Fully Digital Data Acquisition System for the Neutron Time-of-Flight Spectrometer TOFOR at JET

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Introduction

TOFOR is a neutron time-of-flight (TOF) spectrometer installed at JET [1], based on plastic scintillators. In TOF neutron spectrometry for fusion plasmas, the flight-time-scale is on the order of tens of nanoseconds and in order to resolve important spectral features sub-nanosecond timing is required and the system should cope with signal count rates of hundreds of kHz. Until now, while the time information has been stored digitally, the signal processing of TOFOR has been handled by analogue electronics. No information on pulse height is available and therefore it is impossible to correlate energy deposition information with time-of-flight. Replacing the data acquisition (DAQ) electronics of TOFOR with high-resolution, nanosecond-precision digitizers enables pulse height information storage and consequently geometry-based discrimination of the rate-dependent accidental coincidence background. Tests with such a digital DAQ system are currently under way. This paper presents simulations of geometry-based background discrimination applied to TOFOR spectra, comparing them with early experimental results.

The TOFOR Instrument

TOFOR is situated in the JET roof lab, above and outside the concrete torus hall shielding, with a line of sight directed vertically at the centre of the plasma through a port in the vacuum vessel wall. TOFOR consists of two sets of plastic scintillators, S1 and S2, providing start and stop signals respectively. During operation, a collimated beam of neutrons impinge on S1 which is a stack of five, circular scintillators; each 4 cm in diameter and 5 mm thick, with 3 PM tubes attached to it. S2 is a ring of 32

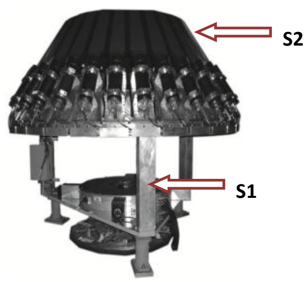

FIG. 1. TOFOR. The collimated neutrons enter the instrument from below.

* See the Appendix of F. Romanelli *et al.*, Proceedings of the 23nd IAEA, Fusion Energy Conference, Daejon, Korea, 2010

scintillators, at a distance of about 1.2 meters from S1 and a mean angle to the direction of the incident neutrons of 30°. They are arranged in a cone-like structure, each attached to one PM tube [1] as shown in figure 1. In the current setup, scintillator event timing is based on analogue CFDs. The CFD output signals are processed by free-running time digitizers [2] where time stamps are generated and stored. A new digital DAQ system is now being developed based on the ADQ412 4-channel, 12 bit, 1 Gsps digitizer from SP Devices. [3] Currently 3 such devices are installed, enabling acquisition of signals from all S1 scintillators and seven S2 scintillators, providing 20% of the total efficiency of TOFOR.

Time-of-Flight Spectrometry and Background Discrimination

When an event is detected in one of the S1 or S2 detectors, the time stamp is determined and stored by the DAQ system. Thus each detector has an associated list of time-stamps. A fraction of the neutrons that scatter in S1 will also cause a scintillator event in S2. From a pair of S1 and S2 time stamps, i.e. a *coincidence,* the neutron TOF can be calculated. Due to the geometry of TOFOR, incident neutron energy of 2.45 MeV (from DD reactions) will correspond to a peak at approximately 65 ns. [1]

From time information alone, it is impossible to know if a given coincidence is due to the same neutron scattering once in S1 and once in S2. Combinations of uncorrelated S1 and S2 events form a background of *accidentals* in the TOF spectrum. Since the emitted neutrons are uniformly distributed in time, the background of accidentals will be flat, with rate-dependent amplitude. [1] If energy information (pulse height) and TOF can be correlated, as is possible using a fully digital DAQ system, some of this background can be discarded based on geometric considerations. The relation between TOF and energy of a coincidence neutron scattered in S1 is $E_{n'} = m_n \left(l/t_{TOF} \right)^2 / 2$ while the energy of the incident neutron is given by $E_n = E_{n'} / \cos^2 \alpha$ where m_n is the neutron mass, t_{TOF} is the time-of-flight, l is the length of the flight-path, E_n is the energy of the incident neutron and α is the scattering angle with respect to the normal of the upward-pointing surface of the S1 array. For a scattered neutron, the deposited energy in S1 is $E_{S1} = E_n - E_{n'} = m_n (1/\cos^2 \alpha - 1)(l/t_{TOF})^2 / 2$. The minimum and maximum flight paths $l_{\min}$ and $l_{\max}$ and scattering angles $\alpha_{\min}$ and $\alpha_{\max}$ correspond to the extreme energy depositions of neutrons $E_{S1,\min}$ and $E_{S1,\max}$ in the S1 scintillators, as functions of t_{TOF}. Since pulse height is related to deposited energy, the correlated energy and time information can be used to remove unphysical energy deposition events from TOF spectra.

Modeling

A simulation study of the potential effects of pulse height-TOF correlation has been conducted using a Geant4 [4] model of 2.45 MeV (DD) and 14.0 MeV (DT) neutrons in the TOFOR geometry. The discrimination method described above has been applied to TOF spectra created using the Geant4 code. [5] Normalized results are shown in figure 2. The signal-to-background ratio is significantly improved in the low energy (high TOF) region. This would be useful in a future DT JET plasma scenario where the DD component of the spectrum would otherwise vanish in the 14.0 MeV background.

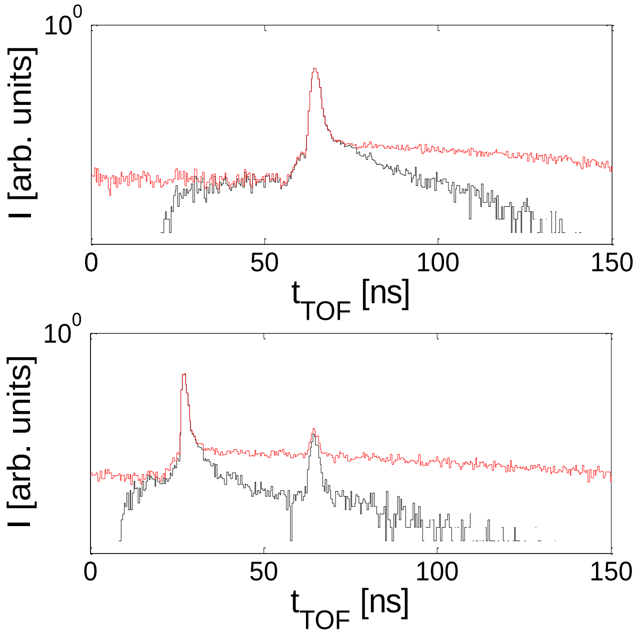

FIG. 2. (Color online) Modell TOFOR spectra of quasi-monoenergetic (top) 2.45 MeV DD and (bottom) 2.45 MeV and 14.0 MeV DT neutrons with raw (red) and discriminated (black) data.

Experimental Results

Figure 3 shows a sum of data acquired using the new, digital DAQ system from several JET plasmas, color-coded as in figure 2. The additional peak at low TOF is due to scattered γ, which are not present in the Geant4 simulation. An energy resolution of 20% at the reference energy 2.45 MeV is assumed, with $E_{S1,\mathrm{min}}$ and $E_{S1,\mathrm{max}}$ adjusted to account for 90% of the broadening.

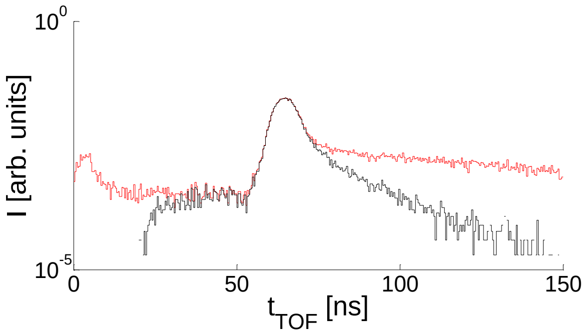

FIG. 3. (Color online) Experimental data obtained using the digital 12 channel system with raw (red) and discriminated (black) TOF data.

Conclusions

We have used simulations and experiments to investigate the improvements that can be gained by equipping the TOFOR neutron spectrometer with a fully digital DAQ system capable of simultaneous measurements of time and pulse height at high count rates. We show that combining such a system with detailed pulse shape analysis can provide broadband DT fusion plasma spectrometry with improved signal-to-background ratio compared to the traditional setup.

Acknowledgments

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