Effect of Poloidal Rotation on the Predictions for the Dynamics of the ITBs and Transport in JET Plasmas

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1. Introduction

Recent results from the measurements of carbon plasma rotation velocity across Internal Transport Barriers (ITBs) on JET show that the velocities are typically an order of magnitude higher than the neo-classical predictions [1]. As a consequence, the radial electric field can be very different from that calculated using the neo-classical value for v_{pol}. This gives further rise to different ω_{ExB} shearing rates, as normally used in transport simulations to predict the ITB dynamics, location and strength. The 1D first-principle transport models, such as the Weiland model [2] or GLF23 [3], have so far failed to reproduce satisfactorily the time dynamics, location and strength of the ITBs [4]. The Weiland model does not typically predict an ITB at all while GLF23 predicts the ITB at the wrong radial location or too weak an ITB. One of the obvious reasons is that the growth rates of the ITG/TEM modes significantly exceed the ω_{ExB} shearing rates calculated from the radial electric field E_r. In the present calculation of E_r in transport codes, the neo-classical value for the poloidal rotation velocity is assumed. The past explanation for the failure of the Weiland model was the oversize growth rates as compared with the ω_{ExB} shearing rate. However, after the recent measurements of v_{pol} in JET, the question to be addressed in this paper is whether the failure to predict ITBs could actually be caused by the incorrectly estimated ω_{ExB} shearing rates, rather than just the oversize growth rates.

2. Experimental and Calculated Carbon Poloidal Rotation Velocities on JET

The time traces and the profiles of one of the ITB discharge with the carbon poloidal rotation measurements are shown in figure 1. The poloidal velocity increases by a factor of up to 5, and even in some cases changes its sign within the ITB layer around at t=5.8s when the ion ITB forms. Unfortunately, within the present time and spatial resolution of the v_{pol} measurements, it is impossible to resolve the causality, i.e. whether the changes in v_{pol} occur before ITB forms or whether the changes in v_{pol} are caused by the changes in the ion temperature profile, when the ITB has already been triggered. However, it seems to be very difficult, unless impossible, to obtain carbon poloidal rotation velocities significantly over 10 km/s within the framework of neo-classical theory, even by using artificially modified, extremely large main ion density and temperature gradients as well as carbon density gradients.

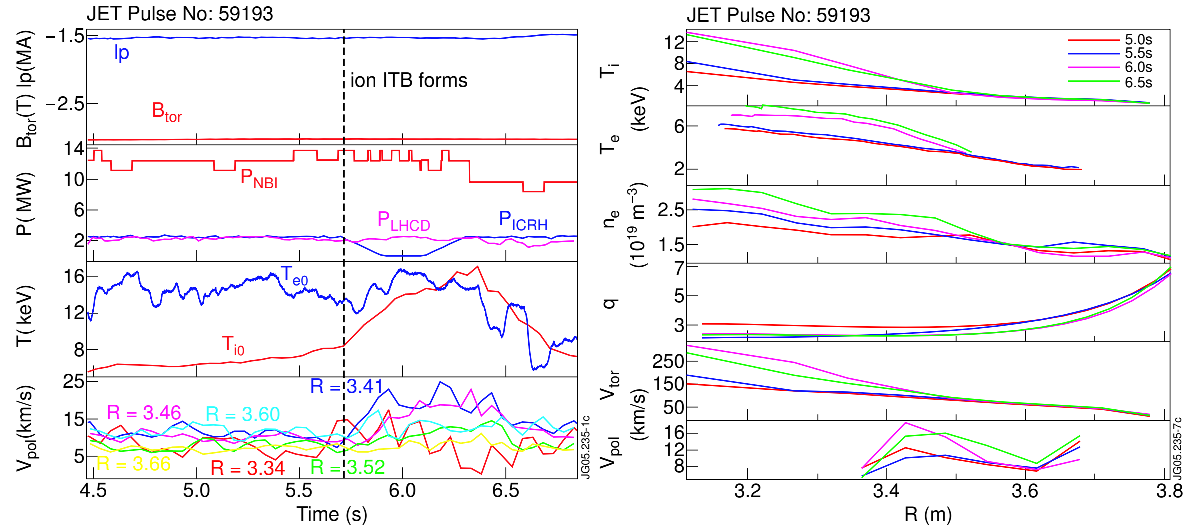

Figure 1. Time traces and profiles at four instants of one of the JET ITB discharges with poloidal rotation measurements. The poloidal velocities are measured at 6 different radii.

The experimentally measured carbon poloidal rotation velocities are compared with the neo-classical estimates calculated with NCLASS code [5] in figure 2 (left frame). The discrepancy between the measured and neo-classical carbon poloidal rotation is largest within the ITB layer, which is shown by the ρ_{Ti}^* controur plot in the right frame. Within the ITB region (4 innermost chords), the measured poloidal rotation exceeds the neo-classical one by an order of magnitude. The measured v_{pol} seems to be also elsewhere larger than the neo-classical one.

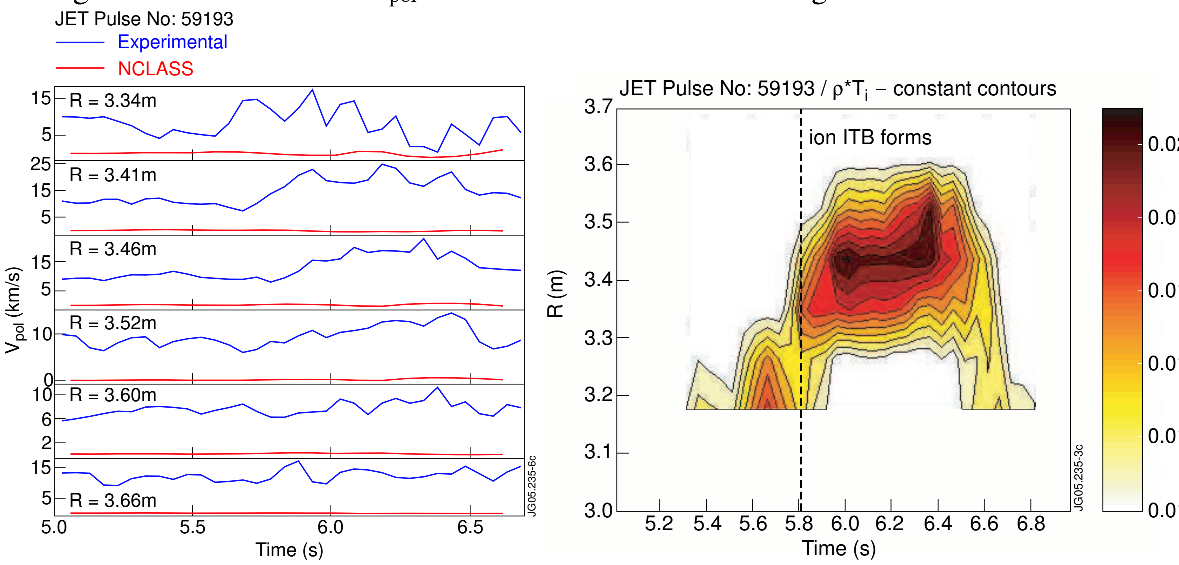

Figure 2. Experimentally measured carbon poloidal rotation velocity compared with the calculated one at each 6 measured radii (left frame). The location and strength of the ion ITB as a function of time and major radius (right frame).

Due to the poloidal velocities being significantly larger than the neo-classical ones, the actual radial electric fields and further the $\omega_{E\times B}$ shearing rates may be very different from those used in transport simulations assuming neo-classical v_{pol}. The effect of using the measured v_{pol} instead of the neo-classical one on E_r and $\omega_{E\times B}$ is studied in section 3 and on the predictive transport simulation with the time dynamics of the ITBs in section 4.

3. Comparison of the Radial Electric Field and the $\omega_{E\times B}$ Shearing Rate

The definitions for the different components in the calculation of the radial electric field are

$$E_r = E_{\nabla p} + E_{pol} + E_{tor} = \frac{1}{eZ_i n_i}\frac{\partial p_i}{\partial r} - v_{pol,i}B_{tor} + v_{tor,i}B_{pol}, \quad (1)$$

where Z_i is the charge number, n_i the density, p_i the pressure, $v_{pol,i}$ the poloidal velocity and $v_{tor,i}$ the toroidal velocity of the ion species i and B_{tor} and B_{pol} are toroidal and poloidal components of the magnetic field. In this paper, the species i is either deuterium or carbon. The ω_{ExB} flow shearing rate is calculated from the radial electric field as

$$\omega_{E\times B} = \left| \frac{(RB_{pol})^2}{B}\frac{\partial}{\partial \Psi}\frac{E_r}{RB_{pol}} \right|. \quad (2)$$

The radial electric field with its three different components are illustrated in figure 3. Three different ways, originating from the different ion species (carbon versus deuterium) or different source for v_{pol} (experimental versus neo-classical), have been employed to calculate E_r. In the case of experimental v_{pol} (blue curves), the radial electric field is calculated from the measured carbon poloidal and toroidal rotation and the measured carbon pressure. In the case of neo-classical v_{pol} calculated with NCLASS, there are two options to calculate the radial electric field. a) Use the calculated deuterium poloidal rotation together with the measured deuterium pressure and carbon toroidal rotation assuming deuterium and carbon v_{tor} to be the same (red curves) or b) use the calculated carbon poloidal rotation together with the measured carbon pressure and measured carbon toroidal rotation (green curves). The black curves in toroidal and pressure gradient terms denote that at least two of the curves are identical.

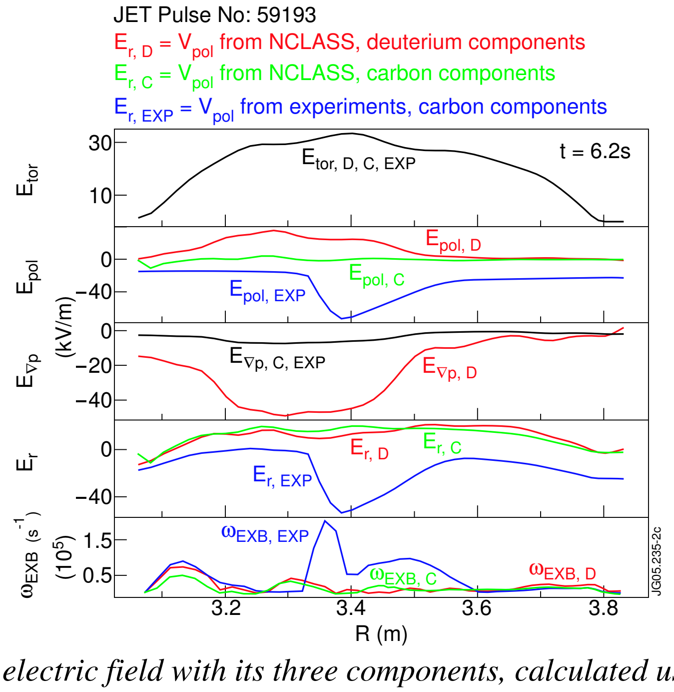

Figure 3. The radial electric field with its three components, calculated using different ion species and different sources for v_{pol}, pressure gradient and density at t= 6.2s. Shown also the corresponding $\omega_{E\times B}$ shearing rates, respectively.

The radial electric field and the ω_{ExB} shearing rates are very different depending on whether the experimental or neo-classical poloidal rotation velocities are used (blue versus green curves). On the other hand, taking the different ion component from NCLASS (green, carbon versus red, deuterium) gives roughly the same radial electric field, indicating that the toroidal rotation velocity of deuterium should be rather similar to that of carbon.

4. Predictive Simulations of the ITB Dynamics Using the Experimental v_{pol}

Two predictive simulations with the Weiland transport model are compared. The only difference between the two simulations is that the first one (red curves) uses the neo-classical poloidal velocity from NCLASS whereas the second one (blue curves) takes the experimentally measured v_{pol} in the calculation of E_r and ω_{ExB} flow shearing rate.

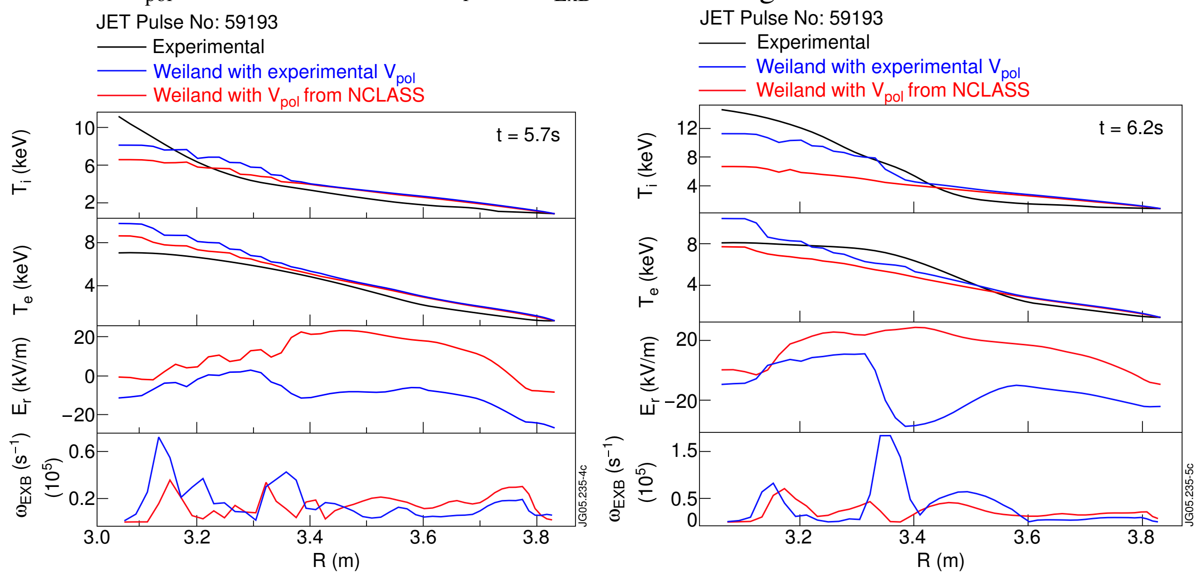

Figure 4. Predictions for the ion and electron temperatures, radial electric field and $\omega_{E\times B}$ shearing rate before the ion ITB formation (left frame) and after it (right frame).

In the case when the experimental poloidal rotation is used, the Weiland model predicts the ion ITB just at the right radial location and right instant with roughly the same ITB strength as measured in the experiments when. On the other hand, otherwise an identical simulation except with v_{pol} from NCLASS does not exhibit any sign of an ITB.

5. Conclusions

If the experimental poloidal velocity is used instead of the neo-classical one to calculate the radial electric field and the $\omega_{E\times B}$ shearing rate, E_r and $\omega_{E\times B}$ are found to be even qualitatively significantly different. This is most pronounced within the ITB layer. As a consequence, the simulation predictions for the dynamics, strength and location of ITBs change and may improve significantly, as shown here in the case of the Weiland model. In addition to changing the predictive transport simulation results, the non-neo-classical poloidal rotation velocities might have a significant impact on the present neo-classical transport theory, for example a source for this non-neo-classical v_{pol} could arise from the anomalous turbulence. This would enable us to find a possible way to couple the neo-classical and anomalous transport theories.

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