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Scaling of turbulence and transport on Tore Supra with dimensionless parameters $\rho*$ and $\nu*$

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Particle and heat transport induced by micro-turbulence play a crucial role in tokamak performances. A useful technique for validating transport models across tokamaks is to use a dimensionless description of the plasma dynamics. The $\rho*$ dependence of the confinement time usually follows a gyroBohm scaling ($B\tau_{th} \propto \rho*^{-3}$) [1, 2, 3]in H-mode plasmas. However, in some dedicated experiments a Bohm scaling has been observed, especially in L-mode plasmas [4, 5, 6]. As of today, there exists no commonly accepted explanation of this discrepancy. Concerning the $\nu*$ dependency several dedicated scans performed in ELMy H-mode plasmas in different $\nu*$ ranges show deviation from a power law such that the $\nu*$ dependence increases with increasing $\nu*$ ($B\tau_E \propto \nu^{*-0.27}$ [1] at low collisionality while $B\tau_E \propto \nu^{*-1}$ [3] at higher collisionality).

In order to contribute to characterize such dependencies, new $\nu*$ and $\rho*$ scans have been performed on Tore Supra, in L-mode plasmas hence without interfering with H-mode edge physics. The Tore Supra tokamak is particularly well suited to perform such experiments due to long discharge operation, which provides long stationary phases allowing comfortable transport analysis and turbulence measurements (improving statistics and/or resolution). In addition, it is equipped with complementary micro-wave diagnostics to measure density fluctuations. While the Doppler backscattering system gives access to the local poloidal wavenumber spectrum between $k = 3-25cm^{-1}$, fast sweep reflectometry can measure the density profile as well as the radial profile of density fluctuation level and its radial wave number spectrum. The present paper focuses on the global analysis and the evaluation of uncertainties for these scans. Turbulence measurements and local transport analysis will b! e presented in a longer publication. Dedicated scans of dimensionless parameters are performed by varying the magnetic field (B) from one discharge to another and adjusting the plasma current (Ip), density (ne) and temperature ($T_{e,i}$) in order to keep the other dimensionless parameters constant. For example, to scan ρ^*, the temperature has to vary as $B^{2/3}$ and the density as $B^{4/3}$. Following these requirements, ρ^* varies as $B^{-2/3}$ constraining strongly the range over which ρ^* can be scanned in a given

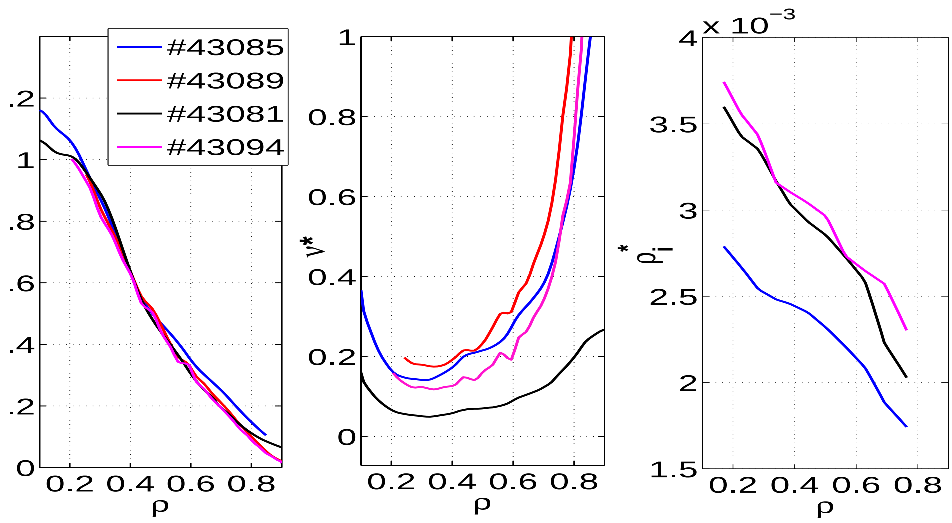

Figure 1: dimensionless profiles during ρ^* and ν^* scans

machine. During a ν^* scan, the density must be kept constant, while the temperature should be varied as B^2, which makes ν^* change as B^{-4} . Thus, it is easier to cover a large range in ν^*. On these Tore Supra experiments, the temperature was changed using ICRH heating in the H-minority scheme, for which the frequency was adjusted according the magnetic field in order to keep a central deposition. The density profiles were! determined using fast sweep reflectometry, the electron temperature p rofiles were measured by electron cyclotron emission radiometer and ion temperature profiles were obtained from charge exchange recombination spectroscopy measurements. The analysis and calculation of the global parameters were performed over a long stationary phase characterized by a time window Δt (larger than 1s). Consistency has been found between experimental parameters and deduced values from CRONOS [7] (magnetic flux consumption, internal inductance, neutrons flux and total diamagnetic energy)

In the first scan, $\nu^* = \nu_{ei}/\varepsilon\omega_{be}$ has been varied from $\nu^* = 0.16$ to $\nu^* = 0.56$ by changing the magnetic fields from B=3.8T to B=2.8T. This scan is complementary to a previous one [9] performed in a higher range of $\nu^* = [0.16 - 0.7]$ (lower additional power). Radial profiles of the dimensionless parameters β, ρ_i^* and ν^* are plotted in figure 1 and show a good matching of ρ_i^* (less than 15% mismatch) and β (less than 10% mismatch) between the selected three discharges (43081, 43089 and 43094) inside $\rho = [0.2 - 0.8]$. Considering first the normalized diamagnetic energy confinement time $B\tau_{dia} = W_{dia}/P_{add}$, it can be seen on the figure 2 that $B\tau_{dia}$ does not change significantly with increasing ν^*, corresponding to a very weak dependence $B\tau_{dia} \propto \nu^{*\alpha\nu}$ with $\alpha_\nu = -0.07$. Note that in this evaluation, the global confinement tim! e was calculated using $\tau = W/P_{add}$ hence including energy losses by radiative processes. Futhermore, the fast ion contribution may be different from the low ν^* case (high ICRH power) to the high ν^* case (low ICRH power). In order to avoid this later effect, we must consider the thermal energy confinement times $B\tau_{th}$. Taking the value of the total thermal energy deduced from the measured profiles (n_e, T_e and T_i) for discharges 43081 and 43097 (during discharge 43089 no T_i profiles were measured), $B\tau_{th} \propto \nu^{*+0.03}$.

In order to evaluate the uncertainty of α_ν, we follow a similar procedure as the one used in [10]. Taking into account the uncertainties on the total energy (W) and the total power (P) and using the expression of the normalized global confinement $B\tau_E \propto \rho^{*\alpha\rho}\nu^{*\alpha\nu}\beta^{\alpha\beta}$ where $\tau_E \propto W/P$, $\rho^* \propto W^{1/2}$, $\nu^* \propto W^{-2}$, $\beta \propto W$, we arrive at : $W^{(1-1/2\alpha_\rho+2\alpha_\nu-\alpha_\beta)} \propto P$.

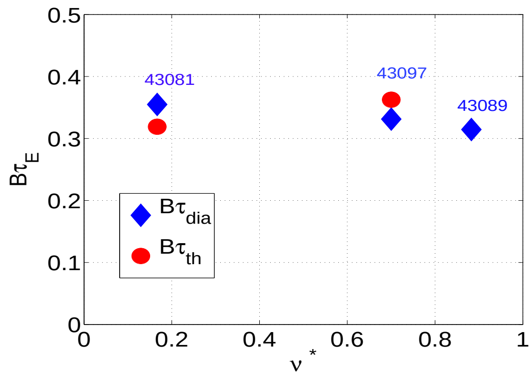

Figure 2: Normalized confinement times during the ν^* scan

Since the quantities W and P are measured independently, the uncertainties are given by:

$$(\delta\alpha_i)^2 = (\partial\delta\alpha_i/\partial P)^2(dP)^2 + (\partial\alpha_i/\partial W)^2(dW)^2 \quad (1)$$

Applying this expression to the case of a 2-points ν^* scan (ν_h^* for high ν^* value and ν_l^* for low ν^*) gives:

$$(\delta\alpha_2)\ log(\nu_h^*/\nu_l^*) = [(1-1/2\alpha_\rho+2\alpha_\nu-\alpha_\beta)^2(\delta W/W)^2 + (\delta P/P)^2]^{1/2}$$

Typical uncertainties for Tore Supra are $\delta W/W = 20\%$ and $\delta P/P = 5\%$. Note that here P corresponds to the total additional power which is coupled to the plasma and not the total power which is absorbed by the plasma. In pure ICRH plasmas, the difference between these two quantities comes mainly from the ripple (up to 7% onTore Supta at the plasma boundary). If we want to take into account the uncertainties on the absorbed power, we have to increase $\delta P_{ab}/P_{ab}$ at least up to 20%. Finally, considering $\alpha_\rho = -3$ (gyroBohm scaling) and $\alpha_\beta = -0.2$ (from dedicated β scaling performed on Tore Supra [11]) the uncertainty for the present scan is $\delta\alpha_\nu = \pm 0.5$.

Considering the second scan, in order to cover the largest possible range of ρ^* values, the magnetic field has been varied from 3.8T to 2.1T corresponding to $\rho_e^* = [4-6.2]e^{-5}$. The normalized energy confinement times of the best three discharges are plotted in figure 3a). he two extreme cases (3.8 T and 2.1 T), we obtain $B\tau_{dia} \propto \rho^{*-1.8}$. Using expression 1, the uncertainty of α_ρ for $\alpha_\nu = 0$ and $\alpha_\beta = -0.2$ is $\delta\alpha_\rho = \pm 0.9$. This value is highly sensitive

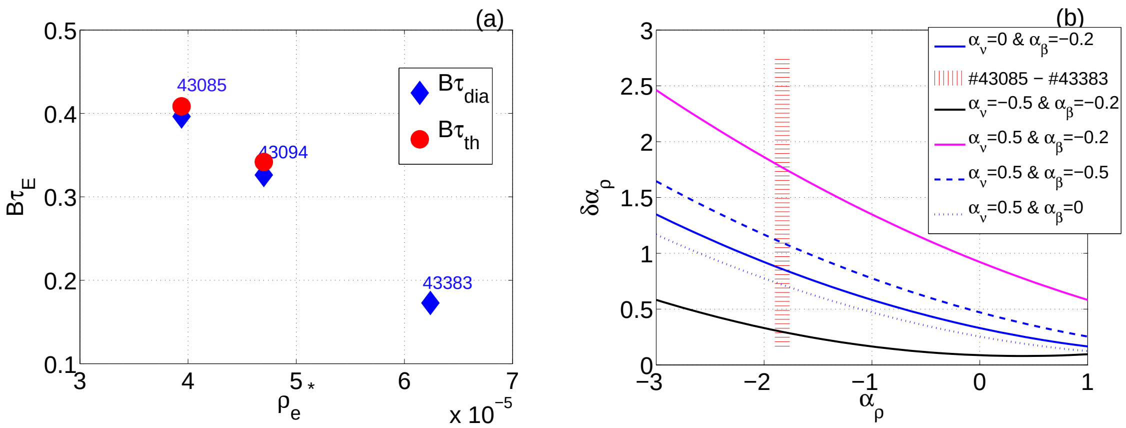

Figure 3: Normalized confinement times (a) during the ρ^* scan and Uncertainties on α_ρ for different values of α_ν and α_β (b)

to the assumption on α_ν and α_β which are not precisely determined. To illustrate this fact, figure 3b) presents the evolution of $\delta\alpha_\rho$ as a function of α_ρ and for different values of α_ρ and α_β. Unfortunately, for the discharge at 2.1 T, density profiles are not available yet , therefore the thermal confinement time could be analyzed only for the 3.8T and 2.8T discharges and are plotted in red color on figure 3a). The dependence obtains from these values is $B\tau_{th} \propto \rho^{*-1.1\pm1.5}$.

In conclusion to this first level analysis, the ν^* dependence obtained is $B\tau_{dia} \propto \nu^{*0\pm0.5}$ while it seems that the ρ^* dependence is between Bohm and gyroBohm scalings. We would like to stress that the uncertainties considered here are only those due to measurements and for example, the mismatch of ν^* and β is not taken into account. Therefore, in this scan (covering a large magnetic field range), it appears impossible to distinguish a Bohm from a gyroBohm scaling using only the global confinement time.

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