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Lawrenceville Plasma Physics, Inc

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

LPPFusion Report
December 24, 2018

Happy Winter Solstice to All!

Summary:

- **Axial Field Coil, New Switches Assembled**
- **Proton-Boron ($p^{11}B$) Fuel Arrives**
- **Plans for the New Experiments**
- **LPPFusion Passes Financial Audit**
- **Looking Back—2018 Highlights**

Axial Field Coil, New Switches Assembled

LPPFusion's research team, working steadily to prepare for the new beryllium electrode experiments, has accomplished two big tasks. First, Research Scientist Dr. Syed Hassan designed and installed the new Axial Field Coil (AFC) in the vacuum chamber. This copper wire coil controls the spin on the plasmoid in our Focus Fusion device. It carries a small DC current, which produces a magnetic field directed along the axis (thus the name). When electric current in the plasma inside the chamber interacts with that field, the resulting forces produce a spin in the plasma. During the shot, the currents in the plasma will induce high-frequency currents in the AFC, so it will also act as a sensor to detect how much spin is induced. Optimizing the spin, we expect, will optimize the density of the plasmoid and thus fusion yield.

The AFC is now protected by high-temperature materials (Figure 1), quartz glass coil, aluminum oxide ceramic connections (white) and titanium-nitride coated wire supports. Previously, the AFC was contained in a simple copper coil. Making the connections with the ceramic turned out to take a great deal longer than we had thought, but the improvements are worth the delay.

At the same time, Dr. Hassan installed upgraded versions of two other coil instruments—the Upper and Lower Rogowski coils. These coils measure the current in the ion beam that the plasmoid emits. The new coils will be paired with Langmuir probes—basically simple wires—that will also detect the ion beams. Since the two probes will react differently to the radio-frequency noise the device produces, they will together make it much easier to separate the signal from the noise and make more accurate measurements of the beam energy and current.

A second big task was the successful installation of two ceramic-protected switches (Figures 2 and 3). The ceramic disks protect the Mylar plastic underneath. The Mylar is needed to prevent a spark from running along the sides of the big plastic insulator, shorting out the switch. But in the past the Mylar degraded rapidly and failed after a hundred shots or so. The ceramic will protect it. In turn the ceramic is held in place by Lexan tabs. Two new switches have been put in place for testing. If they pass after 10 or so shots, we already have the parts to put the other six in place.

The team is now putting together the parts for the new vacuum system, which is the last step before final assembly of the electrodes onto the machine. The vacuum system includes new filters to prevent beryllium dust from escaping into the environment. It also includes a small "dump chamber" where exhausted gas from several shots can be kept. This will be important for the hydrogen-boron shots later in 2019. While the main fusion reaction produces harmless helium, a side reaction produces carbon-11, a radioactive isotope. This material decays very rapidly with a half-life of 20 minutes. So after 8 hours, no radioactivity will be left and the exhaust can be safely pumped out of the dump chamber.

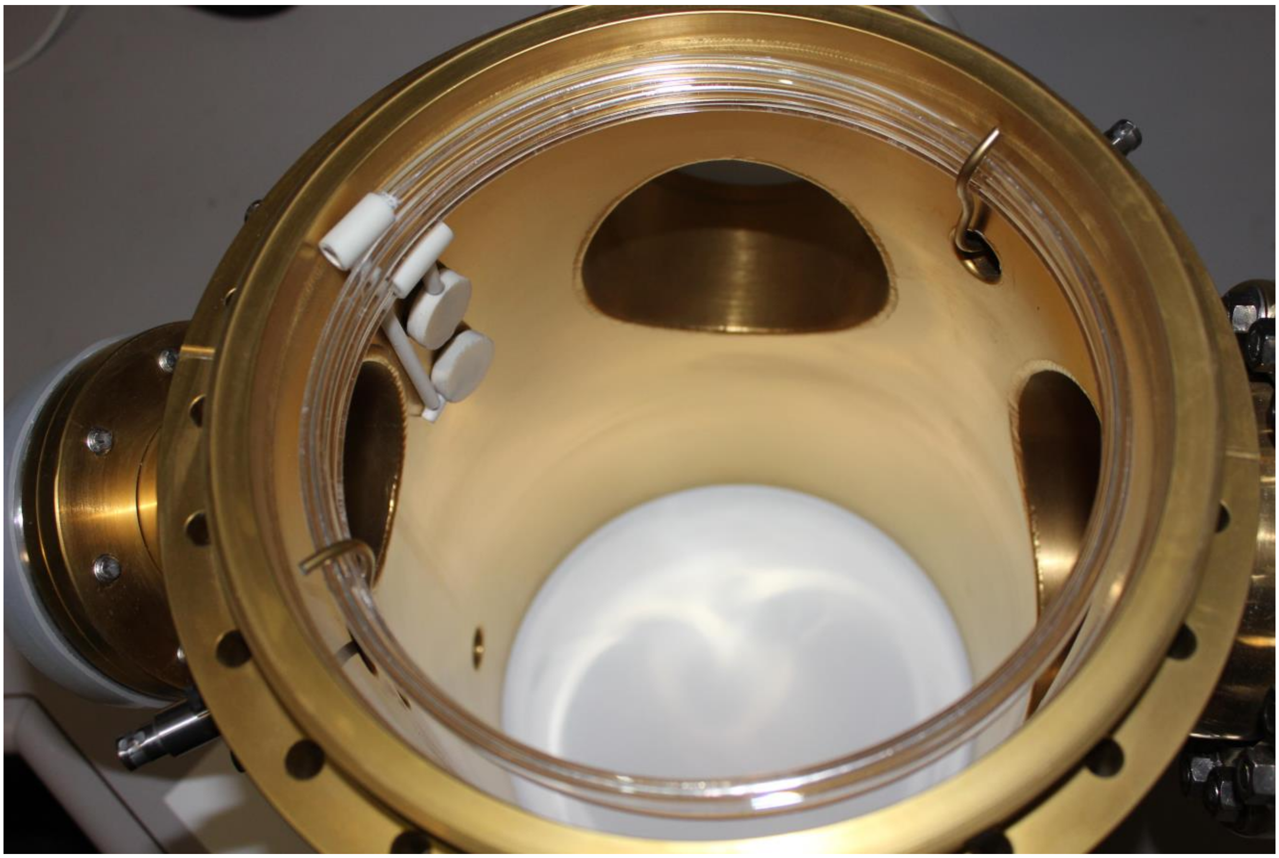

Figure 1. The new Axial Field Coil (AFC) is a copper wire (barely visible) protected by the quartz glass coil, aluminum oxide ceramic connectors (white) and titanium-nitride coated support wires inside the titanium-nitride coated vacuum chamber.

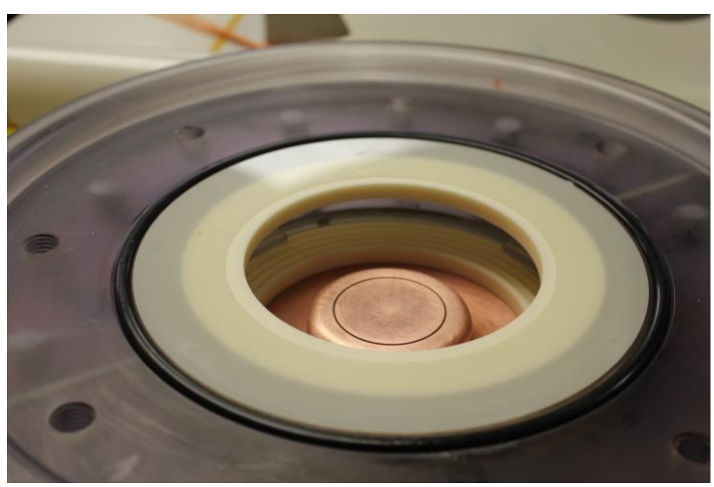

Figure 2. New ceramic-protected switch shown with the top of switch not yet in place. Lexan plastic tabs inserted in the outer (grey) Lexan insulator keep the beige ceramic disks in place. They in turn protect the Mylar plastic insulators.

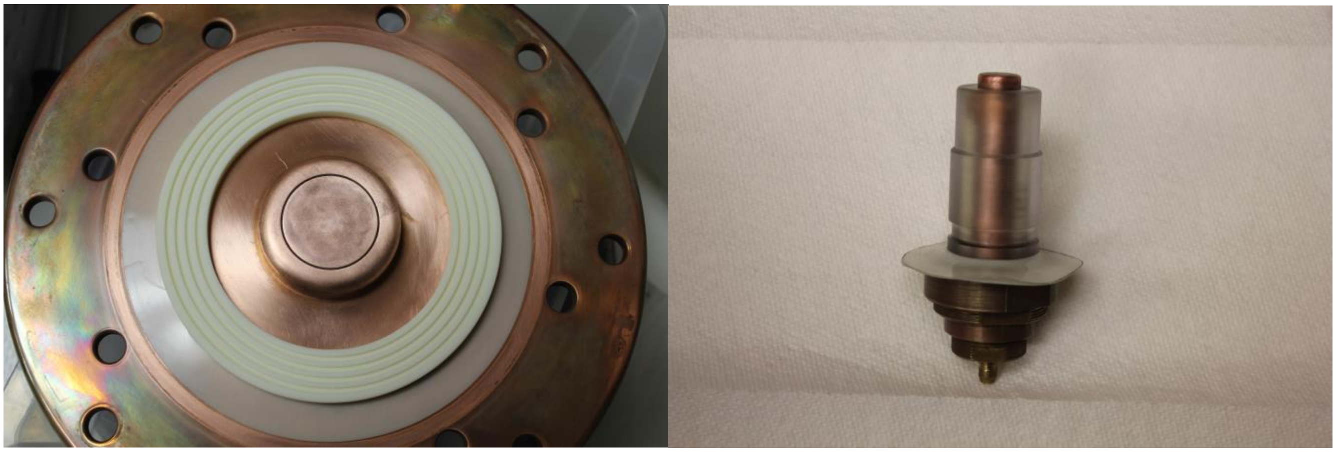

Figure 3. Left: Bottom of switch without the Lexan insulator. Right: The new spark plug (which goes into the top of the switch) with reinforced Lexan insulator.

In addition to the above-described:

- **Upgraded Axial Field Coil (AFC) and ion –beam Rogowoski coils (URC, LRC)**
- **New ceramic switches**
- **New vacuum system with filters and dump chamber**

Other upgrades to our experimental equipment (some of which have been reported on previously) include:

- **Redesigned vacuum chamber with enlarged viewing windows**
- **Quartz protective guards on two vacuum chamber windows to shield against deposition**
- **Hollow anode and new upper electron spectroscope and Rogowski coil to measure electron beams**
- **Remote control over all x-room switches and valves**
- **Improved electromagnetic shielding of our instruments and oscilloscopes**

Proton-Boron ($p^{11}B$) Fuel Arrives

The high-purity proton-boron ($p^{11}B$) fuel we will be using in our experiments later in 2019 arrived at LPPF's NJ facility on Dec. 22. The fuel is in the form of the compound decaborane (chemical formula $B_{10}H_{14}$) with 99.9999% chemical purity. The boron in the fuel is 99.9% boron-11, the isotope that reacts with hydrogen (protons) to produce helium and yield fusion energy. We needed to eliminate as much as possible the other natural isotope of boron, boron-10, as it would react to produce radioactive beryllium-7, with a two-month decay time.

While we only received 93 grams of this fuel, this will be enough for hundreds of experimental shots. This small amount was made at two labs, one in Russia to produce isotopically pure B and the other in the Czech Republic to produce the decaborane compound. Since it was hand-produced as a custom item in laboratories, not a factory, it was extremely expensive—$56,000 or $600 per gm. Mass production would bring this per-gram price down many hundred-fold. Boron is so abundant and easily accessible on Earth that it could supply fusion fuel for billions of years to come.

Plans for the New Experiments

Since our new experiments will start soon, we thought this is a good time to summarize for everyone, including those who have only started following us recently, what our plans for the experiments are, what we hope to accomplish and why we think we can get good results. **The basic plan is to increase the density of the plasmoid and thus the fusion yield by greatly reducing the heavy-metal impurities.** So let's answer some questions about this plan.

1) First, why do we think that reducing heavy-metal impurities will increase fusion yield? We have solid experimental evidence for this hypothesis. **Over the history of our FF-1 experimental device, whenever we reduced impurities, yield went up. Whenever we failed to reduce impurities, yield did not rise and whenever we inadvertently increased impurities, yield went down.** For example, back in 2011, a mis-fitted part created heavy arcing inside the vacuum chamber, releasing large amounts of vaporized copper and steel impurities into the plasma. Fusion yield plunged all the way down to zero. This was the first big clue that led us to believe impurities were a key problem. When we fixed the arcing, and impurities went down, yield went back up.

Again, in 2015 we installed the new monolithic tungsten electrodes that eliminated the arcing between metal pieces inside the chamber. However, we observed a bright golden substance when we started firing and we got very low yield. The golden substance was tungsten bronze, a compound of tungsten hydrogen and oxygen that was very fragile. It was releasing large amounts of tungsten into the plasma—again resulting in high impurities. When we then reduced the oxygen level by baking out the vacuum chamber, the fusion yield in 2016 tripled to a record high. In addition, when we could not pull the oxygen levels further down in 2017, we were unable to increase yield. **The pattern of experiments gives strong evidence that high impurities cause low fusion yield and that thus reducing impurities will increase yield.**

2) How much yield increase do we expect initially, if we do decrease impurities? The dense plasma focus device (DPF), for solid physical reasons, has a fusion output that increases sharply with electrical current—approximately as current to the fifth power. In other words, if current goes up by 2, yield goes up by 2^5 or 32. (Fig. 4). This scaling law, which works for smaller DPF devices, has been interrupted for larger ones—they don't get the yield expected from the scaling law. We think that is due to the larger impurities that powerful DPFs have produced. **So from the results we obtained at lower currents, we anticipate that with low impurities our initial experiments with pure deuterium should get our fusion yield up from about ¼ J—our best result with tungsten electrodes—to over 2 J.**

3) Why are we confident that in this experiment we will radically reduce heavy impurities? We are eliminating, almost entirely, all heavy metals from the experimental chamber. There are both strong theoretical reasons and abundant experimental evidence that impurities affect plasma characteristics, such as electrical resistivity, in proportion to the product fz^2, where f is the fraction (by number) of ions with an atomic charge z. We are switching our electrodes from tungsten, with a z of 74, to beryllium, with a z of 4. This means that, when fully ionized, each beryllium ion in the plasma has 340 times less effect than each tungsten ion. We don't expect a lot more beryllium ions to be vaporized, because the energy to vaporize and ionize one beryllium ion is already ¾ the energy needed for one tungsten ion. So the contribution of the electrodes to impurities will be hundreds of times less in the new experiment. In addition, we are being extremely careful to ensure that the other materials in the chamber, located where the plasma will be at lower temperatures, but will still be hot, can resist vaporization at the temperatures they will be exposed to. That includes the AFC mentioned above.

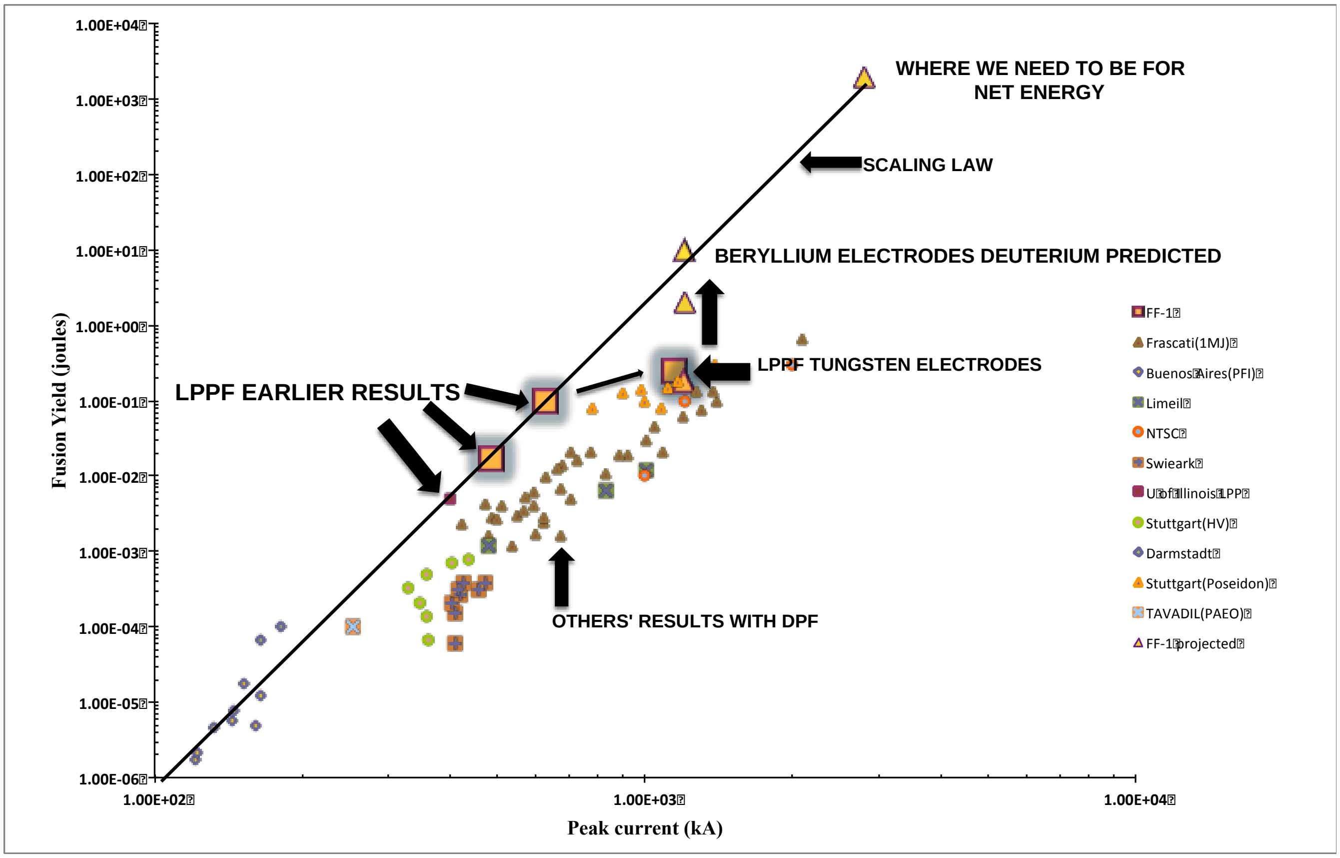

Figure 4. From the scaling law of plasma focus yield vs peak current, we expect to be able to increase yield from 0.25 J (top large orange square) to the scaling predictions (black line and large triangles), lifting yield first to 2 J and then 10 J with deuterium fuel. More current and proton-boron fuel will be needed to go still higher.

In addition, reducing impurities to the level we expect, with the product fz^2 due to impurities reduced to less than 0.1, will mean **we are using plasma as pure as that observed in the sun and other astrophysical objects.** These plasmas are mostly hydrogen and helium with only small amounts of carbon and heavier elements. We know from abundant observations of phenomena like solar flares that plasma filaments are the first stage of compression that lead to dense plasmoids. **With pure plasma, we can confidently use these abundant astrophysical observations to predict the behavior of our plasmas. Just like the Wright Brothers used observations of birds to develop controlled flight, we use observations of the natural behavior of plasma in the Universe to control fusion.**

There are good theoretical reasons to believe that if the compression of the plasma starts at higher densities, because the filaments have produced an initial compression, it will also end at higher densities, leading to greater fusion yield. As early as the 1970's plasma focus pioneers Dr. Winston Bostick and Dr. Vittorio Nardi published extensive experimental studies showing that the filaments led to the production of the densest plasmoids.

In our previous experiments, heating due to impurities destroys the plasma filaments that are the first stage of compression of the plasma. We observed, through our fast camera ICCD images, back in 2013 that the filaments that existed in smaller DPF devices did not exist in our device at the end of the run-down phase, when compression started. This year, we obtained images showing that the filaments formed early in the shot, but blew up at around 500 ns into the shot. Theoretically, we know that impurities, by increasing the resistivity of the plasma, will make the filaments heat up faster and expand before the magnetic pinch forces can build up to compress them**. With low impurities, we confidently expect the filaments to survive until the compression phase, leading to higher density plasmoids.** Our new experiments will enable us to definitely confirm or refute the hypothesis that the filaments are needed for the best compression. The results will then guide us to the optimal conditions for fusion yield.

Following our initial experiments with pure deuterium, we will introduce a mixing gas, either nitrogen or neon, to start simulating the mixture of gases that we will have with our ultimate hydrogen-boron fuel. We expect that this mixture will lead to higher fusion temperatures than with pure D, as the heating mechanism involves the viscosity of the plasma, which also increase with atomic charge. These experiments will be a bit trickier to optimize, as too much higher-z mixing gas will cause the filaments to blow up again. So we will need to get to the "Goldilocks" point here. If we can, **we expect fusion yields to rise above 10 J.**

Our further plans, for the second half of 2019, include upgrading our switches to improve our peak current, again increasing fusion yield. We can now do this without opening up our redesigned vacuum chamber. **Then, in the fall or beyond, we will start introducing our experiments with hydrogen-boron, pB11 fuel.** Since this fuel burns faster and more energetically than deuterium, that will again boost our fusion yields and put us on the track to our goal of getting more energy out of the device than we put into it—net energy.

LPPFusion Passes Financial Audit

Figure 5. Audit passed! No embezzlement, yachts, mansions or car collections!

On December 3, the BKC accounting firm signed off on their financial audit of the 2017 year for LPPFusion (Lawrenceville Plasma Physics, Inc.). They found that our financial statements "present fairly, in all material respects, the financial position of Lawrenceville Plasma Physics Inc. (D/B/A/LPPFusion Inc.)"

This was a big deal for us, because this is our first financial audit in 9 years. Previous financial statements were reviewed by accountants, but not audited, which is a much higher level of scrutiny. Because the last audit was so old, and done by a different firm, BKC reviewed our capital contributions and assets all the way back to our incorporation in 2003. So, investors can now be assured that all our money is going where we say it is—no yachts, Ferraris or Cayman mansions included!

An electronic version of the audited financial statement will be available soon, per request for the prospective or existing investors only. We expect the audit of our 2018 year will go much faster, as it will only cover that year.

Looking Back—2018 Highlights

Technical Milestones:

- **Completed experiments with tungsten electrodes**
- **Observational confirmation of the destruction of filaments**
- **Publication of cosmology results in leading journal—Monthly Notices of the Royal Astronomical Society**

Non-Technical Milestones:

- **Over $950,000 investments from Wefunder**
- **Over $300,000 gift to Focus Fusion Society for aneutronic fusion research**
- **EU patent granted**
- **Founding of Fusion Industry Association**
- **Successful LPPF financial audit**

We expect an exciting 2019! Happy New Year to ALL!