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Measurement and analysis of TOFOR neutron spectra from RF and NB heated JET D plasmas

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Introduction

Neutron Emission Spectroscopy (NES) can be used to study the fuel ion populations in fusion plasmas as has previously been demonstrated at JET in DT experiments [1]. During the spring of 2006, the 2.5-MeV time-of-flight spectrometer TOFOR, designed to work at optimized rate (OR), was installed at JET [2, 3]. High count-rate is an essential figure of merit for NES since the statistical accuracy sets the limit for the information that can be extracted from the data. TOFOR records neutrons from $d+d \rightarrow {}^{3}He+n$ reactions in a time-of-flight (t_{TOF}) spectrum, centered at 65 ns corresponding to $E_n = 2.45$ MeV, with a shape determined by the motional state of the fusing deuterons [2] and refs. there in. The net result is a spectrum that is particularly sensitive to high velocity ions giving rise to distinct signatures such as tails extending up to $E_{\mathrm{n}} = 7$ MeV. The response function of TOFOR has been determined to high precision, allowing for detailed

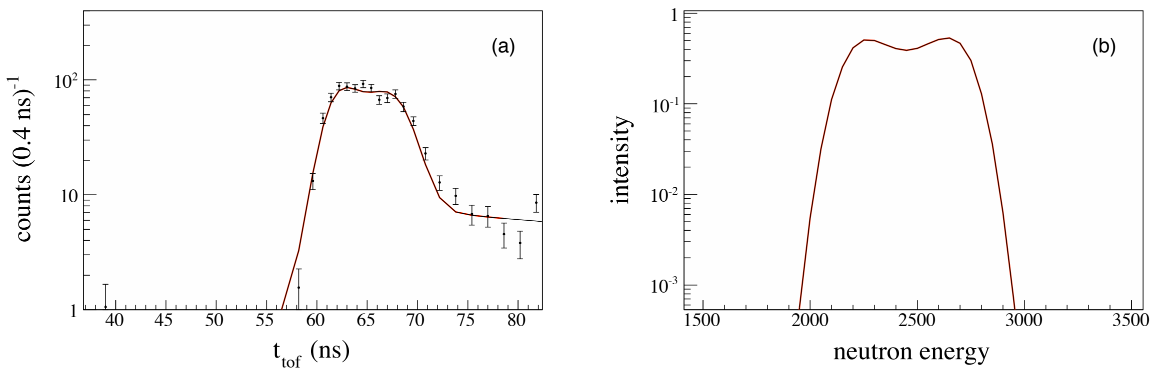

Figure 1: (a) Measured t_{TOF} spectrum of 130-keV NB heated plasma (69242) and fit using neutron spectrum from TRANSP slowing-down distribution (b).

analysis of the data, clearly connecting the signatures in the t_{TOF}- and E_{n}-spectrum and hence the underlying ion population states.

NB heated plasmas

JET discharge 69242, heated with a single 130-keV NB pini, produced the t_{TOF} spectrum shown in figure 1a. The peak centered at $t_{\mathrm{TOF}} \approx 65$ ns is due to single scattered neutrons while the extended level for $t_{\mathrm{TOF}} > 73$ ns is the result of multiple scattering[2]. The lack of events with $t_{\mathrm{TOF}} < 58$ ns indicates that there are no incoming neutrons of energies $E_{\mathrm{n}} > 3$ MeV as expected under the conditions at hand. The shape of the peak shows the typical features of a neutron emission from a plasma with an ion slowing-down distribution connected with NB injection. Indeed, as input for the analysis we used the TRANSP calculated energy/pitch-angle beam-ion distribution (figure 2). These ions were allowed to interact with the bulk population to produce the neutron energy spectrum shown in figure 1b which, in turn, was folded with the TOFOR response function to give the simulated t_{TOF} spectrum in figure 1a [4]. Good agreement with the data was found ($\chi^2_{\mathrm{red}} = 1.3$) where both the width and the square-like shape of the peak were well reproduced.

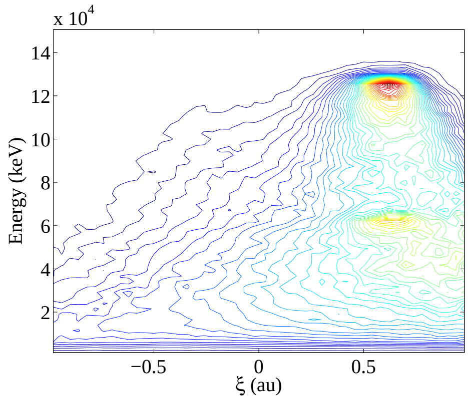

Figure 2: Beam ion slowing-down distribution in energy $\xi = v_{\parallel}/v$ simulated with TRANSP at $t = 59$ s for discharge 69242.

RF heated plasmas and parameterized models

Produced t_{TOF} spectra for discharges 69247 and 69249 with NB heating, as above, combined with 5 MW of RF heating (figures 3 and 4) has notably different shapes compared to the case of NB alone. Especially, with RF there appears a pronounced tail at $t_{\mathrm{TOF}} < 60$ ns which is also different for the cases of RF tuned to 42 MHz and 47 MHz, corresponding to on-axis and inboard (high-field) side power deposition, respectively.

The analysis of these discharges was based on a parameterized model of the ion distributions to create the neutron spectra, which allowed for iterative fitting to the data. A three-component model was used where the component connected with NB injection was calculated from TRANSP input as above. The second component comes from high-energy ions accelerated by RF, mostly in the perpendicular direction. The third component is due to the slowing-down and pitch-angle scattering of the RF ions and is modeled as an isotropic Maxwellian.

In the case of on-axis RF, the three component model was used with a perpendicular Max-

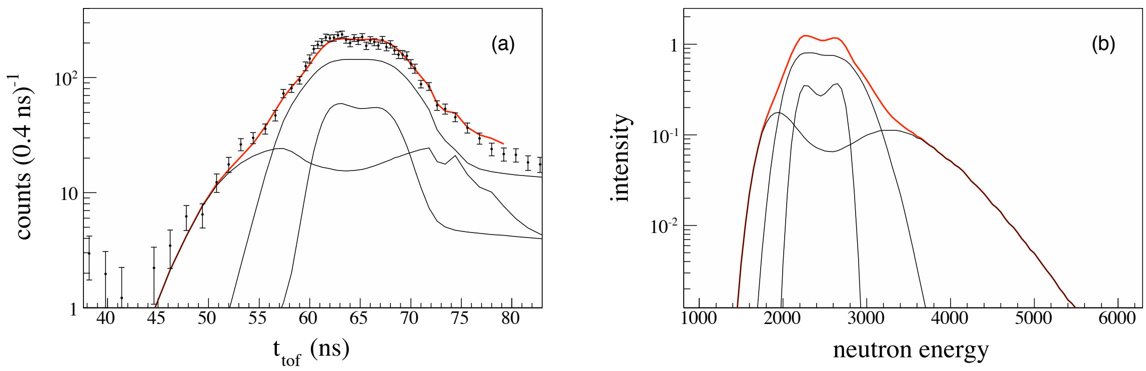

Figure 3: (a) Measured t_{TOF} spectrum and fitted components for on-axis RF heated plasma (69247) with resulting neutron spectrum (b). The curves show NB and low and high energy RF ion contributions

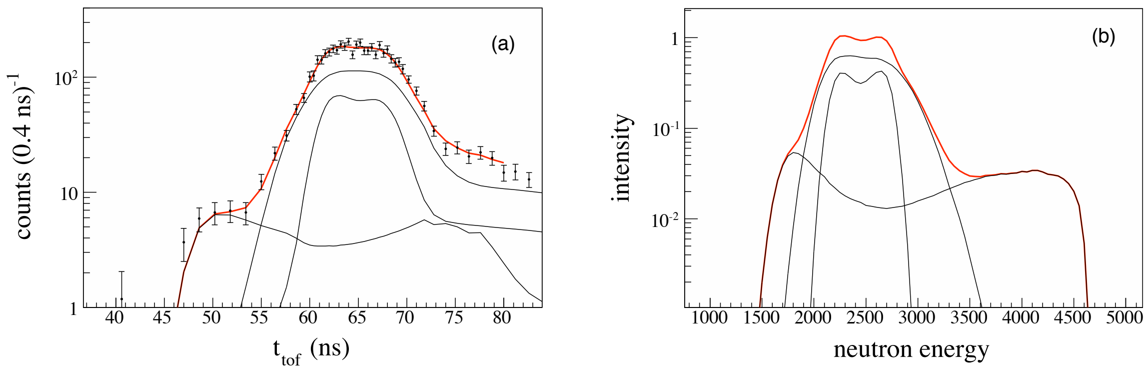

Figure 4: (a) Measured t_{TOF} spectrum and fitted components for inboard heated plasma (69250) with resulting neutron spectrum (b).

wellian to fit the high-energy tail, giving a χ^2_{red} of 1.19. The temperatures deduced were $T_{\mathrm{iso}} = 70 \pm 20$ keV for the isotropic and $T_{\perp} = 270 \pm 50$ keV for the perpendicular Maxwellian. It is interesting to note that the t_{TOF} spectra for the case of high-field side RF is conspicuously different and the high-energy tail could not be described with the regular perpendicular Maxwellian. However, a good fit ($\chi^2_{red} = 0.98$) could be obtained when the high-energy ion tail was limited to $E_d < 1.5$ MeV. It is also noteworthy that the two other spectral components where not affected by the RF frequency change.

Conclusions

Two different approaches have been presented when analyzing neutron emission spectroscopy data for JET D plasmas with auxiliary heating taken with the new TOFOR instrument. With NB heating alone, the predicted beam ion slowing-down distributions from TRANSP was used to generate the neutron spectrum used as input to describe the measured t_{TOF} spectrum. In this approach, TRANSP simulations can be confirmed,as here, or rejected.

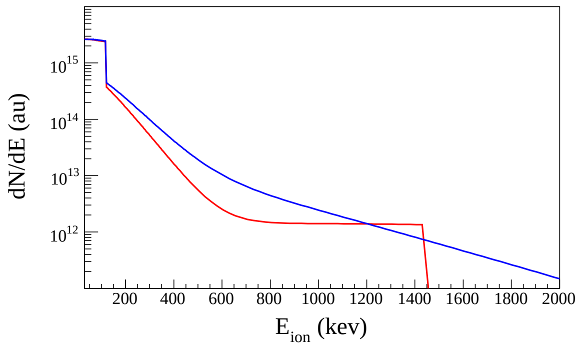

Figure 5: Fitted ion distributions for on-axis (blue) and HFS (red) RF heating.

In the other approach used here in the case of RF, there was no predicted information on the ion motional state, but this was determined based on a certain model used to generate a parameterized neutron spectrum. The latter was varied to give the best fit to the measured t_{TOF} spectrum which allows one to infer information on the velocity distributions responsible for the neutron emission. For instance, the present study has revealed distinct quantitative differences between the ion velocity distributions generated by RF with the resonance position placed on- and off-axis (figure 5).

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