First measurements with a Compact Neutron Spectrometer at ASDEX Upgrade

<u>G. Tardini</u>[1], A. Zimbal[2], B. Esposito[3], F. Gagnon-Moisan[2], L. Giacomelli[4], D. Marocco[3], R. Neu[1], H. Schuhmacher[2], K. Tittelmeier[2], and the ASDEX Upgrade Team

[1] MPI für Plasmaphysik, Euratom Association, Boltzmannstr. 2, 85748 Garching, Germany

[2] Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

[3] Associazione Euratom-ENEA sulla Fusione, Via E. Fermi 45, 00044 Frascati, Roma, Italy

[4] Dipartimento di Fisica, Universit degli Studi di Milano-Bicocca, Piazza della Scienza 3, 20126 Milano, Italy

1 Introduction

The neutron emission rate is measured routinely in tokamaks. It provides an estimate of the plasma confinement performance. However, in presence of a significant suprathermal ion population, e.g. with strong Neutral Beam power, beam-target reactions become dominant [1]. Energy and time resolved measurements of the neutron distribution function can increase our understanding of fast ion physics, such as confinement and the interaction with Ion Cyclotron Resonant Heating (ICRH). For this purpose, a new diagnostic system is installed on ASDEX Upgrade to measure the energy distribution of the emitted neutrons. A compact spectrometer based on the organic liquid scintillator BC501A detects the neutrons and γ rays in the MeV range, collimated to a line of sight crossing the plasma midplane.

Data are acquired with a digital acquisition system. The n/γ discrimination is performed offline based on the "charge comparison method" [2]. The spectrometer measures the neutron distribution function convoluted with the system (detector+board) response. The system has been characterised at the Physikalisch-Technische Bundesanstalt (PTB) accelerator facility, applying monoenergetic neutrons and a "white" neutron field.

The normalised Pulse Height Spectra (PHS) of discharge phases with high NBI power exhibit a larger broadening of the 2.45 MeV line (typical of d-d neutrons) compared to plasmas with less NBI power. This indicates the increasing role (and average energy) of suprathermal ions at high beam power. Experimental evidence of d-t reactions is found. Furthermore, ICRH dominated discharges are compared to NBI heated plasmas.

2 Detector properties and settings

The detector is placed outside the torus hall, 10 m away from the nearest plasma region, as shown in Fig. 1. The line of sight penetrates the wall through a cylindrical cavity in the 2 m thick wall, the diameter being 7.6 cm, crossing the plasma midplane almost radially. Additionally, a collimator box containing polyethylene is placed in the torus hall, with an aperture diameter of 8.8 cm which can be reduced to 1.6 cm by inserting a plexyglas tube containing polyethylene. A lead brick layer around the collimator aperture reduces (and collimates) the γ events, leaving more countrate capacity for neutron pulses. The scintillator cell is a 50.8x 50.8 mm cylinder, coupled to a photomultiplier (PM) col-
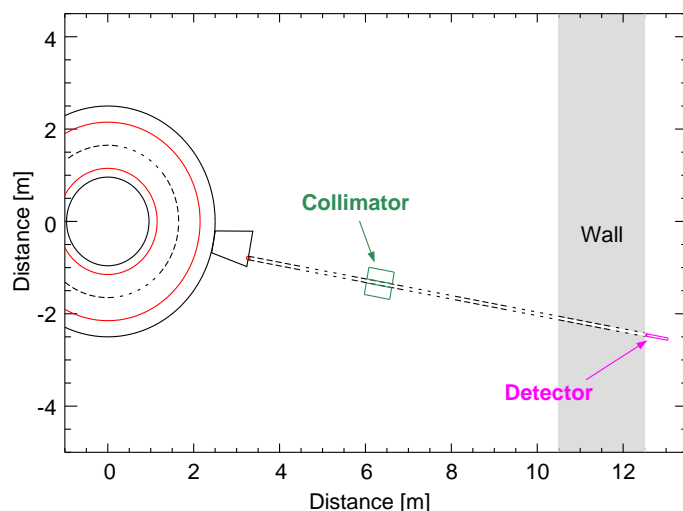
Figure 1. Top view of the detector line of sight. The red circles mark the plasma boundary, the dashed circle the plasma center.

lecting the scintillation light produced by the interaction of neutrons and γ rays with the scintillating liquid; it has been designed at the PTB [3]. The signal is fed to a Digital Acquisition System developed at ENEA Frascati [4][2]. Two ADCs of 100 MHz each are synchronised to provide pulse sampling every 5 ns, which has proven to be sufficient for n/γ discrimination and high count rate neutron spectrometry with liquid scintillators [5]. A dynamical window data acquisition module ensures that only data exceeding a preset noise threshold are triggering an acquisition, optimising the acquisition of useful pulses [5]. Eventually the pulses are stored digitally, with information on the ADC trigger time and the pulse length. Further technical details can be found in [6]. The system is setup to measure neutron energy spectra from about 1.5 to 17 MeV. With the setting used at AUG the saturation limit of the DPSD board is found to be about 7 10^5 events/s, constrained by the data transfer rate of 80 MBytes/s from the board to the RAM of the connected PC. At lower rates the count rates are in good agreement with the default neutron counter (magenta and black traces in Fig. 2).
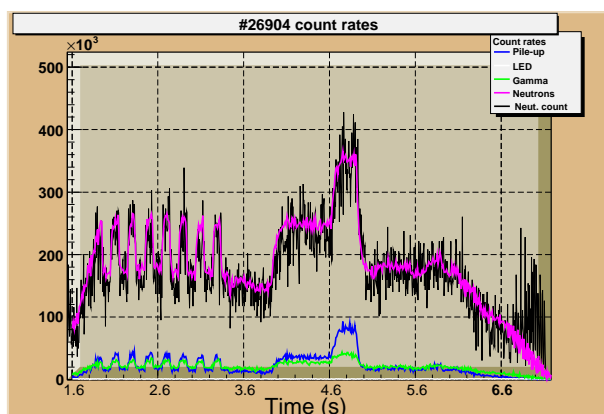

Figure 2. Count rate for γ (green), neutron (magenta), pile-up (blue) and LED events (white) as a function of time. The black line is the time trace of the AUG neutron counter, scaled to match the scintillator count. The wave-like behaviour occurs during NBI power modulation.

4 Pulse processing

The pulses are processed with a Digital Pulse Shape Discrimination (DPSD) software developed by ENEA-Frascati [2][5]. The pulse shape discrimination is based on the ratio of a long (L) to short (S) integration interval of the single pulse, as a function of its total

(T) gate. The S/L ratio is used as separation parameter. For a correct energy calibration, a scaling factor and an offset for T are introduced, in order to match the pulse height scale of the acquired spectrum to the energy scale of a Monte Carlo Simulation. The simulation code gives the expected pulse height spectrum for the well known γ lines of a ^{207}Bi reference source (E_γ = 0.569, 1.064 and 1.771 MeV). Using the ^{207}Bi source as a reference for the gain, measurements done under different experimental conditions or at different facilities can be compared.

A pulsed LED with a frequence of about 1 kHz is used to monitor the PM gain, which varies in time depending on the count rate. The correction to T is applied a posteriori by the DPSD software. Tuning the LED amplitude, the position of the LED histogram can be set in a region of the separation diagram which does not overlap with neutron or γ events (see Fig. 3).
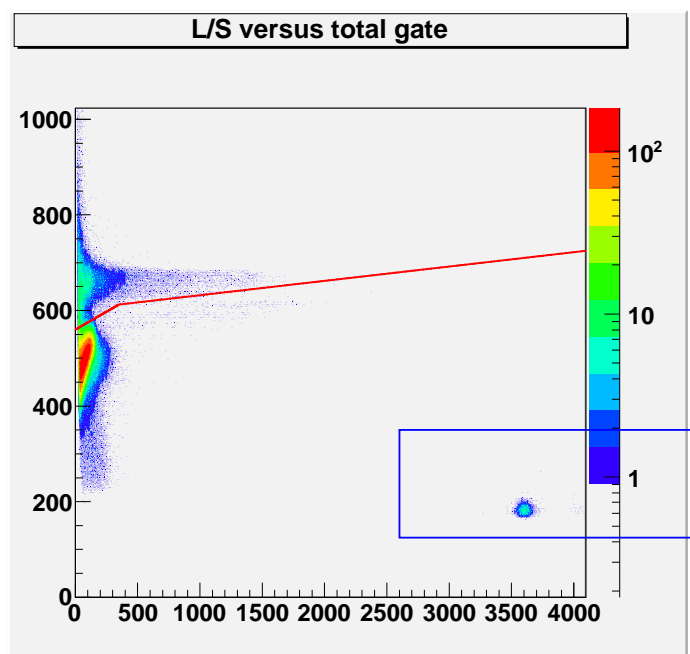

Figure 3. S/L versus T gates for AUG discharge #26904. The red lines separates γ (above) from neutron pulses (below). The user-defined blue rectangle contains LED pulses.

With a 2 straight lines method it is possible to separate neutron and γ pulses, the latter having higher S/L ratio. Pile-up records are also tracked, i.e. pulses with more than one peak in a single time window. The peak detection algorithm has also some free parameters that have to be optimised in order to discard spurious pulses, without rejecting too many useful ones. Each pulse is thus flagged as neutron, γ, LED or pile-up. Their count rate averaged over a pre-set Time Bin, is also an output of the DPSD package (see Fig. 2). d-t neutrons (14 MeV) are detected in Fig. 3: they are single scattered points below the red separation line. However, their statistics is too poor to produce accurate PHS. It is possible to set a threshold value of T to obtain separate counts for d-d and d-t neutrons. These PHS will be unfolded using the response function determined during the characterization experiment at PTB.
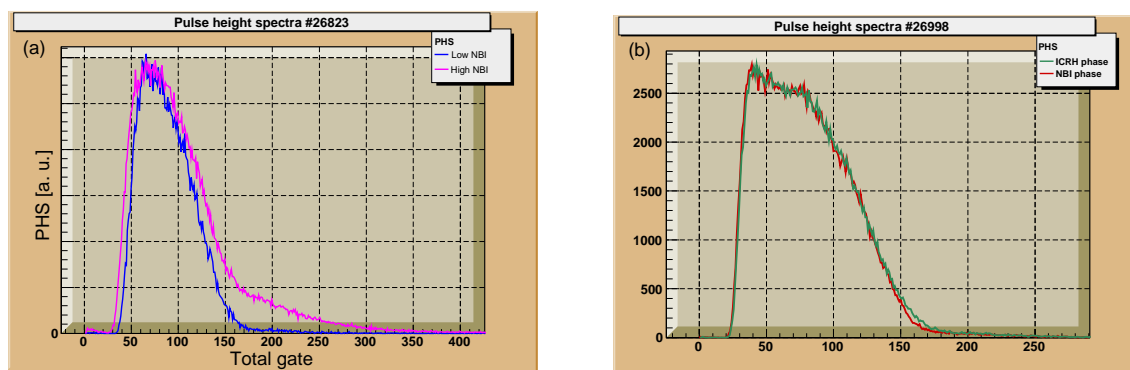
Figure 4. Normalised PHS. (a) The NBI heated discharge #26823 has a phase with $P_{NBI} =$ 10 MW (magenta) and one with $P_{NBI} = 5$ MW (blue). A clear broadening of the 2.45 MeV line is observed at high P_{NBI}, when NBI sources with higher voltage are applied. (b) Discharge # 26998 has a phase with $P_{NBI} = 5$ MW and no ICRH (red), and a phase with $P_{ICRH} = 5$MW $P_{NBI} = 2.5$ MW (green).

Figure 4 clearly shows a line broadening when two additional sources are switched on. In fact, in the first phase the injected beam energy is 60 keV, whereas later two 93 keV sources are added (magenta spectrum), thus increasing the average energy of the suprathermal ion population. For discharge #26998, no significant difference is observed in the PHS when a NBI source is switched off and 5 MW ICRH are coupled to the plasma; however, there is an additional small tail at high energies. This is also expected, because ICRH produces few neutrons itself, but enhances the energetic tail of fast ions. The response of a similar scintillator detector to several plasma scenarios in JET is described in [7].

5 Outlook

A reference ^{207}Bi γ source will be available at ASDEX Upgrade, allowing to quantify differences between laboratory and plasma measurements, possibly due to different cables, or noise picked up from neighbouring signals.

A thicker lead screen, designed for the collimator box in the torus hall, is going to replace the current lead brick wall, ensuring better γ screening.

The evaluation of the response function for all the data collected during the characterisation at PTB is on-going, which is needed to obtain unfolded spectra.

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