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ABSTRACT

A prototype of a fully digital data acquisition system based on 1 Gsps 12 bit digitizers for the TOFOR fusion neutron spectrometer at JET is assessed. The prototype system enables the use of geometry-based background discrimination techniques, which are modeled, evaluated and compared to experimental data. The experimental results are in line with the models and show a significant improvement in signal-to-background ratio in measured time-of-flight spectrum compared to the existing data acquisition system.

1. INTRODUCTION

TOFOR is a neutron Time-Of-Flight (TOF) spectrometer installed at JET1, 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. In addition, the system should cope with signal count rates of hundreds of kHz. Until now, the signal processing of TOFOR has been handled by analogue electronics. The time information has been stored digitally, but the determination of the timing of the scintillator events has been performed by analogue Constant Fraction Discriminators (CFD). Since no information on pulse shape or height is available in this setup, it is impossible to correlate energy deposition information with time-of-flight, or take pulse shape variation into account when determining timing. Replacing the Data AcQuisition (DAQ) electronics of TOFOR with fast digitizers can enable improved timing and also geometry-based discrimination of the rate-dependent accidental coincidence background. Development in digitizer technology has enabled high-resolution signal sampling with nanosecond precision. 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. A short discussion of implications for timing is also included.

2. THE TOFOR INSTRUMENT

TOFOR is situated in the JET roof lab, above the torus hall and outside the concrete torus hall shielding, with a line of sight directed vertically at the center 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 4cm in diameter and 5mm thick, with 3 PM tubes attached to it. S2 is a ring of 32 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].The system is 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.

3. TIME-OF-FLIGHT SPECTROMETRY

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, a coincidence, a TOF can be calculated. Due to the geometry of TOFOR, an incident neutron energy of 2.45MeV (from a DD reaction) will correspond to a peak at approximately 65ns. The shape and width of the peak will be affected by electronic noise, geometric response and various features of the plasma such as temperature, particle orbit effects, heating etc [1].

From time information alone, it is not possible 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. This is further discussed in section 4. Background Discrimination.

In figure 2, a comparison is shown between a TOF spectrum for JET Pulse No: 82657 constructed using the traditional TOFOR setup (blue, full) and the new system (red, dashed). The spectra are normalized. The 2.45 MeV DD neutron peak is at 65ns, together with a multi-scattering tail extending towards higher flight-times (lower energies). The peak at 4ns is due to γ rays. Between these two peaks the accidental background can be seen.

4. BACKGROUND DISCRIMINATION

As described in Sect.2, by using correlated pulse height and TOF along with knowledge of the geometry of TOFOR, some of the background can be suppressed. The relation between TOF and energy of a coincidence neutron scattered in S1 is

$$E_{n'} = \frac{1}{2} m_n \left(\frac{l}{t_{TOF}} \right)^2 . \tag{1}$$

Here, mn is the neutron mass, t_{TOF} is the time-of-flight and l is the length of the flight-path. The relation between the energy of the incident neutron and its scattered counterpart is

$$E_n = \frac{E_{n'}}{\cos^2 \alpha} . \tag{2}$$

E_n is the energy of the incident neutron and α is the scattering angle with respect to the normal of the upwardpointing upwardpointing surface of the S1 array. For a scattered neutron, the deposited energy in S1 is obtained by subtracting (1) from (2):

$$E_{S1} = E_n - E_{n'} = \frac{1}{2} m_n \left(\frac{l}{t_{TOF}} \right)^2 \left(\frac{1}{\cos^2 \alpha} - 1 \right) . \tag{3}$$

Since the geometry of TOFOR is known, the minimum and maximum flight paths lmin and lmax along with the related scattering angles αmin and αmax correspond to extreme values of the deposited energy ES1,min and ES1,max. These define the maximum and minimum energy depositions, as functions of t_{TOF} of fusion plasma neutrons in the S1 scintillators. Since pulse height is directly related to deposited energy, the correlated energy and time information can be used to remove unphysical energy deposition events from neutron TOF spectra. Similarly,
the maximum possible energy deposition in S2 is

$$E_{S2,\max} = \frac{1}{2} m_n \left(\frac{l_{\max}}{t_{TOF}} \right)^2 . \tag{4}$$

4.1. MODELING

A simulation study of the potential effects of pulse height-TOF correlation has been conducted using a Geant4 [4] model of 2.45MeV (DD) and 14.0MeV (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 3, with the raw data shown in red and the discriminated spectrum in black. In particular, it can be noted that 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 the14.0MeV background. Besides a multi-scattering tail in the high TOF part, the shape of the background that remains after discrimination, $B(t_{TOF})$, is understood and follows from eq. (3), the traditional accidental background amplitude B_0 and the maximum plasma emission neutron energy E_0:

$$B(t_{TOF}) = \left(\frac{E_0 - E_{S1,\min}}{E_0} \right) \frac{E_{S1,\max}}{E_0} B_0 . \tag{5}$$

4.2. EXPERIMENTAL RESULTS

In figure 4, 2D histograms of pulse height versus TOF constructed using data from a sum of several JET discharges are shown. The figures show data from S1 and S2 respectively, with data density on a logarithmic scale. As expected, the DD neutron 65ns peak is constrained in pulse height, since subsequent interactions in S2 (i.e. coincidences) will only occur for a limited set of scattering angles. Conversely, the distribution of pulse heights for the 65ns peak in S2 is broader since there are no minimum constraints on scattering angle and therefore energy deposition in S2. The black lines in figure 4 a) represent ES1,min and ES1,max. Any event within these lines is physically allowed. The black line in figure 4 b) shows ES2,max. An energy resolution of 20% at the reference energy 2.45MeV is assumed, with ES1,min and ES1,max adjusted to account for 90% of the broadening.

Figure 5 below shows a sum of data acquired using the new, digital DAQ system from several JET plasmas, color-coded as in figure 3. The additional peak at low TOF is due to scattered γ, which are not present in the Geant4 simulation.

5. FUTURE PROSPECTS

In addition to the background discrimination results presented above, improvements are expected in determination of time-stamps and to some extent in diminished electronic noise.

As mentioned in the introduction, analysis of pulse shapes can aid in determining a better way of timing the neutron induced events. Preliminary studies hint at energy dependence in the pulse shapes, which renders the CFD method imprecise. Knowledge of the pulse shape might help improve spectral resolution.

The complete TOFOR upgrade will consist of 37 channels and is intended as a replacement for the current DAQ system. An added benefit of removing the signal chain of various NIM modules is improved electronic noise, since every step in the signal path diminishes the signal quality.

If a fully digital 37 channel DAQ system were to be employed during the planned DT JET campaign in 2015, the various improvements, in particular background discrimination, will enable TOFOR to act as a broadband system capable of both DD and DT neutron spectrometry.

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 increased spectral quality and improved signal-to-background ratio compared to the traditional setup.

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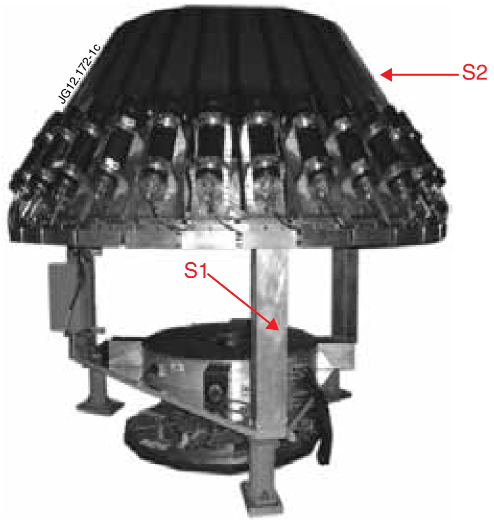

Figure 1: TOFOR. The collimated neutrons enter the instrument from below.

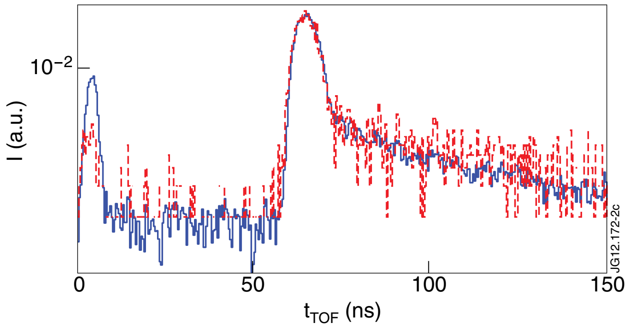

Figure 2: (Color online) Comparison, traditional (blue) and digital (red) spectra.

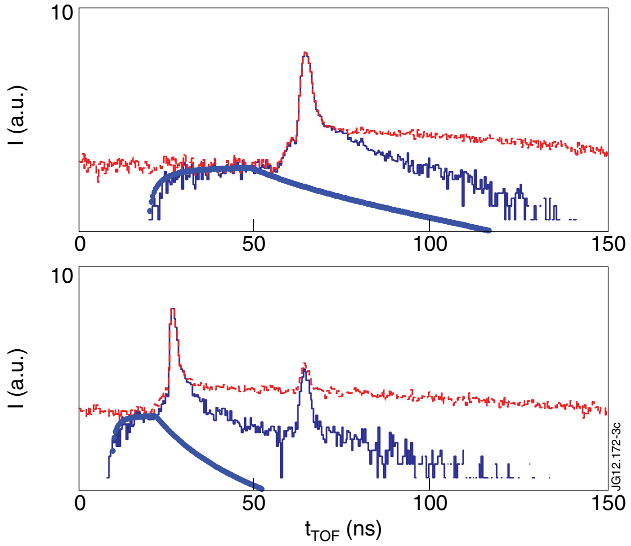

Figure 3: (Color online) Modell TOFOR spectra of quasimonoenergetic (top) 2.45MeV DD and (bottom) 2.45MeV and 14.0MeV DT neutrons with raw (red) and discriminated (black) data. The accidental background that remains after discrimination is shown as thick, blue lines.

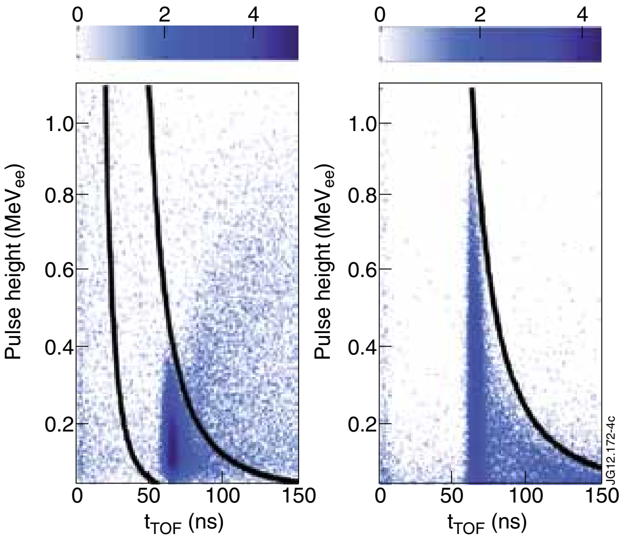

Figure 4: (Color online) Pulse height vs. TOF spectra, data from a) S1 and b) S2.

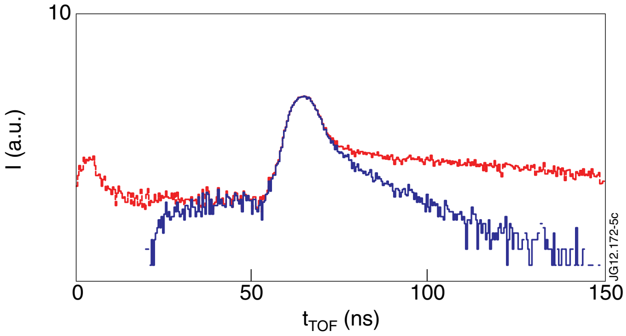

Figure 5: (Color online) Experimental data obtained using the digital 12 channel system with raw (red) and discriminated (black) TOF data.