Lawrenceville Plasma Physics, Inc

High technology research, development and consulting in plasma physics, X-ray sources, and Focus Fusion

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## Summary:

- **LPP's paper ranked #1 most- read in 2012 by the leading journal *Physics of Plasmas***
- **Ion beam peak power jumps four-fold to almost 400 GW, a new record**
- **Compression improves, producing FF-1's tiniest plasmoid, thanks to dramatic leak reduction**

**Recently published but not yet mentioned in monthly reports:**

- **New collaboration begins with Japanese simulation group**
- **Abell Foundation, LPP, Focus Fusion Society call for Senate hearings on US fusion program; letter-writing campaign begins**

# LPP's 150-keV confinement breakthrough was the most-read article in 2012 among plasma physicists

On March 6, ***Physics of Plasmas***, the leading international journal for fusion scientists, released a " Listing of the **Most Read Articles in** 2012 Published in *Physics of Plasmas*"**.** The number one article, most read out of the thousand published by the journal, was not from a giant national laboratory nor a large university group. No, it was **"Fusion reactions from >150 keV ions in a dense plasma focus plasmoid"**, from LPP's small team: Eric J. Lerner, S. Krupakar Murali, Derek Shannon, Aaron Blake and Fred Van Roessel. The paper described the confinement in a tiny plasmoid of ions at a temperature of 1.8 billion ºC for tens of nanoseconds, representing two of three conditions needed to produce net energy from hydrogen-boron fusion. We had already known that this achievement was widely discussed among our fellow physicists. But this announcement shows that our peers considered this among the most interesting developments in the field during the past year, the one most worth their time to read. Better yet, with all those skeptical physicists reading our work, not one has sent us any criticism or correction. Many have offered congratulations and encouragement.

This interest is validation by our peers of LPP's own view, expressed in our last report, that we are the leading R&D laboratory for aneutronic, radioactive-waste-free fusion, the only known means that can produce safe, nonpolluting, and unlimited energy at a cost well below that of existing technology.

# FF-1 ion beam output jumps four-fold to a record 380-GW

The ion beam produced by a plasma focus device will be the primary means of getting electric power out of the device. On February 28, while firing Focus Fusion-1 (FF-1), LPP's experimental plasma focus device, the team observed a record 380 GW peak power in the ion beam. The previous most powerful beam observed had a peak power of 93 GW, so the new beam is a four-fold improvement. In addition, this was the first beam observed that, at least in part, went all the way down the meter-long drift tube that is attached to the underside of the FF-1 vacuum chamber. It was also the first beam that equaled or exceeded our theoretical predictions. Both the higher peak power and the beam's more vertical direction are signs of increasing symmetry of the compression that forms the plasmoid, a key goal of LPP's current efforts.

To give some context for this large power output, the peak input power to FF-1 device from its capacitor bank is currently around 53 GW while the total average electric power used in the United States is 440GW. Indeed, the beam was probably considerably more powerful than the figure we measured, as LPP's Chief Scientist Eric Lerner calculated that about half the beam spread out beyond the 1-cm wide entrance hole to the drift tube. We believe this is the most powerful beam ever measured from a plasma focus device, although we will have to search the literature more thoroughly to make that claim with certainty.

Of course, the beam only lasted 5-ns, so it and the equally powerful electron beam emitted in the opposite direct carried only about 4 kJ of energy, about 1/15$^{th}$ of the total energy fed into the electrodes during the much longer 2-microsecond rise-time of the current from the capacitors. To get more energy out of the beam than is put in will require much higher fusion yield than is presently obtained in FF-1.

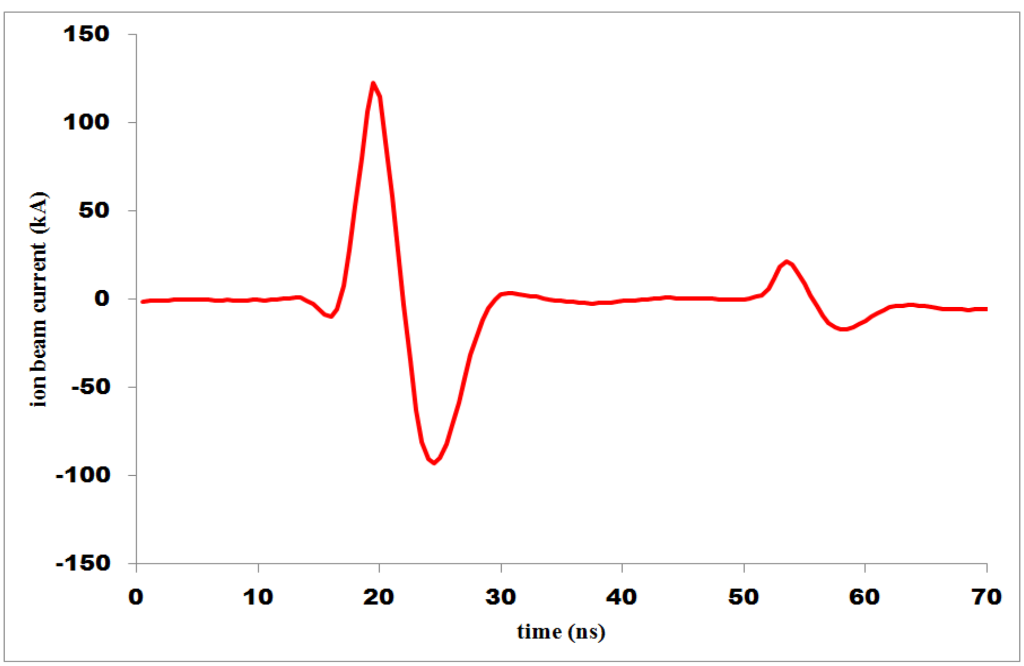


**Fig. 1** The Big Beam of shot 4, Feb.28 as recorded by the Upper Rogowski coil. (This is actually an integrated signal, as the coil signal is proportional to the rate of change of the current.)

The LPP team measured the ion beam with two Rogowski coils near the top and bottom of the drift tube. When a beam of ions or electrons passes through these coils, a current is induced in them, creating a signal that is stored on an oscilloscope. Figure 1 shows the signal from the Upper Rogowski coil, close to the plasmoid, with the large beam to the left and a smaller subsequent beam on the right some 35 ns later. The dips following the beams show a reverse current of electrons drawn along behind the ions.

The height of the integrated Rogowski signal gives the peak current in the beam. The difference in timing between the two Rogowski signals gives the velocity of the beam and thus the energy of its ions—in this case 3MeV (million electron volts), again a new record for FF-1. We can check this energy by comparing the timing of the Rogowski coils with the timing for the signal from an x-ray detector, or photomultiplier tube, that detects when the electron beam hits the anode. Again the result is the exact same energy of 3 Mev. By multiplying the average energy by the peak current of 127 kA, we get the peak beam power of 380 GW.

## Compression improves as we see our smallest plasmoid yet

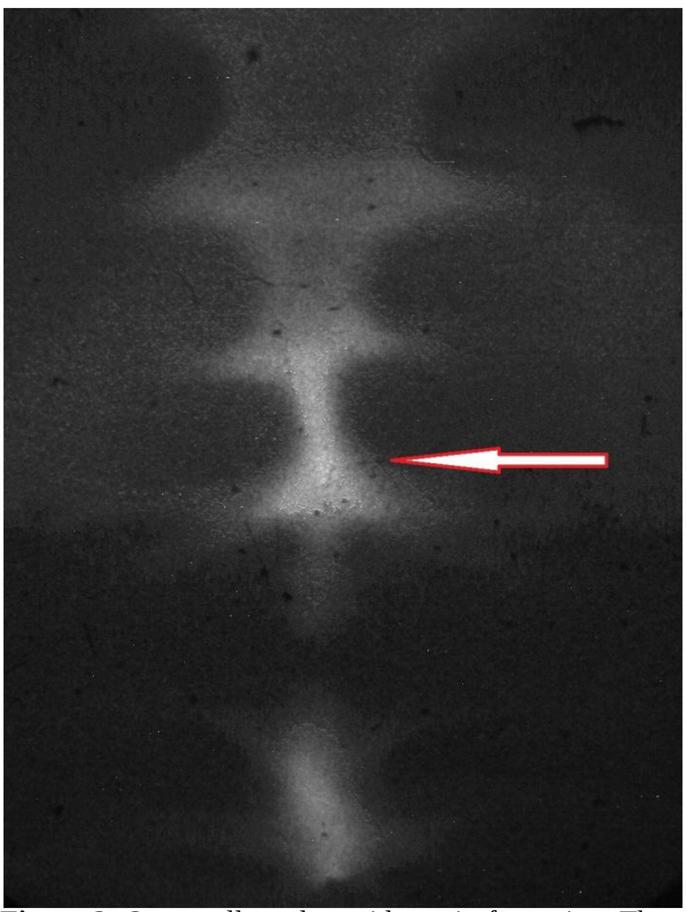

**Figure 2**. Our smallest plasmoid yet, in formation. The plasmoid is forming at the narrowest "waist" of this image, which is 1 cm across. The waist is only 200 microns in radius. The black specks are defects in the ICCD imaging device.

Over the past few months, LPP's experimental team has been trying to improve the symmetry of the compression that creates the plasmoid, so that the plasmoid will become smaller and denser. Higher density will make the fusion fuel burn faster and produce more energy output. Up until now, the core of our plasmoids, which are shaped like the sugar glaze on a doughnut, was no smaller than 300 microns in radius. Although this sounds pretty tiny, our goal was to get it down to 50 microns radius, with much higher density. We know that this is possible, as other researchers using similar plasma focus devices have observed and measured plasmoids this small. We also know that other researchers have achieved ion densities up to a few thousand times higher than what we have achieved, (hundreds of milligrams/cc vs our 0.1 milligram/cc) so we know that this too is possible.

A few shots after we got a record beam, on shot 7 of February 28, we also imaged our smallest plasmoid yet, shown in Figure 2, with a core radius of only 200 microns. This image was taken several ns before the point of maximum compression, so the plasmoid has not fully formed and the smallest radius is probably somewhat smaller than 200 microns. The plasmoid core is seen forming at the narrowest "waist" of the pinch column, before the current has twisted itself up into the fully formed plasmoid. Like the "Big Beam," we interpret this smaller plasmoid as the result of improved symmetry in our compression, due to our progress with the vacuum system.

## Leaks squeezed down by 100-fold

When 2013 began, FF-1 was beset by persistent leaks. These leaks were allowing oxygen to be present during our shots, so that the copper on the anode was rapidly oxidized in uneven patterns. Since copper oxide is an insulator, the current filaments had to cut through this oxide layer to reach the copper below. In the process the filaments would wander around, getting closer to each other in some places and farther in others. This in turn led to asymmetric compression and the "early beam" phenomenon, where energy would be released in filament collisions before compression was complete.

By early March, with the help of consultants and investors, LPP Chief Scientist Lerner and Lab Coordinator Derek Shannon had cut the leak down from 30 milliTorr/min at the beginning of January to only 0.3 milliTorr/min, by the beginning of March. First we got help from our new consultant, Brian Bures, who has had years of experience with small plasma focus devices. Then, we used an idea suggested earlier by LPP investor Rudy Frisch, who is a mechanical engineer. He suggested putting a Teflon restraining ring around the rubber O-ring that seals to the anode, forcing it to have a good seal when it is compressed. That got us a good seal before we fired, but a large leak re-opened after the first shot.

Another investor, Walter Rowntree, came to the rescue by acquiring on LPP's behalf a Residual Gas Analyzer, a sensitive instrument that analyses and identifies the gas in the chamber. Using the new RGA, Shannon rapidly identified the main leak gas as isopropyl alcohol. We had been using the alcohol to check for leaks and it had gotten trapped in a cavity in the anode, bursting out when heated by the current in the anode. Draining the cavity solved the problem.

We are not quite through with leaks as we still have some oxygen in our chamber. But, as with previous engineering challenges such as arcing and high voltage switching, we expect that our growing understanding of the issues will enable us to solve the remaining leaks soon.

## LPP Announces New Collaboration Agreement with Plasma Simulations Group, University of Toyama, Japan—Simulation Yields First Results

(Previously posted, see it published here)

## Call for Senate Hearing on Fusion Policy

(Previously posted, see it published here)