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First results from the new TOFOR neutron spectrometer at JET

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* *See the Appendix of J. Pamela et al., Fusion Energy 2004 (Proc. 20th Int. Conf. Vilamoura, 2004), IAEA, Vienna (2004)*

Introduction

Neutron emission spectrometry (NES) is a powerful tool for the diagnosis of fusion plasmas, yielding information about e.g. the plasma ion temperature or contributions to the neutron spectrum from reactions between fuel ions with different energies, resulting from different plasma heating schemes. At JET, NES has proven its potential with the MPR spectrometer [1] which has been designed for measurements of 14 MeV neutrons produced in $d + t \rightarrow \alpha + n$ reactions in DT plasmas. As part of the enhanced capabilities programme, JET is equipped with two new NES systems. One of those is an upgrade of the MPR [2], the other is TOFOR, a new time-of-flight (TOF) spectrometer which is optimized (O) for high count rates (R). TOFOR is designed for the diagnosis of 2.45 MeV neutrons from $d + d \rightarrow {}^3\mathrm{He} + n$ reactions in D plasmas with good statistical accuracy and time resolution.

Instrumental details

The TOFOR design is described in [3, 4, 5, 6]. As shown in Fig. 1, it consists of two sets of scintillating detectors. In the first one (S1), placed in the collimated neutron flux, the incoming neutrons are scattered and thereby lose a fraction of their initial energy E_n. The remaining neutron energy, $E_{n'}$, depends on the scattering angle according to

$$E_{n'} = E_n \cdot \cos^2 \theta \qquad (1)$$

The flight path to any point on the sphere indicated in the figure is given by

$$L(\theta) = 2 \cdot R \cdot \cos\theta \tag{2}$$

With a second set of detectors (S2) placed on this so-called constant time-of-flight sphere, the initial energy of the incoming neutrons is uniquely determined by the flight time t_{TOF} between the two detectors:

$$E_n = \frac{2 \cdot m_n \cdot R^2}{t_{TOF}^2} \tag{3}$$

For TOFOR, the radius of the constant time-of-flight sphere is R = 705 mm, resulting in a flight time of 64 ns for 2.5 MeV neutrons.

Since the flight time does not depend on the scattering angle, a wide angular region for the scattered neutrons can be covered with detectors without losing time resolution. In order to allow for high count rates, each detector set consists of a number of detectors. The S1 set contains a stack of five cylindrical scintillators (diameter 40 mm, thickness 5 mm) which are read out by three photomultipliers each. The S2 set holds 32 scintillators of trapezoidal shape (length 350 mm, width 95/135 mm, thickness 15 mm) which are read out by one photomultiplier each. With respect to the center of the S1 detectors, the ring of S2 detectors covers an angle of 30° ± 7.5°. The light transfer time through the S2 detectors (≈ 2 ns) has been compensated for by tilting the detectors relative to the constant-time-of-flight sphere.

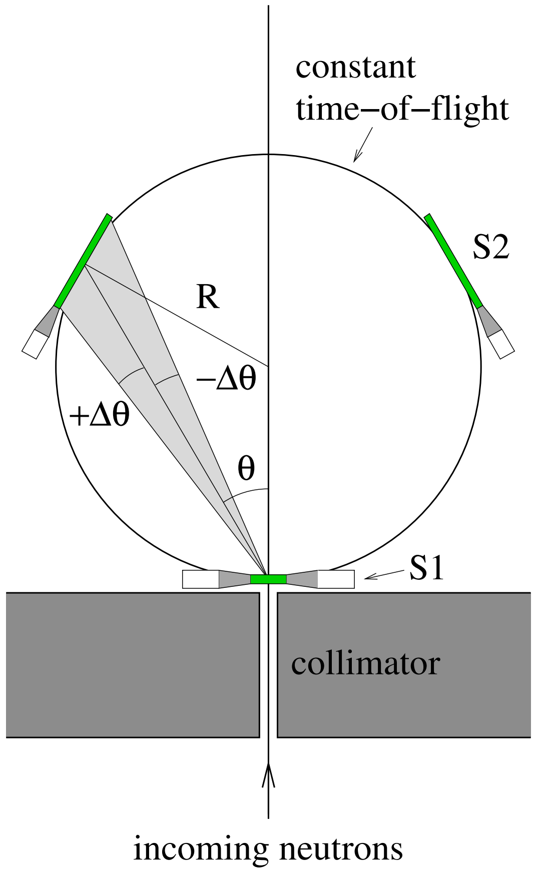

Figure 1: TOFOR principle. The energy of the incoming neutrons is given as a function of the flight time between the S1 and the S2 detectors.

The electrical pulses from the photomultiplier tubes are discriminated and time-stamped in fast, free-running time digitizing PCI boards [7]. TOFOR employs 5 such boards with 8 channels each, so that each of the 37 detectors has its individual channel. The boards are synchronized prior to each plasma discharge. The time digitizers have a bin width (time resolution) of 0.4 ns and can collect events at a peak rate of 1.25 GHz or a sustained pulse rate of 5 MHz. Times are recorded relative to the start of the plasma discharge

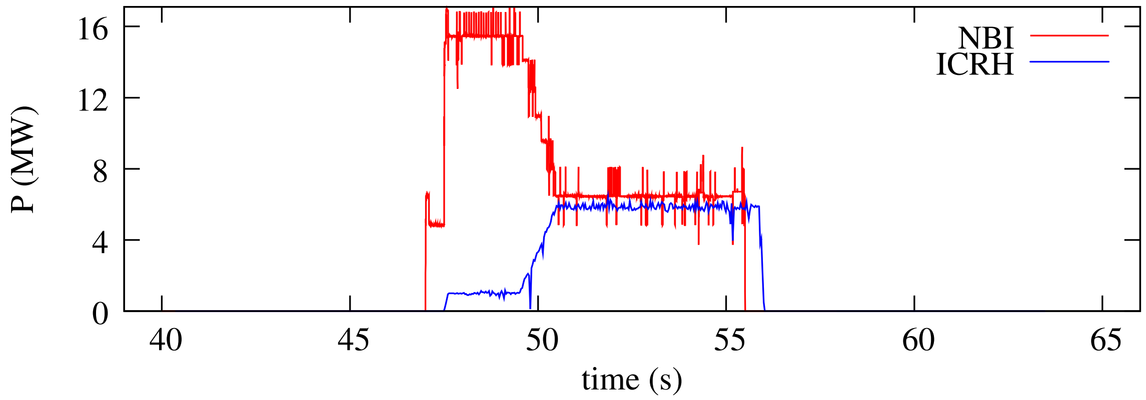

Figure 2: NBI and ICRH heating power for JET shot 66463.

and neutron time-of-flight spectra are extracted off-line. This allows to construct time resolved TOF spectra in order to analyse specific phases of the discharge.

Experimental results

The neutron energy spectrum depends on the plasma heating scenario. As an example, we present data from the JET shot 66463 (19/05/06). During this shot, up to 16.7 MW of NBI (Neutral Beam Injection) and 6.5 MW of ICRH (Ion Cyclotron Resonance Heating) heating power were applied, see Fig. 2. The total neutron yield during the heating period of about 10 s was $5 \cdot 10^{16}$ neutrons.

Time resolved time-of-flight spectra have been extracted for different periods of the pulse, i.e. for different heating scenarios. For the NBI heating, the time range between 48 and 49.5 s has been chosen, for the ICRH heating, the interval is $50.5 - 55.5$ s. Note the the NBI heating power during this latter period is about the same as that from ICRH heating. Fig. 3(a) shows the total neutron time-of-flight spectrum as well as the spectra taken during the two periods. In total, about 10^5 neutron coincidences have been recorded. In addition, about 2000 prompt coincidences from γ-radiation have been detected. The FWHM of the γ-peak is 3.2 ns, reflecting a superposition of the electronics time resolution and an additional broadening due to the light transfer time in the S2 detectors. Deconvolution results in an electronics time resolution of about 2.5 ns or 3.9 %.

Fig.3(b) illustrates the effect of the heating on the neutron emission. The NBI heating leads to a wide distribution of plasma ion energies and thus to a broadening of the neutron emission spectrum. The ICRH heating is tuned to the Larmor frequency of minority ions accelerating them to higher energies. This results in a high-energy (short flight-times) tail in the neutron emission spectrum.

Conclusions and outlook

A new time-of-flight spectrometer has been installed at JET, able to operate at count rates

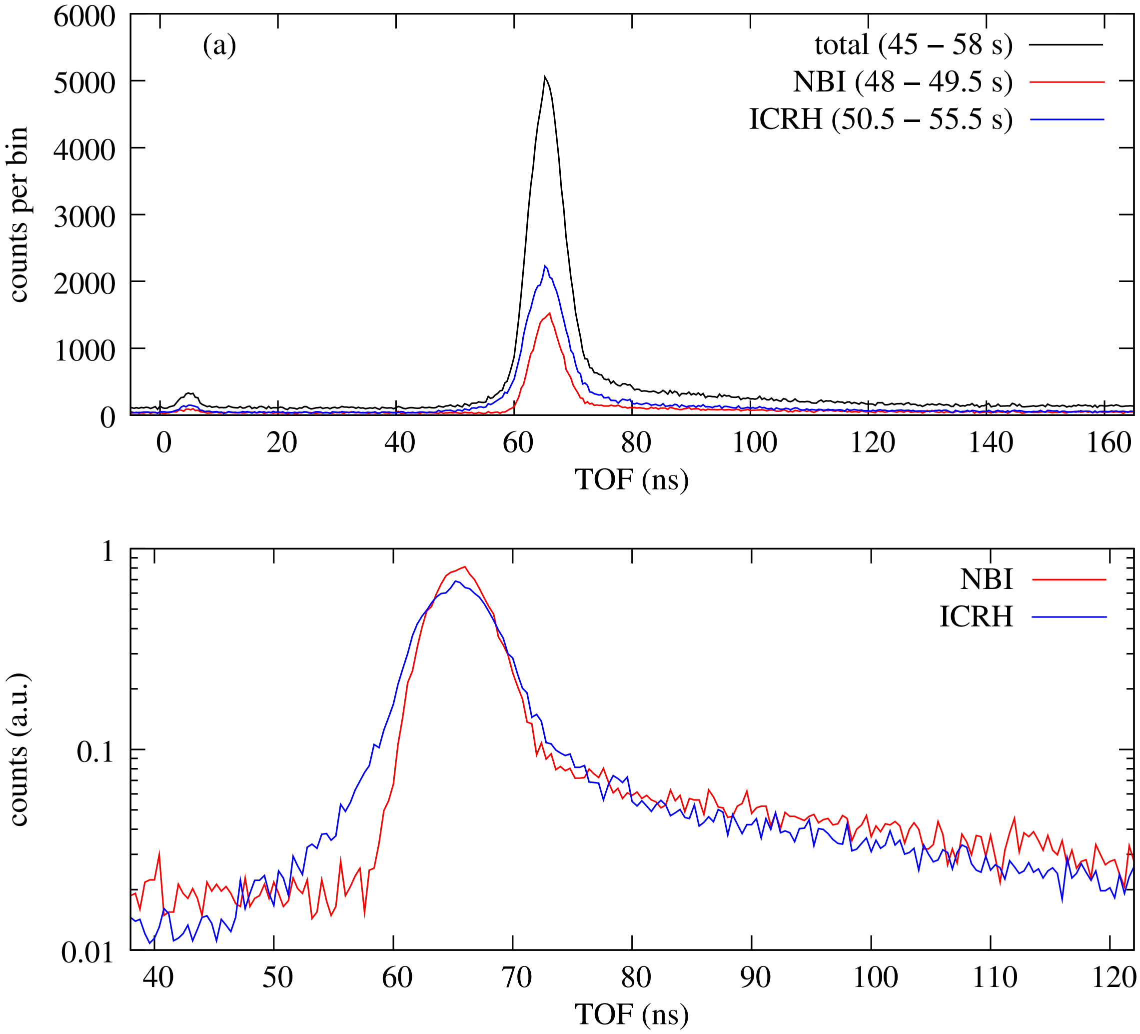

Figure 3: Neutron time-of-flight spectra. (a): Raw TOF spectra. One time bin corresponds to 0.4 ns. (b): TOF spectra from the the early (NBI dominated) and late (ICRH dominated) period of the discharge. Curves are normalised to to the same intensity.

above 100 kHz. First preliminary results show the effect of the plasma heating on the neutron emission. For the more detailed data analysis, a complex spectrometer response function based on neutron transport simulations and experimental results is under development.

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