Enhancements and characterization of the DIII-D energetic particle fluctuation bank

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An exhaustive understanding of the mechanisms behind energetic-particle (EP) transport and losses is of vital importance for the development of future fusion machines [1], as these particles are a key source of energy and momentum. Furthermore, when localized, energetic-particle losses can damage plasma-facing components [2]. The development of new diagnostic and analysis techniques is fundamental to achieving this understanding. Fast measurements of fast-ion losses have proven to be powerful tools, revealing the coherent nature of energetic-particle losses with different plasma instabilities [3]. Such fast measurements, as used in the imaging neutral particle analyzer (INPA) [4], could allow for the characterization of energy transfer between energetic particles and waves. For such fast channels to work effectively, noise must be minimized to detect small fluctuations in the signals, which could be attributed to transport and losses.

This work presents a comprehensive characterization of the various noise sources encountered during the operation of the DIII-D fast channels, along with mitigation strategies to eliminate them. The main source of noise is due to the background radiation (neutrons and gammas) present in the diagnostic lab during experiments, which can hit the photomultipliers and generate large spikes in the signals. Good linear correlations ($r^2 > 0.9$) are found between the average rate of noise spikes in the fluctuation bank and the average neutron rate. Additional noise is caused by the scintillation of the optical fibers used to guide the signal to the acquisition system, which is induced by neutron and gamma impacts. A correlation factor $r^2 > 0.6$ between the baseline noise caused by this scintillation and the signals in the neutron diagnostic was found. Possible mitigation strategies, such as the use of shielding and filters, are discussed. These allow to reduce the noise spike rate by an order of magnitude and the noise baseline by a factor 4. Despite the noise, it is shown that the upgraded fluctuation bank provides enough signal-to-noise ratio to observe coherent fluctuations of the energetic particle population. Examples of these fluctuations captured by DIII-D EP diagnostics will be shown, both on the NTM and TAE range of frequencies. For the case of NTMs, redistributions up to 60% are found in INPA signals, and simulations predicts that any mechanism other than direct kicks to the EP orbits cannot contribute enough to reproduce this large relative amplitude variations [5]. The observed fluctuation of the INPA signal for the TAE modes, on the order of 10%, is much larger than the typical density fluctuation associated to these modes (0.1%) which ensures that the measured fluctuation has its origin in the energetic particle population and is not an artifact of the detector response. The measured TAE fluctuations will be compared to simulations performed with the MEGA [6] and ASCOT [7] codes.

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