ABSTRACT.
The Joint European Torus (JET, Culham, UK) is the largest tokamak in the world. It is devoted to nuclear fusion experiments of magnetic confined Deuterium (D) or Deuterium-Tritium (DT) plasmas. JET has been upgraded over the years and recently it has also become a test facility of the components designed for ITER, the next step fusion machine under construction in Cadarache (France). JET makes use of many different diagnostics to measure the physical quantities of interest in plasma experiments. Concerning D or DT plasmas neutron production, various types of detectors are implemented to provide information upon the neutron total yield, emission profile and energy spectrum. The neutron emission profile emitted from the JET plasma poloidal section is reconstructed using the neutron camera (KN3). In 2010 KN3 was equipped with a new digital data acquisition system capable of high rate neutron measurements (<0.5MCps). A similar instrument will be implemented on ITER and it is currently in its design phase. Various types of neutron spectrometers with different view lines are also operational on JET. One of them is a new compact spectrometer (KM12) based on organic liquid scintillating material which was installed in 2010 and implements a similar digital data acquisition system as for KN3. This article illustrates the measurement results of KN3 neutron emission profiles and KM12 neutron energy spectra from the latest JET D experimental campaign C31.

1. INTRODUCTION
The Joint European Torus (JET, Culham, UK) [1] has recently celebrated the 30th year of operation. Over these years JET activity has been characterized by experimental campaigns for studying Deuterium (D) and Deuterium-Tritium (DT) plasmas. Periods of intervention are also planned to maintain the tokamak as well as to install new equipment and diagnostics. During the 2010 shutdown, the new ITER-like-wall (ILW) [2] made of Beryllium tiles was installed in the JET vacuum vessel to test it in view of ITER [3]. Also upgrades of existing diagnostic instrumentation and the installation of brand new one was carried out. Concerning neutron diagnostics, the upgrade of the data acquisition system of the plasma neutron emission profile monitor KN3 (i.e., neutron camera) and the installation of a brand new compact liquid scintillator neutron spectrometer (KM12) were performed.

KN3 implements two different sets of detectors implemented along 10 horizontal and 9 vertical lines of sight. For neutron measurements, NE213 liquid scintillators are chosen the diagnosis of 2.45MeV neutron emission from D plasmas while thin plastic scintillation detectors are usually used for DT 14MeV neutrons. In addition, CsI gamma scintillators can be inserted in the lines of sight if the plasma gamma emission profile is of major interest. The upgrade of the KN3 concerned the installation of a brand new digital acquisition system (14 bit and 0.2 Gsample/s) [4] in parallel to the old analogue system, which makes use of pulse shape discrimination units [5]. A similar digital acquisition system is implemented in KM12 which response function was measured at the Physicalisch-Technische Bundesanstalt (PTB Braunschweig) [6, 7].

2. KN3 NEUTRON EMISSION PROFILES AND KM12 NEUTRON ENERGY SPECTRA

Two D plasma discharges were selected and analyzed in terms of KN3 and KM12 data from the ongoing JET D experimental campaign C31. The first discharge is from experiments aiming at the optimization of Ion Resonance Cyclotron Heating (ICRH) in H-mode. This is obtained by selecting the most efficient position for gas puffing to improve the frequency coupling of ICRH. The results presented here concern JET Pulse No: 84747 where 5.9MW ICRH were injected into the D plasma at the end of 14.6MW Neutral Beam Injection (NBI) steady phase. The toroidal magnetic field was B_t = 2.7T while the plasma current I_p = 2.5MA. The second discharge, JET Pulse No: 84806 is part of the experiments which goal is to develop hybrid plasmas to lower triangularity and optimizing pumping and fuelling to access lower density. JET shot 84806 featured 25MW NBI auxiliary heating with B_t = 2.3T and I_p = 2.0MA. This shot provided the record neutron rate in JET ILW of 1.8×10^{16} n/s.

The KN3 and KM12 detectors are sensitive to both neutron (n) and gamma (γ) radiations which produce signals of different pulse shapes [8]. The Short/Long gate method is used for n/γ discrimination [9]. A step further in this type of analysis has been conceived to identify the n and γ contributions into the overlapping region at low energies as shown in Fig.1 [10]. The technique consists in a tomographic analysis of the Short/Long vs. Energy distribution (Fig.1(b)). For arbitrary energy ranges (i.e., 5 keVee), the corresponding Short/Long distribution is compared to a model obtained as sum of two Rayleigh distribution functions and background level (Double Rayleigh in Fig.1(a)). The comparison is obtained minimizing Cash statistics *C* [11]. This analysis allows for an accurate determination of the n/γ separation line, i.e., the minimum of the Double Rayleigh model (magenta line in Fig.1(a)), and a detailed identification of the events in the overlapping region of the Short/Long distribution. The n and γ pulse height spectra (phs) are then determined with an improved accuracy at low energies.

With this method, KN3 and KM12 data for JET Pulse No's: 84747 and 84806 were analyzed. Figures 2 and 3 show the n phs and count rates measured along the KN3 different sight lines during the steady NBI and ICRH phase of Pulse No: 84747 (9.10-10.86 s).

The KN3 horizontal central (chs 4 and 5) and vertical (chs 15 and 16) channels are the ones viewing the hottest core of the plasma which feature the highest neutron emissivity for the D ions nuclear fusion cross section. KN3 digital acquisition system was able to reach 70kCps in ch 15 which is well below its capability of 0.5 MCps [4]. A similar analysis was carried out for JET shot 84806 during the steady NBI phase (5.75-8.30s).

From the measured KN3 phs, information on the plasma n and γ emission profile can be obtained (Fig.4). Fig.4(a) shows the trend of measured n and γ events for Pulse No: 84747. The D plasma n emission is peaked in the core corresponding to KN3 central horizontal and vertical channels. The measured γ profile is flat in KN3 horizontal camera since it views the inner ILW through the plasma while it is structured for KN3 vertical camera. Here the central channels receive the γ emission from the tungsten divertor region while the edge channels see mostly the ILW lower part [5]. The higher γ fraction measured by KN3 vertical edge channels can be explained as the effect of background induced by scattered neutrons in KN3 shielding: Detailed calculations are planned to verify this hypothesis. For Pulse No: 84806 (Fig.4(b)) the measured n and γ profiles follow a similar trend as for Pulse No: 84747 but with an abrupt interruption for KN3 vertical chs 17-19 because of a pc fault during the data acquisition.

Concerning KM12 measurements, the measured n phs was unfolded with MAXED code [12] to obtain the corresponding n energy spectrum. A sensitivity analysis of the code's input parameters was set up [13] to select their optimal combinations for the analysis. Figures 5 and 6 show the measured n phs, the MAXED unfolded n energy spectra and the n count rates reached during the steady auxiliary heating phases of the shots as for KN3.

The n energy spectra show similar values of full width at half maximum (FWHM) from which the D plasma effective temperature can be calculated as $T_{eff} = (FWHM/82.5)^2$ with FWHM and T_{eff} expressed in keV [14]. It results in T_{eff} = 17.2keV and 18.4keV for Pulse No's: 84747 and 84806, respectively. The shape of the neutron spectra is different, with the one corresponding to Pulse No: 84747 asymmetric which relates to the application of ICRH heating and to the KM12 line of sight being it horizontal-tangential along the equatorial plane of the machine [15]. The n count rate KM12 reached in Pulse No: 84747 was about 39kCps while, for Pulse No: 84608, it was larger than 0.2MCps.

CONCLUSIONS AND OUTLOOK

KN3 and KM12 measurement results in high power JET D shots demonstrate the good diagnostic capability of both instruments equipped with the new digital acquisition systems. With the improved n/γ discrimination technique [10], KN3 measured n and γ emission profiles and KM12 n energy spectra were determined to extract information of the D plasma position and T_{eff}. Further developments in KN3 data analysis concern the implementation of the energy scales in the n and γ phs and the determination of the efficiency and attenuation coefficients to reconstruct the plasma emission profile. With this information, the comparison of the count rate along the different KN3 lines of sight would allow for the investigation of plasma edge instabilities [16] and of the plasma positioning control in view of DEMO [17,18]. For KM12, new multi component analysis method of the n phs need be designed to achieve information upon the characteristics of the various D ion populations produced during the plasma discharge.

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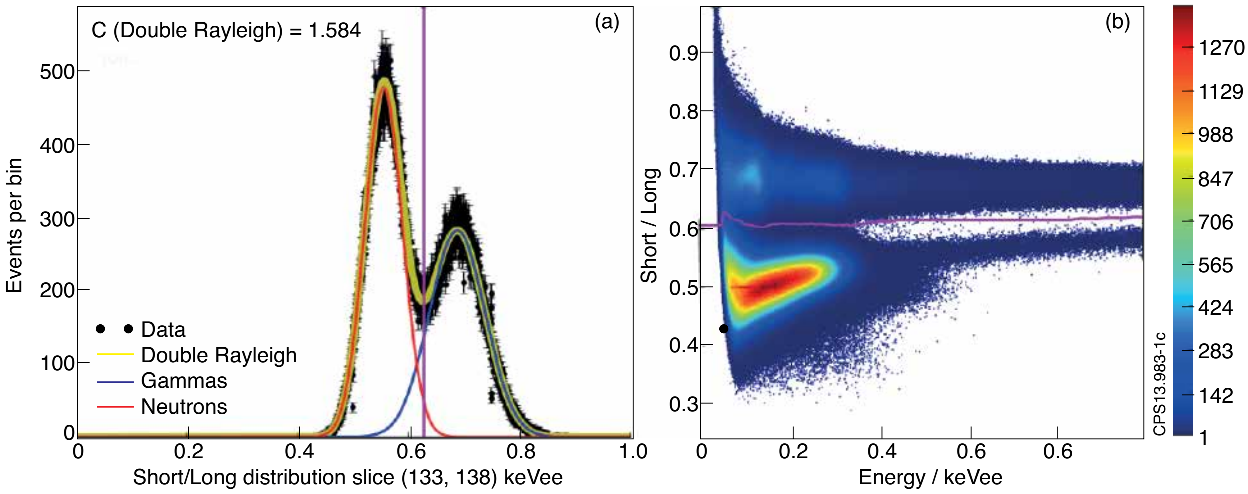

Figure 1: In (a), the KM12 Short/Long distribution corresponding to the energy interval 133-138keVee sliced from (b) and compared to the Double Rayleigh model in terms of Cash statistics C. The magenta line represents the n/γ discrimination line while the red and blue lines corresponds to the n (left) and γ (right) events in this energy interval. In (b), a magnification of the Short/Long versus Energy distribution for KM12 with the n/γ discrimination line (magenta).

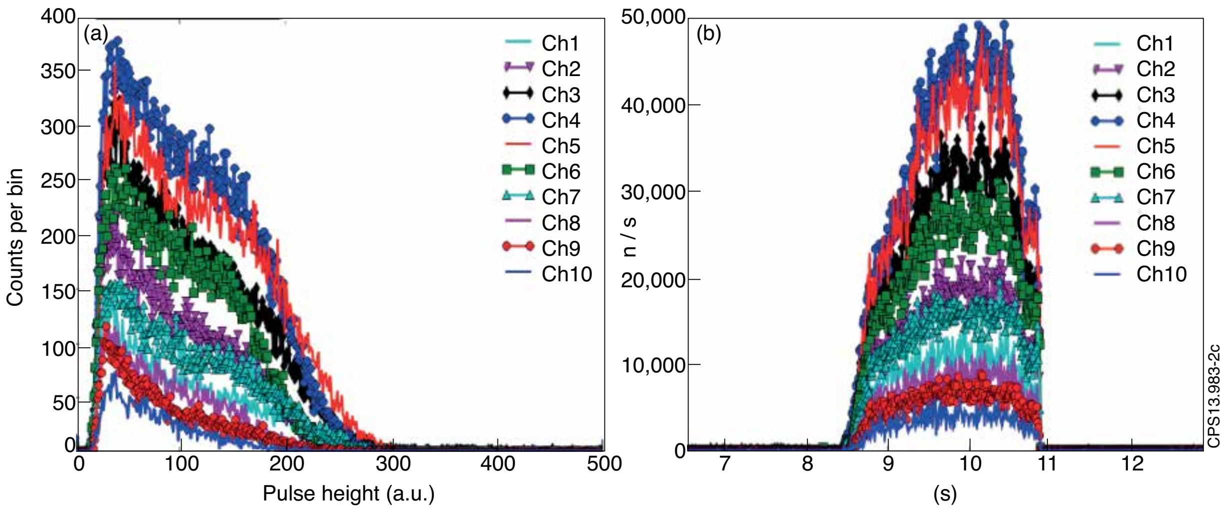

Figure 2: The n phs (a) and count rates (b) measured along the KN3 horizontal lines of sight during Pulse No: 84747.

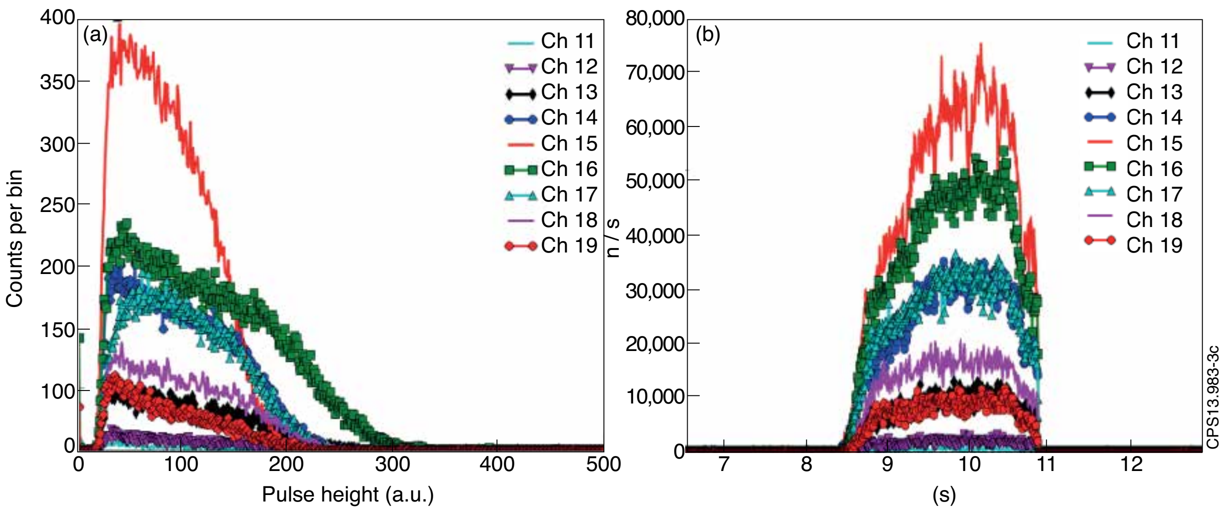

Figure 3: As in figure 2 but for the KN3 vertical lines of sight.

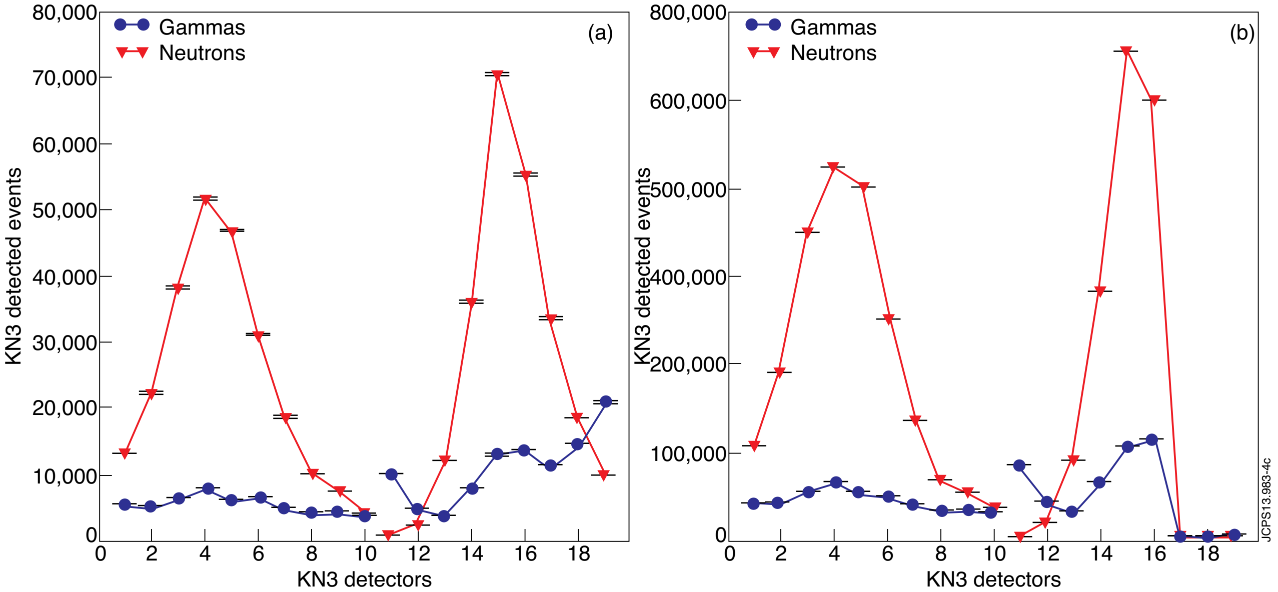

Figure 4: The KN3 measured n and γ profiles for JET Pulse No's: 84747 (a) and 84806 (b).

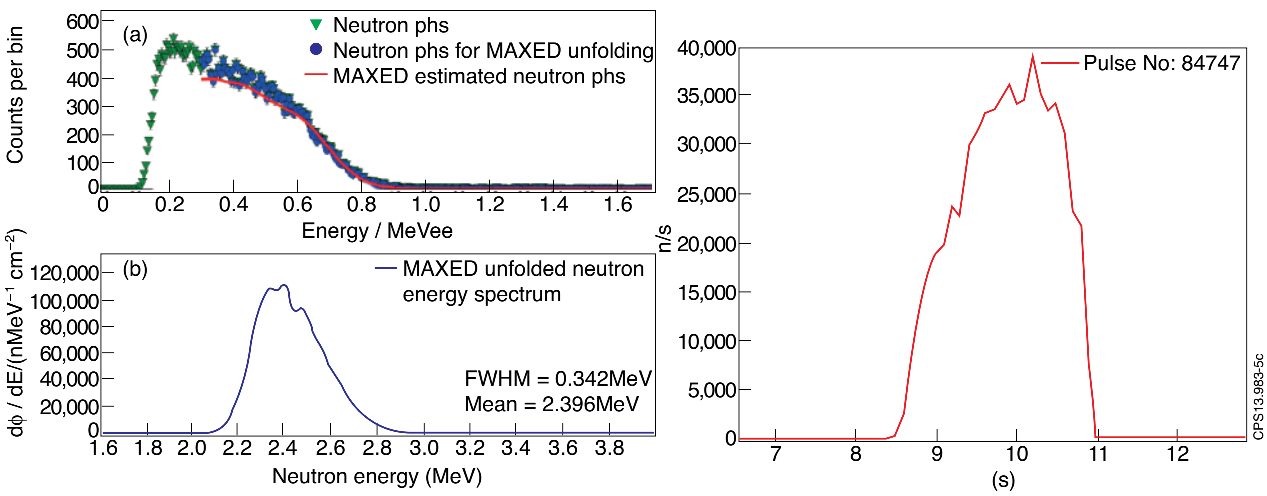

Figure 5: KM12 measured n phs (a), MAXED unfolded n energy spectrum (b) and n count rate for Pulse No: 84747.

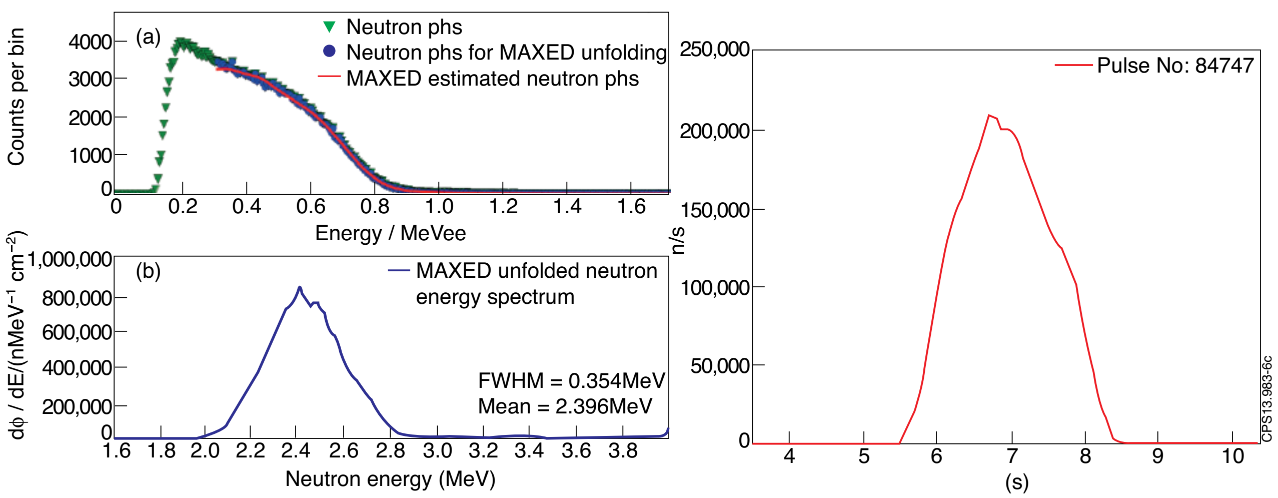

Figure 6: As figure 5 but for Pulse No: 84806.