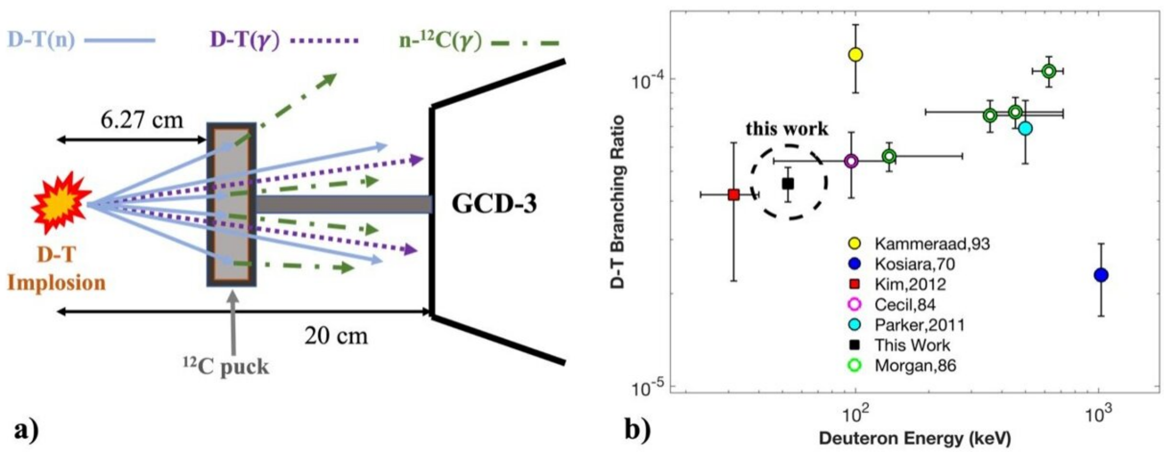
PHYS.ORG

Researchers update measurement ratios key for inertial confinement fusion experiments

April 27 2022



Graphic A depicts the experimental layout, a carbon puck is mounted to the front face of the GCD-3, a commonly used γ diagnostic at ICF facilities. The γ rays produced in the implosion arrive at the detector first. Later in time, neutrons produced in the fusion can inelastically scatter in the carbon sample to produce γ rays. This resulting signal is temporally separated from the D-T fusion γ rays. In graphic B. The plot shows the recent result for the D-T branching ratio (circled in black) against previous measurements. The y-axis represents the value for the branching ratio while the x-axis represents an effective deuteron energy. Credit: LLNL

Lawrence Livermore National Laboratory (LLNL) researchers have refined the measurement of the gamma (γ)-to-neutron branching ratio in deuterium-tritium (D-T) fusion reactions.

This reaction is a viable candidate for fusion energy, as it is known to have the largest cross section at center-of-mass energies below 500 keV. There are different branches of this reaction. These include an intense neutron-producing branch and significantly less intense γ-producing branches, the latter of which are five orders of magnitude less intense than the former.

The D-T γ-to-neutron branching ratio is of fundamental interest from a nuclear and plasma physics perspective and a more precise measurement can augment theoretical efforts in these fields. This branching ratio also is of interest in experimental efforts toward nuclear fusion and related national-security applications.

The results of the work are featured in *Physical Review C*, with LLNL physicist Justin Jeet serving as lead author. The work involved analyzing data from a previous inertial confinement fusion (ICF) experiment conducted in 2015, which was not optimized for this measurement.

"The early stages of the COVID-19 pandemic gave us spare time to revisit this data with the goal of providing a more precise measurement of the D-T γ-to-neutron branching ratio," Jeet said. "The paper augments previous measurements of the branching ratio in ICF implosions and reduces the uncertainty of the reported value by nearly a factor of three."

Jeet explains that constraining its value is paramount to experimental efforts at inertial-confinement and magnetic-confinement facilities.

"For tokamak-based nuclear reactors such as ITER, determination of the power gain factor (Q), defined as the ratio of produced fusion power to that required to maintain the plasma, is essential," Jeet said. "Q can be accurately determined by measuring the D-T fusion γ yield along with the precise value of the D-T γ-to-neutron branching ratio. At inertial confinement facilities, the D-T branching ratio can similarly provide absolute yield measurements based on γ-ray diagnostics."

The deuterium-tritium γ-to-neutron branching ratio is determined in an ICF experiment by utilizing a cross-calibration technique that relies on the inelastic scattering cross section of neutrons in carbon-12 (^{12}C), a better-known cross section. Because an ICF implosion is pulsed, with nuclear production occurring over ≈100 picoseconds (ps), the DT fusion γ rays arrive on a γ detector, the Gas Cherenkov Detector (GCD), first. The produced DT fusion neutrons can interact with a carbon puck, located upstream of the GCD, generating γ rays based on the inelastic scattering. Due to the transit time of neutrons, the ^{12}C γs produced in the carbon puck arrive at the GCD later in time.

The value of this technique is provided by the temporal separation of the γ signals on the detector. The ratio of these signals, both of which are obtained in a single-shot ICF implosion, is used to determine a D-T branching ratio value of $(4.6 \pm 0.6) \times 10^{-5}$. This measurement obviates the need for absolute detector calibrations, which can have large errors, and instead relies on the inelastic scattering cross section of neutrons in ^{12}C and the precision in the measurement of the D-T fusion neutron yield. The former is determined from several experiments conducted in the past and the latter is measured to high precision in ICF implosions. This method results in a branching ratio measurement with a significantly reduced total error compared to previous ICF and accelerator-based experiments.

Jeet said future experiments will be conducted this summer at the Omega Laser Facility of the University of Rochester's Laboratory for Laser Energetics (LLE) in Rochester, New York. These experiments are designed to optimize this measurement and will further improve the precision in the D-T γ-to-neutron branching ratio. In addition to performing a cross-calibration against ^{12}C, different materials are being investigated to further reduce the systematic errors resulting from the cross-calibration technique. These experiments will also aim to provide a cross calibration of the D-^{3}He γ-to-proton branching ratio.

More information: J. Jeet et al, Inertial-confinement fusion-plasma-based cross-calibration of the deuterium-tritium γ-to-neutron branching ratio, *Physical Review C* (2021). DOI: 10.1103/PhysRevC.104.054611

Provided by Lawrence Livermore National Laboratory