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I. INTRODUCTION

In this paper the results from a series of JET ELMy H-mode experiments are described, in which the dimensionless physics parameters β^* and ν^* are varied in turn with the other dimensionless physics parameters β, q_ψ, κ etc. being kept fixed. Recently [1], [2] it has been shown that the dependence of the dimensionless energy confinement time $\omega_e \tau_E \propto B\tau_E$ on β is very weak, and inconsistent with the scaling IPB98(y,2) used in the ITER design which in dimensionless form is

$$B\tau_{E\ IPB98(y,2)} \sim \rho^{*-2.70}\,\beta^{-0.90}\,\nu^{*-0.01}$$

Here we concentrate on the ν^* and ρ^* behaviour. The scans reported here are much more extensive, consisting of 4-6 points, than previous JET ν^* and ρ^* scans [3], which were mainly two point scans. The ρ^* scans were completed for both Type I ($\beta_N = 1.6$) and Type III ($\beta_N = 0.6$) ELMy H-modes in a low q and triangularity scenario ($q_{95} = 2.8$, $\delta = 0.2$, $\kappa = 1.7$, a = 0.95m, R = 2.9m).

The ν^* scan was completed in a high triangularity, high q scenario ($q_{95} = 4.4$, $\delta \sim 0.4$, $\kappa = 1.7$, a = 0.92m, R = 2.9m) which has geometry very similar to that of Alcator C-MOD. The observed scaling $B\tau_E \propto \nu^{*-0.35}$ is also in conflict with that of the IPB98(y,2) scaling but similar to that previously found in ν^* scans [3]. These experiments are being carried out in conjunction with the C-MOD team, to try and determine whether ν^* or the Greenwald fraction is a more relevant dimensionless parameter. The present data set does not match the C-MOD pulses as well is required to give a conclusive result.

The remainder of the paper is split into 2 sections, in the next section the experimental results are presented for the ν^* scan, the Type III ρ^* scan and then the Type I ρ^* scan, in the final section we consider possible explanations for the inconsistency between the β and ρ^* dependence of the IPB98(y,2) scaling and the single scan results.

2. EXPERIMENTAL RESULTS

2.1 ν SCAN*

In these experiments (Table I) the current was varied between 0.68 and 1.17MA, with the field B varied between 0.96 and 1.6T. To keep ρ^*, β and q fixed plasma parameters must scale as $B \propto I$, $n \propto I^0$, and $T \propto I^2$. A set of 4 shots were produced with ρ^*, β and q matched within their measurement errors (taken as 2.7% for ρ^*, 6.0% for β, 10.4% for ν^*, and 8.3% for $B\tau_E$ [1]). The scaling of $B\tau_E$ with collisionality ν^* is shown in Fig.1. The best least squares log-linear fit to the data is $B\tau_E \propto \nu^{*-0.35\pm0.04}$ with a RMSE of 6%. This is a very similar result to that of the 'two point scan' which was completed in 1996 [3] ($B\tau_E \propto \nu^{*-0.28}$).

2.2 r SCAN WITH TYPE-III ELMS*

In a ρ^* scan at fixed β, ν^* and q, the parameters must vary as $B \propto I$, $n \propto I^{4/3}$, $T \propto I^{2/3}$. In these experiments the current was varied from 1.3 to 4.3 MA in 6 steps (Table 2), although at the highest current the β and ν^* were rather on the low side. However for the currents 2.3, 2.7, 3.0, 3.4MA the match in both ν^* and β is very good. Using this data alone gives a scaling $B\tau_E \propto \rho^{*-2.9\pm0.5}$ i.e. close to gyro-Bohm.

A plot of $B\tau_E\,\nu^{*0.35}$ versus ν^* is shown in Fig.2 for the full data set, the solid points having matched ν^* and β. The normalisation of the $B\tau_E$ by $\nu^{*0.35}$ brings the open points on to the same scaling.

2.3 r* SCAN WITH TYPE-III ELMS

In this scan the current was varied from 1.4 to 4MA in seven steps (Table 3). The 4MA discharge (Fig.3) extends the ρ^* scan to within 70% of the ITER value. To keep β and ν^* fixed the density was varied from $3.8-8.9\times10^{19}\text{m}^{-3}$, and the input power which was mainly from NBI, increased from 4 – 23MW. Unfortunately, at the highest currents, which have correspondingly higher density, the heating profile was quite hollow compared with the low current, low density pulse (Fig.4). With these large differences in heating profile, we study instead the behaviour of the local transport coefficients.

In Fig.5 the effective thermal diffusivity, $\chi = (n_e\,\chi_e + n_i\,\chi_i)/(n_e + n_i)$, is shown for the 4MA and 2.3MA pulses. χ scales approximately as 1/B, which is gyro Bohm scaling. The full data set is shown in Fig.6 where χ/B at x = 0.5 is shown versus ρ^{*-3} for the full data set. The best log-linear fit is $\chi/{\sim}\rho^{*\,3.20\pm0.40}$ which is close to gyro-Bohm. Note in this analysis it has been assumed that the temperature profiles stiffness is weak.

3. DISCUSSION OF RESULTS AND IMPLICATIONS FOR NEXT STEP PREDICTIONS.

One obvious concern is that the results of the scans may be affected by the small spread of the "matched" parameters, which must be at least the size of their measurement errors. To assess this for the ν^* scan, $B\tau_E$ is normalised with respect to ρ^* from the Type III scan ($B\tau_{E,N} = B\tau_E\,\rho^{*2.90\pm0.5}$). A log-linear regression of ν^* scan to $B\tau_{E,N}$ results in a scaling of $\nu^{*-0.40}$. The error in the ρ^* exponent (±0.5) propagates to the ν^* exponent as 0.01. Thus, the mismatch in ν^* introduces a small residual increase in the ν^* exponent, whilst the error in the ρ^* scaling has little impact on the error of the ν^* fit.

Another possibility that is being seriously examined [4] is shortcomings in the analysis of the multi-machine database DB3v5. It has been shown the condition of this database is rather poor with respect to the standard 8 variable regression. By selecting data in a narrow range around the ITER values of q, κ and a/R and using only 5 regressor variables I, n, P, R and ε, a new power law scaling $\tau_E \propto I^{0.99}\,n^{0.39}\,R^{1.87}\,P^{-0.53}$, has been derived. This scaling, which in dimensionless form is $\omega_{ci}\tau_E \propto \rho^{*-2.94}\,\beta^{-0.06}\,\nu^{*\,-0.17}$ is more consistent with the single scan results. It gives a modest improvement in the confinement time (~28%) for the standard ITER operation with $\beta_N = 1.8$, however at higher values of β_N (~3) a 100% improvement in energy confinement is predicted for both ITER and reactor designs.

In summary, it has been shown that for quite extensive scans in the dimensionless variables ν^* and ρ^*, that $B\tau_E$ scales as $\propto \nu^{*-0.35}\,\rho^{*-3.0}$ and is consistent with previous 2 point scans [4]. Thus, JET shows a gyro-Bohm transport scaling, consistent with electrostatic drift wave models, with a weakly positive collisionality dependence, consistent with a neoclassical edge. The difference with the multimachine database result has been attributed to the poor condition of that database with respect to 8 variable regressions. The consequences for ITER are a 28% improvement in at the operating point N = 1.8, however a significantly larger improvement at higher N.

ACKNOWLEDGEMENTS

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Pulse	time [s]	I_p [MA]	n [10^{19} m^{-3}]	P_{loss} [MW]	ρ^*/ρ^*_{ITER}	β_N	ν^*/ν^*_{ITER}	$B\tau_\varepsilon$ [Ts]
62662	24.1	0.69	2.77	1.95	2.47	1.25	58.0	0.21
62664	26.9	1.03	2.78	3.49	2.56	1.28	11.3	0.38
62665	28.7	1.18	2.86	5.26	2.54	1.31	6.97	0.40
62705	23.7	1.18	2.86	4.80	2.61	1.39	6.20	0.46

Table 1: ν scan*

Pulse	time [s]	I_p [MA]	n [10^{19} m^{-3}]	P_{loss} [MW]	ρ^*/ρ^*_{ITER}	β_N	ν^*/ν^*_{ITER}	$B\tau_\varepsilon$ [Ts]
58390*	26.1	1.28	1.47	1.58	2.75	0.65	5.97	0.30
58394	26.6	2.33	2.36	4.82	2.36	0.74	1.73	0.69
58400	19.6	2.73	3.29	6.33	2.08	0.81	2.04	0.96
58403	20.5	2.98	3.13	5.40	1.91	0.65	1.45	1.16
62720	17.4	3.42	3.83	6.89	1.90	0.76	1.67	1.39
62723*	16.6	4.28	4.05	8.87	1.58	0.55	1.51	1.54

Table 2: Type III ELMy H-mode, ρ scan*

Pulse	time [s]	I_p [MA]	n [10^{19} m^{-3}]	P_{loss} [MW]	ρ^*/ρ^*_{ITER}	β_N	ν^*/ν^*_{ITER}	χ_{eff}/B [$m^2s^{-1}T^{-1}$]
43599	26.9	1.46	3.80	4.19	3.27	1.92	6.21	1.76
58396	26.1	1.99	4.49	8.06	2.85	1.94	3.23	0.58
58394	22.2	2.34	5.26	11.60	2.50	1.79	3.20	0.48
58400	13.1	2.76	6.41	14.73	2.24	1.81	2.95	0.40
58403	15.4	2.99	6.22	15.07	2.08	1.54	2.71	0.35
60870	14.4	3.44	8.04	18.73	1.96	1.64	3.24	0.20
62213	14.4	3.99	8.95	22.87	1.74	1.45	3.12	0.18

Table 3: Type I ELMy H-mode, ρ scan*

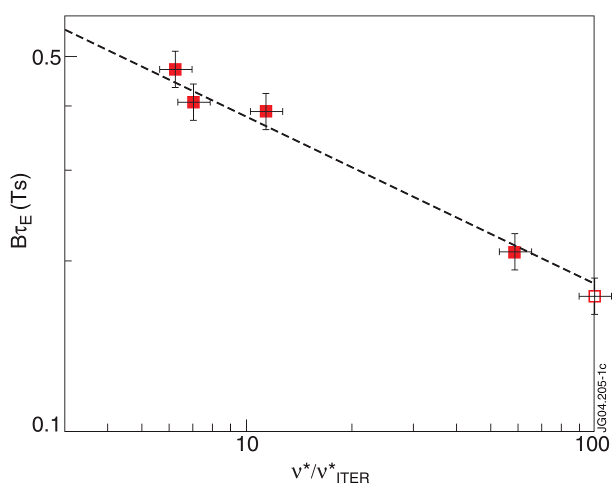

Figure 1: The normalised confinement time $B\tau_E$ versus the dimensionless collisionality ν^* normalised to that in ITER. The best fit (dashed line) is $B\tau_E \propto \nu^{*-0.35}$.

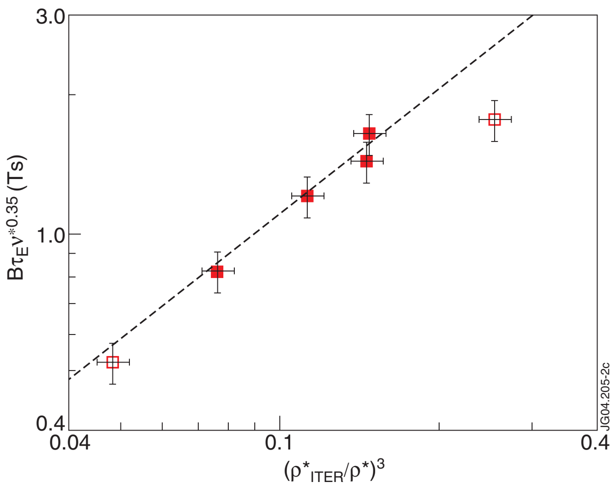

Figure 2: The normalised confinement time $B\tau_E$ multiplied by $\nu^{*0.35}$ versus the inverse dimensionless Larmor radius cubed normalised to ITER, for type III ELMy H-modes. The best fit is $B\tau_E \propto \nu^{*0.35}\rho^{*-2.9}$.

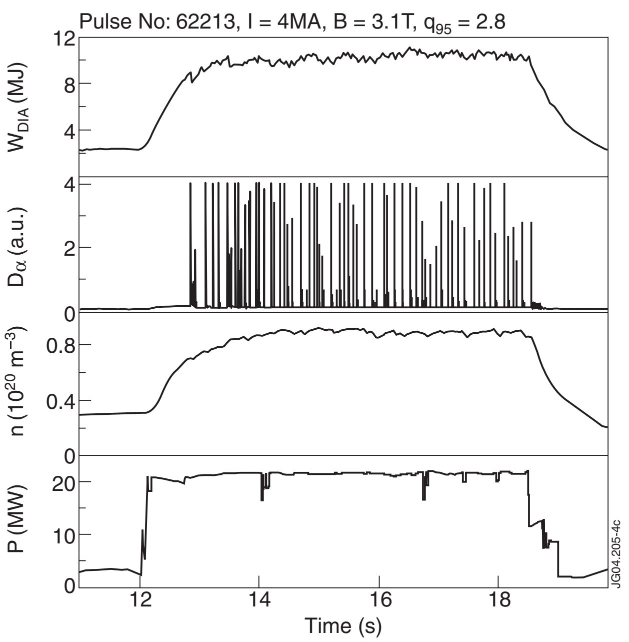

Figure 3: The diamagnetic stored energy, the D_α, the central line averaged density and the input power versus time for a 4MA/3.1T discharge.

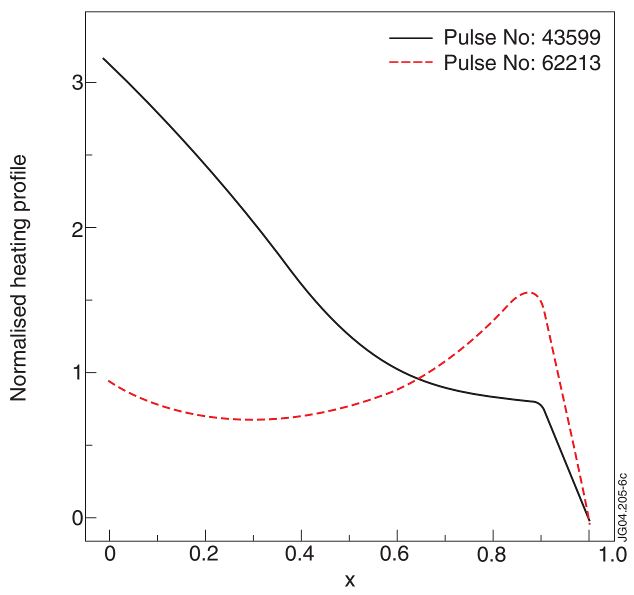

Figure 4: The heating profiles for the low current (1.46MA) Pulse No: 43599 and the high current (4MA) Pulse No: 62213 discharges.

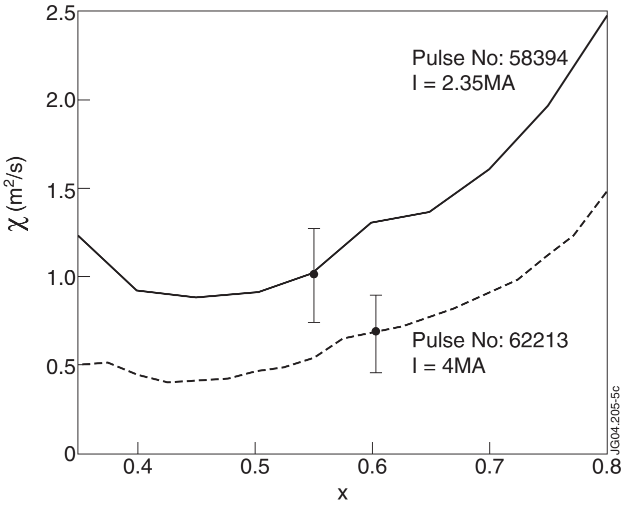

Figure 5: The effective conductivity for a low current (2.35MA) and high current (4MA) pulse versus normalised radius.

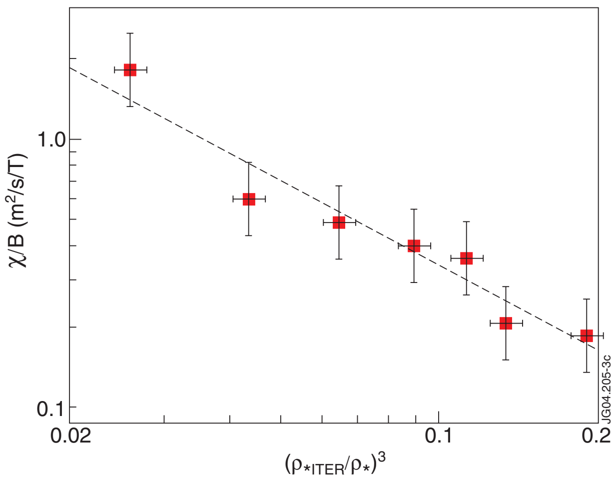

Figure 6: The dimensionless conductivity χ/B versus the inverse dimensionless Larmor radius cubed normalised to the ITER value. The best fit (dashed line) is $\chi/B \propto \rho^{*3.2}$.