

Development of an Integrated Diamond-DAQ Module for High-Count-Rate Fast Neutron Measurements in the KSTAR Tokamak

Youngseok Lee*, Jinseok Ko, and Yong-Un Nam

Corresponding Author : yslee@kfe.re.kr

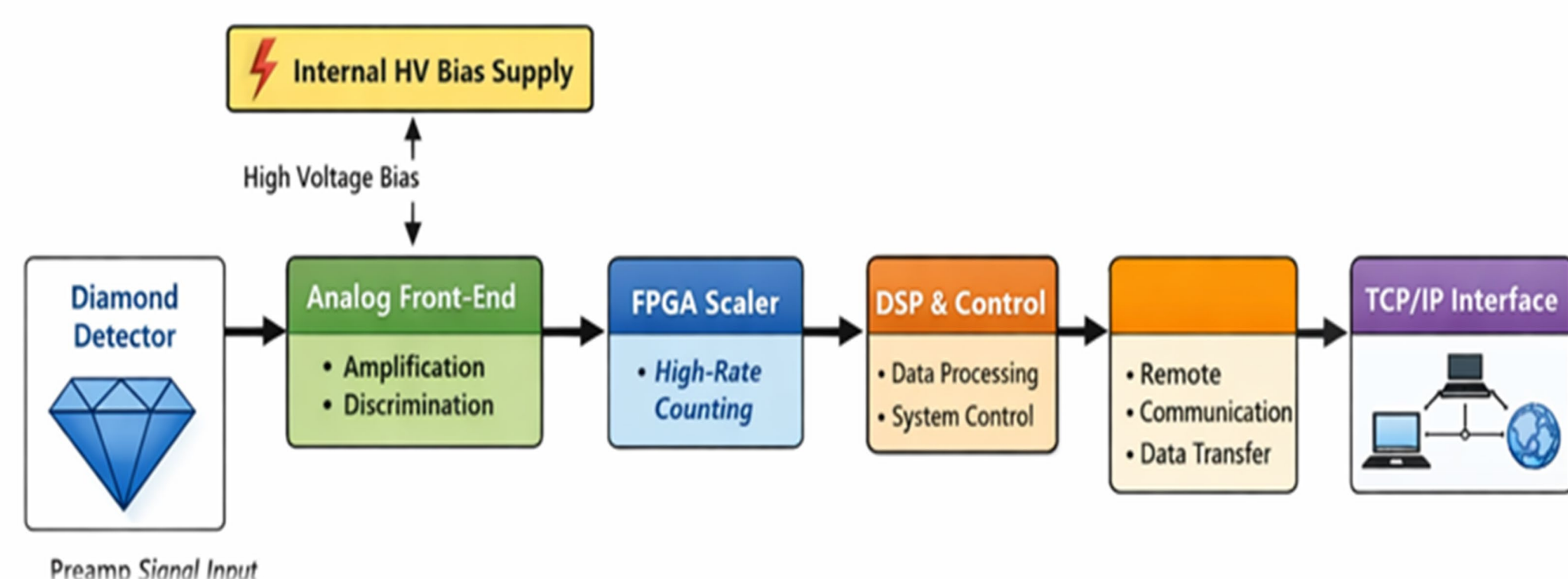
KSTAR Research Center, Korea Institute of Fusion Energy, Daejeon 34133, Republic of Korea

Introduction

Single-crystal CVD diamond detectors are attractive candidates for fast neutron diagnostics because of their radiation hardness, fast charge collection, and relatively low gamma sensitivity, which can improve neutron monitoring reliability in mixed radiation fields. Nevertheless, practical use of diamond detectors in a tokamak requires dedicated DAQ hardware optimized for small, fast pulses and EMI-robust operation. In this work, we develop an integrated Diamond-DAQ module designed for high-count-rate time-resolved neutron measurements and demonstrate its applicability through D-D plasma experiments in the KSTAR tokamak.

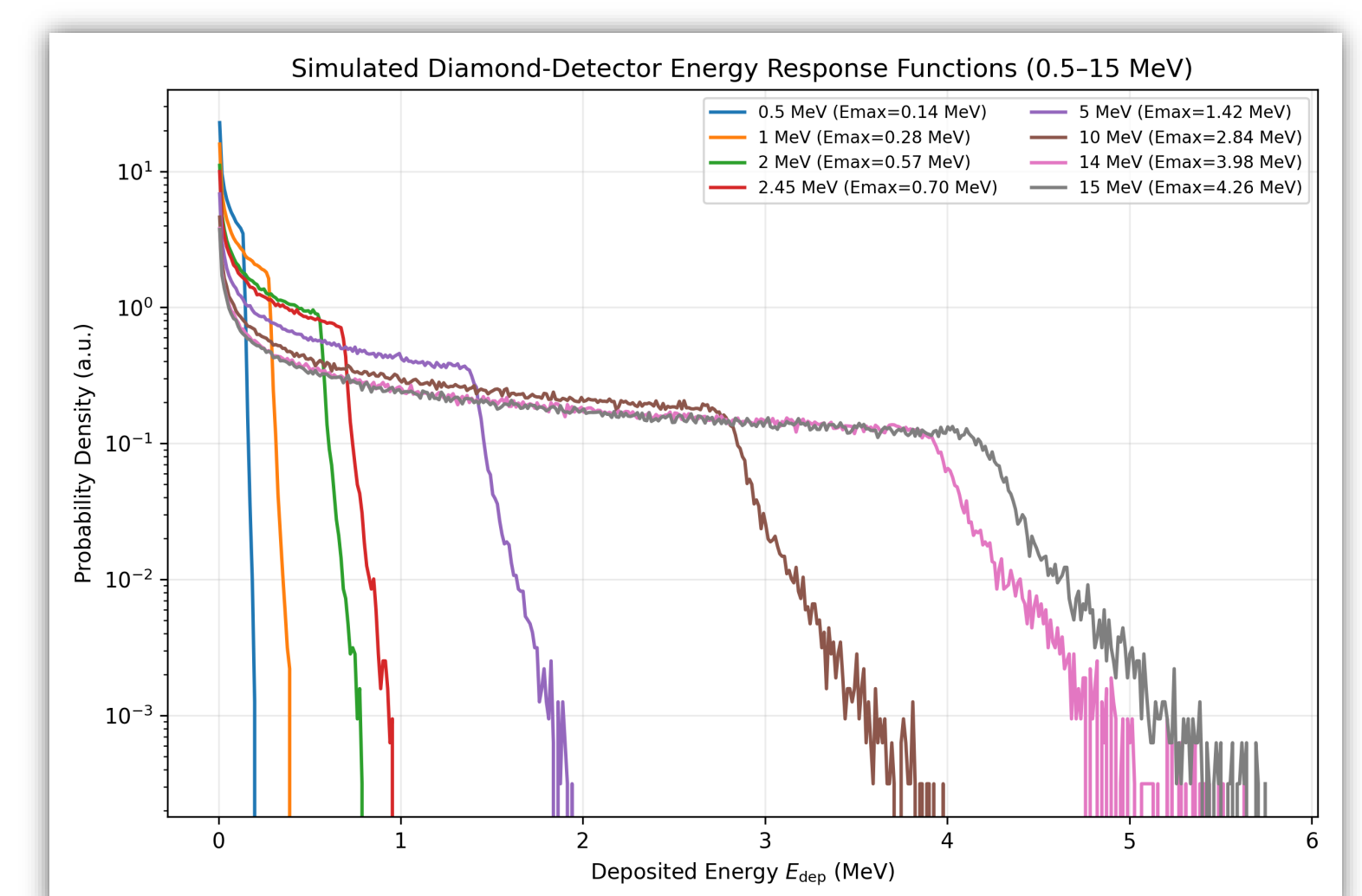
Experimental Setup

To ensure stable operation under the harsh tokamak environment, a dedicated stand-alone data acquisition (DAQ) module was implemented together with the detector hardware. The integrated Diamond-DAQ module consolidates detector biasing, front-end signal interfacing, high-rate counting electronics, and networked control into a compact unit optimized for operation under strong electromagnetic interference and mixed radiation backgrounds. The internal high-voltage generator removes the need for external HV supplies, thereby reducing system complexity and susceptibility to ground-loop noise.



Block diagram of the integrated Diamond-DAQ module for diamond-based fast neutron diagnostics: internal HV biasing, analog front-end interface, FPGA-based scaler, DSP control, and TCP/IP communication.

The analog front-end interfaces with fast Gaussian pulses from the detector and preamplifier chain, while programmable gain stages and discrimination thresholds allow adaptation across a wide range of neutron flux regimes encountered during different plasma operating scenarios. High-rate counting implemented in the FPGA enables time-resolved neutron monitoring under elevated count-rate conditions, and TCP/IP connectivity provides remote configuration, monitoring, and data acquisition from the control room

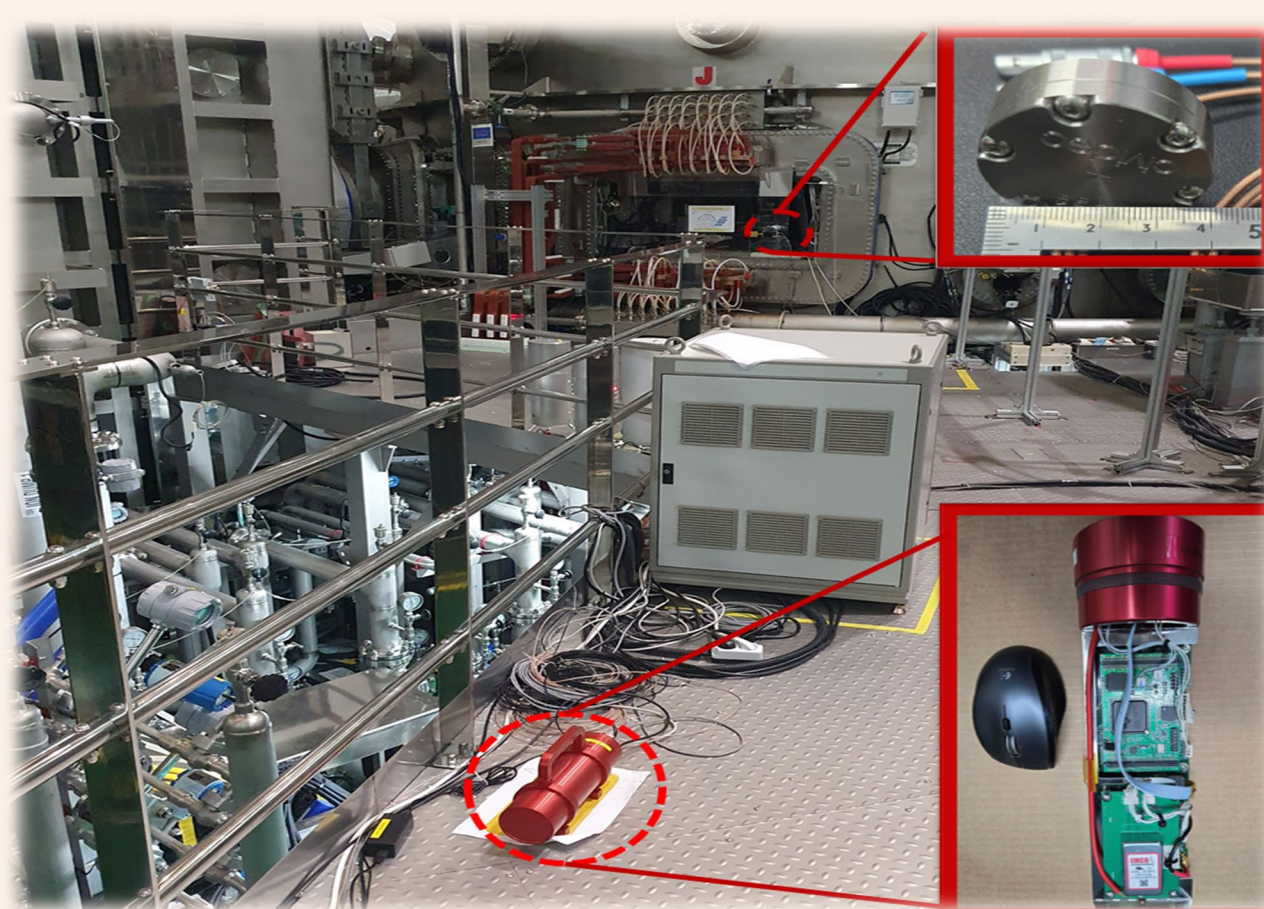


GEANT4-calculated deposited-energy response spectra of the diamond detector for monoenergetic 2.45 MeV and 14 MeV neutrons.

In addition to the experimental measurements, deposited-energy response spectra of the diamond detector for monoenergetic 2.45 MeV (D-D) and 14 MeV (D-T reference) neutrons were calculated using GEANT4 Monte Carlo simulations to support interpretation of the measured detector response and to provide a reference for deposited-energy characteristics.

The energy response spectra of the diamond detector shows the characteristic shoulder and scattering continuum due to the $^{12}\text{C}(n, el)^{12}\text{C}^*$ reaction and the scattering recoil on ^{12}C for each neutron energy in the diamond detector. The energy released into the detector, E_{dep} depends on the incoming neutron kinetic energy (E_n) and on the ^{12}C recoiling angle (θ_R) in the laboratory coordinate system based on the elastic scattering law $E_{\text{dep}} = 0.284 \times E_n \cos^2 \theta_R$.

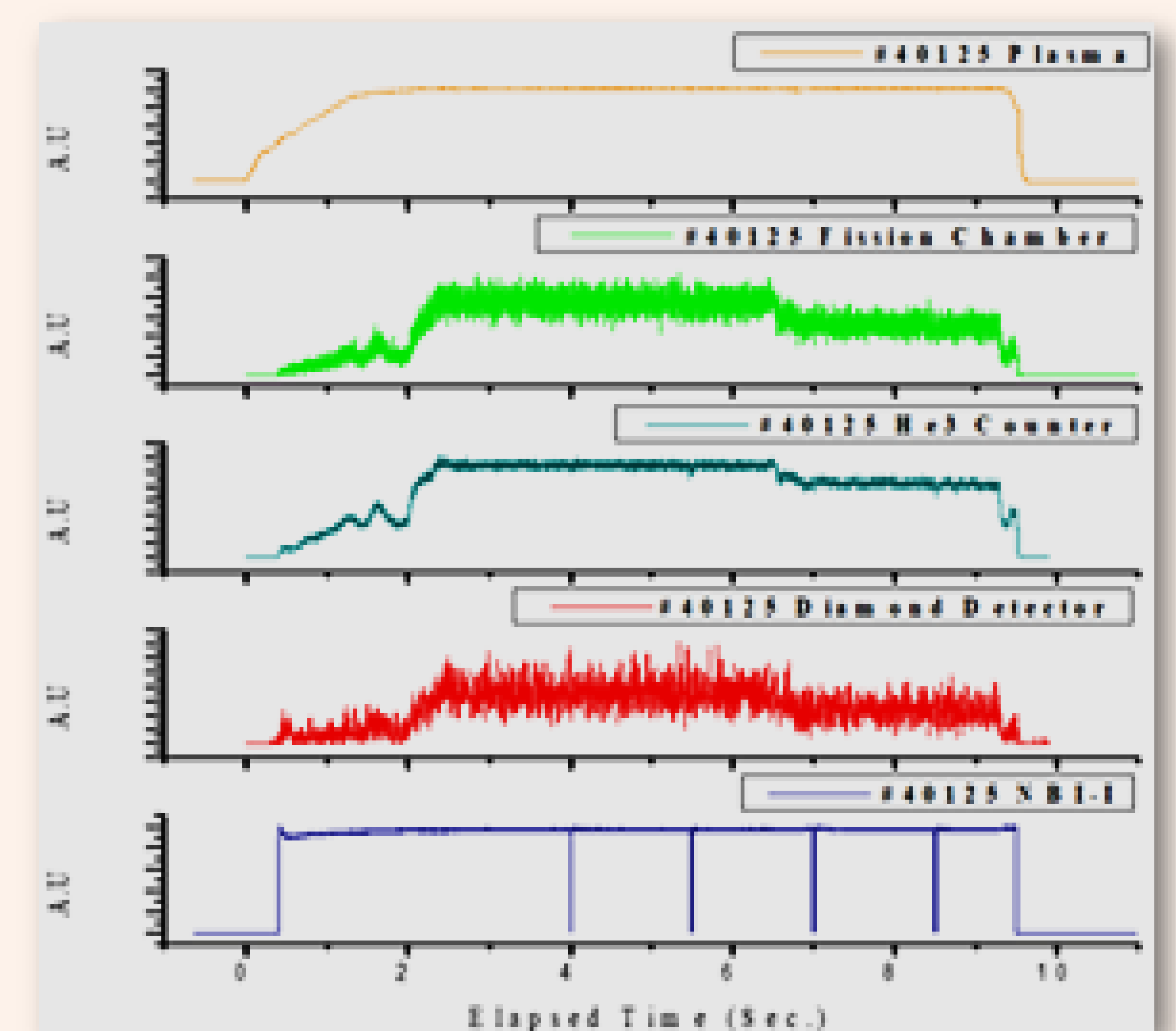
Measurements & Results



Installation of the diamond-based fast neutron detector and integrated Diamond-DAQ module at the KSTAR tokamak.

The integrated Diamond-DAQ system was operated during KSTAR D-D discharges and synchronized with the KSTAR timing system. The measurement chain remained stable over multiple experimental sessions despite strong electromagnetic interference and mixed neutron-gamma backgrounds. The time-resolved neutron count rates exhibited clear correlations with discharge evolution, including the ramp-up phase, auxiliary heating intervals, and discharge termination, indicating that the system captures physically meaningful variations in neutron emission.

Compared with conventional neutron monitors deployed in KSTAR, the diamond-based measurements showed consistent temporal trends, supporting the reliability of the proposed approach. Benefiting from the fast temporal response of the diamond detector and the FPGA-based high-rate counting architecture, transient features during ramp-up and heating phases were more clearly resolved than in conventional monitor signals. The compact, stand-alone DAQ configuration with internal biasing also proved practical for installation in space-constrained diagnostic ports and for remote operation during plasma discharges. While the present system is primarily optimized for time-resolved neutron yield monitoring rather than energy-resolved spectroscopy, the demonstrated stability and performance in KSTAR provide a practical basis for extending diamond-based fast neutron diagnostics to higher-flux environments in future fusion devices such as ITER and K-DEMO.



Time-resolved neutron emission rates measured by the diamond detector and integrated Diamond-DAQ system during KSTAR D-D discharge #40125.

Conclusions

An integrated Diamond-DAQ module was developed and applied to diamond-based fast neutron measurements in the KSTAR tokamak. The combined detector-DAQ system demonstrated stable operation under strong EMI and mixed neutron-gamma backgrounds and provided time-resolved neutron signals correlated with discharge phases and heating scenarios. The measured trends were consistent with conventional neutron monitors, confirming the reliability of the diamond-based diagnostic approach. The demonstrated robustness and time-resolved capability establish a practical hardware baseline that can be extended toward future fusion devices, including ITER and K-DEMO, with further work on multi-channel scalability, radiation lifetime evaluation, and advanced signal processing for spectroscopic capability.

References

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