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Single-event fast neutron time-of-flight spectrometry with a petawatt-laser-driven neutron source

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Fast neutron-induced nuclear reactions are crucial for advancing our understanding of fundamental nuclear processes, stellar nucleosynthesis, and applications, including reactor safety, medical isotope production, and materials research. As many research reactors are being phased out, compact accelerator-based neutron sources are becoming increasingly important. Laser-driven neutron sources (LDNSs) offer unique advantages: ultrashort neutron pulses providing superior energy resolution, high flux per pulse, and a drastically reduced footprint. While single-event neutron spectroscopy has been demonstrated with epithermal neutrons, its application to fast neutron spectrometry is more challenging and remains unproven. This capability demands stable multi-shot operation and detectors resilient to the extreme environment of petawatt-class laser-plasma interactions. Here, a proof-of-concept experiment at the DRACO PW laser in a pitcher-catcher configuration is presented. This setup stably produced $\approx$ 108 neutrons/shot with energies above 1MeV, sustained over more than 200 shots delivered at a shot-per-minute rate. Neutron time-of-flight measurements were performed using a single-crystal diamond detector positioned at 1.5m from the source, capable of resolving individual neutron-induced reactions. Observed reaction rates are consistent with Monte Carlo simulations informed by real-time diagnostics of accompanying gamma, ion, and electron fluxes. With recent advances in repetition rate, targetry, and ion acceleration efficiency, this work establishes LDNSs as a promising, scalable platform for future fast neutron-induced reaction studies, particularly those involving short-lived isotopes or requiring a high instantaneous neutron flux.

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