Measurements and modeling of the EC emission
by LH generated fast electrons in JET

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Introduction and motivation

Multiple angle ECE observations with the new Oblique ECE diagnostic at JET are used to probe the electron velocity distribution function at multiple electron energies [1] and identify possible non-Maxwellian features. In particular, suprathermal ECE spectra below the second harmonics for selected JET pulses with injected LHCD power have been analysed in the frame of LH power deposition and CD efficiency studies. The comparison between experimental data and simulations from the emission code SPECE gives information about several parameters, including the LHCD deposition region, the characteristics of the electron tail, the fraction of driven current. The sensitivity of the simulated spectra to the parameters has been studied, in order to assess the level of confidence on the values obtained from the best fit.

Analysis method

The new Oblique ECE diagnostic system comprises five channels, for 3 lines of sight (0°, 10°, 22° with respect to radial direction) and 2 linear polarizations (mostly X-mode, mostly O-mode) for each oblique line of sight over the 70-350 GHz frequency range, with spectral resolution up to 7 GHz and time resolution of 5 ms [2]. Experimental data have been up to now relatively calibrated.

The ray-tracing code SPECE [3], that computes EC wave emission and propagation in the relativistic formulation for general tokamak equilibria, has been extensively used to support the diagnostic. The code models the distribution function of the fast electron tail driven by Lower Hybrid waves, as superposition of Maxwellian distribution functions with five parameters controlling the shape in momentum and space of the LH driven part of the
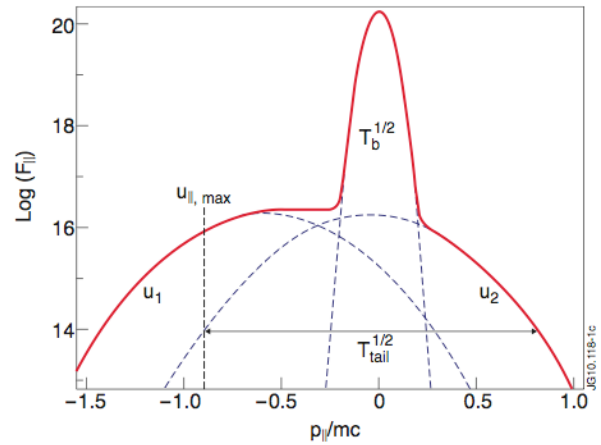
electron distribution function $f(\psi, u)$ [4]:

$$f(\psi, \vec{u}) = \left(1 - \eta(\psi)\right) \cdot f_{M,T_b}\left(|\vec{u}|\right) + \eta(\psi) \cdot \sum_{i=1}^{N} f_{M,T_{tail}}\left(|\vec{u} - \vec{u}_{0,i}|\right),$$ where $\boldsymbol{u} = \boldsymbol{p}/mc$ is the normalized

momentum and ψ is the normalized poloidal flux coordinate. The five parameters are:

- the peak density fraction η_0 of the suprathermal electrons, the position of the peak ψ_0 and

the width of the Gaussian decrease ψ_c related by $\eta(\psi) = \eta_0 \exp\left[-(\psi - \psi_0)^2 / \psi_c^2\right]$

- the temperature of the tail T_{tail} determining its shape in $u_\perp$ and the spacing of the

Maxwellian distribution functions in $u_{//}$ through $u_{0,i} = u_{0,i-1} + 2\sqrt{T_{tail}/mc^2}$

- the maximum normalized momentum $u_{//,max} \sim (N_{//,min}^2 - 1)^{-1/2}$ up to which the suprathermal

tail extends; this sets up also the number of Maxwellian distribution functions used in the

model $N = 1 + \text{int}\left[\sqrt{mc^2/T_{tail}}\left(u_{//,max} - u_{0,1}\right)/2\right]$.

Figure 1: The shape of the electron distribution function $F(p_{//})$ (number of electrons per unit volume and unit parallel momentum increment) in presence of LH power (solid curve) is sketched as implemented in SPECE. Here T_b is the bulk temperature, $u_{1(2)}$ the drift of the first (second) Maxwellian distribution (dashed, wide) modeling the fast electrons tail, superposed to the Maxwellian bulk distribution (dashed, narrow). The function parameters used in this case are: T_{tail}=35KeV, η_0=1.2×10^{-3}, N=2 (u_{max}=0.57), T_{bulk} =1.1 KeV, $n_{e,tot}$=2.05 x10^{19} m^{-3}.

The downshifted emission shows up when the cold resonance n=2 takes place outside the plasma, that is optically thin. The radiation temperature of the peak is $\sim \eta T_{tail}$ and its frequency position depends on $u_{//,max}$ and T_{tail} (higher $u_{//,max}$ and T_{tail} means stronger frequency downshift).

Parameter scan study

The main purpose of this work is to use the comparison between ECE data and simulations to constrain the set of parameters of the electron distribution function in presence of LH power; for this purpose three different JET pulses have been considered (#74087, #77874, #77895). For the pulse #74087, the two considered time slices correspond to steady state phases with 3 and 5 MW injected LH power respectively. The last two pulses have been analysed in the low density transient phase where the downshifted peak is visible before the

subsequent rise of the density reduces LH waves coupling; in this condition both data and simulations are necessarily affected by higher uncertainties that will reflect in the parameter determination.

The scan in the parameters space has been performed by an automatic procedure evaluating the mean squared deviation between the simulation and the data for a given set of parameters. We chose to fix the number of Maxwellian distribution functions to N=2 ($|u_{//,max}| \sim 0.5 \div 0.8$) and to keep constant the radial extent of the affected region $\Delta\rho \sim (\psi_{0+}\psi_c)^{1/2}$ - $(\psi_0 - \psi_c)^{1/2}$ when varying ψ_0, since the ECE spectrum is almost insensitive to ψ_c variation.
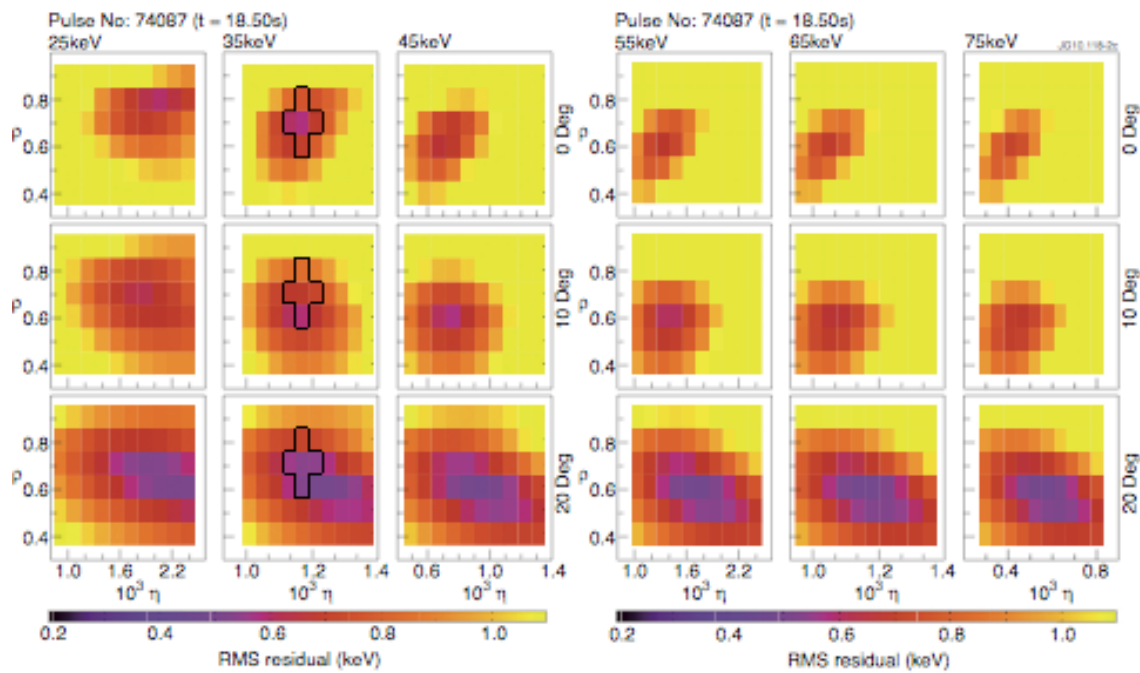

Figure 2: Fit residuals for pulse #74087 at t=18.50 sec; for each plot the peak density fraction is represented on the x-axis and the peak position on the y-axis. Each row of plots refers to the data measured at 0, 10 and 20 degrees respectively and each column refers to a single value of T_{tail}. Darker colors correspond to low residual and good fit, lighter colors indicate large discrepancy between data and simulations. The black cross defines the parameters range of the spectra in Fig. 3 (see below).

In all the considered cases, a "good" fit region can be identified in the 3D parameters' space, but this region is quite extended in T_{tail}. As shown in Fig.2 for pulse #74087 at t=18.50 sec, the parameter more likely to be determined with this procedure is the LH power deposition localisation: the comparison between the all cases suggests that $\rho_0 \ (=\psi_0^{1/2})$ moves from 0.5-0.6 to 0.6-0.7 when LH power (and density) is increased. Taking as a reference the value of T_{tail} for which the three ECE data sets (corresponding to three lines of sight) are more consistent, Table 1 shows the parameters and current drive efficiency for the lower mean squared deviation case for all the analyzed pulses and timeslices. In Fig.3 the simulated spectra in different conditions are compared with measurements; the simulated downshifted

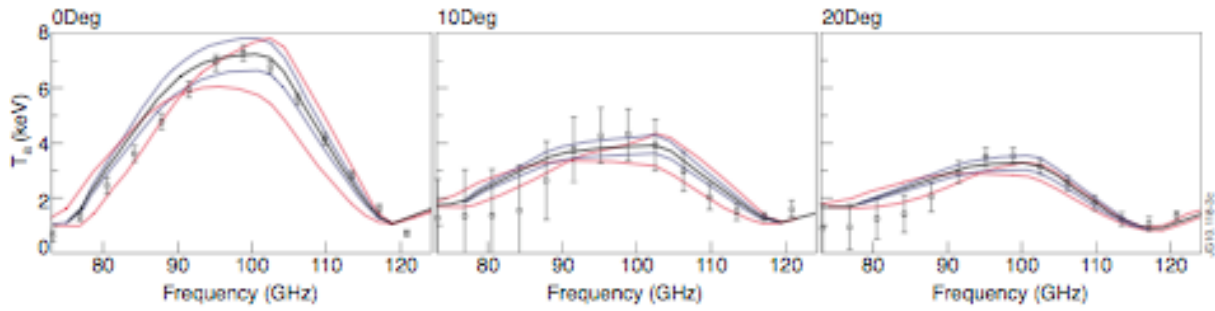peak increases with decreasing ψ_0 and increasing η_0 while shifting towards high frequency.

Figure 3: From left to right the plot shows 0º (Xmode), 10º (Omode+Xmode), 20º (Omode+Xmode) data and simulations for the downshifted peak of the #74087 pulse at t=18.5 sec. For the case here represented T_{tail}=35KeV is fixed; variation ranges of the parameters are η_0=[0.95-1.19]×10^{-3} (blue curves, highest value for the top), ρ_0=[0.57-0.75] (red curves, highest values for the bottom curve). The black curve is the best obtained fit with η_0=1.07×10^{-3}, ρ_0=0.65. The variation range of the parameter is highlighted in Fig.2, together with the LHCD efficiency defined as $\gamma = n_e\ R\ I_{LH}/P_{LH}\ (A/W/m^2)$

Pulse #	T (sec)	P_{LH}(MW)	T_{tail}(keV)	η_0(10^{-3})	ρ_0	γ(10^{19}A/W/m^2)
74087	18.5	3	35	1.07	0.65	0.853
74087	20.10	5	45	0.38	0.75	0.501
77874	4.11	2.5	45	1.39	0.45	1.202
77895	4.11	2.3	35	1.54	0.55	0.869

Conclusions and Acknowledgements

The analysis is intended to test the behaviour of the simulation spectra with the parameters in order to give an estimate of the suprathermal electron energy, of their localization in space, and of the driven current. This method gives confident results on the determination of the deposition location and qualitative evaluation of the driven current; external constraints on some parameters (particularly on the temperature of the tail) would help to improve the confidence on the driven current as well. An improved distribution function model that allows to vary with continuity $u_{//,max}$ is under testing in SPECE.

References

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