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Compact Fusion Experiment Demonstrates Confinement of 100 keV (Billion-Degree) Ions in Dense Plasma

In a breakthrough in the effort to achieve controlled fusion energy, a research team at Lawrenceville Plasma Physics, Inc. (LPP) in Middlesex, NJ, announced that they have demonstrated the confinement of ions with energies in excess of 100 keV (the equivalent of a temperature of over 1 billion degrees C) in a dense plasma. They achieved this using a compact fusion device called a dense plasma focus (DPF), which fits into a small room and confines the plasma with powerful magnetic fields produced by the currents in the plasma itself. Reaching energies over 100 keV is important in achieving a long-sought goal of fusion research—to burn hydrogen-boron fuel. Hydrogen-boron, (also known by its technical abbreviation, pB11) is considered the ideal fusion fuel, since it produces energy in the form of charged particles that can be directly converted to electricity. This could dramatically cut the cost of electricity generation and eliminate all production of radioactive waste.
(See http://focusfusion.org/index.php/site/article/dpf_animation/ee for animation of DPF.)

Previous experiments by LPP and other researchers had observed the high-energy ions, and had obtained evidence that they are confined in dense hot spots of plasma, called plasmoids. But they could not rule out an alternative hypothesis—that the fusion reactions observed were due to a beam of ions cruising unconfined through the diffuse background gas in the vacuum chamber of the experiment. This question is critical to the viability of the DPF as a fusion generator, because only if some ions are trapped, circulating around and around within a dense plasmoid, can they heat the fuel up sufficiently to ignite a self-sustaining burn that will consume most of the fuel in the plasmoids. A diffuse beam alone, traveling on a one-way trip through cold and much less-dense background plasma, will not be able to do that.

The new research at LPP's Middlesex laboratory has now ruled out this beam-only hypothesis by clearly showing that the ions are confined. This conclusion is based on a combination of evidence from several experiments and instruments, obtained over the past nine months, which fit together like pieces of a jig-saw puzzle. The detailed scientific results are being submitted for publication in Physical Review Letters, a leading physics journal.

The evidence for ions with energies more than 100 keV was obtained in three experiments in late September and late October, and were replicated this week. These experiments used deuterium, a heavy isotope of hydrogen, as the fuel, as is standard in most fusion experiments. Researchers observed the neutrons emitted from fusion reactions occurring when the deuterium ions collided with each other. By measuring the difference in the neutron arrival times at two detectors set at different distances—11 meters and 17 meters—from the axis of the fusion device, the physicists could calculate the energy of the ions that produced them. The greater the spread in the neutrons' arrival times, the greater their range of velocities and thus the greater the range of velocities of the deuterium ions that fused to produce the neutrons. More velocity means more energy, so this is a measure of the ions' energy. (See Figure 1.) Eric J. Lerner, LPP's president and lead scientist, explains, "In our best shot, on September 29, we calculate the average ion energy at between 160 and 220 keV, so we feel confident in conservatively saying that ion energies are above 100 keV." Three other shots also exceeded 100 keV (the most recent on January 3, 2011), and these were the upper end of a continuous distribution of ion energies in many other shots, not extreme outliers.

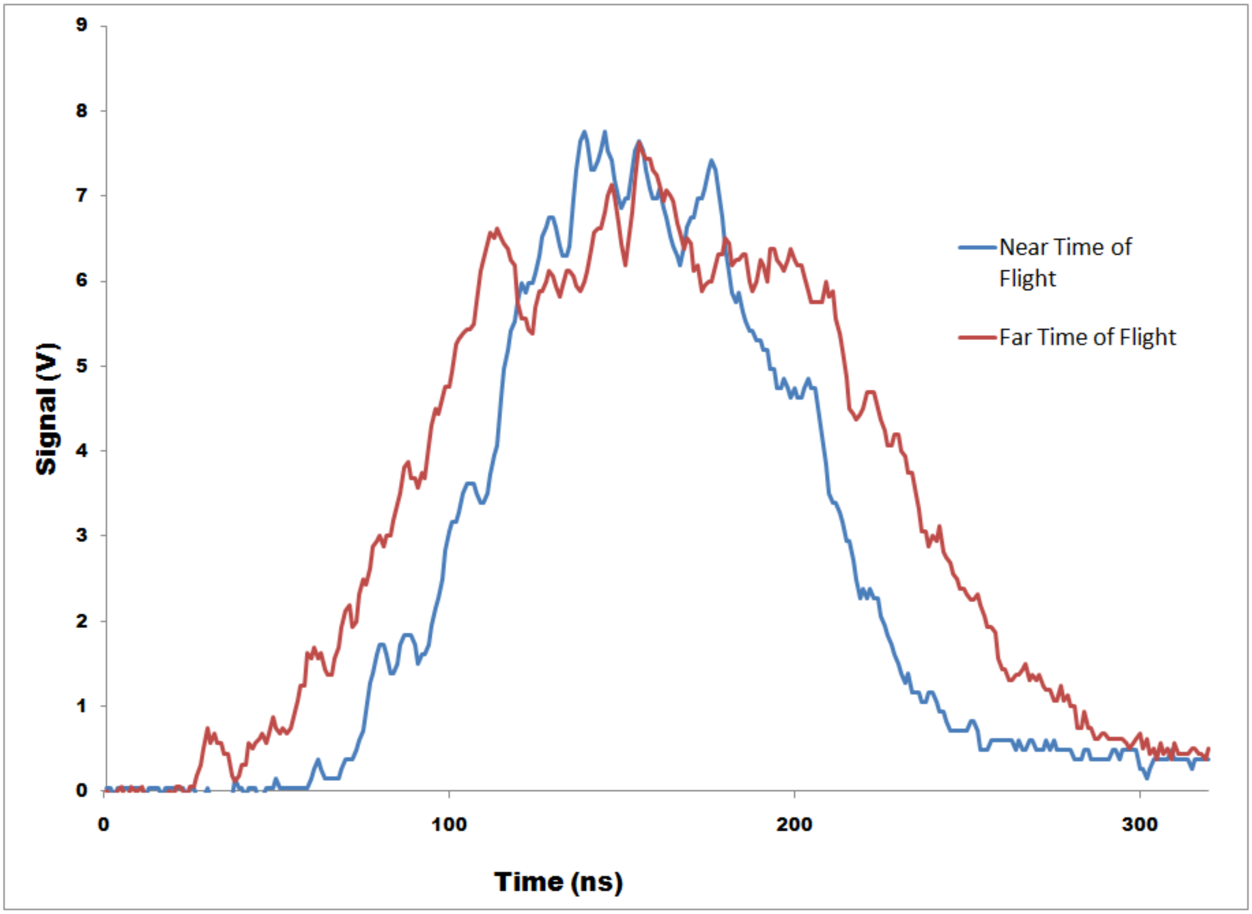

Fig. 1 *These signals are from the 11-meter (near-blue) and 17-meter (far-red) neutron detectors for shot 9301002. The greater spread in the time in the signals at 17 meters was used to calculate that the ions producing these neutrons had energies of between 160 and 220 keV.*

However, to confirm these results, the team needed a close-up inspection of the neutron peak to show that complications like a double peak were not present. These close-ups, taken with instruments at 1.3 meters from the axis of the device, were obtained on Dec. 24, 2010, and they confirmed that a single neutron peak existed, giving confidence in the energy calculations. This was the last piece of the puzzle.

The critical evidence ruling out the beam explanation had already been obtained on March 30, with several shots that achieved a fusion yield of over 10^{11} neutrons with relatively modest peak currents of 600-700 kA. Based on these shots, the team calculated how big an unconfined beam would need to be to create this many neutrons by collisions with nuclei in the diffuse background gas, at a pressure only 1/70 that of the atmosphere. They found that producing such a large beam would require more than twice as much energy as was available, thus clearly ruling out neutron production by the beam as a fusion source for these shots.

Finally, photographs taken in September and October with an ultrafast ICCD camera (with an exposure time of one fifth of a billionth of a second) showed that the hot plasma is confined in plasmoids less than

120 microns across, formed when the current in the device kinks up like a twisted phone cord (see Figs. 2-4). Knowing the approximate volume of the fusion-producing regions, LPP physicists were able to calculate that the density of the plasma in the plasmoids is between 1 and $4X10^{20}$/cc, over 100 times the background gas density.

The dense plasma focus has been studied for over 40 years. However, LPP has been able to make great strides since its "Focus-Fusion-1" experimental device started producing data in October, 2009, due to its unique, patented design. Most importantly, its electrodes, which produce the self-pinching action that concentrates the plasma and current, are much smaller than those of other DPF devices with similar peak currents. The electrode assembly is only 4 inches across and less than 6 inches in length.

The fusion energy yields achieved in these experiments are still far less than the energy used to run the machines. However, LPP hopes to make rapid progress in the coming year when the machine will be running with hydrogen–boron fuel for the first time.

In addition to Mr. Lerner, the LPP experimental team includes Dr. Krupakar Murali Subramanian, Fred van Roessel, and Derek Shannon. Additional technical material is available on request.

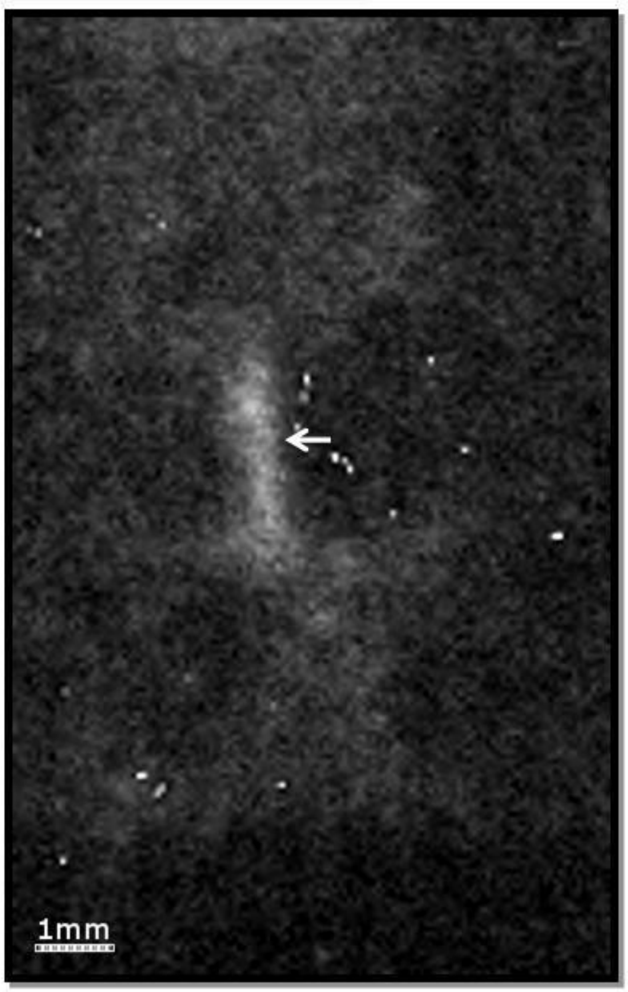

Fig. 2 *In this ICCD 200 ps exposure of Shot 102604, 92 ns before pinch peak, the dense plasma pinch column is condensed, but just starting to form a helix.*

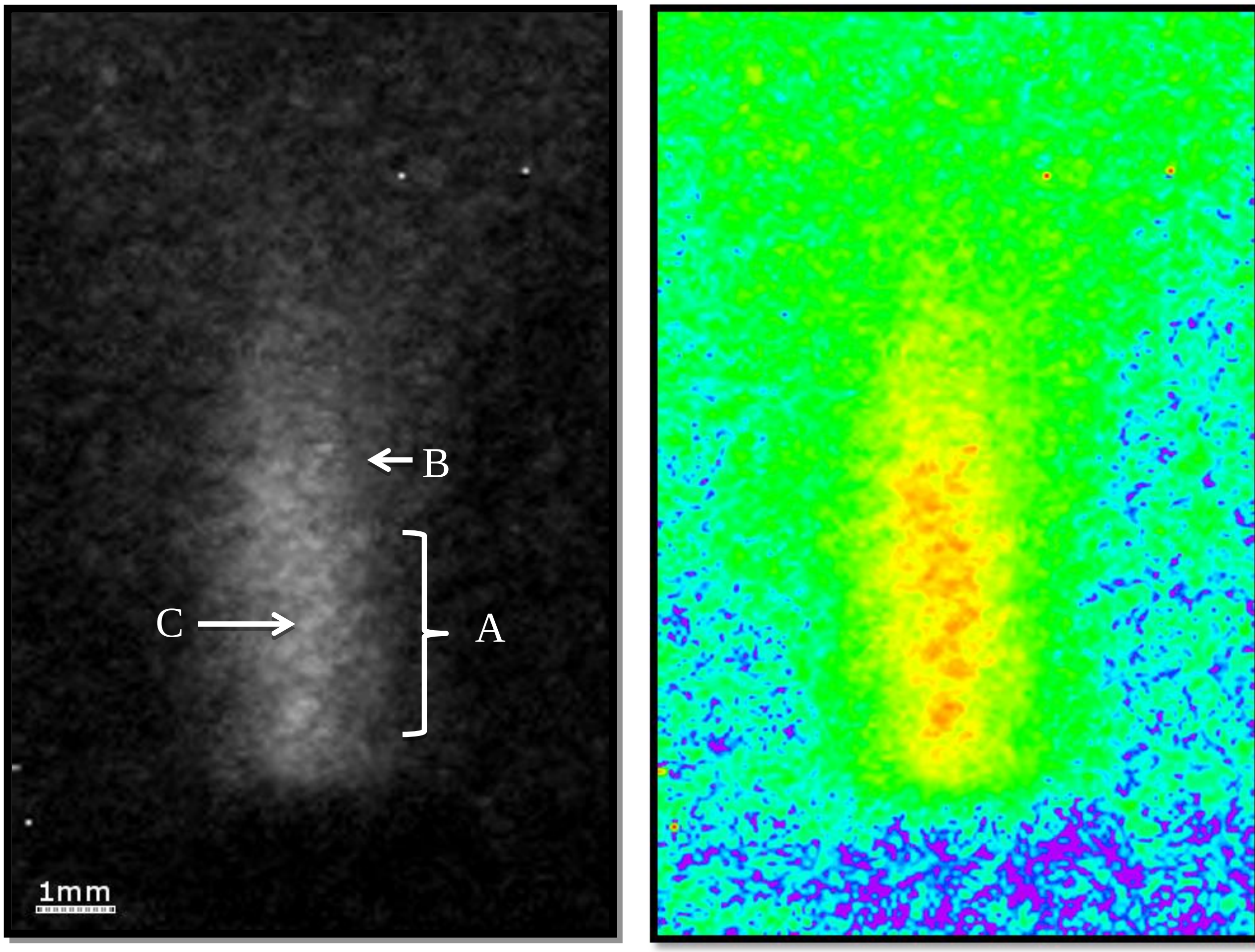

Fig. 3 *The axial condensation from shot 101402, 200 ps exposure, 85 ns before pinch peak. Bright filament [C] is about 240 microns in diameter. The helical filament has started to kink—note the formation of kink [B] at top of helix. False color image at right has brightest radiation as red, dimmest as blue.*

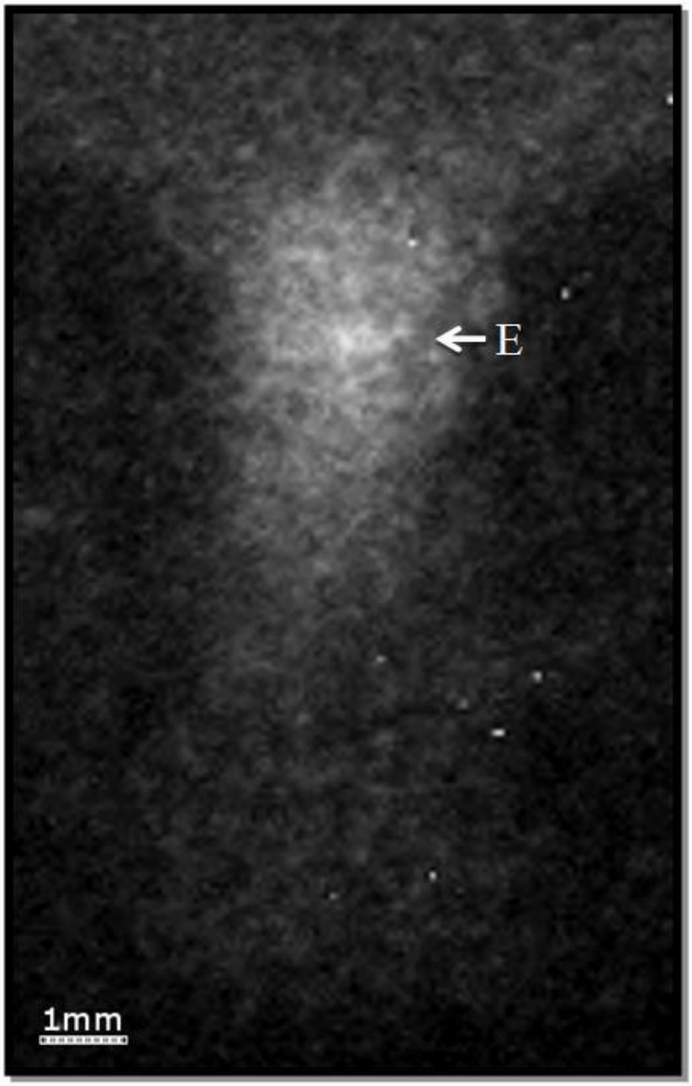

Fig. 4 *Shot 102603, 55 ns before pinch peak. Kink has started to condense into the very dense plasmoid at [E].*