A quantitative comparison between confined fast ion data and models from radio frequency heating experiments with the three ion scenarios at JET

M. Nocente[1], Ye. O. Kazakov[2], V.G. Kiptily[3], T. Craciunescu[4], J. Eriksson[5], L. Giacomelli[1], G. Gorini[1], C. Hellesen[5], E. Lerche[2], M. Mantsinen[6], J. Ongena[2], S. Sharapov[3], M. Tardocchi[1], D. Van Eester[2] and JET Contributors*
[1]*Dipartimento di Fisica and Istituto di Fisica del Plasma, Milano, Italy*
[2]*Laboratory for Plasma Physics, LPP-ERM/KMS, TEC Partner, Brussels, Belgium*
[3]*Culham Centre for Fusion Energy, Culham Science Centre, Abingdon, UK*
[4]*National Institute for Laser, Plasma and Radiation Physics, Bucharest, Romania*
[5]*Department of Physics, Uppsala University, Uppsala, Sweden*
[6]*Barcelona Super Computing Centre and ICREA, Barcelona, Spain*
**See the author list of X. Litaudon et al 2017 Nucl. Fusion 57 102001*
Electronic mail: massimo.nocente@mib.infn.it

Ion cyclotron resonance heating (ICRH) by radio frequency waves is a commonly adopted tool to tailor the plasma discharge and boost the fusion performance. A recent breakthrough in this field has been the theoretical discovery [1] and subsequent experimental demonstration [2] that radio frequency power can be more efficiently absorbed by exploiting the favorable polarization properties of the wave electric field in vicinity of the left handed cut-off layer compared to conventional minority heating. This is possible in the so called 3 ion scenarios, where the plasma mixture is carefully adjusted so that two majority species, say hydrogen and deuterium, define the propagation properties of the wave, while a third species, at typical concentrations of few percents or less, absorbs the power with virtually 100% efficiency.
Experiments at JET on the 3 ion scenarios have so far focused on D and ^{3}He acceleration and have provided unambiguous qualitative evidence of the acceleration of fast ions to the MeV range. This ranges from the excitation of Alfvén eigenmodes to the observation of a rich gamma-ray emission from a variety of nuclear reactions between MeV range fast ions and ^{9}Be impurities in the plasma (see figure 1).

In this work, we present a quantitative study of confined fast ion data from 3 ion scenario experiments at JET and a comparison with predictions from advanced radio frequency codes that solve the wave propagation in the plasma and calculate the distribution function of the fast ions by means of a Monte Carlo kick operator. Synthetic diagnostics are used as means to bridge the gap between simulations of the fast ion phase space and indirect experimental data on the nuclear emission spectra from 3 ion plasmas. Although the enhancement of ICRH in the 3 ion scheme compared to minority heating is unambiguous, we find that data suggest mean fast ion energies which are significantly lower than predictions. Possible additional physics effects that might be needed to reconcile simulations and the experimental findings, such as the role of Alfven eigenmodes in effectively ejecting the most energetic ions or the super-adiabaticity of the fast ions as they get progressively accelerated by the wave electric field, are discussed.

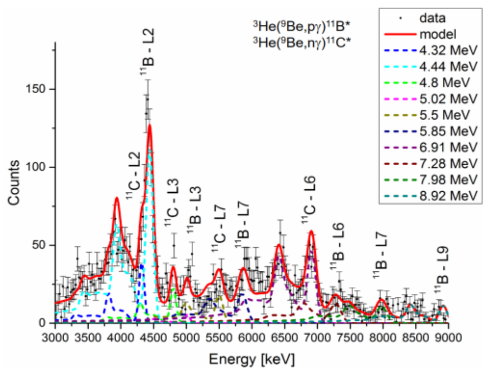

Figure 1. Gamma-ray spectrum from reactions between fast ^{3}He ions and ^{9}Be impurities in 3 ion ICRH experiments at JET. A detailed analysis of the complex gamma-ray spectrum born in these reactions resolves the individual contributions to the emission, which are used to determine the ^{3}He ion energies for comparison with models.

[1] Ye.O. Kazakov et al., *Nucl. Fusion* **55**, 032001 (2015)
[2] Ye.O. Kazakov et al., *Nature Physics* **13**, 973 (2017)