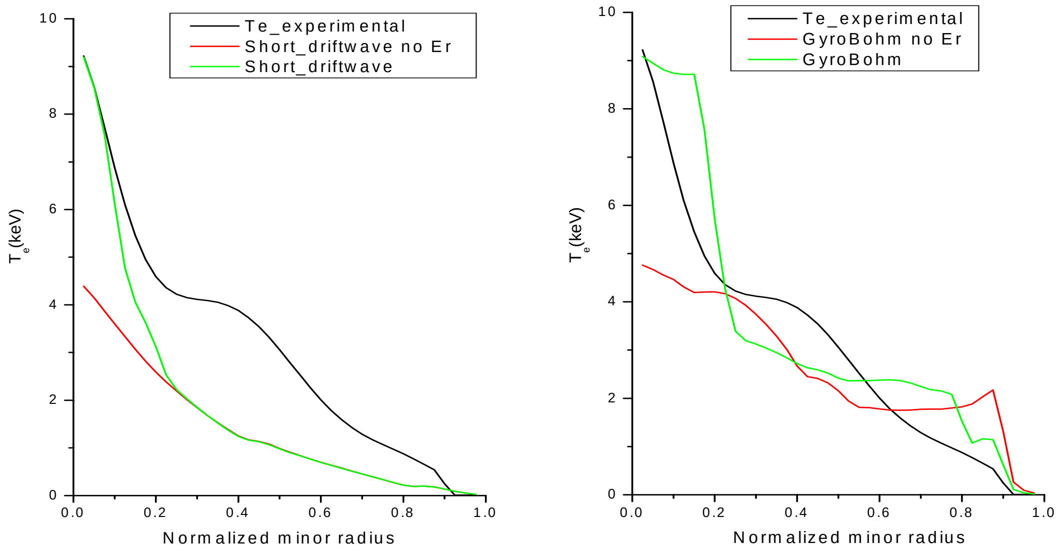

Figure 2 Comparison between short wavelength model (left), GyroBohm model (right) and experimental electron temperature profile, with and without electric field shear effect.

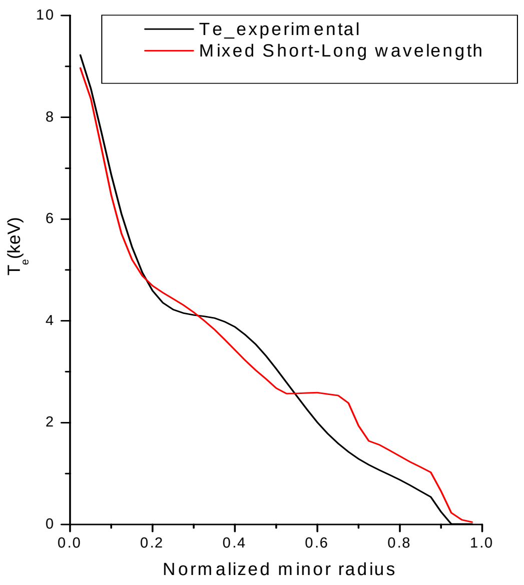

Figure 3 Comparison between mixed short wavelength long wavelength model and experimental electron temperature profile.

In order to study the validity of the previous transport models (GyroBohm and mixed model), not just for one shot with eITB, but for a wide range of plasma parameters, with the aim of reproducing the critical transition between a non-eITB scenario and an eITB one, two simulations have been carried out with the same electron density profile than in the previous section but with different average densities (figure 4). With both simulations a clear transition point is obtained. However, in the GyroBohm model, central temperature dependence on average density is $T_e(0) \propto < n_e >^{-0.72}$, whereas in the mixed model is $T_e(0) \propto < n_e >^{-0.57}$, which results to be quite similar to experimental results [1].

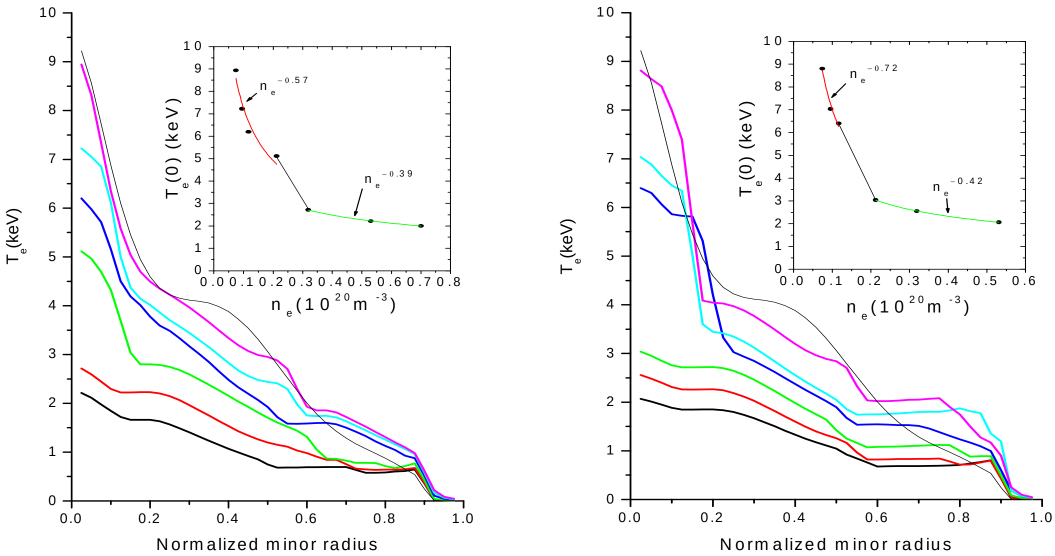

Figure 4 Electron temperature profiles obtained with mixed model (left) and with GyroBohm model (right) for the different average densities appearing in the upper figure.

Conclusions

Some new transport models have been added to the TOTAL code for analysing the ITB formation in the LHD. The analysis of shot #26943 as well as a study of the eITB density sensitivity has been carried out. The results show that the anomalous transport is reduced at the plasma core by the ripple-induced electric field shear leading to the eITB formation. Using a mixed short-long drift wave model and different electron average densities with the same profile, the experimental central temperature dependence on density $T_e(0) \propto \langle n_e \rangle^{-0.57}$, as well as the whole profile has been reproduced with reasonable accuracy, simulating the critical transition between non-eITB and eITB shots. These results lead to the conclusion that the reduction of anomalous transport is due to the combined effect of a high electric field with a high electric field shear and the appearance of small convective cells due to short electromagnetic drift waves in the plasma core, however more experimental data must be required to check it.

References

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