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J. Garcia[1], N. Hayashi[2], G. Giruzzi[1], M. Schneider[1], E. Joffrin[1], S. Ide[2],
Y. Sakamoto[2], T. Suzuki[2], H. Urano[2], the JT-60U Team
and JET EFDA contributors*

***JET-EFDA, Culham Science Centre, OX14 3DB, Abingdon, UK***

*[1]CEA, IRFM, 13108 Saint-Paul-lez-Durance, France*
*[2]Japan Atomic Energy Agency, Mukouyama, Naka City, Ibaraki, 311-0193 Japan*
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## ABSTRACT

Predictive simulations for electron and ion temperatures have been carried out for JET and JT-60U plasmas in order to determine the most appropriate models to this type of plasmas. To carry out this programme, the integrated modelling codes CRONOS [1] and TOPICS-IB [2] are used. Results show that the H-modes are usually well simulated for both devices, whereas for the advanced regimes, as the hybrid, there are clear deviations from experimental data, mainly for JT-60U. The reasons for such discrepancies are analysed.

## 1. INTRODUCTION

In the framework of the construction of new tokamaks, such as JT-60SA, ITER and DEMO, the necessity of predicting the performance of the main operation scenarios has been identified as a main goal, both for the detailed definition of the properties of various machine subsystems (H&CD, control coils, diagnostics) and in order to establish a reliable starting point for plasma operation.

For this purpose, the validation of the main models available for the plasma simulation is mandatory. These include, e.g., energy and particle transport models, pedestal models, rotation sources and transport, synthetic diagnostics. JT-60SA is a machine designed on the basis of the results of JT-60U, and using an upgrade of the JT-60U NBI system; on the other hand, it has practically the same size as JET, which also has NBI as the main H&CD system. Therefore, it appears that simulations of JT-60SA scenarios should be based at least on experimental results of the two machines that are the most similar, for size and configuration: JT-60U and JET. On this basis, an extensive validation exercise has been undertaken with the aim, as well, of expanding the knowledge of these models towards more realistic simulation of future tokamak devices as ITER and DEMO.

A series of representative discharges of the three main operational scenarios, H-mode, hybrid and steady-state have been selected for each device. A subset of these discharges is discussed in this paper: their main parameters can be found in table 1. Predictive simulations have been carried out with three transport models, Bohm-GyroBohm [3], CDBM [4] and GLF23 [5], and by adjusting, as a first step, the pedestal, rotation and density to experimental values whenever available. To carry out this programme, the integrated modelling codes CRONOS and TOPICS-IB are used.

Regarding the CDBM transport model, a modification has been implemented in order to take into account the relatively high fast ion population in some of the discharges. For that purpose, the fast ion pressure is included in the normalized pressure gradient a of function F(s,a) [4] and the gradient ath only including the thermal plasma is used in the other terms.

The original heat diffusivities [4] are mended as follow

$$\chi_{CDBM} = 12\frac{c^2}{\omega_{pe}^2}\frac{v_A}{qR}\alpha_{th}^{2/3}F(s,\alpha)\,G(\kappa) \text{ and } G(\kappa)=(2\kappa^{1/2}/(\kappa^2+1))^{3/2}.$$

Two discharges from JT-60U, H-mode Pulse No: 33655 and Hybrid Pulse No: 39713, have been analyzed with CRONOS and TOPICS by using two different transport models, GLF23 (without E×B shear effect) and CDBM. The density and q profiles for both discharges, shown in figure 1, are kept fixed during the simulation and just the temperatures are predicted. The NBI power is calculated by means of the code F3D-OFMC. In figure 2, the results are compared to the experimental data, showing a good agreement between both codes and for both the electron and ion temperatures for the H-mode Pulse No: 33655. On the other hand, for the Hybrid Pulse No: 39713, although both codes give similar results, they are in disagreement with experimental data, leading to lower temperatures than expected, and with a broad region of flat temperatures in the case of GLF23. One of the main differences of both discharges is the density profile, which strongly peaks at mid radius for the Pulse No: 39713. The impact of this peaking on the quality of the simulation will be analyzed in the following sections. The impact of the E×B shearing rate will be analyzed in the future.

## 2. ANALYSIS OF JET DISCHARGES

Two discharges from JET, H-mode Pulse No: 73344 and Hybrid Pulse No: 77280, have been analyzed with CRONOS by using the transport models, GLF23 Bohm-GyroBohm and CDBM. The density and q profiles for both discharges at $t = 19s$ for 73344 and 7.8s for 77280 are shown in figure 1. The general procedure of the simulations is the same as for JT-60U, however in this case the experimental rotation profile has been used to evaluate the E×B shear since it is available and the NBI power is calculated by means of the SPOT code [6]. In figure 3, the results are compared to the experimental data. There is a general good agreement for the H-mode discharge for both electrons and ions, with some slightly lower temperatures for CDBM transport model. On the other hand, for the Hybrid shot, the Bohm-GyroBohm transport overestimates both electrons and ions and CDBM slightly underestimates both. Regarding GLF23, it is the model that gets closest to experimental data, although it also overestimates the ion temperature. The fact that the ion temperature is overestimated for hybrid scenarios with GLF23, has been found in many other hybrid discharges in JET [7] and it is due to a too strong effect of rotation on confinement obtained with that transport model. For the Pulse No: 77280, with higher fast ion contribution than the H-mode Pulse No: 73344, the CDBM transport model shows better agreement when the new version, which takes into account the correction due to the fast ion population, is applied.

## 3. GYROKINETIC ANALYSIS

A linear gyrokinetic analysis has been carried out with the QualiKiz code [8] for the hybrid Pulse No's: 39713 and 77280 in order to determine the main turbulent regimes. For this purpose, the linear growth rate, $\gamma$, is calculated in the range $k_\theta\rho_s < 2$ for $0.2 \leq \rho \leq 0.8$. In figure 4, the maximum growth rate is shown for both discharges. The growth rate is found to be much higher for the discharge 39713 than for 77280 with a different spectral and spatial distribution. While for the JT-60U discharge the modes are stable in the low shear region, $\rho \leq 0.5$, it is precisely in this region that the modes are the most unstable for the JET shot. However, is the most striking differences are found in the modes spectrum. The ITG modes are dominant at $\rho = 0.25$ for the hybrid scenario on JET, with a maximum at $k_\theta\rho_s = 0.3$, whereas the spectrum for the discharge 39713 at $\rho = 0.55$ reaches the TEM regime at $k_\theta\rho_s = 1.0$ and well beyond. The reason for such a different behaviour can be the different density peaking for both discharges. In the case of the JT-60U discharge, the normalized density gradient at $\rho = 0.55$, $Ln_e = R\nabla n_e / n_e \approx 5.0$ , is much higher than for the JET case, $Ln_e \approx 1.5$. An analysis on the density peaking factor will be carried out in order to confirm that TEM are destabilized by this reason. The impact of these differences on the capability of the different transport models to reproduce the temperatures will be analyzed in the future.

## CONCLUSIONS

Predictive temperature simulations have been carried out with CRONOS and TOPICS for JET and JT-60U plasmas with three different transport models. In general, the H-modes are well simulated for both devices with the models available, GLF23, Bohm-Gyrobohm and CDBM. On the other hand, advanced regimes seem to be more difficult to reproduce. In this case, GLF23 leads to the most reliable results for JET, although it starts to deviate from experimental data mainly for ions. In the case of JT-60U, all the models clearly deviate for both electrons and ions, leading to underestimated temperatures for the Pulse No: 39713.

However, the E×B effect must be analyzed in these discharges. It is worth to point out that the amendment of the CDBM transport model that has been done in order to account for the superthermal pressure seems to be important, since otherwise the predicted temperatures would deviate even more substantially from the experimental data, due to the higher heat diffusivities.

It has been shown that the turbulent regimes are different for JET and JT-60U. Clearly, ITG is dominant for JET whereas TEM are present for JT-60U in the regions of high density gradient and non vanishing magnetic shear. The validity of the different transport models in this regime must be carefully analyzed and eventually the models will be amended in order to improve their performance. Another option is to include alternative models. The work shown here is just the initial step towards a full analysis of the physics differences between JT-60U and JET plasmas. This work will involve the simulation of additional discharges in order to analyse different plasma conditions, the inclusion of the Bohm- GyroBohm model in TOPICS, the simulation of density, rotation and pedestal. If successful, this exercise will provide a sound basis for scenario prediction in future devices as JT-60SA and ITER.

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| **Discharge** | **$q_{95}$** | **κ/δ** | **Bt (T)** | **$\beta_N$** | **$n/n_{Gw}$** | **Ip (MA)** | **Pin (MW)** |
|---|---|---|---|---|---|---|---|
| H-mode JT-60U #33655 | 3.0 | 1.53/0.16 | 3.1 | 1.1 | 0.48 | 1.8 | 10 |
| Hybrid JT-60U #39713 | 4.1 | 1.51/0.34 | 4.1 | 2.5 | 0.40 | 1.8 | 26 |
| H-mode JET #73344 | 3.5 | 1.75/0.40 | 2.7 | 1.5 | 0.75 | 2.5 | 12 |
| Hybrid JET #77280 | 5.0 | 1.75/0.38 | 2.7 | 2.4 | 0.55 | 1.1 | 11 |

*Table 1: Main characteristics of JT-60U Pulse No's: 33655, 39713 and JET Pulse No's: 73344, 77280, where ϰ/δ is the elongation/triangularity, $B_t$ is the magnetic field in the axis, βN is the normalized beta, $n/n_{Gw}$ is the ratio between the plasma density and the Greenwald density limit, $I_p$ is the total current and $P_{in}$ the injected power*

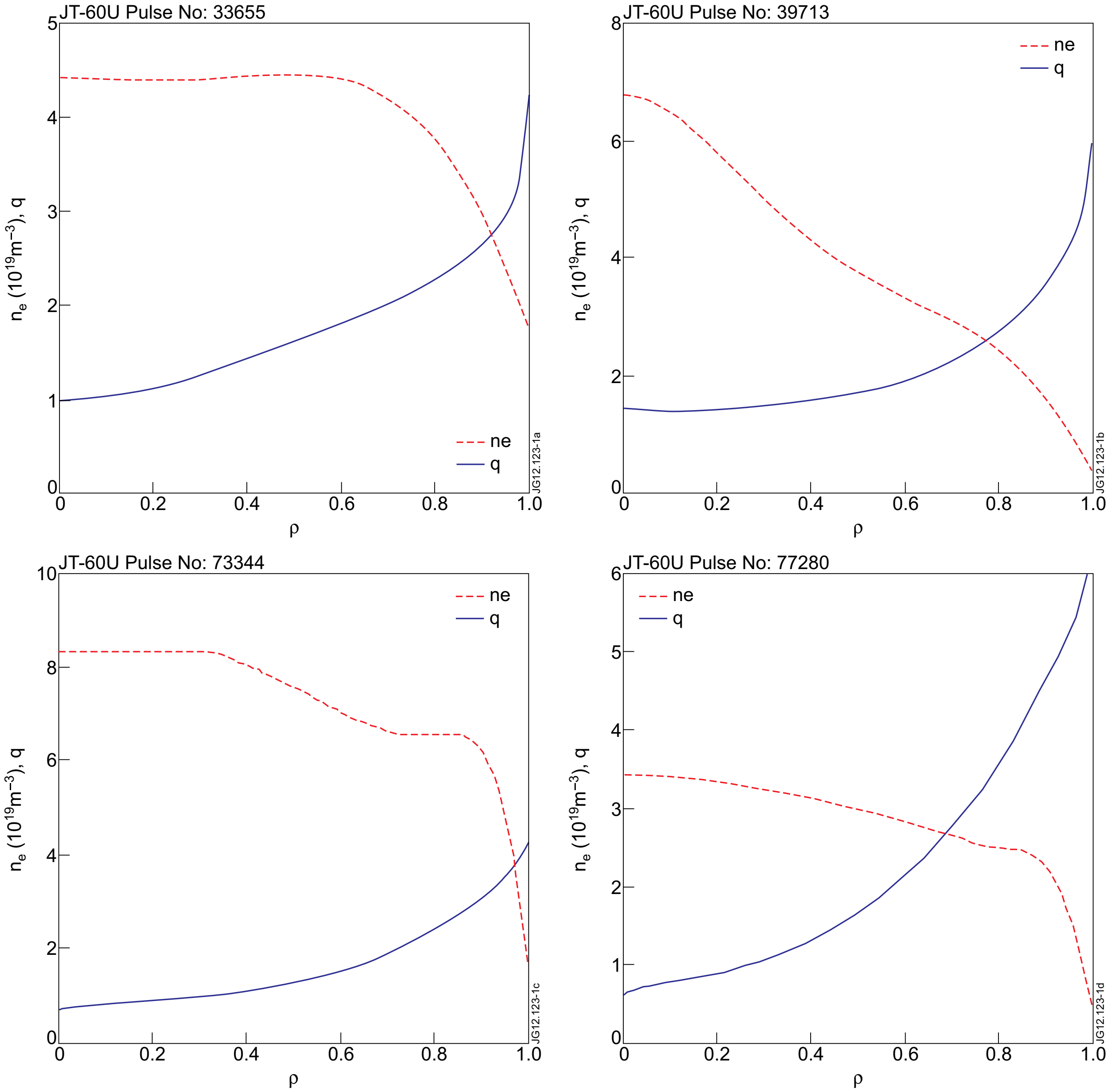

*Figure 1: Density and q profiles used for JT-60U Pulse No's: 33655 (a) 39713 (b) and JET Pulse No's: 73344 (c) and 77280 (d).*

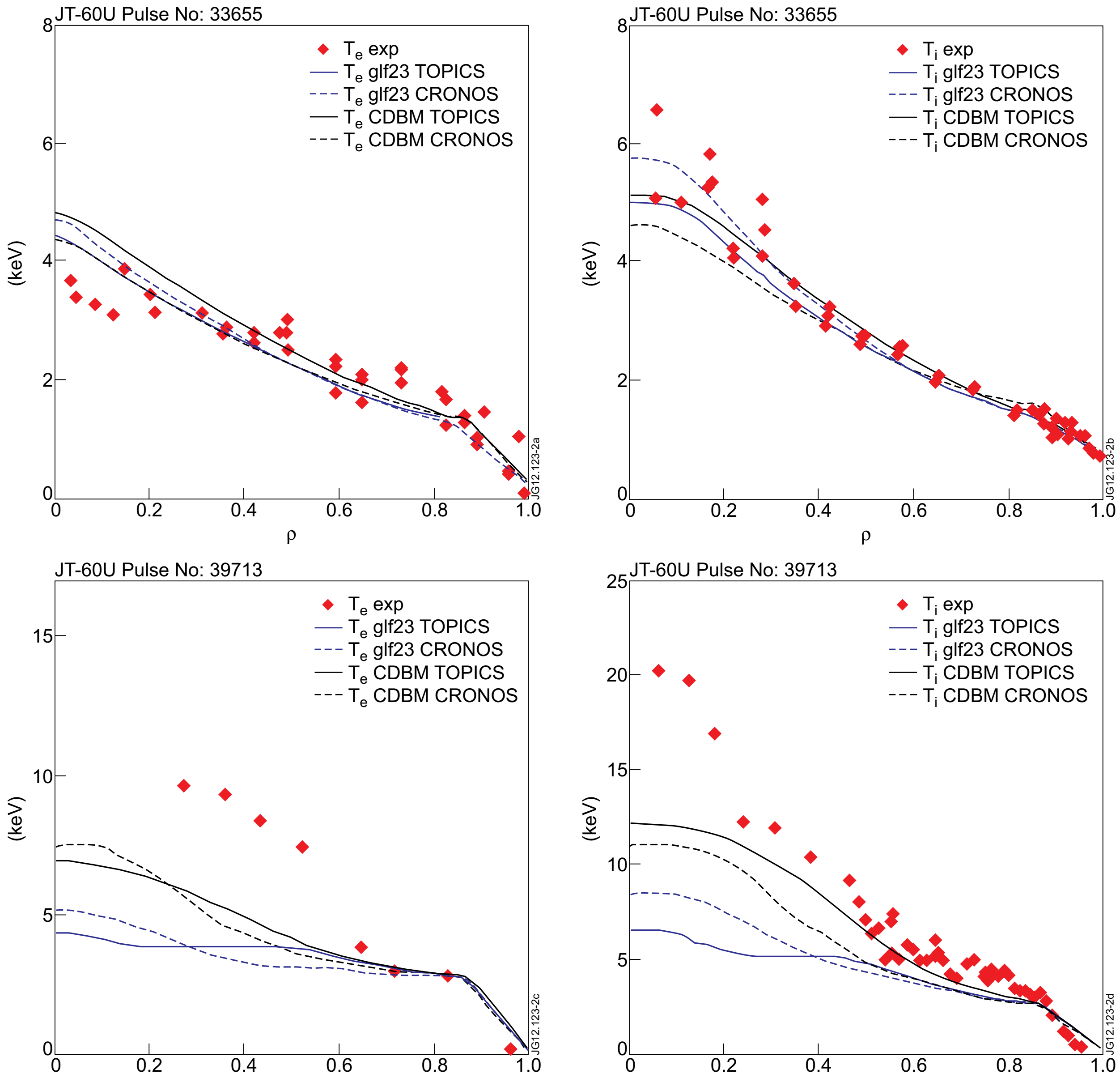

*Figure 2: Comparison between the electron (a,c) and ion (b,d) temperatures profiles with those obtained with CRONOS and TOPICS with GLF23 and CDBM transport models for Pulse No's: 33655 and 39713.*

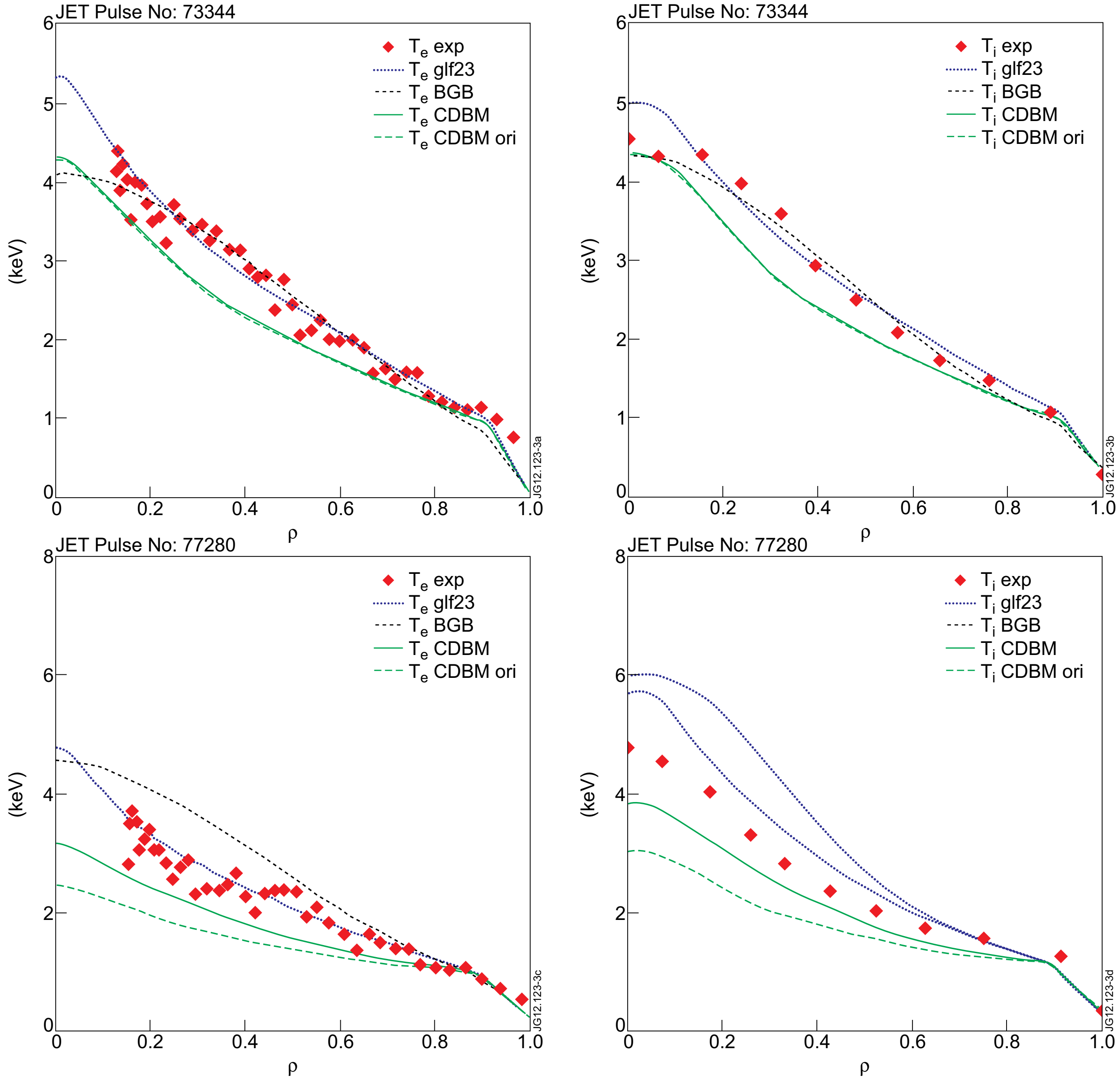

*Figure 3 Comparison between the electron (a,c) and ion (b,d) temperatures profiles obtained with CRONOS with GLF23, Bohm-GyroBohm and new and original CDBM transport models for Pulse No's: 73344 and 77280.*

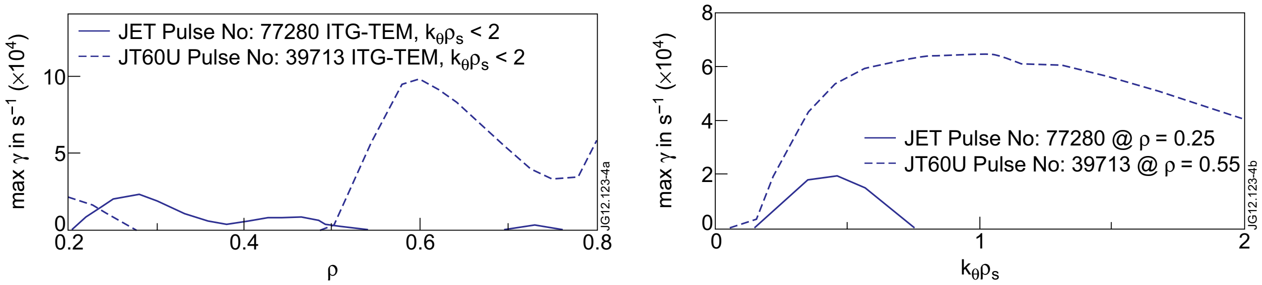

*Figure 4 Maximum growth rate for JET Pulse No: 77280 and JT-60U Pulse No: 39713 hybrid discharges (left) Growth rate spectrum at ρ = 0.25 for JET Pulse No: 77280 and at ρ =0.55 for JT-60U Pulse No: 39713 (right)*